ONR Report ACR-135

Notes on Underwater Sound Research and Applications Before 1939

ELIAS KLEIN
Defense Research Laboratory
University of Texas

September 1967

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DEPARTMENT OF THE NAVY
Washington, D.C.

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PREFACE

This document is based on a series of articles dealing with underwater sound research and applications before 1939, prepared by Dr. Elias Klein for the U.S. Navy Journal of Underwater Acoustics. The first part of this series appeared in the January 1966 issue of the Journal followed by the second part in July 1966, and the third part in October 1966. Because of the historical value of this material and the many requests for it, the three parts are here combined and issued.

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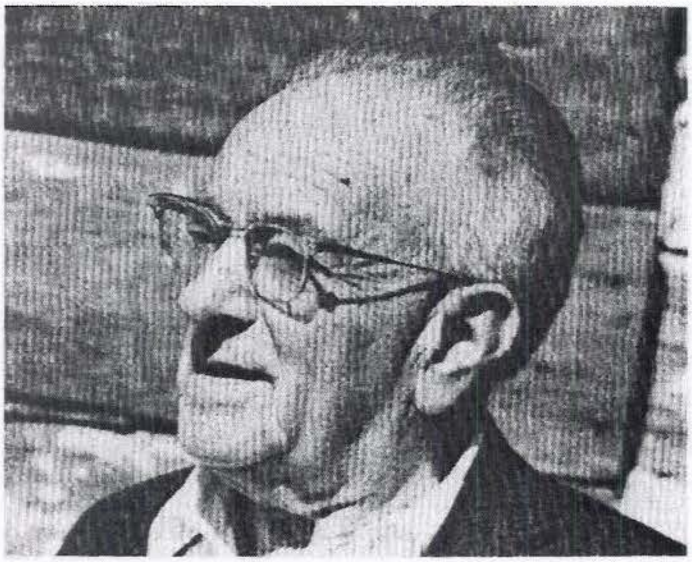
MEET THE AUTHOR

In formally thanking Dr. Klein for preparing "Notes on Underwater Sound Research and Applications Before 1939," a tribute is made to his long and distinguished career in underwater acoustics. Now, approaching his eightieth birthday, at an age when most men are relaxing in the glow of praise for former achievements, he carries on a busy schedule involving two jobs with a vigor that outstrips much younger men. In tribute to the man himself, as well as to his achievements, the following biography is presented.



Elias Klein, a native of Wilno, Poland, 1888, came to the United States as a boy and grew up in New York City. He attended Valparaiso University in Indiana from which he received his B.S. in physics in 1911 and a B.C.E. in structural engineering in 1912. The following five years were spent as an instructor in physics at Valparaiso. He then became a teaching assistant in physics at Yale University where he received his Ph.D. in physics in 1921. The following six years were spent in teaching positions at Saskatchewan University and Lehigh University, and on June 15, 1927 Dr. Klein joined the staff of the Naval Research Laboratory in Washington.

At NRL Dr. Klein became a member of the Sound Division then under the direction of Dr. Harvey C. Hayes. This small group at NRL was the source of the only effort on underwater acoustics within the government at that time, and this group did an outstanding job of filling the hiatus between the two major wars. It is difficult for us to discuss adequately the portion of Dr. Klein's career between 1927 and 1941. Those who were associated with him then are no longer available to help us, and Dr. Klein is so engrossed with the problems of today that he seldom engages in reminiscences, and, until now has resisted efforts to get him to write an account of that period. Among his major efforts during this time was his pioneering work on the characteristics and applications of piezoelectric crystals and his work on the growth of synthetic rochelle salt and ADP crystals. Also, of great significance is his development, in cooperation with the B.F. Goodrich Company, of the so-called "rho-c" rubber for application to underwater acoustics and for other uses where a good acoustic match between water and a material was needed. His original formulation for "rho-c" rubber is still manufactured. For this work Dr. Klein received from the Navy a substantial cash award in 1932.

During World War II, 1941-1946, the staff of the Sound Division at NRL participated in the vast expansion of the Navy effort in underwater acoustics. Many people still active in the field became associated with Dr. Klein during this period, and we are indebted to one of these (Mr. O. M. Owsley, Director of USRL) for the following remarks:

> "He did yeoman work on the basic concept of the Herald System (Harbor Entrance Ranging and Listening Device). This project was the forerunner of the present day Herald devices. He supervised the R&D and the design of this experimental device and directed the cable laying and placement of the initial installation 5 miles off shore at Fishers Island, New York. He was further instrumental in getting established the first Harbor Defense School at Fishers Island. He received the U.S. Navy Distinguished Civilian Service Award in 1945 for his work on Harbor Defense."

The above will perhaps serve as examples of Dr. Klein's work during the war years. He was a "trouble shooter" who was always willing to take on tough assignments of immediate importance and see them through to a successful conclusion; then, without inviting or encouraging plaudits, he would plunge into the next assignment.

In 1946 Dr. Klein organized at NRL a Centralizing Activity to collect, correlate, and disseminate all information in the field of shock and vibration for the Navy. Because of the interest in this work by the other services, the Activity was placed under the Department of Defense, and its scope was enlarged to include other environmental effects such as temperature, pressure, and radiation. Later he organized a similar centralizing activity for harbor defense. He was commended for his leadership and organizational ability by a DOD citation and plaque in 1957. This work included organizing and editing the Shock and Vibration Bulletin, a major outlet for information in this field.

Dr. Klein continued in the above "Centralizing" activities until 1959 when, after a Presidential extension of one year beyond the mandatory retirement age, he retired on January 31, thus ending 32 years of service. Perhaps the word "retirement" is misleading as he has subsequently taken on two jobs. He joined the staff of the Defense Research Laboratory at the University of Texas, and his assignments require him to be stationed in Washington, where he does consulting work for the Office of Naval Research and the Naval Ship Systems Command. He has undertaken a variety of tasks for the Navy as a part of this assignment, but his main concern has been the evaluation and calibration of modern sonar transducers. His work on near-field studies has emphasized this aspect, and much of the progress in this field is due to the support and encouragement of Dr. Klein.

He went to Goddard Space Flight Center in 1959, his second job in "retirement," as a consultant on shock, vibration, and associated environment, after retiring from NRL. At Goddard his work has been a continuation of the creative ability demonstrated by his achievements at NRL. From 1962 through 1965 he organized and directed the Summer Workshop, a unique program that allows university faculty, graduate students, and Goddard personnel to exchange views by working together to solve actual problems at Goddard. Since 1966, Dr. Klein has remained as counselor at Goddard and takes special pride in his contact with the young people who have taken part in his program. The Workshop is continuing essentially the policies established by Dr. Klein. His friends and colleagues join the Goddard Space Flight Center in wishing Dr. Klein many more years of happy and useful work.

On June 15, 1967, Dr. Klein celebrated 40 years of service to his government.

Elias Klein is married to the former Bertha Roseman of Cleveland, Ohio. They have two children and four grandchildren. Mrs. Klein, who has a degree in law, is quite interested in low-income housing projects and is presently a volunteer on the staff of the Consultant to the Landlord-Tenant Branch of the D.C. Court of General Sessions. Dr. David Klein, their son, is a neurosurgeon on the staff of the University of Buffalo Medical School, and Mrs. Marcia Hellerman, their daughter, is the wife of a mathematician at IBM.

September 1967

NOTES ON UNDERWATER SOUND RESEARCH AND APPLICATIONS BEFORE 1939

Elias Klein

INTRODUCTION

This paper gives an account of some aspects of the development of underwater acoustics from the very active period during World War I up to the beginning of World War II. In particular, the acoustics research and technological efforts which were conducted at the Naval Research Laboratory in Washington during this period will be highlighted. The writing of this account was suggested by the Editors of the U.S. Navy Journal of Underwater Acoustics who indicate that they believe it will be of substantial benefit to Journal readers in the perspective of present day research. As they put it, being in the field "the sole active survivor of the small group of workers in government during the twenties and early thirties," it is up to me to provide an account of that period. Since I have spent a major part of my professional life at NRL the reader can hardly expect the NRL parts of the narrative to be wholly objective. After all, it is the product of one who was an active and interested participant in the research and development work which was conducted at the laboratory during the period under consideration.

It is desirable to point out that a tremendous difference in attitude towards science existed in this country some forty years ago as contrasted with the present. Today, science and... technology are dominant realities in our lives. During the twenties and thirties, the impact of science and technology upon our social structure was insignificant in comparison with the meaning and value society places upon modern scientific achievement. This means that between World War I and World War II there was very little enthusiasm for supporting research and development, and a great scarcity of funds for exploring the unknown. Among the military organizations there were even more serious budget limitations for any long range potential improvements and innovations. The day-to-day needs were barely supplied and attempts were made at solving only the immediately urgent problems. New concepts in defensive and offensive systems relating to undersea warfare were, mostly for lack of funds, held in abeyance until war was almost upon us. This was the situation facing the American scientist during that period.

Part I. Underwater Acoustic Research during World War I

Prior to 1914, the use of underwater acoustics was limited almost entirely to navigational aids. Some ships were equipped with hydrophones for locating the direction of an underwater bell, usually installed on a lightship or a lighthouse. The sound of the bell would warn the ships of a danger zone; however, even this form of warning was not common. Few practical applications were made of subaqueous acoustics until the TITANIC tragedy occurred in 1912. Then, the first serious attempt was made to locate submerged obstacles by acoustic echo-ranging, or SONAR[1] as it is called today. In 1912 the Steamship TITANIC collided with an iceberg and sank in the North Atlantic. To prevent the recurrence of such disasters, L. F. Richardson[2] proposed an ultrasonic scheme for detecting and locating underwater objects, like icebergs. His ideas did not materialize even though they were basic in principle. At the same

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[1] The acronym "SONAR" (SOund NAvigation and Ranging) was coined during World War II.
[2] British Pat. 11, 125: 1912 (issued to L. F. Richardson).

time, or within a couple of months, R. A. Fessenden[3] conceived a device which actually detected an iceberg by "echo ranging," on 27 April 1914, at a distance of nearly 2 miles.[4] Concerning the Fessenden device, C. V. Drysdale[5] states, "In 1917 Fessenden appears to have obtained echoes from ships, rocks, and icebergs using his oscillator . . . but this device is nearly nondirectional owing to the relatively low frequency employed (about 1000 cps)." Perhaps the iceberg detection in April 1914 as reported, was accomplished by a system which was developed before the well-known Fessenden Oscillator was put on ships.

About 50 years have elapsed since underwater sound propagation became a necessary and practical means of signalling. Antisubmarine warfare was first pressed into service at the outbreak of World War I, in 1914. Then England and France were struggling to survive the blockade of the German U-boats. To detect and locate these undersea craft, the British and French separately placed into emergency operation several types of listening hydrophones to pick up the submarine sounds. This war crisis and the U-boat threat could well be designated as the beginning of underwater sound technology. For, despite the enormous difficulties of detecting an invisible mobile vessel and the newness of the underwater communications art, the Allies, with their crude devices, did a remarkable job in locating the U-boats for a depth-charge attack. They would stop their ships to listen to the submerged craft then proceed a few hundred yards and stop again. Otherwise, when underway, their own ships noise would drown out the signals from the target. Most of their effectiveness was due to personnel skill, which stemmed partly from desperate persistence. Remarkable team-work with other sound-equipped vessels, aided by the triangulation methods they used, contributed to their early successes.

Soon after the seriousness of the war situation in Europe became apparent, the U.S. Navy decided that submarine detection methods were most important to our national interests. Hence, U.S. technical observers were promptly dispatched abroad to study the antisubmarine measures utilized by the Allies. Also, at about this time, in 1915, the Secretary of the Navy, Josephus Daniels asked Thomas A. Edison to form a technical advisory group to serve the Navy in matters of inventions and scientific endeavors. In response to this request, Edison assembled 24 outstanding scientists and engineers who soon became the "Naval Consulting Board of the United States." The Board immediately proposed the establishment of a well-equipped and well-staffed research laboratory. But the threat of the German submarines and the need to prepare for any emergency delayed the setting-up of the Naval Research Laboratory until 1923. Thus, either by coincidence or design, antisubmarine warfare was activated at the time when NRL was conceived, about 50 years ago. And, so far as I am concerned, the bridge which connected NRL with WWI was the residue of scattered information left by those who took part in anti-submarine warfare in 1914-1918. It was this hunting and searching mostly in the Library of Congress and at the National Academy of Sciences that brought me in close touch with science and scientists of the World War I period. Unfortunately, the efforts in military technology, especially in subaqueous acoustics, carried out in the United States in 1914-1918 were not at all compiled or reported in the highly organized and effective manner of NDRC and OSRD for the years 1940-1946. In fact, the World War I story of science and scientists has hardly been told compared to the descriptions and documentation of the many technical subjects dealt with in World War II. To bring to light some of the scarcely known acoustic developments in the period 1912-1939 is one of my objectives. In particular, I wish to call attention to several unpublished or inaccessible reports by American scientists who helped to make submarine detection possible in World War I.

Even before the United States entered the conflict (April, 1917), German U-boats caused serious destruction of allied tonnage quite near our coastline and, the Council of National Defense established several groups to deal with this menace. In March, 1917, the Chief of the

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[3] United States Pat. App. 744,793:1913.

[4] F. V. Hunt, Electroacoustics: The Analysis of Transduction, and Its Historical Background (Harvard University Press, Cambridge, Mass., 1954), p. 45. (Professor Hunt has an excellent historical perspective of acoustics at sea in the first chapter of this book).

[5] C. V. Drysdale, J. Inst. Elec. Engrs. 58, 586 (1920).

Bureau of Engineering[6] authorized the National Research Council to have Dr. R. A. Millikan implement his proposal to assist in the development of anti-submarine devices. Naturally, the engineers and physicists who participated in this submarine detection effort investigated a large variety of countermeasures against the U-boats. Tests were conducted on magnetic, electromagnetic, optical, and thermal phenomena for submarine detection purposes, but the overall U.S. contribution was mainly in acoustics. It should be noted also that prior to our entry into the war, the allies had tried and, in some cases, actually used non-acoustic submarine detection methods. Some of these non-acoustics schemes have been reinvestigated in this country time and again during the past 40-odd years and so far, underwater sound has proven to be the most effective means for detecting submarines.

No time was lost in this emergency. By August 1917, an outstanding assemblage of scientists was attacking the submarine problem in different parts of the country. There were groups at Nahant, Mass.; New London, Conn.; Columbia University, N.Y. City; Key West, Fla.; and Palo Alto and San Pedro, Calif. Their primary developments dealt with underwater acoustics. While the Nahant and New London groups devoted themselves to the investigations of listening devices in the sonic range of 300 to 1000 cps; the other activities, to a large extent followed the ultrasonic echo-ranging method of detection. The ultrasonic or supersonic[7] means for locating and tracking submarines was an item of discussion at a conference[8] held in Washington on June 1, 1917, where scientific representatives from England and France were present. Sir Ernest Rutherford urged the prosecution of work in listening devices utilizing the binaural effect; while Fabry and Abraham explained the supersonic efforts carried on in France by Prof. Langevin. By the Fall of that year, the Nahant group as well as the Naval Experimental Station at New London had developed a variety of listening devices among which were the C-Tube and acoustic compensators. The supersonic researches were activated at Columbia University and at Stanford and San Pedro on the west coast. There was, to be sure, participation in the anti-submarine effort by many other industries and universities where individual experiments were conducted under the guidance and supervision of the Naval Board which had its Headquarters in New London. Of the many sonic listening devices which resulted from these investigations I shall describe two in some detail. These two were selected because of their operating simplicity; because in a relatively short time they were put to service use in our own Navy as well as having been installed on British vessels early in 1918; and because they remained useful to the U.S. Navy past the middle thirties. The first complete listening system in our Navy—the C-tube or SC-tube, as it was called—was employed during WW I on surface vessels, such as subchasers escorting convoys for detection and location of submarines. The SC-tube served also as a listening device on our submarines while submerged and making a torpedo attack. Figure 1 shows the air tubes which provided communication between the human ears and the rubber bulbs or nipples. The efficiency of transmitting sound from water to air via a thick rubber bulb by the application of the

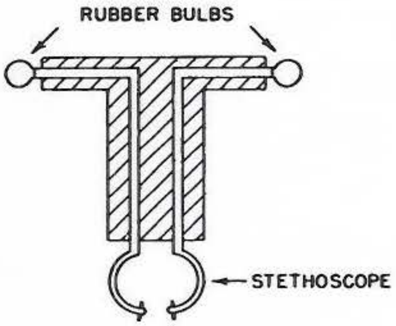

Fig. 1. U.S. type "SC" tube

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[6] Navy Dept. Office of Naval Records and Library History of Bureau of Eng. During WW I; 1922, Publication No. 5, pages 4-7.

[7] In the United States, until about 1947, high-frequency inaudible sound was known as "Supersonics." In England and France the term "ultrasonic" was used to designate super audible sound. In England this system of high frequency submarine detection during WW I was called "ASDIC" which is an acronym for Allied Submarine Devices Investigating Committee.

[8] A very interesting and more complete story of this conference and of subsequent developments in ultrasonics is recalled by W. G. Cady in SOUND, Its Uses and Control 2, 46-52 (1963).

stethoscope principle is discussed by Stewart and Lindsay.[9] H. A. Wilson[10] considered the theory of this type of receiver in water.

A diagram of the SC-tube installation on submarines is shown in Fig. 2. The sound receivers were mounted about 15 inches above the superstructure deck. On the subchasers, the T-shaped structure either hung over the side of or protruded thru the bottom of the ship (see Fig. 3). The two detectors, spaced approximately 4.8 feet apart, were connected (one detector to each ear) to a stethoscope by means of air-tubes leading thru a pipe. In this system the observer judged the direction of the sound source by using his ears as independent receivers to estimate the difference of intensity and phase of the waves being received. When the observer turned the rubber-nipple-receivers[11] so that the arrival of sound thru the stethoscope was in phase on both receivers, the signal appeared to be directly ahead (or directly in back of him, i.e., 180 degrees off). An experienced operator could readily check the 180-degree error by rotating the set, say to the left, 90 degrees. The sound would then have moved to the right ear if the target was located ahead. The spacing of the underwater ears for the average binaural sense was set for 500 cps.

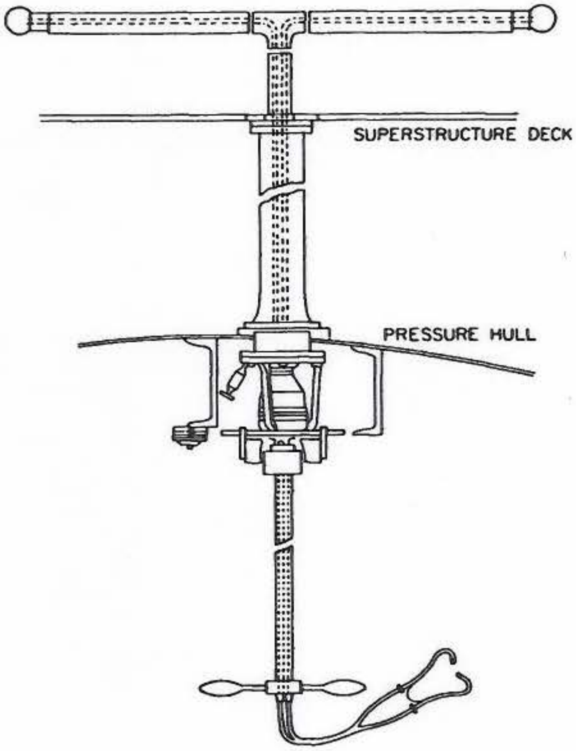

Fig. 2. Type SE-4214 (SC) sound receiver as installed on a U.S. submarine

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[9] G. W. Stewart and R. B. Lindsay, Acoustics (D. Van Nostrand Co. Inc., Princeton, N. J., 1941), p. 236; see also A. Wood, Acoustics (Gordon and Breach Science Publishers, Inc., New York, N. Y., 1930), pp. 188-194.

[10] H. A. Wilson, "The Theory of Receivers for Sound in Water," Physical Review 15, 178 (1920).

[11] A complete description of the (SC) equipment and instructions for use on submarines was presented in Navy Dept Bu Eng Publication N. Eng 150 (1922) (now out of print).

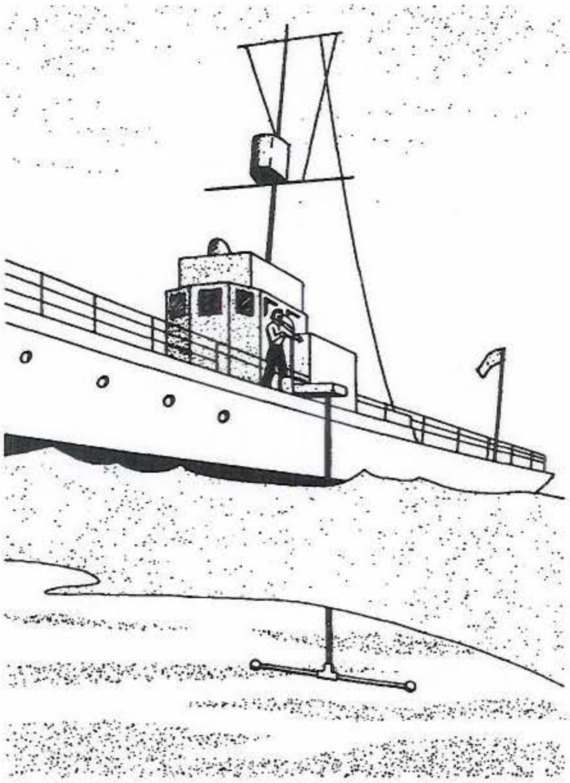

Fig. 3. The SC tube on patrol boat

Another sonic listening device of general utility which may be considered as representative of U.S. developments in WW I was a hydrophone known as the "RAT." Figure 4 shows the RAT's rubber diaphragm and housing which enclosed a watertight space for the carbon-granules microphone and its electrical leads which pass thru a stuffing box. The microphone button was screwed into an anchor-nut which was imbedded in the rubber diaphragm. While the cylindrical housing was made "rigid" by a metal cylinder vulcanized to the rubber, the diaphragm was relatively flexible and was substantially non-resonant. This type of non-resonant hydrophone with a broad frequency response was the preference in the U.S. developments at that time, in contrast with the British resonant detectors for underwater listening. The highly resonant acoustic detectors made it difficult for the operator to identify the type of vessel emitting the sound. Also, they do not reproduce phase faithfully and are therefore, not well suited for utilizing the binaural principle which the U.S. investigators employed widely.

It is the outer casing with its flexible rubber cables that suggested the rodent-like appearance, hence the name "RAT." Any one of the several types of submarine receivers devised by the Nahant and New London groups may have been housed in this casing, namely the geophone, magnetophone, carbon button, and later piezoelectric crystals. It was used in simple (one receiver to each ear) binaural systems, as a component in the multi-unit devices on shipboard, in drifting or towing experiments, and in various arrangements of acoustic-electric compensators. This practical adaptability and interchangeability of the sonic listening apparatus, which was developed during WW I in the United States, accounted for the wide use of American equipment by the antisubmarine forces of our European allies.

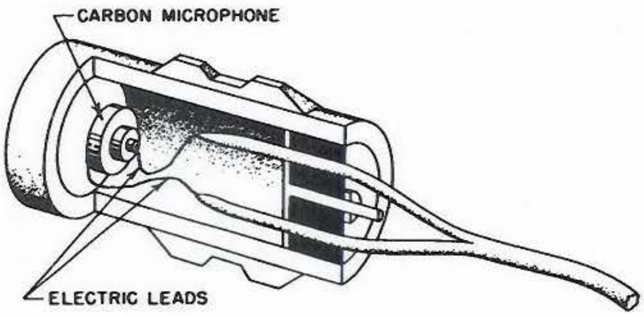

Fig. 4. The Rat

Many variations on this type of listening system were devised and installed by our Allies during the 1914-1918 conflict. All of them operated in the range of 500-1500 cps. They were all handicapped by the now well known problem of signal-to-noise ratio. That is, the disturbances in the sea, the noise caused by the ship movement in which the sound gear was installed, and the gurgling of the hydrophones as they passed through the water did not permit the operator to discriminate between the sounds of the desired target and the general noise background. So long as the hydrophone receiver was omnidirectional, amplification was of no help, especially with the state of the electronic art at that time. These signal-to-noise difficulties together with the stationary or drifting submarine maneuver, which emits little or no sound, emphasized the need for a highly directional active sonar detection method.

So much for the listening devices which were utilized to combat enemy submarines in WW I.[12] Now a few words are in order about the scientists and engineers who created these gadgets. To make sure that the dates, events, and people mentioned in this write-up are correct, I visited the National Archives Building in Washington. Stored there are some WW I reports pertaining to U.S. technological efforts in submarine acoustics and undersea warfare. Upon re-reading these manuscripts after a lapse of nearly 40 years I was particularly elated over the achievements of the U.S. scientists in an 18-month period, especially in a field which was quite new to them. Indeed, the British and French scientists who came to the Washington Conference in June 1917, provided the Americans with 3 years of accumulated trial-and-error experiences in combatting submarines. This guidance and information were, of course, invaluable. But, in my view, a dominant factor which influenced the progress made in this country was the excellent communications and interchange of information among the U.S. workers everywhere. In particular, the reporting of the U.S. Scientific Attachés in England, France, and Italy impressed me as being superb. Their dispatches and memoranda to the Research Information Committee, Washington, represented well prepared, substantive information intended to help those in the United States who were working on that subject. For example, from the Office of the Scientific Attaché, Paris, a memo dated October 31, 1918 was attached to a

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[12] These listening devices and the related underwater acoustic work of this period are described in the several textbooks on acoustics referred to earlier. They are also discussed in the reminiscences of three scientists, A. B. Wood, H. C. Hayes, and R. D. Fay, who participated in the audio sound antisubmarine work of World War I. Their recollections are printed in SOUND its USES and CONTROL, respectively, in Vol. 1 (1962), p. 8; Vol. 1 (1962), p. 47; and Vol. 2 (1963), p. 37. (Editors' Note: The recent appearance should be noted of a Memorial Volume of the Journal of the Royal Naval Scientific Service (Volume 20, July 1965) dedicated to the memory of Dr. Wood. This volume contains the above named article by Dr. Wood along with additional reminiscences covering his entire career with the British Scientific Service.) An historical background of the development of underwater sound and detection equipment is also given in History of Communication-Electronics in the U.S. Navy (BuShips and Office of Naval History, Washington, 1963) Chapter XXVI, pp. 297-312.

manuscript entitled "A Mathematical Discussion on the Propagation of Sound Waves in Pipes," by Prof. Langevin. The Memo contained this note. ... "We believe that both the methods which he employs and the results obtained will be found of interest and possible value to those who have been working on the problem of listening devices from the theoretical standpoint. It is suggested, therefore, that this note be brought to the attention of Dr. G. W. Stewart and Dr. A. G. Webster, and the group in New London which is working on the subject of effects of pipes on the transmission of sound."

Signed/K. T. Compton, Assoc.
Scientific Attaché

Approved and Forwarded
W. F. Durand, Scientific Attaché

Our Scientific Attachés sent to Washington not only information relevant to their missions in the different allied countries (e.g., the above report), but in their eagerness and zeal to be helpful, they dispatched also details of their studied technical opinions which later proved of tremendous help to the U.S. submarine detection problem. The parts played, by S. L. G. Knox, Scientific Attaché, Rome; and, K. T. Compton, Associate Scientific Attaché, Paris, in reporting the sea trials of the "Langevin Supersonic Apparatus" demonstrate the art of communication in depth. Fully aware of the urgent need to make immediate practical use of this echo-ranging device on subchasers, they followed-up their observations with careful discussion of the test results.

Briefly, this is the story of the Langevin apparatus sea trials. In August 1918, this echo-ranging equipment was tested at sea near Toulon, against an actual submarine. Among the many allied technical observers were the two named above. Together, these two discussed different aspects of the tests, and, within a few days, Dr. Compton sent to Washington a full description of the trials they saw. Without waiting to reach Rome and make a report of his own on his observations at Toulon, Knox immediately dispatched to Washington what he called some "discrepancies between my deductions from the tests and my understanding of what I had been told and had read regarding the functioning of the apparatus." Some further correspondence relating to the original Compton report on the trials of the Langevin supersonic apparatus were received in Washington. These contained suggestions for improved operation of the gear and for ease of its installation on the ship. The Compton-Knox discussions and interchange of ideas regarding the Toulon experiments and the interpretation of the results brought to Washington a number of novel suggestions and far-reaching recommendations. These included:

1. A mechanical beam tilting or beam steering arrangement about the horizontal axis of the transceiver. Mr. Knox considered this beam tilting idea of vital importance in the attack on submarines. Otherwise, he felt that the attacking vessel would miss the submarine entirely, in rough water. It was his contention that the range of the apparatus would be greatly reduced in a choppy sea. From his calculations of energy dispersion of the reflected beam, Knox showed that the effective width of the beam is only equal to twice the half angle, as normally measured, for a very short range, and that the beam narrows down as it approaches its effective limit of length. "It must not be forgotten that at maximum range all beams come to a point." For these reasons, Knox urged that the frequency be lowered from 40 to 30 kc and to have the beam capable of tilting about a horizontal axis. (In concept, this beam tilting seems to be the forerunner of the electronic steering array.)

2. Regarding the supersonic echo from a submarine, Mr. Knox said "Notwithstanding the high authority quoted by Dr. Compton in support of the diffuse reflection theory, ... the writer had neither seen nor been able to obtain an explanation of how diffuse reflection can produce the results obtained when the wavelength and nature of reflecting surface are considered." Knox felt quite certain that the echo from a submarine which returns to the face of the quartz-steel radiator is due to regular or specular reflection. And, to prove his point, Mr. Knox requested his Associate Scientific Attaché in Rome, Dr. Edgar Buckingham, to examine quantitatively the influence of the shape of the reflecting body on the strength of the echo at a given

distance from the submarine. In working out numerical examples to illustrate the meaning of the equations he obtained, Dr. Buckingham assumed hypothetical values for the curvatures of the reflecting surfaces. This approach was necessary because the lines of the submarine on which Langevin's experiments were made, were then not at hand. With reasonable assumptions regarding the form of the submarine, his computed relative ranges of audibility in the broadside and end-on positions of the submarine were comparable with those actually observed in practice, according to Mr. Knox. The latter concluded, therefore, that the phenomena of supersonic echoes may be safely regarded as due, in the main, to regular reflection.

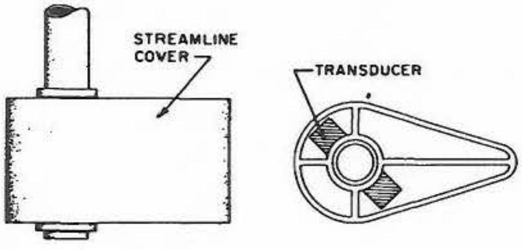

Fig. 5. Streamline cover for transducer

3. In order to reduce the difficulties in steering the flat-faced transceiver in the ship while underway, Knox introduced the idea of a sheet steel, 1/16-inch thick, streamlined cover about the Langevin device. He pictured a spider, top and bottom holding the steel cover and allowing it to float freely on the support (see Fig. 5). This would facilitate the manipulation of the gear in use. (This may have been the first suggestion for a "Dome.")

Because Knox considered the Langevin apparatus as urgently needed for attacking enemy submarines, he followed up his carefully prepared suggestions with relentless devotion. Knox and Compton may have differed on how an underwater acoustic beam is reflected from a submarine, but they were both of a single mind in their dedicated efforts to put the Langevin apparatus to effective use against enemy submarines. Their technical communications played a major role in the ultrasonic developments in the United States, and even though practical underwater echo-ranging did not see service during World War I, the scientific and technological information which they channelled to Washington stimulated a variety of researches in this new field of knowledge.

With the fantastic speed of today's technological developments, it is difficult to describe the U.S. achievements in subaqueous ultrasonics of a half century ago. Nevertheless, the progress made by a handful of scientists in a new field of activity in a period of about 18 months seems to me to be quite remarkable, irrespective of their motivations and pressures. And, to help the reader realize the extent and scope of their accomplishments, two reports of the 1918 vintage are here included as appendices. These were written by U.S. scientists who participated in the sonar work of WW I. Both mention the difficulties that were experienced in constructing a workable Langevin quartz-steel apparatus. The performance of their specimen-projectors, in each case, was dependent upon: (a) how the quartz crystals were cut and oriented in the sandwich-line assembly; (b) what kind of cement was used and how the bonding process was effected; and (c) how the sound output from the transducer was evaluated and measured. The measuring of the intensity of a sound beam emitted by an oscillator, in absolute units, is a very difficult undertaking even with present-day equipment. The radiation pressure devices which they attempted to use in a water tank, with reflecting walls, are at best subject to infinite troubles. But they did their best with what was known and available.

The first report by Professor Morecroft of Columbia University, Appendix A, was an account of the supersonic work in the United States from April 1917 to October 1918. It was presented at an Interallied Conference held in Paris on 19-22 October 1918. The purpose of this conference was to assess the status of the supersonic developments of the Allies, how the construction and distribution could be most quickly secured and what future developments and improvements should be carried out. Each of the four countries most directly involved, England, France, Italy, and the United States, had four delegates each in attendance. Representing the United States were: Professor H. A. Bumstead, Scientific Attaché, London; LCDR E. C. Raguet, USN; Professor J. H. Morecroft, in charge of Development of Supersonic Apparatus for the

U.S. Navy; and Professor K. T. Compton, Associate Scientific Attaché, Paris. There were several sessions at this conference at which the various nationals described their work and exchanged ideas relating to supersonic apparatus.

An idea of the actual experimental approach toward the development of echo-ranging equipment in the United States at that time can be obtained from the second report, Appendix B, prepared by the San Pedro Antisubmarine Group. This group conducted its investigations at two locations in California. Some performed experiments at Leland Stanford Junior College, Palo Alto, while another group worked at Throop College of Technology, Pasadena (now the famous California Institute of Technology).

Finally, I would like to mention an excellent unpublished and little-known manuscript[13] by A. P. Wills, entitled "ASDIC Laboratory Report." It describes ultrasonic work done at the U.S. Naval Experimental Station, New London, from November 1918 to June 1919. This report contains a thorough study of the piezoelectric oscillator receiver for high frequency underwater signalling. Professor Wills developed the theory of a longitudinal quartz-steel sandwich-like oscillator beyond the analysis which had hitherto been available at that time. Guided by the results of his computations, the Group tested a series of these metal-quartz tuned structures and arrived at a design which they considered potentially practicable for naval use. They also measured the intensity of the sound beam emitted by the oscillator into the water. A torsion-vane radiometer was employed to assess the beam's energy per unit volume. Figure 6 (copied from Willis report) illustrates a mosaic oscillator of circular type in which the outer plate is in direct contact with the water when the oscillator is in use. The diaphragm in this case is really part of the front plate and connects with the oscillator near a nodal plane.

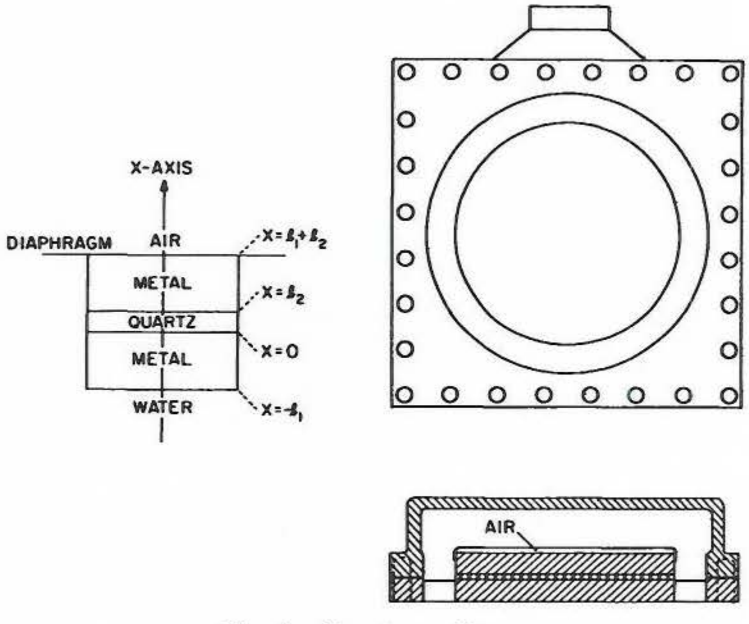

Fig. 6. Mosaic oscillator

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[13] The only reference to this report which I could find in the open literature is in "Theory of Vibration Systems and Sound" by I. B. Crandall. On page 142-footnote: "The sketch following is of certain unpublished experiments made by the Columbia University Group (Professors M. I. Pupin, A. P. Wills, and J. H. Morecroft in 1918." I might add that Crandall also worked in that group.

ACKNOWLEDGMENT

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Appendix A

HISTORICAL SURVEY OF DEVELOPMENT IN THE UNITED STATES*

J. H. Morecroft

Columbia University
New York, N.Y.

"Work in Supersonics in America was started about April 1917 by Professors Pupin and Wills at Columbia University, with funds furnished by some patriotic New York citizens. The Speaker joined the group in September 1917.

"During the summer Pupin and Wills had used a tuned cylindrical condenser for an oscillator and a microphone for a receiver; they were not very successful.

"In September we started to use a Piezoelectric oscillator as well as receiver and started to use amplifiers of our own construction. A tank 40 feet long was built in the University basement and transmission experiments were started.

"Rochelle salt was first used. It was furnished to us by the Western Electric Co., who had used it as a receptor for sound waves of low frequency.

"We found it worked well as an emitter of high frequency sound waves and for two months we used it extensively.

"It has a very high piezo constant if cut in the right direction.

"It can be obtained only in small pieces as the crystals are seldom grown more than 2 inches long.

"The best method of cutting the crystals is to use a wet thread, a scheme developed by Professor Cady of Wesleyan University—I generally used a small hacksaw and ground the pieces to size with coarse sand paper. We are not able to use this material with a high potential gradient impressed—because it melted, apparently due to high internal losses—thus a piece 2-mm thick would melt in less than a minute if 300 volts were impressed at 1000 cycles. Recent experiments show that gradients of considerably higher potential than those that I used may be employed with Rochelle salt if the crystal has been properly treated. Professor Cady and Dr. Hull of the General Electric Co., are at present working on this problem.

"The phenomenon of standing waves in our laboratory tank was shown very well, it being possible to measure the wave length in the water accurately by observing the nodes and antinodes; this was done by moving the receiving crystal (which was very small) thru the water. The signal went thru maximum and minimum values as a wavelength was traversed. The sides and ends of the tank seemed to be excellent reflectors of these high frequency sound waves.

"In these experiments, the sending and receiving crystals were 1 or 2 centimeters on an edge. A few volts (from 1 to 10) were generally used and frequencies were tried from 20,000 to 200,000 cycles.

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*Presented at an Interallied Conference in Paris, 21 October 1918.

"One interesting result of our tank experiment had to do with the effect of turbulent water in the transmission of the supersonic waves.

"When the conditions were adjusted to give a loud signal in the receiving circuit, the water was stirred by a stick so that more or less turbulent water existed between the sending and receiving crystals, the signal would completely disappear then gradually reappear as the water became quiet. It might take as long as 10 minutes for the signal to reappear with its original intensity.

"Upon hearing that Professor Langevin had adopted quartz for use in his transmitter, we immediately started to construct quartz oscillators. We adopted the scheme of building up a large oscillator out of a number of small oscillators, each consisting of a quartz plate from 3-4 mm thick, having a steel plate cemented on either side. Our first quartz plates were about 10 cm on an edge, but we have since used much smaller pieces, with the idea of eliminating the internal losses. It is my opinion that very small quartz plates should always be used in oscillators having cemented joints between the quartz and steel.

"We are working on one now with the quartz plates only 2.5 cm on an edge, and having enough of these small plates to make an oscillator 30 cm square.

"Experiments conducted with various commercial insulating waxes and compounds, with which to fill the spaces between the individual oscillators, did not give very promising results. An oscillator in which these compounds were tried generally broke down and punctured at less than 10,000 volts, at 50,000 cycles. Anticipating that our oscillator might have to stand as much as 15,000 volts or more, we came to the conclusion that we would use oil for our insulator, it having high dielectric strength, low dielectric losses, and furthermore having the valuable property of healing itself automatically after disruptive discharge had past thru it.

"We have tried various cements for sticking the steel plates to the quartz plates, and have at present quite a comprehensive study of cements being carried on at our experimental station at New London, Connecticut, U.S.A.

"We have used various oils in our oscillators, principally kerosene and castor oil; the latter has the desirable characteristics; that is, it does not attack rubber which may be used in the construction of the oscillator and with which the oil may come in contact.

"An interesting feature of oil insulation has been used by us to determine the critical frequency of an oscillator. If one of the small oscillators is suspended in oil, and the frequency is varied until the critical frequency is reached, quite violent bubbling occurs. These bubbles are apparently air, which is being driven out by the high frequency sound waves. At the same time, a very considerable convection current appears in the oil, the oil moving straight way from the face of the oscillator and flowing in at the sides. Some attempts to measure radiation pressure by the deflection of a vane were completely upset by this convection current.

"We have designed and built a sound radiometer in which the effect of convention currents is nullified; it is at present being used at New London to measure the output of our oscillators. It is being used with the oscillator in open water, because we anticipated considerable error due to reflections from the sides and ends if it were used in our tank. I expect that some results will be ready very soon; they will be forwarded to our Scientific Attaché as soon as I return to America.

"The bubbling of the oil enables one to adjust the electrical frequency to the critical frequency within a small fraction of 1 percent, if the cement used with the oscillator is holding well.

"The amount of bubbling increases with increase of voltage, at 10,000 volts the agitation of the oil is such that it has about the same appearance as boiling water.

"As the bubbling has a detrimental effect on the disruptive strength of the oscillator, we tried to do away with it. It is found that by subjecting the oil to rough vacuum (such as is obtained with an ordinary reciprocating pump) for about an hour practically all the entrained air is set free and when this oil is used in the oscillator there is no trouble from bubbling.

"The cement used at present in our oscillators is pure shellac, properly treated. It serves very well so long as the voltage impressed on the oscillator does not exceed 5000 or 6000 volts. With excess voltage the steel pulls loose from the quartz in places and this changes the resonant period and amplitude of vibration. The critical frequency may be lowered as much as 3 or 4 percent and the activity of the oscillator seems to be about 1/10 of what it was before the excess voltage was used.

"In the type of oscillator we use, it is very necessary to have all the individual oscillators of the same natural frequency—otherwise, although excited by the same electrical force, the phase of motion in the different oscillators may vary enough to disturb the beam very much, so that the maximum power is not sent out at right angles to the face of the oscillator.

"As the cement has a considerable effect on the natural frequency it is very important for us to know the properties of various cements. For that reason, the comprehensive study of cements is being carried out.

"During last February, it being too cold to do outdoor work around New York, our party of experimenters went to the Navy Yard at Key West, Florida. The results of our test have been given in a previous report. We attained communication between the sending and receiving stations at a separation of 5 km; at a distance of 3 km the signal was very loud—so loud that we expected to attain communication over, perhaps, 25 km, but the temperature gradients in the water were high and apparently bent the beam down to the bottom.

"We have repeatedly experienced this very sudden disappearance of the signal; it is no doubt due, as Professor Langevin has pointed out, to the curving of the beam with temperature changes in the water.

"In these distance tests our transmitter was quartz, about 10 cm square, excited to 4500 volts. The receiver was a small Rochelle salt crystal about 2 cm on an edge; it was connected to an amplifier which we had built in our laboratory.

"In the Key West tests we experienced a great deal of difficulty from low frequency noises coming into the telephone thru the amplifier. They seemed to be due to waves splashing against the boat and to eddies of water around the receiving crystal. Professor Pupin took to himself the task of building an amplifier which would be selective for a certain definite frequency and hence cut out extraneous noises. He is still busy on that task, but apparently close to a successful solution.

"By using a tuned quartz oscillator as receiver we do not get as much noise as we did with the Rochelle salt receiver and hence the problem of elimination of water noises is not quite so important as we thought it to be.

"In our Key West experiments we obtained a very marked Doppler effect, caused by relative motion of the sending and receiving stations; due to this effect the velocity of the object from which an echo is obtained in the line connecting the object and the sending station, may be measured very accurately. An experiment was performed to show the very small amount of power necessary to attain communication over 600 meters. The input was a small fraction of a watt, spherical distribution of the sound wave occurred and a small receiver was used.

"Echo experiments have been carried out at New London in rather shallow water; surface vessels were used for targets. An echo is obtained from a small schooner drawing about 10 feet of water, when it is distant about 500 meters. Diffuse echoes are obtained from rocky ledges on the shore, about 2000 meters distant. We have not carried out any actual hunts for a submerged submarine as has Professor Langevin, so we cannot say what results we might have obtained under such circumstances.

"In addition to the work outlined above, we have been able to use the supersonic waves in water, suitably modified, to conduct telephony between two stations. The conversation was very clear and there is no reason why this method of communication should not be extensively used between either submerged or surface craft.

"In addition to the experimenters already mentioned we have in America a very active group located at Pasadena, California, presently at work on some of the important supersonic problems.

"I hope to take back with me one of Professor Langevin's outfits, so that it can be directly compared with what we are using. We shall also build some oscillators of the type Professor Boyle uses so as to make comparative tests of the three types which have been developed.

"We have at present under way at New London researches on cement, researches on efficiency of oscillators by radiometer, and researches to investigate the possibility of using oil under high pressure for the back resonating plate of an oscillator. The elimination of the back plate of our oscillator would considerably simplify it and it looks as though the oil backing, of suitable depth, would enable us to accomplish the result.

"The amplifiers used by us seem to be very good but those used by Professor Langevin and Boyle have certain marked advantages over that I have built and I am inclined to think theirs superior.

"In closing I am only too glad to be able to express to Professor Langevin our deep appreciation of the pioneer work he has done and to express at the same time our regret that we could not have the benefit of his advice and counsel as Professor Boyle has been able to have. I feel that our advancement in the problem would have been immeasurably hastened, had we been able to associate with him more closely.

"My personal appreciation of Professor Langevin's work is shown by the fact that in less than a week after I had been appointed in charge of supersonic development for the American Navy, I was on my way to consult him, whom we regard as one of the world's leading physicists."

Appendix B

SUMMARY OF A STUDY OF THE LANGEVIN SUPERSOUND SOURCE-PROJECTOR*

J. A. Anderson, H. D. Babcock, and H. J. Ryan

Throop College of Technology†
Pasadena, California

"This study was undertaken to determine the elements of construction and action of the Langevin Source-Projector that would produce high beam intensities of supersound in water.

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*This Summary, which was dated 1 April 1919, was made in the Pasadena Special Laboratory of the National Research Council U.S.A. at Throop College of Technology by the Committee on Supersound (which was comprised of the authors) of the San Pedro Antisubmarine Group.

†Now the famous California Institute of Technology.

To facilitate the rapid study of many prepared specimen-projectors the following equipment was employed:

Bell-Jar. An inverted, glass, 20-liter, bell-jar contained the body of water into which the supersound was liberated from the face of the specimen-projector held in contact with the water surface. Paper pulp (desk blotters) in the bottom of the jar absorbed the supersound, preventing reflections and the formation of standing waves. This jar served as a calorimeter to determine projector outputs to check with outputs measured with the radiation pressure cylinder and to compare with measured inputs.

A concrete water tank (4 by 4 by 40 feet—1.22 by 1.22 by 12.2 meters) was built into the floor for our work when the laboratory was erected. Later on we learned of the excellent results obtained from echo trials with the Langevin equipment in the open water of the harbor of Toulon. This rendered laboratory work by us in echo receiving quite unnecessary and therefore the tank was not employed.

In-Phase Current Meter. Watts input to the specimen-projectors was determined by measurements of impressed radio frequency voltage and in-phase current. The in-phase current was measured with a three-coil air core transformer having two primaries used differentially and one secondary. The numbers of turns for all coils were alike. Through one primary the specimen projector and through the other primary in magnetic opposition an adjustable air core condenser were connected in parallel to a pair of taps that delivered the required radio frequency voltage from the arc converter source set. The secondary was short-circuited through a Duddell thermogalvanometer. The capacity of the condenser was adjusted so as to produce a minimum aggregate primary residual (in-phase) current which was repeated in the secondary and measured with the galvanometer. Guards or screens of an obvious character were provided to eliminate strays.

Radiation Pressure Cylinder as Supersound Output Meter. The natures of three types of radiation pressure meters were studied for the absolute measure of output—the Vane, Bulb, and Cylinder. The vane and cylinder were made in two forms: supersound absorbent and non-absorbent. The bulb, being made of glass, was non-absorbent. A small absorbent cylinder of blotting paper was finally adopted as being the best for use in the bell-jar. The intensities of supersound emitted from, and close to small surface areas (less than 1 square centimeter) of the specimen projectors could be measured reliably. The length and diameter of the small radiation pressure cylinder were: 6.27 and 5.23 mm, respectively. It had a range from 0.0 to 11.0 watts per square centimeter.

Wavemeter. The wavemeter employed was elementary in character, being made up of a standardized inductance and adjustable condenser connected in series with a hot wire current meter. Its indications were checked independently in absolute measure by means of a supersound interferometer devised for the purpose. Therein a sensitive flame was used to locate and count the nodes or antinodes formed in front of a glass plate that reflected the supersound thrown upon it in air from a solid quartz projector.

Press for Piezoelectric Quality. A press was built suitable to determine with the aid of a high sensitivity galvanometer the piezoelectric quality of quartz plates employed in making up specimen-projectors. Besides these, rough tests were made to determine the transverse electric effects produced by mechanically warping the quartz plates.

The following factors in the make-up or performance of the specimen-projectors were found to have a direct bearing upon the intensity and volume of the supersound emitted by the Langevin quartz supersound source-projector:

1. The irregular distribution of the intensity of the supersound source-action occurring throughout the section of all projectors having either

a. Quartz driving plates with solid metal reactors cemented on, or

b. Solid quartz bodies functioning both as drivers and reactors.

The ratio of the maximum to the average intensity of action was found generally to be about four. The areas of high output were found to be only about 1 square centimeter. Over the remaining intervening areas the intensities of source-action were always very low. The narrow regions of high source-action and of supersound output, called "high spots," would shift position widely with slight changes in frequency showing that the qualities of the driving quartz were not at fault. Such was also found by test in the press for piezoelectric quality.

Specimen-projectors were made in which the ratio of thickness of driving quartz to total thickness of quartz and metal reactors varied from 5 to 100%. All curves that expressed the electrical input and frequency or the supersound output and frequency were complicated; i.e., they had two or more maxima with minima that occurred correspondingly at the frequencies where the shifting of position of the high spots took place. The fact should be emphasized that the high spots constitute the end surfaces of columns or cores that extended through the projectors from face to face. The faces of these columns terminating in the projector surface that was in contact with the water were located by means of the small radiation pressure cylinder, held close up. Correspondingly, the opposing faces of the same columns in the top surface of the projector were located by dust images. The best of these were obtained from a solid quartz projector using on the top surface an electrolytic electrode about 2 mm deep.

Emery flour was spread uniformly through the electrolyte over the top leveled surface of the projector. Synchronous voltage was then applied to the projector and the behavior of the fine emery particles was noted. They would be promptly cleared off the high spots which were found to be directly over corresponding spots in the surface in contact with water as located by the radiation pressure cylinder.

2. The requirements of the cement used to attach the solid metal reactors to the quartz plate drivers are far too great to expect a dependable output much beyond the 1/3 watt/sq cm found by Langevin. The specifications for the cement became apparent when aluminum reactors were substituted for the steel reactors. Only the very best cement held the aluminum reactors fast. In our work, the best combination of ingredients was found to be 1 part vermilion, 1 part beeswax, 2 parts asphaltum, and 3 parts resin.

Much evidence was obtained which indicated that if the high spots could be eliminated and the projector made to work uniformly through its entire body, the requirements of the cement would be lessened considerably, and there would be a corresponding increase in the volume of supersound.

3. The intensity of supersound source-action per millimeter of thickness of the quartz driving plate was found for a given voltage gradient to increase rapidly with the total thickness of quartz used.

4. The transverse piezoelectric drive, i.e., the drive at right angles to the optic axis and in the plane of the normally prepared quartz plate, was found to be virtually as powerful as the longitudinal drive through and normal to the plate. Specimen projectors of solid quartz made up in this manner delivered substantially the same high outputs that were obtained correspondingly from solid quartz projectors cut to operate by the normal Langevin plan. This type of solid quartz source-projector permits the use of much lower driving voltages (on the order of 1/10) depending upon the thickness of the plates adopted. In addition, the study of this form of projector threw much light upon the cause of the formation of the high spots.

The evidence to date indicates that the high spots and the irregular action of the solid projectors of all types, with or without metal reactors, are due to a state of instability that would exist if the action were perfectly regular throughout the projector. Should the action in one region of the projector be slightly in excess of the action in the surrounding territory, the mechanical compressions and elongations of the driving quartz in such territory would be lessened. The effect thereof would be a further diminution of action which in turn would react on the high spot region to enhance its action. The projector behavior thus stabilizes toward the greatest attainable irregularity instead of regularity of action.

5. Solid quartz columns cut either from and at right angles to the plane of the plate driver for longitudinal action or from and in the plane of the plate driver at right angles to the optic axis for transverse action with square or hexagonal cross sections not exceeding 2 sq cm were found to deliver their outputs free of the "high spot" effect.

The intensity of supersound emitted from these columns or units is high over their entire end surfaces in direct contact with water or in contact therewith through a thin metal diaphragm. We have in this manner obtained outputs from 5-10 watts/sq cm at voltage gradients under 500 volts/mm.

In a particular case, two quartz units each 13 by 16 by 46 mm cut to operate longitudinally were bound together with thread near the end faces in contact with the water and at their middle. They were kept apart by two soft rubber separators, 1.5 mm thick and 4 mm wide, placed likewise at the middle and between the ends facing the water. At 12,500 volts or 274 volts per mm and a frequency of 86,000 cycles the intensity of supersound delivered to the water was surveyed with the small radiation pressure cylinder and found to have a maximum of 7.5 and an average of 3.26 watts per square centimeter in the water over an area of 6.75 square centimeters and, therefore, a total output of 22 watts or 7.8 watts per square centimeter of projector face. Since the output increases as the square of the applied voltage, 10 watts per sq cm of projector face would have been radiated at 310 volts per mm.

A shallow pan having a diaphragm bottom of soft copper, 0.075 mm (or 3 mils) thick, was placed over and in contact with the water in the ball-jar. The foregoing double unit specimen-projector was mounted in this pan so as to deliver supersound to the water thru the thin copper diaphragm by cementing the end faces thereto with vaseline. A maximum of 6.1 watts per square centimeter observed by the small radiation pressure cylinder was delivered to the water at an applied electric gradient of 378 volts per mm. Every part operated cold and therefore at excellent efficiency.

Individual units were frequently operated in direct contact with water at outputs of 10 to 11 watts/sq cm at which a phenomenon occurred that we interpret as cavitation. We do not know as yet whether such cavitation would occur at this output intensity when the area of the face of the built-up projector is large, say 500 sq cm (77.5 sq in.).

DESIGN OPTIONS AND LIMITATIONS

If time permitted we would have undertaken to determine the expedients that could and could not be employed to assemble an ample number of units so as to form a full-size powerful projector for practical purposes. We realize, as must all who are familiar with these matters, that initially this is a difficult undertaking. Preliminary trials indicate that the units can be bound together only in their middle, that they cannot be assembled by cementing except near their middle that they may not be immersed in oil for insulation when high voltage gradients are to be employed (i.e., 1000 volts per mm or more on account of friction and consequent excessive heating and the evolution of much gas). Through lack of time we have not been able to make try-outs of methods that appear promising for attaching the diaphragm to the faces of the units required to exclude the sea water in a practical form of projector. The little we have accomplished in this respect leads us to anticipate, however, that this difficulty can be overcome in a satisfactory manner.

Had we continued this work, the first stage try-out design for a powerful projector to be used at sea would have been made in approximate accord with the following specifications:

HIGH VOLTAGE PROJECTOR USING UNITS IN LONGITUDINAL ACTION

1. The projector units are cut square at a cross sectional area of 1.5 sq cm for longitudinal action with a length dependent upon the frequency desired, i.e., 6.5 cm for 40,000 cycles.

2. The units are assembled by cementing them at their middles in a metal rectangular mesh grid supported and insulated at its periphery by porcelain posts having the same square cross section as the projector units, but longer at the rear ends which are cemented into holes at the back of the metal projector case thus providing the necessary air insulation space. At proper intervals throughout the assembly of units, porcelain posts would be substituted for units as required for structural strength and rigidity.

3. A metal diaphragm cemented to the faces of the projector units closes the side of the projector case through which the supersound is delivered to the sea.

4. A thin metal sheet is cemented to the rear faces of the driving units that constitute the essential high voltage electrode. Suitable electrostatic guards, a high-voltage bushing for entering the case and a delivery cable, matters well understood in the technics of high voltage practice, are arranged for the high potential power terminal. The opposing low potential terminal is earthed and connection is thus made to projector case and diaphragm.

5. Specifications for the cementing of the diaphragm and high potential electrode cannot be given herein as time has not permitted the laboratory trials required for the development of a reliable cementing technique for this purpose.

PROJECTOR USING LOW VOLTAGE UNITS IN TRANSVERSE ACTION

These specifications would be much the same as those just given for the use of units in longitudinal action except for the obvious changes due to the use of the lower voltage. In these units the thin metal electrodes are mounted on their sides in lieu of their ends. Such electrodes must be mounted most firmly otherwise they will slip and cause heating, loss of output, and disintegration. Electrodes spattered on electrically in vacuo promise the best service.

If made square in section the units for transverse action at 40,000 cycles would operate at about 1/5 the voltage that would be required for operating the corresponding units for longitudinal action. Lowering the voltage to 1/10 would require double the number of transversely acting units each having a width of face of about 12.0 mm and a depth of about 6.0 mm.

Part II. Sonar Developments at NRL Before 1939

World War I suddenly ended in November 1918. At that time a number of Allied groups were working feverishly to apply the Langevin quartz-steel transducer to the submarine detection problem, and some groups were about to test this echo-ranging equipment against submarines at sea. Our own Navy saw a good deal of future promise in this ultrasonic detection method. With the new electronic tools were created in the wake of the 1918 armistice, the Navy focused its attention now on the development and measuring of underwater electroacoustic signalling. And, despite the many wartime investigators who, at the cessation of hostilities, returned to their peacetime occupations, the Navy was able to interest a few scientific workers in acoustics to carry on its program. Thus, in 1919 a small wartime group, headed by Dr. H. C. Hayes moved from the Naval Experimental Station, New London to the Naval Engineering Experimental Station at Annapolis. Here many of the audio sound problems initiated at New London were continued and further developments of the principle of binaural compensation were made more serviceable for submarine detection by audible means. This work progressed into the peacetime atmosphere of the twenties, when, in 1923, the Naval Research Laboratory was established in Washington, D.C. At that time all the sonar investigations were transferred from Annapolis to NRL.

In its new locale, the Annapolis underwater sound group, now known as the Sound Division of the Naval Research Laboratory, undertook the investigation of the various aspects of sonar. Hayes and his staff presently found themselves concerned with the acquisition of more fundamental knowledge of sound generation and propagation in the sea medium and were no longer under wartime pressure to solve the submarine detection problem immediately, i.e., the demand for quick short-cut solutions no longer existed. What did remain from the 1914-1918 submarine campaign was an impetus toward greater strides in the application of science to many branches of acoustics. It brought into sharper focus the difficulties of submarine detection by a mobile vessel at sea; it showed that self-noise and vibration of the searching vessel cannot be overcome by mere amplification of the wanted signal; and, it revealed that protection of the electronic gear against the effects of shock and vibration is really part of the overall problem of submarine detection. As an underwater sound development station, NRL was well located with respect to its accessibility to the Potomac River and the sea. Figure 1 is a bird's eye view of the U.S. Naval Experimental and Research Laboratory of 1923, which was comprised of a powerhouse, at the River's edge; a patternshop; a foundry, and a huge machine shop. Off to the side is a three-story laboratory building. In the background are the Bellevue Magazine Tower and several other buildings.

To test the numerous factors which were involved in the design and operation of antisubmarine equipments, NRL had seagoing as well as land-based facilities. For preliminary underwater tests, there were two barges moored to a dock in the Potomac River at the edge of the Laboratory grounds. These sound barges were equipped to operate as floating laboratories. When deeper water was required for certain acoustic tests the NRL sound barges were towed to the mouth of the Potomac near Piney Point, Maryland, where the water was about 50 feet deep. In this area it was possible to operate at ranges of 15-20 miles between the sending and receiving barges. For underway sea trials of sonar developments, the NRL Sound Division acquired the use of two World War I patrol craft known as Eagle Boats. These steel vessels were some 200 feet in length and were equipped with sound wells for experimental testing at various speeds. The USS SEMMES, a destroyer, was later added to the sonar experimental fleet. Water facilities at the shore laboratory, consisted of a couple of small mobile tanks in addition to a concrete tank (100 x 9 x 7 feet) constructed in 1932 in the subbasement of Building #2. One end of this tank was shaped as a parabolic reflector for focusing ultrasonic waves in water. Experiments were conducted in this tank on zone-plates, rubber-castor oil lenses, and the effects of various absorbers in water.

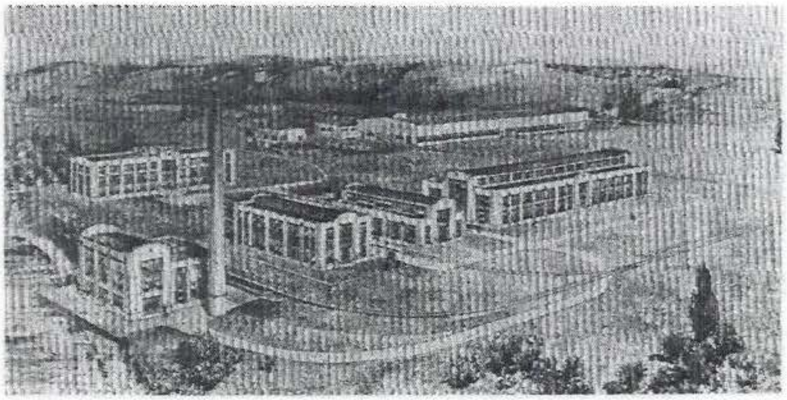

Fig. 1. United States Naval Research Laboratory as it was in 1923

THE QUARTZ-STEEL SANDWICH

A major activity of the NRL Sound Division in 1923 was the study of the quartz-steel ultrasonics for the purpose of improving the Langevin apparatus so as to make it a more effective weapon against submarines. This effort continued under high priority for several years, and when I joined the Sound Division of NRL in June 1927, it seemed to me that the entire Division staff was involved in this task. The work performed by this group from 1923 to about March 1927 on the quartz-steel transducers is described in two comprehensive NRL reports[1] dated, respectively, January 1926 and March 1927; they were submitted to the Chief of the Bureau of Engineering and were signed by H. C. Hayes. These reports discuss the general progress in the development of the quartz-steel apparatus; the comparative tests of the units created and designed at NRL against those procured from France; and, the changes introduced in the different component parts which contributed to the improved operations. For example, serious attention was concentrated upon the laboratory techniques for cutting, grinding, and orienting quartz crystals to the extent that NRL in the mid-twenties, set up a pilot plant for mass-producing quartz crystal blanks. And, by the use of carefully selected crystals, placed between the steel plates in a regular arrangement (as shown in Fig. 2(b)), an improvement was produced

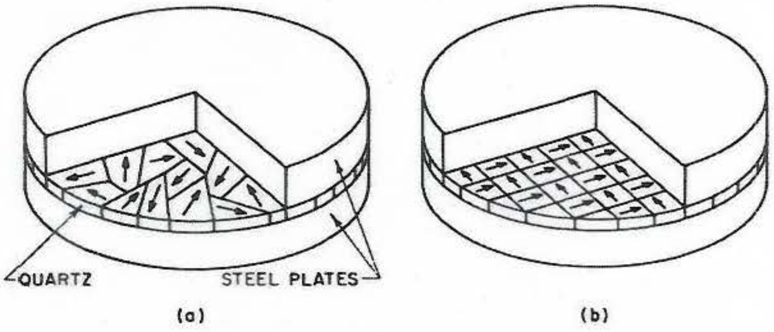

Fig. 2. Quartz-steel sandwich transducer with (a) random distribution of crystals and (b) regular arrangement (diameter about 15 inches)

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[1] To be found in the Federal Record Center, Box #81, Job #7184, Alexandria, Virginia.

in the sound output of the transducer. E. B. Stephenson[2] found that the NRL crystal transducer radiated a stronger acoustic signal into the water than did the French ultrasonic transducer under similar conditions. The stronger signal of the NRL devices was attributed to the precise alignment of the quartz crystal axis, as shown in Fig. 2(b). Stephenson mentions a preference for the regular arrangement of the crystal mosaic as developed at NRL over that of the French, where the distribution of the Y-axis direction in the quartz was random (see Fig. 2(a)). He states also that the electronic generator (the driver which supplied power to the crystal transducer) built at NRL was somewhat more efficient than the one procured from France.

RESEARCH CLIMATE AT NRL

Thus far (1928), while the NRL Sound Division was still devoting its time largely to improvements and redesign of the original Langevin echo ranging apparatus, the French were now marketing this gear to all shippers as depth finders or depth sounders. These NRL developments, known as the XL (and a few were designated as QA) ultrasonic equipment, proved useful on submarine installations as well as on surface craft, even though the ranges were not great enough to serve the Navy's ultimate purpose. (Part III of these Notes, which will appear in the October 1966 issue of the Journal, will, in reply to a query from the Naval Historical Division, reveal the important details of the first official Navy use of Sonar on a real problem.) The Sound Division considered the development of the XL apparatus as its first major contribution. And, according to the Naval Consulting Board, this was precisely the kind of work the Laboratory was supposed to do, e.g., to improve and develop an equipment for more effective naval service application. As the late Dr. A. H. Taylor[3] (the Navy's Chief Physicist at that time and one of the principal scientists who was at NRL from the beginning) describes the plans of the Laboratory in those early days: ". . . It is plain that most of those participating in these early discussions had in mind work of an engineering rather than of a purely scientific type. There were not many naval officers who knew anything about the venture at NRL, and of those who knew about it only a few were thoroughly sympathetic." Also, the Naval Consulting Board specified "... that a naval officer should be in charge (of the Laboratory) and ... under him should be naval heads of broad experience in Laboratory science, and under them should be staffs of civilian experimenters... ." On the other hand, during the early formative years at NRL, a number of scientists and engineers were attracted to the Laboratory by the promises of the Board: "... At this Laboratory (NRL) there will be concentrated all the research of the Navy."

Another interesting comment on the underwater sound research at NRL prior to 1940 is this:[4] "The work (at NRL in the twenties) was costly and funds for scientific research in the military field were scarce. The expense had to be born by the Navy, and the Navy, in the era of the Washington Naval Conference, was having financial difficulties. If it were possible and popular to sink battleships, it was even easier to wreck a research program. The underwater

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[2] To be found in the Federal Record Center, Box #81, Job #7184, Alexandria, Virginia.

Concerning piezo crystals, it should be noted here that during the early years of NRL existence, the staff was very small and could hardly accomplish all the developments that were expected of them. Hence the employment of university experts in certain disciplines for the summer months was a tremendous help to some groups at NRL. Two eminent piezoelectric crystals experts — Drs. Walter G. Cady and Karl S. VanDyke of Wesleyan University — did some quartz-crystal work at NRL in the summer of 1924. This quartz-crystal research aided not only in the sonar applications but helped also in the Navy's communication systems, i.e., high frequency control calibration, precision radio measurements, and the like.

[3] A. Hoyt Taylor, "The First 25 Years of the Naval Research Laboratory," NAVEXOS P-549 (Apr. 1948), p. 12.

[4] John Herrick, "Subsurface Warfare, The History of Division 6, NDRC," The Department of Defense, Research and Development Board, Washington, D.C. (Jan. 1, 1951), p. 7.

sound program was starved for funds. Scientists had to be imbued with both patience and patriotism to put up with the wages the Civil Service scale allowed for first-rank talent. But the Navy Department Bureau of Engineering, which in 1940 became part of the present Bureau of Ships, went energetically, if slowly, ahead."

Whatever may have been the intent of the Consulting Board or the plans of the Navy Department for utilizing the Laboratory after it was dedicated (July 1923), the initial organization of NRL represented a radical departure in naval administration of scientific research. Practically the entire burden of research and technology was placed in the hands of civilian scientists; and, fortunately, the original technical staff was not only of high caliber scientifically, but they had also some years of experience in dealing and working with various naval officers. This situation made for smooth relationships and congenial activity. Of course, the operating needs and requirements of the Fleet were always subject to the advice and recommendations of the naval officers. Nevertheless, as mentioned by Taylor and as substantiated by my own experience, the basic principle of conducting research and development during peacetime solely by civilian scientists has been supported by every Naval Director of NRL from 1923 to date. Creativity and innovation were not only tolerated by the naval staff, they were encouraged and rewarded in many different ways. It was in this sort of scientific climate that the NRL Sound Division performed the various projects about to be described. Generally, that climate improved with time. Even during the depression, the officer attitude toward science continued to be increasingly favorable.

In retrospect I have often wondered how the NRL Sound Division accomplished what it did in the twenties and thirties. When I was added to its staff in 1927, the group of engineers and scientists then totaled five (Hayes, Stephenson, Dudley, Struthers, and Klein). This group, supplemented by several subprofessionals, constituted the Navy's sole in-house capability and competence to perform research and development in the field of underwater acoustics. It was the responsibility of this group to see to it that the most effective underwater communication and detection equipments were available to the Fleet. Moreover, the Government's ability as a sophisticated buyer in the field of R&D work from private enterprise depended almost entirely upon this small group. In addition, the Navy materiel bureaus frequently sought guidance and recommendations regarding test and evaluation of acoustic equipment for specification compliance. And it was considered in the best interest of the Navy generally, and the Laboratory in particular, to have various NRL scientists ride different ships in Fleet maneuvers. This was an opportunity to observe and study, first hand, the operational problems in the Fleet. Upon his return to the Laboratory, each scientist would report his findings and his suggestions.

Apart from these supernumerary tasks which the Sound Division attempted to perform, it still seemed logical to me to find in the record of the early thirties that NRL was carrying two basic and major acoustic problem assignments from the Bureau of Engineering (now the Bureau of Ships). Both were specific. The first was to conduct research and development to provide information and technology for the detection and location of submarines. Whether by listening or echo-ranging, all types of ships should be able to detect submarines. The second was to develop means for analyzing ships' noises; methods for quieting them; and to find the sources of underwater sound generated by naval vessels. Their contributions to the general background of noise picked up by the listening or echo detection apparatus was to be eliminated so as to increase the range and bearing accuracies of the submarine being searched. Work related to these problems is bound to crop up in these notes. The Laboratory has been prosecuting such efforts since the mid-twenties, with or without a specific assignment. They were among the primary requirements in the establishment of the Laboratory.

The above paragraphs might explain in part why the NRL Sound Division files of the twenties and early thirties contain so many incomplete reports; and why I found so many of the personal log-books (including my own) showing unfinished writeups of projects undertaken, even though the tasks were actually carried through to completion. (It should be noted that every engineer and scientist at NRL was issued a numbered notebook for recording ideas, innovations, and, the progress of tasks under development. The log-book is Government property and the scientist or engineer is charged with its custody.) This lack of completeness in record or report indicates hurried crash programs; it usually portrays the jumping from one job to another, as if we were constantly fighting brush fires, or that we were forever engaged in meeting deadlines. From my present vantage point it seems that this situation really existed. Even as late as 1936, we had only a total of 11 scientists and technicians in the Sound Division and each was responsible for more than one job; however, all of us worked as a team when a particular task demanded concentrated effort.

SYNTHETIC CRYSTALS

The development of Rochelle salt piezoelectric crystals as underwater transducers was my first long-range mission at NRL. Hayes indicated to me how important this objective was to the Navy, notwithstanding the improvements which were already effected upon the Langevin quartz-steel echo-ranging device. Many reasons were advanced for undertaking the synthetic Rochelle salt crystal development. These crystals possess the highest piezo activity known. They could be synthesized and produced in this country, while piezoelectric quartz was then procured mostly from other countries, and the sources were becoming unreliable. Hence, the Navy Department, in preparation for emergencies, looked into various potential uses of material which could be produced in this country. A great deal of attention was focussed upon this substance for submarine detection purposes during World War I. At that time, however, these efforts proved to be of little practical utility. Numerous experiments in the audible frequencies were carried out on different forms of Rochelle salt crystals during World War I. Organizations like Western Electric Company perfected (in 1917) a method for growing a particular type of Rochelle salt crystal[5] known as a composite crystal and made numerous applications of it to sound. Also, the General Electric Company grew clear[6] crystals which were used for experimentation. But soon after World War I both of these companies discontinued further development of Rochelle salt crystals, particularly in their application to underwater sound. The main reasons advanced for this abandonment were: (1) The crystals are quite fragile, cannot be exposed to the atmosphere, are not practical to handle or machine, and are very soluble in water; (2) Sharpness of tuning of the crystals is prevented by their internal dissipation; therefore, they were not considered adaptable to high frequency sound use.

Despite these seeming difficulties, NRL maintained a serious interest in Rochelle salt crystals and even experimented with different methods for growing them.[7] The NRL records in the National Archives Building (Box #100) show that considerable work was conducted on these crystals. There is mention in these records of some results of the Rochelle salt activities in the mid-twenties at the Laboratory. This was a part of a program for the educational advancement of NRL employees to conduct their research work using Laboratory facilities. In May 1925, an NRL employee, Edwin Lee White, submitted an M.A. thesis to George Washington University on the velocity of sound (in air) as determined by Rochelle salt crystals at high frequency 60 to 570 Kc. A Pierce interferometer with a moving reflector was employed as the measuring instrument. Acknowledgments were made to Drs. T. B. Brown, Professor at George Washington University, and H. C. Hayes, J. M. Miller, and E. B. Stephenson of NRL. Hayes regarded the development of these synthetic crystals of tremendous importance to the Navy. He suggested that this undertaking would be a challenge as well as an opportunity for me. It was then up to me to devise further improvements in growing and processing these crystals for practical application in underwater sound.

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[5] A. M. Nicolson, "The Piezoelectric Effect in the Composite Rochelle Salt Crystal," Trans. Am. Inst. Elect. Eng. <u>38</u>, 1315-1333 (1919).

[6] R. W. Moore, "A Method of Growing Large Perfect Crystals from Solution," J. Am. Chem. Soc. <u>41</u>, 1060 (1919).

[7] For general methods of producing and growing Rochelle Salt Crystals, see W. G. Cady, Piezoelectricity (Dover Publications, 1964), Vol. 2, p. 522.

At the outset, in 1927, it was my good fortune to find, at NRL, a small chemical laboratory in which Rochelle salt crystals were being produced by a retired Chief Petty Officer, Milton U. Hartmann. He was very interested in this crystal project for naval use, and we joined forces in the growing and processing operations. We grew some crystals (about 2 inches in length) and used them as experimental generators and receivers of underwater sound. There was much to learn about handling, cutting, electroding, and cementing the crystals before putting them to use. Progress was slow until we discovered (1928) that the Brush Laboratories in Cleveland were producing much larger crystals than we were, and by a far more efficient process. Forthwith, the Navy confined its efforts to the sonar applications of Rochelle salt, while Brush supplied NRL with the required crystalline material of different sizes and shapes. This ample supply of crystals enabled us at NRL to investigate the crystallographic orientation of the crystals and their electrical and physical properties under diverse conditions. Even the so-called objectionable property of Rochelle salt mentioned earlier, e.g., internal dissipation which prevented sharpness of tuning, was utilized in the design of an untuned transceiver without any noticeable effect upon its efficiency. In the operating ultrasonic ranges of these untuned transceivers, the Rochelle salt compared most favorably with the highly tuned quartz instruments (XL) at the resonant frequencies of the latter and far excelled them off their resonant points. The superior quality of a non-resonant instrument, like Rochelle salt, made it possible for a practiced listener to be able to separate and identify a submarine from another vessel and to distinguish these from the propellers of his own ship. Furthermore, Rochelle salt crystals of a given frequency when backed by a metal plate of predetermined acoustical thickness were made into transceivers of quite resonant characteristics in the workable ultrasonic range. According to H. C. Hayes, the development of Rochelle salt piezoelectric crystals as underwater transducers constituted the second major contribution of the NRL Sound Division. He made this comment in 1930 when the JK transducer (which used Rochelle salt elements) was completed and used as a receiver of ultrasonic propeller noise from a submerged submarine. No time was lost, however, in demonstrating that the JK listening device when installed on a submerged submarine enabled that submarine to track a surface ship and gain a much greater advantage on the latter than if the situation were reversed. But the primary objective of most sonar developments was still the detection and location of enemy submarines.

Returning to the Rochelle salt developments — there were numerous laboratory experiments conducted in tanks as well as extensive tests on the barges in the Potomac River and on the Eagle boats at sea. All the results indicated that these crystals had suitable properties for the generation and reception of underwater sound; however, the high water solubility of Rochelle salt required a practical water-tight housing which would prevent any seawater from contacting the crystalline material. Moreover, to radiate or receive sound energy to or from the sea most effectively, it was essential that the Rochelle salt elements should vibrate in a liquid medium which has acoustical properties that are identical with those of sea water. In addition, the liquid inside the housing must not affect the Rochelle salt either chemically or physically and, at the same time, the housing should maintain an impervious wall between the liquid inside and the sea outside. This wall in the transducer housing must be capable of transmitting all the sound energy incident upon it. That is, it must play the role of a sound window without changing or distorting the acoustic waves or their energy content in any manner whatsoever. Our tests indicated that pure gum rubber approached these requirements, and the idea was to find a composition of rubber so as to obtain complete transmission through it. This task led to the development and manufacture of Rho-C rubber, about which a few remarks may be of interest to the reader.

DEVELOPMENT OF SOUND-TRANSPARENT RUBBER WINDOWS

Today it is very unlikely that a Government request for industrial help in the development of a product would meet with a negative reply. Perhaps the modern immense body of knowledge concerning the structure of matter and its material properties would prevent the offhand judgment about natural rubber we received from industry in those old days, but that was nearly 40 years ago. In 1928 NRL sought the cooperation of the rubber industry to help the Navy develop a rubber compound through which sound waves would be transmitted without change. At that time most of the technicians in that industry were convinced that rubber absorbs rather than transmits sound waves and professional engineers of many years standing felt that a rubber sound window was not a practical undertaking. The decision not to try the rubber window was made despite our numerous feasibility studies at the Naval Research Laboratory. Nevertheless, among these individuals were some who wanted further evidence of the NRL findings. To that end, an acoustic interferometer similar to that described in Phys. Review[8] with all its accessories was taken in 1929 to the Goodrich Laboratory in Akron, Ohio, to demonstrate how the sound transparency of rubber was measured. A great many compounds were made up by Goodrich and tested in the interferometer system. Finally, a compound called "RHO-C"[9] rubber was developed, which had the desired physical characteristics. Toward the end of 1929 or early 1930, the U.S. Rubber Company also had rubberized a transducer case with a window in which a Rochelle salt transducer was tested.

In justice to the rubber industry of that era, it is necessary to recall the high order of security which prevailed at NRL in the late twenties and early thirties. Substantially all technical programs then under study at the Laboratory were considered to be of a military nature. Hence, only certain phases of a problem could be discussed with a prospective contractor. No doubt this situation was a carry-over from World War I when the Naval Consulting Board decreed that "Secrecy should be a governing factor in the work of the proposed Laboratory." At any rate, on our visits to the rubber industries to present our window problem, we were quite restricted as to what relevant scientific or engineering information we could disclose; these conditions tended to handicap the rubber industry in its development attempts until clearances were established.

As one reflects on the above naval attitude regarding disclosures and contrasts this approach with the current views of the Office of Naval Research and other Defense Agencies on such matters, one is impressed with the tremendous progress that has been made in procedures for negotiating research and development contracts.

As an example, the ONR pamphlet on contract administration states in part: "It is recognized that research cannot be purchased under standard specifications such as are used for material goods.... It should be remembered that Secret work is costly in time and money and is often of inferior quality... ."

By 1930, a water-tight crystal housing was designed and perfected (Fig. 3). With the cooperation of the B. F. Goodrich Company, there was developed a sound transparent window, in a steel-rubber case, which transmitted practically 100 percent of the sound entering or leaving the window. The Rochelle salt crystal array (Fig. 3) was also improved and made more efficient as an untuned transceiver. That is, it was capable of emission and reception of a wide spectrum of ultrasonic frequencies without any noticeable effect upon its efficiency. To begin with, this transducer, known as the JK projector, was used solely as a listening device and was installed on ships in 1931. At the same time adaptations of Rochelle salt were conducted so that these crystals could transmit considerable power into the water and the device could be used as an active sonar. (This was called the QB.) The Rochelle salt crystal transducers were, in all cases, surrounded by evacuated castor oil. This oil has the acoustic properties approximating sea water as well as the RHO-C rubber window. In fact, the QB echo-ranging equipment (Fig. 4) gave excellent performance in the Fleet both for detection and for location of submarines. Commercial production of the QB gear was begun in 1933 by the Submarine Signal Company of Boston. This echo-ranging system became substantially the sonar unit of the Fleet.

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[8] Elias Klein and W. D. Hershberger, "Supersonic Interferometers," Phys. Rev. 37, 760-774 (1931).

[9] The expression "RHO-C" is a registered trade mark of the B. F. Goodrich Company. RHO-C derives from "ρc" the condition necessary for acoustic matching where ρ is the density and c the velocity of sound in the medium.

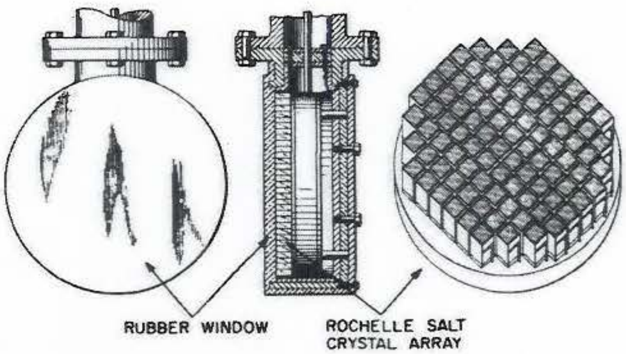

Fig. 3. Rochelle salt crystal array (JK) (end and side views, diameter -- 15 inches)

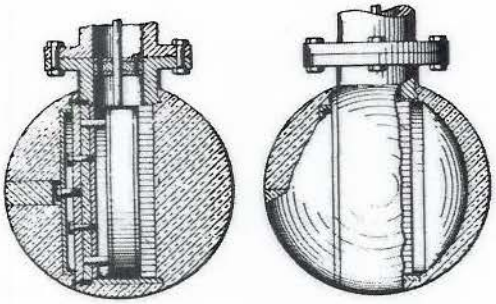

Fig. 4. Rochelle salt crystal echo ranging device (QB)

Its chief drawback was the background noise created about the transducer as the ship moved through the water at speeds above 15 knots. To eliminate this source of noise and make possible submarine detection at higher searching speeds, a streamlined dome was placed around the transducer. This dome-shield housing, a British development, reduced much of the turbulence about the transducer and improved the listening conditions at higher tactical speeds.[10]

MAGNETOSTRICTIVE TRANSDUCERS

While these piezoelectric crystal transducers were being developed, and appeared very promising in their effectiveness, it was still most important for the Navy to be constantly on the lookout for new ideas and to keep abreast of novel devices, materials, and improved methods for tracking submarines. In 1927, Professor G. W. Pierce of Harvard University had shown the possibility of using magnetostrictive materials to generate ultrasonic underwater signals. Hayes saw a likely advantage in employing the magnetostriction concept for generating a much more powerful signal in the water than could be done with quartz or even with Rochelle salt. Hence, he invited one of Pierce's students, E. B. Dallin, to come to NRL and study various magnetostrictive materials to serve as underwater ultrasonic oscillators. Dallin experimented mostly with thin-walled nickel tubes and designed a number of different oscillators in the region of 25 kc. In his 2 years (1927-1929) at NRL, Dallin made considerable progress with various magnetostrictive materials. He built a magnetostrictive depth finder as well as submarine detection apparatus

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[10] It may be noted here that in 1918 the American Attache in Rome, Knox, suggested that a streamlined mechanism be placed about the Langevin quartz-steel transducer -- see Part I of this article in JUA(USN) 16, 10 (1966).

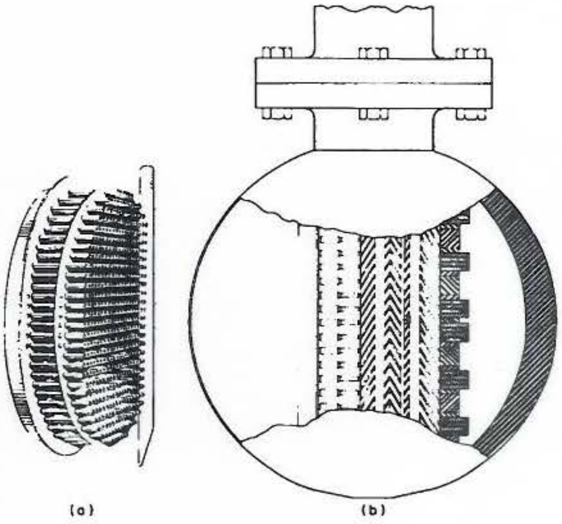

Fig. 5. Combination of two transducers in one housing: (a) Magnetostrictive tube array (QC) with its backing plate. This particular assembly was built by the Submarine Signal Co. and was composed of about 600 tubes fastened to the plate. (b) Combination of two projectors, on the right is a Rochelle salt (JK) listening device with castor oil and the sphericai rubber (Rho-C) window; on the left is a magnetostriction transducer with ethylene glycol-distilled water in front of the radiating plate and a thin stainless steel window.

and contributed much to our knowledge in this area. This work was continued by others at NRL (e.g., R. S. Baldwin and Delmar Hershberger and later by R. L. Steinberger) on low priority until about 1932 when a more serious effort was made in this direction. A number of industrial firms were beginning then to experiment with magnetostrictive materials for underwater signaling, and the Laboratory had not only to monitor these developments for the Navy but had to keep pace with new and useful ideas on antisubmarine devices. Hence, beginning in 1932 NRL produced a wide variety of magnetostriction transducers of different materials, different shapes, and for different applications. In fact, as NRL developments progressed a number of the echo ranging devices were like those shown in Fig. 5; housed in one spherical case were two different types of transducers: one side operated on the magnetostrictive principle (QC) while the other side operated piezoelectrically (QB). These two different transducers (usually, QB and QC) permitted (1) scanning of both sides of the ship during a period of search, (2) comparison of the two types of transducers on a single target, (3) employment of the JK and QB (Rochelle Salt) as a receiver of propeller sounds while the QC (magnetostriction) was employed as an echo-ranging device, and (4) use of both transducers for echo-ranging on different targets but at different frequencies so as to eliminate interference of received signals. Of course, the dual projector assembly when later placed in a streamlined housing had the above advantages plus the advantage of operating at higher speeds.

ABSOLUTE ACOUSTIC STANDARDS IN LIQUIDS

Most of the underwater acoustic measurements made at NRL during its first decade were quantitative comparisons. For example, to measure a newly developed generating device's relation to its immediate predecessor, it was necessary to compare the signal intensities of the two units under identical conditions. Such comparisons were usually made with an audiometer box or with a calibrated amplifier and an attenuator. The relative response of an underwater acoustic receiver was similarly evaluated. Progress on the development of operational gear for shipboard use was assessed by comparing the performance at sea of the new transducer with the most recent one which was accepted for service and which automatically became an interim standard. By 1933-34, the NRL Sound Division had accumulated considerable experience in design and development of diverse sonar equipment for the Navy. In addition, the knowledge gained by the Division from the various problems it tackled helped NRL realize that the need for a definite acoustic reference standard. Also, more accurate calibration and measurement now appeared essential to the progress of the Navy's submarine program. It was, therefore, decided to undertake the development of a practical standard for evaluating underwater transducers in the Laboratory as well as on shipboard.

This was in the early thirties before the reciprocity methods were available for useful applications. Following the earlier investigations which were carried out during World War I by Langevin, Boyle, Wills, and the Stanford group, I regarded the concept of radiation pressure as a likely approach to the solution of this problem. The latter was assigned to me to work on as time permitted; and, for several years, a variety of methods and techniques were explored for the purpose of measuring the absolute intensity of ultrasound in liquids. A description of the final radiation pressure apparatus which permits a dual check of the basic measurements involved, is outlined in JASA.[11] This arrangement also made possible hydrophone calibration for secondary standards (Fig. 6). Two independent torsion balances measured the radiation pressure of the generating acoustic source. Greater accuracy and reliability were provided, however, by the spherical torsion pendulums because of their geometrical simplicity and because the diffraction theory about a sphere was well known. Moreover, by the aid of the spherical torsion balance in a stationary field in the specially constructed cylinder, it was possible to calibrate a tourmaline crystal microphone as a secondary standard. (Figure 7 shows the author using this special apparatus.)

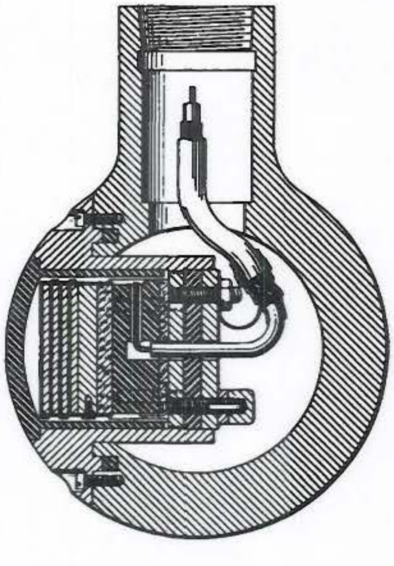
Fig. 6. Heavy steel sphere (6-inch diameter) housing Tourmaline crystals to be used as a secondary standard

Practical use was made of the calibrated tourmaline crystals which were inserted in the center of a quarter-wave plate that fitted into the end of a horizontal rigid cylinder. The latter was about 6 inches in diameter and 15 inches long. Great care was exercised to eliminate radial oscillations in the cylinder. Hence, the design of the cylindrical enclosure was in reality a tubular sandwich, composed of brass-lead-bronze which formed a single tube of over 1-1/8 inches thick after it was machined. The inside brass layer was lined with cork to help eliminate radial oscillations at certain frequencies.

The tourmaline secondary standard was soon adapted as a measuring instrument to determine the acoustic performance specifications of ultrasonic transducers which were about to be installed in naval vessels. In 1936-37, the USS SEMMES was especially equipped[12] for making such tests by means of a calibrated tourmaline crystal, designated as the T-3 device. Its vertical supporting shaft passed through the hull of the SEMMES slightly aft and outboard of the port transducer mounting facility in the Main Sound Room. When the T-3 was adjusted to be on the principal axis of sound radiation from the projector under test, the distance between their faces was 102 inches. Similarly, if the test projector were mounted on the starboard shaft of the Main Sound Room, this distance would be 137 inches. The T-3 system consisted simply of a sound-sensitive set of calibrated crystals, a 12-foot single-conductor shielded cable, and a vacuum tube voltmeter, With this array of equipment, NRL was able to provide the Navy with

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[11] E. Klein, "Absolute Sound Intensity in Liquids by Spherical Torsion Pendula," J. Acous. Soc. Am. 9, 312-320 (1938) and "Absolute Sound Measurements in Liquids," 10, 105-111 (1938).

[12] E. Klein and P. N. Arnold, "Equipment and Procedure for Standardized Projector Performance Tests," NRL Report 1582 (Dec. 1939).

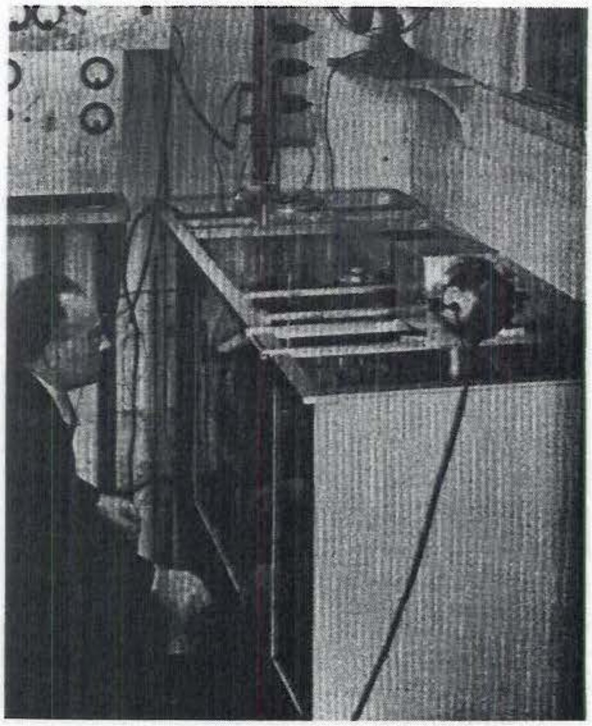

Fig. 7. The author using the apparatus to measure absolute sound intensity in water in the U.S. Naval Research Laboratory. Picture taken from Journal of Applied Physics 10, 8 (1939) article entitled "The U.S. Naval Research Laboratory" by Ross Gunn.

a sound intensity meter in the frequency range of from 15 to 40 kc for determining the acoustic performance characteristics of shipboard generators and receivers and to assess their compliance with specifications.

The performance of the T-3 equipment on the SEMMES proved so satisfactory that the Bureau of Ships requested NRL to develop a similar portable testing instrument which could make periodic determinations of the acoustic gear on destroyers. For that purpose, NRL prepared for service use the MODEL OL PORTABLE TESTING EQUIPMENT.[13] The Model OL was designed to attach temporarily to a destroyer carrying ultrasonic echo-ranging equipment in full operation. The instrument was supported rigidly at the bow of the destroyer in a V-shaped steel structure which was made to fit the stern of any destroyer. Details for attaching the OL gear are given in Ref. (13). At this time I propose only to outline roughly the use of the OL equipment on a destroyer for checking the sonar gear.

Let us assume that the OL instrument is already mounted on the bow of a destroyer. Its vertical line is parallel to that of the destroyer; its receiving crystal array is at the proper height below the keel of the ship; and we are now able to train the instrument so that its pick-up face is looking aft at the projector to be tested. The perpendicular distance between the two

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[13] P. N. Arnold, "Instructions for the Installation and Operation of Model OL Portable Testing Equipment," NRL Instruction Book RA 60A 201A (June 1941).

sound faces under consideration is now about 70 or 80 feet instead of the approximately 7 to 9 feet we had on the SEMMES. This means that the acoustic projector energy falling on the array of crystals at the bow is reduced roughly to 0.01 of that on the SEMMES. For precision measurements, this distance between projector and receiver generally requires amplification of the received signals. In addition, the calibrated receivers which the Bureau of Ships ordered for checking the sound output of the sonar equipments on different types of ships were to be manufactured in considerable numbers; and the availability of uniform quality of piezoelectric tourmaline was quite limited. Hence piezoelectric quartz instead of tourmaline was employed in the OL equipments. This meant that the sound pick-up assembly consisted of a quartz crystal array and an amplifier in the steel case, as shown on sheet 67A of the Instruction Book RA 60A 201A.

ELECTRODYNAMIC TRANSDUCER

By this time, 1933-1934, a number of Fleet destroyers as well as submarines were equipped with ultrasonic listening and echo-ranging systems. The detection range of the QB or QC gear was only about half of what the Bureau of Engineering had expected and for that reason we were still seeking a more intense source. Hence, NRL undertook the development of an electrodynamic type of underwater transducer (see Fig. 8). The late Prescott Arnold designed and studied several models of this type of projector.[14] The models varied from a single ring and one magnetic gap, to eight concentric rings and gaps. They all operated within the frequency range of 23-25 kc. Each vibrating head with its concentric rings was machined from one piece of aluminum alloy metal. The magnetic "pot" with its concentric gaps was similarly made of one casting.

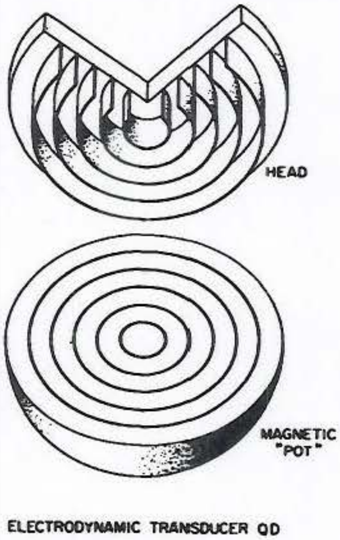

Fig. 8. Electrodynamic type of underwater sound projector (QD)

After investigating at the Laboratory the different models of the electrodynamic transducer, designated as XQD-1 ....XQD-4, a comprehensive set of sea trials was arranged for them on the USS SEMMES and the USS S-20 acting as a target submarine. These tests conducted in July 1937 compared the operating characteristics of two electrodynamic models, XQD-3 and XQD-4, with the then latest service units of the QB and QC projectors. The XQD proved superior in its ability to generate an ultrasonic signal of cavitation amplitude when submerged to 12 feet; and by virtue of its more powerful signal echoes and its high mechanical selectivity, a target could be detected by it at higher speeds of the listening ship. The signal to noise ratio of the XQD was thus much higher than the other types of transducers tested during this period on the USS SEMMES. The XQD proved to have some other advantages (see Ref. 14). Yet, the conclusions drawn from these extensive tests were: The XQD had been developed by Arnold to a point where its operating limits could not be materially extended because of cavitation, even with reduced driving power and increased efficiency. It also proved to have one serious weakness in that the intensity of the secondary maxima were so high that an unskilled operator might mistake their response for the main beam. No doubt, it could have been possible to concentrate the sound energy in the main beam if a new design were undertaken and a study made of amplitude and phase relations of the radiating face. Such changes,

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[14] H. C. Hayes, "Report on Sound Research and Development with Particular Reference to Tests on the USS SEMMES on July 6-28, 1937," NRL Report S-1404 (Oct. 1937); and "Development of Electrodynamic Type of Underwater Sound Projector," NRL Report S-1514 (Feb. 1939).

however, would not materially increase the signal intensity beyond the present maximum which reached cavitation, unless the face area was increased considerably.

THE SELF-NOISE PROBLEM

This series of tests on the SEMMES and their interpretations, as described in Ref. 14, brought about several noteworthy changes in the Sound Division's attack on its major problems. For more than a decade the Division had pursued with high priority and great zeal the development of underwater ultrasound gear to detect and locate submerged craft. It made available to the naval service a good variety of echo-ranging devices. But even the most powerful signal generated was unable to detect the target when the listening ship was underway above 15 knots. Perhaps insufficient attention was paid to other relevant subsurface problems which were occasionally tackled by the Sound Division Staff on a shifting priority basis. It now appeared very likely that a better knowledge and understanding of the sound transmission vagaries of the sea could be realized and that reducing the noise on the searching vessel would contribute as well to the detection range of most targets. It was, therefore, fully understood that progress in submarine detection and location depended on the solution of these assigned problems: (1) "Sound Research and Improvement" and (2) "Reduction of Sound Generated in Naval Vessels." By concentrating on (1), the signal strength of the transducer was increased, and thereby the echo intensity relative to the masking background was enhanced; while (2), which was generally of lower priority, made progress slowly heretofore. Hence in the tests on the SEMMES in July 1937, NRL attempted to carry out both (1) and (2). The availability of some eight different transducers for test and evaluation presented an opportunity not only to assess and compare these devices among themselves, but also to determine the sound created by the SEMMES underway and to analyze the contribution of the target submarine SS-S-20 to the general background of noise picked up by the echo detection apparatus. Moreover, it was possible at this time to make all the measurements in absolute units. The report states, "It may be noted that this report is the first, in this country at least, to record measurement of the absolute intensity of underwater sound signals."

The studies made of problem (2) and, some of the results obtained will be discussed in Part III of these Notes.

A UNI-CONTROL SYSTEM FOR SOUND LISTENING AND ECHO RANGING[15]

Although most of the Sound Division efforts were concentrated on research and technology of underwater acoustics, considerable work was done on the electronic circuitry which was essential to the effective operation of the sonar equipments. The following is one example of the many similar investigations which were conducted in the NRL Sound Division. A convenient and important electronic element in the underwater sound system was devised in 1937-38 by W. W. Wiseman in the form of a uni-control device. This device proved of great help to the operating personnel. It consisted of a transmitter and a receiver-amplifier which could be tuned by a single control through the frequency range of 5-40 kc. In order that the variable frequency of the transducer be simply and easily accommodated, certain unique features were necessary in this electronic unit. They were: (1) a single tuning control for the transmitter and receiver, keeping them electrically interlocked on the same frequency; (2) unlimited continuously variable frequency range; (3) frequency stability inherently high (0.1 percent of ultrasonic frequency); (4) controllable transmitter frequency displacement (swing with no moving parts); (5) continuously variable power amplification of more than 20 db; (6) sharply tuned radio frequency; and (7) maximum usable receiver gain.

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[15] W. W. Wiseman, "Report on A Uni-Control System for Sound Listening and Echo Ranging," NRL Report S-1504 (Dec. 1938).

SINGING PROPELLERS

Since the NRL Sound Division was the only research and development group in underwater acoustics available to the Navy at that time, this group had to tackle a large variety of problems in the field of sound and vibration. One such task which the Division was requested by the Bureau of Engineering to undertake proved of major importance to our Navy. In compliance with this request, four members of the Sound Division Staff (Hayes, Klein, Arnold, and Curtis) boarded the USS YORKTOWN on 1 December 1937 to investigate the noise and vibration in existence there. We soon learned that earlier in 1937, while the USS YORKTOWN and the USS ENTERPRISE[16] were undergoing acceptance tests, serious vibrations were observed in the afterbody of each carrier. These stern vibrations were so severe throughout the speed range of 8-15 knots that it was considered dangerous for planes to land on or take-off from their decks while steaming at these critical speeds. Moreover the intensity of noise and vibration not only disturbed the sleep of ship's personnel in their quarters aft, but the shaking was so violent as to throw a man out of bed in the sick bay on the fifth deck. Also, the deck in the Chief's quarters, adjacent to the sick bay, vibrated to the extent of numbing a man's feet so that they would not support him.

These vibrations were attributed to a variety of causes. Gear teeth irregularities were mentioned; some talked of shaft friction "bearing noise" or "squeals"; the turbine and reduction gear casing were suspect; and much trial-and-error replacement of machinery was done by and for the contractor in order to eliminate these vibrations at the stated critical speeds. These vibrations persisted irrespective of the changes or replacements that were introduced into the ships. The solution to this problem was brought to light after the NRL group analyzed the factors which contributed to the cause of the vibrations. Both theoretical and experimental studies indicated that the source of the strong stern vibration was not located within the ship, but that it originated in the propellers (four in number) or their bearing struts. The analysis showed that a predominant frequency of 140 cps persisted throughout the speed range of 8-15 knots with about equal intensity, whether the ship was driven by propellers 1 and 4 or by propellers 2 and 3, operating in pairs. Moreover, the 140 cps could not be generated by torsional vibrations of the propellers on their shafts since the lengths of the propeller-shafts are quite different for the two pairs. And, the dimensions of the struts supporting the after bearings of propellers 1 and 4 differ considerably from those supporting propellers 2 and 3. Hence, the conclusion that the source of the 140-cycle vibration could not be in the struts. Thus, by a process of elimination based on acoustic measurements made within the YORKTOWN, it was concluded, tentatively, that the vibrations were caused by "singing propellers."

Space does not permit me to reproduce the analyses, the arguments, and the tests which were involved in the solution of this problem. It is my purpose, however, to convey the general ideas pertaining to the elimination of these severe vibrations on the new carriers. The theories advanced in 1937 concerning the mechanisms of "singing propellers" have mostly not held up in the light of more recent studies. Even the 1937 paper by Harry Hunter,[17] whose results supported some of the NRL conclusions, is now in question regarding its basic concepts. Nevertheless, Hunter's statement that none of the "singing propellers" investigated vibrated (or sang) when backing down was experimentally verified on the YORKTOWN as she backed through the critical range of 7-14 knots without a song or whimper from her propellers. But what makes a submerged propeller sing anyway? For an answer we must go back to some fundamental ideas. When an obstacle is drawn through still water, with considerable relative velocity, it is found that eddies or vortices are formed behind the obstacle. Actually, a double series of eddies is formed due to the viscous drag between the opposite surfaces of the obstacle (say the front and rear surface of the propeller blade). With sufficient relative velocity,

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[16] The references for the USS YORKTOWN and ENTERPRISE: File S/68/61, Folder #2, Box #101, Archives; and File S/68-S44, Box #83, J.O. 7184, Federal Record Center, Alexandria, Virginia.

[17] H. Hunter, "Singing Propeller," Northeast Coast Inst., Eng. and Shipbuilders 53, 189-222 (1937); and in J. Am. Soc. Nav. Eng., 49, 258-262 (1937).

these vortices or eddies are moved down the stream in pairs and in parallel rows as if they were in a procession. Now, to paraphrase Richardson,[18] the periodic detachment of vortices from alternate sides of the blade in the water imposes periodic forces, alternate in direction, transverse to the blade. As the blade moves in a direction at a right angle to the stream, it will execute transverse vibrations when the frequency of detachment of the trailing vortices coincides with one of the natural frequencies of the propeller. This coincidence is likely to set up "singing." In the case of air, when the wind strikes a system of wires or cords, the sounds generated were called by Rayleigh "Aeolian" tones.

Roughly, the following steps were taken to determine the cause and to provide a cure for the singing propellers on the YORKTOWN and ENTERPRISE:

1. The hull vibrations adjacent to the four propellers were analyzed at several set values of propeller rpm throughout the ship's range of speed. The ship was driven by "props" 1 and 4, 2 and 3, and a combination thereof. Both airborne and waterborne sounds were measured in the compartment nearest the propellers as well as on the struts in the turbulent flow outside.

2. The ship was dry-docked, and the natural modes of the propeller blades were determined and traced (see Figs. 9(a), (b), and (c)). These showed the frequencies of vibration in air.

3. From previous tests,[19] the pitch of each of these modes was computed for the cases when these propellers are submerged and subjected to water loading. In the water medium, the frequency of vibration of the propeller blade was depressed approximately 1/3 the frequency of vibration in air.

4. By a process of elimination through deductions made from the various experimental tests, it was concluded that the ship's vibrations were caused by the propellers. By modifying the leading edge (chipping about 1/8 inch off each blade) as well as the trailing edge on the YORKTOWN propeller blades, a cure was effected. The ENTERPRISE was similarly treated, thus eliminating the excessive vibrations.

The "singing propeller" was the result of the propeller blade being excited by vortex shedding. Its frequencies were identified by vibrating the propellers in air and in water to

Fig. 9. Natural modes (in air) of vibrating propeller blades of the USS ENTERPRISE (blades No. 1, 2, and 3, respectively)

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[18] For a clear description of this phenomenon, see E. G. Richardson, SOUND, London, England (Edward Arnold & Co., 1927), pp. 139-147.

[19] H. C. Hayes and Elias Klein, "Methods and Means for Determining the Natural Modes of Vibration of Mechanical Structures," J. Am. Soc. Nav. Engrs. 50, 521-526 (1938).

Fig. 10. Driving mechanism used to excite propeller blades

determine their natural nodal contours. The work associated with the YORKTOWN and ENTERPRISE proved that when the cause of the trouble is definitely located, the cure is quite possible to effect. The cause was determined by special equipment and techniques and located in the propeller blades (Fig. 10). Modifying the edge (both leading and trailing) eliminated the excessive vibration in the 8-15-knot speed range.

After the severe vibrations in the YORKTOWN and ENTERPRISE were eliminated, the NRL Sound Division had many requests for help in curing the difficulties caused by "singing propellers." One such request from the War Department, U.S. Engineers Office, was relayed to NRL by the Bureau of Ships. The Army Dredge GOETHALS needed analysis and cure for its terrific hull vibrations, presumably caused by "singing propellers."[20] As shown in Fig. 11, the study and treatment given to this ship (in 1940) was similar to that provided the two aircraft carriers; and, the happy exclamation of the Chief Engineer of the GOETHALS, "Now I can sleep at night. The GOETHALS' propellers no longer sing," tells the story of the job NRL did for the Army dredge. Of course, by solving this problem our knowledge of the cause and cure of singing propellers was increased. Today, however, neither of the available NRL participants in this job can say why "sharpening of the trailing edge of the starboard wheel resulted in complete cure"; while the port wheel was treated on the leading and trailing edges, according to the NRL letter-report to the Bureau of Ships dated 16 July 1940. The letter states: "... but it was not known whether treatment of the leading or trailing edge effected the cure."

In the light of recent studies of vortex-shedding sounds of propellers, my own conviction is that sharpening the trailing edge of the blades on both propellers cured the trouble on the GOETHALS.

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[20] The reference for the USS GOETHALS is in File S44, Folder #1, Box #71, J.O. 117-04, Federal Record Center, Alexandria, Virginia.

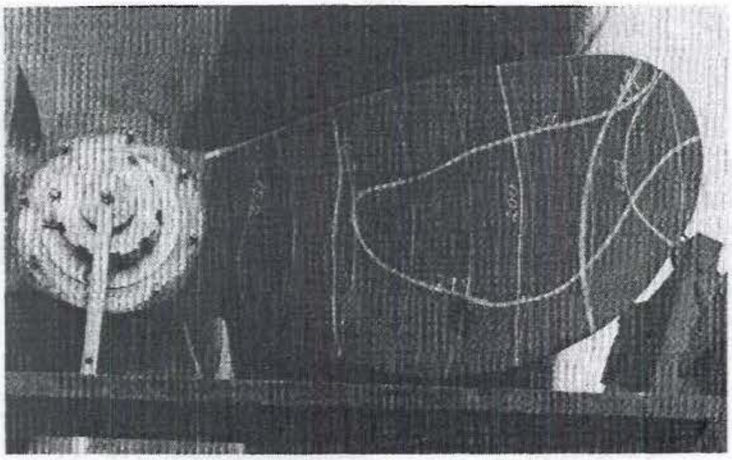

Fig. 11. Natural modes of vibrating propeller blade of USS GOETHALS

THE PERFORMANCE OF AN ELECTRIC-ACOUSTIC SC TUBE[21]

Submarine detection and location in the 1930's were mainly the results of extensive NRL studies in subaqueous acoustics. Echo-ranging and depth finding established ultrasonics as the dominant means for practical and useful naval applications. These investigations also helped to revolutionize the entire field of acoustics. Yet, many submariners, especially among the operating personnel who had developed a fine binaural sense, clung tenaciously to the simple SC Tube. They claimed that the audio frequency, nonelectrical C-Tube was a superior listening device to the now standard JK ultrasonic receiver. This was about 1934-35, when the new fleet installation program was taking place.

To demonstrate the advantages of JK apparatus a combination SC-JK listening system was installed (see Fig. 12) on one or two submarines. These instruments were independent of each other and employed two separate listeners. In fact, they operated on entirely different principles. The SC Tube (the rubber spheres on the ends of the pipe) collected audible sounds — 500-1000 cps — directly from the water and transferred them to the air inside the rubber sphere. From there the air sound was conducted down the tubes to the listener's ears via a stethoscope. By virtue of his expert binaural sense, the listener was able to judge the direction of the noise or target source. In the JK, the variable sound pressures generated by the target in the water which impacted the piezoelectric crystals through the rubber sound window and the castor oil that surrounded the crystals. The tiny squeeze which the crystals received from the sound in the water produced electric charges on their surfaces. These charges were carried along the wire leads from the crystal array to the amplifier in the ultrasonic range, 15-50 kc. There the signal was modulated and made audible to the human ear. The direction of the target source was located by the maximum sound that was heard in the phones or loudspeaker.

Even after the SC Tubes were removed from submarines (about 1936), there were still some binaural listeners who were loathe to abandon their expert ability. So, every now and then the Bureau of Ships received requests for binaural listening devices for submarines. Hence in 1939 the Bureau of Ships requested NRL to investigate the SC Tube by the aid of contemporary electroacoustic elements (see Fig. 13). The purpose was to determine the relative

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[21] P. N. Arnold and L. M. Treitel, "Performance of an Electro-Acoustic SC Tube," NRL Report S-1618 (May 1940).

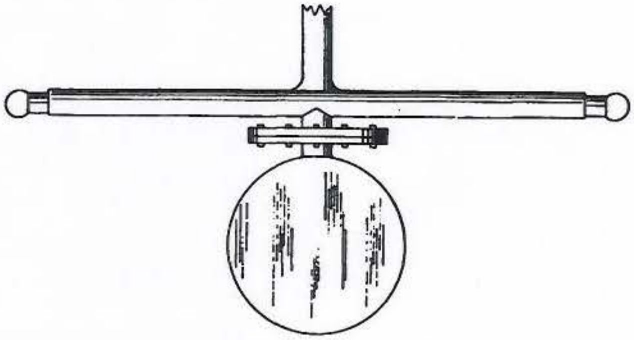

Fig. 12. SC-JK combination

merits of the electrically operated binaural instrument with the air bubble device which converts the sound energy from the water directly into the listeners ears. In the electroacoustic assembly, the same type of nonresonant air bubble takes the sound energy from the water, but a microphone within the bubble converts the airborne sound energy into electrical energy. Because the SC Tube had many desirable features as a low frequency listening device, it was thought that an electroacoustic SC Tube with its amplification possibilities would be a useful advantage to submariners since the latter have an aversion to disclose their position by active sonar.

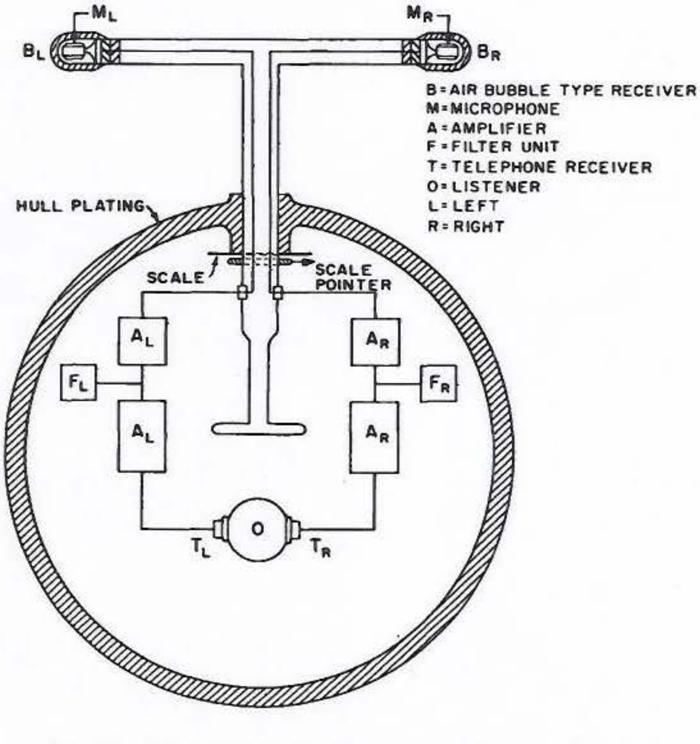

Fig. 13. Electroacoustic SC tube, schematic diagram

The experiments and results of these comprehensive tests are well described in the NRL Report. A few conclusions from the report are noteworthy:

1. Neither the electroacoustic SC Tube nor the acoustic SC Tube compares favorably as a subaqueous direction finding device with other devices already in use in the service (e.g., the JK).

2. The electroacoustic SC Tube is easier to operate than the acoustic SC Tube and can give results in the hands of a less well trained or gifted operator. As a standby instrument, available for use in emergencies, the acoustic SC Tube being simple, rugged, and completely independent of the ships power supply, is to be preferred.

3. In view of all the facts described, it is the considered opinion of this Laboratory that the substitution of an electroacoustic SC Tube for the acoustic SC Tube in the Naval service is not warranted.

Part III. Other Relevant Studies

This is the third and last part of an account relating to subaqueous acoustic studies conducted in this country up to the Second World War. The first part sketched the United States' participation in World War I, and the second part indicated the concrete response of NRL's Sound Division to the assignment of the U.S. Naval Consulting Board regarding the technical needs of the service afloat. Between World War I and World War II, the U.S. Navy followed up the Langevin transducer and developed other means of utilizing ultrasonics for military purposes. Practically all the investigations in this period were conducted in naval laboratories on a long-range peacetime basis, and most of the work was classified. There were only a few underwater sound specialists involved in this effort, since little industrial application of ultrasonic energy was prevalent at that time. This small group of workers carried forward the ultrasonic transducer system in design and method of operation. They advanced the means for generating and receiving underwater acoustic energy, but made very little progress in their understanding of the sea environment in which the transducer must always operate either as a generator or as a receiver. Consequently, we were forced into World War II with meager knowledge of the sea medium in which the transmission characteristics are constantly changing and fluctuating. And, of course, the urgency of war operations made it impossible to examine seriously the mechanism of propagation in the sea and what caused the drastic changes in attenuation.

Along with the developments outlined in Part II of these notes, NRL's Sound Division contributed also to scientific applications of the techniques and tools it created. To be sure, the mission of the Sound Division as a group activity was first and foremost to provide means for detection and location of submerged submarines. But when time permitted, the individual members of the group turned to study the related aspects of the generation and reception of subaqueous ultrasonics. Some were eager to know more about the ocean medium in which their newly developed transducers must operate. Others wanted to apply the knowledge and experience gained from the submarine acoustic efforts to other branches of naval sciences. No matter which additional problem a staff member tackled, his investigations usually contributed to the general knowledge of acoustics. Moreover, most of the results obtained in these intermittent studies were relevant to the technology of antisubmarine warfare.

Here again, it is proposed to highlight only a certain few of the projects which were explored. These are, in a sense, representative of the interests among the Sound Division group. In addition, the selected projects do have some documentation, records, and references to which they can be tied. Let us begin with some of the wide and diversified interests of the then Superintendent of the Division, H. C. Hayes. He not only guided the technical work of the Division, but often actually pitched in to help on a laboratory job which interested him and which he was anxious to complete. In addition, Hayes pursued most of the sea trial programs which were conducted; and there was an enormous number and variety of new ultrasonic developments to be tested operationally. That meant that the Eagle Boats with different submarines as targets and the USS SEMMES with her usual target, the S-20, each had to be manned by at least one Laboratory engineer or scientist to conduct the evaluation of the gear at sea. Hayes, of course, was in on the planning of the trips' operations. The NRL Sound Division, up to about 1932, also had to build, maintain, and repair the ultrasonic apparatus for certain operating ships. These equipments included echo-ranging installations — e.g., XL, JK, QB, and NG depth finders. The years 1928 to 1932 were ones of transition. Many experimental ultrasonic installations were being made in the Fleet, while most ships which carried audio or sonic sound equipment had to wait for the new type of gear to be produced. Hayes, as leader of the Division, was responsible for all these activities.

FOGHORNS AND AIR ACOUSTICS

Despite all this, Hayes' attention was frequently occupied in the late twenties and early thirties with air acoustics in the form of sirens, foghorns, and whistles. This work appeared to follow that of Professor Pierce of Harvard University, who first showed the possibility of employing magnetostrictive materials[1] for generating ultrasonic signals in air and underwater. Hayes then experimented with a magnetostrictive horn[2] as a replacement for the air whistle used on submarines. This whistle had long been considered unsatisfactory. When the magnetostrictive horn which Hayes developed was forwarded to the Control Force for service tests, an engineer from the Lighthouse Service (Department of Commerce) happened to be present. Soon thereafter, the Commissioner of Lighthouses, G. R. Putnam, via the Secretary of the Navy, requested the Bureau of Engineering to enlist Dr. Hayes as a consultant to the engineers in the Lighthouse Service to help develop electrical foghorns for the Department of Commerce. Hayes tried higher frequencies for the air foghorn at first but soon found that absorption in air limits the transmission range of ultrasonic fog signals. He therefore tried, among other means of generating audible sounds, a toroidally-wound, large, nickel cylinder (approximately 18 inches in length, 30 inches in diameter, and 1/64 of an inch in thickness), which generated audible sounds by the principle of magnetostriction. To direct the sonic waves through the atmosphere, Hayes attached a 45-degree reflector to one end of the cylinder and made the entire apparatus rotatable. This device worked well in laboratory tests but proved inadequate as a practical generator of fog signals.

About a year or so later (1929), the Bureau of Aeronautics requested that NRL provide an altitude-drift meter[3] for lighter-than-air ships, e.g., LOS ANGELES, AKRON, and MACON. The possible use of sound, sonic or ultrasonic, was recommended. Again, Hayes personally undertook this development by means of magnetostriction. The altitude measurement procedure was merely that of a depthfinder; however, to indicate drift of the airship, the sound beam was directed obliquely downward at an angle from the vertical and the pitch between signals and echoes served to determine the bearing of the ship. When the signals and echoes had the same pitch (Zero Doppler Effect was achieved by rotating the inclined sound beam about the vertical), the ship's track was perpendicular to the direction of zero drift. Figures 1a and 1b show the magnetostrictive cylinder which expands and contracts radially due to the currents flowing in the toroidal windings. Direct polarizing current was superposed upon the oscillating current. The latter tuned to the natural resonant frequency of the cylinder when it executed pure radial oscillations. High directivity was effected by the phase relationships of the inside and outside reflecting surfaces. Figure 2 shows the transducer mounted vertically downward and the handwheel which can be rotated about a vertical axis so as to tilt the beam. This alti-drift meter system was tested under actual service conditions on the AKRON, and it worked reasonably well. It was then removed from that airship for further improvements and refinement. Hayes and Harrison fortunately missed the last (fatal) trip on the AKRON because time did not permit installation of the modified alti-drift meter system.

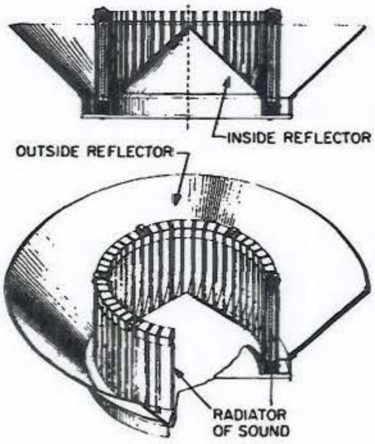

Fig. 1. Toroidally-wound magnetostrictive cylinder

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[1] See Part II: JUA (USN) 16, 414 (1966).

[2] S68/S48-25, "Sound--Foghorns, Whistles, etc.," Archives Box 101, 1928-1933.

[3] S68/F31-3(7), "Sound-Drift and Alti-Meters," Archives Box #100.

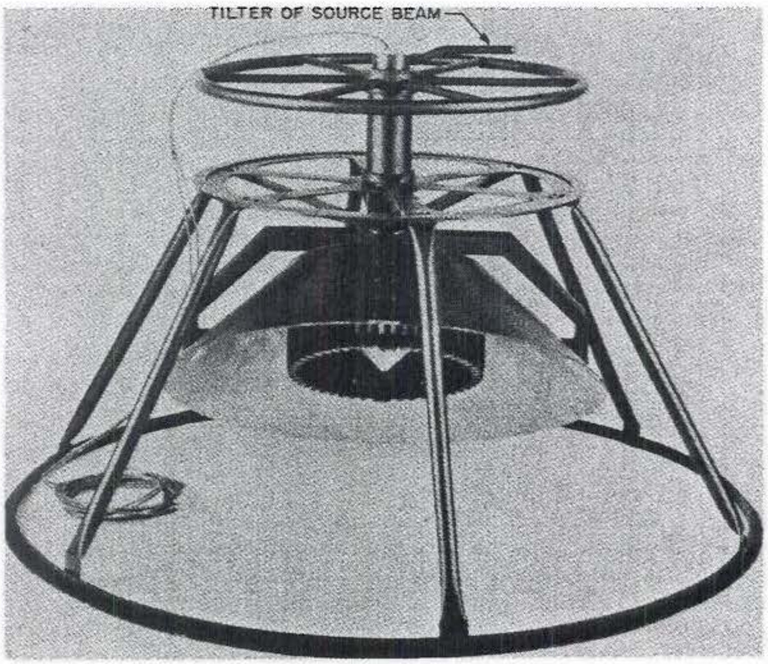

Fig. 2. Vertically-mounted transducer assembly showing handwheel used to tilt the beam

SELF NOISE

Reference was made in Part II[4] to NRL Report No. S-1404 in connection with the tests of the XQD transducers which Arnold designed and brought to fruition. In NRL Report 1404, Hayes also discussed "Reduction of Sound Generated by Naval Vessels," and he devoted a goodly portion of the month's work (July 1937) on the SEMMES to the analysis of noise and turbulence on that ship. The latter had been studied many times in many ways by different members of the NRL group since early 1934 when the SEMMES replaced the USS Eagle 58 as a sonar experimental ship. On this occasion, however, the SEMMES was equipped with the latest instrumentation then available, and Hayes made the most of the situation.

From the noise analysis on the USS SEMMES, Hayes concluded that there are three primary sources of general background noise that may be picked up by the sound gear while the ship is underway: (1) the propellers, (2) turbulence around the hull or the turbulence about the transceiver, and (3) mechanical vibration of the hull or of the transceiver's supporting structure, transmitted directly through the structure to the transducer. Directive, as well as nondirective, noises were studied. The effect of propeller noise was separated from turbulence noise.

Hayes inferred from these studies that: (1) when listening to a ship at a distance the noise produced by hull vibrations was negligible compared to that produced by the propellers, hence (2) the major effort toward the reduction of noise produced in the water by naval vessels should be concentrated on the propellers and their associated structures. (After all these years, the self-noise problem on searching vessels is still with us today.)

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[4] JUA (USN) 16, 418 (1966).

As stated before, Hayes' observations regarding noise reduction on naval vessels were similar to those made earlier by other members of the NRL staff. But with the development of more precise acoustic measuring tools, Hayes emphasized the importance of this future program for the Division. It was recognized that a serious step in the design of our submarines was to provide acoustic insulation in connection with the ships' machinery. There were, in general, two purposes for eliminating noise from ships. One was tactical efficiency and the second, personnel efficiency. The first was concerned with transmission of noise through the hull and into the water, while the second related to the effects and hazards upon personnel. Needless to say, both have been of utmost importance to the Navy; and both were investigated by the NRL Sound Division when time permitted. Hayes would stake out an acoustic area which he deemed important, and he expected that his staff, somehow, could undertake the working of this area with fruitful results. At times his expectations were fulfilled.

SOUND RANGING

E. B. Stephenson had many years of experience in sound ranging before he became a staff member of the NRL Sound Division. First, he was an officer with the Engineer School, U.S. Army, in World War I. After the war, he became a physicist in the Office, Chief Engineers, U.S. Army.[5] He was interested in underwater sound ranging and measured the velocity of sound in sea water.[6] At NRL Stephenson was always ready to study those factors which influenced sound propagation in sea water. Soon after he started to work at NRL (1925), Stephenson realized the tremendous difference in approach of subaqueous ranging by low-frequency sonic methods as compared with ultrasonic means. He, therefore, attempted to correlate his Army experience to the needs of the Navy. In May 1925, the Coast Artillery Corps held a mortar practice at Fort Wright which was of special underwater sound significance, and the Army invited NRL to observe this operation. Stephenson was assigned as NRL representative. He reported his observations to the NRL files.[7]

Tests were conducted at Fort Wright, N. Y. for the purpose of mortar practice; in these tests only the battery commander had data necessary to track the targets. This was the first time such a feat was accomplished by sound methods; this proved to be of great importance to the Navy. It removed any advantage an attacking fleet might have had due to concealment by smoke screen, fog, or darkness. Two sound installations were involved in this system: one for tracking the target and the other for spotting the shots. The latter had six hydrophones placed on a known baseline, so that the difference in times of arrival of the sound waves at these stations was measured. Then a graphic solution was obtained for the point of impact. The tracking system had two water stations connected by cable to two shore stations. Each water station consisted of a 108-foot "T" beam, supported about 10 feet from the ocean bottom with two sets of 12 hydrophones equally spaced along it. The shore stations had the necessary electrical compensations for the 108-foot bases by the aid of which the direction of the target was determined by listening binaurally, since it was impractical to rotate the 108-foot "T" beam.

In addition, it was due to Stephenson's awareness of the Signal Corps' underwater efforts that NRL participated in the early experiments of the Army's subaqueous sound ranging and tracking systems. In the late twenties, the Signal Corps Laboratories studied the possibilities of tracking ships off shore for coastal defense purposes. It was believed by the Army scientists that the accuracy of binaural readings would enable the coast artillery to hit a target-ship at about 20,000 yards. Preliminary studies along these lines were made near Fort Monroe, Virginia, as a result of submarine activity during World War I. At Fort Monmouth, the Signal

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[5] E. B. Stephenson, "Sound Ranging," Occasional Paper No. 63, Engineer School, U.S. Army (1920).

[6] E. B. Stephenson, "Velocity of Sound in Sea Water," Phys. Rev. 21, 181-186 (1923).

[7] E. B. Stephenson, Report on Coast Defense and Sound Installation to NRL Files, July 1, 1925 — C-S68/94 Coast and Harbor Defense, Archives Box 61, Folders 1, 2, and 3.

Corps Engineers devised a subaqueous rotating beam station[8] with 24 equally-spaced hydrophones used binaurally. The length of the rotating beam was 25 feet at first. Later it was changed to 43 feet, and in the thirties the length of the rotating beam was extended to 60 feet. Improvements in the hydrophones were effected gradually, but the acoustics employed in all these devices were low-audible-frequencies for binaural listening. The rotating beam apparatus which carried the hydrophones, usually a steel pipe, was pivoted at the center of its length (i.e., a 12.5-foot arm of the 25-foot pipe was rotated to the left and right of the center). Rotation of the pipe or tube was provided by a motor-gear train which was sealed in the upright pipe of the T-formation (see Fig. 3a). The entire structure rested on the bottom of the sea near the entrance to a harbor. (The hydrophone array was about 10 feet off the bottom.)

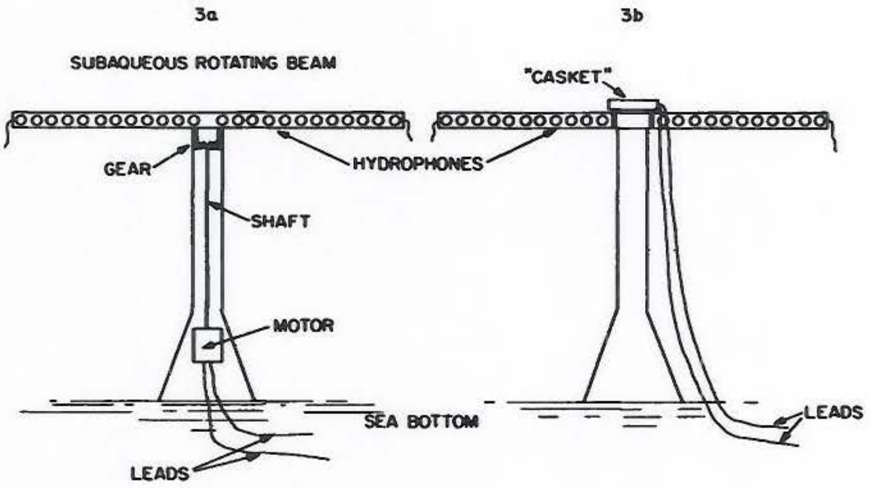

Fig. 3. Audio frequency and ultrasonic "Casket" rotating beam apparatus

The Navy too had been interested in harbor defense and fleet base protection, but the NRL approach to this problem was now (1930) to employ ultrasonic listening for location and active sonar for echo-ranging. Thus when the preliminary models of Rochelle salt crystals were developed at NRL for underwater listening as well as for echo ranging, Stephenson suggested the possibility of trying to track ships by ultrasonics with a small Rochelle salt unit in comparison with the Signal Corps audio-frequency rotating beam device. One of the numerous transducers that were readied at NRL for various service tests was a rectangular Rochelle salt assembly, 6 x 6 x 18 inches. This steel box had a flange around its opening to which a Rho-C rubber window was fastened. The Rochelle salt crystals, backed by an aluminum plate, were embedded in air free, bone-dry castor oil. A major resonant frequency of this plate-crystal combination was in the neighborhood of 30 kc, at about 70°F. The entire assembly was known as the "Casket," and that unit was taken to Fort Monmouth by Hershberger and myself as comparative listening for tracking ships. The "Casket" was attached over the center of the rotating beam, as shown in Fig. 3b. Our ultrasonic listening system consisted of the "Casket"

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[8] Signal Corps Labs., Ft. Monmouth, New Jersey, Engineering Reports No. 10 (Jan. 1932); No. 135 (Sept. 1932); and No. 165 (Oct. 1932). (All three reports deal with Subaqueous Sound Ranging and Tracking Systems and were borrowed from Federal Records Center, 2306 E. Bannister Road, Kansas City, Missouri 64131.)

attached, a couple of miles of unprotected cable, and an amplifier operating in the frequency range of 10 to 50 kc. It gave poor results. The cables from "Casket" to shore picked up high-frequency-noise interference and drowned out the propeller rhythm of the passing ships. This failure, however, taught us many lessons concerning the use of ultrasonics in coastal and harbor defenses where many miles of cables may be required to bring the signals ashore. We learned much about armored cable for subaqueous use and the methods of shielding that are necessary for the elimination of interference. This was in 1929-30. By 1939, when the Navy took charge of certain phases of harbor and coastal defenses, NRL was prepared to assume the responsibility for the design and development of equipment for protecting our harbors against sneak attacks.

SHIP QUIETING

As part of the ship-quieting program, mainly to reduce propeller noise, Stephenson gathered 1000 quantitative measurements of the intensity of propeller noises of the S-20.[9] Different conditions of water, speed, range, and depth of submergence were studied. The measurements were made utilizing the S-20 as a sound source and the SEMMES as a listening ship to determine (1) the effect of covering the propellers of the USS-S-20 with rubber (two different methods were employed: one was to deposit the rubber on the metal blades by an anodic process, and the second was to cement sheet rubber on the blades with Vulcalock — a B. F. Goodrich Product); and (2) to insulate the vibrations of the starboard motor and reduction gear of the S-20 with compressed felt. The aim was to reduce the range at which propeller noise of a submarine could be heard by a listening ship. These changes were introduced in 1934.

From a statistical study of the large amount of data, it was concluded that on the average: (1) covering the propellers with rubber increased cavitation noise at various speeds; (2) the anodic covering caused less noise than the Vulcalock cement did; (3) the felt insulation (installed by Arthur D. Little) increased the noise at 220 turns (3 knots) and decreased it at 260 turns (6 knots); (4) the sound generated in the water by all auxiliaries of the S-20 represented less than 10 percent of her total sound output; and they were, therefore, minor factors in the total noise reduction problem; and (5) when the S-20 was submerged and underway at 205 turns, her range of detection under the above conditions was not affected.

While conducting perhaps the major portion of the sea trials of different sonar models on USS SEMMES and S-20, Stephenson took advantage of any break in the test priorities and utilized the two vessels to investigate sea characteristics in several operating areas. For example, at different times and places, he used the SEMMES and S-20 to collect large amounts of data on the variation of the intensity of the direct signal transmitted from the destroyer to the submarine on the surface at different frequencies and under different water conditions. These data are summarized for the period 1931-1940 in his report — NRL Report No. S-1670 (Dec. 1940). He was probably the most persistent investigator of the absorption and transmission of ultrasonics in sea water who participated in the early work on sonar. Unfortunately, his data gathering was on a hit-and-miss basis, as time permitted. Hence, the wide variations of absorption coefficient with locality, season, weather, and other factors which influenced the results did not warrant an accurate conclusion. Thus, Stephenson decided that for tactical use of the sound equipment then available the loss coefficient must be based on a knowledge of the water conditions obtained preferably by echo-ranging at the particular time and place.

In his concern with the knowledge of ship movement in the sea, Stephenson, aided by other NRL staff members, studied turbulence[10] as a source of noise. This is just one of many investigations he carried out. In order to escape the noise caused by the turbulent layer at the

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[9] E. B. Stephenson, "Sound Analysis of the USS S-20," NRL Report No. S-1199 (25 September 1935).

______, "Sound Analysis of the USS S-20," NRL Report No. S-1282 (17 June 1936).

[10] E. B. Stephenson and W. F. Curtis, "Investigation of Turbulence Beneath a Destroyer," NRL Report No. S-1413 (21 December 1937).

keel of the ship as it moved through the water, it was common practice to install the acoustic transducer through the bottom of a surface ship below the keel. But there had been no data as to how far the turbulence extended. This, of course, was before the advent of domes and streamlined housing which enclosed the sonar device on surface ships. An investigation of this phenomenon was undertaken on the USS-SEMMES, which had several wells through which acoustic devices were projected at different distances from the bow. By means of a specially constructed Pitot tube, the velocity-depth gradients and velocity-time fluctuations were measured. The investigation showed that, for a destroyer of the SEMMES type, in order to eliminate turbulence (caused by the movement of the ship's hull through the water) from the transducer, the top edge of the transducer should be Y feet below the keel when the bow of the ship is X feet from the well. The following equation expresses this relationship:

$$Y = 0.0093X + 0.77.$$

UNDERWATER SOUND INVESTIGATION OF WATER CONDITIONS IN GUANTANAMO BAY AREA[11]

Prior to 1937 the Navy had gathered considerable information on the performance of underwater sound projectors in the deep water near Guantanamo Bay, Cuba. A frequently observed phenomenon was the "Afternoon Effect" in which the amplitude of sound pulses decreased sharply in the afternoon of calm sunny days and subsequently recovered its initial strength during the night. The theory had been offered that the signals were attenuated by gasses released by plankton when stimulated by the afternoon sun. Early in 1937 the Navy mounted an expedition for the purpose of testing this theory. Two ships, USS SEMMES and ATLANTIS of Woods Hole, were employed. SEMMES carried a Navy QC sonar with a 19-inch-diameter, 24.4-kc magnostriction directive sound projector. The acoustic axis was horizontal. ATLANTIS carried a nondirectional quartz crystal underwater sound receiver (hydrophone), a Nansen sounding system, and facilities for sea life observation. The projector and the receiver were rigidly mounted beneath the ships at a depth of 13 feet.

The biological survey established with certainty that in the Bay and in the deep water outside the harbor the water was essentially devoid of sea life. The gas generation theory was, therefore, not tenable. The large decrease of sound signal was, however, very real but sporadic in occurrence. The variable temperature changes previously observed with ordinary thermometry seemed to be too small to be the cause of the Afternoon Effect. Nevertheless, a reorientation of the objective of the expedition was made to test the temperature dependence because a greater precision (±0.015°C) of temperature and depth measurement was now available in the Nansen system.

Angular motion of the projector axis and uncertainties in ranges between ships were minimized by use of a procedure which was entitled the Approach Run. The QC projector was clamped on 000° relative bearing. The angular excursions of the sound beam axis were, by this device, limited to the angle of pitch. This is much less than the angle of roll. The Approach Runs were started at maximum range. The SEMMES, when settled down on course toward the receiver, was held to propeller counts corresponding to three knots. The great momentum of the SEMMES minimized accelerations. Short ranges measured with good accuracy by a stadimeter were used to "calibrate" the ship as to speed-versus-turns count. Other ranges were then determined from elapsed times measured from the instant SEMMES passed ATLANTIS at the end of the Approach Run.

Relative voltage values of the CW signal strengths were measured on a damped output meter at a uniform schedule of time intervals during the run. Throughout each run the QC

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[11] This is a review by Dr. R. L. Steinberger, Head of the Sound Propagation Branch of NRL, of an unpublished paper concerning early measurements of thermal refraction of sound in the ocean. The author is indebted to Dr. Steinberger for preparing this resumé.

projector operated in locked-key condition. Nansen temperature soundings were made at intervals to keep track of the thermal stratification in the water.

Nineteen successive Approach Runs were made in an interval which embraced the time span of two different cycles. One was the cycle of diurnal development and decay of the Afternoon Effect. The second was the weather cycle of a typical calm day followed by a typical windy day. During the calm day, a thermal stratification developed and decayed in a cycle well correlated with the cycle of changes in sound signal dependence on range. The calm-day stratification developed or failed to develop in synchronism with the wind pattern and consequent water stirring.

To arrive at a quantitative relation between sound signal p(R) at a given range R as predicted by the thermal situation T(Z), a set of the temperature (T) depth (Z) observations which were well correlated with the Afternoon Effect were chosen for analysis. This T(Z) function was well represented by three linear segments, each characterizing a layer of water in which temperature was proportional to depth. The speed of sound was linearly related to both temperature and pressure over the narrow ranges of interest here. Refraction constants were computed and shown to result in refracted rays which had the form of circles having parameters which could be computed from the C(Z) function and the angle of emission from the source. Approximate formulas were developed which indicated the location of some of the identifiable characteristics of the sound signals during a cycle of the Afternoon Effect. In the set of conditions chosen for the surface, warming was well developed. The horizontally-emitted rays were bent downward into a layer of constant temperature where the pressure refraction alone was capable of bending the rays back to the receiver.

ANTI-AIRCRAFT SOUND RANGING

Anti-aircraft sound ranging on board naval vessels had been attempted for many years, but the local noise and wind had tended to discourage the use of sound ranging instruments aboard ship underway. Nevertheless, it was felt that the submarine urgently needed an aircraft detector for offense and defense and that a more serious try should be made to provide the submarine with a detector by the use of the most recent microphone developments. Hence, in 1932 the Bureau of Engineering authorized the NRL Sound Division to investigate "An Aircraft Detector for Use on Submarines." This study was pursued by F. W. Struthers for several years on low priority. In 1935 the priority was lifted, and the final report[12] on this subject was issued in 1937.

A careful analysis of this problem showed that even under the best conditions obtainable on the deck of the submarine, any listening system on board would still fall short of the desired response. The receiver must be mounted above the water surface. It cannot function beneath the water's surface because the airborne sounds from the plane reflect away from the water surface with practically full intensity and very little of the sound enters the water. This means that the receiver must be mounted on a periscope and remain above the water surface. It was necessary also to protect the microphone-diaphragm against submerged pressures in order to keep it from collapsing; this protective cover had to insure, as well, the watertight integrity of the microphone. At the same time, the cover had to be such as not to prevent the airplane sounds from reaching the instrument. All in all, the protective cover merely reduced the range of detection of the plane so that at best the latter could be heard a distance only equal to that of the unaided ear.

Another of the many investigations carried out by Struthers was the Reduction of Sound in Diving Helmets.[13] When Navy divers operated with salvage vessels, it was at times practically impossible to communicate between diver and tender-ship. The main source of this

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[12] F. W. Struthers, "Aircraft Detector for Use on Submarines," NRL Report No. S-1375 (25 June 1937).

[13] F. W. Struthers, "Reduction of Sound in Diving Helmets," NRL Report No. S-1538 (7 June 1939).

noise background was traced to the hand-operated air inlet valve. Through redesign of this valve and the installation of a low-pass acoustical filter across the air intake, the intensity of the masking noise background was reduced about 30 db. This permitted fairly satisfactory intercommunications when the standard power telephone system was used. With an inertia or throat-type microphone and head helmet-mounted earphones, it was possible to get almost perfect communications.

Analysis showed a preponderance of high pitched components which tended to mask the s, c, d, and t elements of speech to such an extent that voice communication between diver and tender was ineffective. Sound analysis was also made of the diving helmet with and without filters.

HARBOR DEFENSE AND FLEET BASE PROTECTION

The Navy's interest in developing harbor defense and fleet base protection was mentioned earlier. This interest was emphasized and stimulated after NRL personnel participated (1929-30) in the Signal Corps Laboratories' studies of subaqueous sound ranging and tracking systems. We thus investigated in the thirties the different concepts for coastal defense and looked into the various techniques which were employed during World War I for protecting harbors. Both active and passive sonar were devised for this purpose, including a beamed ultrasonic transducer of the JK or QB type with a special lightweight acoustic mirror. This arrangement provided a rotating beam in azimuth[14] and eliminated the need for slip rings and the difficulties of rotating a large electroacoustic transducer. This type of harbor defense gear was later known as "Herald" equipment, deriving its name from "Harbor Echo-Ranging and Listening Device." The Herald (see Fig. 4) apparatus was perhaps the most versatile of the harbor protection equipments which were ultimately assembled for the purpose at hand. Its ability to track and locate an underwater sneak craft made it also a most valuable detector of enemy submarines. A great deal of intermittent effort was expended in the development of the Herald

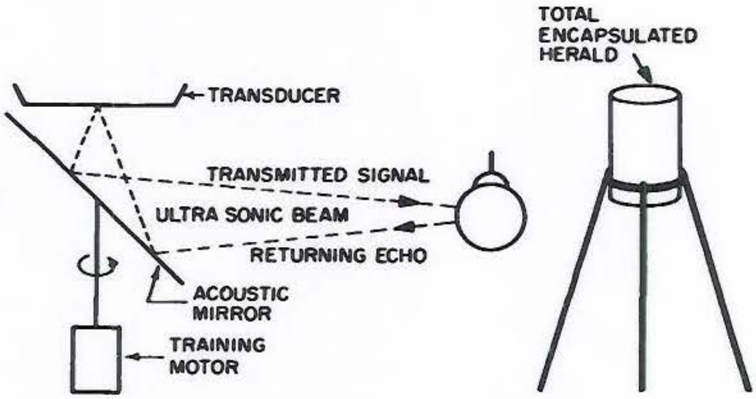

Fig. 4. Ultrasonic beam directed by the acoustic mirror

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[14] Elias Klein and Thomas F. Jones, "Use of Sonar in Harbor Defense and Amphibious Landing Operations," AIEE, Electrical Engineering, 68, 107-114 (Feb. 1949). (Note: Perhaps it should be pointed out that this conference paper was presented at the AIEE in August 1947, about 10 years after the design and development of the Herald equipment had taken place. Moreover, World War II experiences and operational results of the Herald System were before us when this paper was presented.)

system. In the same extended period, the cable-connected hydrophones as well as the anchored radio-sonobuoy were produced at NRL. By 1939 NRL had prepared for harbor defense not only a variety of subaqueous acoustic instrumentations, but also a contemporary version of the magnetic indicator loops. These various equipments were later included in the general scheme for defending harbors in World War II. They represented NRL developments of many years prior to 1939. In fact, some were initially designed to serve quite a different purpose. For example, in the late twenties the NRL Sound Division attempted by the use of piezoelectric crystals to measure the velocity of torpedoes which were run on the test range at Newport, Rhode Island. There in the channel were set up some cable-connected crystal hydrophones, spaced in a definite manner. The function of the hydrophones was to mark the exact time the torpedo passed by or over each crystal device. Similarly, in detecting underwater sneak craft in a harbor, the cable-connected hydrophones performed the same function — that of "advising" or "recording" at the shore station the sequence of positions which the sneak craft held at given times so that the shore station might take proper action against the craft.

Another device employed in the harbor defense array of important acoustic detectors was the Anchored Sono-Radio Buoy. Figure 5 illustrates the operation of this system. Any sneak craft attempting to enter the harbor became audible through the listening device suspended beneath an anchored buoy. Sound waves impressed upon this hydrophone modulated the carrier of an f-m transmitter contained within the buoys. At the shore end, an f-m receiver demodulated the carrier and reproduced for an operator the underwater sound picked up off shore. Each anchored buoy had a preset radio frequency for position identification.

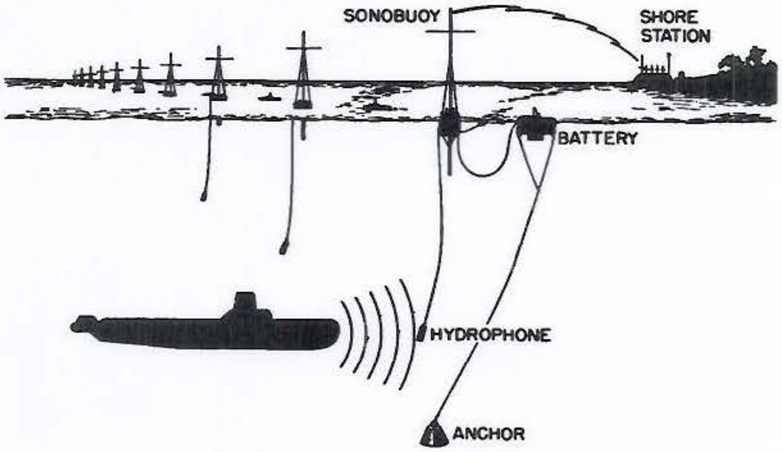

Fig. 5. Anchored sono-radio buoy

SUMMARY

Since this article was published in three parts, in three different issues of the Journal, over a period of nine months, a recapitulation of the contents of these Notes may be helpful to the interested reader; however, before summarizing the subaqueous acoustic developments of World War I, and what followed, I must answer a very pertinent question recently put to me by an officer in the History Division of the Navy Department, thus: "When did the U.S. Navy employ an active sonar device for the first time to solve a real operational problem?" (not simulated in any way).

The answer to this question is roughly as follows: During the week of 17-23 August 1929,[15] Dr. H. C. Hayes and I were on the experimental ship USS Eagle #58, off New London, Connecticut. We were testing and evaluating the XL quartz-steel transducers as well as some new Rochelle salt crystal assemblies. Suddenly a dispatch from Commander, Control Force (Admiral Upham) ordered USS Eagle #58, in effect, to use the newly created experimental sonar apparatus on that ship to find a large pontoon lost that morning in a specified area. All sound exercises were immediately suspended. The USS Eagle #58 headed for the designated area and, by the aid of the echo-ranging acoustic gear, located the lost pontoon.

Now to return to the events of World War I. In 1914 the development and use of subaqueous acoustics became a matter of survival for England and France. The ability of the German U-boats to operate while submerged (even for a brief period) surprised the Allies and raised havoc with their shipping. Independently, the English and the French devised underwater listening apparatus of various kinds by means of which they were able to detect the submerged craft and to destroy them. The British used mostly low-frequency resonant hydrophones in their antisubmarine service, while the French employed some varieties of Broca tubes[16] which operated at low-sonic frequencies, binaurally. At the same time, the French, under the guidance of Langevin, attacked the problem of submarine detection in the ultrasonic range. Although the concept of echo-ranging by ultrasound was introduced by Langevin in 1915, no sonar equipment saw actual service during the first World War. The antisubmarine warfare conducted by the Allies in 1914-1918 was all with low-frequency listening devices of various kinds and types. Each country, however, experimented right along with ultrasonic subaqueous echo-ranging gear. In the United States, two separate groups of scientists, one on the East Coast and another on the West Coast, investigated the field of ultrasonics. Professors Morcroft, Pupin, and Wills of Columbia University, aided by Cady of Wesleyan University, Hull of the General Electric Company, and others, conducted some experiments with Rochelle salt crystals as high-frequency transducers. They constructed also some quartz oscillators following the Langevin design. The West Coast group (Professors Anderson, Babcock, Ryan, and others) studied models of the Langevin projector in an inverted bell-jar full of water and attempted to produce high-beam intensities of supersound in water. Neither group got started on its work before the fall of 1917; but by 1919 each group was fully aware of the Navy's detection requirements in antisubmarine warfare, particularly in the use of ultrasonics.

Thus, at the urging of the Naval Consulting Board and under the war stimulus, a handful of university as well as industrial scientists responded to the critical need of antisubmarine weaponry. They embarked on a Navy program of subaqueous acoustics about which most of them had no previous experience. Yet in a period of some 18 months, substantial and useful results were achieved. This technological effort, however, like most war undertakings, primarily involved applied research. Normally engineers and scientists working against time to provide weapons do not attempt to conduct basic research of a long range nature. One would expect, however, that in the peacetime of 1923 the Naval Consulting Board of the United States in establishing the Naval Research Laboratory would have recognized the essential needs of basic science as well as technology in our national defense. Though this seems a reasonable assumption today, no such ideas were in evidence when NRL was dedicated in 1923. Actually, the interests of the Board were then entirely in the direction of applied research. They were pointed toward the development of practical equipment which could protect our shores as well as our shipping from possible enemy attacks. The Board may have foreseen the value of long-range basic research, but the era following World War I provided little opportunity for investigating pure science. First of all, the situation in this country between 1918 and 1939 was conducive to the growth and progress of industrial technology. Then, because of the war and

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[15] The documentation which led to this answer is discussed in Appendix A at the end of this Summary.

[16] The Broca tube consists of a small metal capsule (aneroid barometer) fixed to a tube; the lower end dips underwater and the upper end leads to the observer's ear. The SC tube described in Vol. 16, No. 1, page 6 (Fig. 2) is a form of the Broca tube.

post-war activities, there was a critical shortage of qualified scientists who could pursue fundamental research. Furthermore, the American scientist of that period was, for one reason or another, far more adept in exploiting technology and inventing gadgets than he was in exploring the unknown. This means that the Naval Consulting Board was fully in tune with the research climate of that period. The Board was more concerned with immediate weapons and protective devices and paid little attention to the potential dividends which might accrue from long-range studies of the frontiers of science.

When the Naval Research Laboratory was established in 1923, all of the Navy's studies in anti and pro submarine underwater acoustics were concentrated in the Sound Division of this Laboratory. Here a large variety of echo-ranging equipments was designed and developed for service use. Most of these devices, both for listening and sending, operated in the ultrasonic range between 10 and 50 kc. Because the dimensions of most shipboard ultrasonic transducers measured across their radiating faces at least five wavelengths of the sound in water, the transmitted and received energy was always in the form of a beam, like a searchlight. By rotating the transducer about a diameter as an axis, the operator could determine the bearing of the target to which he was listening. If sound energy were transmitted by this transducer, and reflected by the target, then the operator could determine by the elapsed time the range to the target. This ability to measure bearing and range of a submarine target gave the ultrasonic transducer a tremendous advantage over the sonic devices which were employed as underwater acoustic detectors in World War I, e.g., the SC tubes. The latter were also very limited in their usefulness when the submarine was barely moving and the searching vessel was well underway.

Before assuming his duties as Superintendent of the NRL Sound Division, Dr. H. C. Hayes and a small group of engineers worked at the Engineering Experimental Station at Annapolis. There they improved and perfected the underwater sonic devices employed in World War I. In their new home at NRL they plunged into ultrasonic developments, utilizing the quartz-steel ideas of Langevin. After a few years of intensive effort a practical echo-ranging apparatus for shipboard use was developed. This equipment was known in the Navy as XL or QA transducer, which required several thousand volts to cause it to radiate acoustic energy in the water. Then (about 1928) came the Rochelle salt crystal transducers of which there was a large variety in shape and size; the two principal shipboard models were known as the JK and QB. The Rochelle salt crystal transducers required but a few hundred volts to make them radiate sound energy into the water. These crystals were imbedded in castor oil; they transmitted their energy through the oil and then through a rubber window. A similar Rochelle salt assembly was made into various depth-sounders or depth-finders for navigational purposes. Here the case was mounted on the ship's bottom with the rubber face looking toward the bottom of the sea and merely measuring the distance between the ocean bottom and the keel of the ship.

The magnetostrictive transducer, known as the QC, was another echo-ranging device which was developed at NRL. It employed nickel or certain nickel alloys for its vibrating elements. These were in the form of rods, tubes, or laminations. All of these elements changed their dimensions when subjected to a magnetic field. Another transducer was developed in the later thirties, known as QD, which was electrodynamic in operation. Several models of this type were built, but none of them went into production even though the signal strength of the QD could be increased many fold above the other transducers. The size, weight, and power required by the QD equipment did not warrant the improvement in signal which was obtained. It was then decided to direct the efforts of the Sound Division toward increasing the signal-to-noise ratio by reducing the local noise background on the searching ship. This decision proved of great value in the Laboratory's antisubmarine research and development program that followed.

With the basic tools for generating and receiving underwater sound ready for use on all types of ships, the NRL Sound Division tackled other acoustic problems that were of interest to the Navy. For example, at the request of the Bureau of Ships, NRL provided a "cure" for the "singing propellers" problem on the aircraft carriers, the USS ENTERPRISE and the USS YORKTOWN. The excessive stern vibrations on these ships prevented their operational use in the Fleet and caused a great deal of annoyance and damage at certain speeds. By analysis and precise experimentation, the source of the vibration was located and eliminated. This approach insured that future propeller design would be free from such noise and vibration. Many other useful applications were made by the NRL Sound group which benefited Fleet operations. For example, the introduction of absolute acoustic standards in liquids facilitated the evaluation of underwater sound projectors installed in ships by manufacturers. Problems like anti-aircraft sound ranging; or ships' quieting; or the cause for variable ultrasound wave propagation in the sea; and a host of others were investigated by different members of the NRL staff. And, on the whole, the results obtained showed reasonable progress, considering the vast diversity of subject matter which was tackled by the small group of investigators.

This summary might be concluded with a project which played a significant role in World War II. This project related to harbor protection in all its phases. The developments of its various facets began about 1935. Both active and passive sonar were anticipated in the need of a defense system, and two equipments in this protective array had special features which are noteworthy. The "Herald" was a remote control sonar device utilizing a sound mirror which could be swept in azimuth and could control the acoustic beam around 360 degrees. An anchored Sono-Radio-Buoy was the other device. It was capable of detecting and locating sneak craft in a harbor and relaying the information to the shore station by means of radio. A number of such buoys were anchored along the entrance to the harbor.

ACKNOWLEDGMENTS

These "Notes" were prepared for the Office of Naval Research under Contract Nonr 3579(02). I am grateful to the Editors of the Journal for the opportunity to trace the developments of subaqueous acoustics in this country between World War I and World War II, particularly, those conducted at NRL. My indebtedness to the Technical Information Division of NRL is immeasurable. The wholehearted cooperation of the Library staff is deeply appreciated. So is the excellent help I received from the Graphic Art Service.

Appendix A

LOST PONTOON FOUND BY SONAR ECHO-RANGING

In April 1965 an officer, Lt. Richard H. Webber, in the History Division of the Navy Department, Washington, D. C., asked me this question: "When did the U.S. Navy employ a sonar device for the first time to solve a real operational problem?" (not simulated in any way).

Except for the precise date and exact location of the pontoon when it was lost, I answered the question promptly and without hesitation. These are the pertinent facts of nearly forty years ago, regarding this incident, as I recalled them. (The independent statements of Dr. Hayes and of Capt. Moore were substantially identical in detail.) Sometime in 1928 or 1929, Dr. H. C. Hayes and I (employees of NRL, Washington, D. C.) were on the USS Eagle #58, testing and evaluating the XL quartz-steel transducers as well as the Rochelle salt crystal devices. The experimental area for this work then was off New London, Connecticut, and probably near Block Island. Suddenly, a dispatch from Commander, Control Force (Admiral Upham) ordered Eagle #58, in effect, to use its newly developed experimental apparatus to find a large pontoon lost that morning in a specific area. All sound exercises were immediately suspended, and Eagle #58 headed for the designated area.

As we approached the general area mentioned, the Commanding Officer of Eagle #58, LCDR L. R. Moore (who was himself a proficient ham operator), ordered the soundman on duty to make a few "pings" on the lost pontoon. Captain Moore then took charge of the key and proceeded to "ping" over the assumed lost object as we steamed on a prearranged course. After several runs, Captain Moore proclaimed "Here it is! Listen to this echo." And there it was — the lost pontoon. A buoy was promptly placed over the supposed spot, and it was soon verified that the object lost was on the bottom beneath the marker buoy.

To obtain documentary and other evidence of this pontoon incident which would substantiate our story with more detailed information as to time and place was the task before me in April 1965. At that time certain pertinent factors which could help in this search were available: (1) The daily log books of the USS Eagle #58 for the years she served as an experimental ship at NRL were at the National Archives. Eagle #58 was part of Eagle Division One which consisted of Eagle #58 and Eagle #35. Both of these vessels were assigned to NRL to help carry out experimental and technical development of the Laboratory. Eagle Division One was under the command of the Control Force in 1927, 1928, and 1929. During these years, Rear Admiral F. B. Upham served as Commander, Battleship Division Three of the Battle Fleet, and Commander, Control Force. Admiral Upham died September 1939. (2) LCDR Louis R. Moore assumed command of the USS Eagle #58 on 16 July 1927 and was relieved of that command on 6 January 1930. Captain Moore now lives in retirement in Florida. His version of the pontoon event is substantially the same as mine, but his dates differ with the log of USS Eagle #58. (3) Dr. Harvey C. Hayes is in his 89th year and since his retirement in 1948 has lived in Dublin, New Hampshire, and in Florida as well. He too remembered the pontoon incident as taking place off Block Island, but he had no idea about time. (4) After the salvage of the S-4 in 1928, there was considerable activity and experimentation in the Navy with gear to recover sunken submarines. In these efforts were involved not only Navy salvage groups but also some civilian companies. Among the naval personnel who participated in the post S-4 salvage work was Admiral Andrew I. McKee (Bureau of Construction and Repair). Admiral McKee, who retired November 1947, now lives at 30 Guntrie Place, New London, Conn. He vaguely recalled the pontoon incident and believes the pontoon was lost in the spring of 1929. (5) Two civilian companies may have been working with the Navy in these salvage and towing operation efforts, and one of them could have lost a large Navy pontoon. Chapman-Merritt and Scott, 99 Park Avenue, New York City, was one of the organizations. Mr. Oberle of this company told me that most of their records as far back as 1928-29 were destroyed. A similar reply was given me by Mr. Lake and Danenhower, Bridgeport, Conn. No records are available of those days, and the old-timers who are still around could not recall any such incident. (6) The source from which I expected positive, sure-fire help in this documentation failed me completely. The 1928 and 1929 log books of USS Eagle #58, which were supposed to record each day's happenings pertaining to the ship's movements, operations, special orders, and so forth, do not mention the pontoon incident, nor the dispatch from Commander, Control Force, ordering a change in operations. This might have been due to the classification of the project at the time or its security. It may have been Moore's modesty. Anyway, Captain L. R. Moore signed each daily page while he was in command and on board. This means 16 July 1927 to 6 January 1930, except some odd days of leave when the Executive Officer Lt. Pearson was acting for the Captain.

Now (as of 11 August 1966) there are indications that the pontoon incident happened in 1929, either in June or in August, somewhere near Block Island, and that the USS Eagle #58 was involved in this activity. The June date comes from Capt. Moore while the August date is from an official NRL log book showing the period when Dr. Hayes and I proceeded to New London for temporary duty on Eagle #58. Following are the records, statements, and telephone calls of some participants or observers of the pontoon incident.

So far it has been established that USS Eagle #58 did locate a lost pontoon by her experimental echo-ranging device somewhere near Block Island, Rhode Island, in the year 1929. Capt. Moore's letter dated the occurrence of this event "about the end of June 1929," whereas the log book of USS Eagle #58 shows that the Eagle #58 (log book title page for June 1929, Fig. 6) operated between Washington, D. C., and Norfolk, Virginia (Piney Point, Lynnhaven Road, and so on) during the entire month of June 1929. On the other hand, title page of August 1929 (Fig. 7) as well as pages 480, 482, 484, 486, and 488 (Figs. 8-12,[17] respectively) of Eagle #58 log book indicated operations of Eagle #58 out of New London, Conn., and in the Block Island area. These days correspond to the NRL log book, page 277 (Fig. 13), which records the fact that Hayes and I proceeded to New London on 17 August 1929 and that I returned 23 August 1929. Furthermore, page 480 of Eagle #58 log shows that on 19 August the Eagle #58 was testing Submarine Signal Company four-Spot compensators, an occasion when neither Hayes nor I would go to sea on Eagle #58 on that day. On Tuesday, 20 August, Eagle #35 was having some engine trouble, and Eagle #58 was standing by for assistance. At 12:45 Eagle #35 was cast off by Eagle #58 to be towed to the Submarine Base. Then Eagle #58 anchored as before (in the Thames River). This indicates that Eagle #58 did not conduct any sound exercises away from New London on that day, 20 August 1929. Therefore, the days which appear most probable for the occurrence of the pontoon incident are Wednesday or Thursday, 21 or 22 August 1929. On each of these days the USS Eagle #58 had a target submarine for the sound exercises of that day. The USS 0-10 worked with the Eagle #58 on Wednesday, 21 August, while the USS 0-4 operated with the Eagle #58 on Thursday. Both submarines show in their log books that each operated on the day indicated in areas 6 and 7. But neither submarine log mentions any sudden change in the operating schedule for the particular day. Despite this lack of record on the three ships involved on 21 and 22 August 1929, it is my studied opinion that the pontoon incident occurred on either 21 or 22 August 1929.

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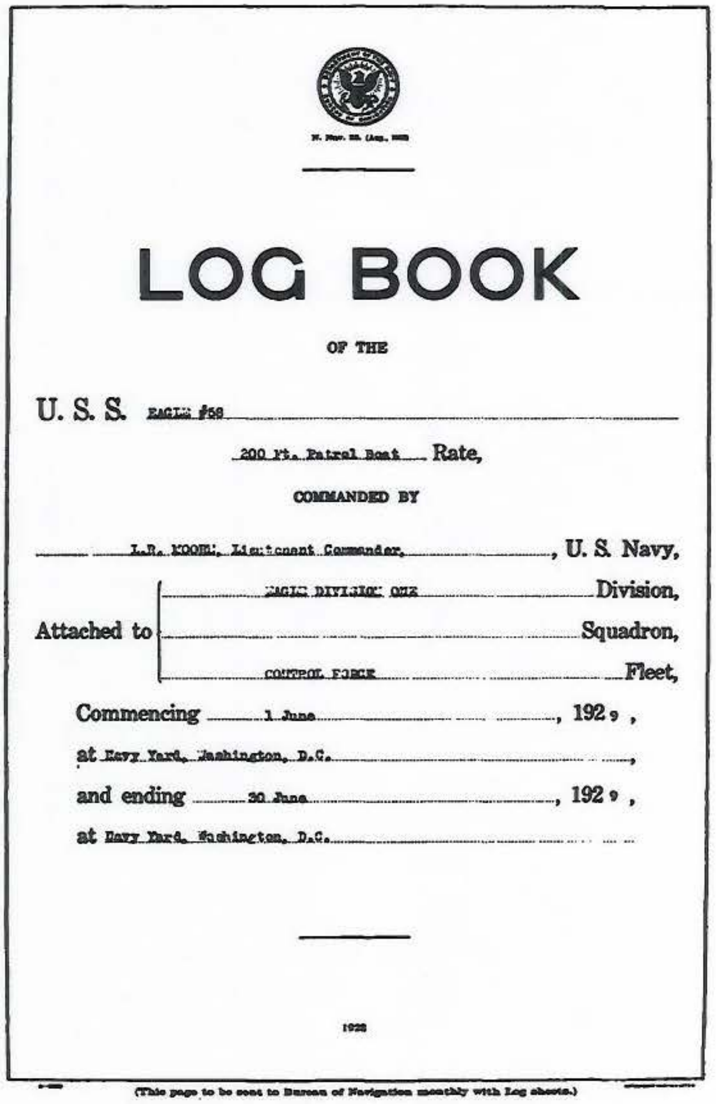
[17] The seven negatives from which the Log Book photographs (Figs. 6-12) were made, were obtained through the courtesy of the U.S. National Archives. The author wishes to express his thanks to Mr. Harry Schwartz, of the Army and Navy Branch, in the National Archives and Records for his generous and valuable assistance given me during the search of old NRL records.



N. Nav. [illegible] (Aug., [illegible])

LOG BOOK

OF THE

U. S. S. EAGLE #58

200 Ft. Patrol Boat Rate,

COMMANDED BY

L.R. KOOHL, Lieutenant Commander, U. S. Navy,

Attached to
EAGLE DIVISION ONE Division,
Squadron,
CONTROL FORCE Fleet,

Commencing 1 June, 1929,

at Navy Yard, Washington, D.C.,

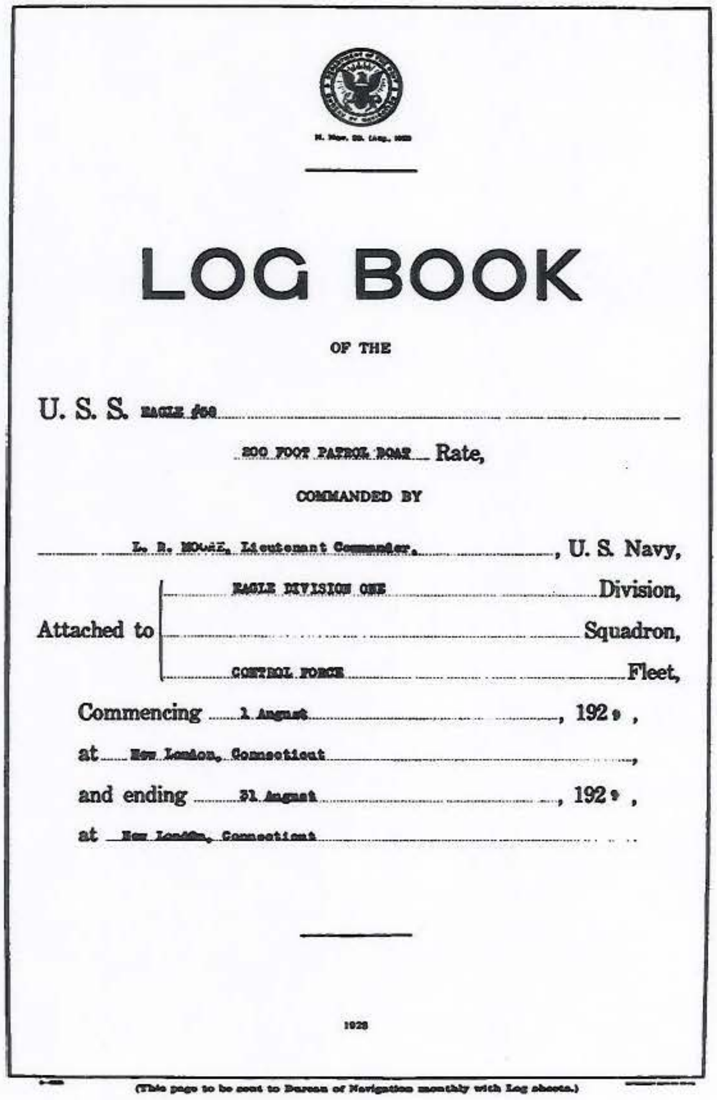
and ending 30 June, 1929,

at Navy Yard, Washington, D.C.

1928

(This page to be sent to Bureau of Navigation monthly with Log sheets.)

Fig. 6. Title page from the Logbook of the U.S.S. EAGLE #58, dated 1 June 1929. Entries in the Logbook indicate that the EAGLE #58 worked the month of June 1929 between Washington, D.C. and Norfolk, Va. It touched Lynnhaven Road, Piney Point, Washington, D.C., and returned to Norfolk.



LOG BOOK

OF THE

U. S. S. EAGLE #58

200 FOOT PATROL BOAT Rate,

COMMANDED BY

L. R. MOORE, Lieutenant Commander, U. S. Navy,

Attached to
EAGLE DIVISION ONE Division,
Squadron,
CONTROL FORCE Fleet,

Commencing 1 August, 1929,

at New London, Connecticut,

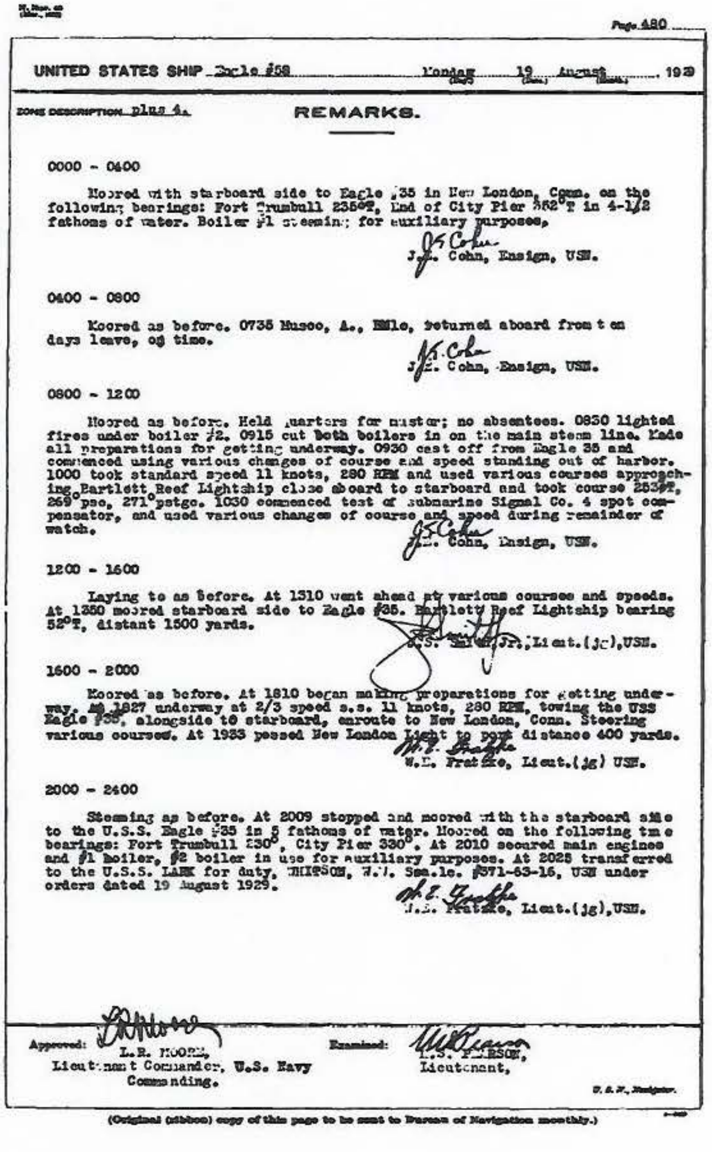
and ending 31 August, 1929,

at New London, Connecticut

1928

(This page to be sent to Bureau of Navigation monthly with Log sheets.)

Fig. 7. Title page from the Logbook of the U.S.S. EAGLE #58, dated 1 August 1929. Entries in the Logbook corroborate the opinions that the EAGLE #58 spent the month of August in the New London area.



N. Nav. 40

Page 480

UNITED STATES SHIP Eagle #58 Monday 19 August 1929

ZONE DESCRIPTION plus 4.

REMARKS.

0000 - 0400

Moored with starboard side to Eagle #35 in New London, Conn. on the following bearings: Fort Trumbull 235°T, End of City Pier 362°T in 4-1/2 fathoms of water. Boiler #1 steaming for auxiliary purposes.

J.E. Cohn, Ensign, USN.

0400 - 0800

Moored as before. 0735 Musco, A., EM1c, returned aboard from ten days leave, on time.

J.E. Cohn, Ensign, USN.

0800 - 1200

Moored as before. Held quarters for muster; no absentees. 0830 lighted fires under boiler #2. 0915 cut both boilers in on the main steam line. Made all preparations for getting underway. 0930 cast off from Eagle 35 and commenced using various changes of course and speed standing out of harbor. 1000 took standard speed 11 knots, 280 RPM and used various courses approaching Bartlett Reef Lightship close aboard to starboard and took course 253°T, 269° psc, 271° pstgc. 1030 commenced test of Submarine Signal Co. 4 spot compensator, and used various changes of course and speed during remainder of watch.

J.E. Cohn, Ensign, USN.

1200 - 1600

Laying to as before. At 1310 went ahead at various courses and speeds. At 1350 moored starboard side to Eagle #35. Bartlett Reef Lightship bearing 52°T, distant 1500 yards.

S.S. Smith, Jr., Lieut.(jg), USN.

1600 - 2000

Moored as before. At 1810 began making preparations for getting underway. At 1827 underway at 2/3 speed s.s. 11 knots, 280 RPM, towing the USS Eagle #35, alongside to starboard, enroute to New London, Conn. Steering various courses. At 1933 passed New London Light to port distance 400 yards.

W.E. Fratzke, Lieut.(jg) USN.

2000 - 2400

Steaming as before. At 2009 stopped and moored with the starboard side to the U.S.S. Eagle #35 in 5 fathoms of water. Moored on the following true bearings: Fort Trumbull 230°, City Pier 330°. At 2010 secured main engines and #1 boiler, #2 boiler in use for auxiliary purposes. At 2025 transferred to the U.S.S. LARK for duty, [illegible], W.J., Sea.1c. #371-63-16, USN under orders dated 19 August 1929.

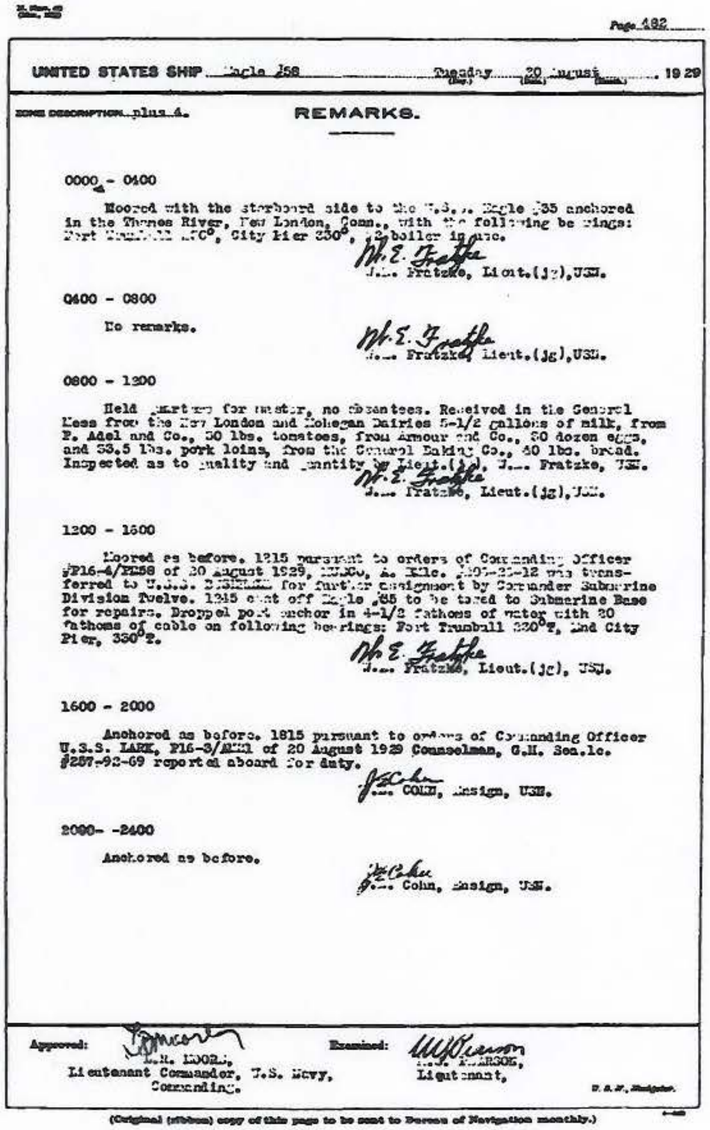
W.E. Fratzke, Lieut.(jg), USN.

Approved: L.R. Moore
L.R. MOORE,
Lieutenant Commander, U.S. Navy
Commanding.

Examined:
L.S. P[illegible]RSON,
Lieutenant,
U.S.N., Navigator.

(Original (ribbon) copy of this page to be sent to Bureau of Navigation monthly.)

Fig. 8. EAGLE #58 Logbook, page 480, 19 August 1929: record shows that on 19 August the EAGLE #58 was engaged in testing the Submarine Signal Company's Four-Spot Compensator. Neither Hayes nor I went to sea that day.



Page 482

UNITED STATES SHIP Eagle #58 Tuesday 20 August 1929

ZONE DESCRIPTION plus 4. REMARKS.

0000 - 0400

Moored with the starboard side to the U.S.S. Eagle #35 anchored in the Thames River, New London, Conn., with the following bearings: Fort Trumbull [illegible]°, City Pier 330°, #2 boiler in use.

W.E. Fratzke
J.[illegible] Fratzke, Lieut.(jg),USN.

0400 - 0800

No remarks.

W.E. Fratzke
J.[illegible] Fratzke, Lieut.(jg),USN.

0800 - 1200

Held quarters for muster, no absentees. Received in the General Mess from the New London and Mohegan Dairies 5-1/2 gallons of milk, from P. Adel and Co., 30 lbs. tomatoes, from Armour and Co., 30 dozen eggs, and 33.5 lbs. pork loins, from the General Baking Co., 40 lbs. bread. Inspected as to quality and quantity by Lieut.(jg), J.[illegible] Fratzke, USN.

W.E. Fratzke
J.[illegible] Fratzke, Lieut.(jg),USN.

1200 - 1600

Moored as before. 1215 pursuant to orders of Commanding Officer #P16-4/[illegible] of 20 August 1929, [illegible], A. [illegible] #[illegible]-12 was transferred to U.S.S. [illegible] for further assignment by Commander Submarine Division Twelve. 1245 cast off Eagle #35 to be towed to Submarine Base for repairs. Dropped port anchor in 4-1/2 fathoms of water with 20 fathoms of cable on following bearings: Fort Trumbull 330°T, and City Pier, 330°T.

W.E. Fratzke
J.[illegible] Fratzke, Lieut.(jg), USN.

1600 - 2000

Anchored as before. 1815 pursuant to orders of Commanding Officer U.S.S. LARK, P16-3/[illegible] of 20 August 1929 Counselman, G.H. Sea.1c. #257-92-69 reported aboard for duty.

J.[illegible] COHN, Ensign, USN.

2000- -2400

Anchored as before.

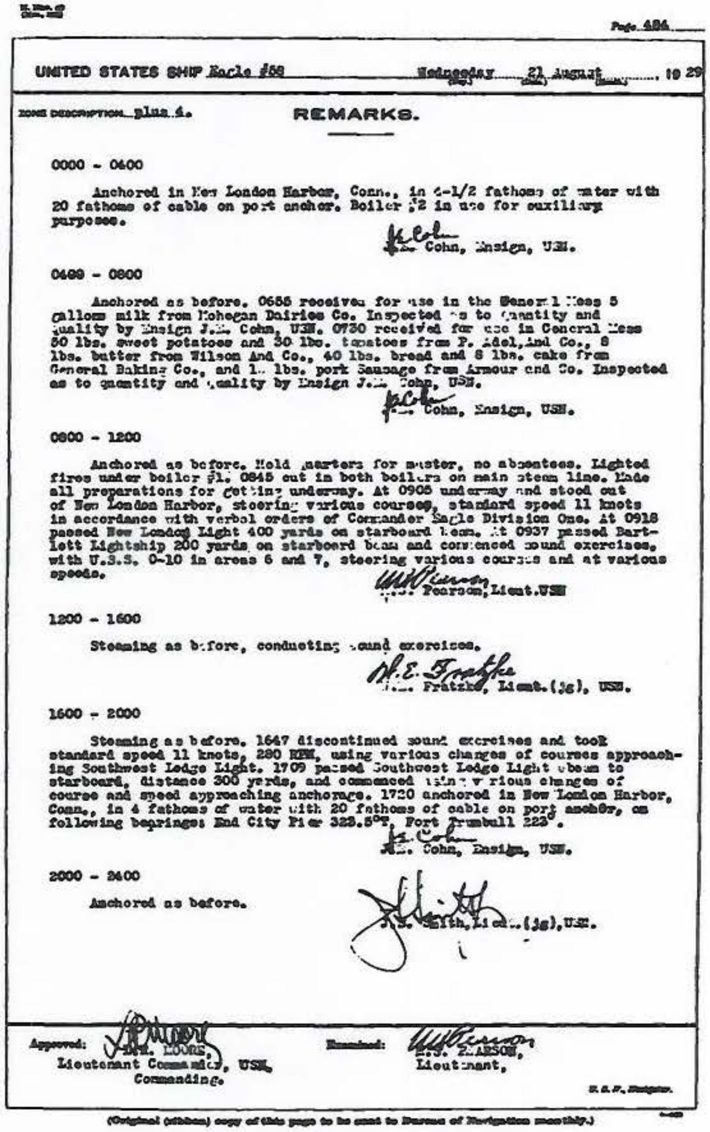
J.[illegible] Cohn, Ensign, USN.

Approved: [illegible]
Lieutenant Commander, U.S. Navy,
Commanding.

Examined: [illegible]
Lieutenant,

(Original (ribbon) copy of this page to be sent to Bureau of Navigation monthly.)

Fig. 9. EAGLE #58 Logbook, page 482, 20 August 1929: on this day EAGLE #58 helped EAGLE #35 with some engine trouble. At 12:45 EAGLE #35 was cast off by EAGLE #58 to be towed to the Submarine Base. Then EAGLE #58 anchored as before.



Page 484

UNITED STATES SHIP Eagle #58 Wednesday 21 August 1929

ZONE DESCRIPTION plus 4.

REMARKS.

0000 - 0400

Anchored in New London Harbor, Conn., in 4-1/2 fathoms of water with 20 fathoms of cable on port anchor. Boiler #2 in use for auxiliary purposes.

J.E. Cohn, Ensign, USN.

0400 - 0800

Anchored as before. 0655 received for use in the General Mess 5 gallons milk from Mohegan Dairies Co. Inspected as to quantity and quality by Ensign J.E. Cohn, USN. 0730 received for use in General Mess 50 lbs. sweet potatoes and 30 lbs. tomatoes from P. Adel, And Co., 8 lbs. butter from Wilson And Co., 40 lbs. bread and 8 lbs. cake from General Baking Co., and 1. lbs. pork Sausage from Armour and Co. Inspected as to quantity and quality by Ensign J.E. Cohn, USN.

J.E. Cohn, Ensign, USN.

0800 - 1200

Anchored as before. Hold quarters for muster, no absentees. Lighted fires under boiler #1. 0845 cut in both boilers on main steam line. Made all preparations for getting underway. At 0905 underway and stood out of New London Harbor, steering various courses, standard speed 11 knots in accordance with verbal orders of Commander Eagle Division One. At 0918 passed New London Light 400 yards on starboard beam. At 0937 passed Bartlett Lightship 200 yards on starboard beam and commenced sound exercises, with U.S.S. O-10 in areas 6 and 7, steering various courses and at various speeds.

W.E. Pearson, Lieut.USN

1200 - 1600

Steaming as before, conducting sound exercises.

H.E. Fratzke

H.E. Fratzke, Lieut.(jg), USN.

1600 - 2000

Steaming as before. 1647 discontinued sound exercises and took standard speed 11 knots, 280 RPM, using various changes of courses approaching Southwest Ledge Light. 1709 passed Southwest Ledge Light abeam to starboard, distance 300 yards, and commenced using various changes of course and speed approaching anchorage. 1720 anchored in New London Harbor, Conn., in 4 fathoms of water with 20 fathoms of cable on port anchor, on following bearings: End City Pier 323.5°T, Fort Trumbull 223°.

J.E. Cohn

J.E. Cohn, Ensign, USN.

2000 - 2400

Anchored as before.

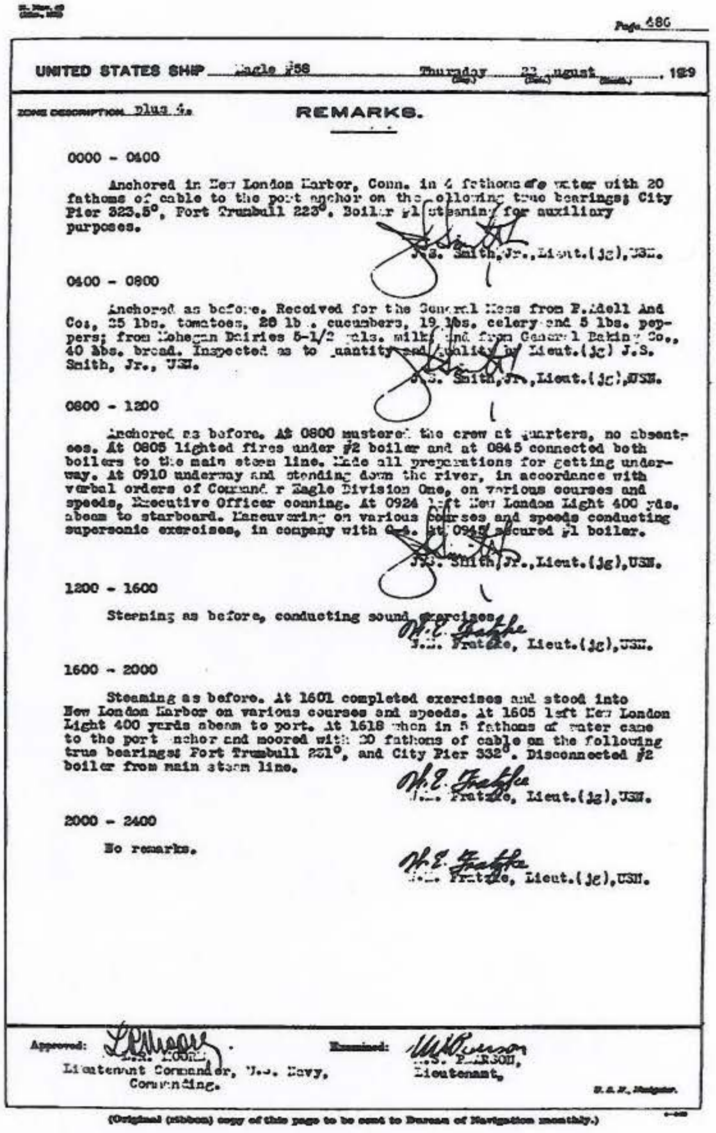
J.S. Smith, Lieut.(jg), USN.

Approved: H.M. MOORE, Lieutenant Commander, USN, Commanding.

Examined: W.E. PEARSON, Lieutenant,

(Original (ribbon) copy of this page to be sent to Bureau of Navigation monthly.)

Fig. 10. EAGLE #58 Logbook, page 484, 21 August 1929: Wednesday, 21 August 1929—EAGLE #58 operated in areas 6 and 7 in company with USS 0-10. This may be the day of the pontoon incident.



Page 486

UNITED STATES SHIP Eagle #58 Thursday 22 August 1929
(Day) (Date) (Month)

ZONE DESCRIPTION plus 4.

REMARKS.

0000 - 0400

Anchored in New London Harbor, Conn. in 4 fathoms of water with 20 fathoms of cable to the port anchor on the following true bearings; City Pier 323.5°, Fort Trumbull 223°. Boiler #1 steaming for auxiliary purposes.

J.S. Smith, Jr., Lieut.(jg), USN.

0400 - 0800

Anchored as before. Received for the General Mess from F. Adell And Co., 25 lbs. tomatoes, 28 lbs. cucumbers, 19 lbs. celery and 5 lbs. peppers; from Mohegan Dairies 5-1/2 gals. milk and from General Baking Co., 40 lbs. bread. Inspected as to quantity and quality by Lieut.(jg) J.S. Smith, Jr., USN.

J.S. Smith, Jr., Lieut.(jg), USN.

0800 - 1200

Anchored as before. At 0800 mustered the crew at quarters, no absentees. At 0805 lighted fires under #2 boiler and at 0845 connected both boilers to the main steam line. Made all preparations for getting underway. At 0910 underway and standing down the river, in accordance with verbal orders of Commander Eagle Division One, on various courses and speeds, Executive Officer conning. At 0924 left New London Light 400 yds. abeam to starboard. Maneuvering on various courses and speeds conducting supersonic exercises, in company with O-4. At 0945 secured #1 boiler.

J.S. Smith, Jr., Lieut.(jg), USN.

1200 - 1600

Steaming as before, conducting sound exercises.

W.E. Fratzke
W.E. Fratzke, Lieut.(jg), USN.

1600 - 2000

Steaming as before. At 1601 completed exercises and stood into New London Harbor on various courses and speeds. At 1605 left New London Light 400 yards abeam to port. At 1618 when in 5 fathoms of water came to the port anchor and moored with 20 fathoms of cable on the following true bearings: Fort Trumbull 231°, and City Pier 332°. Disconnected #2 boiler from main steam line.

W.E. Fratzke
W.E. Fratzke, Lieut.(jg), USN.

2000 - 2400

No remarks.

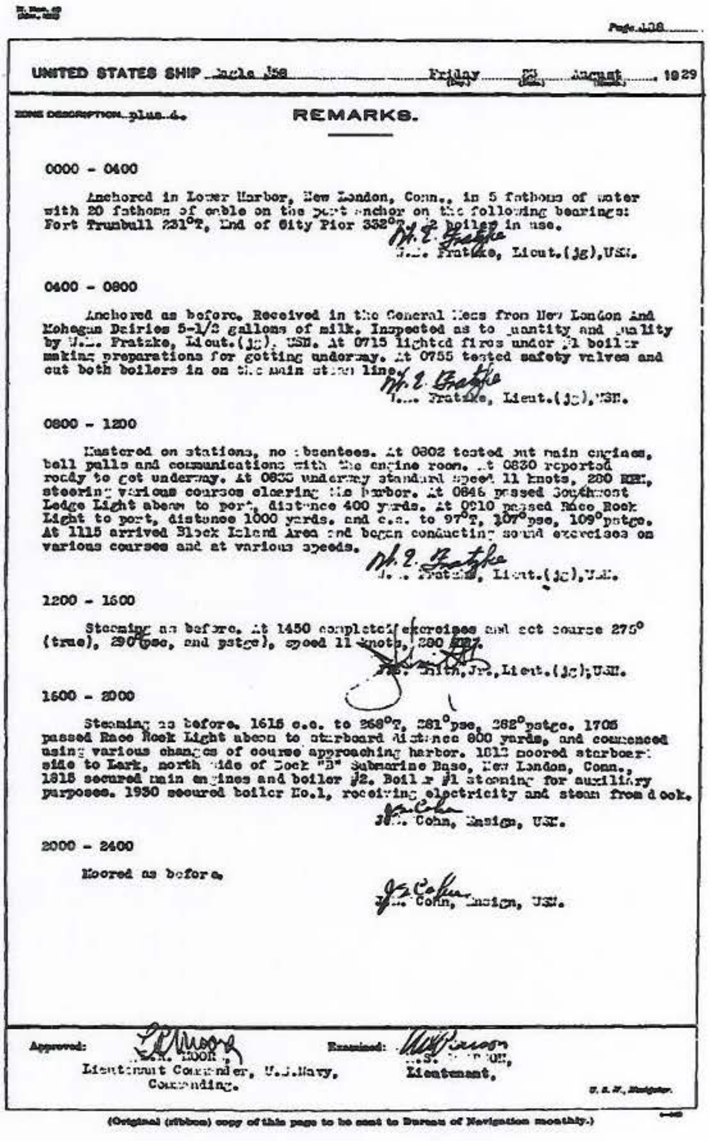
W.E. Fratzke
W.E. Fratzke, Lieut.(jg), USN.

Approved: L.R. Moore
L.R. MOORE,
Lieutenant Commander, U.S. Navy,
Commanding.

Examined: W.S. Pearson
W.S. PEARSON,
Lieutenant,
U.S.N., Navigator.

(Original (ribbon) copy of this page to be sent to Bureau of Navigation monthly.)

Fig. 11. EAGLE #58 Logbook, page 486, 22 August 1929: EAGLE #58 went to sea for sound exercises in company with USS 0-4 in areas 6 and 7. It is possible that the pontoon incident occurred on this day, although the log of 0-4 does not show any suspension of exercises.



Page 488

UNITED STATES SHIP Eagle 58 Friday 23 August 1929

ZONE DESCRIPTION plus 4.

REMARKS.

0000 - 0400

Anchored in Lower Harbor, New London, Conn., in 5 fathoms of water with 20 fathoms of cable on the port anchor on the following bearings: Fort Trumbull 231°T, End of City Pier 332°T. #2 boiler in use.

W. E. Fratzke
W. E. Fratzke, Lieut.(jg),USN.

0400 - 0800

Anchored as before. Received in the General Mess from New London and Mohegan Dairies 5-1/2 gallons of milk. Inspected as to quantity and quality by W. E. Fratzke, Lieut.(jg), USN. At 0715 lighted fires under #1 boiler making preparations for getting underway. At 0755 tested safety valves and cut both boilers in on the main steam line.

W. E. Fratzke
W. E. Fratzke, Lieut.(jg),USN.

0800 - 1200

Mustered on stations, no absentees. At 0802 tested out main engines, bell pulls and communications with the engine room. At 0830 reported ready to get underway. At 0833 underway standard speed 11 knots, 280 RPM, steering various courses clearing the harbor. At 0846 passed Southwest Ledge Light abeam to port, distance 400 yards. At 0910 passed Race Rock Light to port, distance 1000 yards, and c.c. to 97°T, 107°psc, 109°pstgc. At 1115 arrived Block Island Area and began conducting sound exercises on various courses and at various speeds.

W. E. Fratzke
W. E. Fratzke, Lieut.(jg),USN.

1200 - 1600

Steaming as before. At 1450 completed exercises and set course 275° (true), 290°psc, and pstgc), speed 11 knots, 280 RPM.

Smith
[illegible] Smith, Jr., Lieut.(jg),USN.

1600 - 2000

Steaming as before. 1615 c.c. to 268°T, 281°psc, 282°pstgc. 1705 passed Race Rock Light abeam to starboard distance 800 yards, and commenced using various changes of course approaching harbor. 1813 moored starboard side to Lark, north side of Dock "B" Submarine Base, New London, Conn., 1815 secured main engines and boiler #2. Boiler #1 steaming for auxiliary purposes. 1930 secured boiler No.1, receiving electricity and steam from dock.

J. S. Cohn
J. S. Cohn, Ensign, USN.

2000 - 2400

Moored as before.

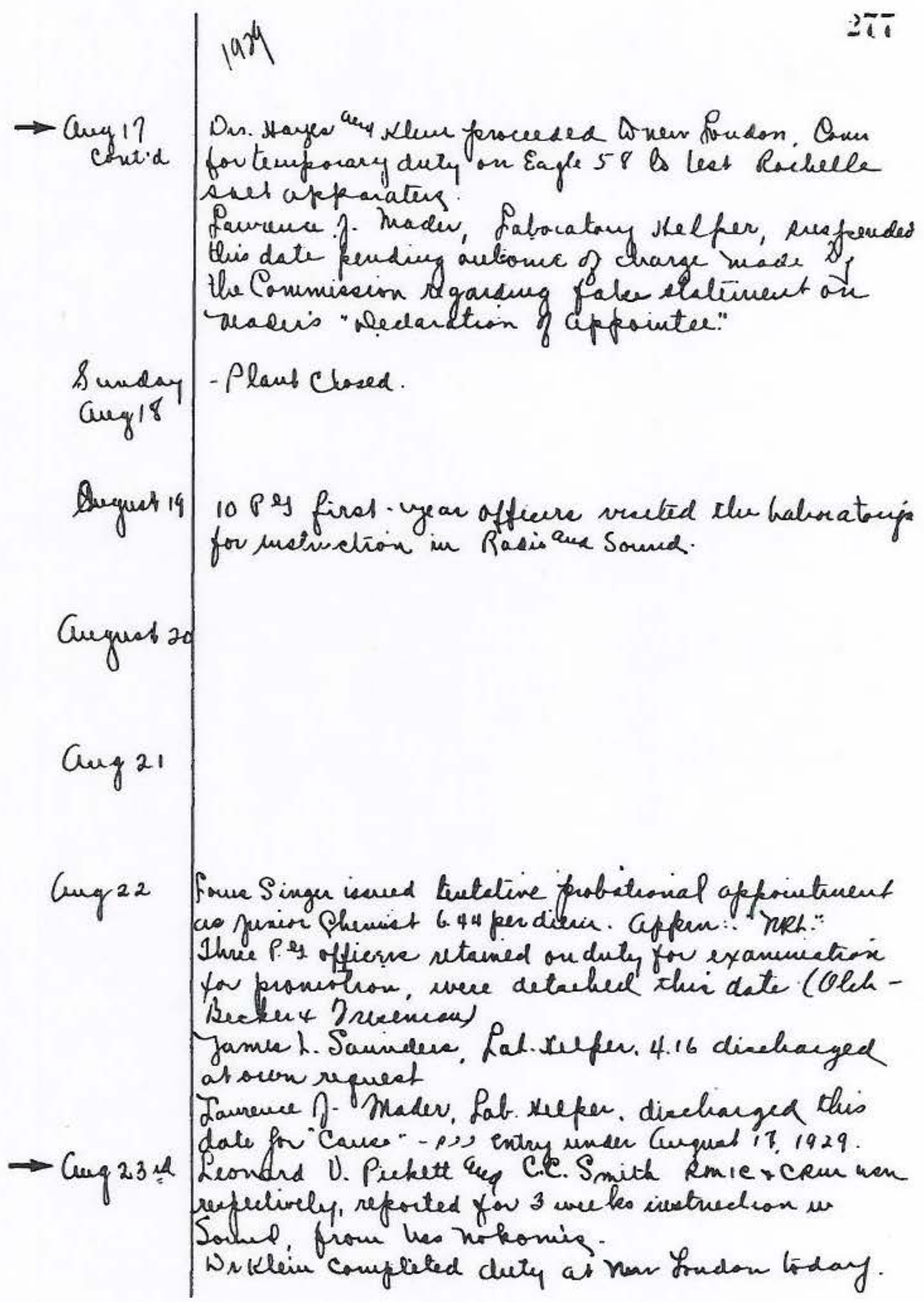
J. S. Cohn
J. S. Cohn, Ensign, USN.

Approved: L. R. Moore
[illegible] MOORE,
Lieutenant Commander, U.S.Navy,
Commanding.

Examined: [illegible]
[illegible],
Lieutenant,
U.S.N., Navigator.

(Original (ribbon) copy of this page to be sent to Bureau of Navigation monthly.)

Fig. 12. EAGLE #58, page 488, 23 August 1929: although EAGLE #58 operated Friday, 23 August 1929, the NRL records show that Klein returned to NRL on Friday; however, I was on the EAGLE #58 when the pontoon was picked up



1929 277

→ Aug 17 Cont'd	Drs. Hayes and Klein proceeded to New London, Conn for temporary duty on Eagle 58 to test Rochelle salt apparatus. Lawrence J. Mader, Laboratory Helper, suspended this date pending outcome of charge made by the Commission regarding false statement on Mader's "Declaration of Appointee."
Sunday Aug 18	- Plant Closed.
August 19	10 P.G. first-year officers visited the laboratory for instruction in Radio and Sound.
August 20	
Aug 21	
Aug 22	Louis Singer issued tentative probational appointment as Junior Chemist 6.44 per diem. Approp: "NRL." Three P.G. officers retained on duty for examination for promotion, were detached this date (Olch - Becker & Freeman) James L. Saunders, Lab. Helper. 4.16 discharged at own request Lawrence J. Mader, Lab. Helper. discharged this date for "Cause" - see entry under August 17, 1929.
→ Aug 23d	Leonard V. Pickett and C.C. Smith RM1c & CRM were respectively, reported for 3 weeks instruction in Sound, from USS Nokomis. Dr Klein completed duty at New London today.

Fig. 13. NRL Station Journal No. 1 (1923-1931), page 277: Aug. 17th listing shows the departure of Hayes and Klein for New London, Conn. and the August 23d listing shows the return of Klein to NRL

Appendix B

PERTINENT MATERIAL

SIGNIFICANT FACTS

1. LCDR L. R. Moore assumed command of USS Eagle #58 on 16 July 1927 and was relieved of that command by Lt. F. R. Dodge on 6 January 1930.

2. Eagle Division One consisted of USS Eagle #58 and Eagle #35. Both of these vessels were assigned to NRL to carry out experiments.

3. Rear Admiral F. B. Upham served as Commander, Battleship Division Three of the Battle Fleet and as Commander, Control Force from 1927 to 1930. Eagle Division One was under the Commander, Control Force in 1927, 1928, and 1929.

4. Dr. Harvey C. Hayes was Superintendent of the Sound Division, NRL, from 1923 to 1948 when he retired. He now lives in Dublin, New Hampshire. I phoned him on 3 August 1966 (Telephone: Area Code 603, 563-5173).

5. Merritt-Chapman and Scott Corporation, 99 Park Avenue, New York City, N. Y., was an occasional contractor to the Navy for ship handling and supplying tugs and barges.

6. Lake and Danenhower, Bridgeport, Connecticut, was a ship-handling contractor, similar to Merritt-Chapman and Scott.

FROM NRL STATION JOURNAL (NO. 1)
1923 THROUGH 1931

On page 277, dated 17 August 1929 (Saturday), "Drs. Hayes and Klein proceeded to New London for temporary duty on Eagle #58 to test R.S. apparatus."

On same page, 23 August 1929, "Dr. Klein completed duty at New London today."

DR. H. C. HAYES' TELEPHONE STATEMENT

On 3 August 1966 I telephoned Dr. Hayes in Dublin, New Hampshire (Area Code 603, 563-5173), regarding the pontoon incident on Eagle #58.

He remembered the incident in detail and even recalled "how very cocky" Captain Moore became when Moore's few pings brought real echoes from the pontoon which proved to be "it."

Hayes said "I am in my 89th year, and I feel very good." He sounded robust and strong. But he had no idea as to the year the pontoon incident occurred or the time of the year. "The passage of time means nothing to me now," he said.

ELIAS KLEIN

TELEPHONE STATEMENTS OF MR. OBERLE OF MERRITT-CHAPMAN AND SCOTT AND MR. LAKE OF LAKE AND DANENHOWER

On 22 July 1966 I talked with Mr. Ciak of Merritt-Chapman and Scott Corporation, New York (Area Code 212, 661-7900) regarding the pontoon incident, and he suggested that I call a Mr. Oberle the next week. He thought that Mr. Oberle might have further information. On 29 July I phoned Mr. Oberle who told me that all of M.C.S.'s records of that period had been destroyed and that unless an employee who had worked for the company at that time remembered the incident Merritt-Chapman and Scott would have no information. His inquiry has so far netted no information.

A similar story was obtained from Mr. Lake of Lake and Danenhower, Bridgeport, Conn., whom I called on 22 July 1966. Mr. Lake reported that no records were available.

EXCERPT FROM CAPT. L. R. MOORE'S LETTER OF JULY 1966 TO ONR

Captain Moore's letter was sent to ONR as an official reply to my telephone conversation with him in June 1966 during which we discussed the pontoon incident:

". . . The U.S.S. Eagle 58, which I commanded in Newport Harbor, on about the end of June, 1929, was ordered to proceed to the vicinity of the entrance to the inner anchorage at Block Island, and to search for and find a pontoon, lost that day by a civilian company, experimenting with recovery gear of sunken submarines.

"I proceeded and anchored where instructed near the supposed anchorage of the pontoon and got my senior operator of the sound gear to searching all around with the horizontal supersonic transceiver, then attached. I thought I would soon get a report of contact.

"Results were disappointing. The above man reported there were myriads of echoes received from all points of the compass but they all sounded alike! I took the receiver and went to all points, carefully listening to and analyzing the pings received. From my many years' experience I could readily hear the differences of the echoes and found one that to me indicated our target had been found.

"I ordered a boat search of the indicated spot, about 2 miles away on true bearing as per search-instrument from my ship. When signalled by two-blocking a signal-flag to the boat it put out a marker and commenced lead-lines soundings overside. Instantly it signalled it had dropped the lead on what seemed to be the pontoon, object of the search. Overside went a regular diver from the tug nearby and without delay confirmation of success came up and was sent on to me on the Eagle 58! We had made the first recorded successful use of the echo-type machine for non-military purpose!

"The tug anchored directly over the object and soon had it on the surface and returned to inner anchorage inside Block Island, near Admiral Upham's flagship, the U.S.S. BUSHNELL.

"Two features were vividly illustrated by this 'feat': (1) The feasibility of such use of a transceiver, and (2) the necessity of and the value of experience in its use. The machine was in perfect shape, due to the care bestowed on it by Naval Research Lab men, notably Drs. H. C. Hayes and E. Klein, and the experience gained by years of underwater operation in proving it out, to show its capabilities."

Louis R. Moore
Capt. U.S.N. (ret.)

Dr. K. Pardon delays
11 July 1966

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13. ABSTRACT

This document describes the development of underwater sound technology in the United States during the period of World War I up to World War II. A number of accomplishments in underwater acoustics of the Naval Research Laboratory are given, emphasizing sonar equipment research and development. Acoustic studies in air and ocean environments carried out at NRL are also described.

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Sonar						
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Quartz-steel sandwich transducer						
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Magnetostrictive transducer						
Electrodynamic transducer						
Sound-transparent rubber window						
Sound ranging						