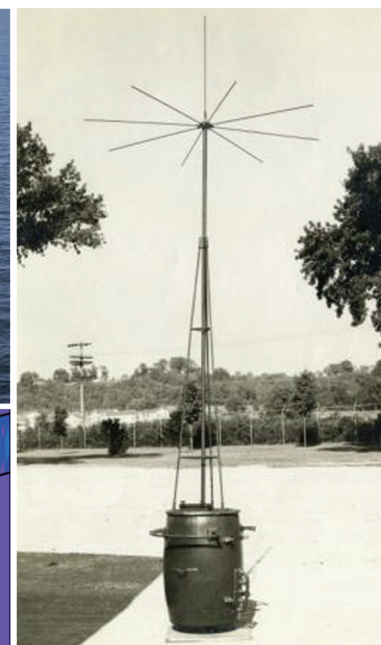
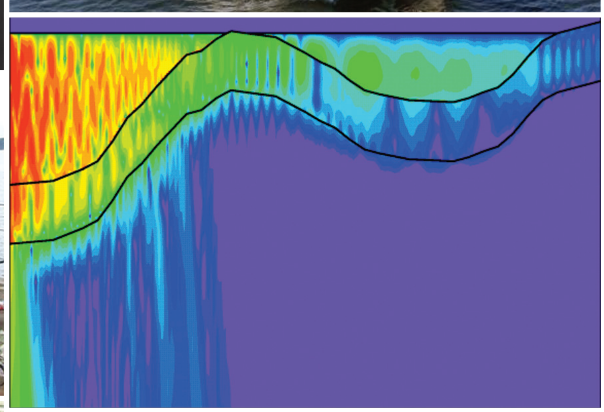
A History of

the Acoustics Division of the Naval Research Laboratory

The First Eight Decades 1923–2008





FRED T. ERSKINE III

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **AUG 2013**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **A History of the Acoustics Division of the Naval Research Laboratory The First Eight Decades 19232008**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Research Laboratory**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
Supporting documents are attached to the report as separate files (PDF files).

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**184**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

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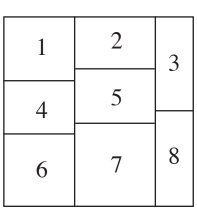

1. Dr. Harvey C. Hayes.
2. USNS *Harvey C. Hayes* (T-AGOR 16) used in at-sea experiments.
3. Early prototype sonobuoy circa 1940s.
4. Deployment of NRL acoustic communications buoys during AUV-Fest 05 in Keyport, Washington in 2005.
5. The Range-dependent Acoustic Model (RAM).
6. NRL's large acoustic tank for in-water structural acoustics studies is 55 ft in diameter, 50 ft deep, and contains 800,000 gallons of deionized water.
7. Deployment of NRL low frequency source transducer from R/V *Wecoma* off the Oregon Coast during NRL field test OREX05 in 2005.
8. Dr. Budd B. Adams aboard USS *Dolphin* (AGSS-555) for underwater acoustic tests in 1973. *Dolphin* was he U.S. Navy's only operational diesel-electric, deep diving, research and development submarine.

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Acknowledgments

This history of the Acoustics Division of the Naval Research Laboratory (NRL) could not have been written without the help of numerous persons. First among these are Dr. David H. Johnson of the Office of Naval Research (ONR) and Drs. Edward R. Franchi and Douglas G. Todoroff of the Naval Research Laboratory who funded this effort. Dr. Leo Slater, NRL's historian, provided many hours of guidance and shared his extensive files with me. Dean Bundy, NRL's archivist, provided much assistance that included the recall of pertinent materials from the Federal Records Center. NRL reference librarians Marybeth Dowdell and Judi Griffin provided extensive help with lists of reports and publications. NRL research librarian Linda Norton also provided much help with publication lists. Gayle Fullerton of NRL's Technical Information Services Branch (TIS) provided much assistance with the search for photographs from her extensive files. Kathy Parrish, Claire Peachey, and Jonna Atkinson of TIS provided invaluable help with the preparation of this publication. Richard Thompson of NRL's Public Affairs Office provided consistent encouragement throughout this project.

John Tomlinson, Lori Heddings, Christine Vonk, Andrew Garner, and Debby Smith of the Acoustics Division administrative staff were all very helpful in providing information from the Division's files. The files of Dr. Burton Hurdle, former associate superintendent of the Acoustics Division, were extremely helpful. Dr. John C. Munson, NRL's third Acoustics Division superintendent, provided many hours of hospitality and valuable advice during my visits with him at his home in suburban Maryland. Dr. David Bradley, NRL's fourth superintendent of the Acoustics Division, provided much insight as well as extensive assistance with the online searches for published papers in the Journal of the Acoustical Society of America. Dr. Joseph Bucaro, former head of the Physical Acoustics Branch, graciously provided a detailed write-up on the history of that branch from his perspective. Dr. Budd Adams, former head of the Large Aperture Systems Branch, provided a write-up on the early history of that branch as well as numerous photographs of at-sea experiments from the 1970s period. Dr. Alan Berman, former NRL Director of Research, provided much insight about the important transitionary period for the Sound/Acoustics Division in the 1960s and 1970s, as well as a detailed review of Project Artemis.

Dr. Roger Gauss and Raymond Soukup of the Acoustic Systems Branch helped by providing assorted background material. John Perkins, head of the Acoustic Systems Branch, provided numerous photographs of sea trials and Arctic experiments as well as a review of matched-field processing developments. Dr. Marshall Orr (now associate superintendent of the Acoustics Division) provided his personal file of historically relevant material, as well as a review of internal wave research. Dr. Jonathan Berkson, a former Acoustics Division researcher, compiled a list of NRL Sound/Acoustics Division persons who served on the staff of the NATO Undersea Research Centre (NURC) (formerly named the SACLANT Centre), La Spezia, Italy. Paul Bucca provided insights about interactions between the NRL Acoustics Division and the Maury Center for Ocean Science. Tommy Goldsberry, a former ONR program manager, provided insights about ONR reorganizations in the 1990s.

Several dozen former and current NRL researchers and managers contributed many hours of their time in the form of recorded audio interviews of recollections about their careers. Particularly meaningful oral interviews were those with Gordon Hayes (son of Dr. Harvey Hayes) and Chester "Buck" Buchanan (former head of the Sonar Systems Branch), both of whom died shortly after our interviews. I am indebted to former NRL historian Dr. David van Keuren for a number of important oral interviews that he conducted with researchers between 1990 and 2003.

James Cole of NRL's Optical Sciences Division and Bernie Cole (formerly of the Naval Underwater Systems Center, New London, Connecticut) provided records of historical importance related to the tenure of their grandfather, Dr. Harvey C. Hayes, NRL's first superintendent of the Sound Division. Several important partial prior histories of the Sound/Acoustics Division were extremely helpful, including those by Dr. Harvey Hayes (1920s to 1940s); Elias Klein (1920s to 1930s); and Homer Baker (1940s to 1960s); as well as several historical reviews of undersea warfare research in the United States covering periods from 1916 to 1945 by Marvin Lasky. In recent decades, important summaries of key NRL research achievements have been spearheaded by Don DeYoung, Executive Assistant to NRL's Director of Research, including one prepared for NRL's 75th anniversary in 1998, and one prepared in 2006. These documents have been quite helpful.

I take full responsibility for any errors in transcribing the comments of interviewees and any omissions of particular research efforts of importance to NRL researchers. The scope of research conducted in this eight-decade period is a bit daunting in its diversity and enormity. By necessity, some important classified research has not been covered in this present volume in order that this history could be fully publicly releasable. I am aware that the history of underwater acoustics and undersea warfare is a very broad subject to which many nations have contributed over a long period of time. Further, within the United States, various Navy laboratories, university laboratories, and private industry organizations have made important research contributions. Due to limitations of time and resources, this volume focuses almost entirely on the research contributions of scientists and engineers from the Naval Research Laboratory. However, the NRL Acoustics Division is indebted to our many colleagues from other organizations whose collaborations with us have helped NRL researchers to make so many technical achievements.

CHAPTER ONE

Introduction

2 Eight Decades of Acoustics Research at the Naval Research Laboratory

4 Key Research Thrusts and Achievements

6 Acoustics Division Timeline

Eight Decades of Acoustics Research at the Naval Research Laboratory

The Naval Research Laboratory (NRL) on the Potomac River in Washington, D.C., is the United States Navy's Corporate Laboratory for research and development of technologies related to national defense. The opening of NRL in 1923 and its rise to prominence as one of the nation's leading defense establishments is well documented (see "Suggestions for Further Reading" at the end of this volume). As one of the two "founding" NRL research divisions, the Sound Division — renamed the Acoustics Division around 1968 — has a long, rich, and diverse history of technical achievement. It has conducted research operations continuously from 1923 to the present day.

This volume recounts some of the key milestones and achievements of the NRL Acoustics Division over these first eight decades — from 1923 to about 2008. Among the motivations for developing this volume was the realization that a coherent history of the Division had not yet been prepared. Several partial histories of the early years of the Division were written many years ago, and much rich and possibly fragile documentation resides in NRL's files and archives. The time appeared right to review the existing documentation and prepare this history. This volume brings together a wealth of material, including scientist biographies, technology descriptions, personal narratives, oral histories, photographs, and extensive lists of publications documenting the acoustics research conducted at the Laboratory.

Establishment of NRL and the Sound Division

The Naval Research Laboratory was established after a suggestion by Thomas Edison that "The Government… should maintain a great research laboratory....In this could be developed...all the technique of military and naval progression without any vast expense." It was 1915, Europe was embroiled in World War I, and the United States was concerned about national defense. Secretary of the Navy Josephus Daniels asked Edison to form a new body of civilian experts to advise the Navy on science and technology matters: the Naval Consulting Board. The Board proposed the creation of a modern research facility for the Navy. Congress allocated $1.5 million for the institution in 1916, and after wartime and other delays, construction began in 1920.

When NRL began operations in 1923, it had two research divisions: Radio and Sound. The Sound Division was quite small prior to World War II, with fewer than ten researchers. However, it pioneered in many important developments in its early decades, including early sonar transducer developments, accurate sound speed measurements, the first operational fathometer, early seismic method developments, the first operational U.S. Navy sonar, early harbor defense research, the first Navy acoustic test range, and tactical antisubmarine warfare planning for World War II. These are discussed in Chapter 3.

At the outset of World War II in the early 1940s, the Sound Division bloomed in size to over one hundred researchers, and since that time, has remained on the order of one hundred researchers total, with retiring or departing researchers being replaced with new hires. In 1968, the Division underwent a significant reorganization and was renamed the Acoustics Division. Beginning in the 1990s, with the dissolution of the Soviet Union and the downsizing of the U.S. Department of Defense, federal government hiring freezes made it harder to bring on new researchers. Thus, the Division, and NRL overall, has experienced approximately two decades during which the workforce has slowly aged and there are somewhat fewer young researchers as compared to earlier periods.

Five Eras of Acoustics Division History

During the eight-plus decades from 1923 to 2008, the Acoustics Division was led by just five superintendents, each of whom had a relatively lengthy tenure. The title "Superintendent" goes back to the early days of NRL in the 1920s and has been retained to the present, referring to the director of each NRL research division. (In 2008, there are eighteen NRL research divisions, most comprising approximately one hundred researchers and staff.)

Each of the five Acoustics Division superintendents placed a significant imprint on the research directions and technical achievements during his era. It is this influence that guided the organization of this history volume. Rather than present the Division's history decade by decade, it is presented in five eras defined by the tenures of the superintendents:

Era 1: Dr. Harvey Hayes, 1923–1947, *The Formative Period and World War II Years*

Era 2: Dr. Harold Saxton, 1948–1967, *The Early Cold War Years*

Era 3: Dr. John Munson, 1968–1984, *The Mid–Cold War Years*

Era 4: Dr. David Bradley, 1985–1993, *The Waning Cold War Years*

Era 5: Dr. Edward Franchi, 1994–2008, *The Post–Cold War Years*

Note: As work on this volume continued in the period from 2009 to 2011, a few important new developments of this period were added. For example, the timeline on the pages ahead includes a section with the Division's sixth and current superintendent, Dr. Douglas G. Todoroff.

List of Key Research Thrusts and Achievements

Fifty-five technical thrusts representing significant research efforts of the Acoustics Division across the five superintendent eras are highlighted in this volume. This selection (listed on the following pages) is considered to be quite representative of the breadth of major research efforts conducted by the Sound/Acoustics Division over the eighty-five year period from 1923 to 2008. Many additional important research efforts were pursued over this long period; however, some were short-term or classified and are not covered here. In the chapters ahead, these fifty-five research thrusts and achievements are discussed in the particular era in which the technical developments reached full maturity, even though much underlying research may have been conducted in earlier periods.

Oral Histories

A review of technical achievements and accomplishments of the NRL Acoustics Division over the eight decades would be incomplete if it were presented without some first-hand accounts from the many talented researchers. It seems that great achievements occurred over the years in the Division because of the dedicated efforts of researchers working not only individually, but often in research teams. The chemistry of these individuals working together is an intangible that is hard to capture but cannot be ignored. The author interviewed several former and present researchers to attempt to fill in part of this story-behind-the-story. The author also consulted oral history transcripts already in NRL's archives. Among those people interviewed or contacted were some who worked at NRL as far back as the 1950s and even in the 1940s. For the earliest decades of the 1920s through most of the 1940s, we have waited too long and must rely on written records only.

The amount of material compiled for this history is voluminous, so a great deal of supplementary material is placed in appendices on a digital medium. The CD associated with this volume contains the oral history notes and transcripts, along with other material listed in Chapter 8.

Overview of Acoustics Division Research Focus Areas

Considering the very modest number of researchers in the NRL Sound Division prior to World War II, the accomplishments of that group were of immense importance for the U.S. Navy. In the 1920s and 1930s these researchers conducted investigations to develop sonar equipment that was installed on Navy vessels at the outset of World War II that helped significantly to turn the tide in favor of the Allied Forces during undersea warfare operations. By the late 1940s, many Sound Division researchers moved on to positions in industry or academia, but were replaced with a new crop of researchers who were eager to tackle research problems that had taken a back seat during the war years due to the urgency of the war effort. World War II era sonar systems that operated well above 10 kHz in frequency had limited capability in detection range, and many mysteries remained about why they sometimes worked well and other times worked poorly. In the 1950s, research was begun to evaluate the potential for lower frequency sonar systems with improved range capability, beginning with systems for 10 kHz, then 5 kHz, then 1 kHz and lower frequencies. Significant engineering challenges confronted the researchers as they developed and tested sonar equipment for lower and lower frequencies since the transducers became larger, heavier, and more unwieldy at these lower frequencies.

In 1943 the NRL Sound Division established the first Navy acoustic test range at Key West, Florida, in order to perform operational tests of sonar equipment. By the early 1950s several research sound barges were stationed adjacent to the NRL pier in the Potomac River that provided convenient access for researchers to perform initial testing of sonar devices. However, as the devices became larger, and as the Potomac River became more environmentally polluted, the sound barges were eliminated. By the early 1960s, the NRL Sound Division established an acoustic transducer calibration facility on Seneca Lake near Dresden, New York, that was more practical for transducer testing and was available to researchers from other Navy laboratories as well. During the 1950s and early 1960s, important new research was begun in the Sound Division on signal processing techniques, the scattering of sound from the ocean boundaries and from underwater objects with simple shapes, the speed of sound in water, and on models to understand how sound propagates in the ocean. In 1964 members of the Sonar Systems Branch assisted the Navy by fielding deep ocean search equipment to locate and photograph the lost U.S. nuclear submarine USS Thresher off the New England coast.

By the mid-1960s the NRL Sound Division was heavily involved in a major Navy long-range, low frequency active system development effort known as Project Artemis. In the 1970s there was considerable research on long-range acoustic propagation and scattering and an increased emphasis on physical acoustics, as well as initial research on fiber-optic interferometric acoustic sensors. The 1980s included much research in Arctic acoustics and was the last decade with primary focus on deep ocean acoustics. In the late 1980s NRL became involved in a decade-long series of sea trials and analyses known as Critical Sea Test designed to provide a scientific basis for low frequency active systems. In the 1990s, with the dissolution of the Soviet Union, the emphasis shifted toward research in the littoral oceans. Also in the 1990s, the acoustics researchers from the Mississippi-based Naval Ocean Research and Development Activity (NORDA)/Naval Ocean and Atmospheric Research Laboratory (NOARL) became part of the Acoustics Division.

In the 2000s the Acoustics Division has maintained a vigorous and diverse program of research in underwater acoustics with emphasis on Navy applications and extensions into new areas such as nanoscience and quantum acoustics.

Acoustics Division Timeline

The timeline on pages 6 through 16 highlights important events in the history of the Sound/Acoustics Division from the 1920s to the present.

Key Research Thrusts and Achievements

ERA 1, 1923–1947

1	Early Navy Sonar Transducer Developments	1923–1939
2	First Operational Fathometer	1924
3	Early Seismic Method Developments	1930–1933
4	First Operational U.S. Navy Sonar	1934–1940
5	First Application of Ray Theory and Normal Mode Theory	1937–1943
6	Early Developments in Harbor Defense	1939–1949
7	Tactical ASW in World War II	1941–1942
8	First Navy Acoustic Test Range	1943

ERA 2, 1948–1967

9	Sonar Graphic Indicator for Range and Range Rate Measurement	1952–1966
10	Deep Towed Seafloor Search System	1963–1980

ERA 3, 1968–1984

11	Accurate Sound Speed Measurements	1923–1974
12	Underwater Transducer Calibration Techniques	1938–1994
13	Signal Coherence and Fluctuation Phenomena	1960–2008
14	Structures and Materials for Absorbing Sound in Water	1976–2002
15	Fiber-Optic Interferometric Acoustic Sensors	1977–2005

ERA 4, 1985–1993

16	Theoretical Foundations of Acoustic Radiation from Transducers	1961–1988
17	Acoustic Imaging and Feature Extraction Techniques	1970–2006
18	Arctic and Marginal Ice Zone Acoustics	1974–1995
19	Seafloor Mapping Science	1975–1994
20	Airborne Magnetic and Gravimetric Measurement Science	1976–1994
21	Matched-Field Processing Techniques	1986–2004
22	Ocean Acoustic Computational Techniques	1986–2003
23	Critical Sea Test Research and Leadership	1988–1996

ERA 5, 1994–2008

24	Acoustics of Sediments	1943–2008
25	Navy-Standard Surface Scatter Models	1947–2008
26	Ocean Bottom Reverberation and Clutter	1952–2008
27	Scattering from Rough Interfaces	1956–2008
28	Scattering and Radiation from Underwater Shapes and Structures	1960–2006
29	Ray Theoretic Propagation Modeling	1964–1997
30	Shallow Water Acoustics	1970–2007
31	Normal Mode Propagation Modeling	1970–2000
32	Passive Acoustic Source Localization and Parameter Estimation	1975–2006
33	Ocean- and Ship-Generated Ambient Ocean Noise	1976–2008
34	Underwater Acoustic Array Systems and Processing Techniques	1976–2003
35	Transbasin and Global Scale Acoustics	1976–2008
36	Development of Navy Standard Parabolic Equation Model	1976–2008
37	Generalized Nearfield Acoustical Holography	1983–2008
38	Ocean Parameter Estimation by Acoustical Methods	1989–2008
39	Passive Acoustic Space-Time Signal Processing Techniques	1992–2000
40	Ocean Volume Reverberation	1993–2008
41	Noise and Scattering from Undersea Bubbles	1993–2008
42	Acoustic Effects Due to Oceanic Internal Waves	1997–2005
43	Mine Detection, Classification, and Mine Countermeasures	1998–2008
44	Acoustic Time-Reversal Techniques	2002–2007
45	Underwater Acoustic Communications Techniques	2003–2008
46	Underwater Intruder Defense	2004–2008
47	Biologic Tissue Imaging Analysis	2004–2008
48	Environmental Uncertainty Science	2005–2008
49	Fault Detection and Localization	2005–2008
50	Nanomechanical Devices	2001–2008
51	Global War on Terror (GWOT) Technologies	2008
52	Development of a Volumetric Acoustic Intensity Probe	2006–2008
53	Ship-Wake Acoustics	2006–2008
54	Perception-Physics-Based Sonar	2006–2008
55	Quantum Acoustic Effects	2005–2008

Era 1

Dr. Harvey C. Hayes

NRL in 1923

NRL circa 1947

1923

Early Sound Speed Measurements

First Operational Fathometer

1930

First Operational U.S. Navy Sonar

First Application of Ray and Normal Mode Theories

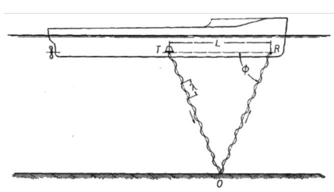
1940

Tactical ASW in World War II

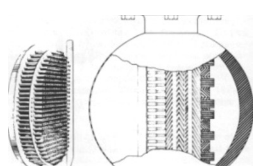
First Navy Acoustic Test Range

1947

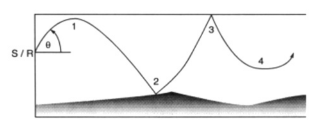
Early Surface Scatter Experiments



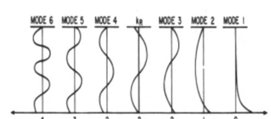
H. Hayes — First Operational Fathometer



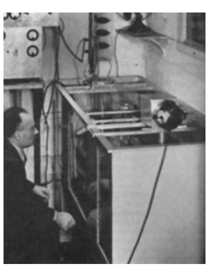
H. Hayes — First Operational U.S. Navy Sonar (QC+QB/JK)



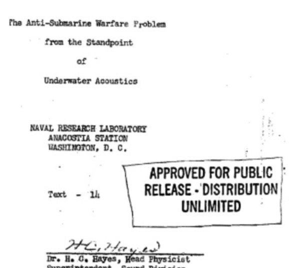
Rays



Normal Modes



E. Klein — Early Sound Speed Measurements



The Anti-Submarine Warfare Problem
from the Standpoint
of
Underwater Acoustics

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D. C.

Text - 14

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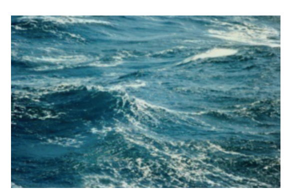
Dr. H. C. Hayes, Head Physicist
Superintendent, Sound Division

H. Hayes — Tactical ASW

Sound Station Key West



Sea Surface Scattering

1922 — USS *Stewart* ran a line of soundings across the Atlantic Ocean using an acoustic echo sounder devised by Dr. Harvey Hayes.

1923 — Dr. Harvey Hayes became the first superintendent of the NRL Sound Division. At that time, NRL had only one other research division, the Radio Division.

1923 — The Coast and Geodetic Survey ship *Guide* was equipped with a Hayes sounding instrument. Over the next five years, virtually all Coast Survey ships were equipped with deep-water acoustic sounding instruments.

1927 — NRL developed the first U.S. echo ranging sonar (XL supersonic equipment), following the principles of Langevin and employing a sandwich type of projector consisting of quartz crystal slabs cemented between steel plates. These were installed on several U.S. Navy ships during that year.

1929 — NRL developed a Rochelle salt crystal receiver (JK supersonic equipment) for passive antisubmarine warfare. The high directivity of this searchlight beam type of receiver reduced the local noise background sufficiently to increase the search range to 5 km while underway at speeds up to 9 knots.

1931 — NRL developed a Rochelle salt crystal transducer (QB equipment), doubling the range of active localization while maintaining the range of passive detection. By 1933, the Washington Navy Yard had begun production for installation on submarines.

1937 — Sound Division researcher R.L. Steinberger became the first to apply ray theory to the successful solution of underwater acoustic propagation effects.

1937 — NRL Sound Division researchers discovered that the downward bending of the sound signal path caused by vertical temperature gradients was responsible for the nonuniformity of echo ranges at various times in the same locality and/or between different localities. This led to the development of tactics to improve the escape of U.S. submarines and improve the attack against U-boats.

1939 — NRL developed methods for sound reduction in diving helmets, greatly improving communications between divers and the surface.

1940 — NRL developed a "dome shield," reducing the noise background to a point where both passive and active ranging became practical up to speeds in excess of 15 knots. This led to a hurried installation program that eventually equipped every patrol ship with a dome-shielded projector and thereby greatly improved their effectiveness against U-boats.

1942 — NRL Sound Division increased in size from fewer than ten persons to more than one hundred persons to support the World War II effort.

1943 — NRL developed remote control hydrophone systems (termed Herald) and the Sono-Radio Buoy, in cooperation with the Radio Division, for harbor protection. These devices found wide use in protecting harbors and fleet bases.

1943 — NRL established the first Navy acoustic test range at Key West, Florida.

1943 — Sound Division researchers J.M. Ide, R.F. Post, and W.J. Fry became the first to apply normal mode theory to the successful solution of underwater acoustic propagation effects in shallow water.

1946 — The Office of Naval Research (ONR) was established, with NRL as ONR's "corporate laboratory."

1947 — Sound Division's Shock and Vibration Branch transferred to the newly formed Mechanics Division and the Crystals Branch to the Solid State Division.

Era 2

Dr. Harold L. Saxton

NRL in 1960

1948

Long Range Sonar Testing

1950

Early Bottom Reverberation Measurements

Early Model Target Scattering Measurements

1960

Early Transducer Theory Research

Project Artemis

Deep Towed Seafloor Search System

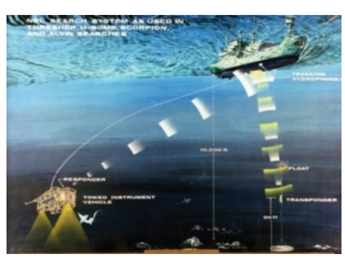
1967

R. Urick — Early Sea Bottom Reverberation

W. Neubauer — Early Acoustic Model Target Scattering

S. Hanish — Early Transducer Theory Research

10 kHz Test Sonar USS *Guavina* (SS362)



C. Buchanan — Deep Ocean Search

USNS *Mission Capistrano*, Project Artemis

1948 — Dr. Harold L. Saxton became the second superintendent of the NRL Sound Division, succeeding Dr. Harvey C. Hayes.

1959 — Dr. Harvey Hayes was awarded the first Pioneers of Underwater Acoustics Medal by the Acoustical Society of America. This award is named in honor of five pioneering underwater acoustics researchers, H.J.W. Fay, R.A. Fessenden, Harvey C. Hayes, G.W. Pierce, and P. Langevin.

1960 — Dr. Harvey Hayes was elected Honorary Fellow of the Acoustical Society of America.

1962 — NRL Sound Division established a transducer calibration facility on Seneca Lake, near Dresden, New York, to serve the needs of the Sound Division, other east coast laboratories, and the Materials Commands of the Navy Department.

1964 — Chester "Buck" Buchanan led an NRL deep ocean search team that located and photographed the lost nuclear submarine USS *Thresher*. The submarine was found in less than eight hours of searching using NRL-developed deep towing technology.

1967 — Robert J. Urick, former Sound Division researcher, published the first edition of his book: *Principles of Underwater Sound*.

Era 3

Dr. John C. Munson

NRL in 1970

NRL in 1981

1968

Early Shallow Water Research

1970

Early Arctic Acoustics Research

Early Passive Source Localization Research

Early Ocean/Shipping Ambient Noise

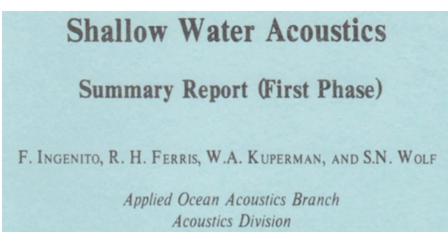
Early Parabolic Equation (PE) Modeling

Fiber-Optic Interferometric Acoustic Sensors

1980

Early Nearfield Acoustic Holography

1984

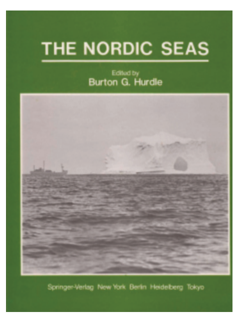

Shallow Water Acoustics

Summary Report (First Phase)

F. Ingenito, R. H. Ferris, W.A. Kuperman, and S.N. Wolf

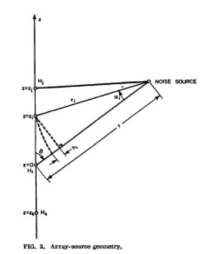
Applied Ocean Acoustics Branch
Acoustics Division

Ingenito, Ferris, Kuperman, and Wolf — Shallow Water Acoustics Report

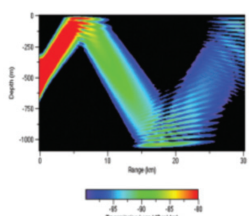


B. Hurdle — Arctic Research

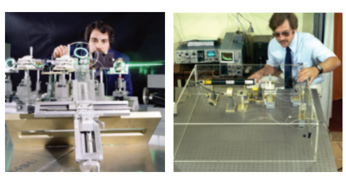
J. McGrath — Ambient Sea Noise



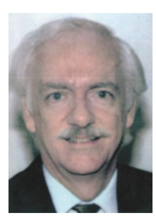
W. Hahn — Passive Localization



Early PE Modeling



J. Bucaro and J. Cole — Fiber-Optic Acoustic Sensors



E. Williams — Nearfield Holography

1968 — Dr. John C. Munson became the third superintendent of the NRL Acoustics Division, succeeding Dr. Harold Saxton.

1968 — Chester "Buck" Buchanan led an NRL deep ocean search team that located and photographed the lost nuclear submarine USS *Scorpion*. Using NRL-developed deep towing technology, *Scorpion* was found in more than 3000 meters of water after nearly six months of searching.

1969 — Dr. C.I. Vigness, former Sound Division researcher, became the first recipient (posthumously) of the Trent-Crede Medal of the Acoustical Society of America.

1970 — Dr. Harold Saxton became the fifth recipient of the Pioneers of Underwater Acoustics Medal of the Acoustical Society of America.

1973 — Dr. Elias Klein, former Sound Division researcher, became the third recipient of the Trent-Crede Medal of the Acoustical Society of America.

1974 — NRL reported the first broadband laboratory scattering measurements. Prior to this development, long pulses were used and then repeatedly changed frequencies to gain frequency coverage.

1977 — NRL developed and demonstrated the first fiber-optic acoustic sensor. Dr. Joseph A. Bucaro, working with Professor Ed Carome (John Carroll University), developed the first fiber-optic interferometric acoustic sensor and the first patent of this technology (1979).

1980 — Dr. Peter H. Rogers, former Acoustics Division researcher, received the R. Bruce Lindsay Award of the Acoustical Society of America.

1981 — Acoustics Division researcher Dr. Sam Hanish published the first of a five-volume treatise on acoustic radiation from underwater transducers, thus establishing a milestone reference work on this subject.

1982 — Acoustics Division researcher Dr. Ralph N. Baer received the R. Bruce Lindsay Award of the Acoustical Society of America.

1982 — Dr. Arthur O. Williams, Jr., former Acoustics Division researcher, became the eighth recipient of the Pioneers of Underwater Acoustics Medal of the Acoustical Society of America.

1982 — Acoustics Division researcher Dr. Earl Williams developed and implemented nearfield acoustical holography for noise characterization and control. This resulted in a technique that from a single array measurement can provide a complete global analysis of the vibration, radiation, and scattering from structures in air and in water.

Era 4

Dr. David L. Bradley

NRL in 1990

1985

Matched-Field Processing Techniques

Ocean Acoustic Computational Techniques

Critical Sea Test (CST)

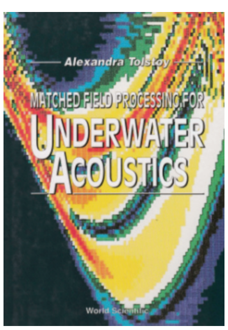
Early Ocean Parameter Estimation Methods

1990

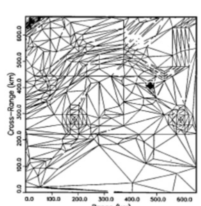
Early Passive Acoustic Signal Processing

1993

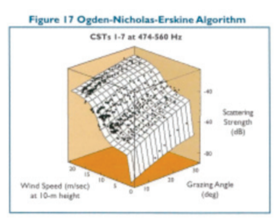
Early Bubble Scattering Research



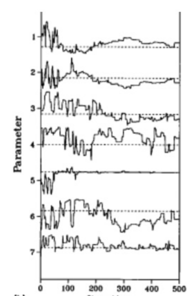
A. Tolstoy — Matched-Field Processing



W. Kuperman — Rapid Computational Techniques

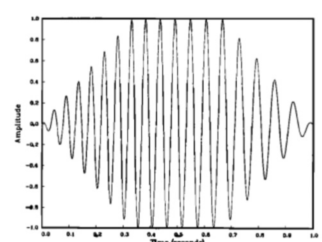


CST Analyses



M. Collins — Ocean Parameter Estimation

M. Nicholas — Salt Water Tank Facility



L. Pflug — Passive Acoustic Signal Processing

1985 — Dr. David L. Bradley became the fourth superintendent of the NRL Acoustics Division, succeeding Dr. John Munson.

1986 — Acoustics Division researcher Dr. Werner G. Neubauer published the reference monograph *Acoustic Reflection from Surfaces and Shapes*, establishing NRL's preeminence in this topic.

1986 — NRL Acoustics Division published a milestone reference monograph (Dr. Burton G. Hurdle, editor) titled *The Nordic Seas* that represented the first multinational, multidisciplinary, detailed environmental characterization of the Greenland-Norwegian-Barents Sea area.

1988 — Robert J. Urick, former Acoustics Division researcher, became the tenth recipient of the Pioneers of Underwater Acoustics Medal of the Acoustical Society of America.

1989 — NRL completed construction of the Laboratory for Structural Acoustics (Bldg. 5), a unique facility for conducting acoustic scattering measurements.

1991 — Dr. Michael B. Porter, former Acoustics Division researcher, received the A.B. Wood Medal and Prize of the U.K. Institute of Acoustics.

1992 — Dr. Christopher H. Harrison, former Acoustics Division researcher, received the A.B. Wood Medal and Prize of the U.K. Institute of Acoustics.

1993 — Acoustics Division researcher Dr. Michael Collins developed a split-step Padé solution for the parabolic equation (PE) method. Collins's Range-dependent Acoustic Model (RAM) later transitioned to become the Navy Standard Parabolic Equation (NSPE) model.

1993 — Dr. Michael Collins received the R. Bruce Lindsay Award from the Acoustical Society of America.

1993 — Dr. Homer P. Bucker, former Acoustics Division researcher, became the twelfth recipient of the Pioneers of Underwater Acoustics Medal of the Acoustical Society of America.

Era 5

Dr. Edward R. Franchi

NRL-DC and NRL-Stennis in 2008

1994

Laboratory for Structural Acoustics

Acoustic Effects Due to Internal Waves

2000

Underwater Acoustic Communications

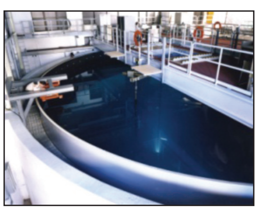
Underwater Intruder Defense

Environmental Uncertainty Science

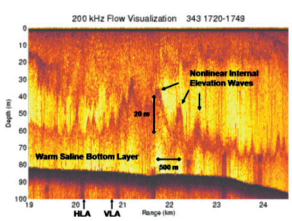
Nanomechanical Devices

Global War on Terror Technologies

2008



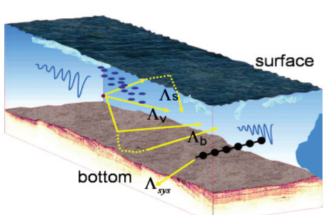
B. Houston — Laboratory for Structural Acoustics



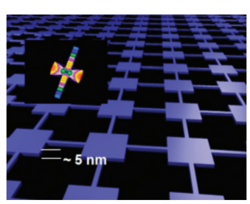
P. Mignerey — Internal Wave Effects

T.C. Yang — Acoustic Communications

S. Stanic — Intruder Defense



S. Finette — Environmental Uncertainty



B. Houston — Nano-Arrays

B. Houston — Global War on Terror

1994 — Dr. Edward R. Franchi became the fifth superintendent of the NRL Acoustics Division, succeeding Dr. David L. Bradley who became Technical Director of NATO's SACLANTCEN (Supreme Allied Command Atlantic Undersea Research Centre) in La Spezia, Italy.

1995 — Acoustics Division researcher Dr. William A. Kuperman became the thirteenth recipient of the Pioneers of Underwater Acoustics Medal of the Acoustical Society of America.

1995 — Acoustics Division researcher Dr. Nicholas C. Makris received the A.B. Wood Medal and Prize of the U.K. Institute of Acoustics.

1996 — The Technical Cooperation Program (TTCP) Group Achievement Award for the TTCP Environmental Signal Processing Experiments (TESPEX) was awarded to NRL's Dr. W.A. Kuperman, Dr. M.D. Collins, J.S. Perkins, T.L. Krout, and J. Goldstein.

1999 — The permanent Dr. Harvey C. Hayes Historical Memorabilia Collection and Room was established in the NRL Quarters A historical residence.

1999 — Acoustics Division researcher Dr. Earl Williams published a milestone reference monograph titled *Fourier Acoustics: Sound Radiation and Nearfield Acoustical Holography*, establishing NRL as the international acoustics community leader in this field.

1999 — Dr. Michael F. Czarnecki, former Acoustics Division researcher, received the National Defense Industrial Association Award for Technical Achievement in Undersea Warfare – Bronze Medal.

2000 — Acoustics Division researcher Dr. Brian H. Houston received the National Defense Industrial Association Award for Technical Achievement in Undersea Warfare – Bronze Medal.

2001 — Dr. Homer P. Bucker, former Acoustics Division researcher, received the National Defense Industrial Association Award for Technical Achievement in Undersea Warfare – Bronze Medal.

2002 — NRL developed the first five-beam scanning laser Doppler vibrometer capable of mapping the two in-plane displacement components in addition to the usual normal component.

2002 — Acoustics Division researcher Dr. Earl Williams developed the first spherical nearfield microphone array which allowed real-time imaging and display of acoustic intensity.

2002 — Dr. Michael Collins received NRL's E.O. Hulburt Annual Scientific Award.

2003 — Acoustics Division researcher Dr. Roger C. Gauss received the National Defense Industrial Association Award for Technical Achievement in Undersea Warfare – Bronze Medal.

2004 — TTCP Group Achievement Award for Multistatic ASW Experimentation was awarded to Drs. Roger C. Gauss and Fred T. Erskine.

2005 — A team led by Dr. Brian Houston demonstrated the first structural acoustics based mine hunting sonar, the Low Frequency Broadband (LFBB) sonar. In 2007, the LFBB technology transitioned to a Navy acquisition program established to introduce it into the Fleet.

2006 — NRL (Dr. Roger Gauss) developed the Navy-standard software algorithms for the accurate prediction of acoustic scattering from the sea surface that is in use for sonar system performance prediction at all Navy commands.

2007 — Dr. William M. Carey, former Acoustics Division researcher, became the seventeenth recipient of the Pioneers of Underwater Acoustics Medal of the Acoustical Society of America.

Superintendent: Dr. Douglas G. Todoroff

2009 — Dr. Douglas G. Todoroff became the sixth superintendent of the NRL Acoustics Division, succeed ing Dr. Edward Franchi who became NRL's Associate Director of Research for the Ocean and Atmospheric Science and Technology Directorate. Dr. Todoroff joined NRL after a three-year appointment to NATO as Deputy Director of the NATO Undersea Research Centre (NURC) in La Spezia, Italy.

2010 — Dr. George V. Frisk, former Acoustics Division researcher, was elected President of the Acoustical Society of America for 2010–2011.

2010 — Dr. Dirk Tielbuerger, former Acoustics Division visiting scientist, became Director of the NATO Undersea Research Centre (NURC) in La Spezia, Italy.

2011 — Dr. Edward R. Franchi received the TTCP 2010 Personal Achievement Award for his contributions to TTCP Collaboration on the Maritime Systems Group, Technical Panel on ASW Systems and Technology, as Panel Chairman from 2002 to 2009.

2012 — Dr. David L. Bradley, fourth Acoustics Division superintendent, was elected President of the Acoustical Society of America for 2012–2013.

CHAPTER TWO

NRL in the Acoustics Research and Development Community: Awards and Research Collaborations

18 Awards

21 International Scientist Exchanges

21 The NRL Acoustics Division and the Office of Naval Research

22 The NRL Acoustics Division and the Maury Center for Ocean Science, the Naval Oceanographic Office, and the Office of Naval Research ASW Environmental Acoustic Support Detachment

24 The NRL Acoustics Division and the NATO Undersea Research Centre

Awards

During the eight-plus decades of performing basic and applied research for the Navy, numerous researchers in the NRL Sound/Acoustics Division have received awards recognizing their important contributions to the Navy and the wider underwater acoustics community.

Pioneers of Underwater Acoustics Medal

One of the most notable awards an acoustics researcher can receive is the Acoustical Society of America's **Pioneers of Underwater Acoustics Medal**. This medal was first awarded in 1959 and its first recipient was Dr. Harvey C. Hayes, the NRL Sound Division's first superintendent. It is awarded to recognize outstanding contributions to the science of underwater acoustics by an individual irrespective of nationality. The award is named in honor of five early pioneers in underwater acoustics research, one of whom is Hayes himself: H.J.W. Fay, R.A. Fessenden, H.C. Hayes, G.W. Pierce, and P. Langevin. Of the seventeen recipients of this medal between 1959 and 2007, seven conducted research in the NRL Acoustics Division. The following page shows all recipients of this award and the cited achievements of the NRL recipients.

Other Awards

Acoustics Division researchers have been the recipients of numerous other awards. Among these is the Acoustical Society of America's **R. Bruce Lindsay Award** presented each year to a member of the Society who is under thirty-five years of age, and who during a period of two or more years immediately preceding the award has been active in the affairs of the Society and has contributed substantially, through published papers, to the advancement of theoretical or applied acoustics, or both. Recipients of this award who have been researchers in the Acoustics Division include Dr. Peter H. Rogers (1980), Dr. Ralph N. Baer (1982), and Dr. Michael D. Collins (1993).

Between 1929 and 2011 the Acoustical Society of America has designated eighteen researchers as **Honorary Fellows**. This award is given to a person who has attained eminence in acoustics or who has rendered outstanding service to acoustics. Dr. Harvey C. Hayes was the seventh recipient of this award, in 1960.

The **Trent-Crede Medal** of the Acoustical Society of America is presented to an individual, irrespective of nationality, age, or society affiliation, who has made an outstanding contribution to the science of mechanical vibration and shock, as evidenced by publication of research results in professional journals or by other accomplishments in the field. Two former Sound Division researchers have received this medal: Dr. Carl I. Vigness (posthumously in 1969) and Dr. Elias Klein (in 1973).

The **A.B. Wood Medal and Prize** of the Institute of Acoustics (United Kingdom) is presented to an individual, preferably under thirty-five years of age, for distinguished contributions in the application of acoustics; preference is given to candidates whose work is associated with the sea. The award is made in alternate years to persons residing in (1) the United Kingdom and (2) the United States of America or Canada. This award has been granted to four Acoustics Division researchers or former researchers: Dr. Michael B. Porter (1991), Dr. Christopher H. Harrison (1992), Dr. Michael D. Collins (1993), and Dr. Nicholas C. Makris (1995).

The National Defense Industrial Association (NDIA) Undersea Warfare Division (UWD) annually presents its **NDIA Award for Technical Achievement in Undersea Warfare – Bronze Medal**. This medal is awarded to recognize outstanding achievements in science or engineering in the field of undersea warfare. Recent recipients include a number of present or former Acoustics Division researchers: Dr. Michael F. Czarnecki (1999), Dr. Brian Houston (2000), Dr. Homer Bucker (2001), Dr. William Kuperman (2002), and Dr. Roger Gauss (2003).

The Technical Cooperation Program (TTCP) is an international organization concerned with cooperation on defense science and technology matters, including national security and civil defense. Its membership comprises Australia, Canada, New Zealand, the United Kingdom, and the United States. In recent decades, researchers in the Acoustics Division have been active in collaborative experimentation under the auspices of TTCP's Maritime Systems Group, Technical Panel on ASW Systems and Technology. In 1996 the TTCP Group Achievement Award for the TTCP Environmental Signal Processing Experiments (TESPEX) was presented to Dr. W.A. Kuperman, Dr. M.D. Collins, J.S. Perkins, T.L. Krout, and J. Goldstein. In 2004 the Group Achievement Award for TTCP Multistatic ASW Experimentation was presented to Drs. R.C. Gauss and F.T. Erskine. In 2011 Dr. E.R. Franchi (fifth Acoustics Division superintendent) received The Technical Cooperation Program 2010 Personal Achievement Award. This award is in recognition for his contributions to TTCP Collaboration on the Maritime Systems Group, Technical Panel on ASW Systems and Technology, which he chaired from 2002 to 2009.

Page 20 lists selected awards received since 1980.

Acoustical Society of America
Pioneers of Underwater Acoustics Medal

The Pioneers of Underwater Acoustics Medal is presented to an individual, irrespective of nationality, age, or society affiliation, who has made an outstanding contribution to the science of underwater acoustics, as evidenced by publication of research results in professional journals or by other accomplishments in the field. The award was named in honor of five pioneers in the field: H.J.W. Fay, R.A. Fessenden, H.C. Hayes, G.W. Pierce, and P. Langevin. Seven recipients of this medal spent time conducting research within the Sound/Acoustics Division of NRL. They are shown in bold.

1959 – Harvey C. Hayes – For outstanding contributions to the science of underwater acoustics. His far sighted recognition of the challenging technical problems in this branch of acoustics and the potentiality of the application of their solution to the defense needs of the Nation resulted in the first sustained research program in underwater sound. (Abstracted)
1961 – Albert B. Wood
1963 – J. Warren Horton
1965 – Frederick V. Hunt
1970 – Harold L. Saxton – For his contributions to both knowledge and practice of underwater acoustics, and particularly for innovative solutions to problems of signal processing and sonar systems and transducers.
1973 – Carl Eckart
1980 – Claude W. Horton, Sr.
1982 – Arthur O. Williams, Jr. – For his contribution to the theory of normal mode propagation of sound in the ocean, to the theory of sound radiation from piston sources, and to the education of graduates and undergraduates.
1985 – Fred N. Spiess
1988 – Robert J. Urick – For his book "Principles of Underwater Sound" and his many experiments on sound propagation, scattering, reverberation, and ambient noise.
1990 – Ivan Tolstoy
1993 – Homer P. Bucker – For ground-breaking work integrating signal processing and acoustic modeling.
1995 – William A. Kuperman – For the development and application of models for ocean acoustic propagation and scattering.
2000 – Darrell R. Jackson
2002 – Frederick D. Tappert
2005 – Henrik Schmidt
2007 – William M. Carey – For contributions to understanding ocean ambient noise and in defining the limits of acoustic array performance in the ocean.

Selected Awards Received by NRL Acoustics Division Researchers in Recent Decades

Name	Award	Year
P.H. Rogers*	R. Bruce Lindsay Award	1980
R.N. Baer	R. Bruce Lindsay Award	1982
M.B. Porter*	A.B. Wood Medal and Prize of the Inst. of Acoustics	1991
C.H. Harrison*	A.B. Wood Medal and Prize of the Inst. of Acoustics	1992
M.D. Collins	R. Bruce Lindsay Award	1993
M.D. Collins	A.B. Wood Medal and Prize of the Inst. of Acoustics	1994
N.C. Makris*	A.B. Wood Medal and Prize of the Inst. of Acoustics	1995
W.A. Kuperman, M.D. Collins, J.S. Perkins, T.L. Krout, J. Goldstein	TTCP Group Achievement Award–TESPEX	1996
M.F. Czarnecki*	NDIA Bronze Medal	1999
B.G. Hurdle	IEEE Oceanic Engineering Society Distinguished Technical Achievement Award	1999
L.R. Dragonette	NRL-Edison Sigma Xi Applied Science Award	1999
B.H. Houston	NDIA Bronze Medal	2000
H. Bucker*	NDIA Bronze Medal	2001
M.D. Collins	NRL E.O. Hulburt Annual Scientific Award	2002
W.A. Kuperman*	NDIA Bronze Medal	2002
R.C. Gauss, F.T. Erskine	TTCP Group Achievement Award–Multistatic ASW	2003
R.C. Gauss	NDIA Bronze Medal	2003
P.M. Jordan	Top Navy Scientists and Engineers of the Year/ Emerging Investigator	2007
B.H. Houston	Navy Meritorious Civilian Service Award	2008
M.H. Orr	Navy Meritorious Civilian Service Award (ONR)	2009
E.G. Williams	Per Bruel Gold Medal for Noise Control and Acoustics	2009
B.H. Houston	Dr. Delores Etter Top Scientists and Engineers of the Year	2011
E.R. Franchi	TTCP 2010 Personal Achievement Award	2011
W.A. Kuperman*	Walter Munk Award for Distinguished Research in Oceanography Related to Sound and the Sea	2011

* Former Acoustics Division researcher at time of award

International Scientist Exchanges

In recent decades the Acoustics Division has been enriched by having scientists from the international community come for extended research visits (typically one to two years). Nations that have sent exchange scientists in recent years include Australia, Canada, Germany, and New Zealand.

International Visiting Scientists in the NRL Acoustics Division in Recent Decades

Michael Guthrie	New Zealand	1981–1983
Arthur Collier	Canada	1982–1984
A.K. Steele	Australia	1983–1984
Dirk Tielbuerger	Germany	1993–1994
Henry Lew	Australia	1998–1999
Frank Gerdes	Germany	2010–2011

The NRL Acoustics Division and the Office of Naval Research

Establishment of ONR

The Office of Naval Research (ONR) was established in 1946. Its history has been well documented elsewhere (see, for example, the 1990 book by Harvey M. Sapolsky, Science and the Navy – The History of the Office of Naval Research). ONR became the first permanent U.S. federal government agency dedicated to sponsoring scientific research. The variety of research sponsored by ONR over the years is at least as diverse as the research conducted at NRL.

From the outset in 1946, the Naval Research Laboratory was considered to be the "corporate laboratory" for ONR and a very close relationship ensued. Vice Admiral Harold G. Bowen, who was a formidable force in establishing ONR in 1946 and became the first Chief of Naval Research, had been the director of NRL during the onset of World War II (1939 to 1942). He was thus well acquainted with NRL's research capabilities.

Acoustics Division–ONR Connections

Over the years, the Acoustics Division at NRL has maintained a close working relationship with program management offices at ONR. ONR has consistently supported the Acoustics Division's basic and applied research efforts at modest levels; however, the NRL researchers have always found it necessary to seek funding support from many other sources within the Navy and the Department of Defense.

In recent decades, a number of experienced senior-level Acoustics Division researchers have assumed program management responsibilities at ONR. To name just a few, these have included Dr. Ellen Livingston, Dr. David Drumheller, Dr. Luise Couchman, Dr. Susan Numrich, Dr. Raymond Fitzgerald, Charles Votaw (Office of Naval Technology), Dr. John Bergin, and Dr. Patrica Gruber (who recently served as ONR's Director of Research). There have also been ONR program managers in ocean sciences who have assumed management positions in NRL's Acoustics Division, including Dr. David Bradley (fourth superintendent), Dr. Douglas Todoroff (sixth superintendent), and Dr. Marshall Orr (current associate superintendent). Further, numerous scientists from other NRL divisions have assumed senior management positions at ONR, including Dr. Fred Saalfeld, Dr. James DeCorpo, Dr. Steven Ramberg, Dr. Joseph Lawrence, and Dr. Frank Herr. Also, in recent decades, two of NRL's Commanding Officers have later been promoted to the position of Chief of Naval Research: Adm. William Miller and Adm. Paul Gaffney. NRL's current Commanding Officer, Capt. Paul Stewart, previously served as ONR's Deputy Director for the Ocean Battlespace Sensing Department and division director of the Ocean, Atmospheric and Space Sensing and Systems Division; additionally, he served as the U.S. National Liaison Officer to the NATO Undersea Research Centre (NURC) in La Spezia, Italy.

The NRL Acoustics Division and the Maury Center for Ocean Science, the Naval Oceanographic Office, and the Office of Naval Research ASW Environmental Acoustic Support Detachment

Among the important research "connections" for the Sound/Acoustics Division in the 1960s through the mid-1970s were the collaborative interactions between researchers in the NRL Oceanology Directorate and researchers affiliated with the Maury Center for Ocean Science. The Maury Center included participants from the Naval Oceanographic Office (NAVOCEANO) and the Office of Naval Research. For most of a decade, these activities were all colocated at the NRL Washington, D.C., campus.

The NRL Oceanology Directorate was led by Dr. Ralph Goodman. It included the Acoustics Division, the Underwater Sound Reference Division (near Orlando, Florida), the Ocean Sciences Division, the Ocean Technology Division, and the Ship Facilities Group.

The Maury Center for Ocean Science was led by Dr. J.B. Hersey. Within the Maury Center was the Long Range Acoustic Propagation Project (LRAPP), managed by Dr. Roy Gaul, which conducted many important deep ocean acoustic propagation measurement sea trials. In addition, the Maury Center housed ONR's Ocean Science and Technology Division, under Gordon Hamilton, and ONR's ASW Environmental Acoustic Support (AEAS) Detachment, headed by Commander Pete Tatro. The Maury Center further included the NAVOCEANO Ocean Science Department, led by E.L. Ridley.

On the following page is an organizational chart for these offices circa 1975.

In memoriam

~ Dr. Ralph Goodman ~

Dr. Ralph Goodman, NRL's Associate Director of Oceanology from 1968 to 1976, died in March 2008. He made many friends and colleagues in acoustics and ocean science during his long career in these fields. In fact, he was active in the study of the physical and acoustical properties of ocean bubbles only days before he died.

Besides his broad technical contributions, Ralph will be remembered for his technical leadership at NRL, the Naval Ocean Research and Development Activity (NORDA, Bay St Louis, MS, now a part of NRL), the SACLANT ASW Research Centre (La Spezia, Italy), and the Center for Physical Acoustics (Oxford, MS). The Chief of Naval Research presented him an award of Distinguished Career Recognition in appreciation of his exceptional leadership and research contributions to the U. S. Navy and the Office of Naval Research. He was praised by the NRL's Director of Research for helping NRL achieve "a remarkable status in the areas of ocean science, ocean technology, and underwater acoustics."

Ralph's infectious enthusiasm for the ocean and how it could be understood through application of good science led to outstanding growth wherever he went. He oversaw the scientific outfitting of USNS *Hayes* at NRL and *Alliance* at La Spezia. His intuition in conversation stimulated many researchers' new thoughts, he never shrank from challenges, and he admirably represented his organizations nationally and internationally.

Ralph received his Ph.D in theoretical solid state physics from the University of Michigan in 1958, but then joined the Naval Electronics Laboratory in San Diego to begin his life-long interest in underwater acoustics. He returned to physics, joining the physics faculty at Colorado State University in 1959, where he remained until he came to NRL, except for two years at La Spezia. He was affiliated with the University of Southern Mississippi in research and was active in the Acoustical Society of America as contributor, supporter, and associate editor. Also, he participated in summer studies for the National Academy of Sciences. ◆

~ written by Sam Marshall

Remembrance of Dr. Ralph Goodman reprinted from the Oct. 26, 2009, issue of *Labstracts*, NRL's internal newspaper.

Organization Chart for Ocean Science Activities Colocated at NRL circa 1975

NRL Code

8000 NRL Oceanology Directorate
Dr. R.R. Goodman (Associate Director of Research)

8001 W.L. Brundage (Special Assistant)
8003 D. Steiger (Shipboard Computing Group)
8004 A.L. Gotthardt (Ship Facilities Group)

8100 Acoustics Division
Dr. J.C. Munson (Superintendent)
8101 R.R. Rojas (Adv. Undersea Surveillance Program)
8102 J.L. Williams (Administrative Officer)
8103 W.J. Finney (Advanced Projects Group)
8104 Dr. S. Hanish (Senior Scientist)
8105 F.C. Titcomb (Special Assistant)
8108 R.C. Swenson (System Engineering Staff)
8109 C.R. Rollins (Systems Analysis Group)
8120 R.H. Ferris (Shallow Water Surveillance Branch)
8130 Dr. C.M. Davis, Jr. (Physical Acoustics Branch)
8150 W.J. Trott (Transducer Branch)
8160 Dr. B.B. Adams (Large Aperture Systems Branch)
8170 B.G. Hurdle (Propagation Branch)

8200 Underwater Sound Reference Division
R.J. Bobber (Superintendent)
8205 J.M. Taylor (Scientific Staff Assistant)
8207 V.A. Lombardo (Personnel Officer)
8210 R.J. Johnson (Security and Safety)
8220 J.C. Michael (Supply and Fiscal Officer)
8240 W.V. Carlson (Engineering Services)
8250 J.D. George (Computer Branch)
8260 M.H. Rhue (Electronics Branch)
8270 I.D. Groves (Standards Branch)
8280 Dr. J.E. Blue (Measurements Branch)

8300 Ocean Sciences Division
Dr. V.J. Linnenbom (Superintendent)
8301 Dr. J.O. Elliot (Assoc. Supt. for Ocean Science Applications and Non-Acoustic ASW)
8302 R. Nekritz (Scientific Staff Assistant)
8303 R.M. Baltzell (Administrative Officer)
8304 Dr. A.H. Schooley (Senior Research Scientist)
8310 H.L. Clark (Applied Oceanography Branch)
8320 Dr. L.H. Ruhnke (Atmospheric Physics Branch)
8330 Dr. C.H. Cheek (Chemical Oceanography Branch)
8340 Dr. J.M. Witting (Physical Oceanography Branch)
8350 Dr. D.W. Strasburg (Marine Bio. and Biochem. Branch)

8400 Ocean Technology Division
Dr. J.P. Walsh (Superintendent)
8401 C.L. Buchanan (Assoc. Superintendent)
8402 A.G. Branham (Administrative Officer)
8403 Dr. R.O. Belsheim (Consultant)
8404 H.C. Pusey (Shock/Vibration Info Center)
8410 G.O. Thomas (Ocean Engineering Branch)
8420 H.A. Johnson (Ocean Instrumentation Branch)
8430 Dr. J.M. Krafft (Mechanics of Materials Branch)
8440 Dr. F. Rosenthal (Applied Mechanics Branch)

9400 Maury Center for Ocean Science
Dr. J.B. Hersey (Director)
Cdr. A.G. Brookes, Jr. (Military Deputy)
Dr. R.D. Gaul (LRAPP Manager)
9410 G. Hamilton (ONR Ocean Science and Technology Division)
9430 Cdr. P.R. Tatro (AEAS Support Detachment)

9420 Naval Oceanographic Office Ocean Science Department
E.L. Ridley (Director)
A.G. Trogolo (Scientific Staff Assistant)
A.J. Heckelman (Physical Science Coordinator)
D.L. Whitlock (Administrative Officer)
J.V. Lackie (Visual Information)
R.S. Winokur (Undersea Surveillance Oceanographic Project)
H.V. French (Airborne Oceanography Project)
E.L. Ridley (Physical Oceanography Division)
Dr. H.C. Eppert, Jr. (Ocean Floor Anal. Division)
R.S. Winokur (Acoustical Oceanography Division)

The NRL Acoustics Division and the NATO Undersea Research Centre

In the late 1950s, the NATO Council emphasized the need for greater scientific cooperation among member nations. This resulted in the creation of a NATO international scientific research organization to study the fundamental problems of antisubmarine warfare and to provide an exchange center for work already being performed by the different national laboratories. The NATO Supreme Allied Commander Atlantic (SACLANT) approved the new institution that became known as the SACLANT ASW Research Centre (SACLANTCEN), located in La Spezia, Italy. In 1988 its name was changed to the SACLANT Undersea Research Centre. In 2004 the name was changed to the NATO Undersea Research Centre (NURC).

For decades, NRL researchers and managers with close ties to the Acoustics Division have assumed key positions at NURC. Dr. John Ide, an assistant superintendent of the NRL Sound Division in the 1940s, became SACLANTCEN's first technical director in 1961. In the 1980s Dr. Ralph Goodman served as SACLANTCEN's technical director, after having served as NRL's Aassociate Director of Research for Oceanology, then as the first technical director of the Naval Ocean Research and Development Activity (NORDA). In the 1990s Dr. David Bradley served as SACLANTCEN's technical director, after having been the fourth superintendent of NRL's Acoustics Division. Dr. Douglas Todoroff, present superintendent of NRL's Acoustics Division, previously served as Deputy Director of NURC. Further, numerous Acoustics Division researchers have served in extended research appointments at NURC. (In 2010, Dr. Dirk Tielbuerger, a former visiting researcher in the Acoustics Division, became technical director at NURC.)

The following table is a detailed list of NRL Acoustics Division persons who served on the staff of NURC (prepared by Dr. Jonathan Berkson, previously a researcher in the Acoustics Division and now with the U.S. Coast Guard).

NRL Sound/Acoustics Division Persons Who Served on the Staff of the NATO Undersea Research Centre (NURC), La Spezia, Italy (Formerly SACLANT ASW Research Centre)

This list includes researchers from the NRL Sound/Acoustics Division as well as from other Navy acoustics groups that were absorbed into NRL. It was compiled by Jonathan Berkson using the *Yearbook of Centre Staff 1959–2008*, SACLANTCEN/NURC Alumni Association, 2008; the mid-decade NRL Sound/Acoustics Division personnel lists in the present volume; and other directories. The SACLANTCEN/NURC yearbook lists only persons who served on the staff and thus would not include NRL personnel who worked on joint projects at the Centre.

The list does not include ten individuals from other NRL (or NRL predecessor) divisions (S. Ramberg, F. Askari, P. Pistek, R. Root, M. Richardson, S. Piacsek, A. Warn-Varnas, D. Lott, H. Perkins, and P. Ranelli). Also not listed are two acousticians (R. Goodman and R. Martin) in administrative positions who significantly shaped policies and programs of the acoustic groups.

Key:
ador-s = Special Assistant, Office of Associate Director of Research NRL-DC
m = Maury Center for Ocean Science (administered by NRL, the Naval Oceanographic Office, and the Office of Naval Research, and located at NRL-DC)
mtd = Marine Technology Division, NRL-DC
n-o = Ocean Acoustics Division, Naval Ocean Research and Development Activity (NORDA) (predecessor of NRL-Stennis Space Center, Mississippi)
t = Exchange scientist at NRL-DC from Admiralty Research Laboratory, Teddington, U.K. for 2 years

NAME	NRL PERSONNEL LISTS	PERIOD AT SACLANTCEN/NURC
John M. Ide	1945	1961–1964 (Director)
Walter L. Brundage	1965, 1975ador-s; 1985mtd	1966–1968
Frank Ingenito	1975, 1985	1990–1995
William A. Kuperman	1975, 1985	1976–1981
Donald R. DelBalzo	1975, 1995	1991–1994
Richard M. Heitmeyer	1975, 1995, 2005	1982–1988
Orest I. Diachok	1975m, 1985	1992–1996
Jonathan M. Berkson	1975m, 1995	1983–1986
Chris H. Harrison	1977t	1999–present
David L. Bradley	1985	1993–1996 (Director)
Michael D. Max	1985	1991–1996
Michael B. Porter	1985	1987–1991
B. Edward McDonald	1985n-o, 1995, 2005	1997–2005
Hassan B. Ali	1995	1982–1986
Ronald A. Wagstaff	1985n-o, 1995	1979–1982
Kevin D. LePage	2005	1997–2002; 2008–present
Wayne A. Kinney	1985n-o, 1995, 2005	1988–1991
Douglas G. Todoroff	- - - -	2005–2008 (Deputy Director)

CHAPTER THREE

Era 1: Dr. Harvey C. Hayes The Formative Period and World War II Years 1923 to 1947

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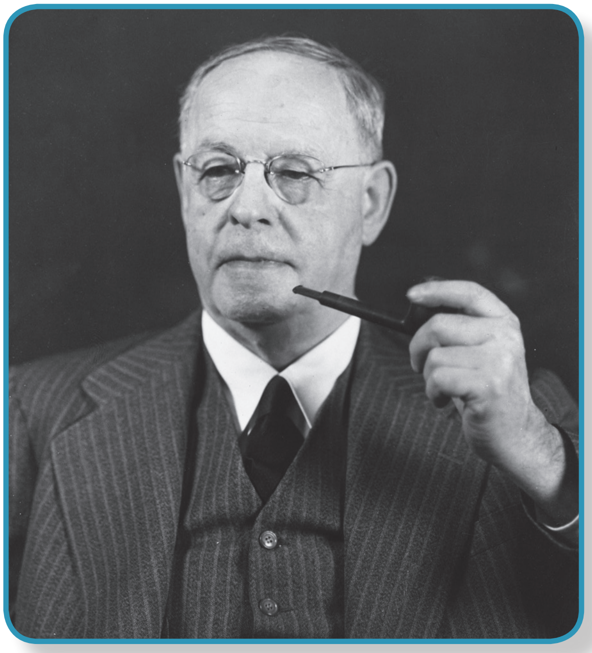


Harvey Cornelius Hayes [redacted] a rural community near Binghamton in which his parents owned a farm. He had two siblings, a brother and a sister. In his youth he assisted with daily farm chores. To make the chore of splitting wood a bit easier, he designed and built a water-powered sawmill on the farm. When it came time for him to attend high school, there was no high school nearby so his parents bought him a suit and sent him to a neighboring town to live with family acquaintances and attend high school there. In short order, Hayes ended up as principal of the high school. He then attended a Normal School (Teachers College) briefly. He considered applying to Columbia University, but changed his mind, then applied and was accepted to Harvard University. His goal was to become a lawyer. However, a physics professor loaned him some physics books to study for a qualifying examination. He did so well that the physics professor convinced Hayes to pursue a career in physics. He received an A.B. degree in physics from Harvard in 1907, then entered the graduate school at Harvard and received an A.M. degree in physics in 1908.

During academic breaks at Harvard, Hayes went to Dublin, New Hampshire, to do some tutoring. It was there that he met his future wife Katherine (Moore). Upon completion of his Ph.D. in physics at Harvard University in 1911, Hayes taught at Harvard for a while and then in 1913 he accepted a faculty position at Swarthmore College near Philadelphia, Pennsylvania, in the physics department. When World War I came along, Hayes heard about a physics research group at the Navy Experimental Station at Fort Trumbull in New London, Connecticut, that was attempting to locate submarines by means of underwater acoustics. He requested and was granted a year of leave from Swarthmore College to join the group in New London. During that year, the progress on the underwater sound research was sufficiently good that Hayes requested a second year of leave. However, Swarthmore College wanted him to return to their campus. The result was that Hayes decided to leave Swarthmore in 1917 to work full-time on his research in Connecticut. Following a period of productive research in New London, Hayes transferred to a Navy research station at Annapolis, Maryland.

When the construction of the Naval Research Laboratory in Washington, D.C., was completed in 1923, Hayes transferred there to become superintendent of the Sound Division. At that time there was only one other research division at NRL, the Radio Division. Hayes remained at NRL for over two decades as Sound Division superintendent until the late 1940s. In the period prior to World War II, Hayes led a small group of only five to eight researchers that was devoted to developing active (echo-ranging) sonar and improved passive (listening) sonar for the Navy's surface ships and submarines. They developed a tunable type of sonar that found widespread use in World War II. They conducted field experiments to take detailed measurements on the propagation of sound in oceanic acoustic ducts. They developed techniques for silencing "singing" propellers in Navy ships and aircraft carriers by sharpening propeller edges.

During World War II, the Sound Division expanded in size about twentyfold and NRL researchers conducted numerous experiments to address Navy concerns regarding sonar performance. Hayes and his NRL Sound Division colleagues made significant advances in a variety of sonar research areas. These included the development of communications equipment for divers, torpedo countermeasures, the development of streamlined sonar domes for ships, control and stabilization of sonar transducers, methods for localization of a submerged target beyond the resolution of the sonar beam, and coordination of sonar systems with fire-control systems. Hayes published his proposed methodology on the use of sonar for defeating the submarine threat in which he reduced the factors of detection and attack to simple form. By the end of World War II, Hayes was engaged in developing new attack sonar systems for surface ships and was developing methods to exploit the blimp and helicopter as sonar platforms.

In the period immediately following World War II, Hayes initiated within the Sound Division new research efforts on shock and vibration, crystal development, physiological acoustics, and other topics. Also, for a few years in the period following World War II, the Navy Experimental Station in New London, Connecticut, became a field station of NRL, reporting to Dr. Hayes. The New London field station later became the U.S. Navy Underwater Sound Laboratory (NUSL).

In 1947, after thirty years of government service, Dr. Hayes retired from NRL and moved to a farm in Dublin, New Hampshire, where he remained until his death in 1968 at age eighty-nine. At the time of death, he was survived by his widow, Katherine Moore Hayes, his daughter Shirley (Mrs. George E. Sermon), and three sons: Gordon B. Hayes, Harvey C. Hayes, Jr., and Benjamin O. Hayes. In the early 1940s Gordon Hayes became a researcher in the Radar Division at NRL. He then transferred to NUSL in New London, where he worked on sonar systems including torpedo countermeasures, environmental acoustics measurements, and development of the AN/SQS-36 sonar system. Among the stepchildren of Gordon Hayes are two notable researchers in underwater acoustics: Bernard (Bernie) Cole who worked at NUSL (later called the Naval Underwater Systems Center) in New London from 1960 to 1995; and James (Jim) Cole who worked in the NRL Acoustics Division from 1978 to 1986 developing fiber-optic acoustic sensors and is currently in the NRL Optical Sciences Division.

Dr. Harvey C. Hayes with toddler son Gordon Hayes, circa 1921. (Photo courtesy of James Cole)

Dr. Hayes was the recipient of numerous accolades and awards. Among these were the Navy's Distinguished Civilian Service Award (bestowed in 1945 by Secretary of the Navy James Forrestal), the first Pioneers of Underwater Acoustics Award from the Acoustical Society of America (ASA) (1959), and Honorary Fellow of the ASA (1960). He was a fellow of the American Physical Society and a member of the Washington Academy of Sciences, the American Geophysical Union, the Philosophical Society of Washington, and the Cosmos Club. He was a member of Phi Beta Kappa, and a recipient of the Louis E. Levy gold medal and the John Scott medal, both from the Franklin Institute, and the Cullum Geographical Medal from the American Geographical Society.

An additional unusual tribute to the contributions of Dr. Hayes and his Sound Division colleagues after World War II was contained in a recovered order of Karl Doenitz, Grand Admiral of the German Navy, that said in part: "For some months past, the enemy has rendered the U-boat ineffective. He has achieved this objective, not through superior tactics or strategy, but through his superiority in the field of science; this finds its expression in the modern battle weapon — detection. By this means he has torn our sole offensive weapon in the war against the Anglo-Saxons from our hands."

Sound Division Organization in Era 1

Prior to World War II, the Sound Division was quite small (fewer than ten researchers). In the 1940s, the Division swelled to well over one hundred researchers due to the efforts to support World War II.

Circa mid-1920s

Dr. Harvey C. Hayes (Physicist) — Superintendent

Key Research Staff
Dr. Edward B. Stephenson (Physicist)
Dr. Elias Klein (Associate Physicist)
F.W. Struthers (Assistant Engineer)
W.W. Wiseman (Assistant Engineer)
J.T. Carruthers (Research Aide)

Circa 1935

Dr. Harvey C. Hayes (Physicist) — Superintendent

Key Research Staff
Dr. Edward B. Stephenson (Physicist)
Dr. Elias Klein (Associate Physicist)
F.W. Struthers (Assistant Engineer)
W.W. Wiseman (Assistant Engineer)
J.T. Carruthers (Research Aide)
W.B. Wells (Assistant Engineer)
R.J. Colson (Electrician)

Circa 1945

Code		
470	**Superintendent**	**Dr. Harvey C. Hayes**
471	Associate Superintendent	Dr. Edward B. Stephenson
471A	Technical Assistant	William W. Stifler
471B	Technical Editor	Robert W. Gordon
471B	Shipments	Kenneth B. Thomson
472	Associate Superintendent	Dr. Elias Klein
473	Special Research	Prescott N. Arnold
473A		Ollie M. Owsley
474	Generation and Reception	Dr. Harold L. Saxton
474A		Melvin S. Wilson
475	Special Development	Dr. Raymond L. Steinberger
475A		George R. Vernon
476	Measurement and Analysis	Dr. John M. Ide
476A		Dr. Horace M. Trent
477	Engineering Design	Wilbert P. Marshall
478	USS *Aquamarine*	
479	Crystal Section	Lt. Paul H. Egli
479A		Dr. Paul L. Smith

Era 1 Group Photo

NRL Sound Division personnel in front of Building 1 circa 1947.

Era 1 Research Overview

Early Sound Division History in the Words of Dr. Hayes

Around 1947 Dr. Harvey Hayes prepared an account of the history of the NRL Sound Division up to that time. This history begins with events around 1917, several years prior to the formal establishment of NRL in 1923, and covers to 1946 — nearly the entire era of Hayes' tenure at NRL. Some of the terminology used by Hayes is outmoded or old-fashioned by today's standards. For example, acoustic frequency is expressed today in hertz (Hz) rather than cycles per second (cps); the regime of acoustic frequencies above the audible range (i.e., above 20 kHz) is now referred to as "ultrasonic" rather than "supersonic." The photo has been added.

A Brief History of the Sound Division, NRL
by Harvey C. Hayes, Physicist

In order to make it a matter of record, available to all readers, this report includes a brief account of progress covering the entire period 1917–1946.

World War I

The Sound Division of the Naval Research Laboratory is a carryover from the U.S. Naval Experimental Station established at New London in 1917 and closed in 1919. The mission of the Station was to devise and develop ways and means of detecting and locating a submerged submarine. Preliminary tests confirmed a prediction from theoretical considerations that the most promising approach to a solution of the problem lay in the field of submarine acoustics.

The efforts of the Station during the two years of its existence were largely devoted to the development of submarine sound receivers. The name "hydrophone" was applied to these devices. Of the numerous types that were developed none met the requirements for directing a submarine attack. Either they lacked the necessary directivity or else they could not operate while under way because of excessive local noise background.

Thus by the end of World War I the U-Boat had demonstrated its potentialities as a powerful future war weapon, but in the meantime the Navy had developed no effective countermeasures. It was therefore decided to continue the antisubmarine work, and in particular to determine the possibilities of the so called MV Hydrophone, which gave promise of meeting minimum requirements but had not yet taken final form. The work program with reduced personnel was transferred to the U.S. Naval Engineering Experiment Station at Annapolis, Md., pending completion of the Naval Research Laboratory at Anacostia.

Submarine Research 1919–1941

Research during the three and a half year period at Annapolis was confined to frequencies within the audible range. The Sonic Depth Finder was a product of this period. Development of the MV Hydrophone was completed. Extensive field tests showed this device to be superior to any of its predecessors by giving fair ranges and directivity at speeds up to about 6 knots. At higher speeds and in a moderately rough sea way, water noises masked the propeller sound of the target. When this device was installed on a submarine noticeably better ranges were obtained because of the lower noise background.

As a matter of interest it may be stated that the principle of operation of the MV Hydrophone, whereby the responses from a multiplicity of spaced hydrophone units are brought into consonance by electrical retardation lines, forms the basis of the Sonic Hydrophone on the U-Boats of World War II.

The work at Annapolis led to the conclusion that the antisubmarine problem could not be solved by "listening devices" alone, since they do not readily give the target range, fail entirely when the target rests on the sea bottom, and in general tend to strengthen rather than to weaken the submarine because of the more favorable listening conditions on a submarine.

Development of ways and means for detecting and locating a submarine by means of signal echoes reflected from its hull was started in 1923 when the work was transferred to the new Station. This resulted in the development of the XL supersonic equipment which, following the principle devised by Langevin, employed a sandwich type of projector consisting of quartz crystal slabs cemented between steel plates.

Exhaustive tests of equipment in 1928 gave reliable results to ranges approximating 1200 yards. Such ranges obviously were inadequate for purposes of search, but the new equipment greatly strengthened the attack once sound contact was made with the target. While the echo range could doubtless be increased through improvements suggested by the tests, it appeared improbable that they could be extended adequately to meet search requirements.

It was therefore decided to tackle the problem of extending the search range through listening to the supersonic components of the submarine's propeller sounds. This led to development of the JK Supersonic Receiver using Rochelle salt crystals as the sensitive elements. The high directivity of this search-light-beam type of receiver reduced the local noise background sufficiently to increase the search range to roughly 5000 yards while under way at speeds up to about 9 knots. The combination XL and JK, perfected by 1932, represented a distinct advance in antisubmarine equipment, since the JK could be used during the search operations to discover and bring a target within range of the XL, which then took over and directed the attack.

The use of Rochelle crystals as a weak supersonic sound source during the study and development of the JK receiver encouraged a belief that such crystals could serve as a supersonic projector of sufficient power for depth sounding purposes. This proved true, and resulted in the supersonic depth finder which in various forms is installed in practically all ships of the Navy.

The success achieved by use of Rochelle salt crystals, both for generating depth-sounding signals and for receiving their echoes reflected from the sea bottom, gave rise to a belief that the functions of both the XL and JK could be combined into a single equipment through further development of the Rochelle salt projector. This led to development of the QB equipment, which gave roughly twice the echo range of the XL and at the same time equalled the listening range of the JK. This QB equipment constituted another marked antisubmarine improvement.

Field tests of the original QB equipment during the summer of 1934 corroborated predictions that the new projector could operate effectively over a relatively wide frequency band (17–30 kilocycles) and permit each of several cooperating patrol ships to tune their equipment to a different frequency and thus minimize interference. They also proved, as predicted, that the lower frequencies gave improved search ranges and that the higher frequencies, with the resulting narrower sound beam, served best for directing an attack. Finally the tests disclosed the need for a tuning-control system that would insure like tuning for both driver and receiver-amplifier, if full advantage were to be taken of the wide frequency range of the QB projector.

Recognition of this need led to the development of the so-called "Uni-Control System" whereby the driver and inverted superheterodyne receiver were coupled and tuned by a single inter-coupled variable frequency oscillator to like frequency throughout the frequency range of the projector. This arrangement permitted a fixed intermediate frequency for the receiver-amplifier and thus allowed the use of band-pass filters in the intermediate stage that compensated at all frequencies for loss of selectivity due to the low Q value of the QB projector.

Development of the Uni-Control System was perfected in 1939 and reported to BuShips with manufacturing drawings and specifications. The QB type projector in combination with the Uni-Control Driver-Receiver System represented another marked improvement in antisubmarine equipment. This combination has played a stellar role in the Battle of the Atlantic.

The variation and lack of reliability of echo ranges obtained with the QC and early QB systems indicated that the physical characteristics of the medium (sea water) were less stable than was anticipated, and that the echo ranges in general fell far short of those predicted from the classical theory of absorption based solely on the viscosity of the medium.

To account for these discrepancies a study of the propagation of sound in sea water was started in 1936. This work led to the conclusion that downward bending of the sound signal path caused by vertical temperature gradients was largely responsible for the nonuniformity of echo ranges at various times in the same locality or between different localities. This study also disclosed the existence of temperature inversions, predicted their screening effect on a submarine beneath such layers, and outlined a procedure for estimating the echo range as a function of temperature gradient and target depth. This information has worked to improve the escape tactics of our submarines and our attack procedure against the U-Boats.

The development of a projector that would generate a supersonic signal of maximum intensity, or in other words that would drive the sound-generating surface to cavitation amplitudes, was also undertaken in 1936. The so called Electrodynamic (E.D.) Projector, which accomplished this purpose, was completed in 1939. By this time, however, the researches in propagation indicated that under many, if not indeed most, sea conditions encountered in practice no worthwhile increase in echo ranges should result from increasing the signal strength beyond that given by the QB projector.

This prediction was supported in part by comparison tests which showed that the more powerful E.D. signals gave no marked increase in echo range, but that at the limiting ranges they did decrease the percentage of signals that failed to return echoes. Wherefore it was concluded that the advantages gained by the use of powerful signals were not sufficient to warrant the increased weight and volume of the equipment and that such gains as the more powerful signals provide should be sought through reduction of noise background.

Following this decision an uncompleted undertaking of surrounding the projector with a sound-transparent streamlined form, that was started four years earlier, was revived. The earlier work had indicated that a form fabricated of thin steel with an interior reinforcing frame should provide the necessary mechanical strength and permit transit of the supersonic signals and echoes with no great loss of intensity. Development of such a "dome shield" of simple design that telescoped over the standard projector and was mounted by welding to the hull was completed by December of 1940.

Field tests proved that the dome shield reduced the noise background to a point where both listening and echo ranging became practical up to speeds in excess of 15 knots. These favorable results led to a hurried dome installation program that eventually equipped every patrol ship with a dome-shielded projector and thereby greatly improved their effectiveness against the U-Boats.

The dome-shielded QB projector with Uni-Control driver and receiver-amplifier must be rated as one of the most powerful antisubmarine developments. Moreover, the same or similar equipment without the "dome shield" has been the main, and in many cases the only, sound equipment on our submarines. The QB submarine equipment has proved to be a powerful aid during search and evasion procedures, and instances are not lacking where a torpedo attack has been carried out with the aid of sound range and bearing data alone without exposing the periscope.

Such in brief is the history of the Sound Division during the period intervening between the two World Wars. The beginning of this period found the Navy sadly lacking in ways and means for combating the relatively simple U-Boats of that time. The end of this period found the Navy with completed developments in the field of submarine acoustics that served to defeat the tougher and more versatile U-Boats of World War II and to increase the effectiveness of its own submarines.

These antisubmarine developments of the Sound Division of N.R.L. contributed in no small measure toward bringing warfare against the U-Boats to a status that elicited from Grand Admiral Karl Doenitz a recovered order that states in part:

"For some months past, the enemy has rendered the U-Boat ineffective. He has achieved this object, not through superior tactics or strategy, but through his superiority in the field of science; this finds its expression in the modern battle weapon – detection. By this means he has torn our sole offensive weapon in the war against the Anglo-Saxons from our hands. It is essential to victory that we make good our scientific disparity and thereby restore to the U-Boat its fighting qualities."

General Research 1918–1941

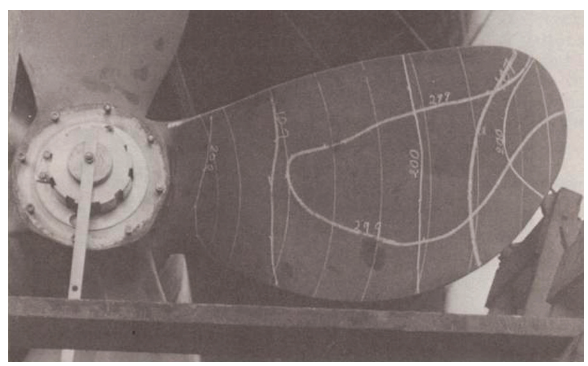
Two of the researches conducted during the interwar period that are only remotely related to submarine warfare led to improvements that should find a place in any history of the Sound Division. These improvements resulted from a solution of:

a. The problem of reducing underwater-sound measurements to absolute units.
b. The problem of silencing the "Singing Propeller."

The need for ways and means of making absolute underwater sound measurements was recognized even before the work at New London was started, but the difficulties to be overcome and the time and man-power required to perfect such means delayed the undertaking until about 1934. By that time it became apparent that such measurements were required to determine the efficiency of the supersonic projectors under development, and that the ability to make such measurements would permit BuShips to set definite performance specifications for projectors in terms of sound power output.

The problem was undertaken in this same year, and by 1938 this pioneering program had resulted in the development of both primary and secondary standards that have helped to coordinate and properly to evaluate the farflung projector developmental program of the War effort.

The problem of the Singing Propeller was not recognized as such when the work that led to its solution was started. This work was undertaken in response to a request from BuShips that the Sound Division attempt to remove excessive stern vibrations on the airplane carriers Yorktown and Enterprise that persisted throughout the approximate speed range 9–15 knots.



Analysis of the natural modes of vibrating propeller blade of USS *Goethals* used to resolve "singing propeller" noise, circa 1940. (After Klein, 1967)

The source of the vibrations was traced to the propellers by analytical processes that were self-evident to one versed in the fundamentals of sound generators, but that were unorthodox to the mechanical engineer. Analysis of the vibration disclosed the predominant pitch. Then the pitch and pattern of the various modes of vibration that could be artificially set up with the ship docked and the propeller in air were determined. These pitch values, corrected for water loading, indicated the vibration mode that caused the stern vibrations.

This vigorous vibration mode was characterized by a single nodal line that formed a closed figure on each blade, thereby proving that the whole edge contour of the blades vibrated in phase. Discovery of this fact led to a belief that the damping factor of this mode could be raised beyond the critical value by sharpening the rounded edges of the blades. The blade edges were sharpened and the troublesome vibrations disappeared.

Such, briefly is the story of solving the problem of the "Singing Propeller" which for years had baffled marine engineers both here and abroad. If its solution accomplished nothing more than to enable the Yorktown and the Enterprise better to accomplish their mission it would still remain a landmark in the history of the Sound Division.

World War II

The applied researches of the Sound Division during the War period resulted as follows:

a. The sound-detecting equipment developed and at hand at the beginning of this period could locate a U-Boat to within a range of roughly 10 yards, and bearing to within plus or minus one degree, so long as the sound beam could be held on the target. But, as early as 1934, the modern U-Boat proved capable of submerging to depths below a horizontally directed sound beam at the shorter ranges involved in an attack. The early visioned need for a projector mount that would permit of measurably tilting the sound beam downward was thus proved to be real. Modification of the standard QC and QB projector mount to permit the sound operator measurably to tilt the projector was completed and thoroughly tested by late 1942 and reported to BuShips with complete manufacturing drawings and specifications early in 1943.*

b. Analysis of the probable tactics of U-Boats operating in pairs or groups indicated the possible hurried need for two independent sound equipments on antisubmarine patrol ships, one for carrying out an attack, and the other to stand guard against being attacked by a second or cooperating U-Boat. The solution of this problem resulted in a dual installation wherein the two projectors, mounted one above the other on concentric shafts, could be trained independently about the azimuth and in addition the lower one could also be measurably tilted to maintain short range contact. The standard QC and QB equipment could be replaced by the dual system using the same hull fittings, the same hoist and train mechanism and the same dome. This development was completed, successfully tested and reported to BuShips early in 1943.*

*Although the need for each of these developments appeared urgent, for reasons not fully understood neither was adopted, and the end of the Battle of the Atlantic found our patrol ships still unable to hold sound contact to the short ranges required for an effective attack on a deep-running U-Boat.

c. Two remote-controlled hydrophone systems termed Herald, a simple one of medium range and a more powerful streamlined design for use in locations subject to strong tidal currents and resulting high noise background were completed in 1943, as was also the Sono-Radio Buoy in cooperation with the Radio Division. These devices found wide use in protecting harbors and fleet bases.

d. The nature of the Type T-5 German homing torpedo was predicted and the requirements to be met by countermeasures outlined. To meet such requirements, the FXP towed sound generator was developed.

e. Three types of acoustical proximity fuse for mines or other purposes were developed and reported to BuOrd prior to 1944.

f. The transmission of low pitched sound as dependent on the depth and character of the sea bottom was investigated and powerful low-pitched sound generator developed. This proved useful for sweeping acoustical mines.

g. The Division pioneered the development and use of very short supersonic signals in locating small objects. Equipment based on this study proved helpful in guiding our submarines through Japanese mine fields and in safeguarding our mine sweepers.

h. The "Gump Gear" a miniature submarine sound communication system that enables Commandos to home on a signaling ship to ranges in excess of 3000 yards and to intercommunicate by voice to ranges beyond 1000 yards was designed and developed.

i. The Division developed portable equipment for locating leaky valves in aircraft hydraulic control systems through reception of the sound generated by such leaks.

j. Technique was developed for determining the acoustical performance of a supersonic projector by tests made in a tank through the use of short impulse type of signals that could be received and recorded, and the receiving system blocked before the arrival of distorting echoes from the sides of the tank.

The end of hostilities found the Sound Division with two major programs of applied research that were well under way. One concerned the development of a gyro-stabilized capsule-enclosed projector for antisubmarine patrol ships; and the other an ambitious pro-submarine program calling for a dome-enclosed remote-controlled hydrophone embodying many of the principles employed in the harbor defense hydrophone and for methods and means of indicating on a c-r [cathode-ray] screen the bearing and range of every object in the projector beam that returns an echo from a single intense impulse type of signal.

A preliminary model of the capsule-enclosed projector installed on the USS FOSS has demonstrated that stabilization of the sound beam against pitch and roll renders search more effective, and maintenance of sound contact with the target more certain, during unfavorable sea conditions. Such promise may possibly warrant completion of this program.

Development of the remote-controlled hydrophone of the pro-submarine program is well along and should be ready for installation in November 1946. The search for ways and means of depicting on a c-r screen the location of reflecting objects within the space covered by the sound beam has resulted in the so-called Sector Scan Indicator (SSI), which gives promise of finding wide application.

This pro-submarine program with slight modification applies equally well to the full-streamlined high-submerged-speed submarines of the future and hence will be vigorously prosecuted in its entirety.

Future Antisubmarine Developments

If, as many believe, the future submarine becomes in reality a fully streamlined craft that for the most part remains submerged and that can proceed at speeds approximating 25 knots, then all present types of antisubmarine craft of top speed less than 25 knots must be regarded as obsolete. In fact, the future antisubmarine ship must possess a speed differential of from 5 to 10 knots to carry out an attack against a 25-knot target. This leaves the destroyer as the only type that can meet the speed requirements. But unless the destroyer can be provided with sound equipment capable of directively detecting and maintaining sound contact with the target at speeds well in excess of 25 knots it also must be consigned to the discard so far as antisubmarine duty is concerned.

It appears probable that sound-detecting equipment can be developed that will enable a destroyer to follow and attack a 25-knot submerged submarine once sound contact with the target has been made. But noise background incident to the high speed will doubtless reduce detection to range limits that are impractically short for purpose of search. Thus there arises an urgent need of ways and means for bringing the destroyer into sound contact with the target.

Search procedure for such a target must be accomplished by listening for its intense propeller sounds. Such sounds can be detected to long ranges by a sensitive detector at rest in the water and thereby exposed only to the low ambient noise background. But in order to stop and listen, and still be able to overtake the target, the top speed of the searching craft must surpass that of the destroyer, and search procedure logically passes from the province of surface craft to that of air craft. It therefore appears probable that the helicopter and/or the flying boat must be depended upon to discover the presence of, and to direct the destroyer into sound contact with, the future submarine, and that if or when the submerged speed of the submarine approaches 40 knots the surface ship becomes ineffective and the antisubmarine problem becomes primarily an aircraft problem.

The nature and content of the applied research program of the Sound Division has been determined in part by the above reasoning. In consonance therewith it gives high priority to the following appertaining problems:

a. To develop listening equipment for destroyers that can serve for detecting and directing the attack on a 25-knot submerged target. (Both keel mounted and towed hydrophones are being investigated.)

b. To develop submarine sound listening equipment for aircraft. (This work is planned to cover flying boats, helicopters and directive sono-radio buoys.)

This research program, as a whole, has been formulated on the assumption that present battle-tested types of sound detection equipment and attack procedure have proved capable of defeating the present types of submarine, and that further development of sound equipment to serve this purpose is neither required nor warranted. Time limits have been set for certain parts of the program (including the above stated problems) in terms of the assumptions that, (a) development of the fully streamlined high submerged speed type of submarine will require about 5 years and (b) present types will be largely replaced within about 10 years.

Key Research Thrusts and Achievements in Era 1

1 Early Navy Sonar Transducer Developments
2 First Operational Fathometer
3 Early Seismic Method Developments
4 First Operational U.S. Navy Sonar
5 First Application of Ray Theory and Normal Mode Theory
6 Early Developments in Harbor Defense
7 Tactical ASW in World War II
8 First Navy Acoustic Test Range

1
[1923–1939] Early Navy Sonar Transducer Developments

Achievement: Starting in 1923, with the opening of the Naval Research Laboratory, the Sound Division was established by the transfer of a small group of scientists headed by Harvey C. Hayes from the Navy Experimental Station, New London, Connecticut, and the Naval Engineering Station, Annapolis, Maryland. Practically all the U.S. Navy's research and development in sonar prior to World War II was carried on by this Division. In the 1920s to 1930s the NRL Sound Division conducted pioneering research on the development of sonar transducers for underwater reception and transmission that operated at relatively high frequencies around 17 to 30 kHz. Among the types of transducers developed were those based on piezoelectric crystal (quartz-steel sandwich and Rochelle salt) technology (significant improvements on the French design by Langevin); magnetostrictive technology; electrodynamic technology; and sound-transparent rubber windows for these transducers. The further development of a "Uni-Control System" by 1939 permitted greatly enhanced frequency selectivity for the sonar systems.

Impact: The development of new types of sonar transducers enabled the United States to maintain a leading role in the science of underwater acoustics (passive and active) in the period between World War I and World War II and it set the stage for the development by NRL of U.S. Navy fleet sonar systems that were used in World War II.

References:

H.C. Hayes, "Status of the Supersonic Problem to Date," Naval Research Laboratory Letter Report 1927-1 (1 Mar. 1927).

W.W. Wiseman, "A Report on a Uni-Control System for Sound Listening and Echo Ranging," Naval Research Laboratory Report S-1504 (Dec. 1938).

H.C. Hayes, "A Brief History of the Sound Division, NRL," Naval Research Laboratory Letter Report 491434/C56S/A1 (1 Jan. 1947).

E. Klein, "Notes on Underwater Sound Research and Applications Before 1939," Office of Naval Research Report ACR-135 (Sep. 1967).

2
[1924] First Operational Fathometer

Achievement: In 1924, one of NRL's first technical accomplishments was the development of the Sonic Depth Finder (now called a fathometer). The ocean depth finder used two U.S. Navy MV-type transducers, one for sonar transmission at frequencies near 1 kHz, and the other for reception. A method was implemented for calibrating the round-trip time for the transmitted sound pulse to travel from the ship's keel to the sea bottom and return to the ship.

Impact: The NRL Sonic Depth Finder was the first ocean depth-sounding fathometer to be installed for routine service in surface vessels and submarines of the U.S. Navy fleet. Its use resulted in greatly enhanced surface and subsurface navigation capabilities throughout the 1920s and 1930s.

References:

H.C. Hayes, "The Sonic Depth Finder," *Proc. Am. Philosophical Soc.* **63**(1), 134–151 (1924).

H.C. Hayes, "Measuring depth by acoustical methods," *The Journal of the Franklin Institute* **197**(3), 323–354 (Mar. 1924).

3
[1930–1933] Early Seismic Method Developments

Achievement: In the late 1920s Harvey C. Hayes developed a methodology that resulted in the award in 1930 of a patent titled "Method for Making Subterranean Surveys." This early description of a seismic method included details of the instrumentation, the geometry for the placement of the acoustic source and receivers, the processing of the received signals, and a method for interpreting the data.

Impact: The results of this research and the method developed provided geophysicists and geologists with an understanding of the physical characteristics of the surface and subsurface of the earth as well as the basic tools to conduct explorations for oil and natural gas.

References:
H.C. Hayes, "Method for Making Subterranean Surveys," U.S. Patent No. 1,784,439 (9 Dec. 1930).

H.C. Hayes, "Geophysical Method and Apparatus," U.S. Patent No. 1,814,444 (14 Jul. 1931).

H.C. Hayes, "Vibration Detector," U.S. Patent No. 1,892,147 (27 Dec. 1932).

H.C. Hayes, "Vibration Detector," U.S. Patent No. 1,923,088 (22 Aug. 1933).

4
[1934–1940] First Operational U.S. Navy Sonar

Achievement: Following up on early NRL research on improved sonar transducers that began in 1923 and continued into the 1930s, an effective sonar system was developed by the mid-1930s that became the U.S. Navy's first operational sonar system. This sonar was based on the JK and QB Rochelle-salt crystal transducer system as a receiver of propeller sounds while the QC magnetostrictive transducer system was used as an echo-ranging device in the frequency range from 17 to 30 kHz. With the addition of the NRL Uni-Control driver-receiver system by 1939, greatly improved frequency selectivity was achieved. By 1940 a sound-transparent dome shield was added to reduce the noise background and permit echo-ranging to be conducted at ship speeds up to 15 knots. The favorable results of system testing led to a hurried Navy effort to equip every Navy patrol ship with such a system.

Impact: Harvey C. Hayes commented on the impact of these NRL sonar system developments between World War I and World War II in his retrospective history of NRL's Sound Division: "The beginning of this period found the Navy sadly lacking in ways and means for combating the relatively simple U-boats of that time. The end of this period found the Navy with completed developments in the field of submarine acoustics that served to defeat the tougher and more versatile U-boats of World War II and to increase the effectiveness of its own submarines."

References:
H.C. Hayes, "A Brief History of the Sound Division, NRL," Naval Research Laboratory Letter Report 491434/C56S/A1 (1 Jan. 1947).

E. Klein, "Notes on Underwater Sound Research and Applications Before 1939," Office of Naval Research Report ACR-135 (Sep. 1967).

H.C. Hayes, "Report on Sound Research and Development with Particular Reference to Tests on the USS SEMMES on July 6-28, 1937," Naval Research Laboratory Report S-1404 (Oct. 1937).

W.W. Wiseman, "Report on a Uni-Control System for Sound Listening and Echo-ranging," Naval Research Laboratory Report S-1504 (Dec. 1938).

H.C. Hayes, "Magneto Strictive Sound Generator," U.S. Patent No. 2,000,741 (25 Jun. 1935).

E.B. Stephenson, "Instructions for Echo Detection Equipment Model XQB," Naval Research Laboratory Report RA55A227 (Aug. 1934).

5
[1937–1943] First Application of Ray Theory and Normal Mode Theory for Comparison with Underwater Sound Propagation Measurements

Achievement: In the mid-1930s the propagation of sound in the ocean was not well understood. R. Steinberger of NRL's Sound Division conducted theoretical and experimental investigations to determine the cause of the so-called "afternoon effect." In the open ocean the sonar detection range decreased in the afternoon relative to the morning. Steinberger calculated the effect of the ocean's temperature variation with depth versus time of day on the propagation of sound using ray theory (the first utilization of ray theory in underwater acoustics). This was followed by at-sea experimentation in February 1937 in deep waters off Cuba. The results clearly showed that the warming of the near-surface waters refracted the sound downwards, thus passing below the undersea target, in agreement with Steinberger's calculations. These results were confirmed by further experimentation conducted in August 1937 in waters near Long Island, New York. In 1943 NRL researchers J. Ide, R. Post, and W. Fry developed a model for sound propagation in shallow waters based on normal mode theory (the first application of this theory in underwater acoustics). This was followed by a series of sound propagation measurements in the Potomac River using USS *Aquamarine* and USS *Accentor* at frequencies between 70 and 400 Hz. The measurements included sampling the bottom sediment characteristics.

Impact: Early experimentation and modeling by NRL Sound Division researchers in the mid-1930s to mid-1940s resolved some poorly understood physical mechanisms for sound propagation in the ocean, including the cause of the "afternoon effect." As part of these research efforts, NRL scientists implemented the earliest Navy modeling based on ray theory for deep waters and normal mode theory for shallow waters.

References:

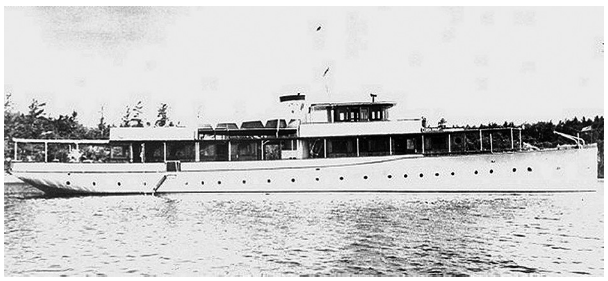
R.L. Steinberger, "Underwater Sound, Investigation of Water Conditions, Guantanamo Bay Area, Feb. 1937," Washington Navy Yard Sound Laboratory report RW3A314A, NRL Acc. 55 & 129,624 (1937).

R.L. Steinberger, "Underwater Sound Investigation in Northern Waters, Cruise of USS SEMMES and Atlantic, August 23 to 31, 1937," Radio Test Shop Navy Yard, Washington, DC (25 Jan. 1938).

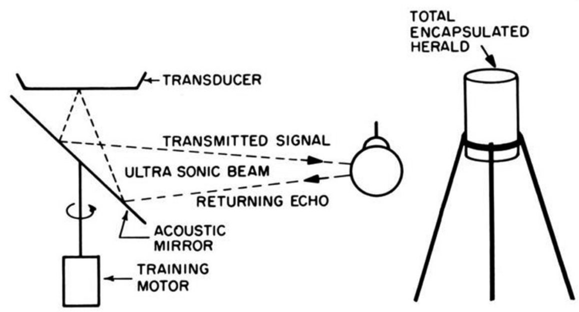
J.M. Ide, R.F. Post, and W.J. Fry, "The Propagation of Underwater Sound at Low Frequencies as a Function of the Acoustic Properties of the Bottom," Naval Research Laboratory Report S-2113/NRL-FR-2113 (15 Aug. 1943).

F.J. Hollweck, "Development of Model XCX Boat Type Sono Radio Buoy," Naval Research Laboratory Report FR-26851 (30 Nov. 1945).

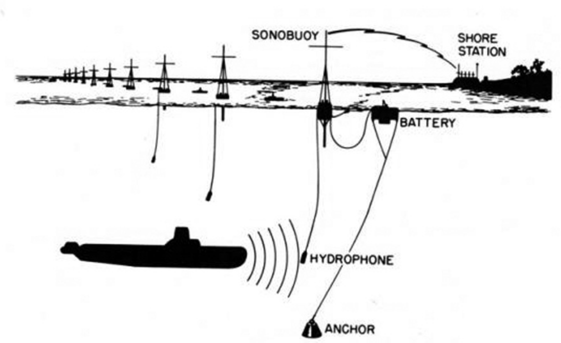
E. Klein, "Notes on Underwater Sound Research and Applications Before 1939," Office of Naval Research Report ACR-135 (Sep. 1967).



USS *Aquamarine* used as a research vessel circa 1940s.



Harbor Echo-Ranging and Listening Device (HERALD): Ultrasonic beam directed by a rotating lightweight acoustic mirror — used for harbor protection circa 1930s. (After Klein, 1967)



Anchored sono-radio buoy system used for harbor defense circa 1940s. (After Klein, 1967)

6
[1939–1949] Early Developments in Harbor Defense

Achievement: Research by NRL Sound Division investigators in the 1930s culminated by 1939 in the development of an underwater acoustic system for harbor defense. The system used a beamed ultrasonic transducer of the JK or QB type with a special lightweight acoustic mirror that provided a rotating beam in azimuth. This harbor defense system became known as "Herald" (Harbor Echo-Ranging and Listening Device). Herald was supplemented by cable-connected hydrophones and NRL-developed anchored radio-sonobuoys.

Impact: In his "Notes on Underwater Sound Research and Applications Before 1939," early NRL Sound Division researcher Elias Klein states, "The Herald apparatus was perhaps the most versatile of the harbor protection equipments which were ultimately assembled for the purpose at hand. Its ability to track and locate an underwater sneak craft made it a most valuable detector of enemy submarines." The underwater cabled hydrophones enabled a shore station to track any sneak craft. Similarly, the anchored sonobuoy system served to further alert a shore station of any intruding underwater craft.

References:

E. Klein and T.F. Jones, "Use of sonar in harbor defense and amphibious landing operations," *AIEE, Electrical Engineering* **68**, 107–114 (Feb. 1949).

7
[1941–1942] Tactical ASW in World War II

Achievement: In 1942, German submarines in the Atlantic Ocean were sinking Allied ships faster than they could be built. Harvey Hayes conducted an operations analysis based on his assessment of the situation. Hayes stated, "The conclusion is reached that we are losing the present anti-submarine war by such a large margin that measures should be immediately taken to outline, codify, and put into action a more effective anti-submarine program." Hayes developed a number of recommendations for the Navy including procedures for carrying out an attack on the enemy submarine. This involved a direct attack by running directly over the submarine and, guided by the depth recorder, dropping a pattern of rapid sinking contact or proximity depth charges.

Impact: The importance of NRL's contributions to tactical antisubmarine warfare in World War II are summarized in A.H. Drury's "War History of the Naval Research Laboratory": "At the close of World War II a naval officer assigned to the Bureau of Ships stated publicly that every important device which was used aboard American vessels for sub-surface detection of submarines had been developed by 1941 and that the major credit for these inventions belongs to a small group of sound engineers at the Naval [Research] Laboratory. Similarly, Admiral Doenitz, Chief of the German U-Boat Fleets of World War II, officially stated that it was the scientific achievements of the United States Navy more than any other cause which had defeated the underwater strategy of the German Navy."

References:

H.C. Hayes, "Analysis of Method and Means of Anti-Submarine Attack," Naval Research Laboratory Report S-1776 (27 Aug. 1941).

H.C. Hayes, "Report on An Analysis of The Anti-Submarine Warfare Problem from the Standpoint of Underwater Acoustics," Naval Research Laboratory Report S-1908/NRL-FR-1908 (17 Jul. 1942).

H.C. Hayes, "The A-B-C's of Anti-Submarine Warfare," Naval Research Laboratory Report S-1959 (5 Nov. 1942).

A.H. Drury, "War History of the Naval Research Laboratory," Naval Research Laboratory unpublished book (1 Nov. 1946).

8
[1943] First Navy Acoustic Test Range

Achievement: In late 1942 the U.S. Navy decided to build an acoustic test range in order to evaluate the sonar systems of convoy escort ships entering and leaving port at Key West, Florida. This was the Navy's first acoustic test range. It was designated the Sound Test Station, Key West, Florida. The Gulf Sea Frontier Command constructed the 12-foot-square building that was on pilings in 32 feet of water and was located about 2000 yards from Key West Light. The floor of the building was 10 feet above the water at low tide and it was built with a four-foot-wide porch on the south and west sides. The ships were directed to pass through a lane of marker buoys with their sonars directed at 90 degrees relative (entering) or 270 degrees relative (outgoing) at a closest approach distance of 100 feet and with the vessel's sonar transmitting continuously. The received signals were recorded and calibrated in the test station. This procedure ensured the proper operation of the sonar system. Tests were generally done at frequencies between 15 and 30 kHz with vessels passing the test station at a speed of 10 knots. NRL designed, provided, and installed the technical equipment for the test station under the leadership of Leo Treitel of the Sound Division.

Impact: This first Navy acoustic test range near Key West, Florida, outfitted by the NRL Sound Division, enabled rapid measurements of the output and directivity of underwater sonar systems of U.S. Navy combatant vessels. The calibrations provided by this acoustic test range were of considerable value for validating the performance of newly installed sonar systems as well as for the periodic maintenance of optimum performance efficiency in Fleet sonars.

Reference:

L.M. Treitel, "The Sound Test Station at Key West, Florida," Naval Research Laboratory Report Acc. No. 666, X145364 (27 Apr. 1943).

First Navy acoustic test range: Sound Station Key West, Florida, circa 1943. (After Treitel, 1943)

CHAPTER FOUR

Era 2: Dr. Harold L. Saxton
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Biography of Dr. Harold L. Saxton

Harold Lavern Saxton was born in Cooperstown, New York, [redacted] the son of Vern F. Saxton and Pearl (Ackerman) Saxton. Two years later the family moved to Fort Plain, New York, where Harold spent his boyhood. He attended Union College in Schenectady where he received a B.S. degree in physics in 1924. In 1925 he was married to the former Elizabeth Bliss. They have one son, John.

Upon graduation, Harold Saxton joined the technical staff of the General Electric Company, first as a research physicist and then as an engineer. In those positions, he developed radio transmitters and receivers and studied radio propagation effects. In addition, he spent a year in the development of a specialized type of electronic vacuum tube known as a thyratron. While working for the General Electric Company, he pursued graduate studies at Union College and was awarded an M.S. degree in 1929. In 1930, Saxton enrolled full-time in graduate studies at Pennsylvania State College where he studied ultrasonics under Professor W.H. Pielemeir. He received a Ph.D. in physics in 1934. His doctoral thesis was concerned with the propagation of ultrasound in gases. While studying at Pennsylvania State College he served also as an assistant instructor in physics. In 1934 he became an instructor and in 1939 he was promoted to the rank of assistant professor.

In February 1940 Dr. Saxton joined the Sound Division of the Naval Research Laboratory to apply his knowledge of ultrasonics to underwater acoustics problems. At that time there were only seven other professional scientists in the Sound Division including the superintendent, Dr. Harvey C. Hayes. During this period the Sound Division grew rapidly in size and Dr. Saxton became a section head within a few months of his arrival. In this initial period after coming to NRL, Saxton developed new and improved types of sonar transducers, an automatic attack plotter to help the conning officer track a target, and an attack trainer used to train sonar operators and officers. He also conducted research on multipath propagation of sound in the ocean. One of his key early contributions was the development of a device known as a sector scan indicator (SSI). This device uses the phase difference between the signals received by two halves of the same transducer to measure the precise bearing of the sound source within the finite sector of the receiving beam. The SSI displays its echoes or other output on a cathode ray tube screen. This display was extremely helpful to sonar operators and it became an integral part of many Navy sonar systems of the era. In recognition of his invention of the SSI and his other research contributions, Saxton was awarded the U.S. Navy's Meritorious Civilian Service Award in 1945.

Upon the retirement of Dr. Hayes in 1947, Saxton was named to become the new Sound Division superintendent. Among Saxton's recommendations shortly after becoming superintendent was for NRL to develop new and larger active sonar systems that could operate at lower frequencies and with higher power than previous sonars; up to that time most sonar systems operated at frequencies above 20 kHz and had rather short detection ranges of just a few miles. As a result of these recommendations, NRL developed new sonar systems that could operate at successively lower frequencies of 10 kHz, 5 kHz, and eventually 1 kHz. It was at 1 kHz that an NRL sonar system first detected echoes from a surface ship at convergence zone range (approximately 30 miles). In order to develop practical sonar systems for the Navy using the results of this new research, Saxton established the East Coast transducer test facility on Seneca Lake in New York state.

In the 1950s Saxton initiated within the Sound Division a vigorous research effort in sonar signal processing. He led and actively participated in this research effort that had as one of its main objectives to develop a better understanding of the propagation of sound in the ocean. Saxton encouraged research within the Sound Division on widely ranging topics related to Navy sonars including studies of the physiology and psychology of the listener, and the chemistry, physics, and biology of the ocean medium. Due to the Sound Division's advanced research on sonar techniques, it was well poised to assist with several research vessels in the successful search for the lost U.S. submarine *Thresher* in the early 1960s.

In addition to his leadership of the Sound Division, Saxton was quite involved in Navy activities and panels outside NRL. He chaired the Underwater Sound Advisory Group (USAG) from its inception in 1949 until 1963. The USAG was the Navy's top-level council responsible for coordinating the scientific efforts of all the U.S. laboratories performing underwater acoustics research. The USAG also sponsored the publication of the *U.S. Navy Journal of Underwater Acoustics (JUA (USN))*, the Navy's only peer-reviewed journal for the publication of classified research results. Further, the USAG sponsored periodic symposia at which Navy classified research results were presented to restricted audiences. In 1962 Saxton received a commendation from the Chief of Naval Research for his service to the USAG. Dr. Saxton was a member of other committees and advisory boards. These included membership on the Research and Development Board's Subpanel on Underwater Sound (1948–52); participant on the Nobska Study on Overseas Transport sponsored by the National Academy of Sciences and the Office of Naval Research; Bureau of Ships Technical Committees on Signal Physics (1963–65), Transducer Program Planning Committee (chairman, 1964–66); and Mobile Sonar Technology (MOST) Committee (1966–67). Saxton also served the Director of Navy Laboratories as a member of the Committee on Undersea Warfare Missions (1966–67), and as chairman of the Subcommittee on Military Oceanography and Acoustics (1966–67).

Saxton served as Sound Division superintendent until his retirement from government service in July 1967. After departing NRL he joined Tracor, Inc., and then served for two years as chief editor of *JUA (USN)*. In this post-NRL period, he authored several technical reports that had as their objective to clarify the physics and mathematics of sonar. He also updated the chapter on "Ambient Noise" in a reference series titled *A Summary of Underwater Acoustic Data* and he prepared a course on sonar for Naval officers.

Saxton was a fellow of the Acoustical Society of America (ASA). He served the ASA as a member of the Executive Council from 1953 to 1956 and was vice president of the ASA in 1965–66. In 1970 Saxton was awarded the Pioneers of Underwater Acoustics Medal by the ASA for his contributions to both knowledge and practice of underwater acoustics, and particularly for innovative solutions to problems of signal processing and sonar systems and transducers. Saxton also was a member of the Washington Philosophical Society, Sigma Xi, Sigma Pi Sigma, Phi Kappa Phi, and Pi Mu Epsilon.

Saxton was well regarded by his colleagues in the Sound Division at NRL and was perceived to be open-minded and always willing to listen to others' ideas and points of view, yet very willing to share his own ideas and have them critiqued. He was fond of filling up his blackboard with equations as he attempted to describe with mathematics the physical bases of sonar system performance in the oceans.

Among Saxton's extracurricular interests were several hobbies that included contract bridge, ballroom dancing with his wife Elizabeth, and piloting private aircraft (a skill he learned at age sixty). He died in 1996 in Sarasota, Florida, at age ninety-four.

Dr. Harvey C. Hayes discussing the progress of the Sound Division with Dr. Mathes, Dr. Saxton, and Mr. Ricalzone.

Sound Division Organization in Era 2

During the 1950s and 1960s the Sound Division under Dr. Saxton was relatively stable in structure and size, with about 130 persons total.

Circa 1955

Code		
5500	**Superintendent**	**Dr. Harold L. Saxton**
5501	Assoc. Superintendent	Dr. Raymond L. Steinberger
5502	Administrative Assistant	Leo T. Curtin
5503	Scientific Staff Assistant	Arthur O. Parks
5504	Consultant	Robert J. Urick
5506	Instrumentation Staff	Frank J. Woodsmall
5510	Propagation Branch	Homer R. Baker
5520	Transducer Branch	Prescott N. Arnold
5530	Electronics Branch	William J. Finney
5540	Sonar Systems Branch	Chester L. Buchanan
5550	Airborne Sonar Branch	Robert H. Mathes
5560	Elec. Applications Branch	Arthur T. McClinton

Circa 1965

Code		
5500	**Superintendent**	**Dr. Harold L. Saxton**
5502	Research Mgmt. Officer	Harry E. Eney
5504	Consultant	Homer R. Baker
5506	Division Services	James G. Larson
5510	Propagation Branch	Dr. Raymond L. Steinberger
5520	Transducer Branch	Robert E. Faires
5530	Electronics Branch	William J. Finney
5540	Sonar Systems Branch	Chester L. Buchanan
5550	Techniques Branch	Robert H. Mathes
5560	Elec. Applications Branch	Arthur T. McClinton

Era 2 Group Photo

NRL Sound Division personnel in front of Building 1 circa 1967.

Era 2 Research Overview

History of the Sound Division in the Words of Homer R. Baker

Around 1967 a brief history of the NRL Sound Division covering the era of Dr. Harold Saxton's tenure was prepared by a Sound Division colleague, Homer R. Baker. It covered the twenty-year period 1948 to 1967. We have retained the original text that contains some outdated or "old-fashioned" terminology [e.g., cycles per second (cps) rather than the more current designation of hertz (Hz) for acoustic frequency, etc.], and have added some acronym definitions in brackets and some photographs.

A Brief History of the NRL Sound Division Under the Leadership of Dr. Harold L. Saxton, 1948 – 1967
by Homer R. Baker

Background

January 1948 marked the beginning of a new era in the research and development program of the Sound Division with the appointment of Dr. Harold L. Saxton as superintendent of the Sound Division. Dr. Saxton succeeded Dr. Harvey C. Hayes who had served as superintendent of the Sound Division from 1923, the year NRL opened its doors, until his retirement December 1947. Dr. Saxton first came to the Sound Division in February 1940 as a branch head under the direction of Dr. Hayes. On January 11, 1948, Dr. Saxton officially became superintendent of the Division to serve until July 1967.

The World War II years, 1940–1945, were years of expansion for the Sound Division. Most of the work in the Division was applied research aimed at immediate solutions of fleet problems. In addition, many scientists from Harvard, MIT, Columbia, Princeton, the University of California, and other schools were organized to do research in underwater acoustics. Due to the frantic activity during the war years a great amount of reports and scientific information accumulated which remained to be published after the war.

The period from the end of World War II in 1945 to 1947 can properly be called a period of readjustment and reorganization. Much of the research and development of the war years was properly documented and published, a notable example being the publication of the NDRC [National Defense Research Committee] reports. Scientific survey teams examined and evaluated the sonar developments of the Germans and Japanese. Operations research people in retrospect were able to put the frantic efforts of the war years in their true perspective. Many able university scientists who worked in underwater acoustics during the war years quietly returned to their primary interests. The Sound Division was slowly decreased in the number of its personnel. In late 1947, laboratory management transferred the Shock and Vibration Branch to a newly formed Mechanics Division and the Crystals Branch to the Solid State Division.

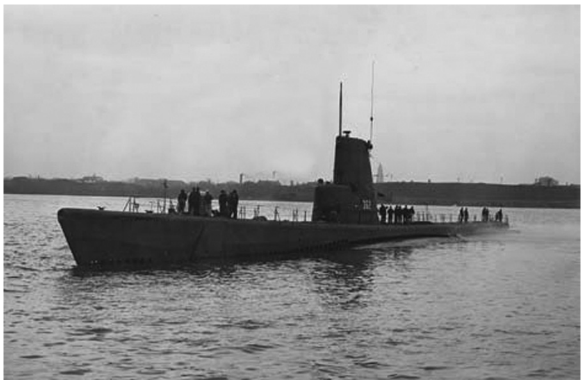
Since 1948, Dr. Saxton has made few organization changes in the Sound Division. However, in March 1954 the Electrical Applications Branch of the disbanding Electricity Division, with Mr. A.T. McClinton as Branch Head, was transferred to the Sound Division. This branch has contributed much to the Division in developing energy storage and control for driving high-power sound transducers and, during more recent years, in providing a better understanding of the range accuracy achievable with active sonar. Another major organizational change occurred in February 1966, when the Sonar Systems Branch, C.L. Buchanan, Branch Head, was transferred to the Ocean Sciences and Engineering Division.

Arthur T. McClinton

Dr. Saxton's first efforts in the Division, after its decrease in size and scope following the war, were to consolidate the Division's personnel into a coordinated team, and to set clear aims for the team's research and development efforts. In discussions with branch heads and key scientists, Dr. Saxton pointed out that existing sonars were no match for the German Type XXI submarine and that research effort must find ways for designing an active sonar to meet the threat. Many new projects were started which were later merged into a coordinated program.

Dr. Saxton has chosen to concentrate on active sonar research; but, at the same time, he has let the branch heads direct their scientific efforts toward problems in which their people had greatest competence. In spite of the apparently loose organization, there has been a coordinated research effort led by Dr. Saxton aimed at greatly improved active sonar.

Starting in 1948, Dr. Saxton made it a practice to work cooperatively with ONR and the other Navy laboratories. He and his staff have given generously of their time and talents to serve on interlaboratory committees and on such special study groups as NOBSCA, ALANTIS and WHITE OAKS. The Underwater Sound Advisory Group [USAG] to the Chief of Naval Research was established in 1959. Dr. Saxton served as chairman of this group from its inception to February 1962. USAG quickly recommended the establishment of a yearly Symposium on Underwater Acoustics for exchange of information between working scientists. USAG also established the Journal of Underwater Acoustics [JUA(USN)] as a medium in which significant classified research could be published. Dr. Saxton has never claimed credit for establishing the USAG or the Journal, but those of us who know him and his passion [for] prompt exchange of research results, suspect that he supplied the spark which ignited both movements. The USAG and the Journal were not, strictly speaking, projects of NRL's Sound Division, yet we are proud of the fact that our superintendent was a moving force in establishing both, for each in its own way has contributed to a more unified and effective research effort in underwater acoustics and to a more effective ASW Navy.



Submarine USS *Guavina* (SS362), Potomac River near NRL (1951).

Dr. Saxton early recognized the place of the Office of Naval Research as the coordinator of the Navy's overall research and development effort. He was instrumental in bringing together a program analysis team under the sponsorship of ONR. The team was chaired by CDR William H. Groverman of ONR (now RADM Groverman) and composed of himself and the scientific directors of the Underwater Sound Laboratory at New London, Connecticut, and the Navy Electronics Laboratory at San Diego, California. One of the first acts of the Program Analysis team was the preparation of an ONR report entitled "Analysis of Long-Range Search Sonars for Surface Ships" published in August 1948. This report was prepared almost entirely by Dr. Saxton with the approval of other team members. The report bore no names and received only a small distribution under a Secret classification, yet it was perhaps one of the most significant reports ever published in terms of its effects on Underwater Sound Research Programs in Navy Laboratories. The report had two parts. Part I was a remarkably clear and concise summary of the basic knowledge of underwater acoustics at the time of the report and an analysis of the sonar equipments of the day as to their capability or lack of capability to meet the Navy's needs. Part II was an analysis of the possibilities for improved sonar performance with recommendations for theoretical studies, experimental work, and oceanographic surveys. Most of the predicted improvements in sonar performance have been achieved through application of the recommended theoretical and applied research programs.

In May 1949, Dr. Saxton published an NRL Report 3467 "Factors Influencing the Design of Long-Range Echo-Ranging Equipment." This report contained the same recommendations as the ONR report, and specifically outlined the research program of the Division for a period of more than five years. Dr. Saxton, in the report, committed the Sound Division to developmental research on an experimental long-range search sonar system. He directed the Division's efforts toward the use of larger transducers, lower frequencies, and higher acoustic power and toward improved signal processing for use in this sonar system. To a large degree, the report has influenced the research program throughout the period of Dr. Saxton's superintendency.

In 1949, these concepts which are widely accepted today, were new and are believed to be original with Dr. Saxton. They demonstrate his insight into the problem, because at that time, many members of the scientific community disagreed with Dr. Saxton's thesis. They believed that increasing the acoustic power of echo ranging equipment would only raise the level of reverberation, and that lower frequency could only result in a higher background noise level.

Before publication of the report, work was underway to develop an experimental long-range search sonar; and in the fall and winter of 1950–1951, it was installed in a submarine, the USS Guavina SSO-362. The experimental system embodied low frequency, high power, a large transducer, and flexibility of signal processing to the maximum degree achievable at the time. Experimental work at sea began in February 1951 and continued through April 1952, at which time the experimental equipment was removed from the Guavina. NRL

Report 4515, "10 Kilocycle Long-Range Search Sonar," published in August 1955, is a detailed account and analysis of work with this experimental system.

Results of experimental work at sea more than justified Dr. Saxton's thesis that active sonar echo-ranges could be greatly increased by using lower frequency, using higher power, and giving careful attention to propagation paths and methods for processing signals. These results of the first long-range search sonar research also indicated the directions which research should take to meet the increasing threat of improved submarines and submarine weapons.

Transducer Research

In the years since 1948, much progress has been made in transducer research toward increased power capability, directivity of transducer beams, lower frequency, and ability to operate at great depth.

The experimental sonar system installed in the Guavina operated at 10kc, not because this was considered to be the optimum frequency but because we did not know how to design and construct a transducer to operate at 5kc or some lower frequency. The late P. N. Arnold, head of the Transducer Branch, designed the 10kc ADP transducer array used on the Guavina, and it was constructed by Robert Colson with the assistance of the NRL shops. The transducer face was 3 ft. in diameter and it weighed 1750 lbs. without its mounting yoke.

Submarine USS *Guavina* (SS362), 10 kHz long range sonar housing (1951).

It was recognized at the time that the lower frequency limit for ADP crystal transducers was about reached at 10kc. Larger crystals were not available, and the practical compromise between mass loading and efficiency could not be further extended.

Since a lower frequency sound source appears to be desirable, research on lower frequency elements began concurrently with the development of the 10kc ADP transducer, and by 1955 a 5kc transducer of piezoceramic elements had been produced. Eventually, the electro-magnetic transducer elements of the shaker box type were developed by John Chervenak of the Transducer Branch to operate at frequencies of 1 and 2kc, and later cubical elements, 1 ft. on a side were developed to operate at 400 cps. This type of element is particularly insensitive to pressure and capable of being operated at great depth.

Through the efforts of Robert Faires of the Transducer Branch and A.T. McClinton who was assigned responsibility for developing a 1-mw [megawatt], 400-cps source for the ARTEMIS research project, a transducer composed of 1440 shaker box elements in a large array was produced. This transducer, completed in 1963, has been operated at a depth of 1200 ft. for several years in connection with an interlaboratory surveillance research project. For special studies of sound propagation from very deep sources, an array has been designed and operated at a depth of 16,000 ft.

With all of the spectacular gains made in the area of transducer research, many problems of interaction between elements of a large array have been encountered and not all of them have been solved. The design of large low-frequency arrays is not yet an exact science, and calibration of these arrays is a difficult business. Current research is aimed at solution of these problems.

In October 1962, the Sound Division opened a Transducer Calibration Facility on Seneca Lake, near Dresden, New York, to serve the needs of the Sound Division, other east coast laboratories, and the Material Commands of the Navy Department. The facility became a necessity because there was no east coast facility capable of calibrating the transducers produced for fleet equipment or the experimental transducers being developed. The decrease in frequency of operational sonars and the corresponding increase in size and weight had made existing calibration facilities obsolete. The water depth at the calibration barge on Seneca Lake is 600 ft., and the cranes have the capacity for handling all operational transducers and all anticipated experimental ones.

Transducer Power

Large transducers with higher acoustic power outputs have proven to be one of the necessary criteria for effective long-range, active search sonars. Sound Division research effort from 1948 to the present has made significant contributions to the design of large low-frequency transducers and to the storage and control of energy to furnish the required high power.

The acoustic power output of active sonar transducers of the World War II period was a few hundred watts. The requirement for increased acoustic power output brought problems of energy storage and control as well as design of amplifiers. For example, the transducer for the experimental sonar system of 1950 had an active area of 7 sq. ft., nearly four times that of the largest fleet sonars of the day. The 10kc transducer could handle 5kw input power in pulses up to 1 sec. in length, the 50% or greater efficiency permitted the radiation of 2.5kw of acoustic power. With such power, the axial sound intensity was about fifty times that obtained with conventional equipment. One 8kva generator supplied power to the driver. Direct-current energy used by the final amplifier was stored in a capacitor bank; or by an alternate method, it was stored mechanically in a flywheel mounted on a special motor generator set. Flywheel storage of energy has been widely used in fleet sonar equipment.

The ever-increasing size and power handling capability of transducers has stimulated research in energy storage and amplifiers. In the ARTEMIS installation, energy for the final amplifiers was stored essentially in the fuel tank of a gas-turbine-driven generator. Significant research in the Sound Division found a method for control of the gas turbine which permitted it to supply power in long pulses without damage to the turbine. Research on transistorized amplifiers has been productive and NRL Reports 5484 and 6379 document results of this research.

Sound Propagation

In his reports, "Analysis of Long-Range Search Sonars for Surface Ships" in 1948, and in NRL Report 3467 "Factors Influencing the Design of Long-Range Echo-Ranging Equipment" in 1959, Dr. Saxton stressed the point that low frequency, high power, and large transducers are not sufficient to assure long-range detection, but it is also necessary to have optimum signal processing. Inherent in his reports is the concept that echoes received over different propagation paths may be altered in different ways and that background noise or reverberation may vary a great deal, depending upon the propagation path traversed, and upon oceanographic conditions. Results with the experimental 10kc sonar in 1951–1952 supported Dr. Saxton's thesis and very-long-range detections in surface ducts were achieved.

The experimental 10kc equipment was designed to have great flexibility for exploiting different propagation paths, and different signal processing equipments. The transducer could be tilted downward for study of the bottom reflected paths, and provision was made for investigating convergence zone paths. It soon became evident that the power limitation would not permit any consistent reception of echoes by way of the bottom reflected path, and no detectable echoes were ever received over the convergence zone path.

Results of long-range-propagation studies with the 10kc experimental system emphasized the lack of knowledge concerning propagation paths and stimulated new research programs. In 1954, the Sound Division performed an experiment at sea in which an unusually low background noise level was achieved by suspending receiving hydrophones from a hovering blimp. This made it possible to separate and detect the multipath signals at long ranges. One-way measurements of propagation loss were then made to a range of approximately 200 miles by way of the surface bounded duct, the bottom reflected path and convergence zone paths. Leakage of energy from one path to other paths as sound is repeatedly reflected from the rough sea surface was also established.

In the years since 1954, much has been learned about propagation of sound in the ocean's depth. The Navy Electronics Laboratory [San Diego, California] has developed sea-going equipment and has conducted extensive research on convergence zone propagation. The Underwater Sound Laboratory [New London, Connecticut] has spent similar effort on the bottom reflected propagation path. The Ships Systems Command has designed and procured sonar systems for the fleet which are capable of utilizing any and all of these propagation paths.

The capability of submarines to escape detection of echo-ranging sonars by hiding in the shadow zone beneath a surface duct still exists, but experimental propagation studies have shown that the shadow zone is not absolute. The reliable acoustic path theory explains that sound from a source near the surface is repeatedly scattered by the roughness of the surface, and some of the scattered energy emerges at the proper angle to penetrate the shadow zone. In deep water, which supports convergence zone propagation, it is possible to insonify the shadow zone by placing the acoustic source at a depth where the sound speed is equal to its speed at the surface. C. L. Buchanan and his branch have operated an acoustic source suspended from a ship at a depth of 16,000 ft., and they have even towed the source at slow speeds. Propagation data collected in this study fully substantiate the reliable acoustic path theory.

To date there is no fleet equipment capable of using the scattered and diffracted acoustic energy which enters into the shadow zone. The ability of submarines to escape detection of echo-ranging sonars by hiding in the shadow zone beneath a surface duct still exists, but only because it has not been possible to design fleet equipment to take advantage of our knowledge. The utilization of these paths is in part a signal processing problem.

In 1948 the knowledge of sound propagation in the ocean was confined to its behavior in the surface and near-surface layers. Today much is known about sound propagation paths throughout the depths of the deep ocean. In both the theoretical and experimental approaches, the Sound Division's research has consistently added to this knowledge. Dr. Saxton's recommendation in the ONR Report of 1948 that theoretical and experimental studies of propagation paths be made including their temporal and spatial distribution has in part been done. The spatial and time distribution of the presence of propagation paths is determined only on a statistical basis and must, therefore, be based on extensive surveys. Such surveys are being made under the ASWEPS [Antisubmarine Warfare Environmental Prediction System] program and various other survey projects.

In the early 1950's measurements of the target strength of submarines made by Urick, Pieper, and Searfoss gave significant statistical values, but the great fluctuation of measured values indicated that the reflection process is not well understood. Basic studies of the reflection of sound from discrete geometric shapes have been pursued for some years with encouraging results by Neubauer and his associates. Also, published reports by Hurdle and his associates have received wide recognition. Their basic study aimed at understanding the processes of reflection and scattering of sound from the surface and bottom of the ocean has yielded useful knowledge.

Such basic studies as the hydrodynamics of towing bodies in the ocean and the effects of pressure on acoustic and electronic components have been very useful in certain cases. Recognizing that the ship's own noise may be and often is the limiting factor in the detection of weak signals, the Sound Division has a research project to study flow-excited noise in the hope that an understanding of the cause may lead to a method of reducing the noise of ASW ships.

Location of the wreckage of the USS Thresher in 1964 by Buchanan's branch can be attributed to their know-how in deep sea technology, gained through basic studies and experience in experimental studies of the reliable acoustic path. These same skills and the additional experience with transponders and acoustic navigation enabled the same group to give valuable assistance in the recovery of the atomic bomb off the coast of Spain.

Signal Processing

The Sound Division research program in signal processing is a healthy balance between the theoretical and experimental and is utilizing all of the available tools to enhance the ratio of signal level to background level.

In 1948 it was pointed out in the ONR Sonar Analysis Team report that long-range active sonar detection of submarines was critically dependent on improvements in signal processing. In the sonar systems of 1948, signal processing consisted of amplification of the signal, associated noise, and reverberation in a relatively wide band amplifier. The bandwidth of the amplifier was determined by the possible limits of the doppler shift due to relative motion of target and echo ranging ship, usually 200 or 300 cps.

In the Sound Division's first experimental long-range search sonar the following receiving equipment was used: a conventional 10kc receiver, with selective bandwidths of 50, 100, and 200 cps; a sector-scan indicator or phase-sensitive receiver which measures the phase angle between the electrical outputs of the two halves of the transducer; a frequency scanning receiver employing a set of narrow filters which perform a spectrum analysis of echo ranging signals; a selective time-delay receiver which required the system to be modified to transmit a series of frequency-coded pulses and the received signals to be selectively channeled by means of filters to a storage device; and a graphic indicator which compared over successive cycles the phases of the echo and a calibrated tunable local oscillator as a frequency reference.

The 10kc receiver, although not new in concept, was an improvement over fleet receivers, especially when operated in the 50-cps bandwidth mode. Two things were learned with this receiver: the lower frequency does not appreciably increase the level of background noise, and the higher acoustic power does not increase the relative level of reverberation with respect to echo level. The combination of an A-scan display and an audio output was effective. The already existing SSI receiver was particularly useful in aiding the operator to train the searchlight beam onto the target.

In the frequency-scanning receiver, the outputs of the individual filters were detected; and the resulting signal envelopes were sequentially sampled by a commutator. Information was presented on a B-scan crt display with range as the ordinate, frequency (doppler) as the abscissa, and intensity modulation of the display as signal amplitude. The use of narrow-band filters to discriminate against broadband noise and reverberation was proven effective. In subsequent years, improvements in filter design and scanning techniques have greatly improved the spectral analysis on a sonar signal.

The graphic indicator, displayed on a B-scan phase relationship versus time, permitted high precision measurement of doppler shifts. The graphic indicator developed in the Sound Division has been further refined and is used in some modern sonars.

The selective time delay receiver employed a multi-stylus chemical recorder for both the storage and display of information. A series of echoes were presented side by side as a horizontally orientated pattern while simultaneously occurring noise and other interfering background components produced diagonal patterns on the display. Whereas the methods for storage and display of information have been greatly improved by further research, the pattern recognition feature of this receiver showed a great potential for detecting weak echoes.

A tape recorder was included as an integral part of the 10kc experimental sonar. Raw or processed sonar data could be recorded on a continuous basis if the operator so desired. The quality of the recorder and of the tape available at the time were not good by today's standards, but this marked the beginning of the standard practice of recording sonar data at sea for later study and analysis. Robert Carson of the Sound Division has done important research to improve the quality of tape and recorders.

The sonar signal processing research, now in progress, recognizes the interrelationship of the transmitted signal to the propagation path or paths and to the type of processing. Many new tools are now available to the signal processing researcher, such as preformed narrow beams, precision recording techniques of the digital and analog types, large capacity information storage, and high-speed computers. The ability to detect submarines at long ranges, has brought with it problems of target classification and attack. The echo trap and the hand-held classification computer developed by Hiller were useful devices developed in the Sound Division. The LORELI long range attack techniques developed by Mathes and Ricalzone is a contender with other attack techniques, and if a real war situation arises, it may prove to be the simplest and most reliable method for attacking a submarine at long range.

Basic Research

The Sound Division's research program has not been entirely systems oriented, nor has it all been applied research. Dr. Saxton has encouraged all possible basic research which could possibly contribute to active sonar research.

Basic research in measurements of the speed of sound in pure water and sea water as a function of temperature, salinity, and pressure [has] been pursued with vigor by Del Grosso. Interferometer equipment designed by Del Grosso is probably the most precise in existence, and NRL's published tables of sound speed in sea water as a function of temperature and salinity are widely used. Tables of sound speed versus pressure soon to be published are expected to be equally precise. Measurements of the absorption of sound by liquids [have] been useful in selecting liquids suitable for sonar applications.

Some of the research accomplished in the Sound Division has found application in other areas – an example is the sector-scan-indicator invented by Dr. Saxton. The principle involved consists of a precise measurement of the phase difference in a wave front as it arrives at the halves of a split transducer. The same technique has been effectively applied in the fields of radio and radar for tracking satellites and in some types of telemetry.

Summary

In summary, the history of the Sound Division over the past twenty years was largely influenced by the scientific insight and vision of Dr. Saxton. The Sound Division has in the main achieved the aims laid down for it by Dr. Saxton in 1948. The fleet does indeed have long-range active search sonars, one of the essentials of a strong ASW posture. It is fair to say that modern fleet sonar is more than a match for the submarine threat envisioned by Dr. Saxton in 1948.

As Dr. Saxton retires, we of the Sound Division have a justifiable pride in our accomplishments under his leadership. We are aware that the nuclear powered submarine, with its high speed, long endurance, and increased depth capability poses a new challenge. The inspiration of Dr. Saxton's scientific competence, broad vision, and wise leadership will be an important stimulus as we seek new knowledge to meet the present and future submarine threats.

Key Research Thrusts and Achievements in Era 2

9 Sonar Graphic Indicator for Range and Range Rate Measurement
10 Deep Towed Seafloor Search System

9
[1952–1966] Sonar Graphic Indicator for Range and Range Rate Measurement

Achievement: Beginning in the early 1950s, NRL Sound Division researchers led by Burton G. Hurdle developed a device known as a sonar graphic indicator. This instrument enabled the graphical display on a cathode ray screen of range rate via acoustic Doppler measurements. It was designed for use on surface vessels and submarines. The resulting device enabled the classification of undersea targets, the measurement of range rate, and the automatic tracking of range. Sea tests were conducted using the equipment in both passive and active sonar applications. The instrument was capable of tracking a target with a range rate accuracy of 0.1 knot and a range accuracy of 5 yards.

Impact: During the middle and late 1950s NRL collaborated with the Navy Underwater Sound Laboratory, New London, Connecticut, to integrate the sonar graphic indicator into the AN/BQQ-2 submarine sonar system. This resulted in the design of the AN/BQA-3 graphic indicator that became a component of the sonar operating system in Navy submarines.

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10
[1963–1980] Deep Towed Seafloor Search System

Achievement: In the early 1960s, NRL's Sound Division conducted a number of tests under the leadership of Chester L. Buchanan on various sensors in preparation for developing a deep towed search system for investigations of the deep ocean seafloor. This system, one of the earliest of its type, with a 21,000 ft towing cable, was being assembled when the Navy received news on 10 April 1963 that the U.S. nuclear submarine USS *Thresher* (SSN 593) was reported missing off the coast of New England. Buchanan's group received an urgent request from the Navy to complete the preparation of the deep towed search system and assist in the search for *Thresher*. In summer 1963 an initial search was conducted in waters off New England at about 8600 ft depth. NRL fielded two Sound Division teams on USS *Rockville* and Research Vessel *Gilliss*. Other researchers joined the search including teams from the Hudson Laboratories, Lamont Geological Observatory, and the Woods Hole Oceanographic Institution. However, operations were suspended on 7 September 1963 with the onset of severe weather. The Navy search operations resumed in May 1964. NRL participated with a much more capable vessel, USNS *Mizar*. Using its deep towed system, the NRL team on *Mizar* made an initial detection of the *Thresher* hull after only eight hours of bottom operations. Later that summer, *Mizar*'s tracking equipment and underwater telephone system were used to guide the submersible *Trieste II* to a position directly on top of *Thresher*'s hull. NRL's deep towed system was able to acquire approximately 100,000 photographs of *Thresher*'s hull. Within several years, NRL's deep towed search system successfully assisted the Navy in other urgent searches. These included locating the lost U.S. nuclear submarine USS *Scorpion* (SSN 589) in October 1968 about 400 miles southwest of the Azores at a depth of about 10,000 ft; and the French submarine FNS *Eurydice* (1970). The NRL system also successfully assisted in the recovery of a lost nuclear weapon (1966) and the sunken Deep Submergence Vehicle *Alvin* (1969); and assisted the Department of Defense in deep water disposal site surveys (1970).

Impact: The NRL deep towed seafloor system provided invaluable assistance to the Navy in the searches for two lost U.S. nuclear submarines, USS *Thresher* and USS *Scorpion*, as well as other important deep ocean searches. In 1980, NRL's emergency search mission was transferred to other Navy organizations and the Deep Ocean Search System was deactivated. To various degrees, NRL-developed search technology now resides at the Naval Oceanographic Office, Submarine Group One, the Navy's Supervisor of Diving and Salvage, the U.S. Geological Survey, and several foreign governments. The U.S. private sector has also adapted the technology for tethered inspection systems for the offshore petroleum industry, and several companies have used this technology to perform deep ocean searches and recoveries for the Navy, NASA, and the airlines.

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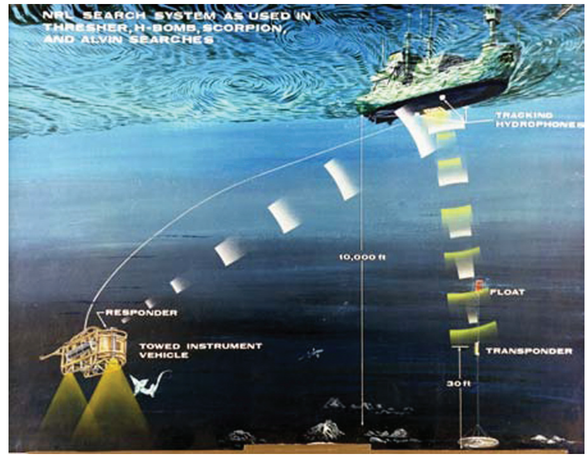


NRL deep ocean search system (mid-1960s).

NRL instrumented towfish for deep ocean search system (mid-1960s).

Award ceremony circa 1965 for NRL team participating in successful 1964 Search for USS *Thresher*. Front: Chester Buchanan, Frank Heemstra, Massis Davidian, Lloyd Greenfield, Capt. Thomas Owen, Walter Brundage, Robert Patterson, Kenneth Stewart, Hanford VanNess, Jervis Jennari. Middle/Rear: Mort Smith, Hester Helms, Ernest Czul, Unidentified, H. Bernard Lindstrom, Howard Barnes, Peter Kaufman, Andrew Findlay, Matthew Flato, Daniel Friedman, Wilbert Jones, Robert Mills, Hollis Gibbs, John Humphrey, James Somerville, Jr.

Further Recollections of Era 2

Reminiscences about Dr. Harold Saxton's Era by Chester L. Buchanan

Prepared for Dr. Fred Erskine, August 26, 2005, in advance of NRL's first "Alumni Day."

Chester L. Buchanan

I Remember Harold

Background about Dr. Harold Saxton

Dr. Harold Saxton received his Ph.D. degree in 1934 from Pennsylvania State University and he remained there in various capacities as instructor and assistant professor of physics. He came to NRL in 1940 as head of the Electronics and Propagation Branch of the Sound Division. In 1947 he became Superintendent of the Sound Division, upon the retirement of Dr. Harvey C. Hayes. Dr. Saxton retired in 1967. My initial employment at NRL occurred at about the time that Dr. Saxton took over as Superintendent, and thus I had many opportunities to work with and for him. These then are a few reminiscences of these times.

During these years I was unaware of his origin and background. Harold never "bragged" and thus I was unaware of his influence on matters related to the WW II war effort. In addition, I was very soon assigned to the task of testing at sea, of a system for passive ranging by submarines. The key element of this system was a device called the Sector Scan Indicator (SSI) developed and patented by Dr. Saxton. To know Dr. Saxton, you must appreciate the SSI.

Development of the Sector Scan Indicator (SSI)

It is difficult to explain to the current crop of researchers the state of signal processing in the pre-computer age we are discussing here! Now Harold was a "Mathematicians mathematician!" If he couldn't put your problem into a mathematical form, he was loath to believe in any answer. I had a much different approach and this led to many interesting episodes where I would sit and watch as Harold covered a whole blackboard with mathematical equations. Lunch hour, quitting time — these meant nothing when he was in the midst of one of these episodes. It never seemed to bother him that I saw things from a different perspective and he never criticized me for it. In fact I think he thoroughly enjoyed these mathematical joyrides!

I am unaware of how Harold came to invent the SSI. There is a patent dated July 12, 1938 (Robert H. Worrall, #2,123,221) that described a radio receiving apparatus that could in essence cancel out the drift of the transmitted frequency of a radio signal. This patent may have been the inspiration for the SSI.

This Worrall patent described a radio receiving system that canceled out the drift of the transmitted frequency. The patent discussed the frequency of the signal components throughout the electrical circuit, but did not discuss the phases of the signals. Harold, as I understand it, recognized (probably after one of those blackboard sessions) that the circuit could be altered so that the phase of the output signal could be made to equal the phase difference between the signals of the two halves of the receiving array. In real life this meant that one can determine the directional position of the origin of a received signal within the beam pattern of the receiving array — be it a radio signal or an acoustic one. This invention was applied to the problem of targeting a submarine by accurately determining the range using an active acoustic ranging system and using this directional tool in an equipment called the "Attack Plotter" to determine the bearing in order to make an attack.

Later during WW II this idea was applied to a passive ranging system for submarines. In WW II submarine combat, the distance to the target was difficult to determine with any accuracy unless one sent an acoustic signal and received an echo. Such a signal gave away the fact that the submarine was there, and thus some way of determining the "range" without giving away the advantage of "stealth" was attractive. Thus it was that the idea of placing two receiving systems far apart on a submarine, and observing the differences in the angle to the target from each of the locations, to determine the range to the target, was developed. Since the submarine is not really very long, the two receiving equipments are constrained to be relatively close together and thus the need for the ability to measure the direction of the target with great accuracy. The physical components of this system had been pretty well designed by the end of WW II, and when I arrived, I was very soon charged with the responsibility of getting this system installed in a submarine and conducting tests to determine the performance of the system. Harold was understandably very interested in the results and thus was very much "looking over my shoulder" during the year or so that these tests were conducted aboard the submarine "Sea-cat."

I'm not sure the following belongs here but I will give a short review of some of the things that came out of these experiments. Each of the two operators controlled the direction of one of the two transducers using a control that consisted of what may have been the origin of the "mouse" that is identified with today's computer control. There was one difference, however — it was installed upside-down. The operator moved this ball with his fingertips as is done in some laptop computers. Rolling the ball away from the operator caused the transducer to tilt up or down and the movement to the right or left caused the transducer to move in azimuth. It became apparent to me that measuring the two angles and then determining the difference between them, using the tools available at the time, was not going to produce a good result, because the two operators tended to hunt back and forth around the direction of the target and thus cause a random variation in the difference between the two angles. Unfortunately there was no way for Harold and his mathematical bent to offer a solution to this problem. In an attempt to improve the system, I changed the control system so that one operator controlled the direction of BOTH the forward and the aft receiving units — both in the same direction. The second operator used a similar control to add or subtract the small angle required to get both transducers either exactly on target, or so that they both were the same amount off target. This proved to reduce the "hunting" that occurred when two operators tried to stay "on target" and resulted in a much smoother result in the difference angle.

These experiments were done using "noisemakers" since the small ships we were assigned to act as targets, did not make enough propeller "noise" to allow our tests to be made at useful ranges. Unfortunately no one knew anything much about the characteristics of the noise these devices produced. These noisemakers used several rods which when towed through the water fluttered and struck each other, making quite a loud noise. Of course if the noise had any appreciable sinusoidal output, the system could give erroneous results. Our knowledge at that time regarding "white" noise and noise coherence was very minimal. We conducted extensive testing of this system and the results were quite good. The only problem was we never had a signal that came from a ship worth wasting a torpedo on. While the results were quite satisfactory, I became very interested in the characteristics of the signal from this noisemaker. At the conclusion of our evaluation I scheduled a day for some tests designed to determine something about the characteristics of the noisemakers we had used. For this purpose we connected the entire forward transducer to one input of the SSI system and the entire after transducer to the other input. I then was given control of the submarine and directed the submarine to change course as I observed the target ship through the periscope. The two transducers were each pointed directly to port while I directed and relayed to the team in the equipment room, the current direction of the target. The display was a CRT with the horizontal axis being the azimuth of the target within the beam pattern. The left side of the display corresponded to −180 degrees and the right side +180 degrees. With a continuous signal there would be no way of telling the difference between −179 degrees and +181 degrees and so on.

With a continuous (CW) signal the directional signal was observed to go from one side of the display to the other and then shift to the other side and repeat. This was to be expected and the question was whether any of this behavior could be seen with our noisemaker? If so, the system would be expected to give erroneous results. When we tried this same experiment with the noisemaker, the signal would usually appear on only one time across the display with perhaps sometimes a dim unstable display on the second crossing. Finally we came in closer to the target ship and used her screw noise as our signal. In this case we never saw any indication of an error signal. At the conclusion of these extensive tests, Harold came to my office and made a kind of speech. In effect he said that they had expected my Branch to be an engineering group to test the equipment. However he said we had far exceeded his expectations and had produced some very valuable data and understanding of the signal processing involved. That was high praise indeed! This was typical of Harold who always gave credit where credit was due!

At the conclusion of these tests I wrote a report indicating that the equipment met the objectives of the program. However, I felt that the size, cost, and mechanical complexity of the system could not be justified and that a different approach should be investigated. The new approach I suggested was to place three receiving arrays on the submarine. One should be on or near each end and one in the center of the submarine. The noise from the propellers of the target ship would be received at each array, and the difference in time of arrival at each listening station be determined by some signal processing system similar to the SSI circuit. I wrote this in long hand and stuck it in my desk drawer, turning my immediate attention to other matters. A month or so later a group from the Naval Ordnance Laboratory (that included Dr. John Munson) visited the NRL seeking support for the design of a passive ranging system for submarines. Dr. Saxton sent this group to see me and I immediately saw that they were describing a system essentially identical to the one I had described earlier. I pulled the handwritten memo out of my desk and handed it to them. This made us friends for life as it gave them the backing of NRL in their search for support. This system was developed and proved useful. Of course by this time there had been much advancement in signal processing techniques and the use of computers was beginning to have an impact.

I have been an amateur radio operator since I was 17 years old. At the time of these events, voice communication among amateurs was rapidly shifting from amplitude modulation to "single sideband". The characteristics of the Worrall and SSI patents seemed to me to indicate the capability to replicate the "carrier" signal so that single sideband reception would be free of the distortion caused by slight errors in tuning of the receiver. I (at my home) put together an experiment to verify this hypothesis, and was able to do some experiments that seemed to indicate that it did indeed work. However, I was required to abandon everything by one of the many emergencies that became the norm for me and my Branch after our stunning success in the second year (1964) of the USS *Thresher* search. I never got back to conclude this investigation!

You should know that patents like the SSI were not published during the war years. While they were published after the war, they are not available today on the Internet by subject. One can only search for them by their patent number. For this reason this period of patents may have been largely overlooked. I have never seen any reference to either of these two patents in any of the communications literature.

One other comment about the SSI: As the space age began there was great competition for computer access. NRL had one of the first computers and it was fully occupied with calculations regarding the proposed launch of the NRL-built satellite. At this same time, NRL was designing a system called "SPASUR" (Space Surveillance). This system was intended to detect and track all objects in space. This included the "space junk," that is, objects lost or discarded from space launch attempts. This consisted of three radio transmitters situated across the North American continent, with receiving arrays to receive echoes from these objects and determine their position in space, and furthermore to determine their orbit. Such objects are of course a hazard to subsequent launches and particularly to the humans in space that was to come later. Roger Easton called me one day and asked me to come to his office and discuss the SSI signal processing system. This I did and as I understand it, the system for receiving these signals today is similar to that of the SSI. I hope this illustrates to you why I feel that Dr. Saxton made very important contributions to the War effort and the Space Race that followed, and these contributions were never acknowledged as far as I know!

Testing of New Low Frequency Sonar Systems

During the late 1950s, Dr. Saxton initiated a demonstration program to build and test sonar systems at frequencies of 10, 5, and 1 kHz, one after the other. At the same time, the Sound Division was reorganized and there were no longer separate sections for submarine and surface sonar systems. Instead there was now a Sonar Systems Branch and I was the Branch Head. Obviously the size of the transducers for these frequencies dictated a different way of launching them into the sea. In search of a viable way to accommodate these ever-larger systems, we chose to propose the use of a small vessel with a "center well" through which we could lower these test platforms into the sea. We were awarded the LSM 398 (*Hunting*) for this purpose and we installed a very large well with a platform above to support a large winch to lower the equipment into the sea. These three systems were constructed and tested over a period of several years. In these three systems we initiated several new signal processing schemes. The most radical of these was a 2 Hz wide comb filter used in the 1 kHz system. This comb filter was based on a mechanical tuning fork! With this system we received echoes from a submarine over the convergence zone! The transmitting and receiving array for this 1 kHz system was very different than any used before. It used rows of spaced transducers in front of a reflective curtain made of "bent tubes" (patent #3,264,605). I cannot remember the way we steered this array.

Reliable Acoustic Path Sonar Developments for Deep Water

At the conclusion of this ambitious project, I proposed a program to be called "RAP" (for Reliable Acoustic Paths). Previous to this, all surface-ship sonar systems were operated very near the surface and were subject to the surface channeling effect caused by certain weather conditions. It was felt that we should separate the effects of weather from our knowledge of propagation in the deep ocean. Dr. Saxton agreed and this was our major effort at the end of the 1950s and the early 1960s. This project was severely hindered by the lack of computational facilities. In desperation I "invented" a slide rule for the purpose. During a number of "skull sessions" it occurred to us that if one calculated the path of sound rays in the deep ocean, and below the weather-affected surface region, that one could separately plot the paths for a small range of inclinations at some specified depth and then by moving the resulting plots so that they intersected at some other depth, one arrived at the paths for this new depth without the necessity of recalculating the sound rays! This was done and resulted in a wonderful "toy" and a remarkable tool for understanding the propagation of sound in deep water.

This project involved many experiments using sound sources at various depths. Most everyone knows of the surface convergence zone, but few realize that there is an inverted convergence zone. The inverted convergence zone was noteworthy for the fact that it is a "true" convergence. That is, all of the rays that reach the inverted convergence zone arrive at the same time so that the signal is not modulated by some rays arriving early or late. (In the surface convergence zone, the near-surface variations in transmission speed cause serious phase interference at the convergence.) In experiments with a very low frequency sound source (I think 400 Hz), mounted near the bottom at 12,000 feet (I think), and emitting a signal that was carefully designed to start at the "crossover" and be exactly 11 cycles long, the signal was received at the first inverted convergence zone and appeared exactly like the one transmitted. Furthermore this behavior was repeated at the second inverted convergence zone! I doubt if many people are aware of these measurements!

This period was a special one since for the first time we had the ability to place equipment any place in the ocean and thus greatly expand the database for measurements in the deep ocean. Unfortunately this came to a sudden halt when our ship the *Hunting* was rendered unfit for sea. This was interesting in that the steel used during the wartime for constructing this ship could not be repaired with new steel. These ships were notorious for corrosion under the engine compartment due to stray electrical current in the water. In an attempt to replace the bottom under the engine room, the steel would always crack at the junction between the old and new steel. In the end the ship was scrapped and we were without any way of operating at sea. Dr. Saxton believed that we should continue the deep ocean "RAP" work after acquiring a new ship, with emphasis on the characteristics of the sea floor, especially the reflections from the floor that frequently masked any echoes. During this hiatus we started preparing for this new task. One of the things we did at this time was to develop a television system that could operate over our standard 4-mile long tow cable. In addition we prepared to expand our ability to photograph the ocean floor.

Loss of the USS *Thresher* in Deep Water

During these preparations we had no idea that we were doing the very things that would be put to practical use when the submarine *Thresher* sank in 8400 feet of water on April 10, 1963. On this fateful day I heard the news about our nuclear submarine USS *Thresher* being lost in deep water. Somewhat later I had a call from the Captain of NRL at the time, Capt. Bennett. He enquired as to whether I know if anyone else had a TV that could be used to search for *Thresher*. Of course there was none. Capt. Bennett said well — I think you may be required to aid in the search operation. I asked if he would like me to come in to the lab now, and he said no — we'll see about it in the morning.

I couldn't sleep so I got up and wrote an OP PLAN for two ships. One was for the *Rockville* which was a PCS assigned to NRL, and the other was for a ship to be assigned. The next morning (without any sleep but with lots of adrenalin), I went to the lab pretty early and quickly made a copy. I then took the original and laid it on the Captain's desk. I put the copy on my secretary's desk with a request that she type it up and if possible slip it on the Captain's desk before he had to read the hand written one I had put there. I had scarcely completed this when the Captain called on the phone. He said "Buck, those plans you put on my desk — GO!" He hung up the phone! Wow! That was the biggest blank check I had ever received!

Well of course I called Dr. Saxton to tell him. I was astounded to find that *Rockville* was outfitted for a trip to Bermuda and that Harold was going to sail with the ship! To make matters worse, his wife was planning to fly to Bermuda to join him there! Well of course those plans were quickly scratched and the equipment for the trip was removed and replaced with that for the new task. The only thing on *Rockville* that was of any possible value in this search was that it had aboard the only sonar system that the Navy possessed that could be tilted downward! The vessel sailed the following morning. (In the end this was a futile matter since *Thresher* was broken into five pieces and all were flooded so there was little or no chance that any echo from the debris would be heard over the bottom reflections.)

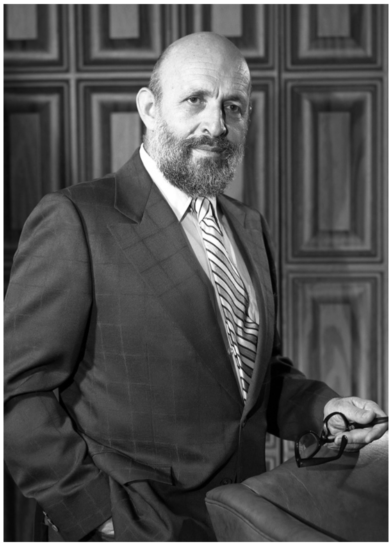
At this juncture the real strength and weakness of Dr. Saxton came out. After he got over the shock of this change in his plans, he called and said he would order another telephone in my office and that he would come over to screen my telephone calls so that I would be free to do the planning that was required. By 10 or 11 AM he arrived at my office and commenced to try to shield me from as many calls as he could. As you can imagine these were many. By the end of the day Dr. Saxton was obviously distraught and he never came to work again for the rest of the week!

After these events, Dr. Saxton was not so much my supervisor any more. Technically I was still in the Sound Division, but everything that I did was directed by outside influences. This condition continued through 1964 when we astounded everyone by succeeding in photographing the USS *Thresher* with our newly outfitted ship the USNS *Mizar*, on the very first attempt.

By this time the new government agency, NASA, was formed and a large number of people from NRL were moved to that new organization. This left a number of employee slots open and everyone was requested to recommend a program to fill that organizational void. I along with some others recommended that we initiate projects in oceanography. This proposal was eventually accepted and a new Directorate called "Oceanology" was organized. In this organization I became head of the Ocean Technology Branch and no longer reported to Dr. Saxton.

Oh yes — I remember Harold.

Project Artemis — A Retrospective View by Dr. Alan Berman



Dr. Alan Berman

Invited paper at the 142nd Meeting of the Acoustical Society of America, session 2pUW: "Underwater Acoustics and Archives and History: How Did We Get Here? Insights into the History of Underwater Acoustics," Ralph R. Goodman, session chair. The abstract is published: abstract 2pUW1 in J. Acoust. Soc. Am. 110(5), Pt. 2, 2688 (Nov. 2001).

Introduction

In the late 1950s, the U.S. Navy initiated and sponsored a massive research program called Project Artemis. In time, almost all members of the U.S. underwater acoustics community became involved in and contributed to this project. The objective of this endeavor was to determine what were the capabilities needed to build an active monostatic sonar that was capable of detecting a submerged submarine at ranges of about 1000 km.

Although no operational capability ever resulted from this effort, the research undertaken by this project identified the limitations in existing technology and in the community's knowledge of underwater acoustics that precluded achievement of the original objective. In the area of technology, the most obvious limitation was the limited speed of available computers that forced the use of cumbersome analog devices for signal processing and for beam steering. Techniques for controlling the location of the source dynamically and for the construction and operation of large-scale acoustic high-powered phased arrays were developed successfully. Unresolved issues that formed the basis for future research efforts related to signal coherence time, low frequency acoustic cross sections of submarines, the development of reliable computation models for propagation loss, low frequency acoustic absorption processes in the ocean, and the development of algorithms that accounted for source Doppler. Project Artemis terminated in the mid- to late 1960s.

USNS *Mission Capistrano* (T-AG 162), used in Project Artemis (mid-1960s).

The Choice of Operating Frequencies and the Sonar Equation

In effect, the first and most profound decision that faced the original panel that designed the program was the choice of the mid-band operating frequency.

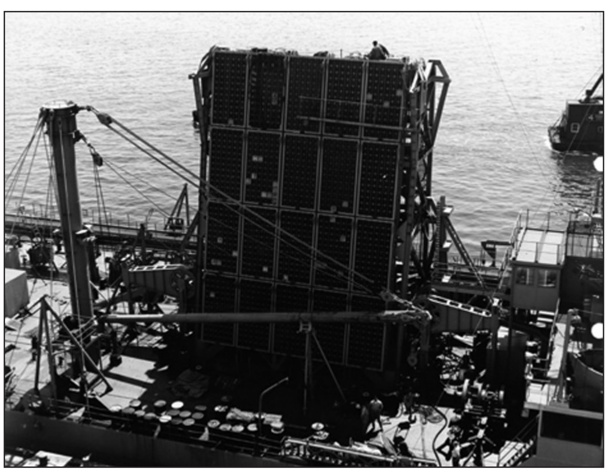
As with the design of any monostatic active sonar system, the requirements of the Sonar Equation guided the implementation of Project Artemis. As is well known, the Sonar Equation considers two-way propagation losses and offsetting system gains. The requirement for a low false alarm detection rate implies that the total of the system gains significantly exceeds the propagation loss. In general terms, the more complex the detection system, the greater the signal excess must be in order to establish an acceptably low false alarm rate in the presence of reverberation and ambient noise.

The Sonar Equation does not provide information concerning reverberation levels that may indeed limit system performance. Reverberation may be the result of scattering of the transmitted signal from: the local bottom, local surface waves, remote sea mounts, distant surface waves, the continental slope, and possibly from biomasses in the ocean. Scattering from the local bottom or surface of the ocean may be time gated out when an attempt is being made to detect and track a distant target. Reverberation that comes within the range bin that is associated with a submerged target can only be discriminated against with signal processing and receiver and transducer directionality. These considerations certainly impacted the choice of system parameters.

All of the factors that generate reverberation are indeed frequency (more properly wavelength) dependent. In the Sonar Equation there is also a strong dependence on frequency. The terms of the Sonar Equation include:

- Ambient noise. In any given location and at any given time, the ambient noise level is a function of local wind and wave conditions, and propagation modifications of the noise generated by distant storms, geophysical activity, biologically generated noise, and the noise generated by distant shipping. All of these mechanisms are frequency dependent.

- Propagation loss. Although acoustic propagation loss in the ocean is predominantly dependent on the structure of the sound velocity versus depth curve, frequency-dependent losses do occur as a result of frequency-dependent boundary scattering losses and molecular absorption processes. Although at the time Project Artemis was initiated, these latter processes were incompletely understood, there was a general understanding that at frequencies above 1000 Hz, absorption and boundary scattering losses increased rapidly with increasing frequency.



Source transducer array on USNS *Mission Capistrano* (mid-1960s).

- Acoustic scattering cross section. The acoustic scattering cross section of an underwater target has both strong aspect dependence and a strong dependence on the ratio of the wavelength of the illuminating signal to the projected dimensions of the target. Although computational capabilities available in the 1950s were insufficient to provide realistic models of submarine target strength as a function of both aspect and frequency, the general trends were understood.

- Receiver and transducer gains. For a given number of sensors or transducers, the array gain that may be achieved is a function of the ratio of inter-element spacing to the acoustic wavelength.

- Source level. For any underwater acoustic transducer design, the transduction efficiency that can be achieved is a strong function of the ratio of the dimensions of the transducer to the wavelength of the acoustic energy.

- Signal processing gain. The maximum signal processing gain that may be achieved is not a direct function of frequency, but of the product of the bandwidth of signal that is transmitted times the duration of the signal. The problem is that underwater transducers are mechanically resonant devices. The more sharply tuned the mechanical transducer, the more efficient the process is. Conversely if the frequency of transduction that is chosen is only 400 Hz (as was the case with Project Artemis) the achievement of a signal bandwidth of 100 Hz implied a relatively broad mechanical resonance and a low efficiency of conversion from electrical to mechanical energy.

Based on consideration of all of these known and unknown frequency dependencies, a center frequency of 400 Hz was selected.

Anticipated Losses and Gains
Propagation loss
If propagation losses were only the result of inverse square law spreading, then the 512 nautical mile round trip loss from source to target to receiver would have resulted in a loss of 240 db. If there were additional losses at 400 Hz from absorption and scattering processes that were unknown in the 1950s, then the total propagation loss would have exceeded the estimate of 240 dB by an unknown amount. In the years after the project was terminated, the existence of low frequency absorption processes was established. These losses at 400 Hz might have served to increase the total loss by as much as 8 or

10 dB over the 240 dB loss that was the basis of project plans.

A good general understanding of acoustic propagation paths through the ocean certainly existed at the time of inception of the project. The objective of the project was the detection of submarines at distances of 500 nautical miles. Since submarines were generally limited to depths of 300 to 350 meters, acoustic paths needed to be selected which would result in the relatively continuous insonification of the top 350 meters of the ocean. Ray tracing calculations were made using typical sound velocity versus depth profiles for the Atlantic Ocean in the areas south and southwest of Bermuda. These computations established that an acoustic source at a depth of 1000 to 1150 meters below the surface would provide the necessary insonification of the region of interest. These computations all indicated the need for the acoustic radiation to be transmitted in a cone of angles between 9 and about 16 degrees above the horizontal. These computations established the operating depth of the source and the required source directivity or array gain.

Goals for System Gains

In order to overcome the inherently large propagation loss of 240 dB and to provide a recognition differential of 15 to 20 dB, an attempt was made to design a system with the largest realizable gain that could be achieved.

Target strength. In the 1950s, no measurements existed concerning the acoustic scattering strength of a submarine. An admittedly questionable assumption was made that it would be the same average value as its measured value at 5 kHz. Also, recognizing that the acoustic scattering cross section was aspect dependent, the Artemis steering committee assumed an average value of 15 dB for this parameter.

Receiver array gain. A fully populated array of receivers with regular inter-element spacings of $(d/\lambda) = 0.5$ should result in an array gain of $10*\log(N)$ where N is the number of elements in the array. If 10,000 elements were employed, the receiving array gain would be 40 dB. Accordingly the steering committee elected to deploy an array with 10,000 elements.

The Artemis receiving array was deployed on the slopes of the Plantagenet Bank, which is an extinct volcano whose peak nearly reaches sea level. An offshore oil-drilling platform, reconfigured as a laboratory and called Argus Island, was established on the top of the Plantagenet Bank. Cables from the sensors in the Artemis array field were terminated at Argus Island and relayed to the project's main laboratory established on the Island of Bermuda.

The underwater array was connected to Argus Island by ten cables each containing 40 twisted pairs. At 40 separate points along each cable, a connection was made to a vertical mast supported by a buoyant underwater flotation device. Each mast carried 25 hydrophones whose outputs were connected together. The signal output of each of the masts was connected to a twisted pair in one of the ten main cables.

In effect, the Artemis receiving array was a three-dimensional array with inherently non-uniform spacings that, by design, experienced problems with multipath propagation caused by bottom reflections received by the mast-mounted sensors. After installation, an extensive program was undertaken to establish inter-element time differences of arrival so that phase corrections could be established and the array could be steered.

Because of its structure, the Artemis array was not a fully populated uniformly spaced array. Consequently it exhibited, as was expected, ghost lobes and non-uniform minor lobe responses. As a result it apparently never achieved the full 40 dB gain that was hoped for. Furthermore, in early 1967, a survey of the Artemis array field was made using the deep submersible vehicle *Alvin*. As a result of this survey, it was found that many float failures took place as a result of the weight of buildup of biological matter and corrosion of some of the floats resulting in leak-induced loss of buoyancy.

Source level and transmitter array gain. The Artemis steering committee elected to try to produce a source with a one-megawatt acoustic output (120 dB). After some initial design failures, the committee agreed on the design of a large billboard type array composed of several hundred magnetostrictive transducers. The total structure weighed about 400 tons.

In order to deploy a transducer of this size, a 20,000-ton tanker (the USNS *Mission Capistrano*) was reconfigured to serve as the source ship for the project. A hole 40 feet wide and 60 feet long was cut through the center of the ship so that the source could be lowered to its operating depth and recovered when it was necessary to relocate the ship.

Power amplifiers were developed, installed on the *Mission Capistrano* and used successfully to drive the array at the desired power level. The transducer array geometry was that of a uniformly spaced fully populated array and as far as the project was able to determine, the anticipated array gain of 40 dB was achieved.

Regrettably a serious and never completely resolved problem was encountered during source operation. Except for the possible exception of elements on the edge of the array, each of the magnetostrictive elements of the source array operated in the near field of its nearest neighbors. If an individual element had a slightly lower radiation resistance than its neighbors, it would begin to absorb radiated power from neighboring transducers. Eventually it would be driven to a point of failure (broken springs). When this process occurred, the array element with the next weakest level of radiation resistance would become the victim.

Although great efforts were made to equalize the radiation resistance of all array elements, the issue of element destruction from inter-element coupling was never solved in a satisfactory manner.

Signal processing gain. The time bandwidth product limits the processing gain that may be achieved in any active detection system. The center frequency of the Artemis transducer was 400 Hz. Because the transducer had a Q of about 4, the bandwidth of the signal that could be radiated efficiently was about 100 Hz. In an attempt to achieve a processing gain of 40 dB, a 100-second-long pulse was transmitted. In principle, in a nondispersive medium without boundary reflections, a target-reflected pulse could be cross-correlated with a replica of the waveform of the transmitted pulse and 40 dB of processing gain would be achieved. In practice, the ocean has complex boundary shapes and the complex dependence of the velocity of sound on depth and range leads to multipath distortions of both the transmitted and received signals.

In the late 1950s and early 1960s, available digital computers did not have sufficient speed, memory or computing power to cross-correlate the transmitted wave form with all possible convolutions the waveform might undergo before being detected by the receiving array. Out of necessity, analog techniques were resorted to. Specifically, an optical correlator was developed and used as the basic signal-processing device. Since this device could not generate all possible convolutions of the transmitted signal that might be received, inherently it could not achieve the full 40 dB of processing gain required by the Sonar Equation.

Another difficulty was that in the course of a 100-second transmission, the *Mission Capistrano* acting under the influence of winds and surface current could drift significant distances. In effect the wind- and current-driven motions of the source induced unknown and unpredictable Doppler distortions to the transmitted signal. These distortions also degraded the signal processing gain that was achievable.

Rather late in the history of the project an attempt was made to maintain the location of the *Mission Capistrano*. Eight large outboard engines were appended to the ship and an attempt was made to use these engines to maintain the ship at a fixed position relative to an acoustic transponder on the ocean floor. All indications were that this system, if pursued to completion, would have solved the random drift and random Doppler problem. Unfortunately the program was terminated before the position keeping system could be implemented.

Experimental Execution of Project Artemis

The Artemis Steering Committee selected the region south and southwest of the Island of Bermuda as the operating area for project experimentation.

One of the earliest activities of the project was to determine the reverberation properties of the basin. In order to achieve an understanding of the possible sources of reverberation, a 10-ton explosive package was detonated at a depth of 100 meters. The signal response of all known underwater hydrophones in the Atlantic Ocean was recorded. When these time intensity records were converted into range bearing plots, a relatively good replica of the Heezen map of the North Atlantic Ocean was obtained. All known sea mounds, the continental shelf of North America and the middle Atlantic ridge were evident. The information derived from this test served to determine the required directivity of both the receiving and transmitting arrays.

After the receiving array was installed, the next order of experimental business was to determine the precise location of individual sensors relative to each other so that delay lines could be constructed and the arrays could be steered. The process of establishing the relative location of array elements was extremely labor intensive and required the detonation of many explosive charges at various depths and ranges from the source.

Once delay lines were constructed it was necessary to measure the far field pattern of the source, so that the wave form structure of a pulse could be developed as a function of range, bearing, and depth below the surface of the sensors used to map the radiated field. This process allowed a number of replicas of the transmitted pulse to be established and used in the optical correlator. Unfortunately the set of replicas was inherently incomplete because they did not provide a representation of the pulse after it had been back scattered from a target.

Final Detection Experiment

After several years were spent in developing, installing, and calibrating the equipment, an effort was made to detect a submarine at a range of 1000 km. The submarine target was equipped with an acoustic repeater that amplified and retransmitted the signal from the *Mission Capistrano*. The amplifier on the submarine was increased in gain until a reliable detection link was established. Detection was not reliable until the retransmission level was boosted by between 20 and 25 dB.

In effect, the results of this experiment showed that the experimental system as designed failed to meet its goals by this amount. A postmortem examination of the system indicated that the failure probably arose from many system deficiencies.

At the time of the final detection tests, the station keeping system for the *Mission Capistrano* was not available. The resultant source motion may have degraded signal processing gain by a few dB. An incomplete set of pulse replicas to represent the convolution of the original pulse after its 2000 km path through the ocean also degraded the signal processing gain that could be achieved. Some estimates of the overall degradation in signal processing gain ran between 6 and 8 dB.

The near field inter-array element coupling process discussed above had not been solved at the time of the final test. As a result of the physical loss of a number of the elements in the transmitting array, the radiated acoustic power may have been reduced by 2 to 3 dB. The loss of elements in the transducer array probably also resulted in a loss of 2 to 3 dB of array gain.

At the time of the final system test, the fact that some (many?) of the towers in the receiving array had fallen and that the previous calibrations of the receiving array were incorrect, was not known. Receiving array gain may have been reduced by 3 to 5 dB.

As was learned from subsequent research, low frequency absorption processes existing in the ocean and in the Artemis frequency band from 350 to 450 Hz over the 2000 km two-way transmission path would have caused an added propagation loss of between 4 to 6 dB.

Argus Island tower on Plantagenet Bank near Bermuda where underwater receiver array cables came together for Project Artemis.

Post-Retirement Letter to NRL Sound Division from Dr. Harold L. Saxton (July 1967)

To my Friends and Colleagues,

You piped me out in a burst of glory which was overwhelming. For Mrs. Saxton and me, at least, the party was the best that we ever attended. The environment was ideal, the cuisine was outstanding and best of all, I knew everyone and they all looked as if they were enjoying it.

There was a wide range of rank present. I'm right in the middle. I value both my friends up the line and those down. I think Superintendents and Branch Heads are most favorably positioned to develop friends in both directions.

The presents are wonderful. I'll probably see more of my flying and dancing colleagues from time to time but the framed remembrances mounted on the wall of our Recreation room will repeatedly remind us of many exciting times.

The camera is just what I needed. I never had much success in taking good pictures. This camera, being automatic, should be easily mastered. The only other requisite is an appreciation of art. Bettie has that now, and I'll work on it.

When the mechanical SSI was presented, I thought "I'll bet my men have actually devised and built a working model." Sure enough, they had. That will start a museum for us. The book-ends will also be valued and useful.

All the letters and pictures, luxuriously bound, and the commemorative poem, will be perused many times because they will take me close to my friends. It has been a wonderful twenty-seven years with a wonderful climax, thanks to all of you.

Sincerely,

Harold Saxton
Washington, DC
July 10, 1967

NRL Notes . . .

Naval Research Laboratory Washington, D. C.

Number 1 1 January 1948

TWO SUPERINTENDENTS APPOINTED

Dr. E. B. Stephenson

Dr. H. L. Saxton

The Director's Office has issued an omnibus Laboratory Order (No. 54-47) which announced the appointment of two superintendents, two consultants, disestablished one division and in its place re-established an old one, and transferred the Shock and Vibration Section. Stated briefly, the Physics Division has become the Mechanics Division, Dr. E. B. Stephenson has been appointed the Superintendent of that division with Dr. G. R. Irwin as his Associate; Dr. H. L. Saxton has been assigned to the superintendency of the Sound Division; the two Shock and Vibration Sections -- now designated Shock and Vibration Sections I and II -- have been transferred from Sound to Mechanics; and Dr. Elias Klein and Dr. W. H. Sanders have been assigned to the Mechanics Division as Consultants.

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Dr. Edward B. Stephenson is a native of Illinois. For the record, he was born in Sparta, attended Sparta High School, and graduated Phi Beta Kappa from Knox College in 1903. After a few years of teaching at Knox and at the University of Illinois he obtained his doctorate in Physics from that University in 1910. During World War I he was an officer in the Army Engineer Corps, and after the Armistice he remained with the Corps as a civilian physicist. Since 1925 Dr. Stephenson has been with the NRL Sound Division, first as Assistant Superintendent and later as Associate Superintendent. In addition to his scientific achievements he has displayed unusual administrative ability as the Problem Secretary, as a member of the Civil Service Examining Board, and as Chairman of the Efficiency Rating Committee. Dr. Stephenson was awarded an honorary degree by Knox College in 1943; he was granted a $2,000 cash award by the Navy in 1931 and he was given the Meritorious Civilian Service Award in 1946. He is a member of Sigma Xi, Phi Delta Theta, and Gamma Alpha.

Dr. Harold L. Saxton, an Upstate New Yorker, graduated from Union College in 1925. After working for the General Electric Company in Schenectady for six years he was called to Pennsylvania State College as a part-time instructor. He obtained his Doctor of Science degree from Penn State in 1934 and a short while later he was appointed Assistant Professor of Physics. He left that position in 1940 to join NRL's Sound Division. During the recent war Dr. Saxton headed the Transmission and Reception Section; since 1945 he has been the leader of the Electronics and Propagation Section. For his wartime achievements, particularly for his activities in the development of new and improved sonar equipment, Dr. Saxton was given the Navy's Meritorious Civilian Service Award. The new superintendent is a member of Sigma Xi, Sigma Pi Sigma, and Pi Mu Epsilon.

Dr. Elias Klein was born in Wilno, Poland. He graduated from Valparaiso (Indiana) University in 1911, and was granted a Ph. D. at Yale in 1921. After a succession of research-instruction positions he was appointed to the Faculty of Lehigh as Associate Professor. He came to NRL in 1927 and in the ensuing years he won wide recognition as one of the country's leading authorities in sound physics. For sometime prior to his transfer to the Mechanics Division, Dr. Klein was a consultant in the Sound Division. He holds the Navy's Distinguished Civilian Service Award.

NRL Notes...

Naval Research Laboratory Washington, D. C.

Number 8 15 April 1948

R. L. STEINBERGER APPOINTED ASSOCIATE SUPERINTENDENT OF SOUND DIVISION

Announcement was recently made of the appointment of Dr. R. L. Steinberger, as Associate Superintendent of the Sound Division, a position left vacant late in December by the transfer of Dr. Stephenson to the Superintendency of the Mechanics Division.

Dr. Steinberger is a native of Wilkinsburg, Pa. He graduated as a physics major from Carnegie Tech in 1921, spent several months at Bell Labs, and then was called to Harvard as a part-time instructor. After obtaining his Masters' Degree in 1924 he held several positions as commercial physicist in Boston, meanwhile continuing his studies at Harvard. He was awarded a doctorate in 1932, and was invited to remain at Harvard as a Textile Foundation Research Fellow. While in the latter position he made a cruise on the SEMMES -- in a joint expedition undertaken by NRL and Woods Hole Oceanographic Institution -- and was one of the first to establish the highly significant fact that sound waves are refracted by thermal strata in the ocean. Dr. Steinberger joined the Government in 1936, working first at the Radio Laboratory at the Washington Navy Yard, and later in the Radio and Sound Division of the Bureau of Ships. He was transferred to NRL in 1941.

During the war Dr. Steinberger was one of the leading experimenters in the sonar program -- work which won for him the Meritorious Civilian Service Award in 1943. For a short time he was Head of the Sound Division's Pearl Harbor Section. When the Sound Division was reorganized after the war, Dr. Steinberger was designated Head of the Sonar Systems Section.

The Sound Division's new executive is one of those hardy souls who transnavigate the Potomac twice daily in an uncovered motor-sailer. His home is in Alexandria; he is married and has three children; a teenage son and a set of boy-and-girl twins.

Mockup of the April 15, 1948 issue of NRL Notes

CHAPTER FIVE

Era 3: Dr. John C. Munson
The Mid–Cold War Years
1968 to 1984

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John C. Munson [redacted] and was raised in Clinton, Iowa. He graduated from high school in 1944 during World War II. Immediately after high school he entered the U.S. Navy's V-12 College Training Program, which was designed to produce a large number of college-educated commissioned officers for the Navy. Under that program he began studies at Iowa State College in Ames, Iowa. In early 1946, with World War II ended, Munson was sent to boot camp at the Great Lakes Training Center. He was then sent to San Francisco, where he was assigned to a destroyer–mine sweeper which had just returned from the Yellow Sea. Virtually all of the crew had disembarked and was discharged, so although he was only a Fireman First Class, he was appointed head electrician. Subsequently, upon returning to civilian life, Munson then returned to Iowa State College where he completed a B.S. degree in electrical engineering (with communications option – electronics, and a minor in mathematics) in 1949.

Upon completing his undergraduate studies, Munson went to work at the Naval Ordnance Laboratory (NOL) in Silver Spring (White Oak), Maryland. Less than a week after arriving in Silver Spring, he met his wife-to-be, Elaine Hendershot, at a church young people's sing. Their children are John, Jr. (Chris) and Holly.

Munson remained in the civilian service, working in the Navy Laboratory system, for thirty-six years. During his first fourteen years at NOL he specialized in the application of signal processing techniques to sonar systems. He was heavily involved in the development of the Passive Underwater Fire Control Feasibility Study (PUFFS) sonar system under Dr. Herman Ellingson. The concept of this system was to use the broadband sound radiated from a submarine at audio frequencies in order to determine range-to-target by measuring the wavefront curvature across the length of an acoustic aperture that extended from the bow to the stern of a Navy submarine. In practice this was done by pairwise and threeway correlation of the signal at sensors located near the bow and stern, and amidships, in order to determine the difference of times of arrival of the signal. The coherence of the sound field across the aperture was found to be adequate to support the PUFFS concept. However, the signal processing hardware available at the time was woefully inadequate for real-time measurement of range and bearing using this concept, even though, in order to reduce computing load, only the polarities of the sensor outputs were being compared (a process known as clipper correlation). In the early 1950s Victor Anderson of the Marine Physical Laboratories developed the concept of a high speed digital clipper correlator (the DELTIC), which Munson realized was the answer to a practical real-time PUFFS; the two of them collaborated on bringing the DELTIC to hardware realization. Many sea trials on submarines followed during proof-of-practicality tests, leading to the AN/BQG-4 and follow-on operational sonars.

In the late 1950s Munson became a member of the steering committee for a major Navy long-range low frequency active sonar research program known as Project Artemis.

Clipper correlation, the DELTIC hardware, and other high-performance digital hardware developed by Munson and NOL associates found much use in subsequent years until the development of a generation of new, extremely fast and small computers. This technology was used in the late 1950s and early 1960s to perform at-sea measurements with a long towed receiver array of hydrophones (in conjunction with a towed source) to estimate how straight such a receiver would remain while it was being towed through the ocean; this was some of the earliest Navy research using long towed arrays. They also measured the signal coherence at low frequencies between arrays spaced hundreds of miles apart and the time-stability of signals arriving at the Artemis sensor arrays (which were spread across the face of a seamount). Also in the late 1950s Munson and Navy colleague Victor Anderson collaborated on a system for installation in a submarine's sonar dome to determine high-precision real-time bearings of targets.

Munson continued his advanced degree studies at the University of Maryland while at NOL and received an M.S. degree in electrical engineering (with a minor in mathematics) in 1952. In 1956–57 he was awarded sabbatical leave as a Navy Scholar to pursue courses in advanced signal processing at the Massachusetts Institute of Technology (MIT). Upon returning to NOL, Munson pursued his doctoral studies in an evening program at the University of Maryland. He completed a Ph.D. dissertation in 1962 on a topic dealing with the performance of memory-less nonlinear circuitry in order to determine how much true signal was still available in the midst of a noisy clipped signal.

In 1963, when NOL became the lead laboratory for the Bureau of Naval Weapons in the field of classification of underwater targets from airborne platforms, Munson became the project leader for three years. In 1967 Munson was loaned by NOL to AIRSYSCOM to act as technical director for the Navy portion of a high-priority Viet Nam–connected Tri-service project known as PRACTICE NINE.

In 1968 Munson left NOL to become the third superintendent of the NRL Acoustics Division, replacing Dr. Harold Saxton who retired in late 1967. With guidance from NRL's Director of Research, Dr. Alan Berman, as well as NRL's Associate Director for Oceanology, Dr. Ralph Goodman, Dr. Munson initiated a fairly major reorganization of the "Sound Division" into the new "Acoustics Division." Within the first two years of his arrival at NRL, there were numerous staffing changes, with the retirement of a number of longtime researchers and the hiring of a significant number of new researchers. Among the new hires were a number of researchers with expertise in long-range low frequency active surveillance associated with Project Artemis who came from Columbia University's Hudson Laboratories, which was disestablished in 1968. The Division had long had deep involvement in Project Artemis, ranging from participation in management of the program; design and development of the huge acoustic source and of the high-power electronics required to drive it; modification of the T-2 tanker that was required to support the acoustic source and its associated electronic and mechanical equipment; to modeling and measurement of signals and of noise and reverberation over the extremely wide receiving aperture that was used. The Division continued extensive participation in Artemis through the early 1970s.

Through the 1970s and 1980s the Acoustics Division conducted extensive measurements on long-range acoustic propagation and reverberation, coherence and directionality of ambient noise, Arctic acoustics, and shallow water acoustics. Many of these experiments were done in conjunction with allied nations including the United Kingdom, Norway, and other partners. In the early 1970s, physical acoustics research included the development of acoustic pool facilities for scale model target scattering studies, combined with theoretical modeling. The physical acoustics research also led to the development of innovative fiber-optic sensor technologies for hydrophones and other applications, and long-term collaborations with NRL's Optical Sciences Division.

Another important effort in the Acoustics Division was the research into the effects of bathymetry and marine geology on acoustic propagation and scattering using research vessels and maritime patrol aircraft as measurement platforms. These studies became extended to include magnetic and gravimetric survey methodologies. Other important research efforts that were ongoing by the early 1980s included the development of sophisticated software and hardware for Navy acoustic signal processing systems and the development of software for passive acoustic narrowband line identification for target classification. The Acoustics Division also conducted important theoretical and engineering developments related to new acoustic transducer concepts.

Dr. Munson retired as NRL's Acoustics Division superintendent in January 1985 after serving in that capacity for seventeen years. The Meritorious Civilian Service Award given to him upon his retirement cited him for, among other things, "building and maintaining the largest group in the Free World dedicated to basic and applied research in underwater acoustics and in acoustics related technology." He is a fellow of the Acoustical

Society of America (ASA) and of the Institute of Electrical and Electronics Engineers (IEEE) (where he served on the governing board of the Signal Processing Society), and a member of the Research Society of America. During his careers at NOL and NRL he served the Navy on a number of panels and committees. These included the Underwater Sound Advisory Group (USAG), the Mobile Sonar Technology (MOST) Committee, the Antisubmarine Warfare Research and Development (ASW R&D) Committee, the Countermeasures Exploratory Development Advisory Group, the Artemis Systems Research Committee, the PRACTICE NINE Acoustical Working Group, the Ad Hoc DEMON Working Group, the Broadband Technical Assessment Panel, The Technical Cooperation Panel (TTCP) Subgroup G (Undersea Warfare), and the U.S. Sonar Team. He received numerous awards for this service.

Upon his retirement from NRL, Dr. Munson served for six years as chief editor of the *U.S. Navy Journal of Underwater Acoustics*, the Navy's only peer-reviewed journal for the publication of key classified research in underwater acoustics. He also has been very active in both local and national not-for-profit organizations, including serving on the boards of trustees or directors of a number of them.

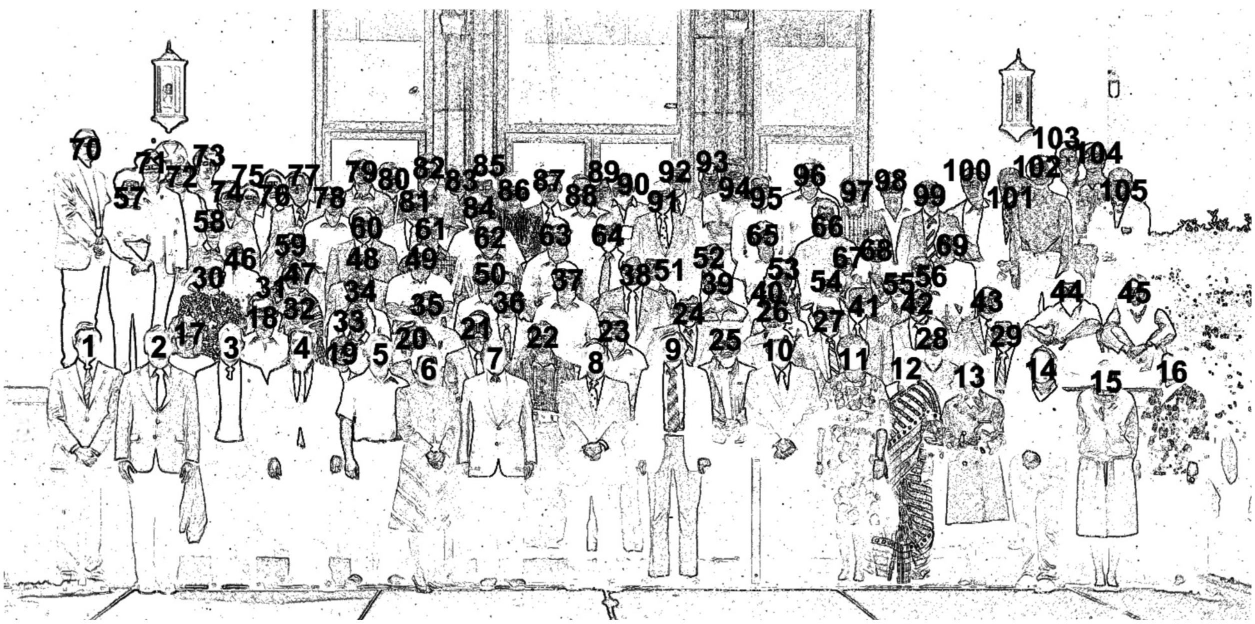
Acoustics Division Organization in Era 3

Circa 1975

Code		
8100	**Superintendent**	**Dr. John C. Munson**
8101	Associate Superintendent	R.R. Rojas
8104		S. Hanish
8105		F.C. Titcomb
8103	Advanced Projects Group	W. J. Finney
8108	System Engineering Staff	R.C. Swenson
8109	Systems Analysis Group	J.C. Knight
8120	Shallow Water Surveillance Br.	R.H. Ferris
8130	Physical Acoustics Branch	Dr. C.M. Davis, Jr.
8150	Transducer Branch	W. J. Trott
8160	Large Aperture Systems Branch	Dr. B.B. Adams
8170	Propagation Branch	B.G. Hurdle

Era 3 Group Photo

NRL Acoustics Division personnel in front of Building 1 circa 1984.



NRL Acoustics Division circa 1984 — group identification (see list, next page).

Names of Persons in NRL Acoustics Division Era 3 Group Photo in Front of Building 1 (Circa 1984)

Bottom Row (Row 1 Left to Right):
1 – Chet Brier
2 – William Johnson
3 – Budd Adams
4 – Rudolph Krutar
5 – David Kaplan
6 – Ruth Stallings
7 – John Munson
8 – Burton Hurdle
9 – Richard Doolittle
10 – Joel Covey
11 – Jean Krause
12 – Santha Kurian
13 – Leah Brotzman
14 – Stephen Wales
15 – Vernice Clanton
16 – Susan Numrich

Row 2 (Left to Right):
17 – Unidentified
18 – Robert Chrisp
19 – Muriel Kost
20 – Unidentified
21 – Charles Votaw
22 – Peter Mignerey
23 – Norm Dale
24 – Nicholas Lagakos
25 – Lee Huston
26 – Leonard Burns
27 – Robert Corsaro
28 – Carol Jarboe
29 – Nate Yen

Row 3 (Left to Right):
30 – Judy Trenck
31 – Myra Whitney
32 – Unidentified
33 – Susan Byron
34 – Scott Brylow
35 – Dean Clamons
36 – Unidentified
37 – T.C. Yang
38 – Basil Decina
39 – Leon Lalumiere
40 – Barbara Jones
41 – L. Bruce Palmer
42 – Fred Erskine
43 – Ralph Baer
44 – Peter Vogt
45 – Charles Gaumond

Row 4 (Left to Right):
46 – Beverly Hauver
47 – Irene Jewett
48 – Stephen Wolf
49 – David Nutile
50 – John Shaffer
51 – Rubin Naber
52 – Maurice Potosky
53 – Sandra Copeland
54 – Alan Dallas
55 – Unidentified
56 – Michael Czarnecki

Row 5 (Left to Right):
57 – Golda White
58 – Roberta Hopkins
59 – Sandy Vermace
60 – Daniel Steiger
61 – Louis Kovacs
62 – Evan Wright
63 – George Giellis
64 – John Perkins
65 – Joe Klunder
66 – David Berman
67 – Joyce Malanka
68 – Mary Peters
69 – Barbara Capossela

Rear Rows (Left to Right):
70 – Kenneth Flowers
71 – Nancy Beauchamp
72 – Rob Johnson
73 – Edward Kunz
74 – Nancy Garito
75 – Alma Porter
76 – Joseph Bucaro
77 – Louis Dragonette
78 – Wendell Anderson
79 – Mark Weber
80 – Henry Dardy
81 – John Siegel
82 – Kenneth Nicolas
83 – Robert Lee
84 – Jack Bright
85 – Paul Gossard
86 – David Gershfeld
87 – Norman Cherkis
88 – Frank Ingenito
89 – Basil Decina
90 – Richard Fizell
91 – Orest Diachok
92 – Ronald Dicus
93 – Brian Houston
94 – Bruce Pasewark
95 – Robert Gragg
96 –Thomas Hayward
97 – John Bergin
98 – Henry Fleming
99 – Jacek Jarzynski
100 – Earl Williams
101 – Russ Hickman
102 – Unidentified
103 – Unidentified
104 – Roger Gauss
105 – Paolo Lanzan

Era 3 Research Overview

Key Research Thrusts

The period from 1968 to 1984, when the Acoustics Division was under the leadership of Dr. John C. Munson, was a time during which longtime researchers departed and many new researchers joined the Division. Under Dr. Munson's guidance, by the mid-1970s there was a reinvigorated emphasis in the Division on the development of new projects for basic and applied research in underwater acoustics, including those involving at-sea and laboratory-based experimentation. There were five core branches: the Shallow Water Surveillance Branch (Code 8120), the Physical Acoustics Branch (Code 8130), the Transducer Branch (Code 8150), the Large Aperture Systems Branch (Code 8160), and the Propagation Branch (Code 8170). A number of new research topics were initiated in this era, while others matured and came to full fruition during this era after extended periods of research.

By 1974 the laboratory-based experimentation of Dr. Vincent Del Grosso resulted in very **accurate sound speed measurements** for seawater and other liquids.

By the mid 1970s, **underwater transducer calibration techniques** developed by Division researchers became quite important. These included the use of large nearfield calibration arrays developed by W. James Trott and colleagues as well as methods implemented by Robert Bobber, Dr. Arnie Van Buren, and colleagues at NRL's Underwater Sound Reference Detachment that enabled accurate absolute sound level calibrations for acoustic sources and receivers.

Throughout the 1970s and beyond, there was considerable Division research on **signal coherence and fluctuation phenomena** (led by Drs. Raymond Fitzgerald, Albert Guthrie, William Moseley, Budd Adams, and colleagues). This research addressed the causes of environmentally induced signal fluctuations as well as spatial and temporal characteristics of signal coherence and provided a physics-based understanding of the practical limits on the sizes of large-aperture sonar arrays.

New research initiated in the 1970s on **structures and materials for absorbing sound** in water (led by Dr. Robert Corsaro and colleagues of the Physical Acoustics Branch) yielded an improved physics-based understanding of acoustic coatings for various underwater acoustic applications.

Innovative research begun in the late 1970s by Dr. Joseph Bucaro and colleagues of the Physical Acoustics Branch on **fiber-optic interferometric sensors** led to collaborations with NRL's Optical Sciences Division and resulted in many new extensions of the fiber-optic technology to include magnetic, thermal, ultrasonic, electric, and other external fields.

These areas of research are discussed in further detail in the section on Key Research Thrusts and Achievements.

Additional Important Research Areas

Other research conducted by the Acoustics Division during this period received much attention. In 1969 and 1971 the Acoustics Division participated in two major multi-ship, multi-nation, at-sea experiments known as **Northeast Atlantic Tests (NEAT-1 and NEAT-2)**. The chief scientist for NEAT was Dr. Ralph Goodman (Associate Director of Research for Oceanology) and the assistant chief scientist was Burton Hurdle of the Acoustics Division. These trials were conducted in the Atlantic Ocean and Norwegian Basin areas and were directed at acquiring and testing the applications of fundamental knowledge in order to give the Navy a better underwater-acoustic submarine-detection capability. Among the measurements made were acoustic propagation loss, ambient sea noise, and numerous oceanographic environmental parameters.

By the early 1980s a major Navy applied research effort was under way to assess **Active Adjunct to Undersea Surveillance (AAUS)** feasibility. NRL's Acoustics Division (under leadership by Drs. Budd Adams and Edward Franchi of the Large Aperture Systems Branch) was integrally involved in AAUS research to develop a basis for active system performance prediction. It emphasized characterization through measurement and prediction of the spectral, temporal, and spatial properties of sea surface and bottom reverberation and undersea target characteristics. This research involved extensive collaboration with other Navy laboratories and systems commands.

In Era 3, researchers in the Acoustics Division (led by Henry Fleming of the Acoustic Media Characterization Branch) developed a unique capability for processing, analyzing, displaying, and interpreting **marine geophysical basic science** data sets, including bathymetric, magnetic, and gravimetric data. In later eras this capability proved useful for large area assessment applications, particularly in areas where previous data were incomplete.

In the early 1980s a new group joined the Acoustics Division, known as the Software Systems Development Branch (Code 5150) under Elizabeth E. Wald. (Toward the end of Era 3, organizational changes at NRL resulted in a change of the Acoustic Division's code from 8100 to 5100.) The mission of the new branch was to facilitate the efficient development of individual **Navy Advanced Data Processing (ADP)** products and operational systems — these included computers and programmable signal processors, language processors, operating systems, and development environments — and to match these products to emerging military requirements. Particular emphasis was placed on identification of processes and hardware, firmware, software, and human interface requirements and tools that transcend single computers, computer platforms, and applications.

In the early 1980s a new research initiative on **nearfield acoustical holography (NAH)** was begun by Dr. Earl Williams of the Physical Acoustics Branch that led to many fruitful developments in later eras. The methodology of NAH addresses the methods and apparatus for holographically reconstructing images of complex acoustic sources.

Key Research Thrusts and Achievements in Era 3

11 Accurate Sound Speed Measurements
12 Underwater Transducer Calibration Techniques
13 Signal Coherence and Fluctuation Phenomena
14 Structures and Materials for Absorbing Sound in Water
15 Fiber-Optic Interferometric Acoustic Sensors

11
[1923–1974] Accurate Sound Speed Measurements

Achievement: From the 1920s to 1970s the NRL Sound/Acoustics Division conducted fundamental research via experimentation and mathematical modeling to obtain accurate estimates for the speed of sound in various liquids (including seawater and fresh water) as well as in many different materials. Knowledge of the sound speed in the ocean is very important for the proper operation of sonar systems.

Impact: During the 1920s to 1930s the NRL laboratory-based interferometric sound speed measurement method was used to develop a sonar transducer window that would match the acoustic impedance of seawater. This resulted in the joint development of the RHO-C rubber transducer window in collaboration with the B.F. Goodrich Co. NRL's methodology was also used to develop transducer- and dome-filling liquids that would match the impedance of seawater. By 1973 the NRL model for sound speed in the Pacific Ocean was considered to be the best one available (accurate to ±0.05 m/s). The accuracy of sound speed in seawater has become increasingly important for the application of long-range ocean basin acoustic tomography methods for measuring ocean temperature as an indicator of climate change.

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12
[1938–1994] Underwater Transducer Calibration Techniques

Achievement: NRL Sound Division scientists initiated research in the late 1930s to develop methods for accurately calibrating acoustic transducers that were used for the transmission and reception of sound in the ocean. The calibration methodologies continued to mature into the 1990s both within the NRL Acoustics Division and in collaboration with colleagues at the Underwater Sound Reference Detachment (later an NRL division) located near Orlando, Florida.

NRL's Underwater Sound Reference Division (USRD) acoustic transducer calibration facility near Orlando, Florida, circa 1980.

Impact: The results of this research and the methods developed provided the U.S. Navy with the ability to provide absolute sound level calibrations for acoustic sources and receivers used for underwater acoustics investigations and Fleet sonar systems.

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13
[1960–2008] Signal Coherence and Fluctuation Phenomena

Achievement: Beginning in the early 1960s, and with more detailed efforts initiated in the 1970s and beyond, NRL researchers conducted experimental and theoretical investigations on the nature and causes of environmentally induced signal fluctuations for sonar systems in deep and shallow waters. Further, they conducted numerous studies regarding the spatial and temporal characteristics of signal coherence. Among the environmental influences considered were stochastic effects due to ocean temperature fine-structure and variability, and ocean boundary effects.

Impact: The results of this research have contributed significantly to the Navy's understanding of sonar signal fluctuation phenomena. These studies have also provided the Navy with a physics-based understanding of the practical limits on the sizes of large-aperture sonar arrays in the ocean environment.

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14
[1976–2002] Structures and Materials for Absorbing Sound in Water

Achievement: In the mid-1970s, researchers in the NRL Acoustics Division initiated three decades of investigations into the sound-absorbing properties of structures and materials for underwater acoustic applications.

Impact: Research in the Acoustics Division from the 1970s to the 2000s on structures and materials for absorbing sound in water led to an improved physics-based understanding of acoustic coatings for various underwater acoustic applications. Among the Navy applications was the development of effective anechoic coatings for tanks used in laboratory-based ultrasonic underwater scattering experiments. This made feasible the design of much smaller tanks, and the conduct of scattering measurements at lower acoustic frequencies without interference from wall reflections.

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15
[1977–2005] Fiber-Optic Interferometric Acoustic Sensors

Achievement: In the late 1970s, investigators in the NRL Acoustics Division, led by J.A. Bucaro, began innovative research on fiber-optic interferometric acoustic sensors. This research developed rapidly into practical applications. In 1977, early research demonstrating the feasibility of fiber-optic hydrophones was published by Bucaro and colleagues in the *Journal of the Acoustical Society of America* and concurrently by J.H Cole and collaborators from TRW. (Shortly thereafter, Cole joined NRL's Acoustics Division and collaborated with Bucaro on further developments.) An initial U.S. patent for a "Fiber Optic Acoustic Sensor" was awarded to Bucaro and colleagues in 1979. The Acoustics Division research on interferometric fiber-optic sensors quickly expanded to demonstrate that such sensors could be designed and modified to sense other external perturbations, including electric fields, magnetic fields, and temperature fields. In 1978, based on the promising early fiber-optic acoustic sensor results, NRL researchers, including B.G. Hurdle, J.A. Bucaro, C.M. Davis, Jr., and J.E. Donovan, convinced sponsors to establish at NRL the first Navy/DoD program in Fiber Optic Sensor Systems (FOSS). This Acoustics Division program, led by J.E Donovan with J.A. Bucaro as acoustics manager, T.G. Giallorenzi as optics manager, and G. Hetland as systems manager, spearheaded a rapidly mushrooming interest in fiber interferometric sensors at NRL, in academia, and in industry. The researchers at NRL, led in the Optical Sciences Division by T.G. Giallorenzi and in the Acoustics Division by J.A. Bucaro, forged significant innovations in fiber-optic sensors in the late 1970s and early 1980s.

Impact: Following on the initial developments of innovative fiber-optic sensors at NRL beginning in the late 1970s, the Navy/DoD established the Fiber Optic Sensor System (FOSS) program in NRL's Acoustics Division to foster new applications of this technology. This became a strongly collaborative effort between researchers from NRL's Acoustics Division and its Optical Sciences Division. By about 1980, the optical fiber sensor research group of J.A. Bucaro comprised twelve full-time scientists and engineers and it was the largest such group dedicated to research on generic fiber acoustic technology. In that era, Bucaro's group developed extensions of the fiber-optic sensor technology to include magnetic, thermal, ultrasonic, electric, and other external fields. Since that time, a number of applications developers, including researchers in NRL's Optical Sciences Division, the Naval Undersea Warfare Center, the Naval Surface Warfare Center, and in private industry, have advanced a number of sensor systems based on the fiber-optic interferometric technology. A real case can be made connecting the initial NRL Acoustics Division innovations and the FOSS program to which it immediately led with the now ubiquitous presence of fiber-optic sensor devices. These include all manner of applications from acoustic, magnetic, electric, and thermal to medical, nondestructive evaluation, vibration, and flow. Alan

Berman, former NRL Director of Research, remarked around 1981 that he considered the fiber-optic acoustic sensor to be among the several most significant accomplishments to take place at NRL during the time of his tenure. In recent decades, the U.S. Navy has benefited considerably from a number of acoustic applications of sensor system technologies based on interferometric fiber acoustic sensors that have been demonstrated by NRL's Optical Sciences Division and the Naval Undersea Warfare Center in concert with industry. Among these applications are: thin, all-optical acoustic towed line arrays with a full complement of fiber-optic environmental sensors; lightweight fiber-optic submarine hull mounted sonar systems; ultra-low-noise, remotely located acoustic monitoring systems; fiber interferometric magnetic heading, intrusion detection, and non-acoustic ASW systems; and fiber-optic, electric field sensing, deployable arrays.

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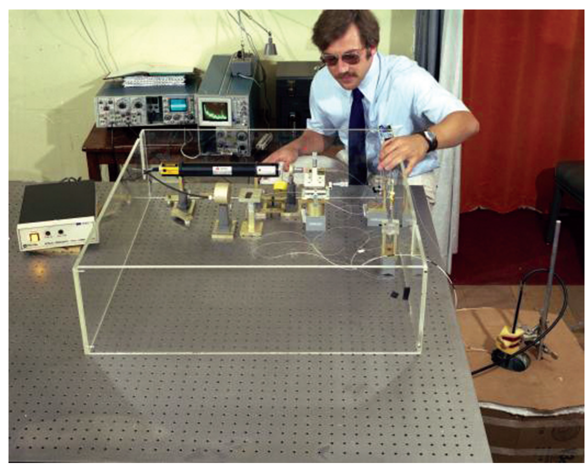
Dr. Joseph A. Bucaro conducting an experiment on fiber-optic interferometric sensors, circa late 1970s.



James H. Cole with initial demonstration fiber-optic interferometric acoustic sensor system, circa late 1970s.

Further Recollections of Era 3

Acoustics Division Year-End Review Letter for 1969 by Dr. John C. Munson

The year 1969 is nearly behind us. The Acoustics Division has posted a number of fine achievements despite the many problems besetting both us and the R&D community in general. Nearly all of our major trials and tribulations stemmed from the Congressional attitude toward Defense Department R&D and the concomitant delay in passing our appropriations. These caused, and we have grappled with: (a) budget cuts and deferrals as well as uncertainties concerning our funding for this fiscal year, (b) NRL ceiling cuts, of which we absorbed our share, (c) a freeze on promotions and hiring, and (d) difficulties in obtaining additional space and in upgrading our existing spaces to provide for our expanded staff and additional program responsibilities. These difficulties result in part from a contest between Congress and the Defense Department regarding what kinds of work shall be performed under DOD sponsorship and the extent of control which shall be exercised by Congress. The long term implications are not yet clear, but it appears that the worst hit will be university laboratories. Naval laboratories will probably fare rather well in comparison to the rest of the R&D community, although the economy mood of Congress presages rather lean times even for NRL. The work of our own Division is receiving strong support from top NRL management and from our major funders, who are trying to help us expand in the face of a shrinking overall funding base. This is a vote of confidence based on demonstrated excellence in some of our older areas of work and on the style with which we have picked up our new responsibilities. As such the future of our Division, in truth, rests on the shoulders of our technical people. Only by consistently superior work clearly relevant to Navy needs, can we hope to retain our support in times like these.

A number of our people were physically relocated during this past year. Code 8120 moved to Building 28. Code 8130 completed, moved into, and have begun use of extensive new facilities. We gave up a room on the first floor to Code 8004. Codes 8108 and 8170 were given some room on the second floor. The Division office staff made several moves. In our attempt to make the most of our existing space we have gone so far as to divert a ladies head to scientific use, having installed the Schlieren system therein. We are pressing for more space. In the near term we hope to have a small building completed within A-59 and a trailer put on top of Building 1 as a Penthouse addition. Anything beyond these additions will require money not now available. This year has seen our Division assume responsibility for Argus Island, the Hudson Laboratories portion of the Tudor Hill Laboratory, and the USNS MISSION CAPISTRANO. Construction of the T-AGOR 16, for which we have responsibility, is proceeding on schedule. The Seneca Lake calibration facility was transferred to USL last August; we thereby lost control of a valuable facility, one for which many people in the Division had worked very hard; the pain of losing Seneca Lake is mitigated somewhat by still having access to the facility and by being relieved of the continuing funding responsibility.

Our new Division organization has been in effect for over a year. There are still a few problems to straighten out, but in the main things seem to be working out rather well. For various reasons the goals of our Branches have been difficult to crystallize (i.e., the proper conjunction of our research personnel and sponsor intent/needs has been difficult to achieve); we have concentrated attention here and the air is gradually clearing.

Our Division, ably supported by the Ship Facilities Group, has definitely joined the big leagues as far as big-ship experiments are concerned. We were on station at sea for 232 ship-days during 1969. In addition, we manned shore facilities for 153 experiment-days. This gave us a total of 385 experiment-days during 1969. The fact that we could mount this effort is a real tribute to the dedication of those persons involved, and the fact that we brought home good data from each trip is a tribute to the scientific and technical skills we brought to bear. Although we brought off our experimental program well in 1969 we did it only by imposing on many of our people to spend much extra time both at sea and in trip preparation, and by delaying data analysis and reporting. The first half of 1970 looks just as bad as 1969 was, but we must earnestly strive to achieve a tenable steady-state experimental program. The involved Group leaders and I will be giving this problem close attention.

During the past year the Acoustics Division posted a number of significant achievements in the more fundamental aspects of acoustics. We established ourselves firmly in a number of important aspects of undersea acoustic surveillance. Probably the biggest splash the Division made was in Operation NEAT, which was a multi-laboratory joint U.S.-U.K. propagation and noise experiment of major proportions. Dr. Goodman was Chief Scientist, with our Division providing most of the technical management horsepower. We also participated in NEAT from a scientific point of view. Through this operation we proved our ability to manage large-scale complex field operations, with simultaneous scientific participation. I believe that the total capability we, together with the Ship Facilities Group, demonstrated cannot be matched by any other laboratory.

Thirty-five full time employees joined the Acoustics Division in 1968 and thirty-two joined us in 1969. Our current full-time staff numbers 134. Thus half of us have been with the Division less than two years. Most of the new persons are working on surveillance, but many are scattered throughout other areas of the Division. The impact of new skills and fresh viewpoints has been most beneficial. Without this new blood we would not have been able to assume the expanded role we have successfully undertaken.

Although the year 1969 has been a difficult one in many ways it has had many high spots. I look for 1970 to be a very good year for us.

John C. Munson
December 1969

Acoustics Division Year-End Review Letter for 1984 by Dr. John C. Munson

This is my seventeenth year-end message to the Division. Most of you know that I will be stepping aside next month, so this will also be the last of my "Missages", as Winnie-the-Pooh would say. They have been a means of communicating a brief State-of-the-Division message, along with my interpretation of what larger events (Navy-wide or national in scope) meant to the Division. I have thoroughly enjoyed preparing them.

I have given a good deal of thought recently to our roots. Many do not know, or have forgotten, that the Laboratory is by far the oldest Navy laboratory (being established in 1923, whereas the Centers have their origins in World War II) and that we are one of the several original Divisions of the Laboratory. Building 1, which houses the majority of the Division, is the oldest building at the Laboratory (the buildings are numbered chronologically), and we were original occupants. The Division led the way in developing the sonars which were instrumental in winning the Battle of the Atlantic in World War II. After the War we pioneered helicopter dipping sonar and the low frequency active sonars which culminated in the SQS-26 and -53. We were major participants in Project ARTEMIS, a Navy-wide program during the late 1950s and early 1960s which established basic feasibility of very long range active surveillance. During the late 1960s we began major involvement in a number of areas which laid the foundations for much of our effort today: fixed and mobile passive surveillance acoustics and technology, shallow water and Arctic acoustics, effects of bottom topology on long range propagation, and target echo physics. All during this period a large fraction of our effort was devoted to studying the physics of sound in the sea and to defining limits on performance imposed by the environment. Thinking back over the past several years, we have made major contributions to the Navy in many areas. I am loathe to list any (try listing which of your children are your favorites). However, I feel that the following have a unique combination of scientific advance and Navy potential:

- Fiber optic sensors which, with their natural ability to provide spatial shading, potential for all-optical sensing systems, EMI immunity and neutral buoyancy, promise to revolutionize sonar receiving technology.

- Active surveillance performance prediction, which lays rational foundation for a new Naval capability.

- HARMCORR, which can be a key tool for automated detection and classification in acoustic systems with many sensors or beams.

- Large area assessment, which brings to bear all available types and quantities of information and understanding and melds them to provide best estimates of parameters of interest in important geographic areas.

- Characterization and control of target echoes, which have immediate application to prediction of the echo characteristics of enemy targets and to reduction of the target strength of our own submarines.

- Common Operational Software, which will greatly reduce the life-cycle costs of future generation data processors.

This year has certainly seen its share of traumas, uncertainties and changes. These include: accusations of incompetence and lack of industry among government employees. Also, there have been major reorientations and cutbacks in R&D programs. On the local level there have been a number of things taking place which, while not threatening in any real sense, have required a good deal of patience among ourselves. These include: a major Division reorganization, the addition of the Ocean Systems Application Group (Code 5103) to the Division and substantial space activity (e.g., rehabilitation of most of Building 29 and the subsequent move into that space by the Software Systems Branch, major modifications/upgrading of Building 71, modifications to the first floor computer facility in Building 1, – however, little has been accomplished to ease the plight of many who are in second class quarters). That we have been able to reach the levels of achievement discussed in the preceding paragraph, while faced with these kinds of conditions, is a tribute to the people who comprise the Division. Incidentally, I have been rereading some of my earlier year-end messages. Even the first ones, as far back as 1968, refer to DOD-Congress problems, budget cuts, program reorientations, ceiling and grade restrictions, Division reorganizations, and space problems. All of this goes to prove that Ecclesiastes was correct when he said, "There is nothing new under the sun."

The Division leaders have worked hard this year developing long term plans for the Division. When the Plan is complete, which will be very soon, it will be submitted to Laboratory Management for approval. In the meantime, you may find the following quotes from the Plan to be of interest:

- The mission of the Acoustics Division is to develop acoustic technology through a program of basic and applied research and to apply acoustics, integrated with related disciplines, to the solution of Naval problems, especially undersea warfare. The Laboratory is the Corporate Laboratory for the U.S. Navy. Acting within that aegis, the Division acts in a corporate role for underwater acoustics technology for the Navy.

- The Division has major responsibility for basic and applied R&D in undersea acoustics. The applied spectrum includes: developing and proving system concepts; signal processing for active and passive detection, tracking and classification of underwater targets; echo strength control; large area assessment; system performance prediction and improvement; and facilitating the efficient development of Navy ADP products. The strength of the applied work is rooted in a complementary basic science and technology program in: estimation and signal processing; ocean acoustics and the associated description of the ocean environment; physical acoustics; and the fundamental structure of ADP machines. The program is designed to be responsive to, and to anticipate, Naval needs. Key to this is extensive interaction with the NAVMAT/SYSCOM/NAVMAT Labs community, CNO and the Fleet and substantial participation in Navy program planning groups.

- Transition to the user community of the fruits of Division R&D is taken very seriously. The Division program is coordinated with the ONR Contract Research Program (CRP); there is substantial collaboration/cooperation and also the Division participates in the CRP, especially in areas where the academic community has little capability. Collaboration and cooperation with NORDA and other laboratories, both U.S. and foreign, is an integral part of the total Division program. The Division interacts with research programs in other parts of the Laboratory in such areas as materials, transducers, deep ocean technology and Artificial Intelligence. It renders consultative services to the Navy, the Department of Defense, other government agencies and private contractors.

- The Division is the largest group in the Free World dedicated to the development of acoustics, and acoustics-related, technology. It presently numbers 123 full time personnel. This full time staff is supplemented by 50 less-than-full-time employees (both scientific and support) and by contract effort. The total number of people functioning within our work spaces is currently 187. In addition, we have active Personnel Action Requests out for 19 vacancies.

- The Division program has been modified extensively over the past couple of years in response to technological opportunities and to market realities. Hence, there are no major areas which we expect to phase out or to deemphasize over the next several years. Most changes will be reorientation/extrapolation of existing effort (e.g., in the AAUS reverberation area the present program will be wrapped up within the next couple of years and the overall Navy program thrusts, including the Division effort, will then move to specific system development and/or other applications).

- The present program of the Division can be characterized as: (1) Basic Science and Technology, which acts as the seedbed for, and undergirds, the (2) Applied Technology Program (some of these latter being performed within the Division and some being integral parts of large multi-performer programs). In addition, the Division is working with NAVMAT Centers and with sponsors to develop major programs aimed at providing the Fleet with advanced systems capabilities. Because of the size and complexity of these programs, and because they are aimed at developing specific systems capabilities, they will require extensive collaboration between ourselves and appropriate NAVMAT Centers.

In the sixty-one years of existence of the Division, I am the third Superintendent. Whether this remarkable stability is bane or blessing I leave to others to judge. At any rate, I have occupied for seventeen years what I consider to be the best R&D position in the Navy. I have had opportunity to affect the future course of the Navy in the critical area of Undersea Warfare to, at least, some extent. I have had a chance to participate in the formulation and guidance of the Division program. And I have had a chance to work with many wonderful people, and become friends with some. I remain convinced that, not only is our Division composed of the finest assemblage of acoustics-related talent anywhere, but our people are truly the salt of the earth. Since the very fiber of the Division is found in the people who comprise it, I have great confidence for the future. I have thoroughly enjoyed working with you all.

John C. Munson
December 1984

A Brief History of the Physical Acoustics Branch, Part 1, 1970–1982
by Joseph A. Bucaro

Dr. Joseph A. Bucaro

1970–1974 The New Physical Acoustics Branch

I joined NRL in November 1970. Dr. Mickey Davis had become branch head the year before. Dr. Ralph Goodman (the Associate Director for Oceanology) and Dr. Alan Berman had agreed that the old Propagation Branch (the one preceding the Physical Acoustics Branch) needed a big change. At the time, the old branch had two major thrusts: ultra-high-precision speed of sound in water (under Vince Del Grosso) and target scattering (under Werner Neubauer). Berman and Goodman brought Mickey Davis from his professor position at American University (AU) and asked him to grow a new, broad physical acoustics thrust in the newly named Physical Acoustics Branch. Davis brought with him from AU Dr. Jacek Jarzynski. Within a year or so, he hired Dr. Robert Corsaro, a new Ph.D. chemical physicist from Maryland, and myself, a new physicist with acoustics and optics experience from Catholic University.

Shortly thereafter, Jacek and Bob began new experimental work in the equation of state of materials including viscous glass melts and liquid metals. The latter topic was of some significant interest because at the time, the nation was considering the development of fast breeder reactors for power, and such systems would be cooled with liquid metals. I began new acousto-optic work, emphasizing first the acoustic aspects while I awaited a fair amount of new optical equipment including a high-powered, ultra-narrow-bandwidth, continuous-wave (cw) argon ion laser. This work included the generation, optical detection, and application of surface acoustic waves on plate-like structures.

In 1972, Dr. Davis moved the branch (except the sound speed laboratory) into the west end of Building 71, the site of the former experimental nuclear reactor and its supporting labs. The principal reason was the large, ~300,000 gallon pool used to cool the reactor when it was active. Soon, Dr. Neubauer began to carry out his acoustic scattering research here after introducing the appropriate instrumentation. A few years later, Louis Dragonette, Hank Dardy, and Luise Schuetz (Couchman) would move the measurements from a time-consuming cw approach to near-real-time data collection using digital processing techniques and hardware.

In 1973 I hired Dr. Henry (Hank) Dardy who was finishing his Ph.D. at Catholic University, and together we built a state-of-the-art *acousto-optics* laboratory (the actual name of my new section). The capability included a number of narrow line-width lasers, multi-pass ultra-high-contrast Fabry-Perot interferometers, a novel optical digital correlator for measuring optical frequency shifts as low as 1 part in 10 trillion, ultra-high-temperature (~2000 degrees C) optical cells for studying Brillouin and Rayleigh scattering from thermal phonons and relaxation mechanisms in glasses above their glass transition temperature, and very high pressure optical cells for studying the effects of pressure on molecular orientation and structural viscosity in liquids. Now with the excellent acoustic target scattering and schlieren work of Neubauer and Dragonette, the ultra-high-precision measurements of sound propagation in water by Del Grosso, the equation of state work in viscous systems of Jarzynski and Corsaro, and the acousto-optic and Brillouin/Rayleigh scattering work in solids and their high temperature melts and in liquids at high pressures by Bucaro and Dardy, the Acoustics Division indeed realized a new, exciting thrust into physical acoustics.

1974–1978 The Invention and Development of the First Fiber-Optic Sensors

In 1974, armed with a state-of-the-art acousto-optics laboratory, having come just a few years earlier from the Physics Department/Vitreous State Laboratory of Catholic University, whose researchers were carrying out some of the world's first work in the fundamentals of optical glass fibers and the lowering of the intrinsic optical loss, and encouraged by the branch head Mickey Davis to search for new ways to detect sound, I and Professor Ed Carome of John Carroll University carried out the work that led to the first fiber-optic interferometric acoustic sensors and the world's first patent of this technology. Having connections to the earlier work at Catholic University, I knew that ultra-low-loss single mode optical fibers were just around the corner. I also knew from my acousto-optic Fourier-optics schlieren work how to estimate acoustically induced phase shifts in optical beams. Putting this together, I realized that one would be able to magnify the small acousto-optically induced phase shifts in glass by using very long lengths of low-loss optical fiber.

To demonstrate the first hydrophone, I used some of the only available single mode fibers at the time (Fiber Communications, Inc.) — very small core diameter fibers whose outer diameter was so thin that protective plastic coatings could not yet be applied to them. It was almost like working with very long spider web materials! Having obtained the results I expected in a small water tank, I quickly prepared a short journal article [*Applied Optics* **16** (1977) 1761–1762]; and then traveling to Cleveland to see my family, I brought the manuscript to Dr. Carome at John Carroll University for his review.

The demonstration of this invention and the associated work literally ignited the world's considerable effort to develop and exploit fiber-optic sensor technology in not just acoustics but in many other areas as well. This part of the Branch story is summarized in the Ivan Amato book *Pushing the Horizon* (reproduced here on the following pages).

Professor Carome was periodically at NRL in 1978 as the first participant in a new program just begun by Dr. Davis called "The Physical Acoustics Center Program." In this program, university faculty came to NRL for a period of time (several months to two years) to carry out joint research with various members of the Physical Acoustics Branch using the unique facilities available at NRL. The program was intended to facilitate rapid transfer of university science and technology to relevant NRL programs, on the one hand, and on the other to provide unique facilities and capabilities at NRL for university researchers. In its almost twenty-three year lifetime, some thirty-three university researchers participated in the program in scientific areas ranging from fiber-optic sensors, acoustic scattering, piezo-polymer devices, photoacoustic spectroscopy, acousto-optic logic devices, finite element modeling, ultrasonic interactions in optical fibers, high order Galerkin methods, phonon effects in thin film microstructures, nonlinear deformation in structures, nonlinear piezo-composites, hidden Markov models, silicon micro-oscillators, to carbon nanotubes.

1978–1982 The Branch Evolves Once Again

In 1978, Mickey Davis suddenly left the Lab when offered an early-out package. I was made acting branch head and not long after, permanent branch head.

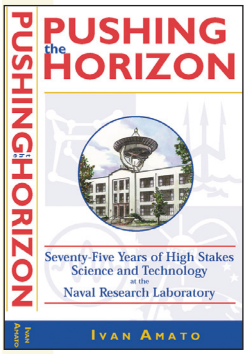
During the next two or so years, I convinced Dr. Earl Williams, who with Jay Maynard of Penn State had just demonstrated the first principles of nearfield acoustical holography (NAH), to join NRL rather than NASA (his original intent) by convincing Earl that he would be able to do both underwater *and* air-based NAH at NRL versus only the latter at NASA Langley. In a very short time, Earl had developed the now famous NAH underwater pioneering research and associated methodologies and laboratory facilities.

The implementation of these new experimental capabilities was made possible by the arrival about that time of a promising young scientist named Brian Houston. From the moment of his arrival, Dr. Houston aggressively undertook the methodical development of an underwater acoustic facility capability unrivaled in the world. His first achievements involved the realization of an experimental underwater capability for carrying out the NAH ideas of Dr. Williams. A good summary of the NAH work is contained on page 63 of NRL's *75th Anniversary Awards for Innovation* monograph (NRL/PU/1001—98-359, June 1998). Ultimately (in 1985), Houston would be given control of the central pool facility, its personnel, and all experimental projects using this facility.

During this time, I also convinced James Cole from TRW (who nearly simultaneously demonstrated a fiber-optic sensor) to join the branch. Upon arriving (circa 1979), Jim worked closely with the members of the Optical Sciences Division in NRL's successful efforts to demonstrate packaged fiber-optic acoustic sensors (we called the first the "Brassboard Sensor"), the insertion of them into NRL's and the Navy's first towed optical array modules, and the subsequent series of at-sea towed optical array tests. During this period, the Physical Acoustics Branch had some ten scientists and engineers devoted to the newly created area of fiber-optic sensors. Their pioneering work included underwater hydrophones, in-air microphones, magnetic sensors, high-bandwidth thermometers, and strain sensors, all using fiber-optic interferometers.

Pushing the Horizon by Ivan Amato (1998)

Excerpt describing the work of the Physical Acoustics Branch to develop the first fiber-optic sensors, pages 312–317.



Hair-Thin, Glassy Pixels

Another set of striking pixels of NRL's big picture emerged from an interaction among researchers in the Optical Sciences Division and the Acoustic Division. The question both groups were asking independently at first was this: what good might optical fibers be for the Navy?

As did many other scientific organizations, NRL first began seriously looking at optical fibers in the early 1970s when glass researchers at Corning Glass Works in upstate New York invented a way to make optical fibers through which light could travel clearly and cleanly for miles rather than the few feet that had been the limit.

In 1976, NRL acoustics scientists, including Joseph Bucaro, C.M. (Mickey) Davis and visiting professor Edward Carome from John Carroll University (University Heights, Ohio), were looking into using optical fibers as sensors of acoustic energy in fluids such as the ocean. For Bucaro and Carome, who was Bucaro's professor a decade earlier when Bucaro was a student at John Carroll University, it was a reasonable pursuit since they knew the pressure waves associated with underwater sound could subtly yet detectably affect the way light traveled down the fibers. In time, they realized they could modify optical sensors with various coatings and in other ways that transformed them into sensors of such phenomena as temperature, electrical fields, and mechanical strain.

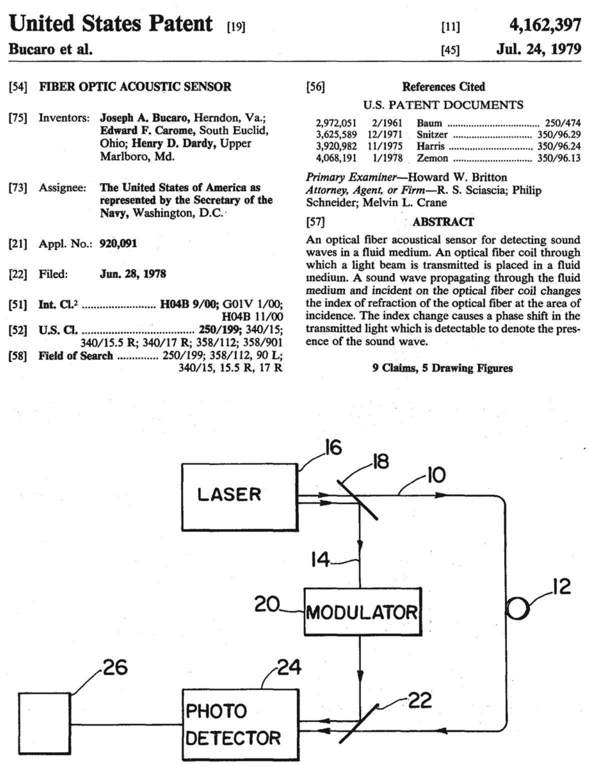
Scientists in the Optical Physics Branch, including Tom Giallorenzi, were approaching optical fibers from another angle. "We started working on all components needed for airborne and shipboard [communications] applications" of optical fibers, Giallorenzi recalls. One of the earliest problems he and his colleagues faced was the way even subtle vibrations, of which there was no shortage on planes and ships, could interfere with light, especially as it passed through a coupling from one fiber and into another. These early optical fiber components could even detect voice-induced vibrations. Since acoustics and vibrations are so closely related, it was practically destined that these two groups would themselves couple into an interdisciplinary fiber optics program. It's just the sort of synergy that Brown identifies as one of NRL's most crucial characteristics.

By early 1977, Bucaro says he and Carome successfully demonstrated the first "interferometric fiber optic external field sensor," which is to say, an optical hydrophone. Bucaro believes this was the catalyst that led to the first DoD program in fiber optic sensors. In September, excited by this and further laboratory successes, Davis, Bucaro, and Burton Hurdle (the Division's ocean acoustics guru) went to DARPA seeking support to develop ocean applications for what had been demonstrated in Bucaro's laboratory. As Bucaro recalls it, their DARPA contact, Captain Harry Winsor, encouraged the NRL researchers to "find a good program manager" and come back with a unified program. By early November, they did just that. Jack Donovan, a hydrophone systems manager just leaving the Naval Materiel Command, was recruited as Program Manager. Davis joined Giallorenzi's group to integrate the work of their respective branches, and together they all convinced one another that optical fibers had to be part of the Navy's future.

With that in mind, the extended group composed a unified proposal to DARPA to develop fiber optic sensor technology that they would demonstrate in the form of a towed acoustic array. DARPA liked what it saw and its subsequent funding gave birth to the Fiber Optic Sensor System (FOSS) program. (According to Mickey Davis, it was no mere coincidence that the project's acronym FOSS, resembled the name of Dr. Fossum, DARPA's new director at the time.) Other funding agencies including the Office of Naval Research and the Naval Materiel Command also supported the project.

The first project — a towable submarine detection system made with a fiber optic-based array of acoustic sensors — married the strengths of the two participating divisions quite naturally. "The Acoustics Division did the acoustic part and Optical Sciences did the optical part and together we were the first to do an at-sea demonstration of fiber optics in a towed array," Giallorenzi noted. One of the most impressive early results came in the guise of a failure. During the first attempt to take the towed assembly into the water, the water pressure broke through the assembly's protective rubber dome and all of the electronics and optical fiber components became flooded. "We dried it out and tried it again and it worked perfectly," Giallorenzi recalls. "Under these conditions of failure, [the Navy observers who would actually make the decision to use such equipment] had never had a sensor that wasn't destroyed."

The crux of these optical arrays was an acoustic sensor that worked according to the century-old concept of interferometry, or the measurement of the way two sources of light interfere with one another. The principle here was to mix the light from a reference optical fiber that was shielded from underwater sound with that light traveling in a second fiber "listening" in the water. The result is a characteristic interference pattern that light detectors can monitor. If the second fiber "hears" something, its light changes and that, in turn, alters the interference pattern its light forms with the light of the reference fiber. The changes that are detectable are exquisitely minute; even tiny sounds will affect the interference pattern. That makes for a very sensitive underwater listening device indeed. Bucaro claims that NRL has the first (U.S. Patent 4,162,397) patent for such a device based on work that he and colleagues in the Physical Acoustics Branch had done before the FOSS program got underway.



United States Patent [19] — [11] **4,162,397**

Bucaro et al. — [45] **Jul. 24, 1979**

[54] **FIBER OPTIC ACOUSTIC SENSOR**

[75] Inventors: **Joseph A. Bucaro,** Herndon, Va.; **Edward F. Carome,** South Euclid, Ohio; **Henry D. Dardy,** Upper Marlboro, Md.

[73] Assignee: **The United States of America as represented by the Secretary of the Navy,** Washington, D.C.

[21] Appl. No.: **920,091**

[22] Filed: **Jun. 28, 1978**

[51] **Int. Cl.**[2] **H04B 9/00;** G01V 1/00; H04B 11/00

[52] **U.S. Cl.** .... **250/199;** 340/15; 340/15.5 R; 340/17 R; 358/112; 358/901

[58] **Field of Search** .... 250/199; 358/112, 90 L; 340/15, 15.5 R, 17 R

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Primary Examiner—Howard W. Britton
Attorney, Agent, or Firm—R. S. Sciascia; Philip Schneider; Melvin L. Crane

[57] **ABSTRACT**

An optical fiber acoustical sensor for detecting sound waves in a fluid medium. An optical fiber coil through which a light beam is transmitted is placed in a fluid medium. A sound wave propagating through the fluid medium and incident on the optical fiber coil changes the index of refraction of the optical fiber at the area of incidence. The index change causes a phase shift in the transmitted light which is detectable to denote the presence of the sound wave.

9 Claims, 5 Drawing Figures

U.S. Patent 4,162,397.

Besides the fibers, this interferometric system required the development of other components, including couplers and light detectors. The work led to dozens of patents for both the acoustics and optics scientists. The first at-sea tests in the late 1970s and early 1980s of a towed array of fiber-optic-based acoustic sensors included plenty of electronic components as well as optical ones. The reason for this was that the light signals intermittently had to be converted into electronic signals and then back again into light. Though necessary at the time, all of these conversions degraded the quality of the signals and the overall capabilities of the system. To circumvent this limitation, Giallorenzi and his colleagues began selling the idea of the next-generation towed array. This one would be almost entirely optical — no light-to-electron transitions, except at the end when people, computers, or both would need to make sense of the signals. "Through a good part of the 1980s, we did various phases of development on that array and, in about 1990, it was chosen to be the replacement array for the Navy," Giallorenzi says.

Many of the Navy's surface ships would have been equipped with the NRL-developed "all-optical towed array" by now had the geopolitical situation not changed so drastically just as the technology development was coming to completion. The end of the Cold War and the fall of Communism beginning in 1989 changed everything, including the perceived need for a new generation of towed arrays for surface ships.

The technology has not languished, however. Instead, it is slated to become a major component of the latest generation of nuclear submarines — the 688 class. "When they put Tomahawk missiles on these submarines, they didn't retain sufficient reserve buoyancy to permit these boats to carry the 42-ton [wide aperture] acoustic array originally specified for the 688s," Giallorenzi says. "They asked us if the fiber array could be lighter," Giallorenzi recalls. Yes was the answer. "It basically was taking the towed array technology and putting it on the side of submarine," Giallorenzi says. At 18 tons, the system shaved 24 tons off of the new submarine's design. The Optical Sciences Division developed yet another incarnation of the all-optical towed array technology. This one is in the form of a rapidly deployable bottom-mounted device whose significantly smaller size and reduced power needs lead to an extremely powerful underwater listening system that can be quickly and readily deployed almost anywhere. Some of the first tests of this version of the work that began in the late 1970s took place in May 1996 off the coast of San Diego.

As Bucaro, Davis, Giallorenzi, and others intuited more than 20 years ago, optical fibers have become useful components of Navy surveillance systems, communications networks, navigational instruments like gyros, and electronic warfare systems.

Optical fibers also have become important tools for research. For example, researchers in the Physical Acoustics Branch, which Bucaro heads, are using them to investigate the acoustic properties of new, stealthier submarine designs. And Fran Ligler's group in the Center for Biomolecular Science and Engineering is investigating their potential use as sensors for biological and chemical warfare agents.

Origin of the Large Aperture Systems Branch by Dr. Budd B. Adams

Dr. Budd B. Adams

Background: Project Artemis and the Hudson Laboratories

In 1958 the Naval Research Laboratory through the Acoustics Division began participating in Project Artemis, a very large Navy 6.3 Advanced Development effort to test the viability of undersea ocean basin wide active acoustic surveillance. The basic idea was to investigate the feasibility of an undersea equivalent of the Distant Early Warning (DEW) radar system operating across the Arctic. Until 1968 the Acoustics Division's efforts were almost entirely concentrated in developing and building the megawatt acoustic source, its power plant, and the mobile support/deployment platform, the USNS *Mission Capistrano*, a T-2 tanker.

Early at-sea acoustics efforts began in 1960 with experimental hydrophone module tests by builder/contractor General Electric and other participants including Bell Telephone Laboratory (BTL, the prime contractor for SOSUS [Sound Surveillance System]), the Naval Underwater System Center (NUSC, New London, Connecticut), and Hudson Laboratories (HL, Dobbs Ferry, New York), the Navy's prime contractor for the entire Artemis program. The technical program was coordinated and directed by the Artemis Research Committee (ARC), whose members included the Marine Physical Laboratory (MPL) of the Scripps Institution of Oceanography, and the Naval Ocean Systems Center (NOSC), both of San Diego, IBM Corp., NUSC, NRL, HL, and others, and chaired by BTL. An offshore tower platform, named Argus Island, was erected in the 200 ft waters of Plantagenet Bank, 20 miles southwest of Bermuda, to serve as the local terminus for the projected 32,000-element, one-mile-square receiving array which was to be microwave-linked to a shore laboratory to house all the processing equipment, built on the U.S. Navy property at Tudor Hill, Bermuda. These massive hardwares were the result of analyses of the requirement to ensonify a submarine at a 400 nautical mile range and receive a detectable echo back over the same 400 nautical mile range.

Through the early and middle 1960s all this apparatus was built and tested, and 10% of the receiving array was installed at a 2000 ft depth on the southwest side of Plantagenet Bank. Engineering and ocean acoustic experiments of increasing complexity, utilizing increasingly larger portions of the assembled research hardware, were carried out basically to find out if and how well the major components worked, first separately to prove and improve them and then to exercise them together in increasingly larger subassemblies.

The major problem areas in 1968 were the following:

1. The acoustic source and platform.

    a. The final 1440-element, 400-ton source had element interaction and backing reflector problems that limited peak power radiated and required more development.
    b. The initial concept of bottom mounting the source on Plantagenet Bank and tending it with the USNS *Mission Capistrano* moored to Argus Island was proved impractical by the sea heights measured at Argus Island after it was built. However, controlling the source/ship orientation was partially solved with one of the first deep ocean positioning systems developed for and installed on the *Mission Capistrano*.

2. The 10% acoustic array was 90% horizontally thinned and thus able to conditionally support horizontal coherence measurements over the full aperture and temporal coherence from a low powered distant fixed source.

    a. Multipath handling was, however, unresolved and reverberation not addressable with the high side lobes of the thinned receiving array.
    b. A fixed fully populated planar receiving array of dipole elements, 2.5 × 3.0 wavelengths, was mounted to the face of the *Mission Capistrano* source by late 1969 to test multistatic system configurations, but not used until later.
    c. The 10,000-beam real-time processing with the optical correlator being developed was not achieved by 1968.
    d. The understanding of low frequency target strength was not fully addressed prior to 1968.

In 1967 the Navy had decided to enlarge the objective of Project Artemis to include an Active Adjunct to SOSUS utilizing a basin-wide passive receiving system already installed and working. However, in 1968 the Office of Naval Research (ONR) decided to divest itself of 6.3 Advanced Development responsibilities and also, in April 1968, to announce the upcoming 1969 closure of Hudson Laboratories. This furthered the absorption of management from HL into a new Naval Electronic Systems Command (NAVELEX), PME 124, which also managed SOSUS. Major Artemis engineering and contract procurements were largely finished, and research utilization of the developed hardware could be contracted directly to ARC members still working on ocean surveillance related issues or others interested. This transition was gradually accomplished by April 1969. As a principal member of the ARC and the USNS *Mission Capistrano* source developer/operator, the Acoustics Division of NRL was asked to continue that function and to further assume the Artemis ocean acoustics efforts of HL. While the *Mission Capistrano* source had NRL staff in two branches and contractor support in place, the personnel and experience utilizing all of the Artemis equipments and research questions were missing. This led to the formation of a new branch in the NRL Acoustics Division to be fittingly named the Large Aperture Systems Branch. In 1968 there were two senior research scientists working Artemis problems at HL, Budd Adams and Ross Williams, as well as a number of engineers and technicians. Dr. Adams elected to lead the new branch at NRL and Dr. Williams chose to stay in Dobbs Ferry, New York, and continue optical correlator development as an NRL contractor.

The Startup of the Large Aperture Systems Branch in 1968

The initial Large Aperture Systems Branch charter was to complete the unfinished Artemis research goals in low frequency large array system performance and active sonar reverberation. One week prior to his arrival at NRL, Dr. Adams was called upon to defend the NRL plans and goals by PME 124 manager, Mr. Leo Treitel. The briefing was successful. Adams arrived at NRL as the first employee of this new branch on September 3, 1968. By January 1, 1969, several additional employees had been added, including Dr. William Moseley, Mr. Dave Deihl, and Mr. Carl Andriani. By early 1969 the Branch conducted a sea test in the area southwest of Bermuda utilizing all of the Artemis facilities. The sea test was designed to address scientific issues related to beamforming with large arrays and measurements of long-range reverberation. This served as an excellent introduction to the Bermuda facilities and the planning and execution of large at-sea experiments for the new branch employees, as well as for Mr. Robert Chrisp, a lead engineer from the Acoustics Division's System Engineering staff.

Branch Research Thrusts in the 1970s

From this initial startup, the Branch quickly developed research thrusts that included an emphasis on the characterization of high space, time, and frequency resolution of acoustic fields. This included stochastic approaches to the data analysis and a significant emphasis on predictive numerical computer model development. The focus was on low acoustic frequencies, less than 500 Hz, since the intended research was to support long-range surveillance sonar development.

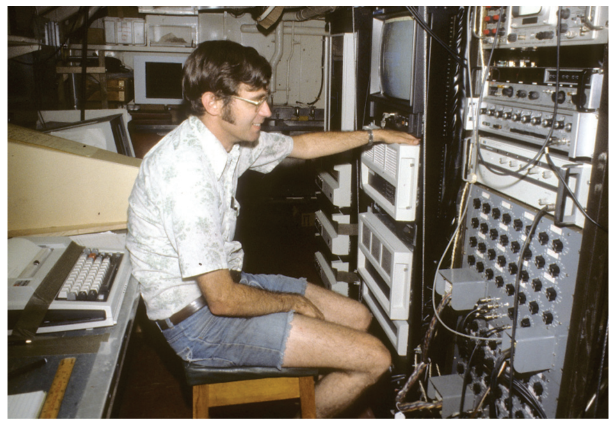
Within a decade, five major at-sea measurement trials were conducted by the Branch that addressed Active Adjunct to Undersea Systems (AAUS), including three sea trials led by Dr. Adams. This intense at-sea experimentation activity involved all of the Branch personnel and was fully supported by the System Engineering Staff and Ship Facilities Group at NRL. Through all these groups, control was exercised to logistically support, secure required engineering developments, direct the ships, and handle liaison with COMOCEANSYSLANT, PME 124, and others. The scientific results from these sea trials were reported to the undersea warfare community, including an invited presentation at the U.S. Navy Underwater Acoustic Symposium in 1971. A subsequent 6.2 Exploratory Development Reverberation Program was specifically requested by PME 124 to be included within the NAVELEX 03 program when that 6.2 office was formed in 1973 to carry on exploratory development research in environmental acoustics in support of active systems. During the 1970s this effort was the only funded research in the Navy in active surveillance. The Large Aperture Systems Branch completed a successful set of interim reports and analyses based on the extensive experimental results, as well as on results from some associated programs (e.g., Expendable Sound Source).

Also around 1970 the Large Aperture Systems Branch initiated a significant research effort on the characterization of submarine target strength. This measurement effort had two thrusts: one was for full-scale targets using the Artemis source and a diesel electric submarine, and the second a measurement effort using the Kamloops mid-scale model submarine. The results from these measurement efforts were published, with the second being the first set of data on bistatic target strength available from any source.

By the mid-1970s NAVOCEANO had developed a significant interest in ocean bottom mapping, including the determination of seamount locations. This led to the involvement of NAVELEX-supported developments on active adjuncts to towed array systems, and to an international measurement collaboration with the New Zealand Defence Scientific Establishment. The Large Aperture Systems Branch conducted its first basin reverberation experiment (TOPO-I) using impulsive vertical line arrays as acoustics sources and a towed horizontal line receiver array in 1976. A follow-on joint sea test was successfully conducted several years later (TOPO-II). These efforts led to concepts of reverberation-suppressing source designs, total basin reverberation estimation algorithms, and associated processing systems. These experiments led to a major ARPA/NAVELEX active sonar test in 1978 with an actual undersea target. The Large Aperture Systems Branch team deployed a variety of point-, vertical line-, and sheet-impulsive arrays as sources from the USNS *Harvey Hayes* in that trial.

In 1978 the Navy sponsored an Active Surveillance Workshop in Monterey, California, that was attended by the various U.S. researchers who had become involved in this type of research. Among the goals of this workshop were to solicit expert opinions from the research community and to provide recommendations for a new system initiative in active surveillance. Dr. Adams was a key participant in this workshop. He presented summaries of the NRL Large Aperture Systems Branch's analyses of recent at-sea experiments. Adams then presented an invited paper on reverberation and active surveillance at the June 1979 DARPA- and Navy-sponsored conference on signal processing and surveillance.

Dr. Budd Adams aboard USNS *Harvey C. Hayes* in the Labrador Sea.



James Griffin monitors received acoustic data from NRL reverberation experiments aboard HMNZS *Tui* (1979).

Origin of the Acoustic Media Characterization Branch

This narrative on the origins of the NRL Acoustic Media Characterization Branch is based on unpublished notes provided by Dr. Burton G. Hurdle. These notes recorded some recollections by former members of this branch that were prepared prior to NRL's 75th anniversary celebrations of 1998. The group that evolved into this branch was established at NRL in 1969 and was transferred from the Acoustics Division to the Marine Geosciences Division during an NRL directorate reorganization around 1993.

The Hudson Laboratories (HL) of Columbia University was a facility in Dobbs Ferry (Westchester County), New York, that was totally funded by the U.S. Navy. Its mission was to conduct acoustic research and to develop advanced undersea acoustic surveillance systems. When the Navy discontinued funding for HL in 1969, a project involving long-range undersea propagation of acoustic signals was absorbed by the Naval Research Laboratory in Washington, D.C. At that time approximately forty scientists and technical staff were transferred to NRL, primarily into the Acoustics Division, to continue this research.

Of these personnel, two research oceanographers, Henry S. Fleming and Norman Z. Cherkis, were moved into the Acoustics Division's long-range undersea acoustic surveillance project in 1969. Later that year Fleming and Cherkis were the first researchers to predict, locate, and track the locations of Soviet submarines using a crude model of the poorly known North Atlantic Ocean seafloor topography (bathymetry). These techniques were transferred to COMOCEANSYSLANT, and proved that the prediction of Soviet submarine movements was possible with some degree of accuracy. Previously, while still at HL, Fleming and Cherkis discovered and mapped a 180 km offset in the Mid-Atlantic Ridge. This was the largest offset in the North Atlantic portion of the Mid-Atlantic Ridge. They named it the Gibbs Fracture Zone in honor of the research vessel *J.W. Gibbs* (T-AGOR 1). The management of this vessel was transferred to NRL when HL closed. In 1970 two additional oceanographers, Robert K. Perry and Robert H. Feden, came to the NRL Acoustics Division from the Naval Oceanographic Office (NAVOCEANO). From these modest beginnings, there emerged within the Acoustics Division in the 1970s the Environmental Sciences Branch (Code 8110) that around 1980 through the early 1990s became the Acoustic Media Characterization Branch (Code 5110).

This Branch represented one of the most effective oceanographic groups outside the purview of the Oceanographer of the Navy. The main expertise of this group was in mapping the bathymetry of the seafloor relating to specific problems of undersea surveillance and antisubmarine warfare (ASW). Fleming and Cherkis had previously demonstrated that seafloor topography was effective in blocking and/or shadowing acoustic noise emanating from transiting submarines. If a submarine was located by the SOSUS network, the knowledge of the seafloor topographic characteristics could be used to predict where the submarine might next be "illuminated" (detected) by the discrete noises it made in the water. Aside from some portions of the North Atlantic Ocean that had been surveyed by the Ocean Survey Program of NAVOCEANO, little was known about the bathymetry of ocean basins, including the central North Atlantic Ocean and the sub-Arctic regions of the Norwegian and Greenland Seas. The latter two ocean basins held the routes for Soviet submarines entering and exiting the North Atlantic Ocean across an undersea ridge connecting Iceland with Greenland on the west and Great Britain on the east.

In 1970 Fleming and Cherkis conducted acoustic propagation experiments in the region between the Canary Islands and the Azores, proving that the acoustic shadowing theory was correct. Additional depth measurements of the seafloor added to the Navy's bathymetric database, which contained almost no information in the area. By the end of 1970 the small research group had gained two researchers and it became known as the Environmental Sciences Group (ESG) within the Acoustics Division's Propagation Branch (Code 8170).

The ESG became interested in developing more rapid methods for surveying the gross bathymetry in the Norwegian and Greenland Seas. These areas later became termed the Nordic Seas at the recommendation of Burton Hurdle. In 1971 the ESG began to conduct aeromagnetic surveys using fleet ASW aircraft. They soon had access to dedicated research (P-3) maritime patrol aircraft for these surveys. These airborne measurements yielded gross maps indicating bathymetric features. Within two years the ESG had confirmed the existence of the Jan Mayen Fracture Zone, the Aegir Ridge, the Jan Mayen Ridge, and the Mohns Ridge. They also mapped the Vesteris Seamount (a major solitary seamount with 3100 meters of total relief) in the Greenland Sea, as well as the Greenland Fracture Zone and multiple smaller features that would affect submarine surveillance in the Nordic Seas region. These airborne investigations included remote areas, including the North Polar Ice Cap, that were not accessible by surface vessels, except via large icebreaker vessels. In the early 1970s the available bathymetric data in these areas of interest were very sparse and large areas were uninvestigated.

The aeromagnetic investigations were followed up by surface ship operations which were directed to areas where the geomagnetic data showed potentially interesting bathymetry features. Other areas where the geomagnetic data showed smooth features were ignored by the ship surveys since large bathymetric features nearly always exhibit significant geomagnetic anomalies. As an example, the Vesteris Seamount exhibits a 2200 nT geomagnetic anomaly.

The ESG conducted three such survey research cruises to the sub-Arctic regions. During one of these cruises in October 1972, USNS *Mizar* (T-AGOR 11) became trapped in early season ice after a storm closed a "lead" in which the vessel was sailing. Although it was trapped and icebound for ten days, *Mizar* continued to collect both acoustic and environmental data while drifting in a generally southward direction. Another storm that was not indicated on any of the weather maps arose in the Greenland Ice Cap after ten days of ship drift and after the barometric pressure fell to a low value of 27.36 inches of mercury. This storm created 80-knot winds which opened the ice pack. *Mizar* was then able to become free from the ice with the assistance of a U.S. Coast Guard icebreaker. Norm Cherkis was aboard *Mizar* on that cruise.

Dr. Susan Numrich adjusting chart recorder during Arctic testing aboard USNS *Mizar* in 1974.

In late 1972 the ESG became named the Environmental Sciences Section (ESS, Code 8174) within the Propagation Branch (Code 8170). At about this time, the ESS participated in research cruises aboard USNS *Kingsport Victory* and USNS *Mizar* near the Mid-Atlantic Ridge south of the Azores. The cruise objective was to map and photograph the seafloor in advance of a planned international survey project called FAMOUS (French-American Mid-Ocean Undersea Study). FAMOUS subsequently used the NRL pre-test data to direct the first deep submersible diving efforts on the mid-ocean ridge/rift system. The seafloor photographic data were joined in mosaic-tile fashion on one-meter-square tiles and spread out on the floor of NRL's Recreation Club basketball court. These photographs yielded a visual roadmap for the submersible pilots and were later featured in the May 1975 issue of *National Geographic* magazine.

USNS *Harvey C. Hayes* (T-AGOR 16).

In 1973 a new research vessel with a catamaran hull was delivered to NRL. This vessel was the USNS *Harvey C. Hayes* (T-AGOR 16). During its maiden cruise, ESS researchers visited an area in the North Atlantic Ocean where Soviet submarines were known to hold regular patrols. During this voyage the Hayes Fracture Zone was discovered, and other previously known fracture zones were more precisely located. The investigations of these fracture zones, coupled with data collected on other earlier cruises further to the north, caused a re-thinking of the spatial distribution of North Atlantic fracture zones. These fracture zones were now known to occur on the seafloor at intervals of approximately 35 nautical miles. This realization shed new light on seafloor spreading concepts and became of much interest in the geophysical community.

Late in 1975 ESS researchers participated in a cruise aboard USNS *Hayes* in the Norwegian Sea. They were able to map part of the region with a 12 kHz narrow-beam echo sounder, using Transit Satellite aids to navigation. This was the first time a large seafloor survey was conducted in the Norwegian Sea using the then state-of-the-art instrumentation.

By 1980, this group of ESS researchers became the Acoustic Media Characterization Branch (Code 5110), headed by Hank Fleming. It is worth enumerating some of the further important research efforts of this group.

In 1973 NRL researchers aboard USNS *Hayes* discovered the Molloy Deep, the deepest point in the oceans north of 65°N latitude. This depth was later refined to 5608 meters by NRL researcher Norm Cherkis during a 1984 cruise aboard the German icebreaker research vessel *Polarstern* using a SeaBeam (multibeam) echo sounder.

In the period from 1975 to 1979, NRL researchers conducted aeromagnetic surveys to investigate large oceanic crustal areas in the South Pacific Ocean. The airborne surveys were done at considerably less expense than would be required for shipboard surveys. These aeromagnetic surveys enabled NRL researchers to accurately predict the existence (or lack thereof) of seafloor topographic (bathymetric) features and were useful to vector scientific research cruises to areas of interest. The aeromagnetic technique was able to indicate the presence of oblique seafloor spreading in some regions, as well as the location of triple junctions and propagating ridges. These features were subsequently confirmed by shipboard and submersible investigations by other nations, including Australia, Great Britain, France, and Japan.

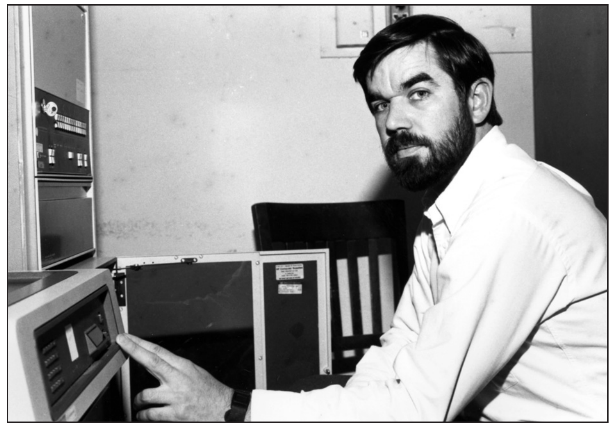
In the period from 1979 to 1989, NRL researchers participated in collaborative experiments in the South Atlantic Ocean via a bilateral agreement with Brazil. Operations were conducted aboard USNS *Hayes*, Research Vessel *Conrad*, and Research Vessel *Almirante Camara* (Brazilian vessel, ex-USNS *Sands*); and included eight detailed aeromagnetic investigations. These experiments investigated the southern Mid-Atlantic Ridge for geological, geophysical, and oceanographic parameters. Multibeam echo soundings revealed that the structure of the southern Mid-Atlantic Ridge is significantly different than that of the northern Mid-Atlantic Ridge. Fracture zone spacing was accurately measured. Prior to these investigations, a major seamount group in the Brazil Basin was portrayed as having seven major seamounts. Analysis of the new data from these joint experiments of 1986, 1988, and 1989 revealed that the actual seafloor configuration included a group of forty-five seamounts. As a result of these experiments the bathymetry chart covering the South Atlantic area was completely revised.

In 1987 NRL researchers led by John Brozena demonstrated the feasibility of airborne gravity measurements in conjunction with aeromagnetic measurements for improved surveys.

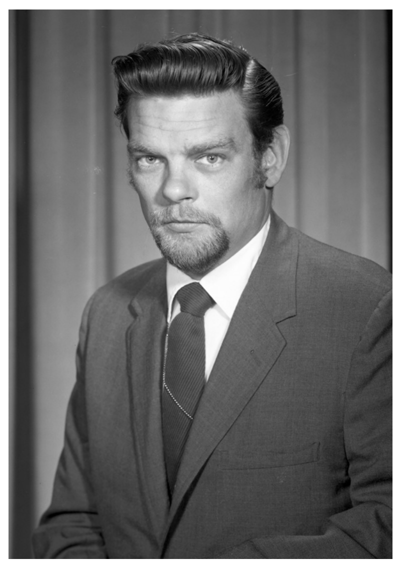
In 1990 NRL researcher Norm Cherkis conducted the first detailed mapping of Vesteris Seamount by multibeam echo sounding aboard a German icebreaker.

In the period 1991 to 1992, NRL researchers led by John Brozena conducted airborne geophysical surveys over Greenland that resulted in rapid coverage over all of Greenland. The measurements revealed the crustal depth below the ice cap and were repeatable to within five percent.

Around 1993 the Acoustic Media Characterization Branch transferred from the Acoustics Division to the Marine Geosciences Division (Code 7400) under division superintendent Dr. Herb Eppert. It was renamed the Marine Physics Branch (Code 7420). In 2003 Hank Fleming retired and John Brozena became its new branch head.



Dr. John M. Brozena, Jr.



Henry S. Fleming

CHAPTER SIX

Era 4: Dr. David L. Bradley
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Biography of Dr. David L. Bradley — Era 4: 1985–1993

David L. Bradley [redacted] in the Highland Park suburb of Detroit, Michigan. He lived there and in the Royal Oak suburb of Detroit until the spring of 1945 when his family moved to Gladwin in central Michigan where they purchased an 80-acre farm. He attended a one-room schoolhouse there until eighth grade; he then attended Gladwin High School for four years. In September 1956 he enrolled at Michigan College of Mining and Technology (now called Michigan Technological University) for his undergraduate education. He graduated in 1960 with a B.S. degree in physics, then immediately accepted a position as a researcher in the Acoustics Division of the Naval Ordnance Laboratory (NOL) in Silver Spring (White Oak), Maryland. In his first year at NOL he had rotating assignments that exposed him to a variety of types of NOL research, including speed of sound measurements in alcohols (under Wayne Wilson), Polaris missile development, and research on the properties of heavy water and also acoustic transduction materials (under Mickey Davis).

In September 1961 Bradley received a fellowship and was granted leave from NOL for two years to begin physics graduate studies specializing in ultrasonics under Professor Walter Mayer at Michigan State University in East Lansing. He received an M.S. degree in physics in 1963 and then returned full-time to NOL to pursue shallow water acoustic propagation research under Robert Urick. In the mid-1960s Bradley began further graduate studies in underwater acoustics via evening classes in the Department of Mechanics and Mechanical Engineering at Catholic University in Washington, D.C. In 1966 Bradley received support from NOL to devote full-time to his graduate studies. He was a mechanical engineering major with a minor in mathematics. In June 1970 he completed his Ph.D. thesis on a topic related to acoustic propagation in shallow water using data collected in the Virginia Capes area off the North Carolina coast.

In the early 1970s Bradley continued underwater acoustics research at NOL and became manager of several research projects in Arctic acoustics. He participated in field experiments to the marginal ice zone. Research platforms included U.S. Coast Guard ice breaker vessels with helicopters that were used to take the NOL scientists inland about 50 miles from the ice edge to perform experiments.

By the mid-1970s Bradley became the NOL Acoustics Division head, supervising a group of about thirty-five researchers. In late 1978 Bradley was invited to become involved in managing the Navy's LRAPP project (Long Range Acoustic Propagation) that had earlier been managed at the Maury Center at NRL, but that moved to the Naval Ocean Research and Development Activity (NORDA) in Bay Saint Louis, Mississippi, in 1976. Bradley thus spent about one year at NORDA while affiliated with LRAPP. In 1979 Bradley accepted a three-year position at the Pentagon (OP-37) managing Navy mine warfare projects. In 1982 Bradley moved to the Office of Naval Research (ONR) under Gordon Hamilton managing programs in geology and geophysics as well as underwater acoustics. He remained at ONR for three years during which time he fostered research in several new areas including the development of multibeam sonar systems and research on sediment dynamics.

In 1985 Bradley was invited to become the fourth superintendent of the Acoustics Division at NRL to succeed retiring superintendent Dr. John Munson. Bradley assumed this new position in a relatively smooth transition, under the guidance of NRL's Director of Research, Dr. Timothy Coffey, and the Associate Director of Research for the Systems Research and Technology Directorate, Mr. Richard Rojas. The associate superintendent under Bradley was Burton G. Hurdle (and later J. Thomas Warfield). In the mid-1980s there were about 140 persons in the NRL Acoustics Division and the Navy was still in the Cold War era and concerned with deep ocean undersea warfare research.

There was considerable breadth of research interests within the Acoustics Division in that period that included topics such as deep water propagation and reverberation, target characteristics, physical acoustics, fiber-optic sensor developments, Arctic acoustics, marine geophysics, and environmental acoustic modeling. During this period, funding for Acoustics Division researchers was relatively stable. Bradley maintained close interactions with Navy sponsors, including ONR, the Office of Naval Technology (ONT), and various Navy Systems Commands. He regularly attended meetings of the Acoustical Society of America and initiated contact there with potential promising future NRL researchers. During his tenure at NRL, Bradley also taught evening graduate courses in advanced underwater acoustics at Catholic University. In addition he regularly attended the periodic Navy-sponsored technical meetings such as the Navy Symposia on Underwater Acoustics and the Undersea Warfare Conferences to stay connected with big-picture Navy developments and concerns.

Late in Bradley's tenure as superintendent, around 1991–1992, the Navy decided to make NORDA (which became NOARL, the Naval Ocean and Atmospheric Research Laboratory, located at Stennis Space Center, Mississippi) a part of NRL. This had a significant impact on the Acoustics Division. The components of NORDA that became part of NRL's Acoustics Division included NORDA's Center for Environmental Acoustics, headed by Edward Franchi, the Ocean Acoustics Branch, headed by Dan Ramsdale, and the Acoustics Simulation and Tactics Branch, headed by Jim Matthews. At the same time, the NRL Acoustic Media and Characterization Branch, headed by Hank Fleming, moved from the Acoustics Division to the Marine Geosciences Division, under Herb Eppert.

In 1993, shortly after the merging of the NORDA research components into NRL, Bradley was offered and accepted a position as technical director of NATO's SACLANTCEN (Supreme Allied Command Centre Atlantic) in La Spezia, Italy, a position that he held for three years. Bradley's official retirement from NRL and government service occurred in February 1994 after eight years as Acoustics Division superintendent. Bradley was succeeded as superintendent by Dr. Edward R. Franchi.

In late 1996 Dr. Bradley returned to the United States and accepted a position as professor of acoustics and senior scientist at the Applied Research Laboratory of the Pennsylvania State University in State College.

Bradley is a fellow of the Acoustical Society of America and has served the ASA in various capacities including committee memberships and chairmanships [Underwater Acoustics (1972–1975; 1988–1991; 1997–2000), Books, Medals and Awards, Regional Chapters] and he served from 1997 to 2002 as associate editor of the *Journal of the Acoustical Society of America (JASA)*. He is a member of the American Geophysical Union. He served as a member of the Ocean Studies Board of the National Academy of Sciences (1998–2001) and as a member of the National Academy of Sciences Committee on Potential Impacts of Noise in the Ocean on Marine Mammals (2001–2003). He is a recipient of the Navy Meritorious Civilian Service Award (1982) and the Navy Superior Civilian Service Award (1993).

Acoustics Division Organization in Era 4

1985

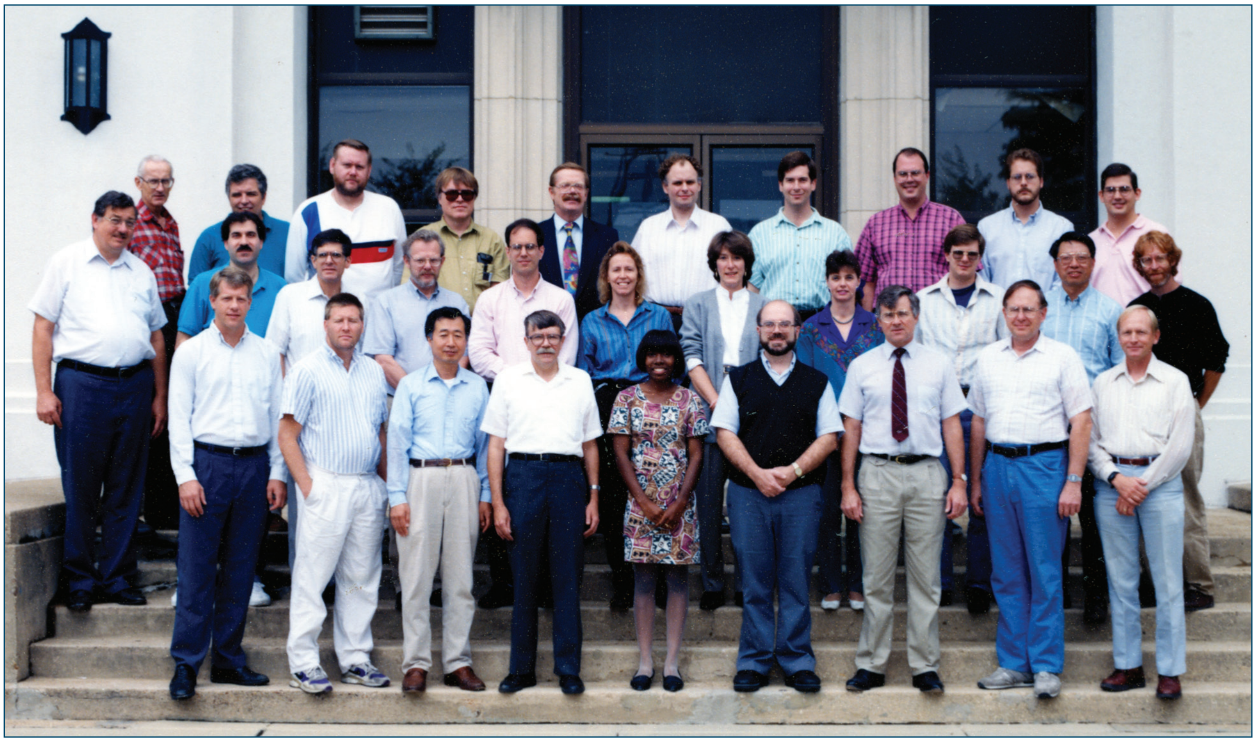
Code	
5100	**Dr. David L. Bradley (Superintendent)**
5101	Dr. B.G. Hurdle (Assoc. Superintendent)
5101A	Dr. J.R. McGrath
5101M	Dr. J.C. Munson (Editor, JUA (USN))
5102M	R. McGregor
5104	Dr. S. Hanish
5106	C.R. Rollins
5109	M. Potosky
5103	Ocean Systems Applications Group Daniel Steiger (Group Head)
5110	Acoustic Media Characterization Branch Henry S. Fleming (Branch Head)
5120	Applied Ocean Acoustics Branch Dr. Orest I. Diachok (Branch Head)
5130	Physical Acoustics Branch Dr. Joseph A. Bucaro (Branch Head)
5150	Software Systems Development Branch Elizabeth E. Wald (Branch Head)
5160	Large Aperture Systems Branch Dr. Budd B. Adams (Branch Head)

April 1993

[Stennis Space Center, Mississippi, acoustics research groups now included]

Code	
7100	**Dr. David L. Bradley (Superintendent)**
7103B	Dr. Burton G. Hurdle
7104	Dr. William A. Kuperman (Sr. Scientist)
7104M	Dr. B.E. McDonald
7106	R. McGregor
7120	Acoustic Signal Processing Branch Dr. Marshall Orr (Branch Head)
7130	Physical Acoustics Branch Dr. Joseph A. Bucaro (Branch Head)
7140	Acoustic Systems Branch L. Bruce Palmer (Branch Head)
7105	Center for Environmental Acoustics Stennis Space Center, Mississippi Dr. Edward R. Franchi (Head)
7170	Ocean Acoustics Branch Dr. Dan J. Ramsdale (Branch Head) J.G. McDermid
7171	Computer Resources
7172	Arctic Environmental Acoustics
7173	Shallow Water and Coastal Acoustics
7174	High Frequency Acoustics
7175	Boundary Acoustics
7176	Tactical Noise
7180	Acoustic Simulation and Tactics Branch James E. Matthews (Branch Head) Dr. B.B. Adams
7181	Acoustic Simulation
7182	Environmental Assessments
7183	Naval Acoustics Tactical Applications

Era 4 Group Photos



Acoustic Signal Processing Branch (Code 7120) circa 1993.

Front Row:
Edward Kunz, John Talman, Kwang Yoo, Stephen Wolf, Shannon Whitmire, Stephen Wales, Marshall Orr, John Siegel, Peter Mignerey

Middle Row:
George Giellis, Joseph Brust, Jonathan Berkson, Richard Heitmeyer, Brad Orchard, Alexandra Tolstoy, Ellen Livingston, Barbara Wood, Douglas Cooper, T.C. Yang, Steven Finette

Back Row:
Robert Lee, George Vermillion, Bruce Pasewark, Dennis Creamer, Rudolph Krutar, James Smith, Fred Feirtag, John Wolf, Jeffrey Kinder, Christopher Scannell

Physical Acoustics Branch (Code 7130) circa 1993.

Front Row:
Joseph Shirron, Joseph Cates, Nicholas Lagakos, Curtis Carter

Middle Row:
Douglas Photiadis, Karl Washburn, Charles Gaumond, Nate Yen, Robert Corsaro, David Peters

Back Row:
Brian Houston, Joseph Bucaro, Cathy McCauley, Louis Dragonette

Acoustic Systems Branch (Code 7140) circa 1993.

Front Row:
Robert Gragg, David Drumheller, David Fromm, Richard Menis, Joseph Jeffrey, Ralph Baer, Michael Nicholas, Laurie Fialkowski

Middle Row:
Jeanette Faber, Christopher Ziemniak, Paula Osborn, Peter Ogden, Roger Gauss, Dalcio Dacol, Nicholas Makris

Back Row:
B. Edward McDonald, Michael Collins, L. Bruce Palmer, Fred Erskine, Gregory Orris, Raymond Soukup, Dennis Dundore, Richard Pitre

Center for Environmental Acoustics (Code 7105), Stennis Space Center, Mississippi, circa 1993.

Vivian Regan, Edward Franchi, Betty Choat, Jean Rapp

Ocean Acoustics Branch (Code 7170), Stennis Space Center, Mississippi, circa 1993.

1-Charles Thompson
2-George Smith
3-Joal Newcomb
4-James Showalter
5-Dan Ramsdale
6-Robert Farwell
7-Ashok Kalra
8-Marcia Wilson
9-Gerald Morris
10-Wayne Kinney
11-Pat Carter
12-Ed Besancon
13-Karen Dudley
14-Mary Rowe
15-Tony Pogue
16-Stephanie Kooney
17-Lisa Pflug
18-James LeClere
19-Desiree Swilley
20-Rick Love
21-Kristen Savage
22-E.J. Yoerger
23-Ted Kennedy
24-Howard Chandler
25-Veronica Ross
26-Teenia Perry
27-Lonnia Rosche Allen
28-Steve Stanic
29-Tim Ruppel
30-Debra Flanagan
31-Jacob George
32-Robert Fisher
33-Hassan Ali
34-Craig Fisher
35-Christopher Feuillade
36-Michael Broadhead

Acoustic Simulation and Tactics Branch (Code 7180), Stennis Space Center, Mississippi, circa 1993.

Left to right:
Curtis Favre, Gary Bullock, James Miller, Keith Davis, Elmer White, Christopher Burkhalter, James Matthews, David King, Michael Werby, John Dubberly, George Kerr, Robert Zingarelli, Guy Norton, Budd Adams, Mona Collins, Roger Oba, Billie June Crawford, John Ellis, Susan Starke

Acoustics Division Administrative Staff (Code 7100A) circa 1993 (Washington, D.C.).

Front Row:
Lori Heddings, Ruth Stallings, Karen Turner, Christine Burns

Back Row:
Jane Ihnat, Nancy Garito, Nancy Beauchamp

Era 4 Research Overview

Key Research Thrusts

The period from 1985 to 1993, during which the Acoustics Division was under the leadership of Dr. David L. Bradley, was a time of transition that included the ending of the Cold War, the renewal of interest in littoral ocean acoustics, a zenith of interest in Arctic acoustics, the development of new data processing techniques and computational methods, the maturing of airborne measurement methods, and the merging of researchers from Stennis Space Center, Mississippi, with the Division.

By the mid-1980s, research was conducted within five primary branches: The Acoustic Media Characterization Branch (Code 5110), the Applied Ocean Acoustics Branch (Code 5120), the Physical Acoustics Branch (Code 5130), the Software Systems Development Branch (Code 5150), and the Large Aperture Systems Branch (Code 5160). By the end of Era 4 in 1993 there had been a significant reorganization resulting in five primary branches (and a change in the Division's Code from 5100 to 7100): the Acoustic Signal Processing Branch (Code 7120), the Physical Acoustics Branch (Code 7130), the Acoustic Systems Branch (Code 7140), and two new branches located in Mississippi, the Ocean Acoustics Branch (Code 7170) and the Acoustic Simulation and Tactics Branch (Code 7180).

A number of key research topics and thrusts came to maturity during Era 4, some of which had begun in the 1960s and 1970s, while others were begun and came to fruition during this era.

The research on **theoretical foundations of acoustic radiation from transducers** that was begun in 1960 by Dr. Sam Hanish resulted in a five-volume treatise that was published over an eight-year period in the 1980s.

Investigations by researchers in the Physical Acoustics Branch (including Drs. Werner Neubauer, Louis Dragonette, Joseph Bucaro, and colleagues) starting in the 1970s to develop **Acoustic imaging and feature extraction techniques** came to fruition in the 1980s (under leadership by Drs. Charles Gaumond, Luise Schuette, Phillip Abraham, Brian Houston, and colleagues), thus permitting visualization of acoustic scattering from submerged objects.

Beginning in the 1970s and becoming a major interest in the 1980s was Division research on **Arctic and Marginal Ice Zone acoustics** (under leadership by Drs. T.C. Yang, Orest Diachok, Stephen Wales, Ellen Livingston, Patricia Gruber, Mr. Charles Votaw, and colleagues). These efforts included detailed experimental and theoretical investigations of the characteristics of acoustic propagation, scattering, and ambient noise at northern latitudes and contributed to the 1986 landmark book *The Nordic Seas*, edited by Dr. Burton Hurdle.

The 1980s was a period of intense research in the Acoustics Division on **seafloor mapping science**, particularly within the Acoustic Media Characterization Branch (under Henry Fleming, Norman Cherkis, Dr. Peter Vogt, and colleagues) and the Large Aperture Systems Branch (under Drs. Budd Adams, Edward Franchi, Fred Erskine, and colleagues), using multibeam sonar and other techniques for bathymetry surveys.

Beginning in the 1970s (under Robert Feden), but coming to maturity in the 1980s (under John Brozena) was the development of methods to conduct **airborne magnetic and gravimetric measurement science** investigations by researchers in the Acoustic Media Characterization Branch, thus permitting rapid surveys in remote regions.

The 1980s was the formative period during which Acoustics Division researchers (including Drs. Richard Fizell, Michael Porter, William Kuperman, Orest Diachok, Alexandra Tolstoy, Ellen Livingston, Mr. John Perkins, and colleagues) conducted considerable theoretical, computational, and experimental research on a new technique known as **matched-field processing** (MFP). MFP is a parameter estimation technique for localizing the range, depth, and bearing of a point source from the signal field propagating in an acoustic waveguide. The fundamentals of MFP are reviewed in detail in the 1993 monograph *Matched Field Processing for Underwater Acoustics* by Dr. Alexandra Tolstoy.

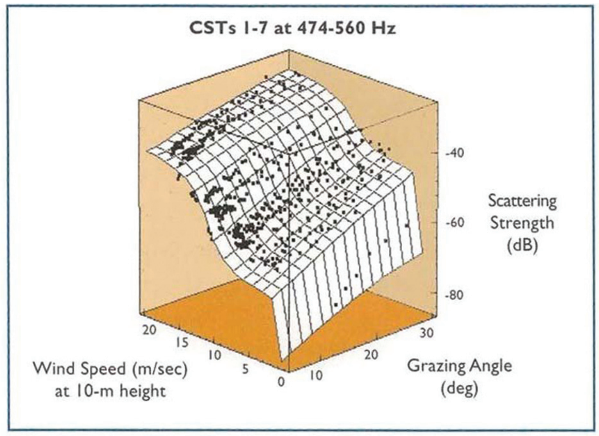
The 1980s to early 1990s was a period in which Acoustics Division researchers (including Drs. William Kuperman, Michael Porter, Frank Ingenito, Mr. John Perkins, and colleagues) developed new **ocean acoustic computational techniques** as tools to perform rapid, high-fidelity simulations of complex ocean acoustic problems of high interest to the Navy.

In the late 1980s to mid-1990s Acoustics Division researchers were key contributors to a major Navy science and technology program known as **Critical Sea Test** (CST). CST originated in fiscal year 1987 as a Chief of Naval Research Urgent Antisubmarine Warfare Research and Development Program (CUARP) initiative to provide broad-based support to a variety of developing low frequency active acoustics (LFAA) systems within the air tactical, surface tactical, and surveillance communities. Science and technology issues were addressed via a series of complex sea tests conducted in deep ocean and littoral seas over roughly a decade. Chief Scientist for CST was Dr. F.T. Erskine of NRL's Acoustics Division. Acoustics Division researchers were integrally involved in all CST sea tests, particularly with regard to conducting experimentation and analysis to improve the Navy's understanding of environmental acoustics (EVA) issues. Particular focus by NRL researchers was on understanding and resolving the nature of the physical mechanisms for acoustic scattering from the sea surface, the sea volume, and the sea bottom, especially at low frequencies below 1 kHz.

Highlights of NRL Research in Critical Sea Test

Sea Surface Scattering and Reverberation

Prior to 1987 there were many unexplained surface scattering effects seen in LFAA data from Navy experiments such as Project Artemis, Active Adjunct to Undersea Surveillance (AAUS), and other sea trials, including a persistent zero-Doppler feature, strong spiky returns, and other effects. During the CST program, NRL researchers collected a large database of high-quality surface scattering data covering a wide range of wind speeds (2 to 36 knots) at frequencies from 70 Hz to 1.5 kHz (CST-1 through CST-8). They performed high-quality dedicated surface scattering and air–sea boundary experiments in CST-7 Phase 2 (1992). They collaborated with colleagues in the ocean acoustics community to demonstrate the importance of subsurface bubbles as a dominant scattering mechanism at high wind speeds, and the importance of the air–sea interface scattering primarily at low wind speeds and low frequencies. They developed empirical surface scattering algorithms (Ogden-Nicholas-Erskine Algorithm) to replace the Chapman-Harris algorithm that had been in Navy use for three decades. They demonstrated that surface scattering measurements using impulsive sources and pulsed waveforms give equivalent results. They demonstrated convincingly that a persistent (but wind-speed dependent) zero-Doppler spectral component of distant surface reverberation was due to scatterers at depths of 1 to 2 m, consistent with the bubble cloud-scattering hypothesis. They demonstrated that the Bragg-shifted frequency component of surface reverberation was observed only during low wind speeds and at low frequencies, and is well fit by modeling based on air–sea scattering.



The Ogden-Nicholas-Erskine algorithm. Empirical fit by NRL researchers Peter Ogden, Michael Nicholas and Fred Erskine to Critical Sea Test sea surface scattering data sets from seven CST field experiments. This algorithm was accepted for inclusion in the Navy's Oceanographic and Atmospheric Master Library as a Navy-standard sea surface scattering algorithm for use in Navy sonar system performance modeling.

Ocean Volume Scattering and Reverberation

Before 1987 the Navy relied on the Oceanographic and Atmospheric Master Library (OAML) Volume Scattering Strength Data Base (VSSDB) for high frequencies (2 to 20 kHz). Very few measurements were available for low frequencies below 2 kHz. The source of volume scatter was known to be relatively large fish. Preliminary acoustic models for fish scattering were available. During the CST sea trials, NRL researchers collected substantial new data sets on fish scattering in deep and littoral areas at low frequencies (below 1.5 kHz) where previous data had been sparse. They demonstrated that a low frequency acoustic fish scattering model using fisheries data as input can predict low frequency volume scattering levels. They demonstrated that fish scattering can be comparable to sea surface or sea bottom scattering levels in some geographic areas, even for high wind speeds (as found in the Norwegian Basin in CST-1). They obtained additional substantial volume scatter data sets in deep and littoral areas at tactically relevant frequencies of 2 to 20 kHz. They observed resonant scattering from salmon swim bladders in the Gulf of Alaska with a spectral peak around 400 to 500 Hz and a strong time-of-day-dependence (robust scattering during the day when fish were at 40 m depth, but none at night when fish were near the sea surface). They observed low-amplitude volume scattering strengths at low frequencies (below 1.5 kHz) in several littoral regions: Medina Bank (Central Mediterranean), Washington coast, and Gulf of Oman. However, resonances of fish in the Eastern Mediterranean and in the Gulf of Oman are likely to result in very high volume reverberation at high frequencies (5 to 10 kHz). Based on CST measurements, NRL Acoustics Division researchers Richard Love and Redwood Nero provided a low frequency extension to NAVOCEANO's OAML VSSDB for the Pacific Ocean north of 30 degrees N, as well as for the Atlantic Ocean and Norwegian Sea east of Greenland and north of the southwestern United Kingdom.

Ocean Bottom and Subbottom Scattering and Reverberation

Prior to 1987, measured bottom scattering strength data were available primarily at middle and high frequencies (above 1 kHz); low frequency estimates were derived by extrapolation. Very little low grazing angle (below 25 degrees) bottom scattering data were available. The Mackenzie-Lambert scattering approximation technique had been in Navy-wide usage for decades with unknown low grazing angle errors. The importance of subbottom effects in scattering was not well understood. Very little geoacoustic modeling had been accomplished to unravel bottom scattering physical processes. In the CST program, NRL researchers collaborated extensively with colleagues from various Navy laboratories, university laboratories, and industry partners on measurements and analyses to improve our understanding of bottom and subbottom scattering. This collaboration enabled identification of the principal scattering mechanisms in the CST data: sediment volume scattering at low grazing angles and basement scattering at intermediate angles. This understanding provided an initial foundation for extrapolation of measurements in grazing angle, frequency, and environment. It was determined that the Navy oceanographic survey community needed a survey technique for measuring low grazing angle bottom scatter. It was found that the then-current extrapolation technique for converting scattering estimates from middle to low grazing angles was often inadequate, and CST research identified the parameters that define those angular regimes. An initial bottom scattering databank based on CST measurements was delivered to NAVOCEANO by Dr. Roger Gauss of NRL's Acoustics Division in 1996.

Key Research Thrusts and Achievements in Era 4

16 Theoretical Foundations of Acoustic Radiation from Transducers
17 Acoustic Imaging and Feature Extraction Techniques
18 Arctic and Marginal Ice Zone Acoustics
19 Seafloor Mapping Science
20 Airborne Magnetic and Gravimetric Measurement Science
21 Matched-Field Processing Techniques
22 Ocean Acoustic Computational Techniques
23 Critical Sea Test Research and Leadership

16
[1961–1988] Theoretical Foundations of Acoustic Radiation from Transducers

Achievement: Beginning in the early 1960s, NRL Sound Division researcher Sam Hanish conducted detailed theoretical studies aimed at solving a number of problems facing Navy acoustic transducer designers. His extensive research culminated in the publication by NRL in the 1980s of a five-volume treatise on acoustic radiation. In Volume I the strengths of simplex and complex surface and volume acoustic radiators are assumed known in the calculation of sound fields. In Volume II the theory of acoustic transduction is reviewed in detail to expose underlying energy conversion processes which generate the source strengths used in Volume I. Volume III emphasizes bond graph modeling of acoustic transducers with many examples drawn from U.S. Navy sonar practice. Volume IV is devoted to mutual radiation impedance and other special topics. Volume V addresses the theory and practice of large-amplitude sources and their radiation fields.

Impact: The research of NRL Acoustics Division scientist Sam Hanish on the theoretical foundations of acoustic radiation from transducers has provided the Navy with a considerable knowledge base with regard to transducer design. His detailed physics-based studies on this subject have had numerous practical applications for the Navy. His analyses in the mid-1960s provided a basis for understanding and resolving difficulties caused by extensive mutual interactions of the transducers in a large low frequency active acoustic source array in Project Artemis.

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17
[1970–2006] Acoustic Imaging and Feature Extraction Techniques

Achievement: Around 1970, researchers at NRL began extensive research on the use of schlieren visualization techniques to observe acoustic scattering from objects. Photographs and movies obtained using the NRL schlieren system demonstrated the usefulness of the technique for identifying the individual diffracted components of the diffracted field. The method was used to examine ultrasonic wave interactions with bodies of various materials and shapes, with a size limitation imposed by the lenses used. As described by Neubauer (1986) for the case of scattering from cylinders: "The total field is a combination of many effects resulting from waves that are diffracted in the outer medium, travel circumferentially inside the cylinder or on the interface, and travel through the body of the cylinder. Isolation of specific waves and identification of exact causes for them has been largely achieved." In recent decades several alternative methodologies have been investigated for the visualization of acoustic scattering from objects, including tomographic techniques. In the past several years, research has been conducted on spatial auditory display techniques for sonar data.

Impact: In the past four decades, NRL researchers have pursued research on methods for visualization of acoustic data. These techniques complement more conventional methods and have yielded new physics-based insights into complex phenomena involved in acoustic scattering from objects.

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18
[1974–1995] Arctic and Marginal Ice Zone Acoustics

Achievement: Beginning in the early 1970s, NRL Acoustics Division researchers began two decades of intense experimental and theoretical investigations on the characteristics of acoustic propagation, scattering, and ambient noise in the Arctic and Marginal Ice Zone regions. The Navy was motivated to understand these regions better due to Cold War considerations and by the possibility of submarine operations under the Arctic ice cover. NRL researchers participated in numerous field experiments at sea and in the central Arctic during this period. Many of these experiments were conducted in collaboration with international partners. By the 1990s, Navy interest in the Arctic began to wane, upon the dissolution of the Soviet Union.

Impact: NRL Acoustics Division research conducted from the 1970s to the 1990s on the acoustic characteristics of the Arctic and Marginal Ice Zone regions contributed significantly to the Navy's understanding of the potential for sonar operations in these challenging areas. Many of the experimental efforts were accomplished in collaboration with international partners. The book *The Nordic Seas*, edited by NRL Acoustics Division researcher B.G. Hurdle (1986), encapsulates much of the new science gained in the course of this research.

NRL Acoustics Division scientists on the ice in the central Arctic during Exercise Outpost Heritage in 1986. (Courtesy of C.W. Votaw)

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19
[1975–1994] Seafloor Mapping Science

Achievement: In the mid-1970s a group of NRL Acoustics Division researchers led by H.S Fleming, many of whom had earlier transferred to NRL from the Hudson Laboratories of Columbia University, initiated extensive investigations on seafloor mapping. Using mulitbeam sonar and other techniques, these researchers conducted systematic bathymetric surveys in many strategically important ocean basins to develop improved resolution ocean bottom contour and sediment character maps for Navy applications. Also, starting in the 1970s, other researchers in the Acoustics Division developed long-range reverberation-based techniques to survey ocean basins for the presence of uncharted seamounts. By the mid-1990s, Fleming's Acoustic Media Characterization Branch transferred to the Marine Geosciences Division under Herb Eppert where its seafloor mapping efforts have continued to the present.

Impact: Since the 1970s, NRL Acoustics Division seafloor science specialists have developed improved techniques for conducting detailed bathymetric surveys of the world's oceans. These efforts have provided high-resolution bathymetric maps in many regions that had previously been sparsely surveyed. The resulting NRL ocean bathymetry and sediment character maps have been of great benefit to the operational Navy and to the international science community. The NRL seafloor mapping efforts have been fully complementary to the ocean bottom surveys that are conducted by the U.S. Naval Oceanographic Office.

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20
[1976–1994] Airborne Magnetic and Gravimetric Measurement Science

Achievement: In the mid-1970s research was initiated in the Acoustics Division by R.H. Feden and colleagues to use NRL Maritime Patrol P-3A Orion research aircraft to conduct airborne magnetic surveys to complement ship-based surveys. These surveys were conducted under the auspices of the crustal geophysics program in order to explore the dynamic processes acting on the Earth's crust and upper mantle. The results enabled age-dating of the Earth's crust through magnetic anomaly analyses, and the airborne technique facilitated wide-area coverage over ocean basins. By the 1980s these efforts were extended under the leadership of J.M. Brozena to include extensive surveys of variations in the Earth's gravity field and undersea bathymetry. Among the detailed surveys conducted under Brozena was a thorough aerogeophysics survey of Greenland. By the mid-1990s, Brozena's group was transferred from the Acoustics Division to the Marine Geosciences Division (under Herb Eppert) as part of the NRL reorganization during which NORDA/NOARL researchers from Stennis Space Center, Mississippi, joined NRL.

Impact: From the 1970s to the 1990s, researchers in the NRL Acoustics Division developed techniques for conducting rapid wide-area airborne magnetic, gravimetric, and bathymetry surveys. The resulting surveys have been of considerable benefit to the U.S. Navy. These surveys have provided quantitative information for use in compensation of inertial guidance systems; improvements in gravitational and geoidal models of the Earth used in orbital calculations; crustal density determination in regions of known topography; estimation of topographic structure in oceanic areas with sparse bathymetric data; and improved knowledge of Earth's geologic processes.

NRL airborne magnetic and gravimetric survey systems on board NRL maritime patrol aircraft (P-3).

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21
[1986–2004] Matched-Field Processing Techniques

Achievement: From the 1980s to the 2000s, investigators in the NRL Acoustics Division conducted considerable theoretical, computational, and experimental research into a technique known as matched-field processing (MFP). MFP is a parameter estimation technique for localizing the range, depth, and bearing of a point source from the signal field propagating in an acoustic waveguide. It is a generalization of conventional one-dimensional plane wave beamforming. The plane wave beamformer steers an array by "matching" the measured field with plane waves for all look directions; this is accomplished by weighting the outputs of the individual array elements with the conjugate of the plane wave phase associated with each look direction and summing. The generalized matched-field beamformer matches the measured field at the array with replicas of the expected field for all source locations. The unique spatial structure of the field permits the localization in range and depth. MFP techniques can be applied not only for source detection and localization, but also for estimation of the environmental parameters of the acoustic waveguide. The fundamentals of MFP and its applications are reviewed in the 1993 monograph by NRL Acoustics Division researcher Dr. Alexandra Tolstoy, *Matched Field Processing for Underwater Acoustics*.

Acoustics Division researcher Dr. Alexandra Tolstoy.

Impact: Research in the NRL Acoustics Division from the 1980s to the 2000s on underwater acoustic matched-field processing techniques has contributed considerably to the peer-reviewed literature on this subject. The U.S. Navy has benefited by having available new methods for underwater source localization and tracking, as well as powerful techniques for performing inversions to obtain environmental parameters of the oceanic waveguide.

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22
[1986–2003] Ocean Acoustic Computational Techniques

Achievement: From the 1980s to the 2000s NRL Acoustics Division researchers have placed increasing emphasis on ocean acoustic computational techniques. A few examples are given in the references below. The tools of computational acoustics are used to address a wide range of problems in ocean acoustics from propagation and scattering to structural acoustics. Among the advantages of computational acoustic methods is that these techniques are increasingly becoming faster and less expensive than actual at-sea experimentation, yet are becoming capable of approximating the full complexity of ocean acoustic problems. Among the mathematical tools that have found application for computational ocean acoustics are techniques known as finite difference methods, finite element methods, and boundary element methods.

Impact: In recent decades, NRL Acoustics Division researchers have begun increasingly to apply computational ocean acoustic techniques to the solution of complex problems. The computational methods have enabled researchers to develop tools for high-fidelity and rapid simulation of a broad range of real-world ocean acoustic problems of high importance to the Navy.

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23
[1988–1996] Critical Sea Test Research and Leadership

Achievement: In 1996, the Critical Sea Test (CST) Program completed a decade-long history of contributions to the use of low frequency active acoustics (LFAA) in undersea warfare. The CST Program originated in fiscal year 1987 as a CNO Urgent Antisubmarine Warfare Research and Development Program (CUARP) initiative to counter the growing capability of the Soviet Navy to develop ever-quieter submarines. By design, CST was an experimentally focused program involving numerous U.S. Navy laboratories, university laboratories, and private industry, providing broad-based support to a full variety of developing LFAA systems within the air-tactical, submarine-tactical, surface-tactical, and surveillance communities. As an experimental, at-sea-focused program, CST participants developed a

Research Vessel *Amy Chouest* at Kodiak, Alaska during preparations for a Critical Sea Test field experiment in the Gulf of Alaska in 1992. (Courtesy Dr. R.C. Gauss) number of experimental capabilities and measurement techniques that have proven to be of continuing value to both the research and data acquisition/oceanographic survey communities. CST also made numerous contributions in the areas of environmental acoustics and system performance prediction as well as LFAA signal and information processing. NRL Acoustics Division researchers were involved in the planning, at-sea conduct, and post-test analyses phases of all CST experiments, and were among the leading researchers for experiments on sea surface/bottom/volume scattering and reverberation. NRL's Acoustics Division also provided the chief scientist for the CST Program (F.T. Erskine) who coordinated all CST reports from all participating organizations.

Impact: NRL Acoustics Division researchers were actively involved in the Navy's decade-long at-sea measurement and analysis effort to address important undersea warfare science and technology issues for low frequency active acoustics. Based on NRL-designed experiments on sea surface, ocean bottom, and volume scattering and reverberation, new high-quality data sets were acquired and analyzed. The results of these NRL analyses have enabled NRL researchers to develop new insights about the physical mechanisms involved in the scattering processes. As a result of these analyses, we now understand much more clearly the important role of near-surface bubble layers in sea surface reverberation; and a series of increasingly physics-based (now Navy-standard) surface scattering models have been developed by NRL researchers. As a result of the CST experimentation on volume scattering, we have a much better physics-based set of models for scattering from fish layers. As a result of CST experimentation on bottom scattering for a wide variety of bottom types, we have a much better understanding of the impact of bottom reverberation on system performance prediction. CST experiments on long-range reverberation by NRL researchers have yielded new insights and models regarding the spectral and statistical properties of reverberation.

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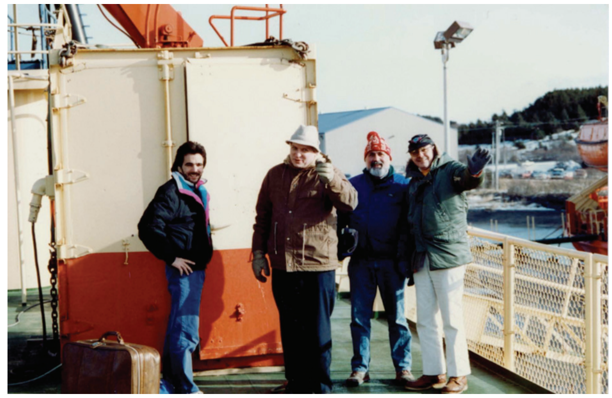


Preparing to depart for a Critical Sea Test field experiment in the Gulf of Alaska (CST 7 Phase 2) to perform air-sea boundary and sea surface scattering measurements aboard R/V *Cory Chouest* in 1992. From left to right: John Crockett, Peter Ogden, John Chester (Naval Underwater Systems Center, New London, Connecticut), and Fred Erskine. (Courtesy Dr. R.C. Gauss)

Further Recollections of Era 4

A Brief History of the Physical Acoustics Branch, Part 2, 1982–1992 by Dr. Joseph A. Bucaro

1982–1992 A New Active Sound Cancellation and Scale Model Technology Focus

Within several years of taking over as branch head [ca. 1978], I made a decision to capitalize on two unique, albeit secondary (at the time), branch capabilities. First, NRL's small scale submarine model technology (for the most part based on copper and soldering as developed by Neubauer who left the branch in 1978) appeared ready for a new burst of improvements. In response, the branch aggressively pursued the exploitation of new laser welding techniques and the ability to work stainless steel and nickel materials into high-fidelity model components. Second, Dr. Corsaro had just demonstrated the world's first "smart acoustic skin" using piezo-polymer layers and simple feedback electronics with variable gain. I believe this was the first active sound control work in the Navy and perhaps in the United States.

Connecting these two technologies together — physical scale model submarines and active sound control — in 1983 I visited Dr. Edward Harper, the Technical Director of NOP02 under Admiral Bruce DeMars. I proposed a program at NRL which would capitalize on its small scale model technology and pool facility to address active control of the echo response of submarines, particularly at low frequencies where conventional coatings would have to be too thick to be of any practicality. Dr. Harper then launched NRL's first high-level active control program. From 1985 to 1990 the program had a number of successes which led to several demonstrations in the pool facilities provided for high-level DoN officials. For example, in just one year (Aug. 1985 to Aug. 1986) these visiting officials included Admiral Lewin (NOP21), Admiral Mooney (CNR), G. Keyworth (President's Science Advisor), and R. Rumpf (PDASN). In the next year (Sep. 1986 to Sep. 1987), the list included Admiral K.R. McKee and Vice Admiral P.F. McCarthy (NOP08); and a letter of appreciation for the branch's pioneering and important work in active cancellation for NOP02 was sent by the CNO to the NRL Director of Research, Dr. Timothy Coffey. Again in 1988 another demonstration was carried out in the Building 71 facility for high-level DoD personnel including Admiral Cooper (NOP02). In 1987, Admiral Baciocco (NOP098) attended one of the demonstrations. Based on the results, he asked NRL to build a state-of-the-art pool facility dedicated to these efforts. In fact, he wrote instructions to me on the back of a piece of scrap paper describing exactly what information he required to secure the funds. Not more than one month later, the funds (~$10M) arrived, and the construction process for the Building 5 Laboratory for Structural Acoustics was begun. The facility went on line in 1989. Then, and still, it represented a world-renowned, one-of-a-kind facility.

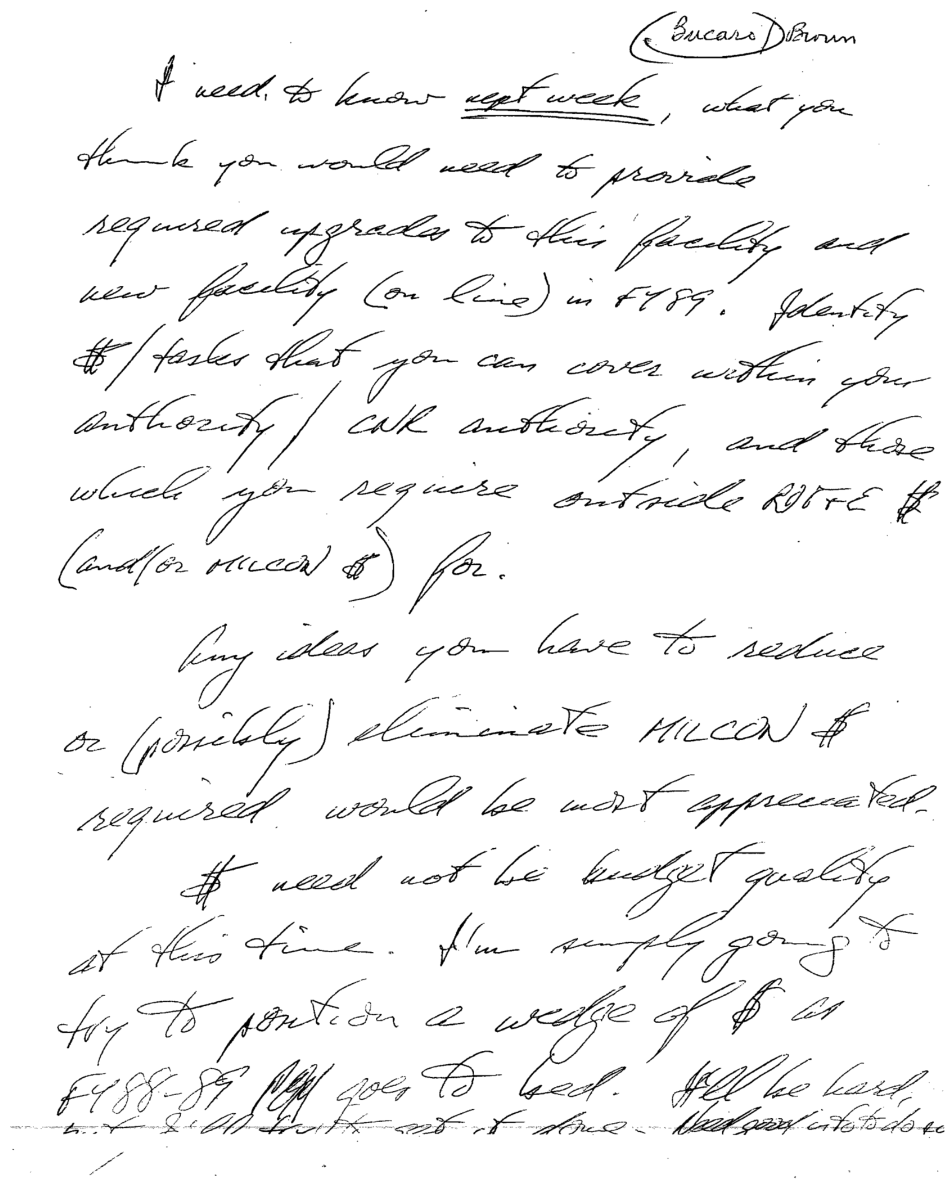
The NRL Laboratory for Structural Acoustics contains a large tank for in-water structural acoustics studies. The tank is 55 ft in diameter, 50 ft deep, and contains 800,000 gallons of deionized water.

Over the ensuing twenty years, critical studies have been carried out for a very large number of applications and structures including small scale model submarine targets (both U.S. and threat), simple research targets such as the shell with hundreds of attached internal mechanical oscillators, submarine hull sections supporting sensor evaluations, surface ship models, torpedoes, mines, unexploded ordnance, swimmers and divers, sound transducers, and many more. In the active control work begun earlier in the decade representing the Navy's first serious research into active sound control, several pioneering technologies were developed and demonstrated. As with the case of the fiber-optic towed array, the end of the Cold War together with the collapse of the Soviet Union eventually moved the branch research focus away from submarine active sound cancellation. However, the new technologies which are considered "on the shelf" can be tapped when required by new threats.

The advance of our small scale model technology over this same period was quite remarkable as evidenced by the so-called T-64 model of the Ohio class submarine in 1991. This physical model made at 64:1 scale had an unprecedented amount of detail in its free flooded areas and inside its pressure hull. In all, approximately 70% of the real submarine's total weight was represented in the model. The finished model was highlighted in a visit to the facility by Dr. Gerald Cann (PDASN for R&D). Five minutes after leaving the Building 5 facility, Dr. Cann returned to ask about the cost of building such a detailed model. I answered about $300K, to which Dr. Cann responded that he lost the bet since he had estimated the cost to be well over $1M!

In 1990, we hired Dr. Douglas Photiadis who, having done his Ph.D. work at Cornell University in high energy and condensed matter physics, was carrying out engineering acoustic work at the Carderock Laboratory. The new venue at NRL for Dr. Photiadis turned out to be the ideal setting for such a capable, creative physicist. Over the next two decades he would make seminal discoveries in both the structural acoustics of Navy targets and in the elastodynamics of quasiperiodic macro- and nanostructures.

Admiral Baciocco Instructions Written on a Piece of Scrap Paper


(Bucaro) Brown

I need to know next week, what you think you would need to provide required upgrades to this facility and new facility (on line) in FY89. Identify $/tasks that you can cover within your authority/CNR authority, and those which you require outside RDT+E $ (and/or MILCON $) for.

Any ideas you have to reduce or (possibly) eliminate MILCON $ required would be most appreciated.

$ need not be budget quality at this time. I'm simply going to try to position a wedge of $ as FY88-89 POM goes to bed. It'll be hard, but I'll try to get it done. Need good info to do so

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Matched-Field Processing at NRL, Part 1
by John S. Perkins

John S. Perkins of the Acoustic Systems Branch

Early Development of Matched-Field Processing

Matched-field processing (MFP) is essentially an extension to plane-wave beamforming used in processing the acoustic data from an array of hydrophones. Instead of matching the received data to plane-wave replica fields corresponding to arrival directions, a computer simulation is used to model the replica fields from many potential source locations, and these replicas are matched to the data.

The concept holds great promise for detecting and locating quiet acoustic sources. Following the introduction of the concept by NRL's Homer Bucker[1] in 1976, Frederick Tappert[2] stated in 1985, "By this means the distorting effects of the oceanic medium and its boundaries can be removed, thereby rendering the ocean transparent." The work of these scientists is highly regarded. Both Bucker and Tappert have been awarded the Pioneers of Underwater Acoustics Medal from the Acoustical Society of America.

Frederick Tappert's vision has not been realized. While the concept is simple, there are many practical issues that arise when attempting to use MFP in the field. These problems are mainly a product of three facts that are hard to avoid: (1) the most important cases involve very low signal-to-noise ratios, (2) the problem is not stationary since targets and interfering noise sources are generally in motion within an evolving environment, and (3) since simulation of acoustic fields is required, the environmental conditions become a major aspect of the problem. NRL has been a leader in bringing these issues to light and developing techniques to overcome them.

The environment has a double impact: (1) certain environments naturally lead to ambiguous source positions, and (2) it is often difficult to precisely know the environmental conditions at the exact time and place the data is measured. NRL has worked to address both of these issues, but the second has an interesting secondary impact. Efforts to measure and deduce the environmental conditions eventually led to the realization that when the source/receiver positions are well known, it is possible to then use MFP to invert for unknown environmental parameters. NRL was a leader in developing this concept now known as matched-field inversion. Developments in this area are discussed in "Matched-Field Processing at NRL, Part 2" in the next chapter.

Early NRL Research and the High Gain Initiative

Research on MFP began at NRL in 1981 in an Office of Naval Research 6.1 project addressing high-resolution beamforming in shallow water. Following the introduction of the concept by Bucker, scientists at NRL (R. Heitmeyer, W. Moseley, and R. Fizell) presented the first simulations at a workshop in 1983 using what is now known as the Conventional or Bartlett processor and is the baseline and most widely used matched-field processor. The first experimental demonstration of MFP using field data was reported by NRL scientists (R. Fizell and S. Wales) in 1985. Included in this demonstration was the use of Capon's Minimum Variance Distortionless Filter algorithm.[3] This has become the basis for the most widely used adaptive or high-resolution processor in MFP. These processors, together with the analytical techniques developed under the 6.1 project, were used as the theoretical basis for research programs on shallow-water MFP conducted in the mid-1980s at the SACLANT ASW Research Centre (Italy) and at NORDA (later NRL-Stennis). In addition, the original work led to 6.2 funding for deep-water work on MFP conducted at NRL. This work provided much of the theoretical basis for the research conducted under the Office of Naval Technology (ONT) High Gain Initiative (HGI) from 1988 to 1993. This program experimentally demonstrated that MFP is a viable approach for long-range surveillance systems in deep-water environments. Coincidently in 1993, NRL scientist Alexandra Tolstoy published the only text devoted to MFP,[4] and William Kuperman contributed to one of the earliest and most cited overview articles.[5]

The High Gain Initiative was the Navy's most ambitious experimental research program in applied ocean acoustics in thirty years. ONT selected NRL (Chief Scientist O. Diachok) to be the lead laboratory for its first major experiment. Researchers from NRL (R. Heitmeyer) and SAIC (P. Michalevsky) were responsible for analyzing the MFP results. The HGI also had a large simulation component, and NRL scientists (W. Kuperman and J. Perkins) played a leading role in simulating expected results for ocean basin scale MFP.[6] There were two key components to these simulations: (1) the ability to incorporate ambient noise generated by the ocean surface and interfering surface ships, and (2) the ability to model a three-dimensional array in a three-dimensional environment.[7,8]

The HGI experiments demonstrated (1) the feasibility of matched-field processing on omnidirectional and extended sources (the latter are of particular interest to the Navy) at very long ranges and (2) the sensitivity of the performance of the matched-field processor to uncertainties in the sound speed environment (internal wave fluctuations, bathymetric irregularities, and geoacoustic parameters). These experiments provide the basis for development of a new generation of surveillance systems. Envisioned systems would have the capability of passive, three-dimensional tracking of hostile submarines at long ranges.

Other Developments 1980–1990

Coincident with the HGI program, in 1987 NRL (T.C. Yang) proposed and demonstrated a processing technique similar to MFP known as matched-mode processing.[9] This approach is essentially range and depth beamforming done in mode space. The technique was demonstrated using data taken in the 1982 FRAM IV Arctic Ocean experiment.

In 1990, NRL scientists (Kuperman and Perkins) demonstrated through simulations that MFP, even with a purely vertical array, held the possibility to locate a source in azimuth due to the directional dependence introduced into the replicas because of variations in the environment.[10] The principle became known as environmental symmetry breaking, and was demonstrated in the TESPEX experiments [see "Matched-Field Processing at NRL, Part 2"].

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CHAPTER SEVEN

Era 5: Dr. Edward R. Franchi The Post–Cold War Years 1994 to 2008

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Biography of Dr. Edward R. Franchi — Era 5: 1994–2008

Edward R. Franchi [redacted] in Huntington, New York, on Long Island. He was raised in nearby Huntington Station. After graduation from high school in 1964, he attended a small technical college, Clarkson College of Technology (now Clarkson University) in Potsdam, New York, about 20 miles south of Eisenhower Locks on the Saint Lawrence Seaway in northern New York state. He graduated with a B.S. in mathematics in 1968. In that year he began his graduate studies at Rensselaer Polytechnic Institute (RPI) and received his M.S. degree in applied mathematics in 1970. He then continued his graduate studies at RPI under Professor Mel Jacobson, who was principal investigator on a research contract from the Office of Naval Research (ONR) in underwater environmental acoustics. During his graduate school years at RPI, Franchi worked both as a teaching fellow and a research assistant in mathematics. His dissertation topic at RPI was the development of environmental acoustic models describing the effects of ocean currents on acoustic propagation, for which he received a Ph.D. degree in applied mathematics in 1973.

Following completion of his Ph.D., Dr. Franchi became a senior scientist at Bolt, Beranek, and Newman, Inc. (BBN) in Rosslyn, Virginia, from 1973 to 1975. At BBN, Franchi conducted research involving theoretical studies and experimental measurements of underwater acoustic propagation, ambient noise, and volume reverberation. The BBN research was performed under a contract from the Navy's Environmental Support project at the Maury Center on base at the Naval Research Laboratory in Washington, D.C. Through that work, Dr. Franchi became acquainted with colleagues in the Acoustics Division at NRL. In March 1975 he accepted a position as a research mathematician in the Large Aperture Systems Branch of NRL's Acoustics Division under Dr. Budd Adams and division superintendent Dr. John Munson. Initially, he conducted research on low-frequency, long-range reverberation under Dr. Tom Warfield who headed the Reverberation Effects Section. In the mid-1970s, Dr. Warfield, Dr. Franchi, and Mr. Jim Griffin were the only NRL researchers conducting long-range active acoustic reverberation and scattering investigations because the Navy's ability to track submarines was quite effective using passive acoustic surveillance arrays.

By the end of the 1970s there were changes in Soviet submarine construction that resulted in a great deal of noise quieting. Active acoustics research once again became important and Dr. Franchi was named as head of the Reverberation Effects Section. As his section grew in size, Dr. Franchi led efforts to perform extensive research in low frequency acoustic reverberation and scattering, including design and conduct of field experiments, development of signal processing techniques, data analysis and interpretation, computer prediction models, and active sonar performance studies. In 1986, he succeeded Dr. Adams as head of the Acoustic Systems Branch, where he was responsible for programs that emphasized theoretical, experimental, and computational research to understand the physical mechanisms of acoustic propagation, scattering, and ambient noise that control the design and performance of large-aperture passive sonar systems, low frequency active sonar systems, and shallow water sonar systems.

In July 1988, Dr. Franchi was selected as the Associate Technical Director of the Naval Ocean Research and Development Activity (NORDA) and as its Director of Ocean Acoustics and Technology under Dr. William Moseley. NORDA was established in 1976 at the Stennis Space Center near Bay Saint Louis, Mississippi. At NORDA, Dr. Franchi managed basic, exploratory, and advanced research and development in the areas of acoustic model development and simulation, ocean acoustics measurements, and ocean engineering in support of the Navy's undersea warfare missions. In 1992 this directorate became the Center for Environmental Acoustics in the Acoustics Division of NRL, with Dr. Franchi as director. In October 1993, Dr. Franchi was selected to become the fifth superintendent of NRL's Acoustics Division, replacing retiring superintendent Dr. David L. Bradley.

In the period between October 2001 and May 2002, Dr. Franchi served temporarily as NRL's acting associate director of research for the Ocean and Atmospheric Science and Technology Directorate. In that period, Dr. Joseph Bucaro became acting superintendent of the Acoustics Division. Dr. Franchi continued as superintendent of NRL's Acoustics Division through 2008, when he was selected to become the new head of the Ocean and Atmospheric Science and Technology Directorate following the retirement of Dr. Eric Hartwig.

Dr. Franchi is a recognized authority on underwater acoustic scattering and reverberation and has played a major role in the Navy's development of low frequency active sonar programs. He has authored and co-authored over thirty-five publications. Throughout his career he has represented the Navy in many leadership positions for international research collaborations. He is a U.S. National Representative to the research planning committee for the NATO Undersea Research Centre (NURC). He is chair of The Technical Cooperation Program (TTCP) Maritime Systems Group (MAR) Technical Panel Nine (ASW Systems and Technology). He is a member of the Acoustical Society of America and the Mathematical Association of America.

Acoustics Division Organization in Era 5

1995

Code	
7100	**Dr. Edward R. Franchi (Superintendent)**
7103B	Dr. Burton G. Hurdle
7103S	Dr. Sam Hanish
7104M	Dr. B. Edward McDonald
7106	R. McGregor
7120	Acoustic Signal Processing Branch Dr. Marshall H. Orr (Branch Head)
7130	Physical Acoustics Branch Dr. Joseph A. Bucaro (Branch Head)
7140	Acoustic Systems Branch L. Bruce Palmer (Branch Head)

At NRL Stennis Space Center in Mississippi

7170	Ocean Acoustics Branch Dr. Dan J. Ramsdale (Branch Head)
7180	Acoustic Simulation and Tactics Branch Dr. Stanley A. Chin-Bing (Branch Head)

2005

Code	
7100	**Dr. Edward R. Franchi (Superintendent)**
7101	Dr. Fred T. Erskine (Associate Superintendent)
7103	Dr. Burton G. Hurdle
7105	Lt. Theodore G. Dorics
7106	Dr. Earl G. Williams (Senior Scientist)
7120	Acoustic Signal Processing Branch Dr. Marshall H. Orr (Branch Head)
7130	Physical Acoustics Branch Dr. Joseph A. Bucaro (Branch Head)
7140	Acoustic Systems Branch John S. Perkins (Branch Head)

At NRL Stennis Space Center in Mississippi

7180	Acoustic Simulation, Measurements, and Tactics Branch Dr. Stanley A. Chin-Bing (Branch Head)

Era 5 Research Overview

Key Research Thrusts

The period from 1994 to 2008, during which the Acoustics Division was under the leadership of Dr. Edward R. Franchi, was an era in which many research topics and thrusts that had been initiated decades before came to full fruition, while many new and innovative research thrusts were begun.

During this era of the 1990s and 2000s the Acoustics Division organizational structure was relatively stable. During most of this period, research was conducted within four primary branches: the Acoustic Signal Processing Branch (Code 7120), the Physical Acoustics Branch (Code 7130), the Acoustic Systems Branch (Code 7140), and in Mississippi, the Acoustic Simulation, Measurements, and Tactics Branch (Code 7180).

The key research thrusts, described in more detail in the next section of this chapter, are introduced here.

Research on the **acoustics of sediments** has been a long-term interest of Division researchers to better understand the role of the sea bottom on the propagation and scattering of sound in the ocean. In the 2000s this research has been extended via detailed laboratory-based and at-sea experimentation and theoretical developments (by Drs. Harry Simpson, Brian Houston, Altan Turgut, T.C. Yang, Kwang Yoo, Steve Stanic, Ms. Laurie Fialkowski, Mr. Raymond Soukup, and colleagues).

Systematic experimentation by Division researchers, particularly since the 1980s, has sought to unravel the physical basis of acoustic scattering from the sea surface and near subsurface regions, with increased emphasis on low frequencies of application to low frequency active acoustic (LFAA) systems. High-quality data sets acquired by Acoustics Division researchers during focused sea trials such as Critical Sea Test (CST) have enabled the development of new **Navy-standard surface scattering models** by Dr. Roger Gauss and colleagues. In 2006 NRL transitioned to the Navy's Oceanographic and Atmospheric Master Library (OAML) the Semi-Empirical Surface Scattering Strength algorithm (SESSS version 3.0) that includes full bistatic angle coverage.

Another long-standing topic of interest to Division researchers has been investigations of the physical basis of **ocean bottom reverberation and clutter** that have important impacts on the performance of Navy active sonar systems. NRL researchers have been participants in numerous Navy-sponsored sea trials devoted to investigating these phenomena, including the Bathymetric Hazard Survey Test, the Critical Sea Test Program, the Acoustic Reverberation Special Research Program (ARSRP), and the Littoral Warfare Advanced Development (LWAD) project, as well as many international collaborative sea trials. In the 2000s, continuing NRL analyses of data from these sea trials (by Drs. Roger Gauss, Kevin LePage, Robert Gragg, Mr. Raymond Soukup, and colleagues) have led to considerable advances in our understanding of the physical basis of bottom reverberation and clutter and have enabled the development of new models to predict these phenomena.

Scattering from rough interfaces has been a research topic of interest in the Division for decades. This research has wide-ranging applications to improving our understanding of the physical basis for scattering from the ocean bottom, the ocean surface, subsurface bubble layers, and the under-ice canopy. In the 2000s this research has continued (under leadership by Drs. Richard Keiffer, Guy Norton, Robert Gragg, Jason Summers, Michael Collins, David Calvo, Mr. Raymond Soukup, and colleagues). It has involved laboratory-based and at-sea experimentation and various types of modeling approaches and has resulted in numerous physics-based sub-models that have become components of Navy sonar system performance prediction models.

Investigations of **scattering and radiation from underwater shapes and structures** have been the subject of intense research for which the Acoustics Division has been an internationally recognized leader for decades. The general problem of identifying and characterizing a submerged object by its active acoustic response has applications in multiple areas including ocean acoustics and ultrasonic detection for medical applications. In recent decades, Division researchers (including Drs. Angie Sarkissian, Joseph Bucaro, Brian Houston, Douglas Photiadis, Charles Gaumond, Louis Dragonette, David Calvo, Dalcio Dacol, and colleagues) have developed increasingly powerful experimental and theoretical methods to unravel the complex physics issues involved.

Research on **ray theoretic propagation modeling** has important applications for understanding sound propagation in the deep ocean. NRL research in the 1960s and 1970s led to increasingly robust ray propagation codes. By the 1990s Acoustics Division researchers (led by L. Bruce Palmer, Dr. David Fromm, and colleagues) had incorporated accurate ray-theoretic propagation codes in several widely used models such as the Range-Dependent Active System Performance Prediction Model (RASP) and the Bistatic Range-Dependent Active System Performance Prediction Model (BiRASP).

In the 1970s and 1980s several Division researchers (including Drs. William Kuperman, Frank Ingenito, Stephen Wolf, and colleagues) performed extensive experimental and modeling efforts to better understand the difficult problems related to sound propagation in shallow ocean areas. This research on **shallow water**

acoustics became increasingly important after the end of the Cold War when the Navy began to emphasize littoral antisubmarine warfare applications. In the 1990s, Division researchers became key participants in several major Navy at-sea measurement efforts that addressed these littoral applications. These included the Critical Sea Test Program and the Littoral Warfare Advanced Development project. Chief scientist for both of these Navy sea trial programs was Dr. F.T. Erskine of NRL's Acoustics Division.

In the 1970s and 1980s NRL Acoustics Division researchers (including Drs. Frank Ingenito, Raymond Ferris, William Kuperman, Stephen Wolf, Anthony Eller, T.C. Yang, and colleagues) initiated theoretical efforts along with at-sea experimentation to develop accurate **normal mode propagation modeling** methods. The acoustic field at long ranges is propagated in the discrete normal modes of the shallow water duct. This required special experimental methods to resolve individual modal fields so that their measured characteristics could be compared with theoretical predictions. By the 1990s, Division researchers developed advanced normal mode modeling tools such as KRAKEN (Dr. Michael Porter) and BIKR (Dr. David Fromm and colleagues) that have found widespread use among researchers for a variety of important Navy applications. Acoustics Division research using normal mode methods has continued to be applied to at-sea validations in the 2000s.

A long-standing topic of Acoustics Division research has been **passive acoustic source localization and parameter estimation.** As the Navy's interest shifted by the 1990s from the deep oceans to the littorals, and as passive undersea platforms became much quieter, NRL research (led by Drs. William Kuperman, Michael Collins, Nicholas Makris, T.C. Yang, Steven Finette, Peter Mignerey, Ralph Baer, Kwang Yoo, Mr. John Perkins, Ms. Laurie Fialkowski, and colleagues) successfully adapted to address these changes by developing improved analysis techniques.

A research topic of quite intense interest by Acoustics Division researchers since the 1970s has been **ocean- and ship-generated ambient ocean noise**. Experimentation and modeling have become increasingly refined in recent decades to address the causes and characterization of sea noise in the deep oceans, the shallow oceans, and the surf zone. As of the late 1990s to the 2000s, Division researchers (led by Drs. Richard Heitmeyer, Stephen Wales, Steven Means, T.C. Yang, Kwang Yoo, Ronald Wagstaff, Joal Newcomb, and colleagues) have continued to be in the forefront of research on ambient ocean noise.

In recent decades the Navy has had a high level of interest in **underwater acoustic array systems and processing techniques**. As of the late 1990s to the 2000s, Acoustics Division researchers (including Drs. T.C. Yang, Kwang Yoo, Steven Finette, Roger Oba, and colleagues) have continued to develop important processing algorithms to enhance the performance of horizontal and vertical arrays for towed and stationary Navy surveillance applications.

For decades, Acoustics Division research has contributed much to our understanding of **transbasin and global scale acoustics** through experimental and theoretical investigations. Initially these investigations were aimed at improving our ability to model and predict long-range propagation and reverberation for undersea surveillance and bathymetry reconnaissance applications. Since the 1990s there have been significant contributions by Division researchers (led by Drs. Michael Collins, B. Edward McDonald, William Kuperman, Kevin Heaney, and colleagues) and collaborators within the ocean acoustics community in applications of global scale acoustic propagation as a probe for global warming.

A very significant thrust within the Acoustics Division (both in Washington, D.C., and at Stennis Space Center, Mississippi) in recent decades has been the **development of a Navy Standard Parabolic Equation model**. Since its introduction in the 1970s by colleague Dr. F. Tappert, NRL researchers have made numerous successive improvements to the parabolic equation (PE) ocean acoustic propagation model methodology. Dr. Michael Collins (at NRL-DC) and Dr. Robert Zingarelli and Dr. David King and collaborators (at NRL-Stennis) have developed a new, robust, fast, and accurate version of the PE that is known as the Range-dependent Acoustic Model (RAM). This has been incorporated into the Navy's Oceanographic and Atmospheric Master Library as the Navy Standard Parabolic Equation (NSPE) model. NSPE is in widespread use by the Fleet and at all Navy commands for conducting rapid, high-fidelity sonar system performance predictions.

Since its initial development in the 1980s by Acoustics Division researcher Dr. Earl Williams, the methodology known as **generalized nearfield acoustical holography** has been significantly improved and extended into the 2000s. This technique has been demonstrated to be a powerful methodology for both civilian and military applications to uncover and characterize sources of noise and vibration in complex structures. The U.S. Navy has benefitted considerably from the applications of nearfield acoustical holography (NAH) to the problems associated with the quieting of submarines and surface vessels. The civilian aircraft industry has benefitted from NAH as a tool for facilitating the quieting of aircraft interiors. Current research is extending the methodology into the electromagnetic domain for a variety of applications. The fundamentals of NAH are fully described in the 1999 book by Dr. Williams, *Fourier Acoustics: Sound Radiation and Nearfield Holography*.

In the past several decades, Acoustics Division investigators (led by Drs. Michael Collins, William Kuperman, T.C. Yang, Altan Turgut, Michael Nicholas, Gregory Orris, Dalcio Dacol, Kwang Yoo, B. Edward McDonald, Ms. Laurie Fialkowski, Mr. John Perkins, and colleagues) have pursued innovative research on **ocean parameter estimation by acoustical methods** in order rapidly and accurately to probe and invert for properties of the oceanic environment. Development of these new methods is important because direct sampling of the oceanic environment for parameters such as sound speed and bottom/subbottom properties can be costly and time consuming; yet knowledge of these parameters is very important for conducting accurate sonar performance prediction modeling.

In recent decades, considerable research has been spearheaded within the Acoustics Division, particularly by researchers at NRL-Stennis (led by Lisa Pflug, Robert Field, James Leclere, and colleagues), on **passive space-time signal processing techniques**. This research has led to advanced mathematical and higher-order statistical signal processing techniques for classifying passive transient signals from undersea targets.

In the 1990s, Acoustics Division investigators led by Dr. Richard Love and colleagues at NRL-Stennis began several decades of experimental and theoretical research to better understand the physical causes and predictability of **ocean volume reverberation**. Data collected in Critical Sea Test and other sea trials have enabled the development of models based on viscous-elastic fish swimbladder characterizations for individual fish and fish schools. Comparison of these data and models with synoptic fisheries data has enabled a better understanding of the dependence of volume scatter on the fish characteristics and population statistics. Recently, Dr. Roger Gauss and collaborators have developed a fish scattering strength algorithm for consideration as a Navy-standard model. In related research, Dr. Orest Diachok has conducted experimental and theoretical investigations on the resonant absorption of sound in the ocean by fish and fish schools with applications to propagation loss in the littorals. Additional recent research by Raymond Soukup and colleagues has advanced our understanding of sediment volume scattering effects via laboratory-based scale model scattering experiments.

In the past several decades, NRL Acoustics Division researchers have had a leadership role in a community-wide effort to better understand the physical causes of **noise and scattering from undersea bubbles**. Data from the Critical Sea Test experiments have contributed significantly to this effort. Laboratory-based experiments in the Division's Salt Water Tank Facility have enabled controlled studies to be conducted by Drs. Gregory Orris and Michael Nicholas. Recently, Drs. Steven Means, Richard Heitmeyer, and colleagues have extended this research via experimentation and modeling to investigate noise from breaking waves.

From the late 1990s into the 2000s Acoustics Division researchers (led by Drs. Marshall Orr, Peter Mignerey, Stephen Wolf, Bruce Pasewark, Steven Finette, Roger Oba, Altan Turgut, Dirk Tielbuerger [visiting scientist], and colleagues in the Acoustic Signal Processing Branch) have collaborated extensively with colleagues in the underwater acoustics community to investigate **acoustic effects due to oceanic internal waves** in littoral ocean areas. These investigations have included numerous large-scale field experiments. Analyses from these sea trials have contributed significantly to our understanding of the effects of continental shelf break small-scale fluid processes on acoustic propagation loss, signal intensity fluctuations and coherence, array gain, and other factors that influence sonar system performance in the littorals.

Since the late 1990s, Acoustics Division investigators (primarily from the Physical Acoustics Branch, including Drs. Harry Simpson, Brian Houston, Joseph Bucaro, and colleagues) have been conducting innovative research on **mine detection, classification, and mine countermeasures**. This research is exploiting new low frequency approaches to mine detection and classification that avoid some of the drawbacks of earlier high frequency imaging systems. NRL investigators are pursuing methods based on seeking structural acoustic clues such as mine casing resonances, elastic wave propagation, and internal scattering. At low frequencies the ocean sediment is more readily penetrated by acoustic waves, thus exploiting the potential for buried mine detection. This research is also addressing the potential for long-range mine identification, thus increasing the speed and reducing the risk of mine clearing operations.

In the 2000s, NRL Acoustics Division researchers (including Drs. Charles Gaumond, David Fromm, Joseph Lingevitch, B. Edward McDonald, Kevin LePage, Geoffrey Edelmann, David Calvo, and colleagues) have conducted experimental and theoretical research on the feasibility of **acoustic time-reversal techniques** for enhanced undersea target detection and remote sensing applications in littoral ocean environments. The basic physical principle is that acoustic waves can be turned around (time-reversed) and sent back to their source, no matter how complex the environment. Using these techniques, such a time reversal mirror (TRM) can focus sound energy in the ocean. Acoustics Division researchers have demonstrated an ability to enhance target echo levels and reduce boundary reverberation relative to that achieved by conventional sonar systems using TRM processing techniques.

In the past decade, researchers in the NRL Acoustics Division (led by Dr. T.C. Yang of the Acoustic Signal Processing Branch) have conducted extensive theoretical and experimental research on **underwater acoustic communications techniques** (ACOMMS). This research is aimed at improving our understanding of the environmental acoustic physics-related issues that impact ACOMMS system performance and bit error rate at low, middle, and high acoustic frequencies. Among the Navy applications that will benefit from this research are submarine communications at speed and depth, undersea networked sensors, and autonomous underwater vehicle operations.

Recent research in the 2000s by Acoustics Division investigators (led by Drs. Steve Stanic, T.C. Yang, and colleagues) is addressing problems related to **underwater intruder defense**. This research is aimed at improving maritime port security. Water depths in these port areas are typically quite shallow (around 10 to 50 m). Potential threats include undersea divers, diver delivery vehicles, and mini-submarines. Research approaches have included testing bottom-mounted conventional and fiber-optic sensors, as well as laboratory-based testing. Significant advances have been achieved using both passive and active acoustic methods.

In the 2000s new research has been initiated in the Acoustics Division on **biologic tissue analysis (**by Drs. Anthony Romano, Nicholas Valdivia, Joseph Bucaro, Brian Houston, and colleagues of the Physical Acoustics Branch). This research has been conducted in collaboration with colleagues at the Mayo Clinic in Minnesota to develop improved tissue imaging analysis techniques. Focus has been on techniques based on magnetic resonance elastography (MRE) that is capable of measuring elastic displacements throughout biological (high spin density) materials. Current research on low spin density MRE poses significant challenges, but offers much promise for distinguishing cancerous tissues from healthy tissues. Results of these efforts have provided new approaches for wave visualization within materials and have enabled the development of entirely new conformal spatial-spectral wave analysis methods for vibrating structures that promise broader civilian and military applications in the future.

An important new thrust for research in recent years within the Acoustics Division (led by Drs. Steven Finette, Kevin LePage, Roger Oba, Robert Zingarelli, and colleagues) is **environmental uncertainty science**. This research is aimed at new approaches to understanding acoustic field uncertainty. This research is of high interest to the Navy and is aimed at the development of improved "next-generation" tools for ocean acoustic simulation, with emphasis on a physically consistent, predictive modeling capability for acoustic propagation in littoral regions.

In the past few years, Acoustics Division researchers (led by Drs. Joseph Bucaro, Anthony Romano, Joseph Vignola, Harry Simpson, Nicholas Valdivia, and colleagues in the Physical Acoustics Branch) have conducted extensive research on the development of improved techniques for **fault detection and localization** in mechanical structures. This research has considerable military and civilian applications. The NRL researchers were recently invited to demonstrate and evaluate their new fault detection and localization techniques for assessing the integrity of art-bearing walls and ceilings in the U.S. Capitol. The NRL techniques were successful at detecting and locating faults in supporting structures underlying original art in the Capitol. The NRL technique using a scanning laser Doppler vibrometer (SLDV) approach compared quite favorably to other techniques employing radar and thermal imaging. The NRL researchers anticipate future extensions of their methodology to include general application to large-scale structures such as ships and aircraft as well as other applications to much smaller structures at micro- and nanoscales.

In the past decade, Acoustics Division investigators (led by Drs. Jeffrey Baldwin, Brian Houston, Maxim Zalalutdinov, and colleagues in the Physical Acoustics Branch) have pursued new and innovative research on applications of **nanomechanical devices**. These devices represent a new class of artificial crystals with many applications of potential interest to the Navy. A key goal of this research is the development of a new class of artificial crystals formed from large arrays of integrated nanoscale mechanical resonators that will be integrated with actuation and sensing. These devices have many unique physical properties including ultra-low power, capability to approach very high speeds (around 10 GHz), extremely high mechanical "Q," high force sensitivity, low heat capacity, and active mass. Among the anticipated future applications of interest to the Navy are integrated sensors and processors for a variety of types of sensors; very sensitive mass spectrometers; and novel analog processing arrays.

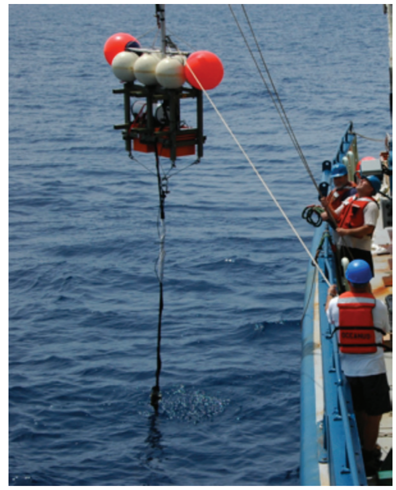
In recent years the Department of Defense and the Navy have encouraged research to address **Global War on Terror (GWOT) technologies**. Researchers in the Acoustics Division (led by Drs. Joseph Bucaro, Brian Houston, Harry Simpson, and colleagues of the Physical Acoustics Branch) have been contributing to this effort through the application of structural acoustics techniques and broadband acoustic scattering methods to identify unexploded ordnance (UXO). These experiments may be the first of their kind and are yielding promising results for the development of techniques to detect and identify UXO targets in shallow water environments.

In the past few years, researchers in the Acoustics Division (led by Dr Earl Williams of the Physical Acoustics Branch and Division Senior Scientist) have invented and furthered the **development of a volumetric acoustic intensity probe (VIP)**. This probe is relatively portable, compact, and inexpensive. It is intended as a very useful tool for the Navy to be used to locate the sources of sound in confined interior spaces like the cabins of military vehicles, surface ships, submarines, and aircraft. The VIP operates in real time with LCD displays on a notebook computer, locating noise sources as the probe is moved around. Future applications are envisioned that include electromagnetic vector field sensing.

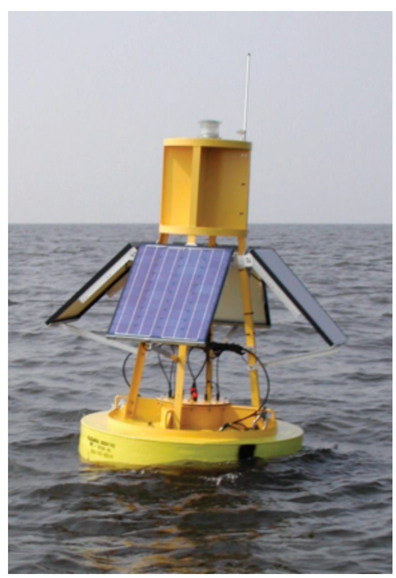
Recently, researchers in the Acoustics Division (led by Dr. Steve Stanic at NRL-Stennis) have conducted experimental and theoretical investigations on **ship-wake acoustics**. A ship's wake is a mixture of bubbles and turbulent seawater. The bubbles in a wake cause complex frequency-dependent changes in underwater sound speed and sound absorption characteristics. The time-varying properties of these effects as the wake decays are a subject of intense research. The NRL research is contributing to a better understanding of the complex physics of acoustic signals propagating through ship wakes and is enabling the development of a predictive capability.

In recent years, Acoustics Division researchers (led by Drs. Jason Summers, Charles Gaumond, and colleagues in the Acoustic Systems Branch) in collaboration with researchers in NRL's Information Technology Division have initiated investigations on **perception-physics-based sonar**. This research is aimed at better understanding the process by which the human ear is able to hear and discriminate between the sounds of different types of active sonar echoes and to develop software algorithms to mimic and automate this process. The results of these efforts have led to an improved understanding of the cognition and physics associated with auditory perception of different types of sonar echoes. Further developments of this research will benefit the Navy by providing new models for automatic classification of sonar echoes.

In the past several years, investigators in NRL's Acoustics Division (led by Dr. Douglas Photiadis and colleagues of the Physical Acoustics Branch) have initiated theoretical and experimental basic research into **quantum acoustic effects** in phononic crystals. A goal of this research is to observe quantum behavior in the macroscopic regime. A phonon is a quasiparticle characterized by quantization of the modes of lattice vibrations of periodic, elastic crystal structures of solids. Phononic crystals are periodic composite materials with lattice spacings comparable to the acoustic wavelength. The researchers anticipate potential future benefits of this research that will be of high interest to the physics community and the Navy. These include the development of new high-performance microsensors for acoustic, chemical, and magnetic applications.



The Acoustic Division's drifting echo repeater supports low- to mid-frequency active sonar research for target detection and classification in littoral environments. It is a research tool to simulate targets with predefined scattering characteristics. Its in-buoy signal processing capability provides flexibility to perform match-filtering, beamforming, and acoustic time-reversal in real time.



The Shallow Water Ship Acoustic Signature Buoy measures ship acoustic signatures in shallow water channels and at port entrances for detection and identification purposes. The system is the acoustics component of NRL's Modular Sensor System (MSS), which is designed to provide track information and local identification of vessels as they approach U.S. ports.

Key Research Thrusts and Achievements in Era 5

24 Acoustics of Sediments
25 Navy-Standard Surface Scatter Models
26 Ocean Bottom Reverberation and Clutter
27 Scattering from Rough Interfaces
28 Scattering and Radiation from Underwater Shapes and Structures
29 Ray Theoretic Propagation Modeling
30 Shallow Water Acoustics
31 Normal Mode Propagation Modeling
32 Passive Acoustic Source Localization and Parameter Estimation
33 Ocean- and Ship-Generated Ambient Ocean Noise
34 Underwater Acoustic Array Systems and Processing Techniques
35 Transbasin and Global Scale Acoustics
36 Development of Navy Standard Parabolic Equation Model
37 Generalized Nearfield Acoustical Holography
38 Ocean Parameter Estimation by Acoustical Methods
39 Passive Acoustic Space-Time Signal Processing Techniques
40 Ocean Volume Reverberation
41 Noise and Scattering from Undersea Bubbles
42 Acoustic Effects Due to Oceanic Internal Waves
43 Mine Detection, Classification, and Mine Countermeasures
44 Acoustic Time-Reversal Techniques
45 Underwater Acoustic Communications Techniques
46 Underwater Intruder Defense
47 Biologic Tissue Imaging Analysis
48 Environmental Uncertainty Science
49 Fault Detection and Localization
50 Nanomechanical Devices
51 Global War on Terror Technologies
52 Development of a Volumetric Acoustic Intensity Probe
53 Ship-Wake Acoustics
54 Perception-Physics-Based Sonar
55 Quantum Acoustic Effects

24
[1943–2008] Acoustics of Sediments

Achievement: In the early 1940s the NRL Sound Division began investigations to better understand the role of the sea bottom on the propagation and scattering of sound in the ocean. This research gained considerable momentum in the 1970s and remains a subject of intense study to the present. The investigations have included extensive at-sea experimentation as well as physics-based model development for a wide variety of sea bottom types.

Impact: NRL research since the 1940s on the properties of the sea bottom has led to a significantly improved understanding of sea bottom characteristics and how acoustic energy is absorbed and scattered for various bottom types. Improved techniques have been developed for probing the sea bottom and subbottom characteristics. The results of these efforts are important for improved operation of passive and active Navy sonar systems, particularly in areas where the propagation is bottom interacting, including the littoral oceans.

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25
[1947–2008] Navy-Standard Surface Scatter Models

Achievement: In the late 1940s NRL Sound Division researchers began investigations to understand the causes of sea surface backscatter and reverberation. By the 1980s and 1990s, through carefully planned at-sea experiments, particularly during the Critical Sea Test measurement series, clear trends emerged. Through empirical data analyses and physics-based modeling efforts, several new NRL-developed Navy-standard algorithms have been implemented for surface scattering. These algorithms permit the prediction of surface scattering strength as a function of frequency, grazing angle, and environmental descriptors such as wind speed, wave height, and subsurface bubble properties.

Impact: NRL Acoustics Division researchers led by Roger Gauss have provided the Navy with a series of increasingly sophisticated algorithms to predict the surface scattering contribution to reverberation. In 2006 the Navy’s Oceanographic and Atmospheric Master Library (OAML) accepted as a Navy standard the NRL-developed Semi-Empirical Surface Scattering Strength algorithm (SESSS version 3.0) that includes full bistatic angle coverage. This algorithm serves as a state-of-the-art input to Navy-standard active sonar performance prediction models that reside on all Navy combatants and at all Navy commands.

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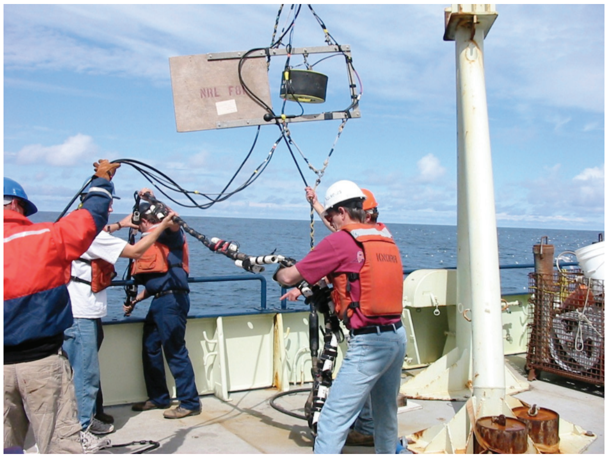
26
[1952–2008] Ocean Bottom Reverberation and Clutter

Achievement: From the 1950s to the present, NRL Acoustics Division researchers have conducted experimental and modeling investigations to better understand the nature of reverberation from the sea bottom in shallow and deep waters. These investigations have included both direct-path (short-range) and distant (long-range) studies. In each decade, further advances in our understanding of bottom reverberation have been achieved. NRL scientists participated in many Navy-sponsored sea tests, including the Bathymetric Hazard Survey Test, the Critical Sea Test, the Acoustic Reverberation Special Research Program, and the Littoral Warfare Advanced Development project, as well as many international collaborative sea trials. Since the 1990s, significant advances have been made by NRL researchers in the development of modeling tools to better understand the physics of bottom reverberation and clutter.

Impact: NRL research on the causes and characteristics sea bottom reverberation and clutter have resulted in significant advances in our ability to predict reverberation levels and clutter statistics. These advances are enabling Navy active system performance prediction models to yield much more reliable and realistic estimates of performance for a wide variety of bottom types and ocean areas.



NRL deployment of ocean bottom scattering measurement system during T-MAST 02 field experiment in 2002.

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27
[1956–2008] Scattering from Rough Interfaces

Achievement: In the mid-1950s NRL Sound Division researchers began experimental and theoretical studies to better understand acoustic scattering from rough interfaces. These studies have application to a wide range of types of scattering from the ocean bottom, the ocean surface, subsurface bubble layers, and the under-ice canopy. Such boundary scattering impacts sonar reverberation and propagation loss in shallow and deep waters. Experimental approaches included at-sea measurements and laboratory-based scale-model measurements. Modeling approaches included physics-based analytical, numerical, and stochastic calculations.

Impact: The results of NRL's investigations on acoustic scattering from rough surfaces from the 1950s to the present have yielded significant benefits for the Navy. These have included numerous physics-based sub-models that have become components of Navy sonar system performance prediction models for passive and active systems.

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28
[1960–2006] Scattering and Radiation from Underwater Shapes and Structures

Achievement: Since about 1960 the NRL Acoustics Division has had a vigorous ongoing theoretical and experimental research effort devoted to characterizing acoustic scattering and radiation from underwater shapes and structures. The general problem of identifying a submerged target by its active acoustic response has applications in several areas including ocean acoustics and ultrasonic detection for medical applications. The problem is complex and it involves physics-based issues such as the interaction of pressure waves at the solid-fluid interface, the generation of vibrational modes in the target bodies, and the presence of secondary scattering bodies. The research also involves a host of mathematical difficulties required for solving elastic scattering problems for finite bodies of arbitrary shape. Initially, NRL researchers developed exact mathematical models for simple canonical problems (e.g., plates, spheres, cylinders, etc.) based on theoretical formulations that retain the physical detail needed to identify fundamental physical mechanisms. Experimental measurements were performed to validate the modeling results, and algorithms were developed to isolate in the measurements the key mechanisms. Measurements were then extended to more complicated finite bodies that could not easily be handled analytically. Increasingly capable world-class experimental measurement facilities were developed as the research progressed, while more advanced computational methods were applied as well.

Impact: The theoretical and experimental research conducted by the NRL Acoustics Division on acoustic scattering from underwater shapes and structures has resulted in major advances of great benefit to the Navy. This research is internationally recognized for its high quality and productivity.

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29
[1964–1997] Ray Theoretic Propagation Modeling

Achievement: Beginning in the 1960s, NRL Sound Division researchers began using ray theoretic methods to help understand sound propagation in the deep ocean. In the 1970s they used these tools to investigate propagation in deep basins and the vicinity of seamounts, and to investigate the effects of caustics. In the 1990s they incorporated NRL-developed ray propagation codes into active system performance prediction models. They also investigated methods to overcome chaotic rays and published research on potential innovative methods for high frequency underwater acoustic ray computations using a molecular computer.

Impact: Since the 1960s NRL Acoustics Division researchers have made extensive use of ray computational methods to predict underwater sound propagation in the ocean. They have contributed significantly to our understanding of propagation in the deep ocean and have developed new modeling tools for Navy sonar system performance prediction applications.

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30
[1970–2007] Shallow Water Acoustics

Achievement: Around 1970, researchers in the NRL Acoustics Division initiated detailed investigations to better understand the complex physics of shallow water acoustics. Sonar systems that operate in the littoral coastal regions face challenges involving numerous boundary interactions that complicate their operation as opposed to systems operating in the deep oceans where there tend to be fewer boundary interactions. To sort out the shallow water sonar propagation and scattering effects, the NRL researchers developed a balanced approach of at-sea measurements and theoretical studies. By the 1990s NRL researchers assumed leading roles in several major at-sea programs to address issues related to sonar operations in the littorals. The Critical Sea Test Program (with science and technology oversight by ONR) conducted numerous sea trials to advance our understanding of the use of low frequency active acoustics in undersea warfare. The Littoral Warfare Advanced Development project (managed by ONR) provided the infrastructure and scientific leadership to permit investigators from numerous organizations to field at-sea experiments for basic research and applied research investigations in the littorals.

Impact: The research by NRL Acoustics Division investigators that was begun around 1970 on shallow water acoustics and sonar operations in the littoral oceans has been of much benefit to the U.S. Navy. It has led to a physics-based understanding of the nature of sound propagation and scattering in the littorals, including recommendations about optimum frequencies for sonar operations. NRL Acoustic Division researchers have further contributed in scientific leadership and principal investigator roles to major Navy efforts to address experimental issues for the littorals, including the Critical Sea test Program and the Littoral Warfare Advanced Development project.

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31
[1970–2000] Normal Mode Propagation Modeling

Achievement: In the early 1970s, NRL Acoustics Division researchers initiated theoretical and computer modeling efforts accompanied by at-sea experimentation to develop improved normal mode models for shallow water applications. The initial goal was to determine if wave theory can be used to predict the acoustic field in shallow waters at long ranges. The wave equation for the physical model was solved by numerical methods and implemented on a high-speed general purpose computer. Since the acoustic field at long ranges is propagated in the discrete normal modes of the shallow water duct, special experimental methods were used to resolve individual modal fields so that their measured characteristics could be compared with predictions. A normal mode model was developed whose salient features included variable sound speed in the water, slowly variable water depth, statistically rough boundaries, sediment layering, and both shear-wave and compressional-wave propagation in the sea bottom. Later model versions included more advanced physics including the capability to predict bistatic reverberation and signal fluctuation statistics.

Impact: The development of advanced normal mode models at NRL has provided the U.S. Navy with important tools for the prediction of the acoustic signal field for shallow water sonar system applications. These models have been widely used by researchers and applications developers in the United States and the international community.

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32
[1975–2006] Passive Acoustic Source Localization and Parameter Estimation

Achievement: In the mid-1970s NRL Acoustics Division researchers initiated three decades of theoretical and experimental investigations on improved methods for passive acoustic source localization and parameter estimation. As the Navy's interest shifted by the 1990s from the deep oceans to the more complex littorals, and as passive acoustic undersea targets became much quieter, the NRL research successfully adapted to these changes.

Impact: Over the past three decades, NRL Acoustics Division research on methods for improved passive acoustic source localization and parameter estimation has provided the Navy sonar signal processing community with increasingly advanced tools to meet current challenges.

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33
[1976–2008] Ocean- and Ship-Generated Ambient Ocean Noise

Achievement: From the 1970s to the present, Acoustics Division investigators have conducted detailed experimental and theoretical research on the physical characteristics of ambient sea noise. These investigations have included both natural (wind, wave, seismic, etc.) and ship-generated noise in the oceans. The experiments and modeling have addressed sea noise in the deep oceans, the shallow oceans, and the surf zone. Studies have focused on the causes of sea noise, its vertical and horizontal directionality, and its geographic, temporal, and spectral characteristics. Physics-based models have been developed to accurately predict the characteristics of ambient sea noise under a wide variety of natural and shipping-based conditions.

Impact: NRL Acoustics Division experimental and theoretical investigations conducted since the 1970s on the causes and characteristics of natural and shipping-based ambient sea noise have contributed significantly to our understanding of these phenomena. The physics-based models developed during these research efforts have provided the underwater acoustics community and the U.S. Navy with important tools for the prediction of ambient sea noise under a wide variety of environmental and shipping-based conditions and sites throughout the world's oceans.

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34
[1976–2003] Underwater Acoustic Array Systems and Processing Techniques

Achievement: In the 1970s NRL Acoustics Division researchers initiated decades of research into methods for improving the gain and resolution of horizontal and vertical acoustic arrays. These arrays are among the most important tools for passive and active research in underwater acoustics. The ability to form stable high-resolution beams is challenging in the temporally and spatially variable and inhomogeneous ocean medium, especially in shallow waters. A diverse set of advanced methods have been developed by NRL researchers for processing acoustic array data to compensate for these medium-induced variabilities.

Impact: Research by NRL Acoustics Division investigators from the 1970s to the 2000s has considerably advanced the science associated with the use of horizontal and vertical acoustic arrays for underwater acoustics. This research has resulted in data processing algorithms that have enabled the formation of more stable, higher resolution and higher gain acoustic beams to compensate for a wide range of deep and shallow water oceanic conditions. The studies of the environmental limits imposed on undersea array beamforming are of direct benefit to the U.S. Navy relative to the performance of its towed and stationary undersea arrays.

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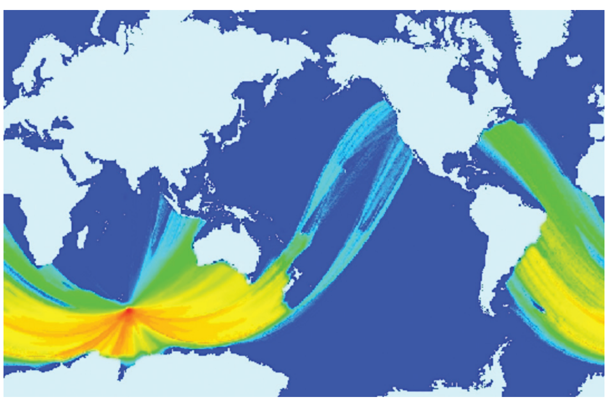
35
[1976–2008] Transbasin and Global Scale Acoustics

Achievement: From the mid-1970s to the present, researchers in the NRL Acoustics Division have conducted experimental and theoretical investigations in undersea transbasin and global scale acoustics. Initially these studies were motivated by scientific interest in understanding long-range acoustic propagation and reverberation for undersea surveillance and bathymetry reconnaissance applications. Since the 1990s there has been additional interest in global scale acoustic propagation as a probe for global warming. NRL modeling tools have further been applied to understanding acoustic propagation in the atmosphere of Jupiter following the impact of Comet Shoemaker-Levy 9.



Global-scale acoustic propagation modeling of the Heard Island Feasibility Test of 1991.

Impact: NRL research since the 1970s to the present on long-range transbasin and global scale acoustics has contributed significantly to our understanding of long-range oceanic acoustic propagation and reverberation. Increasingly advanced models have been developed to accurately simulate results of experiments. These studies have had benefits to the U.S. Navy in a variety of ways: improved understanding of very long baseline acoustic propagation for undersea surveillance; development of methods for remote long-range acoustic reverberation techniques for seamount surveys; development of long-range acoustic propagation-based methods for monitoring global scale ocean temperature changes for global warming studies; and development of methods for monitoring undersea explosions. NRL modeling has also provided a scientific basis for understanding cometary impacts in planetary atmospheres such as the impact on Jupiter of Comet Shoemaker-Levy 9 in 1994.

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36
[1976–2008] Development of Navy Standard Parabolic Equation Model

Achievement: The parabolic equation (PE) is one of the most important computational models for underwater sound propagation. Since the PE was described for underwater acoustics applications by F.D. Tappert ["The parabolic equation method," in *Wave Propagation and Underwater Acoustics*, eds. J.B. Keller and J.S. Papadakis (Springer, New York, 1977)], NRL Acoustics Division researchers have devoted much research effort to extending its capabilities, accuracy, and efficiency. Some of the improvements have included: capability to handle three-dimensional problems, rough interfaces, and interactions with elastic ocean bottoms; higher-order extensions for improved accuracy at large propagation angles; a rotated coordinate extension providing improved accuracy for sloping ocean bottoms; a time-domain extension for solving pulse propagation problems; split-step Padé algorithms for increased speed; coupled-mode algorithms for energy conservation; extensions for gravity and acousto-gravity waves; extensions for two-way propagation applications; and stabilized self-starting algorithms. Much of the research at NRL on PE improvements has been led by Michael D. Collins, who developed a version known as the Range-dependent Acoustic Model (RAM). RAM is based on a user-selected multiple-term Padé approximation of the PE operator. Because this solution allows range steps much greater than the acoustic wavelength and does not require fine vertical gridding, it is a very fast model. Further, RAM can be tuned to smoothly trade accuracy and speed as the operational situation requires. Also, several parallelization methods are applicable, allowing further speed improvements. The Navy Standard Parabolic Equation (NSPE) is a version of PE based on NRL's RAM that is robust, fast, and accurate, and has been incorporated into the Navy's Oceanographic and Atmospheric Master Library for operational Fleet use.

Impact: Since the 1970s, NRL Acoustics Division researchers have developed many improvements to the parabolic equation ocean acoustic propagation model. These enhancements to the PE have made it widely recognized as a leading propagation model for research use. NRL model developers have further evolved a version of the PE known as RAM into a robust, fast, accurate, and standardized Navy Standard Parabolic Equation model. This model has been extensively validated against real-world data sets and benchmarked against other capable models. It has been incorporated into the Navy's Oceanographic and Atmospheric Master Library and is in widespread use by the Fleet and at all Navy commands for conducting rapid, high-quality sonar system performance predictions.

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37
[1983–2008] Generalized Nearfield Acoustical Holography

Achievement: In the early 1980s researchers in the NRL Acoustics Division, led by Earl Williams, began innovative theoretical and experimental research on a technique known as nearfield acoustical holography (NAH). The NAH technique relates generally to measurements of the radiation properties of an acoustic source; and NAH addresses the methods and apparatus for holographically reconstructing images of complex acoustic sources. An important area of acoustics is the study of radiation of sound into a medium (air or water) by a complex vibrator. This research has military applications such as tactical quieting of military equipment, especially naval vessels, and passive and active sonar detection of enemy vessels. Other areas of interest include civil and industrial applications such as environmental noise abatement and loudspeaker and musical instrument design. There is additional interest in related fields such as electromagnetic radiation (antenna design) and hydrodynamics (flow-noise research). The fundamental objective of NAH research is to correlate properties of the vibrator, such as structural features or vibrational modes, with the properties of the radiated sound, such as the farfield radiation pattern and the source vector intensity field. Because of the complex nature of the actual sound sources, the measurement of all the relevant properties using customary techniques is extremely involved, time-consuming, and inefficient. The NAH technique circumvents many of these difficulties and enables rapid estimation of the detailed characteristics of the complex sound sources.

Impact: Research in the NRL Acoustics Division from the 1980s to the present on nearfield acoustical holography has greatly advanced the scientific understanding and practical applicability of this technique. NAH has been demonstrated to be a powerful methodology for both military and civilian applications to uncover and characterize the sources of noise and vibration in complex structures. The U.S. Navy has benefitted considerably from the application of NAH to the problems associated with quieting of submarines and surface vessels. The civilian aircraft industry has benefitted from NAH as a tool for facilitating the quieting of aircraft interiors. Research is ongoing for extensions of NAH techniques in the electromagnetic domain for both military and civilian applications. The NRL advances in NAH methodology have been well described in the peer-reviewed literature and in a 1999 book by E.G. Williams, *Fourier Acoustics: Sound Radiation and Nearfield Acoustical Holography*.

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38
[1989–2008] Ocean Parameter Estimation by Acoustical Methods

Achievement: From the 1980s to the present, NRL Acoustics Division researchers have conducted research using a variety of acoustical methods to probe and invert for properties of the oceanic environment. The pursuit of these methods is important because direct sampling the oceanic environment for parameters such as sound speed and bottom/subbottom properties can be costly, time consuming, and impractical for Navy applications. Methods such as matched-field processing, nonlinear inversion using simulated annealing, reverberation inversion, perturbative inversions, global optimization techniques, waveguide invariant methods, time-angle analysis methods, ship-noise inversion, and passive fathometry have been demonstrated to be quite useful and efficient for ocean environmental parameter estimation.

Impact: In recent decades, NRL Acoustics Division researchers have pursued and refined a variety of acoustic methods for probing the oceanic environment to rapidly and accurately assess a host of environmental properties such as sound speed and bottom/subbottom parameters. Accurate knowledge of these parameters is very important for conducting sonar performance model predictions. The environmental assessment tools developed by NRL researchers enable much quicker environmental assessments relative to the canonical direct environmental sampling methods used in the past, thus facilitating much more rapid Fleet sonar system performance predictions.

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39
[1992–2000] Passive Acoustic Space-Time Signal Processing Techniques

Achievement: In the early 1990s, NRL Acoustics Division researchers initiated a decade of research on techniques for passive acoustic space-time signal processing techniques. Much of this research was led by Lisa Pflug and collaborators at NRL-Stennis in Mississippi. Significant progress was made in development of mathematical and higher-order statistical signal processing techniques for detecting and classifying passive transient signals from undersea targets. This is a challenging problem due to the oceanographically complex and acoustically noisy undersea environment.

Impact: Research was initiated in the NRL Acoustics Division in the early 1990s to develop advanced passive acoustic signal processing techniques for detecting and classifying undersea transients. The mathematical and statistical algorithms developed during these research efforts have contributed significantly to the Navy's toolset for undersea passive acoustic space-time signal processing applications.

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40
[1993–2008] Ocean Volume Reverberation

Achievement: An important component of ocean reverberation that impacts the performance of low frequency active sonar systems is volume scattering from fish. In the early 1990s, researchers in the Acoustics Division, led by R.H. Love at NRL-Stennis, began two decades of systematic theoretical and experimental investigations to better understand the causes and predictability of volume reverberation. High-quality volume scattering data sets were collected in the Critical Sea Test Program and other sea test programs. Theoretical models were developed based on viscous-elastic fish swimbladder characterizations for individual fish and fish schools. These acoustic data and models were compared with synoptic fisheries data and have led to a much better understanding of the dependence of the volume scatter on the fish characteristics and population statistics. Recently, R.C. Gauss and collaborators have developed a Fish Scattering Strength Algorithm for consideration as a Navy-standard model. In the past decade, O. Diachok has conducted detailed theoretical and experimental investigations on the resonant absorption of sound in the ocean by fish and fish schools with direct applications to acoustic transmission loss in the littoral oceans. Recently, R.J. Soukup and colleagues have conducted scale-model scattering experiments to investigate volume scattering effects in sediments.

Impact: Research by NRL investigators on the physical causes and characteristics of ocean volume scattering — especially backscattering and absorption by fish and fish schools — has led to significant advances in our understanding of the physics of these phenomena, and the potential impact on the operation of Navy sonar systems. Physics-based models have been developed for submission to OAML as Navy-standard volume scattering models.

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41
[1993–2008] Noise and Scattering from Undersea Bubbles

Achievement: In the early 1990s there arose within the underwater acoustics research community an increased level of interest in the subject of noise and scattering from undersea bubbles. Although this was a topic that had been studied for quite some time, the renewed interest arose in part because of the new awareness of the importance of scattering from bubble layers as a component of sea surface backscattering, due in part to the Critical Sea Test experiments. At about this time, researchers also began a renewed effort to understand the role of undersea bubbles in generating ambient sea noise, including the roles of spilling and breaking waves. Investigators in NRL's Acoustics Division contributed to this community-wide effort with new experiments, and especially by applying new theoretical analyses to these problems.

Impact: Researchers in the NRL Acoustics Division from the 1990s to the present have focused renewed attention to the problems of scattering from undersea bubbles to better understand the physical bases of sea surface backscattering. They have also devoted considerable effort to understanding the role of undersea bubbles and bubble layers as causes of ambient sea noise. The Navy has benefitted from these efforts through the development of new physics-based models to describe these phenomena.

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42
[1997–2005] Acoustic Effects Due to Oceanic Internal Waves

Achievement: In the late 1990s researchers in the NRL Acoustics Division began significant collaborative studies in conjunction with colleagues in the underwater acoustics community of the effects of nonlinear oceanic internal waves on acoustic propagation in the littoral oceans. The shelf/slope water column is often composed of layers of water of differing density of sound speed. Navy sonar operators usually treat the layers as time-invariant. The layers, however, can be temporally disturbed (vertically displaced) as the result of tidal flow over sloping ocean bottoms. Tidal flow over the break causes the layers of water to be displaced in the vertical. This displacement generates waves that displace the interfaces between the water layers and propagate away from the shelf break. These waves are called internal waves because they do not noticeably displace the air/sea interface as do ocean surface waves. The internal waves are generated on every tide and propagate away from the shelf/slope break with a known speed. Detailed cooperative experiments have been conducted around the world's oceans to measure these oceanographic phenomena and to assess their impact on sonar system performance in the littorals.

Impact: As Navy interest in ocean acoustics became increasingly focused on studies of the littoral oceans in the 1990s, NRL Acoustics Division investigators entered into collaborative experiments to develop a better understanding of the effects of nonlinear oceanic internal waves on underwater acoustic propagation. Results from these experiments have contributed significantly to our understanding of the effects of continental shelf break small-scale fluid processes on acoustic propagation loss, signal intensity fluctuations and coherence, array gain, and other parameters that impact sonar system performance in the littorals. The Navy is benefiting from these studies by gaining a better understanding of how to conduct sonar operations in continental shelf regions.

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43
[1998–2008] Mine Detection, Classification, and Mine Countermeasures

Achievement: Naval mines are self-contained explosive devices placed in the water to destroy ships or submarines. They are generally deposited and remain in the water or sediment until they are triggered by the approach or contact with an enemy vessel. The detection and classification of sea mines remains a difficult technical challenge. One class of acoustic mine-hunting systems attempts to form acoustic images that replicate the rough geometric shape of the target. To obtain sufficient resolution, these systems must operate at relatively high acoustic frequencies, thus requiring time-consuming, close-in examinations of the target. These systems often confuse mines with false mine-like targets such as oil drums. Researchers in the NRL Acoustics Division are exploring alternative approaches to mine detection and classification that avoid some of the drawbacks of these higher frequency imaging systems. NRL investigators are pursuing methods based on seeking structural acoustic clues such as mine casing resonances, elastic wave propagation, and internal scattering. These methods use lower acoustic frequencies and are designed for longer ranges of operation in order to exploit unique "fingerprints" by which to identify a target as a mine. Also, at these lower frequencies, the ocean sediment is more readily penetrated by acoustic waves, thus exploiting the potential for buried mine detection.

Impact: In the past decade, researchers in NRL's Acoustics Division have been exploring new techniques for detection and classification of undersea mines that have considerable advantages over earlier techniques. The NRL approach uses lower frequencies than previous methods and exploits structural acoustic clues. The NRL approach is capable of greater standoff ranges and has the potential to detect and classify undersea mines, both in the water column and in sediment layers. This new ability to detect and identify buried mines can reduce serious risk to the Fleet. In addition, long-range identification can greatly increase the speed of mine clearing operations and reduce the risk to assets by eliminating close-range operations as have been required in the past.

A 21-inch-diameter AUV is used for detection and classification in mine hunting and antisubmarine warfare applications.

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44
[2002–2007] Acoustic Time-Reversal Techniques

Achievement: In the past decade there has been within the underwater acoustics community an increasing interest in an acoustic processing technique known as time-reversal acoustics. Early research was based on laboratory table-top experiments, but more recent research has evolved into large-scale open ocean experimentation. The basic physical principle is that acoustic waves can be turned around (time-reversed) and sent back to their source, no matter how complex the environment. Thus, unlike conventional sonar signals that disperse as they propagate away from their source, a time-reversal mirror (TRM) can focus sound energy in the ocean. In practice, time-reversal mirrors are realized by constructing an array of collocated source and receiver elements. Researchers in the NRL Acoustics Division have developed and deployed a source-receiver array that has been used to test time-reversal methods on problems of interest to the Navy. In recent experiments, NRL researchers have demonstrated an ability to enhance the target echo levels and reduce boundary reverberation relative to that achieved by conventional sonar systems by using TRM processing.

Impact: In the past decade, researchers in the NRL Acoustics Division have conducted experimental and theoretical research on the feasibility of time-reversal mirror techniques for enhanced undersea target detection and remote sensing applications in shallow water ocean environments. At-sea experiments have been conducted with a unique 64-channel source-receiver array. The NRL experiments have demonstrated that time-reversal techniques can benefit Navy sonar systems because of the ability of time-reversal processing to focus energy in uncertain environments. NRL research is oriented towards development of improved technologies for antisubmarine warfare, wide-area bathymetry mapping, and mine hunting applications.

Dr. Charles F. Gaumond during OREX05 acoustic time-reversal tests aboard R/V *Wecoma* off the Oregon Coast in 2005.

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45
[2003–2008] Underwater Acoustic Communications Techniques

Achievement: In the past decade, researchers in the NRL Acoustics Division, led by T.C. Yang, have conducted extensive theoretical and experimental research on underwater acoustic communications (ACOMMS) techniques. The conduct of effective underwater acoustic communications presents significant challenges due to the complex oceanographic medium and its boundaries. The NRL research has been aimed at improving our understanding of the environmental acoustic physics-related issues that impact the ACOMMS system performance and bit error rate (BER). Key signal parameters include the signal temporal coherence (or Doppler spread), signal spatial coherence, and the variance of random (symbol) phase fluctuation. NRL research has addressed the various environmental-physics and signal processing-related challenges at low, middle, and high acoustic frequencies. This research has also explored techniques for covert underwater acoustic communications.

Impact: Recent theoretical and experimental research in the NRL Acoustics Division on improvements in underwater acoustic communications (ACOMMS) technology has led to significant advances of considerable applicability to the Navy. This research has led to much better understanding of the physics of the acoustic channel and has enabled the development of more reliable signal processing algorithms for ACOMMS. Among the Navy applications that will benefit are submarine communications at speed and depth, undersea networked sensors, and autonomous underwater vehicle operations.

Deployment of NRL acoustic communications buoys during AUV-Fest 05 in Keyport, Washington in 2005.

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46
[2004–2008] Underwater Intruder Defense

Achievement: Recently, the underwater acoustics community has developed an increased interest in underwater intruder defense. Protection of our commercial and military harbor facilities in the United States and abroad has become a high priority. Port facilities are generally located in areas where the water depths are quite shallow — typically from about 10 m to 50 m. Researchers in the NRL Acoustics Division have begun to explore acoustic methods for coastal and harbor surveillance, target detection, and target identification. Potential threats include undersea divers, diver delivery vehicles, and mini-submarines. Initial at-sea testing has begun, using bottom-mounted conventional and fiber-optic sensors to passively detect underwater threats such as divers using open-circuit breathing systems. Other efforts have included laboratory-based testing and investigations of active acoustic methods as well as structural acoustics methods for exploring classification clues. Additional research is exploring the feasibility of low source level active acoustics using semi-continuous, high-duty-cycle transmissions for clutter rejection via Dopplergrams.

Impact: Recent research in the NRL Acoustics Division is addressing problems in underwater intruder defense to improve maritime port security. Significant advances have been achieved in both passive and active acoustic methods.

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47
[2004–2008] Biologic Tissue Imaging Analysis

Achievement: Recently, investigators in the NRL Acoustics Division, led by A.J. Romano, have collaborated with colleagues at the Mayo Clinic in Rochester, Minnesota, to develop improved tissue imaging analysis techniques. This research has received impetus from the knowledge that the elastic moduli of cancerous tissues differ from those of healthy tissues by as much as an order of magnitude. Thus, visualization of wave propagation within biologic media would enable material parameter determination for noninvasive evaluation of the pathological state of tissues being investigated. This joint research is aimed at the development of a new approach to quantitatively visualize dynamic elastic displacements within the interior of a class of materials characterized by low or modest spin densities using magnetic resonance elastography (MRE). MRE was developed by researchers at the Mayo Clinic in 1995 as a method to quantitatively measure elastic displacements throughout biological (high spin density) materials using phase contrast magnetic resonance imaging. The current research on low spin density MRE poses significant challenges such as low signal-to-noise ratio, short relaxation times, and magnetic susceptibility inhomogeneity effects. Recent research on the feasibility of elastic wave visualization within polymeric solids using MRE has yielded encouraging results. The research has been further extended to include the characterization of anisotropic, biological media, with displacements measured using dynamic MRE. In one approach, a waveguide constrained analysis is applied to physical structures, such as muscle, which evaluates the velocities of wave propagation along arbitrarily oriented fibers or fiber bundles in a local fashion using a spectral filter and a sliding window spatial Fourier transform. In another approach, the anisotropic equations of elasticity, in variational form, are inverted for a determination of the complex moduli comprising the medium.

Impact: Recent joint research efforts by investigators at NRL's Acoustics Division and the Mayo Clinic have enabled significant advances in techniques for biologic tissue imaging analysis. A Cooperative Research and Development Agreement (CRADA) has been developed by NRL and the Mayo Clinic for mutually beneficial projects funded by both the Office of Naval Research and the National Institutes of Health. These research efforts have provided new approaches for wave visualization within materials and, by virtue of these capabilities, have enabled the development of entirely new conformal spatial-spectral wave analysis methods for vibrating structures. Follow-on research in NRL's Acoustics Division on novel transform methods in structural/physical acoustics promises to have broader civilian and military applications.

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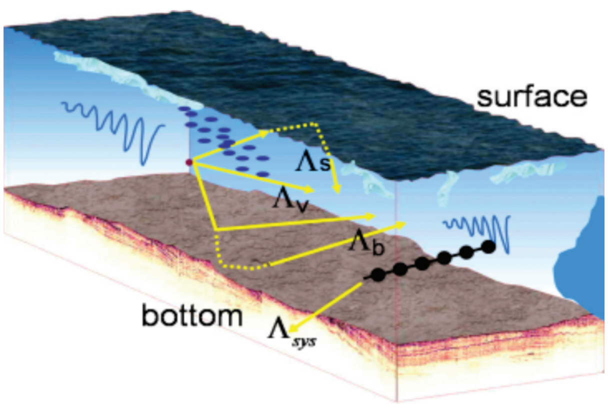
48
[2005–2008] Environmental Uncertainty Science

Achievement: Recently, investigators in the NRL Acoustics Division, led by Steven Finette, have pursued research of increasing importance to the Navy on the topic of acoustic field uncertainty. As described by Finette (2008): "When modeling ocean acoustic systems, the environmental information necessary to compute the acoustic field properties is assumed to be accurately specified by various parameters, fields, and boundary conditions. However, in real world applications, these quantities are subject to uncertainties due to our incomplete knowledge of the waveguide environment. This form of uncertainty involves errors that are quite distinct from the numerical errors that can arise when a mathematical model is discretized, implemented on a computer, and solved with finite precision arithmetic. In effect, the environmental uncertainty introduces spurious degrees of freedom into the system. In order to make reliable simulation-based predictions, this uncertainty needs to be quantified and incorporated in the simulation process itself. The idea of embedding uncertainty into the simulation framework and elevating its status to a subject worth studying on its own merits represents a paradigm that has stimulated research in several disciplines." The recent NRL research has as its goal to develop a physically consistent, predictive modeling capability for acoustic propagation in littoral regions. The approach has been to quantify uncertainty in a mathematically rigorous manner to include computations for ocean dynamics as well as acoustic propagation.



NRL research to develop computational tools for embedding environmental uncertainty in ocean acoustic modeling in littoral regions.

Impact: Recently, NRL Acoustics Division researchers have pursued new approaches to understanding acoustic field uncertainty. This research is of high interest to the Navy and is aimed at the development of improved "next-generation" tools for ocean acoustic simulation. Considerable initial progress has been made. NRL researchers have constructed a mathematical framework for including environmental uncertainty in ocean acoustic modeling; they have developed software for quantitative estimates of uncertainty; and have applied their methodology to narrow and wide-angle parabolic equation, coupled modes, and fluid-dynamic problems. This research on the quantification of uncertainty is contributing significantly to the Navy's ability to make meaningful numerical predictions in complex environments.

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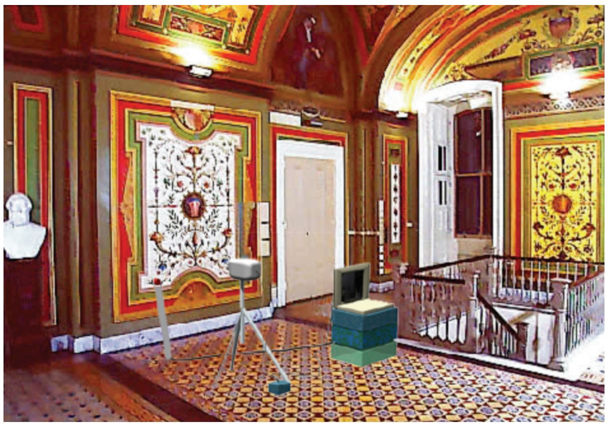
49
[2005–2008] Fault Detection and Localization

Achievement: Recently, investigators in the NRL Acoustics Division have conducted extensive theoretical and experimental research on applications of fault detection and localization techniques. As described in the *2005 NRL Review* by Bucaro, Vignola, and Romano, "Structural health monitoring techniques have become increasingly important to the Navy of the 21st century whose strategy is to emphasize advanced designs and new material technologies in its modern high performance structures while utilizing existing aging structures beyond their planned lifetimes. At the same time, the Navy would like to reduce manning levels on naval platforms, reduce time in repair and total ownership costs, and increase survivability. Among other things, these trends have driven the need for the development of reliable, automated, structural health assessment methodologies. In response to this need, we have been addressing the feasibility of structural acoustic techniques for monitoring the mechanical condition of structures." The authors further explain, "Mechanical fault monitoring using the dynamic response of a structure by externally applied forces is not new. For the most part, traditional methods involve some application of modal analysis techniques that typically extract changes in resonance frequencies and/or associated mode shapes. One drawback of such modal approaches results from the fact that local changes in a structure caused by a fault often produce only very small changes in these global modal parameters whereas unavoidable environmental changes can have a large impact on these measured characteristics. In addition, even when modal analysis is used successfully to indicate a



NRL demonstration of fault detection and localization techniques for assessing the integrity of art-bearing walls and ceilings in rooms of the U.S. Capitol.

structural problem, localization of the detected flaw is in general difficult." The NRL research has been aimed at developing techniques that not only use the traditional mechanical dynamic response, but are able to detect and characterize local changes in the structural dynamics caused by the presence of the fault. Further, the NRL research has been directed at the development of a set of inversion algorithms that can operate efficiently in the presence of noise on the scanned surface displacements of the vibrating structure to produce a meaningful map of some fault-sensitive mechanical parameter. Several methods have been used to acquire surface displacement data in NRL experiments for these studies. One method is a technique employing a scanning laser Doppler vibrometer (SLDV). Another, less well known surface displacement technique uses a miniature scanning acoustic microphone to sample the evanescent sound pressure field emanating from the vibrating structure. Using the principles of nearfield acoustical holography, the measured pressure fields are back-projected onto the structure's surface, converting them to spatial displacement information. NRL experimental studies have confirmed the efficacy of implementing structural acoustic fault detection methodologies.

Impact: NRL Acoustics Division investigators have recently conducted extensive research on the development of improved techniques for detecting and localizing faults in mechanical structures. This research has considerable military and civilian applications. One important civilian application has recently been pursued. The NRL researchers were invited to demonstrate and evaluate their new fault detection and localization techniques for assessing the integrity of art-bearing walls and ceilings in various rooms in the U.S. Capitol. The Capitol building has large expanses of important fine art and decorative paintings executed directly on the original lime plaster. In support of a comprehensive infrastructure modernization program in the building, the integrity of the supporting structures is being evaluated so that degradations underlying the artwork can first be located and repaired. In general, the NRL techniques were very successful at detecting and locating faults when they existed in structures underlying the art. Among the problems identified were areas of unconsolidated plaster, various size regions having delaminations between plaster layers, and places where there is complete detachment of the plaster from its typically brick foundation. The NRL SLDV-based structural acoustic approach compared favorably to other techniques used at the Capitol including those employing radar and thermal imaging. The NRL researchers anticipate future development and applications for its new fault detection and location methodology, including general application to large-scale structures such as ships and aircraft as well as applications to much smaller structures at micro- and nanoscales.

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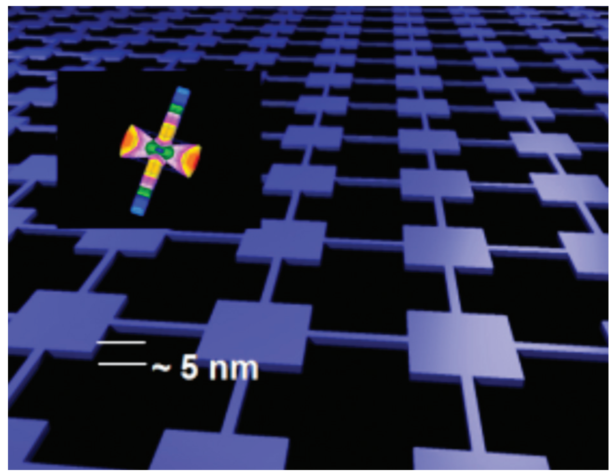
50
[2001–2008] Nanomechanical Devices

Achievement: In the past decade, investigators in the NRL Acoustics Division, led by Brian Houston, have launched innovative new theoretical and experimental research on integrated nanomechanical device arrays. These devices, in essence, represent a new class of artificial crystals with many novel applications of potential interest to the Navy. Crystals found in nature may have lattice constants of order 0.5 nanometers (5 angstroms); however, the newly fabricated artificial "crystals" may have a lattice constant one hundred times larger (around 50 nanometers). The broad goals of this NRL research are to produce and demonstrate a new class of artificial crystals formed from large arrays of integrated nanoscale mechanical resonators (integrated with actuation and sensing), and to capitalize on coherent detection/processing of a large number ($>10^5$) of devices. Further goals are to design, fabricate, and ultimately control basic device properties such as density of states, frequency (seek the upper limit), inelastic behavior (control the dissipation), and interface (to be able to communicate with these arrays). A variety of experiments have been performed including broadband, broad temperature range, scaling, and surface science investigations to determine the hard limits set by the fundamental physics. A number of significant breakthrough achievements have been attained. Among these are: the first successful fabrication and characterization of nanoresonator "phononic structures"; the first successful fabrication and characterization of a single-crystal diamond nanoresonator; attainment of a world's experimental record for the highest "Q" reported in micro/nanoresonators ($Q = 1.3 \times 10^6$ at 10 K and 6.3×10^5 at 300 K); the first measurements on the internal friction for nano-diamond films; development of new metrology techniques including infrared micro-laser Doppler vibrometry extended to higher limits than previously attained; successful fabrication of advanced micromechanical and nanomechanical resonators in complementary metal-oxide semiconductors (CMOS); integration of electronics with micromechanical and nanomechanical resonators in CMOS; development of new formulations for the optical patterning (deep ultraviolet) of functionalization of diamond and silicon; and seven patents/patent applications.

Impact: In the past decade, theoretical and experimental investigations by researchers in NRL's Acoustics Division have led to numerous advances in the fabrication and characterization of the physical properties of integrated nanomechanical device arrays. These devices have novel physical properties that include ultra-low power (10^6 elements and 1 microwatt); capability to approach electronic speeds (around 10 GHz); extremely high "Q" (higher than electronic components); high force sensitivity (approximately 10^{-18} newton resolution); low heat capacity (less than 10^{-21} J/K); and active mass (attogram). Among the potential applications of interest to the Navy are integrated sensors and processors for magnetometers, bolometers, and acoustic sensors; one-dalton mass spectrometers (uncharged species); and analog processing arrays (e.g., radio frequency and beyond — spectrum analyzers, mixers, filters, networks for pattern identification, etc.).



NRL research on the development of integrated nanomechanical device arrays.

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51
[2008] Global War on Terror Technologies

Achievement: A subject of much recent interest to the Department of Defense and the Navy is to seek improved technologies to support the Global War on Terror (GWOT). Recently, investigators in the NRL Acoustics Division have been contributing to this effort through the application of structural acoustics techniques and broadband acoustic scattering measurements of underwater unexploded ordnance (UXO). To evaluate the potential for detection and identification of UXO targets by exploiting their structural acoustic responses, recent experiments have been conducted in the large indoor pool facilities of NRL's Laboratory for Structural Acoustics (LSA) as well as at sea. For example, NRL researchers conducted broadband monostatic scattering measurements over a full 360 degrees of aspect angle. Measurements have been made on (inert) UXOs including two mortar rounds, an artillery shell, and a rocket warhead, and on false targets including a cinder block and a large rock. Measurements were taken in a low structural acoustics frequency regime in which the wavelengths are comparable to or greater than the target characteristic dimensions. Results indicate that in general there are aspects that provide sufficiently high target strength levels so that UXO targets should be detectable via their structural acoustics signatures in most acoustic environments. The measurements are being extended to include the exploitation of bistatic echo responses. Further, the experiments are being expanded in the LSA sediment facility to include scattering from proud, half-buried, and fully buried UXO targets. At-sea measurements are being conducted on these same UXOs in shallow water near Panama City, Florida, in a sandy-mud bottom for comparison to the laboratory-based measurements. Research is also under way on development of theoretical models to simulate the detailed structural acoustic responses of UXOs and to develop classification measures to enable discrimination between UXOs and false targets.

Impact: Researchers in NRL's Acoustics Division have recently conducted experimental and theoretical studies to evaluate the potential for using structural acoustics techniques to detect and identify unexploded ordnance. Initial experiments have been conducted on a variety of UXO types as well as false targets during laboratory-based and at-sea measurements. These experiments may be the first of their kind, and the results show considerable potential for the development by NRL of viable techniques for the detection and identification of UXOs in shallow ocean environments.

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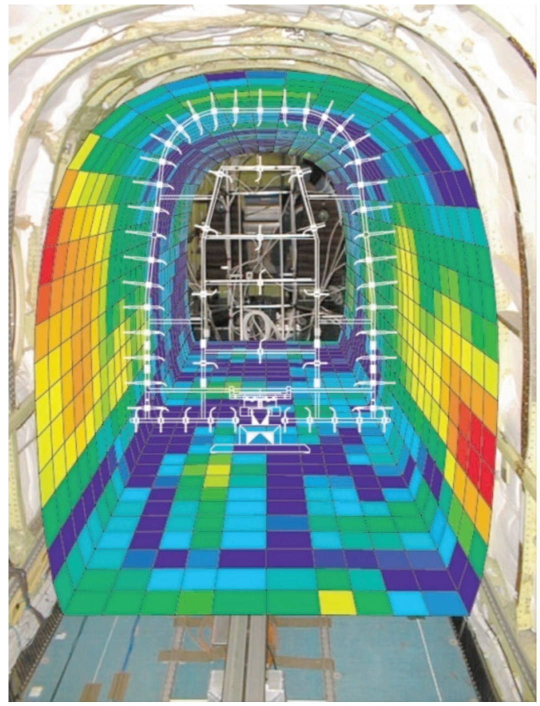
52
[2006–2008] Development of a Volumetric Acoustic Intensity Probe

Achievement: Recent research in the NRL Acoustics Division, led by Earl Williams, has resulted in an advanced type of volumetric acoustic intensity probe. This development was motivated in part by the need for better methods for probing military vehicles and aircraft or habitation spaces on ships and submarines to localize annoying sources of noise that promote fatigue and may interfere with mission success. As explained by Williams in his *2006 NRL Review* article, "Identification of these sources is crucial so that measures may be taken to quiet them. Pressure or vibration sensors are generally not successful in localization and identification of noise sources. Modern metrology has turned to intensity probes for a solution. These probes have had marked success since they measure the direction and magnitude of energy flow at the measurement point. When used to scan over surfaces or in an array configuration, they are effective at locating noise sources. The ability to locate detrimental noise sources and quantify them has taken a quantum leap forward with the invention at the Naval Research Laboratory of a new and radically different type of intensity probe. Called the Volumetric acoustic Intensity Probe (VIP), it works by imaging the acoustic intensity vector in a volume nearly a cubic meter in size using an array of relatively inexpensive microphones. This holographic-like imaging capability is remarkable since it tracks the energy flow throughout this volume at points in space where measurements are not made. Furthermore, energy-flow tracks of multiple noise sources are separated by state-of-the-art, front-end signal processing. This new measurement device can be used to diagnose any complex noise source, whether flow-noise or shock induced, for example."



Measurement of aircraft interior wall vibration distribution using a Volumetric Acoustic Intensity Probe.

Impact: Researchers in the NRL Acoustics Division have invented and developed a new and very capable type of volumetric acoustic intensity probe (VIP). It is relatively inexpensive and portable. It has received considerable attention in the commercial aircraft industry. In addition it is an ideal tool for the Navy as it provides the ability to locate sources of sound in confined interior spaces like the cabins of military vehicles, surface ships, submarines, and aircraft, as well as in exterior spaces such as near a ship's hull. The VIP tracking algorithm is quite rapid so that the probe can be used in real time, with LCD displays on a local notebook computer locating noise sources as the probe is physically moved, scanning for noise sources in a field application. The underlying technology is not limited to acoustic applications, but with a change from pressure sensors to electromagnetic field sensors, one would be able to image the Poynting (electromagnetic intensity) vector in the volume in the same manner.

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53
[2006–2008] Ship-Wake Acoustics

Achievement: Recently, researchers in the NRL Acoustics Division, led by Steve Stanic at NRL-Stennis, have conducted experimental and theoretical investigations on acoustic propagation through ship wakes. A ship's wake is a mixture of bubbles and turbulent seawater generated by a ship's hull and its cavitating propellers. Bubbles, even in small amounts, cause considerable frequency-dependent changes in underwater sound speed and sound absorption characteristics. The ship-wake bubble cloud characteristics and its effects on underwater sound propagation are somewhat complex. As a ship wake initially ages, it experiences a violent breakup and mixing of bubbles due to turbulence. As the turbulence decays, the bubbles begin to rise toward the surface due to their buoyancy, thus changing the buoyancy of the water mass. Since bubbles of different sizes rise at different rates, as the wake ages, the horizontal and vertical distributions of bubble densities result in changes both to the sound speed profiles and the sound absorption within the wake. These frequency-dependent sound speed profiles have large effects on propagating acoustic signals. The NRL research on ship-wake acoustics is aimed at better understanding the complex physics of acoustic signals propagating through ship wakes and developing a predictive capability.

Impact: Recent NRL research on acoustic propagation through ship wakes has resulted in an improved understanding of the frequency-dependent effects caused by a wake as it decays. This research is of benefit to the Navy because it is providing quantitative data and performance estimates for target detections in and below a surface ship wake.

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54
[2006–2008] Perception-Physics-Based Sonar

Achievement: In recent years, researchers in the NRL Acoustics Division and the NRL Information Technology Division have collaborated on research in applications of perception-physics-based sonar. This research is aimed at better understanding the process by which the human ear is able to hear and discriminate between the sounds of different types of sonar echoes and to develop software algorithms to mimic and automate this process. This research is sometimes characterized as "auralization." As explained by J.E. Summers (2008), this term (for the room-acoustics community) has come to mean "the process of rendering audible, by physical or mathematical modeling, the sound field of a source in space." This research has used data sets containing actual sonar echoes from different types of underwater objects, and progress has been made in development of algorithms for discriminating and classifying different echo types.

Impact: Recent collaborative investigations in perception-physics-based sonar by researchers in NRL's Acoustics Division and Information Technology Division have led to an improved understanding of the cognition and physics associated with human auditory perception of different types of sonar echoes. This research will benefit the Navy by providing new models for automatic classification of sonar echoes.

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55
[2005–2008] Quantum Acoustic Effects

Achievement: Recently, investigators in NRL's Acoustics Division, led by Douglas Photiadis, have initiated theoretical and experimental basic research into quantum acoustic effects in phononic crystals. This research addresses issues concerning the fundamentals of measurement theory in quantum mechanics. A goal of this research is to observe quantum behavior in the "macroscopic" regime (of order 10^8 to 10^{14} atoms). A phonon is a quasiparticle characterized by quantization of the modes of lattice vibrations of periodic, elastic crystal structures of solids. Phononic crystals are periodic composite materials with lattice spacings comparable to the acoustic wavelength. They have a general interest in physics because they have significant effects on acoustic wave propagation, including acoustic band gaps; and they have potential applications as sound filters and in transducer design. The NRL research uses phononic crystals because they are an excellent platform to test current measurement theory predictions; they have large mass, a large range of length scales, and are well coupled to measurement probes. Current efforts include searching for the signature of quantization in a single nano-oscillator. This is challenging because the measurement of an individual quantum system involves intrinsically small energies. Among the techniques being used are thermodynamic methods (specific heat) and optical methods (Brillouin scattering).

Impact: Recent research in the NRL Acoustics Division is addressing issues in quantum acoustic effects in phononic crystals. The payoff for the physics community and the Navy is the potential for the development of new high-performance microsensors for acoustic, chemical, and magnetic applications.

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Further Recollections of Era 5

A Brief History of the Physical Acoustics Branch, Part 3, 1992–2008
by Dr. Joseph A. Bucaro

1992–2002 Structural Acoustic Detection of Underwater Mines, Nearfield Acoustical Holography for Aircraft, High Q Oscillators at Sub-Kelvin Temperatures, and MRE with the Mayo Clinic

In 1993 the Physical Acoustics Branch initiated our first formal work in the structural acoustics (SA) of mines. One year later, we made the very important discovery in our laboratory pool facilities of the presence of exploitable structural acoustic features in the acoustic scattering from operational undersea mines. This work soon led to new ideas in classification of such underwater targets by using features in the time-frequency echoes (acoustic color) as opposed to the conventional imaging techniques. These discoveries were quickly followed by both internally funded (I briefed a 6.2 FY96 program successfully to the NRL Research Advisory Committee) and externally funded programs (e.g., Dr. Wallace Ching of the ONR Ocean, Atmospheric, and Space Department, Sensing and Systems Division) seeking to exploit these phenomena.

On June 3, 1998, I, Tim Yoder, Brian Houston, and Luise Couchman briefed Dr. Randy Jacobsen at ONR about our progress in using acoustic color, time reversal, and acoustic inverse scattering for mine identification. This led to the start of a focused ONR/NRL program to demonstrate the concept at sea using a towed body. At about the same time, ONR organized a mine countermeasures (MCM) workshop to explore new broadband concepts, which was held in August 2000 in Park City, Utah. When I briefed the panel on our new SA concept, they essentially said it was not practical because it would operate at low frequencies where it would not be possible to realize strong active sources compact enough to go on a small platform such as an autonomous underwater vehicle (AUV). The critics were proved wrong by the work at NRL of Drs. Thomas Howarth and James Tressler who developed a new "cymbal" source technology with both high source strengths and small size footprints. In 2002, a team led by Dr. Brian Houston successfully demonstrated the first structural acoustic mine sonar in a test off the coast of Panama City, Florida. Ultimately this work would lead, approximately five years later, to a Navy acquisition program for introducing this nonconventional technology called Low Frequency Broadband (LFBB) into the Fleet, and to the bestowal of the Navy Meritorious Civilian Service Award to Dr. Brian Houston for his successful efforts in the development of LFBB.

Dr. Earl Williams also successfully extended his underwater nearfield acoustical holography (NAH) technology to interior aircraft cabin noise, which resulted in a long-term research effort in this area funded by NASA Langley. Based on the success of our new initiatives in NAH in air, NRL approved a ~$1M procurement of a new In-Air Structural Acoustics Facility in which were implemented the state-of-the-art measurement and sound processing technologies which were so successful in our underwater facilities. This facility came on line in August 1999. Dr. Williams designed and fabricated the first spherical nearfield array in 2002 which allowed real-time imaging and display of the flow of acoustic intensity.

In 1998, about half of the branch personnel moved to the Acoustics Division space in Building 2. The area is located in the northwest corner of the building in a space originally dedicated to the Public Works Division's electroplating activities. I worked with Mr. Ed Rank to design the office and conference room spaces, and Mr. Rank provided an outstanding suite of well-furnished rooms. This partial move of Code 7130 into the division's building was an important factor in reconnecting the branch and other division personnel who since the move from Building 1 to Building 71 in 1972 had become more and more decoupled.

In 1999, the branch recruited Dr. Xiao Liu from Cornell University where pioneering work was being carried out in very high Q mechanical silicon oscillators. This expertise was transferred to the branch, and in a short time we were publishing seminal papers regarding the mechanisms of loss at Kelvin temperatures in high Q silicon oscillators. In 1996, I, Dr. Anthony Romano, and Dr. Brian Houston set up a joint effort with Georgetown University Hospital using their magnetic resonance imaging (MRI) equipment to begin exploring how we might obtain data to support our new interests in acoustic field reconstruction techniques. Although this effort at Georgetown was short-lived, the effort led to interactions with the Mayo Clinic MRI research group led by Dr. Richard Ehman. Their major development of magnetic resonance elastography (MRE) allowed for the first time the use of MRI technology to quantitatively image dynamic acoustic displacements throughout a biological material sample. Aware of this new capability, in 1998 Dr. Anthony Romano made the first of his pioneering breakthroughs in local inversion algorithms and applied it to material parameter determination in these materials. The marriage of the Mayo efforts with those of the Physical Acoustics Branch led to the seminal work in which the local displacements imaged with MRE were inverted into local internal shear modulus maps, thus providing high spatial probing of breast tissue to detect and localize any high stiffness regions (down to 1 mm size!) characteristic of cancerous tissue. Soon thereafter, the seminal paper was published: "Evaluation of a material parameter extraction algorithm using MRI-based displacement measurements," by A.J. Romano, J.A. Bucaro, R.L. Ehman (of the Mayo Clinic), and J.J. Shirron, in *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control* **47** (2000) 1575–1581.

Also during this period, Dr. Photiadis carried out his seminal work in flexural Bloch waves and Anderson localization in moderately irregular structures. Here he created pioneering physics for these structures while at the same time connecting the discoveries directly and significantly to important issues regarding the structural acoustics of submarine hulls.

2002–2008 New Physical Acoustics Laboratories in the NRL Institute for Nanoscience, Fault Detection at the U.S. Capitol Building, Quantum Acoustics, and IED, UXO, and Threat Swimmer Detection

Dr. Romano has continued his interactions with the Mayo Clinic to the present time, having been given an honorary adjunct position in the group. His contributions to their important medical mission have continued, including breakthroughs in MRE in fibrous materials (e.g., muscles) and tissue alteration by high intensity ablation. Simultaneous with this research on inversion algorithms, the branch was developing advanced scanning laser Doppler vibrometer techniques. These included the first five-beam system capable of mapping all three vector dynamic displacement components associated with a solid surface and micro- and nano-devices with unparalleled spatial resolutions (down to 50 nm!). Having coupled the inversion work with the scanning vibrometer capabilities, thereby creating a novel fault detection technology, in 2003 we were invited to compete our approach against thermal imaging and radar techniques at the U.S. Capitol building. This pilot program was established by the Architect of The Capitol (AOC) to establish the approach that would be used to evaluate the "state of health" of the fresco-laden plaster walls in the House and Senate parts of the building. Huge expanses of these walls and ceilings bear priceless frescoes painted in the mid-1800s by the Italian artist Brumidi. As the AOC contemplated a large-scale infrastructure improvement program in the Capitol, there was grave concern that areas of plaster over time may have detached from the masonry or deconsolidated, which might lead to loss of the frescoes under the disturbances that would take place when the infrastructure work was taking place. Our technique, which we used collaboratively with several scientists from the University of Ancona, Italy, won the competition by finding subsequently verified faults in some of the walls and ceilings studied in the pilot program. Some of these results were published in an award-winning article (The Torry Fuller Award), "Locating faults in wall paintings at the U.S. Capitol by shaker-based laser vibrometry," by J.F. Vignola, J.A. Bucaro, B.R. Lemon, G.W. Adams, A.J. Kurdila, B. Marchetti, E. Esposito, E. Tomasini, H. Simpson, and B.H. Houston, in *APT Bulletin: The Journal of Preservation Technology* **36** (2005) 25–33.

Also during this period, Dr. Nicholas Lagakos and Dr. J.A. Bucaro with the help of Dr. Jacek Jarzynski developed a new fiber optic microphone technology which employed a specially designed seven optical fiber probe and a silicon micromachined diaphragm. The microphone was sensitive, very low cost, all optical at the sensor end, and exhibited very low 1/f noise making it able to monitor pressure signals at ultra-low frequency, something the best electrical microphones cannot do. This work led to a licensing agreement between NRL and a private company and several patents, one of which was awarded the 2008 NRL Edison Patent Award.

During this same period, under the leadership of Dr. Brian Houston, the branch and its collaborators from the Naval Surface Warfare Coastal Systems Station (CSS) and industry carried out the system-related work to demonstrate the structural acoustic mine identification technique on a succession of improved AUV platforms. In November 2005 this team carried out the first successful blind test in the Gulf of Mexico. This event set in motion the formal process to transition the technology to the Fleet. As mentioned above, this work and the subsequent transition program resulted in Dr. Brian Houston's receipt of the Navy Meritorious Civilian Service award in 2008.

Beginning in 2005, the branch began to successfully apply its structural acoustic target recognition techniques to the Global War on Terror. These efforts included an LDV-based detection system for vehicle-borne improvised explosive devices (IEDs), long-range detection of threat divers by their active acoustic signature, seismic wireless detection of terrestrial-based intruders, and the structural acoustic detection and identification of explosive belts beneath the clothing of a would-be suicide bomber. Beginning in January 2006, the branch began its work for the Strategic Environmental Research and Development Program (SERDP) to develop a structural acoustic–based technology for finding underwater unexploded ordnance (UXO), research that continues to the present time.

Also during this period, led by Dr. Houston, branch researchers continued their seminal work in the physical acoustics of nanostructures in both simple nanostructures and in nanoarrays. Based on the initial work here, the branch was allowed to create two dedicated laboratories in NRL's new state-of-the-art Institute for Nanoscience research facility (Building 215).

In September 2007, Dr. J.A. Bucaro retired after approximately thirty-seven years as a federal employee at NRL, and Dr. Brian Houston was made acting branch head. Since that time Dr. Houston, now official branch head, has expanded the branch's research program considerably and has added new components including autonomous distributed acoustic sensor systems powered and buoyed by bacterial processes and AUV-based ASW systems.

Matched-Field Processing at NRL, Part 2
by John S. Perkins

TTCP Environmental Signal Processing Experiments

TESPEX

In 1993 and 1994, two at-sea experiments (TESPEX-I and TESPEX-II) were coordinated by The Technical Cooperation Program (TTCP). These experiments emphasized the use of satellite telemetry combined with efficient environmental inversion and processing to produce matched-field processing (MFP) results in near real time. The 1993 experiment took place out of Auckland, New Zealand, and the data was telemetered by satellite back to Auckland for processing. The 1994 experiment took place off of Darwin, Australia, and the data was telemetered back to Darwin as well as back to NRL in Washington, D.C. Several NRL scientists (W. Kuperman, J. Perkins, M. Collins, T. Krout, and J. Goldstein) were honored by a TTCP group achievement award for the success of these MFP experiments.[1,2]

RDS

The Technical Cooperation Program also coordinated a series of at-sea tests for Rapidly Deployable Systems (RDS). The first of these (RDS-I) took place in 1997 off the coast of Halifax, Nova Scotia. NRL deployed an L-shaped array (a horizontal leg and a vertical leg) to explore the benefits of such a multidimensional array to MFP. One of the main results was that the two legs could be independently processed and then combined incoherently.[3]

Other Developments 1990–2000

SWellEX-96

Depending on the receiver geometry and the environmental conditions, single-frequency MFP is often plagued by many ambiguous source locations and the MFP equivalent to sidelobes in beamforming. Using data collected during the SWellEX-96 experiment off the coast of San Diego and telemetered back to shore, NRL investigated two techniques designed to help overcome these problems.

First, if several frequencies are available in the source signal, then some type of broadband MFP can result in significant reductions in these ambiguities and sidelobes. NRL developed a matched-phase coherent multifrequency matched-field processor and demonstrated it using SWellEX-96 data.[4] While this approach showed great promise, especially for the very low SNR problem, it was considered at the time to be an intolerable computational burden on an approach that was already considered too computationally complex to be practical.

Second, tracking the source position over time can help distinguish the true source from sidelobes and help maintain contact through periods where the SNR goes through significant fades. The SWellEX-96 data was also used to demonstrate a tracking method known as ambiguity surface averaging.[5]

DARPA Robust Passive Sonar Program

In spring 1998, NRL participated in an at-sea experiment in the Santa Barbara Channel. The main feature of this experiment was a multidimensional array, consisting of five vertical line arrays, deployed by the Robust Passive Sonar (RPS) program under DARPA sponsorship. The main signal processing techniques to be studied on this array were MFP processors. NRL investigated coherent/incoherent approaches to combining the five sub-apertures.

Inversion for Environmental Parameters with Matched-Field Processing

When used as a location technique, MFP can be degraded significantly when there are uncertainties in the ocean acoustic environment. Many papers by NRL scientists and other researchers have investigated these MFP limitations. Interestingly, this sensitivity has actually led to another application for MFP: the determination of environmental parameters. That is, when the source/receiver positions are well known, it is possible to then use MFP to invert for unknown environmental parameters. This is known as matched-field inversion.

One of the first such inversions, conducted by NRL, was for sea ice parameters in the Arctic (Livingston and Diachok).[6] Also, NRL scientists (O. Diachok and A. Tolstoy) were awarded a patent for a technique for synoptic inversion for oceanic sound speed parameters at mesoscale ranges (competing methods are nonsynoptic).[7]

One of the earliest papers on this technique, and one of the most important, was written by an NRL scientist (M. Collins) on the subject of efficient search of the parameter landscape.[8] However, the paper proved more useful than the title might indicate. The method produces eigenvalues and eigenvectors that indicate not only the parameter hierarchy, but also the coupling between parameters. This is extremely valuable information because the data will often not support a unique determination of all parameters.

In 1998 NRL conducted the Key West Inversion Experiment (KWIX-98). This was focused on matched-field inversion for geoacoustic parameters using the L-shaped array used in RDS-I. One of the key results demonstrated was the ability to include elastic parameters in the inversion.

In 2001 ONR supported NRL (S. Chin-Bing and D. King) to conduct the Geoacoustic Inversion Workshop. In this workshop, highly trusted forward propagation models were used to generate synthetic data, and workshop participants were asked to invert this data for the environmental parameters. Not only did NRL conduct the workshop, other NRL scientists participated in the blind tests using the synthetic data.[9]

Later, in 2006, SPAWAR funded a committee to make recommendations for the first Geoacoustic Inversion Toolkit (GAIT). Two NRL scientists (D. King and J. Perkins) were on this committee that reported its findings in a technical report.[10] One of the algorithms in this report has been implemented (by NRL scientist J. Lingevitch) in an ONR Future Naval Capabilities (FNC) project to invert sonobuoy data.

In a separate effort, NRL scientists (L. Fialkowski, T.C. Yang, and K. Yoo) have developed a towed-array inversion technique to determine geoacoustic inversion below the towed array.[11] The algorithm is currently being applied to Fleet data to determine transition suitability.

Active Matched-Field Processing

Although the matched-field concept originated as a passive signal processing method, there is not a conceptual limitation to the passive acoustics case. NRL has made initial efforts to explore the application of matched-field ideas to the active detection problem.[12,13]

Recent Developments

As discussed above, matched-field methods can be degraded by the motion of the source and interferers. One possible approach to this problem is to calculate replicas that take into account the radial velocity of the source. This adds another dimension to the search space, but initial results indicate that significant gains may be possible.

One of the possible drawbacks of MFP is that most of the research has involved vertical apertures. This is because the arrival structure in the vertical is more complex than in the horizontal and this helps distinguish one source location from another. However, given enough aperture, or a planar geometry, there is no reason MFP cannot be applied to purely horizontal arrays. The idea would be to use the array in a conventional manner to make possible detections in different directions and then MFP could be applied to locate or classify the source.

MFP has always been difficult because of the extent of the numerical computations required. However, with a reduction in the dimensionality of the task (for example, not having to search in azimuth) and an increase in parallel computing via graphical processing units (many of the tasks are highly suitable to parallel processing) there has been a recent increase in applications for MFP techniques.

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NRL Research on Acoustic Effects due to Oceanic Internal Waves
by Dr. Marshall H. Orr

Dr. Marshall H. Orr

The Acoustics Division's Acoustic Signal Processing Branch has quantified the impact of shallow water fluid dynamics on both the sound speed field's variability and the performance of horizontal and vertical acoustic hydrophone arrays. This research focused on understanding variability caused by fluid dynamic processes related to the ocean's tide, internal tide, and associated mode 1 nonlinear internal wave packets.

The branch established a firm experimental and theoretical connection between array gain variability, array beam wander, and the spatial and temporal variability of acoustic signal coherence caused by the fluid dynamic processes. The work, initiated in 1994, studied acoustic signals (200–500 Hz frequency band) propagating in continental shelf and slope waters with depths ranging from 50 to 150 m. It expanded on the observations of Weston[1] who related acoustic signal amplitude variability in the 0.431–4.44 kHz frequency band to the presence of internal waves along a 23 km propagation path in the United Kingdom's Bristol Channel (water depth 35 m).

Research included theoretical development, numerical simulations, and the interdisciplinary field experiments required to guide and focus the theoretical, numerical, and analytic efforts. An overview follows.

Theory

A theoretical development by Creamer[2] predicted that the scintillation index of shallow water acoustic signals propagating through internal waves should grow exponentially and not, as predicted by earlier work, saturate with range. This effect is caused by the subbottom absorption (mode stripping) of the acoustic energy that was being continuously coupled into higher order modes by internal wave scatter.

Simulation

Three-dimensional numerical simulations[3,4] of acoustic signals propagating through a sound speed field perturbed by a Garrett–Munk internal wave background field and propagating nonlinear mode 1 internal wave packets of elevation (summertime temperature and salinity structure) were used to estimate a horizontal acoustic array's gain variability and beam wander as a function of array angle as compared to a propagating nonlinear internal wave field's wavenumber vector. The simulations quantified the angular and the time-dependent variability of the array gain and beam wander and were quantitatively similar to field measurements. This work was extended by using the NRL nonhydrostatic coastal ocean model to generate temporally variable three-dimensional sound speed fields.

The three-dimensional simulation effort morphed into a research effort that attempted to develop a method to estimate the temporal and spatial uncertainty in calculated acoustic signal field properties when the temporal and spatial variability of the sound speed field is calculated with nonhydrodstatic models[5] that are initialized and updated with temporally and spatially sparse ocean temperature, salinity, and velocity fields.

Experiments

The Acoustic Signal Processing Branch was the lead planner in two national experiments and a major participant in an international shallow water acoustic experiment. Each experiment focused on a specific aspect of shallow water random media acoustic signal propagation. The first, SWARM (Shallow Water Acoustics in a Random Medium), was focused on measuring the impact of internal waves on the sound speed field and acoustic signal properties. At the time of the experiment, many members of the underwater acoustics community did not think internal tides and associated internal wave packets would impact acoustic signal properties in a measurable fashion. The second experiment, ASIAEX (Asian Seas International Acoustics Experiment), focused on measuring horizontal array gain variability at the shelf break of the South China Sea. This area is considered to be one of the world's most dynamic internal tide/internal wave packet environments. The third experiment, RAGS (Relationship Between Acoustic Array Gain Variability and Shelf Break Fluid Dynamic Processes), measured the response of horizontal arrays in wintertime water mass conditions. This experiment measured, during wintertime conditions, significant horizontal array gain and beam wander in the presence of the shelf slope front and associated nonlinear internal wave packets of elevation.

The SWARM[6] experiment (1995) was conducted during summertime conditions (shallow mixed layer) on the New Jersey Shelf. It was conceived and designed by NRL (Orr) with the objective of measuring the impact of internal waves on the sound speed field and acoustic signal properties. SWARM was performed in conjunction with three academic research institutions, the University of Delaware (Badiey), the Rensselaer Polytechnic Institute (Siegman), and The Woods Hole Oceanographic Institution (WHOI) (Lynch). This experiment definitively showed a correlation between the internal tide/nonlinear internal wave packet perturbation of the sound speed field and the variability in the phase, amplitude, and coherence of acoustic signals (200–500 Hz frequency band) received on vertical acoustic arrays. The experiments used multiple vertical acoustic arrays moored at 10 km increments from moored acoustic sources operating in the 200–500 Hz frequency band. Physical oceanographic measurements included satellite synthetic aperture radar (SAR) imagery of the ocean surface, in situ physical oceanographic measurements using temperature sensors on all arrays, "tow-yo" conductivity-temperature-depth (CTD) measurements, acoustic Doppler current profilers (ADCPs), and marine geophysical bottom property measurements. The approximately 18-day experiment found a persistent midwater duct which minimized acoustic signal interaction with the bottom.

During ASIAEX,[7] NRL and WHOI conducted measurements at the shelf break of the South China Sea from late April to May 2001. The experiment used a horizontal (WHOI) and vertical (WHOI) hydrophone arrays and moored acoustic sources operating at a center frequency of 220 Hz (WHOI, pseudorandom noise [PRN]), 300 Hz (NRL, continuous wave [CW] and linear frequency modulation [LFM]), and 500 Hz (NRL, CW and LFM). The temporal variability of the horizontal array's gain was measured for 37.79 km upslope and 18.9 km cross shelf propagation paths. This collaborative effort between WHOI and NRL correlated horizontal array gain variability to the presence of highly nonlinear internal waves in the acoustic propagation paths. This was a first.

The RAGS experiment[8] was planned and conducted solely by the Acoustic Signal Processing Branch in the late fall/early winter of 2003. RAGS was designed to take data during the summer to winter thermocline transition period. Twenty oceanographic and acoustic arrays were deployed, and "tow-yo" CTD, ADCP, and meteorological data were taken from two research vessels. One 400 m horizontal hydrophone array, three vertical arrays and three acoustic sources were placed along a 30 km propagation path. Well-mixed shelf water overlay a migratory intrusive slope front which moved periodically through the acoustic signal propagation path. This front was perturbed by an internal tide and internal waves of elevation during each flood tide. The resulting internal wave perturbation of the sound speed field generated significant array signal gain variability, array beam wander, and temporally and spatially variable signal coherence. These are the first known measurements of the impact of the shelf/slope front on the performance of horizontal and vertical acoustic hydrophone arrays.

Recent Simulations by the Acoustic Simulation, Measurements and Tactics Branch

The Acoustic Simulation, Measurements and Tactics Branch has recently performed a series of simulations using a primitive equation nonhydrostatic model to generate solitons and the sound speed field to study mode linkage between internal solitons and acoustic fields.[9] Earlier work studied acoustic propagation through internal waves generated by flow over a sill.

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Dedication of the Harvey C. Hayes Memorabilia Collection and Room in NRL Quarters A

NRL Quarters A

Portions of this text are based on an article in the June 7, 1999, issue of *Labstracts*, NRL's internal newspaper.

On May 21, 1999, a ceremony was held at the Naval Research Laboratory to dedicate a Memorabilia Collection and Room in NRL Quarters A in honor of the distinguished NRL scientist Dr. Harvey C. Hayes.

Dr. Hayes was the first superintendent of NRL's Sound Division (now Acoustics Division), serving from 1923, when NRL opened its doors, to 1947. Dr. Hayes pioneered the world of ocean acoustics and sparked a family interest in underwater science that has lasted for three generations. Dr. Hayes is recognized as one of the first persons to accumulate a substantial amount of ocean acoustics data at sea, and was later responsible for one of two operational sonar equipments used by the Navy at the outbreak of World War II.

The development of underwater acoustics at NRL played an important role during World War II, which was noted in a letter to Dr. Hayes by Fleet Admiral Chester W. Nimitz, USN. Further affirmation of the significance of Dr. Hayes' work came from Grand Admiral Karl Doenitz of the German navy. During the latter part of the war, the German submarine commander remarked that "the enemy has rendered the U-boat ineffective, not by superior tactics or strategy, but through superiority in the field of science which finds its expression in the modern battle weapon: detection." Over the years, Dr. Hayes was honored with many scientific awards, a research vessel was christened with his name, and an undersea mountain is also named after him. He died in 1968.

Mr. Gordon Hayes, the son of Dr. Hayes, donated historical memorabilia to NRL in the May 21 ceremony. The collection of medals, papers, and letters, including correspondence from FADM Nimitz, will be placed on permanent display at NRL. The younger Hayes, who was an amateur radio operator as a young man, later worked at NRL from 1942 to 1949 on the identification friend-or-foe (IFF) program and on radar beacons. He then went to work at the Naval Underwater Sound Laboratory (NUSL) — later named the Naval Underwater Systems Center (NUSC) — in New London, Connecticut. There, following in his father's footsteps, Gordon worked on underwater systems such as torpedo countermeasures, sonar systems like the AN/SQS-36, and acoustic environmental measurements.

Mr. Bernard Cole, stepson of Gordon Hayes, also worked for NUSC, from 1960 to 1995. He is a recognized expert in shallow water acoustics and has worked on many programs, including OMAT, which provided measurements of the acoustic environment in the Mediterranean Sea. Mr. James Cole, also a stepson of Gordon Hayes, worked in NRL's Acoustics Division from 1978 to 1986, and along with three other colleagues, is considered a pioneer in fiber-optic sensors and fiber-optic hydrophones for underwater acoustic detection.

Dr. Edward Franchi presents remarks at the dedication of the Harvey C. Hayes Memorabilia Collection and Room at NRL Quarters A on May 21, 1999.

Capt. Bruce Buckley, NRL Commanding Officer (left), Mr. Gordon Hayes (center), and Dr. Timothy Coffey, NRL Director of Research, visit in the Harvey C. Hayes Room in Quarters A.

CHAPTER EIGHT

Guide to the Appendices

Appendices are electronic files on the enclosed CD-ROM

Appendix 1: The Patents of Dr. Harvey C. Hayes

Appendix 2: The Career of Dr. Burton G. Hurdle

Appendix 3: Acoustics Division Staff Listings

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Appendix 7: Acoustics Division *NRL Review* Articles

Appendix 8: Acoustics Division Publications in the *Journal of the Acoustical Society of America* (1933–2008)

Appendix 9: Notes and Transcripts from Oral Interviews Conducted with NRL Acoustics Division Researchers and Colleagues

Appendices

In the preparation of this history of the Naval Research Laboratory Acoustics Division, much supplemental material has been gathered and placed in appendices on a digital medium. This chapter provides a brief explanation of each appendix.

Appendix 1: The Patents of Dr. Harvey C. Hayes

During his long career as a researcher in acoustics, Dr. Harvey C. Hayes, NRL's first Sound Division superintendent, obtained seventy-six patents over a five-decade period starting in 1923. These patents had applications in a diverse set of fields including underwater acoustics, air acoustics, distance and depth measurements, navigation, sound generation and reception, and geological exploration. Included here is a reproduction of his first patent, number 1,470,733 titled "Sound Detection," awarded October 16, 1923.

Appendix 2: The Career of Dr. Burton G. Hurdle

Dr. Burton G. Hurdle has had a particularly long and productive association with the NRL Acoustics Division. He began work in the Sound Division as a research physicist in 1943. Except for a brief period in the late 1940s when he worked in industry, Hurdle was continuously employed as a researcher and manager in the Acoustics Division for nearly seven decades, working under all of the first five Division superintendents. Among Hurdle's research interests were quieting of ship-radiated noise; development of improved sonar domes; scattering of acoustic energy from the ocean bottom, surface, and volume; deep ocean sound propagation; acoustic cavitation; sea water acoustic absorption; and fluctuation and coherence of acoustic fields in the ocean. A particularly important subject of his research was Arctic acoustics. In the 1970s he served as head of the Propagation Branch and Deputy Chief Scientist for Project NEAT (Northeast Atlantic Test). In the 1980s he served as Associate Superintendent of the Division, then later as a Division senior consultant. He was particularly involved as liaison between the Acoustics Division and NRL's national and international research partners and collaborators.

Appendix 3: Acoustics Division Staff Listings (Sampled at Mid-Decades)

For those who may be interested in knowing the names of all Sound/Acoustics Division researchers and staff at various times in the Division's history, this appendix presents a set of full listings of Division employees sampled approximately in the middle of each decade from the 1920s to the 2000s. By perusing these lists one can follow the evolution of the Division's structure, from a small set of researchers (fewer than ten) prior to World War II to a fairly steady size of over one hundred researchers in most later eras.

Appendix 4: Acoustics Division Photographs

The NRL photographic archive contains many photographs illustrating the Acoustic Division's diverse activities. Included here are several hundred representative photographs covering the period from the 1920s to the 2000s, organized roughly in chronological order. These photographs show individual researchers, groups of researchers, field experiment and sea test activities and equipment, laboratory facilities, and retirement and award ceremonies. Included among the earliest photographs are some rare pictures of the first Sound Division superintendent, Dr. Harvey Hayes, taken in the 1920s and 1930s that were provided by his descendants.

Appendix 5: Acoustics Division Major Facilities

The NRL Acoustics Division has numerous facilities that support laboratory and at-sea measurements conducted by Division researchers. Included here is information on each of these facilities from the *NRL Major Facilities 2008* publication (available online at http://www.nrl.navy.mil/media/publications/major-facilities/). The short write-ups include the function, description, and instrumentation for each facility. The facilities discussed are: Acoustic Communications Measurement Systems; High-Frequency Acoustical Flow Visualization Sonar Systems; Instrumentation Suite for Acoustic Propagation Measurements in Complex Shallow Water Environments; Rail-based Broadband Synthetic Aperture Ocean Measurement System; Structural Acoustics In-Air Facility; Laboratory for Structural Acoustics; Shallow Water Acoustic Laboratory; Autonomous Acoustic Receiver System; Salt Water Tank Facility; Underwater Acoustic Time-Reversal Mirror; Shallow-Water High-Frequency Measurement Systems; 300 Hz and 500 Hz Autonomous Acoustic Sources; Sediment Geo-Probe System; Drifting Echo Repeater; Shallow Water Ship Acoustic Signature System; Geoacoustic Physical Model Fabrication Laboratory; and Sono-Magnetic Laboratory.

Appendix 6: Acoustics Division Recipients of Alan Berman Research Publication Awards

Each year since 1969 the Naval Research Laboratory has issued awards to researchers who have published the most significant papers in their division based on their current research. Included here is a full list of these Alan Berman Research Publication Awards received by Acoustics Division researchers in the period 1969 to 2008. These awards are named in honor of Dr. Alan Berman, former NRL Director of Research. The award is quite competitive, given to only one or two papers from each division from a field of several dozen high-quality papers submitted each year for consideration.

Appendix 7: Acoustics Division *NRL Review* Articles

Each year the Naval Research Laboratory publishes a compilation of research articles highlighting key research in each division. These articles, prepared by NRL investigators, provide a good window into the full spectrum of types of unclassified research done at NRL. This publication began in 1967 as the "Annual Report." For a few years it was named either "Highlights" or "Review" (preceded by a numerical year). By 1979 it became simply the *NRL Review*. Each year since 1967 the Sound/Acoustics Division has contributed articles representing some of its most important research efforts. Included here is a complete list of these articles from 1967 to 2008. For completeness, this list also includes many articles submitted by the Underwater Sound Reference Detachment (USRD) near Orlando, Florida, whose researchers were closely allied with colleagues in the Acoustics Division.

Appendix 8: Acoustics Division Publications in the *Journal of the Acoustical Society of America* (1933–2008)

The Acoustical Society of America (ASA), founded in 1929, is the leading professional organization for acoustics researchers in the United States. Each month it publishes numerous peer-reviewed papers in all fields of acoustics including underwater acoustics, physical acoustics, acoustical oceanography, signal processing in acoustics, engineering acoustics, animal bioacoustics, structural acoustics and vibration, and other subfields. The first NRL Sound Division researcher to publish a paper in the *Journal of the Acoustical Society of America (JASA)* was Dr. Harvey C. Hayes in 1933. From 1933 to 2008, NRL Sound/Acoustics Division researchers published nearly 1500 papers in *JASA*. By performing an online search for all such papers (with extensive help from former Acoustics Division superintendent Dr. David L. Bradley) we have assembled what we believe to be a fairly complete chronological list of these *JASA* papers.

Appendix 9: Notes and Transcripts from Oral Interviews Conducted with NRL Acoustics Division Researchers and Colleagues

This appendix consists of notes or transcripts of oral interviews with thirty-four former and current Sound/Acoustics Division superintendents, researchers, and managers or persons who have impacted the work of the Division in important ways. The period of NRL research covered is from the 1940s to the 2000s. Some of the oral interviews were conducted by a former NRL historian, the late Dr. David van Keuren. The remainder of the interviews were conducted by the author, either in person or over the telephone. The total duration of all these interviews is approximately 42 hours. For a few of the interviews conducted by Dr. van Keuren, formal written transcripts were prepared. For the remainder of the interviews, the author has listened to the oral recordings and prepared detailed notes summarizing key points in rough chronological order. In many of the interviews, we gain insights about the researcher's early life and education and learn how they came to start work at NRL. We are then able to follow their career at NRL and learn about why their research was important, the dynamics of working with their NRL colleagues, and the challenges and rewards of their careers at NRL. The original audio recordings from these interviews are on file with the NRL historian, Dr. Leo Slater. The following table lists all interviewees.

NRL Acoustics Division History Project Oral Interviewees List

#	NAME	NRL YEARS	COMMENTS
1	Adams, B.	1968–1985	Researcher at Hudson Laboratories of Columbia University (affiliated with Project Artemis in 1960s); NRL Acoustics Division branch head for Large Aperture Systems Branch (1960s–1980s); then at NORDA
2	Andriani, C.	1968–1975	Researcher at Hudson Laboratories of Columbia University (affiliated with Project Artemis in 1960s); researcher in NRL's Large Aperture Systems Branch (1960s–1970s); later Director of Undersea Surveillance at the Space and Naval Warfare Systems Command (SPAWAR)
3	Berman, A.	1967–1981	Underwater acoustics researcher (Technical Director of Project Artemis) and Director of Hudson Laboratories of Columbia University (1963–1967); NRL Director of Research (1967–1981)
4	Bradley, D.	1985–1993	Researcher and division head in the Acoustics Division at the Naval Ordnance Laboratory, Silver Spring, MD (1960s–1970s); manager for Navy's Long Range Acoustic Propagation Project (LRAPP; late 1970s); manager for Navy mine warfare projects (Navy OP-37, early 1980s); manager at the Office of Naval Research for programs on geology and geophysics, underwater acoustics, and Arctic research (early 1980s); fourth superintendent of NRL's Acoustics Division (1985–1993); technical director of NATO's SACLANT Centre (1994–1996); professor of acoustics and Senior Scientist at the Applied Research Laboratory of Pennsylvania State University (1990s–2000s)
5	Bucca, P.	1993–1999	Researcher for NAVOCEANO and the Maury Center for Oceanographic Research at NRL (affiliated with the Long Range Acoustic Propagation Project (LRAPP) in the 1960s–1970s); later at the Naval Ocean Research and Development Activity (NORDA); then at NRL Stennis Space Center, MS
6	Buchanan, C.	1946–1975	NRL Acoustics Division research leader for deep sea searches; Sonar Systems branch head
7	Cherkis, N.	1968–2000s	Oceanographic bathymetry survey researcher for NAVOCEANO (early 1960s); at Hudson Laboratories of Columbia University (1960s); then in NRL's Acoustics Division (1960–1990s); later in NRL's Marine Geosciences Division (1990s–2000s)
8	Chrisp, R.	1956–1995	Engineer in NRL Acoustics Division's Electronic Applications Branch (1950s); later in the Large Aperture Systems Branch
9	Ciuffetelli, D.	1968–1998; 1999–2000s	Oceanographic technician at Hudson Laboratories of Columbia University (1950s–1960s); then affiliated with NRL Acoustics Division's System Engineering Staff (1960s–1990s); later provided oceanographic sea test support for NRL's Acoustics Division as a contractor employee (2000s)
10	Davis, C.M.	1970–1978	Researcher at the Naval Ordnance Laboratory, Silver Spring, MD (1950s–1960s); professor of physics at American University (1960s); head of the NRL Acoustics Division's Physical Acoustics Branch (1970s)

#	NAME	NRL YEARS	COMMENTS
11	Diachok, O.	1976–1992; 1996–2005	Researcher for NAVOCEANO and the Maury Center for Oceanographic Research (Arctic research specialty; 1960s–1970s); NRL Acoustics Division researcher and branch head: Large Aperture Systems Branch; and Applied Ocean Acoustics Branch (1970s–1990s); Chief Scientist at NATO SACLANT Centre [Supreme Allied Command Atlantic Centre] (1990s); researcher on sound attenuation by fish at NRL's Acoustics Division (1990s–2000s); senior researcher at Johns Hopkins Applied Physics Laboratory (2000s)
12	Dragonette, L.	1963–2002; 2000s	NRL Acoustics Division researcher in Physical Acoustics Branch (1960s–2000s); then an NRL rehired annuitant researcher in the Acoustics Division (2000s)
13	Fitzgerald, R.	1969–1985	Researcher at Hudson Laboratories of Columbia University (1960s); researcher of underwater acoustic propagation effects and signal processing techniques in NRL's Acoustics Division (1960s–1980s); Underwater Acoustics Program Manager at the Office of Naval Research (1980s)
14	Fleming. H.	1968–2000s	Ocean bathymetry survey researcher at Hudson Laboratories of Columbia University (1960s); researcher in NRL's Acoustics Division (1970s); branch head for the Acoustic Media Characterization Branch (1980s–1990s); branch head for the NRL Marine Geosciences Division's Marine Physics Branch (1990s–2000s)
15	Franchi, E.	1975–1988; 1993–2000s	Senior Scientist at Bolt, Beranek and Newman (1970s); researcher and branch head in NRL Acoustics Division's Large Aperture Systems Branch (1970s–1980s); Associate Technical Director and Director of Ocean Acoustics and Technology at NORDA (1980s–1990s); fifth superintendent of NRL's Acoustics Division (1994–2008); NRL's Associate Director of Research for the Ocean and Atmospheric Science and Technology Directorate (since 2009)
16	Frosch, R.	--	Underwater acoustics researcher (Technical Director of Project Artemis) and Director of Hudson Laboratories of Columbia University (1951–1963); then affiliated with the Advanced Research Projects Agency (ARPA); later Assistant Secretary of the Navy for Research and Development (1960s–1970s)
17	Hayes, G.	1942–1949	Son of Dr. Harvey Hayes; worked in NRL Radar Division (1940s), then worked in underwater acoustics at the Navy Underwater Sound Laboratory (NUSL), New London, CT for remainder of his career
18	Hurdle, B.	1943–2005	NRL Acoustics Division researcher (ambient sea noise, scattering, propagation, and Arctic acoustics specialties) and branch head, then Associate Superintendent, and later an NRL rehired annuitant in the Acoustics Division
19	Lackie, K.W.	1960s–2000s	Researcher for NAVOCEANO and the Maury Center for Oceanographic Research at NRL (affiliated with the Long Range Acoustic Propagation Project (LRAPP) in the 1960s–1970s); later an NRL contract employee
20	Love, R.	1965–1967; 1993–1999	Researcher in underwater acoustics at NRL Washington, DC (1960s); then at the Naval Oceanographic Office (NAVOCEANO); and at the Naval Ocean Research and Development Activity (NORDA); then at NRL Stennis Space Center, MS
21	Marshall, S.	1970–1977	Assistant professor of physics at Colorado State University (1960s); researcher of ambient sea noise in the NRL Acoustics Division's Large Aperture Systems Branch (1970s); researcher and head of NORDA's Acoustics Division (1970–1980s); Navy Science Assistance Program (NSAP) adviser and director (1980s); private industry researcher, Bolt, Beranek and Newman (1980s); Lockheed Corporation (1990s)

#	NAME	NRL YEARS	COMMENTS
22	Max, M.	1985–1991; 1996–1999	Researcher in the NRL Acoustics Division's Acoustic Media Characterization Branch specializing in marine geology and gas hydrates (1980s–1990s); researcher at NATO's SACLANT Centre (1990s)
23	McGrath, J.	1962–1988	Researcher in the NRL Electronics Division's Energy Conversion Branch (early 1960s); researcher on ambient sea noise in NRL's Acoustics Division (1960s–1970s); researcher in NRL's Ocean Sciences Division (1980s)
24	Moseley, W.	1968–1983; 1993–1999	Researcher in NRL Acoustics Division's Large Aperture Systems Branch (1960s–1970s); head of NRL's Applied Ocean Acoustics Branch (1980s); Technical Director of NORDA (1980s); Superintendent of NRL's Oceanography Division (1990s)
25	Munson, J.	1968–1984	Underwater acoustics researcher and technical manager at the Naval Ordnance Laboratory (NOL), Silver Spring, MD (1940s–1960s); third superintendent of NRL's Acoustics Division (1968–1984); chief editor for *U.S. Navy Journal of Underwater Acoustics* (1985–1990)
26	Neubauer, W.	1953–1983	NRL Acoustics Division researcher in physical acoustics
27	Nishimura, C.	1980s–2000s	Researcher in the NRL Acoustics Division's Acoustic Media Characterization Branch (1980s–1990s) specializing in biologic acoustics; continued research in the NRL Marine Geosciences Division's Marine Physics Branch (1990s–2000s)
28	Ramsdale, D.	1970s–1990s	Researcher in the NRL Acoustics Division's Large Aperture Systems Branch (1970s); researcher and branch head at NORDA (1970s–1990s); branch head at NRL Stennis Space Center, MS (1990s)
29	Rojas, R.	1970–1995	Researcher at Hudson Laboratories of Columbia University (affiliated with Project Artemis in 1960s); director of the Advanced Undersea Surveillance Program within NRL's Acoustics Division (1970s); NRL's Associate Director of Research (ADOR) for the Oceanology Directorate (1970s–1980s); ADOR for NRL's Systems Research and Technology Directorate (1980s–1990s)
30	Rollins, R.	1964–1984	Researcher in NRL Acoustics Division's Systems Analysis Group
31	Titcomb, F.	1951–1978	Researcher in NRL's Radar Division and NRL's Naval Analysis Staff (1950s–1960s); later a member of the Acoustics Division staff and head of the Systems Engineering Branch (1970s)
32	Vogt, P.	1970s–2000s	Arctic researcher at NAVOCEANO (1960s–1970s); marine geology researcher in the Acoustics Division's Acoustics Media Characterization Branch (1970–1990s); continued research in the NRL Marine Geosciences Division's Marine Physics Branch (1990s–2000s)
33	Votaw, C.	1952–1989	NRL Acoustics Division Arctic researcher; program manager for the Office of Naval Technology (ONT) in the 1980s
34	Yang, T.C.	1979–2000s	NRL Acoustics Division researcher specializing in Arctic acoustics, ambient sea noise, underwater acoustic communications and signal processing techniques (1970s–2000s); branch head, Acoustic Signal Processing Branch (2000s)

Suggestions for Further Reading

Naval Research Laboratory Corporate Publications

The most current issues are available on the NRL web site:
http://www.nrl.navy.mil/media/publications/

NRL Review
http://www.nrl.navy.mil/media/publications/nrl-review/

NRL Fact Book
http://www.nrl.navy.mil/media/publications/fact-book/

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Dr. Fred T. Erskine III was born and raised in the Pittsburgh, Pennsylvania area. He received a B.A. degree from Washington and Jefferson College (1964), an M.S. degree from Worcester Polytechnic Institute (1966), and a Ph.D. degree from the University of Iowa (1976) — all in physics. He has conducted research in biophysics, radio astronomy, and underwater acoustics, and has taught various courses in physics, astronomy, mathematics, and general science at the secondary school and university levels. In 1981 he joined the NRL Acoustics Division as a research physicist. In 2008 he retired from the position of Associate Superintendent of the Acoustics Division. Dr. Erskine is a member of the Acoustical Society of America, the IEEE Oceanic Engineering Society, The Oceanography Society, The American Geophysical Union, The American Astronomical Society (and its Solar Physics Division), The Federation of American Scientists, Sigma Xi (Life Member), and Pi Delta Epsilon (Journalism). He is presently affiliated with Sotera Defense Solutions, Inc.

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REVIEWED AND APPROVED
NRL/PU/7100--13-570
RN: 13-1231-1694
August 2013

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NAVAL RESEARCH LABORATORY

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APPENDICES

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#	Patent ID Number	Patent Title	Patent Awardee(s)	Date Filed	Date Awarded
1	1,470,733	Sound Detection	Harvey C. Hayes	25-Jun-1919	16-Oct-1923
2	1,483,547	Method of Determining Distances	Harvey C. Hayes	25-Jun-1919	12-Feb-1924
3	1,512,222	Follow-Up Mechanism	Harvey C. Hayes	2-Jan-1924	21-Oct-1924
4	1,525,182	Sound Transmitter and Receiver	Harvey C. Hayes	7-Jul-1923	3-Feb-1925
5	1,530,176	Speed Control Apparatus	Harvey C. Hayes	30-Jun-1924	17-Mar-1925
6	1,532,108	Determination of Wave Energy Direction	Harvey C. Hayes	25-Jun-1919	31-Mar-1925
7	1,551,105	Sound Reproducer	Harvey C. Hayes	2-Mar-1925	25-Aug-1925
8	1,557,161	Sound Producer	Harvey C. Hayes	2-Mar-1925	13-Oct-1925
9	1,565,361	Method and Apparatus for Determining the Direction of Wave Energy	Harvey C. Hayes	31-Jan-1922	15-Dec-1925
10	1,577,254	Sound Reproducer	Harvey C. Hayes	9-Jan-1924	16-Mar-1926
11	1,584,451	Method and Apparatus for Transmitting and Reproducing Sounds	Harvey C. Hayes	7-Jul-1923	11-May-1926
12	1,593,972	Apparatus for Determining Ranges by Means of Sound Waves	Harvey C. Hayes	30-Jun-1924	27-Jul-1926
13	1,624,946	Microphone	Harvey C. Hayes	7-Jun-1923	19-Apr-1927
14	1,632,331	Submarine Sound Receiver	Harvey C. Hayes	2-Jan-1924	14-Jun-1927
15	1,632,332	Electromagnetic Sound Reproducer	Harvey C. Hayes	28-Sep-1925	14-Jun-1927
16	1,636,510	Directive Sound Transmission	Harvey C. Hayes and Max Mason	25-Jun-1919	19-Jul-1927
17	1,649,113	Submarine Sound Transmitter	Harvey C. Hayes	9-Jan-1924	15-Nov-1927

#	Patent ID Number	Patent Title	Patent Awardee(s)	Date Filed	Date Awarded
18	1,671,719	Method and Apparatus for the Transmission of Fluids Through Pipes or Conduits	Harvey C. Hayes	3-Sep-1921	29-May-1928
19	1,681,982	Directive Sound Transmission	Harvey C. Hayes and Max Mason	25-Jun-1919	28-Aug-1928
20	1,692,119	Method for Measuring Distance	Harvey C. Hayes	31-Jan-1922	20-Nov-1928
21	1,704,084	Sound Reproducer	Harvey C. Hayes	4-Jan-1927	5-Mar-1929
22	1,709,573	Method and Apparatus for Measuring Distance	Harvey C. Hayes	31-Jan-1922	16-Apr-1929
23	1,729,383	Apparatus for Transforming Sound into Electrical Energy	Harvey C. Hayes	30-Jun-1924	24-Sep-1929
24	1,729,579	Apparatus for Fluid Propulsion by Vibratory Diaphragms	Harvey C. Hayes	23-Oct-1926	24-Sep-1929
25	1,729,595	Distance Measuring Device	Harvey C. Hayes	23-Mar-1927	24-Sep-1929
26	1,742,704	Apparatus for Receiving and Determining the Direction of Submarine Sounds	Harvey C. Hayes	12-Aug-1924	7-Jan-1930
27	1,743,071	Sound Receiver	Harvey C. Hayes	17-Aug-1927	7-Jan-1930
28	1,749,284	Apparatus for Transforming Sound into Electrical Energy	Harvey C. Hayes	30-Jun-1924	4-Mar-1930
29	1,749,285	Apparatus for Transforming Sound into Electrical Energy	Harvey C. Hayes	30-Jun-1924	4-Mar-1930
30	1,751,035	Acoustical Wave Filter	Harvey C. Hayes	3-Mar-1927	18-Mar-1930
31	1,755,583	Sound Receiver	Harvey C. Hayes	17-Aug-1927	22-Apr-1930
32	1,757,938	Acoustic Instrument	Harvey C. Hayes	13-Apr-1925	6-May-1930
33	1,784,439	Method for Making Subterranean Surveys	Harvey C. Hayes	15-May-1922	9-Dec-1930
34	1,787,536	Method and Apparatus for Determining Gravity Variations	Harvey C. Hayes	21-Nov-1928	6-Jan-1931

#	Patent ID Number	Patent Title	Patent Awardee(s)	Date Filed	Date Awarded
35	1,792,013	Apparatus for Determining the Force of Gravity at Sea	Harvey C. Hayes	16-Aug-1927	10-Feb-1931
36	1,814,444	Geophysical Method and Apparatus	Harvey C. Hayes	15-May-1928	14-Jul-1931
37	1,847,243	Measuring Apparatus	Harvey C. Hayes	11-Jul-1925	1-Mar-1932
38	1,860,740	Oscillograph	Harvey C. Hayes	15-May-1928	31-May-1932
39	1,892,147	Vibration Detector	Harvey C. Hayes	23-Sep-1927	27-Dec-1932
40	1,900,015	Method and Apparatus for Sound Ranging	Harvey C. Hayes	4-Jan-1927	7-Mar-1933
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Patented Oct. 16, 1923. **1,470,733**

UNITED STATES PATENT OFFICE.

HARVEY C. HAYES, OF NEW LONDON, CONNECTICUT, ASSIGNOR TO SUBMARINE SIGNAL COMPANY, OF PORTLAND, MAINE, A CORPORATION OF MAINE.

SOUND DETECTION.

Application filed June 25, 1919. Serial No. 306,688½.

To all whom it may concern:

Be it known that I, Harvey C. Hayes, a citizen of the United States, residing at New London, in the county of New London and State of Connecticut, have invented new and useful Improvements in Sound Detection, of which the following is a specification.

The present invention relates to sound detection. One feature of the invention relates to an arrangement of a plurality of microphones spaced in a row and provided with compensated connections between the microphones and the ear for determining the direction of the sound by bringing the impulses from the several microphones into phase. Other features of the invention relate to the structure of the microphone housing and to a towing device for trailing the microphones behind a ship. Still other features of the invention relate to certain arrangements and combinations of parts hereinafter more particularly pointed out, the advantages of which will be apparent to one skilled in this art from the following description.

Referring to the drawings, Fig. 1 is a diagrammatic view showing a multi-unit microphone line with compensated connections. Fig. 2 is a side elevation of a sound detecting device usually designated as an eel. Fig. 3 is a side elevation in section of the head of the eel. Fig. 4 is a vertical section through the eel at one of the microphone units. Fig. 5 is an elevation partly in section of the tail of the eel. Figs. 6 and 7 are side and end elevations respectively of one of the microphone housings. Fig. 8 is a vertical section through the microphone housing. Fig. 9 is an end elevation of the microphone. Fig. 10 is a side elevation partially in section of the microphone. Fig. 11 is a diagrammatic view illustrating a multi-unit microphone line as applied to the side of a ship.

The direction of a sound source may be determined by the binaural sensation of hearing. If the sound waves reach the right ear first, the sound is heard on the right side. If the sound waves reach the two ears at the same time, the sound is heard in a direction at right angles to the line joining the two ears, that is to say either straight ahead or straight behind. The direction of sound travelling through the water may be similarly determined by binaural listening. If two submarine receivers are spaced about 5 ft. apart in the water and are connected respectively to the right and left ear of the observer and the sound waves strike the right receiver first, the sound will be heard as coming from the right by the observer. If the two submarine receivers are turned about each other so that the line joining them is broadside to the sound, the sound will appear to be centered in the head of the observer or appear to be heard directly ahead or behind. The manipulation of the submarine receivers to bring the sound waves to the ears at the same time is known as binaurally centering the sound and is used to determine the direction from which the sound is coming. The direction of the sound may be determined binaurally by having the two receivers in a fixed position in the water and compensating the paths of the received waves from the receivers to the ears of the observer. For example, if two submarine receivers are spaced apart under water and are connected to the right and left ears of the observer respectively and the sound approaches from such a direction as to strike the right hand receiver first and consequently appears to be heard at the right, the sound may be brought to a binaural center by introducing in the connection between the right receiver and the right ear, enough time lag so that the impulses from the two receivers will reach the two ears of the observer at the same time and thus give the impression that the sound is heard directly ahead. In case the two receivers are connected to the ears by air columns, one air column may be lengthened to introduce the necessary time lag for binaural centering. By means of a suitable calibrated scale connected with the means for introducing time lag into the connections, the angular direction of the sound waves with respect to the base line between the receivers may be read directly.

If a number of receivers are employed, the direction of the sound may be determined by focusing, by means of which the sound is heard at a maximum when the sound waves are received by the several receivers and brought together in phase at the ear. Suppose a number of receivers are spaced in a straight row and that the receivers are all connected to the ear by wave conducting leads or paths requiring the same time for the waves to pass over them. Then if a sound wave strikes the row of receivers broadside the sound waves as brought to the ear from the several receivers will be in phase and the sound heard will be at a maximum. If the sound strikes the row of receivers at an angle the sound waves from the different receivers will reach the ear out of phase and the intensity of the sound heard will be cut down by interference. The direction of the sound may be determined by bodily turning the row of receivers until the sound is a maximum. The same effect may be had by having a row of receivers fixed in direction and introducing the proper amounts of time lag into the several leads from the receivers to the ear so that a wave front which strikes the row of receivers at an angle will have the waves conducted along the leads from the several receivers brought into phase at the ear.

The direction of sound may be determined by combining focusing with binaural centering, by having a row of receivers with some of the receivers connected to one ear and others connected to the other ear.

In determining the direction of submarine sounds it is desirable to employ in many cases microphones as the sound receiving devices. If microphones are employed they may be installed in a device towed from the ship and thus be considerably isolated from the ship's own noises, the connections to the compensator being made through a cable. If the listening devices are mounted on the ship's hull or within any of the various inside tanks of the ship, microphones have an advantage in that they can be readily installed and in that the compensator by which the direction of the sound is determined may be placed anywhere on the ship and at a distance from the microphones.

Referring to the drawings, Fig. 1 shows diagrammatically a row of microphones and compensator connections for determining the direction of a sound wave.

The microphones indicated by numerals 1 to 12 inclusive are disposed in a row with predetermined spacing between the microphone units. The row of microphones is fixed in direction, as for example being arranged longitudinally in a device towed behind the ship or arranged in a row along the ship's hull. The microphones are connected to a compensator indicated generally by reference numeral 13. The compensator has a number of receivers indicated by reference characters 1^a, 2^a, 3^a, etc., to 12^a. These receivers resemble the ordinary telephone receiver and convert the undulations of the electric microphone current into sound waves. One of the receivers is shown diagrammatically in cross section as comprising a magnet 30 which actuates the diaphragm 31 which causes sound waves in the air column below it. The microphones have a common connection 14 which includes the battery 15. The microphone is connected to its receiver 1^a by means of the lead wire 1^b and the transformer 1^e. The other microphones are similarly connected with their respective numbered receivers. The receivers 1^a, 2^a, 3^a etc. set up sound vibration in the air column in the telescopic tubes 1^c, 2^c, 3^c etc. The ends of the telescopic tubes are connected to a lever 20 pivoted at 21 so that the lengths of the air columns in the tubes 1^c, 2^c, 3^c etc. may be varied. The several telescopic tubes are connected by leads 1^d, 2^d, 3^d etc. to the collecting tubes 22 and 23 and thence to stethescope ear pieces 24 and 25 for the left and right ears respectively. The several leads 1^d, 2^d, 3^d are of equal length, as are the tubes 22 and 23.

In constructing a microphone line as here indicated the microphones are first matched, that is, the microphones are tested and microphones having the same time constants are chosen so that if sound waves which are in phase strike the several microphones simultaneously the electric currents set up in the respective microphone circuits will also be in phase. If the time constants of the microphone are not the same then the currents set up by one microphone will lag behind or be in advance of the currents in the other microphones and the waves cannot readily be brought into focus by the compensator. Also microphones having a sound intensity as nearly alike as possible are chosen. When the compensation is accomplished by air columns of varying length as shown in the diagram, the electrical connections from the several microphones to the receivers in the compensator should have the same electrical time constants so that varying lag will not be introduced into the different electric circuits.

Assume that the sound comes from a direction at right angles to the row of microphones 1–12 inclusive. Then the sound waves as collected by the several microphones will be in phase and if the lever 20 is turned to a horizontal position so that the telescopic tubes 1^c, 2^c, etc. are of the same length, the sound waves will be brought into focus at the ears of the observer, so that the sound will be heard as a maximum. Also the time of arrival of the waves at the right and left ears will be the same so that sound will appear to be binaurally centered. The observer noting the position of the lever 20 will therefore know that the sound is coming in a direction at right angles to the base line of the row of microphones.

Suppose, however, that the sound is coming at an angle, other than perpendicular, the sound wave having a wave front as indicated by the dotted line S in Fig. 1. The sound wave will strike the microphones 1, 2, 3, etc., successively so that if the telescopic tubes 1^c, 2^c, etc. are of the same length, the sound waves will interfere and a maximum sound will not be heard. Moreover since the wave front strikes the left hand side of the line first, the sound will not be binaurally centered but will appear to be in the left ear. The sound at the ears may however be brought to a maximum and also binaurally centered by turning the lever 20 and thereby lengthening the telescopic tubes at the left hand end of the lever and shortening them at the right hand end. The ratio of the velocities of sound in air and water is approximately 23 to 100. The sound wave in water will be delayed in arriving at the microphone 2 after striking microphone 1 by the time necessary to travel the distance d. If the length of the air column in the telescopic tube 1^c is increased over the length of the air column in the telescopic tube 2^c by an amount $23/100\ d$, then the sound waves striking the microphones 1 and 2 will be brought into phase by the air columns in the telescopic tubes. The same is true of the sound waves striking the other microphones, if the several telescopic tubes are relatively lengthened or shortened in respect to each other as shown in the diagram, and the waves of the wave front S as received at the several microphones will all be brought into phase at the ears and the sound will be heard as a maximum. Also since the sound waves are in phase at the two ears the sound will be binaurally centered. By calculating the lengths of the air columns and by a suitable calibrated scale 40 adjacent to the lever 20, the observer may read directly the angle of incidence of the sound with respect to the base line of the row of microphones.

The action of the plurality of microphones is not only to bring the sound waves from the source set upon by the compensator into phase and thereby cause this sound to be heard with a maximum intensity, but is also to diminish the sounds heard coming from sources at other angles. Suppose for example the compensator is set to listen to sound coming from a particular source and having the wave front S as shown in Fig. 1, and suppose that sound from a source located at another angular bearing is also present. The sound impulses from the second sound source as received by the several microphones and brought together at the collecting tubes will be out of phase and therefore will tend to neutralize each other by interference and such sound will be heard but faintly by the observer, and will cause slight, if any, interference in making of a binaural setting on the first sound. The ability to eliminate sounds from extraneous sources which is possessed by a line having several microphones from which the sound impulses are combined, gives it a distinct advantage over a listening device in which but a single microphone is connected to each ear, because in the latter case sounds from all directions are heard with the same intensity. This suppression of other sounds is of particular advantage in submarine listening for determining the direction of a particular ship when there are other ships in the sound field. Moreover, a listening device in which a plurality of microphones are connected to each ear has a range in any desired direction greater than a listening device in which but a single microphone is connected to each ear for the reason that the bringing of the impulses from the several microphones into phase increases the amplitudes.

For the sake of explanation, an electric-air compensator having telescopic tubes is illustrated in Fig. 1, because the principle of compensation can best be explained by it.

The necessity of properly matching the microphones so that they will have substantially the same time constant should be emphasized in constructing a multi-unit focusing microphone line. It is apparently much more important that the microphones be matched to have the same time constants than it is that the microphones should all be of the same loudness.

In addition to having the microphones matched, the microphone housings should be designed so as not to introduce unequal time constants in transmitting the sound from the water through the flexible diaphragms to the microphones, and so the several receiving units, each including the microphone and its sound receiving diaphragm, will have the same time constants. If all the units are properly matched the currents set up by the microphones will all be in phase in case the wave front strikes all the microphones simultaneously, or will lag behind each other by equal amounts in case the wave front comes at such an angle as to strike the several microphones successively. The microphones and housings illustrated in Figs. 6 to 10 have been found by repeated experiments to be capable of successful use in making a microphone line in which the several units have the same time constants. In Figs. 2 to 10 the microphones are shown as arranged in a line carried by a device designed to be towed from a ship.

The device as a whole is indicated at 50 in Fig. 2 and is ordinarily termed an eel. The eel consists of a hollow flexible tube 51 of rubber. In practice, eels containing twelve microphones have been made about fourteen feet long with twelve inch spacing between the microphones and of soft rubber tubing about four inches in outside diameter. The eel is provided with a stream line nose or head 2 and is towed through the water by a cable 53 which contains the electrical leads to the microphones. In case twelve microphones are used, the cable should contain thirteen leads, one being a common connection and the other twelve being connections to the individual microphones. A stuffing box 54 is provided in the head of the eel to take the strain of the cable and to prevent leak. The forward end of the rubber tubing 51 which forms the eel body has an internal flange 55 which fits in a groove, formed in a rearward extension of the eel head. The rubber is securely held in this groove by a metal band 56. The eel is provided with a tail (60) secured to the end of the rubber body in the same way as the head. The upper fin 61 of the tail is hollow and contains air while the lower fin is weighted. This keeps the eel from turning over in the water and thus it prevents rolling carbon in the microphones. The hollow space inside of the rubber tube 51 is filled with water, and when so filled the eel has a neutral buoyancy so that it may be towed through the water without tendency to go to the bottom or come to the surface. It is found that when the eel is towed at speeds from ten to fifteen knots the weight of the cable will keep the eel below the surface. At speeds above this it is advisable to add extra lead weights to the cable. In ordinary practice the eel is towed with about four hundred feet of cable out from the ship.

The microphone housings indicated generally by reference numerals 70 are spaced along inside of the eel body. Each microphone housing 70 comprises a cup-like body of india rubber 71 generally of a cylindrical form provided with a plurality of radial flanges 72 in which are formed a circumferential groove 73 which does not, however, reach the bases of the flanges. The housing 70 is held in the eel body as shown in Fig. 4. An internal rib 74 formed on the interior of the rubber body tube 51 fits into the circumferential groove 73 in the flanges 72. This holds the housing 70 in place. A metal band 75 countersunk into the outside of the eel body, securely retains the rib 74 in position in the groove 73. The spaces between the rib 74 and housing 70 between the flanges 72 permit the conductor wires to be run by the several housings 70 also permit the water to run by the housings when the eel body is being filled.

In the eel shown in Fig. 2 there are twelve microphones spaced twelve inches apart, the position of the microphones being indicated by the twelve metal bands 75.

When the eel is assembled the rubber tube 51 is placed in an outer iron pipe of an inside diameter about an inch greater than the outside diameter of the tube 51. The ends of the tube project a few inches from the ends of this iron pipe and are turned over the ends of the pipe and the air is exhausted between the surrounding iron pipe and rubber tube, thus expanding the tube. The housings 70 are held properly spaced by long, slender, iron rods lying between the flanges 72 and are then put in the expanded rubber tube. The air is then allowed to re-enter between the tube 51 and the surrounding iron tube, and the ribs 74 shrink into place around the housings 70 and the iron spacing rods are removed. The tube 51 is then stretched lengthwise which reduces its thickness somewhat, and the metal bands 75 are slipped in place. Then the head and tail are applied.

In assembling the microphone housings 70, the cup shaped rubber body 71 is drawn over a brass shell 80. This brass shell has a cylindrical shape as shown in Fig. 8, being open for its full diameter at one end and having its edges turned in at the other end to form the short inwardly extending flange 85. This flange is conical in shape being slightly inclined to a plane at right angles to the axis of the shell 80, so that the edge of the flange extends slightly to the left as shown in Fig. 8. The thick end 81 of the rubber body 71 forms the sound transmitting diaphragm. A metal microphone support 82 is molded into the rubber and carries the microphone 83 which is of the inertia type. The microphone is shown in detail in Figs. 9 and 10. The carbon plate is rigidly connected with the stud 91 which screws into the metal support 82 so that the plate 90 is vibrated by the rubber diaphragm 81. The metal microphone shell 92 is supported from the stud 91 by means of the double mica diaphragms 93 and 94. The metal shell 92 carries the second contact plate 95 of the microphone cell. The carbon granules 96 lie between the plates 90 and 95. The metal shell 90 with the plate 95 forms the inertia element of the microphone. When the diaphragm 81 vibrates under the received sound the contact plate 90 vibrates with it. The rest of the microphone, however, tends to remain stationary because of its inertia, and the carbon granules 96 are subject to alternate pressure and release thus giving the resistance variations to set up undulating currents in the microphone circuit.

The several microphone housings are all of uniform quality and construction. The method of assembly insures that the diaphragms 81 are all under the same tension and have the same time constants. In assembling the housing the brass shell 80 is heated and covered with a rubber cement. Then the rubber casing 71 is drawn over the brass shell and the edge of the flange 85 pressed hard against the inside of the diaphragm 81.

The operator grasps the flanged part of the rubber and in pulling hard against the flange 85, stretches the rubber and reduces its thickness near the flanged end of the shell. While thus stretched a continuous metal band 86 is slipped over the rubber, which is then released. When released the rubber contracts longitudinally and expands against the band which thus firmly grips the rubber against the brass shell. The brass shell is preferably formed with slight beads spun in it to give a better grip in the rubber. The rubber between the band 86 and the flanged end of the brass shell is left under a certain amount of tension, which holds the inside of the diaphragm firmly seated against the flange 85. It is found that in applying the metal bands in this manner the diaphragms are put under a more uniform tension than is the case when a split metal band is applied and its ends drawn together and secured. In the latter case the rubber is drawn around with the band as it is clamped and fits the diaphragm under a certain amount of distortion. The stretching of the rubber and the application of the continuous ring in the manner described not only gives a uniformly distributed tension over the individual diaphragm but secures a uniformity among the diaphragms of the several housings.

The flange 85 may be omitted, in which case the edge of the diaphragm is drawn against the end of the cylindrical body of the shell 80. The internal vibrating area of the diaphragm is that of the shell 80.

It is found that with the rubber diaphragm drawn against the end of the shell in the manner above described with or without the flange 85, the diaphragms of the several housings are uniformly seated against the brass shell and have a substantially equal tension, pitch and time constants.

The flange 85 is usually preferred in housings for submarine listening devices, because the flange 85 supports the diaphragm 81 and enables it to withstand the hydrostatic pressure of deeper submergence without rupture. It also gives a higher natural frequency to the diaphragm and eliminates the lower pitched components of received sound which are characteristic of so-called water noise, causing the higher pitched sound components which are characteristic of the rythm of a ship's propeller to be heard more prominently.

After the housings are assembled, the microphones 83 are screwed on the supports 82. These microphones have previously been tested and are all selected to have the same time constants and approximately the same loudness. It is found that by using previously matched inertia microphones mounted as described, it is possible to get substantially the same time constants for each unit and that much greater uniformity can be thus obtained than has been obtained with the use of the pressure type of microphone in which some contact has to be provided for the stationary microphone plate.

The microphone is enclosed in an air space 100 in the housing which is sealed up water tight by means of a sandwich packing. This sandwich packing comprises two brass plates 101 and 102 with a layer 103 of soft india rubber between them. The plates 101 and 102 are pressed together by means of a screw 104 and nut 105 expanding the rubber 103 into a tight fit against the metal shell 80 and around the lead wires 106 and 107. An internal rib 108 is formed on the metal shell 80 and the brass plate 101 seats against this abutment. The water pressure against the packing tends to crowd the plate 102 inwardly still further compressing the rubber layer 103 so that the greater the pressure the better the seal.

One of the leads 107 is the common ground connection indicated diagrammatically at 14 in Fig. 1, while the other lead from the microphone forms one of the individual leads indicated in 1^b, 2^b, etc., in Fig. 1.

The eel when towing behind the ship has a base line parallel to the ship's keel and by a suitably calibrated compensator the direction of the sound can be determined.

While the eel shown in the drawing has twelve microphones any number of microphones may be used. For example so-called two spot eels having two microphones one at the head and the other at the tail, have been built.

If a single eel is towed the readings on the compensator will indicate the angle of the sound to the base line of the eel, but with a single eel this angle may be either from the port or starboard side. The port or starboard ambiguity may be eliminated by towing two eels spaced several feet apart with units in both eels connected to a compensator, as will be readily understood by one skilled in this art.

The soft rubber walls of the eel allow the sound waves to pass freely from the surrounding water to the body of water within the eel and to the microphone housing diaphragms. The soft rubber eel body is free from resonance and does not change the character of the sound. Neither does it introduce resonant sounds of its own when towed through the water, as is often the case with rigid towed devices.

The eel is flexible throughout its length and follows without yawing the pull of the towing cable. The flexibility prevents skidding or yawing to one side when subject to cross currents or swirls in the water. This makes it possible to tow two eels spaced apart five or six feet and have them run side by side with substantially constant spacing and not cross each other and tangle the cable lines.

The flexibility of the eel renders it more rugged to rough handling than rigid towed devices, as there is nothing to be permanently bent out of alignment, and the flexible eel body will always straighten out when towed and run true in the water, whereas if a rigid towed device is bent even slightly, it will yaw to one side when towed at the end of a cable.

The eel has a long stream line body and offers for its cubical capacity a minimum of resistance to towing. It is free from water noise when towed. It has nothing to catch obstruction as it can be dragged through seaweed or along the bottom without catching.

The head, the tail, the microphone housings, and the body of the eel when filled with water each have a neutral buoyancy, which makes the eel of a neutral buoyancy, throughout its length and gives it a uniform lineal density. This causes it to maintain a horizontal position in the water even when drawn slowly along, as for example from a ship drifting in a slight wind. The uniform and neutral linear density of the eel with respect to the sea water prevents jarring of the various parts with respect to one another due to unequal acceleration of the various parts.

While the microphone lines have been illustrated as arranged in a towed device such as an eel, it is obvious that a multiple microphone line may be otherwise constructed. For example a plurality of microphones 120 may be mounted as shown in Fig. 11 along the side of a ship's hull 121.

The present invention is not limited to its illustrated embodiment but may be embodied in other structures within the scope of the following claims.

I claim:

1. A device for determining the direction of sounds comprising a plurality of spaced microphones and compensated connections for collecting the impulses from the microphones and bringing them to the ear in phase so that the impulses from the several microphones reinforce each other and produce a maximum.

2. A device to determine the direction of sounds comprising a row of spaced microphones and connections leading from a plurality of microphones at one end of the row to one ear and from a plurality of microphones at the opposite end of the row to the other ear, said connections having provision for the introduction of progressive time lag therein so that the impulse coming from several microphones may be brought into phase and produce a maximum and a binaural centering.

3. A device for determining the direction of sounds comprising at least four spaced microphones, and compensated connections comprising paths variable in length leading from at least two of the microphones to each ear and serving to bring the impulses from the several microphones into phase at the ears so as to produce both a maximum and a binaural centering.

4. A device for determining the direction of sounds comprising a row of spaced microphones, connections from the microphones for collecting the impulses from the several microphones and bringing them together and into phase at the ear so as to produce a maximum, including means of introducing graduated time lag into said connections to compensate for an earlier arrival of the sound at their respective microphones.

5. A submarine sound detection device comprising an elongated flexible body arranged to be towed through the water and containing a plurality of microphones.

6. A submarine sound detecting device comprising a long, hollow rubber tube arranged to be towed at the end of a cable and containing one or more sound detecting devices.

7. A submarine sound detecting device comprising a long flexible rubber tube filled with water and containing one or more sound detecting devices.

8. A submarine sound detecting device comprising a long flexible rubber tube having a series of internal ribs formed thereon, and a series of microphone housings enclosed in the rubber tube and having grooves engaged by the ribs.

9. A submarine sound detecting device comprising two members one a long flexible rubber tube, the other a plurality of microphone housings therein, a circumferential rib on one of said members, and a corresponding circumferential groove on the other of said members to hold them in relative position, and a band on the outside of the tube to hold the rib and groove in engagement.

10. A submarine sound detecting device comprising an outer casing, and a microphone housing therein having radially extending flanges engaging the outer casing and leaving spaces between the outer casing and housing.

11. A microphone housing for submarine sound detection, comprising a hollow rubber casing having a rubber body reinforced with metal on the sides and at one end, leaving one end free to form a sound transmitting diaphragm.

12. A microphone housing for submarine sound detection comprising a cylindrical rubber body having a plurality of ribs formed thereon and adapted to act as the mountings for the microphone housing.

13. A microphone housing for submarine

sound detection comprising a hollow flexible body having an opening therein provided with an internal abutment, and a water-tight closure for the opening comprising an inner plate seated against the abutment, a layer of flexible water-proof packing materia[1], and an outer plate, and means for forcing the plates together to compress and laterally extrude the packing material, the pressure of the water on the outer plate acting also to compress the packing material and make a tighter closure.

14. A microphone housing comprising a rigid shell having an open end and a cup shaped rubber body having a diaphragm at its end drawn over and against the end of the metal shell.

15. A microphone housing comprising a rigid internal shell having an open end with an inwardly extending flange restricting the area of the open end, and a cup-like rubber housing drawn over the shell and against the flange, the portion of the rubber housing which covers the opening forming a sound transmitting diaphragm.

16. A microphone housing comprising a shell having an open end and a rubber housing having a diaphragm fitting over the open end of the shell and means for holding the diaphragm seated under tension of the rubber against the end of the shell.

17. A device of the kind described comprising a shell having an open end, a cup-shaped rubber housing surrounding said shell in close contact therewith, the closed end of said rubber housing pressing against the end of said shell and forming a diaphragm, and a rigid band surrounding the rubber housing and holding it against the outside of the shell whereby the diaphragm will be maintained in p'ace against the shell.

18. The method of assembling a cup-shaped rubber housing over an internal rigid shell which consists in stretching the housing over the shell with its end pulled hard against the end of the shell thereby longitudinally elongating and reducing the thickness of the portion of the housing around the shell, slipping a band over the housing while stretched, and releasing the tension on the housing thus allowing it to expand and be gripped between the shell and the ring.

19. A submarine sound detecting device comprising a towed elongated flexible body having a substantially uniform linear density.

20. A submarine sound detecting device comprising a towed elongated flexible body having throughout its length a substantially neutral buoyancy with respect to the water.

HARVEY C. HAYES.

Oct. 16, 1923. **1,470,733**

H. C. HAYES

SOUND DETECTION

Filed June 25, 1919 3 Sheets-Sheet 1

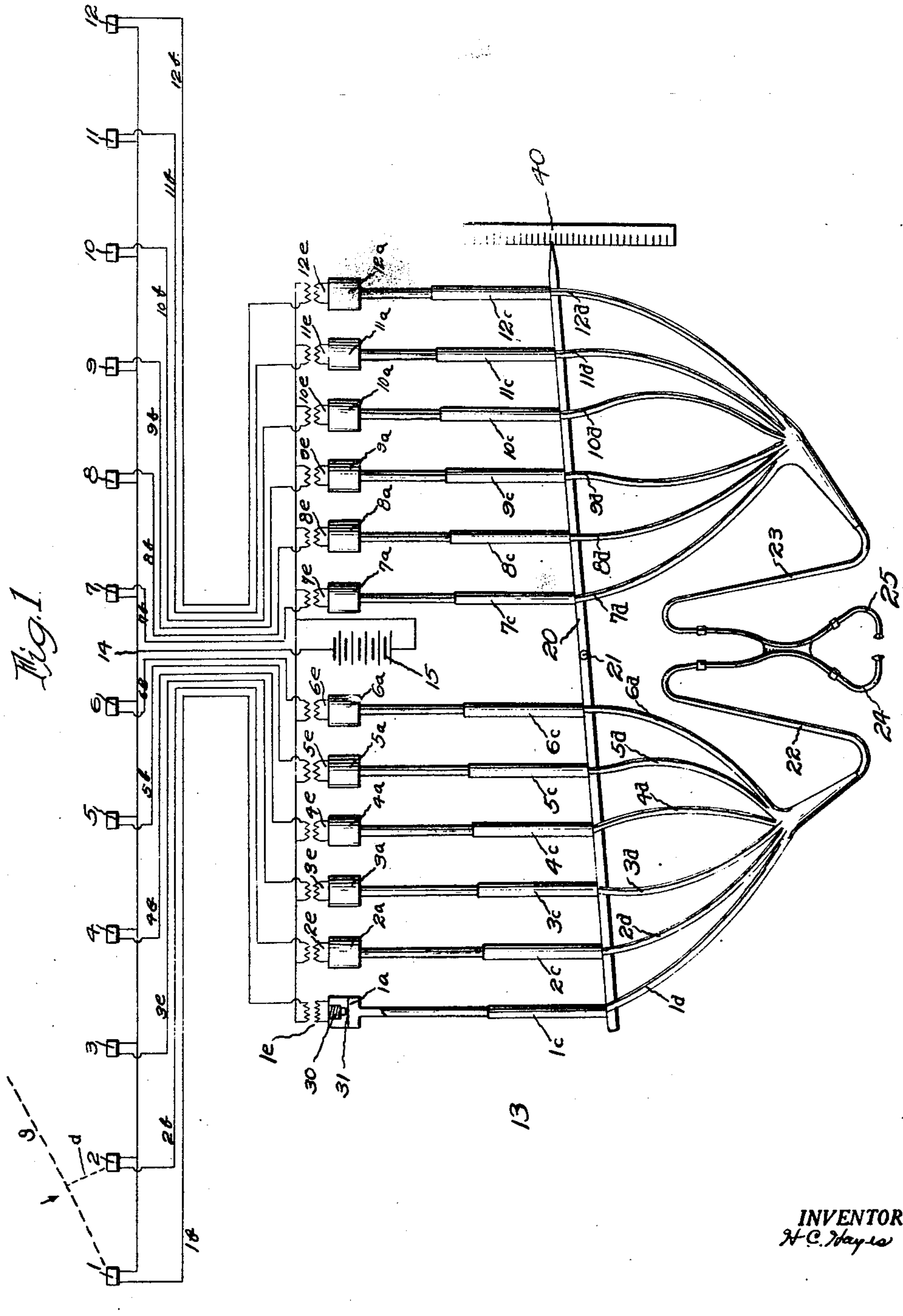


Fig. 1

INVENTOR.
H. C. Hayes

Oct. 16, 1923. **1,470,733**

H. C. HAYES

SOUND DETECTION

Filed June 25, 1919 3 Sheets-Sheet 2

Fig 2.

Fig. 3.

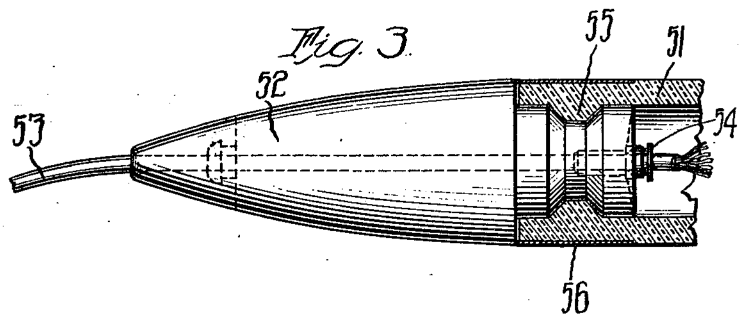


Fig 4.

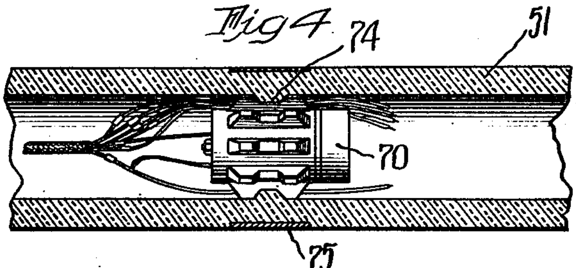
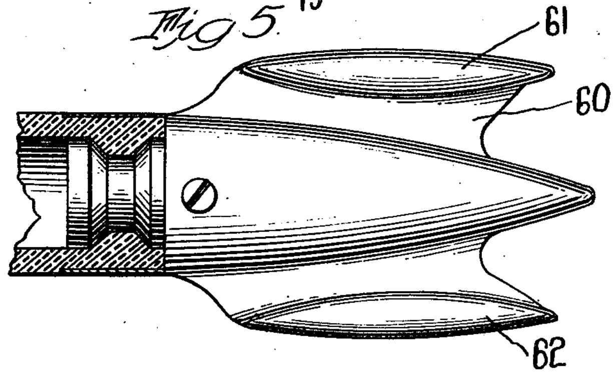


Fig 5.



INVENTOR.
H. C. Hayes

Oct. 16, 1923. **1,470,733**

H. C. HAYES

SOUND DETECTION

Filed June 25, 1919 3 Sheets-Sheet 3

FIG. 6.

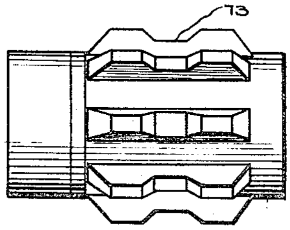


FIG. 7.

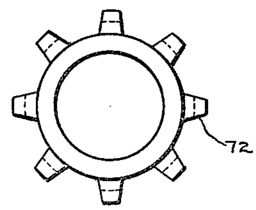


FIG. 8.

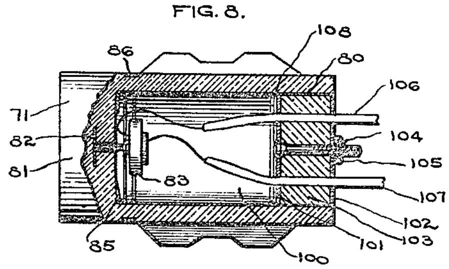


FIG. 9.

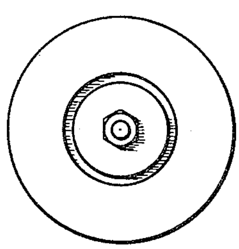


FIG. 10.

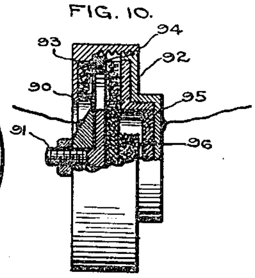
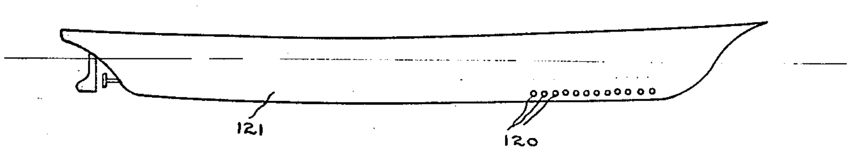


FIG. 11.



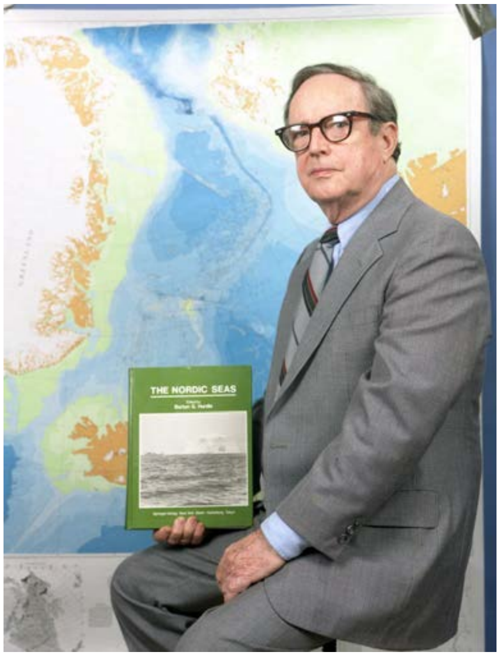
INVENTOR.
H. C. Hayes

Appendix 2

The Career of Dr. Burton G. Hurdle

Dr. Burton G. Hurdle has had a particularly long and productive association with the NRL Acoustics Division. He began work in the Sound Division as a research physicist in 1943. Except for a brief period in the late 1940s when he worked in industry, Hurdle was continuously employed as a researcher and manager in the Acoustics Division for nearly seven decades, working under all of the first five Division superintendents. Among Hurdle's research interests were quieting of ship-radiated noise; development of improved sonar domes; scattering of acoustic energy from the ocean bottom, surface and volume; deep ocean sound propagation; acoustic cavitation; sea water acoustic absorption; and fluctuation and coherence of acoustic fields in the ocean. A particularly important subject of his research was Arctic acoustics. In the 1970s he served as head of the Propagation Branch and Deputy Chief Scientist for Project NEAT (Northeast Atlantic Test). In the 1980s he served as Associate Superintendent of the Division, then later as a Division senior consultant. He was particularly involved as liaison between the Acoustics Division and NRL's national and international research partners and collaborators.

The Career of Dr. Burton G. Hurdle



Burton Garrison Hurdle was born in 1918 in Roanoke, Virginia, the son of Grover Cleveland Hurdle and Bronna Rene (Garrison) Hurdle. He was raised during the Great Depression and graduated from Jefferson Senior High School in Roanoke in June 1936. After graduation from high school he went to work for the Norfolk and Western Railway that had its headquarters in Roanoke. In that period he started taking night classes and then switched to becoming a full-time undergraduate student at Roanoke College. He majored in physics with a minor in mathematics. He continued part-time employment (evenings) with the Norfolk and Western Railway. In 1941 he received his B.S. degree in physics and then enrolled at Virginia Polytechnic Institute (VPI) for graduate studies. He intended to major in mechanical engineering but after only two weeks decided to major once again in physics. While he was studying for his master's degree in physics he taught some classes in the mathematics department at VPI to supplement his income. He also had an industrial fellowship with the Standard Register Company (of Dayton, Ohio). This was during World War II. His draft board was encouraging him to do something to contribute to the war effort. Although he was within about a year and a half from receiving a doctorate in physics, it was imperative that he leave VPI, so he was awarded an M.S. degree in general physics. While at VPI he had interviewed with recruiters from the Naval Research Laboratory. After considering several other potential job opportunities, he accepted a position in the Sound Division at NRL as a research physicist and started work there on 1 July 1943. NRL was doing much applied research then in support of the war effort. Much later, in the 1980s, Hurdle had an opportunity to complete his doctorate in engineering mechanics (1988) via the United Kingdom's Open University. His thesis topic was on the subject of acoustic interference fields in the ocean.

Dr. Hurdle has worked under all five superintendents of the NRL Acoustics Division: Dr. Harvey Hayes, Dr. Harold Saxton, Dr. John Munson, Dr. David Bradley, and Dr. Edward Franchi. Hurdle's first supervisor at NRL was Dr. Raymond Steinberger. Hurdle's early senior NRL colleagues included Harvey Hayes, Raymond Steinberger, and Prescott Arnold, who were all Harvard-educated scientists. Among his other early close colleagues were Dr. Elias Klein and Dr. E.B. Stephenson, who was associate superintendent. In the early 1940s the Sound Division was divided into four research groups: Transducers (headed by Prescott Arnold); Signal Processing (headed by Harold Saxton); General Problems and Applications (headed by Raymond Steinberger); and Shallow Water Applications (headed by John Ide). Hurdle became part of Dr. Steinberger's group that was doing research on oceanic sound propagation and noise. Another project in which Hurdle was involved in the early days of his career was one whose goal was to attempt to reduce the radiated noise from ships. This was done by placing a band (essentially a hose with holes in it) around the ship near the bow to create a cloud of bubbles around the ship's hull while the ship was underway. Testing was done in the Chesapeake Bay and Potomac River using a research yacht (the *Aquamarine*). Hurdle and colleagues demonstrated a quieting of the ship's radiated noise in the 20 to 30 kHz band of about 20 decibels. Later the Navy implemented this methodology on operational vessels. Hurdle also did research from a sound barge that was anchored in the Potomac River near the NRL pier. Among the additional Sound Division research developments to which Hurdle contributed in the period from 1943 to 1947 were the following: investigations of the characteristics of British sonar domes; studies on the effects of compounding and curing of natural and synthetic rubbers on sound speed, acoustic impedance, and absorption; development of an acoustic interferometer for measuring sound speed in rubber stocks; development of practical rubber sonar domes; measurement of acoustic properties of various liquids for closed dome systems; investigation of the effects of marine fouling of sonar domes; and measurement of the acoustic properties of mercury in the frequency range 10 to 1000 MHz, demonstrating that there was no dispersion over this frequency range.

Hurdle briefly left NRL around 1947–1949 to work at Engineering Research Associates in their Physics and Chemistry Division in Arlington, Virginia. During this period Hurdle worked on several research projects including further investigations of the sound speed and absorption in liquids using an interferometer; development of methods for calibration of accelerometers using free-free bars; and development of methods for calibrating acoustic pressure gauges and impulse gauges for use in measuring the propagation of elastic energy in soil and rock.

In 1949 Hurdle returned to the Sound Division at NRL. In the period from 1949 to 1956 he participated in and led several research efforts including the following: investigations on the scattering of acoustic energy from the bottom, surface, and volume of the ocean; deep ocean acoustic convergence zone propagation characteristics; acoustic cavitation phenomena; sea water acoustic absorption at low frequencies; and the development of a Sonar Graphic Indicator for the measurement of target range-rate.

In 1956 Hurdle was promoted to supervisory physicist and in the period from 1956 to 1970 he headed the Acoustic Scattering Section. In this position, Hurdle led a group of researchers in the conduct of theoretical and experimental investigations to understand the fundamental mechanics and characteristics of acoustic scattering from rough surfaces and inhomogeneous volumes associated with the ocean. The research objective was the development of methods to predict the three-dimensional scattered field in terms of both deterministic and statistical physical descriptions. Hurdle had responsibilities for the scientific and administrative aspects of conducting experiments at sea, participation on committees and working groups in acoustic and antisubmarine warfare problems. During this period he was deputy chief scientist for Project NEAT, an international acoustic propagation and noise experiment conducted in the Northeast Atlantic Ocean over a six-week period. From June 1958 to June 1959, Hurdle participated in a twenty-five member study panel known as Project White Oak that was conducted under the auspices of the Undersea Warfare Committee of the National Academy of Sciences for the Chief of Naval Operations. The subject of the panel's study was the protection of merchant shipping from enemy submarines in the North Atlantic. Hurdle was the chief coordinator for the panel's report.

In the period 1970 to 1976, Hurdle headed the Acoustics Division's Propagation Branch. In this capacity, Hurdle supervised a group of approximately thirty research scientists. The major research areas for the Branch were long-range acoustic propagation experiments and modeling; scattering from the ocean surface, bottom, and volume; and fluctuation and coherence of acoustic fields in the ocean. In addition, during this period Hurdle led an Arctic Underwater Acoustics Program at NRL that included the development of inter-laboratory and international scientific cooperative programs and experiments. An example of such a cooperative effort was an Arctic experiment conducted in 1972 in which five U.S laboratories or agencies and three nations participated (the United States, the United Kingdom, and Norway). The goal of the joint sea trial effort was to investigate the interaction of the environment and the acoustic characteristics of the Norwegian-Greenland-Barents Sea Basin. This trial utilized five ships, two aircraft and three shore stations from the various nations. Hurdle's role during the trial was to coordinate the experiment from a command activity based in Norway.

During a one-year overseas assignment in 1976–1977, Hurdle was visiting scientist at the Admiralty Research Laboratory in Teddington, England. In the half-decade prior to Hurdle's assignment to the UK, NRL's Acoustics Division had engaged in extensive research in the Norwegian-Greenalnd and Barents Seas as part of its Arctic Program. In the conduct of this program there was extensive cooperation between NRL, the Arctic Submarine Laboratory of the Naval Undersea Center, and the Naval Oceanographic Office, as well as scientists from the United Kingdom and Norway. A large body of knowledge was thus accumulated including numerous reports, data books, and personal files residing in the participating countries. A project was formulated to draw together this body of information in a coherent two-volume scientific document. The report was prepared by the Admiralty Research Laboratory, the Norwegian Defence Research Establishment, and NRL with Hurdle as chief scientist and chief editor whose role as visiting scientist in the UK was to coordinate the efforts of a group of senior authors and contributing authors from the three nations.

In 1977, Hurdle returned to NRL's Acoustics Division as a supervisory physicist in the new role of assistant superintendent, under superintendent Dr. John Munson. He remained in that position until 1985. In this role, Hurdle assisted in managing and directing the Acoustics Division's staff of approximately 165 persons dedicated to basic and applied research and development in underwater acoustics and acoustics-related technology, in addition to continuing to conduct his own research.

In 1985, Hurdle continued in the newly renamed position of associate superintendent of the Acoustics Division. In addition, Hurdle served as acting superintendent between 25 January and 4 August 1985 after the retirement of Dr. John Munson, but prior to the arrival of Dr. David Bradley as the new superintendent. After an additional several years as associate superintendent, Dr. Hurdle retired from the civil service on 2 July 1988. He then returned as a full-time rehired annuitant on 5 July 1988. He continued as acting associate superintendent until 15 January 1989.

Beginning in 1989 Dr. Hurdle served for over a decade as a senior scientist and consultant for the Acoustics Division. In that role he performed a diverse set of duties that included the development of new research concepts for the division, the conduct of personal research including publication of a two-volume set entitled *The Nordic Seas* (1986), and *The Acoustics of the Nordic Seas* (1991). He has also conducted research on the use of complex ocean interference fields to enhance knowledge of the acoustics of the oceans, and the effects of geophysics and gas hydrates on low frequency propagation. He has facilitated the coordination of Scientist Exchange Agreements with international partners, and has been a consultant to the Chief of Naval Operations staff regarding international programs on ASW technology transfer and the establishment of international agreements with Allies in the area of acoustics and ASW research and development.

Dr. Hurdle is a fellow of the Acoustical Society of America (ASA). He has served the ASA in various capacities including the Membership Committee, the Underwater Acoustics Technical Committee, the Nominating Committee, and the Publications Policy Committee. He is a fellow of the Washington Academy of Sciences, and a member of Sigma Xi. He has served as associate editor of the *U.S. Navy Journal of Underwater Acoustics* (1979–2004). He has served as general chairman and session chairman at meetings of the U.S. Navy Symposia on Underwater Acoustics. Dr. Hurdle has received numerous awards and commendations including the Alan Berman Research Publication Award for *The Nordic Seas* in 1985 and the Navy Superior Civilian Service Award in 1987. In 1998 he was the recipient of the Distinguished Technical Achievement Award from the Oceanic Engineering Society (OES) of the Institute of Electrical and Electronic Engineers (IEEE). He was cited for his outstanding contributions to understanding the oceanography and acoustics of the Nordic Seas.

Appendix 3

Acoustics Division Staff Listings (Sampled at Mid-Decades)

For those who may be interested in knowing the names of all Sound/Acoustics Division researchers and staff at various times in the Division's history, this appendix presents a set of full listings of Division employees sampled approximately in the middle of each decade from the 1920s to the 2000s. By perusing these lists one can follow the evolution of the Division's structure, from a small set of researchers (fewer than ten) prior to World War II to a fairly steady size of over one hundred researchers in most later eras.

NRL Sound Division Personnel in Mid-1920s

Superintendent **Dr. Harvey C. Hayes (Physicist)**
Key Research Staff
Dr. Edward B. Stephenson (Physicist)
Dr. Elias Klein (Associate Physicist)
F.W. Struthers (Assistant Engineer)
W.W. Wiseman (Assistant Engineer)
J.T. Carruthers (Research Aide)

NRL Sound Division Personnel in 1935

Superintendent **Dr. Harvey C. Hayes (Physicist)**
Key Research Staff
Dr. Edward B. Stephenson (Physicist)
Dr. Elias Klein (Associate Physicist)
F.W. Struthers (Assistant Engineer)
W.W. Wiseman (Assistant Engineer)
J.T. Carruthers (Research Aide)
W.B. Wells (Assistant Engineer)
R.J. Colson (Electrician)

NRL Sound Division Personnel in 1945

Code		
470	**Superintendent**	**Dr. Harvey C. Hayes**
471	Assoc. Superintendent	Dr. Edward B. Stephenson
471A	Technical Asst.	William W. Stifler
471B	Technical Editor	Robert W. Gordon
471B	Shipments	Kenneth B. Thomson
472	Assoc. Superintendent	Dr. Elias Klein
473	Special Research	Prescott N. Arnold
473A		Ollie M. Owsley
474	Generation & Reception	Dr. Harold L. Saxton
474A		Melvin S. Wilson
475	Special Development	Dr. Raymond L. Steinberger
475A		George R. Vernon
476	Meas. and Analysis	Dr. John M. Ide
476A		Dr. Horace M. Trent
477	Engineering Design	Wilbert P. Marshall
478	USS Aquamarine	
479	Crystal Section	Lt. Paul H. Egli
479A		Dr. Paul L. Smith

NRL Sound Division Personnel in 1945 (continued)

Division Staff and Researchers:

Donald E. Albert
Cecil T. Anderson
George W. Barnes
Ens Emily G. Bayly
Theodore L. Benz
Dr. Carl E. Black
Charles A. Bloedorn
Mary L. Brennan
Dorothy E. Brittingham
Alan T. Campbell
John L. Carter
Alfred J. Child
Aldo Ciaffardini
Robert J. Colson
Dr. Jesse J. Coop
Ens. Joseph A. Crutcher
Charles A. Darner
Ens. Mary S. Davis
Ens. Richard A. Dempster (USS Aquamarine)
Albert L. Dickson
James W. Fitzgerald
Harvey J. Fletcher
Ens. Robert W. Fritz
William J. Fry
Hollis Gibbs
John J. Goodwin
David W. Green
Claude M. Gunn
Paul R. Hadley
Herbert Hager
Stephen D. Hart
Curtis L. Hemenway
Martin Higgs
William Higgs
F. Harold Holland
Burton G. Hurdle
John F. Jewett
Ens. Ralph R. Johnston (Commodore USS Aquamarine)
Thomas F. Jones
J. T. Kare
Lt. Andrew A. Kasper
Dr. Harry J. Kolb
Aldon V. Lokken
Rex E. Lovejoy
George L. Mason
Ens. John O. McCarty
George McPherson
Richard W. Meyer
Ens. Carlton L. Morse
Ens. Conrad R. Neth
Gustaf E. Nordstrom
Keith H. Odenweller
Maury F.M. Osborne
Ens. Charles R. Parkerson
Edward J. Pember
Vincent Z. Peterson
Arthur G. Pieper
Richard F. Post
Morton S. Raff
Franz H. Rathmann
Frederick M. Reitz
Richard H. Rhodes
Lauro C. Ricalzone
James R. Richards
Thomas S. Richbourg
G. Roy Ringo
Albert J. Saur
William H. Schmieder
Walter R. Silvester
Stewart I. Slawson
Jack S. Steller
Norman T. Stevens
Vivien H. Stone
Francis W. Struthers
Albert H. Taylor
John M. Taylor
Lt. William T. Thomas
Kathleen V. Thompson
Kenneth B. Thompson
Sanford P. Thompson
Leo M. Treitel
Garret S. VanSickle
Maude E. Walker
Ens. James B. Wallace
Walter B. Wastfield
Weiant Wathen-Dunn
Murray L. Wax
Gene O. Whetzel
Richard H.G. Whitehead
John K. Wilkinson
Stenisy C. Williams
Frank J. Woodsmall

NRL Sound Division Personnel in 1955

Code		
5500	**Superintendent**	**Dr. Harold L. Saxton**
Dorothy L. Whitlock		
5501	**Assoc. Superintendent**	**Dr. Raymond L. Steinberger**
5502	**Administrative Asst.**	**Leo T. Curtin**
Sara J. Held		
Nathaniel Shear		
5503	**Scientific Staff Asst.**	**Arthur O. Parks**
5504	**Consultant**	**Robert J. Urick**

5506 Instrumentation Staff
Frank J. Woodsmall
Joseph R. Bown
Lawrence W. Briggs
Thomas O. Dixon
Delphus J. Dorsey
Harry E. Eney
Charles W. Hughes
William R. Kendrick
Nicholas L. Molloy
Virginia D. Shilling
Arthur R. Trickett
Walter B. Wastfield

5510 Propagation Branch
Homer R. Baker
Charles A. Boudreau
Robert W. Bryant
Vincent A. DelGrosso
Martin D. Eisenschmied
Ann Glunt
Ivan Ladany
Kenneth M. Murray
John G. Parker
Arthur G. Pieper
Clark W. Searfross
Reuel Q. Tillman

5520 Transducer Branch
Prescott N. Arnold
Roland V. Baier
Berthel K. Carmichael
Robert H. Carson
John Chervenak
Chester Clark
Robert Colson
Robert E. Faires
Bruce J. Faraday
Raymond H. Ferris
John Flowers
Dorsey J.G. Gregan
Roger J. Harrell
John L. Hoover
Burton G. Hurdle
George R. Kirk
James G. Larson
Raymond E. Lauver
Robert M. Lee
Robert J. MacKey
Oscar J. McKay
Candido B. Mediran
Gustaf E. Nordstrom
George Pida
Richard L. Statler
Allen R. Stickley
Kingsley P. Thompson
Hazel C. Watts
John E. Zajic

5530 Electronics Branch
William J. Finney
John H. Berbert
Herbert W. Cooper
Carlisle L. Dieter
John V. Ellison
Clifton L. Gibbons
John J. Goodwin
Gilbert Lieberman
Richard M. Michaels
Werner G. Neubauer
Herbert L. Peterson
John W. Ryan
J. Matthew Shaw
Lewis W. Shetler
Victor R. Simas
Ruth W. Staub
Donald P. Sturgis

(1955 continued)

5540 Sonar Systems Branch
Chester L. Buchanan
Wesley J. Bodin
George K. Bryant
Raphael D. Cahn
Isidore Cook
William Foster
Hollis Gibbs
Albert L. Gotthardt
Ralph N. Gran
Thomas G. Hall
Frank W. Heemstra
Hester M. Helms
Richard H. Houston
John B. Humphrey
Peter Kaufman
H. Bernard Lindstrom
H. Robert Lynn
Edward D. Melendey
Thomas O. Moore
Donald B. Sill
Charles W. Votaw
Evan W. Watson
James S. West
Robert H. Wunderley

5550 Airborne Sonar Branch
Robert H. Mathes
Marjorie L. Caya
Francis X. Downey
Matthew Flato
Nathan Gaynor
Rudolph M. Haisfield
Basil E. Hardgrove
John C. Held
Alexander J. Hiller
Arthur L. Lake
James C. MacFarlane
Christos L. Maskaleris
Chester A. Matthes
Paul D. Pasquine
Joseph Purcell
Lauro C. Ricalzone
James D. Rigdon
Arthur D. Swanson
Marjorie R. Townsend
Henry T. Wensel
William A. Wheeler
John J. Yagelowich

5560 Elec. Applications Branch
Arthur T. McClinton
Clarence H. Baldwin
John Cybulski
Frank H. Ferguson
John E. Hart
William P. Jones
Chesley H. Looney
John P. O’Connor
Irene V. Wierstak

NRL Sound Division Personnel in 1965

Code
5500 Superintendent Dr. Harold L. Saxton
5502 Research Mgmt Officer Harry E. Eney
Donna M. Carpenter
Deanne G. McGlennon
Anna M. Orloski
5504 Consultant Homer R. Baker

5506 Division Services
James G. Larson
Phillip J. Beaton [Calibration Facility, Lake Seneca, NY]
Joseph R. Bown
Lawrence W. Briggs
David P. Burgess [Calibration Facility, Lake Seneca, NY]
John P. Campbell
Delphus J. Dorsey
Albert L. Gotthardt
Gordon L. Hansen [Calibration Facility, Lake Seneca, NY]
Jules B. Houghtaling [Calibration Facility, Lake Seneca, NY]
Loretta A. Hrin
Nicholas G. Laios
Josephus Neeley
Frank K. Thompson
Walter B. Wastfield

5510 Propagation Branch
Dr. Raymond L. Steinberger
Edward D. Andrus
Jonathan Asher
Owen C. Blankenbaker
Vincent A. DelGrosso
Louis R. Dragonette
Bettie Jean Holloway
Gary H. Koopman
Leon P. Lalumiere
Werner G. Neubauer
Anthony J. Rudgers
Clark W. Searfross
Charles W. Votaw

5520 Transducer Branch
Robert E. Faires
Roland V. Baier
Marvin A. Blizard
William E. Brown
Berthel K. Carmichael
Robert H. Carson
John Chervenak
Chester A. Clark
Sam Hanish
Douglas M. Kopp
Gustaf E. Nordstrom
George Pida
Carolyn Shely
Dr. Gerard F. Songster
Allen R. Stickley
Edward Tuck
Hazel C. Watts

5530 Electronics Branch
William J. Finney
Hubert W. Charlton
Clifton L. Gibbons
Caldwell McCoy
George G. Nacht
George V. Olds
Herbert L. Peterson
J. Matthew Shaw

5540 Sonar Systems Branch
Chester L. Buchanan
Howard E. Barnes
Richard B. Bridge
Walter L. Brundage
Roger B. Cooley
Massis Davidian
Andrew M. Findlay
Edward J. Finn
Matthew Flato
Daniel Friedman
Jervis J. Gennari
Hollis Gibbs
Lloyd S. Greenfield
Frank W. Heemstra
Hester M. Helms
John B. Humphrey

(1965 continued)

Wilbert L. Jones
Peter Kaufman
H. Bernard Lindstrom
Robert L. Mills
Robert B. Patterson
Morton M. Smith
James A. Somerville
Kenneth R. Stewart
David Yuen

5550 Techniques Branch
Robert H. Mathes
Edward A. Abbott
Frank R. Alexander
Robert C. Beckett
John D. Charlton
Norman H. Dale
Walter C. Diehl
Lewis G. Galli
Rudolph M. Haisfield
George F. Hickey
Alexander J. Hiller
Charles W. Hughes
Charles W. Klee
William B. Nefedov
Lauro C. Ricalzone
Alan H. Rich
James E. Roberson
Donald F. Wilson
Mary M. Wood

5560 Elec. Applications Branch
Arthur T. McClinton
Ralph L. Armbruster
Robert W. Chrisp
Harry U. Criss
John Cybulski
Raymond H. Ferris
Kenneth D. Flowers
Eugene Q. Gordon
John B. Gregory
Charles P. Hatsell
Frank L. Hunsicker
Burton G. Hurdle
Wilmer M. Lawson
Robert M. Lee
Richard A. Oswalt
John D. Pope
Theodore L. Reuwer
Carl R. Rollins
Kingsley P. Thompson
Zenaide J. Wooldredge

NRL Acoustics Division Personnel in 1975

Code		
8100	**Superintendent**	**Dr. John C. Munson**
8100	J.E. Toronto	
8101	Assoc. Superintendent	R.R. Rojas
8102	M.L. Hawkins	
8102	M.D. Kramer	
8102	A.M. Marchetti	
8102	J.O. Picciotta	
8102	C. Shiplett	
8102	J.L. Williams	
8104	S. Hanish	
8105	F.C. Titcomb	

Advanced Projects Group (8103)
W. J. Finney
W.L. Anderson
J.R. Fisher
A.A Gerlach
D. Hankins
W.R. Johnson
L.E. Maiden
C. McCoy
W.P. Morrogh
G.G. Nacht
G.V. Olds
H.L. Peterson
H.B. Shelley
D.A. Swick
F.M. Young

System Engineering Staff (8108)
R.C. Swenson
S. Adler
R. Anderson
C. Brier
J. Bright
R.W. Chrisp
D.O. Ciuffetelli
W.C. Diehl
A.W. Gonda
B.H. Hendrix
G.F. Hickey
W.F. Horner
C.W.Hughes
L.M. Huston
T.A. Kelly
N.G. Laios
W.M. Lawson
S. Liapunov
M.F. Marek
G.J. McCoy
H.J. Mellace
R. Naber
L.C. Ricalzone
C. Rucci
J.M. Sandvik

Systems Analysis Group (8109)
J.C. Knight
W.C. Dixon
W.R. Hahn
J.S. Jamison
M. Potosky
C.R. Rollins

Shallow Water Surveillance Branch (8120)
R.H. Ferris
A.I. Eller
M. Flato
F.L. Ingenito
W.A. Kuperman
J.F. Miller
J.F. Peery
T.L. Reuwer
R.F. Smith
A.O. Williams
S.M. Wolf

Physical Acoustics Branch (8130)
C.M. Davis, Jr.
J.A. Bucaro
L.A. Burns
D.M. Carpenter
R.D. Corsaro
H.D. Dardy

(1975 continued)

L.R. Dragonette
L. Flax
T.R. Hickman
J. Jarzynski
C.W. Klee
J.D. Klunder
T.A. Litovitz
W.E. Moore
L.K. Nelson
W.G. Neubauer
J. Schroeder
L.S. Schuetz
R.H. Vogt

Transducer Branch (8150)
W. J. Trott
R.V. Baier
C.E. Balfourd
M.E. Bruemmer
D.J. Dorsey
D.J. Gregan
B.J. King
J. Neeley
Y.R. Pelosi
A.J. Rudgers
E.L. Shepler
J.A. Sinsky
A.L. VanBuren
R.A. Walker
J.F. Zalesak

Large Aperture Systems Branch (8160)
B.B. Adams
C.R. Andriani
R.N. Baer
E.H. Bebbs
M.J. Beran
S.D. Boze
J. Cybulski
D.T. Deihl
D.R. DelBalzo
D.M. Dundore
E.R. Franchi
P.A. Glass
J.M. Griffin
R.M. Heitmeyer
P.J. Hirshfeld
W.W. Krieger
S.W. Marshall
J.J. McCoy
J.R. McGrath
W.B. Moseley
W.E. Mulrooney
M.A. Pike
E.C. Stansbury
S.C. Wales
J.T. Warfield
E.B. Wright

Propagation Branch (8170)
B.G. Hurdle
E.J. Anderson
M.L. Blodgett
J.M. Brozena
J.T. Butler
B.K. Carmichael
N.Z. Cherkis
N.H. Dale
J.A. DeSanto
M.A. Dolan
S.P. Falci
R.H. Feden
R.M. Fitzgerald
H.S. Fleming
K.D. Flowers
G.V. Frisk
G.R. Giellis
A.N. Guthrie
B.J. Hauser
B.C. Heezen
T.O. Heywood
G.G. Jackson
J.C. Krause
L.P. LaLumiere
R.M. Lee
J.V. Massingill
S.K. Numrich
D.A. Nutile
D.F. O'Neill
D.R. Palmer
R.K. Perry
S.M. Pierce
D.J. Ramsdale
C.W. Searfross
J.D. Shaffer
C.W. Votaw
J.P. Walsh
W.W. Worseley

NRL Acoustics Division Personnel in 1985

Code		
5100	**Superintendent**	**Dr. David L. Bradley**
5100A	R. Stallings	
5101	Assoc. Superintendent	B.G. Hurdle
5101A	R.B. Hopkins	
	J.R. McGrath	
5101G	C. Gross	
5101M	J.C. Munson (Editor, *JUA(USN)*)	
5102	N.J. Beauchamp	
5102A	N.A. Garito	
5102S	F. Soriano	
5102M	R. McGregor	
5102P	A.M. Porter	
5104	S. Hanish	
5106	C.R. Rollins	
5109	M. Potosky	
5109A	L.E. Maiden	

Ocean Systems Applications Group (5103)
D. Steiger
J. Bright
M. Brunjes
D.O. Ciuffetelli
J.D. Clamons
J.G. Eskinzes
R.A. Gordon
B.M. Hauver
L.M. Huston
R. Naber
M. Ostrow
W.D. Robey
L.J. Rosenblum
J.W. Seigel
W. Stasior
Y. Thomas
R. Wilkerson

Acoustic Media Characterization Branch (5110)
H.S. Fleming
J.M. Bergin
C. Bobbitt
J.M. Brozena
C. Bush
B.L. Caposella
N.Z. Cherkis
M. Czarnecki
R.H. Feden
I.F. Jewett
L.C. Kovacs
L.P. LaLumiere
P. Lanzano
M.D. Max
J.F. Peery
M. Peters
S. Rhoades
S.E. Vermace
G. Vink
P.R. Vogt
M.C. Whitney

Applied Ocean Acoustics Branch (5120)
Dr. Orest I. Diachok
W.L. Anderson
T. Bordley
J. Brust
C.L. Byrne
A. Calcagnini
D.A. Cole
B.A. Decina
R.L. Dicus
R. Doolittle
R. Fizell
K. Flowers
A.A. Gerlach
G.R. Giellis
P. Gruber
T.J. Hayward
J.C. Krause
E.L. Kunz
R.M. Lee
E. Livingston
J.T. Magpuri

(1985 continued)

P.C. Mignerey
D.A. Nutile
T.J. Orndorff
M. Porter
S. Shaffer
E. Sudol
A. Tolstoy
C.W. Votaw
S.C. Wales
K. Wilson
S. Winings
T.C. Yang
A. Zwirko

Physical Acoustics Branch (5130)
Dr. Joseph A. Bucaro
P.B. Abraham
L.A. Burns
J.H. Cole
R.D. Corsaro
J.F. Covey
N.H. Dale
A.G. Dallas
H.D. Dardy
R.A. Douyon
L.R. Dragonette
C.F. Gaumond
K.B. Gifford
T.R. Hickman
B.H. Houston
J. Jarzynski
B.H. Jones
J.D. Klunder
N. Lagakos
J.M. Malanka
R.T. Menton
S.K. Numrich
A. Parvulescu
M.L. Picciolo
L.S. Shuetz
M.B. Sullivan
D. Weaver
E.G. Williams
N.C. Yen

Software Systems Development Branch (5150)
E.E. Wald
C. Brier
L. Brotzman
C. Bubb
A.A. Gonda
V.L. Greenwell
G.F. Hickey
R. Hillson
W.R. Johnson
D.J. Kaplan
B. Kenny
R. Krutar
L. Maddox
P. Martin
K.W. Morin
C. Osgood
C.L. Ross
D. Rowe
B. Shambaugh
D. Sheppard
R. Stevens
J.E. Trenck
B. Wagner
H. Webb
L. Wilson
L. J.-Y. Wu

Large Aperture Systems Branch (5160)
Dr. Budd B. Adams
L.Z. Avelino
R.N. Baer
D.H. Berman
D. Bernard
S. Brylow
R.W. Chrisp
B. Cronin
D.K. Dacol
M.J. Davis
P.Davis
T.R. DiResta
D.M. Dundore
F.T. Erskine
M.J. Fierst
D. Forrestel
E.R. Franchi
J. Fulford
R.C. Gauss
D.A. Gershfeld
P. Gossard
R. Gragg
D. Harrington
T.J. Hayward
F.L. Ingenito
M.S. Kost
T. Krout
W. Kuperman
M. Mague

(1985 continued)

D. Meredith
T.C. Merendo
K.R. Nicolas
J.S. Padgett
L.B. Palmer
E. Papalambros
B.H. Pasewark
J.S. Perkins
R. Piquette
R. Pitre
J.F. Prince
R. Soukup
R. Whitley
S.N. Wolf
E.B. Wright

NRL Acoustics Division Personnel in April 1993

Code

7100 **Dr. David L. Bradley (Superintendent)**
7100A Ruth Stallings
Phyllis Kehres
7100T K. Turner
7102 Nancy J. Beauchamp (Administrative Officer)
7102A Nancy A. Garito (Human Resources)
7102B C.L. Burns
7102L Lori Heddings
7102I Jane N. Ihnat
7103B Dr. Burton G. Hurdle
7104 Dr. William A. Kuperman (Senior Scientist)
7104M Dr. B.E. McDonald
7106 R. McGregor

7120 **Acoustic Signal Processing Branch**
Dr. Marshall Orr (Branch Head)
J.M. Berkson
C. Bogart
J. Brust
E.W. Carey, Jr.
J. Cole
D. Cooper
D. Creamer
B.A. Decina
F. Feirtag
S.J. Finette
G.R. Giellis
T.J. Hayward
M. Healey
R. Heitmeyer
J. Kinder
R. Krutar
E.L. Kunz
G. Kupstas
R.M. Lee
E. Livingston
P.C. Mignerey
B.T. O'Connor
B. Orchard
B.H. Pasewark
C. Scannell
J.W. Siegel
J.F. Smith
J. Talman
A. Tolstoy
S.C. Wales
S. Whitmire
J.W. Wolf
B. Wood
T.C. Yang
R. Yarussi
K.B. Yoo

7130 **Physical Acoustics Branch**
Dr. Joseph A. Bucaro (Branch Head)
G. Carpentier
C. Carter
J. Cates
R.D. Corsaro
L.S. Couchman
J.F. Covey
A. Dallas
L.R. Dragonette
L. Farr
C.F. Gaumond
B.H. Houston
J.D. Klunder
N. Lagakos
M.H. Marcus
C. McCauley
A. Parvulescu
D.F. Peters
D. Photiadis
P.E. Powell
S. Saluter
A. Sarkissian
J. Shirron
K.B. Washburn
E.G. Williams
K.E. Yeatman
N.C. Yen
N. Zimmerman

(1993 continued)

7140 Acoustic Systems Branch
L. Bruce Palmer (Branch Head)
L.Z. Avelino
R.N. Baer
M.D. Collins
J.P. Crockett
D.K. Dacol
N.R. Davis
B.T. Do
D.M. Drumheller
D.M. Dundore
F.T. Erskine
J. Faber
L. Fialkowski
D.M. Fromm
R.C. Gauss
R.F. Gragg
J. Gray
M. Jackson
J.A. Jannucci
J. Jeffrey
E. Jennings
T.L. Krout
K.H. Luther
N.C. Makris
R. Menis
T.T. Nguyen-Phan
M. Nicholas
P.M. Ogden
G. Orris
P. Osborn
J.S. Perkins
R. Pitre
R. Pomager
J. Roginsky
E. Rowe
M. Solsman
R.J. Soukup
K. Staples
B. Walsh
D. Wurmser
C. Ziemniak

7105 Center for Environmental Acoustics
Stennis Space Center, Mississippi
Dr. Edward R. Franchi (Head)
Vivian G. Regan
Jean Rapp
Betty T. Choat

7170 Ocean Acoustics Branch
Dr. Dan J. Ramsdale (Branch Head)
D.E. Flanangan
J.G. McDermid
L. Rosche

7171 Computer Resources
P.A. Carter
E.T. Kennedy
J.A. Mobbs
A.T. Pogue

7172 Arctic Environmental Acoustics
D.L. Bell
R.A. Fisher
S.D. Gardner
P.M. Jackson
A.E. Leybourne
R.W. Meredith
C.T. Mire
G.B. Morris
V.M. Ross
K.D. Savage
A.S. Smith

7173 Shallow Water & Coastal Acoustics
H.B. Ali
M.K. Broadhead
H.A. Chandler
R.L. Field
J.H. Leclere
P.T. Perry
L.A. Pflug
T. Ruppel
D. Schallenberg
G.B. Smith

7174 High Frequency Acoustics
E.C. Besancon
R.W. Farwell
C. Feuillade
C. Levenson
R.H. Love
R.W. Nero
J.S. Stanic
C.H. Thompson
M.A. Wilson

(1993 continued)

7175 Boundary Acoustics
J.W. Caruthers
J.K. Fulford
A.K. Kalra
W. Kinney
P.C. Rowe
J.A. Showalter
R.R. Slater

7176 Tactical Noise
J.E. Breeding, Jr.
K. Dudley
C.A. Fisher
J. George
S.F. Kooney
J.J. Newcomb
D. Swilley
R.A. Wagstaff

7180 Acoustic Simulation and Tactics Branch
James E. Matthews (Branch Head)
B.B. Adams
M.J. Baker
L.M. Berry
K.O. Davis
F.T. Theriot

7181 Acoustic Simulation
C. Burkhalter
S.A. Chin-Bing
J.R. Dubberly
R.S. Keiffer
D.B. King
R.W. McGirr
G.V. Norton
R.M. Oba
M.F. Werby
R.A. Zingarelli

7182 Environmental Assessments
P.J. Bucca
G.P. Cloy
B.R. Gomes
G. Kerr
J.V. Soileau

7183 Naval Acoustics Tactical Applications
G.L. Bullock
J. Campbell
M.J. Collins
B.J. Crawford
R.E. Delgado
J.W. Ellis
C.B. Favre
J. Gossner
M.L. Ling
J. Miller
W.G. Popovich
S.M. Starke
E. White

NRL Acoustics Division Personnel in 1995

Code	
7100	**Superintendent Dr. Edward L. Franchi**
7100A	V. DeStefano
7101A	P. Kehres
7102	N.J. Beauchamp
7102A	N. Garito
7102B	C. Burns
7102L	L. Garito
7102I	J. Ihnat
7103B	B.G. Hurdle
7103S	S. Hanish
7104M	E. McDonald
7106	R. McGregor

Acoustic Signal Processing Branch (7120)
Dr. Marshall H. Orr
J. Berkson
E. Carey
S. Finette
T. Hayward
R. Heitmeyer
B. Jones
E. Kunz
E. Livingston
P. Mignerey
S. Omer
B. Pasewark
D. Tielburger
A. Turgut
S. Wales
S. Whitmire
S. Wolf
K. Yoo

Physical Acoustics Branch (7130)
Dr. Joseph A. Bucaro
G. Carpentier
C. Carter
R. Corsaro
L. Couchman
J. Covey
L. Dragonette
L. Farr
R. Foreman
C. Gaumond
B. Houston
T. Howarth
D. Hughes
J. Klunder
N. Lagakos
M. Martin
C. McCauley
A. Parvulescu
D. Peters
D. Photiadis
A. Sarkissian
J. Shirron
E. Williams
K. Yeatman
N. Yen

Acoustic Systems Branch (7140)
L. Bruce Palmer
R.N. Baer
P. Burns
R. Cederberg
M. Collins
D. Dacol
D. Drumheller
F.T. Erskine
J. Faber
L. Fialkowski
D.M. Fromm
R.C. Gauss
R.F. Gragg
M. Jackson
J. Jeffery
T. Krout
R. Kurichh
N. Makris
R. Menis
G. Moss
M. Nicholas
B. O'Connor
P. Ogden
G. Orris

(1995 continued)

J. Perkins
R. Pitre
J. Roginsky
G. Short
R. Soukup
Q. Ton
D. Wurmser

Ocean Acoustics Branch (7170)
Dr. Dan J. Ramsdale [NRL Stennis, MS]
H.B. Ali
J.E. Breeding
M.K. Broadhead
J.W. Caruthers
H.A. Chandler
L. Durey
C. Feuillade
R.W. Fidler
R.A. Fisher
S.D. Gardner
J. George
P. Jackson
E.T. Kennedy
W. Kinney
S.F. Kooney
A.E. Leybourne
R. Love
J.G. McDermid
R. Meredith
C.T. Mire
J.A. Mobbs
R.W. Nero
J.J. Newcomb
L.A. Pflug
T. Ruppel
J.A. Showalter
G.B. Smith
J.S. Stanic
F.T. Theriiot
C.H. Thompson
R.A. Wagstaff
M.A. Wilson
E.J. Yoerger

Acoustic Simulation and Tactics Branch (7180)
Dr. Stanley A. Chin-Bing [NRL Stennis, MS]
M.J. Baker
D. Bloom
P.J. Bucca
G.L. Bullock
J. Campbell
M.J. Collins
B.J. Crawford
D. DelBalzo
R.E. Delgado
J.R. Dubberly
J.W. Ellis
C.B. Favre
J.K. Fulford
R. Goggins
B.R. Gomes
J. Gossner
R.S. Keiffer
G. Kerr
D.B. King
J.H. LeClere
M.L. Ling
J. Miller
C. Mullins
G.V. Norton
R.M. Oba
W.G. Popovich
B. Randall
J. Rapp
L. Rosche
S.M. Starke
M.F. Werby
J. Wheatley
R.A. Zingarelli

NRL Acoustics Division Personnel in 2005

Code	
7100	**Superintendent Dr. Edward L. Franchi**
7100A	C. Carlson
7101	Dr. Fred T. Erskine [Assoc. Superintendent]
7102	J. Tomlinson
7102A	L. Burnell
7102B	C. Vonk
7102C	A. Garner
7102D	D. Harris
7102N	N. Beauchamp
7103	Dr. Burton G. Hurdle
7105	Lt. Theodore G. Dorics
7106	Dr. Earl G. Williams [Senior Scientist]

Acoustic Signal Processing Branch (7120)
Dr. Marshall H. Orr
E. Carey
X. Chen
S. Davis
S. Finette
P. Gendron
T. Hayward
R. Heitmeyer
C. Lefler
E. Livingston
M. McCord
S. Means
P. Mignerey
Y. Na
R. Oba
B. Pasewark
J. Schindall
A. Turgut
S. Wales
R. Whittington
S. Wolf
T.C. Yang
K. Yoo

Physical Acoustics Branch (7130)
Dr. Joseph A. Bucaro
P. Abraham
B. Baden
J. Baldwin
A. Berdoz
C. Carter
L. Chaplin
R. Corsaro
L. Couchman
D. Datta
L. Dragonette
L. Farr
P. Frank
H. Haucke
P. Herdic
B. Houston
J. Jarzynski
J. Judge
J. Klunder
J. Kost
L. Kraus
N. Lagakos
S. Liskey
X. Liu
J. Lowe
M. Marcus
T. Metcalf
C. Mithen
K. Opachko
D. Photiadis
E. Porse
J. Rogers
A. Romano
M. Saniga
A. Sarkissian
J. Shirron
H. Simpson
W. Szymczak
J. Tressler
N. Valdivia
J. Vignola
R. Volk
T. Yoder
M. Zalalutdinov

(2005 continued)

Acoustic Systems Branch (7140)
John S. Perkins
R.N. Baer
P. Burns
D. Calvo
M. Collins
D. Dacol
G. Edelmann
J. Fialkowski
L. Fialkowski
D.M. Fromm
C.F. Gaumond
R.C. Gauss
C. Gorgone
R.F. Gragg
E. Kim
E. Kunz
K. LePage
J. Lingevitch
C. Mays
E. McDonald
R. Menis
M. Nicholas
G. Orris
W. Siegmann
R. Soukup
J. Summers
D. Wurmser

Acoustics Simulation, Measurements, and Tactics Branch (7180)
Dr. Stanley A. Chin-Bing [NRL Stennis, MS]
L. Allen
M. Baker
P. Banas
R. Brown
H. Chandler
S. Cognevich
S. Dennis
J. Ellis
B. Ervin
M. Esler
J. Fabre
C. Favre
C. Feuillade
R. Field
R. Fisher
J. Fulford
J. George
J. Graber
K. Hemsteter
P. Jordan
R. Keiffer
T. Kennedy
D. King
W. Kinney
J. LeClere
A. Leybourne
D. Malley
J. McDermid
P.M.J. McDowell
R. Meredith
R.W. Nero
J. Newcomb
G. Norton
S. Owen
L. Pflug
J. Rapp
T. Ruppel
W. Sanders
G. Smith
S. Stanic
H. Vosbein
G. Voulgarakis
M. Wilson
R. Zingarelli

Appendix 4

Acoustics Division Photographs

The NRL photographic archive contains many photographs illustrating the Acoustic Division’s diverse activities. Included here are several hundred representative photographs covering the period from the 1920s to the 2000s, organized roughly in chronological order. These photographs show individual researchers, groups of researchers, field experiment and sea test activities and equipment, laboratory facilities, and retirement and award ceremonies. Included among the earliest photographs are some rare pictures of the first Sound Division superintendent, Dr. Harvey Hayes, taken in the 1920s and 1930s that were provided by his descendants.

Era 1 Photographs (1923–1947)

Naval Research Laboratory and Potomac River as seen from the air looking to the north circa 1923.
The U.S. Capitol can be seen in the distance. (Photo courtesy of James Cole)

Dr. Harvey Hayes relaxing

Coffee served in Dr. Hayes’ NRL office with colleagues, from left to right: Carlos B. Mirick (Radio Division), Dr. Harvey C. Hayes, Robert W. Gordon, Dr. E.B. Stephenson. Dr. Hayes and several NRL colleagues usually have their lunch in Dr. Hayes’ office on the third deck of Building 1. Carlos Mirick was a guest. Their coffee is ground straight from the bean in an old coffee mill that Dr. and Mrs. Hayes bought shortly after their wedding in 1906. A friend had given them a 50-pound sack of imported coffee as a wedding gift. This little mill had long since been put away, but when the group decided to try “bean” coffee, Mrs. Hayes found the mill and donated it to the cause.
[From NRL Archives]

NRL Sound Division leaders circa mid-1940s.
Near front: Horace Trent, E.B. Stephenson, Harvey C. Hayes, Elias Klein.
At rear: Prescott Arnold, Paul Egli, Raymond Steinberger, Harold Saxton, Irwin Vigness.

Dr. Harvey C. Hayes with Sound Division support staff circa 1947.
Front row: Maude McGlasscock, Louise Leslie, Dr. Harvey C. Hayes, Glenna Milligan, Vivian Barr. Middle row: Berthel Carmichael, Beverly Hartzell, Jane Green, Joan Byrd, Bertha Harris. Rear: Lola Dennary, Ethel Herzog.

Dr. Harvey C. Hayes with Allen R. Stickley

Dr. Edward Franchi presents remarks at dedication of the Harvey C. Hayes Memorabilia Collection at NRL Quarters A on 21 May 1999

Capt. Buckley, Mr. Gordon Hayes (center), and Dr. Timothy Coffey, NRL Director of Research, visit inside Quarters A, in the Harvey C. Hayes Room

Dr. Harvey C. Hayes with son Harvey Hayes, Jr. launching model sailboats circa early 1920s (Photo courtesy of James Cole)

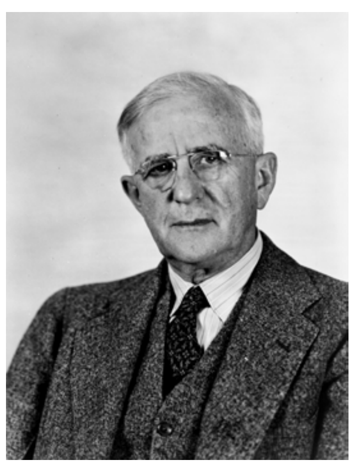

Dr. Harvey C. Hayes with infant son Gordon Hayes circa 1921
(Photo courtesy of James Cole)


Dr. Harvey C. Hayes with toddler son Gordon Hayes circa 1921
(Photo courtesy of James Cole)


Dr. Harvey C. Hayes on board USS Breckenridge (DD-148)
on 20 May 1921 during a field test (Photo courtesy of James Cole)

Dr. Harvey C. Hayes fishing circa 1940s
(Photo courtesy of James Cole)

Oil pastel portrait sketch of Dr. Harvey C. Hayes
by Grace D. Reasener (1945)



Dr. E.B. Stephenson (circa 1948)

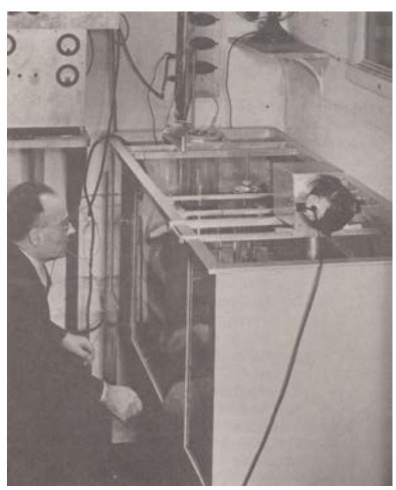
Dr. Raymond L. Steinberger (circa 1965)

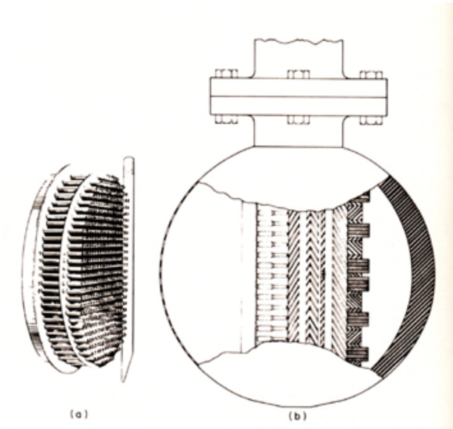
Dr. John Ide (circa 1950)
(Photo courtesy of Bernard Cole, Mary Ellen Hanrahan, and Cynthia Ide Rockwell)

Prescott Arnold (circa 1940)

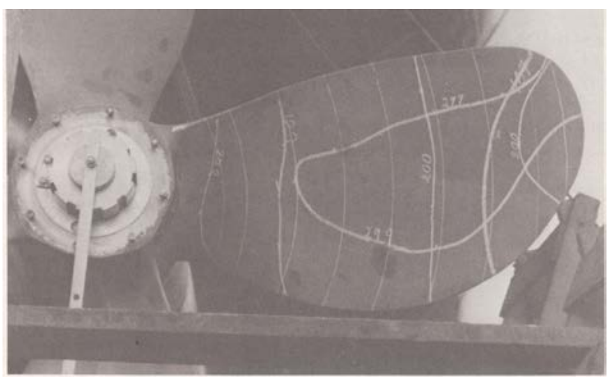

Dr. Elias Klein (1945)


James Fitzgerald

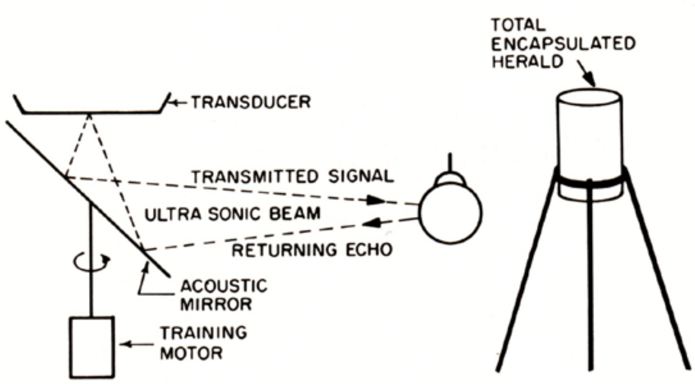

Dr. Elias Klein conducting absolute sound intensity measurements at NRL Sound Division circa 1938 [After Klein, 1967]



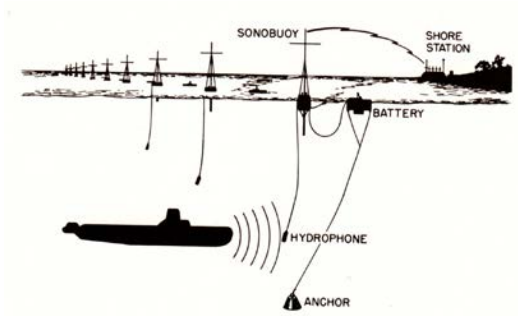
Combination of two transducers in one housing circa 1930s: (a) Magnetostrictive tube array (QC) with its backing plate; (b) Combined transducer set: On left is a QC magnetostrictive array with ethylene glycol-distilled water in front of the radiating plate and a thin stainless steel window. On right is a Rochelle salt (JK) listening device with castor oil and the spherical rubber (Rho-C) window. [After Klein, 1967]



Analysis of the natural modes of vibrating propeller blade of USS Goethals
used to resolve "singing propeller" noise, circa 1940 [After Klein, 1967]

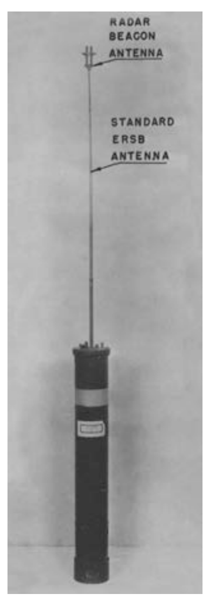


Harbor Echo-Ranging and Listening Device (HERALD): Ultrasonic beam
directed by a rotating lightweight acoustic mirror – used for harbor protection
circa 1930s. [After Klein, 1967]

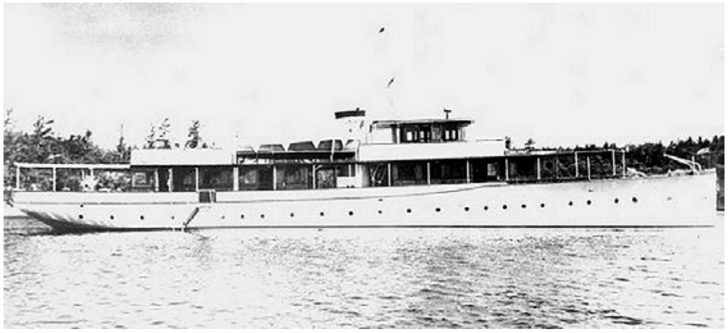


Anchored sono-radio buoy system used for harbor defense circa 1940s
[After Klein, 1967]


Early prototype sonobuoy circa 1940s
[From NRL Photo Archive]



Further prototype sonobuoy circa 1940s
[From NRL Photo Archive]


USS Aquamarine used as a research vessel circa 1940s


First Navy acoustics test range: Sound Station Key West, Florida circa 1943
[After Treitel, 1943]

Era 2 Photographs (1948-1967)

Dr. Harold L. Saxton congratulated upon his retirement by NRL colleagues
Dr. Alan Berman (on left) and Dr. Werner Neubauer (on right); July 1967.

Dr. Harold L. Saxton congratulated upon his retirement by
Assistant Secretary of the Navy for Research and Development,
Dr. Robert Frosch; July 1967.

Retirement luncheon in honor of Dr. Raymond L. Steinberger's retirement circa 1970. At main table, left to right: Dr. Ralph Goodman, Dr. Alan Berman, Dr. Harold Saxton, Mrs. Steinberger, Rear Admiral Thomas Owen, Capt. James Matheson, Dr. Raymond Steinberger, Dr. John Munson, (and two unidentified colleagues).


Dr. Alan Berman congratulates Dr. Raymond L. Steinberger upon his retirement


Chester L. Buchanan


Arthur T. McClinton


Dr. Sam Hanish


Dr. Louis Dragonette


Dr. Vincent DelGrosso


Charles Votaw


William Finney


Robert Urick


Walter Brundage


Albert Gotthardt

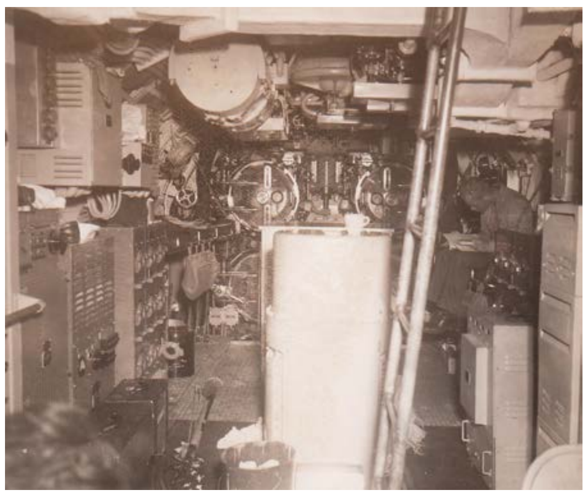

Matthew Shaw


Robert Patterson


Earl Carey


Ernest Czul

Submarine USS SeaCat SS399, XDG sonar equipment (1950)



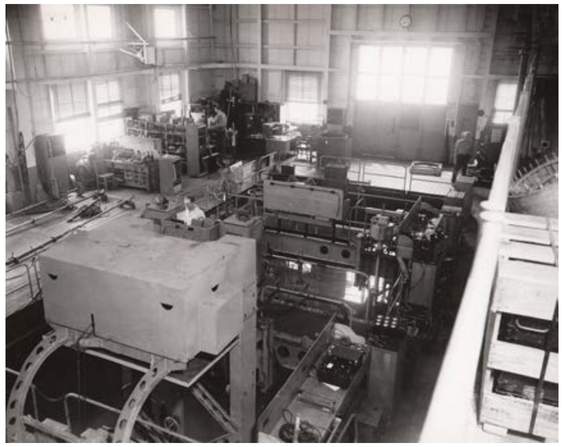
Submarine USS SeaCat SS399, interior view (1950)

Submarine USS Guavina SS362, Potomac River near NRL (1951)

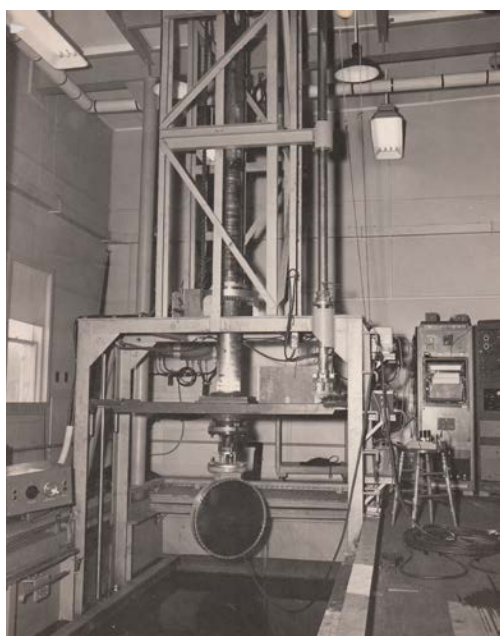
Submarine USS Guavina SS362, 10 kHz long range sonar housing (1951)

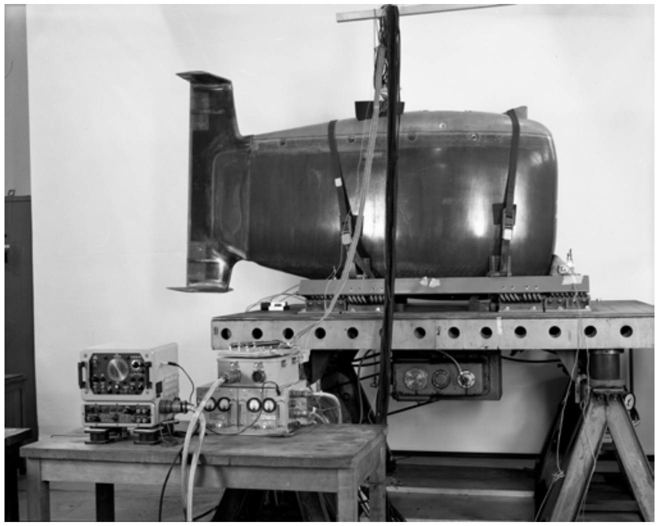
Submarine USS Guavina SS362, interior view of 10 kHz sonar operating position (1951)

NRL sound barges, NRL pier (circa 1952)

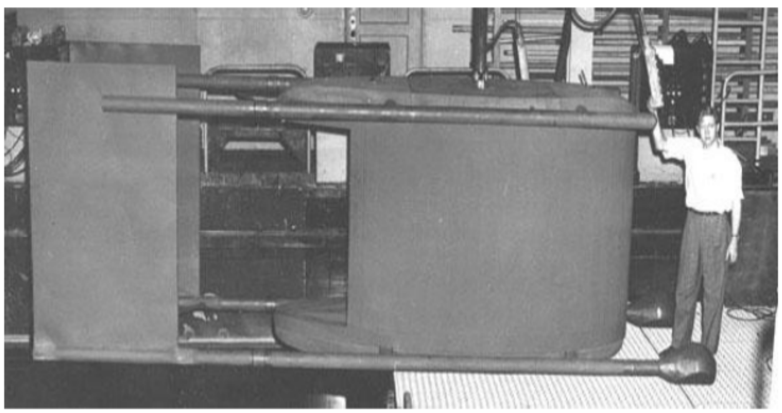

Interior view of NRL sound barge YFNX-13 (circa 1952)


U.S. Navy field testing station, Dodge Pond, Niantic, Connecticut (1950s)

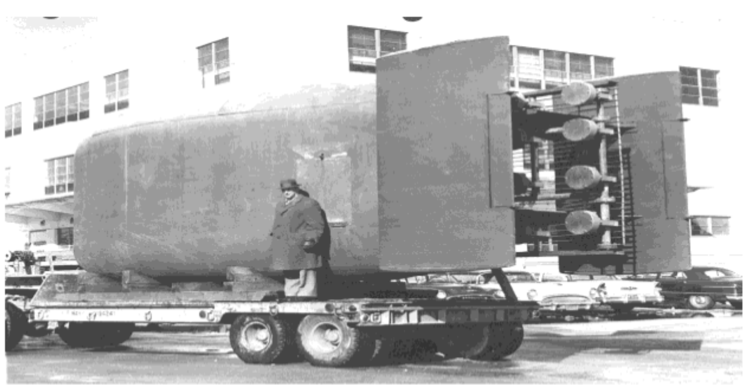

Sonar transducer testing at Dodge Pond (1950s)



NRL experimental 10 kHz transducer (1950s)

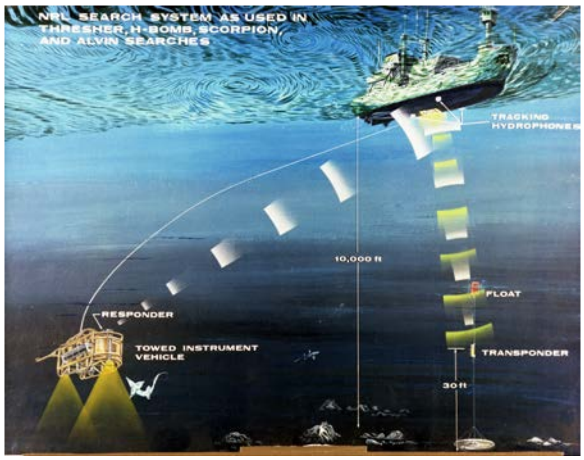


NRL experimental 5 kHz source transducer (1950s)



NRL experimental 1 kHz source transducer (1950s)

USS Thresher (circa 1963)



NRL deep ocean search system (mid-1960s)

NRL instrumented towfish for deep ocean search system (mid-1960s)

USNS Mizar (T-AGOR 11), used in deep ocean searches (mid-1960s)

Interior view of USNS Mizar during search for USS Thresher (1964)

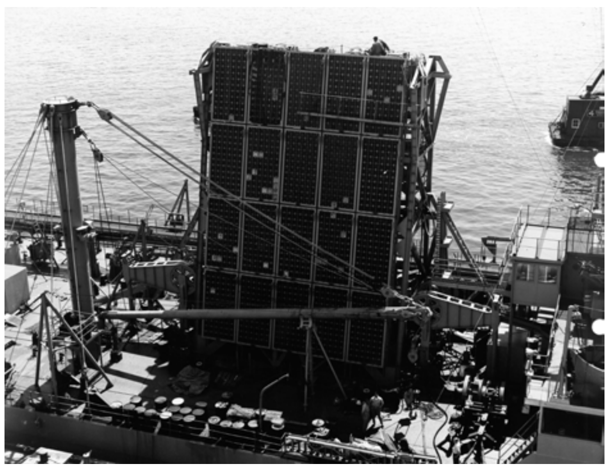
USNS Gilliss (T-AGOR 4), used in initial search for USS Thresher (1963)

Left: composite photograph of USS Thresher (1964).
Right: photograph of USS Scorpion (1968) illustrating improvement in photographic technique.

Award ceremony circa 1965 for NRL team participating in successful 1964 search for USS Thresher. Front: Chester Buchanan, Frank Heemstra, Massis Davidian, Lloyd Greenfield, Capt. Thomas Owen, Walter Brundage, Robert Patterson, Kenneth Stewart, Hanford VanNess, Jervis Jennari; Middle/Rear: Mort Smith, Hester Helms, Ernest Czul, Unidentified, H. Bernard Lindstrom, Howard Barnes, Peter Kaufman, Andrew Findlay, Matthew Flato, Daniel Friedman, Wilbert Jones, Robert Mills, Hollis Gibbs, John Humphrey, James Somerville, Jr.

Award ceremony for NRL team participating in successful 1966 search for a lost U.S. nuclear warhead in the Mediterranean Sea near Palomares, Spain. Front row: Chester Buchanan, Richard Love, H. Bernard Lindstrom, Lloyd Greenfield, Massis Davidian, Albert Gotthardt, Unidentified. Rear: Frank Heemstra, Wilbert Jones, Peter Kaufman, Capt. Thomas Owen, Hester Helms, Hollis Gibbs, Unidentified, Howard Barnes, Unidentified.

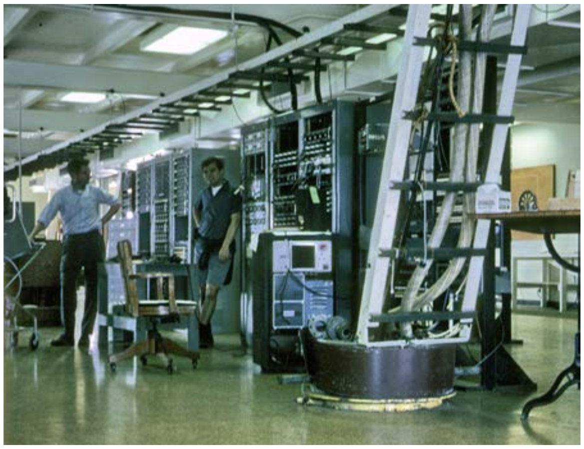
USNS Mission Capistrano (T-AG 162), used in Project Artemis (mid-1960s)



Source transducer array on USNS Mission Capistrano (mid-1960s)

Tudor Hill Laboratory at Bermuda, used for received signal processing in Project Artemis

Argus Island Tower on Plantagenet Bank near Bermuda where underwater receiver array cables came together for Project Artemis



Interior of Argus Island Tower used in Project Artemis

NRL Sound Division's nearfield calibration array at U.S. Navy's field test site on Lake Seneca, New York (1960s)

Era 3 Photographs (1968–1984)

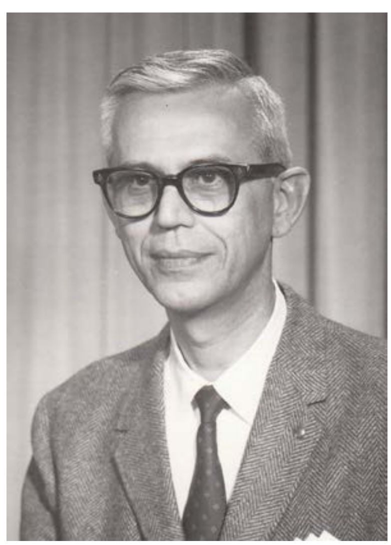
Dr. John Munson and Mrs. Munson at NRL Acoustics Division holiday luncheon circa December 1984

Richard R. Rojas

Forrest C. Titcomb


Dr. Budd B. Adams


Henry S. Fleming

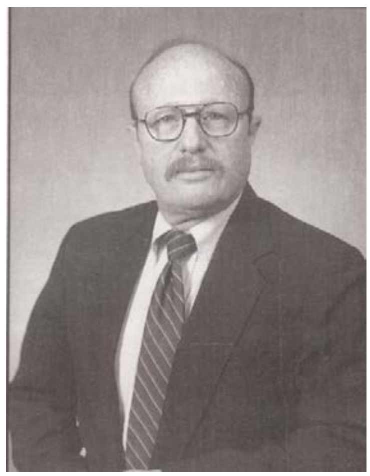

Dr. Albert A. Gerlach


Raymond H. Ferris

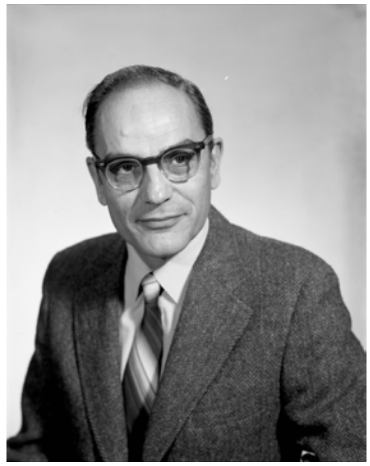

Dr. William B. Moseley


John C. Knight


Dr. George V. Frisk

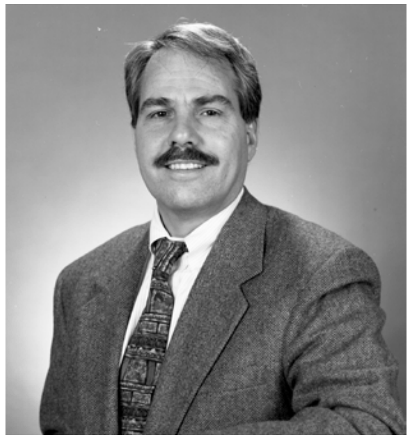

Dr. William A. Kuperman

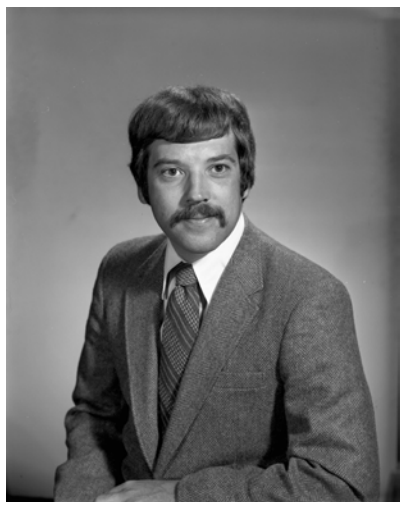

Dr. James McGrath


Dr. Frank Ingenito


Dario O. Ciuffetelli


Dr. Charles M. Davis, Jr.

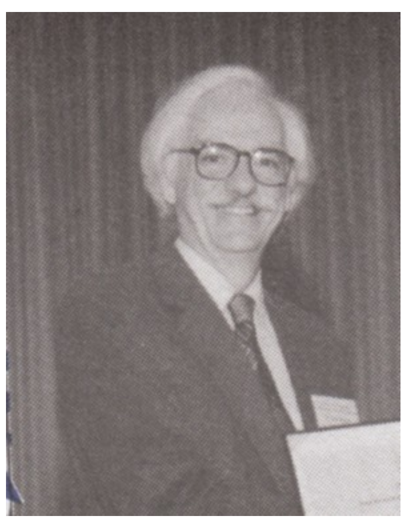

Dr. Joseph A. Bucaro


James H. Cole


Dr. Robert D. Corsaro

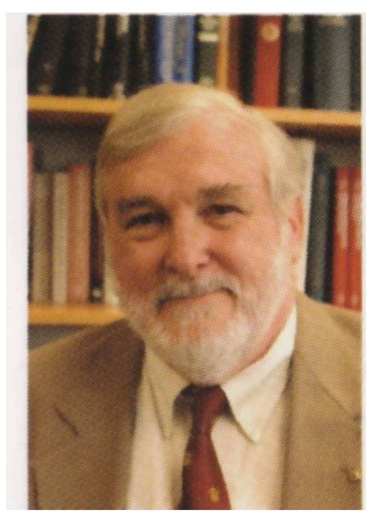

Dr. Nicholas Lagakos


Dr. Lawrence Flax

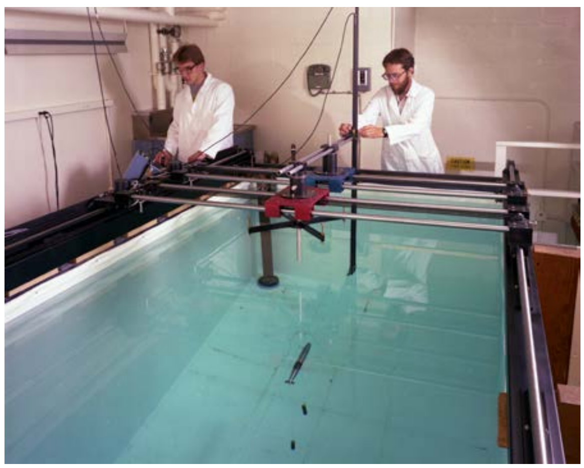

Dr. Earl G. Williams


Dr. Brian H. Houston


Dr. Fred T. Erskine


Dr. William M. Carey


Dr. Bruce H. Pasewark


Michael L. Picciolo (left) and Dr. Charles F. Gaumond conduct an acoustic scattering experiment in a small test tank using a scale model underwater target circa 1987


Redwood test tank (9 m diameter, 6 m deep) used for underwater scattering experiments

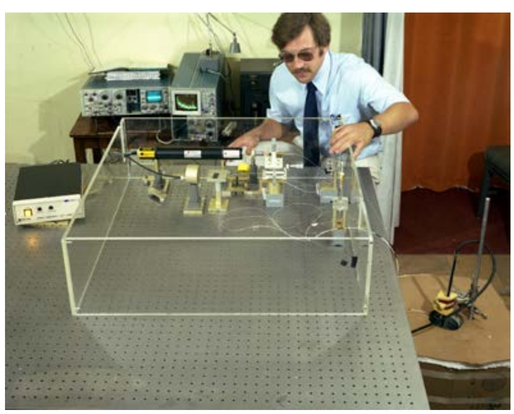
NRL's decommissioned nuclear reactor pool that was placed in use as a large acoustic test pool facility in the early 1970s (approximately 8 m x 10 m x 6 m deep at the shallowest point; with 150,000 gallons of filtered and deionized water)

Inspection of the large acoustic test pool circa mid-1970s. Present from left to right: Dr. John C. Munson, Capt. John T. Geary, two visiting dignitaries, and Dr. Charles M. Davis, Jr.

Dr. Werner G. Neubauer performing a scattering experiment in the large acoustic pool circa mid-1970s


James Cole (at left) and Dr. Henry Dardy shown with the schlieren acoustic visualization system circa late 1970s


Dr. Joseph A. Bucaro conducting an experiment on fiber-optic interferometric sensors circa late 1970s


James H. Cole with initial demonstration fiber-optic interferometric acoustic sensor system circa late 1970s

BERMAN'S FLEET

USS ALLEGHENY, ATA-179

RV MANNING, T-514

USNS MISSION CAPAISTRANO T-AGOR-162 162

USNS J. WILLARD GIBBS T-AGOR-1

USNS MIZAR T-AGOR-11

USNS HARVEY G. HAYES T-AGOR-16

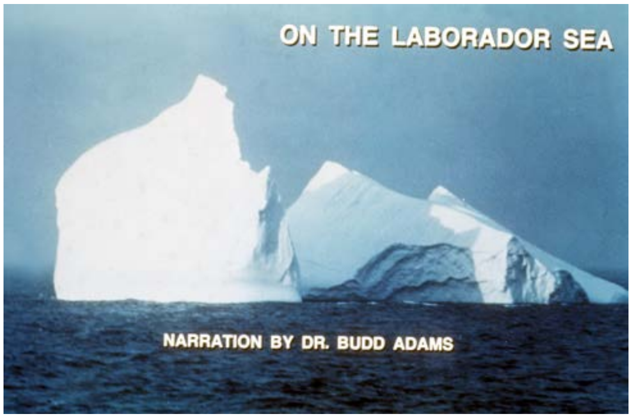
ARGUS ISLAND

EARLINE

NRL platforms for at-sea underwater acoustic experimentation circa early 1970s

U.S. Navy underwater acoustic testing site at Lake Pend Oreille near Bayview, Idaho; used by NRL Acoustics Division researchers circa 1970s. (Courtesy Dr. B.B. Adams)

Preparation of one-quarter scale underwater target for NRL testing in Lake Pend Oreille (1971)



Icebergs in the Labrador Sea (1972) (Courtesy Dr. B.B. Adams)


USNS Harvey C. Hayes (T-AGOR 16) used in at-sea experiments in the Labrador Sea (1972)

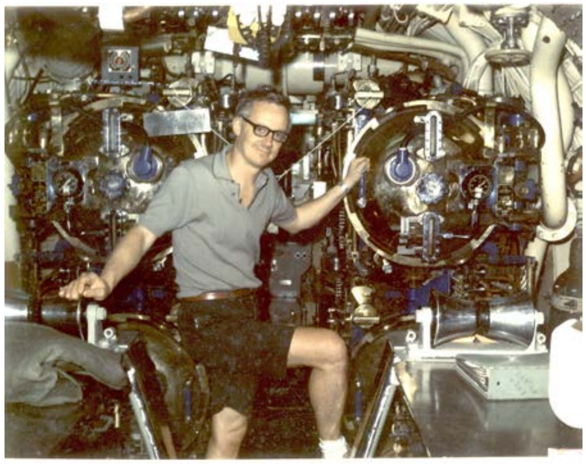

NRL technicians (Lee Huston at right) prepare an ambient sea noise buoy for deployment in the Labrador Sea (1972) (Courtesy Dr. B.B. Adams)


Deployment of an ambient sea noise buoy in the Labrador Sea from USNS Harvey C. Hayes (1972) (Courtesy Dr. B.B. Adams)

Monitoring the recording of acoustic data in the Labrador Sea aboard USNS Harvey C. Hayes (1972)
(Courtesy Dr. B.B. Adams)

Dr. Budd B. Adams aboard USNS Harvey C. Hayes in the Labrador Sea

Dr. Budd B. Adams aboard USS Dolphin (AGSS-555) for underwater acoustic tests in 1973. The USS Dolphin was the U.S. Navy's only operational diesel-electric, deep diving, research and development submarine.


Dr. Budd B. Adams inside USS Dolphin (AGSS-555) in 1973

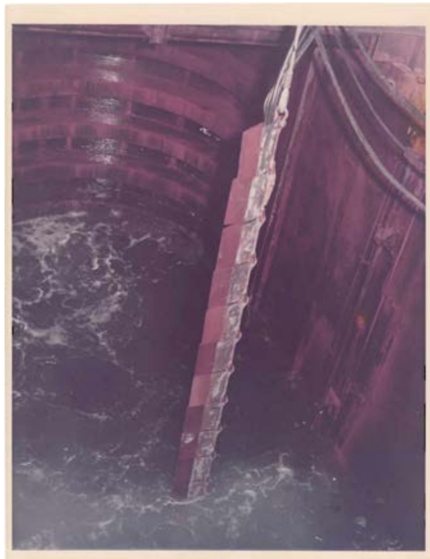

USNS Mizar (T-AGOR 11) on an NRL Arctic sea trial in the Norway Basin in 1974


Anthony Zuccaro, NRL scientific navigator, aboard USNS Mizar during underwater acoustic testing in the Norway Basin in March 1974

John Ostrander plotting USNS Mizar's course during NRL underwater acoustic tests in the Norway Basin in 1974

John Ostrander (left) and Charles Votaw in USNS Mizar's communications center during Arctic tests in 1974

Deployment of an acoustic source transducer for Arctic transmission loss tests from fantail of USNS Mizar in 1974



Acoustic source tow cable with anti-strum fairings as deployed from center well on USNS Mizar during Arctic testing in 1974

Berthel Carmichael operating a precision depth fathometer during Arctic testing aboard USNS Mizar in 1974

Dr. Susan Numrich adjusting chart recorder during Arctic testing aboard USNS Mizar in 1974

Dr. Susan Numrich performing acoustic data analysis aboard USNS Mizar during Arctic testing in 1974

Preparations for NRL underwater acoustic testing on the Arctic sea ice with assistance from U.S. Coast Guard vessel and helicopter (circa mid-1970s)

NRL Acoustics Division scientists preparing to deploy underwater acoustic equipment from the Arctic sea ice (circa mid-1970s)


Oceanographic survey and research vessel HMNZS Tui near Auckland, New Zealand during preparations for NRL Acoustics Division bathymetric hazard survey testing experiment TOPO II in 1979 (Courtesy Dr. B.B. Adams)


NRL ordnance expert Jason Husty Taylor preparing for NRL experiments aboard HMNZS Tui in 1979 (Courtesy Dr. B.B. Adams)


Deployment of underwater sound source transducer during NRL experiments aboard HMNZS Tui in 1979 (Courtesy Dr. B.B. Adams)


Preparation for deployment of towed horizontal line array of receiving hydrophones from HMNZS Tui during NRL testing in 1979 (Courtesy Dr. B.B. Adams)


Deployment of towed horizontal line array receiver from HMNZS Tui during NRL testing in 1979 (Courtesy Dr. B.B. Adams)

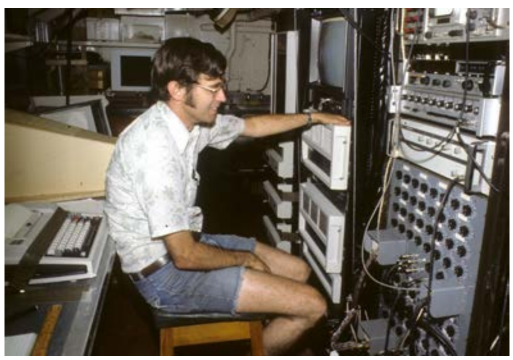

Jason Husty Taylor preparing to deploy a monitoring hydrophone for direct-path acoustic scattering tests from HMNZS Tui in 1979 (Courtesy Dr. B.B. Adams)


Jason Husty Taylor adjusting paper chart recorder for the monitoring hydrophone during NRL testing aboard HMNZS Tui in 1979 (Courtesy Dr. B.B. Adams)

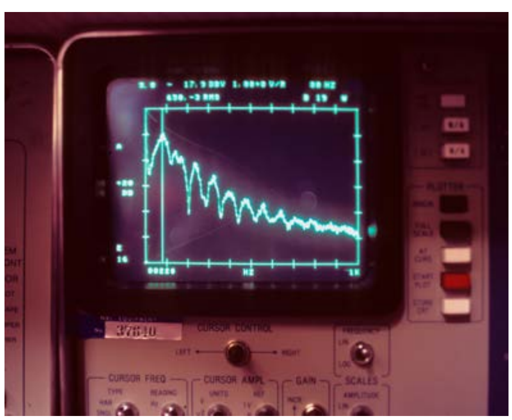

Deployment of underwater sound source with mechanical drag plate to slow its descent during direct-path scattering experiments on board HMNZS Tui in 1979 (Courtesy Dr. B.B. Adams)


Jason Husty Taylor prepares to deploy an impulsive acoustic source for measurements of reverberation from distant seamounts in the Liouville Ridge during NRL experiments aboard HMNZS Tui in 1979 (Courtesy Dr. B.B. Adams)

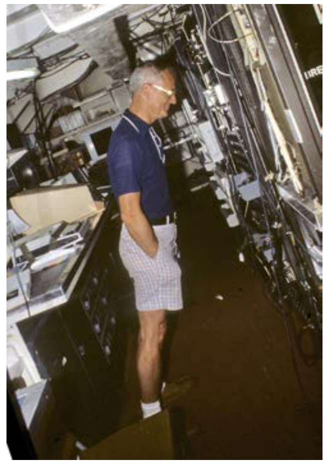
Jason Husty Taylor preparing an impulsive acoustic source line array for reverberation experiments aboard HMNZS Tui in 1979 (Courtesy Dr. B.B. Adams)



James Griffin monitors received acoustic data from NRL reverberation experiments aboard HMNZS Tui in 1979 (Courtesy Dr. B.B. Adams)



Spectrum analyzer display showing characteristic "bubble pulses" for monitoring the quality of received reverberation from impulsive source data (Courtesy Dr. B.B. Adams)



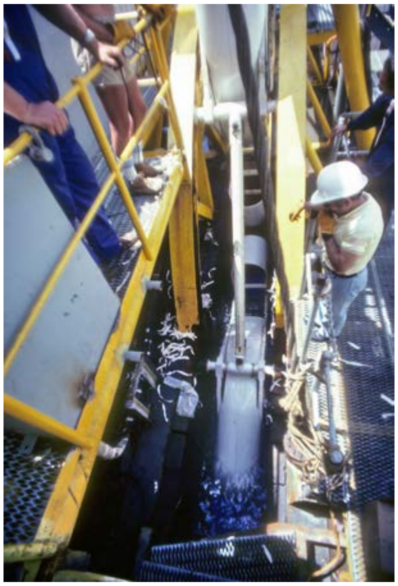
Dr. Budd B. Adams aboard HMNZS Tui during the TOPO-II sea test in 1979

The U.S. Navy conducted a series of low frequency active acoustic sea tests in the early 1980s that were named "Overbid Leo" (also known as AAUS-Active Adjunct to Undersea Surveillance) in honor of early NRL Sound Division researcher (and later a Navy Program Manager) Leo Treitel. These tests were conducted cooperatively by technical teams from NRL, the Naval Ocean Systems Center, San Diego, California, and the Naval Civil Engineering Laboratory, Port Hueneme, California. (Courtesy Dr. B.B. Adams)

The R/V Acadian Navigator (a converted oil industry "mud boat") was the test platform for the AAUS test series in the Pacific Ocean and Gulf of Alaska in the early 1980s (Courtesy Dr. B.B. Adams)

Rear deck of the Research Vessel Acadian Navigator showing the scientific equipment trailers and the five-element experimental low frequency source transducer array on its deployment track (Courtesy Dr. B.B. Adams)

Research Vessel Acadian Navigator showing spool and winch for the towed horizontal line receiving array at dock of the Naval Civil Engineering Laboratory, Port Hueneme, California (Courtesy Dr. B.B. Adams)

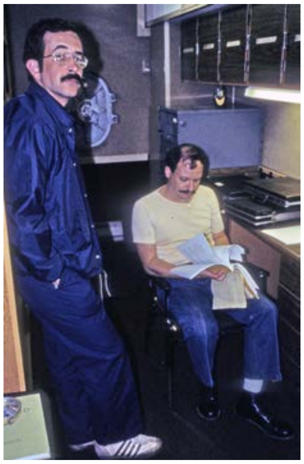


Deployment of the five-element experimental low frequency acoustic vertical source array in the center well of the Research Vessel Acadian Navigator (Courtesy Dr. B.B. Adams)

NRL Acoustics Division researchers Dr. Roger C. Gauss (left) and Dennis M. Dundore monitor the quality of received hydrophone data aboard Research Vessel Acadian Navigator during an AAUS experiment (Courtesy Dr. B.B. Adams)

NRL Acoustics Division researchers Robert W. Chrisp (at keyboard) and Dr. Fred T. Erskine prepare documentation on results of an AAUS sea test on board Research Vessel Acadian Navigator (Courtesy Dr. B.B. Adams)

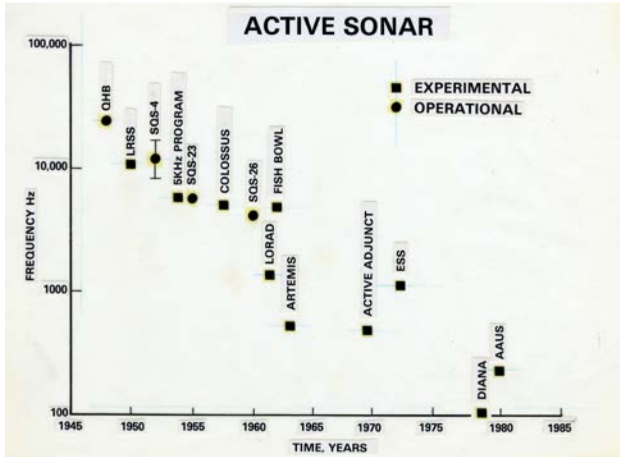
NRL researchers Robert W. Chrisp (at keyboard), Dr. Edward R. Franchi, and Jon A. Jannucci during conduct of an AAUS sea test on board Research Vessel Acadian Navigator (Courtesy Dr. B.B. Adams)



NRL researchers Dr. Edward R. Franchi (on left) and Dr. Fred T. Erskine studying the sea test plan during an AAUS experiment on board Research Vessel Acadian navigator (Courtesy Dr. B.B. Adams)

Data processing facility of NRL's Physical Acoustics Branch circa 1980. Dr. Henry D. Dardy studies a computer printout at rear.

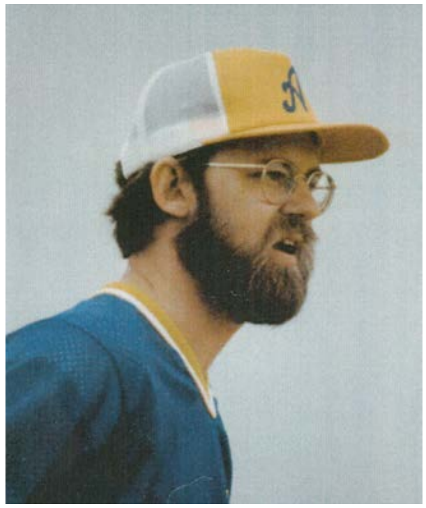
NRL's Underwater Sound Reference Division (USRD) acoustic transducer calibration facility near Orlando, Florida circa 1980



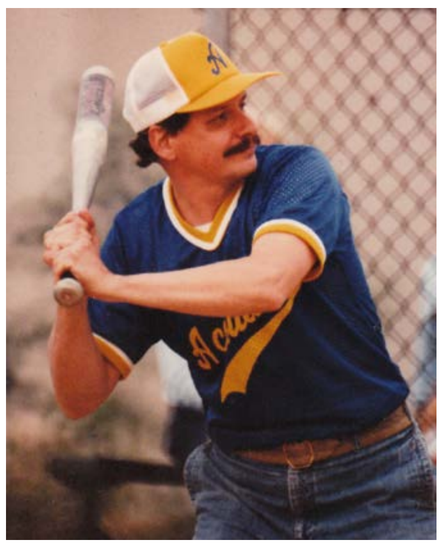
Plot illustrating the trend toward lower and lower frequencies for U.S. Navy experimental and operational active sonar systems from the 1940s to the 1980s (Courtesy Dr. B.G. Hurdle files)

NRL Acoustics Division softball team circa 1982. Front row (left to right): Fred Erskine, Edward Kunz, Don DelBalzo, Edward Franchi, David Berman, Ralph Baer. Back row: Dennis Dundore, Daniel Krause (Materials Science and Technology Division), David Lubbers, L. Bruce Palmer, John Padgett, Roger Gauss, Richard Fizell.

L. Bruce Palmer pitching for the NRL Acoustics Division softball team circa 1982



John S. Perkins during a game of the NRL Acoustics Division softball team circa 1982



Fred Erskine at bat during a NRL Acoustics Division softball team game circa 1982

Era 4 Photographs (1985–1993)

Dr. David L. Bradley greeted by Capt. John J. Donegan, Jr., while Richard R. Rojas and Dr. Timothy Coffey look on, circa 1990

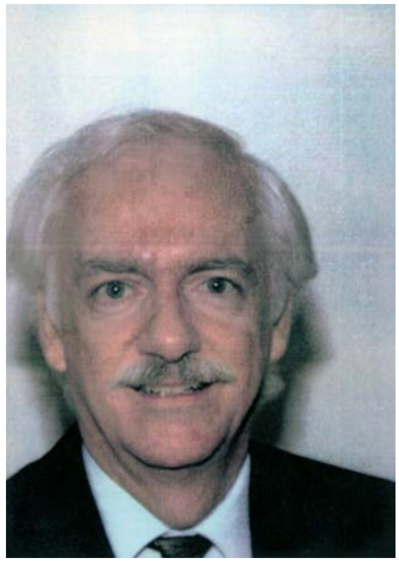
Dr. David L. Bradley (left) receives congratulations from Dr. Timothy Coffey and Capt. Paul G. Gaffney II on the occasion of his receiving the Navy Superior Civilian Service Award in 1993

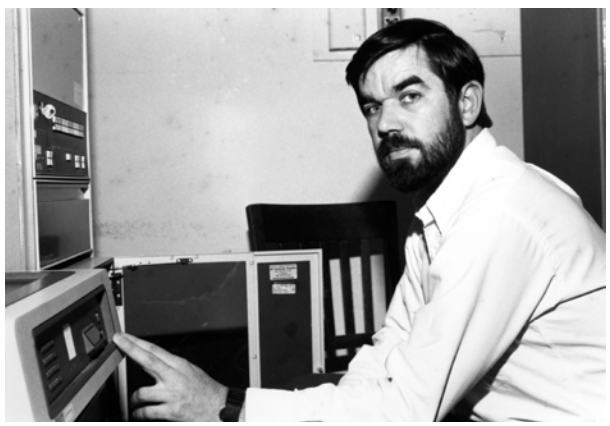
Dr. David L. Bradley in late 1993, shortly before his retirement from NRL. He is accompanied by members of the Acoustics Division administrative staff who are each wearing one of Dr. Bradley's Navy-related t-shirts (left to right): Karen Turner, Ruth Stallings, Lori Heddings, Dr. Bradley, Christine Burns, and Jane Ihnat.

Dr. William A. Kuperman

Dr. Marshall Orr

Henry S. Fleming


Dr. Earl G. Williams


John M. Brozena, Jr.


Dr. Clyde E. Nishimura


Dr. Steven I. Finette

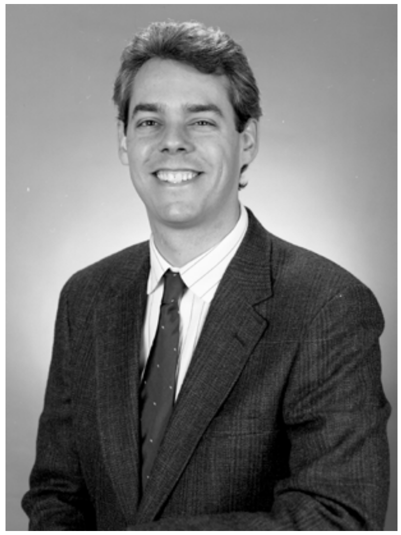

Dr. Peter M. Ogden


Dr. Robert F. Gragg


Raymond J. Soukup


Dr. Nicholas C. Makris


Dr. Brian H. Houston

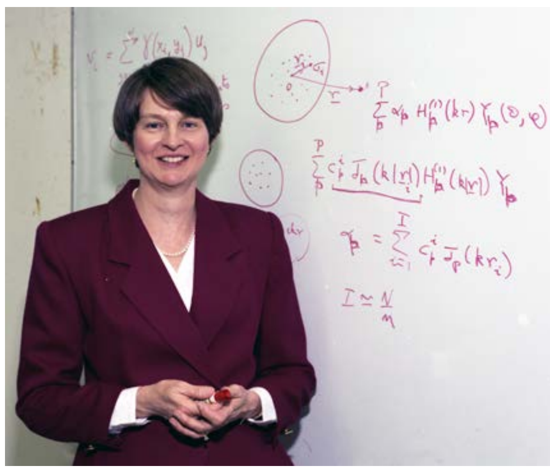


Joseph J. Shirron

Capt. William C. Miller, USN, NRL's Commanding Officer, looks on as Shirley Votaw affixes her husband's award, the Department of the Navy Superior Civilian Service Award (1987)

Elizabeth E. Wald

Dr. Susan K. Numrich



Dr. Luise S. Couchman

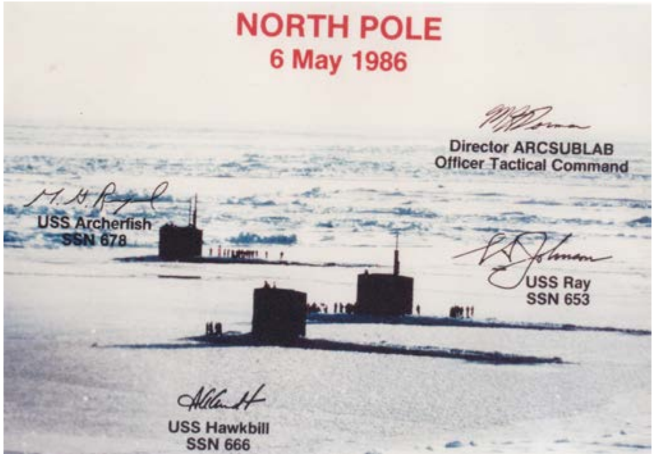
Dr. Ellen S. Livingston


Dr. Alexandra Tolstoy


Dr. Patricia L. Gruber


Laurie T. Fialkowski

Lilimar Z. Avelino



NRL Acoustics Division scientists participated in U.S. Navy Exercise Outpost Heritage in the central Arctic. Three U.S. nuclear submarines surfaced at the North Pole 6 May 1986: USS Archerfish, USS Hawkbill, and USS Ray. (Courtesy C.W. Votaw)

NRL Acoustics Division scientists on the ice in the central Arctic during Exercise Outpost Heritage in 1986 (Courtesty C.W. Votaw)

NRL airborne magnetic and gravimetric survey systems on board NRL maritime patrol aircraft (P-3)


John M. Brozena, Jr., during NRL Acoustics Division airborne survey operations


NRL Acoustics Division's Laboratory for Structural Acoustics. Large acoustic tank for in-water structural acoustics studies. It is 55 ft in diameter, 50 ft deep, and contains 800,000 gallons of deionized water.

Cooperative Education trainee Matthew Fierst performs modification of a sonobuoy acoustic receiver in preparation for Acoustics Division airborne sea surface scattering experiments

Cooperative Education trainee Matthew Fierst (center) assists Navy personnel in deployment of sonobuoys from an NRL P-3 research aircraft during an airborne sea surface scattering field experiment

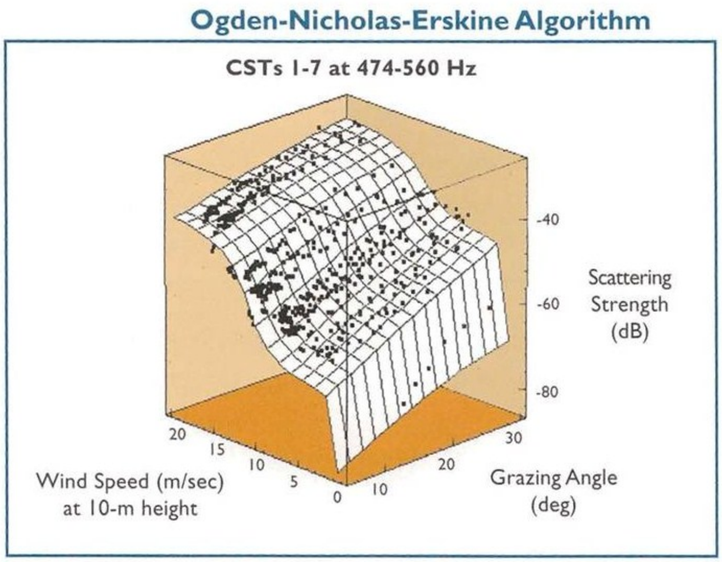
Cooperative Education Trainee Matthew Fierst monitors acoustic data recordings aboard a NRL P-3 research aircraft during an airborne sea surface scattering field experiment

Cooperative Education trainee John Crockett logs acoustic data from multiple sonobuoy receivers on board an NRL P-3 research aircraft during an airborne direct-path sea surface scattering field experiment

Research Vessel Amy Chouest at Kodiak, Alaska during preparations for a Critical Sea Test field experiment in the Gulf of Alaska in 1992 (Courtesy Dr. R.C. Gauss)

Preparing to depart for a Critical Sea Test field experiment in the Gulf of Alaska (CST 7 Phase 2) to perform air-sea boundary and sea surface scattering measurements on board research vessel Cory Chouest in 1992. From left to right: John Crockett, Peter Ogden, John Chester (Naval Underwater Systems Center, New London, Connecticut), and Fred Erskine. (Courtesy Dr. R.C. Gauss)

Dr. Fred Erskine, Chief Scientist for Critical Sea test field experiment CST 7 Phase 2, during preparations at Kodiak, Alaska in February 1992 (Courtesy Dr. R.C. Gauss)



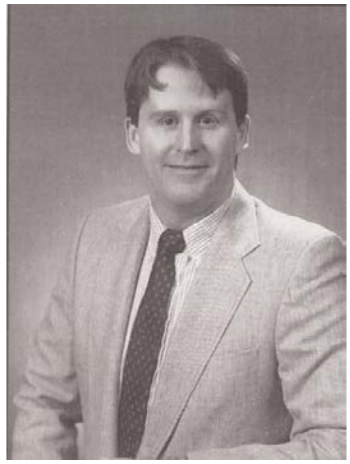
Empirical fit by NRL researchers Peter Ogden, Michael Nicholas, and Fred Erskine to Critical Sea Test sea surface scattering data sets from seven CST field experiments. This algorithm was accepted for inclusion in the Navy's Oceanographic and Atmospheric Master Library as a Navy Standard sea surface scattering algorithm for use in Navy sonar system performance modeling.

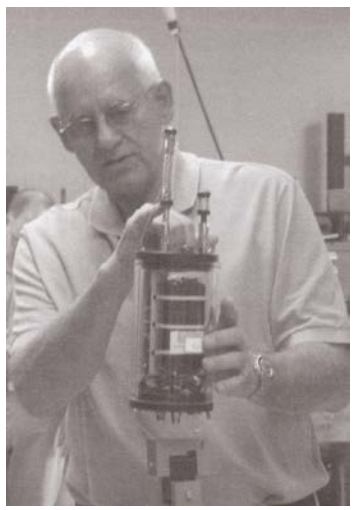
Era 5 Photographs (1994–2008)

Dr. Stanley A. Chin-Bing

Dr. T.C. Yang (right) receives a publication award from Dr. Timothy Coffey (NRL Director of Research) for his Featured Research article in the 2001 NRL Review on phase coherent underwater acoustic communications

Dr. Joseph A. Bucaro

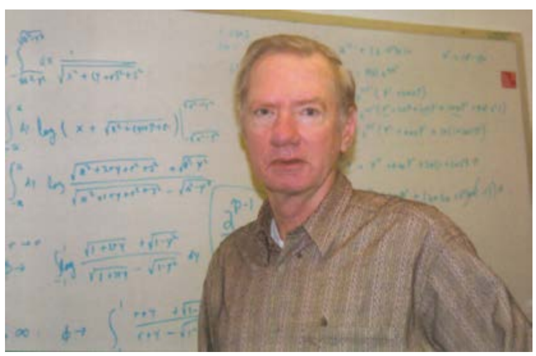

Dr. Michael D. Collins


Dr. J. Stephen Stanic


Dr. Ronald A. Wagstaff

Dr. Charles F. Gaumond


Dr. David M. Fromm

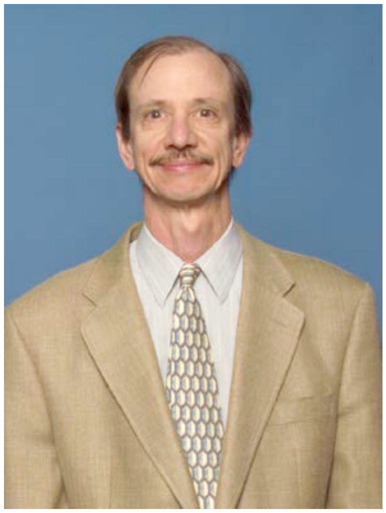

Dr. B. Edward McDonald


Dr. Joseph F. Lingevitch


Dr. Christopher Feuillade


Dr. Jason E. Summers


Dr. Joseph F. Vignola



Dr. Roger C. Gauss

Dr. Fred T. Erskine

Dr. Burton G. Hurdle

NRL Acoustics Division researchers on a field experiment in Wales, United Kingdom in 1991. Left to right: Front Row: Unidentified school student, Dr. Michael Collins, John Perkins; Back row: Dr. Nicholas Makris, Unidentified, Laurie Fialkowski, Dr. William Kuperman, Timothy Krout, Dr. Jonathan Berkson. (Courtesy John Perkins)

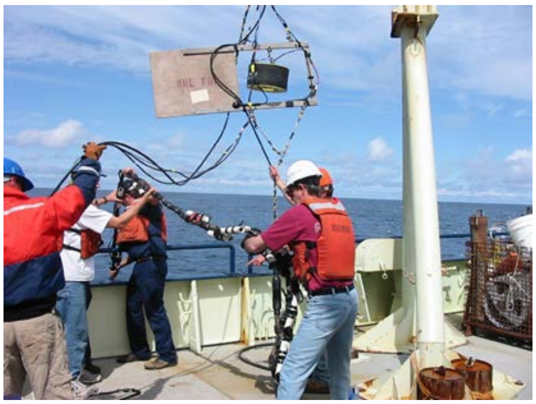
NRL Acoustics Division researchers on a field experiment based at the NATO SACLANT ASW Centre in La Spezia, Italy in 1992. Front row: Gary Murphy (Planning Systems, Inc.), John Perkins, Laurie Fialkowski, Dr. William Kuperman; Back row: Dr. Michael Collins, Timothy Krout, Dr. Jonathan Berkson, Dr. Nicholas Makris. (Courtesy John Perkins)

NRL Acoustics Division researchers and colleagues on board the NATO Research Vessel Alliance during a 1992 field experiment near Adventure Bank in the Mediterranean Sea. In front: Dr. William Kuperman, Dr. Michael Collins, and Dr. Jonathan Berkson; At rear: Andrea Caiti, John Perkins, Dr. Frank Ingenito, Timothy Krout, Gary Murphy (Planning Systems, Inc.), Aage Kristensen, Laurie Fialkowski, Dr. Michael Max, and Dr. Nicholas Makris. (Courtesy John Perkins)


Pierside preparations for the T-MAST 02 Field Test in Glasgow, Scotland in July 2002. At front: Peter King and Joseph Mingrone (C&M Technologies). At rear: Dr. Michel Nicholas and John Perkins. (Courtesy Dr. Michael Nicholas)


Deployment of the NRL Acoustics Division's bottomed vertical line array receiver and digital acquisition unit during the T-MAST 02 Field Test near the west coast of Scotland in July 2002. (Courtesy Dr. Michael Nicholas)

NRL Bottom Scattering Experiment team on board Research Vessel Knorr during the July 2002 T-MAST 02 Field Experiment. Seated: Richard Menis. Standing, left to right: Dr. Roger C. Gauss, John Dubberly, Edward Kunz. (Courtesy Dr. R.C. Gauss)



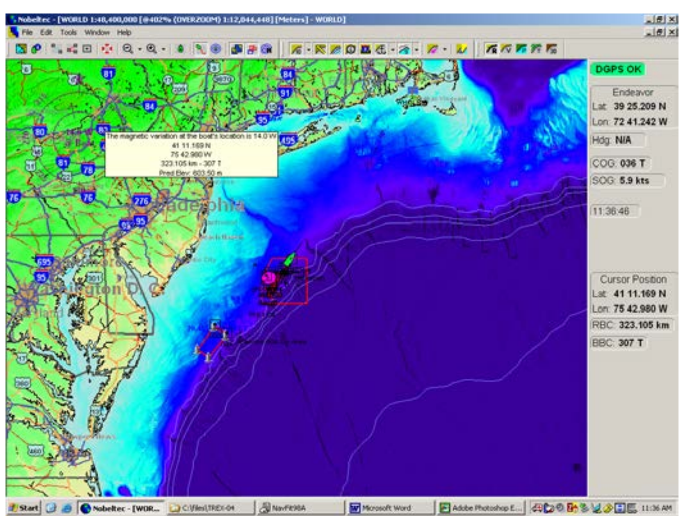
Deployment of bottom scattering vertical line array receiver and source transducer from Research Vessel Knorr during the T-MAST 02 Field Experiment in July 2002. (Courtesy Dr. R.C. Gauss)

Meeting of The Technical Cooperation Program (TTCP) Maritime Systems Group (MAR) ASW Systems and Technology Panel (TP-9) held at the Naval Undersea Warfare Center, Newport, Rhode Island in October 2004. Present are representatives from Australia, Canada, the United Kingdom, and the United States. Panel chairman is Dr. Edward R. Franchi from NRL's Acoustics Division (seated in front, third from left). (Courtesy Dr. Edward R. Franchi)

Meeting of the TTCP MAR TP-9 Combined Multistatic ASW Sonar Technology (CMAST) Specialists at the Naval Research Laboratory, Washington, DC in June 2004. Present are technical specialists from Australia, Canada, the United Kingdom, and the United States. The meeting chairperson is Dr. Fred Erskine (front row, second from left). (Courtesy Simon Taylor, DSTO, Australia)


Dr. Roger C. Gauss presenting a lecture on NRL sonar research to Australian scientists at the Defence Science and Technology Organisation (DSTO), Edinburgh, South Australia in 2007 (Courtesy Dr. R.C. Gauss)


Dr. Roger C. Gauss with Australian colleagues during his sonar lecture series in 2007 (Courtesy Dr. R.C. Gauss)



Map showing the location of NRL's Time Reversal Experiment 2004 (TREX04) off the coast of New Jersey in 2004 (Courtesy Dr. D.M. Fromm)

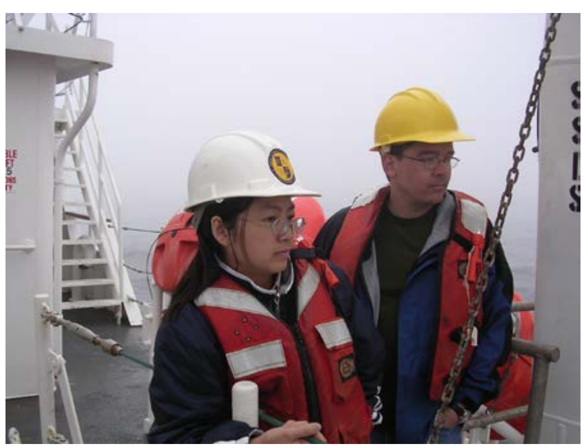
NRL dockside pre-test equipment preparations for sailing on Research Vessel Endeavor (University of Rhode Island) during TREX04 at the University of Rhode Island's Graduate School of Oceanography field site in Narragansett, Rhode Island in 2004. Navy reservists are assisting NRL Acoustics Division scientists. (Courtesy Michael McCord)

Research Vessel Cape Henlopen (University of Delaware) as seen from R/V Endeavor during NRL's TREX04 field experiment (Courtesy Michael McCord)

Drs. Wen-Bin Yang (left) and T.C. Yang participating in dockside preparations for acoustic communications tests during TREX04 in 2004 (Courtesy Michael McCord)

Deployment of NRL acoustic communications equipment from R/V Endeavor during TREX04 in 2004 (Courtesy Michael McCord)

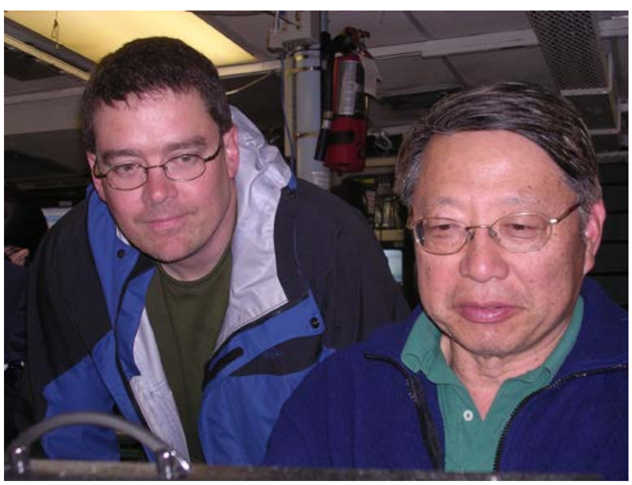
Discussion of NRL acoustic communications experiment, led by Dr. Paul Gendron (second from left) aboard R/V Endeavor during TREX04 field test in 2004. Navy reservists were active participants in the experiments. (Courtesy Michael McCord)



Drs. Xuemei Chen and Jeff Schindall participating in NRL acoustic communications testing aboard R/V Endeavor during TREX04 in 2004 (Courtesy Michael McCord)

Raymond Soukup operating cable winch aboard R/V Endeavor during NRL field test TREX04 in 2004. R/V Cape Henlopen is seen in the distance. (Courtesy Michael McCord)

Richard Menis managing acoustic source operations aboard R/V Endeavor during TREX04 in 2004 (Courtesy Michael McCord)



Drs. Jeff Schindall and T.C. Yang monitoring the collection of acoustic communications data aboard R/V Endeavor during TREX04 in 2004 (Courtesy Michael McCord)

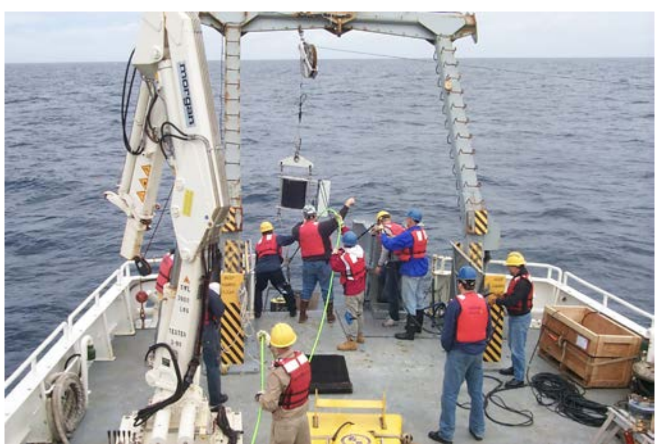
Dr. Xuemei Chen participating in acoustic communications experimentation aboard R/V Endeavor during TREX04 in 2004 (Courtesy Michael McCord)

Dr. Fred Erskine aboard R/V Endeavor during NRL field test TREX04 in 2004. R/V Cape Henlopen is seen in the distance. (Courtesy Michael McCord)

Michael McCord monitoring the tracks of NRL acoustic communications buoys from R/V Endeavor during TREX04 in 2004 (Courtesy Michael McCord)

Dr. Wen-Bin Yang discussing acoustic communications experiments with colleagues aboard R/V Endeavor during TREX04 in 2004 (Courtesy Michael McCord)

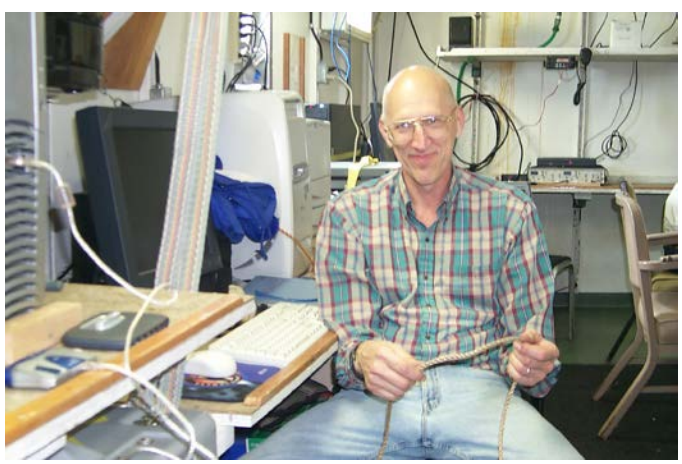
Oregon State University's Research Vessel Wecoma in Newport, Oregon during preparations for NRL field test OREX05 in 2005 (Courtesy Dr. D.M. Fromm)



Deployment of NRL low frequency source transducer from R/V Wecoma off the Oregon Coast during NRL field test OREX05 in 2005 (Courtesy Dr. R.C. Gauss)

Dr. Redwood Nero during OREX05 volume scattering tests aboard R/V Wecoma off the Oregon Coast in 2005 (Courtesy Dr. R.C. Gauss)

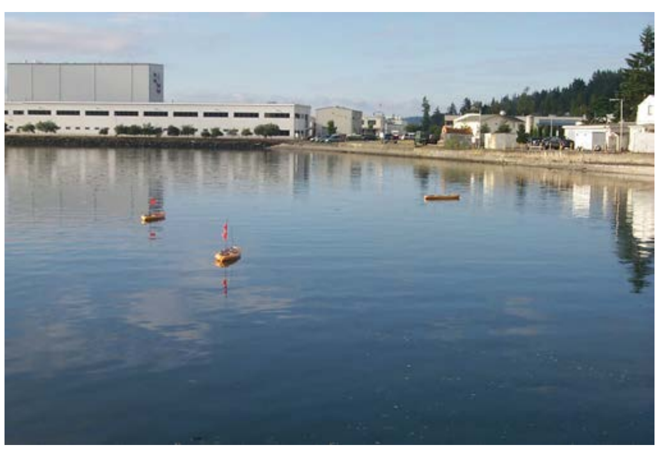
Dr. Charles F. Gaumond during OREX05 acoustic time-reversal tests aboard R/V Wecoma off the Oregon Coast in 2005 (Courtesy Dr. C.F. Gaumond)



Dennis Dundore assisting with field testing during OREX05 off the Oregon Coast in 2005 (Courtesy Dr. C.F. Gaumond)


Richard Menis monitoring acoustic source operations during OREX05 off the Oregon Coast in 2005 (Courtesy Dr. R.C. Gauss)


Dr. Paul Gendron during dockside preparations for AUV-Fest 05 at the Naval Undersea Warfare Center (NUWC) Very Shallow Water (VSW) Range in Keyport, Washington, May–June 2005 (Courtesy Michael McCord)


Site of NRL’s participation in AUV-Fest 05 in Keyport, Washington in 2005 (Courtesy Michael McCord)

Dr. Paul Gendron, Dr. Jeff Schindall, and Dr. Wen-Bin Yang prepare NRL acoustic communications buoys for testing in AUV-Fest 05 in 2005 (Courtesy Michael McCord)

Deployment of NRL acoustic communications buoys during AUV-Fest 05 in Keyport, Washington in 2005 (Courtesy Michael McCord)

Dr. Jeff Schindall prepares to monitor the performance of NRL acoustic communications equipment from a small boat during AUV-Fest 05 in Keyport, Washington in 2005 (Courtesy Michael McCord)

Michael McCord monitors signals received from NRL acoustic communication buoys during AUV-Fest 05 in Keyport, Washington (Courtesy Michael McCord)

NRL scientists participate in Scientist-to-Sea opportunity aboard USS Harry S. Truman (CVN 75) off the Virginia coast in July 2005 [Photos courtesy of Michael McCord and Lt. James McArdle (Center for Bio/Molecular Science and Engineering)]

“The Island” aboard USS Harry S. Truman (CVN 75) during NRL Scientist-to-Sea visit in July 2005


Transport aircraft that took NRL scientists to the USS Harry S. Truman (CVN 75) in July 2005


Michael McCord (foreground) aboard the C-2A aircraft preparing to take off from USS Harry S. Truman (CVN 75) in the Atlantic Ocean off the Virginia Coast


Michael McCord aboard USS Harry S. Truman (CVN 75) during Scientist-to-Sea visit in July 2005


F/A-18 aircraft parked on the flight deck of USS Harry S. Truman (CVN 75) in July 2005

Appendix 5

Acoustics Division Major Facilities

The NRL Acoustics Division has numerous facilities that support laboratory and at-sea measurements conducted by Division researchers. Included here is information on each of these facilities from the *NRL Major Facilities 2008* publication (available online at http://www.nrl.navy.mil/media/publications/major-facilities/). The short write-ups include the function, description, and instrumentation for each facility. The facilities discussed are: Acoustic Communications Measurement Systems; High-Frequency Acoustical Flow Visualization Sonar Systems; Instrumentation Suite for Acoustic Propagation Measurements in Complex Shallow Water Environments; Rail-based Broadband Synthetic Aperture Ocean Measurement System; Structural Acoustics In-Air Facility; Laboratory for Structural Acoustics; Shallow Water Acoustic Laboratory; Autonomous Acoustic Receiver System; Salt Water Tank Facility; Underwater Acoustic Time-Reversal Mirror; Shallow-Water High-Frequency Measurement Systems; 300 Hz and 500 Hz Autonomous Acoustic Sources; Sediment Geo-Probe System; Drifting Echo Repeater; Shallow Water Ship Acoustic Signature System; Geoacoustic Physical Model Fabrication Laboratory; and Sono-Magnetic Laboratory.

Acoustics Division

- Acoustic Communications Measurement Systems
- High-Frequency Acoustic Flow Visualization Sonar Systems
- Instrumentation Suite for Acoustic Propagation Measurements in Complex Shallow Water Environments
- Rail-based Broadband Synthetic Aperture Ocean Measurement System
- Structural Acoustics In-Air Facility
- Laboratory for Structural Acoustics
- Shallow Water Acoustic Laboratory
- Autonomous Acoustic Receiver System
- Salt Water Tank Facility
- Underwater Acoustic Time-Reversal Mirror
- Shallow-Water High-Frequency Measurement Systems
- 300 Hz and 500 Hz Autonomous Acoustic Sources
- Sediment Geo-Probe System
- Drifting Echo Repeater
- Shallow Water Ship Acoustic Signature System
- Geoacoustic Physical Model Fabrication Laboratory
- Sono-Magnetic Laboratory

Acoustic Communications Measurement Systems (ACOMMS)

FUNCTION: Design and develop adaptive signal processing techniques to improve underwater acoustic communications and networking. Phase coherent and incoherent signal patterns are transmitted from NRL's acoustic projector source systems through the underwater medium to NRL's receiver systems. Improved signal processing techniques are developed and refined to minimize the bit error rate and to evaluate environmental influences on the processor's performance.

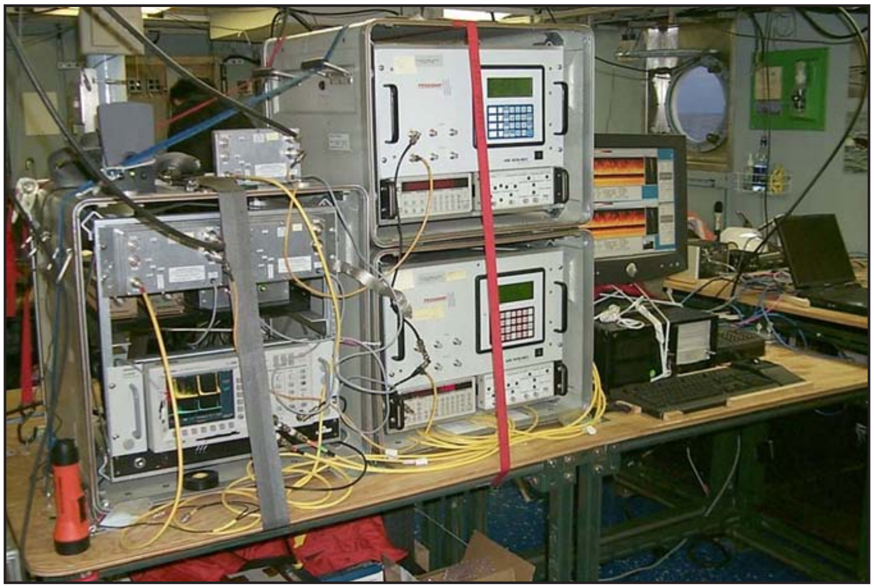
ACDS surface unit being deployed from the research vessel *Endeavor*

DESCRIPTION: Our acoustic communications research systems enable our team to conduct experiments at frequencies from 3 to 60 kHz. Source signal patterns are designed by NRL, transmitted into the ocean medium, and received at distances out to 15 km. The received signals are processed in situ and recorded for post-experiment data processing. Acoustic Communications Data Storage (ACDS) buoy systems transmit at source levels up to 185 dB. For higher sound pressure levels, an acoustic projector mounted in our 4-ft V-fin towbody develops up to 200 dB. ACDS buoy systems include 8-element vertical line arrays with variable apertures. Our shipboard-based vertical array has a wide aperture of 16 elements and is deployed from a vessel at anchor. Relative position, speed, and depth of our projectors and receiver arrays are carefully controlled throughout the experiments. Impact of Doppler and signal-to-noise ratio on system performance is measured and algorithms developed to improve performance. Our ACDS systems are normally moored to the sea floor with the acoustic elements suspended in the water column. However, one ACDS system has been modified for attachment to a tow frame, and in this configuration it provides a near-ideal autonomous undersea vehicle (AUV) test platform. Each of the ACDS systems provides semi-autonomous operations for up to 78 hours. Custom-designed software is used for onboard data monitoring and signal processing. Back in the lab, advanced signal processing algorithms are applied to the recorded signals to extract the phase-encoded bit patterns and to improve communication accuracy.

INSTRUMENTATION: (1) ACDS buoy systems include three deployed modem systems, a shipboard control station, and wireless local area network (WLAN) communication links. Each deployed modem system includes one acoustic projector (3, 10, or 20 kHz), eight hydrophones, 300 GB of data storage, and three computers. The systems can be moored to the ocean bottom or towed behind a surface vessel. (2) Towed source systems include 3- and 4-ft V-fin towbodies mounted with acoustic projectors, driven by 2-kW power amplifiers. (3) Shipboard-based receiver system includes a custom 16-channel hydrophone array, signal processing electronics, and data monitoring and data recording equipment.

CONTACT:
Code 7120 • (202) 767-2945
LOCATION:
NRL, Washington, DC

High-Frequency Acoustic Flow Visualization (HFAFV) Sonar Systems



HFAFV systems on board the research vessel *Endeavor*

FUNCTION: Flow visualization of fluid processes on the continental shelf; e.g., internal tides, ear instabilities, and nonlinear internal gravity waves (solitons).

DESCRIPTION: Our HFAFV sonar systems are used to image the fluid processes that perturb the density/sound speed field in the littoral. A patented high-speed transmit-receive switch provides NRL with the receive sensitivity necessary to detect the small-amplitude signals backscattered from particulates and temperature/salinity variability associated with large density gradients in the thermocline. At the laboratory, the data is processed and analyzed with the objective of improving our understanding of the generation and propagation of internal waves and fine structure and their effect on the sound speed field.

INSTRUMENTATION: Two similar systems, differing only in operating frequency:

(1) Matec PR5000 gated sine wave pulse generator and power amplifier, NRL-developed transmit-receive switch, custom-designed transducer (200 kHz)

(2) Matec PR5000 gated sine wave pulse generator and power amplifier, NRL-developed transmit-receive switch, custom-designed transducer (350 kHz)

Also, a personal computer–based data acquisition system, using off-the-shelf analog-to-digital converters and ISIS software from Triton Elics.

CONTACT:
Code 7120 • (202) 767-2945
LOCATION:
NRL, Washington, DC

Instrumentation Suite for Acoustic Propagation Measurements in Complex Shallow Water Environments

Deployment of instrumentation sled for 96-element acoustic horizontal line array receiver system

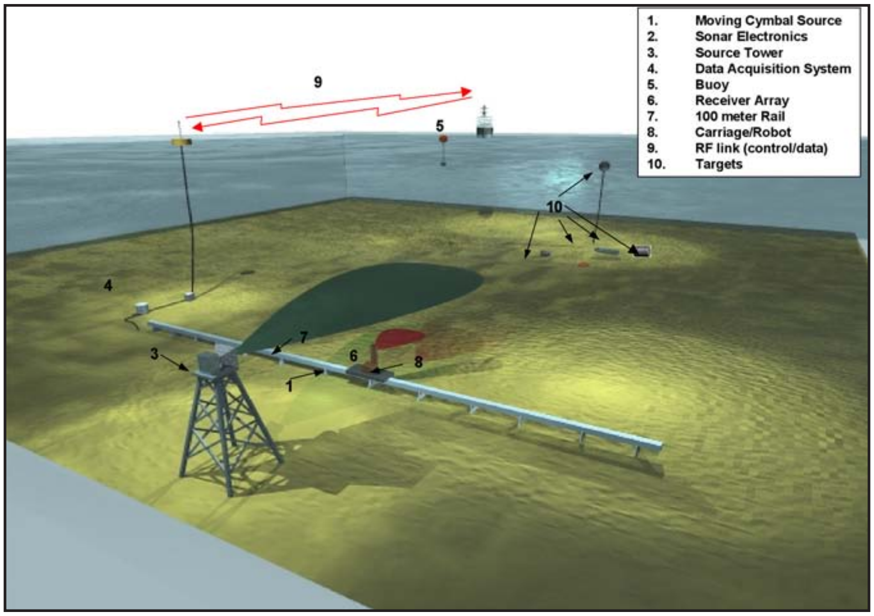
FUNCTION: Obtain at-sea measurements to test theoretical and modeling predictions of acoustic propagation in dynamic, inhomogeneous, and nonisotropic shallow water environments. The theories and models predict variations of signal amplitude, coherence, and travel time due to interaction of sound with small- to large-scale volume inhomogeneities within the water column and ocean sediment. The instrumentation suite provides calibrated measurements of these acoustic quantities in the frequency range 50 Hz to 20 kHz.

DESCRIPTION: The multiple sources and receivers in this instrumentation suite allow measurement of acoustic propagation variability as a function of both time and range over horizontal and vertical apertures. The autonomous systems can operate in severe weather conditions since they have no sea-surface expression, while the RF telemetered receiver system can provide real-time information on acoustic propagation. The acoustic receiver systems each have an operational lifetime up to 20 days at a sampling frequency of 4 kHz. The operational lifetime for each acoustic source is ~25 days at 50% duty cycle. Clocks having rubidium-standard accuracy control all timing functions for the acoustic sources and receivers, including waveform synthesis and sampling of the received signals. This feature permits measurement of absolute travel time and its variations to better than millisecond accuracy and allows data from each of the autonomous receiver systems to be time-synced together for phase-coherent processing.

INSTRUMENTATION: The instrumentation suite consists of several acoustic sources and receiver array systems, augmented by sensors to characterize the oceanographic environment. The current equipment suite is composed of two autonomous arbitrary waveform acoustic sources, two autonomous continuous-wave acoustic sources, three autonomous 32-element acoustic vertical line array receiver systems, one autonomous 96-element acoustic horizontal line array receiver system, and one 32-element RF telemetered acoustic vertical line array receiver system.

CONTACT:
Code 7120 • (202) 767-3210
LOCATION:
NRL, Chesapeake Beach, MD

Rail-based Broadband Synthetic Aperture Ocean Measurement System



Depiction of the 100-m-long rail deployed in shallow water together with the source tower, data acquisition system, RF link to surface vessel, and scattering targets

FUNCTION: Enables collection of broadband acoustic scattering databases where acoustic sources and receivers can be translated on a precise linear path under program control. Further, the phasing of the source and data acquisition is highly coherent such that scattering data can be processed to form synthetic apertures. This facility supports research in the collection of high-quality scattering cross sections of mines and the associated clutter, with the intent of perfecting techniques required for unmanned undersea vehicles (UUVs).

DESCRIPTION: The facility is a portable measurement system that can be deployed in an ocean environment. A 100-m-long rail supports a robotic carriage that can be positioned precisely at any point along the rail using an encoder feedback system. The sources and receivers can be attached to the carriage to collect quasi-monostatic data, and a separate source tower enables bistatic scattering data collection. All data acquisition, process control, and signal conditioning are contained within a pressure vessel that sits on the sea floor adjacent to the rail. Bidirectional control and data transfers are made over a dedicated RF link to a surface platform.

CONTACT:
Code 7136 • (202) 404-3840
LOCATION:
Ocean deployed

Structural Acoustics In-Air Facility

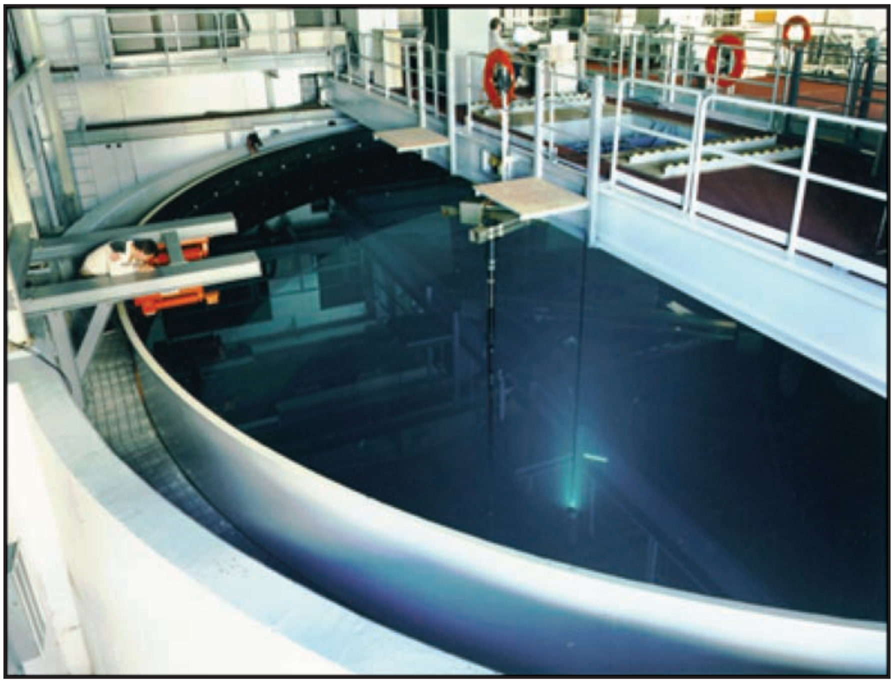
FUNCTION: Supports experimental research where broadband acoustic radiation, reflection, transmission, and surface vibration measurements are required. Typically, ultra-high-precision, highly spatially sampled measurements are conducted on scaled submarine structures, satellite payload fairings, active and passive material systems for sound control, and new transducer and sensor systems.

DESCRIPTION: The large, acoustically treated facility is 50 ft × 40 ft × 38 ft high. The laboratory is instrumented with precise acoustic and vibration measurement systems. These include large workspace robotic scanners capable of generating nearfield acoustic holography (NAH) radiation, reflection, and transmission databases. In addition, three-axis laser vibrometers are used to generate very highly sampled surface vibration maps.

INSTRUMENTATION: Broadband source/receiver systems; large workspace (3D) robotic scanners for NAH; scanning laser Doppler vibrometry (LDV); multiple workstations to support acquisition, analysis, calculations, and visualization; and structural acoustic codes: SARA2D, SARA3D, ANSYS, NISA, FEMLAB, and SONAX.

CONTACT:
Code 7136 • (202) 404-3840
LOCATION:
NRL, Washington, DC

Laboratory for Structural Acoustics



FUNCTION: Supports experimental research where acoustic radiation, scattering, and surface vibration measurements of fluid-loaded and non-fluid-loaded structures are required. Typically, ultra-high-precision measurements are conducted in this pristine laboratory environment using submarine hull backing impedance simulators, torpedoes, scale-model submarine structures, and deactivated mine targets.

DESCRIPTION: The large acoustic tank—the core research capability for in-water structural acoustics studies—is 55 ft in diameter, 50 ft deep, and contains 800,000 gal of deionized water. The entire tank is vibration and temperature isolated. The laboratory is instrumented with precision measurement systems that include large workspace in-water robotic scanners capable of generating nearfield acoustic holography (NAH) radiation and scattering databases.

INSTRUMENTATION: Network-based automated data acquisition and process control including extensive use of robotic scanners. Other attributes and resources include compact measurement ranges using nearfield sources and receivers; multiaxis laser Doppler vibrometry (LDV) for noncontact surface motion measurements; extensive interferometric fiber-optic sensor instrumentation; matrix processors that support MIMO control applications; multiple workstations and file servers to support acquisition, structural acoustics calculations, and visualizations; and structural acoustics codes: SARA2D, SARA3D, ANSYS, NISA, FEMLAB, and SONAX.

CONTACT:
Code 7136 • (202) 404-3840
LOCATION:
NRL, Washington, DC

Shallow Water Acoustic Laboratory

FUNCTION: Supports experimental research where high-frequency acoustic scattering and surface vibration measurements of fluid-loaded and non-fluid-loaded structures are required. Typically, ultra-high-precision measurements are conducted in this pristine laboratory environment when acoustic interactions with sediments are important.

DESCRIPTION: This facility includes a large concrete pool (250,000 gal of deionized water) equipped with high-resolution, computer-controlled target source and receiver manipulators. It is used for high-frequency acoustic scattering characterization of scale-model submarines and deactivated mine targets. The pool has a deep, sandy bottom and a high-resolution Cartesian nearfield acoustic holography (NAH) scanner to accommodate the controlled acoustic study of buried and near-buried mines.

INSTRUMENTATION: Network-based automated data acquisition and process control including extensive use of robotic scanners. Other attributes and resources include broadband source/receiver systems; compact measurement ranges using nearfield sources, receivers, and projection algorithms; multiaxis Doppler vibrometers for noncontact surface motion measurements of porous media water interfaces; multiple workstations to support acquisition analysis, calculations, and visualizations; and structural acoustics codes: SARA2D, SARA3D, ANSYS, NISA, FEMLAB, and SONAX.

CONTACT:
Code 7136 • (202) 404-3840
LOCATION:
NRL, Washington, DC

Autonomous Acoustic Receiver System

Surface telemetry buoy connected to a 64-element acoustic receiver

FUNCTION: Collects underwater acoustic data and oceanographic data. Data are recorded on-board an ocean buoy and can be telemetered to a remote ship or shore station in real time. The system is configured for command-and-control and data download. It can operate unattended for periods of up to one month.

DESCRIPTION: The heart of the Autonomous Acoustic Receiver (AAR) system is the data acquisition unit (DAU) containing the analog-to-digital converters for 64 channels at rates up to 8192 samples per second. One 64-element or two 32-element acoustic receive arrays can be attached to this DAU. If used vertically, there is also capability to add four tilt/head/depth sensors spaced throughout the vertical array. Once digitized, the data are sent up a 2000-ft fiber-optic umbilical cable to a surface buoy, where they are stored on hard disk. The data can then be telemetered to another location. The line-of-sight link can also be used to send command-and-control information to the system.

INSTRUMENTATION:

- 16-bit, 64-channel DAU, 8192 sample per second
- 64-element, 1.25-m spacing acoustic receive array
- 32-element, 2.5-m spacing acoustic receive array
- 32-element, 5-m spacing acoustic receive array
- 2000-ft fiber-optic double-armored umbilical cable
- Battery-powered buoy with enhanced line-of-sight capability
- Command-and-control/data downlink station with GPS-linked steerable directional antenna (for remote ship or shore station).

CONTACT:
Code 7145 • (202) 404-4826
LOCATION:
NRL, Chesapeake Beach, MD

Salt Water Tank Facility

The main salt water tank provides excellent optical access to the controlled saline environment

FUNCTION: Provides a controlled environment for studying complex bubble-related processes found in the ocean. It is an experimental pool facility for studies of underwater acoustics, fluid dynamics, and air-sea interface environmental topics, under saline conditions. This facility is currently being used to study the acoustics of bubbly media.

DESCRIPTION: The main salt water tank measures 20 ft × 20 ft × 12 ft high, with four 12 × 8 ft windows on each of the vertical walls. The water is recirculated every 10 h through particulate and UV filters, and the tank contains a high-capacity water chiller for controlling temperature. A separate chiller independently handles air temperature. Catwalks and a gantry provide access around and over the main tank, and a three-axis computer-controlled positioning system with four independent stages places and moves equipment within the tank. The tank is contained within a thermally insulated 50 × 26 ft laboratory area furnished with an overhead crane, a staging area, and a 20 × 10 ft room for instrumentation and data analysis.

INSTRUMENTATION:

- Acoustic sources, amplifiers, and hydrophones spanning 1 Hz to 700 kHz
- Environmental sensors to measure water temperature, salinity, dissolved gas concentrations, and surface tension
- Digital holographic imaging system to size particles down to ~5 μm
- Two high-speed digital cameras providing image acquisition up to 2000 full frames per second
- LabVIEW-based data acquisition system with laboratory-wide network access
- Brickwall filters, digital and analog oscilloscopes, data loggers, and power supplies.

CONTACT:
Code 7145 • (202) 404-4826
LOCATION:
NRL, Washington, DC

Underwater Acoustic Time-Reversal Mirror

Preparing 64-element source/receive array for deployment

FUNCTION: Records underwater acoustic signals and has the capability to time-reverse and re-broadcast these signals. This provides the ability to focus and scan acoustic energy for the detection of underwater objects. The signals can be emitted from guide sources or received in the form of ocean reverberation.

DESCRIPTION: The heart of the system is a 64-element transducer array that can alternately operate as a receiver array or an array of acoustic sources. The time-reversal functionality involves the capability to record signals, reverse them in time, and then re-broadcast them. This provides, for example, the capability to have a received signal returned to its point of origin where it will focus in both time and space. The importance of the concept is that this can be accomplished without detailed knowledge of the complex multipath structure produced by the ocean waveguide. Applications include enhanced echos from target objects, such as submarines or ocean mines, and reduced clutter echos from the ocean bottom or ocean surface.

INSTRUMENTATION:

- 64 6-in. spherical source/receive elements in a linear array with 1.25-m spacing (78.75 m aperture)
- Array elements independently controllable over the 500 to 3500 Hz frequency band
- A data digitization and recording system
- A pressure vessel to enclose system electronics for bottom-moored deployment
- Fiber-optic umbilical cable for connection between pressure vessel and ship/surface buoy.

CONTACT:
Code 7145 • (202) 404-4820
LOCATION:
NRL, Chesapeake Beach, MD

Shallow-Water High-Frequency Measurement Systems

FUNCTION: Supports a broad range of shallow-water high-frequency research programs, from acquiring a fundamental understanding of the physics of shallow-water propagation and boundary interactions to applied mine countermeasure and torpedo issues. The development of these systems has made NRL a leader in high-frequency shallow-water environmental acoustics research. Scattering and propagation measurements have been conducted in areas from the Gulf of Mexico to the Mediterranean. The data have been used in synthetic aperture sonar and torpedo simulations and design.

DESCRIPTION: These systems cover the 18 to 200 kHz frequency range. System control and data acquisition are carried by fiber-optic cables that terminate in a portable instrumentation van where the data are digitized and recorded on optical disks.

INSTRUMENTATION: These systems include high-resolution source and receiver combinations that operate in shallow to very shallow (7 to 30 m water depth) coastal areas.

CONTACT:
Code 7184 • (228) 688-5235
LOCATION:
NRL, Stennis Space Center, MS

300 Hz and 500 Hz Autonomous Acoustic Sources

FUNCTION: Provide acoustic researchers with autonomous, bottom-moored sound sources, which provide precise, highly stable frequency transmissions at GPS trackable times. The accuracy of the sources enables research into environmental perturbations of sound propagated through ocean media.

DESCRIPTION: The equipment consists of two sources, one centered at 300 Hz and another at 500 Hz. Each source uses a pressure-compensated flexural bar projector. The sources have a bandwidth of +/−10% about the center frequency. The accuracy of the transmit time and transmit frequency is controlled by a rubidium oscillator that can be disciplined to the GPS satellite system before deployment. The output level is adjustable with a maximum output of 183 dB. Pucks of D-cells contained in two pressure housings provide energy. The systems are rated to 200 meters. A full complement of pucks allows the sources to operate for 21 days at a 50% duty cycle and output level of 181 dB. Each system has an internal rubidium oscillator, and PC-104 electronics for timing and frequency generation. The systems are capable of continuous-wave, frequency modulated (FM) waveforms and arbitrary pseudorandom waveforms. Waveform types can be mixed within a transmit schedule, being limited only by the projectors, available programmable system memory, and energy levels desired.

INSTRUMENTATION: There are two independent systems. Each system consists of an EAI projector, Seascan signal generator/system, PC-104 electronics, and Webb Research assembly. One operates at 300 Hz and the other at 500 Hz. Each system includes a pressure-compensated projector, two pressure housings, and internal programmable electronics for transmit frequency and waveform, plus timing control.

CONTACT:
Code 7120 • (202) 767-3210
LOCATION:
NRL, Chesapeake Beach, MD

Sediment Geo-Probe System

Deployment of the geo-probe system

FUNCTION: Provides wideband in situ measurement capability of compressional wave speed and attenuation and their spatial variability in marine sediments.

DESCRIPTION: In situ ground-truth measurements of sound speed and attenuation are needed to validate geoacoustic inversion algorithms or high-resolution subbottom profiling techniques that are being used for bottom characterization. The wideband capability provides unique measurements of frequency dependency of sound speed and attenuation in various types of marine sediments. In addition, tomographic measurements of sediment sound-speed variability can be used to validate bottom scattering models. The system can be used to characterize large geological provinces in survey mode since the required measurement time per site is about 10 minutes.

INSTRUMENTATION: The geo-probe system has four probes populated with 1-inch-diameter ring transducers (Channel Industries) and a data acquisition unit with networking capability. The data acquisition unit can be pre-programmed or controlled through a standard oceanographic CTD cable. Wideband pulses (3–150 kHz) are generated and recorded with a sampling rate of 1 MHz. The system can be deployed at depths up to 1500 m and probe lengths can be varied up to 2 m. The source and receiver arrays on each probe allow spatial variability measurements of compressional wave speed and attenuation by using acoustic tomography.

CONTACT:
Code 7120 • (202) 404-8620
LOCATION:
NRL, Chesapeake Beach, MD

Drifting Echo Repeater

Deployment of the drifting echo repeater

FUNCTION: Supports low- to mid-frequency active sonar research for target detection and classification in littoral environments. Tests and validates new signal processing algorithms by using simulated targets with proper scattering kernels in multi-static configurations.

DESCRIPTION: The drifting echo repeater system is a research tool to simulate targets with pre-defined scattering characteristics. Its in-buoy signal processing capability provides flexibility to perform match-filtering, beamforming, and acoustic time-reversal in real time. Recently, it was used in mid-frequency (1.5–3.5 kHz) bistatic active sonar sea tests at ranges up to 15 km. The system can be used in drifting or moored configurations. The data storage and power budget provide two days of continuous recording of 16 channels and 10% duty-cycle sound transmission.

INSTRUMENTATION: The drifting echo repeater system has a wideband (240 Hz to 20 kHz) acoustic source, an 8-element vertical line array, and an 8-element Mills-Cross horizontal array. Acoustic data are sampled at each channel with a 20 kHz sampling rate and monitored in real time by using a wireless local area network (WLAN). High-accuracy GPS positioning is used to track the drifting system location in real time.

CONTACT:
Code 7120 • 404-8620
LOCATION:
NRL, Chesapeake Beach, MD

Shallow Water Ship Acoustic Signature System

Shallow Water Ship Acoustic Signature Buoy in the Chesapeake Bay between Chesapeake Beach and Tilghman Island, MD

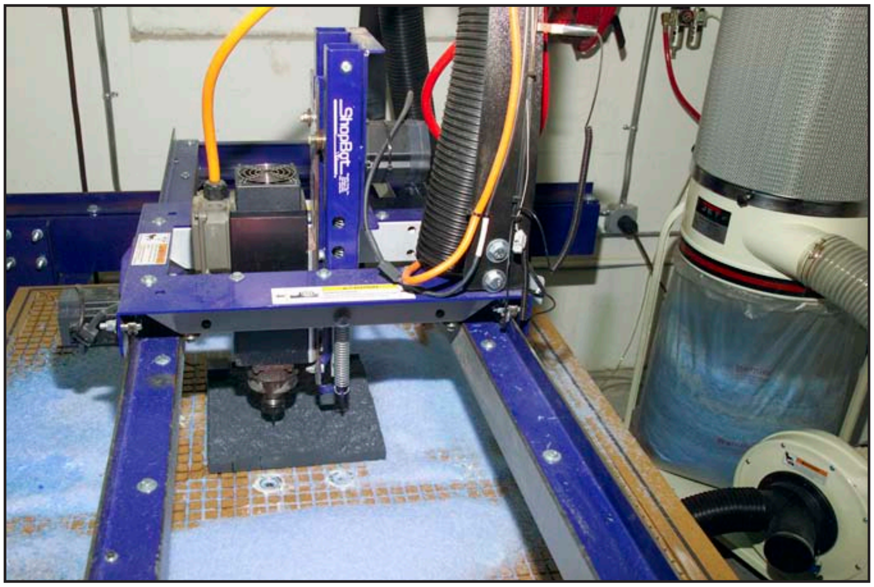
FUNCTION: Measures ship acoustic signatures in shallow water channels and at port entrances for detection and identification purposes. The system is the acoustics component of NRL's Modular Sensor System (MSS), which is designed to provide track information and local identification of vessels as they approach U.S. ports.

DESCRIPTION: The system is composed of two components, a buoy with two acoustic barrier lines and a monitoring system on shore. The acoustic lines contain hydrophones to form a barrier stretching out from the central buoy. The buoy is solar powered but also contains a rechargeable battery pack capable of running the buoy for 1 to 2 weeks; this is inside the central well along with the buoy's electronics. The monitoring system is composed of a computer. Communications are by Ethernet-link radio. The system is composed totally of commercial off-the-shelf (COTS) components with the exception of the NRL-developed array interface electronics. The buoy system is capable of fully independent operation, including detection and acoustic data acquisition of passing ships. More frequently, the onshore monitoring system cues the buoy to acquire data based on information passed to it from the MSS. The hydrophone sensitivities, A/D gains, channel selection, sampling rate, and data acquisition period are all remotely programmable.

INSTRUMENTATION: The COTS buoy includes a radar reflector and has an omnidirectional antenna and a self-powered strobe mounted on top. It is two-point moored to prevent twisting the acoustic lines. The lines are each 1 km long and have six hydrophones each. Inside the buoy's central well are power management, array interface, and A/D data acquisition electronics, a computer with a solid-state drive, an Ethernet-link radio, and the battery pack. The monitoring system is composed of a computer, a radio, and a directional antenna.

CONTACT:
Code 7120 • (202) 404-8149
LOCATION:
NRL, Chesapeake Beach, MD

Geoacoustic Physical Model Fabrication Laboratory



FUNCTION: Fabricates three-dimensional rough surfaces (e.g., fractals, ripples) out of materials such as PVC or wax to simulate the roughness properties associated with ocean bottoms. The rough surfaces have been employed in water tank facilities with acoustic sources and receivers to study acoustic scattering and propagation at frequencies up to 500 kHz.

DESCRIPTION: The facility enables computer-numerically controlled (CNC) fabrication of arbitrary single-valued topographies with submillimeter precision from machinable materials up to 1.2 m x 1.2 m in size and nominally 0.15 m in thickness. A suite of software allows a surface model and machining strategy to be developed for topography specified either explicitly as a digital elevation map or statistically in terms of spectral parameters. Multiple roughing, re-roughing, and finishing strategies are possible, depending on the nature of the surface to be fabricated. Surfaces are fabricated on a three-axis CNC mill equipped with a precision high-speed spindle, vacuum part fixturing ("hold-down"), liquid-free vortex tool cooling, a retractable ball-transfer system for part alignment, and a vacuum dust-collection system. Materials suitable for fabrication include soft metals, plastics, and wood. The facility also allows for submillimeter precision measurement of topographies of existing surfaces using a kinematic-resistive touch-trigger probe.

INSTRUMENTATION:

- Computer-numerically controlled three-axis milling machine.
- Part fixturing table equipped with a vacuum hold-down system and a retractable ball-transfer system.
- 5 HP precision spindle (0–24,000 rpm) accepting tools up to 0.5 in. (outer diameter).
- Vacuum dust-collection system.
- Liquid-free vortex compressed-air tool cooler.
- Carbide cutting tools as small as 0.01 in. (outer diameter), suitable for metal, plastic, and wood.
- Software suite including CAM and surface-generation programs.
- Touch-trigger measurement probes and control software.

CONTACT:
Code 7144 • (202) 404-4833
LOCATION:
NRL, Washington, DC

Sono-Magnetic Laboratory (SOMALab)

Experimental chamber of SOMALab under construction in FY07

FUNCTION: Conducts research on the interaction between arbitrarily directed magnetic fields and the motion of weakly conducting fluids under the influence of acoustic fields. This interaction causes an induced magnetic field capable of being detected with a flux-gate magnetometer.

DESCRIPTION: The facility is a double-hull Faraday cage constructed from steel plate and beam of the very high magnetic-μ HY-80 steel. The experimental chamber, or inner room, measures 2.5 m x 2.5 m x 4.5 m and is connected by insulated 50-cm-diameter cylindrical waveguide conduit to an external acoustic source chamber that is electromagnetically isolated from the remainder of the facility. Acoustic signals are propagated through the waveguide conduit such that prescribed particle velocities are induced within a 1 m x 1 m x 2 m Plexiglas tank atop a vibration-damped optical bench at the center of the experimental chamber. A set of three-axis Helmholtz coils is used to control the direction and magnitude of magnetic field. Induced magnetic fields from the interaction between the mechanical vibration of a conducting liquid and the Helmholtz coils are detected on a magnetometer.

INSTRUMENTATION:

- High-μ HY-80 Faraday cage
- Acoustic source waveguide
- 1 m x 1 m x 2 m Plexiglas tank
- Non-magnetic vibration-damped optical table
- Flux-gate magnetometer
- Acoustic sources and amplifiers
- Filtration and refrigeration system for experimental fluid

CONTACT:
Code 7145 • (202) 767-1741
LOCATION:
NRL, Washington, DC

Appendix 6

Acoustics Division Recipients of Alan Berman Research Publication Awards

Each year since 1969 the Naval Research Laboratory has issued awards to researchers who have published the most significant papers in their division based on their current research. Included here is a full list of these Alan Berman Research Publication Awards received by Acoustics Division researchers in the period 1969 to 2008. These awards are named in honor of Dr. Alan Berman, former NRL Director of Research. The award is quite competitive, given to only one or two papers from each division from a field of several dozen high-quality papers submitted each year for consideration.

NRL Acoustics Division Recipients of Alan Berman Research Publication Awards

1969:
Werner G. Neubauer
"The Experimental Examination, by Means of Pulses, of Circumferential Waves on Aluminum Cylinders in Water"

1970:
Anthony J. Rudgers
"Acoustic Pulses Scattered by a Rigid Sphere Immersed in a Fluid"

1971:
Werner G. Neubauer and Louis R. Dragonette
"Observation of Waves Radiated from Circular Cylinders Caused by an Incident Pulse"

1972:
John D. DeSanto
"Scattering from a Periodic Corrugated Structure: Thin Comb with Soft Boundaries"

1973:
Raymond H. Ferris
"Comparison of Measured and Calculated Normal-Mode Amplitude Functions for Acoustic Waves in Shallow Water"

1974:
Carl R. Rollins
"Active Surveillance Optimization Study"

Werner G. Neubauer
"Observation of Acoustic Radiation from Plane and Curved Surfaces"

David T. Diehl, L. Bruce Palmer, J. Thomas Warfield, and Budd B. Adams
"Spectrum and Envelope Analysis of Low-Frequency Pulsed CW Monostatic Reverberation"

1975:
Sam Hanish, Roland V. Baier, Benson J. King, and Peter H. Rogers
"Electroacoustic Modeling of Magnetostrictive Shells and Rings: Part 1 – Mathematical Modeling"

Joseph A. Bucaro and Lawrence Flax
"Application of Acoustic Surface Waves to the Study of Surface Properties of Ion-Exchanged Glass"

Albert N. Guthrie, Raymond M. Fitzgerald, David A. Nutile, and John D. Shaffer
"Long-Range Low-Frequency CW Propagation in the Deep Ocean: Antiqua Newfoundland"

William B. Moseley and Donald R. DelBalzo
"Oceanic Horizontal Random Temperature Structure"

1976:
Joseph A. Bucaro, Henry D. Dardy, and Robert D. Corsaro
"Strain Relaxation in Glass by Optical Correlation and Pressure Jump Relaxation"

1977:
Werner G. Neubauer and Richard H. Vogt
"Relationship Between Acoustic Reflection and Vibrational Modes of Elastic Spheres"

William B. Moseley
"Horizontal Correlation of Acoustic Signals"

1978:
Joseph A. Bucaro, Henry D. Dardy, and Edward F. Carome
"Fiber-Optic Hydrophone"

1979:
Louis R. Dragonette, Lawrence Flax, and Herbert Uberall
"Theory of Elastic Resonance Excitation by Sound Scattering"

Richard M. Heitmeyer and William B. Moseley
"Towed Array Performance for Long-Range Acoustic Propagation"

1980:
Wayne Alan Kinney, William B. Moseley, and Budd B. Adams
"Performance of a Towed Array at Extreme Range"

Robert H. Feden, Henry S. Fleming and Peter R. Vogt
"Magnetic and Bathymetric Evidence for the „Yermak Hot Spot" Northwest of Svalbard in the Arctic Basin"

Stephen N. Wolf
"Shallow Water Acoustic Transmission Loss Measurements: Project SHALLEX July 1976"

Robert D. Corsaro and Jacek Jarzynski
"Compact Parametric Hydrophone Using Nonlinear Interaction Within a Cylindrical Rubber Waveguide"

1981:
Stephen N. Wolf
"Measurements at Two Shallow-Water Sites of Acoustic Signal-to-Noise Enhancement by a Short Vertical Array"

1982:
Jacek Jarzynski, Ronald G. Hughes, Thomas Hickman, and Joseph A. Bucaro
"Frequency Response of Interferometric Fiber-Optic Coil Hydrophones"

1983:
Joseph A. Bucaro, Nicholas Lagakos, James H. Cole, and Thomas G. Giallorenzi
"Fiber Optic Acoustic Transduction"

1984:
Robert D. Corsaro and Jacek Jarzynski
"Phase-Diffusing Anechoic Coating/Window"

1985:
John Brozena, Jr.
"A Preliminary Analysis of the NRL Airborne Gravimetry System"

1986:
Robert D. Corsaro, Joel F. Covey, and Jacek Jarzynski
"Modification of the Acoustic Impedance of a Reflective Surface Using Electronic Feedback"

Burton G. Hurdle
"The Nordic Seas"

1987:
Albert A. Gerlach
"Principles and Applications of Harmonic-Correlation Processing"

Peter R. Vogt and Brian E. Tucholke
"The Western North Atlantic Region"

1988:
Earl G. Williams, Henry D. Dardy, and Karl B. Washburn
"Generalized Nearfield Acoustical Holography for Cylindrical Geometry: Theory and Experiment"

1989:
Richard D. Doolittle, Alexandra I. Tolstoy, and Michael Buckingham
"Experimental Confirmation of Horizontal Refraction of CW Acoustic Radiation from a Point Source in a Wedge-Shaped Ocean Environment"

1990:
Colin Y. Shen
"The Evolution of the Double-Diffusive Instability: Salt Fingers"

1991:
Earl G. Williams, Brian H. Houston, and Joseph A. Bucaro
"Experimental Investigation of the Wave Propagation on a Point-Driven, Submerged Capped Cylinder Using K-Space Analysis"

William A. Kuperman, Michael D. Collins, John S. Perkins, and Nolan R. Davis
"Optimal Time-Domain Beamforming with Simulated Annealing Including Application of a Priori Information"

1992:
Michael D. Collins
"Higher-Order Padé Approximations for Accurate and Stable Elastic Parabolic Equations with Application to Interface Wave Propagation"

1993:
Michael D. Collins
"A Self-Starter for the Parabolic Equation Method"

Douglas M. Photiadis
"Anderson Localization of One-Dimensional Wave Propagation on a Fluid-Loaded Plate"

1994:
Michael D. Collins
"A Split-Step Padé Solution for the Parabolic Equation Method"

Steven Finette, Peter C. Mignerey, James F. Smith III, and Christ D. Richmond
"Broadband Source Signature Extraction Using a Vertical Array"

1995:
Douglas M. Photiadis, Joseph A. Bucaro, and Brian H. Houston
"Scattering from Flexural Waves on a Ribbed Cylindrical Shell"

Richard S. Keiffer, Guy V. Norton, and Jorge C. Novarini
"The Impulse Response of an Aperture: Numerical Calculations Within the Framework of the Wedge Assemblage Method"

1996:
Earl G. Williams
"Supersonic Acoustic Intensity"

Christopher Feuillade
"Scattering from Collective Modes of Air Bubbles in Water and the Physical Mechanism of Superresonances"

1997:
Nicholas C. Makris
"The Effect of Saturated Transmission Scintillation on Ocean Acoustic Intensity Measurements"

Ronald A. Wagstaff
"AWSUM: A Digital Filter for Achieving Increased Signal-to-Noise Ratio and Other Signal Processor Enhancements"

1998:
Altan Turgut
"Inversion of Bottom/Subbottom Statistical Parameters from Acoustic Backscatter Data"

Roger C. Gauss and John R. Preston
"The Role of the Environment in Active Sonar Performance"

1999:
Tsih C. Yang and Thomas Yates
"Matched-Beam Processing: Application to a Horizontal Line Array in Shallow Water"

Luise S. Couchman, Dilip N. Gosh Roy, and Jeremy Warner
“Inverse Neumann Obstacle Problem”

2000:
Earl G. Williams, Brian H. Houston, Joseph A. Bucaro, and Douglas M. Photiadis
“Localization of Submarine-Radiated Noise Sources Using Scale Models”

Charles F. Gaumond
“Echo Components for Aspect-Independent Detection and Classification”

2001:
Gregory J. Orris and Michael Nicholas
“Collective Oscillations of Fresh and Salt Water Bubble Plumes”

Richard S. Keiffer and Jorge C. Novarini
“A Time Domain Rough Surface Scattering Model Based on Wedge Diffraction: Application to Low-Frequency from Two-Dimensional Sea Surfaces”

2002:
Roger C. Gauss, Robert F. Gragg, Redwood W. Nero, Daniel Wurmser, and Joseph M. Fialkowski
“Broadband Models for Predicting Bistatic Bottom, Surface, and Volume Scattering Strengths”

2003:
Roger M. Oba and Steven I. Finette
“Acoustic Propagation Through Anisotropic Internal Wave Fields: Transmission Loss, Cross-range Coherence and Horizontal Refraction”

Brian H. Houston, Douglas M. Photiadis, Martin H. Marcus, Joseph A. Bucaro, Xiao Liu, and Joseph F. Vignola
“Thermoelastic Loss in Microscale Oscillators”

2004:
Marshall H. Orr and Peter C. Mignerey
“Nonlinear Internal Waves in the South China Sea: Observation of the Conversion of Depression Internal Waves to Elevation Internal Waves”

Earl G. Williams, Brian H. Houston, and Peter C. Herdic
“Fast Fourier Transform and Singular Value Decomposition Formulations for Patch Nearfield Acoustical Holography”

2005:
William G. Szymczak, Steven L. Means, and Joel C.W. Rogers
“Computations of Bubble Formation and Pulsations Generated by Impacting Cylindrical Water Jets”

Pedro M. Jordan
“An Analytical Study of Kuznetsov’s Equation: Diffusive Solitons, Shock Formation and Solution Bifurcation”

2006:
Tsih C. Yang
“Correlation-Based Decision-Feedback Equalizer for Underwater Acoustic Communications”

Pedro M. Jordan
“Growth and Decay of Acoustic Acceleration Waves in Darcy-type Porous Media”

2007:
Steven Finette
“A Stochastic Representation of Environmental Uncertainty and its Coupling to Acoustic Wave Propagation in Ocean Waveguides”

Douglas Photiadis, Joseph A. Bucaro, and Xiao Liu
“Quantum Statistical Effects in Nano-Oscillator Arrays”

2008:
Tsih C. Yang
“A Study of Spatial Processing Gain in Underwater Acoustic Communications”

Gregory J. Orris, Dalcio K. Dacol, and Michael Nicholas
“Causality and the Velocity of Acoustic Signals in Bubbly Liquids”

Appendix 7

Acoustics Division *NRL Review* Articles

Each year the Naval Research Laboratory publishes a compilation of research articles highlighting key research in each division. These articles, prepared by NRL investigators, provide a good window into the full spectrum of types of unclassified research done at NRL. This publication began in 1967 as the "Annual Report." For a few years it was named either "Highlights" or "Review" (preceded by a numerical year). By 1979 it became simply the *NRL Review*. Each year since 1967 the Sound/Acoustics Division has contributed articles representing some of its most important research efforts. Included here is a complete list of these articles from 1967 to 2008. For completeness, this list also includes many articles submitted by the Underwater Sound Reference Detachment (USRD) near Orlando, Florida, whose researchers were closely allied with colleagues in the Acoustics Division.

List of *NRL Review* Articles on Acoustics Topics

2008 NRL Review
Underwater Acoustic Communications for Bottom-Mounted Sonar Networks
P.J. Gendron

Environmental Acoustic Variability Characterization for Adaptive Sampling
J.P. Fabre, C. Rowley, G. Jacobs, E. Coelho, C. Bishop, X. Hong, and J. Cummings

Single Crystal Diamond Nanomechanical Dome Resonator
M.K. Zalalutdinov, J.W. Baldwin, B.B. Pate, J. Yang, J.E. Butler, and B.H. Houston

2007 NRL Review
Modeling Reverberation Time Series for Shallow Water Clutter Environments
K.D. LePage

Measuring Undersea Noise from Breaking Waves
S.L. Means and M.A. Sletten

2006 NRL Review
Volumetric Acoustic Intensity Probe
E.G. Williams

Sub-Bottom Profiling and Geoacoustic Inversion Using a Ship Towed Line Array
T.C. Yang, K.B. Yoo, and L.T. Fialkowski

Seismo-Acoustics in Laterally Varying Media
M.D. Collins, D.C. Calvo, H.J. Simpson, R.J. Soukup, J.M. Collis, E.T. Kusel, D.A. Outing, and W.L. Siegmann

Acoustic Propagation Through Surface Ship Wakes
S. Stanic, T. Ruppel, and R. Goodman

2005 NRL Review
Fault Detection and Localization Using Laser-Measured Surface Vibration
J.A. Bucaro, J.F. Vignola, and A.J. Romano
[Featured Research]

Ambient Noise and Marine Mammal Acoustics
J. Newcomb, G. Ioup, G. Rayborn, and S. Kuczaj

Toward the Creation of the World's Smallest Radio
B.H. Houston and M. Zalalutdinov

2004 NRL Review
Applications of Time-Reversal to Underwater Acoustics
J.F. Lingevitch, C.F. Gaumond, D.M. Fromm, and B.E. McDonald
[Featured Research]

Passive Swimmer Detection
S. Stanic, C.K. Kirkendall, A.B. Tveten, and T. Barock

Passive Acoustic Ranging by Multimode Waveguide Interferometry
A. Turgut, M.H. Orr, and B.H Pasewark

2003 NRL Review
Roughness-Induced Ocean Bottom Scattering
R.J. Soukup and R.F. Gragg

Simultaneous Inversion of Bio- and Geo-acoustic Parameters in the Yellow Sea
O.I. Diachok and S.C. Wales

RAM to Navy Standard Parabolic Equation: Transition from Research to Fleet Acoustic Model
R.A. Zingarelli and D.B. King

Simulations of Low-Frequency Bubble Pulsations Generated by Impacting Cylindrical Water Jets
W.G. Szymczak and S.L. Means

2002 NRL Review
Parabolic Equations for Atmospheric Waves
J.F. Lingevitch, M.D. Collins, D.K. Dacol, D.P. Drob, J.C.W. Rogers, and W.L. Siegmann

Perturbation of the Littoral Sound Speed Field by Small-Scale Shelf/Slope Fluid Processes
M.H. Orr and P.C. Mignerey

A Time-Domain Model for Acoustic Scattering from the Sea Surface
R.S. Keiffer

Thin Profile, Low-Frequency, Underwater Electroacoustic Projectors
J.F. Tressler, T.R. Howarth, and W.L. Carney

2001 NRL Review
Phase-Coherent Underwater Acoustic Communications: Building a High-Data-Rate Wireless Communication Network in the Ocean
T.C. Yang
[Featured Research]

Acoustic Modeling of the Northwest Providence Channel on 15 March 2000
D.M. Fromm, G.V. Norton, and J.F. McEachern

Ocean-Acoustic Soliton Modeling Predictions
S.A. Chin-Bing, A.C. Warn-Varnas, D.B. King, Z.R. Hallock, R.A. Zingarelli, and J. Hawkins

Unifying Acoustic Boundary Scatter Modeling
R.C. Gauss, R.W. Nero, and D. Wurmser

2000 NRL Review
In-Flight Acoustic Holography
E.G. Williams and B.H. Houston

Adaptive ASW Search Tactics in Littoral Areas
D.R. DelBalzo

1999 NRL Review
A Search Algorithm for Resonance Anomalies (SARA)
S.A. Chin-Bing, D.B. King, R.A. Zingarelli, and A. Warn-Varnas

Sound Propagation Through a Sand-Water Interface
H.J. Simpson and B.H. Houston

Estimation of Seabed Properties from Chirp Sonar Data
A. Turgut, S.N. Wolf, and M. Orr

1998 NRL Review
Structural Acoustic Techniques to Identify Underwater Mines
J.A. Bucaro, B.H. Houston, and T.J. Yoder

Bioacoustic Absorption Spectroscopy
O.I. Diachok

1997 NRL Review
Influence of Subsurface Bubbles on Acoustic Scattering
R.C. Gauss, P.M. Ogden, and M. Nicholas

Supersonic Acoustic Intensity – a Key to Source Identification
E.G. Williams, B.H. Houston, and J.A. Bucaro

1996 NRL Review
Influence of Internal Gravity Waves on Acoustic Propagation
S. Finette, S. Wolf, M. Orr

High-Frequency Shallow-Water Signal Fluctuations
S. Stanic, C. Mire, and E. Kennedy

Fiber-Optic, Noise-Filtering Acoustic Velocity Sensors
J.A. Bucaro, N. Lagakos, and B.H. Houston

1995 NRL Review
Naval and Commercial Applications of Acoustic Scattering from Fish
Charles H. Thompson, Redwood W. Nero, and Richard H. Love

Imaging the Mid-Atlantic Ridge with Reverberation
N.C. Makris, L.Z. Avelino, and R. Menis

Structural Acoustics and Interior Noise of Aerospace Vehicles
B.H. Houston

Plate Tectonic Studies Using SOSUS Data
C.E. Nishimura and C.J. Bryan

1994 NRL Review
Structural Acoustics of Nearly Periodic Structures
D.M. Photiadis

Acoustic Reverberation at Selected Sites in the Mid-Atlantic Ridge Region
J.W. Caruthers, J.R. Fricke, and R.A. Stephen

Overcoming Chaos
M.D. Collins and W.A. Kuperman

USRD:
Cylindrical Wavenumber Calibration Array
L.D. Luker and A.L. Van Buren

Direct Measurement of Edge Diffraction from Acoustic Panels of Decoupling Materials
J.C. Piquette

1993 NRL Review
Trans-Oceanic Acoustic Propagation and Global Warming
B.E. McDonald, W.A. Kuperman, M.D. Collins, and K.D. Heaney
[Featured Research]

BiKR – A Range-Dependent, Normal-Mode Reverberation Model for Bistatic Geometries
S.N. Wolf, D.M. Fromm, and B.J. Orchard

Predicting Acoustic Signal Distortion in Shallow Water
R.L. Field and J.H. Leclere

USRD:
Electroacoustic Transducer Transient Suppression
J.C. Piquette

1992 NRL Review
A Pictorial Analysis of Vibrating Shell Physics
E.G. Williams

Acoustic Backscattering from the Sea Surface
P.M. Ogden and F.T. Erskine

USRD:
Transducer Calibration in Multipath Environments
P.L. Ainsleigh

Piezoelectric Composites for Transducer Applications
K.M. Rittenmyer

1991 Review
A New Approach to Ocean Acoustic Tomography
A. Tolstoy and O.I. Diachok

Underwater Acoustic Imaging
L.J. Rosenblum, B. Kamgar-Parsi, and E. Belcher

Mushroomlike Currents on the Ocean Surface
R.P. Mied and G.J. Lindemann

USRD
Propagation of Thermoacoustic Waves in Elastic Media
A.J. Rudgers

Edge Diffraction Technique
J.C. Piquette

Improved Reliability Submarine Sonar Connector
G.D. Hugus

1989-1990 Review
Environmental Signal Processing
W.A. Kuperman and J.S. Perkins

Investigating the Potential of Parallel Processing
H. Webb

USRD:
Offnormal Incidence Reflection Measurements on Thick Underwater Acoustic Panels
J.C. Piquette

The Shock Test Facility: A Water-Filled Conical Shock Tube
J.F. Zalesak and L. Poche

Development of Polymers for Constrained Layer Damping
R.N. Capps

1988 NRL Review
Prediction of Acoustic Scattering and Radiation from Elastic Structures
L.S. Schuetz, J. Shirron, and J.A. Bucaro

Efficacious Methods of Characterizing Active Systems Performance
R.C. Gauss

The Processing Graph Method
D.J. Kaplan

High-Speed, Long-Range, Unmanned Underwater Vehicle Communications Link
J.G. Eskinzes and J.R. Bashista

USRD:
Symbolic Integration of Special Functions
J.C. Piquette

An Evanescent Wave Generating Array
D.H. Trivett, L.D. Luker, S. Petrie, A.L. Van Buren, and J.E. Blue

1987 NRL Review
3D Ocean Acoustic Reverberation Prediction
L. Bruce Palmer, Edward R. Franchi, and Edward Powell

USRD:
Ferroelectric Hydroacoustic Particle Velocity Sensor
Kurt M. Rittenmyer, George C. Alexandrakis, and Peter S. Dubbelday

Sonar Transducer Reliability Improvement
Robert E. Montgomery

Low-Frequency, Tow-Powered Sound Source
Harvey C. Schau, Arnie L. Van Buren, and Joseph E. Blue

1986 NRL Review
Rapid Three-Dimensional Ocean Acoustic Computations
W.A. Kuperman, M.B. Porter, and F.L. Ingenito

Inertial Wave Dynamics
R.P. Mied, G.J. Lindemann, and C.L. Trump

Nonlinear Salt-Finger Simulation
C.Y. Shen

Ship-Wake Experiment for Remote Sensing
J.A.C. Kaiser, W.D. Garrett, S.E. Ramberg, and R.D. Peltzer

USRD:
Constrained-Layer Damping of Structure-Borne Sound
P.S. Dubbelday

Analytic Representations of Viscoelastic Moduli
A.J. Rudgers

1985 NRL Review
Investigation of an Anomalous Acoustic Loss in Sonar Rubber Domes
J.F. Covey, R.D. Corsaro, C.D. Beachem, and W.B. Moniz

Horizontal Refraction in a Wedge-like Ocean
R. Doolittle, A. Tolstoy, and B. Decina

New Acoustical Measurement Technique for Mapping Structure-Borne Energy Flow
E.G. Williams and H.D. Dardy

USRD:
Transducer for the Detection of Intercranial Aneurysms
T.A. Henriquez

Analytical Reduction of Diffraction in Panel Tests
J.C. Piquette

1984 NRL Review
Modeling Long-Range Arctic Acoustic Propagation
S.C. Wales and O.I. Diachok

Frequency Dependent Modal Excitation and Attenuation in Shallow Water
D.A. Gershfeld

Scattering from Rigid Bodies of Arbitrary Shape
C.F. Gaumond and A.G. Dallas

USRD:
Porous Ceramic Loss Mechanism
K.M. Rittenmyer and R.Y. Ting

Glass Ceramics for Sonar Transducers
R.Y. Ting

Dynamic Bulk Modulus Measurement
P.S. Dubbelday and J.C. Piquette

Extrapolation of Thick-Panel Reflection Measurements
J.C. Piquette

1983 NRL Review
Underwater Nearfield Acoustical Holography
E.G. Williams, H.D. Dardy, and R.G. Fink

Source Localization in Complex Acoustic Environments
R.G. Fizell

A New Acoustic Method of Measuring Properties of the Ocean Bottom
T.C. Yang

Acoustic Propagation and Ambient Noise in a Wedge-Shaped Ocean
M.J. Buckingham

Failure Analysis and Nondestructive Testing of Sonar Dome Rubber Windows
R.D. Corsaro, J. Covey, R. Falabella, W.B. Moniz, and C.D. Beachem

USRD:
Measurement of Hydroacoustic Particle Motion by Hot-Film Anemometry
P.S. Dubbelday

Acoustically Transparent Pressure Chamber
J.F. Zalesak and L.B. Poche

1982 NRL Review
Airborne Gravimetry
J.M. Brozena

Geometric Dispersion in an Ocean Channel
K.D. Flowers

Acoustic Identification of Underwater Targets
S.K. Numrich, N.H. Dale, and L.R. Dragonette

USRD:
Sound Radiation Caused by Extensional Waves
A.J. Rudgers and P.S. Dubbelday

1981 NRL Review
Estimation in Fourier Analysis
R.M. Fitzgerald and C.L. Byrne

Acoustic Surveying of Large Undersea Topography
D.E. Schifter, E.R. Franchi, and B.B. Adams

Microbend Fiber Optic Sensor
N. Lagakos

USRD:
Experimental Constant-Beamwidth Transducer
L.D. Luker, A.L. Van Buren, M.D. Jevnager, and A.C. Tims

Digital Benchtop Calibrator For Hydrophone Arrays
J.F. Zalesak, L.D. Luker, R.E. Scott, Jr., and C.K. Brown

Electrical-Reliability Estimation for Sonar Transducers
L.P. Browder

Expendable Sonobuoy Hydrophone
A.C. Tims and T.A. Henriquez

1979-1980 NRL Review
Mathematical Model of Surface-generated Underwater Noise
F. Ingenito

FREDDEX – The Front and Eddy Exercise
D.R. DelBalzo, D.M. Dundore, and W.B. Moseley

USRD:
Receiving Array Performance Improved by Element Shading
A.L. Van Buren

Long-Life Hydrophones
A.C. Tims

1978 Review
Acoustic High-Gradient Experiment
W.A. Kinney, W.B. Moseley, and J.S. Perkins

Sound Propagation Modeling with a Realistic Ocean Bottom
C.W. Votaw and G.R. Giellis

Sound Scattering by Rough Surfaces
S.K. Numrich

USRD:
Nonlinear Pulse Propagation Studies
P.H. Rogers and A.M. Weiner

A Unique Broadband Underwater Acoustic Source
A.M. Young

Acoustical Behavior of Coated Steel Plates
A.J. Rudgers

1977 Review
Optical Fiber Acoustic Sensor
J.A. Bucaro and E.F. Carome

Acoustic Transmission Through an Ocean Eddy
R.N. Baer

Bathymetry of the Norwegian-Greenland and Western Barents Seas
R.K. Perry and H.S. Fleming

USRD:
An Improved 3-D Tracking Transducer
T.A. Henriquez

A Constant-Beamwidth Transducer
A.L. Van Buren

Properties of an Alternate Sonar Transducer
C.M. Thompson

1976 Review
Aeromagnetic Studies in the South Pacific
R.H. Feden

TOPO ONE: An Ocean Acoustics Exercise Conducted Jointly with New Zealand
J.T. Warfield

Cooperative Study in Shallow Water Acoustics
S.N. Wolf

Ultrasonic Technique for Measuring Thermodynamic and Acoustic Properties of Materials
J. Jarzynski

Radiated Ship Noise Measurements
J. Cybulski

USRD:
Rare Earth Magnetorestrictive Underwater Sound Transducer
R.W. Timme and S.W. Meeks

1975 Review
Shallow-Water Acoustic Propagation in a Range-Dependent Environment
S.N. Wolf

Greenland Sea Bathymetric Studies
N.Z. Cherkis and R.K. Perry

Comparison Between Computed and Measured Directional Ambient Noise
S.W. Marshall

Infrasonic Sea Noise
J.R. McGrath

Shipboard Towed Array Calibrator
J.F. Zalesak and W.J. Trott

USRD:
Shore-Based Towed-Line Array Evaluation
T.L. Whalen, H.J. Hebert, J.E. Donovan, and J.E. Blue

Measurement of Noise Generated in Cylindrical Hydrophones by Slow Water Currents
T.A. Henriquez

1974 Review
Parametric Generation of Low-Frequency Sound

A Method for Estimating the Effects of Variations in the Sound-Speed Profile Upon Low-Frequency Acoustic Wave Transmission

Directional Low-Frequency Hydrophone

Attenuation of Sonar Signals by Rough Ocean-Boundaries

Modeling of Shallow-Water Transmission Loss

Moored Environmental Profiler

Cylindrical Nearfield Calibration Array

1973 Review
LIBEC and FAMOUS

Predicting the Performance of New Underwater Acoustic Projectors

Low-Frequency Ambient Noise Prediction

Frequency Dependence of Convergence Zone Spacing

Propagation of Low-Frequency Acoustic Signals Under the Arctic Ice of the Greenland Sea

The Charlie Gibbs Fracture Zone – A Part of the Hercynian Front

Oceanic Horizontal Random Temperature Structure and Acoustic Propagation

Reflection from Elastic Spheres

USRD:
Shipboard Hydrophone Calibrator

1972 Review
Surface Channel Propagation at Long Ranges

The Ocean Floor in the Norwegian-Greenland Seas

Designing Nonplanar Nearfield Calibration Arrays

Static and Dynamic Properties of Glasses

Acoustic Determination of Diffusion Coefficients in Solids

Acoustic Reflection at the Rayleigh Angle

Low-Frequency Reverberation Studies

Bottom-Reflectivity Measurements

USRD:
Infrasonic Power Amplification

Analysis of Air Gun Signatures

Measuring Directivity Index

Calibration Error Analysis

Target Impact Sensor

1971 Review
Recently Discovered Fracture Zones on the Ocean Floor

Scattering From Periodic Surfaces

Ambient Noise Studies

Measurements of Acoustic Normal Modes in Shallow Water

Measurements of the Physical and Acoustic Properties of the Oceanic Random Medium

Rayleigh Wave Probe for Surface-Treated Glass

High-Frequency Accelerometer Comparator

Acoustic Densitometer

Acoustic Slow Waveguide

USRD:
New Hydrophone Designs

1970 Review
Subsurface Ambient Noise Buoy System

Ray Models for Propagation Studies

Variation of Signals in Long-Range Propagation

Radiation from Cylindrical Shells

Acoustic Radiation Program for Ring Transducers

Radial Spheroidal Wave Functions

USRD:
High-Power, Low-Frequency Sound Source

Superdirective Sonar Arrays

Computer-Controlled Hydrophone Calibration System

Acoustic Properties of Water-Saturated Feltmetal

1969 Highlights
Measurement of Normal-Mode Attenuation in Shallow Water

New Sonar Calibration Capability

Scale Model Transducer Array Studies

Computer Display of Array Response

USRD:
Wide-Range Probe Hydrophone

Calibration of Piezoelectric Elements at High Hydrostatic Pressure

Acoustics of Wood at High Hydrostatic Pressure

1968 Annual Report
Assured Range Studies

Statistics of Scattered Acoustic Pulses

Scale Model Acoustic Studies

USRD:
Sonar Calibration at Simulated Great Depths and Low Temperatures

Cavitation Threshold

High Power Underwater Source

Reliable Deep-Submergence Hydrophone

1967 Annual Report
Acoustic Radiation from Spheroids

Creeping Acoustic Waves

Near-Field Calibration

USRD:
Measurement of Impedance at High Power

International Round-Robin Calibration of Hydrophones

Appendix 8

Acoustics Division Publications in the *Journal of the Acoustical Society of America* (1933–2008)

The Acoustical Society of America (ASA), founded in 1929, is the leading professional organization for acoustics researchers in the United States. Each month it publishes numerous peer-reviewed papers in all fields of acoustics including underwater acoustics, physical acoustics, acoustical oceanography, signal processing in acoustics, engineering acoustics, animal bioacoustics, structural acoustics and vibration, and other subfields. The first NRL Sound Division researcher to publish a paper in the *Journal of the Acoustical Society of America* (*JASA*) was Dr. Harvey C. Hayes in 1933. From 1933 to 2008, NRL Sound/Acoustics Division researchers published nearly 1500 papers in *JASA*. By performing an online search for all such papers (with extensive help from former Acoustics Division superintendent Dr. David L. Bradley) we have assembled what we believe to be a fairly complete chronological list of these *JASA* papers.

List of NRL Acoustics Division Publications in the *Journal of the Acoustical Society of America* (1933–2008)

Recent Developments in Generators and Receivers of Directive Sound Signals in Air (A)
H. C. Hayes
J. Acoust. Soc. Am. 5 63 (1933)

Spherical Torsion Pendulum as Supersonic Radiation Pressure Meter in Liquids (A)
Elias Klein
J. Acoust. Soc. Am. 8 210 (1937)

Detection and Location of Laminations in Steel Plates (A)
Harvey C. Hayes
J. Acoust. Soc. Am. 8 209 (1937)

Detection and Location of Laminations in Steel Plates
Harvey C. Hayes
J. Acoust. Soc. Am. 8 220 (1937)

Radiation Pressure by Torsion Pendulum and by “Weighing” on Spring Balance (With Demonstration) (A)
Elias Klein
J. Acoust. Soc. Am. 9 75 (1937)

Absolute Sound Intensity in Liquids by Spherical Torsion Pendula
Elias Klein
J. Acoust. Soc. Am. 9 312 (1938)

Absolute Sound Measurements in Liquids (A)
Elias Klein
J. Acoust. Soc. Am. 10 86 (1938)

A New Acceleration Meter (With Demonstration) (A)
Harvey C. Hayes and W. F. Curtis
J. Acoust. Soc. Am. 10 84 (1938)

Absolute Sound Measurements in Liquids
Elias Klein
J. Acoust. Soc. Am. 10 105 (1938)

An Under Water Sound of Natural Origin
E. O. Hulburt
J. Acoust. Soc. Am. 14 173 (1943)

Transmission, Reflection, and Guiding of an Exponential Pulse by a Steel Plate in Water (A)
M. F. M. Osborne and S. D. Hart
J. Acoust. Soc. Am. 17 100 (1945)

Transmission, Reflection, and Guiding of an Exponential Pulse by a Steel Plate in Water. I. Theory
M. F. M. Osborne and S. D. Hart
J. Acoust. Soc. Am. 17 1 (1945)

Transient Analysis of Linear Systems, Using Underwater Explosion Waves (A)
M. F. M. Osborne and J. L. Carter
J. Acoust. Soc. Am. 18 252 (1946)

Transmission, Reflection, and Guiding of an Exponential Pulse by a Steel Plate in Water. II Experiment (A)
M. F. M. Osborne and S. D. Hart
J. Acoust. Soc. Am. 18 251 (1946)

On the Vibrations of a Whirling Wire
A. Victor Maskei
J. Acoust. Soc. Am. 18 216 (1946)

Transmission, Reflection, and Guiding of an Exponential Pulse by a Steel Plate in Water. II. Experiment
M. F. M. Osborne and S. D. Hart
J. Acoust. Soc. Am. 18 170 (1946)

Surface Reflection of Short Supersonic Pulses in the Ocean
R. J. Urick and H. L. Saxton
J. Acoust. Soc. Am. 19 8 (1947)

On the Absolute Calibration of Phonograph Test Records by Means of Light Patterns (A)
Weiant Wathen-Dunn
J. Acoust. Soc. Am. 19 288 (1947)

Surface Reflection of Short Ultrasonic Pulses in the Ocean (A)
R. J. Urick and H. L. Saxton
J. Acoust. Soc. Am. 19 285 (1947)

The Detection of Internal Leaks in Aircraft Hydraulic Systems (A)
Richard G. Nuckolls and Horace M. Trent
J. Acoust. Soc. Am. 19 284 (1947)

Ultrasonic Measurement of Wall Thickness in Diesel Cylinder Liner (A)
Francis W. Struthers and Horace M. Trent
J. Acoust. Soc. Am. 19 284 (1947)

A Micro-Displacement Meter (A)
R. F. Post and R. L. Howard
J. Acoust. Soc. Am. 19 283 (1947)

Some Acoustic Properties of Marine Fouling (A)
J. W. Fitzgerald, M. S. Davis, and B. G. Hurdle
J. Acoust. Soc. Am. 19 283 (1947)

The Propagation of Underwater Sound at Low Frequencies as a Function of the Acoustic Properties of the Bottom (A)
John M. Ide, Richard F. Post, and William J. Fry
J. Acoust. Soc. Am. 19 283 (1947)

The Acoustical Concomitants of Cavitation and Boiling, Produced by a Hot Wire. II
M. F. M. Osborne
J. Acoust. Soc. Am. 19 21 (1947)

The Acoustical Concomitants of Cavitation and Boiling, Produced by a Hot Wire. I
M. F. M. Osborne and F. H. Holland
J. Acoust. Soc. Am. 19 13 (1947)

Ultrasonic Measurement of Wall Thickness in Diesel Cylinder Liners
Francis W. Struthers and Horace M. Trent
J. Acoust. Soc. Am. 19 368 (1947)

The Detection of Internal Leaks in Aircraft Hydraulic Systems
Richard G. Nuckolls and Horace M. Trent
J. Acoust. Soc. Am. 19 364 (1947)

Some Acoustic Properties of Marine Fouling
James W. Fitzgerald, Mary E. Davis, and Burton G. Hurdle
J. Acoust. Soc. Am. 19 332 (1947)

A Distortion Reducing Stylus for Disk Reproduction
E. F. McClain, Jr.
J. Acoust. Soc. Am. 19 326 (1947)

Velocity and Absorption of Sound in Suspensions and Emulsions (A)
R. J. Urick
J. Acoust. Soc. Am. 19 729 (1947)

Theoretical and Observed Absorption of Sound in Suspensions (A)
R. J. Urick
J. Acoust. Soc. Am. 20 225 (1948)

The Absorption of Sound in Suspensions of Irregular Particles
R. J. Urick
J. Acoust. Soc. Am. 20 283 (1948)

Reciprocity Calibration of Primary Vibration Standards (A)
Sanford P. Thompson
J. Acoust. Soc. Am. 20 596 (1948)

The Chemical Effects of Ultrasonic Irradiation: Reaction between Carbon Tetrachloride and Water (A)
Alfred Weissler, Herbert W. Cooper, and Stuart Snyder
J. Acoust. Soc. Am. 20 589 (1948)

Audible Noise from a P-80 Jet Airplane (A)
Weiant Wathen-Dunn
J. Acoust. Soc. Am. 20 587 (1948)

Ultrasonic Investigation of Molecular Properties of Liquids, Cyclic Compounds (A)
Alfred Weissler
J. Acoust. Soc. Am. 20 585 (1948)

The Calibration of Phonograph Reproducers (A)
Weiant Wathen-Dunn
J. Acoust. Soc. Am. 20 584 (1948)

Reciprocity Calibration of Primary Vibration Standards
Sanford P. Thompson
J. Acoust. Soc. Am. 20 637 (1948)

Some Background History of Ultrasonics
Elias Klein
J. Acoust. Soc. Am. 20 601 (1948)

Self-Reciprocity in a Plane Wave Sound Field (A)
B. D. Simmons and R. J. Urick
J. Acoust. Soc. Am. 21 63 (1949)

A Pulse Phase Comparison Method for the Measurement of Sound Velocity in Semisolid Substances (A)
J. R. Richards and E. J. Pember
J. Acoust. Soc. Am. 21 63 (1949)

The Propagation of Sound in Composite Media (A)
R. J. Urick and W. S. Ament
J. Acoust. Soc. Am. 21 62 (1949)

Remarks on the Reciprocity Calibration of Vibration Probes
Sanford P. Thompson
J. Acoust. Soc. Am. 21 142 (1949)

The Propagation of Sound in Composite Media
R. J. Urick and W. S. Ament
J. Acoust. Soc. Am. 21 115 (1949)

Air Shock Wave Velocities over Water
Elias Klein
J. Acoust. Soc. Am. 21 109 (1949)

Determination of Pressure Nodes in Liquids
D. E. Goldman and G. R. Ringo
J. Acoust. Soc. Am. 21 270 (1949)

On the Reciprocity Free-Field Calibration of Microphones
Weiant Wathen-Dunn
J. Acoust. Soc. Am. 21 542 (1949)

Theoretical Aspects of the Reciprocity Calibration of Electromechanical Transducers
Sanford P. Thompson
J. Acoust. Soc. Am. 21 538 (1949)

The Plane Wave Reciprocity Parameter and Its Application to the Calibration of Electroacoustic Transducers at Close Distances
B. D. Simmons and R. J. Urick
J. Acoust. Soc. Am. 21 633 (1949)

The Effect of Sound on Laminar Propane-Air Flames
S. Loshaek, R. S. Fein, and H. L. Olsen
J. Acoust. Soc. Am. 21 605 (1949)

Recent Methods for the Measurement of Sound Transmission in the Ocean (A)
R. J. Urick
J. Acoust. Soc. Am. 22 87 (1950)

A Small Crystal Probe Transducer for Ultrasonic Studies (A)
Herbert W. Cooper
J. Acoust. Soc. Am. 22 86 (1950)

Supplementary Paper No. 1. Force Equations of Motion (A)
R. E. Roberson
J. Acoust. Soc. Am. 22 81 (1950)

An Equivalent Circuit for a Vibrating Beam Which Includes Shear Motions (A)
H. M. Trent
J. Acoust. Soc. Am. 22 81 (1950)

An Equivalent Circuit for a Vibrating Beam Which Includes Shear Motions
H. M. Trent
J. Acoust. Soc. Am. 22 355 (1950)

The Velocity of Sound in Sea Water (A)
Alfred Weissler and Vincent A. Del Grosso
J. Acoust. Soc. Am. 22 684 (1950)

Some Applications of Square-Wave Testing Techniques to the Evaluation of Disk Recording Systems (A)
Samuel R. Bradshaw and Weiant Wathen-Dunn
J. Acoust. Soc. Am. 22 673 (1950)

The Velocity of Sound in Sea Water
Alfred Weissler and Vincent A. Del Grosso
J. Acoust. Soc. Am. 23 219 (1951)

Cavitation in Ultrasonic Depolymerization
Alfred Weissler
J. Acoust. Soc. Am. 23 370 (1951)

Random Noise in an Attenuating Fluid Medium
Robert E. Roberson
J. Acoust. Soc. Am. 23 353 (1951)

The Aural Recognition of Pulsed Signals in Very Narrow-Band Noise Backgrounds (A)
C. L. Dieter, G. Lieberman, H. L. Peterson, and W. J. Finney
J. Acoust. Soc. Am. 23 633 (1951)

A Liquid with Unusually High Sound Velocity (A)
A. Weissler and V. A. Del Grosso
J. Acoust. Soc. Am. 23 629 (1951)

Random Noise in an Attenuating Fluid Medium (A)
Robert E. Roberson
J. Acoust. Soc. Am. 23 628 (1951)

Noise Discrimination Factor and Noise Discrimination Index: Concepts for Discussion (A)
Weiant Wathen-Dunn
J. Acoust. Soc. Am. 23 622 (1951)

A Piezoelectric Method for Determining Young's Modulus and Its Temperature Dependence
H. E. Stauss, F. E. Martin, and D. S. Billington
J. Acoust. Soc. Am. 23 695 (1951)

An Experimental Study of Sound Reflection from a River Bottom (A)
R. J. Urick
J. Acoust. Soc. Am. 24 455 (1952)

The Effects of Very Narrow Band Filtering on the Aural Recognition of Pulsed Signals in Noise Backgrounds (A)
R. C. Bauman, C. L. Dieter, G. Lieberman, and W. J. Finney
J. Acoust. Soc. Am. 25 190 (1953)

Instrumentation for Psychoacoustic Testing (A)
C. L. Dieter and R. C. Bauman
J. Acoust. Soc. Am. 25 190 (1953)

Sound Propagation in Gross Mixtures
W. S. Ament
J. Acoust. Soc. Am. 25 638 (1953)

The Backscattering of Sound from a Harbor Bottom (A)
R. J. Urick
J. Acoust. Soc. Am. 26 148 (1954)

The Backscattering of Sound from a Harbor Bottom
R. J. Urick
J. Acoust. Soc. Am. 26 231 (1954)

Isomorphisms between Oriented Linear Graphs and Lumped Physical Systems
Horace M. Trent
J. Acoust. Soc. Am. 27 500 (1955)

Experimental Study of the Effect of Bond Thickness and Position on Q in Butt-joined ADP Crystal Plates (A)
B. J. Faraday and D. J. G. Gregan
J. Acoust. Soc. Am. 27 1011 (1955)

Reflection of Plane Sound Waves by an Irregular Surface (A)
J. G. Parker
J. Acoust. Soc. Am. 27 1006 (1955)

Reflection of Plane Sound Waves from an Irregular Surface
J. G. Parker
J. Acoust. Soc. Am. 28 672 (1956)

On Physical Equivalents to Spectra Notions (A)
Horace M. Trent
J. Acoust. Soc. Am. 29 187 (1957)

Mechanical Dissipation and Breaking Stress of Butt-Joined ADP Crystal Plates (A)
B. J. Faraday and D. J. G. Gregan
J. Acoust. Soc. Am. 29 179 (1957)

Frequency Difference Limens for Narrow Bands of Noise
Richard M. Michaels
J. Acoust. Soc. Am. 29 520 (1957)

Experimental Study of Mechanical Dissipation in Butt-Joined ADP Crystal Plates
B. J. Faraday and D. J. G. Gregan
J. Acoust. Soc. Am. 29 1001 (1957)

Response Spectra by Means of Oscillograph Galvanometers
Robert W. Conrad and Irwin Vigness
J. Acoust. Soc. Am. 29 1110 (1957)

On the Dynamics of a Bull Whip (A)
Barry Bernstein, Donald A. Hall, and Horace M. Trent
J. Acoust. Soc. Am. 30 691 (1958)

Impact Type Accelerometer Calibrator (A)
R. W. Conrad, E. W. Clements, and Irwin Vigness
J. Acoust. Soc. Am. 30 686 (1958)

On the Construction of Schematic Diagrams for Mechanical Systems (A)
H. M. Trent
J. Acoust. Soc. Am. 30 685 (1958)

On the Construction of Schematic Diagrams for Mechanical Systems
H. M. Trent
J. Acoust. Soc. Am. 30 795 (1958)

On the Dynamics of a Bull Whip
B. Bernstein, D. A. Hall, and H. M. Trent
J. Acoust. Soc. Am. 30 1112 (1958)

On the Conceptual Necessity and Use of Perfect Couplers in Schematic Diagrams (A)
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Timothy K. Stanton, Dezhang Chu, and Guy Norton
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David C. Calvo, Mario Zampolli, and Alessandra Tesei
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Douglas Drob, Milton Garces, Robert Meier, and Michael Picone
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Harry J. Simpson, Brian H. Houston, Michael L. Saniga, and Joseph A. Bucaro
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Jon M. Collis, Michael D. Collins, Harry J. Simpson, Raymond J. Soukup, and William L. Siegmann
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Raymond J. Soukup, Edward L. Kunz, Gaetano Canepa, Harry J. Simpson, and Jason E. Summers
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Earl G. Williams, Brian H. Houston, Nicolas Valdivia, and Peter C. Herdic
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Kevin D. Lepage
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Richard Allard, Charlie Barron, Frank Bub, Emanuel F. Coelho, James Cummings, J. Pacquin Fabre, Robert Helber, and Clark Rowley
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John Dubberley and Robert Zingerelli
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Yu Yu Khine, Steven Finette, and Roger Oba
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Kevin D. Lepage
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James Ballas
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Altan Turgut
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Incorporation of acoustic level analysis with sonar operator workstation workflow using hierarchical hidden Markov models (A)
Justin Nevitt and James Ballas
J. Acoust. Soc. Am. 123 3345 (2008)

Modeling the mechanism and neural substrate for aural categorization of sonar echoes (A)
Jason E. Summers, Charles F. Gaumond, Derek Brock, and Ralph N. Baer
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Kazuhiro Takashima, Hiroshi Nakagawa, and Earl G. Williams
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Near-field Acoustic Holography for partial measurements inside complex structures (A)
Nicolas Valdivia and Earl G. Williams
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Earl G. Williams and Kazuhiro Takashima
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Henrik Schmidt and Kevin D. Lepage
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T. C. Yang
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Xuemei Chen, Steven L. Means, William G. Szymczak, and Joel C. W. Rogers
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What exactly is meant by the term “auralization?”
Jason E. Summers
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In situ measurements of velocity dispersion and attenuation in New Jersey Shelf sediments
Altan Turgut and Tokuo Yamamoto
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Geoffrey Edelmann, Shaun Anderson, and Paul Gendron
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Steven Finette
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Altan Turgut
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A mode-based technique for estimating uncertainty in range-averaged transmission loss results from underwater acoustic calculations
R. A. Zingarelli
J. Acoust. Soc. Am. 124 EL218 (2008)

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T. C. Yang and Wen-Bin Yang
J. Acoust. Soc. Am. 124 3632 (2008)

Appendix 9

Notes and Transcripts from Oral Interviews Conducted with NRL Acoustics Division Researchers and Colleagues

This appendix consists of notes or transcripts of oral interviews with thirty-four former and current Sound/Acoustics Division superintendents, researchers, and managers or persons who have impacted the work of the Division in important ways. The period of NRL research covered is from the 1940s to the 2000s. Some of the oral interviews were conducted by a former NRL historian, the late Dr. David van Keuren. The remainder of the interviews were conducted by the author, either in person or over the telephone. The total duration of all these interviews is approximately 42 hours. For a few of the interviews conducted by Dr. van Keuren, formal written transcripts were prepared. For the remainder of the interviews, the author has listened to the oral recordings and prepared detailed notes summarizing key points in rough chronological order. In many of the interviews, we gain insights about the researcher's early life and education and learn how they came to start work at NRL. We are then able to follow their career at NRL and learn about why their research was important, the dynamics of working with their NRL colleagues, and the challenges and rewards of their careers at NRL. The original audio recordings from these interviews are on file with the NRL historian, Dr. Leo Slater.

1. Budd Adams

Notes Prepared by Fred Erskine on a Recorded Telephone Interview with Dr. Budd B. Adams held on Tuesday 23 April 2008 at 1130 AM EDT (1 hour 30 minutes)
[Dr. Adams' revisions received 14 October 2008]

Preface

We reviewed the basic objectives of the current project to document the history of the NRL Acoustics Division. The project will cover roughly eight decades from the inception of NRL in 1923 and go forward to the 2000s. Dr. Harvey Hayes was the first Superintendent (1923-1947), followed by Dr. Harold Saxton (1948-1967), then Dr. John Munson (1968-1984), Dr. David Bradley (1985-1993), and Dr. Edward Franchi (to 2008); The Acoustics Division was in NRL Building 1 from 1923 to 1996; then they moved to Building 2 when Building 1 underwent extensive renovations.

Early Life, Education and Career

Budd B. Adams was born in 1930 in Chicago, Illinois. He received a B.A. degree from the University of Chicago in 1951 as well as a B.S. degree from the University of Illinois in 1953. He graduated with a Ph.D. degree in geophysics from the University of Wisconsin in 1957. He then took a job with a company called Carter Research to do research and development on acoustical oil well logging; the company was a wholly owned subsidiary of Standard Oil of New Jersey. This firm changed names several times in the late 1950s and became the Jersey Production Research Company. Budd made a presentation to an audience of several hundred persons on his research on the estimation of lithology (determination of geologic rock types) using wide aperture seismic arrays to determine interval velocities and other parameters. The company president did not agree with Budd's interpretation of the results, so Budd began thinking ahead about other job options.

The Move to Hudson Laboratories and Involvement in Project Artemis

Budd interacted with a colleague from Columbia University's Hudson Laboratories (HL) in Dobbs Ferry, New York (directly across the river from the Lamont-Dougherty Geological Laboratory) who suggested that he apply there for a position. Budd then joined HL in March 1961 and became the first (and at that time only) person to do research on Project Artemis. It was a research program to develop a long-range low frequency active sonar that would be capable of covering an entire ocean basin. It was to be the undersea equivalent of the United States' DEW (Defense Early Warning) Line Radar system. HL was established by ONR to be an alternative to some of the Navy laboratories that were perhaps too closely tied to specific systems developments. HL was the prime contractor for Project Artemis. A research committee (initially headed by a person from Bell Telephone Laboratories) was established to review the Project Artemis plans and progress. Dr. Robert Frosch was the Director of HL and Dr. Alan Berman was Associate Director of HL at that time and they were also on the Artemis Committee. Initially, Dr. Frosch was Chief Scientist of Project Artemis (and a bit later Dr. Berman succeeded him as HL Director and Chief Scientist of Project Artemis). There were several NRL persons also on the Artemis Committee (including Art McClinton). The Artemis source was a planar array and was quite massive; the source array weighed 450 tons. It was deployed from the USNS *Mission Capistrano*, a refurbished 17,000 ton T-2 tanker; the source was raised and lowered via a large center well cut in the middle of the vessel for this purpose. The source was built by a firm called MASSA. NRL managed the source design, construction and testing. HL managed the design of the receiver array (of 32,000 hydrophones on vertical staves, each about 50 ft high, mounted on the deep ocean bottom on Plantagenet Bank, near Bermuda). The array gain was anticipated to be 39 dB (extremely high). The processing system was to be a 3000 channel optical correlator. The project never got to its goal on the large receiver size; they ended up building about ten percent of the receiver array consisting of 210 vertical staves with about 32 hydrophones on each stave. The phased receiving array covered a mile square on the southwest slope of Plantagenet Bank at 2000 ft depth. The signals were cabled to a manned laboratory known as Argus Island that was located on a 250 ft tall offshore drilling platform standing in 185 ft of water on Plantagenet Bank 20 miles southeast of Bermuda. This offshore laboratory facility contained preamplifiers, multiplexers and a microwave link to a larger shore laboratory on Tudor Hill, Bermuda, where the bulk of the signal processing and analysis was housed. Later, a much smaller but close-packed dipole planar receiving array was installed on the face of the USNS *Mission Capistrano* source array, enabling independent monostatic sonar system tests.

One of Budd's initial research tasks for Project Artemis was to carefully determine the three-dimensional locations of all the hydrophones in the bottom-mounted receiving array so that accurate receiver beam pointing could be accomplished — this a was very successful effort. The overall accuracy of the location of the hydrophones was about +/−1.5 ft, which was quite adequate considering the acoustic wavelength of about 10 ft (corresponding to a center frequency of approximately 400 Hz). Budd's research then turned to an investigation to determine if the oceanic medium could actually support coherent acoustic beamforming. The data were recorded on large analog tape recorders. By the mid-1960s, while still at HL, Budd began thinking about all aspects of this bistatic active sonar system and realized that the key to understanding the acoustic performance of the whole system was to develop a computer model that could include the characteristics of the source and receiver arrays, as well as the acoustic propagation and reverberation effects.

By the late 1960s, the NRL portions of Project Artemis efforts were administered out of the Maury Center in a building located just outside the main gate at NRL-DC. In 1967, Dr. Alan Berman left Hudson Laboratories to become Director of Research at NRL. Dr. Robert Frosch had departed HL several years earlier and had become an Assistant Secretary of the Navy for Research and Development. Dr. James Heirtzler became the Director of HL, following Dr. Berman's departure. However, after protracted and unsuccessful negotiations with the Navy about the future role for Hudson Laboratories, the Navy announced that HL would close its doors by April 1968.

<u>The Move to NRL's Acoustics Division</u>

With the closing of HL, a number of HL scientists and staff transferred to the Acoustics Division at NRL, including Budd Adams and Carl Andriani, as well as some other researchers and support technicians. Dr. Ross Williams was another researcher at HL working on the Artemis Project. When HL closed, Dr. Williams formed his own company (Ocean and Atmospheric Sciences, Inc., in Dobbs Ferry, NY) to continue research on Artemis. Williams was one of the developers of the Artemis optical correlator system. Hank Fleming was also at HL in the 1960s, but he did not work on Project Artemis. There were about 150 people at HL in the mid-1960s, including numerous oceanographic support persons and contract managers; the professional staff numbered about 25 persons.

Budd transferred to the NRL Acoustics Division on Labor Day (September) 1968. Upon his arrival, as head of the new Large Aperture Systems Branch, Budd was immediately tasked to give a high-level Navy brief on the status of NRL research accomplishments on the Artemis Project that had just been turned over to NRL from HL. Dr. Munson had just recently arrived at NRL himself (to replace retiring Acoustics Division superintendent Dr. Harold Saxton). Dr. Berman urged Dr. Munson to initiate significant staff and organizational changes in the Acoustics Division. Some long-time Division employees retired, including Vince DelGrosso, and a number of new researchers were hired to reinvigorate the research programs within the Division. While at HL, Dr. Berman had a rather informal approach to management. At NRL, however, Dr. Berman ran a tight ship and instituted numerous reforms that in retrospect turned out to be very positive for NRL. At NRL he initiated a process known informally as "Breakfast with Berman." He would start each day of the week by meeting individually with a different NRL branch head and then would repeat the process periodically. In these meetings, he would quiz the branch head about the status and progress of research efforts and personnel in the branch and would make suggestions for improvements. Berman would study a detailed computer printout to prepare for each such daily meeting; then he would host the branch head for an informal breakfast for about a half hour, followed by an intense one-hour query on the status of the branch. There were 85 branches then, so a branch head would meet with Dr. Berman two or three times per year. Many branch heads were very rattled by this process. Budd took advantage of this opportunity to present an extensive wish list to Dr. Berman of things the branch needed — and future such meetings were very productive. Budd viewed these meetings as extremely valuable. After Dr. Berman left NRL, his successor Dr. Tim Coffey attempted to initiate such breakfast meetings, but they did not continue after the initial round.

At NRL, Budd's Large Aperture Systems Branch continued research using data collected under the Artemis Project. One of the first persons Budd hired was Dr. Bill Moseley (he had done very relevant research on acoustic propagation in the atmosphere). Moseley picked up Budd's earlier initiative on propagation in random media and lateral spatial coherence, and the environmental limits to large, low frequency arrays.

<u>Post-NRL Career</u>

Around 1983 Budd took a leave of absence from NRL for a one-year assignment at ONR in Arlington, Virginia, working for Dr. Phil Selwyn, to help ONR assess the effectiveness of the Navy's 6.2 Exploratory Development research efforts across all Navy laboratories. Dr. Selwyn was a very effective ONR manager and was extremely astute. Budd and his ONR colleagues visited all the Navy Laboratories that were performing 6.2 research in undersea warfare. One of the most effective labs was the one located at China Lake, California.

Budd commented that it is not good to stay at a job too long — perhaps five or six years is appropriate. Budd applied for the division superintendent position when Dr. Munson retired, but he was not selected. Budd then moved to the Naval Ocean Research and Development Activity (NORDA) at Stennis Space Center, Mississippi, around 1986. Budd found it to be a good research career move for himself and he became the Technology Base project manager at NORDA.

<u>Further Comments</u>

Budd commented that Dr. Sam Hanish was an expert theoretician on the topic of acoustic source design. He did much analysis to help understand the inter-element mutual interactions in the large Artemis source array; prior sonar systems were not of such large scale, so the Artemis developments were breaking new ground.

The Large Aperture Systems Branch of NRL's Acoustics Division did cutting-edge developments in signal processing for long towed arrays beginning in the 1970s. They made extensive use of hardware-based array processors to accomplish the complex computations needed for the real-time processing systems. Dave Diehl led the way in these Branch developments. The system was based on hardware supplied by DEC Computer Corporation. Later, Jim Griffin took over the Branch computer system developments. Budd commented that most organizations have very short corporate memories. It was further noted that Dr. Patricia Gruber, who was a researcher in the NRL Acoustics Division in the 1980s, had recently become Research Director at ONR.

2. Carl Andriani

Notes Prepared by Fred Erskine on a Recorded Telephone Interview with Mr. Carl Andriani of Ocean City, Maryland held on 4 November 2008 Tuesday at 11:50 AM EST (40 minutes)

Early Life and Education

Carl Andriani was born in 1937 in New York City. He never graduated from high school — he quit high school at age 15 years and went to work. However, after taking entrance examinations, he was admitted to New York University, Division of General Education. He obtained a bachelor's degree in physics as well as a master's degree in physics from NYU and pursued several years of additional graduate study in physics beyond the master's degree.

Early Career at the Hudson Laboratories

After completing his master's degree at NYU around June 1962, Andriani applied for a job at Columbia University's Hudson Laboratories in Dobbs Ferry, New York. He was hired to work in the Analysis Department starting in the summer of 1962. At that time Hudson Labs had various projects related to antisubmarine warfare (ASW) including the detection of submarines (via acoustic and non-acoustic methods). Andriani became involved in a project related to long-range low frequency active acoustic methods for submarine detection known as Project Artemis. Andriani worked closely on this project for about three years with Dr. Ross Williams. As a side effort, they collaborated on the development of optical signal processors and Carl had a small laboratory devoted to this research. They were developing a panchromatic optical correlator system. Andriani's primary research was on the fundamentals of long range active sonar systems, including how to measure and quantify false alarm rates. The data analysis involved much tedious examination of Sanborn pen and ink paper charts.

At Hudson Labs Andriani acquired extensive training in various subdisciplines of ASW such as underwater acoustics and signal processing. He was involved in field tests at sea on the USNS *Mission Capistrano* (the Project Artemis acoustic source ship). He had extensive field duty participating in experiments at the Tudor Hill signal processing facility in Bermuda. Andriani may possibly have achieved the most long-range active sonar detection on record (525 nautical miles) by using the Project Artemis system in a deep water acoustic convergence zone environment with an echo-repeater as a surrogate for an actual submarine. This was an unusually good detection, but the ocean environment cooperated by giving excellent acoustic propagation and the source, receiver, and signal processing equipment were working optimally at that time.

The Career Move to NRL's Acoustics Division

Andriani remained at Hudson Labs until they closed down around late 1968 when a number of Hudson Labs scientists and engineers were hired by the NRL Acoustics Division. Andriani was actually the first scientist to transfer to NRL from Hudson Labs (even prior to Budd Adams' transfer to NRL). At NRL Andriani joined the new Large Aperture Systems Branch (Code 8160) under Dr. Budd Adams. Shortly thereafter this branch hired a number of very competent scientists (not necessarily from Hudson Labs). These included an expert acoustician, Dr. Bill Moseley, who later became Technical Director at the Naval Ocean Research and Development Activity (NORDA) at Bay Saint Louis, Mississippi. Another key research collaborator at NRL was Dr. Tom Warfield who explained many difficult concepts to Andriani.

Research on Submarine Target Characteristics

At NRL Andriani remained involved in the analysis of long range active sonar data, but he then branched out by becoming involved in detailed experimental and modeling investigations of submarine target strength. At that time the NRL Physical Acoustics Branch (Code 8130) under Dr. C.M. (Mickey) Davis had been conducting scale model submarine acoustic target scattering experiments in specially instrumented tanks at NRL for several years. NRL researchers had also been developing mathematical models for submarine target strength. After about three years of studying the literature and interacting with other NRL researchers in this field Andriani felt he understood the “state of the art” on target strength and had an appreciation of future research needs on this topic. Andriani was the first researcher to then perform some intermediate scale target scattering experiments in the field with a submarine model known as Kamloops at Lake Pend Oreille in Idaho. These were the trials in which Bob Chrisp worked closely with Andriani. Another very competent experimenter who assisted with this field research was Andy Gonda (who transferred to NRL from Hudson Labs). Early in those field trials the weather was very uncooperative with hurricane-like winds (over 100 miles per hour). This caused significant delays in starting the experiments and resulted in the loss of some equipment and engineering drawings.

The Career Move to the Naval Electronics Systems Command and SPAWAR

After the intensive period of the 1960s and early 1970s when there was significant Navy funding for active sonar research (e.g., under Project Artemis) the Navy’s focus in ASW turned sharply towards passive sonar developments, and funding levels for active sonar research were significantly decreased. Andriani approached numerous Navy program offices in the Washington, DC area but was unable to secure new funding for his active acoustics research in target strength. This was quite discouraging. Around 1975 Mr. Richard (Dick) Rojas of the Acoustics Division told Andriani of an opening for a temporary assignment at the Naval Electronics Systems Command (NAVELEX). Andriani took the position with the understanding that it would be for two years, but it turned into a permanent job. Eventually the Navy organizational structure changed and Andriani’s employer became the Space and Naval Warfare Systems Command (SPAWAR). Much later Andriani eventually rose to the position of Director of Undersea Surveillance at SPAWAR. Capt (later Admiral) Dempster Jackson was PME-124, followed later by Capt (then later Admiral) Ray Witter. Jackson was very interested in the technology of ASW and frequently called Andriani to his office for hours of discussion about how various technologies worked.

When SPAWAR moved its headquarters from Arlington, Virginia (Crystal City) to San Diego, California in the 1990s, Andriani remained in the Washington, DC area and was based at the Office of Naval Research (ONR). He was assisting ONR with issues related to the transition of ASW technology development projects to the Navy Systems Commands. During that period Andriani had frequent interactions with NRL research projects and NRL’s Director of Research, Dr. Timothy Coffey. He also had considerable involvement with ongoing projects at the Naval Sea Systems Command (NAVSEA) and the Naval Air Systems Command (NAVAIR).

Retirement

Andriani retired twice. The first time was his retirement from government service (with the Space and Naval Warfare Systems Command - SPAWAR) around 2000. The second time was several years ago when he retired from the South Carolina Research Authority (under contract with SPAWAR).

Further Recollections about NRL’s Acoustics Division

Andriani noted that Dr. Ed Franchi arrived at NRL’s Acoustics Division around 1975 (about 6 months before Andriani departed NRL). In that period, Franchi and Andriani collaborated on some investigations on the sensitivity of acoustic propagation and scattering to the details of the sound speed profile in the near surface region (in the upper 10 meters or so where deep bathythermographs and acoustic velocimeters did not give detailed measurements). They collaborated with modelers at the Naval Underwater Systems Center (NUSC), New London, Connecticut and concluded that sonar performance was significantly affected by sound speed changes in this upper part of the water column.

Andriani noted that he had written a paper on acoustic transmission loss in the Labrador Sea in collaboration with the Long Range Acoustic Propagation Project (LRAPP). LRAPP was having difficulty convincing Navy sponsors about the importance of long range acoustic propagation to undersea surveillance. Budd Adams turned over reams of chart paper containing experimental measurements on propagations loss from the Labrador Sea to Andriani to examine “in his spare time.” After about six months of analyzing these records to essentially make contour plots of propagation loss, Andriani was able to complete a paper on this research that showed interesting properties such as megaphone effects on the bathymetric slopes, etc. The LRAPP managers, however, decided not to publish these results, much to Andriani’s disappointment.

Postscript

Carl inquired about the NRL Acoustics Division History Project and he noted that one of the problems will be to properly cull down the wealth of material so as not to get too “lost in the weeds” but to retain the coherence of the story over the roughly eight decades to be covered (1923 to the early 2000s). He asked briefly about several former NRL Acoustics Division colleagues. He mentioned that Bob Chrisp was a particularly genial and helpful colleague and that he had spent eight weeks with Bob on a field test under difficult conditions at Lake Pend Oreille in Idaho.

3. Alan Berman

Notes Prepared by Fred Erskine on an In-Person Recorded Interview with Dr. Alan Berman, held in Alexandria, Virginia on Tuesday 26 May 2009 at 12:20 PM EDT (1 hour 50 minutes)

Preface

The following is a discussion regarding Dr. Alan Berman's association with the Hudson Laboratories of Columbia University in the 1950s and 1960s as well as his interactions with the NRL Acoustics Division during the 1970s when he was NRL's Director of Research.

World War II Military Service and Education

Alan Berman was drafted into the Army during World War II. While he was in the Army he was selected out from his unit on the day of the Battle of the Bulge for specialized training and was sent for one year to the University of Maine. This specialized training was in electrical engineering (where he learned about things like rotating machinery, transformers, etc.). When he was discharged from the military service, he completed his final semester of undergraduate college studies at Columbia University with financial support via the GI Bill. He then pursued graduate studies at Columbia University and completed his doctorate in the spring of 1952.

Employment at the Hudson Laboratories in 1952

While nearing completion of his graduate studies he was negotiating for a teaching position at the Massachusetts Institute of Technology. Since the position at MIT would not begin until the fall term, his major professor suggested he take a summer job with Columbia University's newly established (at that time only several months prior) Hudson Laboratories in Dobbs Ferry, New York. Hudson Labs was conducting research in underwater acoustics for the U.S. Navy. During the summer of 1952 Berman participated in several sea tests and became engaged in acoustic propagation research. By late summer Hudson Labs was preparing for a complex multi-ship sea test and Berman was handling all the logistics planning. As it turns out, Berman was on the short list for the position at MIT. When officials at MIT contacted him at the end of the summer of 1952 and asked if he could come to MIT immediately, he said "no." That one word essentially changed the rest of his life.

Involvement in Underwater Acoustics Research and At-Sea Experiments

Hence, he became a permanent employee of the Hudson Labs and rapidly became heavily engaged in various research projects such as measurement of the oceanic ambient background noise spectrum, acoustic propagation effects, signal detection processes, phase matching concepts, etc. Initially, Berman encountered a delay in receiving his security clearance at Hudson Labs. This came about because 1952 was the era of the McCarthy Hearings in the US Senate during which people's political affiliations were under scrutiny. As it turns out, one of the persons that Berman had given as a personal reference on the security application was an acquaintance who was a clergyman who had been involved in political activities during World War I as a pacifist who was opposed to America's participation in that war. This person's name got on a list of "undesirables" (a fact that was not known to Berman). As a result, Berman's clearance approval was held up. In that same period Berman's former Columbia University classmate Robert Frosch came to Hudson Labs and had no delays receiving his own security clearance. In that early period, Berman was very actively involved in planning and executing at-sea experiments, even though he had no clearance, while Frosch was very involved in analyses of the newly acquired data sets. The data analysis results would often quickly become classified and therefore Berman could not see his own reports. A further complication that continued for three or four years was that Berman could not attend any technical meetings at Hudson Labs that involved classified technical discussions. The situation was getting to be untenable because Berman was rapidly becoming a more senior researcher and incoming employees were submitting Berman's name as a reference which resulted in those persons not receiving their clearances. The logjam was finally broken around 1956 when a Navy Captain named Armand B. Sherry arrived at Hudson Labs. He was a highly decorated submarine commander and World War II hero. He immediately arranged to have Berman's clearance issues resolved. Berman then became fully involved in all pertinent technical discussions at Hudson Labs. In this period of the mid- to late-1950s the underwater acoustics research was focused on problems of passive acoustics such as determining the optimal locations for the placement of SOSUS arrays. The theoretical skills of Hudson Labs researchers were quite strong and in spite of the primitive nature of computers, they were able to develop important analysis tools such as accurate propagation ray tracing algorithms. Among the very capable technical researchers were people such as Ivan Tolstoy, C.S. Clay, Robert Frosch, etc.

Project Artemis

In the late 1950s (circa 1958-59) the planning began for a large project involving active sonar. This project was called Project Artemis. Bob Frosch became the Project Artemis technical leader. Gradually Berman also became involved in the planning for this project. There were two main engineering developments for Project Artemis. One was the development of a large acoustic source array to be deployed from the USNS *Mission Capistrano*, a large converted T-2 tanker. The other was the development of an extensive fixed volumetric receiver array (with 10,000 hydrophones) to be deployed off Bermuda in relatively deep water (on Plantagenet Bank) with signal cables coming to a specially constructed tower called Argus Island, and a data collection and analysis facility at a shore station on the southern end of Bermuda (at Tudor Hill). Project Artemis was really a Navy research community effort that involved multiple Navy Laboratories and private industry firms. NRL was heavily involved under Harold Saxton and Art McClinton with the source array developments and its installation on the USNS *Mission Capistrano*, including the modification to include a large center well for deployment of the source. Also involved were the Navy labs in San Diego, California and New London, Connecticut. The early versions of the acoustic source elements were developed by Frank Massa (private industry). These sources had great difficulties with mutual interactions. They were eventually replaced with electro-mechanical elements of a more successful but different design (called shaker boxes). Technical managers from the Office of Naval Research, Code 466, closely monitored the Artemis developments.

Project Artemis was very challenging technically and was really ahead of its time, in part because the needed computational power was not yet available in the 1960s era. It was, however, based on rational assumptions about sonar physics. The low center frequency of 400 Hz was chosen because it was considered optimal for long range propagation. The engineering design challenges were significant. These included the issues of station keeping for the USNS *Mission Capistrano* in order to keep the source array position stable.

Becoming Director of Hudson Laboratories in 1963

In 1960 Bob Frosch became Director of Hudson Labs, but he remained the technical leader on Project Artemis. In 1963, when Frosch left Hudson Labs (to go to the Advanced Research Projects Agency, and later became Assistant Secretary of the Navy for Research and Development for about eight years), Berman became Director of Hudson Labs and technical leader on Project Artemis. Also in 1963 the nuclear submarine USS *Thresher* was lost off the coast of New England. Buck Buchanan of NRL's Sound Division led several of the intensive search efforts to locate the sunken submarine. Berman and Hudson Labs colleagues also participated in this search effort. At the time of the *Thresher* sinking in 1963 the Navy had very limited deep search capability. It was during the ensuing search efforts that Berman became well acquainted with Chester L. ("Buck") Buchanan and his deep ocean search team. At Hudson

Labs, C.S. Clay and Berman developed a side scan sonar system for this search, but it was lost at sea. In 1963 the ship navigation capability was not very accurate. They had LORAN-C (good to about one mile). Berman frequently had to perform repairs on the LORAN receivers (operating with vacuum tubes) with no schematic diagram available. Given the primitive search capabilities it was somewhat amazing that the *Thresher* search was eventually successful. Berman was approached by (then) Lt. Brad Mooney who would be driving the submersible *Trieste* for assistance in laying out a track for the *Trieste*. Berman developed a scheme for laying out a series of sash weights on the ocean bottom to guide the *Trieste*. Only several decades later did Mooney tell him that the sash weights ended up in random positions on the bottom and were of little use.

Becoming Director of Research at NRL in 1967

In 1967 Berman was invited by Capt. Tom Owen to come to NRL to become Director of Research. He arrived in the new position in late May 1967. The transition from Hudson Labs to NRL was rather seamless, especially with regards to interactions with NRL's Acoustics Division. In 1967 it was not yet evident that Hudson Labs would soon be closing its doors. Several things happened that soon led to this closing. By 1968 the Vietnam War was becoming quite unpopular and student protests were taking place at various universities in the United States. The Columbia University Board of Trustees began to consider divesting itself of some of its Defense Department-supported research, particularly those projects that involved classified problems. The Office of Naval Research decided that it would not renew its contract with Hudson Labs in 1969. This involved the loss of major funding for Columbia University. A decision was made by Columbia University to close Hudson Labs by mid-1969. The staff of Hudson Labs was encouraged to find other employment and a significant number of technical researchers migrated to NRL's Acoustics Division. The oceanographic research equipment was dispersed among the Navy labs and private industry organizations that had been participating in Project Artemis.

Retrospective Thoughts about Project Artemis

Project Artemis struggled on for several more years. A position paper was prepared by a man named George Sebastian to close out Project Artemis. In retrospect, this project had achieved many of its goals in demonstrating the feasibility of a long range active sonar system. Several years ago Berman was invited by Ralph Goodman to give a retrospective review of the accomplishments of Project Artemis at a meeting of the Acoustical Society of America. Berman believes that the fundamental physics underlying Project Artemis developments was done correctly. The sonar equation was as valid then as it is now. One could argue that the attempted long ranges were slightly ambitious. Basically, the Project Artemis team of researchers from various organizations was given the most difficult technical problem imaginable and they did an admirable job of advancing the state of knowledge for that era.

Thoughts about Dr. Harvey Hayes, First Superintendent of NRL's Sound Division from 1923 to 1947

Berman had met Dr. Harvey Hayes long ago in the 1950s. At that time he was a rather elderly pipe smoking gentleman. He had a reputation as a first rate researcher during his period as Superintendent of NRL's Sound Division from 1923 to 1947. Berman decided to name the research vessel USNS *Hayes* after Dr. Hayes. During the several decades prior to World War II nearly all underwater acoustics research in the United States was conducted within the Sound Division at NRL. Early in World War II the level of research effort in underwater acoustics ramped up considerably with the introduction of numerous new performing organizations (both within the Navy and universities). Berman recalled hearing of the many accomplishments of the small cadre of NRL underwater acoustics researchers in the 1920s and 1930s. In particular, Berman recalled that his own father was an acquaintance of Dr. Elias Klein whose accomplishments Berman's father considered legendary. In Berman's view the United States owes a lot to those early NRL Sound Division researchers including Klein and Hayes. The U.S. was lucky that when we entered World War II, that small group of NRL researchers had pioneered numerous sonar developments in the 1920s and 1930s that enabled the U.S. to prevail against the German (and Japanese) submarine threats in the 1940s. Berman agrees with Gordon Hayes (son of Harvey Hayes, now age 88 years) that previous histories of NRL have not done sufficient justice to the high quality of work performed in NRL's Sound Division in the 1920s and 1930s. Berman comments that this may be due in part to the fact that much of that body of research was classified for a long period of time and thus was not readily accessible to previous historians.

Thoughts about Dr. Harold Saxton, Second Superintendent of NRL's Sound Division from 1948 to 1967
When Berman arrived at NRL as Director of Research in mid-1967, the Sound Division was headed by Dr. Harold Saxton. Saxton was a very courtly gentleman who had become Superintendent in 1948 after Dr. Harvey Hayes retired. Berman considered Saxton to be a very competent manager and administrator who had struggled with issues such as NRL's limits on the number of new researchers that could be hired, etc. Saxton was also challenged by the fierce competition between the various Navy labs, including those in San Diego and New London for Navy research funding, especially that from the Bureau of Ships. Saxton had initiated several new areas of research within the Sound Division such as the research on countermeasures headed by Bob Mathes. The Navy's sonobuoy research really was centered at the Naval Air Development Center in Johnsville (Warminster), Pennsylvania. Propagation and ambient noise research had been farmed out by ONR in the 1950s to Hudson Labs. Much of the advanced signal processing developments were centered at Bell Telephone Laboratory. As a result, much of the research projects Saxton managed at NRL were on the margins as opposed to being in the mainstream of underwater acoustics research.

The Selection of Dr. John Munson as Third Superintendent of NRL's Acoustics Division in 1968
As Harold Saxton approached retirement in 1968, Berman began the process to hire a new superintendent for the NRL Sound Division. He sought an experienced technical leader and manager who was familiar with the important technical challenges in underwater acoustics and signal processing techniques and who was also highly capable of promoting NRL's value to Navy funding organizations. This led to the selection of Dr. John Munson who was a protégé of Greg Hartman at the Naval Ordnance Laboratory in White Oak/Silver Spring, Maryland. This period in the late 1960s was in essence a turning point for the NRL Sound Division. Many of the technical researchers had been in the Division since World War II and were poised to retire after about thirty years. It was time to bring in a cadre of younger researchers with fresh ideas and vigor. The name of the Division was changed to the Acoustics Division, Code 8100. Among the immediate new hires was a group of researchers and technical support staff from Hudson Laboratories that included Dr. Budd Adams who became head of the new Large Aperture Systems Branch.

Comments about Research Management Style and Acoustics Division Organization in the Late 1960s and the 1970s
Shortly after becoming NRL's Director of Research in 1967, Berman instituted regular "Breakfast Meetings" with the NRL branch heads. There were eighty-eight branches. Berman would rotate these meetings through all the branches and then repeat the process. Thus he would meet with each branch head roughly two or three times per year, as scheduled by Tony Hollings, Berman's assistant. This was done to permit Berman to become intimately familiar with the research progress in each branch and to give the branch heads an opportunity to convey in an informal setting their concerns and challenges. After an informal breakfast in the NRL cafeteria around 7AM, Berman and the branch head would move to the building that housed the branch office at about 8AM for an additional hour. This also afforded Berman an opportunity to meet many of the researchers in each branch. Berman noted that attendance

by the branch researchers on the day of these visits seemed particularly good. In order to prepare for these meetings, on the evening prior to his visit Berman would read through personnel documentation from the branch and would review his notes from the last breakfast meeting in order to formulate some reasonable questions to ask of the branch head.

By the mid-1970s the Acoustics Division was under NRL's Associate Director of Research for Oceanology, Dr. Ralph Goodman (Code 8000). With Dr. Munson (Code 8100) as Superintendent, in 1975 the Acoustics Division included five research branches. These were the Shallow Water Surveillance Branch (Code 8120), headed by Ray Ferris; the Physical Acoustics Branch (Code 8130), headed by Mickey Davis; the Transducer Branch (Code 8150), headed by Jim Trott; the Large Aperture Systems Branch (Code 8160), headed by Budd Adams; and the Propagation Branch (Code 8170), headed by Burt Hurdle. In addition there were three ancillary groups: the Advanced Projects Group (Code 8103), headed by Bill Finney; the System Engineering Staff (Code 8108), headed by Rick Swenson; and the Systems Analysis Group (Code 8109), headed by J.C. Knight.

Research Continuity at NRL

Berman noted that NRL may be one of the few organizations within the U.S. government where a few hardy individuals continued to work in excess of fifty years. These included notables such as Burt Hurdle of the Acoustics Division, Homer Carhart of the Chemistry Division, and Pete Wilhelm of the Naval Center for Space Technology. In general, the corporate memory of technical developments at NRL is fairly strong. However, at the Office of Naval Research, NRL's parent organization, the tenure of scientific program managers tends to be relatively short, resulting in a less durable corporate memory.

Comments on NRL Acoustics Division Personnel Rosters

As part of the NRL Acoustics Division History Project, lists of NRL Sound/Acoustics Division personnel have been prepared for the mid-decade periods starting in the 1930s to the 2000s. Several of these lists were reviewed up to the 1980s. In the 1930s the list was quite short and it included Dr. Hayes and about seven other principal researchers. Of the persons on that list, Berman was familiar only with the name of Elias Klein. By the 1940s the Sound Division had swelled to over 100 persons. Berman was unfamiliar with the majority of the names on that list with several notable exceptions. Burt Hurdle was on this list since he began work at NRL in 1943. Albert J. Saur departed NRL in the late 1940s to pursue graduate studies and then in 1952–53 he shared an office with Berman at Hudson Labs. Leo Treitel eventually left NRL to later become a very influential Navy program manager.

The list for 1955 contained a number of names that were familiar to Berman based on interactions between Hudson Labs and NRL's Sound Division. Among the familiar names of Sound Division persons were Harold Saxton (Superintendent); Raymond Steinberger (Associate Superintendent); Vincent Del Grosso and Art Pieper (Propagation Branch); Ray Ferris and Burt Hurdle (Transducer Branch); Werner Neubauer (Electronics Branch); Buck Buchanan, Al Gotthardt, Frank Heemstra, Hester Helms, Charlie Votaw (Sonar Systems Branch); Bob Mathes, Matt Flato, A.J. Hiller, Art Lake (Airborne Sonar Branch); Art McClinton, John Cybulski (Electronic Applications Branch).

The list for 1965 contained further names that were familiar to Berman. These included: Harold Saxton (Superintendent); D. Burgess, G. Hansen, J. Houghtaling (Calibration Facility, Lake Seneca, New York); Ray Steinberger, Vince Del Grosso, Lou Dragonette, Gary Koopman, Leon LaLumiere, Werner Neubauer, Charlie Votaw (Propagation Branch); Sam Hanish (Transducer Branch); Bill Finney and Matt Shaw [who later transferred to become Code 7001, Special Assistant to Dr. Herb Rabin, Associate Director of Research for Space Science and Technology] (Electronics Branch); Chester Buchanan and his colleagues including Dick Bridge, Wally Brundage, Andrew Findlay, Matt Flato, Jerry Gennari, Lloyd Greenfield, Frank Heemstra, Hester Helms, Bob Patterson (Sonar Systems Branch); Bob Mathes, George Hickey, Walt Diehl, Alan Rich (Techniques Branch); Art McClinton, John Cybulski, Ray Ferris, Burt Hurdle (Electronic Applications Branch).

The list for 1975 was the first one that had direct overlap with Berman's tenure as NRL's Director of Research. Berman was familiar with the following persons: John Munson (Code 8100, Superintendent); Richard Rojas (Code 8101, Associate Superintendent); Bill Finney, Wendell Anderson, Al Gerlach, Caldwell McCoy (Advanced Projects Group); Rick Swenson, Andy Gonda (came from Hudson Labs), Tom Kelly, Mike Marek; J.C. Knight, Maury Potosky, Ray Rollins (Systems Analysis Group); Ray Ferris, Bill Kuperman (then a young researcher but now the Director at Scripps Institution's Marine Physical Laboratory), Steve Wolf (Shallow Water Surveillance Branch) [Berman was quite proud of this group's accomplishments]; Mickey Davis, Len Burns, Bob Corsaro, Hank Dardy, Lou Dragonette, Larry Flax, Jacek Jarzynski, Ted Litovitz (consultant), Werner Neubauer (Physical Acoustics Branch); Jim Trott, Arnie VanBuren (Transducer Branch) [some members of this Branch moved to the Orlando, Florida Calibration Facility]; Budd Adams, John Cybulski, Dave Diehl, Don DelBalzo, Ed Franchi [later to become Division Superintendent, then eventually an NRL Associate Director of Research], Dick Heitmeyer, John McCoy, Jim McGrath, Bill Moseley [later to become a branch head, then eventually Technical Director of NORDA], Tom Warfield (Large Aperture Systems Branch); Burt Hurdle, John Brozena, B. Carmichael, Norm Cherkis, John DeSanto, M. Dolan, Bob Feden, Ray Fitzgerald, Hank Fleming, George Frisk, Al Guthrie, B. Hauser, Tom Hayward, B. Heezen, G. Jackson, Leon LaLumiere, J. Massingill, Sue Numrich, Dave Nutile, D. O'Neill, Dave Palmer, Dan Ramsdale, Charlie Votaw (Propagation Branch).

Berman also perused the 1985 Acoustics Division personnel list that covered the period a few years after his departure from NRL. He noted some organizational changes and some familiar names. The Acoustics Division was now under Mr. Richard Rojas [formerly of the Acoustics Division], the NRL Associate Director of Research for Systems Research and Technology (Code 5000). Dr. David Bradley was the new Superintendent (now Code 5100) and Burt Hurdle was the Associate Superintendent (Code 5101) [Hurdle was shortly to publish his book on the Nordic Seas]. Dr. Sam Hanish (Code 5104) published a multi-volume Treatise on Acoustic Radiation; Dr. John Munson had retired, but retained an office in the Acoustics Division as Chief Editor of the *Journal of Underwater Acoustics*. The Ocean Systems Applications Group (Code 5103) was headed by Dan Steiger; the Acoustic Media Characterization Branch (Code 5110) was headed by Hank Fleming [who came to NRL from Hudson Labs; in that branch were Dr. John Bergin and Bob Feden, both of whom later became Program Managers at ONR]; the Applied Ocean Acoustics Branch (Code 5120) was headed by Dr. Orest Diachok [In Code 5120 at that time were Dr. Ellen Livingston, who later became Program Manager for Ocean Acoustics (Code 321OA) at the Office of Naval Research, as well as Dr. Patricia Gruber who later became Research Director at ONR; also in that Branch were Dr. Richard Doolittle and Charlie Votaw who both also later became ONR Program Managers.]; the Physical Acoustics Branch (Code 5130) was headed by Dr. Joe Bucaro [In that branch were Dr. Sue Numrich and Dr. Luise Couchman both of whom later became Program Managers at ONR; Dr. Earl Williams of that branch later became the Division Senior Scientist and in 1999 published a book titled *Fourier Acoustics: Sound Radiation and Nearfield Acoustical Holography*; Werner Neubauer who had just retired published a book in 1986 titled *Acoustic Radiation from Surfaces and Shapes*; the Software Systems Development Branch (Code 5150) was headed by E.E. (Betts) Wald; the Large Aperture Systems Branch (Code 5160) was headed by Dr. Budd Adams [Adams shortly thereafter spent a year at ONR]; Dr. Ralph Baer later went on assignment to ONR; Raymond Soukup, who was then a student, later became a Program Manager at ONR; Dr. Alexandra Tolstoy published a monograph titled *Matched Field Processing for Underwater Acoustics* in 1993; Bill Kuperman was an Associate Editor of the *Journal of the Acoustical Society of America* and headed a section that was developing innovative computational underwater acoustic techniques; Berman commented that he was very proud of Kuperman's accomplishments and noted that he had paid for Kuperman's Ph.D. studies out of NRL overhead funds.

Comments about Acoustics Division Archive Photographs

Berman then perused a number of historically relevant equipment- and people-related photographs that captured a variety of activities in NRL's Sound/Acoustics Division. He reviewed a good photograph of the Project Artemis source array on board the USNS *Mission Capistrano* (a converted T-2 class tanker from World War II) while relating some recollections about the details in the photograph. There was a large center well in the vessel that was over forty feet wide, thus permitting the Artemis engineers to lower the source down to about 3000 ft depth on cables. Berman was proud of his involvement with this project.

Berman viewed a good photograph of the Sound Division's large nearfield acoustic array that was deployed from a barge on Lake Seneca in New York in the 1950s. The use of this array happened well before Berman arrived at NRL and he could not elaborate on its use. [This array was designed by Sam Hanish based on a technique developed by Jim Trott. It contained 2500 elements in a 50x50 configuration with 8-inch element spacings covering an area 33 ft square. The useful frequency range was 1 to 6 kHz. This array is described in a 1970 NRL book by Robert J. Bobber of NRL's Underwater Sound Reference Division, Orlando, Florida, that is titled *Underwater Electroacoustic Measurements*.]

Berman reviewed a series of photos of the entire Sound/Acoustics Division that were each taken several decades apart in front of NRL's Building 1. The first was taken around 1947 at the end of Harvey Hayes' tenure as Superintendent. Most of the persons in the photo are not yet identified. The second such group photo was taken around 1967 near the end of Harold Saxton's tenure as Superintendent. Many of the persons in this photo remain unidentified at present; however, Berman was able to identify some of the individuals including Harold Saxton, Bob Mathes, John Cybulski, Art McClinton, and Matt Shaw. The third such group photo was taken around 1984 during the latter phase of John Munson's tenure as Superintendent. Most of the persons in this photo can be identified.

Next, Berman reviewed selected people photos, including some from various award ceremonies. One of these photos was for the award to Chester Buchanan's Sonar Systems Branch circa 1965 for the NRL deep ocean search efforts that located the USS *Thresher* in 1964. Another photo for an award ceremony about a year later honored Buchanan's team for the successful search for a lost H-bomb off the coast of Spain.

Another award ceremony photograph possibly circa 1970 included Werner Neubauer, Bill Kuperman, Joel Sinsky, and Ralph Goodman.

Another photo was of a small group observing the former swimming pool reactor facility in NRL's Building 71 that was beginning to be used by the Physical Acoustics Branch for scale model acoustic scattering studies. Included in the photo were Mickey Davis, John Munson, and Capt. John Geary.

Several photos depicted the retirement ceremony for Harold Saxton circa 1967. In attendance were Drs. Berman and Frosch as well as Dr. Elias Klein. Related photos of another luncheon depicted Ralph Goodman, Alan Berman, Admiral Owen, Capt. Matheson, Raymond Steinberger, and John Munson in attendance.

Berman noted that a special session was held recently at a meeting of the Acoustical Society of America in honor of Dr. Ralph Goodman. The presentations from that session may be of interest relative to the Acoustics Division History Project. Berman commented that he hired Ralph Goodman to come to NRL as an Associate Director of Research for Oceanology because Ralph had strong leadership skills.

Berman also reiterated that some years ago he was invited to give a presentation on the history of the Artemis Project at an ASA meeting.

One photo with pictures of research vessels was labeled "Berman's Fleet." In the photo were the USS *Allegheny*, RV *Manning*, USNS *Mission Capistrano*, USNS *J Willard Gibbs* (T-AGOR-1), USNS *Mizar* (T-AGOR-11), USNS *Harvey Hayes* (T-AGOR-16), the ERLINE (transport vessel), and the ARGUS Island Tower.

4. David Bradley

Notes Prepared by Fred Erskine on a Recorded Telephone Interview with Dr. David L. Bradley held on Wednesday 19 November 2008 at 3:20 PM EST (3 hours)

Early Life and Education

David L. Bradley was born in 1938 in the Highland Park suburb of Detroit, Michigan. He lived there and in the Royal Oak suburb of Detroit until the spring of 1945. Then his family moved to central Michigan where they purchased an 80-acre farm. Dave attended a one-room schoolhouse there until eighth grade. He then attended Gladwin high school for four years. In September 1956 he enrolled at Michigan College of Mining and Technology (now called Michigan Technological University) for his undergraduate education. It is located in the upper peninsula of Michigan and he was influenced in his choice of a college by the opportunity to enjoy snow sports including skiing there. While growing up he was generally interested in things mechanical (auto repairs) and electrical (crystal radios and radio-related projects) and was heavily involved in helping out at the farm. In college he chose to major in physics because it was a broadly based curriculum. There were eight physics majors in his class.

Early Career at the Naval Ordnance Laboratory (NOL)

In his senior year of college he interviewed with a recruiter from the Naval Ordnance Laboratory (NOL) in White Oak, Maryland and accepted an entry level position there with hopes of specializing in nuclear physics research. He started on 5 July 1960 in the Acoustics Division at NOL. He was involved in a program that permitted a series of three 4-month rotating assignments within NOL. The first of his three tours were in Acoustics (working with Wayne Wilson, an expert in the measurement of the speed of sound in seawater) doing measurements of the speed of sound in alcohols. In his second assignment, he worked on the Polaris missile (an exciting engineering-oriented assignment with severe deadlines). The third assignment was working with Mickey Davis (who was working on a Ph.D. at Catholic University on a two-state molecular model of water) on the properties of heavy water. As an aside, there was also extensive research being done then at NRL by Vincent Del Grosso on the speed of sound in seawater, and Mickey Davis later moved to NRL to head the Physical Acoustics Branch in which that research was conducted. Bradley's third assignment also involved research on solid state physics to investigate various acoustic transduction materials (e.g., alfenols) in conjunction with a magnetics group at NOL. As a further aside, Davis was a very pleasant supervisor who worked hard and also had a good sense of humor. In 1961 at the end of his first year, Bradley returned to the NOL Acoustics Division under Wayne Wilson. As another aside, the nuclear physicists at NOL discouraged Bradley from pursuing research in nuclear physics — in part because the resulting research papers in journals such as *Physical Review* often involved large groups with many authors.

Master's Degree Studies and Continued Research at NOL

During this period NOL had a visit from Professor Walter Mayer (now Professor Emeritus at Georgetown University) who was part of a large ultrasonics research group at Michigan State University. As it turned out, Professor Mayer offered Bradley a fellowship to pursue physics graduate studies at Michigan State University in East Lansing, which Bradley readily accepted in September 1961 (by taking leave from NOL). During this initial two-year period of graduate studies, Bradley returned each summer to work at NOL. Upon completion of his master's degree in physics in 1963 he became married and returned to full-time work at NOL under Wayne Wilson.

In late 1963 or early 1964 NOL encouraged Bradley to take a leading role in a project involving underwater acoustics measurements. Bradley's supervisor on the project was Robert Urick who earlier (in the 1940s) worked in the Sound Division at NRL and later (in the 1980s) authored a widely used textbook, *Principles of Underwater Sound*. The topic area was shallow water acoustic propagation. It involved field measurements in the Key West, Florida area using impulsive sound sources (Signals, Underwater Sound, SUS charges).

Doctoral Degree Studies and Continued Research at NOL

In the mid 1960s Bradley became aware of opportunities to pursue further graduate studies at Catholic University in Washington, DC. There was a Department of Mechanics and Mechanical Engineering within which one could pursue research in underwater acoustics in a program headed by a former naval officer named Frank Andrews. Bradley was selected under an NOL program to pursue graduate studies at Catholic University in their evening classes. In 1966 Bradley pursued these studies full-time with NOL support. He was a mechanical engineering major with a minor in mathematics. He completed his Ph.D. thesis in June 1970 on a topic related to acoustic propagation in shallow water using data collected in the Virginia Capes area off the North Carolina coast. He presented a paper on his thesis results at a meeting of the Acoustical Society of America in Houston, Texas. As an aside, he met future U.S. president George H.W. Bush briefly at the hotel where the meeting was held.

Advancement at NOL

Bradley then continued research at NOL and was given management opportunities as well. He became heavily involved in Arctic acoustics research in the early 1970s. One project was called Polar Bear One in which his group used buoys that had been developed at NRL under Project Nutmeg. In the 1971–72 period, Bradley met Chester Buchanan of NRL's Acoustics Division. Also in that period he "re-met" John Munson, the new superintendent of NRL's Acoustics Division (who had previously worked at NOL). The Arctic research involved the use of U.S. Coast Guard ice breaker vessels. These vessels carried several helicopters that were used to take the NOL scientists inland about 50 miles from the ice edge to perform experiments. By the mid-1970s Bradley became the NOL Acoustics Division head, supervising a group of about 35 researchers. Other groups at NOL also did acoustics-related research (such as mine warfare, explosives research, and signal processing developments).

Career Move to NORDA as Manager for LRAPP

In late 1978 Bradley was invited to become involved in managing the Navy's LRAPP project (Long Range Acoustic Propagation) that had earlier been managed at the Maury Center at NRL, but that moved to the Naval Ocean Research and Development Activity in Bay Saint Louis, Mississippi in 1976. Bradley thus spent about one year at NORDA while affiliated with LRAPP. The LRAPP project had both a modeling part (headed by naval officer LCDR Kirk Evans) and a measurements part (headed by Bradley). During this period (in 1979) the large LRAPP receiving array was lost at sea. The Navy's intention (OP-95) was to build a replacement array, and continue at-sea tests. Bradley's preference was to have the Applied Research Laboratory at the University of Texas at Austin under the direction of Lloyd Hampton have a pivotal role in the measurements portion of the program. However, the NORDA Technical Director Ralph Goodman opposed this.

Career Move to the Pentagon as Manager for Mine Warfare Projects

In late 1979 Bradley decided to leave NORDA to take a 3-year position at the Pentagon (OP-37) managing Navy mine warfare projects under a two-star Admiral. During this period American hostages were taken in Iran. There was a brief consideration of using mines to blockade Iranian waters — but this was not pursued.

Career Move to the Office of Naval Research (ONR)

While at the Pentagon, Bradley actively sought a position at the Office of Naval Research (ONR). Bradley heard about an opening at ONR from Bob Winokur (assistant to the ONR Technical Director). In late 1982 Bradley accepted a position at ONR managing programs in geology and geophysics, underwater acoustics and Arctic research (under Gordon Hamilton). He remained at ONR for three years. During this period several new research areas received attention including development of multibeam sonar systems and research on sediment dynamics.

The Career Move to NRL as Acoustics Division Superintendent

In his third year at ONR, Bradley was invited by Richard (Dick) Rojas of NRL to apply for the position of Superintendent of the NRL Acoustics Division. Dr. John Munson had already retired from that position and Burton Hurdle was Acting Superintendent. At that time, Bradley was in a Senior Executive Service position at ONR, so the transition to NRL in late 1985 went smoothly after receiving approval from NRL's Director of Research, Dr. Timothy Coffey. The Associate Superintendent under Bradley was Burt Hurdle (and later Tom Warfield). In the mid 1980s there were about 140 persons in the Acoustics Division and the Navy was still in the Cold War era and concerned with deep ocean undersea warfare research. The research interests within the Acoustics Division were fairly broad and included topics such as deep water propagation and reverberation, target characteristics, physical acoustics, fiber optic sensor developments, Arctic acoustics, marine geophysics, environmental acoustic modeling, etc.

During Bradley's tenure as Superintendent there were several short-lived Branches that dealt with research or support services that were later dissolved or moved into other Divisions at NRL. Dan Steiger headed a group (Marine Systems Branch, Code 5170) that provided oceanographic support. Elizabeth (Betts) Wald headed a branch (Signal Processing Branch, Code 5150) that developed a Navy-standard computer processing system (EMSP) using ADA software. Eugene (Gene) Rudd headed a branch (Ocean Dynamics Branch, Code 5140) that specialized in oceanographic remote sensing techniques.

The primary research activities within the Division were conducted in the Acoustic Media Characterization Branch (Code 5110), headed by Henry (Hank) Fleming; the Applied Ocean Acoustics Branch (Code 5120), headed by Orest Diachok; the Physical Acoustics Branch (Code 5130), headed by Joe Bucaro; and the Acoustic Systems Branch (Code 5160) headed by Budd Adams (and then later by L. Bruce Palmer). Ruth Stallings was the very capable Division Administrative Assistant.

From Bradley's perspective, the funding situation for research projects in the Acoustics Division in the mid-to late 1980s and early 1990s was healthy due to the high quality of the research. Bradley had productive interactions with various Navy sponsors, including ONR, and would frequently visit various Navy program offices, accompanied by NRL branch heads or principal investigators to brief them on research progress. In this period the funding for basic research (6.1 funding category) remained relatively level. The funding for exploratory development research (6.2 funding category), however, increased significantly (from about $2M to over $20M). During this period the 6.2 funding became managed via "Block Programs" from the Office of Naval Technology (ONT) at ONR. Among the ONT managers with whom Bradley had very productive interactions about the NRL research were people like Phil Selwyn, A.J. Faulstitch, Capt John Harlett, and Capt Bob Fitch. Bradley also had productive interactions with program managers at the Space and Naval Warfare Systems Command (SPAWAR) such as Capt Kirk Evans.

Bradley also considered it important to regularly attend meetings of the Acoustical Society of America (ASA) and to seek out graduate students there as potential future NRL researchers. During his tenure as

Acoustics Division Superintendent, Bradley also taught evening graduate courses in advanced underwater acoustics at Catholic University, generally with class sizes of eight to ten students. Bradley developed a set of course notes that he used in this advanced course. He also occasionally taught from standard textbooks by authors such as Kinsler and Fry, Urick, Medwin and Clay, and others in more general graduate courses having about two dozen students in the class. From one special topics class that Bradley taught, seven of eight graduate students went on to focus their doctoral theses on topics developed in that class. Bradley also regularly attended the Navy's periodic meetings in San Diego, California such as the Navy Symposia on Underwater Acoustics and the Undersea Warfare Conferences to maintain an NRL presence and to stay connected with big picture concerns of the Navy.

The Incorporation of NORDA/NOARL into NRL

Late in Bradley's tenure as Superintendent, around 1991–1992, the Navy decided to make the Naval Ocean Research and Development Activity (NORDA) [also later known as the Naval Ocean and Atmospheric Research Laboratory, NOARL] a part of NRL. This had a significant impact on the Acoustics Division. The components of NORDA/NOARL that transferred to the Acoustics Division included the Center for Environmental Acoustics (Code 7105), headed by Ed Franchi, the Ocean Acoustics Branch (Code 7170), headed by Dan Ramsdale, and the Acoustic Simulation and Tactics Branch (Code 7180), headed by Jim Matthews. Further, there was a decision to place the Acoustic Media and Characterization Branch, headed by Hank Fleming, organizationally under the Marine Geosciences Division, headed by Herb Eppert at NRL Stennis Space Center in Mississippi, although Fleming's branch remained at NRL Washington, DC.

Post-NRL Career Intentions

Bradley recalled that in 1985 when he had his initial interview with NRL's Director of Research, Timothy Coffey, Bradley was approximately 47 years of age. He mentioned to Dr. Coffey that by the time he turned age 55 he would have about 32 years of government service and his intention was to then retire from the government and pursue other endeavors (perhaps teaching at Catholic University).

The Career Move to NATO's SACLANTCEN as Technical Director

Around 1992 Bradley was contacted by his close colleague Bob Winokur who notified him of a forthcoming opening for the position of Technical Director of NATO's SACLANTCENTRE (Supreme Allied Command Atlantic Centre) in La Spezia, Italy with a late 1993 start for the position. Bradley decided to apply for the position, knowing that it could take up to a year and a half for a decision to be made regarding the NATO position. The time was right for such a career change for Bradley as his four children were grown up by then. Bradley previously had close acquaintance with Gerry Cann (effectively the Navy's ASW "Czar") while working at the Pentagon and Cann had influence regarding the NATO position. Bradley interviewed for the SACLANTCEN position in late 1992 after a trip to a TTCP meeting in the UK. He was eventually offered the NATO position and he accepted with a start date of 1 November 1993. He remained at SACLANTCEN for three years. Bradley's successor at NRL as Acting Superintendent of the Acoustics Division was Dr. Ed Franchi. Bradley's supervisor during most of his tenure at NRL was Richard (Dick) Rojas (and during the final year it was Eric Hartwig).

Retirement from Government Service

Coincidentally, around 1993 Bradley was close to being offered a full-time faculty position in the Mechanical Engineering Department at Catholic University. Also in 1993 Bradley received the Navy's Superior Civilian Service award at NRL (presented by the Chief of Naval Research, Admiral Paul Gaffney). Bradley's "official" Navy retirement occurred in February 1994.

The Career Move to Pennsylvania State University

In 1996, about six months prior to completing his SACLANTCEN tour, Bradley began exploring job possibilities in the US. He had informal discussions about possible positions at various university laboratories including Scripps Marine Physical Laboratory, the Applied Physics Laboratory–University of Washington, the Applied Research Laboratories–University of Texas at Austin, and the Applied Research Laboratory–Pennsylvania State University. Eventually he accepted an offer of a position at Penn State University where he has remained for the past twelve years as a Professor of Acoustics and Senior Scientist.

5. Paul Bucca

Notes Prepared by Fred Erskine on a Recorded Telephone Interview with Mr. Paul J. Bucca held on Monday 27 April 2009 at 2:10 PM EDT (1 hour)

Early Life and Education

Paul J. Bucca was born in 1945 in Passaic, New Jersey. His parents were second generation Americans. His mother had Polish heritage and his father had Italian heritage. Their parents came to the U.S. via Ellis Island in the early 1900s. Paul's father had a Ph.D. degree in microbiology and was a bacteriologist who spent most of his career at the communicable disease center in Atlanta, Georgia. As Paul was growing up the family moved from New Jersey to Staten Island, New York, then to Montgomery, Alabama, and then to Atlanta where Paul spent most of his youth. He graduated from high school in Atlanta in 1963, and recently attended his 45th high school reunion. After high school he enrolled in college at the University of Georgia at Athens where he received a B.S. degree in biology in 1967.

Employment at NAVOCEANO in 1967

Although his father advised him that the undergraduate degree in biology might not be helpful to Paul in seeking employment, that turned out not to be the case. Immediately after college, Paul was able to secure a job with the U.S. Naval Oceanographic Office that was headquartered in Suitland, Maryland. Bucca was hired by Charlie Bates who was NAVOCEANO's scientific and technical director as part of a new program called "Division-X." The purpose of this new program was to bring in a number of newly hired scientists and to circulate them around within NAVOCEANO to various departments in order to give them a broad exposure to NAVOCEANO's activities. Bucca's first assignment was at the Maury Center located on-base at NRL in Washington, DC in a group devoted to ocean acoustics studies. His first supervisor there was Don Atkocius who placed Paul in the oceanography section under Don Fenner. Bucca's initial assignment was to take large numbers of punched computer cards containing bathymetric data to the NRL computer center in order to make data printouts. His tasking was to conduct an assessment of the bathymetry measurement track coverage worldwide to determine where the "holes" in coverage were located. The analysis that came out of this assessment eventually resulted in a bathymetric survey requirements document that was co-authored by Bucca and his NAVOCEANO colleague John Duncan. This document was intended to provide guidance for future surveys. It was the first of about 110 publications that Bucca authored or co-authored during his career. Don Fenner was an excellent mentor to Bucca in this early phase of his career, and he taught Paul the skill of writing good reports. However, Fenner's interactions with other NAVOCEANO colleagues were less than smooth. Bucca and Fenner became increasingly involved in providing oceanic environmental characterizations to support acoustic measurements that were obtained by Navy researchers and the fleet. The resulting reports often pertained to specific Navy operational areas or to specific at-sea Navy exercises.

In this early phase of Bucca's career at NAVOCEANO, Brackett Hersey headed the Maury Center and had an office one floor above Paul's. Hersey was viewed as a "workaholic" who frequently carried two briefcases and who eventually retired with over forty years of government service. Fenner eventually encouraged Bucca to become more independent. As a result, Bucca was able to enroll in many career enhancing technical courses through NAVOCEANO and to begin to publish reports on his own. Later, after NAVOCEANO moved to Mississippi around 1976, Fenner had some personal difficulties and left NAVOCEANO. Bucca's first sea test was in 1968 out of Honolulu, Hawaii. After that he typically went to sea two to three times per year. He was responsible for all phases of these experiments from test planning, test execution, data analysis, and report writing. He found this to be very satisfying and thrived in this work atmosphere. He developed a skill for coordinating technical activities at NAVOCEANO. He was fortunate always to have worked under excellent supervisors and he never had to ask for a promotion – they just came naturally. In the early 1970s Bucca's immediate supervisor was Jim Audet, with whom Paul had a great working relationship. In that period Bucca worked in NAVOCEANO's Undersea Surveillance Oceanography Center (USOC). His closest colleagues in the USOC then were Warren Randlett, John Duncan, Jim Audet, and Roger Van Wyckhouse. At that time there were three components within the Maury Center on-base at NRL. They were: NAVOCEANO's R&D staff; the ASW Environmental Acoustic Support (AEAS) program and the Long Range Acoustic Propagation Project (LRAPP), headed by Roy Gaul; and the Office of Naval Research (ONR) basic research Ocean Science management group. In the mid-1970s Bob Winokur headed the NAVOCEANO R&D effort and Bucca worked under Skip Lackie. Other colleagues with whom Bucca worked closely then were Dan Watress, Mary Middleton (an oceanographer), and Basil Shears (a biologist).

The Move to NORDA in 1976

When the Naval Ocean Research and Development Activity (NORDA) was established in 1976 in Mississippi with Dr. Ralph Goodman as its Technical Director, the entire R&D contingent at NAVOCEANO was transferred to NORDA, including Bucca. However, fewer than fifty percent of NAVOCEANO's R&D staff actually agreed to make the move south from the Washington, DC area. After Bucca's move to NORDA in 1976, he worked in an environmental effects research section under Roger Van Wyckhouse. Later, Jim Matthews succeeded Van Wyckhouse and then eventually Bucca succeeded Matthews as section head. Separate from the environmental effects group were several acoustic research groups. One group headed by Dan Ramsdale performed sea tests. Another group was primarily developing acoustic models and it included Stanley Chin-Bing and Dave King. Another group that did fleet applications research was headed by John Ellis. Eventually in the late 1980s NORDA's name changed to the Naval Ocean and Atmospheric Research Laboratory (NOARL), but Bucca continued to be involved in environmental effects research as before.

Joining NRL's Acoustics Division in 1992-93

Around 1992, NOARL became part of NRL. At NRL-Stennis Space Center, Mississippi, Bucca and colleagues initially worked within NRL's Center for Environmental Acoustics that was headed by Dr. Ed Franchi. By 1994 Dr. Franchi succeeded Dr. Bradley as Superintendent of NRL's Acoustics Division and the NRL acoustics researchers in Mississippi became part of Code 7180 in NRL's Acoustics Division. At NRL-Stennis, Bucca continued to participate in frequent sea tests and to provide detailed environmental acoustics measurement and analysis support for Navy exercises. Bucca and colleagues at NRL-Stennis participated with their Acoustics Division colleagues from Washington, DC in the Navy's Critical Sea Test (CST) experiments in the mid 1990s. In 1996 ONR's Littoral Warfare Advanced Development (LWAD) project began frequent at-sea experiments with NRL as the leading science support laboratory. Bucca headed an LWAD team from NRL-Stennis, including Bruce Gomes, Bob Fisher, Rick Love, Charles Thompson, John Dubberly, Bob Delgado and others that provided detailed environmental acoustics support for those sea tests.

Other Recollections

During the mid- to late 1980s, while at NORDA, Bucca was involved in Arctic research programs and participated in three ice-camp experiments (e.g., Ice Camps Red and Rose)in collaboration with Dan Ramsdale, Ed Gough and others. He received strong programmatic support on the Arctic sea tests from Ken Dial at ONR. Bucca also had collaborations with Beau Buck of the Polar Research Center, but was not on sea tests with him. Bucca had international collaborations with the Canadians from the Defence Research Establishment Pacific (DREP). Among the U.S. organizations that Bucca had scientific collaborations with were: the Naval Ocean Systems Center, San Diego (NOSC), the Applied Research

Laboratories, University of Texas at Austin (ARL:UT), the Applied Research Laboratory, University of Washington (APL/UW), the Naval Air Development Center, Warminster (NADC), the Naval Underwater Systems Center, New London (NUSC), the Naval Undersea Warfare Center Division Newport (NUWC), and the Woods Hole Oceanographic Institution (WHOI). Bucca noted that he prepared the Appendix titled "Bibliography of LRAPP Documents" for the book by Louis P. Solomon, *Antisubmarine Warfare and the Long Range Acoustic Propagation Project: A True Tale of the Cold War*, dated October 2002.

Retirement in 1999

Paul Bucca retired from government service in 1999 and presently lives in Idaho.

Supplemental Information on LRAPP Provided by Paul Bucca (28 April 2009)

THE IMPORTANCE OF ENVIRONMENTAL DATA TO THE LRAPP PROGRAM

The Navy's Long Range Acoustic Propagation Project (LRAPP) placed great importance on environmental data collection, data analysis and reporting. These activities were unprecedented in the Navy's Environmental Acoustics (EVA) efforts. The program managers were among the first to realize that an understanding of the environment was often a primary variable in acoustic detection and, unlike other programs in the 1960s and early 1970s, they systematically set funds aside to address this issue.

As part of its role in promoting acoustic model development, LRAPP soon realized that, as the models became increasingly sophisticated, their accuracy often was not physics limited, but instead environmental data limited. Historical environmental databases such as that held by NODC (Naval Oceanographic Data Center) and later GDEM (General Development Environmental Model) were used. However the models' increased sophistication necessitated the collection of quasi-synoptic environmental data sets to adequately assess their true capabilities. This was vitally important in the conduct of inter-model comparisons. The LRAPP program was first to realize this and responded with the classical data-intense quasi-synoptic environmental data sets collected along the 143° 30' W baseline during exercises Church Anchor in 1973 and Church Opal conducted in 1975.

A maturing and unprecedented process whereby environmental data was reported evolved under the LRAPP program. Since the program had the dual role of acoustic systems advanced development as well as a model development responsibility, the LRAPP managers realized that the archiving of environmental data was a necessity. Due to the classified nature of the program, the environmental measurements could not be entered into the NODC database, hence all data sets were cataloged and documented "in-house" in a secure mode.

It was also during these early days when LRAPP was able to make substantive contributions to the SOSUS community. LRAPP environmentalists were called on to quantify bathymetric obstructions in the deep sound channel that may affect this system's capability. Out of this large series of "station brochures" came analyses of parameters such as "depth difference and depth excess," variables that quantified the position of bathymetric features in relation to the sound channel along specific underwater paths.

During this era, two documents were produced under LRAPP auspices that provided definitive documentation of the sound speed structure of large ocean areas: "The Sound Speed Structure of the North Atlantic Ocean" (1971) and "The Sound Speed Structure of the North Indian Ocean" (1972) (both authored by D.F. Fenner and P.J. Bucca). At a time when an understanding of the importance of the depth, permanency and bathymetric occultation of the deep and shallow sound channels and their tactical use was in its infancy, these documents provided an invaluable insight of the geographic distribution of these parameters to the exercise planner as well as the tactician.

As the program further matured, the concept of the environmental data package was devised as an expeditious method of disseminating data. This method involved the immediate processing of a selected data set very soon after the experiment for a specific user. Pre-exercise assessments became an important part of planning for future sea tests as the Navy began to understand that advance knowledge of the ocean environment was increasingly important to the sophisticated emerging acoustic systems and models. Often the environmental assessments were useful in locating a geographic region specific to a desired environment that the system was to be tested in (i.e., bottom limited, a specific geoacoustic region, areas containing a double sound channel, etc.).

The final exercise report of virtually every experiment had an environmental data analysis section and the production of a stand-alone environmental report for each exercise was ubiquitous. The environmental documentation contained focused analyses between acoustic sensors and sound sources as well as perceived acoustic implications of the observed variability – the latter being a unique attribute in the early days of acoustic experiment reporting. In response to the sophistication of the deployed systems and next generation acoustic models, the number of analyzed parameters also increased. Toward the end of the program, data on geoacoustics, arctic sea floor photography, and satellite imagery for use in ocean surface thermal temperature data were being collected in addition to the earlier parameters which included sound speed, bathymetry, currents and meteorological variability.

In response to the integrated approach to fleet requirements in the 1990s, LRAPP funded a series of regional shallow water environmental assessments. These documents, which addressed the Navy's ability to determine system performance in areas of potential regional conflicts, were designed to be of multi-community use and included ASW, mine, amphibious, and special warfare. By necessity of its multi-use focus, the number of assessed parameters was greatly expanded.

The collection of environmental data at-sea also underwent a maturing process. In the very early days of the program (circa PARKA) electronically recording conductivity-temperature-depth (CTD) probes were infrequently used. Instead, Nansen casts were still the standard. A Nansen cast consisted of a number of Nansen bottles that were lowered through the water column and were activated by a “messenger” weight sent down the hydrographic cable. This messenger “tripped” the Nansen bottles at discrete depths that in turn collected water samples and provided temperature readings using reversing thermometers. The conduct of these casts and the compilation of the accompanying “A” sheet calculations were time consuming. The advent of the electromechanical CTD units and later the auto-recording units represented a quantum advance in both time saving and measurement accuracy.

In the 1960s and 1970s, the environmental principal investigators had as their responsibility not only the collection of the environmental data, but often full time navigation duties as well. Before the advent of GPS and automated navigation plotting, each Loran or Transit (Satnav) position was hand plotted. This was a laborious and time consuming task. Other duties that routinely were relegated to the environmental PI included SUS (Signals, Underwater Sound) charge deployment as acoustic sound sources. Environmental PIs also provided shipping surveillance and Airborne Expendable Bathythermograph (AXBT) services to the early LRAPP experiments. An assessment of these parameters provided the acoustic analyst with a relatively precise synoptic picture of the surface-generated noise as well as the oceanographic environment. The early airframe of choice was the World War II vintage P-2 aircraft. These aircraft were usually manned by naval reserve squadrons; however, most of the later air operations were performed using the P-3 Orion ASW aircraft.

The importance assigned by LRAPP management to the collection of a comprehensive supporting set of environmental data that augments the acoustic measurements and model development was unprecedented in its time. Without this high regard for the environment, neither the surveillance systems nor the models that provide the Navy with its current state-of-the-art capabilities would have been possible.

6. Chester Buchanan

Notes Prepared by Fred Erskine on a Recorded Telephone Interview with Chester LeRoy (Buck) Buchanan held on Thursday 19 February 2009 at 2:45 PM EST (2 hours)

Preface

Chester LeRoy ("Buck") Buchanan presently lives in White Bear Lake, Minnesota and is 93 years of age. The purpose of this interview is to collect some background information that will be useful in the preparation of a history of NRL's Sound Division (later called the Acoustics Division).

Buck Buchanan has already prepared an informal two-volume memoir of his life. Volume One deals with his personal life and Volume Two deals with his technical career — most of which was spent at NRL in the Sound Division, and later in the Ocean Technology Division. He is presently finishing a new memoir covering the very intense decade (starting in 1963) during which he was involved in the use of NRL's deep-towed sensor systems in response to some major crises.

Early Life

Buchanan was born in 1915 and was raised in Cass County, Indiana. His family usually lived on a farm, but sometimes they had a business. When the Great Depression hit in 1929, Buck's dad lost his job and they moved to the farm. At that time Buck was in junior high school, but he was able to be quite useful on the farm. When Buck graduated from high school in 1933 there were no jobs. Buck's mother was a school teacher. Somehow it was just understood by the family that the four children would go to college. Buck was born on his brother Forest's eleventh birthday. Forest attended Butler University where he studied chemistry and had hopes of becoming a medical doctor, but he just couldn't handle college so he dropped out. Forest then managed to get a job with the Campbell Soup Company in Camden, New Jersey. Later, when Buck graduated from high school it was still very hard to find a job. Forest suggested that Buck come to New Jersey where the Campbell's Soup Company was hiring summer workers to process tomatoes. Buck went to New Jersey and worked at Campbell's Soup for the remainder of the tomato season at which time most of the seasonal employees were released, but partly due to his brother's influence, Buck continued on at Campbell's. He continued working there for two years (1934–35). The time in New Jersey was a very broadening experience for Buck. In retrospect the time on the farm had been very valuable as well because it instilled in him the qualities of hard work and self-discipline (the cows had to be milked whether we wanted to or not!). Buck's work week consisted of 35 hours (2:30PM to 10:00PM each work day). During that period Buck was very active in his amateur radio hobby (that was helpful to him in his later technical career). While in New Jersey Buck joined the local Presbyterian Church and became a youth advisor — they had a basketball court, pool tables and other activities to keep the young people busy. In that period he began to have a "social life" for the first time. There was a men's organization that he joined. The ladies had a separate organization, but the two groups frequently did things together.

The College Years

At the end of this two-year period in New Jersey, Buck used some of his savings to purchase a 1928 Model-A Ford. Then he packed up all his belongings and headed back west to Indiana. He then enrolled at Purdue University in chemistry, but he discovered he did not like chemistry. Somewhat influenced by his interest in amateur radio, he switched to electrical engineering as a major. Buck had taken some night classes at Temple University in Philadelphia while he was in New Jersey and he was able to transfer a few of those course credits to Purdue. The coursework at Purdue got a bit easier after his sophomore year when he completed all the basic courses and could concentrate on the engineering courses. While at Purdue he built a little “shed” (8-ft x 16-ft) that he could park behind the house where he had initially stayed. He shared this dwelling for a while with a buddy from the school band. They prepared their meals there and had an inexpensive place to sleep. By the last two years in college, he built a somewhat larger house-trailer that was parked on a nearby lot. He recalls that he paid five dollars per month for the privilege of running an extension cord and using the bath facilities in a nearby house. He graduated in 1939 with a degree of Bachelor of Science in Electrical Engineering.

Employment after College

Buchanan was fortunate to find a job even before he graduated from Purdue. This job was with Stewart-Warner Company in Chicago, Illinois, making parts for all of the major automobile companies. The work involved developing a number of instruments, some with magnetic parts. He recalled that it cost about ninety cents to build a car speedometer, but his part of the speedometer cost only about five cents. Through some efficiencies of design and modification of procedures he was able to cut that cost in half. About that time the federal government initiated a big project on rural electrification. Stewart-Warner got a big contract to make the meters to monitor the electric power going to homes. He designed the system for magnetizing the magnets in the power meters. The next summer, while on vacation back in his home town of Logansport, Indiana, he got a better job offer with another company (RBC, in Logansport) that made parts for automobiles, as a design engineer. He designed various electrical parts such as switches. The U.S. was attacked at Pearl Harbor, Hawaii on Sunday 7 December 1941 — and the next day the U.S. cancelled all automobile production. Immediately most of the male employees at RBC were released and many of them signed up for military duty. Buchanan remained at RBC with a large cadre of women employees. He quickly developed a talent for responding to government requests for proposals and was able to procure contracts for RBC that were relevant to the defense needs. There were also a number of emergency requests for specialized parts and Buchanan was able to organize a quick turnaround on several of these. As a result he developed a bit of a reputation as being able to provide quick-response actions for RBC. At the end of a year RBC asked Buchanan to become their factory foreman to supervise 306 women and two men.

Joining the Navy During World War II

At this time (1942) he was already married with one child and another one expected soon. However, he learned from some of his friends who had entered the military service about their exciting work on some new technologies such as radar and advanced electronics. He decided to leave RBC and join the U.S. Navy. He could have remained at RBC because he was working in a critical industry and was exempt from the draft. His Navy basic training was in Arizona. He used his experience in amateur radio there by organizing a group to signaling by use of flashing lights. There were 800 men all sleeping in the field house at the University of Arizona. While there Buchanan was in the Navy band. He played a trombone-trumpet (a trombone without a slide). They marched every day in the heat of Tucson, Arizona.

He completed this basic training and was sent by the Navy to Key West, Florida. One reason he was sent there was because his experience with musical instruments meant he had a keen ear and would be a suitable candidate to work with Navy sonars. He was assigned to the Sonar Maintenance school. To Buchanan this was like arriving in heaven. With all his prior experience in amateur radio and the construction of electronic equipment this was a technology that greatly interested him. The Sonar Maintenance course was taught by two Navy Chiefs. It soon became evident that they did not know the course-material as well as some of the students, including Buchanan. Very quickly Buchanan became an instructor in Sonar Operation and Maintenance. The Navy then sent Buchanan to Massachusetts Institute of Technology (MIT in Cambridge, Massachusetts) to take a course in Advanced Sonar Techniques and Electronics. As part of that training, Buchanan was fortunate to be able to visit virtually all of the government and university laboratories and all of the private industry companies on the East Coast that were working on sonar systems. One lab that really impressed Buchanan was the Naval Research Laboratory, Washington, DC. He just did not believe that there could be any place as wonderful as NRL. When he visited NRL they were working on a Passive Ranging System for submarines under Harold Saxton. He continued teaching for a while longer at Key West and also assumed duties as an electronics laboratory instructor. Buchanan very much enjoyed the period at the Naval Station in Key West. He was able to have his family join him. They had frequent official visitors from around the U.S. and also some technical specialists from the Soviet Union came to visit his lab there. By the end of World War II, Buchanan was the Officer-in-Charge at the Key West Sonar School, but things were starting to wind down there. At that time NRL was conducting at-sea experiments out of Key West. Buchanan was offered a Navy job as liaison between the NRL experimenters and the military — but he turned this down.

Post-World War II Civilian Career Beginnings at NRL's Sound Division

Buchanan started thinking ahead about future civilian job prospects. He studied up on his Morse Code and got his code speed up to 25 words per minute. He then went to Miami and passed the examinations to obtain commercial radio licenses for shipboard and land-base operations. Very soon he was out of the Navy as a civilian and he took his family back home to Indiana. Shortly thereafter (circa 1946) he traveled to Washington, DC and visited NRL for a job interview. Within one day he was hired to work in the Sound Division at NRL. He started out in the Submarine Sonar Section that was headed by George R. Vernon. One of the other primary research groups was the Surface Sonar section. Buchanan's first assignment was to design a power amplifier capable of 1 kilowatt output at 24 kHz.

Rapid Rise in the NRL Sound Division

In that period immediately after World War II, many researchers left the NRL Sound Division for other employment. George Vernon also departed from NRL at that time. The Submarine and Surface Sonar sections were then combined into one group under Melvin S. Wilson. Within six months, Wilson developed a collapsed lung and left NRL. During each of these staffing departures Buchanan moved up higher in the organizational ladder — so that quickly (before he even had his "feet wet") he became a Section Head, then a Branch Head. In that period all of the Sound Division personnel were in NRL Building 1. However, shortly thereafter there was some additional reorganization of the Sound Division and two branches were moved to Building 28, one dealing with Surface Ship Sonar, and one dealing with Air-Deployed Sonar, including the use of helicopters. Buchanan then became head of the Surface Ship Sonar Branch.

At-Sea Experimentation Under Dr. Harold Saxton

Buchanan's research group then began a series of extensive at-sea measurements from surface vessels in which they towed various arrangements of sonar gear. This involved the deployment of single, double, and triple cables including various arrangements of faired cables to reduce acoustic "strumming." For Buchanan, this was the perfect introduction to the types of deep sea towing operations that would later become his forte. Buchanan's branch was renamed the Sonar Systems Branch. One research problem of great interest then was how better to detect submarines that were below the surface sound channel. By the late 1940s the new Sound Division Superintendent, Dr. Harold Saxton, directed Buchanan's branch to begin developing new sonar systems for lower frequencies, starting with 10 kHz, then moving down to 5 kHz and eventually to 1 kHz. The ships that they were using at the time were not very adequate for the testing they needed to accomplish. It was really "terrible" and Buchanan was not sufficiently experienced to tell management that they needed better ships. They did not have too much difficulty testing the 10 kHz sonar gear. They were just able to also manage testing of the 5 kHz sonar equipment. They were still able to design sonar transducers using crystal technology at 5 kHz. But at 1 kHz the sonar equipment was too large to handle with the available ships, and crystal technology was not adequate. Buchanan developed an idea for a different deployment methodology to make deployment of large sonar gear manageable. This involved cutting a center well in the middle of the research vessel. This was first tried with the R/V *Hunting*. They were successful in testing gear for all three frequencies with the *Hunting*. At that time the Potomac River was navigable so they did some testing in the Potomac River and some testing in the Atlantic Ocean out of Norfolk, Virginia. This testing arrangement was still not very pleasant or very safe for the personnel on board the research vessel, but it was a step in the right direction.

The Sound Division was successful in testing a new type of transducer for 1 kHz. It was a huge device. The technology was electro-mechanical rather than being based on piezo-electric crystals as were the higher frequency units. They were successful for the first time in obtaining target echoes at first convergence zone range (about 30 nautical miles). However, the processing for the 1 kHz signals was very narrowband — about 1 Hz — this was a bit problematic and challenging. They used tuning fork filters.

<u>Recollections about the NRL Sound Barges on the Potomac River</u>

Buchanan commented about earlier transducer testing that had been done by the Sound Division using the Sound Barges that were moored next to the NRL pier in the Potomac River. There had been a huge influx of people to Washington, DC during World War II, but the infrastructure to handle this influx was totally inadequate. As a result the Potomac River was extremely polluted in the late 1940s. Sewage from the DC area was stored in pools just over the fence on the south side of NRL Building 28 (the Cafeteria Building). The air around that side of NRL was very corrosive such that locks and metal fittings on buildings would quickly rust away. In order to work in the NRL Sound Barges, scientists and engineers had to have inoculation shots and special permissions. One day the technicians who were working inside the Sound Barge were welding some equipment and the "water caught fire!" There was a layer of methane on top of the water and it just "flashed." When one walked down the NRL pier it was evident that all manner of things were floating in the Potomac. The situation became untenable and NRL got rid of the Sound Barges. After that, much of the Sound Division's transducer testing was instead done at Lake Seneca in the Finger Lakes region of New York state.

<u>Some Recollections about Sound Division Research in the 1950s</u>

Backing up a bit: before the Sonar Systems Branch started developing the active sonar systems, they were in charge of testing for the Passive Ranging System at Key West, Florida. They could not afford to pay for the services of an actual ship as a passive noise target so instead they towed an artificial noisemaker. In those days, "white noise" was almost a "myth." We did not know much about "white noise." Also — we had no "delay lines" and no computers. We were doing all this testing using a signal generator whose noise characteristics we did not understand. In spite of these difficulties we were quite successful in obtaining good directional information using Dr. Saxton's Sector Scan Indicator (SSI). On the last day of at-sea experimenting from a submarine at depth, Buchanan decided to do one more test of his own. He connected the two stations — one on the bow and one on the stern of the submarine — with one going to the input of the right side of the SSI and one going to the left side of the SSI. Buchanan then proceeded to "conn" the submarine — using the two "stations" as a delay line. He was able to determine that the noise from the submarine's propellers did not "lap" over the display of the SSI. However, the artificial towed noisemaker would go about three-times out over the span of the SSI display. The artificial noisemaker was made of a bunch of pipes that rattled together. Those pipes had enough resonance to produce an almost pure (sine-wave-like) tone for short periods of time. Later, after

Dr. Saxton read the test report, he came to Buchanan's office. He could not believe how good the results were. He said — "You know we hired you to execute these tests, but we never dreamed you could produce good scientific results like these!" He was very complementary about the results.

In spite of the success of the testing with Dr. Saxton's SSI, Buchanan was bothered about the large and cumbersome amount of hardware required. He started thinking about possible simpler alternatives. He realized that if they could somehow measure the difference in "time of arrival" of signals between three sensors distributed along the outer hull of a submarine they could have a simpler way of implementing passive ranging. At about that time they were visited by a group from the Naval Ordnance Laboratory (NOL), Silver Spring (White Oak), Maryland that included Dr. John Munson. During meetings with the NOL group, the NOL scientists presented their concepts for a new method of passive ranging. Buchanan pulled out his previously written notes from his thoughts on the subject — and the two groups became "friends for life!"

The Beginnings of NRL's Deep Ocean Search Capabilities

At about that time (perhaps early 1950s) they put the R/V *Hunting* in the "yard" for overhaul. To their dismay, they discovered that they could not weld new steel to the old steel hull — it would crack! These types of ships often had a problem with hull corrosion beneath the engine room. The R/V *Hunting* was declared unfit for further use. In the process of attempting to fix the R/V *Hunting*, all their ship-funds were expended. However, by then they had completed the series of tests demonstrating active sonar systems for 10 kHz, 5 kHz, and 1 kHz and were considering new projects. Buchanan suggested they consider doing measurements to explore the interaction of acoustic energy with the sea bottom. They were beginning to get prepared to do at-sea operations in the deep ocean. They had ordered and received 21,000 ft of cable.

The Loss of the Nuclear Submarine USS *Thresher* and Initial Searches by NRL's Sound Division

When the USS *Thresher* sank on 10 April 1963, they were one of the few research groups that had been preparing for research involving deep ocean towing experiments. NRL's Commanding Officer, Capt. Bennett, called Buchanan and asked if he had heard about the sinking of the *Thresher*. Buchanan had earlier had an opportunity to show some of the deep-tow apparatus to Capt. Bennett including a television camera system that had been borrowed from NASA. It took about one minute to send the video image via the long cable. When the *Thresher* sank, Capt Bennett asked Buchanan if any other organization had such a deep-towed imaging system. At the time Buchanan was not aware of any other such system, but much later they learned that a similar system existed in Hong Kong. Capt. Bennett alerted Buchanan that his system might need to be involved in the *Thresher* search. That evening, Buchanan prepared two Operations Plans ("OP Plans"). One was for the R/V *Rockville* (also known as PCR 851). This vessel was outfitted with 24 kHz sonar gear that had been used in earlier submarine detection experiments. This sonar gear had a capability to be tilted in a downward-looking direction, but it was uncertain if it could see objects on the bottom in the deep ocean. As it turned out, Burt Hurdle then went out with the R/V *Rockville* on an initial search for the *Thresher*, with no success. The second OP-Plan prepared by Buchanan was for an unknown vessel to deploy his new deep-towed sensor system, including the imaging apparatus. After seeing this plan the following morning, Capt. Bennett called up Buchanan and said "Go." That was the biggest "blank check" Buchanan had ever seen!

Aside: Around this time (early 1960s) the Navy was seeking a design for new hydrographic research ships. Dr. Saxton announced at a meeting that NRL was going to get one of these new ships. After seeing the ship specifications, Buchanan explained to Dr. Saxton that these new types of ships were not suitable for the planned deep sea research. This is the only time that Dr. Saxton ever got angry with

Buchanan. Dr. Saxton ordered Buchanan to use this vessel. It was the R/V *Gillis*. It had one screw (propeller) and one rudder. It was driven directly by a diesel engine. These characteristics made operations at slow speed impractical. In order to provide for low speed operation, the vessel was provided with an “inboard motor” deployed via a small center-well. This was a retractable device similar to that on a motorboat, and was driven by an extremely noisy airplane engine. The ship’s structure was such that there was no way to launch the NRL deep-towed gear other than at the stern. We happened to have two different devices that we could use for launching in this manner, so we selected one of them that seemed to us to be the most suitable. We installed all of our equipment on the R/V *Gillis* and without any “shakedown” we proceeded to the search area. We could not go at speeds slower than about three knots. However, we took quite a lot of photographs. One of our cameras was designed by Harold Edgerton. Illumination was provided by some 200 watt flashes. Bob Patterson was Buchanan’s chief camera engineer. This initial search in late summer 1963 was not very successful and had to be cut short due to rough weather. Later, Bob Patterson found some optical equipment (Norden Bomb Sights) that had spherical windows. This gave him some ideas for significant improvements in their deep-towed wide-angle camera setups with hemispherical housings.

Follow-On Search for USS *Thresher* using USNS *Mizar*
In fall 1963, Capt. Bennett asked Buchanan if he would be interested in continuing the *Thresher* search in summer 1964. Buchanan responded yes, but on the condition that they could find a more suitable vessel. Capt. Bennett said to go ahead and start a search for a better vessel. As it turns out, both Buchanan and his chief mechanical engineer, Jerry Gennari, were reserve naval officers. Gennari requested to do his summer reserve officer training performing a review of available ships. He went to the Bureau of Ships where he had access to records of all the ships in the Navy. In this tour he found the perfect ship — the USNS *Mizar*. It was designed in the shape of an icebreaker. It had a hull that was twice the thickness of a normal design and in addition it had a second hull inside the first one. This meant that the ship had an unusual amount of weight far from the center of the ship and therefore would be very sluggish in its roll. In addition this ship had a diesel electric propulsion system so that it could operate easily at any speed even down to very slow speeds. Furthermore, it had twin propellers and a single rudder that would give it great maneuverability even at slow speeds. Buchanan received approval to use this vessel for the upcoming 1964 operations.

For the deep ocean search work it became very important to have reliable and accurate ship navigation information. The available (US) Loran and (Canadian) Decca navigation systems were not very precise relative to NRL’s needs. In 1963 NRL learned about a transponder system developed by the University of Washington in Seattle which would enable them to place some reference acoustic sound sources on the sea bottom to greatly enhance their navigation localization capability. NRL was able to borrow this system and it was put to good use in the 1964 operations. Installation of this system on the USNS *Mizar* involved the placement of three receiving hydrophones under *Mizar*’s hull. In order to take full advantage of this system Buchanan hired a computer specialist from Purdue University (Dean Clamons). In preparation for the 1964 operations, Buchanan’s group also developed much improved camera systems. While preparing for the 1964 operations they carefully examined all the photographs that had been taken in the 1963 operations. In one photograph they found an image of what appeared to be the *Thresher*’s “mushroom anchor.” That gave them a starting point for the 1964 search. As it turned out — on the first day of the 1964 operations they were able to take photographs of the *Thresher*.

During the deep ocean search operations, one challenge they had to overcome was to find an appropriate ship track for the search since the instrument package was very far below the ship (at a depth of perhaps 8000 ft) and at any given time was passing a section of the bottom where the ship had been about an hour ago. Buchanan had heard a story about an expedition to the Amazon region of South America in which the explorers (missionaries) were flying an airplane and were able to lower a basket of supplies to the local residents on a long cable. They managed to keep the basket stationary relative to the ground by flying in a circle high above the basket. This gave Buchanan some ideas about an appropriate ship track to take in order to have his instrument package remain fairly stationary near the sea bottom. However, the *Thresher* had broken into four sections. Buchanan was able by laborious use of a flower-petal type set of ship tracks to survey and photograph all four sections.

The Search for the Lost Nuclear Submarine USS *Scorpion*

Jumping ahead a bit — Buchanan's team had additional motivation to attempt keeping the deep tow sensor sled roughly stationary on the sea bottom in later sea trials. In 1968 Buchanan's team was asked to participate in the search for the sunken nuclear submarine USS *Scorpion* in deep water in the eastern Atlantic Ocean (south of the Azores). During initial operations in the *Scorpion* area Buchanan's team was having difficulty with their University of Washington transponder system — they discovered that some transducers were mounted upside-down. They got that fixed and were given permission to continue their operations on the USNS *Mizar*. At that time there were no accurate bathymetric maps of that part of the Atlantic Ocean. The Naval Oceanographic Office was tasked to assist by doing some map surveys of the region. Buchanan proceeded to run some straight tracks about 10 nautical miles in length with the deep towed camera system. After developing numerous photographs, one image showed something that appeared to be metallic — perhaps stainless steel (it appeared white in the image). His team had been out all summer. Buchanan personally participated the first, third, and fifth month. The Navy was reluctant to allow Buchanan's team to continue the search. However, Buchanan requested some time to further test his transponder-based navigation system. He decided to do this test at the spot where his intuition told him was the most likely spot — and then almost immediately they located the USS *Scorpion*.

Unfortunately, just then a three inch shaft on the *Mizar*'s winch broke with the result that they lost all their deep-tow gear and their latest photographs. They carried a spare deep-tow sled, but it was in disrepair and they had to get it ready quickly. They were able to repair the winch as well. Another challenge was that the wind increased in intensity so that their ship tow would have to be done at a ship speed of about five knots rather than the usual one knot. But they were pretty certain that they had located the *Scorpion* and now needed to find a ship track that would enable the deep-towed gear to remain nearly stationary near the deep ocean bottom (again at around 8000 ft depth). The ship track pattern that Buchanan finally determined was useful was to go in a square pattern, the sides of which were about half the ocean depth in length (about one mile approximately). This resulted in the towing cable taking a spiral-type pattern to the bottom, where it remained nearly stationary. As an aside, earlier Buchanan had tasked a mathematician to help determine what kind of towing track would allow the deep equipment to remain stationary. The mathematician did some calculations and said it was impossible. Then Buchanan rigged up a drill press with a cable and a weight in a bucket of water and demonstrated that it should be possible to keep the deep equipment stationary. After fixing a sign error in his calculations the mathematician agreed with Buchanan.

In these final operations in the *Scorpion* area, Buchanan took the *Mizar* directly into the wind at about six knots, and then they would go downwind at a ship speed of about one knot. They started getting returns from their magnetometer indicating that they were close to the sunken submarine. They brought the camera system to the surface and had to wait for the camera system to warm up in a bath of warm water before they could open it and develop the film. This took about half an hour. In the meantime they were preparing the sled to be lowered again. The ship captain came down and said

"Buck — we got some great pictures — you can quit anytime!" Buchanan decided to do another run. At a ship speed of six knots they could not hear their sea bottom transponder signals — so they had to slow down to capture the navigation data. It was very nerve-wracking. They got spectacular photographs. The submarine remained in one piece, but it was obviously far below its crush depth. Amazingly, it became compressed in the lengthwise direction, such that the propeller shaft was sticking out about forty feet behind the stern of the submarine.

Further Recollections about the NRL Sound Division in the 1940s to the 1960s

Much of the deep-towed sensor technology that was developed by Buchanan's group was done while they were in the Sonar Systems Branch of the Sound Division at NRL. Around 1966 Buchanan's group became part of the new Oceanology Division, but they retained close ties with the Sound Division.

Buchanan mentioned his recollections regarding his interactions with a number of NRL colleagues. Bernie Lindstrom was a mechanical engineer in his branch who designed several important devices and had a hand in the design of the very large 1 kHz sonar system. He retired to a sixteen acre home in southern Virginia and Buchanan visited him not long ago. Ernest Czul was a mechanical engineer who worked under Jarvis Gennari. He was a valuable employee. He was conning the *Mizar* when the winch shaft broke. He stopped the winch before they ran out of cable and really saved the day. As an aside — Buchanan tried hard to get a good electrical engineer who could help them bridge the gap between the older vacuum tube technology and the newer solid state technology. Jarvis Gennari was a very valuable colleague — he was "money from heaven." He knew a lot more about ship operations than did Buchanan. He almost single-handedly masterminded the entire *Mizar* installations. The first installation was just a "temporary" one in which they essentially towed the instruments from a "spar" over the side of the vessel. This worked but it was rather inefficient and remained cumbersome. The later installation was much better. It involved modifying the *Mizar* to install a center-well from which all the deep sea equipment could be deployed. It was covered and enabled very safe and efficient operations round the clock in all types of weather.

When Buchanan came to NRL around 1946, the average age of employees in his branch was about 20 years. He hired Hester Helms, who at that time was around 49 years old. She did a great job of keeping the entire branch focused on their research tasks and Buchanan can't thank her enough for a job well done! Peter Kaufman was a bit unusual and Buchanan sometimes had difficulty communicating with him — but he was an effective part of the team. Matthew Flato was an electronics support person. Wilbur Jones was the only African American staff person in the branch. He was an excellent mechanical engineer who developed some key patents. [When the team went on assignment to Key West, Florida they all stayed at the Navy's Bachelor's Officers Quarters (BOQ) because Jones was not permitted to stay at the nearby hotels]. Hollis Gibbs was the ultimate electronic technician and was a very valuable team member. Frank Heemstra was a physicist who was very capable with electronics. He was a big help with the transition from vacuum tube to transistor technology. He designed their proton precession magnetometer. It was made from a child's toy called "rock-a-stack." Its construction involved a carefully wound set of coils and a glass tube filled with kerosene. An applied magnetic field was turned on, thus causing the proton spins in the sample to maintain a particular orientation. When the applied field was cut off, the protons precessed towards north. If the local magnetic field was perturbed by the presence of a nearby metal object the device could easily detect its presence. The response was in the audio range. It was set so that no sound was heard unless something anomalous was found. It was activated just prior to taking each deep tow photograph. Massis Davidian came from another branch and was quite useful. Lloyd Greenfield was a good worker.

Walter Brundage was hired as the first oceanographer at NRL. Buchanan felt that the Sound Division needed an oceanographer. He turned out to be a great benefit in many ways. He was very helpful in reviewing the deep tow photos and in writing up the results of the various at-sea expeditions. Brundage was responsible for identifying some new biologic species in some of the deep ocean photographs. Bob Patterson was a physicist. He became Buchanan's photo equipment design expert. As an aside — Buchanan recalled an event shortly after he started working at NRL that gave him an idea for a future project. He was returning from Indiana with his family and was crossing from Ohio to Pennsylvania near Pittsburgh. There was a great deal of fog over the Ohio River. The visibility was very limited. Suddenly a tanker truck came up close behind his car with its bright headlights and at once Buchanan could see much farther ahead in the distance (even with his own headlights dimmed). Years later Buchanan's group (led by Bob Patterson) developed an effective system for deep sea photography known as LIBEC (Light Behind Camera) that used an analogous principle.

Albert Gotthardt was a very good mechanical engineer. He did a lot of work on the Passive Ranging System. Later he had a position at NRL managing all the research vessels. Art McClinton was a power engineer rather than an electronics specialist. Buchanan did not work closely with McClinton but found him very likeable. Buchanan's career paralleled that of Burt Hurdle somewhat since they both started in the Sound Division in the 1940s; however, Hurdle was much more involved in scientific measurements and Buchanan was more involved with engineering developments. Raymond Steinberg was a branch head when Buchanan arrived at NRL around 1946. Steinberg had been instrumental during the 1930s in unraveling the mystery about sound shadowing for objects beneath the acoustic near-surface channel. Elias Klein had done pioneering research in the Sound Division before Buchanan arrived at NRL. When World War II started the Sound Division greatly expanded in size. However, immediately following WW II there was an almost complete turnover in Sound Division personnel.

Buchanan mentioned that he had done some interesting research on acoustic communications at low frequencies utilizing long range propagation to the ocean bottom. Buchanan also had a consultant (a university professor named Finn from Virginia) who did ray trace calculations related to this problem. Buchanan was able to turn the results into an analog calculator device to enable quick determination of long-range propagation to the ocean bottom.

Postscript

Chester Buchanan died in 2009 at age 93 years, about six months after this interview.

7A. Norman Cherkis

AN INTERVIEW WITH NORMAN CHERKIS

by Dr. David K. van Keuren
History Office
Naval Research Laboratory
22 October 2001
Interview #1

Task Number: T-27-1496-028A
Norman Cherkis
Date: 22 October 01

Van Keuren: Today is October 22, 2001. This is David van Keuren, History Office, Naval Research Laboratory. I am sitting down with Dr. Norman Cherkis.

Cherkis: Mr.

Van Keuren: Mr. Norman Cherkis, retired of the Naval Research Laboratory. I am talking to him about his career in oceanography at the Naval Research Laboratory and elsewhere. Norman, can you start me off by telling me when and where you were born?

Cherkis: I was born in Brooklyn, New York in 1941.

Van Keuren: And what did your father do?

Cherkis: My father was a haberdasher.

Van Keuren: And he worked in Brooklyn?

Cherkis: He worked in Brooklyn and later in Queens, but he was a men's clothing salesman.

Van Keuren: Did he own his own store or?

Cherkis: No. He wasn't -- he worked for somebody else.

Van Keuren: And your mother?

Cherkis: My mother was a housewife.

Van Keuren: Housewife. And Cherkis, is that a Russian name or?

Cherkis: It is a Russian name. The name actually goes back to the Caucauses. There was a group called the Cherkassy who were some sort of warriors for the Tsar or something like that.

Van Keuren: The Kakassi?

Cherkis: Cherkassy.

Van Keuren: How do you spell it -- oh, with C-H?

Cherkis: C-H-E-R-K-A-S-S-Y I think is the --

Van Keuren: And the Caucascus then --

Cherkis: And the Caucausus, yeah.

Van Keuren: Do you anything about your family history in there?

Cherkis: Not very much. I don't know when my grandfather came over. He was living, by that time, in -- I believe what is now Belorussia, or Moldavia, or maybe Ukraine. I don't know -- it was somewhere near Torasapole (sp). He came over in the early 1900s. He was already married. My grandmother came over in 1905 with three daughters. And my father was the last to be -- well, the next to the last to be born. He was a twin. He was born in 1910 and he was the last of seven surviving children.

Van Keuren: All in New York?

Cherkis: Yeah. Or living in New York, yeah. And they lived in Manhattan for a while, and then moved to Brooklyn.

Van Keuren: How did your parents meet?

Cherkis: I don't know, but they met in Brooklyn somewhere. A friend of a friend type of thing. I would imagine.

Van Keuren: And do you have any siblings?

Cherkis: I have a brother.

Van Keuren: A brother. Are you the younger or the older?

Cherkis: I'm the older.

Van Keuren: Can you tell me about your early schooling and education?

Cherkis: Public schools. City of New York, kindergarten right through high school. Moved from Brooklyn to Queens in 1957. Completed my last year of high school in Queens, I still consider myself a Brooklyn-ite. I went to Lafayette High School. This was one of the premier high schools for famous people in New York. People like Larry King, and Sandy Kofax, and Paulie Sorveno.

Van Keuren: Paulie Sarveno?

Cherkis: Sorveno. Paul Sorveno. He's an actor. He has a daughter who is an actress.

Van Keuren: So, you went to Lafayette High School. Did you have a penchant for science at that point?

Cherkis: I did and I didn't. The earliest I remember about being interested in science was actually in geology. I was in the second grade. I found a rock, it looked really neat, so I brought it into school. Asked the teacher what it was and she was a great teacher. She said I didn't know -- I don't know, but I'll find out. And she did, and it was a piece of Manhattan schist. And I used to bring in rocks in after that periodically, and get people to identify them for me, and I had a small rock collection. My penchant, because I was lazy, was to write anything I wrote in very short sentences. I wasn't very much on adjectives. So, I decided that I wanted to go into journalism and --

Van Keuren: This was in high school?

Cherkis: This was in high school, right. And I was -- I did some things with the school paper, the school magazine, that sort of thing. And then I went to college. Went to college and I -- this was the Bronx campus, the Bronx Campus is now Lehman College. They renamed it.

Van Keuren: How do you spell Lehman?

Cherkis: L-E-H-M-A-N, like in Herbert. And I was on the school paper. I was intended to go into journalism.

Van Keuren: Did you enter Hunter attending to go into journalism?

Cherkis: I did.

Van Keuren: Okay.

Cherkis: But after four consecutive semesters in D in English, the English Department decided that they didn't want me any further. And by this time I had already taken a couple of classes in geology just because they were fun, and it was interesting, and they were easy -- it was easy for me because I understood earth processes by that time.

Van Keuren: How did you understand those?

Cherkis: Observation mostly.

Van Keuren: Observation?

Cherkis: Yeah. And I spoke to the people in the geology department. They had nine people in their department, and they told me that if I knew the difference -- if I got an undergraduate degree and knew the difference between a claw hammer and a rock hammer when I graduated, I could get a job making good money.

Van Keuren: Working as what?

Cherkis: Working in the geological field. Well, it was 1958. In 1962 they were laying off people with 12-15 years experience. So, there were no jobs there and I sent out 189 letters for employment, and got three that were actually interested. One was, you know, Venezuela, an oil company. And then they had a revolution there. They were burning down the oil wells. One was New York, Rossya and Honduras, which was a mineral company in Central America. And they had a fire that leveled their facility so that one went away. And the third was with Kennecott Copper in the Atacama Desert in Chile. And the papers were signed --

Van Keuren: What's the name of the desert?

Cherkis: Atacama, A-T-A-C-A-M-A.

Van Keuren: A-T-A-C?

Cherkis: A-M-A. The Ugaba Prospect (sp). Papers were signed and I was getting ready to leave within two months, filing -- finishing up everything. Getting my things in order. They had an earthquake and it took the entire facility down the hill. Fifteen hundred people died. So, I dodged three bullets, but then there were no other jobs. No other prospects. So, I went to work for Metropolitan Life as a claims approver in major medical. While I was at Metropolitan Life I got a call from the CIA, would I be interested in working for them.

Van Keuren: How did they know about you?

Cherkis: I don't know. But they were interested in me as an aerial photograph interpreter, and of course this is late 1962, just after -- a year after the Cuban Missile Crisis. I don't know how they knew about me, but somebody put them onto me.

Van Keuren: Did you have expertise in that area?

Cherkis: In UFO -- yeah. Well, I had trek -- when you look at aerial photographs they use a stereoscopic viewer, and you do -- you match a common point onto photographs and do the interpretation of what the topography looks like. I had -- I don't know if it's a gift, or a trick, or what, there but I could hold them out at arms length and find the common point and blink once or twice and visualize 3-D. And I was doing this while I was in school.

Van Keuren: Who were you doing it for?

Cherkis: In college. They would just -- you know, structural geology classes, geomorphology classes.

Van Keuren: So, you were doing this as part of our course work?

Cherkis: Yeah.

Van Keuren: So, probably one of our professors?

Cherkis: Yeah. Probably, but the CIA didn't tell me anything. I didn't press the issue, I was looking for a job. I came down here in November of 1962 and had three days of intensive testing. I asked them -- probably asked more questions than I should have. I went to different facilities around, took different tests including polygraph, psychiatric, personal -- personality profiles, current events. And they told me I failed the current events exam. After those three days I really wasn't interested in working for them anyway. They were really spooky people. So I went back to my job at Metropolitan Life. Took a civil service exam in January.

Van Keuren: 1963?

Cherkis: 1963, yeah. And in -- end of May, I think, it was in that timeframe of 1963, I got a call from the U.S. Naval Oceanographic Office. Would I be interested in working for them as a geologist. Well, hell, I didn't know anything about oceanography other than, you know, something I read. So, I bought a book, came down for an interview, read the book on the train coming down. Interviewed, and the basic questions were, do I know how to make topographic maps? Contour maps. And I said yep. And they said do you know the difference between undersea topography and land topography? Sub-area of photography. And I said sure.

Van Keuren: Controut, how do you spell controut?

Cherkis: Contour.

Van Keuren: Oh, contour.

Cherkis: Contour.

Van Keuren: Got it (unintelligible).

Cherkis: Sure. On land the big number is up, in the water the big number is down. And they said, when can you start? They were really hard-up, but I did make contour maps when I was in, you know, as part of my coursework. And it was an abstract (unintelligible) that's probably an off-shoot of the aerial photography. You know, I am able to visualize like that so --

Van Keuren: Anybody else in your family have this skill?

Cherkis: I don’t know if they have that skill. My brother is a photographer. He was a graphic artist, so there is a certain amount of creativity -- mental creativity there. I never saw it in my parents, so I don't know. You know, it's possible that they had it, but that's not what they did. But in any case, I went to work for the Oceanographic Office in Suitland.

Van Keuren: Beginning in?

Cherkis: January 1963.

Van Keuren: You also got married that year?

Cherkis: I got married -- I was scheduled to get married. I was already heavily involved, shall we say.

Van Keuren: Okay. How did you meet your wife? The woman that became your wife?

Cherkis: How did I meet the woman? A friend of ours -- a friend of mine was looking for guys to date friends of his girlfriend. And we became a little group. We lived nine miles away.

I lived in the city, my wife lived in Nassau County. And we went out and we dated each other, and you know, I dated different girls. And I was dating one girl who became a little oppressive. Wanted to get married right away and I didn't want to get to get married right away, no. No way. So she -- her father had -- was -- had means and finally I just told her, you know, tell your father to buy you somebody else. And I left her at the same time one of my best friends who was dating one of the other girls -- had just broken up with her. And somebody in college had owed me some money and gotten a couple of theater tickets and wanted to know if I wanted them in return. I said yeah, sure. And my wife knows all about this. After going through my little black book there, I came through six no's because this is on Thursday and the tickets are for Saturday night. And no girl in those days would admit that she didn't have a date for Saturday night. But I knew that this one girl had broken up with this friend, so I called her and she said yeah. I'm not busy. I'll go. You know, we already knew each other, you know, friendly type. So we went. Went to the theater, we saw "Dear Liar" with Maureen O'Sullivan, and Bryan Ahern. That was April 1, 1960, April Fool's Day, that was our first date. And three months later I asked her to marry me, but after I graduated from school. And she said okay. So, we got married November 19 -- November 17, 1963.

Van Keuren: You moved on -- you moved down to Washington in January 1960 --

Cherkis: No. I moved down in June of 1963.

Van Keuren: June of 1963?

Cherkis: Right. Actually not the Washington area, it was Suitland, Maryland.

Van Keuren: Tell me about your work at NAVOCEANO.

Cherkis: NAVOCEANO. My work at NAVCEANO?

Van Keuren: Uh-huh.

Cherkis: Well, they told us it was all classified. What I was doing basically was taking numbers from ships that were out collecting soundings on single tracks, transferring them to collection sheets, and making contour maps. Seafloor contour maps. And then we went out and did some survey work and, of course, when you do a survey you get a lot more data, and the lines are closer spaced, so that the contours look a whole lot smoother and more representative of the earth's surface. We also did things -- I was involved in navigation systems development. We were using a short range high frequency backpack navigation system. It was a UHF system made by Tellurometer, a South African Company.

Van Keuren: Spell the name, please.

Cherkis: T-E-L-L-U-R-O-M-E-T-E-R. And the system was called Hydrodist, all one word. And the accuracy was plus or minus a meter and a half, up to 25 miles. It was radio directional.

Van Keuren: And you were?

Cherkis: I was running -- I was running some of the systems. We were building the navigation charts, doing small surveys, positioning ships, and so forth.

Van Keuren: You were using the Hydrodist?

Cherkis: Using the Hydrodist, yeah.

Van Keuren: So, you'd be on a ship. You'd be using this system and then --

Cherkis: Ship and shore.

Van Keuren: Ship and shore. And using it to kind of place --

Cherkis: Exactly. We would position a ship to within a meter and a half -- two transmitters receivers on the ship and two transceivers on shore. And all the survey -- all the track line navigation and the penetrator that was collected was all done onboard the ship.

Van Keuren: And the (unintelligible) was acquired by what sort of technology?

Cherkis: Single beam, wide beam echo sounder which is what was available. And there was also a portable system that we hung over the side of small boats when we were doing shallow water work. And we did that in Bermuda, and we laid the -- did the survey one year and then the next year we went back and put in shore-in cables in for SOSUS.

Van Keuren: I was going to say, this sounds like the early SOSUS work.

Cherkis: Absolutely. The deep water surveys that we did at NAVOCEANO were both reconnaissance, and sight surveys, and point surveys for actually putting the SOSUS in. And I saw three other systems go into the water.

Van Keuren: The first time you were in Bermuda you were doing testing? Concept testing?

Cherkis: Not the -- these were the cables that came into Bermuda.

Van Keuren: Yeah. So you were -- okay. What can you tell me about that?

Cherkis: The systems for the -- the actual hydrophone systems were way out at sea, but the -- there was a US Naval facility which is no longer --

Van Keuren: Yeah. A (unintelligible) station, yeah.

Cherkis: Yeah. In Bermuda.

Van Keuren: And you were helping them lay the cable as you were assigning them?

Cherkis: No. We were helping to lay the cables.

Van Keuren: Why were you doing that as an oceanographer?

Cherkis: Because it was -- we were positioning the ships -- the cable ships, the shallow water cable ship that was laying the cable because of the pedometry, we had to steer around -- steer the cables around coral heads and --

Van Keuren: I see.

Cherkis: -- so it was all --

Van Keuren: So, you were mapping the seafloor bottom with the best -- come up with the best situation for the cable?

Cherkis: Right.

Van Keuren: Connecting to the -- for connecting to the arrays.

Cherkis: Connecting to the deep water arrays, yeah.

Van Keuren: Tell me about the first time you went on board ship.

Cherkis: I got sick as hell. Got sick as hell. Flew to Boston. It was 1963. Well, on ship or on -- on survey?

Van Keuren: Both.

Cherkis: Okay. On survey July 1963 I was with NAVOCEANO for one month and we went to Bermuda for about six weeks. And we did these surveys for the -- half of July, half of August, and the first part of September. We did the surveys for the cable routes, the initial cable route surveys. We blew up some coral heads. I had an air card and a scuba ticket so I got to go down and help -- because when you're sitting there and they are getting ready to blow these things, you're not surveying there so, you know, go and have some fun there. And haversacks full of C4 onto primer cord and we blew one cable and --

Van Keuren: On what?

Cherkis: Primer cord.

Van Keuren: Primer cord, okay.

Cherkis: Primer cord is the detonator cord. DET-cord as the spec ops guys call it now.

Van Keuren: They call it a what?

Cherkis: The specs ops, the special operations guys. They call it DET-cord.

Van Keuren: Okay. I'm going to ask you about some of these words because the transcriber will need --

Cherkis: Okay. We blew a coral head that was 35 feet high right in the way of the cable route. So it had to go. It was about 150 feet from the beach, from the shoreline. And none of the

Navy divers, the explosive guys, explosive ordinance disposal team had ever blown anything this close to shore before. They didn't know how much explosive to put into it. But before we did it, we cleaned it out. We used spear guns and took all the lobsters out of it. Chased out some moray eels and things like that, and then packed all the holes full of explosives. We got the governor of the island, governor-general of Bermuda who was also a scuba fanatic -- he was a fanatic. They put him out in a Zodiac with the lieutenant and gave him the -- what do you call it, the detonator, and he turned the button. And we blew debris 35, 40 feet in the air. I took pictures of the stuff going up and coming down.

Van Keuren: You mean it just came out of the water and went into --

Cherkis: It just blew straight up in the air and -- yeah.

Van Keuren: Wow.

Cherkis: And then we picked up about 400 pounds of dead and dying fish before the sharks showed up and we had a big fish fry and lobster fry that night. We dressed out 230 pounds of lobster meat. It was over 500 pounds of fish all together there. It was cooked up and eaten by the base. So, that was a fun thing.

Van Keuren: You would have never been able to do that 10 years later, would you?

Cherkis: No. You would have had every environmentalist out there -- well, Bermuda has a law that says you're not allowed to take lobster within three miles of the beach, and then only with a Hawaiian sling, which is a broom handle with a trident on the end there, and a rubber band. And that’s the only way you're allowed to take lobster. And there we are 150 feet from the beach with gas operated spear guns and scuba going them out --

Van Keuren: So, you had to get special permission --

Cherkis: We had the Governor.

Van Keuren: Right.

Cherkis: It was a tacit approval, shall we say.

Van Keuren: And this was the first time on -- did you say this was the first time on ship or the first time on survey?

Cherkis: On survey.

Van Keuren: That's right.

Cherkis: We used a small boat, it was a motor whale boat that we pitched a tent over because it got kind of hot. Ad there were days when lunch didn't agree with me and went back in the water.

Van Keuren: Where was this again? Where was this?

Cherkis: Bermuda.

Van Keuren: This was Bermuda?

Cherkis: This was Bermuda, yeah. And I got seasick, there's no question about it. And if you were on shore every night you can't take seasick pills here because they will just wipe you out and you wouldn't be able to work. So that was the first -- anyway. And I periodically would get sick, and so would other people and there was no big thing about that. And then I headed back in September, in the first part of September, and then went out the --

Van Keuren: 1963.

Cherkis: 1963, and then went out to Maine. To the Maine Sonobuoy Range which is up near Boothbay Harbor. And we were trying to locate using a Navy shallow water cable there. It's the U.S. Yamacraw, Y-A-M-A-C-R-A-W, designator ARC-5. And we were using that ship to, I guess they were picking up the old cables, and the old hydrophones and putting new ones in. But our job was mainly -- on that was mainly to keep the ship in position so they could relocate again -- again using the Hydrodist. And we set up the instruments on lighthouses. On operating lighthouses. Set them up on the catwalks on the outside.

Van Keuren: What was the instrument again?

Cherkis: We used the Hydrodist.

Van Keuren: The Hydrodist?

Cherkis: Yeah. We were the Hydrodist survey team. And the first night -- we picked up the ship in Boston. The first night out of Boston I was, again, feeding the fish. But after two days on the ship I felt fine. I felt absolutely fine. And I realized that seasickness when you're at sea is not a -- even if you're in shallow water is not a permanent thing. And so that was -- that was my first time at sea. I got back about the 25th of October, I was getting married a month later. And I did on November 17th. I didn't have any more travel for the rest of the year. Even the Navy decided that they weren't going to send people out in December and January. But three months from the day, February 17, 1964, I went out on my first deep-sea survey. We went out of Portsmouth Naval Shipyard in Kittering, Maine, on the USS Aelois, another cable layer. A-E-O-L-I-S, ARC-3 is the designator.

We were out about two weeks, this was a 49 day cruise. We were out about two weeks and two thirds of the perfect storm came up. One northeaster, and one up the coast and beat the ship up to the point that the ship had to come back for repairs and to transfer injured personnel. We took a 47 degree roll, you're not supposed to come back from those, but we did. The ship was a cable layer. It was -- it had no cable in the tanks, so it was high and dry. It was one of these -- it was converted. It was an AKA -- you know, a cargo ship. A Navy cargo ship that was built in 1944. Built in 30 days. No expansion seams. And we come over one of these big waves and the screws would come out of the water and the ship would just vibrate. People on board the ship that walked around with life jackets all the time. It was interesting. But we -- we came back into port. We were in port for a week while they repaired the ship, and then we went back out.

Van Keuren: Where were you?

Cherkis: Four hundred miles east of Boston in February and March. Got back --

Van Keuren: And you actually laid -- you weren't laying cable or -- you said --

Cherkis: No. We weren't laying cable. We were just surveying. We were surveying --

Van Keuren: Doing a survey?

Cherkis: We were doing -- it was a reconnaissance survey for SOSUS -- another SOSUS array. And I won't go into which one because as far as I know it is still classified. Came home. I was home two weeks and three days. I was going to Bermuda for three months. I bought my wife a ticket and took her with me. And we were in a rented cottage. Six guys and my wife. And we -- she spent all day getting tanned and -- she has relatives that live there anyway, so she would visit relatives and things like that. And I went out and surveyed and laid cable from mid-April until mid-July. Eighty-eight days. I was home for a month and then went out again for a month. This time down off of Puerto Rico. Chased around by three hurricanes. Wound up coming in a little early. Final port was Guantanemo Bay, that's how we got to Cuba.

Flew back to McGuire Air Force base -- flew back to McGuire Air Force base and came back to Washington from McGuire. I had -- as soon as we got back I put in for leave, it was my first anniversary. And they approved it and then two weeks later cancelled it because they had a west coast shallow water survey job for another SOSUS array. And I explained hey, you can't do that. That’s my first anniversary. They said well, take it in Seattle with your bride. And depressed, I left the office that day. And we had a big snowdrift fence out in front of the parking lot that was already in place. And instead of walking around it there I hoped over it. I caught my heel, fell on my shoulder, and broke my collarbone. Well, if you have to break a bone, that's the bone you want to break. I mean, it's easy. It's really not painful. It heals okay. But it keeps you from going to Seattle. So, I got my first anniversary at home.

Van Keuren: Right. Tell me about when you were working at doing surveys. What your general procedure during a day would be? When you would -- I mean, what was your work like?

Cherkis: Okay. Small boat surveys, we worked about 12 hours a day. Actual time on the boat we worked as long as it was light, more or less. Run one line, these are -- you would set up your lines at night. The lines were going to run the next day on a plotting sheet.

Van Keuren: These are the acoustic lines that you were going to --

Cherkis: The survey lines, yeah.

Van Keuren: (Unintelligible) lines.

Cherkis: Yeah.

Van Keuren: Yeah.

Cherkis: And you would set these up on a navigation -- right on a navigation sheet there which had the radio -- this is curvilinear lines so we would take, you know, just run our surveys so that we would be optimum to the navigation systems. You didn't want a line that was 90 degrees from the navigation system there because it would create errors. So you never want to have a line that was more than 60 degrees from the navigation system. So, we'd lay out the lines for optimum survey each night. The next morning we would leave the dock somewhere about 8:00 o'clock, come back in at 8:00 o'clock at night, and do about two hours back at the house, go to sleep, wake up the next morning and go do it again. And do it again. And do it again. And we would work about eight days and then take two days off. During those two days the boat would get taken out of the water. It was a small survey boat. The boat would get taken out of the water and they would do all the maintenance on the boat. And we would plot by hand, and write all the numbers from our records, which also had to be scaled.

Van Keuren: So, did you just have depth, or were you able to do any sort of detail on the floor bottom?

Cherkis: Well, we take it -- the depth is continuous. So we would take a point every three minutes, also all changes in slope. All highs, all lows, and it was a micro-topography out there. So, if there was a bump that was two feet, we would know it.

Van Keuren: So, you were on the continental shelf?

Cherkis: Absolutely.

Van Keuren: And it was very flat?

Cherkis: Yeah. Yeah. We were working in depths shallower than 100 feet. Because when you come to the edge of the Bermuda shelf there which is 20 fathoms, 120 feet, it drops straight off from 120 feet down into 3,000 meters of water. And I realize I'm saying feet and meters here. In those days it was all fathoms, but it just drops straight -- straight off the end of Bermuda. So, it's just an (unintelligible) at that point.

Van Keuren: So, you would spend -- on shore you would draw up the navigation map?

Cherkis: Right.

Van Keuren: With the lines you wanted to do, you'd go out and do those lines. You'd get the data off of this single beam Fathometer did you call it?

Cherkis: Yes.

Van Keuren: Fathometer?

Cherkis: And in fact it was a Fathometer. It was made by Raytheon. Raytheon owned -- Raytheon bought -- it was originally the -- the company was Submarine Signal Corporation. And Raytheon bought the name Fathometer from them, along with the company, and used it as the Fathometer. It is actually a trademark name along with Kleenex and Band-Aids, but it's -- a Fathometer is a -- whereas other systems, you know, they were -- they would call them Fathometers, but they weren't. they were echo sounders.

Van Keuren: And you had -- so every three minutes you would take a reading. You would store that -- when you came back to shore you would take that data and plot it?

Cherkis: The data was stored in analog form on paper charts, paper strip charts, so the recording was continuous. When we took the --

Van Keuren: It was automatic? It would just produce a strip chart with the data on it?

Cherkis: Yeah.

Van Keuren: And then -- so when you went back to shore you had your strip charts and then you would read them?

Cherkis: We read the strip charts.

Van Keuren: And apply the information to the large charts?

Cherkis: Right. And everything is based on time. Time is the lowest common denominator. The time of day is the lowest common denominator. Navigation goes back to time. It's the time and the position. And the positions were also collected every three minutes, so we knew with reasonable accuracy just where we were all the time. That's what we did in shallow water. And there were long days, but I used to be young.

Van Keuren: What about the deep water? You said you were -- during this period of time the first two or three years that you were working for NAVOCEANO you -- and you worked for NAVOCEANO from 1963 until 1969?

Cherkis: 1966.

Van Keuren: 1966, I'm sorry. So, you worked for three years?

Cherkis: Three years, one month, and eleven days.

Van Keuren: Uh-huh. And so you spent your time between shallow water and deep water?

Cherkis: Right.

Van Keuren: Was it kind of equal or did you --

Cherkis: No. There was more deep water than shallow water.

Van Keuren: More deep water. And what was your procedure on deep water?

Cherkis: Deep water we worked two/four hour watches. Watches were set up in four hour increments. We worked two/four hour watches, plus another four hours usually plotting the data that was collected. Taking the numbers off the charts -- off the strip charts because these were off of -- on one ship it was the Navy Fathometer system, which was the AN-UQN1.

Van Keuren: A-N-Q?

Cherkis: AN-UQN1.

Van Keuren: Q1?

Cherkis: Right. And then on other ships they were -- this was a 12-inch strip chart recorder with a -- using the ships hull mounted transceiver. Or -- yeah. Transceiver.

Van Keuren: How many people were on your watch?

Cherkis: Usually two.

Van Keuren: Two?

Cherkis: One on the Fathometer, and one on the navigation.

Van Keuren: So, you would work for four hours -- two/four hour shifts and then four hours during the day you would take your data from the strip charts and plot it?

Cherkis: Right.

Van Keuren: And the average cruise lasted?

Cherkis: About 40 days.

Van Keuren: About 40 days. And was this all off the US coast? Was this all kind of --

Cherkis: No. This was off the US Coast. This was in the West-European basin. This was in the Greenland Sea, the Norwegian Sea. You know, SOSUS was --

Van Keuren: Yeah. All over the North Atlantic and North Pacific.

Cherkis: Right. Yeah. Right.

Van Keuren: So, you'd be working on different arrays? You'd be working on the location for different arrays?

Cherkis: Right.

Van Keuren: And the arrays are --

Cherkis: And Europe was all array intensive, really. It was all based on where to put the arrays. These were the surveys. Now, while I was in the office, when I wasn't out there, we were just thinking the random tracks, the soundings from random tracks and putting them on collection sheets, and just building other mathemetric charts which were BC series.

Van Keuren: BC stands -- means?

Cherkis: Bottom contour. This was of the Naval Oceanographic Office.

Van Keuren: And the random -- the random charts were just from Navy ships who had the Fathometer working or --

Cherkis: Yeah. From Navy ships, from merchant ships.

Van Keuren: The merchant ships had to -- how did you get the information from the merchant ships?

Cherkis: The Navy had a deal. The Navy -- NAVOCEANO had a -- they had field offices in Japan -- in major ports. They had them in Japan. They had them in Liverpool. They had them in London. They had them like in Rotterdam. One in San Diego. One in San Francisco. One in Seattle. Philadelphia. And they had one person in each one of these ports. Now, what happened was that the -- when a ship, a merchant ship, would be traveling along, they had the -- they knew that they could get an updated chart, a nice clean new updated chart if they turned in an old one with some soundings on it. So, what they would do is turn on their Fathometer, or their echo sounder, or whatever it was for a couple of hours, and just do something along those lines, and get some data and then give it to the NAVOCEANO rep in port and they would get a new chart.

Van Keuren: So, they would just turn it on for -- they would keep it on consistently.

Cherkis: Not in the US, no. No they -- it was all a Navy effort. There was no scientific effort involved with this. So -- well, there were in other countries, and there were, you know, academic institutions that were involved in collecting bathymetry. This was not part of the Navy effort. The Navy just wanted tracks. Wherever you went, they wanted a track.

Van Keuren: So, it was really an ad-hoc sort of program?

Cherkis: Yeah.

Van Keuren: You collected the tracks from Navy and other merchant ships and laid them down on charts?

Cherkis: Yeah. And we collected all the soundings on -- you know, we would get like maybe 60 tracks across a sheath that’s seven degrees in latitude by ten degrees on longitude, at a scale of one to one million. Put them all -- all those soundings would go on a sheet, and you can make contour maps from those. Unfortunately for that, there is that most of the ships were -- the navigation was miserable. The navigation was plus or minus five miles. You know, star fixes LORAN A, CONSOLAN.

Van Keuren: What's that one?

Cherkis: C-O-N-S-O-L-A-N. Those were the old navigation systems that were -- they were used by commercial ships.

Van Keuren: I know the LORAN, I hadn't heard of CONSOLAN.

Cherkis: Right. Well, this is LORAN A. This is where you actually have to sit there on a CRT with two dots and match the signals from two different transmitting stations. And then they start to spread and you have to move them back again. But that's what we had. So, you know, it’s a little better than Captain Cook, but not a whole lot. And what we -- put all these soundings on a sheet there, but what we found that, you know, a lot of ships were just following a great circle path right between Boston and Liverpool. So, everything would be along the same line there, and then you'd have big open areas.

Van Keuren: I was going to say, you would get ships following standard navigation path between major ports. And so you'd get the same signature over and over again where everything in between would be uncharted space.

Cherkis: Right. And we did, indeed, have a lot of that. I have -- I have some of those old charts that show things where you have one line there and you have some little bumps sticking up there. And someone would make a contour map and, you know, have these two little bumps there looking like little bulls eyes there. Kind of making something look like an alligator or a fish, or a man with a hat. And we didn't know what we were doing. And in that type of topography, and this was in the days before we started getting an understanding of things like mid-ocean ridges, sea floor spreading. Sea floor spreading was a concept, but it certainly wasn't nailed down at that time, and mid-ocean ridges would be just a very generalized term. We did not, you know, it wasn't continuous. We didn't know about fracture zones or any of those things which a lot of these things turned out to be off-sets of the mid-ocean ridges. These are things we learned later on. By 1965 we were already -- the learning curve had ramped up to, you know, about 70 degrees. We were really flying. We started getting a real understanding of what these things were all about.

Van Keuren: Okay. You were keeping track of the literature of the people --

Cherkis: Yeah.

Van Keuren: (Unintelligible) like Deets, and Hass, and others?

Cherkis: Right.

Van Keuren: So, you were doing a lot of reading on the side. You were reading this post oceanographic literature. You were doing the geologic literature.

Cherkis: Yes.

Van Keuren: You were familiar with the debates in the journals?

Cherkis: Right. But we also had -- at NAVOCEANO there was a guy who had a -- he had -- I guess ONR contracts at the time there, but he was basically a scientist, and his name was Bruce Heezen. Bruce used to come down to the NAVOCEANO to look for soundings because he was building his map of the mid-ocean ridge. The mid-Atlantic ridge, and he would come down and just take -- just the soundings between two points you know, along with where he thought the mid-Atlantic ridge was. We didn't know what he was doing, but he was just interested in the sounds. He would collect a whole bunch of soundings, and disappear for a couple weeks, then come back and get some more.

Van Keuren: Were these soundings classified?

Cherkis: No.

Van Keuren: They weren't?

Cherkis: Those soundings weren't. There were classified soundings that were either taken by Navy ships, especially by submarines, and those never saw the light of day. Those went into long black files (sp).

Van Keuren: But these are the ones from merchant ships that you were talking about?

Cherkis: Yeah.

Van Keuren: So, the merchant ships aren't classified, but the Navy -- the soundings taken by Navy ships were. Why were the Navy ship soundings classified?

Cherkis: Because they told us they were. The Navy didn't need a reason -- didn't give us a reason for classifying something. They just said confidential, and if it's confidential you don't look at it. Or not much -- you have a need to know.

Van Keuren: But -- so Heezen just got the merchant ships that NAVOCEANO collected?

Cherkis: Right.

Van Keuren: Yeah.

Cherkis: One of the other programs that I worked on at NAVOCEANO was -- and I was actually a team leader. We were working this as an overtime project in late 1964 and early 1965. It was a series that the Army -- that wasn't at the time. It was the Defense -- I guess it was the Defense Mapping Agency at the time.

Van Keuren: This was approximately when?

Cherkis: 1964, 1965. Late 1964, early 1965, and it was a series of sheets known as combat charts. These were the invasion charts for Vietnam. And all the ships had Doppler Radar, all off the shelf and it was all shallow water, of course, because the South China Sea is reasonably shallow. But that entire area down there, we got soundings from every warship going in and out of that area. And it was -- that was totally military -- those were totally military vessels. You know, we would take all those soundings and build the sheets going in there so that, you know, the landing ships, the LSTs, whatever, wouldn't run aground. And we did it not only for South Vietnam, but North Vietnam, and Hinon-Tao.

Van Keuren: Hainan?

Cherkis: Hinon, H-I-N-O-N, T-A-O, hyphen T-A-O.

Van Keuren: Which is island in Chinese?

Cherkis: Island in Chinese, yeah. Hinon-Tao. And then we were -- we would take spot soundings from whatever other charts were available. And it was at that time there that I got involved with Russian charts that were classified. They weren't classified because the Russians classified them. They were classified because we had them and it means that somebody probably stole them or bought them from some -- someone -- a human intelligence type of thing.

Van Keuren: And these were charts of which --

Cherkis: This was charts of the South China Sea.

Van Keuren: The South China Sea.

Cherkis: And I couldn't read what they said. So I got Russian-English dictionary, taught myself the alphabet and realized that, you know, hey, look at that. I can read Russian. And it came much handier later on, but I was using Russian charts. And also at that time I started collecting lists. On the charts they would tell you features. What the name of the feature was in both -- whatever the native language was and in English. At least for a lot of the charts, and I started keeping lists of -- you know, what a fan coral head, reef, bank, you know, it developed into a list of charts.

Van Keuren: Of charts?

Cherkis: Of undersea features. You know, what the -- you know, undersea feature names.

Van Keuren: Uh-huh.

Cherkis: Undersea feature types, rather. Which led later on to a publication at NRL in 1970.

Van Keuren: And that was a glossary of World Bathymetric Terms in the English Language equivalents.

Cherkis: Right.

Van Keuren: A 1970 Report of NRL Progress.

Cherkis: Right.

Van Keuren: Was that your first publication?

Cherkis: That was --

Van Keuren: No. You did something in 1967 I remember.

Cherkis: Oh, we did a couple of them at Hudson Labs, but that was after I left NAVOCEANO. I left NAVOCEANO -- by the time 1966 rolled around I had two kids. I had already had a bleeding ulcer that kept me out of the field for 10 months.

Van Keuren: Was that stress related or --

Cherkis: They thought it was stress related. The doctor thought it as stress related. I don't know, but it was -- I spent an awful lot of time away from home and I wasn't watching my kids grow up. It was difficult on my wife. So, by the time -- the end of 1965 rolled around, I was already starting to think that there has got to be something else other than this. I mean, the money was good. The money was really good there. Not only was I getting my basic civil service salary --

Van Keuren: But you were getting sea time.

Cherkis: I was getting sea -- well, we weren't getting sea time. We were getting overtime and for -- in the GS5, GS7, and GS9, you could get up to 88 hours per pay period. Well, up to 44 hours per pay period, 88 hours a month. No. Eighty-eight hours per pay period, 44 hours a week. Eighty-eight hours of overtime and --

Van Keuren: So, you were more than doubling your salary?

Cherkis: Yeah. And it was -- because that was time and a half. And the money was good there, but after a while the money didn't look so good anymore. You know, there were other things that were important. So I started looking at the end of 1965 while I was still recuperating from my ulcer. And I went to see the Navy doctor on about the 15th of December, 1965, and they pronounced me fit. I could go back to sea. And I sailed -- I flew to the Marshall Islands for a survey on January 2, 1966.

Van Keuren: This was for another SOSUS survey?

Cherkis: No. This was for something called SWILS, S-W-S-W. S-W-S-I-L-S. S-W-S-I-L-S, that's Shallow Water Single Impact Landing System. This was a project that was for the Air Force, and the Air Force needed a survey of the lagoon in Eniwetok. The reason for that was the Air Force was sending missiles up from Vandenberg Air Force Base in California and a warhead would explode somewhere over Bikini, about 90 miles away, and send little ceramic projectiles toward Eniwetok. This was the precursor to the MIRV. And they were testing the explosive directional capabilities of these warheads. And these things would fall into the lagoon, and they all had instruments on them.

And the Air Force wanted them back but they couldn't find most of them. By using an acoustic systems -- by putting an acoustic system in the lagoon, they could triangulate where these things had actually hit the water. But they had to know where the bottom was first. What the bottom looked like so they would know, you know, where they got a reverberation, where they would have a reef, whatever, you know, that might be blocking the transmission -- acoustic transmission or whatever. So, we went out there and spent seven weeks surveying the lagoon.

During that time there were a few snowstorms in the Washington area. At that time I only had one son. And she was trapped in the house, in the apartment, twice with these monster snowstorms while I was out there getting sunburned. And that made me feel pretty low, pretty rotten. And I had another cruise scheduled for April, and I begged out of that one, but I couldn't get out of the one in June. By that time I had already found a job with Columbia University.

Van Keuren: Hudson Labs?

Cherkis: Hudson Labs. And I went out on the --

Van Keuren: So, you'd been actively looking then?

Cherkis: Right. Yeah. And the -- I went out on the June cruise.

Van Keuren: Which was where?

Cherkis: Norwegian Sea.

Van Keuren: Was this your first time to the Norwegian Sea?

Cherkis: I want to say yes. Yeah.

Van Keuren: And we can see the place where you spent a lot of time later, I assume?

Cherkis: Right. And this was a cable lay. This was a SOSUS implantment, and a cable lay all the way back to the SOSUS site. And I can't tell you anymore about that there because that site is still operational.

Van Keuren: Was this -- once again, cable laying, you were simply doing the bathymetry of --

Cherkis: Right.

Van Keuren: -- for laying cables.

Cherkis: Right.

Van Keuren: From the arrays into the listening posts?

Cherkis: Yeah.

Van Keuren: So, it was just basic bathymetry.

Cherkis: This was -- right. This was basic bathymetry, deep water all the way back to where the shore-in cables came in.

Van Keuren: Was there any difference between doing deep water bathymetry and shallow water bathymetry?

Cherkis: Deep water bathymetry was a lot less accurate there because the echo-sounder was a wide beam. The footprint, you know, 1500 fathoms was significantly large so that when you took a sounding at 1500 fathoms that, what you were getting there was echoing from probably somewhere around 1,000 feet on either directional from the center. So, you were getting all this -- you had some kind of a ridge, or something sticking up, or something dropping off, you would get echoes from both the low points and the high points, and you could never really understand what it was. You had lots of errors in it. In shallow water it was ping, ping, ping, ping, ping. Also in deep water you have to wait for the ping to come back. From the time it leaves the transducer until the time it returns to the transducer. So, at 1500 fathoms it was a full second in between pings whereas in shallow water you get 10 pings a second.

Van Keuren: Okay.

Cherkis: It was very rapid fire.

Van Keuren: So, it took longer and --

Cherkis: And it was a lot less accurate.

Van Keuren: -- it was a lot less accurate. But you still -- the procedure was the same?

Cherkis: Correct.

Van Keuren: And all you were collecting at this point was the basic bathymetry?

Cherkis: That's correct.

Van Keuren: Later on some of these cruises would do a lot more -- collect a lot more data.

Cherkis: Right.

Van Keuren: And we'll get into that later.

Cherkis: Yeah. NAVOCEANO was only interested in bathymetry at that time, at least for SOSUS. NAVOCEANO had a gravity group, they had Marine Magnetics Group, but they were separated. They also had a Bottom Sediments Group and that sort of thing, and we knew people in this. Plus we knew people in the physical oceanography realm that were also within the building. But I was in the bathymetry division and that's what we did. We collected soundings and made charts of the sea floor.

Van Keuren: The Bottom Sediments Group, the Marine Magnetics Group, did they have their own cruises or?

Cherkis: Yeah. Yeah. And they --

Van Keuren: But they weren't involved -- were they involved at all in the SOSUS work at this point, or were they different?

Cherkis: They were not involved in the SOSUS work, but they were collecting soundings when they went out as well as -- because -- but by the time -- late 1965 rolled around there were enough of us, and there were nine or ten in the group of about 40, who were interested in other things besides just the bathymetry. And we tried to convince the powers that be that, you know, it doesn't cost any more to put a gravimeter on board with one of these gravity guys there and collect the gravity. And then we'll know what it is over there. Or, you know, the tow magnetometer. Well, if you tow a magnetometer then it's going to slow the ship down and they -- it was always a reason why they couldn't do it. Now, unbeknownst at the same time, there was another group at NAVOCEANO that was collecting gravity -- not magnetics, but gravity and bathymetry for another program that was called the OSP, the Ocean Survey Project.

Van Keuren: Do you know about that project?

Cherkis: We did not -- we knew of the project, but they were in a secure area. And the guys that went out on those things didn't talk about what they did.

Van Keuren: And what was the point behind that?

Cherkis: Behind the Ocean Survey Program?

Van Keuren: Yeah.

Cherkis: They were making submarine navigation maps.

Van Keuren: Okay.

Cherkis: In specific areas. And they were using the SASS, the first sea beams, the multi-beam systems. The technology was available, but not for SOSUS. It was available for submarine navigation maps.

Van Keuren: You called it SASS?

Cherkis: Yeah.

Van Keuren: S-A-S-S?

Cherkis: Yeah. I have no idea what the acronym means, but it was made by General Instruments and it was the precursor to Seabeam.

Van Keuren: Is that one word, Seabeam?

Cherkis: Yeah. That's a commercial name. Those ships operated out of Portsmouth, England. Two ships, the Bowditch and the Dutton. B-O-W-D-I-T-C-H.

Van Keuren: Right.

Cherkis: And then D-U-T-T-O-N.

Van Keuren: D-U-T-T -- the Dutton?

Cherkis: Right.

Van Keuren: So anyway, from 1963 until 1966 you were doing basic bathymetry.

Cherkis: Right.

Van Keuren: In shallow water, deep water, both surveys and cable laying in a variety of AGORs basically.

Cherkis: Right.

Van Keuren: Would the AGORs know that they were --

Cherkis: No. I worked on cable layers and AGSC. Cable layers and I worked on three cable layers. The Aelois, the THOR and the -- the Aelois, the THOR, and the Yamacraw. There were -- there was also the Neptune, but I never sailed on that one. And the Navy -- the Army had also given up a cable layer called the Meyer.

Van Keuren: M-E-Y --

Cherkis: M-E-Y-E-R, Alva J. Meyer. And that was an MSTS, a precursor to MSC, operated ship. The ships I rode on were all Navy owned, Navy operated, Navy personnel ships.

Van Keuren: What does MSC-operated?

Cherkis: What is MSC?

Van Keuren: You said MSC-operated ship.

Cherkis: Right.

Van Keuren: What does that mean?

Cherkis: The crew was civilian. Military Sea Lift Command. It was MSTS, Military Sea Transportation Service and then it changed -- and they changed their name to MSC. But they were civilian crews. And in fact civilian crews were on the AGORs, but I was kind of an opinionated person from time to time, I would get into a little trouble, so they would never send me on any of these civilian ships. I rode all the Navy ships that were the rotten food, and the butter that was frozen in 1944, and things like that. And so I also wrote AGSs which was general survey. The general survey ships. The AGSs were really bad riding ships. They were mine sweepers that didn't get sunk. They were iron bottom mine sweepers with a demagnetization, a degaussing ring around the hull. And I spent a lot of time on the rail on those things, too.

Van Keuren: Well, none of these were flat bottoms, were they? Some of the transports were flat bottoms.

Cherkis: The AKAs, the cable layers were all flat bottoms. These things were not. These things were pointy bottoms there, but one of them, the Sheldrake, S-H-E-L-D-R-A-K-E, the USS Sheldrake was listed four degrees to port at the pier. Tied up at the pier. That was the ship I got sick the worst on. I was so sick for the first hour I was afraid I was going to die, and for the next 18 hours I wished I had. And that was the ship -- when I got off that ship I was grounded because of the ulcers.

Van Keuren: Right. One last question for this morning. Getting back to ocean spreading. When did you personally become first aware of that theory?

Cherkis: Continental drift as it was called, my very first geology field class the instructor that I had, and his name was Joaquin Rodriguez, J-O-A-Q-U-I-N Rodriguez with a zed at the end. He had not yet defended his thesis, so he was in -- still Mr. Rodriguez. And he was an instructor in geology 101. And we were on a field trip on a Saturday --

Van Keuren: This was at Hunter?

Cherkis: Yeah, this was at Hunter. And he had this idea that certain geological concepts, classic geological concepts were not in tune with the modern thinking. And he told us about alternate theories there, and went to Alfred Wegener and continental drift. And he said that off the record the Department does not hold to that theory, and that peneplaneation, P-E-N-E-P-L-A-N-E --

Van Keuren: Peneplane?

Cherkis: Peneplane is a flat area that has been sitting for a long time. Has been eroded down to base rock. And he felt that the earth --

Van Keuren: You mean planeation? One word?

Cherkis: Yeah. Peneplaneation was his term. That the earth -- he felt that the earth could not stay stable in one place long enough for peneplaneation to take place. Because the earth he felt was dynamic. And he was probably 23, 24 years old and everyone else in the department was 50-60 years old. I think he was the only one that didn't have tenure also. So, he was a little nervous about even telling us about this. But he gave it to us as an alternate concept. And it was one of those things that, yeah well, that sounds okay, and you just tucked it away for future use until by late 1965 there we were starting to read things by Hess, and Ewing.

Van Keuren: Ewing was a big opponent of (unintelligible).

Cherkis: At first. At first, but it was nice to see that, you know, there were people talking on both sides of the fence.

Van Keuren: This was in the scientific literature?

Cherkis: Yeah.

Van Keuren: Which you were reading when you were working for NAVOCEANO?

Cherkis: Yeah.

Van Keuren: You were coming up to speed and --

Cherkis: Right. It was mainly Geological Society of America papers, that sort of thing.

Van Keuren: And you weren't -- really, you were so busy, you weren't given the opportunity to do research and write any (unintelligible).

Cherkis: There was no research. There were no -- there was no publishing done at NAVOCEANO. None.

Van Keuren: So, you were aware of the debates going on --

Cherkis: Right.

Van Keuren: -- but you -- but you weren't involved in --

Cherkis: Right. And we started making conscious decisions about, you know, what's happening here, but you're not really in tune with the scientific processes. And so finally at the end -- I came back from the last trip at the end of June at NAVOCEANO in 1966 and left them three weeks later.

Van Keuren: To go to Hudson labs?

Cherkis: To go to Hudson labs in New York.

Van Keuren: Okay.

[END OF INTERVIEW]

7B. Norman Cherkis

AN INTERVIEW WITH NORMAN CHERKIS

by Dr. David K. van Keuren
History Office
Naval Research Laboratory
1 November 2001
Interview #2

van Keuren: Today is November 1, 2001. I'm talking with Norman Cherkis about his life and career. Norm, last time we went up to1966 and your work with NAVOCEANO. In 1966 you left NAVOCEANO to go to Hudson Labs.

Cherkis: Right.

van Keuren: Let's recapitulate that transition. Why and how did you decide to go to Hudson Labs?

Cherkis: Okay. Well I, the first part of 1966, when I left my wife and 5-month old son I went to Eniwetok on January 2nd, 1966. I was already feeling a lot of pressure-- personal stress leaving the family. While I was in Eniwetok, there were two major snowstorms here, and my wife was trapped. So when I returned in late February '66, I started looking for another job, something that I wouldn't have as much extensive travel. It was mainly the length of time away from home that bothered me. A cousin was working at- he's an electronic engineer- he was working at Hudson Labs on hydrophone systems. Navy, it was a navy-sponsored lab. And my cousin was working on building hydrophone systems there, and through the grapevine, he heard that they were looking for an environmental scientist, someone who understood the bottom, because for the first time they realized, or they were starting to realize, that they were getting a lot of interference in sound propagation, and they suspected it was the bottom.

van Keuren: And who were these?

Cherkis: These were the engineers at Hudson Labs and the acousticians, because it was an acoustics lab.

van Keuren: They were working on, they were doing research connected to SOSUS, weren't they?

Cherkis: Well, yeah, it was a lot of things- Artemis-

van Keuren: Project Artemis?

Cherkis: Yeah. And a number of different hydrophone designs were being, well they were building a lot of different hydrophone systems. The director of the lab was Alan Berman who later became the director here. So I went up and interviewed in May, and they thought that there was a place for me up there. I didn't want to return to New York; I was happy with Washington, but circumstances being what they were, I did return to New York. I was able to ... The benefits that they offered were pretty good. They moved me lock, stock and barrel- you know everything from the soap and the soap dishes was moved. They had a good health plan, they were offering me 1200 dollars a year more than I was making with the government, and when I asked about sea time, they said, "Oh, well, you will have to go to sea," and I said, "How long are the trips?" and they said, "Oh, some of them are pretty long." And I said, "What's pretty long?" They said, "Three weeks." Well, after what I was doing, three weeks sounded like, "Oh! I can do that standing on an ear!" So, I went on one more trip with NAVOCEANO in June , which I was already committed to. That was the one where we put in one more SOSUS array in the Norwegian Sea, and when I came back from that, I put in my papers and resigned.

van Keuren: And so when did you actually begin work with-

Cherkis: In August.

van Keuren: August ’66?

Cherkis: Yeah. Right. And in September of ’66, I went on a three-week cruise. Actually 17 days!

van Keuren: Were you actually working for a specific division in Hudson Labs?

Cherkis: No, Hudson Labs was an acoustic laboratory. All of the contract, the entire laboratory were under navy contract. PME124 was the main sponsor.

van Keuren: What is that?

Cherkis: It was a project management that was long-range acoustics.

van Keuren: So there were no internal divisions into sections?

Cherkis: There were sections. There was, but it was loosely coordinated. There was no firm wiring diagram, so to speak. It was… They had people that were building arrays, they had people that were doing acoustic research, and I don’t remember the name of the group that I was in, but the director of the group was Wilton Hardy.

van Keuren: Wilston Hardy?

Cherkis: Wilton Hardy.

van Keuren: What’s his background?

Cherkis: Acoustics.

van Keuren: He was an acoustician?

Cherkis: Acoustician, acoustic physicist. He was, I guess, one of the two associate directors under Berman, and that’s when I met Hank Fleming, because Hank had been hired about 2 months earlier, I think, to do the same kind of thing. Hank’s background, I assume you’re going to interview Hank, so you’ll find out what he did, but he actually came from Lever Brothers Laboratories where he worked.

van Keuren: Lever Brothers?

Cherkis: Yep. He was doing animal testing, of products. He had a chemistry background there, but he worked in environmental sciences when, you know, earlier on he spent time up on an ice flow on one of the ice camps with Lamont. He went on summer cruises while he was in high school with Lamont. So, anyway, we got along quite well, and he had already been to sea, so he knew what seagoing was all about, and the two of us worked reasonably well together.

van Keuren: What was the history of the laboratory, Hudson Labs? It was established as a contract lab, wasn't it?

Cherkis: Right.

van Keuren: With Columbia University?

Cherkis: With Columbia University, right. I don't remember what year they started it, but the first director was Robert Frosch. And after Frosch came Berman. And there was no dress code. Berman walked around all summer in a pair of cut-offs, dirty t-shirt, and Jesus shoes.

van Keuren: What sort of shoes?

Cherkis: Uh, sandals.

van Keuren: Uh huh.

Cherkis: Jesus shoes. I pointed him out to my wife one time, and she thought he was the janitor. And I said, "No, no. That's the director of the lab." And then she said, "And I suppose that's the Assistant Director?" and she pointed at Wilton Hardy, and I said, " No, that's the Associate Director! He's my boss." He was wearing a pair of long, paint-spattered khakis and a t-shirt and a pair of sneakers. So, she understood that this was a very laid-back type of operation, doing good science, but very laid-back. And she was happy. You know, a 17-day cruise was something that she very much enjoyed. You know, having me around.

van Keuren: So you were there less than a month when you went on a 17-day cruise?

Cherkis: Right.

van Keuren: What was the cruise?

Cherkis: It was an acoustic operation with towing an acoustic source, a noisemaker, testing hydrophones on the east coast there. We went from Bermuda to Spain.

van Keuren: And what was the purpose of it? There were arrays already in place, and you were testing the sensitivity?

Cherkis: Yeah. But we were also looking at the geophysics. We had a magnetometer, and someone who had a background in geomagnetics, a geophysicist-type. His name was Joseph Brakl. He was the magnetics guy and-

van Keuren: You were mapping the geomagnetics of the seafloor, right?

Cherkis: Right, but we were also collecting bathymetry along the-

van Keuren: Along the way.

Cherkis: Right.

van Keuren: So it was a multi-purpose cruise?

Cherkis: Right.

van Keuren: Magnetometry, bathymetry and –

Cherkis: And acoustics.

van Keuren: And acoustics.

Cherkis: Right.

van Keuren: Now was this characteristic of the cruises?

Cherkis: Characteristic?

van Keuren: Yeah, multifunctional.

Cherkis: I'm sorry, I missed the question.

van Keuren: Was this type of multifunctional cruise characteristic of the cruises that went on at Hudson Labs?

Cherkis: Yeah, yeah, yeah. All of the cruises I went on with Hudson Labs, we did magnetometry, and we eventually later on got a seismic profiling array with an airgun and collected sub-bottom profiles as well as the other stuff: the bathymetry and the magnetics, as well.

van Keuren: The seismic profiling ... Maurice Ewing's group of Lamont was famous for it, too.

Cherkis: Right.

van Keuren: Did you do any cooperative work with Lamont?

Cherkis: No. They received all of our data, mainly because, you know, they were doing the basic research. This was more applied and we got pretty good at it. At both running the systems, looking at the information that we collected, and seeing how it applied to backscatter acoustic attenuation. We were learning at the time that the sediment actually absorbed sound, so we were getting low returns in the frequency that the acoustic projector was putting it out there so that the sound wasn't returning to the hydrophones that were listening.

van Keuren: And uh, you were collecting the bathymetry. How were you collecting the bathymetry? What were you using?

Cherkis: Fathometers.

van Keuren: Fathometers.

Cherkis: Right. We had a Raytheon system, it was a Raytheon precision depth recorder.

van Keuren: This is the same sort of instruments that you had been using for NAVOCEANO?

Cherkis: Yeah. PDR; it was called a PDR, precision depth recorder.

van Keuren: And you would collect the data and then map it when you were off, during science watch.

Cherkis: Right, edit, right.

van Keuren: During science watch?

Cherkis: Yeah.

van Keuren: So-

Cherkis: And later on we were adding it to the database.

van Keuren: So, you were doing very similar things to what you were doing for NAVOCEANO?

Cherkis: Right.

van Keuren: What were the big differences, mainly?

Cherkis: Much less sea time.

van Keuren: You were doing much more lab stuff?

Cherkis: Right, and there was also ... At NAVOCEANO, it was like I was a marble in a sack of marbles. We did one part; we did bathymetry; we never knew what happened to it; we never knew where it went. Our job was just to build bathymetric maps. At Hudson Labs, we were able to apply the bathymetry to something that was useful, useful to the Navy, useful to the acoustic program, and at the same time, we were able to do our own research: What is this stuff all about?; how does the mid-Atlantic Ridge look? We found on subsequent cruises that we were locating fracture zones and finding that the sound was passing through fracture zones from one basin to another. It was a really interesting program overall.

van Keuren: So, the combination of doing applied work but also having time to do more basic research on your own?

Cherkis: Right, yeah.

van Keuren: And was there ... Did a percentage of your time, was there a set percentage of your time that went to your own basic research? Was there some sort of formula?

Cherkis: No. No, it just happened. We were able to take the data that we got there, and we eventually published a couple of papers. We published within Columbia University; within Hudson Labs we produced trip reports that had all the bathymetry and all the navigation. They were the basic trip reports that we were able to get out, and then there were others that we did collaborative work with Lamont. And in fact, in 1968, we discovered, I guess – no, not really discovered -- but we delineated the Gibbs Fracture Zone. Our ship was the USNS Gibbs, which was the first AGOR; it was AGOR-1. And it was assigned to Hudson Laboratories. The ship was a converted seaplane tender. It was the USS San Carlos. Geez, just remembering this stuff -- it just pops right up!

van Keuren: What was your specific topic of research during this time?

Cherkis: Bathymetry and marine geology.

van Keuren: Did it apply to sea floor spreading and the Mid-Atlantic Ridge, or…

Cherkis: No, not so much sea floor spreading, but that was an outgrowth of the research. We weren't doing the research for sea floor spreading.

van Keuren: You were applying-

Cherkis: But we were applying it to the sea floor spreading concept.

van Keuren: So the topic of your personal research was to take information you had and do the maps?

Cherkis: Yep.

van Keuren: Bathymetric mapping.

Cherkis: Right.

van Keuren: Okay.

Cherkis: And at the same time we were looking at the magnetic profiles there, and then we started realizing there that we were getting the same magnetic anomalies on both sides of the ridge, so we were able to spread it further and further out, and that's when we got involved with Jim Heirtzler, who was at Lamont, and he had the landmark paper in the North Pacific Basin on magnetic anomalies and how they applied to sea floor spreading there, and we realized we were actually looking at something akin to a magnetic tape recording of sea floor spreading.

van Keuren: So you had read his work-

Cherkis: Yep.

van Keuren: …in the journals and you realized that what he was talking about was what you were similarly seeing in the mid-Atlantic?

Cherkis: Right.

van Keuren: But he had worked in the mid-Pacific? Where did he do his work?

Cherkis: East Pacific. Northeast Pacific, from Alaska down along the Juan de Fuca Ridge and the East Pacific Rise down to, about, central California. And his was, I think, the landmark paper on how the magnetics could be applied to the concept of seafloor spreading.

van Keuren: So you were mapping the bathymetry and then mapping the magnetics onto the bathymetry?

Cherkis: Right.

van Keuren: And this was '66, '67, '68?

Cherkis: Right.

van Keuren: Tell me some of the other cruises that you were involved in.

Cherkis: Well, we did total applied geophysics, or total applied acoustics where we actually tested different arrays in the Caribbean, well not in the Caribbean, but in the Atlantic, east of the Leeward Islands. Again, with an acoustic source, three and a half ton acoustic source. We were collecting or we were running the source to see what the reception capabilities were of the SOSUS arrays that were down off the Leeward Islands. We did a very close experiment called Boomerang Four. I think it was Boomerang Four, might have been Boomerang Three, I don't remember now, but it was one of the Boomerang experiments. We did that one directly over one of the SOSUS arrays and found that the array, which was supposed to be sitting on sediment, was actually sitting on bare rock and that the noise was being intensified when it was reflected off the rock and overloading the system. So eventually, I think, they repositioned one of the arrays on that site.

van Keuren: What were the Boomerang experiments?

Cherkis: They were acoustic reflections; they were reflection experiments where we were towing the source and doing that, but at the same time we were also collecting bathymetry because the surveys that were out there were nil, so wherever we went, we did collect bathymetry.

van Keuren: And this was work all in the North Atlantic, North and Central Atlantic?

Cherkis: No.

van Keuren: You talked about doing some work for NAVOCEANO in the Greenland-Norwegian Sea, but did you do any work there? Where was your work centered, mainly?

Cherkis: Well, we were mainly in the Atlantic. I think all of our work was in the Atlantic, except... Well, we picked up the Gibbs in 1968 in Naples and came out through the Strait of Gibraltar and then went north to do this survey, the delineation of the Gibbs Fracture Zone, and the reason that we went there was because on an earlier experiment when they towed an acoustic source they found that when they got to a certain point some of the arrays couldn't receive the sound any more. It was just like it was a quick shutdown of the noise, and that's when they realized that Heezen's concept of the Gibbs Fracture Zone, or Heezen's portrayal of the Mid-Atlantic Ridge, showed that there was a big sinuous excursion from the northeast. It went northwest and then went north again up the Reykjanes Ridge. The Reykjanes Ridge comes out of the Reykjanes Peninsula on Iceland and when it hits about 52, about 53 degrees it stops. We found in towing our source through the Reykjanes Ridge, or through what turned out to be the Gibbs Fracture Zone, that the systems that were the furthest south […] in the Leeward Islands, off the Leeward Islands in the Atlantic, which were designed for something like 5000 miles, were actually picking us up all the way through the basin where we had expected the sound to stop. We were getting the sound being continued to be received all the way to the Iceland-Faeroe Ridge.

van Keuren: So the fracture valleys were channeling the sound?

Cherkis: It was an offset in the mid-Atlantic ridge. The mid-Atlantic Ridge stopped at 52 degrees and started up again at 53 degrees. It was almost 60 miles. We later found that there was a smaller ridge segment that shows up between 50/30 and 51/30, or about, excuse me, 52 and 52/30. I can draw you a picture of this better than...

van Keuren: Anyway…

Cherkis: Anyway, the sound was just pouring right through-

van Keuren: This break in the ridge?

Cherkis: This break in the ridge, and so we did a survey of it. That was a long trip there; that was 34 days. But we did a big open pattern and you know, my God, here's this huge fracture zone.

van Keuren: That's the Gibbs Fracture Zone.

Cherkis: That's the Gibbs Fracture Zone. At the same time, we presented the evidence at an AGU meeting, I believe. I'm not sure, but I think it was an AGU meeting, and Leonard Johnson from NAVOCEANO, G. Leonard Johnson from NAVOCEANO, presented his paper noting that there was a fracture zone there, and he called it the Charlie Fracture Zone. His paper came just before ours, and there was a controversy over who named it. He called it the Charlie Fracture Zone because of ocean weather station Charlie, part of the old Coastguard shipping lane and ocean weather stations along the shipping lanes, and the reason he did that, he confided, was that he was trying to get money out of the Coastguard for a buoy program. So, he called it the Charlie Fracture Zone. Heezen didn't like the Charlie Fracture Zone. Heezen said, "No, it's the Gibbs Fracture Zone, because the Gibbs was the one that actually did the survey." It wasn't a real tight survey; it was kind of an open, zigzag pattern. One of these things, a saw tooth-type of thing. But we delineated it from 30 degrees West to 35 degrees West, which was what, about a 180-mile offset in the ridge. So, we actually discovered it, Hank and I and our boss, he was on the ship; it was Wilton Hardy. And that was in '68.

van Keuren: Any other memorable cruises or work during this time?

Cherkis: Nothing that stands out as being monumental. I was on one cruise at the end of '67. That was one of the Boomerang Cruises down off the Leeward Islands, and my wife sent a message to the ship that she needed me home; she being seven months' pregnant at the time, and they dropped me off in Antigua, and I had to make my way from Antigua back. I had a ticket home from Puerto Rico, which was the final destination. They dropped me in Antigua and from Antigua, I got a flight to Puerto Rico by way of Barbados, Trinidad, Venezuela, in order to get the flight back. It was the wrong time of the year for getting a direct flight there. The first flight went completely around it. When you got to Venezuela, they had us out on the ... The plane landed on the runway, they dropped a whole bunch of people off on the runway. They brought a ladder out, a whole bunch of people came off, they opened up the belly, took the bags off and left. And we could see all along the runway there they had these jeeps there with machine guns facing out away from the plane. So, they were having some kind of a revolutionary type of thing happening at the time. But they didn't let the plane get anywhere near the terminal. Then I got to Puerto Rico, and then I got home, so it took me two days to get home. Then my second son was born in January '68.

van Keuren: The work that Hudson Lab as doing, could you give me description overall of the work of Hudson Lab during this period? It's come out in bits and pieces here, but if you'd like to summarize the mission of Hudson Lab and how it related to the work you were doing.

Cherkis: Okay. Hudson Labs, as I said, was an acoustics laboratory. It was a captive lab of the Navy. They did basic acoustics; they did applied acoustics; they built hydrophones; they tested the hydrophones. That was their basic mission. I don't remember which year, I think it was in early '68, the Navy was trying to decide where to put in an array in the Pacific, and it was my job to check the bathymetry to check what sites would be good. They wanted to look at China, so we were looking a the Philippine Sea and what would be good sites in the Philippine Sea to implant arrays.

van Keuren: What would define a good site in general terms?

Cherkis: That has a clear look that is not blocked by bathymetry.

van Keuren: So you really liked abyssal plains?

Cherkis: Oh, yeah. Abyssal plains were the good stuff where you wouldn't get any attenuation or reflection. And I had to come up with 5 sites, and I did, and I remember getting a phone call. I picked up the phone and the first words was, "Where the hell is Babelthuap?"! I said, "Who is this?" The voice on the other end said, "This is Al Berman. Can you come up?" "Sure." So, I went upstairs with a map and showed him where Babelthuap.is. It's in the Paracel Islands? I don't remember any more. But there was a reef on the north side of that called, Nguarangl Reef, and on the north side of that, I thought that would be a really good place to hang a hydrophone there because there was a look straight on into the South China Sea. It was a clear shot. And what we did ... One of the things I did was I used ray tracing to ... These are the acoustic rays, how they travel through the water. You use the basic acoustic ray model -- it's a sinusoidal wave that travels through the water conversion zones, or approximately every 35 miles. That was the basic model, and I had to find and apply the sound velocity profiles through all these things to see how the physical oceanography could affect the sound, and I picked out, as I said, five sites. One of the sites I thought would be really neat because I could throw a saddle. I could put it on both sides of a ridge and not only look at China, but if you throw it over on the other side, there I could also look at Petropavlovsk. It was the Kamchatka, the Pacific Russian nuclear submarine base, the main one. And I ran up the ray traces there and a good reciprocity showed from both ways that it would, it was at the right position for both. And then, Berman called me one day and said, "Okay, the project's finished. Write it up." So, I wrote it up, a point paper type of thing. And he said, he called a week later and said, "Okay, we have to go to Washington on Thursday." I said, "We?" and he said, "Yeah, I want you to present this on Friday." I said, "To who?" He says, " Just some people down in Washington." So, on the plane, I asked him, "Who is down, you know, who am I going to see?" and he says, "Oh, Brackett Hersey, Admiral Moorer and Admiral Turner and Al Vine", who is up in Woods Hole, and he says "and a couple of other hangers-on" and I'm thinking to myself, "These are the top guns in the Navy. I'm going to talk to these people? ", and I was visibly nervous. So, I said, "I don't know if I can do that." "Don't worry about it just think of them as human beings." He says, " Number one, everyone performs certain biological functions in the same way; if not it rolls down their leg." And I understood what he was saying. He said, "Then, realize that these people know absolutely nothing about what you're doing. They're gonna ask a bunch of stupid questions for five minutes, after which they're gonna leave the floor open to you. You know your subject?" I said, "Yeah." And he said, "Okay, well just present it as it is. They're gonna stop, and they're gonna listen, and they're gonna take notes." And so I did in over here in what was Bldg. 58, which is now nothing. I gave the presentation. And-

van Keuren: This would have been part of the Maury Center at that time?

Cherkis: Yeah, it was the Maury Center. And at the end of the presentation Admiral Moorer asked, "Did you happen to look at any of the Russian sites from this area?" and Berman said, "Well, that wasn't in the contract there so we didn't have…" I don't remember his exact words but he said that it wasn't part of the contract. And I broke in and said, " but I had an extra few hours of computer time available there so actually I did." and just smiled and said, "We like to anticipate things." And I showed them the data that I had run, the acoustic profiles and so forth, and of all the sites, that was the only site that ever went. They thought that the Chinese are so far behind there that it's gonna be a long time before they finally develop a nuclear submarine, and I don't think they have one yet. And they stuck the one down in the Pacific that looked straight up across the Japan Trench right into the back door of the Russians.

van Keuren: So they didn't do the other side of saddle; they just did the one side facing northwards, facing Petropavlovsk?

Cherkis: Yeah, but facing northeast into the thing. And-van Keuren: And so the contract you'd been working on-

Cherkis: That was a coup!

van Keuren: Right, clearly, but the contract that Hudson Labs had been working on was to develop possibilities for array sites for China?

Cherkis: Yeah, and later on NAVOCEANO, who were doing the actual SOSUS array surveys, went out and surveyed that, and one of the guys who later came over here, Bob Perry, was the party chief, NAVOCEANO senior rep. on that cruise.

van Keuren: How did the work of NAVOCEANO and Hudson Labs interface? I mean you said that they were doing the surveys, but then what were you guys doing? You weren't doing surveys, you were doing ...?

Cherkis: We were doing the basic research –

van Keuren: Of the ambient conditions?

Cherkis: Acoustic propagation.

van Keuren : Of the ambient conditions in the water?

Cherkis: Right.

van Keuren: But you needed to have some idea of where you wanted to see. You had prospective sites?

Cherkis: Yes, well, we had a target. We had a target to look at. A target, whether it was a base, or a target as to an area where Russian submarines were active, known to be active, and our job was to see what the bathymetry was in that area and how we could better the SOSUS system.

van Keuren: So the arrays were already in place and your job was improvement of performance?

Cherkis: Right. Also prediction, also doing prediction, where we could, if a Russian submarine was picked up. For example, when it came over the Iceland-Ferroes Ridge, it was picked up in those days, they were Yankee-class submarines and they were noisy as hell, and the Yankees, they'd pick them up and then they'd lose them, and then they'd pick them up again somewhere else, and then they'd lose them again. They really didn't understand why or what was happening, and what we did, we developed a model that later on when we came back down here from Hudson Labs, when we came down here to NRL, we were able to apply and actually make it work, where we were actually able to show that, "Hey, this model works, and that if you lose the submarine at such-and-such a place, you should be able to find it again. Provided the submarine is traveling at the same course and speed, you should be able to find them again when he hits this point, and in fact it did work, but that's later on. Now, Berman left Hudson Labs at the beginning of 1968, to come down to NRL, to become the Director at NRL, and at that time, they were looking for another director, and Jim Heirtzler, who was at Lamont, took over as acting and then assigned director of Hudson Labs. That was in, I believe, January of '68. And Heirtzler's first job was to trim some of the quote "fat" from Hudson Labs. Hudson Labs was rife with nepotism. Everyone's cousin and brother and son and daughter and everyone else was working there, and Heirtzler, his first job was to cut 10% of the people, so they went from 440 people down to about 400. And then, on April 1st

1968…Well, let me back up… In February and March of ’68 they had the ‘troubles’ so-to-speak, at Columbia University.

van Keuren: Was that when Ewing left?

Cherkis: That was… No, no. This was down at the main campus.

van Keuren: Oh, the student riots.

Cherkis: This is the Students for a Democratic Society, SDS. Mark Rudd was the head of that group, and they had broken into, they took over the, the President of Columbia University, took over his office, and hired a professional safecracker to get into his safes, but during that period when they broke into the safe, they found all these classified contracts. So, the kids were gonna come up to Dobbs Ferry, where Hudson Labs was, Dobbs Ferry, N.Y. and they were going to burn the building down. And I remember the end of March or middle of March the Dobbs Ferry Police Force, all 8 of them, were at the road coming north, which was US 9 East, or New York 9, New York Route 9 East, and they were waiting there for the kids to come- all 8 of them- wearing shields, and they had their Billy clubs waiting for the kids to come ‘cause the kids announced when they were coming. Well, the kids never came, but the Navy decided that this is not a great thing, to have this publicized that we’re involved with universities doing classified research. So, the Navy pulled the contract.

Side Two

Cherkis (cont): April 1st, 1968, we got this notice that the laboratory was closing. We were fired. We had 56 weeks notice. And they set up an employment office, and, in fact, I interviewed with General Dynamics in November of ’68 in Rochester. They wanted me to work at the AUTEC Range, which was Grand Bahama, and I’d be six months there and six months, I’d be don there all winter and back in Rochester New York during the summer.

van Keuren: General Dynamics was involved in producing some of the arrays?

Cherkis: They were building hydrophones, doing hydrophone testing, and that sort of thing-- shallow water stuff. And we couldn’t get together on price. We also couldn’t get together on a lot of little things. There wasn’t much of a difference there but, I felt that I was worth more than what they were offering, because by that time there I had, I knew quite a bit about acoustic propagation and bathymetry and so forth. At the same time, I was going to leave my wife for 6 months all winter in Rochester, New York? I mean I was up there in November, and I saw snow piled 4 feet, 5 feet high on both sides of the road and I thought to myself, "Uh-uh!" I asked when the sun comes out again, and they said, "March." That was not a good place. So I didn’t go there, but I was still looking for a job when NRL made an offer.

van Keuren: Had you applied to NRL?

Cherkis: I had not applied to NRL.

van Keuren: So how did they know?

Cherkis: Well, Berman was down here ...

van Keuren: Right.

Cherkis: …and Berman wanted the long range acoustic propagation program. There were about 40 people that were involved in the Boomerang Project, the long-range projects. And so I signed on with NRL, I think, in February of '69, but stayed up until Hudson Labs closed, and if I can backtrack again, in April they announced that the laboratory was closing, and, of course, everyone thought it was an April fool's joke, but they came out and reiterated it on April 2nd.

In May, we got a call, I got a call, on a Sunday night about 8 o'clock, "Be at the laboratory at 6 o'clock tomorrow morning." And Fleming got the same and another guy, his name was Jack Anderson, who also came down here to the project. His name was Eugene Anderson, was his full name. But the three of us had to be at the lab 6 o'clock. "There's a crisis". Well, we went in, and there was an armored truck waiting for us. The armored truck had all of the recordings from the SOSUS sites all around the Atlantic. The Scorpion went missing, and through our involvement with looking, doing the acoustic testing, we were looking at the rolls, the recordings from the SOSUS sites. So, we were kind of like the pros from Dover; we knew what to look for as far as a spike type event. They didn't want the Navy to do it for some strange reason, but at the same time, we weren't allowed to tell anybody that we were doing this, still working for Hudson Labs, because the Navy had just announced that they were closing the Lab, and all of a sudden they find out that the only people that have the expertise are at Hudson Labs. So if you remember the book, *Blind Man's Bluff*, on page 93 they talk about Dr. Wilton Hardy from the Naval Research Laboratory. Wilton Hardy never worked at the Naval Research Laboratory. It was done at Hudson Labs. And "his crack team of experts". His crack team of experts were Fleming, Anderson, and Cherkis. We were the three, and we looked, and within ... This was on Monday morning. By Wednesday afternoon we had found an event, which had turned out to be the implosion, on enough sites, so that we were able to give them a zone of approximately two miles, a two-mile circle, which we narrowed down to about three-quarters of a mile by Friday, on where to look. And then Buck Buchanan from NRL went out with the Mizar searching. And I think they were using LIBEC [the Light-Behind-Camera deep-towed system].

van Keuren: They were.

Cherkis: And it was 32 days before they were sure they had it. They had photographs of it. But we pointed them to where to go look. Of course, we did have some information about where their last known point of radio contact was and what their approximate path would be.

van Keuren: So they brought in all the recordings, or all the graphs?

Cherkis: All the recordings. This was all done on paper tape, on you know paper recording. They were I guess about 12" rolls of paper.

van Keuren: And so you were looking at the graphs that were produced by from the various stations?

Cherkis: Right.

van Keuren: And so you examined these looking for spikes which would indicate an implosion?

Cherkis: Right. And the spike was actually a low-frequency spike.

van Keuren: So how did you know how to recognize it?

Cherkis: We just were told to look for an 'event', between this time and this time.
van Keuren: Did you know what the event was?

Cherkis: We did not know. We did not know when we started on Monday. When we had enough of them on Tuesday they told us that that's what we're looking for, and on Wednesday, we gave them the two-mile circle.

van Keuren: And did they tell you ... On Tuesday they told you they were looking for a submarine that had gone down?

Cherkis: Yeah, and that we were probably looking for an explosion or an implosion. But they didn't know at the time.

van Keuren: And did they ever announce what caused the implosion?

Cherkis: I've heard, well, there was an explosion and an implosion, but I heard that it had something to do with the Mark 37 torpedo. The Mark 37 torpedo that had a history of occasionally doing a 'hot run', just start up by itself, and I'm saying this is what I've read and heard. You know there's a lot of theories, but what they thought was that it had a hot run, and what they did, the procedure was to do a quick 180 turn to confuse the gyro, at which point it would shut itself down.

van Keuren: But it didn't work. But they think that it might have worked.

Cherkis: Yeah, but it just exploded, and the forward compartments were flooded, but the after-compartments because they were probably in battle stations by that time, the after-compartments were still sealed there, but there was probably so much water in it there that when it went down it took the back end of the ship with it, of course, and that would have caused an implosion. It got to the crush depth, in other words.

van Keuren: This is what they suggest in "Blind Man's Bluff."

[Pause]

Cherkis: Yeah. At NAVOCEANO, I was just making bathymetric maps. That's all I was doing.

van Keuren: Right, but ...

Cherkis: Putting soundings on and making contour maps.

van Keuren: But at Hudson Labs, you were under contract to the Navy. Who assigned you a task? I mean, where did it come from?

Cherkis: It came from upstairs somewhere.

van Keuren: You don't know?

Cherkis: No.

van Keuren: The Navy said, "We would like you to look at the following area or following target zone and come up with acoustic information."?

Cherkis: Right. Hardy would come, and we would have a storm session type of thing, and he'd say, "Okay, this is what we need now," and then we'd go look at it.

van Keuren: And that style set up the cruise from Bermuda to Spain, and then you'd go out and run a cruise and try to come up with a pathway, and the pathway would indicate the best possible terrain for laying an acoustic array or improving on an existing array?

Cherkis: Yeah, well I have the feeling, that was my first cruise there and I didn't know a whole lot, but I had a feeling because we towing an acoustic array, that when we were testing a SOSUS site, and we went along a specified path, and this would have been a ray path where they either got a reflection or they had propagation. I have a feeling it was reflection. We first started out, the acousticians, with models where "this is the Atlantic Ocean," you know? And it was the case that we had to educate these guys that there's stuff out there that, you know, this is the reason you're getting propagation loss, this is the reason you're not getting cross-ocean penetration. It's because there's topography out there. Topography is stopping the sound from traveling, because when the sound travels like this, if it hits anything, it goes backwards, or it, you know, the ray just shows that if it hits it, it stops. And it was a bundle of about 40 rays of going through the water, but it was a bundle. I mean we just, wherever they started, if they hit something, they stopped. That was what it told the computer. If it happened to go like this and graze it, it could go [demonstrating path]; you know, it could have just missed it. It was so position-dependent that if you move the thing 5 miles, you'd go over the top of the mid-Atlantic Ridge without ever touching it. So, it was things like that which were important to the early understanding of ray propagation, acoustic ray propagation.

van Keuren: And that's where you helped provide, create bathymetric understanding of the propagation path?

Cherkis: Yep.

van Keuren: So that they could fine-tune the whole system?

Cherkis: Uh, hm.

van Keuren: Okay. So in Spring of '69 you came ... Was it you came to the lab in 1969?

Cherkis: Right.

van Keuren: What was the date of arrival, approximately?

Cherkis: Uh, I signed on sometime in February '69, but didn't ... I came down here periodically. We were assigned to the Acoustics Division.

van Keuren: Okay, and you were, which branch or section was it?

Cherkis: The Acoustic Propagation Branch, I believe.

van Keuren: Acoustic Propagation Branch of the Acoustics Division?

Cherkis: Yeah. And it was Code… I don't remember what the code was.

van Keuren: Acoustic Propagation Section?

Cherkis: Yeah, I think it was.

van Keuren: And who was head of that?

Cherkis: Homer Bucker. I think John Munson was the division director. He might not have been at the time I came on, but became the division director very shortly thereafter. And the guy that hired me was Burton Hurdle. And we were on the 4th Floor in Bldg.1, and they stuck Hank and I in one office, along with our safes. We brought two safes down from Hudson Labs with us.

van Keuren: Now, 40 people of the Long Rang Acoustic Propagation group were brought down, but three of you were taken into the-

Cherkis: Were taken into the Propagation Section, yeah.

van Keuren: And the others went where?

Cherkis: Well there were a lot of um… They brought down engineers that went into another part. Everyone went into the Acoustics Division. The guy who was our navigator, who was a retired Navy chief quarter master, Tony Zuccaro, he was a scientific navigator, so they brought him down. Chet Brier, he was an engineer; Rubin Naber, he was a technician, electronics tech; Hugo Mellace, he was a mechanical technician; Tom Kelly, another mechanical tech.

van Keuren: These guys were doing what at the laboratory?

Cherkis: One more, Dario Ciuffetelli, also a mechanical tech.; Jason Taylor, Husty Taylor, another mechanical technician. Okay, these guys were the seagoing guys. These are the guys that made the equipment work. Chet was more, was in the design, hydrophone design area, but all the technicians are the guys that made the stuff work, and indeed they made it work really well.

van Keuren: So, these are all engineers, whereas you and Hank Fleming and Jack Anderson were oceanographers, were scientists?

Cherkis: Yeah.

van Keuren: Was the laboratory doing a lot of SOSUS work at this point?

Cherkis: They were just starting into ... They were starting at the heavy-duty SOSUS work there. They had some SOSUS work before then, but this was, I guess, the big push, which was the reason that they hired us.

van Keuren: And so efforts, a lot of the efforts for Hudson Labs were being transferred into in-house here at the laboratory?

Cherkis: Right, yeah. And that was the program that the Navy felt that they wanted to keep and keep going. And that was in… So, by July 1st, 1969 we were up and running and not only designing experiments again, because the ships also, the Mizar and the ... Well, the Mizar was already here, but the Gibbs was transferred here as well. So, we were still working with our same equipment, and we brought our computer programs with us, you know, hundreds of cases of punch cards and things like that.

van Keuren: And so you were in a new location, a new lab, but did your work change at all initially?

Cherkis: Not initially, no. No, what we continued to do for the first year was to continue on a report that we had started at Hudson Labs. We had started a report at Hudson Labs dealing with acoustic shading, where we could see, where we could predict, and where we knew that they would go blank. And we produced the first report, which was the southern part of the North Atlantic, the early part of 1970, if I remember correctly.

van Keuren: So, your work from ’69, this was the result of your first work here at the laboratory?

Cherkis: Yeah, and a follow-on to the work we did at Hudson Labs. And this first report, we tested the thing down in Norfolk, down at COMOCEANSYSLANT. We went down to brief it, and the time we went down to brief it there they just happened to be tracking a sub, and they said, “Well let’s see if it works.”They said, “Well if your report is correct there we should be able to see this submarine showing up in about twenty-eight minutes.” Well twenty-eight minutes came and went, and I said, “Well, back to the drawing board.” But about 4 minutes later, one of the watch officers said, “Uh, sir, I have an excursion.” And they started looking at the excursion on their recordings and their recordings started coming up, and it was a signature from this same Russian submarine. So, four, five minutes, all of a sudden, hey! We were heroes! And it was neat that, yay, it really worked, and it was really something else. But we had one experiment here in ‘69. We went out to sea. And in 1970, we had one in the Pacific. It was the first one that we had done in the Pacific, and I developed a bleeding ulcer, the third bleeding ulcer while I was out at sea, and when I came back they told me that I couldn’t go to sea anymore, unless I did something about it, because when I started bleeding we were on the Gibbs 1500 miles northwest of Hawaii. The Gibbs could make 240 miles a day, and I bled for 8 days. And I ate an awful lot of bread, and by the time I got back there I weighed more than I ever weighed in my life. I weighed almost 200 pounds, which went away very quickly thereafter. But in September of 1970, I had surgery which took out 45% of my stomach. They put me back together again, and I was fine, but at that time the surgery was good, they also cut the nerve that goes from the brain to the stomach that says “make acid.” so I wasn’t making acid anymore except by direct stimulation of food over the stomach wall. And I did a conscious lifestyle change. I decided I wasn’t going to worry about anything anymore. I’ll let tomorrow take care of itself, and I’ll take care of today. And it seemed to work. My attitude changed, and I’m still walking around. I haven’t taken a Maalox since 1970.

van Keuren: How long were you off work?

Cherkis: I was off work for six weeks, but Fleming was bringing work home to me because I was going nuts. By that time we had already picked up someone from NAVOCEANO who was getting a little unhappy with being with NAVOCEANO, and he was a good bathymetrist, as well. He ... I forget when he came on, but he came on, and that was Bob Perry. Bob came over in 1970, and so then we were three, and Bob got into the acoustic propagation ‘mode’, if you will, pretty quickly. We continued on, and I think we did some really significant work. We were able to fine-tune SOSUS a lot, and that was really what we were here for.

van Keuren: Fine tuning SOSUS. And this was work that you did in the ‘70s?

Cherkis: Yeah.

van Keuren: Why don’t we pick up there?

Cherkis: Okay.

7C. Norman Cherkis

AN INTERVIEW WITH NORMAN CHERKIS

by Dr. David K. van Keuren
History Office
Naval Research Laboratory
16 November 2001
Interview # 3

van Keuren: Today is 16 November 2001. This is David van Keuren, Naval Research Laboratory. I'm talking with Norman Cherkis about his career in oceanography at the Laboratory and elsewhere. This is Interview #3. Norm, last time we left off we were talking about you at the Laboratory and doing work essentially fine-tuning the SOSUS system in the 70s. I want to step back just half a step and talk about Project NEAT which happened, I believe, in 1969, in which you were involved.

Cherkis: Right. Project NEAT, which was the acronym for Northeast Atlantic Test, was September 12th through November 1st, 1969, and was on the USNS Gibbs, which was the NRL ship. This project was the pre-emplacement test for the acoustic characteristics and the environmental characteristics of the West European Basin. This was prior to putting in one of the SOSUS systems.

van Keuren: Where exactly is the West European Basin? Excuse me.

Cherkis: The West European Basin goes from the UK down off the Iberian Peninsula. It basically extends from the Azores north to the Reykjanes Ridge, rather to the Iceland-Ferroes Ridge. Okay, it goes from the Azores north to the Iceland-Ferroes Ridge and from the Reykjanes Ridge and the Mid-Atlantic Ridge eastward to the European shelf which includes UK on the east France Bay of Biscay, the Iberian Basin. The Iberian Peninsula is the eastern margin.

van Keuren: Okay. And this project was a series of cruises?

Cherkis: It was broken into three parts. The dates are extensive. And our basic program was to look at the oceanography and the geophysical parameters of the Basin -- number one to test, to see where they wanted to put the sites in, and number two to see what the acoustic characteristics were of the Basin.

van Keuren: As part of that they did a broad range oceanographic survey?

Cherkis: Right.

van Keuren: They studied the water column? They studied bathymetry? They studied the...

Cherkis: Right, seismic profiling. We used the magnetometer. There was no gravity done.

van Keuren: And what part were you and your cohorts at the Lab involved in?

Cherkis: Okay. We were doing the environmental parameters of the Basin. We did the bathymetry. We did the sub-bottom profiling. The magnetometer was an adjunct that we just deployed just for knowledge. It wasn't part of the actual program.

van Keuren: So even here you were applying as much physical knowledge as you could?

Cherkis: Right.

van Keuren: In addition to the kind of basic profiling for the acoustics?

Cherkis: Yes. And we also collected the oceanographic parameters. And I don't remember if we were actually the only ones that were on board the ship collecting -- that's probably in your profile. I know we did a lot of xbts.

van Keuren: Xbts?

Cherkis: Yes. Expendable (unintelligible) demographics. Sippican probes.

van Keuren: What was the second one?

Cherkis: They were probes built by Sippican Corporation. I believe we did Nansen casts. We hadn't yet gotten the rosette sampler for Niskin (N-I-S-K-I-N) bottles which were the newer water collection sampling device -- also had reversing thermometers on board. I don't remember if that was the one we did that on because it's just too long ago. But I know I've run a salinometer in the past, and I still have my own reader.

van Keuren: Salinometer?

Cherkis: Salinometer, S-A-L-I-N-O-METER.
van Keuren: For salinity?

Cherkis: For salinity, because salinity, along with temperature, determines sound speed.

van Keuren: Right. Were there other scientific teams involved in it, from the UK or other countries? From NAVOCEANO... ?

Cherkis: On NEAT 1, I believe it was totally an NRL cruise, but I don't remember. What does it say in that? The British ship, the Saint Margaret's, and we sold the ship the chain, were also involved in the 1, but I don't know. We worked independently of each other, so I don't know what they were.... On the Gibbs we collected, we did sediment coring to see just what the upper layers of the sediment were. They were shallow cores for the most part -- 3 meter cores or less. And we also did some bottom photography using our SHIPEK (S-H-I-P-E-K) camera frame -- did lowerings at various sites just to see what the sea floor looked like, what we were looking at. Was it a basin? Was it a rocky basin full of sediment or were there other things there?

van Keuren: So this studied the West European Basin in terms of both its water column and the sea floor characteristics, and the U.S. was involved in that, the UK...

Cherkis: Woods Hole.

van Keuren: Woods Hole. Were there any other European countries involved other than the UK?

Cherkis: No.

van Keuren: Just the US and UK?

Cherkis: Yeah, because the system would eventually be manned as a joint UK/US system facility.

van Keuren: Is there anything more you can tell me about Project NEAT? It seems, from what I can see here, it has certain procedures that became characteristic of laboratory work that in order to either do a survey for an array of test-proofing they collected a lot of environmental data, they mapped it, they studied not just the acoustic characteristics but the general characteristics of the ocean bottom, the water column, et cetera, and did kind of an oceanographic area.

Cherkis: I think that before Fleming and I came to the Laboratory, the oceanography that was conducted here was for the most part physical oceanography, in support of physical and chemical oceanography; it was in support of other Naval programs. After Fleming and I came to the Lab, we had been working in the bottom, the sea floor, and because of that we were -- I wouldn't say uniquely qualified -- but we were the qualified people at the Laboratory to continue the program that we had started earlier at Hudson Laboratory. And these programs were of vital interest to the Acoustics Division. And so what we did for the Laboratory added another dimension to the oceanographic program.

van Keuren: How had they dealt with this type of information, with collecting this type of information before you came to the Laboratory? Did they contract it out?

Cherkis: No. They got data from other Navy programs. The U.S. Naval Oceanographic Office was heavily involved in bathymetry and to a lesser extent in seismic profiling, but the Oceanographic Office was very heavy in geomagnetics and gravity and sea floor characteristics from the standpoint of the sedimentary characteristics. NAVOCEANO actually analyzed the cores that we collected on NEAT 1 because neither Fleming nor myself felt that we were qualified sedimentologists, that we could do a decent job analyzing the cores themselves. We could look at the basic horizons within the cores, but as far as doing grain size analysis and things like that, neither one of us was qualified.

van Keuren: This was the first project that your new branch undertook -- the Long-Range Propagation, Acoustic Propagation Branch?

Cherkis: Actually, we had a cruise earlier on the Gibbs -- doing multi-disciplinary research in the North Atlantic Ocean, May and June.

van Keuren: Of sixty... ?

Cherkis: Of sixty-nine ('69). It was on the Gibbs, but I'd have to go back and look at my field books, if I have anything, to see just what that was all about. I just don't remember.

van Keuren: So this was actually the second cruise that you participated in.

Cherkis: Yeah. Right.

van Keuren: How did NEAT 1 segue into NEAT II?

Cherkis: NEAT II was performed two years later in '71, I believe -- yes, 7 September to 24 October 1971. And the first program that we undertook was reconnaissance. On NEAT II we looked more at sites that we collected data from. We were honing in more or less on sites where we might want to put SOSUS. On the NEAT II project I was the Chief Scientist on the Mizar. The Mizar cruise was -- we were told we had an acoustic projector making a lot of noise. We had hydrophones in the water, both on an anchored chain that one of the other ships -- I don't remember whether it was the Knorr or the St. Margaret's, British ship -- I don't remember which, but one of them had an anchored chain, and we were towing an acoustic that projected along specific lines for measuring acoustic transmission. And we worked further to the south on NEAT II, if I remember correctly. I remember one long line that we took. It was a long straight line that we took going out from the Iberian Peninsula towards the Azores. And basically this was pre- this generation of SOSUS that they were going to put in, in subsequent years, but the cruise that we took... what we did was to see how, for example, on a radio off the Iberian Peninsula, would handle looking out westward towards the Azores -- the reason for that being that Russian submarines, especially the Yankee Class by this time, were becoming more stealthy, and instead of operating on the west side of the Mid-Atlantic Ridge, they were operating almost exclusively on the east side of the mid-Atlantic Ridge, at least as far their transits went. And it was kind of like trying to put in a turnstile so that we could check them in and check them out. So we could look at them from both Basins. I remember specifically that it was to look at the Yankee Class submarines.

van Keuren: The arrays in NEAT II would have been on the east side of the Atlantic?

Cherkis: That's correct. East of the Mid-Atlantic Ridge.

van Keuren: So they would have had to have been picked up by a different array system when they passed over the Ridge?

Cherkis: Yes. That was the U.S.-based SOSUS, a set of arrays -- well, it was U.S. and Canada -- and it ran all the way from Canada all the way down to the West Indies.

van Keuren: So for NEAT II you really did site surveys?

Cherkis: No, they were not site surveys. This was not for the emplacement of the arrays. That was undertaken by NAVOCEANO. NAVOCEANO did the actual what they call lug point surveys which were the site surveys. That was the point that they placed the arrays in. These were really tight quarter mile bathymetric surveys so they could determine just what the bathymetry was.

van Keuren: So you were doing closer analyses of specific areas that led up to the actual site surveys for emplacement?

Cherkis: Right.

van Keuren: But that would have produced pretty careful mapping of pretty discrete areas?

Cherkis: Yes. Our biggest problem in those days was navigation. And we used the TRANSIT system as much as we could. But on NEAT II we also had a set of charts for Omega, which was supposed to be the next best thing to a satellite but in fact we had lots of times that the Omega was either inoperable or very inaccurate. We couldn't have transited what the Omega said we did in that specific period of time. We were going against the Gulf Stream, so we know we were slowed down.

van Keuren: So actual precise placement was still a problem back in the early 70s?

Cherkis: Right.

van Keuren: When was GPS complete enough that it became useful in your work?

Cherkis: GPS started going in sometime in the 80s. I don't remember when. But when I operated in the Brazil Basin in the mid-80s, we had enough GPS. We had anywhere from 6 to 10 hours where we had GPS coverage. The whole constellation wasn't in, but we were able to do a lot better job of knowing where we were. Our positional areas were on the order of a quarter mile or less while we were under GPS, and we were able to adjust other tracks that were done just by using the TRANSIT satellites to give us a much more accurate placement of what we were doing. That was in the mid-80s, I think in '88 and '89. I did two surveys in the Brazil Basin which were entirely navigated by GPS.

van Keuren: So it's actually another 10 years in the future at this point...

Cherkis: Yeah.

van Keuren: ... where you used it extensively. Any other comments about Project NEAT?

Cherkis: I think number one anecdotal thing, we were headed for our second in-port into Lisbon, and the chain was at the Knorr. The Knorr was the Woods Hole ship line. The Knorr had a buoy that was a submerged buoy, an acoustic buoy, and they were trying to recover it. We wanted to go to Lisbon. We'd been out long enough so we were out of all kinds of fresh fruits and vegetables and things like that. And the people who were directing the show from the beach, Burt Hurdle and, I think, John Cybulski, both from the Acoustics Division, wanted us to stay out and help the Knorr find their buoy. The seas were picking up. We were getting low on fuel and everything else, and they wanted us to stay out. And for some reason I remember sitting in the radio room telling them that they were breaking up and that I couldn't read their message which was saying "Stay out," and I said, "We understand that you were saying do not rendezvous with the Knorr, to go to port", and I was clicking the microphone at the same time, breaking up the transmission in both directions. So we came into port, and people were a little unhappy, but the Knorr eventually did find their buoy. I felt that having three ships out there looking for a buoy -- the British Ship, the St. Margaret's, was out there as well -- having three ships out there looking for a buoy, and whether that was less than comfortable would have been hazardous and at the same time we were low on fuel, we might have compromised the engines on the ship, and we still had one more leg to go, and for that and morale sake decided, I made a command decision: "Come into port." Yes, that was, I think that that was pretty much it. And I think that we ended the last line of the Azores in '71. I think we flew home from Lajes Air Force Base.

van Keuren: Which Air Force base?

Cherkis: Lajes, L-A-J-E-S.

van Keuren: That's in the Azores?

Cherkis: That's in the Azores. It was a joint US-Portuguese airfield. I'm pretty sure that was the one because we couldn't get a flight out for several days. I believe that was the time that Spiro Agnew was coming back from a trip to Greece as Vice President of the U.S. I think that that was the cruise. And we tried to get on Air Force One to come back to Washington, and they wouldn't let us. It was worth a try.

van Keuren: NEAT II concluded in 1972, 1973?

Cherkis: The NEAT II cruises were completed in '71, I believe. What does your book say there?

van Keuren: So the cruise from NEAT II was completed by October of '71.

Cherkis: Right. The Mizar leg ended on 24 October '71.

van Keuren: Which completed the Laboratory's work in this area for the NEAT Project?

Cherkis: For the NEAT Project, yeah.

van Keuren: What other projects were you working on in this period?

Cherkis: In this period of time, in 1970, we had one cruise in April on the Gibbs, and that was towed projector and also geophysics in the Canary Basin and then out to the Mid-Atlantic Ridge. And that was a joint program with Columbia University and Peter Rona, R-O-N-A. He was the geophysicist on that cruise. He was from Columbia, later went to NOAA, then University of Miami, and is presently at Rutgers. But he was the Columbia University guy. And we did a multidisciplinary cruise. We took xbts. A lot of that had to do with an area just at the Mid-Atlantic Ridge that the Russian Yankee submarines were using as a holding area, and the Navy wanted to know what the environmental characteristics were of the area just east of the Ridge, again, for possible surveillance.

van Keuren: So you were collecting general data which would have been used in surveillance. What was Peter Rona interested in?

Cherkis: Geophysics of the Canary Basin. He had done some work out there earlier, and he was working on the seacoast spreading characteristics.

van Keuren: So he wasn't involved in any of the SOSUS for you?

Cherkis: No.

van Keuren: So this was a kind of multi-functional cruise where you had both academic researchers pursuing their work and laboratory work doing, once again, fine-tuning or SOSUS-related?

Cherkis: Right. And then June 11th to July 12th, 1970, we took Gibbs to the Pacific for the first time and worked on the Musicians Seamounts -- Musicians like in Beethoven, Bach, and Brahms.

van Keuren: Musicians or Musician?

Cherkis: Musicians Seamounts.

van Keuren: How did it get that name?

Cherkis: Some Scripps group named them earlier. They found a large cluster of seamounts, like 1500 miles northwest of Hawaii, and what we were doing on that cruise was, again, our basic geological, geophysical studies, but again we were towing our noisemaker. This was because some of the Pacific SOSUS were having interference in that area. They were getting topographic interference...

van Keuren: Topographic?

Cherkis: Yeah. Interference when Russian submarines that they were tracking in the Pacific were moving through that area, they were having problems holding them, so we did an immense survey, well over a month, just going back and forth over these things to try to get a decent determination of what they looked like, doing bathymetric analysis. But at the same time we were towing the noisemaker, so the SOSUS on the U.S. West Coast could see where they could track us between the seamounts and so forth, and they could fine tune West Coast SOSUS.

van Keuren: The West Coast Pacific SOSUS arrays, they were all in the North Pacific?

Cherkis: Yeah.

van Keuren: Between north of Hawaii and south of the Aleutians, generally?

Cherkis: They actually went from the south side of the Aleutians then down, nothing in Canada, there was one in Washington, one in Oregon, several in California. Those were the active SOSUS at that time.

van Keuren: When you say they were active, do you mean the traffic station to land stations?

Cherkis: Yeah, and the arrays were out there in the water. I'm not going to go any further than that.

van Keuren: But the waters around Hawaii were of great interest or was that too far south?

Cherkis: It was too far south. We sailed from Hawaii, to and from Hawaii, but we were not involved at that time.

van Keuren: It would have been the water north of Hawaii?

Cherkis: Yeah. By this time, in 1970, we had acquired someone else who came from NAVOCEANO. His name was Bob Feden.

van Keuren: How do you spell that, please?

Cherkis: F-E-D-E-N. Robert H. Feden. And Bob brought along a good expertise in sedimentary properties, things in seismic reflection profile analysis, and he also had expertise in magnetics, so we were expanding our capabilities, and I could concentrate more on the bathymetry, which was my area of expertise, and we could divide our talents. And Feden was on this Musicians Seamounts cruise. On that cruise my bleeding ulcer came to the forefront for the third time, and I bled for 8 days.

van Keuren: That's not fun. You came back (inaudible). They told you that you had to get it fixed and not go to sea again.

Cherkis: Right. That's when I was eating loaves of white bread.

van Keuren: Okay, so you studied the Musicians Seamounts area. When you would study an area, would you do a detailed bathymetric map, or what would be the end product of the cruise?

Cherkis: Normally we would do a detailed bathymetric map of it. On this cruise, when we returned, the Navy had a major funding cut, and our directive was to go back and concentrate on the Atlantic again. As a result, the data on this cruise were never fully analyzed. There was never a full bathymetric map made. The data were never digitized. And I have no idea where the data went. I have searched for them for years. All the fathogram rules, everything was just put in boxes and put in storage.

van Keuren: Fathogram? What was that word?

Cherkis: Fathogram. The echo-sounding records, the hard copy. In those days we were digitizing, but what we were doing was making lists by hand, actually reducing the data by time, taking the high points, low points, taking a sounding every five minutes plus highs, lows, changes of slope, and measuring time. This was all done manually. One would read, one would write, and after a half hour we'd switch off because you can't do this continuously. And all the reduction that we had done on the ship was all put in the box along with the records, and it all disappeared. It's unfortunate, because it was quite a program.

van Keuren: You came back to the U.S. You had your operation. You were off, I recall, like six weeks?

Cherkis: Right. And I was pronounced "fit" by December.

van Keuren: Of 19-?

Cherkis: Seventy.

van Keuren: 1970.

Cherkis: So in March of '71 I went out to sea again. That was just a science cruise, if I remember correctly, the one in 1970. Yeah, that was a short cruise. We worked -- that cruise -- March 10th to March 23rd, 1971 -- we sailed from Puerto Rico, and we worked off of St. Thomas. We were just collecting bathymetry and seismic reflection on that cruise. And there was an area there between St. Thomas and St. Croix that was a submarine calibration range, the Navy used to calibrate systems on submarines. And we went there just to map it for the first time in any detail, to see what it looked like. So it was purely that kind of thing.

van Keuren: It was later that year that you went out and did the cruises for NEAT II.

Cherkis: Right. But in between that cruise, from 30 June to 30 July, I picked up the Hayes. This was the second cruise of the USNS Hayes. And I picked up the Hayes in the Azores and towed an acoustic projector northward. This was a boomerang-type cruise that we had done at Hudson Labs there. But this was in the West European Basin for the first time, so the first SOSUS was on the drawing boards. They still hadn't found out where it is, but they wanted one more line in an area that was close to the Mid-Atlantic Ridge. And the first cruise from the Hayes went south of the Azores, and that's when they found the Hayes Fracture Zone. And I believe Bob Perry was the Chief Scientist on that one. And then I picked it up as Chief Scientist for the cruise north to I think about 53 North with that cruise. And by that time we had noticed that there was a submarine channel, a sea channel down in that area that seemed to have come out of Iceland, and I zigzagged back and forth across it and followed it down to the West European Basin, I mean down to the Iberian Basin before the cruise ended. For the life of me I can't remember where the cruise ended.

van Keuren: So the submarine basin went all the way from Iceland south to the Iberian Basin?

Cherkis: The cruise started at the Azores and went north.

van Keuren: The submarine basin that you discovered, that you followed.

Cherkis: It went from, yeah, and we reported on it. We were going to call it the Viking Sea Channel. It's kind of like an eastern coral area to the mid-ocean canyon that Heezen found back in the 50s that traveled down to the Labrador Sea into the Sohm Plain area.

van Keuren: Which area?

Cherkis: The Sohm, S-O-H-M. The Sohm Plain. But unbeknownst to us, for the second time, NAVOCEANO was working in the area north of 53 and had actually mapped a portion of this channel going up towards Iceland. And we gave back-to-back papers at the Geological Society of America, and they called it the Maury Channel, named for Matthew Fontaine Maury. And I was not about to get involved in another brouhaha about names, so I just acquiesced and said, "Well, Maury's a good name. It's as good as Viking." The reason I was going with the name of Viking was that Peter Vogt, who was at NAVOCEANO at the time, had other features in the area that he had named for Vikings: Aegir, A-E-G-I-R, which was on the other side of the Iceland Faeroe Ridge, but there were other Viking names that he had given in that area. So I was just kind of following on, and then NAVOCEANO threw me a curve, so I just rolled with it. Naming wasn't really that important. On that cruise I also discovered a seamount which was about 2500 meters in total relief north of the Azores, and when I came back I sent in a naming request to the U.S. Board on Geographic Names. I wanted to call it Beverly Seamount -- my wife. And they came back and said, "No, you can't do that. It's frivolous. Name it for the ship." And I responded that the ship already had one named for it. They said, "Well, then, name it for the Captain." And I responded, "Well, the Captain already has one named for it." They said, "Well, then, name it for the Chief Scientist." Then I never heard another word. And it wasn't until I was doing the editing of the Arctic short that the NRL published, the Perry/Fleming and others in 1986 -- by that time Perry had already left NRL, and I was doing the final edit of the whole short, and because it's a U.S. publication, a U.S. Government publication, we have to adhere to the standards of the U.S. Board on Geographic Names Advisory Committee on Undersea Features, and so I wanted to find out the proper names to put on this chart. And I was looking for Chukchi Cap. Was it Chukchi Cap? Chukchi Plateau? C-H-U-K-C-H-I.

van Keuren: Again?

Cherkis: C-H-U-K-C-H-I. It's north of the Chukchi Peninsula, Russia, eastern Russia. And I was looking, on that page, in the Gazetteer, on the same page, there was Cherkissima. Wow. So I went back, and I still have the original records, and unrolled it. I had a photograph made here at the Lab with Cherkissima, and I have it hanging over my desk.

van Keuren: So they named it after you?

Cherkis: Yeah.

van Keuren: Cool.

Cherkis: So I'm immortal.

van Keuren: This was 197-?

Cherkis: '71.

van Keuren: Seventy-one, again.

Cherkis: Correct. And that was before NEAT II.

van Keuren: NEAT II followed up later in the year.

Cherkis: Yeah. And that was my third cruise that year.

van Keuren: So the famous two cruises were in the kind of late summer, early fall of '71.

Cherkis: Right.

van Keuren: What are some of the other high points of cruises and work that you did in the early to mid-70s?

Cherkis: In '72, I was on the Mizar. We went north from Iceland, and this was a three-ship operation, or a two-ship operation. The Hayes was along. The Mizar was ice-reinforced, but the Hayes...

SIDE TWO

Cherkis: We worked in the Greenland Sea in '72, and the Mizar was testing the SOSUS which was already in place in the Greenland Sea and Norwegian Sea.

van Keuren: When were these SOSUS arrays put in generally into the Greenland and Norwegian Seas -- a rough date?

Cherkis: Well, I know that one in particular went into the water in 1966 because I watched it go over the side when I was with NAVOCEANO, so that would have been in June of '66, so I think they were all in place by 1970.

van Keuren: Okay.

Cherkis: Okay, so, anyway, we were doing an acoustic program. We had two Coast Guard icebreakers with us, the Edisto and the South Wind. Before we went into the ice, the South Wind had an engine fire and was only running on three-quarter power, so they didn't go into the ice with us. The Edisto went into the ice with the Mizar.

van Keuren: D-I-S-T-O?

Cherkis: E-D-I-S-T-O, like in North Carolina.

van Keuren: Edisto?

Cherkis: Yeah. Is Edisto in North Carolina, or is it in Oregon? I don't know. It's named for some town, some coastal town.

van Keuren: Never heard of it.

Cherkis: Okay. Anyway, we sailed north up a long wide lead. We'd been harassed by the Russians earlier that there was a Russian "fishing factory" with 2700 antennas on the bridge that was coming along. They'd come to within 30' to 40' of us. They're good ship handlers, but we had the balls up because we were towing gear -- we had over-the-side gear. So we had the international signal so that they wouldn't cross our stern and cut that there because that would have created an international incident. They spent a lot of time looking at our starboard side. We were throwing the gear through the moon pool on the Mizar, and every time we opened the door to the hatch, to the room where the moon pool was, which was forward of the main cabin, the main super structure, the Russians, you could actually hear the cameras clicking. And we'd put black-out curtains around there, even though you couldn't see anything, we were just playing games with the Russians. We actually mooned them one time. They opened the doors, and there were five guys, myself included, with the moon. Just something to do. But anyway, we went into the ice, and the Russians did not come into the ice with us. And we sailed up this long lead, and then in the morning there were walruses in the water and seals on the ice. We saw a polar bear, birds everywhere, it was a great day. This was October 2nd, 1972, and in the afternoon the sky got very glassy. And no one paid very much attention to it except someone said, "What happened to all the birds?" Don't know. The birds had all disappeared. That night there was a storm that came up. The winds were over 60 knots. Came down off the side of Greenland. There was not any weather map. We couldn't, even though we were, the ice started to close around us. And the Edisto, that Coast Guard icebreaker, was in front of us. They were breaking ice for us until the point that we couldn't actually push the ice that they broke away, so they took us in tow. And we went together through the ice for a period of five or six hours, until about three in the morning we heard this thump and crunch and almost like a crashing sound. And found out from the bridge that we had had a collision with the icebreaker. Ice had gotten in between the stern of the icebreaker that was towing us and the bow of the Mizar and started to rise up, and the pressure of the ice was strong enough to stretch the wire rope and pull us out of the towing notch which was on the stern of the icebreaker. And when the ice moved away, moved to the starboard side, and we were slingshotted back against the fan tail of the icebreaker and missed the towing notch, and the cable slid down the side, the port side, of the icebreaker and knocked out all of their life lines and all their railings and the stanchion that held up their helipad. And we bumped into the helipad and put a hole in our bow, ten feet down from the deck -- 15 feet above the water line. And the hole was about 4" wide and about 2.5" high. We bent, I think, four frames in the collision, and we stopped. And the icebreaker -- we let go of the cables, and the icebreaker moved away to assess her damage, not knowing that the ice was underneath her starboard screw. And the starboard screw was locked in place by the ice against the hull. And the shaft was still trying to turn until finally there was enough torque to shear the starboard screw off the icebreaker. The starboard screw fell away. The ice came back up to the surface and knocked the lower pinion post off the rudder. So the icebreaker, 35-40 feet from us now, had no -- the shaft overspin and burned up the electric motors that ran the pumps for the heeling tanks that caused the icebreaker to rock back and forth side to side so we could crush ice -- pumps water back and forth. So the icebreaker had no heeling tanks, no starboard screw, and no operational rudder, and they were 40 feet from us. And they were the rescue experts who were now in deep trouble. They radioed back, and the Coast Guard Public Information Office here in Washington put out a notice saying that a U.S. Navy Survey ship and a Coast Guard icebreaker were in a collision 900 miles north of Iceland. Neither ship is in any immediate danger of sinking. The operational word there is "immediate", because of course the news services picked this up, and the way I found out about it was I was standing on deck with a little shirt pocket transistor radio picking up skips through the ionosphere, and I was listening to Seattle -- the first station I heard, KOMO in Seattle. I heard that, and I heard KSL in Salt Lake with a similar broadcast. Then a Chicago station, WLS, I think, then a Boston station, then WCBS in New York. And when I heard CBS in New York, I knew that my wife was going to find out about it. We were about to send out a message saying we are going to be extended, because we were locked in the ice. We knew we'd get out eventually there, but we were not going to put out any kind of information about having been in a collision, because there was essentially, I think, cosmetic damage. The ship (unintelligible) closed up this hole in about a half hour with a piece of plate. They just welded a piece of plate over our 2", 2" by 4" hole. But the Coast Guard had issued this thing there. So of course this made all the wives incredibly nervous, and people were calling from the Lab -- were calling the wives and giving them twice daily updates on everything that was going on. I know my wife was called by Dick Schwimm from the Lab. Dick was in the oceanographic group, Buck Buchanan's oceanographic group, and had a lot of experience on the Mizar. And he was trying to explain to her just where this was and that there was no danger and the Mizar was a double-hulled ship anyway, so we were in no danger. And not only that, the ice wouldn't really bother us because we were capable of handling ice crunches and things like that. And we spent 10 days in the ice. We drifted south with the current, with the ice pack, for 10 days at a rate of about a half a knot. Never stopped taking echo soundings. And then on the 13th, Friday the 13th of October, 1972, we were sitting in the laboratory and someone noticed that the graph barometer that we had sitting on a table, the arm was hanging off at the bottom, and mentioned that there was something wrong with the barometer. Someone else called the bridge, "What's the barometric reading?", and the guy on the bridge was saying, "I can't talk to you right now, the wind's too high." The winds were over 75 knots. Another storm came off of Greenland. The barometer had dropped in less than three hours from 2990 something down to 2630-something -- dropped 3" in 3 hours. That's how steep the gradient was. And the next morning the sun was shining, and the ice was open. And we were a quarter mile from open water. The South Wind had been hanging out outside the ice because she was afraid to go in because of her only three-quarter power just broke this little bit of ice, took the Edisto in tow and we all took our sail and went back to Iceland. So that cruise turned out to be 34 days, but all the time we were up there in the ice, we were pinging. We were taking bathymetry, and it was the first time that anybody had gotten any soundings in that area. So we got to 80 degrees five minutes north in the Framm Strait then continued all the way back down. It was a great bathymetric cruise.

van Keuren: What had been the original goal of the cruise?

Cherkis: It was an acoustic transmission loss experiment. That was the basic mission of the cruise, but we were collecting the environmental package at the same time. So that was the highlight of 1972. Earlier, the Hayes was, well, maybe I shouldn't say that because I don't know if it was '72 or '73. The Hayes was in both the Norwegian and Greenland Seas, and the Hayes was collecting bathymetry and seismic profiles, and they were also doing some testing of the SOSUS. But that was a cruise that Bob Perry was on and Fleming and, I believe, Peter Vogt, who had come to the Lab by '72. Peter was also on board.

van Keuren: Now, at that point, you now had the crew of people, four people, who put together the Nordic Seas (unintelligible).

Cherkis: Right. We were, and I don't remember when we changed our name to the Environmental Sciences Group, but it was around that time. We became an Environmental Sciences section within the Acoustics Division, and by that time we had also acquired a scientific draftsman who we stole from Engineering Services on the Lab originally -- Wayne Worsley. So Wayne was our technician. W-O-R-S-L-E-Y. Wayne Worsley. And he was our technician, and then the rest of us were all professionals: Fleming, Perry, Kovacs (Skip Kovacs) who had come from NAVOCEANO, Feden, Vogt and myself.

van Keuren: K-O-V-A-X?

Cherkis: A-C-S.

van Keuren: A-C-S.

Cherkis: He's still over there.

van Keuren: And this within the core of Environmental Sciences?

Cherkis: Right. Well, we were the Environmental Sciences Section. It wasn't until much later that we became larger, much larger than that.

van Keuren: When did the Laboratory get involved in the Greenland or Norwegian Sea?

Cherkis: I would say 1971. There was a cruise by Mizar in '71. Massingill, Rusty Massingill, M-A-S-S-I-N-G-I-L-L, James B. Massingill -- Rusty was his nickname -- he was the Chief Scientist on that. Rusty had come from NAVOCEANO, and he had been doing many seismic interpretations. His expertise was actually in the Gulf of Mexico, so now he was up there in the Arctic in '71. He was our person aboard there. I believe that Charlie Votaw from the Acoustics Division was also the Chief Scientist on the icebound block in '72. I believe Charlie was the Chief Scientist on the '71 cruise also. But that was in '71. In '72 we had the Hayes cruises in the Norwegian Sea and up around the Bear Island. And we were up on the Mizar in the Greenland Sea and in the ice.

van Keuren: By this point the systems, the arrays, were already in place.

Cherkis: That's right. And we were doing a lot more basic science. And at the same time there was an underlying thrust by the Navy. They wanted more and more information about the Arctic. The Russians were still running submarines up and down through the Arctic area, and the further north we could get and get more environmental information, the better, the happier
was the Navy.

van Keuren: Why was the Navy happier?

Cherkis: For their databases, for their black programs, whatever. Because by this time the Navy was already sending submarines up under the ice. The Navy started sending submarines up under the ice actually in 1958 with the Nautilus. The Nautilus went up in '57 but aborted, '58. In 1960 -- I have a whole list of these things -- I have every cruise that went under the ice. I have a list of them. It's all unclassified. The ones that went to the North Pole and so forth. I have a full list of these things. And of these cruises, these submarines were operating totally in the blind. No one had collected any bathymetry before there, so whatever data they were collecting was eventually -- actually in 1972 -- our section, we sent people to San Diego, and then we got the rest of the data. It wasn't '72. [Pause] Yeah, it was 1982 that we digitized all of the cruise data from all of the submarines that had gone under ice from 1958 to 1982. We had a scientific navigator who had been on submarines during his time in the Navy, and we navigated all of the cruises, the interocean navigation numbers, so we got a better idea of where the submarines were. And we digitized all of these data through the 1982 cruises, at which point the Navy took over the digitizing program -- put it into a black box. But there were 22 cruises that collected bathymetry between 1958 and 1982.

van Keuren: From submarines?

Cherkis: From submarines. And we got that digitized in 1982-83. Of course between '83 and '88, there were another 22 cruises.

van Keuren: So the cruises that the Lab was involved in, starting about '71 into Greenland/Norwegian Sea, it wasn't so much for, the purpose was not so much to fine tune the SOSUS arrays?

Cherkis: Not any more, no. From say '73 on, it was more basic science. It was a lot more ONR-supported. It was basic science. The Navy wanted to know all they could about the Arctic regions. About that time I started getting involved with some of the foreign scientists and visiting other laboratories and squirreling out, pulling out data from other data sources, mainly Norway which had huge data sources up and around Spitzberg and the Barents Sea that was just collected and sitting there. They didn't do anything with it. They just had it. Germany, France did cruises in '78 on one of their survey ships in the southern part of the Greenland Sea, but the Norwegians had surveys, not quite hydrographic quality surveys but close to being hydrographic, all around Spitzberg and all around Greenland -- no, all around Jan Mayen. And we just started collecting this with the idea of first building a bathymetric map of the Norwegian and Greenland Seas and the Western Barents Sea which was first put out -- I think that was our first publication in 1980, our first chart, I think. And from there we went on to the Pole Arctic which was based on everyone's data that we could get our hands on plus a lot of older data plus the geophysics from aeromagnetics that we were able to get our hands on or collect ourselves.

van Keuren: What did the Navy do with this basic scientific data on the Arctic?

Cherkis: The Navy probably had applications. I would guess mainly for submarines. But I was not privy to that information. But when you are an ocean floor mapper and you get an opportunity to go bravely where no man has gone before, you go for it.

van Keuren: The Arctic had been an understudied area up to this point?

Cherkis: More than understudied. It had almost been non-studied. The basic science up there was almost nil. We knew about the Mid-Ocean Ridge. We had general plans where the Kolbeinsky Ridge, which is the Mid-Atlantic Ridge extension north of Iceland comes out of the Kolbeinsky Peninsula (K-O-L-B-E-I-N-S-K-Y). And that goes north to, that's the current spreading regs, and that goes north of the Jan Mayen fracture zone. Then the Mons Ridge goes from the eastern side of the Jan Mayen fracture zone obliquely to a point where the ridge changes direction and becomes the Knipovich Ridge along the northern, northwestern Barents Sea and then dies off again somewhere up near the Malloy Deep. And we discovered the Malloy Deep in 1976, I want to say, on the Hayes. I wasn't on that cruise, but that was Bob Perry's cruise. It was the deepest known point north of the Arctic circle. We had a depth of about 5,365 meters. A few years later -- that was 1976 -- in 1984 I was invited to go aboard a German research icebreaker, the Polar Stern, and using multi-beam. The Hayes had only single beam. We used a CB. And we surveyed the Malloy Deep. And we had a depth of 5,608 was the deepest point in that. And there's a little piece of Mid-Atlantic or Mid-Ocean Ridge segment that shows up east of the whole, and then there's another small segment -- these are things that showed up much later than the NRL surveys -- but we did discover that Malloy Deep and the Malloy Fracture Zone. We did a lot of extensive work there, and we worked all of those data into the charts.

van Keuren: ONR is beginning to put some support monies in?

Cherkis: At this point, yeah.

van Keuren: In the early 70s?

Cherkis: Yeah, mid-70s.

van Keuren: Mid-70s.

Cherkis: And we were also getting DMA money because DMA...

van Keuren: Defense Mapping?

Cherkis: Yeah. They were very interested in this because they were building charts for the submarines to travel, and it just continued on and on. The Arctic itself, if you've never been there, is, you'd think just a bunch of ice, but it becomes a very magnetic thing. Once you've been there one time, you either love it or you hate it. And if you love it, you want to go back, because every time you turn your head you have a different vista. Everything changes every time you blink your eye. It's the most amazing yet barren thing you've ever seen.

van Keuren: So the Malloy Deep work was...

Cherkis: Seventy-six.

van Keuren: Seventy-six ('76). But what was your first personal introduction to this area?

Cherkis: My personal first introduction was in 1966 when I was with NAVOCEANO, and we were working in the Norwegian Sea.

van Keuren: And then?

Cherkis: And then, our group, Environmental Sciences Group or Section, actually it was Bob Feden who wanted to look at the aeromagnetics. He wanted to look at the magnetic signatures of the Arctic. And at that time NRL was just getting its first research aircraft. And NAVOCEANO already had a research aircraft, the Project Magnet aircraft. And Feden arranged a program using an operational P-3 out of Keflavik, and the NAVOCEANO plane, the Project Magnet plane, in '71, they took the detection gear out of the operational aircraft and put just a straight proton precession magnetometer into the tail section. And we, I think Feden did it by himself in '71, but using the two aircraft flew a series of lines back and forth across the Norwegian Sea. And that was more of test than anything else there, but it was to see what the magnetic lineations looked like, because by that time we knew about magnetic lineation showing sea floor spreading. And the results were quite promising. We could see the magnetic lineations showing up and documenting themselves as being same beach on both sides of the Kolbeinsky Ridge. And that first year of 1971 when Feden worked that program, that was quite the, the Navy became really interested in this capability there because magnetics actually showed bathymetry. There was a pointer where the sea floor would be rougher or smoother because of the magnetic signature of the ridges and seamounts, which were much greater. And the program continued in 1972 up to Jan Mayen Island and just north of Jan Mayen, also with Feden and Fleming and Joseph Phillips who was then with Woods Hole. He was a geophysicist and Feden knew him from when Feden was actually a student at Woods Hole. So Phillips collaborated on the '72 cruise, on the '72 aeromagnetic ops. And I was a member of the group in '73, and we flew the Greenland Sea. And Phillips and Feden were along for most of that. I think Fleming actually joined us for two or three flights as well. We were learning, you know, we were learning how the magnetics work. One of the highlights on the '73 flight that I remember is that we had one unconfirmed seamount that was showing up on a Norwegian fisheries chart called Vesteris Bank (V-E-S-T-E-R-I-S)... is what was shown on a Norwegian fisherman's chart in 1962. And it was pretty much unconfirmed. And when we flew the mission in '73, we went directly over it. And at first we thought we were getting noise on the magnetometer because it was climbing so steeply. We went up on one side of it and came down directly over the top of it, came back on our return leg directly over the top of it. And the magnetic anomaly, the magnetic signature, the anomaly from the ambient magnetic signature of the area was over 2200 gamas or nanoteslas. And then we caught a side of it on the third one. This was a seamount with a very strong iron core that was confirmed later on in 1973 by the USNS Lynch. It was a NAVOCEANO cruise that was going up there, and we asked them to divert to see if they get a line over it. And they got 179 meters for a top depth. They did not hit the peak. Later on the true peak was hit by Polar Stern on two cruises that I was on in 1985 and 1990. But we confirmed the existence of this seamount. Seamount came out at 3,300 meters to a depth of 173 meters by the Lynch. It was 21 miles long and 10 miles wide. And it's the only seamount in that area. And it's an anomaly. Why is it there? It's an enigma. And to this day it's an enigma. The later studies on the thing -- dredges and things like that -- have taken the material. The material is not related to Jan Mayen. The volcanic material is not related to Jan Mayen, which is the closest volcanic edifice to it. It's more related to the stuff in the Canary Islands, Teneriffe thing, at least according to the chemical composition of the rock. What was determined was that the seamount was probably sub-areal during the last (unintelligible). The top is smooth. This was determined with the Polar Stern using TV cameras. We could actually see that it was smooth, that the wave action had cut it smooth. I wrote a paper on that the last cruise I was on. But that was one of, at least for me, the highlight of that set of flights in '73. And then NRL continued with aeromagnetic flights up the ridge using NRL aircraft and

NAVOCEANO aircraft and in conjunction with NAVOCEANO all the way until actually 1999. John Brozena has been flying up in the high Arctic since the early 90s, and if he gets the funding he'll go back next year for one more set of flights out of Spitzbergen on the Arctic Mid-Ocean Ridge. But the amount of information that's been coming out has been incredible. That started with the NRL Aeromag programs.

van Keuren: So the NRL involvement really began with this program on aeromagnetics?

Cherkis: Right. And one cruise in that same 1971 time frame.

van Keuren: Who was on that cruise?

Cherkis: Rusty Massingill.

van Keuren: That was the Rusty Massingill cruise?

Cherkis: Right. And that was on the Mizar.

van Keuren: And that was the beginning of the involvement, the Laboratory involvement?

Cherkis: Right.

[END OF TAPE]

7D. Norman Cherkis

AN INTERVIEW WITH NORMAN CHERKIS

by Dr. David K. van Keuren
History Office
Naval Research Laboratory
5 December 2001
Interview # 4

van Keuren: This is December 5th, 2001. I'm David van Keuren, History Office, Naval Research Laboratory. I'm talking with Norman Cherkis about his career in bathymetry and oceanography within the Navy Department, and particularly with the Naval Research Laboratory. Norm, last time we finished up talking about your aeromagnetics work with the P-3s in the Greenland and Norwegian Seas. I'd like to follow up on that and have you talk about the extension of these aeromagnetic studies to the South Pacific.

Cherkis: In late 1976 we were contacted by Dr. Alex Malahoff, —A-L-A-H-O-F-F. He was the new Science Officer for NOAA – Senior Scientist for NOAA. And he wanted to know if we could conduct aeromagnetic surveys around Fiji. The reason for that was that the Russians had offered Fiji assistance in developing their economic potential. And the U.S. State Department said, "Just a second, we need to show the flag and talk to NOAA." And NOAA – Alex -- who was previously at ONR, contacted us about conducting an aeromagnetic investigation around Fiji. We laid out some tracks for an initial study. We already had experience in the area from earlier work that Bob Feden had done out of New Zealand in 1975, so this was a logical tie-on. And we laid out a number of flights, flight tracks, around Fiji. These were to the west of Fiji, south and west of Fiji, all the way around to the northern part of Fiji. And we figured out approximately how many flights we did conduct. I think there were 14. We could do about half of the Fiji Island area during the '77 field season. So we took the airplane and set it up for our aeromagnetic program and flew out to Fiji. On the way out, our inertial navigation system failed immediately, or somewhere over the U.S. when we were flying from PAX (Patuxent River) to the West Coast, so we flew out and stopped at Lockheed in Van Nuys, California, and replaced our Litton-51 navigational system, or one of them, then flew up to Moffett Field for down time. That was our first...

van Keuren: Moffett?

Cherkis: —O-F-F-E-T-T. It's a Navy base at the south end of San Francisco Bay. We stayed there overnight and flew to Hawaii the next day to Barber's Point. Had a one-day crew rest there then went on to Fiji. Half the logistics were set up with the Fijian Civilian Authority because Fiji doesn't have a military air base. We got our passes to go in and out of the airport at our convenience. All the logistical things were taken care of. And then we began flying fights, flying survey flights. Starting from the southwest of Fiji, we flew somewhere between four and six lines a day, depending on the length of the legs. And we met the magnetic anomalies to the west of Fiji, showing that there was some sea floor spreading activity between Fiji and Vanuatu, V-A-N-U-A-T-U, which is the former Condominium of the New Vederes. We flew just about to the coast of Vanuatu and then turned and came back to Fiji. And we were running, as I said, between four and six lines a day. The average flight was 12 hours, which meant one hour free flight, one hour post flight at the air field. So they were 14-hour days, for all intents and purposes. The following day we processed the data we collected on the first flight, and then continued that program. We flew Monday, Wednesday, Friday and processed Tuesday, Thursday, and Saturday, which gave us Sunday to go swimming. We collected a lot of data, all of which showed that there were a great number of sea floor spreading signatures there in the Fiji Basin, the North Fiji Basin, but there were no, there was nothing there that indicated any great sedimentary depths of anything that might be construed as being of economical potential for Fiji, and especially in hydrocarbons which is what they were interested in.

van Keuren: And this information went into bathymetric maps or magnetic maps?

Cherkis: This went into magnetic maps. This was the preliminary. We didn't publish at that time because we were intending to go back to finish the Fiji area and flew, as I said, 14 flights starting from the southwest and went in sort of a fan shape around to almost due north of the Fiji Islands. And that's where we stopped.

van Keuren: What's the date for this?

Cherkis: The date is 12 October to 22 November.

van Keuren: 1977?

Cherkis: Right.

van Keuren: Did you ever go back?

Cherkis: We went back in 1979 and picked up, redid the first line again and then continued around in a fan shape to the northeast and then the east over the Lau Group all the way to the Tonga, to the edge of the Tonga Islands or the Kingdom of Tonga. It's an independent country. One of the highlights on that deployment was that we saw what we thought was an oil slick to the northeast of the Lau Group, and this oil slick, upon closer inspection, turned out to have kind of a brownish iridescence to it, so we told the Fijian Coastal Patrol about this, and they sent a small boat out of Fiji, out of Suva (S-U-V-A), and they learned or they sampled the water and found that in fact it was not an oil slick but rather a submarine volcanic eruption from

Eephouu or something like that. It's one of the submerged reefs, volcanic islands on the north end of Tonga, and it put several hundred square kilometer pumice raft. This is floating volcanic material all over the area. And then one morning I was awakened at about four o'clock in the morning. We had a flight that day. But I was awakened at four, about an hour before I would normally get up, by a telephone call from the Smithsonian who was interested in this because it was one of the short-lived events...

van Keuren: Epiphenomena.

Cherkis: Yeah. Epiphenomena. Yeah. And they wanted us to track it and see how long we could spot it. So we took a look at it every day and just watched the raft. Then the raft disappeared, which meant that the volcanic eruption had ceased, but the raft just eventually dissipated when it got to the northwest of the Tonga Islands. That was just a little something extra on top of the aeromagnetics. But after we finished the program there and found some very interesting sea floor history, spreading history, we did in fact publish two small papers and gave a presentation at the CCOP-SOPAC meeting in Suva in 1982.

van Keuren: Was it ever published -- your mapping?

Cherkis: Yes, the maps were published in the proceedings and then later in a paper that was -- first off it was Malahoff, and the paper was published in 1984, I believe, and showed all the aeromagnetic lineations.

van Keuren: Cool. You also did the same survey, aeromagnetics, in the Antarctic, south of Australia.

Cherkis: Right. That was a program that was set up in 1977. We were looking to go a little further afield and test out the aeromagnetic program in places where bathymetry was very poor. We were using the magnetics to predict bathymetry. In areas where there was no magnetic signature, we could assume a flat topography, and where it was very steep and had a lot of anomalies, we would determine that those were areas that needed to be more thoroughly investigated by ships, if possible. And in the area south of Australia, the weather is incredibly bad most of the year. We took the aircraft down to Australia and, in concert with the Australian Air Force, who also have P-3s, we installed a system on an Australian P-3 B-model and started flying flights first out of Adelaide and then finally out of Perth. These were all flying south. We would fly out of Perth. We would fly 3 hours at 16,000 feet and drop down to our operating altitude which is nominally 300 meters or about 1,000 feet, and then work down there for 6 hours (3 hours down, 3 hours back) in the area called Roaring 40s and Howling 50s. On some of the flights we'd get head winds that would slow our progress to about 180 knots going down a line and maybe we'd do 280 knots with a tail wind coming back on the line. There was one line down, one line back. One day the weather was so bad that we got one and a third lines before we had to climb back up to altitude.

Otherwise we would have run out of gas, fuel. But we flew down, and we flew the area called the Australian-Antarctic Discordance, which is the suture where Antarctica and Australia disassociated. Those were published as a folio by the Australian Defence Group -- I don't remember the exact name, but I can get that for you -- but it was published as a folio showing the bathymetry which was taken from ship tracks, random crossings of the area. And then we used the magnetics to make a very credible determination of the physical attributes of the Australia-Antarctic Discordance Zone, which is the eastern end of the south East Indian Ridge, part of the Meadows and Ridge system. We determined that there was actually a propagating, that the Meadows and Ridge was propagating to the west until it reached a fracture zone. These fracture zones are easily mappable on the magnetics. And at that point the entire area became very dislocated in north and south directions. I believe found 11 fracture zones. And then when we got to the western side of the Discordance, it smoothed out again and became just a normal ridge. That was just done as a scientific effort but also to show the Australians that they could do this span of work using available aircraft.

van Keuren: Was there any other reason behind it? Was the State Department involved in this?

Cherkis: No.

van Keuren: Or anybody else?

Cherkis: No. It was just NRL and the Australian Air Force. Fleming and Feden had gone down earlier to do the preliminary work, the ground work and to get the agreements in order. And then we just went down and got beaten up. The flights were so rough that from the time -- the pilots would give us 15 minutes warning that we were going to go down to operational depth or operational altitude, and at that point we strapped ourselves into the seat and stayed there for 6 hours, because if you got up you'd fall down. The weather was so rough that we had zero Gs on a number of occasions, just trying to keep the aircraft at altitude -- I'd say nominally 1,000 feet. We were anywhere from 500 to 1500. At one time we had actually dropped to about 300 feet. It was not a good situation. The waves looked very, very close. But no-one got airsick. That was comforting.

van Keuren: So you were doing aeromagnetics first in the Greenland and Norwegian Sea, then in the sea around Fiji and then south of Australia. In the period from the early 70s and finishing up in about 82...

Cherkis: I finished up in 1979.

van Keuren: '79.

Cherkis: But we had other programs -- the Branch did. There was one that was done on the south of Newfoundland on what they call the

Eastern -- Western J-Anomaly Ridge, which had a correlator in the Eastern Atlantic off of Morocco.

van Keuren: What was that name again?

Cherkis: Eastern J-Anomaly Ridge. I think Kovaks was the Chief Scientist on that one. And there were a number of other activities that were done. One comes to mind. Peter Vogt had one in the central Indian Ocean flying out of Diego Garcia. And Brozena picked up the program as a full-time program and continued aeromag in lots of places. They flew in the Antarctic -- flew out of Ushuaia (U-S-H-U-A-I-A), Argentina.

van Keuren: And the point behind all this was that by getting magnetic mappings of sea areas you could actually come up with a pretty good indicator of the bathymetry of it?

Cherkis: Yes.

van Keuren: So your real interest was in the bathymetry?

Cherkis: Right.

van Keuren: And aeromagnetics was a way of getting to the bathymetry?

Cherkis: Right. Now, also, beginning around 1979 -- my memory has been jogged -- through about 1985, Brozena flew a number of missions out of Brazil. This was a 10-year program called Centratlan (C-E-N-T-R-A-T-L-A-N) with the Brazilian Hydrographic Office and several universities in Brazil. This was something that also went through the State Department, aid and assistance to Brazil. We flew -- or Brozena flew -- a lot of places in the Brazil Basin and also in the Angola Basin. They had one operation that was flying flights out of Libreville, Gabon. Then I got involved on the shipboard activities on those operations, starting in '79.

van Keuren: So they were aeromagnetic surveys, and they were shipped to follow-up or they were simultaneous aeromagnetics and shipboard?

Cherkis: No. Aeromagnetics was first and then the ship follow-up.

van Keuren: So the aeromagnetics would come up with the anomalies and then the ships would come in to look at the interesting areas where there were magnetic anomalies?

Cherkis: Right. In the Brazil Basin, the magnetic map that was made showed that there was one huge seamount group of which we knew just a little bit about them. We know that there were 9 known seamounts. And in later years, in '88 and '89, I took RV Conrad in there with Seabeam. I took that ship in there with Seabeam, and we came up with 45 seamounts.

van Keuren: For the countries like Brazil, Fiji, Gabon, other countries that might have been involved, was their interest bathymetric mapping or were they interested in potentially honing in their own scientific teams, or was it more economic? Were they looking for potential sources of minerals and petrochemicals?

Cherkis: It was a combination. It was the intent that their people would get trained on our more or less advanced systems, at which they had none, and possibly through aid get the systems of their own or buy systems of their own if they were capable of doing that, and also for indicators of economic importance. In fact, the Brazil Basin, we determined that there was nothing of economic importance in the deep water, although the Brazilian Shelf is loaded with oil.

van Keuren: There must have been some political rationale behind this, too. You were invited into international cooperative sensitive oceanographic mapping. The State Department was involved in this, and they invited you usually and who was the U.S. lead in this? Whose idea was it? Was it the State Department who approached the Laboratory and say, "We would like you to do the following program." How did the dynamics work?

Cherkis: This is strange. I don't know the entire background. Dick Rojas who was the ADOR at the time was involved in the political part of that as was Hank Fleming. The first cruise we had was in 1979.

van Keuren: This was Brazil?

Cherkis: Yeah. And that was kind of a show-the-colors type of thing, and we did ports in Brazil. And then they did some preliminary surveys out of Brazil, thinking the Brazilian scientists -- there was a Brazilian scientist who had gotten his PhD from Lamont. His name is Marcus Gorini (G-O-R-I-N-I). And he was a good friend of Fleming's. And they decided what areas they wanted to look at. Gorini had ties to two universities; he had his own independent consulting company; and he also had ties to the Brazilian Hydrographic Office. So they were more or less telling us what areas they were interested in, but in the end there we covered most of the Brazil Basin. We also covered a good stretch in the mid-Atlantic Ridge between 6 degrees south and 17 degrees south. We did this with both aeromagnetics, followed on by intense shipboard studies.

van Keuren: The sense I'm getting is that these are instances of attempts to improve international relations during the Cold War through the use of science.

Cherkis: I guess you could say that. We were not that altruistic, though. We were interested in the science itself. We wanted to know what the mid-Atlantic Ridge looked like out there because the charts showed a very even fracture zone pattern, and we knew from our shipboard studies in the North Atlantic that it wasn't the case, so we wanted to see just what this area looked like and in fact found some very interesting fracture zones. We found double trough fracture zones, and we found quite a number of large and small fracture zones. We found topographic highs off the ridge that hadn't been previously known about.

van Keuren: Who funded these flights and these cruises?

Cherkis: ONR, NIMA, and I don't know but there was probably money coming from other places as well. But NIMA was the Defense Mapping Agency in those days.

van Keuren: Right.

Cherkis: But they were interested in it from a military standpoint, getting a good magnetic map of the world that was done at a better spatial resolution at 1,000 feet than you did from the NAVOCEANO Project Magnet (unintelligible) at about 20,000 feet, just straight lines that we had systematic observations rather than just individual track lines. So that was the first part. There was actually a term "magnetic bathymetry", which in fact is a misnomer because magnetics and bathymetry are completely different. And also the fact that the size of the feature over which the magnetics are collected, the magnetic signature is collected, is not a one-to-one relationship. It depends on the amount of iron in the core of the seamount. There were some seamounts that had minimal magnetic signatures because they were around 85 million years old and had been leeched of most of the iron. They had relief of no better than 2,000 meters. So there was no one-to-one correlation. It just told you that there was something out there.

van Keuren: You could then look at, using Seabeam or surface...

Cherkis: Sonar is the only true mapping tool that we have.

van Keuren: So this work was done in the second half of the 70s and beginning of the 80s?

Cherkis: Right. Actually, it went all the way through to 1989.

van Keuren: So you continued it throughout the 80s.

Cherkis: Uh-huh.

van Keuren: What were some of the other highlights of the second half of the 1970s in your own research? You talked about some of the high points with aeromagnetics, the work in Brazil. What about the Greenland and Norwegian Seas? Will you continue to do work up there?

Cherkis: The Lab was involved. I was not going to sea in the Arctic in the mid-70s, after the mid-70s, but the Lab was involved. Our Branch had cruises in 1972 with the Hayes, when they discovered the Molloy (M-O-L-L-O-Y) Deep and Molloy Fracture Zone.

van Keuren: You discussed that last time, right?

Cherkis: Right. And they also did some other surveys in the Norwegian and the southern Greenland Sea in '72. I believe they were there in '74, '76, but I wasn't a part of those programs. When the bathymetry was collected and came back, I was compiling it along with Bob Perry. We were building charts of the Norwegian and the Greenland Seas.

van Keuren: And this work that was being done by your colleagues in the Environmental Sciences section on the Greenland-Norwegian Sea helped produce the basic material that went into the Nordic Seas that came out in '86.

Cherkis: Right.

van Keuren: Is that right?

Cherkis: Right.

van Keuren: And the main players in that were Burt Hurdle, Peter Vogt and any others?

Cherkis: Bob Perry.

van Keuren: Bob Perry. What was your understanding of the core part of producing that book? Do you know any background of that project?

Cherkis: It's probably faulty. There were a number of studies that were done as joint programs with the U.S. and the U.K. Defence Research Establishment in Portland, and they were looking at propagation loss. Burt was building propagation loss models, but in order to do a good prediction of propagation loss, sound propagation loss, we needed to know what the bathymetry was there. So I was building the bathymetric maps and putting Burt's propagation models over there. Then we could refine the model based on what the topography looked like and also explain areas where there was no decent transmission.

van Keuren: To which they were also adding other environment information on the water column and the sea floor bottom geology.

Cherkis: Right. In addition to the bottom, sub-bottom, physical characteristics of sediments, dredge samples of the rocks, in addition to that every cruise that went up there had physical oceanographers or people collecting physical oceanography for later analysis back here at the Laboratory.

van Keuren: The first part was just basic science? Was there any applied?

Cherkis: There were many applied aspects to this. The Norwegian Basin was an area where the Russian submarines were coming down. The Northern Fleet had to transit the Norwegian Basin, all through the Nordic Seas, and the more we understood about the oceanography, the better we could track.

van Keuren: So the more environmental information you had in every facet, the better your tracking models would be?

Cherkis: Exactly. And there are a number of SOSUS sites in there.

van Keuren: So it was combined. It was the collection of basic scientific data that could have very applied uses?

Cherkis: Right. This, I think, went all the way through the sixth floor.

van Keuren: And this work was being done in the 70s and the early 80s?

Cherkis: Right. And it was done with a lot of joint effort with the Norwegians.

van Keuren: And the interest of the Norwegians was, do you have any insight into what they were getting out of this?

Cherkis: The Norwegians were neighbors of the former Soviet Union, and periodically some Russian submarine would go into their fjords and poke around in their fjords, and never call, but they knew what was in there. But since the submarines would transit down right along the entire coast of Norway, the Norwegians were very interested. There was a NATO aspect in there as well.

van Keuren: Okay.

Cherkis: The first ones were the bad guys.

van Keuren: This was definitely Cold War. Okay. So your involvement in the CENTRATLAN cooperative research with Brazil spanned a period from '79 to '89?

Cherkis: It was a 10-year program.

van Keuren: Did you go every year? Were the cruises every year?

Cherkis: There were cruises every year. Yeah. There were cruises on other vessels besides the Hayes. The Brazilians had a retired Agor (A-G-O-R) which was given to them. It was the USNS Sands. It was given to Brazil, and they turned it over, and it became the RV Almirante (A-L-M-I-R-A-N-T-E) Camara (C-A-M-A-R-A).

van Keuren: Almirante Camara.

Cherkis: Right. The Almirante Camara was a Brazilian Admiral who at one time was owned by the Brazilian Department of Hydrography and Navigation, their hydrographic department. DHN is their shortened name. And we used that vessel on one cruise. It wasn't a particularly well-maintained vessel, but we used that. There was another one that was used by the group that I was not aboard, which was the Tahiti Seahorse.

van Keuren: The Tahiti Seahorse?

Cherkis: Right. I think that was an oil company-type work boat. They used that in shallow water, but also it went quite a ways off the shelf, but they did the seismic profiling, mainly on that cruise.

van Keuren: The CENTRATLAN -- did that include both aeromagnetic and sea surface sonar mapping?

Cherkis: Yes.

van Keuren: And the aeromagnetics used the U.S. P-3s?

Cherkis: U.S. P-3s, yes, exclusively.

van Keuren: From the Laboratory. So you were using the Mizar?

Cherkis: No. The Hayes.

van Keuren: You were using the Hayes.

Cherkis: And then when the Hayes retired, we used the university ships that we contracted -- the RV Conrad.

van Keuren: When did the Hayes retire?

Cherkis: '83 or '84.

van Keuren: So it was early.

Cherkis: Yeah.

van Keuren: And you contracted university ships after that?

Cherkis: Right. We used the Conrad in '85, '86, '88, '89.

van Keuren: This was funded by ONR. It was funded by NIMA. It was funded by, you said, did you say anybody else was involved?

Cherkis: Not that I know of.

van Keuren: ONR and NIMA were the main funders for this. And of course the Brazilians were putting in some of their own money for their ships?

Cherkis: They were supplying their ships, and they were supplying their personnel, but all the rest of it was ours. They got a copy of all the data that we produced. They had observers on board which was a standard practice. Two or three naval officers. We took graduate students from the different universities that were involved in the program -- two universities in Rio.

van Keuren: You published a number of papers on aeromagnetics and bathymetry. Did you collect any kind of other oceanographic data like water column information or sea floor bottom information?

Cherkis: We collected bottom information.

van Keuren: So you were doing sampling?

Cherkis: Yes. That's the way we determined the ages, the positive ages of the seamounts and the Bahia (B-A-H-I-A) seamounts. It's standard practice that we take a temperature measurement every four hours.

van Keuren: At which depth?

Cherkis: Down to 1500 meters.

van Keuren: So you did a series of temperature measurements down to 1500?

Cherkis: No, just one 1500-meter.

van Keuren: 1500-meter temperature.

Cherkis: Yeah. XBT.

van Keuren: Using what sort of technology?

Cherkis: It's an XBT, expendable bathythermograph (XBT).

van Keuren: Does that radio its information back? How does it work?

Cherkis: It works on a wire.

van Keuren: Works on a wire. So if it's expendable, you don't pull it back?

Cherkis: No. It just breaks off at the end of 1500 meters and continues down to the bottom.

van Keuren: How does it send its information back?

Cherkis: Back up the wire to the ship.

van Keuren: So it's radioing back?

Cherkis: I guess. It just comes back. It's a 2-way electronic probe. In the nose of the probe there's a thermocouple -- excuse me, not a thermocouple -- a thermistor.

van Keuren: Which probably contracts, and that feeds an electronic imprint which goes back and then there's a gauge there.

Cherkis: Exactly.

van Keuren: And that gives you a temperature.

Cherkis: Yeah. And it's a continuous profile all the way until it breaks off.

van Keuren: So it goes all the way down and is consistently sending back signals, so you have a temperature profile all the way down to 1500. Did you say feet or fathoms?

Cherkis: 1500 meters.

van Keuren: 1500 meters.

SIDE TWO

van Keuren: ... of this whole project, this 10-year study of the South Atlantic?

Cherkis: Well, there were a number of scientific papers that were published in both English and in Portuguese. There was the Bathymetric Map of the South Atlantic Ocean, the first time that the South Atlantic Ocean was, in my humble opinion, adequately mapped.

van Keuren: Who published the map?

Cherkis: We did.

van Keuren: The Laboratory?

Cherkis: Yeah. It was an NRL publication. Also, we published it through the Geological Society of America. It covered the South Atlantic Ocean from 3 degrees south to 40 degrees south. The reason it didn't start at the Equator was because we weren't working north of 3 degrees south, and the earlier map that our group had published, which was The Bathymetry of the North Atlantic Ocean, actually went to 3 degrees south.

van Keuren: When did the earlier map come out?

Cherkis: I don't remember. It was Perry, Fleming, et al.

van Keuren: And it was an NRL map also?

Cherkis: Yeah. Also Geological Society.

van Keuren: And that went from approximately the Equator, a little bit south of the Equator, to how far north?

Cherkis: The North Atlantic went to, I think, 64 north.

van Keuren: 64 North. And so, and then the bathymetry mapping you were doing in the Norwegian Sea went from north of there up to the Arctic, up to the ice?

Cherkis: Right. The first one we published, and that was 1980, that was Perry, Fleming, Cherkis, so forth. That was The Bathymetry of the Norwegian-Greenland and Western Barents Sea. It was also a Geological Society of America publication. And that was the first of the series of maps that our group published.

van Keuren: On the Greenland-Norwegian Sea?

Cherkis: All of them.

van Keuren: All of them. That was 1980. That was the first one?

Cherkis: That was the first one that was published as an independent map, a stand-alone map. And the information that we got between 1980 and 1990 -- and 1986 -- we were able to completely revise that territory and then from there on every time we published something else there was another revision of the information in a new map. We didn't republish that old map as a revised edition.

van Keuren: You just re-did it entirely. And so the North Atlantic map from the Equator to about 64 degrees came out approximately when?

Cherkis: I want to say around 1984.

van Keuren: And the South Atlantic map came out... ?

Cherkis: In 1988-1989.

van Keuren: And you'd also done, published some aeromagnetic maps of Fiji earlier?

Cherkis: Right.

van Keuren: So your group was involved in producing a number of bathymetric and magnetic maps around the world?

Cherkis: Right.

van Keuren: With emphasis upon the Atlantic, particularly the North Atlantic, but you [unintelligible] into the South Atlantic and you did some South Pacific?

Cherkis: Right. The bathymetry that we used for the South Pacific map, which underlay the aeromagnetics, was all based on random tracks across the area, mainly tracks going to the Antarctic from the Australia-Antarctic Discordance. But there were some other data... [unintelligible] couple of Lamont cruises that went down through there in the 70s. That was all we had, just using that and a good magnetic map.

van Keuren: That you got from doing this survey south?

Cherkis: Yeah. We could then make a reasonable determination of what the bathymetry looked like.

van Keuren: And this map was just south of Australia or did it include any areas east of Australia and north?

Cherkis: No, just south of Australia.

van Keuren: Okay.

Cherkis: Most of it was south of the Great Australian (unintelligible).

van Keuren: So this mapping was primarily done in the 1980s, some of it dating back to the late 70s?

Cherkis: Right.

van Keuren: And this took up a lot of your cruises, I note, in this period of time. But in the late 80s you were also involved in the CEAREX Projects.

Cherkis: CEAREX -- I don't remember what the words for CEAREX are (Central Eastern Arctic Reconnaissance or Research Expedition) -- and actually it was not Eastern Arctic, it was Eastern European Arctic. We used, it was an ONR-sponsored university cruise using both the U.S. Coast Guard icebreaker Northwind and a research ship, the Polar Bjorn, which is Norwegian for polar bear. It was a converted Norwegian sealing ship.

van Keuren: Sealing?

Cherkis: Yeah, like in seals -- go catch-go kill seals. And they converted her into a research ship, and we went north. The reason that the icebreaker was needed was because the Polar Bjorn was going to be iced in. We went up to about 84 degrees north, with the icebreaker, and made a little harbor in the permanent ice pack, and the ship was frozen in for three months. The Polar Bjorn was frozen in for three months. We left them up there, and they had aircraft supply and aircraft personnel changes. They were using twin otters.

van Keuren: Twin what?

Cherkis: Twin otters.

van Keuren: Is that a type of engine?

Cherkis: That's an aircraft. Used twin otter aircraft for short takeoff and landing capability to do personnel and supply changes. And the reason I was asked to go along is they didn't have anyone to collect bathymetry.

van Keuren: But they were stuck in the ice.

Cherkis: No, I was on the icebreaker.

van Keuren: You were on the icebreaker.

Cherkis: Right. And we needed to go, it was an opportunity to collect more data. The icebreaker did not have the greatest capability to collect bathymetry. They didn't have any specialized equipment. But it was quite successful as long as we weren't really bashing and ramming the ice. The ship was incredibly noisy. When you're bashing and ramming, you just don't get any sea floor return. The ship sailed from Tromso. We rounded Spitzbergen and then went northeast, and after a couple of tentative moves, we got into the heavy ice. We were looking for the least, a lead that would give us the least effort to get where we were going.

van Keuren: What time of year was this?

Cherkis: September/October.

van Keuren: Right, September.

Cherkis: September.

van Keuren: What was the point of the project?

Cherkis: Oceanography, physical oceanography. We were a support ship; the Northwind was a support ship.

van Keuren: But frozen in the ice, it was collecting data on the ocean column?

Cherkis: Right.

van Keuren: There was something in place, a scientific laboratory?

Cherkis: Right.

van Keuren: And how did they choose the one point where they froze it in?

Cherkis: It was as far as they could get. They wanted to get as far north as they could.

van Keuren: And they wanted to understand the water column?

Cherkis: Right. Also the circulation.

van Keuren: And the environment that far north.

Cherkis: Right. And the circulation patterns. And, in fact, when the ice started moving, it was moving them in the wrong direction into the Soviet area, Soviet zone, and eventually when the ice opened up and let them out, they were within 200 miles of Soviet territory but were able to go right along the ice edge and then get back to Norway, which they did in late December.

van Keuren: And so, once again, this was related to, I assume, collecting information for submarine mapping and for submarine transit through the ice? Why were we interested in it that far north?

Cherkis: Why is anybody interested in science? This was pure science.

van Keuren: So you're saying this was pure science?

Cherkis: Yeah. This is pure science.

van Keuren: This was pure science.

Cherkis: Nobody had been there before. I was the only military-connected person there. No, that's wrong. There was someone from ONR there as well. There was University of Washington...

van Keuren: The Northwind was a United States Coast Guard vessel?

Cherkis: Right. No guns.

van Keuren: Why was the Coast Guard interested?

Cherkis: The Coast Guard's got the icebreakers. Period.

van Keuren: So they would provide that anyway.

Cherkis: Right. The Northwind was built in 1944, and this was her last cruise. And she came back from that cruise and became a monument. She's a museum in Elizabeth City, North Carolina, or Wilmington, North Carolina, which was her home port.

van Keuren: Who were the university people involved?

Cherkis: University of Washington, University of Alaska, Oregon State University, Lamont, several Norwegian universities (Tromso, Bergen, Oslo). There was someone from Michigan State University there. There was someone who had come along in a Coast Guard Public Relations capacity. She was an artist, and she was doing sketches of the ice, which was absolutely fascinating. That's the thing about the Arctic. It grabs you when you, the first time you go up there you say, "Gee, who wants to look at a bunch of ice?" Every time you look around, the topography's different. And it's just an environment that most tourists don't get to go to, and here somebody's paying you to do it. When we came back, after leaving the Polar Bjorn, instead of returning the same way which is what the captain had originally thought he would do after I had a conversation with him, we traveled right down within 10 miles of the International Convention line through the islands east of Spitzbergen, and there never had been a track through there before. So we got a good bathymetric track between Victoria Island and White Island. And then we took a diagonal transit through the Barents Sea and got some good information to tie in some east-west lines that we had from previous cruises.

van Keuren: Did this information result in another map of the area?

Cherkis: It was used in a later update of a map. Of course, all of this information went into the military data bases for making charts for submarine transits.

van Keuren: So this would have come out in a classified map?

Cherkis: Yeah.

van Keuren: Not in the open literature that your group was producing?

Cherkis: That's correct, but we did then produce maps later on, in 1990, I believe, I did one of the Barents and Kara Seas, which is totally out of print.

van Keuren: And did that map have anything to do with the trip that you made on the Polarstern that year?

Cherkis: No. The Polarstern in 1990 went to the east coast of Greenland.

van Keuren: So that was much farther west?

Cherkis: Yeah. But I had been working on the Barents and Kara Seas just as a continuation of the earlier projects. The CEAREX line, as I said, tied in a lot of the information there. The Barents and Kara Seas chart came out in 1990. And then in 1994, working with an old Russian friend, we produced the bathymetric map of the Franz Joseph Land area -- he being Russian and having information inside the Archipelago of Franz Joseph Land.

van Keuren: This was also after the fall of the Soviet Union.

Cherkis: Yeah.

van Keuren: I want to get on to that, how things changed after '89, but let's talk about your trip first, your second trip on the Polarstern in 1990.

Cherkis: That was my third trip.

van Keuren: That was your third trip. You went in '84.

Cherkis: '85.

van Keuren: And you went in '85 again.

Cherkis: And then in '90.

van Keuren: And what was the '85 trip?

Cherkis: The '85 trip was in the Greenland Sea. We worked more on the Fram Strait, which is that area between Greenland and Spitzbergen. We filled in some lines there. The Polarstern, to give you a little background, is a ship that is owned by the German Ministry of Science and Technology or something like that -- Bundesministeriat. And the main operator of the vessel is the Alfred Wegener Institute for Polar and Ocean Research -- short name is AWI (A-W-I). And it's a multidisciplinary ship. It was built purely for science and resupply. Science, because it is an icebreaker. Resupply because the Germans have Antarctic stations that they need to supply. And so that's why the ship was built. They carry about 45 scientists, crew. The ship's complement is 41. The scientific party is 45. But they can carry as many as 75 scientists because they have extra bunks. These are mainly used for transits to the Antarctic when they bring people down there and leave them there to do on-continent work. But the ship has a multi-beam echo sounder which was Seabeam in those days. It was changed to a German system later on. So being a German national ship, they carry a full complement of scientists -- everything from graduate students through old-time professors. And the science that's done is multidisciplinary. Steaming is not the only thing that it does. It sits on station. It takes water casts. It takes TV stations.

van Keuren: How big is it?

Cherkis: 118 meters long.

van Keuren: It's a good-sized ship.

Cherkis: Yeah. Twenty-six meters wide.

van Keuren: It's almost built on the size (unintelligible) that the Russian ships were.

Cherkis: No. No. This was designed from the keel up.

van Keuren: And the Russian ships aren't? Like the Logachev, for example?

Cherkis: The which?

van Keuren: Like the Logachev.

Cherkis: I don't know. Logachev is not an icebreaker.

van Keuren: No. But I'm talking just purely oceanographic ships.

Cherkis: It was designed as an oceanographic research vessel.

van Keuren: It's large and has a full complement of oceanographers all across the board instead of being specialty, running groups of specialists.

Cherkis: Exactly. They have a wet laboratory, a set of wet laboratories that run up and down one entire hall so that they can look at everything in the water column. There are people that collect biologics from mid-water depths. They have a skidway for trawl.

van Keuren: They're all on-board simultaneously?

Cherkis: All the people are on-board simultaneously. The experiments, unless you can piggyback an experiment or a sampling, are done separately. And they have a large bottom sampler. They have a grab sampler. They have a box corer which takes a half meter cube of sediment. They take underwater television.

van Keuren: Do they do that off a sled or on a sled with a television camera on it?

Cherkis: Yeah. They can also mount a television camera on top of the grab sampler so that they can see what they're going to grab before they grab it. They may say, "Let's not grab it here; let's move a little bit" and so forth. The ship has position keeping. It has two thrusters for dynamic positioning.

van Keuren: So it had dynamic positioning so it could stay in place?

Cherkis: Yeah.

van Keuren: And on your three cruises with the Polarstern, you were involved with bathymetric support. You did the '80 cruise and you've been talking about the '84 cruise.

Cherkis: Right. The '84 cruise and the '85 cruise.
van Keuren: Excuse me, the '84 and the '85. You were in the Molloy Deep area?

Cherkis: Right. We were in the Molloy Deep area. We were on the Greenland Shelf in '84 and '85, but we worked the Greenland Shelf, we worked the Greenland Fracture Zone, and the Greenland Sea.

van Keuren: And the '90 cruise?

Cherkis: Also on the '85 cruise there was one graduate student that wanted seismic profiles on Vesteris Seamount, and we ran eight seismic profiles over that site as well. That's down in 73. That was that same seamount that we had found by magnetics 10 years earlier and then...

van Keuren: This was your return to it?

Cherkis: Yeah. That was in '85. And we got some very interesting data at that time, and they tried, they attempted a dredge and were unsuccessful, but time was running out, so they left. They found out later on, on the 1990 cruise, that the reason that they were unsuccessful is that the top of the seamount was probably subaerial at one time and smoothed its wave cut or waved smooth, so that's probably the reason that it didn't...

van Keuren: That's when you put cameras down and studied...

Cherkis: Yeah.

van Keuren: The '90 cruise?

Cherkis: Right.

van Keuren: So you returned to it in '90?

Cherkis: Right. We returned to it in '90, and we did a full multi-beam survey of it and published.

van Keuren: Was the Vesteris Ridge the...

Cherkis: Vesteris Bank.

van Keuren: Excuse me, the Vesteris Bank.

Cherkis: Called the Vesteris Seamount.

van Keuren: ... the main focus of that cruise?

Cherkis: No. That was one of the foci of that 1990 cruise. We actually started on the Kolbeinsey Ridge, collecting rocks for volcanologists. The Kolbeinsey Ridge is the present active spreading center for the mid-Ocean Ridge. It runs north of Iceland from Kolbeinsey Island to the on-lying fracture zone, at which point there's an offset in the ridge and to the east of Jan Mayen, the Mons Ridge picks up diagonal.

van Keuren: How fast does it spread? Is it a fast-spreading zone?

Cherkis: It's reasonably fast. It's somewhere around 3.8 centimeters per year.

van Keuren: And so you looked at that spreading zone. And were there any other foci?

Cherkis: There was a lot of oceanography, a lot of physical oceanography. There was some sampling in the Greenland Basin, but in the deep water. We didn't get into shallow water in the Greenland Basin, other than going over Vesteris Seamount.

van Keuren: So this really capped off 10 years of being involved in a lot of international surveys in one form or another.

Cherkis: I had another one after that.

van Keuren: Which one?

Cherkis: 1997.

van Keuren: And that one was?

Cherkis: On the Polarstern.

van Keuren: When did you get on the Polarstern and where were you?
Cherkis: Antarctica.

van Keuren: So the Polarstern went south in '97.

Cherkis: The Polarstern goes south every year.

van Keuren: Really?

Cherkis: Yes.

van Keuren: Every year.

Cherkis: Every year. They work in the north during the European summer and the south during the (unintelligible) summer.

van Keuren: So they're involved year-round.

Cherkis: Right.

van Keuren: That was the first time you went south with them?

Cherkis: Right. And truth be known, that was the only place I ever wanted to go in my entire life -- Antarctica.

van Keuren: And?

Cherkis: And I made it!

van Keuren: And was it what you expected?

Cherkis: It was more than I expected. The way that occurred is the Chief Scientist who is a very good friend -- we've become more than just colleagues -- we're family, really. He was sitting at my dinner table in '86 and told me that he had the ship -- excuse me, in 1996 -- and he said he had the ship to go south in 1997. My first question was, "How long?" And he said, "63 days at sea". And I just looked at my wife, and she just closed her eyes and gave me the approval, because unless she said "yes", I wouldn't have gone. But she knew how much it meant to me. And with travel it came out to 10 weeks. I got home 3 days before my first grandson was born, which was good because I had the video camera.

van Keuren: And what did you do on that cruise?

Cherkis: Bathymetry. We collected over 11,000 track miles of bathymetry. We surveyed the South Sandwich Trench for the first time -- first time that's been done systematically. We did work in the back arc basin of the South Sandwich Islands. And we surveyed the South Shetland Trench off the Shetland Islands.

van Keuren: So you were surveying it; you went south.

Cherkis: Right. It was also the worst ice year in 20 years. We had to break 150 miles of ice just to get into the Antarctic Peninsula. The ice hadn't yet started coming out, and when we got down there we couldn't get close enough to shore to off-load supplies to the German station. We couldn't get to their ramp which they had that went from the ice shelf down to sea level. So we off-loaded the containers on the sea ice and unloaded 70 tons of equipment by hand, box by box, onto sleds, put onto helicopters, flown up to the base. A hundred fifty trips in two days. And it was just an amazing thing to be standing there and having two Emperor penguins standing behind you looking at you, asking you what you're doing! It was truly amazing. Saw penguins. Saw seals. Again, you know, icebergs the size of New Jersey. It is the most impressing thing you'll ever see in your life from a standpoint of pure physical observation. There are people who would say that the canopy in New Guinea or the Matto Grasso, the tree canopy there is great -- and it probably is -- but for me, that was the greatest personal experience just from a purely selfish point of view.

END OF RECORDING

7E. Norman Cherkis

AN INTERVIEW WITH NORMAN CHERKIS

by Dr. David K. van Keuren
History Office
Naval Research Laboratory
4 January 2002
Interview #5

van Keuren: Today is January 4th, 2002. This is David van Keuren at the Naval Research Laboratory, and I'm talking to Norman Cherkis about his life and career. This is Interview Number Five. Norm, last time we finished up talking about your four cruises on the Polarstern, with the last being in 1997/98 to Antarctica. I want to pick up there and talk about your work in the 1990s and leading up eventually to talk about your retirement and what you've been doing after retirement. So you did a 1992 cruise in the Polarstern?

Cherkis: 1990.

van Keuren: 1990. That's right. 1990 cruise on the Polarstern. And what after that?

Cherkis: The 1990 cruise on the Polarstern was an invitational cruise. I was invited to go aboard for the third time, and it was because of -- they called it my expertise in bathymetry and in the Norwegian/Greenland Seas. We were basically looking at the area north of Iceland on the Kolbeinsey Ridge, the Jan Mayen Fracture Zone, and Vesteris Bank or Vesteris Seamount. (That's V-E-S-T-E-R-I-S.)

van Keuren: Okay. We talked about this in the last interview.

Cherkis: Okay. And we used the multi-beam echo-sounder and completely covered the Seamount. We had 110% coverage and found some very interesting patterns. There was also some very interesting geology that went along with it that the vulcanologists have discovered. After that cruise I was not involved in lab field work as much any more. The work that I was doing became more of an administrative activity, and I became involved in things like shipboard funding for the lab. Dr. Hartwig had come aboard as ADOR (Associate Director for Research), and I was given the task of first building the spreadsheet, designing the program to give the money to other researchers that were going to sea to not give them the money but pay for their ship time. And I was getting a million dollars a year from Hartwig's 6-1 fund.

van Keuren: This is ONR money?

Cherkis: This is ONR money. Right. And with that million dollars a year we decided what cruises were deserving of the money and which ones were less deserving. And we funded or I funded the cruises for people at Stennis and people at NRL up here. This was mostly shipboard money but we also funded airborne projects for aerogeophysics using the P-3s and the remote sensing people who were doing work with the aircraft on a project called SAR-SEA (Synthetic Aperture Radar - SEA). Those were fairly interesting projects.

van Keuren: What were they using the Synthetic Aperture Radar to look for?

Cherkis: They were looking at the altimetry of the sea surface, measuring to see if they could determine what the depths were. This was all done on continental shelf. One of their projects actually worked with the space shuttle. It was a combined effort. The space shuttle was getting the gross footprint from the orbital area, and the aircraft was flying at 300 meters getting a much more clearly defined spatial signature of the altimetry of the sea surface and how that could predict sea floor topography.

van Keuren: And were there any results from that, that you know of?

Cherkis: The results were published at the Lab. Several documents came out. I don't remember them off-hand.

van Keuren: Do you remember what they said? Can you use measurements of the sea surface in order to predict sea floor topography?

Cherkis: Not on a one-to-one scale. Grossly, yes, you can tell where there are depressions in the sea floor, where there are rises in the sea floor, but to measure the actual height of the floor depth of the feature is not something that we can do right now. And in fact the GEOSAT satellite which flew in the late 80s, I believe, all the data has since been released, they were measuring gravity and altimetry, and the people who have done the analysis (Dave Sandwell at Scripps and Walter Smith at NOAA) have created a number of maps. The first map was strictly an altimetry map and showed grossly the major features of the sea floor. In the year since they started working there, they've been plugging in the bathymetry. And by plugging in the known bathymetric soundings, they've been able to refine it, but only 15% of the sea floor has ever been covered by a ship, so there's a lot of areas that are just mapped by altimetry. Now while it's a real pretty picture, it does not accurately reflect the depth of the sea floor.

van Keuren: Does it give enough information to tell an oceanographer that this is an interesting area to go back and look at?

Cherkis: For the most part. For the most part. The altimetry, one example, on the last Polarstern cruise that I was on in 1997/98, on our way to Antarctica, after leaving Capetown, South Africa, we were sailing for something that looked like a moderately sized bump as shown in the altimetry map. And in fact it was a 2600-meter seamount. There was a lot of smooth topography around it which probably dampened the signature of the altimetry readings. The data that we collected by multi-beam echo-sounding revealed this fairly substantial seamount but, again, it was smooth around the edges so we didn't see this great correlation. There was another episode on our way back from Antarctica where in the Cape Abyssal Plain off of South Africa showed possibly a small rise, and again this was a 1300-meter high peak. We estimate that probably there's about two kilometers of sediment around the edges, though, so the area is just not active, tectonically active, any more. The altimetry, as I said, shows gross relief very well but does not give you the fine relief that we're looking for if you're building a good bathymetric map.

van Keuren: So it's not going to take the place of doing good ship-based or air-based altimetry.

Cherkis: Right.

van Keuren: At least not in the near future.

Cherkis: No. There's not enough ground truth data to tie it in. I actually used the GEOSAT data when I was building the chart of the South Atlantic Ocean -- the bathymetry of the South Atlantic Ocean that we published in our group -- and there were some areas where I didn't have a sounding for 120 miles and yet I was able to move the contours based on what the geophysics and what the GEOSAT told me. I was able to move contours through those areas, in a rough scale. Ships have gone through since then, and some of the academic researchers swear I was using classified data because the correlation is that good. And I said, "No, I was just using the available tools, which was the GEOSAT."

van Keuren: I've actually come across that belief before that there are academics who believe there are these great archives of classified data about the sea floor and sea conditions that are hidden away. Are there such things?

Cherkis: For the most part, no. In my first interview I was talking about something called the OSP, the Ocean Survey Project of NAVOCEANO. That project, as I said, was based, was designed, for submarine navigation, so that submarines could navigate knowing where the topography would get in their way and where it wouldn't. And they used multi-beam sonar for quite a bit of that data, to collect quite a bit of that data -- not all, but quite a bit of it. And those data are classified and probably will never see the light of day, although Admiral Gaffney tried to get it released at one time, but was unsuccessful. But those data are really the only super classified systematic surveys over large areas. There were, of course, the small surveys where the SOSUS arrays went in. And the Navy had other high areas of interest, where the Grace had sunk. Do you remember the Grace?

van Keuren: I've heard of it.

Cherkis: It's the nerve gas ship that sunk. And for obvious reasons the Navy doesn't want anybody knowing the detailed bathymetry there unless they go out and collect it themselves. And you can't stop them because it's deep water, international waters.

van Keuren: The Ocean Survey Project information -- is that detailed bottom topography?

Cherkis: Very detailed bottom topography.

van Keuren: Are those extensive areas?

Cherkis: The entire North Atlantic Ocean.

van Keuren: Really? So that is a major reservoir of information on ocean topography.

Cherkis: Yes.

van Keuren: And the Navy did not want to release that because it would tell too much about submarine groups?

Cherkis: No. The Navy doesn't want to release it because it would allow hostile submariners to use the same information. We can't stop other people from going out and collecting the data, but to do it systematically takes a lot of time and a lot of money. We out-spent the Russians -- out-spent the Soviet Union. Of course their collapse... so that's really the basis for that. At times pieces of it were released. Peter Vogt and someone else -- I think it was Eric Schneider (S-C-H-N-E-I-D-E-R) -- they were at NAVOCEANO at the time, and they published a paper in the Geological Society of America Bulletin.

van Keuren: I'm sorry, what?

Cherkis: The Geological Society of America Bulletin -- GSA Bulletin... on topography or bathymetry of the Reykjanes Ridge from 47th and 51 degrees, I believe, was where they had operated, although it could have been -- no, it couldn't have been 47th. It would have had to have been north of 52 degrees. And they published it with the blessing of the Commanding Officer of NAVOCEANO at the time. But they couldn't show the actual tracks and the actual data, and several internationally known geophysicists at the time, knowing that the Navy had this data but they had no access to it, published letters in the Journal saying, "How can we prove that these data even exist? How can we see, how can we ground truth this if we don't even see where the track lines are?" And the community at large felt that it was more important to have the data as it was presented than to discount it completely because of the lack of information about where the tracks were. But for the most part the data were never released and never will be released. The data that were released, this Vogt and Schneider paper, they actually sanitized the contours. They took out the little wiggles that defined bathymetry. If there were sharp turns that showed up in the collected data, the sharp turns were removed. And it was only on the Reykjanes Ridge, a segment of the Reykjanes Ridge.

van Keuren: Interesting. So, actually the theory that there is data out there is partially true.

Cherkis: Oh, yes.

van Keuren: There is this OSP data. But that's the only reservoir that you know of?

Cherkis: Yeah.

van Keuren: Cool. So during the 90s you were working on administrative functions for the branch?

Cherkis: Right. The shipboard funding project was the biggest of them. I also worked on collecting data for our other programs. Having been in the business as long as I had there, I developed a fairly substantial data base of personal contacts who would provide data with the understanding that the data would not go out into the public domain, that we could use the data but not publish it.

van Keuren: What kind of data?

Cherkis: Bathymetric -- magnetic, seismic data. We could not publish the data, but we could use the data. But these were all a result of personal contacts.

van Keuren: And what sorts of purposes would the data be used for?

Cherkis: Building larger area charts, looking at other geophysical problems that the branch was evolving into, and also some classified programs that we worked on needed the data. Even though it was unclassified data, we needed it to complete a data set here or there. A classic example would be the Persian Gulf. We were desperate. We had a tasking to build a bathymetric chart of the Persian Gulf, and there were lots of foreign institutions that had worked in the Persian Gulf and had track line information there, but were not sharing it. But I knew the right people to ask and the right things to promise, mainly "we will not publish your data, period". And the data were put into the charts that were used just after Desert Storm because we had an increased presence in the Gulf. But it was mainly something we could use to navigate our own vessels and to just look at it and say, "this area would be used as an area where an enemy could lay mines or hide a submarine, a foreign submarine could lay in wait, which would be a hazard to our interest." I got the data for the Persian Gulf region. We did other work that was in the Greenland Sea and the Barents Sea. This was part of a NATO project. And, again, I was able to find data that was not normally available to any...

van Keuren: And it went into building better maps?

Cherkis: Yeah.

van Keuren: So it kept you busy in the 90s. You retired in '97?

Cherkis: '99. January 2nd, 1999. That's three years and two days ago.

van Keuren: Congratulations! Almost an anniversary.

Cherkis: Huh?

van Keuren: It's almost an anniversary.

Cherkis: Just was.

van Keuren: Yeah. And what have you been doing since you retired?

Cherkis: Immediately after I retired I had already found that my services would be needed by former funders and by the Lab. And the Lab has a contract with one service provider who hired me with the proviso that I brought in my own project funds. And my former provider of funds didn't want to set up a personal services contract with me because the paperwork would be horrendous, so they send the money through NRL and into the NRL funders account, or the NRL contractors account, and I get paid that way.

van Keuren: Who's the funder?

Cherkis: The funder is NIMA.

van Keuren: NIMA. And what do you do for them?

Cherkis: Whatever they want.

van Keuren: So you're kind of an expert on call?

Cherkis: When they bathymetric information or Russian charts or other geophysical information, they call on me, and I know the right people, so I can get the data. Again, it's usually with the same qualifiers or caveats that the data are not going to be released. So most of the data that I get for NIMA is proprietary, and NRL gets a copy of those data for their data base, which is also kept in a proprietary data base.

van Keuren: So it's available for general purposes but not for publication?

Cherkis: Right. Well, and the source is not revealed. Also, starting back in 1984, I became involved with GEBCO (G-E-B-C-O). That's General Bathymetric Chart of the Oceans. It's an international program funded in part by IOC (Intergovernmental Oceanographic Commission) and IHO (International Hydrographic Organization). And this is for building a better general bathymetric chart that can be used by the public, originally it was for academic exercises but more and more people are using them now for law of the sea claims. But, again, they are generalized. And I became involved with them in 1984 on one of their subcommittees, the Subcommittee on Digital Bathymetry, and have continued to be active with them analyzing and collecting data. They use the South Atlantic Chart as part of their series on the ocean. But also in this program is the Arctic Ocean. And through the GEBCO offices, the IOC became interested in sponsoring an international bathymetric chart of the Arctic Ocean using whatever data are available. The area that was the least known, well, outside of the deeper Arctic Basin, the area that was the least well known or understood, was the Siberian Continental Shelf. The data existed but only in hard copy on Russian hydrographic charts. And through contacts in Russia I was able to purchase 158 Russian hydrographic charts in the Arctic Region. So the first project that I did, which was a pro bono project (in other words, I wasn't getting paid for it), was to take the 158 charts and convert them into contour maps. These were hydrographic sailing charts, you understand. So I took them and turned them into bathymetric overlays at scales ranging from 1 to 5000, to 1 to 5,000,000 -- whatever charts were available were contoured. And with a doctoral candidate at the University of Stockholm, Sweden, we scanned the charts, put digital labels on each of the contours, reduced them to a common scale, and produced a chart of the Siberian Continental Shelf. And at the third meeting of the International Bathymetric Chart of the Arctic Ocean, we presented these data for inclusion in the chart, and the Russians nearly had an apoplectic fit.

van Keuren: I was going to ask you about that.

Cherkis: They accused me of knowing where all the U.S. submarines were working in their territorial waters, and I said, "No, they weren't territorial waters -- we had no submarines working in their territorial waters -- and even if I did know where, I wouldn't tell you. But as far as I know they weren't. And the data were all taken from Russian hydrographic charts." And they said, "Where did you get the Russian hydrographic charts?" And I said, "I bought them." "Who did you buy them from?" They wanted to know what person was stealing the charts for me. And it turned out that no one was stealing the charts. I had the invoices with me. "I bought them from the Russian Hydrographic Office." And they were absolutely amazed that the rendition of the data were that good. They showed old glacial valleys that went into the rivers in estuarine areas. But eventually they calmed down about that and realized that their cat was no longer in the bag, that we had pulled a coup out in the open without ever trying to do anything covertly. It was something they just had to live with. And then, about two months later, I received a request from the Russians to edit a new chart of the Arctic Ocean, contour chart of the Arctic Ocean, that they were producing. And I agreed. They sent the data for the chart, prototype charts, and I did the edits for them, fixed a lot of their errors where I could find them, and also gave them an English language version which they wanted, so they were very happy to have that, and we had the data two years before it was published.

van Keuren: "We" being?

Cherkis: "We" being the U.S., the U.S. Navy, because being a prototype, it was not yet ready for sale or release, and they said they couldn't pay me any money (the Russians never have any money), so what did I want as an exchange product? And I said I'd like to have 50 copies of the map when it's printed, which I then distributed to people within our community, the Arctic community.

van Keuren: How has it changed dealing with the Russians on oceanography -- from Cold War and post-Cold War? What are your major ideas on that?

Cherkis: The Russians are a very secretive people as a group, and that goes back to their heritage, their days in the Soviet Union when they weren't allowed to show anything, and they became very secretive about their data. When they did publish in their own journals, they used diagrams rather than actual contours. They never showed data. And in fact to this day, other than the data that are all on the hydrographic sailing charts, they provide no data, no actual sounding lines. In our conversations we knew that the Hydrographic Office had something on the order of about 30 million track miles of bathymetric data collected worldwide, and these data were never shown any where. The track lines were never shown. Probably most of it is in hard copy in analog form that has not been digitized. But they have not ever released any of these data, and these are data that are outside of their continental limits, data that are thousands of miles from their shores or anybody else's for that matter, in the South Atlantic Ocean, for example. Now, I had contacts in the former Soviet Union at the time it was still the Soviet Union. I actively searched out people that I could talk to, people who were working in areas where I was working to see if we could perhaps make some sort of an unclassified data exchange, talk in the open. In 1987, I think, there was a meeting of the International Union of Geology & Geophysics held in Washington, and the meeting was held at the Smithsonian Institution. And they were having a reception one evening, and a friend of mine who works at the Smithsonian invited me to come down and told me that guys from Russia were going to be there who were working in the South Atlantic and would be interested in talking with me. At that time I was building the big chart of the South Atlantic, so I brought down a prototype mock-up copy that was something like 40 page-sized sheets taped together and showed them, sat down with them on the floor in front of the elephant at the Smithsonian, and showed them where we had data and where we were looking for data. And one of the Russian guys said that they have an expression in Russian that doesn't really translate well but it's like "making something that is already made". And I said, "Well, we call it reinventing the wheel." And he said, "Yes, it's very similar." But what they had were multi-beam data that they had collected. It was brand new multi-beam system that they had on their ship, built within, as was the system, and these data were overlapped by about 25% with the data that we had. And he said, "Had we known, we could have done more work in a complementary area, and we could have exchanged data and done it more successfully." So I said, "Well, what's the chance of getting your multi-beam data?" He said, "Probably none, but I will check." Two years later at a GEBCO meeting the Russian delegate to the GEBCO handed me an envelope, and he says, "This is from the Vernadsky Institute." And it was hard copy of a cruise report with a translation of the cruise report and a hard copy track line diagram of their multi-beam bathymetry. And it was a case that they were giving us the data to be included in the new bathymetric chart that was being produced.

van Keuren: So they gave you some of the data but not all of it?

Cherkis: They gave us all of the data from that cruise there. You could see places where...

van Keuren: But, I mean, not all the data that they possess on the South Atlantic.

Cherkis: That's correct. That's correct. But for this one cruise, this was kind of opening the door to more exchanges. A lot of us were real happy about getting the Russians to produce the data, and I started adding it in to our data. I had to do some photographic correction to get the scales comparable, but the data were perfect fits where they overlapped ours. I was putting this in, and then I got a phone call from the oceanographer of the Navy, and the statement was, "We understand that you got some Russian multi-beam data. Can we see it?" "Sure." I didn't ask how they found out. I just said, "Sure." So I brought it down there, with a copy, and the comment was, "We've been trying to find out for the last three years whether the rumors about them having a multi-beam system were true, and you have the data. How did you do it?" I came back with a question, "Well, how have you been going about it?" And they said, "Well, through normal intelligence channels." I said, "That means you've been trying to steal it. Why didn't you ask them for it?" And the Admiral said, "You asked them for it?" "Yep." "And they gave it to you?" "Yep." "And what did you offer them in return?" I said, "The hope of future cooperation." "And that's all?" "And that's all." And then the Admiral said, "Well, it's probably no good. They probably distorted it the way they've been distorting all their maps over all the years." And I said, "No, actually it's very good." And I showed them the one-to-one correlation, within the limits of navigation, within a quarter mile it was a one-to-one correlation. And they said, "What have they been using for navigation?" I said, "GLO NASS, their GPS system." They were using their data and they just gave it to me. The guy at Vernadsky has remained a friend to this day.

van Keuren: What was the day of the gift?

Cherkis: The day of the gift was 1988.

van Keuren: So it was before the Fall?

Cherkis: Oh, yeah. In fact, I visited the Vernadsky Institute on two occasions, 1994 and 1997. And brought presents, that sort of thing. The Vernadsky Institute has a classified wing and an unclassified wing. And they have a guard with a visible weapon in front of the classified wing. But I was shown right into the unclassified wing without any problem at all. But it's something that can only be done on a personal level, can only be done scientist to scientist. Otherwise, if you go through official channels, it winds up in some bureaucrat's in box.

van Keuren: Would you say then that, compared to Cold War and post-Cold War, you haven't seen any major changes in institutional behavior but there's more openness to scientific exchange on a personal level? Is that what I take from your discussion?

Cherkis: Yes, that's correct. There's been more freedom for the scientists to travel, and they speak about the old days when they had to get 12 layers of approval to travel to an international meeting in Germany from St. Petersburg, and now they just have their passport and get on a plane and go. They talk more freely, but on a one-to-one basis...

SIDE TWO

Cherkis: There was an openness among the scientific community, and we discussed our problems, where we need bathymetry. We'd meet at the international meetings and discuss the problems of the science without the politics. And my collaboration, if you will, with Russian scientists goes back actually to 1974. I don't know if I mentioned that earlier, but I used to receive mail here at the Lab from Russian scientists and had to go to the security office to open it up. Had I mentioned that before?

van Keuren: I'm not sure. I don't think so.

Cherkis: I met someone in a meeting in 1971 and asked him for a copy of the chart he had shown, and he told me it wasn't possible. Three years later I received a copy of the chart, with a letter, and it came to the Lab. And I opened it in front of the people in the security office. There was a letter there in English, bad English, but English, and they were asking for copies of journal articles from the Geological Society of America Bulletin, the Journal of Geophysical Research, General of Sedimentology. This scientist was in Murmansk, and there was a really good chance that they didn't have copies of the journals. So I asked, "Can I do this?" to the people in security. They said there wouldn't be any problem there. Of course there was a problem when I tried to send it out from the Lab in their Navy frank mail. They balked at that, but they told me I could send it out under private mail without any problem. And so I did it that way. But I was debriefed by all of the intelligence agencies about my contacts with the Russians, and then I got requests for other journal articles which I refused unless they dealt with oceanography because I didn't want to compromise the people with whom I was dealing. Those people were, if nothing else, sacred contacts that I wanted to keep. But they were also scientists, and you don't really want to get a scientist into trouble with his own people, especially in an area like the Soviet Union, because that would be counterproductive. So I dealt with this guy from 1974 and never met him until 1991, other than the original meeting in 1971, but I met him again in 1991 at the Office of Naval Research. He brought a set of charts with him, and after the meeting at ONR he showed these charts to me and said, "Can we get in the West?" And I looked at them and tried to keep my eyes from popping out of my head, and I said, "Of course". He said he'd like copies of them, and I brought him back here and gave him Xerox copies of them plus photograph slides and viewgraphs for him of those before he left to go back to Murmansk. And then I spent the next month working on it at home. His geographic grid was hand-drawn and needed to be redone to proper scale. It took a little bit of work, but I put it all together and made it into a proper map and put the bathymetry around the area. These data that he gave me were of Franz Joseph Land. Franz Joseph Land was one of those areas that the Navy knew nothing about other than some very old chart and survey information that they had back in the 1930s. And what these new data showed is that there were glacial channels in between some of these islands that were deeper than 600 meters and very possibly, or at least the intelligence thought, the Russians were actually using these channels to exit their submarines from Murmansk into the Arctic Ocean, and that's why we weren't able to find them once they left port, because they sailed north and then disappeared. And that's where they were probably going through the islands because they knew what the bathymetry was. He gave me contours. There were no soundings. But I trusted his contours, and I put all the data outside the area, and we published it as a joint publication with the Geological Society of America in 1994 -- the bathymetry of the Franz Joseph Land area and region. And I insisted that his name went first. He wanted my name to go first. I insisted that his name went first, with the logo from his institution, which made him incredibly happy. I found out that publication costs would run about $12,000, which is what I charged NIMA for digitizing the chart. So we were able to get it published without penalty to Lab funds, and NIMA got the contours in digital form, something they really wanted for their charts. And they actually got it at a very cheap price because it cost them nothing for the collected data. So things like this build friendships. I've worked with the Russians on a number of occasions. When I went to sea on the Polarstern I took an atlas with me that they had given to me to turn into English. They gave me the words on a floppy disk that was machine translated, and all the technical words were untranslated. And I had a copy of the hard copy of the atlas, and I worked on it over 600 hours. I was aboard the ship, on the Polarstern, so I had the time to do it. But it took over 600 hours to put that into proper form.

van Keuren: So contact, cooperation, still remains on a one person-to-person basis now?

Cherkis: That's correct.

van Keuren: In the Post Cold-War period? You don't see any major thawing in the behavior of Russian institutions?

Cherkis: The institutions themselves have always been free to talk. As far as producing data, they have not been free. These are actual data points.

van Keuren: That's still true.

Cherkis: That's still true. And they still have to go through a layer of bureaucracy that still has the Cold War mentality. The Hydrographic Office in St. Petersburg is run by a 4-star Admiral who is a former Commander of the Soviet Submarine Fleet Pacific. He gets his orders from the Northern Fleet Command. The Northern Fleet Command will not allow data to be released. It was the Northern Fleet Command that was responsible for their submarine Kursk sinking last year.

van Keuren: You spent a lot of time on the Polarstern, comparatively. How would you compare the way the Germans pursue the oceanography and the way the Americans pursue oceanography, or the Russians, for example? Are there any major national differences there?

Cherkis: The Germans are more intense. I've been on U.S. academic vessels where things are a lot more laid back. The Germans are very intense. They're very regimented, rigidly working their time and getting their results. The Polarstern carries about 45 scientists comfortably. They can carry as many as 75, but that's usually for transiting. But for working, about 45 scientists work on the Polarstern. They have an enormous capability for physical oceanography, for biological oceanography. I don't remember how much the ship cost to build, but they spent probably an equal amount of money on outfitting it for science. They can take 100-foot cores. They have a skidway on the fantail for bringing nets in and out so that the biologists can work and collect their samples. These are usually mid-water trawls or even bottom sample trawls. And it's a very professional operation. They're very free to show you what they're doing. They have no secrets about, "This is my data, and I'm going to hide it, guard it." Whereas a lot of more senior scientists in the U.S. have that mentality that they don't want to show you anything until they have exhausted all possibilities and all publications possible. The Germans are very open. "Let me show you what we're doing! We found these diatoms, a diatom colony on the sea floor. Look at this." They're so open and excited about their science. They carry a lot of graduate students, a few undergraduates, but mostly graduate students. Probably two-thirds of the complement of the scientific party are graduate students. And they are very international in flavor. On the four cruises that I've been on, the majority are German students, but we've had Swedish, Finnish, Icelandic, Norwegian, French, British, Swiss, Italian, Russian, Estonian, Danish, Japanese, and one Turk. Oh, and one Mexican. So their cruises are all very international in flavor. And this is something that is dictated by the German Ministry of Science and Technology. They want these cruises to be international because the ship is their showcase. And the more international cooperation they can show, the more funding they get. It's as simple as that. But the Germans are very intense about their science. They go at it with a lot more fervor than Americans. Americans will generally work for a while then get up and have a cup of coffee. Germans sit there and work for four hours looking through a microscope without ever getting up for a head break or to get a cup of coffee or anything. And the conditions under which a lot of the sampling is done is a lot less than optimal, and yet it's all done very, very professionally. I cannot remember ever having been on a U.S. ship where any of the scientific party were required to wear lifelines or hard hats, whereas on a German ship you cannot go on deck unless you have a safety belt and a hard hat. Otherwise you cannot go on any of the working decks. Of course you can go on the decks outside your state rooms. The state room decks are above the working decks. But you can't go on the working decks unless you're wearing the hard hat, and if you do someone immediately comes and hands you a hard hat. It's as simple as that. And their deck crew are international as well. They're German, Spanish, Portuguese, Basque. There's one Frenchman and one Chilean who were working on the ship. And they all take their job very seriously. There was an American woman on one of the cruises who wanted to assist in the launch of her gear. She was putting a sediment trap into the Norwegian Sea, and she wanted to help launch it. And they wouldn't let her. And she felt that they were doing it because she was a woman, but the fact is they were doing it because their job is to launch. She can watch, but she can't put her hands on it.

van Keuren: Right, the same way that the engineering crew launches everything. Scientists have to watch. So Germans are like the Russians that way.

Cherkis: Yeah. It's something that, they take a lot of pride in their work, though, too. When they put the stuff over the side, they watch it until it goes below. When it comes up, everyone has their own station to handle the data when it comes aboard. Their core lab is bigger than some of the ships that I've been on, just for handling the core!

van Keuren: Peter Vogt has been very active in what he called GOMAPs, an attempt to try to get a consistent overview mapping of the sea floor bottom. And I'm sure you've been involved in that, too. What do you think about that overall? Is it viable? Any general comments about the program at large?

Cherkis: Is it viable?

van Keuren: Politically, economically?

Cherkis: Politically I think it's viable. Economically, I don't think it'll ever happen. Peter gave some statistics that showed in order to do a systematic multi-beam echo-sounding of the deep ocean -- that's off the shelves -- would take 219 ship years, 219 years of ships operating 300 days a year. There are not that many ships available. There's no money to do it. We can spend $400 million to put a tractor on Mars, but we couldn't spend $200 million to fit a submarine to do a systematic five-year program mapping the Arctic Ocean. So in our country the mechanism is not there. We don't care about the bottom of the ocean as much as we care about the back side of the moon. And it's a real downer for people who work in the community and know this. I can get on the soap box and preach this for hours, that we in the ocean community are getting short-changed when it comes to science. Now, 219 ship years, in the old days it could have been done. At one time the Russians had 135 ships in the Hydrographic Fleet alone, which is a lot more than most other countries have in their entire Navies, but most of those ships have been laid up, scrapped, or are just sitting idle. There are not that many multi-beam systems available. It would take a lot of money and a lot of time.

van Keuren: If the classified data in the OSP project and in the Russian products are released, to what extent would that move towards meeting this goal?

Cherkis: It would be, you would have the North Atlantic reasonably well covered. As I said, there were some areas where data were collected by single beam, and those areas would need to be resurveyed, but that's not a lot of the project. There are some gaps in the OSP data that would have to be filled in, but could probably be filled in by someone who understands bathymetry without going back and resurveying. The gaps are probably on the order of 2 or 3 kilometers wide. But on the overall scheme of things, the North Atlantic, which is not a big ocean compared to the Pacific, is fairly well covered. So getting that out of the way, we would have to do the South Atlantic, the Indian Ocean, and the Pacific Ocean. And there are probably, or at least according to the GEOSAT data, on the order of about 15,000 unsounded seamounts in the South Pacific Ocean.

van Keuren: Fifteen thousand?

Cherkis: Yeah. These are things that rise 1,000 meters or more off the sea floor. Probably a lot of them are in the 1,000 to 1,200 meter relief range, but the GEOSAT shows that these seamounts are there. It's just that no ship has ever gone across them. The Pacific Ocean is a real big ocean. It's a really big ocean. And the survey ships or the academic ships don't normally go to places like that unless they have a reason. And to get the reason to go there they'd have to get funding. Or to get the means to go there they have to get funding, which means they have to provide to the National Science Foundation or some foreign science funding organization with the reason to go there. There's a seamount chain in the Southeastern Pacific Ocean called the foundation seamounts. They run west of Chile, and they're on the west side of the Mid-Ocean Ridge, the East Pacific Rise. And it's an enormous chain of seamounts that have been worked on by French and German scientists for a number of years, and a few Americans are occasionally aboard as well. But there are a lot of seamounts in that thing, and they were only discovered within the last 10 years. And we're talking a major set of seamounts. And that's one that's fairly close to shore. It's within three days steaming of Valparaiso. We're used to looking at places out in the middle of the Pacific where there are no islands. It takes a long time to get there. Now, the French have been working within their EEZ, all of their Pacific islands. They have been doing multi-beam within their areas of interest so that they can provide proof for their law of the sea claims. And it's a continuing program. I've seen a number of the data, but the data are not for public release, not for even public consumption. But having friends in France, they like to show off what they've done, and they know that I'll say "Heed" to our people here. They have got a great data set within this area. That's why I'm sort of carrying the message to Garcia that...

van Keuren: They're not releasing any?

Cherkis: No, they're not releasing it. Now, I can get the center beam tracks from them on a proprietary basis.

van Keuren: So doing any consistent, persistent ocean floor mapping is unlikely?

Cherkis: It's very unlikely. It's very unlikely. In the next 20 years, all of the claims will be submitted to the UN for territorial claims on the Law of the Sea Convention of 1982. And until all those data are collected, no one is going to go and survey the deep ocean as a national campaign.

van Keuren: Any overall comment, any concluding comment you'd like to add?

Cherkis: Do you have 3 days? In addition to my working through the contractor here at the Lab, I also have my own private consulting business, and in my private consulting business I've done work for the private sector, for one green organization (the National Resources Defense Council), for other government agencies who want things like Russian hydrographic charts or data from other places that are normally unavailable or they don't know where to look. They're mostly small contracts, and I'm comfortable with that. They are all non-conflict of interest with my work under the NIMA contract. I also am involved with the University of New Hampshire, for example, working on locating data for the U.S. EEZ. And they were interested in the conterminous U.S.-Hawaii-Alaska until I also remembered that there were places like the Virgin Islands, Puerto Rico, the Northern Marianas, Guam, Baker and Howland islands that are also U.S. possessions, and that we have to make claims for those as well. So this could turn in to be a larger project than we first imagined, but in the meantime what I'm trying to determine is where we have data so we can then go and direct academia or U.S. ships to work to fulfill our requirements for making a claim to territory. And one of the main areas, of course, is the Arctic Shelf. We have the Arctic Shelf, the Slope, put the language of the Law of the Sea Convention states that your normal claim is 200 miles from your baseline, your 12-mile limit. Beyond that you can go another 150 miles if you have continental shelf that goes that much further. Or to the base of the continental slope at a depth of 2500 meters unless you can prove that there are deposits deeper than that level that are of economic value to your national needs. And so the area on the north slope of Alaska, which also includes a part of the Chukchi Sea is of interest. There is a plateau that extends out into the Arctic Basin from the area of the Chukchi Sea which is within 350 miles of the U.S. but is an extension of the continental shelf, or appears to be an extension of the continental shelf, which might have petroleum deposits, and we are very interested in that. But we need to show what the area looks like underwater, number one, and number two, we have to have geophysical information that gives us the right to claim it. A portion of it also falls within 350 miles of the easternmost Russian territory of Herald Island. And so there will have to be some international wrangling in that venue as well.

van Keuren: You have a lot of work ahead of you.

Cherkis: Yeah. And it's fun. As far as my retirement goes, my contracting, my consulting, I don't wake up early in the morning any more.

van Keuren: Do you miss not going to sea?

Cherkis: Yes, but not for the lengths of time I used to go. I have been invited by the Explorer's Club to go to the North Pole as a guest scientist, and I'll probably be doing some lecturing. And this is aboard a Russian nuclear icebreaker. And at the North Pole they're going to put the Russian Mir submarines into the water and take tourists to the real North Pole, the bottom of the ocean at the North Pole, to a depth of 4,113 meters, plus or minus 6, where they are going to see brown mud, because that's all there is. But they're going to charge these people $50,000 each. Now, they were supposed to go two years ago, and they couldn't get the logistics properly set up. Then they were supposed to go last year, and they couldn't get enough people signing up for it, probably because the economy went sour and the dot.com people didn't have enough money to pay the extra $50,000 for the dive. But there's a probability that it's going this year. And that's a two-week cruise, a week up and a week back to the North Pole on a 75,000 horse power nuclearized brig. So I've been invited to go on that. And then there's a search for a Canadian research ship that sunk in 1913 north of the Bering Strait Karluk. That's the name of the ship that sunk in 1913, and they lost a lot of people. It was crushed in the ice. They lost a good amount of their scientific party. Do you want the name of the Chief Scientist on that? Anyway, there's someone who wants to go up and look for that and has invited me to go along there because of my knowledge of bathymetry in the area.

van Keuren: So you get to return to the Arctic at least twice.

Cherkis: At least twice. At least twice. And my wife knows that that's my mistress, and she also knows that when I die I would like to be cremated and have my ashes spread in the Arctic. And the Alfred Wegener Institute has offered to do it on one of their cruises.

van Keuren: That sounds like a great place to stop. Thank you very much for your time.

Cherkis: A pleasure.

[END OF RECORDING]

8. Robert Chrisp

Notes Prepared by Fred Erskine on a Recorded Telephone Interview with Mr. Robert (Bob) W. Chrisp held on Monday 28 April 2008 at 1 PM EDT (50 minutes)

Early NRL Career

Bob Chrisp started working in the NRL Sound Division in the spring of 1956 as a Cooperative Education (COOP) undergraduate student (electrical engineering) from Virginia Polytechnic Institute (VPI). He started working for Art McClinton in the Electronic Applications Branch of the Sound Division. John Cybulski was his Section Head. Bob stayed with them for his entire undergraduate COOP period. Upon graduation from VPI he had a two-year commitment with the Army. After that was completed he came back to NRL in 1962 and remained there until his retirement from the Large Aperture Systems Branch in 1995 (at age 55).

Mid-Career at NRL

By the time Art McClinton retired in the mid-1970s, Bob was working in the System Engineering Staff, a group that then underwent a significant revision of their role and tasking within the Division. During the 1950s and most of the 1960s the Division Superintendent was Dr. Harold Saxton. In the 1960s Bob's branch was in the east wing of the 2nd floor of NRL's Building 28. Later on they moved to the west wing of the 3rd floor of Building 1. In the early to mid-1970s the System Engineering Staff did a lot of support work for the Large Aperture Systems Branch under Budd Adams. Rick Swenson headed the System Engineering Staff after Art McClinton retired. Swenson had his "favorite" projects and he wanted to focus on those projects. He was very interested in working with private industry to investigate the use of Kevlar for oceanographic applications. Bob spent about a year in Arlington (Crystal City), Virginia working in a Navy Program Office (Naval Electronics Systems Command, NAVELEX); but Bob did not enjoy that desk job since it took him away from the day-to-day engineering work at NRL.

The Move to the Large Aperture Systems Branch

When Bob returned to NRL, Budd Adams asked him to join the Large Aperture Systems Branch. This was a very good career move. In the late 1970s Bob sailed on the Bathymetric Hazard Survey Test (BHST) sea test near the Canary Islands to help perform long range low frequency reverberation mapping experiments. Some others who participated in that at-sea experiment included Budd Adams, Jason Husty Taylor (an explosive sound sources expert), and Gig Gallatin. In the Large Aperture Systems Branch, Bob worked in the Systems Development Staff Section that was headed by Jim Griffin. Others in that section in the 1980s and early 1990s included Dennis Dundore, Jon Jannucci, John Padgett, Trinh Nguyen, Tim Krout, and various COOP students.

Miscellaneous Recollections

Bob recalled that in the early part of his career at NRL, he was detailed to assist Chester Buchanan on a sea test. Buchanan later became renowned for his developments of deep ocean search capabilities. In the period around 1968 Bob was in NRL Code 8108 (System Engineering Staff); some others in that group included: Fred Horner (an electrician from public works), Joe Cestone (their equipment specialist, from the Tudor Hill facility in Bermuda), Vince Cavaleri, Mike Marek (a COOP student), and Wilmur Lawson. Additional staff in Code 8108 included Chet Brier (electrical engineer), Seymour Adler (mechanical engineer), Andy Gonda, Rubin Naber (an electronic technician) and Tom Kelly (all came from Hudson Labs); Rolf Anderson (headed the group of technicians), Owen Blankenbaker, Bob Carson (helped set up sophisticated recorders for a project using deep submergence buoys with enormous reels of tape), Dario Ciuffetelli, Fred Horner, Hugo Mellace (a wizard mechanical technician), Bill Montgomery (stayed at the Tudor Hill facility), Bill Mulrooney (an electronic technician from Hudson labs), Harriet Porter (secretary), and Emil Sekyra.

We reviewed some personnel from an old staff listing circa 1968:
Code 8110 [Acoustic Warfare Branch]: Walter Diehl and Matt Flato (ended up in Code 8108); Lew Galli came from Tudor Hill and went to the Underwater Sound Lab facility at Orlando, Florida; George Hickey worked for Art McClinton (from Buchanan's group); Bob Mathes (worked with Buchanan).
Code 8120 [Shallow Water Surveillance Branch]: John Cybulski, Ray Ferris (Branch Head), Ted Reuwer, Frank Ingenito, and Bill Kuperman
Code 8130 [Physical Acoustics Branch]: Vince Del Grosso, Lou Dragonette, Ray Steinberger, Charles Votaw, Werner Neubauer, Leonard Burns, Owen Griffin, Anthony Rudgers
Code 8140 [Signal Processing Branch]: Bill Finney, Herb Peterson, and Matt Shaw
Code 8150 [Transducer Branch]: Sam Hanish, Dorsey Gregan, and Lee VanBuren
Code 8160 [Large Aperture Systems Branch]: Budd Adams, Carl Andriani, David Diehl (went to work for private industry, transducer firm), Bill Moseley
Code 8170 [Propagation Branch]: M. Vertner Brown, Bob Lee, Burt Hurdle, Clark Searfross, John Shaffer, Jim McGrath, John DeSanto, Ken Flowers, George Frisk, David Nutile, Evan Wright, Charles Votaw

Note — in the mid-1950s at NRL there was a standalone building (Bldg 40B) at the west end of Building 28. In there was a 600 horsepower Caterpillar Diesel running a taco alternator (high frequency acoustic range). It fed an array of high power resolvers — to feed an array of transducers — to make a steerable high energy acoustic beam.

In the 1960s Bob worked under Art McClinton on Project Artemis. McClinton was in charge of the Artemis source array development, installation and testing on the USNS *Mission Capistrano*. Bob spent a significant amount of time in New Orleans for the outfitting of the ship. There were problems with the Bendix Corporation source developments; they ended up using the MASSA shaker boxes.

Wilmur Lawson (a University of Maryland graduate) and Ted Reuwer worked on the development of solid state amplifiers for acoustic sources. Bob did not have much interaction with Dr. Harold Saxton.

Retirement from NRL

Bob retired from NRL in 1995, but shortly thereafter he returned to NRL as a private industry contractor for about a year to assist the Division with planning for the move from Building 1 to Building 2 (formerly the NRL Machine Shops) so that Building 1 could undergo renovations.

9. Dario Ciuffetelli

Notes Prepared by Fred Erskine on a Recorded Telephone Interview with Mr. Dario Ciuffetelli held on Monday 28 April 2008 at 9 AM EDT (40 minutes)

Early Career at Hudson Laboratories

Dario Ciuffetelli started work at Hudson Laboratories (HL) of Columbia University in 1959. Dario was hired in part because he had experience handling explosives, including when he had worked with his father in a stone quarry. He worked in the Mechanical Department at HL. At that time, HL was involved in research in antisubmarine warfare (ASW) using underwater acoustics, including the use of explosive sound sources. HL sent Dario to school in New Jersey for additional training. From 1959 until 1969 when HL closed down, Dario was involved HL's underwater acoustics research projects. He worked for a physicist named Dr. Theodore Pochapsky. Dario recalled that in the late 1960s the students at Columbia University were protesting the Vietnam War and the fact that Columbia University had an affiliation with HL that was conducting defense-related research. The Director of HL had been Dr. Alan Berman who left HL to become Research Director of NRL in 1967. Dr. James Heirtzler then became Director of HL and he decided to close HL by 1969.

At HL, Dario was involved in a group that did a lot of ocean survey work including experiments led by Hank Fleming. Dario did a lot of explosives handling. Dario initially worked for Dr. Pochapsky who invented the "neutral duckling" — this was a more sophisticated version of a "swallow float." The Pochapsky floats were adjusted in density to be neutrally buoyant; they were spherical buoys slightly over one foot in diameter and they included a hydrophone deployed on the ocean bottom, as well as an acoustics transponsder. They were deployed in multiples as master and slave units; two signals were transmitted. The master communicated to various slave units. This enabled the determination of buoy depth and temperature as well as buoy separations, etc. Each buoy had a coded signal to interrogate other buoys. When the nuclear submarine USS *Thresher* sank, Pochapsky used these buoys to assist in the search. He was an early investigator of internal waves.

Later Career at NRL

Upon the closing of HL, Dr. Berman arranged for some of the HL researchers and staff to interview for job positions at NRL. Some of those who moved from HL to the Acoustics Division at NRL (mostly into Code 8108, the System Engineering Staff of the Acoustics Division, that was headed by Art McClinton) included the following: Rolf Anderson (became head of an electronics group), Jason Husty Taylor (an expert on explosives handling), Hank Fleming (a researcher on sea bottom properties), Andy Gonda (a mechanical engineer), Seymour Adler (a mechanical engineer), Anthony Zuccaro (a navigator — a retired Navy Chief), John Ess (an engineer), Bernie Hendrix, Rubin Naber (an electronics technician), Thomas Kelly, Hugo Mellace, and William Mulrooney.

Dr. John Munson had just arrived in 1968 as the new Superintendent of NRL's Acoustics Division. One of the leading HL scientists who came from HL to NRL to head the Large Aperture Systems Branch (Code 8160) was Dr. Budd Adams. In the 1970s Dario was involved in various at-sea projects, particularly for Dr. Adams. NRL had formed an explosives safety committee and Dario served on the explosives certification board at NRL. In the mid 1980s NRL's oceanographic support group was disbanded. After Art McClinton retired, Code 8108 was headed for a while by R.C. Swenson. Dario retired from NRL in 1998 but has continued to support several NRL projects on a part-time basis as a private industry contractor.

10. Mickey Davis

Notes Prepared by Fred Erskine on a Recorded Telephone Interview with Dr. Mickey Davis held on Tuesday 5 May 2009 at 10:30 AM EDT (40 minutes)

Early Life, Education, and Careers at the Naval Ordnance Laboratory (NOL) and American University

Dr. Charles Mitchell ("Mickey") Davis was born in 1925 in Washington, DC. He attended high school in Washington, DC. After high school graduation in 1948 he studied at Catholic University in Washington, DC and received a B.S. degree in physics in 1952. Around 1950 he began working at the Naval Ordnance Laboratory (NOL) in Silver Spring (White Oak), Maryland. While working at NOL he performed graduate studies at Catholic University and received a M.S. degree in physics around 1954. He continued further graduate studies at Catholic University and received a Ph.D. in physics in 1962 based on studies of the anomalous properties of water. He then accepted a position on the physics faculty at American University in Washington, DC, eventually becoming a full professor. At American University he supervised graduate students and conducted research on the properties of liquids at high temperatures and pressures. From 1962 to 1970, while at American University, Davis also continued as the leader of a research group at NOL (on a one day per week basis).

Joining NRL's Acoustics Division in 1970

In 1970 he departed American University to take a full-time position in the Acoustics Division at the Naval Research Laboratory in Washington, DC under Division Superintendent Dr. John Munson and Director of Research Dr. Alan Berman in order to establish a new Physical Acoustics Branch. Initially he only expected to work at NRL for about two years in order to get this new research group going, but instead he remained at NRL for eight years.

Retirement from Government Service in 1978

In 1978 he decided to retire from government service by taking an "early out" opportunity. He then became affiliated with Dynamic Systems Inc. and continued to conduct research.

Some History of the Acoustics Division's Physical Acoustics Branch and Fiber Optic Sensor Developments

In the 1950s and 1960s, prior to his arrival at NRL, there had been some NRL Sound Division research in physical acoustics, primarily on two topics: the scattering of sound from objects by Werner Neubauer; and the speed of sound in water by Vince Del Grosso. After Dr. Davis became head of the Physical Acoustics Branch, the research on scattering from objects was extended from simple shapes such as spheres and ellipsoids to scattering from actual scale-model submarines. These measurements were conducted using the acoustic pool facility in NRL Building 71 that had previously been used as a "swimming pool" research nuclear reactor.

About the time Davis came to NRL, Corning Glass Corporation had just developed a low loss single mode optical fiber. In considering new areas of research for the Navy, Davis decided to initiate a small research effort on the properties of fiber optic magnetorestrictive materials for underwater transducer applications. In order to move this research forward, Davis invited a number of ONR-supported university researchers to conduct research at NRL under short-term appointments. An arrangement was made by which NRL would pay their salaries and ONR funds could be used to purchase new research equipment that would be used in an NRL "Fiber Optics Institute." Professor Ed Carome from John Carroll University participated in this program. Carome had developed a method of producing an acoustic pulse that would be quite useful for Werner Neubauer's scattering studies. Davis suggested that Carome consider examining the feasibility of developing a fiber optic hydrophone. As a result, Carome and his graduate student Joe Bucaro began looking at this problem. Carome and Bucaro found that optical fibers were quite sensitive as acoustic detectors. Around 1971 David hired Dr. Joe Bucaro to conduct further research on fiber optic sensors. During meetings on the topic of fiber optic sensors held at the Defense Advanced Research Projects Agency (DARPA), Davis met Dr. Tom Giallorenzi, Superintendent of NRL's Optical Sciences Division. DARPA suggested combining efforts of the NRL Acoustics and Optical Sciences Divisions in this new fiber optic sensor research effort. Giallorenzi's initial interest was in fiber optical accelerometers for potential applications on Global Positioning System research. These research discussions eventually led to the establishment of the Fiber Optic Sensor System (FOSS) program at NRL. Jack Donovan became the FOSS program manager at NRL. Donovan had been at the NRL calibration facility (Underwater Sound Reference Division, USRD) at Orlando, Florida and had funded some of Werner Neubauer's research. Donavan also had been on assignment to the Naval Sea Systems Command when he was tapped to manage the FOSS program.

While at NRL, Davis attended a Naval War Game exercise at the Naval War College in Newport, Rhode Island. In these games, Davis assumed the role of an adversary submarine platform. It was during the course of these games that Davis became interested in the topic of why U.S. towed acoustic arrays of hydrophones had difficulty operating well at high tow speeds. Back at NRL Davis studied this further and came to the conclusion that the extraneous flow noise at high speeds was due to the rubber hose encasing the hydrophones. He further postulated that a fully fiber optic sensor could integrate out the extraneous flow noise. This was the underlying motivation that led to the establishment of the FOSS program at NRL. Seed funding to get the FOSS program started was provided by Acoustics Division Superintendent John Munson as well as DARPA. NRL hosted a conference on fiber optic sensors and numerous private industry participants were invited. The response from industry was very positive. DARPA responded with additional funding. Initially, Davis was identified as the FOSS chief scientist. Then a search began for someone with appropriate managerial experience which resulted in the hiring of Jack Donovan to oversee the daily activities of the FOSS program at NRL.

Further Recollections about the Physical Acoustics Branch

Davis noted that the NRL nuclear reactor in Building 71 had only been decommissioned a few years prior to his arrival at NRL. As one of his first acts at NRL, he was instrumental in making the case for its use as an acoustic testing pool. It had a very good electrical ground system and an excellent water filtration system that provided extremely pure water that would not corrode any scale model submarines that might be used in the pool. He was able to hire one staff member who had previously worked with the pool when it was a nuclear reactor and was very familiar with its characteristics.

Davis provided a few recollections on researchers and staff in the Physical Acoustics Branch during the 1970s. Leonard Burns was a skilled technician who had expertise in the construction of scale model submarines. Dr. Robert Corsaro was a chemist who was hired around the same time as Dr. Joe Bucaro. Dr. Hank Dardy came to NRL from John Carroll University (as did Joe Bucaro). Then, while at NRL he received a Ph.D. in physics at Catholic University under Professor Ted Lebovitz. He later transferred to NRL's Center for Computational Science in the Information Technology Division. Dr. Lou Dragonette was working with Dr. Werner Neubauer when Davis came to NRL, but was also studying for his Ph.D. in physics at Catholic University in the 1970s. Larry Flax was a physicist who had extremely strong skills as a mathematician. Thomas Hickman was a technician. Like Davis, Dr. Jacek Jarzynski had come to NRL from American University and he was a very competent physicist. Later, Jarzynski left NRL to go to Georgia Tech, and then returned to NRL as a part-time employee. Joe Klunder was a technical support person. Luise Schuetz (Couchman) was a very accomplished scientist. Charles Mader was a very accomplished technician who had earlier been of great assistance to Werner Neubauer in constructing scale model objects.

Davis recalled that some of the research he had done while at NOL (White Oak, Maryland) on magnetics was of direct application much later in the FOSS program when NRL was developing fiber optic magnetic sensors. Davis also recalled that David Bradley had worked under him at NOL and had done his master's degree project under Davis.

Concluding Thoughts about NRL

Davis commented that his career at NRL was extremely enjoyable and rewarding. He further remarked that in his view, Dr. Alan Berman, NRL's Director of Research in the 1970s, was the best technical director of any research institution in the United States. Berman had a policy that several times per year he would have a breakfast meeting with each one of NRL's branch heads. During these meetings with Berman there was excellent communication and Berman would share useful information about pertinent research being conducted elsewhere at NRL in other Divisions. Davis also commented that Dr. John Munson, Superintendent of the Acoustics Division in the 1970s, was extremely helpful as a manager and supervisor.

11. Orest Diachok

Notes Prepared by Fred Erskine on a Recorded Telephone Interview with Dr. Orest Diachok held on Monday 22 March 2009 at 8 PM EDT (3 hours)

Early Life

Orest Diachok was born in 1940 in Berlin, Germany. At the beginning of World War II his father was an officer in the Polish Army, but later he was captured by the Germans who then handed him off to the Soviets. However, his father managed to escape and the family was fortunate to have moved to the western sector of Berlin from the eastern sector just before the Berlin Wall went up. Around 1949 the U.S. Congress passed a law permitting displaced persons to come to the U.S. After the end of World War II, the Diachok family waited in Germany for four years for the passage of that law and then when Orest was age 9 they were able to emigrate to the U.S. Orest attended elementary school grades one to three in Germany. After the family arrived in Boston, they traveled to New York City where his father's uncle met them. They resided there for several months before moving to Spring Valley, New York near West Point Military Academy. They lived there for about six months with Orest's uncle who was a priest. That uncle then was relocated to Washington, DC so Orest's family moved there with him. Orest's uncle was the first parish priest of the Ukrainian Catholic Church in Washington, DC that was located on the grounds of Catholic University. Orest served as his uncle's altar boy. Orest had to repeat parts of grades one and two and all of grade three in Washington, DC. He then was able to skip fourth grade and caught up with his appropriate age group in fifth grade at Saint Gabriel's grade school. He then attended high school on the campus of Catholic University. Orest's interest in science was sparked by an excellent physics teacher named Mullen in his senior year of high school who later became chairman of the physics department at Villanova University.

College

Orest enrolled in undergraduate studies at the University of Maryland in College Park in 1958. During the first year of college Orest remained living with his parents who then resided in Takoma Park, Maryland, but he hitchhiked to class each day. By his second year he acquired a car and was able to drive to campus. Orest's father was a civil engineer. Following in his father's lead, Orest majored in civil engineering in his freshman year, but he found it to be somewhat boring. In his sophomore year Orest switched to majoring in electrical engineering, but he found the curriculum to be a bit too rigid. In his junior year Orest switched to a major in physics. One professor that particularly captivated Orest's interest in physics was Jerry Marion. Diachok really excelled in his physics courses and he decided that a degree in physics would be a good basis for any later occupation, but at that time he did not have a vision of attending graduate school. He delayed his college graduation by six months in order to take several courses in nuclear engineering, thinking that this might be a possible career path or might help him get into graduate school if he should decide to apply.

NAVOCEANO and Graduate School

Shortly before graduating from college Diachok received an unsolicited letter from the Naval Oceanographic Office (NAVOCEANO) that advertised some of their job openings and offered an opportunity to "do oceanography and see the world." He applied for a position with NAVOCEANO and was immediately accepted for an entry-level GS-7 position. In the first several years Orest worked at their main site in Suitland, Maryland and also at their site at the Washington Navy Yard. His early tasking involved measurements of earth's gravitational field over the oceans. He became familiar with gravimetric instrumentation, particularly as deployed from submarines. The typical NAVOCEANO employee schedule in that early period for someone in his position was to spend about one-third of each year at sea collecting data and then spend the remaining two-thirds of the year at NAVOCEANO performing data processing and writing technical reports. Instead, Diachok convinced NAVOCEANO to permit him to spend eight months of the year at sea because he really enjoyed being at sea and visiting various ports. Most of his research cruises were on a World War II era diesel-electric submarine that had been converted into an oceanographic measurement vessel (the USS *Archerfish*, SS-AGSS-311). This ship served two main functions: it acquired gravimetric measurements all over the Pacific Ocean, and it also served as President Lyndon Johnson's "goodwill ship." It had a requirement that all the ship's naval officers, enlisted, and scientists had to be bachelors because it had no home port. Diachok participated in *Archerfish* cruises from 1963 to 1967. In this period he was able to work intensely for eight months of each year and then he could take off work for four months of the year to attend graduate school at Georgetown University. He did this for five years, and eventually quit his job with NAVOCEANO to enroll full-time in graduate school. He received a scholarship at Georgetown University to study physics. The reason he received the scholarship was because he had earlier taken two courses in nuclear engineering and Georgetown University had a Van de Graaff particle accelerator. However, after enrolling at Georgetown, Diachok found that he had little interest in the accelerator research, but was still able to retain the scholarship. Instead, he developed an interest in working with Professor Walter Mayer, who was an expert in acoustics. Diachok recalled that on the submarine research cruises, generally the naval officers held the scientists in low regard with one exception. The scientists who were knowledgeable about underwater acoustics were held in extremely high regard and Diachok made a good impression on those officers because of acoustics skills he had learned at NAVOCEANO. He received his Ph.D. degree in physics in 1970. His thesis project involved acoustic reflectivity at the Rayleigh angle from crystalline solids for frequencies from 5 MHz to 50 MHz. His graduate school mentor cautioned that when he graduated he should not continue to do research in the same sub-field but should broaden his horizons. Diachok was able to follow that advice for his entire career until several months ago when he once again (after forty years) began investigations into reflections from crystalline solids at the Rayleigh angle, i.e., the crust of the ocean.

<u>The Maury Center at NRL</u>

By 1970 jobs in physics were starting to become more difficult to obtain, but Diachok began sending out job applications. He received three offers. One was from the Bose Corporation, which Diachok declined. Another job offer was to work for a private company at a location in Iceland. This sounded potentially interesting. However, Diachok really wanted to get back into research related to the oceans and this was one of his primary motivations for studying acoustics in graduate school. Diachok had been talking to Bob Winokur at NAVOCEANO for about 6 months regarding his interest in returning to oceanographic and ocean acoustics-related research, but at that time there was a government hiring freeze in effect. However, after he told Winokur about the job offer to work in Iceland, within two weeks Winokur was able to make Diachok an offer to come back to NAVOCEANO in a GS-12 position at the Maury Center on-base at NRL to do ocean acoustics research. At that time the Maury Center had three "arms." One arm hosted NAVOCEANO's scientific groups that conducted research in several areas including underwater acoustics (under Winokur), physical oceanography, satellite remote sensing, and sea ice investigations. Diachok was hired to perform Arctic acoustics research under Winokur via funding from the sea ice group. A second "arm" of the Maury Center hosted the ONR basic research Ocean Science management group. Diachok recalled that one of the key ONR managers and scientists was Dr. Hugo Bezdek, who later became director of NOAA's Atlantic Oceanographic and Meteorological Laboratory in Miami, Florida (1980–1997). A third "arm" of the Maury Center was the ASW Environmental Acoustic Support (AEAS) program (managed by Capt. Pete Tatro) that provided theoretical expertise for the Long Range Acoustic Propagation Project (LRAPP). The titular head of the Maury Center was Brackett Hersey. The LRAPP effort was headed by Roy Gaul. Diachok related his consternation upon recalling that the LRAPP effort spent much time collecting important acoustic data sets, but then re-used the magnetic data tapes in a following experiment by writing over the previous data sets. Although Diachok was heavily involved in the NAVOCEANO Arctic research, he had productive interactions with a number of AEAS researchers including John Hanna, Chuck Spofford, Ray Cavanagh and others. Diachok pointed out that Kenneth W. (Skip) Lackie is an excellent resource person regarding the history of the Maury Center activities.

Arctic Acoustics Research at NAVOCEANO

Diachok decided that he would conduct all his Arctic experiments from Navy Maritime Patrol Aircraft (P-3s). One focus of his research was to measure under-ice scattering loss in the central Arctic. He used a NAVOCEANO P-3 aircraft that was outfitted with a downward-looking laser system that enabled measurements of the roughness on top of the ice. Diachok was able to use computer models to relate these data to the predicted number of under-ice ridges. His flights originated from various sites including Norway, Iceland, Greenland, and Alaska. One of Diachok's major collaborators was Henry W. (Hank) Kutschale, an Arctic expert, from Lamont-Doherty Geological Observatory of Columbia University. Kutschale created a very accurate and fast computer propagation model called the Fast Field Program (FFP). Diachok noted that at present the leading expert on the use of the FFP model is Dr. Stephen Wales of NRL's Acoustics Division. This model includes compressional and shear effects. Although it is a range independent model, it is applicable to Arctic environments because the acoustic propagation is primarily in a surface duct that is controlled by the sound speed gradient with little bottom interaction. Diachok's method for measuring under ice propagation loss was via the use of impulsive acoustic sources (SUS: Signals, Underwater Sound) and sonobuoy receivers. The sonobuoys were specially modified and calibrated via a technique developed by Ed Davis of NAVOCEANO. Davis moved to Mississippi in 1976 when NAVOCEANO was relocated there, but he later transferred to a management position at the Naval Air Systems Command (NAVAIR) in the Washington, DC area.

The second focus of Diachok's Arctic research was the measurement of ambient noise in the vicinity of the open ocean-ice boundary known as the Marginal Ice Zone. Diachok's measurements revealed that this boundary was a major source of oceanic noise caused by the action of ocean waves that were breaking up the ice. Later, in the late 1980s, ONR decided that this subject was of sufficient Navy interest that they launched a five-year research initiative on this general topic of Arctic research.

The Move to NRL

Diachok's research on under-ice scattering became widely disseminated so that he became well known as an expert in this sub-field of underwater acoustics. However, he was interested in branching out to other sub-fields. In 1975 Diachok was promoted by NAVOCEANO to head of the Boundary Effects Branch. This provided an opportunity for Diachok and his research group at the Maury Center to conduct theoretical and experimental measurements of the physical properties of the upper oceanic crust. However, in 1976 NAVOCEANO was relocated to the Bay Saint Louis, Mississippi area. Although some NAVOCEANO employees were willing to make the move, there were many who wanted to remain in the Washington, DC area. Diachok considered several possible alternative options regarding his future employment. He had serious discussions with Bill Von Winkle at the Naval Underwater Systems Center (NUSC) in New London, Connecticut about going there. However, the Navy was strongly trying to encourage NAVOCEANO staff to move to Mississippi and was discouraging other Navy labs from hiring NAVOCEANO researchers. Diachok received an offer of a job with a promotion to GS-13 level from Dr. Ralph Goodman, the new Technical Director at the Naval Ocean Research and Development Activity (NORDA) in Mississippi, but Orest's family wished to remain in the DC area. Diachok also met with Dr. John Munson of NRL's Acoustics Division at meetings of the Acoustical Society of America to indicate his interest in joining NRL. During this period Dr. Munson worked behind the scenes to try to find a way to hire Diachok. Orest would receive periodic updates on Munson's progress from Bill Kuperman who frequently would come to the front gate of NRL to keep Diachok posted on the progress of these negotiations. As it turned out, someone from NRL (possibly Budd Adams) approached ONR and was able to get one exemption so that Diachok could come to NRL. During the negotiation period, Diachok had met with Dr. Munson and Mr. Dick Rojas for a job interview. As a humorous aside, Mr. Rojas decided to turn off the lights in Dr. Munson's office, so that by the time the interview ended (late afternoon in winter) — the office was totally dark. At the end of the interview Mr. Rojas turned on the lights and said "very interesting — we will see what we can do." It was another two months until Diachok received a job offer from NRL. By late 1976, Diachok was working at NRL in the Large Aperture Systems Branch (Code 8160) under Dr. Budd Adams. Orest headed a small section that was performing research on ambient noise. This group had previously been headed by Dr. Sam Marshall, who had just left NRL. Among the researchers in Diachok's section by the early 1980s were Steve Wales, Ron Dicus and Roger Gauss. This section did extensive research on bottomed acoustic arrays and methods to correct signal degradation due to bottom variability effects.

Around 1983, when Budd Adams went on a year-long assignment to ONR, Diachok became Acting Branch Head for the Large Aperture Systems Branch (by then it was Code 5160). A year later, when Adams returned to NRL, Diachok was offered and accepted a position to head the Applied Ocean Acoustics Branch (Code 5120). Dr. Bill Moseley had headed that Branch but was leaving to become Technical Director at NORDA in Mississippi. Several of Diachok's closest associates including Steve Wales and Ron Dicus accompanied him in the move to Code 5120. Roger Gauss remained in Code 5160 and was by then involved in reverberation effects research.

Matched Field Processing Research at NRL

Prior to leaving NRL, Dr. Moseley had established a significant NRL "base-funded" research effort in innovative signal processing techniques in Code 5120. One of the techniques under investigation for passive acoustic applications was matched field processing that was rather new at that time. Dr. Dick Heitmeyer of Code 5160 had done some preliminary calculations that indicated that matched field processing techniques might be worth pursuing. Several decades earlier Parvulescu and Clay had done some calculations that had provided a basis for this technique as well. Clay had been convinced in the 1960s that this technique might revolutionize signal processing in underwater acoustics, but he was not able to interest Navy sponsors in his ideas on this. Homer Bucker, who had been in NRL's Acoustics Division for a short period, but then moved to the Navy lab in San Diego, published some calculations that showed that matched field processing was theoretically feasible. Diachok decided to apply all of the funding from Moseley's signal processing project to the study of matched field processing, and to abandon other signal processing developments in Code 5120. Included among the researchers who turned their talents to this problem were Dick Heitmeyer, Ron Dicus, Dick Fizell, Steve Wales, Alexandra Tolstoy, Ellen Livingston, Michael Porter and others. Livingston and Diachok published a paper that demonstrated, using actual under-ice data, the experimental feasibility of matched field processing at long range. Diachok collaborated with Alex Tolstoy on matched field tomography. The concept involved the air-deployment of four sonobuoy receivers, followed by having the aircraft fly in a large circle around the sonobuoy field while dropping impulsive sources to enable ocean tomography analyses in order to search for oceanic fronts and eddies. The sonobuoys were deployed about 50 km apart while the impulsive sources were dropped around a much larger box about 300 km on each side. Walter Munk of Scripps Institution of Oceanography had been advocating such a tomographic technique for several years, but using slowly moving ships. Diachok was convinced that the airborne technique could allow for a much more rapid data collection that could be done in a synoptic fashion in a few hours. Diachok noted that this technique is feasible in deep ocean areas, but would probably not work in shallow waters due to the bottom interactions. In general, matched field techniques have taken a back seat since the Navy began to emphasize littoral ocean applications in the 1990s.

The research by NRL and other organizations on matched field processing techniques led to the Navy's High Gain Initiative. This was a Navy applied research effort managed by the Office of Naval Technology (ONT). Diachok recalled that the research in his branch on matched field processing motivated Bill Kuperman, Art Baggeroer and others to conduct extensive theoretical research on this topic. Diachok also recalled that in the mid-1970s when he became head of the Applied Ocean Acoustics Branch, Dick Doolittle was a member of his branch. Doolittle was doing research on the effects of horizontal refraction by sloping ocean bottoms. After several years Dolittle left NRL to work in program management at a Navy program office (PME-124). The High Gain Inititative was managed by Newell Booth who worked under Phil Selwyn and A.J. Faulstitch at ONT. Booth was a strong advocate for matched field techniques and believed that the High Gain Initiative could revolutionize ASW. Booth was a very good manager who received excellent support from ONT and was able to arrange to split his time between his parent lab (the Naval Ocean Systems Center) in San Diego and ONT in the DC area via frequent commutes back and forth. Diachok maintained excellent rapport with Booth. Planning for High Gain Initiative at-sea testing was begun. Two three-km-long arrays were constructed. One array was built by the Scripps Institution of Oceanography Marine Physical Laboratory (SIO-MPL) under John Hildebrand that worked well. A second array was built by the Naval Ocean Research and Development Activity (NORDA) in Mississippi, but it did not work properly. An excellent experiment was done in the Pacific Ocean using vertically deployed arrays that involved multiple institutions including NRL, SIO-MPL, Harvard University, and NORDA. The experiment was a great success. The unclassified SIO-MPL portion of the trial was called SLICE. It was headed by Walter Munk and was focused on ocean tomography measurements. The successful matched field processing results were published in proceedings of the Navy Symposia on Underwater Acoustics (NSUA). After several years Booth returned to San Diego full-time. Dick Doolittle then became the High Gain Initiative program manager at ONT. Doolittle, however, was not an advocate of matched field processing. Doolittle brought in Dr. David Middleton, a signal processing expert, to review the High Gain Intitiative efforts. Middleton and Doolittle tended to believe that matched field processing would not work, although the successful sea test demonstrated otherwise. As program manager, Doolittle eventually decided to terminate the High Gain Initiative. Diachok's funding was cut off prior to the project's termination. Another High Gain Initiative sea test was performed around 1990 in the Atlantic Ocean but it was not very successful.

Diachok commented that in spite of his intense interest in studying the scientific basis for matched field processing during the 1980s, he had always been a bit skeptical that this technique would have a direct applicability to Navy systems for long range surveillance. He did, however, always believe that it would become a very powerful environmental inversion method to characterize the oceanic environment. He also believed that these techniques might have direct Navy applications for target classification at short ranges out to perhaps 20 km (e.g., depth determination). Among the scientific papers on matched field processing that had considerable impact was one that demonstrated convincing simulations by Mike Porter, Ron Dicus, and Dick Fizell published in *IEEE Journal of Oceanic Engineering* in 1987 when they were working under Diachok. Others included the paper by Livingston and Diachok in *JASA* in 1989 (the first experimental demonstration of the technique using Arctic data); and the papers by Baggeroer, Kuperman, Schmidt and colleagues in *JASA* around 1988 that provided a theoretical foundation for the technique.

During the period when Diachok's group was heavily involved in the matched field processing research, his branch was also heavily involved in Arctic research. Among the Arctic researchers in Diachok's branch who won an award from ONT for their efforts were Diachok, T.C. Yang, Tom Bordley and Tom Hayward. Diachok commented that Hayward was the first researcher to apply "global search" algorithms to underwater acoustics problems. The global search technique turned out to be very important for matched field processing. Diachok recalled that polar researcher Beau Buck had done extensive experimental measurements in the Arctic over a ten year period to determine an optimal geometric configuration for deployment of acoustic arrays through the ice. When Diachok asked Hayward to apply his global search algorithms to this Arctic problem, amazingly Hayward was able to solve it in five minutes.

Diachok recalled that Dr. Patricia Gruber was a researcher in his branch for a number of years. He noted that Ron Dicus and he had supervised her Ph.D. research that was done in affiliation with the University of Miami in cooperation with Dr. Harry DeFerrari. Eventually Dr. Gruber left NRL to work in private industry, and then later moved to the Applied Research Laboratory at Penn State University to become involved in program management. More recently she moved to the Office of Naval Research as Chief Scientist.

Diachok also noted that Dr. Ellen Livingston, who had worked in his branch at NRL, is an excellent resource person regarding historical interactions between NRL's Acoustics Division and ONR in the past several decades. Dr. Livingston earned a Ph.D. in signal processing and then worked in the naval intelligence community prior to coming to NRL around the time Diachok became branch head. After conducting research in matched field processing for a number of years, Dr. Livingston moved to ONR in program management for ocean acoustics research.

<u>The Move to SACLANT Centre</u>

Diachok expressed a great fondness for his years at NRL. He stated that it is a truly amazing organization. In 1992 he left NRL to go to NATO's SACLANT [Supreme Allied Command Atlantic] Centre in La Spezia, Italy as a researcher. Dr. Marshall Orr, who had been a program manager for ocean acoustics at ONR, came to NRL then as the new head of the Applied Ocean Acoustics Branch to replace Orest. At SACLANT Diachok initially became a section head, supervising about five scientists. By this time the Cold War had ended and Diachok sought an exciting new research problem at SACLANT that had applications to the littoral oceans. After he was at SACLANT for about six months, the position of Chief Scientist opened up. He approached the Director (Foxwell) to express interest in the position and offered to help SACLANT formulate a plan for research in the post-Cold War era. The previous long-time Chief Scientist, Dr. Ole Hastrup, had been at SACLANT for about thirty years and was a legendary scientist. Diachok was offered the position. Over the next two years Diachok developed a strategic plan for SACLANT by performing an extensive review of previous unclassified and classified research in shallow water while keeping in mind potential future areas of research for SACLANT. Much of the previous shallow water research had been done by Europeans. He reviewed the previous U.S. shallow water research within only a few weeks (e.g., papers by Steve Wolf, Frank Ingenito, Bill Kuperman, and others). As a result of this process of reviewing the literature, Diachok was able to produce two reports outlining his recommendations for future SACLANT research. Also, in the process of reviewing previous research efforts, he stumbled upon David Weston's publications on reverberation and attenuation of acoustic energy due to fish populations. Weston's work was a landmark study in which he had a fixed active acoustic system operating around the clock in the shallow waters of the Bristol Channel off the coast of the United Kingdom for about three years. Weston's study resulted in a remarkable series of papers and it was not likely ever to be repeated due to its expense and complexity.

Research on Sound Attenuation by Fish and Return to NRL's Acoustics Division

Diachok decided that his personal research at SACLANT would further explore the topic of sound attenuation by fish. Diachok did an initial experiment on fish absorption while he was at SACLANT and the results were published in *JASA*. Following that initial effort, he departed SACLANT and returned to NRL around 1996 as a researcher in his old branch that had been renamed the Acoustic Signal Processing Branch, Code 7120. He was able to secure basic and applied research multiyear funding from NRL for five years to continue research in sound attenuation by fish. With his funds he had to purchase equipment for experiments. He needed equipment that did not exist, including a broadband source. It took a year to find someone who could build a source to his specifications that included a total weight under 300 pounds (including battery), a frequency capability from 200 Hz to 10 kHz, and had to be able to operate continuously for at least two days. The source was built by George Cavanaugh of MASSA Products Inc. in Boston. The source consists of several types of transducers. One is a barrel-stave transducer (developed by Dennis Jones of the Defence Research Establishment Atlantic in Dartmouth, Nova Scotia, Canada) for frequencies below 1.5 kHz. The other type of transducer is called a multi-port ring transducer for frequencies above 1.5 kHz. The system is designed to transmit continuous wave (CW) tones (one frequency at a time) across the frequency band from 200 Hz to 10 kHz. One sophisticated part of the design is that it has a separate impedance matching circuit for each transmitted frequency.

Retirement from Government Service in 2005

After the five year period the NRL Research Advisory Committee decided not to continue to support Diachok's project even though Orest provided strong arguments that the research was revolutionary in nature. Considering that he had many years of government service, in 2005 Orest decided it was time to retire from the government and consider other employment options.

Post-NRL Period

In February 2005 Diachok became affiliated with the Johns Hopkins University Applied Physics Laboratory in Laurel, Maryland as a Senior Research Physicist under Dr. Bruce Newhall where he continues research on a variety of problems related to acoustics. Initially Diachok conducted interesting research on whale vocalizations. Recently he has received funding from the Space and Naval Warfare Systems Command (SPAWAR) to continue further research on sound absorption by fish to explore applications to Navy sonar systems including mid-frequency hull-mounted sonars. About a year ago Diachok was invited by Joe Clements to give a lecture to the Applied Research Laboratories, the University of Texas at Austin (ARL:UT) on sound absorption by fish and related topics. Since then he has developed a fruitful collaboration with Clements and colleagues who are very interested in developing improvements for Fleet sonars.

12. Lou Dragonette

Notes Prepared by Fred Erskine on an In-Person Recorded Interview with Dr. Louis R. Dragonette held in Woodstock, Maryland on Friday 13 March 2009 at 10:00 AM EDT (3 hours)

Early Life and Education

Dr. Louis R. Dragonette was born in Philadelphia, Pennsylvania in 1939. He attended St. Thomas More Catholic High School in Philadelphia, and then pursued undergraduate studies at St. Joseph's University in Philadelphia where he received an academic scholarship. Initially he intended to study to become a lawyer, but instead decided to take an undergraduate curriculum that emphasized electronic physics. He graduated in 1961 with a B.S. degree in physics and he then won a scholarship sponsored by the Atomic Energy Commission (AEC) to pursue graduate studies at Vanderbilt University in Nashville, Tennessee. At Vanderbilt he took the standard graduate physics and mathematics courses, but also pursued several minor course tracks in radiation physics and health physics. He met and married his wife while he was at Vanderbilt. She had won the same AEC physics scholarship and was enrolled in the graduate program at a nearby university. While he was at Vanderbilt he had a cooperative education appointment at nearby Philco Corporation. His assignment at Philco was to write computer test cards for their computer which filled up an entire room. In 1963 he received his M.S. degree in physics under Dr. Lagemann, an acoustician who was the head of the physics department at Vanderbilt University. The topic of Dragonette's master's thesis was on the absorption of sound in methane.

Early NRL Career and Doctoral Research

Dragonette's master's segree research was what sparked his interest in acoustics. In the post-Sputnik era around 1963 science and technology were considered to be high priority fields of study in the U.S. and specialists with degrees in physics were highly sought after by employers. While completing his M.S. degree, Dragonette interviewed with numerous organizations including the Central Intelligence Agency, the Air Force Research Laboratory in Tullahoma, Tennessee, the National Security Agency, and various private industry firms. Burt Hurdle came to the Vanderbilt University campus on a recruiting trip from NRL and he interviewed both Lou and his wife for possible positions at NRL. Both Lou and his wife decided to accept positions at NRL and started work there around June 1963. Lou went to work in the Sound Division and his wife went to work for Dr. Jerome Karle.

In that era there were only two Ph.D.-level researchers in the Sound Division: Dr. Harold Saxton (the Superintendent) and Dr. Raymond Steinberger. Initially Lou worked in the Propagation Branch that was headed by Dr. Steinberger. Some other key researchers in the Division around 1963 were Bill Finney, head of the Electronics Branch (he had an M.S. degree from MIT); and several colleagues in the Propagation Branch including Charlie Votaw who was pursuing a master's degree in naval architecture at the University of California at Berkeley; Werner Neubauer who was about to begin Ph.D. studies; and Clark Searfross who organized the annual at-sea experiments for Dr. Steinberger, who did most of the data analysis and technical report writing. In addition to the seagoing measurements under Dr. Steinberger, there were three laboratory-based measurement efforts in the Propagation Branch. These included acoustic scattering measurements under Werner Neubauer, assisted by Lou Dragonette and Tony Rudgers; speed of sound measurements under Vince Del Grosso, assisted by Leon Lalumiere and Bill Walker; and a third lab-based measurement effort under Charlie Votaw, assisted by Gary Koopman. Eventually a number of these researchers completed their Ph.D. degree studies, several of which were sponsored by the NRL Edison Memorial program, including Werner Neubauer and Lou Dragonette. Lou received his Ph.D. in 1978 (at age 39) from Catholic University with a specialization in acoustics via a program within the mechanical engineering department under a physicist, Professor Uberall.

Dragonette's Ph.D. dissertation topic was on measurements of acoustic scattering from spheres and cylinders. Others in the Sound Division who received their doctorates at Catholic University while at NRL included Vince Del Grosso , Gary Koopman, and Sam Hanish. By 1970 Dr. Mickey Davis came to NRL from American University to head the new Physical Acoustics Branch. The number of researchers in the Acoustics Division with doctorates began to increase rapidly. Dr. Davis soon hired a number of researchers with recent Ph.D.'s including Joe Bucaro, Bob Corsaro, Hank Dardy and others.

Comments on NRL Sound Division Research in the 1950s and 1960s

Werner Neubauer had come to NRL around 1953 and began a long-term research program in laboratory-based measurements of acoustic scattering from objects in various acoustic tanks. Dragonette characterized Neubauer as an amazing scientist — probably the best "bench scientist" he had ever known. Dragonette stated that it is hard to describe the type of precision measurement equipment that was developed in Neubauer's group at that time. They had an NRL-designed frequency synthesizer that was as large as a bookcase (such a device was not commercially available at that time). At that time in the 1960s NRL provided a precise 100 kHz signal in all key research buildings that could be used as a time-base. Neubauer designed a vacuum tube gating unit for which he had to test hundreds of tubes to find a correctly matched pair that would provide the best possible signal-to-noise ratio. Neubauer received a B.S. degree in physics in 1952 at Roanoke College (where Burt Hurdle had earlier received a B.S. in physics in 1941). Neubauer wanted his NRL group to have a balanced approach between theory and experimentation. Tony Rudgers wanted to do the theoretical work, so Lou Dragonette handled the experimentation under Neubauer. Dragonette initiated a series of scattering measurements in a wooden tank on the ground floor of NRL's Building 1 that was about 12 ft. long and about 6 ft. deep. They expected to publish their scattering results in terms of a percentage vs. angle (as opposed to the more modern usage of decibels). In those days a scattering measurement accuracy of 10 dB or 20 dB was considered acceptable.

The very first thing that Dragonette did was to measure the speed of sound in water in the tank in order to "calibrate" the tank. As an aside, Vince Del Grosso's group at NRL had been conducting precise measurements of the speed of sound in water since the 1950s. There was an ongoing controversy at the time between Del Grosso's group and a group at the National Bureau of Standards under Martin Greenspan. The two groups obtained different results for the speed of sound in water. Dragonette's measurement of the speed of sound in water was slightly lower than that of either Del Grosso or Greenspan. Dragonette characterized Del Grosso as an excellent scientist, but one who was often challenging in his interpersonal interactions with NRL colleagues. As a result of Dragonette's measurement results, Del Grosso and Neubauer were at odds trying to reconcile the two sets of NRL measurement results. It turned out that Dragonette's results were later verified by a scientist named Brooks who made some free field measurements. To be fair about this controversy, both Del Grosso and Greenspan were making measurements in seawater and then projecting what the results would be in fresh water — a procedure that can be tricky.

Dragonette thus succeeded in calibrating the tank and was then able to use the advanced measurement system that had been devised by Neubauer to proceed with careful acoustic scattering measurements. He began by making measurements on elastic bodies and then published results for elastic spheres. Those results were compared to results of Robert Hickling who had made careful computations (based on the work of Feran) for this geometry. In those days, computational capability was rather limited compared to that at present. Hickling was able to carry the computation out to perhaps a "ka" value of about 10. Today we can easily carry out such a computation to much higher "ka" values of perhaps several hundred on a laptop computer. Among the most important scientific measurements that were done by Dragonette and colleagues was the first broadband scattering data set. In Neubauer's early scattering measurements, he used long pulses and then repeatedly changed frequencies to gain frequency coverage. In the revised technique used later they transmitted very short acoustic pulses to obtain broadband scattering spectra. These totally new scientific results were compared to theoretical predictions and were published in the *Journal of the Acoustical Society of America* (JASA) around 1970. In Dragonette's view, that paper should have been included in the list of "benchmark papers in acoustics."

<u>Comments on NRL Acoustics Division Research in the 1970s, 1980s and Beyond</u>

In 1970 Dr. Mickey Davis arrived at NRL to head the new Physical Acoustics Branch that incorporated some of the researchers from the Propagation Branch, including Neubauer and Dragonette. The seagoing measurements remained in the Propagation Branch while the Physical Acoustics Branch focused on laboratory-based measurements including extensive use of the former NRL research reactor in Building 71 as an acoustic scattering pool facility. In the 1970s Dragonette and colleagues began to make use of a VAX computer in Building 71 to perform acoustic scatter data analysis and modeling computations. Larry Flax had developed the computer code for detailed computations on elastic scattering from spheres, cylinders, spherical shells, cylindrical shells and other shapes. Janet Mason came over from NRL's Research Computation Center to assist Dragonette and colleagues with implementation of these codes on the VAX computer. At that time there were no "canned" software codes for certain mathematical procedures so Mason programmed the high order spherical Bessel Functions and other mathematical operators in FORTRAN for use in the Flax approximations. The results of these computations were then published in *JASA*. After Mickey Davis retired in 1978, Joe Bucaro became head of the Physical Acoustics Branch. Dragonette became a section head, and Werner Neubauer became a Special Assistant for Target Characteristics under Dr. Munson. Among the researchers in Dragonette's group were Dr. Sue Numrich, who did experimental measurements; Dr. Nate Yen; Richard Vogt (who had worked with the NRL nuclear reactor); Dr. Brian Houston (then a student); Laurence Frank; Dr. Charles Gaumond; and several others. Dragonette's group continued the experimentation and modeling work into the mid-1980s. Larry Flax departed for a Branch Head position at the Naval Coastal Systems Center, Panama City, Florida. Sue Numrich departed for a series of other appointments at NRL and in the late 1990s became a Branch Head in the Information Technology Division. Laurence Frank departed for a position at the Johns Hopkins University Applied Physics Laboratory. Eventually Brian Houston became the leader of the scattering measurements group and a much larger acoustic pool facility was built in Building 5. Dragonette continued to lead a small data analysis group that included Dr. Angie Sarkissian, Dr. Nate Yen and Dr. Charles Gaumond. By the 2000s the pool facility in Building 71 was being used for sandy bottom scattering measurements.

<u>Retirement from Government Service</u>

Dragonette formally retired from full time government service in January 2002. He then returned to the Physical Acoustics Branch as a "rehired annuitant" on a part-time basis (about three mornings per week) to continue his research up to the present time.

<u>Further Recollections about the Sound Division in the 1960s</u>

In the mid-1960s the Sound Division management structure was roughly as follows: Division Superintendent: Dr. Harold Saxton (Dragonette recalls him as a gentlemanly manager, but not too involved in monitoring closely the research of Dragonette and colleagues); Propagation Branch: Dr. Raymond Steinberger; Transducer Branch: Robert Faires; Electronics Branch: Bill Finney; Sonar Systems Branch: Chester Buchanan; Techniques Branch: Bob Mathes; Electronic Applications Branch: Art McClinton (Dragonette recalls McClinton as the most prominent Division branch head of that era, and further recalled that McClinton may have been Acting Division Superintendent briefly between the tenures of Dr. Saxton and Dr. Munson around 1968). In the mid-1960s Burt Hurdle was in Art McClinton's branch. Dr. Steinberger had been in the Sound Division then for many years (since the Harvey Hayes era). He wanted to continue working with the Division's seagoing measurements group at NRL; however, in that era there was a mandatory retirement age of 70 years, so Dr. Steinberger finally retired at the end of the decade and he died a few years later.

Review of Some Old Sound Division Photographs

Dr. Dragonette perused some old Sound Division photographs and provided a few comments about the people in the photos. Around 1984 a group photo was taken of the entire Acoustics Division in front of Building 1. Many of the persons in that photo are easily recognizable and quite a few of those persons are still at NRL. A Division group photo was taken around 1947 at the close of the Harvey Hayes era and many of the persons in that photo cannot be identified. Another Division group photo was taken around 1967 at the close of the Harold Saxton era. Lou was able to identify many of the persons in this photo that was taken a few years after he arrived at NRL.

13. Raymond Fitzgerald

Notes Prepared by Fred Erskine on a Recorded Telephone Interview with Dr. Raymond M. Fitzgerald held on Wednesday 25 March 2009 at 08:30 AM EDT (1 hour)

Early Life and Education

Raymond Michael Fitzgerald was born in 1940 in New York City. He attended Fordham College and graduated with a B.S. degree in physics in 1962. Starting in 1963 he attended evening graduate school at the City University of New York. There he met several researchers from Columbia University's Hudson Laboratories in Dobbs Ferry, New York. In order to meet expenses he decided to accept a research position at Hudson Labs in 1963 and he worked there full-time for two years. In 1963 he completed an M.S. degree in physics at City University of New York. Around 1965 he started full-time graduate studies at City University of New York and received a Ph.D. degree in physics in 1969. His doctoral thesis was in field theory under his adviser, Professor Schiminovich.

Employment at the Hudson Laboratories

In the period from about 1963 to 1965 Fitzgerald worked under Loring Tyson in the Analysis Department at Hudson Labs. The Analysis Department consisted of a pool of junior scientists and students whose job it was to provide technical support to more senior researchers at Hudson Labs, including Ross Williams, Antares Parvulescu, Vertner Brown and others. At that time, Dr. Alan Berman was the Director of Hudson Labs and it was his custom then to wear very casual attire at the Lab.

The Career Move to NRL in 1969

In the late 1960s it was becoming harder for a Ph.D. physicist to find a permanent position as compared to a decade earlier. However, Fitzgerald knew some researchers at the Naval Research Laboratory in Washington, DC who had secured employment there when Hudson Labs was disestablished in the 1968−69 period. Dr. Al Guthrie encouraged Fitzgerald to apply for a job in NRL's Acoustics Division. As a result, Fitzgerald came to work at NRL in late 1969 to work under Guthrie in the Propagation Branch (Code 8170) that was headed by Homer Bucker, then later by Burt Hurdle.

Two weeks after arriving at NRL, Fitzgerald participated in a field test from a shore station on Antigua in the eastern Caribbean. The experiment was performed in collaboration with NRL colleagues Al Guthrie and John Shaffer and it involved long range low frequency underwater acoustic propagation loss measurements between Antigua and Newfoundland. Fitzgerald recalled that in the 1970s when funding became available for the Propagation Branch research groups on the fourth floor of NRL's Building 1, there was a tendency to spend it by hiring additional personnel as opposed to purchasing equipment or computers. The researchers were encouraged to use NRL's mainframe computers in this "pre-desktop" computing era. Thus it was not possible then to digitize data that were acquired in sea tests. Rather, it was customary to play back the analog data tapes and to plot the data using a hardcopy strip-chart recorder for use in further visual analysis. This approach was extremely manpower intensive. Fitzgerald noted that the Large Aperture Systems Branch (Code 8160) under Dr. Budd Adams was an exception to this in that Adams invested heavily in hardware and computers.

After Fitzgerald had been in the Propagation Branch for while, Homer Bucker requested of Fitzgerald that he should write a normal mode propagation modeling software program in the FORTRAN language. However, at that time Fitzgerald did not know anything about computers or computer programming. Fitzgerald was handed a FORTRAN instruction manual and he proceeded to study it. When he saw an instruction that said "n=n+1" he thought that surely "this is nonsense." Homer Bucker then patiently worked with Fitzgerald to teach him the fine points of FORTRAN programming. Fitzgerald then wrote a normal mode program called “MLC-Grid.” It consisted of a full “tray” of punched cards. Bucker explained to Fitzgerald that there was an existing software program that treated the depth dependence of sound speed as a sequence of iso-velocity layers, but he wanted a new program that treated the depth dependence in a smoother, more continuous fashion. Fitzgerald then devised a new approach that required treatment of the sound speed by using straight line, constant derivative segments instead of zero derivative segments as approximations. He wrote Airy function routines that were modified to achieve higher precision. Fitzgerald attempted to find his own basic research funding to establish his own research project based on the normal mode modeling, but it was difficult to get funding. He suggested to management that if the computer code was not of sufficient importance to be the basis for a new research project, perhaps it should be discarded (but he kept a copy).

Interest in Signal Processing Research

Fitzgerald attended an interesting seminar in the Acoustics Division that was presented by Bill Hahn on maximum entropy techniques for signal processing. This sparked Fitzgerald’s interest in doing research on innovative signal processing approaches. Later, he collaborated with Hahn on some research that involved advanced statistical methods. Hahn noted that Fitzgerald was not trained in the fundamentals of statistics but was able to do advanced research in this subject. Around 1980 Fitzgerald enrolled at Catholic University in a graduate statistics course in their mathematics department. The course was taught by Charlie Byrne, a very talented pure mathematician. Fitzgerald and Byrne started a fruitful long-term collaboration on acoustics research as a result of this initial interaction.

Fitzgerald recalled that in the 1970s the Maury Center was located near the front gate of NRL. However, Fitzgerald commented that there appeared to be little direct research interaction between the NRL Acoustics Division and the researchers at the Maury Center.

Fitzgerald recalled that occasionally he was called upon to brief some Navy “panels of experts” such as the “MOST” Group. He found that panels like this often dismissed as “obvious” some problem solutions that were in fact not at all obvious. In Fitzgerald’s mind this removed the “halos” from such panels of experts and enabled him to feel free to always question any “assumptions.”

By 1980 Fitzgerald was working in the Applied Ocean Acoustics Branch, Code 5120, that was headed by Bill Moseley with whom Fitzgerald had a very good working relationship. Fitzgerald found Moseley to be unusually open to accepting new ideas and found this to be very refreshing.

Fitzgerald also recalled that Burt Hurdle was always extremely helpful and was continually interested in “what’s new?” During the period in which Fitzgerald was developing a research collaboration with Charlie Byrne on acoustic signal processing techniques, Hurdle became sufficiently interested in their research that he helped them find funding at NRL to pursue this research further. However, the funding came from another Directorate under Dr. Bruce Wald, which resulted in frequent “challenges” to Fitzgerald’s technical approaches. He was always able to defend these challenges.

One of the signal processing approaches that has been extensively pursued by Fitzgerald over the years is known as “adaptive processing.” Although his research has led to very successful new developments, Fitzgerald commented that Navy managers are often reluctant to try new things and often prefer to stick to older approaches.

The Career Move to the Office of Naval Research (ONR) around 1985

After spending about fifteen years in NRL's Acoustics Division, Fitzgerald decided to seek some new occupational experiences that would broaden his outlook on Navy research and the Navy funding process. Around 1985 he moved to the Office of Naval Research in Arlington, Virginia as a program manager for basic research. At ONR Fitzgerald headed a new program that merged two previous programs, the Underwater Acoustics program that had been headed by Peter Rogers, and the Ocean Acoustics program that had been headed by Mike McKisic. As an amusing anecdote, Fitzgerald attempted to meet briefly with the Chief of Naval Research, Admiral Brad Mooney. Fitzgerald had met (then Lcdr) Mooney around 1963 during the search for the USS *Thresher* when Fitzgerald was a scientific observer aboard the submersible *Trieste*. Fitzgerald received a call from Dr. Fred Saalfeld's office notifying him that he would not be permitted meet with the CNR because their office handled such interactions. Fitzgerald commented that it was a wonderful experience to work at ONR. He made many "road trips" to research organizations including various university laboratories.

After spending about five years at ONR, Fitzgerald returned to NRL for about six months to work with Al Gerlach to help him solve some problems that he was having with a software package known as HARMCORR. This collaboration resulted in a published paper.

Retirement from Government Service Followed by a Career in Industry

Around 1989 Fitzgerald retired from government service to work under Gerry Cann at General Dynamics. At General Dynamics most of Fitzgerald's colleagues were former nuclear submarine officers who had the highest code of ethics one could imagine. Cann held a group meeting every Monday morning for staff and researchers and everything was on the table. The communication between researchers was excellent. Fitzgerald worked in a group that was responsible for developing new technologies that took advantage of the capabilities of various divisions within General Dynamics. In 1989 the General Dynamics budget for research and Development was $300 million per year. It was Cann's intention that this could be used to start research on thirty new systems per year with each one funded at the level of about $10 million. Cann felt that if only one or two of these systems had success then General Dynamics might become the most profitable company in the world. However, this goal was not realized because the world situation changed rapidly about then with the collapse of the Soviet Union. By 1993 General Dynamics released many employees and closed down. When General Dynamics closed down, Fitzgerald had been working on an antisubmarine warfare system concept that used sonobuoys. Some initial testing had been done and General Dynamics permitted Fitzgerald to keep much of the hardware. He then literally stored a large number of sonobuoys in his basement. Fitzgerald was not able to interest the Navy in his concept, however. He briefly worked for several small private industry firms, but in 1996 he decided to form his own company, called Dzintech. After two years, in 1998 he formed a successful new company called Creative Science and Software Solutions (CSS Solutions, Inc.) in collaboration with Mike McKisic.

14. Hank Fleming

Notes Prepared by Fred Erskine based on Recorded Interviews with Mr. Henry (Hank) Fleming by Dr. David van Keuren (NRL Historian) in Four Sessions from June to September 2002

Interview #1, 10 June 2002

Some Background

Hank Fleming was born in 1938 in New York, New York (Manhattan Borough). His parents were naturalists; his mother worked at the Botanical Gardens; his father was an entomologist and botanist with the New York Zoological Society (the Bronx Zoo). Hank was raised in northern New Jersey, Brockland County. He attended Great Marl High School in Lakewood, NJ; then he attended New England College; he was interested in biology early on.

At age 16 Hank went to sea for the first time. He took off high school to go to sea for a year on the R/V *Bema* beginning around Jan. 5, 1955 (or 1956). Maurice Ewing was a chief scientist. The research involved geophysical work; this included doing coring each day as well as Nansen bottle sampling. His duties included helping the deck crew. He earned $35/month pay. The research also included conducting bathymetry and magnetic measurements. The ship ran on a shoestring budget. The crew was mostly Canadian. It was a Panamanian flagged ship. They found the ship in a scrap yard. All of the crew had seaman papers in order to avoid entry into ports.

After the year at sea, Hank then resumed high school. Then in the summer of 1958 Hank went on an expedition to an Arctic ice camp. This was funded by the US Air Force. The camp was called Ice Station Alpha. It eventually broke up (early) and they moved to bigger ice pieces; they then lost their air runway etc. Hank was then 20 years old and was on that expedition for 3–4 months. He then became captain of a small boat (a torpedo retriever). Following that he became captain of a tugboat.

Hank then attended New England College. He was influenced on the decision to pursue undergraduate studies by his parents as well as by William Beede and other naturalists. Also, around that time he got married (he had met his future wife in high school). In 1960 he received his undergraduate degree in chemistry. After college he worked at a lab in Edgewater, New Jersey as chemist, where he did research on the properties of skin that included animal experiments using guinea pigs and rats. Hank recalled that his daughter had experienced a fever 106 degrees and that event influenced his choice of career in chemistry.

Joining Hudson Laboratories in 1965

In June 1965 Hank joined the Hudson Laboratories (HL). Dr. Alan Berman was Director of HL. Hank went to sea in July 1965 and he became a Senior Scientist by 1966 [SSOB; Senior Scientist on Board]. The sea tests involved research in antisubmarine warfare (ASW). They performed measurements to map and chart the ocean floor and to investigate the influence of topography on sound. As part of the "boomerang" program they towed sources all over the North Atlantic. They used SOSUS arrays as acoustic receivers. Hank was at HL was for three years. In that period he sailed on research cruises two to three times per year. Hank hired Norm Cherkis from NAVOCEANO during that period. They looked at long range acoustic propagation as well, but the main interest was in research on topographic effects. They used their own bathymetry mostly, but they collaborated with Bruce Heezen at Lamont. They found a ridge with lots of valleys but couldn't tell Heezen (it was classified); however, Heezen got some Russian data, and he saw the valleys. The Russians had sailed south to north. Hank saw the transverse faults — the mid-Atlantic Ridge appeared as a picket fence. They couldn't publish re this [even in

JUA(USN)]. The Navy held this knowledge very close — it was the cold war days — but the Russians knew about this topography. The Russians did very detailed surveys before sending their submarines out (they surveyed the Caribbean as well). The HL results went to SUBLANT (and if permitted to NAVOCEANO as well).

Dr. Berman was funded by ONR. HL had five ships at one point, including the USNS *Mission Capistrano*. The vessels were always very busy. Detecting submarines became very important once we realized we had long range propagation. We could not share the HL results with Bruce Heezen at Lamont. Lamont was able to be much more open and to publish (pure science research). Underwater acoustics advances in the US Navy helped a great deal to bring the Russians to their knees. They could not keep up with us. The Walker case hurt the US; but we kept pressing them; they tried to out-spend us, but we could find their submarines very effectively. However, they knew a lot about our techniques and system; they thought our system was bigger than it actually was. In the 1960s–1970s to early 1980s there was a lot of funding spent on underwater acoustics. US submarines were so quiet that sometimes Russian submarines ran into our submarines. Funding started to drop in the late 1970s; then it fell off rapidly. There were lots of jobs in underwater acoustics in the high-funding period; the capability expanded greatly in that period.

Hank commented about his motivation to go to HL in 1965. Hank had kept up with oceanographic literature. Lever Brothers wanted to send him to school for his Ph.D. degree — but he wanted to get back to sea. Hank noted that it was unexpected to be able to see coast to coast acoustically. Hank was interested in where we could see submarines and why. There were seamounts that occluded propagation; sometimes depth charge detonations were not received at coastal stations for unknown reasons; Hank started investigating this at HL.

Interview #2, 23 June 2002

Continued Research at Hudson Laboratories

Hank became a SSOB at HL on a project that was looking a topographic channeling. Hank wanted to determine why a submarine target would drop out. He looked for seamount blocking relative to the locations of SOSUS stations. His group conducted acoustic tows at ship speeds of about 8–10 knots. They would have all the arrays looking at the towed high level sound source; then they asked all SOSUS stations to report back when they received the source. They compared the results to the topography. They always collected environmental data and bathymetry on these cruises. The research was driven by Dr. Alan Berman and Dr. Bob Frosch. Research ideas would be proposed to Dr. Berman and if he thought it was a good idea he would allow us to proceed. Hank's research colleagues were Norm Cherkis, Farrell, Husty Taylor (retired Navy Chief), Bernie Hendricks, Rubin Naber, John Shaffer, Budd Adams, and Carl Andriani.

The Career Move to NRL's Acoustics Division

When HL closed, about 35 people came to NRL. There was much resentment when HL closed in 1968. There were riots at Columbia University; they could not have students storming the facility. The students took over the university president's office; cold war tensions were high. NRL interviewed many of the HL researchers and staff. Hank could have also gone to the University of Hawaii. NRL offered Hank a GS-13 and said he could stay at HL until June 1969 to finish up. He was to come to NRL for 5 years — then was expected to go to Hawaii. The atmosphere at HL was similar to that at NRL. Dr. Berman ran HL tightly — he would call people to his office — and say do not tell management about this "special project." At NRL he also called scientists into his office to question them about research results; the work was very secretive. People went off on short notice on special projects. We also did some basic research; but 90%

of the work was classified. Some of the research results could be published in JUA(USN) or in classified NRL reports. The Naval Electronic Systems Command (NAVELEX) was the sponsor for much of our research. At NRL Dr. Berman frequently had 3-star and 4-star Admirals in his office. The Maury Center Office was run by Brackett Hersey. At HL relations were good with Lamont (Bruce Heezen). Hank used to visit Lamont on a biweekly basis; but Lamont always looked down on HL because we did not publish much. HL had better ships than Lamont; the USNS *Gibbs*, USNS *Mission Capistrano*; R/V *Manning*; R/V *Allegheny*. The USNS *Hayes* was supposed to go to HL; it was built as a catamaran; 30 ft shorter etc. so Great Lakes shipyard could bid on it; could hang a submersible between the two hulls for seep sea search. Hank had joined HL in 1965, after the *Thresher* incident. NRL pioneered in ocean bottom surveying remotely by surface ship — but followed on by submersible examination — this later became standard procedure.

Project Artemis

In the 1960s HL and NRL were heavily involved in the Artemis Project. Artemis was motivated by measurements indicating that they could look across the whole ocean in some places (e.g., between picket fence in mid-Atlantic Ridge). Initially, the Artemis Project put an experimental array in Eleuthra; then the Navy moved the Artemis testing off Bermuda. It was all brand new research. Russian submarines were very noisy unless at slow speed; the US Navy wanted to detect and localize them. Artemis had a major impact on active acoustics research. Presently we have towed active systems in the Navy (e.g., SURTASS). Much of the basic work was done at NRL by Budd Adams et al. under John Munson.

Some Deep Ocean Tragedies

In 1968 Hank got a call regarding a sinking (the USS *Scorpion*) — and he was asked to come to NRL — then was briefed by a Cdr from ONR (Wilton Hardy) and a NAVOCEANO person (Donald Atkocius). They pored over charts and acoustic data during all night sessions and then came up with two positions. Although they had located the actual position — they did not believe it because the data showed the USS *Scorpion* going east — and they thought it was going west. There were two implosions; but there was a lack of understanding of submarine tactics in emergencies. Dr. Berman had teams looking at different aspects of this incident. John Craven was there with Dr. Berman in NRL Bldg 43. They did not want to alarm the families — so they kept the information close. It appeared that a torpedo went off (first explosion); the submarine then turned around and headed east (the submarine then broke up; the report may be in the NRL library). They tried to work out from SOSUS where the submarine sank; this information then vectored the USNS *Mizar* out to try to find it. The submarine was too far from any port to go for help. Another submarine went down (the French submarine *Eurydice*); Buck Buchanan was involved with all the searches, including the search for the lost H-Bomb off Spain.

Other Comments Regarding Long Range Sound Propagation

In the 1960s HL researchers proved that long range propagation was possible. Initially, the Navy did not believe the results (ten times further than expected). Recently, a big bomb was detonated, and the sound went around the world. The Union of South Africa detonated an atomic bomb off Prince Edward Island. The sounds were picked up by the SOSUS system. Hank was called into Berman's office to discuss this event. Satellites had detected the detonation. Dr. Berman investigated this — he put Jack Brown in charge.

More Comments About the Move of Researchers from Hudson laboratories to NRL

Dr. Berman expected attendance at his special projects meetings (weekends included). Dr. Heirtzler (came from Lamont) announced that HL would close on 1 April 1968. HL had received over $5M/year of

Navy funds. A rumor was that Dr. Berman wanted to increase the NRL Acoustics Division capabilities by drawing from HL staff. NRL came to HL with three lists of employees: the 3rd list was a Berman (short) list (staff that wanted NRL to get); Dr. Munson offered Hank a GS-12 — but Hank was on the Berman (short) List — so he got a GS-13. Budd Adams was the most senior person to come to NRL (but the total was about 35 people transferring to NRL). Hank joined NRL on 3 Jan 1969 — but stayed at HL until June 1969 to finish up some research publications and chart preparation.

Interview #3, 5 August 2002
The Northeast Atlantic Test (NEAT)
Hank moved to NRL in June 1969. He had more resources at NRL than at HL (ships, aircraft; people to collaborate with; direct access to Pentagon and other Navy commands). Hank still studied acoustic shadowing; but he was looking at the use of aircraft to do airborne magnetic measurements; had better access to classified information at NRL. An important sea test series was NEAT (Northeast Atlantic Test), Burt Hurdle was a chief scientist; the UK collaborated as well as WHOI. NEAT measurements characterized the Northeast Atlantic acoustics environment: from the Canary Islands to the Faeroe Islands and the GIUK Gap. They found a double minimum in the sound speed profile. It was a major three month operation to characterize this environment and it was considered a big success. All the reports were classified. The UK colleagues came from RAF (they flew aircraft) as well as their UK research laboratory. Ralph Goodman was the person in charge of the NEAT experiments. At that time, he was NRL's Associate Director of Research for Oceanology. Goodman went to sea on NEAT-I. The tests demonstrated again the impact of the undersea topography on the acoustics. NRL management was very supportive of these NRL Acoustics Division efforts.

LRAPP
The LRAPP (Long-Range Acoustic Propagation Program) effort (led by Brackett Hersey of WHOI) was a predecessor program that gained important knowledge about the deep sound channel. LRAPP was an operationally oriented program. Dr. Berman was Chair of the LRAPP Committee (this responsibility got passed on to Brackett Hersey when Dr. Berman became too busy). They had meetings periodically every 3 to 6 months.

Research in the 1970s and Early 1980s
The Navy was interested in finding future sites for SOSUS arrays; they funded Hank Fleming to help with this re his knowledge of acoustic shadowing effects and propagation. Hank frequently had to brief various operational Navy offices (usually Captains) on NRL results. This resulted in sources of funding for further research. Submarines were relatively noisy then and rather predictable in their behavior. Dr. Berman would pick up the phone and talk to Admirals frequently.

WHOI had been doing magnetic measurements in the Atlantic in the early 1970s. NRL decided to do aeromagnetic measurements. Capt John Brozena at NRL was instrumental in pushing this (he is the father of John Brozena who later worked for Hank). They could see fracture zones in the magnetic records (circa 1973). Initially NRL borrowed equipment from WHOI (then collaborated with them as well). Ship measurements on magnetics were done for "ground-truthing." Early measurements were done near the Azores. Airborne magnetic measurements were done in the Project FAMOUS sea tests; before that we did measurements in the Norwegian/Greenland Sea.

Multibeam sonar became available in the late 1970s on university ships. The Navy started multibeam sonar measurements in the late 1950s, however (via NAVOCEANO). Sheila McDonnell's father (a Navy Captain) was instrumental in promoting this at NAVOCEANO.

In the 1970s our research community was fairly small — everyone knew everyone else for the most part. Chester Buchanan developed the light behind camera system (LIBEC) — and Ralph Goodman made it available to Hank's group to take images of the bottom.

In 1973 NRL was involved in finding the Hayes Fracture Zone as part of the ground-truthing measurements that were done from a ship; this was a continuation of investigations of the mid-Atlantic Ridge. Hank's group flew out of the Azores around 1973–74. Also in the 1970s, Hank did some research in the Pacific Ocean regarding seamount shadowing. His group performed airborne magnetic measurements out of New Zealand and Australia. They wanted to explain topographical anomalies. They flew at 1000 ft altitude south of Australia and had salt spray coming up on the aircraft. They decided to do tests in the South Pacific because they wanted to explore new and different areas from those in the Atlantic.

Later they were able to get operational P3 aircraft to fly out of Iceland and into the Arctic to perform aeromagnetic measurements. They also flew around Ascension Island. In the 1980s they flew out of Brazil. They had no information on the South Atlantic (the Navy was worried about being denied use of Suez Canal and being forced to go through the South Atlantic). Hank's group collaborated with scientists in South America, e.g, off Brazil (where they discovered seamount chains etc., then followed up with ship measurements). They were actually interested in areas all over the world. Aeromagnetic measurements were used for quick-reconnaissance of ocean bottom characteristics. They were also developing airborne gravity measurements in the 1970s. Later Hank's group did over-land surveys over Greenland. The Navy uses gravity for accurate inertial navigation — this motivated some of the accurate gravimetric measurements.

Hank became interested in Norwegian-Greenland Sea investigations in 1973. He has worked up there every year since then. Burt Hurdle was doing joint testing with the Norwegians in the early 1970s; his interests eventually led to the book on the Nordic Seas.

The eventual availability of GPS was extremely helpful in their mapping and charting efforts. In the early days the navigation was spotty (in the 1950s they sometimes went several days without getting a fix). Later they had Loran A (plus/minus 5 mile accuracy); then Loran C (about 2 miles accuracy); Omega (about 8 miles accuracy); then SatNav (APL system) was much better (about 1 mile); then GPS got us down to 30-40 feet; then the classified version of GPS got us down to centimeter accuracy. They had a very good navigator named Jack Ostrander who helped them a great deal (he kept them in the center of an ice lead — and they found a very deep area in the Arctic). Burt Hurdle played a very big role in getting their mapping programs underway in the Norwegian Sea area.

<u>Interview #4, 4 September 2002</u>

<u>Further Comments about Arctic Research</u>

Hank commented further on his group's Arctic research in the Norwegian and Greenland Sea areas. Waldo Lyon (of the Arctic Submarine Laboratory) had the Arctic bathymetric data (circa 1970s) — but he refused to let NRL have the data to digitize it. Hank went to NAVOCEANO and was able to digitize the data (only the dates, vessel names, etc were sensitive — so they did not use that information). Eventually all this data was declassified in the 1990s. Burt Hurdle helped a great deal in facilitating their Arctic data collection. NRL worked on ice camps, and from ships and aircraft (but not from submarines). They went to the Arctic on research cruises (with airborne measurements also) at least once per year. The P-3 aircraft flew a grid with lines spaced about 10 miles apart at altitude of about 1000 ft. They used operational aircraft (e.g., VP-24 out of Iceland; and out of Norway). They flew coast to coast east to west along great circle tracks in order to identify fracture zones, undersea ridges, or topographical anomalies. They worked for Burt Hurdle. Note — the Navy has lost interest in the Arctic in recent years. They also collected water column data, and ambient noise data. They performed towed source measurements in addition to bathymetry measurements. The unclassified book on the Nordic Seas was the end result of this research; there was a classified version as well. At sea, Hank's group was often closely followed by the Russians starting in the 1980s — as close as 200 yards! They had to be careful in making their turns on ships to avoid collisions with the Soviet AGI (intelligence collection) vessels. They would pick up our garbage (plastic bags) as well as well as some of our sonobuoys. They always had someone on their bridge with high power binoculars watching us. With the USNS *Hayes* and USNS *Mizar*, Hank's group deployed gear through a center well and it was harder for the Soviets to observe us.

Summary of Major Achievements

Hank's major achievements — mainly these included new info re the earth's magnetic field; and new information regarding long range propagation (especially in the Arctic). Note — the Greenland-Norwegian Sea is only 55 million years old; we started mapping in the Arctic around 1968 and continued for about 30 years. Hank's group dedicated about 30% of its efforts on the Arctic surveys; other research involved the South Atlantic surveys, South Pacific surveys and various international collaborations (Canadians, UK, Norwegians, Brazilians, New Zealand, Australia, etc.). All the data went into data banks. The main purpose was to help the warfighter. We were doing measurements north of New Zealand (on the Fiji Plateau; funded by ONR) and the Australians invited us to join some operations with them (south of Australia) after that; much of the planning was via the Australian Embassy in Washington, DC in the late 1970s.

Additional History About Hank Fleming's Research Group

Some history of Hank's group: Hank came to NRL's Acoustics Division in 1969. Initially he worked for Burt Hurdle in the Propagation Branch. He got split from Burt's group when Burt went to the UK on sabbatical (Burt eventually got his PhD degree in 1988 via a UK university). Hank then reported to Dick Rojas (then the Associate Superintendent of the Acoustics Division). Hank's group stayed in the Acoustics Division until the reorganization with NORDA. Eventually, Herb Eppert (NRL-Stennis; Marine Geosciences Division) became Hank's boss (mid-1990s). Hank's group was always doing environmental science research. This connection to Stennis had both positive and negative impacts on Hanks' group; the administration was at Stennis Space Center, Mississippi, but Hank's group still had a lot of freedom with their research. Dr. Eric Hartwig replaced Mr. Rojas as Associate Director of Research (under NRL's Director of Research, Dr. Timothy Coffey), but not much changed for Hank's branch. Hank's branch has always had some healthy 6.1 basic research funded by ONR (it was only loosely tied to the more classified research); they had another small group doing only applied classified research.

Hank recently saw Dr. Coffey (now associated with the University of Maryland) who commented about how the university research is very disconnected from the "real world."

Note — Dr. Joan Gardner just got her Ph.D. (2002); she has had attractive outside offers from industry but has chosen to stay at NRL.

Right now the government is suffering because we cannot keep up with outside salaries. There are more persons leaving government than coming in to government.

End Interview #4 4 September 2002

15A. Edward Franchi

Notes Prepared by Fred Erskine on an In-Person Recorded Interview with Dr. Edward R. Franchi held at NRL on Tuesday 29 July 2008 at 1:30 PM EDT (1 hour 30 minutes)

In 2008, Dr. Edward R. Franchi is NRL's Associate Director of Research for Ocean and Atmospheric Science and Technology (Code 7000) and also Superintendent of the Acoustics Division (Code 7100).

Early Life, Education, and Initial Career

Edward R. Franchi was raised in Huntingdon Station, New York (about 40 miles east of New York City). He pursued undergraduate studies at a small technical college, Clarkson College of Technology in Potsdam about 20 miles south of Eisenhower Locks on the St. Lawrence Seaway in northern New York State where he majored in mathematics and received a B.S. degree in 1968. Ed performed his graduate work in applied mathematics at Rensselaer Polytechnic Institute (RPI). His Ph.D. thesis advisor was Dr. Mel Jacobsen. Ed studied the effects of ocean currents on acoustic propagation under an ONR grant. During his doctoral research he received exposure to Navy problems. Ed completed his Ph.D. in 1973 and then accepted a position as a Senior Scientist at Bolt, Beranek, and Newman (BBN) in Rosslyn, VA. BBN had a contract under the Navy's Environmental Support project at the Maury Center on base at NRL.

The Career Move to NRL

Through his research at BBN Ed met several NRL Acoustics Division researchers including Dr. Sam Marshall. In March 1975 Ed accepted a position in the NRL Acoustics Division's Large Aperture Systems Branch under Dr. Budd Adams. Initially, Ed worked on low frequency long range reverberation under Dr. Tom Warfield. Tom was a section head in Dr. Adams' Branch. At that time, Tom Warfield, Jim Griffin and Ed Franchi were the only NRL researchers doing science and technology reverberation and scattering investigations at NRL because in the 1970s the Navy's efforts on antisubmarine warfare (ASW) and tracking of submarines were done very effectively by use of passive towed arrays. By the end of the 1970s decade there were changes in Soviet submarine construction that resulted in a great deal of noise quieting (in part, we learned later, due to the spies passing U.S. information to the Soviets). As a result, Budd Adams' branch received funding from the Naval Electronics Systems Command (NAVELEX 612) to perform investigations in low frequency long range active acoustics. Thus, Ed conducted research on the effects of reverberation and scattering on low frequency active sonar performance. In the early 1980s Ed brought on board several additional researchers to collaborate in this research, including Dr. Fred Erskine, Dr. Mark Weber, Dr. Roger Gauss, and others to work on a number of at-sea experimental programs and data analyses and modeling. In 1986 Ed succeeded Dr. Adams as Branch Head.

The Career Move to NORDA

On 7 July 1988 Ed transferred to the Naval Ocean Research and Development Activity (NORDA) at the Stennis Space Center in Mississippi as Associate Director of Research and Director of the Ocean Acoustics and Ocean Technology Directorate. NORDA was an independent laboratory from NRL. However, in early 1992 NORDA became part of NRL as a result of decisions by Dr. Fred Saalfeld, the Executive Director of ONR, who wanted to consolidate three separate laboratories (NRL, NORDA, and the Naval Environmental Prediction Research Facility (NEPRF) in Monterey, California).

Becoming NRL's Acoustics Division Superintendent

In Oct 1993 Dr. David Bradley retired from NRL as Acoustics Division Superintendent to become research director at the NATO Supreme Allied Command Atlantic Centre (SACLANTCEN) in La Spezia, Italy. In

October 1993 Ed was assigned to be Acting Acoustics Division Superintendent and in April 1995 he became permanent Superintendent. As of 2008, Ed has been Acoustics Division Superintendent for about 15 years.

Recollections about NRL's Acoustics Division

When Ed came to NRL in 1975, most of his colleagues had been hired in the previous decade. The research atmosphere has not changed greatly since the 1970s — analytical research, at-sea and laboratory experiments, numerical modeling, exploiting the environment, development of signal processing techniques, etc. In 1975, work on active sonar was at a sub-critical mass of employees. They were, however, investigating the relevant environmental effects related to reverberation and scattering. In the Acoustics Division there was research underway on the limits of passive towed arrays for undersea surveillance. The experiments being conducted then were among the first to demonstrate the coherence limits for long towed arrays in the deep ocean for low frequencies (below about 1 kHz). This is important because the Navy wanted to develop long towed arrays for improved gain in detecting undersea targets. NRL researchers were able to demonstrate that there are limits to useful array apertures due to limitations of the oceanic environment. These investigations were performed in a wide variety of environments, including ones with mesoscale eddies and quiescent environments as well. There was a large effort to understand the sources of ambient noise in the ocean and to be able to predict the noise environment for acoustic systems. This included studies of shipping noise that dominates at low frequencies, as well as studies of wind generated noise. There was a large research effort to study acoustic system performance in the Arctic region. There was a branch that specialized in research on shallow water acoustics.

The Division has for a long time had a branch devoted to research in physical acoustics. In the late 1960s through the 1980s they were focused largely on structural acoustics to investigate how sound interacted with structures, particularly submarines, in support of antisubmarine warfare. Their investigations looked at how sound scattered from submarines as well as how vessels generated their own radiated noise internal to their structures. There have been a number of branches that came and went from the Acoustics Division over the years. We had a branch headed by Hank Fleming that focused on applications of marine geology and geophysics to underwater acoustics. As part of the consolidation of NORDA and NOARL into NRL, Hank Fleming's Branch remained at NRL-DC but was transferred organizationally to the Marine Geosciences Division, headed by Herb Eppert at NRL Stennis. We had a Branch under Elizabeth (Betts) Wald that worked on improved signal processing software and hardware for Navy sonar system applications (Navy Standard Processor). The Division had a branch headed by Eugene Rudd that investigated remote sensing applications for ASW. Currently we have a branch within the Acoustics Division at NRL Stennis (Acoustic Simulation and Tactics Branch), headed by Stanley Chin-Bing. This branch is the merger of two earlier branches at Stennis, including one headed by Dan Ramsdale. The Stennis groups have previously been involved in Arctic research and extensive at-sea instrumentation development. Ron Wagstaff headed an effort on ambient noise characterization and signal processing developments aimed at separating out and resolving ambient noise components (e.g., elimination of interfering shipping noise, etc.). The Stennis group currently has a significant thrust in acoustic performance model development for ASW applications. Steve Stanic continues to head a group focusing on high frequency acoustic measurements. When Dan Ramsdale passed away we consolidated the Stennis efforts into a single branch, Code 7180.

Comments on Some NORDA Chronology

When NORDA was established in 1976, the first Technical Director was Dr. Ralph Goodman (who had previously been at NRL as Associate Director of the Oceanology Directorate). Dr. Goodman later became

Technical Director of SACLANTCEN. Following Dr. Goodman, Jim Andrews became Technical Director of NORDA until about 1987 when he was succeeded by Dr. Art Bisson for a period of less than one year (Dr. Bisson had previously been Technical Director of the SSBN Security Program. Dr. Bisson then returned to Washington, DC to resume his previous position with the SSBN Security Program). A valuable resource person to consult about the history of the NRL's Acoustics Division will be Dr. Bill Moseley. Bill performed research with long low frequency passive towed arrays in Budd Adams' branch in the early 1970s. He then headed the Shallow Water Acoustics Branch when Ray Ferris retired. Around 1984 he moved to NORDA as Associate Director of Research and Director of the Ocean Acoustics and Technology Directorate. Then around 1988 he was selected as Technical Director of NORDA. At that time (July 1988) Ed Franchi moved to NORDA to take over Dr. Moseley's position as Director of the Ocean Acoustics and Technology Directorate. Additional resource persons to consult regarding the genesis of the work leading up to the Acoustics Divisions Branch at NRL Stennis will be Stanley Chin-Bing and Dave King who both have extensive knowledge of the research performed at Stennis since NORDA's inception in 1976.

Comments about Some National and International Collaborations

Prior to Ed's involvement (in the early 1970s) there was a joint US-UK research effort call MATAPAN. It involved the use of a large hull-mounted sonar. Don DelBalzo was an NRL principal investigator on this effort. Ed was also aware of significant research to map the seafloor and measure its properties in the Arctic Seas (partly in collaboration with allied nations, including Norway). Those research efforts were spearheaded by Dr. Burt Hurdle who later edited a book on the Nordic Seas that documented the resulting research discoveries.

In early 1983 NRL participated in some preliminary collaborative at-sea experiments in active acoustics with the NATO SACLANTCEN. Then later in 1983 and in 1984, NRL collaborated with the Naval Ocean Systems Center (NOSC, San Diego, California) and the Naval Civil Engineering Laboratory (NCEL, Port Hueneme, California) to perform a series of sea tests called Overbid Leo (in honor of Leo Treitel — a pioneer in active undersea surveillance and former NRL Sound Division researcher). The goal of these experiments was to advance the Navy's knowledge in low frequency, long range, basin-wide active acoustic surveillance applications using large aperture towed receiver array systems in conjunction with large towed vertical source array systems with improved signal processing systems. NRL's research emphasis was on understanding the effects of reverberation and scattering from the ocean boundaries as well as on improved understanding of submarine acoustic target strength. We worked with NAVELEX and OPNAV to perform a series of joint sea tests with the United Kingdom in areas west and northwest the UK. We performed four of these joint US-UK experiments in the period August to November 1984. These sea tests were actually done as a foreign military sale to the UK. The UK called this Project Glengarry.

The NRL collaboration in active undersea surveillance has since expanded to the present era to involve other allied nations under The Technical Cooperation Program (TTCP), including also Canada, Australia, and New Zealand. There have been many other NRL international collaborations. In the 1980s, we continued the collaboration with the UK and Canada in the Navy's Critical Sea Test (CST) sea test series (from 1988 to about 1995) as well as via the Navy's Low Frequency SURTASS program sea test series. As these collaborative efforts evolved, the collaborating nations increasingly contributed experimental systems and sea test support (including research vessels, aircraft, submarines, oceanographic measurement capabilities, logistical support and personnel) which have greatly enhanced these collaborations from the US perspective. In more recent years NRL has had valuable bilateral collaborations with additional nations including for example: Taiwan, Korea, Brazil, Argentina, Germany, etc. Further, since the 1970s or earlier we have had valuable exchanges of scientists between NRL and research laboratories in other nations. Dr. Tom Warfield was an exchange scientist to New Zealand in 1978–79. Many NRL researchers have participated as exchange scientists to the NATO SACLANTCEN (now called the NATO Undersea Research Centre, NURC) — typically for periods of 3 to 5 years.

The Uniqueness of NRL

The Naval Research Laboratory is true to its name — i.e., our principal activity and product is "research." The Navy Warfare Centers (e.g., Naval Undersea Warfare Center, Newport Division, RI; Naval Air Warfare Center, Aircraft Division, Patuxent River, MD; Space and Naval Warfare Systems Command, Systems Center, San Diego, CA; Naval Undersea Warfare Center, Coastal Systems Station, Panama City, FL; Naval Undersea Warfare Center Dahlgren Division, VA; Naval Undersea Warfare Center, Carderock Division, MD, etc.) in general perform much more highly applied research, engineering and prototype development for specific operational Navy systems than does NRL. Many of the countries that have sent researchers on exchanges to the US have specifically requested that they be sent to NRL because of our strong grounding in experimental and theoretical research. The US is unique among nations in having this distinct separation between its research laboratory and its systems development and systems acquisition laboratories.

Some Comments on Changing Research Emphases

There has been a continual evolution in emphases for research in various categories at NRL since the 1970s. We had a construct of "Block Programs" managed by Navy Program Offices at ONR until the mid-1990s. Since then our Acoustics Division scientists have had to propose directly to the NRL Research Advisory Committee (RAC) for funding in the 6.1 (Basic Research) and 6.2 (Applied Research or Exploratory Development) categories. This has in effect permitted them to "think outside of the box" a bit more than in the prior period. The downside may be that our researchers may in some instances be less in touch with the needs and requirements of the operational Navy. Thus NRL can take a bit more risk than in the past in initiating research projects, but there is still constant pressure to make our projects relevant to the short-term needs of the Navy for system improvements and enhancements.

Thoughts about Long-Range Planning

In the 1960s to 1980s the Acoustics Division prepared long-range planning documents to help guide future research efforts. In recent years we have had few such long-range strategic plans; we find that they are very hard to implement in light of the rapidly changing landscape of the Navy's research requirements. Even though our mission is to have a long-range view to do fundamental research to address the strategic needs of the "Navy after next," in practice we often operate on a rather "tactical" time scale. When Ed became Acoustics Division Superintendent in 1993, Dr. Timothy Coffey, NRL's then-Director of Research, passed on to him a long-range strategic plan for the Division that was developed under the previous superintendent, Dr. Dave Bradley. It was well written, but in practice, it was not closely followed. Ed held a Division Strategy retreat in the late 1990s. The comfort zone for predicting the Division's research directions was really only for the next 2 to 3 years based on rapidly evolving world developments. Such strategic plans may have less value in the present era as compared to past decades. New directions for research have rapidly arisen in importance in ways that could not necessarily been predicted a few years ago (e.g., mine warfare and harbor defense, anti-terrorism issues, maritime domain awareness, etc.). On the other hand, we do need to look carefully at our long-range research needs in terms of improved research facilities and at-sea and laboratory-based research equipment as well as for improved data and information processing and modeling capabilities. We need always to be mindful of our long-term needs to reinvigorate our research workforce, as we anticipate future employee retirements and types of technical capabilities needed.

Thoughts about the Future of Our Workforce

In recent years it is true that our workforce at NRL has been aging and there is a need to bring in younger researchers. This problem is pervasive across all of NRL. There are systemic problems with the long time frame needed to hire new employees. In difficult economic times, the government has a hard time competing with salaries offered on the outside — in commercial industry and academia. NRL operates as a "working capital fund" — so all funds available at NRL to pay salaries must come from "customers" who are willing to pay for our research services. Thus, when our funding outlook is uncertain, we tend to be rather conservative in our outlook about hiring new employees. The NRL personnel demonstration project that started in 1999, however, allows us to evaluate new employees for a period of three years as opposed to the old system that allowed probationary period of one year — this is an improvement. We have opportunities via student cooperative education programs and postdoctoral programs that can help us to bring in young scientists who may be candidates for future full-time employment with us. Dr. John Montgomery, NRL's current Director of Research, has recently initiated new incentives including wavier of overhead charges for the hiring of postdoctoral appointees and for researchers hired within a year of their graduation.

Thoughts about the Project on the History of NRL's Acoustics Division

Dr. Burt Hurdle compiled much information in the period leading up to the 1998 celebration of NRL's 75th anniversary about the accomplishments of the Acoustics Division in prior years — and this documentation may be of use in the present effort to document the history of NRL's Acoustics Division. We may also want to review older classified reports (that could now potentially be declassified) for additional useful and historically valuable information about the early Sound Division's research efforts. The history of the Acoustics Division will be a useful reference work for new employees in order to give them a sense of continuity about what Division research was conducted in previous decades. We need a balance in coverage of research efforts across the various eras and a balance between text and photographic documentation. We need to consider carefully about our inclusion of key bibliographic references. It is not realistic to be totally comprehensive in our coverage over the approximately eight decade period. It is probably better to be illustrative in our coverage to elucidate key examples of projects, people, and research accomplishments over this long period of time. It may be better to be rather selective in our choice of bibliographic references (e.g., books and monographs, etc.). We should keep the readership level sufficiently challenging that we can expect the reader will have some technical background — e.g., at the level of the *NRL Review* that is published annually. Those *NRL Review*s may in fact be useful as resource material. It is not clear that we have a story that lends itself to interest on the part of the general public. The NRL Technical Information Services Branch will be helpful as we select appropriate photographs for inclusion. Perhaps we could pick some themes such as key facilities and show the evolution over the years. Note that the fiber optic acoustic sensor development program was started by the Acoustics Division — and its story will be important to include. We have occasional photos that were taken of the entire Division that may be appropriate for inclusion. Dr. Leo Slater, NRL Historian, will be very helpful as will be the NRL Archivist, Dean Bundy, the NRL photo archivist, Gayle Fullerton, and the NRL Research Librarians, including Marybeth Dowdell.

15B. Edward Franchi

Interview with Dr. Edward R. Franchi
Center for Environmental Acoustics
Naval Research Laboratory
Stennis Space Center, Mississippi

9 September 1993

Interviewer: Dr. David K. van Keuren
NRL History Office

The Center for Environmental Acoustics down here is part of the larger Acoustics Division at the Lab. It consists of about a hundred people. Our primary focus, as the title implies, is trying to relate acoustic phenomena in the water to some of the basic oceanography and sea floor characteristics. We are down here at Stennis, co-located with the Oceanography and Seafloor Sciences Division for that purpose and trying to do a lot of collaborative work with them. Also, one of our main customers, for acoustic as well as environmental data bases is the Naval Oceanographic Command, the Naval Oceanographic Office, which is also down here. We try to do programs that kind of focus, if you will, on the impact of the environment on acoustic phenomena. Traditionally, that has been aimed at Anti-submarine Warfare which was a major effort in the Navy for many years.

I think many of the essential things that we develop down here, looking to the future, have probably three directions that we want to go with. One, with the changing geo-political climate, we need to obviously address acoustic issues in shallower water areas. So at the lower frequencies, hundreds of hertz to a few kilohertz, the theme is still to keep areas sanitized from warfighting ships and submarines. The challenge is we can't, as we could in open oceans, we can never ignore the effects of the environment, particularly the interactions with the bottom. So, we have measurement, basic research, and modeling programs that are designed to look at propagation through the sediments, scattering of acoustics in the sediment, generation of compression waves to shear waves, things of that nature. We will try to do some fundamental measurements in the field to get some understanding and insight and to validate our computational modeling abilities.

The second area that I think we are going to be applying our technical abilities to in the future is the issue of mine warfare. Particularly, how to detect, classify, identify, and neutralize mines. This, by and large, is going to put us into higher frequencies, typically ten kilohertz up to, maybe, five hundred kilohertz for various sonar systems that are under development or are in service now.

Again, we have had a basic research program in high frequency acoustic phenomena for a number of years. That is one area that we think is going to grow. In terms of making measurement, the interaction with the environment is now on different scales. We need to worry about phenomena like turbulence; we need to worry about, in the sediments, fine grain structure, how porous and granular the sea bottom is. So we are looking to build new programs very closely with the programs in oceanography and seafloor sciences.

Again, the modeling challenges are we still need to take full wave theoretic approaches to understanding these phenomena. We need to look at building computationally efficient propagation and scattering algorithms that can handle these problems. Typically, for a variety of reasons, the higher in the acoustic frequency you go, the more computational drag these algorithms have because the algorithms tends to step through a step and distance range that is proportional to how many wavelengths you have. The higher the frequency you go the much shorter the wavelength. Traditionally, you need to look for ways, for new innovative techniques to overcome a computational difficulty.

So, again, the modeling, the measurements to understand and validate that, is a component. In both of those areas, the shallow, anti-submarine warfare, and the mine countermeasures, we're developing new a facility here called the Tactical Oceanography simulation Lab, which is designed to be able to take these computational algorithms, couple them together in a fully coherent way, interface them with the data bases that are emerging, and be able to do simulations for predicting the performance of sensors, both existing and new ones that are coming on line, as well as looking in a tactics sense at how knowledge of the environment might improve tactics operationally. A commander doing a mine warfare scenario might exploit the environment. So, our traditional line of work is going to be focused in these two directions.

In the dual use area, I think the key here is looking at acoustic sensing of the ocean and the seafloor, improving the abilities to get fundamental environmental parameters from acoustic sensing as opposed to direct measurements. I think, perhaps, our applications in the commercial area are probably more limited than some of the other divisions will have. But there are a couple of things we are doing. One here at Stennis, the Center for Environmental Acoustics, is we're beginning to look at what we call inverse scattering and forward geophysical inversion. We believe that we really understand the acoustic interaction with sediments, for example, well enough that we can actually use acoustic returns to back-out, if you will, fundamental environmental measurements. In trying to describe and monitor in a changing environment how the sediments transport wastes, for example, I think there are some applications in that area.

There is an area that I want to mention to you that is being done in the Acoustics Division in Washington that you ought to get a dump on. That has to do with some really nifty advances in acoustic holography. I don't know if you are aware of those. They are being done by Joe Bucaro's Physical Acoustics Branch. Basically, we are using near field holographic techniques and using acoustics to basically get all the response characteristics of objects. That has traditionally been helpful in looking at submarine responses to acoustic energy. For mines, we expect to be able to extend that to characterizing mine responses to acoustic energy. It has applications in imaging any sort of an object. It has applications to noise control, as well. I think one of the things that Joe Bucaro is pursuing vigorously with NASA is looking at applying these techniques to aircraft cabin noise, for example. Being actually able to, in this holographic sense, show how an external noise source, like a jet engine, how that maps the sound field inside the cabin, and what sort of counter-sources , if you will, we might put there externally to actually control that cabin noise. So, there are lots of applications, in that area.

Some of our acoustic signal processing techniques, which we develop both here and in Washington, are basically aimed at suppressing the extraneous background, the noise if you will, and enhancing the signal. Without getting into details, I think some of our potential commercial transitions are where some of these algorithms can work well on airborne noise, for noise control problems.

So, that's an overview as I see it.

Q. As opposed to where you are now, in terms of both basic and applied research in acoustics, where do you hope to be in ten years? What do you see the direction you are moving in which is a shift from where you have been?

A. I think the shift will be to .... I tend to think of it in terms of changing Navy missions that we are trying to support. I think ten years from now, we are going to be studying a much broader band of frequencies, in general. I think we are going to, in order to do computational techniques efficiently, we are going to be utilizing much more high performance computing. We've traditionally utilized the vector type machines, like the Cray in the past, but we, and this is a future direction, are hard looking at parallel processing and other advanced computational capabilities and how we can better implement and get more sophisticated in our numerics by using these capabilities.

I think another area that we are going to try to support, which is still Navy-oriented, is looking at autonomous underwater vehicles, whether they are remotely operated or unmanned underwater vehicles, and looking at acoustics for sensor systems that are going to perform on these vehicles. Basically, trying to deal with much smaller scale phenomena, as well as the dynamics. I think our measurement programs, which have typically used large aperture antennas, fixed measurement sites and systems, are going to rely more and more ROVs and those kinds of things to make our measurements in the future. So, I think in our capitalization area we are looking very strongly to opportunities to acquire and utilize remotely operated vehicles in our work. I think you will get a similar response from the Oceanography and Seafloor Sciences Divisions, who also see these sorts of unmanned vehicles as being essential to some of the basic environmental acoustic characterization that we are going to do in the future.

Q. ASW is long been a central research point for your group. With the movement to an emphasis upon littoral warfare, and a lessening of the submarine threat, do you see a decreased research in your area on ASW? Are you shifting over to anti-mine warfare and similar sorts of studies?

A. I think there is a shift, and the shift is going to affect the acoustic frequency bands that we concentrate on. It is going to affect the scales of environmental characteristics that we need to deal with, and it is going to make essential our understanding of the fine structures in the sediments. NRL has always done, in acoustics, basic and applied research from first principles. So, a lot of our computational abilities, a lot of our measuring capabilities, a lot of our signal processing, and the special facilities we have developed are adaptable from the deep water ASW problem to other applications. So, hopefully, our overall programs will remain overall stable, but there will be a shift in, if you will, the applications to higher frequencies, both for mine warfare and for littoral anti-submarine warfare for shallow water. It is just not a matter of taking what you've got and running the computer simulation at a different frequency with different inputs. There a lot of research to go back and make sure that we have the physics that controls the processes at higher frequencies in our models, and, if not, developing those. That's where I believe the future directions are going.

16. Robert Frosch

AN INTERVIEW WITH DR. ROBERT FROSCH

by Dr. David K. van Keuren
History Office
Naval Research Laboratory
13 August 2003

Tape 1 – Side 1

van Keuren: Today is 13 August 2003. I'm David van Keuren from the Naval Research Laboratory. I'm talking with Dr. Robert Frosch about his experience both at the Hudson Labs and as the Assistant Secretary of the Navy. Dr. Frosch, I know you've been interviewed at length both by Naomi Oreskes and Gary Weir so I'm going to limit my questions to the topic of US Naval Oceanography and Oceanographic and Development, in support of sea-power and Naval strategy during the Cold War. Now, you had a long connection with the Hudson Laboratories of Columbia University. Can you tell me about how your connection to the Hudson Laboratories came about?

Frosch: Yeah. Well I -- in 1951 I was finishing my doctoral dissertation in physics, theoretical physics at Columbia and I defended actually in June and did some additional work on my dissertation, got my degree in February of 1952, but in the Spring of 1951 I was looking for a job and talked to various people on the faculty, and somebody suggested that I talk to Gene Booth who was -- had just been head of the physics department and who was starting a new laboratory for the Navy. And so I got the phone number and called up Hudson Labs and found myself talking to a guy named Bill Nierenberg who was there for the summer, everybody else having gone to Bermuda to do their -- get their feet wet in salt water. So, I went up to the lab to be interviewed and it was just -- Bill and a couple other people were there and I really just talked to Bill. And as I told Naomi it was a typical Bill Nierenberg interview. He said, so tell me what you've been doing and I got in about four sentences and he talked for about 45 minutes and then he said well, that's sounds fine. How would you like a job? And it sounded interesting so I went there, started in the middle of September of 1951. I think there were only half a dozen people in the lab at the time, and thinking it was temporary but in fact I was there for twelve years so --

van Keuren: How and when were Hudson Labs organized?

Frosch: Well, the -- the Navy apparently came out of World War II, and specifically the battle of the Atlantic, scared to death that they had survived the submarine warfare ASW business by a mixture of luck and the skin of their teeth. And there was a thing called -- I think the Hartwell Commission, Admiral Hartwell, to look at what to do about it. And interestingly enough one of the recommendations was that they establish another laboratory to look at the fundamentals of oceanography and underwater acoustics to see whether there are things that could be done that hadn't been done. And ONR -- I guess together with BuShips, but ONR in the lead, decided to approach Professor Rabi at Columbia, Nobel Prize winner and the guy who had been very heavily involved in both the nuclear business and in the radar -- the reissue [unintelligible] at MIT to establish a laboratory, and that's how Hudson Labs got established.

van Keuren: And this was after the Hartwell Commission so it would put it in the late 1950s?

Frosch: Well, I think it started sometime in the spring of 1951.

van Keuren: And what was the mission, the specific mission of the lab?

Frosch: Well, the mission -- the mission was to look at -- understand it was an ONR kind of sensible basic research mission to understand enough about the oceanographic factors that affected underwater acoustics so that one could get a better handle on using it for ASW. And SOSUS -- I guess SOSUS had already begun and the -- the Ewing, Worzel work on the Deep Sound Channel had been published, Peckeris's work on shallow water mode propagation had been published, and the general flavor was to look into low frequency acoustics. Ted Hunt at Harvard had been trumpeting an ocean an hour with low frequencies and see what could be done with it. So, we were given kind of an open -- open mandate to invent our own program in that direction and see what we can do.

van Keuren: So, it wasn't just acoustics, it was kind of the broader physical oceanography which affected the acoustics, too?

Frosch: Yeah. That was really the -- the style of the thing was to say well, nature -- nature sets rules and if you learn the rules then you know how to use them and when you use them you can build devices that will work. A lot of the early stuff we did was, in fact, in support of understanding how to do SOSUS better. My first task, my first theoretician's task was to figure out how to decide whether SOSUS arrays were at the right depth or whether they should be deeper or shallower and so on, I did some work on that.

van Keuren: Uh-huh. Did you come in as a theoretician?

Frosch: I came in as the theoretician. I can show you, I have six thumbs on each hand. But I rapidly, you know, I went through a whole transformation which affected my later career tremendously because I was doing theory, but then nobody knew how to do the experiments to go with the theory, so we were inventing ways to do experiments. And then it turned out we didn't quite know how to design equipment to do the experiments, so I ended up going to sea and sort of dabbling in everything. But basically I was the house senior theoretician.

van Keuren: How many people were at the lab when you joined it?

Frosch: Oh, it can't have been more than a dozen or two dozen.

van Keuren: So, you were really one of the earliest people?

Frosch: I was -- there were three or four of us who were scientists.

van Keuren: And who was running the lab at that point?

Frosch: Gene Booth who was a physicist. Jack Nafe who was a physicist turned geophysicist who was working with Doc Ewing at Lamont, and then there was another theoretician, Frank Pollock and I and Al Berman joined us a little after that, and so on. We began to build up, so it was just about at the beginning.

van Keuren: And most of the people came from physics, were they acousticians or --

Frosch: Not particularly. Gene Booth, I think, was basically a nuclear guy. Jack -- Jack had been a molecular beams guy, I think, and had become a geophysicist. I was -- I was -- I would call myself a theoretician, a quantum mechanic. Frank Pollack was much the same. Al Berman was a molecular beam guy, so we were all busily learning -- well, we knew some acoustics, but we were busy learning acoustics and oceanography and so on.

van Keuren: How did a molecular beams guy come into acoustics oceanography?

Frosch: Looking for a job. Actually I think I recruited -- somebody -- somebody in the place was looking for -- see, we were coming out of the -- out of the World War II, all scientists turn their hands to whatever they can do to help the war effort, and the physicists had done a lot. So ONR had turned to a physicists, the senior physicist at Columbia and said build us a lab so when he -- Gene Booth became director he naturally reached out to the nearest guys who were young physicists getting out of -- out of Columbia. I don’t know that anybody came in who really knew any acoustics. Maybe Dana Mitchell did. He was an older professor of physics, but he knew acoustics. He had done a lot of classical physics, but he also -- he was an experimentalist that designed useful equipment.

van Keuren: So, what we’re seeing is kind of an expertise -- a knowledge transfer from physics to --

Frosch: Yeah.

van Keuren: -- to related fields, like what happened in radio astronomy, with what happened a little bit later in X-ray astronomy.

Frosch: Yeah.

van Keuren: And what’s happening from physics to a kind of acoustic stenography.

Frosch: Yeah. And you know, I remember my friend and colleague Brackett Hersey who was at Wood’s Hole not at Hudson, somebody asked him what was -- what was he doing being an oceanographer. And he says well, I’m just a physicist, geo-physicist practicing his trade and I just happen to be practicing it in the ocean.

van Keuren: Huh. You had -- you served in several roles at the Lab, moving from being a bench scientist, to head of the Theoretical Division, to director. How did your -- how did your work change as you moved from the bench lab to the head of the Theoretical Division?

Frosch: Well, when I came in I was the -- I was -- two of us were the theoreticians and then they got to be experimentalists. What -- Bill Nierenburg came in one day and said -- and said you are now the head of the theoretical division which consisted of two of us. Later it consisted of three of us, so my life didn’t change much. That was -- that was simply a way to, I don’t know, on Bill’s part to sort of begin to have an organizational diagram, have people with distinct roles. And that was the role I was playing, and I guess as they got to be more experimentalists I used to come around and play theoretician with them and -- and suggest ideas and so on. And we, you know, it was a small lab and everybody collaborated is what it amounted to.

van Keuren: Well, I understand it maintained its informality through pretty much its entire lifetime.

Frosch: Oh, yeah. It was always a very informal place.

van Keuren: Uh-huh.

Frosch: The old time -- I remember Bill coming in one day waving a piece of paper. He came into a staff meeting, I don’t know, half a dozen or a dozen of us there, waving the piece of paper and saying this is the organizational diagram of Hudson Labs. The Navy says we have to have one, and somebody said let me look at it. He says, I’m not going to show it to you guys. You’ll start a power battle. I’m just gonna lock it at the bottom of the safe.

[LAUGHTER]

Frosch: That was kind of the style.

van Keuren: You became Director in 1956?

Frosch: Yeah. There’s -- yeah.

van Keuren: So, how did that come about?

Frosch: Well, it came about -- let’s see. What happened was that Gene Booth was -- was Director and Jack Nafe was Deputy Director for a couple years. Then they wanted to go back and do what they were doing, and they brought in Bill Nierenberg who was then -- he was Associate Professor or Professor of Physics at Michigan. And he came in and brought his Deputy Director, Frank Levin who had been working at

Jersey Standard Production, an actual geophysicist. And Bill's intention was to stay for a couple years, which he did, and then he went to Berkeley. And Frank Levin went back to Jersey Standard, which by then I think had another name but I don't remember. And Bill then proposed that I be Director and the Navy kind of looked at it, and looked at my CV, and said let's see, this is 1955, so this guy is 27, I don't think so. Incidentally, that was the summer we did [unintelligible] in the -- in the Norwegian Sea. So, there was a lot of discussion of what to do. Bill was trying to be pretty firm that he thought I was the one to be Director, and there was another senior guy in the Lab at that point named Al Guthrie who was a professor on leave from Brooklyn College, another physicist.

van Keuren: Uh-huh.

Frosch: And an older guy, and the conclusion was that the next thing that should happen would be he would be Director and I would be Deputy Director for 1955 through 1956, and if it worked out all right then he wanted to retire back to Brooklyn or maybe retire, I don't remember whether he was going emeritus or not. I don't think so, but he didn't want to be Director all that long any way, and that if by then the Navy might be convinced and I would become Director. So, in 1956 the Navy -- ONR was convinced and -- and Al Guthrie wanted to do something else so I became Director and Al Berman became Deputy Director.

van Keuren: Okay. How did the Lab interface with the operational Navy?

Frosch: Well, not much. Not much directly.

van Keuren: No.

Frosch: We borrowed submarines, so to speak, used them sometimes went on them. We had an operating Naval vessel assigned to us as a research vessel, and ATA seagoing tug named the Allegheny, 179, I think that was the right [unintelligible] which we outfitted with an A -- stern A frame and winch and so on and used that. We had a lot of contact with all the Navy labs, with Woods Hole, some with Scripps, and particularly the Marine Physical Lab at Scripps. Fred Spiess and those guys, with NEL, with other -- other labs that were sort of attached to the Navy, with us -- a lot with us [unintelligible] NRL, Buck Buchanan later, but not much very directly that I can recall with the operating Navy. It was sort of via BuShips and ONR that we dealt with them, and most -- what we were doing was -- except for SOSUS, way far away from things that we would put on ships.

van Keuren: How -- what about the other groups – R&D community within the Navy, such as NRL?

Frosch: Oh, yeah. We -- we were sort of -- those days that ONR and BuShips had put together I guess it amounted to a kind of consortium of laboratories. They actually formalized it with a thing called the Undersea Warfare Research and Development Planning Council which was a formally existent body advisory to the Navy, that was contact with the Senior Navy, and I don't know whether one could do it today. It -- it had academic laboratories, all the Navy labs that were in underwater acoustics, there must have been half a dozen of them at least, some of the contractors, Western Electric who was doing SOSUS and Bell Labs, and a couple of the others, and we got together and worked on the question of what should the Navy's program in underwater -- undersea warfare and acoustics be. The Scripps MPL guys were all a part of it, so it was actually a functioning community which actually had meetings. I remember once after we got the Gibbs, we took an old AVP out of mothballs and later -- the Navy made it a research ship for us and then after a while we actually took a -- had a meeting of the Undersea Warfare R&D planning council aboard the ship in the tongue of the ocean, because most of us hadn't been there and we wanted to actually see where the range was going so --

van Keuren: Uh-huh.

Frosch: So, this was a community of people involved with -- with Navy underwater acoustics, sort of with the Navy at the center of it and funding it. It was a very useful construct.

van Keuren: And it included academics, too?

Frosch: It included academics.

van Keuren: Scripps, Woods Hole, Lamont?

Frosch: Scripps, Woods Hole, I don't remember whether Lamont was involved. They probably were, and Scripps, Woods Hall, Lamont, Hudson, there may have been somebody from APL Washington, I don't remember. That's -- I'm sure that's in the archives.

van Keuren: Uh-huh.

Frosch: We can -- we can find that.

van Keuren: Okay. Tell me about Medea?

Frosch: Oh. Medea, okay. The Navy came to us, well actually it came to us in --

van Keuren: Us being Hudson?

Frosch: Hudson. I don't remember whether they came to Bill or whether -- I think they must have come to Bill and very rapidly it was me.

van Keuren: Uh-huh.

Frosch: And said we're trying to figure out whether the oceanographic conditions in the Norwegian Sea, or the acoustical conditions really, make it suitable for SOSUS. And you know, what do you think? So, you know, we looked at what we knew about it, which wasn't a hell of a lot. It was -- it was -- there was, there were Nansen cast data, and temperature and all of that. And as far as we could tell it looked as if it was all right, so the next question instantly which they were going to ask anyway, would you run an expedition -- organize and run an expedition for two months in the summer of 1955 to find out? So, we organized an expedition and it was a fairly typical operation that fits with the committee I was just talking about. It was Hudson, Woods Hole, [unintelligible] Bell Labs or Western Electric, I was never sure which was which. Probably both, I think some guys from NRL, there may be others. It was a five ship expedition. The five ships were the Rehoboth, which was an MSTS -- no, it wasn't. It was a Navy commissioned survey vessel, a hydro-vessel. There was a DE which was used for dropping charges. Bell Labs chartered a small cable layer so they could lay stuff on the bottom, and there were two EPCERs which I think were assigned, they were either both ships that were used by USNUSL, or one by USNUSL and one by NRL, I don't remember. And the team went to sea after some elaborate planning, to do the low frequency acoustics in the Norwegian Sea and to test some of the schemes that USNUSL in particular and NRL had the GIUK gap closing.

And it was a -- it was a -- I had to write the Op-plan. There was an Op Officer assigned, but in the spring or late winter when the operational planning was starting he got ill or something and the Navy said they couldn't find somebody else. And they called me up and said would you also be Ops Officer? I have to say I didn't know much about being an Ops Officer, obviously, but I figured well I could plan the expedition. So I sat down and worked out -- and this was, you know, it was working out where the source ship or ships were going to be, where the listening ships were going to be, how to coordinate the logistics, move everybody around, give the USNUSL people a shot at being in the GIUK gap, and we put together a two month plan. And went off to sea as -- stopping at Earl, New Jersey to pick up explosives and -- for deep sound, and I guess we had a towable source. A fifty cycle source, seven cycle source? I don't remember, and the cable layer, and we had a scheme for putting hydrophones in deep water using signal corps wire which mostly worked, but had its troubles. And we carried out a two month expedition and I wrote the -- the expedition report, you know, it was the kind of data where you analyzed it on the fly, so we pretty well knew what we had. At the end I wrote it on the ship going back from Greenock.

van Keuren: From -- from where?

Frosch: From Greenock, Scotland, Glasgow, and the conclusion was yes, you could certainly run SOSUS in the Norwegian Sea, which we had guessed from doing some ray tracings and so on. It was a very interesting experience. Two months in the Norwegian Sea in the summer.

van Keuren: Was this your first extended experience at sea?

Frosch: Well, I'd been at sea for two or three weeks at a time, but I'd never been at sea for a month and short -- short stopping [unintelligible] it was fine.

van Keuren: The -- when -- do you know when SOSUS began to go into the Greenland Norwegian Sea? Was it immediately afterwards?

Frosch: I don’t know.

van Keuren: Don’t know?

Frosch: I think it was a couple years afterwards. Not, I think, because there was a question about it, but because it was tacked on to whatever SOSUS installation schedule they had and there were probably a string of them ahead of it in line would be my guess. And of course, you could only do -- there are lots of places you could do it nearly any time of year, but up there you didn’t want to go up except in the summer. So, my impression is that it was simply added to the list and something was put in, not very long after, but somewhat after, I don’t know the dates. I [unintelligible].

van Keuren: So, we’re talking like maybe 1957, 1958 possibly?

Frosch: Yeah. Maybe even 1959 or 1960, I don’t remember.

van Keuren: And it raises the question, why so late? You would think that the GIUK Gap would be an obvious place?

Frosch: Well, I think the -- well, I think it was, but remember, this was -- they started doing this when? The first arrays must have gone in about 1950, 1949, and you know, it was quite expensive and nobody was quite sure. You know, you weren’t -- it wasn’t until a few arrays were in that you’d really track much and be sure what you were doing, so I think the Navy was simply doing it on a -- on a let’s protect the -- our own coastline east and west first, and then we’ll -- then we’ll move forward. I’m guessing at it, but I think --

van Keuren: So, more central north Atlantic and then expand from there?

Frosch: More North Atlantic and Pacific, do the US coast protection because it was don’t let -- at that point it was don’t let any Soviet submarines unattended within 600 miles because -- I think it may have been paced also partly by the range of Soviet missiles and so forth, which I don’t remember.

van Keuren: [unintelligible]. Did -- was Hudson Labs working on any other major projects, other than SOSUS?

Frosch: Oh, yeah. We were -- we were looking at signal processing schemes. We did a lot of work on ambient noise, ambient noise spectra, we did the first work and I gather from some of the JASA literature is coming back in style, on vertical arrays. We did a lot of work on vertical arrays. And in fact, if our engineering -- if the engineering state of the art had been better we might have done more with three dimensional arrays. And then of course in 1959 it would be, the Navy came and asked us to do Artemis. Well, they didn’t ask us to do Artemis. They said look, this passive stuff is great, but we don’t understand why the Soviets aren’t quieting their submarines as fast as we’re quieting them, but some day they may so we better see what we can do about long range active.

Of course I didn't help by saying, you know, it's possible that the Russians are being cagy and their submarines are perfectly quiet except they have wooden blocks next to all the sound isolators, and [unintelligible] there's a guy with a sledge that knocks out the blocks. The isolators -- it comes down on the isolators and everything goes down by 32 db. It turned out not to be true but -- and it was not that kind of noise anyway. It was mostly propeller noise. But they very much wanted to see what could be done with long range sonar. Well, so they asked -- they literally asked us to start another project which was Artemis and it was a -- I won't say it was money no object, but it was a sort of don't worry about doubling the lab or that kind of thing. And in fact we did. We went from 100, 125 people to 300 or 350 when we did Artemis. We very rapidly, you know, a few weeks work with the sonar equation and it was pretty clear that whatever this was going to be it was going to be big, because you -- you know, even at convergence zones it was going to be big.

And so we set out to do Artemis and the heroes in Artemis, well, Al Berman and Harry Sonneman, Bucky Buchanan because he -- he saved their [rear end] on the source. And I guess you know how Artemis turned out. You've looked -- you've seen the literature. Our first try at a source was something Boeing was going to do which was gonna be an array of -- I forget, nine I guess, magneto-restrictive transducers that were going to be doughnuts six feet in diameter each backed by a reflector or an absorber reflector. And the idea was you made this giant magneto-restrictive doughnut which you do by rolling up sheet steel with epoxy and then you wind coils on it, and when you put the juice to it it goes -- contracts and pushes out so that you get this giant piston kind of effect. That didn't work. It didn't work for any fundamental reason.

It didn't work because no matter what they did they could not produce a magneto-restrictive coil that scaled with the epoxy flaw-free. There were always bubbles and so on no matter what they did. Every bubble became a heat concentrator and you'd burn out the insulation, so you'd get into trouble right away with all the heat. And we worked at that for quite a while, even to the point of calibrating some of the doughnuts at Lake Pend Oreille, but then it was clear that that was not going to work and we cast around for another source.

And Bucky Buchanan had been working with the shaker boxes which were sort of a one inch steel cube and inside the steel cube separated from the cube with an array of springs was a magnetic shaker so you shook the inside. And if you had all the parameters right you were shaking the outside, then you made a big array of them and shook them all together so you had a piston. And we had wanted to avoid that because it was a hell of a lot of parts. And somehow the attractiveness of you made these nine kind of solid things once and you were into the electrical business, but we got convinced that that was the way to do it, so we made this gigantic array. And I think -- I don't know who actually manufactured the shaker boxes. They may have been manufactured at NRL, I don't remember. And then, of course, we had the problem of how do you handle this giant 50 or 100 ton source. So we got the Navy to take a 10,000 ton tanker out of I guess the reserve fleet again, put it in a yard and cut a sea chest through it -- we could hang -- so it was -- it was a mobile source.

Then, of course, [for] the [receiving] array we needed a hell of a big array and what we finally did was Harry Sonneman devised a way of making array elements which were self-erecting towers.
They went to the bottom -- they were a hole -- a vertical -- well, a square cylindrical tower is what you ended up with, with 20 hydrophones on it, but the elements of the tower were essentially strings, wires, with buoyancy at the top and a concrete anchor at the bottom. What you did was you compressed the whole tower like an accordion so it was sitting in a recess in the concrete anchor and tied down with a dissolvable -- a slow dissolvable link and then you'd put these on a cable and lay a string of them on the bottom and then the links would dissolve and all these things would pop up.

It worked fairly well, although Naomi Oreskes found some evidence that Alvin had looked at it and some of the towers were -- and so on. It was not as good as we thought. But they looked -- they looked at it some time later so I don't know what it was like when the experiments were done. That -- all these -- there was -- let's see, it was 20 by -- 20 cables, of 20 towers, of 20 hydrophones, so whatever 20, 20 cubed is it. Each tower already had its beam formed in it, so that the shore beam foreman had to do -- had to do with 400 elements. And all these cables were connected -- these were laid on a slope of a reef, southeast of Bermuda and --

van Keuren: In Eleuthera? Is that --

Frosch: No, Bermuda.

van Keuren: Bermuda.

Frosch: Bermuda, and all came together in one of the early Texas towers which was the junction box, sitting on top of the reef, which we -- because of the way amplifiers were in those days some people had to live on it that do the care and feeding of the electronics, and then a cable ran to shore to a laboratory under the top of Tudor Hill on Bermuda. We shared Tudor Hill with the SOSUS guys. Now, I was no longer at Hudson. I had gone to DARPA by the time the actual experiments were done.

van Keuren: You left for DARPA in 1963?

Frosch: I left for DARPA -- in 1963, the fall of 1963, and I think the real experimental work was done after that. And I gather from the literature I've seen that they got echoes at the third convergence zone -- so it can be done, but if that's what you have to do to do it at the time, it didn't look like a very promising scheme. Now, you know, forty years later low frequency sonar is irritating the whales so maybe we're back closer to it, although it's a somewhat higher frequency but not that much. Not that much higher. I forget what the frequency of Artemis was. It was pretty broad band. It was somewhere in the 100, 150 [unintelligible].

van Keuren: So, that project would have occupied your last few years at Hudson?

Frosch: Well, we were doing a lot of oceanographic acoustics and passive acoustics with underwater sound. It was technically it was two projects. Hudson Labs was Project Michael originally, and it was still Project Michael but it was also Project Artemis. And of course, we were dabbling in -- what we used to refer to unsound detection, meaning non-acoustics. Looking at all sorts of wave generation and so on, but basically it was passive and active low frequency acoustics.

van Keuren: Uh-huh. If you were to summarize, could you tell me what you consider to be your major achievements --

Frosch: Oh --

van Keuren: -- as Director?

Frosch: -- well, we did Artemis and proved that could be done. Perhaps not as director but I think what the Lab did was demonstrate that to a very good approximation low frequency underwater acoustics is coherent. Now, when we started in the business everybody had worked at high frequencies where you lose coherence very rapidly, and we sort of looked at the ocean and said what's out there that's fast enough to make a 50 hertz signal or 100 hertz signal incoherent?

We concluded we couldn't think of anything, so we were asserting that you could do -- that you could make very long arrays. The idea was that a SOSUS array was about as long as you could go after that you'd sort of lose coherence. Al Berman and I did an experiment with a 50 hertz source in, I don't know, mid-50s anyway, in which we demonstrated that we could -- we could measure the Doppler shift of that source against a Hewlett-Packard oscillator, by the way, it must have been their first product, out to six or seven hundred miles.

And in fact we could tell when the ship made a turn. So that was one and then -- because nobody was convinced about the arrays we did an experiment -- who was it by? Tour de Force by the Western Electric, by the AT&T long lines department, because at Hudson Labs we had the direct signal of a hydrophone from Eleuthera, a hydrophone from South Carolina, I think it was. Wherever Hatteras -- the Hatteras array was, one from New Jersey, Cape May array, and one from Sable Island. And we were able to show with a sound source out in the Atlantic that you could operate those four hydrophones as an array.

We said well, if you're not convinced by 2000 miles, what do we do next? The point being that in fact, if you just sat there with a source in one place and watched the beat, the ocean moved slowly and the phase would go in and out, but not so that you couldn't get the phase [unintelligible]. So, I think that was very important because it changed the whole view of what you would likely be able to do. Now, fifty years later people are going back to finding what the level of incoherence is, and there is some, but basically it's fairly [unintelligible].

So, that was important. We did help the SOSUS people on questions of depth and signal processing and so on. [unintelligible] Media and Artemis I think were important, so I think we were a big force in putting the usefulness of low frequency acoustics on the map and a big force [unintelligible]. I won't say that's what I did as Director, that's what the Lab -- the Lab did really.

van Keuren: Okay. How did you end up at ARPA?

Frosch: Well, I got a phone call from Jack Ruina who was the -- I later discovered that just leaving Director of ARPA, he said I have a job for you in Washington that you can't refuse. Now, I've established that the -- where he -- I never understood where he got my name, and basically he got my name I think from either Jim Wakelin or probably Harvey Brooks, actually, because Harvey was familiar with Hudson Labs. He had been on a -- on an oversight committee, so Harvey, or Jim Wakelin, or Bob Morris. Jim had been -- he was Assistant Secretary of the Navy, R&D, and Bob was his successor, anyway he called me up and I told -- I told my wife, she remembers it well. I have to go to Washington to refuse a job.

[LAUGHTER]

Frosch: And Jack talked me into it, and so I left Hudson in September of 1963, I guess, and went to ARPA as Director for Nuclear Test Detection. I think partly the idea was that the Hudson -- I had and the Hudson Lab guys had built big -- big stuff, big detection stuff. Artemis and worked with long arrays, and understood that kind of thing, and we -- I would at least understand the underwater part of nuclear test detection, which is obviously trivial. You can't make a nuclear device small enough so you won't hear it everywhere, and I probably -- and I could do all right with the geophysics of underground detection, which was the going problem. And so I came to do that and built some large array stuff and sized molecules as well. So, I was dragged out of there.

van Keuren: You left oceanography to nuclear detection?

Frosch: Yeah.

van Keuren: How -- you -- two years later you became Assistant Secretary of the Navy for R&D, or about two or three years later.

Frosch: Yeah.

van Keuren: How did that happen?

Frosch: Well, let's see. The Assistant secretary for the Navy for R&D who I replaced was Bob Morse. Now, Bob Morse was an old acoustics guy who I had met with another one of the labs when I first got in the business at Hudson [Labs], Bob was a professor or assistant professor of physics at Brown who was working at the acoustics lab at 180 Hope Street with Lindsay and other people there. And so I knew Bob and I had known Jim Wakelin because of the Hudson Labs connection with the Navy, and I think that Bob suggested that when he left he'd put my name on the list.

van Keuren: So, it was Wakelin then Morse?

Frosch: Wakelin then Morse..

van Keuren: Yeah.

Frosch: Yeah. Bob Morse is now dead, he went from that job to be the President of Case Western Reserve. Well, it was then Case Institute, he merged it with Western Reserve, and then he went to Woods Hole. And so Bob arranged what I later discovered was a job interview with Bolisa who was the Secretary of the Navy. And what happened was that Bob called up one afternoon and said hey, the Secretary of the Navy wants a briefing on ballistic missile defense, I was then Deputy Director of ARPA, on ballistic missile defense.
I understand Charley -- Charley Hertzfeld was my then boss, is out of town. Is it okay if you do that? And I said, sure. Charley -- my view is I'm the Deputy for -- if anything that has to be done, I do it. Okay. Well, he wants it tomorrow for half an hour, can you do that? So yeah, I talked to the head of BMD and got the boards together. In those days you carried big -- big cardboard boards that were your slides and went in to brief the Secretary of the Navy. And Paul Bolisa was a nice guy and when the half hour became an hour and a half, much to his aide's consternation, and that was that. He was happy with the briefing.

I went away and about -- I don't know, some time later Johnny Foster who was then DDR&E called me -- I was actually at Lincoln Labs because I was working on some ARPA problem in a meeting up there, called me out of the meeting -- called me out of the meeting. DDR&E has to speak to you, it's urgent. And I said oh, my God, what have we done now? And he got on the phone and said hey, do you mind if the President nominates you to be ASN R&D, I said not at all. Not at all.

[LAUGHTER]

Frosch: I called my -- I called my parents, it's all hush, hush, and I called my parents and all my father could think of was gee, FDR was Assistant Secretary of the Navy once.

[LAUGTHER]

Frosch: So I became ASN R&D.

van Keuren: Uh-huh. What were the responsibilities of the position?

Frosch: Well, then it really was R&D and a, the Navy -- the Navy Secretary was in a unique position with regard to R&D, probably a left over from the early ONR days. You need to change that tape?

van Keuren: Yes. We've got about half a minute.

Frosch: From the early ONR days. The Navy, the Secretary of the Navy and hence the ASN R&D is responsible -- directly responsible for the RDT&E budget. That is it belongs to the Secretary and not to the CNO oddly enough.

[END OF TAPE SIDE 1]

Frosch: And that budgetary responsibility is direct -- is direct so that I had to worry about that budget directly in a different way in which the Army and that Air Force Assistant Secretary do, to the Chief of Naval Research reports to the Secretary of the Navy as well as to the -- as a military officer to the CNO. So, strictly speaking ONR was -- was reporting to me, and in fact, my controller for the Navy RDT&E budget was always the ONR Controller.

So, it was kind of a hands-on relationship. Then, of course, while -- so that meant that NRL through ONR was -- the other Navy labs of course reported up through other commands that I wasn't responsible for. And I'm not sure it was all the whole RDT&E budget, but it was certainly 6.1, 6.2, 6.3, and I think I signed off on the rest of the budget. I don't know what the -- the current situation I think is the same, but it's more diluted because the Assistant Secretary also has acquisition, and if I understand what really goes on, the poor guy is so consumed by acquisition that there is nobody watching R&D, but I'm not sure.

So, there was that -- but there was a responsibility for the R&D laboratories and we watched over -- because most of their money came through that budget, and in fact I had -- I don't remember when it was established, but there was a Director of Navy Laboratories that was responsible for that oversight.

van Keuren: Did he report to you?

Frosch: Yeah. I think he was double-hatted in some odd way, but he was -- among other things regarded as a member of my staff. So, I watched over all of Navy R&D and its connection with the rest of the Navy and was sort of the advocate for taking things that were in R&D. If they weren't successful hitting them on the head, and if they were somehow trying to get them into the -- into the operating Navy. So, that was -- spent ones time doing that, and trying to keep track of what was really going in a significant way in the R&D program so that you could be a useful advocate, but also when necessary being a negative advocate.

You know, why are we doing this and in fact, early in my career I kept being dragged to "project manager and program management meetings" and after a while I stopped going because they wouldn't -- they were always -- seemed to be two questions that nobody wanted to discuss. Militarily speaking why are we doing this, and scientifically speaking how does it work.

[LAUGHTER]

Frosch: I discovered that happened in briefings, too, and finally we made a rule that says if either of these two questions, why are we doing it -- and I don’t necessarily mean because we can do a weapon. It’s legitimate to say because we think it’s important to understand this because, or how does it work, then that’s the end of the briefing.

van Keuren: Uh-huh.

Frosch: We got -- briefings got better after that. So, there was a lot of that, and what I would call, you know, I don’t know what to refer to it as, visiting laboratories in the field and also getting myself better acquainted with the operating Navy. Visiting ships, and flying, and sort of participating in Navy things, and meeting the Admiralty, and a lot of time spent on budgets, and congressional testimony, and going to Congress, and paying pastoral visits on Capitol Hill, and meeting with my counterparts, and arguing systems analysis and conferring with DDR and the inner-staff and so on, all over the Pentagon.

van Keuren: Uh-huh. What was the status of Navy research and development when you came on board as the Assistant Secretary? Was it in a healthy state or --

Frosch: Oh, I think it was quite healthy.

van Keuren: Uh-huh.

Frosch: Now, it didn’t always have as much money as we’d like and so on, but in terms of its ability to do things and being what I’ll call technically, scientifically, engineering healthy, I think it was pretty healthy. I mean, I could -- if my memory was good enough I could find soft spots and hard spots, but it was pretty good. It was very good.

van Keuren: And on the Office of Naval Research, which was reasonably unique at that point among the services?

Frosch: It was certainly much -- there were equivalent things or similar offices on the other side. I think it was the strongest, and from the point of view of attitude towards research, and how to use it, and what to do with it, it was much the strongest.

van Keuren: Uh-huh.

Frosch: That got -- the other services got much better. Partly while I was there they --

van Keuren: Uh-huh.

Frosch: -- but I think it was very strong.

van Keuren: And how did the Naval Research Laboratory fit into the spectrum of Navy Research?

Frosch: Well, the Laboratory always referred to itself as the Corporate Laboratory, and for a while I never quite understood what they meant, but I would say it was the most -- it was sort of the broadest spectrum lab in the sense that it had very fundamental stuff in it. All the way to some things that were, you know, pretty operational or close to operational development. But the emphasis was on basic stuff, and it did things that, you know, weren’t being done elsewhere in the Navy. And there were lots of things that were unique, you know. The whole astronomy program, all the way into Herb Friedman's X-ray astronomy program, the time program which basically lead -- was the forerunning and led to GPS. Omega navigation, a lot of the acoustics, Bucky Buchanan’s stuff, some of the deep photography and submersible stuff they did out of Woods Hole was [unintelligible] that as well. Interesting things that aren’t done anywhere. I don’t know if it’s the Homer Carhart’s fire program both in terms of fire safety and prevention, and what does fire do, and the whole program on if something is burned -- electronics are burned, can you rescue it. All sorts of things like that. It was a very bright place. Always has been.

van Keuren: Now, getting a bit more specific, in 1968 you signed a letter requesting Waldo Lyon to prepare an overview of the Navy’s research commitment in the Arctic. Do you remember anything about this?

Frosch: Only very vaguely, this, but there was always a lot of discussion about what to do about the Arctic, and it was obvious during the Cold War that, you know, that was a major -- I don’t know what to call it, frontier, boundary, between North America and the Soviets. Alaska was up there practically contiguous to it, Canada was interested and protective, but didn’t have an awful lot of capability, but was cooperative. We assumed that missiles would come over the pole from the land mass, and the question was what to do about ASW.

The assumption was that there wouldn’t be much surface naval warfare there. The ice would be -- just make it too inconvenient, but having demonstrated that our submarines could go up there, and while not quite at liberty or at any time and place come up through the ice, they could given a little warning pretty well come up through the ice and in principle they could fire missiles and the Soviet’s could too. So, there was always discussion about what to do with it. A lot of the Navy didn’t want to ever want to have anything to do with the Arctic. It just didn’t look like reasonable naval warfare to them, and their view was that’s it going to be -- would be terribly expensive and difficult to do anything about it. We’re not going to build an ice-capable Navy. Maybe submarines, and sort of don’t spend your money there. And then there were always operating Naval officers and some people in the R&D part of the Navy, Waldo Lyon was a prime example, who said gee, this is likely to be a big arena of warfare. It’s sort of geographically four [unintelligible] a day. So, this was a continual running battle, and it extended all the way down to the issue of how much money and effort should we spend in understanding the Arctic.

van Keuren: Do you know when this debate initiated about the Arctic? Was it immediately after the War, World War II or --

Frosch: I don’t really know. All I know is -- it was -- it was rumbling in the background when I -- when I got to the Pentagon. I suspect it’s still rumbling in the background. And you know, it’s -- it’s a place some people love but most people hate. So, and we had the ice island which was always a problem, and always somebody up there, and always some floating issue about anybody who went up there was likely to get into trouble if there was a rescue effort. So, there was this strong pro and con thing, and I don’t remember specifically what led up to the letter. It -- it -- it is obviously -- I can read from the letter that it wasn’t something I invented. That is the idea of writing the letter might have been, but that it wasn’t that I said gee, we’ve got to do -- suddenly do a review of the Arctic at this because I heard something. It must have come into the office through either one of the naval commands, or ONR, or one of my assistants.

[PAUSE IN TAPE]

van Keuren: We’re back on.

Frosch: Yeah. Guy Harris, I knew him and I liked him, and he was -- I remember him suddenly -- suddenly being ill.

van Keuren: So, if it came from ONR, for example, Max Britton, that -- it would be -- there would be a tradition of that because it was the program manager in ONR that initiated the Navy TENOC program --

Frosch: Yeah. Yeah.

van Keuren: -- oceanography and then -- and then the National Academies -- NASCO committee on oceanography --

Frosch: Yes.

van Keuren: Both of which were ten year plans and I note that this was a ten year plan, too.

Frosch: Yeah. And I’ll -- this -- that’s perfectly -- perfectly likely and it probably came to me probably from -- I don’t remember who was Chief of Naval Research at that point.

van Keuren: It was Tom Owen.

Frosch: Was it Tom Owen?

van Keuren: I think.

Frosch: Yeah. I think it probably would have been Tom Owen, and Tom -- Tom would have brought it to me directly. I don't actually remember, but I would -- I would -- we were always -- we were on good terms. In fact, I think I'm -- all the Chiefs of Naval Research that I was around with, Tom was there for quite a while, and I were on good terms. Tom used to come over -- call up and in his booming voice say, hey boss. I got a problem.

[LAUGHTER]

van Keuren: Uh-huh.

Frosch: Or whatever. Probably I guess because it's my style, partly because it's the ONR style, and partly because of the way the Navy Secretariat was then, things were always according to etiquette but not very formal. So, you know, lots of people who worked for me would just call up directly and the office would put them through directly, or somebody would come in and say hey, Admiral Owen is on the phone, do you want to talk to him?

van Keuren: Uh-huh.

Frosch: So I mean, and we were -- my wife and I were sort of socially friendly with just about everybody so --

van Keuren: It would not have been --

Frosch: -- it would not have been --

van Keuren: -- unlikely?

Frosch: -- strange for -- for something like this, for Tom to have called up, or come into the office, or what other -- and say look, look we've got this problem and I think what we ought to do with it is this. And probably one of my special assistants was involved and concurred, and we asked whoever was the Chief of Navy Laboratories, and decided roughly what was going to go in the letter and I would suspect ONR or one of the assistants wrote the letter and we looked at it, and said okay, let's go.

van Keuren: Uh-huh.

Frosch: And see what we can do. The argument would certainly would have been whether or not the Navy wants to put a big fleet or submarines or anything in the Arctic, it sure is our job to understand it and know whether or not from a science and engineering point of view we can recommend that it be done or not be done, or whatever it is to be done be something that will work up there. You know, that was the sort of -- the Navy's view of oceanography then. I'm not sure it is now, was the Navy operates in the oceans, therefore we better understand them, so we are the patron of oceanography. I mean, that's -- it was generally agreed and that was it. And to some extent I think it’s true, but it’s not as true as it used to be, unfortunately. So, yeah, I think it makes -- it all makes sense to me whether I remember the details or not.

van Keuren: Uh-huh.

Frosch: I wish I did, and that would be a lot better, but after all this is now 35 years so I’m not a little surprised that my memory is fuzzy.

van Keuren: Right. So you would have -- it was likely that it would have come from ONR, Britton, through Owen and saying we need -- we need --

Frosch: Yeah.

van Keuren: We need a more concerted attack plan for research in the Arctic?

Frosch: That’s likely. It’s also possible that something had come from Waldo or from NEL, either to one of my special assistants, a research guy or whoever, or through the Director of Navy Laboratories, or both ways, you know, it was not unusual to hear messages that had been started in one or two places and came -- eventually came in from all directions.

van Keuren: Uh-huh. Now, I’ve noted in Waldo Lyon’s papers a sense of a conflict between Britton, and some of the people in ONR, and Waldo Lyons over the nature of the Navy investment in Arctic research, with Waldo Lyon saying it was too hit and miss, too academic, and needed to be more mission oriented. Did you ever remember any sense of a conflict within the Navy over -- over the direction of research in the Arctic or other fields like this?

Frosch: There’s always a conflict, you know, and there’s a whole spectrum of views. There’s always somebody who wants to take what we know now and build a weapon, or build a detector, or build a whatever, and somebody else who says gee, we better understand the circumstances better. And in fact, one of the things that ASN R&Ds do is preside over that argument and decide where to put the weight.

van Keuren: Uh-huh.

Frosch: In fact, laboratory directors do that. I did a lot of that at GM, did a lot of that at NASA if it comes to that.

van Keuren: Uh-huh.

Frosch: Yeah, I mean it’s a typical kind of argument, and it’s not unusual for some of the lab guys to want to push to get this stuff into production, so to speak, or into the operating Navy sooner than some of the academics, or some of the scientists at headquarters wanted to do.

van Keuren: And --

Frosch: It partly -- it’s partly a function of the personalities and interests of the people, and the fact that somebody is at a laboratory as opposed to headquarters doesn’t necessarily mean they have academic, you know, let’s get more knowledge before we do anything so it’s a --

van Keuren: Uh-huh.

Frosch: -- and Waldo -- Waldo was gung ho for understanding the Arctic but for doing something in the Arctic.

van Keuren: Uh-huh.

Frosch: And Max may have been a little more gee, I think we better know more.

van Keuren: More tied to the academy?

Frosch: More tied to the academy, yeah.

van Keuren: Uh-huh. Was there any shift in orientation in the Navy at this time? This is the point of the -- of the -- what was it, the Fulbright Amendment. The Fulbright Mac -- no, it was -- Fulbright Amendment? Mac -- you know what -- in other words, put restrictions upon DOD funding of -- of -

Frosch: Oh, yeah.

van Keuren: -- Arctic research.

Frosch: No, it wasn’t the Fulbright Amendment.

van Keuren: It wasn’t the Fulbright. It was --

Frosch: The guy from Washington. The one I’m thinking of is McCormick and [unintelligible].

van Keuren: How about Magneson?

Frosch: Not Magneson, not McCormick.

van Keuren: It’s the Mansfield Amendment.

Frosch: Mansfield Amendment. That’s -- you got it. The Mansfield Amendment. Well, I always thought it was a joke. I remember the Mansfield Amendment very well and Johnny Foster sent a memo around saying here’s this Mansfield Amendment and I want to know in the light of the Amendment what parts of your program you’re canceling because they don’t apply to DOD. And I sent back a memo, or a message, or called Johnny, or whatever -- oh, I know what it was. We were supposed to send down a form thing which was listing all the programs. I didn’t list any and sent it down, and Johnny called up and said what’s this all about. And I said oh, come on Johnny, you know that I can defend every single item in the -- in the Navy's RDT&E budget and explain why it is connected with the Navy's interests. He says, I know you can and I can too, but we've got to put something on the form or the Secretary will be embarrassed. So, we dug around and found -- found a few things that we were -- that we were willing to sort of throw -- throw out of the slate of the wolves and -- or I guess for the Navy, out of the boat to the sharks.

van Keuren: Uh-huh.

Frosch: To keep them happy, but I never had any trouble explaining to Congress why we were doing something, because we'd explain it to ourselves before we did it. We weren't running around spending money on odds and ends. I was occasionally embarrassed by the question. My favorite one is not in this area, I was testifying before -- I guess it was House Appropriations, and Congressman Glenn Lipscomb from California, nice man, submarine named after him, was an accountant. And he thought about these things in kind of a precise way, and he would sit there listening to this year's testimony with last year's testimony and budget in front of him. Just as an indication of how careful he was. A very good guy. Very fair, a Republication and this was -- originally I was in a Democratic administration, and one day he looks at me in the middle of the -- of testifying about something else, and he says Mr. Secretary, I wonder if you would explain the project on page 270 something or other, or whatever, for the nuclear powered blimp. And I said Mr. Lipscomb, the what? And he says, the nuclear powered blimp, and I said, Mr. Lipscomb, I don't know about the nuclear powered blimp but I think we're probably going to have a luncheon recess, Mr. Chairman, pretty soon, I'll know after lunch. So, I came back after lunch and it was very simple. There is a small contractor in California who thinks the nuclear powered blimp is going to solve all ASW problems. You know, it will hop it like a low satellite and he wants to study it. And we didn't particularly want him to study it, but in order to study it he has to have a clearance. In order to have a clearance, which we were perfectly willing to give him because he could get cleared he had to have a contract. So we have a contract to study the nuclear powered blimp for one dollar.

[LAUGHTER]

Frosch: Oh, okay. That's the -- but, no. But I think the Mansfield Amendment -- I don't, you know, Mansfield was under the deep suspicion that, you know, we were spending money for the amusement of scientists, and I don't think we were. You know, I can't guarantee that down in the thing there weren't some peculiar odds and ends, but we kept looking for them.

van Keuren: But you -- so, it didn't result in any major internal changes of funding [unintelligible].

Frosch: That didn't directly, no.

van Keuren: No. Did other issues did?

Frosch: Oh, yeah. I mean, there were big budget cuts from time to time and the, you know, I remember once, I don't remember when or what administration, we got an instruction from the Secretary's office sort of late in the afternoon, that by ten o'clock the next morning he had to have on the Secretary of Defense's desk, through DD R&E a ten percent cut in the Navy's R&D budget. I said, how do you make a ten percent cut -- it eventually went away. It was a smaller cut but we had to put that down. The only thing we did was I got my assistants in and I guess we got -- maybe there was somebody from ONR who came over, maybe not, maybe somebody from the other [unintelligible] and we went through the six hundred items in the -- at the first level, or the second level of the budget, did something with them. You know, it was a good enough group so that either somebody in the room knew about every item because they specialized, or somebody would say I don't know, but I'll go call somebody and come back in ten minutes. So, we cut ten percent of the budget.

Funny side story, come in the next -- next morning. It's not so funny side story, next morning and whoever -- Peter Waterman I think was the electronics guy, I don't remember, another NRL guy. He was my electronics guy. He came -- he or somebody came in in the morning and said boss, I don't think you or we intended to put NARL out of business, but yesterday somehow or other you know, a bunch of separate cuts we really hit that lab hard. You want to do that, and I said no, I don't want to do that. It's a very good laboratory. So, we went back and rearranged some priorities. Spread a little pain elsewhere and fixed that. I think it is instructive because it -- it can give you a sense of the degree to which the office knew what was going on and sort of watched over things. And of course, you know, if we had put that in and something terrible had been in it, we would have gotten phone calls and screams and [unintelligible] fix it. Now it never got to the ten percent but we had several percent cuts and when that happened you threw some things over the side. There wasn't anything else to do.

van Keuren: Was this due to the -- was it the expenses of the Vietnam War?

Frosch: Well, you know, I suppose in the sense that there were budget cuts. More, what I remember more were sort of total Defense Department cuts that were sort of parceled around. The Vietnam War, I think was, it put budget pressure on, but I -- my recollection and this is, you know, twenty-five, thirty years later -- thirty years later, thirty five years later, was that you couldn't actually say any time, you know, they took your money away to put it in this budget. For one thing they couldn't do that. I mean, the Secretary didn't have that much reprogramming authority. Now, in effect Congress could do that, but the way they would do it would be they would mark down the RDT&E budget and put money someplace else, but it would be very hard to detect. If you go back presumably through all the Congressional debates and discussions and through the OMB literature, the -- it might be that you could track that. I think you would have a very hard time proving your case, even though it may well be true.

van Keuren: Uh-huh. Okay.

Frosch: Actually, in some ways for some purposes we got money into the RDT&E budget because there were things that were wanted and needed. It was a little tougher for 6.1 and 6.2, but there were a lot of things that were in 6.1 and 6.2 that were dragged into 6.3 and 6.4 and turned into something.

van Keuren: Okay. Let's summarize the Arctic stuff. Do you have any general comments upon the Navy's investment in the research in the Arctic, during your tenure in the office?

Frosch: It always seemed -- it always seemed to be [unintelligible]. I'm -- if you just, you know, occasionally in this kind of a discussion you say somebody tell me how much RDT&E were actually spending in the Arctic, you know, never mind that the nuclear submarine goes up there on -- I don't want the operating money, but I want all the RDT&E money, and I don't remember what the numbers were, but we'd look at them and say look, it's really not very large. But -- particularly since we were spending a lot of money in the Antarctic, partly because we had the support responsibility, but the difficulty in putting more RDT&E into the Arctic was always that in order to do something serious up there, you had large logistic costs. At one point, I remember vaguely having a discussion of building some kind of a, or upgrading, I don't remember what, some sort of a serious Arctic research lab in Barrow. I don't remember whether there was something there, there was something there.

van Keuren: It was the Naval Arctic Research Lab, yeah.

Frosch: Yeah. NARL, yeah. And there was a lot of discussion of building it up, but --

van Keuren: And that would be about 1966? They added a -- 1966, 1967 they -- big new laboratory built.

Frosch: Yeah. We did do that, was that in Barrow? Yeah. We did do that, but it was very hard to sustain, because if you wanted it you could build a building all right, but if you wanted to do something serious out in the Arctic Ocean, there wasn't such a thing as a small -- small expedition. I mean, even maintaining a few people on the Ice Island was very expensive from a logistics point of view. So, the bill always looked enormous to do something serious, and somehow we never -- we never got enough -- in order to do something like that we would have had to get some kind of an operating -- an operational commitment for the logistics. We couldn't just buy it, and we could never get -- this was my recollection and, you know, it may be refutable by what's in the Navy -- we could never find -- we could never find a strong enough Navy -- operating Navy sponsor that we really wanted. You know, if you went -- if you wanted to do something expensive in the Atlantic or in the Pacific, you go to CINCPAC or you convince somebody and then you go to CINCLANT. There wasn't an equivalent.

I don’t remember who was responsible for the Arctic, what fleet or whatever, but there was no -- there was no sponsor for the Atlantic. You know, the Antarctic was my responsibility because there was an agreement that the Chief of Naval Research would run logistics for the Ataractic Research Program, so you know that was it. It was in the budget, and it was in the budget, NSF would defend it, and systems -- until it was shifted to NSF, of course, but -- so the Navy had taken that on as a responsibility. We could not find a way -- we couldn’t find a way for anybody to agree that ONR -- the Chief of Navy Research would take on another responsibility like that out of the RDT&E budget. And we couldn’t find any way to get Congress or anybody else to go up operationally to argue that the money should go into RDT&E, so it would be a question of finding an operating force that was interested enough to help with the logistics. The only ones who were really interested were the submariners and they would help. You know, if we wanted a -- if there was a submarine going up there we could put somebody on it or whatever, but they were always spread pretty thin and that’s -- and remember, this also -- this was where Vietnam was there, so the fleet was spread pretty thin. And they didn’t want to spend logistics efforts or operating ships to go up into the Arctic. We had a couple of ice breakers, but you know, they eventually went out and it was the Coast Guard’s responsibility which had to buy service from the Coast Guard. So, there was never any way for it to come together and I’d have to say I’m not sure that wasn’t really high on my priority list.

van Keuren: Uh-huh.

Frosch: Because there was too much other stuff going on.

van Keuren: What about the Marginal Ice Zone? I begin noting interest in the 1960s, 1970s about the ability of Soviet submarines to operate undetected in the Marginal Ice Zone. Do you ever remember any talk about that?

Frosch: Well, I remember talk about it, but that’s about all I remember. That it was discussed. I have a vague recollection of the argument being they could operate there undetected but somebody else in the room saying yeah, but that’s about all they can do. They can’t do anything there. I mean, they could lurk there, but there’s lots of places they could lurk so.

van Keuren: Uh-huh. Do you have any views overall of the success of the Navy’s research efforts in the Arctic and in Naval oceanography generally?

Frosch: Well, I think in the Arctic it was pretty spotty. It was never very continued, and my impression is that we probably don’t know a hell of a lot about Arctic oceanography and even less about Arctic acoustics [unintelligible]. Now, in oceanography generally, I think it was a -- I think it’s a very good record. And for a long time the Navy was the prime sponsor of oceanography and one could write a -- I can’t out of my head, but one could write a very persuasive history that the Navy was -- was key in bringing oceanography out of -- out of kind of nothing. And then, of course, somewhere in the -- when? In the late 1960s or the 1970s, it's probably later than the 1960s, maybe in the 1970s there was a transition from almost total Navy responsibility to shared responsibility to NSF, and I guess NSF is the bigger player and the Navy is the smaller player.

van Keuren: That came out of --

Frosch: I don't think that's too good for the Navy actually.

van Keuren: That came out of the NASCO report which came out in 1960.

Frosch: Yeah. Well, but it took a while to happen.

van Keuren: Yeah. I remember doing a paper on that.

Frosch: Yeah. It took -- took quite a while to happen, and I'm not sure it was a good thing. It was a kind of a 1960s you can't have a military service responsible for science, kind of thing, which I don't think is right. I think it was a bad idea that the Navy should be a sole sponsor, but for the Navy to be kind of half and half would be reasonable.

van Keuren: Uh-huh. You think that was a reasonable sort of thing?

Frosch: Yeah. I think that would have been reasonable. Yeah.

van Keuren: And would you say -- was the Navy's interest in oceanography driven by the Cold War because of the Soviet threat?

Frosch: Well, I think it started that way, but I think it got generalized in the sense that most of the Naval officers I knew, you know, whether they were in RDT&E, or operating, or whatever, had a very strong sense that they were at the mercy of the sea. That all their systems operations depended on being able to operate in, on, through the ocean as a weather generator, as a heavy seas generator, as a generator of whether the systems worked or not, and had very much a feeling of not being quite confident that enough was known about what they were doing. So, it was very common for operating Naval officers to say gee, we've got -- we somehow have to know more about this. Now, I don't know if that's still true. It was very much true when I was there.

van Keuren: Did the Thresher accident play a role in this at all? That's the beginning of the Navy's involvement in deep submergence, I believe.

Frosch: No. No. The Navy -- the Navy was involved -- well, that was the beginning of the Navy's program in deep submergence. But the Navy's involvement in Alvin, for example, was a Navy involvement from the very beginning. The Navy -- the Navy paid for it, it was a Navy boat, and in fact, one of the things I think happened and that I did while I was Assistant Secretary was buy a new sphere for -- the Navy's own deep submergence program came out of Thresher and starting with the rescue things. Now that -- that was a strange chapter because the submariners were not pushing for the rescue system. Their feeling was that if you get in that kind of trouble, Squalus is an unlikely situation. It was other people in the Navy than the submariners who were pushing for it. In fact, the sub -- you know, submariners are a very special crowd. They are sort of loners by the nature of it and very, very proud service and piece of the service, and somehow the admission that there had to be a special rescue system for submariners made them feel as though they were being insulted, is almost the way to put it.

And so it was a very difficult argument because the circumstances under which you could actually conduct that kind of a rescue probably are not most of the circumstances in which you'd lose a boat. On the other hand, you had the argument from others in the Navy, and particularly very senior people in the Navy who had some political sense of the thing, that for the Navy to be in a position where there was a sub down and almost certainly live sailors on it, and have to say we have no way to do anything about it was intolerable. That would be sort of couldn't face ourselves and the nation if we hadn't done -- and therefore we constructed the system. I thought it was a good idea, but that was partly because I thought it was an important exercise for the Navy to learn how to do that. Quite aside from whether the rescue boats were the point, but that was not exactly a popular -- a popular view.

van Keuren: Uh-huh.

Frosch: So then we -- we developed that program and the other submersibles, and of course the whole business has sort of blossomed since -- since then. Partly for reasons that have little to do with the Navy's deep submersible program, but much more to do with the fact that the technology got better, the oil patch began to do things where it was very helpful to have submersibles, and so it was a whole commercial submersible business. And now of course it's into ROVs and so on and so forth, that whole technology is exploding.

And the -- but I have to say, the Navy's sponsorship of oceanography generally and the engineering that went with it, and if Alvin and Bob Ballard's stuff and so on, JASON, Argo -- it was very important in developing all the background knowledge and technology.

The commercial guys won't admit this but the early commercial technology was a knock off of Navy technology. It was used -- the acoustics, and the navigation, and the communication, and so on and so forth. Now it's taken on a life of its own in the current generation of people who do -- have no idea that they're living off of Navy technology -- the beginnings were Navy technology thirty or forty years ago. That's another kind of technological mystery that gets lost. This sort of tracing where the things come from.

van Keuren: Do you have any opinions about the current Navy efforts in oceanography during the Post Cold War era?

Frosch: Well I -- what I -- what I mostly know is that -- is sort of through the eyes of people at Woods Hole to some degree, and Scripps. And some of them are very close to the Navy still, particularly engineering people. Things like Arnold Hayes, and AUVs, but generally they kind of look over at the Navy and are sort of thankful for the connections they have but -- but sort of worried that they're not as strong as they used to be. They're mostly -- most of the oceanographers look down on NSF. It wouldn't occur to them to go to -- and that I think is not good for the Navy. I think in the long run the Navy is going to need the oceanographic community, and the oceanographic community ought to need the Navy, in order to be a stronger linkage. And it isn't just -- it isn't just budget sizes or how much money. That's important, but there were days when ONR was a kind of a center for the oceanographic universe. That's vanished too much. Maybe it shouldn't be the center, but it should be much more in -- much more deeply in the conversation even more than I think it is. It hasn't vanished by any means. The Navy does lots of things, but I don't, for example, think the Navy is training enough Naval officers in the basic knowledge of the sea and ocean engineering. That's, you know, it's one of the things when budgets get tight why you -- you do something else. But it's probably -- it probably would be sensible to pay more attention.

van Keuren: Any other closing comments?

Frosch: No. It's kind of fun to talk about the tasks. I remember a little more than I thought I would. And the only other comment is, you know, I'm around, I'm on E-mail, we can get on the phone, I come to Washington, so if you want more we can -- we can do that.

van Keuren: Okay. Well, thank you for your time.

Frosch: Yeah. You're very welcome.

[END OF INTERVIEW]

17. Gordon Hayes

Notes Prepared by Fred Erskine on a Recorded Telephone Interview with Mr. Gordon Hayes held on Wednesday 21 May 2008 at 4 PM EDT (1 hour 20 minutes)

Preface

Mr. Gordon Hayes is one of the children of Dr. Harvey Hayes (the first superintendent of NRL's Sound Division) and in 2008 he is 87 years of age. Gordon lived in Bethesda, Maryland in the 1940s and worked at NRL in the Radio Division starting in late 1942 until he left NRL in 1949. Gordon recalled that in the late 1940s he took a trip to visit his father (recently retired from NRL) at the family farm in New Hampshire. Along the way he stopped at the Navy Underwater Sound Laboratory (NUSL) in New London, Connecticut for a job interview with the Director, Dr. John Ide. He was hired for the job at NUSL to do research in underwater acoustics. Several years earlier, Dr. Hayes had been grooming his NRL colleague Dr. Ide to become the second superintendent of the Sound Division at NRL. However, Dr. Hayes sent Dr. Ide for some technical training at New London and as it turned out Dr. Ide was hired as the new director of NUSL. Dr. Harold Saxton was then selected to replace Dr. Hayes at NRL as the Sound Division's second superintendent.

Early Life

Gordon was born in 1921 in Annapolis, Maryland [Burt Hurdle was born in 1918 and knew Gordon's dad quite well]. Gordon attended Phillips Andover Preparatory School in New England. In his 3rd year he developed styes (inflammation) in both eyes and missed many classes. He withdrew from Phillips Academy and finished up at Woodrow Wilson High School in Washington, D.C. He had a good friend in high school, Marshall Patterson, who lived a block away in Cleveland Park, D.C. They strung a wire between their houses and used this connection to learn Morse code. They both got their amateur radio licenses in June 1940 and they received the call signs W3IUN and W3IUK respectively. Gordon has remained an active amateur radio operator and presently holds the call letters W1IUN. There is a group of hams who are former NUSL employees that meet via radio at 9 AM daily on a frequency of 3940 kHz for a communications net. He has an attic antenna at present.

Gordon's father, Dr. Hayes, worked at Fort Trumbull, New London, Connecticut around the time of World War I. Then Dr. Hayes transferred to a Navy facility at Annapolis, Maryland. Thomas Edison had been an advisor to the Naval Consulting Board and was instrumental in recommending the establishment of a Navy research laboratory. The lab became NRL and was located on the Potomac River in Washington, D.C. Dr. Hayes moved to Washington in 1923 to become the first superintendent of NRL's Sound Division. For about the next three years the Hayes family lived in the first block west of the intersection of 34th Street and Porter Street. Then Gordon's brother Ben was born and they moved to a larger house on Newark Street about five blocks away. It had three stories with three bedrooms on the third floor. They lived there until Dr. Hayes retired from NRL and sold the house around 1947.

Early Career at the Carnegie Institution of Washington

Gordon finished high school around 1940. His first (and most important) job was with the Carnegie Institution of Washington's Department of Terrestrial Magnetism (DTM) under Dr. Merle Tuve. Dr. Hayes knew Dr. Tuve via their mutual memberships at the Cosmos Club in Washington, D.C. Gordon worked on a project to help develop a proximity fuze. The research on this fuze had begun in the United Kingdom and the basic circuit design was initiated there. As implemented in the U.S., the devices used miniature vacuum tubes. A major problem was the fragility of the devices because they needed to sustain large accelerations. The tungsten filaments kept breaking, but tungsten was scarce and hard to procure. The tubes would frequently crack and break at 2500 g (axial rotation). There was a test field in southern Maryland at Stump Neck where the devices could be tested by shooting them straight up in the air. The firings took place two to three times per week in the fall of 1941. They had to account for the wind currents and be able to locate the shells when they hit the ground, then dig them up to assess the damage to the devices. One day shortly after 7 December 1941, Gordon and another researcher were chosen to transport the shells for testing from Silver Spring, Maryland to Stump Neck. Gordon had done some testing by dropping the shells from the top of a building down to a metal plate as a way of determining the survivability of the devices. The internal circuit contained a radio frequency oscillator that had a center frequency in the amateur radio band at 2.5 meters wavelength. The devices would be tuned up and could be bench-tested by waving a half-wavelength metal rod in their vicinity, while monitoring the current in the oscillator circuit. They let a contract to Crosley Corporation to see how production units would perform. There were three observation stations at this field site. One was by the Potomac River and another was by the woods. Gordon manned the station by the woods. The shell flight time was about one minute total. He developed an ability to accurately predict where the shells would land and as a result they were able to increase the number of shells tested from about 30 per day to about 250 per day. During testing they could monitor the signal from the oscillator in each shell. On one day a yellow navy biplane came inadvertently across their testing field (Mattawoman Swamp) and flew just south of Gordon's observation station by a few hundred feet. A shell passed right by the plane and a smoke cloud in the shell went off — and Gordon knew the proximity fuze was working. This story may not have been told before. Gordon felt that this was the most important technical contribution of his career because the proximity fuze helped to save many lives during World War II.

Career Move to NRL and Further Recollections about his Father, Dr. Harvey Hayes

In 1942 Gordon applied for a job in the Radio Division at NRL without telling his father, Dr. Hayes. After he was hired by NRL, he let his dad know about it. They had a car pool of about five people from Washington, D.C. to NRL each day. One of the riders was Carlos Mirick (NRL Radio Division); one was a woman. Dr. Hayes' close colleague, Dr. A. Hoyt Taylor, was not in their carpool since he lived in the southeast section of D.C. Harvey Hayes had the best office at NRL — it was on the top floor of Building 1 and it looked out on the Potomac River. There were five buildings at NRL in the early days. A lot of the NRL scientists, including Dr. A. Hoyt Taylor, would frequently come to Dr. Hayes' office to have their lunch and to discuss technical topics. When some of the Radio Division scientists mentioned about anomalous radio signals being received during tests across the Potomac, Dr. Hayes suggested that this was due to radio reflections from the external structure on passing ships. Gordon noted that the book by Ivan Amato (*Pushing the Horizon*), circa 1998, about the history of NRL in its first 75 years, touched only lightly on the accomplishments of the Sound Division. Gordon further noted that his dad had a great rapport with Navy personnel. Dr. Hayes talked to the NRL Commanding Officer on a frequent basis and he had a significant influence on research directions at NRL in the early days.

Gordon commented on what it was like growing up as the son of Harvey Hayes. They never played ball together. Dr. Hayes did not interact with the children in the family much — rather Gordon's mother had a great influence on the children. Harvey Hayes instilled in the children that it was very important to always tell the truth. Gordon would occasionally run his scooter down the hill on 34th Street — and it was hard to stop at the intersection. This was invariably reported to Gordon's dad. As a result it seemed that Gordon received a spanking via a hairbrush from his dad nearly every day of his life back then. Gordon has some very early recollections of a period when he was about five years of age (circa 1926) during which his father took him on occasion to NRL when there were just five white buildings on the NRL campus: a power plant, a heating plant, a workshop, a metal shop, and a scientific laboratory building. There was a lot of surplus war material scattered around a field at that time.

Harvey Hayes seldom spoke of his own parents. They had a farm near Binghamton, New York. Harvey had a brother and a sister. Gordon only visited that farm once or twice and has only a vague recollection of his grandfather. It was a humble beginning for Harvey who had to split wood as a youngster — so he designed and built a water-powered sawmill on the farm to accomplish this job. When it came time for Harvey to attend high school — there was no high school nearby — his parents got him a suit and sent him to a neighboring town to live with some family acquaintances to attend high school there. In short order Harvey Hayes ended up as principal of the high school. Harvey then attended a Normal School (Teachers College) briefly. He considered applying to Columbia University, but changed his mind and applied to Harvard University. His goal was to become a lawyer, but a physics professor loaned him some physics books to study for some sort of qualifying exam. He did so well that the physics professor convinced Harvey to pursue studies towards a career in physics. Following the completion of his undergraduate studies, Harvey then entered the graduate school at Harvard to pursue a Ph.D. degree. During breaks Harvey went to Dublin, New Hampshire to do some tutoring. It was there that Harvey met Gordon's future mother. Upon completion of his Ph.D., Harvey obtained a faculty position at Swarthmore College as chairman of the Physics Department. When World War I came along, Harvey heard about a group at New London, Connecticut that was attempting to locate submarines by means of underwater acoustics. He asked for a leave of absence for a year to go to New London. The research progress was quite good, so at the end of a year he asked for a second year's leave — but it was refused — so he left Swarthmore College. Following a period of research in new London, he transferred to a research station at Annapolis, Maryland and thence eventually to NRL in 1923.

Postcript

Gordon Hayes died in 2009 (about eighteen months after our interview).

18A. Burton Hurdle

Notes Prepared by Fred Erskine on a Recorded Interview with Dr. Burton G. Hurdle by Dr. David Van Keuren (NRL Historian) held on 15 May 1990 at NRL (45 minutes duration)

Early Life and Education

Burton Garrison Hurdle was born in 1918 in Roanoke, Virginia. He grew up during the Great Depression and this undoubtedly affected his outlook on life. After graduation from high school he went to work for the Norfolk and Western Railway that had its headquarters in Roanoke. In that period he started taking night classes and then switched to becoming a full-time undergraduate student at Roanoke College. He majored in physics with a minor in mathematics. He continued part-time employment (evenings) with the Norfolk and Western Railway. In 1941 he received his bachelor's degree in physics and then enrolled at Virginia Polytechnic Institute (VPI) for graduate studies. He intended to major in mechanical engineering but after only two weeks decided to major once again in physics. While he was studying for his master's degree in physics he taught some classes in the mathematics department at VPI to supplement his income. He also had an industrial fellowship with the Standard Register Company (of Dayton, Ohio). This was during World War II. His draft board was encouraging him to do something to contribute to the war effort. Although he was within about a year and a half from receiving a doctorate in physics, it was imperative that he leave VPI, so he was awarded a master's degree in general physics.

Joining NRL's Sound Division in 1943

He had interviewed with recruiters from the Naval Research Laboratory. After considering several other potential job opportunities, he started work at NRL in 1 July 1943. NRL was doing much applied research then in support of the war effort. In the late 1980s Hurdle had an opportunity to complete his doctorate in engineering mechanics (1988) via the United Kingdom's Open University. His thesis topic was on the subject of acoustic interference fields in the ocean. Dr. Hurdle has worked under the first five superintendents of the Acoustics Division: Harvey Hayes, Harold Saxton, John Munson, David Bradley and Edward Franchi. Hurdle has very positive recollections of the people in the NRL Sound Division in the early 1940s when he arrived at NRL. Dr Harvey Hayes was an outstanding scientist and he was surrounded by a number of very accomplished researchers. Hurdle's first supervisor was Dr. Raymond Steinberger. Harvey Hayes, Raymond Steinberger, and Prescott Arnold were all Harvard-educated scientists. Other colleagues were Dr. Elias Klein and Dr. E.B. Stephenson (who was associate superintendent). In the early 1940s the Sound Division was divided into four research groups: Transducers (headed by Prescott Arnold); Signal Processing (headed by Harold Saxton); General Problems and Applications (headed by Raymond Steinberger); and Shallow Water Applications (headed by John Ide). All of these persons, except for Dr. Ide, remained at NRL to complete their careers. After World War II, Dr. Ide left NRL to become the technical director at the Navy Underwater Sound Laboratory in New London, Connecticut.

Sound Division Research in the 1940s

Hurdle became part of Dr. Steinberger's group that was doing research on oceanic sound propagation and noise. Steinberger's group also did a variety of other types of investigations including a project to develop torpedo decoys that could be towed from ships. This project was headed by Keith Odenweller who had previously been involved with geophysical research for the oil industry in South America. Another project in which Hurdle was involved in the early days of his career was one whose goal was to attempt to reduce the radiated noise from ships. This was done by placing a band (essentially a hose with holes in it) around the ship near the bow to create a cloud of bubbles around the ship's hull while the ship was underway. Testing was done in the Chesapeake Bay and Potomac River using a research yacht (the *Aquamarine*). They demonstrated a quieting of the ship's radiated noise in the 20 kHz to 30 kHz band of about 20 decibels. Later the Navy implemented this methodology on operational vessels. Hurdle also did research from a sound barge that was anchored in the Potomac River near the NRL pier. The *Aquamarine* was also stationed near the NRL pier. Hurdle participated in research on the calibration of transducers that were designed by the Sound Division's Transducer group. At that time most transducers were of the crystal type (piezoelectric). These were ammonium dihydrogen phosphate (ADP) crystals and at that time NRL had a pilot plant in the basement of Building 12 for growing such crystals. This research was headed by Paul Egli and Paul Smith. Smith was in Saxton's Signal Processing research group, but has since done much research on ceramic transducers.

When Hurdle started working at NRL during World War II, the research atmosphere at NRL was very intense. They worked six days each week with only Sundays off. There was an important technical paper written in the early 1940s by John Ide that addressed propagation of sound in shallow water from the point of view of normal mode theory. Raymond Steinberger came to NRL in the mid-1930s from the Washington Navy Yard. He did important early research on the ray theory of sound propagation. He had collaborated with Columbus Iselin of the Woods Hole Oceanographic Institution (WHOI) using the research vessel *Atlantis* to demonstrate that the ray theoretic approach to sound propagation was correct. At that time the Navy was experiencing difficulties in that sonar systems were giving inconsistent detection ranges, particularly in the afternoons when the ocean surface waters became warmer. This would modify the sound propagation paths to bend them downwards, thus causing an acoustic shadow zone. This phenomenon was called the "afternoon effect." Steinberger was able to explain this effect and to also later provide a theoretical for understanding deep water convergence zones. Steinberger headed the Propagation group for many years and also was Associate Superintendent of the Sound Division.

Another problem that was causing difficulties for the Navy sonars was that of designing an effective sonar dome. The early domes were somewhat fragile and would often not withstand the rigors of high seas. Hurdle worked on this problem with a small group that included Jim Fitzgerald and others. The early domes were made of a thin stainless steel sheet that was spot welded to a housing around the sonar transducer. They experimented with a vertical metal grid with a molded rubber covering over it. This worked very well and was successfully implemented on Navy sonars later in World War II.

An additional problem arose related to sonar domes in that they were subject to fouling by marine organisms, especially in tropical waters. Hurdle and colleagues investigated the degrading effects of this fouling on the sonar systems. They collaborated with NRL's Chemistry Division to experiment with painted coatings to ward off the marine organisms. Various coated panels were prepared and were put in Biscayne Bay near Miami, Florida for extended periods to measure the effectiveness of the coatings. They were able to develop an effective coating that was then implemented by the operational Navy on its sonar domes (initially on metal domes, then later on rubber domes).

The Sound Division had close cooperation with the Bureau of Ships (BuShips) and the various shipyards during the sonar dome testing and they received good feedback on the effectiveness of their dome improvements. There was also close cooperation with sonar developers in the United Kingdom at that time, including personnel on the British Naval Staff who represented their research and development community.

It is interesting to review what happened to some of these early Sound Division researchers after World War II. Prescott Arnold remained head of the Transducer group until he died. Arnold's group was outstanding in their ability to develop transducers, especially those involving crystal materials. They paved the way for the next generation of transducer developments, including ceramic transducers. Ollie M. (Maury) Owsley who had worked under Arnold later left NRL in Washington, D.C. to head the Underwater Sound Reference Division (USRD) in Orlando, Florida. As mentioned earlier, Dr. John Ide left NRL to head the Navy Lab in New London, Connecticut, then later went on to become the second director of the NATO SACLANT Centre In La Spezia, Italy. He then returned to the U.S. and was one of the persons instrumental in establishing the National Academy of Engineering. William J. (Bill) Fry left NRL and went to the University of Illinois to set up a biological acoustics laboratory. Thomas F. (Tom) Jones left NRL and became a full professor at MIT. He then moved to Purdue University as Dean of Engineering. Following that he became president of the University of South Carolina. He later returned to MIT as Vice President of Research. He had a very effervescent personality. Richard F. Post left NRL and became well known for his research in nuclear physics at Stanford University.

There was innovative research in the Sound Division on the development of impulsive sound sources (including explosives) and their characterization. Francis W. Struthers did important research on the fatiguing of aircraft propellers as well as fundamental research on the high-Q vibration of quartz crystals in a vacuum.

Hurdle had significant interactions with researchers in a variety of other NRL Divisions, including Materials Science (Dr. Ross Gunn et al.), Chemistry (Dr. Perry Borgstrom et al.), etc.

The complexion of NRL changed after World War II (when Commodore Schade came to NRL) in the direction of more fundamental research, after an intensive period of conducting highly applied research during the war.

Additional Recollections about the Sound Division in the 1940s

Hurdle related some recollections about people who moved out of the NRL Sound Division to other notable positions. These included Horace Trent who became a division superintendent (Mechanics Division) after WW II; and Weiant Wathen-Dunn who left NRL to work at the Air Force Cambridge Research Laboratory. E.B. Stephenson had done early work on measurements of sound speed in the ocean. Prior to coming to NRL he worked with the Army on acoustic methods for improving the accuracy of artillery shell firings. Elias Klein had been an early researcher in the Sound Division. He worked closely with the submarine force on various problems, and on the silencing of propeller noise, and on the measurement of sound speed in liquids and solids using interferometry techniques.

The NRL Sound Division spearheaded the movement of operational sonars from high frequencies around 20 kHz to 30 kHz (during World War II) to lower frequencies (around 10 kHz, then down to 5 kHz, and eventually to below 1 kHz). NRL also was at the forefront of improved signal processing techniques, including problems related to man–machine interfaces etc. NRL was at the leading edge of at-sea experimentation to better understand sound propagation effects in the open ocean.

An example of some innovative research that Hurdle was involved in after World War II is the study to extend ultrasonic acoustic techniques to shorter wavelengths than previously had been attained — even to the short distances involved in intermolecular spacings. Attempts were made to develop sound transducers for the very high frequencies around 3 Kilo-Mega-Hertz (3×10^9). This did not succeed, so the team backed up to lower frequencies of about 10 MHz and slowly worked up to about 1 Kilo-Mega-Hertz with success.

In general, after WW II, NRL's Sound Division was somewhat institutionally funded by the Navy (e.g., by ONR, BuShips, and CNR, etc.). Hurdle briefly left NRL around 1947–1949 to work at Engineering Research Associates. This company had two divisions. One was in St. Paul, Minnesota (Electronics) and the other was in Arlington, Virginia (Physics and Chemistry) where Hurdle worked. The head of the Arlington division was James Wakeland. One of the department heads went on to form Atlantic Research Corporation. A number of key staff at Engineering Research Associates departed and Hurdle decided to return to NRL in 1949.

18B. Burton Hurdle

Notes Prepared by Fred Erskine on a Recorded Interview with Dr. Burton G. Hurdle by Dr. David Van Keuren (NRL Historian) held on 10 January 2001 at NRL (40 minutes duration)

Brief Summary of Early Life and Education

Dr. Burton G. Hurdle attended Roanoke College and graduated with a bachelor's degree in physics in 1941. He then attended Virginia Polytechnic Institute (VPI) to pursue graduate studies in physics. In 1943 it was recommended that he contribute to the war effort. After receiving his master's degree from VPI he accepted a position as a researcher in the Sound Division at the Naval Research Laboratory in Washington, D.C. Much later (in the mid-1980s) he had an opportunity to pursue a doctorate via The Open University in the United Kingdom and he received a Ph.D. in engineering mechanics in 1988.

Early NRL Research that Led to an Interest in Ocean Bottom Properties

When Hurdle started work at NRL in 1943, he worked on a project related to quieting of ships. A method was developed whereby a compressed air hose with numerous holes in it was wrapped under the hull of a research vessel thus creating a layer of bubbles under the vessel. This resulted in a significant reduction in the radiated noise from the ship. This method was later implemented by the operational Navy. Later, Hurdle became heavily involved in research on the propagation of sound in the ocean. He was also quite involved in studies of the scattering of sound from the ocean bottom and rough surfaces. During these investigations it was noticed that in some places in the ocean there was significant penetration of acoustic energy into the bottom. In part, this sparked his interest in ocean regions that contained gas hydrates. In some of these regions acoustic energy at low frequencies could penetrate into the bottom and then at some distance further away it would be refracted back up into the ocean.

Collaboration with Dr. Michael Max on Gas Hydrate Research

Hurdle's primary research collaborator within the Acoustics Division on these studies related to gas hydrates was Dr. Michael Max. In the mid-1980s they did some mathematical modeling to attempt to predict the acoustic propagation and scattering effects in gas hydrate regions. As these investigations progressed, Hurdle became interested in the potential of gas hydrate regions as an energy source. The earliest investigations on gas hydrates were done in the early 1980s by various researchers outside NRL, including the U.S. Geological Survey (USGS). Much remains to be done to better understand the effects of gas hydrates on underwater sound. We need a better understanding of the physics of the absorption of sound (e.g., acoustic loss) due to the mixture of the methane gas and oceanic sediments.

Hurdle had contact with some Congressional staff including Patrick McGarey (on the staff of Senator Daniel Akaka of Hawaii, who was on the Energy Committee). Congress was interested in having Hurdle as a consultant on gas hydrates and as a result he provided some testimony at various Congressional hearings on this topic in the mid-1990s. Hurdle noted that the Senate passed a bill appropriating $10M for research on gas hydrates. Hurdle also worked with industry and USGS on hydrate investigations. Hurdle and Max contemplated on what might happen if a meteor hit the ocean (such as the one that impacted the ocean near the Yucatan peninsula in ancient times) so as to release vast quantities of methane. He and Max published a paper on this topic in *GeoMarine Letters* in early 2000. This generated some interest in the scientific community. He was contacted by the editor of *New Science* (a British periodical) who later published an article on this topic, but somewhat misquoted Hurdle as stating that this could be a contributing factor in the demise of the dinosaurs.

Hurdle suggests that much research remains to be done to investigate the potential of hydrates as an energy source. For example, it may be possible to tap the hydrates via pipelines if the practicality of this methodology could be determined. Hurdle's role as of 2001 was to continue to encourage various groups to pursue research on hydrates. He suggests that the U.S. needs an integrated research program on hydrates in order to investigate hydrates as a potential energy source in the future.

18C. Burton Hurdle

AN INTERVIEW WITH DR. BURTON G. HURDLE

by Dr. David K. van Keuren
History Office
Naval Research Laboratory
24 January 2001

van Keuren: This is January 24th, 2001. I am David van Keuren of the Naval Research Laboratory History Office, and I'm sitting with and talking to Dr. Burton Hurdle about his career at the Laboratory. Burt, let's start out by talking about when and where you were born.

Hurdle: Well, I was born in Roanoke, Virginia, in 1918.

van Keuren: What did your parents do?

Hurdle: Well, my mother was a home-working woman. She didn't have a job outside, although she occasionally helped out in school some. My dad was in the insurance business in Roanoke.

van Keuren: Did you have any siblings?

Hurdle: I had one brother. His name is Thomas G. Hurdle, and he currently lives in Fayetteville, North Carolina. He's a retired MD. I think urologist was what his profession, his major.

van Keuren: Can you tell me about your early schooling and education?

Hurdle: Well, my grade school was right across the street from where I lived almost, and so I didn't have much of a difficulty going to grade school. I had to walk. In fact, I walked to grade school, junior high school -- well, I went to two junior high schools -- and then to high school. I walked to every one of those.

van Keuren: And did you have any favorite subjects or teachers when you were in grade school and in high school?

Hurdle: I just remember the principal of the grade school, his name was Mr. Hook, and he had a forefinger that was stiff and straight. He'd come out and ring the bell to start school with that finger sticking out there. Any how.

van Keuren: Did you have any favorite subjects?

Hurdle: I don't remember a particular favorite subject. I wasn't terribly bright.

van Keuren: Well, when did you get interested in science?

Hurdle: Well, I guess I got interested in science in high school, I guess. I was fairly active in high school in various areas. As a matter of fact, I liked playing basketball, but I wasn't good enough for the basketball team so I was the manager of the basketball team.

van Keuren: What about academic subjects?

Hurdle: Nothing special in high school. What happened was, this was back in 1936 when I finished high school, and I was offered a job at the Norfolk and Western Railroad, and I couldn't turn it down, so I didn't go to college right away. What I did was take some night classes. Then I got laid off from the Norfolk and Western Railroad, and so I started at Roanoke College. And I went to Roanoke College till I got my degree in Physics and minored in Math.

van Keuren: How did you choose Physics? Why Physics?

Hurdle: Well, actually, I had the idea that I wanted to be a Mechanical Engineer, so that was a basic for Mechanical Engineering. And when I finished in Roanoke College in 1941, I went up to Virginia Polytechnic Institute and started school there and registered in Mechanical Engineering. Well, it turned out, after I'd been in that course about a week or two, I decided I wanted to go back to Physics. So I switched back to Physics and I was working on graduate work in Physics at VPI. And this was during World War II, and so I had been there about two and a half years doing graduate work when I got a letter from the government saying I needed to get out and do something useful for the war effort, so I got a job at the Naval Research Laboratory, and I've been here ever since! They gave me a Master's Degree, incidentally.

van Keuren: And this was when you came to the Laboratory in 1943 in the Sound Division?

Hurdle: Uh-huh.

van Keuren: Let me step you back a minute. Was there any tradition of interest in science or engineering in your family?

Hurdle: Well, my brother was a... Well, my dad was interested in science, but he was not a scientist. My brother decided to be an MD, so he did basic work in college. He went to Roanoke College also, and he decided to go into medicine.

van Keuren: Did you acquire your interest in Mechanical Engineering from working with the railway?

Hurdle: Well, I'll tell you, it might have been working with the Norfolk and Western Railroad because I was working in what was called the Erection Shop, in which we tore down old engines for repair and put them back together. So that probably made me sort of interested in Mechanical Engineering.

van Keuren: When you came to the Naval Research Laboratory in 1943, what did you do for the Laboratory? First of all, how did you come to the Laboratory? How did the employment opportunity open up?

Hurdle: There was somebody -- and I don't remember who it was -- doing some recruiting at VPI, and I talked with them, and I thought it was a good place to come. I also had some offers at one of the aircraft companies -- I forgot now where it was -- but I decided that the Laboratory, based on coming here and having a little interview, I decided that was the best place to go.

van Keuren: And you interviewed with whom, do you recall?

Hurdle: Well, I came into the Acoustics Division.

van Keuren: Did you interview with Harvey Hayes?

Hurdle: Harvey Hayes was my boss's boss.

van Keuren: Who was your boss?

Hurdle: My boss was Ray Steinberger when I came here. And he was the Branch Head. I worked with him for a number of years in the area of -- we were trying to shield the ship from radiating noise.

van Keuren: That was your first job?

Hurdle: That was just about my first job, yeah. My job was to take the old *Aquamarine* research ship at that time and install a pipe around up near the bow, and that pipe was filled with a fire hose that if you put air pressure on it, it generated bubbles, and the bubbles came out and floated back along the hull of the ship. And that isolated the radiation from it. Now one of the things that this was to do was also to prevent the noise from the ship from interfering with the acoustic signals that were coming in, in a dome that extended below this layer of bubbles. So. I worked on that for quite a while. We took the ship up and down the river and down into the bay and so forth.

van Keuren: And what were the results of your research?

Hurdle: Well, the results, eventually they did, the Model Basin sort of picked up on this and did some work with it. I don't think it is currently in use.

van Keuren: So you did this sort of work -- noise abatement essentially, noise abatement research, noise reduction research...

Hurdle: Noise reduction.

van Keuren: You worked on this through the war and up until 1947?

Hurdle: Well, that was my first job. Then I got into acoustic propagation. Let me think here, exactly what the next thing.... The next work, in the ‘50s, I did work in propagation.

van Keuren: Let's not get there yet. Let's not jump there yet. How is it that you ended up working for the Sound Division as opposed, for example, to the Radio Division or some other division?

Hurdle: Well, I was interested in that subject more than I was in radio or radar because I had taken some courses in acoustics in graduate school. And that, I think, enticed me.

van Keuren: And graduate school being Virginia Polytechnic Institute.

Hurdle: Right.

van Keuren: What other courses did you take as a graduate student?

Hurdle: Well, I took courses, broad courses, in Physics. I took Spectroscopy, General Physics, Optics, and Acoustics.

van Keuren: Did any of the professors in those areas have a particular influence on you?

Hurdle: Well, there were a couple of them. I can't right at the moment remember their names. I can dig them out. My sort of advisor for my degree, which incidentally even to get a Master's degree there you had to take an exam, a general exam, and go through a grilling by faculty.

van Keuren: But you really liked the courses in Acoustics, then? They had a big impact on you, intellectual impact?

Hurdle: Uh-huh.

van Keuren: So when you went to the Laboratory, did you request to interview with the Sound Division?

Hurdle: No. Actually, I was sort of offered the job in the Sound Division. That's the one I took.

van Keuren: Okay.

Hurdle: I may have had other choices, but I thought that was -- I was quite happy with that.

van Keuren: You worked on acoustics, various problems in acoustics, until 1947, I see, and then you left the Laboratory for a couple of years. Do you want to tell me about that?

Hurdle: Well, I went with the Engineering Research Associates on sort of a temporary, but I still worked at the Lab on weekends, so I didn't actually leave the Lab. The Lab was sort of secondary at that point, but I actually came in on weekends and worked at the Lab to continue some of the things that I had been doing. At Engineering Research Associates, they decided to amalgamate with some other people, and so I left and came back here to the Laboratory.

van Keuren: And what did you do for them?

Hurdle: Well, I was an editor for a couple of newsletters type of thing. I worked with them on looking at the explosion of a bomb relative to a nuclear bomb in which you recorded what the influences of those explosions had. In fact, we did an experiment down in a military base south of Fredericksburg -- I've forgotten the name of the base now -- in which we put about 2500 pounds of TNT, buried it down about 20 feet in the ground and exploded that, and it generated a crater about 50 feet in diameter and 40 feet deep.

van Keuren: So you were looking at the seismics of this?

Hurdle: And we made recordings of the pressure and the displacement and all that, various aspects, to try to be able to project that to a nuclear explosion.

van Keuren: And why was it that you left the Laboratory in '47 to work for Engineering Research Associates?

Hurdle: Well, they enticed me. There were some other people who had been to the Laboratory that were with them, and they asked me to come with them, and there were also people who had been at ONR who were at that organization, so I think it was a pretty good organization, but some people who controlled it decided to amalgamate with another company.

van Keuren: So you left them in 1949 to come back to the Sound Division at the Laboratory. And when you came back in 1949, what did you do?

Hurdle: Well, I did propagation work down in the... particularly starting at lower frequencies, because the interest had … You see, during World War II, once the sonar frequency was about 25 kilohertz, the Laboratory decided to, or we in the Division decided that we should do research at lower frequencies. I did some work down in the Gulf of Mexico and out of Puerto Rico in propagation at the lower frequencies. And we started moving down lower and lower, and the Laboratory put a low frequency transducer on an old submarine – I've forgotten the name of that submarine (I'll have to dig that one out for you) -- on which the Laboratory did experiments, sonar experiments, at the lower frequencies from that submarine.

van Keuren: Okay. And what else did you work on during this period?

Hurdle: Well, from then on I have become more interested, and still am interested, in very low frequency propagation in the ocean, and I think we should even look at lower frequency propagation in the ocean, for detection and tracking of submarines.

van Keuren: And this was in line with your job then because you were promoted at this point. You became Head of the Acoustics Scattering Section, right?

Hurdle: Right. And the other thing that I worked on, following that, was a device called the sonar graphic indicator. This was a device for measuring the Doppler shift of acoustic frequencies when you tracked a submarine or when you tracked a transmission that was from a submarine. And they have patents on that. Then we worked with the people up at New London to include that into a submarine system, and it was included there for a number of years into the submarine system.

van Keuren: And this is the work that your section was doing?

Hurdle: Well, when did I become a Branch Head?

van Keuren: Nineteen seventy (1970).

Hurdle: I think that work was up until about the time I became the Branch Head, and then I went back more to doing work in Acoustic Propagation and Scattering.

van Keuren: Was this work that you were doing in the 1950s on acoustic scattering related to the ASW work? How did it fit into the thrust in ASW?

Hurdle: The thing is you had to deal with reverberation, which is actually scattering from the volume and from the bottom and from the surface, and so we needed to know how that occurred, and this is the reason for doing that.

van Keuren: So you were looking for ways of detecting reverberation and also ways of preventing it?

Hurdle: Detecting and how it influenced or interfered with the detection of the submarine, both from an active point of view and a passive point of view. Then, in the late ‘50s, I was selected to be a member of what was called "Project White Oak." This was a project that was supported by the Naval Science Board of the Academy, and it included a number of people in various areas of the Navy, and it was conducted out at White Oak. There were a number of people from out of town, but since I was local, the head of the group (and I'll have to get back to you with his name; at the moment I can't think of it) who was from Columbia University, and I had an office out at White Oak, and I spent most of my time there. Only occasionally did I come in to the Laboratory just to sort of coordinate what I was doing with the Laboratory, or what this group was doing with the Laboratory. The object of this study was the protection of merchant shipping in the year 1965, and we were doing the study in the late ‘50s to project, for that reason.

van Keuren: I see you have written here June 1958 to June 1959, the date of the study.

Hurdle: Right.

van Keuren: And you were looking at protecting shipping. In what way? What were you looking at?

Hurdle: Well, we were looking at all aspects of anti-submarine warfare: from the aircraft, from ships, and on submarines, because there was some fear during the Cold War that we might have problems of that sort.

van Keuren: Did you come up with any conclusions?

Hurdle: There's a whole large report on that. Currently it is still classified, but I think we ought to probably look at it to see if it can become declassified at the moment.

van Keuren: And this report was published when?

Hurdle: It's in the references. The title is Project White Oak Operational Plan.

van Keuren: Published when again?

Hurdle: Published in August 18, 1969.

van Keuren: So why did it take a whole 10 years from the conclusion of the study till the publication date?

Hurdle: I'm going to have to check that. Let me take a look. Fifty-nine.

van Keuren: You think that's a misprint? It was 1959?

Hurdle: Because the working group was from '58 to '59. I think that's an error in the date here. I'm going to have to get that corrected.

van Keuren: Okay. So you published the report, you think, in 1959.

Hurdle: Well, what happened is that the study was done in the summer of 1958, and it was about a three- or four-month study, but I was still attached to the office there, and the director and I started getting the report together from the various people that were involved, and it took us a number of months to do that, and at that point he was detached and went off to become the Director of the SACLANT CENTRE Laboratory at La Spezia, Italy, and I was left with getting the report out. And I brought the report back to the Laboratory, and we published the report.

van Keuren: Was Project White Oak related in any way to Project Neat? Were they entirely independent projects or not?

Hurdle: Well, not really related to that, because it was more as to what we should be doing in research to protect the shipping. Although it wasn't totally unrelated, it wasn't directly related.

van Keuren: Uh-huh. Was Project Neat the next major project you worked on? Project Neat dates to 1968, '69.

Hurdle: Right.

van Keuren: So actually there was a 10-year gap.

Hurdle: In between those I worked on propagation work and scattering from the ocean bottom.

van Keuren: And this was while you were Head of the Acoustics Scattering Section -- you were looking at acoustic propagation scattering?

Hurdle: Right, right.

van Keuren: And the background for that was ASW again -- detection?

Hurdle: That's right.

van Keuren: Basically that was the reason.

Hurdle: The reports that are listed in the references here indicate what we worked on.

van Keuren: Who was funding this research? Did this come out of ONR monies?

Hurdle: Well, back in those days the division didn't have to go out here and scrounge for money like we do today. The division was funded, and I was funded, quite well.

van Keuren: So did you know who was funding your research?

Hurdle: We had our own research ships. I am not sure of the exact date we lost those, but what happened was that McNamara came along as the Secretary of Defense, and he wanted everything accounted nickel by nickel, so the costs of running the research ships went up so high that we just couldn't afford to keep them at the Laboratory. In fact, I think that's one of the major losses of the Laboratory, losing its research ships.

van Keuren: And this loss came in the 1960s?

[Pause]

Hurdle: Now, what I want to do is go to start on our work in the Arctic.

van Keuren: Okay, I want to talk to you about your work in the Arctic Seas material, but as just a little preface to that, can you tell me about Project Neat?

Hurdle: Project Neat?

van Keuren: Yeah.

Hurdle: Oh, didn't we cover that last time?

van Keuren: No.

Hurdle: Oh. Alright. Project Neat was on propagation and ambient noise in the Iberian Basin off of Gibraltar, primarily. We had three ships. It was a joint British and U.S. -- U.S. had two ships. We positioned those ships at three different locations and at three different phases down in the Iberian Basin, and we flew aircraft that dropped SUS charges from Iceland to the Cape Verdes and from Gibraltar to the Azores. During that time the RAF flew the aircraft for us, and we dropped 7,000 SUS charges.

van Keuren: What type? Dropped what?

Hurdle: Seven thousand SUS charges.

van Keuren: What's a SUS charge?

Hurdle: It's a small acoustic charge that is detonated by dropping in the ocean, and when it reaches a pressure depth it detonates.

van Keuren: S-U-S?

Hurdle: S-U-S.

van Keuren: What does it stand for?

Hurdle: I forgot. I think Underwater Sound Source or something like that -- Source of Underwater Sound. Anyhow, didn't I tell you about planning for that?

van Keuren: Yeah, but we haven't talked about it on tape.

Hurdle: So we don't need to go back over that, do we?

van Keuren: We do, because no one recorded it.

Hurdle: Oh, okay. In the late ‘50s, we started planning for Project Neat, and this was to be a British-U.S. joint effort, and the Admiralty Research Laboratory in U.K. was the principal British laboratory with the RAF being a partner in this operation, particularly for flying these things. Now, in planning this, Ralph Goodman at the Laboratory was the Chief Scientist, and I was the Deputy Chief Scientist for the U.S., and John Gill was the Deputy Chief Scientist for the U.K. -- Dr. John Gill. So we put together, working with them, and also with people at Woods Hole and people at Bell Labs, we put together the Op Plan for this operation. And that is designated here as the Project Neat Operational Plan -- Advance Copy 8 August 1969. Now, we had a meeting then on this subject. I represented the U.S. at the meeting, and I laid out the operational plan that we had put together. Brackett Hersey, who was at the Office of Naval Research at that time, attended the meeting, and he had different ideas, and he suggested, "Well, we need to make this change, that change, and another change." Well, since it was an international meeting, I didn't stand up and argue about it. I just came back to the Laboratory and I discussed this with the Director, Alan Berman, and Ralph Goodman, and they backed me and told Brackett Hersey if he wanted to conduct this, take it and the Laboratory would not be involved. Well, he decided that he didn't want to do that, and he couldn't, and so I was given free rein then on getting the Op Plan out. And following that, as the plan indicated. Now, to implement this, we were given an operational base at the Royal Aircraft Base in England. It was very near Portsmouth, and it was RAF Mountbatten. Here we were given an operational building which was a very interesting one. It had been a building that was sort of designed for taking the operational problems of World War II, and it had a moat around it, and it had very thick earth piled on its roof. It was concrete. In this building there were other things for the RAF there. They had a communications station, which had classified work. They also had a meteorological area, which we had access to. And in our area we set up a communications system for a big radar antenna to communicate back with the Laboratory here with their radar antennas here -- communication antennas; they weren't radar antennas. And we set up whips and line antennas to communicate with the ships and other places. And we could use their secure communications center also. As a matter of fact, we could talk to the Laboratory just about as clearly as we can talk here today. So it was a very interesting place. Now, we conducted this in three phases. I had two RAF officers assigned to me there at the operational center. I had one U.S. Naval officer from the Office of Naval Research in London. I had a group of technicians from a laboratory and one or two scientists from the Admiralty Research Lab. We conducted the first phase, and then the ships came in to Portugal at a port there for changing personnel and for bringing back data. We took the data from the ships back to the operational center and started working on analyzing that data. We did this between each phase, so we went back to Portugal after the next phase. Some of the people came back from the ships and stayed with us at the center where they were transferred, came back, and helped work on the data. This went on for about eight or nine weeks, and then we closed it up, brought the ships home, and we all came back to the U.S. and started analyzing the data.

van Keuren: What was the point of the project?

Hurdle: The point of the project was to measure the propagation from various parts of the Atlantic into that basin, or from that basin into the other areas, to enable establishing an undersea surveillance area.

van Keuren: So this would kind of advance, expand SOSUS into this area?

Hurdle: Right, right. It was in support of the SOSUS system.

van Keuren: At this point SOSUS was in the Western Atlantic?

Hurdle: It was in the Western Atlantic, and it was also in some of the Norwegian areas and Canada. The report was '69. This was Neat One. And October '72 was when the final report came out.

van Keuren: For Neat One, and there was a follow-up to it called Neat Two.

Hurdle: Right, there was a follow-up on a smaller scale that didn't involve the British in Project Neat Two.

van Keuren: Did it cover the same area?

Hurdle: No, it covered more off of our coast than that one there.

van Keuren: So it was closer to the U.S.

Hurdle: Well, yeah. Close to the U.S.

van Keuren: Close to the U.S.

Hurdle: Right.

van Keuren: I see. And so this was all background for expanding the SOSUS system?

Hurdle: Yeah.

van Keuren: And Project Neat ran in the late 1960s. What were the actual dates of the research? Sixty-nine, starting in late '69?

Hurdle: Sixty-nine to seventy.

van Keuren: Nineteen sixty-nine to 1970, with a report coming out in '72, once you'd analyzed the data?

Hurdle: Uh-huh. Now, we also had several visits of the British and ourselves to sit down and make sure we were all in agreement on the results of Project Neat, before the report came out.

van Keuren: Why did they want to expand SOSUS into this specific area?

Hurdle: We wanted to cover all of the Atlantic, anyhow, in this, and this was part of it.

van Keuren: Anything more about Project Neat?

Hurdle: I think that's enough at the moment, unless you have anything else.

van Keuren: Okay. Let's then move on to the work that was done up in the Norwegian Sea.

Hurdle: Alright.

SIDE TWO

van Keuren: Neat went up to 1969, to 1970, and this overlaps to work that you and the Laboratory were beginning on in the Greenland-Norwegian Sea and the Barents Sea -- work that pretty much spanned the era between 1969 and 1975. Do you want to tell me about this work?

Hurdle: Well, one of the reasons for doing that was the same thing, to support undersea surveillance, particularly in the Norwegian-

Greenland-Barents Sea. We sat down in the late ‘60s with Waldo Lyon, who was out in the San Diego Lab.

van Keuren: What's the last name?

Hurdle: Lyon, L-Y-O-N. Waldo.

van Keuren: Okay.

Hurdle: Waldo was a submarine research guy that was looking at how we operated in the Arctic with submarines, particularly how we penetrated ice with a submarine, to surface through the ice in the Arctic, and how to operate under ice in the Arctic. That was his area. Our area was to look at the environment and the acoustics of the Arctic. But we sat down and concluded with the Navy that the most important area of the Arctic was what I'll call the eastern part of the Norwegian-Greenland-Barents Sea, and then moving on to the central Arctic and the western Arctic. And that's pretty much how this evolved over time, so that between about 1969 and the late 1970s -- or middle and late 1970s -- we worked primarily in that part of the world, although there was still work going on in the central Arctic with the submarine. In this operation we were doing it jointly with the Norwegians in Norway and the British also. The two laboratories involved were the Norwegian Defense Research Establishment in Norway and the Admiralty Research Laboratory and also people in Britain and Norway independent of the laboratories, particularly from the point of view of environmental work.

van Keuren: Academic scientists?

Hurdle: Academic scientists. I can list a number of people that were involved that we worked with. Enrich Notbedt who was a senior scientist...

van Keuren: Can you spell these names?

Hurdle: N-O-T-B-E-D-T. Enrich. I'll get that better for you. And Ingjeld Engelsen.

van Keuren: How do you spell that?

Hurdle: E-N-G-E-L-S-E-N, and I-N-G-J-E-L-D, Ingjeld.

Hurdle: [Unintelligible]... Grenness, G-R-E-N-N-E-S-S. Now, Johanneson was also an author in this, but he was at the Norwegian, the University of Bergen in Norway. The people associated with this at the Admiralty Research Laboratory were Dr. John Gill again and Commander David Newing, N-E-W-I-N-G. Peter Wadhems (W-A-D-H-E-M-S). He was at the Coal Regents Laboratory. Oh, at the Scott Polar Lab at Cambridge. Ian Davies, who was a Director at the Admiralty Research Laboratory. William Reay (R-E-A-Y) and Ronald Morris. Ian (I-A-N) Roebuck. David Weston (W-E-S-T-O-N). Ronald Morris (M-O-R-R-I-S).

van Keuren: What was that last one?

Hurdle: M-O-R-R-I-S.

van Keuren: Ronald Morris.

Hurdle: Right. And Commander Tom McAndrew, who was at the Ministry of

Defence there.

van Keuren: M-C ?

Hurdle: M-C-A-N-D-R-E-W. Well, they were some of the people that we worked with. Some other people that we worked with in Denmark were Jan (J-A-N) Smed (S-M-E-D), and he was the Director of ICES, which was the International Committee for the Exploration of the Sea. And Leif Bjorno at the University of Bergen, I believe.

van Keuren: He was Norwegian?

Hurdle: Yeah.

van Keuren: How do you spell the last name?

Hurdle: B-J-O-R-N-O. B-J-O-R-N-O, L-E-I-F. So these are some of the people that we were involved with.

van Keuren: So there were Americans, British...

Hurdle: Right.

van Keuren: ... Norwegians and Danes involved?

Hurdle: Right. We conducted our first joint operation with them in 1971, and we had a group from the Laboratory on our ship, the MIZAR, and we also had the Hayes, and we had Norwegian ships. The British were involved with some of their hydrophones, as opposed to having ships there at that time. In 1972, we did an operation there, and the Norwegians gave us a location to conduct and communicate with the various ships involved. A NATO Laboratory or base out of Bergen, Norway, was located in the middle of a mountain, and I took Norman Dale who was at our Laboratory and happened to be a Norwegian and spoke Norwegian...

van Keuren: What's the name?

Hurdle: Norman Dale, D-A-L-E. ... with me to assist me during this operation because I wanted somebody who could communicate over the radio that knew Norwegian well. Where did I say this was? Out of Bergen? No, this was out of a little town up on the coast.

van Keuren: North of Bergen?

Hurdle: Yeah, north of Bergen. Anyhow, this was an interesting operation. We had seven ships involved in that. We had another Navy ship besides the MIZAR, and we had two Norwegian ships, and we also had acoustic sources that were brought into an island. The island was called Ruholmen, which was a lighthouse, and so I happened to spend some time...

van Keuren: How do you spell that?

Hurdle: R-U-H-O-L-M-E-N, I believe. I'll have to check that. The island was covered with tundra. It was a small island, but it was a very interesting operation there for several weeks, recording the acoustic sources that are emitted by the MIZAR -- acoustic sources on the MIZAR. Now, this went on until the late ‘70s actually, or the mid-70s.

van Keuren: Seventy-five?

Hurdle: Yeah. And then I went to the Admiralty Research in '76 as a visiting scientist and to sort of pull together all the information we had in preparation for the *Nordic Seas* and the *Acoustics of the Nordic Seas*.

van Keuren: You were collecting all the acoustic data during this time, '69-'75? You were trying to acquire background on the acoustic characteristics of the Nordic Seas?

Hurdle: Well, one of the things that we wanted to do was to provide a multidisciplinary book on the environment, which included the general environment that involves and influences the acoustic propagation, but it didn't involve the propagation itself. That was kept for the *Acoustics of the Nordic Seas*, which is currently still classified. And I'm not sure whether it's appropriate yet to be able to get that declassified.

van Keuren: Was it your goal from the very beginning to do the complete Nordic Seas environment, or was that an add-on?

Hurdle: Well, no, our goal was to do the environmental, because we knew that we had to understand the environment before we could understand the propagation, and that was the reason that we included the environment into the acoustics aspect. Then we brought other people into this that helped write the book. It's a multidisciplinary book.

van Keuren: Were they funded by your project or were they people who already had backgrounds and were asked to write articles for the book? Did you actually do research into the environment or did you simply collect existing information?

Hurdle: Well, we did research, and we also collected and pulled together the information because we tried to pull together all the information that we had obtained and what was available to give a good picture of the environment of that whole area.

van Keuren: But your research funding -- your NATO funding -- funded the acoustics research?

Hurdle: It was acoustics but we had a branch in the Acoustics Division that dealt with just the environmental aspects of the ocean, so they were involved.

van Keuren: And what sort of work did they do?

Hurdle: Well, they did measurements of sound speed and measurements of temperature and pressure in the ocean, and other aspects of the environment. The only part that the Nordic Seas doesn't really cover is the biology of the area.

van Keuren: This is the book, *The Nordic Seas*. So between '69 and '75 you collected the acoustic data. You also collected some general environmental data on the Nordic Seas, all directed toward your publication in this area? That was your goal from the beginning, to do a publication, a reference publication?

Hurdle: Well, we wanted to publish it. I don't think the first year we viewed this in '71, we viewed this as a book at that time, but the further we got along the more we saw, at least I felt that we should put out a book. Now one interesting point you might be interested in, I discuss in there the use of the Nordic Seas as a term for looking about the whole area, and define the area in the book. Now, recently, it was proposed by the international group that sets the name for ocean areas that the Nordic Seas was proposed to be adopted, and it has been. Both the Nordic Seas and the Nordic Basin has been adopted for that area, based on this book, or based on the definition of it in this book. I consulted with a number of people before I did this for the book, and no one objected, and it looked like an appropriate name, so instead of having to use the Norwegian-Greenland-Barents Sea area each time you talked about it.

van Keuren: You proposed the name "Nordic Seas?"

Hurdle: It's in there. Yeah.

van Keuren: And how did you decide upon "Nordic Seas?"

Hurdle: Well, I tried to think of an appropriate name for the whole area and came up with that because it was in the Nordic countries, surrounded by the Nordic countries primarily.

van Keuren: Now the book includes articles on things like bathymetry, tides, sea floor topography, plate tectonics. How did this material make it in there? This is not research that you funded as part of your project, right?

Hurdle: Well, that wasn't research that was funded as part of this, but the people that did the chapters in here generally provided the funding for their work.

van Keuren: So you solicited people to write on these areas?

Hurdle: Yeah, right.

van Keuren: Like, for example, Peter Vogt. Was he involved in the acoustic end of the research? He was a specialist on the area.

Hurdle: That's right, in this aspect of it.

van Keuren: So you solicited him to write articles?

Hurdle: Uh-huh.

van Keuren: And the book, tell me about the publication of the book.

Hurdle: Well, let's see, it came out in what, 1986, and so it took me about 10 years to get this together.

van Keuren: Why did it take so long?

Hurdle: Well, I wanted to do it right, and so I persuaded the people, and I had to encourage them to get it done, and then I had to work through it from an editorial point of view on it.

van Keuren: And I note on the cover of it you show an iceberg and a ship that looks like maybe a research ship of some type. Do you want to tell me the story behind that cover?

Hurdle: Well, that picture of that iceberg is one taken -- it's in the Naval Archives, so I used it.

van Keuren: But the ship, there's no real ship here, is there? Isn't that something....

Hurdle: That's just a...

van Keuren: Paste-on?

Hurdle: Yeah.

van Keuren: Is there any ship in here at all?

Hurdle: No.

van Keuren: Who took, so the picture in the Naval Archives is simply of an iceberg?

Hurdle: The illustrator put it in.

van Keuren: Uh-huh. And this picture was taken from an atomic submarine, wasn't it?

Hurdle: It was taken up in that area, yeah.

van Keuren: By a U.S. nuclear submarine?

Hurdle: I've forgotten now exactly. I could probably track it back as to who took it, but it was from the Naval Archives.

van Keuren: But the cover is simply a piece of artifice. Um, so between 1976 and 1986 you worked on soliciting articles and editing the data and coming up with this kind of big tome. It's almost 800 pages with index on the Nordic Seas, as a reference point, but the research, getting back to the research project that you undertook between '69 and '75, looking at the acoustic profiling of the Nordic Seas, what was the end result of that research. Looking simply, thinking simply of the acoustic profiling that you did in the early ‘70s, what did you learn there and what use was it put towards?

Hurdle: Well, this also established the basis for undersea surveillance operations that were extended in that area.

van Keuren: So SOSUS was based on this information, was extended?

Hurdle: Yeah.

van Keuren: These would be the ocean floor listening stations that extended into the Greenland-Norwegian Seas?

Hurdle: Uh-huh.

van Keuren: So you worked on two projects which basically were developing the acoustic informational background, the data, the acoustic data, for later establishing the hydrophone rays: One in the western Atlantic for NEAT, and then in the Nordic Seas with the research that you did with the British, the Danes and the Norwegians in the early ‘70s.

Hurdle: Now, one of the things that I was very careful to do was not refer to any operational systems in the Navy in this book or even in the *Acoustics of the Nordic Seas*, so I think at some point it can be declassified. But in order to declassify the *Acoustics of the Nordic Seas*, we have to have the consent of the Norwegians and the British for this.

van Keuren: Now with this work done in the early ‘70s, which led to the Nordic Seas, was it the first major engagement of the Naval Research Laboratory in this area, oceanographically speaking?

Hurdle: Primarily, yes, as far as I know there was no real work in the Arctic. Now, we moved on at that point from operating in this part of the world to operating on ice camps and so forth in the central Arctic, but that's a different story.

van Keuren: What about the U.S. Navy? Was this the first large-scale kind of scientific work that the Navy funded in the Nordic Seas? I mean, the Navy had been operating in the Nordic Seas, but had it ever funded large-scale investigations there before?

Hurdle: Nothing of this scale anyhow. They may have had some little individual projects around that area.

van Keuren: But this was the first, as far as you know, the first major engagement in a scientific sense of the U.S. Navy in this area of the world?

Hurdle: Right, yeah.

van Keuren: And it was all related to the extension of the SOSUS system?

Hurdle: Right.

van Keuren: But it had a big impact on oceanography in the Nordic Seas. Do you want to tell me about the impact it had in terms of the science that was produced?

Hurdle: Well, I think one of the things, the major impact that it's had is the Nordic Seas brings together a multidisciplinary approach to the environment of that area, which to my knowledge has not been done before, and that may be the major impact. A year or two ago the Institute of Ocean Science, which is part of the IEEE, considered this to be a significant accomplishment in oceanography and presented me with an award on that basis.

van Keuren: So this really was a major undertaking, and it really in many ways helped establish the scientific oceanography of this area?

Hurdle: It was very interesting. I have a number of reviews on this book. Even Alan Berman reviewed it for the Acoustical Society of America.

van Keuren: What do the reviews say?

Hurdle: Well, the reviews thought it was a pretty good book. And the reviews by people that, for example, physical oceanographers thought the physical oceanography part was great, but they didn't think it was too important in the rest of it. People that were interested in the geophysics of the ocean bottom thought that was good, and they reviewed it, but they didn't think the rest of it was necessary, which was interesting.

van Keuren: And the whole basis of it was the felt need to understand the entire environment in order to understand the acoustics?

Hurdle: Particularly an integrated, multidisciplinary look at the whole environment, and I think this is very important for environmental problems everywhere. See, most of our environmental problems are multidisciplinary.

van Keuren: Have there been any similar projects that look at other areas of the ocean, that follow up on this?

Hurdle: This way?

van Keuren: Yeah.

Hurdle: Not to my knowledge. There have been some projects from the Arctic point of view that looked at the biology aspect that complements this book, I think.

van Keuren: Any more comments in general about the history of the Nordic Seas, your research in this area?

Hurdle: Not at the moment.

van Keuren: Have you done, after the work that was done here, did you personally do any further research on the Nordic Seas?

Hurdle: Not except from a sort of a consulting basis.

van Keuren: So this was your major involvement in oceanography?

Hurdle: At that time, yeah.

van Keuren: But the Laboratory continues to be involved in that area with the work of Peter Vogt and Kathy Crane and others?

Hurdle: They're involved in other aspects of it as opposed to...

van Keuren: ... the acoustics?

Hurdle: Yeah.

van Keuren: They're more interested in the geomagnetism and the tectonics and the hydrothermal activities?

Hurdle: There have been some significant advances and things found that we didn't know at that time since then.

van Keuren: Okay. Like what? What would you say have been the major additions?

Hurdle: I think some of the research that Peter Vogt has done on the mud volcanoes and what you might call warm seeps up in that area and the aspects of gas hydrates on the ocean bottom in that area have become more important.

van Keuren: Okay. Have there been any aspects of this research in the Nordic Seas and the background to this book that I've overlooked?

Hurdle: Not that I know of, at the moment.

van Keuren: Okay. Thank you very much.

Hurdle: Thank you.

19. Kenneth (Skip) Lackie

Notes Prepared by Fred Erskine on a Recorded Telephone Interview with Mr. Kenneth W. (Skip) Lackie held on Wednesday 22 October 2008 (1 hour)

College Graduation and Early Career

Kenneth W. (Skip) Lackie was hired by NAVOCEANO shortly after graduation from college (Bucknell College, bachelor's degree in chemistry, 1961) to work in the Washington, DC area. When Lackie first worked for NAVOCEANO in the early 1960s, they did a lot of chemical water sampling (e.g., 200 m, 200–2000 m; and deep — all the way to the ocean bottom) using glass Nansen bottles. They did dissolved gas analysis as well. His first several years were with NAVOCEANO in Suitland, Maryland. Then after several years his group moved to the Washington Navy Yard; the ship load-outs then were at the Navy Yard. Around 1966 he moved on-site to NRL. The NAVOCEANO employees were scattered at various facilities in the Washington, DC area at that time because there was not sufficient room for all of them at the main campus in Suitland, Maryland. Herb Eppert was also employed by NAVOCEANO then, but he was stationed at a facility in Chesapeake Beach, Maryland.

A Bit of History About the Maury Center and LRAPP

In the early late 1960s to early 1970s time frame the Maury Center was active in a set of buildings just southeast of the NRL Main Gate that had recently been vacated (Buildings 58 and 69). At that facility there were researchers and program managers who were employed by various Navy organizations including the Naval Oceanographic Office (NAVOCEANO), the Office of Naval Research (ONR Code 480 – Ocean Science and Technology), and the Naval Research Laboratory (NRL Code 8000 – Oceanology Directorate). The Maury Center was headed by Dr. Brackett Hersey. Dr. Roy Gaul led the Long Range Acoustic Propagation Project (LRAPP) that was a decade-long effort (established around 1967) to improve our understanding of the ocean acoustic environment. The LRAPP project eventually led into a new effort called the ASW Environmental Acoustic Support (AEAS) program, with which Lackie became affiliated. LRAPP was unusual in that it was a Navy 6.3B project that was actually mostly funded via Navy 6.1 funds. The LRAPP project is documented in detail in a book titled *Antisubmarine Warfare and the Long Range Acoustic Propagation Project: A True Tale of the Cold War*, October 2002, by Louis P. Solomon and members of the ASW community. It is reasonably accurate in its treatment of the subject. Lackie does not have the Navy documentation on the establishment of the LRAPP project. Admiral Harold Shear (OP-95) was instrumental in establishing LRAPP. A goal of LRAPP was to rapidly transition efforts from research and development on oceanography and environmental acoustics into prototype products that can help the Navy understand why Navy sonars (passive and active) often gave such inconsistent results in terms of submarine detection range.

Sea Trials under LRAPP

Dr. Hersey sponsored a series of experiments in the late 1960s called PARKA (Pacific Acoustic Research Kaneohe to Alaska). These sea trials were focused on performing acoustic propagation measurements in deep water. They deployed a large buoy known as "sea spider" that had long radially extended arms [developed earlier by Hersey and colleague Bob Corel (of the University of New Hampshire) at Woods Hole Oceanographic Institution (WHOI)]. It had three steel legs — each several miles in length — with thick cables containing hydrophones and other sensors on the legs. The sea spider was to be suspended at a depth of about 100 meters. A smaller version was first tested in Buzzards Bay off the coast of Massachusetts in shallow water. The PARKA I Sea Trial (circa 1968) was directed by Gerard Fisher (of Hudson Laboratories). Around May 1969, about a month before the closing of Hudson Labs, Lackie visited Hudson Labs and arranged to have numerous records and data from the PARKA Sea Trials transferred to the Maury Center at NRL. As an aside — Lackie has some records on the demise of Columbia University's Hudson Laboratories and the subsequent move of some Hudson Labs staff and researchers to NRL around 1968. Dr. Alan Berman had been the Director of Hudson Labs, but had moved to NRL as Director of Research in 1967. Dr. James Heirtzler was Hudson Lab's director in its final year. [It is noteworthy that Dr. Alan Berman was chosen as NRL's Research Director in the late 1960s at a time when the Navy was emphasizing oceanography and environmental acoustics.]

Around 1966–67 NAVOCEANO performed some acoustic propagation experiments in the Atlantic and Pacific Oceans by arranging for acoustic sources (e.g., SUS charges) to be deployed from ships of opportunity so that the signals could be monitored by SOSUS receiving stations. This effort had actually been initiated at Hudson Labs around 1965 but was taken over by NAVOCEANO. When Dr. Hersey initiated LRAPP, he decided to follow up on this earlier experimentation by performing more carefully designed experiments using the sea spider equipment. Unfortunately, the sea spider engineering methodology did not work. Unless the sea spider legs were under full tension, some of the cable came unwound and telemetry was lost. Interstate Electronics, Inc. was the prime contractor for PARKA-II in 1969 that was conducted in the Pacific Ocean several hundred miles north of Oahu, Hawaii. Lackie was present in the wardroom in 1969 when Dr. Hersey arrived and fired the entire PARKA test team on the spot. Lackie had been involved in a related effort (out of ComForPac, now Com Third Fleet) to attempt acoustic performance modeling for these experiments (it was considerably ahead of its time; i.e., the models were too primitive, the computers were not powerful enough, and the experience with such modeling was in its early stages). Subsequently they did an experiment (for three months: September to December 1969) using the FLIP platform rather than Sea Spider. It was called PARKA-IIA. This experiment was successful; it involved nine vessels and as many as twelve aircraft. Then in March 1970 they did a smaller experimental effort called PARKA-IIB, also using FLIP. Dr. Hersey then conducted one additional experiment in December 1970 — near Bermuda in the Atlantic Ocean — called Testbed. However, the landline cable back to Bermuda failed. After that, Roy Gaul was brought in to direct the LRAPP effort (under Dr. Brackett Hersey, who remained the Maury Center director). Gaul was able to turn the LRAPP experimental efforts around by simplifying the approach to use research and development hardware rather than complex system prototype hardware. Gaul continued to employ on LRAPP a very versatile team of researchers from various Navy laboratories, university laboratories and industry. At that time, Chuck Spofford, John Hanna, Ray Cavanagh and colleagues worked in the Acoustic Environmental Support Detachment (AESD) at the Maury Center as ONR-funded researchers. The first sea trial initiated by Roy Gaul in 1971 under LRAPP was known as IOMEDEX (Ionian Sea Mediterranean Experiment).

NEAT I and NEAT II

The NEAT experiments (I and II) were important sea trials that were conducted in the Atlantic Ocean and in the Norwegian Sea beginning in the late 1960s. These were multi-organization/multi-national efforts in which NRL had a central role. Dr. Ralph Goodman, NRL's Associate Director of Research for Oceanology, was Chief Scientist for those sea trials.

Some Comments about the Formation of NORDA and Connections to the Maury Center

When the Naval Ocean Research and Development Activity (NORDA) was formed (and the Maury Center at NRL-DC was disestablished), only about 20 percent of the Maury Center personnel actually moved to Stennis Space Center. Roy Gaul was designated as Manager for the Establishment of NORDA. Lackie became his assistant on that effort. Ralph Goodman became the first Director of NORDA. Lackie and Winokur remained in the Washington, DC area. Among those who moved to Stennis were those who had ties to the South, including Herb Eppert and Paul Bucca. Bob Winokur (now with NOAA) may have additional insight about the 1960s – 1970s period and about the establishment of NORDA around 1976. The Maury Library at Stennis Space Center, Mississippi was a consolidation of the Maury Center holdings and NAVOCEANO holdings. However, when the Maury Center was disestablished, Lackie noted that many data tapes were destroyed, rather than being transferred to Stennis. Similarly, many classified documents were destroyed (maybe as much as three-fourths of the Maury Center holdings).

The NRL Acoustics Division's Code 7180 (Acoustic Simulation, Measurements, and Tactics Branch) is the remainder of what was a whole division at NORDA. When NORDA was about to be established (around 1975–76), Lackie was instrumental in explaining to the CNR (Admiral Baciocco) why it was necessary to establish a separate Navy laboratory that would focus on the ocean environment, with underwater acoustics to be an important part of its research portfolio. The 1970s was in essence the decade of the ocean; the office of the Oceanographer of the Navy was established in that decade.

Miscellaneous Comments

Note – Roy Gaul initiated an effort to declassify most of the LRAPP classified documentation; this was only partially successful (e.g., for data from the Caribbean).

Note – NRL's research vessel USNS *Hayes* did not work out very well due to its handling characteristics in rough seas.

Note – The Orlando, Florida acoustic calibration facility (the Underwater Sound Reference Laboratory/Underwater Sound Reference Division) was affiliated with NRL's Oceanology Directorate and the Acoustics Division until the Navy's Base Realignment and Closure 1995 (BRAC-95), after which the facility's management moved to the Naval Undersea Warfare Center (NUWC), Newport, Rhode Island.

20. Richard Love

Notes Prepared by Fred Erskine on a Recorded Telephone Interview with Dr. Richard H. (Rick) Love of Fort Worth, Texas on 15 October 2008 Wednesday (1 hour)

Early Life, Education, and Initial Career

Richard H. (Rick) Love was born in Brooklyn, New York in 1939. His family moved to Cumberland, Maryland in 1941, where he was raised and graduated from Allegheny High School. After high school he attended the University of Maryland in College Park where he received a bachelor's degree in mechanical engineering in 1961. He then pursued a master's degree (in fluid mechanics) at the University of Maryland and completed it in 1963 (while waiting for his fiancée Kay to graduate; they then married). He then worked for two years with a company called Hydronautics, Inc. of Laurel, Maryland (located west of the Johns Hopkins University Applied Physics Laboratory). While at Hydronautics, he continued studies at the University of Maryland towards a Ph.D. degree in fluid mechanics.

Career Move to NRL's Sound Division

He applied unsuccessfully for a position with the Naval Ordnance Laboratory (NOL) in White Oak, Maryland. He then applied for a position in the Sound Division at the Naval Research Laboratory, Washington, DC. In his interview with Jerry Gennari of the Sound Division he was informed of a job opportunity to do field research at sites including Bermuda and the Bahamas. He started work at NRL on 1 November 1965 and was assigned a task to determine how to magnetically measure the length of cable as it was unwound from a winch (this turned out to be the only job in his career that involved mechanical engineering). From November 1965 to August 1967 Rick continued to work for Jerry Gennari in Chester Buchanan's Sonar Systems Branch in the NRL Sound Division. Rick was part of that group when they received an award for AIR SALVOPS/Med (for the successful search and recovery of a lost hydrogen bomb off the coast of Spain). Rick has a photo that was taken on the occasion of this award.

Career Move to NAVOCEANO

Rick Love remained in the NRL Sound Division (in Building 28) for about one year and nine months until August 1967, at which time he transferred to the Naval Oceanographic Office (NAVOCEANO) in the Washington, DC area. Shortly thereafter he took a two-semester course in underwater acoustics that was taught by Bob Winokur of NAVOCEANO at the US Department of Agriculture Graduate School. Near the end of the second semester, Winokur offered Rick a promotion from a GS-11 to a GS-12 for a position with NAVOCEANO at the newly established Maury Center at NRL in Building 58 (this was outside NRL's gate, but with an additional Maury Center gate outside NRL's gate). At that time, Dr. Brackett Hersey was director of the Maury Center. Building 58 was an H-shaped building. The NAVOCEANO staff were located in a wing on the east side (near Overlook Ave, SW). The ONR staff and scientists working on the Long Range Acoustic Propagation Project (LRAPP) were located in the west wing of Building 58 (closer to NRL). Chuck Spofford, John Hanna, and Ray Cavanagh worked for Roy Gaul and Pete Tatro on ONR's LRAPP project at the Maury Center. LRAPP later became the ASW Environmental Acoustic Support (AEAS) program at Stennis Space Center, Mississippi. Paul Bucca was another NAVOCEANO researcher at the Maury Center at that time. There were employees of NAVOCEANO, ONR, and NRL all working at the Maury Center.

Early Fish Scattering Research

While he was with NAVOCEANO, Love continued working under Bob Winokur, who worked under Frank Schule and Ed Ridley of NAVOCEANO. Early in his research career at NAVOCEANO (around 1967), Rick was assigned by Bob Winokur to perform investigations on the scattering of acoustic energy from fish (volume scatter). The results of this research were published in 1969 and 1971 in the *Journal of the Acoustical Society of America* (*JASA*). Fred Bowles assisted Rick with some of his fish scattering measurements that were done in a tank facility at the Chesapeake Bay detachment of NAVOCEANO.

The Career Move to NORDA/NOARL/NRL-Stennis

Love remained at the Maury Center until he transferred to the newly formed Naval Ocean Research and Development Activity (NORDA) at Stennis Space Center, Mississippi in July 1976. When NORDA was established in 1976, only about one-third of the NAVOCEANO employees in the Washington, DC area actually moved to Stennis Space Center. Roy Gaul was designated as the Manager for the Establishment of NORDA (assisted by Skip Lackie). The first Technical Director of NORDA was Ralph Goodman (who had been an Associate Director at NRL).

At NORDA there was a Code 100 (upper management), Code 200 (ONR staff), Code 300 (oceanographic and acoustics researchers), Codes 400, 500 (LRAPP), 600. NORDA (1976–1989) then became the Naval Ocean and Atmospheric Research Laboratory (NOARL) for about two years prior to becoming part of NRL.

At Stennis Space Center, Rick worked under Dan Ramsdale. Previously, Tommy Goldsberry headed that group. Goldsberry initially did not believe fish scatter would be significant, but later changed his mind and promoted Rick to a GS-15 based on results of experiments in the Critical Sea Test series.

Rick recommends that we contact Skip Lackie for additional information about the establishment of NORDA. Among the additional persons who might be able to provide further information about the formation of NORDA are people like Herb Eppert, who had worked for NAVOCEANO's Research and Development Division at the Chesapeake Beach, Maryland detachment prior to moving to NORDA in 1976.

Note — the Hudson Laboratories Library was transferred to NAVOCEANO at the Maury Center when Hudson Labs closed around 1969. This library was later transferred to NAVOCEANO at Stennis Space Center upon the establishment of NORDA.

Retirement from NRL

Dr. Love retired from NRL on 2 January 1999. Since then he has conducted part-time research under affiliation with private industry.

21. Sam Marshall

Notes Prepared by Fred Erskine on a Recorded Telephone Interview with Dr. Sam W. Marshall held on Thursday 27 August 2009 at 10:30 AM EDT (1 hour 30 minutes)

Early Life, Education, and Academic Career

Dr. Sam W. Marshall was born in 1934 in Dallas, Texas where he was raised and graduated from Highland Park High School in 1951. He then pursued undergraduate studies at Virginia Military Institute where he received a B.S. degree in physics in 1955. Following graduation he worked for Humble Oil (Exxon) for two years while pursuing part-time graduate studies in physics at Rice University. He then entered pilot training and completed a 3-year tour in the US Air Force. Then, after some additional graduate studies at Rice University he transferred to Tulane University where he conducted research in solid state physics (nuclear magnetic resonance) and received a master's degree in physics in 1963. He then continued further experimental solid state physics research (on the Mossbauer effect in gold) at Tulane and received a doctorate in 1965. Following graduation he became an Assistant Professor of Physics at Colorado State University for four years where he taught physics courses. It was at Colorado State University where Sam met Dr. Ralph Goodman who was a Professor of Physics. During this period Sam began research studies in acoustics that involved setting up an experimental tank facility in collaboration with Dr. Goodman.

The Career Move to NRL's Acoustics Division

In 1968 Dr. Goodman moved to the Naval Research Laboratory in Washington, DC as Associate Director of Research for the Oceanology Directorate, under Dr. Alan Berman. Dr. Goodman then became chief scientist for an upcoming multinational at-sea experiment known as the Northeast Atlantic Test (NEAT-I). The organizations that were collaborating in NEAT-I were NRL, Woods Hole Oceanographic Institution (WHOI), and the Admiralty Research Laboratory (Teddington, United Kingdom). Burton Hurdle of NRL was at that time a visiting scientist at ARL and was an assistant chief scientist for NEAT-1. Earl Hays coordinated the WHOI participation. In 1969 Goodman approached Sam and asked him to come to NRL as a visiting scientist to assist with coordination of the calibrations for the experimental equipment that was to be used in the sea test in order to assure that all the data sets would be compatible among the participating organizations. The data acquisition systems all included analog third-octave filters for analyzing impulsive acoustic signals. Part of Sam's tasking involved making certain that all the different systems gave consistent results. While on leave from Colorado State University, Sam participated in the NEAT-I experiment that was conducted in late 1969 in ocean areas off Portugal and near the mid-Atlantic ridge. NEAT-I involved numerous measurements of acoustic propagation loss and ambient noise using bottomed hydrophone receivers and was a highly successful sea test. As a result of this experience, Sam became very interested in undersea surveillance research. He was then invited by NRL to become part of NRL's Acoustics Division as a researcher and he accepted a full-time federal government position at NRL in summer 1970. NEAT-II was a successful follow-on sea test conducted in 1971 in the same general ocean areas. Sam started his NRL career in Burt Hurdle's Branch doing ambient noise research. Dr. John Munson had arrived in 1968 as the new Superintendent of the Acoustics Division and Dick Rojas was Assistant Superintendent. In 1973, after an experiment known as Square Deal, Sam and the Ambient Noise Section transferred into the Large Aperture Systems Branch under Dr. Budd Adams. At that time Sam was heavily involved with ambient noise research at NRL in collaboration with other key researchers that included Bill Moseley and Dick Heitmeyer in the Large Aperture Systems Branch. Sam remained in that branch until 1977 at which time he transferred to the newly established Naval Ocean Research and Development Activity (NORDA) in Mississippi.

Some History About Undersea Research Developments and NRL in the Late 1960s to 1970s

Sam commented on some of the reasons why the NRL Acoustics Division became such an important organization in the 1970s. By the 1960s much of the undersea surveillance research in the US was led by private industry (Bell Laboratories) and university laboratories (e.g., Hudson Laboratories of Columbia University, and other university laboratories). It is noteworthy that Dr. Alan Berman had headed Hudson Laboratories in the 1960s until he became Director of Research at NRL in 1967. The Executive Branch of the government decided by the late 1960s that Navy laboratories including NRL should become the leading centers for undersea research in the US. This was an important factor that led to the eventual closing of Hudson Laboratories by 1969 and the transfer of key researchers and scientific equipment from Hudson Labs, WHOI and Bell Labs to NRL by the 1970s. Dr. Berman and Dr. Goodman were very instrumental in facilitating this process so that it could happen as smoothly as possible. Among the researchers who departed Bell Labs were Chuck Spofford and John Hanna, both of whom transferred to the Maury Center that was at established at NRL. Brackett Hersey came from WHOI to head the Maury Center. Budd Adams, Carl Andriani, and numerous key researchers came from Hudson Labs to NRL's Acoustics Division.

At the Maury Center, Hersey led the Navy's Long Range Acoustic Propagation Project (LRAPP). When Hersey transferred to the Office of Naval Research, Roy Gaul became the leader for LRAPP. Gaul then asked Sam to become directly involved in LRAPP ambient noise measurements in the period from 1972 to 1977. This worked out well. However, Ralph Goodman and Roy Gaul were continuously at odds regarding Gaul's management of LRAPP and LRAPP's approach to at-sea testing. During this five-year period, Sam successfully acted as an intermediary between Goodman and Gaul on these matters. Roy Gaul had an instrumental role in developing the plan for the establishment of NORDA and Gaul became its first Acting Director in 1976. By mid-1976, however, Ralph Goodman was selected to become NORDA's full-time Technical Director and he left NRL to take that position. Gaul then remained as the leader of LRAPP, while working at NORDA under Goodman. Eventually LRAPP was renamed AEAS (ASW Environmental Acoustic Support). By about 1977 Goodman and Gaul had developed a productive working interaction. Sam commented that there was a special session on 19 May 2009 at the 157th meeting of the Acoustical Society of America in Portland, Oregon commemorating Ralph Goodman's career in acoustics; and a DVD video of that session has been prepared.

In the late 1970s Sam was involved with developmental research using long towed arrays for acoustic surveillance. As these developmental arrays evolved they had acronyms like LAMBDA, TASS, ITASS, and eventually SURTASS. Sam was also involved with research on suspended array systems such as SASS. By the late 1970s the Navy's research on these complex arrays had primarily narrowed to the SURTASS towed array system and the ADS bottomed array system.

Sam recalled that in the brief period between the retirement of Dr. Harold Saxton in 1967 and the arrival of Dr. John Munson in 1968, Art Mc Clinton was Acting Superintendent of NRL's Acoustics Division. Sam also recalled from a recent conversation with Bill Kuperman that McClinton had hired Kuperman as a researcher in the Shallow Water Branch in the late 1960s. At that time Kuperman was a graduate student at the University of Maryland. As an aside, Sam mentioned that he may have influenced Kuperman to become interested in ambient noise research, a field in which Kuperman later had a leading role. McClinton was instrumental in developing the Acoustics Division's ambient noise buoys around 1970. These buoys were 40-inch-diameter spheres with hydrophones on their outside that were often tethered to the ocean bottom or mounted on the ocean bottom. They recorded ambient noise data for extended periods of time. These buoys were deployed in deep water. NRL researcher James McGrath used some of these buoys to record ambient noise for entire winter periods under the ice near Greenland. NRL researchers learned a great deal in the early 1970s by using these ambient noise buoys in deep water. The insights gained included a much better understanding of the limits of coherence for arrays and ways to mitigate loss of coherence due to towed array motion effects (especially via the research of Bill Moseley and Dick Heitmeyer), as well as knowledge of the directional properties of ambient noise and signal to noise ratio vertically throughout the water column.

Among some other key researchers who transferred from Hudson labs to NRL's Acoustics Division to work in Burt Hurdle's Branch around 1969–70 were Hank Fleming, Norm Cherkis, and Bob Perry. Some other Division colleagues with whom Sam had productive interactions in the 1970s were Charlie Votaw (Arctic research), Ray Rollins (Operations research), and Orest Diachok. Sam shared an office with George Frisk for a few years starting in 1969. Sam noted that two recent presidents of the Acoustical Society of America were previously researchers in NRL's Acoustics Division: Bill Kuperman and George Frisk. Sam commented on some of the early computers circa 1970 that he used for acoustic data collection and analysis. These included a PDP-11 system. The input was via paper tape, while the output was on magnetic tape.

Sam commented that Ralph Goodman supervised the preparation of the scientific suite of equipment for the USNS *Harvey C. Hayes* in the early 1970s. This was a dual-hulled research vessel that was used on numerous NRL sea tests. It was soon found that this vessel had some difficult handling characteristics and several modifications were made to mitigate these problems. Later, Goodman was very instrumental in helping to design the scientific equipment suite for the new Research Vessel *Alliance* at NATO's SACLANTCENTRE in La Spezia, Italy. Among the capable research vessels at NRL in the 1970s were the USNS *Hayes*, the USNS *Mizar*, and the USNS *J. Willard Gibbs*.

Post-NRL Career and Retirement

By the late 1970s Sam was interested in seeking advancement to a higher level position in the government. In 1976 NORDA was formed at the Stennis Space Center in Mississippi. Also at that time the Naval Oceanographic Office was moved from the Washington, DC area to Stennis. Many NAVOCEANO staff did move to Stennis and some went to NORDA. Bob Winokur had been the head of NAVOCEANO's Acoustics Division, but he elected to stay in the DC area. He notified Sam of an opening at NORDA to head NORDA's Acoustics Division. Sam then applied for and was appointed to that position at NORDA. Thus Sam left NRL in 1977 to go to NORDA. In 1982 Ralph Goodman left his position as Technical Director at NORDA to become Technical Director at SACLANTCENTRE in Italy. Jim Andrews then became NORDA's Technical Director. By 1982 Sam had filled many of the staff vacancies in NORDA's Acoustics Division with researchers that included Rick Love and others. In 1982 Jim Andrews asked Sam to take over the leadership the Analysis Group at NORDA on a temporary basis. Sam did so, but quickly found this group to be quite capable. It included researchers such as Ron Wagstaff and Gerald Morris. One of Sam's tasks in this period was to develop a strategic plan for NORDA. This was a very enlightening process that ultimately resulted in a more productive workforce at NORDA.

By 1984 Sam was offered and accepted a new government position as NSAP (Navy Science Assistance Program) Science Adviser to SURFLANT in Norfolk, Virginia. After a short while in Norfolk, Sam was offered and accepted the position of NSAP Director that was based at the Naval Surface Warfare Center (NSWC) in White Oak (Silver Spring), Maryland. This was a productive time. However, Sam decided that before he retired he wanted to work in the private sector for a while. Sam was invited by Harry Cox to join Bolt, Beranek and Newman. From 1987 to 1990 Sam worked at BBN in Rosslyn, Virginia. In 1990

Sam was offered and accepted a position at Lockheed Corporation in California. He remained there until his retirement in 1997.

22. Michael Max

AN INTERVIEW WITH DR. Michael Max

by Dr. David K. van Keuren
History Office
Naval Research Laboratory
14 June 2000

van Keuren: Today is fourteen June, the year 2000. I'm David van Keuren, historian with the Naval Research Laboratory. I'm sitting today with Dr. Michael Max, formerly of the Naval Research Laboratory and now Chief Executive Officer (CEO) of Marine Desalination Systems, Limited.

Max: LLC -- it's a partnership.

van Keuren: Partnership. We're going to talk about the Gas Hydrate Research Program at the Naval Research Laboratory.
Okay, Michael, to go over your background briefly, you went to school at the University of Wisconsin and the University of Wyoming, where you studied geology. From 1966 to 1969, you did graduate work at Trinity College, Dublin, from which you graduated with a Ph.D. in geology. Subsequently, you were employed by the Geological Survey of Ireland, from July 1969 to August 1985. During the last five years of your employment with the Survey you served as Senior Geologist. Is this correct?

Max: Yes, yes.

van Keuren: Just an outside question -- what was your thesis at Dublin on?

Max: My thesis was on metamorphic rocks in northwest County Mayo, Ireland. Fundamentally, my background in geology is fairly broad, but I was a metamorphic geologist dealing in crystal growth, crystal dissociation, under changing pressure temperature conditions and the resulting geological structures in orogenic belts, this sort of thing. At Wisconsin, although I started in soft rock, I was also more or less a specialist in the same sort of thing. And at Wisconsin I had a minor in chemistry. I've kind of an odd background in that I did a joint, I have two majors. I have a major in history and a major in geology. And I was actually offered a teaching assistantship at Wisconsin to do a Ph.D. in history, and I thought, "No, I want to work outside." So I went off to Wyoming and did a master's degree in petroleum and economic geology. In the petroleum geology, of course, we went into the organic chemistry a little bit, the mechanisms of concentration of hydrocarbon deposits, how gases form from the organic material and the sediments and all the sort of thing that any exploration geologist would know. Wyoming was a very strongly applied school, and they had a very high regard in industry as such. And everybody who did a master's degree was sponsored by someone in industry. And everybody got two or three job offers. And even in down periods, Wyoming still places people. It was a good school for that sort of thing.

van Keuren: Were you sponsored?

Max: My thesis for my master's degree was on a stratigraphic and economic evaluation of a gypsum deposit in the Big Horn Basin so that the state could assess taxes. US Gypsum was going to build a gypsum plant there, and the state needed a good tax base, so they needed to know the amount of the gypsum there and also the impurities, hemihydrate and other things that wouldn't actually, they're calcium sulphates....

van Keuren: Hemihydrate?

Max: Hemihydrate, like hemispherical cylinders on a Chrysler. There's lots of minerals in a gypsum deposit that you can't actually use to make wallboard, so you've got to know how much isn't there. Interestingly enough, that was a strata bound mineral deposit, and hydrate is a strata bound mineral deposit. So there was a funny congruence of things in my background that meant that when I got to hydrates I had a lot of background with which to look at them. Interesting. And I was kind of placed in the US Gypsum offices in Denver for a couple of weeks to find out just how the business went, how they ingested the raw material, what they did with the rubble, and this sort of thing. So they were effectively my sponsors for that period. I didn't do a petroleum-related thesis. It was strata bound, that gypsum deposit, and as far as I know that deposit is still working.

van Keuren: How did you choose Trinity College, Dublin, for your Ph.D. work

Max: By accident. When I left Wisconsin, although I was offered a Ph.D. in history, my grades in geology weren't as good as my grades in history, so they said that I had to go off and do a master's degree somewhere, and if I got that successfully somewhere, then I could come back to Wisconsin. Having done that, I was accepted back at Wisconsin for the September term in 1966 to do a Ph.D. in marine geology under Bob Dott, D-O-T-T. So that meant that I was going to either have to get statistics or a second language to go along with what little Spanish I had to crate through that exam. So I thought, "Well, I'll go off to France. That's a nice place to go." And I got accepted at the University of Grenoble. I went there because they have a very strong geology department there. At the time, in the 60s, they were one of the leading structural geology departments in the world. So I did a cours pour etranger, etudiant etranger, for three months at Grenoble.

I became kind of living in France, doing French, in a total immersion. You go hungry for the first couple of days if you don't have any French, but after a while you start to pick it up, and then a combination of going to school, going to films, talking to people, all that sort of thing, I became functional in French -- relatively functional, and probably enough to get through my Ph.D. exams at Wisconsin. And I started traveling in Europe with girlfriends and guys. Students in those days could travel very cheaply. I happened to be in London with a girlfriend at the time, and she said, "Let's go to Dublin; I'd like to see Dublin." And I said (it's a longer story than this), "Okay." We went to Dublin. And I was walking down the street, and I saw Trinity College, Dublin, well, Trinity College. And Dublin was a really nice place. It was a really nice place. And one weird thing that I learned at Laramie was if you're going to spend time in a place being a student, it's really nice if it's a nice place. So while I was in Europe generally, the thought percolated through that maybe I wouldn't go back to Wisconsin, maybe there'd be someplace, some university in Europe that I could go to. And France, it took too long to get a Ph.D. They didn't really have the same thing. I also attended the University of West Berlin, and the staff/student relationships there were terrible. I didn't think that I would be part of that very easily. I met some English students, and I was going to go around to some English departments and look in on those, but I found myself in Dublin, and it was just a terrific place, a lot of fun. And it was very cheap. I mean, it was inexpensive. And I found they had a geology department. I went, and I interviewed. And they gave me, three or four staff members spent a couple hours with me interviewing me, and they said, "Okay, have three references sent in, and you can be taken on here." And that's what happened. That's how I went. I didn't even know it existed. I read about it in *The Ginger Man*, but I thought he made it up. I didn't even know there was a Trinity College. And that's how I went there. And I did my thesis in structural metamorphic petrology geology. Britain and Ireland were at the time undergoing a real renaissance in structural geology, headed by the geology departments of Imperial College, London, Liverpool, Leeds, Edinburgh, and Glasgow, and a number of very bright researchers in relatively small universities. And geology is something that you can do relatively cheaply. You don't need a lot of expensive equipment. And there just came a sudden congruence of bright people and a revolution in plate tectonics and what it meant to mountain building and being able to use polyphasal analysis techniques to sort out how the tectonism of mountain belts actually took place. And our focus was on the caledonian mountain belt, the caledonian appalachian mountain belt, which runs down from Norway through Scotland, Britain, into Newfoundland, down through Canada, the United States, all the way to Georgia. And that at one time was an active plate boundary for the Iapetus Ocean. And the opening and closing of that ocean became the focus of my research for a considerable period of time, and basement tectonics in general.

van Keuren: That's what you studied?

Max: That's what I studied at Trinity and also at other institutions. I spent two months at the University of Liverpool, under the tutelage of Dr. Rast, Nick Rast, who was one of the leading structural petrologists in the world at the time. And basically it was probably very similar to the situation of the physicist prior to World War II where these guys were just kind of a loose community of people all interested in the same thing, and they all traveled around to each other's institutes, and the institutes put them up and looked after them or gave them money or something like that. Research students in Britain and Ireland at the time had the same freedom of going from one university to another and being able to, as it were, pick the brains of some of the best people, who were available. It was a totally unique experience. It was really something -- doesn't exist at all any more, of course, because they came under what we would generally call "American project funding," and that easy, casual relationship between the universities turned into one of competition. And now they don't talk to each other much.

van Keuren: And you went to work for the Geological Survey of Ireland?

Max: That's right. They were in Dublin. Of course we got to know them. And Ireland had just, or within Ireland a strata bound copper, zinc, lead deposits had just been identified, which made Ireland a major exporter of lead, copper, and zinc. And the government decided to put some money into the survey. And it went from three people to about sixty people over the period of time that I was finishing up my Ph.D. So I applied for a job there largely because the research environment in the survey looked very good and indeed proved to be extremely good. And I was given the opportunity to do what most Ph.D. students would like to do, and that's completely revisit their field of research before they actually publish, which I was able to do, basically re-map the whole area that I did for my thesis. And, of course, I had the advantage of experience.

van Keuren: You did that in Wyoming?

Max: No, no. All in Ireland.

van Keuren: All in Ireland.

Max: My Ph.D. thesis in Ireland was in Ireland. Ireland was a very convenient place to work. The farthest, my field area was five hours from my office. Traveling was very easy. And, again, it was relatively inexpensive at the time. Ireland is now expensive, but it was really very cheap in the late 60s, early 70s.

van Keuren: And what did you write your thesis on? The title?

Max: Gee, the title was something like "Geology of the Northwest County Mayo Metamorphic Inlay" or something like that. I've got it written down.

van Keuren: And this work with, how did you enjoy your... [inaudible]?

Max: Oh, I really liked it, really liked Ireland. I'm kind of a traditional immigrant's profile. I lived in Ireland nineteen years and then emigrated largely because of economic reasons. The survey decided to reorganize itself, like many small surveys around the world, and they decided to cut out the research element completely and let the universities do that. And I thought that rather than work for a fairly low wage in a poorly funded institution in Ireland or Britain, which is even worse, that coming back to America seemed to be a pretty good idea.

van Keuren: So it was really economic reasons that caused you to migrate?

Max: Well, economic and research. I wanted to stay involved in research, and if I'd stayed in Ireland, that wouldn't have been possible.

van Keuren: You came to the Naval Research Laboratory in August of 1985 as a new member of the Acoustics Division. How did this come about?

Max: I applied, very broadly, to a number of places. My CV was circulated through the Navy Labs.

van Keuren: How did that happen?

Max: A good friend of mine was John Lehmann, Secretary of the Navy. I also interviewed with the USGS at Woods Hole.

van Keuren: You knew John Lehmann or his secretary?

Max: John Lehmann.

van Keuren: You knew John. How do you know John Lehmann?

Max: We met each other in Air Force ROTC doing push-ups in a mud puddle in 1963.

van Keuren: Okay. So your CV circulated pretty widely both in government labs and...

Max: No, he only circulated them within the Navy.

van Keuren: Did you apply outside the Navy?

Max: Yes. I applied for various jobs in academics. I was interviewed for the head of the Department at North Carolina State. I was on the final list there. And I also went to Woods Hole where I interviewed. And there were a number of other places that I was in the process of applying for and doing follow-up questionnaires and things like this, although I hadn't actually been brought over to any others, and everything kind of came together at the same time. Some of this was caused by my wife's mother dying, so that she felt that she could leave Ireland. She's Irish. And so, you know, we kind of pulled up stakes and took the best job. And it was really, I was going to interview here at NRL and also down at Stennis with NORDA, but when I found that it would be possible for me to work at NRL, a place where I'd known of the people like Peter Vogt and Norman Cherkis and all sorts of people who really publish a lot of good stuff. And I thought the opportunity to work at NRL was just too good to pass up.

van Keuren: Did you know them or did you know of them?

Max: I knew of them. I hadn't actually met any of them, although my first publication using geophysical information was a geophysical data set that was done by NRL or at least NAVOCEANO when Peter Vogt was working with NAVOCEANO.

van Keuren: So you applied widely. You got a job offer from NRL Acoustics Division, and you decided to come here?

Max: Yes.
van Keuren: And the date for that was 1985?

Max: Yes. Well, that's when I turned up. And I also got an offer from North Carolina State, but I was already coming here, and I just said, "Sorry, guys." But first they told me I was second on the list, and then a little bit later they said, "How would you like the job?" And I said, "I'm going to NRL." I thought the opportunity was better here.

van Keuren: Hm. So tell me about the Acoustics Division in 1985.

Max: The Acoustics Division in 1985 was a lot of fun. They, of course, had a lot of people who all had physics backgrounds, math backgrounds, and they were acousticians. And my background was in geology and geophysics, which included seismics, which is a particular branch of acoustics. And I basically set up working arrangements with these people and tried to help them out doing what they were doing. Bottom acoustic interaction was my specialty area. And I rapidly developed a way of looking at the sea floor materials through geological eyes but in a frequency-dependent way so that we could input the information, map an area accurately with respect to its anticipated bottom acoustic interaction, which is something they didn't have any feel for.

van Keuren: Was this part of your job description?

Max: Yes.

van Keuren: To be a geological expert?

Max: Yes, yes. Initially that was what I was supposed to be doing. And I was brought in to work in shallow water. There was a shallow water problem, and I was brought in to do that. I did up a series of reports and very quickly was able to start getting money from the systems commands to do work. And I became independent. I became funded in excess of my salary and overheads quite quickly, and remained so until I left in 1991. I developed geo-acoustic terrane analysis. And this is based on a system for describing the complex details of orogenic belts by breaking them up into tectonal stratigraphic units which behave in the same way. So what I did was bring to the Acoustics Division the expertise of my analytical approaches which were developed for other reasons but which were directly applicable to characterizing the materials in the shallow water for bottom acoustic interaction purposes. And I also had to learn enough of what these guys were doing to be able to talk to them and make sure that what I was doing was relevant to what they were doing. I also became involved with the BLUG program. This is the Bottom Loss Upgrade Program that was run by Office of Naval Research, mainly through the contractors PSI and SAIC. And I started to work very closely with PSI. And the maps that I was making went straight into the systems databases through PSI. I was funded at 6.3 the whole time. I was never funded at 6.1, although I did a lot of 6.1 work to get to the 6.3 product.

van Keuren: And while you were a member of the Acoustics Division you came into Hydrates Research. How did this happen?

Max: There were a number of areas where BLUG was hopeless. BLUG was a pretty bad model anyway, but it was a simplistic approach to predicting bottom loss. It was a Navy product used on ships for sonar prediction purposes so that they could set the sonars and this sort of thing. And there were many places, especially around continental shelves, where the experimental data was very different from what they were getting from the model prediction. So I was one of those people asked to look at what could possibly be causing this. And I started studying fairly widely the sedimentary environment and the structural environment. And I looked through everything that all the acousticians had done, none of which had actually explained what was going on, decided it must be some sort of diagenetic feature of the sediments because the sediments themselves were being deposited very broadly. And the bottom acoustic interaction anomalies could not be associated with any first order feature like the location of slumps. So I thought maybe it's diagenetic. And I started looking, and I found, I started to read about, the word gas hydrate came up somewhere. I have no idea where I saw it first, and I started following up on this. And I found that this was a solid crystalline material that occurred in the sediments, and it displaced water, so obviously it's going to change the bottom acoustic character of the sediment. Well, how much of it was there? Well, generally speaking nobody had the faintest idea. So I spoke personally with absolutely everybody who had any experience with this at all, all the people in LEG 77 [sp?], John Ewing, Rudy Marcoll, John Stoll, all of the chief scientists who had ever seen any of this stuff. I talked to some people on the West Coast. I talked to Dave Scholl. I talked to all sorts of people who dealt with this. In fact, another guy named Hart who was in the USGS -- I forgot his first name now -- he's not working. He worked with hydrates a little early on. Tim Collett and Bill Dillon were the most important of these people. And I got to know all of them by basically picking up the phone, talking to them on the phone, getting to know more, having them send me their publications, and really going into it. And at one stage my branch head Fleming came in to me and said, "Where's all this hydrate stuff going? What do you think it's going to amount to?" And I said, "I don't know, but leave me with it for a while. I think it could be important." And he said, "Okay." And that, I guess, is how I was instructed to do gas hydrate.

van Keuren: This was approximately how long after you came to NRL?

Max: Fairly soon, fairly soon, actually. What I did was, here, while I was in NRL I kept a list of all of the briefs I did and who I briefed to, plus a few other things. This wasn't normally done, and I found the earliest reference here to my giving a brief to anybody on hydrates was the 25th of October 1988, when I briefed the British Navy staff on gas hydrates. And I don't see hydrate before that, but geo-acoustic terrane analysis, going back, I would have been including the hydrates in that for a while, but the first mention of it in these records, which are not really complete -- they're just outlines -- and of course I didn't know gas hydrate was going to be important. So clearly I started doing this sometime in 1987. And I'll leave this with you. This is a record of all the things, for instance, the first time I briefed hydrate down at Stennis was March '89. And that's in the record also. So I'll leave this with you so that you have a copy of that.

van Keuren: But you don't remember where exactly...

Max: No, I don't remember the exact date.

van Keuren: ... no, where the idea of looking at hydrates came to you, just from reading or talking?

Max: No. I read very widely, you know, you don't know where stuff comes from, really. So I started following. Nobody ever ordered me to do it, that's for sure.

van Keuren: So there was no real program of research in hydrates at NRL at this point?

Max: None at all.

van Keuren: Was there a program in hydrate research anywhere that you know of?

Max: USGS.

van Keuren: USGS?

Max: The USGS had the only hydrate research program. Bill Dillon was the head of it and specialized in the oceanic hydrates. Tim Collett at Denver was the specialist for the permafrost hydrates, and he worked mainly in Alaska. And between the two of them, they more or less had the preponderance of information about hydrates. People with memorable parts like Keith Kvenvolden who was of course one of the real old people who started this work also, he was one of the real old people in that, too. USGS had the bulk of the information that there was. NSF had funded a little bit of ODP work that related to hydrates, but in most cases the work wasn't for hydrate work. They just encountered hydrate because they went there and drilled, so they were able to study the hydrate a little bit, mainly off the West Coast and a little in the Blake Ridge area.

van Keuren: Was USGS doing any oceanic hydrate stuff?

Max: Yes.

van Keuren: And that was the work that Tim Collett was doing?

Max: No. Woods Hole. Bill Dillon at Woods Hole was doing the oceanic work. And basically I got interested in working with these people. And Burt Hurdle who everybody knows, whose one great talent was putting different people together, got me together with some people in the Acoustics Division who I already knew and said, "Look, he wants to do some bottom acoustic loss measurements." So I devised a new geo-acoustic profile which for the first time showed what the anticipated geo-acoustic profile in the presence of hydrate was going to be, and this proved to be really quite accurate when later experimental data and field data came in. And then Bill Kuperman and Mike Collins set me up on their VAX machine where they had a range independent model called Safari running. And they showed me how to set up the data tables so that I could model my geo-acoustic profile. And I did an acoustic analysis for bottom loss using this profile so that I would have a comparison between the sediment with no hydrate, sediment with hydrate, and sediment with hydrate underlain by gas. I modeled those three cases for different sediment types.

van Keuren: Where did you get your data from?

Max: Which data?

van Keuren: For the three different cases, did you actually go out and do sampling and compare data?

Max: Oh, no, not at all. You don't have to do that.

van Keuren: You don't have to do that?

Max: No, no. First place, you model the results for the sediment alone, and basically you take that out of drilling records for the area so that you're dead accurate. And then the other two geo-acoustic profiles and the attenuation of velocities, all this sort of thing, I guess I pulled out of the air myself by saying, "Okay, if we have so much hydrate and the velocity is this, it's going to change by such-and-such and so-and-so." And there were some very simple velocity measurements available that USGS had done by regressing or by processing multi-channel seismics, so I had some general idea of what sediment plus hydrate mixture was going to be, but they had very, very crude two and three-layer analyses which wouldn't give us any result at all. So I had to modify that so that I could do a more fine scale, multi-layer model of the changing geo-acoustic properties and do the model. And fundamentally nobody helped me do that. I just did that. But, as I say, working with these guys in the Acoustics Division, I became familiar how to do it. So it's kind of like on-the-job training. But this was, I suppose, my first real acoustical work in the Acoustics Division as opposed to supporting acoustical work. And that's published. In 1991, or in 1990, that came out as a Blue Report, blue-cover report -- unfunded. ONR, although we briefed them on a number of occasions, refused to see any merit in the hydrates at all. I found them very retrogressive and of no help at all. The AEAS program gave me a bit of money, but mainly because I was working with SAIC. AEAS was an ONR program, but it was a 6.3 program, and it was for doing bottom acoustic interaction work. And I worked with PSI on that. And I also worked fairly closely with a guy named Paul Vidmar, who, we cracked another problem. I made a suggestion to him that some of the BLUG anomalies which were frequency-dependent and also area-specific might be due to a Bragg effect of interaction of certain frequencies at certain angles of incidence. And he looked into that, and in fact he has a blue-cover report that shows that for PSI. So I was having a lot of fun, and we were getting a lot of very positive results. And then I went off to SACLANTCEN.

van Keuren: You helped develop a joint DOE, USGS and NRL research project in gas hydrates, a cooperative project. What is the background of your involvement in this cooperative project?

Max: Of course I got familiar with Bill Dillon at the USGS very quickly. In fact, I'd interviewed with him before I came to NRL. They had some positions open. But Woods Hole was kind of out of the way, and I didn't think that I was going to fit in there very well, whereas NRL is right here in Washington. There was a lot going on, and it looked a much better place to come, but that's when I met Bill first in 1984, I think it was, '83 or '84. Anyway, and I'd met him at meetings before, but we'd never really chatted or became friendly or anything. But he was working in hydrate, and I became more and more interested in hydrate, and although it didn't become my total work -- I was funded, in fact, to do other things completely different from hydrate, and I was able to deliver all of those and do hydrate kind of as a subsidiary thing, which is normally the way research goes. You have to develop your next research area before you can get funded on it. So this conforms pretty well with the way new research topics come into existence. But I was unsuccessful in getting ONR to pay any attention to it before I left, even though, as I say, we briefed them a number of times. There are some other long stories I won't get into. David Bradley of the Acoustics Division might help you out on more background there, but it's not really relevant here. Suffice it to say that I made a lot of waves, but the results always were good enough so that people couldn't be terribly offended.

van Keuren: How was the DOE involved?

Max: DOE had a funded program in gas hydrates. A very good guy named Rodney Mallone at Morgantown Research Facility, Fossil Energy Division of the Department of Energy, started that program in 1983, and to this day the bulk of really good experimental information is still that body of information. It's starting to be overtaken by other work, but DOE put about a million dollars a year into that, and it just generated a terrific amount of extremely good data that everybody has recognized. The Japanese, the Indians, they've all told me that this is the body of data that really attracted them to look at hydrate from a resource potential. And this is a classic example of government money being spent in exactly the right way.

van Keuren: So the format to this cooperative tri-agency....

Max: It was informal. There was no....

van Keuren: You just shared information?

Max: We just shared information. We tried to develop a -- how should I say? -- a critical mass of interest. I was still working on ONR, to no avail. DOE was funding USGS to do some things. And after I left in

'91, it started funding them at a pretty good level. I had the choice of staying at NRL and getting some funding from DOE to work on hydrates then or go off to SACLANTCEN and actually finish and prove my geo-acoustic terrane analysis method, which I did.

van Keuren: So you went off to SACLANTCEN.

Max: I went off to SACLANTCEN to follow up on that because I thought that's what I was really going to be doing. That's where my expertise lay. And going to SACLANTCEN meant that I would be able to do oceangoing research in all of the aspects that I needed to do to prove the technique as a military viable approach.

van Keuren: Okay, I want to get into that, but I have a couple of questions before we move there. I notice that you delivered your first paper on gas hydrates in 1989 at the AGU. Is this your earliest kind of publication?

Max: I think it probably was, yes.

van Keuren: And this, of course, was the paper entitled "Seismic Delineation of Subsea for Permafrost and Gas Hydrates in Identification of Trapped Gas". That was AGU, fall of that year.

Max: Yes. I also did a report that we gave to the submarine people on the effect of permafrost and hydrate on sonar propagation on a frequency-dependent basis in the Arctic Region because, as you remember, our antagonist at the time had a lot of submarines, and this was his stamping ground. And there was a lot of interest in submarines in the Arctic and using the environment to both mask your presence and optimizing your receiver placement to pick up the other people.

van Keuren: This was a marine permafrost...

Max: Submarine.

van Keuren: Submarine.

Max: Submarine hydrate.

van Keuren: And where does the data come from?

Max: The USGS and company work. And then once we understood more about how hydrate formed, we were able to push those, we were able to push estimates of where hydrate was liable to be into the Chuski Sea, the Laptev Sea, the Barents Slope, and other places where let's call them more forward areas.

van Keuren: Right.

Max: Remember, what I was doing was 6.3 and above. And a lot of the work that I produced for gaming of this stuff is still classified.

van Keuren: So this was all classified research?

Max: No, not at all. It was, in fact, I don't think I ever received a penny of funding from anybody for the hydrates. They were funding me to do geo-acoustic terrane analysis. But for the Arctic Region I was able to include hydrate in the terrane analyses for purposes of sonar propagation.

van Keuren: But that was a classified report?

Max: Those things are all classified. I have no idea where they are any more.

van Keuren: And I think I may have answered my next question, but this was many of your early papers on gas hydrates, the ones from the 80s, are related to oceanographic studies of the Greenland-Norwegian Sea and the Arctic. Is this because of the naval interest in this area?

Max: That's where our group was funded to work, so I pushed my, I always look at those areas. The Barents Sea in particular. I did some other work up there, too.

van Keuren: ... calculated from this other work to a wider range....

Max: Well, I just included it. Yeah, that's right, but the Norwegian-Greenland Sea and the Arctic was where our group, which was [Code] 5110 at the time and now it's [Code] 7420, has a lot of experience, expertise, data, et cetera. So basically there I was just working with the group, supporting the group activities.

van Keuren: Interestingly, in 1990 you co-authored a joint paper at the AGU on the possible role of methane and gas clathrates in the ocean and atmospheric disruption at the K-T Boundary. Very interesting work. Can you tell me about the origins of this work, this particular paper?

Max: Well, start from this end. It finally got published in, I think, 1998 or 1999.

van Keuren: Geo-Marine Letters?

Max: Yeah, that's it, which shows that I may not be a great scientist, but I am persistent. It took ten years to get that damn thing published.

van Keuren: Geo-Marine Letters of 1999 was actually this AGU presentation in 1990?

Max: Yes, that's true. The reason we had difficulty getting it published at the time, Clyde Nishimura and I worked that up. He had just come to NRL as a post-Doc, and he really was very good to work with, a great little researcher, and dug out most of this stuff. And we worked on this together. And because, you know, it was just one of those many scenarios that you look at, "Well, if there's hydrate in the ocean now, there would have been hydrate then. What would have happened when the meteor smacked in?" And we started to do some research. And what we started to find was in fact there was extremely good evidence for a sudden burst of methane and partially combusted methane at that time from the soot in the K-T Boundary layer. The problem we had was that in the late 80s when we first presented this, it was not yet accepted fully by the scientific community that it was a meteor that did it. There was still a very large body of opinion that said no, it was somehow volcanic in origin that led to the K-T Boundary disruption, so that a lot of our paper was a long argument about why it had it to be a meteor. And basically it was just ahead of its time. By the time I came back from NRL, the whole meteor controversy was over. Ninety-nine point something percent worth of the scientists on earth now understand that it was a meteor that did it, so we didn't have to spend any time on that. And also there were some other evidences, mainly from the soot layer, that also supported the general conclusions. And then I brought Bill Dillon onboard because he had some seismic data that also bore on the matter that made it look like we could see paleo blowouts, very large paleo blowouts at the K-T Boundary. And we said this allowed us to reinterpret some of the seismic lines, which are included as figures in the paper, as this blowout and disruption caused by near surface phenomenon in the sea floor. And gas hydrate is a really good bet. And we argued that out in the paper, and it's now published.

van Keuren: But originally, what got you going on this topic? What led to the inception of the idea?

Max: Which idea?

van Keuren: Of the K-T Boundary and the blowout. Well, hydrates. I mean, it's not exactly, it seems like it's almost perpendicular to what you were doing at the time.

Max: I do a lot of perpendicular stuff. For instance, my latest paper is a paper on gas hydrate on Mars.

van Keuren: I read that. Very interesting.

Max: You know, it's just one of these things. I was attending a meeting looking at autonomous drilling on Mars. NASA has a program of trying to pick new technologies to send to Mars to look for life and this sort of thing. And it's clear, if there is life on Mars, it's not on the surface, it's some distance down. But nobody knows how far down it might be. And I was listening to these people talk about exobiology, and it became, suddenly I realized that the exobiology they were talking about would have been methanogenic bacteria. And if there were methanogenic bacteria over a long period of time, and we were going into a period of formation of cryosphere on the planet's surface, then there would probably be gas hydrate, like methane genesis. And I wrote a... Steve Clifford, who's an expert on the cryosphere, who had given a talk there, who seemed to be the most broad thinking person who presented a paper there, I sent him a one paragraph thing which was just pure logic saying, "If there were, then there were, if there was, then this must have, so and so, so let's look at this." And he sent back a note saying, "Oh, yeah, okay, send me something." So I did up a first draft and sent it to him. And that became the paper. And that's now led to another paper which has also been accepted on how the water came to the surface of Mars in that early history of Mars to form the erosion channels. That's accepted by JGR Letters now, too. So I do a lot of lateral thinking. That's one of my problems.

van Keuren: And that's how the work on the K-T Boundary developed?

Max: Well, yes, and you talk to people. You know, you're always talking to people. And it's tough when you're dealing with a lot of people to say, "I thought of it." It's hard to say whether maybe Burt Hurdle thought it, said "You know, I wonder what would be, if..." or, I don't know, Pallenbarg might have said, "Oh, you know, that meteor." Or Peter Vogt. Just with all of these interesting people all of the time, you never know exactly where the kickoff comment came from that sets you off down a line of research. One thing is sure, this is not programmatic.

van Keuren: What has been the response to that paper, to that latest version, and Geo-Marine Letters?

Max: It got a lot of public attention. And the off prints went very, very quickly. And then, like most scientific papers, it's kind of settled back into the general literature, and now people reference it, I guess.

van Keuren: Say "Wow, why didn't we think of this before?"

Max: Something like that, yeah. A guy at USGS did that. Came into Bill Dillon and said, "Hey, do you know, if a meteor hit this stuff...." And Dillon said, "Here's a copy of the paper. Go read about it."

van Keuren: Hm. Okay. Moving back to NATO SACLANTCEN, between May 1991 and May 1996 you worked for NATO. What did that stand for?

Max: SACLANTCEN is -- what is the thing again? -- let's see.

van Keuren: It was the NATO Atlantic Center for Sonar Research in La Spezia.

Max: SACLANT is the head of the NATO Marine. There's SACLANT and SACEUR. SACEUR is the land operation in NATO. NATO's split into two commands: SACLANT and SACEUR. And he is the Supreme Allied Commander Atlantic -- that's it: SACLANTCEN. So this is the center, the sonar research center of the Supreme Allied Commander....

[END SIDE A]
van Keuren: How did you end up working for them for this five-year period?

Max: I applied to go over when I found out that this place existed and that they were block funded, which meant that you didn't have to spend any time looking for money. There were a number of people in the commands I was working for who were interested that I prove my geo-acoustic terrane analysis as a methodology that they could use for rapidly going into an area, characterizing it, developing some bottom acoustic loss measurements that then can be applied to a wider region. And so I had generally pretty wide support for going over there.

van Keuren: And besides doing your terrane research, were you able to continue to work on hydrates?

Max: I didn't really do any hydrate work there at all.

van Keuren: I notice you continue to publish in hydrates during that period.

Max: Well, that's largely because I had a bunch of papers in progress, and some even in press. For instance, in 1991, or the autumn of 1990, I went to Tromso, Norway, or maybe it was the summer, because the sun was still up. It had to be the summer of 1990, I went to Tromso, Norway, and Norm Cherkis and I gave some papers on the Barents Sea where we looked at the disposition of the bottom features (unclassified things from what we'd been doing). I mean, you know, that's normally the way we worked at NRL -- you could publish the unclassified aspects of the research that you were doing. And we were doing a lot of work with the Norwegians. So we went up there. And I also gave a paper on the likelihood of gas hydrate in the Arctic Basin. This was something that nobody else had done. And it was a first estimate of where hydrate might be and if it were there, how much there might be based on what we knew at the time. And when I was speaking, there were some people there from BBC who'd come to the meeting, and they asked me afterward if I wanted to take part in a kind of a little science show. They would come over and form this, because hydrates is very interesting. Everybody at the lecture thought, they were all petroleum geologists, and I came along and gave this talk about hydrates, and most of them never heard about hydrates before. But I seemed to be able to keep an audience's attention, and it went over pretty well. And the paper was published. But that publication didn't come out until '93. So, I mean, that's a long time. So that's one of the reasons why stuff got published after I went to SACLANTCEN. The only paper I actually initiated while I was at SACLANTCEN -- and, again, I did that in my spare time -- was with Allen Lowry who's a consulting geologist down in the Gulf area. And he and I did a paper, which was published in '96 just as I came back, in general petroleum geology, basically identifying hydrate as a new, as a frontier area for energy research -- 1996 -- Max and Lowry. And as luck would have it, when I came back to NRL, the Japanese had already established their national hydrate program in 1995, so that this paper of ours hit the news stands just at the same time that knowledge of the Japanese Government setting up their program and funding it and getting it going also became known. And in 1996 the Indian Government, acting through GAIL (Gas Authority of India, Ltd), also set up a national hydrate program. So there was a sudden upsurge of interest in hydrate. And I was basically able to ride the crest of that wave.

van Keuren: But between '91 and '96 you'd simply taken a five-year sabbatical from hydrate while you were at SACLANTCEN on your terrane research?

Max: Yes. You don't need to look far in SACLANT publication work to see what I was doing. I also developed a geographical information system which served as the basis for rapid data fusion in electronic communication. And we migrated that to a military-like system and did a military exercise with it. And actually I was working in something -- it made my terrane analysis really work because we had a receptical that we could put all my information into, including the bottom acoustic loss data, and even the settings, I did reports where we even calculated the settings for the sonar that the European mine sweepers were using. And we were able to go into an area, two weeks, do it up, do the analyses, process the experiments onboard, and then make the information available for the whole map on a frequency-specific basis as part of a data base that the sonar operators could just bring up on their screen and turn the dials and set their instruments the way they wanted. And that's what I call applied. As far as I know, a couple of nations are using it in Europe. I came back to the U.S., and I found that it was impossible to do anything cheaply and simply. The Navy at this stage was using Loral to do something at the same thing, and they hadn't achieved anywhere near the capability we had in NATO. I was told I could get funding in that program, but I would fundamentally have to give up everything else. And I didn't want to do that. So I just kind of dropped out of that. Had a couple of publications in that also.

van Keuren: So your paper with Lowry came out in '96, "Methane Hydrate: A Frontier for Exploration in New Gas Resources". It piggy-backed on to a Japanese program, so suddenly....

Max: Well, it didn't piggy-back on it, but suddenly there were a lot of people interested in hydrate. So it wasn't a case of piggy-backing on anything. If anything, it was piggy-backing on my own work that I'd already done, because there were very few other publications available. But there was a lot of data out there, and the Japanese Government had gone and commissioned a lot of private work which still is not published formally, and most of which I've seen.

van Keuren: So by May of 1996, on your return to Washington and NRL, the pace of your efforts in gas hydrate research increased markedly.

Max: Well, yes, because it looked like the things that I'd planned on working in I wasn't going to be able to get any money for. For instance, when I left NRL, my branch 5110 was in the Acoustics Division. When I came back it was a branch in the Marine Sciences Division, and no effort at all was made to involve me in anything that they were doing that might bear on this sort of thing. And I don't think they were really doing much. It wasn't really the hard acoustic applications that I had been doing. And there's one immutable barrier in NRL that money does not cross, and that's called divisional boundaries. And I found it impossible to do funded work in Acoustics any more. So I had to basically find something else to do. And that was hydrate. It was that simple. To get funding, hydrate was my only quick option. And within a year I was self-funded through the Department of Energy.

van Keuren: You developed a concerted NRL gas hydrate program between 1996 and 1999. How did this happen?

Max: Basically by just identifying a lot of different people in NRL who had skills that could be brought into hydrate research and talking to them and just kind of, you know, developing a research plan. Dr. Rath was absolutely instrumental in this. He saw very quickly that hydrate was a branch of material science that offered great promise for scientific research. It was obviously going to be an area of emerging research, and he threw his weight behind my efforts and in many respects, although I was in the Marine Sciences Division, and I was funded by the Department of Energy, I was actually working directly to Dr. Rath who was in code 6000. But this was all rather informal. Fortunately, NRL was at the time still a relatively informal place. I'm not sure what the new management system is going to lead to, but I don't think it's going to lead to the same type of informality.

van Keuren: Had there been any work going on in hydrate during the period of your work in Europe?

Max: At NRL?

van Keuren: Yeah. Had anybody picked up on your work while you were gone?

Max: Not up here at NRL. A very interesting thing happened. Just before I left, I became aware that Stennis -- well, it was NORDA as it was at the time -- was doing work that might bear on it. Joe Gettrust came up, and I think it was 1991, because I was just going off to SACLANT. Now, I could be wrong. It could be 1990, and I could have compressed all this, because you know how time passes. But this was a publication that they did on Deep Towed Seismic. Joe developed this DTAGS for characterizing fine scale velocity characterization of sediments in the deeper seas. You get everything right down near the bottom and you can do your fine scale analysis. And they did this on the Blake Ridge area. And when he showed me these figures of the velocity structure in the sediments, especially things like this where you notice the bright spots are coming in the anticlines, and you get this funny sort of discontinuous character, and you get little high velocity spikes coming up and then spreading out, and I said to him, "Joe, this looks like it could be gas hydrate." Had he ever considered gas hydrate as the source of these because it looked to me like it was a diagenetic effect superimposed on an original stratigraphic. That's what it looked like. It didn't look like a single, it didn't look like a feature that was a result of some one single thing but of two things, so you've got to have dia-something: diagenetic and something earlier. And these were the first really detailed results of that sort of acoustic structure I'd seen. I pointed that out to him at the time. And you can look through this, and there's no mention of gas hydrate in this at all. There's mention of variation in the geologic structure. And as I remember at the time that geological structure were tons of lobes of slumps and things like this, a perfectly reasonable conclusion except that it didn't really quite fit the data. But it was the only first order thing that fit. The problem with hydrates is it's a second order thing, so when you get, so what you're looking at in the velocity is a first and second order function. And when he left NRL, I thought we were going to be working together on analyzing some of his data, so I was real surprised when I never heard from him again. I never followed it up because I was off, of course, doing my thing in geo-acoustic terrane analysis. But when I came back, they were characterizing DTAGS as an instrument that was being used for hydrates where of course it was never designed for that. But it was perfect for it. It was just, you know, it was deep toad seismics, you know, for the bottom acoustic interaction program. It's one of those things where it just kind of fell into place. So whatever Joe was doing during those times, they did a few cruises, they got a little bit of data. Mary Rowe and he wrote a couple of papers. And they never actually made me privy to what they were doing or involved me in what they were doing in any way whatsoever, which at the time I thought was kind of a shame, because it looked like great data that I could get into. And I've done a lot of my work by taking other people's data sets and working them up and analyzing them. My paper where I was senior author on the analysis of the magnetic data set of the Argentine Module, for instance, I had nothing to do with collecting that data. It's just that because this was continental crust, people who were oceanic crust geophysicists couldn't make head or tails of it because, of course, it's polyphasal geological structure, which is a result of collision of continental masses and developing of cratonic belts and all this sort of thing that I could approach because I'd worked in that environment before and had published on very similar things before. So, I would have liked to have gotten into that, but in fact I seem to have been excluded from everything they were doing. And when I came back, one of the first things I did was go down to Stennis because I was actually in the division that was headquartered down there, gave them a big brief on all that I was doing, but I found it very difficult to get a division-wide hydrate program going. It seemed to devolve into competition.

van Keuren: But you did get DOE funding.

Max: I got DOE funding.

van Keuren: How did that come about?

Max: Oh, I contacted the people at Morgantown again and said, "Okay, I'm back, and this time I need funding." And they said, "Okay, send us a proposal." They were so happy with what I'd done before. And they said, you know, "What do you want to take as a specialty?" And I said, "Well, let's see if we can get interest up. I'll be kind of your briefer in Washington. You can pay me, you know, to go around and brief people and try and get interest up in this, and I'll look specifically at the reservoir characteristics of a hydrate deposit and look at getting how we get the methane out." And I had various publications at the Offshore Technology Conference in exactly that sort of thing. So we had four work elements, and I performed on all of those for DOE. I got $200K a year for two years, and there was more coming when I left.

van Keuren: So your first year....

Max: Well, the first year I was carried by the Division -- well, the first part of the year I was carried by the Division. And then when I found it impossible to get money for bottom acoustic interaction work or to do any acoustic work at all, because I was in the wrong Division now, it took me a while to get that funding in place. But it's normal, people coming back from SACLANTCEN are carried for a while. That's part of the deal.

van Keuren: You helped the DOE develop a national U.S. gas hydrate research program.

Max: Yes.

van Keuren: How did that happen?

Max: Well, basically, we tried to do that earlier. Bill Dillon, Rodney Mallone and myself tried to do that. We held a meeting, which was my initiative, at USGS in Reston in 1991, Spring of '91, which we grandiosely called the First National Gas Hydrate Workshop. And basically I sent out every invitation from NRL, and people all came. I was absolutely amazed. We said, "Let's have a meeting." And I invited all these people, and everybody said, "Fine". They're coming. And we had a two-day meeting which really went off exceptionally well. We had about one-third industry, one-third government, and one-third universities/NSF (National Science Foundation). We had really everybody. I know a lot of people, and it was just one of those things that just worked out really well. And a report was published of that meeting by DOE as a DOE report.

van Keuren: What happened to the effort?

Max: Nothing. DOE got a new secretary, Admiral Watkins, who killed the Hydrate Research Program in DOE.

van Keuren: Why?

Max: He liked nuclear energy. Apart from that, I mean, why does anything happen in DOE? I don't know.

van Keuren: So what about the second DOE project, the one that you....

Max: Well, when I came back, Rodney was ill, but he was able to still exert a lot of influence. A guy named Hugh Guthrey then was the man that I dealt with all the time, a senior advisor. He became aware that this was really an important area. He took on board that Japan and India had both set up programs. And we went around and talked to people. And I set up a briefing at the LERDWG meeting of DOE. It was a DOE Laboratory Oversight Group.

van Keuren: Called the....

Max: L-E-R-D-W-G. I don't know exactly what it stands for, referred to as Lerdwig. And there was to be a big meeting in Washington. And Hugh Guthrey helped me get on the agenda, and Tim Collett and I gave a talk on hydrates and why DOE and the government should be interested in hydrates. And basically I just gave the same brief that I'd been giving to ONR in 1989 and '90 and '91. You know, it was kind of the same thing, updated all the time, of course. You know, it's bigger than a single government department. It's national significance, energy security, et cetera, et cetera, et cetera. The whole thing. And we pointed out how much there could be and, of course, fed in the newest information which really made it look like it was happening, and news of the Japanese interest especially. And at that meeting there were three people from the President's Committee of Advisors on Scientific Research (PCASR). And hydrates was put into their report on the energy resources of the United States, and that was really the beginning of official notice. And that was published in September/October of '97, something like that. And it went to the President. Then it was referenceable. And the figures referring to what it would cost were kind of off-the- envelope figures that Tim Collett and I gave at that meeting for how much this program would cost. And then, through Burt Hurdle, we went to the Senate Energy Committee, read the Navy Representative there, was all done kosher. I gave the brief there, and we interested a couple members of that panel. And we thought that a good way of really getting this moving at a national level was to do a Bill or an Act on gas hydrate research. And that bill was signed by the President on the 2nd of May 2000.

van Keuren: That was the Methane Hydrate Research and Development Act?

Max: Yes.

van Keuren: That dates back to that meeting where you appeared before the Senate Committee?

Max: Yes. It wasn't a Senate...; it was a group of Senate staffers from the Senate Energy Committee.

van Keuren: So you briefed staffers.

Max: Yes.

van Keuren: And that was the beginning of that.

Max: That was it. That was the beginning.

van Keuren: Did you later....

Max: We helped them.

van Keuren: ... testify before leaving?

Max: I wasn't asked to testify. I believe I helped write the

Navy response, but I was never asked to testify. Nobody from NRL was.

van Keuren: What does the Development Act do?

Max: It establishes hydrate as an energy resource, a potential energy resource of national importance and says that it should be funded as part of the U.S. budget to do research in this to establish the hydrate as an energy resource.

van Keuren: Is there a funding bill that goes along with it?

Max: The first time we did it, we didn't go to Appropriations first. We were fairly short on time, and they just said, "Get the bill in and we'll do Appropriations as soon as we get this through." That bill failed because they basically ran out of time, and it was the Gingrich Congress gone crazy, you know, and everything was stalled, and stopped, and bartered. It fell through. And then when we started it up again the next year, the advice we had was, "Let's go to Appropriations at the same time so that they know it's coming so that we can put in, we can give an indication of the amount of funding that's required, and Appropriations will be involved up front, and that means it's much more likely to go through." So that's what we did. The Appropriations Committee was involved from the outset.

van Keuren: Who were the major backers in House and Senate, do you recall?

Max: Senator Koch was a big backer, Senator Craig, Landreau of Louisiana, and Trent Lott signed onto it. That was a big step. There were others, but those are the ones that come to mind.

van Keuren: So it was bipartisan?

Max: It was bipartisan. It's never been anything other than bipartisan. I have never heard, in any of the meetings I've been to or in any of the meetings between staffers, any partisan comments. Now, we did some steering on this, so as to try and make it, you know, to stress the national issue on it, you know. I mean, it's clear that states that don't have borders on the ocean aren't going to have any hydrate. And others for other reasons won't either, so some states may be more interested than others. But we all the time stress the national side of the issue and the national security side of energy supply and the global climate and the other scientific things. And it worked. It never broke down into a partisan rank.

van Keuren: And there was a funding bill that was passed with the bill at this time?

Max: I'm not exactly sure. The Appropriations bills are going through now, but the Appropriations Committee was involved in this a year ago. And so far as I know everything is okay.

van Keuren: So this really will mark the beginning of a national program?

Max: Absolutely. Absolutely.

van Keuren: And you played a principal role in it.

Max: NRL generated that, you know. Burt got us in to talk to the staffers, and I gave the brief and did a lot of follow-up work with them, including drafting the first bill which included NRL by name, which is how you know I was involved. And, yeah, we were the ones behind it.

van Keuren: Stepping back just a couple of years, you also served as a consultant to the Gas Authority of India regarding gas hydrates in the 1990s. How did you become involved here?

Max: Well, that was through Dr. Rath. He wanted to establish a formal relationship, a formal research relationship with GAIL, the Gas Authority of India Limited, because that would be a source of income to NRL. And he sent myself and Joe Gettrust, who runs the DTAGS thing down in Stennis, over to India. And I said, "Look, we better send Bill Dillon, too, because he's the one who really has a lot of credibility with these guys. A lot of the people of NIO in India, they know him. Bill's got the track record here. Send Bill along." So he did. This was State Department money, not NRL money. Or I think it was State Department money administered by ONR, something like that. It was called the India Fund. And Dr. Rath was one of the people who could direct where that was spent. So we were sent over on that. The travel orders were State Department travel orders. They bought the tickets, that sort of thing. So it didn't cost the Navy a penny. And we went over there, and we looked at their data, and we all made comments, and we made presentations. But mainly we looked at their data. Insofar as we consulted for them, that was it pretty much. Then we had a meeting here, a workshop in the Lab, to formally identify the people in the Lab who might take part in an NRL program, lay out an NRL program, and then see how we could mesh together with the Indian program to basically help both of us. During that workshop the head of their program, a Mr. Budarajha, he came over to that meeting, and we did up an MOU (Memorandum of Understanding). Dr. Rath, myself and he did up the MOU, and we signed it, or they signed it. I couldn't sign it. I still have the original MOU in my computer. And we were on to a good thing. Then we sent them proposals as to what we were going to be doing for their money. They had foreign currency that they could send us, but that's now all completely fallen flat because the Indian

Government has decided not to involve NRL in anything they're doing. That's another story, but we've fallen out of that loop now.

van Keuren: Was it directed at the U.S. or NRL in particular?
Max: NRL and the U.S. You've got to remember, we sanctioned these guys. They're still under sanction. There are still institutes that we have under sanction or they want to give us money for it, especially when they think we're going to take their, you know, all their data and use it against them sometime.

van Keuren: To what extent would the NRL program in hydrates be part of a larger international effort in gas hydrate research?

Max: There is no large international effort in gas hydrate research. There are national efforts, and Europe, The European Union has an effort, but that's really a Federation. That's a single effort, really.

van Keuren: So the attempt to establish a working alliance between NRL and the Indian program....

Max: It would have been bilateral.

van Keuren: Bilateral?

Max: Yes.

van Keuren: It's kind of a case contrary to the point, it's pretty nationally oriented. I guess my question here is that in terms of gas hydrate research there is no international program then. It's really national interests working in each case. The India case would have been a counter example, but it didn't really work.

Max: Yeah. There is no national program, or there is no international program in gas hydrate research. Bob came in just at the right time. [Question number] thirteen.

Dillon: Thirteen. Okay, yeah. Lucky number.
van Keuren: You resigned from NRL in 1999 in order to establish a private company.

Max: Yeah, let's make this fourteen.

van Keuren: Of which you are CEO. Can you tell me about this? Why did you resign? A little background to this whole thing.

Max: Okay. One of the things I did when I came back was Bob and I did up a pamphlet on using methane hydrate for desalination. And we did this up as a patent disclosure. We put it into NRL, and much to their surprise it survived the process and was recommended to be a patent filing. Then much to everybody's surprise it was awarded a patent straight away. So a patent exists in both our names as the inventors. So we're the inventors of that. We tried very hard, we really did, to get some money to develop that while staying here at NRL. And there was no money in the tech transfer office. We were told to go just bootstrap this ourselves, and basically there was no way I could do that. DOE was not going to want to be told that I couldn't do their stuff because I was off working on gas hydrate. You know, I estimate it was about six months worth of work that had to be put in, and I just couldn't be unfunded for that period of time. NRL appeared to have no internal funding to support developments like this, even though there was an existing patent that a lot of people thought had economic potential, but it needed more work. And we found that it was not possible to do this. We found that dealing with water companies outside, they didn't really want to support this kind of work. It was a little iffy, certainly at the levels that we would need support here at NRL. You've got pretty high overheads here. So I started looking at the possibility of leaving NRL and doing this in the private sector, because that's the way of the drift of things. That's where things are happening now. There's not much internal support for work of this type. And I got together, after about a year of hunting around, I got together some private finance which allowed me to leave NRL and be the only paid person in that company. And we've been trying to commercialize that. My company has been selected as the licensee for my patent, for our patent, and we're still in the process of negotiating the terms of that license now. That's about as nutty as you can get, I think, but there you are. So I would have, if I could have got funding to do this in NRL, I would have stayed, I think. But there didn't seem to be any way of doing that. In fact, there wasn't any way of doing it. So that's why I left.

van Keuren: How did you come up with the idea for the patent?

Max: It's just one of those things, you know.

van Keuren: Bilateral, or... not bilateral, but....

Max: No, it's just an idea, you know. I was watching a video.

Dillon: Describe the light bulb incident with the video tape.

Max: I was videotaping. Peter Brewer did a... in 1990, I kind of envisaged the possibility of this happening. And I put in a patent disclosure which was turned back because it was just insufficient, and kind of the germ of the idea was there. But in fact, you know, that all went through after I went to SACLANTCEN. So it just got forgot about. And when I came back, Peter Brewer and Keith Kvenvolden had done an experiment off of the California coast where they took down a research ROV, and they pumped hydrate into water-filled glass tubes to see what would happen. And they saw two things. One is that the hydrate formed spontaneously, very, very quickly. And, of course, hydrate being a crystalline material, it only takes into that crystalline material the molecules that form that crystal, which is water and gas, the methane. So effectively it's a desalination process. It extracts water from the sea water. And this then floated upward and became collected in the top of these glass columns. And I was looking at this, and I thought, "What if you took that column all the way to the surface?" Suddenly it was all there. That was it. The rest was just sitting down and writing. And then, you know, I went to Bob and said, "Bob, let's look at this." He said, "Oh, I think this will work."

Dillon: We saw the video together, and the light bulb went on in both our heads at the same time, so it was very simple the procedure.

Max: And it was one of those things, again, as I was explaining earlier, when you're working with people, it's hard to say where an idea comes from. It's hard to say, "I had the idea" or "He had the idea" when you're actually working really collegially with people. It's really tough. You may get a little bit of there and a little bit of it there, and then everybody would be sitting around and suddenly, "Oh!" You're kind of at the same level of development. And then we would go to meetings where they showed the same tape, and it was clear that the other people in the room were not at the same level of development. In other words, they didn't have the background and the side swipes and all this other stuff.

Dillon: They saw exactly what was happening, but it didn't register.

Max: Didn't register at all. It's just one of those things.
van Keuren: So your work now is working toward the development of this other idea, the business sense.

Max: Yes. I'd taken the basic idea and changed it a lot in that the original method that we had was a very elegant way of doing it at sea, and I've now put in some very thick patent applications for my company which take the general idea and make it work on land, which previously it wouldn't. See, for our method, unless the oceanographic conditions are absolutely correct, it won't work. So it won't work in the eastern Mediterranean, the Persian Gulf. A lot of places it won't work. It worked fine off of southern California, which is what we had in mind.

van Keuren: What happens to the methane?

Max: You reuse it.

van Keuren: Reuse it? Recycle it back?

Max: You recycle it. Almost nothing is lost. Methane's almost insoluble.

van Keuren: Are you doing any other work in methane hydrate other than this at the moment?

Max: I'm still trying to help NRL get money out of DOE. I'm still trying to help DOE put a national program together.

Dillon: The DOE has problems with Los Alamos.

Max: And it's now possible for me to talk directly to Congressional staffers without fear of prohibitive legislation on the Federal employees. And I helped the bill through by talking to the House side, Energy and Resources Committee, and the House Science Committee. So I think I remained influential literally right up to the final. They also had problems over nomenclature, and some group tried to change it to hydrate instead of methane hydrate, which meant CO2 would have got, hydrate would have got a lot of money out of it. So we headed off the worst of the predations. It's really something up there on the Hill, I've got to tell you.

van Keuren: What do you think should be the current thrust of NRL research in this area? Where should the Laboratory go in terms of methane hydrates?

Max: Well, the first thing NRL needs to do is carve out a sum of money out of the DOE, out of the money in the national hydrate program. When we worked with DOE to get that, there was a clear kind of unstated agreement with the people in DOE that NRL by right had claim on a certain amount of money. Now, we didn't talk about percentages or anything else, but what we didn't want to get wound up in was competing at the proposal level for every penny. And that was fine with DOE. They were funding me at $200K a year. I felt that going up to $500K a year was absolutely doable, and maybe as much as a million a year if their national program went in excess of ten million a year. And this needs to be approached on two levels. You need to approach it on a programmatic, "Hey, we helped. You wouldn't have that money if it wasn't for us. We want our piece." You know, that's the way it's got to be done. And anybody who thinks that you're going to get that on the basis of arguing for good science, competitive science, is absolutely bonkers. It's not going to happen. If people here are reduced to putting in proposals, what good is it being at NRL? They could do better in a university where they didn't have to support such a high overhead. You need to get some money in up front at NRL to be able to absorb some of that overhead so that the money that people actually bring in on a proposal basis isn't all eaten up in overhead. I mean, I was bringing in $200K a year. I gave Burt some of that money. Bob got some of the money. There fundamentally wasn't any money for me to do anything except sit down and think at my computer. I couldn't do anything. USGS gets $70K. They can do a cruise, because everybody is already paid for. It's time NRL woke up to the way things are. You've got to go out and get some of that hydrate money as a block, otherwise it doesn't matter what I think people at NRL should be doing. It just doesn't matter.

van Keuren: What about the national effort? Where should this be going?

Max: Well, it should be focused broadly between basic research and applied research. And I think national funding should be skewed to some degree toward basic research, and NRL should be one of the premier leaders in that effort as opposed to doing work that an oil company could do if it got paid to do it. I think there's an awful lot of really basic research that we need to understand about hydrate, and NRL should try and take a corner of the basic research area and become one of the real experts in the basic, fundamental research, working possibly with Canadian National Research Center and these places.

van Keuren: What are your own personal long-term plans?

Max: [Laughter] Well, aspirations one has. Plans, one doesn't have. I have a pot of money that's running down, and I'm looking to get some industrial partners to fund the next stage of the research and development which includes some test and pilot apparatus. And my plans don't go beyond that. I've got many aspirations that go beyond that, but no plans.

van Keuren: What would the aspirations be?

Max: Make a lot of money. That's one of the reasons I left NRL. I mean, one of the reasons I left was I went to my boss before I left and I said, "Hey, if I bring in a million bucks a year from NRL, can I get a fifteen?" And I was told, "No, there are no promotions in the Division." They were top-heavy, management said. "So I'm going to bring in a million dollars and I'm just going to stay on my salary?" Didn't seem like sense to me. That combined with the whole, with the greater opportunity of getting something on my own and making something out of it, and the possibility of making a lot of money out of it, presented itself. And I'm not getting any younger. I probably should have done this years ago. But I can't go back here, so I had to do it now. I'm probably just young enough to be able to pull it off.

van Keuren: And any closing thoughts or comments?

Max: On hydrate?

van Keuren: Anything that we've talked about.

Max: Yeah. I think that NRL is kind of at a crossroads as to where it's going to go, in terms of what's done here on the science. And it really needs to take a hard look at the way scientists are supported.

And they need to put some internal money on supporting stuff. The whole desalination thing walked out the door because there was no money available. There was no support available. There was no enthusiasm. There was nothing. Basically we were asked to do somebody else's work at our own cost. And that didn't seem to make much sense to me. So basically the times have changed, and NRL really needs to adopt a new strategic focus and/or reorient toward that strategic focus, whether it means a properly funded group of 500 scientists or fewer, they need to look at that and then arrive at whatever they want as soon as they can. Otherwise NRL is going to really dribble away. A lot of people have left, including me, and my post wasn't filled. Cherkis' post wasn't filled. When I came back from SACLANTCEN, our group had twenty-four people in it. I think it's down to somewhere between nine and ten now, something like that. You're down to the point where, you know, it's not the critical mass that's starting to be absent, certainly in my own group. And I think this might happen elsewhere. And I really like NRL. I had a lot of good times here, and I would hate to see it just kind of whittle away. As a closing statement, you know, and getting some money in from DOE for the hydrate is one place to start. But they have to get a good program and get it going, not just in hydrate but a lot of other things. The way it's going now, the future is not great for NRL. As Churchill once said of an opponent, he said, "His future lay behind him."

van Keuren: Alright, thanks.

Max: Okay?

[END OF RECORDING]

23. James McGrath

Notes Prepared by Fred Erskine on a Recorded Telephone Interview with Dr. James R. McGrath held on Saturday 17 October 2009 at 11:20 EDT (1 hour 20 minutes)

Early Life, Education, and Career

Dr. James R. McGrath was born in 1932 in Chicago, Illinois. He grew up in Oak Park on the west side of Chicago and graduated from Fenwick High School. After high school he began undergraduate studies at Catholic University, interrupted by the Korean War. During that period he served in the U.S. Navy aboard a destroyer escort in the Caribbean. While in the Navy he learned about sonar techniques and became involved in training sonar operators aboard submarines and destroyers. After his military service he returned to Catholic University where he graduated with a B.S. degree in aeronautical engineering in 1957. Shortly thereafter he decided to pursue a second undergraduate degree in physics at George Washington University where he received a B.S. degree in 1962. He then pursued graduate studies in physics at Catholic University and received an M.S. degree in physics in 1965. His master's degree project was a basic research experimental study on underwater exploding wires. His formal adviser on the master's project was Dr. Malcolm Henderson. However, his actual supervisor on the experimental work was Dr. M.F.M. Osborne of NRL's Solid State Division. In October 1962 McGrath had begun working on a full-time basis at NRL in the Energy Conversion Branch of the Electronics Division. That branch was headed by Jim Wilson. Around 1965 both McGrath and his colleague Don Horan of the Electronics Division received NRL Edison Scholarships to pursue doctoral studies at Catholic University. McGrath started his doctoral studies in Catholic University's physics department, but soon transferred to the mechanical engineering department. By the late 1960s McGrath had moved to NRL's Acoustics Division and was doing research on ambient sea noise. During his doctoral studies he continued working full-time at NRL and completed his doctoral degree in November 1971. The subject of his doctoral thesis project was heat transfer from a wavy ocean surface.

NRL Acoustics Division Career

Initially, McGrath had much interaction with Burton Hurdle in the Acoustics Division. Hurdle had extensive research interests in ambient sea noise and propagation studies as well as in boundary scattering phenomena. McGrath recalled the work of Chester Buchanan on deep ocean search techniques. McGrath also recalled that after the closing of Columbia University's Hudson Laboratories around 1968–69, a number of researchers came to work in NRL's Acoustics Division under the new Division Superintendent, John Munson, including Budd Adams, Hank Fleming, Norm Cherkis, Carl Andriani and others. By about 1970, Ralph Goodman, the NRL Associate Director of Research for Oceanology, recruited Sam Marshall from Colorado State University to join NRL's Acoustics Division. McGrath recalled that Ralph Goodman had a strong interest in the development of ambient sea noise as a key research area at NRL. McGrath participated in the Northeast Atlantic Test (NEAT-1) for which Goodman was chief scientist. On that test McGrath also had significant research collaboration with Ted and Elizabeth Arase who had previously done extensive research on ambient sea noise at Hudson Laboratories. The NEAT-1 sea trial was a multi-organization/multi-national effort that included NRL, the Woods Hole Oceanographic Institution and the Admiralty Research Establishment of the UK. McGrath recalled the use of Shackleton aircraft in NEAT-1. These were former Lancaster bombers from the World War II era that had been upgraded with turbine-powered engines for longer range capability. McGrath also participated in a follow-on sea test called NEAT-2. He recalled that in the early 1970s the Acoustics Division had the use of several capable research vessels and that about the time of NEAT-1 the research vessel USNS *J.W. Gibbs* was sold to the Greek navy for one dollar. This vessel had been heavily used for at-sea experiments by the Sound Division in the 1960s and was in need of extensive refurbishment. The replacement research vessel was the newly constructed dual-hulled ship, the USNS *Harvey C. Hayes*. The *Hayes*, however, had handling problems in high seas that were only partially mitigated by several modifications.

Through the 1970s McGrath continued research on ambient sea noise at NRL in collaboration with Sam Marshall that included additional sea tests. McGrath was given responsibility for research on ambient sea noise in the vicinity of the marginal ice zone. He recalled that every time the NRL research vessel sailed north of the Shetland Islands a Soviet AGI vessel (intended for intelligence collection) would appear nearby and trail the NRL vessel at about two miles away. Hank Fleming was often the senior scientist on board during NRL cruises to perform a deep deployment of a fairly sophisticated ambient noise buoy. This buoy was capable of recording ambient sea noise for one minute periods every four hours over a full year, for later recovery and analysis. The NRL team developed a covert technique for buoy deployment (and recovery a year later) during periods of heavy fog. The ambient noise results were later published in the open literature in the *Journal of the Acoustical Society of America* (*JASA*). Another frequent collaborator on the ambient sea noise scientific analyses was Robert Urick (of the Naval Ordnance Laboratory in Silver Spring (White Oak), Maryland). When Sam Marshall later left NRL, Orest Diachok was hired as Marshall's replacement. In an eighteen-month period around 1976 McGrath published about a half-dozen peer reviewed journal papers on the results of the ambient sea noise research. During this period of the early to mid-1970s John Munson was Acoustics Division Superintendent and Richard Rojas was Associate Superintendent. McGrath recalled many pleasant interactions that he had with colleagues in NRL's Acoustics Division in the mid-1970s, including Ray Ferris, Ray Rollins, and others. He specifically recalled that Mickey Davis taught him to become proficient with differential equations. The management chain in the mid-1970s that included Dr. Alan Berman (NRL's Director of Research), Dr. Ralph Goodman (Associate Director for Oceanology), and Dr. John Munson (Acoustics Division Superintendent) had really invigorated the Acoustics Division's research programs as compared to a decade earlier.

<u>Further NRL Recollections</u>

McGrath looks back upon his association with the NRL Acoustics Division as perhaps the most important and enjoyable part of his career. During that part of his career he developed many close connections with colleagues and learned a great deal of things that have been valuable to him in later phases of his career. He looks back on his NRL career with some degree of pride, yet also some degree of ennui in that he feels that the mission of NRL has changed in recent decades. He senses that when he worked at NRL there was more emphasis on basic research and that there was more international recognition then for NRL's efforts. He acknowledges that nowadays there is much more research competition from other organizations and that funding schedules are more short-term than in the past. McGrath recalled some additional notable NRL colleagues. Tony Zuccaro was a navigator on many of the research cruises who worked under Al Gotthardt in NRL's Ship Facility Group. He was a retired Navy Chief who had a very strong personality and many of the scientists were fearful of him, but McGrath was able to work well with him. Another very assertive person was Art McClinton, an extremely competent engineer who had a very serious demeanor. Another very intense person was Walt Diehl who worked for McClinton. Diehl was the son of a well known Navy Captain, Walter S. Diehl, who from 1918 until his retirement in 1951 directed the Navy's work in aerodynamics and hydrodynamics, and was the author of an authoritative text "Engineering Aerodynamics." The elder Diehl was credited with initiating action that led to the establishment of the David W. Taylor Model Basin at Carderock, Maryland, the Aircraft Research Station at Chincoteague, Virginia, and the Navy's test flight unit at the Naval Air Station, Anacostia, D.C., which later developed into the U.S. Naval Air Test Center, Patuxent, Maryland. McGrath also recalled pleasant associations with Dario Ciuffetelli and Bob Chrisp. McGrath further recalled especially pleasant interactions with Dr. Homer Bucker, who had headed the Propagation Branch for several years. Homer came to NRL from the Naval Ocean Systems Center in San Diego (now known as SPAWAR Systems Center) and eventually returned to California to complete his career.

Post-NRL Career

After the intense period of research on ambient sea noise in the mid-1970s McGrath began to look for other career options. In 1972 he had become involved in the Marine Corps Reserves. This activity had broadened his outlook on things of interest to the Navy and Marine Corps. In the early 1980s he remained an employee of NRL, but was working in the Ocean Sciences Division. In 1985 he accepted a three-year detail as an NRL employee assigned to the Quantico Marine Corps base. In December 1988 he retired from NRL and went to work for Boeing Corporation in Huntsville, Alabama on a NASA project related to the development of the future Space Station. McGrath's Boeing responsibilities included the integration of foreign components such as the Canadian manipulator arm. He retired from Boeing after about five years. While in Alabama he had become a licensed pilot with both private and commercial aircraft certifications. He relocated to the Northern Neck of Virginia and became a ground school instructor. After several years he moved to the Lexington Park area in southern Maryland where he went to work for a small firm doing risk management on the manufacturing process for the V-22 Osprey aircraft. Shortly thereafter he joined Lockheed Corporation to do risk management for the development of the presidential helicopter (a program that was later cancelled). After taking some time off, he went back to work on advanced digital techniques for air traffic control management using radar. He currently works for ARINC (Aircraft Radio Incorporated).

24. William Moseley

Notes Prepared by Fred Erskine on a Recorded Telephone Interview with Dr. William B. Moseley held on Wednesday 25 March 2009 at 10 AM EDT (1 hour 30 minutes)

Early Life and Education

William B. Moseley was born in 1942 in Savannah, Georgia. He grew up in Savannah and attended Benedictine Military High School there that was run by Benedictine Monks. After high school he attended Georgia Institute of Technology in Atlanta where he received a B.S. degree in physics in 1964. He then pursued graduate studies at Georgia Tech and received a M.S. degree in physics in 1966 and a Ph.D. degree in physics in 1968. He entered the workforce while he was studying for his doctorate via a program hosted by the Air Force Cambridge Research Laboratory (AFCRL) that covered his educational expenses. The problem that he studied addressed questions regarding how rapidly a nuclear event that ionized the upper atmosphere and possibly blanked out radar coverage would dissipate. His thesis was on the topic of turbulence in the upper atmosphere. They performed experiments by launching rockets from Eglin Air Force Base in Florida out over the Gulf of Mexico. At altitudes of 100 km to 150 km the rockets would release chemi-luminescent clouds. These clouds could be observed via optical tracking devices against the background stars in order to measure physical parameters such as the diffusion coefficients, degree of turbulence, the wind shear, etc. From those measurements one could calculate the dissipation rates for an ionization event. These launches often occurred around 3 AM local time and sometimes were observed by the public and resulted in reports of unidentified flying objects, because the clouds were relatively bright and could move quite rapidly (on the order of hundreds of km per hour) with rapid changes of direction as they moved through various atmospheric layers. During the period when he was working on his Ph.D. degree, he was married and he sought to supplement his income with some teaching duties at Georgia Tech. He taught several courses in celestial mechanics and orbital mechanics in the Aerospace Engineering Department.

Employment at NRL in the Acoustics Division in 1968

Around the time Moseley was completing his Ph.D. degree in 1968 it began to become evident that after the U.S. landed astronauts on the moon, the space program at NASA would begin to scale back its efforts. He had originally been hoping to have a career in the space program, but began looking at other options. He started a series of job interviews with various organizations and was most impressed with NRL. He interviewed with Alan Berman, Ralph Goodman, John Munson, and Budd Adams for a possible position in the Acoustics Division. This was period of rapid changes in top management at NRL. Alan Berman had arrived at NRL in 1967 as Director of Research from his previous position as Research Director at Columbia University's Hudson Laboratories. Ralph Goodman had arrived at NRL in 1968 to become Associate Director of Research for Oceanology, Code 8000. John Munson had arrived at NRL in 1968 from the Naval Ordnance Laboratory to become Superintendent of NRL's Acoustics Division, Code 8100. Budd Adams had come to NRL in 1968 from Hudson Laboratories to head NRL's Large Aperture Systems Branch, Code 8160. Moseley and Adams quickly established a good rapport and Moseley agreed to join Code 8160 in late 1968. The other researchers in Code 8160 then were Carl Andriani (also from Hudson Labs) and Dave Diehl. Their offices were on the third floor NRL's Building 1, but within a few years they moved to the first floor as Code 8160 grew rapidly in size.

Project Artemis Research

At Hudson Labs in the 1960s Budd Adams had worked on a large Navy program called Project Artemis. This involved the development of a major low frequency active surveillance system that was installed near Bermuda. At NRL, Adams continued research on Project Artemis and Moseley became involved in this project. In the period from about 1969 to about 1971 Project Artemis continued to operate a powerful acoustic source and collect data on oceanic reverberation and other effects. It was the data sets from these experiments that were the subject of detailed analyses by Adams and colleagues in Code 8160. Among the scientific objectives of that project were investigations to determine the feasibility of using very large source and receiver apertures for undersea surveillance. The equipment remained operable until about 1971, but there were frequent problems with both the source and receiver arrays. The source was deployed from the USNS *Mission Capistrano*, a large converted T-2 tanker with a center well designed so that the source aperture could be lowered to operational depths through the well. The receiver consisted of many vertical staves of hydrophones fixed to the sea bottom in deep water that were cabled to a tower known as Argus Island. The main scientific laboratory was on shore in Bermuda at Tudor Hill. Art McClinton of the Acoustics Division's System Engineering Staff provided engineering support each time Budd Adams' group performed an experiment using the Artemis system. In these tests there were collaborations with researchers and engineers from the Naval Underwater Systems Center (NUSC) in New London, Connecticut as well. The panels where the receiver cables came in looked like an old fashioned telephone switchboard. Each plug-in connection corresponded to a particular receiver beam steering direction in the vertical (elevation) and horizontal (azimuth) directions. It was possible to record simultaneously hundreds of receiver beams on analog tape. These receiver beams were formed via a drum delay beamforming system. The receiver was used for both passive and bistatic active operations. It had a complex system of indicator lights that could be viewed from under a cloak that enabled the user to determine in real time the peak direction to within 0.2 degree for received sonar signals within a particular beam direction that may have had a width of order plus/minus 4 degrees of azimuth and 6 to 8 degrees of elevation. It was possible to observe in real time the scintillations due to acoustic multipath arrivals. The planned full size receiver array was never actually built. However, the prototype that was installed had perhaps 20,000 hydrophones that covered an area on Plantagenet Bank of around one nautical mile by one-half nautical mile. Moseley recalled that it was quite an adventure to get to the Argus Island tower. One would approach it in a small boat. Then a large net would be lowered from the tower. The arriving scientist would then place his arms and legs through the net and be hoisted up to the tower platform. By about 1972 or 1973 the Argus Island tower was taken down and it was no longer possible to collect new data with the Artemis system. It may have been another decade before any Navy receiver systems such as towed hydrophone arrays began to approach the large size apertures of the Artemis system.

Moseley's research was concerned with analysis of the signals received by the Artemis receiver. Although the system was designed for the low frequency of about 400 Hz, it was possible to extract useful information at frequencies about ten times higher than that design frequency in order to highly resolve signal components. Analysis of these data sets enabled Moseley and colleagues to learn much about signal coherence effects as related to aperture geometry distortions, but also enabled them to begin measuring physical effects due to oceanic internal waves at long ranges. The scientific results were published in Navy Symposia on Underwater Acoustics (NSUA) proceedings and the *U.S. Navy Journal of Underwater Acoustics* (*JUA-USN*). Some years later, many of the lessons-learned from the 1970s research with large aperture arrays were published in a paper by William M. Carey and William B. Moseley in the *IEEE Journal of Oceanic Engineering*, Vol. 16, No. 3, 3 July 1991, titled "Space-Time Processing, Environmental-Acoustic Effects."

In Project Artemis, Moseley and colleagues found that signal coherence was maintained across the ocean basin. A few years later in the 1970s, Moseley and colleagues performed longer range experiments in the Pacific Ocean between New Zealand and Hawaii with success. Also in the 1970s they did some early experiments on time reversal acoustic effects at long ranges in the deep SOFAR channel.

NRL Branch Head in Applied Ocean Acoustics

In 1980 Moseley left the Large Aperture Systems Branch (then called Code 5160) to head the Applied Ocean Acoustics Branch (Code 5120) that had previously been headed by Ray Ferris. Code 5120 had a variety of types of ocean acoustics research under way when Moseley became Branch Head. One research thrust involved Arctic studies under Charlie Votaw, TC Yang, and others. Another thrust was on studies of shallow water acoustics under Frank Ingenito, Steve Wolf, and colleagues. Other studies in Code 5120 addressed environmental effects including acoustics near the marginal ice zone in the open ocean that used the USNS *Mizar*. Researchers from Code 5120 even managed to get the *Mizar* stuck in the ice for a week or so before it could break out with help from an icebreaker vessel. Extensive use was also made of maritime patrol aircraft including NRL's P-3 aircraft. In the early 1980s the Code 5120 computing capabilities were still somewhat primitive by today's standards. Some other key researchers in Code 5120 in the early 1980s included Ray Fitzgerald, John DeSanto, Mike Buckingham (exchange scientist from the UK). Moseley continued as Code 5120 branch head for three years.

The Move to NORDA and NOARL

In the early 1980s there was an annual meeting of directors of the various Navy laboratories. The meeting for 1982 was to be held at the Naval Ocean Research and Development Activity (NORDA) at Stennis Space Center, Mississippi. Dr Alan Berman asked Moseley to come to that meeting to present a summary on some NRL Acoustics Division research efforts. While Moseley was at that meeting he received a preliminary job offer to become head of the Ocean Acoustics and Technology Directorate at NORDA. Upon his return to NRL, Moseley discussed this offer with Alan Berman, John Munson, and Budd Adams to help him decide whether to accept the job offer of a Senior Executive Service position at NORDA. With some reluctance they advised Moseley that this would be a good career move for him. Ralph Goodman had just departed as NORDA's Technical Director to become Director at the NATO SACLANT Centre in Italy and Jim Andrews replaced Goodman at as Technical Director of NORDA. In 1983 Moseley accepted the position as Directorate Head and he remained in that position for about four years. At that time there were several other directorates at NORDA including one for Oceanography and one for Geosciences (headed by Herb Eppert). In 1987 Moseley became NORDA's Technical Director and he hired Ed Franchi to become the new head of NORDA's Ocean Acoustics and Technology Directorate. Around 1989 there was a further consolidation of several Navy activities and NORDA's name changed to the Naval Ocean and Atmospheric Research Laboratory (NOARL), with Moseley as Technical Director. Among the Navy activities that became part of NOARL at that time was a Navy meteorological facility known as NIPRF that became NOARL's Atmospheric Sciences Directorate (headed by John Hovermall). By 1991 NOARL was providing much environmental support and guidance to the Department of Defense during the first Gulf War.

The Formation of NRL-Stennis

Around 1992 there was another round of Navy consolidation efforts during which Moseley participated in discussions with NRL's Director of Research, Dr. Tim Coffey, and with the Chief of Naval Research about having NOARL become part of NRL. As a result, by 1993 NOARL became part of NRL and was named NRL-Stennis Space Center. Dr. Eric Hartwig came from ONR to head NRL's new Ocean and Atmospheric Science and Technology Directorate, Code 7000, after a search process of 6 to 8 months during which Moseley was Acting Code 7000. The acoustics researchers at NRL-Stennis became a new branch (Code 7180) within the Acoustics Division (Code 7100). New NRL Divisions were formed at NRL-Stennis for Oceanography (Code 7300) and Marine Geosciences (Code 7400); and the Marine Meteorology Division (Code 7500) was established in Monterey, California. Also as part of this consolidation and reorganization two other divisions were established within Code 7000: the Remote

Sensing Division (Code 7200), and the Space Science Division (Code 7600). As a result of this consolidation and downsizing process of 1992–1993, the size of the workforce at NRL-Stennis was reduced from over 500 persons to about half that size.

Oceanography Division Superintendent

Moseley wished to remain in Mississippi and was offered the position as Superintendent of the new Oceanography Division at NRL-Stennis. This was a comfortable transition for Moseley since he had many previous interactions with the Oceanography researchers at Stennis when he was NOARL's Technical Director. It also was a natural transition considering the nature of his doctoral research in atmospheric physics in the late 1960s. Moseley commented that in the period from about 1988 to 1999 the Oceanography researchers at Stennis had frequent collaborations with the staff of NAVOCEANO that was also located on base at Stennis Space Center. In that period NAVOCEANO hosted the Navy's supercomputer that was used to run global ocean and atmospheric models. Moseley noted that during the 1990s productive collaborations were begun between NRL's Oceanography and Acoustics Divisions to explore topics of mutual interest.

Retirement

In 1999 Moseley retired permanently from government service and he has not been employed since then. He continued to live in the area near NRL-Stennis during retirement. On 29 August 2005 Hurricane Katrina passed directly over his house. His home was completely obliterated leaving only a concrete slab. He commented that the Hurricane prediction models used by NOAA are derived from ones previously developed at NOARL. The various models that were run about 48 hours prior to Hurricane Katrina did in fact show that Katrina would pass right over Moseley's home. With advance warning that this was likely, Moseley and his family evacuated about 200 miles inland to Jackson, Mississippi. By the time Hurricane Katrina arrived at Mississippi's capital city, Jackson, it still had hurricane-force winds and it knocked out power there for a week. The citizenry became rather paralyzed because of the loss of electricity and services. Cars ran out of gas because the gas pumps required electricity. The law has since been changed to require a certain number of independent gas stations in a given area to have independent electric generators. Unlike Louisiana, the state of Mississippi invited the Mississippi National Guard to come in immediately after Katrina to patrol the Gulf Coast. The National Guard essentially set up marshal law. They came in and set up tents and provided security, food and other essentials for the public. This was not well publicized but it was really incredible. On the Gulf Coast there were 65,000 buildings destroyed. There were no stores, hospitals, police, fire department or other services available. Initially the roads were impassible. It took about ten days until the public could come back to the area. Checkpoints were set up by the National Guard. Residents had to show their driver's licenses. These were compared to lists of residents and addresses in that local area and if a match was found, the residents could proceed. Moseley and his family were permitted to see their neighborhood and they found that nothing was left standing. They were accompanied into their neighborhood by Special Forces personnel who were extremely helpful. It took about eighteen months to resolve issues with the homeowner's insurance company. Moseley was fortunate to sell his property in Mississippi. Since then he splits his time at two residences, one in Lafayette, Indiana and one in Safety Harbor, Florida.

25. John Munson

Notes Prepared by Fred Erskine on In-Person Recorded Interviews with Dr. John C. Munson held in Adamstown, Maryland on Monday 30 June 2008 and Tuesday 15 July 2008 (5 hours 30 minutes total)
[Dr. Munson's revisions and some additional details added on 17 July 2009]

Monday 30 June 2008 (Morning Discussion)
Early Life, Education and Military Service
John C. Munson was born in 1926 and grew up in Clinton, Iowa on the Mississippi river. He graduated from high school in 1944 while World War II was still raging. He went into the Navy V-12 Program. They sent him to Iowa State College in Ames, Iowa to study. By 1946, with WW II being over, the Navy did not need many new Ensigns — so they sent him to boot camp at Great Lakes Training Center. He was assigned to a destroyer–mine tender that had just returned from the Yellow Sea to San Francisco. Although he was only a Fireman First Class, he became the head electrician on board since nearly all the crew was discharged as soon as the ship reached San Francisco. The ship sailed to Bremerton, Washington, where it was then mothballed. He then got out of the Navy and returned home to Clinton, Iowa. He returned to Iowa State College and finished his undergraduate degree in Electrical Engineering (with communications option – electronics, and a mathematics minor). In fact all three of his degrees have the same mix of engineering major and mathematics minor.

Early Career at the Naval Ordnance Laboratory (NOL)
Munson finished his undergraduate degree in March 1949 and went to work for the Naval Ordnance Laboratory (NOL) in Silver Spring (White Oak), Maryland. He wanted a job that had a research and development component — and ended up in the Acoustics Division at NOL. He worked on a variety of projects there — all in the audio frequency range. He did some work on very low frequency micro-barometric detection of nuclear bomb detonations and seismic detection of atom bombs. The apparent direction of the signal arrival was measured by determining the time differences of arrival at spatially separated sensors through use of correlating signal arrivals. Initially this correlation was done by hand (each of the two signals was sampled at regular intervals — for simplicity, only the polarity was noted and then the number of agreements in polarity was counted — this was repeated for a variety of delays between the two signals; this is known as polarity coincidence, or clipper, correlation). The relative signal delay, then, was that at which the signals were best correlated. This early work fostered new ideas about using correlation between spatially separated sensors to determine directionality information. At that time, however, there was virtually no hardware available to support practical realizations of such ideas.

Dr. Herman Ellingson, who was Munson's supervisor at NOL, developed the idea of measuring at audio frequencies the sound radiated by a submarine to passively obtain its range by measuring the wavefront curvature across the length of an acoustic aperture that extended from the bow to the stern of one of our submarines — one sensor was located near the bow, one amidships and one near the stern. This was called the passive underwater fire control feasibility study (PUFFS). John Munson pursued this idea by designing and building a clipper correlator, and combining this with a tape recorder purchased from Ampex with three moveable heads (to provide variable intersensor delays). They found sufficient coherence to enable useful accuracy of estimation of range. However, since it took several days to process the data to provide a single range estimate, it was of no operational utility. At a meeting in Washington, D.C., Victor Anderson of the Marine Physical Laboratory of Scripps Institution of Oceanography presented a talk on an invention of his called the "DELTIC correlator." It was a polarity coincidence correlator that would enable real-time measurement of a correlation function (it was in effect a special purpose computer operating at a 10 MHz clock rate, which was extremely fast for those days). Munson worked with him to bring the DELTIC from a concept to actual hardware. DELTIC correlators were then used in a system that they took to sea with three hydrophones spread along the centerline of a submarine. They got ranges that were useful for fire control out to 8000 yards in a band around 1–4 kHz, and it was more accurate at closer ranges. This became of great interest to the operational Navy. It became operational on some U.S. submarines as the AN/BQG-4 and follow-on sonars, and was of interest to the intelligence community. The implementation happened around 1960.

Further Education and Continued Research at NOL

Munson continued his advanced degree studies during the NOL period and received a master's degree in 1952. In 1956–57 he got a year's sabbatical at MIT (Navy Scholar). At MIT they were teaching courses in signal processing that were unique in the world, and these were exactly the kind of courses Munson needed to further refine concepts related to Navy acoustic correlator developments. Munson then completed his Ph.D. at the University of Maryland in 1962 (during the evenings while working full time at NOL in the daytime). Interestingly, the University did not have any faculty members with sufficient expertise to evaluate the quality of Munson's Ph.D. dissertation on the performance of memory-less nonlinear circuitry, in terms of how much true signal was still available in a noisy clipped signal. Munson would periodically submit chapters to his Ph.D. advisor for review and at the end of this process his advisor agreed that the thesis was completed and approved. The results of this thesis research appeared subsequently in a series of classified NOL reports, but not in the peer-reviewed literature. NOL was named the Lead Laboratory for Underwater Acoustics Airborne Target Classification in 1963. Munson was appointed director of this effort. This required extensive work with the Naval Air Development Center as well as colleagues at NOL and the Bureau of Aeronautics. Dr. Robert Urick was at NOL then and was writing the first edition of his book *Principles of Underwater Sound*.

Clipper correlation, the DELTIC hardware, and other high performance digital hardware developed by Munson and NOL associates found much use in subsequent years. For example, they performed at-sea measurements with two ships using a long towed receiver array in conjunction with a towed source to estimate how straight such a receiver would remain while it was being towed through the ocean. This was important in order to determine how well it would be possible to form stable beams with the receiver array. This was some of the early research using long towed receiver arrays, with at-sea recordings made using an analog data tape recorder. Also in the late 1950s the *Albacore* (the first high speed submarine) was undergoing trials. Vic Anderson had developed an array to go in the submarine's sonar dome. Munson installed a correlator system on board to measure real-time bearings of targets. Further, in the late 1950s Munson became a member of the Project Artemis Steering Committee. In the early 1960s Vic Anderson and John Munson did measurements using the Texas Tower system of receiver staves installed on a seamount using Munson's correlator system to evaluate the stability of receiver beam bearing estimates.

In 1967 Munson was assigned in Washington, D.C. to be the technical director of the Navy portion of a high priority Viet Nam Tri-Service Project called "Practice Nine." This was a project whose concept involved parachuting, via P2V aircraft, modified sonobuoys into trees in Vietnam to have them listen in the air for events of interest. Multiple Navy organizations participated in this project including NRL, NOL, the Naval Air Development Center (NADC), and sonobuoy manufacturers. The devices were designed to transmit signals via radio frequency links only when sounds of interest were detected. The devices included self-destruct capability. Much of the prototype testing was done at NADC, Warminster, Pennsylvania, though some was done in Panama, since the conditions there approximate those in Viet Nam.

The Career Move to NRL

In March 1968 John Munson was called to NRL to become the Superintendent of the Acoustics Division. Munson knew the NRL Director of Research, Dr. Alan Berman, quite well based on their previous technical interactions within the Artemis Project. Dr. Berman instructed Dr. Munson to make the NRL Acoustics Division an exciting place to work. Times were changing from a funding point of view: The total amount of Research (6.1) funds available for relatively unfettered research was decreasing. Further, the individual program offices in the Office of Naval Research, the Systems Commands and other potential R&D funders (6.2 and above) were demanding much more involvement in shaping program goals and plans, and were requiring full-scale proposals with timelines for deliverables and for funding profiles. This meant that Division- and Branch-level managers spent much time dealing directly with the sponsors, both to secure funding and to ensure continued support of programs. There were quite a few "old timers" then at NRL who were accustomed to receiving research funding via their connections with Navy program offices — and they were averse to performing "marketeering" to seek out new funds. In short order many of these persons were no longer Branch Heads due to personnel shifts by Dr. Munson. In many cases those Branch Heads were very competent "bench scientists" who were not well suited to being managers and administrators, and NRL benefitted by having them return to doing productive research. There also were some voluntary staff departures and retirements at that time as a result of these changes. This was a difficult period.

The Connection with the Hudson Laboratories of Columbia University and Project Artemis

The Navy closed out support of Columbia University's Hudson Laboratories in 1968. They had been the key laboratory involved in the Artemis Project (though the NRL Sound Division, among other labs, had played a major role since the beginning of the project). Many of the responsibilities of, and functions performed by, Hudson Labs were transferred to NRL at that time. John Munson consulted with Dr. Berman on the roster of HL staff and developed a list of "candidates" that NRL should approach regarding possible employment at NRL. As a result of these negotiations, several dozen HL researchers and staff then moved to the NRL Acoustics Division. This included Budd Adams, Hank Fleming, Andy Gonda and other professionals, as well as some oceanographic technicians. Some HL staff remained at the Tudor Hill facility in Bermuda where the cabling for the Artemis receiving array was terminated. The Artemis source array developments were largely the work of NRL researchers and engineers in the early 1960s. The transducer was about 50 feet high and hung down into the ocean via a center well cut in the USNS *Mission Capistrano* (an 8000-ton T-2 tanker). The large planar source operated at a frequency of about 400 Hz at depths down to about 1200 feet. The vessel had a huge audio amplifier to drive the source array as well as a sophisticated station keeping system with side thrusters to keep the ship nearly stationary even in high seas. The NRL Acoustics Division's Transducer Branch developed the high-power deep-submergence "shaker box" source modules (the entire source was comprised of 1440 of these modules). Dr. Sam Hanish did much analytical analysis to determine the cause and means for mitigating inter-transducer mutual interference effects that turned out to problematic. Several decades later Dr. Hanish published a major treatise on transducer design that is now considered a major reference work on the subject. Art McClinton was the lead NRL engineer in the Acoustics Division who was responsible for the engineering design, construction, installation, operation, and maintenance of the acoustic source and its associated electronic and mechanical equipment.

One of the concepts pursued in the Artemis project with NRL's assistance was the possible use of the Artemis source in conjunction with the Navy's SOSUS arrays as a bistatic active surveillance system. Analyses of Artemis data continued in the Large Aperture Systems Branch in the 1970s under Dr. Budd

Adams with the publishing of some key classified papers on the characteristics of long range monostatic and bistatic reverberation at low frequencies.

National and International Connections

Through the 1970s and 1980s the Acoustics Division conducted measurements on long-range propagation and reverberation, coherence and directionality of ambient noise, etc. Many of these experiments were done in collaboration with allied nations including the United Kingdom. In some instances we had bilateral agreements with several nations (e.g., the UK and Norway) under which we could share specific classified information with each nation individually, but that information could not be shared in a forum that included all three of our nations.

As Superintendent, John Munson was encouraged to be "point man" for discussions with managers at other organizations in the U.S. and overseas to negotiate joint experiments and research projects. Further, he was a member of the U.S. Sonar Team that included managers from other U.S. labs, as well as Carey Smith of NAVSEA. This group was charged with monitoring the international Defense Exchange Agreements for underwater acoustics. As part of their tasking, the Sonar Team visited various nations, one year visiting western hemisphere countries (e.g., the UK, The Netherlands, Norway, France, Germany and Italy (the SACLANT Centre there)), and in the next year Far East countries (including Japan, Australia, New Zealand; and later Taiwan and Korea). Dr. Munson also served on a number of "advisory committees," e.g., to advise ONR, NAVSEA, etc. regarding the thrust and levels of funding for research and development in underwater acoustics and anti-submarine warfare; the focus was primarily on deep water open ocean undersea surveillance.

There was within the Acoustics Division a branch devoted to shallow water acoustics research. The expertise developed in this branch became quite important later on (in the 1990s). There was considerable research on Arctic acoustics in the Acoustics Division during Dr. Munson's tenure.

Some General Observations

The Acoustics Division had "5-year plans" — but because sponsor priorities and projected funding levels changed frequently, in reality they were reviewed and changed about twice per year. The NRL Acoustics Division had considerable involvement in the establishment and implementation of the *U.S. Navy Journal of Underwater Acoustics* [JUA(USN)]. Dr. Harold Saxton was a chief editor as was Dr. Munson later on (after his retirement from NRL in January 1985). *JUA* is a classified peer-reviewed publication of high quality and is the chief forum for archival documentation of the Navy's classified undersea warfare research. It is a very specialized publication. A strong motivation is that we realize that corporate memory is not very long and *JUA* greatly helps with avoiding redundancy of research over long periods of time. Dr. Munson was the third superintendent of the Acoustics Division. Each has had a long tenure (three in 63 years). This has both positive and negative potential impacts.

Monday 30 June 2008 (Afternoon Discussion)

Tank and Pool Facilities and Sound Barges

NRL's Acoustics Division had a tank facility in Building A-59 that was managed by the Transducer Branch (cylindrical in shape-approximately 30 feet in diameter and about 20 feet deep). When Munson first came to NRL in the late 1960s we had two Acoustics Division sound barges at the NRL waterfront on the Potomac River, but they were in the process of being decommissioned. At that time the pollution in the Potomac River was so severe that scientists working on the sound barges had to have inoculations just as if they were traveling to southeast Asia. The sound barges were no longer needed because other types of improved transducer calibration and testing facilities became available elsewhere. By the 1970s we had an acoustic pool facility in Building 71 that had been converted for our use from its previous role as NRL's nuclear pool reactor in the 1950s. It was primarily used for scale model target echo characteristics measurements. The newer large acoustic pool facility in Building 5 had not yet been envisioned during Munson's tenure at NRL.

Some Acoustics Division Research Thrusts in the 1970s and Early 1980s

In the late 1970s and early 1980s we did much research on ambient noise investigations with individual hydrophones as well as with long towed arrays and also using the Navy's SOSUS array network. When the USS *Scorpion* sank, NRL became heavily involved in locating it using data from SOSUS recordings. One could hear the collapse of the various compartments in the acoustic recordings. Dr. Berman was the overall Navy leader in the acoustics efforts related to locating the *Scorpion*. We note that NRL's efforts to locate the USS *Scorpion* and the earlier effort to locate the USS *Thresher* are documented in the memoir by Chester Buchanan (from his perspective).

The 1970s and early 1980s were a period of intense research on acoustics in the Arctic. There was concern that the Soviets would develop a capability for their submarines to navigate under the Arctic ice. The Arctic research was done primarily in Burt Hurdle's branch. Hurdle later compiled a massive report on Arctic acoustics that developed into his book on the Nordic Seas (with both unclassified and classified versions). One effort that disappeared from the Acoustics Division early in Dr. Munson's tenure was the Acoustic Warfare Branch headed by Bob Mathes; they conducted research involving the development of countermeasures for acoustic torpedoes, etc.

Another important effort in the Acoustics Division was research to investigate the phenomenon of shadowing of acoustic energy by seamounts. When a number of widely spaced undersea arrays were passively listening to the passage of a distant submarine, the variation in sound level was in part determined by its passage behind seamounts. Using detailed knowledge of the bathymetry it was possible to use the shadowing effects as clues to assist in determining the distant submarine's location. The interest in using sonar methods to survey the ocean bottom topography led to the development of additional methods for characterizing the bottom including magnetic survey measurements (using magnetometers) as well as gravity survey measurements. The branch headed by Hank Fleming specialized in developing these survey methodologies using both surface ships and aircraft. Hank's group performed many such surveys in the Atlantic Ocean and as a result they became very interested in the geologic phenomena associated with seafloor spreading including the area around the mid-Atlantic Ridge. From these investigations new scientific discoveries were made that were published in the peer-reviewed literature.

In the mid-1970s the branch headed by Elizabeth (Betts) Wald became part of the Acoustics Division. This branch developed sophisticated software and hardware for Navy acoustic signal processing systems. They were very instrumental in developing Navy standard software (ADA) for a Navy standard signal processor (EMSP). Another thrust was under Al Gerlach. His group developed software for passive acoustic narrow band line identification for target classification. It was known as HARMCORR. This was a highly classified project at the time. There was a significant research effort on shallow water acoustics headed by Ray Ferris (and earlier by Burt Hurdle) that included investigations to characterize spatial acoustic modes via modeling and at-sea measurements.

Many of the ocean experiments that were performed by researchers in the Acoustics Division were sufficiently complex that it was really necessary to develop collaborations with other U.S. laboratories as well as allied nations. It is worth noting that when the U.S. Sonar Team of high-level Navy persons made visits to allied nations, NRL was the only U.S. lab that could immediately commit assets and equipment to future joint sea trials. Other U.S. labs had more complex lines of authority to gain approval to involve sea test assets.

One of the key branches was the Large Aperture Systems Branch, headed by Budd Adams. The research conducted in this branch via at-sea measurements as well as computer modeling contributed greatly to the Navy's understanding of the performance limits of long towed arrays of hydrophones in the deep ocean for undersea surveillance applications.

New directions of effort for NRL's Code 8130, the Physical Acoustics Branch, were well established by the early 1970s. An important effort within the Physical Acoustic Branch was the research via scale model and full size acoustic measurements and modeling to characterize submarine target strength. This work was pioneered by Werner Neubauer, Mickey Davis, Lou Dragonette, and Joe Bucaro. In some of the early work this group developed schlieren acoustic visualization techniques that enabled researchers to "see" the flexural acoustic waves progressing around a structure. This research resulted in methods for predicting echo strength and reducing target strength. Dr. Neubauer became the lead researcher for the Navy's entire effort on target echo characterization.

Another key advance was the research within the Physical Acoustics Branch on the development of fiber-optic hydrophones. They were able to sufficiently demonstrate the feasibility of fiber-optic hydrophones for use in long towed arrays that the Navy was able to develop operational SURTASS arrays for using this new technology. A special group was formed, headed by Jack Donovan, that was affiliated with both the Acoustics and Optical Science Divisions at NRL known as the Fiber Optic Sensor System (FOSS) office in order to foster these developments.

Some Comments on the NRL Acoustics Division Organization Circa 1970

Pete Titcomb was John Munson's key assistant for many years. Later, Burt Hurdle became Assistant Superintendent. Burt had a very extensive set of connections with underwater acoustics researchers, managers, and funding agencies all over the world. To some extent, for purposes of day-to-day business of the Division, John Munson would handle internal Division matters, while Burt Hurdle would handle some matters external to the Division, including interactions with various U.S. Navy offices and overseas laboratories.

Some Code designations circa 1968: Code 8106: Transducer calibration facility at NRL-DC; Code 8108: System Engineering Staff, headed by Art McClinton (e.g., Artemis source developments, etc.); Code 8110: Acoustic Warfare Branch, headed by Bob Mathes; Code 8120: Shallow Water Surveillance, headed by Ray Ferris; Bill Kuperman was a researcher in this group then, as was Ray Rollins (later Rollins and J.C. Knight became the core of the Systems Analysis group in the Division); Code 8130: Physical Acoustics: This group was headed by Raymond Steinberger in the 1960s; a key researcher was Vince DelGrosso who measured the speed of sound in water with great precision; Werner Neubauer, Lou Dragonette, and Charlie Votaw were members of this group; Votaw performed research on turbulence using Prince Albert tobacco smoke; Work began on the fiber-optic hydrophones in this branch under the leadership of Mickey Davis, who headed the branch at that time and who later departed for industry; Joe Bucaro succeeded him; Code 8140: Signal Processing Branch, headed by Bill Finney; This branch performed sonar operator performance studies; Matt Shaw was a member of that branch; Code 8150: Transducer Branch; was headed by Sam Hanish (who was a very strong theoretician) and earlier by Jim Trott (who was a very imaginative inventor of hydrophone concepts); Code 8160: Large Aperture Systems Branch; headed by Budd Adams; Bill Moseley was a member of this group; Code 8170: Propagation Branch;

headed by Burt Hurdle (the largest branch in the Division at that time); studying long range low frequency propagation effects; they were involved in the Navy's LRAPP project; Charlie Votaw was a member of this branch, but later headed the Arctic research efforts.

<u>Tuesday 15 July 2008 Tuesday (Morning Discussions)</u>
<u>Review of Some Archived NRL Career Records</u>
John Munson reviewed a box of old records. He found his second Christmas Message of December 1969 from the Acoustics Division Superintendent to the Division employees. It contains some news about the status of the Division: The Division assumed responsibility for the Project Artemis Argus Island Texas Tower acoustic receiving array, the Hudson Laboratories (HL) portion of the Tudor Hill Laboratory, and the USNS *Mission Capistrano*. Beginning in 1969 the NRL Acoustics Division also acquired a significant number of HL staff. Construction of the T-AGOR 16 (USNS *Hayes*) was proceeding on schedule. The Seneca Lake calibration facility was transferred to the Navy Underwater Sound Laboratory (NUSL) in New London, Connecticut in August 1969. NRL worked very hard to establish this facility; however, NRL researchers will continue to have access to it. NRL conducted Operation NEAT, a joint US-UK propagation and noise experiment. Ralph Goodman was Chief Scientist for NEAT (while he was Associate Director for Oceanology). Through this sea trial NRL proved its ability to manage complex multinational field operations, with simultaneous scientific participation.

Munson also has his last Christmas Message of December 1984 (at the end of his 17th year as Superintendent). He noted that NRL is the oldest U.S. Navy Laboratory by far (with most others coming into existence during the WW II era). This Christmas letter reviews some of the major NRL Acoustics Division achievements over the years. Munson reiterated the importance of the numerous outside collaborations with other U.S. laboratories and international partners. Munson has several letters he received upon his retirement (in early 1985) from cooperating organizations (e.g., New Zealand, noted the scientist exchange, Mike Guthrie to NRL; DREA, Dartmouth, Nova Scotia, Canada, mentioned TTCP collaborations as well as NSUA symposia). The December 1984 message included a single page listing of the External Committee Assignments of John Munson and Burt Hurdle (e.g., Technical Assessment Panel, Mobile Sonar Technology (MOST) Committee, U.S. Sonar Team, etc.).

Munson located the Acoustics Division Long Term Plan of 1985. He also located some photos: USNS *Gibbs* (named after Josiah Willard Gibbs; pictures are both at NRL and at the Navy Yard), USNS *Mission Capistrano*, and the USNS *Mizar*. Munson has a good picture of the USNS *Gibbs* on the wall in his study. He also has material related to his Senior Executive Service Objectives (circa 1979–1983).

<u>Tuesday 15 July 2008 Tuesday (Afternoon Discussions)</u>
<u>Some Comments on the Plans for the NRL Acoustics Division History Project</u>
John Munson provided some comments on Fred Erskine's write-up circa May 2008 on the proposed scope and structure of the NRL Acoustics Division's history. A chronological approach is good; a logical starting point — cover a bit of the work done by Harvey Hayes et al. circa WW I as the base with which they began the research efforts in the Sound Division at NRL in 1923. We may need to cover a little about the establishment of NRL (so that this history can be fairly "stand-alone") — a few paragraphs perhaps — but we need not duplicate the extensive NRL historical documentation about the early days of NRL. Munson likes the idea of producing the history as a DVD (this will help to keep the cost down as well). Munson also likes the idea that the history write-up be "an easy read." He suggests that we consult an archivist on what medium is most appropriate for long term storage. [note — NRL's Archivist Dean Bundy said microfilm is the most permanent medium.] Munson recommends an archivist that he knows. Munson agrees that the amount of material to be "mined" covering the approximately 80-year

time frame (circa 1923 up to the 2000s) is quite vast. There are important side stories to mention such as the transition of expertise from Hudson Labs to NRL and the merger of the Stennis Space Center, Mississippi group into the Acoustics Division; and the integration and separation of the USRD Orlando calibration facility into the Division — but we should not get into these topics in too great an amount of detail. Some of these topics do not lend themselves to a decade-by-decade breakdown. It may be useful to include some tables and/or charts (e.g., number of full-time employees vs. time; number of contractors doing research jobs in certain periods) — but it may be difficult to obtain this kind of information (can the NRL HRO office help with this? — possibly not). The telephone directories will be helpful to identify who was in the Acoustics Division at any given era. Note — if we did this history decade-by-decade it would be 1920-1929, 1930-1939, etc. What about listing the ARPAD "Best Papers"? — this may be too restrictive because there is much other work that is also significant — including much first-class classified research material. If we decide to publish an Acoustics Division bibliography in an electronic format, as opposed to a hardcopy format, it could be quite extensive.

Note — the recollections via oral interviews of former employees might be used in this project as background material rather than including transcripts of them as whole cloth. Munson suggests that we save the recordings and put them on DVD. They will, however, likely have to be somewhat edited. Note — there are some prior oral interviews that were conducted by the previous NRL Historian, Dr. David Van Keuren, that exist on 8-mm audio tapes and we will obtain many of these for use in this project. Munson asked if NRL has electronic archives of historically relevant documents. There is a current project to scan and digitize much of this type of material, as well as photographs, over the next 5 to 10 years. Note — for the present and future research produced by NRL, most NRL reports will exist in electronic form, but not necessarily so for journal papers.

Note — we will tap into the NRL Technical Information Service Branch's vast photo archive of 300,000 photos to select appropriate photo documentation for this project. Selected awards and patents will also be useful to review for this project.

Note — we can look at all the publications and reports, but the personal recollections will help us assess the "work environment and quality of staff interactions" in the Acoustics Division in various eras. This will be much harder to assess for the very early period (e.g., 1920s through 1940s); there are lots of examples of good leadership in the Acoustics Division at NRL over the years even amongst persons who were not managers, but who may have been very competent bench scientists.

Note — for the early period, we can probably rely heavily on some existing partial histories (e.g., those by Harvey Hayes (regarding his era), and the one about the Harold Saxton era). Munson suggests that we consult Burt Hurdle to seek his assistance in reviewing some of this early-era material (although Burt is now 90 years of age).

Note — for the NRL 75th Anniversary (1998), prior to the book by Ivan Amato (*Pushing the Horizon*), the Acoustics Division (led by Burt Hurdle) prepared some write-ups on Division accomplishments over the 75 years, and these may be helpful if we can collect these.

Note — There are a few very "old-timers" still around, but we should seek out several of these persons (e.g., Ted Reuwer, Chester Buchanan, etc.). Bob Chrisp started at NRL around 1955 as a COOP student and he recalls Art McClinton quite well; Munson noted that this kind of a history should be updated in each generation, but the Acoustics Division history has not been kept up in that fashion — so we have a real challenge in the preparation of this document.

Note — A question to ask ourselves is "What does all this mean for the Navy?" We note that for some developments like surface ship sonar — NRL was the "only game in town" for several decades. This story does not lend itself to a simple decade-by-decade breakdown in this project. We may want to take some major topics like "active sonar" — this leads into surface ship sonar developments, the Artemis long-range low frequency active undersea surveillance system developments, etc. The gestation periods for some of these important developments are quite long — multiple decades. This includes the 6.1-level basic research which is the underpinning for many basic theoretical and experimental research developments at NRL. If we decide to approach this history write-up via some of the major "topic areas" — we may only include a very selected set of relevant references pertaining to such a general topic area.

Note — we have recently uncovered the Large Aperture Systems Branch 30-year complete bibliography (1970s through 1990s) — that was started under Budd Adams. We may not have such bibliographies for other branches. We have a challenge to keep things in balance across the many projects of importance to the Navy.

Munson commented about Fred Erskine's preliminary list of Acoustics Division organizational structure in various eras — these will require further scrutiny and editing — if we decide to use such material. We need to think about whether we want to list personnel down to say the Branch Head level. Some of this may be useful to help us determine when there were major organizational changes in the Division, since this may tell us something about the evolution of major research thrusts with time across different eras. Note — Ray Rollins may be available to consult; Pete Titcomb started in the Division in the late 1960s but was at NRL much before that; perhaps we may only want to list the last 20 years of detailed organizational structure.

Munson commented briefly on the preliminary list of technical achievements. For the early period (1920s-1930s, etc.) we must rely heavily on some of the early write-ups by Harvey Hayes et al. In the 1930s they discovered and quantified the reason that the maximum detection for an active sonar was sometimes much shorter in the afternoon than during the rest of the day (a phenomenon dubbed the "afternoon effect") with the high frequency sonars then in use. Munson was told that Raymond Steinberger figured out that the surface water was heating up in the afternoons and it caused downward refraction and put the target in the shadow zone. This was a nice accomplishment and it was useful to the Navy. A lot of research was started at NRL but then taken over by other labs (e.g., the "singing propeller" research evolved into the program for control of radiated noise that became one of the prime streams of research at the David Taylor Model Basin). NRL did important research in determining absolute calibrated acoustic levels. Munson is not sure if NRL actually established the first acoustic calibration test range (probably so). Note — the Electronic Warfare Branch was in the process of being disestablished when John Munson came to NRL circa 1968 — but they may have done some interesting research (Bob Mathes headed that effort and he may still be around to consult). The Sector Scan Indicator (SSI) with CRT Display of Harold Saxton may have been modeled after some earlier radar developments. Project NEAT did important research on long-range propagation. The Arctic research started in the 1970s — Charlie Votaw was a central figure in that research.

Note — the exchange of scientists between NRL and other nations is important to mention — it was always a modest effort — but quite worthwhile.

26. Werner Neubauer

Notes Prepared by Fred Erskine on a Recorded Telephone Interview with Dr. Werner Neubauer held on Friday 29 May 2009 2 PM EDT (50 minutes)

Early Life and Education

Dr. Werner Neubauer was born and raised in White Plains, New York. He graduated in 1952 from Roanoke College in Virginia with a B.S. degree in physics. He received a scholarship to pursue graduate studies in physics at Johns Hopkins University in Baltimore, Maryland but he became ill and was only able to attend for a year. He had developed kidney stones in his freshman year at Roanoke College and has had over 300 incidences since then.

Early NRL Career

Around February 1953 he started work in the Sound Division at the Naval Research Laboratory in Washington, DC as a research physicist and he continued working there for nearly thirty years until his retirement from government service. His initial supervisor was Bill Finney who wanted Neubauer to specialize in electronic engineering applications, but Werner had little interest in this topic. Neubauer consulted with the Sound Division's Associate Superintendent Dr. Raymond Steinberger who was establishing an acoustics research group. Neubauer was invited to join this group which was better suited to his interests and permitted him to conduct basic research. Neubauer was interested in doing experimental research on acoustic scattering from objects. A small wooden tank was built on the ground floor of NRL's Building 1 for this purpose. It had rough dimensions of about 5 ft x 10 ft with a depth of about 6 ft. It was filled with distilled water and served the purpose well for these initial measurements. Neubauer started by studying reflection from simple shapes such as cubes. This research progressed to scattering from spheroids and eventually to objects that were shaped more submarine-like. These fundamental studies are fully described in a 1986 NRL book by Neubauer titled *Acoustic Reflection from Surfaces and Shapes*. Eventually Neubauer received a security clearance that was higher level than that held by the Associate Director of Research, Mr. Rojas.

Mid-NRL Career

Neubauer continued to receive strong encouragement in his research from Dr. Steinberger, who was a Harvard graduate and had received his Ph.D. under a Nobel Laureate. When Dr. Steinberger retired around 1969 (at an age when most researchers would already have retired), Neubauer became interim head of the Propagation Branch for about three years. However, Neubauer did not like being in a management position and was ready to return to full time research. Around 1970 the NRL nuclear "swimming pool" reactor was closed down and this facility in Building 71 was made available as an acoustic measurement tank. This facility had an excellent water filtration and purification system that made it quite good for acoustic scattering research. Also around this time Neubauer joined the newly established Physical Acoustics Branch with Mickey Davis as Branch Head. Earlier, in the 1960s, while performing acoustic scattering measurements using the wooden tank in Building 1, Neubauer and colleagues seemed to be getting an incorrect answer for the speed of sound in water (in the 4^{th} or 5^{th} decimal place). They kept re-checking their results and still got the same answer. Eventually it was established that Neubauer's measurements were correct and the previously accepted values for sound speed in water by Del Grosso were then superseded. In this mid-career period Neubauer engaged in graduate studies at Catholic University in Washington, DC under Professor Uberall and he received a Ph.D. in physics based on research he had conducted at NRL.

During this period in the 1960s Neubauer shared an office with Robert Urick (who later published a well known book, *Principles of Underwater Sound*). Neubauer characterized Urick as a rather gruff but gracious and kind person. Also during this period Dr. Harold Saxton was Superintendent of NRL's Sound Division. Neubauer characterized him as a rather reserved gentleman-scientist. Neubauer commented briefly on several other Sound Division colleagues with whom he interacted over the years. As it turns out, Neubauer and Burt Hurdle are fraternity brothers and both attended Roanoke College (over a decade apart). When Neubauer was an undergraduate physics major, Burt Hurdle visited campus on a recruiting trip for NRL and he came by the fraternity house to introduce himself to Neubauer and tell him a bit about NRL's Sound Division. Later, during Neubauer's career at NRL, Hurdle was always a confidante to whom Werner could turn for career advice. Another NRL colleague who encouraged Neubauer's career was the Superintendent of the Optical Sciences Division (Dr. John Sanderson). He encouraged Neubauer to publish his early scattering results in the *Journal of the Acoustical Society of America* (JASA), at a time when Sound Division researchers were publishing less frequently in peer-reviewed journals than in later years. One of Neubauer's closest and most helpful colleagues in the Sound Division was Lou Dragonette. In the 1970s it was Mickey Davis who monitored the progress on Dragonette's Ph.D. rather than Neubauer, because Neubauer was considered to be too close a colleague of Dragonette's. Another close and helpful colleague of Neubauer's was Larry Flax, a theoretician. Flax was very proficient at developing computer programming code for acoustic applications. He had a cutting-edge ability to work out difficult Bessel function and other approximations that had not previously been done, but Flax found it difficult to write papers on his results so he was able to collaborate with Neubauer and others on publications.

Late NRL Career and Retirement

Around 1980 Neubauer moved from the Physical Acoustics Branch to work under the Superintendent, Dr. John Munson, as Special Assistant for Target Characteristics (Code 5108). In that capacity he was assigned to review all draft publications by Division researchers prior to submission for publication. Also in the early 1980s Neubauer was a consultant to the Office of Naval Research to review research proposals that were submitted by various organizations including universities. Neubauer was critical of many of the proposals based on technical merit. As a result, ONR looked unfavorably on further funding of some NRL Sound Division projects. Also in this period Neubauer began work on his book. He retired from NRL in 1983. At that time he became a private industry consultant five days per week in Providence, Rhode Island, while maintaining his residence in the Washington, DC area. Also, after retiring he was Associate Editor of *JASA* for Physical Acoustics for about a decade. After retirement he continued to regularly attend semi-annual meetings of the Acoustical Society of America. Robert Beyer of the Acoustical Society was particularly helpful to Neubauer during this period as Associate Editor. Around 1997 Neubauer fully retired and moved to the Memphis, Tennessee (Germantown) area to be nearer to his daughter. In retrospect, Neubauer stated that it was a very rewarding experience to have worked in NRL's Sound (Acoustics) Division for about three decades.

27. Clyde Nishimura

AN INTERVIEW WITH DR. CLYDE NISHIMURA

by Dr. David K. van Keuren
History Office
Naval Research Laboratory

Today is June 25, 1993. This is David Van Keuren of the Naval Research Laboratory. I'm speaking with Dr. Clyde Nishimura of the Naval Research Laboratory about the research project WHALES '93.

Van Keuren: Dr. Nishimura can you tell me something about the background to the project?

Dr. Nishimura: Background to the project? In terms of the WHALES '93, there was a meeting in Seattle at the end of July 1992 in which the meeting was for IUSS alternative use. That's what it was called at that point. Now it's called dual use. In which [meeting] it was proposed that we begin monitoring whales and seismic activity in the Atlantic Ocean. Commodore John Parrish, who is stepping down as commodore next week, retiring from the navy, basically told the scientific community to come on in and use their system. The program officially began in the first week of November, and it's continued to run to this date. There is talk about WHALES 94, etc., but at this point it's just an ongoing program. The two chief scientists were selected. Myself, in terms of looking at earthquakes, and Chris Clark of Cornell University for looking at whales.

Van Keuren: This all dates back to that Seattle conference of 1992?

Dr. Nishimura: Yes.

Van Keuren: Obviously, this conference didn't develop out of a void. What's the background to the conference itself?

Dr. Nishimura: At least two years ago Commodore Parrish realized with the change in the political climate the surveillance system [SOSUS] wasn't being used to its fullest capabilities. He noticed that his operators weren't as busy as before and was very astute to realize that something had to be done to keep up the training and also to find alternative uses for this system, partly to justify the use of this system. He then began a series of initiatives at the various naval facilities. Marine mammals .... Actually, I better not say what the other ones are. I don't know if they're classified or not.

They started a series of initiatives at each site. For instance, one was to look at surface traffic in anticipation that you might be able be able to track illegal fishing. I guess to track merchant shipping. One site was tasked at looking at marine acoustic signals primarily from whales. All those initiatives turned out to be very successful, and at that point, last year, he decided to pursue it in a more formal scientific program with the help of Space and Naval Warfare Systems Command (SPAWAR). I guess PD-80 and PMW-183.

Van Keuren: How did Commodore Parrish know which alternative objects to focus upon?

Dr. Nishimura: I guess intuition more than anything else. I never asked him about what made him decide it. Some of them were pretty logical. Merchant shipping is something that the navy used to look into and hasn't for the last decade or so. The system is capable of picking up merchant traffic. It's just one of those things they've decided not to look at. There's a lot of merchant traffic.

Van Keuren: Two aspects that came out of the Seattle conference were whales and seismic activity. Two scientists were appointed at the Seattle conference?

Dr. Nishimura: No. The whale component was the elite component, and that was the principal objective of the WHALES '93 program; hence the name. Our Naval Research Lab works closely with SPAWAR on many different other projects. We have a good working relationship, and we do produce products for them. After the meeting, my boss, Hank Fleming, our branch head of Code 7420, was asked if he wanted to be so-called "test director" of this program, to oversee some of the program. Make sure the program was running smoothly. We'd been pursuing this point for over a year, and so we said, ``Yes. We would like to do it.'' Something we'd be willing to do. Because of my involvement I suggested that they can also look at seismic activity also, while also monitoring the whales. The navy agreed it would be worthwhile to do. It was not sent out for proposals or anything like that because of the haphazard nature of the way the program was set up. There was no funding really intact for this. It was sort of, "Take it out of your core money or find alternative funds for it, but are you interested in doing this." We said yes.

Van Keuren: Commodore Parrish offered the information and assistance if you could find the funding to use it?

Dr. Nishimura: Commodore Parrish provided the most critical aspect: Access to his arrays and the help of the active navy to support, in terms of personnel, time, and money, also. He wasn't funded to do this, either. He paid for this out of his own pocket.

Van Keuren: Had the IUSS program collected data in the past which was clearly from non-human sources? They must have realized that they were getting information on non-submarine sources, non-human sources. Did they keep any of this information?

Dr. Nishimura: Yes and no. When the systems were being developed back in the `50s, let's say, they were recording many strange sounds, some from subs, some from ships, and some from unknown biologics. Over the years they realized that some of the unknown biologics were from whales. They didn't know which type of whales, but they suspected they were from whales.

Van Keuren: Why?

Dr. Nishimura: Well, it's a slow, evolving process in terms of they looked at a signal, and by other knowledge they knew that it was a whale migration. It was a slow process, basically, of trying to identify some of the signals in terms of marine biologics. So, they had a basic understanding that it was whales. Then the next step was what species was it, and that took a longer time. So, since that wasn't part of their objectives, the navy objectives, they gave it some rather creative names. For instance, the Blue Whale signature that the operator sees was called a comma.

Van Keuren: A what?

Dr. Nishimura: A comma. The punctuation mark, the comma. That's what it looked like on their records. They basically said it was the sound from a snapping shrimp which is an animal that's very, very small. Fortunately, in hindsight, it was one of the more comical identifications, but it didn't matter what they called it because they weren't interested in it. Signals for minkes were known as the A Train. Signals from the finback were called seismic profiling because they thought it was a seismic exploration boat doing its survey. Those are the major ones, the snapping shrimp being the most humorous.

Van Keuren: Did they save any of this data?

Dr. Nishimura: No.

Van Keuren: But they knew the data was there and was collectable.

Dr. Nishimura: Yes.

Van Keuren: How was the Seattle conference organized, and who was invited?

Dr. Nishimura: I'm not particularly sure how it was organized to tell you the truth. The attendees basically were a mixture of active navy personnel, some from the science community, academic community, from federal labs, primarily navy, and also NOAA, and the rest from industry -- the standard suppliers of products that were used by IUSS. There was quite a mixture of people, but I'm not particularly sure how the meeting was all set up.

Van Keuren: Did you attend that meeting?

Dr. Nishimura: No. I was out at sea at the time.

Van Keuren: Hank Fleming was there from NRL?

Dr. Nishimura: And Dave Bradley also. Dave Bradley being the supervisor of the Acoustics Division.

Van Keuren: What is the first professional contact you ever had with the SOSUS system?

Dr. Nishimura: It was back in 1989 in which there was a major seismic swarm on the Reykjanes Ridge which is just south of Iceland. We convinced the navy, I guess paid the navy, the actual fleet navy, to send a P3 aircraft out and drop sonobuoys, underwater hydrophone receivers, on that site and they recorded a large number of earthquakes. At the same time, we managed to get a hold of some lofargrams, low-frequency recordings from unnamed SOSUS array sites in the Atlantic. At that time I could not identify the signals on the lofargrams. I wasn't told which arrays they were from, but it was pretty intriguing to look at these paper records wondering what was I looking at.

Van Keuren: Where were you at the time?

Dr. Nishimura: I was a postdoc here at the Naval Research Lab in the same branch.

Van Keuren: Did you know where the material was coming from?

Dr. Nishimura: No. They wouldn't tell me. Despite the fact that I was holding these lofargrams in my hand. They were classified secret. Despite the fact that I was holding these secret grams in my hand they said that I did not have the need to know where the arrays were.

Van Keuren: Just that it was a navy array?

Dr. Nishimura: I knew that they were SOSUS arrays, but they wouldn't tell me where they were located.

Van Keuren: You didn't know where the seismic recording was coming from.

Dr. Nishimura: It was sort of a moot point because I couldn't interpret the records at that point, anyway. Even if I knew where the arrays were, it wouldn't have been of any use to me at the time. We have subsequently gone back and looked at the LOFAR grams that we still have and observed a very, very high level of seismic activity on those grams.

Van Keuren: Was this the first time that data had been released from the SOSUS system for non-military use?

Dr. Nishimura: No. I suspect that other data has been released in the past, but I can't say for certain. Other investigators might have gone into the sites and gotten hold of some data. Around that same time, NOAA, this being the Pacific Marine Environmental Lab out of Hatsfield [Hatfield], Oregon, was trying ...

Van Keuren: Hatchfield, Oregon?

Dr. Nishimura: Hatsfield [Hatfield]. After Senator Hatsfield [Hatfield] from Oregon. Hatsfield [Hatfield] Marine Center or something like that. But NOAA on the west coast was attempting to tap into the arrays or collect data from the arrays at Whidbey Island in

Washington State for looking at seismic activity along the Juan de Fuca Ridge, which is off the coast of Oregon and Washington.

Van Keuren: The date for this was?

Dr. Nishimura: I'm not particularly sure. I think it was also at that time because we heard rumors at that time that they were exploring that possibility.

Van Keuren: So this should be `89?

Dr. Nishimura: '89. I believe they began collecting data in 1990. This is part of their VENTS program.

Van Keuren: Does it stand for anything?

Dr. Nishimura: I don't know.

Van Keuren: So back in `89 there were at least two cases in which data collected by SOSUS was being released. One to NOAA and one sent to you, for different events.

Dr. Nishimura: I think NOAA was still exploring that possibility.

Van Keuren: Of getting the data. After the conference in Seattle, Hank Fleming came back to Washington and asked you to become involved or did you ask to become involved? How did you become involved in this project?

Dr. Nishimura: I've been pursuing this point, like I said, since my return to NRL. I was a postdoc at NRL, left for a year, and returned, now as an employee. I kept telling Hank we should start collecting. If NOAA is collecting data from SOSUS, we should be collecting data from SOSUS. Eventually, Hank agreed and thought it was a good idea. So, we had already ordered equipment to install at one of these sites. We didn't know which site. We were then going to pursue the possibility of installation. So, we were sort of gambling at that point. This was back in April of `92 that we started purchasing. So when this program began we already had equipment here, ready for installation. NOAA helped us quite a bit on this. It's a basic clone of the system they had installed at Whidbey. So we were in an opportunistic position to immediately participate in data collection. I would have attended the meeting if I was not out at sea. Hank represented my position which was that NRL was definitely interested. The role NRL played was that being a DoD lab, we are a naval research lab, we formed an ideal .... We had a foot basically in the academic world and also in the navy world, so we were in ideal position.

Van Keuren: To act as an intermediary?

Dr. Nishimura: Intermediary. You've got to remember for the navy, active navy at least, this is a brave new world, of doing something like this. I think they felt very comfortable with a DoD lab participating. We did not have expertise in large marine mammals. In fact there were very few places with expertise in the acoustics of large marine mammals, so we had to go outside of the lab. In this case, Chris Clark, who already had clearance and had been working on some of the things, was selected.

Van Keuren: How did you select him?

Dr. Nishimura: I'm not particularly sure. Partly his personality, his expertise, and the fact that he had been doing work for the navy contributed.

Van Keuren: What sort of work had he been doing for the navy?

Dr. Nishimura: I think looking at the effect of low frequency acoustics on whales. This being out in the Pacific, I believe. It also helped that he had clearance. Very few marine biologists have security clearances. Plus he's a specialist in bio-acoustics, as opposed to many people who study whales, who are a specialist in more pure biology. At this stage of the program it was an acoustics problem.

Van Keuren: So the meeting was held in Seattle. NRL became involved at that time. Set up a program in which there were two components: One for seismic monitoring and one for whale monitoring. You were selected as chief scientist for seismic monitoring. Chris Clark was brought in as chief scientist for whale monitoring.

Dr. Nishimura: The program was set up by SPAWAR. Dr. Dennis Conlon was selected as the program manager. [Dennis Conlon is the staff oceanographer at PMW-183]

Van Keuren: He's at SPAWAR?

Dr. Nishimura: Yes, PMW-183. He was from the beginning the overseer of this program.

Van Keuren: This was immediately after the July conference in Seattle?

Dr. Nishimura: Actually, his position at SPAWAR was such that he was involved with IUSS. Any kind of program in IUSS dual use would probably be administered by SPAWAR, and Dennis Conlon was the logical person.

Van Keuren: The NRL program was set up when? August of `92, September of `92?

Dr. Nishimura: Actually, we were pursuing it in May and June.

Van Keuren: Before the conference?

Dr. Nishimura: Yes, before the conference. In fact we had proposals in to SPAWAR and planning letters in to SPAWAR to do something. In fact, our first planning letter went in to SPAWAR in January of `92.

Van Keuren: Were you at all influential in setting up the Seattle conference?

Dr. Nishimura: Not me personally.

Van Keuren: Were people from NRL?

Dr. Nishimura: No. I don't think so.

Van Keuren: Do you think that the laboratory, the NRL, interest in using this data was influential in getting Commodore Parrish to open up the program?

Dr. Nishimura: Hard to say but I don't think so. Commodore Parrish was wise and perceptive enough to realize that this had to be done.

Van Keuren: And the Laboratory had good contacts?

Dr. Nishimura: We had good contacts.

Van Keuren: The Laboratory knew that Commodore Parrish was interested in doing this, and so they sent their proposal in early.

Dr. Nishimura: We already had a proposal in before we knew that Commodore Parrish wanted to do this, so we were pursuing these things on parallel lines, unaware of what the other side was doing.

Van Keuren: When did you hear that Commodore Parrish was interested in doing this, approximately?

Dr. Nishimura: When I first heard about there was going to be this Seattle meeting.

Van Keuren: That was early `92?

Dr. Nishimura: That was in June.

Van Keuren: June of `92.

Dr. Nishimura: Now that I remember, the first time I heard about this was from Chris Fox who works out at NOAA, out in Oregon. He's a good friend, and he was here for another meeting. He mentioned that they were going to have this meeting in Seattle and that I should attend. Within two days we got called by SPAWAR saying that there was this meeting in Seattle that we should attend.

Van Keuren: You already had a proposal sitting in SPAWAR since January?

Dr. Nishimura: We had a planning letter.

Van Keuren: Planning letter?

Dr. Nishimura: Basically indicating our interest in doing this.

Van Keuren: Even before you knew Commodore Parrish was interested in the dual use of the technology. That's interesting. Let me get some background on your own research. You're a geophysicist. Right?

Dr. Nishimura: That’s correct.

Van Keuren: You did your Ph.D. at Cornell University?

Dr. Nishimura: No, Brown University.

Van Keuren: At Brown, that's right, I'm sorry. What was your thesis on?

Dr. Nishimura: Looking at the upper mantle velocity structure in the Pacific.

Van Keuren: The Mantle Velocity Structure.

Dr. Nishimura: The velocity structure in the upper mantle in the Pacific constrained by surface wave velocities, Rayleigh Waves and Love waves. Surface waves.

Van Keuren: This is acoustic propagation?

Dr. Nishimura: We call it seismic propagation.

Van Keuren: OK.

Dr. Nishimura: At that time I decided I didn't want to look at surface waves. It's a field called solid earth seismology. We look deep into the earth. I never really liked that. After a while I sort of soured on that type of research, and I wanted to do something shallower, in which you can actually have better confirmation whether or not you're right or wrong. So, I started doing sea floor mapping.

Van Keuren: When was this approximately?

Dr. Nishimura: I started looking at sea floor mapping in 1986. Immediately after I finished my Ph.D work.

Van Keuren: Where were you then?

Dr. Nishimura: I was doing a postdoc at Brown. I stayed at Brown.

Van Keuren: When did you become involved with the navy and the Naval Research Laboratory?

Dr. Nishimura: In 1988 I came to the Naval Research Lab as a NRC postdoc. It was because of my work in sea floor mapping, not because I did surface waves. But it turned out we were in the Acoustics Division at the time, and my seismology background was good for looking at acoustics also. So I also became very, very interested in acoustics.

Van Keuren: Your sabbatical was 1990-1991?

Dr. Nishimura: In which I took a position at the University of Hawaii. I didn't like that position, so I asked Hank Fleming if I could return to NRL. Apparently Hank was waiting for me to ask, and I got hired.

Van Keuren: You were hired to do sea floor mapping?

Dr. Nishimura: Still at that time, sea floor mapping. There were other components too. The sea floor mapping was the principal component but, like I said, when I got back I said we should start doing this SOSUS monitoring also, and Hank thought it was a good idea.

Van Keuren: When did you first hear about SOSUS?

Dr. Nishimura: Tom Clancy's book Hunt for Red October. I guess I heard about it before, but I can't place the time. I guess my main .... [When] it became really clear was Hunt for Red October, but I knew about SOSUS before then. I don't know why.

Van Keuren: You came back, and you talked to Hank Fleming, and you said there's a SOSUS system, and we ought to be using it.

Dr. Nishimura: Right. Like NOAA was doing this, and we can do it in the Atlantic.

Van Keuren: You knew NOAA was doing this?

Dr. Nishimura: Yes, because I know the people involved in this program at NOAA.

Van Keuren: Once again the date for this was `89?

Dr. Nishimura: I returned here in 1990. No, 1991.

Van Keuren: That's when you made your suggestion to Hank Fleming?

Dr. Nishimura: Yes.

Van Keuren: Who else at the Laboratory in Acoustics has been involved in this project, WHALES '93, and acoustic monitoring?

Dr. Nishimura: Not much. We started to expand, talking to a lot of acousticians, getting them interested.

Van Keuren: Who?

Dr. Nishimura: Various acousticians here in this building.

Van Keuren: Acoustic statisticians?

Dr. Nishimura: Acousticians. That's what they call themselves.

Like I'm a geophysicist, they're an acoustician.

Van Keuren: Acoustician. That's a new term for me.

Dr. Nishimura: For instance, we've gotten a lot of support from Dave Bradley on this. He thinks it's a good idea. Dave Bradley being the division superintendent. Ironically, we are no longer in the Acoustics Division. With the reorganization of NRL my branch is in the Marine Geosciences Division.

Van Keuren: All the people involved in this project at NRL were originally in Acoustics and are not in Marine Geosciences. It includes yourself. Who else?

Dr. Nishimura: Hank Fleming; Mary Kappus worked on this; and we have a new postdoc, Carol Bryan, who will be working on this. Then we have Chris Jones providing technical assistance. Bob Gordon.

Van Keuren: Technical assistance includes what?

Dr. Nishimura: Engineering, setting up facilities. Bob Gordon and Scott Loflin, but it's been a limited number of people even for the whales. This program has always had a limited number of people participating in it, which is not surprising for a program that's not really funded.

Van Keuren: Where's the funding been coming from so far?

Dr. Nishimura: SPAWAR. And something for equipment, and we've taken it out of our 6.1 core money.

Van Keuren: Can you give me a short history of the project at NRL since it's been setup?

Dr. Nishimura: I returned from sea in August 1992 and immediately started working on this. We started having planning meetings with the various participants. We put together a test plan with the major help of Marine Acoustics, Incorporated (MAI), over in Crystal City and began making what seems to be a weekly visit to Dam Neck, Virginia or to Norfolk, Virginia. We installed the clone of the NOAA data acquisition system in the middle of October.

Van Keuren: Excuse me, what is this?

Dr. Nishimura: It's a 16 channel data acquisition system.

Side 2

We installed the data acquisition system back in October 1992. The official start of the program was in the first week of November.

Van Keuren: `92

Dr. Nishimura: `92. All the participants look back upon that fateful week with a big smile on our faces because the orders went out from the command, CUSL.

Van Keuren: Which stands for?

Dr. Nishimura: Commander Undersea Surveillance Atlantic. The orders went out to the various naval facilities in the Atlantic to start monitoring the whales and seismic activity. Basically throwing them into the fire immediately. Near chaos reigned for the first couple of months. The first week was the absolute worst. The first two weeks. Needless to say actually things got better as the program progressed. Chris Clark and myself made visits to all the naval facilities in the Atlantic to brief the sailors, petty officers, and officers on this program. We have made numerous trips to Dam Neck to work closely with the Navy personnel. We've given numerous briefings at NOPF for what we call the VIP tours.

Van Keuren: NOPF?

Dr. Nishimura: NOPF: Naval Ocean Processing Facility, Dam Neck, Virginia. We've given numerous briefings at Dam Neck to VIPs. That's what we call them at least. People from NOAA, congressional staffers, people from the Marine Mammals Commission. Although, by now actually the Navy is quite capable of giving the briefs themselves. They have picked up on this almost immediately. Right now the people at Dam Neck are leading the scientific charge, I guess you could say. I have to drop this name. The person who is really responsible for the success of the scientific components is Lt. Chuck Gagnon, who is basically the scientist in charge at Dam Neck.

Van Keuren: Tell me about some of the people you're working with at SPAWAR and CUSL. What are they like - the people in charge, the people collecting the information. What do they think about the project?

Dr. Nishimura: Well, everyone who has participated in this project is enthusiastic about it. It's sort of a mission now. It has taken on its own personality. The program has worked so well because we're all totally committed to this program. It's no longer just science or just another program. It's something more personal, I believe. The reason for that is because of the Commodore. He impressed upon us why the program was important, and it really starts from the top down. Commander Lysa Olsen. She is the current Operations Officer. Also known as the OPSO at CUSL. Dr. Dennis Conlon at SPAWAR. Commander Dale Liechty. He works for Dennis. He's been helping coordinate a major portion of this program. Of course, Hank Fleming, myself, Chris Clark, Chuck Gagnon at NOPF.

Van Keuren: What about the ordinary sailor who's sitting behind the machine collecting the data? What do they think about it.

Dr. Nishimura: At first they were very skeptical, very skeptical. This was something that they looked at us and said, ``Why are we doing this?'' When this program began Chris Clark and myself gave a series of talks at Dam Neck to basically explain what the science behind all this was. In some essence it was to basically convince a very skeptical community that this was worthwhile doing. As it turns out, I think we were very successful because suddenly, no, not suddenly, but the people started realizing this was not `busy' work. That there was a huge gap in our knowledge about what occurs in the deep water, and they were going to make significant contributions to science. As soon as they realized that, the majority of people pulled behind the project. It was quite amazing.

The thing to remember is that the so-called OTs, Ocean Technicians, the young sailors that do the analysis, when they enlisted that signed up to be oceanographers. The surveillance system is classified so they were not told what they were going to be doing, which was finding submarines. So they had a natural inclination towards oceanography. Not everybody, of course; I'll say the vast majority. Chuck Gagnon, who's head of readiness and training at Dam Neck, selected a handful of people, about a half a dozen, to do the bulk of the work. He picked them very carefully. They have been very, very enthusiastic. Although at times during this program I think they were ready to kill the scientists because things were out of control, at times. But as soon as they caught on and they understood on their own what was being done and what had to be done they did an excellent job. They were driving science forward like I said. Really, the big push at Dam Neck has been Chuck Gagnon. This has been like a personal crusade to him.

Van Keuren: Tell me how SOSUS works in an unclassified fashion.

Dr. Nishimura: The acoustic signals get recorded on a series of underwater hydrophones. The signal is transmitted back, by some means, to a shore based facility where it gets processed and gets displayed as a lofargram.

Van Keuren: Displayed on what?

Dr. Nishimura: They're displayed on what's known as dirty paper. It is basically a hard, not electrostatic ... I don't know how to describe that.

Dr. Hurdle: Electrochemical.

Dr. Nishimura: Electrochemical. It is basically a piece of paper etched. The gram is etched on it. At Dam Neck they have a more modern system, computerized system, with CRT screens to display the same information and from that the analyst has been trained to identify signals.

Van Keuren: The signal will appear on the CRT?

Dr. Nishimura: You'll see various signals, lines, other things.

Van Keuren: The data output is continuous?

Dr. Nishimura: Yes. Continuous with time. The analyst has been trained to identify signals on it. It takes many, many years of experience to become a good analyst. It takes a lot of experience.

Van Keuren: Is a hard copy made of the signal?

Dr. Nishimura: At various sites there's a hard copy. At Dam Neck it's more computerized.

Van Keuren: But it can be reproduced again and put into storage. How long is the data kept for?

Dr. Nishimura: I don't know if that's classified or not.

Van Keuren: But you have accesss to the data, I assume. Or, do you have access to the analysis of the data?

Dr. Nishimura: Yes. We do have access to it, but at the various sites, the naval personnel are looking at it real time and are monitoring the whales and earthquake activity.

Van Keuren: Is it ever transmitted into the form of a live acoustic signal?

Dr. Nishimura: No. That's what we're recording on the NOAA data acquisition system.

Van Keuren: Real live acoustics?

Dr. Nishimura: That's right. That we now process here at NRL.

Van Keuren: How do you process it?

Dr. Nishimura: Standard signal processing techniques to try to extract out the signal that we're interested in.

Van Keuren: NOAA has its own collecting system, right?

Dr. Nishimura: Right.

Van Keuren: How does it differ from the SOSUS system?

Dr. Nishimura: In this case we're collecting the real time series and saving it all. On the SOSUS system if time series data is collected and saved it's on a limited basis. The volume of data that could be collected, if you wanted to collect everything is too large.

Van Keuren: Does NOAA actually have a collection system, an underwater collection system?

Dr. Nishimura: No, what they do is when the signals are coming into the site they're tapping off of the lines.

Van Keuren: Into the SOSUS system? They're tapping off and collecting the live signal.

Dr. Nishimura: Yeah, and thats what we're doing too.

Van Keuren: So you're no longer relying upon the data coming from SOSUS. You're collecting it at the same time that SOSUS gets it.

Dr. Nishimura: It turns out that what's being recorded by the actual navy system and processed by the navy system and displayed is of adequate scientific utility. It could be better, of course. The system is not designed for this. It was designed for looking at submarines. It's rather surprising, actually, why the system should work so well.

Van Keuren: Do you both, you and the navy, analyze the data? Do you have your own access to the data so you can do your own analysis?

Dr. Nishimura: Yes.

Van Keuren: Can you store your information?

Dr. Nishimura: Yes.

Van Keuren: So, if you get an interesting analysis from navy data you can go back to it on your own collection and do a re-analysis.

Dr. Nishimura: Since we're not at the site, it depends on whether we're recording this data or not. What we told the navy, and they've been doing a nice job, is that when they see something interesting to change the system. Basically, not switch wires but to change what's being recorded to record interesting things. Basically we said that we totally trust them to be able to identify what's interesting and what's not.

Van Keuren: You're mainly relying upon their collection and analysis.

Dr. Nishimura: Yes. Most of the hard science that's been generated has been done by the navy, not by the scientists themselves. What we're primarily providing is guidance more than anything else.

Van Keuren: What do you do when you get the data, when it comes to you?

Dr. Nishimura: We analyze it in more detail than what the navy usually does, and we provide feedback to them to identify what they're seeing at a higher resolution.

Van Keuren: Tentatively, what sorts of research results have you acquired this early?

Dr. Nishimura: We know there's a lot of earthquakes being recorded. At least a hundred times more than the land based arrays. Tens of thousands of whale detections. Not necessarily different animals. Sometimes multiple recordings of the same animal, but lots of recording off of whales. The blue whale, fin-back, minke, and the humpback primarily.

Van Keuren: Can you identify individual whales or species?

Dr. Nishimura: We can identify different species. Identifying individual whales we can do under certain circumstances. We're still learning how to do all these things. It's very difficult.

Dr. Hurdle: He has to look at the time series, the spectrum, and the whole bag here and see if he receives this whale on this sensor and on another sensor, and can I correlate those two?

Dr. Nishimura: No, but just to identify the individual signals off an array is difficult enough.

Van Keuren: Have you been able to take this whale data and come up with any significant behavior or information?

Dr. Nishimura: Yes. For one thing, keep in mind that most observations of whales are done in coastal areas, done by small boats that can't operate in the deep water. So, our knowledge of whale migration paths, etc., are biased by the shallow water coastal perspective. This system, the SOSUS system, is designed to look into deep water. As it turns out, the whales migrate and live also in deep water. So, for the first time, we're getting a very, very good glimpse, at this point, of observations of where the whales are in deep water. We're finding out they're all over the deep water regimes of the North Atlantic.

Van Keuren: Are you acquiring information on migratory patterns and information on total numbers of whales?

Dr. Nishimura: Part of the objectives were to obtain the complete migration pattern and make an estimate of the populations. There's some difficulties in doing this, and it's part of the scientific plan. We were very naive. When the program began we hoped to track individual whales coming down. As it turns out, there are a lot of whales out there, and the system was overloaded. We couldn't track individual whales many times. We just saw this mass of whales coming down. Now when I say mass of whales just think, let's say, of a hundred whales up in the North Atlantic making noise. That's a large number of whales.

Dr. Hurdle: To keep track of.

Dr. Nishimura: If there's a thousand whales, let's forget it. But a thousand whales, let's say, if that's the the total number of whales, that's not a lot of whales, from a population perspective.

Dr. Hurdle: When you spread them out.

Dr. Nishimura: We saw whales swimming by the arrays. We got some tracks on them. Because this was pretty much of a learning experience. We started right in the midst of the migration season, we didn't do a great job when the program started. They're just trying to re-analyze some of the data now, and they can see a lot better. They're getting better fixes and better identifications. Next year, well, we'll do a better job.

Van Keuren: What are your long range objectives?

Dr. Nishimura: Long range objectives are still the same. Understand where the whales are at what time of year. What general migration path they're taking. The population estimate will require some assumptions because not all the whales are making noises. We need more visual confirmations of the whales. There's a lot of scientific components. Right now we just know that we've recorded a large number of whales spread all over the North Atlantic. Now let's take a better look at it and get a more detailed picture.

Van Keuren: Do you hope you'll eventually be able to sort all the signals from the different types of whales?

Dr. Nishimura: We can identify the different species. The signals are distinct enough.

Van Keuren: What about, for example, the sperm whale?

Dr. Nishimura: We're not picking up the sperm whale at this point. The whales we haven't picked up [are] the sperm whale. We hope to pick up the right whale, but we have not done so.

Van Keuren: The white or the right?

Dr. Nishimura: It was the right whale, and it was big and fat and slow.

Van Keuren: What about the acoustic data? What are you learning from your seismic monitoring? What do you hope to learn?

Dr. Nishimura: From the seismic we knew we were going to pick up a large number of earthquakes, and we have. We've picked up more earthquakes than we've expected. At least a hundred times more. What we're going to obtain is a more detailed picture of low level, low magnitude earthquakes, in the Atlantic. Currently, we can't locate events smaller than magnitude 4.5 in the middle of the Atlantic because the seismic stations are on land. They're away from the ocean basin. SOSUS is capable of recording signals from these smaller events, so we can get a better idea of what the low level seismic pattern is. We have. Right now, basically, we're looking for patterns. That's also true for the whales too, at least this past year.

Van Keuren: Back to the collecting. Has any sort of whale culture developed amongst the people working at the facility.

Dr. Nishimura: Oh, yes.

Van Keuren: Do you want to describe that?

Dr. Nishimura: Every site will have at least one whale poster up on the wall. Some more than one whale poster. There's whale paraphenalia lying all over the sites. At briefings, and at other times, enlisted, and at times captains, are known to imitate, or try to imitate, whale sounds. It is quite amusing to hear a captain with his four stripes and nice uniform try to imitate a whale. Rather pathetically at times, but at least trying. Everybody who has been involved in this program has basically fallen in love with whales.

Van Keuren: There is wide enthusiasm.

Dr. Nishimura: Yeah. When this program initially started a bunch of the enlisted decided to go on a whale watching tour. Of course, they didn't see any whales, but they decided to try it anyway. And we're reading more and more about whales, and find it fascinating.

Dr. Hurdle: I guess this shows you how military culture can change.

Dr. Nishimura: Military culture can change, but, like I said, these people had a natural inclination toward oceanography. But not everybody. Some people could care less about the whales.

Dr. Hurdle: When are you going to think about tracking these Arctic hurricanes.

Dr. Nishimura: First things first.

Dr. Hurdle: Ok. However, that one, I think, would make a significant contribution to the weather planning situation.

Dr. Nishimura: Tracking Arctic hurricanes could, and, of course, if we're going to do something like that we have to wait for the season to begin. It would also help if we had recording equipment at these sites, which we don't have at this point. We're gonna have it, and when we do we're going to start recording that.

Dr. Hurdle: I think we need, overall, much better ambient noise recordings from a lot of places, as a function of time.

Dr. Nishimura: There are various components to this program, and one of them is ambient noise and tracking of storms. The priority item still is whales, at this point.

Van Keuren: And then seismic activity?

Dr. Nishimura: No. I guess in terms of national priorities the emphasis is on whales and tracking illegal fishing.

Van Keuren: You can track those using your system?

Dr. Nishimura: You talk to the ocean technicians and they'll say they sure can.

Van Keuren: Any general concluding points or anything you want to add that I should ask and I haven't?

Dr. Nishimura: You've been quite thorough. To summarize, this program has been quite interesting. It's been very rewarding, I think, for both the navy personnel and for the scientists. It's been quite an eye opener to actually work with active navy personnel. In this case, these people are highly intelligent, incredibly intelligent people. They basically work with their heads. The nicest thing about it is they've really been incredibly supportive to these so-called civilians coming into their system. That's been the biggest thing. There's a lot of enthusiasm right now, and we hope that this program will continue in the Atlantic and extend itself to the Pacific.

Van Keuren: Right now it's only in the Atlantic?

Dr. Nishimura: Right now it's primarily in the Atlantic. There's some things being done in the Pacific, but it's not quite the same coherent program that it is in the Atlantic. Don't ask me why. Once again, they're undergoing a new change of command in the Atlantic. Unfortunately, Commodore John Parrish is retiring from the Navy, and the various people that participated at Dam Neck are disbursing to other sites. But, that's good, in some sense, that their expertise is spreading out.

Van Keuren: And they'll be teaching their knowledge to others.

Dr. Nishimura: Like I said, to become a good technician, analyst you need senior people explaining and educating. It's real hands-on. A mentor program. It's basically an apprenticeship, and it takes many, many years to build up this knowledge and skills. What's happening now is this new set of knowledge is now going to extend throughout the IUSS community. That's really your key.

Van Keuren: OK. Thank you very much.

Dr. Nishimura: Ok.

28. Dan Ramsdale

Interview with Dr. Dan Ramsdale
Acoustics Division
Naval Research Laboratory
Stennis Space Center, Mississippi

9 September 1993

Interviewer: Dr. David K. van Keuren
NRL History Office

Starting two weeks from now, we will be occupying the Ocean Acoustics Simulation Laboratory that will have the capability, with large state of the art computers, to generate ocean acoustic model predictions linked with ocean models to give predictions for the fleet. The group that I have does the measurement end of that, to provide inputs to these models, and model validation and verification in different environments.

Q. This will be on line in another two to three months?

A. People will move into the building this month. A lot of the software and computers have been developing over the last year or so. This is a new initiative that started a year ago in the tactical oceanography program.

Q. What sorts of products will come out of this?

A. One of the areas that we are trying to look at is the increasing importance of ASW in shallow water areas. So a lot of the new shallow water data bases will be included in this capability. So we will be able to predict how well we will be able to conduct ASW in these shallow water areas, like the Korean Straits or the Persian Gulf.

Q. This is a dramatic increase in your capability for modeling acoustic and other phenomena?

A. Yes. Modeling, simulation, and being able to rapidly visualize the results. There are a lot of issues of scientific visualization here that can be used. If you go look at the building, there is a large war room area that will have large display screens and where we will be able to experiment with some of these scientific visualization techniques.

Q. Besides this, what do you think are your other major capabilities at the present and in the near future?

A. One of the areas that we have been strong on in recent years, and is of increasing importance, is the high frequency acoustic area as it is applied to mine countermeasures. As you may recall, one ship, the *Princeton* that was struck by a mine in the Persian Gulf. That served as a wake-up call to the Navy that we needed more capability if we are to continue to be involved in littoral warfare. So, one of the areas we have been working on for several years has been high frequency acoustics, as it is applied to mine countermeasures. I think that area will become more important in the next few years.

Q. Are there any other capabilities that you think are particularly striking, either now or coming on line?

A. The other area that I think is important is part of this whole acoustic simulation program that is coming about. It is the area of predicting ambient noise in shallow water areas. That is a very difficult and much more complex problem than it is in the open ocean, for a number of reasons. One, there are a lot more sources, fishing boats, etc. The coastal areas are a lot more heavily populated with traffic than the open ocean. The sources are a lot more complicated, and the environment that the energy propagates in is a lot more complicated. We have a program now to develop a shallow ambient noise model that will be part of this overall simulation effort.

Q. These are all new functions and capabilities of the Center for Environmental Acoustics?

A. Right. Most of those are part of this tactical oceanography thrust.

Q. Are you involved in any special projects or research that you see as having potential carry-over to the private sector?

A. Probably not right now. We had some preliminary discussions with NASA, with the NASA technology transfer office, to explore some of these. But I don't think I could identify one right now.

Q. Getting back to the more basic research of the Center, what research projects are you working on that you think are particularly exciting intellectually?

A. I guess I am familiar with the acoustics work. There are two branches of the Center for Environmental Acoustics, mine and Jim Matthews'. The basic research projects involve, in my case, the HF acoustics area in which we are trying to look at the basic issues involved with the interaction of acoustic energy with the bottom. The real application there is to try to better understand this process in order to detect totally buried mines or partially buried mines. We are really interested in understanding how the sediments affect the scattering, how different surface characterizations affect the scattering. We are looking a lot into what are called the Biot properties, which are typical coastal porous bottoms which have gas trapped under the sediments.

The other area that we have been involved in for a number of years is an area called matched field processing. It is a way of taking advantage of the maximum amount that we know about the ocean environment in processing data to try and localize targets, such as mines, or ASW (which it has been to date). One of the things we've done here is to look at robust schemes that are less sensitive to exact knowledge of the environment. We know, realistically, that we will never have perfect knowledge of the environment. We want to utilize the technique but not be so sensitive to miss matches in the true environment and what our model thinks it is. So that is another basic area here that we have looked at -- some very innovative processing techniques to try and reduce the importance of the knowledge of the environment.

In Jim Matthews' group, he has an outstanding researcher, Mike Werby, who has authored more than 150 journal articles. His real forte is scattering theory. Mike has some real innovative work. He has looked at prolate spheroids, which when you look at them look a lot like a submarine. Again, one of ultimate applications is to help us understand better how to conduct ASW.

The other area that Jim has people working in is basic propagation theory for looking at new techniques of computing the acoustic field. Not so much deterministically but stochastically. The idea is to take our deterministic knowledge and be able to have stochastic models that will give us some probabilistic feeling for the acoustic field will be. This has a lot of application in shallow water.

Q. You depend a lot upon various technologies for collecting your data. Where does this technology come from?

A. In the past, and this is still often the case, we have gotten engineering support for hardware and sensor development internal to the lab, from the Engineering Technology Group. Some of the hydrophone development came from companies located here on the Gulf Coast. A lot of companies have sprung up or relocated here to provide contract or technical support to both the Naval Oceanographic Office and NRL.

Q. How are your models, your research results, transitioned to the fleet?

A. There are two answers to that. There are some areas where we have direct contact with the fleet -- personal often. The strict formal approach is that we would take things we developed to NAVOCEANO, and that's their job. There are examples of both cases working well.

Q. Considering that I am going to try and present a short overview of the 7000 area for Sea Technology, what sorts of capabilities, what aspects of the work you do, would you like to see emphasized?

A. What I guess I would like to see highlighted would be the mine warfare, mine countermeasures efforts that we're doing. If you look back in history for the last ten years, HF acoustics had a secondary role to ASW because the real emphasis was on tracking Soviet submarines. We have had a modest HF effort for a number of years. When the National Academy of sciences did their recent littoral warfare review, the only research program in HF that they could identify was that here at Stennis. Because of that long history, we have the people, the equipment, and the expertise to really make an impact, I think, on how the Navy is going to conduct MCM in the future. HF is important for MCM (to detect, classify, or detect the mines) because the wavelengths are small compared to the object you are looking for and also because of lack of need for large propagation ranges. About 1550 yards in front of a ship is sufficient; you don't need to see hundreds of kilometers.

When you were asking about basic research areas, there is one area we do in my group that is part of a larger ONR effort. It is called the Special Research program for Bomb Scattering. It is more of a LF acoustic issue. I have one entire group working on this issue. We do a lot of cooperative work with the ONR-sponsored university community on this.

29. Richard Rojas

Notes Prepared by Fred Erskine on a Recorded Telephone Interview with Mr. Richard R. Rojas held on Wednesday 22 April 2009 at 10 AM EDT (40 minutes)

Early Life, Education, and Employment

Richard R. Rojas was born in 1931 in Manhattan (New York, New York). He grew up in Manhattan and attended Stuyvesant High School. Upon graduation from high school he attended the College of the City of New York (CCNY). He received a B.S. degree in electrical engineering (BSEE) from CCNY in 1952. After college he got a job at Philco Corporation in Philadelphia, Pennsylvania. He was involved in classified work on missile systems. After about a decade he went to work for a small company named General Atronics where he started to become involved in work on underwater acoustics. He became involved in contract work with the Naval Underwater Systems Center, New London (NUSC), but especially with Columbia University's Hudson Laboratories in Dobbs Ferry, New York.

Affiliation with Hudson Laboratories and Project Artemis

In collaboration with Hudson Labs, Rojas began to be involved with research for Project Artemis. Artemis was a large Navy project to develop a long range low frequency active undersea surveillance prototype system for research purposes. It involved the deployment a low frequency acoustic source array from a converted T-2 tanker known as the USNS *Mission Capistrano* as well as an extensive bottomed receiver array system that was installed in deep water on Plantagenet Bank near Bermuda. In the 1960s the Sound Division at NRL was quite involved in the system engineering and the source developments for Project Artemis. Art McClinton from NRL's Sound Division was in charge of many of those engineering developments. In the early to mid-1960s, Dr. Alan Berman was the Director of Hudson Labs; and he led the Hudson Labs Artemis research efforts and was also the Navy's Chief Scientist for Project Artemis. In 1967 Dr. Berman left Hudson Labs to become NRL's Director of Research. About a year later, Hudson Labs was disestablished and many of the Hudson Labs researchers and oceanographic support staff moved to the Acoustics Division at NRL, including Dr. Budd Adams, Hank Fleming and others.

During the 1960s Rojas taught a course on signal processing techniques at Hudson Labs. Also during the 1960s, while he was working at General Atronics, Rojas pursued graduate studies at Drexel University and received an M.S. degree in electrical engineering. Also during this period Rojas taught graduate courses in mathematics at Penn State University (Extension Branch in Philadelphia). As a result, Penn State University offered Rojas a full time teaching position at their main campus, but he declined this offer. After receiving his master's degree, Rojas enrolled in a doctoral program in electrical engineering at the University of Pennsylvania. He got quite far along in his Ph.D. studies and passed the comprehensive oral examination, but did not finish the degree work.

The Move to NRL's Acoustics Division

In 1969 Rojas applied for a position in the Acoustics Division at NRL under Dr. John Munson (Code 8100). By 1970 Rojas was at NRL and was in charge of the Advanced Undersea Surveillance Program (Code 8101). He had a number of branches and groups under him including the System Engineering Staff (Code 8108, headed by Art McClinton); the Systems Analysis Group (Code 8109, headed by Pete Titcomb, and J.C. Knight); the Propagation Branch (Code 8170, headed by Homer Bucker), among others. Rojas remained in the Acoustics Division for about seven years.

Associate Director of Research at NRL

In the late 1960s and early to mid- 1970s Dr. Ralph Goodman was NRL's Associate Director of Research for Oceanology (Code 8000). In 1976 Dr. Goodman left NRL to become the first Technical Director at the Naval Ocean Research and Development Activity (NORDA) in Mississippi. By 1977, Rojas was promoted to replace Dr. Goodman as NRL's Oceanology Directorate head. In 1977 there were four divisions in the Oceanology Directorate. These included the Acoustics Division (Code 8100, headed by Dr. John Munson); the Underwater Sound Reference Division (Code 8200, headed by Robert Bobber and located at Orlando, Florida); the Ocean Sciences Division (Code 8300, headed by Dr. Victor Linnenbom); and the Ocean Technology Division (headed by Dr. J. Paul Walsh). By 1981 there were additional organizational changes under NRL's new Director of Research, Dr. Timothy Coffey. At that time, Rojas became Associate Director of Research for Systems Research and Technology, Code 5000. The major organizational units under Rojas in 1981 were: the Acoustics Division (Code 5100, headed by Dr. John Munson); the Radar Division (Code 5300, headed by Dr. Merrill Skolnik); the Tactical Electronic Warfare Division (Code 5700, headed by Lynwood Cosby); the Marine Technology Division (Code 5800, headed by Dr. Richard Swim); and the Underwater Sound Reference Detachment (headed by Dr. Joseph Blue and located in Orlando, Florida). By 1993 there were additional major organizational changes at NRL. At that time Rojas became Associate Director of Research for the Warfare Systems and Sensors Directorate, Code 5000. The major organizational units under Rojas by 1993 were: the Technical Information Division (Code 5200); the Radar Division (Code 5300); the Information Technology Division (Code 5500); the Optical Sciences Division (Code 5600); the Tactical Electronic Warfare Division (Code 5700); the Research Computation Division (Code 5800); and the Underwater Sound Reference Detachment (Code 5900). By 1993 the Acoustics Division (Code 7100, headed by Dr. David Bradley) came under the new Associate Director of Research for Ocean and Atmospheric Science and Technology, Dr. Eric Hartwig (Code 7000).

Throughout the period when Rojas was Associate Director of Research at NRL he had strong interactions with NRL's transducer calibration and testing facility, the Underwater Sound Reference Division in Orlando, Florida. In the late 1990s the management of this facility was transferred from NRL to the Naval Undersea Warfare Center, Division Newport.

Further Recollections

Rojas recalled that during his tenure at NRL the Acoustics Division participated in many sea tests. NRL managed a number of research vessels including the USNS *Harvey C. Hayes*, the R/V *Gibbs*, and the USNS *Mizar*. Due to budgetary constraints, eventually all these vessels were released to other organizations. Rojas recalled frequent collaborations between Acoustics Division researchers and international colleagues from a variety of nations that included the UK, Canada, Australia, New Zealand, Norway, Brazil, and also collaborations with the NATO SACLANT Centre. Rojas recalled the strong interactions between Acoustics Division researchers and ONR management. There were particularly good interactions with Dr. Fred Saalfeld, the Technical Director at ONR, as well as with the Chief of Naval Research. The CNR generally hosted an annual 2 to 3 day offsite program review with NRL management. These were quite productive for both NRL and ONR. Rojas recalled the "Breakfast with Berman" meetings. It was Dr. Alan Berman's practice to meet several times per year with each of NRL's branch heads and to tour the branches. These meetings provided good opportunities for Dr. Berman to assess the technical progress in the branches and for the branch heads to enlighten Dr. Berman on any problem areas.

Retirement

In 1995 Rojas retired from government service. He currently resides in suburban Maryland.

30. Ray Rollins

Notes Prepared by Fred Erskine on a Recorded Telephone Interview with Mr. Ray Rollins of Solomons, Maryland held on Wednesday 22 October 2008 at 3:25 PM EDT (45 minutes)

Early Life, Education, and Initial Career

C.R. (Ray) Rollins was born in 1924 in Buffalo, New York. He was in the Army Signal Corps in World War II and graduated from Rensselaer Polytechnic Institute (RPI) with a bachelor's degree in electrical engineering (BSEE) in 1950. He then pursued theological studies at Knox College, the University of Toronto and upon completion of those studies was pastor of a Presbyterian Church in Nova Scotia, Canada for three years. He then became an instructor and pursued further technical studies at the University of Buffalo, attaining a master's degree in electrical engineering in 1960. His master's research topic was related to the detection of single turn faults in power transformers.

The Career Move to NRL

While at the University of Buffalo, Rollins developed an interest in acoustics (via analogies in electrical circuits and also in sound and noise control). Also during that period, an NRL recruiter visited the campus and Ray learned about a job opportunity in acoustics at NRL. He accepted an offer of a position at NRL in the Sound Division and moved to the Washington, DC area in July 1964. His supervisor at NRL was Ray Ferris. Dr. Harold Saxton was Superintendent of the Sound Division at that time. A.T. McClinton was a Branch Head then. The large Project Artemis source array had just been completed. It was located on the USNS *Mission Capistrano*. Rollins participated with Ray Ferris and others during testing in the Bahamas. The Artemis source array was deployed through a large center well in the USNS *Mission Capistrano*. Ferris had designed a long boom that was used to deploy hydrophones away from the ship in order to make source level measurements at various azimuths and depths. This was Ray's first at-sea measurement experience with NRL.

Further Involvement in At-Sea Experimentation

In 1966 Ray participated in some two ship experiments to measure propagation loss in the Atlantic Ocean and up into the Norwegian Sea. In 1968, Rollins participated with Ray Ferris on an operation known as "Stage One." It was a three-week operation from an oil-platform type structure in the Gulf of Mexico. Rollins was in charge of the technical team and he kept a detailed log of events. He considers this to have been his most exciting sea trial while at NRL. The challenges included storms and equipment failures. The USNS *Lynch* (an AGOR vessel) also participated. Lines of hydrophones were deployed radially outward from the Stage One platform and an acoustic source was placed in the water in order to perform shallow water propagation loss measurements.

Research in the Acoustics Division's Systems Analysis Group

In 1968 Dr. John Munson arrived as Division Superintendent and shortly thereafter he instituted an Acoustics Division reorganization. Ray requested to join the Systems Analysis Group, initially under Pete Titcomb as interim head, then later under J.C. (Ian) Knight when he arrived in the Division. The thrust of this new group was to interpret the results of the Acoustics Division's basic research efforts in terms of sonar systems applications for the Navy (especially as the results pertained to long range low frequency passive undersea surveillance). Others in this group included Maury Potosky, Bill Hahn, and Bill Dixon. They also did a lot of studies on long-range low frequency active acoustic surveillance. There were significant collaborations with other Navy research groups on this, including the Naval Ocean Surveillance Center (NOSC), San Diego, California, the Naval Underwater Systems Center (NUSC), New London, Connecticut, as well as private industry organizations. In these collaborations they did a number of detailed studies on long range active surveillance. Their studies at that time were rather pessimistic about the potential for long-range low frequency active sonar systems because of the difficulty of reverberation and clutter as well as the challenges of target classification. The Systems Analysis Group continued to do additional studies in the late 1970s and early 1980s for various Navy offices including some studies for PME-124 on system performance. Their group also collaborated with other Acoustics Division researchers performing studies in the Arctic (e.g., Charlie Votaw, Burt Hurdle, and others).

Career Wrap-Up

Around 1983 Rollins went on assignment on a special Navy project in Arlington, Virginia (Crystal City) for a year. He then retired from NRL in 1984.

Further Recollections about NRL's Acoustics Division

Rollins provided some additional recollections about some Acoustics Division colleagues: Hank Fleming came to NRL from Hudson Labs to perform environmental oceanographic studies. Budd Adams and Carl Andriani also came from Hudson Labs to pursue research on long-range low frequency active acoustics. There was signal processing group in the Acoustics Division that was headed by Al Gerlach. That group was an early user of ARPANET (that later became the internet). There was a group doing physical acoustics research (under Mickey Davis, and later under Joe Bucaro) that did scale model target scattering experiments. Chester (Buck) Buchanan did important research on deep sea search techniques. A.T. McClinton was a guiding force behind the Project Artemis source developments. Sam Hanish worked closely with a researcher named Roland (Bud) Byer in the Transducer Branch. Joel Sinsky joined that branch for a while, then later left NRL to work in various Navy funding organizations (particularly as relates to 6.2 Exploratory Development research). Sinsky worked at the Navy Materiel Command, and then became director of PME-124. Bob Chrisp was a very capable engineer who developed signal processing systems. Bob Lee was also an engineer who was very capable regarding seagoing systems. Rollins has numerous 35-mm slides from various sea trials, but they have not yet been digitized. He has good photos of the Artemis source array.

31. Pete Titcomb

Notes Prepared on an In-Person Interview with Forrest Carlton (Pete) Titcomb held in Columbia, Maryland on Thursday 9 October 2008 (3 hours 30 minutes)

Thursday 9 October 2008 (Morning Discussion)

Early Life and Education

Forrest Carlton (Pete) Titcomb was born in 1925 (age 83 in 2008) in Lawrence, Massachusetts. He was raised in New Hampshire, but left high school in his junior year to join the Navy. He spent just over three years in the Navy during World War II (February 1943 to March 1946). He attended boot camp at Sampson, New York, and then was assigned to Virginia Beach, Virginia – Radar Operators School. There he was invited to become an instructor; and he continued that until September 1944. He was then reassigned to Pacific Ocean duty (New Guinea, then Leyte Gulf, Philippines). He came back to the US and was discharged from the Navy on 15 March 1946. He remained interested in radar. On 18 March 1946 he re-entered high school in Keene, New Hampshire and graduated in 1947. He then pursued a course in electrical engineering at the University of Vermont and graduated with a BSEE degree in 1951.

Career Beginning at NRL in the Radar Division

During his senior year of college in the spring of 1951 there was a recruiting person from NRL (Mr. Peter Waterman) who mentioned about a job opening involving research in radar. Pete applied for the job and was hired at NRL to work under Waterman (a branch head) on missile guidance radars. The emphasis shifted to research on missile launching from aircraft. It involved an F4 aircraft firing rockets. Dr. Page was Superintendent of the Radar Division when Titcomb came to NRL, but later Dr. Page became Research Director of NRL and Dr. Guthrie became the Radar Division Superintendent. The group in which Titcomb worked completed the development of a radar system for the F4 aircraft (this aircraft later became the primary fighter aircraft in the Vietnam War). The radar for the F4 was built by Westinghouse (at the plant south of Baltimore, Maryland). The Navy asked NRL to find out why this radar was not working properly (it had a mean time between failures of three to four minutes). Mr. Waterman (later Dr. Waterman) led this effort to diagnose the problems with this radar. Titcomb was involved primarily as Mr. Waterman's assistant on this project. The radar was the APQ-50 (with the AERO-13 fire control system). The collaboration with Westinghouse was very productive. Initially, the Navy halted the production of these radars, pending resolution of the problems. In 1957 Waterman's team received a monetary award of $20,870 for this effort (at that time it was the largest single such award ever given out by the Navy).

Continued Career in the NRL Radar Division

A new program came along late in the APQ-50 development period; it was related to what later became the fleet ballistic missile program (later the Polaris, Poseidon, Trident systems). The NRL group under Waterman was involved in outfitting the first six so-equipped nuclear submarines. This program was really pushing the envelope of technology at that time. This was at the same time as Project Vanguard, the Sputnik launch, etc.; it was a very exciting time. The primary contractor on the missile project was Lockheed Corporation in Sunnyvale, California. Titcomb made many short trips to Sunnyvale for meetings related to this effort. The system was successfully deployed in the SSBN fleet. They had progressed to the level of advanced sea based deterrence.

Joining NRL's Naval Analysis Staff

Eventually Peter Waterman moved out of the Radar Division to establish the Naval Analysis Staff at NRL (it included NRL and ONR people) in Building 97. Titcomb joined this group and he moved more and more into the role of a facilitator. The work of this group resulted in NRL Report 6111 — it consisted of approximately 26 volumes for which Titcomb was chief editor. There was an organization headed by John Craven that reviewed this work. Titcomb attended all of those meetings, generally representing Mr. Waterman. One of Titcomb's roles in this effort was to act as scientific officer on approximately two-dozen technical contracts. (Aside — your best friend was the secretarial staff.) The Naval Analysis Staff then split into specialty areas. In the early 1960s Titcomb became coordinator for studies on the topics of strategic warfare as well as unconventional warfare, however, these efforts did not move forward.

Involvement in the Practice Nine Project and Initial Collaboration with Dr. John Munson

In the mid-1960s (during the Vietnam War) the Defense Department initiated a cross-service research project. Dr. John Munson led the Navy portion of this project (called "Practice Nine"). Pete Titcomb worked on this project. It entailed research on air-acoustics applications for jungle surveillance. Titcomb headed a group of about eight researchers who did field testing from Eglund Air Force Base of specially designed air-deployed acoustic buoys. Titcomb had disagreements with General Starbird (three stars) on this project. The General's staff took a statistical approach. Titcomb's team had results that disagreed with analyses by the General's team. The General's team won out. In the end, however, General Starbird asked Titcomb to take the Navy team to Vietnam (Khe Sanh) for actual in the field testing. But as events transpired, they did not go to Vietnam. During this project, Titcomb became part of an acoustics working group under John Munson. At that time Dr. Munson was on assignment (in Washington, DC) from the Naval Ordnance Laboratory (NOL; White Oak, Maryland). In 1968, however, Dr. Munson was selected for the position of Superintendent of the Acoustics Division at NRL, to replace retiring Superintendent, Dr. Harold Saxton.

The Career Move to NRL's Acoustics Division

In the late 1960s, when he was working with the NRL Special Projects Office, Titcomb had become a principal liaison person at NRL for interactions between the various divisions. As a result, he knew many persons (including Division Superintendents) in different NRL divisions. Then, further as a result of these cross-division interactions, Titcomb moved over to work under Dr. Munson in the Acoustics Division on the Division staff and in this capacity acted as general facilitator for solving Division problems. For a while in the mid 1970s, Titcomb headed the System Engineering Branch (when Art McClinton retired). Dr. Munson decided to establish a Systems Analysis Group within the Acoustics Division; J.C. (Ian) Knight (Ph.D. from the University of Edinburgh, Scotland) was chosen to head this group; Ray Rollins and Maury Potosky joined this group. Also, for a while after moving to the Acoustics Division, Titcomb continued some of his work on projects related to the fleet ballistic missile developments (including the monitoring of contracts such as the one with Mantech International). Titcomb recalled also that for a while he served as executive secretary for the Navy's Undersea Warfare Working Group (Chaired by Dr. Berman).

Titcomb supported Dr. Munson with many miscellaneous tasks. One such task was to design the new office for Dr. Munson on the southeast corner of the second floor of Building 1 (this office had in an earlier era been occupied by NRLs technical director). Dick Rojas joined the Acoustics Division then under Dr. Munson (but shortly after this, Mr. Rojas became an NRL Associate Director of Research, succeeding Dr. Ralph Goodman, in charge of multiple divisions, including Acoustics). Titcomb also assisted Dr. Munson in sorting out the Division budget details. When Dr. Munson came to the Division there was a significant reorganization. Many of the "old guard" researchers retired at that time. Sam Hanish of the Transducer Branch was working intensely on his Ph.D. research at that time. The technical productivity of the Division increased significantly after Dr. Munson took over the Division. Dr. Munson carefully scrutinized each technical paper prior to its submission for publication (even to the point of working out all the mathematical formulas and equations to check their validity). [Munson once told Titcomb that during his college years he would always find more than one way to solve each textbook problem in order to verify that the answers were consistent.]

<u>Retirement from NRL</u>

Pete Titcomb retired from government service in 1978 (after about 27 years at NRL). He has a kept greeting card that was signed at that time by many persons in the Division. Titcomb recommended contacting Walter (Wally) Brundage, who assisted Dr. Ralph Goodman for recollections about the 1960s and 1970s period.

Thursday 9 October 2008 (Afternoon Discussion)

<u>Further Recollections about the NRL Acoustics Division</u>

Robert H. Carson of the Sound Division made many audio recordings as a service to NRL (possibly from the 1940s to the 1960s) of important speeches at NRL (and possibly elsewhere). At that time NRL encouraged "home projects" and Bob Carson had some NRL sound recording equipment in his home. After Carson passed away, Titcomb retrieved the NRL equipment and returned it to NRL.

There was a period in the early years that Titcomb was at NRL that the Laboratory encouraged much interaction between researchers in different divisions. Later this changed to the extent that researchers were advised to not share their research results outside their small group.

When the USNS *Hayes* was built it was discovered that the *Hayes* had a tendency to slap down on the water in high seas. This problem was never completely eliminated. Art McClinton was heavily involved in the design and problem-solving related to the *Hayes*.

Titcomb kept handwritten notes of the periodic Acoustics Division meetings that Dr. Munson held with the Branch Heads. Most of these raw notes were not kept, but were instead submitted to NRL Security for destruction.

There were some acoustic tank measurement facilities in the Sound Division in the early 1970s. These included the pool facility in Building 71 that had earlier been used as a nuclear reactor (in the 1950s). There was a circular wooden tank in Building A-59 as well. Sam Hanish and Werner Neubauer used these facilities for transducer testing.

Note - Titcomb acquired the nickname "Pete" during his time in the Navy (in New Guinea) in 1944. His ship was a converted LST (the conversion was done in Australia) — to a dedicated tender for PT boats. They had a radar system that nobody knew how to use. Titcomb became the radar operator. He reported to Ed Seigel, head of the radio group who decided it was easier to call Titcomb "Pete" rather than Forrest; this nickname stuck, and Titcomb continued to use in later life.

32A. Peter Vogt

Notes Prepared by Fred Erskine based on Recorded Audio Tape Interview of Dr. Peter Vogt by David van Keuren (NRL Historian) held on 13 August 1996 aboard the Research Vessel Professor Logachev [Approximately 45 minutes duration]

Background on Dr. Vogt

Peter Vogt received an undergraduate degree in geophysics at Caltech in 1961. Up to that time he had not done any oceanographic research, nor had he taken any courses in oceanography. Later he attended the University of Wisconsin to pursue graduate studies. He became involved in oceanographic research there and was supervised by Dr. Ned Ostenso who was affiliated with the Polar Research Center at the University of Wisconsin. Vogt participated in two icebreaker cruises in the Barents Sea and the Kara Sea. In 1967 Vogt went to work at the Naval Oceanographic Office where he continued Arctic research. In 1975 he came to work at NRL in the Acoustic Media Characterization Branch of the Acoustics Division and he has been involved in Arctic research continuously since then. Around 1993 there were organizational changes in the Acoustics Division and his Branch became the Marine Physics Branch under the Marine Geosciences Division. Over the years his Branch has been involved in various international collaborations including joint research with Norwegian scientists.

The events leading up to the Logachev cruise had their genesis at a symposium at the Woods Hole Oceanographic Institution (WHOI) in the late 1980s

In discussions with Norwegian scientists it was noted that side scan sonar had not previously been used to any great extent in the Norwegian Greenland Sea area. In the early 1980s the SEAMARC System was developed and had been used extensively around the east-Pacific rise and mid-Atlantic Ridge areas and had given spectacular results. This system was originally developed by the minerals industry and was used to prospect for manganese nodules. It was owned by International Nickel Company (INCO). When the nickel prices plummeted in the early 1980s and at the same time the uncertainties related to the law of the sea came into effect, INCO dropped this project. The inventor of this side scan sonar had been a colleague of Vogt's at the University of Wisconsin (Jim Fitzallis, a brilliant engineer). The SEAMARC system and its team became involved in university research. SEAMARC operates at twice the frequency (11-12 kHz) of the more well known British Gloria system that has a broader swath-width but less spatial resolution. An additional advantage of SEAMARC was that Christian de Moustier demonstrated that not only could it produce detailed pictures (including backscattering strength) of the sea bottom but it could also produce bathymetric contours.

Proposals were submitted to use SEAMARC in the Norwegian Greenland Sea. The Norwegians (Eric Sundborg et al.) offered up a research vessel, the Haaken Mosby. A joint US-Norwegian research team sailed in late 1989, starting at Tromso northward to the Bear Island Fan (a ridge area that is the plate boundary between the North American and Eurasian plates). On the return south they transited some continental margin areas and discovered some unusual features. They returned for a second joint cruise of three weeks on the Haaken Mosby in 1990. The merged data set on the mid-Atlantic Ridge was analyzed by a student of Cathy Crane named Andy Dotts (Hunter College). Vogt was interested in sedimentary characteristics and he discovered in these data a number of previously undiscovered features on the seafloor whose origin was not understood. One feature was an oval shaped feature about one kilometer in diameter with a weak backscatter rim. In the center there was no measurable topographic relief. It took several years to obtain funding to go back and further investigate some of these interesting features. In 1995 NRL returned to the area using the vessel Haaken Mosby (but had to pay $4K per day for its services this time). This time some bottom sampling was done including extraction of gravity cores. Upon returning to the interesting oval shaped object, much to their surprise they discovered a very high heat flow. This was believed to be the highest heat flow ever measured away from an active plate boundary. The mud smelled of hydrogen sulfide. Some worms were discovered that were further evidence of methane venting from the seafloor. This type of feature is now called a gas seep or mud volcano.

These discoveries motivated the present cruise on the vessel Professor Logachev. The cruise has three basic goals: - to return to the mud volcano for more detailed examination; - to do further charting of the mid oceanic ridge; - to go to a latitude of 80 degrees north to perform some sedimentary sampling for Ohio State University.

The third goal was a somewhat minor goal. We had been collaborating at a low level with Ohio State University for a while. A Russian researcher at Ohio State was interested in some cores on the Spitzbergen shelf – to determine if the ice sheets from the last glaciations extended from in-between the troughs to the shelf edge. We expected to take some of these cores in exchange for having Ohio State University support some of the Russian studies and also in exchange for Ohio State providing some of the coring equipment that is quite expensive.

There were other minor projects that we assisted by collecting selected data during out cruise – mostly these were related to ground-truthing by examining particular objects or features. In 1990 NRL participated in an earlier cruise in the Norwegian Basin and collected SEAMARC imagery. In that cruise NRL chartered the Lamont ship, the Maurice Ewing. The Hawaii Institute of Geophysics (that operated SEAMARC) participated. We mapped an extinct spreading Ridge called the Aegir Ridge in the Norway Basin. On that cruise we did not have time to examine a number of interesting features. We noticed some “pockmarks” and some features that looked like sediment waves. When we later looked at the data more closely we saw that these were not sediment waves but rather were little crevasse-like pockets filled with soft stratified sediment. On the Voring Plateau we also looked at some diapirs that were of interest to the Norwegians. The collaboration with the Norwegians was important since we were working in waters around Norway.

At the time of this interview we have completed the primary goal of examining the mud volcano and we are just beginning work on the second goal to examine the mid-Atlantic Ridge area. We hope to find evidence of hot-water venting on the floor of the Ridge. If we do not find evidence of that – the data we collect will still be very valuable because this Ridge has not been examined in any greater detail than out previous SEAMARC imagery which gives a resolution of about 100 to 200 meters. By running the deep-towed side scan sonar we can get imagery of a much higher resolution – operating at a higher frequency of 30 kHz – and it is towed much closer to the seafloor. (Unfortunately this sonar stopped working about an hour ago). Already we can see lots of interesting structure in the side scan sonar data including faults and fissures. We are steaming down the Plate boundary between the North American and Eurasian Plates – a place where new earth crust is being manufactured. Even if we do not find the hot water venting plumes (considered to be “icing on the cake” and we have a low probability of finding them) – we will be happy just to get good quality data in this area.

The present work is really the “third-stage” of exploration in this area. Up to 1989 we had “first-stage” data with resolution of only about 5 to 10 km. Then in 1989-90 we collected the “second-stage” level of data using SEAMARC with resolution of a few hundred meters (i.e., about two orders of magnitude improvement in resolution). Dr. Kathleen Crane from Hunter College in New York briefly joined the interview. She said that the side scan sonar is being brought up to the surface to see if it can be fixed.

David van Keuren asked Dr. Vogt why hot water venting would be important. Vogt responded that it is not important from an oceanographic thermal balance point of view. However, thermal venting is important with regard to geochemical balance of the world's oceans – including recycling of the elements. It is an important mechanism for cooling of the earth's lithosphere. Further, there are particular communities of biota that are uniquely found near these thermal vents in the deep oceans. The basis of their food chain is not photosynthesis, but rather it is based on chemosynthetic bacteria that live in the guts of tube worms and other organisms. Years ago nobody suspected that life on earth could be based on something other than photosynthesis. This raises interest in the origin of life on earth – such as the Urey-Miller hypothesis that lightning bolts zapped through the reducing atmosphere in the early earth's history (e.g., the early Precambrian era) when the atmosphere had much methane and hydrogen. The theory hypothesizes that complicated organic molecules resulted from these reactions in the atmosphere – possibly leading to simple organisms. However, researchers studying Ridge venting have hypothesized that it may have been more plausible for life to arisen in the Ridge vent environments. Biologists are interested in finding out how life forms arise at these vents. Presently we are quite far from any known hot vents. We are presently at 78 deg Latitude, and the closest deep water hot vents are south of the Azores (at 39 deg Latitude). There is a closer one in shallow water near Iceland, however. There is also interest in the hot vents form a mineralogical perspective. The Rift Valleys here are close enough to land-forms that sediments can be deposited and perhaps become mineralized. It is not known if this is at al exploitable, but study of these sediments may yield insight about the formation of ore bodies on land (e.g., copper, nickel, sulfides).

As an aside – there is some interest around the world in using hot vents as energy sources. However, early attempts to exploit his energy source have been hampered by deposition of sulfides on the equipment. In Iceland, much use is made of low temperature geothermal heat as well as high temperature steam generating plants on land.

The present cruise has been enormously successful from a scientific point of view. We were concerned that the Russians might not be able to field such an expedition because of limited financial resources. The Professor Logachev is well equipped to do the necessary ground-truthing. We have a very diverse set of scientists here as compared to a normal US cruise. We have approximately thirty scientists, engineers, and graduate students from a variety of disciplines – a number that is much larger than on a normal research cruise (perhaps equaled only by the complement of technical persons on the Glomar Challenger). Instead of the normal procedure of analyzing cores and other samples months later after the cruise, we have teams of scientists on-board this cruise who are presently analyzing these types of data. While we were at the mud volcano site I was being handed the results of core analyses and tables of compositions of water samples from two teams (chemistry and sedimentation). It is impressive that the Russians have caught up with their computer systems and are using PCs and workstations. They are collecting data on magneto-optical disks rather than just on ink-pen recorders. We will return to NRL with four such disks and will have access to all the data in digital form. The photographic sled is an important component. We note, however, that much of the equipment has been purchased from the United States. The side-scan sonar is of their construction, but the photo sled is from the US. The sled has multiple instruments including sonars, photo equipment, water sampling apparatus, bottom profilers. On-board we have a complete suite of laboratory analysis capabilities. Due to funding limitations, we did not bring a large complement of scientists from NRL – this is one of Dr. Vogt's disappointments. We would have liked to have brought along a number of sediment specialists from NRL's Marine Geosciences Division at Stennis Space Center, Mississippi – who were eager to participate in this cruise. We did bring to the table some of our expertise, and arranged for Professor Kathy Crane to bring her Seabird CTD (Conductivity-Temperature-Depth) system. This device is being attached on all our deep tows and will help us look for temperature and salinity anomalies close to the seafloor in the lower part of the water column that might be due to plumes of hot water rising from vents. You may have heard that I bet Professor crane that we would not find any significant temperature anomaly above the mud volcano because the probability of finding one there is less than one percent relative to finding one finding one near the mid-Atlantic Ridge. However, I have already lost this bet – since we did find evidence of some hot water near the center of this mud volcano. It appears that this is a unique and new finding. This observation corresponded to at temperature of about 12 deg Centigrade relative to the surrounding zero degree water. It is a gradient that has rarely been found in the oceans except on the mid-ocean ridge – so this is quite exciting. We also brought from NRL the capability to copy the data and a young computer engineer who was just hired for that purpose. We brought a graduate student (Stefanie Harrington) who is working on the oceanography. We brought the heat flow measurement equipment (courtesy of Professor Crane and colleagues).

David van Keuren asked what we now know about the mud volcano that we did not know previously. Dr. Vogt responded that the temperature in the center of the mud volcano was so high that the heat flow apparatus went off-scale. This implies that the methane hydrate that we cored in the center of the mud volcano can only be a few meters thick because it gets so warm that the hydrate cannot remain stable. That is a major discovery. The finding of the temperature anomaly in the water column is the major discovery. We found methane in the water column – this is always an exciting finding in the oceans. In general the oceans are saturated with oxygen and the methane cannot survive long – so when we see methane it is always exciting. As regards biota – we did not see a single shell of any sort on the mud volcano in any of the photographs. In geology – the absence of something is also interesting – we have to ask ourselves “why are there no clams here?” However, we do not have biology specialists in this field on-board and we will have to await further analysis of the photographs on this topic. The composition of the cores on the mud volcano have been up to twenty percent methane hydrate – this is probably as high as has ever been reported anywhere. We have many unanswered questions about the origin of the mud volcano and its history. We have some data that suggests its depth may be at least 1000 meters.

David van Keuren asked for further elaboration on the international aspects of the cruise and comment on prospects for future research. Dr. Vogt commented that the collaboration has really been outstanding. However, the language problem has been a challenge. Dr. Vogt speaks a little Russian, but finds it hard to follow the scientific discussions amongst the Russians. Similarly, the Russians have difficulty following the discussions amongst the English speaking scientists. During the Soviet period, English was not emphasized in the Russians’ schooling as much as in western Europe. In spite of these communications challenges, all the basic ideas have been communicated between the participants. As a minimum, in the future we will be collaborating with the Russians on the analyses and co-publishing scientific papers. Email makes it easy to communicate. We hope to find funds to bring some of the Russian scientists to the US for a workshop or perhaps to the Spring Meeting of the American Geophysical Union in the Baltimore area. We could easily come up with a list of potential follow-on cruises. This ship is a great resource. It would be a great tragedy if the ship were turned into some kind of a coastal freighter or a tourist vessel - which it is in danger of becoming.
Concluding remarks: It was very difficult to put this cruise together funding-wise. We went to the National Science Foundation. We went to the Research Director at NRL, Dr. Timothy Coffey – I personally pleaded with him for some of his “sweep-up” funds. It was only by a “hair” that we managed to pull this cruise off. Our Russian colleagues also have severe funding problems. There is a danger of job layoffs on both sides. We have to hang together.

David van Keuren asked Dr. Vogt to review the list of institutions represented on this cruise. Dr. Vogt responded: The Shirshov Institute of Oceanology in Moscow (this is the organization NRL had hoped to collaborate with in the early 1990s on the radioactivity in the Kara Sea – that cruise came to nothing and it soured people on such a collaboration because much funding and time went into that cruise – it was apparently a political problem and had nothing to do with the scientists); most of the scientists on-board are from St. Petersburg, Russia; we have a student from the University of Oslo, Norway (Alf Nielsen); we have a graduate student from MIT who is studying there under a three-year ONR fellowship (Stefanie Harrington); we have a graduate student from George Washington University as well. It's a nice mix of students and senior scientists with a good spread of ages, talents and professions levels. Polar Expeditions runs the Professor Logachev; they supply the engineering support. Dr. Vogt noted that NRL used to have research vessels. When he came to NRL we had the R/V Harvey C. Hayes; it was run by MSC or MSTS; The Hayes went away in 1982 (fourteen years ago). Since that time our field work has been done on other ships, such as those from the Naval Oceanographic Office, Norwegian vessels, in this case a Russian vessel. There are positive and negative qualities to not having our own ship. NRL still has its own P3 aircraft. In the case of the Professor Logachev, it was advantageous to just be able to walk on-board and have all support services provided. We just brought any specialized equipment that would complement the equipment already provided, such as the CTD, the heat-flow probe, and the gravity coring apparatus. It would have been extremely expensive if we had to completely outfit the ship from scratch (e.g., millions of dollars).

[End of Interview]

32B. Peter Vogt

AN INTERVIEW WITH DR PETER VOGT DR. KATHY CRANE AND DR. GEORGIY CHERKASHEV

by Dr. David K. van Keuren
History Office
Naval Research Laboratory
21 August 1996

This is David van Keuren, Historian with the Naval Research Laboratory, and I'm speaking from the Russian Oceanographic Research vessel the PROFESSOR LOGACHEV, and I'm talking on the 21st of August 1996.

This evening I want to discuss the results of the recent American, Russian, and Norwegian joint research cruise to the Norwegian Sea.

Dr. van Keuren: Right. Peter, why don't you start us off. We've now spent almost twenty-eight days on the LOGACHEV. We'll be going on twenty-nine tomorrow. Any general reflections on how the cruise has gone?

Dr. Peter Vogt: Well Dave, as you know, you interviewed me only a week ago so what you will find on the previous tape will not be too different. I think we're all in agreement and certainly I feel very strongly that we've had an exceptionally successful cruise. I cannot recall having been on a research ship where such a variety of research was done. I would call this ship a floating laboratory, in fact. I am satisfied beyond all expectations. We had a little bit of down-time with the equipment, but I would say, compared to my experience on US ships, it was at the same level or possibly less than what I recall, for the different types of equipment. I would say that a great advantage of having a ship that has so many research tools is that we could switch from one project to another quickly and make maximum use of the ship time, so that at no time was the shiptime actually wasted. We were able to arrive at a consensus here as to how to switch from one project to another. That was also a very good aspect that you don't have on other ships. My only comparable experience being on a ship with many scientists like this was the GLOMAR CHALLENGER. Twenty years ago I was on the drill ship, and this is the most nearly comparable experience.

Dr. van Keuren: Kathy. Comments on the same topic.

Dr. Kathy Crane: On the same topic, since I don't remember when you last interviewed me. We're still afloat. That's a good sign. We're going into Spitzbergen, I think with all of our projects accomplished. We were doing a lot of exploratory work, and had, by nature, to use a lot of different kinds of equipment because science is integrated into one whole. I'm really happy with what we've come up with. I think we've got some really beautiful photographs of the sea floor, and great samples that will increase the number of rocks we've got from the mid-ocean ridge in this area [by] how much? One hundred percent? Probably.

Dr. Peter Vogt: More than double the existing dredge collection.
Dr. van Keuren: How does this compare to other oceanographic cruises that the two of you have done? And I may also ask that of Gosha, who is sitting in on this.

Dr. Kathy Crane: I think I've been on over thirty expeditions so they've been really varied. Well, by far, there's a very large number of people on this ship. Generally, when I've worked in hydrothermal areas in the past we've had a large number of scientists from many different disciplines. That's the nature of the science. Biologists, chemists, geologists, physical oceanographers. And so, in that aspect, it hasn't been different for me. Maybe in the last few years I've been working on very small Norwegian ships where we've had a much tighter type of science, I guess. A narrow range of science being done on the sea floor. So, I haven't really done this type of work in ten years, I guess, in a serious way on the ocean ridges. In terms of the international aspect of it, I think it's the first really tri-lateral expedition I've taken part in. I've worked very often with many different ships from Italy, France, Russia, Germany, Sweden, Norway, and where else. So, that aspect, the collaberation, I think, has been fruitful on this expedition. I'm glad, from the very beginning, we had been able to set this up through people who worked together in the past rather than starting out cold without knowing the different partners.

Dr. Peter Vogt: I'd like to make a comment about the Norwegian participation. This is tri-lateral, and not withstanding my best efforts, we were only able to get two individuals on board. One a student and one a senior level technician, and they're wonderful people, and I'm glad they're out here. They did contribute a lot to the cruise, but to call it truely a tri-national expedition would have been .... To really qualify for that term I would have liked to see a greater participation by Norwegian scientists. Maybe having four or five Norwegians instead of just two, but we tried and there were logistic and conflict problems involved [so] that we didn't have a bigger turnout.

At the same time, as far as the U.S. participation, I'm sure you've gathered by now that Kathy and I are, as we're getting a little older, spreading ourselves over greater areas of research. We're becoming generalists, and a scientific generalist is very useful as a chief scientist because we have some feeling for these different disciplines, and we can synthesize, and we can say, ``Well, let's go over and use that tool in that particular area.'' But what we're lacking as far as the U.S. team and the Norwegian team is to have some more specialists. That's my own feeling. Possibly Kathy and Gosha don't agree. I would like to, if we do a cruise like that in the future, to have some Americans come out with specialized pieces of equipment that would contribute in a laboratory setting and exploit the fact that the ship is large and has laboratory space. Then we could do analyses on samples together with the Russians. That's one aspect I would like to see happen. Also, as you know Dave, NRL has some very interesting geophysical and geochemical research tools. I could just name one: the DTAGS system. When it works, the Deeptow Multichannel System, which is the only one like it in the world, which would allow you to get a high resolution seismic image and the velocity structure for the top circa five hundred meters of sea floor.

That would be a wonderful addition, and this ship would be the perfect vessel to host a system like that. So, in the future, if we can find the funding, I would like to add to the set of research tools that we have out here and involve some more participants.

As you know, all of you, I tried very hard to bring people in from our Marine Geoscience Division down at Stennis, where the focus is more on sediments than what Kathy and I do. I was unable to get even one person to come out, so that was a disappointment. It largely has to do with the funding situation that we have right now at NRL this year, which you're very much aware of. So, I'm still extremely satisfied, and I can't see how we could have accomplished more than we did, but, nevertheless, I can see that the makeup of the teams could be a little more complete or representative.

Dr. Kathy Crane: Can I comment on that? I just think it would have been completely impossible to have done that this year because it was the seed money coming in to start a first major collaborative expedition with Russian scientists. From my perspective of raising money on the outside of NRL, they're willing to support the bare bones but nothing more, and if we were successful in pulling it off with a few number of American scientists [and] with expertise from Russia, then the statements were that [there was] much bigger likelihood, in the future, of bringing in a suite of experts. From my experience, that was the way it was, and we had no chance of raising the money for more scientists.

Dr. Peter Vogt: We barely accomplished this. There were so many `ifs' that we barely accomplished this.

Dr. Kathy Crane: By the skin of our teeth.

Peter Vogt: An odds maker wouldn't have given very big odds for us to have succeeded a half year ago. I understand that our colleagues at Lomonosov and St. Petersburg were probably shaking their heads when we left. They didn't think it was very likely we would get this money over to them in three weeks and that we would actually go to sea with them.

Dr. van Keuren: Comments Gosha?

Dr. Georgiy Cherkashev: No. Maybe I'll comment about the scientific results a little bit later.

Dr. van Keuren: We had a very rich scientific agenda on board starting out. There were several different research projects over several different types of areas. How much of that did we successfully accomplish?

Dr. Peter Vogt: Well, having been the sort of primary initial instigator of the draft plan, I started out by proposing a number of research sites with the full realization that we wouldn't have time to do all of them. But, for practical reasons, it's good to have as many options as possible. Even if some sites have to be deleted, and, as you know, we had to delete some. We deleted three or four based on time constraints. We deleted one because the ice wouldn't let us get to the area. The overall background for this research was the SEAMARC sidescan imaging, the reconaissance imaging, that was done in 1989 and '90, as you know.

Historically you are aware that -- I think I told you before -- that in 1991 and '92, we, I and colleagues, tried unsuccessfully on several ocassions to mount a major expedition to come here and ground-truth, meaning to go and look at specific problems like the object which we now know is a wonderful little mud volcano with all kinds of interesting anomalies. We tried, and failed, a number of times to come out here. Most recently, two years ago, Chris de Moustier, who's a professor at Scripps, who is into deeptow sorts of sidescan, and I submitted a proposal to NSF to come here with the Scripps deeptow system and other tools, although not as many as the LOGACHEV has. We never talked about having a complement of scientists out here doing analysis of methane and pore water and stuff. In this funding climate, the proposal got excellent reviews, but we got this typical letter back saying, ``We get more good proposals than we can fund.'' I, personally have waited a long time, and this has been a wonderful fulfillment of six years now of wondering what some of those things are on the sea floor. We've learned a lot, and one of the things that we've learned is that we have to be very careful about interpreting. We shouldn't be too quick about looking at -- and I'm talking about myself now -- seeing some little white lines down there and saying, ``Ah! Those are sediment waves''. It turned out they were little crevases in the sea floor, and we didn't have the capability with SEAMARC to look at the topography associated with those patches. Had we investigated them in detail with other ships we would have known that.

Another area where we went in the Lofoten Basin we also discovered things that we didn't expect. It was counter to our expectations. We found that there were places there which we thought were soft sediment waves, and we found it was impossible to even take sediment cores it was so hard and so forth. I think we all agree that our premier accomplishment was the investigation of the mud-volcano, and I think the fact that the sonar imagery was so exciting and showed all these new features, in that we found a temperature anomaly, which cost me a case of champagne, in the water above the mud volcano, which is probably a historic first: Nobody has ever, over a so-called cool or warm seap, found a temperature anomaly. If it stands up to analysis. I guess I concede that it does, and I will buy the case of champagne.

Then the finding the methane in the water column and the extremely high heat flow in the center: the gradient does five degrees per meter, which is a stunning temperature gradient for a passive continental margin. So, there were many exciting aspects which were not entirely predictable. We had little clues from last year, but now we know a lot more. I think, probably, if you took a vote on the ship you would say that, by far and away, the Haakon Mosby mud volcano was the most exciting thing we looked at, but some of the other problems were also very exciting.
O.k. I've talked enough.

Dr. van Keuren: Do you agree with this Kathy?

Dr. Kathy Crane: About which areas were the most exciting?

Dr. van Keuren: The portion of our agenda that we actually accomplished. What do you think are our major accomplishments scientifically?

Dr. Kathy Crane: Actually, I was surprised when I came on the ship. I sort of missed out on the last couple of weeks of planning. I was doing other work, so we ended up doing about a hundred twenty percent of what I originally thought we were going to do. So, I wasn't prepared for some of these other stations in the south, which added on to the variety of things. Yeah, I think we've had marvelous success. I'm really glad we were able to bring color photography to these issues. I think that we discovered a lot of very really interesting features about this region along the Senja fracture zone between the Barents Sea and the Norwegian/Greenland Sea. Along the Knipovich Ridge there are some really interesting areas. We have some enticing pieces of information that may lead us to come back and do further studies in particular areas. So, I think we had a lot of success.

Dr. van Keuren: In your eyes, what one accomplishment on this trip would make your colleagues back home pay attention?

Dr. Kathy Crane: Pay attention? I would say that the photography of the methane hydrates frozen on the sea floor. Just because, all the sampling .... You bring it up, and it's gone. You don't know it's there. So, we took all these photographs, you see. Beautiful contrast, the whites against the dark. The frozen hydrates are just incredible. Pictures are a thousand words often, so one photograph of that plus a beautiful sidescan sonar image of the mud volcano. It is just stunning. I think a couple of those things together would really be a wonderful eye opener to a lot of people.

Dr. van Keuren: What about the Knipovich Ridge?

Dr. Kathy Crane: We had some debates about it. I actually think we found bacterial mass. There's a question whether or not it's a developer, but there were a couple of frames on both rolls -- the Russian roll and the U.S. roll of color film -- at the same time. They were developed separately, and they had the same pattern on them, so Pete's going to check this out. They're in an area of subtle temperature anomalies, and the topography is so rough there it would really take us at least two weeks to a month to really investigate that area thoroughly. We just had such a quick run through. Normally with mid-ocean ridges when we are investigating them we would spend a whole month in an area like that. Because it's such complicated photography, and plus it's fascinating for me to see the basalts. Some areas which we thought were very fresh but had a dusting, more than a dusting, of sediment on them. But they were like fresh basalts in the sediment. So, I think it's some kind of different terrain, and there's a lot to be .... Well, Knipovich Ridge doesn't reveal its secrets easily, I think. So, it will take us some time to really go there and investigate it with a whole bunch of instruments.

Dr. Peter Vogt: Yeah, we could easily spend five successive cruises looking at the ridge system. I like to think back to exactly thirty years ago now when I was a student on board the navy ice breaker ATKA, previously the SOUTHWIND. I think it's one that the Soviets had during the Second World War. Then it was given back to the United States because they still had some plates and cyrillic lettering on the ATKA. We worked in the Barents Sea, and on the way back we took a couple of dog-legs, the first tier of a polygon. I crossed the Knipovich Ridge rift valley, and I stuck them into my thesis, and at that time we thought we had discovered something new, and we called it the Atka Ridge. Later we found out that the Soviets had already discovered the feature, and so the name Atka Ridge was not to last. But I think back, looking at those profiles, and this was before plate tectonics had been formulated but after Vine and Matthews. At the time, we argued what the function of this linear feature was. Whether it could be a fracture zone, or a spreading ridge, or even a trench. You know, our hypotheses were all over the map. For me, it's kind of historic to come back, virtually to the same place, thirty years later.

Dr. Kathy Crane: We should have fireworks.

Dr. Georgiy Cherkashev: Maybe some additions about the mud volcano, that unique place. As I know, this the first time we've found huge surfaces where gas hydrates are on the surface of the sea bottom. We made a very good record there and a lot of interesting things. As for Knipovich Ridge, this is the first step, but a very successful step because it was a surprise for me that we found the temperature anomaly. Finally we found the mineralization -- low temperature but nevertheless hydrothermal mineralization. So, it is a signature that is the rock must be here making a high temperature. This is a very good result.

Dr. van Keuren: Any major disappointments?

Dr. Peter Vogt: No, the only disappointment I have is that even though we've been out at sea now for thirty days I still have not really got to know a lot of the scientists well, and that may be partly, speaking personally, a language problem and partly because there are many people, and we try to work with the people that we normally work with. They're a part of our working group. So, if I had any disappointment it would be that I didn't get to know the other scientists better than greeting them in the passage ways and so forth, but maybe that's for the future to correct.

Dr. Georgiy Cherkashev: It's a little bit of a pity that in last stage, the last part of our voyage, that there was a problem with the sonar, and we couldn't have this data for a big section of the Knipovich Ridge. We studied only a short segment, but this is for the future.

Dr. Peter Vogt: When we write a proposal and put in the sample of the deep-tow side scan and some of the pictures, I think we will be miles ahead and the people will want to pay us, I hope, to image the rest of it with that kind of resolution.

Dr. Kathy Crane: Major disappointments?

Dr. Georgiy Cherkashev: Kompot?

Dr. Kathy Crane: Not for me. For the interviewer that was a major disappointment. I actually like Kompot. Let's see. Major disappointments? Nothing beyond the normal disappointments of going to sea and have things break down, but that's normal for me. There are so many people on this ship and thirty days, almost thrity days, went by really fast for me. There were a lot of people I just didn't have a chance to go to. Seminars were always during the time I wanted to fall asleep the most. During watch and after watches. I think we did the best we could in the situations. Good opportunities for people to mingle and mix every now and then. I just see it as a stepping stone toward further collaberation. I, personally, would have liked to have seen a lot more photographs of the seafloor.

Dr. Peter Vogt: Can't get enough.

Dr. Kathy Crane: Yeah, can't get enough photographs. I'm always surprised that what you really see on the sea floor, and how it's often different from what you imagined for years and years about being there. I have always had this experience in diving in submarines. When every time we actually go to the sea for a week, we discover new things visually. It has a real impact on me visually rather than indirect interpretations. It helps to really clinch some things, you know.

Dr. Georgiy Cherkashev: It was a moment in the evening [that] we had a a video tape of basalts and very strang forms. It was a discussion if it was basalts or maybe it was sulfites. So it was a very dramatic situation because we hadn't yet the color photo, so it was not possible to recognize for sure if it is sulfites or not. We decided to have a dredge there. Finally we got basalts, and it was a little bit of a disappointment. When it was finally dated it was not a sulfite.

Dr. Kathy Crane: You were probably right next to the vent.

Dr. Peter Vogt: I don't think we proposed, or anybody expected, to find a black smoker with the tools we have on-board. It was the first step in prospecting. We probably got more than we expected. I didn't think we'd find even any temperature anomalies. So we were already ahead. We found the smoke from either a big gun or a cap pistol but ....

Dr. Kathy Crane: A couple. One on the volcano and one on the Ridge.

Dr. Georgiy Cherkashev: It seems that we were very near, very close to this hot vent. It was maybe this seamount near the Valley. Now, I can say that maybe we should work more there, but we concentrated in the Valley where we could take the channel, but the origin was in the slope on this seamount. Maybe next time we have an assignment we'll discover [it] there.

Dr. Peter Vogt: Well, for one week .... It was really a lot accomplished in just a single week.

Dr. Kathy Crane: There is an example of when we did the first long tows along the mid-ocean ridge in `83 and '84. I think it was the first time anyone tried to prospect for hydrothermal features, along the ride back when we crossed it. We first started it on the Juan de Fuca Ridge and later on the East Pacific Rise. It took us about an entire month to really do it well with sidescan and temperature anomalies. Then we patched everything together, so it's a lot longer period of time to work on.

Dr. Peter Vogt: We really should propose to spend a month and just tow the sidescan from south to north and then north to south again with the CDT attached and just not bring up the sonar as long as it works. We'd just keep on towing it. So, Dave, if you know of any funding sources you're welcome to take any materials that we have and go around to funders and wet their appetite and tell them where we can be found. Pass our e-mail and fax numbers out to them.

Dr. van Keuren: How did the American and Russian scientific teams mesh together?

Dr. Georgiy Cherkashev: Without any problems.

Dr. Kathy Crane: Especially at ping pong. I think things went fairly well. There were some areas where we didn't have comparable people working in the comparable fields, but when we were working on the deck and box core sediments there was some expertise that we had like heat flow or the CDT work or other expertise the Russians had but which didn't overlap too much. Personalities did just fine.

Dr. Georgiy Cherkashev: I remember that before, during the period before, we spoke of whether it is good or not to have a specialist in the same fields on a ship. We were agreed that it would be good, it would be more good for cooperation. So, I think that in the future we should do it.

Dr. van Keuren: Is there any difference in what I might call the scientific styles in which Russians and Americans work at sea? There has been a lot of discussion in historical sources of scientific styles. Particularly how scientific styles differ between countries. Did we see any of that here? Do Russians and Americans pursue oceanography, particularly oceanography at sea, in different ways? Did any of that manifest itself during our cruise?

Dr. Kathy Crane: I don't know. Maybe all the expeditions I've been on, that are not on small ships, we had a very strict watch schedule where we would take whoever was there and break people up so they all worked together on one watch rather than in separate teams. So that we'd have things covered round the clock we'd all work together. It's my impression that the Russians operate things more in teams rather than having pieces of teams broken apart so you have members of different teams working together all on one watch for four hours. I think there's probably some little differences there, I don't know, maybe because people spend a lot more time at sea in Russia.

Dr. Georgiy Cherkashev: It's only in this situation because we have a lot of teams here, from Moscow, from Lomonosov Polar Expedition, from our institute, and from Moscow from three institutes: from Academy of Sciences, from Shirshov Institute, Microbiological, and Geochemical Institute. So, it's a mosaic. It was not very easy to do it, but finally it has been a success.

Peter Vogt: Normally, we're used to doing more.

Dr. Kathy Crane: Working more on the deck.

Peter Vogt: Working more and not necessarily being the primary deckr or winch operator. I've never operated a winch except for an old ex-PT winch, but still I felt that everything was done, which was great. I was kind of lazy on this ship, but everything was done.

Dr. Kathy Crane: But you found that frustrating, too.

Dr. Peter Vogt: A little bit. You feel ambivalent about it. I felt like a bystander, like I had suggested the problem and then everybody covered all the fields. You know, when we go out we swizzle the knobs much to the dismay of the technicians. We go to the graphic recorder, and we change the rates, and we fiddle around with the tuning, and often we end up producing a worse record than if there were a single technical peerson responsible. So, I have to say from a purely technical point of view, taking, for example, the profiler, which I was interested in -- and it's the type of equipment we run continuously -- to have Peter Kiritsky's group responsible for it, and tuning it, and kind of keeping us away from it had the benefit that the quality of the data is probably better than it would have been if I had fooled around with it. I've heard that complaint in the U.S. often from the technical people, that the scientists come in, and they take over, and they swizzle the knobs, and they try to get this better and that better, and there are so many variables, and we don't have the experience. Kathy may disagree. I know I have fooled around with it, but often somebody who has devoted their life to a piece of equipment is in a better position, even though they are not geologists, to tune the instrument to get the best possible record. Particularly if they have a little direction from the scientist. So, there's two sides to that, like I've gone in and fooled around with the record.

Dr. Kathy Crane: I do have mixed feelings about it. As students in America .... I don't know whether it's right now, but it was our job on the watch to change all the records, do everything from the ground up. So, you really got to understand how profiles are made, what they meant. Your job was to sit there to make sure that the profiles didn't run off the page, and log everything. So, that was our job.

Dr. Peter Vogt: Sure, but you wouldn't have done as good a job as I've seen what watchstanders do on our ships and with very few exceptions.

Dr. Kathy Crane: It depends on what you want. If you're in a training mode of coming out to train oceanographers to have a real understanding of what it is they're looking at, you'd be someone who's always been exposed to everyone else fixing the records and changing them and would have no idea even what a change in scale is, but that's my opinion.

Dr. Peter Vogt: We've had the benefit of having gone through that phase where we had to change the paper and fiddle around, but for a student to come out who didn't have to do that it is possible that they would have less understanding for it.

Dr. Kathy Crane: The same thing goes for transponder navigation. I had to do all the navigation, and we had to launch all our transponders, and we had to navigate them in as scientists. We had to do all that work. So you had to complete, we had to learn all the technical aspects before we could even interpret the geology. Then, on the other hand, it really helps you if you're planning a survey and someone says, ``Should you use transponders here? Where should we put them?" Maybe you have in your mind different scientific objectives than an engineer would have. There are positive attributes to both areas. I personally enjoy going to sea to work with equipment and to fly instruments. That's why I became an oceanographer, otherwise I would have stayed at home. Most American ships would keep records going all the time through the whole expedition. Would never turn anything off. You would collect data from the very time you left port.

Dr. Peter Vogt: Because you never know where it's going to be important.

Dr. Kathy Crane: Ship time is so expensive. It's twelve thousand dollars a day in America now.

Dr. Peter Vogt: But I can see where here the fear of equipment breaking down and not having spares. That's probably the driving reason why we had to twist arms to get the recorders running all the time. My experience has been different from Kathy's in some respects. There are things we've done on the ship that I have never been a part of. For example, the transponder work. I have been on ships that have done sidescan, of course, but I have not ever been on a ship before that did camera sled runs. I've been on a ship where we did photo type, you know, single pictures, but even that I have very little experience with. So, my experience has been more with cruises where we did mowing-the-lawn type surveys, and also I've done some things in the field like going out on an aircraft. We come at it from little bit different perspectives.

What?

Dr. Kathy Crane: I did aircraft work in Kenya.

Dr. Peter Vogt: She did the airborne heat flow work. They'd drop a heat flow probe and circle around until ....

Dr. Kathy Crane: No, I didn't. [giggles] I flew over Masai in Kenya.

Dr. Peter Vogt: Kathy's done everything. It's hard to best her.

Dr. Kathy Crane: No I haven't done everything.

Dr. van Keuren: Is there any way you could pinpoint in which, as a result of this being an American and Russian cruise, it has differed from what a purely American cruise would have been like with the same objectives?

Dr. Peter Vogt: We've already touched on some of that. I think, partly for economic reasons, we are unable to bring .... I say, for economical reasons, we would not have a ship that is a floating laboratory like the JOIDES RESOLUTION or that the GLOMAR CHALLENGER was, and this ship is. (A) because our ships aren't big enough. That's part of the reason but also the high labor costs, the high insurance costs, the high ship costs. Everything is so prohibitive that we tend more to go out and do a specific thing like running the ship back and forth, pulling along the SEAMARK, without having a large number on people aboard. So that's the difference.

Dr. Kathy Crane: People came for a month and then left, at the end of the month. American expeditions. People flew into port, and then flew out again after a month. Then a new team came in. Imagine people riding the ship for six months.

Dr. Peter Vogt: That's a big difference there.

Dr. Kathy Crane: You need a big ship.

Dr. Peter Vogt: It becomes more like a home, like the Russian or Soviet era ships were more like home. They stayed out for months, even up to a year at a time. It would be unthinkable [for an American ship]. There are union laws that prevent that. I think, now the typical cruise is a month, or twenty-eight days for U.S. ships. So, that's a difference. From a cultural point of view, I haven't experienced as much cultural life on U.S. ships. I think people tend to be more insular, and they stay in their staterooms. Your experience has been different [speaking to Kathy Crane]. My experience has been not to have any parties or have very little in the way of parties or the cultural things we've had, like giving Russian lessons and things like that. It makes the life out here more complete. And the lectures. If you have enough scientists, then you can have lectures and that's a new experience. Only on the GLOMAR CHALLENGER did we have scientists give talks because there were enough. My experience has been, going to sea, is I'm the chief scientist, and I have four or five or six people working with me, and there were no, maybe one or two, people that could be called a scientist, and so we weren't giving lectures, and weren't having parties, or any of it.

Dr. Kathy Crane: On a navy ship?

Dr. Peter Vogt: Well, yeah. NAVOCEANO, and NRL ships, and so forth. Also I mentioned this before, NRL, for economic reasons, lost its last ship in the year 1982. So, in a way, we were in a similar kind of boat, if I can use a bad, ironic pun there, as our collegues in Russia. Starting already -- not now, not 1996, but fourteen years ago -- we no longer had our own ships, so we had to start working on other peoples' ships, which also makes a big difference if you have your own ship or not.

Dr. Georgiy Cherkashev: You said about the seminars. I remember there is an educational aspect of our expedition. We have a team of students, international students team, of ten persons.

Dr. Peter Vogt: Yeah, total.

Dr. Georgiy Cherkashev: It's very important for them, for their future work, and for science in Russia and in Norway.

Dr. Peter Vogt: Yes. Absolutely so. We not only have a floating mini-laboratory, but we have a floating mini-university. The LOGACHEV University.

Dr. van Keuren: I'd like to throw that same question back at Gosha. Has the presence of Americans on this ship in any way changed what it would have been like if it had been a purely Soviet, or let me say Russian, trip.

Dr. Georgiy Cherkashev: Not a lot. It was a usual atmosphere on the cruise, but usually it [there] was some influence of guests. It is traditionally in Russian's character: If you have a guest the best for them and for us. It was the Soviet time, and now too, foreigners for us was some exception. But now when the differences between us are less and less this is not an unusual situation for us. We work together with Finish specialists and with Americans and French, so this is not very different than if it were pure Russian cruise. It's more concentrate of science because it's very good that we enrich each other by our knowledge. This is very important to us, this cooperation.

Dr. van Keuren: Will we see more of this sort of international scientific cooperation? Particularly between Russia and America?

Dr. Georgiy Cherkashev: Sorry.

Dr. van Keuren: Will we see more of this type of international cooperation between the Americans and Russians?

Dr. Georgiy Cherkashev: It depends, but I hope it will be. It must be.

Dr. van Keuren: Kathy, Peter. Any comments on that?

Dr. Kathy Crane: Well, I hope so. I've been working for four years trying to build Russian-American collaborative programs. I think it's extraordinarily important for world peace. That's why I'm really interested in this, this whole effort. I don't approach this just as science objectives. To be quite honest, I'm more interested in the international relations aspect of it, between Russia and the United States. It's far reaching. So, I hope that in this next year .... I intend to work on getting follow-up expeditioms that will be collaborative programs going between us.

Dr. Peter Vogt: It would be great if it were possible to set up a longer term collaboration so we don't go through all these machinations for just a single cruise, but we [would] have, for example, a five year plan, and we've planned a number of cruises. Maybe one every other year, maybe one every year, maybe a smaller one and a big one, and there's some continuity to it instead of a one shot effort like this. That would be my wish. It would be terrific if we could convince funders to do that.

Side 2

Dr. van Keuren: What follows on after the cruise of the PROFESSOR LOGACHEV? What's next?

Dr. Georgiy Cherkashev: For the ship?

Dr. van Keuren: For the ship.

Dr. Georgiy Cherkashev: For our team?

Dr. van Keuren: For the team.

Dr. Georgiy Cherkashev: For the team. I hope they'll continue our relations, and we'll begin to process this data which we received, and we have some plans for the near future and for next year, not only connected with this material but new research.

Dr. van Keuren: Can you get me more details on this?

Dr. Georgiy Cherkashev: Maybe Peter can say better.

Dr. Peter Vogt: Well, in the first place what we plan to do is work collaboratively on the data and, as you know, the final product should be a series of co-authored scientific publications in the best scientific journals that are most widely read. That's objective number one. What we would also like to, what we will probably start to work on right away is planning for some kind of a workshop which we might host in the United States. It would be logical to have it in Washington because most of us are located there. So, we have tossed out, first as a joke, and then we thought more seriously about it, is to have a workshop maybe next year in connection with the American Geophysical Union meeting in Baltimore and to have some Russians from this expedition go there and present their results. I, half in jest, suggested that the ship should come across the Atlantic to the United States. I think that would be a great thing if we could pull that off. I guess I'm drunk with success. We were able to do this so I figure if I can do this, we can get the ship over there, which would solve some other problems, like the cost of putting people up and the transportation. If we could think of some creative, fundable project for them to do in the Atlantic and bring them over as a part of the research cruise in the Atlantic. Again, I don't know if we can do it in time for the next A.G.U. It's less than a year from now. Something like that would be a terrific coup. Of course, we would plan to take some trips to Russia also, Kathy and I, to follow up.

Dr. van Keuren: [To Kathy Crane] What's next?

Dr. Kathy Crane: Funding. Right now we have a program, Gosha and I have a proposal, for collaborative work-up of the data. It's through a program called -- I forget what it is. Civilian Research or something.

Dr. Peter Vogt: CRDF.

Dr. Kathy Crane: Defense Foundation. Money particularly to go to Russian scientists working with us. Whether or not that's funded I don't know. We should find out soon. Another plan we have would be the use of Russian submersibles, the MIRs, on certain of these targets in the next year, and I know they are very interested in this. Whether or not that would involve some very interesting juggling of money, raising money from, I think, several different countries and organizations. That's what I can perceive right now as being follow-up. Then we also have this additional program of which many people here are involved. That's the International Arctic Environmental Program, which is not related to this, but there's overlap between the institutions. That may, or may not, have on-going funding within the next year, and, if so, it would have a major impression on my salary, and I know a lot of other Russian salaries could benefit from that too. A lot of these things are just up in the air. Election year in the U.S. and directions -- you don't really know which way things are going. Maybe things will have resolved themselves this last month while we have been gone, I don't know. But we have made efforts before the cruise for continuing funding. We'll just have to wait and see, I think, right now.

Dr. Peter Vogt: Then, we're also considering the possibility of coming out here to collect deep sea ooze and marketing it in New York City as a medicinal ointment. Dr. Kathy Crane has plans to have this material tested for its toxicity. There are rumors around which we can deny and therefore make them vettable. It will prolong life and verility, and maybe we can get the Chinese to buy deep sea clay from us instead of shooting rhinoceroses for their horns. So, those are my closing thoughts.

Dr. Kathy Crane: Fifty dollars for a five ounces, I'm sure. No problems.

Dr. van Keuren: Any other closing thoughts?

Dr. Kathy Crane: It's been a lot of fun for me. Normally when we go to sea on American ships it's just so exhausting because you have to do everything. We never have parties and never have any fun at all. So I just feel exhausted after an American expedition and during them. Before, during, and after.

Dr. Peter Vogt: Not to speak of the HAAKON MOSBY.

I do have one final thought, and there are not all oceanographers that have iron stomachs. There are many times in my life when I have regretted ever becoming involved in ocean research, but when the storms end and you go back you forget all that stuff, and then you go out again.

[Dr. Kathy Crane: Except on a Norwegian ship.]

Particularly the HAAKON MOSBY, which is the ship we used for the SEAMARC work. We had to pay the dues to collect those data, the SEAMARC data, which really formed the basis of this follow-up.

Dr. Kathy Crane: You can't find a whole month of ....

Dr. Georgiy Cherkashev: We were very lucky with the weather. It was a gift of Neptune, I think, for us for our cooperation, for the science. We should continue our efforts.

Dr. van Keuren: Thank you very much.

33. Charles Votaw

Notes Prepared by Fred Erskine on a Recorded Telephone Interview with Mr. Charles W. Votaw held on Friday 20 March 2009 at 2:00 PM EDT (1 hour 15 minutes)

Early Life and Education

Mr. Charles (Charlie) Wharton Votaw was born in St. Louis, Missouri in 1930. His father died when he was two years old. His mother then had four children to parent, but she was able to find a government job at an Army base. Later she moved to Washington, DC and worked for the U.S. Treasury Department in the Procurement Division that purchased all the pencils, paper and similar supplies for the entire U.S. government. About the time Charlie was in first grade he joined her and they lived in an apartment in southwest Washington, DC. Most of his schooling was in Washington, DC and he finished high school at Central High School. He then enrolled at Purdue University in Indiana where he received a B.S. degree in mechanical engineering in 1952.

Employment at NRL's Sound Division in 1952

Following college, Votaw was obligated to enter the military. He attempted to obtain a commission in the Navy but was told that he did not have the required 20-20 vision. His brother, Martin Votaw, had started work at the Naval Research Laboratory about five years earlier in the Radio Division and Martin suggested that Charlie apply for a job at NRL while waiting for further word from his draft board. Charlie also had a brother-in-law, Roy Larson, working at NRL in the Radio Division who encouraged him to consider employment at NRL. Charlie was offered several possible positions at NRL. One potential position was to design enclosures for the NRL Linear Accelerator. A more attractive position was to work under Isidore Cook in the sonar dome section of the Sonar Systems Branch that was headed by Chester Buchanan. Charlie accepted this position in the Sound Division in September 1952 and began testing sonar domes using a sound barge (the YFNX-13) on the Potomac River at the end of the NRL pier. The early rubber domes were not holding up well, so they were testing ones made of metal and plastic. The barge had a large enclosed area from which equipment could be lowered into the river for testing. In the early 1950s the Potomac River was fairly clean and it was enjoyable to work in the sound barge. Later, the river became polluted and the sound barges were eliminated in favor of more distant testing sites. Among the early projects that Votaw worked on was the design of a sound repeater system to determine transducer directional pattern characteristics. The results were presented as a polar plot on chart paper. Various materials were tested for both sound transmission and reflection properties for use in domes. Votaw also participated in at-sea experiments on ships to test actual prototype sonar domes. He recalled riding ships from places such as Cuba back to the U.S. while peering through small windows in experimental domes to ascertain whether cavitation phenomena were causing acoustic noise problems. Votaw collaborated with researchers at the David Taylor Model Basin (DTMB) in Carderock, Maryland to better understand the solutions to cavitation problems. Votaw also worked on designing enclosures for towed acoustic transducers and arrays.

Graduate Studies in California in the Late 1950s

Votaw recalled some of the persons he worked with in NRL's Sonar Systems Branch during those early years. These included Al Gotthardt, Raphael Cahn, and Isidore Cook. Both Cahn and Cook went to work at DTMB around 1955 or 1956. Around the mid-1950s NRL received an invitation from Commodore Schade (who previously had been NRL's Commanding Officer) via ONR to send several researchers to the University of California at Berkeley to study naval architecture. The first candidate chosen for this graduate study program was Jim Rigdon, another one of Votaw's colleagues in the sonar dome section. As it turned out, Rigdon declined this opportunity and NRL suggested that Votaw apply. After sending in the application materials in 1957, Votaw did not receive an immediate reply from the University. In a bold move, knowing that classes would start very soon, Votaw decided to send off a letter stating that he was "on his way," then he drove to California. When he arrived, the dean at the University said they were going to turn down Votaw's application, but since he had already arrived on campus he could take one year of undergraduate courses and would remain on probation for that period, pending admission to the graduate school. After one semester he was admitted to the Naval Architecture graduate program and he continued those studies for another year and a half. He graduated with an M.S. degree in naval architecture in 1959. While he was at the University of California, Votaw met some other students who had come from the Naval Electronics Laboratory in San Diego. Several of them had worked with Waldo Lyon of the Polar Research Center and had told Votaw about Lyon's Arctic research efforts. Votaw had an opportunity to meet Lyon shortly after his pioneering voyage in the USS *Nautilus* under the Arctic ice.

Return to NRL's Sound Division Research in the 1960s

By the time he returned to NRL after his graduate studies, the Potomac River had become quite polluted and it was no longer feasible to conduct testing on the sonar barge due to the health hazards. Upon his return to NRL, Votaw was assigned projects under Jervis (Jerry) Gennari in the Sonar Systems Branch for a few months. The tasking that was assigned by Gennari seemed too mundane for Votaw and they did not work well together. Votaw consulted with the Superintendent, Dr. Harold Saxton, who suggested that Votaw write a plan for a research program that could make best use of his new graduate school training. Upon examining this plan, Saxton decided to assign Votaw to the Propagation Branch under Dr. Steinberger. This worked out very well and Dr. Steinberger was an excellent mentor who gave Votaw a great deal of freedom to start his new research project. In some respects, initially Votaw was in "over his head" with difficult technical problems. One of the technical issues was to find the mechanism responsible for "singing propellers." This is a hydro-elastic phenomenon that is quite complex to understand. Votaw decided to try to understand better the "forcing function" that involved the shedding of vortices at the edges of the propeller blades. He went back to basics by studying the performance of right circular cylinders. He then studied the hydro-elastic vibrations of a simple wire. He got excellent data sets including good photographs. However, Votaw was not able to develop an adequate mathematical description of the physical phenomenon. He continued by studying the vibration damping of very thin cylinders that were basically one layer of aluminum foil placed in a vacuum to eliminate the effects of aerodynamics. The instabilities generally happened only over a small range of Reynolds numbers. Votaw next began studying the effects of rotating flat plates in water including ones with small holes in them. The plates easily went into a singing mode much like a saw blade. NRL and ONR began to suggest that the research of Votaw involved more hydrodynamics than acoustics and that perhaps it belonged under the NRL Mechanics Division. Votaw, however wanted to remain in the Sound Division. Eventually progress was made in understanding that the "singing propeller" effects could be greatly reduced by sharpening the trailing edges of the blades. This general problem had been the subject of considerable research in NRL's Sound Division prior to World War II and good progress had been made at that time on simple propeller shapes. However, the reason this became a subject of research again in the 1950s was because of the development of more complex five-bladed submarine propellers. One of Votaw's Sound Division colleagues, Owen Griffin, decided to move to the Mechanics Division to continue some of this research and Votaw moved on to other research topics.

NRL Arctic Research in the 1970s

Around 1970 Votaw's next area of research was Arctic studies under Burt Hurdle in the Propagation Branch that was headed by Ray Ferris for a short while before Hurdle became Branch Head. Votaw's initial foray into Arctic studies was to participate on a two-month research cruise on the fast attack nuclear submarine USS *Hammerhead* (SSN-663) under the ice to the North Pole. Votaw's project on this cruise was to record under ice echo returns (reverberation) from the forward looking sonars. He had a borrowed four-channel analog tape recorder with differing gains for each channel. Votaw was the only NRL researcher on the cruise. After returning to NRL, Votaw and colleagues had great difficulty making sense of the recorded data and they were not able to completely sort out the reasons for this. On the cruise Votaw was able to collect water samples and oceanographic information of importance to other Navy researchers. The scientific contingent on the cruise consisted of just four persons including Votaw, Dr. Waldo Lyon, and two other researchers from the Polar Research Laboratory in San Diego. Votaw recalled that Lyon's laboratory on Point Loma was an impressive facility. It had a very large "freezer" that was capable of freezing a swimming pool's volume of water to a depth of six feet, but it required a large amount of electric power. Eventually the Navy decided to close that facility.

Next, Votaw participated in sea tests in the vicinity of the marginal ice zone. These sea trials were known as NEAT-I and NEAT-II (Northeast Atlantic Tests). The chief scientist was Dr. Ralph Goodman and Burt Hurdle was the assistant chief scientist for these experiments that were intended to measure ambient noise and propagation loss. Votaw participated on board the USNS *Mizar*. In experiments of this type Votaw became very involved in the logistics and sea test preparation to make sure the NRL team was fully prepared. These experiments became increasingly applied towards "real world" goals as opposed to Votaw's more basic research experiments earlier in his NRL career. These tests were more like engineering tests than science experiments. They collected a large amount of good data but the underlying science was often difficult to extract from these types of rather applied experiments. This situation improved considerably around 1979 when they hired Dr. T.C. Yang who was very adept at designing experiments and extracting the key scientific results from the data sets. Many of the Arctic experiments provided results that were later incorporated into Burt Hurdle's book *The Nordic Seas*. There was considerable angst among some of the researchers who wanted their results to be published because this book took much longer than expected to finish. Portions of the book were completed by Hurdle during a scientist exchange visit to the United Kingdom. In the 1980s the NRL Arctic researchers participated in frequent experiments on the ice in the central Arctic. NRL frequently collaborated with several other nations on Arctic research, including Canada, Norway, and the UK.

Miscellaneous thoughts: Votaw assisted in the search for the USS *Scorpion* in 1968 by working for about a month at the Woods Hole Oceanographic Institution (WHOI) on data plotting and interpretation. Votaw recalled that he had some interactions in the 1970s with scientists at the Maury Center that was on-base at NRL. One of those scientists who later came to the Acoustics Division was Dr. Orest Diachok.

<u>Post-NRL Career and Retirement</u>
Around 1989 Votaw transferred from NRL to the Office of Naval Technology to work under A.J. Faulstitch and Phil Selwyn managing applied research efforts for the Navy. Several years later he retired from government service, but continued supporting ONT efforts as a private industry contractor at Mandex, Inc. In 1994 Votaw fully retired and moved to North Carolina where he currently resides.

34. T.C. Yang

Notes Prepared by Fred Erskine on an In-Person Recorded Interview with Dr. T.C. Yang held at NRL on Thursday 9 April 2009 at 1:30 PM EDT (1 hour) [Revised by Dr. Yang 24 July 2009]

Comments on Early Life and Education

Dr. T.C. Yang was born in 1943 in Zhejiang Province, south of Shanghai in China. At age four years his family moved to Taiwan. He attended Taichung First Middle School (grades 9 to 12). He then attended Tung Hai University for four years and graduated in June 1965 with a B.S. in physics. In 1966 he moved to the United States to pursue graduate studies in high energy physics at the University of Rochester. He worked under Professor Robert Marshak and Professor Mathur and he received a Ph.D. in elementary particle physics in 1971. For the next eight years he conducted research via a series of two-year post-doctoral appointments in theoretical physics at various institutions including the University of California at San Diego, the University of Maryland, Deutsches Electron Synchrotron Laboratory-DESY (in Hamburg, Germany), and the University of Massachusetts at Amherst. During that eight-year period Dr. Yang published approximately 32 peer-reviewed scientific papers for which he was generally the first author.

Early NRL Career and Arctic Research

By 1979 Dr. Yang was seeking a permanent position. He had known Dave Palmer during the graduate school years in Rochester, NY. By 1979, Palmer was working in the NRL Acoustics Division's Applied Ocean Acoustics Branch (Code 8120, headed by Raymond Ferris) on propagation studies. Palmer introduced Yang to Charlie Votaw of that branch who immediately offered him a job without an interview. [As an aside, Dr. Yang stated that for all the jobs he has ever held he has never had to undergo a job interview]. Yang started work at NRL (on the fourth floor of Building 1) in September 1979 to conduct studies on Arctic acoustics. Others in the Arctic group besides Votaw (group leader) and Yang included Norman Dale and Bob Lee. Yang became immediately involved in the planning and execution of Arctic experiments. His first experiment (FRAM II) was conducted in the spring of 1980 in the central Arctic using sonobuoys as receivers and light bulbs as deployed acoustic sources to measure under ice scattering. Yang and Votaw published the results in the *Journal of the Acoustical Society of America* (*JASA*). This was the first published paper using light bulbs as impulsive acoustic sources, to the best of our knowledge.

Yang's next Arctic experiment was FRAM IV around 1982. In this sea test NRL collaborated with Massachusetts Institute of Technology (MIT, under Ira Dyer, Art Baggeroer, and Peter Mikhalevsky), the Woods Hole Oceanographic Institution (WHOI), and Columbia University (Hank Kutschale and Charles Monjo). In FRAM IV NRL deployed a long vertical array of hydrophones through the ice (32 elements; total length around 600 meters). Researchers from MIT and WHOI deployed an L-shaped horizontal array of hydrophones. The FRAM IV experiment was designed to investigate ambient noise as well as normal mode propagation properties at low acoustic frequencies (generally below 500 Hz). Yang and colleagues performed matched mode analyses on the data as well as mode decomposition studies. Extensive use was made of impulsive acoustic sources for source localization using acoustic dispersion analyses.

After 1982, NRL's Arctic program was focused on 6.2 aimed at potential naval applications. The collaboration was mostly with Naval Ocean Systems Center (San Diego), the Polar Research Center (under Beau Buck at Santa Barbara, California), and with the Navy's AEAS program. Around 1985 NRL developed an ice-mounted volumetric surveillance array concept and produced a prototype array for evaluation. The array consisted of about five vertical strings, each having about eight hydrophones deployed to a depth of about 100 meters. Under ONR support, with the Naval Ocean Systems Center (NOSC) as the lead laboratory (under Mike Morrison), several additional tests were conducted, using improved hardware and software, with encouraging successful results. This array project transitioned to the operational Navy around 1989.

Afterwards, NRL continued its involvement in Arctic research under an ONR advanced development project known as Spinnaker that was led by Barbara Sotirin of NOSC. The acoustic array was a bottom-mounted array that was U-shaped, with one horizontal leg and two vertical legs. It was cabled all the way to the shore. Several experiments were conducted using this array concept from northern Canadian waters that were not too deep. These tests were performed in collaboration with Canadian colleagues from the Defence Research Establishment Pacific (DREP) and they always included measurements of transmission loss. The testing included the use of ice-mounted geophones as well. This project lasted about five years. Dr. Yang's last time for his direct participation in these experiments on the ice was around 1991, with data analysis continuing until about 1994. The scientific results were published in various journals including *JASA* and the *US Navy Journal of Underwater Acoustics*.

Mid-NRL Career

Around 1995 Dr. Yang received NRL exploratory development "base" funding to begin studying the feasibility of matched-beam processing concepts. Several years later Dr. Yang received ONR funding support from Dr. John Tague of ONR to further mature the matched-beam processing concepts for possible transition to the operational Navy. Dr. Yang collaborated on these developments with researchers from the Naval Undersea Warfare Center Division Newport including Judith Bishop.

Around 1998 Dr. Frank Herr of ONR provided seed funding for Dr. Yang to begin investigations on underwater acoustic communications (ACOMMS). NRL was to examine ACOMMS technology on Decision Feedback Equalizers (DFE) that was under development by WHOI researchers. By about 1999 Dr. Yang initiated a new three-year NRL-base-funded exploratory development project to study the impact of the ocean environment on ACOMMS. Noting that each ocean area has somewhat different acoustic multipath propagation characteristics that depend on the ocean bottom composition and roughness as well as variations with time of day and season and sea state, the challenge is to understand under what conditions the WHOI ACOMMS DFE processing methodology failed to work. It was concluded that the WHOI algorithm was not sufficiently flexible to learn the acoustic channel characteristics. To be successful, the WHOI algorithm required an expert in the loop. Making the acoustic modem work autonomously is a challenging technical problem that was not yet fully solved.

Recent NRL Career

In 2002 Dr. Yang initiated another three-year NRL-base-supported ACOMMS project that was supportive of ONR's new Future Naval Capabilities (FNC) advanced development project of Tom Curtin on Autonomous Operations. It was agreed upon that NRL would investigate mid-frequency (MF: 2–5 kHz) effects while ONR's investigators would investigate high-frequency (HF: 15–25 kHz) effects. NRL was able to develop the first mid-frequency algorithms that were very robust and could be automated. It is called the correlation-based equalizer, which couples the time reversal physics with the signal processing. Among ONR's leading technical performers on the FNC project were researchers from NUWC. It has remained a challenge to convince NUWC colleagues on the advantages of the NRL algorithms.

In 2005 Dr. Yang initiated a new three-year NRL-base-supported ACOMMS project on high frequency underwater acoustic communications for unmanned underwater vehicles (UUVs). The HF channel fluctuates rapidly with time and is presented with many scattered returns due to sound scattering from the rough surfaces or turbulences; in some channels, the signal coherence time is very short (0.1–1.5 sec). WHOI always used the same algorithms for processing at MF and HF. But they were limited to processing of only about 5000 symbols, corresponding to about 5 seconds at MF and about 1 second at HF. NRL developed an autonomous processing algorithm that permits communications for about 20 seconds by tracking the temporal variations of the acoustic channel. The algorithm works by dividing the data into blocks where the correlation based equalizer is coupled with channel estimation, and is processed iteratively to improve the bit error rate. NRL participated in the Navy's "UUV-Fests" in 2005 and 2007. Dr. Yang has also developed methodologies for covert underwater acoustic communications. Dr. Yang's group has also participated in recent international experiments under the auspices of The Technical Cooperation Panel's (TTCP) Maritime Systems Group (MAR) Technical Panel Nine (Undersea Warfare) Undersea Networking Specialists (UNET-06 and UNET-08). Dr. Yang's NRL collaborators on all the recent ACOMMs experiments included Dr. Wen-Bin Yang, Dr. Jeffrey Schindall, Dr. Paul Gendron, and Michael McCord.

In 2008 Dr. Yang initiated a new four-year NRL-base-supported project on Multiple Input Multiple Output (MIMO) acoustic communications. The MIMO methodology enables one to increase the data rate in proportion to the number of transducers or sources used. If one has eight sources one can talk, in principle, to eight UUVs at the same time. This project, augmented by a NRL Capital Equipment Purchase (CPP) award, has enabled Dr. Yang to acquire a new acoustic source and receiver array. The initial proof-of-concept experiment on the MIMO technique is to be demonstrated in May 2009 on the New Jersey Shelf, where the data rate should increase eight times by eight sources using code division multiple access (CDMS) signals (which it does). The goal of the experiment is to determine the MIMO multiplicity gain and diversity gain. MIMO is a very difficult problem.

In 2010 Dr. Yang's group will begin execution of an NRL base-supported low frequency (LF) ACOMMs project that will complement the earlier work done at MF and HF. There will be a parallel effort on LF ACOMMs supported by ONR. The experiments will be managed by ONR. This project will be oriented towards deep ocean studies. The communication ranges of interest will be around 3000 km.

<u>Other Projects</u>

In addition to the work by Dr. Yang and colleagues in the past several decades on Arctic acoustics and ACOMMs techniques, this group has conducted investigations on other topics related to underwater acoustics. Over a seven year period, Dr. Yang led two back-to-back NRL-base-supported exploratory development projects on passive geoacoustic inversion techniques for towed acoustic arrays in littoral oceans. This project has now ended, but the methodology was successfully demonstrated using data collected by colleagues at the NATO Undersea Research Centre (NURC). Another NRL-base-supported project that has been executed by Dr. Yang's group (2007–2009) is called Acoustic Dopplergrams for Intruder Defense. This project is oriented towards harbor defense applications.

<u>Conclusion</u>

Dr. Yang underscored that the NRL Acoustics Division has been a great place to work and perform research. He has had the freedom to explore innovative ideas from both the theoretical and experimental approaches. He has found that the NRL Research Advisory Committee (RAC) has been quite supportive of his team's efforts and has permitted the establishment of multiple follow-on projects that have built on earlier research, but have delved into new frontiers. The research collaborations with other Navy organizations as well as international partners have been particularly fruitful and have resulted in much cost sharing as well. In his final remarks, Dr. Yang commented that he hopes to retire in a few years. It has been a problem to hire and train younger researchers that can carry on the type of research conducted by his group. In the present era there is increased pressure for researchers to submit research proposals for projects that will be "groundbreaking" and "cutting-edge." There is little opportunity for young researchers to spend the many years needed to also become thoroughly familiar with the "fundamentals." [In underwater acoustics research (e.g., sonar propagation, sonar signal processing, etc.) one needs to spend many years learning the basics such as propagation in random media, such as how to do experiments properly, etc.] New researchers who are coming on board may not be as aquatinted with all the underlying science and engineering art of doing complex at-sea experiments as those who had the freedom to learn on-the-job in decades past, and may not be familiar with the extensive past research accomplishments of the Acoustics Division. This situation has been exacerbated by the government hiring freezes of the past several decades.