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DATE: 5 December 1996

FROM: Burton G. Hurdle (Code 7103)

SUBJECT: REVIEW OF REF. (a) FOR DECLASSIFICATION

TO: Code 1221.1

VIA: Code 7100

REF: (a) NRL Confidential Report #6224 by A.J. Hiller, 6 May 1965

1. Reference (a) is a discussion of the utilization of oceanographic instrumentation and measurements employed in an integrated manner in the detection of passing submarines in the ocean.

2. The technology and equipment of reference (a) have long been superseded. The current value of this report is historical.

3. Based on the above, it is recommended that reference (a) be declassified and released with no restrictions.

Burton G. Hurdle

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Acoustics Division

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Superintendent
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NRL Report 6224

Oceanographic Instruments as a Basis of Submarine Detection and Classification Systems

[UNCLASSIFIED TITLE]

A. J. HILLER

Techniques Branch
Sound Division

May 6, 1965

U.S. NAVAL RESEARCH LABORATORY
Washington, D.C.

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[redacted]nstruments as a Basis of Submarine Detection and Classification Systems

[Unclassified Title]

A. J. Hiller

Techniques Branch
Sound Division

The transit of a submerged submarine subjects the ocean environment to many subtle changes. During the past several years specialized in situ oceanographic instrumentation has been designed to sense these physical, chemical, and biological modifications of the ocean. The concept of interdisciplinary research, aimed toward obtaining a broad spectrum of knowledge prior to hardware development, is considered the key to future systems reality. Laboratory research results show the many facets of the problem and the general usefulness of the ocean as a ready-made complex easily changed by a transiting submarine. The submarine-generated energy transfers, acoustic and hydrodynamic, are detectable by simple optical instruments. The results of several field operations have demonstrated the performance of turbidimetric and colorimetric sensors used for wake sensing of a submerged submarine during recent field operations in the Florida Straits. Emphasis on submarine detection and classification systems suggests useful comparisons to conventional acoustic signal processing, where the ocean-environment noise for a given parameter, such as turbidity, is treated in terms of bandwidth, sampling time, resolution, detection, false-alarm probability, and signal-to-noise ratio.

INTRODUCTION

Military oceanography is usually thought of as a supplemental science supporting the ASW roles of detection, localization, classification, and attack. Oceanographic data are principally used to predict performance of acoustic systems and establish tactical doctrine. It is therefore logical to study carefully the operating environment, when the system used is sensitive to the environment. It also is logical to view the environment as being sensitive to the submarine, the object of all ASW.

This viewpoint is not new, and early researchers devised systems based on physical changes to the environment induced by the submarine. These were MAD (magnetic anomaly detection), UEP (underwater electric potential), and more recently, mass transport. The latter system assumed a transport of warm water to the surface, where a remote infrared sensor could be used for detection. Systems were successfully built and thermal wakes were detected, but the results obtained did not bear out the assumptions. Today, after more than two decades, we are still learning how the ocean environment is modified by the submarine, and intensive research is continuing to explain the thermal wakes which are being observed. It is fortunate that this scientific challenge resulted, for a coordinated interdisciplinary research effort is now reading the true complexity of the ocean and yielding basic knowledge on which new ASW systems can be based and the performance of old ones better explained (see Bibliography).

DETECTION CONSIDERATIONS

Oceanographic instruments, as a basis for submarine detection and classification, are dependent on a redistribution of sea-water components or changes in the sea water itself, caused by an energy transfer from the submarine to the ocean medium. The major energy transfer is usually hydrodynamic. This effect manifests itself in the turbulent wake and mass effects related to density gradients. Schooley* has demonstrated by the

NRL Problem S01-36; BuShips Project SR [illegible]. This is an interim report; work is continuing on this and other phases of the problem. Manuscript submitted January 18, 1965.

Note: This report is based on a paper presented Oct. 7, 1964, at the [illegible] Seminar on Oceanographic Instrumentation for Military [illegible], Ministry of Defence, Whitehall, London. The author also served [illegible] of the working group on surface ship instrumentation. [illegible] of the seminar will be published by the Ministry of [illegible] and will include the recommendations of the various [illegible] complete texts of the papers presented.

*A. H. Schooley and R. W. Stewart, "Experiments with a Self-Propelled Body Submerged in a Fluid With a Vertical Density Gradient," J. Fluid Mech. [illegible]

[redacted]

[illegible] model the Stewart-Hickman collapsing [illegible] when a density gradient is present, and [illegible] spreading without the gradient. Both cases result in a redistribution of sea components. In certain cases, the effect of the generated wake reaches the surface, where it can be detected by oceanographic instruments.

The following equation shows the relation between surface tension, temperature, chlorinity, and a general term labeled "impurities."*

$$\text{Surface Tension} = 75.64 - 0.144t + 0.0399\,\text{Cl} - K$$

where

t is temperature in degrees Centigrade

Cl is chlorinity

K represents impurities.

Surface tension is a prime factor in submarine-induced surface effects, and intensive research has been conducted on surface films related to capillary-wave damping and evaporation rates. It is known that very small changes in surface tension can greatly modify the surface as seen by an infrared or high-resolution-radar sensor, but little attention has been devoted to the "impurities" factor.† Since the particulate material in the sea can be measured with relatively simple and highly sensitive turbidimetric instruments, NRL research has been concentrated in this area. NRL objectives are to obtain basic information on how the submarine modifies the distribution of particulate matter and to use this information to design wake-detection and submarine-classification systems.‡

*H.U. Sverdrup, M.W. Johnson, and R.H. Fleming, "The Oceans, Their Physics, Chemistry, and General Biology," New York Prentice-Hall p. [illegible], 1942

†Particle size and distribution studies were conducted in October 1964 and January 1965 in the Key West operating area. The redistribution of particulate material indicated by the October tests was established by the January tests, which demonstrated the particle profile stability of the ocean from a temporal and spatial relation. This research used a Coulter Counter particle size and distribution analyzer set up in a shore laboratory for analysis of the samples recovered by [illegible] research ships.

‡The importance of "impurities" in modifying surface tension and resulting in capillary wave damping has taken on greater importance as a "surface-effects" factor since recent trials with submarines show [illegible] changes in the particulate components at the surface [illegible] to the submarine. Analyses by a Coulter Counter shows [illegible] high particulate counts (one million particles in 2 ml) and [illegible] changes in the counts after submarine passage. (See [illegible] [illegible] pages.)

If it is assumed that the ocean is modified by the submarine and that this modification is retained for a period of time, the ASW usefulness of different systems can be evaluated. This of course assumes that knowledge of system noise, ocean noise, signal strength, and type of sensing platform is available. The "noise" of an oceanographic instrument is the time variation of its output for a fixed input, and the "system noise" is the time variation of its output as the actual oceanographic parameter is being measured in the ocean. This of course implies spatial and time factors which may be considered similar to sample size and bandwidth in a conventional electrical system.

TRAIL DETECTION

In order to illustrate some of the factors of oceanographic ASW systems, one system based on the measurement of turbidity by continuous flow analysis of water received from a pickup unit mounted on a ship platform is compared to a passive acoustic system in Fig. 1. Similarities and differences are worthy of attention. The acoustic system records where the submarine is and the oceanographic system determines where the submarine has been. The acoustic system has its sensor removed from the submarine, while the other system's sensor must be directly in the trail at a point where the "memory" of the ocean is still sufficient to give a usable signal-to-noise ratio. The signal processing in both systems is similar, and the system output is sent to an operator-interpreter or automatic analyzer. Search rates may also be compared. In one situation a point is interpreted with a search arc, and in the other a trail is intercepted with a search line (Fig. 2). The usual point target is in the second case extended to a line which is a function of the trail persistence. Surface scars have been known to last many hours, but little is known about persistence of turbidity changes.

A possible application of an oceanographic instrument detection system is the establishment of a barrier line at a submarine egress zone (Fig. 3). If a two-hour trail memory is assumed for a given signal-to-noise ratio and false-alarm rate, a single search vehicle would be required to cover line AB in Fig. 3 every two hours. This coverage

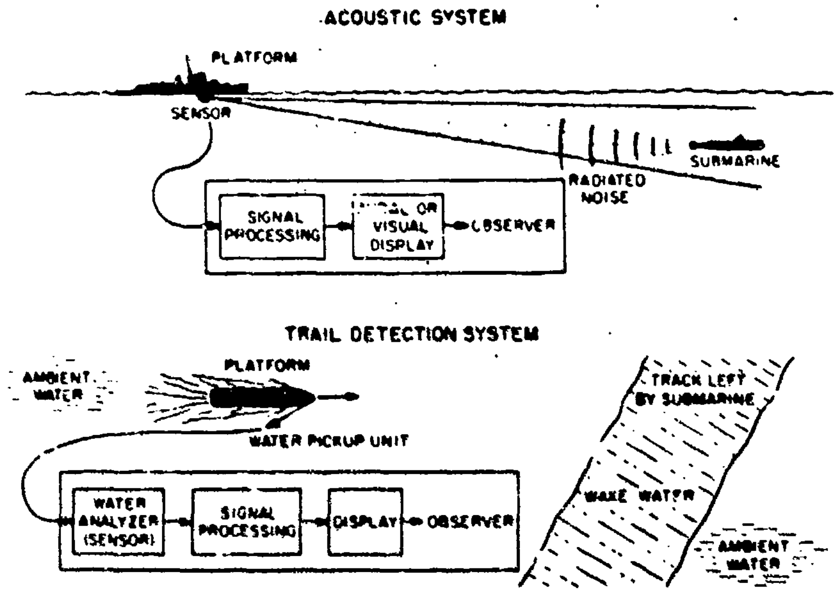

Fig. 1 — A comparison of a passive acoustic system and a trail-detection system

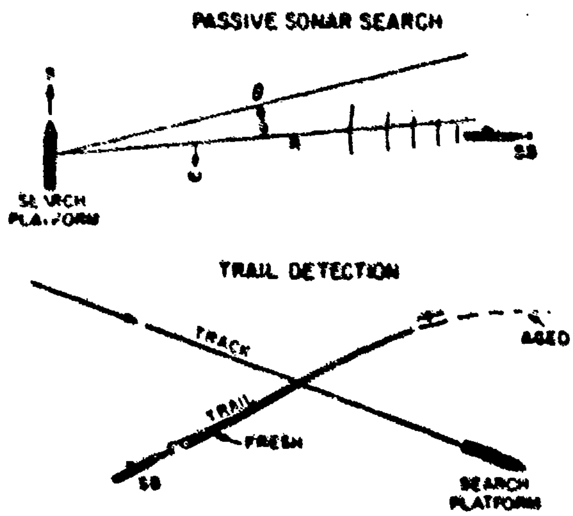

Fig. 2 — A comparison of the dynamics of passive sonar search and trail detection

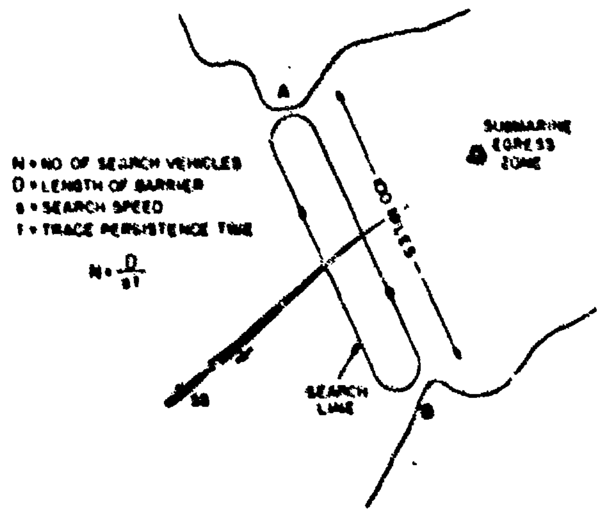

Fig. 3 — Application of trail detection to a barrier search pattern

requires an average search speed of 50 knots for a single platform, and fractions thereof for multiple-vehicle search.

ENVIRONMENTAL EFFECTS

Figure 4 illustrates, in general terms, the complexity of the ocean environment and the multitude of changes which could occur by the intrusion of a submarine. The principal problem one encounters when studying the ocean for changes is to determine how to make measurements without disturbing the environment. During the past several years techniques have been developed which minimize or eliminate such disturbances. Some of these use radio-controlled, air-dropped, and time-delay samplers, and aircraft and V-fin-towed water pickup devices and measuring instruments. Oceanographic data have been obtained during field

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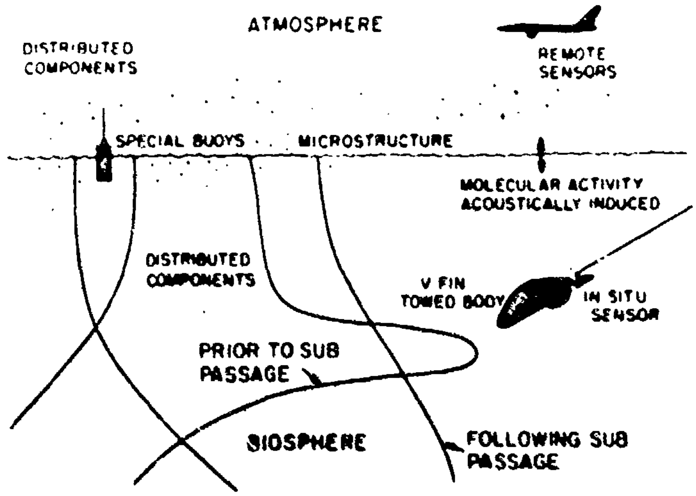

Fig. 4 — Methods of detecting the modifications of the sea environment caused by the transit of a submarine. The curves suggest the disturbances in the undersea environment related to the passage of a submarine.

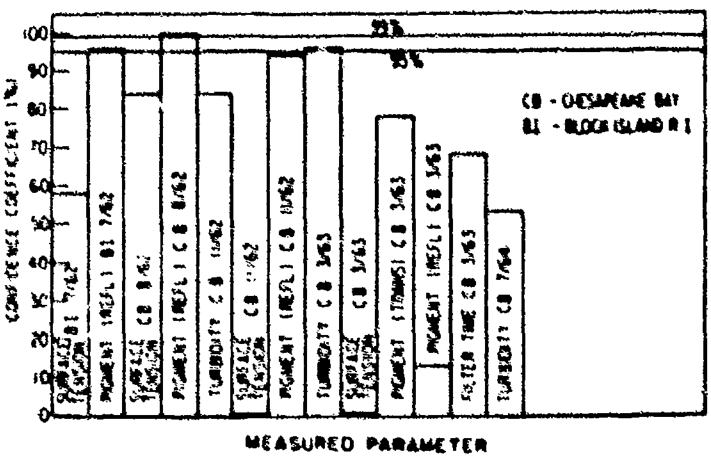

Fig. 5 — Confidence that a difference exists between wake and ambient water

operations with submarines in the Block Island, Key West, and Bermuda operating areas, and locally in the Chesapeake Bay using a small submarine, the SSX-1. Turbidimetric, colorimetric, and biometric data were obtained in ambient and wake waters by analysis of water samples and by in situ measurements. Figure 5 summarizes some of the salient data. The confidence levels shown give the probability that the samples are from different water populations (ambient and wake) and should not be confused with detection probability. The latter may be calculated from single sample probabilities, sample size, and false-alarm criteria in a manner used for acoustic systems.

Figure 6 shows an interesting correlation between weather data and test results observed during NRL tests in the Key West operating area (April 1964). The best results seem to occur when the sea surface is wind disturbed. Similar results have been reported by others using the infrared (Clinker) sensor. The overall objectives of this test series are shown in the following list.

OBJECTIVES OF KEY WEST FIELD TESTS

To study ocean-environment changes in near-surface waters caused by transit of a submerged submarine using

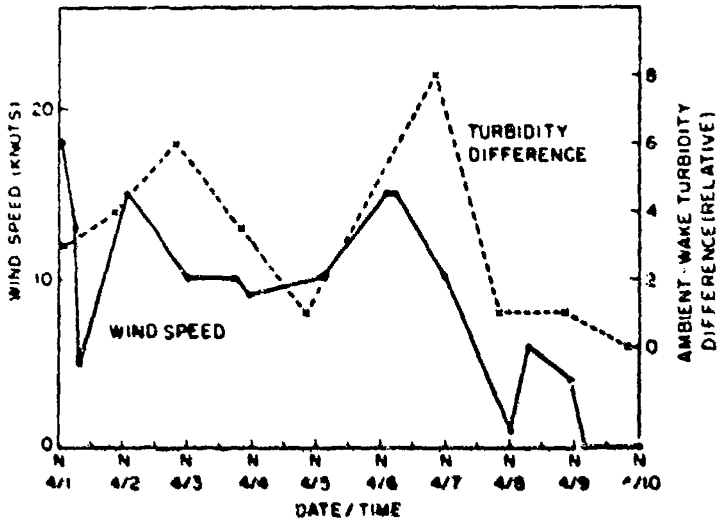

Fig. 6 – Correlation between wind speed and turbidimetric data. April 1964, Key West field trials. The letter N indicates noontime. The turbidimetric data (right-hand coordinate) are presented as the difference between the ambient and wake turbidity.

- Continuous-flow low-range HACH turbidimeter
- Collected samples in ambient and disturbed water, measured in laboratory
- Membrane filters made from continuous flow in ambient and wake water
- High-intensity-pulsed light turbidimeter
- Measured changes in depth profiles
- Measured acoustic effects

SEA-WATER SAMPLING

The NRL analysis of distributed sea-water components has also been extended to particulate carbohydrate, and to soluble and particulate iron. Wilson* has observed submarine-induced changes by analysis of surface samples taken from ambient water and water from the trail of a submerged submarine. The high sensitivity of present analytical methods makes it mandatory that the sampling methods or instruments do not induce contaminants. Nansen bottles are no longer adequate for ASW oceanography. All-plastic and inert material samplers are required. Early work with radio samplers in which the only metal part was a small stainless steel flow valve showed a high contamination of ferric hydroxide, which has pigment color similar to some natural pigments.

During the recent cruise of the PILLSBURY, the Miami Institute of Marine Sciences' newest research vessel,† new noncontaminating samplers were used; the oceanographic community finally realizes the importance of introduced contamination. It is also interesting to note that the PILLSBURY research included measurements on the distribution of organic and trace components.

An instrument which measures a single oceanographic parameter may be insufficient to insure a high detection probability. NRL water sampling has been primarily confined to the surface and near surface, because of V-fin towing limitations and a greater interest in surface effects. However, improved techniques and a new concept using laser profiling may permit higher-trail-detection speeds down to submarine depth.

More sophisticated systems will probably require multiple sensors which can measure simultaneously turbidity, pigments, color, surface tension, etc., and determine detection probability by computer techniques. It is also obvious that more oceanographic data are needed from areas of strategic interest. One attempt toward this objective is being made at this time during the

*D. E. Wilson, "Some Oceanographic Observations in the Vicinity of [illegible] Submarine," NRL Memo. Rept. 1487 (Confidential Report, Unclassified Title), Jan. 1964.

†J. E. Jones, "Maiden Voyage," Sea Frontiers [illegible] (1964)

... BURTON ISLAND. With the cooperation of the U. S. Navy Oceanographic Office,* turbidity profiles are being obtained in the Bering Straits, and in the Chukchi and East Siberian Seas.

NRL has made some measurements on the redistribution of marine bacteria caused by a transiting submarine. The Russian investigators Kriss, Lebedeva, and Mitzkevich† have utilized bacteria as indicators of hydrological phenomena while studying the Indian Ocean waters between Africa and the Antarctic and between the Antarctic and Asia (Fig. 7). NRL has made measurements using bacteria as indicators of the water redistribution by a submarine in the Bermuda area and locally in Chesapeake Bay, where distinct changes in vertical distribution were observed. The technique used was similar to that of the Russians. The water samples were filtered through membrane filters upon which the bacteria were cultured and counted. This method is, of course, not practical operationally, but new techniques using particle-size-distribution analyzers and particle selection may eventually make such a scheme useful. The explanation for the stratification of bacteria has been presented by Sisler and Senftle.‡ They theorize that bacteria, when moving in an ocean current, are carried down to a given depth by electromotive forces, as charge carries in a magnetic field.

Another class of indicators has its origin in the submarine. The submarine, which is dissolving at a minute rate, leaves certain metallic ions in its trail. Attempts have been made to detect zinc and copper ions by Hudson Laboratories.§ Using sensitive flame-absorption spectroscopy, they have successfully detected these ions in the trails of surface ships and surfaced submarines.

In the HACH turbidimeter system (Fig. 8), the water picked up by the V-fin is delivered to

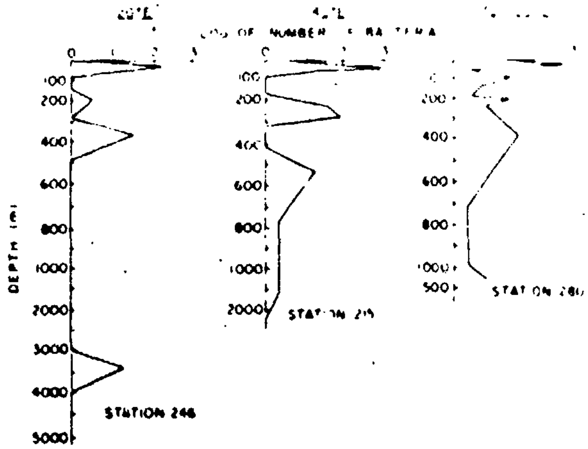

Fig. 7 – Vertical distribution of heterotrophs in the Indian Ocean between 60°S and 70°S, in number of bacteria per 40 ml volume of water (Kriss, Lebedeva, and Mitzkevich)

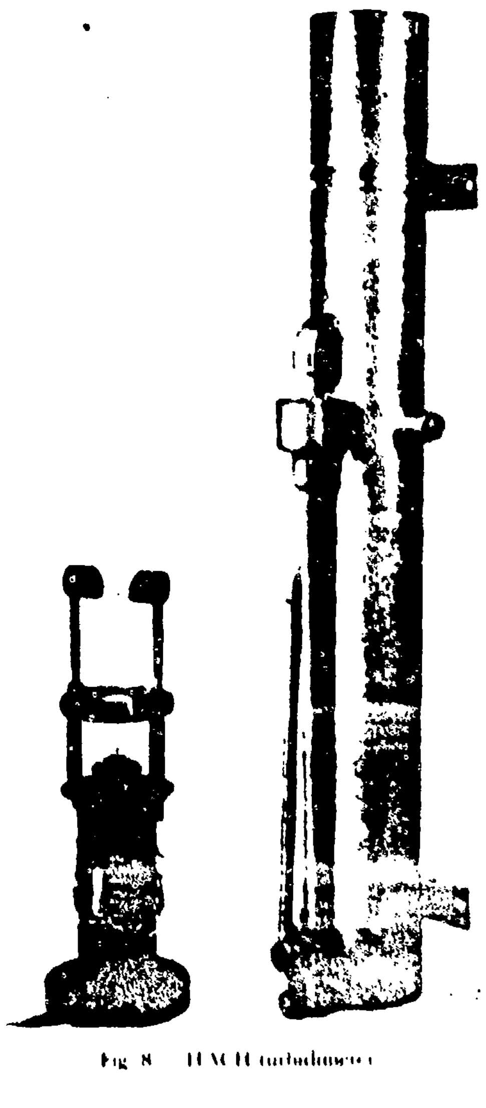

Fig. 8 – HACH turbidimeter

*The turbidity profiles from the BURTON ISLAND cruise have been received by NRL and are now being analyzed.

†A.E. Kriss, M.N. Lebedeva, and I.N. Mitzkevich, "Microorganisms as Indicators of Hydrological Phenomena in Seas and Oceans – II," Deep-Sea Research 6 (3):173-183 (1960).

‡F.D. Sisler and F.E. Senftle, "Possible Influence on the Earth's Magnetic Field on Geomicrobiological Processes in the Hydrosphere," Symposium on Marine Microbiology, 1963.

§C.P. Talarico, R.R. Sawyer, and E. Imbembo, "Further Studies of Atomic Absorption Analysis of Wakes," Hudson Labs. of Columbia Univ. Report 115 (Confidential Report, Unclassified Title), Mar. 17, 1964.

the measuring chamber, where a pair of photocells continually senses the scattered light. The electrical signal is amplified and displayed on an Esterline Angus recorder. One mode of operation is direct readout; another mode utilizes a bridge circuit and presents the output above a given threshold level. The latter system is for weak-signal detection. A sample chart record is shown in Fig. 9. This record was obtained during Chesapeake Bay tests with the SSX-1. The water was exceptionally clear during these tests, with a turbidity of about 1.5 ppm relative to silicon dioxide. Profile sampling showed a uniform distribution down to submarine depth, as measured by a Helige turbidimeter. A very small change in turbidity of about 0.05 ppm was caused by the passage of the submarine directly under the measuring platform. At other times in the Bay, turbidities of 15 ppm have been observed, and changes of several parts per million have occurred in the wake.

SIGNAL-PROCESSING TECHNIQUES AVAILABLE

Chart data, which have been reduced to punched tape for computer processing, will permit the signal processing necessary for the low signal-to-noise ratios often likely. As in acoustic processing, sensitivity of the sensor is not the problem; system and ambient noise are the factors that limit detection capability. With the computer tapes, the time and space noise factors can be determined, as well as noise plus signal statistics; then by knowing the system bandwidth and sample size detection and false-alarm probability can be computed.

Some useful comparisons can be made between the parameters of a flow system and conventional signal-processing parameters. In Fig. 10, a comparison is made between electrical time constant and tank-clearance time constant. In addition to a system delay of two minutes (time for water to reach the tank from the V-fin) for the HACH, there is a clearance time of 1.5 minutes for a 1/e value. Figure 11 relates the time in wake to ship speed and track length. Together, these parameters determine the system resolution or capability of detecting a wake of given dimensions. In general, a fast-moving platform requires a fast clearance time. If individual particles are considered as information bits, sampling-theory criteria must also be satisfied. This condition would occur in a system designed to detect a characteristic particle such as a copper ion.

The importance of sample size is shown in Fig. 12. These data, obtained with an early model turbidimeter, illustrate the improvement gained by increased wake-sampling time.

An ideal classifier takes advantage of the unique and exclusive properties of the submarine, such as the ability to cause a magnetic anomaly, the emission of man-made noise, and characteristic size and shape. The latter characteristic is probably the simplest to utilize, but generally it requires the use of a short-range high-resolution sensor. It appears that trail detection may require a localization capability (such as the LORELI technique), if classification is considered. The analysis of the trail up to the point of origin may well indicate features exclusive to the pressure of a submarine, when the energy transfer related to the submarine is considered. In addition to the hydrodynamic effects, NRL has explored the modifications to sea-water systems by low level acoustic energy approximating the level directly above a slow-speed, shallow submarine.*† Laboratory research using small tanks has shown changes in surface tension, degassing of low-solubility gases, and the solution of a soluble gas, CO_2. At the interface, sound energy stabilizes the thermal structure by molecular mixing. There is also some evidence of particle agglomeration and aggregate formation resulting from the irradiation of membrane-filtered sea water.

CONCLUSIONS

A 12-channel particle-size distribution analyzer has recently been procured for the NRL research program. With this the redistribution of particulate material caused by a transiting submarine can be quantified, and thereby an improved turbidimetric system can be designed.

*A. J. Hiller, "Some Exploratory Investigations of the Influence of Sonic Energy on Aqueous Mixtures as Related to Surface Effects," NRL Memo. Rept. 1289 (Confidential Report, Unclassified Title), Feb. 1962.

†A. J. Hiller, "Some Investigations of Sea Water System Modifications by Acoustic Energy in Small Tanks," NRL Memo. Rept. [illegible] (Confidential Report, Unclassified Title), Nov. 1963.

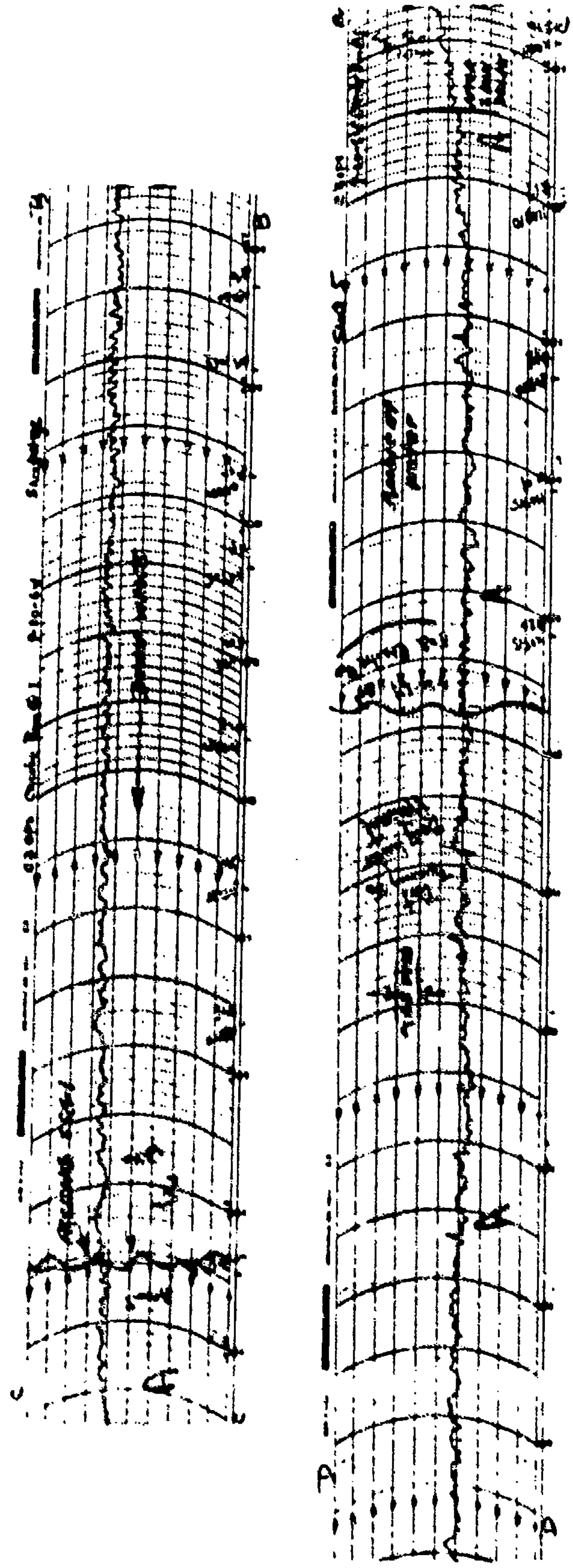

Fig. 9 — Record of HACH turbidimeter made in Chesapeake Bay during SSX-1 submarine test runs

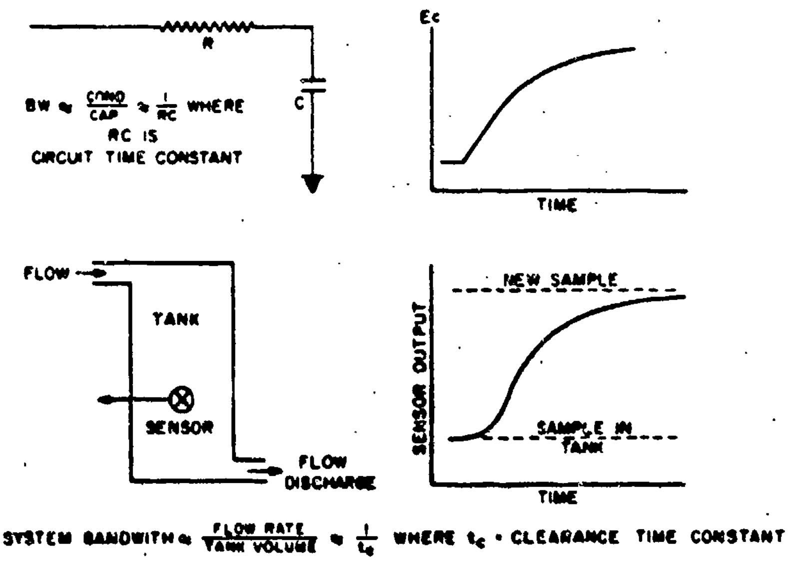

Fig. 10 – Comparison of electrical time constant to tank-clearance time constant

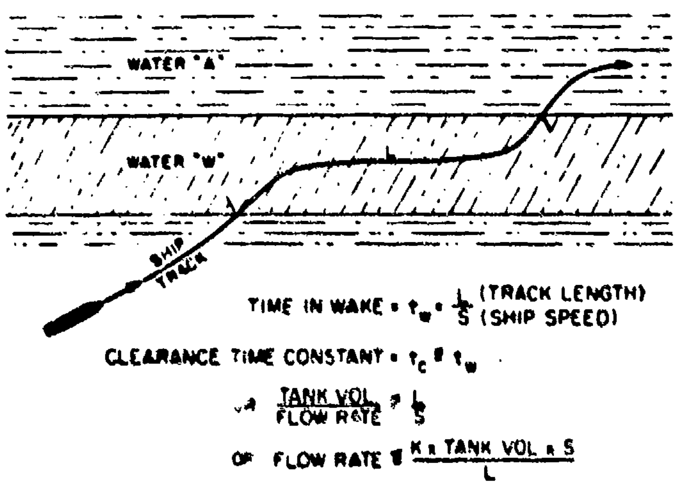

Fig. 11 – Flow-system resolution

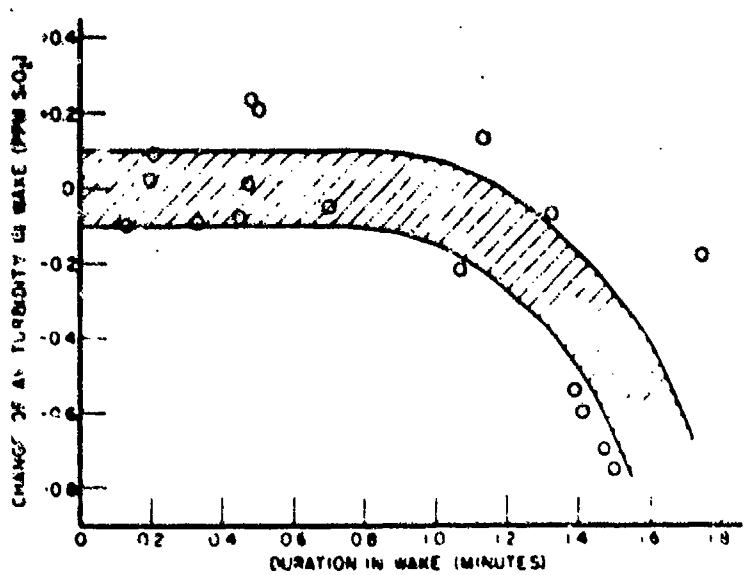

Fig. 12 – Turbidity in surface-ship wakes, BLOCK ISLAND tests, July-Aug 1962

[illegible] related to ASW will require the use of more sophisticated instruments* and demand the accumulation of data in strategic areas concerning horizontal and vertical distributions of the sea components. The integration of oceanographic instruments must be integrated into a trail-detection system and the performance of these systems must be evaluated using submarine targets in areas of interest. The results must be correlated with meteorological and hydrological data in order to establish predictions as to when such systems can be used to an advantage.

*The use of a sophisticated instrument such as the Coulter Counter particle-size-distribution analyzer has suggested a more basic approach to reverberation theory. Using the particle data with Rayleigh scattering theory, reverberation-index computations may reveal heretofore unsuspected factors in volume reverberations. Research is continuing to identify the particles and their relations to the overall ocean complex. It is also suggested that acoustic systems may be useful to sense environmental changes by placing emphasis on reverberation analysis.

ACKNOWLEDGMENTS

The author expresses his gratitude to the many members of the Techniques Branch who have assisted in the field operations and in the collection of data vital to the concepts and basic considerations set forth in this report.

The services of the men operating the submarine, small boats, aircraft, and the research ship JAMES GILLISS (AGOR 4) are sincerely appreciated. The support given by the U.S. Navy Oceanographic Office field oceanographers was also of inestimable value in obtaining the depth-profile data, which are the foundation for the more recent work on particle studies.

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	Dept. of the Navy (Bureau of Ships)

13. ABSTRACT

The transit of a submerged submarine subjects the ocean environment to many subtle changes. During the past several years specialized in situ oceanographic instrumentation has been designed to sense these physical, chemical, and biological modifications of the ocean. The concept of interdisciplinary research, aimed toward obtaining a broad spectrum of knowledge prior to hardware development, is considered the key to future systems reality. Laboratory research results show the many facets of the problem and the general usefulness of the ocean as a ready-made complex easily changed by a transiting submarine. The submarine-generated energy transfers, acoustic and hydrodynamic, are detectable by simple optical instruments. The results of several field operations have demonstrated the performance of turbidimetric and colorimetric sensors used for wake sensing of a submerged submarine during recent field operations in the Florida Straits. Emphasis on submarine detection and classification systems suggests useful comparisons to conventional acoustic signal processing, where the ocean-environment noise for a given parameter, such as turbidity, is treated in terms of bandwidth, sampling time, resolution, detection, false-alarm probability, and signal-to-noise ratio.

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
[illegible] distribution analysis						
[illegible]marine warfare						
Surface effects						
Nonacoustic ASW systems						
Flow-system parameters						
Turbidimetric measurements						
Hydrodynamic effects						
Acoustic interaction						

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U.S. Naval Research Laboratory. Report 6224. [Conf.]
OCEANOGRAPHIC INSTRUMENTS AS A BASIS OF SUBMARINE DETECTION AND CLASSIFICATION SYSTEMS [Unclassified Title], by A.J. Hiller. 12 pp. and figs., May 6, 1965.

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[redacted] [GRP-3] (over)

1. Submarines – Classification
2. Submarines – Wake – Detection
3. Submarines – Wake – Biological factors

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