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ARCTIC/COLD WEATHER OPERATIONS SYMPOSIUM

Proceedings Of

1985
U.S. NAVY SYMPOSIUM

on

ARCTIC/COLD WEATHER OPERATIONS OF SURFACE SHIPS

Sponsored by

DEPUTY CHIEF OF NAVAL OPERATIONS
FOR
SURFACE WARFARE

Approved for Public Release: Distribution Unlimited

3-4 December 1985

DEPARTMENT OF THE NAVY
OFFICE OF THE CHIEF OF NAVAL OPERATIONS
WASHINGTON, DC 20350-2000

IN REPLY REFER TO

RE: U.S. Navy Symposium on Arctic/Cold Weather Operations of Surface Ships

Gentlemen:

The purpose of the U.S. Navy Symposium on Arctic/Cold Weather Operations of Surface Ships was to discuss the operational and environmental conditions of arctic/cold weather surface ship operations and their impact upon ship systems and tactics. As stated by RADM Storms in his luncheon speech - "a necessary part of our defense strategy is the ability for our ships to operate under cold conditions as well as in the northern regions adjacent the the Arctic and in the marginal ice zone. Based on our limited operations in the Arctic thus far, we have observed a number of problems that must be overcome if we are to successfully send our ships into Arctic waters on a routine basis." As stated by RADM Mooney in his keynote speech - "The strategic importance of the Arctic is increasing. Soviet capabilities, coupled with the extensive deployment of Soviet surface ships and submarines in the Arctic/Subarctic Oceans near Europe make the region an area of growing importance to both commercial and strategic defense interests of the United States." Accordingly, preparedness on the part of the United States is mandatory. The surface fleet must continue to conduct Arctic exercises on a regular basis to become familiar with the special environmental problems of Arctic regions.

It has been our attempt during this Symposium to gather representatives from the Government, academia, and industry to help us prepare for these types of operations. We believe that there is a great deal of information and experience already available that can be applied to our surface combatants. We want to use this repository of knowledge to help us prepare for Arctic operations in the most expeditious and efficient manner possible.

Hopefully, this Symposium will be only the first of a series of periodic operational and technical meetings designed to assist us in our cold weather operations. We have tentatively scheduled a second symposium for the Spring of 1987.

CAPT Robert K. Barr Jr., USN
Head, Surface Ship Survivability Office
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U.S. NAVY SYMPOSIUM ON ARCTIC/COLD WEATHER OPERATIONS OF SURFACE SHIPS

AGENDA

TUESDAY, 3 DECEMBER 1985

0800-0900 Registration, Sheraton

0900-0915 Opening Remarks - CAPT Robert K. Barr, OP-03C2

0915-1000 Keynote Address - RADM J.B. Mooney, Jr., Chief of Naval Research

1000-1015 Break

Moderator - James U. Kordenbrock, OPNAV

1015-1045 Overview of the Cold Weather Program, Mr. J.U. Kordenbrock, OP-03C2

1045-1110 Arctic Environment - Mr. Jerry Reshew, NOAA

1110-1135 Seaway Performance Improvement Program - CDR R.B. Bubeck, NAVSEA

1135-1200 Four Recent Encounters with Topside Icing - Mr. Peter Zahn, ARCTEC

1200-1315 Lunch - Speaker - RADM James G. Storms, III

1315-1340 Operational Experience - SHAREM 55 and 62 - LCDR J.R. Oakes, SURFLANT

1340-1405 Operational Experience, U.S. Coast Guard: High Latitude Operations - A View from the Bridge, CDR L.W. Brigham, and Ship/Helo Interface, CAPT Patrick A. Wendt, USCG

1405-1430 Considerations for Propellers and Propulsion Plants Operating in Northern Latitudes - Mr. E.J. LeCourt, ARCTEC

1430-1445 Break

1445-1510 Status of Cold Weather Operations of Combat Systems - Mr. H. DeMattia, NAVSEA and CAPT Donald M. Budai, NAVSEA

1510-1535 LAMPS MK III Environmental Capabilities - CDR John Olmstead, NAVAIR

1535-1600 Engineering Analysis of Anti-Icing of RAST and Trough for HELO Operations - Mr. David Boston, NAVSEA

1600-1625 Underway Replenishment in Cold Weather (Port Hueneme) - Mr. George Lyon, NSWSES

1625-1650 Degradation of Surface Ship Operations in Arctic/Cold Weather Environments - Ms. Susan L. Bales, DTNSRDC

1650-1750 Project Updates

1800-1930 Cash Bar

1930-2100 Dinner - Speaker - RADM John R. Seesholtz

WEDNESDAY, 4 DECEMBER 1985

0800 Coffee

Moderator - James U. Kordenbrock, OPNAV

0830-0855 Sea Ice Spray - Mr. Steve Ackley, CRREL

0855-0920 Anti-Icing and De-Icing of Naval Surface Ships - Mr. George Garbe, TRACOR

0920-0945 Prevention and Retardation of Ice Formation at Sea - Mr. David T. Minasian, C.W. Estes, Co.

0945-1010 Break

1010-1035 Ice Strengthening for Naval Combatants - Mr. R. Chiu, DTNSRDC

1035-1100 Cold Weather Clothing - Mr. Richard Wojtaszek, NCTRF

1100-1125 Arctic Surface Warfare Hovercraft Program - Mr. Jim Schuler, E&SA

1125-1150 Shipboard Icing Experiments - Mr. Robert Rogalski, DTNSRDC

1200-1315 Lunch - Speaker - Office of Ice Operations, USCG (Speaker to be announced)

1315-1340 Hull Stress Monitoring System for Arctic Ships - Mr. John Carter, German and Milne

1340-1445 Project Updates

1415-1430 Break

1430-1600 Future Plans - Open Discussion, Panel Members:

- CAPT R.K. Barr, OPNAV
- CDR O.W. Spahr, OPNAV
- Mr. A. Johnson, NAVSEA
- Mr. J.U. Kordenbrock, OPNAV
- Ms. S. Bales, DTNSRDC

PROJECT UPDATES FOR DECEMBER 3

Time	Subject	Presenter/Affiliation
1650	Current Arctic Programs at the U.S. Army Cold Regions Research and Engineering Laboratory	Dr. K.F. Sterrett
1655	Great Lakes as a Laboratory	John Bannan, CDR, USCG Ice Operations Division
1700	Naval Arctic Environmental Support	Warren W. Denner, SAIR
1705	Northern Latitude Logistic Support	Don Kover/DTNSRDC
1710	Superstructure Icing: Non-suitability of Current Forecasting Aids for Navy Ships	Richard Jeck, Naval Research Laboratory
1715	CG-47 Class Cold Weather Studies	John D. Crowley/ Bath Iron Works Corp.
1720	Spray Ice Bonding to Super-structure Coatings	Prof. W.M. Sackinger Geophysical Institute University of Alaska Fairbanks, Alaska 99775-0800
1725	Gas Turbine Intake Deicing	Glenn Reinauer Marine Project Engineer Hamilton Standard
1730	Cold Weather Protection of Weapon Systems using Self-regulating Heaters	Michael Watts Raychem Corporation
1735	Commander Operational Test and Evaluation Force Arctic Concerns for New Systems	CDR Steve Schrobo

PROJECT UPDATES FOR DECEMBER 3 (Cont.)

Time	Subject	Presenter/Affiliation
1740	Arctic Vessel Research Laboratory and Program	M. Jeffrey, Director National Research Council of Canada Institute of Marine Dynamics
1745	Arctic and Antarctic Marad Polar Class Deployments	Larry Schultz ARCTEC Engineering

PROJECT UPDATES FOR DECEMBER 4

Time	Subject	Presenter/Affiliation
1340	Medical Cold Weather Program	Thomas J. Contreras, CDR Naval Medical Research and Development Command Bethesda, MD 20814-5044
1345	The Coast Guard's New Polar Icebreaker	Bob Williams Chief, Design Branch U.S. Naval Engineering
1350	Coast Guard Icebreaker - Current Operations	Dennis Sobeck, LT, USCG Ice Operations Division
1355	Ship Hull Ice Loads, The Ship Structure Committee Project on USCG Cutter Polar Sea	J. Coburn ARCTEC Engineering
1400	Modeling of Spray Ice Accretion Experiments	Prof. W.M. Sackinger Geophysical Institute University of Alaska Fairbanks, Alaska 99775-0800
1405	Ice Islands as Locations for Arctic Data Collection	Prof. W.M. Sackinger Geophysical Institute University of Alaska Fairbanks, Alaska 99775-0800

THE OPENING REMARKS OF
CAPT ROBERT K. BARR, OP-03C2
TO THE
U.S. NAVY SYMPOSIUM ON ARCTIC/COLD WEATHER
OPERATIONS OF SURFACE SHIPS

Good Morning Gentlemen:

I would like to take this opportunity to welcome you to the first Navy-hosted Symposium on Arctic/Cold Weather Surface Ship Operations.

The Assistant Deputy Chief of Navy Operations for Surface Warfare established a Cold Weather Working Group as part of the ship characteristics and improvement board, referred to as a SCIB, in order to address the problems of surface ship operations in an Arctic and cold weather environment. This working group was established in July of this year.

As chairman of this working group, I have presided over four group meetings since 1 August 1985. These meetings were conducted to bring together the various personnel responsible for the Navy aspects of arctic ship operations. Additionally, personnel from other government agencies and from industry have participated, as well as British and Canadian Naval personnel.

These meetings provide information on various cold weather topics and in turn solicit advice from the attendees knowledgeable in various aspects of Arctic and Cold Weather Operations.

I believe that symposiums such as this offer the opportunity for experts like yourselves to offer suggestions, criticisms, and advice to identify problem areas and provide direction to assist the Navy in its cold weather efforts.

We appreciate your participation in this Symposium and ask for your help in solving some of the shortfalls in our cold weather operations.

Thank you for coming and let me assure you that we appreciate your participation.

KEY PEOPLE

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KEYNOTE SPEAKER

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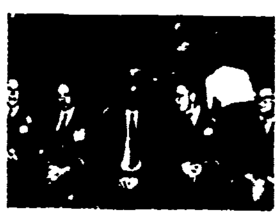
Asst. Dep. Chief of Naval Operations,
Surface Warfare (OP-03B)
LUNCHEON SPEAKER

RADM J. Richard Seesholtz, USN
Oceanographer of the Navy
DINNER SPEAKER

CDR John Bannan, USCG
USCG Ice Operations Divison
LUNCHEON SPEAKER

Mr. Joseph K. Taussig
Special Asst Secretary of the Navy,
Safety and Survivability
INVITED SPEAKER



(L-R): RADM Mooney (ONR),
RADM D.P. Roane (NAVSEA),
Mr. Taussig (SECNAV),
RADM Seesholtz (NAVOCEANO)
Capt. Barr (OPNAV)

BIOGRAPHIES

A native of Portsmouth, New Hampshire, Rear Admiral J.B. Mooney, Jr., was graduated from the U.S. Naval Academy in 1953. He is the 15th naval officer to be designated Chief of Naval Research. As Chief of Naval Research, Rear Admiral Mooney has responsibility for the Office of Naval Research, the Office of Naval Technology and the Department of the Navy's Research, Engineering and Development Centers and Laboratories.

He served as Officer-in-Charge of the bathyscaph TRIESTE II and the U.S. Navy Deep Submergence Group. He was at the controls of the TRIESTE II when, in 1964, it located the hull of the sunken submarine USS THRESHER on the floor of the Atlantic at a depth of 8,200 feet. He also served as advisor and coordinator of the deep submersible search and recover of the hydrogen bomb off the coast of Spain in July 1966. (He later was involved in search operations for the lost submarine USS SCORPION while serving as the Plans and Programs Officer for the Deep Submergence Program Coordinator in the Office of the Chief of Naval Operations, 1968-1971).

From the TRIESTE, Rear Admiral Mooney commanded USS MENHADEN (SS-337) in the Pacific, including two deployments in the Vietnam Combat Zone. Rear Admiral Mooney served on the CNO's Deep Submergence staff and, in 1971, became the Chief Staff Officer of Submarine Group ONE. He assumed duties as Commanding Officer of Naval Station, Charleston, South Carolina, in 1973, Deputy Director of Deep Submergence Systems Division in 1975, Commander of the Naval Training Center, Orlando, Florida, in 1977, and in 1978, became Director of the Total Force (Manpower, Personnel, and Training) Planning Division in the Office of the Chief of Naval Operations. From there he became the Oceanographer of the Navy in 1981, in which capacity he was serving when selected as Chief of Naval Research

Rear Admiral James G. Storms III, was born in West Palm Beach, Florida, on 16 August 1931. He attended Rensselear Polytechnic Institute in Troy, New York, under the NROTC Programs and was commissioned Ensign on 11 June 1954.

Following graduation he served in USS CHARLES R. WARE (DD-865) and USS NORTHAMPTON (CLC-1) until May of 1959 when he was assigned to the Office of the Chief of Naval Operations where he was the Plans and Program Coordinator for the Director of Naval Communications (OP-94). From May 1961 until May 1963, he served as Executive Officer of the USS BROUGH (DE-148), and in June 1963, returned to Rensselear Polytechnic Institute for his Masters Degree. He then served as Commanding Officer, USS FEARLESS (MSO-442), Executive Officer, USS SEMMES (DDG-18), and Commanding Officer of the USS VAN VOORHIS (DE-1028). In January 1969, he reported to Commander, U.S. Naval Forces, Vietnam and served as Commander, River Assault Squadron ELEVEN, Chief of Staff Officer of the FIRST SEALORDS, and as Task Group Commander of TG 194.4. After his tour in Vietnam, he attended the Armed Forces Staff College in Norfolk, Virginia, until August 1970 when he took command of the USS JOHN KING (DDG-3).

In May 1972 he returned to the Office of the Chief of Naval Operations and then attended the Industrial College of the Armed Forces. In July 1975, he reported to OPNAV as Programs Coordinator of the Strike Cruiser and DDG-47 programs, until August 1976 when he left to command USS ALBANY (CG-10). After leaving the USS ALBANY, as Commanding Officer, in November 1978, Rear Admiral Storms assumed the duties as Deputy Director, Combat Systems Division (OP-35), until March 1980 when he reported to duties as rector, Surface Warfare Manpower and Training Requirements Division (OP-39). Rear Admiral Storms served as Senior Member, United Nations Command Military Armistice Commission, Deputy Commander, Naval Component Command and Commander, U.S. Naval Forces, Korea from July 1981 to July 1983. From August 1983 to August 1985 he served as Commander, Naval Logistics Command, U.S. Pacific Fleet at Pearl Harbor, Hawaii. He reported as Assistant Deputy Chief of Naval Operations (OP-03B) in September 1985. Rear Admiral Storms was promoted to the rank of Rear Admiral on 1 July 1982.

Rear Admiral John R. Seesholtz is currently serving as Oceanographer of the Navy (OP-006) in the Office of the Chief of Naval Operations (CNO). He assumed duties as Oceanographer in October 1983. His duties include being the Naval Deputy to the Administrator of the National Oceanic and Atmospheric Administration (NOAA). He is a 1956 graduate of the U.S. Naval Academy and holds a 1968 Ph.D. in Oceanography from the Massachusetts Institute of Technology. He is qualified in both submarines and surface ships, has worded extensively in research and development efforts, and spent a tour as an airborne test director.

Rear Admiral Seesholtz previously served as Director, Command and Control Development Division (OP-986) in the Office of CNO. This division coordinates Navy sponsored development efforts in telecommunications, environmental sensing, and space systems.

From early 1980 to October 1982, Rear Admiral Seesholtz served within the CNO's Long Range Planning Group in Washington. This work included assessing the future technology environment and developing long-term guidance for Navy programs. He was also a member of the Corporate Boards of the Office of Naval Research and Office of Naval Technology.

During his career, Rear Admiral Seesholtz served Executive Officer of the submarines, USS TIGRONE and USS DOLPHIN, and subsequently as Commanding Officer of the DOLPHIN. The USS DOLPHIN is the world's deepest diving submarine. During his tour as Commanding Officer, deep sonar operations were undertaken which for the first time demonstrated the complete path of convergence zone sound propagation under unique oceanic conditions. Rear Admiral Seesholtz also commanded the repair ship USS AJAX (AR-6).

Captain Robert K. Barr is from West Palm Beach, FL, where he enlisted in the U.S. Navy in March 1951. His enlisted service includes tours at Recruit Training Center, San Diego; Damage Control Training Center, Treasure Island, San Francisco; USS PRAIRIE (AD15); Instructor Duty at Camp Elliott Retraining Command, San Diego, and USS GRAPPLE (ARS7), where Captain Barr served as a Chief Damage Controlman until commissioned a Limited Duty Officer in October 1961.

BIOGRAPHIES (CON'T)

Upon completing LDO Officer Candidate School at Newport, RI, in 1962, Captain Barr was assigned to USS CABILDO (LSD16) as Damage Control Assistant and Ballasting Officer. During the tour in CABILDO, he augmented to unrestricted line, then was assigned to CIC training at Glynco, GA, prior to proceeding to USS WALLER (DD466) as Operations Officer in July 1965. In March 1967, Captain Barr took command of USS ROCKVILLE (EPCER851), homeported at Little Creek, VA. In June 1968, he reported to Fleet Training Center, Norfolk, where he served as Director of Navigation and Leadership Training until October 1970, when he was assigned to the 3rd Marine Division, Okinawa, as the Staff Naval Gunfire Officer.

In April 1972, Captain Barr was assigned to the Naval Safety Center's Surface Ship Di-ectorate as Head of the Safety Information Division. He served as Executive Officer, USS HALEAKALA (AE25) in the Pacific Fleet from January 1975 until October 1976. He was assigned to the Atlantic Fleet Weapons Training Facility where he served as the Live Ordnance Range Officer at Vieques Island, Puerto Rico, from December 1976 to July 1978. In November 1978, he became Commanding Officer of USS PLYMOUTH ROCK (LSD29) until December 1980. He was Executive Officer of the USS SAIPAN from February 1981 to January 1983. He then reported to DCNO Surface Warfare as head of the Ship Survivability office in March of 1983.

Captain Barr attended Palm Beach High School prior to entering the Navy and while in service attended Old Dominion University at Norfolk, VA.

His awards include the Meritorious Service Medal with Bronze Star, Navy Commendation Medal with Bronze Star, Navy Achievement Medal with Bronze Star. Meritorious Unit Citation, the Battle Efficiency E, Good Conduct Medal with two Bronze Stars, National Defense Medal with one Bronze Star, Korean Service Medal, Armed Forces Expeditionary Medal with Second Award, Humanitarian Service Medal with Bronze Star, Republic of Korea Presidential unit Citation, and the United Nations Service Medal.

CDR John Bannan, U.S. Coast Guard, is currently the Assistant Division Chief of the Ice Operations Division at U.S. Coast Guard Headquarters. Mr. Bannan graduated from U.S. Coast Guard Academy in 1966. His service has included six tours of Sea Duty, these have included two Polar Working Icebreakers, which operated in the Arctic and Antarctic regions. His most recent tour afloat was as Executive Officer aboard the Icebreaker MACKINAW which is the Coast Guard's largest Icebreaker on the Great Lakes.

Mr. J.U. Kordenbrock, is a graduate Aeronautical Engineer from the University of Cincinnati. He has worked in the Aerospace Industry in various aircraft and space related programs and became involved in advanced marine vehicles in 1960. In that year he became involved with the U.S. Navy's SKMR-1 air cushion vehicle program during its test phases. His involvement has been in the advanced marine vehicle field since that time.

BIOGRAPHIES (CON'T)

In 1970 he joined DTNSRDC as Program Manager for the Arctic Surface Effect Vehicle Program which was sponsored by DARPA. This 18 million dollar program produced a wealth of technical data applicable to ACV designs, particularly for Arctic applications. This program was completed in 1974. Since that time, he has been active in the JEFF(A) and JEFF(B) programs as well as the LCAC program.

Since the early 1970s, Mr. Kordenbrock has remained active in cold weather programs with the Navy, Marine Corps, and the State of Alaska. This has included work on the ice at Barrow and Bethel, Alaska, in Tromso Norway, and in the Navy's ANORAK EXPRESS AND SHAREM 55 exercises.

In July of 1985 he was detailed to OPNAV as a Staff Assistant on the Ship Characteristics and Improvement Board (SCIB) staff (OP-03C2), to help guide the Surface Ship Arctic/Cold Weather Program. He remained active in this program which is structured to improve the operation of surface ships under Arctic conditions.

EXECUTIVE SUMMARY OF
REAR ADMIRAL JOHN B. MOONEY, JR.
TO THE
U.S. NAVY SYMPOSIUM ON ARCTIC/COLD WEATHER OPERATIONS
OF SURFACE SHIPS

Ladies and Gentlemen:

It is a pleasure to be here today to participate in this symposium on Arctic Cold Weather Operations of Surface Ships.

I have a special appreciation for Arctic operations.

In 1968, I was assigned to the submarine warfare desk in the Office of the Chief of Naval Operations. One of my duties in that position dealt with Submarine Arctic Operations. At that time, there was no Navy activity in the Arctic regions, either above or below the surface.

Seeking to rectify the situation, I took two actions: One was to hold a symposium on Arctic Warfare at White Oak, which started people thinking about the problem; the other was to update an OPNAV Instruction which resulted in yearly cruises by submarines of alternating fleets.

Then, prior to my present position, I served as Oceanographer of the Navy, which included the duty of coordinator for Navy Arctic interests. During that tour of duty I spent 10 consecutive days in the Arctic with VXN 8 in October on a "freeze-up flight" coordinated with a Sub Ice EX. Our meanderings started at about 150 W longitude to about 20 E longitude over land, the Central Arctic Basin and Marginal Ice Zone.

In 1981, with the threat escalating, the Director of the Office of Naval Warfare, Vice Admiral Baggett, and I agreed that his office should take the lead as Arctic coordinator to more fully represent the entire Navy community. Recently there has been a great acceleration in interest and activity by both the surface and sub-surface communities.

Regardless how one defines polar regions, the United States most definitely has polar interests. The U.S. is one of the six Arctic-rim countries that bound the Arctic Ocean: Alaska has 1,060 miles of Arctic coastline.

A recent presidential document emphasizes the growing importance of the Arctic to the United States.

The President signed National Security Decision Directive 90 (NSDD 90) in response to the 1982 Interagency Arctic Policy Group Study on future federal levels of effort in the Arctic. This document affirms that the United States has resource and energy development, scientific inquiry, and environmental protection. The directive recognizes that the Arctic warrants priority attention in light of its growing importance and bases United States Arctic policy on the following major elements:

- Support for sound and rational development in the Arctic region, while minimizing adverse effects on the environment;

- Promotion of scientific research in fields contributing to knowledge of the Arctic environment or of aspects of science which are most advantageously studies in the Arctic; and

- Promotion of mutually beneficial cooperation in the Arctic to achieve the above objectives.

Viewgraph No. 1 Map of Arctic

Let's take a look at the scenario of the Arctic Ocean and adjacent seas.

Small dots show research stations; the heavy dotted line is the Distant Early Warning Line; large filled-in circles are Ballistic Missile Early Warning System (BMEWS) sites; heavy solid line shows northern sea route; (weight of line indicates relative importance); solid triangle is Soviet ICBM site; filled square denotes Soviet regional missile site; ice edge denotes average summer positions.

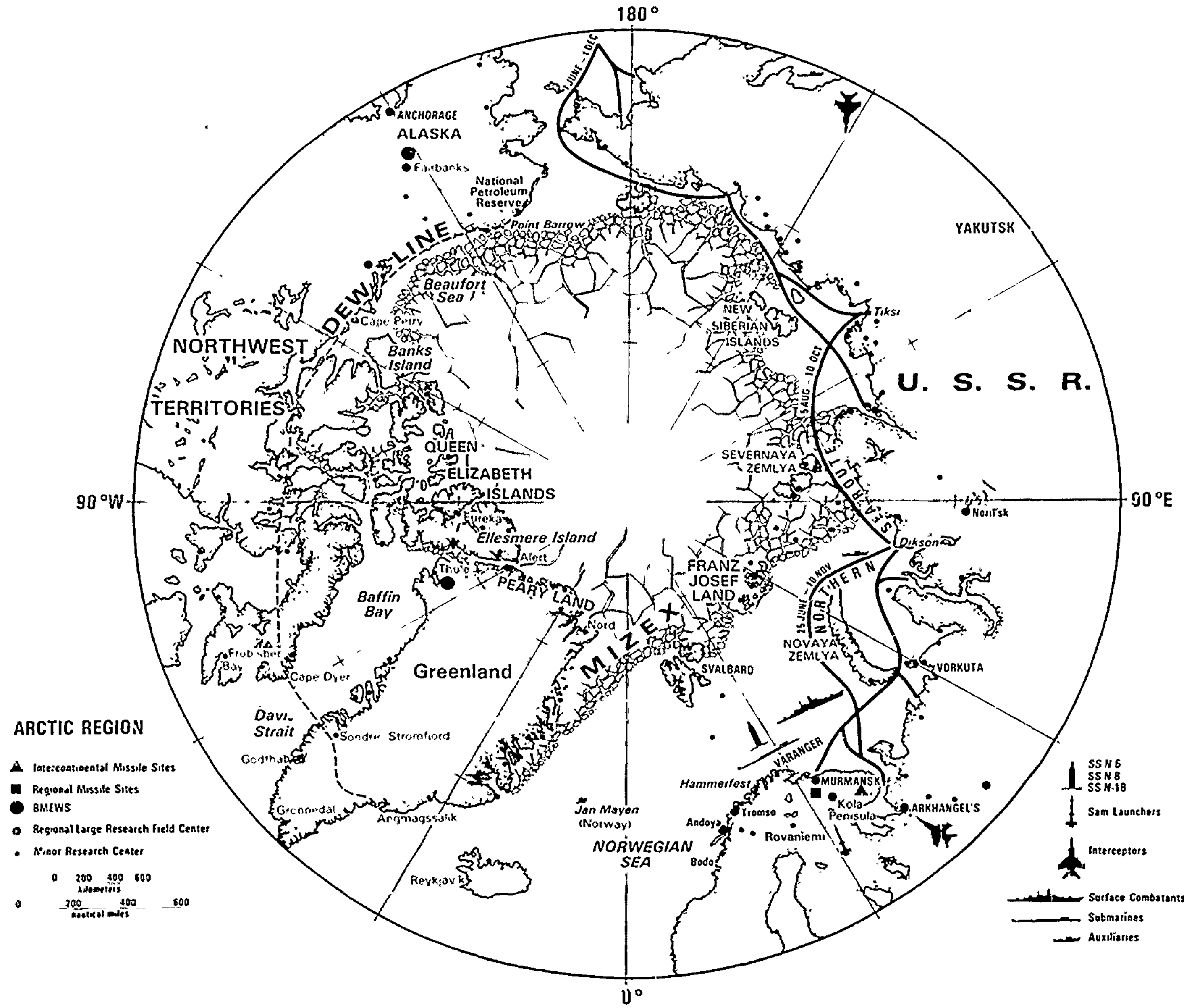
The Arctic is of strategic importance to the United States for a variety of reasons. First, it is the only region in which the United States shares a common border with its superpower rival, the Soviet Union. Second, the Arctic Ocean serves as an important defensive barrier to attack from the north. The level of Soviet military activity in Arctic waters is increasing, and of special concern is the presence of submarines with Intercontinental Ballistic Missile (ICBM) capability in the Barents and adjacent seas.

The threat of bomber and ICBM "over-the-top" attacks is also of great concern. Early warning systems on both the North American and Eurasian sides of the Arctic Ocean have been in place for many years to detect such attacks. The need to protect the present and future economic interest of the United States in the high latitudes is also of national importance, in particular the important reserves of oil, gas, coal, and strategic minerals that occur in arctic Alaska.

The Chief of Naval Operations, Adm. James D. Watkins, visited an Ice Camp in the Arctic -- one of three scientific research camps established there this past spring -- and described how and why the Navy is operating in that demanding area of the world. In his words:

"The Arctic is an area which the Soviets have almost assumed is their private lake, a hideaway where they have sole autonomy.

Over the past 20 years, the Navy has been involved in modest experimental work in the Arctic -- periodic deployment of our submarines, and the like. But in the last four years I have accelerated our program. The whole concept of the Soviet Union is one of deployment of their forces out of their Northern Fleet into the Atlantic or into the Arctic the Arctic specifically in the case of their ballistic missile submarines.



Viewgraph No. 1 Map of Arctic

Viewgraph No. 2 ICBM's/Subs

"From this vantage point. were the United States not to have any Arctic operational capabilities, it would give the Soviets a free reign, a sanctuary. Our whole strategic concept is forward-deployed forces to carry the fight to the enemy. Therefore, we must master this area where they have found this particular hideaway."

To master this area, we must address several problems. For the surface fleet the harsh Arctic environment will be a major obstacle. With the exception of the recent exercise SHAREM, the surface fleet has little experience in working in this complex area.

Viewgraph No. 3 Ice Seascape

Sea ice is a formidable problem. The recent photographing of the Titantic obtained by Bob Ballard reminds us of its potential harm. The U.S. Navy has no ice reinforced combatant vessels excepts for the USS PT LOMA which is used as a submersible support vessel on the West Coast.

Viewgraph No. 4 Coast Guard

The main asset we have are five Coast Guard Icebreakers. This vu-graph shows the status of the Coast Guard fleet. It should be noted that conceptual design has been completed and preliminary design started on an new icebreaker which will hopefully be launched in 1993.

The Soviets have 41 deep water icebreakers, eight ice strengthened cable layers, and three research icebreakers.

Shipboard ice can also be a major problem. The following vu-graphs illustrate this problem. They show build-up of ice on USS CAPODANNO (FF 1052) while transiting from Norfolk to Newport in January. The effects observed include:

Viewgraph No. 5 Ship--Bow

- Rapid continuous ice accumulations from sea spray

  Horizontal surfaces: 8"
  Vertical surfaces: 1/2" to 8"

Viewgraph No. 6 Stairs

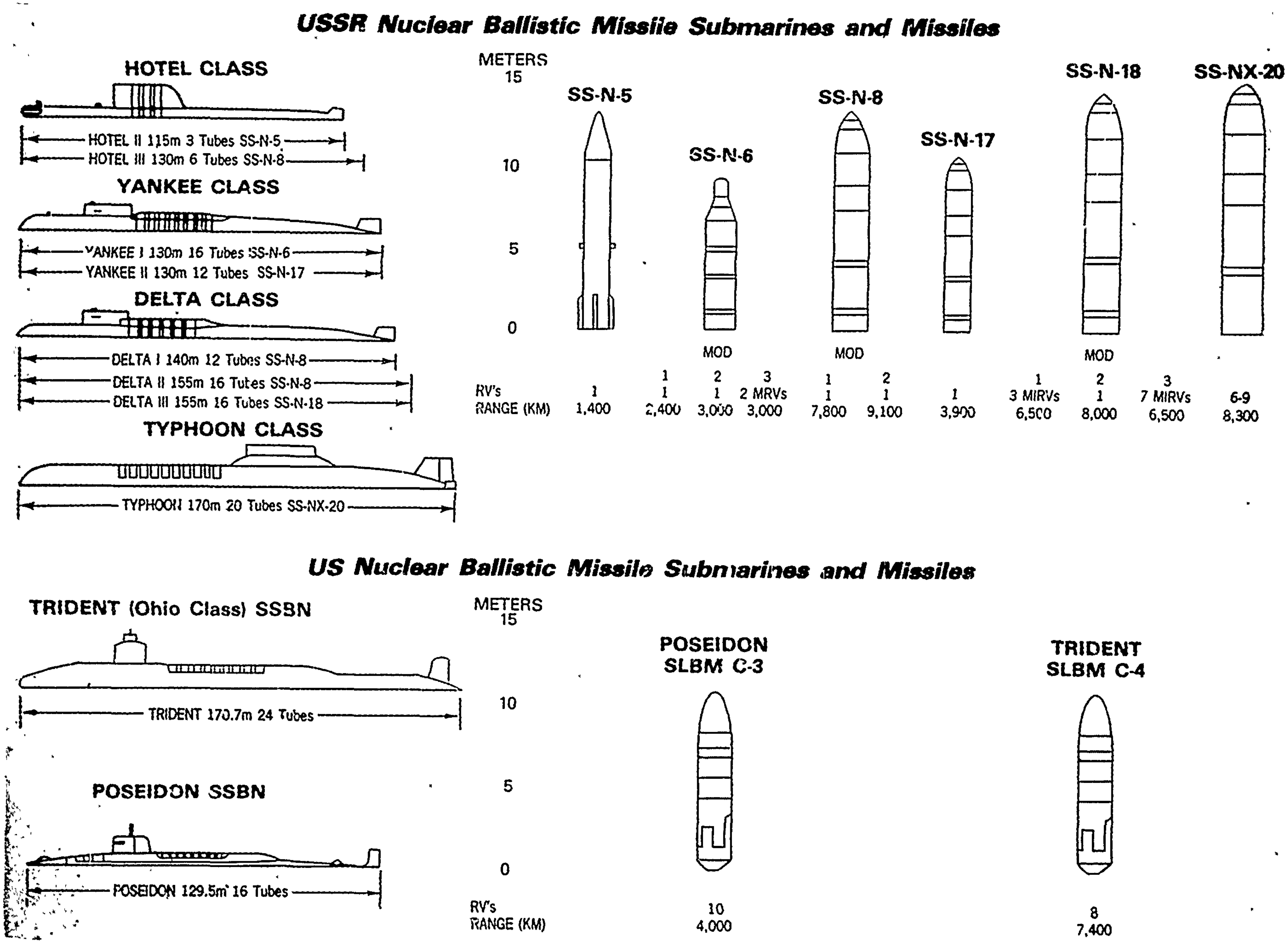
- Ice covering machinery space, ventilation SSDG intake 100% covered

Viewgraph No. 7 Bridge

- Bridge windows iced inside and out

Viewgraph No. 8 Anchor/Rails

- Satellite antennas unable to operate properly



Viewgraph No. 2 ICBM's/Subs

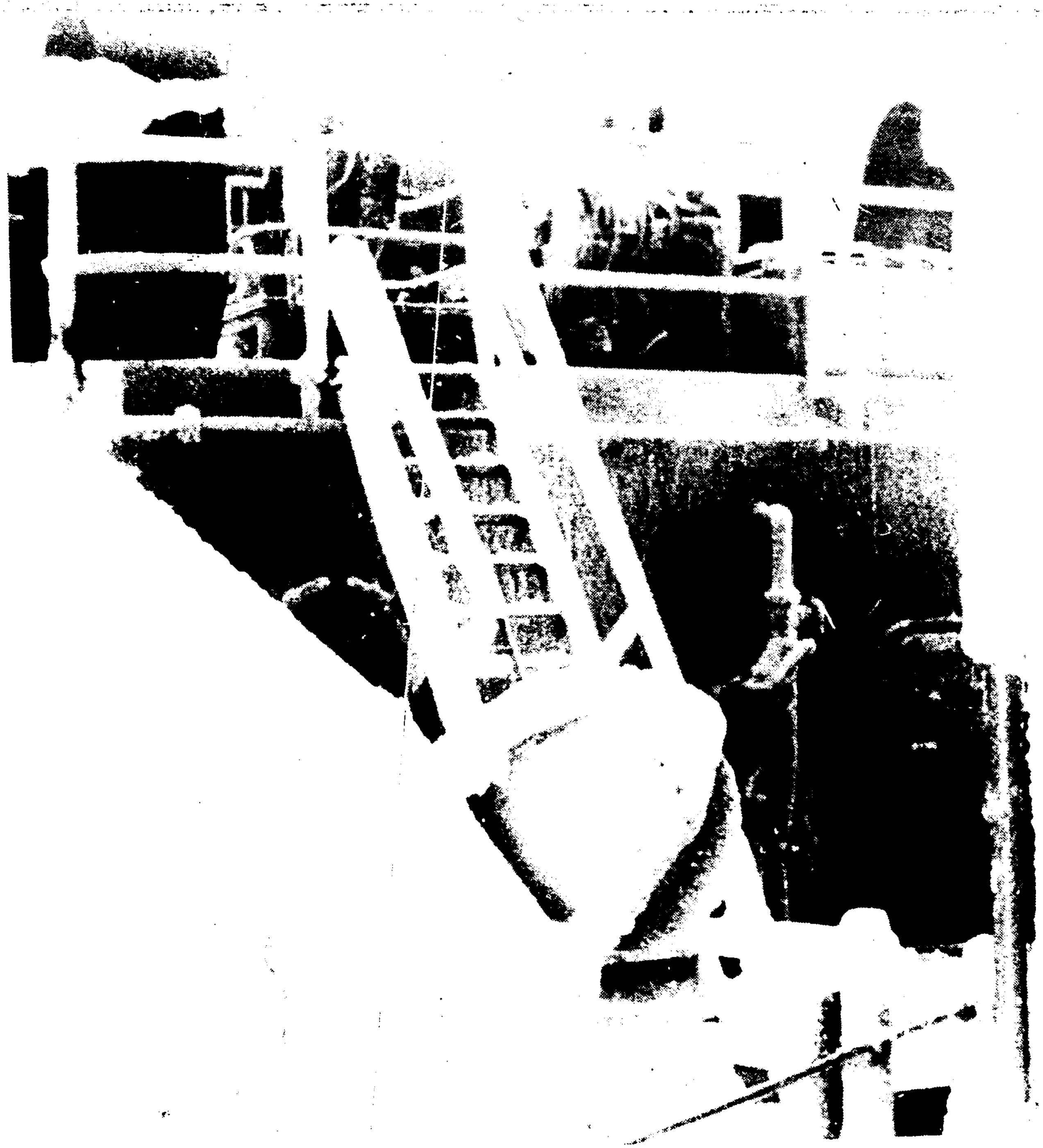
Viewgraph No. 3 Ice Seascape

COAST GUARD

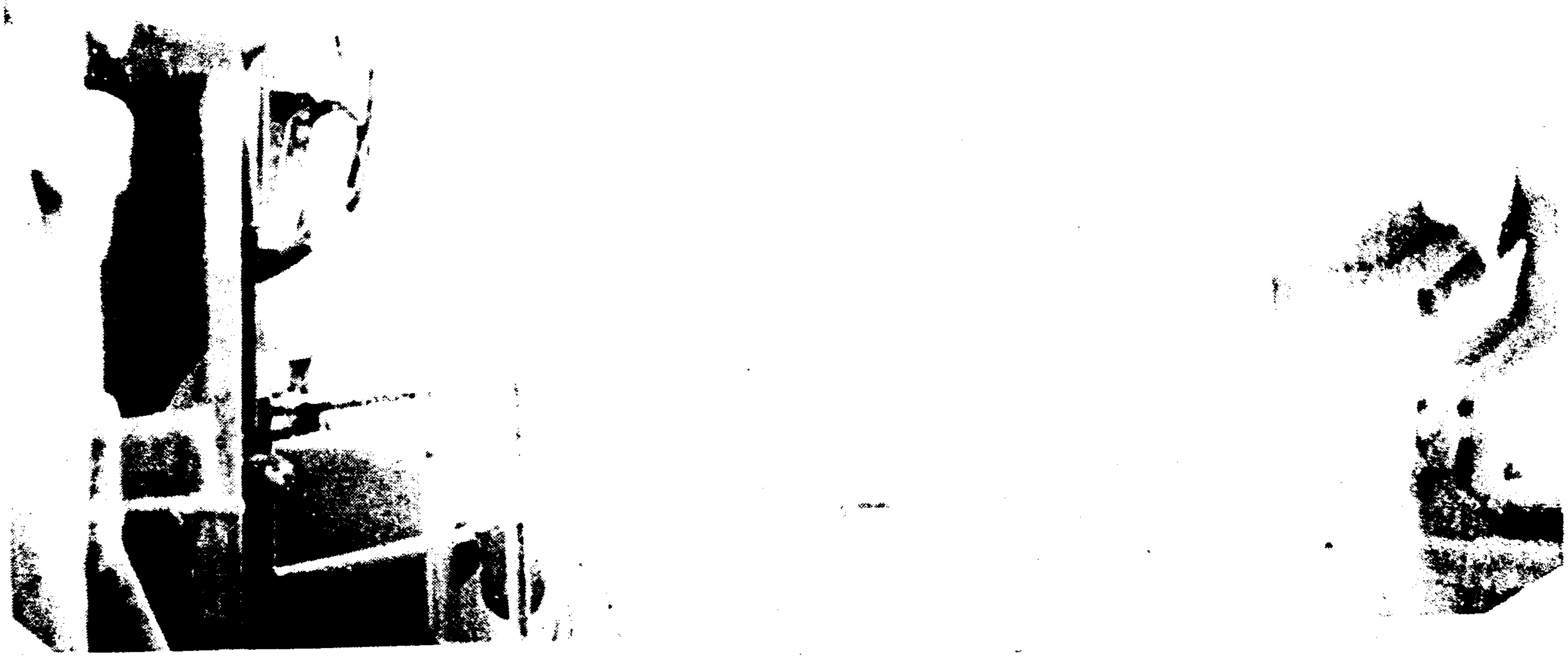
NO. OF SHIPS	YEAR BUILT	FY 71 - FY 78	FY 79 - FY 86
POLAR CLASS	1973, 1975	0-2	2
GLACIER	1954	1	1
WIND CLASS	1943, 1944	6-2	2

Viewgraph No. 4 Coast Guard

Viewgraph No. 5 Ship--Bow



Viewgraph No. 6 Stairs



Viewgraph No. 7 Bridge

Viewgraph No. 8 Anchor/Rails

This happened during relatively benign conditions far south of the Arctic Circle, with freezing sea smoke.

The Navy designs ships with an emphasis towards peacetime deployment climates. We can keep the internal spaces of our ships cool with air conditioning in the Indian Ocean, but we cannot de-ice the outside in the Bering Sea. Top level requirements of the Chief of Naval Operations call for designs capable of cold weather operations. For example the following requirements are levied on the FGG-7 and DDG 51 classes.

Viewgraph No. 9 Requirements

An FFG exposed to 20 F air temperature, 30 F sea surface temperature, 40 knots of wind at Sea State 6, would have a very high probability of heavy to severe icing. A build up of 6", per day would be a reasonable expectation. The frigate would eventually be at risk in stability, may lose mobility and would most certainly not be able to fight. The DDG would face similar, though not as serious problems.

The top level requirements require a design capable of cold weather operations, but because our peacetime operations are geared toward warmer regions, we do not enforce the top level requirement on our designs.

Weather is also a problem of Arctic operations.

Viewgraph No. 10 Ship in Fog

Arctic regions -- and especially the region adjacent to the ice -- are characterized by fog and low stratus clouds. In the Greenland Sea last summer our vessels found that fog conditions in the Marginal Ice Zone exceed 90% of the time.

Viewgraph No. 11 High Seas/Ice

Explosive cyclogenesis is also found in Arctic regions with small (approx. 100 km diameter) intense lows. These lows move fast and will clear through an area in 24 hours, but they often carry winds in excess of 80 knots. Their small size and rapid movement make them particularly hard to detect and forecast with any accuracy. When the high seas are combined with icing conditions, these storms can be very dangerous to all but the largest ships.

The oceanographic conditions are particularly hard for ASW. This vugraph is an infra-red satellite picture of the northern Greenland Sea. Open water is yellow, red and blue; ice and low clouds, white; high clouds, black.

Viewgraph No. 12 Eddy

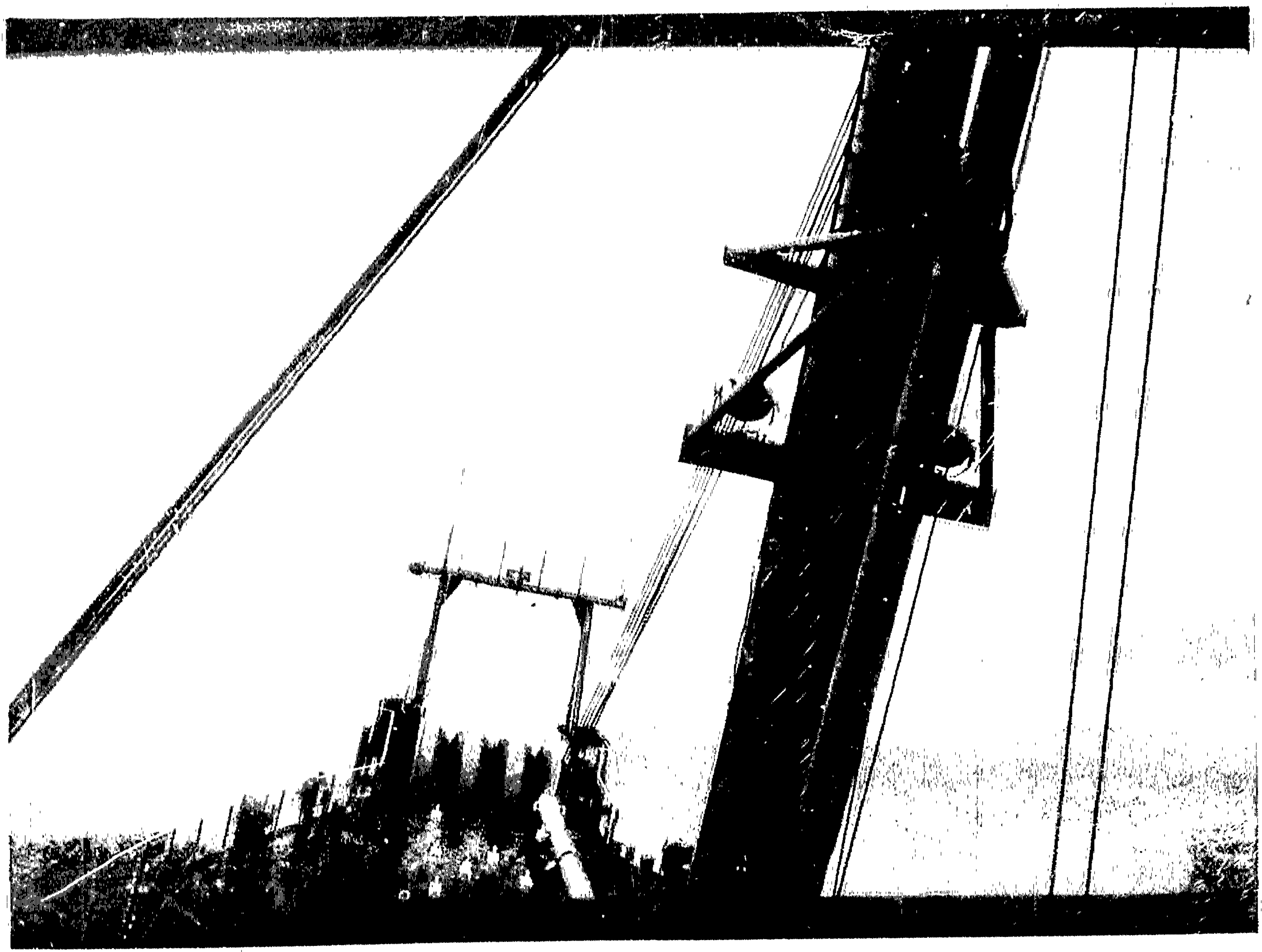
As is apparent, fronts and eddies are common. On a tactical leves, eddies are common in the Marginal Ice Zone and show up well. This eddy is about 10 miles in diameter. We must expect that our adversary will use these fronts and eddies to his advantage.

REQUIREMENTS

PERFORMANCE REQUIREMENT	FFG CONDITIONS	DDG CONDITIONS
MISSION ESSENTIAL EQUIPMENT AND MACHINERY INSTALLED IN EXPOSED LOCATIONS, PULL SYSTEM CAPABILITY	20°F TO 120°F 40 KNOTS STEADY	– 20 TO 100°F
ALL SYSTEMS FULL CAPABILITY	0 TO 100% HUMIDITY 28-85°F SEA SURF TEMP	10 TO 100% HUMIDITY 28-85°F SEA SURF TEMP
REPLENISHMENT & STRIKEDOWN	SEA STATE 5	SEA STATE 5
CONTINUOUS EFFICIENT OPERATION (EXCEPT UNREP)	SEA STATE 6 28 KNOTS WIND	SEA STATE 6 30 KNOTS WIND

Viewgraph No. 9 Requirements

Viewgraph No. 10 Ship in Fog



Viewgraph No. 11 High Seas/Ice

Viewgraph No. 12 Eddy

Viewgraph No. 14 Soviet Oceanographer Flag

Sea worthiness, too, is a problem in the storm tossed sub polar seas. Once while I was at an International Hydrographic Organization meeting, a German Navy officer remarked to me that the U.S. Navy must expect to see action only in the temperate waters as our ships were not constructed for heavy seas in northern latitudes.

It has been estimated, for example, that during winter months in the Greenland-Iceland United Kingdom (GI-UK) gap, U.S. frigates may be unable to use their hull mounted sonars or helicopters nearly 75% of the time.

Some aspects of these problems need to be addressed with research. In the past, Navy's research emphasis has been in both the eastern and western Arctic basin.

Basic research attention is now being focused on the marginal ice zone of the Norwegian/Greenland and Barent Seas as they are potential operating area for NATO forces.

The Secretary of the Navy has presented U.S. with an opportunity to modernize our oceanographic research fleet. We are currently developing specifications for a class of ice-strengthened (Class C) Oceanographic Research Ships for construction in the early 1990's.

An expanded naval applied research program was planned in 1983 and is now addressing the following warfare objectives:

1. Development of effective Arctic military systems;

2. Development of enhanced sonar capabilities to exploit Arctic and marginal ice zone acoustic characteristics;

3. Increase of ocean and atmospheric data collection and forecasting capabilities to support real-time multiplatform operations;

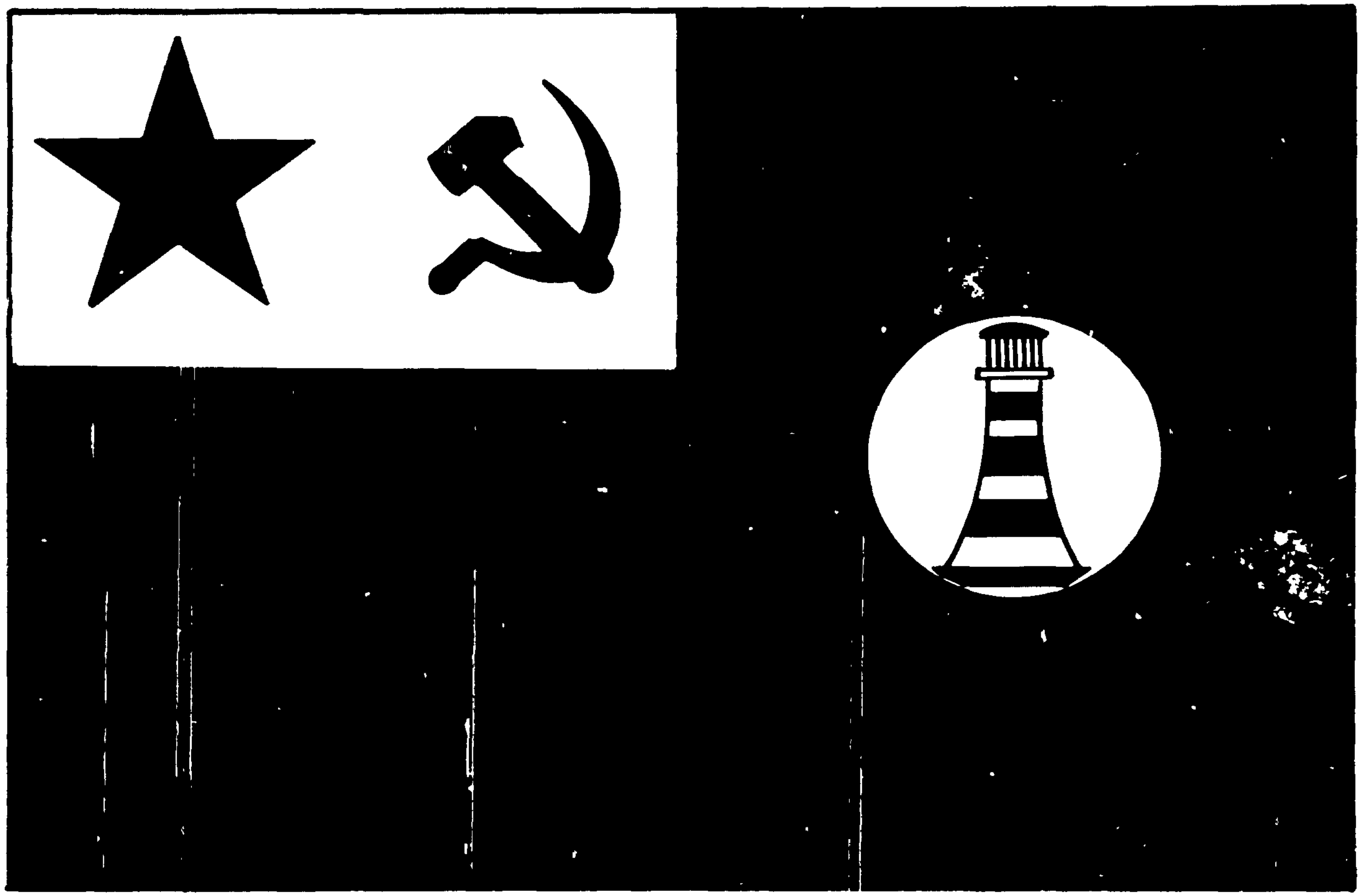
4. Assessment of the capability of current and proposed weapon systems; and

5. Development of emergency surfacing capability for nuclear submarines.

The environmental research program will be tailored toward providing engineers with sufficient understanding of the Arctic, and a realistic environmental data base, so they may select the most efficient and effective sensor design, system signal processing, and system configurations.

We have initiated new research programs within my command to improve both ice and weather forecasting, and preliminary models are undergoing fleet validation. Programs on shipboard icing and how to prevent and forecast it are starting up.

Exploratory development efforts are also underway aimed at improving ship seaway performance in Northern Latitudes. Advanced hull forms and control tech-



"It is my responsibility to ensure that every SOVIET SUBMARINE understands the ocean and how to hide in it."

RADM A. I. RASSOKHO
Soviet Naval Oceanographer
PARIS 1973

Viewgraph No. 14 Soviet Oceanographer Flag nologies are being developed for future surface ship designs. For today's fleet, techniques are being identified for increasing the operability of weapons and sensors, as well as the capabilities for underway replenishment in high sea states.

SUMMARY

The strategic importance of the Arctic is likely to increase. Soviet capabilities, coupled with the extensive deployment of Soviet surface ships and submarines in the Arctic/Sub-Arctic Oceans near Europe, make the region an area of growing importance to both the commercial and strategic defense interests of the United States.

The Soviet Union has made a clear commitment and massive investment toward development of the Arctic and of its military capabilities there. It appears that one goal of Soviet efforts is to consolidate their northern defense system. Areas such as the Kola Peninsula are therefore of great military value to the Soviets. They have an appreciation of the advantages and disadvantages of military operations in the Arctic.

The Soviet deployment of intercontinental ballistic missile submarines in northern waters, their capability to intercept the NATO Strategic Lines of Communication, and to reach the entire United States directly with bomber-launched cruise missiles, demands the attention of policy makers, as well as of military strategists and tacticians. Continued surveillance of Soviet forces is necessary for the defense of the United States and its NATO allies.

The close proximity of the United States to the Soviet Union in the Bering Sea further ensures the strategic importance of this area. Both economic and national security reasons imply that we must be prepared to protect these vital assets.

The United States must, to the maximum extent practicable, support its northern allies. A strong, experienced surface fleet that can make things difficult for the soviets in the northern sector and contain their northern fleet is a must.

Preparedness on the part of the United States is mandatory. The surface fleet must continue to conduct Arctic exercises on a regular basis to familiarize themselves with the special environmental problems of the Arctic regions. The United States should also invest in the design, testing, and production of the military equipment that is necessary for a strong defense of our economic and strategic interests in the Arctic.

The Arctic is a formidable challenge to the surface fleet, but on which I am confident we can meet.

EXECUTIVE SUMMARY OF
REAR ADMIRAL JAMES G. STORMS, III
TO THE
U.S. NAVY SYMPOSIUM ON ARCTIC/COLD WEATHER
OPERATIONS OF SURFACE SHIPS

It is a real pleasure for me to be here today and to welcome you to this Arctic/Cold Weather Symposium. This is the first such conference that the Navy has hosted, although a similar conference was held in 1983 in Bath, Maine.

In my role as Deputy to Vice Admiral Metcalf, I am responsible for Surface Warfare Programs. This includes the responsibility for the Ship Characteristics and Improvement Board and the Associated Ship Survivability Office which is under CAPT Robert Barr. The Arctic program is administered by CAPT Barr's Ship Survivability Office.

Today, in surface warfare, we see ourselves looking toward geographic regions that we have operated only occasionally in the past. One of these regions is the Arctic.

The ability for our ships to operate under cold weather conditions as well as in the northern regions adjacent to the Arctic and in the marginal ice zone is a necessary part of our defense and maritime strategy.

Our limited operations in the Arctic have revealed a number of problems that must be overcome if we are to successfully send our ships into these waters on a routine basis. Topside icing, for example, can make deck equipment unusable unless we can either control the ice build up or rapidly remove its accumulation and reduce its adverse effects. Additionally, the weight of the topside ice has a detrimental effect on ship stability.

Last year, we had two ships enter an ice covered port and the presence of floating ice caused some uncertainty by the ship captains as to the procedures they should follow in maneuvering their ships into port. Should the screws be allowed to turn or not, what could be the potential damage to the sonar dome, and what about the other underwater appendages . . . we should be able to answer these questions in advance and I would like to think that this symposium can provide some answers for us.

We need answers to ice accumulation rates, ice prevention and removal, proper lubricants that should be used, and consideration of potential damage to underwater apparatus.

We realize that we must learn by our experiences in future operations in northern latitudes. You can help us in this effort. You are the experts. Initially, we believe that there is a lot of information and experience already available that can be applied to our combatants. We want to use this wealth of information so we don't try to "re-invent the wheel." We also recognize that there will be a need for technical investigations into a number of problem areas and we intend to encourage those efforts. A large research and development program is not anticipated, however.

In bringing together knowledgeable personnel, as represented by you gentlemen here today, we want to apply known operating and technical procedures for arctic operations to our Fleet. We look to you to help us in this important endeavor.

Hopefully, this symposium will be only the first of a series of periodic operational and technical meetings designed to assist us in our cold weather operations.

I wish you success during these two days and thank you for responding so well to our request to participate in this symposium.

EXECUTIVE SUMMARY OF
REAR ADMIRAL J. RICHARD SEESHOLTZ
THE OCEANOGRAPHER OF THE NAVY
TO THE
U.S. NAVY SUMPOSIUM ON ARCTIC/COLD WEATHER
OPERATIONS OF SURFACE SHIPS

In his epic work "The Ancient Mariner," Samuel Taylor Coleridge, described the plight of a ship driven into the polar region by a fierce storm.

"And now there came both mist and snow.
And it grew wondrous cold:
And ice mast high, came floating by,
As green as emerald.

"And through the drifts the snowy cliffs
Did send a dismal sheen:
Nor shapes of men nor beasts we keen -
The ice was all between.

"The ice was here, the ice was there,
The ice was all around:
It cracked and growled, and roared and howled
Like noises in a swound!"

You can see it was not a pleasant world, but very true as those who've been there will confirm.

Much of man's view remained unchanged toward the polar regions for most of the nearly 200 years since that poem was penned, but in the last few decades the Arctic Region has risen in economic value and grown in strategic and political significance. The ice covered waters of the Arctic are an excellent place for the Soviet Union to hide its submarines. Thus the Navy must do more to prepare itself to operate in that perilous environment.

Hydrocarbon exploration successes in the American, Canadian, and Soviet Arctic have established the area as a significant source of energy. American and Canadian knowledge of the arctic environment has grown greatly as a result.

The Arctic Ocean is essentially a deep, ice-covered over-sized Mediterranean Sea surrounded, except for sea access at the Bering Strait and the North Altantic, by land areas of North America and Eurasia. Five nations border the Arctic: the United States, Canada, Greenland which is affiliated with Denmark, Norway, and the Soviet Union. Sovereignty problems exist. There is a lack of agreement on the extent of coastal state jurisdiction over the arctic seas and on Norway's claim to exclusive control of the continental shelf resources of Svalbard: an island group between the Barents and Greenland Seas. Controversy also marks the effort to establish a Norwegian/Soviet continental shelf boundary in the Barents Sea. Compounding the problems are the difficulties posed by landfast and drifting ice in distinguishing between sea and land and the lack of agreement over the method of delineating the continental shelf boundary between adjacent nations.

Pressures from the United Nations Law of the Seas negotiations have generated added interest in defining national and international rights and obligations in the Arctic Ocean. Issues such as jurisdiction over marine resources in a 200 mile economic zone, navigation through international straits, pollution control, and freedom of marine scientific research pose difficult questions. The U.S. position that a maximum 12 nautical mile Territorial Sea is recognized, is the one of greatest interest to us and I believe the best established. The Arctic Ocean is, in fact, part of the high seas.

How do we cope in this hostile environment? The reknowned arctic explorer and scientist Fridtjof Nansen attributed "The success of a polar expedition. To depend principally upon the preparations which were made before the expedition started out." Sounds familiar to those who go to sea. It was Nansen that was responsible for the design and construction of a vessel, specially built with a rounded hull to withstand the tremendous pressures of sea ice. That vessel was the FRAM, and it served effectively in the numerous Norwegian Arctic and Antarctic explorations which followed.

The United States Navy is placing increased emphasis on the operation of surface ships in the arctic and cold weather environment. The success of our arctic operations will be dependent upon how well "we" prepare. That preparation must draw upon government and private sector resources both nationally and internationally. The polar environment can be a dangerous place, as a true story might illustrate.

At one time those graduating from the United States Naval Academy got to select their duty in turn based on numbers drawn from a hat.

Getting a rather late choice by this method a young midshipman realized his selection might be limited and he looked for unusual opportunities in that event. Sure enough, when his turn came the cruisers, destroyers, and other "more desirable" duty stations were gone.

He opted for an AKA (amphibious cargo ship) destined for a trip to Antarctica.

The 31st of December of his graduation year found him at Moubray Bay in the Western Ross Sea on the coast of Victoria Land. The morning watch provided an idyllic polar scene.

The bright low-sun, deep blue sky and water, scattered ice floes and a few puffy clouds marked the day's beginning rather than the frequent dose of fog. Penguins and a few whales seemed to enjoy the "summer day".

By noon a light wind had come up from the east and scattered clouds moved in. Loose pack ice began setting into the bay. By the early evening the wind was gusting to forty knots with heavy overcast and light snow. Pack ice now had restricted movement of the ship. One large floe had caught the ship's port bow and swung it sharply to starboard against a very large floe. The starboard side had been punctured flooding the paint locker to the water line within a few minutes.

By midnight, New-Years 1957, the USS ARNEB (AKA 56) was severely beset in pack ice with pressure building on her hull. Winds were gusting over 60 knots, there was 14 feet of water in No. 2 hold and 6 feet in No. 4 with all pumps going strong. The escorting icebreaker, USCGC NORTHWIND, lost a propellor coming to ARNEB's aid and was unable to effectively help, except to pass additional portable pumps. In the early morning, New Year's Day, a small berg moved through the pack and passed within 200 yards of the ship. The captain used the small relief in pressure to move the ship. He positioned the ship so ice pressure was directed fore and aft rather than athwatships. ARNEB chewed up her propellor and rudder in this maneuver.

For two more days the wind blew, while the ship pumped and shored. Finally on 3 January the wind changed and within an hour the ice pressure was gone and the danger past.

We dewatered and surveyed the damage. One blade of the four bladed screw was completely gone, 1/2 of another missing, the rudder bent 15° to starboard, with many plates at and below the waterline dished in.

For two months we limped around Antarctica, building stations, making turns for 14 knots to make good 11, carrying 15° left rudder to go straight ahead.

Our reward, two weeks at Cockatoo Island Naval Shipyard in Sydney Australia. A worthwhile exchange. Perhaps that is why I'm here speaking tonight, I've the distinction of being on a U.S. Navy ship which came closest to being lost in the Polar Regions during our lifetime. I learned more about damage control in those three days than at any time in my career. It was a wonderful opportunity to meet - Sir Hubert Wilkens; RADM Byrd and Dufek, CAPT Thomas, USCG and I've sea stories for a lifetime.

In December 1981, the Federal Republic of Germany's 93 meter/4000 ton ice strengthened research vessel the GOTLAND II was operating in a flaw lead off the coast of Northern Victoria Land, Antarctica about a hundred miles from where the ARNEB was beset some 24 years earlier. Strong northerly winds persisted, rapidly increasing the pressure against her hull, finally causing severe damage to her starboard side. A major leak developed in the hold with emergency discharge pumps functioning at full capacity. Several hours later on the eighteenth of December 1981 the pumps could no longer keep up with the incoming water and the ship sank. Fortunately the ship's helicopter evacuated all of the ship's crew and scientific staff to safety.

In October of 1983, forty tankers and ships of a Soviet Northern Sea route convoy became beset in the sea ice of the Western Chukchi Sea along the coast of Siberia. The vessels were navigating along a shore lead when an extended period of northerly winds brought sea ice and increasing pressure into the shipping lanes. Two ships were sunk and many damaged, including the nuclear powered icebreaker LEONID BREZNIEV. The Polar Regions are usually not forgiving.

The Arctic is dominated by rigorous cold and characterized by days to months of continuous daylight alternating with long periods of near or total darkness. The popular concept that the Arctic is a region of perpetual bitter cold and deep snow is incorrect.

Throughout the long Arctic winter, snow cover is persistent and blowing snow is common hazard, but the amount of actual snowfall is light. Duration of snow cover varies from about 10 months over the central ocean to about seven months in the subarctic.

The area of permanent icepack at the core of the Arctic Basin is characterized by persistent cold but not extreme cold, and surprisingly modest annual temperature ranges. Conditions during the sunless winter are usually cold and stable, often with clear skies.

Summer conditions on the icepack are quite different. Rain as well as snow can fall during this season. Weather is typically damp and frequently foggy. During windy weather the fog is often lifted to form a low ceiling of stratus clouds.

Several Arctic areas benefit from warm ocean currents. The coast of Norway and Kola Peninsula are readily approachable year round. Although thus tempered, it is nevertheless a harsh climate, but our Soviet competitors have adapted well.

Four factors particularly frustrate man's effort to operate in the Arctic:

First is the certainty that most places in the Arctic Ocean will be covered with ice each winter.

Second is the uncertainty of when that event will occur in any given place.

Third is the dynamic and complex nature and distribution of sea ice, and

Fourth is the generally "rotten" weather which may presist for lengthy intervals. In the Aleutian Island area it is said the wind can blow at 20 knots for 20 days with 20 meters visibility. For those interested in a history of sub-arctic operations. The book "The Thousand Mile War" makes very good reading.

Ice in the Polar Regions appears in a profusion of forms, it may be categorized on the basis of origin (i.e., sea ice versus glacial orland ice), age in years, degree of deformation, and dynamic status.

Because of the nearly landlocked nature of the Arctic Ocean, ice in the Arctic Seas can survive for many years and may appear in complex forms. Each autumn that part of the Arctic icepack that has survived the summer thaw begins to expand from a summer average of about five million square kilometers to winter average of about 11 million square kilometers. In the course of its southward growth and drift the outer margin of the pack eventually merges with sheets of new ice and drift ice growing seaward from the coastline. This merging ends surface navigation for all ships except for icebreaker-assisted operations along the fringes of the ice pack. Variations in size, age and thickness of ice floes can often be quite dramatic even within short distances.

The notion that the Arctic pack is three meters thick is somewhat misleading.

The collision of ice floes within the moving ice pack creates a zone of complex linear pressure ridges and shear zones, ice 10 meters thick or is more frequently encountered.

Also the pileup of ice both above and below the icepack creates noise, disrupting an overally usually quiet acoustic environment of the Arctic Ocean.

Though the Arctic ice pack is commonly thought to be desolate, the margins of the pack support a rich life chain consisting of a small number of species having quite large populations. The marginal ice zone is also a very noisy environment. The movement of ice caused by waves, winds, and currents keeps ambient sea noise 10 DB higher than under the pack or in the open sea.

We in the surface forces operate at a disadvantage compared to our aviator and submariner comrades.

The nuclear submarine avoids most of the severe weather and sea problems by operating submerged. He encounters special problems with charts, navigation, communications, and sonar system performance, but avoids many of our headaches.

The aviators, especially those patrol squadron types who frequent exotic places such as Adak and Keflavik, face a tougher problem. Nevertheless once airborne their mobility is certainly better than ours in the marginal or ice pack areas. Still poor visibility, icing, communication and navigation problems plague them also and the ice covered ocean frustrates their use of sensors (esp., sonobuoys) and weapons.

The USCG with its icebreakers will on occasion venture deep into the pack or even readily transit the northwest passage with the polar class ships.

On the other hand, we in the surface navy are restricted in most cases to approaching ice covered areas with only extreme caution. Even then, thin new ice easily will tear a rubber covered dome badly. The hazards of heavier ice were described earlier. Only an informed and prepared sailor should venture into such an environment.

Oceanographic, hydrographic, and meteorological support services to Navy units in Arctic and cold weather areas are provided by the U.S. Navy's Environmental Support Organization, the Naval Oceanography Command.

The purpose of this program is to meet worldwide military requirements for environmental support, which includes analyses and forecasts of environmental parameters of importance to sensors, weapons systems, platforms, and operations.

Varying numbers of environmental support personnel are assigned to ships, staffs, and shore establishments according to the specific requirements for environmental support.

The "Highly Perishable" nature of operational environmental information requires regional centers to perform near real-time handling and processing from the time of observation to ultimate delivery of the finished tailored product to the user.

Most of the environmental support routinely required by fleet units is available on a regularly scheduled basis, that is by means of Fleet broadcasts. Support services tailored for specific Arctic and cold weather operations are also available to ships and activities ashore on request.

For example, a naval force operating in the Norwegian Sea would automatically receive and warnings and area forecasts by means of the Fleet broadcast; sea ice and acoustic range predictions for ASW work, however, would be provided only as specifically arranged for in advance.

There are four Navy Regional and Oceanography Command Centers and two production centers which produce polar environmental guidance and tailored products, and oceanographic and bathymetric nautical charts.

Notably the Naval Polar Oceanography Center/Navy-NOAA Joint Ice Center at Suitland, MD, provides ice services worldwide and meteorological services for the high polar areas north of 66°N in the Pacific and north of 60°N to 70°N in the Atlantic. Ice analyses are mapped routinely utilizing the latest available data from Defense Meteorological Satellite Program, NASA, and National Oceanic and Atmospheric Administration Satellites, as well as special reconnaisance flights.

One of the production centers, the Fleet Numerical Oceanography Center, Monterey, CA, is linked with the data collecting and distributing networks of the U.S. Air Force, the National Oceanic and Atmospheric Administration, and the World Meteorological Organization. From these data, basic and applied numerical ice forecast products are generated and provided to the Naval Polar Center.

The Naval Oceanographic Office in Bay St. Louis, MI plans and conducts oceanographic and mapping, charting and Geodesy Survey Programs in support of Department of Defense and U.S. Navy Operational Requirements. Arctic surveys are accomplished by assigned ships and aircraft, fleet assets when available, and cooperative programs with other government agencies and foreign countries.

As I have just described it, U.S. Naval Environmental Support in the past and up to the present has depended heavily on centrally prepared products produced ashore. Present and future weapons systems, tactics, and command and control require ever more responsive support to the tactical commander.

Thus, while present support arrangements are effective and will remain in place, new efforts are underway to upgrade the on-scene capabilities.

A look to new future capabilities includes higher resolution data from the DMSP and GEOSAT satellites as well as regionally tuned sea ice forecast models. In addition to the operational support I've mentioned, we sponsor annually a strong Arctic advanced development research of nearly $10M. By the early 1990's N-RUSS. The Navy Remote Ocean Sensing Satellite will help in forecasting conditions in ice edge areas and Sub-arctic open waters.

Here in the United States most of our population's normal day-to-day activities routinely take place in the relatively warm environment of the mid-latitudes. Our affinity for the sun belt is reflected in the homeporting and local operating areas for much of our fleet. Our potential adversaries on the other hand live, work and routinely operate in the high latitudes, or the Sub-arctic.

How do we compete here? There are numerous unique problems associated with the Arctic and cold weather environment, to be successful you must cope with them. Among the noteworthy problems are:

- Experience. The half-life of Arctic experience seems to be about five years. Arctic programs must be organized as long term systems projects to insure we don't fall off the learning curve. And that we pass what we've often painfully learned on to newcomers. Then they too must practice in the Arctic environment.

- Communications. Long periods of communications blackout caused by ionospheric disturbances affect the behavior of radio waves in the low, medium, high, and very high frequency ranges. We do fairly well here, but still are too often surprised. Additional knowledge on cause and effect is needed.

- Acoustic Forecasts. Current acoustic forecast products require much improvement, especially in the difficult marginal ice zone. We are working to compile better information in that area. Local measurements seem certain to provide the best information.

- Sea Ice Analyses and Forecasts. Higher resolution, all weather detection of ice and open water, polynyas, is required for real time tactical operations. The best long term answer is probably a space-based SAR, but in the meantime present information sources and models must be exploited. CNR-SIR (Shuttle) and ERS-1.

- Super Structure Icing. Additional knowledge on the affects and prediction of superstructure icing on weapons, communications devices, and particularly stability in smaller vessels is required. You have heard and seen examples about this problem today.

In summary the success of naval arctic and cold weather surface ship operations will be dependent upon the effectiveness and completeness of our understanding, our planning, and our preparation. The Navy is looking to all of you to assist us in meeting those important tasks. Those who are well prepared will most often do well, but if you've not been far north or spent only a brief time there, and have not seen the fury of the climate, I would offer some words from Administrative Robert Peary's "The North Pole." In it he makes an observation upon his return from what seemed a relatively uneventful trip back from the pole. His eskimo companion, Ootah, had his own explanation for the relatively easy journey. Said he: "The Devil is asleep or having trouble with his wife, or we should never have come back so easily."

I would advise --

The Devil in the Arctic is not often asleep or distracted, so be prepared.

EXECUTIVE SUMMARY OF
COMMANDER JOHN D. BANNAN
U.S. COAST GUARD
TO THE
U.S. NAVY SUMPOSIUM ON ARCTIC/COLD WEATHER
OPERATIONS OF SURFACE SHIPS

(The opinions expressed in this paper are the personal opinions of the author and do not necessarily reflect the official position of either the U.S. Coast Guard or the Department of Transportation.)

U.S. Policy Considerations

Early in this decade two presidential documents emphasized the growing importance of the Arctic and Antarctic regions to the United States. The icebreaking mission in the polar regions is in pursuit of the objectives of National Security Decision Directive 90 (NSDD 90) of 14 April 1983 and the Presidential Memorandum of 5 February 1982 on the United States Antarctic Policy and Programs.

The President signed NSDD 90 in response to the 1982 Interagency Arctic Policy Group study on future federal levels of effort in the Arctic (Department of State press release no. 161 of 9 May 1983). NSDD 90 affirms that the United States has unique and critical interests in the Arctic related directly to national defense, resource and energy development, scientific inquiry, and environmental protection. The directive recognizes that the Arctic warrants priority attention in light of its growing importance and bases United States arctic policy on the following major elements (which are quoted directly from the press release):

- Protection of essential security interest in the arctic region, including preservation of the principle of freedom of the seas and superjacent airspace;

- Support for sound and rational development in the arctic region, while minimizing adverse effects on the environment;

- Promotion of scientific research in fields contributing to knowledge of the arctic environment or of aspects of science which are most advantageously studied in the Arctic; and

- Promotion of mutually beneficial cooperation in the Arctic to achieve the above objectives.

The Presidential Memorandum on Antarctic Policy and Programs was issued in response to the Antarctic Policy Group's 1981 study of United States interests in Antarctica and related policy and program considerations. The memo states that the "Antarctic Program shall be maintained at a level providing an active and influential presence in Antarctica designed to support the range of U.S. Antarctic interests. This presence shall include the conduct of scientific activities in major disciplines; year-round occupation of the South Pole and two coastal stations; and availability of related necessary logistic support".[1]

Design Background

Given this background, in 1983 the Office of Management and Budget called for

> . . . an Interagency Policy Committee (DOT, MARAD, Coast, DOD, NSF, NOAA, OMB) to develop an analysis of polar icebreaking requirements for the balance of the century. Recommendations on how many polar icebreakers may be required and how they should be budgeted should be developed. . .[2]

That direction resulted in the Polar Icebreaker Requirements Study (PIRS) which was completed in July 1984. That study concluded that the NORTHWIND and WESTWIND (commissioned in the mid-1940's) would reach the end of their useful life in 1990/91 and that GLACIER's useful life would end in 1992. The study recommend that

> Work should be stared immediately on the design of a new polar icebreaker. The Coast Guard in considering the design of new icebreakers, will consult with the User Council, which has the responsibility for taking into account the requirements of primary and secondary users. The design of the new icebreakers should enhance research support, while retaining essential escort and logistic support capabilities. The User Council and the DOT acquisition process should carefully review whether adaptation of a recent off-the-shelf icebreaker design could satisfy user needs and save many months in the design and procurement cycle.[3]

On 30 October 1984 the President signed the Coast Guard Authorization Act of 1984 in which Congress had addressed this national need. The Act stated that we

> . . . shall prepare design and construction plans for the purchase of at least 2 new polar icebreaking vessels to be operational by the conclusion of fiscal year 1990 . . .[4]

Final Ground Work

The Ice Operations Division, as program manager, then set to the tasks of developing a Mission Needs Statement followed by the Sponsor's Requirements Document for the new icebreakers. (It should be noted that the science capabilities of the new vessels were only addressed in general terms in the latter.) The recently completed PIRS provided the base for the needs expressed in these documents.

For the next year much effort was applied in fleshing out the science requirements. Meetings to gather inputs from the scientific community were scheduled in conjunction with other meetings of polar scientists, such as immediately following the annual U.S. Antarctic Program Planning Conference. Responses to a survey were received from approximately 100 of the U.S.'s leading polar scientists.

Meanwhile, studies by both the Coast Guard's Naval Engineering Division determined that there was no off-the-shelf design suitable to meet the Sponsor's Requirements. Although there are a number of modern, excellent icebreakers in the service of other nations, none of them were designed to meet the combination of mission requirements which are expected to be within the capability of the U.S. Icebreaking Fleet.

Conceptual Design

The conceptual design has been completed and the Naval Engineers are well into the studies involved in the preliminary design. As operators, we are very pleased with what the new ship looks like. Before I continue with a sort of "word picture" it must be remembered that I am describing a preliminary design. Much work is being done before money is appropriated and steel is cut.

Major Characteristics

I. Enhance Scientific Capability

II. 80 Day Endurance Without Refueling:
Mission Profile:
- 20 days ice free transit
- 15 days full power icebreaking (12 hour days)
- 20 days half power icebreaking
- 25 days hove to/at anchor

III. Minimum Continuous Icebreaking Capability:
- 4.5 feet level ice at 3 knots

IV. Survivability:
- 2 compartment floodable length standard
- 100 knot beam wind intact stability

V. Propulsion:
- Diesel-electric, AC/AC cycloconverter with inport generator
- 2 shafts
- 4 medium speed diesels

VI. Complement:

Ship's company	110
Avaition Detachment	14
Scientists	30
Total	154

VII. Conceptual Design Statistics:

Length	451 ft
Beam	88 ft
Draft	31 ft
Displacement	15,951 tons
Shaft horsepower	30,000
Ordinance	2, 50 cal.MG

Planned Research Support Capability

- o Berthing for 30 embarked scientists
- o Multiple laboratories - wet, dry, computer/navigation
- o Inter-lab cable runs and communications network
- o Winches and cranes for hydro casts, coring, deploying moorings
- o Ship controls in vicinity of work deck
- o Accommodations for portable vans, including recompression chamber
- o Multi-beam, multi-frequency sub-bottom profiling and bathymetric survey system
- o Bow boom for instrumentation
- o Helicopters - two HH65A "Dolphins" (short range)
  Platform strengthened to accommodate heavy lift helos such as SA60.
- o Boats - survey boat, ridged hull inflatable, landing craft
- o Diving support
- o Satellite communication - voice and data
- o Satellite imagery receiving and processing
- o Precision navigation - GPS
- o Science office/conference room/library
- o Ship's data video display and annotation terminals
- o Hazardous cargo storage
- o Access to the ice - personnel and equipment

The Coast Guard is now well into the preliminary design phase. We are firming up the details of the scientific requirements. By late summer we should be into the contractual design phase. Our goal is to award a contract for the first vessel in late 1988. (We do realize that many gates remain to be opened for this to happen.) Given that a contract is awarded in late 1988, the first new icebreaker should see her first test in her element during the summer, 1993. The second vessel should follow a year later.

One of the major gates to be opened is the approval for and appropriation of funds. For that we will need your support. "Why?" you ask. Although these will be Coast Guard Cutters, they are very much national assets. Their missions go far beyond the normal responsibilities of the Coast Guard. In fact only about 20% of the polar operations is for the Coast Guard; the remainder is for the many "User Agencies". With these vessels, the United States will operate and project its presence in a very visible way.

Notes

1. Most of the "U.S. Policy Considerations" section is taken directly from the "Polar Icebreaker Requirements Study" (PIRS), Interagency Report of 11 July 1984, p. 1-5.

2. PIRS, Preface.

3. PIRS, P. 11-2.

4. Public Law 98-557, sect. 6.

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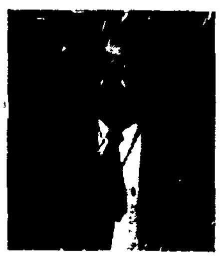

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OVERVIEW OF THE COLD WEATHER PROGRAM

THE U.S. NAVY'S ARCTIC/COLD WEATHER PROGRAM FOR SURFACE SHIPS

by Mr. James U. Kordenbrock

The U.S. Navy's Arctic/Cold Weather Program for surface ships was undertaken in July of 1985 when a Ship Characteristics and Improvement Board (SCIB) was formed at the direction of Rear Admiral Altwegg, OP-03C. He recognized the need for providing the Fleet with the necessary instructions and hardware to operate ships in Northern Latitudes, particularly since most ship operations have taken place in warmer climates. The impact of cold weather and topside icing were recognized as problems that the Fleet must be prepared to cope with in order to operate safely and successfully in Arctic regions. Admiral Altwegg appointed Captain Robert K. Barr as the Chairman of the Working Group. I have been assigned to the staff of Captain Barr's office to assist in the direction of this cold weather program.

The SCIB Working Group, consisting of representatives from most Navy departments, has met regularly since August of 1985 on a monthly basis. The delineation of various cold weather problems and an approach to their solution has been undertaken by this group, and a comprehensive management plan for solving the various problems is being formulated. It is also recognized that a lot of information is already available from a number of sources and can be readily applied to the Navy's ships. It is expected that this Symposium - during the next two days - will provide valuable information for application to the Navy's needs. We therefore welcome your participation in this Symposium and look forward to the papers and discussions that will follow.

In order to assist you in supporting us in this Cold Weather Program, I will outline the program (Figure 1) and then answer any questions you might have.

I will describe the background which led to the decision to initiate the Cold Weather Program and then list its primary objective.

I will discuss the program approach, which has been carefully formulated in order to achieve the objective in a timely manner and within reasonable cost constraints. The method of implementation will encompass the work of the SCIB working group as well as the approach to formulating the overall management plan. Finally, I will indicate the current status of the program and list a number of conclusions to show that the program is "on track".

In 1983, two OPNAV instructions (Figure 2) were issued that outlined the approach for operating in Arctic regions. The first of these two instructions, both of which are classified "Secret", provides general policy guidance for operating in arctic polar regions. The second instruction provides details for implementing this policy. These documents are mutually supportive of the Maritime Strategy of the Department of Defense.

AGENDA

- INTRODUCTION
- BACKGROUND
- OBJECTIVE
- APPROACH
- IMPLEMENTATION
  - SCIB WORKING GROUP
  - OVERALL PLAN
- STATUS

Figure 1

BACKGROUND

1. TWO 1983 OPNAV INSTRUCTIONS

- S 3470.5A "U.S. NAVY POLICY REGARDING ARCTIC POLAR REGION", 4 MARCH 1983
- S 3470.6 "U.S. NAVY WARFARE PROGRAM", 4 MARCH 1983

2. VARIOUS OPERATIONAL CONCERNS

- SHAREM 55
- GULF OF FINLAND
- USS CAPODANNO

Figure 2

Operational experience with a number of our surface combatants in recent times has highlighted the shortcomings of our ships to cope with the rigors of cold weather and icing. During the operation called SHAREM 55 (an acronym for "Ship ASW Reliability Effectiveness Measurement Program") the shortcomings in normal ship operations during cold weather in rough seas was evident. Although snow and ice events were minimal, their handling and removal highlighted some potential problems that would occur under more severe conditions (which could have a negative impact on ASW effectiveness). Helicopter operations were hampered by lack of on-board deicing and anti-icing equipment. The general lack of experience with the nature of floating ice was also quite evident.

In 1984 two of our combatants visited an ice covered port in the Gulf of Finland. After an icebreaker opened a path to the port, the two ships were actually towed into the port with their propulsion systems shut down because of concern about potential damage to the screws.... The USS CAPODANNO was iced over during an ice fog off the Virginia Capes in the winter of 1985. The accompanying photos (Figures 3 and 4) show some of the heavy ice accumulation that very quickly formed on the CAPODANNO. There have been numerous other examples of icing on our ships. Since we cannot completely avoid icing conditions, we must learn to cope with the situation so that the ship's systems, including her combat systems, can function as required - and when required.

The objective of the Arctic/Cold Weather Program, as shown in Figure 5, is to simply ensure that the surface navy can operate in an Arctic environment and that it can function as required to maintain its military effectiveness. Although the top level requirements of most of our ships require their operation in cold weather and in heavy sea states, these two requirements seldom are combined. The resultant topside icing from ship generated spray could become a serious threat to the operation of the ship.

The approach to be followed in carrying out this program is initially to concentrate on the two most important aspects: first, establish operating limitations of existing ship classes, and second, investigate relatively quick fixes that can be implemented to improve the operation of these ship classes. Cold but dry weather will perhaps cause some problems, but cold-wet weather will likely be much more severe in its impact on ship operations. Ship generated spray will be the most likely cause of topside icing and its resultant problems in prevention and removal. The recommendation of specific design improvements for new ship designs, the third item, will follow naturally from the first two items.

The application of techniques for coping with cold weather and icing conditions must be effectively transmitted to shipboard personnel for implementation. Recognizing that the "corporate memory" will be short or non-existent because new crews will probably be first-timers in the Arctic, effective training aids must be utilized to disseminate this knowledge about cold weather operations. Training films are expected to be necessary, as well as written instructions and graphic demonstrations. Training will be high on our list of priorities after appropriate techniques and equipment have been applied.

Figure

Figure 4

OBJECTIVE

DEVELOP AND OVERSEE THE EXECUTION OF A PLAN OF ACTION TO ENSURE THAT THE SURFACE NAVY CAN OPERATE WITHIN THE ARCTIC ENVIRONMENT REQUIRED BY THE TOP LEVEL REQUIREMENTS AND THE MARITIME STRATEGY.

Figure 5

Lastly, our approach must be conducted within reasonable cost constraints. We must utilize the vast amount of data which is already in existence and apply this to our surface combatants. We recognize, for example, that the Coast Guard has a large amount of experience in operating in both the Arctic and Antarctic and that this experience must be applied to the Navy's operations. Similarly, other nations, notably the Canadians and British, have cold weather experience that should prove useful to us. We are in fact working closely with these sources, and will also do so with commercial operators. These groups are, in fact, members of our Working Group. Following the application of known data, the resulting shortfalls in our knowledge will be investigated as required by various research and development methods.

The implementation of this program (Figure 6) rests with the SCIB Working Group and the overall management plan that they are assembling. The tasking that will result from this management plan will then involve OPNAV, NAVSEA, various government laboratories such as the David Taylor Naval Ship R&D Center (DTNSRDC), the Federal Clothing and Textile Research Facility at Natick, Massachusetts, and various contractors.

The SCIB Working Group was established by Admiral Altwegg in his memorandum of 16 July 1985. This memorandum listed four items, that required specific attention. The first item, to review the extent of surface wartime operations in the Arctic, will establish the areas of the Arctic that our combatants will be expected to operate in which will then dictate the specific environment to be expected. The second item, to review and update cold weather instructions, provides for updating the various cold weather instructional documents that relate to surface ships and their air detachments. The third item is most important in establishing the effectiveness of our operating capabilities and the effectiveness of the improvements which will be implemented. But of critical importance is that surface ship exercises under Arctic conditions are necessary to help uncover our shortcomings under realistic conditions. Operations to date have been very sparse, with amphibious operations in Northern Norway our primary exposure to cold conditions. These NATO operations have been very useful, but due to the presence of the Gulf Stream along the Norwegian coast, the cold weather conditions have not been as severe as in other areas of the North Atlantic or the Bering Sea. The fourth item relates to the establishment of design recommendations for new ship construction and conversion, and will be most important as our operations increase in the Arctic in the future.

The overall plan for the program is shown in Figure 7. To prevent "re-inventing the wheel", we must make maximum use of existing data relating to cold weather and Arctic operations. This data must then be reviewed for applicability to our Navy combatants and applied where it can be most effective. The Navy, under the sponsorship of NAVSEA, has been undertaking a number of cold weather investigations to help overcome some of our known shortfalls. For example, our laboratories have been looking at various low ice adhesion coatings, ice removal methods, hull plating resistance to ice impacts, and tactical decision aids for minimizing effects of sea state and spray by varying ship course and speed, to name some of these programs. The results of these efforts and information from other sources will be utilized in our program.

IMPLEMENTATION

- SCIB WORKING GROUP
- OVERALL PLAN

Figure 6

OVERALL PLAN

- REVIEW EXISTING DATA
  - CURRENT COLD WEATHER INVESTIGATIONS
  - ADDITIONAL SOURCES OF DATA
- PREPARE OVERALL PROGRAM PLANS (P.O.A.&M)
  - SYMPOSIUM
  - SHAREM 62
  - SHIP ICING TEST
  - MAJOR PROGRAM TASKS
- IMPLEMENT PROGRAM PLANS

Figure 7

The preparation of an overall management plan for implementing the necessary tasks is most important in this initial stage of the program, and it is expected that this plan - which is now well underway - will be completed early in 1986. In addition to these major program tasks, other activities are being planned for implementation in the near future. Notable among these is participation in SHAREM 62 to obtain information on ship icing and operational problems in a cold, wet environment, a ship icing test which is tentatively scheduled for the winter of 1987, and of course, this Symposium which is expected to provide us with current information on what is being done in related cold weather investigations and in providing suggestions for our program tasking. Each of these items will be discussed in further detail.

As mentioned previously, the Navy has been pursuing a number of cold weather investigations. The impact of superstructure icing on the FFG 7 class ships and the CG 47 class has been investigated to determine the effects on ship stability, as well as the impact of the ice on the hull structure's hogging and sagging loads. Another program which is still underway is to determine the capability of the bow plating of surface combatants to resist impacts with floating ice. Initial results indicate that plating gages are not adequate to provide very much protection, which of course is a function of a number of considerations, particularly ship speed. Various ice resistant coatings have been tested for their suitability in preventing or significantly reducing ice build up on various exposed ship systems. These tests have not yet produced a viable ship coating, but investigations are continuing not only for ships but for offshore structures. Protection of hull and deck machinery from both cold weather and icing has been considered, but to date the use of canvas or plastic covers has offered some measure of protection. Operational experience during various ship exercises such as SHAREM 55 and 62 has been helpful in documenting shortfalls, such as potable water generating systems and sea chests. Experience from the Coast Guard icebreakers is being reviewed to obtain additional information that will be applicable to our combatants.

Figure 8 lists a number of sources of cold weather data and we recognize that this list is quite incomplete. I want to indicate, however, that these and other sources will be used to assist us in applying cold weather experience to our ship operations. We have invited personnel from many of these organizations to become members of our Working Group and their efforts have been useful to us.

The Symposium that we will be participating in today and tomorrow, Figure 9, should indicate to you that the Navy is serious about its Cold Weather Program and that we hope to expand interest in cold weather operations for our surface ships. We are particularly interested in your experiences, which will be presented in the formal papers. We also want you to tell us about related efforts during the project update sessions. The planning session scheduled for tomorrow afternoon will provide us with the opportunity to hear your comments and suggestions for our program. We encourage you to participate in this session.

SOURCES OF EXISTING COLD WEATHER DATA

- U.S. NAVY OPERATIONS
  - SHAREM 55 AND 62
  - NATO AMPHIBIOUS OPS
- U.S. COAST GUARD
  - ICE BREAKERS
- NAVOCEANO
- U.S. ARMY CRREL
- ARCTEC
- UNIVERSITY OF WASHINGTON
- DTNSRDC
- BRITISH NAVY
- CANADIAN NAVY

Figure 8

COLD WEATHER SYMPOSIUM

DATE: 3 AND 4 DECEMBER 1985

LOCATION: SHERATON POTOMAC HOTEL, ROCKVILLE, MD

THEME: NAVY SURFACE SHIP OPERATIONS IN ARCTIC/COLD WEATHER CONDITIONS

PARTICIPATION: GOVERNMENT, INDUSTRY AND ALLIED NAVY PERSONNEL

PURPOSE: DISCUSS OPERATIONAL AND ENVIRONMENTAL CONDITIONS, AND THEIR IMPACT ON SHIP SYSTEMS AND TACTICS.

1. EXPAND INTEREST AND ACTIVITIES IN COLD WEATHER OPERATIONS.
2. REVIEW PROGRESS SINCE 1983 CONFERENCE.
3. DISCUSS REQUIREMENTS FOR FUTURE WORK.

Figure 9

Ship operations in the Arctic or near the Arctic are infrequent, but when an operation does occur we try and participate by placing observers on board and by conducting simple experiments to obtain data useful to our program. The SHAREM exercises provide this opportunity periodically, and SHAREM 62 (Figure 10) was the latest of such exercises. Although the exercise was just north of Newfoundland, it did provide the opportunity to obtain useful data. Accordingly, we were able to place seven observers on board for this early November exercise. Unfortunately, the weather was warmer than hoped for and there were no icing encounters. Still, valuable experience was gained by our observers and they will be better equipped for the next operation.

A ship icing experiment has been planned at the start of the cold weather program. This proposed experiment would ice over a combatant while at anchor near a port where the temperatures would permit forming ice by spraying a fine mist of water over the superstructure. Objectives of the experiment are listed in Figure 11. Advanced preparations would establish predicted results and then the test would provide verification. Various methods of overcoming expected problems would then be implemented and their effectiveness determined. This type of test would establish the capabilities of the selected ship class under icing conditions and provide the opportunity for employing corrective measures (Results would be applicable to other ship classes with similar shipboard systems). Planning for this test will be started in about one month and the actual test is tentatively scheduled for the winter of 1987.

The preparation of a management plan to detail the required tasking is already underway. The approach to this plan is outlined in general terms in Figure 12.

There are a number of shortfalls that will impact any surface ship operations in cold weather and arctic environments. These shortfalls will affect the various ship classes differently due to configurational characteristics, but there will also be similarities. The missions of the ships will have an effect, too, because of the particular weapon systems and the methods of operation. All of these factors must be considered in finding solutions to the shortfalls, by applying both existing data as well as newly generated data that may be required to achieve a satisfactory solution.

A Plan of Action and Milestones (POA&M) is being prepared by the various Working Group participants to provide detailed tasks that must be accomplished. These tasks are either known deficiencies or perceived shortfalls based on the experience of the personnel familiar with specific ship systems. In effect, the POA&M is a Management Plan which provides the guidance and tasking for achieving the desired objectives of the program.

One of the various tasks, outlined in Figures 13 and 14, will be to review the existing cold weather documents that are in the Fleet and update them as required. Some of these documents, which number close to 30, have not been updated for a long time and there is sufficient new information to permit a meaningful update. Additionally, stability data for various ship classes due to topside icing is not available for all our ships and should therefore be prepared and made available for onboard use.

SHAREM 62 PARTICIPATION

SHIP	NO OBSERVERS	PURPOSE
USS NICHOLAS FFG 47	4	LAMPS III; ICING/ICE REMOVAL COMBAT SYSTEMS
USS VALDER FF 1096	3	LAMPS/ICING
USS TRUCKEE T-AO	3	HULL & DECK MACHINERY ICING/ICE REMOVAL
USS RADFORD DD 968	2	GENERAL OBSERVATIONS
USS FAHRION FFG 22	0	

Figure 10

OBJECTIVES OF THE ICING EXPERIMENT

- STABILITY IMPLICATIONS OF TOPSIDE ICING
- ACTIONS TO MAINTAIN HULL, MECHANICAL, AND ELECTRICAL SYSTEMS READINESS
- NEW METHODS FOR ANTI-ICING AND DE-ICING SHIP'S SUPERSTRUCTURE
- CURRENT ANTI-ICING AND DE-ICING CAPABILITIES BUILT INTO WEAPONS SYSTEMS
- LAMPS III SUPPORT SYSTEM CAPABILITIES

Figure 11

PROGRAM APPROACH

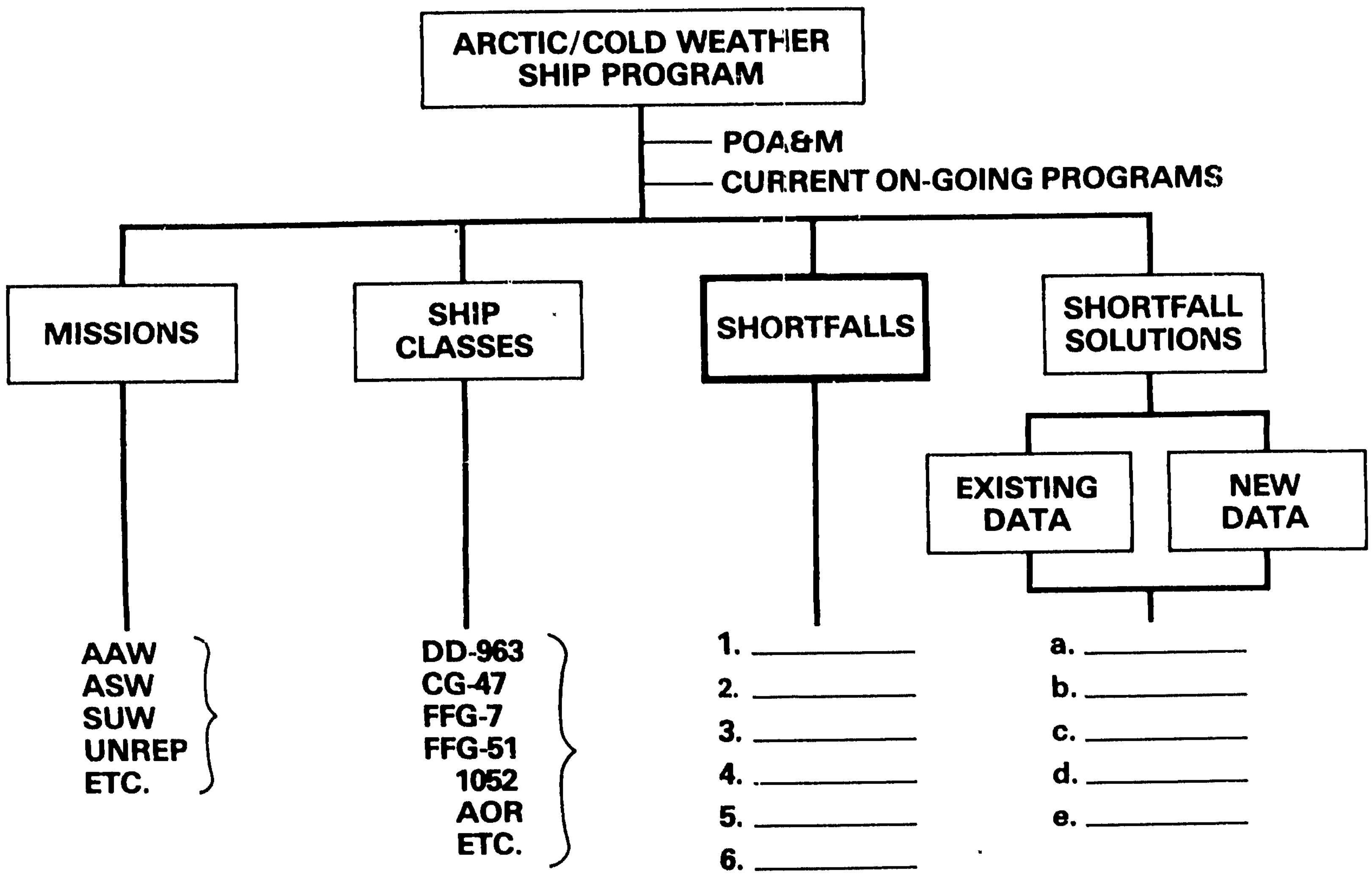


Figure 12

PROGRAM TASKS (POA&M)

LIST OF TASKS	START	COMPLETE	POINT OF CONTACT
• CONDUCT COLD WEATHER SYMPOSIUM	9/18/85	12/4/85	DTNSRDC 1231 P. YARNALL
• PLAN SHIP ICING EXPERIMENT	10/1/85	1/4/86	DTNSRDC 2724 R. ROGALSKI PMS 400 DTNSRDC PMS 399 NAVSEA
• PARTICIPATE IN SHAREM 62 EXERCISE	8/29/85	11/29/85	DTNSRDC 0600 D. WINEGRAD NAVSEA 61R DTNSRDC
• PARTICIPATE IN COAST GUARD ICE BREAKER OPERATIONS	TBD	TBD	OP-321D4 LCDR S. CORCORAN
• UPDATE COLD WEATHER FLEET INSTRUCTION DOCUMENTS • REVIEW EXISTING DOCUMENTS • UPDATE TACTICAL DOCUMENTS • PROVIDE FLEET LEVEL INSTRUCTIONS • PROVIDE SHIP STABILITY DATA FOR VARIOUS SHIP CLASSES			OP-951 D CAPT SCHANTZ NAVSEA 61 R NAVSEA 55W SURFLANT N54 DTNSRDC 2724 DTNSRDC 1561

Figure 13

PROGRAM TASKS (POA&M) (CONT'D)

LIST OF TASKS	START	COMPLETE	POINT OF CONTACT*
OPERATING & SAFETY CONSIDERATIONS			
• COMBAT SYSTEMS			NAVSEA 61R4*
— GUNS & MISSILES			DEMATTIA
— SONAR DOMES			NAVSEA 62
• H. M. & E.			NAVSEA 05R*
			CDR. R.E. BUBECK
— HULL & DECK MACHINERY			NAVSEA 56
— HELO INTERFACE			NAVSEA 55W4
— PROPULSION & AUX. MACHINERY			DTNSRDC 1561
— STABILITY			DTNSRDC 2724
— STRUCTURES			DTNSRDC 2724
— UNDERWATER APPENDAGES			

Figure 14

The ability of combat systems to operate under cold weather conditions is critical to the effectiveness of these combatants. The actual utilization of these systems to prove their capabilities under both cold weather and icing conditions must be undertaken during real life conditions. Initial predictions of possible shortfalls must first be made, with potential corrective measures prepared for incorporation and testing. The maneuvering of ships in areas of floating ice could pose problems for the bow-installed sonar domes and this possibility must be examined. Propeller impacts with floating ice is another concern.

Hull, mechanical, and electrical equipment must function properly during operations in cold weather and under icing conditions. Each item of equipment must be examined for potential problems, potential shortfalls highlighted, and corrective measures promulgated. Testing will undoubtedly be required either in the laboratory or preferably under realistic arctic conditions on board ship.

A schedule of the various major tasks, although incomplete at this time, is outlined in Figure 15. It is anticipated that this plan will be completed by the first quarter of calender 1986.

Although the Arctic/Cold Weather Program has been in existence less than six months, the progress to date has been encouraging and the efforts of the Working Group members are providing positive results. Figure 16 lists some conclusions that can be made at this time. We are sensitive to the fact that there is a lack of awareness of some of the severe arctic environmental conditions that must be overcome in order to operate our ships in the Arctic. We must increase this awareness throughout the fleet. The bottom line in knowing what our real capabilities are in operating in the Arctic is to actually operate in the Arctic! Our combatants must participate in Arctic operations in the forseeable future to provide the necessary information on our ship's capabilities as well as the capabilities of the ships' crews.

Preparation for Arctic operations must be realistic and thorough, and this can only be accomplished by providing the necessary training documents and training films to disseminate this information. Most crews will probably be going to the Arctic for the first time, and this makes training all the more important.

Lastly, we must show results as quickly as we can in order to not only provide an improved capability to the Fleet, but to demonstrate that a Cold Weather Program can produce meaningful and pertinent results to the Fleet.

COLD WEATHER PROGRAM

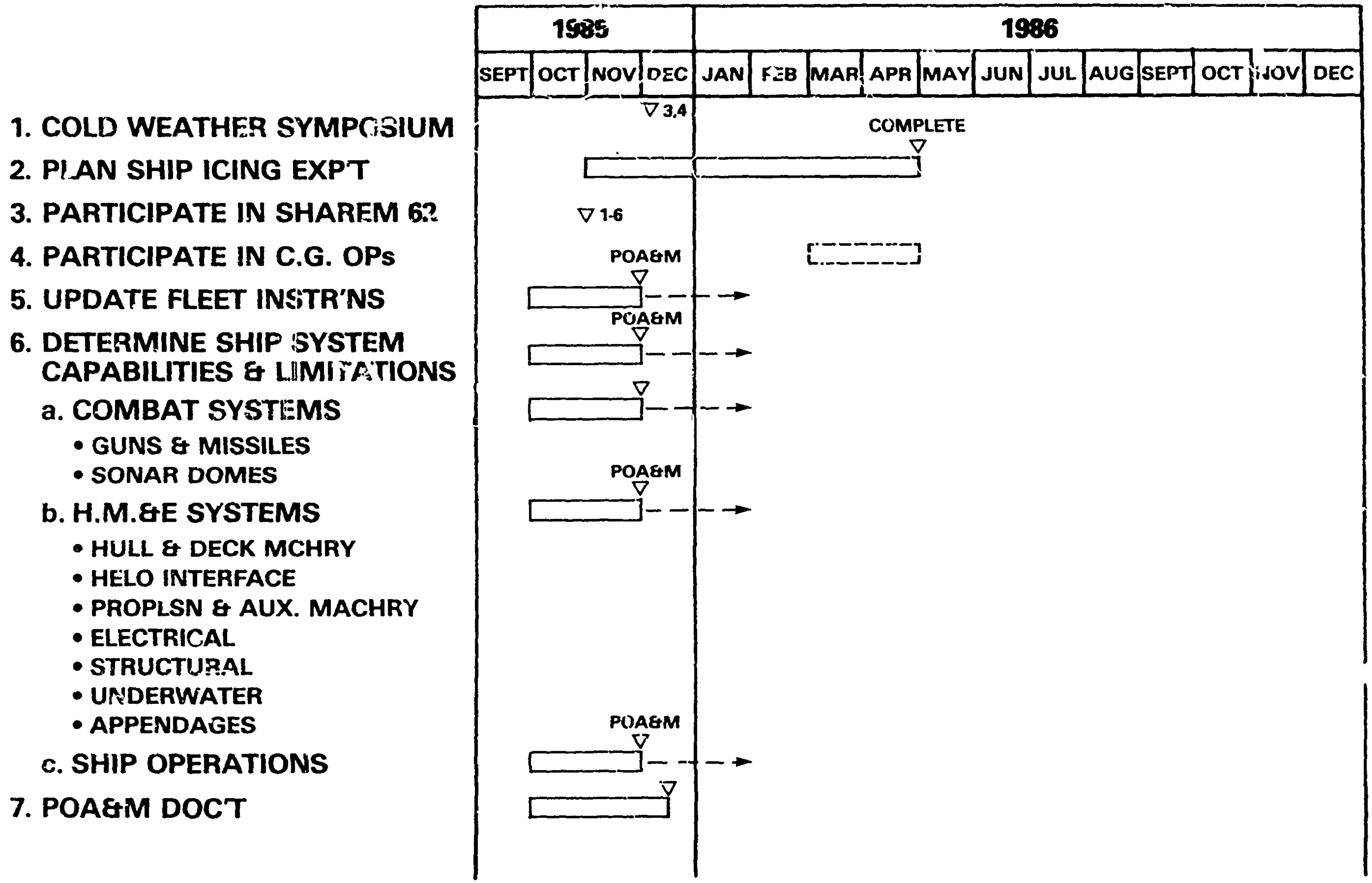


Figure 15

CONCLUSIONS

1. THE PROGRAM IS ORGANIZED AND FUNCTIONING
2. THERE IS A NEED FOR PROVIDING AN AWARENESS OF ARCTIC REQUIREMENTS
3. INTEREST IN ARCTIC SHIP OPERATIONS MUST BE ACTIVELY PURSUED
4. SOLUTIONS TO IMPORTANT OPERATING PROBLEMS MUST BE INVESTIGATED AND RESULTS DISSEMINATED
5. TRAINING DOCUMENTS AND FILMS MUST BE PROVIDED TO THE FLEET
6. IMMEDIATE RESULTS ARE NECESSARY TO MAINTAIN INTEREST
7. EXISTING FLEET COLD WEATHER DOCUMENTS MUST BE UPDATED

Figure 16

Jerry W. Reshew
Naval Oceanography Command

ARCTIC ENVIRONMENT

INTRODUCTION

The Naval Oceanography Command has the major claimant responsibility, under CNO (OP-006), of providing operational oceanographic, meteorological and certain mapping, charting and geodesy services to the Fleet. We provide this support through our subordinate activities, the Naval Oceanographic Office, Naval Polar Oceanography Center, Fleet Numerical Oceanography Center and various regional Centers, Detachments and Facilities. Products which we provide result from Fleet requests through a structured requirements submission program and are generally very specific in scope and format. It is toward a new and broader set of products which we are directing the efforts of our activities and which we have termed the "Arctic Initiative" program.

Operations in the Arctic region are limited by the obvious environmental considerations, plus the lack of knowledge of the acoustic structure and the topography of the basin. We were asked, in 1984, to prepare a program which could be accomplished using off-the-shelf technology wherever possible. This program would be operational rather than research, and would have a product ready for delivery as an objective.

A management tool which is used by the Oceanography Command is the "Program Integration Team." Each team consists of representatives of the various command departments, subordinate activities, and from other organizations outside of the claimancy. These formal committees agree to accept verbal tasking toward attacking a problem, the tasking developing during the team's meetings. A team was established to address the Arctic operational initiatives.

The mission of the Command can be described as either:

o Providing some prediction over time, i.e., weather, ice, ASW acoustics, etc.

o Providing a snapshot of present conditions, i.e., ice coverage, mass structure of the ocean, sound speed, etc.

Capabilities which we use to satisfy the mission are:

o Observations (in situ) using our aircraft (RP-3), participating in Fleet exercises, satellites, moored or drifting buoys.

o Climatology - data sets, historical files, computer resident data bases, etc.

o Models - ice related models resident in our Fleet Numerical Oceanography Center.

ARCTIC INITIATIVES

Our charter for this program is best viewed as having four specific constraints:

o Achievable Near Term Goals - The program covers a five year period and we want a product deliverable available early in the program.

o Operational Potential/Low Risk - The new initiative must have a real potential to help Naval operations and be of minimum risk of failure.

o We must satisfy a real need - no "nice to have" projects are desired.

o Our R&D and Operational actions must be coordinated - no duplication of effort is expected.

FIVE YEAR PROGRAM

The Program Integration Team used all available sources to identify environmental requirements that were not being addressed in the command managed programs. Some of the concerns which could be developed into the service or products to suit our charter are classified, but the flavor of what we are doing can be sampled by the following projects.

Ice - Measurement and Characterization

The ability to measure the thickness of the ice mantle remotely with a ± 20% assurance, is a goal which can be satisfied using present technology. We are scheduled to test three systems which have the ability to give us near real time ice measurement capability from RP-3 aircraft. The systems are:

AEM - Airborne Electro-Magnetic. A system which is used commercially in the oil exploration industry is the DIGHEM III frequency domain AEM. The Defense Mapping Agency has funded the Navy to determine the suitability of such a system to measure water depth in shallow areas. The Naval Ocean Research and Development Activity (NORDA) proposed using this technique for ice measurement. The physical principle used in this system is the production of a secondary magnetic field by the induction of eddy currents in the ground or water. As the eddy currents decay, a measurable secondary magnetic field is present when the power used to generate the primary field is turned off. This secondary field varies as to conductivity and shows a discontinuity when different densities are present. AEM systems have a small footprint when flown at low altitude and have demonstrable accuracy. We will use the AEM in conjunction with:

KA-BAND RADAR. This system provides a brightness temperature map of an ice scene. A product of this map is a color portrait of open water, frazil, old ice and first year ice. The picture is digital and can be combined with a ground truth track (the AEM) to yield an ice thickness chart. A dual pulse radar will also be evaluated as a ground truth device.

If our demonstration flight in February/March 1986 results in meaningful data, we will prepare a specification for development of an operational system to provide our Polar Oceanography Center with a flow of near real time data to be used in our forecasts. It should be noted that we are not attempting to provide scientific ice measurements. We are trying to provide a product that will give the ship or submarine a quick picture of meaningful ice thickness - that magical number which will allow penetration, up or down, by specific weapons. A "go" or "no go" product is probably the result.

We are not going this alone. The Army Cold Regions Research and Engineering Laboratory (CRREL) and NORDA are involved and will run the demonstration flight.

GEOSAT

Altimeter information from the GEOSAT vehicle is being analyzed at this time to determine the most effective way to extract ice edge data. Since the satellite can provide data during the Arctic winter darkness, our ice coverage program can be based on measurements which are not now available. Communications links are established and the data will flow from the Naval Oceanographic Office to the Fleet Numerical computers for distribution to the user.

BUOYS

Lack of observations in the Arctic has made weather prediction a difficult proposition. In order to provide long term measurements in the region, we are installing ten on-ice meteorological buoys and three through-ice oceanographic buoys each year for five years. These remote stations will transmit data to the Command Centers for update of the predictive models and will result in more accurate forecasts. These data are the only environmental measurements available on a regular basis. Our first deployment will be in March 1986. Wind speed, temperature, barometric pressure and position will be transmitted six times a day from the meteorological stations. The oceanographic buoys will transmit depth and temperature information down to 350 meters, plus geographic position.

ACOUSTICS

Our weapons systems requiring acoustic data are affected by the difficulty of acquiring data in the Arctic. NAVOCEANO is assembling an Acoustic Data Base to be used in preparation of operational products. While we cannot discuss much of the process in an open meeting, let it suffice to say that the data base will be resident in an easily accessble computer file and will contain quality controlled information on ambient noise and the vertical structure. The products which are transmitted by the Fleet Numerical system will be consistent in the use of these data base items and our acoustical forecasts will be improved.

SENSORS

Procurement of special sensors for arctic ocean measurement will be increased, and the deployment rate of these sensors will be stepped up. Measurements in the region are sparse and we cannot provide adequate information on the ocean environment using models alone. As work progresses by the development laboratories and by the private sector, we will incorporate the resulting devices in our oceanographic and meteorological instrumentation suites.

FORMAT

Distribution of oceanographic forecasts to platforms in the Arctic is difficult, particularly to submarines. We are redesigning many of our electronically transmitted products to a compact format. These transmissions will most probably be of a "change to last report" type which will drastically reduce transmission time. Some effort is being put into using standard desk top computers as host for a pre-packaged data base which could be operated on by a broadcast. Our initial reduced load format should be partially operational this year.

SATELLITE PROCESSING

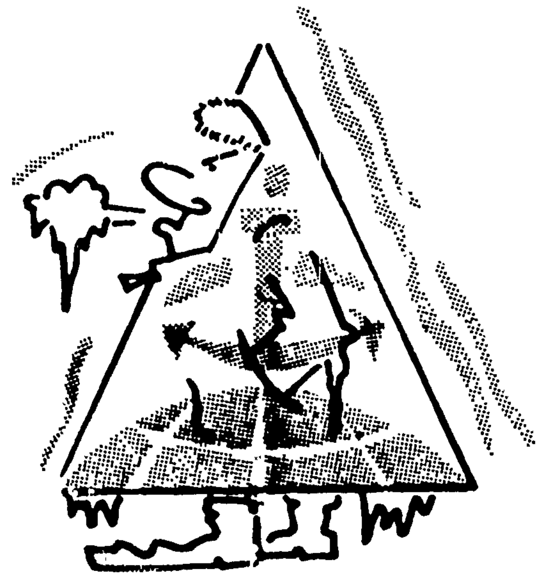
The Polar Oceanography Center will be provided with a digital image processor capability. With this system, an analysis of imagery can be performed and transmitted, via a link with Fleet Numerical, in near real time. This procedure will upgrade the ice coverage forecasts significantly.

ENVIRONMENTAL GUIDES

A hard copy product produced by NAVOCEANO has been redesigned as an Arctic Environmental Guide. Each guide contains climatological, geophysical and acoustic information for a standard ocean area. The guide is being prepared for priority areas and will be available commencing at the end of the year.

While the description of our support is intentionally broad due to the classification problems at such a meeting, I hope that I've left you with the feeling that we are doing something for the operator in this part of the world ocean. Our role is that of a service organization. You are our customers and we hope to hear from you if we can be of help.

NAVAL OCEANOGRAPHY COMMAND



ARCTIC OCEANOGRAPHY PROGRAMS

1 SEP 85

MISSION

- PREDICTION
  - WEATHER
  - ICE
  - ASW
- SNAPSHOT
  - ICE THICKNESS
  - MASS STRUCTURE
  - SOUND SPEED

1 SEP 85

CAPABILITY

- OBSERVATIONS
  - BIRDSEYE/SEASCAN
  - FLEET ICEX
  - SATELLITES
  - BUOYS
- CLIMATOLOGY
- MODELS
  - (APL-UW) THORNDIKE-COLONY
  - (CRREL) HIBLER
  - (NAVY) NORAPS, NOGAPS, ETC.

1 SEP 85

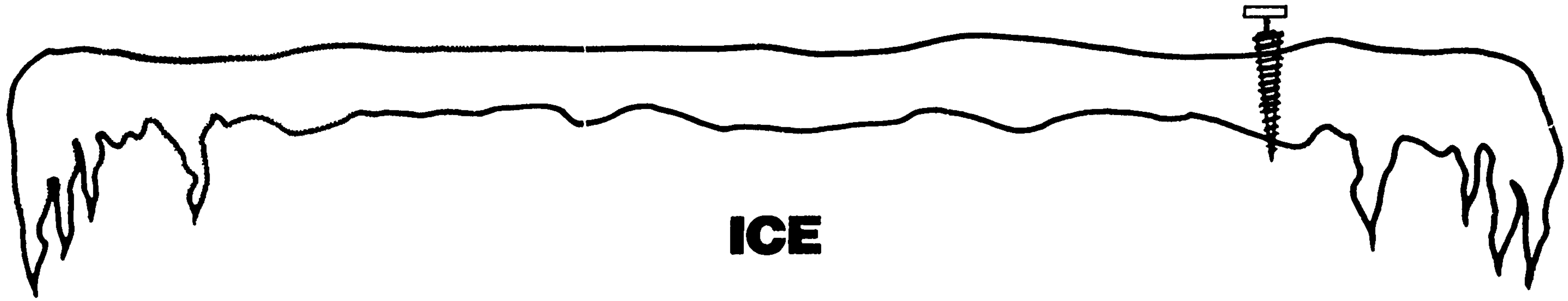
INITIATIVES

- ACHIEVABLE NEAR TERM GOALS
- OPERATIONAL POTENTIAL/LOW RISK
- SATISFY REAL NEEDS
- COORDINATED R&D AND OPERATIONAL PROGRAM

1 SEP 85

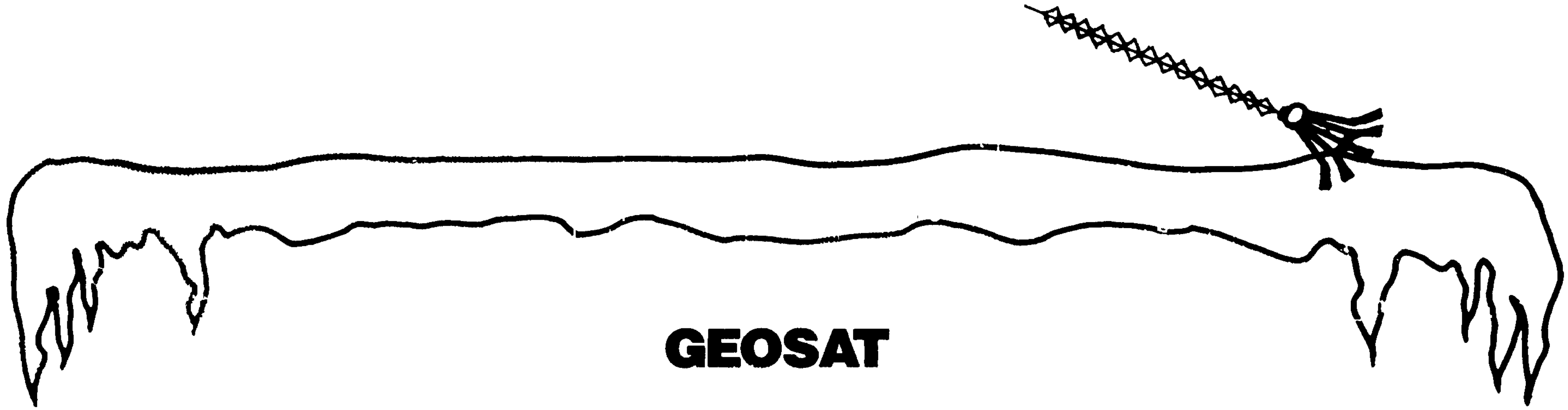
5 YEAR PROGRAM

1 – ICE
2 – GEOSAT
3 – CLASSIFIED
4 – BUOYS
5 – ACOUSTICS
6 – SENSORS
7 – RESERVED
8 – CLASSIFIED
9 – FORMAT
10 – CLASSIFIED
11 – SATELLITE PROCESSING
12 – GUIDES



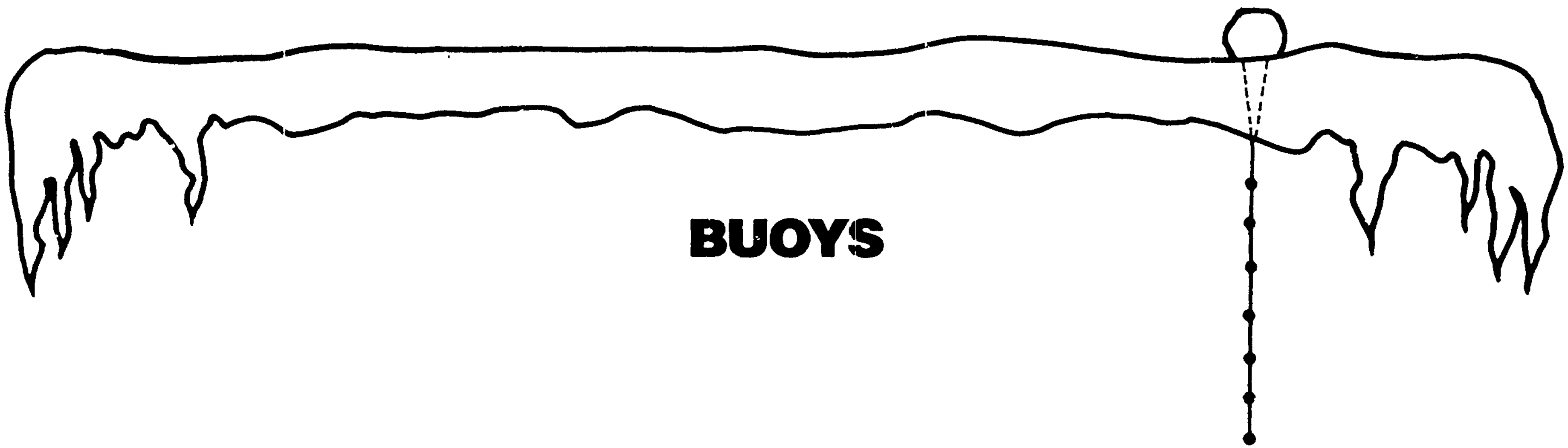
ICE

- MEASUREMENT AND CHARACTERIZATION USING:
  - AEM
  - K-BAND
  - RADAR
- COMBINED RESOURCES OF NORDA AND CRREL
- FLIGHT IN EARLY 1986
- NEAR REAL-TIME RESULTS $\pm$ 20%



GEOSAT

- ALTIMETER DETERMINES ICE EDGE
- 24-HOUR SYSTEM
- FLENUMOCEANCEN AND NAVPOLAROCEANCEN WILL INCORPORATE INTO PRODUCTS



BUOYS

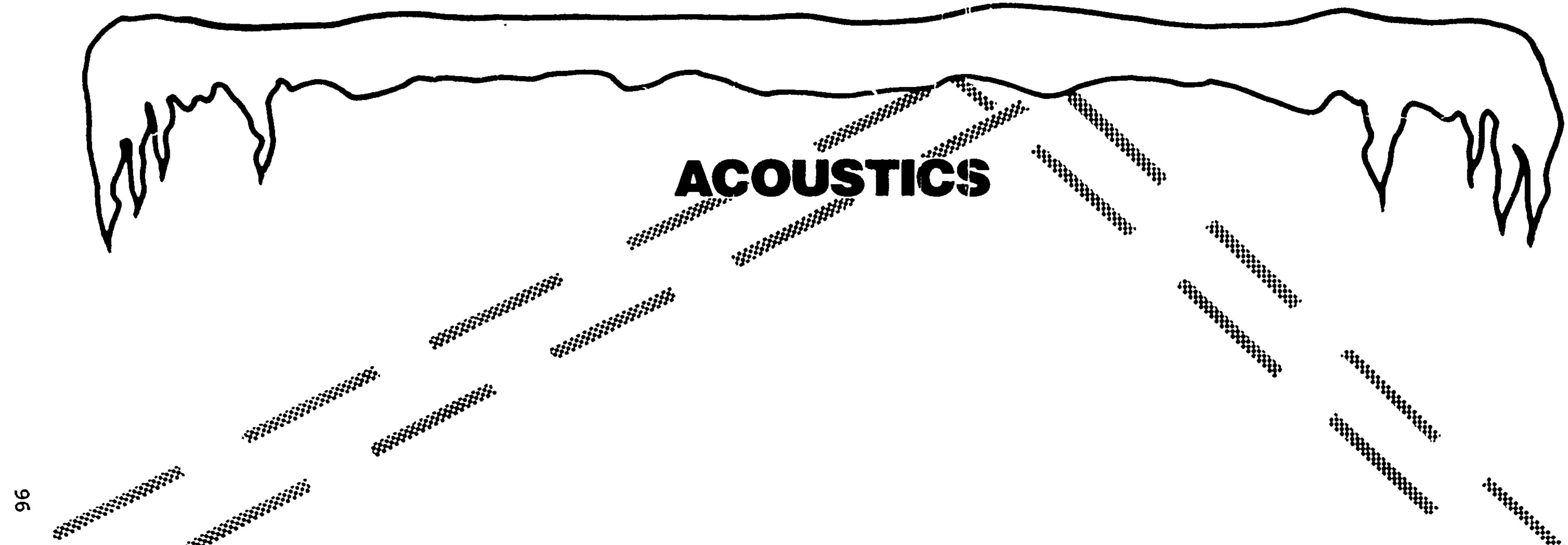
- METEOROLOGICAL

  10 PER YEAR ON ICE

- OCEANOGRAPHIC

  3 PER YEAR THROUGH ICE

- VERTICAL STRUCTURE TO 350 M. ONLY ACOUSTIC INPUT AVAILABLE ON REGULAR BASIS



ACOUSTICS

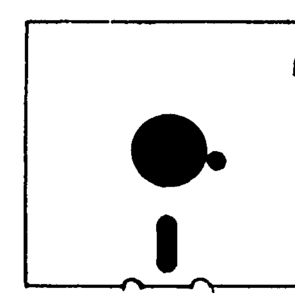
- DATA BASE USING AMBIENT NOISE AND VERTICAL STRUCTURE INFORMATION
- FEEDS REAL-TIME PROGRAM

SENSORS

- NAVOCEANO WILL DEPLOY EXPENDABLES AT GREATER RATE

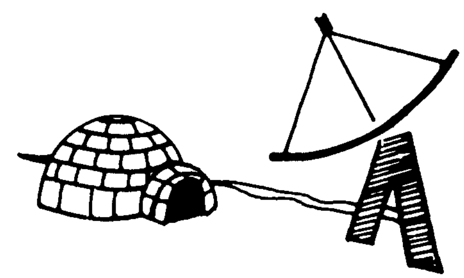
FORMAT

- WEATHER AND OCEAN DATA ARE BEING COMPACTED
- PROBABLY WILL BE "CHANGE TO LAST REPORT" FORMAT
- PRIMARILY TO ASSIST SUBMARINES



SATELLITE PROCESSING

- DIGITAL IMAGE PROCESSING AT NAVPOLAROCEANCEN
- ENHANCED CAPABILITY TO REPORT ICE COVER



GUIDES

- ENVIRONMENTAL GUIDES BY NAVOCEANO
  - CLIMATOLOGICAL AND GEOPHYSICAL
  - ACOUSTIC
  - COMPACT AND COMPREHENSIVE
- ARCTIC PRIORITY AREA

SEAWAY PERFORMANCE IMPROVEMENT PROGRAM

CDR R.B. BUBECK, NAVSEA

The requirement for surface ships to operate in the northern latitudes will push the operability of current ship designs to the upper limits. A methodology for evaluating the measure of effectiveness of ship systems exposed to the harsh environment of cold weather climates has been developed and used to evaluate generic examples of ship systems. The proper use of environmental data allows the preparation of contour plots for measuring the effectiveness of ship systems and ship operations. This methodology is used to accomplish trade off studies of different ship configurations, thus showing how improvements in ship systems can affect performance under harsh environmental conditions.

SEAWAY PERFORMANCE IMPROVEMENT PROGRAM (SPIP)

PROGRAM MANAGER: SEA 05R
TECHNICAL DIRECTOR: SEA 55W3
LEAD LABORATORY: DTNSRDC

seaway performance improvement program

OBJECTIVE

IMPROVE THE SEAWAY PERFORMANCE AND COMBAT CAPABILITY OF SURFACE SHIPS TO ENHANCE THE EXECUTION OF NAVY MARITIME STRATEGY IN EXTREME NORTHERN OPERATIONAL AREAS

APPROACH

APPLY SEAWAY PERFORMANCE TECHNOLOGY TO EVALUATE CURRENT SHIP MISSION LIMITATIONS AND DEVELOP ALTERNATIVES WHICH MINIMIZE DEGRADATIONS IN SHIP, WEAPON AND SENSOR SYSTEMS

PERFORMANCE INFLUENCE PARAMETERS (PIP)

ISSUES:

- INSUFFICIENT PROJECTIONS OF COMBAT SYSTEM PERFORMANCE IN ADVERSE ENVIRONMENTS.
- LACK OF INVESTMENT/DESIGN TRADE-OFF BETWEEN SHIPS AND COMBAT SYSTEMS.

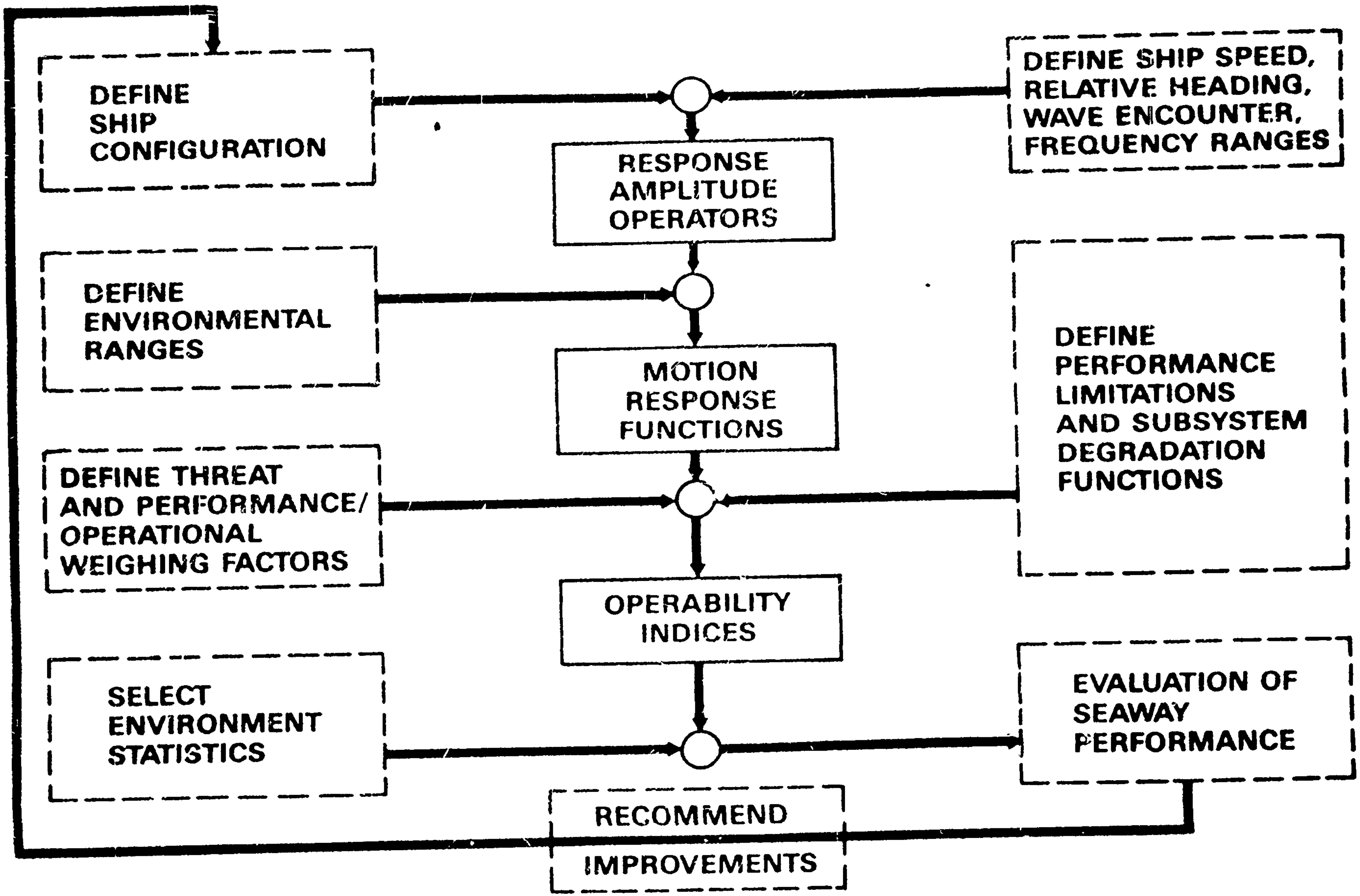
NAVY NEED

- DESIGN DISCIPLINE TO ENABLE COMPREHENSIVE PROJECTIONS OF NEW CLASS SHIPS COMBAT PERFORMANCE.
  - NORTHERN LATITUDES
  - FORCE STRUCTURE PLANNING
  - TACTICAL PLANNING
- DESIGN DISCIPLINE TO ENABLE COST AND PERFORMANCE TRADE-OFF BETWEEN SHIP AND COMBAT SYSTEM.
  - COST EFFECTIVENESS
  - IMPROVED PERFORMANCE

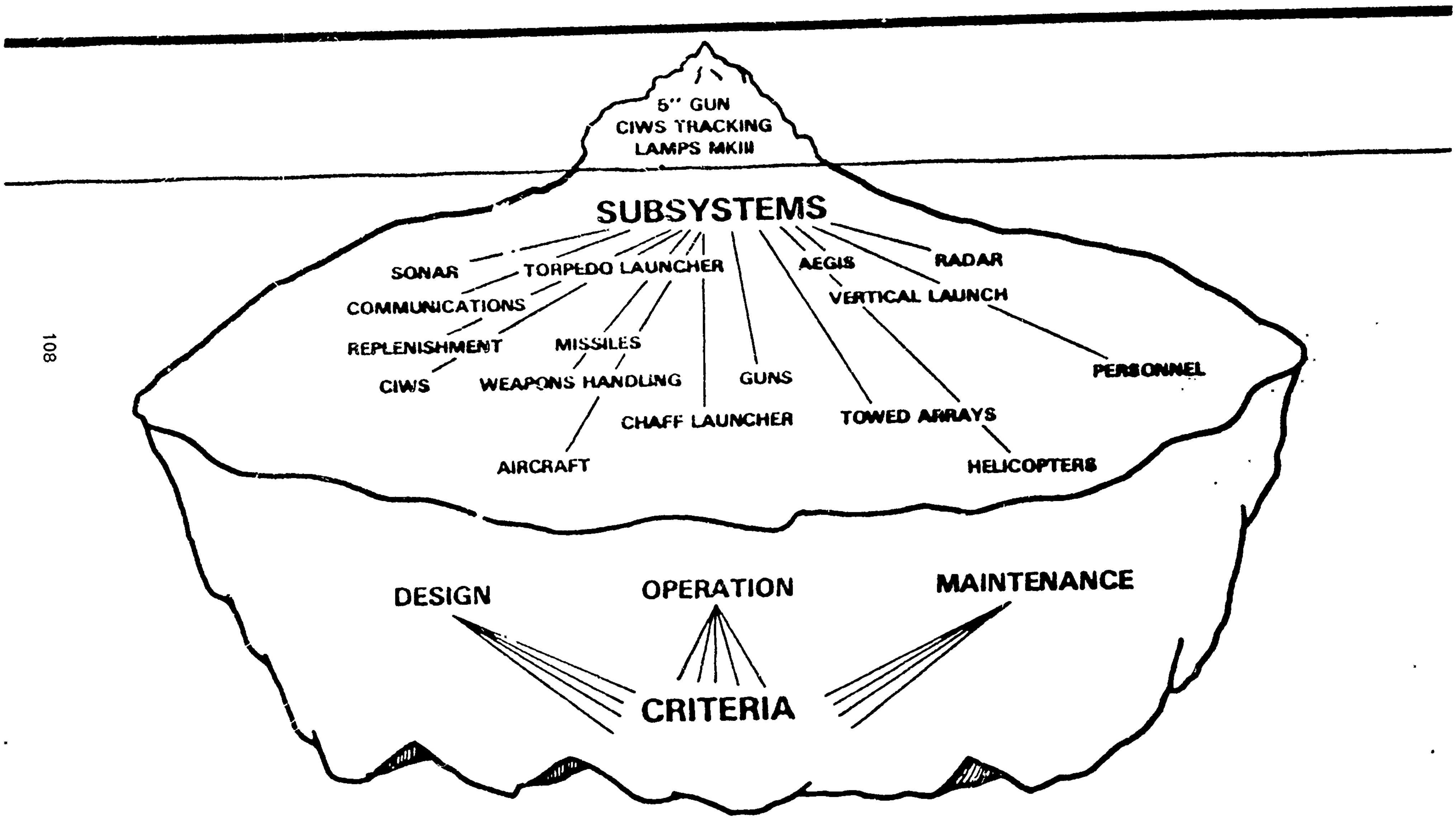
APPROACH

- DEFINE SHIP PERFORMANCE AS THE DEGREE TO WHICH SHIPS SUCCESSFULLY FULFILL THEIR MISSION
- DEFINE ENVIRONMENT AS BOTH THE PHYSICAL ENVIRONMENT (WIND, WAVES, CURRENT, PRECIPITATION, ETC.) AND THE EXTERNAL THREAT
- DEFINE A MEASURE OF MERIT, WHICH INDICATES HOW SUCCESSFULLY A SHIP CAN FULFILL ITS MISSION, AS THE OPERATIONAL PERCENTAGE FOR THE SHIP SUBSYSTEM AND CREW
- ESTABLISH THE OPERATIONAL PERCENTAGES FOR THE SHIP'S SUBSYSTEMS AND CREW IN THE ENVIRONMENT

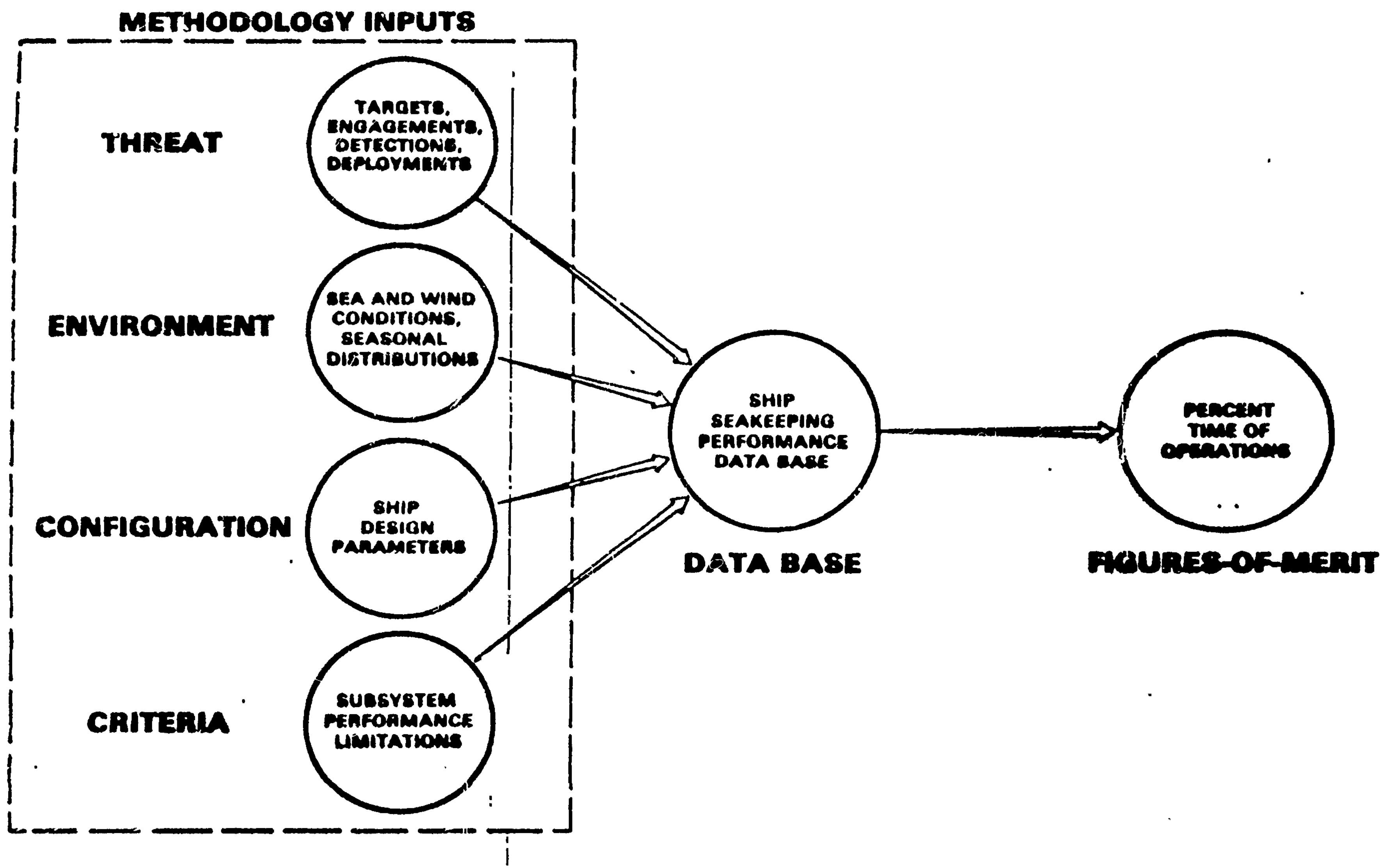
seaway performance analysis methodology



TIP OF THE CRITERIA ICEBERG



OPERATIONAL PERFORMANCE ASSESSMENT METHODOLOGY



GUN MOUNT
GUNFIRE CONTROL SYSTEM

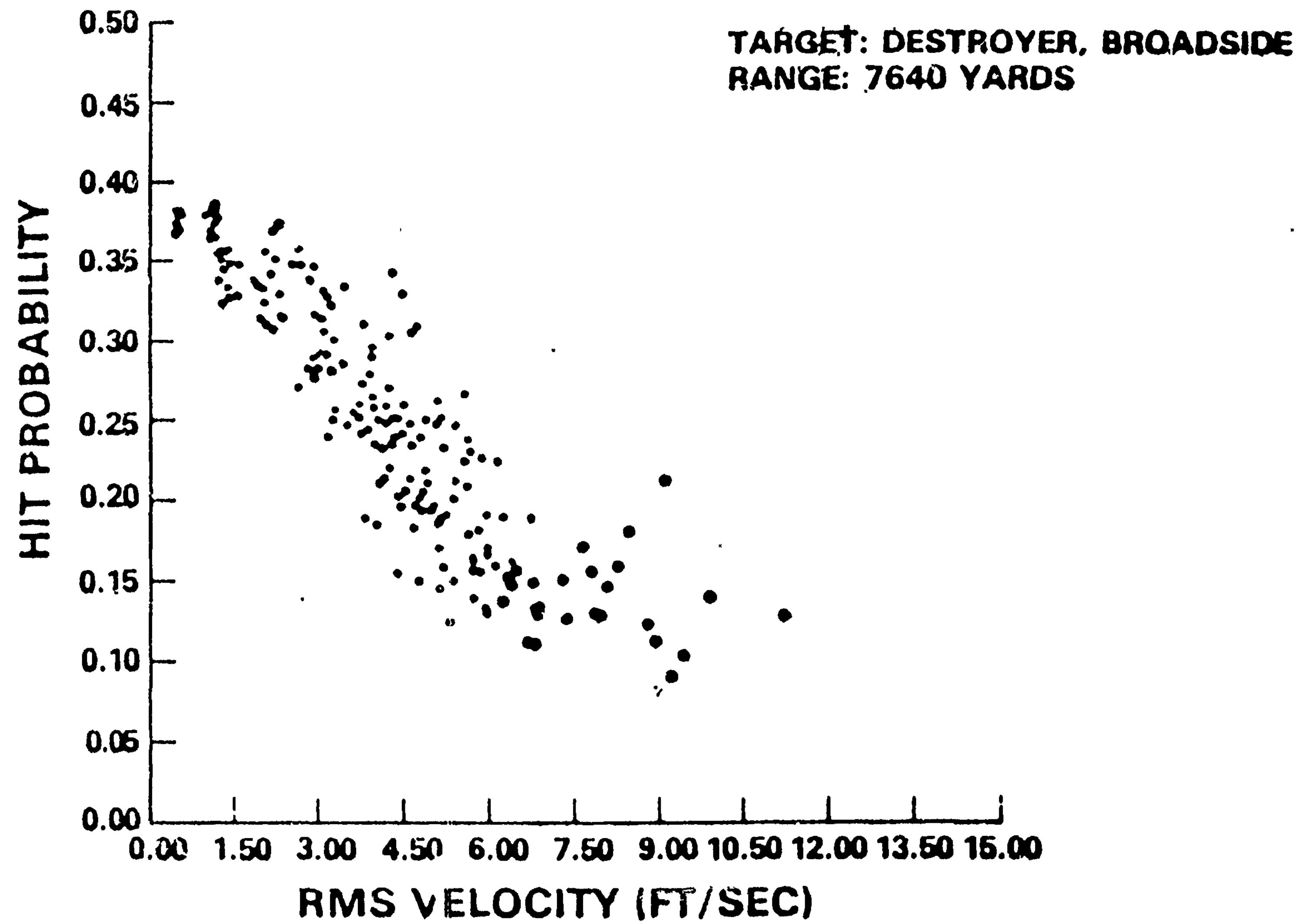
THREAT: DESTROYER, BROADSIDE
- RANGE 7640 YARDS
- BEARING 0° AND 90° RELATIVE

ENVIRONMENT: SEA STATES 5 AND 6
- SIGNIFICANT WAVE HEIGHTS 10-20 FEET
- WAVE PERIODS 8-17.5 SECONDS

CONFIGURATION: FRIGATE WITHOUT FIN STABILIZERS

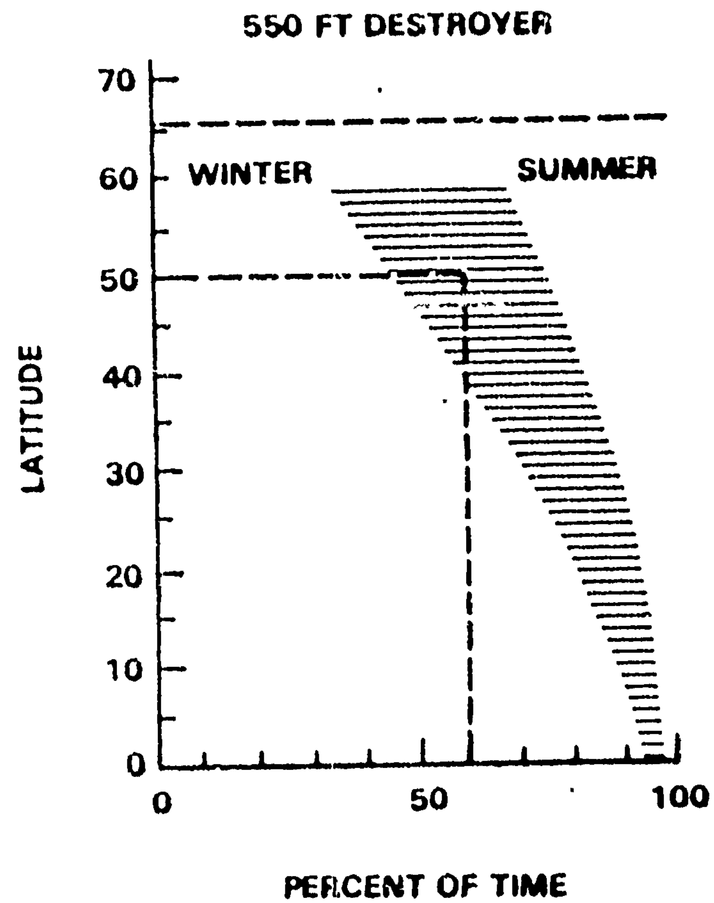
CRITERIA: SINGLE SHOT HIT PROBABILITY

HIT PROBABILITY VS GUN MOUNT VELOCITY



ANNUAL PROBABILITY OF NOT EXCEEDING 3 FEET/SECOND AT THE GUN MOUNT (ANNUAL HIT PROBABILITY WITH 10—SHOT SALVO)

SURVEY RESULTS ON HELICOPTER OPERATIONS IN OPEN OCEAN NORTH ATLANTIC



LIGHT AIRBORNE MULTIPURPOSE SYSTEM LAMPS MKIII

THREAT: SUBMARINE

ENVIRONMENT: SEA STATE 5

- SIGNIFICANT WAVE HEIGHTS 7-13 FEET
- WAVE PERIODS 7-15 SECONDS

CONFIGURATION: FRIGATE

- WITHOUT FIN STABILIZERS
- WITH RAST SYSTEM

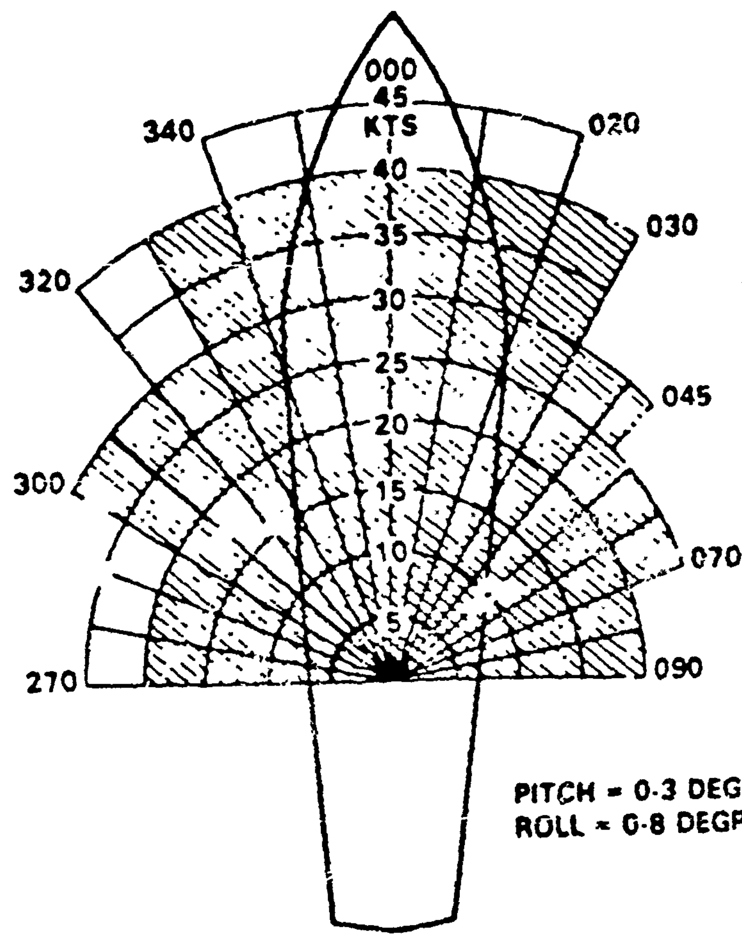
CRITERIA: LAUNCH, RECOVERY, AND TRANSIT

- RELATIVE WIND, ROLL, & PITCH
- MOTION-INDUCED INTERRUPTIONS
- HANGAR/HELICOPTER CLEARANCES

LAMPS III DAY LAUNCH AND RECOVERY LIMITING WIND ENVELOPE (ENVELOPE A)

ENVELOPE A

SH-60B DAY LAUNCH AND RECOVERY LIMITATIONS

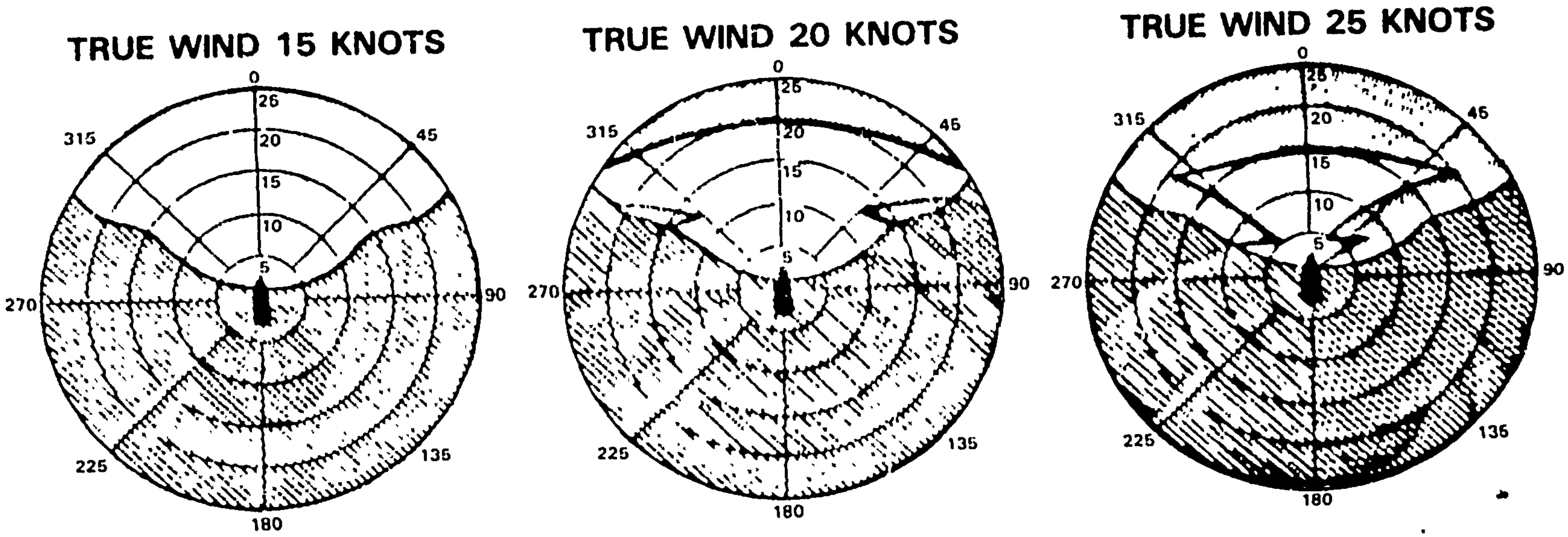


PITCH = 0-3 DEGREES
ROLL = 0-8 DEGREES

- HELICOPTER ALIGNED WITH SHIP CENTERLINE
- SHIP PITCH AND ROLL MEASURED AT LSO STATION
- RSD = RAPID SECURING DEVICE
- USE ENTIRE ENVELOPE FOR:
  (1) LAUNCHES WITH OR WITHOUT RSD
  (2) RECOVERIES WITH CABLE AND WITH OR WITHOUT RSD
- USE SHADED ENVELOPE FOR:
  RECOVERIES WITHOUT CABLE AND WITH OR WITHOUT RSD

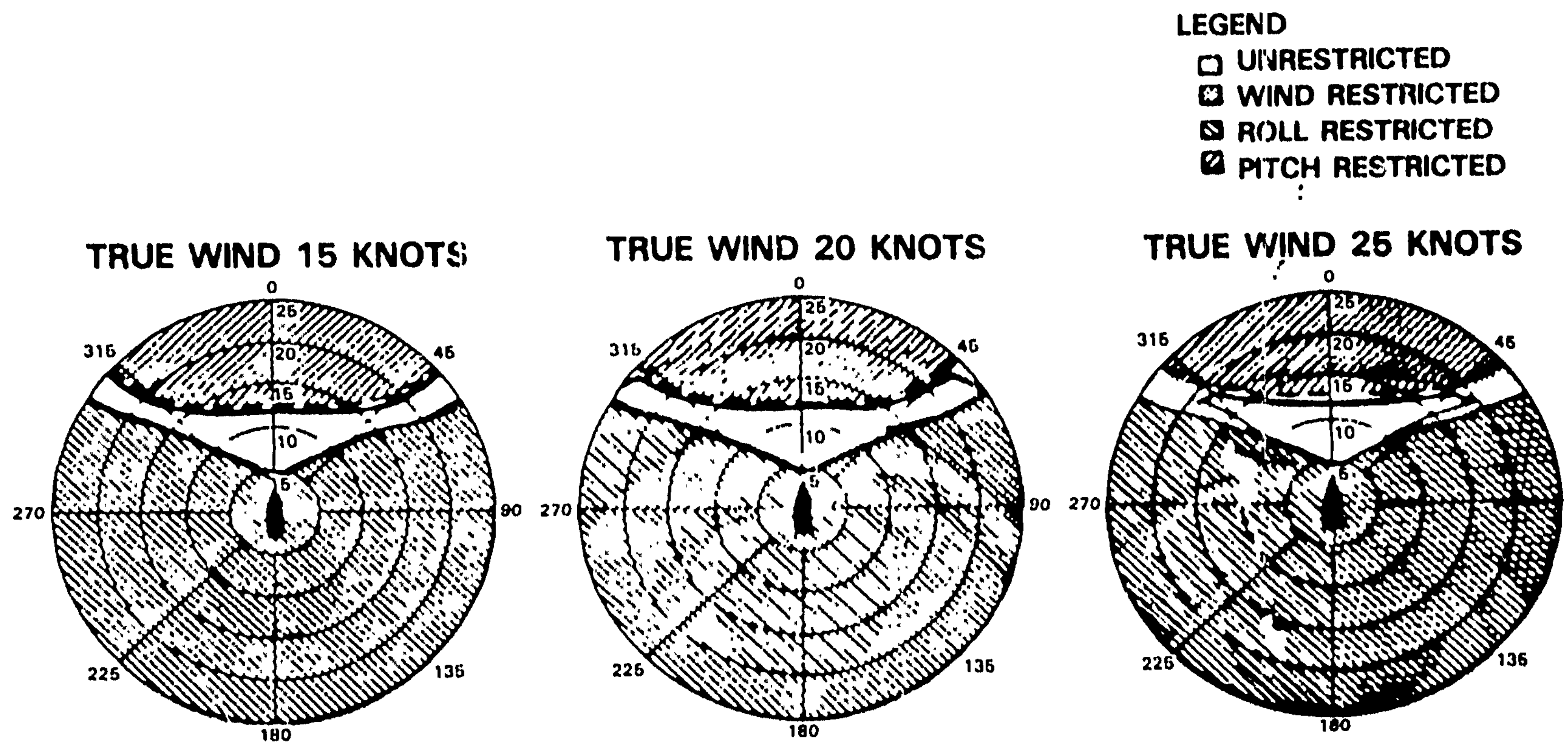
LAMPS MKIII OPERATIONAL ENVELOPES
DAY LAUNCH/RECOVERY

LEGEND
- UNRESTRICTED
- WIND RESTRICTED
- ROLL RESTRICTED
- PITCH RESTRICTED



SEAWAY: SHORTCRESTED, 9 FEET, 7 SECONDS
MOTION LIMIT(S): ROLL 8 DEGREES

LAMPS MKIII OPERATIONAL ENVELOPES
DAY LAUNCH/RECOVERY

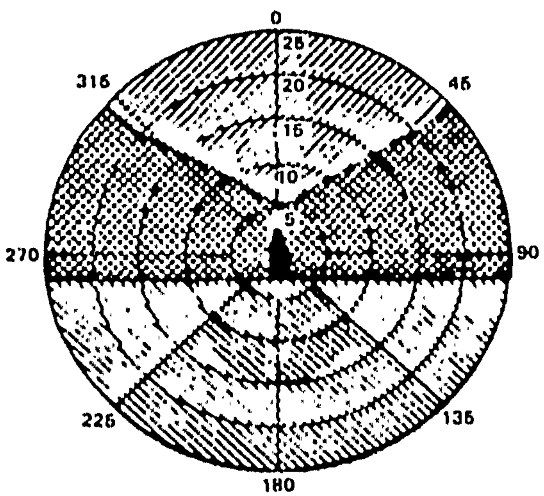


SEAWAY: SHORTCRESTED, 9 FEET, 9 SECONDS
MOTION LIMIT(S): ROLL 8 DEGREES
PITCH 3 DEGREES

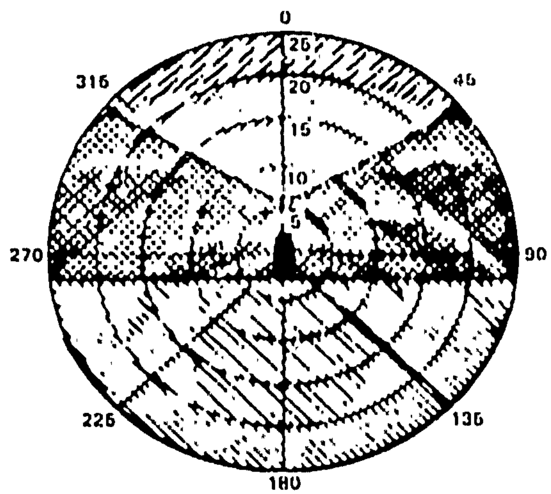
LAMPS MKIII OPERATIONAL ENVELOPES
DAY LAUNCH/RECOVERY

LEGEND
- UNRESTRICTED
- WIND RESTRICTED
- ROLL RESTRICTED
- PITCH RESTRICTED

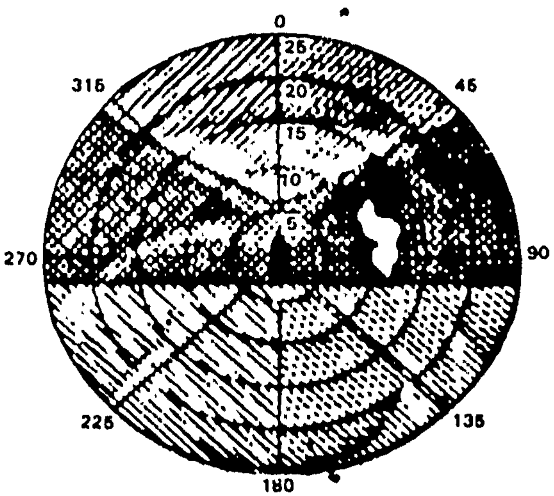
TRUE WIND 15 KNOTS



TRUE WIND 20 KNOTS



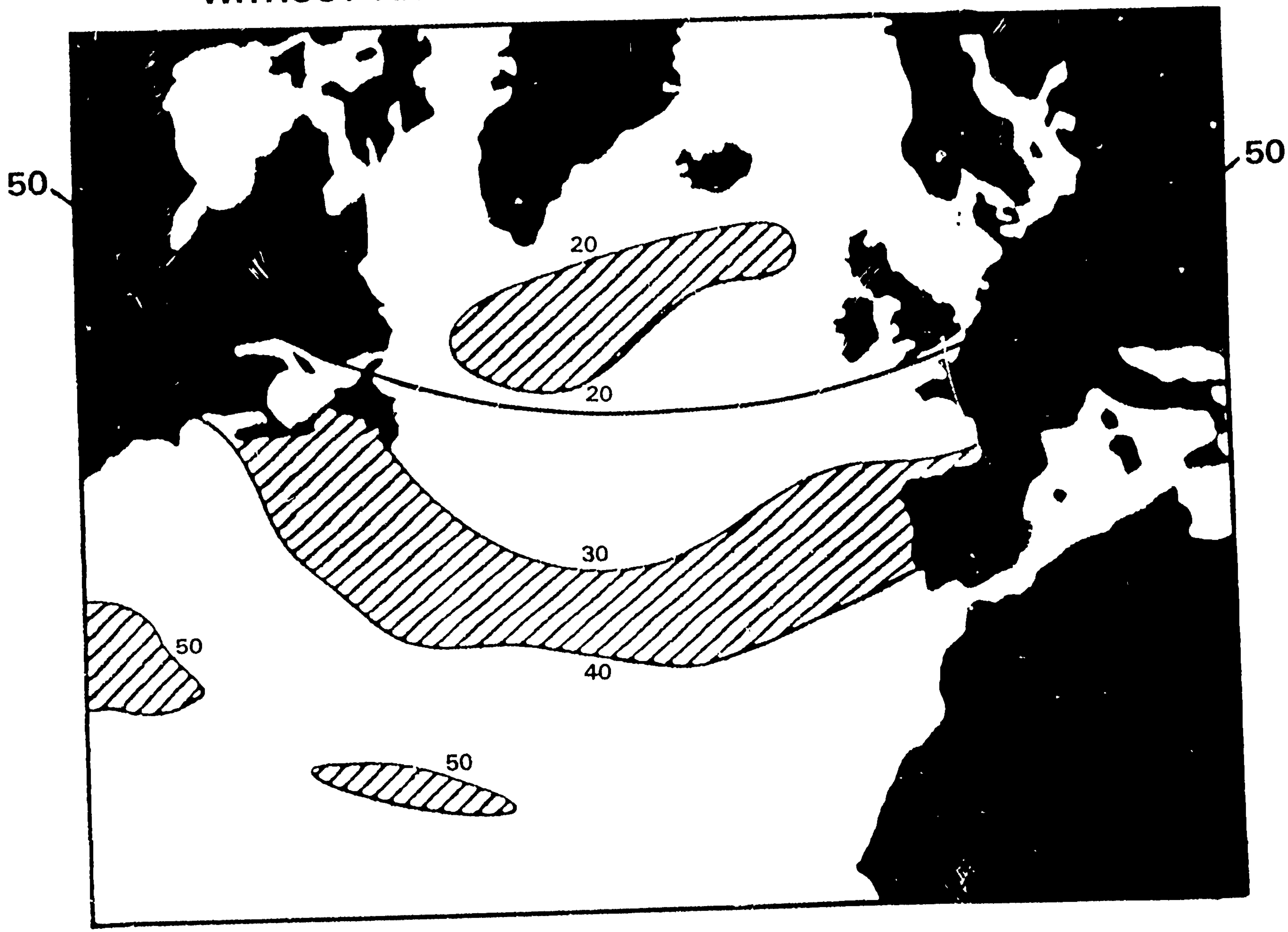
TRUE WIND 25 KNOTS



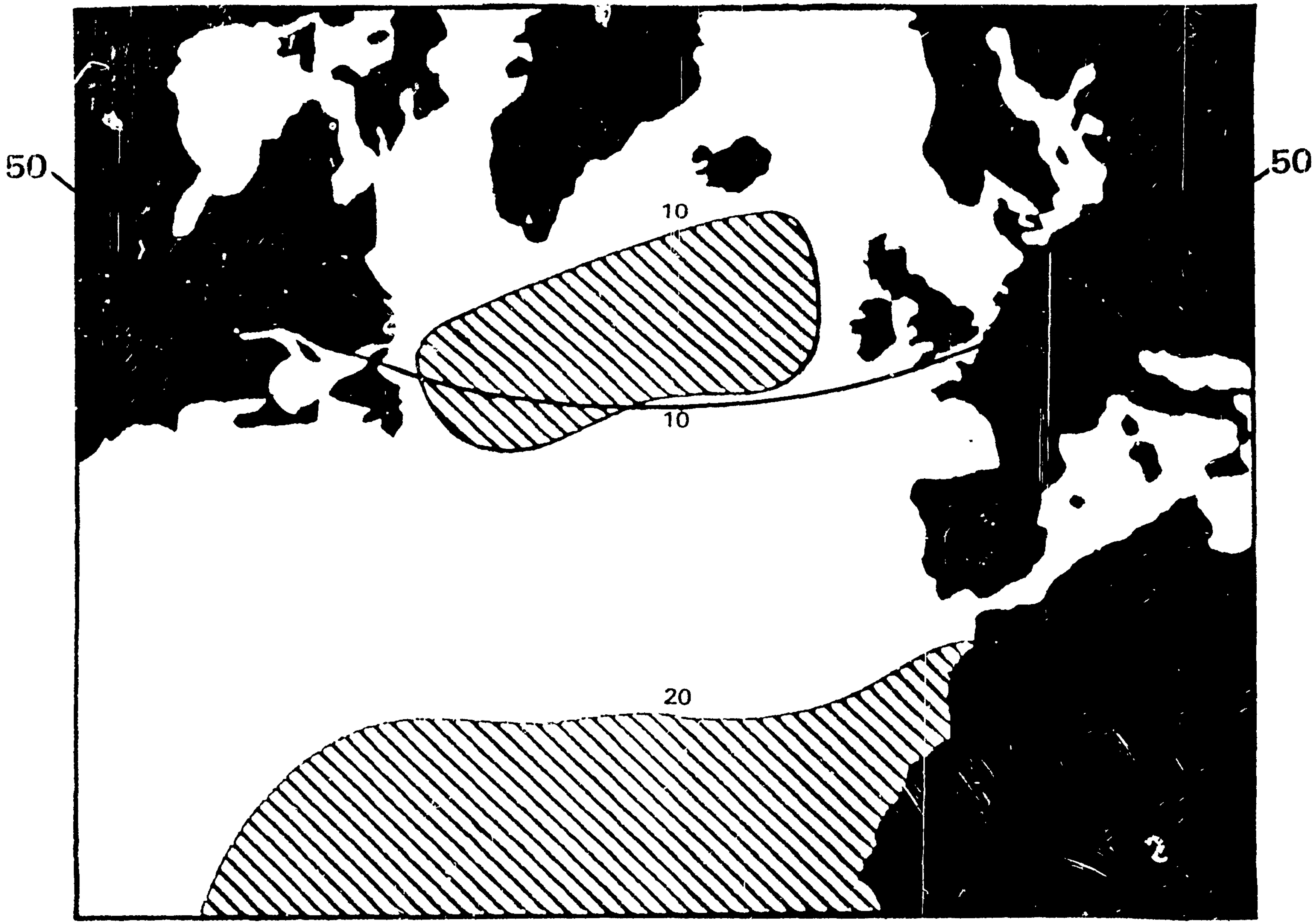
SEAWAY: SHORTCRESTED, 11 FEET, 9 SECONDS
MOTION LIMIT(S): ROLL 8 DEGREES
PITCH 3 DEGREES

ANNUAL PERCENT OPERABILITY OF LAMPS MK III ON FRIGATE WITHOUT FIN STABILIZERS; TRUE WIND = 15 KNOTS

ANNUAL PERCENT OPERABILITY OF LAMPS MK III ON FRIGATE WITHOUT FIN STABILIZERS; TRUE WIND = 20 KNOTS



ANNUAL PERCENT OPERABILITY OF LAMPS MK III ON FRIGATE WITHOUT FIN STABILIZERS; TRUE WIND = 25 KNOTS



THE SOLUTION

- IMPROVE/DEVELOP COMBATANT CAPABILITY ASSESSMENT TECHNOLOGY
  - ACQUIRE ACCURATE SUBSYSTEM/WEAPONS CRITERIA
  - EVALUATE CRITERIA VS. SHIP DYNAMIC BEHAVIOR
- INTRODUCE ASSESSMENT TECHNOLOGY TO COMBAT SYSTEMS/SHIP DESIGN ASSESSMENT AND TRADE-OFF PROCESS
  - COMBAT SYSTEMS PERFORMANCE FIGURES-OF-MERIT
  - OPERATIONS ANALYSIS
  - TRADE-OFF BETWEEN SHIP PERFORMANCE AND COMBAT SYSTEMS PERFORMANCE
- INTRODUCE NEW DISCIPLINE INTO PLANNING OBJECTIVE MEMORANDUM PROCESS
  - FLEET MODERNIZATION PROGRAM IMPROVEMENTS
  - SHIP CONCEPTS FORMULATION
  - TECHNOLOGY INVESTMENT ASSESSMENT
- DEVELOP/REVISE OPERATIONAL DOCTRINES
  - MAINTENANCE AND TRAINING
  - SHIP OPERATOR GUIDANCE TO REDUCE SHIP MOTIONS/SUBSYSTEM LIMITATIONS

RECENT ENCOUNTERS WITH TOPSIDE ICING

By

Peter B. Zahn
Richard P. Voelker

ABSTRACT

This paper presents a description of three topside icing events that occurred aboard our nations POLAR Class icebreakers during the last three years. Environmental and wave conditions were recorded as well as the magnitude of icing. Photographic documentation is also provided. Results from an analytic model (Stallabrass) is also provided and include rate of icing as a function of air tempaerature, sea temperature, wind speed, wave height, and wave heading as a function of ships course. This is followed by a brief discussion on the impact of icing on ship design and operations.

BACKGROUND

Topside icing of ships is not a new problem. It was recognized as a danger with travel to the Arctic Sea hundreds of years ago. Yet scientific investigation into this problem did not begin until relatively recently.

Beginning in the late 1950's, the icing of vessels due to sea spray was a research topic of wide interest. This research, which was largely concerned with the icing of small vessels, was carried out through the 1970's. It was carried out in response to the over 80 vessels believed lost due to icing from 1955 to 1970, as reported by the World Meteorological Organization [1].

Concern over the safety of small vessels, particularly fishing vessels, resulted in the formation of an IMCO (now IMO) panel on fishing vessel safety. One of the tasks of this panel was to examine the icing problem and recommend new design criteria. Numerous countries contributed to this effort; the result of which forms the basis of much of our current knowledge on topside icing.

Because there is generally a lack of well-documented icing events and four such events have occurred during the last three years, of the Maritime Administration's, POLAR Class Trafficability Program, a decision was made to consolidate the data into this paper. This program, begun in 1979, is a joint industry-government program designed to support Arctic marine transportation research and development. The program has traditionally been referred to the POLAR Class Trafficability program because it requires the use of our nations most powerful icebreakers; POLAR STAR and POLAR SEA. These ships have principal dimensions 400 ft in length, 84 ft beam, 32 ft draft, and a displacement of 13,000 tons. They are operated by the U.S. Coast Guard and have been used successfully throughout the program. The three primary objectives of the program are:

- assess the feasibility of year-round shipping in the Arctic
- collect environmental data
- develop improved design guidelines for ships and offshore structures

During this current program, a number of unscheduled events have occurred. Among these is the icing of the POLAR Class icebreakers during open water transits between the Aleutian Islands and the ice edge in the Western Arctic. Fortunately, these three icing events were documented and studied by on-board project members. Presented in this paper is a discussion of these icing events.

GEOGRAPHICAL AND ENVIRONMENTAL

Figure 1 shows a map of Northern Hemisphere icing incidents reported in Russian literature in the 1970's (2). The map shows a high reoccurrence of icing in the eastern Bering Sea. Other areas of economic and strategic importance where icing problems are severe include the east coast of Canada, Gulf of Alaska, and Norwegian Sea [2,3,4]. Each of these areas is characterized by low air temperatures which are an obvious requirement for icing to occur. Other contributing factors to the occurrence and severity of ship icing include water temperature, wind speed, salinity, and wave height. Figure 2 shows the results obtained by Stallabrass [5] from parametric variation of a simple analytic icing model. The figures show that variations in air temperature and sea temperature produce the greatest changes in icing severity.

One variable which has only recently been given attention is the liquid water content of the sea spray cloud, or, precipitation event [6,7]. For both small and large vessels, the primary source of moisture for freezing is sea spray generated as the vessel passes through waves. Table 1 shows a breakdown of Russian icing reports by source of icing, showing only 2.7 percent of icing incidents occurred without sea spray [8]. Unfortunately, the amount and distribution of water in spray is highly variable and little data exists. What is known is that the variation of ship heading and speed has a significant impact on the amount of spray generated. Figure 3 shows the results of Russian tests with a medium sized trawler; i.e., indicating maximum spray intensity occurs with waves off the bow at 15 to 45 degres [9].

RECENT EXPERIENCES DURING TRAFFICABILITY TEST PROGRAMS

As noted previously, the Bering Sea has often been characterized as a severe icing environment. For the past 3 years, the USCG POLAR Class icebreakers have encountered substantial icing during transits from the Aleutian Islands to the ice edge as part of deployments associated with the Trafficability Test Program [11,12,13,14]. Each of these incidents occurred during force five to six storms. The following descriptions cover what is known about these incidents. It should be recognized that although all aboard were aware of the incident, no icing rate information was gathered and only cursory descriptions of total accumulated thickness are available. Standard data collection procedures were not and are not in existance.

February 1983

On the afternoon of February 18 while transiting in 30-40 knot winds and 10 ft seas, ice began to accumulate on the forward part of the ship. Falling temperatures and increasing wave conditions caused the icing to continue through the night and into the next day. Accumulation finally ended the next evening as the ship entered the ice. Table 2 shows the meteorological conditions during the icing period. Figures 4 and 5, show the progression of ice growth on the bow as viewed from above. Figure 6 shows the same area without icing. Accumulations of at least 6 inches were common and as much as 12 inches accummulated on the forward cargo crane. Figures 7 and 8 show on the starboard side of the superstructure with and without icing. Looking at the guardrails it is seen that ice accumulation on the 02 and 03 decks was similar but considerably less than that at the 01 level. This supports the obvious assumption that the amount of spray in the air, or liquid water content, decreases with height. Above a certain height, the remaining windborne droplets remain suspended.

No information on the nature of the ice was reported, but review of the photographs clearly shows it to be 'dry' or hard rime icing. The conditions were thus conducive to freezing all of the incident water on the structure with no runoff. This corresponds well with the results of Japanese investigations shown in Figure 9. Likewise, the total accumulation during the 32 hour period agrees fairly well with the predictive nomograph of Figure 10, which was developed by analysing large numbers of North Atlantic icing incidents and modified for Alaskan use [15], [4]. In effect the rate of icing was "very heavy".

1984

In February of 1984 the POLAR STAR experienced icing after leaving Dutch Harbor, Alaska, enroute to the ice edge. By 1200 hours on February 21, the air temperature had dropped to 27°F (sea water freezes at about 28°F.) Winds steadily increased during the day and were recorded at over 30 knots with waves recorded at 7 feet in height. These conditions usually generate enough sea spray to cause significant icing. In addition, as the ship moves through the waves, the quantity of spray increases, particularly for bow and beam seas.

As shown in the data in Table 3, conditions from noon on the 21st until 1600 hours (4:00 PM) on the 22nd, were suitable for deck and superstructure icing. During the last 24 hours of this 28 hour time period, the average air temperature was 11.5°F and the average wind velocity was 34 knots. However, only during 16 hours of this time period was the ship at a heading which would generate the foredeck icing, that is, head and beam seas.

Upon inspection of the foredeck, it was observed that an average of 3 inches of icing had accumulated on all flat surfaces including the forward crane, and the forward crane topping lift wires (approximately 2 inches in diameter) which were coated with ice to 7 inches in diameter. It is interesting to note that after the icing event, the ship proceeded north through the ice field and arrived at Nome on March 2. The ice which had accumulated on the deck and superstructure from the south Bering Sea was basically intact. Continued icebreaker operations in the Bering Sea ice fields with below freezing air temperatures precluded significant deterioration of the shipboard ice. It was about 2 weeks after the icing event before some deterioration of the shipboard ice was noticed.

1985

On March 28, the POLAR SEA began to accumulate ice on the forecastle and superstructure during the transit from Dutch Harbor to the ice edge. Icing was recorded at about 1600 hours and continued until the ship entered the ice the next morning.

Meteorological and oceanographic conditions prior to and during the icing event are shown in Table 4. Air temperature was observed to have fallen from 29°F at 1300 hours to 26°F at 1600 hours. Temperatures continued to fall through the next 18 hours to a low of 15°F. Wind speed was 23 knots at 1600 hours and increased to the 28-37 knot range during the next 18 hours and sea surface temperatures decreased from 37 to 33°F. Wave height varied from a high of 6.5 feet to a low of 1.5 feet. It is believed that the moderate air temperatures and low waves combined to prevent heavier icing.

During this light icing event about two inches of ice accumulated on the forecastle and from 0.5 to 2 inches elsewhere on the decks. The crew was set to work with bats and axe handles to break and remove the ice missing that had accumulated. Figure 11 shows this operation and illustrates the low technological level (but proven effective) for ice removal aboard ships.

IMPACT ON SHIP DESIGN AND OPERATIONS

Following several of the icing events, access to the foredeck was lost due to the freezing of access hatches through forward bulwarks and spray barriers. All of the foredeck equipment, including windlasses, chocks, and cargo cranes were iced to the degree that they were inoperable for as long as two weeks or more. The icing on the exposed deck areas aft of the pilothouse made personal passage treacherous and incapacitated the davits and motor lifeboats. Subsequent tests have been conducted which indicated that a light ice accumulation leads to only minor difficulties in deploying inflatable liferafts, but it was obvious during heavier icing incidents that the rafts would not be readily available in an emergency.

The problems experienced on the POLAR Class had only minimal effects on day to day operations since most of the affected systems were not required for transit through the ice fields. On commercial ships, the problem has had more severe impacts. The accumulation of icing on the cargo hatches and unloading mechanisms of Great Lakes bulk carriers has led to substantial delays in loading/unloading operations. The freezing of cargo manifolds and valve actuators has led to similar problems on tankers travelling in the North Atlantic. The most serious effect, however, is the loss of stability and subsequent capsizing of smaller vessels, particularly fishing vessels. Shellard, [1], reports that from 1955 through 1970 over 80 vessels ranging from 40 to 800 gross tons were believed lost due to icing.

Ice accretion on combatant and naval support vessels has become a more active concern with the anticipated increase in activity of NATO vessels in the more northern latitude. The proliferation of deck equipment, communications, surveillance, and weapons systems on a modern warship are all subject to icing. As in the case of fishing vessels and offshore drilling equipment (supply boats), the large amount of equipment serves as an ideal spray ice collector. The Canadian forces design criteria, DMSE-01, allows for as much as 600 tons of accreted ice on a ship of 14000 tons displacement.

While loss of intact stability is obviously a worst case scenario, other effects of icing may be felt in a naval ship's ability to carry out primary missions. Icing may accrete on primary systems such as RAST, VLS and magazine hatches, gun mounts, and cargo gear. This could temporarily limit not only combat capabilities but even regular helicopter operations and provisioning. Experience has shown that active radar scanners are not normally succeptible to damage from icing due to their inherent vibration and movement. Idle scanners, however, may be frozen in place and become inoperable. Problems associated with freezing sea spray on phased array systems, such as on the TICONDEROGA class, still represent unknowns.

CURRENT RESEARCH AND FUTURE DIRECTIONS

The study of marine icing is typical of many engineering problems in that interest waxes and wanes with current operational requirements. After completion of the small fishing vessel related studies in the late 70's, research was again placed on the back burner. With an increase in petroleum exploration and military operations in northern latitudes, the problem of marine icing is again coming under heavy study.

Current research is divided into two distinct areas. The first is development of mathematical models for accurate prediction of icing loads. Work is ongoing in Canada, Finland, and Norway, as well as the U.S., on large time-domain models of the icing process to allow development of both regulatory and operational criteria for icing loads using measured and hindcast environmental conditions, ([6], [7]). Work on model tests and full scale icing measurements are an important part of the validation of these models. The second major area of research is the development of valid anti-icing and de-icing systems and procedures. Past work in this area concentrated on coatings to reduce adhesion and pneumatic devices to break the adhesion bond, [5]. Currently planned research has added to this list such concepts as thermosyphons, trace electrical heating in critical areas, and high pressure water or steam cutting lances. All of these concepts have been tested in the past, but there is now new impetus for more information concerning specific applications.

Even the current work in the analysis and mitigation of marine icing leaves considerable uncertainty and possibilities for further improvement in the understanding of the phenomenon. A review of icing work related to shoreside power transmission and aircraft problems shows that models exist with much greater detail than any currently available or planned for marine icing. The two primary reasons are the relative simplicity of the shapes involved, in the shoreside problem allowing more rigorous flow modeling, and a better understanding of the nature of atmospheric icing sources. The latter is one of the principal areas the authors see requiring future effort. There is very little information available on the makeup of sea spray, including liquid water content, droplet size distributions, and vertical extent. Information on variability due to ship and meteorological conditions are woefully inadequate. If this information could be obtained it would allow a significant increase in the confidence associated with mathematical models of spray ice accumulation.

CONCLUSIONS

The events experienced on the POLAR Class icebreakers in the Bering Sea have given us a new insight into the severity and unpredictable nature of marine icing at high latitudes. Work performed in the past by ARCTEC and other organizations in relation to icing of small fishing vessels has left us still unable to accurately predict and effectively combat icing of large surface ships and offshore drilling vessels. Current work on these problems is beginning to show results, especially where past experience forms a basis for continuing efforts, but substantial work remains to be done before there is a clear understanding of how much ice will form and how best to prevent or remove it.

ACKNOWLEDGEMENTS

The icing events and data reported in this paper were collected during the Maritime Administration Trafficability Program. This multiyear program has been sponsored by a number of industry and governmental organizations. They include the U.S. Coast Guard, the Canadian Ministry Transport, participating companies of the Alaskan Oil and Gas Association, the State of Alaska, the interagency Ship Structure Committee, Newport News Shipbuilding, Bethlehem Steel Corporation, and the Navy (NavSea). It is only through the cost-sharing of project activities that have made the POLAR Class deployments possible.

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* Documents available through the National Technical Information Center, Springfield, VA 22161

TABLE 1

SOURCES OF SHIP ICING (BORISENKOV 1974)

CONDITIONS	% ICING CASES
All Cases:	
Sea spray	89.8%
Sea spray and rain or fog or front	6.4%
Sea spray and snow	1.1%
Rain or fog or frost	2.7%
Arctic Regions:	
Sea spray	50.0%
Precipitation and sea spray	41.0%
Fog	3.0%
Precipitation	5.0%

TABLE 2

METEOROLOGICAL AND OCEANOGRAPHIC CONDITIONS
FROM POLAR SEA LOGS, FEBRUARY 1983

DATE	TIME	WIND DIR (true)	WIND SPEED (kt)	AIR DRY (°F)	AIR WET (°F)	DIR (true)	HEIGHT (ft)
2/18	1000	013	32	35	32	000	05
	1200	049	37	31	29	030	10
	1400	030	35	28	27	020	10
	1600	052	28	26	26	030	10
	1800	029	46	23	22	020	14
	2000	017	41	20	20	020	12
	2200	015	44	18	18	020	14
	2400	010	35	18	18	020	10
2/19	0200	015	35	16	16	Obscured	
	0400	019	37	17	17	Obscured	
	0600	010	40	16	16	Obscured	
	0800	007	42	15	15	000	10
	1000	002	38	15	15	000	09
	1200	016	34	13	13	355	10
	1400	023	46	12	12	355	10
	1600	008	35	15	15	005	08
	1800	014	40	15	14	010	08
	2000	011	44	13	13	Ice Edge	

TABLE 3

METEOROLOGICAL AND OCEANOGRAPHIC CONDITIONS
FROM POLAR SEA LOGS, FEBRUARY 1984

DATE	TIME	SHIP COURSE	SPEED (kts)	WIND DIR (true)	WIND SPEED (kt)	AIR DRY (°F)	AIR WET (°F)	WAVES DIR (true)	WAVES HEIGHT (ft)
2/21	1200	250	07	070	34	27	25	060	07
	1300	340	09	070	34	33	32	060	08
	1400	340	11	070	40	25	25	060	07
	1500	000	11	056	40	23	23	045	08
	1600	000	11	049	39	18	18	045	14
	1700	000	11	038	42	15	15	045	10
	1800	000	11	042	40	12	12	045	10
	1900	180	11	046	40	09	09	045	06
	2000	000	11	039	36	12	12	045	07
	2100	180	11	040	35	12	12	045	07
	2200	000	08	039	36	12	12	045	07
	2300	000	09	042	40	12	12	045	07
	2400	180	08	026	30	10	10	030	05
2/22	0100	180	10	033	28	10	10	035	07
	0200	000	06.5	056	30	11	11	050	06
	0300	180	10	035	40	08	08	045	07
	0400	180	10	030	35	10	10	Not Recorded	
	0500	000	10	035	36	14	13	Not Recorded	
	0600	180	10	030	29	14	13	Not Recorded	
	0700	180	09	050	25	15	14	025	06
	0800	147	08	040	31	10	10	025	06
	0900	147	05	022	35	11	11	035	05
	1000	190	05	037	22	11	11	040	05
	1100	195	08	030	32	13	13	040	05
	1200	195	08	021	30	14	14	025	06.5
	1300	042	11	025	35	14	14	025	08
	1400	042	11	029	35	14	14	025	08
	1500	042	12	032	35	10	09	020	07
	1600	077	10	030	33	08	08	020	06
	1700	Ship Entered the Ice Field							

TABLE 4

METEOROLOGICAL AND OCEANOGRAPHIC CONDITIONS
FROM POLAR SEA LOGS, MARCH 1985

DATE	TIME (AST)	SHIP COURSE (true)	SHIP SPEED (kt)	WIND DIR (true)	WIND SPEED (kt)	AIR DRY (°F)	AIR WET (°F)	WATER (°F)	WAVES Period (true)	WAVES Height (ft)
3/26	1000	210	5.0	290	19	27	23	37	07	3.5
	1300	209	9.5	290	26	26	25	38	07	5.0
	1600	334	4.0	320	23	27	23	37	09	5.0
	1900	340	1.7	330	26	26	19	37	05	3.5
	2200	332	1.0	330	25	26	14	38	05	5.0
3/27	0100	332	2.5	340	15	23	18	37	05	3.5
	0400	119	3.0	360	11	25	16	37	04	3.5
	0700	322	1.0	360	19	25	16	37	04	3.5
	1000	030	3.0	030	27	28	19	37	04	3.5
	1300	219	5.2	070	19	30	25	37	06	3.5
	1600	029	4.5	040	09	32	27	37	08	3.5
	1900	310	8.0	100	17	31	23	37	08	3.5
	2200	320	14.0	080	30	32	27	38	06	6.5
3/28	0100	300	15.0	060	32	32	27	38	07	8.5
	0400	332	13.0	050	29	29	23	38	07	13.0
	0700	300	13.0	060	29	29	23	38	07	13.0
	1000	300	12.0	030	29	29	28	37	07	5.0
	1300	300	14.0	050	29	29	19	37	05	5.0
	1600	300	14.0	040	26	26	23	37	07	6.5
	1900	039	12.0	030	24	24	18	36	06	5.0
	2200	040	11.0	030	24	24	16	34	06	5.0
3/29	0100	320	11.0	010	17	17	10	34	02	1.5
	0400	310	11.0	360	15	15	5	34	03	3.5
	0700	310	11.0	010	15	15	7	33	04	5.0
	1000	310	14.0	360	17	17	9	33	06	3.5

SHIP ENTERED ICE FIELD

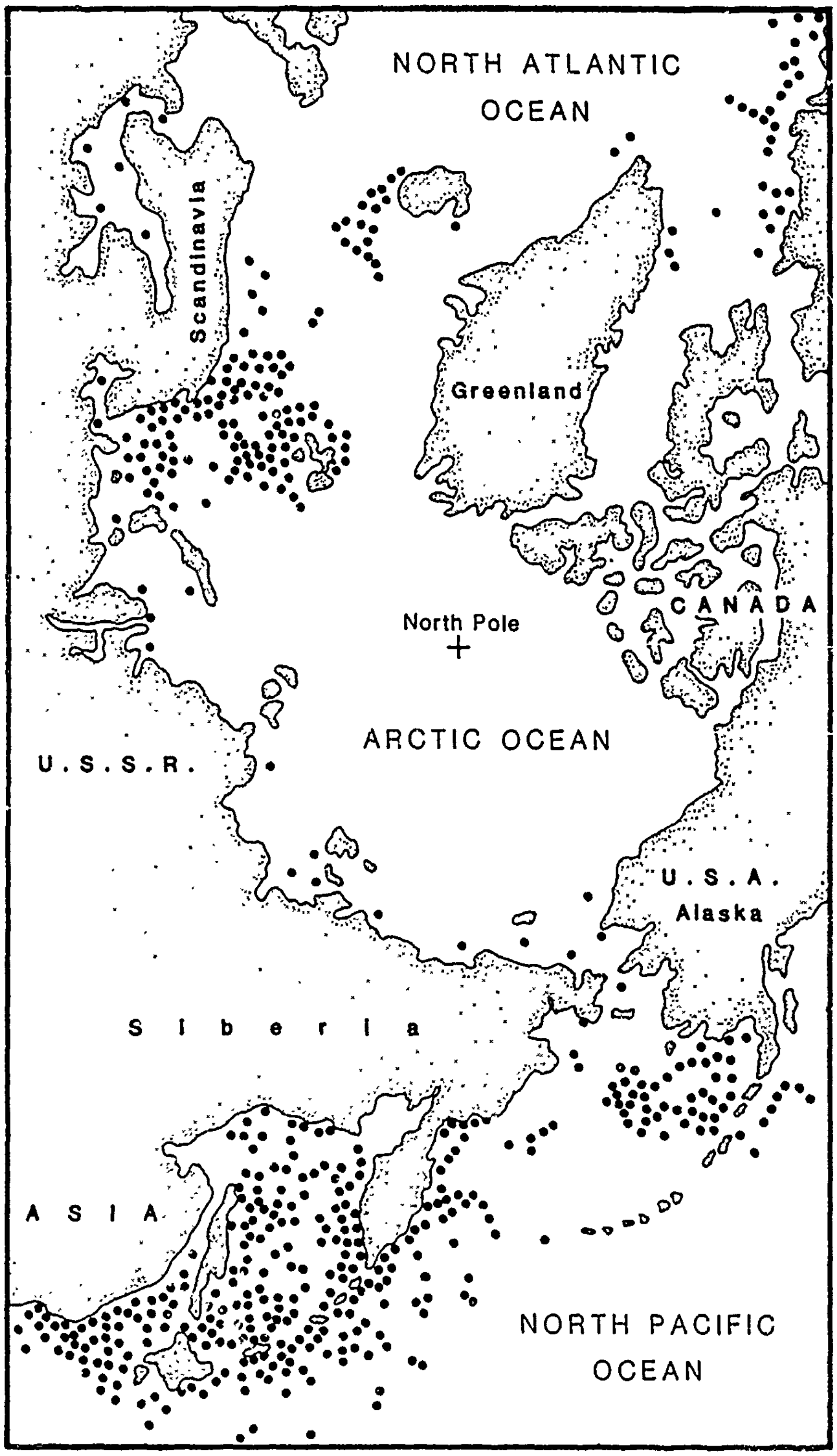
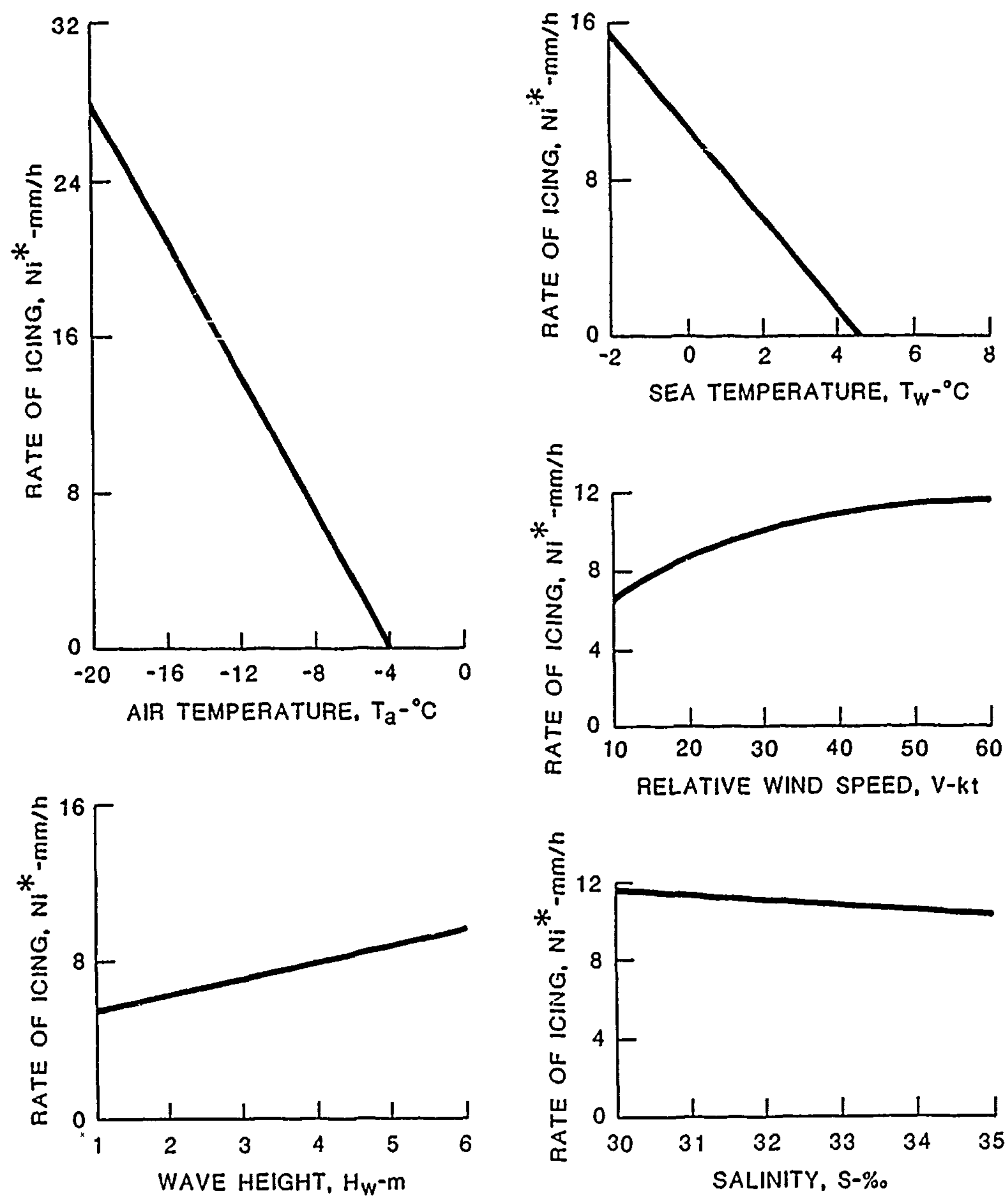


Figure 1

REGIONS WHERE SHIP ICING WAS OBSERVED BY SOVIET OBSERVERS ACCORDING TO PANOV (1978)



Standard conditions taken as: T_a =-10°C
T_W = 0°C, V = 40kt, H_W = 3m, S = 32%
Each parameter varied in turn (Stallabrass, 1979)

Figure 2

EFFECT OF MAJOR VARIABLES ON THE RATE OF ICING

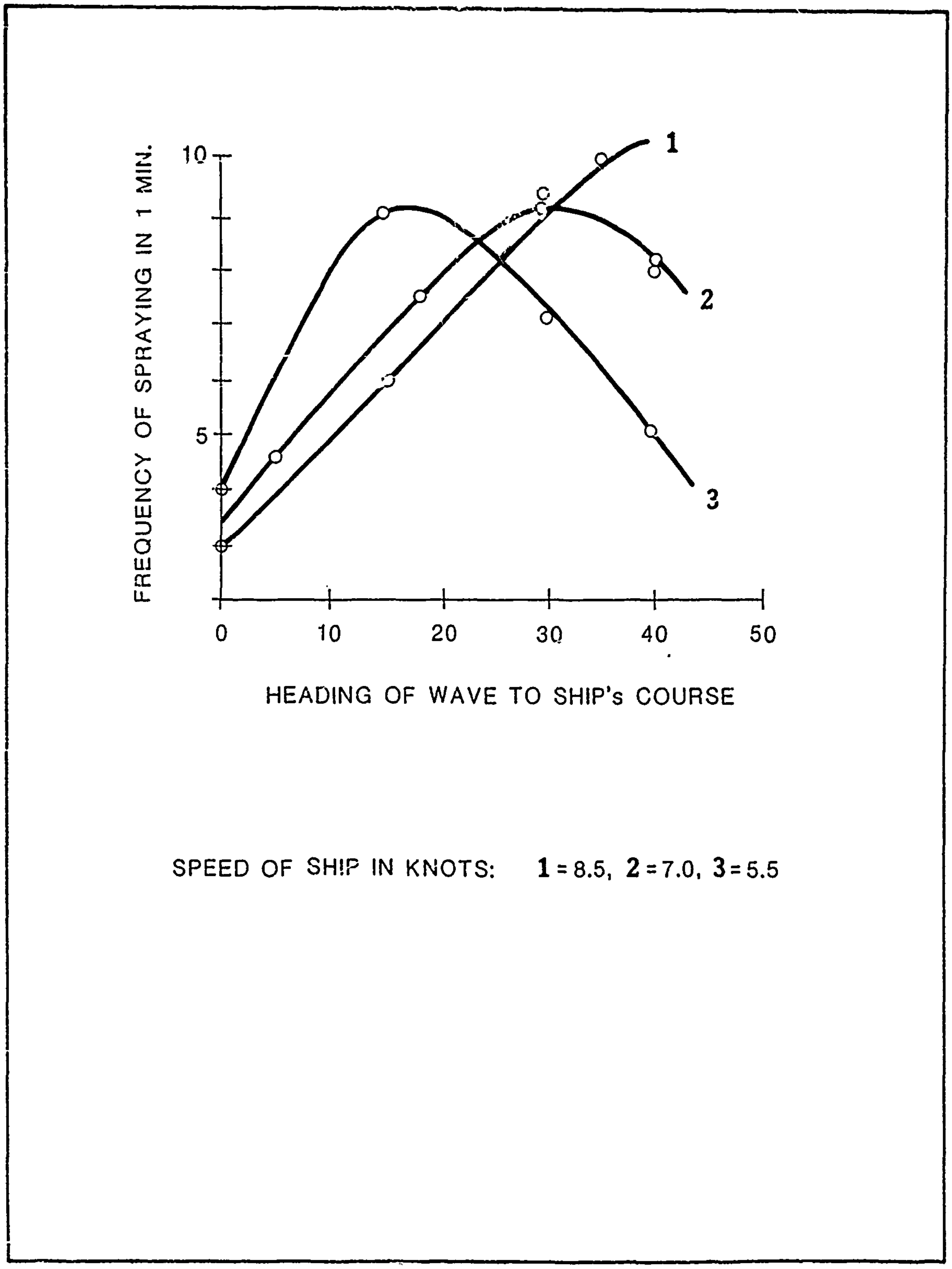


Figure 3

DEPENDENCE OF SPRAY INTENSITY ON SPEED AND WAVE HEADING (Kultashev, et al)

Figure 4 EARLY STAGES OF ICING ON THE BOW OF THE **POLAR SEA** IN FEBRUARY 1983

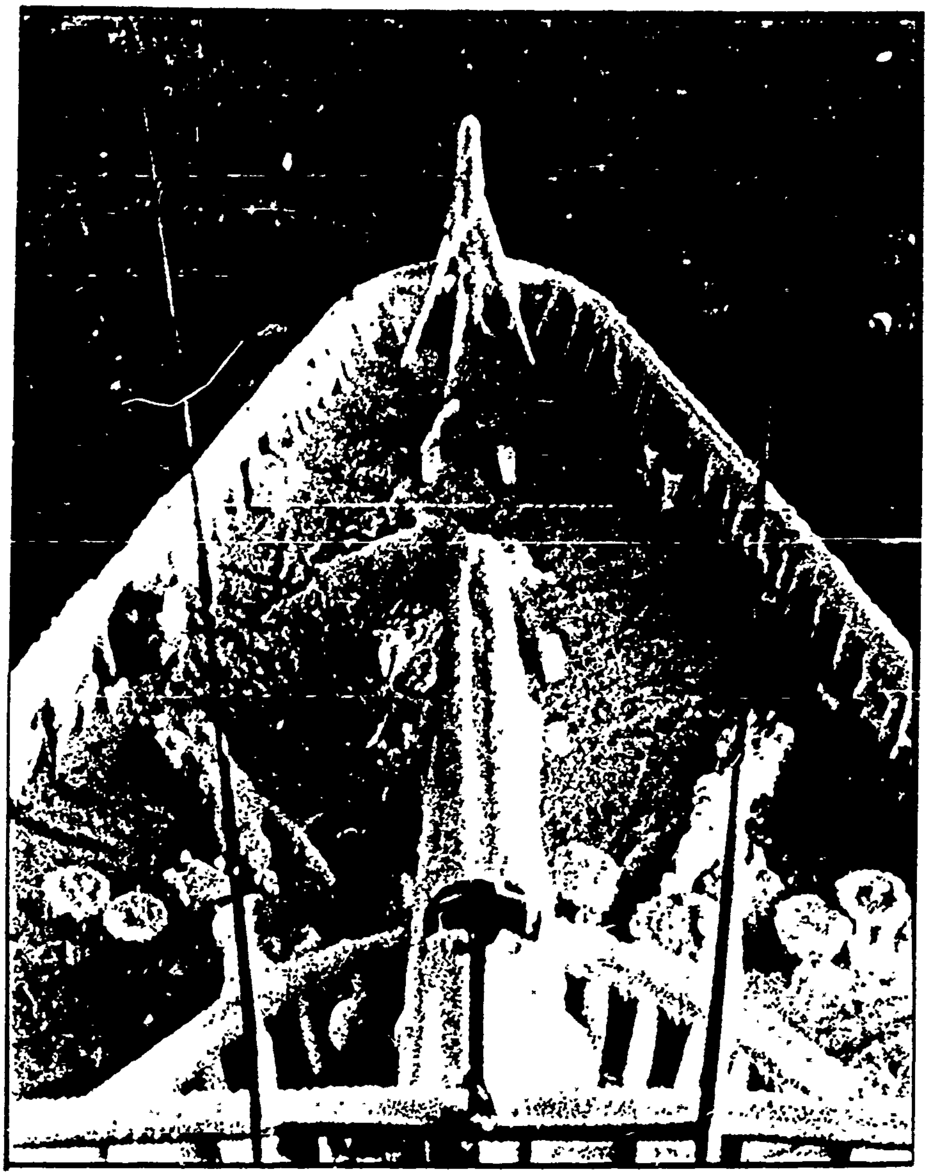


Figure 5 VIEWOF THE **POLAR SEA**'S BOW
12 HOURS AFTER ICING CEASED

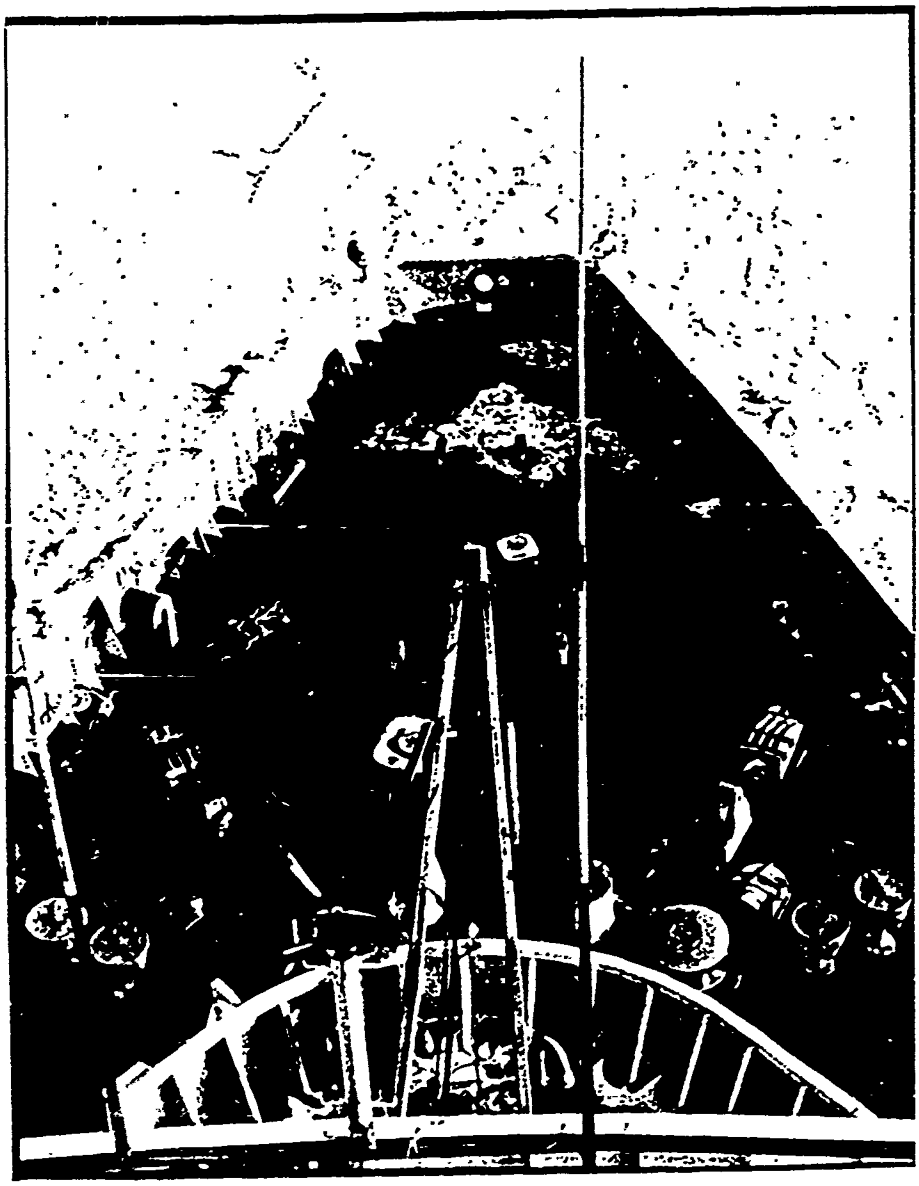


Figure 6 BOW AREA FREE OF ICING

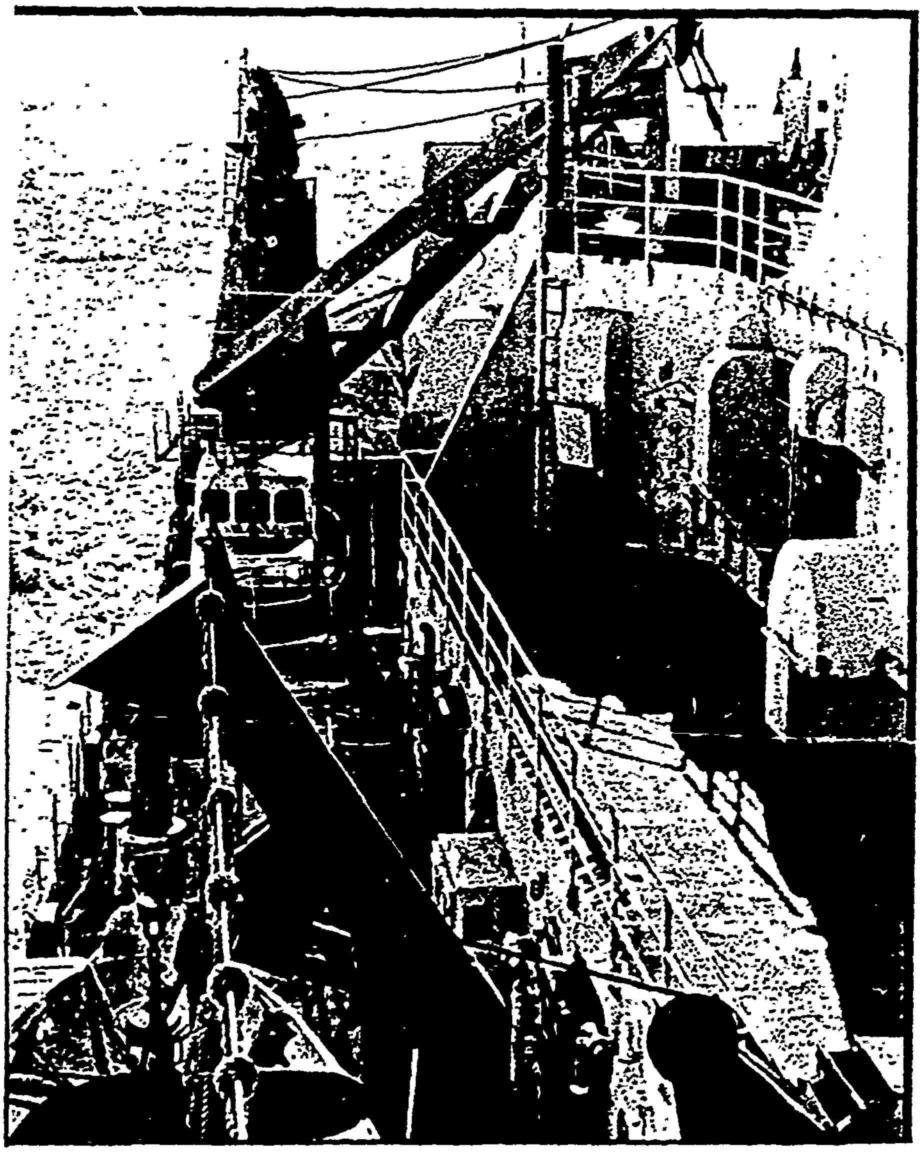


Figure 7 STARBOARD VIEW OF 01 & 02 DECK AREAS LOOKING AFT FROM THE BRIDGE

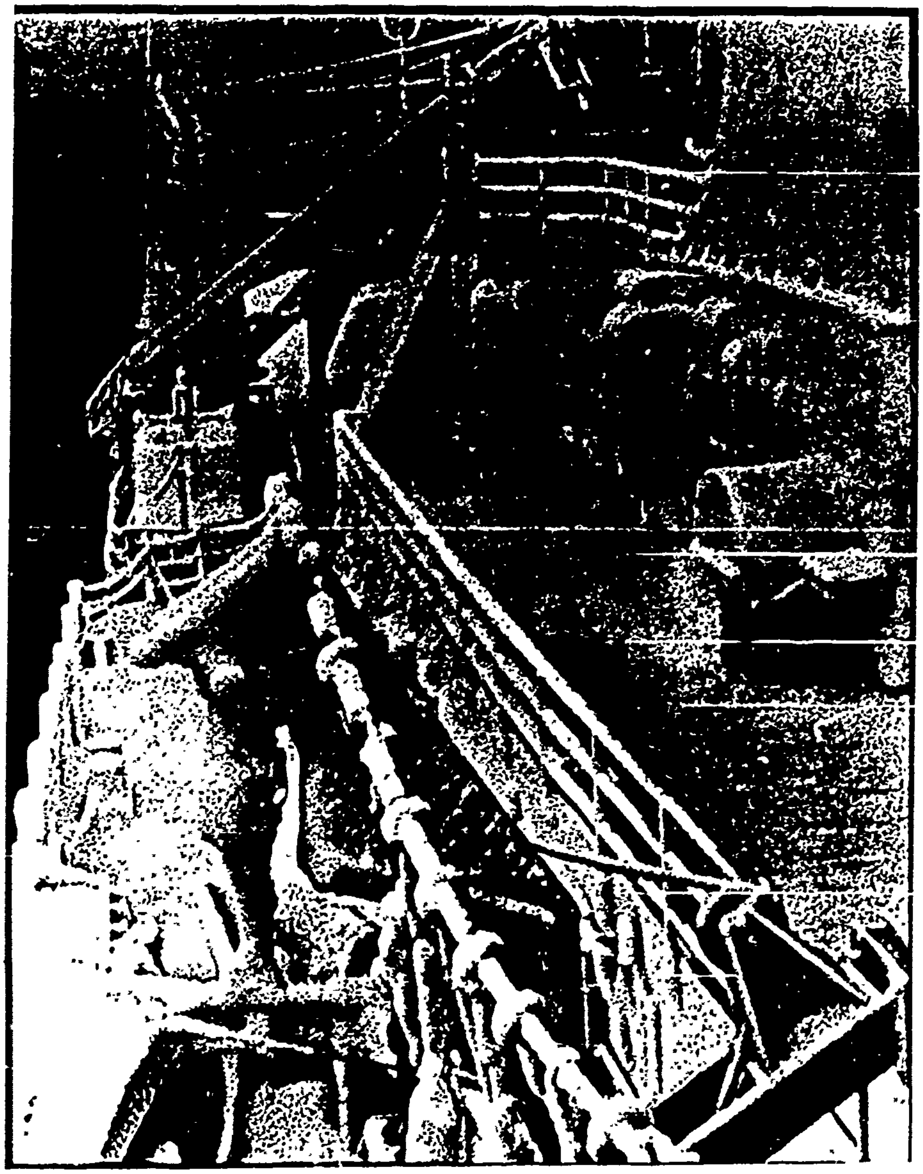


Figure 8 VIEW OF THE SAME AREA SHOWING ICING ON FEBRUARY 19, 1983. THE HELIDECK IS INOPERATIVE, AS WELL AS THE BOATS AND RAFTS. ICING CONTINUED FOR 12 HOURS MORE.

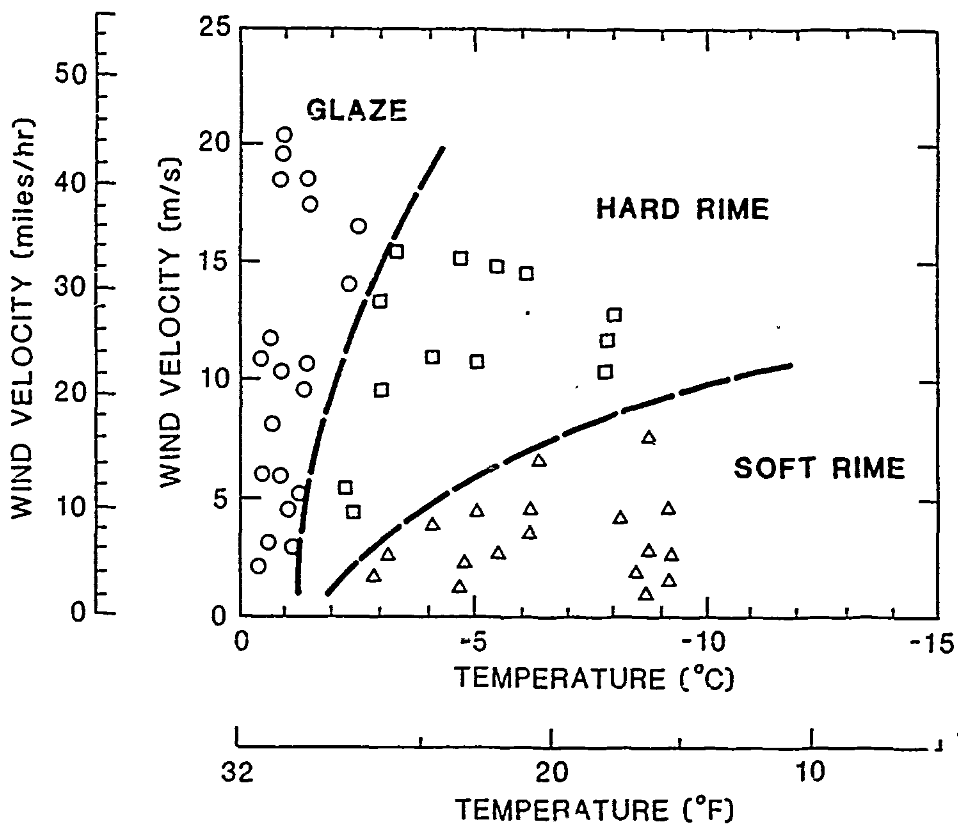


Figure 9

RELATIONSHIP BETWEEN METEOROLOGICAL CONDITIONS AND TYPE OF ICING (Kuroiwa, 1965)

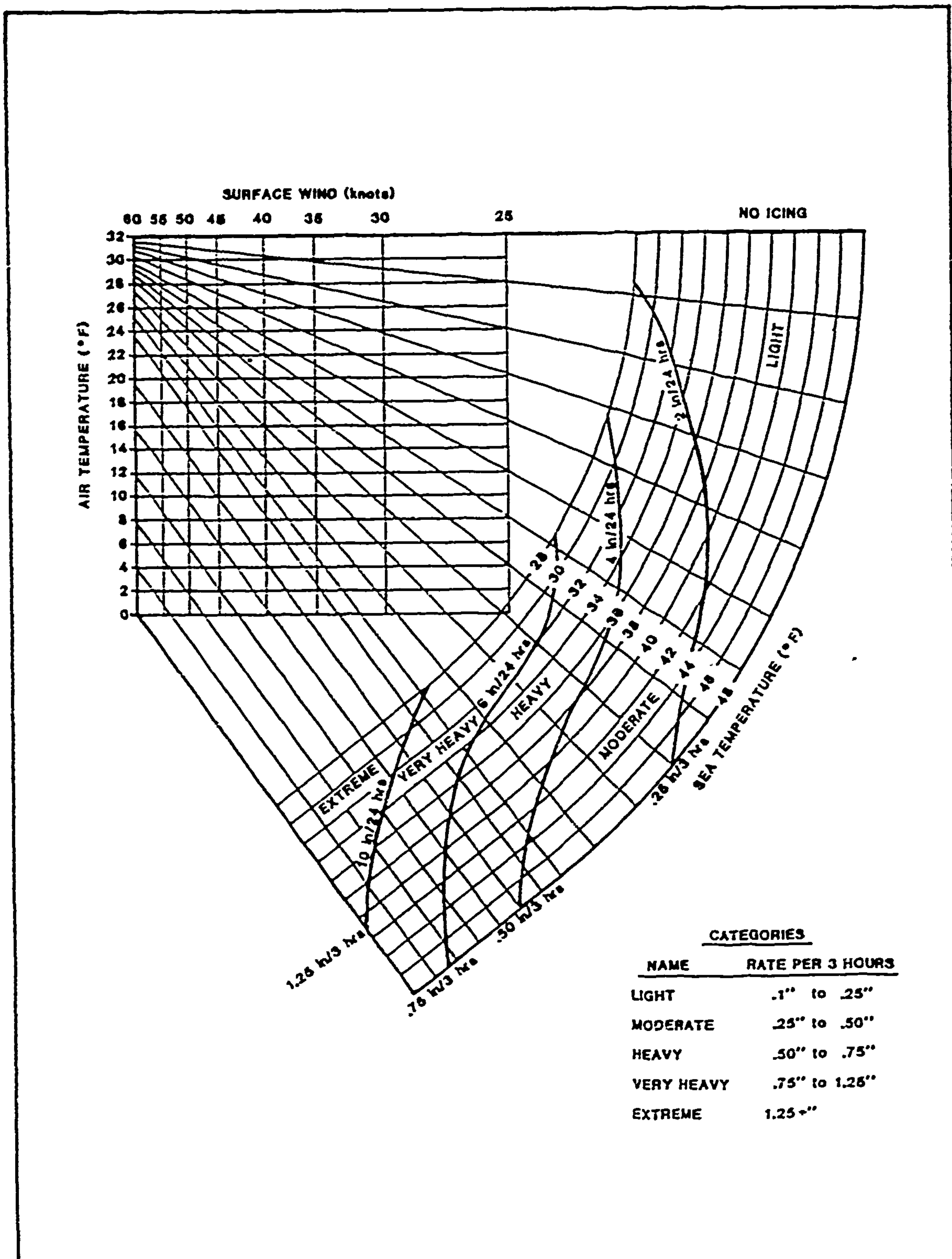


Figure 10

NOMOGRAM DERIVED FOR ICING PREDICTIONS IN THE GULF OF ALASKA AND EASTERN BERING SEA

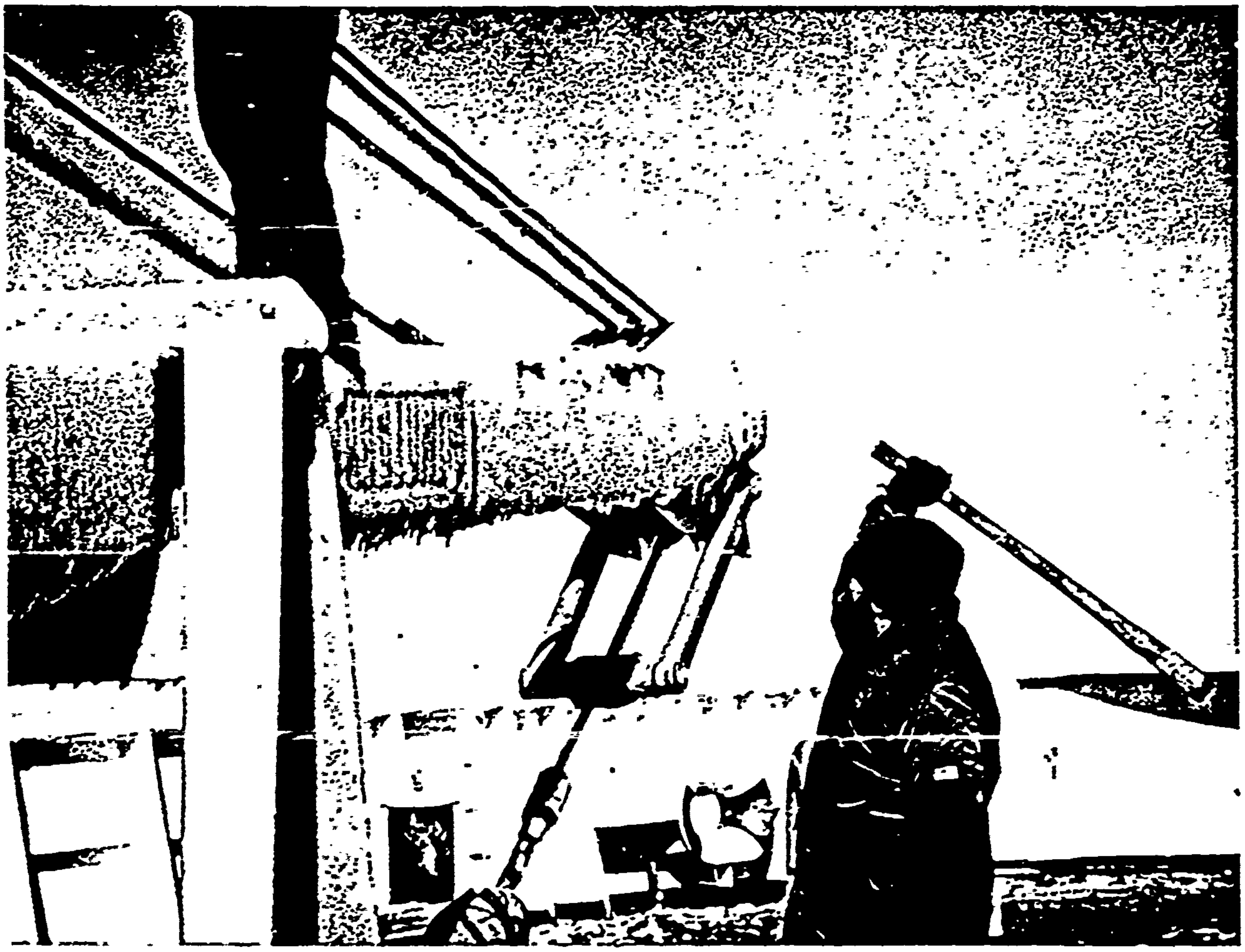


Figure 11 REMOVING ICE FROM THE FORWARD CRANE ONBOARD POLAR SEA IN 1985.

SHAREM COLD WEATHER EXPERIENCE
LCDR John R. Oakes, USN

Mr. Kordenbrock has told you all that I am the SHAREM Project Officer and that I am stationed at the Surface Warfare Development Group (SWDG). Those of you who are involved with tactical development and evaluation in general and with anti-submarine warfare in particular are familiar with both SURFWARDEVGRU and SHAREM but I imagine that many of you may be wondering why I've been asked to stand up in front of you and hold forth of the subject of cold weather operattions. So, to establish my credentials, I'd like to begin with a few words about SWDG and SHAREM and how it came to pass that I was annointed an "expert" in cold weather ops.

Surface Warfare Development Group is located in Norfolk, Virginia. We occupy somewhat of a unique position within the surface Navy in that our Commanding Officer reports to both COMNAVSURFLANT and COMNAVSURFPAC. He is the designated agent of both type commanders for surface force tactical development and evaluation (TAC D&E). SWDG has a legitimate oar in both oceans for TAC D&E and in addition, we have recently been designated the primary review authority for the NWP-60 series of tactical publications, a collection of documents which contains tactical doctrine dealing with all surface warfare mission areas.

My particular area of specialization is anti-submarine warfare (ASW) and my job as SHAREM project officer is one of the best ASW billets in the Navy. The acronym SHAREM stands for SHip Antisubmarine warfare Readiness and Effective Measurement. The SHAREM program was established in 1969 and I think that the fac that it's still around after 16 years is pretty conclusive evidence that someone thinks that what we do is worthwhile. T'e program is sponsored by CNO with program direction coming from OP-951. Our funding comes through the Naval Space and Warfare Systems Command. COMSURFWARDEVGRU is the CNO Executive Agent for the program and the Naval Undersea Systems Command (NUSC) is the primary support lab for the project.

The mission of the SHAREM program is to measure the effectiveness of in-service surface ship ASW systems and tactics. We do this by designing exercises which permit us to investigate specific tactical issues in the ASW mission area which have been identified by the Fleet and Type Commanders; then observing, reconstructing, and analyzing the exercises.

The particular forte of the SHAREM program is the collection of high quality data which can be used to quantify equipment performance and tactical effectiveness. The unique value of the SHAREM program lies in the fact that we've retained the raw data from each of the sixty-one exercises we've conducted to date. If you ask us a question, our answer will reflect a search through the files of all 61 exercises; the numbers we give you will be based upon data you can trust; and if you prefer to do your own analysis we can provide the raw data to you.

We try to stress realism in our exercises. We know that ships whose equipment has been peaked and tweaked by a battalion of tech reps and whose crews have an army of experts looking over their shoulders can turn in exceptional performances. However, what we're really interested in is how well those ships and crews will perform when they're at representative levels of material readiness and training. Therefore, we don't go to heroic lengths to provide special equipment grooms to the ships or intensive training to the personnel participating in a SHAREM. Our quest for realism suff'rs somewhat when we try to study things like fire control system accuracy or torpedo detection and evasion. Topics such as these can't be examined properly anwhere other than on an instrumented underwater tracking range. Twenty-five SHAREMs have been conducted on the ranges at AUTEC and PMRF, but the remainder have been open ocean exercises in what we refer to as "tactically significant waters."

We define "tactically significant waters" as the particular pieces of ocean where we expect to conduct ASW operations if we ever do go to war. At this point, I can finally make the connection between the SHAREM program and my presence at a symposium on cold weather operations. Two of our recent exercises, SHAREM 55 in March 1983, and SHAREM 62 in November 1985 were conducted in "tactically significant waters" where it just happened to be cold.

SHAREM 55 was conducted north of Iceland in an area bounded on the west by the Greenland ice pack and to the east by Jan Mayen Island. These are "tactically significant waters" in the fullest sense of the word. We expect that the Soviet SSBN force may attempt to "hide" under the ice pack. While our own submarines will have the job of going in after them, it's important for the Surface Force to know how effectively we can help to locate enemy submarines hiding under the ice and how we should operate to be in a postion to intercept and attack any submarines which may be flushed out from under the ice pack. Participants in SHAREM 55 were:

COMDESRON 26

USS SPRUANCE (DD 963)

USS BOWEN (FF 1079) with LAMPS Mk I

USS THOMAS C. HART (FF 1092) with LAMPS Mk I

USS MCCLOY (FF 1038)

USS MILWAUKEE (AOR 2) with H-46

USCG NORTHWIND (WAGB 282)

USS STURGEON (SSN 637)

SHAREM 62 took place just last month, November 1985, in Notre Dame Bay on the northeast coast of Newfoundland. When I say that these are also "tactically significant waters" I don't mean to imply that we necessarily expect to operate against Soviet submarines off the Newfoundland coast. However, as anyone who read the newspapers during the NATO exercise Ocean Safari is aware, we do intend to operate our carriers in Norwegian fjords and we need to determine the best means of providing ASW protection to a carrier operating in the fjords. Ideally, we would conduct a SHAREM in a Norwegian fjord to investigate this issue but for a number of reasons, not the least of which is the cost of the fuel that it would take to sail an ASW force to Norway for an exercise, this hasn't been done yet. Notre Dame Bay, however, in many respects is topographically, bathymetrically, oceanographically, and climatologically similar to the Norwegian fjord environment. It's also a lot closer to home and the Canadian government not only agreed to let us conduct an exercise there but also provided a Canadian submarine as the opposition for our ASW force. Participants in SHAREM 62 were:

COMDESRON 26

USS ARTHUR W. RADFORD (DD 968) with SH-3

USS VALDEZ (FF 1096)

USS NICOLAS (FFG 40) with LAMPS Mk III

USS FAHRION (FFG 22) WITH LAMPS Mk I

HMCS OJIBWA (SSK 71)

SHAREMs are ASW exercises first and foremost, and our first priority in embarking observers is reserved for the technical and tactical experts who will assist us in our reconstruction and analysis of the exercise. However, the SHAREMs also provide excellent opportunities for specialists in other fields to get to sea and collect some data in support of their various projects in an operational environment. During SHAREMS 55 and 62, representatives of the following commands were embarked in one or more of the ships:

SHAREM 55

NAVAL UNDERSEA SYSTEMS CENTER

NAVAL OCEAN SYSTEMS CENTER

NAVAL OCEANOGRAPHIC RESEARCH AND DEVELOPMENT AGENCY

NAVAL SEA SYSTEMS COMMAND

NAVAL POLAR OCEANOGRAPHY CENTER

NAVAL OCEANOGRAPHY COMMAND

NAVY SCIENCE ADVISORY PROGRAM

SHAREM 62

DAVID TAYLOR NAVAL SHIP RESEARCH & DEVELOPMENT CENTER

NAVAL SEA SYSTEMS COMMAND

NAVAL EASTERN OCEANOGRAPHY CENTER

NAVAL UNDERSEA SYSTEMS CENTER

NAVY SCIENCE ADVISORY PROGRAM

SHAREM 55 and SHAREM 62 are the two exercises which earned me the invitation to speak today, and I'm sure that you're all wondering "How cold was it?" After listening to this morning's Coast Guard presentation and seeing a few of their pictures of life on an icebreaker, I have to admit that it really didn't get very cold at all during either SHAREM 55 of SHAREM 62. Let me cite a few statistics to give you an idea of what the weather was like during these two exercises:

SHAREM 55 SHAREM 62

	Predicted/Observed	Predicted/Observed
Gale Force Winds	10-20% / 20%	NONE / NONE
Air Temperature	20-28 F / 12-28 F	36-39 F / 24-45 F
Seas > 12 ft	10% / 10%	NONE / NONE
Visibility < 5 NM	30% / 90%	20% / 50%
Sea Surface Temp	32 F / 28-37 F	32-39 F / 35-42 F

I have to add a few comments because I don't think that the figures above tell the whole story.

First of all, I'm sorry to disappoint those of you who are interested in ship icing but there was no significant icing during either of these exercises. Light icing during SHAREM 55 provided somewhat of an opportunity to evaluate some anti-icing coatings which had been applied to selected areas of the superstructures of several ships but there were no opportunities to observe any effects of icing upon ship stability.

Secondly, the table records only conditions between the formal COMEX and FINEX of the respective exercises. After both of the exercises, the ships ran into some really terrible weather during their transits back to port. Observers who came along to see how the ships handled themselves in heavy weather had a chance to fill their notebooks on the way home even if conditions during the exercises weren't really all that bad.

Third, although it didn't get extremely cold during either exercise and there weren't any dramatic accumulations of ice on the ships, the exercises did provide good tests of combat systems operability under the sort of conditions in which we would expect a ship to remain on station and perform its mission. When the weather really gets nasty though, a prudent Commanding Officer will probably look for an island with a lee that will shelter his ship or else head for open water and run with the storm.

Finally, although its possible to stand here today and say that it wasn't very cold during these exercises, the consensus on the bridge wings in real time was that it was cold enough.

The final report on SHAREM 55 has been completed and is available through the Navy Tactical Library located at the Navy Tactical Support Activty (NTSA). Work is is progress now on the SHAREM 62 report and it will also be available through NTSA when published. I won't subject you all to a detailed blow-by-blow of both exercises - those of you who are interested in such an account should read the reports. Please contact me if you have any questions or if you've like access to the exercise data.

I do think that there are several things we learned during these two exercises that are worth keeping in mind when planning future surface force cold weather operations.

A. PREPARATIONS PAY OFF.

Perhaps "scared" is not a word I should use in describing the frame of mind that prevailed as ships began to prepare for SHAREM 55. "Extremely cautious" will probably do as well. Nobody with experience in operating in the marginal ice zone was available to assist in preparing the ships for the exercise. The surface force's corporate knowledge of cold weather operations included some information on amphibious ship operations but very little to say about how to ensure the effective operation of modern cruiser/destroyer combat systems.

Fortunately, the ships which were to participate in SHAREM 55 were identified well in advance of the exercise and there was time for a methodical approach to the problem. A draft Cold Weather Handbook containing everything from the stock numbers of cold weather lubricants to lesson plans for lectures on the physiological hazards of cold weather operations was prepared by COMNAVSURFLANT to provide assistance to the ships in preparing for the exercise.

The preparations were effective and there were no major equipment or personnel casualties during SHAREM 55 attributed to cold weather. The draft Cold Weather Handbook was revised to incorporate the lessons learned in preparing for SHAREM 55 and has been promulgated as COMNAVSURFLANT INSTRUCTION 3470.1.

SHAREM 62 participants were identified approximately three months prior to the exercise. They were able to complete their preparations for cold weather operations much more quickly thanks to the groundwork laid by SHAREM 55 and to such actions as SURFLANT's establishement of a pool of cold weather clothing and equipment which they could draw upon to meet their requirements.

Once again, there were no major personnel or equipment casualties during SHAREM 62 attributable to cold weather. These successes were the result of hard work and long, conscientious preparation. It is safe to say a ship selected at random down at the piers in Norfolk, Charleston, or Mayport could not operate effectively in cold weather without the benefit of at least two to three month's preparations.

B. COLD WEATHER SEAMANSHIP IS SLOW & MANPOWER INTENSIVE

Cold weather seamanship evolutions such as underway replenishments or the movement of helicopters into and out of hangars are likely to take half again as long and require twice as many people as they do when conducted in good weather. Cold weather clothing is heavy and bulky and restricts movements. Gloves make line handling, use of tools, and manipulation of controls clumsy and awkward. Additional trained personnel may be required since severe wind chill factors may make it unreasonable to expect the "first team" to stay on deck to see an evolution through from start to finish.

C. ADEQUATE EXTREME COLD WEATHER CLOTHING IS NEEDED

Standard shipboard allowances of extreme cold weather (ECW) clothing are inadequate particularly in light of requirements for sufficient ECW clothing to outfit reliefs for personnel already on deck and the time required to dry ECW clothing if it should become soaked.

Navy issue ECW clothing was generally considered inferior to commercially available alternatives such as the "MUSTANG" suit. The Navy Safety Center should make a determination as to whether the inherent buoyancy of MUSTANG-type suits is sufficient to do away with the requirement for kapok life jackets for linehandlers and UNREP riggers.

D. COLD WEATHER AND HEAVY WEATHER COME TOGETHER

During both SHAREM 55 and SHAREM 62, sudden changes in the weather were observed. Only the in-situ forecasts by a meteorological detachment embarked in one of the SHAREM 55 ships provided sufficient warning of an approaching storm to permit timely storm evaision.

Even when weather is not severe enough to warrant storm evasion, the constant effort of fighting a ship's motion in a heavy seaway significantly affects the alertnes of watchstanders. Some evolutions, such a the movement of helicopters into and out of hangars, become quite dangerous in a seaway.

E. PREVALENCE OF OVERCAST, LOW VISIBILITY, TRACE MOISTURE HAS SIGNIFICANT TACTICAL IMPLICATIONS.

During SHAREM 55, LAMPS Mk I operations were severely restricted by persistent low visibility and possible icing conditions. In the marginal ice zone, low visibility creates a significant hazard to surface ships since an alert visual watch is the only reliable means of detecting bergy bits and growlers large enough to cause major damage to a ship's hull. Celestial navigation is often impossible for extended periods.

Certain tactical advantages do accrue to surface ships during periods of low visibility. The submariner at periscope depth is probably more handicapped by low visibility that the surface ship. Reconnaissance aircraft above an overcast may be forced to radiate active emitters to locate a surface force observing strict electronic EMCON.

F. OPERATIONS IN THE MARGINAL ICE ZONE ARE POSSIBLE BUT TOWED ARRAYS SHOULD STAY OUT.

During SHAREM 55, the edge of the marginal ice zone shifted by as much as 15 NM within 24 hours depending on local wind conditions. Ice reconnaisance flights by P-3 aircraft proved unable to locate the ice edge with sufficienct accuracy to ensure surface ship safety. An alert visual watch from a ship's bridge proved to be the only reliable means of detecting bergy bits and growlers large enough to cause significant hull damage and agile maneuvering was often required to avoid collision with the ice.

Based on SHAREM 55 experience, ships with towed arrays streamed should remain clear of the marginal ice zone.

Other ships may enter but they must remain constantly alert. All ships should clear the marginal ice zone and head of open water at night and during periods of poor visibility.

G. COMBAT SYSTEMS WERE EFFECTIVE IN SHAREMS 55 & 62

With the exception of the severe limitiations upon LAMPS Mk I flights due to low visibility and trace moisture conditions, the cold weather conditions encountered during SHAREM 55 and SHAREM 66 did not significantly degrade the effectiveness of the ships' installed combat systems.

HIGH LATITUDE OPERATIONS - A VIEW FROM THE BRIDGE

BY CDR LAWSON S. BRIGHAM
U.S. COAST GUARD

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TRAIN TO WIN IN THE NORTH ATLANTIC:
Preparation for Ship Helo Operations in the Polar/Sub-Polar Regions

By

CDR Patrick A. Wendt, USCG

To operate effectively in the arctic environment, man and machine must be properly prepared. This paper will deal primarily with lessons learned in the training and equipping of aircrews for Coast Guard helicopter operations in the polar environment. It will peripherally discuss the helicopter/ship interface.

Coast Guard pilots have flown helicopters from icebreakers since the early 1960's. Initially, the helicopters and crews were taken from the air unit closest to the icebreaker's home port. In 1969 the Icebreaker Helicopter Support Unit was established in Mobile, Alabama and POPDIV (Polar Operations Division), as it is now called, has supported the icebreakers since. POPDIV is treated as unique from other ship deployments. The training and equipment are specialized. The extended deployments to remote areas require a larger maintenance force and a more extensive parts inventory. The maintenance force is used for flight deck operations--tiedowns and LSO crews--not ship's force. Even the more liberal weather minimums are distinct from the rest of Coast Guard aviation owing to the dual helicopter operations and to the unusual weather patterns that frequent the polar regions.

At its inception, POPDIV was an infant on the polar learning curve and at the very end of the supply chain. But the wisdom of deploying from one unit to all regions of the arctic and antarctic bore fruit as the corporate memory grew.[1]

The following sections on Survival, Weather and Ice, Aviation Clothing, and Physiology and Psychology will discuss dangers to be anticipated and lessons learned in twenty years of polar helicopter operations.

Survival. In 1969 arctic survival kits to carry aboard helicopters were assembled with equipment left over from the Korean war--maybe even World War II--when the philosophy was "bulk equals warmth." Aircrews were given a survival course which consisted of a weekend on a deserted island in the Gulf of Mexico. We've improved to a lightweight, compact survival kit that's half the weight and twice the protection and a state-of-the-art polar survival training course that's considered one of the best in the world.

Polar operations were formed on the tail end of "the more the better" philosophy. Polar survival kits grew to include nearly everything but the kitchen sink. Like safety education and equipment in general, survival training and equipment was--and to some extent still is--reactive and too often not recognized except in retrospect. Then, the tendency was to be over-reactive, oftentimes with an effect just the opposite of that desired. Polar operations survival kits started heavy and grew to 200 pounds and that weight became a deciding factor in all flight operations, including a helicopter crash at the 11,200 foot level of Mt. Erebus in Antarctica in 1971 when the kit was left behind because it weighed too much. Belatedly, a piece-by-piece assessment of the kit and a thorough review of survival training was begun in 1981.

Advances in materials and packaging methods have reduced the size and weight of the kit. Lightweight, water repellent, ripstop nylon, Nomex, Goretex, polypropylene, thinsulate, ensolite and other "magic fabrics" are vast improvements over the likes of cotton/canvas. Smaller and lighter-weight survival radios, ELT's and SARSATs have reduced rescue time to hours and days, vice weeks and months. Nevertheless, modern survival equipment and hands-on training are essential elements of "coming back alive" because weather and the proximity of rescue forces, especially in the polar regions, will always frustrate rescue attempts. Man's mental attitude can render useless the best equipment if he is not optimally conditioned to cope with accidental thrusts into alien environments.

Centuries ago, the Buddhist priest Yashida Kenko wrote "In winter it is possible to live anywhere . . . ." He referred to a Japanese custom of warming from within rather than outside the body. POPDIV developed the same philosophy. Provide a survival kit that insures individual personal comfort in the temperature extremes of the polar regions without requiring a heat source external to the body. The present kit will protect and sustain three aircrew and three passengers for six days at -40° F, weighs less than 100 pounds, is compact (36" x 20" by 20") and is air deliverable by helicopter hoist or parachute. Vacuum packing permits three goose down sleeping bags, three goose down parkas and pants, a four-man tent, goose down booties, Goretex raingear, rations and miscellaneous survival implements to fit in the container. Emphasis has been placed on layered individual shelters and the conservation of energy. The second priority is the means to acquire water; food is provided principally for morale. A six-man, insulated, covered and ballasted raft took the place of one-man rafts which are totally unsatisfactory for polar ditching.[2]

POPDIV survival training was designed to be a natural progression of flight training. Aircraft crashes place extraordinary stress burdens on the aircrews not unlike the accepted stresses of flying--only magnified. Pilots are not expected to fly without first becoming familiar with their aircraft on an individual basis, yet most survival courses consist of group learning, not individual instruction. At our polar survival school, four students (to simulate an aircrew) make up a class. Two days of classroom instruction is followed by four days of field exercise at an elevation of 9,000 feet to 12,000 feet in an area which simulates as closely as possible the worst-case polar crash scenario using the actual equipment in our survival kits. The instruction is heavily weighted toward assessing and prioritizing basic needs including physiological effects of the cold. Basic survival skills are taught, leaning heavily on preparation for rescue vice outdoor camping. The final exam is a 24-hour solo separated and out of sight of anyone with only the clothes on one's back, snowshovel, pad, cup, one ration, candle, and three matches. The most important and critical element of successful training is the acceptance of mind over environment. Man is capable of extraordinary achievement in survival situations. Tragic survival stories are usually about people who didn't understand that they had it in them to continue until rescued. Survival is a personal war against giving in. As the solo is the big stepping off point in learning to fly, so also is the solo the biggest boost to survival--once experienced, never forgotten.[3]

The wisdom of being prepared is not lost on the Norwegians who must fly in polar conditions nearly year around. Their terrain, sea temperature and weather seldom, if ever, offer ideal conditions for forced landings; therefore, all aircrewmembers in Norway must complete an extensive winter survival course before they become operational and are required to complete a refresher every third year. The Royal Navy of the United Kingdom use this course as well.

Weather and Ice. In the sub-polar/polar regions, weather is the dictator. It decides whether we fly or sail, for we have not yet equipped our helicopters or surface ships, other than icebreakers, to operate with relative impunity as they do in the temperate zones. The winter darkness that in Tromso, Norway, for instance, is complete from mid-November to the end of January, adds to the challenge.

The Norwegian Sea normally remains ice-free along the Scandinavian coastline due to warm currents and air masses from the Atlantic. Westward, the marginal ice zone, or the extent of the ice pack, whether near Greenland in the summer or extended eastward in the winter, is characterized by rain, snow, and fog. During windy weather, the fog can lift to form low ceilings. During the summer, quick-forming eastward-moving frontal systems injected with moist southern air clash with cold polar air and create unpredictable cyclones of severe intensity. High winds are common along the coastlines in all seasons.

The uncertainty of where sea ice will occur in any given place and the dynamic and complex nature of the ice owing to tides, storms, currents and anomalies in ocean circulation and coastal configuration will frustrate any attempt to operate unreinforced vessels at will in the marginal ice zone. Enough examples exist over the history of polar exploration of vessels damaged and often sunk from the action of the ice. The canopener-like ripping of the side of the CGC WESTWIND, an icebreaker with a reinforced hull of five-eighths to an inch and five-eighths steel in the area of the tear, is a recent occurrence that should lend caution to polar operations.

Coast Guard icebreakers have the capability to receive real time satellite imagery which has been a boon to navigation and predicting flight conditions. Reconnaissance flights using various equipment, including infra-red, laser, and special radars provide valuable data even during the Arctic darkness and forecasting is provided by the Naval Fleet Weather Facility. However, they all have their shortcomings. Vessel and helicopter crews should stay wary.

Coast Guard and Navy fleet helicopters are not equipped for sustained flight in icing conditions. The most likely temperature range for icing is from +5°C to -10°C or just about every day in the Norwegian Sea. Most, but not all, are equipped with engine anti-ice capabilities, but are not able to shed rotor or fuselage ice. Navy VERTREP helicopters would be severely limited in this environment. Research is underway to develop de-icing for helicopters, however the problem is particularly difficult because of the dynamic components of the drive system and its sensitivity to balance.

The hazards of the polar climate on helicopters are many. Frost or snow can form on the flight surfaces if left unhangared or uncovered and alter the aerodynamics of the blades. It must be de-iced with fluid or heaters before flight. Helicopters can become cold soaked or cooled to the point where they cannot be started and must be warmed. Thinner oils are helpful. Drained batteries can cause polarity changes and the danger of explosion. Because batteries function poorly in the cold, Coast Guard helicopters carry two. Fuel and oil leaks from hardened seals, collapsed oleos, low blade dampers, high or low oil pressure indications and stuck or incorrect gauges are quirks of the cold. Icy surfaces can cause the helicopter fuselage to spin on deck when the rotors are engaged. Ice inhibitors must be used to keep ice from forming in fuel lines. Flying into colder air can cause altimeters to read low. Static electricity can become a serious problem and render radios useless, however often correctable with a change in altitude. Quick buildups of static electricity can make VERTREP particularly hazardous. Lack of contrast for visual cues is often prevalent and white-out is a frequent danger when loose snow covers the surface.

This is only a brief outline of the dangers facing helicopter operators in the polar/sub-polar regions. Any operation by the uninitiated should be preceded by thorough briefings and, preferably, hands-on training by those who have experienced it such as the U.S. Coast Guard or the Royal Norwegian Air Force.[4]

Aircrew Clothing. Clothing worn by Coast Guard aircrews in polar operations has evolved from the Navy QD-1 "Poopy suit," through wetsuits of various designs to a combination shorty wetsuit and insulated fire retardant flight coverall. Studies conducted for the Coast Guard have shown that this combination provides better protection than either the wetsuit or aviation coveralls alone in the cold wind and spray conditions that would be encountered in a forced ditching in the northern seas. Additional research on protection provided by anti-exposure clothing against immersion hypothermia in calm versus rough seas concluded that the wetsuit, shorty or long, provided the next best protection to a full dry survival suit. For years, a happy medium had been sought between comfort and protection. It's uncomfortable and fatiguing to fly in a full wetsuit and impossible in a dry type survival suit. Many aircrew recognized that, after "pleasure dips" in the arctic seas, they would "feel" colder in a strong wind out of the water and the thin Nomex flight suit over the wet suit wouldn't provide comfort against the wind and spray. The development of the Nomex insulated flight coverall filled our needs and the research confirmed our "feelings." At present the combination shorty wetsuit and Nomex flight coverall provide the best combination of fire protection, flying comfort, immersion protection and wind and spray protection. Nomex undergarments are recommended over other fabrics, such as cotton, for their fire protection as well as their ability to wick moisture. The layered clothing concept appears as effective in the maritime environment as over land.[5]

Generally, the first thing to get cold and the last to warm up on an aircrewman is his feet. Coast Guard polar operation crews tried everything from mukluks to "bunny boots" and all had their drawbacks. Research into a variety of footwear concluded that the most desirable features were: protection to -50°C, leather, economical, hiking boot size, shearling wool insert, ridged toe, side laces, and the fewest number of seams. The maximum comfort reach of any boot we tested was -50°C and we concluded, unscientifically, that the warmer we could keep the feet, the better. New materials like thinsulate and ensolite, combined with the shearling, help to produce the warmth without bulk. Leather was preferred over other materials for its breathability and strength. The Navy standard "bunny boot" offered the best protection from outside moisture, but we didn't expect our crews to stand in water more than they had to. However, we recognized the need to keep our feet dry and fewer seams would predict less penetration. The "bunny boots" were clumsy, would not fit into footholds for inspecting aircraft components, and caused foot sweating. We had known from uncomfortable experience that the standard steel-toed flight boot was a heat sink, but companies had experimented with coatings and non-metallic materials that were costly but effective. We like the safety advantage. We liked the side laces on one test boot because the laces didn't fill with snow and ice and hamper removal. We approached several companies and only one responded to "build" the boot we desired. The company continues to make improvements and, surprisingly, it is nearing competition with the standard-issue flight boot in cost.[6]

With the new insulating materials, we have found a variety of gloves that offer warmth, dexterity, protection, and strength. Studies have demonstrated that with the hands and feet insulated to 10 clo (one clo is the insulation required for inactive comfort at 20°C air temperature), the body can tolerate low temperatures ten times longer than uncovered. It cannot be overstressed--don't forget the feet and hands.[7]

The Coast Guard development and implementation of the underwater escape rebreather life vest satisfied our desire to protect against the sudden immersion reflex (the uncontrollable gulp of air on entering cold water) and provide breathing air to escape a capsized helicopter.[8]

We continue to seek innovation and refinement, however our search is not sparked with the prior sense of urgency. We're comfortable.

Physiology and Psychology. The question of whether the Navy can extend itself effectively into the Norwegian Sea will be answered by the ability of the servicemen to acclimate or adapt to the environment. Equipment is available for individual protection. Research will solve the topside and helicopter icing problems and better detection and forecasting will allow a wider scope of operation. Systems and procedures can be refined so the least number of people would be required "outside." However, our methods of operation would still require a sizable number to work in the environment. With material, we can improve upon improvements, but with personnel turnovers, we're always training from the beginning. The Soviet Northern Fleet has the advantage of working where they live and living more austerely. Our personnel are accustomed to limiting their exposure to harsh climates. Training in actual climatic conditions is essential to decrease the anxiety of servicemen towards the unaccustomed and increase their confidence in adapting to an alien environment. The complexities of operating north of the Arctic Circle for the surface Navy are magnified by unfamiliarity. To effectively reduce that unfamiliarity, training must give the full sensory impact of operating continuously in the cold. Video tapes are good, but they provide only a sight picture without the feel of the environment.

Psychologically, a whole naval system of attitudes require readjustment. For instance, crusty chiefs have to get away from wanting their boys to sweat and to learn to teach the opposite attitude. Sweating is the harbinger of death in the polar regions. Conservation of energy is an attitude to be cultivated. Knowing when to apply it once the knowledge is imparted is a matter of common sense.

Three physiological dangers face man in the polar region: hypothermia leading to the eventual loss of central nervous functions, tissue injuries resulting from a lack of protection of the extremities, and reduction of sensor motor functions resulting in a loss of manual dexterity. Man can either adapt, that is, use his intellect to manage his environment, or acclimate by forcing a biological readjustment, or pursue a combination of the two, which is the usual result; i.e., in going from sea level to a training exercise on a 12,000 foot mountain, we acclimate to the altitude and adapt to the cold.

Man's fitness to resist cold exposure is measured by a number of factors including his capability to raise his metabolism in muscular exercise, age, sex, diet, and frequency of physical activity.

It's been demonstrated that discomfort caused by cold and shivering is reduced with repeated cold exposure (acclimation) while the body is able to tolerate lower temperatures for extended periods of time if the extremities are protected (adaptation).

Even seemingly-acclimated arctic people can be subjected to unanticipated cold stresses, as witnessed by facial burns resulting from the introduction of skidoos or ski mobiles in Alaska. The Eskimos were acclimated to the cold, but not acclimated to going fast in the cold. It's best to be prepared, because even the most inquisitive can't anticipate everything.

Fear of the polar regions and the stress of cold on the body can be overcome with training, common sense, knowledge, and the proper equipment. In order to defend Norway and win the battle of the Norwegian Sea, the naval surface fleet personnel must be trained and equipped to operate above the Arctic Circle. And they aren't--yet.

CDR Wendt began his polar experience in 1969 with an Arctic West Deployment that resulted in a transit of the Northwest Passage escorting the super oil tanker USS MANHATTAN. He deployed to Antarctica in 1971. He has served on every class of ocean-going icebreaker in the United States in every area of operation. In 1981 he became Chief of Polar Operations for Aviation. He left in 1984 to assume command of Coast Guard Group/ Air Station Cape May, NJ.

Additional information can be obtained from the following sources:

1 U.S. Coast Guard Polar Operations Manual
Polar Operations Division
Coast Guard Aviation Center
Mobile, Alabama 36608
tele: 1-205-344-6150

2 Arctic/Antarctic Survival Kit
Same as above.

3 Polar Survival School
Quest Polar Survival School and Research Center
Greg Wiggins-Director
P.O. Box 629
Monument, CO 80132
tele: 1-303-481-2331

4 Norwegian Helicopter Operations
Royal Norwegian Air Force
337 Squadron
Bardufoss Air Station, Norway

5 Coast Guard Research on Protective Clothing:
A Comparison of the Protection Against Immersion Hypothermia Provided by Coast Guard Anti-Exposure Clothing in Calm Versus Rough Seas.
Report No. CG-D-17-85
Available through National Technical Information Services, Springfield, VA 22161

A Comparison of Coast Guard Protective Clothing in Cold Wind and Spray.
On Scene--The National Maritime SAR Review No. 3/1985. Available through
Commandant
U. S. Coast Guard (G-OSR-1)
Washington, D.C. 20593
tele: 1-202-426-1914

6 Aviation Polar Flight Boot
Chippewa Shoe Co.
P.O. Box 2521
Fort Worth, TX 76113-2521
Tele: 1-800-362-3049
Attn: Mr. Palmer Beebe

7 Study on Protection Extremities in Cold Weather
Environmental Physiology Branch
Environmental Medical Division
6570th Aerospace Medical Research Laboratory
Wright-Patterson AFB, OH 45433

8 Underwater Escape Rebreather (UER)
Commandant
U.S. Coast Guard (G-OSR-2)
Washington, D.C. 20593
tele: 1-202-426-0952

9 Polar Physiological Research (partial)
NATO Advisory Group for Aerospace Research and Development, AGARD Report number 630
National Technical Information Service
Springfield, VA 22161

CONSIDERATIONS FOR PROPELLERS AND PROPULSION PLANTS OPERATING IN NORTHERN LATITUDES

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LOADS ON THE MAIN PROPULSION SYSTEM

Ship operations in high latitudes lead to a variety of machinery problems. Operating in broken ice fields causes additional loads on the propulsion system due to the increase in ship resistance. Ice impact and ice milling with the propeller put extreme loads on the propeller blades, shafting, and machinery; and shaft and hull virbrations are excited by the propeller-ice interaction. There are other problems caused by the ice and low temperatures, but this discussion will be limited to the loads on the main propulsion machinery.

The normal load on the machinery plant is the hydrodynamic torque of the propeller as it develops the thrust to drive the ship. The propeller load torque is a function of the ship speed as well as the propeller speed (RPM). The curve labeled FREE ROUTE in Figure 1 is a graph of propeller shaft torque vs shaft speed for an unrestrained ship. As the propeller speed increases, the ship speed increases until at rated RPM the ship is moving ahead at full speed and the propulsion plant is developing rated power.

In ice the ship encounters additional resistance which will slow the ship and will result in an increase in the propeller load torque above the free route torque. If the ship is stopped by the ice, the propeller load

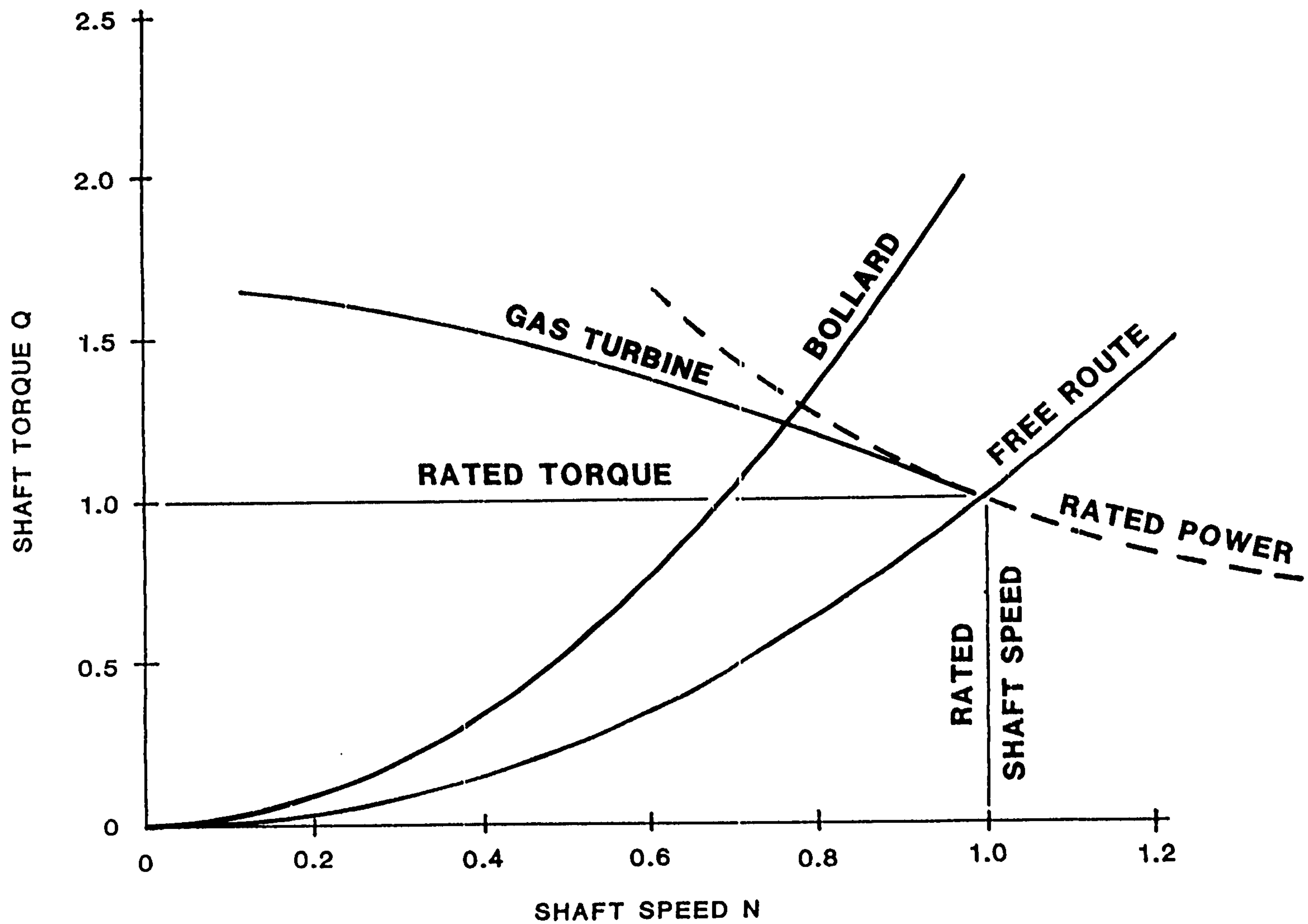


Figure 1. PROPELLER HYDRODYNAMIC TORQUE vs. RPM

torque will follow the curve in Figure 1 labeled BOLLARD (ship speed equal to zero). It can be seen that at any RPM the torque at the bollard condition is higher than the free route torque and to maintain full RPM will require power far greater than the rated power.

Diesel engines have a maximum torque which is typically independent of RPM. At bollard conditions the diesel plant will be limited to about 70% of full RPM and will not be able to develop full power. Gas turbines have a more desirable torque characteristic for operation in ice. The torque developed by the gas turbine rises as the shaft speed drops, allowing operation under bollard conditions at near rated power but at approximately 80% of full RPM as illustrated in Figure 1.

PROPELLER ICE IMPACT LOADS

Interaction between the propeller and ice takes two forms--ice impact and ice milling. The distinction is in the mechanism of the interaction. In ice impact the pieces of ice are relatively small and are moved by the propeller blades. For ice milling the ice floe is large enough that there is no ice movement, and propeller blade carves or mills grooves in the ice. Ice impact loads are less than those of ice milling but are still high enough to cause problems.

A computer model has been developed for the U. S. Coast Guard to estimate ice impact loads. The model is based on the propeller blades crushing the ice as depicted in Figure 2. As the ice is crushed a force develops which accelerates the ice floe, and it moves away from the propeller blade.

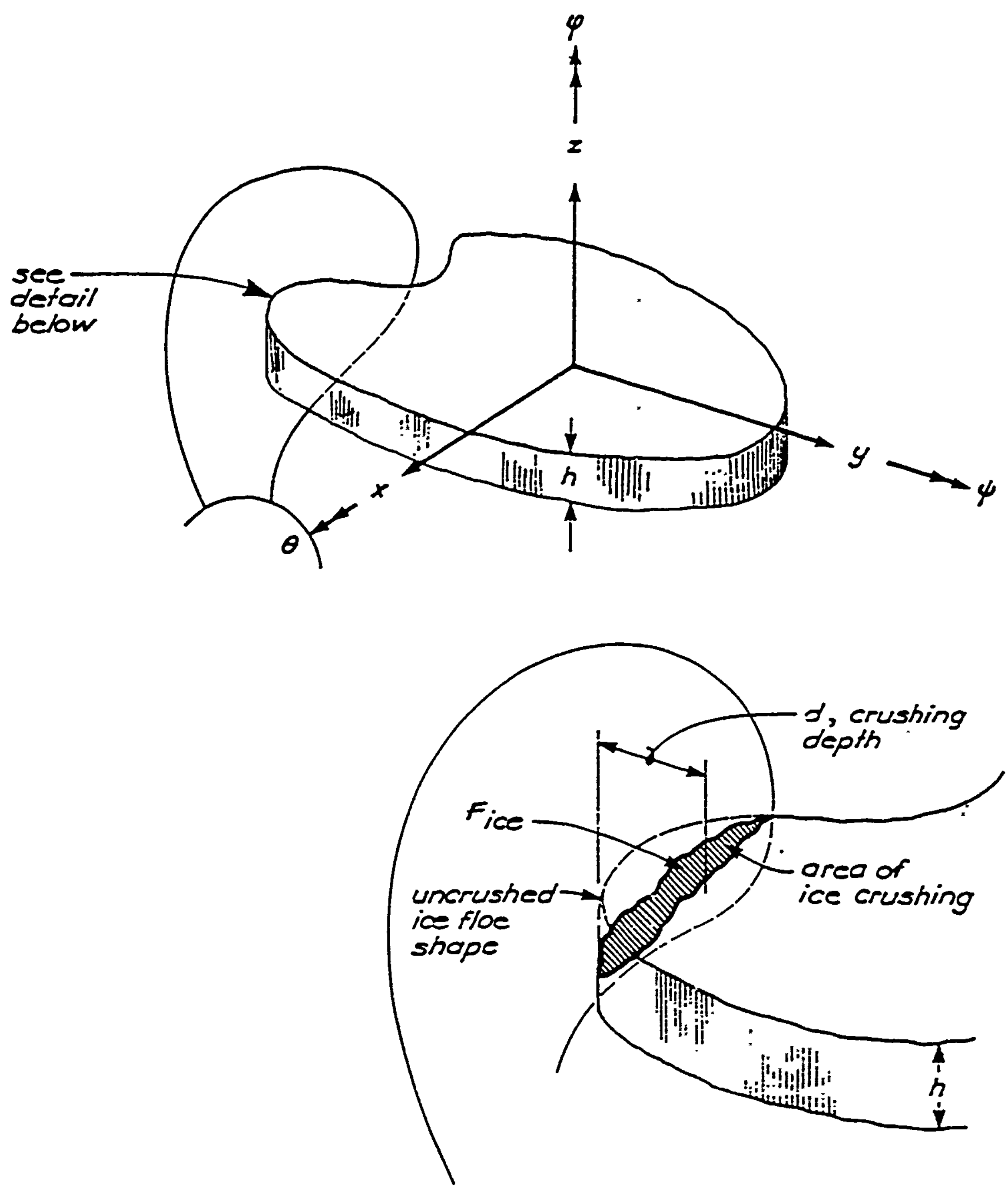


Figure 2. PROPELLER BLADE - ICE FLOE IMPACT

This model has been run for a propeller similar to that used for the FFG 7. The 5-bladed propeller is 16.5 feet in diameter with a pitch-diameter ratio equal to 1.5. Rated power is 40,000 HP. The ice floe dimensions are five feet in diamter and two feet thick, and the ice strikes the blade at 0.8 radius. The results of the calculations are plotted in Figure 3. For each propeller RPM the ship is initially at the steady-state free route speed prior to the propeller blade impacting with the ice. The estimated ice impact load is added to the free route hydrodynamic torque as shown in the figure. It is seen that these ice torque loads are substantial, but do not exceed the rated torque of the machinery plant. This loading will excite machinery and hull vibrations; and, at low shaft RPM, loads of these magnitudes could stall a diesel engine.

PROPELLER ICE MILLING LOADS

The computer model also predicts ice milling loads where the blades cut grooves in the ice. In this case the ice does not move and ice torque loads are much higher.

Evidence of ice milling has been frequently observed during Coast Guard icebreaking operations. Large pieces of ice with grooves have floated to the surface clearly showing that milling has occurred. This typically occurs during ramming operations when ice conditions are severe enough to prevent continous operations, and the icebreaker must back and ram the ice to make progress.

Estimates for ice milling torque for a four-bladed icebreaker propeller 16 feet in diameter are shown in Figure 4. The depth of the grooves cut in the ice is one foot. These torque loads are very high--2.5 times rated

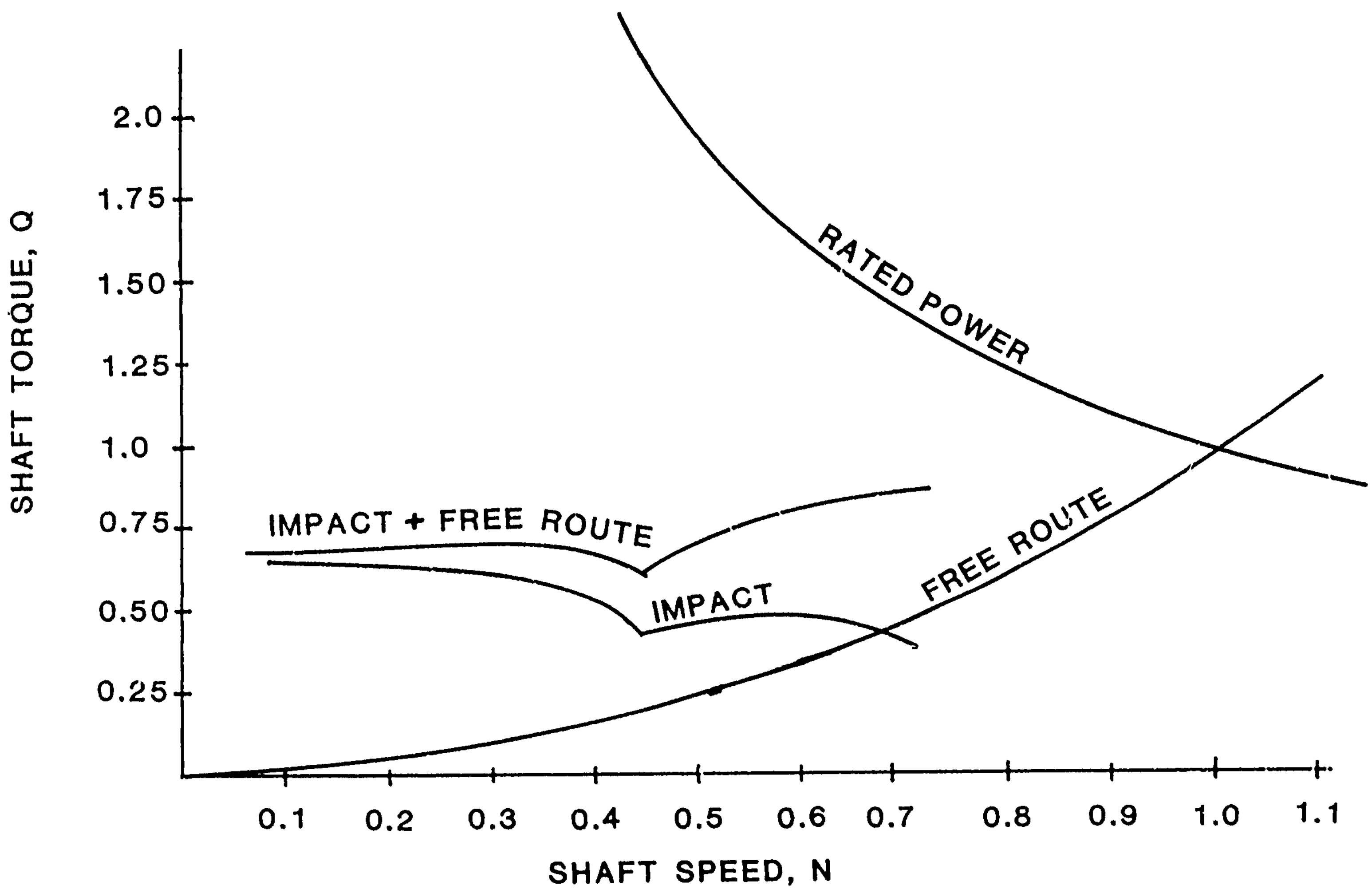


Figure 3. ICE IMPACT TORQUE vs. PROPELLER RPM

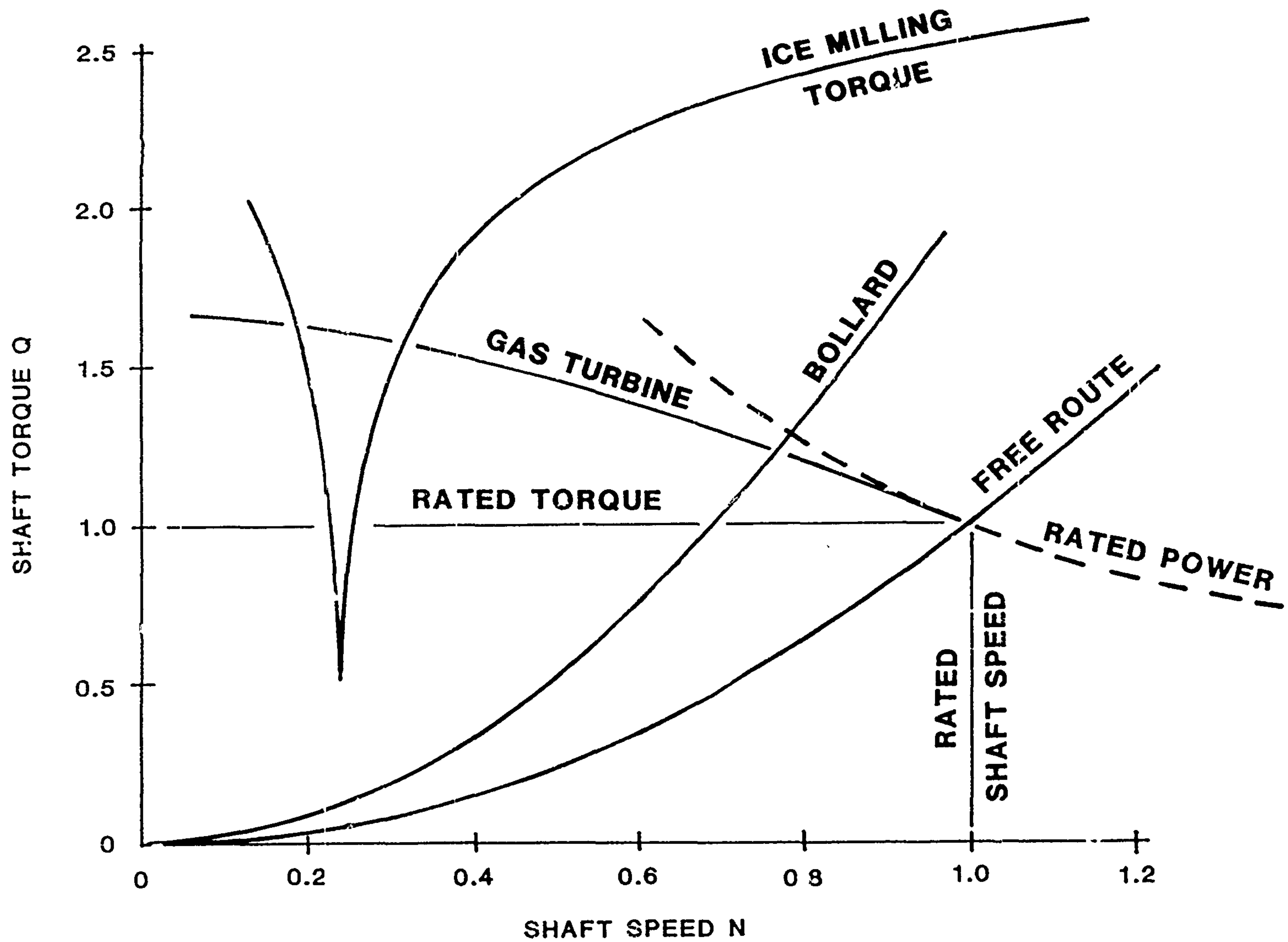


Figure 4. ICE MILLING TORQUE vs. PROPELLER RPM

torque. Icebreaker propellers, shafting, and machinery must be designed for this type of loading.

EFFECTS OF ICE LOADS ON PROPULSION SYSTEMS

The effects of the ice loads on the main propulsion system show up in several ways:

- rated power cannot be maintained when the ship is slowed by ice resistance
- stalling the main engine can be caused by ice impact and ice milling with the propeller
- hull and machinery vibrations are excited by propeller ice interaction.

A thorough understanding of these problems by the ship's officers and crew will permit appropriate modification to operating procedures and ensure full utilization of the main propulsion system capabilities while operating in ice fields.

STATUS OF COLD WEATHER OPERATIONS OF COMBAT SYSTEMS

BY MR. H. DeMATTIA, NAVSEA

AND

CAPT DONALD M. BUDAI, NAVSEA

Text not available at time of printing.

LAMPS MK III Environmental Capabilities

CDR JOHN OLMSTEAD, NAVAIR

LAMPS MK III is a shipboard/aircraft weapon system currently deployed on FFG-7 and CG-47 class ships - soon to deploy on DD-963 and later on DDG-993 class ships.

The Specific Operational Requirement (SOR) for Light Airborne Multi-Purpose System (LAMPS) is a generic document created by Admiral Zumwalt that covers both LAMPS MK I (SH-2F aircraft) and LAMPS MK III (SH-60B aircraft). This SOR, dated 23 April 1970, states among other things that:

1) the helicopter is not expected to operate in extreme weather conditions, i.e., severe or moderate icing, thunderstorms, very high sea and wind conditions

2) the helicopter is capable of flying in both instrument and visual flying rule conditions.

Decision Coordinating Paper 85 (DCP-85) and Test and Evaluation Master Plan 189 (TEMP-189 rev B), on the other hand, specifically govern only LAMPS MK III. These documents require that the LAMPS MK III ship/air weapon system be suitable for operations in sea state 4 required, 5 desired, day or night under both visual (VMC) and instrument (IMC) meteorological conditions. It should be noted that sea states in excess of 5 have been demonstrated during developmental testing.

Shipboard operating limitations are governed by the following documents and experience:

1) sea state greater than 5 is not required by DCP-85

2) ceiling below 200 feet and visibility less than 1/2 mile are governed by NWP-42. My experience has shown that ceiling and visibility restrict flight operations more frequently than do other operating limitations.

3) ice on deck creates slippery (hazardous) personnel conditions

4) loose deck/structure ice creates a Foreign Object Damage (FOD) and personnel hazard

5) hangar door icing may preclude opening, thus leaving the aircraft captive and unusable.

In the past, I have observed the following methods of reducing the above listed ice hazards on FF-1040 and AFS-1 class ships:

1) sand and/or salt - itself a micro FOD hazard. All local ice must be melted or all loosened ice removed, because loose ice is a major FOD and personnel hazard when propelled by helicopter downwash.

2) steam - either applied directly, or to the overhead of a compartment below the flight deck. This vehicle for ice removal should be used only in moderate temperatures, since the condensed steam generally freezes at a temperature higher than sea water.

3) bonfire built directly on the flight deck - works well for low spots on the flight deck that hold significant depths of ice. The ashes prevent rapid re-freeze, but pose a FOD hazard.

The SH-60B SEAHAWK helicopter has the following operational limitations:

1) main rotor blade spread, blade fold, engagement or disengagement - 45 knots of wind across the deck

2) tail pylon spread and fold should, if at all possible, be performed with winds of 30 knots or less.

It should be noted that with the Recovery Assist, Secure and Traverse (RAST) system to hold the aircraft secure, it is almost always possible to find a ship course and speed to accommodate these aircraft wind limitations.

The aircraft is designed to operate in ambient temperatures between -40°F(-40°C) and +140°F(+60°C); in visible moisture (rain, clouds, etc.) above +4°C without limitations, and in trace or light icing conditions. Operation in moderate or severe icing is prohibited. All SH-60B aircraft are equipped with systems for engine air inlet and engine anti-ice, pilot and copilot windshield anti-ice, pitot tube heat, and main/tail rotor blade de-ice provisions. Fifty percent of the production aircraft are delivered with kits that provide main and tail rotor blade de-ice capability. These kits are controlled by each air Type Commander, and provided to any units anticipating operations in icing conditions. These kits are installed at the organizational level, and require approximately one man hour. The kits weigh approximately seven pounds, and two of the three kit components are spared in the Pack-Up Kit (PUK).

SH-60B icing tests were conducted by NAVAIRTESTCEN/BIS personnel in February 1985. The test aircraft was flown behind and below an Army H-47 helicopter equipped with a water spray system to create visible moisture. The SH-60B main/tail rotor blade de-ice system works by intermittently heating the leading edge of the rotor blade. The de-ice controller is designed to automatically measure the ice accretion rate, and adjust the heat-off cycle accordingly. A back-up manual mode is also available to the pilot. In this mode, the pilot must estimate the atmospheric water content, or the ice accretion rate, and manually set the heat-off cycle time. During the February 1985 BIS icing trials, the manual mode was selected. The tests were terminated prior to completion due to tail rotor blade damage caused by ice shed from the main rotor blades. The theory of operation of the rotor blade de-ice system involves allowing a controlled amount of ice to build up on the leading edge, intermittently heating the leading edge to allow pre-determined sizes of ice to be shed due to centrifugal force. If the heat is applied too frequently, the ice never forms on the leading edge, but forms on the unheated mid-section and trailing edge. The resultant aerodynamic degradation can cause catastrophic results. If the heat is applied too infrequently, the ice thickness becomes thicker than desired and, once shed, can damage dynamic components. This is the scenario experienced during the February 1985 icing tests. The icing testing will be continued during February - May 1986. Since aircraft icing significantly increases aerodynamic drag and aircraft weight, you may wonder how commercial airlines deal with this problem. In addition to being equipped with features similar to those of the SH-60B, these aircraft are sprayed with an anti-ice solution prior to take-off, and generally fly at altitudes above those where visible moisture is present. Helicopters generally do not have the last option.

The Navy SH-60B SEAHAWK aircraft is a derivative of the Army UH-60A BLACK HAWK. Both aircraft have identical engine anti-ice and blade de-ice elements. The Army uses a different blade de-ice controller, has heated droop stops, and recently incorporated center windshield anti-ice. These enhancements allow Army aircraft to fly in forecast or known moderate icing conditions. The addition of heated droop stops and other enhancements to be defined during the 1986 icing tests, could, at significant expense, result in a capability for the SH-60B to operate during moderate icing conditions. The chart titled "NAVY ASW HELICOPTER DE-ICE/ANTI-ICE COMPARISON" shows the capability of all Navy ASW helicopters. The SH-60B is the best we have.

No known RAST limitations exist with respect to icing conditions. The Rapid Securing Device (moveable hold-down dolly) exerts 30,000 PSI under its rollers. These pressures would displace any ice beneath the rollers. RAST ice operations to date have been terminated by the ship's Commanding Officer due to a 1/2" coating of ice on all weather decks that hazarded personnel. The RAST worked as advertised during those conditions.

Commander Olmstead is the LAMPS MK III Deputy Program Manager in PMA-266. He made 6 extended deployments with H-46 VERTREP and SH-2F LAMPS MK I helicopters aboard aviation facility ships,and commanded a LAMPS MK I squadron. He is a graduate of the Naval Test Pilot School, and conducted the initial flying qualities and performance testing on the SH-60B helicopter.

LAMPS MK III ENVIRONMENTAL CAPABILITIES

FOR

U.S. NAVY SYMPOSIUM ON ARCTIC/COLD WEATHER SURFACESHIP OPERATIONS

3-4 DECEMBER 1985

BY

CDR A. J. OLMSTEAD, JR.
DEPUTY PROGRAM MANAGER
LAMPS MK III

11/13/85

UNCLASSIFIED

NAVAIR

REQUIREMENTS

- SOR
  - LIGHT AIRBORNE MULTI-PURPOSE SYSTEM OF 23 APRIL 1970
    - HELO NOT EXPECTED TO OPERATE IN EXTREME WEATHER CONDITIONS, i.e., SEVERE OR MODERATE ICING, THUNDERSTORMS, VERY HIGH SEA AND WIND CONDITIONS
    - HELO VFR AND IFR CAPABLE
- DCP
  - DCP-85 LAMPS MK III SHIP/AIR WEAPON SYSTEM
    - OPERATIONS IN SEA STATE 4 REQUIRED, 5 DESIRED, DAY OR NIGHT UNDER VMC AND IMC
- TEMP
  - TEMP 189 REV B
    - SAME AS DCP

06/26/85

UNCLASSIFIED

SHIPBOARD OPERATING LIMITATIONS

- SEA STATE GREATER THAN 5 – DCP 85
- CEILING BELOW 200 FT – NWP 42
- VISIBILITY LESS THAN ½ MILE – NWP 42
- DECK ICE CREATES SLIPPERY (HAZARDOUS) PERSONNEL CONDITION
- LOOSE DECK/STRUCTURE ICE CREATES FOD/PERSONNEL HAZARD
- HANGAR FACE/DOOR ICE MAY PRECLUDE OPENING

$\left.\right\}$ LAMPS MK I EXPERIENCE

11/12/85

SH-60B OPERATIONAL LIMITS

OPERATION	LIMIT
ROTOR ENGAGE/DISENGAGE	45 KNOTS
MAIN ROTOR BLADE SPREAD/FOLD	45 KNOTS
TAIL PYLON SPREAD/FOLD	30 KNOTS (RECOMMENDED MAX)
AMBIENT TEMPERATURE	−40°C (−40°F) TO +60°C (+140°F)
FLIGHT IN VISIBLE MOISTURE WITH TEMP +4°C OR BELOW (ICING)	TRACE OR LIGHT ICING ONLY (NOT MODERATE OR SEVERE)
FLIGHT IN RAIN	NO LIMITATIONS

SH-60B ICING EQUIPMENT

• ENGINE AIR INLET	ALL AIRCRAFT
• ENGINE ANTI-ICE	ALL AIRCRAFT
• WINDSHIELD ANTI-ICE	ALL AIRCRAFT
• PITOT TUBE HEAT	ALL AIRCRAFT
• MAIN/TAIL ROTOR BLADE DE-ICE PROVISIONS	ALL AIRCRAFT
• MAIN/TAIL ROTOR BLADE DE-ICE KIT	50% OF FLEET AIRCRAFT

NAVAIR

MAIN/TAIL ROTOR BLADE DE-ICE KIT

- THREE COMPONENTS
  - DE-ICE CONTROL PANEL
  - DE-ICE TEST PANEL
  - DE-ICE CONTROLLER
- INSTALLED AT "O" LEVEL
  - APPROX ONE MAN-HOUR REQUIRED
- PROCURED FOR EVERY OTHER LOT II AND SUBSEQUENT AIRCRAFT
- DELIVERED AS LOOSE EQUIPMENT
- CONTROLLED BY TYPE COMMANDER
- TWO KITS AVAIL FOR 18 FRS AIRCRAFT
- KIT WEIGHS APPROX 7 LBS
- PUK SPARES TWO OF THREE COMPONENTS

11/12/85

BIS TESTING

- RESULTS
  - BIS ICING TRIALS SUSPENDED
    - TAIL ROTOR BLADES DAMAGED BY ICE SHED FROM MRB
- ASSESSMENT
  - DE-ICE SYSTEM NOT OPERATED IAW NATOPS
  - TEST CONDITIONS MORE SEVERE THAN PROGRAMMED
  - NO PLANS TO RESCIND NATOPS AUTHORIZATION TO FLY IN TRACE/LIGHT ICING
- PLANNED TESTS
  - CONTINUATION OF ICING TRIALS IN FEB-MAY 86

ICING CONDITIONS

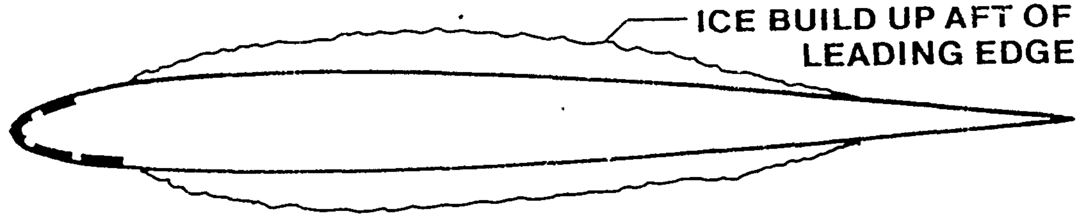
- MAY OCCUR WITH AMBIENT TEMP +4°C OR BELOW, WITH VISIBLE MOISTURE PRESENT
- MEASURED AS LIQUID WATER CONTENT IN GRAMS PER CUBIC METER
  - TRACE 0 - 0.25 G/M^3
  - LIGHT 0.25 - 0.5 G/M^3
  - MODERATE 0.5 - 1.0 G/M^3
  - HEAVY >1.0 G/M^3

UNCLASSIFIED

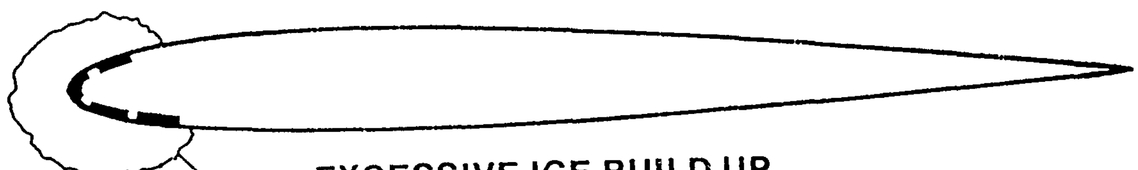
NAVAIR

MANUAL DE-ICE SETTING

- TOO HIGH A SETTING



- TOO LOW A SETTING



6/28/85

UNCLASSIFIED

NAVY SEAHAWK/ ARMY BLACK HAWK COMPARISON

- IDENTICAL DE-ICE EQUIPMENT (WIRES, ELEMENTS, ETC.)
- DIFFERENT CONTROLLERS
  - ARMY HAS ICE RATE METER (GIVES PILOT INDICATION OF ICE BUILD-UP)
  - ARMY HAS HEATED DROOP STOPS
  - ARMY RECENTLY INCORPORATED CENTER WINDSHIELD ANTI-ICE
- ARMY FLIGHT PERMITTED INTO FORECAST OR KNOWN MODERATE ICING
- NAVY FLIGHT PERMITTED INTO FORECAST OR KNOWN TRACE/LIGHT ICING

UNCLASSIFIED

NAVAIR

SH-60B MODERATE ICING CAPABILITY

Lamps

- TECHNICAL
  - POTENTIAL CONFIGURATION CHANGES
    - ADDITION OF HEATED DROOP STOPS
    - ADDITION OF ICE RATE METER
    - ADDITION OF CENTER WINDSHIELD ANTI-ICE (OPTIONAL)
- SCHEDULE
  - MONTHS FROM GO AHEAD – 30
- COST
  - PRODUCTION FORWARD FIT
    - NON-RECURRING – SIGNIFICANT
    - UNIT RECURRING – LOW
  - RETROFIT
    - NON-RECURRING – MODERATE
    - UNIT RECURRING – MODERATE
  - TOTAL PROGRAM COST – MAJOR CONSIDERATION

11/12/85

UNCLASSIFIED

NAVAIR

LAMPS MK III SHIPBOARD OPERATIONS IN ICING CONDITIONS

lamps

- RAST LIMITATIONS
  - TRAVERSE
    - NONE PUBLISHED
    - TRAVERSE WINCH 10,000# PULL CAPABILITY
    - RSD ROLLERS HAVE 30,000 PSI LOADING ON DECK
- OPERATIONS TO DATE
  - FFG-50 USS TAYLOR, JAN 85
  - FLIGHT DECK COVERED ½ INCH ICE DURING TESTING
  - CO TERMINATED OPS WITH "CLEAR OF WEATHER DECKS"

06/27/85

UNCLASSIFIED

NAVAIR

NAVY ASW HELICOPTER DE-ICE/ANTI-ICE COMPARISON

	LAMPS MK III SH-60B	LAMPS MK I SH-2F	CARRIER SH-3H
ENGINE AIR INLET	YES	YES	YES
ENGINE ANTI-ICE	YES	YES	YES
WINDSHIELD ANTI-ICE	YES	YES	YES
PITOT TUBE HEAT	YES	YES	YES
MAIN/TAIL ROTOR BLADE DE-ICE	YES	NO	NO
ICE DETECTION SYSTEM	YES-KIT	NO	NO
FUSELAGE DE-ICE	NO	NO	NO
FLIGHT IN ICING CONDITIONS	YES (TRACE/LIGHT)	PROHIBITED	PROHIBITED

06/26/85

UNCLASSIFIED

Engineering Program On
Anti/De-Icing of the Rast Track

David A. Boston

INTRODUCTION

The Recovery Assist Securing Traversing (RAST) system is an integral component of the LAMPS MK III system. The potential for a malfunction of the RAST system is significantly increased during arctic/cold weather operations as the result of probable ice accumulation in the RAST track. While a variety of equipment and several methods are available for the prevention of ice adhesion (anti-icing) and the removal of accreted ice (de-icing); no system has been designed specifically to solve the problem of icing on the RAST track. This paper is a description of the engineering effort required to develop a design solution to this problem. Effort is made to describe the variables, parameters, and system requirements which must be analyzed in order to determine the performance requirements of any potential anti/de-icing system for the RAST track.

BACKGROUND

The RAST track is a component of the RAST system which consists of equipment, some installed on the aircraft and most installed in the ship, which together assist in helicopter recovery, securing to the deck, maneuvering on the deck, traversing into and out of the hangar, and helicopter launch assist. The major components of the system are schematically illustrated in Figure 1. The track is fabricated in eight foot long sections with a typical cross section as illustrated in Figure 2. The total length of the track is approximately 110 ft. with 65 ft. exposed to the weather. Since the top surface of the track serves as a deck surface, it is coated with non-skid. The bottom of the trough is equipped with six-two and one-half inch diameter drains.

For the purposes of this study, the function of the RAST track is to guide the Rapid Securing Device (RSD); failure of the RSD is the inability of the RSD to traverse the length of the track; and further, this inability to traverse must be the result of accumulated ice. The key element of this study is to define the critical level of ice accretion and its location which will result in this failure. The ambient conditions which will generate the critical mass of ice, the time required for this accretion, and the energy and time required to remove it are critical elements of this analysis.

Arctic conditions, under which deck equipment is designed to operate, are defined, in the 1985 edition of the General Specifications for Ships of the U.S. Navy, as minimum air temperatures of minus 65 degrees F with maximum winds of 100 knots. In order for the severity of these conditions to be appreciated, it must be realized that a film of water exposed to these conditions will freeze instantly. Whats more, any exposed human flesh will freeze in less than 30 seconds. This rapid freezing is a manifestation of what is referred to as wind chill. Essentially, wind chill is the resultant heat flux due to convection and conduction. The wind chill index is the temperature at which the same heat flux will occur solely due to conduction as occurs at the elevated temperature due to both conduction and convection at the given wind speed. Figure 3 illustrates wind chill indexs. The RAST system is required to operate under the conditions of sea state five at a minimum temperature of -20 degrees F. The implication of the severity of arctic conditions is to require that an ideal anti/de-icing system design would involve a minimum amount of labor and the crew exposure time must be as short as possible.

OBJECTIVES

The program objectives will be accomplished through four major phases: problem definition, system analysis, system design, and system integration.

The primary objective of this program is to quantitatively define the problem of icing/de-icing of the RAST track as follows; given the conditions of ambient temperature, wind speed, and sea state, what is the rate at which ice will accumulate in/on the RAST track? Also; what thickness of ice in what locations can be tolerated without causing the RAST system to malfunction? This phase is schematically illustrated in Figure 4. The second objective is to determine, through comparative analysis, the most cost effective approach to solving the problem. This could be either anti-icing, the prevention of ice accumulation; de-icing, the removal of accumulated ice; or some combination of the two. Finally, this program will culminate in a design of a system which will either prevent the accumulation of the critical thickness of ice and/or remove the accumulated ice within the operational time constraints established for the system.

The core of the analytical aspects of this program is a computerized model of the RAST track. As illustrated in Figure 5, this finite element model of the RAST track will predict various responses to the indicated inputs. The temperature distribution over the track surface will determine the locations of the maximum accumulation of ice; indicate optimum locations for insulation; and suggest locations and capacities for thermal de-icing units. A secondary benefit of the temperature distribution is the capability to predict thermal stresses and strains and thus thermal shock. The inputs to the computer program include such fixed parameters as the track geometry, dimensional tolerances, and material. In addition, environmental conditions such as wind speed, air temperature and water flow can be varied at will.

A major complexity in the study of ship icing is the modeling of the ice formation process. The salt and air content of the sea water; the water content and droplet size of the sea spray; and the frequency of wave impact are all factors which determine the formation of ice on ship surfaces. In general these complexities can be avoided by making a basic assumption that the ice formed on the RAST track is the result of water (sea water or fresh) flowing over the track at a particular flow rate. In terms of ship operations, this represents a worst case scenario. The water flow could come from a wash down operation, fire fighting or something as simple as a ruptured pipe. In any event, the postulate here is that if an anti/de-icing system can be designed to handle a layer of frozen water with properties, some real and some assumed, which will place the severest demands on that system, then it would be adequate to manage ice in any form which would be encountered at sea. Schematically, this model is illustrated in Figure 6.

DESIGN APPROACHES

There are three approaches which could be followed in designing a system: anti-icing, de-icing, or some combination of the two. Anti-icing can involve the prevention of water contact with the track; the minimization of ice adhesion; and the prevention of water freezing on the track. The prevention of water contact implies that some waterproof cover is applied to either the entire deck, or to the RAST track only. This cover must maintain its flexibility under arctic conditions, be strong enough to with-stand flight deck traffic, be easily handled by a minimum number of crew men, and be easily and quickly stowed. One proposal for a track cover is illustrated in Figure 7. An additional advantage of this type cover is that it would eliminate convection heat transfer from the track. Low adhesion coatings significantly reduce the adhesive forces between the ice and the surface and thus minimizes ice accretion and eases ice removal. It has been reported that in some cases, ice will fall from some vertical surfaces, which have been treated with low adhesion coatings, due to its own weight or as a result of small vibrations. Low adhesion coatings have been used in the marine industry and are readily available on the commercial market. It should be noted that minimizing ice adhesion cannot be considered to be a solution in and of itself since the pieces of ice must be totally removed from the flight deck of a LAMPS ship in order to prevent damage to the aircraft engines (FOD). In situations in which the heat flux from the deck is not too severe, freezing can be prevented by providing sufficient heat to the track to maintain its temperature above the freezing point of water. In addition to the typical sources of heat, large volumes of sea water can be pumped over the deck to prevent freezing.

There are four major approaches to de-icing; mechanical, hydrodynamic devices, thermal energy application, and chemical de-icers. Some of the more promising de-icing systems are analyzed in Figures 7 through 9. Mechanical de-icing would include the use of mallets, scrapers, brooms, etc. However, because of the reliance on manpower, these should be considered to be last resorts and unexceptable under extreme arctic conditions. Hydrodynamic systems for ice removal have been widely used commercially. These systems remove ice by directing a high pressure stream, of either water or steam, at the ice mass and thus fracturing it. The safety and effectiveness of these water and steam lances, in a naval environment, under extreme arctic conditions, still has to be demonstrated. De-icing systems which utilize thermal energy are perhaps the most promising. Thermal energy, either from electric resistance heaters, steam pipes, hot water pipes, or hot gases, is the most effective means of removing ice. However, there are many issues surrounding these systems which have yet to be resolved. There are limits to the capacity of the electrical systems, now available, to provide adequate quantities of heat in short time spans. Further, these systems could place a considerable demand on the ships electricity generating capacity. The remaining sources of heat energy typically have a significant impact on the ship's limited stowage space and weight margins. Chemical de-icers would have limited usefulness in the naval environment. This is primarily due to the fact that they tend to be corrosive, bulky, and are effective over a limited temperature range.

In general it should be observed that while many anti/de-icing systems have been successfully used commercially; it cannot be readily assumed that they can be easily adapted to the U.S. Navy. Navy equipment may have to meet shock specifications, safety requirements, and limits on reliability and maintainability which are not imposed in commercial applications. Prior to being placed in service, new equipment must undergo extensive testing and evaluation.

The systems integration aspect of this engineering program speaks to the problem of getting the anti/de-icing system into the fleet. For new ships, under construction, new equipment is added under the Engineering Change Proposal (ECP) process. Existing ships are modified through the Ship Alteration Proposal (SAP) process. In either case, many factors must be considered. It must be demonstrated that all new equipment meets all applicable specifications and requirements. The maintenance requirements must be clearly defined and integrated into the ship's Planned Maintenance System. If special training is necessary for the crew to safely and effectively operate the new equipment, it must be identified. Finally, and inventory of spare parts must be incorporated into the ship's allowance.

SUMMARY

While the problems associated with arctic/cold weather operations are formidable, a program such as this provides a methodology for solutions. It is anticipated that as other potential problem areas are identified, this program for the solution of the problem of icing of the RAST track can serve as a model.

RAST SYSTEM GENERAL ARRANGEMENT

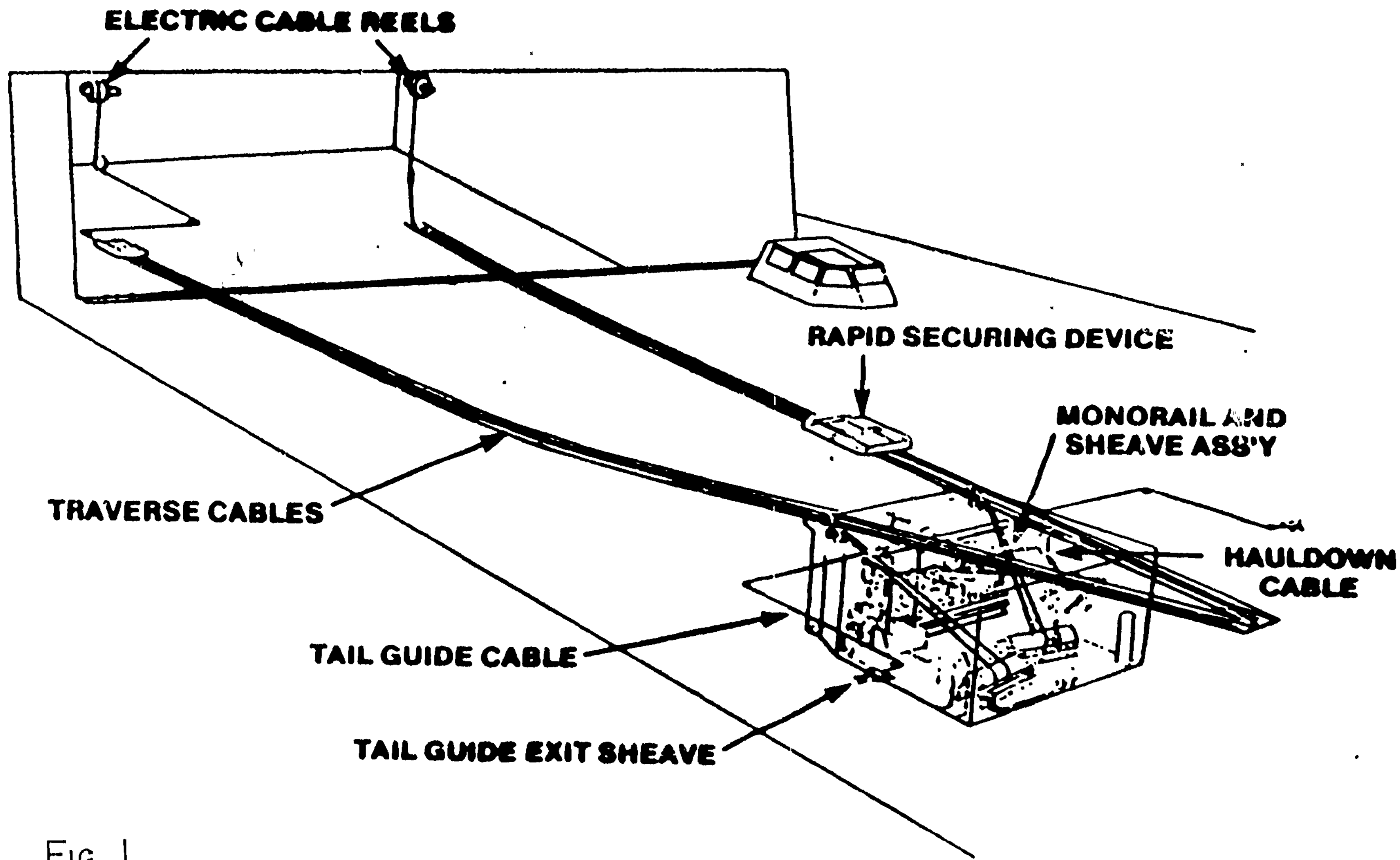
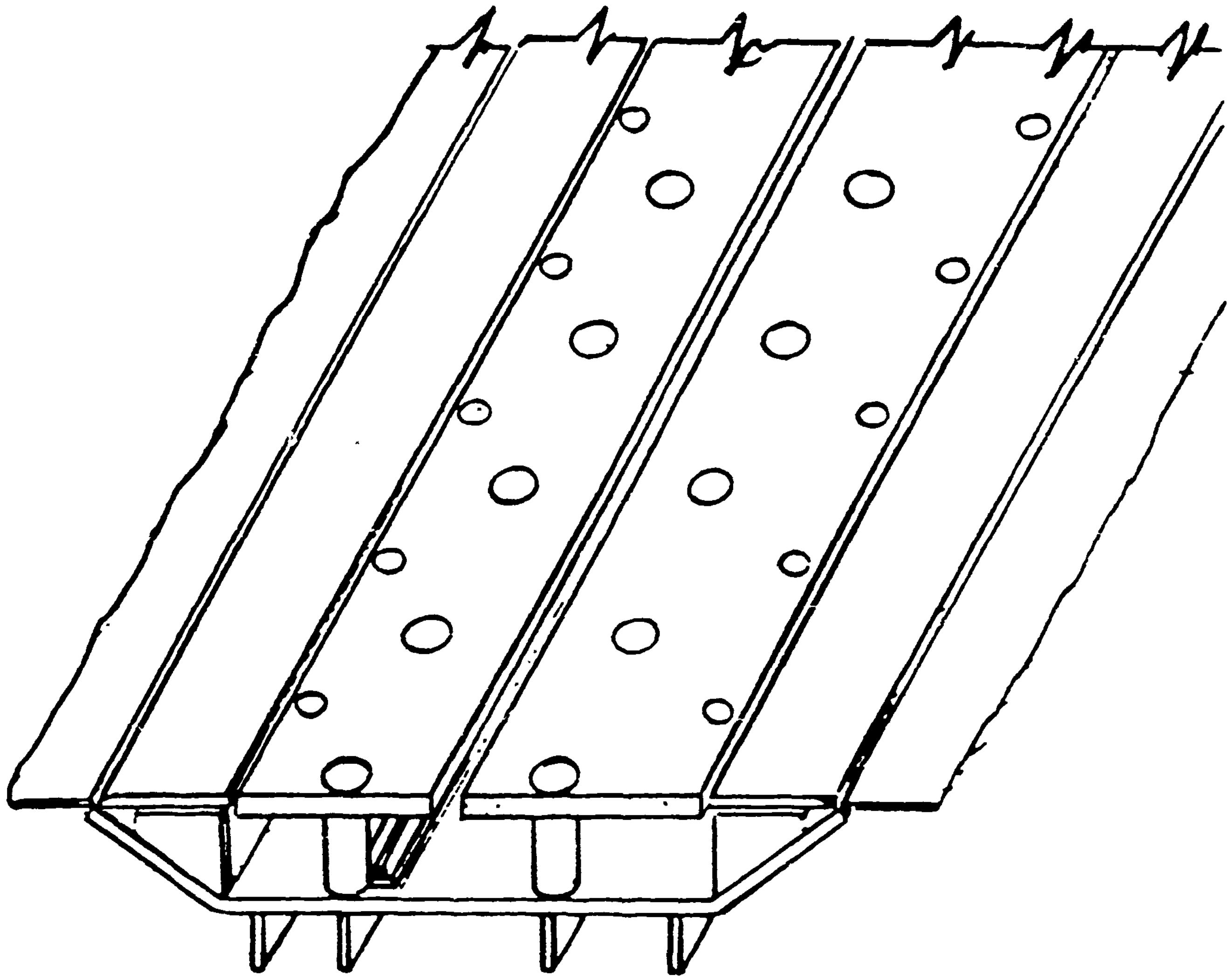
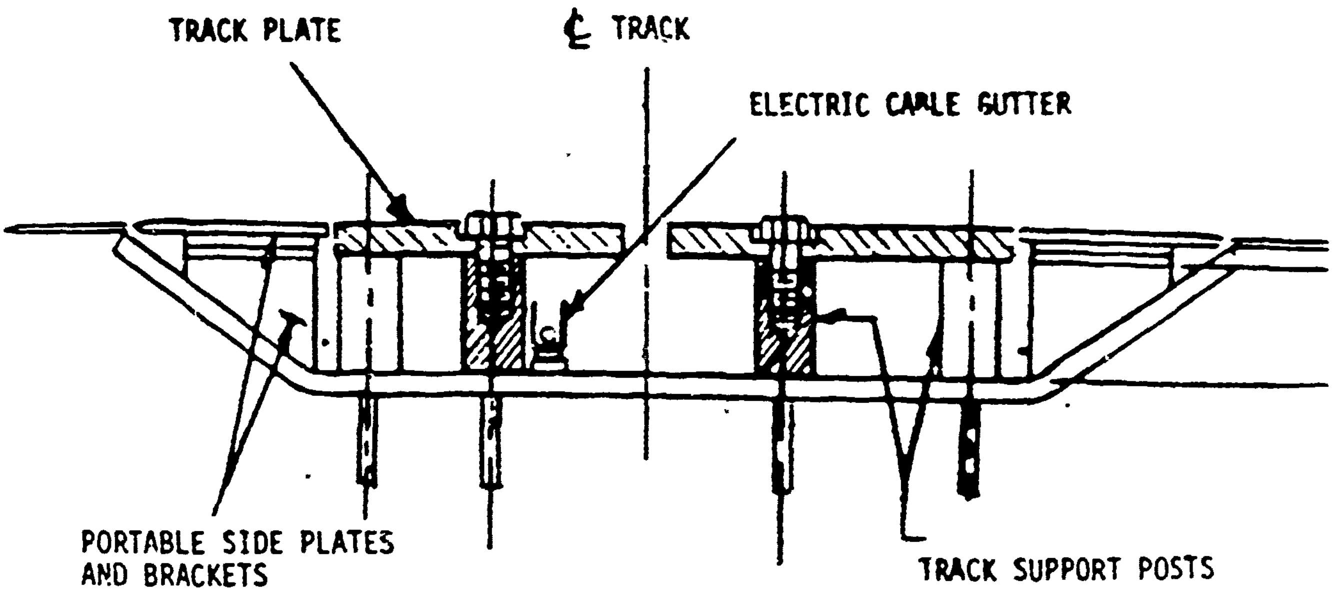


FIG. 1



VIEW OF RAST TROUGH AND TRACK



RAST TROUGH

FIG. 2

WIND CHILL FACTOR

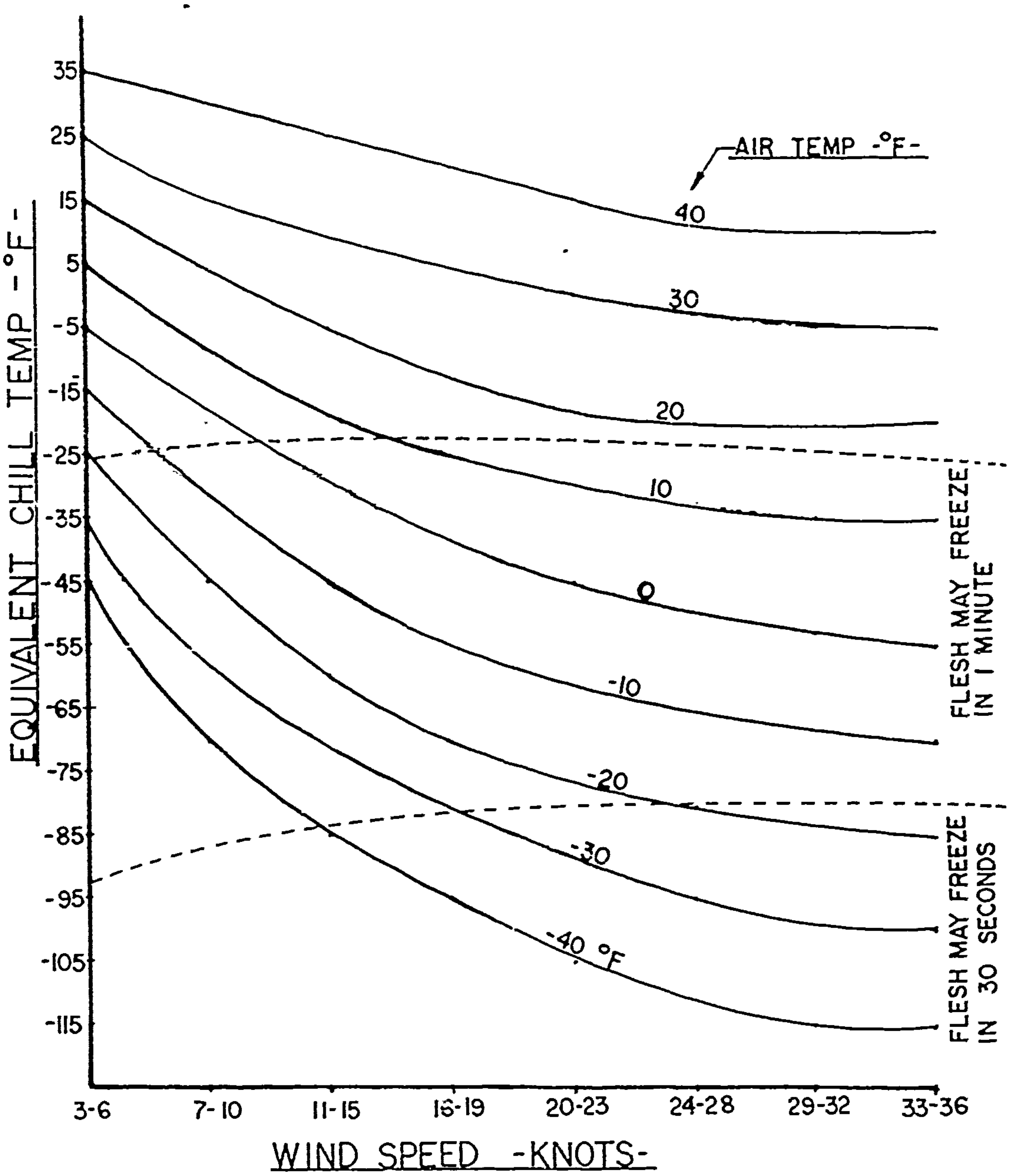


FIG. 3

Ref. Weather for the Mariner, William J. Kotsch, RADM (Ret), 1983, U.S. Naval Inst, Annap, Maryland

DEFINITION OF PROBLEM OF ICE ACCRETION ON RAST TRACK

SYS OPERATIONAL REQUIREMENTS	PROBLEM DEFINITION	DETRIMENTAL EFFECT OF ICE
CONSTANT AVAILABILITY	WHAT QUANTITY/LOCATIONS WILL CAUSE AN RSD MALFUNCTION?	REDUCED CL'RANCE
30 MIN CYCLE	WHAT TIME IS REQUIRED FOR THAT AMOUNT OF ICE TO ACCUMU-LATE?	EXCESSIVE BOLT LOADS
-28 C 31 KN WIND SEA ST 5	TIME/EFFORT REQUIRED TO REMOVE EXCESSIVE ICE ACCRETION	EXCESSIVE POWER PLANT LOADS
		PERSONNEL SAFETY

FIG.4

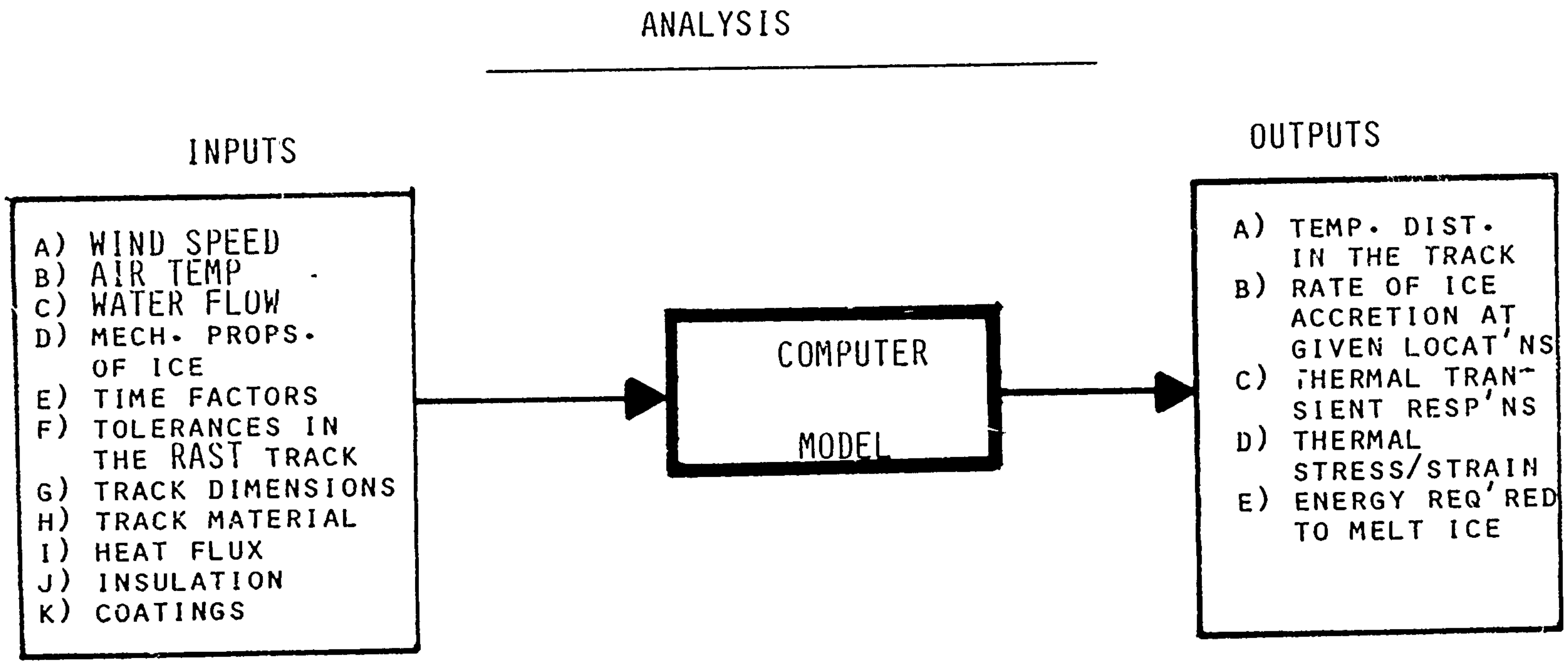
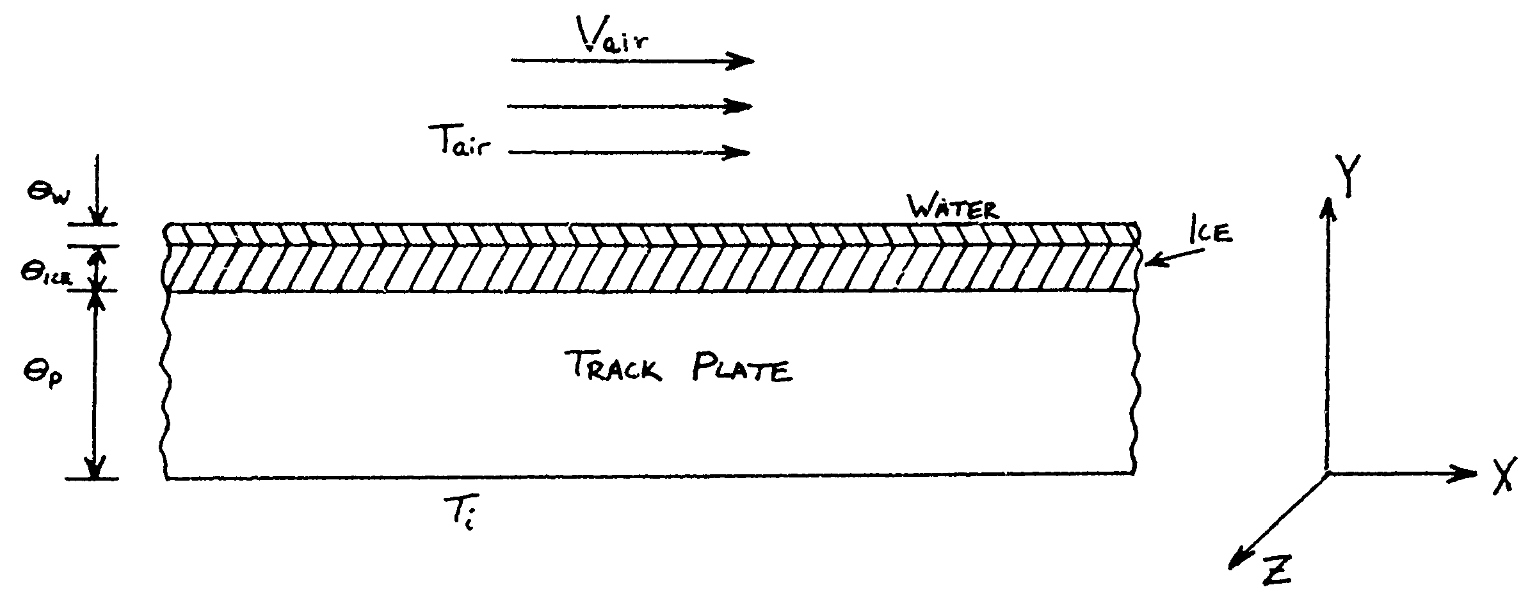
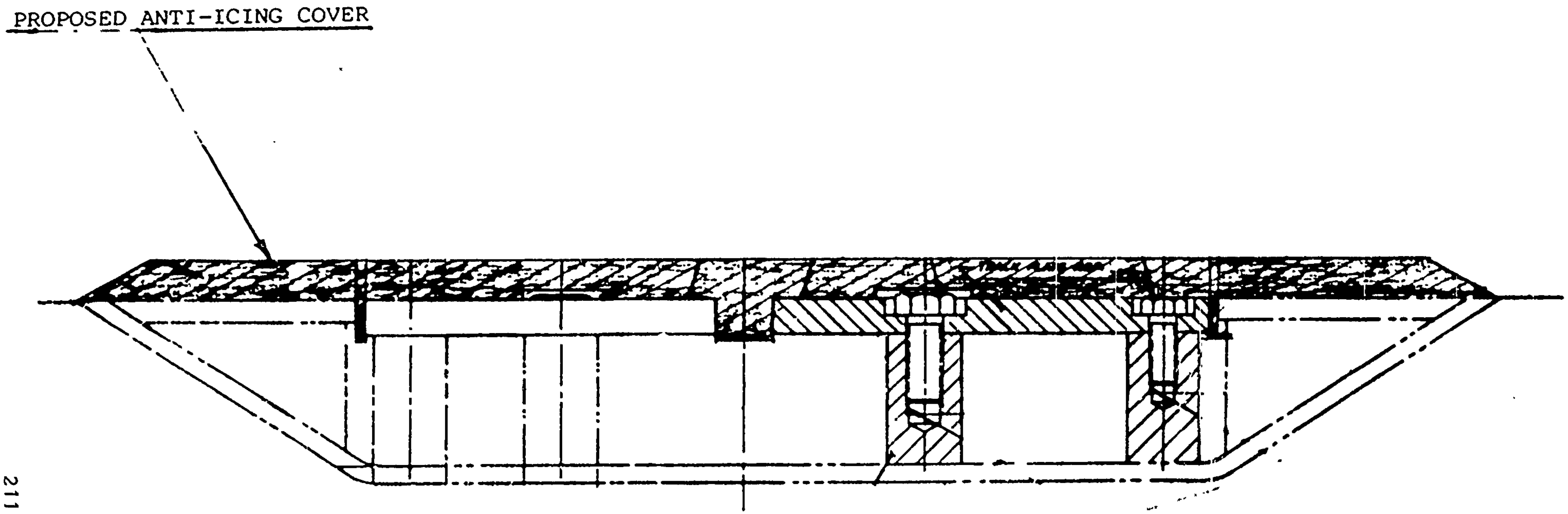

ANALYSIS
INPUTS
A) WIND SPEED
B) AIR TEMP
C) WATER FLOW
D) MECH. PROPS. OF ICE
E) TIME FACTORS
F) TOLERANCES IN THE RAST TRACK
G) TRACK DIMENSIONS
H) TRACK MATERIAL
I) HEAT FLUX
J) INSULATION
K) COATINGS
COMPUTER MODEL
OUTPUTS
A) TEMP. DIST. IN THE TRACK
B) RATE OF ICE ACCRETION AT GIVEN LOCAT'NS
C) THERMAL TRANSIENT RESP'NS
D) THERMAL STRESS/STRAIN
E) ENERGY REQ'RED TO MELT ICE

FIG. 5



Theta(w) = Thickness of the water layer, a function of time
Theta(ice) = Thickness of the ice layer, a function of time
Theta(p) = Plate Thickness
T(i) = Temp. of the inner surface of the plate, constant
T(air) = Air temp, assumed constant
V(air) = Air Velocity, assumed constant

FIG. 6



CROSSECTION OF RAST TROUGH

Note:
1. The proposed cover should have the following properties:
   a. High elasticity through a temperature range of -40 F to 140 F.
   b. Low adhesion to ice.
   c. High toughness.
2. It is proposed that this cover will be in place at all times that the RAST system is not in operation. Therefore it should be:
   a. capable of withstanding the same conditions as the flight deck.
   b. quickly and easily removed
   c. readily stowable

FIG. 7

WATER LANCE

ATTRIBUTES	DEFICIENCIES	UNKNOWNS
USES FIREMAIN WAT	REQ'S FILTRATION	MAINTAINABILITY
PORTABILITY	NEW DESIGN	RELIABILITY
USES LP AIR	REQS STOWAGE	SAFETY
	REQS TRAINING	EFFECTIVENESS
	REQS MANPOWER	
	MAINTENANCE	

FIG. 8

STEAM LANCE

ATTRIBUTES	DEFICIENCIES	UNKNOWNS
BURNS JP-5	REQ'S FRESH WATER	MAINTAINABILITY
PORTABILITY	MAINTENANCE	RELIABILITY
MULTIPLE USE	REQS STOWAGE	SAFETY
PROVEN HISTORY	REQS TRAINING	EFFECTIVENESS
MOBILE	REQS MANPOWER	

FIG. 9

ELECTRIC STRIP HEATERS

ATTRIBUTES	DEFICIENCIES	UNKNOWNS
PERFORMANCE HISTORY	LIMITED CAPACITY	TRANSIENT BEHAVIOR
LIGHTWEIGHT		RELIABILITY
SMALL SIZE		
COMPATIBLE		
LOW MAINTENANCE		
CONDUCTION HEATERS		
SELF REGULATING		

FIG. 10

UNDERWAY REPLENISHMENT IN COLD WEATHER

MR. GEORGE LYON, NSWSES

Underway replenishment (UNREP) is required for battle groups to patrol or fight for as long as needed. U. S. Navy experience with UNREP has been mostly in the temperate climates of the Mediterranean, South China Sea, or Indian Ocean. Peace time UNREP during Fleet exercises in cold weather have generally been limited to only necessary fueling. Missile and ammo UNREPs have not been attempted. Other dry cargo UNREP, such as stores and critical parts have been transferred by Vertical Replenishment (VERTREP).

Repetitive UNREP of fuel, ammo, stores, and missiles will be required in time of war. With Standard Tensioned Replenishment Alongside Method (STREAM) transfer rigs it is possible to conduct connected replenishment (CONREP) in up to state 5 seas. Now, consider the necessity of rearming compounded with cold weather - and, a whole new array of problems opens up.

In February 1977, Commander Service Group 1 (CSG-1) conducted a cold weather UNREP operation with USS ROANOKE (AOR 7) and USNS TALUGA (T-AO 62) in the Bering Sea. (1) The purpose was to investigate UNREP capabilities and to identify problem areas in UNREP equipment maintenance and operation in this cold environment. All types of Replenishment At Sea (RAS), Fueling-At-Sea (FAS), and material handling equipment were utilized including VERTREP. Later on studies were conducted and reported during FLEETEX-83 in the Northern Pacific and in other ship exercises such as reported by ROANOKE in February 1982.

Large numbers of deck personnel are required during UNREP. Their safety and ability to function were observed. Equipment problems and handling problems were identified.

Cold weather is harsh on hydraulic winches and equipment. During the 1977 CSG-1 exercises, some winches were found difficult to start due to viscosity changes of hydraulic fluids. There was no positive way to determine if sump heaters were operating properly. Below 40 °F cavitation was noted upon light-off of some winches. Air gages failed; H.P. air systems experienced freezing moisture.

Some recommendations coming out of the exercises included: (1) That deck winches be run continuously in cold weather conditions, (2) Smaller hydraulic equipment must be checked for presence of moisture in their sumps, (3) Air lines must be blown down and dryed out - possibly with a nitrogen charge.

Some actions taken include: (1) Lighter viscosity oils have been recommended in certain generations of winches for cold ops, (2) Sump heaters have been added as Alterations Equivalent to Repair (AERs).

Our new Navy standard underway replenishment winches have been designed for operation in extreme climatic conditions. They have continuous running replenishment pumps. Their performance has undergone environmental lab testing down to -30 °F.

Material handling such as moving dollys or fork truck operation requires clear, ice-free decks. It is necessary to move, stage, and transport bombs, projectiles, rockets, missiles and all manner of stores. Findings included the need for non-skid surface to cover as much deck area as possible. Sand was found useful for traction but can not be used near VERTREP areas. In the snowy but not severe icing conditions, shipboard weapons elevators operated satisfactorily. The major hazard was slippery decks. Fork truck operation showed the need for a more suitable tire; perhaps one with non-metallic studs, was suggested. Although there were no significant control problems, operators had difficulty gaining positive traction.

As indicated earlier, UNREP is labor intensive/people intensive work. NSWSES is currently working on new innovations to reduce manpower required. One will be discussed at the end of this presentation.

Replenishment requires the use of hand tools, and the use of deck hands. Dexterity is required; in rigging, hook-up, passing lines, operating controls, and generally for all line handling and deck seamanship. In the Fleet exercise lessons learned/recommendations, there was much discussion about gloves and mittens. Personnel frequently removed them to "get the job done". Lines could not be faked-out early due to freezing and loss of flexibility.

Snow and ice removal also require manpower, and constant attention; and can become a matter of grave concern. Current snow removal techniques employ such tools as shovels and brooms. Ice removal is accomplished with steam, perhaps fire hoses, and/or an array of such tools as baseball bats, shovels, hammers, ice picks, axe handles, etc.

Of interest with a discussion of icing is a Soviet technical paper: "Icing of Ships and Vessels" by A. Plathotnik, translated from a 1982 issue of Morsky Sbornik. (4) The introductory paragraphs follow:

"There is often icing of fishing and transport vessels in high and middle latitudes in the winter. It is also useful for navymen to know about this phenomenon inasmuch as at times it can complicate substantially the operation of surface combatants and naval support vessels.

"The deposit of ice on the deck, sides, superstructure, weapons, masting, and rigging increases the ship's weight and draft, decreases the freeboard, hinders the employment of weapons, impairs the operation of deck machinery, and disrupts or even completely cuts off radio communications. The chief danger of icing, however, lies in an increase in the ship's center of gravity and its wind resistance, which under storm conditions may lead to a rapid loss of stability and to capsizing. Experience shows that the capsizing of an iced-up vessel occurs so quickly that the crew at times does not have time to give a distress signal and the exceptionally difficult weather conditions in which such a tragedy usually occurs provide no opportunity of survival for the people who end up in the water."

This paper proceeds to give examples and relates the dangerous phenomenon of icing to larger vessels including container carriers as well. A discussion of types of icing, rate of icing, and the broad range of the seas and parts of ocean where icing may occur is included. To avoid or reduce icing, searching for shelter, reducing speed, selecting ship's headings with least wetness, continously chipping ice, pre-rigging lines to access masts and rigging are recommended. The need to consider anti-icing preparation of surfaces including chemicals, silicone-based paints, rubber coated surfaces, thermal heating, and special coatings is discussed. Although no specific solutions are given, it shows a deep interest in the subject on their part. As discussed earlier, current known methods of removing ice and snow, once accumulated, are relatively primative.

FLEETEX 83 was conducted in the Northern Pacific with high seas and cold weather. Some comments on clothing follow: (2) "The Navy issue extreme cold weather outfit (A-1), consisting of trousers, jacket, hood and mittens performed extremely well". The Navy submarine extreme cold weather gear was preferred because of the tight seal provided by velcro adjustments, ease of donning and storage. "Navy cold weather clothing which was least effective covers those parts of the body which are most affected by cold weather; the feet, hands, and head". Mittens were found to provide poor manual dexterity; leather ski gloves were commerically purchased and used by many units.

Clothing comments from the 1977 CSG-1 exercise included a statement that the then existing gloves and mittens were removed by personnel "to get the job done". Although warm, they did not provide dexterity. Personnel were wearing their normal steel-toed shoes at the beginning of the exercise, but they quickly discovered that they are no substitute for cold weather boots.

It should be noted that a paper presented at this symposium identified the existence of new cold weather clothing available in the supply system. This includes new gloves to replace mittens, face masks, phone talkers' hoods, new cold weather boots, and an improved submarine exposure suit now available for deck personnel. Type Commanders should disseminate this information to their units and consider establishing cold weather clothing pools.

Helo operations for VERTREP are severely hampered by extreme cold weather and heavy seas. In 1983 NORPAC OPS (3), it was observed that chain tie-down padeyes iced-up. Chains and chocks required five men vs two men; chocks were left in for take offs. Crews had great difficulty detecting visible moisture during night ops. Increased fatigue factors necessitated shorter operations. The transfer of passengers must be for operational necessity only. All personnel and passengers must be fitted out with survival gear. Other obvious problems include the hazards of moving helos on iced decks.

When H-46's are prohibited from flying into forecasted icing conditions, conventional UNREPs will be more frequent and of longer duration. This comes back to the problems of the many personnel on deck. Rough weather and icing conditions make the open deck environment a potentially hazardous place to be.

The Naval Ship Weapon Systems Engineering Station (NSWSES) is currently working on improvements in line handling to decrease manpower requirements.(5)

With the introduction of the personnel highline STREAM rig, the number of line handlers required to keep a highline tensioned was reduced to one winch operator. Another deck evolution still manpower intensive is the hauling over of the highline/spanwire.

By modifying a Navy standard 3/2 speed saddle winch with air clutches inside two "rigging" drums, NSWSES has a prototype tensioned connect up rigging winch. Already initially evaluated at our UNREP test site, the rigging winch is being operationally evaluated aboard a CSG-1 UNREP ship. The tensioned connect up rigging winch will reduce the number of personnel required aboard the receiving ship from approximately 15 to only three for this evolution.

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DEGRADATION OF SURFACE SHIP OPERATIONS IN ARCTIC/COLD WEATHER ENVIRONMENTS

by

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David W. Taylor Naval Ship Research and Development Center

ABSTRACT

Until recently, U.S. Navy surface ships have been designed almost exclusively to benign environments. Hull forms were optimized for calm water speed and deck machinery and combat systems were generally designed for operation in temperatures above -18 °C (0 °F). Therefore, it is not surprising that performance is moderately to heavily degraded when these same ships are required to operate in higher sea states, subzero temperatures, and near floating ice. Recent experience during Arctic SHAREM's (Ship/Helo ASW Readiness Exercise Measurements) has indicated that it may be possible to improve cold weather operability of our existing ships by taking full advantage of our knowledge of the prevailing environment. For example, minimization of ice accretion through course and speed changes is entirely possible, while, on the other hand, approaching the pack ice can reduce ship motions as the ice will dampen the waves and produce a lower sea state.

This paper proposes some Tactical Decision Aids (TDA's) which should optimize mobility and combat system performance in cold regions. These TDA's could become part of a "cold weather kit" supplied to our existing ships when they must operate in those regions. While these TDA's do not "fix" existing ship designs, they give the operators additional information to incorporate into the operations planning process.

A further important consideration is to incorporate additional environmental standards for cold weather regions into new ship designs. A brief outline of a northern latitude environment design standard is given. This was developed for the ongoing SWATH T-AGOS design.

INTRODUCTION

Until recently U.S. Navy ships have been designed almost exclusively to nearly benign environments. Hull forms were optimized for mid-latitude environmental conditions. Hull, propulsion, and auxiliary systems, including deck machinery were designed for above -18 °C (0 °F) operations. Therefore, it is not surprising that performance is moderately to heavily degraded when these same ships are required to operate in higher sea states, subzero temperatures, and near floating ice. Recent experience during Arctic SHAREM's (Ship/Helo ASW Readiness Exercise Measurements) has indicated that it may be possible to improve cold weather operability of existing naval ships be taking full advantage of our knowledge of the prevailing environment. For example, minimization of ice accretion through course and speed changes is entirely possible, while, on the other hand, approaching the pack ice can reduce ship motions as the ice will dampen the waves thereby reducing the sea state in which the ship is operating.

With the increased interest in the Navy's ability to conduct sustained combat operations in cold weather environments, it is important that every effort be expended to ensure that existing naval ships are capable of operating in northern latitudes, and that future ships be designed with cold weather and higher sea state operations in mind. Figure 1, which was provided by RADM J.B. Mooney, USN, Chief of Naval Research, provides a geographic distribution of Soviet assets and hence why it is so important that our ships be capable of operating in an Arctic environment.

ICE ACCRETION

While ship icing is generally associated with far northern latitudes, it has also been reported in more southerly waters, such as off the coast of Norfolk, Virginia, in the Sea of Japan, and in the Black Sea.

As shown by Figure 2 [1]*, a soviet analysis of various trawler classes shows a 70 percent or greater probability of icing in northern latitudes during the winter months. This percentage should be less for larger combatants due to their greater freeboard but a significant probability still exists.

Various algorithms and nomograms exist for determining the possibility of ice accretion and predicting the rate of accretion. Figure 3 is an example of such a nomograph and was developed by Wise and Comiskey [2] to predict icing in the northern Pacific Ocean. As a general rule, in order to experience icing, the air temperature must be below freezing and the water temperature below 6°C (43 °F).

By far, the greatest cause of ice accretion is salt water spray due to ship motion, waves, and winds. The height to which the ice is accreted on the ship depends on the height of the waves, the speed of the ship through the water, and the relative wind direction and speed. To a lesser extent, icing occurs as a result of precipitation and fog. This latter type of icing produces uniform icing over the ship--including the entire mast area--and occurs primarily in the vicinity of land masses or when operating near the marginal ice zone.

Ice accretion raises the center of gravity if a ship with a resulting loss of stability. When icing becomes severe, stability margins can become critical and there are numerous documented cases of fishing vessels capsizing due to the combination of ice accretion and large roll angles caused by heavy seas. The accretion of ice in an asymmetric manner due to 15-45° courses into the wind is of particular concern for naval ships. This causes a list toward the exposed side and in combination with extreme beam winds could greatly affect the stability of the ship and the ability to maneuver.

During Arctic SHAREM's 55 and 62, ice gauges were installed on the forward main decks of various ships to aid in measuring ice accretion. These measurements were made to aid in evaluating ice accretion algorithms and also to provide the Commanding Officer with an indication of the amount of ice

* References are noted in brackets and listed at the end of the text.

accumulation on his ship. This ice accumulation measurement was designed to assist the Commanding Officer in his evaluation of the effect ice might have on stability. The ice gauges were made of steel or aluminum and painted with alternating bands of black and international orange for easy viewing from the bridge using binoculars. Also, they eliminated the need to put personnel on deck to measure ice accretion. A picture of a gauge as installed on the USS VALDEZ (FF-1096) during SHAREM 62 is shown in Figure 4. There was little or no ice accretion during either SHAREM exercise so the effectiveness and value of these gauges has yet to be determined.

The 1/8 inch thick mild steel gauge did provide a graphic example of the power of ocean waves during SHAREM 62 however. A gauge installed on the forward main deck of the USNS TRUCKEE (T-AO 147) was bent 19.05 cm (7.5 inches) to the rear by a wave which equates to a 6 PSI load due to green water. This gauge was located under the port lifeline, 36.6 m (120 feet) aft of the forward perpendicular on the 199.7 m (655 foot) oiler at a height of 4.9 m (16 feet) above the waterline.

TACTICAL DECISION AIDS

Recent advances in the state-of-art tools for environmental forecasting and ship motion predictions may now permit the development of Tactical Decision Aids (TDA's) to assist ship operators during cold weather operations. These TDA's could take the form of a small hard-copy package in a "cold weather kit" which would be supplied to individual ships as the need arose. These would provide the operator with a quick reference documenting methods to follow in order to maintain stability and mobility in the event of icing, and procedures to minimize icing.

These TDA's can be developed using the following steps:

- classify ships as light, moderate, or heavy "icers", e.g., FF-1052 is a heavy icer due to its low freeboard

- develop criteria for icing levels; gradual, rapid, or very rapid in terms of visual parameters, e.g., inches of ice accretion per hour

- develop contours of "synoptic" icing in the North Pacific and North Atlantic Oceans and in the Norwegian, North, Barents, Baltic, Black, Japan, and Okhotsk Seas (use wind, wave, and temperature climatologies)

- develop criteria for icing from the geometry of low and high pressure systems

- translate accumulated ice into effects on stability

- translate bow wetness (spray) predictions to icing probabilities

- provide speed polar graphs to select courses and speeds which will minimize icing

Figures 5 through 7 are examples of various graphs which could be provided as a part of the TDA package.

Figure 5 shows the percent availability of frigate helo/sonar during the winter in the North Atlantic. This same format with isolines of percent probability of light/moderate/heavy icing based on climatology would be of value in planning for operations in northern latitudes.

Figure 6 was prepared at the request of COMDESRON 26 in preparation for SHAREM 55. This provides an indication as to the effect of ice accretion as measured on the forecastle on the stability of the USS MC CLOY (FF-1038) as measured by an increase in roll period. Since roll period is readily observable on the bridge, this could be of particular value during darkness by giving an indication that an unacceptable amount of ice was forming on the ship and that steps should be taken to minimize the chance of ice accretion until some of the ice could be removed.

The Speed Polar Graph, Figure 7, has been used for several years by designers and operators to illustrate best/worst heading/speed combinations in a given seaway from the viewpoint of seakeeping performance. In this case, the concentric circles indicate ship speeds and radial lines show the course of the ship with respect to the dominant wave direction. At the heading and speed indicated by x, this ship was operating at 17 knots with waves on the port bow when it sustained substantial superstructure damage. This speed polar format could be extended to identify courses/speeds that would minimize salt water spray and hence minimize icing in cold weather.

The above are only a few examples of "quick fixes" which could be rapidly developed and deployed in "cold weather kits." However, there is another side to the problem which, if solved, could make such "quick fixes" unnecessary in the future.

With regard to TDA usage, it is important that an accurate description of the natural environment (forcing function on ship) be available. During Arctic SHAREM's 55 and 62, it was noted that available wave data from land based forecasts could be in error by a factor of two or more. Had a highly skilled meteorological team not been aboard to provide local forecasts, no reliable data would have been readily available, particularly in periods of low visibility. Therefore, it is suspected that in situ or remotely flown environmental sensors may be required to provide adequate quantification of ship performance.

SWATH T-AGOS DESIGN CRITERIA

The "quick fixes" mentioned above might not be required if environmental standards for cold weather operations were incorporated into new ship acquisition cycles. This was attempted in September 1985 for the ongoing SWATH T-AGOS design since early documentation indicated that this ship should be capable of operating at 70^0 N throughout the year.

The primary environmental criteria which were found to be critical are sea state, wind speed, air temperature, sea surface temperature, ice accretion, and floating ice. For the SWATH, with its large horizontal deck area, ice accretion could be a most significant degrader in cold weather. For example, some icing will occur with wind ≥ 17 knots, sea surface temperatures ≤ 6 °C (43 °F) and air temperatures between -2.2 °C (28 °F) and -18 °C (0 °F). Heavy icing will occur with winds of 34 knots or greater.

In order to describe the total natural environment that the ship would encounter during the winter, Figures 8 and 9 were developed using available U.S. Government oceanographic and climatological publications. These figures indicate those areas in which the mobility of the SWATH T-AGOS and its ability to successfully accomplish its assigned mission might be hampered by high seas, ice accretion, and floating ice. They do not take into account any atmospheric or subsurface phenomena which might also affect the performance of the combat systems.

A study of these figures shows that ice accretion will be a limiting factor on operations in the western portion of both oceans. Also, the limiting sea state (e.g., Sea State 7)* for SWATH does not usually occur in the vicinity of the 10 percent ice cover or where ice accretion might be hazardous. Although not shown by these figures, it was also found that in areas near land masses and near the pack ice, air temperatures may reach -29 °C (-20 °F) due to the cold air mass blowing off the cold land or ice pack. In the open ocean, -18 °C (0 °F) are typical of the minimum temperatures encountered. Since our ships will often be in port or seek shelter in the lee of a land mass, these lower air temperatures (-29 °C) must be considered when designing ships and equipment for full operability.

CONCLUSIONS

Tactical Decision Aids can be developed rapidly for use during deployments to cold weather regions. Refinement and extension will come as a natural course of feedback emerging from the ship operators. In situ or remote environmental sensors may enhance the applicability of Tactical Decision Aids.

While we have emphasized environmental factors associated with the cold, we must remember that our sailors must still contend with other factors such as the sea itself. During SHAREM 62, in addition to the previously mentioned damage to the ice gauge, the USS VALDEZ took heavy seas over the box (Sea State 6)** and one of the flight deck safety nets was damaged. This damage was sustained in lower latitudes during transit from the operations area.

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* Sea State 7 corresponds to significant wave heights of 6 to 9 m (19.7 - 29.5 feet, see Reference 3.

** Sea State 6 corresponds to significant wave heights of 4 to 6 m (13.1 to 19.7 feet), see Reference 3.

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3. Bales, S.L. "Designing Ships to the Natural Environment," Naval Engineers Journal, Vol. 95, No. 2, March 83, pp. 31-40.

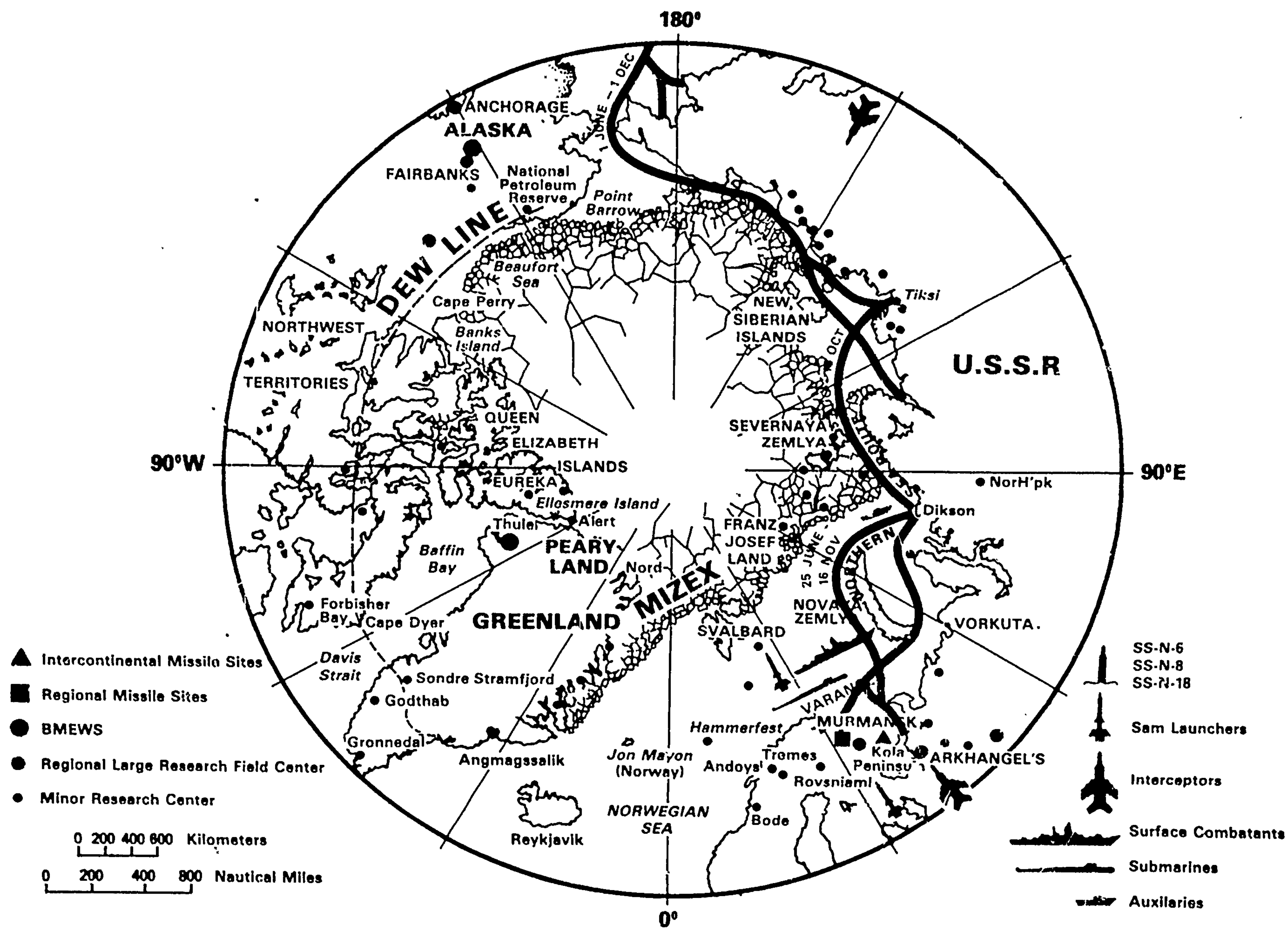


Figure 1 - Strategic Value of the Arctic Ocean

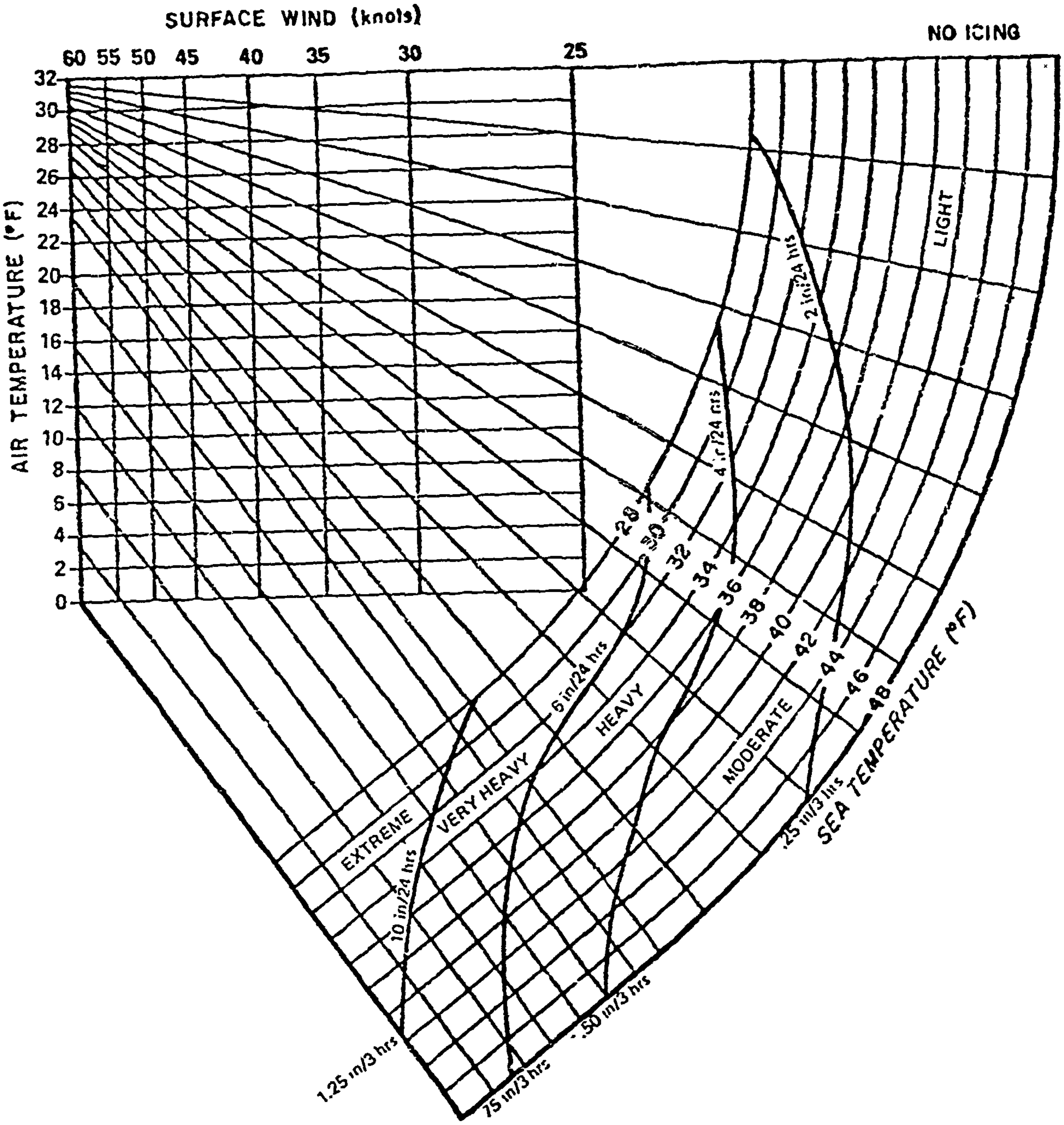
SOVIET ANALYSIS (VARIOUS TRAWLER CLASSES)

Seas and Ocean Sectors	No. of Cases	Period of Icing	Frequency %
NW part of Atlantic	85	15 Dec - 15 Mar	92
Norwegian & Greenland Seas	109	15 Dec - 31 Mar	77
Northern part of Atlantic	63	15 Dec - 15 Apr	92
Barents Sea	390	1 Jan - 15 Mar	78
Baltic Sea	21	15 Dec - 29 Feb	(85)
Baffin Sea, Hudson Bay	7	1 Dec - 31 Mar	(96)
Newfoundland region	15	1 Jan - 15 Mar	(79)
Bering Sea	185	1 Dec - 31 Mar	70
Sea of Okhotsk	337	1 Dec - 31 Mar	70
Sea of Japan	226	1 Dec - 29 Feb	85
NW part of Pacific	183	15 Dec - 31 Mar	79
Arctic seas (Kara, Laptevykh, East Siberian and Chukchi)	71	15 Jun - 15 Nov	100

CONCLUSION:

THESE PERCENTAGES WOULD BE SOMEWHAT LOWER FOR NAVAL COMBATANTS (GREATER FREEBOARD, LESS MOTION).

Figure 2 - Icing Frequency in Northern Latitudes



CATEGORIES

NAME	RATE PER 3 HOURS
Light	.1" to .25"
Moderate	.25" to .50"
Heavy	.50" to .75"
Very Heavy	.75" to 1.25"
Extreme	1.25+"

Figure 3 - Ice Accretion Nomogram

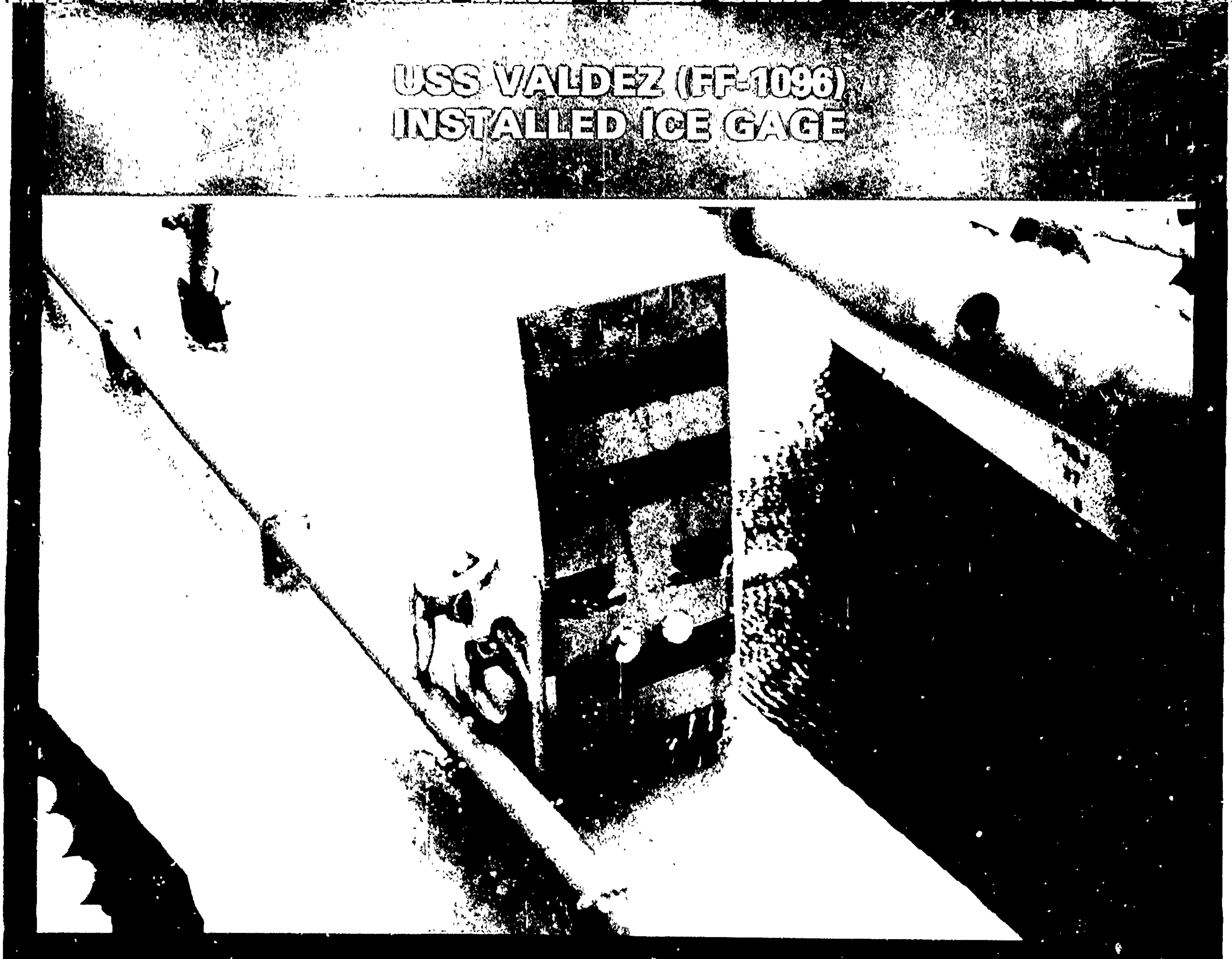


Figure 4 – Ice Accretion Gauge

HINDCAST PERCENT AVAILABLE FRIGATE HELO./SONAR DURING WINTER

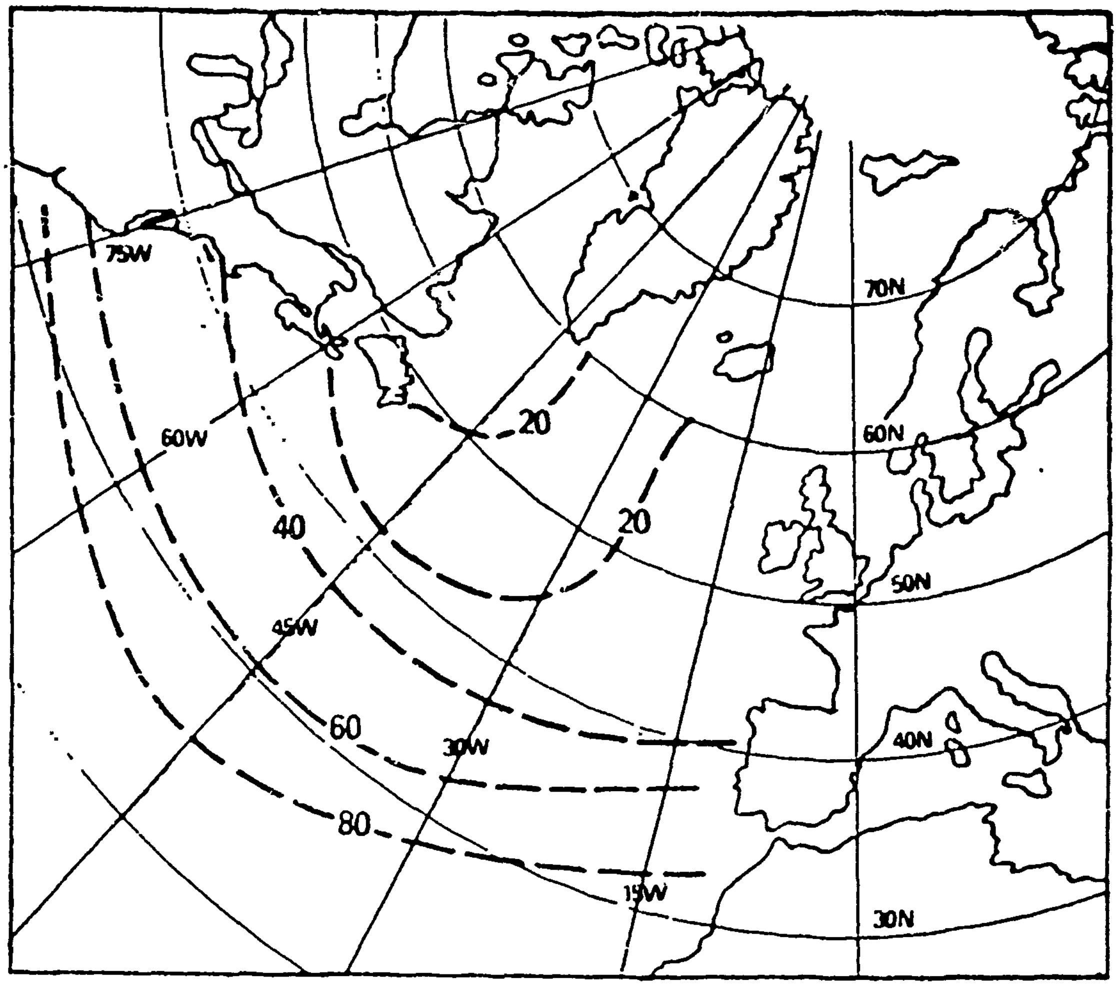


Figure 5 - Format to Show Icing Probability

ARCTIC SHAREM (MARCH 1984)

FF-1038 USS MCCLOY ESTIMATED ROLL CHANGE

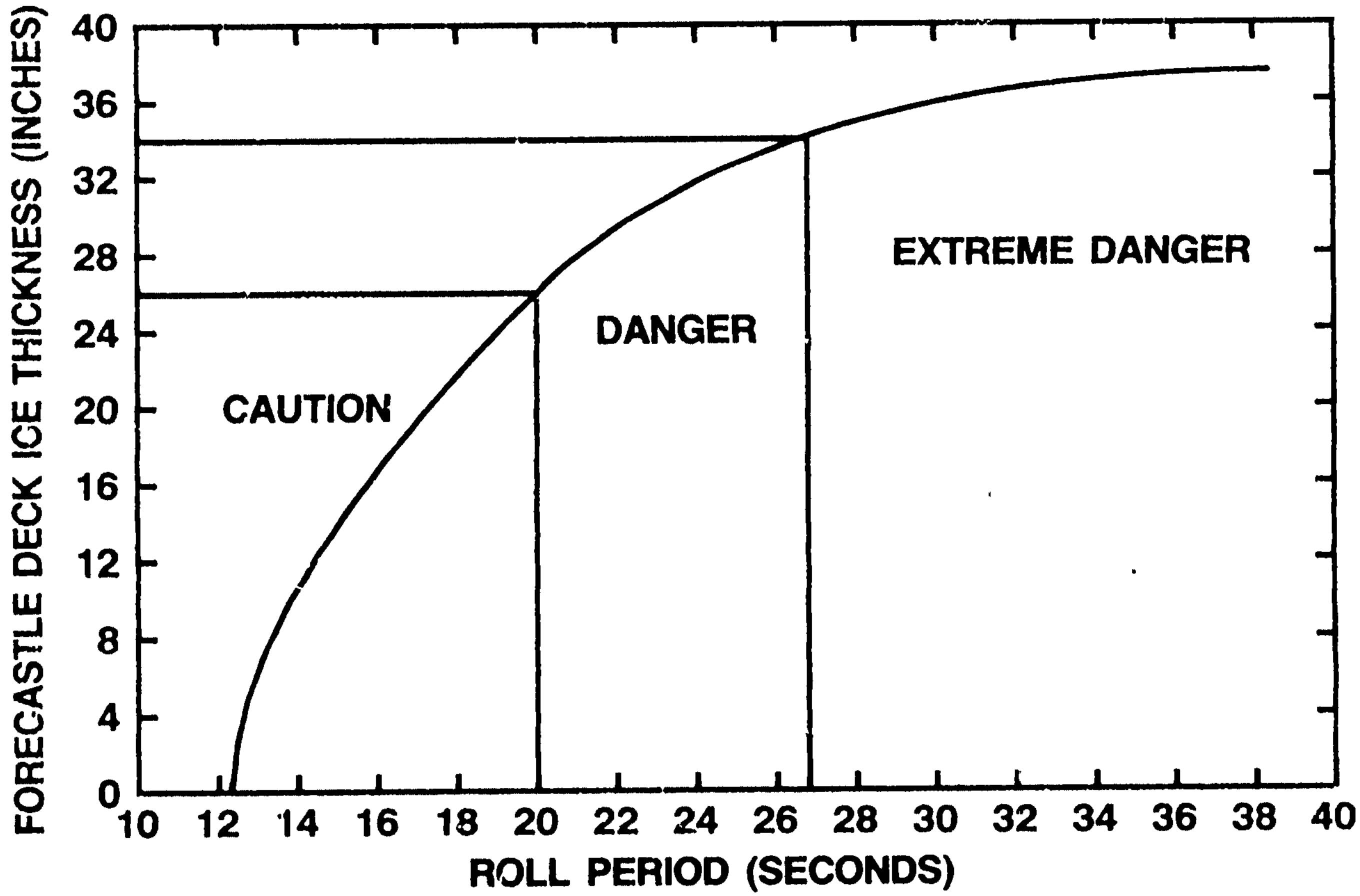


Figure 6 - Ice Accretion Stability TDA

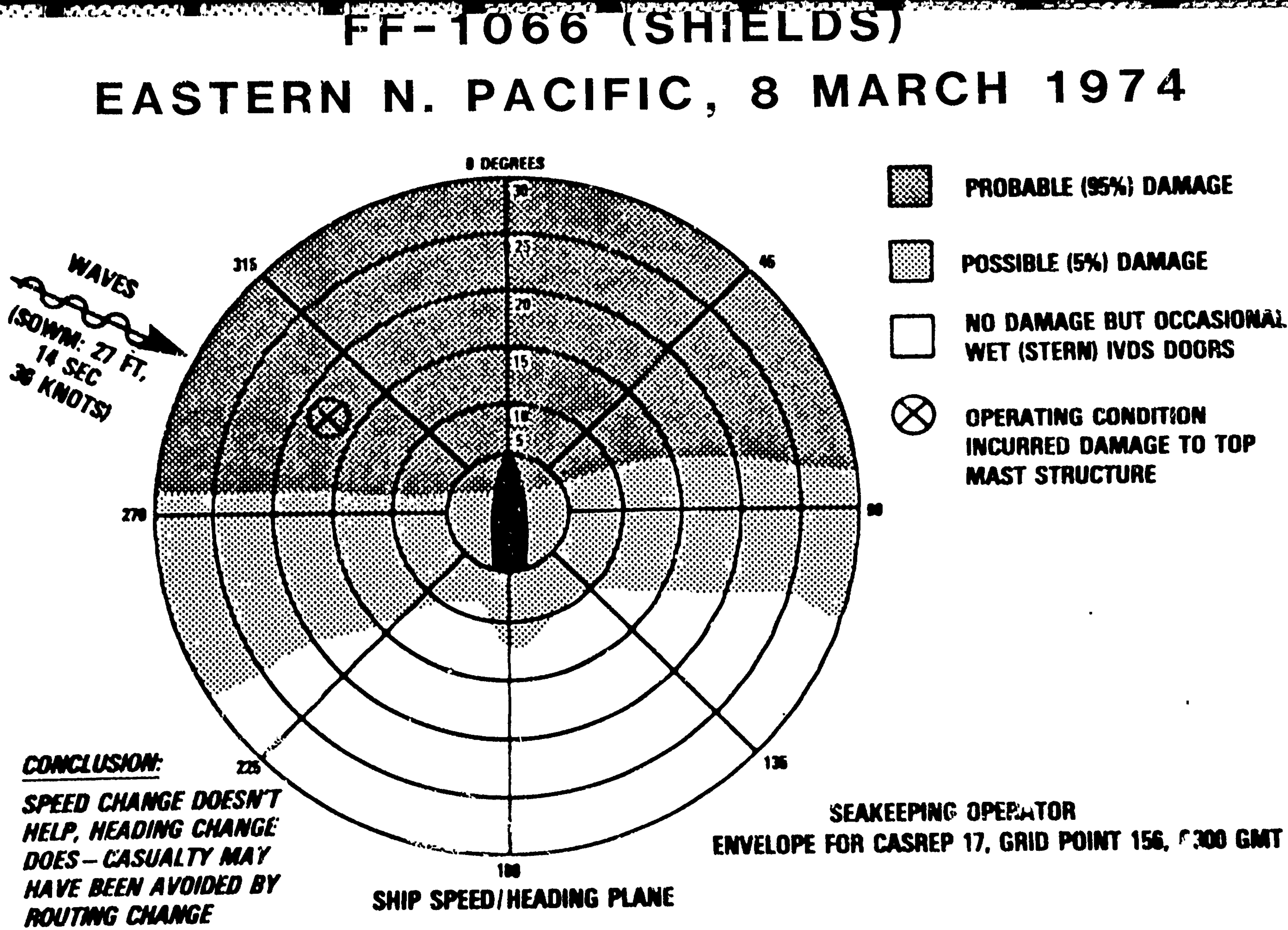


Figure 7 - Format for Minimizing Icing

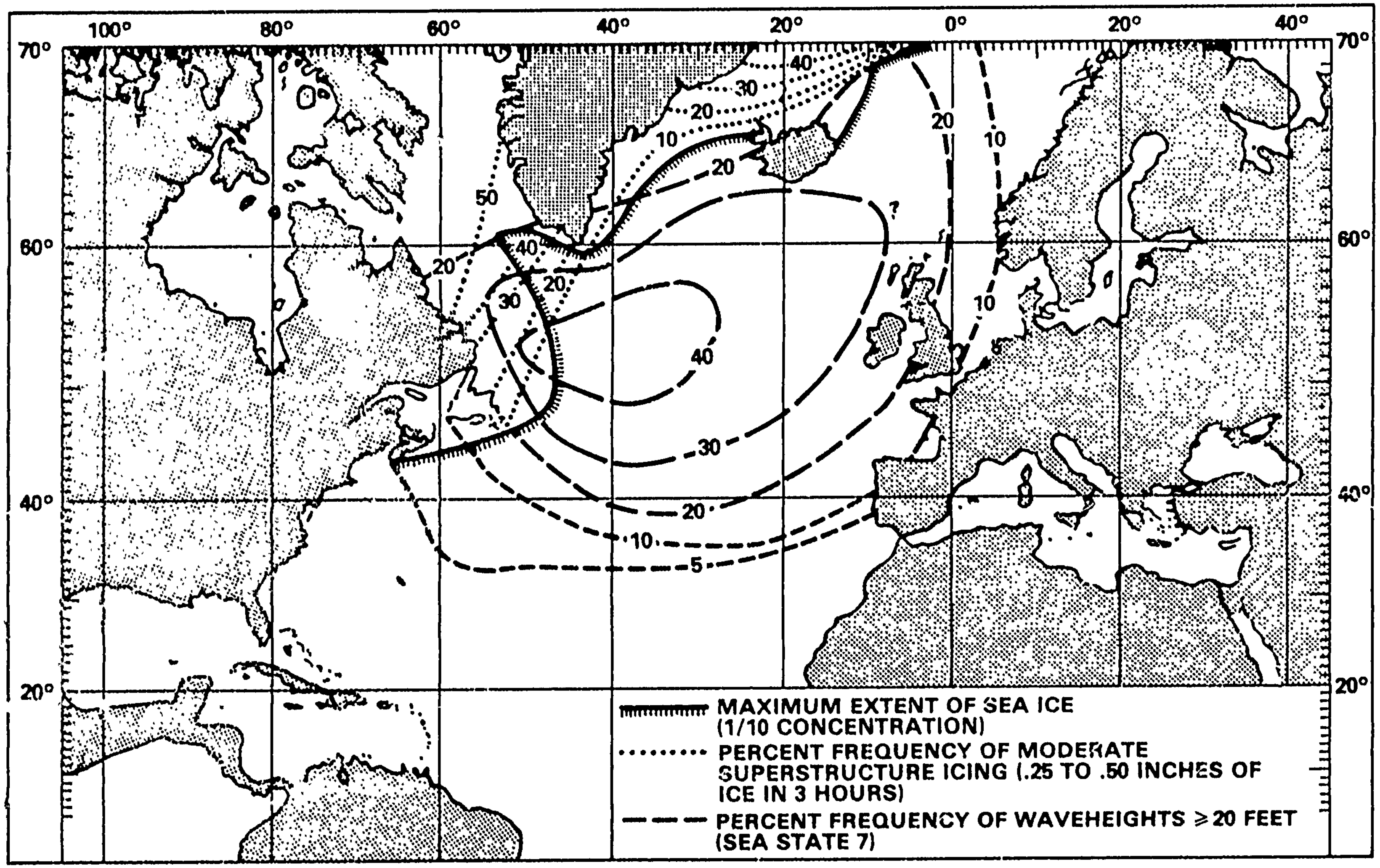


Figure 8 - SWATH T-AGOS Operational Environment (Atlantic)

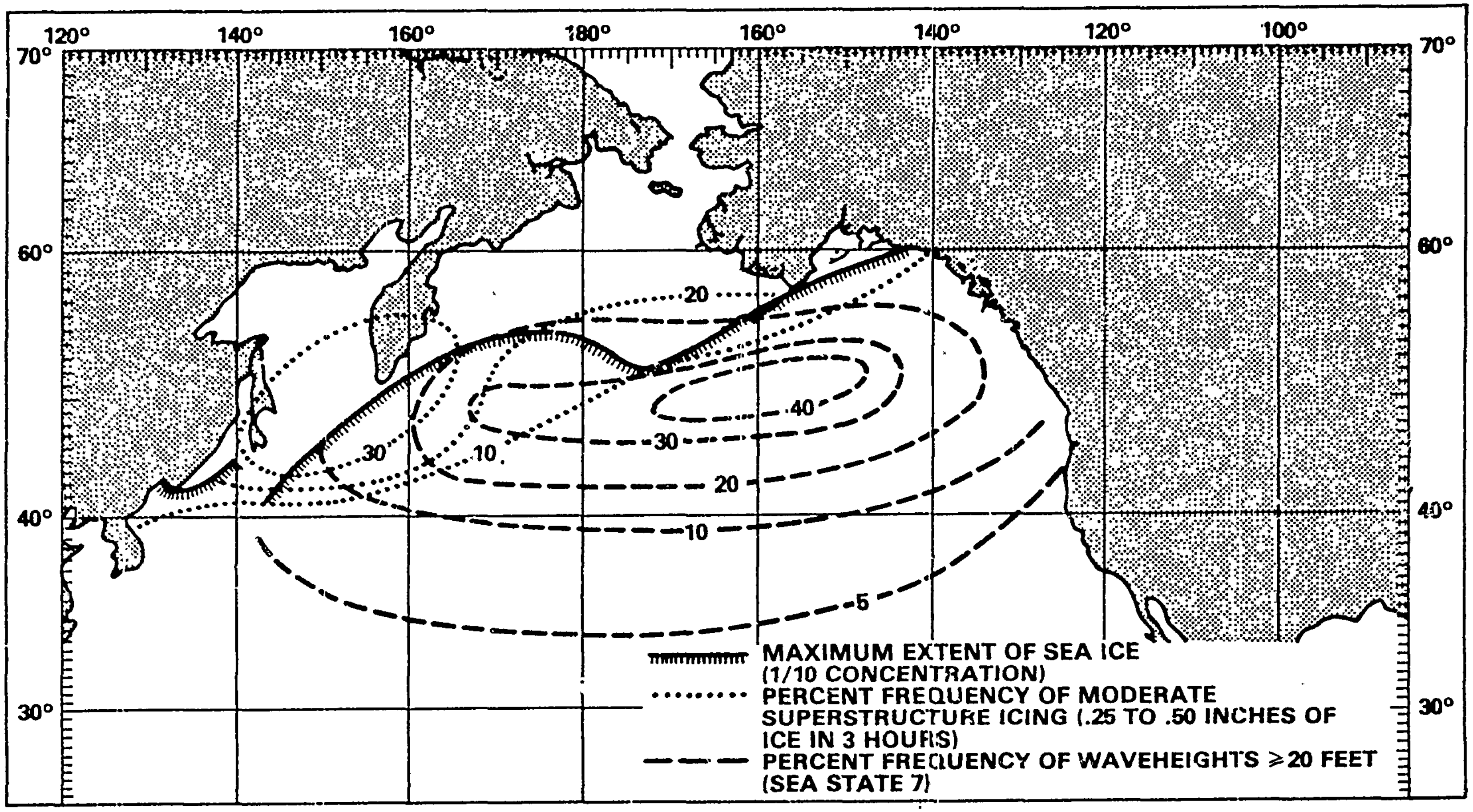


Figure 9 - SWATH T-AGOS Operational Environment (Pacific)

SEA SPRAY ICING: A REVIEW OF CURRENT MODELS

by

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Dec 1985

Paper presented at:
U.S. Navy Symposium
on Arctic/Cold Weather Operations of Surface Ships
Rockville, Md. 3-4 Dec 1985

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Introduction

In this paper, we review some of the current modeling efforts to predict the intensity of sea spray icing. Our first objective is to provide some background on the basic physical processes that contribute to this problem in as much quantitative detail as our current sparse state of knowledge allows. From such an exercise, we can then group the data, extrapolate it to currently unknown situations and design future observations and experiments to test and improve the model accuracy in describing those situations.

The second purpose is to point out the need for some quantitative detail in assessing the impact of sea spray icing on combat surface ships. At present, for example, we have some fishing trawler data from which qualitative predictions of icing can be made in categories varying from "trace" to "heavy" (Fig. 1). These have also been translated into numerical accumulation rates but are generally valid only for ships similar to trawlers. The problem in using such information is that there are vertical variations in the ice accumulation; ships vary in how much spray they accumulate and where it is deposited; ship velocity and heading relative to wave direction also critically affect the deposition pattern. There are also strong variations between different ship systems in their response to differing degrees of icing. These responses are enhanced for surface combatants since a diminished combat capacity can be as crippling as loss of stability (due to icing) might be to a commercial vessel. The problem we have in using the present data base is the variation it presents in extrapolating between different classes of ships and the sensitivity of different systems to varying degrees of icing. For example, a condition that predicts moderate icing for a trawler may be only "light" on a larger surface ship because of the absence of rigging to collect ice, less sensitivity to top loading induced instability and higher freeboard. On the other hand, a predicted trace or light icing condition as encountered by a trawler may be unacceptably "heavy" for radar antennas, weapon systems, and communications gear since light icing may incapacitate them for combat purposes.

Some prediction of where icing might be distributed for different classes of vessel could then be useful for determining how limited deicing or anti-icing capability might be allocated, and whether prolonged exposure is merely inconvenient or life-threatening. Modeling may also give some idea of the extrapolation possible from limited icing encounters, and suggest experimental design that would maximize our ability to generally predict the effects of sea spray icing.

We first review some of the physical processes and environmental conditions that define spray ice accretion on marine vessels. An example of spray ice accumulation estimates on a simple stationary marine platform (offshore structure) is then given as recently presented by Horjen and Vefsnmo (1984). This effort is part of a program to define environmental problems associated with petroleum development in the sub Arctic offshore region.

Environmental Conditions

As previously shown in Fig 1, the rate of sea spray ice accumulation is apparently related to the two environmental parameters of relative wind speed (true wind velocity and vessel velocity) and air temperature. The point of interest is, however, that these curves are presented only for low vessel velocities. It turns out that the velocity and air temperature are "proxy" estimates of the fundamental parameters of interest, the mass flux defining how much water is brought to the surface and the heat flux which defines how much

(4)

of that "accumulated" water can be converted into ice. The mass flux is a relatively complicated matter for sea spray since two parameters of interest are the spray liquid water content and the droplet diameters. The droplet diameter is important since the interaction with the flow field, which is a function of droplet size, determines the flight path of the droplet and where it eventually impacts on the structure (as well as how much it is cooled along the way). Similarly, the spray liquid water content can be considered a function of the droplet size and the force generating mechanisms that cause it. For the sea spray case, these are not only unknown functions but also widely vary. The table (after Makkonen) shows that sea spray is the primary source for icing but that the ranges of droplet diameter and liquid water content are quite wide. Fig. 2 shows some data that indicates the variations of sea spray on a vessel and that it depends on heading (relative to the wave field), wave size, and vessel speed. Not shown here but an obvious point is that the sea spray amount will also vary with height above the sea surface (again with variation between vessels).

The heat flux may be slightly better defined since, although complex, portions of it can be broken down into terms which are slightly more general and not as specific to a particular vessel as the mass flux is. The primary parameters defining the heat flux are the relative velocity, the air temperature, (which may not vary greatly, vertically, in the well-mixed surface layer regimes that are typical of sea spray icing) and the water temperature. Other terms of decreasing importance that will be discussed later are the humidity, radiation and heat conduction terms (from the object to the ice). These can be of significance, however, their variation may not be as great and estimates of them can be made effectively knowing velocity and the air and water temperatures.

Modeling of Two Conditions - Wet Growth and Dry Growth

Dry growth and wet growth are defined as the two icing regimes where the surface temperatures are either below the freezing point (dry growth) or at the freezing point (wet growth). The terms arise since if the surface temperature is at the freezing point, the heat transfer is insufficient to freeze all the incoming water leaving a wet surface on the accretion.

In helicopter and aircraft icing we generally regard wet growth as the more complicated condition. This arises because we have to look at the complexities of runback icing where the unfrozen water moves to a different location on the object surface. For a given geometry and set of initial conditions we can, if not easily, at least straight-forwardly compute the droplet impacts that occur on the surface for constant specification of liquid water content and droplet size distribution. For dry growth, where all the impinging water freezes, we can then assume the water freezes at the location where it hits. The buildup of ice and its effect on the load, drag and other characteristics of interest can then be examined. An example of such a calculation is shown in Fig. 3 from Egelhofer, 1983. As shown, we can even throw in an additional element without too much difficulty, in this case the rotation that occurs as ice is loaded onto a twistable structure such as an overhead power line. The complication in the atmospheric icing case arises when not all the water that impinges is frozen and instead flows back to another location. If that location is beyond the separation point for the object we have at present no rigorous way of dealing with it. Our computations are based on the relatively good approximation that potential flow makes to the flow and heat fields in the region in front of the separation point. In order to compute the heat transfer beyond the separation point we have to use some turbulent heat transfer ideas which have not been presently numerically formulated for the icing problem.

For sea spray icing, on the other hand, some indications are that wet growth may be computationally easier than the dry growth condition (Horjen and Vefsnmo, 1984). Several reasons are given for this assumption. The main one is the difficulty in specifying the initial conditions of liquid water content and the droplet size distribution for sea spray cases. Those parameters, along with the velocity, determine the mass flux, and are the primary determinants of the icing rate in dry growth conditions. Our current information is quite poor of how these parameters vary. Fig. 2 -(from Carstens) shows the variability that exists in sea spray intensity (or liquid water content) as a function of vessel heading, speed and significant wave height. Another vessel in the same operating conditions would probably measure different values because of different behavior in the wave field. For a given set of conditions the sea spray intensity also obviously varies, hopefully systematically with the height above the surface. For example, for a stationary structure (such as an offshore platform), this intensity is assumed to drop off as an exponential function with height above the surface (Horjen and Vefsnmo 1984). The higher drag and inertia tells us that the larger droplets impact in shorter flights at lower heights than smaller droplets which can be carried further and also cool more quickly. The character of the problem compared to aircraft icing is also different. For aircraft icing, especially on air foil surfaces, the small changes in shape that can be produced by runback icing in wet growth are highly important to the flight characteristics of the aircraft and exact geometries are the most difficult to predict. In ship icing, the major consideration has been of icing rate or total load estimates without a particular regard for the exact shape of the ice accretion. For the extreme cases of sea spray icing, there are difficulties in constructing the mass flux while it is somewhat less difficult to estimate the heat flux. Once enough mass flux is reached such that wet growth occurs, the amount of icing appears less sensitive to the current unknown variability in mass flux. Therefore the heat flux limited case, in which wet growth is suggested, may be the more tractable one for computations of sea spray icing and, fortuitously, may be the more physically realistic case as well. This concept leaves some hope for forecasting ship icing in a general way. Given a combination of wind speed, air temperature, and water temperature the ice growth rate at a given height may be somewhat independent of mass flux (the ship-ocean interaction) giving a "reasonable" forecast for a wide variety of ships as long as "wet growth" is common to all. For example, in Fig. 2, if the "cut off" for a wet growth condition is a certain rate of spray encounters, then the dependence of ice accumulation as opposed to spray encounters may not be a sensitive function of vessel speed above the "cut off" value. Modeling may assist us in making these determinations.

Model for Sea Spray Ice Accumulation on a Stationary Structure

Horjen and Vefsnmo (1984) give some background for the current state of this modeling. These calculations were developed for application to offshore icing of structures used for petroleum exploration and development in subarctic waters. Fig. 4 shows the type of structure (a cylinder or plate) used for this calculation. Shown schematically are the expected zones of dry icing, wet icing and no icing. These zones are later defined quantitatively as given by the value of the freezing fraction n. The freezing fraction is that portion of total water catch (both impinging flux by droplets and rundown water from above) that is converted into ice.

$$n\ (i) = \frac{R(i)}{Rw(i)+Rrw(i)}$$

where R = ice accumulation, Rw = impinging spraycloud catch and Rrw = runoff water.

Mass Flux

The impinging spray accumulation is given by

$$Rw^{(i)} = BEc^{(i)}\, U^{(i)}\, M^{(i)}$$

where B is an aerodynamic shape term ($B = \frac{2}{\pi}$ for a cylinder, B=1 for a plate) $Ec^{(i)}$ is the collection efficiency, $U^{(i)}$ the velocity, and $M^{(i)}$ the mass concentration, all at level i.

The collection efficiency is a function of droplet diameter, object diameter and freestream velocity. These can be determined by solving the equation of motion for a droplet in the flowfield. These solutions are also given by empirical functions with ranges for the functions defined by the velocity and sizes of the droplet and size and shape of the object. Horjen and Vefsnmo (1984) give the forms for these based on earlier work on aerodynamic icing (Langmuir and Blodgett, (1946) Lozowski, et al., 1979 and Stallabrass 1980).

The droplet distribution function based on limited sea spray data is given by

$$f(d) = \frac{kd^{k-1}}{d_2^k - d_1^k}$$

Values of d_1 d_2 and k for Wave-generated and Wind generated sea spray are given below

	d_1 (µm)	d_2 (µm)	k
Wave generated sea spray	1000	3500	3.17
Wind generated sea spray	5	$434.0 \left(\frac{Hw}{2z}\right)^{1.22}$	2

(Hw/2 is the wave height and z the distance above sea level).

Heat Flux

In order to find the freezing fraction (n) the heat budget is computed as (in equilibrium) (Horjen and Vefsnmo, 1984):

$$\dot{Q}c + \dot{Q}e + \dot{Q}w + \dot{Q}rw + \dot{Q}f + \dot{Q}r + \dot{Q}v = 0$$

where $\dot{Q}c$ = convective heat loss

$\dot{Q}e$ = evaporative heat loss

$\dot{Q}w$, $\dot{Q}rw$ = heating (or cooling) of impinging and runoff water to the equil. surface temperature

$\dot{Q}f$ = latent heat released during freezing a fraction (n) of the impinging and runoff water

$\dot{Q}r$ = heat loss or gain due to radiation

$\dot{Q}v$ = viscous heating in the boundary layer

These last two terms are usually very small but can be included for completeness.

For section i this heat balance can be written as:

$$\beta(\Theta_a - \Theta_s(i)) + \frac{\beta\Theta a}{p}[e(\Theta_{dp}) - e(\theta_s(i)] + C_w R_w(i)[\Theta_w - \Theta_s(i) - \chi(\Theta_w - \Theta_a)]$$
$$+ C_w R_{rw}(i)[\Theta_s(i-1) - \Theta_s^{(i)}] + \ell_f(\Theta_s(i), S_i(i))n(i)(R_w(i) + R_{rw}(i))$$
$$+ \beta_r(\Theta_a - \Theta_s(i)) + \beta n U^2/2_{cp} = 0$$

The order of terms is as given in the previous equation. Here the Θs are: air temperature (Θa), surface temperatures $\Theta_s(i)$, and $\Theta_s(i-1)$; dew point temperature, Θ_{dp}; and water temperature Θ_w. β's are the coefficients for convection and radiation, e's are vapor pressures, ℓ_f the latent heat of freezing (a function of temperature and salinity). χ is a cooling factor parameterizing the droplet cooling from Θ_w to Θ_a.

$$\chi = 1 - \frac{1}{E_c}\int_{d_1}^{d_2} f(x)E(x)\exp[(-C(x)t_f(x)]dx$$

Where E_c is the total collection efficiency $E_c = \int_{d1}^{d2} f(x)E(x)dx$; $t_f(x)$ is the droplet flight time, and C is a relaxation parameter. Given only convective cooling and constant relative velocity between droplets and air, the relaxation parameter C becomes $C=2644.6|Vrel|^{0.6}\ d^{-1.4}(s^{-1})$ (Vin $^m/_s$ and d in μm).

Physical Property Assumptions in the Computation

Given the specification of the variables a computation of the ice accretion rate can be made by solving the heat flux equation. Some very important assumptions are taken to compute rates.

One of these is the value taken for the latent heat of the ice. Based on observations from Tabata, et al (1963) and recently confirmed by Launiainen, et al (1983) in spray icing wind tunnel tests, the salinity of the accreted ice is about half that of the original sea water, (Figure 5). At near freezing temperatures, therefore, about half the accreted ice is unfrozen sea water. This unfrozen water remains in brine inclusions that drain or freeze after some time. It is highly important however to reduce the latent heat (initially) in the heat balance to account for this since the short term topside loading will be determined by the combined effect of the ice and the brine contained within it. This factor also explains why spray ice accretions have shown such rapid buildup rates since for the same thickness of sea spray ice, only half the effective heat transfer is required compared to a fresh water ice accretion.

The brine trapped in the ice and the brine film covering the ice layer are assumed to have the same salinity (S_b). The result obtained for section i is then

$$S_i^{(i)} = \frac{S_b^{(i)}}{2} = \frac{\tilde{S}^{(i)}}{2-n^{(i)}}$$

where $\tilde{S}^{(i)} = \dfrac{R_w(i)\ S_0 + R_{rw}(i) S_b(i-1)}{R_w(i) + R_{rw}(i)}$

S_0 = sea surface or spray salinity

The surface equilibrium temperature θ_s is equal to the freezing temperature of the brine film on the icing surface.

Based on sea spray flux measurements (Itagaki 1977), the liquid water content distribution (mass concentration) in wave-generated sea spray is taken as:

$$M_1=0.1H_w\exp(H_w-2z),\ z>H_w/2$$

Similarly for wind generated spray (for winds 15 to 25 ms^{-1}) the mass concentration is computed as

$$M_2=9.45\times10^{-6}\ \exp\ (2-z)$$

(As seen here, the mass associated with wave-generation is significantly larger.)

If both wind and wave-generated spray are occurring the total catch becomes

$$R_w=R_w{}^I+R_w{}^{II}$$

and the cooling factor

$$X=\frac{R_w{}^I X^I+R_w{}^{II} X^{II}}{R_w{}^I+R_w{}^{II}}$$

where I, II refer to wave and wind-generated spray.

The heat balance equation is solved for the freezing fraction from the top, or from a position where all the incoming water is frozen (n=1). Horjen and Vefsnmo, (1984) use a method of hyperbolic interpolation for this procedure. Once the freezing fraction is determined, the icing intensity is determined by

$$R=n[BU(E_c{}^I M^I+E_c{}^{II} M^{II})+R_{rw}]$$

where I, II refer to the wave and wind-generated spray fields, and B the geometry, U the velocity and R_{rw} the rundown water respectively.

Example Results from Icing Model Computations.

In fig. 6, (Carstens, unpubl.) a result of an icing computation is shown for a given set of temperatures, salinity, and object size and shape (as shown). The resulting ice thickness and height distributions are non-dimensionalized to the height of the maximum accretion at the 15 m/s wind velocity (h15 max) and are shown as functions of the 10m windspeed U_{10}. A few interesting features appear from this computation. The first is the shift in the position of maximum ice accretion as the wind speed increases. The maximum ice amount also increases linearly with the wind speed. Another interesting point is the intersection of the curves for different windspeed, that is at a given point on the structure the same amount of ice accretes for different wind conditions even though the position of maximum accumulation is different. The exponential tail-off at greater height is representative of the assumed exponential distribution in mass flux associated with both the wind and wave-generated sea spray conditions.

Figure 7 (after Horjen and Vefsnmo 1984) shows ice thickness distribution for different sized columns from wave-generated sea spray icing during a two-week period for the computation. Input fields were time-varying based on meteorological and wave height data from the region. As shown here a similar vertical pattern existed for the modeled accretions on different diameter columns but the ice was significantly thicker on the smaller diameter column than on the two larger ones. There is also a significant dropoff in wave-generated sea spray icing vertically with little seen at heights above 10m on the structure. However a calculation which included combined snow and sea spray conducted over the same time periods showed six to 10cm of ice accumulation at heights up to 75m above the sea surface. While these amounts would not contribute much to the loading compared to the ice accumulated below 10m, components such as antennas can be rendered inoperative by that level of ice accumulation.

Conclusions

At present, modeling provides a means of comparing the effects of icing at different levels within the assumptions implicit in the models. These assumptions are still tenuous because of the lack of a significant data base for either the environmental conditions or vessel characteristics that contribute significantly to ice accumulation. For example, a different choice for the wave-generated sea spray droplet distribution with height increased the ice accumulation by a factor of three over the simulation shown in Figure 7.

Significant advances have been made in the modeling and it provides a mechanism for testing the sensitivity of the icing to variables in the environmental conditions. We see from Fig. 6 that measurements that relied on ice accumulation at one or two selected points could be ambiguous in determining the extent of the ice accumulation and its dependence on, for example, the wind speed. The modeling has already shown that significant accumulations of ice can be expected in quite "mild" conditions because the heat removal requirement to freeze is only about half that required for fresh water ice due to the incorporation of brine. Density of the accretions and how that density changes over time is an important parameter to determine for estimating loads and design of anti-icing or deicing solutions for key areas on vessels.

We therefore conclude that physical modeling can be an important contributor to quantifying icing predictions on vessels from proxy data such as windspeed, temperature, wave heights and the like.

An example of how this can be applied could use the analysis of vessel icing in Alaskan Waters recently reported (Overland, et al., in press). Based on vessels of intermediate size (20 to 75m lengths) reporting icing, a statistical algorithm developed indicates spray icing rates greater than three times that of previous nomograms. Whether the increased icing rates are due to better reporting of environmental co[illegible] ions or faster or different sized vessels than the previous reports is an important consideration. A modeling approach that can predict these icing accumulations in a physically-based way will significantly increase our capacity to forecast icing for different situations on different vessels, perhaps with only the previously mentioned proxy data as input.

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Table 1. Characteristics of icing sources in the atmospheric surface layer.

Source	Droplet diameter (μm) Range	Mean	Liquid water content ($g\ m^{-3}$)	Reference
Sea spray on a moving ship	1000 - 3500	2400	0 - 219	Borisenkov and Panov (1974)
Sea spray in first 10 cm	10 - 1000	200	--	Wu (1979)
Sea spray on a stationary ship				
$v > 15\ m\ s^{-1}$, $h = 2\ m$	3 - 2000	5 - 30	0.03	Preobrazhenskii (1973)
$v > 15\ m\ s^{-1}$, $h = 7\ m$	3 - 90	5 - 30	0.00	Preobrazhenskii (1973)
Marine advection fog	--	8 - 16	0.03 - 0.17	Fitzgerald (1978)
Coastal fog	4 - 20	--	0.01 - 0.16	Goodman (1977)
Evaporation fog	6 - 120	13 - 38*	0.01 - 0.30	Houghton and Radford (1938)
Evaporation fog	--	--	0.04 - 0.14	Bashkirova and Krasikov (1958)
Evaporation fog	--	8 - 10	0.20	Currier et al. (1974)
Arctic fog	7 - 130	16	0.00 - 0.15	Kumai (1973)
Arctic fog	2 - 75	18	0.02	Kumai and Francis (1962)
Arctic fog	6 - 60	--	0.04 - 0.17	Reiquam and Diamond (1959)
Continental winter fog	--	10	0.00 - 0.45	Pinnick et al. (1978)
Mountain fog	--	7 - 23*	0.05 - 0.30	Bain and Gayet (1982)
Low stratus	2 - 43	5	0.05 - 0.25	Pilie and Kocmond (1967)

*Median-volume diameter.

FIGURE CAPTIONS

Fig. 1. Trawler sea spray icing data plotted as a function of wind speed and air temperature for vessels with average speed of four knots. (After Stallabrass, 1980).

Fig. 2. Sea spray collection on a 60 ft. vessel using timed spray collection devices. The left side shows the volume per spray and spray frequency as a function of vessel speed for a constant significant wave height of H 1/3 = 1m. The right side shows the spray volume and spray frequency as a function of significant wave height for a constant vessel speed of 8-9 knots. (After Carstens, Unpubl.)

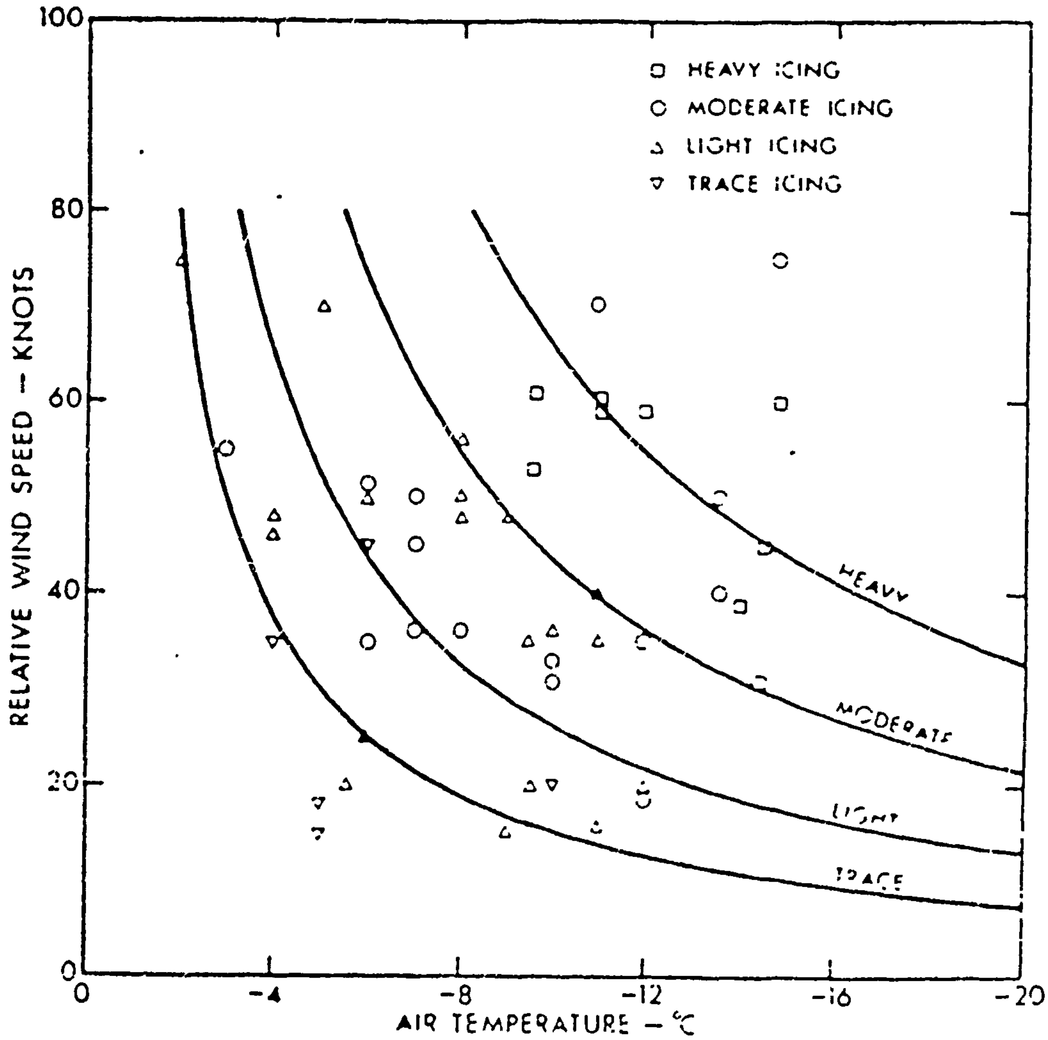
Fig. 3. Computer simulation of a 20 minute atmospheric icing event on a twistable structure (e. g., an electric power transmission line). The parameters of torsional rigidity, time, droplet radius, liquid water content, air temperature, line length, line diameter, wind velocity, and final twist angle, are shown on the figure. (After Egelhofer, 1983).

Fig. 4. Schematic of a vertical structure of height 15m segmented into the sections used for a sea spray icing simulation. The regions of dry icing (surface temperature below freezing), wet icing (surface temperature at freezing), and no icing (surface temperature above freezing) are shown. (After Horjen and Vefsnmo, 1984).

Fig. 5. Salinity of ice in a sea spray ice accretion as a fraction of initial water salinity (e. g., .5 on the vertical scale corresponds to an ice salinity of 18 0/00 for water salinity initially at 36 0/00). The top plot shows the fractional salinity as a function of ice growth rate and the bottom as a function of the product U x Ta (wind velocity times air temperature). (After Launiainen, et. al., 1983).

Fig. 6. Relative sea spray ice thickness as a function of height above the sea surface for various windspeeds. The values are scaled to the height of the maximum thickness for the 15 m/s windspeed. (After Carstens, Unpubl.).

Fig. 7. Ice thickness vs height above sea level for a two week simulation of sea spray icing on a stationary vertical structure. The D's are diameters of the vertical columns. (After Horjen and Vefsnmo, 1984).



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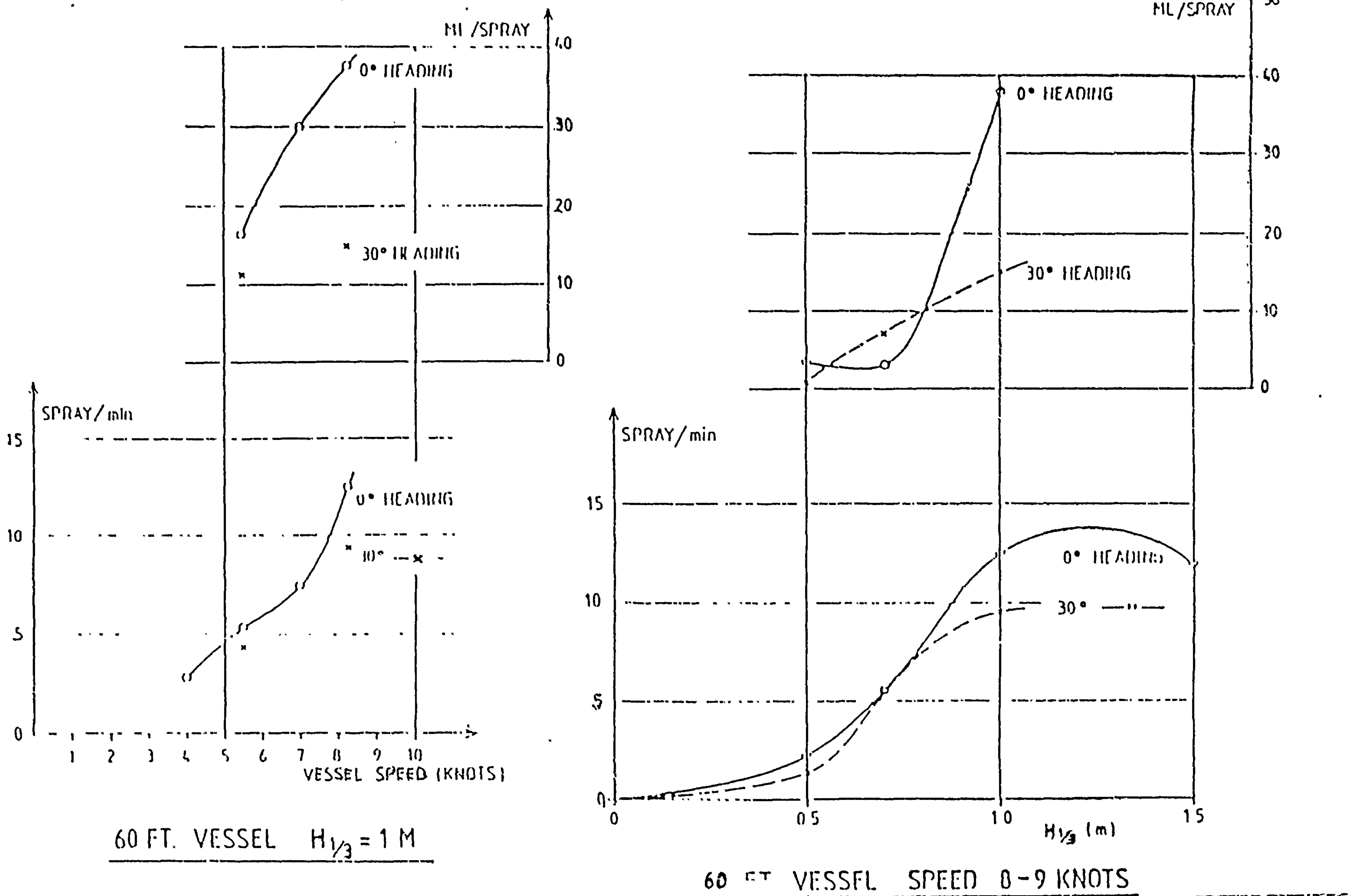

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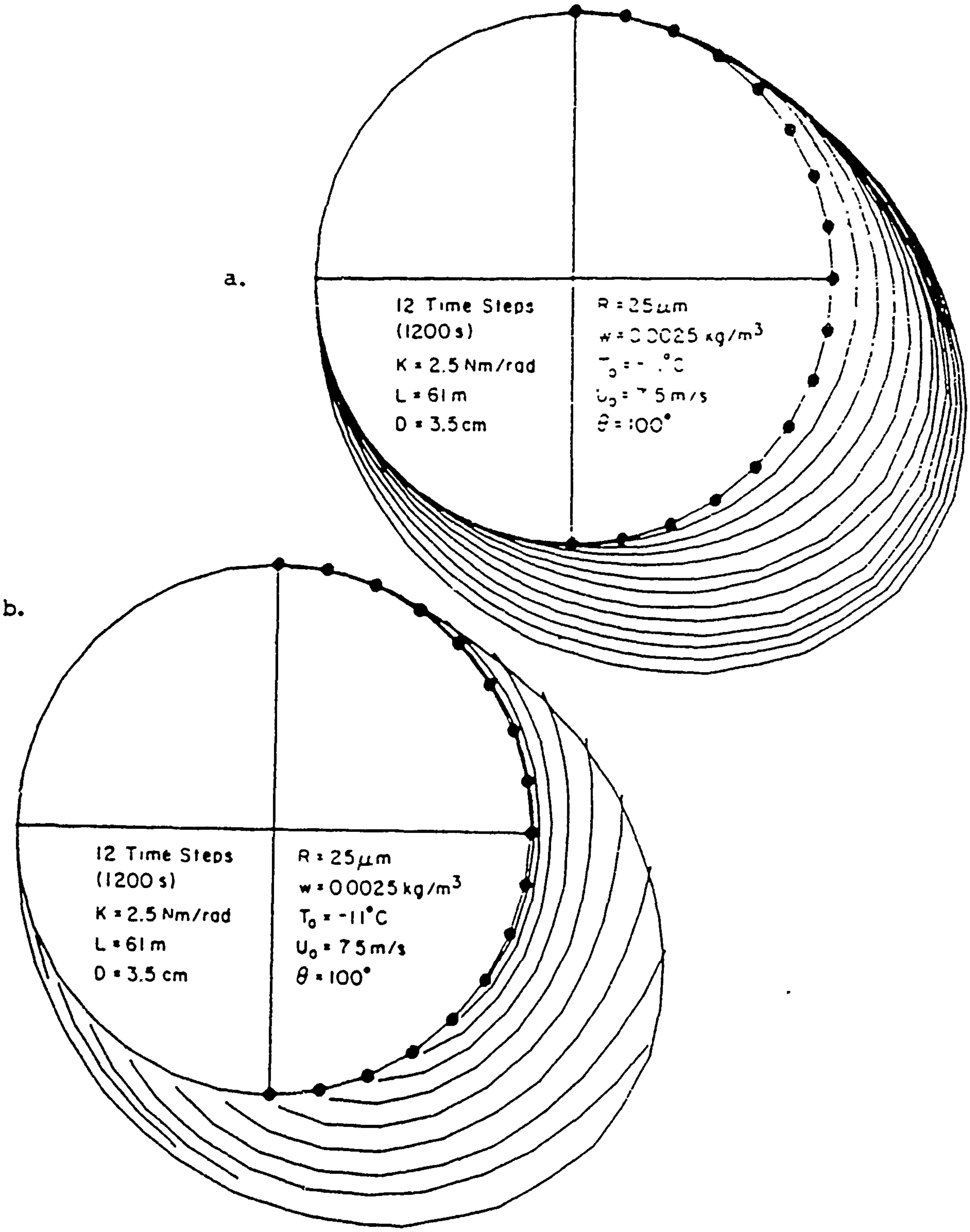

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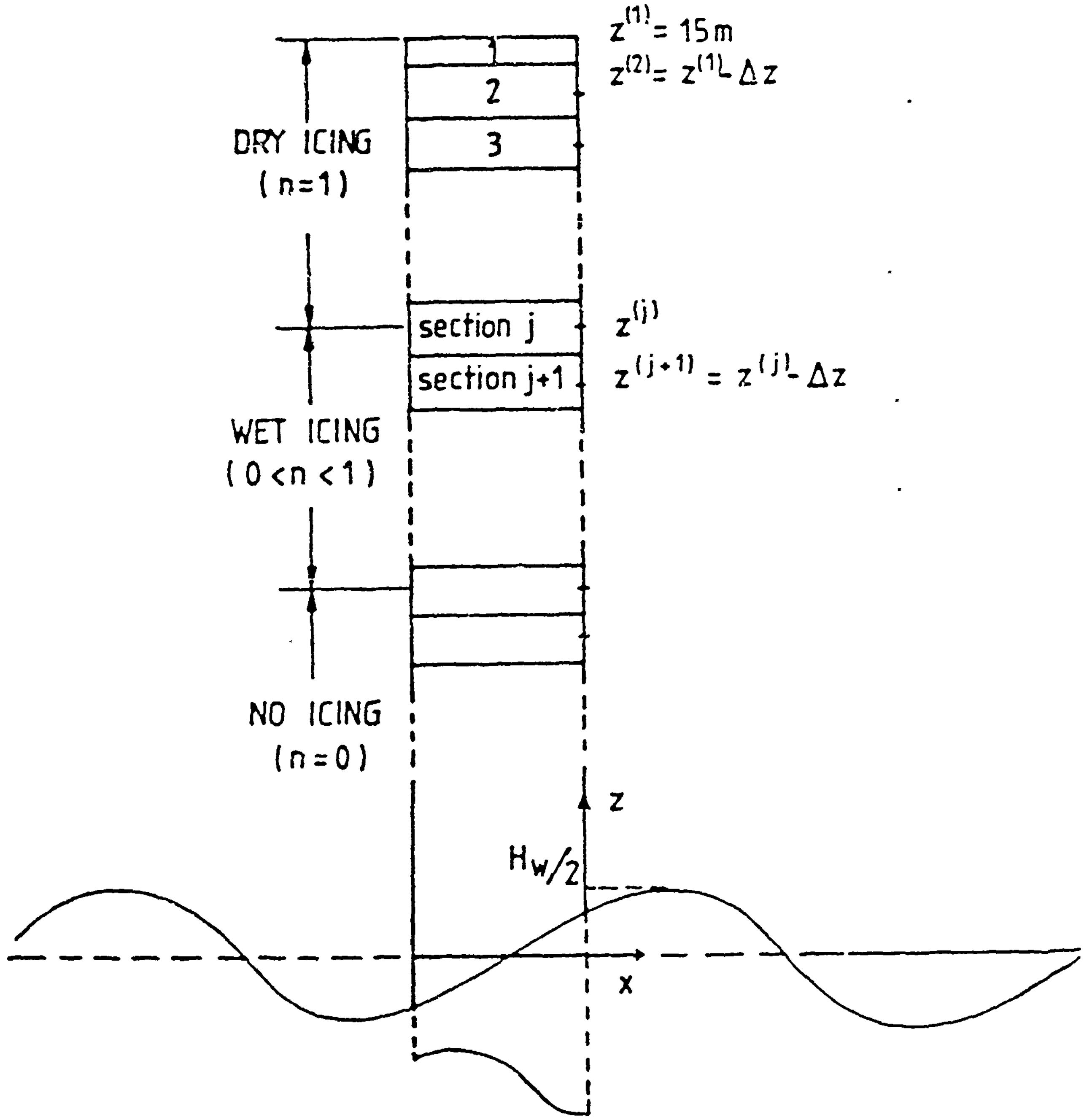

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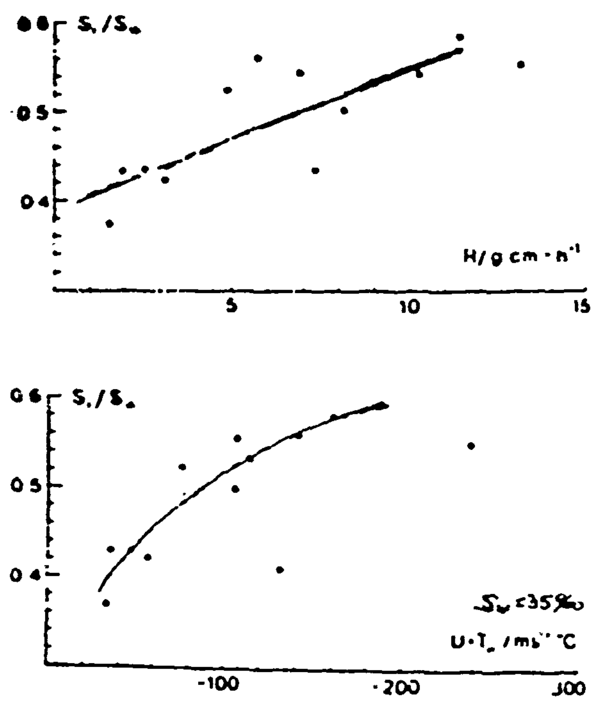

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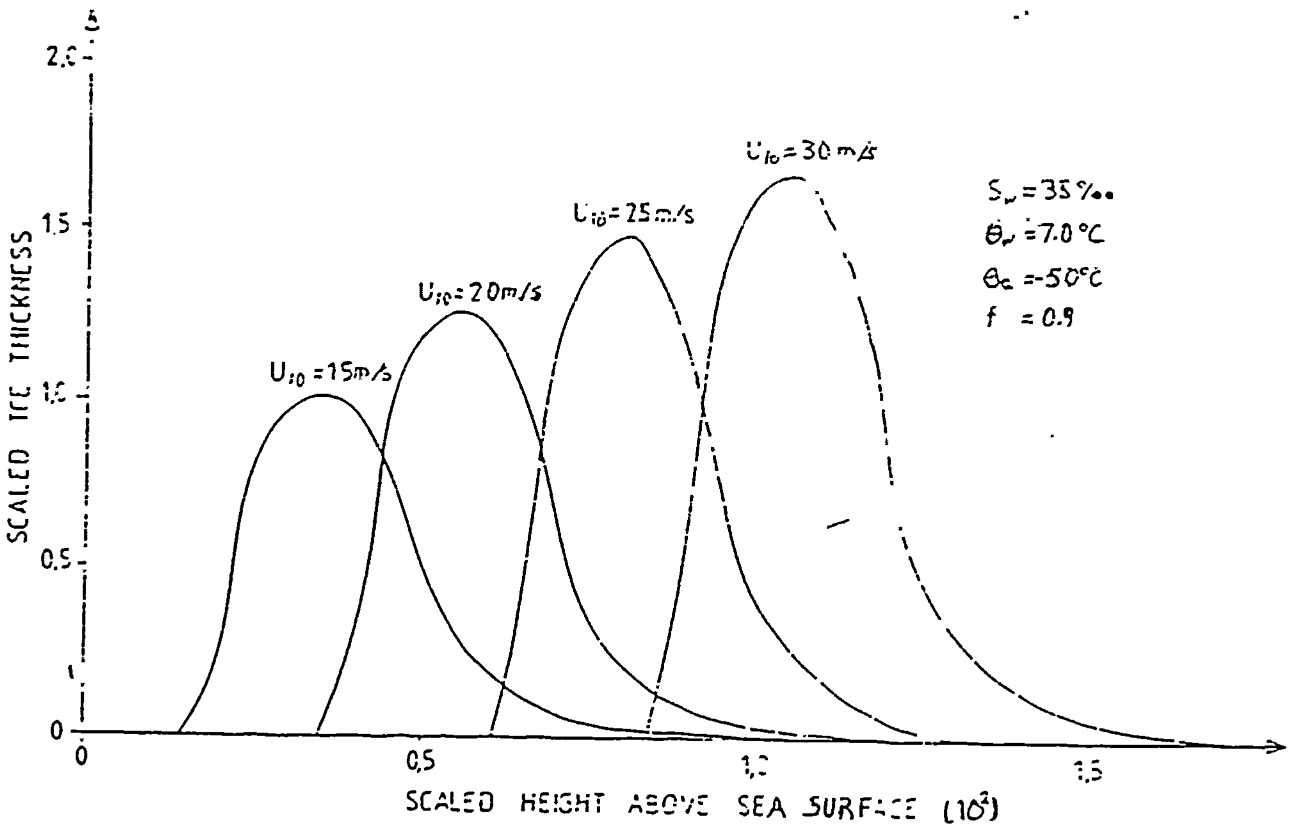

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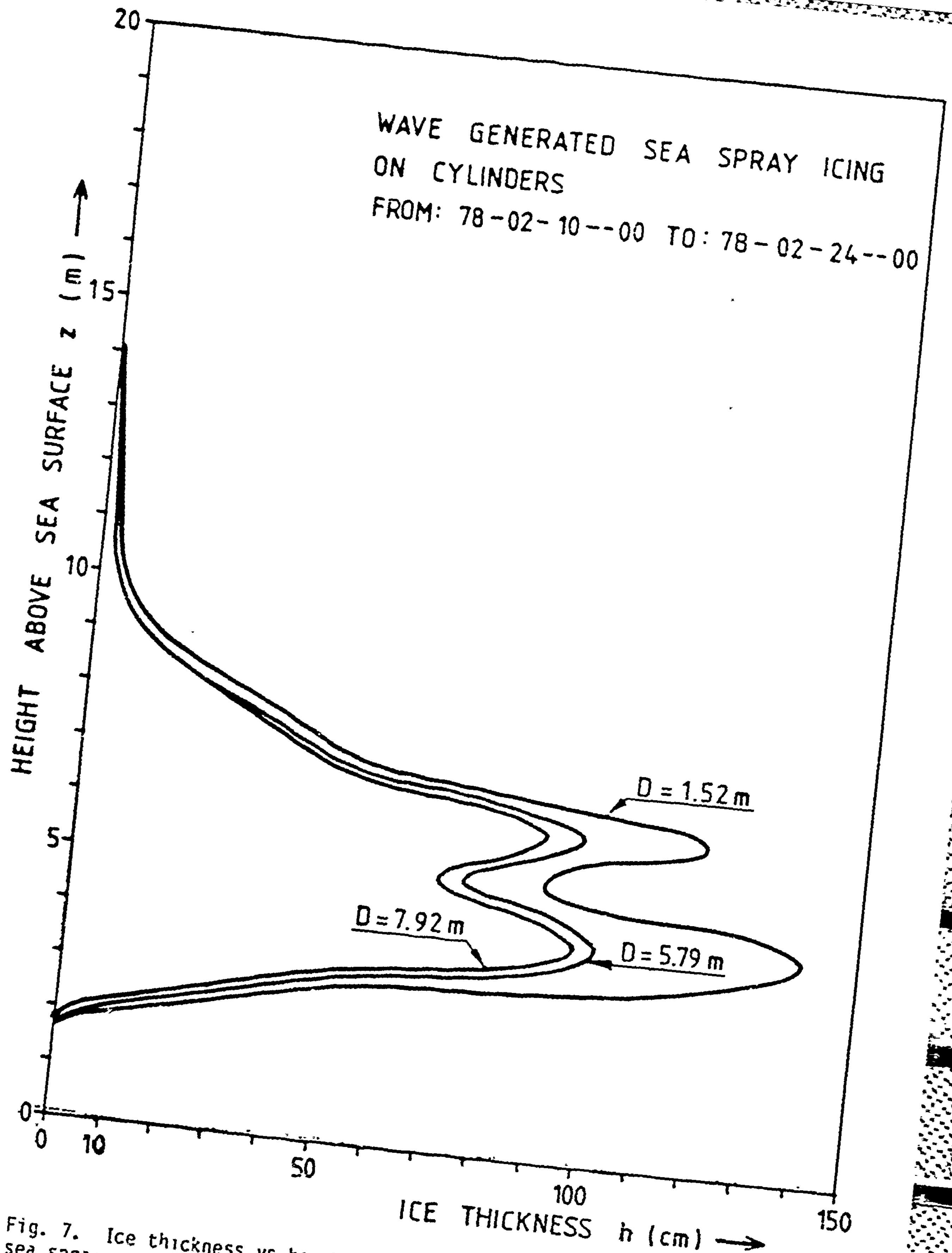

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ANTI-ICING AND DE-ICING OF NAVAL SURFACE SHIPS

GEORGE H. GARBE[1], CAPT, USCG (RET)

ABSTRACT:

Current U.S. Navy thinking envisions a significant shift from the traditional ocean operating areas to much colder climes. The potential threat of enemy submarines operating from under the Arctic ice pack to interdict SLOC's or to launch attacks against U.S. cities is all too real. The need to counter this threat is a matter of priority. Equipping our ships to function in the cold weather arena is an issue demanding solutions. Material presented in this paper looks at past attempts to address cold weather operational problems and offers some ideas which may prove useful in improving ship stability during icing conditions as well as insuring the operational readiness of exposed equipment, weapon systems and helicopter handling systems such as RAST.

INTRODUCTION:

During the winter of 1981-82, a U.S. Navy FFG 7 Class ship arrived in Bath, Maine carrying a 5° starboard list caused by a load of topside ice. This was significant because FFG 7 was designed as an austere ship with rather narrow weight and KG margins. Weight growth since inception had encroached steadily on these margins so that eventually, the FFG 7 Class SHAPM, PMS399, found it necessary to place the ship in stability status 2. This meant that

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no additional weight could be added to the ship without an offsetting weight and moment compensation. Unfortunately, mother nature has little respect for such decrees and the ship mentioned ended up with a large amount of unwanted weight at a fairly high location. While the incident ended without harm, it caused PMS399 to take a hard look at the icing issue. A review of the Top Level Requirements (TLR) for the Class revealed that FFG 7 was not expected to operate in polar regions except on special assignment. The fact that the Class was in stability status 2 however raised a red flag within the PMS399 staff. It was obvious that a ship need not be in a polar region to encounter icing; the north Atlantic in winter could certainly provide such conditions. With a weight and KG critical ship, it seemed prudent to consider such an eventuality.

BACKGOUND:

At PMS399's direction, Tracor in 1982 began a study of how the maritime world historically approached the issue of icing. An attempt was made to determine what tools were available to combat icing and what could be done to improve the capabilities of the FFG 7 Class per se.

It should be stated at the outset that margins for ice loading are normally included in any new ship design (whether they be U.S. or foreign or whether the ships be naval or merchant in type). This is considered to be good design practice. In the case of FFG 7, improvements to weapon suites during the construction phase effectively wiped out these margins due to the accompanying weight growth.

Another normal design practice is to provide exposed weapon systems and sensors on naval ships with sufficient anti-icing capabilities to insure operability in cold weather. In the case of the FFG 7 Class LAMPS MK III RAST System this was not considered to be a design requirement because it was not envisioned that the ships would operate in the Arctic.

Two points that emerged from the Tracor study that should be raised at this point are:

- That while a significant amount of reasearch has been accomplished both in the U.S. and abroad, no significant innovations for preventing or removing topside ice have appeared on U.S. Navy or merchant ships in recent times. In many cases, the baseball bat is still the cutting edge of technology.
- That the operational and safety hazards which can accompany ice loading, while duly impressed upon the awareness of naval architects, are not generally appreciated within the naval community. A surprising amount of complacency exists even among experienced sailors. I say this not as an indictment, but rather to reflect the lack of urgency concerning icing since World War II which I feel has been engendered by a shift of operating areas during peacetime to warmer climes.

In the last 1-2 years, an awareness has been growing in the U.S. Navy of the need to be prepared for cold weather operations, particularly ASW along the edge of the Arctic ice pack. This, of course, implies frequent exposure of surface ships and their weatherdeck systems to the possibility of ice formations. Since FFG 7 is primarily an ASW ship, PMS399 decided to examine the capabilities of the Class for cold weather operations and Tracor was tasked to assist PMS399 in developing a plan to tackle the FFG 7 ship icing problem head on. By October 1982, a plan was ready and was presented to the PMS399 CCB for consideration. Major features of the plan included the following:

- Development of a special ballasting plan to compensate for topside icing.
- Development of portable de-icing kits.
- Recommendations for a T&E effort to assess or develop a variety of potential anti-icing and de-icing tools.

Of these, the special ballasting plan was adopted and eventually incorporated in the FFG 7 damage control book. The others were deferred due to a lack of funds and a lack of priority.

A second plan was prepared in 1983 which proposed a substantial T&E effort for development of RAST track anti-icing, high-pressure steam and water jet hand held de-icing lances and low ice adhesion (or icephobic) coatings. This plan was also deferred for lack of funds.

Now that interest in cold weather/Arctic operations is again rising, the details of these plans are worth a second look.

Special Ballasting Plan:

The basic stability criteria for the FFG 7 Class are predicated on the ship being able to withstand a 100 knot beam wind without capsizing. Unfortunately, with topside icing, a unique stability problem is created in that the addition of weight occurs in an uncontrolled way and in generally high locations on the ship. As ice thickness increases, KG rises and the amount of the tolerable beam wind decreases. The use of sea water ballast then becomes a means to compensate for this condition. For FFG 7, a special ballasting plan was developed with a 70 knot beam wind arbitrarily set as the goal to try to maintain. An example is shown in figure 1 which is based upon

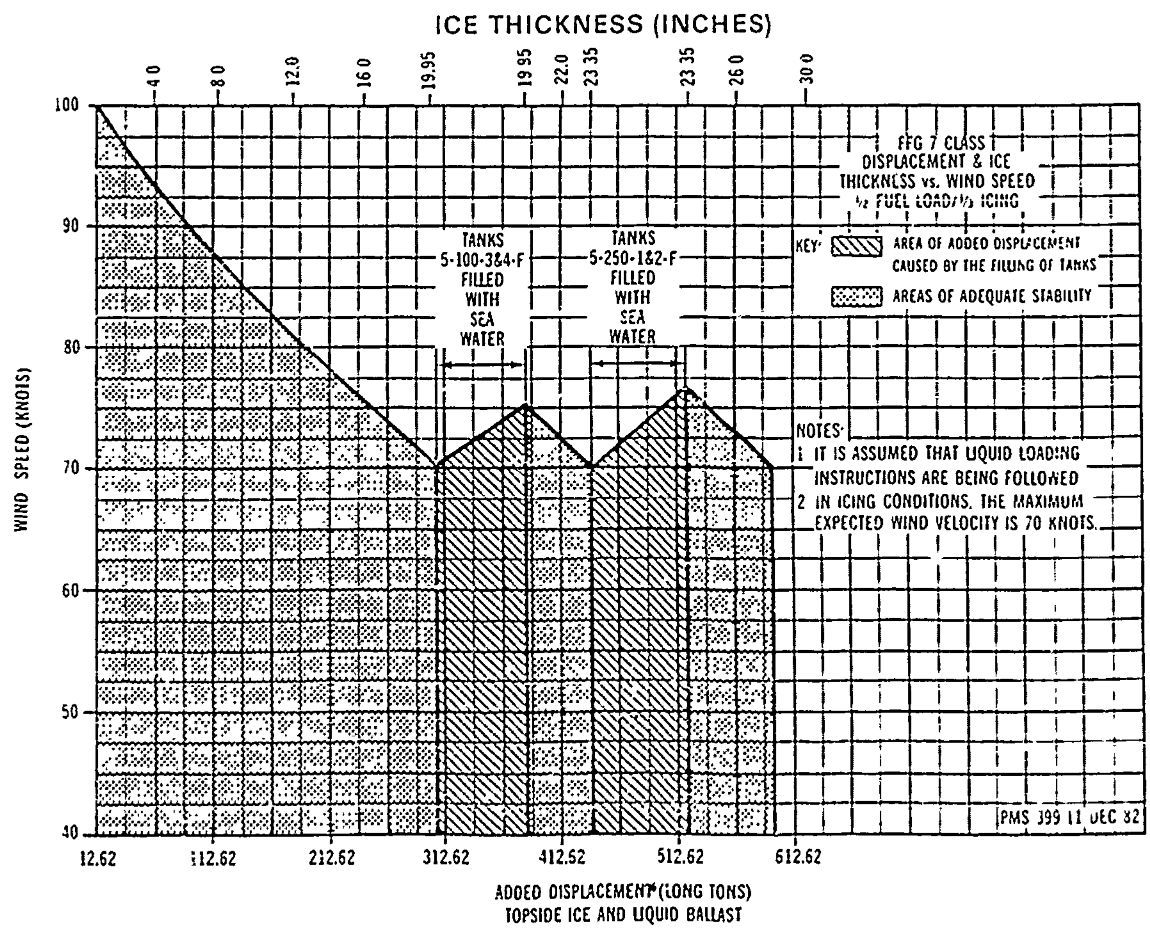

Fig. 1 Typical FFG 7 Class Ballasting Curve For Topside Icing

a 1/2 fuel load with ice loading uniformly distributed over the first 1/3 of the ship [1] [2]. As the ice thickness increases and tolerable beam wind decreases to 70 knots, ballasting of two selected fuel tanks take place, thereby increasing the tolerable beam wind back up to 75 knots. As more ice accumulates and tolerable beam wind again reduces to 70 knots, a second pair of fuel tanks are ballasted. This increases the tolerable beam wind back up to 78 knots. By the time the tolerable beam wind again reduces to 70 knots, the ship will be carrying nearly 22 inches of ice over the entire first third. Thereafter, as additional ice accumulates, the situation will begin to deteriorate steadily. The benefit derived however, is that by ballasting, the ship has the ability to carry approximately 12 inches more ice for the same beam wind than would otherwise have been possible. The curve provides the ship's crew with a convenient tool to estimate their stability situation under icing conditions and to take appropriate action. For FFG 7, separate curves have been developed for both the 1/2 fuel and full load conditions with ice loading over either the first 1/3 or the entire ship. Development of similar curves for other classes of ships may be desirable if problems with KG margins are being encountered.

It should be noted that as the accumlation of ice increases, the added weight may cause displacement to exceed design limits. Excessive ice loading can therefore also present problems in regard to structural hull strength. However, if the ship cannot remain upright, this will very quickly become a moot point.

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[2] Numbers in brackets designate references at end of paper.

De-icing Kits:

It makes sense for ships deploying to cold weather areas to carry along some kind of de-icing kit. Traditional methods for removing ice generally include manual tools such as bats, mauls, axes, scrapers, shovels and brooms. These are tried and true methods and should not be overlooked. Other items which might be carried include:

- Portable covers for protection of exposed machinery, weapon systems and electronic sensors.
- Portable heaters may be useful for localized de-icing in small areas.
- Use of chemical de-icers such as rock salt or urea might be considered. These however tend to add significant weight and cube and have the disadvantage of being highly corrosive to metals of all kinds.
- Isopropyl alcohol or ethylene glycol for de-icing helicopters may be desirable and are non-corrosive to metal. Again, weight and cube will be a limiting factor.

The size and content of a de-icing kit for any given type of ship is an arbitrary decision and will most likely be a compromise based on weight and storage considerations. As an example, a recently proposed kit for the FFG 7 Class is illustrated in figure 2. Overall weight of the kit is estimated to be a little over one long ton. For this Class of ships, anything larger would undoubtely be impractical. Even at that, an offsetting weight reduction would have to be identified to put the kit on board.

ITEM NO.	DESCRIPTION	QTY	EST. WEIGHT (LBS)
1	Portable hand held de-icing lance	1 ea	250-360 depending on type
2	Portable equipment covers for the following equipment: CIWS, 76MM gun mount, STIR Antenna, MK 13 GMLS launcher and torpedo tubes.	6 ea	600
3	Lifeline for maindeck and 02 level	100 ft of ½" line	300
4	Tools for mechanical removal of ice:		
	a. Wooden bats or mallets	24 ea	120
	b. Long handled ice chippers scrapers	12 ea	60
	c. Long handled shovels	12 ea	120
	d. Long handled street brooms	12 ea	120
5.	Ethylene Glycol	Two 55 gal drums	750
		Approx. Total	2430 LBS

Fig. 2 Proposed FFG 7 Class Cold Weather Kit

De-icing Lances:

Going back to figure 2, one of the items suggested for inclusion in the FFG 7 portable cold weather kit is a portable, hand-held de-icing lance. There are several options which fit this description:

- Steam Hoses. Historically, some operators have employed the use of steam hoses to remove topside ice. For ships with an adequate steam supply, this can be an effective ice removal tool. I believe that the method could be improved by development of a dedicated nozzle to improve its efficiency. To my knowledge no such nozzle presently exists. The CG 47 Class for example has a steam hose in the hangar for use in de-icing the ship's flight deck and RAST tracks. Without a nozzle designed especially for this purpose, it is probable that much of the energy available in the steam will be lost to the atmosphere. Moreover, the concept basically envisions melting the ice, a sometimes slow and tedious process. A properly designed nozzle would permit the steam to penetrate to the metal surface and destroy the ice-to-metal bond. This would permit faster removal by breaking away masses of ice rather than just melting it away. I would like to note that the use of the laundry boiler for this purpose on FFG 7 was considered and rejected by PMS399 due to the small quantity of steam the equipment could generate. See references [2-3] .

- <u>Heated Fire Main Water</u>. Another historical method is the use of heated fire main water applied with fire hoses. This requires an internal piping arrangement to mix heat from a suitable source, such as steam, with fire main water to raise the temperature to say, 135°F. This can work well because of the high volume of water that can be applied to an ice covered surface. As with steam hoses, however, the method as presently employed is inefficient in that much of the energy is dissipated before it can do any work and the method relies more upon melting than on breaking the ice away. Alternate heat sources for this method might include turbine bleed air or SSDG waste heat for ships that do not have a steam supply. In any case, internal piping or ducting arrangments required to apply heat to the fire main water exact a weight penalty that may be unacceptable in weight critical ships. The temperatures involved can also be hazardous to personnel.

Two fairly recent ideas proposed to NAVSEA are portable steam generators and portable high-pressure water jets both employing hand-held lances.

- **Portable Steam Generators**. The idea of a portable steam generator was advanced by USS SIDES (FFG 14) following a North Pacifc deployment in 1983. The ship had taken along an Alkota Brand Model 6430 hot/high pressure steam cleaner which had been purchased specifically as a de-icing tool. The 360 lbs device burns DFM diesel fuel to generate 108 GPM of steam at 700 PSI. Its 100 foot length of hose makes it capable of reaching all areas above deck. Unfortunately, the ship did not encounter icing conditions and the unit did not receive a full evaluation. Regardless, the ship and SURFPAC recommended that such machines he provided for all ships without steam hoses despite the lack of testing [4].

- **Portable High Pressure Water Jets**. The use of high pressure water jet equipment has also received some attention. A prototype device was built by Tracor Hydronautics, Inc. and placed aboard the USS JACK WILLIAMS (FFG 24) for evaluation during Arctic exercises in 1984. It consists of a portable, wheel mounted system designed to provide high pressure sea water at ambient temperature by use of an electrically operated pressure intensifier. The water is pumped through an electrically heated hose to a hand-held lance which the operator then can direct in a narrow, high pressure, pulsating water jet (approximately 3000 psi) to the ice covered surface. Demonstrations at the company's plant showed the equipment to be very effective in removing large ice accretions from a variety of surfaces. Unfortunately, no actual icing conditions were encoutered on ARCTIC SHAREM '84, and as with the Alkota 6430 steam cleaner, the equipment did not receive a true operational test. The JACK WILLIAMS however endorsed the equipment as "an invaluable tool for ice removal" based on their limited evaluation [5] .

While the Tracor Hydronautics prototype was especially designed for use on FFG 7 Class ships, there is every reason to believe it would also work on other classes as well. The device weighs approximately 190 pounds and is easily moved about the ship. It is made to hook up to any standard fire hydrant for its sea water supply and plugs into any 440 volt electric power outlet on the ship. This permits the pumping unit to remain inside where it is warm. A 200 foot hose is run out through the nearest hatch and extended to where the lance is needed. With this arrangement, any weatherdeck location that is within arm's reach of the operator can be de-iced. The hose and lance are electrically heated to prevent freeze-up when not in use.

Conceptually, the two portable systems described above seem to offer the most significant advance in de-icing tools that have apeared on the scene to date. It would certainly appear to be in the Navy's best interests to evaluate them further.

Low Ice Adhesion (Icephobic) Coatings:

Examination of some Soviet technical papers written in 1972 on the subject of low ice adhesion coatings revealed that experiments were conducted on board a Soviet Marine Fisheries Vessel in the Baltic and Barents Seas with what were described as "organoepoxy silicon base coatings and polymer base coatings with a perflourinated surface film" [6] . The results of these experiments allegedly proved that when used, such coatings:

- o Retard the formation of ice in the initial stage of icing thereby slowing down the rate of ice accretion.
- o facilitate the removal of ice from exposed ship surfaces including masts, antennas, railings and rigging by drastically reducing the force required to break the ice away.
- o can successfully be used on decks and will retain their icephobic properties through numerous icing-deicing cycles despite mechanical damage caused by normal wear and tear. In this regard, polymer base coatings with perflourinated surface films were found to be perferable because organoepoxy silicon base coatings were found to be very slippery and polymer base coatings were not. This is an important safety consideration for crewmen working in exposed locations.

In this country, a copolymer icephobic coating developed by the U.S. Army's Cold Regions Research and Engineering Laboratory (CRREL) in New Hampshire, is presently under investigation by DTNSRDC. The coating is a light weight, brush-on substance which reportedly reduces water surface tension by a factor of 700, thus inhibiting the formation of ice [7] . The Coast Guard is reportedly using a TECHTANE™ polyurethane coating with a TECHTANE™ LFHR low friction additive to reduce ice adhesion on steel buoys [8] . NASA is experimenting with Gelled Anti-icing Agents, a totally new concept whose application to shipboard use is as yet, unexplored [9, 10] . Evaluation of all of these various coatings in an environmental laboratory under carefully controlled conditions seems to be the most logical way to assess their viability. Such facilities exist at CRREL, at the Air Force's Cold Chamber at Eglin AFB, Florida and at several commercial facilities such as ARCTEC, Inc. in Maryland. Attempts to evaluate such coatings aboard ship as opportunities permit, too often prove to be disappointing as the desired conditions frequently fail to materialize when needed. Eventual use of such coatings, possibly in combination with other anti-icing or de-icing systems, definitely appear to be the way of the future.

One final aspect of icephobic coatings that may bear investigation by the Navy was identified in the 1972 Soviet technical papers. This is referred to as "combined current conducting coatings." The paper lacks sufficient detail to identify these materials precisely. However, it implies the Soviets have had successful experimental results in keeping both vertical and horizontal sample plates which were protected by such coatings generally ice free. Moreover, power consumption was reportedly between 100 to 1000 times less than other non-specified thermal anti-icing systems. The paper gave a high priority to development of a coating which combined the current conducting features of one coating with the low ice-adhesion characteristics of the other to produce a hybrid icephobic-current conducting coating. I know of no counterpart to such a coating in this country. Liaison by the U.S. Navy with CRREL may shed some light on this subject. It may prove to be an area of new technology worthy of a dedicated R&D effort.

RAST Track Anti-icing:

The subject of RAST track anti-icing is one which has received considerable debate over the last 3 years. Is it needed to insure the overall operational readiness of the LAMPS MK III ASW system or isn't it? As a former Coast Guard Icebreaker helicopter pilot, I am one who feels this is a feature which should be incorporated on all RAST equipped ships. First of all, the entire system of launching and retrieving the SH60B LAMPS III helicopter is dependent upon a functioning RAST system. Without this, helicopter operations would be seriously impaired, if not totally halted. I don't believe that the SH60B can safely be moved across a moving deck by hand and I certainly wouldn't recommend it. An operating RAST system is believed to be essential to safe and efficient operations. With increasing emphasis on Arctic ASW operations along the edge of the ice pack, it seems evident that RAST systems will be subjected to icing conditions sooner or later. In this regard, the actual cold weather experience of some Navy men can be dangerously misleading. Some sailors and airmen who have operated in cold weather, even extensively, may feel that RAST track icing is not a serious problem because, in their experience, they have never witnessed severe icing conditions. I believe these people have been fortunate, but it is foolhardy to conclude from this that it can't happen. Encountering ice can be likened somewhat to being struck by lightning. The likelihood of it happening may be relatively small, but when it does, the results can be devastating.

Examination of a typical RAST trough will show that clearances are tight as the entire internal structure is cluttered with baffles and support posts. (See figure 3). Should a significant amount of ice form inside the troughs, there is no place for it to go even if it could be broken free. The notion that the RSD could break its way through the ice and push it aside may work if only a light coating has accumulated. At some point however, it is predictable that the RSD would jam and that either the RSD, the tow cable or some

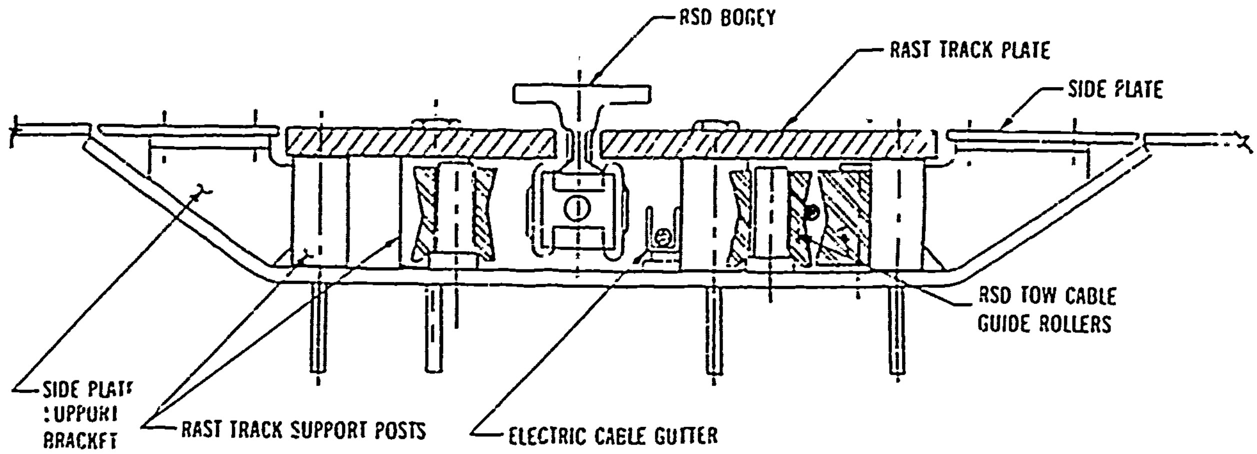

Fig. 3 Typical FFG 7 Class RAST Track Cross Section

of the RAST track support structure might break. A second problem is that once the ice has formed, the narrowness of the RAST track slot would preclude insertion of any kind of de-icing tool even if one were available. The only viable alternative for a severely iced RAST trough would be to wait until the ice melted. This could take a long time and might easily occur just when the system is needed most.

A more prudent approach would be to provide a system of RAST trough anti-icing. In 1983, Tracor conducted a study which showed that an FFG 7 RAST trough anti-icing system using electric strip heaters was viable. A plan to actually develop such a system was formulated within PMS300 but could not be carried forward due to a lack of funding. It is still a good idea. Development of such a system in an environmental laboratory under rigidly controlled conditions using actual RAST trough mock-ups is the recommended approach for addressing this problem. This would permit the optimization of strip heater positioning to produce the most effective system for any given ship class. An example of such a mock-up is shown in figure 4. Figures 5 and 6 are illustrations of possible strip heater configurations for the FFG 7 Class RAST troughs which preliminary heat transfer calculations indicate may provide effective RAST anti-icing [11]. This would have to be verified experimentally however, because of the complex nature of the heat transfer problem and the highly variable nature of the physical factors involved (e.g., wind velocity, temperature, wind direction, amount and type of spray).

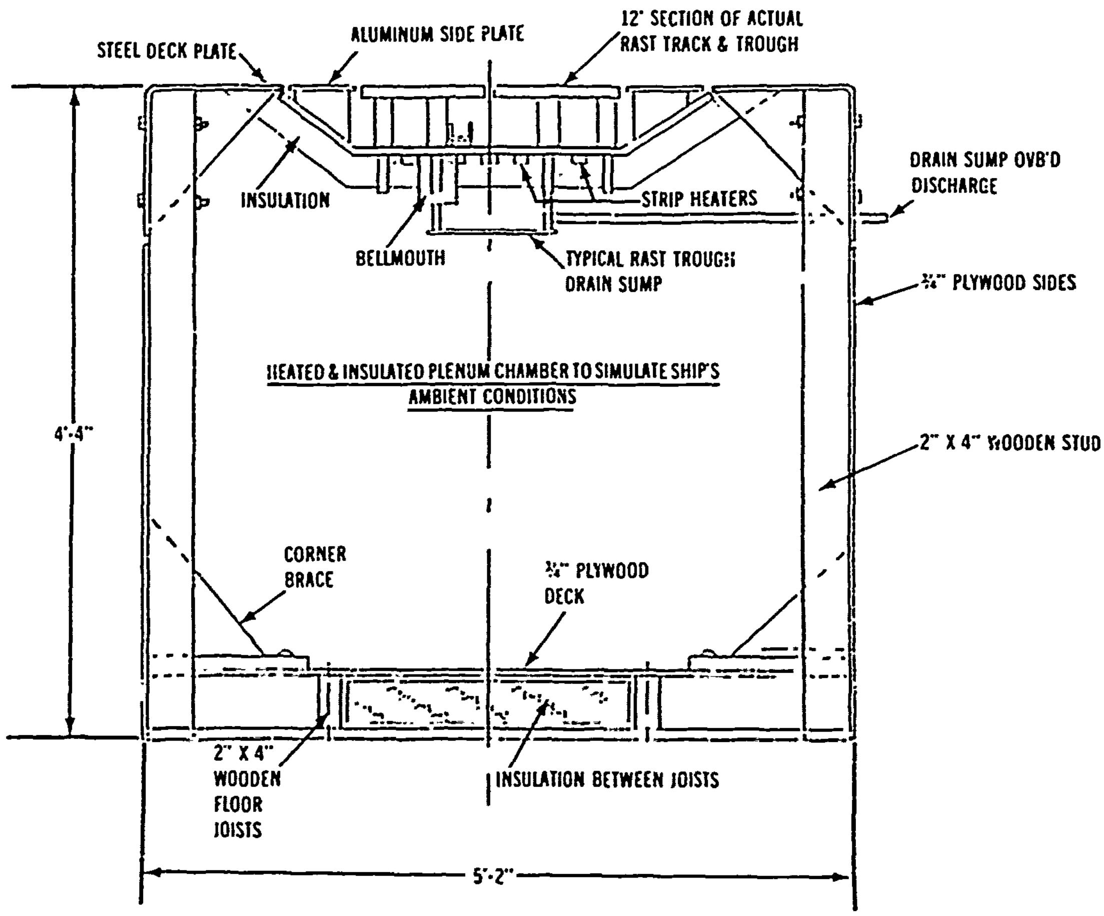

Fig. 4 Mock-up for Development of RAST Track Anti-Icing System Using electric Strip Heaters

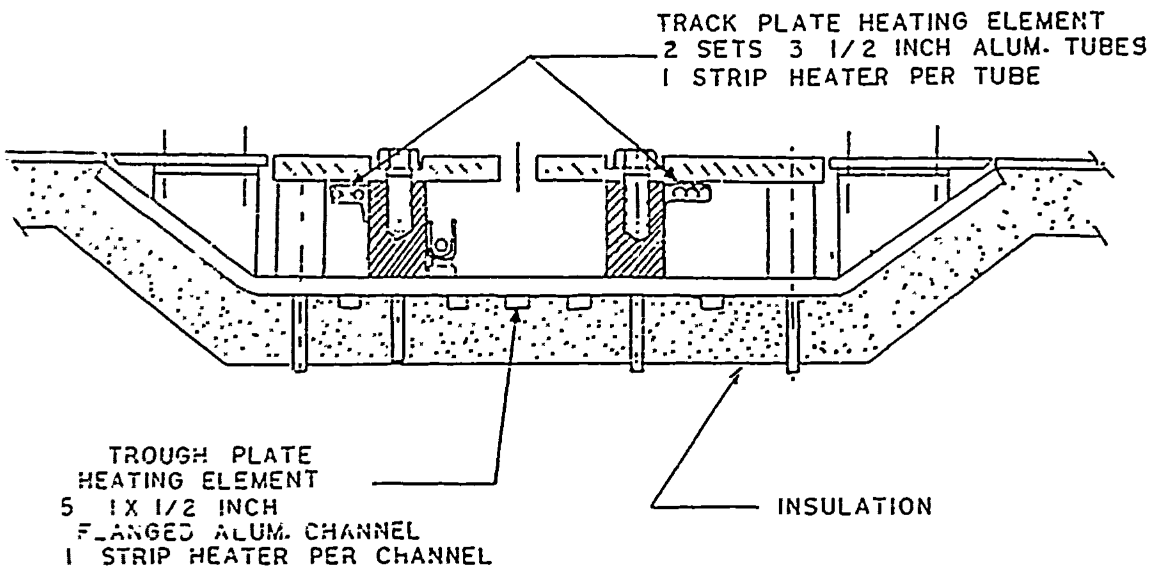

Fig. 5 Proposed FFG 7 Class RAST Trough Strip Heater Configuration "A"

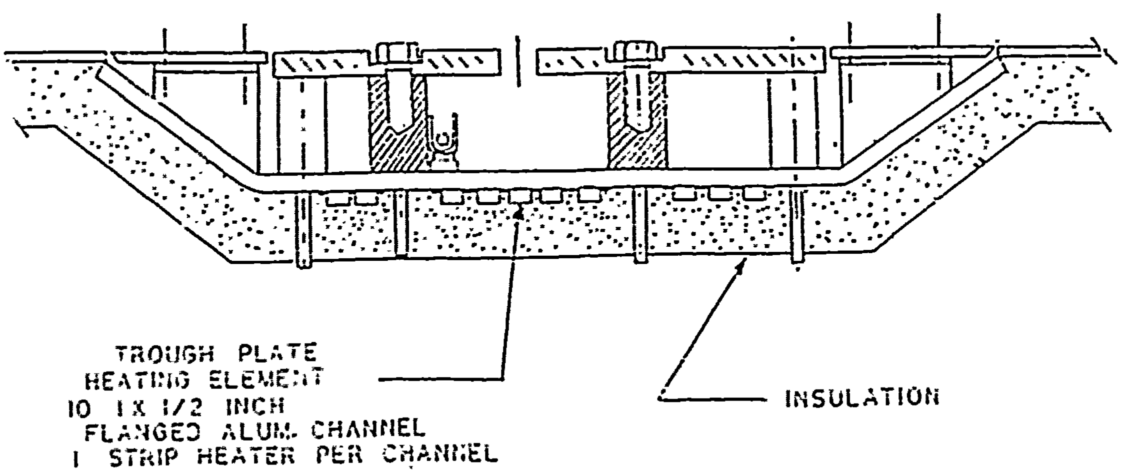

Fig. 6 Proposed FFG 7 Class RAST Trough Strip Heater Configuration "B"

It is interesting to note that the preliminary design for the proposed Canadian Patrol Frigate includes an electrically anti-iced RAST track. While the RAST system is configured quite differently than the U.S. Navy's, the idea is still the same. I believe the time has come to recognize the need for RAST anti-icing on U.S. Navy ships and to initiate steps to acquire this capability without further delay.

<u>Summary</u>:

In summary, I would like to suggest that the Navy's approach to improving its posture for cold weather operations include the following:

- That the Navy consider development of special ballasting plans for other classes of ships as may be appropriate, similar to the plan for FFG 7.
- That every ship deploying to cold weather areas be provided with a portable cold weather kit. Such kits should be tailor made for each Class so as to provide a reasonable selection of ice removal tools, protective covers and chemicals within the ship's ability to store and carry them.
- That the Navy consider development of specialized nozzles for use with heated fire main water and steam hoses on ships which have these capabilities.
- That the Navy evaluate portable, hand-held de-icing lances (either steam or water jet) as might currently be available, or to launch an effort in conjunction with industry to develop them.
- That the Navy evaluate available icephobic coatings for shipboard use, or, commence an R&D effort to develop them.

- That the Navy fund an R&D effort to develop electrically heated anti-icing systems for RAST with the goal of installing them on all RAST equipped ships.

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PREVENTION AND RETARDATION OF ICE FORMATION AT SEA.

DAVID T. MINASIAN

SUBJECT: PREVENTION AND RETARDATION OF ICE FORMATION AT SEA

Abstract:

Icing imperils operations of vessels at sea affecting such things as ship stability, operation of on-board communications and navigation equipment as well as fixed and floating aids to navigation.

This paper deals primarily with the shipboard environment, discussing the basic dynamics of ice-formation, a review of current methods of removing ice, limiting ice adhesion or preventing ice formation.

Key to the topic is a discussion of a unique coating which deals directly with the prevention of significant retardation of ice formation under many conditions encountered at sea. The term "superhydrophobicity" is coined here to describe a phenomenon of this coating which permits air occlusion at the water/surface interface. Documentation of various data from tests conducted mainly on land based communication systems is presented and provides a rationale for extending the coatings' use at sea to prevent or retard ice formation.

INTRODUCTION

GOOD MORNING

Perhaps no-where on earth does ice present more of a threat to survival than at sea. Conditions which allow water to freeze on surfaces defy every effort we can devise to cope with slabs of ice a foot thick or more that accumulate on the superstructure of a vessel at a faster rate than men, armed with ice axes, can remove it. The stability of the vessel is threatened and capsizing can be the result. In addition, communications equipment encrusted with ice may be severely damaged or rendered useless due to signal attenuation and navigation equipment both on land and at sea are exposed to the same hazards.

The rigors of cold weather operations at sea have, in the past, been severe enough to cause many seamen to accept the risks as inevitable. A few generations ago, survival was not thought possible if the seaman was dumped into the water after the loss of his vessel. In fact it was not unusual to find fishermen with lead weights in their boots in order to bring about a quick end to the agonies of hypothermia. But modern technology has changed traditional beliefs. Epirbs, strobe lights, survival suits, and modern self inflating life rafts, now give us a different perspective on the chances for survival.

Although I am not here to talk about hypothermia or survival in sub-freezing water, I mention this only to emphasize that on the subject of the hazards of ice, new technology may soon be changing some of our traditional beliefs. The need for our technical capability to solve the problems of ice formation has never been more critically important.

Experience tells us that if a surface is cold enough, ice formation is inevitable when drenched with water. What then has been accomplished so far in our attempt to reduce the hazards of ice formation?

Although we will undoubtedly hear several approaches to the problems of ice formation at this symposium, it is safe to say that previous attempts to control the threat of ice have not been practical or totally effective. The threat remains. We have already mentioned the direct frontal attack with ice axes but such attempts are limited by the ability of a man to reach the high regions of the superstructure or to chop away at a rate faster than ice can accumulate. And there is always the possibility of doing irreparable damage to delicate electronic equipment.

Vibration has been studied as a means of shaking ice free of a surface, and results have been mixed.

The FAA has been successful in reducing ice formation on airplanes while they are on the ground by spraying them with ethylene glycol. The method works well during a moderate rain, sleet, or snow storm, but repeated sprayings are necessary as the intensity of the storm increases. Hence, one has to wonder whether such a system would be practical at sea as a ship faces the deluge of water from waves ranging up to forty feet.

Not long ago a naval architect designed a system of using the heat from stack gasses piped to certain critical portions of the ship to maintain sufficiently high surface temperatures to reduce ice formation. This innovative approach to the problem is limited by the enormous demand for heat required to accomplish the objective on large areas of the superstructure. It is further limited by the amount of heat available from modern engines which are becoming more and more efficient.

However, we believe a more practical approach deals with the surface itself and the use of compounds to reduce ice adhesion and ice formation.

The seamen from earlier ages resorted to tars and greases in an attempt to discourage ice formation and to make it easier to remove. Today there are many waxes, silicones, and fluorocarbon compounds which are cleaner and easier to handle. There is no doubt that these compounds have improved the art of ice removal but they have done little to discourage ice formation.

However, I would like to propose to you this morning that one of the most promising avenues of investigation into the prevention or retardation of ice, lies in studying the interface between the substrate and water, and dealing with that surface by altering its physical and chemical characteristics. This is by no means the only approach to the problem but it is certainly basic and may provide a practical and effective way to achieve success. If we can address the problem at the very instant ice would normally form on a surface, and prevent it from forming in the first place, all other means of control could become secondary.

At this point, I would like to concentrate this discussion on the physical and chemical characteristics of various surfaces and examine a surface treatment which is effective in preventing or retarding the formation of ice.

To begin we must first understand something about the dynamics of surface wetting and ice formation. I must confess that I am not an authority on this subject. The fact is I know just enough about the subject to achieve some degree of success. I will further admit that my sources of information though limited are quite comprehensive and authoritative. I will refer frequently to John M. Sayward, and in so doing, I will be calling your attention to report #79-11 titled "Seeking Low Ice Adhesion" published in 1979 by the U.S. Army Cold Regions Research and Engineering Laboratory. John Sayward is the author of this report and I recommend this as basic reading for anyone interested in understanding the basics of ice formation and adhesion.

First let's explore water itself. I'm sure that most of us have seen high speed photographs of water droplets falling freely in air and observed that they are nearly spherical in shape. Sayward explains this. The water molecules simply have nowhere else to go and hence all the energy which makes them mutually attracted to each other draws them uniformly toward the center of the drop. Except for the disturbing influence of air, the shape of the droplet is round. But the instant the droplet comes in contact with a surface a different flow of forces occurs. Like anxious sailors rushing ashore after months at sea, the water molecules make a dash for the surface and the near perfect shape of the sphere is destroyed. Now, just as there are ports highly favored by sailors who have spent many months at sea, so there are surfaces which are very attractive to water molecules. Their energy finds greater satisfaction in close proximity to the molecules of the substrate rather than within the confines of the droplet. These surfaces are highly wettable and are also known as high energy surfaces. Glass for example readily wets in contact w: water and water appears only as a flat sheet on the surface.

Other surfaces however, may not be quite so attractive to the water molecules. Such substrates as polyethylene, a freshly painted surface or a recently waxed automobile may not readily attract the molecules. Hence the droplets, though considerably flattened, still tend to exhibit some degree of roundness.

Since all surfaces vary in their ability to be wetted by water, we may expect to see differences in the shape of water droplets at rest on these surfaces. Indeed a profile of this difference in shape has become an accepted method of measuring the wettability of a surface. The units of measurement are degrees of an angle called "contact angle", and is formed by two lines, one being the substrate or base, and the other, a line drawn tangent to the side of the droplet. The higher the contact angle the more non-wettable the surface. The profiles of droplet shapes may range from hemispheres having contact angle of approximately 90 degrees or to a shape similar to a paint blister with a contact angle of 20 degrees or less. A film of water has no measureable contact angle.

Sayward draws a comparison between ice adhesion and contact angle. In general, he concludes that surfaces with the highest contact angles demonstrate the poorest ice adhesion.

Ice forms on a wet surface when that surface is cold enough to draw sufficient heat from the droplet. When a high energy surface such as glass for example, is thoroughly wetted, water is in such intimate contact with the surface that heat is lost rapidly and the resulting ice adheres tenaciously to the surface. The effort needed to scrape ice from a windshield is a good demonstration of strong ice adhesion to a highly wettable surface. Lower energy surfaces will cause ice to form in more bead-like shapes and ice adhesion is somewhat less.

Sayward also describes ice as a true adhesive and points out that when ice forms, another type of bonding force is at work called hydrogen bonding. These forces are greater than the Van Der Waals forces described in the mere wetting of a surface and these hydrogen bonds greatly enhance ice adhesion. In addition surface roughness further increases adhesive strength by enlarging the surface area and hence the H-bond sites.

Although the seaman from past generations knew well the pleasures of returning to port after a long voyage at sea, I am sure he knew nothing of water molecules, Van Der Waals forces and contact angles. Yet he was surprisingly on target when it came to treating a surface to discourage ice formation or reduce adhesion. Tar and grease are after all relatively low energy surfaces but neither these nor other low energy compounds have yet totally solved the problem of ice formation. True, ice adhesion may be substantially reduced, but ice can still form.

Now, armed with this basic understanding of wetting and icing, I would like to share with you an approach to the problem which has demonstrated considerable success in its ability to prevent the formation of ice. I have made available to you a small plastic sheet on which a unique coating has been applied. In the development of this coating, we confronted the problem of ice formation by creating an extremely low energy surface. Using contact angle as a measure of surface energy the energy of this surface is low enough to yield a contact angle of 140 degrees.

Remember the contact angle of water on glass is nearly zero. By comparison, the contact angle on aluminum may be as high as 50 degrees. Fluorcarbon and silicone may yield contact angles from 95 to 105 degrees.

A contact angle of 140 degrees approaches the near spherical shape of a droplet in freefall. Using Sayward's corelation of contact angle to ice adhesion, we can conclude that the adhesion of ice to this surface is extremely poor. However by careful observation of a water droplet on this surface you will also see an air layer at the interface. The presence of the air layer, plus the near spherical shape of the droplet leads us to the conclusion that the energy of this surface is so low that the molecular forces continue to be directed toward the center of the mass. Referring back to our analogy of sailors and water molecules, it may be just as difficult to conceive of a surface as non-wettable as this, as it would be to imagine a port of call so repulsive that not one sailor wants to leave the ship. This phenomenon, ladies and gentlemen, is "Super-Hydrophobicity". No, it is not a new disease but it is an effective means of preventing the formation of ice.

A surface as hydrophobic as this, when constantly pelted by rain and sea spray, causes two unique phenomena to occur which play important roles in the prevention of ice formation.

First, upon impact, the droplets shatter and appear to bounce away from the surface. Hence, they remain constantly in motion and when in motion, water has less of a tendency to freeze. Second, the layer of air at the interface retards the loss of heat to the surface thereby discouraging the water from becoming ice.

Sayward states repeatedly in his report that the occlusion of air at the interface may be one of the most important factors in reducing ice adhesion. He is quite correct. However, what we have observed in the hundreds of tests and on-site applications of this coating which have been made on radomes and antennas exposed to rigorous ice forming conditions from the east coast to Alaska, is that we have not just been successful in reducing ice adhesion, but preventing its formation. We can only theorize that in this instance, the very high contact angles typical of this coating provide a correspondingly high volume of air at the interface, enough to provide sufficient insulation against the loss of heat from water to the substrate.

We have explored the traditional views regarding icing problems, briefly touched on past methods of controlling the problem, explored the dynamics of ice formation and been told of an approach which is effective in preventing or at least greatly reducing its formation.

The ultimate question is, does it work?

The answer is yes.

Let me quickly review for you just a few of many field applications and tests which have been conducted which demonstrate the remarkable ability of this coating to retard ice formation.

Work first started about 5 years ago in an intensive research program for the FAA and Bendix Corp. The objective was to find a suitable coating for M.L.S. radomes that would both prevent water sheeting and ice formation. Coated surfaces showed total absence of wetting and ice. However, the earlier versions of the coating had to be made more durable. A current application on an M.L.S. Radome is located at the Vadez Alaska Airport and has withstood three winters with no sign of ice formation during that period.

G.T.E. Sprint has coated a radio tower in the mountains above Salt Lake City and has reported the tower free of ice during conditions which would normally cause heavy icing and loss of transmission power.

General Electric,at Vandenberg A.F.B.,coated a teflon radome surface with this coating and during severe rain conditions reported that extremely high bore sight shift errors experienced with the teflon surface had been completely eliminated with the new coating.

Ford Aerospace conducted a similar test on a variety of radome materials reported to be water repellant and found this coating to demonstrate no signal attenuation at rain rates up to 27MM per hr. The other surfaces tested showed losses as high as 8DB.

Numerous field tests and commercial applications have been made on a wide variety of commercial satellite communications systems all showing dramatic reductions or complete elimination of icing.

Although most of our experience has been on land based communication systems, two significant tests were conducted at sea last winter which indicates the coating does perform in the marine environment.

A number of test panels measuring 12 inches square were placed aboard fishing vessels operating in Alaskan waters during the winter. All reported no ice accumulation on the panels in spite of heavy accumulation on surrounding areas of the hull and superstructure.

Portions of a 65' offshore lobster boat in Rhode Island were coated and the master reported similar results. No ice accumulation in the coated areas.

So..........

At this point I would like to conclude my remarks and invite any questions which you may have in the time remaining.

ARCTIC ICE IMPACT ASSESSMENT FOR

NAVAL SURFACE COMBATANTS

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and

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December 1985

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ABSTRACT

An investigation has been performed to assess technologies relating to the performance and design of U.S. Navy surface combatant hull structures operating in the arctic marginal ice zone (MIZ). Existing naval combatants are highly optimized ship systems with far greater power-to-displacement ratios than most arctic-capable ships, and these ships generally have lightweight waterline structures where ice impact is most likely to occur. In addition, numerous appendages, including rudder, propellers, sonar domes, and fin stabilizers may be susceptible to ice impact damage. Commercial and Coast Guard experience has led to the development of ice-strengthening design criteria which may apply poorly to U.S. Navy ships because of differing hull form, powering, and structural configuration. For safe utilization of existing and proposed navy combatants within the MIZ, it will be essential to modify the existing ice-strengthening criteria to apply to naval hull configurations or develop new criteria altogether. Structural assessments of appendage and propulsion systems will have to be performed in order to utilize these ships to their full potential within the MIZ.

INTRODUCTION

A need has arisen to investigate U.S. Navy surface fleet operations within the arctic marginal ice zone (MIZ),[1*] which is described as that region between open water and pack ice within fifty kilometers (31 miles) of the pack ice.[2] In addition, commercial development of the vast mineral resources of the U.S. and Canadian arctic regions has led to increased ship traffic within these remote areas by icebreaking and ice-strengthened cargo ships. Support of this commercial fleet will necessitate a competent arctic/cold weather-capable naval surface fleet.

A literature search has been performed to investigate technologies relating to U.S. Naval surface combatants operating in the high arctic MIZ. Of particular

* A complete listing of references is given on page 44

interest has been the response of the primary hull structure and appendages to impacts from broken and unbroken pack ice resulting from operations within this region.

Conventional naval surface combatant design philosophy has led to the development of highly optimized ship systems not intended for operation in an ice hazard environment. Ice strengthening of ship structures requires specialization generally in conflict with conventional operational constraints. For this reason, ice strengthening has not been specified for U.S. Navy surface combatants, although some design requirement may be necessary in order to safely utilize these ships in the MIZ.

A great deal of experience has been gained relating to ice strengthening of commercial and coast guard ships. This is reflected in the design criteria published by the ship registries of all major countries with northern climate interests. In all cases where commercial ships are intended for operations in the arctic MIZ as opposed to the non-arctic MIZ (i.e., Baltic Sea, Gulf of St Lawrence), ice loads govern design and control ship configuration and arrangements.

A large number of icebreakers and ice-strengthened ships have been built by various countries, and much research has been conducted to establish safe design guidelines and related technologies for these ships.

Naval experience within the MIZ has largely involved either submarines or noncombatant ice-strengthened ships, including icebreakers. In general, naval surface combatants are the most complex of ship systems and are thus the most highly optimized. Radical structural modifications required for high-intensity ice strengthening would adversely affect conventional combatant ship operations.

Hence, existing ice strengthening technologies may be unacceptable for these ships.

The principal purpose of this study is to summarize the background information relating to surface ship structural response to ice loading. This includes assessment for ice pressure loadings as well as hull and appendage structural response analysis.

A wide variety of sources have been utilized to obtain relevant information. These include the USCG, the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), NORDA, NOAA, the Ship Structures Committee (SSC), ABS, ARCTEC, Inc., various foreign sources including Canadian, Soviet and Scandinavian sources, and other academic and commercial sources.

For naval surface combatant ships operating in the MIZ, information is lacking in certain important areas. These include ice impact damage surveys, operations in broken ice, high speed ice impact pressures, ship response to high speed ice impact, response of longitudinally stiffened ship hull structures to ice impact loading, flow of ice fragments against a ship hull, response of appendages including rubber sonar dome windows, rudders and CP propellers, navigation in the MIZ, and safe operations for non-ice-strengthened ships operating within ice.

U.S. NAVY OPERATIONAL SCENARIOS

The arctic MIZ occurs in both the Atlantic and Pacific Oceans although the North Atlantic regions present the most severe operational conditions because of the highly variable weather, wind and current patterns, icebergs originating in the Greenland ice sheets, and greater likelihood of encountering thick, multi-year ice formations.

The North Pacific arctic regions present a significantly different set of conditions because of containment by the Bering Straits and because of the absence of large glacial ice sheets to produce icebergs. Multi-year ice formations are not generally encountered south of the Bering Straits.

Conditions in the antarctic differ radically from those of the north. Geographically, the arctic is a large body of water surrounded by land masses while the antarctic is a large body of land surrounded by water. Therefore, significantly different environmental conditions exist at the south, which is characterized by massive floating ice sheets of great thickness and age which break up to form vast tabular icebergs. These exist in addition to first-year break up to form vast tabular icebergs. These sheets of ice exist in addition to first-year and multi-year ice similar to that of the arctic regions. Greenland icebergs are more typically towering angular structures resulting from the calving of ice from the land-based glaciers as opposed to the antarctic tabular icebergs which are huge fragments of the antarctic ice shelves.

Because of the great volume of scientific research that has been conducted in Antarctica, which has required naval support, much of the existing data applicable to ice strengthening criteria has been obtained in this region. The most extensive example of ice damage applicable to naval combatants has been obtained from the U.S. Coast Guard from the damage sustained by the icebreaker WESTWIND which was severely damaged by a freak impact with an antarctic ice sheet of great thickness in 1983.

The arctic environment is characterized by great variability of climate which results in ice formation, storms, and fog conditions which can limit safe ship operation. Ice may exist within this environment in many forms including pack ice, icebergs and iceberg fragments called growlers. Although radar can generally be depended on to detect this ice hazard, it cannot be absolutely trusted, especially with small, isolated ice fragments in rough seas conditions. Generally, visual observation is considered the only dependable method of ice detection.

The marginal ice zone is described in terms of the fraction of open water to ice-covered water in terms of tenths or eighths. In other words, 4/8 or 5/10 ice would be half open water and half ice floes.

Within a non-arctic region, such as the Baltic or Gulf of St. Lawrence, the edge of the MIZ would be the operational limit for a non-ice-strengthened ship such as a naval combatant. However, it is important to emphasize the difference between the arctic and non-arctic MIZ. The non-arctic MIZ would be characterized by ice floes of variable size less than about three feet in thickness occurring in primarily temperate to northern climates, while the arctic MIZ will be characterized by floes of much greater thickness existing in northern temperate to arctic climates. Clearly, broken ice floes in the arctic MIZ will present a far greater threat to ship operations than similar ice conditions in a non-arctic region.

Icebergs and growlers present an extreme hazard to ship operations because the ice tends to be thicker and more massive than sea ice and is composed of fresh water ice which may be up to three times stronger than sea ice under similar conditions.

Generally, the surface combatant will be subjected to operating conditions and requirements quite different from those of other ships. The commercial ship will view the MIZ as an obstacle to be avoided or crossed if absolutely necessary in order to reach a distant port. When necessary, commercial ships will follow icebreakers through a broken channel. The primary function of these icebreakers is to maintain passable transit through pack ice for the commercial fleets. Surface combatants, on the other hand, might be required to operate as deeply as possible in the MIZ without actually engaging in icebreaking operations which require ice strengthened, specially configured hulls which are poorly optimized for conventional naval operations.

Severe ice strengthening requirements may be necessary for naval combatant operations near the arctic MIZ. The MIZ involves a complex structure of large floes with open leads, all of which are constantly in motion. A surface combatant operating in wartime might be required to extend itself deeply into these open leads to perform its mission. Once within a lead, ice may shift and close the lead off such that the ship will be forced to break a channel to get out if it is not following an icebreaker.

Without exception, ship operations in pack ice require slow speed to reduce the magnitude of ice impacts. However, a warship would conceivably be required to use full power during emergency conditions if engaged by enemy ships or aircraft while in the ice. As combatants are highly-powered ships, this would result in extremely high impact loads to hull and appendages.

Hence, for combatants operating in the arctic MIZ, the highest degree of ice-strengthening, comparable to that employed for icebreakers, might be required to permit the ship to safely perform its mission.

Particular structural areas where ice impact will be of concern include the following:

1. Hull shell structure including plating, stiffeners and frames
2. Propulsion system including shaft, shaft struts and propellers
3. Appendages including sonar dome, stabilizers, rudders, and bilge keels
4. Miscellaneous structures including hull air masker system

For the U.S. Navy combatants, ice impact loading is not a design criterion for any of these structures.

Although not strictly a cold regions problem, topside icing may present significant structural loads which should be addressed for naval combatant operations not only in the MIZ but in any environment subjected to sub-freezing temperatures and storm sea conditions.[3]

Severe cases of topside icing have been reported on naval combatant ships operating in temperate regions during winter months. In fact, this icing condition is a more severe problem in the temperate climates where bad winter storms combined with optimal icing temperatures are common.

Although reduced stability with risk of the ship capsizing is the principal topside icing concern, structural effects may be significant, including increased primary hull bending stress resulting from ice buildup. As icing will occur during storm conditions when maximum bending stresses would normally be encountered, any additional weight is reason for concern as it may cause excessive levels of stress which may lead to a severe overload condition and possibly to failure.

There are no modern primary hull failures of U.S. Navy ships attributable to wave effects encountered during storm conditions. Hence it is probably safe to state that these ships have always been built with at least an adequate margin of safety for these loads. However, with the increased use of sophisticated computer techniques for loads, response, analysis and ship design, a tendency for minimized structural scantlings is observed. This reduction is especially notable with the intensively optimized nature of modern combatants which are continuously requiring an increasing amount of non-structural systems hardware to adequately perform their missions.

In addition to primary hull loadings resulting from topside icing, ice removal loads imposed by ship's personnel may be a possible cause of local structural damage. Because overall ship stability may be threatened by severe topside icing, it is critically important to remove the ice with maximum haste. Hence, baseball bats and nylon hammers are maintained aboard ship for the purpose of ice removal, and during severe icing it is conceivable that these would be utilized with utmost enthusiasm by a ship's crew in an attempt to prevent loss of the ship due to capsizing.

For these reasons, dynamic impact loads and analysis techniques might necessarily be considered for design of topside structures, particularly highly optimized topside structures, such as metallic sandwich or composite structures, that are currently under consideration as a weight-savings alternative to conventional structures.

SUMMARY OF EXISTING ICE STRENGTHENING CRITERIA

A large number of ice strengthening design criteria exist and are included in various commercial ship registries and other sources including the ABS Rules, Lloyd's Register, the Canadian Arctic Shipping Pollution Prevention Requirements (CASPPR), the Finnish-Swedish Ice Class Rules (FSICR), the Soviet Register Rules, U.S. Coast Guard guidelines, and a variety of others.

In general, these criteria cover two ranges of ice strengthening including strengthening for non-arctic waters such as the Baltic Sea and arctic waters under icebreaker design. Generally, the criteria are quite vague in specifying limits as far as ice conditions, season and other environmental parameters.

Most of these criteria are intended for transversely-stiffened hull structures and apply poorly to longitudinally-stiffened structures such as U.S. Navy combatants.

In general, the various criteria account for ice loading as a uniform pressure load applied to the hull. For plating design, the pressure load is applied to the entire plate panel. For frame design pressure is applied as a discrete band. Plating design is based on thickness sufficient to permit formation of three ideal plastic hinges in the plating without development of permanent set at the midspan hinge location. This idealized theory is based on the great ductility of most structural steels.

Most of the regulatory agencies define the ice load by specifying design pressures for an icebelt structure for the ship's hull. This icebelt is divided into several regions including bow, mid and stern sections to which specified pressures are applied. When calculating plating thickness and frame section modulus (longitudinal or transverse) for these regions, the design ice pressure varies with highest pressure in the bow region. For a given design, this pressure is applied to equations for calculating specific structural scantlings. The only other common parameter is the vertical extent of the ice belt. This value will vary depending on the thickness of ice that the ship is likely to encounter. The following is a brief synopsis of existing ice strengthening criteria and analytical procedures:

1. The Canadian Arctic Shipping Pollution Prevention Regulations (CASPPR).[2] These rules are the most comprehensive standards in use today. They include nine icebreaking classes and five ice strengthening classes, with the lowest class having no ice strengthening applied. A total of sixteen zones, broken down by geographic area and time of year, define where a certain class of ship is allowed to go. The ship itself has six hull regions with specified design ice pressures ranging from 100 to 1500 psi, depending on ice class and hull location. No explanation of the development procedures for the design ice pressures was determined. Therefore, it is difficult to ascertain exactly how these rules were derived. An important limitation is the geographic restriction to Canadian waters and nearby arctic regions. Additionally, these rules do not take into account yearly variations in ice coverage and thicknesses. The rules appear to be based on a statistical analysis of the ice. A minimum ice pressure is set, by geographical area and season, to which all ships will be strengthened.

No attempt has been made to take into account the ship's hull, displacement or horsepower. However, these rules are intended for pollution prevention and are not the rules of a regulatory body.

2. The Finnish/Swedish Ice Strengthening Criteria (FSICR).[2] These rules are based on B.M. Johansson's ice strengthening work[4] which defines minimum ship parameters for operation in Baltic Sea ice conditions based on ship damage survey histories for this region. Specifically, this relates design ice pressure as a function of ship's shaft horsepower and displacement. There are four classes of ice strengthened ships including extreme, severe, medium and light; and one icebreaker class. However, these categories are not defined in terms of ice conditions. Instead, the Finnish Board of Navigation issues periodic reports outlining the geographic boundaries that define the specific ice conditions. These reports are good only for the Baltic region. Nevertheless, a number of commercial regulatory bodies do include a version of these rules in their own regulations. These agencies include the American Bureau of Shipping, Bureau Veritas (France), Det Norske Veritas (Norway), Nippon Kaiji Kyokai (Japan), and the ice strengthening classes of CASPPR.

3. Johansson's Approach.[4] Johansson's work follows the same principles and is the basis for the FSICR rules. However, Johansson has assumed a lower damage probability and consequently has higher design pressures. He also uses a plastic section modulus for framing analysis rather than elastic criteria. The design ice pressures do not exceed 430 psi (30 kg/cm2) and the vertical extent of the design ice load is fixed at 2.62 ft (800 mm) which is the normal thickness after one winter in the Baltic region.

4. Soviet Register Rules (SRR).[5] These rules have several interesting aspects. First, they take into account the shape of the ship's hull. A ship that is more wall-sided amidships and that has a higher waterplane coefficient is penalized more heavily that a ship with a fine bow and an angled frame at the waterline. This method allows the rules to account for different impact angles between the ice and hull resulting in a change in the overall force transmitted to the hull. These rules also take into account the ship's shaft horsepower and displacement. The rules are based on the work of Yu. N. Popov and D. Ye. Kheisin[6] who present an analytical model that solves the differential equations of motion for the ship-ice interaction. Using parameters involving the ship's mass and speed relative to the ice floe, displacement, hull shape, ice properties and ice shape, a collision between ice and ship is solved. The equations provide the pressure loading on the ship, the vertical extent of the ice contact and the total force applied to the ship.

5. Percentage Increase in Scantlings.[2] For ice strengthening, a number of regulatory bodies just increase the plating thickness and frame section modulus a certain percentage over the nominal values calculated from the rules for non-ice-strengthened ships. These percentages vary with the regulatory bodies and do not have any apparent

analytical basis. Additionally, the various ice classes do not specify the ice conditions for that class. Regulatory bodies which have such regulations include Bureau Veritas, Registro Italiano Navale (Italy), Ge' anischer Lloyd (West Germany) and Polski Rejestr Statków (Poland).

6. U.S. Coast Guard (USCG).[7] The USCG has a wealth of experience in ice operations. However, most of their efforts are directed towards icebreaking rather that ice strengthening. Reference 7 explains the rationale behind the design of the POLAR class icebreaker. Ice design pressures of 300 to 600 psi were utilized for the design of this ship. Various factors, including ship hull region, dynamic or static loading conditions, contact area and data reliability were applied to this ice pressure to arrive at the hull design pressure. Finite element analysis methods were used for structural analysis of the plating and framing. An interesting study done during the design cycle was a computer analysis of the loading distribution which was used to determine impact load and area as a function of location. The results demonstrated the validity of modeling the ice load as a uniformly distributed pressure load. Recent reports[8] indicate that plastic analysis methods are now accepted for plating design. This analysis method reduces plating thickness and structural weight while maintaining acceptable plating strength.

7. Analytical Methods.[9,10] Several analytical methods were reviewed to appraise their applicability to design methods. In reference 10, R.A. Major, et al, provide a computer simulation of the ship-ice interaction, based on the analytical model derived by Popov and Kheisin. By solving the differential equations for the ship-ice interaction, the force applied to the ship and the loading distribution can be found. Major's model includes the effects of acceleration and six degrees of freedom to the Popov model for solution using computer techniques. However, this model predicts higher impact forces than those observed in full scale experiments. This difference was thought to be the result of variations between actual ice which has many imperfections and the uniform, uncracked ice modeled analytically.[6] Reference 6 describes the results of full scale trials conducted in ice on the ore carrier LEON FRAZER and on the icebreaker MACKINAW to measure ice impact loads. Equations are provided for predicting the force exerted on the hull for specified ice conditions. However, no distribution for this force over the hull's surface is given, and there is a large degree of scatter in the observed data.

8. Proposed American Bureau of Shipping Rules (ABS).[6] These new rules are similar to the SRR rules in that they are based on the analytical work done by Popov and Kheisin. They take into account the ship's hull shape, displacement and shaft horsepower when calculating design ice pressures and the vertical extent of the ice load. The ship's hull is divided into seven regions, similar to the CASPPR, where different ice pressures are applied. More information is available to the designer. The ice classes are defined by the ice thickness and/or ice coverage that a ship would be expected to withstand if strengthened according to these rules.

9. Foreign Naval Design Standards.[11] Ice strengthening design standards were obtained for the United Kingdom and Canada. Both countries stipulate that if a ship is to be built for ice strengthening it should follow commercial guidelines. Canadian standards do have provisions for strengthening of warships for impact by brash ice. However, even with this light ice condition, the design pressures for the shell plating range from 145 to 220 psi although this load is applied only for a short distance along the hull in the bow region.

ICE IMPACT HISTORIES

According to the U.S. Navy Safety Office,[12] which maintains a data base on ship damage events, there is no incident of ship damage due to impact with floating ice at least since World War II for U.S. Navy ships. Prior to this time, data is unavailable; however, encounters with ice conditions probably occurred during Allied naval operations out of the northern Soviet ports during World War II.

The Naval Historical Office maintains records of ship's logs which would be usable for obtaining details of these naval operations during World War II. Unfortunately, this voluminous data base is not indexed and thus probably unusable at the current time for conducting this type of research.[13]

Apparently, ship damage casualties have occurred due to ice impact on Military Sealift Command (MSC) ships while involved in arctic supply missions.[14] Details of these incidents are currently being investigated.

The current WIND Class of U.S. Coast Guard icebreakers were built during WWII and commissioned as Navy ships which did see service in the MIZ during this time period, and these experiences should still provide useful data for any proposed combatant operations near the MIZ.

With regards to reports of ice impacts to operating combatants, it is probable that numerous impacts have occurred but gone unreported. In all likelihood, the ice, if small enough, would be far behind the ship before it could be seen, or it would remain unseen or unheard by the crew. Waterline inspections of most combatants reveal small dents and scrapes resulting from many causes ranging from docking maneuvers to possible impact with ice. It is unlikely that minor dents would be reported as ship damage unless they affected the overall ship performance.

A number of ice impact incidents have occurred with the commercial fleet which is actively operating in ice-covered waters. The most notable is an incident involving the 28000 DWT ore carrier M.V. ARCTIC which, although strengthened, suffered severe damage from a random ice impact while transitting in the Canadian arctic.[2]

This ship received a thirty-foot gash in its side as a result of an impact with what is believed to have been a growler. Although a severe impact, it went unnoticed by the crew until the ship developed a list while under way. The ship was able to make port and was subsequently repaired. This incident significantly illustrates that even an ice-strengthened ship, configured for ice breaking with heavy plating and framing can be damaged by ice impact from a piece of ice small enough to go undetected while the ship is underway. This incident emphasizes the hazards of high speed ice impact to non-ice-strengthened ships such as naval surface combatants.

A very severe ice damage incident occurred to the U.S. Coast Guard icebreaker WESTWIND while engaged in operations in the antarctic during 1983.[16]

The WESTWIND was operating in heavy pack ice adjoining an expanse of shelf ice that stood about thirty feet out of the water. This shelf ice occurs in only a few scattered places in the arctic and does not achieve the thickness of the antarctic shelf ice. The WESTWIND apparently lost headway and was squeezed against the shelf by forces great enough to heel the ship. A combination of this list and the extreme thickness of the ice resulted in ice loading above the ice-belt where the steel plating is only one half inch thick. After an initial puncturing of the hull by the ice, motion forces opened a tear in the hull greater than one hundred feet in length due to a "canopener" effect. This extensive tear was only a few feet above the waterline and during the event there was great danger of loosing the ship. It was observed that a minor wave action or a greater list would probably have resulted in complete loss of the ship with probable loss of life.

It is significant to note that the shape of the tear indicated little deformation of the ice during the incident which indicates very great ice strength. In all likelihood, this ice, which stood well out of the water, was probably fresh water ice of much lower temperature than the surrounding seawater. Decreasing salinity and temperature tend to greatly increase the strength of ice.

However, it is notable that the damaged plating on the WESTWIND is similar in size to thicker waterline hull plating on existing surface combatants which might be operating in the arctic MIZ. In fact, since this plating is transversely framed, with a 16" frame spacing, it is probably far more resistant to a horizontally progressing load than equivalent longitudinal structure.

ICE STRENGTH PROPERTIES

Ice strength properties are highly dependent on temperature, salinity, crystal structure, load orientation, and load rate. Because sea ice typically exists at very nearly its melting temperature, these effects are especially significant and will result in a very wide range of observed strength properties.[17,18,19,20,21,22]

Additionally, arctic ice is formed by a variety of different processes which greatly alter its strength properties. The principal types are sea ice and glacier ice in the form of icebergs.

Sea ice is the predominant ice form and is formed from freezing sea water. Sea ice formation is characterized by rapid initial growth followed by gradually decreasing rate of formation. This decreasing rate of growth is a result of ice growth on the bottom of the ice sheet which is increasingly insulated from the very low temperatures of the top surface as the ice thickness increases. In northern temperate climates this may result in winter ice buildup of up to three feet, and in the arctic ice pack, it may build up to six foot thickness in a season.

The salinity of sea ice will decrease its compressive strength by a factor of up to three. However, with increasing time, the brine inclusions in the ice will tend to migrate downward resulting in reduced salinity and increased strength. In addition, the temperature of the ice floe will vary widely through the thickness depending on air temperature at the top surface. These effects result in widely varying strength properties across the thickness of of the ice floe which are difficult to assess.

Strength properties of sea ice also differ widely with direction of load. Vertically, in the direction of ice growth, the strength greatly exceeds the strength in the horizontal direction. Ship impact with ice will normally be perpendicular to the growth direction, but a random impact direction might be possible in broken ice.

Pack ice will form over broad regions that are continuously subject to the effects of wind and currents. This causes ice floe motion which results in high lateral ice loads which can endanger ships within the ice and lead to the development of pressure ridges and rafted ice. These formations can greatly increase the thickness of ice which a ship may encounter, especially in the arctic regions where the magnitude of the ice pack is much greater.

As a result of this, it must be assumed that a ship operating within the arctic MIZ will encounter ice at all points below the waterline icebelt structure.

Icebergs and fragments of icebergs called bergy bits and growlers result from the calving of glaciers where they intersect the sea. This ice is freshwater ice originating as inland snowfall which has subsequently accumulated and been greatly compressed resulting in maximum hardness and strength properties and a homogeneous structure.

Although icebergs may be huge in size, sonar and radar will adequately detect these at great distances such that they may be safely avoided by a ship under way.[23] The greatest iceberg threat to ships in the arctic probably results from the growlers which are small fragments of icebergs that can only be safely detected by visual observation, especially during rough seas when they will be well hidden from radar detection by waves. Even though relatively small in size, these growlers may still weigh hundreds of tons and are capable of causing great damage to even heavily ice-strengthened ships.

Icebergs present an additional low-speed navigational hazard to ships operating in the MIZ because they will frequently move at a different speed and direction than the pack ice.[15] This occurs because of the great draft of the icebergs which subjects them to deep-water currents which may differ from the surface currents and wind controlling the motion of pack ice. This is a principal reason for wide avoidance of icebergs by experienced arctic pilots.

Ice strength properties are difficult to rationally quantify because of the wide variation of descriptive parameters. For this reason, most of the available ice engineering data is based on a limited number of empirical studies. In general, the results of these studies have varied so widely that no simple, rational set of design values can be obtained from them and, indeed, it is probably not possible to do so.

The most recently performed empirical studies,[24] conducted jointly by several commercial and government agencies, have utilized the USCG POLAR SEA with instrumentation to measure ice impact strains over a wide forward region of the icebelt. Based on these measurements, icebreaking loads and pressures were calculated, and it was shown that, during impact, ice does not provide a truly uniform pressure loading but rather, a variable pressure loading. In addition, it was shown that the average pressure loading decreases as the total loaded area increases. Hence, describing ice strength with a single ultimate pressure load, as is generally done, is a coarse approach which can probably be improved with more rational methods.

Current design methods utilize ice pressures ranging from about 100 psi to about 600 psi depending on a range of parameters. Loading is generally applied as a uniform pressure load distributed across a plate panel surface. These methods presume relatively thick plating and impact with large ice floes such that the ice is fully deformed plastically so as to provide a high magnitude, uniform pressure load.

Therefore, it may be necessary to retain the existing structures and determine operational limitations based on ice load capability, in lieu of ice strengthening for naval surface combatants. Because these ships utilize thin plating at the waterline, conventional analytical procedures may be invalid as they presume high loads with fully plastic ice behavior. For thin plating, concentrated and small patch loadings may determine ultimate ice load before fully-plastic ice behavior is achieved. In addition, because high-speed operation is anticipated, ice properties at very high strain rates, which are poorly defined at present, may govern the analysis procedure. It may also be necessary to consider effects of random impacts with iceberg fragments which would necessitate application of high ice strength properties.

To summarize, rational selection of design ice pressure is difficult and consists of either selecting an average, basically arbitrary pressure, selecting a maximum pressure taken from the existing data base of ice strength values, which may be excessively conservative, or obtaining a pressure based on theoretical solutions which may vary widely from actual strength data.

ICE LOADINGS

Several analytical methods exist for rationally predicting the magnitude of ice impact loading to the ship's hull. Based on these loads, ice pressures may be obtained for design purposes. These methods are particularly important for framing and stiffener design where large-scale loading will apply.

It is possible to solve for the equations of motion between two colliding bodies in a viscous fluid, taking into account plastic deformation of all the bodies, to predict the magnitude of the impact force resulting from the impact. This approach has been used in a variety of the ice-strengthening criteria including the new ABS Proposed Rules and and the Soviet Register Rules (SRR). These theoretical procedures are described in detail by R.A. Major[10] who compares these theoretical loads to loads observed during impacts with small, first-year ice floes in the St. Lawrence Seaway. These theoretical and observed loads show poor agreement, with the predicted loads greatly exceeding the observed loads. However, there are many governing variables, and the empirical data may not have been representative.

Ice impact will result from the interaction of floating ice fragments with the hull and its appendages, and is a more severe hazard with increasing ship's speed. This ice impact will be complicated by flow patterns around the hull and by suction from the propellers.

It is well understood that ice normally flows around all wetted surfaces of an icebreaker hull as the ship is breaking ice.[25] However, these ships are configured for this and are radically different from conventional surface combatant hull forms. It is particularly important to determine whether ice fragments will impact the surface combatant appendages, particularly the sonar dome structures, which have relatively deep draft.

Even at relatively low ship speeds, propeller suction may be significant. Clearly, there will be an increased flow velocity around the stern structures and a variety of appendage and propulsion structures will be subject to this increased flow. Of particular concern here is the effect of ice interacting with the propeller leading to ice milling. Obviously, under certain circumstances, the torque capacity of a non-ice-strengthened propeller will be exceeded leading to increased threat of damage.

Stern hull structures will normally entail heavier plating and framing because of hydrodynamic and vibration loads. For this reason structural weight increases due to ice-impact loads may be minimized in this region.

ICE FAILURE MODES

As previously described, a variety of parameters significantly affect the strength properties of ice including temperature, salinity, load rate, crystal structure and load alignment.

Depending on load rate, ice will behave over the full range of material behaviors from fully plastic at very low strain rates to brittle at the upper range of impacts. These properties will be highly affected by the nature of ice confinement against the hull during impact. For a small fragment of ice, brittle fracture may govern during the initial stages of impact. However, as the size of the load patch increases, the ice in the center region of the load patch will experience a degree of ice confinement which will tend to cause the ice to behave plastically and will result in a great increase in the magnitude of the impact load.

LOADING AND RESPONSE METHODS FOR ICE IMPACT WITH SHIP STRUCTURES

The ship/ice interaction will result in a pressure load distribution to the ship hull structure. Ship hull response to ice impact is a measure of the stresses and deflections resulting from this pressure load with prediction of this response forming the basis of most design and analysis techniques.

Because loadings will range from static to transient/dynamic for a full range of ice properties, precise response prediction is particularly difficult for ice loadings and any techniques for such analysis will require a large degree of approximation.

A brief review of available response techniques is necessary to determine the best possible methods applicable to the needs of the U.S. Navy design community. These techniques have currently been incorporated into a number of ice-strengthening criteria in worldwide useage.

In general, ice loadings will be treated as localized loadings which will not be combined with other loads for design purposes as is normally done for conventional hydrostatic loadings. This design philosophy is based on the nature of ice loading which is typically encountered in still-water conditions such that wave-induced primary hull stresses are most unlikely to be encount ered concurrently with ice impact loads. In addition, ice impact will be severe in the forward and aft regions of the ship where primary hull girder bending forces are negligible. Also, because the waterline hull structure is typically near the ship's neutral axis of bending, a large degree of conservatism is already built in to these structures because of design guidelines that require a minimum bending stress to be applied to all primary structure regardless of calculated stress conditions. In general, ice loadings will govern design because of the severity of ice loadings relative to conventional ship loadings; hence ice strengthening will be applied to the smallest region possible along the ship hull to save weight and cost. This so-called icebelt structure will generally occur along the waterline although for icebreaking ships it may entail all structure below a certain height on the ship in order to permit full ice navigation which will require passage of ice beneath the ship.

The following ice-impact structural failure modes are significant to naval combatants operating in the marginal ice zone:[2]

1. Excessive permanent set to plating (dents; non-catastrophic)
2. Plating rupture
3. Buckling failure of stiffener leading to increased effective plate panel size. This will result in increased probability of plate rupture.
4. Yielding or buckling of transverse web frames leading to loss of overall structural integrity
5. Impact damage to following structures and/or appendages:
    a. Sonar dome and sonar
    b. Rudders and/or steering gear
    c. Propellers
    d. Propeller shaft and/or shaft struts
    e. Fin stabilizers

Generally, transverse stiffening arrangements are used on all ships intended primarily for arctic operations, including commercial and coast guard vessels of various countries including the United States. This is done, at the expense of primary strength contribution from the stiffeners, in order to reduce the load on the individual frame, which will be excessive for typical wide spacings on U.S.

Navy combatants. It is not envisioned that a transversely stiffened system would be incorporated within the existing naval combatants although a system of intermediate lateral framing could be incorporated to reduce the severity of the load in the existing transverse frame system.

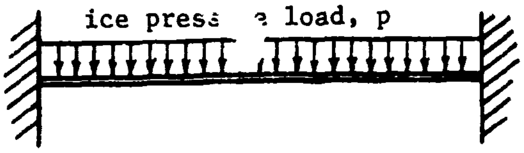
PLATING RESPONSE METHODS

In general, plating design for ice impact loads is performed using techniques similar to those for conventional plating design.[26,27,28] This involves the application of long-panel or beam theory within elastic or plastic ranges of cross-sectional response for the plate such that plate response is given by the following general equation for all conditions:

$$t \geq \frac{b}{f_1} \times (f_2 \times p \times \sigma_y)^{0.5} + t'$$

where, t = plate thickness, in.
b = plate span, in.
f_1 = elasticity/plasticity factor
f_2 = load factor
p = uniform pressure load, psi.
σ_y = plate material yield stress, psi.
t' = wear/corrosion allowance, in.

Within this approach, the plate panel is assumed to behave like an infinitely long fixed panel modeled as a simple fixed beam in bending. Elastic theory provides a bending moment due to a uniform load such that a linear cross-sectional response is maintained but such that the level of bending stress in the plate at the edges just reaches yield as shown in Figure 1.

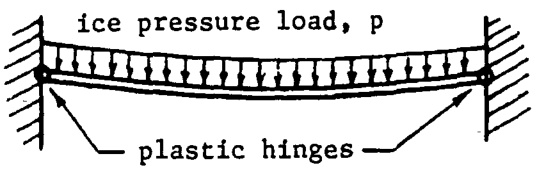


for this case, $f_1 = \sqrt{2.00} = 1.414$

$f_2 \geq 1.00$

Figure 1 - Elastic Plating Response

The <u>two-hinge plastic mechanism model</u> applies fully-developed plastic hinges to the panel edges while maintaining elastic response at midspan. The fully-developed plastic hinge is described by stress level just reaching yield throughout the plate cross-section. This model permits the initiation of plasticity while assuring no occurrence of significant permanent set after release of load. This model represents the beginning of elastic/plastic response and is described in Figure 2.

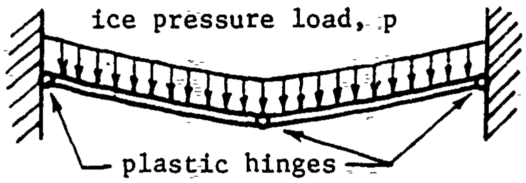


for this case. $f_1 = \sqrt{3.00} = 1.732$

$f_2 \geq 1.00$

Figure 2 - Initiation of Plastic Plating Response
(2-Hinge Plastic Mechanism Model)

The <u>three-hinge mechanism model</u> represents initiation of full plastic response for the plate panel as shown in Figure 3. At loads greater than those required to just initiate formation of the third hinge some level of permanent set will result after release of load although these techniques do not provide the magnitude of this deflection.



for this case, $f_1 = \sqrt{4.00} = 2.00$

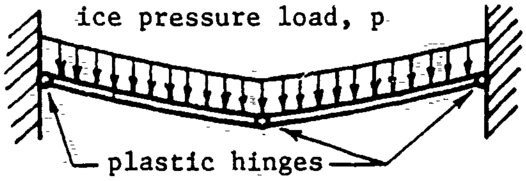
$f_2 \geq 1.00$

Figure 3 - Initiation of Full Plastic Plating Response
(3-Hinge Plastic Mechanism Model)

The three-hinge plastic mechanism method can be extended such that a degree of permanent set deflection is permitted with increase in pressure load. This theory accounts for membrane effects following formation of the three-hinge mechanism. Within this context, two ranges of permanent set may be considered. These include small-deflection which limits permanent set to the thickness of the plate and large-deflection in which permanent set exceeds the plate thickness as shown in Figure 4.

The U.S. Navy plating design criteria for hydrostatic and uniform loads follow these procedures but apply conservatism through the use of load and elasticity/plasticity factors.[26] The same techniques are also used within all the current ice-strengthening criteria which apply a variety of load and plasticity factors which differ from the navy factors in both derivation and purpose. It is significant to note that the Navy criteria provide for thinner plating thicknesses than all of the ice criteria because of the more poorly-defined nature of the ice loads as opposed to the conventional loads. It is a straight-forward task to compare the various criteria in order to fully ascertain applications and possible modifications which might be required for extension of the U.S. Navy plating design criteria to ice impact loads.

These techniques are based on the high post-elastic capabilities of most structural steels, especially the medium-strength steels.

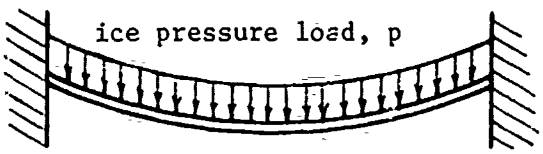


Small-deflection Permanent-set Plasticity
(3-hinge plastic mechanism model)

for this case, $f_1 = 2\times(1 + \frac{w}{t})$

$f_2 \geq 1.00$

where, w = permanent set deflection, in.
deflection, in.



Large-deflection Permanent-set Plasticity
(cable-membrane response)

for this case, $f_1 = 8 \times \frac{w}{t}$

$f_2 \geq 1.00$

Figure 4 - Permanent-set Plasticity Response for Plating

FRAMING RESPONSE METHODS

Similar methods of plastic analysis may be applied to framing and stiffener response although several of the assumptions normally applied involve a reduced degree of uncertainty.

As described previously, the structural response for a conventional, longitudinal stiffening system subjected to ice impact will be more severe than the response for a transversely stiffened system. These differences will be outlined in the following paragraphs.

The transversely stiffened system will consist of an array of main and intermediate frames aligned such that the governing ice load will consist of a uniform load applied to a discrete length of the frame with a width equal to that of the plate panel. This load is normally applied as an equivalent load of reduced pressure magnitude which covers the full length of the frame. In this way, a conventional pressure load rather than a discrete patch load may be applied for a simpler analysis procedure. This same load is applied to the plate panel.

For conventional, longitudinally-stiffened hull structures, both longitudinal stiffeners and transverse frames must be designed. Longitudinal stiffeners must be designed for a full ice impact load acting across the full panel for which the stiffener is support. Transverse frames must be designed for a discrete load band of full ice impact pressure across the full frame spacing. In both cases, load conditions will exceed those for the transversely stiffened structure.

Generally, stiffeners and framing will entail a lower degree of plastic reserve capacity than plating because of stability considerations and greater stiffness. In addition, the consequences of excessive frame permanent set or failure are more severe than for plating. Hence, plastic response methods for framing and stiffeners are less applicable than for plating. For these reasons, elastic or elasto-plastic response methods will generally be used for frame and stiffener design. Elastic, elasto-plastic and plastic response methods are compared in Figure 5.

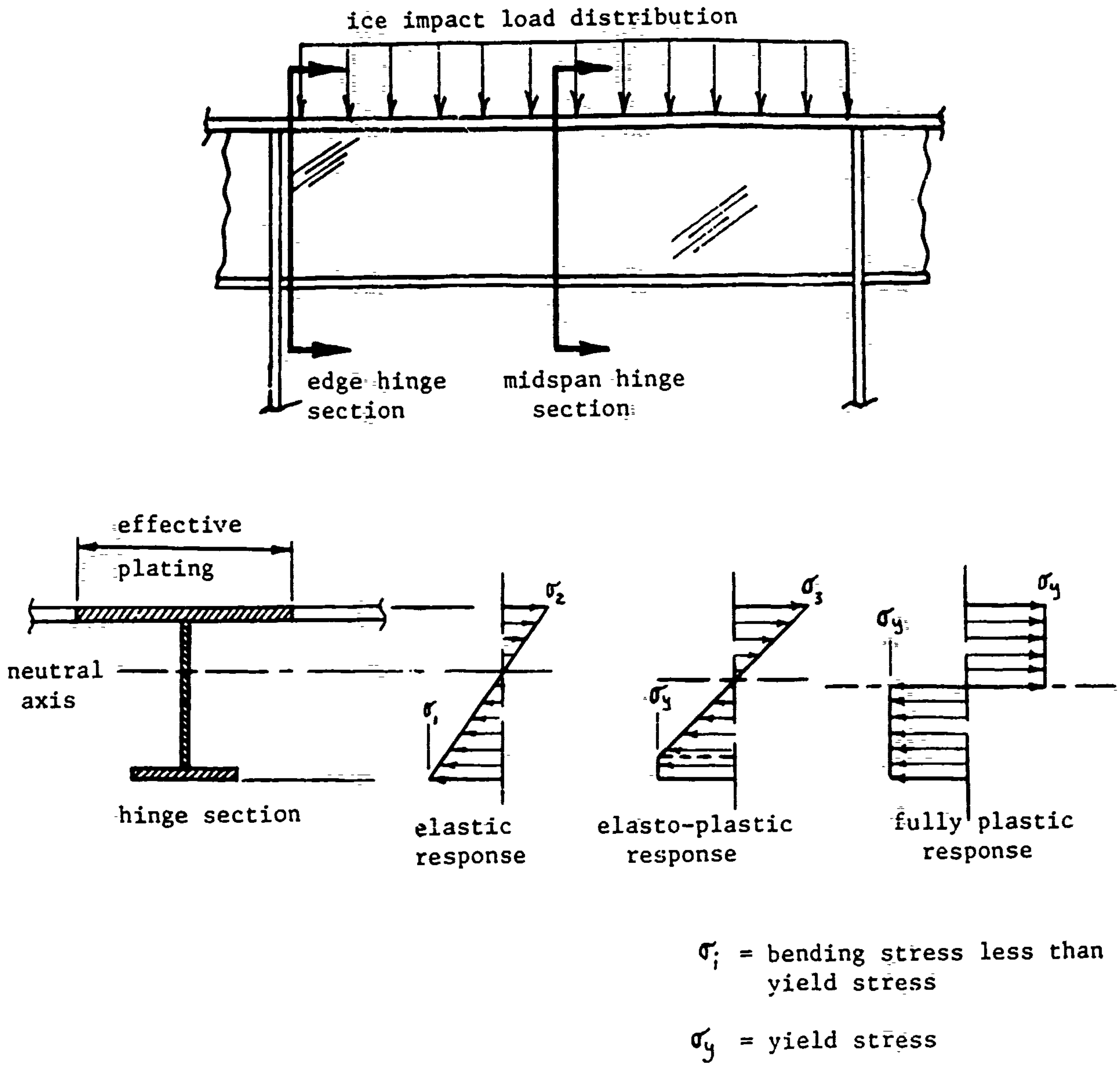


Figure 5 - Elastic, Elasto-plastic, and Plastic Framing Response

ICE IMPACT TO PROPELLERS

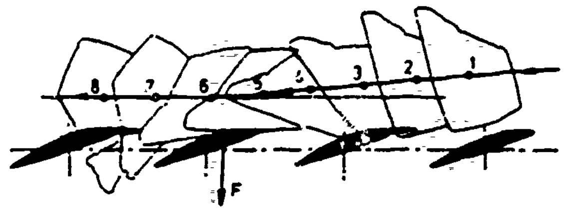
Damage to the ship's propeller due to ice milling is probably the most commonly encountered form of ice damage for ships operating in the MIZ, including icebreakers.[29,30] In addition, ice milling loads are probably the most difficult to analyze and the most difficult to avoid during normal operations in the ice.

Several important variables affect propeller ice milling. Milling loads will be more severe for multiple propeller ships as opposed to single propeller ships because the outboard propellers will be located more directly in the flow stream where the incidence of impacts will be higher.

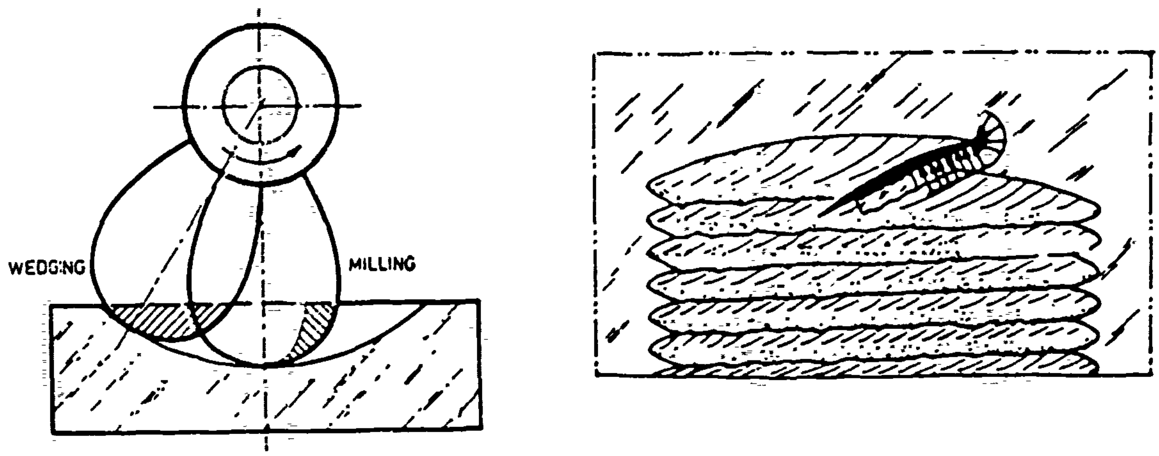
The type of propulsion system is a critical consideration. The structural response of a fixed-blade propeller is basically that of a cantilever beam of varying cross-section. For the controllable-pitch blade, however, many possible failure modes exist depending on the particular design. Principle considerations include cantilevered blade strength, bolt strength, trunnion strength, and internal mechanism strength for the blade pitch controls.

These considerations are particularly important for gas-turbine powered naval surface combatants which have controllable-pitch propellers and which will tend to have high torque, even at low ship speeds required by normal operations in the MIZ.

In general, propeller design for ice impact or milling is based on the conditions shown in Figure 6. For a particular blade, a series of load conditions is encountered as the blade progresses through the ice block. Normally a discrete number of particular cases are analysed in order to estimate the critical condition. For design purposes, the most severe case of only a single blade at a time milling the ice is applied. In addition, design is performed with only a single blade on the shaft to maximize imbalance forces. The entire process involves an excessive number of approximations and hence involves an unknown degree of uncertainty. However, the large number of propeller failures that have been recorded indicates that current design procedures are marginal and that extremely large forces will be encountered by propellers operating in the ice.[30]



Successive stages of ice impact to propeller blade.

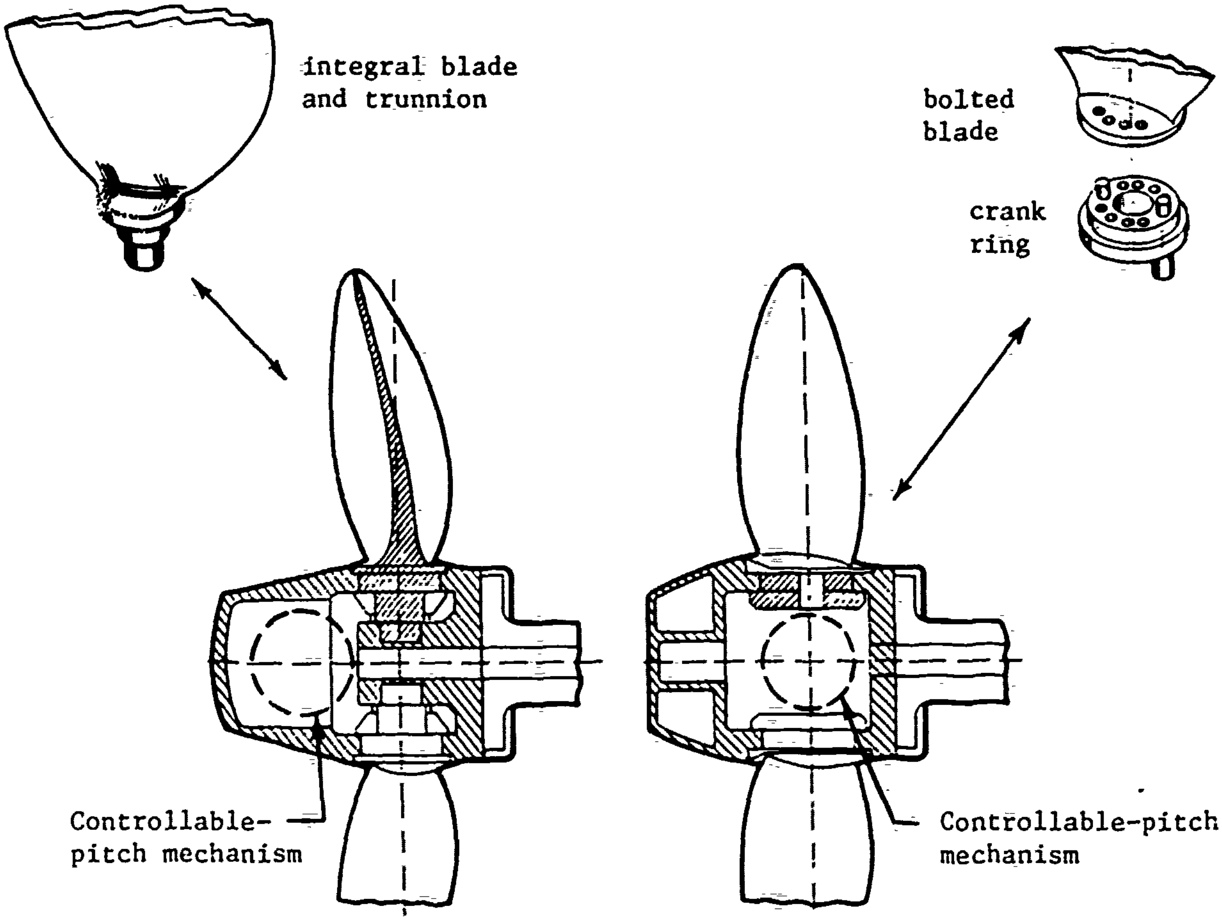


Ice impact with resulting milling. Propeller blade force and shaft torque vary through entire sequence.

Figure 6 - Propeller Ice Milling (From Reference 31)

USCG experiences with the POLAR class icebreaker propellers indicates the inadequacies of existing rational design procedures. These icebreakers are equiped with three controllable-pitch propellers originally designed for severe ice-milling loads. On the first operation in heavy ice, both outboard propellers experienced catastrophic failures in blade pitch control linkages within the hub mechanism rendering them unoperable. Clearly, rational design procedures applied to these mechanisms had been insufficient. The repair retrofit for these mechanisms was based primarily on applying as much material increase as hub volume constraints permitted and was not entirely based on rational ice load re-assessment.[32]

Controllable-pitch propeller designs for the POLAR class propellers and the Navy surface combatant propellers are radically different as shown in Figure 7.



Trunnion-type CP propeller similar to type on USCG POLAR-class icebreaker with integral blade and trunnion

Collar or Crank-ring-type CP propeller with bolted blade similar to type used on typical US Navy combatant

Figure 7 - Comparison of Different Propeller Types
(From Reference 33)

A critical design feature of U. S. Navy propellers is the blade flange bolts which have no corresponding component in the POLAR class propeller which utilizes an integral blade and trunnion design with eliminates the bolts entirely. In addition, the blade pitch control mechanisms within the hub are entirely dissimilar. For these reasons, it is difficult to apply experience with the POLAR classs propeller to the Navy propeller operating in ice. However, preliminary studies have suggested that ice milling loads will result in a blade torque at least 4 times as great as that resulting from normal hydrodynamic loading alone. Based on this and the poor response of the original POLAR Class propeller, it is possible that the Navy propeller would perform poorly when operating in conditions permitting severe ice milling.

As part of a general propeller analysis, it will be essential to determine the nature of ice flow around the ship hull, especially in the region of the propeller where localized currents will greatly exceed the ship's velocity. In particular, the nature of ice suction into the propeller flow stream is significant as it will cause impact not only to the propellers but also to shafts, struts, rudder structures and stern shell plating.

Ice operational experience has shown that ice milling wear and abrasion will significantly reduce the operational life of the propeller blade operating in ice. In addition, blade fracture and loss has been frequently experienced by these ships. For these reasons, materials with high strength and toughness properties are essential for ice propeller applications. The U.S. Navy utilizes a high strength Ni-Al-bronze propeller on the surface combatants which has uncertain response properties for ice milling operations.

Ducted propellers have been successfully used commercially to reduce the magnitude of ice impact loads to propellers. However, these can only be used a significant increase in drag and power requirement and have a tendency to ice jam.

SONAR DOME APPENDAGES AND BOW IMPACT RESPONSE

Sonar dome structures may be subject to impact hazard from floating ice during operations within ice.

During normal still-water operations, the upper edge of the sonar dome will be deeply submerged and, at very low speeds, could only be impacted by extremely large ice masses. Such ice masses would include multi-year ice, iceberg ice, and more commonly, rafted first-year arctic ice. The incidence of deep impacts during such operations is largely uncertain. It is presumed that brash ice will not impact the ship at great enough depth to endanger the sonar dome.

A great deal of uncertainty exists as to the nature of ice flow around the bow structure at ship speeds more typical of possible naval operations. It is accepted that for icebreakers and other ships with a bow configured specifically for ice breaking, ice fragments will break and flow completely under the hull thus impacting and abrading with all parts of the wetted hull. Normally, however, the icebelt structure does not include the lower regions of the hull for the lower ice classes and very little data exists as to the magnitude of impacts to this region of the hull. Quite possibly, impact pressures may be much greater at the waterline region before momentum is transfered to the ice fragment. Soviet researchers have observed and measured ice abrasion wear on icebreaker hulls and have concluded that the the region of most severe wear is well below the waterline, and that all parts of the wetted hull are subject to some wear during icebreaking.[34]

For naval combatants, computer studies[35] have shown that seawater flow is largely horizontal in the bow region above the dome which implies that broken ice will not be pulled down to impact the sonar dome. Although no specific data exists for verification, it appears probable that the extremely sharp angle of the bow above the sonar dome would prevent floating ice from being forced down into the dome but would rather be fractured to flow around the bow at the waterline. This bow structure is radically different from the icebreaking bow which is designed to fracture the ice in vertical bending by riding up on it and pushing it down and under the ship.

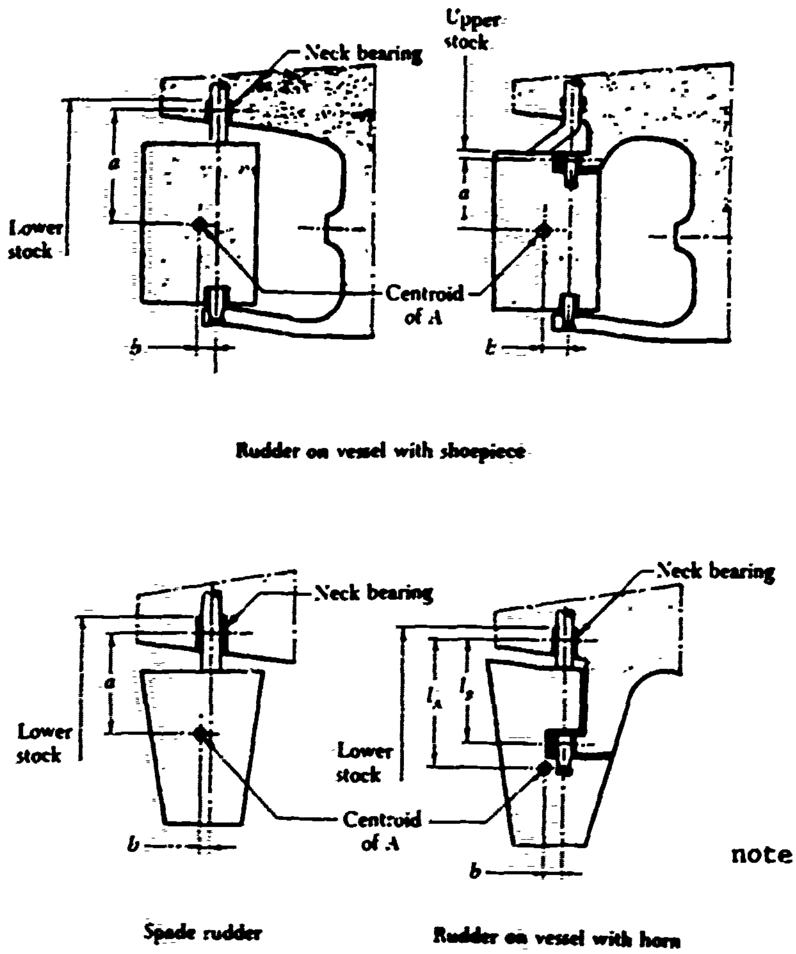
Studies have shown[36] that during normal icebreaking operations, a ship's forward trim will change relatively little while breaking the ice. As the ship pushes down on the ice and breaks it, the ice is pushed down to a far greater degree than the bow is pushed up. Hence, it can be assumed that safe draft for the sonar dome will not be significantly affected by forward impact to ice flow. This same statement cannot be made for sideways impacts which may significantly heel the ship during severe impacts.[16]

Qualitatively, it appears that operations in relatively thin pack ice or brash ice would not present a substantial hazard to the SDRW structure although such hazard may be significant for operations in more severe ice conditions or at high ship speeds.

ICE IMPACT TO MISCELLANEOUS STRUCTURES

All structures external to the hull shell structure may be susceptible to ice impact hazard while operating in the MIZ. These include rudders, propellers, propeller shafts, shaft struts, fin stabilizers, and the hull air masker system.

Ship rudders fall into several broad catagories as shown in Figure 8.



note: rudder is balanced if dimension b is small

Figure 8 - Comparison of Various Rudder Configurations
(From Reference 37)

In all cases, the rudder structure will consist of a plate structure supported by one or two stock shafts. Clearly, based on simple mechanics, the spade rudder arrangement will result in the most severe bending moment at the neck bearing while the use of a shoepiece will greatly reduce this moment for the same lateral load to the rudder. This latter arrangement is utilized on typical icebreakers to optimize performance while operating in ice, while the spade rudder, poorly optimized for ice, is used on current frigate and destroyer classes. The spade rudder arrangement is also described as a balanced rudder as the center of hydrodynamic pressure is close to the shaft. It is probable that ice loadings could occur at any position on the blade thus leading to a condition of severe imbalance.

For ice impact strength assessment, it is necessary to consider the strength of the plate structure, the adequacy of the stock and bearing to the overall lateral impact load, and the torque capacity of the steering gear when subjected to impact. The critical design condition is encountered when the ship is backing such that the rudder will be subject to full impact load rather than secondary impacts. It has been shown[38,15] that backing operations are frequent and unavoidable during ice operations, especially when following an icebreaking ship through a channel. In addition, for naval combatants, the rudder is located immediately aft of the propeller and will be subjected to a continuous flow of high speed broken ice from the propeller when the ship is encountering ice.

Some of the smaller combatant classes utilize outboard fin stabilizers to reduce rolling while underway. These stabilizers can be operated in either active or passive mode and are attached near midship at the turn of the bilge. These structures are not retractable and would probably respond poorly to major ice impacts.

PREVENTION OF ICE IMPACT DAMAGE WITH DEFLECTING DEVICES OR APPENDAGES

The concept of special ice protecting coverings, appendages or mechanisms has been considered since the early days of ice navigation when wooden ships were predominant.

Historically, temporary steel and wood plank icebelt structures and internal wood shoring for frame support have been applied to enhance the strength of the shell structure for ships while in the ice. The elastic and toughness properties of wood planking are especially well suited to the types of loading encountered while impacting ice. Such temporary systems would be particularly difficult to apply to modern warships considering the cost and complexity which would be required.

Recently, a variety of similar concepts have been investigated including bow ice-breaking/protecting cowls, stern deflectors, stern cages, excessive bilge keels, bubbler systems, thrust nozzles, ducted propellers, and mechanical ice breakers.[40]

A temporary icebreaking bow cowl would permit a ship to perform as an ice-breaker, although the concept has never been applied to an actual ship. Clearly, such a device would severely limit a ship's operation in open water hence would have to be attached immediately prior to deployment in the ice. No practical methods currently exist for transporting and attaching such a device and its response is unknown. However, use of such a device would probably enhance the ice capability of the ship and improve the protection of the bow sonar dome structures.

The USCG conducted a study to evaluate possible use of protecting and deflecting appendages for ice operations.[40] The primary emphasis of this study was methods for directing ice away from propellers, shafts, struts, and rudders. In addition to effectiveness, the study considered noise, speed, weight and cost effects of these devices which included fins on shaft bossings, a protective stern cage, bilge keels, a bubbler system, nozzle propulsion, ducted propellers, and mechanical devices.

Within this study, the mechanical devices, nozzles and bubbler system were rejected outright as either too unknown, impractical or overly expensive to use or install and were not quantitatively investigated. Bubbler systems are currently in use on a number of icebreakers but this application is for decreasing ice friction during icebreaking not for deflecting ice from the stern structures.

For the remaining concepts, model tests and engineering weight/cost studies were performed for comparison with the alternative approach of retaining conventional structures enhanced structurally for ice impact.

The results of this study implied that in all cases, modifying the conventional ship structure specifically for ice impact without the use of deflecting appendages was the best design course to follow. This study provided several interesting results.

It was found that fins actually worsened the problem by funneling ice into the propellers.

The stern cage eliminated significant impacts but tended to trap ice and jam, expecially during backing operations. In addition, there were vibration problems associated with its use.

All methods tended to significantly increase drag, especially the stern cage and the ducted propellers, which caused a 75% to 85% increase over the baseline design.

The use of special bilge keels was the most effective method although it did not eliminate the problem but only reduced it.

The use of retractable appendages was not addressed. Retractable devices would permit normal low-drag operation in ice free areas but would provide propeller protection when operating in or near ice where low speeds make drag effects negligible.

CONCLUSIONS

A series of general conclusions can be drawn from this study which addresses structural applications of naval surface combatants operating in the arctic marginal ice zone (MIZ).

A limited data base exists for derivation of empirically-based analysis procedures for load assessments involving ice impact. In addition, variable ice properties make rational analysis methods difficult.

For naval operations in the arctic it would probably be necessary to dictate a fairly rigorous ice impact design requirements. Low level ice strengthening is generally specified for non-arctic northern temperate climates such as the Baltic Sea where ice thicknesses will rarely exceed about three feet. However, in the arctic MIZ, first-year ice may be six feet thick with rafted or multi-year formations of much greater thickness, and, within the North Atlantic, icebergs or iceberg fragments may be present.

Currently, no ice strengthening requirements exist for naval surface combatants, and existing design procedures result in very lightweight structures at the waterline where ice impact hazard is greatest. However, at least since World War II, no cases of structural damage to naval combatants have been reported although few naval operations involving non-ice-strengthened ships have been undertaken.

A variety of mostly commercial and coast guard ice strengthening criteria exist for a variety of ice conditions. However, significant differences between these ships and existing naval surface combatants make direct application of these criteria to the combatants difficult. Principal differences include structural arrangements, sonar dome structures, hull form, mission requirements, propulsion capability, and propeller and rudder configurations.

Existing ice strength design criteria specify ice loads as discrete uniform pressure bands of high magnitude. As all current ice-strengthened ships have entailed transverse stiffening arrangements, these criteria result in excessive structural increases when applied to longitudinally-stiffened arrangements. However, based on the nature of floating ice impact, which primarily results is horizontal load bands, it is not anticipated that longitudinally-stiffened arrangements will optimize well. This poor optimization is principally due to excessive transverse frame size requirements and stability problems with longitudinal stiffeners. It is anticipated that the principal structural modification to the combatant hull structure will be a system of partial intermediate transverse frames fitted within the existing arrangement so as to make the hull respond more like a transversely-stiffened ship in the region of ice impact. In addition, increases in plating thickness and frame or stiffener sizing may be required.

For design of specific plate and stiffener component structures, it is anticipated that existing U.S. Navy design criteria can be modified to account for discrete pressure loads and a greater degree of allowable permanent set using methods of plastic design.

It is estimated that relatively thin ice will present little danger to sonar dome structures because of relatively large draft and the overall hull shape. However, thicker or rafted ice presents an unknown, probably greater hazard. The response of the sonar dome window structures to ice impact is unknown although finite-element analyses using existing models may provide a solution procedure.

Damage to propellers due to severe ice milling overloads is probable to surface naval combatant ships operating in the MIZ. Studies for existing icebreaker propellers have indicated loads of perhaps four times the conventional hydrodynamic load based on model and full-scale trials tests. Analytical ice load predictions for propellers are difficult to perform and validate. Ice overload capacity for the existing naval surface combatant propellers is uncertain, and analysis of these propellers is difficult because of the complexity of the controllable-pitch propeller and its mechanisms.

Existing naval surface combatants utilize a balanced, spade rudder design that is poorly optimized for ice impact. These ice impacts are most severe during backing manuevers and may be difficult to assess due to propeller flow. Generally, ice-strengthened ships will utilize a shoepiece rudder design to reduce bearing loads due to ice impact. Rudder analysis will consist of assessment of the stiffened plate structure comprising the rudder and analysis of the rudder stock and bearing due to overall rudder loads.

The response of the propeller shafts and struts to ice loads is uncertain although conventional engineering procedures should apply well to these structures. Problems may result with these structures due to their exposed design on existing surface combatants.

It has been shown that the use of ice deflecting appendages and devices, including coverings, fins, bilge keels, stern cages, thrust nozzles, ducted propellers, mechanisms, or bubbler systems is generally impractical in lieu of conventional structural modifications to withstand the ice loads. These deflectors may be a practical solution if retractable during normal operations outside of the ice.

In addition to floating ice impact, a structural hazard may exist in the event of severe topside icing during foul weather. Severe icing may impose hundreds of additional tons of weight on the ship which, in addition to threatening the ship's stability, may cause excessive primary hull girder bending stresses.

It should be possible to assess these additional stresses using conventional methods of naval architecture.

The removal of topside ice by ship's personnel using baseball bats and nylon hammers may impose high localized loads that should be a consideration during the design stages.

RECOMMENDATIONS

The following recommendations are made in order to develop and extend the arctic and cold weather navigational capability of the U.S. Navy with respect to ship structural capabilities.

Development of ice-strengthening criteria for U.S. Navy combatants and other ships, such as auxiliaries, will be necessary. These criteria should be extensions of methods utilized by commercial and coast guard agencies which have performed extensive R&D efforts to develop ice-strengthening criteria which have been successfully applied to hundreds of ice-capable ships. However, naval ice-strengthening criteria should be extended to provide the following details:

1. A capability to assess the structural integrity of non-ice-strengthened ships operating in brash ice and relatively open pack ice.

2. Development of ice operational limitations for all classes of ships based on environmental parameters for ice.

3. Development of design and analysis procedures specifically intended for ice impact to thin plating. These methods should address strucural response due to discrete or concentrated loads rather than uniform ice pressure loads.

4. Extension of ice criteria for longitudinally stiffened ships in addition to transversely stiffened ships. Existing criteria for longitudinally-stiffened ships are poorly detailed in the existing rules as such ships are discouraged for ice navigation. Because of severe ship optimization requirements for naval combatants, it is unlikely that heavier, transversely-stiffened hull structure will be specified for these ships in order to increase their perceived ice-impact capability. Special criteria for longitudinally-stiffened plating may be able to benefit from the most-recently

obtained empirical ice load data[24] which indicates that ice impact pressure significantly decreases as the area of impact increases.

5. Extension of the ranges of plating span widths within the existing criteria to cover all ranges applicable to existing and proposed naval ships.

6. A practical means of ice strengthening retrofit for application to existing ships such that cost and weight penalties are minimized.

On a more immediate level, U.S. Navy interests will benefit from extension of the existing data base on ice properties, particularly strength properties. Of particular interest is data describing impacts from brash ice, broken floe ice and minor iceberg fragments which is particularly lacking in the open literature as impact from such ice is of less immediate interest commercially where ice-breaking loads are more applicable. This data shculd particularly be obtained for the arctic MIZ which will differ in severity from other regions. This data should be obtained for a wide range of ship speeds and hull forms representative of naval ships. Continuing literature survey should be heavily utilized to benefit from worldwide R&D in this area and reduce data acquisition costs.

Specific propulsion system studies should be performed for existing and proposed naval ships intended for use in the MIZ. Coast Guard and commercial experience indicates that naval CP propellers would probably not withstand severe ice milling loads without damage. It is probable that these systems are the most vulnerable ship systems to ice impact damage. Complex analyses involving mechanical, structural, hydrodynamic and material studies will be required. Sophisticated analytical techniques and extensive full-scale and model testing will be essential to assess capabilities. It appears that, for ice operations, propellers must be designed and analysed as machine tools in addition to propulsion devices.

Hydrodynamic analyses of ice flow around naval combatant hulls for a wide range of ship speeds and ice conditions should be performed based on both model tests and computer studies. A wide range of facilities including DTNSRDC should be capable of performing such studies.

Structural assessments of all appendages subject to ice impact should be performed for new and existing naval ships intended for operation in the arctic MIZ. Sonar dome structures will require extensive investigation as the reponse of these structures to ice impact is largely uncertain.

Structural assessments of other appendages should be performed using accepted analysis procedures and appropriate ice loadings.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to Mr. A. B. Stavovy, Head, Ship Structures Division, DTNSRDC, for technical direction and Messrs. R. H. Chiu and N. S. Nappi of DTNSRDC for beneficial suggestions and review of this text. The technical assistance of Messrs. D. Martin, P. Dudt, and T. Judy of DTNSRDC in the area of propeller strength assessment is appreciated. The overall program management provided by Mr. J. E. Gagorik, NAVSEA 05R26, is acknowledged.

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COLD WEATHER CLOTHING

by

Richard Wojtaszek

The Navy Clothing and Textile Research Facility (NCTRF) in Natick MA is responsible for the development of the majority of clothing worn by Navy personnel. Since the 1930's the Navy has been persuing the development of protective clothing including cold weather gear designed to be worn in a cold air sea environment.

In the sixteenth century in a trade port city called Kajhihode, pursers bought a course cotton unbleached calico sailcloth called dongeryns. Sailors not only made sails from this material but also made rough work trousers which they called dungarees a name that has survived in the Navy for many years and through numerous uniform changes. In the early days of the U.S. Navy, men wore whatever clothing they owned and it wasn't until 1813 that uniforms were prescribed by regulation and bought under contract according to samples held in the officer of commandants of Navy yards. The uniform was comprised of full bottomed trousers, frocks, short jackets, vests and low crowned hats. As work uniforms shipboard personnel normally wore their oldest uniform either blue or white in color and for all weather conditions.

In 1869 the first working uniform was introduced for enlisted personnel. The uniform was constructed from the white cotton duck material and was styled similar to the jumper/trouser used today by Navy personnel A similar styled uniform constructed from blue cotton denim fabric containing a jacket and cap for colder environments could be worn by all personnel.

During the World War II era only four textile fibers were available for the fabrication of materials used in military or commercial cold weather clothing. Silk, a product of Japan was no longer available, while nylon was entirely devoted to the production of parachute fabrics Navy organizational cold weather clothing, blue in color, consisted of overalls, trousers, and jackets. They were constructed from finely woven cotton bedford cord fabrics and were lined with wool flannel material. This clothing was found to be inadequate for winter destroyer operation in the North Atlantic so the Navy Clothing Depot at that time embarked on a mission to search for alternate fabrics to meet the expanded potential demands of a wartime Navy. Several garment construction methods were explored including the impregnating oilkins to provide water repellancy supplemented by sheepskin liners for warmth No real success was achieved until a joint venture between the Navy Depot and National Bureau of Standards produced a thick wool and alpaca pile fabric which provided good insulation for cold weather clothing in a cold environment.

In 1944, the Navy Clothing Depot established a research and development division and built a special cold/wet room to supplement its capabilities to evaluate experimental cold weather clothing at temperatures as low as minus 40°F and extreme wet conditions.

The first product generated utilizing the new test facilities was a submarine deck exposure suit. Constructed from neoprene coated nylon as a waterproof outershell and fiberglass batting as insulation. The clothing was evaluated by the USS SNAPPER in training exercise off the eastern end of Long Island and was found to be acceptable to the cold wet environment present in the area.

The information developed during World War II, along with the new testing facilities set the stage for important clothing developments in the 1950's. The insulated cold weather boot was probably the most important achievement of the Navy Clothing Depot in this time period Navy boots developed using a double moisture barrier principle, two layers of rubber sealing in wool insulation, were extremely effective and could eliminate trenchfoot as was proven by the U. S. Marines the following year.

The boot was developed in two types one for topside submarine personnel and the other for surface ships. During the same time period the Navy laboraory developed rachel cotton knit underwear to replace woolen underwear which was becoming costly because of the critical supply of wool. The scarcity of wool also led to expanded research in fiber blending to develop cheaper durable and more available fabrics.

In the mid 50's to early 60's, a high strength nylon neoprene coated fabric was developed and introduced for use in the Submarine Deck Exposure Suit and the A-1 Cold Weather Ensemble. Coupled with a nylon fleece liner the garments provided good personnel protection in a cold wet environment.

A similar ensemble labelled an A-2 outfit was constructed from a blend of cotton/nylon and was used for cold dry conditions. In extreme cold weather environments, the A-1 ensemble was recommended to be worn over the A-2 clothing.

The A-1, A-2 clothing ensemble concepts are still in the supply system today but are varied in their structural components An unsuccessful attempt to provide combined cold weather and ballistic protection and inherent buoyancy in one garment led to addition of the closed cell-foams currently found in todays Navy cold weather clothing. These ensembles provide protection in a cold wet environment and provide limited flotation to personnel in emergency man overboard situations.

The A-1 ensemble designed for extreme cold weather is comprised of a jacket, trouser and two types of hoods, one designed for use with the phonetalkers headset. The outer material is a neoprene coated nylon twill which is virtually water resistant. Warmth is provided by a quilted foam liner in the jacket and nylon fleece liner in the trouser and hood The submarine deck exposure suit, also an extreme cold weather garment, originally was designed for submarine personnel but has now been authorized for all topside shipboard personnel. A one piece coverall, it is constructed from the same material as the A-1 ensemble and is lined totally with foam and a nylon inner shell. In addition to warmth and flotation, this garment offers extended in water hypothermia protection in a nominal sea state.

Hand protection for both ensembles is provided by a newly designed glove shown here constructed from neoprene dipped cotton shell and polyurethane foam liner laminated to a urethane coated nylon tricot liner cover. This glove replaces the neoprene coated nylon fleece coated liner glove now in the supply system.

Both the submarine deck exposure suit and A-1 ensembles are designed to be worn with the cold weather insulated boot for extreme cold weather conditions. The boot comprised of vulcanized black rubber contains a double moisture barrier principle sealing in wool cotton insulation Combined with the use of wool/cotton socks protection can be afforded to temperatures well below 0°F,

The A-1 Γ ,emble and Submarine Deck Exposure Suit can provide protection in extreme environments only if properly worn and enhanced with compatible undergarments. To sustain temperatures below 0°F thermal underwear, constructed from 100% cotton waffle knit utility clothing either cotton or poly/cotton, plus an organization a wool sweater are required attire.

An A-2 Intermediate Cold Weather Ensemble is available for temperatures down to 20°F. The ensemble comprised of jacket, trouser, and cap is fabricated from a water repellent cotton/nylon sateen material lined with nylon fleece insulation. The ensemble is commonly found on most ships as standard cold weather clothing.

A new face mask constructed from 100% aramid fiber and moisture vapor permeable liner will soon be available to Navy personnel to replace the nylon coated wool insulated mask.

On the horizon NCTRF is continually evaluating new commercial products and techniques available for military application. Coupled with the overall requirements of fire retardant clothing new intermediate cold and extreme cold weather ensembles are under development. A fire retardant intermediate cold weather Jacket, Trouser, and Cap are being designed to replace the current A-2 ensemble. At the present time three candidates will undergo testing this winter. Shown here are a 100% Nomex version and an FR wool type.

A FR cold weather working survival suit is being designed to replace the A-1 and submarine deck exposurte suit. This garment using a Nomex Goretex laminate fabric will provide a fire retardant vapor permeable/water repellent garment for temperatures to $-40^{O}F$ and provide in water hypothermia protection in a man overboard situation Preliminary tests are scheduled for January 1986.

NCTRF is actively persuing the development of cold weather clothing for shipboard personnel Although numerous fabrics fibers and finishes seem to offer potentially favorable qualities for particular clothing applications, they must be assessed against the full scope of requirements demanded by a Navy operating in a cold air sea environment.

Arctic Surface Warfare Hovercraft

by

James Lee Schuler

The basic structure of this presentation was prepared two years ago. At that time, the CNO had just issued new policy guidance on Arctic and Cold Weather Operations and the SECNAV was stressing a forward press strategy based on Northern Latitude operations. The technical community was familiar with the results of the Arctic Surface Effect Vehicle R&D sponsored by DARPA and we were all aware of the emerging hovercraft being developed for Amphibious Assault.

We saw a promising technology push which could be matched to a real requirements pull. So we put together a program connecting the two ideas. Since that time, it has been on the back burner and in the back of our minds.

Two recent developments have been added to the picture. One was the outstanding performance of the JEFF(A) when it was leased to SOHIO by the Navy to operate in Prudoe Bay. The other was a recent CONFORM Design Study of an Arctic Air Cushion Vehicle (ACV).

Wilf Eggington from RMI provided some data on the JEFF(A) deployment. Dave Lavis provided some information on the CONFORM Study which they recently completed. These items were folded into the old presentation and the current presentation emerged.

It starts by noting the truly amphibious nature of the Air Cushion Vehicle. At proceeds to spell out some of the unique capabilities which make the Amphibious Hovercraft a natural vehicle for Arctic Operations. The SEV experience is briefly reviewed and the six concepts which were studied in 1974 are described. A new concept for a hoverbarge and a combat tug is unveiled.

This is followed by a brief survey of the facts derived from the JEFF(A) experience wherein heavy loads were carried at high speed, reliably and safely over a route which traversed land, water and ice. Some of the technical lessons learned are noted in the modifications made to "arctize" the JEFF(A). Highlights are noted. This is followed by a few words about the key features of the Arctic ACV recently studied.

The presentation concludes with a statement of suggested program goals followed by some mission capabilities which could be demonstrated. A program logic is displayed together with identification of some key participants and a program schedule. (The schedule is two years out of date).

The estimated cost of the proposed program has been deleted from the presentation. The stated conclusion is,

"OPERATIONAL CHARACTERISTICS, PAYLOAD CAPACITY AND MISSION FLEXIBILITY INDICATE THAT HOVERCRAFT ARE SUITED FOR BOTH DIRECT AND SUPPORT ASSIGNMENTS IN THE ARCTIC REGION".

The unstated conclusion is,

"LET"S GET ON WITH IT"

ARCTIC SURFACE WARFARE HOVERCRAFT PROGRAM

(ASW HOVERCRAFT)

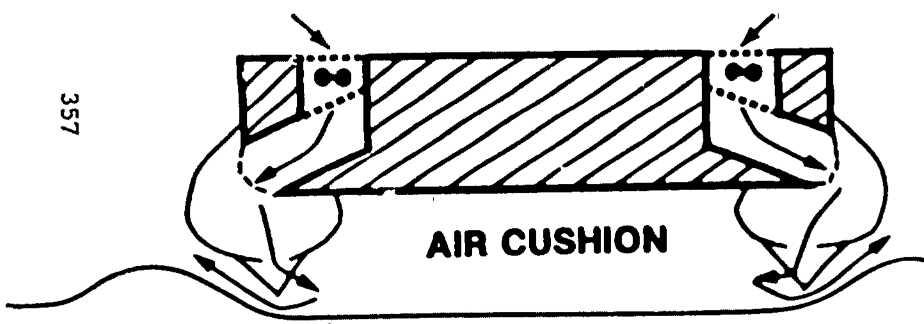
ARCTIC SURFACE WARFARE HOVERCRAFT

A PROMISING TECHNOLOGY "PUSH"
MATCHING
A REAL REQUIREMENTS "PULL"

JAMES L. SCHULER, NAVSEA 05R12, 692-0043
8 SEPTEMBER 1983

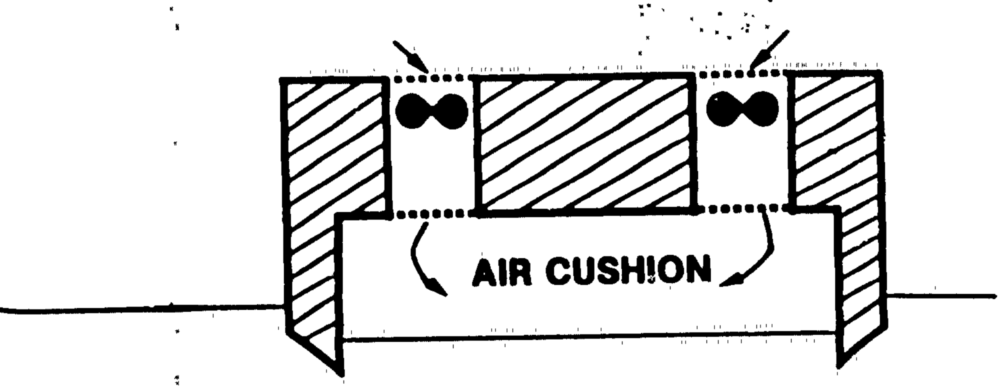
TWO KINDS OF HOVERCRAFT

AIR CUSHION VEHICLE (ACV)
(AMPHIBIOUS)



FULL PERIPHERAL
(FLEXIBLE SKIRT)

SURFACE EFFECT SHIP (SES)
(NON-AMPHIBIOUS)



RIGID SIDEWALLS
(FLEXIBLE BOW & STERN SEALS)

AMPHIBIOUS HOVERCRAFT FOR ARCTIC OPERATIONS

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UNIQUE CAPABILITIES OF AMPHIBIOUS HOVERCRAFT

ARCTIC SURFACE WARFARE HOVERCRAFT

ALL TERRAIN CAPABILITIES

- WATER
- LAND
- SWAMP
- ICE
- TUNDRA

SPEED CAPABILITIES

- OPERATE AT HIGH SPEEDS IF NEEDED
- HOVER AT LOW SPEEDS ON CUSHION
- LOITER AT ZERO SPEED ON OR OFF CUSHION
- FLOAT AT SLOW SPEEDS ON OR OFF CUSHION

OTHER FEATURES

- HIGH PAYLOAD FRACTION
- LOW FOOTPRINT PRESSURE
- LOW PRESSURE SIGNATURE
- LOW UNDERWATER NOISE SIGNATURE

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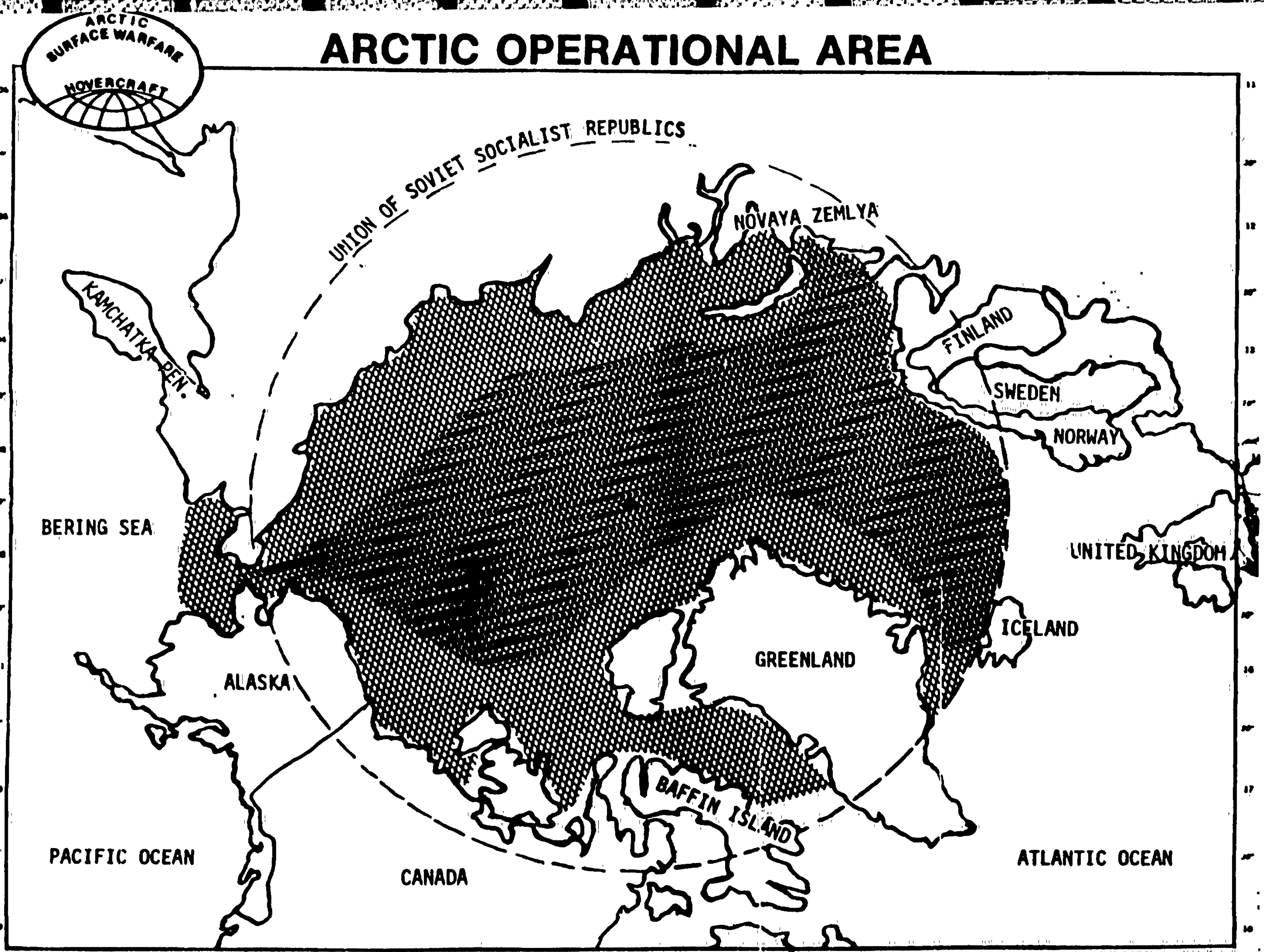
ARCTIC OPERATIONAL AREA



HOVERCRAFT OPERATING AREA
(3.9 MILLION SQUARE MILES)

SUBMARINE OPERATING AREA
(2.5 MILLION SQUARE MILES)

ARCTIC HOVERCRAFT EXPERIENCE

ARCTIC SEV PROGRAM

- DARPA SPONSORED 1970-1974, $18.6M
- STUDY OF TECHNOLOGY AND ENVIRONMENT
- DEMONSTRATED OPERATIONS OF SMALL ACV

COMMERCIAL EXPERIENCE IN RESOURCE EXPLOITATION

- DOT ALASKA DEMONSTRATION
- ALASKA OIL FIELD SUPPORT

CANADIAN EXPERIENCE

- CANADIAN AIR CUSHION TECHNOLOGY SOCIETY
- CANADIAN COAST GUARD OPERATIONS

CURRENT U.S. NAVY LEASE OF JEFF(A) TO RMI/SOHIO

ARMY COLD WEATHER LABORATORY PROVIDES DATA INPUTS

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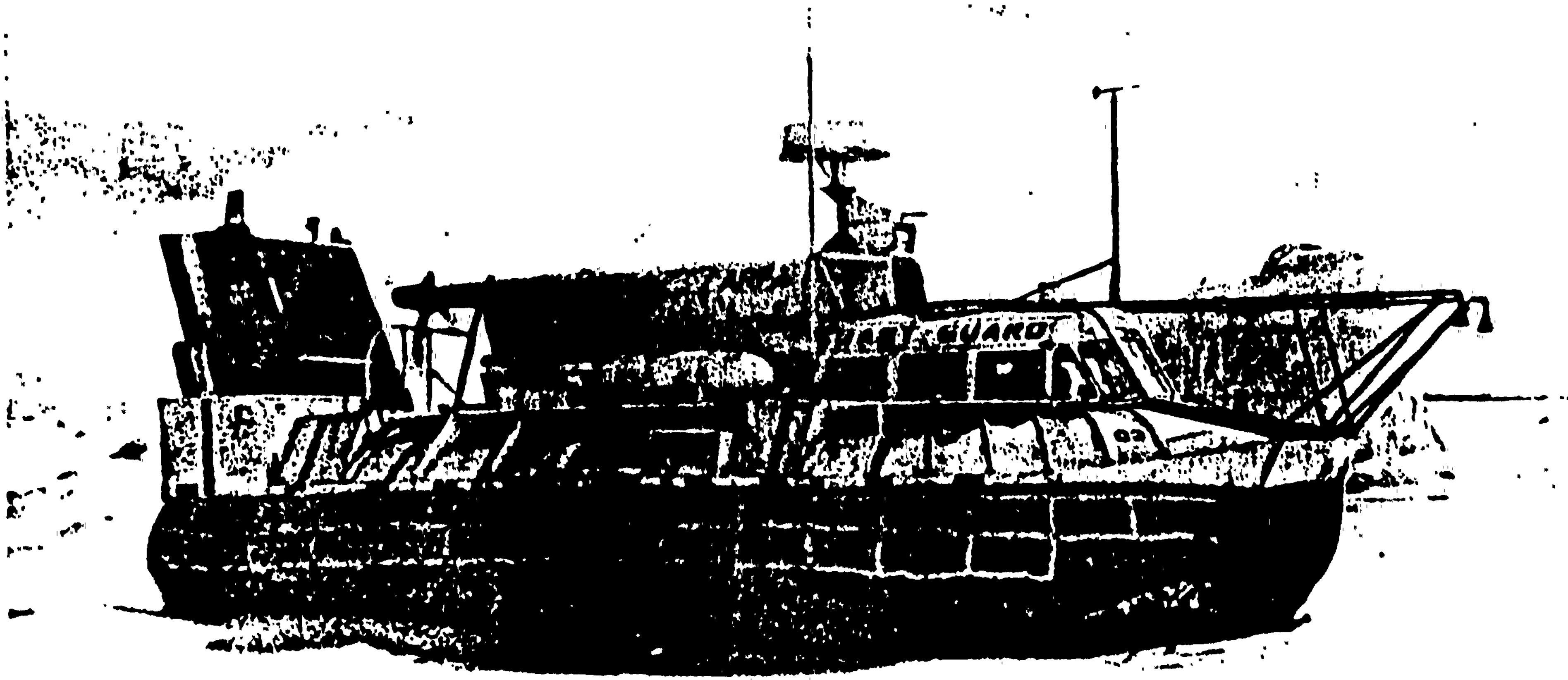
SMALL HOVERCRAFT IN ARCTIC



SK-5 IS A SEVEN TON CRAFT TESTED BY DTNSRDC AND U.S. COAST GUARD FOR DARPA IN 1971

DARPA ARCTIC HOVERCRAFT DESIGN CONCEPTS - 1974

PRINCIPAL APPLICATION	SMALL-UNIT TRANSPORT	SUPPORT VEHICLE	TACTICAL DEPLOYMENT	STRATEGIC SUPPORT PLATFORM	ARCTIC CONTROL CAPABILITY
DISPLACEMENT	14 TONS	90 TONS	150 TONS	650 TONS	2000 TONS
LENGTH/BEAM	52 x 28 FEET	90 x 43 FEET	96 x 48 FEET	180 x 80 FEET	225 x 100 FEET
USEFUL LOAD	4-7 TONS	25-40 TONS	65-100 TONS	250-450 TONS	750-1500 TONS
RANGE	200-300 NM	200-400 NM	300-500 NM	1000-3000 NM	3000-4000 NM
SPEED	50-80 KNOTS	30-60 KNOTS	40-60 KNOTS	50-80 KNOTS	80-100 KNOTS
CLEARANCE	4-6 FEET	4-8 FEET	4-8 FEET	8-12 FEET	12-20 FEET

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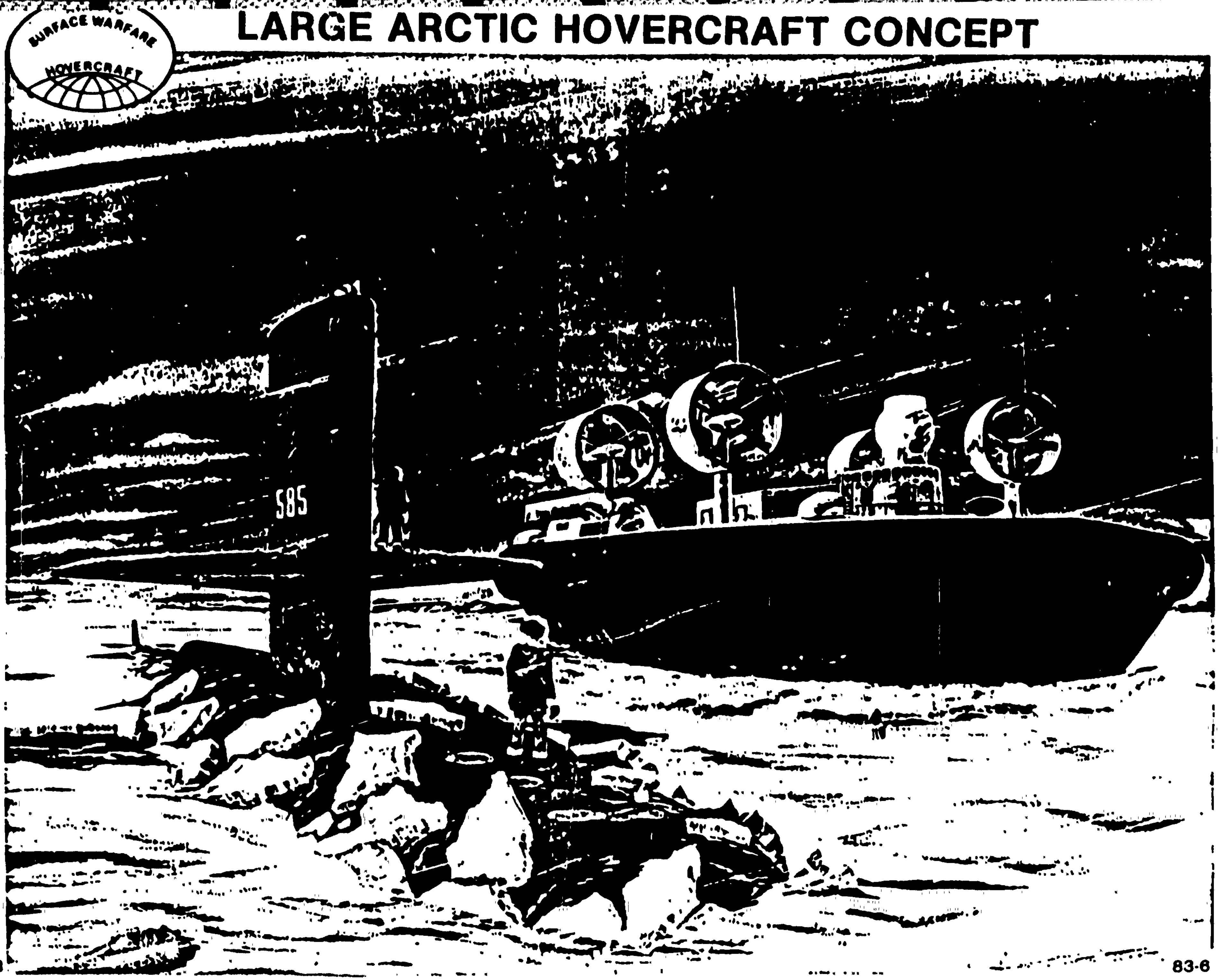
83-5R1

LARGE ARCTIC HOVERCRAFT CONCEPT



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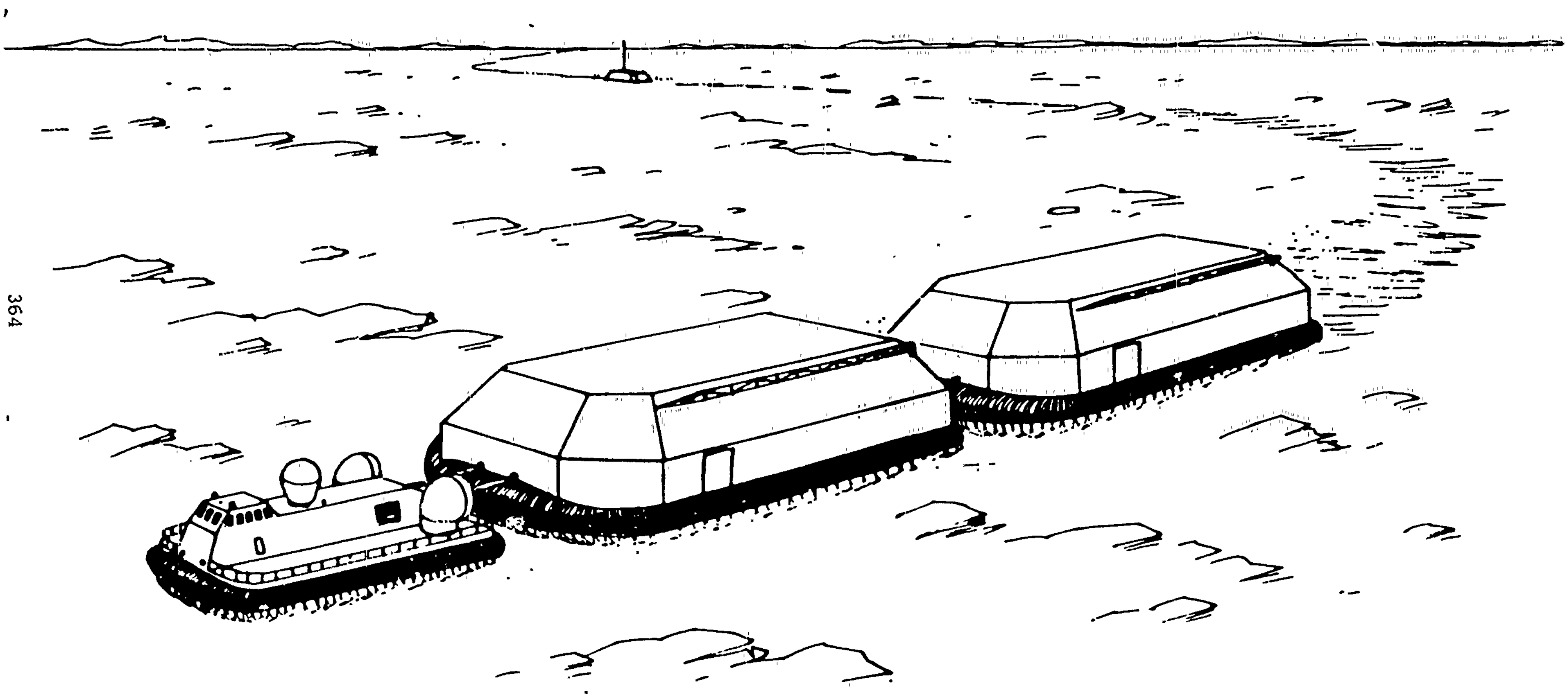
ANOTHER ASW HOVERCRAFT CONCEPT

COMBATUG AND HOVERBARGES



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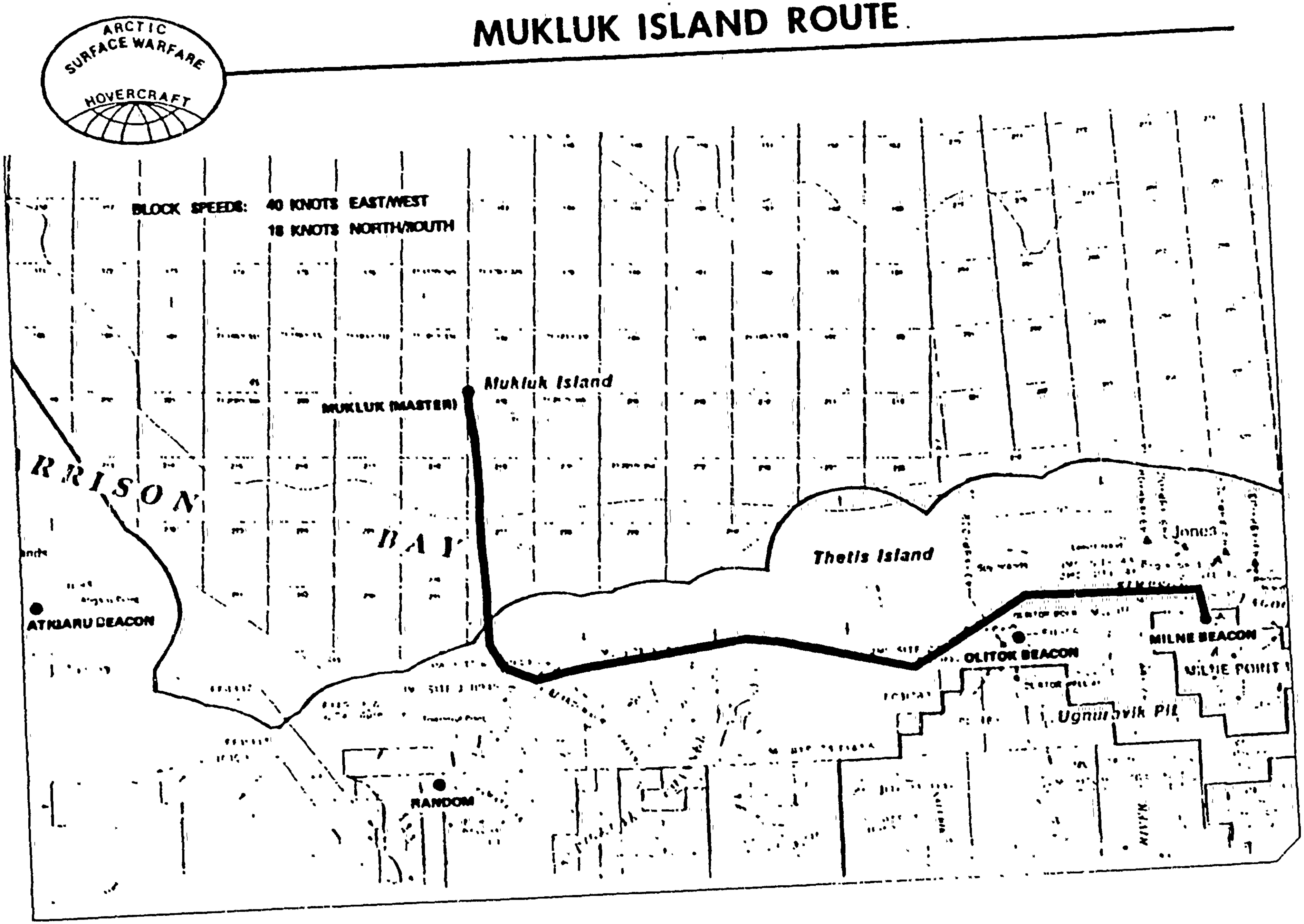
83-34.1

ARCTIC SURFACE WARFARE HOVERCRAFT

JEFF (A) ARCTIC PROGRAM MILESTONES

June 1, 1983	JEFF (A) leased from U. S. Navy by RMI and time chartered to SAPC.
August 16, 1983	RMI winterization of JEFF (A) begins.
November 5, 1983	JEFF (A) Arctic Test Program begins.
January 11, 1984	RMI arctic cargo service for SAPC begins.
February 8, 1984	Total cargo carried by JEFF (A) exceeds 1 million pounds.
February 13, 1984	JEFF (A) accomplishes single lift of 102 tons.
February 21, 1984	Two runs to Mukluk Island - 294,000 pounds of total cargo.
March 21, 1984	Mid-winter test program begins.
April 14, 1984	JEFF (A) Spring Lay-Up begins.

MUKLUK ISLAND ROUTE



JEFF (A) ARCTIC MODIFICATIONS

Installation of natural rubber skirts and spray aprons.

Insulation of control and navigation cabins and heated windows.

Reconstruction of the stern ramp to accommodate cargo trailers.

Installation of gas turbine and gear box lubrication oil heating systems.

Insulation and heating of all hydraulic and fuel systems.

Features to meet U.S. Coast Guard safety and certification.

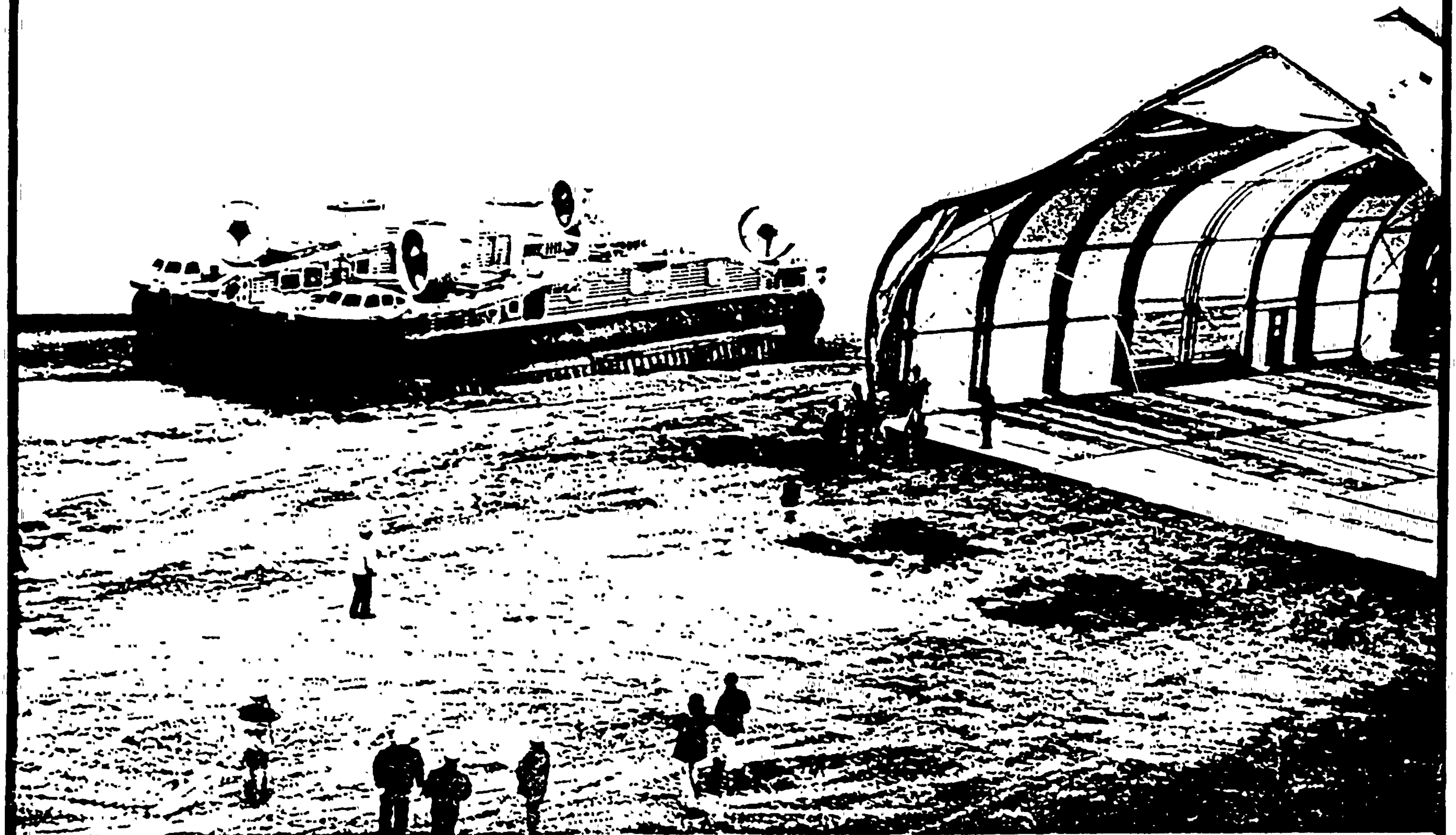
Additional high intensity lighting.

Modification of craft electrical system to accommodate increased loads.

Installation of fire retardant, closed cell urethane foam and plywood sheating on the cargo deck and selected external areas of the machinery enclosure.

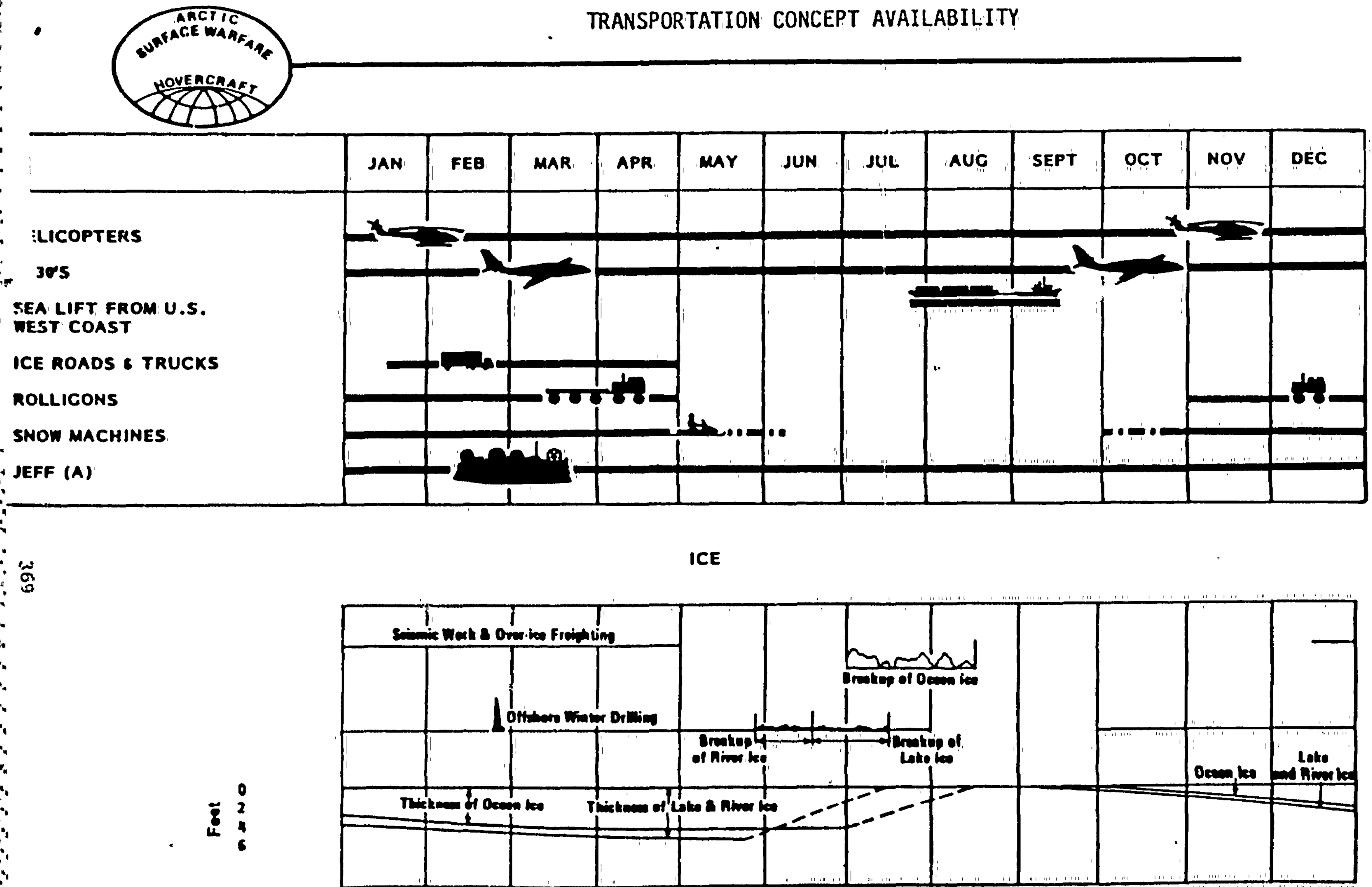
ARCTIC SURFACE WARFARE HOVERCRAFT

JEFF (A) AND PORTABLE SHELTER



RMI, Inc.

TRANSPORTATION CONCEPT AVAILABILITY



JEFF (A) ARCTIC PROGRAM HIGHLIGHTS

Cum. Operating Time (November 1 - April 14)	268 hours
Cum. Cargo Carried (November 1 - April 14)	1,748,000 pounds
Heaviest Single Load	102 tons
Craft Operational Availability (January 1 - April 14)	85 percent
Highest Sustained Operating Speed	50 knots
Shortest One-Way Transit Time to Mukluk (41.7 Miles)	1 hour 17 minutes
Shortest Round-Trip Transit Time to Mukluk (83.4 Miles)	2 hours 41 minutes

FY 1985 CONFORM DESIGN STUDY OF ARCTIC ACV

OBJECTIVES:

- Provide mobile surface logistic supply service
- Enhance Search and Rescue (SAR) in Arctic

CONFIGURATIONS:

AACV-1 based on parametric analysis	(250 tons)
AACV-2 based on LCAC modification	(200 tons)

TECHNOLOGY INPUTS:

- JEFF (A) experience in Arctic
- JEFF (B) tests @ Eglin Air Force Base
- Study of Arctic SEV for DARPA
- Environmental data and portable shelters from Army CRRL

KEY FEATURES:

- Open payload deck
- High clearance skirts
- On-board accommodations for ten persons
- Folding hydraulic cargo crane forward
- Use Global Positioning System (GPS) and on-board radar
- Internal fuel tanks
- Auxiliary winch
- Some weapons and signature reduction
- Includes acquisition and life cycle cost estimates

ARCTIC HOVERCRAFT PROGRAM GOALS

ADVANCED DEVELOPMENT PROGRAM OBJECTIVE (6.3)

DEFINE, DEVELOP, DEMONSTRATE AND DOCUMENT THE PERFORMANCE OF AN ARCTIC SURFACE WARFARE HOVERCRAFT SYSTEM TO PROJECT U.S. NAVAL POWER INTO THE ARCTIC REGION

THE ASW HOVERCRAFT SYSTEM WILL BE ABLE TO OPERATE INDEPENDENTLY AND/OR IN SUPPORT OF OTHER SURFACE, AIR, AND SUBMARINE ELEMENTS

THE PROGRAM WILL INCLUDE DEMONSTRATIONS OF THIRTY DAY OPERATIONS (ONE IN JANUARY AND ONE JULY)

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ARCTIC HOVERCRAFT MISSIONS

MISSIONS OF THE ASW HOVERCRAFT SYSTEM CAN INCLUDE:

- DETECT, LOCALIZE CLASSIFY, AND TRACK FRIENDLY AND HOSTILE SUBMARINES
- ASSIST USN SUBMARINES TO DETECT, ATTACK, AND DESTROY HOSTILE SUBS
- DEPLOY AND MONITOR SENSORS AND NAVIGATIONAL AIDS
- SEARCH AND RESCUE OF FRIENDLY SUBMARINES AND AIRCRAFT
- ANTI-SURFACE WARFARE AGAINST ENEMY HOVERCRAFT (POWER PROJECTION)
- LOGISTICS SUPPORT OF FRIENDLY SUBMARINES, AIRCRAFT, AND ICE CAMPS
- CONDUCT LIMITED SELF-DEFENSE AGAINST AIR AND SURFACE THREATS (AAW)
- PERFORM HYDROGRAPHIC SURVEYS AND ENVIRONMENTAL MONITORING

SYNERGISM

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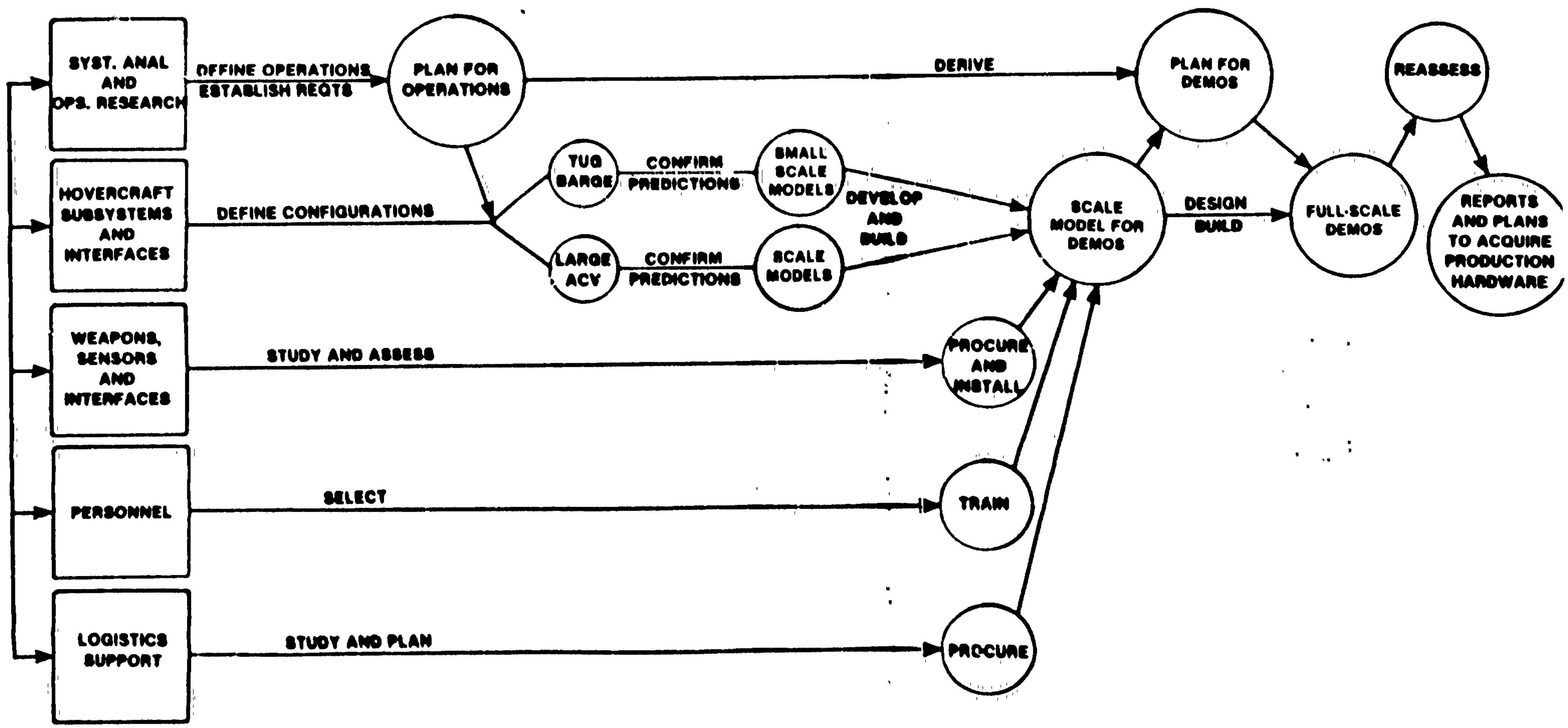
PROGRAM LOGIC



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PROGRAM PARTICIPANTS

NAVY

NAVAL SEA SYSTEMS COMMAND

DAVID TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

NAVAL SURFACE WEAPONS CENTER

NAVAL OCEAN SYSTEMS CENTER

NAVAL PERSONNEL RESEARCH AND DEVELOPMENT CENTER

OTHER

ARMY COLD REGIONS RESEARCH AND ENGINEERING LABORATORY

STANFORD RESEARCH INSTITUTE

HRA

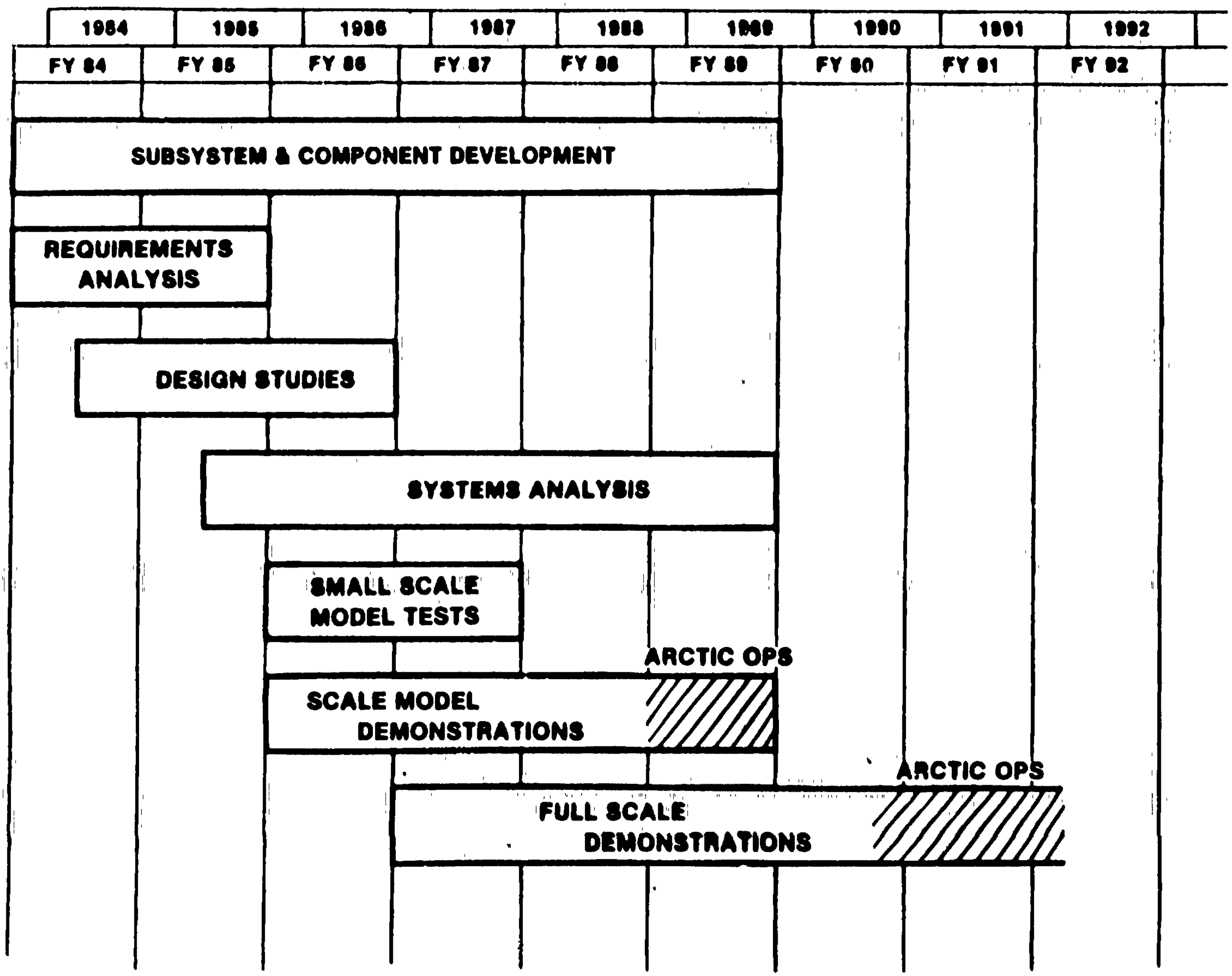
MAR, INC.

WHEELER INDUSTRIES

UNIVERSITY OF WASHINGTON

OTHERS TO BE SELECTED

PROGRAM SCHEDULE



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CONCLUSION AND RECOMMENDATIONS

CONCLUSION

OPERATIONAL CHARACTERISTICS, PAYLOAD CAPACITY, AND MISSION FLEXIBILITY INDICATE THAT HOVERCRAFT ARE SUITED FOR BOTH DIRECT AND SUPPORT ASSIGNMENTS IN THE ARCTIC REGION

RECOMMENDATIONS

- DEVELOP ARCTIC SURFACE WARFARE HOVERCRAFT SYSTEM
    - SYSTEMS ANALYSIS AND OPERATIONS RESEARCH
    - HOVERCRAFT SUBSYSTEMS AND INTERFACES
    - SENSORS, WEAPONS AND INTERFACES
    - PERSONNEL AND TRAINING
    - LOGISTICS SUPPORT IN THE ARCTIC REGION

SEP 83

83-13R1.1

SHIP ICING EXPERIMENT

A MEANS FOR IDENTIFYING AND SOLVING COLD WEATHER OPERATIONAL PROBLEMS

PRESENTATION TO:

U.S. NAVY SYMPOSIUM ON ARCTIC/COLD WEATHER SURFACE SHIP OPERATIONS,

3 - 4 DECEMBER, 1985, WASHINGTON, D.C.

PRESENTED BY:

Robert Rogalski, Code 2724
DTNSRDC, Annapolis, MD 21402-5067
(301)267-3230/2540 (A/V 281)

ABSTRACT

SHIPBOARD ICING EXPERIMENT: A MEANS FOR IDENTIFYING AND SOLVING COLD WEATHER OPERATIONAL PROBLEMS

An experiment to "ice over" a ship in a harbor, which is currently in the planning phase, is expected to be conducted by the David Taylor Naval Ship Research and Development Center during the winter of 1986-87. The purpose of that experiment is to identify the problems associated with spray ice formation on ship hull, superstructure, and topside equipment and to evaluate various methods for ice prevention and removal. Details are provided on how the experiment is projected to be carried out and on particular ship equipment and systems that may be tested. Specific logistics, safety, and technical concerns related to the experiment are addressed. Conclusions are given on expected results and benefits from the tests and on how the project will assist in making the surface fleet better prepared for cold weather/arctic missions.

HOW SERIOUS IS THE PROBLEM OF SHIP ICING?

During the winter of 1985, several messages were received from the fleet regarding lessons learned and problems encountered in cold weather operations. These contained concerns about ship systems being subjected to extreme cold weather conditions which could lead to equipment failure or damage. Events on USS CAPODANNO demonstrated the seriousness of the problem.

The USS CAPODANNO (FF 1093) encountered 8 inches of icing from sea spray and sea smoke in a 12 hour period at night while transiting from the Bay Capes to

Newport, RI. The ambient conditions were: 35 to 45 knot winds, sea state 4, visibility of 10 to 20 ft, dense sea smoke as high as 60 to 80 ft above sea level, ambient air temperatures of 0°F and a wind chill factor of minus 50°F.

The amount of icing was severe: 8 inches thick on all horizontal surfaces including deck fittings and ground tackle, and one half to 8 inches on the vertical surfaces.

The effect of this weather on ship operation was significant.

(1) Ice covered the machinery space ventilation intakes causing degradation of the ventilation system.

(2) Ice covered the ship service diesel generator (SSDG) air intakes. The ship's commanding officer remarked that the situation could have been critical if the SSDG's had been required since the intakes were 100 percent ice blocked.

(3) Ice covered the interior and exterior bridge windows faster than window heaters could control its removal.

(4) Topside lookouts had to be rotated every 30 minutes due to the wind chill.

(5) The anchor windlass brake froze due to water intrusion.

(6) Ice accumulation prevented the WISKEY 3 OE-82 antenna from operating properly.

(7) Five pre-heater heating coils ruptured when intakes froze.

(8) Changes were noted in the ships roll period due to increased topside weight.

(9) Weather and sea conditions prevented dispatching topside patrols to remove ice.

Exhibits 1 through 12 are photographs of the ship after the ice over.

The significance of the USS CAPODANNO icing experience is that it provides a perspective on the characteristics of ship icing. This perspective will be extremely valuable when conducting ship icing experiments. Futhermore, the incident pointed out that ship icing is not confined to arctic areas but can occur instead in locations normally considered benign.

WHAT IS A SHIP ICING EXPERIMENT

Overview

The "ship icing experiment" refers to a planned tests that involve icing over a combatant vessel by using equipment for artificially generating the ice. A general arrangement of the scenario for the experiment is shown in exhibits 13 and 14. Key components of the test include: (1) a surface combatant at anchor; (2) gas turbine-driven pumping units called light weight firefighting modules (LWFM's or Fireflies, as they are nicknamed) on a Navy YC barge and on the ocean-going tugboat, and (3) multiple flow spray nozzles mounted in a manifolded arrangement on the YC barge and the tug.

This type of spraying and pumping arrangement has been tested at sea but not in extreme cold weather (CW). Cold weather tests of the Fireflies have produced enough spray ice to knock trees down. The ocean-going tug with the mounted Firefly unit would move around the ship to selectively spray a desired ice thickness (distributed similar to that experienced in actual ship icing incidents).

Also shown in exhibit 13 is a spray which surrounds the surface combatant. Recently the University of Alaska, under contract to the David Taylor Naval Ship R&D Center (DTNSRDC), conducted a simulation of the freezing of sprayed seawater to produce artificial spray ice. Based on the results of that study[1], the ideal weather for heavy, artificial spray icing is an air temperature of -18°C (0.4°F) and a sea surface temperature of -1.8°C (28.8°F). Under those conditions, sprays from typical fog nozzles would contain the following frozen percentages for each droplet: (1) individual small droplets, 83%, and (2) individual large droplets, 23.5%.

This data is for the freezing of a plume of seawater in still air and is based on a theoretical model that has been partially substantiated by empirical test data. The effect of any appreciable wind speed is to increase the fine droplet hang time and increase the percentage of ice generation in the spray; but this is offset by less control in accurately positioning the spray on the target (ship). High wind speeds will be helpful if the spray pattern hitting the ship can be controlled without constant repositioning of the barge and tug containing the spraying systems.

The temperature effect maybe summarized as follows: (1) it is crucial to have seawater temperatures at or slightly above the freezing point of seawater when the winds and wave action are not severe; and (2) as the air temperature rises from -18°C (-0.4°F) to -1.8°C (28.8°F), the frozen percentage of each fine droplet decreases. At some point (for a given set of ambient conditions) the larger droplets do not completely subcool; hence, no freezing of large droplets will occur. By utilizing empirical results of a spray ice generating test expected to be conducted in April 1986, modifications and refinements will be made to the existing model to account for the effect of wind.

Spraying System for Ice Generation for the Experiment

Exhibit 15 shows a photograph of three Firefly units and a fuel truck mounted on a Navy YC barge prior to a ship dewatering test. These are portable, rugged units in the inventory of the Naval Facilities Engineering Command (NAVFAC). Exhibit 15 shows a photograph of a manifold arrangement of multiple nozzles producing a wall of water spray during Firefly unit tests. NAVFAC has two models of Fireflies available: one can pump up to 2500 gallons per minute (gpm) while the other, up to 5000 gpm. Exhibit 17 shows one unit drawing a suction through portable hoses dropped from the barge. Exhibit 18 shows the Firefly in a truck and trailer-mounted configuration which contains all the accessories required for deployment. An evaluation of the spray ice generating capability of this system is planned as a pre-test in April 1986 in Alaska. In those tests, a truck and trailer mounted unit is planned to be used. Exhibit 19 shows a spray produced from a Firefly unit mounted on the stern of the "Kingspointer", an ocean-going tug operated by the U.S. Merchant Marine Academy. Exhibit 20 is a close-up view of the portable, skid-mounted nozzle arrangement on the stern of the "Kingspointer." The significance of these photographs is that they illustrate that expected ship icing experiment configurations involving the Fireflies have already been previously demonstrated. The main concern is how well they will perform in winter weather to provide controlled spray ice generation.

REASONS FOR SHIP ICING EXPERIMENT

In COMNAVSURFLANT Instruction 3470, the Cold Weather Handbook for Surface Ships, it is stated that "cold weather operations present many problems not ordinarily encountered by U.S. Naval surface forces which are not designed to operate under such stringent environmental conditions." The ship icing experiment can be viewed as an early phase in a program to evaluate and improve surface fleet preparedness in extreme cold weather and under icing conditions. This experiment can be done safely at anchor in a controlled setting without deploying a ship into an ice storm at sea to determine survivability when iced over.

Since little is known about operability under such extreme conditions, the Navy needs to do controlled experiments beyond the component level and into the ship system and platform level. Component and system level testing in cold rooms and ice rooms may actually be more expensive to perform on several systems for several days than the cost of deploying and operating the spray system on the barge and tug for a 2 to 3 week period where numerous systems and equipments can be evaluated simultaneously. Any such testing in cold weather rooms and in the laboratory, although needed to provide preliminary design data, does not satisfactorily model ship conditions and, thus, is insufficient to provide all the data needed to make final decisions on cold weather equipment suitability.

A centralized, coordinated effort is required to discover limitations and develop corrective actions for extreme cold weather operations. In order to preserve and maintain this knowledge, a centralized corporate memory needs to be founded. The ship icing experiment will provide key parts of this corporate memory.

By getting directly into shipboard testing of items used by other Navies and tested in other labs, which have already been identified as potential solutions to Navy cold weather problems, the long process of individual component development and extensive laboratory testing might be by-passed. Thus, the time and cost of the problem-solution implementation cycle can be substantially reduced through such a ship experiment.

For many CW-related design limitations, various Navy project teams have generated matrices of problems and potential solutions. These potential solutions must be verified by testing. The ship icing experiment and the ship transits to and from the testing area provide excellent opportunities to do this evaluation of many normal ship operations and perform some corrective actions.

Corrective actions, once initiated on a ship, should be monitored for effectiveness over several winter seasons. The ship research and design community needs this long term relationship with a test platform before a decision is made to implement major cold weather related changes to ship equipment. The ship selected for the icing experiment could serve as such a platform.

The current Maritime Strategy projects that surface operations in northern latitudes in both the Atlantic and the Pacific ocean will occur during seasons when the probability of encountering extreme cold weather and ship icing is high. One question here is: How are we going to fight and conduct necessary deck operations when the ship is in these environments? The answer to this question is quite incomplete since the systems, as well as the ships, have seldom, if ever, been tested in such conditons. The icing experiment is intended to give us a much better understanding of the problems in conducting warfare and ship operations in extreme conditions.

The labor intensity of current U.S. Navy ice removal techniques is yet another reason for proceeding with ship icing and deicing experiments. Hand removal rates of 6 to 7 man hours per ton of ice have been confirmed by ship operators. The removal rate for certain deicing lances used by foreign operators (but not the U.S. Navy) is 0.6 to 1.8 man hours per ton. Continuous ice removal and ice prevention can be achieved with anti-icing systems such as heat pipes, heat tapes and tarps, electrically-activated coatings, other low ice adhesion coatings and electropulse systems. These new approaches have not yet been evaluated by the U.S. Navy. A ship icing experiment would allow their evaluation under realistic shipboard conditions.

OBJECTIVES OF THE SHIP ICING EXPERIMENT

Shown in exhibit 21 are the original set of objectives for the experiment. A recently formed Navy steering committee for the experiment is currently re-evaluating all plans, objectives, scope, and funding requirements for the project. Therefore, it is expected that some of the objectives may be reformulated to reflect the concerns and priorities established by that committee.

PRE-EXPERIMENT PREPARATION TASKS

Before any ship icing experiments can proceed, it is necessary to accomplish a number of preparatory tasks. Planned tasks for the experiment, summarized in exhibit 22, are described below.

Detailed Project Summary Plan

A detailed project summary plan is to be completed. This plan will include: description of the approach, itemized and totalized resources requirements, documentation requirements, summary and task level milestone charts, critical path network, master schedule, itemized and totalized funding and manpower requirements, a work breakdown structure, a personnel/agency responsibility matrix, and a risk assessment.

Icing Thickness-Distribution Model

A model will be developed to describe the distribution of ice on the ship. It will use empirical results of the CAPODANNNO and GALLERY (FFG-26) icing incidents as a baseline. The model will serve as a guide for generating ice accumulation on the test ship. It will also be cross checked with a NAVSEA ship stability model applied to the test ship for iced-over conditions.

Experimental Site Analysis and Selection

This task will develop criteria for the candidate choices of test sites. A description of the effort to date on this task is discussed later.

Simulation Model of Ship Ice-Over by the Fireflies

The University of Alaska under contract to DTNSRDC recently conducted the theoretical modelling and analysis of the freezing of sprayed seawater to produce aritificial spray ice when using the NAVFAC Firefly modules and various nozzle systems. This model will be verified through icing experiments planned for the winter of 1986.

Failure Mode Effects and Criticality Analysis (FMECA)

This analysis will survey key systems on the test ship with regard to potential failures that could develop due to icing and establish what the resultant effect might be on the system and ship. After weaknesses in the equipment or system design are isolated, a set of recommended actions will be suggested for failure avoidance.

Ship Stability Analysis

Recent NAVSEA and Gibbs and Cox stability reports for ice-over of various ship classes will be used. If the selected test ship doesn't have such a stability analysis, one will be completed. Based on the ice loadings derived in the model, the safety implications on ship stability will be established for a ship at anchor and at sea (if at sea tests are done). The degree of ship list at which the experiment should cease adding ice will be determined.

Ship Structural Analysis

A structural analysis of the CG-47 class in an iced-over condition has been done. No similar analysis has been done for other ship classes. Such an analysis will be done for the ship selected for the ship icing experiment. A plan will be made for instrumenting the test ship with strain gauges for evaluation of the impact of ice loading and subsequent deicing on the ship structure.

Winter of '86 Pre-Test

This is a test which is currently planned for April 1986 in Prudhoe Bay and Nome, Alaska and has the following objectives:

(1) Demonstrate the Firefly equipment and the operator suitability for winter testing,

(2) Demonstrate the concept of using the Firefly pumping modules and various ancillary devices for generating spray ice from seawater,

(3) Evaluate the effectiveness of math model for predicting spray ice formation,

(4) Identify target (ship) - source (spray nozzle) locational relationships, and

(5) Qualitatively evaluate some candidate low ice adhesion coatings.

Cold Weather Kit Development

This task would define and procure a cold weather kit for the test ship. Since the kit is a function of the icing experiment detailed plans, the total scope of the kit is undetermined at this time.

Anti-Icing and Deicing Subsystem Studies

This will be a set of design application studies of various types of anti-icing and deicing concepts/equipment that could be evaluated in the experiment. Some will be off-the-shelf equipment; others will be tailored to the specific system, component, or location on the ship. Those items which are not available or not selected for evaluation in the first ship icing experiment could be ready for any such experiments on other ship classes in future years.

Topside Weapons Systems, Sensor and Communication Systems

Under guidance from the combat systems community, individual test plans will be developed and patterned after portions of ship acceptance trial tests, combat system qualification test (CSQT) plans, and daily system operating tests (DSOT) plans tailored to extreme cold weather and for an iced-over ship.

LAMPS MK III - Ship Support System Protection

With guidance from the Naval Air Systems Command, test plans and cold weather kit items will be developed to ensure that the experiment evaluates key ship support system aspects and normal ship operational evolutions pertaining to LAMPS MK III helicopter operations.

Ship Preventive Maintenance for CW Protection

If time permits, an evaluation of required preventive maintenance actions for key ship systems should be done for the test ship. No such cold weather PMS package exists for any ship class. Enhanced mission preparedness and system failure avoidance can result from good preparations prior to an extreme CW deployment. The effectiveness of the PMS package, if available, would be evaluated during this experiment.

Electric Load Buildup and Weight-Moment Analysis

During the Arctic SHAREM 55 (55th Ship Anti-Submarine Warfare Readiness Exercise Measurement), numerous electrical heaters were used, causing local load buildups that faulted power circuits. Since it is envisioned that additional electrical power will be required for deicing and anti-icing systems, CW protection, and space heating during the ship icing experiment, a close watch must be made of the electric loads. When test plans are complete and firm with regard to increased electric loads, a study will be made of the ship capability to handle the additional electrical needs.

Since additional weight will be carried by the ship due to coatings, instrumentation, anti-icing and deicing equipment, other CW kit items, ice, extra personnel, etc, a weight-moment analysis should be done to determine the effect on ship stability.

Pre-Experiment Ship Preparation

Some minor modifications of the test ship will be required to prepare ship's forces and the ship itself for the experiment. This will include the installation of any CW kit items, anti-icing and deicing subsystems, instrumentation, FMECA-suggested fixes and CW PMS items. In addition orientation and training of ship's forces responsible for carrying out portions of individual test plans will be required.

SITE ANALYSIS AND SELECTION

Spray Systems Constraints

The current DTNSRDC/University of Alaska study on the use of pumping systems to produce artificial spray ice from seawater has defined the parameters needed from the spray system, and the degree of subcooling and freezing of the droplets for various air and seawater temperatures. These constraints will be used in the site selection process and verified by testing before the ship icing experiment.

Candidate Sites

Initially, Newport, RI and Portland, ME were considered leading candidate test sites. Newport has the facilities of the Navy Training Center and currently is the home port for two FFG's. Portland, ME, has the ship repair facility of Bath Iron Works. Based on the climatology, these locations provide ambient conditions which require that the experiment be conducted at night; the optimum air and water temperatures for artificial spray ice formation do not occur except at infrequent periods.

A transit a little further north can provide daytime temperatures that are colder, more consistent, and assure a good daytime test with a minimum or no waiting time for the proper ambient conditions. This fact justified looking for alternate test sites. Sites in Alaska, Canada, and Greenland are, in fact, being evaluated for their potential.

Site Selection Analysis Grid

A matrix of data is being developed in an approach to identify a suitable site. Data requirements for the site selection analysis grid are as follows:

1) climatology (air and seawater temperatures, wind speeds, consistency, proximity to the ice edge),

2) logistic support requirements (port availability, adequate channel size and depth, berthing facilities, anchorages, nearby areas for at-sea combat system testing, airport, marine facility support, availability of barges, tugs, cranes, and moorings, uncongested test area, lack of hostile intelligence presence, etc),

3) transiting aspects (acceptability of fuel costs, environmental risk and transit time),

4) ice generating capability of test site (capability of daytime versus night time ice-making operations; number of hours per day that are suitable for ice-making; percentage of time suitable for generating ice over a one, two or three week period; ice making capability over several candidate winter months).

These factors all have to be evaluated before a final selection of the site is made. Timely and early identification of a test site is critical to ensure the initiation of the ship experiment by February 1987.

TASK AREAS OF INVESTIGATION FOR THE ICING EXPERIMENT

The major task categories proposed for the experiment are as follows:

(1) superstructure (Exhibit 23),

(2) topside equipment (Exhibit 24),

(3) main and auxiliary machinery (Exhibit 25),

(4) combat systems (Exhibits 26 and 27),

(5) LAMPS III - ship integration (Exhibit 28),

(6) cold weather training and safety (Exhibit 29),

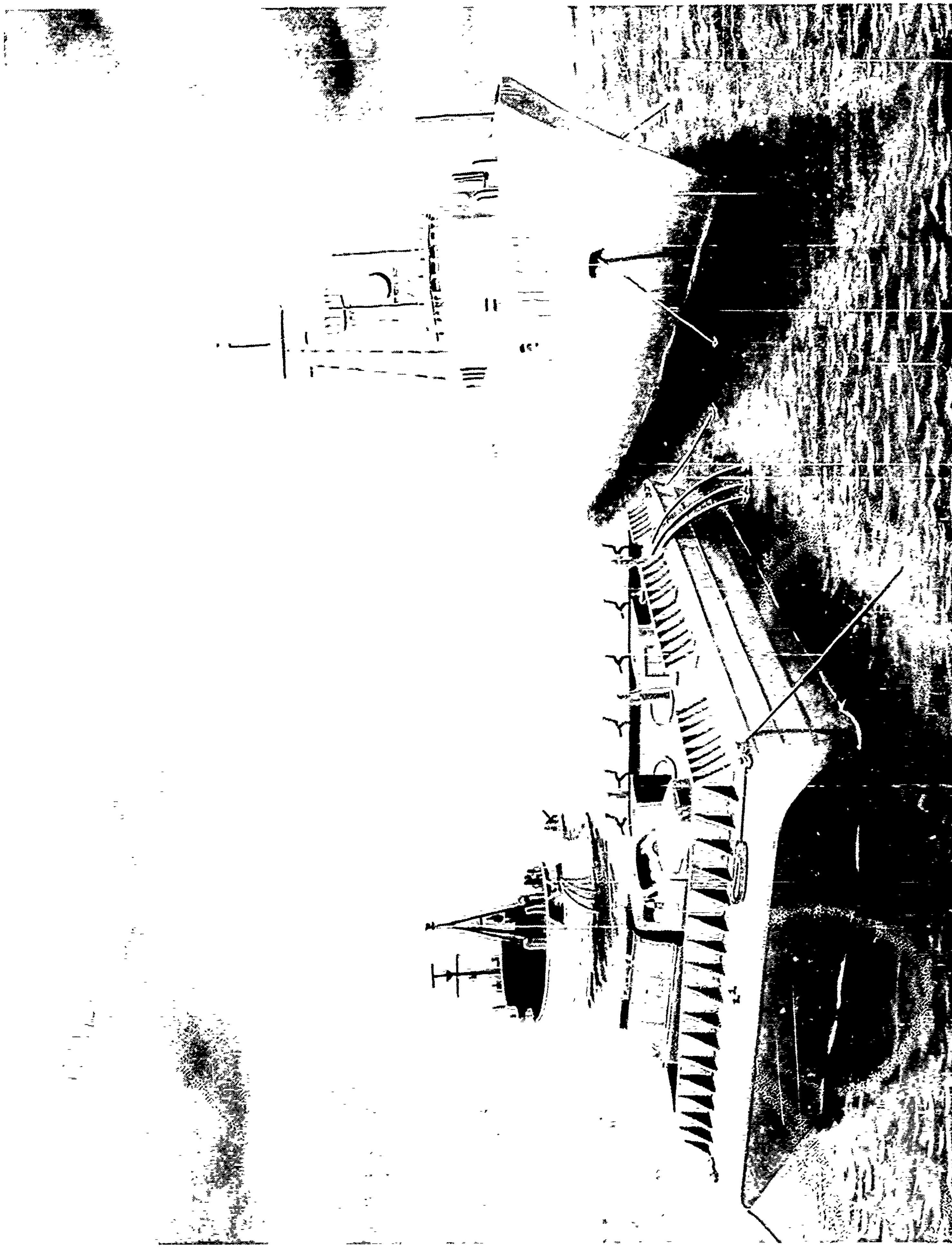
(7) cold weather bill and handbook verification (Exhibit 30).

Under each task category are listed specific cold weather and icing/deicing related work areas that are suggested for investigation as part of ship icing experiments. The list incldues both specific equipment that may be subject to cold weather and icing problems (e.g., doors, hatches, and scuttles) as well as possible solutions to a cold weather problem (e.g., icephobic coatings; heat pipes and tapes).

It should be noted that a number of the tasks are specific to the FFG-7 class as the proposed test ship. However, primary intent of the list is to provide an understanding of the nature of task areas that should be investigated--for whatever ship is ultimately selected.

SHIP ICING EXPERIMENT STATUS

A summary of the status of this project is provided in Exhibit 31. A considerable amount of planning has already been completed with regard to: (1) identifying the availability of key equipment such as the Fireflies, (2) determining funding required, and (3) establishing key personnel and technical organizations that can contribute to the experiment design and implementation. Obviously a substantial task lies ahead to make the icing experiment a reality and, thereby, provide the Navy with the data necessary to develop a combat-ready, cold weather fleet.



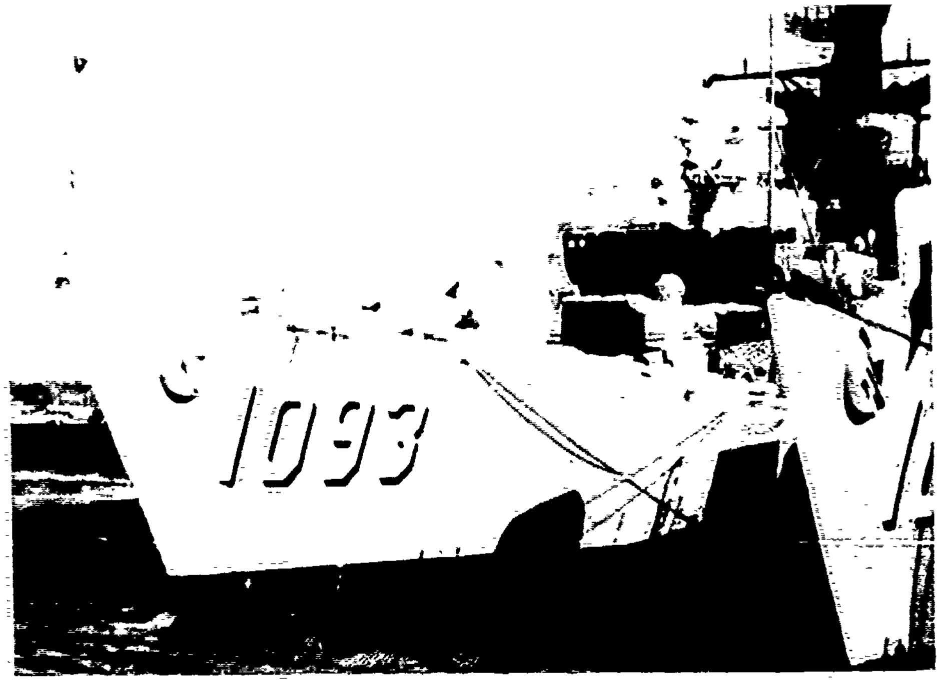


Exhibit 1 - View of Forward Section of USS CAPODANNO
Following Icing in January 1985

Exhibit 2 - Iced Over Davit and Chain Hand Rails on USS CAPODANNO

Exhibit 3 - Front View of Forward Gun on USS CAPODANNO

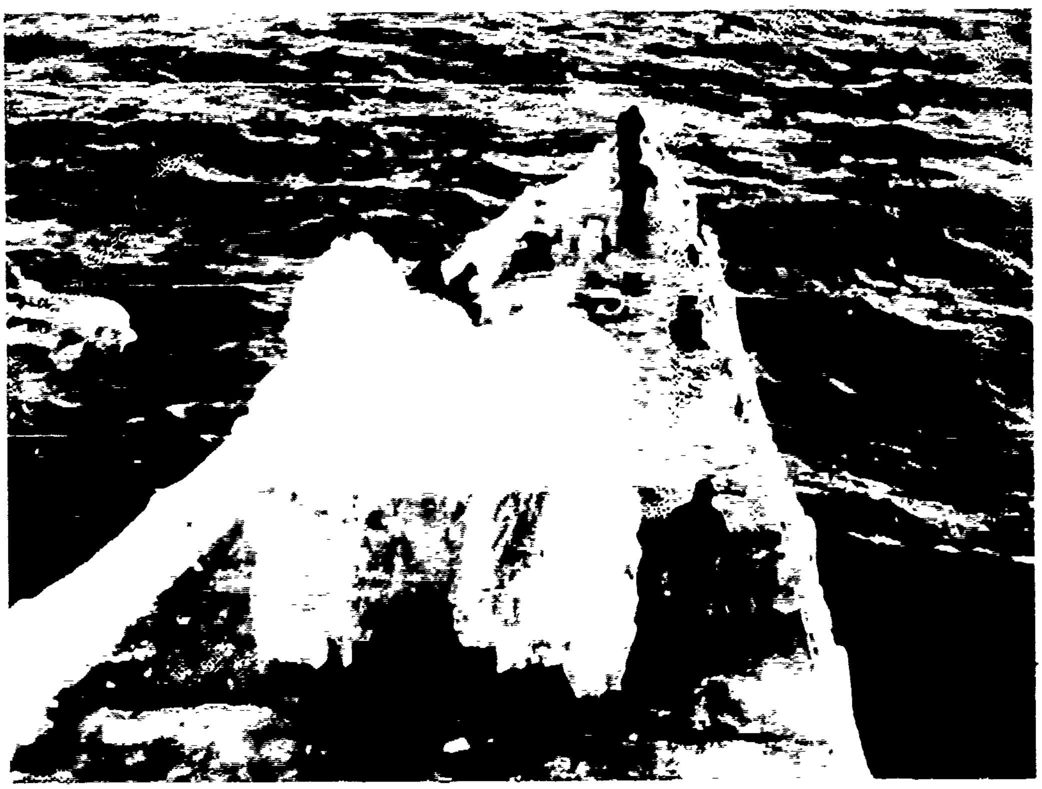


Exhibit 4 - Top Rear View of Forward Gun on USS CAPODANNO

Exhibit 5 - Rear View of Forward Gun during Ice Removal Operations on USS CAPODANNO

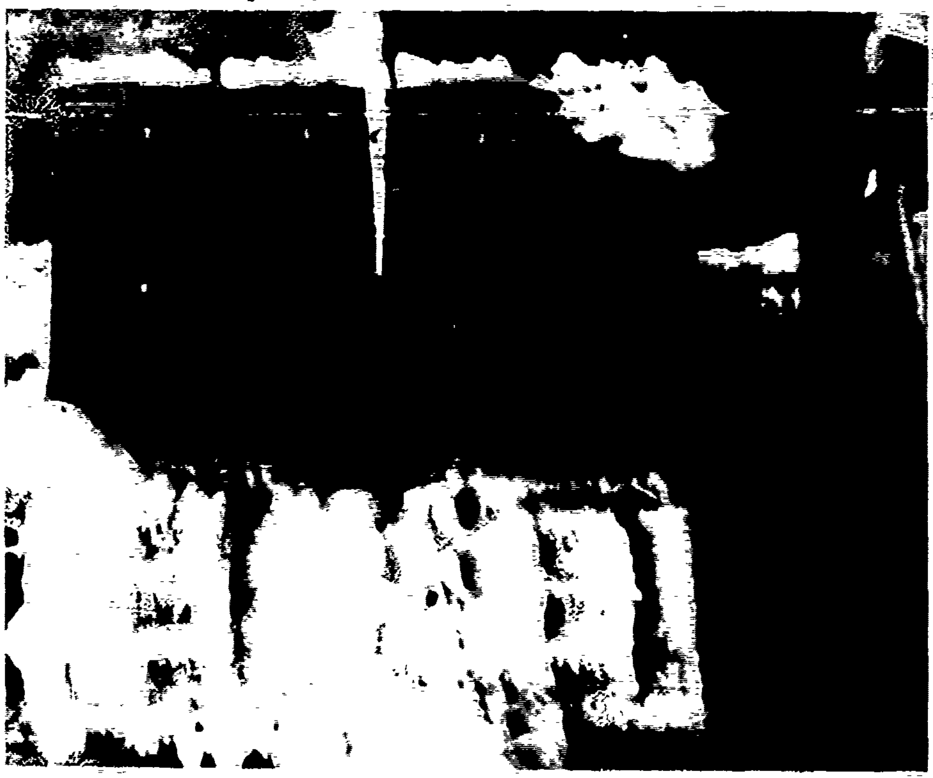


Exhibit 6 - Iced Over ASROC Launcher (Note that heated doors are ice-free but unheated canister and base are not)

Exhibit 7 - Iced Over Bow on USS CAPODANNO Showing Chocks, Anchor Chains, and Chain Hand Rails

Exhibit 8 - Iced Over Capstans on USS CAPODANNO

Exhibit 9 - Iced Over Ladder and Deck Housings on USS CAPODANNO

Exhibit 10 - Iced Over Safety Nets on USS CAPODANNO

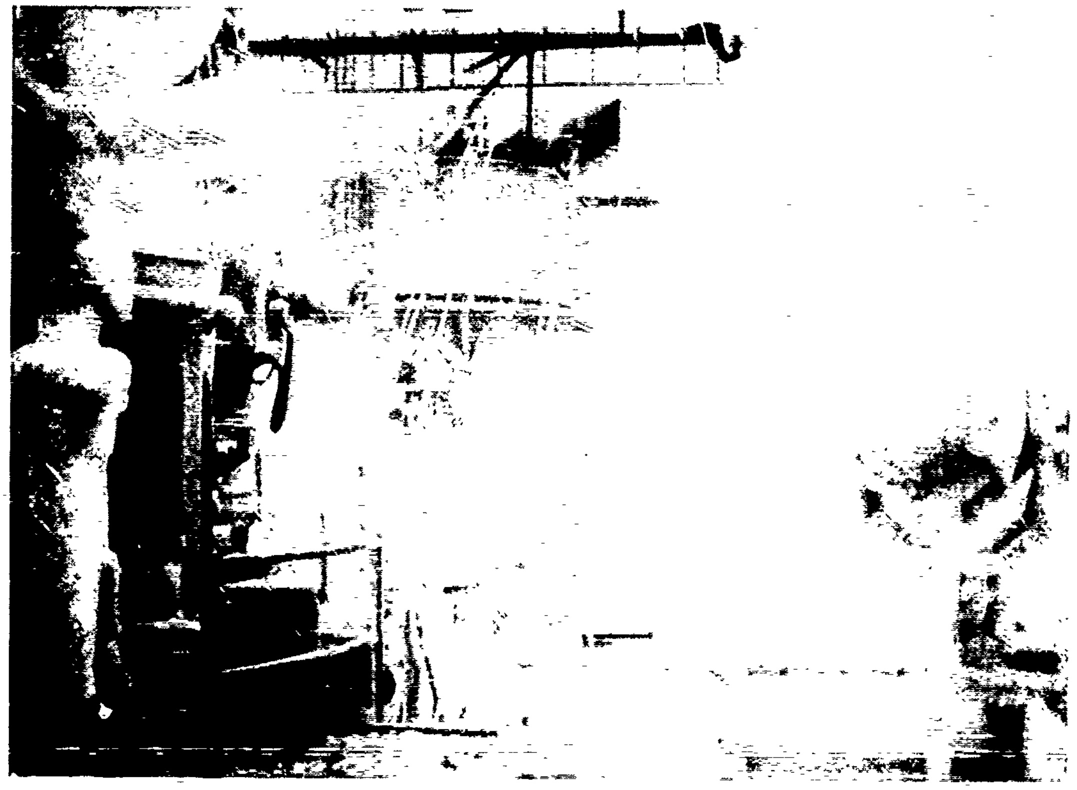


Exhibit 11 - View of Ship Ice from the USS CAPODANNO Bridge

Exhibit 12 - Iced Over Walkway Aboard USS CAPODANNO

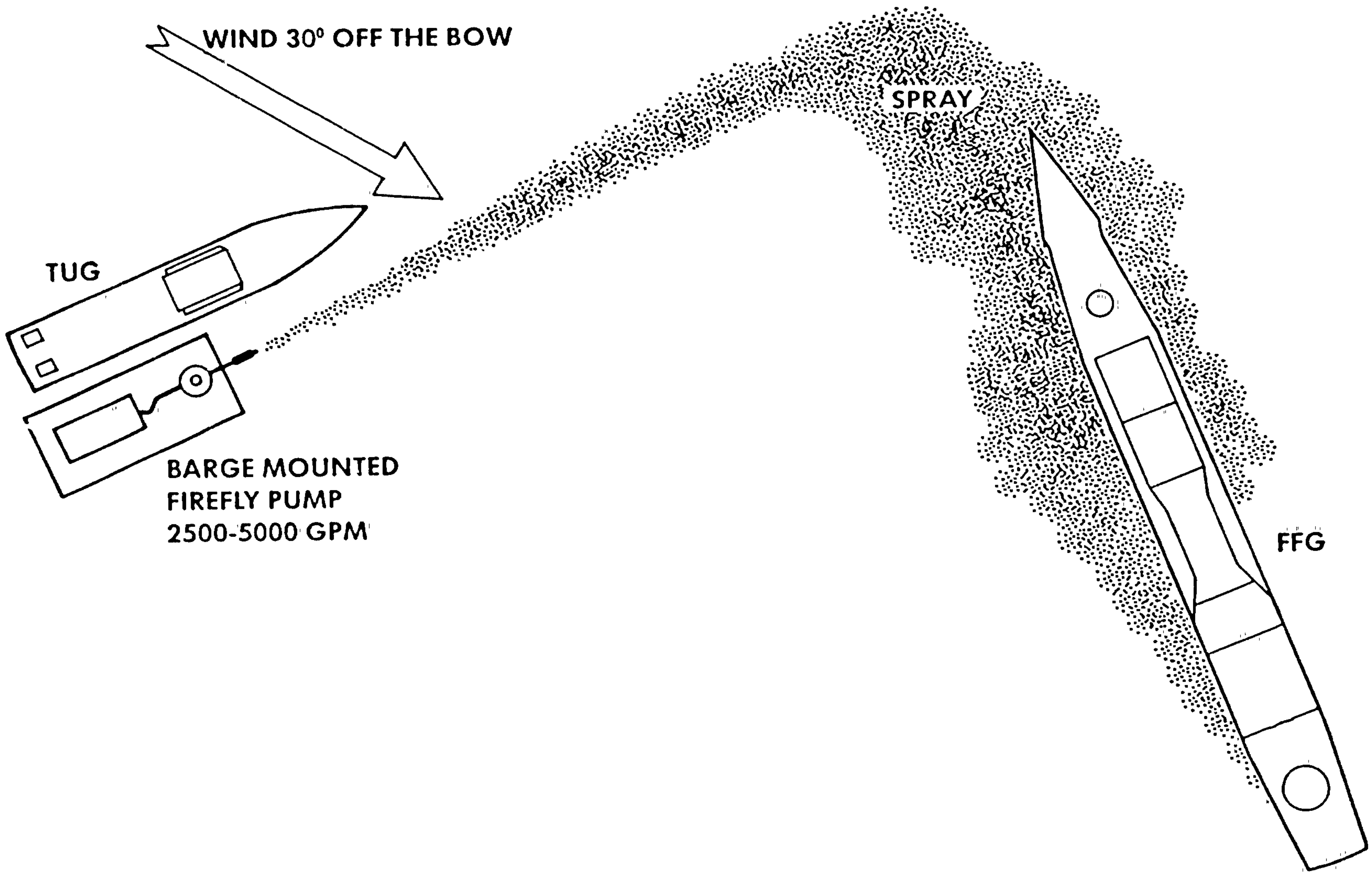


Exhibit 13 - General Arrangement for the Ship Icing Scenario

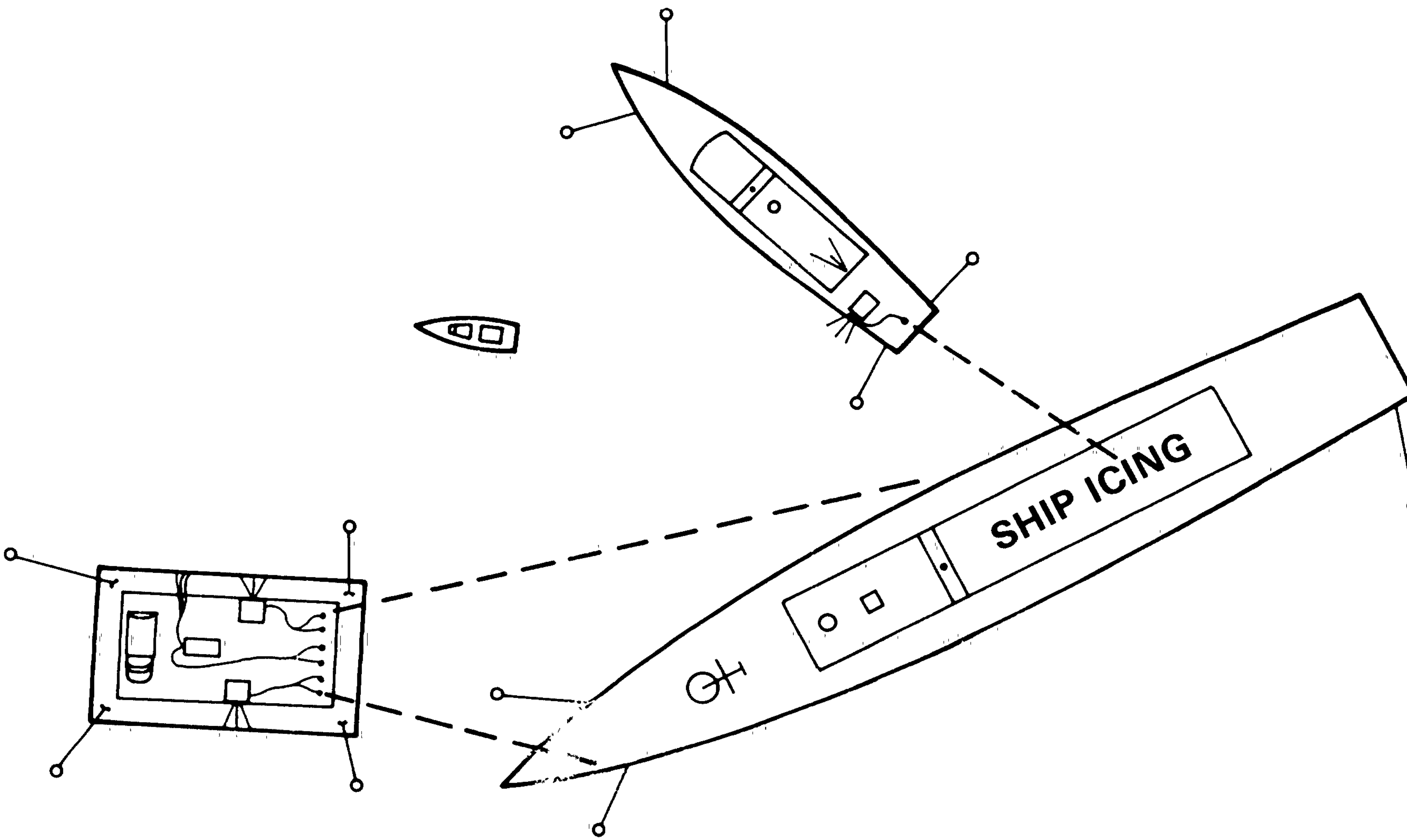


Exhibit 14 - Top View of the Ship Icing Scenario

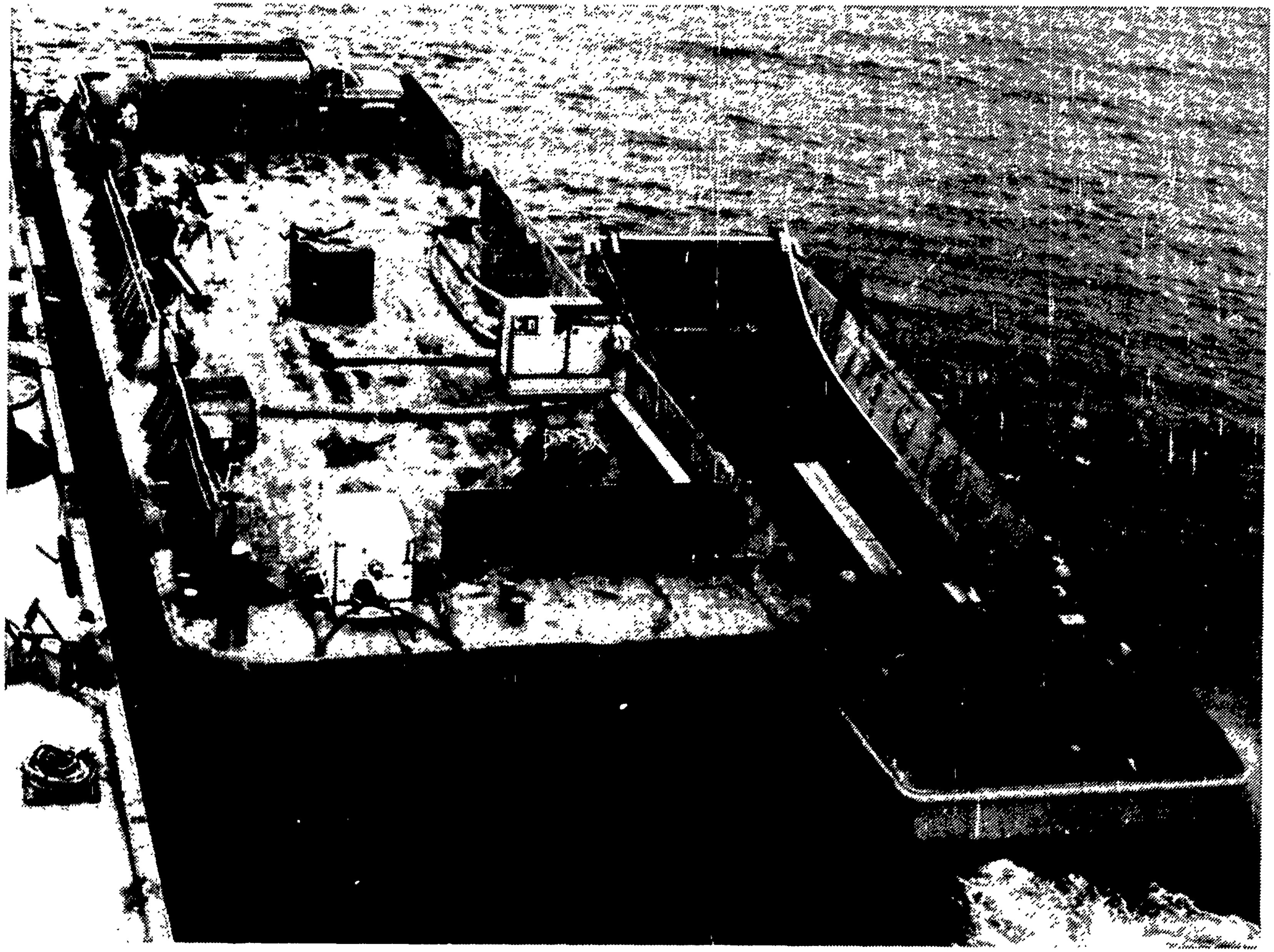


Exhibit 15 - Three Firefly Modules and Fuel Truck Mounted on Navy Barge

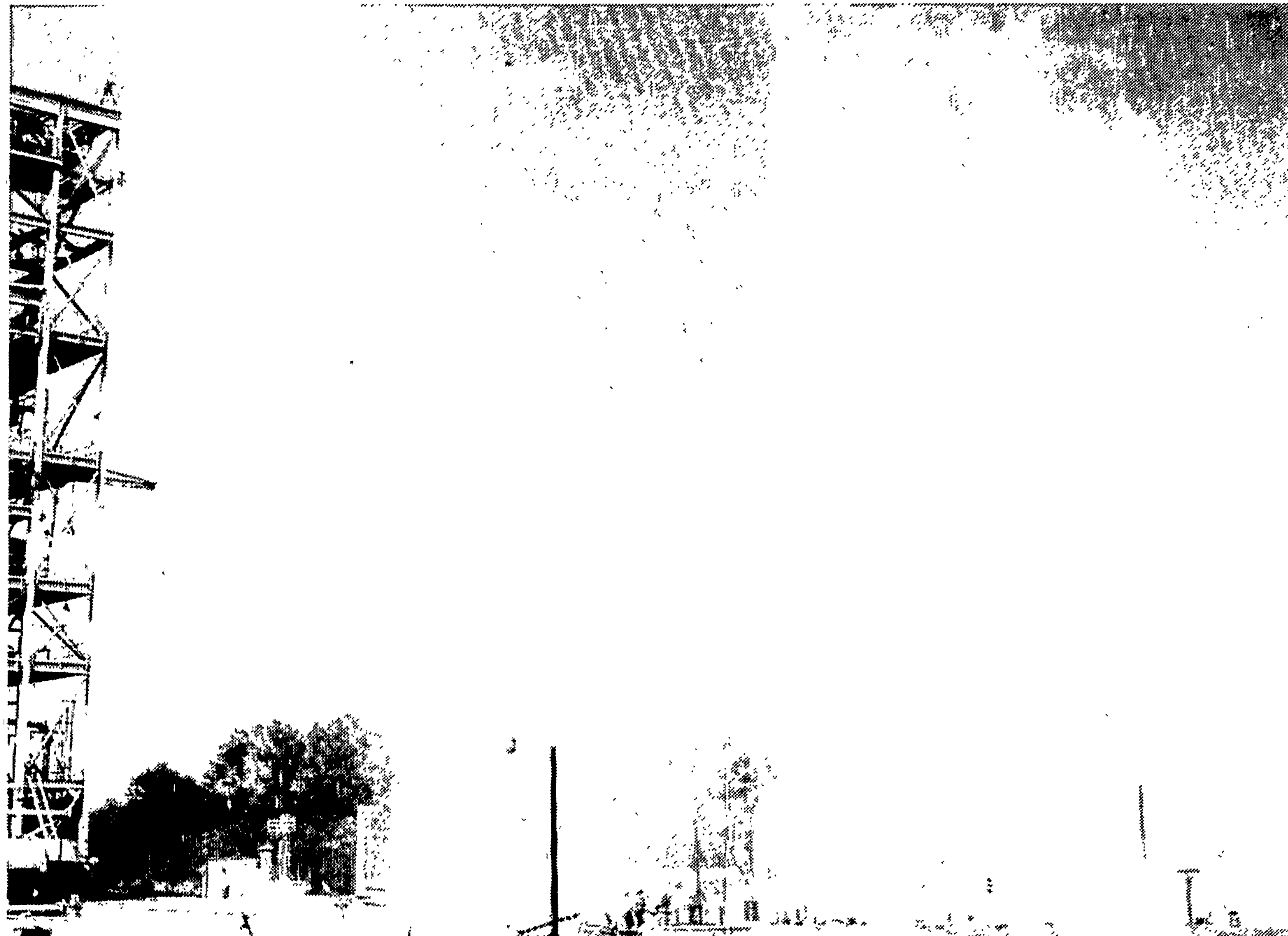


Exhibit 16 - Manifolded Arrangement of Multiple Nozzles Producing a Wall of Water Spray during Firefly Tests

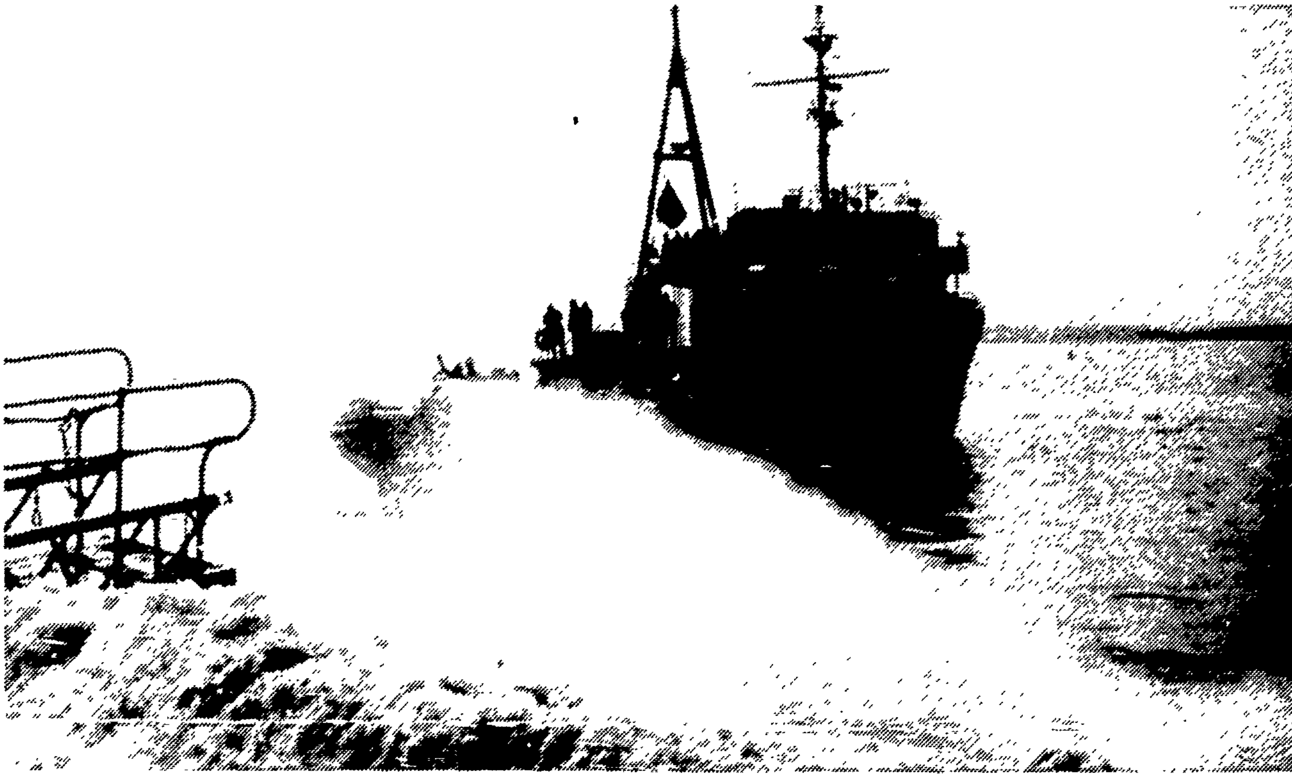


Exhibit 19 - Spray Produced by Firefly Unit Mounted on Stern of Tug "Kingspointer"

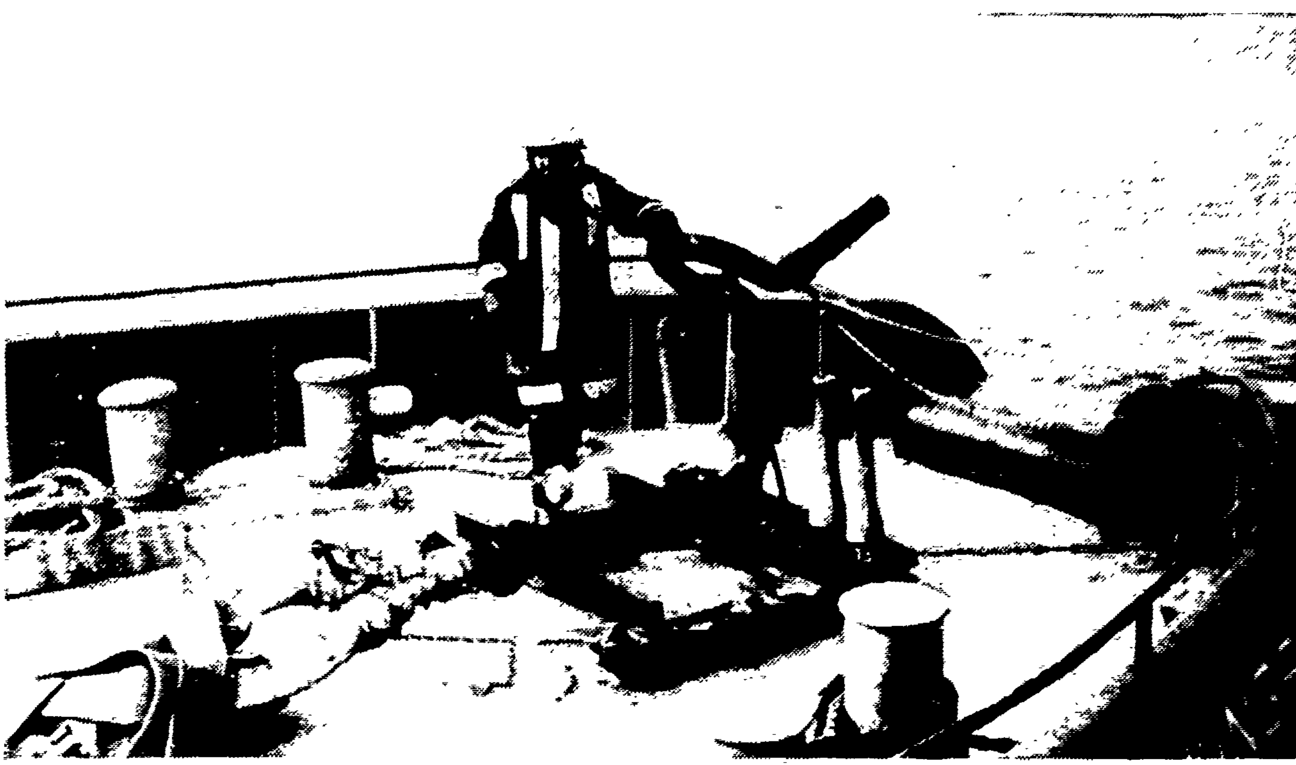


Exhibit 20 - Portable Skid-Mounted Nozzle Arrangement on the Stern of Tug "Kingspointer"

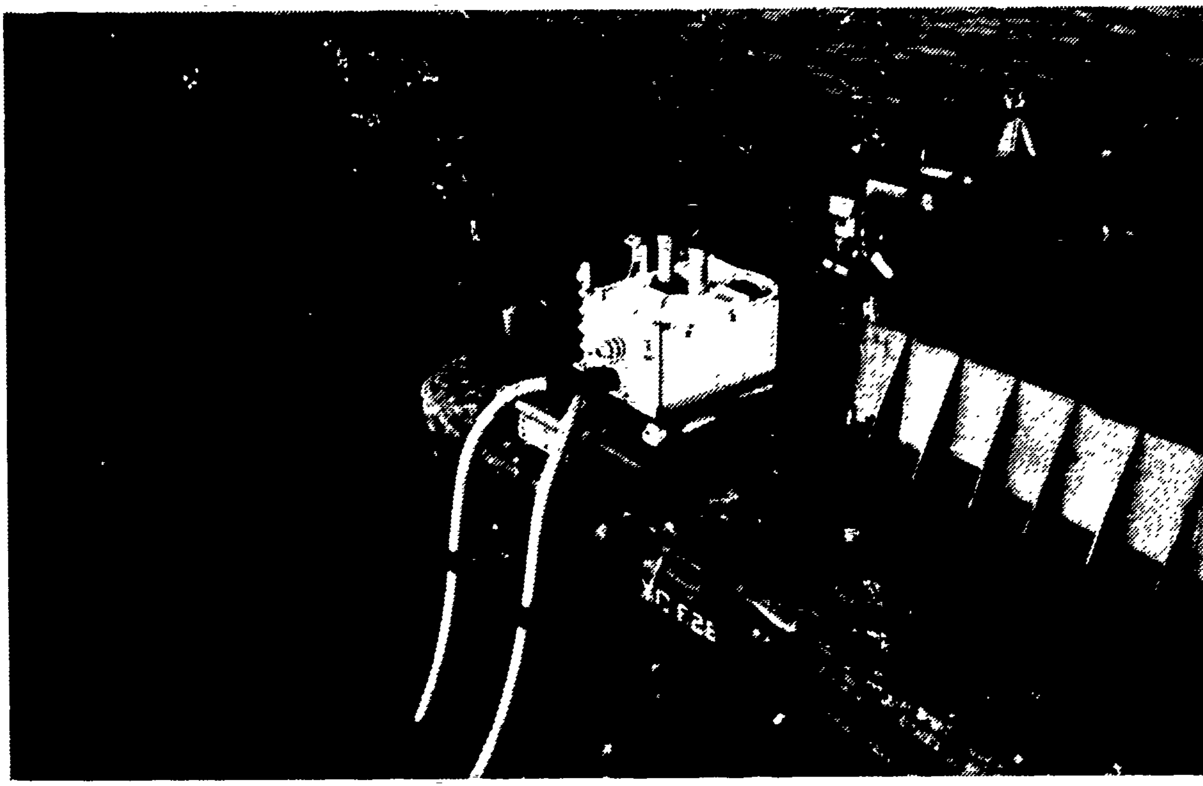


Figure 17 - Firefly Unit Drawing Suction Through Hoses Dropped from YC Barge

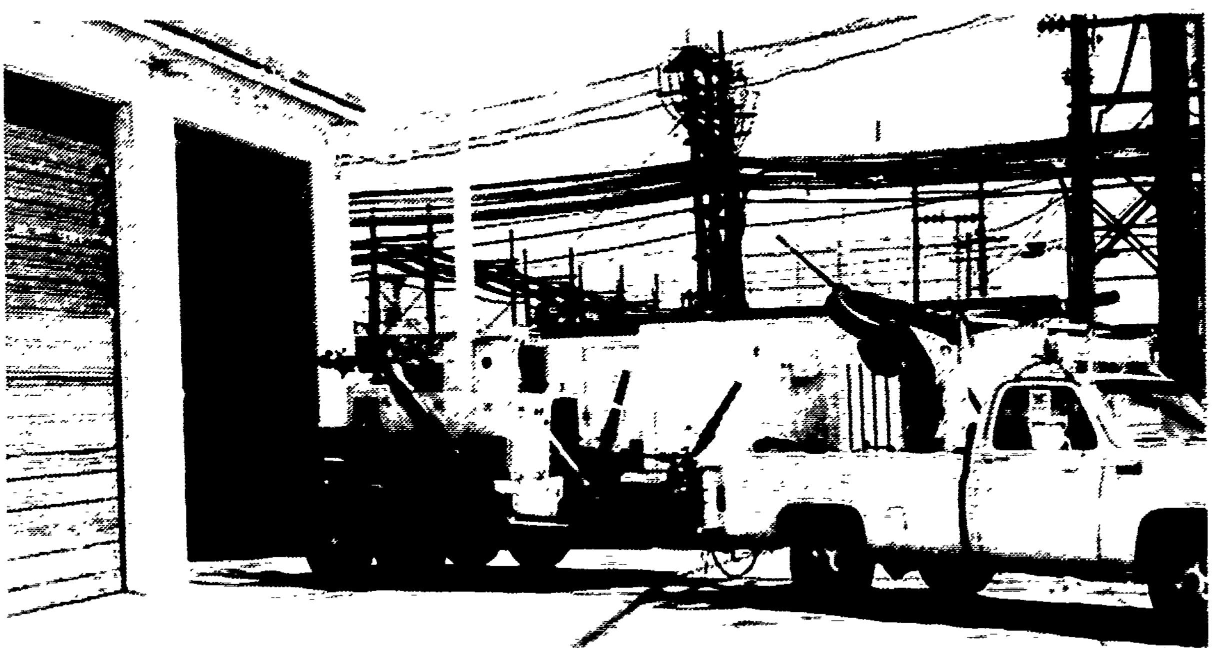


Exhibit 18 - Firefly Module and Accessories in Truck and Trailer Mounted Configuration

INVESTIGATE:

- STRUCTURAL AND STRENGTH IMPACT ON A SURFACE COMBATANT DUE TO ICE LOADING
- DYNAMIC SAGGING AND HOGGING IMPACTS BASED ON STATIC ICE LOADING
- STABILITY IMPLICATIONS OF TOPSIDE ICING, INCLUDING VERTIFICATION OF THE SHIP DAMAGE CONTROL BOOK CURVES FOR STABILITY UNDER ICING CONDITIONS
- THE CURRENT ANTI-ICING AND DE-ICING CAPABILITIES BUILT INTO SHIP WEAPONS SYSTEMS
- NEW METHODS FOR ANTI-ICING AND DE-ICING OF THE SHIPS SUPERSTRUCTURE AND TOPSIDE EQUIPMENT
- ACTIONS REQUIRED TO MAINTAIN HULL, MECHANICAL AND ELECTRICAL SYSTEMS READINESS DURING EXTREME COLD
- THE LAMPS III SUPPORT SYSTEMS/SHIP INTEGRATION DURING EXTREMELY COLD WEATHER

RECOMMEND:

- IMPROVEMENTS TO THE TYPE COMMANDER COLD WEATHER BILL, AND CLASS SPECIFIC DOCUMENTS
- ENGINEERING CHANGE PROPOSALS FOR MAJOR DESIGN IMPROVEMENTS TO FACILITATE COLD WEATHER OPERATIONS
- THE DEVELOPMENT OF A KIT DESIGNED TO ENHANCE SHIP READINESS IN COLD WEATHER

SUPPORT:

- THE PRODUCTION OF TRAINING FILMS ON COLD WEATHER OPERATIONS AND SAFETY

ENSURE:

- AN ACCIDENT-FREE EXPERIMENT
- COST EFFECTIVE EXPENDITURE OF LIMITED R&D FUNDS

Exhibit 21 - Objectives of the Ship Icing Experiment

- ICE IMPACT ON DESIGN SUPERSTRUCTURE LOADS
- ICEPHOBIC COATINGS
- HEAT PIPES AND TAPES
- FIREMAIN HEAT EXCHANGERS
- SUPERCAVITATING WATER JETS
- TARPS
- STEAM AND BLEED AIR
- NBC COUNTERMEASURES WASHDOWN

Exhibit 23 - Proposed Superstructure Task Areas of Investigation

- PROJECT SUMMARY PLAN
- ICING THICKNESS-DISTRIBUTION MODELS
- PRIORITY EQUIPMENT TEST PLANS
- EXPERIMENTAL SITE ANALYSIS
- SIMULATION MODEL OF SHIP ICE-OVER BY LFFM'S
- FAILURE MODE EFFECTS AND CRITICALITY ANALYSIS (FMECA)
- SHIP STABILITY ANALYSIS
- SHIP STRUCTURAL ANALYSIS

- WINTER OF '86 PRE-TEST OF ICE MAKING WITH LFFM'S. CORRELATE WITH MODEL
- DEFINE AND PROCURE COLD WEATHER KIT
- CONDUCT VARIOUS ANTI-ICING AND DE-ICING SUBSYSTEM DESIGN APPLICATION STUDIES
- EVALUATIONS OF TOPSIDE WEAPON SYSTEMS, SENSOR AND COMMUNICATION SYSTEM, LAMPS-SHIP SYSTEM PROTECTION
- PREPARE SHIP PMS CARDS FOR COLD WEATHER PROTECTION. CONDUCT PMS.
- ELECTRIC LOAD BUILDUP AND WEIGHT-MOMENT ANALYSIS

- INSTALL ANY CW KIT ITEMS, ANTI-ICING AND DE-ICING SUBSYSTEMS FMECA-SUGGESTED FIXES, AND INSTRUMENTATION ON SHIP

Exhibit 22 - Pre-Experiment Preparation Tasks

- RAS/FAS REPLENISHMENT AT SEA/FUELING AT SEA
  - -INFLATABLE BAGS
  - -LG 380 COMPOUND
  - -HEAT TAPE
  - -HEATED TARPS
  - -BLEED AIR, STEAM, HEATED FIREMAIN
  - -DOCTRINE
- FIREFIGHTING EQUIPMENT
- LIFE RAFTS/BOATS
- DOORS, HATCHES, AND SCUTTLES
- ANCHOR WINDLASS, HOUSING, AND CAPSTANS
- LADDERS
- TOPSIDE VALVES
- WINDOWS

Exhibit 24 - Proposed Topside Equipment Task Areas of Investigation

I. GAS TURBINE AIR INTAKES
   - ICE, SNOW REMOVAL FROM INTAKES
   - BLOW IN DOOR ACTIVATION
   - USE OF ANTI-ICING AIR

II. OVERBOARD DISCHARGE AND SEA CHESTS

III. SHIP SERVICE DIESEL GENERATOR (SSDG) INTAKES

IV. LM 2500
   - WATER WASH TECHNIQUES
   - ENGINE BELLMOUTH DE-ICING
   - ANTI-ICING AIR
   - NAVAL DISTILLATE WAX PREVENTION

V. EVAPORATOR OPERATION IN LOW TEMPERATURE

VI. POTENTIAL FOR HEAT EXCHANGER ICING

Exhibit 25 - Proposed Main and Auxiliary Machinery Task Areas of Investigation

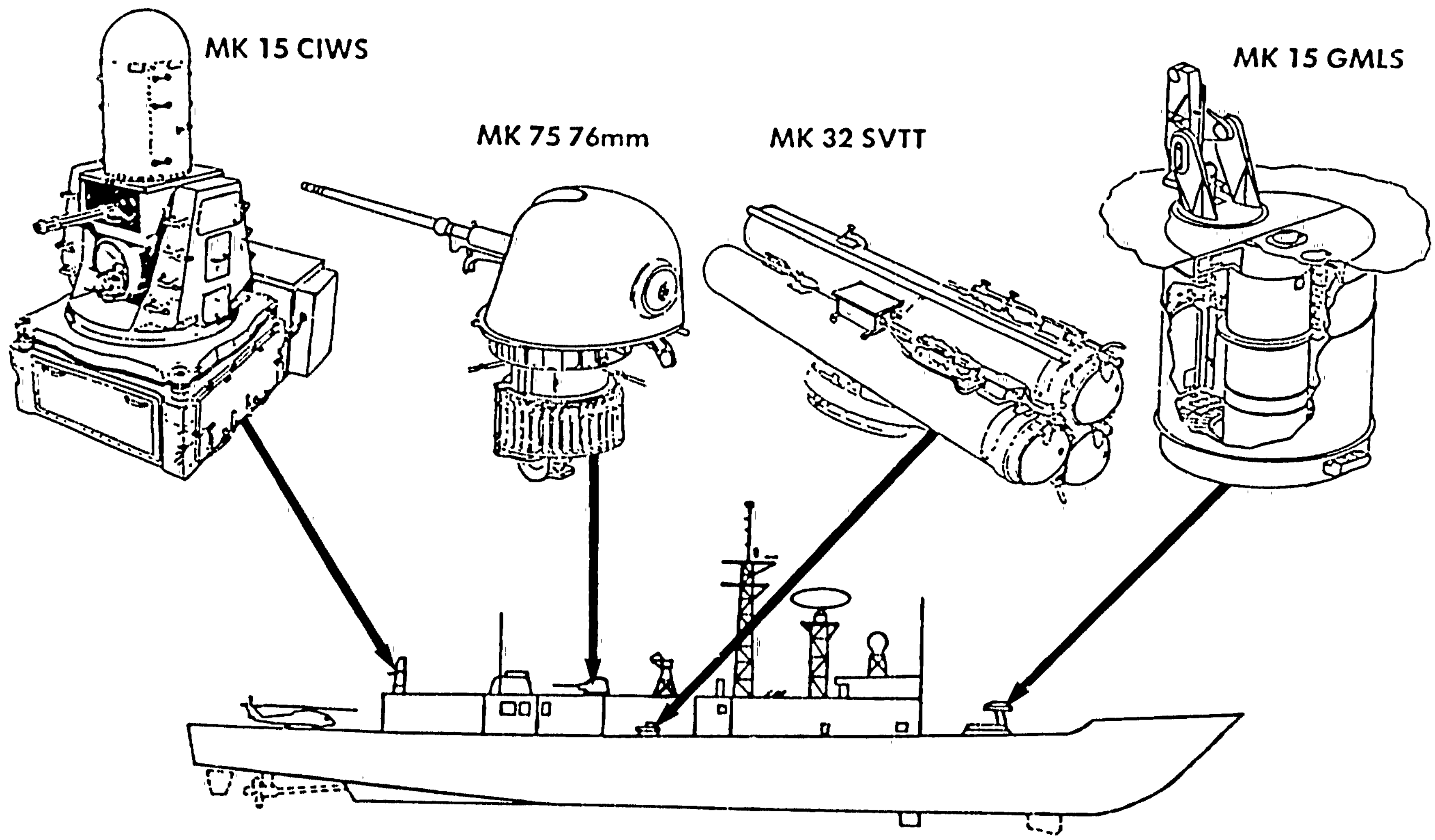


Exhibit 26 - Profile of FFG-7 Class Showing Selected Combat Systems

I. MK 13 GUIDED MISSILE LAUNCHER SYSTEM (GMLS)

RELOAD HATCH
RETRACTABLE RAILS
TRAIN AND ELEVATION
LAUNCH OBSERVATION WINDOW
CONTACTOR BOOT
ROTATION RATES

II. MK 32 SURFACE VESSEL TORPEDO TUBE (SVTT)

TRAIN
RELOADING

III. OTO MELARA 76 MM GUN

WATER COOLED BARREL
TRAIN AND ELEVATION
SHELL EJECTION
TARGET DESTINATION TRANSMITTER (TDT)
FIRING AND CYCLING RATE

IV. VULCAN PHALANX CLOSE-IN WEAPONS SYSTEM (CIWS)

HEAT EXCHANGER
EXPOSED AMMUNITION BELT
TOPSIDE ELECTRONICS CABINETS
SHELL EJECTION
RELOADING
FIRING AND CYCLING RATE
ROTATION RATES

V. SURFACE LAYER QUALITY (SLQ) SLQ-32

SIGNAL SENSITIVITY
ANTENNA ICE REMOVAL
V3 ACTIVE CAPABILITY UNDER ICE

VI. SUPER RAPID BLOOM OFFBOARD CHAFF (SRBOC)

VII. MK 92 MOD 2 CAS/STIR

ECCM CAPABILITY

VIII. TACTASS/NIXIE

XI. WSC-3 OE 82

X. 35′ WHIP/WIRE ROPE HF ANTENNAS

ICE ACROSS INSULATORS
ELECTROMAGNETIC INTERFERENCE

Exhibit 27 - Proposed Combat Systems Task Areas of Investigation

I. RECOVERY ASSIST AND TRANSVERSE (RAST) TROUGH
- DRAINAGE
- HEATING TAPE
- TARPS

II. RAPID SECURING DEVICE (RSD)
- HANGAR STORAGE
- EQUIPMENT ROOM
- ELECTRICAL CABLE TERMINATION

III. HANGAR DOOR

IV. FLIGHT DECK/TIE DOWNS
- DE-ICING SOLUTIONS
- TARPS
- FOD

V. AUXILIARY LAMPS SYSTEMS
- HORIZONTAL REFERENCE SYSTEM
- LSO STATION

VI. CRASH AND RESCUE
- DRY VS WET
- RAPID ACTIVATION OF DRY
- ANTI-ICING OF WET SYSTEMS

Exhibit 28 - Proposed LAMPS III Ship Integration Task Areas of Investigation

I. TESTING CW CLOTHING

II. IMMERSION SUITS FOR DAMAGE CONTROL

III. HVAC REVIEW OF UNHEATED SPACES

IV. SAFETY PRESENTATIONS FOR THE CREW
- OVERVIEW OF THE EXPERIMENT
- MEDICAL PRECAUTIONS
- ICE REMOVAL SAFETY

V. PRODUCTION OF TRAINING FILMS

VI. VARIOUS NORMAL SHIP EVOLUTIONS

Exhibit 29 - Proposed Areas of Investigation in Cold Weather Training and Safety

I. SHIP PREPARATION IAW CNSL 3470.1
HVAC
ANTENNAS
WEAPONS
SENSORS
SHIP'S BOATS
ENGINES
FLIGHT DECK

II. IDENTIFY/RECOMMEND COLD WEATHER GUCL

III. REVIEW, IMPLEMENT, IMPROVE SHIP'S BILLS

IV. IDENTIFICATION OF CW STORAGE

Exhibit 30 - Proposed Areas of Investigation for Cold Weather Bill and Handbook Verification

- SOME SEED MONEY FOR PLANNING FROM NAVSEA 05R. SEEKING ADDITIONAL FY 86 AND 87 FUNDS FOR BULK OF EXPERIMENT EFFORT.
- PROJECT SUMMARY PLAN DRAFTED.
- PRELIMINARY SET OF RESOURCE ESTIMATES ITEMIZED.
- ENDORSEMENT FROM NAVFAC ON USING LFFM'S.
- DISCUSSIONS WITH U.S. MERCHANT MARINE ACADEMY ON USING "KINGS POINTER".
- DEVELOPED LIST OF EXPERIMENT TASKS FOR AN FFG AS A TEST SHIP.
- COMPLETED STATE OF THE ART SURVEY OF ANTI-ICING AND SHIP SYSTEM COLD WEATHER PREPAREDNESS TECHNIQUES.
- INITIATED TASK ON ANTI-ICING SUBSYSTEM FOR RECOVERY, ASSIST AND TRANSVERSE (RAST) SYSTEM.
- INITIATED TASK TO DEVELOP SIMULATION MODEL OF SHIP ICE-OVER BY FIREFLY PUMPING UNITS.
- CONTACTING GOVERNMENT LABORATCRIES AND CONTRACTORS FOR INPUT AND PARTICIPATION.
- PRESENTED EXPERIMENT TO VARIOUS NAVY ACTIVITIES.

Exhibit 31 - Ship Icing Experiment Status

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N A W S -
A Hull Stress Monitoring System for Arctic Ships

Prepared for:
Arctic/Cold Weather
Operations Symposium
December 1985

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WORK ORDER No. 6647 **February 1986**

INTRODUCTION

There is more variation in ice conditions than there is in the whole range of sea states. It used to be said that Eskimos had 57 words for different varieties of snow, and it can now be claimed with some justification that there are nearly that many words in common use amongst ice researchers to describe their own medium.

The ice which is encountered in Canadian and U.S. waters covers the full spectrum, from fresh water ice in the Great Lakes through ice from the brackish waters of the St. Lawrence and on to saline ice off the East Coast or in the Arctic seas. In some areas, the sea ice is all first year; in other places, there are greater or lesser concentrations of multi-year ice and glacial fragments. Figure 1 shows a satellite photograph of a typical mix of conditions. In operation of a ship in ice infested waters or in pack ice, the ship's personnel can feel the effects of the ice from the overall response of the ship. However, only the most experienced officer with typically 10 or more years of ice experience has the conditioning and the ability to detect the possibility of ice damage. To do this, he must feel the slightest change to the sound, vibration, acceleration or decceleration of the ship and have detailed knowledge of the ship's structure. To a less experienced person the overall ship response does not accurately or sometimes even remotely indicate the localized forces from the ice on the ship's structure at or below the waterline. Further, because ice can vary by a large factor in strength, even experienced personnel can misjudge ice, sometimes with serious consequences.

It is this variability which makes ice navigation so hazardous to ships and particularly to those with limited ice strengthening. Another factor which can mislead operators is the nature of ice failure, which can lead to high pressures being generated over quite small areas of the hull. The total force on the ship may remain too low to produce a noticeable response in the hull as a whole, and the Captain may, therefore, be unaware that he is risking or actually suffering local structural damage until long after the event. This also makes it difficult to establish the probable causes of incidences of damage, which does nothing to help establish what constitutes safe operational procedures for a given vessel in different conditions. There have, of course, been numerous incidences of dramatic damage where the cause was quite obvious, but those cases have generally involved neglect of even rudimentary caution or blatant disregard of possible risks.

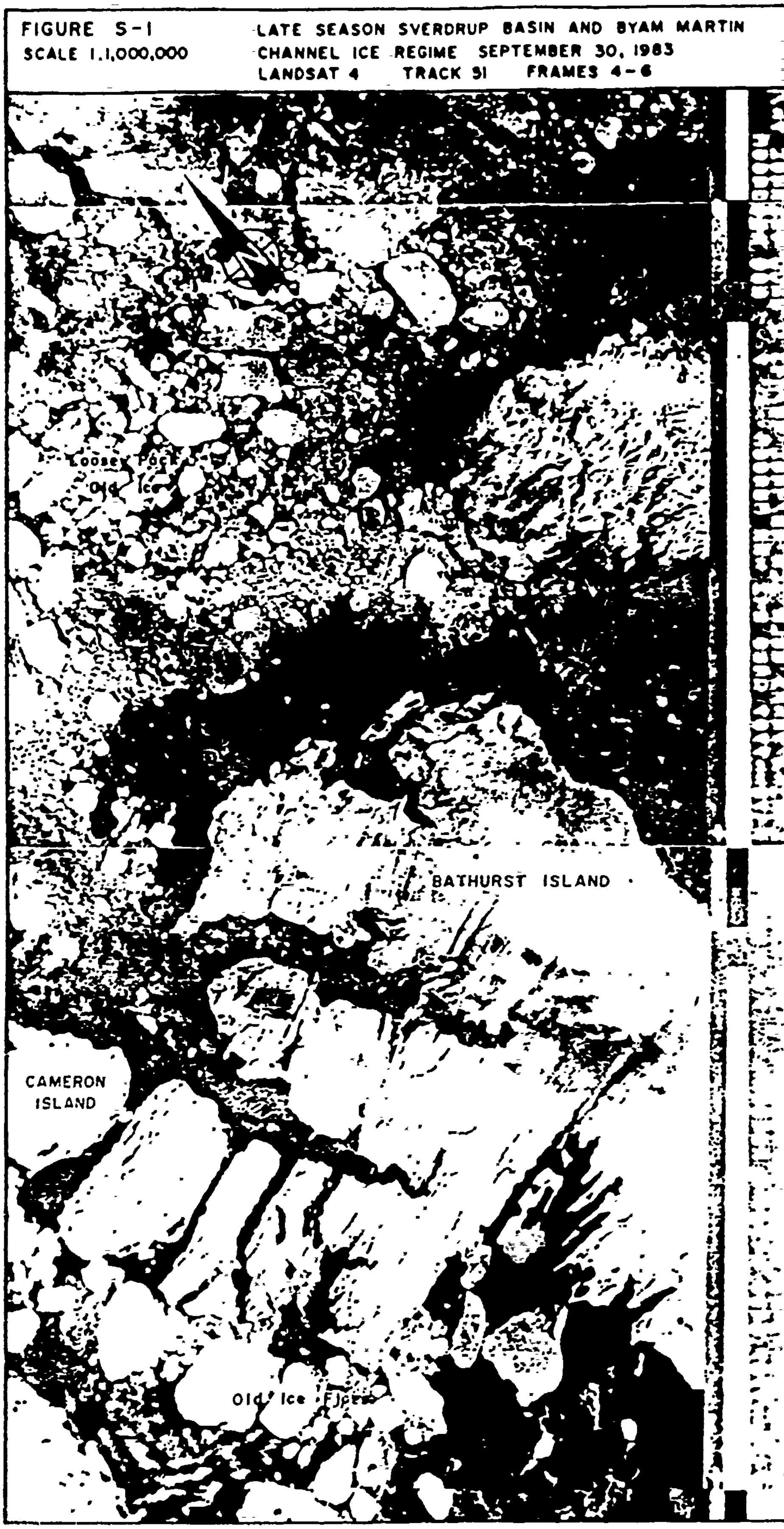


FIGURE S-1
SCALE 1:1,000,000
LATE SEASON SVERDRUP BASIN AND BYAM MARTIN
CHANNEL ICE REGIME SEPTEMBER 30, 1983
LANDSAT 4 TRACK 51 FRAMES 4-6
BATHURST ISLAND
CAMERON ISLAND

FIGURE 1

The Canadian Coast Guard has a large number of vessels, most of which are ice-capable to some degree but none of which are strong or powerful enough to operate throughout the year in all Canada's Arctic waters. Other Canadian ships operating for all or part of the year in ice include a number of ferries, lakers, and cargo vessels, the latter of which include some which regularly visit the Arctic archipelago. The actual ice damages (including several near disasters) suffered by this fleet led Transport Canada to commission German & Milne Inc., in co-operation with the Canadian Transportation Development Centre to develop what is now known as the NAWS system, as a navigation aid for vessels operating in ice.

The primary objective of this proposed program was to develop a device that would inform navigating officers of unsafe stress levels in the hull under icebreaking conditions.

The request for this type of bridge instrumentation resulted from a desire to know the impacts being sustained by the vessel when working in heavy pack ice or ridges. In such cases, the vessel is brought to frequent stops and has to resort to ramming in order to make headway. Under these circumstances, it is very difficult to estimate what stresses are being experienced in the bow and/or the hull structure and whether the vessel is being operated beyond her design capability.

It should be appreciated that the application of such a system, while designed in this instance as an aid to Arctic navigation, could be equally valuable for monitoring hull stresses in open water conditions. This latter possibility is equally relevant due to the fact that no existing navigation aids are available to signal excessive hull stress and allow the navigating officers to take appropriate action.

FUNCTIONS

From strain gauges welded to the inside of the main frames, the associated electronic instrumentation of the NAWS system monitors the level of stress created in the structure by the response of the hull to the external conditions.

The system analyzes and interprets the monitored information and uses it to display the information on the navigation console.

When the detected stress exceeds a predetermined level, yellow or red indicators and an audio signal are actuated. In this way, the NAWS system provides discretionary guidance, just as other modern electronic navigation systems supplement the traditional forms of navigation. The system augments the navigator's own sense of the traditional feel of the ship.

When the sensors exceed the predetermined values, the data and the time of occurance are either recorded and/or printed to provide a permanent logged record.

DESCRIPTION

The NAWS system is comprised of four units:

1. Strain Gauge Array
2. Remote Sensor Unit
3. Master Control
4. Repeater

A schematic layout of the NAWS system on an icebreaker is shown in Figure 2.

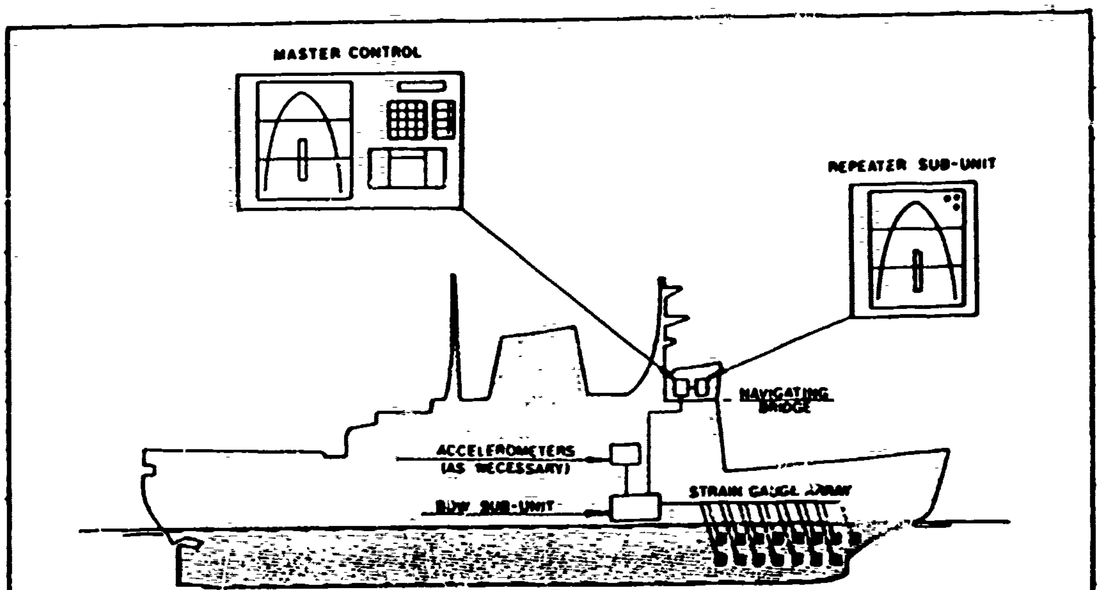
1. Strain Gauge Array:

The strain gauges are welded to the inside of the hull at selected locations. To ensure integrity, a specially developed grease block cable is sealed to the strain gauge at the time of manufacture. After welding, the gauge and cable are thoroughly covered with a water resistant sealant.

2. Remote Sensor Unit:

The Remote Sensor Unit obtains and processes basic data from the strain gauges or other sensors such as accelerometers. In turn, it transmits the information to the Master Control on the navigation bridge where the information is displayed for the navigator.

Each strain gauge forms one arm of a Wheatstone Bridge, the output of which is fed to a high gain, low drift instrumentation amplifier. The amplifier provides a signal of 0 to 5 volts proportional to range of +2000 to -2000 microstrains being registered by the strain gauge. A low frequency bandpass filter with a cut-off frequency of 40 Hz removes high frequency noise prior to analogue to digital conversion.



TYPICAL NAWS INSTALLATION

FIGURE 2

An Intel 8085 microprocessor within the Remote Sensor Unit sequentially samples the A/D convertor of each strain gauge 75 times per second. Software performs a sample and hold function to ensure that the maximum deviation from a mean value is recorded. The mean value of a strain gauge is calculated with an exponential smoothing filter over a long time period to allow for drifts or hull deformation. A drift of more than ± 1500 microstrains causes the microprocessor to declare the gauge as inoperative.

Each Remote Sensor Unit (RSU) can handle up to 64 sensors and the Master Control unit can handle up to 8 RSUs. Normally the number of strain gauges required is less than 64 by virtue of location and selection criteria.

An EIA RS422 serial data link conveys information from the microprocessor in the Remote Sensor Unit to the microprocessor in the Master Control. On request from the Master Control unit, the strain level for each sensor is fed sequentially to the transmitter of the Remote Sensor Unit and via the RS422 serial data link to the receiver at the Master Control located on the navigation bridge. Only a twisted pair is required as time-domain multiplexing techniques are employed. A parity bit is appended to each transmitted word for the detection of transmission errors, providing more reliable transfer of information.

3. **Master Control:**

A microprocessor within the Master Control co-ordinates all activities of the NAWS system. The Master Control samples each Remote Sensor Unit sequentially and displays the information on the front panel which is shown here. The Master Control also lists bad sensors on the printer for the information of the operator.

The yellow and red lights for intermediate and high level impacts respectively are graphically arranged on an outline of the bow section of the ship at the icebreaking waterline. Hence, illumination of these coloured lights gives the navigator information on both magnitude and location of the impact encountered. The maximum stress level encountered by the gauges is shown in a bar graph format on the front panel to display the maximum level of any gauge to provide a semi-quantitative visual output. The bar graph is sub-divided into 30 levels. The lower 10 levels are green, the next 10 are yellow, and the top 10 are red.

A numeric display on the top right hand side shows the highest stress (as percentage of yield stress) from among all gauges monitored. When this value exceeds 50%, the printer on the lower right hand side of the front panel makes a permanent record of this impact data (percent yield stress, structural location and time of occurrence).

Additional features on Master Control unit are a printer, a keypad, an audio alarm, a real time clock and a 5-digit numeric display. Switches on the front panel allow disabling of the audio alarm, printer and the 5-digit display when not required. The keyboard and display help test, maintenance and other operations.

4. **Repeater Unit:**
A repeater unit provides a display of the yellow and red indicator lights and the bar graph. This is intended to provide a simple real time display at a location easily visible to the navigator. This unit is powered by the Master Control unit.

The effectiveness of the hull stress monitoring system depends primarily on the strain gauge configuration. Therefore, it is essential for effective performance that much attention be given to selecting the locations of the strain gauges.

When considering installation of the NAWS system, the first step then is to identify and analyze the high risk areas.

The most vulnerable locations are the shoulders of the vessel, where the curvature of the hull causes the mode of icebreaking to change from bending to the more hazardous crushing mode.

This is not only true at the waterline, but also diagonally down the ship's hull as in the ramming mode the vessel rides up changing - sometimes quite dramatically - the waterline of the vessel.

Figure 3 illustrates these low shoulders for a class of icebreaking supply ships. Plating damage was experienced on one vessel due to a high frequency of ridge

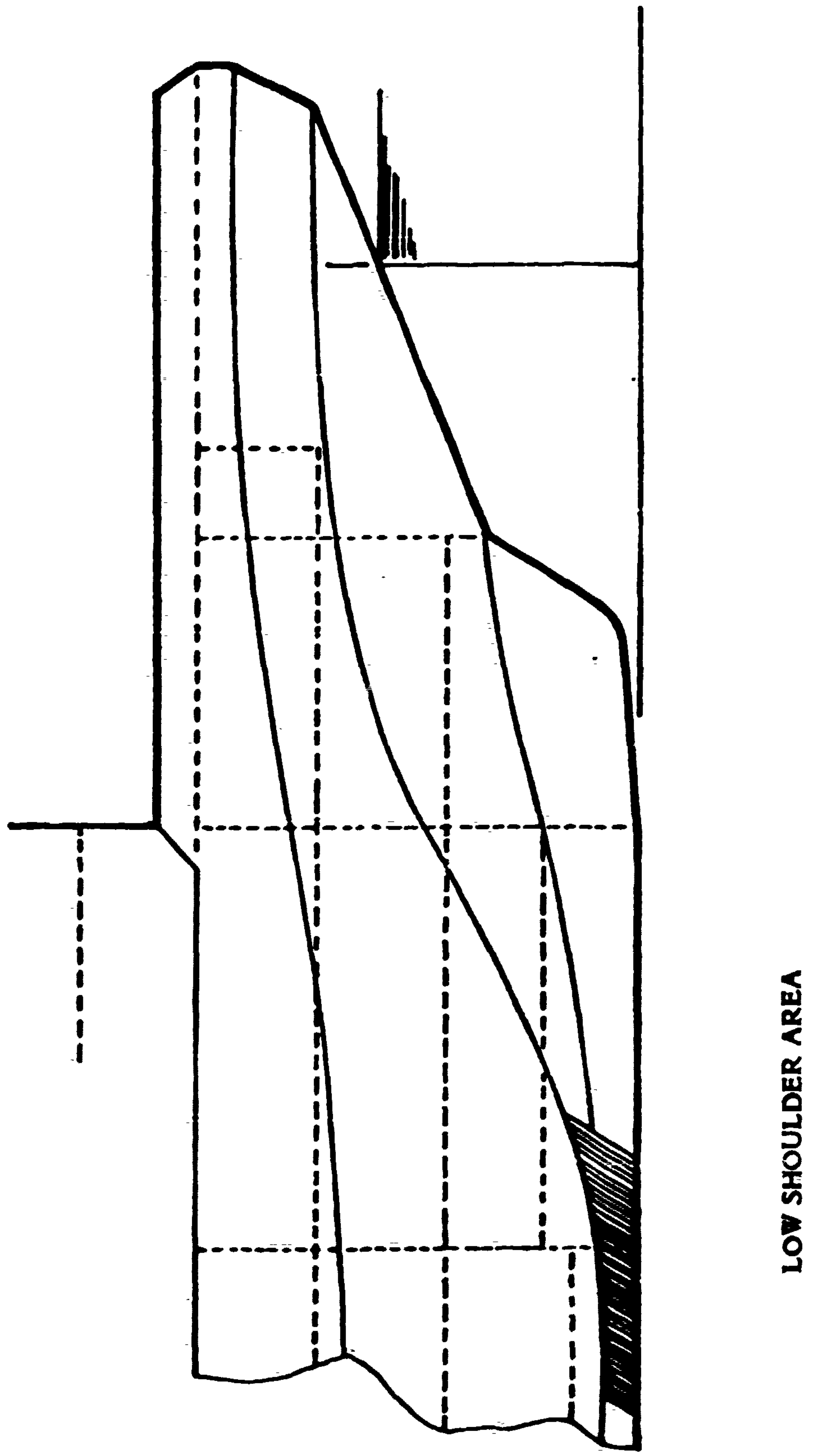


FIGURE 3: ILLUSTRATION OF LOW SHOULDERS ON CLASS 4 ICEBREAKER

ramming, and her sister ship suffered some internal damage. Subsequent fitting of gauges in this area showed stress levels in excess of 80% of yield during a series of ramming trials at quite moderate speeds.

There are, of course, other 'risk' areas which may be readily identified as those areas of least support, i.e., away from bulkheads, webs, deck structure, etc.

The location of each gauge then is arrived at by a combination of theories on ship/ice interaction, establishment of loading regimes using finite element analysis and from casualty analysis data where available. For example, on the CCGS PIERRE RADISSON, the placement of the strain gauges was based on a FEM analyses of the hull structure. In addition, results from full-scale trials conducted on the ship in the Arctic in July/August 1978 and in the St. Lawrence River in February 1979 were available.

The number of gauges will depend to some degree on the size of vessel, the hull form and structural arrangement but, in general terms, a total in the order of 32 gauges is deemed the minimum which should be considered up to a probable maximum of in the order of 64.

Figure 4 shows the profile of the new building CCG Type 1200 icebreaker and indicates the location of the gauges to be installed - a total of 40 in all, 20 port and 20 starboard. One can note the general pattern, with one line representing the sensors which will respond primarily in the level ice mode of icebreaking and a second line responding to ice impact in the ramming mode on ice blocks moving down the hull.

Analysis and experience has shown that the best location for placement of the gauges in the hull is on the inboard face of the frames.

OPERATIONAL EXPERIENCE

A special test and evaluation program was conducted on the CCGS PIERRE RADISSON in the summer of 1983, while on escort duty in the high Arctic. During this period, a test engineer was on board to monitor the system and assist the operators in use and interpretation of information provided by the system. Further, the response of the crew to the system with their comments was solicited by the test engineer through personal interviews and questionnaires.

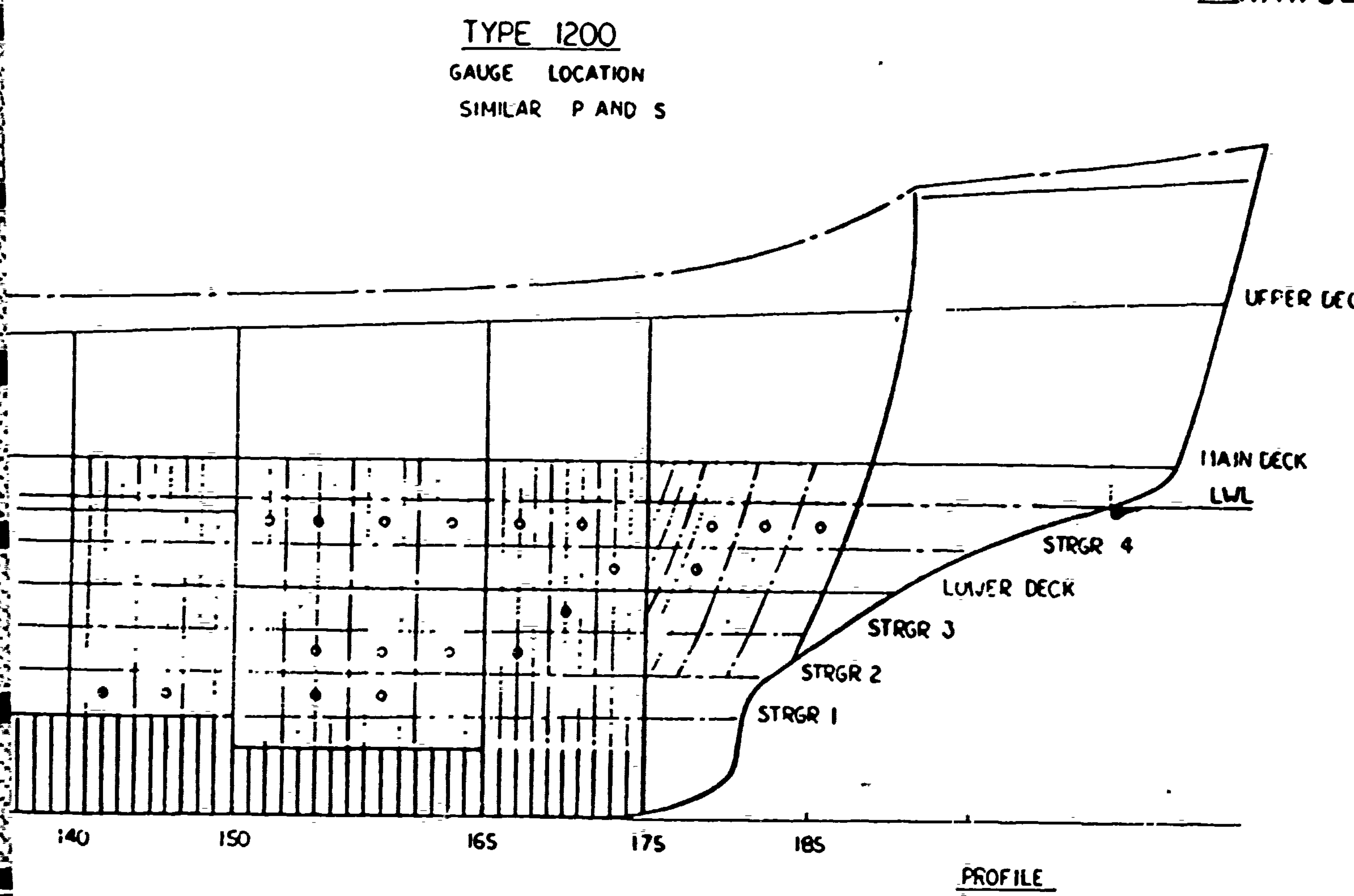

TYPE 1200
GAUGE LOCATION
SIMILAR P AND S
UPPER DEC
MAIN DECK
LWL
STRGR 4
LOWER DECK
STRGR 3
STRGR 2
STRGR 1
140
150
165
175
185
PROFILE

FIGURE 4

The objectives of the test and evaluation programs:

1. To determine the effectiveness of the strain gauge array as a sensing device for ice impacts.
2. To determine the suitability of the selected threshold levels.
3. To evaluate the ergonomic features of the information displayed on the front panel.

Findings on the NAWS system performance were obtained by the German & Milne engineer through personal interviews with the Captain and navigating officers and through the NAWS questionnaire.

The NAWS system generated gratifying enthusiasm from the Captain and officers on the ship and remains on board in continuous use. The system achieved its principal objectives, functioning as a tool to help navigating officers monitor hull stress in ice.

A number of findings were obtained in interviews and through the questionnaires and these led to modifications of the prototype system which have also been incorporated in subsequent installations.

An example of this is the provision of a slave display unit in a position immediately visible by the navigator. The original installation was located on the aft navigation console, allowing testing and validation to proceed without disruption to the crew's regular duties. However, once the installation had proven its reliability, the ship staff requested that the extra display be provided.

Other modifications were made to the display resolution, retention time, and alarm threshold levels. The original selection of 50% and 80% of yield for yellow and red thresholds was eventually retained as they were found to give an appropriate level of warning. Too frequent alarms can irritate the operators, while at the other extreme, high thresholds can prevent them from appreciating how a hazardous situation is developing.

CONCLUSION

The NA' 5 system developed over the past three years has initiated a new concept in ice avigation. During this period, two generations of the system were tested and evaluated on different ships. The system is currently in operation on the CCGS PIERRE RADISSON for both summer and winter ice navigation operations.

The system functions as a response monitoring system that detects stress in the hull structure and conveys the information to the ice navigator. This information is categorized and displayed as low, intermediate and high stress levels. Knowing the actual level of stress in an identified area of the hull structure during icebreaking manoeuvres, is a definite advantage to the operator.

In the hands of an experienced officer, the NAWS system provides confirmation of the operator's intuition for the stress values being experienced. For less experienced officers, the continuous feedback will accelerate the learning process of the icebreaking technique, reducing the risks involved during changeover of command and easing the demands on the Captain's time. The feedback transmitted to the operator helps in narrowing down the precise relationship between what has actually happened to the ship and what was actually felt. Such a system, it is felt, not only provides for safer use of the icebreaker, but also helps in making its operation more efficient by allowing the Captain to operate the ship to its full potential.

Not only does the system lend support as an operational device, but valuable information can also be compiled, registered and printed when required for immediate use, or for reference in later use. The databank generated will be available to designers as well as regulatory bodies in making ice navigation safer and less hazardous.

While the primary function of the NAWS system is monitoring of ice impacts, the operating principles can be extended to monitor critical stresses caused by other environmental conditions. These applications include monitoring of field pressure in ice, and slamming and fatigue monitoring in heavy seas. These applications are currently under investigation.

Highlights of Panel Discussion

CAPT Barr's primary charge: Develop long term requirements, milestones, dates, etc. This is a full range Management Plan vice the basic POA&M.

Human Factors: Items On Clothing

- There is a need to designate a central point of information for ships since there is a lack of information in the fleet relative to Cold Weather Clothing (centralize information in the fleet). Second point of contact - Type Commanders. Also need to get accurate feedback on the performance of Cold Weather Clothing.

- Insufficient cold weather gear being provided to shipboard personnel. Minimum manning ships have higher percent of personnel conducting outside evolutions. NAVSUP indicates aid needed to specify requirements vis-a-vis clothing development.

- Propose that Navy conduct more arctic exercises in order to learn by doing.

Health:

- Improve communications between OP-93 and the operational forces to know what is happening. Communication through working groups.

- Get medical personnel involved in the actual operations. Obtain information from NASA relative to the ability of the individual to stand extreme cold. Propose that the ships cold weather bill specify the exposure time for personnel on deck.

HM&E: Ice Prevention and Removal

- Gas turbines: Make sure that combustion air intakes are working properly and effective. Loss of combustion air looses total ship system capability. Propose that de-icing kits be as complete as possible. Select pieces maintained onboard but a good majority of kits should be maintained shoreside and assigned to a ship when it deploys to the arctic area.

- Relative to ship operations, need to develop a procedures for towing in ice fields.

- Relative to methods, to prevent accumulation of ice on ships windshields, there is a specification. Is the specification adequate? This is relative to window heaters. Also develop some sort of check list to make sure items work before getting underway. A lot of problems, both in Canada and US, electrically heated windows blowing out glass. Need for better maintenance.

- Need to establish a stability criteria taking into consideration potential ice build-up. Propose to look at what the oil companies do in the North Sea areas for specifications and stability criteria. Propose design of superstructures that are clean and do not catch the ice.

Systems Problems:

- Basic evidence indicates that there is not significant fluctuations on electrical loads between hot and cold environments.

- Relative to reverse osmosis water systems apparently a number of problems occurring. Need to assess systems and their operation in cold environments. Carry specific cold weather lubricants, etc. onboard.

Hull Stresses:

- Provide decision aids to Commanding Officer relative to cold weather operations.

- SWATH advantages: higher structural weight density because of hull design, shed ice more quickly, shrouded propellers, better navigational ability on ice.

- OPNAV specified that these meetings should be "ship specific".

Hank DeMattio relative to combat system problems:

- OP-03 to task SWIG to do AAW initiative exercises in a cold weather environment.

- Suggestion to have reserve groups develop some of the data bases.

- Proposal to either develop or modify ASW weapons to work through the ice.

PROJECT UPDATE PRESENTERS

Dr. K.F. Sterrett
Cold Regions
Research &
Engineering
Laboratory

CDR J. Bannan
U.S. Coast Guard

Dr. W.W. Denner
Science
Applications, Inc.

Mr. D. Kover
David Taylor
Naval Ship
R&D Center

Mr. R. Jeck
Naval Research
Laboratory

Mr. J.D. Crowley
Bath Iron Works
Corp.

Prof. W.M. Sackinger
University of Alaska

Mr. G. Reinauer
Hamilton Standard

PROJECT UPDATE PRESENTERS (CONTINUED)

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Raychem Corp.

CDR S. Schrobo, USN
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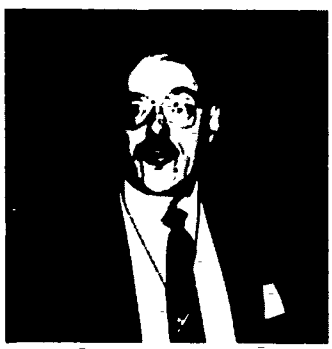
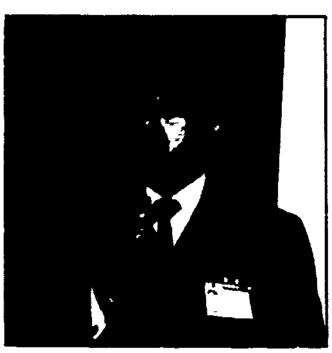
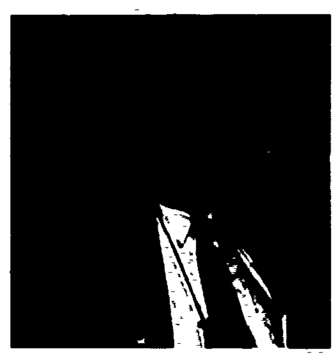


Mr. M. Jeffrey
National Research
Council of
Canada

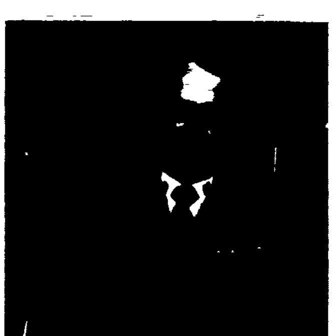
Mr. L. Schultz
ARCTEC, Inc.



CDR T.J. Contreras
Naval Medical
Research & Development
Command



Mr. R. Williams
U.S. Coast Guard
Headquarters



LT D. Sobeck
U.S. Coast
Guard

Mr. J. Coburn
ARCTEC, Inc.

Project Update

Dr. K. F. Sterrett
U.S. Army Cold Regions Research and Engineering Laboratory
72 Lyme Road, Hanover, NH 03755-1290

USACRREL is currently conducting the following projects:

1. Development of Tactical Decision Aids (TDAs) for the prediction of icing conditions.

2. Development of a Radiosonde Icing Detector under the Small Business Innovative Research (SBIR) program.

3. Development of improved icing sensors for use on Unmanned Aerial Vehicles (UAVs).

4. Basic studies on techniques to predict ice accretion utilizing data correlations obtained through a survey of icing experienced on radio and television antenna towers in New England.

5. Development of improved mechanical designs for the prevention (and/or reduction) of icing.

6. Basic studies on the solid state physics of ice and on the adhesion of ice to substrates.

7. Use of coatings to alleviate (and/or reduce) ice adhesion.

THE GREAT LAKES

Sub-Arctic Laboratory

Given that much research has been done in the polar environments, today we are able to do a great deal of research in relatively inexpensive laboratory settings in convenient locations. We are also able to plan extensive operations while in the confines of warm offices and conference rooms. But once in the Arctic, excuting the plan, something generally happens to prove "you don't know if you have not been there."

Much closer than the North Slope or Thule is a lab which many have found a worthy testing place and is worth considering in future planning -- The Great Lakes.

Specifically, on the Great Lakes you can find a dependable supply of plate ice (large floes) 18 to 20 inches thick. In some areas plates of 24 to 28 inches are common. The ice may be snow covered or wind swept. Windrows (the equivalent of pressure ridges) as well as brash ice fields can be found. It is common for the windrows to develop to a thickness of 10 to 12 feet in the vicinity of the Straits of Mackinac. Winter storms of gale force frequently set the ice fields in motion, particularly in locations such as the Straits of Mackinac or Whitefish Bay (at the east end of Lake Superior). The unique properties of brash ice can commonly be experienced in the mouths of open bays and in rivers such as the lower St. Clair. In contrast stable ice can be found in Green Bay, Grand Traverse Bay, and in the "Lakes" of the St. Mary's River system.

The problem of ice escort is frequently addressed on the lakes. Barges, scows, lakers, and salties (ocean going ships of convential hull form) are routinely escorted, frequently in restricted waters, by both CG icebreakers and by commercial tugs. At the time of this writing, a MARAD contractor is conducting a full scale test to determine the actual hull resistance of an icebreaker moving through plate ice. This is being done in Green Bay where the USCGC MACKINAW (290 feet, 5200 tons, and 10,000 SHP) is towing the USCGC MOBILE BAY (140 feet, 660 tons) through 15 to 18 inches of unbroken ice. Suitable load sensors have been installed in MOBILE BAY for these tests. It is expected that the results will be used to more accurately correlate towing basin work with vessels operating in the actual environment.

What is the goal of your research? Can it be done in a lab -- must it be done in the polar environment -- or would the Great Lakes provide a suitable site?

Just some ideas.

Submitted by John D. Bannan
Commander, U. S. Coast Guard
Asst. Chief, Ice Operations Div.

ARCTIC ENVIRONMENTAL SUPPORT

Dr. Warren Denner
Science Applications International Corporation

Introduction

The subject of this symposium was arctic and cold weather operations of surface ships. Most of the papers dealt with the impact of cold weather on surface ships, aircraft and combat systems once they are experiencing certain environmental conditions (superstructure icing, rough seas, snow, etc). These impacts are important, but only a part of the problem. Another part is to provide the operating forces with environmental forecasts of operating conditions for planning and tactical purposes. Furthermore, the Arctic is a unique and hazardous environment where experience takes on a significant value.

My remarks are directed toward the forecasting and operating experience requirements. They are based on nearly 20 years experience with Navy polar science which included 3 years living in the Arctic and three and one-half years in the sub-Arctic (Newfoundland).

Environmental Considerations

The Arctic and adjacent seas are unique and hazardous environments for naval operating forces. A few of the unique aspects which must be addressed are:

- Freezing temperatures
- Continuous darkness in winter
- Stormy conditions
- Fog
- Snow
- Superstructure icing
- Sea ice and icebergs
- Poor communications
- Limited logistic support
- Extreme contrasts caused by small/local scale forcing
  - Katabatic winds near coastlines
  - Strong low level temperature inversions
  - Stability changes near ice edge/leads/polynyas

Any of these can have a significant adverse impact on operations and, in combination, can be very dangerous. The unfortunate situation is that we are poorly equipped to predict environmental conditions in the Arctic and sub-Arctic because our predictive models have been optimized for mid-latitude forecasts and we lack basic environmental data required by the models.

Environmental Prediction

Modern environmental predictions are heavily based on numerical weather prediction (NWP) models of the atmosphere, ocean and, at higher latitudes, sea ice. Denner and Mendenhall (1982) discuss some of the factors limiting numerical sea ice forecasting in support of polar operations. Numerical models require initializing data generally based on observations which may be collected from several sources -- surface pressure, radiosondes, satellites, etc. The observations are usually combined by a set of procedures referred to as an analysis. The model predictions are strongly influenced by the quality of the "first guess" provided by the analysis. Unfortunately, there is very limited data from high latitudes and most ocean areas. For example, Figure 1 shows the distribution of radiosondes for the Northern Hemisphere. Note the absence of observations in and around the Arctic.

Another factor is the specification of boundary conditions. This requires more than just the specification of the geographical boundaries, which in itself is a problem using a numerical grid with a finite resolution. For a regional atmospheric model, lateral boundary conditions (wind,

W.W. Denner and B.R. Mendehall, 1982. Environmental Factors Limiting Numerical Sea-Ice Forecasting in Support of Polar Operations. Oceans 82, MTS, Washington, DC, pp 1242-1246.

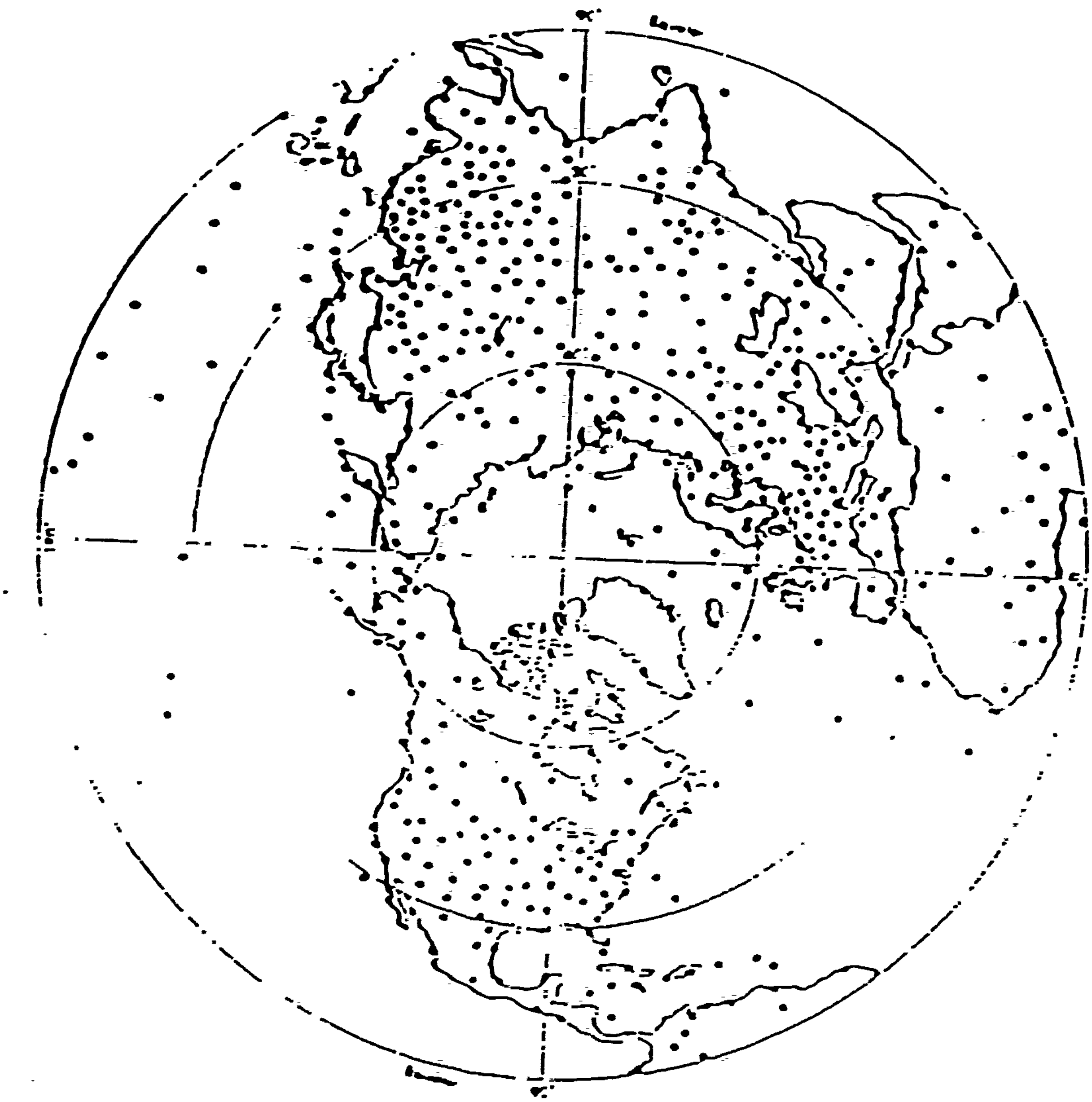


Figure 1. Radiosonde stations in the Northern Hemisphere

temperature and moisture) must also be specified. In most cases these are specified based on the output fields of large scale models, observations, climatology or a combination of these. Again, working in a data deficient area, the large scale NWP model fields, observations and climatology may all be weak.

In addition, the surface and marine boundary layer conditions must be specified. In regions such as the Greenland Sea, where the Greenland ice plateau has a few thousand meters of relief over a few tens of kilometers, and the pack ice trunctions to open ocean at the ice margin, the specification of surface boundary conditions becomes very difficult.

Many arctic weather producing forces are sub-synoptic, therefore below the scale of resolution in NWP hemispheric or global models. Events such as polar lows, katabatic winds, strong low level temperature inversions, and ice/water boundaries cannot be depicted in proper scales by numerical analysis, let alone in NWP. Very few studies have been performed to 1) evaluate operational numerical models in polar regions, or 2) relate the larger scales that can be depicted in NWP to the occurrence of smaller scale weather producing forces in polar regions. In comparison, much effort has been spent on parameterizing convection activity (tropics/mid-latitudes), mid-latitude frontal activity, jetstream, model-output-statistics (MOS) for weather parameters (visibility, etc.), and statistical models for tropical and mid-latitude events.

Operational forecasters need some sort of practical references for use in rapid development of polar weather insights. Forecaster handbooks which emphasize the integrated interpretation of NWP products in the polar region with satellite imagery and conventional observations and polar environmental events would be a suitable reference.

Existing atmospheric boundary layer models are basically reflective of mid-latitude/tropical regimes. The polar boundary layer differs significantly from that of these more studied regions. It also varies widely from season to season and from underlying ice/snow, water, and bare/vegetation covered surfaces. Work is needed in both areas of NWP and conceptual modeling of the polar atmospheric boundary layer.

Based on the above remarks it must be concluded that it will be a challenge for the Navy environmental forecasting community to meet the needs of operating forces.

Certain problems are known to exist:

- Forecasting sub-synoptic systems which can evolve very rapidly
- Specification of marine boundary layer conditions
- Forecasting ocean wave conditions, particularly wave-ice interaction
- Forecasting fog
- Forecasting superstructure icing
- Forecasting sea ice conditions

Questions that need to be addressed are:

- What are the operational requirements for environmental support in the Arctic and other cold weather regions?
- How well do existing forecasting techniques meet these requirements?
- What research and development is necessary to correct differences?

Experience

The final issue I would like to discuss is the importance of experience in arctic operations. As the Director of the Naval Arctic Research Laboratory (NARL) from 1973-1976 I was able to learn first hand the importance of experience.

A classic case is native people. The survival skills that had been handed down over the centuries were lost on many young people in the 50's and 60's when they were sent out of the Arctic as teenagers to attend school. As more modern technology has become available (aircraft, snow machines, radios, etc.) more of the historical survival skills were lost among the younger native population due to lack of experience.

More relevant to naval problems are ship, submarine and aircraft operations in the Arctic. In each case captains and some of the crew should, and usually do, have some operational experience. However, NARL at one time required pilots to have 2000 hours of flight time above the Arctic Circle. This points out the importance placed on experience for pilots who are going to operate in that environment. Commanding officers of icebreakers generally have served at least one prior tour in the Arctic or Antarctic. However, it is fair to say that only a few Navy personnel have significant experience in the Arctic. Education and training can make up for some lack of first hand experience, but not all. In contrast, the Soviets have an enormous amount of experience in all phases of arctic operations. This fact cannot be over emphasized, nor can the importance of providing the best environmental knowledge we can to our operating forces and engineers designing new systems for the Arctic.

NORTHERN LATITUDE LOGISTIC SUPPORT

Don Kover

Introduction

Northern Latitude Logistic Support was initiated in FY86 under the Fleet Logistics Readiness Technology Program, at the David Taylor Naval Ship Research and Development Center. Its objective is to develop a technology base to enhance operability and sustainability in the resupply of our military forces when operating in high tempo, high threat scenarios in the extreme cold and heavy weather of the northern latitudes. Areas of concern are Underway Replenishment (UNREP), Logistics Over-the-Shore (LOTS), and Strategic Sealift. The first year's effort will concentrate on documenting the UNREP problem areas.

Underway Replenishment (UNREP)

The extreme cold and icing conditions of the northern latitudes causes UNREP equipment to malfunction, which in turn causes a break in the logistics chain. These conditions also create severe safety hazards for UNREP personnel who are required to be topside in unprotected locations.

1. Material handling equipment should be modified to accommodate operations in cold weather and icing conditions.

2. A temporary shelter should be designed for installation at the receiving/loading stations for personnel protection.

3. Ways should be studied to quickly remove ice and prevent ice build-up during UNREP operations.

4. Steps must be taken to ensure proper electronic control panel operation.

Logistics-Over the-Shore

An over-the-shore capability is necessary since there is no guarantee of an existing port in the amphibious objective area, and the trend in merchant shipping has been towards increased port dependence. The Navy's dependence upon merchant shipping has resulted in the requirement to develop means for offloading these merchant ships in the stream. The procedure is to offload cargo from Roll-On/Roll-Off (RO/RO) and containerships onto Navy LCU's and causeway ferries for transport to beach facilities where the cargo is removed from the lighters. Containers are trucked to the hinterland marshalling areas.

1. RO/RO Operations: The RO/RO discharge facility is comprised of the causeway platform facility, the calm water ramp, and the fendering system. Rolling stock is driven from the ship, down the ramp to the causeway platform, and onto waiting lighters. Although the system is currently being upgraded for higher sea states, additional studies are needed to account for possible icing conditions. Of particuar concern are:

   a. the lack of traction on the ramp, platform, and lighters; and,
   b. the lack of shelter for personnel working on the platform.

2. Container Operations: The current operational procedure is to unload containers from a containership moored to a crane ship in the stream. Some potential problems that must be evaluated are described below.

a. Ice on the lighter decks can effect container positioning and the capabilities of the cargo handling crew.

b. Containers Ice-covered and/or frozen into position could overload cranes trying to lift them.

c. Icing on topside containers will inhibit the attachment of crane spreader bars and/or slings. The conditions for personnel atop these containers will be hazardous.

d. Manual or hydraulic spreader bars can be expected to lock-up, thus hampering container movement.

e. Electronic monitoring of container contents during offload may experience problems associated with the cold.

3. Lighterage: Causeway ferries are powered by attaching warping tugs or powered causeway to the last causeway in the string. Once beached, causeway ferries are offloaded using Rough Terrain Container Handlers (RTCH), or the rolling stock is driven off onto the beach. LCU's can beach (container and RO/RO operations), discharge onto beached/floating causeway sections (RO/RO operations), or moor to the Elevated Causeway System (ELCAS) where cranes remove containers.

a. Mooring to the ship will be a problem with ice on the deck and the possibility of the recessed mooring bitts being encased in ice.

b. The lighterage used to move the cargo to the shore can encounter visibility and communications problems. They must be able to transit a minimum of one mile from the cargo ship anchorage to the shore, day or night. Batteries in radio sets will not last as long as in warmer climates.

c. Causeway ferries have little freeboard and the cargo and crew are exposed to the elements. The cargo can become frozen into position from the spray during loadout and transit to the beach. A shelter must be provided during transit for the crew members of the causeway ferries, side loadable warping tugs, and/or powered causeway sections. Crew rotation may be required since container loadout of causeway ferries can take hours.

d. Causeway ferries are made by end-connecting 90'X21' pontoon sections. This process involves the receiving of flexors from one causeway section into the mating recepticle of the other section and locking them into place with a "guillotine". With the low freeboard, icing can seal these recepticles and the associated guillotines preventing the joining of the sections. These problems must be overcome since these causeway sections are a major part of the Navy's logistics-over-the-shore resupply equipment.

e. Tides and currents impose operational restrictions. Improved equipment and procedures should be developed for operations in northern latitudes.

f. Use of RTCH's, LACH's or fork lifts to offload lighters at the beach may be inhibited, if not halted, by ice buildup on lighter ramps and decks. Deicing techniques or methods for maintaining traction should be investigated.

4. Elevated Causeway System: The ELCAS is a temporary roadway/pier made by elevating a series of end-connected causeway sections. The problems of end connecting are therefore the same as for causeway ferries. The

lack of vehicle traction is a problem that must be overcome.

a. Current pile driving capability is limited to SS2. The jacking operation to elevate the ELCAS has not been developed for these temperatures. This system should be investigated to identify and correct deficiencies.

b. The hydraulically operated cranes used for construction of the ELCAS must be evaluated for their capability to operate in the cold climate. They were subject to numerous failures in the recent warm weather JLOTS II test. Cold weather would compound the problems and icing could create extra weight on the boom and loads, and crane movement problems on the deck of the causeway sections. The problem of lifting ice laden and encrusted containers with the existing crane must be investigated to determine if the crane capacity must be upgraded or if deicing techniques must be developed.

c. The problems associated with the mooring of lighters must be solved. These problems include line handling on icy decks and the possibility of mooring bitts being encased in ice.

d. The operation of the turntable, located at the end of the ELCAS, has never been proven under these extreme temperatures and needs to be investigated.

5. Shoreside Equipment: Shoreside handling equipment must be able to start and function in the conditions characteristic of the region. Installation and durability of the temporary roadway systems must be investigated. Regional problems must be analyzed against current capabilities.

6. Petroleum, Oil and Lubricants (POL): The Services are working on improving the capability of transferring POL from an offshore tanker to the shore. This capability is currently restricted even for warmer climates. The POL system should be examined in terms of the known problems of the northern latitudes. Areas of particular concern are listed below.

a. The system currently being developed includes a single point mooring buoy which is anchored by a flooded barge resting on the bottom. The hoseline to the beach also rests on the bottom when operating. This system should be studied for the very deep water locations where it might be deployed.

b. When the submerged hoseline surfaces at the beach, the temperature can get much colder which will effect the viscosity and amount of water that condenses out. This will adversely impact the pumping rate.

c. Systems for short term use rely to a large extent on mild conditions for installation and operation. Exposure of personnel and equipment are critical areas.

d. The local terrain needs to be considered for its impact on the fuel transfer operation. For example, mountain sides dropping into the water might eliminate the capability for storing fuel on the beach and could greatly increase the pumping requirements.

Strategic Sealift

In addition to the commercial ships employed for delivering cargo and providing cargo offloading capabilities, there are other types of ships which have been studied for specialized loadout of outsized military cargo. Furthermore, anytime a ship is considered for operations in the northern latitudes, its mission should be tempered by the conditions known to exist there.

1. Lighter Aboard Ship (LASH): The LASH ship figures prominently in plans to deliver military equipment to the objective area. Logistic support equipment is stored in the holds and on the weatherdeck. The offloading of this equipment has always been a calm water operation, but efforts are currently underway to increase the sea state capability. The operation of this vessel in the environment characteristic of the northern latitudes should be examined for ways to overcome the equipment and cargo handling problems in an iced condition and to ensure the operation of the ship's equipment.

2. SeaBee: The SeaBee vessel is similar in function to the LASH vessel in that it carries outsized logistic support equipment on the weather-deck and on its two protected decks. Impacts of the colder weather should also be examined for this vessel.

3. Semisubmersible: This vessel has recently been acquired for carrying selected outsized cargos. These outsized cargos have a considerable amount of overhang which could get ice buildup causing loading to exceed the inherent structural characteristics or significantly alter centers of gravity. These ships also would require a wider swath through ice. The operation of this vessel should also be examined for the northern latitude conditions.

4. Auxiliary Crane Ship (T-ACS): Use of nonself-sustaining (NSS) containerships has led to the development of the T-ACS. Some of the problems described under "Container Operations" above apply to this vessel.

Recommendations

Developmental work to solve the known problems should be started immediately. Tests should be scheduled in the northern latitudes to validate the operational capabilities of developed equipment and procedures. Tests away from home support have the advantage of forcing serious planning since backup cannot be expected from commercial or port facilities.

SUPERSTRUCTURE ICING: NON-SUITABILITY OF CURRENT FORECASTING AIDS FOR NAVY SHIPS

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Abstract

Three currently available graphical aids (nomograms) for use in forecasting superstructure icing due to wind blown spray are reviewed for applicability to U.S. Navy vessels. It is concluded that these aids are not very suitable in their present form because they are biased toward fishing trawlers and other small displacement vessels, and they do not distinguish differences in the freeboard among various vessels.

Introduction

Icing on the decks and superstructure of vessels may occur from blowing spray in windy conditions when the air temperature is below freezing. It may also occur due to bow spray in heavy seas and subfreezing air temperatures.

A dozen or so major studies have been done in the past on the hazards, occurrences, climatology and forecasting of superstructure icing. Most of these studies concentrated on the plight of fishing trawlers because these vessels, as a class, have been most frequently exposed to icing conditions. The effects of icing are greater the smaller the vessel, with capsizing due to accumulated topside weight being the greatest hazard.

There are three forecasting aids (graphs, or nomograms) currently available as a result of some of these studies. But the data base from which these aids were derived consists of icing reports from a mix of vessel types and sizes, most of which appear to be these fishing trawlers. Therefore, it is not clear at all that these forecasting aids even apply to navy ships, except perhaps for a few types that are similar in size to the trawlers.

Since naval operations are usually staged in areas where the hazards and complications of these environmental conditions can be avoided, there appears to be very few reports of icing occurrences on navy ships. However, there is an increasing importance for submarine tracking, and potential antisubmarine operations, in the northeastern Atlantic, for example. Future mission requirements may place surface vessels more frequently in these areas where superstructure icing can occur. Therefore, even if superstructure icing has been unimportant in the past, it may become more important in the future.

The object of this report is to briefly describe the available forecasting aids and their shortcomings. Additional details, along with some suggestions for improving the data base for such aids, are given in a recent report with the same title [1].

Status of Available Forecasting Aids

As of this writing there are three, known, published graphical aids for assessing or forecasting superstructure icing intensities due to wind blown spray. These aids, sometimes called "nomograms", are based on reported cases of superstructure icing and they relate ice accretion intensity to observed or forecast surface air and sea conditions. These three aids are described briefly as follows.

Diagram Due to Sawada

This forecasting aid [2,3] is the oldest and simplest of the three listed here. As is shown in Fig. 1, it relates icing severity in qualitative terms to surface air temperature and windspeed. This aid is applicable to fishing trawlers and other small vessels susceptible to capsizing under the weight of severe ice accretion. Many of the vessels Sawada lists [4] as having sunk due to icing are fishing boats with displacements less than 200 tons.

It will be noted in Fig. 1 that the indicated icing intensity is very sensitive to windspeed at low temperatures, and to temperature at high windspeeds.

Diagrams Due to Mertins

These forecasting aids [2,5] shown in Fig. 2 are the second oldest of the three. They are more complicated than Sawada's because they take into account the additional variable of sea surface temperature (SST). There is some disagreement [2] as to the need for SST in forecasting aids for superstructure icing, however. Mertin's diagrams apply to the bow and superstructure of relatively large stern trawlers moving at slow speeds, and to some "cargo" ships. As a forecasting aid, there is still considerable sensitivity to errors in the forecasted variables [2]. For example, if the forecast is for windspeed = 8 ± 1 Beaufort, SST = 1 ± 1° C, and air temperature = -4 ± 4° C, the predicted icing severity would be anything from <u>none</u> to <u>severe</u>.

Diagrams Due to Wise and Comiskey

These forecasting aids [6] in Fig 3. are the newest and most complicated of the three listed here. They are an integrated version of Mertin's diagrams which have been specifically adjusted for conditions in the northeast Pacific as determined by climatological considerations and some 50 icing reports from that area. These reports are from a mix of vessels, including a semi-submersible drilling platform which supplied 25% of the reports.

The susceptibility of a given type of ship evidently depends mainly on the freeboard at the bow, and in some cases at the fantail or amidships. Ships with very high freeboards (e.g., CVs, LPHs) may be insignificantly affected by icing from blowing spray. Intermediate sized ships (eg., FFs DDs, CGs) may be more susceptible, especially to bow spray. Small craft (e.g., patrol, service, and combatant vessels) are obviously the most susceptible. The currently available forecasting aids illustrated in Figs. 1-3 may be reasonable guides for these small craft but maybe not for the intermediate sized ships.

In any case there will be uncertainties in applying any forecasting aid unless the aids can take into account 1) differences in the height of the freeboard among various ships types, 2) the applicability to the bow or fantail (helo pad) sections of the ships, and 3) the heading of the vessel relative to the wind and waves.

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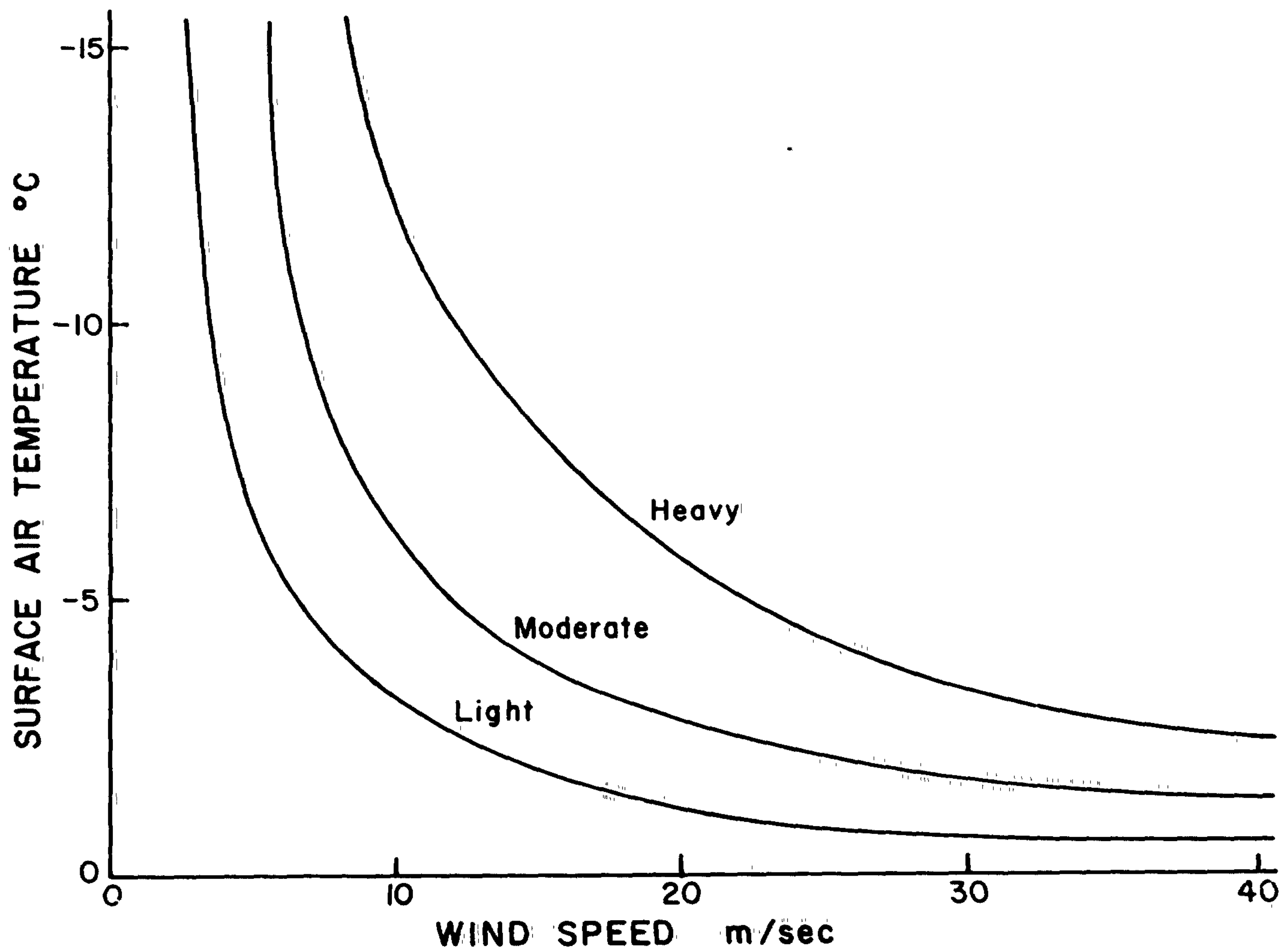

Fig. 1. Sawada's diagram relating icing on ships to surface air temperature and windspeed.

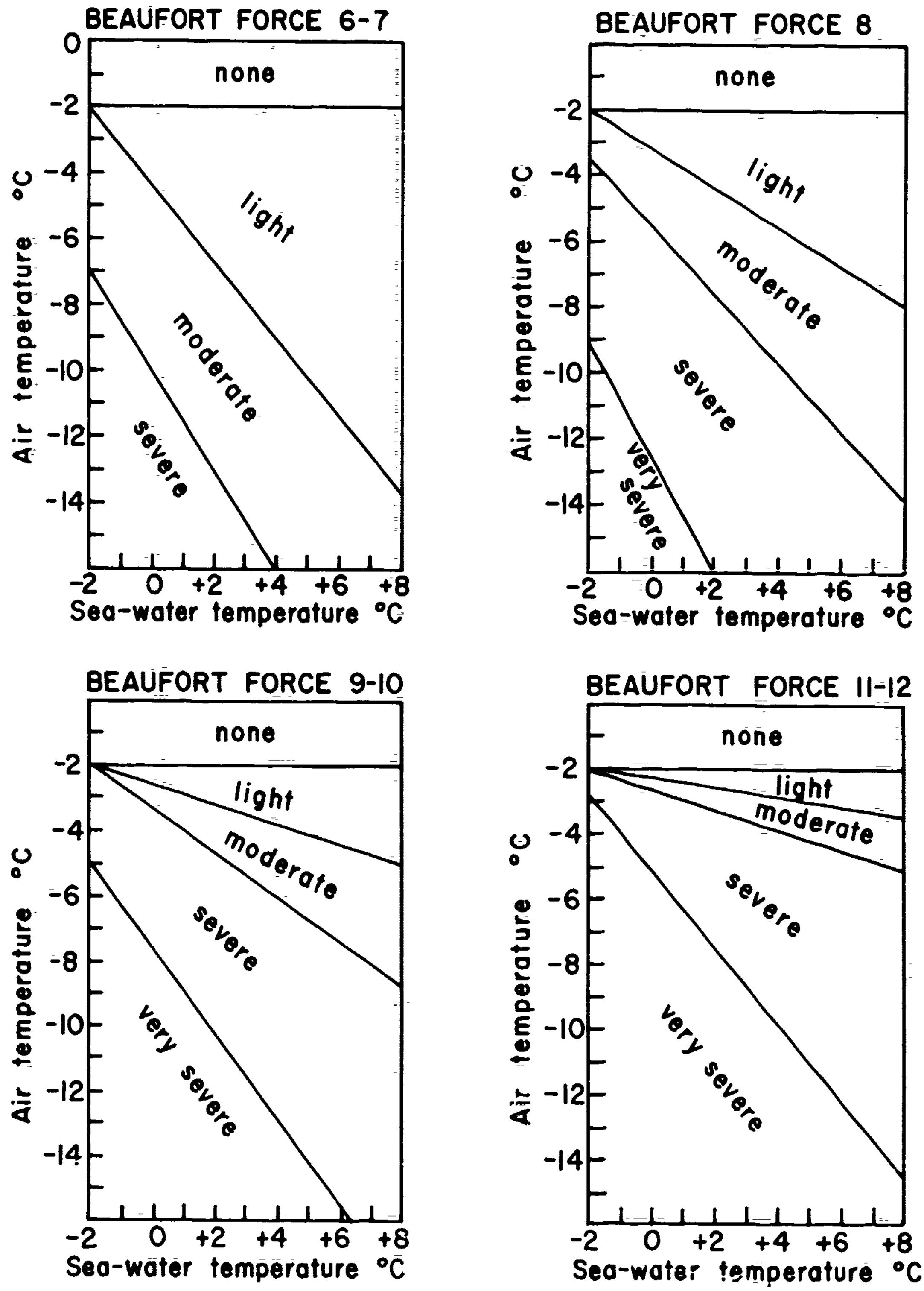

Fig. 2. Mertins' diagram for icing on low speed fishing vessels. Icing intensities are defined in terms of the following accumulations per 24 hour period: light = 1-3 cm, moderate = 4-6 cm, severe = 7-14 cm, and very severe $\geq$ 15 cm.

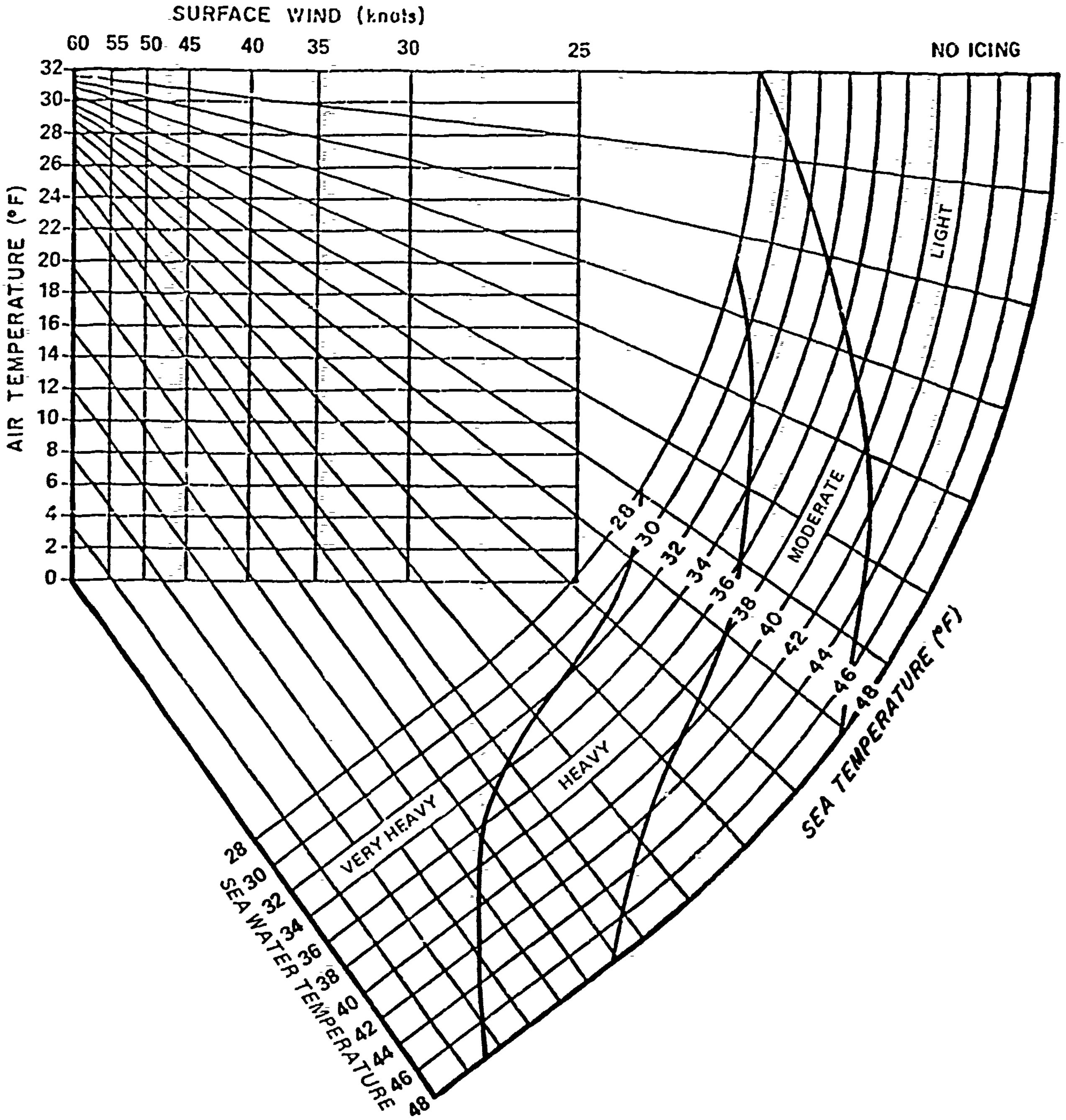

Fig. 3. One form of Wise and Comiskey's nomograms. Icing intensities are defined in terms of the following rates of accumulation per three hour period: light = 0.05-0.2 in., moderate = 0.2-0.3 in., heavy = 0.3-0.75 in., very heavy > 0.75 in.

PROJECT UPDATE: BATH IRON WORKS CORPORATION
COLD WEATHER OPERATIONS STUDIES FOR THE
CG 47 CLASS CRUISER PROGRAM

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As part of its contract for building the CG 51, Bath Iron Works has been conducting engineering studies in support of the CG 47 Cruiser Class program. Three of these studies have focused on the cold weather operation of Naval ships. While aimed specifically for the CG 47 Class Cruisers, the information developed is applicable to a wider range of naval operations. The report titles and their executive summaries are as follows:

1. Bath Iron Works Corporation: CG 47 Class Cold Weather Operations -- Interim Report June 22, 1984; Product Improvement Task C51-014 Contract N00024-82-C-2011

EXECUTIVE SUMMARY

The high latitude environment and the CG 47 Class ship were examined to identify potential problems of cold weather operations.

The history of U. S. Navy operations and the stratigic and geopolitical situation were reviewed to point out:

° A low fraction of U. S. Navy surface combatant experience has been in higher latitude operations; and
° Current strategic needs demand capability for year round U. S. surface combatant capability in high latitude regions.

A Notional Environment was defined for cold region operations. An icing scenario was presented and, for this scenario, a very severe icing load was described in detail for a CG 47 class cruiser.

Top level requirements, ship specifications and equipment and system specifications were reviewed in light of the Notional Environment. High wind and low temperatures imply severe icing conditions. Many specifications are silent regarding anti-icing or de-icing capabilities.

Using the detailed severe icing load, the stability and hull girder strength of the CG 47 Class were examined. The icing load degrades the intact stability of the CG 47 Class. A maximum DDS-079-1 beam wind of 70 knots is allowable with the icing load. Maneuverability is also degraded. The icing load produces significant increase in hull girder hogging loads and stresses. The design of the CG 47 Class should withstand such a load.

Possible effects of equipment icing, and of impairment or damage of systems in severe cold were noted. Over thirty areas for further study were identified. Recommendations for such studies were made.

Key conclusions include:

- A crucial problem for the U. S. Navy is the maintenance of institutional memory regarding cold weather operations, problems and solutions. Positive steps to expand and ensure that memory are essential.

- The stability and hull girder strength of the CG 47 Class are adequate to withstand a very severe icing condition.

- The winter seaway will be a limiting factor in northern operations, probably of greater significance than icing.

- A crucial survival requirement is the maintenance of gas turbine combustion air in the face of severe icing or snow.

- Studies should be conducted to ascertain:
    - The ability of installed equipments and systems to withstand severe icing or deep cold.
    - The extent of degradation of system performance during periods of heavy icing or deep cold.

- Studies should be conducted to evaluate improved anti-icing or de-icing methods and the effectiveness of new icephobic coatings.

A list of over 100 references was provided.

2. Bath Iron Works Corporation: <u>CG 47 Class Cold Weather Operations -- Final Report</u> December 28, 1984, Product Improvement Task C51-014; Contract N00024-82-C-2011

<u>EXECUTIVE SUMARY</u>

Five studies on Cold Weather Operations of the CG 47 Class Cruiser were performed: <u>Gas Turbine Air Intakes, Overboard Discharge Freezing, Topside Weapons Handling, Cold Weather Fire Fighting, Close-In Weapons Systems.</u>

Chapter 1, Gas Turbine Air Intakes reviewed available data from U.S. and foreign sources (marine and stationary) and concluded GT air intake blockage and ice ingestion have both been problems. Service experience or testing of the CG 47 configuration is lacking. Preliminary recommendations are that the bleed air system be simplified, and that manual rather than automatic blow-in door operation is preferable. In operation, parallel operation of several units lowers face velocity and may reduce blockage. Service experience and full scale testing are needed.

Chapter 2, Overboard Discharge Freezing, reviewed all weather exposed overboard discharges of the CG 47 Class. Discharge freezing should not affect any vital systems. A list of discharges and locations and measures for thawing discharges was provided.

Chapter 3, Topside Weapons Handling reviewed operational (not replenishment) weapons handling. Major problems are anticipated handling torpedoes to aircraft. Icing problems with footing and access impede handling of CIWS, SRBOC, sonobuoys and pyrotechnics. Suggested measures include relocating torpedo storage, rerouting sonobuoy and SRBOC handling and the use of kit items for deicing and to improve footing and dolly traction.

Chapter 4, Cold Weather Fire Fighting identified problems of freeze damage to fire main and AFFF systems, access problems to firefighting equipment and general access problems. Recommended measures include intensive training of crew in cold weather fire fighting, modification to assure drainage of all exposed firemain and protected storage for extra hoses and fire fighting equipment.

Chapter 5, Close-In Weapons Systems identified problems with reloading, heat exchanger freeze-up, warm up times and maintenance during bad weather. Use of the new, larger drum alleviates urgency of reload problem. Alterations to avoid freeze up and a maintenance shelter were recommended.

3. Bath Iron Works Corporation: CG 47 Class --
Cold Weather RAS/FAS
Cold Weather Kit
Cold Weather Bill

November, 1985; Product Improvement Task C51-014; Contract N00024-82-C-2011

EXECUTIVE SUMMARY

Three studies on the cold weather operation of the CG 47 Class Cruisers were performed: Underway Replenishment, Cold Weather Kit and Cold Weather Bill. These studies are based on earlier tasks coordinated by BIW.

Chapter I, Underway Replenishment, contains the evaluation of effects of cold weather upon replenishment operations. Recommendations for improvement in the cold weather UNREP are operational, equipment, ship and ship documentation oriented. Appendices to the Chapter include AEGIS Change Proposal Synopses for both ship and ship documentation.

Chapter II, Cold Weather Kit, sets forth proposals for materials and equipment to improve the operability of the CG 47 Class ships in the cold environment. Appendix A to the Chapter is a kit list and Appendix B includes AEGIS Change Proposal Synopses for:

- o Changes to enable use of kit equipment
- o Changes to design in lieu of kitting equipment.

Chapter III, Cold Weather Bill, is based upon a review of several ships' Cold Weather Bills; ATP 17, NAVAL ARCTIC MANUAL; COMNAVSURFLANT's COLD WEATHER HANDBOOK; and a broad base of cold weather data gathered by Bath Iron Works. Appendix A to the Chapter is an expanded COLD WEATHER BILL, suitable for inclusion in a Ship's Organization and Regulations Manual. Annexes to the Bill are:

Annex I: Cold Weather Kit
Annex II: Fire Fighting Planning
Annex III: Ship Icing and Ice Removal.

It is noted that both the Kit and the Cold Weather Bill are based upon cold weather operating studies to date and should be updated in view of the results of further studies. It is recommended that NAVSEA and Fleet personnel review these studies. Modifications to the Kit and the Bill should be made based upon this review. Thereafter the final Kit and Bill should be made available for use to the CG 47 Class.

It is noted also that the real test of both the Kit and Bill are operational experience, not further studies. Excellent communication between the Fleet and NAVSEA should be maintained to identify new problems, to collect new data, to examine better solutions, and to keep the Kit and Bill updated.

SPRAY ICE BONDING TO SUPERSTRUCTURE COATINGS*

by

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The problem of spray ice accumulation on the superstructures of navy ships is most clearly recognized in the northern waters in the vicinity of the edge of the arctic ice pack. The same ice accumulation can take place on semi-submersible oil drilling platforms, oil industry workboats, and also on the many fishing vessels that use these same northern waters.

The research program which was begun two years ago by the Geophysical Institute, under the sponsorship of the U.S. Department of Energy, Arctic and Offshore Program, has been oriented towards the evaluation of various candidate coatings for the superstructures of drilling platforms and service vessels which would have a minimum shear strength for the adfreeze bonding between accumulated spray ice and the candidate coating. Accordingly, spray ice samples have been collected from three separate icing events at three separate locations. Spray ice was first collected from a beach location at St. Paul Island, Alaska, where densities of ice ranging from a low of .44 g/cm^3 to a high of 1.00 g/cm^3 were obtained. Ice salinities likewise ranged from 1 $^o/oo$ to 12 $^o/oo$ from this coastal location. The inclusion of many voids and air bubbles was noted in samples obtained from this location, and the

*Paper presented at Arctic/Cold Weather Surface Ship Operations Symposium, Rockville, MD., December 3-4, 1985.

samples with highest density values also had incorporated within them the very fine-grained sands from the sea floor near the beach. A second kind of spray ice was collected from the bow of the U.S. Coast Guard icebreaker Polar Sea during their Bering Sea cruise of March 1985. This ice typically had salinities ranging from 16 $^{0}/oo$ to 10 $^{0}/oo$, a density in the range of .80 to .89 g/cm^3, and a very fine-grained crystal structure. These two separate icing events have lead us to realize that a wide variety of spray ice can be created during the many varied spray icing conditions in the Arctic.

Four categories of spray ice may be distinguished. In the first category, fog from the sea surface causes condensation of supercooled water droplets upon the cold superstructure surfaces of ships, leading to a gradual buildup of dense, low-salinity ice. A second variety of spray ice may accumulate when high winds and high wave conditions produce liquid spray droplets which impact upon the cold superstructure of the ship, causing instantaneous freezing-upon impact-of a small fraction of the liquid droplet, with the majority of the brine draining away. The very rapid freezing process at the surface of the ship in this case results in high salinity values for the ice that is formed, as well as high ice densities. A third kind of spray ice formation which takes place is during the condition where the spray produced by the wave tips of breaking waves can be carried relatively large distances by the high ambient winds. If the droplet sizes are smaller than 1 mm, and the time of flight in the air of these small droplets is in the range of 10-100 seconds, an appreciable fraction of the droplet may be transformed into ice prior to the impact of the droplet upon the ship's surface. As much as 50% of the droplet arriving at the ship surface can be ice, and the remainder of the droplet will be high-salinity brine, which will subsequently drain away to the sea. The ice which adheres to the ship in this circumstance will be of low salinity, perhaps 1 $^{o}/oo$ to 4 $^{o}/oo$, and of low density, containing many air bubbles and/or brine drainage channels. The highest parts of a ship may accrete this type of ice during most icing storms. Finally, a fourth variety of sea spray ice which can be produced involves the floating frazil ice particles which are thrust by violent wave action into the air, whereupon they are transported laterally over to the ship surface and are frozen onto the ship's surface upon impact. This category of spray ice can readily incorporate marine debris and, in the surf zone, any seafloor fine-grained material. The salinity of this variety of ice is apparently in the range of 10 $^{o}/oo$ to 12 $^{o}/oo$, and the density is in the range of .77 to 1.00 g/cm^3, depending upon the type of nucleation centers incorporated in the frazil ice formation process while the ice particles are still floating within the water column.

In conclusion, one can say that the effective coating for superstructures of Navy ships must have the property of preventing the bonding of all four types of spray ice, or, if bonding does take place, the bond strength must be sufficiently low for all varieties of spray ice such that removal of the spray ice is relatively easy, and can be done by gravity, simple vibration, or other inexpensive and reliable methods.

UNITED TECHNOLOGIES HAMILTON STANDARD

MARINE GAS TURBINE INLET DE-ICING

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Discussion

Air inlets on marine gas turbines are generally equipped with moisture separator systems to remove salt spray and airborne contaminants. These systems provide effective engine protection in the majority of marine environments. A typical inlet system is illustrated in Figure 1.

During cold weather operation, ice and snow may form on the moisture separator elements, restricting passage of air through the separator and increasing the differential pressure across the system. If ice formation is severe, the high differential pressure will activate an emergency air bypass system which allows unfiltered air to enter the gas turbine. If the intake is not equipped with an emergency air bypass system, the ice and snow buildup will be detrimental to the performance of the gas turbine and may lead to eventual engine shutdown.

Some gas turbine powered vessels are equipped with compressor bleed air de-icing systems that inject hot bleed air in front of the moisture separators to raise the temperature in the incoming ambient inlet air. These systems tend to be complex and expensive. They produce high ambient noise levels, reduce engine efficiency and can present personnel safety hazards. Furthermore, because of space or engine performance limitations, this type of system may be impracticable to install on many ships.

An alternate approach to snow/ice protection of mositure separators is currently under development at Hamilton Standard (see Figure 2).

This concept employs a Propylene Glycol spray that is similar to that employed by the military and the commercial airlines to de-ice aircraft. The glycol can be sprayed on the moisture separators by means of a permanent or portable spray system. While a portable spray system offers simplicity, it does not require the exposure of ships personnel to potentially hazardous foul weather. A permanently installed system on the other hand eliminates this difficulty and can also serve as a water wash cleaning system when operating in warmer climates.

During the winter of 1985, United Technologies Hamilton Standard Division conducted performance tests on a glycol de-icing system in a simulated marine gas turbine intake system. Two differential moisture separator configurations were tested; a two stage separator similar to those installed on the DD963, DDG993, CG47, and MCM classes, and a three stage severe service separator similar to those installed on LCAC, SWCM, CG26, MSB, and AN/ALQ-166 classes. These tests were conducted under both icing and blowing snow conditions with the separators operating at normal engine air flows (typically endurance cruise speeds).

The test program determined the feasibility of using a glycol spray to de-ice the moisture separators. A typical performance curve of the differential pressure drop through the intake system under icing conditions is illustrated in Figure 3. These tests demonstrated that:

- A glycol de-icing spray effectively removes accumulated ice from a two stage separator and restores pressure drop to within 5% of initial clean conditions while the gas turbine is operating at normal power levels.

- A glycol de-icing spray is even more effective on a three stage severe service moisture separator.

- Periodic application of a glycol spray can act as a temporary deterrent to ice formation.

In all test runs the glycol was diluted with seawater to provide more effective protection at low temperatures and to reduce the amount of glycol required. Seawater was chosen because it is readily available. Measurement of salt levels downstream of the moisture spearators have verified concentrations below the maximum set forth by the major marine gas turbine engine manufacturers.

While this testing has demonstrated the feasibility of using glycol as a de-icing and possible anti-icing agent on marine gas turbine intake systems, additional research and development is necessary prior to the introduction to the fleet.

The primary objective of any additional research should be to minimize glycol usage. Investigation toward this end will have to further evaluate various glycol/seawater ratios, spraying sequences, glycol reclaiming systems, and heated glycol mixtures.

The equipment needed to spray the glycol onto the moisture separators should also be examined. This will be necessary because of the variety of gas turbine intake configurations already in the fleet or under development. While the possibility of adding cold weather retrofit kits exists for most vessels. The use of the exsiting water wash systems such as those on DDG993 should also be evaluated to minimize costs.

Conclusion

While test conducted to date by Hamilton Standard have demonstrated the feasibility and promise of using a glycol/seawater spray to remove ice and snow from gas turbine moisture separators, additional tests are necessary to develop effecient systems that can be readily adapted to existing and future inlet configurations. Furthermore, this approach or a variation may also be appropriate to use in other areas such as diesel and ventilation intakes that may also require ice and snow protection.

UNITED TECHNOLOGIES HAMILTON STANDARD

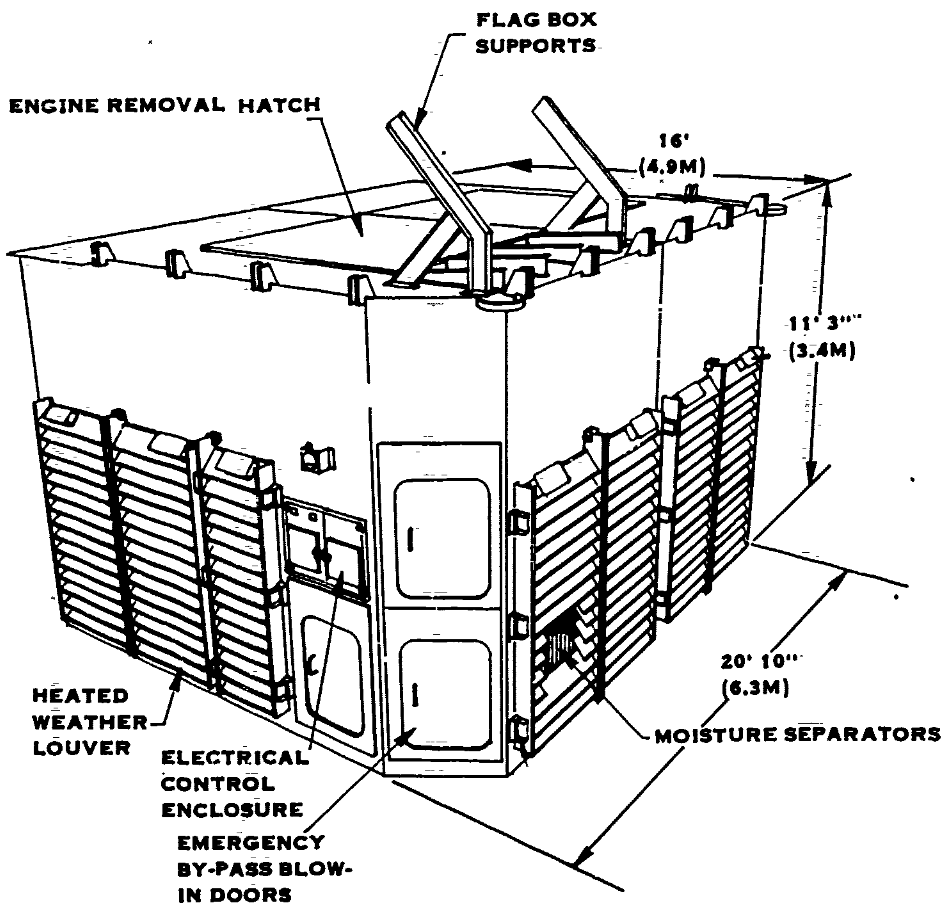


Figure 1 CG52 Intake System

UNITED TECHNOLOGIES HAMILTON STANDARD

ICE/SNOW PROTECTION

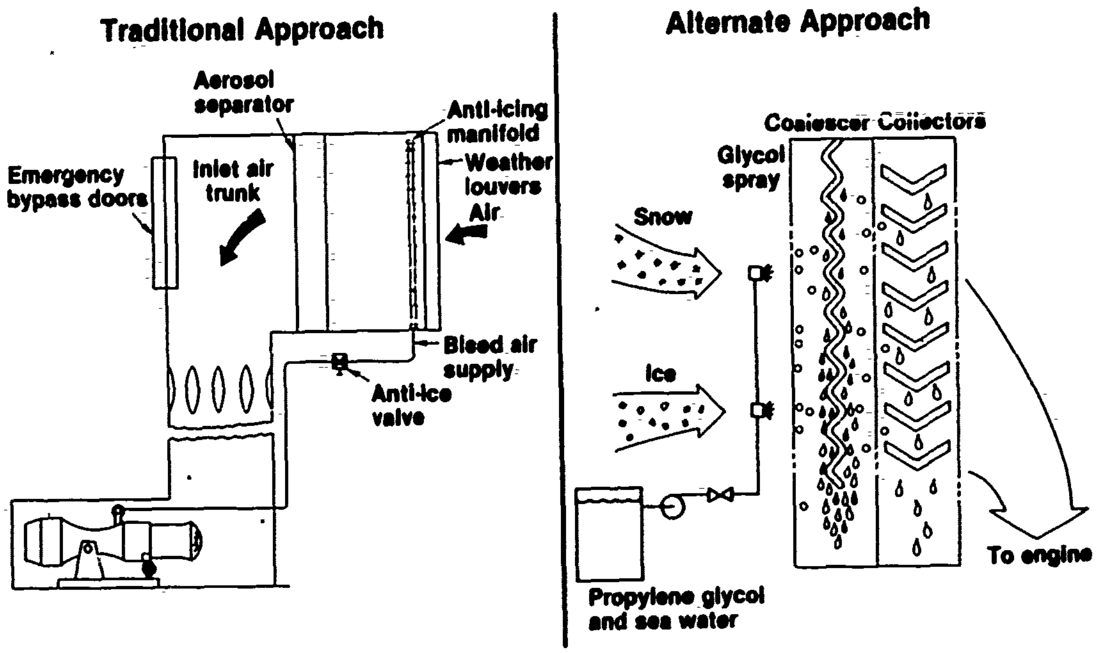


Figure 2

GLYCOL TEST

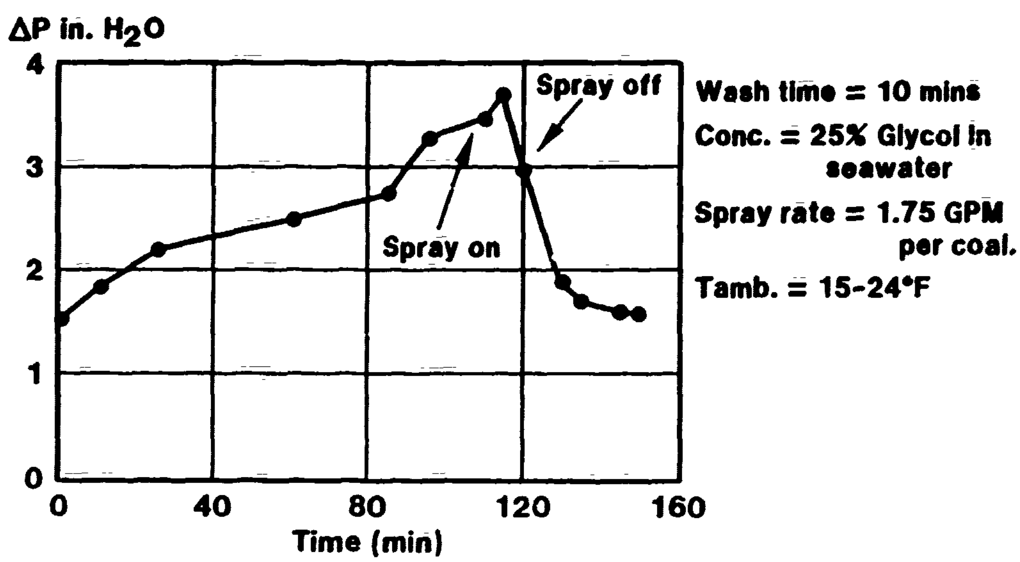


Figure 3

COLD WEATHER PROTECTION OF WEAPON SYSTEMS

USING SELF-REGULATING HEATERS

M. Watts
RAYCHEM CORPORATION
300 Constitution Drive
Menlo Park, CA 94025

Self-regulating heaters are well established in the commerical marketplace for the freeze protection of pipes and the temperature maintenance of industrial processes. Raychem has pioneered the use of self-regulating heaters in Marine applications for anti-icing and de-icing of decks, helicopter pads, antennae, steps and handrails on ships and offshore oil rigs in the Arctic and North Sea.

Weapon systems on naval ships are susceptible to freezing and icing conditions. Components that can render a weapon system inoperable are: frozen bearings; iced gun port shields; launcher tubes and covers; cold batteries and gyros. Raychem has worked with the NATO navies and their suppliers to analyze cold weather problems, and to design and manufacture heaters to provide reliable solutions. In the U.S. Raychem is working with the suppliers of the MK50 torpedo to protect the propulsion system from freezing.

The self-regulating feature ensures that the heater does not overheat and eliminates the need for complex control systems. This feature combined with the rugged polymeric construction leads to the high reliability required for weapon systems.

Commander, Operational Test and Evaluation Force
Presentation by
Commander Stephen M. Schrobo, USN

The purpose of this Navy symposium is to discuss the operational and environmental conditions of Arctic/Cold Weather Surface Ship Operations and their impact upon ship systems and tactics. The Commander, Operational Test and Evaluation Force (COMOPTEVFOR) evaluates new and improved weapon systems and their operation in high latitudes/Arctic locations.

As stated in OPNAVINST 5440.47F, the mission of COMOPTEVFOR is:

> To test and evaluate weapon systems, Ships, Aircraft, and Equipment in the anticipated operational environment and against the anticipated threat; to develop and validate procedures and tactics for employing these weapon systems, ships, aircraft, and equipment, when required; and, when directed by the CNO, to assist developing agencies (DAs) in the accomplishment of necessary developmental test and evaluation (DT&E).

Currently, COMOPTEVFOR has the assigned responsibility for over 940 active CNO projects. In each of these programs, the level of performance and readiness/supportability to be achieved (in each important system characteristic) is specified in terms of a threshold. In accordance with OPNAVINST 5000.42B;

> Separate thresholds should be established for DT&E and OT&E. The measures used for the former are determined by the program manager, for the latter COMOPTEVFOR. The numerical levels for both are established by OPNAV.

The DT thresholds generally employ technical criteria for evaluating system performance (e.g., signal strength, rate of climb, operating temperatures, etc.). In OT&E, it often is not possible to specify measurements. The objective is often simply to replicate combat conditions in realistic environments and evaluate results. This philosophy is equally applicable to weapon systems that will operate in the Arctic latitudes.

As outlined in OPNAVINSTs 5000.42B and 3960.10B, part of COMOPTEVFOR's responsibility in the Navy acquisition process is the contribution to program documentation. To COMOPTEVFOR, the Test and Evaluation Master Plan (TEMP) is the most important single document associated with an acquisition program. It summarizes all the significant aspects of the program and relates the types of T&E (OT&E and DT&E) that will evaluate system performance. A TEMP is prepared by the DA and COMOPTEVFOR.

In addition to reviewing and commenting on the entire TEMP, COMOPTEVFOR prepares the OT&E outline (part IV). This part summarizes Critical Operational Issues, OT&E to date, future OT&E and critical OT&E items. In the Critical Operational Issues section, operational effectiveness and operational suitability issues are identified. Employment and operations of new and modified weapon systems in the Arctic latitudes can be addressed here. If a weapon system is thought to be sensitive to the environment, e.g., DT thresholds for operating temperatures are too restrictive, then the effectiveness issue "Vulnerability" would contain wording to determine the systems degradation from the natural environment. If the systems operations can be significantly degraded by the realistic operational environment then a separate effectiveness issue entitled "Operating Environment" is included. With these two possible inclusions in part IV of the TEMP the effects of Arctic/Cold weather on weapon systems operations are addressed.

In a 12 Oct 84 Memorandum from CNO to Deputy Chief of Naval Operations and Directors of Major Staff Offices (DCNOs and DMSOs) Admiral Watkins wrote, "When operationally testing a system, I expect COMOPTEVFOR to try to defeat it on its own terms. I want program managers to deliver systems that cannot be defeated... ." With the recent renewed interest in operations in the Arctic latitudes and under cold weather conditions COMOPTEVFOR will ensure that all weapon systems currently in the acquisition cycle will be reviewed for operations in those regions and, wherever possible, will be tested and evaluated in those regions. Due to safety considerations while operating in those harsh conditions, the lack of cold weather ranges and the long transit times involved, it is almost impossible to adequately test in these latitudes. COMOPTEVFOR's bottom line is "To test and evaluate each system under realistic operating conditions" and if a weapon system is supposed to operate in Arctic conditions we must test it there.

ARCTIC VESSEL RESEARCH LABORATORY AND PROGRAM

N.E. Jeffrey

Director, Institute for Marine Dynamics
National Research Council of Canada

Kerwin Place, P.O. Box 12093, St. John's, Newfoundland A1B 3T5

Just a few miles southeast of the SHAREM 62 exercise, and also in November 1985, the National Research Council of Canada (NRCC) officially opened the world's largest refrigerated towing tank. Accompanied by cold rooms, equipment and staff for ship and offshore structure trials in ice-affected waters, it is one of the principal laboratories in Canada's newest national research facility, the Institute for Marine Dynamics. The Institute comprises one of the most comprehensive groups of laboratories and supporting services for research in marine transportation and offshore engineering in the Arctic ice and open ocean.

The 93m x 12m x 3m deep ice tank is equipped with a towing carriage having a maximum speed of 4 m/s. Level ice can be grown to a thickness of 15cm, and both ridges and floes can be modelled. Air temperatures of -30°C can be achieved and ice accretion, ice distribution, ice physics and mechanics studies carried out.

The Arctic Vessel Laboratory conducts research on the interaction of ice with ships, offshore structures, their systems and components. Work includes use of the ice tank to study hull-ice interactions, the properties of model and full-scale ice, and the performance of ice-transiting ships. Staff also carry out full-scale field trials for validation of model and theoretical predictions.

Powering performance, maneuverability, stability, seakeeping and component hydrodynamic characteristics can also be investigated in the Institute's cavitation tunnel and new stability and towing tanks, the Hydrodynamics Research or "Ship Laboratory". Ship and other models up to 12m in length can be manufactured using the CAD/CAM system, then tested in the basins. The stability tank is being fitted with a most advanced wave-making system.

The new Institute for Marine Dynamics, incorporating both the Arctic Vessel "Ship Laboratories", performs R & D and carries out tests and evaluation for the Canadian navy and coast guard as well as for the marine industry and ship operators. There are close ties with DTNSRDC and CRREL, and frequent contacts with USCG, Tracor Hydronautics, and Arctec.

National Security Decision Document 90 (NSDD90), April 14, 1983, states that "Promoting mutually beneficial international cooperation in the Arctic..." is a basic element of U.S. Arctic policy. Canada's National Research Council has facilities programs and accomplishments which may be shared.

In addition to the new Arctic Vessel Research Laboratories, there are important capabilities in other NRCC divisions including, for example, the Low Temperature Laboratory in the Division of Mechanical Engineering. Cold tests of vehicles and systems can be conducted at temperatures down to -40°C in the Climatic Engineering Facility. A unique full-scale Helicopter Icing Rig is used to determine the effectiveness of rotor blade de-icing systems. Other applications of the rig include in-flight icing tests of helicopter engine intake screens and air data sensors. Other NRCC laboratories have continuing research programs and facilities directly relevant to the Arctic. Amongst these are the application of radar, infrared, laser, and acoustic science to the detection, classification and management of ice conditions; the effect of cold on materials, lubricants and construction, the physics of ice, ice fracture mechanics and other failure mechanisms. The Stallabrass model for ice accretion described in Peter Zahn's paper "Four Recent Encounters with Topside Icing" is the result of NRCC research.

The majority of papers presented at this symposium described Arctic problems, effects on surface ship design and operation, and future directions--already an important integral part of Canadian R & D. In common with the U.S., Canada has capability requirements in the north. NRCC has national facilities dedicated to support defense, coast guard, commercial and industrial requirements for development, research and transportation in the Arctic. The National Research Council of Canada has a responsibility to collaborate with other nations in the conduct of research and development of technology in areas of potential economic and social benefit to Canada. Given:

- many common requirements;

- some existing mechanisms and a history of successful R & D collaboration between the USN, USCG and Canada;

- new Canadian facilities and programs directly relevant to Arctic problems and opportunities identified at this symposium;

- the stated intent of the U.S. Arctic Research and Policy Act of 1984;

there would appear to be every reason to identify, select and implement specific new cooperative projects. If you wish, early in 1986 I could provide a more comprehensive briefing on NRCC facilities, programs and possibilities for Arctic research and development.

Project Update

U.S. Maritime Administration's Arctic Marine Transportation Program

Lawrence A. Schultz
Vice President
ARCTEC ENGINEERING, Inc.

The U.S. Maritime Administration initiated a multiyear research program in 1979 directed toward determining if the risks and uncertainties associated with surface ship operations in the Arctic could be eliminated or reduced. The objectives of the program are to:

1. Define the environmental conditions in the Bering, Chukchi, and Beaufort Seas,

2. Obtain data for improving design criteria for ice-worthy ships and offshore structures,

3. Demonstrate the operational feasibility of commercial ice-breaking ships along possible future Arctic marine routes.

The program is based on the operation of our nation's two U.S. Coast Guard POLAR Class icebreakers, the POLAR STAR and the POLAR SEA. These ships are the world's most powerful non-nuclear icebreakers, and the only U.S. ships capable of mid-winter Arctic operations. The first seven years of the program, with an average of two deployments per year, have resulted in major accomplishments in each of the three program areas.

For recent programs, typical data collected onboard the icebreakers include measurements for the determination of machinery performance including shaft torque, thrust, RPM, and propeller pitch, the measurement of ship motions using fixed accelerometers, and the measurement of ice impact loads on the bow structure of the icebreaker. On-ice actvities include the measurement of ice thickness along with salinity and temperature profiles for the determination of ice strength, and the complete profiling of pressure ridge geometry using on-land surveying techniques to determine snow depth and sail elevation, and a combination of sonar, video, and photography for profiling the underwater keel of the ridge. Other measurements include the collection of ice cores for crystallography studies, the determination of ice drift velocities, and the determination of ice edge characteristics. As a part of this program, the U.S. Coast Guard's POLAR Class icebreakers completed their first winter transit to Point Barrow, Alaska in 1981, and the second winter transit to Wainwright, Alaska in 1983. The program also provided the first real time satellite ice imagery reception aboard icebreakers in 1983 to aide in ship routing in Arctic regions.

The program has been supported by a number of government agencies and industrial organizations. The Maritime Administration is keenly interested in maximizing the value of the program by combining the technical program interests of various program participants whenever possible, and cost sharing the sponsorship of the program. This program is therefore available as a resource that can be used in support of U.S. Navy projects concerned with cold weather and arctic surface ship operations.

NAVAL MEDICAL RESEARCH AND DEVELOPMENT COMMAND

COMBAT CASUALTY CARE IN ENVIRONMENTAL EXTREMES PROGRAM

The Naval Medical Research and Development Command's medical cold weather program, entitled, "Combat Casualty Care in Environmental Extremes" is currently addressing cold weather related medical problems encountered by the U.S. Fleet Marine Force on land. The cold weather areas presently being investigated include:

(1) Psychophysiology Effects of Cold Exposure in Navy/Marine Corps personnel. These studies investigate and identify basic underlying mechanisms of cold acclimation, integrating physiological and biochemical variables and perimeters. Physiological studies are directed toward analyses of neuroendocrinological profiles associated with acclimation, and biochemical studies assess the neurochemical hemostatic mechanisms of acclimation to cold. It is hoped that biochemical testing protocols can be developed to aid in the preselection of personnel with a degree of acclimation to cold weather.

(2) Psychophysiological Enhancement of Performance in the Cold. Thermal stress is a major source of degradation of performance and health of naval personnel under operational conditions. These studies assess the effect of thermal stress, especially cold stress, on physiological, biochemical and behavioral variables. Physiological studies focus on understanding/quantifying acclimation protocols and the interactive effects of multiple environmental stresses. This research also pays particular attention to changes in cardiorespiratory variables (including fluid balance) during alterations in thermal balance and acclimation. Behavioral studies integrate neurophysical performance changes in response to thermal stress.

(3) Effect of Hypothermia on Hemostasis and Myocardial Function. These efforts are conducted to develop protocols to treat hypothermic casualties who develop cardiac arrhythmias and to treat hypothermic patients who are bleeding.

(4) Develop optimun protocols for the resuscitation of dehydrated, hypovolemic, hypotensive, and hypothermic casualties.

New research and development efforts are planned in the near future to address the operational problems associated with non-freezing cold injury (NFCI) as encountered by both the Fleet Marine Force and Shipboard naval personnel.

NAVAL MEDICAL RESEARCH AND DEVELOPMENT COMMAND

COMBAT CASUALTY CARE IN ENVIRONMENTAL EXTREMES PROGRAM
(CONTINUED)

Attendance at this Arctic/Cold Weather Operations Symposium is essential to our Command in order to identify the cold weather requirements the operational Navy may encounter in the area of human factors as the Navy address its arctic/cold weather operational needs. We, in the medical community, depend on you, the operational side, to identify those health care related problems, the medical research and development community must address. Therefore, I request that this symposium, whose purpose it is to discuss the operational and environmental conditions of arctic/cold surface ship operations and their impact upon ship systems and tactics, also discuss the cold weather human factor related problems associated with these operations so that those problems may be identified and addressed by the Naval Medical Research and Development Command who is mandated to study and provide solutions to these problems. All health related issues identified should be forwarded to CNO, Director, Naval Medicine, OP-093 for submission to the Naval Medical Research and Development Command, via Commander, Naval Medical Command for tasking.

Donna Wray Kelly for

THOMAS J. CONTRERAS
CDR, MSC, USN
PROGRAM MANAGER
FLEET HEALTH CARE SYSTEMS

THE COAST GUARD'S NEW POLAR ICEBREAKER

BOB WILLIAMS, CHIEF DESIGN
BRANCH, U.S. NAVAL ENGINEERING

A brief synopsis was presented on the status of the Coast Guard's Replacement Polar Icebreaker design.

The ship's mission calls for:

4.5 feet continuous icebreaking at 3 knots

8 to 10 feet icebreaking in the ramming mode

80 days endurance without refueling

180 days provisions without replenishment

2 HH-65A Helicopters

Major scientific capability including accommodations for 30 scientists and 5 laboratories plus 4 laboratory vans on deck.

Conceptual design was completed in September 1985. The Preliminary Design phase is now underway with completion scheduled for June 1986.

The principal characteristics of the ship at the completion of Conceptual Design were:

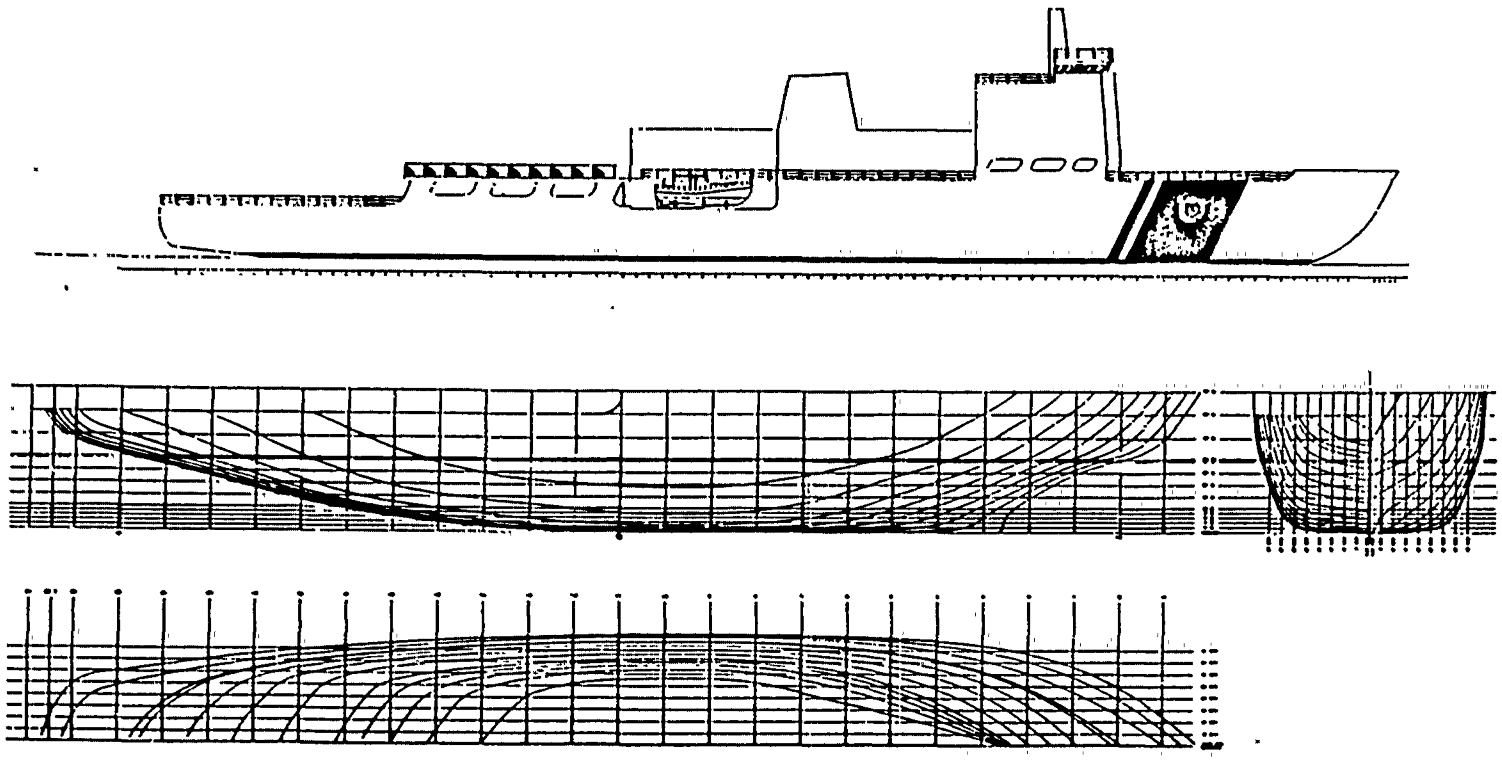
LOA: 451 feet

Beam W.L.: 87.6 feet

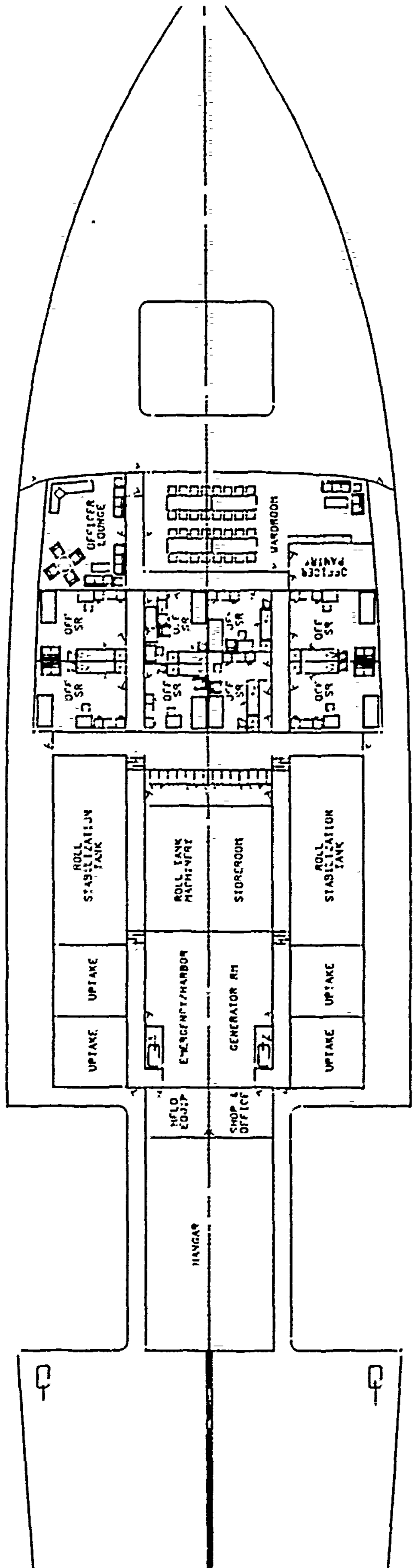
Draft: 31 feet

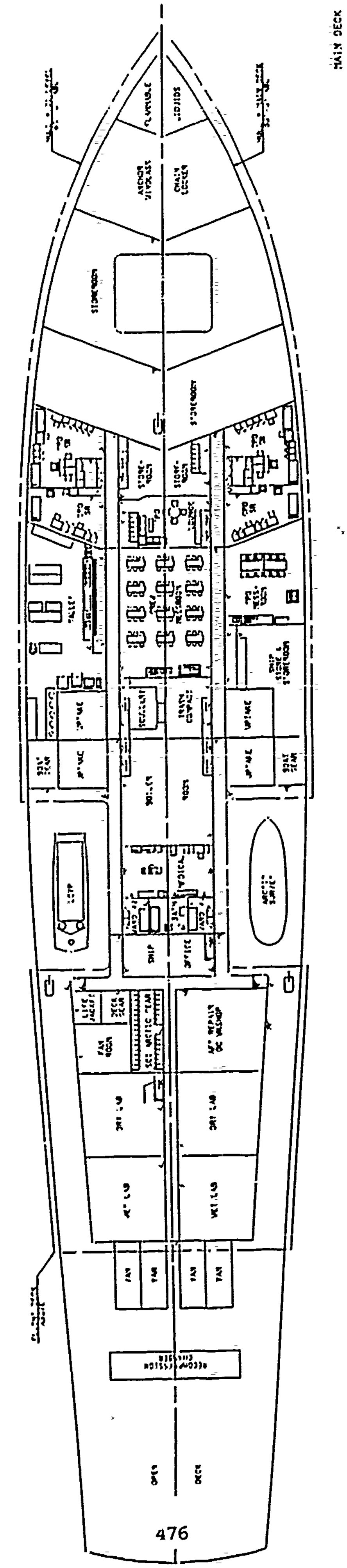
Displacement: 16,000 tons

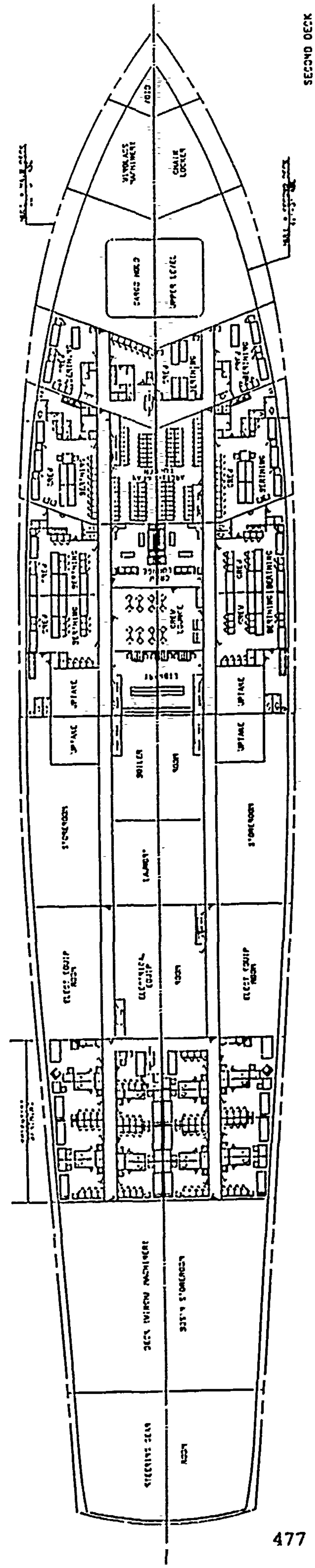
Propulsion: 30,000 SHP, AC-AC drive



Loa:	451'
Lwl:	393.4'
Bwl:	87.6'
Draft:	31'
Disp.:	15,951 L.T.


OFFICER LOUNGE
WARDROOM
OFFICER PANTRY
OFF SR
OFF SR
OFF SR
OFF SR
OFF SR
OFF SR
OFF SR
OFF SR
ROLL STABILIZATION TANK
ROLL TANK MACHINERY
STOREROOM
ROLL STABILIZATION TANK
UPTAKE
UPTAKE
EMERGENCY/HARBOR
GENERATOR RM
UPTAKE
UPTAKE
HELO EQUIP
SHOP & OFFICE
HANGAR


MAIN DECK
STOREROOM
UPTAKE
DRY LAB
WET LAB
FAN
OPEN DECK


SECOND DECK
CHAIN LOCKER
CARGO HOLD
UPPER LEVEL
CREW LOUNGE
UPTAKE
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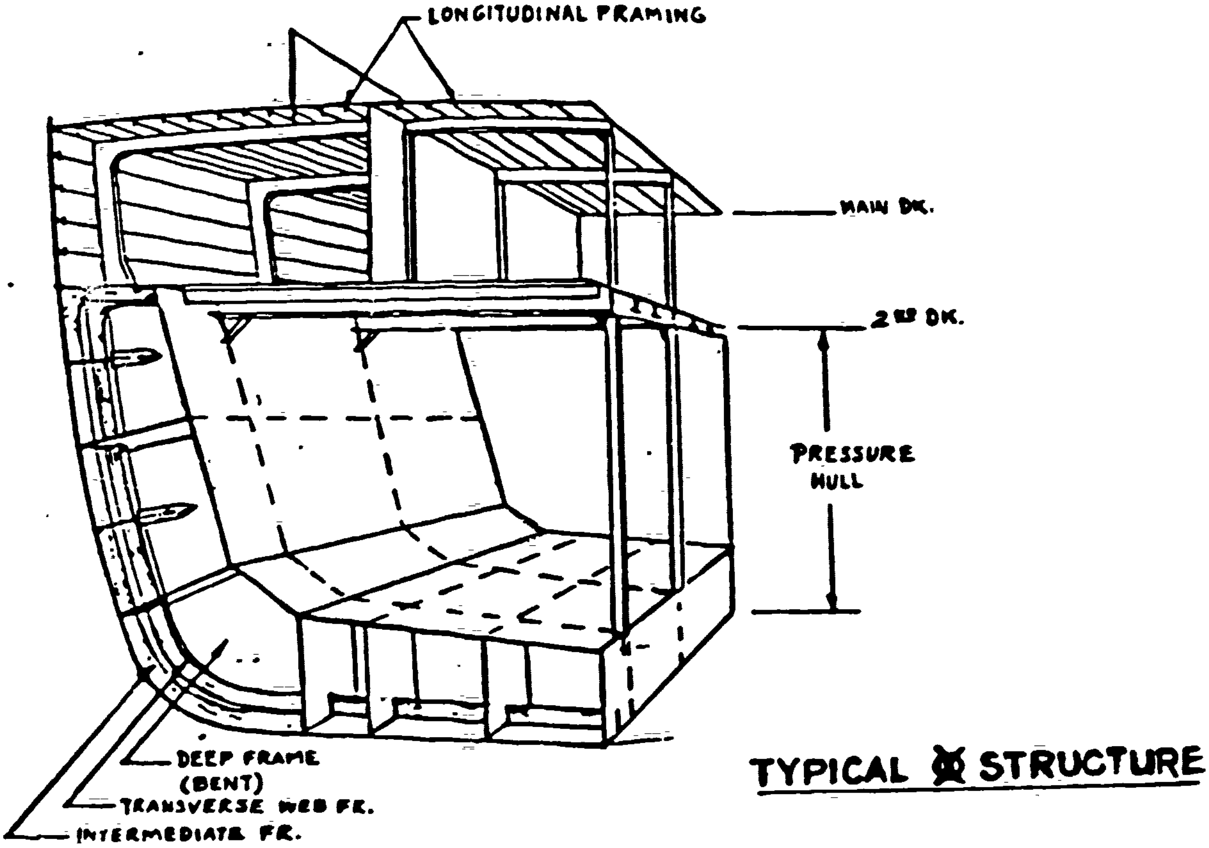
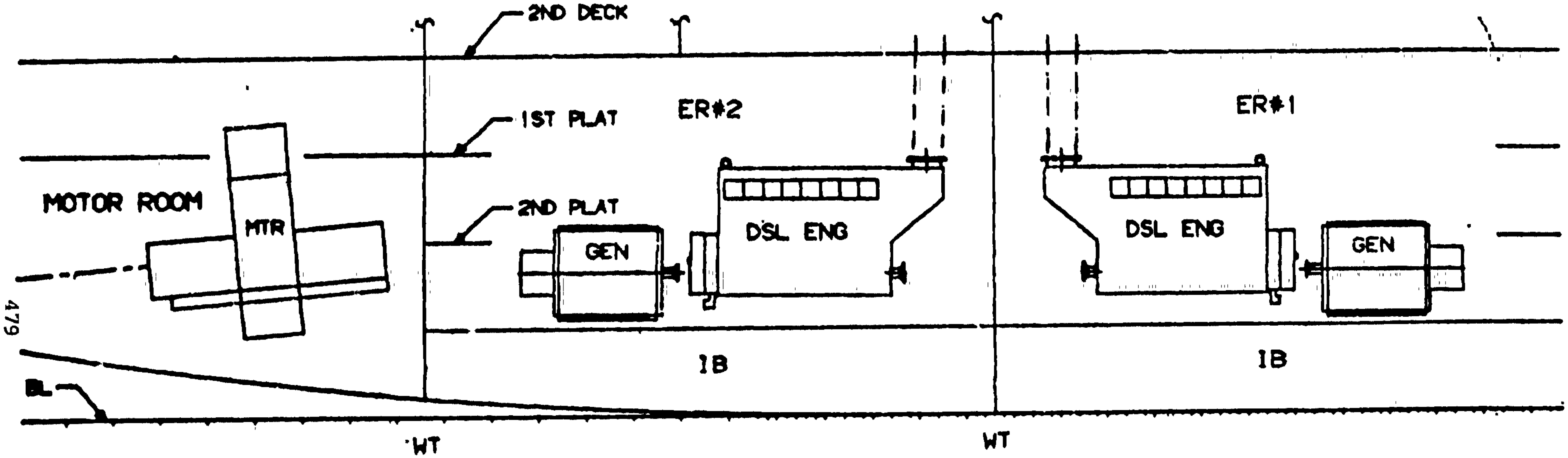
STOREROOM
STOREROOM
ELECT EQUIP ROOM
ELECT EQUIP ROOM
STEERING GEAR
ROOM

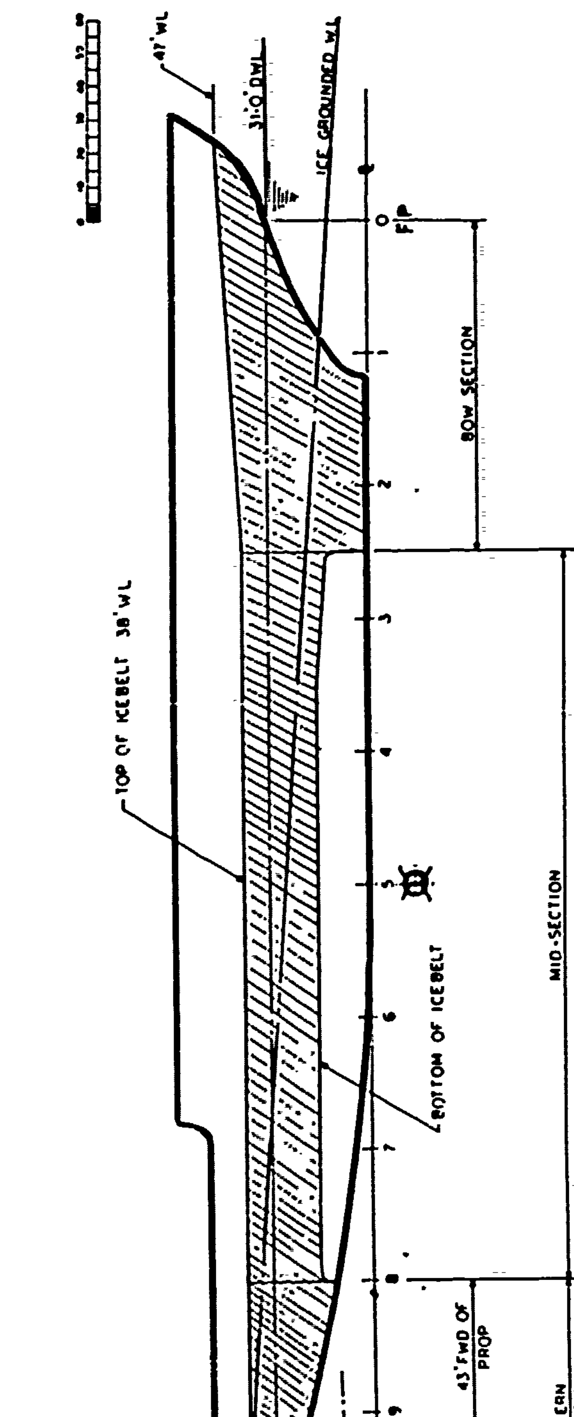


CONCEPTUAL STRUCTURAL CONFIGURATION

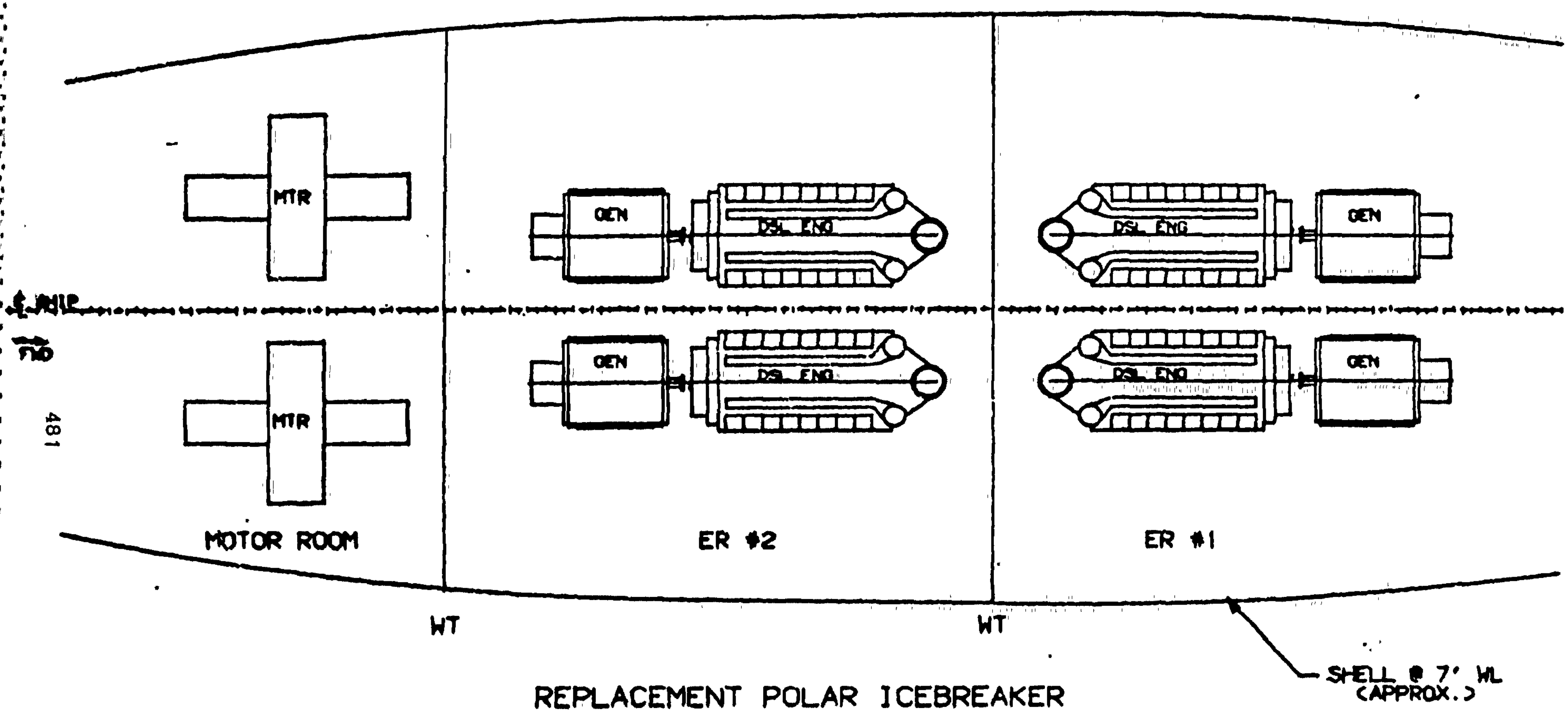


REPLACEMENT POLAR ICEBREAKER
30,000 SHP

MACHINERY ARRANGEMENT (NOT TO SCALE)
ELEVATION



47' WL
31'-0" DWL
ICE GROUNDED WL
TOP OF ICEBELT 38' WL
BOTTOM OF ICEBELT
0
FP
1
2
3
4
5
6
7
8
9
10
AP
BOW SECTION
MID-SECTION
45' FWD OF PROP
STERN SECTION



REPLACEMENT POLAR ICEBREAKER
30,000 SHP

MACHINERY ARRANGEMENT (NOT TO SCALE)

PLAN VIEW

REPLACEMENT POLAR ICEBREAKER

MACHINERY CHARACTERISTICS

PROPULSION SYSTEM

GENERAL - TWIN SCREW; DIESEL ELECTRIC DRIVE; 30,000 MAXIMUM CONTINUOUS SHAFT HORSEPOWER

PRIME MOVERS - FOUR DIESEL ENGINES; 450 RPM

TRANSMISSION - AC-CYCLOCONVERTER-AC; COMMON BUS

MOTORS - ONE PER SHAFT; SYNCHRONOUS ALTERNATING CURRENT; 15,000 HORSEPOWER

PROPELLERS - TWO FIXED PITCH

AUXILIARY SYSTEMS

COMBINED HARBOR/EMERGENCY GENERATOR

SEWAGE AND OILY WATER POLLUTION CONTROL EQUIPMENT

OTHER AUXILIARIES CONSISTENT WITH CURRENT USCG PRACTICE

COAST GUARD ICEBREAKER - CURRENT OPERATIONS

BY LT DENNIS SOBECK

U.S. COAST GUARD, ICE OPERATIONS DIVISION

Text not available at time of printing.

HULL STRUCTURE SUITABILITY FOR OPERATIONS IN BROKEN ICE

Joseph L. Coburn, Jr.

ARCTEC ENGINEERING, Inc.
Columbia, Maryland

Alternative rules and approaches to ice strengthening for ships are reviewed. Particular attention is focused on the requirements for operating in broken ice. An example is worked out for the strengthining required for the USNS Southern Cross operating in a broken ice channel. Guidance for the determination of safe operating speed is also developed.

Text not available at time of printing.

MODELING OF SPRAY ICE ACCRETION EXPERIMENTS*

by

Prof. W. M. Sackinger
Geophysical Institute
University of Alaska
Fairbanks, Alaska 99775-0800

In an accompanying paper in this symposium, the idea of the examination of an entire ship under conditions of spray ice accretion was presented. The idea, which was discussed by Mr. Rogalski, involved the coating of a ship with spray ice under controllable experimental conditions at a benign location. His concept is to use large marine firefighting equipment to create a jet of sea water, which would be cooled by the ambient wind conditions enough to cause the formation of spray ice when the sea water droplets of the spray descend upon the ship. We are involved in the theoretical analysis of this kind of experiment, and have segmented the problem into two categories. In the first part of the analysis, one must consider the appropriate equations to describe the trajectory of the water stream as it leaves the water jet nozzle. The water stream gradually loses its velocity and, near the apogee of the trajectory, it begins to break up into droplets, each of which may then be separately subjected to a trajectory analysis. After the droplets have passed the apogee, they descend and soon acquire terminal velocity, finally striking the test ship superstructure surfaces. The division of the trajectory into these three regions is illustrated in Figure 1.

*Paper presented at Arctic/Cold Weather Surface Ship Operations Symposium, Rockville, Md, December 3-4, 1985.

Calculations may also be made of the cooling of each droplet during its transit along the trajectory shown in Figure 1. Cooling takes place by a combination of thermal convection, radiation, and evaporation from the droplet. After consideration of the problem, it becomes evident that the radiative transfer from droplets in the interior of the spray is negligible, inasmuch as those droplets are surrounded by others which are at very nearly the same temperature. It is also obvious that the maximum amount of heat transfer takes place between the droplets and the ambient air after the individual droplets have been formed at the beginning of Region 2. The effect of a wind is to impart an additional horizontal velocity component to the droplets in Region 2 and Region 3. The wind which is transverse to the initial direction of motion will act upon the smallest droplets throughout their time of flight, which will be of considerably longer duration because of their smaller values of terminal velocity as shown in Figure 2. The downwind region of the impact area in that case will contain small, partially frozen droplets, whereas the upwind segment of the impact area will contain larger droplets which have had a shorter transit time and consequently a smaller amount of heat extracted from them. It therefore appears quite feasible to replicate the conditions of spray ice formation referred to in the accompanying paper using this approach. If the upwind portion of the impact area is allowed to impinge upon the ship, liquid droplets may be arriving so frequently as to increase the temperature of the ship's surface to that of the arriving water droplets. If the droplet impact area is moved so that the central part of the pattern descends upon the ship, one would expect fewer droplets of smaller sizes and the condition in which the liquid droplets freeze upon impact could be duplicated.

Finally, if the downwind edge of the impact area were moved so that it impinged upon the ship, the very small droplets could be expected to freeze partially into ice during their transit through the air, producing a spray ice coating of low salinity and low density as described in the accompanying paper.

Detailed analysis of these heat flow considerations and trajectory equations is nearly complete and will be reported at a later date. However, the conclusion is that it will be feasible to simulate spray ice accretion on the superstructure of a ship in a controlled manner, using the artificially generated spray ice from a water jet. We are looking forward to an experiment to confirm the details of this versatile engineering approach to ship survivability assessment under Arctic conditions.

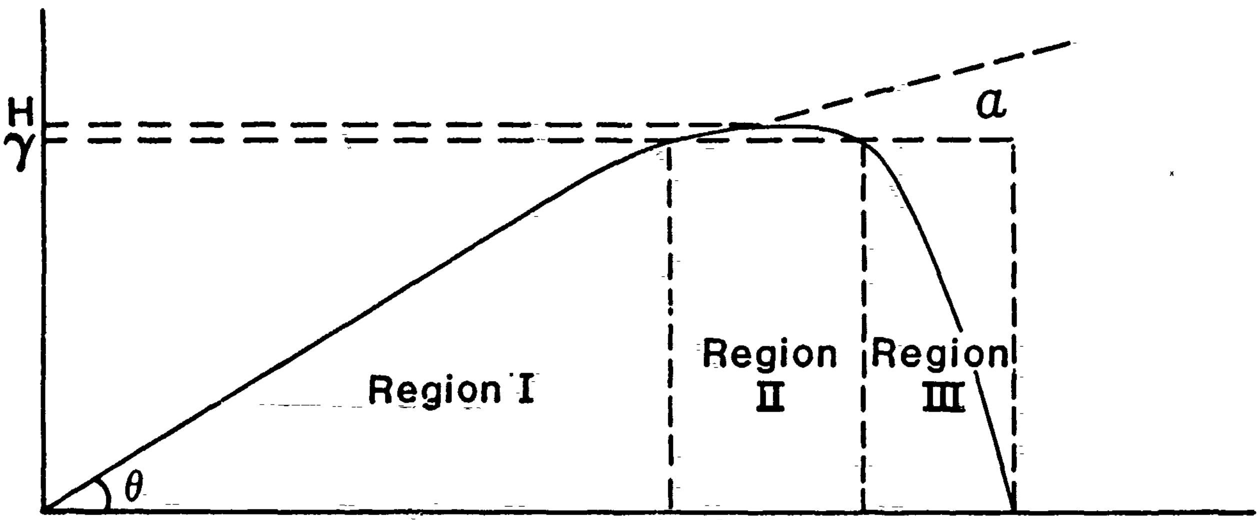


FIGURE 1. Schematic separation of trajectory into three regions for analysis: Region I (coherent water stream); Region II (droplet region with dominant horizontal velocities); Region III (droplet region with dominant vertical velocities).

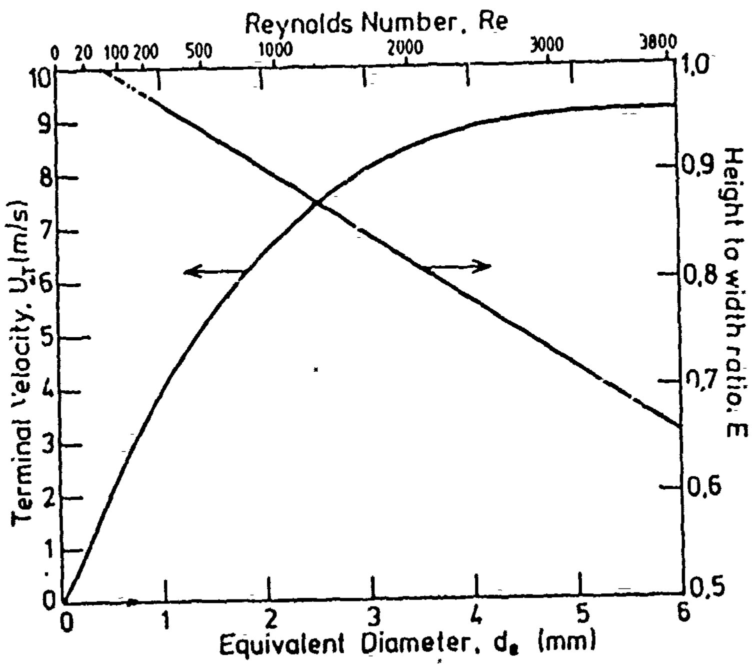


FIGURE 2. Terminal velocity and aspect ratio of water drops falling freely in air at 20°C and 1 bar (after Clift et al., 1978).

ICE ISLANDS AS LOCATIONS FOR ARCTIC DATA COLLECTION*

by

Prof. W. M. Sackinger
Geophysical Institute
University of Alaska
Fairbanks, Alaska 99775-0800

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The existence of ice islands has been noted since the discovery of the island T-1 on August 14, 1946, at 76°15'N, 160°15'W. This floating ice mass was about 29x24 km in size with an area of about 500 km^2. The most studied ice island was T-3, discovered on July 29, 1950 at 75°24'N, 173°00'W. These and other ice islands were characterized by an undulating surface topography of gradual ridges and troughs, and thicknesses exceeding that of normal pack ice, up to 40-50m thickness. It became apparent that these drifting islands of ice had been produced by calving from the ice shelves adjacent to the north coast of Ellesmere Island. Early explorers noted an ice shelf fringe extending along the entire northern coast of Ellesmere Island, which also had long prairie-like swells following parallel to the main contour of the shore. In fact, the journal of Commander Robert Peary, U.S.N., during his 1906 expedition provides the most comprehensive view of the details of the ice shelves. Peary traveled by dogsled westward from Cape Sheridan to Axel Heiberg Island and described undulating ice surfaces all the way around the coast extending across Nansen Sound to the northern extremity of Axel Heiberg Island. Spedding (1977) has estimated that the

*Paper presented at Arctic/Cold Weather Surface Ship Operations Symposium, Rockville, MD, December 3-4, 1985.

Ellesmere Island Ice Shelf at that time had a maximum area of about 7500 km^2. The largest shelf remaining today is the Ward Hunt Ice Shelf, which is shown in Figure 1. One of the islands which calved from the northern edge of the Ward Hunt Ice Shelf in the fall of 1982 is shown in Figure 2. During the calving event in 1982, a cluster of ice islands, containing at least 10 separate islands, was produced. The thickness of these is of the order of 44 meters, and the largest one, of dimensions 4km x 9km, has been named Hobson's Ice Island; it has a research camp recently established upon it by the Canadian Polar Continental Shelf Project.

With modern satellite telemetry systems, it is quite feasible to obtain oceanographic and meteorological data from these drifting ice island platforms, using unmanned, automated equipment. A major advantage is that stability is assured, even in the presence of compressive and shear movements of the pack ice. The islands also are large enough to permit the landing and takeoff of large aircraft, and in fact could be convenient points for the staging of emergency search and rescue operations in the Arctic. Oceanographic and acoustic data could be obtained continuously from instruments suspended beneath the ice islands, and meteorological information could be obtained from readily available instrumentation mounted on the upper surface of the island. The island also normally moves at a velocity slightly lower than that of the surrounding pack ice, so that there is usually an open water or thin-ice-covered lead adjacent to the island which could be used for emergency submarine-related operations.

The islands typically drift around the Arctic Ocean for several decades; T-3, for example, remained in the Arctic until July 1984 when it was sighted off the southern tip of Greenland. The suggestion to be considered is for the use of ice islands, which can be considered as semi-permanent, durable hard spots in the arctic ice pack, as platforms for the collection of surface meteorological data as well as oceanographic and acoustic data. This can be accomplished by remote automated equipment, with estimated operation time of 6-10 years between visits. The drifting of the arctic ice pack can take these stations not only around the Beaufort Gyre, but throughout the entire arctic basin.

Because of the hazards posed by ice islands, which would perhaps strike offshore oil and gas production structures, a program has been established by the U.S. Department of Energy to instrument several of the islands to determine their location, as well as the ambient barometric pressure and temperature, for a period of six years. This program should be viewed as only an initial attempt to use the ice islands as arctic data collection platforms, and a more complete suite of instruments on each island would certainly be appropriate.

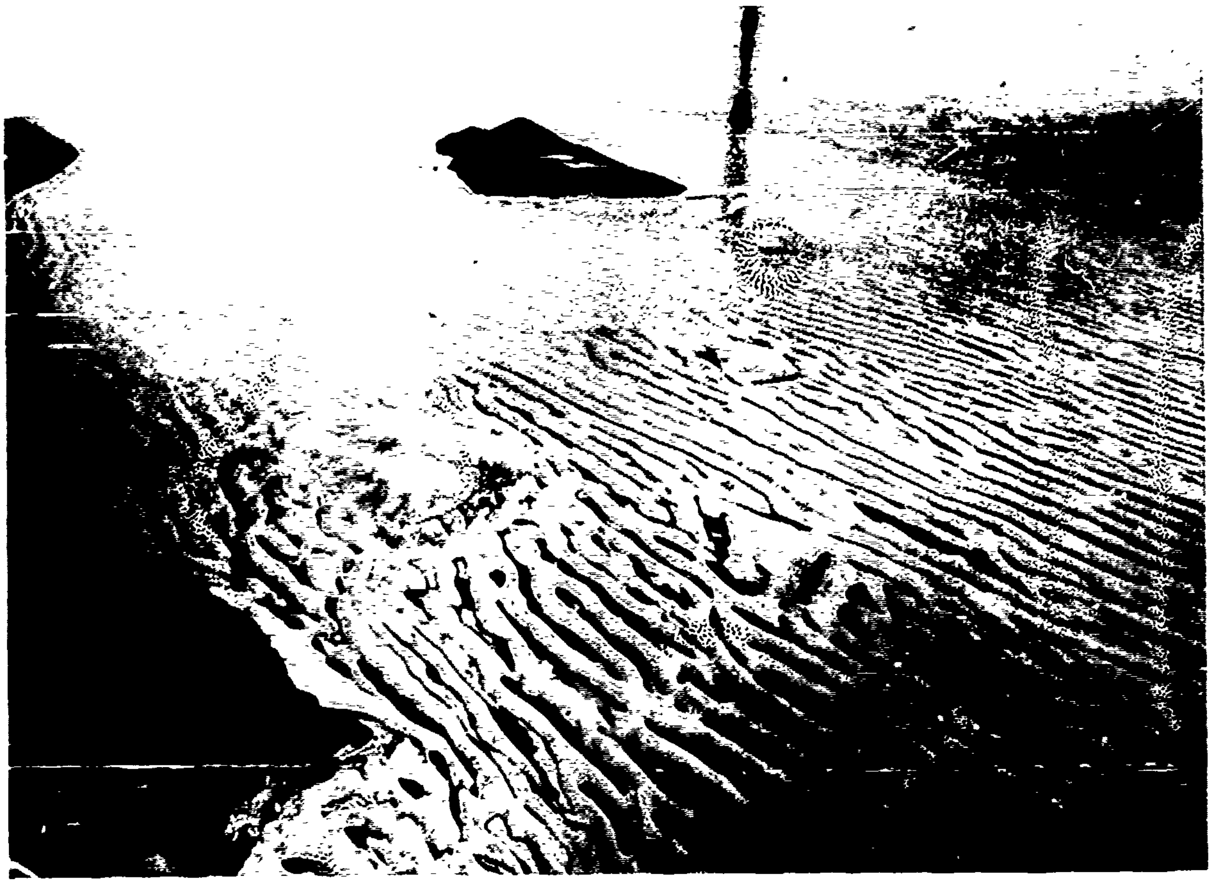


FIGURE 1. *Photograph of Ward Hunt Ice Shelf taken on July 24, 1984, looking west beyond Ward Hunt Island; altitude 3,047 meters.*

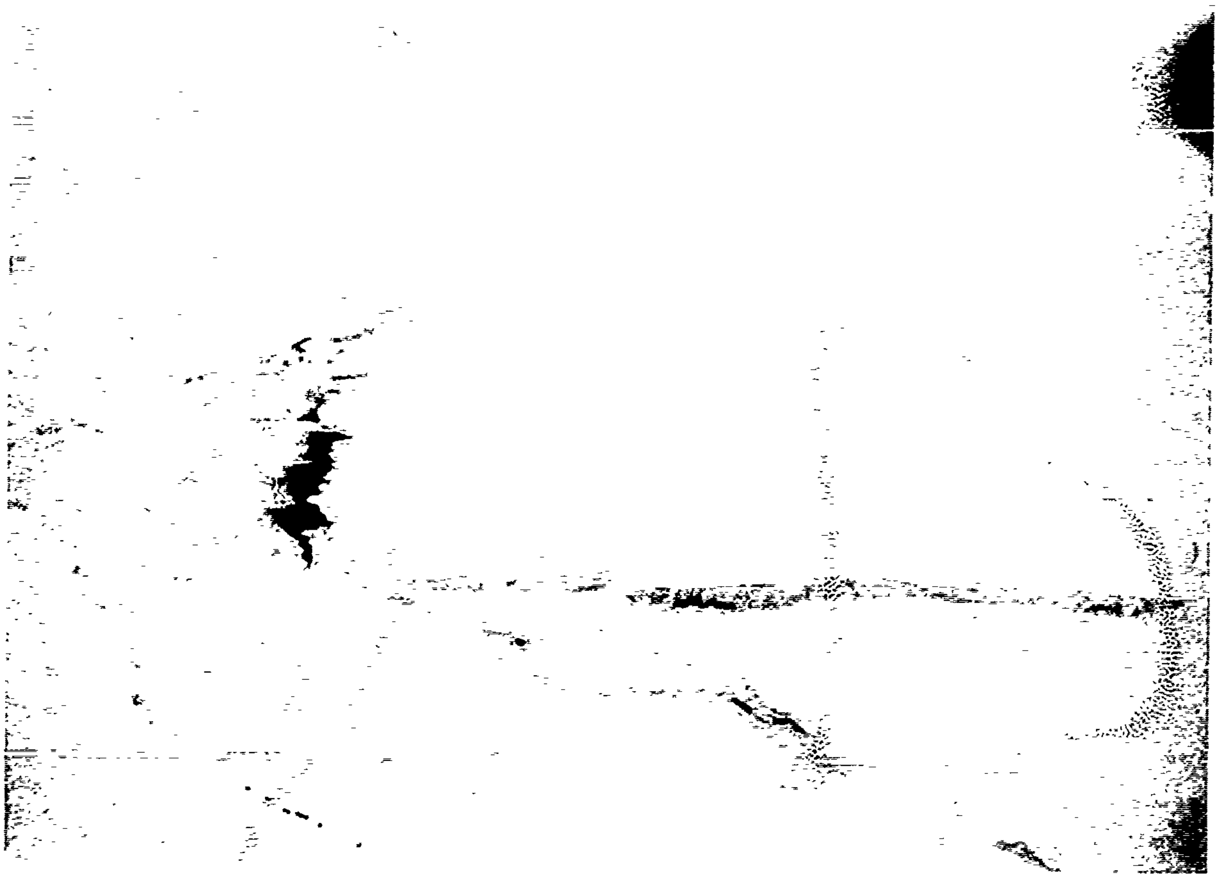
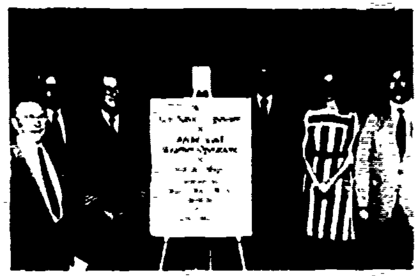


FIGURE 2. Ice Island "Delta" drifting 12km north of Alert Point on October 19, 1983.

SYMPOSIUM ACTIVITIES



Symposium Organizers
Mr. J. Kordenbrock, Mr. J. Richard, Capt. R.K. Barr, Mr. P. Yarnall, Mrs. P. Holcomb, Mr. R. Rogalski

Symoosium Coordinators
(L-R) Pam Holcomb and Joe Richard, MAR, Inc. and Phil Yarnall, DTNSRDC

Symposium Audience
Front Row (L-R): RADM Roane, NAVSEA; Mr. J. Taussig, SECNAV; RADM J.R. Seesholtz, NAVOCEANO; Capt R.K. Barr, OPNAV; Mr. J. Kordenbrock, OPNAV

Symposium Audience
Front Row (L-R): CDR R.B. Bubeck, NAVSEA; CAPT K. Duff, NAVSEA

Coffee Break
(L-R): Mr. A. Stavovy, DTNSRDC. Mr M. Jeffrey, NRC-Canada; CDR R.G. Meryon, U.K. Navy Staff; Mr. J. Cerminara, Westinghouse

Coffee Break
(L-R): Dr. R Allen and Dr. W. Deitz, DTNSRDC

The Panel
(L-R): CAPT K. Duff, NAVSEA; CAPT R.K Barr, OPNAV; CDR O Spahr, OPNAV; CAPT R. O'Keefe, OPNAV, Mr. L. Thomas, DTNSRDC

The Dinner
(L-R) Mrs. J.R Seesholtz; CAPT. T.R O'Keefe, OPNAV; Dr. R Levin MAR, Inc.; CAPT R.K. Barr, OPNAV; Ms. S. Bales, DTNSRDC

FREEZE PROTECTION AND TEMPERATURE MAINTENANCE OF SHIPS, SHIPBORNE EQUIPMENT AND ELECTRONIC SYSTEMS

FOR THE PROCEEDINGS OF THE

1985

U.S. NAVY SYMPOSIUM

ON

ARCTIC/COLD

WEATHER OPERATIONS

OF

SURFACE SHIPS

3-4 DECEMBER 1985

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CONTENTS

1.0 INTRODUCTION

This paper is concerned with the application of Raychems self-regulating electric heater technology to the areas of freeze protection and temperature maintenance of ships, shipborne equipment and electronic systems. Evolving from the heater technology a range of products are available for use in extreme marine environments.

2.0 DECK AND SUPERSTRUCTURE FREEZE PROTECTION

2.1 ICE ACCRETION

2.1.1 Icing

Icing on ships can be caused by either atmospheric icing or induced by sea spray.

Atmospheric icing is due to supercooled fog or clouds and is the same as found on aircraft. For this to happen the superstructure has to be high above sea level. This phenomenon can also be called 'arctic frost smoke'.

The most serious cause of icing in marine environments is sea spray generated by the passage of a vessel through heavy seas when the air and sea surface temperatures are sufficiently low.

The degree of icing on decks, superstructures and equipment depends on many meterological parameters and also on geometry of the object. The most important parameters are found to be wind speed, air and water temperature and liquid water content in the air.

2.1.2 Types of Icing

There are two types of ice to be found at sea - Rime and Glaze ice.

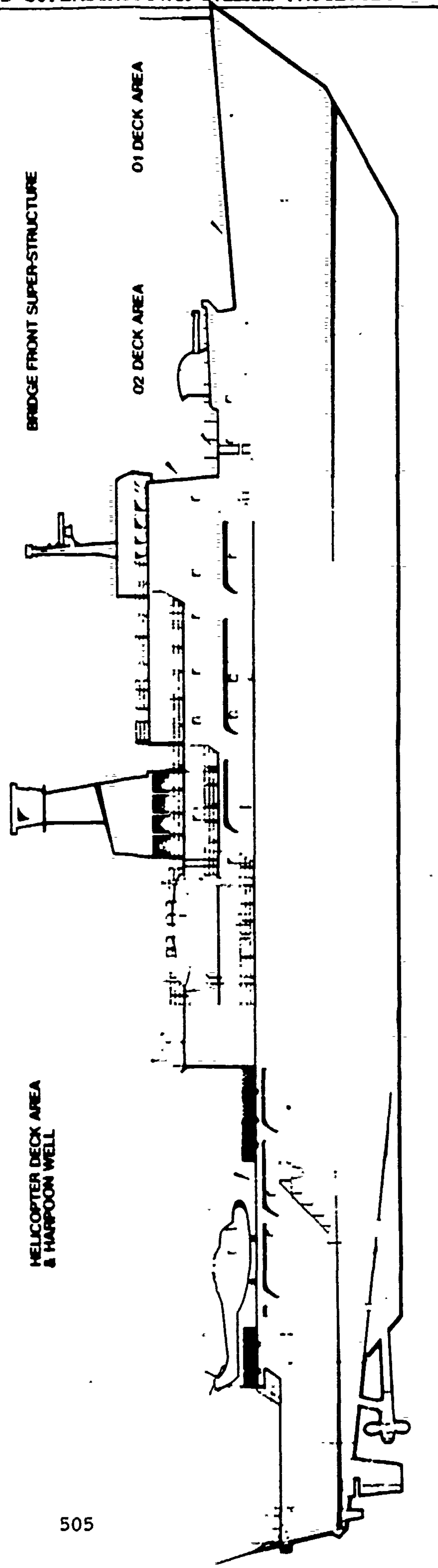
Rime has low adhesive strength and can be removed by hand or brush. It can form anywhere on the ship. The frozen droplets are caused by wind or ship spray. This type of ice is caused when the wind speed is cold enough to cool the droplets but not to freeze them.

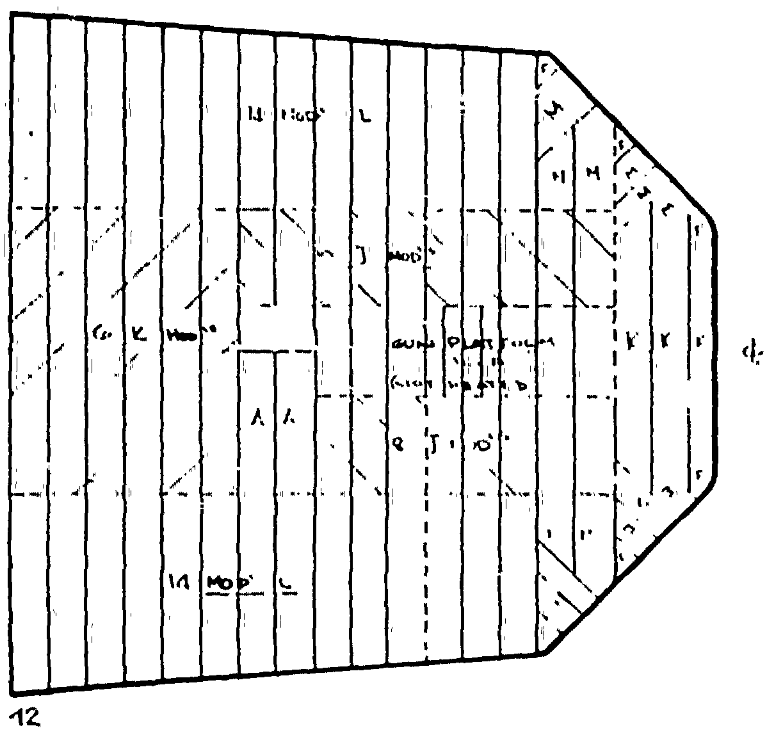
Glaze ice is the most dangerous on ships because it is very dense due to a combination of low temperature, wind speed and sea water droplet size which makes it very difficult to remove. We design to protect from this form of icing.

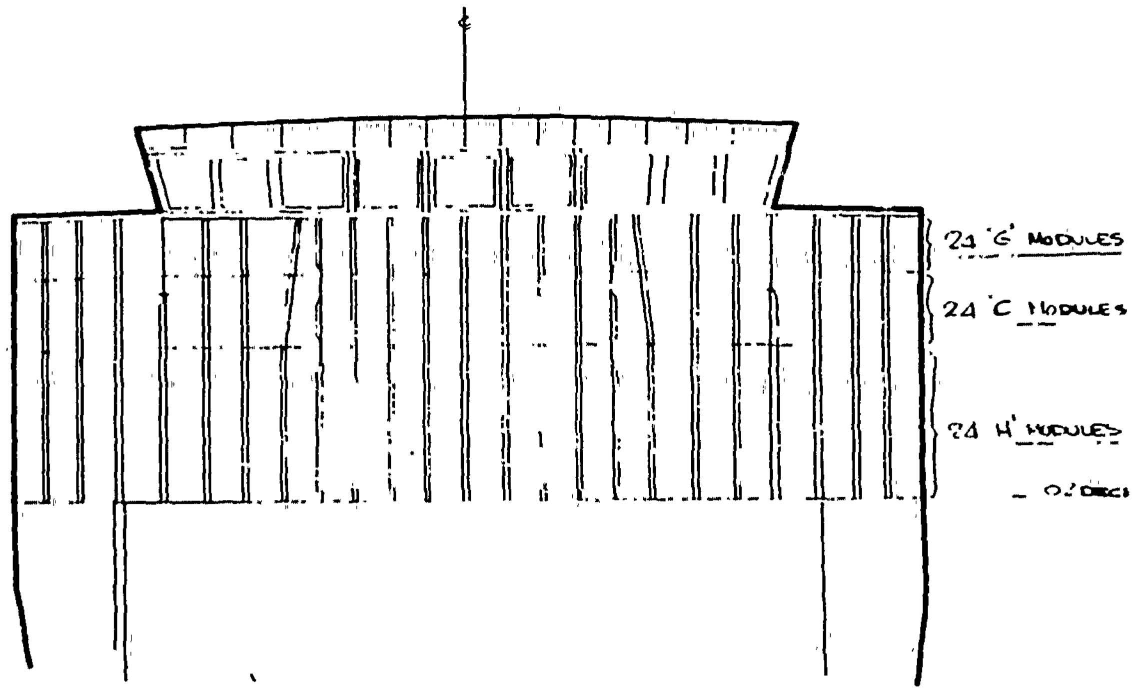
2.2 BASIC CALCULATIONS

The amount of heat required to heat a deck/superstructure to prevent the accretion of ice or to facilitate its removal is that which will overcome the losses due to conduction; convection and radiation. Radiation losses can usually be ignored due to the low temperatures involved and conduction losses to any ice layer and/or thermal insulation will always be relatively small.

The formulae used to determine the power requirements for the heat tracing of a deck or a superstructure include a certain safety factor and make certain assumptions i.e. where the underside of the deck/superstructure area is either insulated or exposed to an ambient temperature in excess of 0°C, heat losses from the underside can be ignored. If, however, the underside of the deck/superstructure is not insulated or is exposed to an ambient temperature less than 0°C, losses must be taken into account.


O1 DECK AREA
BRIDGE FRONT SUPER-STRUCTURE
O2 DECK AREA
HELICOPTER DECK AREA & HARPOON WELL





12

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MODULE	QTY	MODULE DIM² APPROX
A	7	2400 × 600
F	6	400 × 600 APPROX
J	18	1600 × 600
K	9	4800 × 600
L*	28	3000 × 600
M*	14	1100 × 600

NOTE / MODULE AVERAGE LENGTHS

* L = 3000 MM
* M = 1100 MM

MODULE	QTY	MOD' DIM² APPROX
C	24	1200 × 600
G	24	900 × 600
H	24	2600 × 600

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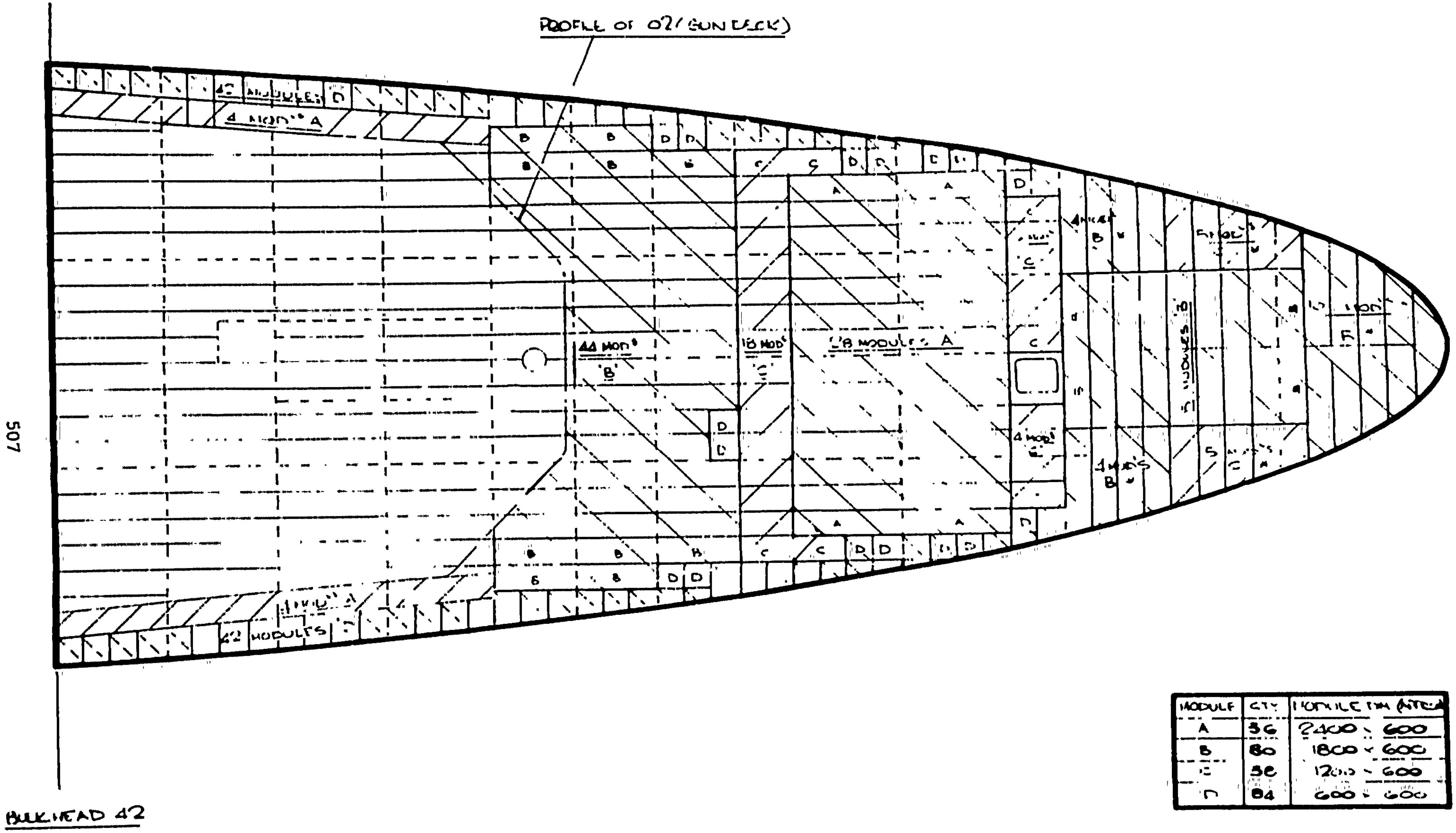
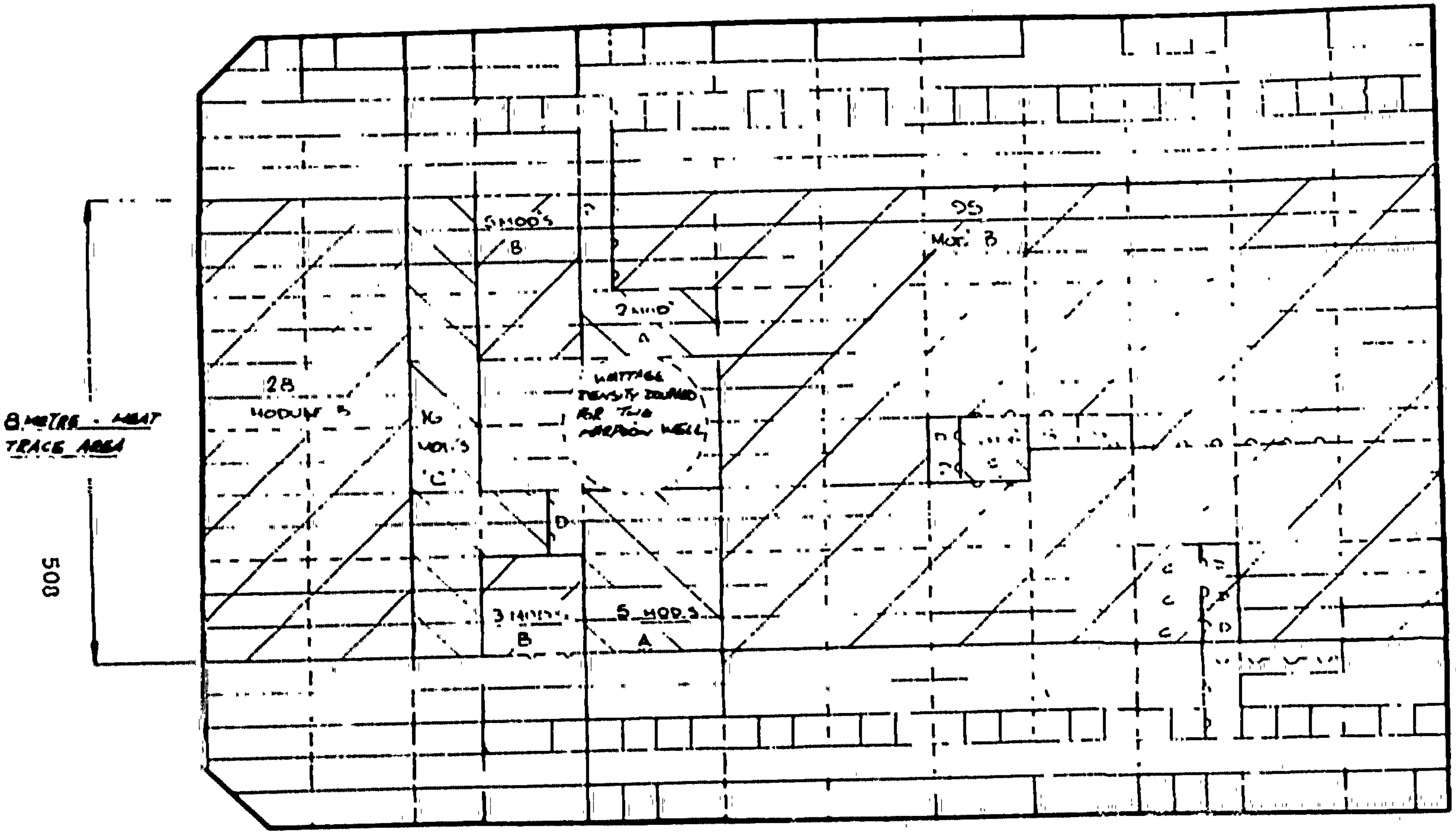
02 DECK (Gun Deck) and FRONT OF BRIDGE SUPER-STRUCTURE



MODULE	QTY	MODULE DIM (AREA)
A	36	2400 x 600
B	80	1800 x 600
C	30	1200 x 600
D	84	600 x 600

Raychem

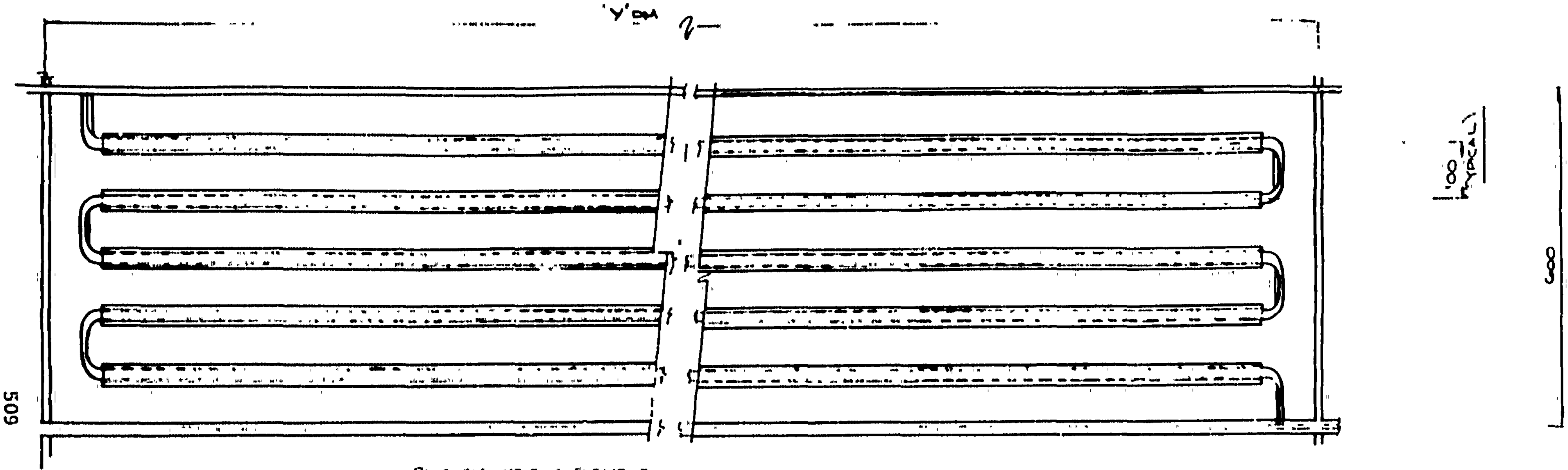
01. DECK



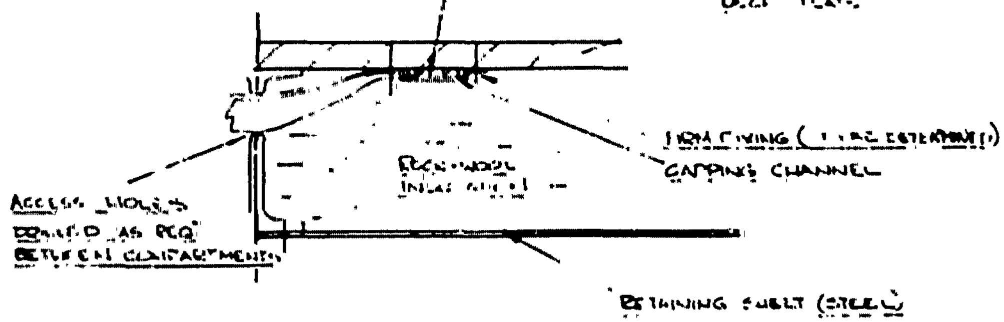
Module	Qty	Mod' Dim's Assy
A	7	2400 ×600
B	151	1800 ×600
C	21	1200 ×600
D	10	600 ×600
G	2	900 ×600

Raychem

02 DECK (Flight Deck)



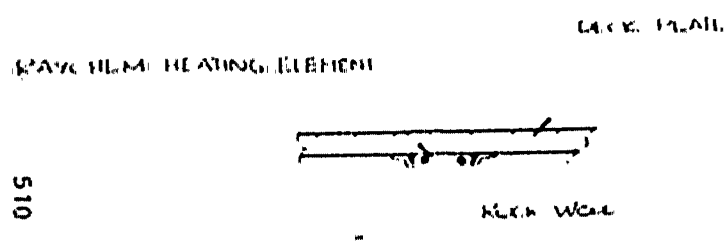
MODULE	Y DIM
A	2400
B	1800
C	1200
G	900
I	2400
J	1,000
K	4800



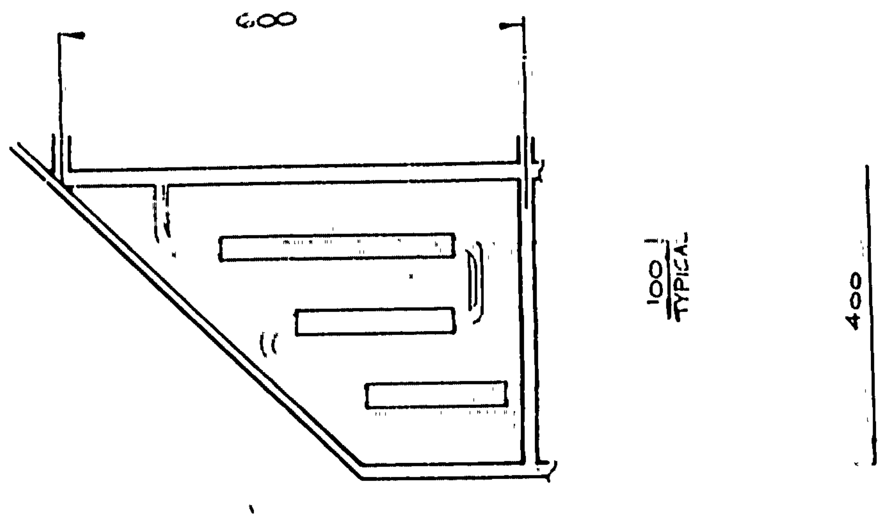
TYPICAL SECTION THRU' INSTALLATION

Raychem

TYPICAL INSTALLATION MODULES 'A','B','C' & 'G'



TYPICAL SECTION THRU' INSTALLATION



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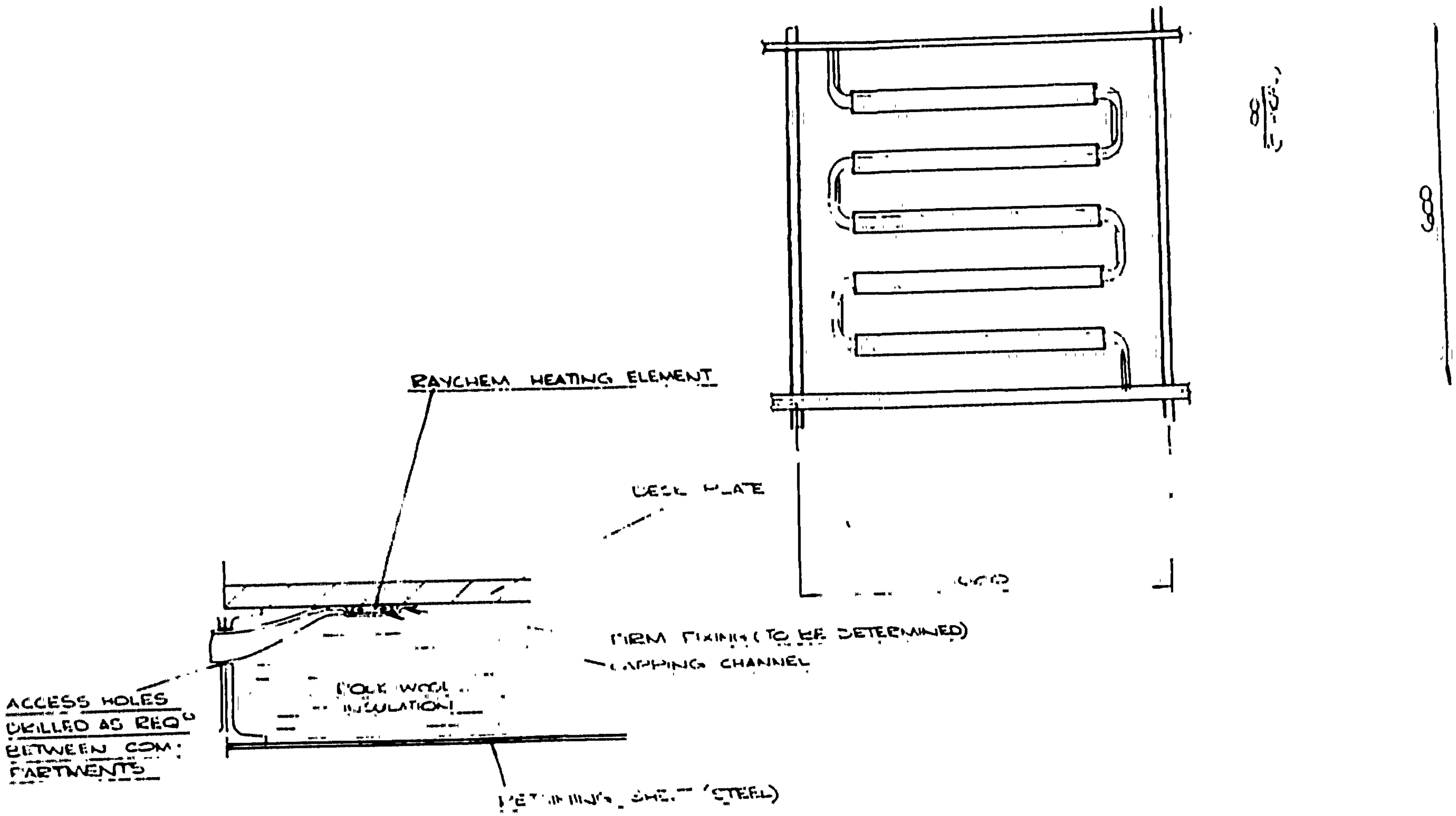
TYPICAL INSTALLATION MODULE 'F' (non-rectangular module)



TYPICAL SECTION THRO INSTALLATION

TYPICAL INSTALLATION MODULE 'D'

Raychem

2.4 DOORS AND HATCHES

There are many examples where cargo hatches and access doors need to remain functional under icing conditions.

The protection normally needed is to ensure that there is no ice bond between the door or hatch seal and the respective sealing face and/or there is no possibility of any ice bridging between the door/hatch and its frame.

In most cases the heater strip can be fitted to the fixed structure as shown in Figure 1. There are other possible configurations for example that shown in Figure 2 for protecting the seal on an emergency escape hatch.

For all hatch/door applications the heaters can either be supplied terminated ready for installation or alternatively the heaters can be terminated on site by shipbuilders.

2.5 MOISTURE SEPERATORS

2.5.1 General

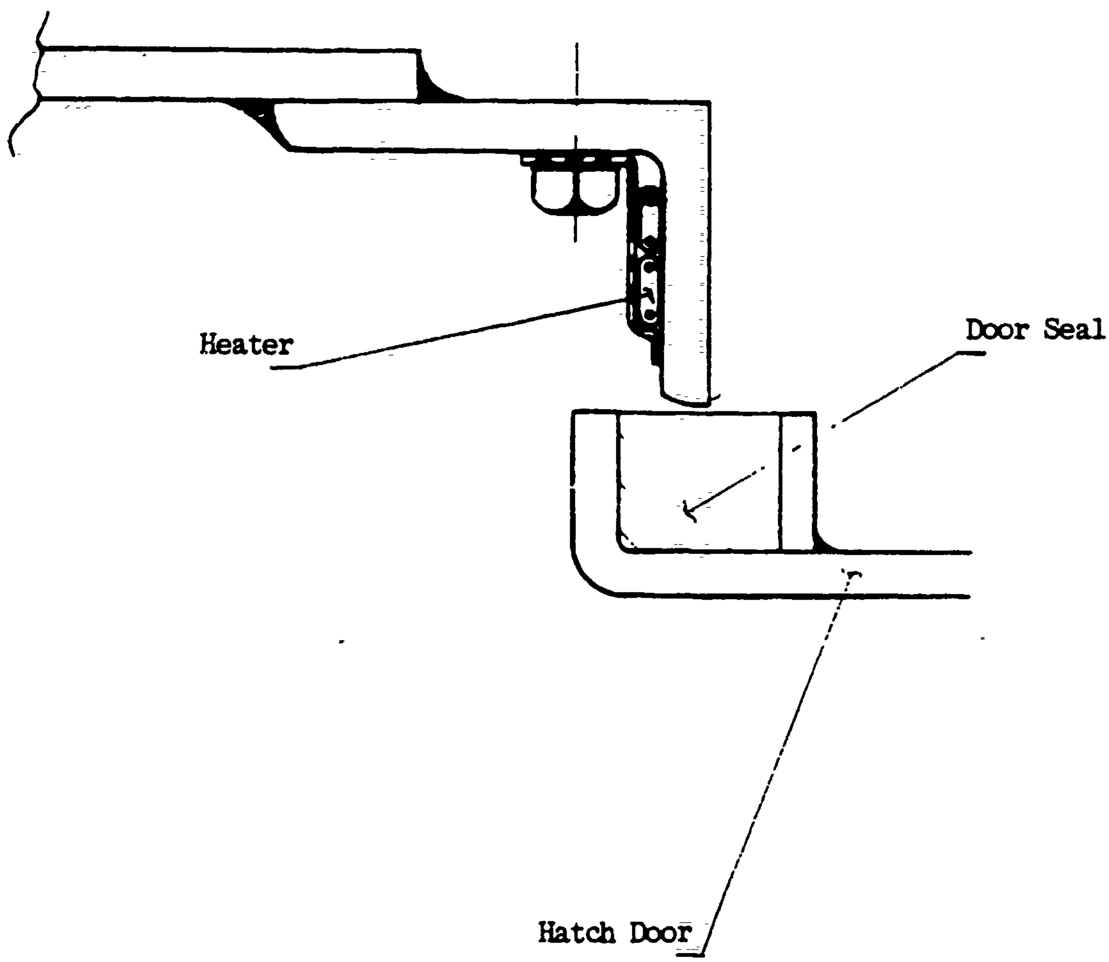
Moisture separators are normally fitted to the engine air intakes of most marine installations.

The function of the separator system is remove moisture and salt particles from the air supply. Effective separator systems achieve this aim with low pressure drop, compact dimensions and prolonged resistance to atmosphere attack.

Typical systems can either be one, two or three stage depending on the application. The function of each stage is described below.

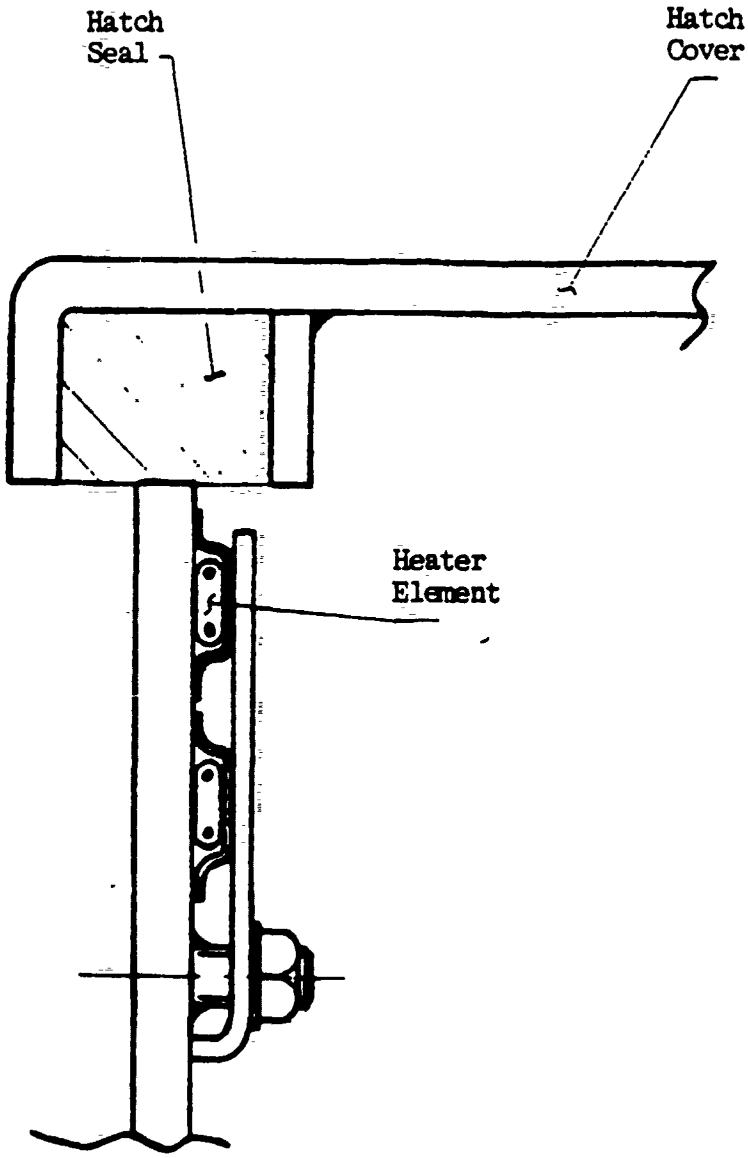
The First Stage

The purpose of the first stage is to remove all large water loads from 'green sea' intensity down through the sprays and mists to aerosol droplets of approximately 13 microns in diameter. It is necessary for the first stage to be extremely efficient in the removal of these entrainments in order to prevent excessive loading of the second stage coalescer. Predictions by the National Gas Turbine Establishment, who have conducted investigations into the subject, show that a very large proportion of the salt moisture in a marine atmosphere will fall into this, equal to, or greater than, 13 micron diameter size range. In addition, most ship generated sprays and rain droplets will also



TYPICAL DOOR SEAL HEATER

FIGURE 1



ESCAPE HATCH HEATER

FIGURE 2

fall into this category.

The Second Stage

The second stage acts as a filter/coalescer serving to catch and coalesce the smaller aerosol droplets which may have passed through the first stage. These enlarged coalesced droplets will then either drain off the second stage itself, or be re-entrained into the airstream and carried on to the third separator stage.

The Third Stage

The third stage of the system is the final separation stage and removes from the airstream those relatively large coalesced droplets which are re-entrained off the second stage. It also serves to protect the airstream against the re-entrainment of highly concentrated droplets of brine solution which are generated in the second stage media when the system is operated at relative humidities below approximately 70%. In this environmental condition the second stage acts as a filter and captures dry salt particles. These collect in solid form and when the relative humidity of the environmental rises above 70% the hygroscopic nature of the salt will cause condensation to occur along with some re-entrainment of brine droplets which contain high concentrations of salts. The third stage serves to prevent the passage of these droplets into the airstream entering the engine intake.

Normally three stage systems are used for gas turbine intakes on ships.

For other installations where heavy water loads are not experienced or the separators are well protected, two stage units can be used. The two stage system uses the first and second stage as described above.

Single stage systems, i.e. first stage only can be used where it is necessary only to produce an airstream free from visible droplets.

3.0 TEMPERATURE MAINTENANCE OF SHIPS SYSTEMS AND EQUIPMENT

3.1 BATTERY HEATING

It is well known that both the charge acceptance and discharge capacity of lead-acid batteries deteriorate with falling temperatures.

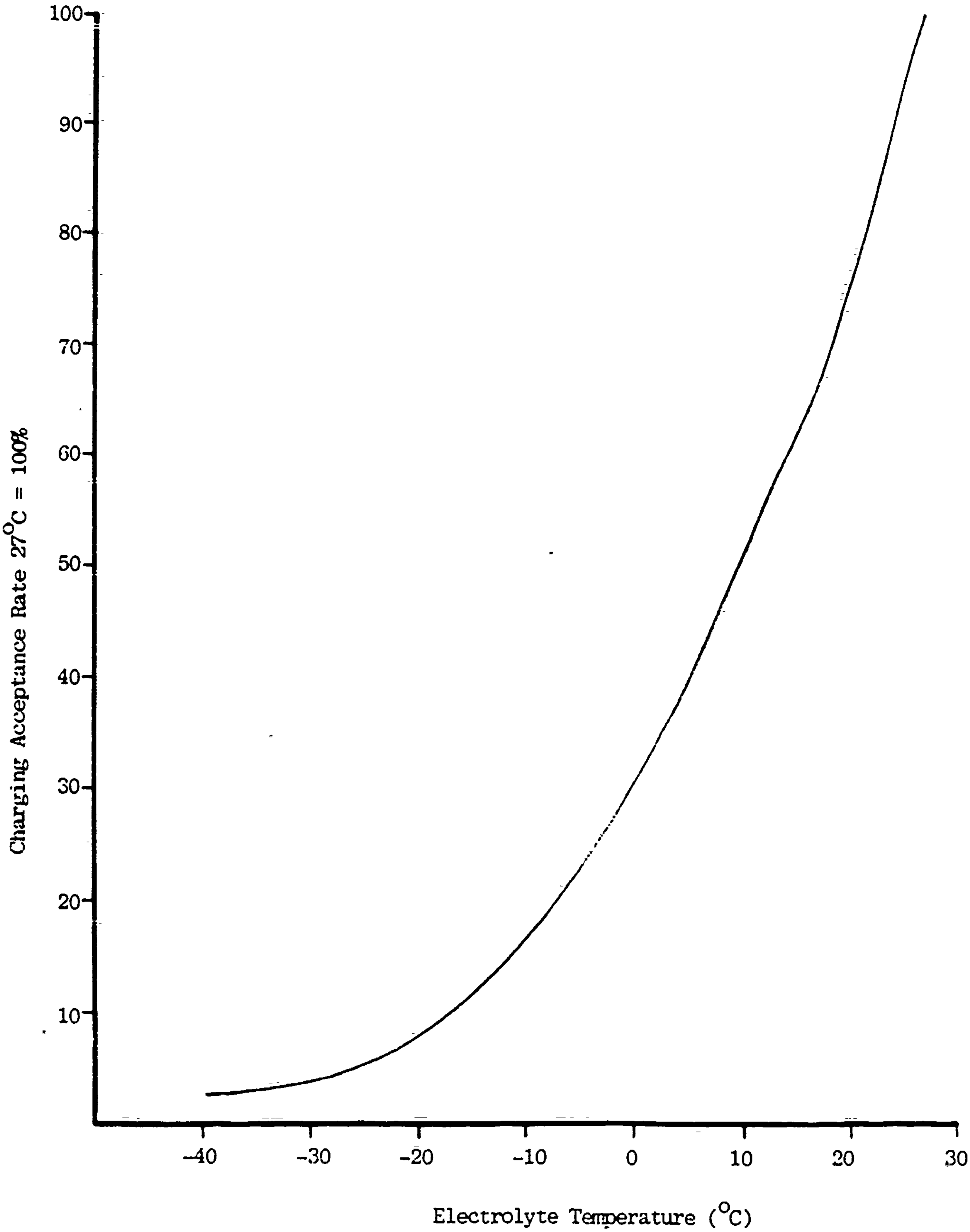
Figure 1 shows typically how the charge acceptance rate varies with electrolyte temperatures and it can be seen that at 0°C the charge acceptance rate is approximately 40% of the rate which exists at +26°C.

In a similar way Figure 2 shows how the discharge capacity of the battery is also reduced at low temperatures and in fact typically the discharge capacity at 0°C is approximately 60% of that which is available at +26°C.

There is also the possibility of battery damage which can occur if a partially discharged battery is exposed to low temperatures. Figure 3 shows how the electrolyte freezing temperature varies with its specific gravity.

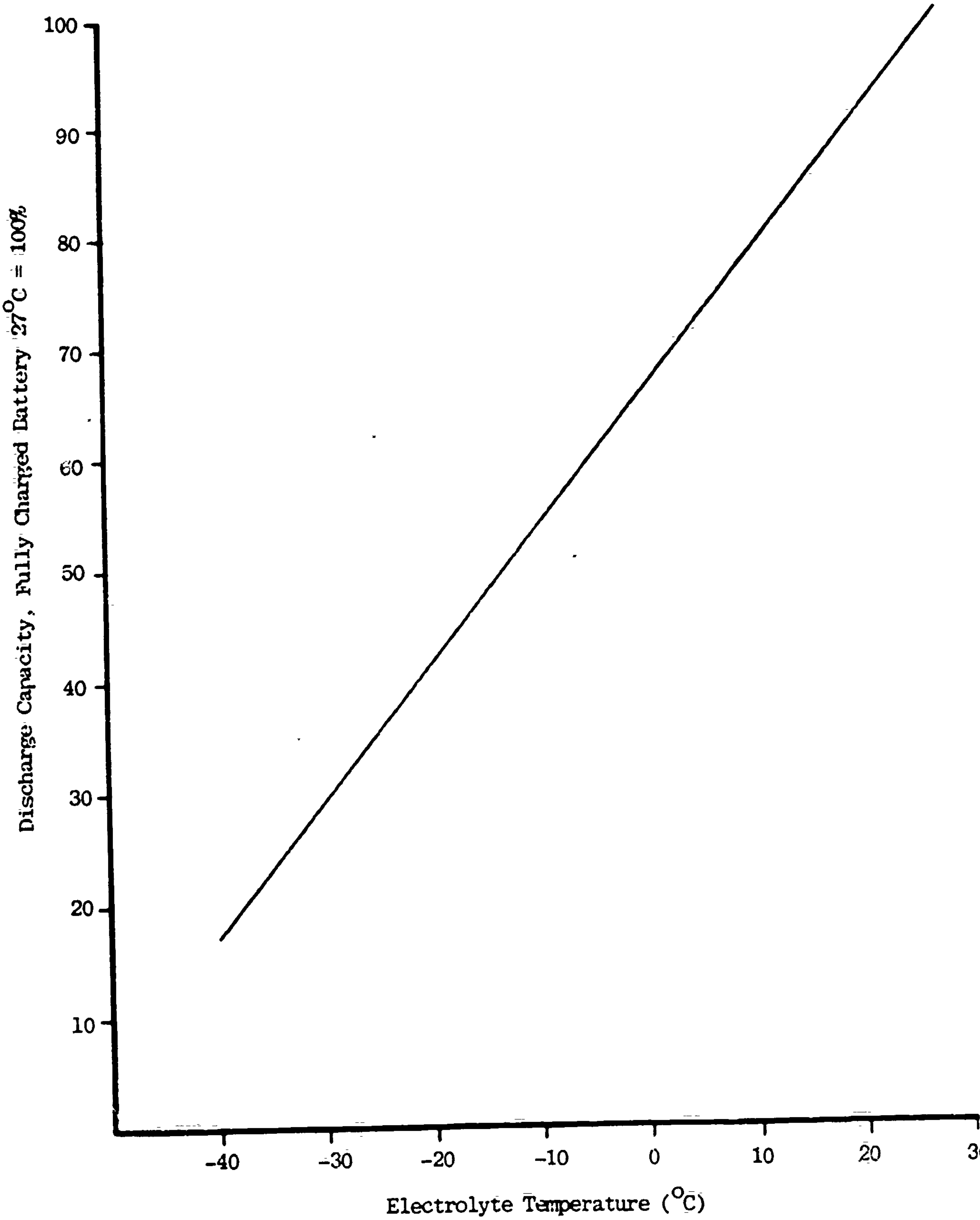
Raychem's self-regulating heaters can be used very effectively as a means of overcoming all three of the problems discussed above without the need for temperature monitoring devices. With constant wattage heaters these monitoring devices would be necessary to ensure that the maximum permissible battery exposure temperature was not exceeded.

A typical Raychem battery heater is illustrated in Figure 4. In this solution the self regulating heater strip is enclosed in a low profile metal tray upon which the batteries sit. The complete heater can be made in a variety of configurations to heat either a single battery or multiples of batteries.



Charging Acceptance Rate 27°C = 100%
100
90
80
70
60
50
40
30
20
10
-40
-30
-20
-10
0
10
20
30
Electrolyte Temperature (°C)

FIGURE 1



Discharge Capacity, Fully Charged Battery 27°C = 100%
100
90
80
70
60
50
40
30
20
10
-40
-30
-20
-10
0
10
20
30
Electrolyte Temperature (°C)

FIGURE 2

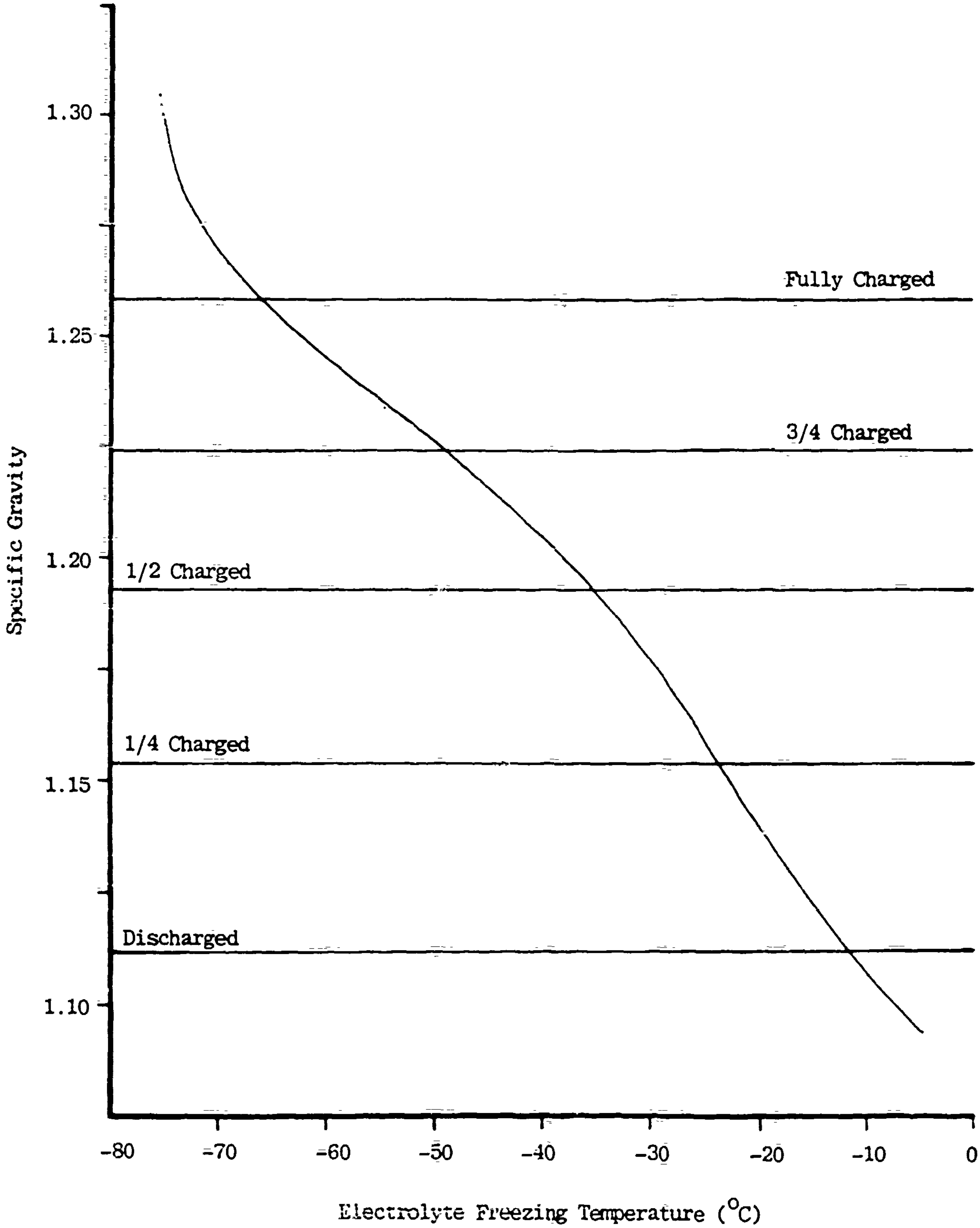
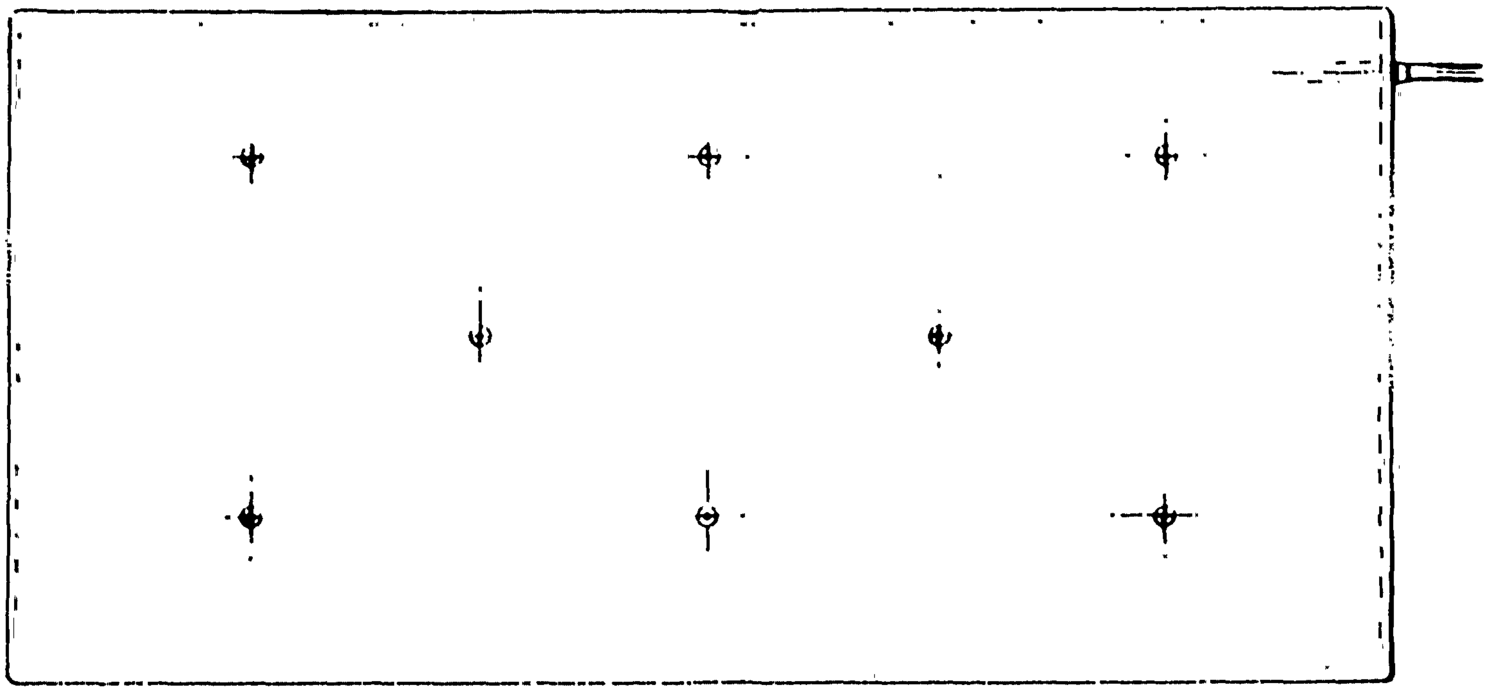

1.30
1.25
1.20
1.15
1.10
Specific Gravity
Fully Charged
3/4 Charged
1/2 Charged
1/4 Charged
Discharged
-80
-70
-60
-50
-40
-30
-20
-10
0
Electrolyte Freezing Temperature (^{O}C)

FIGURE 3



TYPICAL BATTERY HEATER

FIGURE 4A

TYPICAL BATTERY BOX HEATER

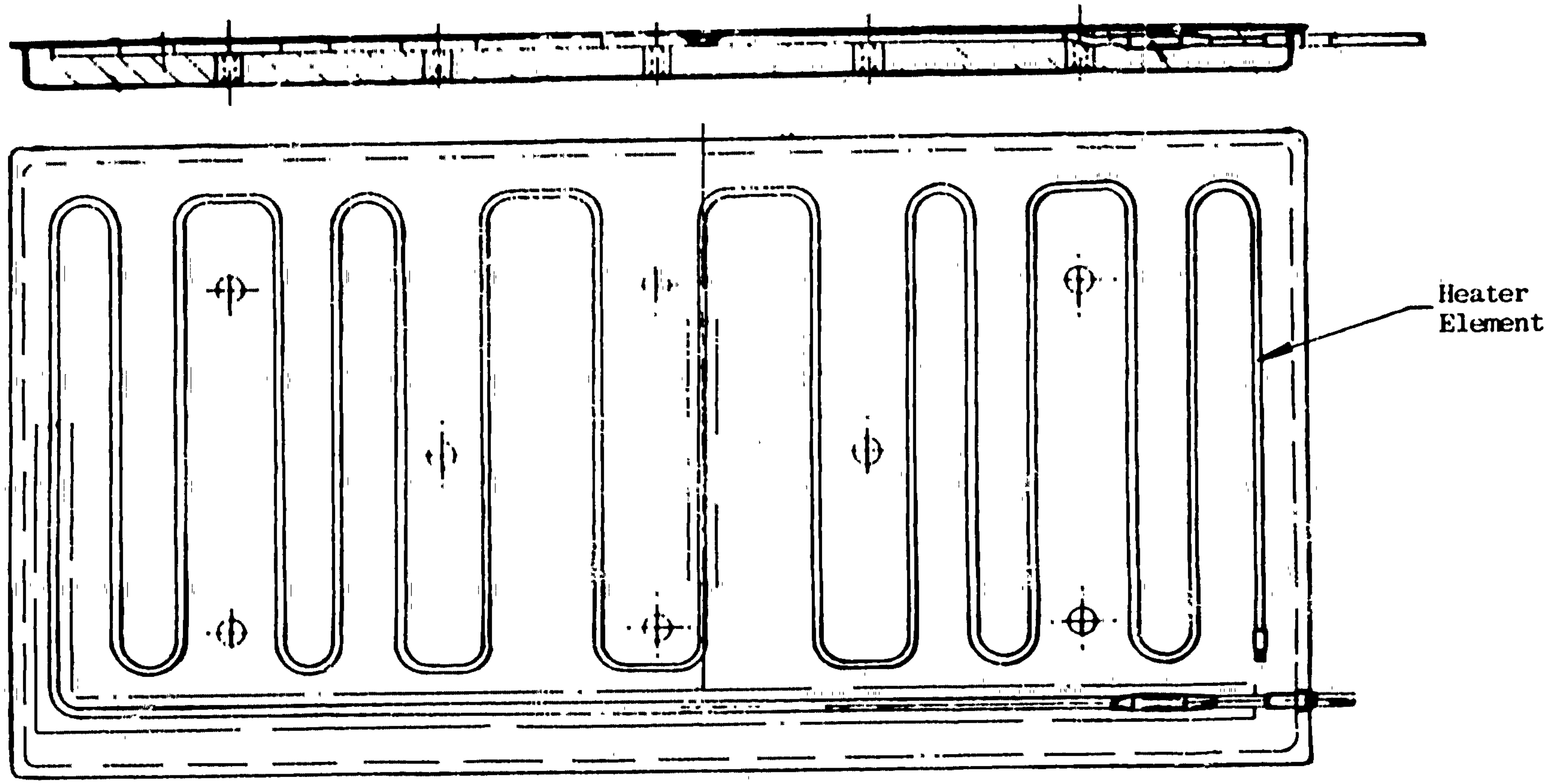


FIGURE 4B

3.2 MARINE FUEL

3.2.1 General Background

a) Almost all ships built nowadays are diesel engine powered. Depending on the size of the vessel, the engines will either be slow, medium or high speed and depending on engine speed, vessel type or duty cycle the fuel used will either be marine diesel oil or one of the many residual fuel oils which are available.

b) British Standard BSMA100:1982, "Petroleum Fuels For Marine Oil Engines and Boilers", classifies these fuels under the references class M1 to class M12 (see Figure I).

Class M1 and M2 are both distillate fuels and in most cases do not require to be heated. The remaining classifications cover residual fuel oils and can be broken down into two groups. The group M3 to M9 have density limitations as part of their specification and are for use in situations where density has to be limited to suit shipboard handling and treatment requirements. The remaining group M10 to M12 have no density limitations.

c) Class M1 fuels are designated for diesel engines for emergency purposes (e.g. ships lifeboats). The standard does not attempt to define applications for the other fuels because of the different requirements of diesel engines and boilers.

d) Residual fuels require heating to ensure that they can be pumped through the fuel system and also to condition the fuel viscosity prior to injection into the engine cylinders. As a general rule the higher the original fuel viscosity the greater the heating requirement. Figure II shows the relationship between original viscosity and the necessary fuel temperature to give the required fuel viscosity at specific parts of the fuel system. (The data given refers to Shell fuels.)

Residual fuels are generally referred to as Heavy Fuel Oil and for the remainder of this report will be identified as HFO. Similarly distillate fuels are referred to as Marine Diesel Oils MDO.

Table 2. Properties of marine fuels

Property	Class M1	Class M2	Class M3	Class M4	Class M5	Class M6	Class M7	Class M8	Class M9	Class M10	Class M11	Class M[illegible]
Density at 15 °C, g/mL, max	-	0.9000	0.9700	0.9910	0.9910	0.9910	0.9910	0.9910	0.9910		-	-
Viscosity, kinematic, at 40 °C, cSt*, min	1.50										-	-
max	5.50	11.00	14.00								-	-
Viscosity, kinematic, at 80 °C, cSt*, max	-			15.00	25.00	45.00	75.0	100.0	130.0	75.0	100.0	130.0
Cetane index, min.	45	35	-								-	-
Carbon residue, Ramsbottom, % (m/m), max.	-	0.25	2.5								-	-
Carbon residue, Ramsbottom on 10 % residue, % (m/m), max	0.20										-	-
Carbon residue, Conradson, % (m/m), max.	-			12.0	14.0	20.0	22.0	22.0	22.0		-	-
Flash point, closed Pensky Martens, °C, min	43.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0
Water content, % (V/V), max	0.05	0.25	0.30	0.50	0.80	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Sediment by extraction, % (m/m), max	0.01	0.02										
Ash, % (m/m), max	0.01	0.01	0.05	0.10	0.10	0.15	0.20	0.20	0.20	0.20	0.20	0.2[illegible]
Sulphur content, % (m/m), max	1.00	2.00	2.00	3.50	4.00	5.00	5.00	5.00	5.00	5.00	5.00	5.0[illegible]
Cloud point, °C, max	-16											-
Pour point, upper†, °C, max (1 December to 31 March)		0	0	24	30	30	30	30	30	30	30	30
(1 April to 30 November)	-	6	6	24	30	30	30	30	30	30	30	30
Vanadium content, mg/kg, as V, max.	-		100	250	350	500	600	600	600	600	600	600

* 1 cSt = 1 mm²/s

† The [illegible] 'upper' does not apply to classes M2 and M3

FIGURE I

A -- BULK STORAGE TANK MIN. TEMP.

B — TEMP. FROM B.S. TANK OUTFLOW HEATER

C — TEMP. FROM INTERMEDIATE TANK OUTFLOW HEATER

D — CETRIFUGE TEMP.

E — FUEL RAIL TEMP. (70-80 SECS RW Nº1 VISCOSITY)

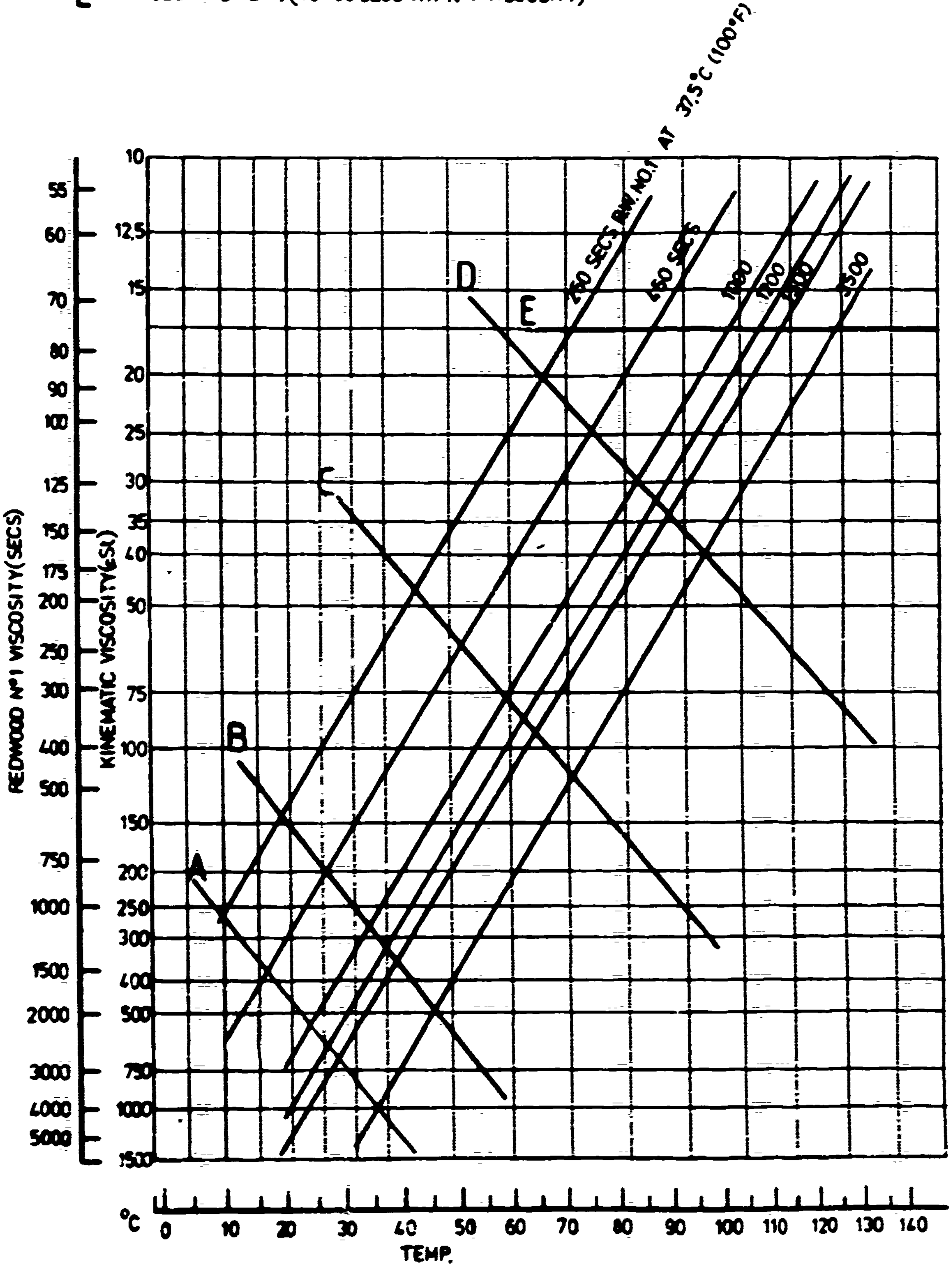


FIGURE II

3.2.2 Typical Fuel System

Figure III shows a typical fuel system for a ship which uses HFO for main propulsion cruising and MDO for harbour manoeuvring, start up and also for running auxillary engines.

The main parts of the system are described below.

a) Main Storage Tanks

These tanks normally exist between the outer and inner skin of the ship and are usually located along the bottom and sides. Main storage tanks for HFO are always heated by steam heating coils.

b) Settling Tank (Item 7 Figure II)

Fuel arrives at the settling tank from the transfer pump and in doing so will pass through a duplex strainer.

Settling tanks for HFO are heated to reduce the viscosity of the oil and so allow heavy impurities and any water to settle at the bottom.

c) Separator

After leaving the settling tank the fuel passes through a two stage centrifuge treatment system referred to as a separator. The system consists of a purifier and a clarifier. The purifier will separate most of the water and solid impurities from the oil and the clarifier will extract any small amount of water or impurities which remain. For heavy fuel oils the separation will take place at temperatures between 80°C and 95°C depending on the viscosity of the original oil.

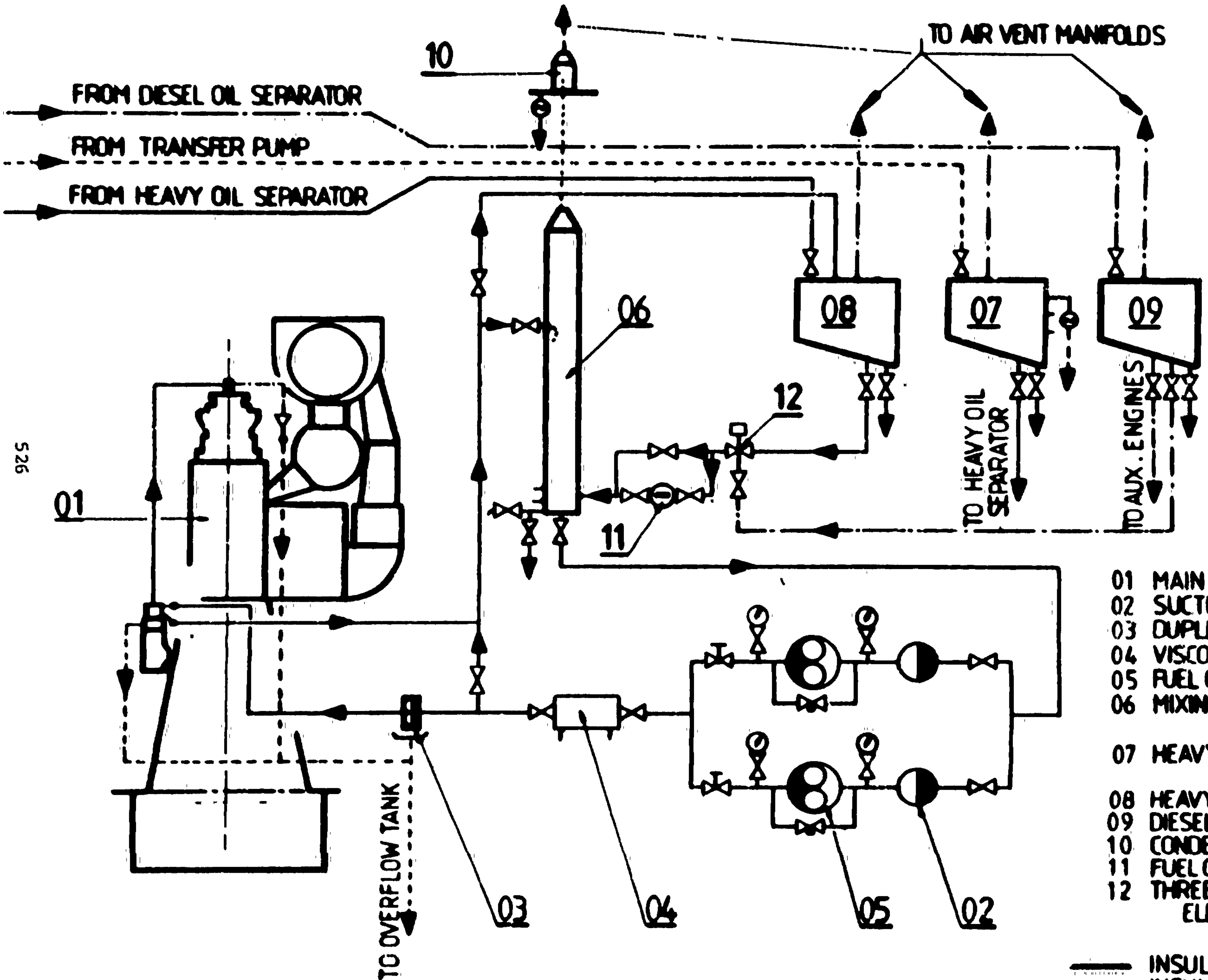
d) Day Tank (Item 8 Figure II)

This storage tank is often referred to as the service tank and normally holds sufficient fuel for 24 hours operation. HFO day tanks will normally be lagged to prevent heat loss and will always be fitted with outflow heaters.

e) Mixing Tank (Item 6 Figure II)

After leaving the day or service tank the HFO goes to the Buffer or Mixing tank. This tank is also heated and as well

FIGURE III



01 MAIN ENGINE
02 SUCTION FILTER, HEATABLE
03 DUPLEX FILTER, HEATABLE
04 VISCOSITY CONTROL
05 FUEL OIL BOOSTER PUMP
06 MIXING TANK HEATABLE & INSULATED.
07 HEAVY OIL SETTLING TANK, HEATABLE.
08 HEAVY OIL DAILY TANK, HEATAB
09 DIESEL OIL DAILY TANK
10 CONDENSATION WATER TRAP
11 FUEL OIL FLOW METER
12 THREE-WAY VALVE, PNEUMATIC (ELECTRICALLY OPERATED

—— INSULATED & HEATED PIPE

as receiving fuel from the day tank also takes excess fuel recirculated via the fuel busrail on the engine. Mixing tanks are normally heated by steam coils but electric heaters positioned adjacent to outflow pipe are also used.

f) <u>Viscosity Control Unit (Item 4 Figure II)</u>

The viscosity control module consists of a heater module and a viscosity sampling module. The sampling module continually monitors the viscosity of the fuel flow and regulates the heater module to ensure correct fuel temperature and hence correct fuel viscosity.

Systems for heating the fuel use either steam, thermal oil or electric power.

g) <u>Fuel Pipes (For HFO)</u>

Pipes between the Main Storage Tanks and the Settling Tank will always be insulated and in some cases if the pipe runs are long, will also be heat traced. Pipe runs down stream of the settling tank will normally be heat traced and insulated. Pipe runs downstream of the Day tank will always be heat traced and insulated.

3.3 ELECTRONIC CONTROL CABINETS

Introduction

In cold, humid climates electronic and electro-mechanical devices can malfunction either because of the low temperature or due to moisture and ice formation on circuitry or contact.

An effective, well designed heating system can completely eliminate these problems.

When the electrical devices are housed in an enclosure or cabinet there are three possible solution approaches:-

a) Provide discrete heaters for the individual components at risk.

b) Provide a system which heats the racking and fitments holding the components, thus heating all the components and a zone of air surrounding them.

c) Provide a space heating system to warm the internal air and all components within the enclosure.

The range of Raychem ThermoSpace* heaters provide a solution for the space heating system approach.

* Raychem Trade Mark

3.3.1 Raychem ThermoSpace Heaters

The ThermoSpace standard range comprises two distinct types of heater with both types being available in a variety of voltages and wattages.

Flat Panel Heater

The flat panel heater is constructed using a terminated strip of self-regulating heater, permanently sandwiched between two thin gauge aluminium plates. A typical heater assembly is shown in Figure 1.

Multi-Finned Heater

In this version the terminated self-regulating heater strip is assembled into a channel shaped aluminium extruded section. The open side of the extrusion is closed off with an aluminium blanking plate and the ends of the extrusion are capped using a thermoplastic moulding. The moulding is made from glass reinforced PBT and meets the V-O classification in accordance with UL test subject 94. A typical heater assembly is shown in Figure 2.

General

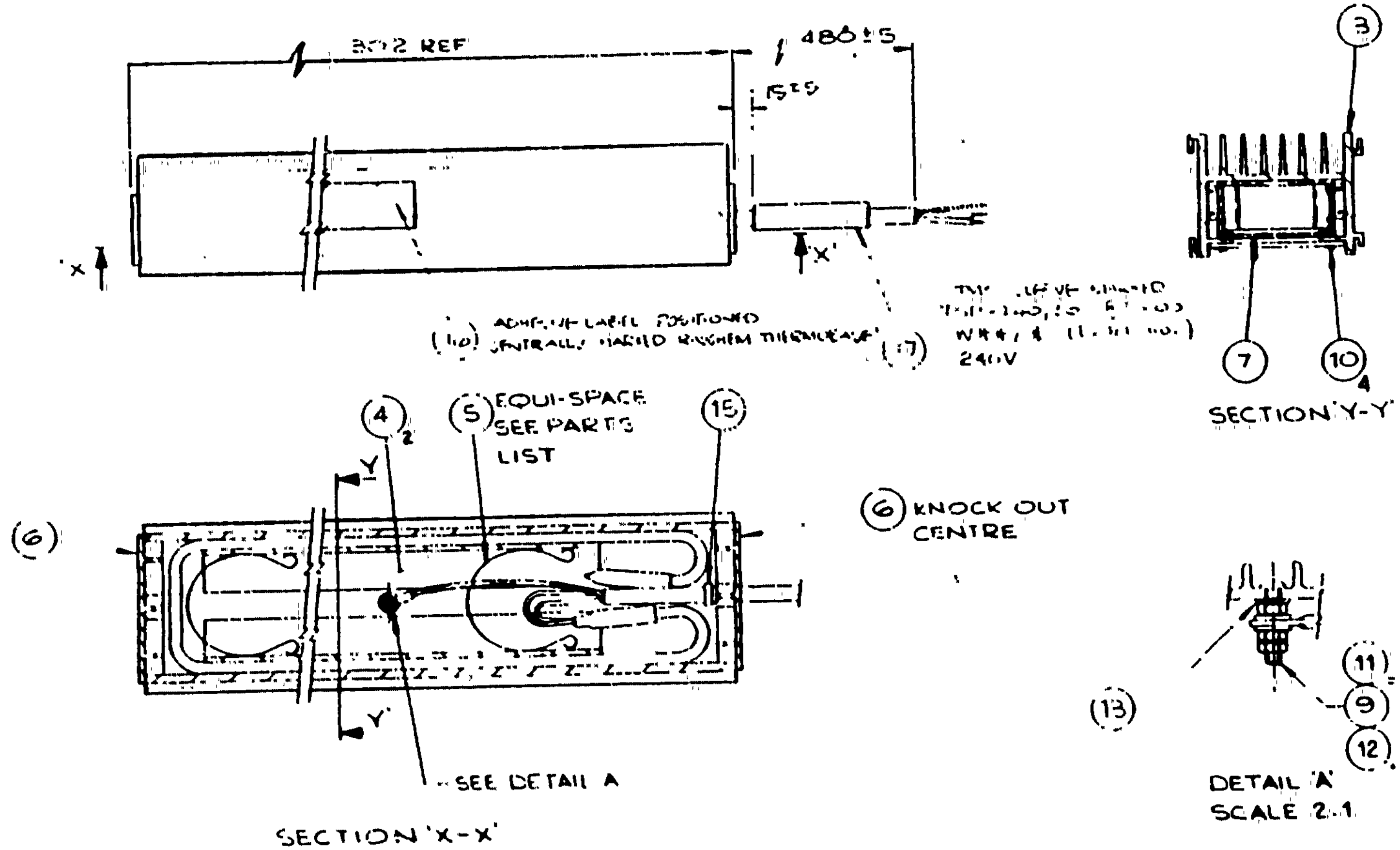
Both heaters are electrically earthed devices and are fitted with Raychem 3 core. ZERO-HAL* jacketed cables, 500mm long. The three conductors are colour coded, brown, blue, green/yellow (earth).

All heaters are identified with part number, batch number and voltage.

Both heater types are provided with mounting features. The flat panel version having a series of fixing holes punched through the aluminium sandwich and the multi-finned version have the mounting feet as an integral part of the end cap moulding.

For large cabinets requiring multiple heaters, it is possible for the multi-finned version to be gang mounted side by side using a feature on the side of the aluminium extrusion. Applications of this nature should be discussed with Raychem to ensure most cost effective solution.

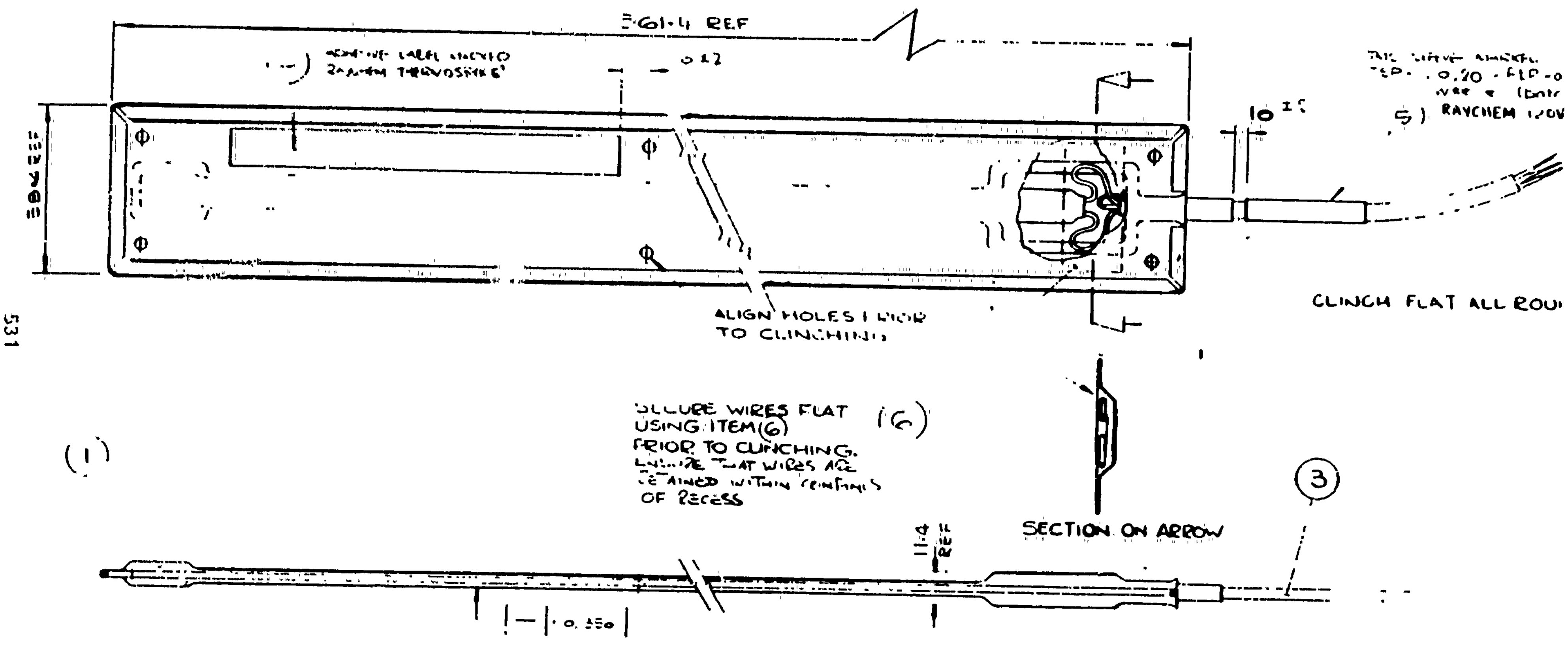
IF IN DOUBT - ASK   THIRD ANGLE PROJECTION   DO NOT SCALE



DRAWN BY	G ELEY CSF DESIGNS
MATERIAL	SEE DETAILS
TITLE	FINNED HEATER ASSEMBLY

Raychem

IF IN DOUBT - ASK   THIRD ANGLE PROJECTION   DO NOT SCALE



FINISH: PRIME & FINISH COAT WITH AIR DRYING MATT BLACK CELLULOSE PAINT.

DATE	ISS	MODIFICATIONS	APP'D

Raychem	UNLESS OTHERWISE STATED ALL DIMENSIONS ARE IN mm AND TOLERANCES ARE GENERAL ± 0.75mm 1 DEC PLACE ± 0.25mm	DRAWN BY BC/C&F	DATE 2/85	MATERIAL SEE DETAILS & SCHEDULE	TITLE THERMOSPACE PANEL HEATER
		CHECKED	2/85		

4.0 SELF-REGULATING PARALLEL HEATERS

The heating medium in the self-regulating type of heater is semi-conductive carbon-loaded polymer core. The resistance of the core is formulated according to the specified power output and supply voltage. The core material is PTC , i.e. it has a Positive Temperature Coefficient of resistance so that the resistance increases as the temperature increases.

In self-regulating heaters the core is constructed around and between two parallel conductors spaced several millimetres apart (see Figure 1). This gives a cut-to-any-length capability on the job site. Means of making field installed conenctions, splices and tee joints are accordingly available.

As the resistance increases due to temperature increase so the power output decreases (Figure 2). As the temperature falls the power output increases. This is the "self-regulating" feature which is also sometimes known as "self-limting". The highest temperature at which the heater gives useful power is determined by the change in resistance. The self-regulating feature allows unlimited overlap of cable without danger of overheating.

If a self-regulating heater is subjected to temperature beyond its maximum exposure temperature a permanent resistive increase may result. This gives a safe (cold) failure mode rather than the hot spot failure associated with wire element heaters.

The core is insulated from an earthed metal braid and has a polymer oversheath for environmental protection. Several families of self-regulating heaters are available. Each family has a different polymer base depending on the maintain temperature and maximum exposure temperature and each has a different self-regulating characteristic.

Three of these families together with their maximum exposure temperature range are:-

- freeze protection 65°C - 85°C
- process temperature maintenance 110°C - 150°C
- steam cleaned applications 110°C - 185°C

4.1 SYSTEMS DESIGN

The use of electricity for trace heating requires a detailed assessment

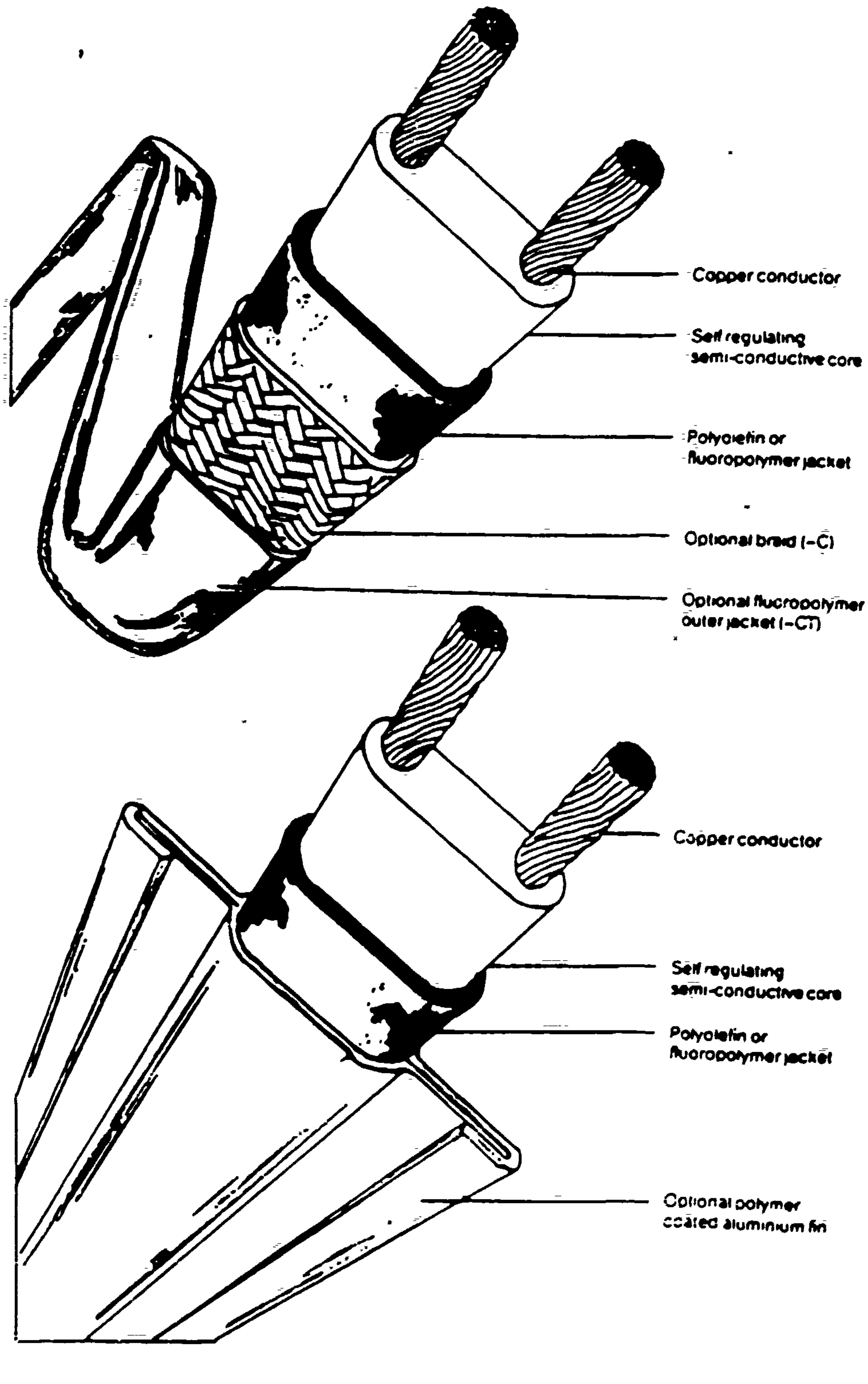

Copper conductor
Self regulating semi-conductive core
Polyolefin or fluoropolymer jacket
Optional braid (-C)
Optional fluoropolymer outer jacket (-CT)
Copper conductor
Self regulating semi-conductive core
Polyolefin or fluoropolymer jacket
Optional polymer coated aluminium fin

FIGURE 1

TECHNOLOGY

SELF REGULATION

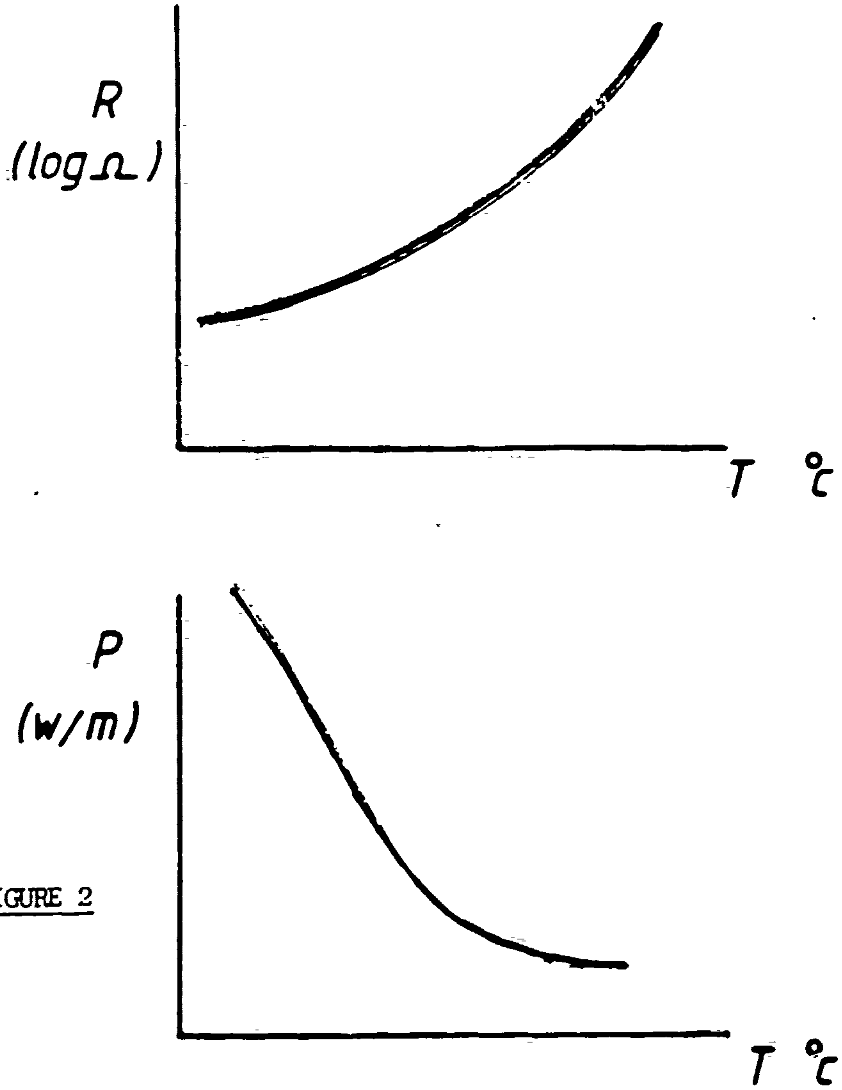


FIGURE 2

LOAD LINE

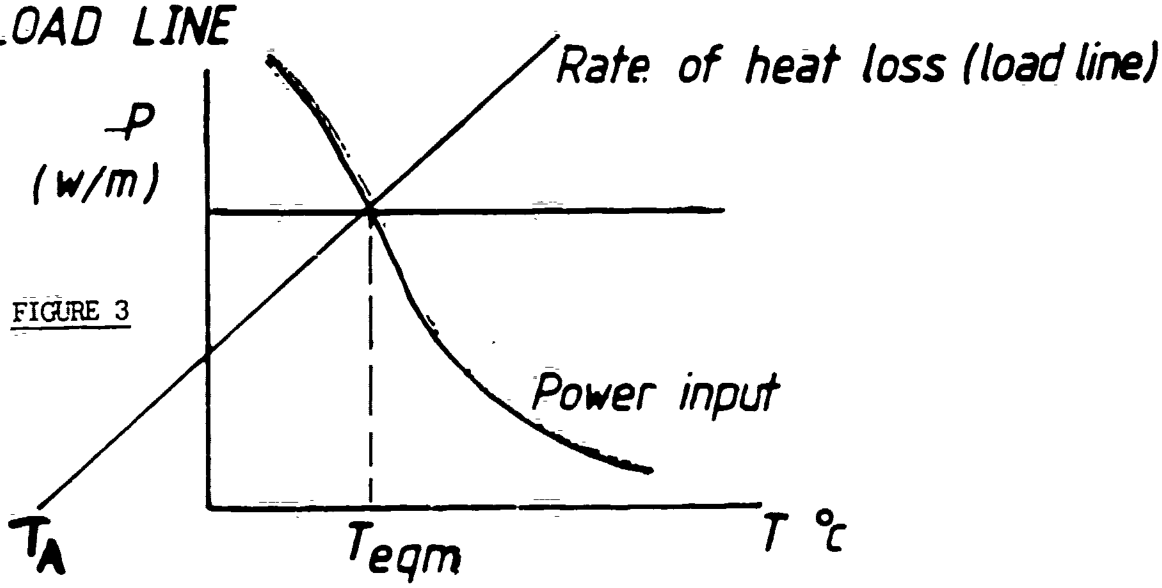


FIGURE 3

T_{eqm} = Equilibrium Temperature

of the complete system involving:

- calculation of heat losses
- heater selection by matching output to losses and to meet environmental conditions
- specification of control methods
- choice of connection system components and accessories
- design of electrical distribution system

This must be done within the standards, codes and practices appropriate.

Important considerations in relation to the above factors are discussed in the following sections:

4.1.1 Temperature Maintenance

Heat Losses

The formulae used to determine the power requirements for the heat tracing of a deck or a superstructure include a certain safety factor and make certain assumptions i.e. where the underside of the deck/superstructure area is either insulated or exposed to an ambient temperature in excess of 0°C, heat losses from the underside can be ignored. If, however, the underside of the deck/superstructure is not insulated or is exposed to an ambient temperature less than 0°C, losses must be taken into account.

The equation for determining the heat density for overcoming CONVECTION losses where the deck/superstructure is to be kept ice free is:-

$$Q = hA\bar{T}$$

where Q = heat density in watts/metres^2

h = function of wind speed, geometry, air temperature and interface temperature and is calculated from the equation:-

$$h = 6V^{0.8} \text{ watts/metre}^2 \text{ K}$$

A = area (1 metre^2 usually)

$\bar{T}$ = the difference between the air temperature and the desired deck/superstructure temperature.

This can be graphically represented as shown in Figure 3. As the substrate temperature increases above ambient temperature the heat loss increase proportionately. For the same substrate and thermal insulation conditions the slope of the heat loss line remains a constant. Thermal output of both constant wattage and self-regulating heaters can be plotted on a similar graph as shown in Figure 2. The heat traced substrate equilibrium temperature is reached when the heat loss equals the heater power output. This condition can be graphically determined by the intersection of the heat loss and thermal output curves as shown in Figure 3. The purpose of trace heating is thus to maintain temperatures by compensating the heat loss from the substrate with a heat input from the tracing cable.

Heater Selection

Constant Wattage Heaters - For both the series and series-parallel types a unit with a power output equal to or greater than the heat loss is chosen (See Figure 3).

Self-Regulating Heaters - For self-regulating heaters the heat loss is balanced by the choice of heater having required output at temperature.

Limiting The Maximum Temperature

Self-regulating heaters can be considered as a special case of stabilised design, i.e. an uncontrolled system. For a change in air ambient from t_a to t_a. Figure 4 shows the equivalent change in maintain temperature t_s to t_s. This change in maintain temperature is always less than the change in air ambient and depends on the slopes of both loss and heater output lines.

Self-regulating heaters can therefore extend the range of application without control devices. They are also less likely to damage substrates. Furthermore, the self-regulating heater varies its response along the substrate and compensates for variation in local conditions.

Temperature Classification

Figure 4 also shows a further inherent characteristic of self-regulating heaters. As the ambient increase towards the self-regulating temperature so the substrate maintain temperature also increases towards the self-regulating temperature. If the ambient or substrate temperature exceeds the self-regulating

DISADVANTAGE OF CONSTANT WATTAGE HEATERS

VARIATION IN AMBIENT CONDITIONS

t_A (max) = Maximum Ambient Air Temp °C
t_A (min) = Minimum Ambient Air Temp °C
} Range of Temperature expected

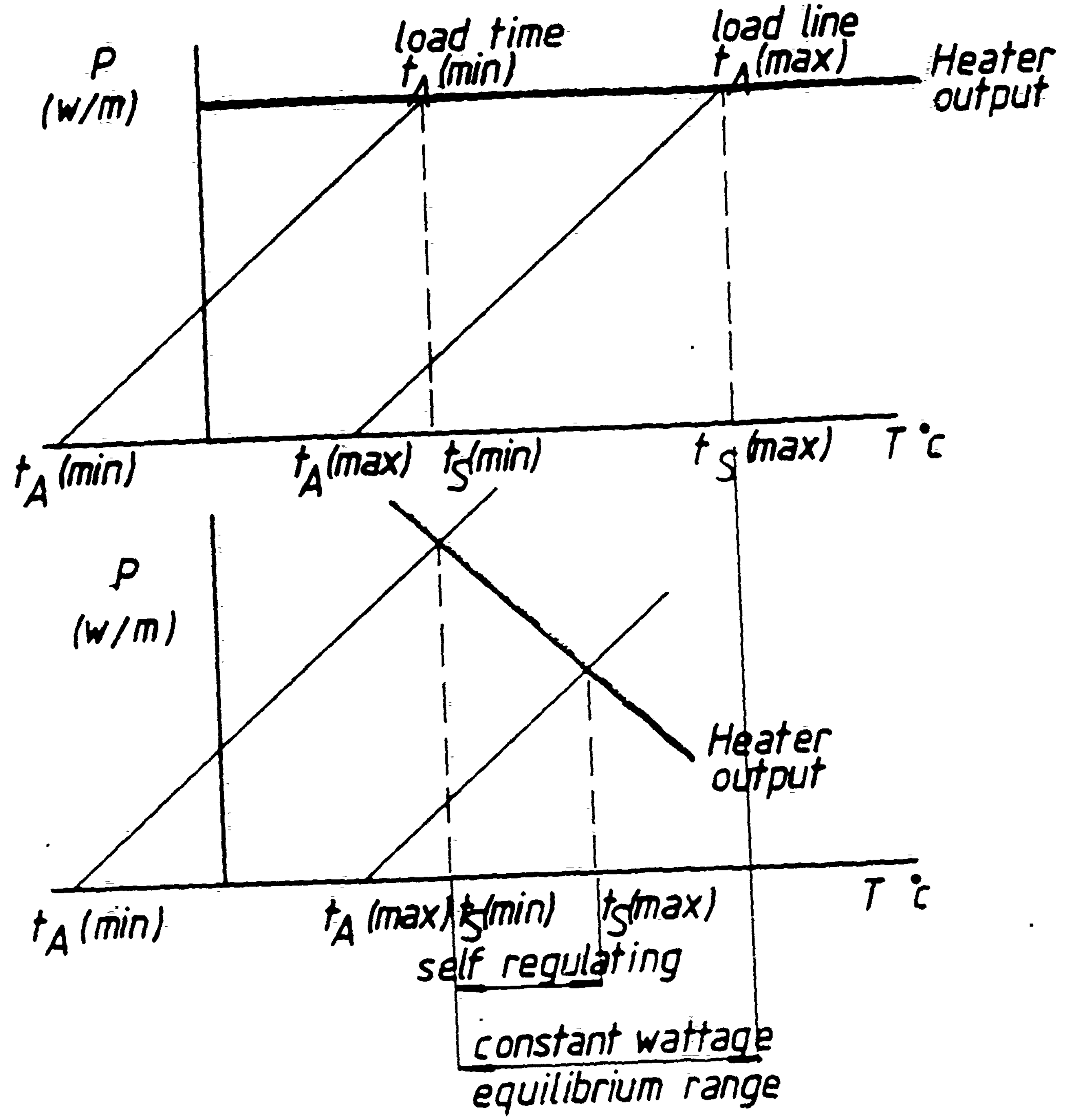


FIGURE 4

temperature the heater no longer produces heat and therefore does not contribute to any additional rise in substrate temperature.

4.1.2 System Performance

As shown temperature control by heat tracing must operate within somewhat wide tolerances. Several factors which affect system performance are addressed. With correct understanding and interpretation of these factors a heating system can be operated effectively.

Supply Voltage Variations

The power output of a resistive heater will vary due to variation in supply voltage. The supply voltage can vary on board a ship.

As the power output of a self-regulating heater is dependent on the heater temperature any change in supply voltage effects both the heater output and its temperature. The combined result of these two effects is that the power output of a self-regulating heater is a linear variation with voltage rather than the V^2 relation ship which applies to constant wattage heaters.

As shown in Figure 5 these variations in power output will result in a maintained temperature variation. The magnitude of substrate maintained temperature variation will depend upon the heat losses as these determine the slope of the heat loss line (Figure 5).

The significance of Figure 5 is that it shows that a self-regulating heater will give a tighter band of maintain temperatures for a fixed band of power output than constant wattage heaters.

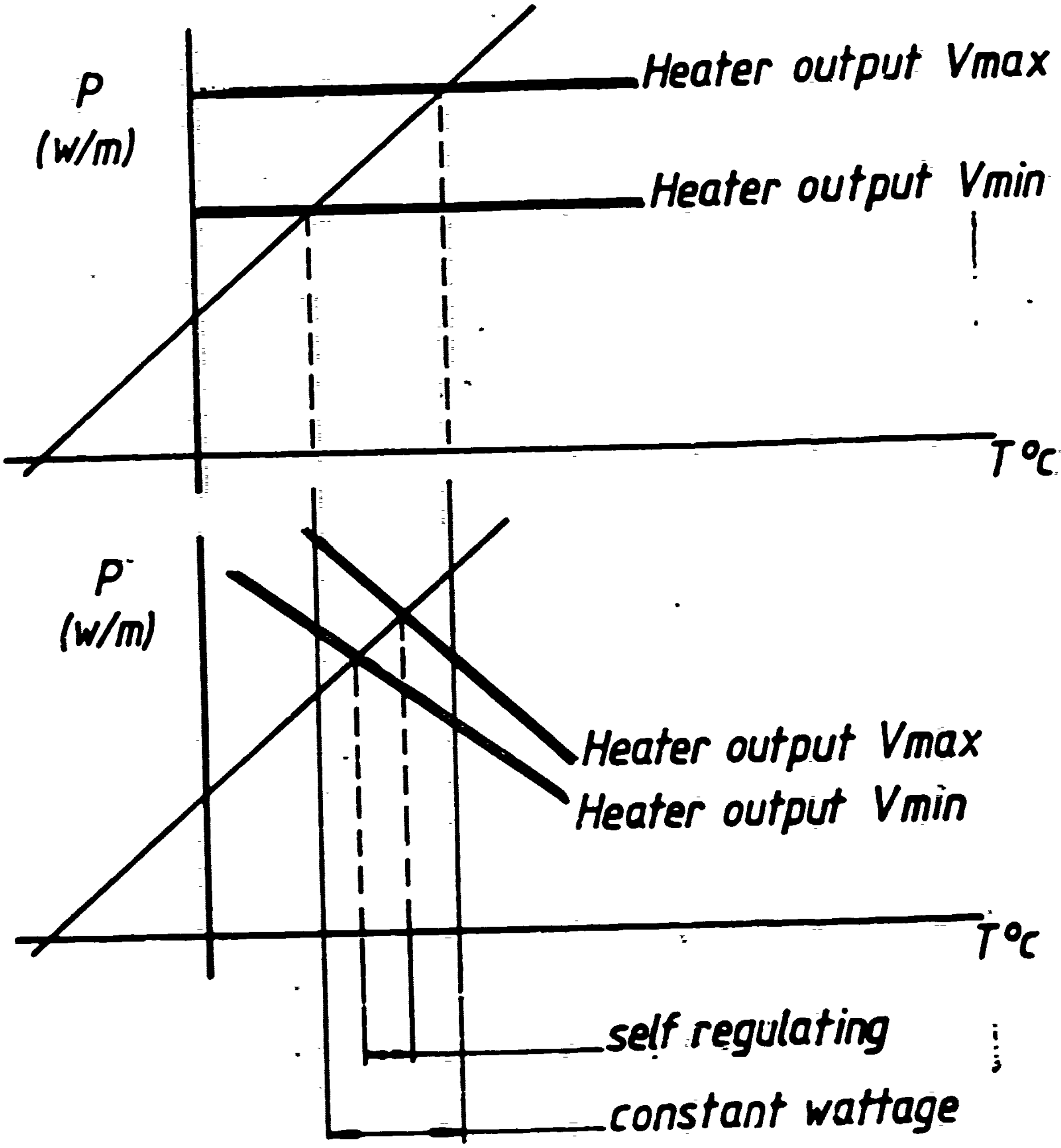
Table 1 shows the variation in substrate maintain temperature due to changes in supply voltage. For example shown a 5% change in supply voltage to a temperature maintenance application, will result in a maintain temperature variation of 8°C for the constant wattage heater but only 2°C for the self-regulating heater.

Self-regulating heaters are therefore less sensitive to supply voltage variations than constant wattage heaters. They maintain temperatures within closer tolerances than constant wattage heaters.

VARIATION IN VOLTAGE

Vmax = Maximum Voltage

Vmin = Minimum Voltage



Heater output and temperature varies much more - Typically 4x with constant wattage heaters.

FIGURE 5

Table 1 Variation of maintain temperature due to variation in supply voltage

Variation in supply voltage (%)	Type of Heater	Variation in power output (%)	Maintain Temperature Variation (°C)	
			Freeze Protection	Temperature Maintenance
5	Constant Wattage	10	3	8
	Self-Regulating	5	1	2
10	Constant Wattage	21	6	17
	Self-Regulating	10	2	4

Variations In Heat Losses

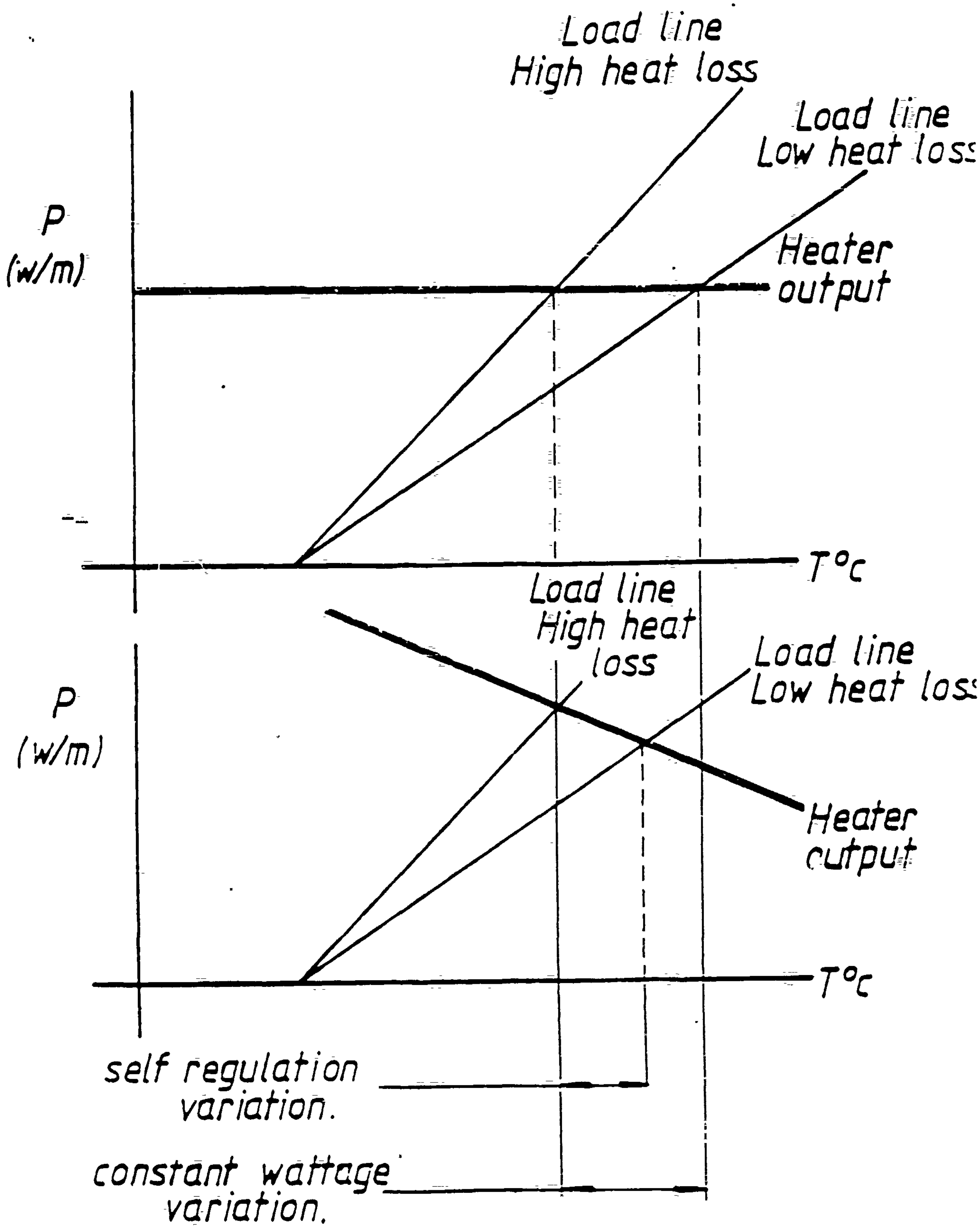
Several factors which influence the variation of heat loss are discussed. They can influence the performance of the system. See Figure 6.

TEMPERATURE SOURCE CONCEPT

From the discussion above it will be seen that self-regulating heaters can be considered as a temperature source as distinct from a power source. Temperatures are maintained within close bands without the use of controls under a wide range of application conditions. Compared with constant wattage heaters the maintained temperatures with self-regulating heaters are less sensitive to variations in ambient temperature, supply voltage fluctuations and variations in heat loss conditions.

As self-regulating heaters have infinitely parallel circuit construction these close bands of temperatures are independently maintained at each point along the whole length of the heater. Each part of a self-regulating heater responds to the local conditions of ambient temperature and heat loss. Therefore self-regulating heaters adjust their performance to maintain temperatures within close bands when and where necessary.

VARIATION IN THERMAL ENVIROMENT
(FOR EXAMPLE WIND)



Self regulation provides better control
for range of thermal conditions.

FIGURE 6

Excessive temperatures cannot be generated by self-regulating heaters so that they cannot overheat and burn out due to their own heat generation. They were designed to self-regulate below their maximum withstand temperatures.

Systems using self-regulating heaters are therefore also considered to give the most safe and reliable heat tracing available for hazardous areas.