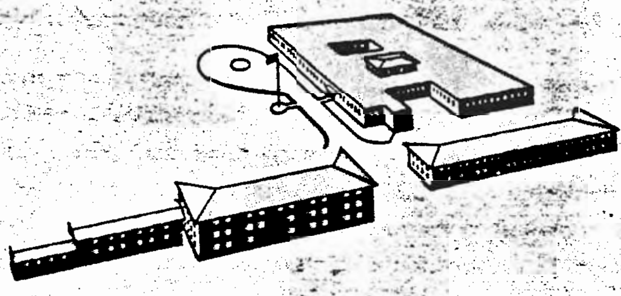
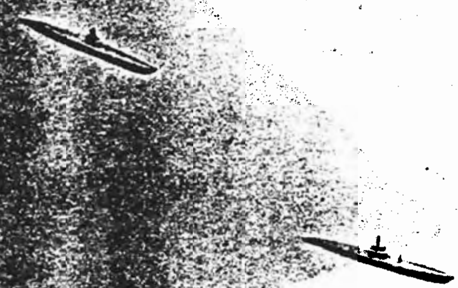
completion report

made to
the Chief of the Bureau of Ships
Navy Department
covering
Operations of the University of California
Division of War Research
at the U.S. Navy Electronics Laboratory
San Diego, California
under
Contract NObs-2074
(formerly OEMsr-30)

from
26 APRIL 1941 TO 30 JUNE 1946





CITATION OF THE WORK OF THE UNIVERSITY OF CALIFORNIA DIVISION OF WAR RESEARCH AT THE U.S. NAVY ELECTRONICS LABORATORY, FOR THE SUBMARINE FORCE, DELIVERED BY CAPTAIN J. W. BLANCHARD, USN, COMMANDER SUBMARINE SQUADRON 5, ON THE OCCASION OF PRESENTING A PLAQUE TO DR. G. P. HARNWELL, DIRECTOR, UCDWR, ABOARD THE USS FULTON, SAN DIEGO BAY, 19 JANUARY 1946.

We are gathered here this morning to show in a small way our appreciation of the excellent work done for the Submarine Force during World War II by the Division of War Research of the University of California. As head of that Division and responsible for the coordination of that work, Dr. Harnwell is here to accept this token on behalf of his organization. The proposal to present some evidence of appreciation originated with Captain Wilkin, but I know that the entire Submarine Force would be in full accord.

By June 1945, the Jap sea lanes were practically depleted of shipping. Hunting was not good. Admiral Lockwood, ComSubsPac, realized far in advance that such would be the case. He realized, too, that the last of the Jap shipping would be operating in the Sea of Japan. There were two approaches through which submarines could enter this sea; one from the north through the various passages in the Kuriles, and one from the south through the heavily protected Straits of Tsushima. All approaches, we knew, were heavily mined.

UCDWR was given the task of developing equipment that would enable our submarines to negotiate these approaches. After an urgent program of experimenting, testing, producing, and training, this equipment was installed on some of our boats. In June of 1945, nine of those boats cleared the Straits of Tsushima successfully and entered the Sea of Japan, right in the Jap's backyard. Those boats accounted for over 100,000 tons of shipping sunk, and many thousand tons damaged. Without the special equipment developed by UCDWR, that operation would have been practically impossible.

The average layman gives little credit to the contribution made by scientific laboratories, but the men of the Submarine Service know what credit Dr. Harnwell's organization deserves. When the final pages of submarine warfare history are written, many of those pages will be devoted to the fine work done for the Submarine Force by the UCDWR. In recognition of its services, I am very happy this morning to present this plaque to Dr. Harnwell.

preface

The University of California Division of War Research (UCDWR), the operation of which is described in this report, was established for the purpose of conducting research and development in subsurface warfare under the provisions of a Contract between the Office of Scientific Research and Development (OSRD) and the University of California.

The original Contract, designated as OEMsr-30, dated 15 August 1941 but effective as of 26 April 1941, was supplemented from time to time. On 1 March 1945 it was assigned by the Office of Scientific Research and Development to the Navy Department, Bureau of Ships, and was henceforth known as "NObs-2074 (formerly OEMsr-30)." The present report to the Chief of the Bureau of Ships is made in accordance with Article 1(d) of the latter contract which provides in part:

> "**The Contractor shall report the progress of the work from time to time as may be directed by the Chief of the Bureau of Ships, and shall furnish . . . . . a complete final report of its findings and conclusions in connection with services under this Contract.**" (Boldface ours)

This obligation was interpreted in a letter from the Chief of the Bureau of Ships to the Director, University of California Division of War Research, Serial No. C-0156(940Ds) dated 11 October 1945. The letter, in commenting on the administrative section of the report, stated:

> "The Bureau attaches great importance to the preparation of a permanent record on this subject. The problems encountered in organizing a large and active research laboratory are many and various; a thorough discussion of these problems, and the ways in which they were solved, would be useful for reference in case necessity required the organization of a similar laboratory. Since this subject will not be covered in any other report, it is suggested that this section be written in some detail. It is hoped that emphasis can be placed primarily on the reasons underlying the organizational setup rather than on the simple facts of the organization."

In addition, the letter noted that the research and development program was "of somewhat less interest . . . since the description of the individual devices will be given in more detail elsewhere."

As a consequence of this directive, the present report emphasizes the Laboratory's organization and history, but supplements brief general descriptions of the scientific programs with an appendix including a complete bibliography of Laboratory reports and publications to which reference can be made by interested persons.

The period covered by the report begins with the establishment of the Laboratory in June 1941 and ends at approximately 1 April 1946. Contract NObs-2074 formally extends until 30 June 1946, but it is obvious that in order to submit the report during the contractual period, an earlier closing date, for reporting purposes, had to be chosen. Since, however, a large portion of the scientific program has been or will be assumed by the U. S. Navy Electronics Laboratory (formerly the U. S. Navy Radio and Sound Laboratory), and plans for this transfer are well advanced, a reasonably accurate forecast of operation for the remaining period is made herein. The report thus includes a summary of some ninety-five per cent of the Laboratory's activities.

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introduction

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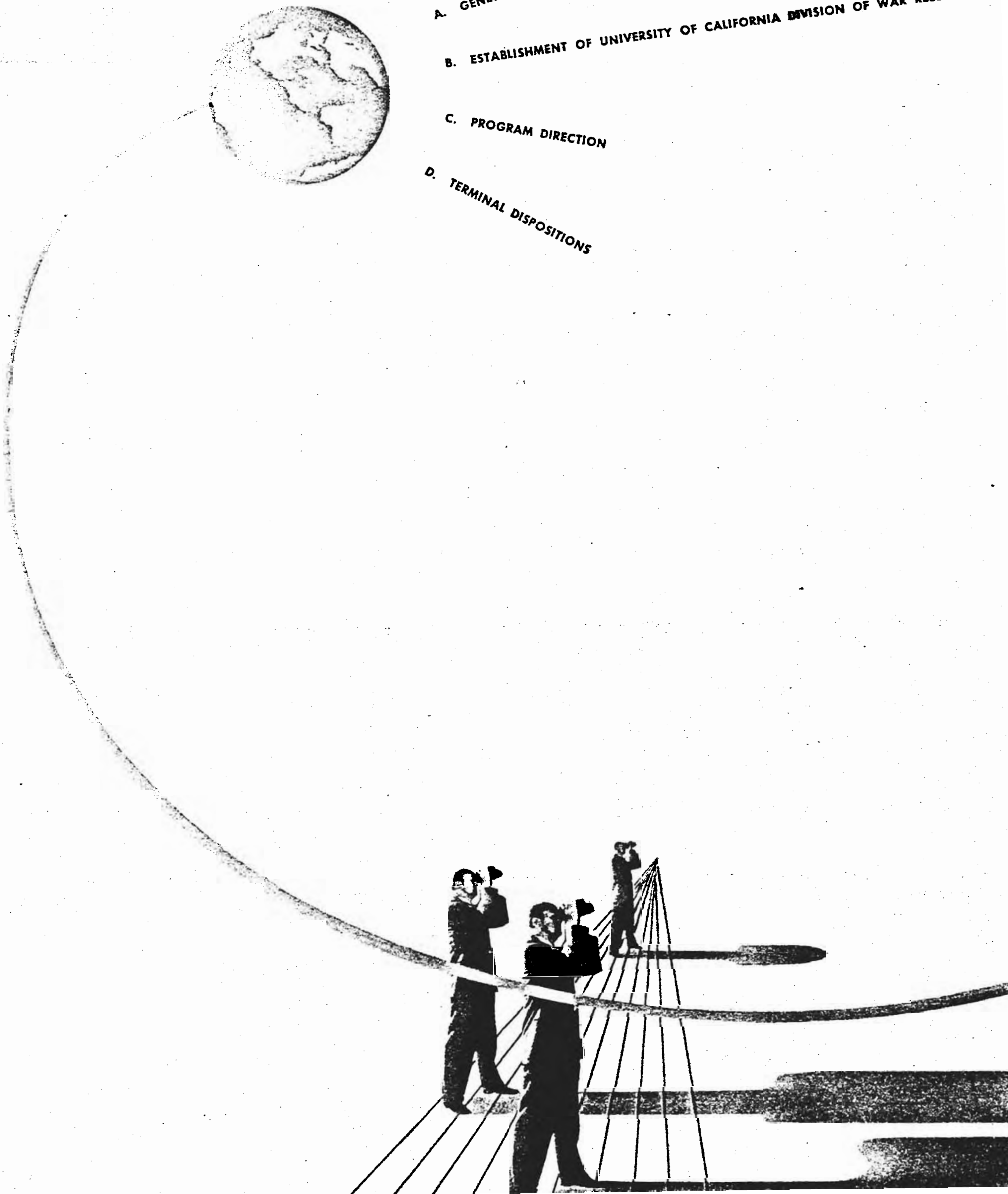
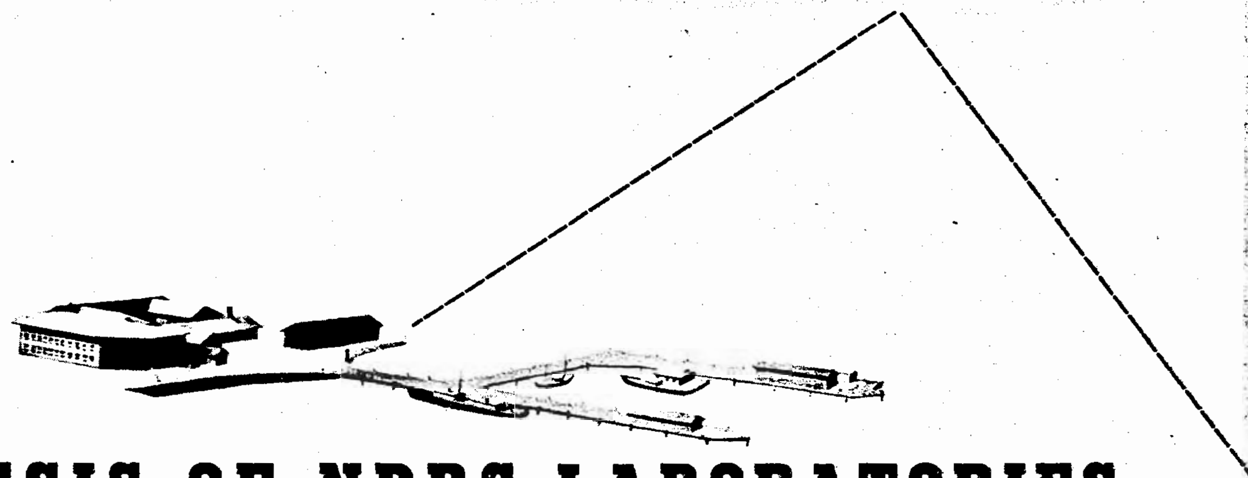


A.



GENESIS OF NDRC LABORATORIES

The ominous rise of militant autocracies in Europe and Asia during the preceding decade led responsible military and scientific groups in this country to survey critically our national scientific preparedness for war. The maintenance of our national interests and the discharge of obligations to potential allies were clearly dependent on the success of our naval operations, and the submarine was recognized as an outstanding threat to all surface ships. The successful combatting of this serious menace and the exploitation of the possibilities inherent in our own submarine force were seen to require the best in technical equipment that could be devised. The awareness of the serious situation confronting the country led to a thorough survey of our preparations for undersea warfare by the Committee of the National Academy of Sciences. This committee, which met during the closing months of 1940, submitted a report to the Academy which was in turn transmitted to the Navy Department for its consideration.

As a result of the study of this problem by the Navy, the Chief of the Bureau of Ships requested Dr. Vannevar Bush, Chairman of the National Defense Research Committee (NDRC), early in 1941, to give further thought to the steps which should be taken for the improvement of our technical facilities for subsurface warfare. In response to this request, NDRC prepared a memorandum containing its recommendations for the conduct of a research and development program. This memorandum proposed a comprehensive investigation of the methods for detecting a submerged or partially submerged submarine, as well as the development of special devices and equipment.

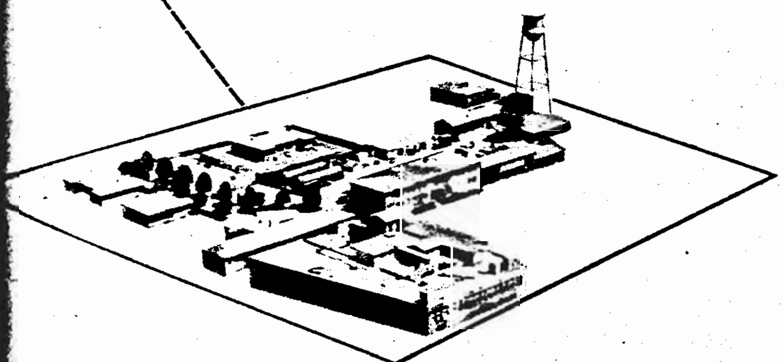
It was proposed that such a program be accomplished in part by groups of competent scientists and engineers working in existing commercial, academic, and government laboratories and that, in addition, special laboratories be established for this specific type of work. Two such laboratories were suggested, one to be located on the Atlantic Coast and the other on the Pacific Coast. It was further recommended that the Atlantic Coast laboratory, because of its promixity to Washington and large manufacturing centers, be concerned with the development of equipment and the final design of prototype gear, while the Pacific Coast laboratory would concern itself primarily with fundamental investigations which, it was hoped, would suggest promising techniques or procedures for detecting and successfully combatting submarines.

This proposal was discussed with and adopted by the Navy Department, and in the late spring of 1941 arrangements for establishing these two laboratories were initiated. One was located at the U.S. Navy Underwater Sound Laboratory in New London, Connecticut, and the other at the U.S. Navy Radio and Sound Laboratory in San Diego, California. It was originally proposed that these laboratories be established under contract between NDRC and Columbia University and the University of California, respectively, but in consequence of the re-organization taking place at that time, the contracts were written at a somewhat later date by OSRD, which assumed responsibility for the projects inaugurated by NDRC. The latter organization remained the responsible directing body of the scientific program undertaken.

B.

ESTABLISHMENT

of University of California Division of War Research



The early organizational arrangements during the late spring and early summer of 1941 were authorized in correspondence between NDRC and OSRD and the University of California. Dr. V. O. Knudsen, Dean of the Graduate School of the University of California in Los Angeles, was appointed Special Investigator to supervise the undertaking on 13 May 1941. In consequence of the NDRC-OSRD organization taking place at that time, no formal authorization for the making of expenditures was received by the Laboratory prior to 24 July. On that day a Letter of Intent was written by Dr. Bush, Director of OSRD, justifying the prior commitments which the University had already undertaken on its own responsibility. A final Contract, "Contract OEMsr-30," between OSRD and the University of California was executed on 15 August 1941 and made retroactive to 26 April 1941 in order to cover the previous commitments that had been made for inaugurating the program, which was by that time well under way. The original University activity was known as the "University of California Division of National Defense Research," but was frequently referred to simply as the "San Diego Laboratory." At a later date, after the United States had entered the war, the name was changed to the "University of California Division of War Research," (UCDWR) and this name is used throughout this report.

The terms of the OSRD-UCDWR Contract provided that the Contractor would equip, staff, and operate a laboratory for studies and experimental investigations in connection with and for the development of equipment and methods involved in submarine warfare. Further provisions authorized the conduct of tests, the acquisition and equipment of vessels, and all other activities deemed requisite for the successful conduct of the program envisaged. Responsibility for supervision of the Contractor's activities was vested in Section C-4 of NDRC. Dr. F. B. Jewett, Chairman of Division C, Dr. J. T. Tate, Chief of Section C-4, and other members of the Division corresponded with Dr. Knudsen and conferred with him and the original members of the staff whom he secured, both in New York and San Diego, on the many problems involved in the initiation of the Laboratory.

The novelty of the undertaking for both the Contracting Officer and the University presented many difficult problems which were successfully overcome by the diligent work of the individuals involved and the sympathetic cooperation of the contracting parties. The urgency of the general situation necessitated the greatest haste and justified the many

C. PROGRAM DIRECTION

procedural expediencies that had to be adopted in order that a start could be made on an undertaking of such vital importance to the Navy. The initial nucleus of personnel under the direction of Dr. Knudsen was housed for the first few months in the same building as the U.S. Navy Radio and Sound Laboratory, then under the direction of Captain W. J. Ruble, USN. The group of scientists and their assistants grew slowly by recruiting from the staffs of universities, colleges, industrial laboratories, and technical groups. These men were innocent of any indoctrination or training in the specific problems which they were to undertake or in the conduct of operations jointly with naval activities. In consequence, much of the early period was spent in acquiring the background of knowledge essential for the intelligent and efficient approach to the various problems with which they were confronted. The situation was an obvious outgrowth of the unfortunate conditions which had generally existed in preceding years, during which the scientist-engineer and the naval officer had been without common technical or personal contacts.

During this early period, the operation of UCDWR was complicated by the fact that the original memorandum on which its activities were based had not outlined the division of responsibility between the Directors of the Navy Laboratory and UCDWR with sufficient clarity. This confusion seriously inhibited the effectiveness of UCDWR's activities for several months, but was merely one unavoidable instance of the inability to foresee the many contingencies that would be encountered in such civilian participation in a little-known technical field and in association with a military organization. As the staff grew and the scientific program took form, the need for proper procedures became apparent in order that the various duties and responsibilities of civilian and naval personnel should be understood and discharged. As Laboratory personnel acquired competence in this novel field and merited confidence in their efforts, the difficulties initially encountered were considerably ameliorated. With the passage of months and successive changes in Laboratory organization and cooperating naval commands in the area, a most cordial relationship of mutual understanding and assistance resulted. It is evident in retrospect that the effectiveness of the scientific group increased in direct proportion to the improvement in local liaison and the establishment of intimate working relations with the U.S. Navy Radio and Sound Laboratory, the U.S. Fleet Sonar School, the local Submarine Squadron, and other naval commands.

In accordance with the terms of the Contract, the University undertook to conduct such studies and experimental investigations as might be requested from time to time by the Contracting Officer of the OSRD or his authorized representative. Authority for the cognizance of the University's work was delegated to the chief of the appropriate NDRC section, which was originally Section C-4 and subsequently Section 6.1. The offices of Dr. J. T. Tate and Dr. E. H. Colpitts, Chiefs of Division 6 and Section 6.1, respectively, were in New York, and formal authorization for the University's undertakings was furnished by those officers. Members of this Division and Section constituted an advisory committee for the subsurface warfare program of which UCDWR was an integral part. Representation of the Laboratory through its Director, Dr. G. P. Harnwell, who succeeded Dr. Knudsen on 1 April 1942 and who was a Member of Division 6, provided the point of view of the Laboratory scientists in the broad planning and allocation of the work and insured an appreciation by the Laboratory of its role in the program as a whole. Frequent conferences between the Division and representatives of its contractors contributed immeasurably to liaison between the various groups engaged in studies and experimental work and fostered intimate collaboration between groups which were geographically widely separated. The maximum feasible flexibility of the various contributing groups consistent with the necessary requirement of formal supervision by a responsible government officer was maintained. This method of operation was necessary in order to secure the highest degree of effectiveness from groups of scientists engaged on a research program.

As the objective of the independent civilian scientific program was the ultimate improvement of the Navy's facilities in subsurface warfare, it was essential that it be closely integrated with the Navy's own program of research and development and also with the operating units of the Fleet. The liaison established to accomplish these purposes was of two kinds.

The first was a central liaison between the Navy and OSRD through the Office of the Coordinator of Research and Development for the Navy. Problems which arose in operating units of the Fleet were referred to appropriate naval bureaus, and these in turn submitted recommendations to the Office of the Coordinator in those instances where it appeared appropriate to enlist OSRD assistance. Proposals made by the Coordinator to the Director of OSRD were then considered and assigned to the appropriate subdivision of the civilian agency. If they lay in the field of subsurface warfare, cognizance was generally assumed by Division 6 and the projects authorized in the laboratory of one of the Division's contractors. In many instances, initiative was assumed by a contractor or an NDRC division, and comments and cooperation were invited from the appropriate naval bureau through the channels indicated above.

Upon the establishment of a project in UCDWR, the second type of liaison, bringing about the necessary close local cooperation, was authorized by the Office of the Coordinator. As an instance, the program of assistance in the selection and training of sound operators and officers was greatly facilitated by the establishment of direct channels of communication between UCDWR and the Sonar Schools and Operational Training Commands on both coasts. Such arrangements were necessary for the conduct of day-to-day operations, and proved most fruitful in the stimulus they afforded both civilian and naval participating groups. The responsible OSRD officers, the naval coordinating office, and the interested bureaus and commands were kept informed of the progress of all undertakings through the periodic reports issued by UCDWR.

Late in 1943 it became apparent that the success of our military operations justified a careful reconsideration of the projected program. Beginning in the latter part of 1943 and for the remainder of the period of active work, the diminishing threat of submarine action and the great activity of the Submarine Force in the Pacific caused the prosubmarine aspects of the UCDWR program to assume major importance. This aspect of the Laboratory's work was promoted most effectively by the increased intimacy of working relationships with the Submarine Desk of the Bureau of Ships and the Submarine Command in the Pacific Fleet. With over half of the Laboratory's activities directed toward one or another aspect of prosubmarine warfare, the visits to the Laboratory of Admiral C. A. Lockwood, Jr., Commander Submarine Force Pacific Fleet, and his interest in many of the devices under development, greatly stimulated this part of the program. By the middle of 1944 UCDWR had representatives in the Pacific Area attached to the Submarine Command almost continuously, and a newer and closer relationship with the Bureau and the Navy Laboratory tended materially to the reduction of formal administrative routine associated with the travel and assignment of UCDWR personnel and equipment in connection with these duties.

D. TERMINAL DISPOSITIONS

With the possible termination of the war in view and considering the necessary period between initial research and combat employment, the desirability of associating this work with a permanent organization, rather than a temporary emergency agency such as OSRD, became increasingly obvious. In consequence, the Navy was invited to consider assuming the responsibility for such programs as that of UCDWR in which it would have a continuing long-term interest. The initial stages of instituting the Laboratory's operations and procedures had been accomplished and a going organization was in existence which could presumably be transferred to Navy auspices with little risk of impeding its operations.

Cognizance of the UCDWR program was accordingly transferred to the Navy Department on 1 March 1945. The Contract, as "NObs-2074 (formerly OEMsr-30)," was taken over by the Navy on assignment from OSRD and thenceforth the Bureau of Ships, Code 940, assumed responsibility for the direction of the Contractor's work. The careful preliminary consideration that had been given to this action enabled the transfer to be effected without necessitating any major changes in the Laboratory's operations. After the assignment, the Contracting Officer (the Chief of the Bureau of Ships) delegated certain responsibilities to the Director of the U. S. Navy Radio and Sound Laboratory as Technical Inspector for the Contract. This was Captain P. H. Hammond, USN (Ret), who had relieved Captain Ruble late in 1942, and both he and Captain P. W. Hord, USN, his successor in August 1945, played important roles in the subsequent program of UCDWR. Fiscal operations were greatly facilitated through the efforts of the Technical Inspector and the cooperation of the Bureau of Supplies and Accounts. The continuing scientific work was established under a series of task orders set forth by the Chief of the Bureau of Ships in a letter to UCDWR (BuShips conf ltr Serial No. C-4335(940D) of 21 March 1945). The program of the Laboratory was continued essentially as before and the direct responsibility assumed by the Bureau enabled UCDWR representatives to establish an improved liaison with the Bureau desks and technical staff representatives having particular interest in the work of the Laboratory. This proved especially beneficial in promoting intimate relationships with various local Navy activities and with units of the Pacific Fleet.

The success achieved by UCDWR during its final year of operation is largely attributable to the excellent discharge of duty by all Bureau of Ships personnel charged with the supervision of its undertakings. The cooperation of the Technical Inspector and the Navy Laboratory under his direction likewise contributed very materially to the effectiveness of UCDWR's operations. A liberal understanding of the point of view of personnel engaged in research and development was demonstrated, and willingness to leave the choice of ways and means adopted in the solution of technical problems to the scientists responsible for the program promoted the highest accomplishment.

A summary of the organization and operation of the Laboratory will be given in the following chapter, and this one will be concluded with an account of the terminal disposition of the contractual program.

The advent of V-J Day directed the thought of the Navy and the University toward the most appropriate disposition of the Laboratory and its program, facilities, and personnel. After careful study by the Navy, it was determined that the major part of UCDWR's program should be continued in the permanent Navy Laboratory with which UCDWR had been cooperating more and more closely in recent months. The name of the Navy Laboratory was changed from "U. S. Navy Radio and Sound Laboratory" to "U. S. Navy Electronics Laboratory," (NEL) as it is known henceforth in this report. Authority was given to NEL to assume cognizance of UCDWR's work according to a schedule satisfactory to both activities. The problems presented by this transfer of the program were many and complex, and a Joint Planning Committee of the two Laboratories was appointed to anticipate these and study them as they arose. Recommendations were then furnished to the two Directors, and the necessary steps were taken successively to insure transfer of going operations with a minimum of discontinuity or sacrifice of achievement.

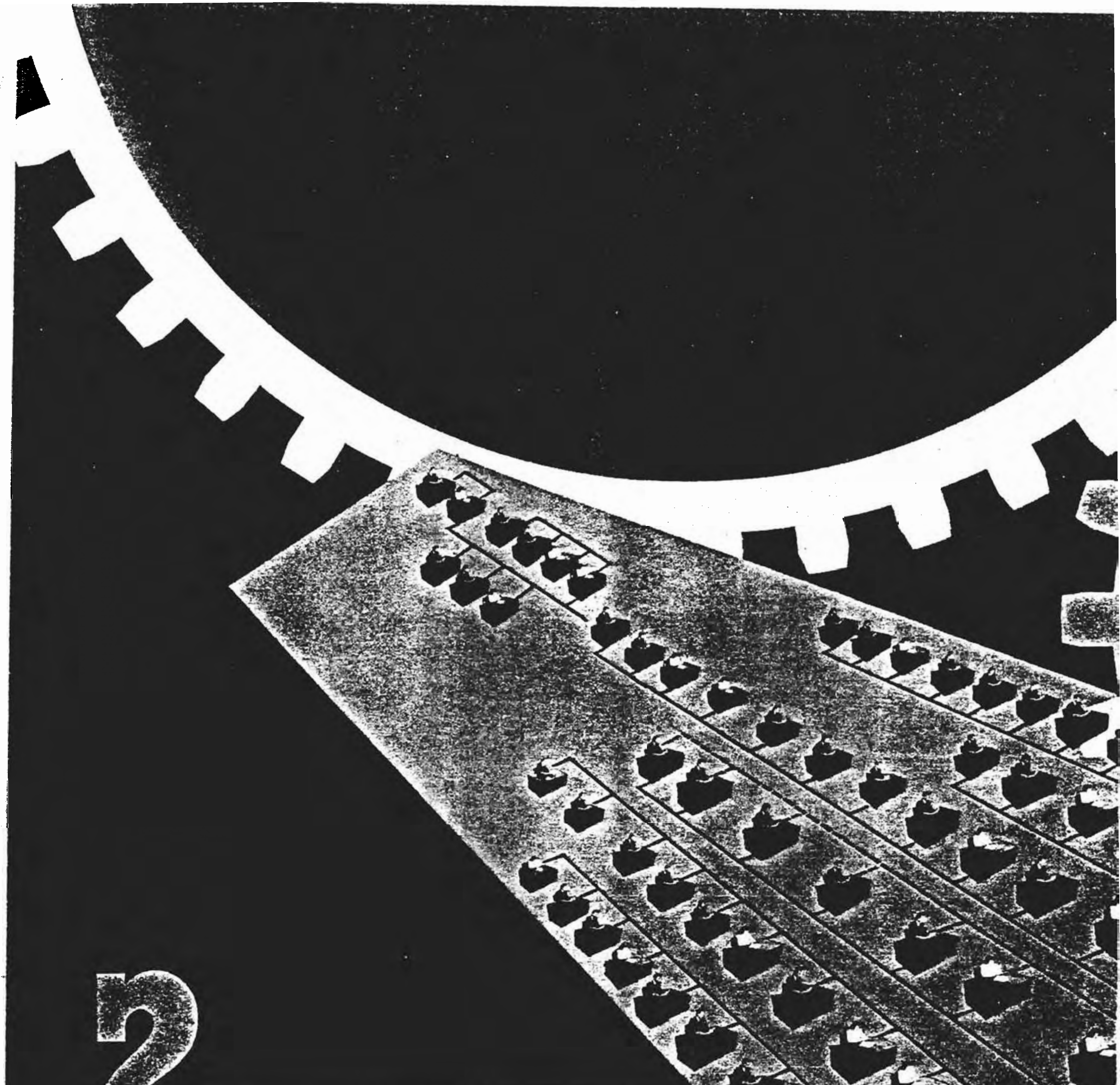
Title to all equipment had vested in the Navy since the transfer of cognizance on 1 March 1945, and the only problem presented in this regard was the transfer of custody and accountability from the University to the Navy. The details for this procedure were worked out in conference between the Business Manager of the Laboratory, the Technical Inspector, and representatives of the Bureau of Supplies and Accounts.

Personnel, who were in many instances anxious to return to their normal peacetime activities, presented a more difficult problem. The transfer of the experimental program to the Navy Laboratory did not represent the conclusion of the Contractor's responsibility, as the urgency of the wartime program had rendered it impossible to complete currently the reporting of the Laboratory's work. During the concluding months of the Contract, the majority of the effort was expended on the assembly and completion of records and the issuance of reports covering various phases of the Laboratory's activities. Through the close cooperation of personnel officers of the two Laboratories and the diligent conduct of individual surveys, arrangements were made for retention of the employment of an initial skeleton group to insure the continuity of operation. Employment transfers were effected concurrently with the transfer of responsibility for experimental work, and mutual understanding of the programs of the two Laboratories by the Directors promoted the greatest possible flexibility in the handling of personnel relationships, without which the continuity of the program would have been gravely jeopardized. A considerable fraction of the Laboratory's personnel were of necessity retained on the Contract during the closing months to insure the reporting of earlier work and the completion of all contractual obligations.

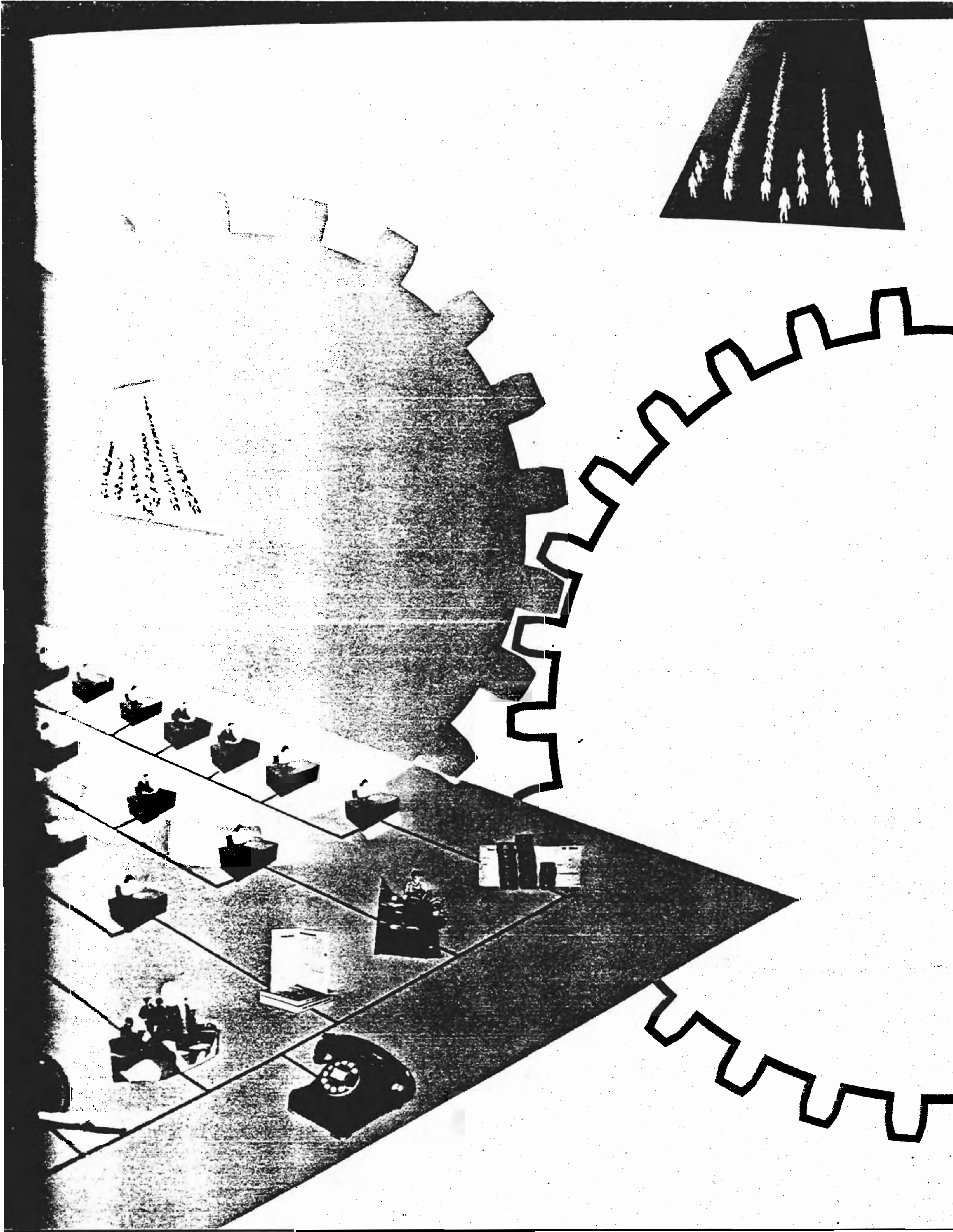
The reporting of patentable discoveries had been summarized at the time of transfer from OSRD to the Navy, and a release from OSRD had been secured. A second summary, in accordance with procedures established by the Navy, was furnished early in 1946 on the occasion of the transfer of responsibility for the majority of the experimental work from the Contractor's cognizance to that of the Navy Laboratory.

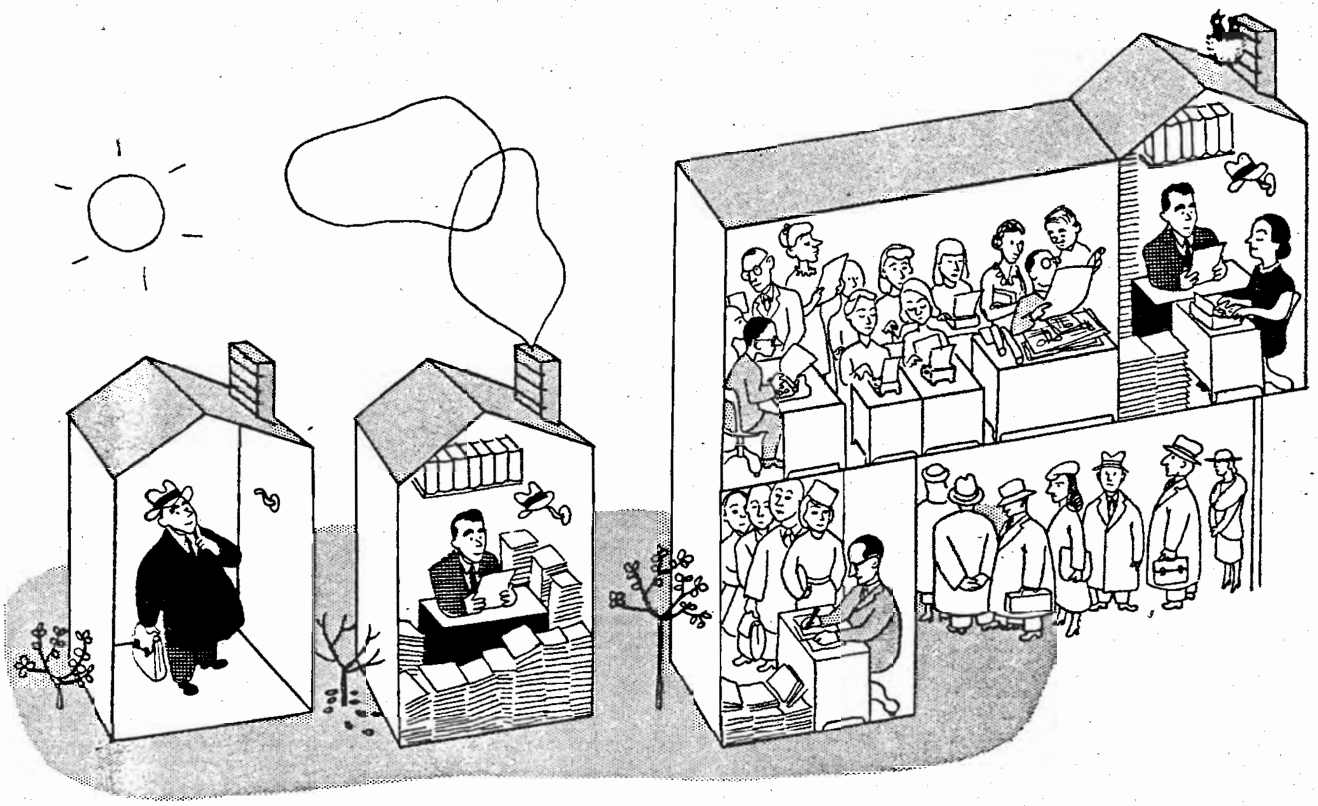
This Completion Report of the Contractor's activities was the subject of consideration by the Bureau and the Contractor during the late months of 1945, and a draft was submitted for Bureau approval early in 1946. In order to clarify operations during the concluding six months of the Contract and to insure that due consideration be given both to the orderly transfer of activities and to the contractual interests of the University and the Navy, a number of conferences were held in Washington and San Diego. In accordance with the decisions reached, a summarizing letter was prepared by the Director of UCDWR and, with the concurrence of all officers of the Contractor and the Navy, transmitted to the Bureau.

Although this Completion Report is of necessity written prior to the termination of the Contract, it would appear that all of the more important problems of transfer and termination were anticipated, and the success so far achieved in the program transfer indicates that the desired objectives should be largely achieved. UCDWR is greatly indebted to the sympathetic understanding and cooperation in these negotiations exhibited by the Director, NEL, (as Technical Inspector) and his staff.



2 operation and organization





A. ORGANIZATIONAL GROWTH

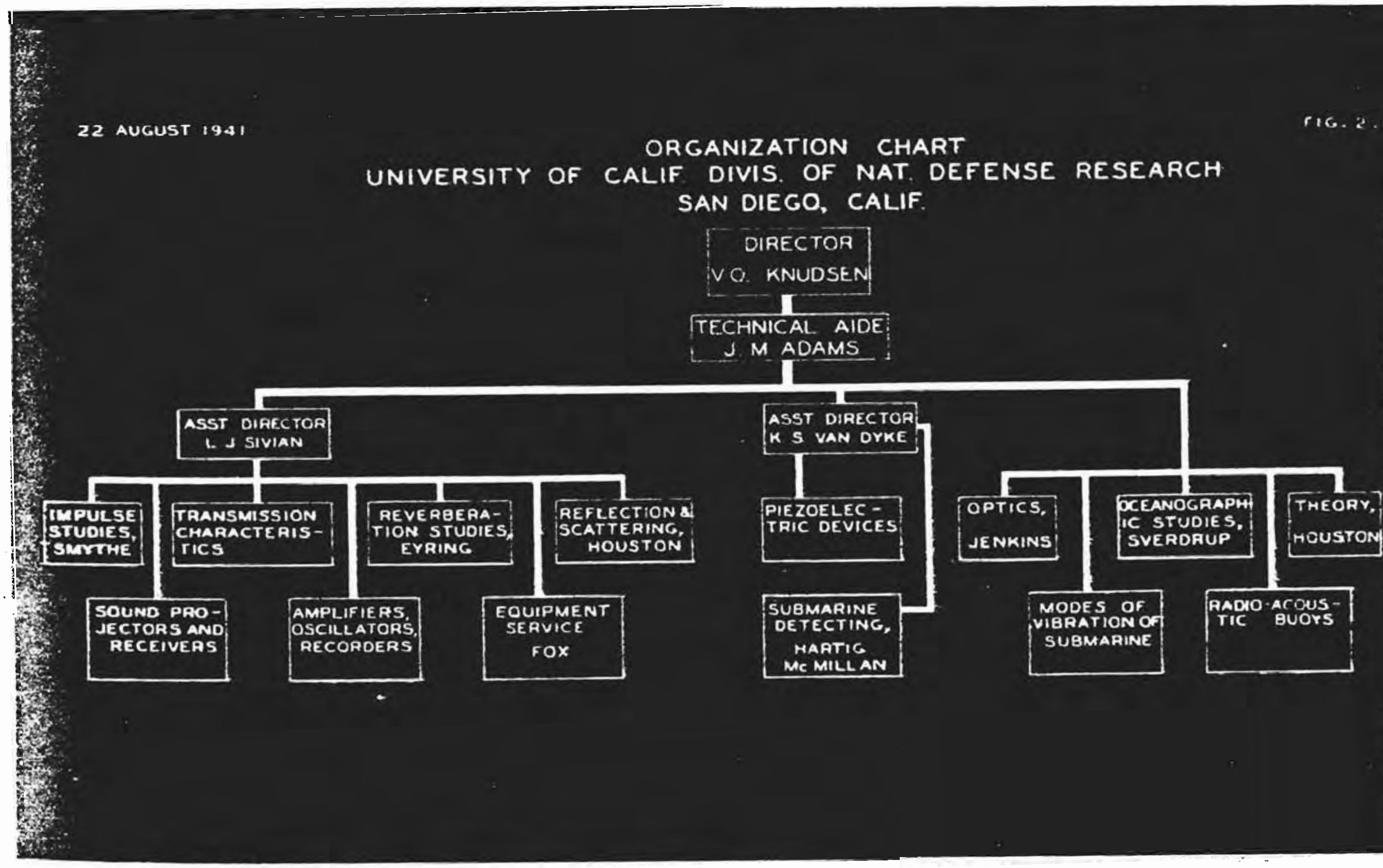
A consideration of the activities and procedures of UCDWR should be prefaced by a survey of the growth of the organization from a small, loosely-knit group of a score of scientists in the summer of 1941 to an integrated organization of some 600 persons comprising physicists, engineers, geologists, psychologists, writers, artists, machinists, draftsmen, and so forth, by the summer of 1945. The very fact that the objective was research precluded detailed and definite preliminary planning, but this was far from being the only handicap to the initial establishment of a satisfactory organization. The field to be explored was a pioneering one; very few scientists were already acquainted with it, and still fewer had had any experience in operating with the armed forces. The general turmoil among the populace impeded planning for more than a month or two ahead, and specific requirements of the Navy led to a succession of urgent requests carrying overriding priorities which disrupted all plans for an orderly and considered program. Although these factors persisted largely throughout the life of UCDWR, their effects were most prejudicial in the earlier days and, as inevitably happens in the direction of organizations, methods of coping with these difficulties were devised as the work progressed and the handicaps therefore became less and less evident.

Any consideration of the early period of the Laboratory, however, must give great weight to the conditions under which the operations had to be conducted and the fact that, more frequently than not, the organization had to be contrived about persons who were available and whose individual characteristics and idiosyncrasies could not be ignored. In 1942 and 1943, as the organization grew, other and sometimes better qualified persons for the various essential positions were included, although competition with other laboratories never permitted the acquisition of an adequate number of skilled specialists, and it became possible to establish a more logical and better integrated organization giving due consideration to over-all objectives. It is believed that the organization charts from 1943 on represent a division of function and responsibility of considerable merit for a laboratory of its type.

The original primary objective of the Laboratory was the prosecution of fundamental sonar studies. This conception controlled the initial selection of personnel and the organizational division. Subsequent developments and shifting emphasis raised work in the fields of antisubmarine and prosubmarine devices and training to a comparable level, and this will be seen to be reflected in subsequent organization charts. .

The initial organization is indicated by the chart for 22 August 1941, which is shown as Figure 2.1. The Director was Dr. V. O. Knudsen, a man of wide experience in the field of fundamental acoustic investigation. He was administratively assisted in such non-scientific matters as reports, personnel, clearance, etc., by Dr. J. M. Adams from the University of California, who served as Technical Aide. The largest group of scientific personnel, concentrated on submarine acoustics, was directed by Dr. L. J. Sivian, who was secured on leave from the Bell Telephone Laboratories. His broad experience and distinguished accomplishments in electroacoustics contributed greatly to the formulation of this phase of the work. This group was responsible for the fundamental measurement program as well as for the equipment necessary to its accomplishment. Another smaller group was headed by Dr. K. S. Van Dyke, on leave from Wesleyan University in Connecticut, whose special field had been piezoelectricity, a fundamental technique in transducer design. These persons were concerned chiefly with the investigation and development of detection devices. The third group, with no nominal head, served largely as consultants and were concerned with many special methods and techniques that were suggested in the early conferences leading to the Laboratory's establishment. The people constituting this initial group were drawn largely from university laboratories and were heavily weighted on the side of theoretical and experimental scientists. The necessary technical assistance was not secured until somewhat later, and the need for service departments had as yet to be acutely felt.

There was little change in organization for the next six or eight months, although the number of employees increased to nearly 100 by the early spring of 1942. The division of responsibility remained approximately the same, except that a



somewhat more detailed breakdown was made in the lower levels. In April 1942, Dr. Knudsen's services were urgently requested for work with the central directing organization of NDRC, and he was relieved by Dr. G. P. Harnwell, Director of the Randal Morgan Laboratory of Physics and Chairman of that Department at the University of Pennsylvania. Dr. Harnwell had obtained some insight into the scientific work on subsurface warfare through his contacts during the preceding year with Section C-4, NDRC. During the latter part of his work with the central committee in the East, his chief concern had been the initiation of assistance to the Navy in the technical field of sonar training.

Concurrently with Dr. Harnwell's assumption of the directorship, conditions led to a rapidly increasing growth in the Laboratory's activities. By August 1942, approximately 200 persons were employed, and the organization is indicated by the chart of 1 August 1942 reproduced as Figure 2.2. Dr. Sivian had unfortunately been recalled to the Bell Telephone Laboratories for their own military research program, and Dr. Van Dyke served as Associate Director in charge of the research program. This had expanded to include a Department of Oceanography under Dr. R. H. Fleming of the Scripps Institution of Oceanography, and the design and development of sonar gear had also begun to assume a larger share of the Laboratory's attention. This work was conducted by Dr. F. N. D. Kurie of Indiana University, Dr. E. M. McMillan of the University of California, and Mr. J. N. A. Hawkins from the Walt Disney Studios. The program of fundamental investigations continued under Dr. C. F. Eyring from Brigham Young University, and Mr. F. A. Everest of Oregon State College. Dr. Carl Eckart of the University of Chicago was also very active in this work, in addition to serving in a theoretical advisory capacity to the Laboratory staff as a whole. In response to the request of the Navy through OSRD channels, a division concerned with the rendering of assistance in training had been established under Dr. H. E. Hartig of the University of Minnesota. The essential role of technical service groups in the Laboratory's program became more thoroughly understood, and a group concerned with supplying such assistance was organized under the leadership of Dr. Kurie.

The importance of the non-scientific side of the Laboratory administration had become evident to the Director during the spring of 1942, and an effort was made to expand the personnel concerned with such matters. The first step was the appointment of Mr. F. B. Hanley of the University of Minnesota as Executive Secretary, assisted by Dr. Adams and Mr. N. Most. This arrangement assisted materially in the conduct of local non-scientific operations, such as those associated with reports, documents, transportation, employee relations, etc.

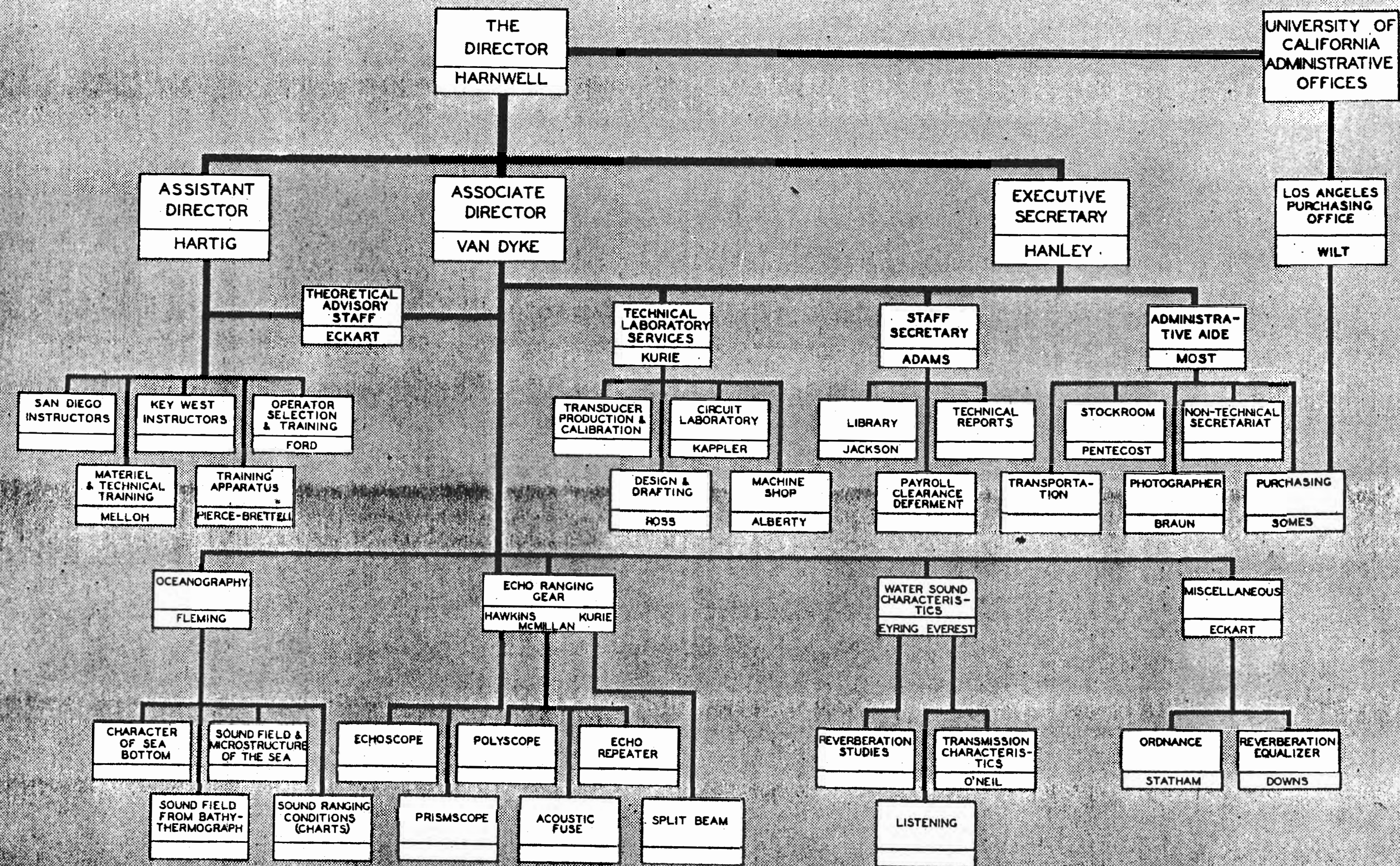
It was recognized at that time that purchasing and accounting methods were still inadequate for the magnitude that the program was assuming, but further experience in the operation of established procedures was required before a suitable arrangement could be initiated by the Contractor for ameliorating the various difficulties that were being encountered. The Laboratory's operation was considerably handicapped by the fact that its location, though well chosen for its scientific work, was divorced geographically from any permanent division of the University. Initially business activities were conducted almost entirely from the University campus in Los Angeles where actual purchasing was handled. It was early seen that this procedure was too cumbersome for effective operation and that a business staff at San Diego was necessary to act as liaison between the Laboratory and the University's business departments which were, understandably, quite unfamiliar with the Laboratory's problems. A small group from the University's Purchasing Department was brought to San Diego during the latter part of 1942 and served as a nucleus about which a considerable department subsequently expanded.

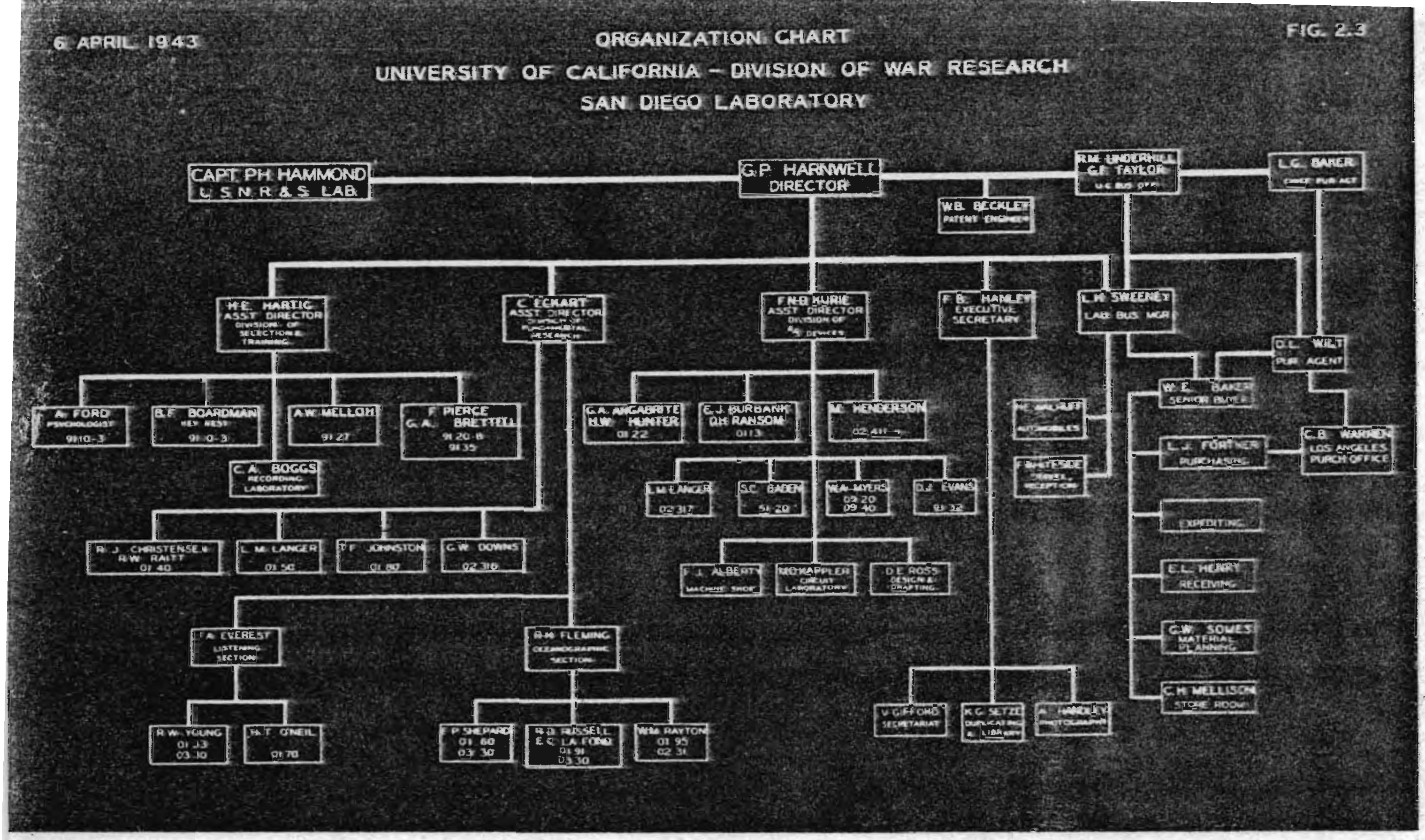
The next organization chart, Figure 2.3, represents the Laboratory's administration as it had developed by 6 April 1943. Dr. Van Dyke had been called away to an urgent War Department assignment, and a considerable change in organization resulted. The division of scientific work shown in Figure 2.3 represents in all essential features that which was maintained throughout the existence of the Contract. The Training Division was headed by Dr. Hartig, who supervised work at both Sonar Schools and device development work within the Laboratory. The Fundamental Research Division, subsequently known as the Sonar Data Division, was headed by Dr. Eckart, who had cognizance of high and low frequency propagation programs and also of the Oceanographic Section, which contributed directly to both of these. The Sonar Devices Division, under Dr. Kurie, had again expanded greatly and was concerned with all matters of combat-device design. Initially the service depart-

1 AUGUST 1942

ORGANIZATION CHART
UNIVERSITY OF CALIFORNIA DIVISION OF NATIONAL DEFENSE RESEARCH
SAN DIEGO CALIFORNIA

FIG. 2.2





ments were included in this division, because the greater portion of their activities was involved in this phase of the Laboratory's work. This undesirable association of the service departments with a scientific division was accepted because of the Laboratory's inability to secure an adequate supervisory staff at this time. Mr. Hanley continued as Executive Secretary concerned with the activities indicated on the chart.

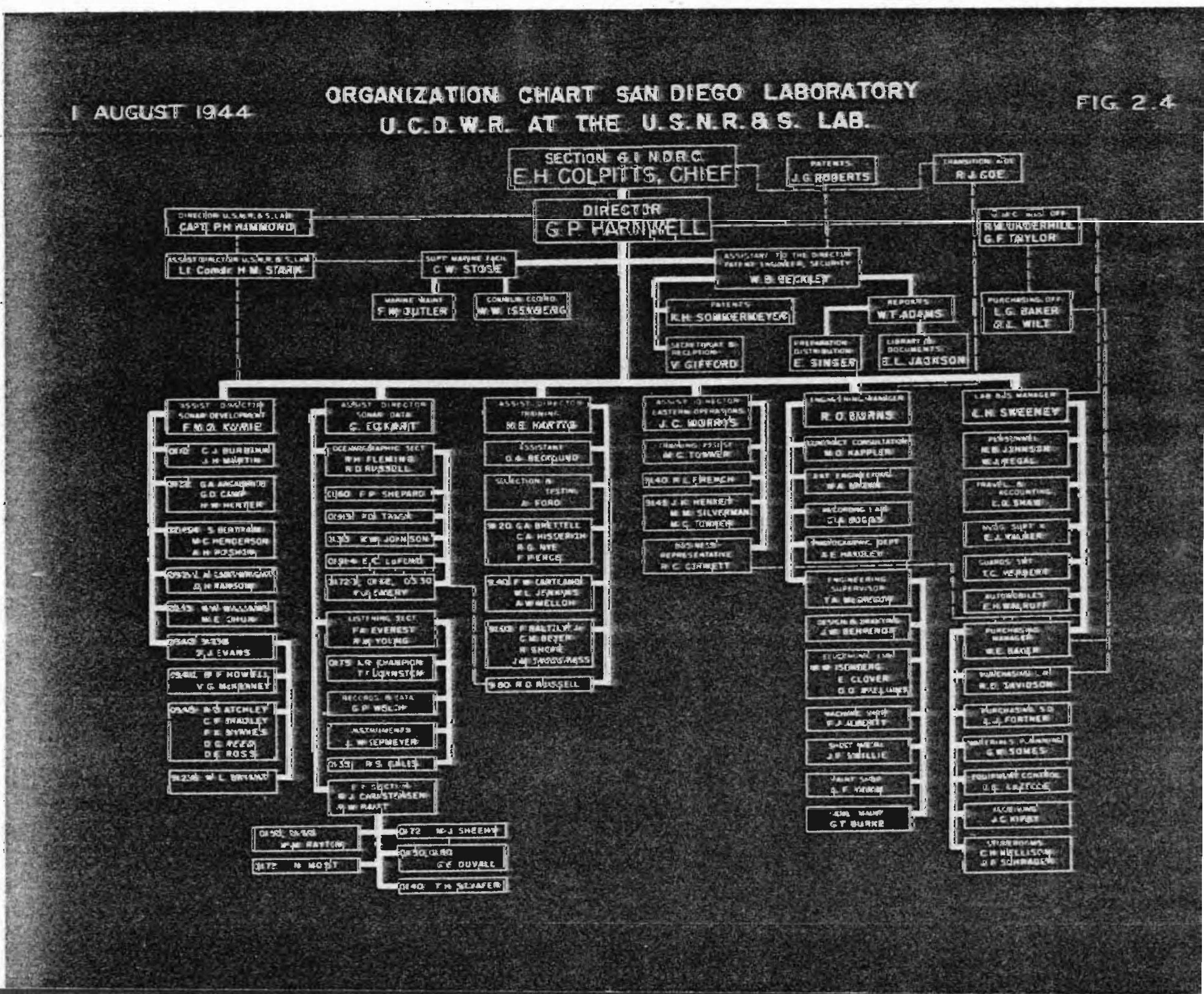
In response to the demonstrated need for more adequate business administration in San Diego, the University of California liberated Mr. L. H. Sweeney from its Los Angeles campus to assume the position of Laboratory Business Manager. This arrangement materially improved purchasing, procurement, and accounting, and represents the chief forward organizational step taken in the spring of 1943. The importance of this move cannot be overemphasized, as a thoroughgoing knowledge by the Business Department of the work being conducted, its priority, the type of equipment and components necessary, and related information, is essential to a proper discharge of its functions and results in a saving of effort, time, and money. Such intimate acquaintance with the operating program can be gained only by close local association. A much larger fraction of the business work was conducted from the San Diego Laboratory thenceforth, although a considerable amount of purchasing continued to be done at the Los Angeles office of the University. Mr. G. F. Taylor, Business Manager of the University at Los Angeles, assumed more responsibility for fiscal administration than before, and the University's confidence in the ability of the San Diego organization to conduct all phases of the Laboratory's affairs was greatly increased.

Two additional points merit some comment. The obligations of the University under the Contract to report patentable inventions had been recognized for some time, but the press of urgent work had led to some neglect of the steps necessary to accomplish this properly. The services of Mr. W. B. Beckley, patent counsel from San Francisco, with experience in the F.B.I., were secured as Patent Engineer, and the first invention survey was conducted. Procedures for maintaining workbooks and other records necessary for patent purposes were instituted and continued thereafter. The relations of UCDWR with NEL had crystallized and greatly improved during the preceding year, and evidence of the increasing intimacy of the relationship is given by the liaison connection with Captain P. H. Hammond shown on the chart (Figure 2.3).

The following year represented a rapidly expanding period for the Laboratory, and by the autumn of 1944 it achieved its maximum size of approximately 600 persons. The Laboratory population continued at about this figure until termination plans were put into effect. Although the organization expanded, it retained the essential features previously discussed, as can be seen from Figure 2.4, which is the organization chart for 1 August 1944. The three scientific divisions are clearly recognizable with the same Assistant Directors.

At the request of the Navy, a considerable program of maintenance-manual preparation was undertaken, and the necessity of liaison with the Bureau of Ships, the Executive Office of the Secretary of the Navy, Navy manufacturers, and publishing firms indicated that this activity should be established in the East. Dr. J. C. Morris of Tulane University was secured to take charge of this undertaking, and its geographic separation clearly indicated its establishment as a separate Laboratory division whose work was closely related to that of the Training Division. The Laboratory's earlier experience enabled the Director to assign a Business Director to this group from its inception, and this materially improved the effectiveness of its operations on the other side of the continent.

A major step in improving the effectiveness of the scientific divisions was the establishment of an Engineering Division under Dr. R. O. Burns from the Celotex Company's plant in New Orleans. Services such as drafting, electronics, machine work, etc., were grouped together under the supervision of Mr. T. A. McGregor and operated as a unit in serving the needs of the scientific divisions. As the design of training and combat equipments advanced and prototypes were made for operational tests, the Devices and Training Divisions drew very heavily upon the Engineering Division. Certain other local services, such as the Photographic and Recording Laboratories, likewise reported to Dr. Burns and served the three scientific divisions about equally. The need for larger numbers of prototypes for testing and the necessity of supplying small



numbers of units of training equipment in particular led to the establishment of groups concerned with extension engineering and contract consultation. These groups essentially expanded the facilities of the Laboratory by including those of manufacturing plants in the San Diego and Los Angeles areas. Some of this work was done on purchase order and some on subcontract, and the program played an important part in the ability of the Laboratory to accede to the many requests received throughout this period for prototypes and service equipments by the Navy. The extensive activities of UCDWR in this field were coordinated with similar phases of the work of other OSRD contractors by Mr. R. J. Coe, Transition Aide to the Chief of Section 6.1, NDRC.

The Business Division under Mr. Sweeney expanded and assumed larger responsibilities, gradually concentrating all procurement activities within the Laboratory itself. It also assumed responsibility for extensive local and distant travel arrangements and the complex personnel procedures required by government regulations.

The increasing importance of reporting the Laboratory's work is reflected by the formation of a small reports group headed by Mr. W. T. Adams, under the cognizance of Mr. Beckley, who had assumed responsibilities of Assistant to the Director in addition to those of Patent Engineer and Security Aide. As will be seen from a later chart, this publication activity continued to become more and more important as the program of the Laboratory as a whole reached a more mature stage.

Finally, it may be remarked that the operation of the Laboratory's marine facilities required the establishment of a small supervisory staff under Mr. C. W. Stose. This group also arranged for the establishment of communications and assisted the Recording Laboratory in the provision of an FM radio link to record in the Laboratory sounds picked up at sea.

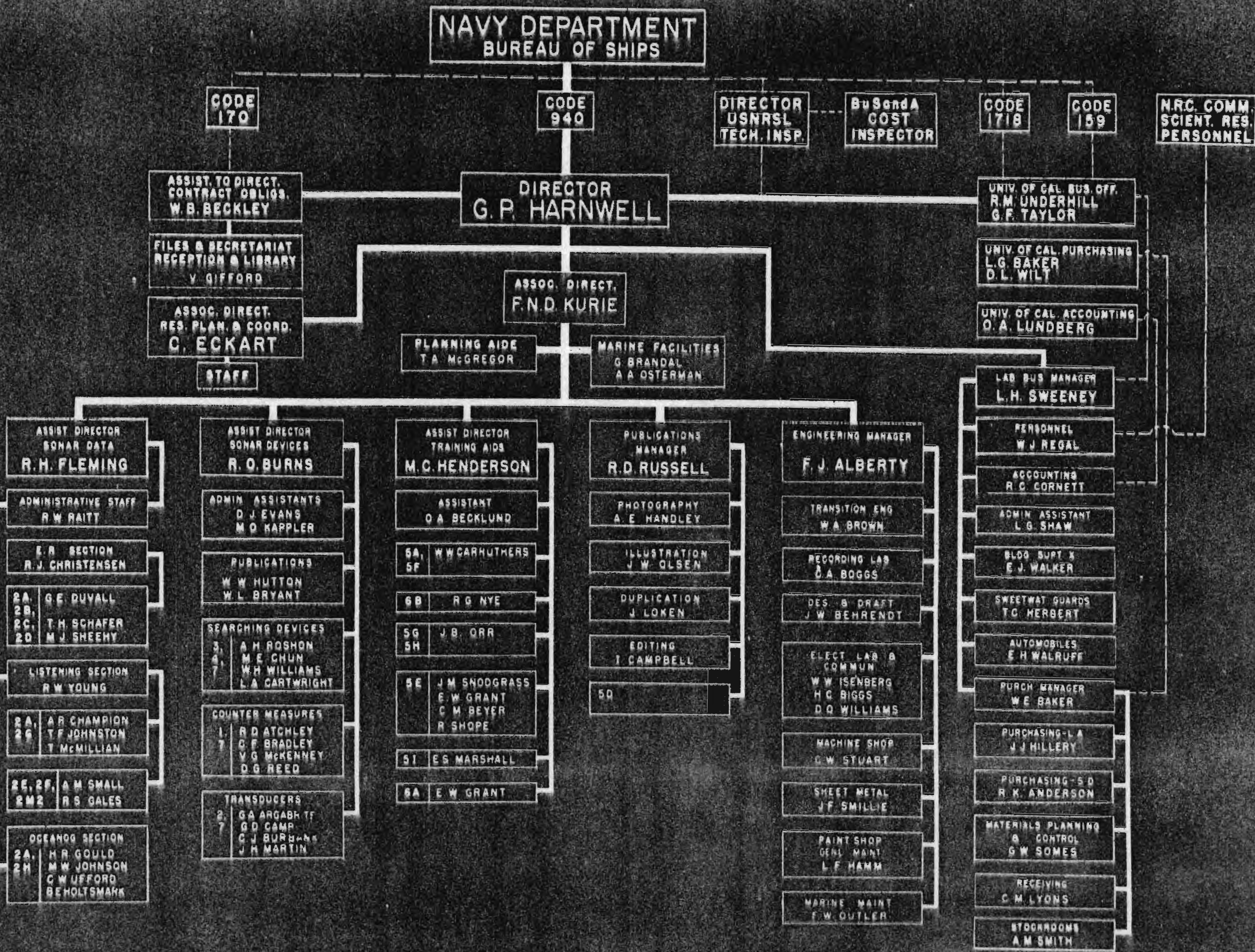
No considerable change in organization occurred during the following year, and the transition from OSRD to Navy auspices was effected on 1 March 1945 with a negligible effect on Laboratory operation as a whole. Figure 2.5 displays the organization effective 1 October 1945 and reflects certain changes brought about by the developing program and the imminence of termination rather than by naval supervision. It will be seen that the Director reported on the scientific program to the Chief of the Bureau of Ships, Code 940 (Electronics Division—Sonar), being charged with the chief responsibility for the assignment of problems and the cognizance of the work. In patent matters, direct liaison was established between the Patent Engineer and Code 170 (Office of Research and Invention) of the Bureau, and on contract matters the University dealt directly through the Secretary of the Board of Regents with Codes 1718 (Contract Division—Electronics) and 159 (Office of Counsel—Supply Contracts). Certain responsibilities under the Contract were delegated by the Chief of the Bureau to the resident Technical Inspector, who was the Director of the adjacent Navy Laboratory. Through him close relations were maintained with the Bureau of Supplies and Accounts and the Eleventh Naval District. This arrangement materially improved the processing of purchase orders and vouchers and the payment of advances and claims. The development of the Business Division indicates the increasing responsibilities that it assumed. All fiscal activities were centralized in the San Diego group, and the Accounting Department reported directly to the University Accounting Department in Berkeley. All checks were written and business conducted from the Laboratory's Business Division. The Personnel Department had also by that time expanded its staff and established liaison with national scientific committees which assisted in Selective Service procedures.

The many problems associated with the transfer of the University's program to the direct cognizance of the Navy indicated certain shifts in organization, as shown on the chart. Dr. Eckart assumed the position of Associate Director in charge of research planning and coordination, and much of his time was given, in cooperation with Division 6, to the issuance of the Summary Technical Reports covering the Division's activities during the war. Dr. Kurie likewise became an Associate Director, with the particular responsibility of integrating UCDWR's local operations with those of NEL. A Joint Planning Committee was appointed by the Directors of the two Laboratories, and Mr. T. A. McGregor, a member of this Committee, served as Planning Aide to Dr. Kurie. In order to continue the work of the scientific divisions, Dr. Fleming, Dr. Burns, and Dr. M. C. Henderson from Dartmouth College assumed the responsibility for the Data, Devices, and Training Divisions, respectively. The need of the University of Minnesota for Dr. Hartig's services in

1 OCTOBER 1945

ORGANIZATION CHART
U.C.D.W.R. AT THE U.S.N.R.&S. LAB.

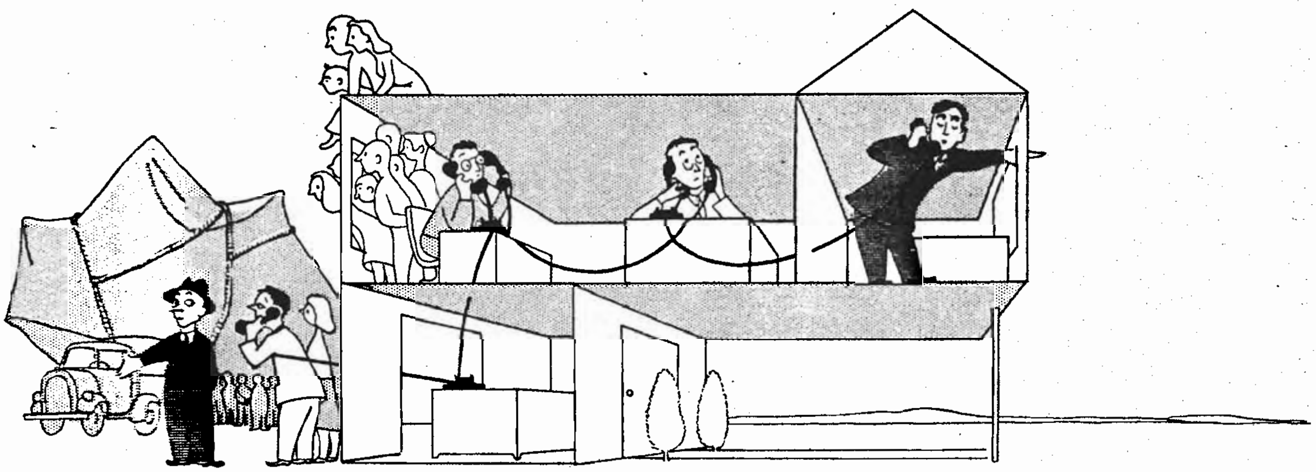
FIG. 2.5



reconverting for peace-time operation could not well be denied, so to UCDWR's regret he returned. Dr. Burns was succeeded by Mr. F. J. Alberty as Engineering Manager, and the magnitude of extension engineering decreased as the demands for Navy equipment from the Laboratory were relaxed. The paramount necessity for properly reporting the work accomplished by the Laboratory was recognized by the establishment of a Publications Division under Dr. R. D. Russell. Dr. Russell had previously been engaged in the work of the Oceanographic Section of the Sonar Data Division and had come to the Laboratory from the State University of Louisiana.

Transfer and termination procedures were briefly outlined in Chapter One of this report. As cognizance of the experimental work of the Laboratory was taken over by NEL in the early spring of 1946, Laboratory emphasis turned increasingly to the final work of reporting and accounting, and arrangements were made for the retention of as many suitable persons as possible for these functions.

Late in January 1946, Dr. Harnwell was obliged to return to the University of Pennsylvania, and Dr. Kurie succeeded him as Director of the Laboratory for the remaining five months of the contract.



B. LABORATORY ADMINISTRATION

I. executive direction

The chief administrative officer of the Laboratory was the Director who was appointed by the Contractor with the concurrence of OSRD and the Navy. His responsibility was fourfold. In the first place, it was his obligation to assemble a staff and conduct the scientific program of the Laboratory in all of its divisions. Secondly, he was considered by the University to be the head of one of its wartime departments, and he was responsible for all fiscal matters to the Secretary of the Board of Regents, in accordance with the delegation of authority made by the President of the University. Thirdly, it was his responsibility to carry into effect the general assignment of the scientific program made by OSRD, and later by the Navy, and insure the maintenance of liaison with special OSRD and NDRC committees and the laboratories of other contractors. Fourthly, he was charged with the maintenance of naval liaison with the Office of the Coordinator of Research and Development, the Bureau of Ships, local naval activities in the San Diego area, and also collaboration with Fleet units as authorized from time to time.

It has been seen in Section A of this chapter that various administrative assistants were appointed to carry out the work of the Laboratory falling under the four general groupings of the preceding paragraph. The following sections of this chapter will consider the work of the three scientific divisions and the two service divisions in some detail, bringing out significant interrelationships which materially affected the performance of the organization as a whole. As projects were accepted from the authorized government representative, they were assigned to appropriate groups for prosecution under the immediate supervision of a Group Leader. In general, such a project fell naturally within one of the three scientific divisions of the Laboratory, and the Group Leader reported to the Assistant Director in charge of that division. These Assistant

Directors, together with the Business and Engineering Managers heading the two service divisions, constituted an advisory Administrative Committee to the Director. Regular meetings of this group at approximately two-week intervals contributed greatly to the maintenance of close integration of the program. The Assistant to the Director served essentially as secretary of this Administrative Committee and supervised the maintenance of records and the conduct of established correspondence.

The effective operation of the Laboratory in its somewhat remote location required a broad delegation of local autonomy, which was wisely made to the Director first by OSRD and later by the Bureau of Ships. Initiative in the undertaking of special work was frequently assumed by the Laboratory as being necessary in order that an adequate basis for judgment should be available to the Contracting Officer for the subsequent formal assignment of projects as they assumed greater magnitude or broader implications. The entire program of the Laboratory was conducted under the formal authorization of the Chief of Section 6.1, NDRC, prior to 1 March 1945, on which date the Chief of the Bureau of Ships assumed the duties of the Contracting Officer. Prior to this date, all supplies and equipment were the property of OSRD in the custody of the Contractor. As devices were made or special equipment assembled for Navy test or use, these were formally expended by the Contractor in association with the naval activities assigned to the Laboratory. On those occasions when devices or other equipment were made in quantities exceeding reasonable experimental prototypes, authority was given by OSRD to transfer them to the Navy. In some instances, reimbursement was requested, and funds were exchanged between the Navy and OSRD. These, however, did not accrue to the Contract. The effect on the Laboratory's budget was nevertheless recognized by the Contracting Officer and his delegates on the occasion of periodic assignment of additional funds under successive Contract Supplements. Following 1 March 1945, title to all expendible and capital equipment vested in the Navy Department, and authorization to deliver devices and equipment to naval activities was secured from the Director, NEL, who was the Technical Inspector under the Contract.

The operation of the Laboratory was to some extent handicapped by the dispersion of its activities imposed by the nature of its organization and the local facilities available, which are described in more detail in Chapter Seven, Section B. During the first years of its growth, it was administered from a group of buildings on the crest of Point Loma which were well situated for radio and radar research but too remote from the water for effective contact with sonar operations. Shortly after the erection of the group of buildings on the water front, the administrative offices were moved to that location, to the benefit of the operations of the Laboratory as a whole. Space was not available for the Business or Publications Divisions at either location, and in consequence a third major unit of the Laboratory was housed in a large residence some miles away. Finally, test stations at Sweetwater and El Capitan were required for special phases of the work, but these were from three-quarters of an hour to one hour distant by car from the other buildings. These separations required the maintenance of a considerable group of sedans, station wagons, and trucks for the transportation of personnel, documents, and equipment between the several locations. Extensive use was also made of telephone tie lines. In short, the problems of local operation reflected in miniature those of liaison with the other scientific and naval groups with which the Laboratory worked.

The directing staff assembled and issued a Manual of Administrative Procedures for the guidance of administrative officers and group leaders. This was made up of administrative circulars issued from time to time, covering in considerable detail the responsibilities of Laboratory personnel and the administrative procedures established for the conduct of their assignments. The scientific work was codified in accordance with the filing system originally established by Section 6.1, NDRC, in order that it could be integrated with the programs of other contractors as well. The administrative circulars established relationships in this filing system with the Navy's project and problem numbers and the various requisition codes associated with particular jobs for purposes of cost breakdown.

As a compromise between flexibility and strict control, authorization was delegated by the Director for the initiation of preliminary requisitions by various members of the Laboratory. In general, group leaders were authorized to requisition material from stockrooms or suppliers up to the value of $50 upon their own signature. Items up to $500 required countersignature by an Assistant Director or the Engineering or Business Manager. The Business Manager was accorded authority to sign requisitions up to $1000 and, on the occasion of the absence of the Director from the Laboratory, he could at his discretion authorize purchases for routine supplies to a greater amount. In general, however, all requisitions exceeding $500 were approved by the Director.

The work of the Laboratory required a great deal of correspondence, and in order that this might be conducted with a minimum of delay, a delegation of authority was made somewhat similar to that for the procurement of supplies and equipment. Correspondence relating to basic contractual provisions passed through the hands of the Secretary of the Board of Regents, who was the responsible officer for the Contractor. Correspondence dealing with the scientific and business work was handled by the Laboratory staff in accordance with the following general delegation of authority: The Director conducted basic correspondence relating to the assignment, modification, or discontinuance of projects comprising the Laboratory program, as well as all correspondence involved in matters beyond the individual cognizance of the Assistant Directors or Managers, and also correspondence directed to commanding officers or directors of other activities. The Assistant Directors and Managers conducted supplementary correspondence relating to the conduct of the projects within their divisions. The Personnel Manager likewise conducted correspondence relating to employment, War Manpower restrictions, and Selective Service. Procurement correspondence was conducted by the Purchasing Manager; and the Assistant to the Director, who was also the Patent Engineer, was in charge of correspondence relating to patent matters and the receipt and issuance of reports. In certain cases, and from time to time, authority was given to group leaders to correspond directly with engineers in other laboratories.

The contact of the University Administration with that of the Laboratory was limited largely to fiscal and other business affairs. From time to time, the Secretary of the Board of Regents visited the Laboratory, and frequent conferences were held between him and the Director and Business Manager in San Diego, Los Angeles, and Berkeley. Supplemented by occasional correspondence, this served to keep responsible University officers apprized of the discharge of contractual obligations. Requests for the issuance of Contract Supplements and the negotiations pursuant to Contract assignment to the Navy were carried on jointly by the Secretary of the Board of Regents and the Director of the Laboratory. On fiscal and business affairs, a close liaison with the Business, Purchasing, and Accounting Offices of the University was maintained by the Business Manager resident in San Diego. His thorough familiarity with University procedures and his facility in general and governmental accounting practices contributed greatly to the efficient conduct of business matters under the Contract.

The maintenance of close understanding with OSRD and NDRC administrative groups and the conduct of joint operations with other contractors presented a difficult problem in liaison. A very large amount of transcontinental traveling was found to be absolutely necessary in order that the program could be kept in step with the constantly changing requirements urgently imposed by the exigencies of military developments. The extent of travel necessary to the conduct of the work is indicated in Chapter Seven, Section C, and the importance of this factor cannot be overemphasized. The extensive use of the long-distance telephone was also essential for efficient operation. Practically all correspondence was conducted by airmail, but if this had been relied on exclusively, days, and in many cases weeks and months, would have been lost, resulting in a delay in the program which would have materially reduced the effectiveness of the Laboratory's contribution to the war effort. Personal contacts between the Laboratory staff and civilian scientists and naval officers were particularly essential during the earlier years of the Contract because of the novelty of the work to the scientists engaged in it and the lack of any previous association between them and the naval officers for whom the work was essentially done.

A very large part of the time of the Director and his staff was devoted to the establishment and maintenance of proper channels of communication for the interchange of instruction and information. As the work of the Laboratory progressed, the problem of naval liaison expanded to take in wide contacts with the Fleets in both ocean areas. Here the problem was frequently one of interpreting scientists to non-scientific naval administrative personnel and engendering those conditions conducive to the mutual appreciation of groups with diverse abilities and talents. The effectiveness of the Laboratory's work, however, was very largely dependent upon enlisting appreciation by naval personnel of the potentialities of new devices, and the fostering of intimate personal and professional relationships between scientists and officers contributed greatly to this end.

II. administrative staff activities

The great majority of the Laboratory's activities were comprised within the five divisions indicated by the organization charts previously discussed. However, there were o considerable number of essential functions relating to the Laboratory as a whole or integrating the work of those divisions which were conducted by the administrative staff of the Director.

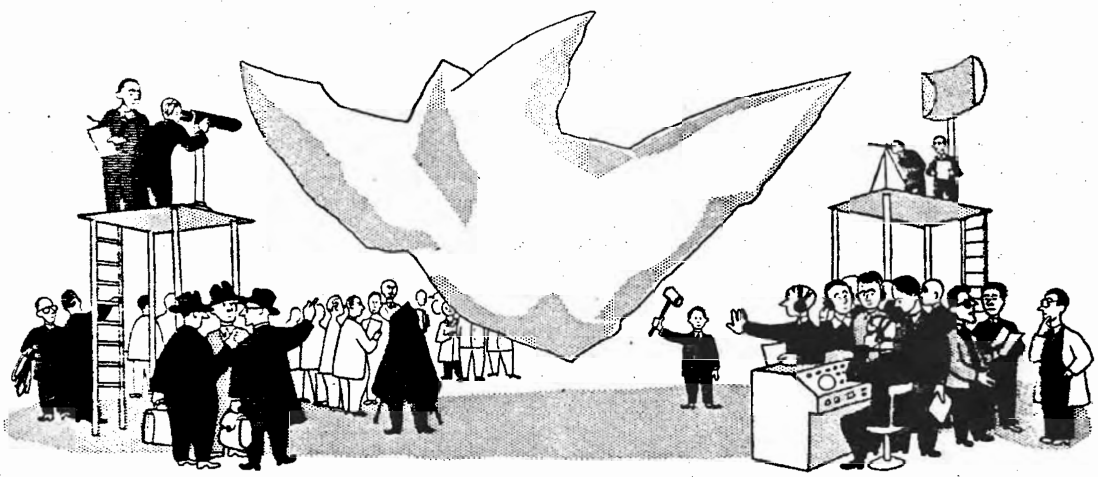
An important function performed by the Senior Secretary was the establishment and maintenance of all files and records and the determination and execution of filing and secretarial procedures (see Chapter Nine, Section C). Miss V. Gifford served the Laboratory in this capacity from October 1942, and under her guidance a complete Central Files of all Laboratory correspondence was maintained.

Mr. W. B. Beckley, Assistant to the Director and Patent Engineer, served likewise as Security Aide. The Laboratory's security presented a number of different aspects. In the first place, satisfactorily flexible systems for the control of and access to classified material had to be set up. Secret material and documents from our Allies were accorded special treatment and kept in safes under the immediate supervision of one or two specifically designated persons. Documents of lower classification were made more generally accessible to the Laboratory as a whole and were housed in locked cabinets under the general surveillance of a 24-hour guard service. The problem of classification of documents originating in the Laboratory was handled by the Director and his Assistant, with occasional advice from OSRD and the Bureau of Ships (see Chapter Nine, Section E).

The second aspect of the security problem was the clearance of Laboratory personnel. Methods and procedures were adopted as discussed in Chapter Eight, Section B, and their administration was in charge of the Personnel Department of the Laboratory. The basic responsibility for maintaining the security of the premises was that of the Director of the adjacent Navy Laboratory, and all local security problems were worked out in conference with him. From time to time a third aspect of security assumed importance in connection with the external manufacture of devices developed by the scientific groups. In such cases, clearance to disclose information and to undertake joint development and manufacturing work was secured through OSRD, the Navy, or the Ninth Service Command of the Army. The remoteness of the Laboratory location proved to be a particular handicap in such undertakings, and a considerable amount of telephoning and correspondence was generally entailed.

Procedures for carrying out the obligation to report on patentable discoveries were worked out by the Assistant to the Director, and an administrative circular was issued for the instruction of the staff (see Chapter Nine, Section D). The rights to all inventions and discoveries made in the course of the work were entirely at the disposition of the Government, which could, at its option, acquire by assignment an entire interest in any invention. The procedures set up insured the protection of the Government's rights and, in accordance with them, the scientists and engineers maintained dated workbooks containing all pertinent material concerning the problems upon which they were engaged. Dates of conception, reduction to practice, operating tests, etc., were carefully recorded in these workbooks and witnessed. Photographs of equipment were taken at various stages in design and development and stapled into this record.

During the larger part of the Laboratory's operation, responsibility for the publication and issuance of reports was also assumed by the Assistant to the Director. The nature of these reports is indicated in detail in Chapter Nine, Section F, and a complete bibliography appears in Appendix A. Although the essential role of adequate reporting was appreciated from the earliest days of the Laboratory, the shortage of qualified people and the urgency of immediate assignments combined to prevent adequate emphasis on this phase of the administration's obligations. The first reports issued by the Laboratory did not have wide circulation and were written in an informal manner for a small and specialized audience. As the Laboratory expanded and the group of persons interested in its activities came to include a wide variety of civilian specialists as well as naval officers of the Bureaus and Fleets, greater attention was given to the editing of texts and the provision of a wide variety of illustrations as well as convenience of binding and referencing. In the concluding period of the Contract, a separate Publications Division was established in order that the work of the Laboratory could be completely reported within the contractual period.



C. SCIENTIFIC DIVISIONS

The work of the scientific divisions of the Laboratory was the primary function of the entire organization to which all other activities were oncillary and subordinate. In accordance with the request of the Bureau, this Laboratory Completion Report emphasizes the operational and administrative phases of the undertoking. In consequence the space devoted to an account of the scientific accomplishments is not representative of the actual emphasis accorded this work in Laboratory operation. In order that the emphasis should not be too distorted, however, summary accounts of the work of the scientific divisions are given in Chapters Three, Four and Five, and here they will be considered briefly with particular reference to interrelationships between them and their cooperative work with other agencies.

I. sonar data division

The Sonar Data Division was concerned with fundamental research, primarily directed to the investigation of all acoustic propagation phenomena. This was the chief specific assignment to UCDWR upon its initial organization, and as the Laboratory developed, approximately one-third of the effort of the staff was directed to the work of this division.

The Navy projects and task orders authorizing this activity are not adequately representative of the program as a whole. They emphasize the specific requests made by the Bureau for particular information required in connection with immediate operational problems, and minimize the basic long-term program which was essential to the understanding of the basic phenomena encountered. The exigencies of the military situation were responsible for the frequent and urgent redirection of the group's activities which handicapped the program as a whole and often retarded the conduct of systematic observations. It was recognized by both the Bureau and the Laboratory staff that compromises had continuously to be made between the securing of urgently desired observations and the conduct of a basic over-all investigation which, in the long run, would undoubtedly have been more beneficial.

The best judgment available at the time was used in the direction of this program but, in retrospect, it would appear that a greater continuity of applied work on the propagation program would have been more beneficial and the answers to specific questions would from a long-range point of view have been more complete and dependable.

In addition to the program of acoustic measurements, a corollary oceanographic program was carried out which was essential to the proper interpretation and understanding of the acoustic results. A second subordinate phase of investigation lay in the field of psychoacoustics because of the importance of hearing in all practical naval applications.

The basic program of acoustic research and the subordinate programs in psychoacoustics and oceanography were closely related to the activities of other Laboratory groups. The service departments were of course drawn upon heavily in the construction of experimental equipment, in the operation of programs at sea, and in the recording and reporting of results. The relationship with the Devices Division was particularly intimate, as the design and development work of that Division depended to a large extent upon basic information furnished by the Sonar Data Division. This was particularly true in the Sonar and Countermeasures Sections. In return, the Devices Division was of great assistance to the Data Division in the design and calibration of experimental equipment. The psychoacoustic program had much in common with the work of the Training Division, and the closest relationship was maintained between this program and the training activities of the Sonar Schools and the groups concerned with the design of training equipment. The mutual assistance rendered was most beneficial to both the Data and Training Divisions.

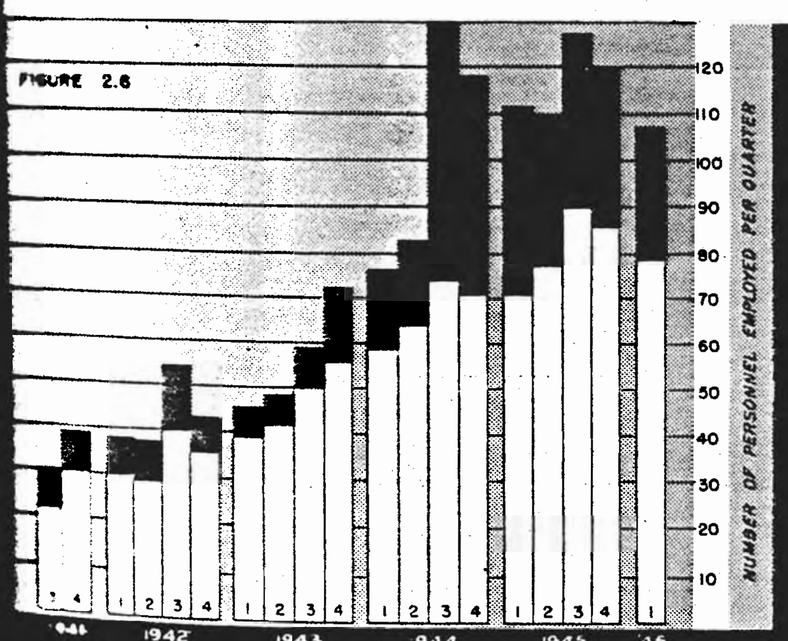
The efficient conduct of the Navy and NDRC programs as a whole required the establishment of direct liaison between divisions within UCDWR and groups elsewhere in the country or abroad concerned with similar problems. In the experimental work, close relations were maintained with the Scripps Institution of Oceanography and the Woods Hole Oceanographic Institution and also with the Sonar Analysis Group of NDRC which was continued later in association with the Bureau of Ships, Code 940. This latter Group had the general responsibility of integrating the work of the contractors in basic sonar research, and later assembled and issued a number of the Summary Technical Reports covering the entire program.

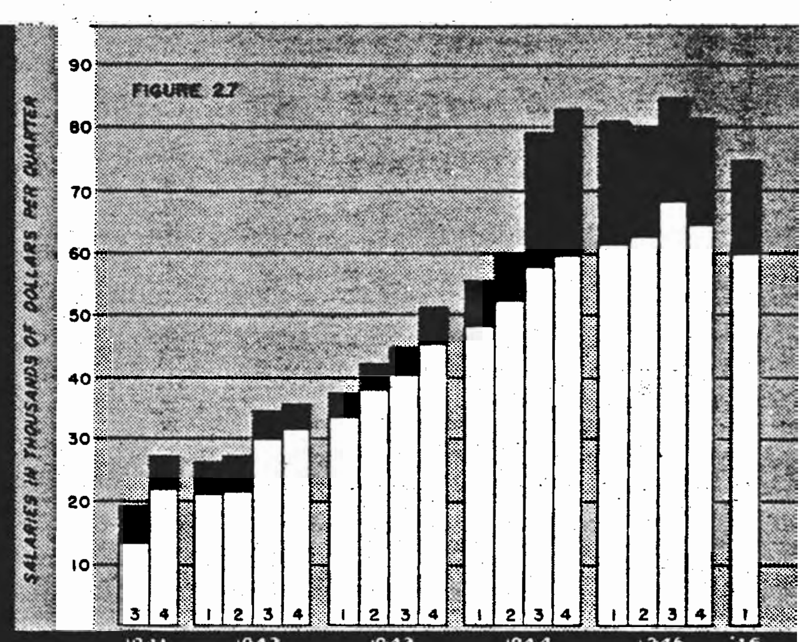
In addition to research cooperation, external connections were established for making the results of the program available directly to those naval offices and commands most directly concerned. Charts of various types prepared in the Laboratory were submitted to the Hydrographic Office for official issuance. In some cases and prior to such issuance, charts prepared by hand were furnished directly to the Commander Submarine Force, Pacific Fleet. Also, in the bathythermograph program, direct liaison was maintained under the general cognizance of NEL with the Service Forces of the Pacific Fleet, and the Hydrographic Office and Bureau of Ships were kept informed of these activities as they developed.

The accompanying charts (Figures 2.6 and 2.7) indicate the personnel and payroll statistics by quarters for the Sonar Data Division, and are indicative of the growth and general assignments within the program. A somewhat broader summary of the personnel and fiscal phases will be found in Section D of this chapter.

FIGURE 2.6. A CHART OF THE GROWTH OF PERSONNEL ASSIGNED TO THE SONAR DATA DIVISION. BECAUSE OF THE GREAT OVERLAPPING OF ALL THE WORK IN THIS DIVISION, IT IS NOT POSSIBLE TO BREAK THIS CHART INTO ANYTHING OTHER THAN TWO BROAD SECTIONS. ONE, SONAR RESEARCH, DEALT WITH PROBLEMS OF TRANSMISSION, REVERBERATION, ATTENUATION, ETC.; WHILE THE OTHER, SONAR STUDIES, DEALT WITH A MISCELLANY OF PROBLEMS AS NOTED. THE STEADY GROWTH OF BOTH GROUPS, AS THE SCOPE OF THE WORK BROADENED, WILL BE NOTED. HOWEVER, THE NUMBER OF PERSONS EMPLOYED ON SONAR RESEARCH CEASED TO INCREASE SO RAPIDLY BY THE MIDDLE OF 1944, BECAUSE OF THE SATURATION OF MARINE FACILITIES AND WORKING SPACE. ON THE OTHER HAND, SONAR STUDIES SUDDENLY BECAME A LARGER GROUP BECAUSE OF AN INCREASE IN THE NAVY'S REQUIREMENTS FOR CHARTS, MANUALS, AND OTHER SUCH SERVICES.

FIGURE 2.7. A CHART SHOWING THE GROWTH OF SALARIES PAID TO PERSONS ASSIGNED TO THE SONAR DATA DIVISION. TOTAL ACCUMULATED COSTS OVER THE PERIOD INDICATED ARE ALSO NOTED ON THE CHART.





KEY

TOTAL SALARIES

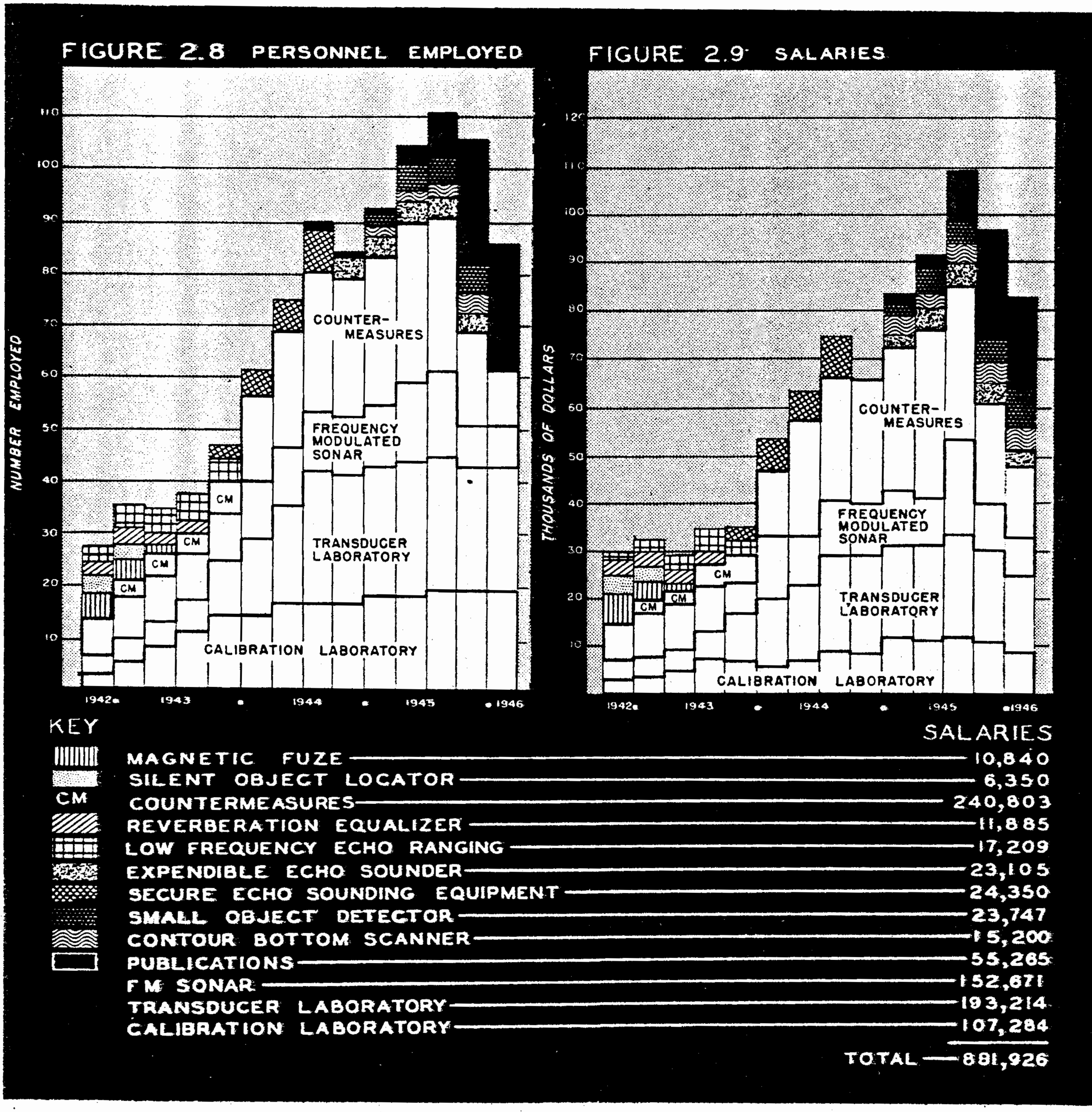
SONAR RESEARCH — $ 843,406

SONAR STUDIES, THERMAL INVESTIGATIONS, BOTTOM SEDIMENT CHARTS, BT PROCESSING & ANALYSIS, SONAR CHARTS, SUBMARINE SUPPLEMENTS. — 186,223

INCLUDES PERSONNEL AT SIO

FIGURE 2.8. A CHART OF THE GROWTH IN THE NUMBER OF PERSONNEL ASSIGNED TO THE SONAR DEVICES DIVISION. BECAUSE OF THE LATE BIRTH OF THIS DIVISION, DATA ON IT EARLIER THAN THE LAST QUARTER OF 1942 ARE NOT SIGNIFICANT. A PERIOD OF STEADY GROWTH THROUGH 1943 WAS FOLLOWED BY A RAPID EXPANSION THROUGH 1944 TO A CONSTANT LEVEL MAINTAINED DURING EARLY 1945. A GENERAL REDUCTION OCCURRED AFTER V-J DAY. THE EXPANSION OF THE COUNTERMEASURES PROGRAM AND THE CONCOMITANT GROWTH OF BOTH THE TRANSDUCER AND CALIBRATION LABORATORIES RESULT FROM THE INCREASED EFFORT IN PROSUBMARINE DEVELOPMENT. THE LARGER NUMBER OF PEOPLE ENGAGED IN THE DIVISION'S PUBLICATION WORK AFTER AUGUST 1945 WILL BE NOTED.

FIGURE 2.9. CHART SHOWING THE SALARIES PAID TO PERSONNEL ASSIGNED TO THE SONAR DEVICES DIVISION. THESE ARE BROKEN DOWN BY PROJECT AND THE TOTALS FOR THE PERIOD COVERED ARE ALSO NOTED.



II. sonar devices division

As indicated in the first section of this chapter, the Devices Division grew somewhat more slowly than the Data Division because of the initial philosophy under which it was presumed that the developing and designing of combat devices could be carried out more effectively in eastern laboratories. It soon became apparent, however, that suggestions for such devices emerged naturally from the scientific program, and after a few unsuccessful attempts to transplant these to another laboratory, it was appreciated that nascent ideas were too perishable to withstand the long transcontinental trip. In consequence, the alternatives were to disregard UCDWR's suggestions or to make provision within the program of the Laboratory for the development of these ideas, at least to the stage where they could be taken up by other groups without serious loss of continuity. The second alternative was wisely adopted, and after a year or two of operation, the Devices Division actually assumed somewhat the largest role in the Laboratory's activities.

In distinction to the Data Division, the emphasis of this work was on design, development, production, installation, and operational testing. During the first years of the Laboratory's operation, the Division was concerned almost exclusively with antisubmarine sonar devices, where its role was somewhat secondary to that of the eastern laboratories. During the last two years of the Contract, however, its efforts were redirected to the prosubmarine sonar and countermeasures fields, and here a number of factors combined to make its contribution particularly effective.

Owing to the smaller number of submarines than surface vessels, the Laboratory's scale of production could be much more effectively utilized by the Navy. The general level of technical interest and competence of the Submarine Forces was particularly high and enabled the establishment of intimate professional relationships between the scientists and submarine officers. This had a marked effect on the promotion of joint experimental and development programs.

For a long time the Devices Division had associated with it the engineering services of the Laboratory, and throughout the entire life of the Contract, the effect of this could be clearly noted. The groups concerned with the design and development of crystal and other transducers remained a part of the Devices Division, and the testing and calibrating stations were likewise sections under this Division throughout the Laboratory's existence. These groups contributed most directly to the sonar and countermeasures projects in hand by the Devices Division, but they were also of broad general use to the Training and Data Divisions as well. Cooperative work with the latter Division has been briefly touched upon earlier, and the relationship with the Training Division was equally close. One of the first major development undertakings of the Laboratory was in the field of practice targets, and here the conduct of the work was actually in the hands of the Devices Division although it constituted essentially a training function. On many other occasions, mutual services were performed by these Divisions. These became evident formally on the adoption of Laboratory-developed devices by the Navy and the institution of training programs for operators of them at the Sonar Schools or Training Commands.

The external liaison of this Division was almost as extensive as that of the Data Division. The work was integrated with that of eastern laboratories through Section 6.1, NDRC, and the maintenance of adequate channels of communication with the Bureau of Ships required the almost constant presence of one or another member of this Division in Washington. In procurement and manufacturing matters, the Transition Aide of NDRC was frequently utilized, and the services of more distant manufacturers were drawn upon. Direct naval liaison became particularly important in connection with the submarine work, and the QLA and Sound Beacon programs necessitated the continuous retention of Laboratory representatives at West Coast Navy Yards, and in Pearl Harbor, and led to many individual trips farther into the Pacific.

The accompanying charts (Figures 2.8 and 2.9) indicate the personnel and payroll statistics by quarters for the Sonar Devices Division. A comparative summary of these matters for the different Divisions will be found in Section D of this chapter.

III. training aids division

The developments leading to the establishment of a Training Division have been indicated in Section A of this chapter, and as the work progressed the Division assumed a definite character presenting a number of points of contrast with the Data and Devices Divisions. The work undertaken can conveniently be considered as of three types: the first was concerned with selection and training methods and techniques, the second with the design and development of training devices, and the third with the preparation of maintenance manuals. Quite different types of personnel were involved in these categories, but the efficient conduct of the work of each required the maintenance of the closest relationship between them and also involved extensive contributions from the other Laboratory divisions.

The work on selection and training techniques was carried out by a group consisting of physicists, engineers, applied psychologists, and technical assistants. These persons brought the necessary specific skills to the undertaking but had had little previous experience in working together and none in working with military organizations. One of the first requisites for the sound establishment of a program in this field was the fostering of mutual understanding between the different groups concerned. Eventually this selection and training group became well established with representatives in many areas and in association with many commands. They served as the eyes, ears, advisers, and critics of the second category within this Division, which was concerned with the design and furnishing of training devices. This second group was composed largely of physicists, engineers, and technicians, was resident in the Laboratory itself, and drew upon all local facilities for the conduct of its work. The third group, resident in New York City for convenience, was composed of technical writers and engineers.

There was somewhat less opportunity for collaboration between the widely dispersed Selection and Training Section and the other Laboratory Divisions, although in a sense the training people engaged in this work served as Laboratory liaison and representatives with all naval activities, as each of these is concerned with training to a greater or less extent. It has been mentioned that the psychoacoustic program in the Data Division had many points of common interest with the training groups at the Sonar Schools and with Training Commands. On many occasions, operational testing, tactical evaluation, preliminary operation, and maintenance training of Laboratory-developed combat devices were effectively furthered by members of the training groups who were strategically located for such purposes. The engineers concerned with the development of devices were closely integrated with all other UCDWR personnel, and were regularly resident members of the staff. Their relationship to the training-techniques group was particularly close and in consequence they were brought intimately in contact with naval training activities at all stages.

The operation of the Training Division as a whole is outlined in more detail in Chapter Five, but the actual method of bringing the Laboratory's contribution most effectively to bear on the Navy's problems in this field deserves brief mention here. The need for training assistance was sometimes appreciated first within the Fleet itself, sometimes at a Sonar School or Training Command, sometimes within an Evaluation Command such as AsDevLant, and sometimes by the civilian scientists themselves. The wide area from which these suggestions might emanate points clearly to the necessity for a widely-dispersed but closely-integrated and flexible organization. To some extent, integration was supplied by the Selection and Training Committee of Division 6, NDRC, and to some extent by the staff of the Commander-in-Chief. Upon the recognition of a need for a device, conferences between all persons properly concerned led to the establishment of a Laboratory program for design and development. Subsequently, with the continuing cognizance of everyone, initial units were furnished to Training or Evaluation Commands and preliminary instructional programs were undertaken. As a result of careful and critical study, errors and inadequacies were recognized and steps taken to effect the design and assist in the procurement of an adequate supply of the device for Navy use. Thereafter the training-techniques group continued to work closely with Training Commands utilizing a device in the perfection of instructional techniques. The nature of the external liaison implied in the operation of this Division is sufficiently clearly indicated in the summary of its method of operation, and it is clear that the maintenance of close and harmonious relationships between a wide variety of civilian specialists and naval officers played a particularly important role in this aspect of the Laboratory's undertakings.

The accompanying charts (Figures 2.10 and 2.11) indicate the personnel and payroll statistics by quarters for the Training Aids Division. A comparative summary of these matters for the different Divisions will be found in Section D of this chapter.

FIGURE 2.10.
CHART SHOWING THE GROWTH IN THE NUMBER OF PERSONNEL ASSIGNED TO THE TRAINING AIDS DIVISION. DURING THE PERIOD COVERED BY THIS CHART THE TRAINING AIDS PROJECTS GREW STEADILY; THE NEED FOR SONAR SCHOOL INSTRUCTORS DIMINISHED WITH THE GROWTH OF THE SONAR SCHOOLS; AND WORK ON PRACTICE TARGETS WAS STOPPED AFTER SUBMARINES BECAME MORE AVAILABLE. THE LARGE SIZE OF THE MAINTENANCE MANUAL PROJECT THROUGH 1944 AND 1945, AND THE GROWTH OF TRAINING AND DEVICES IN CONNECTION WITH THE BATHYTHERMOGRAPH IN 1944, ARE TO BE NOTED.

FIGURE 2.11.
CHART SHOWING THE SALARIES PAID TO PERSONNEL ASSIGNED TO THE TRAINING AIDS DIVISION. THESE ARE BROKEN DOWN BY PROJECT, AND TOTALS FOR THE PERIOD COVERED ARE ALSO NOTED.

FIGURE 2.10

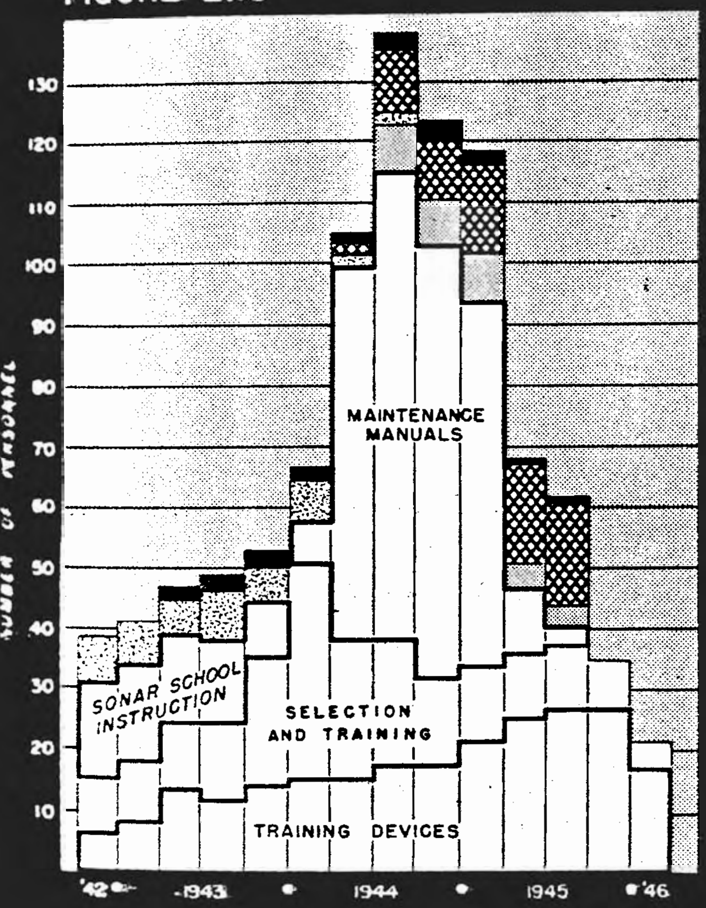
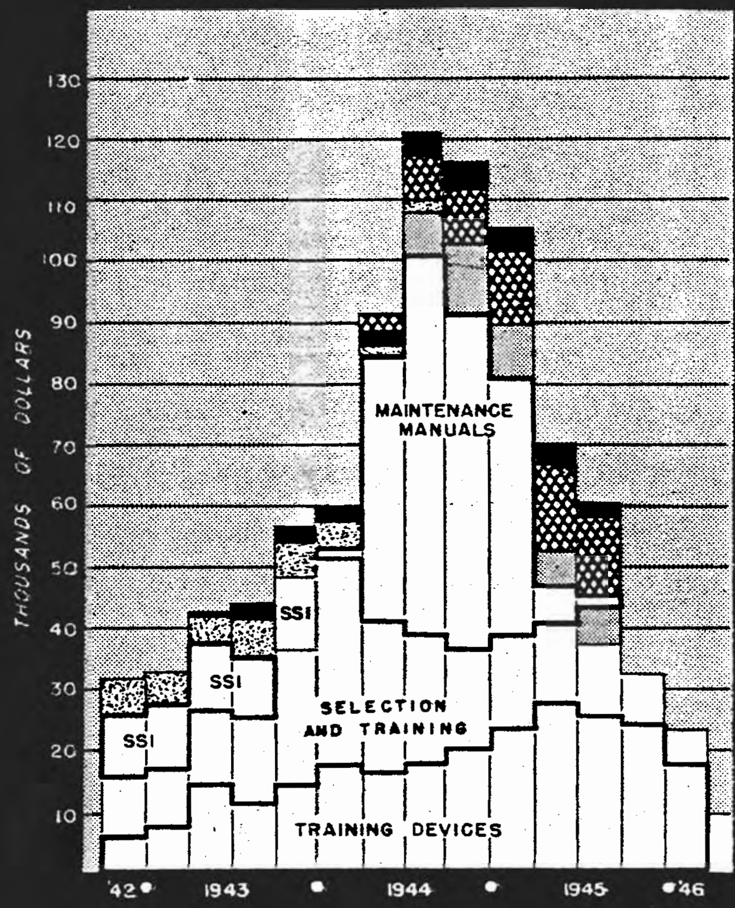
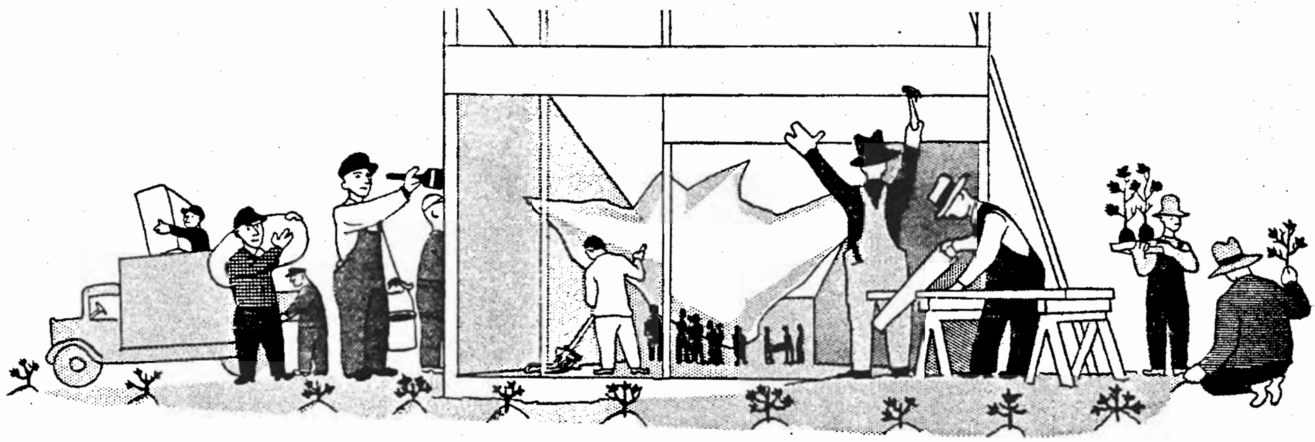


FIGURE 2.11



KEY	TOTAL SALARIES
INSTRUCTIONAL MATERIAL	23598
BATHYTHERMOGRAPH TRAINING AIDS	58069
PRACTICE TARGETS	37229
BATHYTHERMOGRAPH FIELD TRAINING	36725
SSI SONAR SCHOOL INSTRUCTION	47612
TRAINING DEVICES	241265
SELECTION AND TRAINING	218112
MAINTENANCE MANUALS	214095
TOTAL—	8767604



D. SERVICE DIVISIONS

I. engineering services division

The conduct of the scientific problems assigned to the Laboratory required the furnishing of a wide variety of services common to all three scientific divisions. It early became apparent that these technical services could best be furnished by a division of the Laboratory independent of those persons charged with the conduct of particular scientific problems. This separation into scientific and service activities was not entirely clean-cut in all cases, and, in particular, it was by no means true that scientific personnel were employed exclusively in the scientific divisions and non-scientific personnel in the service divisions. The Engineering Services Division in particular included many people of high technical skill. As instances, the Design and Drafting Department, the Electronics Laboratory, and the Recording Laboratory were staffed by specialists engaged in work essentially comparable to that of equipment designers and electronic engineers in the Training and Devices Division. The service groups, however, were distinguished by the assisting role which they played in collaboration with the scientific divisions. Particular jobs were assigned to them on job-order requisitions from project leaders, and continuity of occupation of the several subdivisions of the service groups contributed greatly to the efficiency with which their work was performed, besides adding importantly to the flexibility of UCDWR's operations.

The Engineering Services Division performed a wide variety of functions for the scientific groups of the Laboratory, and, in magnitude, its payroll was approximately one quarter that of the Laboratory as a whole.

One subdivision of the Engineering Services Division, concerned with the operation of all local engineering service activities, was the Design and Drafting Department, which was drawn upon by all Divisions almost equally for design work involved in their programs. Central records of prints and drawings were kept by this group, which also assumed responsibility for their proper classification and custody. This was of material assistance in bringing about uniformity of procedures and also was invaluable in cooperation with the Extension Engineering and Subcontract Departments when the assistance of external manufacturers had to be enlisted.

The Machine Shop was much the largest of the local service groups and, together with the Sheet Metal and Paint Shops, formed a mechanical unit for the production of experimental equipment, trial models, and prototypes, in addition to assisting on many occasions with urgent production work which could not be produced to specification or in time by commercial shops in the area.

The Electronics Laboratory, as its name implies, designed, fabricated, and tested electronic components of equipment required by the scientific divisions, collaborating closely with the Drafting and Mechanical Construction Departments as was required in the construction of the units. Skilled electronic designers were of particular assistance to the Sonar Data Division, where few personnel were available with the requisite electronic experience for the design of the equipment required for their measurement program. All divisions made equal use of the Electronic Laboratory and the Transformer Laboratory for the actual construction of experimental and service equipment.

The other subdivisions of the Engineering Services Division were somewhat independent units less closely integrated with engineering services than with the programs of particular scientific projects or routine services to the administrative group of the Laboratory. The Recording Laborotory, for instance, divided its time nearly equally between work for the Sonar Data Division and the Training Aids Division. Occasionally work was done for the Devices Division as well, but the routine recording of sea results of the transmission program and the construction of training recordings occupied most of the time of this group. It rendered an involuable service through these two associations and demonstrated the essential role played by skilled recording personnel in sonar research and training. The connection between the Recording Laboratory and the Communications Group was a close one, as much of the work handled by both involved the receipt of radioed information from Laboratory and naval vessels at sea. The Communications Group was also linked by common interests and personnel with the Electronics Laboratory, and the closest cooperation was maintained between these groups and the local naval communications authorities.

The Photographic Laboratory was initially instituted as a subdivision of the Engineering Services Division, but its work was divided about equally between assisting the scientific divisions on the one hand and the reports group on the other. Some assistance was rendered the Personnel Department in the taking of employee photographs and other routine services, and a special program was set up for the development of oscillographic recordings taken by the Sonar Data Division. However, the greater portion of the time of the photographic personnel was devoted to the picturing of devices in various stages of completion and to furnishing suitable prints for all types of reports. At a later stage of the Laboratory's operation, this group was transferred to the Publications Division, as this proved to be a more efficient arrangement when the Laboratory effort was largely directed to the reporting of its previous program.

The Engineering Services Division had charge likewise of the equipping and maintenance of the Laboratory's marine facilities. The E.W. SCRIPPS and the M.V. TORQUA, which were not naval vessels, required a certain amount of ordinary marine maintenance, which was furnished during most of the Laboratory's existence by a small group organized for the purpose. The general supervision of personnel aboard these ships was also in the province of the Engineering Services Division. These two vessels, and also the Naval vessels assigned to the program, carried extensive installations of scientific apparatus for the conduct of the various projects. In general, this was designed and built by the Engineering Services Division and then installed and maintained by engineers assigned to the Marine Facilities Department of this Division. These men served essentially as equipment curators aboard the vessels. Their services were indispensable in maintaining the equipment in operating condition and in adapting it to the day-to-day requirements of the various scientific programs which shared its use.

One of the most important functions of the Engineering Services Division was that of procuring devices constructed to Laboratory specifications from suppliers both in the Southern California area and elsewhere. When designs had reached a stage at which no further research or development was anticipated, units were procured by purchase order in suitable quantity for operational test. When it was anticipated that further research would be required, the Government's interests were protected by the procuring of devices under subcontract. The group of engineers forming the Extension Engineering and Subcontract Department of the Engineering Services Division performed the essential functions of assisting the Purchasing Department in locating suitable suppliers, interpreting Laboratory specifications to them, and furnishing technical advice and supervision in the course of the manufacturing program. Through this section, UCDWR's ability to provide those services requested by the Navy was greatly expanded. It would have been impossible to provide the necessary space and facilities in the Laboratory itself for the manufacturing programs that were from time to time undertaken, and, had the attempt been made to do so, it would have reacted unfavorably on the experimental and pioneering development which was the chief obligation of the Laboratory. On the other hand, adequate naval evaluation required the provision of many units of different types of devices, and this was accomplished both expeditiously and economically through enlisting the services of local manufacturers, whose efforts were integrated with the Laboratory's program through the activities of the Engineering Services Division.

II. business division

In the same sense that the Engineering Services Division provided general Laboratory services in engineering fields, the Business Division provided services in material and personnel procurement and control, and handled the various fiscal functions requisite to Contract administration and Laboratory operation. The Business Manager not only reported to the Director of the Laboratory on all administrative matters but likewise served as the local representative of the Regents of the University in connection with fiscal procedures. In this dual role, his influence upon the smooth and efficient operation of the Laboratory was very great.

The largest subdepartment of the Business Division was the Purchasing Department, which was concerned with all phases of material procurement. The detailed functions and procedures of this Department are described in Chapter Seven, Section A, and here its relationship to other Laboratory activities will be considered briefly. All the work of the scientific divisions required the purchasing of materials, and the securing of satisfactory devices or components presented a serious problem under wartime conditions. The Purchasing Department worked closely with the scientific divisions, assuring itself that it had an adequate grasp of the requirements of the various projects, and suggesting from time to time substitutes and expedients made necessary by shortages and over-riding priorities. However, the specifications determined by the scientific divisions, modified as they might be by conditions over which the Laboratory had no control, were the determining factor, and every effort was made by the Purchasing Manager and his assistants to secure suitable equipment and supplies in response to the wide variety of requests.

A Materials Planning Section of the Purchasing Department endeavored to anticipate Laboratory needs and provide for a continuous flow of equipment of the more standard types, complying with the planning schedules imposed by other departments of the Government. Actual purchasing was conducted in accordance with University precedent modified by wartime conditions, the urgency of the different undertakings, and the limitations imposed by the governmental agencies under whose auspices the program was conducted. The Purchasing Department was also responsible for the receiving of equipment, the maintenance of records, and the establishment of stock controls. It rendered extensive assistance to the Engineering Services Division in procurement for the various departments of that Division, and aided in the extension engineering and subcontract work. The Purchasing Manager was a party to all preliminary negotiations for large purchase orders or subcontracts, and his cognizance of these matters at the earliest stage contributed immeasurably to the smoothness with which subsequent negotiations were conducted. It should be remarked that the role played by effective procurement, balancing control against flexibility, is an extremely vital one, and the establishment and maintenance of efficient routines contributed greatly to the smooth operation of the scientific divisions.

As personnel problems were common to all Laboratory divisions and more closely related to business operations than the conduct of any one of the scientific problems, the Personnel Department was established within the Business Division. Here it functioned in close cooperation with the Payroll and Accounting Departments in the recruiting of personnel, routine administration, and terminations. Although all employment arrangements were the responsibility of this Department, as will be described in detail in Chapter Eight, it was greatly assisted in the recruitment of scientific personnel by the scientists in the operating divisions. These men, who were members of the rather small and loosely-knit group of the nation's scientists, were in the best position to recommend suitable people for special openings as these appeared from time to time. Recruitment in the non-scientific category, however, was almost exclusively the province of the Personnel Department, and there little special assistance could be rendered by Laboratory personnel except as personal acquaintanceships suggested suitable employees for the organization.

Certain phases of the routine operations of the Personnel Department, such as the conduct of Selective Service negotiations, assistance in housing, clearance procedures, etc., did not necessitate particularly close liaison with the scientific divisions. In these activities the Personnel Department was concerned with the proper presentation of the Laboratory's requirements to the governmental agencies established for the administration of manpower legislation and security maintenance. These functions required extensive external contacts. Constant use was made of the telephone and other rapid means of communication to handle the various urgent situations as they arose, frequently with little warning and always with great personal pressure. The other aspect of the operations of the Department, including the establishment of wage scales, the conduct of salary reviews, maintenance of employment records, etc., necessitated close coordination with all other local Laboratory divisions. Over-all policies were established by the Director after discussions in Administrative Committee meetings, of which group the Personnel Manager was a member. Thereafter the interpretation of the regulations in individual cases involved close working relations between the Personnel Manager and the Assistant Directors, Group Leaders, and individual employees. The work of the Personnel Department was an essential one in the maintenance of a smoothly-working, effective organization, and the Laboratory administration would have been well advised to have given earlier attention to its importance.

Another subdepartment of the Business Division was the Accounting Department, which increased in size and undertook constantly greater responsibility as the work of the Laboratory developed. The details of these operations are given in Chapter Seven, Section A, and it can be seen from that account that the most intimate relations of this Department were with the University's Accounting Department and the fiscal offices of OSRD and the Navy. This Department reported administratively to the Business Manager, but, particularly in the final stages of Laboratory development, it properly assumed direct responsibility to the University Accountant, providing that detached impartiality essential to the conduct of accounting procedures. The problems presented to this Department growing out of unusual wartime conditions frequently required departure from those routines to which the employees had been previously accustomed, and the adaptability with which they accustomed themselves to the requirements of the Government's Accounting offices contributed markedly to the success of fiscal operations.

The Business Division was likewise in charge of a considerable number of minor service groups, including the maintenance of automobile transportation, guard service, mail and messenger service, telephone service, etc. These all played important minor roles in the Laboratory's operation, and the Business Division proved to be an excellent coordinating agency for them.

An additional function of the Business Division requires brief mention because of the essential role it played in the Laboratory's operation where procedural coordination was necessary. The reference is to the initiation and conduct of procedures incident to personal travel. The importance of traveling in a program which was of necessity closely related to other similar ones being conducted at widely separated locations was fortunately recognized at an early date. However, it was necessary to establish both suitable internal controls and methods for facilitating travel arrangements during a period when common carriers were badly overcrowded and the securing of reservations presented problems of the greatest difficulty. Arrangements for authorizing travel and also some of the methods used for securing reservations and priorities are described in Chapter Seven, Section C. These negotiations were conducted by the administrative assistant to the Business Manager. In addition to the formal procedures recounted in Chapter Seven, extensive personal contacts were required both within the Laboratory to justify the travel requests made and outside the Laboratory to take advantage of all avenues for securing reservations and accommodations. Relationships with the railroads and airlines were very close, but these were of necessity supplemented by assistance from naval travel bureaus, the Regional Air Priority Boards, and in many cases the Army and Navy Transport Commands. Through the diligent efforts of Mr. L. G. Shaw, who was in charge of this work, essential arrangements were always finally achieved.

III. fiscal summary

In Chapter Seven an account is given of the procedures under which funds were made available to the Contractor. As the progress of the Contractor's program indicated the need for additional funds, they were allocated by Contract Supplements in a broad way, without earmarking to special projects and without the requirement of detailed estimates or cost breakdowns. Thus the needs of the Navy and the Contractor's ability to contribute to them were the paramount considerations, and the program was never handicapped by the imposition of purely financial limitations.

TABLE 2.1

PERCENTAGES OF SALARIES ($5,500,000) EXPENDED IN VARIOUS PHASES OF THE LABORATORY'S OPERATION

ADMINISTRATION:

LABORATORY ADMINISTRATION	8.1	
MATERIAL PROCUREMENT & CONTROL	5.7	
MISCELLANEOUS BUSINESS SERVICES	1.9	
TOTAL		15.7%

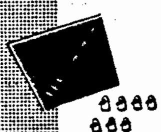
ENGINEERING SERVICES:

MACHINE, SHEET METAL & PAINT SHOPS	11.0	
ELECTRONICS LABORATORY	5.1	
MISCELLANEOUS ENGINEERING SERVICES	5.8	
TOTAL		21.9%

REPRODUCTION SERVICES:

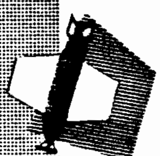
PHOTO LABORATORY	1.3	
RECORDING LABORATORY	0.9	
PUBLICATIONS	1.9	
TOTAL		4.1%

TRAINING AIDS DIVISION:



TRAINING DEVICES DEVELOPMENT	5.3	
SELECTION & TRAINING OPERATIONS	8.8	
MAINTENANCE MANUAL PROJECT (NY)	4.8	
TOTAL		18.9%

SONAR DEVICES DIVISION:



QLA SONAR	4.4	
BEACONS	4.4	
MISCELLANEOUS SONAR	6.0	
TRANSDUCER DESIGN & DEVELOPMENT	3.8	
TOTAL		18.6%

SONAR DATA DIVISION:

SOUND PROPAGATION	15.4	
MISCELLANEOUS SONAR RESEARCH	5.4	
TOTAL		20.8%

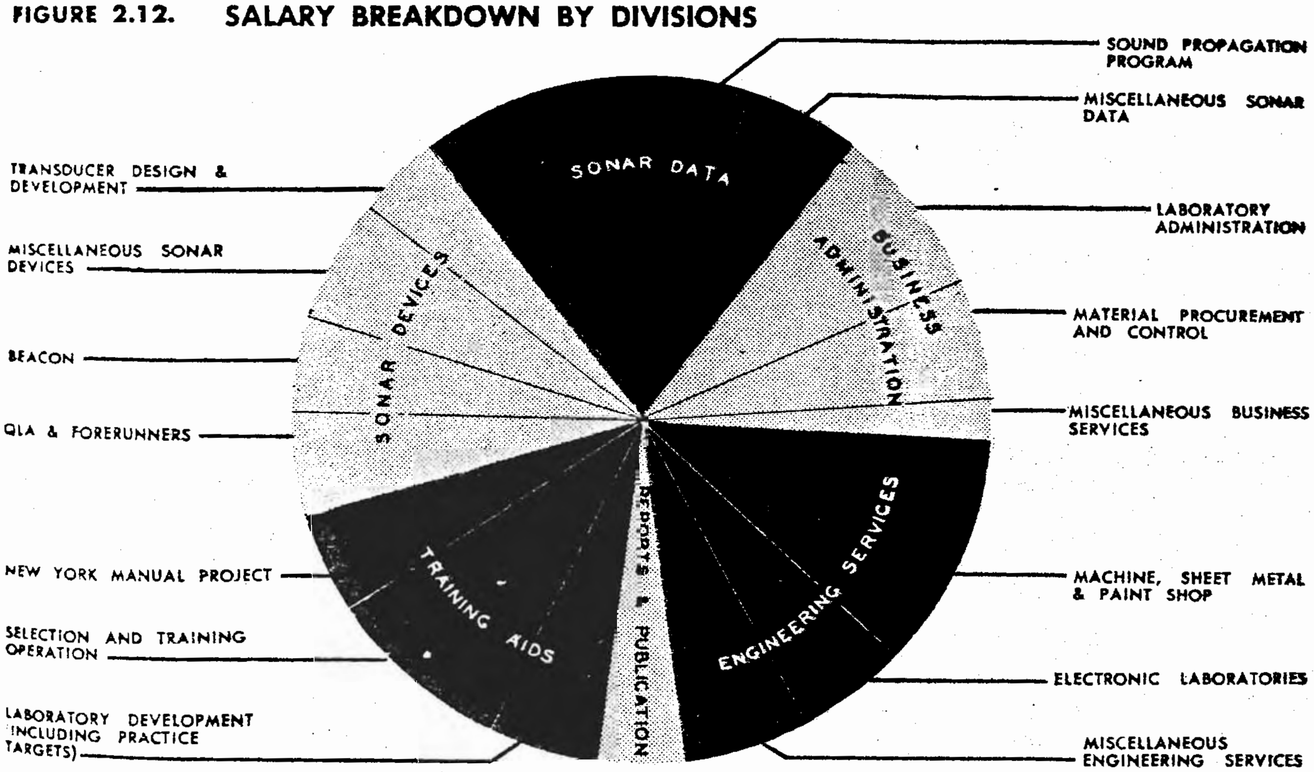
100%

Every effort was made by the administration to achieve the greatest possible economy of operation, and suitable control was maintained through the purchasing and accounting procedures. However, it was recognized that speed was an expensive commodity, and discretion was accorded the Director in the adoption of policies and procedures which would lead to the most rapid and efficient operation. Through the cooperation of the scientific and business divisions, purchasing and procurement were expedited to the utmost and it was infrequent that any material increase in over-all cost was entailed. As the work of the Lobaratory was research and development, it was recognized by the sponsoring agencies that detailed cost accounting would be inappropriate and would impose a severe handicap on expeditious operation. Records were kept in great detail of all procurement; and within the service departments, records were also maintained of the time spent on projects of the various divisions. From these records, response could be provided to occasional requests received for cost estimates as a guide in the procurement of large quantities of various devices, but in general no detailed fiscal breakdown of operation can be given for the Laboratory projects. However, as is pointed out in Chapter Seven of this report, a close relationship exists between salaries and material expenditures for the Laboratory as a whole. From intimate acquaintance with Laboratory operations, a reasonably correct estimate can be made of suitable factors of proportionality for allocating material expenses to the major Laboratory divisions.

A careful survey of all Laboratory personnel was made during the closing months of the project to determine the divisions with which their contribution had been associated and the proportion of their salary properly chargeable to different phases of the work. On the basis of this survey, the accompanying table (Table 2.1) has been prepared, showing the percentage of total cumulative payroll properly chargeable to arbitrarily chosen categories of operation. The total sum expended for salaries under the Contract was approximately $5,500,000, and the percentages given in the table are the corresponding fractions of this amount.

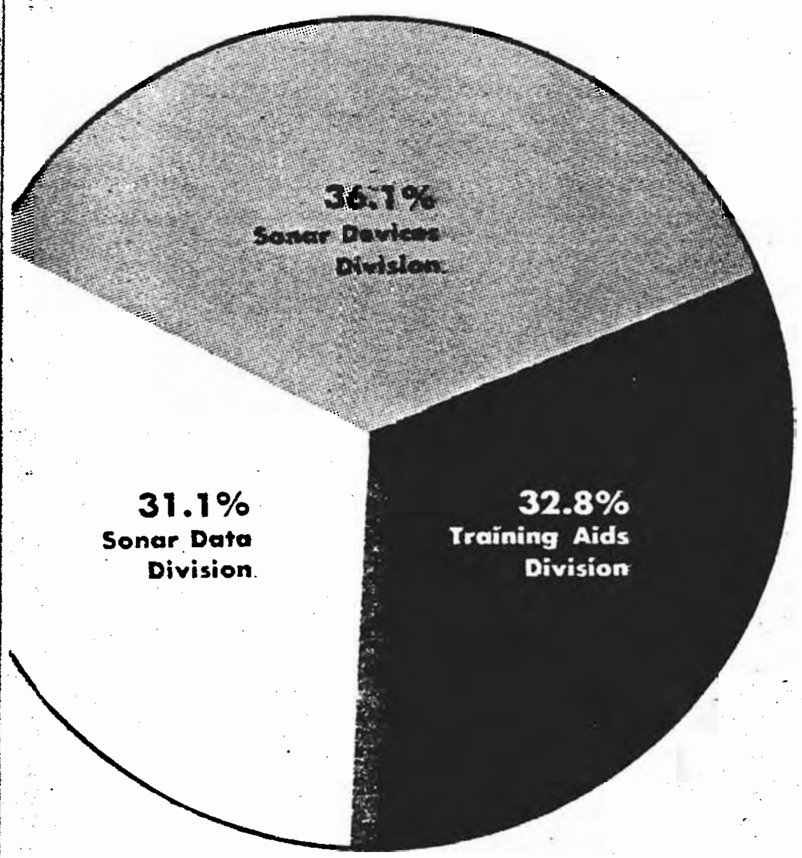
It can be seen from these figures and from the accompanying graph (Figure 2.12) that each of the scientific divisions represented approximately one-fifth of the total payroll. The Engineering Services Division alone accounted for approximately one-fifth of the payroll, and the administrative and business functions, together with publication, for the remaining fifth.

FIGURE 2.12. SALARY BREAKDOWN BY DIVISIONS



As the ultimate effectiveness of the Laboratory's program reached the Navy only through the scientific divisions, it is appropriate to attempt a somewhat further allocation of service and administrative expenses to these three divisions. The Devices and Training Divisions made greater use of the Engineering Division than did the Sonar Data Division, and, in the judgment of the Director, it would appear appropriate to divide the percentage of salaries associated with the Engineering Services Division in accordance with a weighting of one, two, and three for the Data, Training, and Devices Divisions respectively. Assuming equal weighting for the administrative, business, and reproduction services, the percentages of the payroll of the services departments accruing to the Data, Training, and Devices Divisions are 10.3, 13.9, and 17.5 respectively.

Breaking down total payroll expenses in terms of the three scientific divisions results then in the following figures:

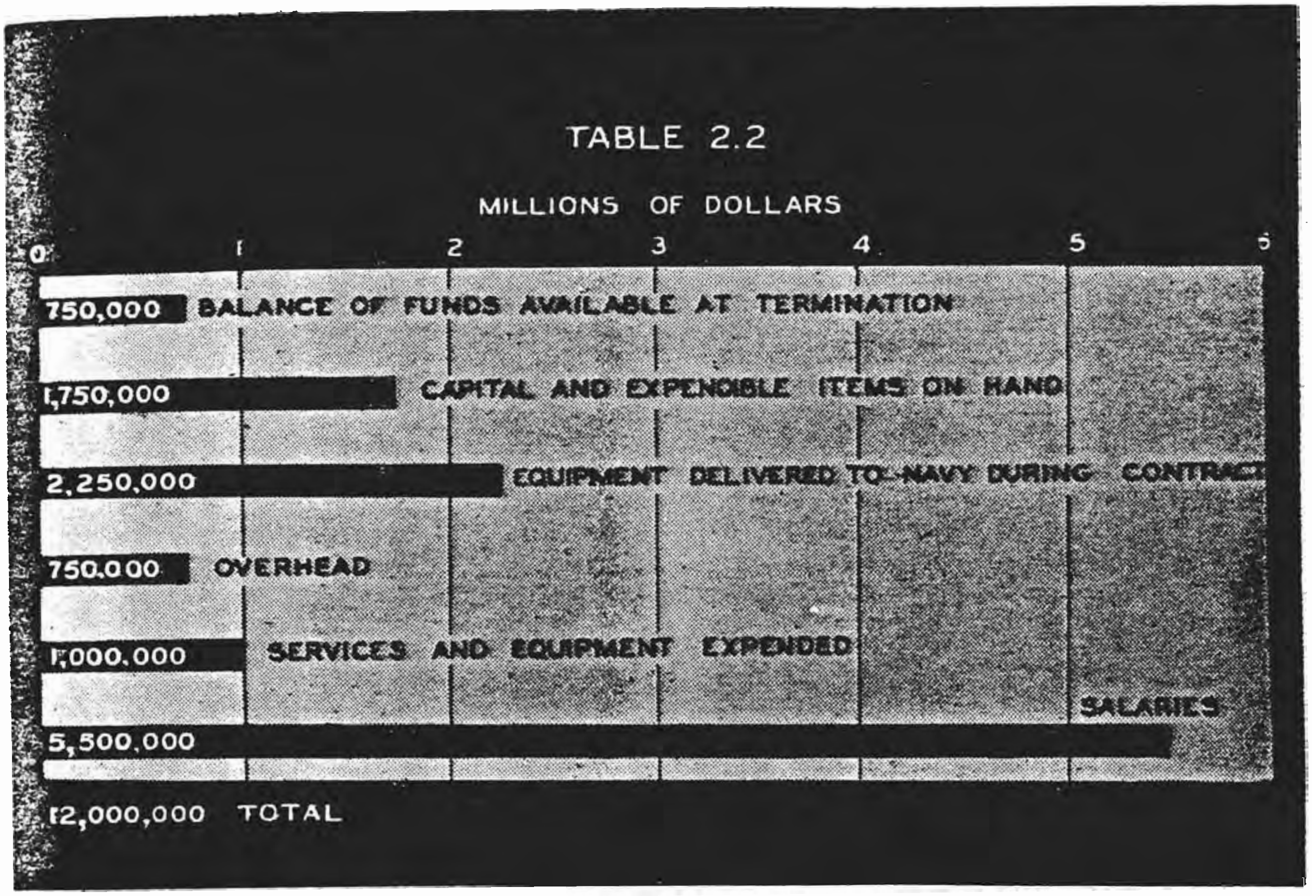


Sonar Devices Division....36.1%
Training Aids Division....32.8%
Sonar Data Division........31.1%

From these figures it can be seen that in terms of payroll expenditures, the Sonar Devices Division consumed the largest percentage of funds, and the Sonar Data Division the smallest. However, the differences between the three divisions are not large, and it may be said approximately that the activities of the Laboratory were divided almost equally among these three fields.

It is not possible to make as accurate a breakdown of expenditures other than salaries, although the records that are available and the estimates by the administrative staff enable the formulation of an approximate accounting to the nearest quarter of a million, which represents a precision of approximately 2% of total funds allocated. About three-quarters of a million should be available at the termination of the Contract as unexpended funds, and negotiations were initiated as early as 1 January 1946 for the transfer of a substantial fraction of this sum to NEL for the continuance of the scientific projects transferred from UCDWR. Likewise it was estimated that expendible and capital equipment on hand, the custody of which was transferred to the Technical Inspector during the final months of the Contract, represented approximately $1,750,000. In the course of the Laboratory's operations prior to 1 March 1945, approximately $750,000 worth of equipment was authorized by OSRD for transfer to the Navy. Subsequent to that date, approximately $1,500,000 was transferred from the Laboratory to the Navy on the authority of the Technical Inspector. The accumulated overhead provided for during the five years of operation amounted to something over $750,000. The balance of $1,000,000 represents expenditures for services and equipment completely consumed in the course of Laboratory operations (Table 2.2).

It should be noted that appropriations to the Contract did not represent completely the cost of operating the project because the Navy bore the cost of the premises, ships, and certain other minor items. Assuming a rental rate of 5c per square foot, per month, quoted by the San Diego Realty Association as an average for loft space, the rent that would have had to be paid by the Contractor for securing equivalent premises comes to $100,000. Utilities, guards, and janitors furnished by the Navy bring this figure to approximately $400,000. The rental cost of piers and other waterfront facilities should be added to this figure. From estimated charter rates for the ships furnished to the Con-



tractor, and allowing for expenses of operation and crew, it would appear that the Navy directly furnished materials, premises, and services to the value of approximately two million dollars.

Allowing for the fact that the greater portion of the equipment actually expended was consumed by the Devices and Training Divisions and the largest fraction of materials and services furnished by the Navy was used by the Sonar Data Division, it is not unreasonable to consider that the total of approximately $7,500,000 for salaries, retained overhead, expended equipment, and Navy-furnished material was divided equally between the three divisions, representing an average annual cost for each of approximately $500,000. For this expenditure the Navy secured about $1,500,000 worth of equipment from the Sonar Data Division and $750,000 worth from the Training Division. However, this by itself is an inadequate and misleading conclusion, because the purpose of the Contract was for the conduct of research and development and not primarily for the procurement of equipment. The Devices Division contributed much more in improved techniques, the devising of new methods, and the contriving and testing of new designs than is represented by the value of equipment delivered, and, to an even greater extent, the Training Division rendered services which far outweigh the value of devices furnished. Finally, the Sonar Data Division's contribution was almost exclusively knowledge and information, the value of which to the Navy cannot be reckoned in dollars.

In conclusion it should be pointed out that the joint operation of these three divisions provided for more economical prosecution of the work than would have been possible had any one of the three operated separately. The areas of common interests and techniques made the association between them a most natural and profitable one. Many and varied factors unite to determine the optimum size of an organization, but it is the opinion of the Laboratory administration that this optimum size was not exceeded by UCDWR under the conditions of its operation and that the gains resulting from unity of administration and the sharing of common facilities distinctly outweighed the handicaps incident to the administrative procedures appropriate to an organization of its size and type.

3 sonar data division

A. INTRODUCTION

B. RELATION OF SONAR DATA DIVISION TO OTHER ACTIVITIES OF UCDWR

C. SCOPE OF PROGRAM

D. THE RESEARCH PROGRAM

I. STUDIES OF THE MEDIUM
PROBLEM NOS. 2A, 2G, 2H
FILE NOS. 01.331, 01.40, 01.60, 01.911, 01.913, 01.93, 01.94, 01.95, 03.30, 21.00

II. STUDIES OF SOUND TRANSMISSION
PROBLEM NOS. 2A, 2G
FILE NOS. 01.31, 01.71, 01.72, 01.73, 01.74, 01.75, 01.76

III. STUDIES OF INTERFERING SOUNDS. I—BACKGROUND NOISE
PROBLEM NO. 2G
FILE NOS. 01.31, 01.331, 01.332

IV. STUDIES OF INTERFERING SOUNDS. II—REVERBERATION AND SCATTERING
PROBLEM NO. 2A
FILE NOS. 01.40, 01.60

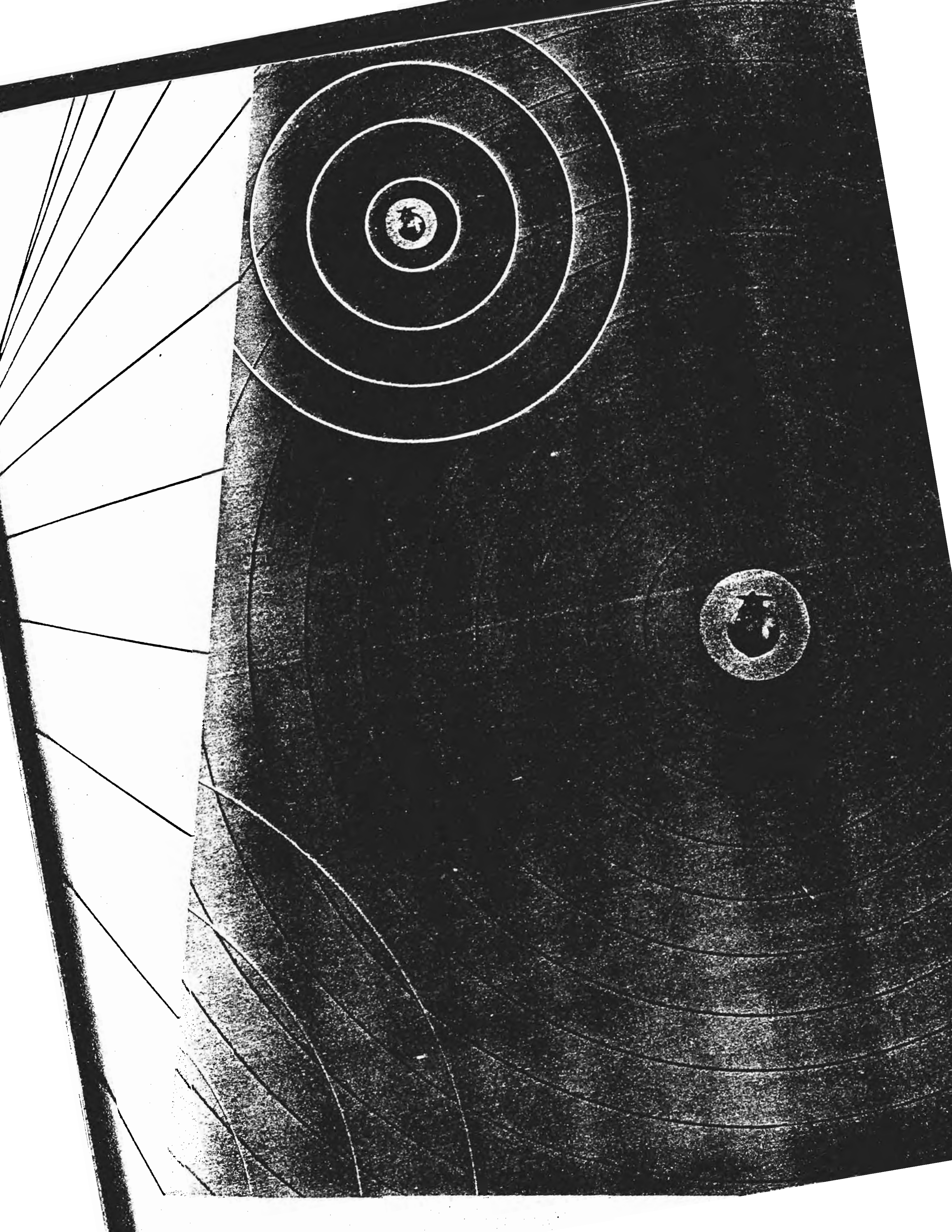
V. STUDIES OF ECHOES
PROBLEM NOS. 2C, 2D
FILE NOS. 01.80, 02.133

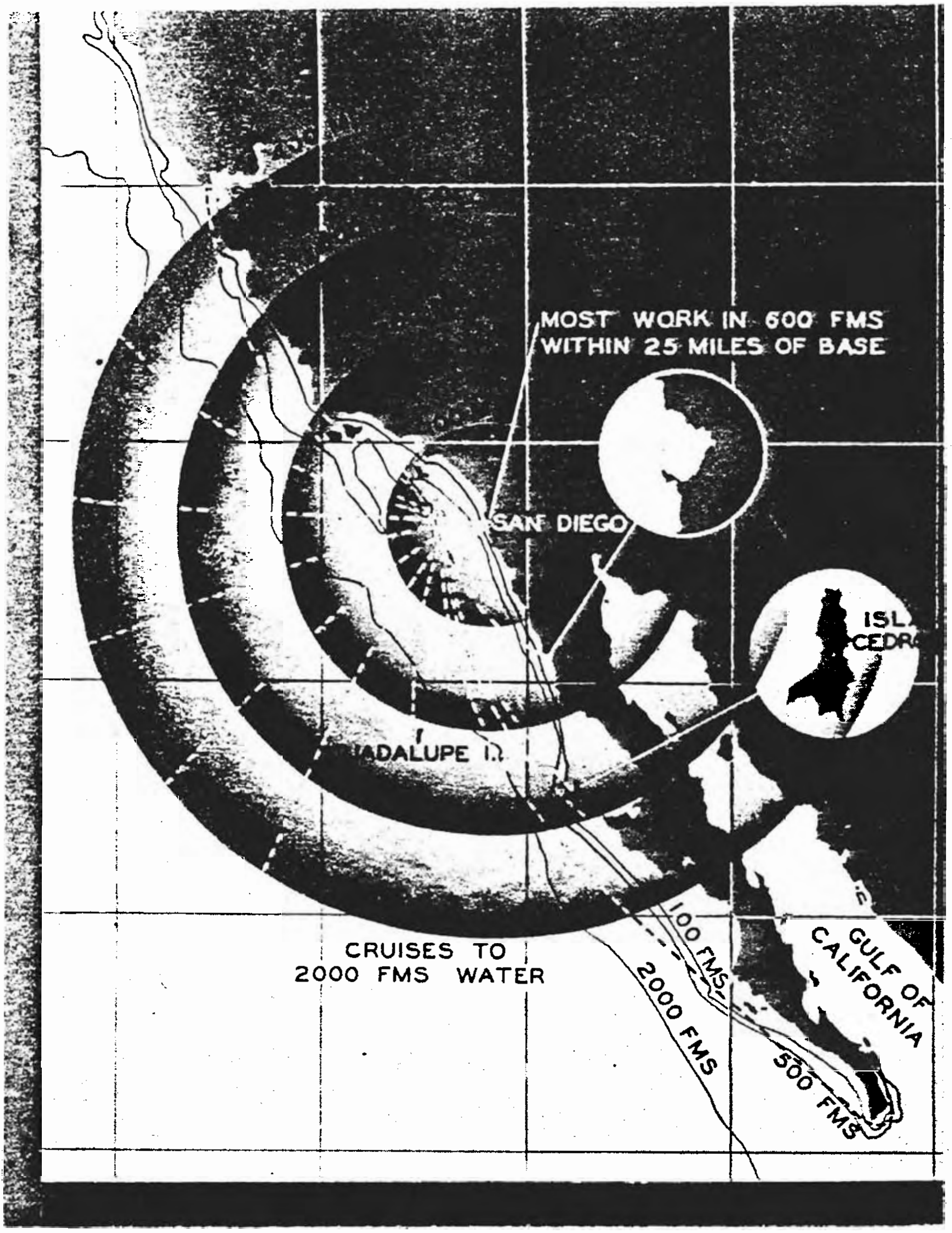
VI. STUDIES OF WAKES
PROBLEM NO. 2B
FILE NO. 01.50

VII. STUDIES OF SOUND RECOGNITION
PROBLEM NOS. 2E, 2F, 2M2
FILE NOS. 01.35, 01.41, 01.42

E. INTEGRATION OF RESULTS
PROBLEM NOS. 2A, 2H, 5D
FILE NOS. 01.911, 01.913, 01.921, 01.922, 91.80, 100.00

F. RECOMMENDATIONS





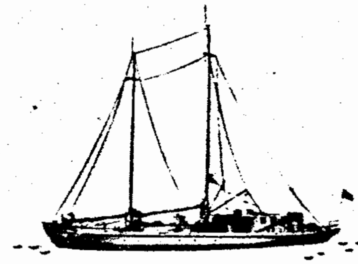
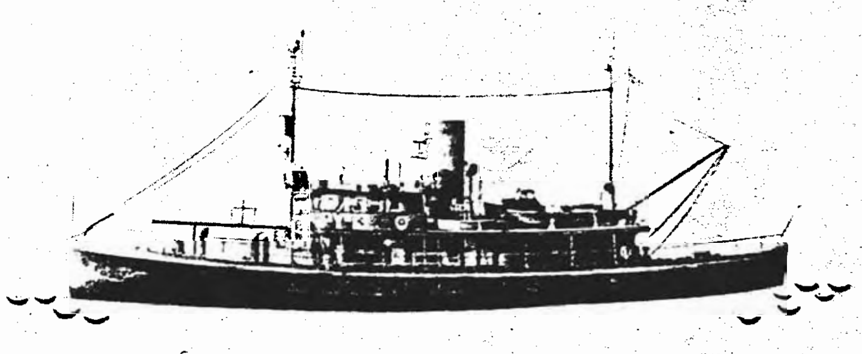
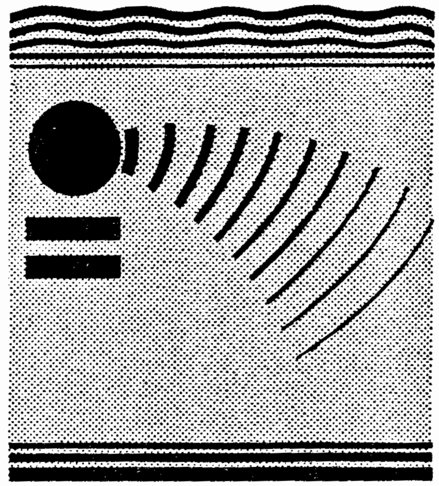


FIGURE 3.1. LABORATORY VESSELS USUALLY OPERATED WITHIN 25 MILES OF SAN DIEGO WHERE MAXIMUM DEPTH, 600 FATHOMS, COULD BE OBTAINED. REPEATED TRIPS WERE MADE AT DIFFERENT SEASONS OF THE YEAR TO STUDY SOUND TRANSMISSION AND REVERBERATION IN SHALLOW WATER AREAS NEAR TODOS SANTOS BAY AND ISLA CEDROS. DEPTHS OF 2000 FATHOMS COULD BE REACHED WITHIN 150 MILES OF SAN DIEGO.





A. INTRODUCTION

Research on fundamental problems of subsurface warfare was one of the specific assignments of UCDWR, and immediately after the establishment of the Laboratory certain problems were undertaken. As these investigations progressed and as the understanding of the field of subsurface warfare increased, it became obvious that the program at San Diego was fragmentary and suffered from lack of contact between the groups working on the several projects. Coordination of the work and a more complete and balanced program gradually emerged during the first two years' work. The Sonar Data Division, established in December 1942 to unify the different groups, undertook additional problems from time to time either in response to requests for specific types of information, or on the initiative of the Laboratory. In the following account of the work of the Sonar Data Division the topics of research will be considered with respect to the organization and formulation of problems that existed during the last year or so of the Laboratory. The transfer of UCDWR from Section 6.1, NDRC, to the Bureau of Ships on 1 March 1945 formalized the research activities into a series of problems under Task 2 (see Appendix A), which are given at the head of each section. Although this subdivision of the research program was followed in reports issued after March 1945, it does not reflect the actual organization of the Laboratory, nor the relative size of groups working on different phases of the program. The reason for this difference is that the problem assignments under Task 2 were based on the types of information desired by the Bureau of Ships and not on the organization and functions necessary to produce the information and results.

The principal activities of the Sonar Data Division, as indicated by its title, have been concerned with the origin, propagation, and recognition of sound in the sea. Certain non-acoustic problems were undertaken during the early days of the Laboratory, such as those directed towards optical methods for the detection of submerged submarines. Some work was done on the detection of wakes by thermal measurements, on oceanographic factors affecting the operating behavior of submarines, and harbor defense equipment of various types. One of the desired products of the fundamental research was methods for predicting echo and listening ranges. This governed to a large degree the general character of the research program, and methods of prediction were revised as knowledge of underwater sound improved. The revision of prediction methods required the synthesis of virtually all aspects of research carried on by the Sonar Data Division. UCDWR cooperated with other activities concerned with these problems as has been described in Chapters One and Two.

During the first two-and-a-half years, only two Laboratory vessels were available on a part-time basis for the use of the Sonar Data Division, namely, the USS JASPER (PYc-13) and the E. W. SCRIPPS. As these proved inadequate, two additional vessels were assigned in February 1944 for the specific use of the program on low-frequency transmission. These vessels were the YP-267 and YAG6 (see Chapter Six, Section C, IV). With these four ships, routine and special measurements were conducted using San Diego as the base of operations. The need for exploring oceanographic conditions not encountered near San Diego made it necessary to extend operations as far north as San Francisco, as far south as the Gulf of California, and to distances of about 500 miles from the coast, as indicated in Figure 3.1. Most of the seagoing programs had as their objective the collection of data under as widely varying conditions as possible within the operating range of the vessels. The accumulation of large amounts of data led to the establishment of groups within the Division whose primary assignment was routine processing and analysis of observations. The ultimate products of the research program took the form of reports of two general types: (a) technical reports describing equipment, observations, and conclusions, and intended for distribution to cognizant naval organizations and research activities under the auspices of the Navy or NDRC; (b) official Navy publications, some intended primarily as training material, some concerned with tactical doctrine involving the use of sonar information, and others (such as the Sound-Ranging Charts and Submarine Supplements) containing information primarily of tactical interest. As the greater part of the information obtained was of a basic character and not directly related to a specific device or piece of equipment, it was considered to be of permanent value and a conscientious effort was made to lay a firm scientific foundation for the work. All observational material was obtained with the most accurate equipment available; records were made as complete as possible on all seagoing programs and have been preserved in such form that the material can be re-examined at any time for information incidental to the primary objective of the program. In addition to the mass of data in technical reports and in the files of the Laboratory, the personnel of UCDWR contributed both directly and indirectly to the preparation of the Summary Technical Reports of Division 6, NDRC, thus synthesizing the essential theory and observations which were brought to light during the work.

The results of the research program had three general applications during the life of the Laboratory: (1) basic engineering design data provided for sonar equipment developed at UCDWR or elsewhere, (2) information necessary to estimate the effectiveness of Navy sonar equipment under different operating conditions and to devise doctrine for the most efficient use of existing equipment, and (3) data from which the Navy modified tactical doctrine in subsurface warfare, both prosubmarine and antisubmarine, and various types of pertinent information valuable in strategic planning.

B. RELATION OF SONAR DATA DIVISION TO OTHER ACTIVITIES OF UCDWR

During the life of UCDWR there was increasing coordination between the Sonar Data and other Divisions of the Laboratory. The accumulation of essential information provided an increasing amount of material to those concerned with the design of sonar devices. This was particularly true in the development of SOD equipment (see Chapter Four, page 93) where simultaneous research was conducted by groups in both the Sonar Data and Sonar Devices Divisions. The Sonar Data Division was concerned primarily with factors affecting the range of detection of small objects, while the group in Sonar Devices incorporated the results of these findings in their designs. In return, the equipment developed provided the fundamental studies group with means for obtaining additional information at sea on the basic operating factors. A somewhat similar problem concerned QLA gear (see Chapter Four, page 88) where assistance was provided in establishing the factors that limit the range of mine detection and lines of development which might lead to better performance and longer ranges. The Transducer Laboratory performed an essential function in providing special types of projectors and hydrophones designed to meet the unique requirements of the research program. These requirements involved problems of design and construction beyond those usually encountered in development of equipment for use by the Navy. In addition, the Calibration Group provided necessary information on standard and specialized sound sources and hydrophones.
Assistance to the Training Aids Division was represented by material for inclusion in training manuals and instruction courses. The flow of such information increased steadily and, following the spring of 1944, was principally directed towards the com-

pletion of a series of manuals for the Bureau of Ships (see Chapter Five, page 122) dealing with the theory of underwater sound and the application of oceanographic data to Navy problems of several kinds. In addition, personnel were provided from time to time to aid in instruction programs, particularly at the U. S. Fleet Sonar School, San Diego, and to act as field engineers in connection with the surface vessel and submarine bathythermograph program.

The Engineering Division of the Laboratory provided many facilities for the Sonar Data Division; for example, the Machine Shop work for the Sonar Data Division represented about ten per cent of the output of that group and some work was required of the Electronics Laboratory. Special services were provided by the Recording Laboratory in connection with several of the programs, and the high-fidelity radio link with the experimental vessels was used in numerous ways to provide high-quality acoustic recordings. These were used particularly in the psychoacoustics program and in measurements of ships' sounds and ambient noise. The Photographic Laboratory, in addition to rendering routine services, made special provisions for developing oscillograph records, both on film and photographic paper, and for copying bathythermograms (see Figure 3.2).

The Sonar Data Division profited greatly from other groups in the Laboratory, and it was undoubtedly both efficient and economical to share common facilities and services. Without the Transducer Laboratory many of the investigations would have been virtually impossible because special transducers had to be developed which required repeated testing at sea and modification before they were satisfactory. Competition for shop time and the high priority assigned to development work was often frustrating to those in the fundamental research groups but a special piece of equipment several weeks or months late was better than no equipment at all.

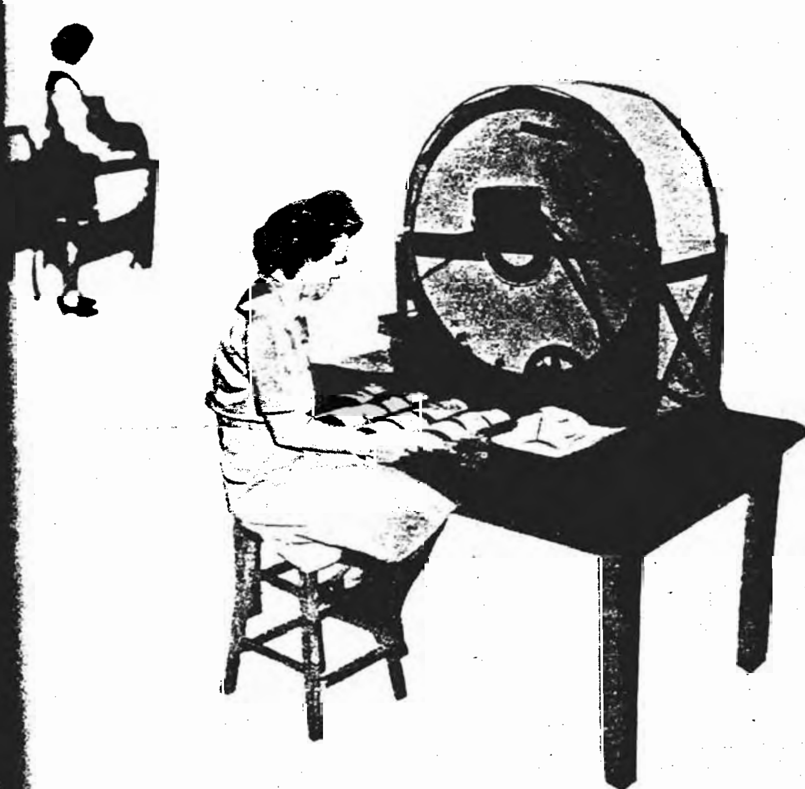


FIGURE 3.2. FACILITIES USED IN DEVELOPING AND PROCESSING BATHYTHERMOGRAPH RECORDS PRIOR TO ANALYSIS IN THE LABORATORY

C. SCOPE OF PROGRAM

The primary objective of the Sonar Data Division was to study the factors affecting the behavior of sound in the sea. As these factors are involved in more than one phase of the program, it is convenient to discuss certain characteristics of the ocean before considering their effects on sound in the ocean. It must be recognized that although tremendous advances have been made during the past four-and-one-half years, knowledge of the behavior of sound in the sea is still far from complete. The simple theories of ray acoustics, although useful guides in analysis, cannot be applied to the complex situations in the ocean. On the other hand, no comprehensive theory was developed, and as a result much of the research had to be conducted on a semi-empirical basis. This required that acoustic tests be conducted under as wide a variety of ocean conditions as possible in order to determine which factors are important and the manner in which any one of them affects the sonar problems. Experiments of this type differ in two important ways from conventional laboratory research. In the first place, the range in variables is limited to those which can be found within the operating radius of the laboratory vessels. Secondly, field studies are more difficult than those in the laboratory because it is virtually impossible to conduct tests in which only one of the independent variables is altered. This complication makes it exceedingly difficult to separate the effects of the different variables. Experiments must be carefully planned, but even then the investigation of sound in the sea necessitates the accumulation of large amounts of data and hence the progress of the work appears to be regrettably slow. The conclusion to be drawn from this is that basic research on underwater sound should be maintained as a continuing peacetime program so that action during a national emergency will not be delayed by the time lag involved in the development of research equipment, the conduct of investigations under a wide variety of oceanic conditions, and the analysis of the data.

Although pure water is an effective medium for the transmission of sound, the ocean is far from ideal. The ocean waters are inhomogeneous, and the boundaries—namely, the surface and bottom—which reflect and scatter sound, are rough. The depth of water modifies the sound field, and just as the changing aspects of the sea surface affect sound, so do the composition and the character of the sea bottom. The principal characteristics of the sea which have so far been found to affect sonar operations are:

A. Properties of the Water Column
   (1) Vertical variation of sound velocity, determined primarily by the temperature but also by changes in salinity and pressure. Gradients near the surface are most important in many applications.
   (2) Inhomogeneous character of the water: turbulent movements, air bubbles, solid particles, and plant and animal life.

B. Properties of the Sea Surface
   (1) The roughness of the sea surface, usually measured by wind force or sea state.

C. Properties of the Sea Bottom
   (1) Depth of water.
   (2) Topography of the bottom.
   (3) Composition of the bottom.

These and probably other variables have important effects on underwater sound. The difficulty of trying to disentangle these effects is obvious when it is realized that within any one variable there is a variety of conditions often hard to characterize or measure (for example, the roughness of the sea surface) and that it is virtually impossible to find conditions when only one is changing progressively.

The evaluation and prediction of listening ranges involve knowledge of four quantities (Figure 3.3):

A. The acoustic characteristics of the source of wanted sound (i.e., the target).
B. The transmission of sound of different frequencies to different ranges and depths (i.e., the sound field) and its time fluctuations.
C. The acoustic characteristics of noises at and in the sonar system (i.e., masking noise).
D. The ability of the ear or eye to detect the wanted signal in the presence of the masking noise (i.e., recognition differential).

A consideration of these four quantities shows that all are affected to a greater or lesser extent by the oceanographic conditions. (See Table 3.1.) The source of wanted sound is least affected, although the sound output of a surface vessel is modified by the state of the sea surface and by the high concentration of bubbles which surrounds the ship in a rough sea. Submerged sound sources are not affected if deep enough to be below wave action.

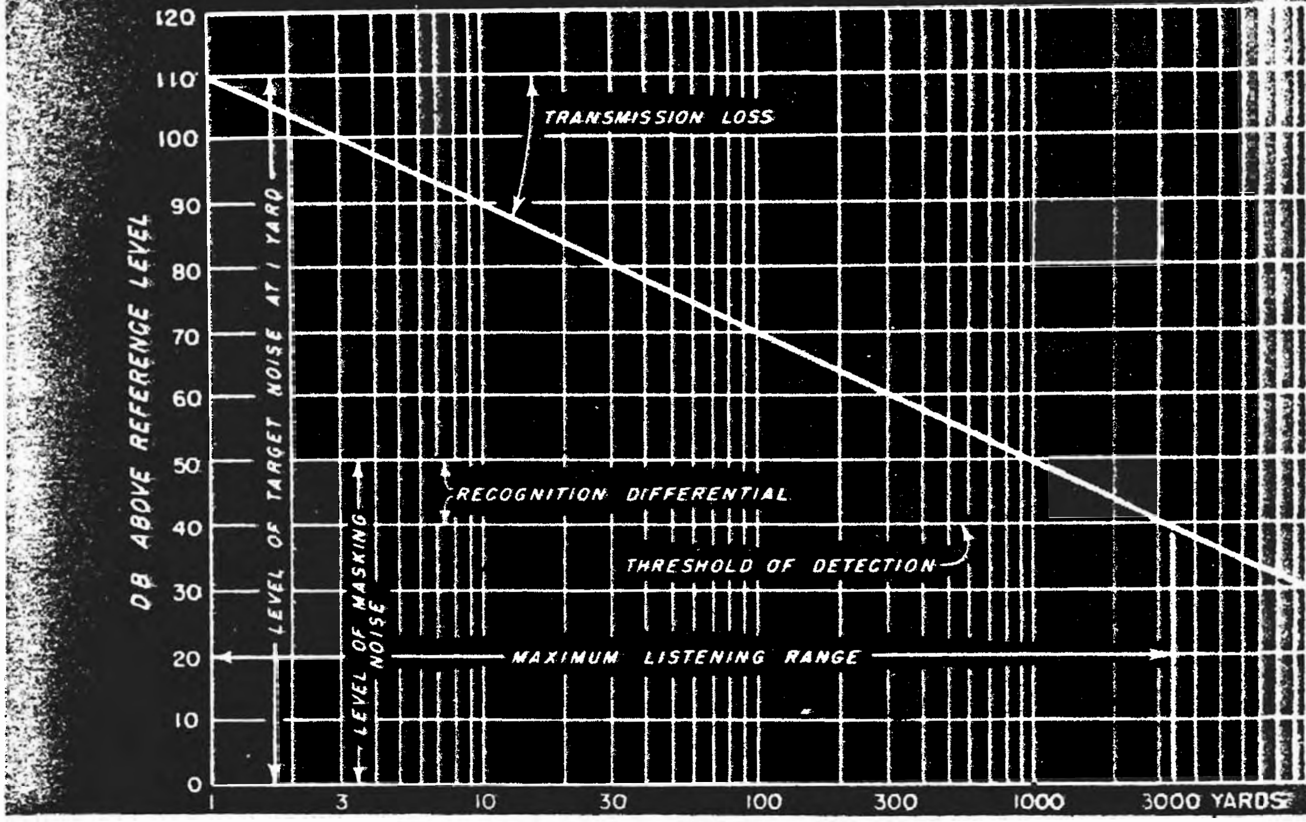


FIGURE 3.3. THE MAXIMUM LISTENING RANGE DEPENDING UPON THE NOISE OUTPUT OF TARGET, THE LEVEL OF MASKING NOISE, THE RECOGNITION DIFFERENTIAL, AND THE TRANSMISSION LOSS. IN THIS DIAGRAM THE TRANSMISSION LOSS IS ASSUMED TO BE INVERSE SQUARE. CHANGES IN ANY OF THE FOUR FACTORS WILL AFFECT THE MAXIMUM RANGE AS INDICATED BY THE INTERSECTION OF THE TRANSMISSION LOSS CURVE WITH THE THRESHOLD OF DETECTION.

The sound field is influenced by all the factors listed. Background noise is affected for one or more of the following reasons:

A. Ambient sea noise is produced by the surface waves and thus varies with sea state.

B. Biological noises are indirectly affected because the distribution of noise-making animals is determined by water depths, bottom character, temperature, and other factors.

C. The level of ambient noise may be related to the transmission conditions.

D. The self-noise of the listening vessel or installation is affected by sea state, currents, etc.

The recognition of the wanted signal is primarily a psychophysical problem and depends upon the observer as well as the type of gear employed, but the characters of both the wanted signal and back-

TABLE 3.1 OCEANOGRAPHIC FACTORS AFFECTING SONAR RANGES

OCEANOGRAPHIC FACTORS	QUANTITIES AFFECTING LISTENING AND ECHO RANGES					
	BOTH LISTENING AND ECHO RANGES				ECHO RANGES ONLY	
	SOURCE	TRANSMISSION	BACKGROUND NOISE	RECOGNITION DIFFERENTIAL	REVERBERATION	TARGET STRENGTH
A. PROPERTIES OF THE WATER COLUMN						
1. SOUND VELOCITY DISTRIBUTION	NO*	YES	YES	?	YES	NO
2. INHOMOGENEITIES	YES	YES	YES	?	YES	NO
B. PROPERTIES OF THE SEA SURFACE						
1. ROUGHNESS	YES	YES	YES	?	YES	?
C. PROPERTIES OF THE SEA BOTTOM						
1. WATER DEPTH	NO	YES	YES	?	YES	NO
2. TOPOGRAPHY	NO	YES	YES	?	YES	NO
3. COMPOSITION	NO	YES	YES	?	YES	NO

*Temperature will affect output of certain types of sound sources; for example, those containing X-cut Rochelle Salt.

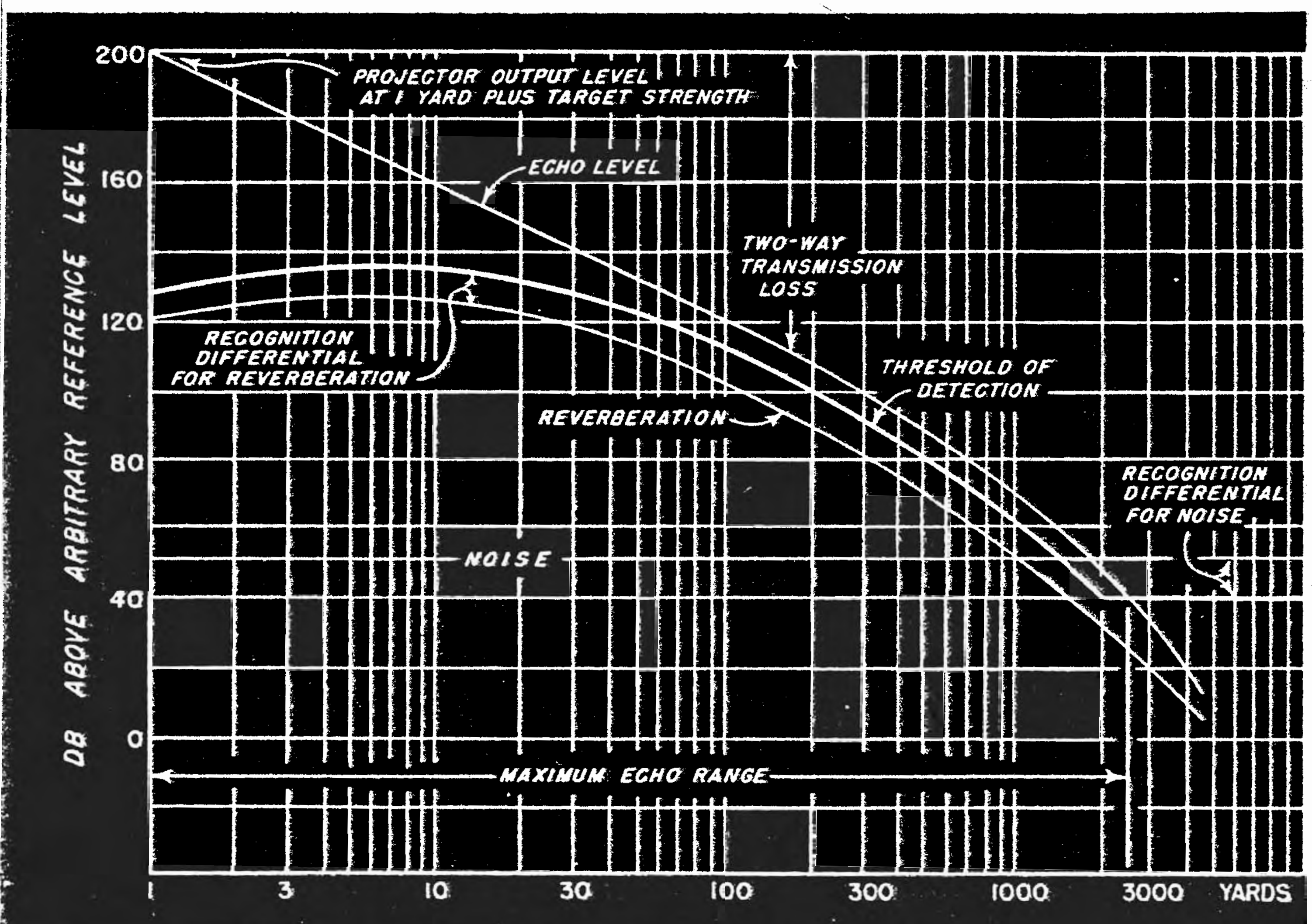
ground will be influenced by the oceanographic factors.

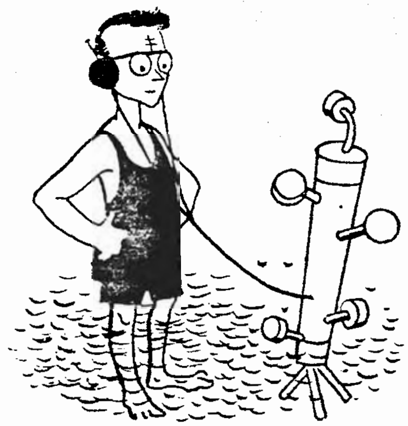
The evaluation and prediction of echo ranges are more difficult than listening ranges because two additional quantities must be known, namely, the character of the reverberation and the acoustic size or strength of the target. As will be shown later, the reverberation is made up of sound scattered from the surface and bottom as well as from the volume of the water, and is closely dependent upon the transmission conditions as well as upon the roughness of the sea surface and the depth and character of the bottom. Under any particular situation either noise or reverberation may dominate; thus noise may be higher for one part of the range, and reverberation for the other (Figure 3.4). The target strength is probably the one quantity virtually independent of the oceanographic conditions.

It was not practical, because of lack of facilities and personnel, to study simultaneously all phases of either listening or echo ranging. Instead the problems were broken down into projects roughly corresponding to the four quantities involved in listening and the six in echo ranging. Tests were then made on each of them under as wide a range of oceanographic conditions as possible.

Although the discussion thus far has dealt primarily with sonar problems, the basic research at UCDWR extended into other fields, particularly during the earlier years of the Laboratory's operation. For example, the study of the optical properties of water was actively pursued in connection with proposed methods for submarine detection and the development of underwater cameras. A number of harbor surveys were made in cooperation with NEL and USNUSL in which oceanographic factors affecting magnetic loops as well as acoustic detection devices were studied. The thermal detection of wakes received some attention and also the diving behavior of submarines, although these problems were primarily the responsibility of NEL and WHOI, respectively.

FIGURE 3.4. THE MAXIMUM ECHO RANGE DEPENDING ON PROJECTOR OUTPUT, TARGET STRENGTH, TRANSMISSION LOSS, NOISE, REVERBERATION, AND RECOGNITION DIFFERENTIAL FOR NOISE AND REVERBERATION. IN THIS FIGURE THE TRANSMISSION LOSS IS ASSUMED TO BE INVERSE SQUARE PLUS AN ATTENUATION OF FIVE DB PER 1000 YARDS.





D. RESEARCH PROGRAM

I. studies of the medium

(See File Nos. 01.331, 01.40, 01.60, 01.911, 01.913, 01.93, 01.94, 01.95, 03.30, 21.00)

Oceanographic investigations fell into two categories: first, those directly related to and taken simultaneously with the acoustic measurements, and second, those collected independently. The first set of data were used to establish the relationships between the acoustic properties and the temperature distribution, sea state, etc. The second type were largely bathythermograph observations, accumulated by U. S. Navy surface vessels and submarines, and material available in the literature; they provided a means of estimating the most probable conditions to be expected in prospective operating areas and formed the basis of the Sonar Charts, Bottom Sediment Charts, and Submarine Supplements (see pages 38-39).

Initially, the Oceanographic Section was responsible for both phases of the work, but as the methods were standardized, the personnel collecting acoustic data also made the necessary oceanographic and meteorological observations. Generally these involved measurements of temperature by means of a bathythermograph, estimates of wind force and sea state, bottom depth by echo sounding, and bottom sampling by means of a snapper or other type of sampler (Figure 3.5).

Submersible cameras developed at WHOI were used extensively in establishing the character of the bottom in shallow water. This technique, not available prior to 1941, proved extremely useful in the study of rock bottom, which cannot be ade-

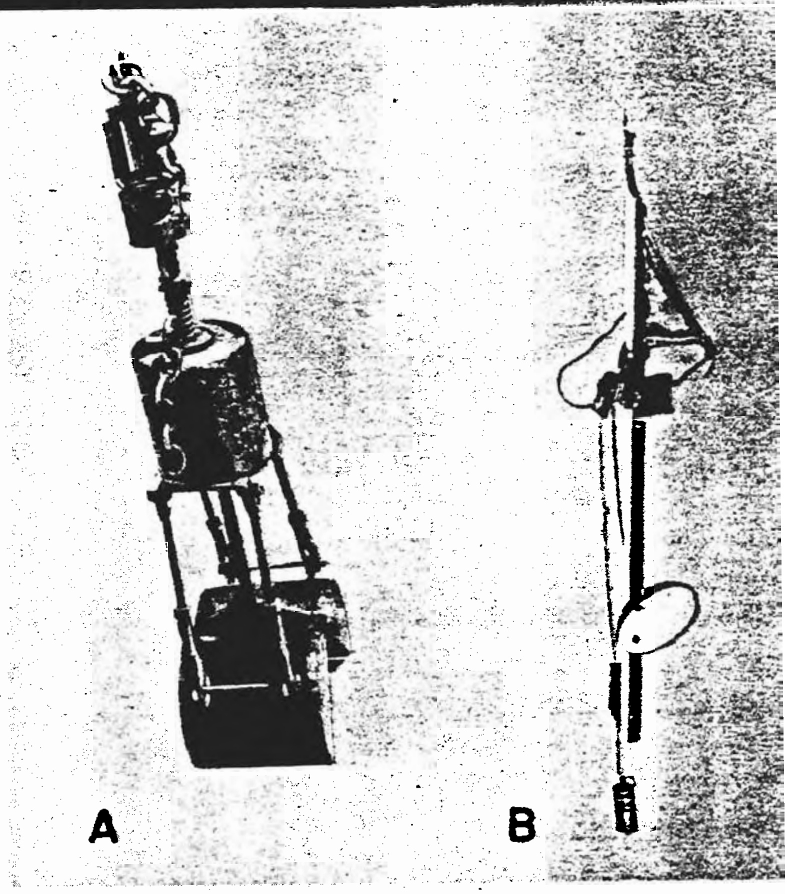
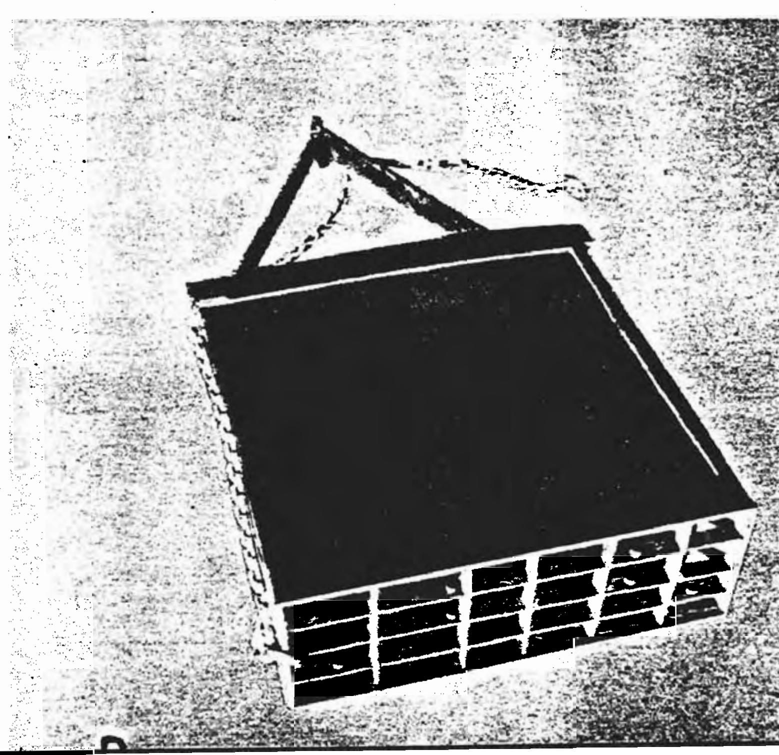


FIGURE 3.5 TYPES OF OCEANOGRAPHIC EQUIPMENT USED FOR THE STUDY OF THE SEA:
(A) LARGE SNAPPER FOR COLLECTING BOTTOM SAMPLES.
(B) UNDERWATER CAMERA AND FLASHBULB FOR PHOTOGRAPHING SEA BOTTOM.

(C) BATHYTHERMOGRAPH FOR MEASURING TEMPERATURES AT DEPTHS.
(D) METAL DREDGE FOR COLLECTION OF ROCK SPECIMENS FROM SEA BOTTOM.



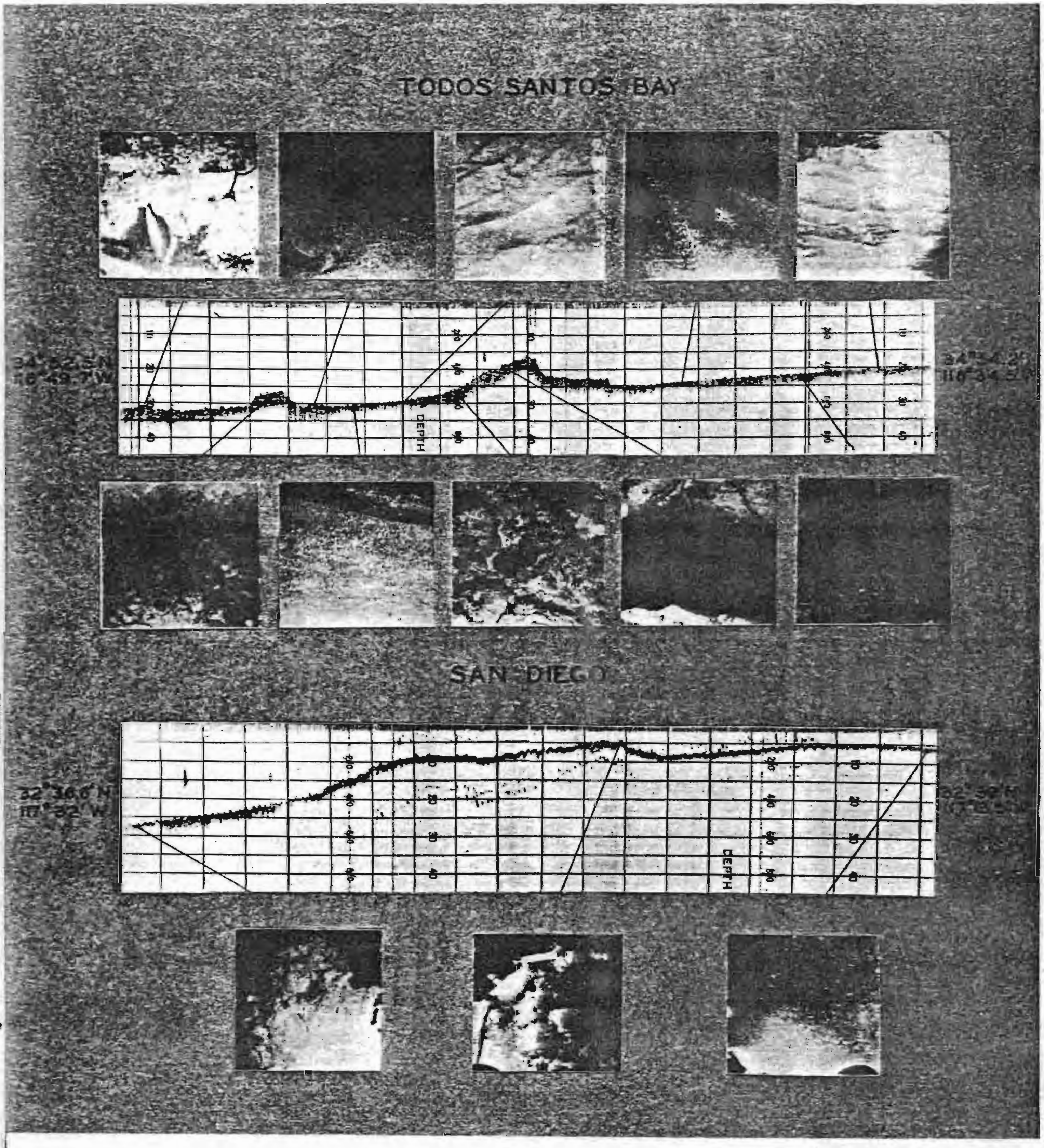


FIGURE 3.6.
THE RELATION OF BOTTOM CHARACTER AND BOTTOM TOPOGRAPHY SHOWN BY FATHOGRAMS, BOTTOM PHOTOGRAPHS, AND THE EXAMINATION OF BOTTOM SEDIMENTS IN THE LABORATORY.

quately sampled with any existing device. Bottom photographs also made it possible to examine the microtopography of the bottom, and particularly to establish the presence and form of ripples occurring in certain areas where there are strong currents. (Figure 3.6.)

Because of their permanent character, depths and bottom type could be studied independently of the acoustic tests. Surveys were conducted in many areas within about 500 miles of San Diego to find regions with suitable depths and sufficiently uniform bottom types. Restrictions on ship movements during 1942 and 1943 meant that most of the field work had to be done close to San Diego and hence severely limited the choice of conditions. However, increased traffic made the local waters undesirable for acoustic experiments and during 1944 and 1945 less and less of the work was done close to San Diego. This applies particularly to observations in shallow water. Contour maps showing bottom character have been prepared for all the areas of Laboratory operations.

Although apparently far removed from sonar problems, marine biology was called upon to assist in the program. Animals, such as certain fish and shrimps living in shallow water, were found to produce sound of sufficient intensity to interfere with listening and echo ranging. Once the noise-producers were identified, it was possible to predict the existence of such noise in other areas (see page 24). Other strange sounds are believed to be of animal origin, probably produced by whales, porpoises, and fish, although their identity has not been established. "Non-sub" echoes, received from whales and schools of fish in certain areas of the ocean, have proved a considerable nuisance to ASW forces, their classification as non-submarine consuming both time and depth charges. The deep scattering layer (see page 29) is thought to be of a depth-concentration of small animals. Many such problems are yet to be solved and marine biology will play an important part in continued research.

Most of the temperature studies were made with bathythermographs, some of them specially modified for greater sensitivity in response to temperature or depth. The important role of the temperature distribution in controlling the sound field stimulated research into means for obtaining additional or more detailed data and into the factors influencing the distribution of temperature. Various attempts to develop a rapid-response thermometer which would detect small thermal inhomogeneities met with only partial success. Because of their effects upon local temperature fluctuations and their importance in submarine operations, internal waves were investigated. Internal waves occur at depths where there are large changes in temperature and produce periodic vertical movements of the thermal gradient. Special recording thermocouples were developed to measure the character of internal waves having periods as short as a few minutes.

The immense amount of data collected by naval vessels as well as that accumulated by the Laboratory was used in studies of the geographic, seasonal, and diurnal variations of temperature gradients near the surface. The studies were of value in the preparation of the Sonar Charts and in estimating the relative importance of different types of temperature conditions in areas where the Fleet was operating. It was possible to show the relative importance of solar heating, evaporation and cooling, and the effects of wind mixing, and from this to develop rule-of-thumb procedures by which the progressive change in sound conditions could be estimated.

Besides the study and analysis of conditions in the Laboratory's operating areas, investigations were made in other locations, particularly in connection with the harbor defense surveys conducted in co-operation with NEL. For these surveys, field parties were sent to San Pedro and San Francisco on several occasions, to two localities in the Puget Sound area, and to three localities in the 14th Naval District (Pearl Harbor, Kaneohe, and Midway). Similar work in cooperation with USNUSL and CUDWR at New London was done on the East Coast of the United States at New York and Block Island. The harbor surveys included topographic charting, bottom sampling, studies of the currents, and temperature and salinity measurements, as well as studies of ambient noise and sound transmission. Recommendations were made concerning the optimum disposition of detection devices as well as estimates of the effective ranges to be expected. The Sonar Data Division contributed to an official Navy publication on this subject, namely, "Herald Ranges," NavShips 900,070, March 1945.

Bottom Sediment Charts were made for a number of areas not visited by the Laboratory. The biggest of these undertakings involved the preparation of material for the Western Pacific area. In all, 44 charts were prepared and submitted to the Hydro-

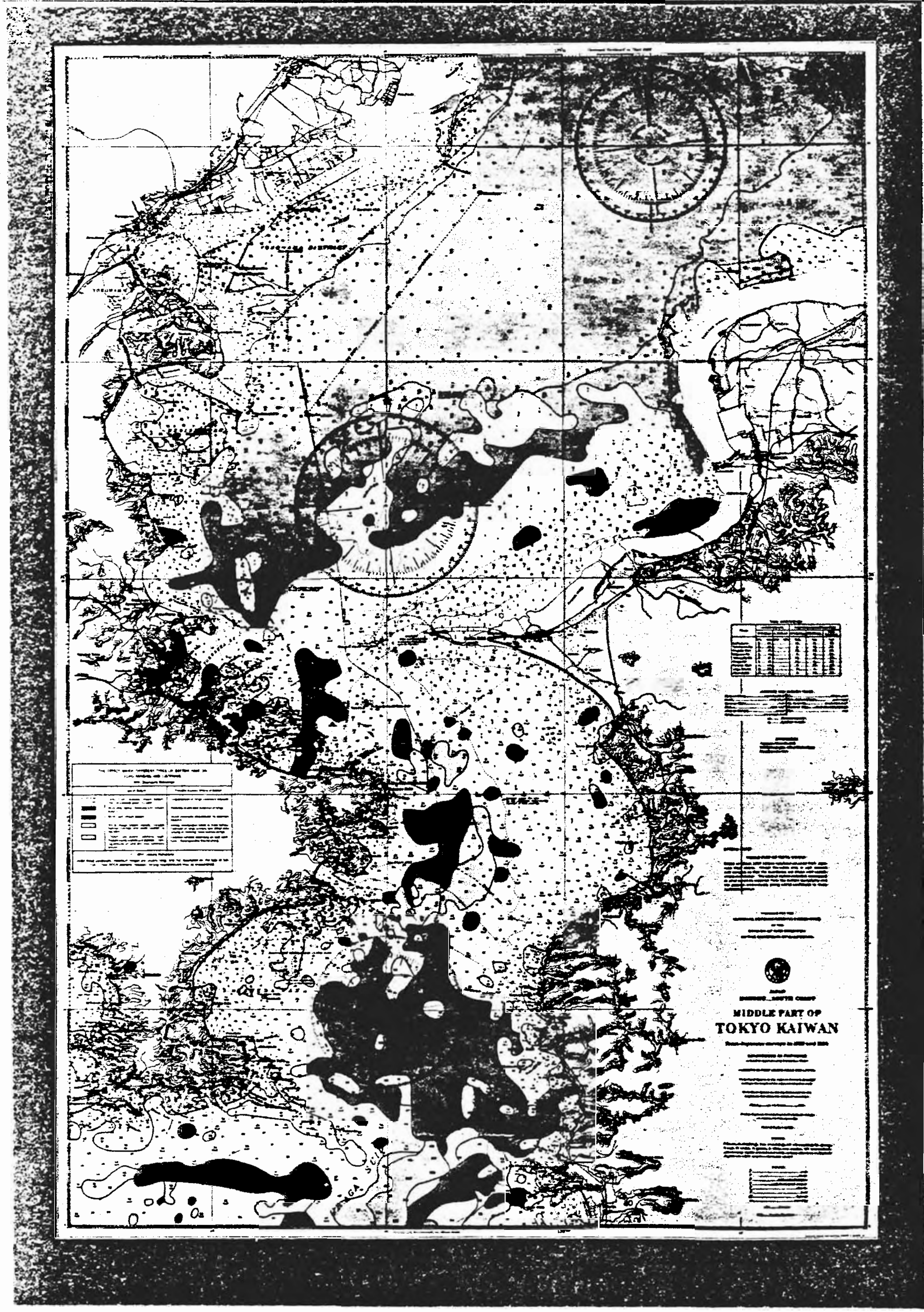
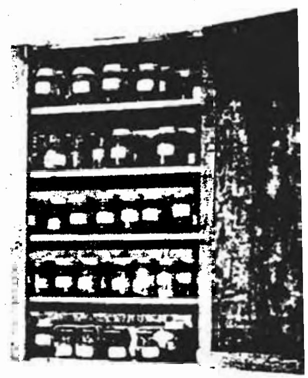


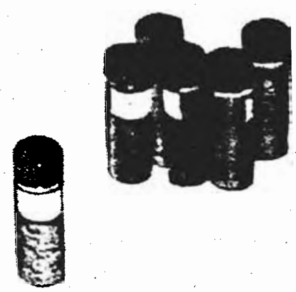
FIGURE 3.7.

EXAMPLE OF BOTTOM SEDIMENT CHARTS OF FOREIGN AREAS FOR PUBLICATION BY THE HYDROGRAPHIC OFFICE BASED UPON STUDIES MADE AT UCDWR. AREAS FOR WHICH CHARTS WERE PUBLISHED ARE SHOWN IN FIGURE 3.20.

graphic Office for publication, and 39 of these were printed and distributed to the Fleet. As these charts were of principal use to the submarine forces, later material was rushed to the Commander, Submarines, Pacific Fleet, in manuscript form. The charts of foreign areas were based almost entirely upon the notations found on the most detailed charts published by foreign governments. In addition, manuscript material was provided by the British Admiralty, and, in domestic waters, by the U. S. Coast and Geodetic Survey. Although based on geological data, the Bottom Sediment Charts showed by colors those parts of the shallow bottom believed to have similar acoustic properties (Figure 3.7). As similar work was carried out at WHOI, close contact was maintained between the two activities so that the finished products would be directly comparable. Material from the published charts and from additional areas was included in the Submarine Supplements and was also used in contributions to JANIS reports prepared by the Hydrographic Office.



During 1944 and 1945, one of the relatively large activities was the processing and analysis of bathythermograms collected by U. S. Navy surface vessels and submarines. Prior to 1 January 1946, over 50,000 observations by surface vessels and over 20,000 records from submarines were received from the Pacific and Indian Oceans. This was source material for the Sonar Charts and Submarine Supplements and was also used for a number of other purposes. The greatest amount of effort was consumed by the routine processing of the data, namely, plotting locations, making photographic copies of the bathythermograms, and transcribing supplementary information. Never before had such a mass of data on temperature distribution been collected, and besides its wartime use, it forms an invaluable reservoir for oceanographic research. To insure safety of the material and make it readily accessible, copies of the photographic reproductions were provided to the Hydrographic Office and Scripps Institution of Oceanography.



It is obvious that future developments of our understanding of sound in the sea must depend to a large extent upon increased knowledge of the oceanographic conditions and their geographic distribution. More refined methods of measurement are necessary and must be used in conjunction with acoustic tests and later extended to distant areas of the sea to permit extrapolation of acoustic conditions into all parts of the oceans.

II. studies of sound transmission

(See File Nos. 01.31, 01.71, 01.72, 01.73, 01.74, 01.75, 01.76)

The problem of transmission involves the measurement of the sound field of any source as a function of the oceanographic conditions. If the source of sound is a ship, this involves a spectrum analysis as a function of range and depth of the hydrophone. If, in addition, the source can vary in depth (as with a submarine), this effect must also be evaluated. The time variations must also be considered; for example, a single pulse emitted from the source may arrive by different paths and appear as a series of discrete or interfering pulses. Even if a steady tone of constant intensity is emitted, the observed sound fluctuates in intensity, and such fluctuation is one of the characteristics studied. Sound transmission measurements were made using the following as sound sources: ship and screw sounds, various types of noisemakers developed for mine sweeping, explosives, standard echo-ranging projectors, and especially constructed transducers emitting one or more frequencies. During the progress of the work, the experimental program depended on special transducers to a greater and greater extent.

Simple theories, neglecting refraction and the irregular character of the surface and bottom, suggest that the sound field can be predicted from the geometric divergence and an attenuation coefficient that depends only upon the frequency. The lack of adequate data stimulated a program designed to evaluate the attenuation for frequencies between 0.1 and 100 kc, which was first undertaken in the shallow waters of San Diego Bay. Because of the unknown effects of the surface and bottom, the program was extended to deeper water using vertical beams and measuring the intensity of the bottom-echo received in different depths of water. Although generally substantiating the earlier results, the data were not as accurate as might have been desired. The greater importance of other factors led to the abandonment of this program.

Interest in the possibilities of detecting submarine echoes from explosions led to the study of the transmission of explosive pulses created by blasting caps. Although this program did not prove the feasibility of explosive echo ranging, it did provide a valuable tool for studying the effects of refraction and bottom and surface reflections. The value of explosions as sound sources lies in the very short duration of the pressure pulse and the ease with which charges can be exploded at different depths (Figure 3.8). Another source of information on sound transmission was the harbor surveys. Although the sound sources were unreliable, data were accumulated for a variety of conditions, almost all in shallow water. The results obtained from this program work were suggestive rather than conclusive, but from them plans for future work were developed.

It was not until the spring of 1943 that a determined effort was made to obtain adequate information on sound transmission. In March 1943, BuShips requested UCDWR to assist NEL in a program of study of the sound field of echo-ranging gear. Initially, studies were largely of 24 kc sound, but some work was done at 14 kc and at 56 or 60 kc. The USS JASPER normally served as source vessel, making runs away from and towards the E. W. SCRIPPS, which acted as receiving vessel, with two or sometimes three hydrophones lowered to different depths. This program collected data for over two years and measurements were made in both deep and shallow water under a wide variety of oceanographic conditions. Some of the results are summarized below.

In deep water, where bottom reflections can be disregarded, the transmission of horizontal beams of supersonic sound depends chiefly upon the temperature distribution in the surface layers. When the temperature decreases sharply in the first 30 feet, the transmission is very poor, whereas if the water is well mixed and of uniform temperature, the transmission is best as shown in Figure 3.9. The effects of the temperature distribution are roughly independent of the frequency, but an attenuation constant which increases with frequency cuts down the transmission at higher frequencies. When there is a sharp temperature gradient underlying an isothermal layer, the transmission to a hydrophone

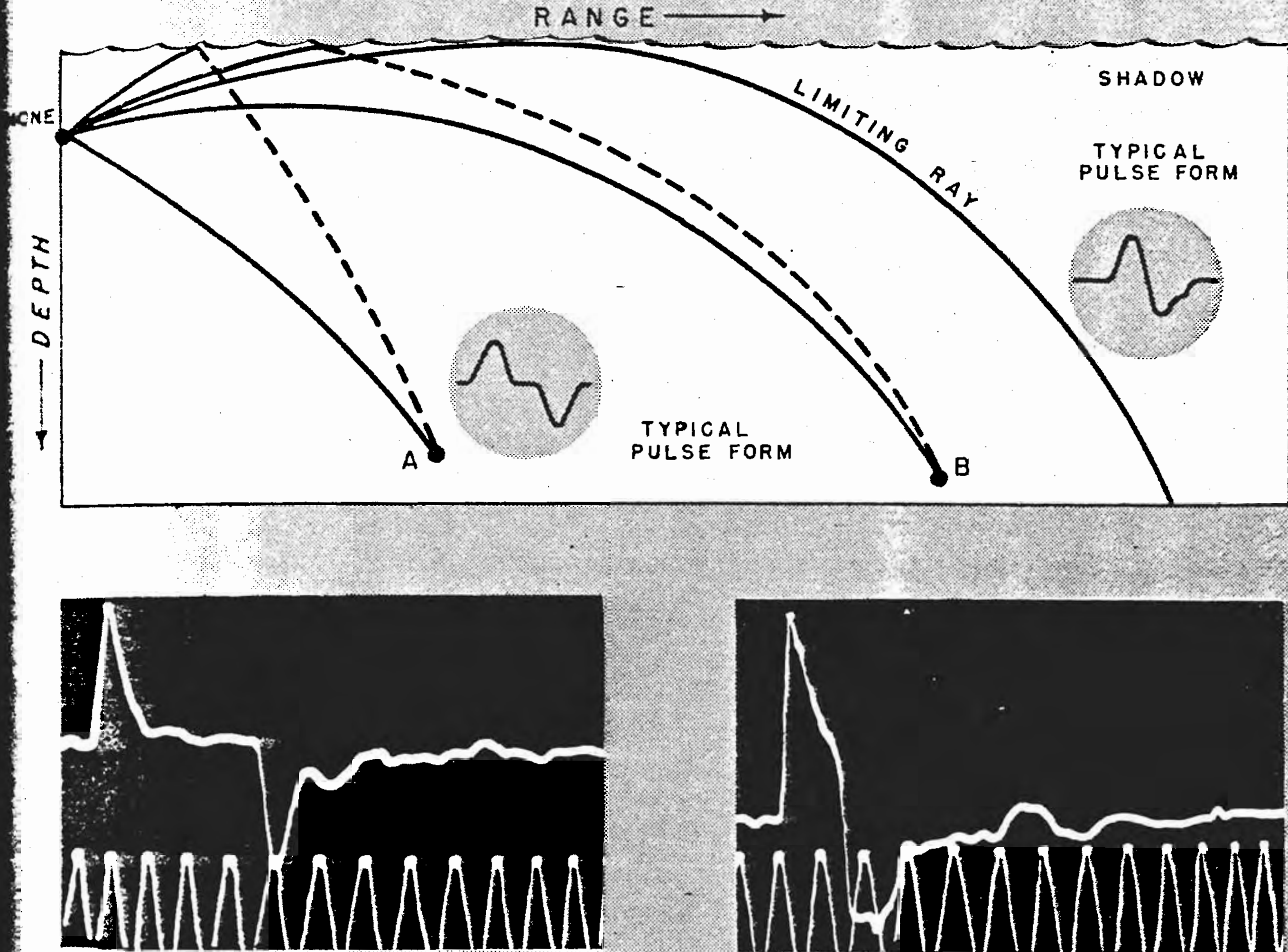
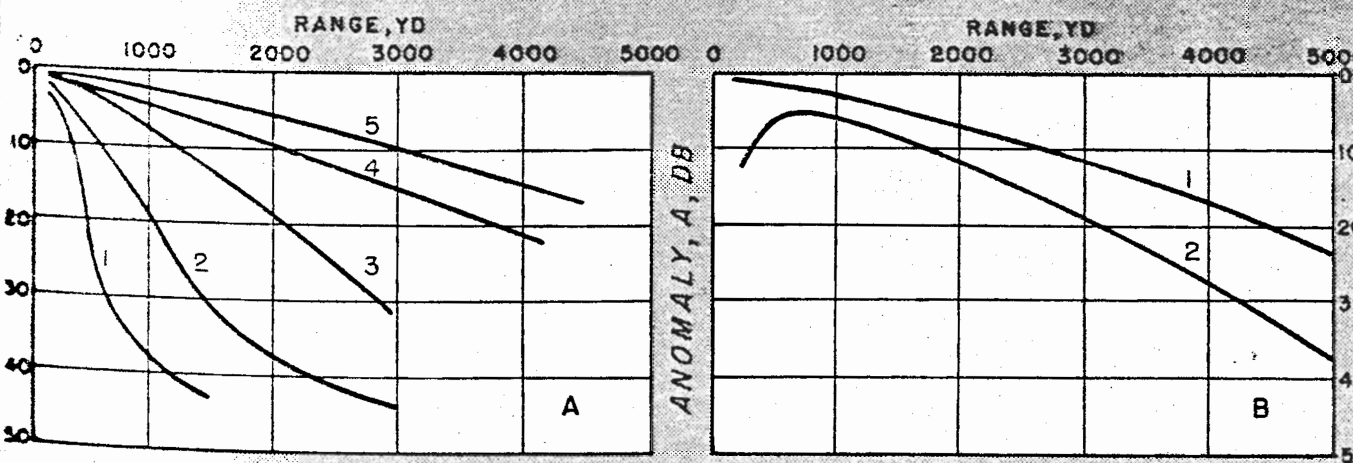


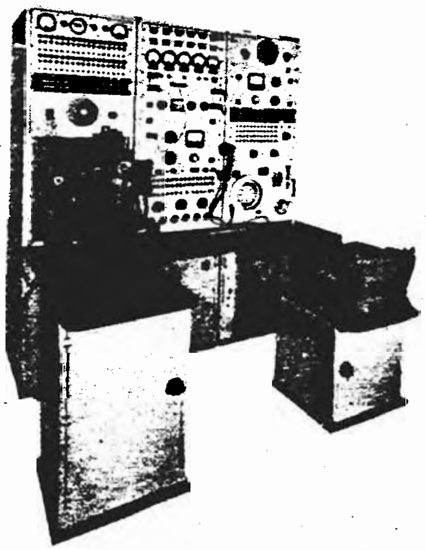
FIGURE 3.8.

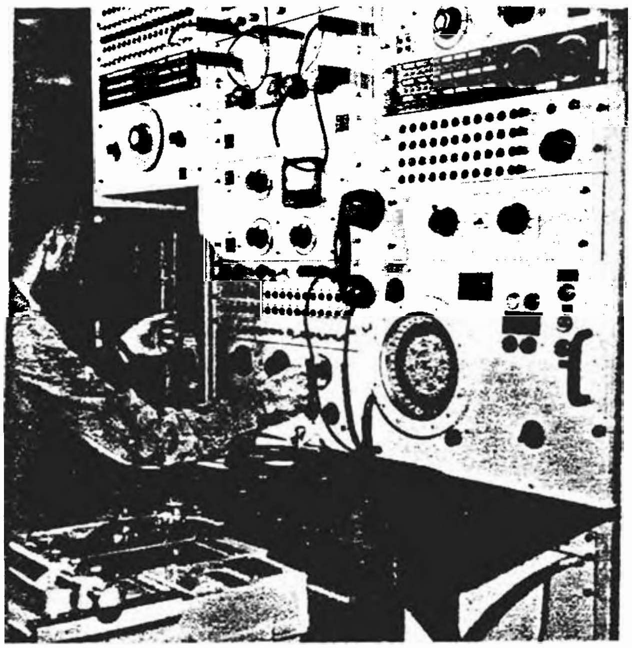
OSCILLOGRAMS OF IMPULSES FROM ELECTRIC BLASTING CAPS FIRED AT THE DEPTHS INDICATED IN A RANGE OF 1100 YARDS AND RECEIVED ON A HYDROPHONE AT A DEPTH OF 11 FEET. UPWARD DEFLECTIONS INDICATE THE DIRECT SOUND AND DOWNWARD DEFLECTIONS THE SURFACE DEFLECTED PULSES. THE DIAGRAM INDICATES HOW THE SIGNALS VARIED AT DIFFERENT RANGES.

FIGURE 3.9.

FIGURE (A) SHOWS THE TRANSMISSION ANOMALY FOR 24 KC SOUND TRANSMITTED AND RECEIVED NEAR THE SURFACE FOR A VARIETY OF TEMPERATURE CONDITIONS. CURVE 5 REPRESENTS VERY GOOD OCEANIC CONDITIONS AND CURVE 1 STRONG NEGATIVE GRADIENTS NEAR THE SURFACE. FIGURE (B) SHOWS EFFECT OF VARYING HYDROPHONE DEPTH.







beneath the layer is poorer than in the mixed surface layer. This "layer effect" reduces the range at which a deeply submerged submarine can be detected and is now a part of ASW doctrine and a standard item considered in planning submarine evasive tactics. Rough seas have been shown to have an adverse effect upon transmission. In shallow water the problem is more complicated because of the bottom reflections, and both water depth and bottom type must be taken into account, as well as temperature distribution and sea state. As a general rule, transmission becomes poorer as the temperature gradients and sea state increase. Transmission improves with bottom types in the following order: mud, sand and mud, rock, sand. The relation between water depth and transmission is a complicated one, which also involves the temperature conditions. Under certain conditions the sound intensity will decrease smoothly with range, and in others "skip-distances" (regions in which the intensity is lower than at longer ranges) will occur. See Figure 3.10.

The fact that a variety of oceanographic conditions of operational importance could not be explored near San Diego led to the assignment by NDRC of a similar project on high-frequency transmission to WHOI. During the summer of 1944, a duplicate set of measuring equipment was constructed and turned over to the group on the East Coast so that confirmatory as well as unique data could be obtained without instrumental uncertainties.

The initial results of the high-frequency transmission program were so encouraging that in October 1943 it was agreed that similar study should be made of sonic frequencies. As no equipment existed for this program, approximately one year elapsed before two vessels, the YP-267 (source) and YAG6 (receiving ship), could be outfitted to make simultaneous measurements at 0.2, 0.6, 1.8, 7.5, and 22.5 kc. This second program produced abundant data during 1945 and provided the first reliable information on a number of points.

The same set of oceanographic factors as mentioned in the discussion of high-frequency transmission was found to be important. However, it was possible to measure sonic frequencies to much greater ranges; even in 2000 fathoms of water, the bottom reflected sound was strong, first, because of the small attenuation, and second, because of the nondirectivity of the sources. At lower frequencies there

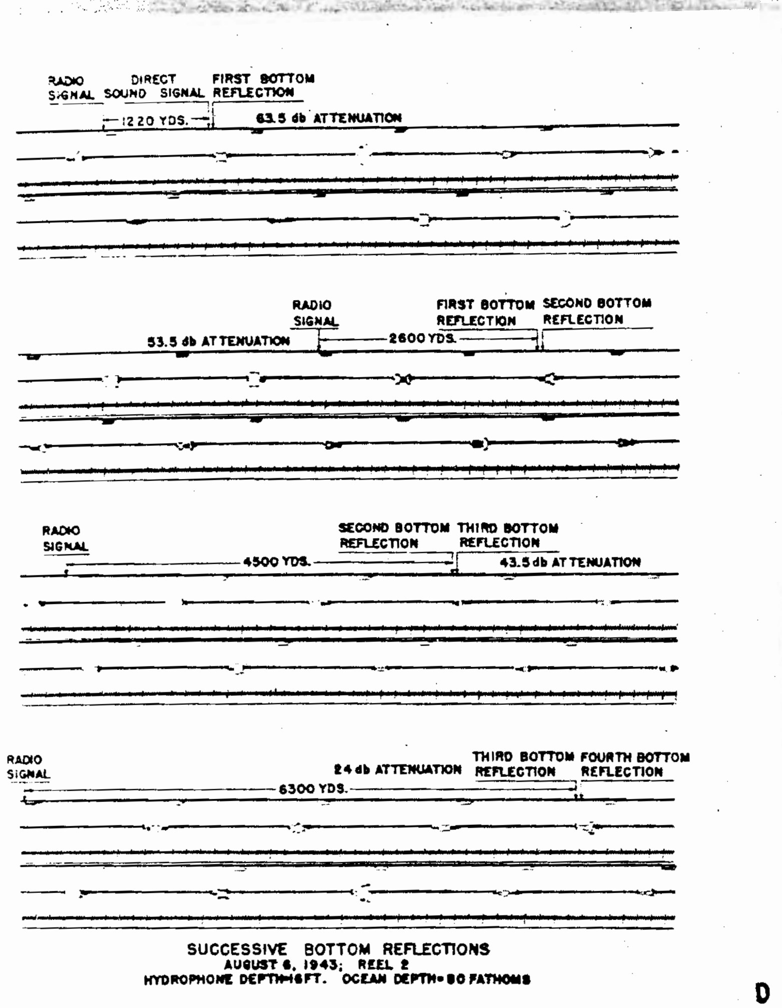
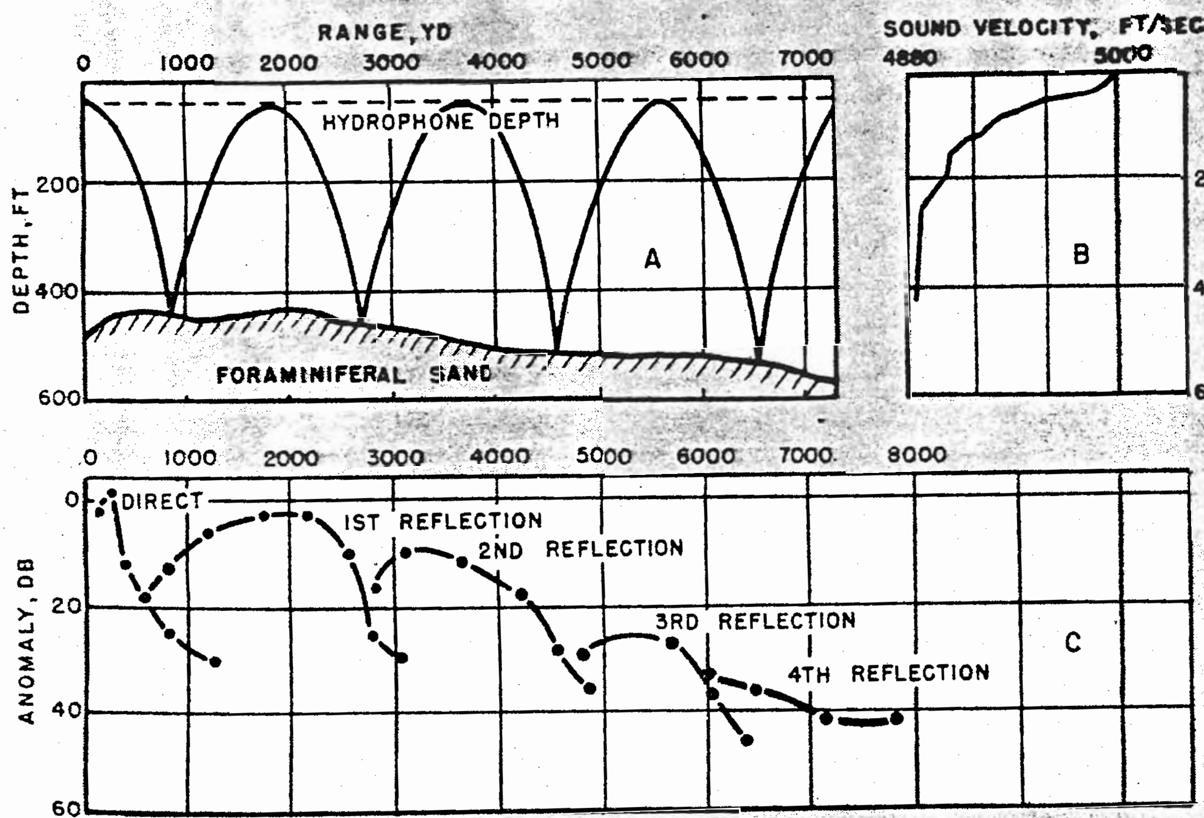


FIGURE 3.10.

(A) THE SCHEMATIC DIAGRAM SHOWING THE REFRACTION OF SOUND AND MULTIPLE REFLECTION FOR THE BOTTOM FOR THE TEMPERATURE CONDITIONS SHOWN IN (B).

(C) THE TRANSMISSION ANOMALY FOR 24 KC SOUND OBSERVED UNDER THE CONDITIONS INDICATED ABOVE.

(D) SAMPLE SECTION OF OSCILLOGRAMS OBTAINED UNDER CONDITIONS DESCRIBED ABOVE SHOWING THE COMPLEX CHARACTER OF THE TRANSMITTED SIGNALS AT DIFFERENT RANGES.



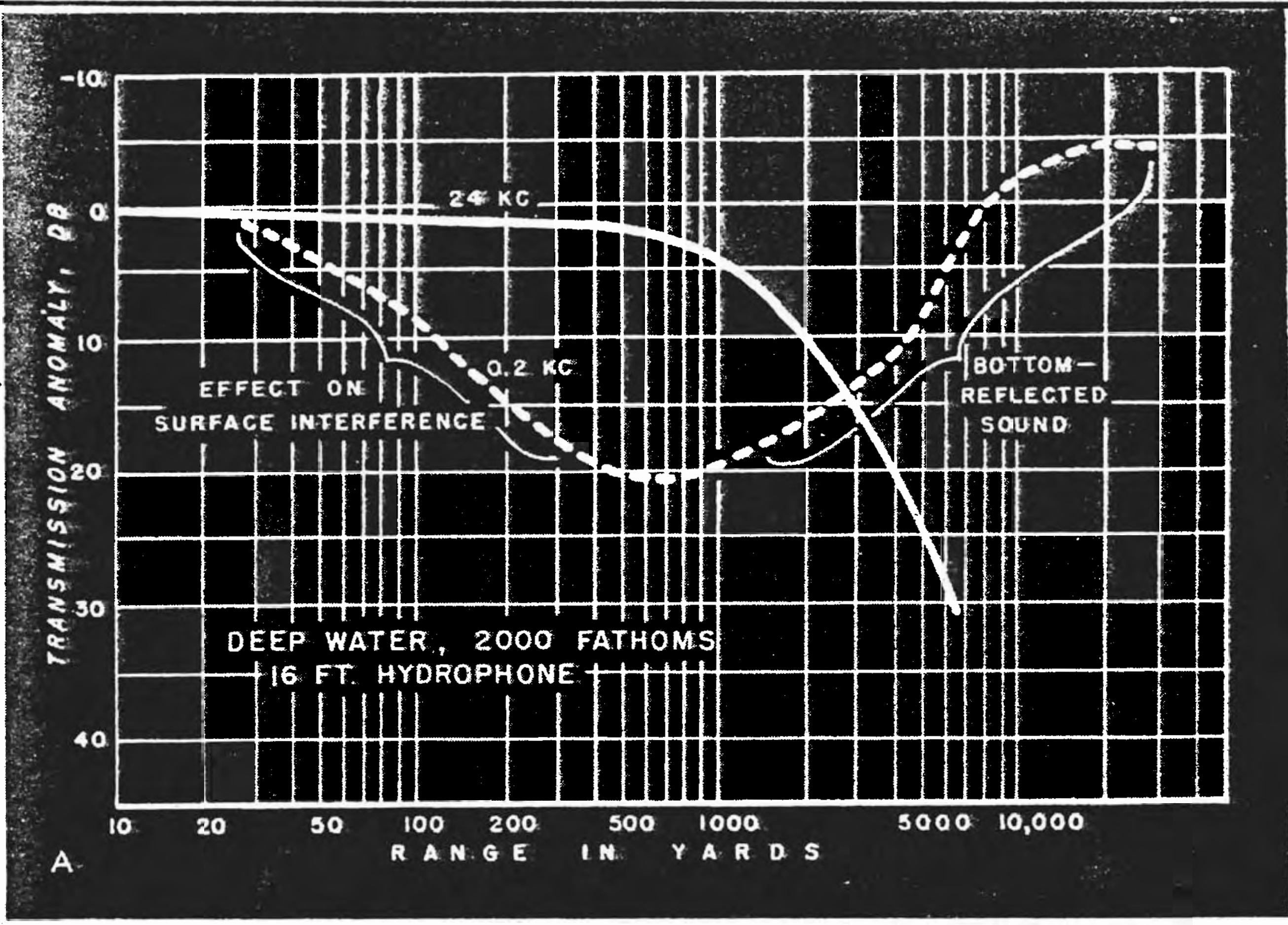
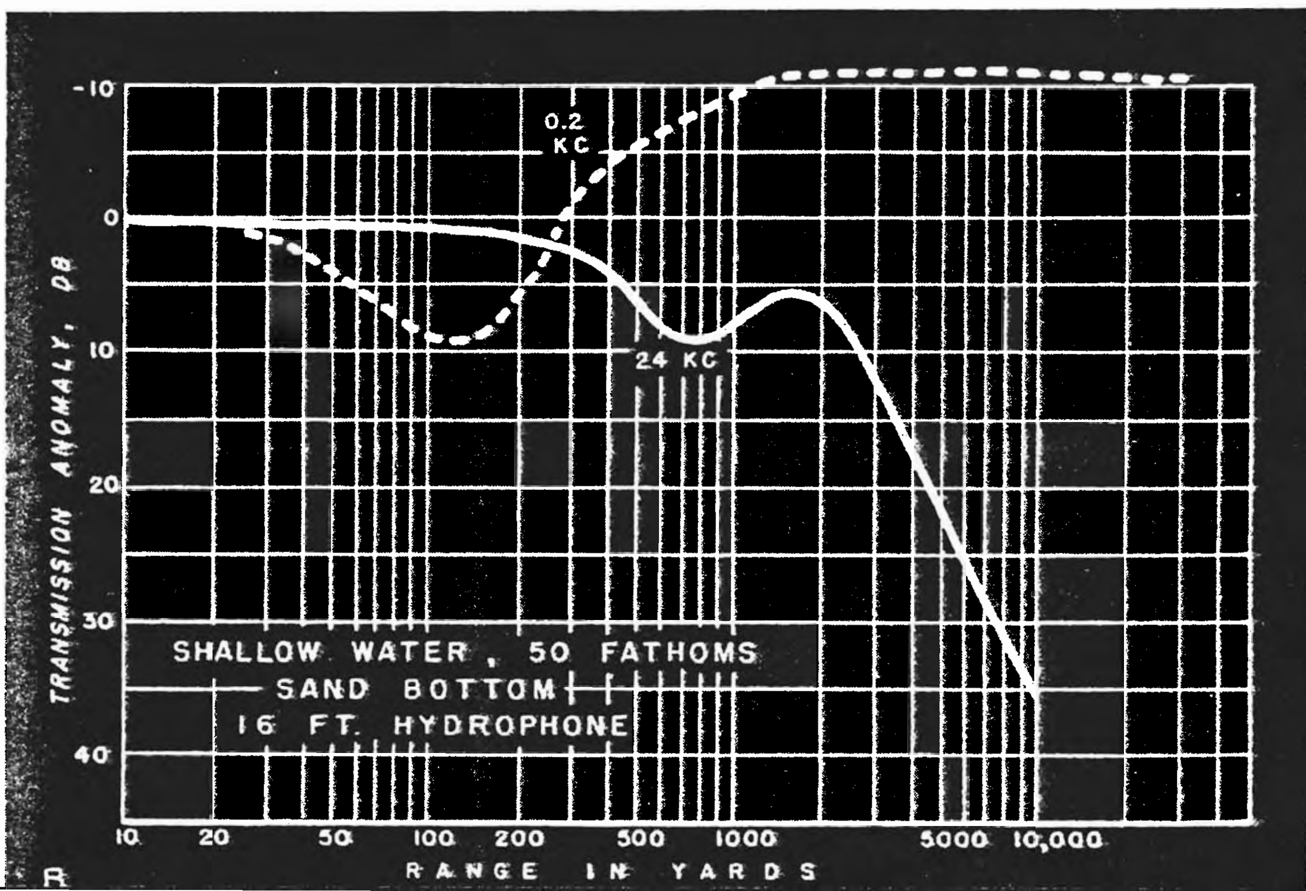


FIGURE 3.11.

(A) COMPARISON OF TRANSMISSION ANOMALIES FOR 24 KC AND 0.2 KC SOUNDS IN DEEP WATER. THE TRANSMISSION OF LOW FREQUENCY SOUND AT MODERATE RANGES IS POORER ON ACCOUNT OF SURFACE INTERFERENCE; GOOD AT LONG RANGES BECAUSE OF THE PRESENCE OF BOTTOM REFLECTED SOUND. AT 24 KC THERE IS NO INDICATION OF BOTTOM REFLECTED SOUND BECAUSE OF THE DIRECTIONAL TRANSDUCER USED AS A SOUND SOURCE, AND DECREASES AT LONGER RANGES ARE DUE TO ABSORPTION.

(B) TRANSMISSION ANOMALIES FOR 24 KC AND 0.2 KC IN SHALLOW WATER OVER A SAND BOTTOM. THE RISE IN LEVEL WITH INCREASING RANGE IS DUE TO THE PRESENCE OF BOTTOM REFLECTED SOUND BUT AT 24 KC ABSORPTION LOSS REDUCES THE LEVEL OF 24 KC SOUND.



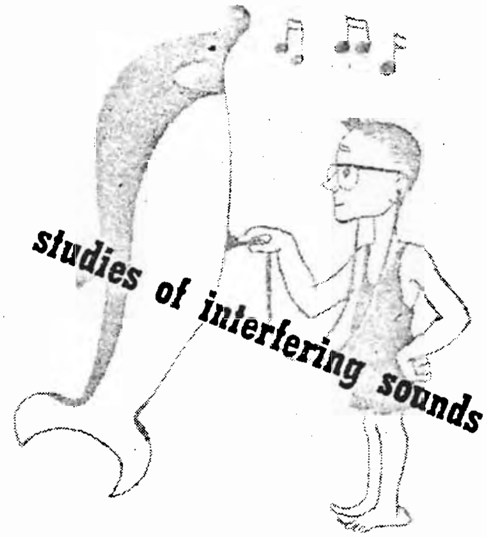
is interference between the sound arriving by different paths, particularly between the direct sound and that reflected once by the surface. This Lloyd Mirror or image-interference effect tends to cut down the intensity at intermediate ranges, and at short ranges it causes irregular changes in intensity. Because of bottom-reflected sound it was sometimes possible to transmit 0.2 kc and 0.6 kc sound successfully to more than 60,000 yards in deep water and to somewhat greater ranges in shallow water over sand bottom. A better understanding of low-frequency transmission may indicate ways of increasing the range of detection of enemy vessels. It was found that the effects of temperature conditions on the direct sound were similar to those for the higher frequencies, except that the change of intensity with range was increased by the image interference, as shown in Figure 3.11.

This section has dealt with the transmission of sound without regard to the character of the source. Actually, detailed information on the spectrum level and time modulation of the source is essential, whether it be a ship or a supersonic transducer, because such information is required for the interpretation of the transmission measurements and for predicting listening or echo ranges. Consequently a great deal of information of this type was accumulated during the course of the programs. Directivity, power output, and frequency characteristics were measured with the cooperation of the Calibration Group of the Laboratory, and detailed information was obtained on a number of surface vessels and submarines. Some of this information was secured incidentally to the program, and on other occasions it was the specific purpose of the measurements, as in cases of noise measurements on submarines. During 1944 a bottom-mounted hydrophone was set up in the entrance to San Diego Harbor to obtain high-fidelity recordings of the noise characteristics of different kinds of vessels as well as to detect those which were unusually noisy. It is difficult to decide whether the source or the transmission was the primary subject in certain types of measurements, because the two problems are interdependent and because at sea it is impossible to make tests at a standard reference distance from the source. Numerous experiments were therefore made at short ranges to establish the laws by which measurements could be adjusted to a standard distance. One of the striking features found was that the image interference made the exact measurement of low-frequency sounds very difficult.

The study of sound transmission at UCDWR provided the first reliable set of information on this problem at frequencies between 0.2 kc and 60 kc, but the study remained far from complete. Only the broad outlines are known, and much remains to be done to gain complete understanding of the way in which the various factors affect the sound field.

The knowledge gained during the investigations has proved invaluable in predicting listening and echo ranges and in a number of different operational and engineering-design problems.

III. studies of interfering sounds



I. background noise

(See File Nos. 01.31, 01.331, 01.332)

With echo ranging or listening there is always some unwanted noise or sound above which the echo or wanted signal must be detected. The higher the level of the interfering sound, the shorter the range of detection. In listening, the unwanted sounds are referred to as background noise; and in echo ranging, reverberation as well as background noise must be considered. The nature of the background presented to the operator is in part determined by the characteristics of the sound equipment and the means of presentation (e.g., sonic vs. supersonic, aural vs. chemical recorder); and, if aural preception is used, the air-borne noise in the sonar hut may be troublesome.

As a general rule, background noise can be subdivided into three general categories:

- A. Ambient Noise
  - (1) Sea noise
  - (2) Biological noise
  - (3) Traffic noise
- B. Self-Noise
  - (1) Hydrophone motion
  - (2) Noise from own ship
  - (3) Circuit noise
- C. Air-Borne Noise
  - (1) Other sonar gear
  - (2) Speech
  - (3) Gunfire

It is apparent that both categories A and B pass through at least part of the sonar gear and can therefore be grouped together as amplified noise. Increasing the gain of the sonar system will not improve detection against either ambient or self-noise, because they too are raised in output level.

Ambient noise can be treated as independent of self-noise, hence does not involve specific types of equipment nor the actual operation of the listening vessel or station. It is in this field that UCDWR concentrated its efforts. Self-noise is more of an engineering problem and has been the concern of laboratories having freer access to standard naval vessels and their gear. The one exception is self-noise in echo-ranging gear, for which very few reliable data were available and for which, consequently, UCDWR made measurements from 1944 on as opportunities presented themselves. Air-borne noise was measured in only a few cases. Ambient noise was studied not only with reference to sonar equipment on board surface vessels and submarines but also in connection with harbor defense installations and sono buoys.

Studies of sea noise were directed towards an understanding of the causes of such noise and the known or easily-measured variables that could be correlated with it. The most striking relationship is that with sea state or wind force. Rain is also known to create considerable noise. Other sources have been suggested such as surf, volcanic action, etc. (Figure 3.12).

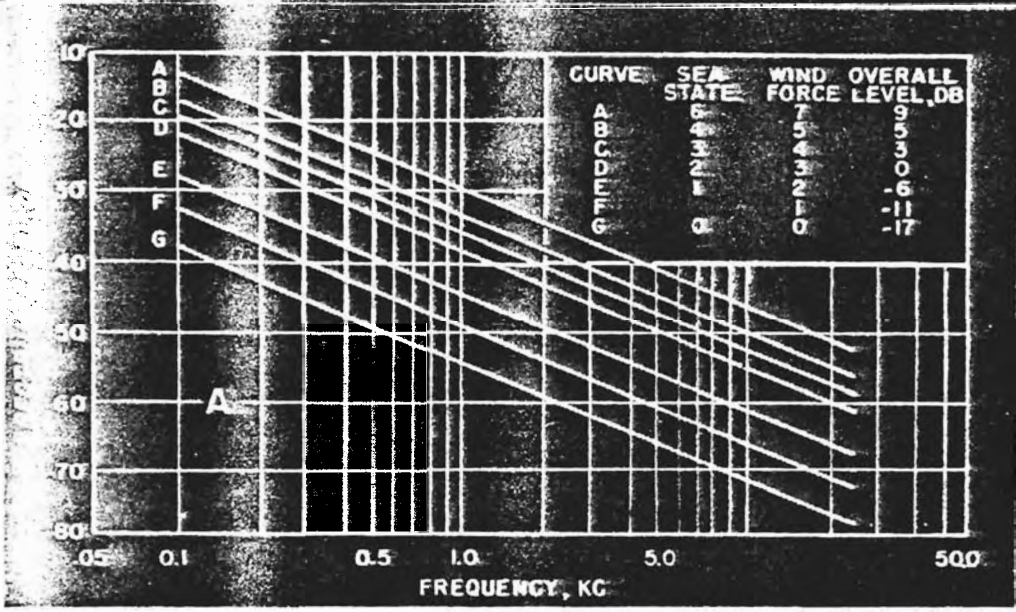
Biological noise received considerable attention both at UCDWR and elsewhere subsequent to the discovery that certain animals produced noise in the sonic or supersonic ranges. Such noise can be particularly troublesome in shallow water.

Traffic noise is that created by other vessels either friendly or enemy. In listening it might appear contradictory to place enemy vessels in a category of **unwanted** sound. However, attempts to detect an enemy escort against a background of other vessels shows that such situations do exist. A similar case may occur if the enemy uses artificial noisemakers. A further example is that in which a submarine or harbor defense unit may wish to obtain the range on an enemy target but finds that the echo is masked by the noise output of the target.

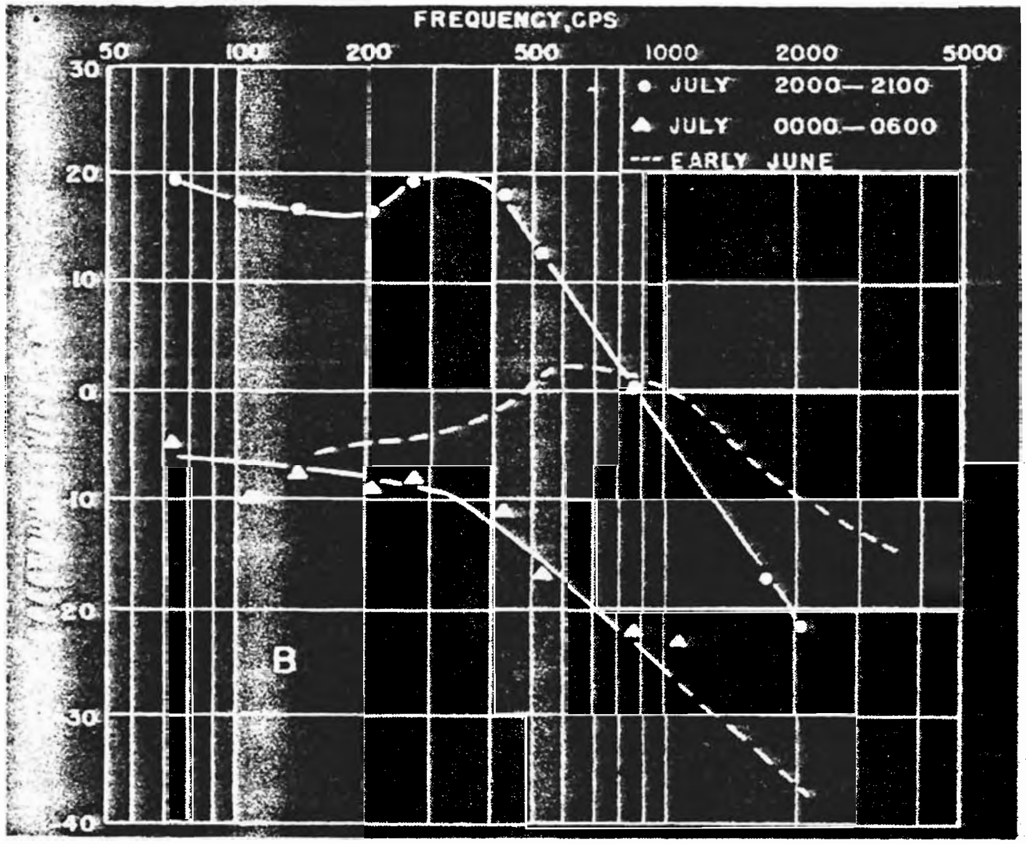
First studies were made in San Diego Bay and in the immediate vicinity of San Diego. The relationship between sea state and spectrum level based on a large number of observations is shown in Figure 3.12 and indicates that sea noise can be

FIGURE 3.12.

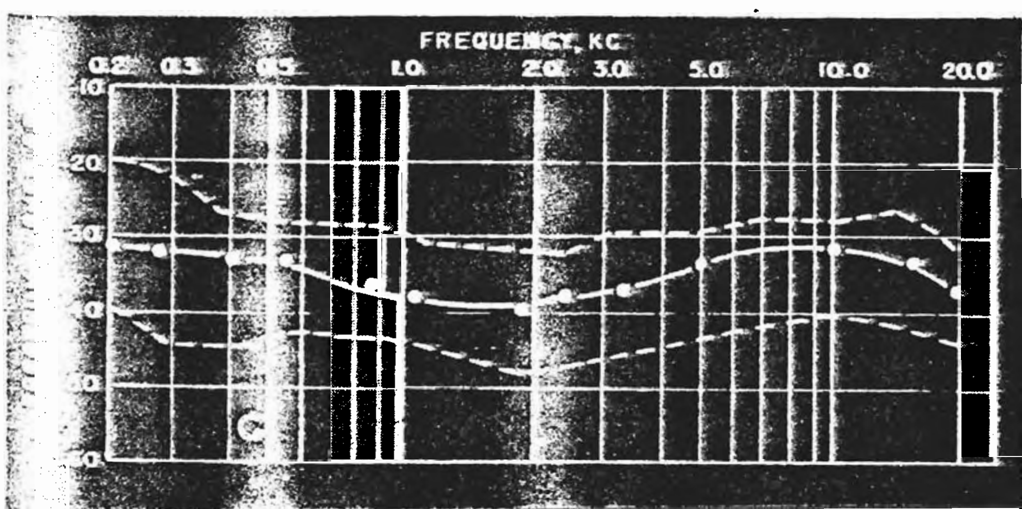
A. AMBIENT NOISE SPECTRA FOR DIFFERENT CONDITIONS OF SEA STATE AND WIND FORCE.



B. SOUND SPECTRA FOR AMBIENT NOISE IN THE PRESENCE OF CROAKERS, WHICH ARE PARTICULARLY ACTIVE DURING THE EVENING HOURS.



C. AMBIENT NOISE SPECTRUM IN THE PRESENCE OF SNAPPING SHRIMP. NOTE THE RELATIVELY UNIFORM SPECTRUM LEVEL AND THE HIGH FREQUENCY COMPONENTS CHARACTERISTIC OF THIS TYPE OF UNDERWATER NOISE.



predicted from sea state or wind force. Detailed measurements were made in a number of West Coast harbors in connection with the harbor defense surveys, and these revealed that ambient noise near San Diego was often characterized by a high-frequency crackling sound, not found farther north. The apparent correlation of this sound with shallow rock bottom indicated a possible biological origin, and careful search finally established that the snapping shrimp were the couse of the crackling sounds. Once the noisemakers were identified, it became possible to predict the occurrence of this noise from the known distribution of the snapping shrimp (Figure 3.13). To confirm the predictability, special tests were made at a number of localities on the East and West Coasts of the United States and in the 14th Naval District. A cooperative study with CUDWR and NOL was made in the Florida-Bahamas area and with NOL in the South Western Pacific. All of these indicated that the crackling sound could be expected in shallow water (30 fathoms), within the known distribution of the animals, and when over or near rock, coral, gravel, or shell bottom. Some other biological noisemakers were identified, but other sounds believed to be of animal origin have not yet been traced to their makers.

Where the sources of ambient noise are not concentrated near the hydrophone, their levels and spectrum are related to the transmission conditions. This is particularly true with isolated sources such as snapping shrimp and or traffic noise. Because the snapping shrimp can be detected by echo-ranging gear, their bearing can be determined when the listening vessel is not immediately over the bed. Submarines have made operational use of rock bottom to avoid detection and have also used bearings on shrimp noise when navigating near islands in lower latitudes, where they have generally reported it as **reef noise**.

Knowledge gained on ambient noise during the program has had immediate application to various operational problems. Further investigations should be directed towards a more complete understanding of the sources of sea noise and biological noise, because these are beyond the control of the engineer and can be only minimized by proper design. Traffic noise should obviously be studied further, and the effort toward reducing self-noise to a minimum should be continued. There is urgent need for studies in air-borne noise with the aim of providing more adequate facilities for the sonar operators.

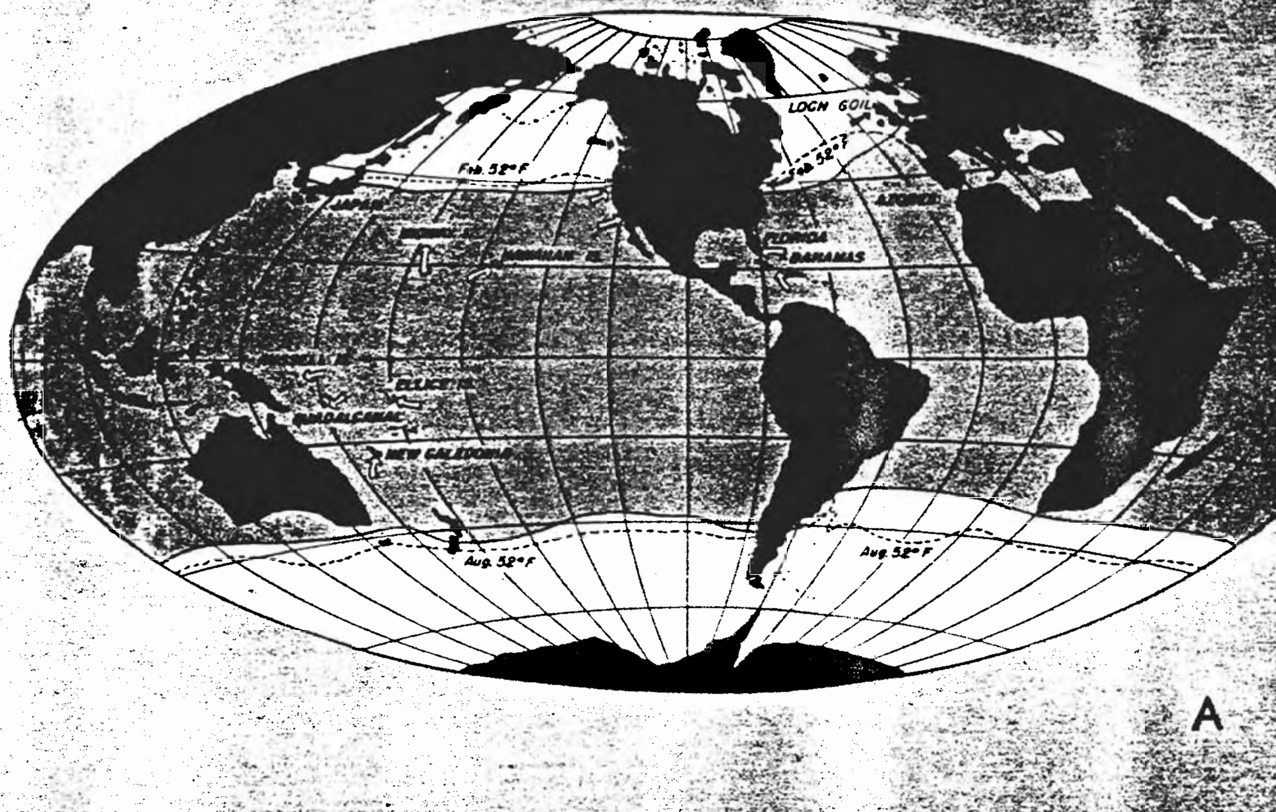


FIGURE 3.13.
(A) THE DISTRIBUTION OF SNAPPING SHRIMP, BASED ON BIOLOGICAL INVESTIGATIONS AND LOCATIONS AT WHICH THEIR CHARACTERISTIC SOUNDS HAVE BEEN STUDIED. (B) THE LARGE CLAW OF THE SNAPPING SHRIMP, WHICH IS USED TO PRODUCE SOUND.

IV. studies of interfering sounds

II. reverberation and scattering

(See File Nos. 01.40, 01.60)

The reverberation present in echo-ranging gear arises from a composite of small echoes originating at scatterers in the water, at the sea surface, and on the sea bottom. It differs from amplified noise in that it is almost a pure tone and in that following the emission of the sound pulse it generally diminishes with time (hence range), although the rate of decay is far from uniform. Because the reverberation varies with range while the background noise remains constant, beyond certain ranges the reverberation will drop below the noise. Hence, in echo ranging, both reverberation and background noise must be known. Although reverberation is sometimes troublesome and reduces ranges, it also has at least one valuable feature in that it provides a reference frequency tone against which the dopplered echo from a moving target can easily be detected.

UCDWR undertook studies of reverberation as soon as the Laboratory was established and continued them on a broadening program until the end of the Contract. Research was directed along the following lines:

A. Variation of reverberation with directivity, power output, frequency and ping length.
B. Effects of oceanographic factors.
C. Identification of scatterers.

Frequencies from 10 to 80 kc were studied, although the largest number of data were accumulated at 24 kc. A wide range in pulse lengths was investigated but most of the routine work was done with pings of about 100 millisecond duration. In addition to studies with fixed-frequency gear, some preliminary work was carried on with frequency-modulated signals, and, in connection with SOD, the pulse length was reduced to a fraction of a millisecond.

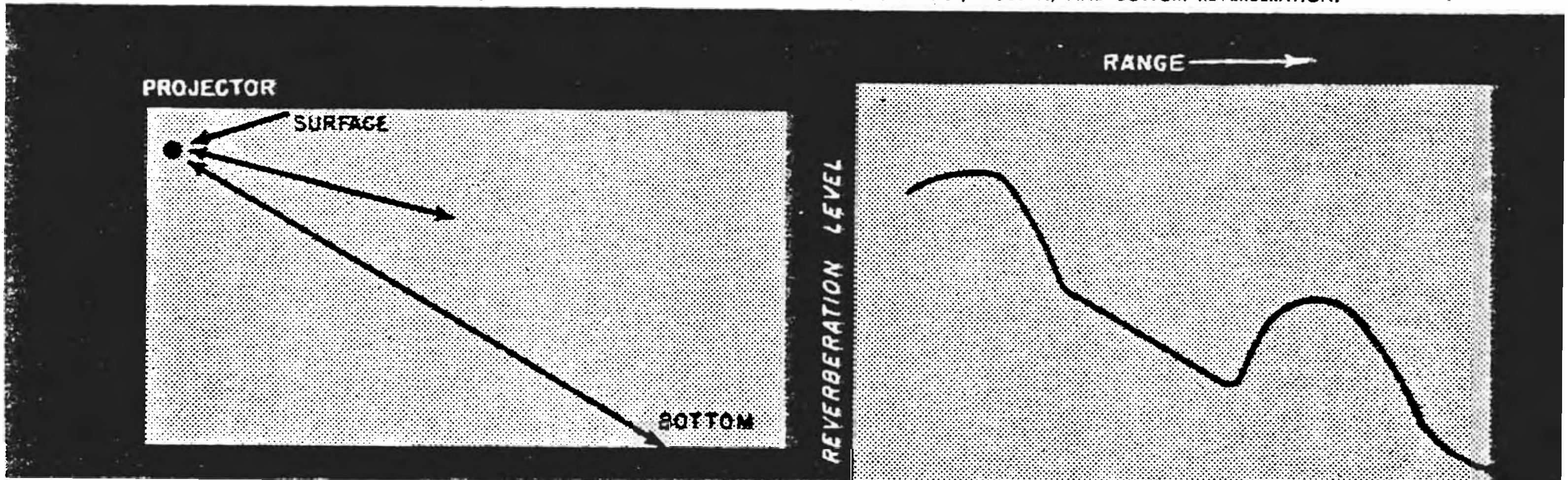
In the early days, most of the experiments were conducted in the Laboratory pool, and later, as ships and gear became available, in the Bay and oceanic waters near San Diego. As the importance of the oceanographic factors was realized, the field program was extended to greater distances to encompass a wider variety of conditions. During 1943, the program was slowed down while the high-frequency transmission studies were started and then both were carried on simultaneously, so that both transmission and reverberation would be known for the same combinations of oceanographic variables. In addition to these routine studies, special attention was directed to the identification of scatterers so that the characteristics of reverberation could be based on more than empirical relationships. It also extended into the fields of investigations concerned with echoes from wakes, small targets such as mines, the structure of echoes, and the acoustic properties of the sea bottom.

At the outset of the investigations, virtually nothing was known about reverberation. The broad features are now understood, and as in the other fields, the results have had immediate application to many operational and design problems. It is only possible to note briefly the general results of the research program. Under the complex conditions existing in the sea, the simple theories cannot always be applied, but certain generalizations are found to hold true, namely, that reverberation decreases with increased directivity and increases with power output and ping length. Also it is possible to identify reverberation as originating at the surface, in the volume of the water, or at the sea bottom. If the projector is near the surface, this is the source of reverberation at close range, and on the average the surface reverberation decays rapidly and at longer ranges drops below the volume reverberation. In shallow water, bottom reverberation is usually strong and appears first as an abrupt rise in intensity and then has a fairly rapid decay (Figure 3.14). The range at which the bottom reverberation appears depends on the directivity of the projector, the depth of water, and the refraction conditions. The average rate of decay therefore depends on the geometry, and the level upon the intensity of scattering at the surface, bottom, and at different depths in the volume. During the course of a single reverberation, the intensity fluctuates from instant to instant, and there is very little similarity in detail from ping to ping, although the major features repeat themselves.

Surface reverberation was found to increase with sea state (or wind force) and to be influenced by the transmission conditions as affected by the temperature distribution. Bottom reverberation depends on the character of the bottom, being least over mud bottoms and then increasing in the order: sand and mud, sand, and rock. The level of bottom reverberation is also determined by the transmission conditions, being higher when conditions are favorable for sound transmission. It was found that scatterers are not uniformly distributed in the water, and that in many cases it is possible to detect a deep scattering layer centered at about 1000 feet which behaves like a false "bottom" and can even be detected with standard echo-sounding gear.

The identification of the surface and bottom scatterers is simple in principle although the mechanisms have not been explained for all types. Bubbles entrapped by breaking waves undoubtedly are important near the surface, as are the irregularities of the surface itself. On the bottom, irregularities in structure and composition scatter sound, and as pointed out above, an irregular rocky bottom returns more sound than a smooth homogeneous mud bottom. It proved extremely difficult to identify the volume scatterers. Whales, certain fish, and kelp are known to reflect sound, but the sounds returning

FIGURE 3.14. SCHEMATIC ILLUSTRATION OF THE THREE TYPES OF REVERBERATION: SURFACE, VOLUME, AND BOTTOM REVERBERATION.



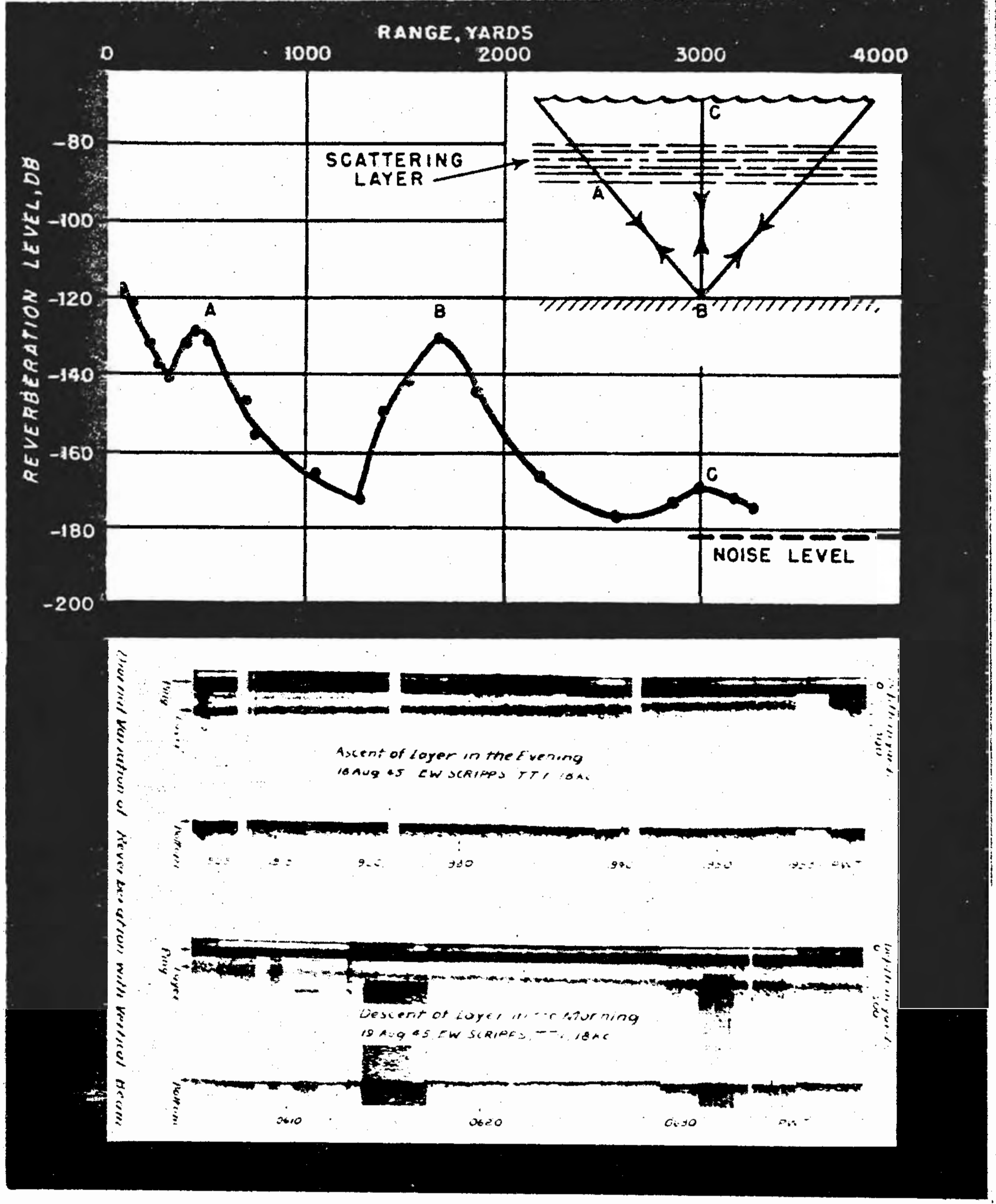
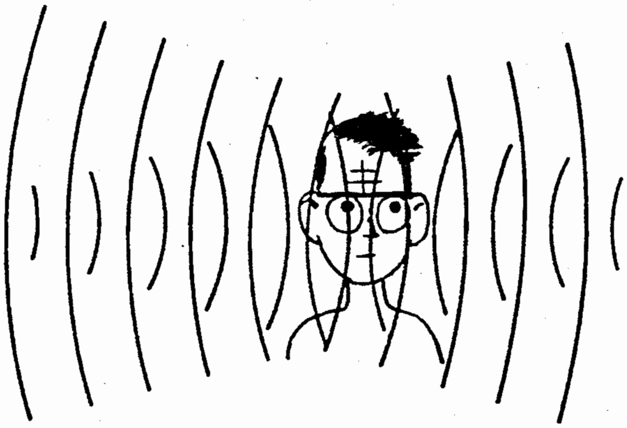


FIGURE 3.15.
REVERBERATION STUDIES, VERTICAL PULSING AND TRANSMISSION STUDIES INDICATE THE PRESENCE, AT A DEPTH OF ABOUT 1000 FEET, OF A LAYER SEVERAL HUNDRED FEET THICK WHICH SCATTERS SOUND. THIS LAYER SHOWS A DIURNAL MOVEMENT, APPROACHING NEARER THE SURFACE DURING EVENING HOURS AND SINKING AT ABOUT DAWN. THE FATHOGRAM SHOWS THE RISE AND FALL OF THIS LAYER.

from these larger objects are usually referred to as "echoes" and they are neither abundant enough nor distributed in a way to account for the omnipresent volume reverberation. Studies of the deep scattering layer revealed that it changes in depth and character during the day, usually rising and becoming more diffuse at night (Figure 3.15). This suggested that small deep-sea fish and plankton animals, which are known to make a vertical migration, upward near sunset and downward near daybreak, may be responsible. If this is true and if the causative animals can be identified, it will be possible to predict the geographic and seasonal distribution of the deep scattering layer.

Much laboratory as well as field study must be conducted before the mechanisms involved in reverberation are understood. The notable advances made have had wide application to operational problems involving maximum echo ranges and in the design of new equipment. Reverberation can, to a certain extent, be controlled by the optimum selection of design parameters which depend upon the specific purpose of the equipment under consideration. A shortened ping length and increased directivity are both parameters which can increase the range of detection. The actual operational use of the equipment can also be planned so that reverberation will be minimized.



V. studies of echoes

(See File Nos. 01.80, 02.133)

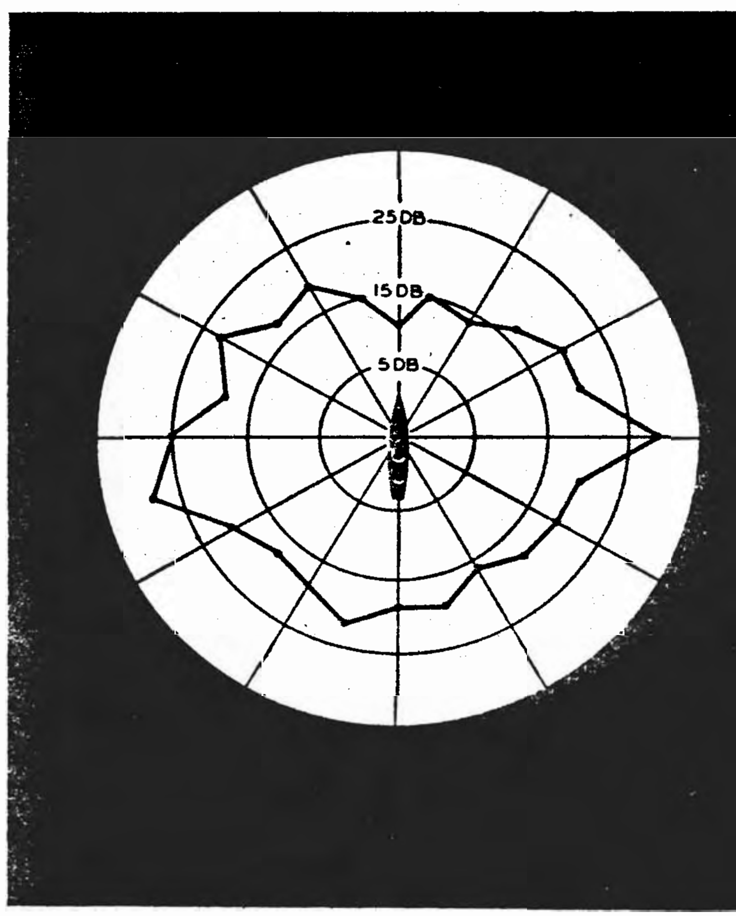
The term **echo** is usually applied to the sound returning from some **wanted target.** In certain cases where the echo is strong, there is no problem in detecting it by various means of aural and visual presentation. However, the more critical problem is the detection at maximum range where the echo is barely detectable against the background noise or reverberation. To recognize an echo in the presence of reverberation, one or more of the following conditions must apply:

A. The echo amplitude must be high relative to the background.
B. It must be limited in range and bearing.
C. The echo must show a doppler shift compared to reverberation.
D. The echo must differ in tonal quality from reverberation.

All four of these may be employed in aural recognition but only the first two in visual presentation (as on a chemical recorder). If a cathode-ray tube presentation is employed, the form of the echo may be helpful.

For a variety of purposes it is desirable to know the acoustic size or target strength of different types of vessels, mines, and other objects. These are needed in predicting maximum echo ranges, in operational problems, in programs studying methods of reducing target strength, and in equipment design. The general program was concerned with the character of echoes received from different types of targets operating in different ways as a function of frequency and pulse length. Targets studied ranged from large surface vessels, submarines, and their wakes, to mines and small model spheres. From the spring of 1945, special effort was directed towards the study of the physics of small object detection to provide design dato for those concerned with the development of mine-detection gear.

Target strengths are expressed on a decibel scale (Figure 3.16) or may be expressed in terms of equivalent spheres. Experimental tests with spheres indicate target strengths different from the theoretical values. These discrepancies are attributed to the difficulties involved in measurements at sea and to the fact that most of the targets have irregular surfaces and are not perfect spheres. Measurements of target strengths of vessels are even more complicated, but the following values are representative: the equivalent sphere for a Fleet submarine on the beam is about 90 yards in diameter and on the bow about 12 yards, while that for an S-class submarine on the bow is about 8 yards. Typical spherical mine cases 3 feet in diameter had target strengths equivalent to spheres about twice the size.

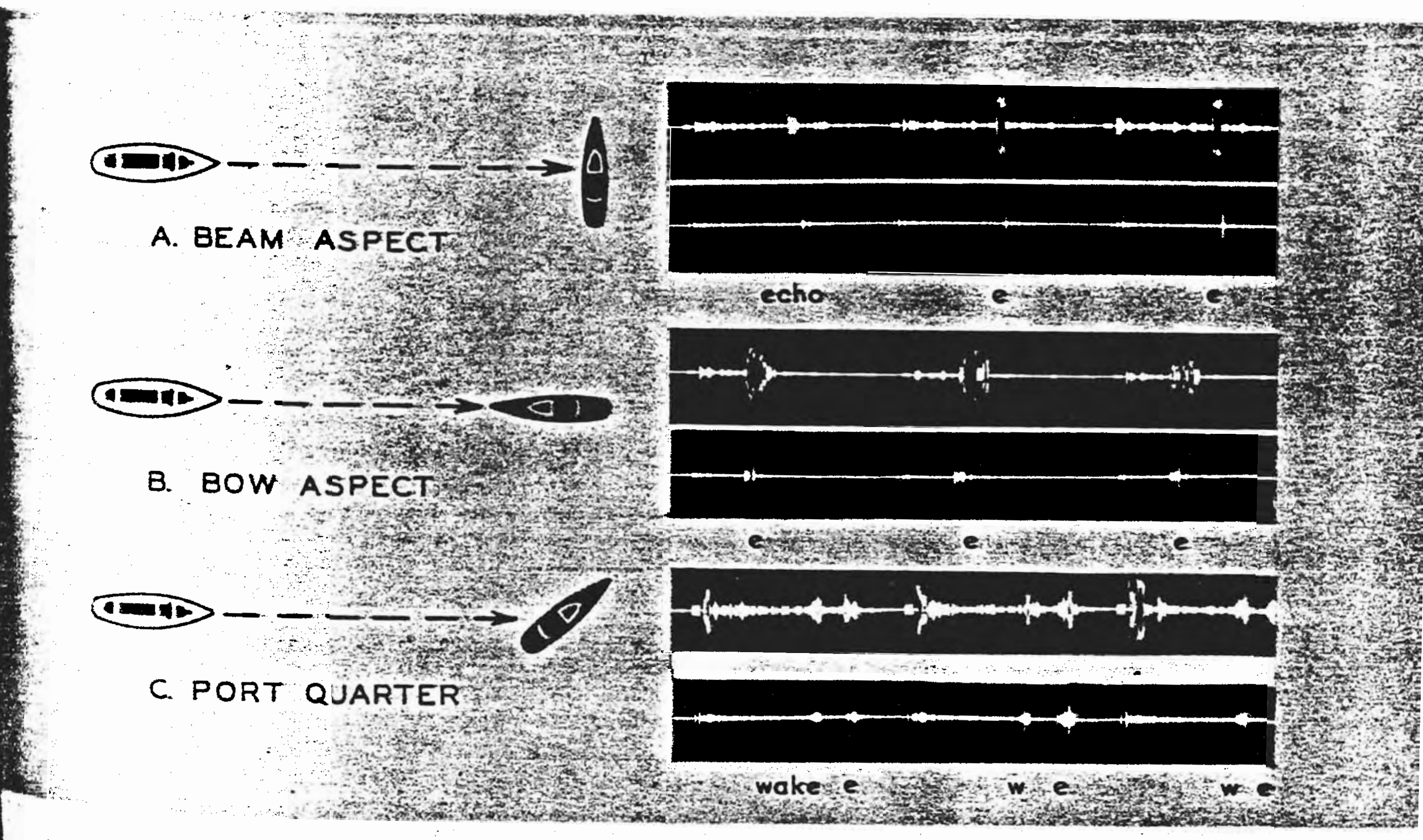


The values given above indicate that the ship's aspect plays an important role, the target strength on the beam being from 10 to 15 db higher than that on the bow. So far only the maximum intensity of the echo has been considered. The elongation of the echo becomes very noticeable when not on the beam of the target, and near the bow or stern the elongation in range is nearly equal to the projected length of the target. To try to determine what parts of the submarine contributed to the echo, careful studies were made of the character of echoes as a function of aspect using very short pings. These indicated that there are actually a large number of small echoes returning from the submarine which add together when longer pings are employed. While no clear dependence of target strength on frequency has been established, shortening the ping length to less than 10 milliseconds produces a definite decrease in the target strength of submarines.

Target strengths have proved so difficult to measure at sea and the structure of echoes so complicated that attempts were made to simplify the problems by the use of model experiments. In 1942 some optical experiments were made using a submarine model to gain information as to the probable location of acoustic highlights for different aspects. In 1945 tank experiments were made in connection with the SOD program to study echo structure using demountable sectionalized spherical shells. These tests supported the idea that the highlights are the chief contributors to the echo.

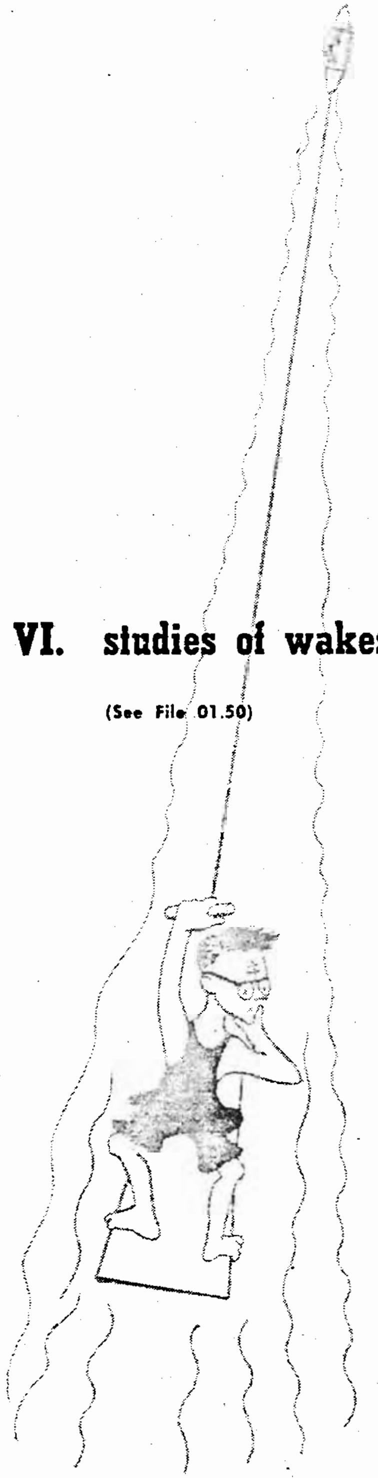
The study of echoes is one of the most important phases of research on echo ranging, and it is unfortunate that experimental difficulties and lack of personnel restricted advances in this problem. The scattered information, incomplete and inconclusive as it is, had immediate application to the prediction of echo ranges, to operational procedures both antisubmarine and prosubmarine, and to engineering design studies involving detection of vessels and mines. Carefully planned laboratory experiments and theoretical studies should supplement intensive measurements on targets at sea.

FIGURE 3.16. THE TARGET STRENGTH OF A SUBMARINE IS GREATEST FOR BEAM ASPECT AND LEAST FOR BOW ASPECT. THE CHARACTER OF THE ECHO ALSO DEPENDS UPON THE ASPECT OF THE TARGET AS SHOWN BY THE OSCILLOGRAMS.



VI. studies of wakes

(See File 01.50)



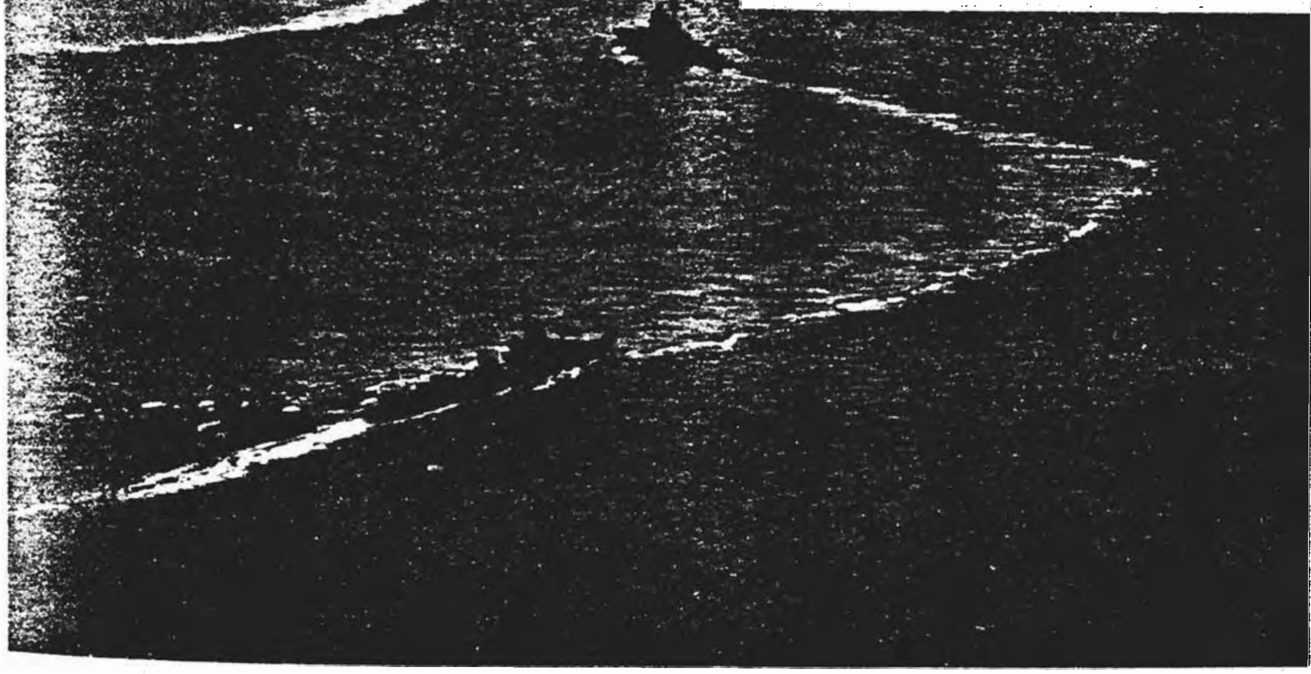
Interest was first stimulated in the study of wakes by statements that echoes could be obtained from surface wakes laid several hours previously and that submarines were able to create wake "knuckles" during evasive maneuvers. Furthermore, the suggestion was made that wakes might be detected thermally; hence some work was done on this nonsonar problem. In order to obtain representative data, the echo characteristics of wakes were studied for different types of vessels at various speeds (and for submarines, depths of submergence) under a variety of oceanographic conditions. In addition to the echo-ranging problems, certain questions were raised about the quenching and sound-screening properties of wakes. These became matters of extreme urgency in the design and use of noisemakers when the enemy introduced acoustic torpedoes. Aside from the empirical results, it was desirable to determine the physical processes involved in sound absorption and scattering in wakes. The primary cause of the acoustic properties of wakes was believed to be bubbles of air, and fundamental studies on these were undertaken at other laboratories (CUDWR, NEL, and WHOI). If air bubbles are the primary cause of sound scattering in wakes, it is difficult to account for their presence in the wakes of submerged submarines where entrainment of atmospheric gases is excluded. The most reasonable explanation seems to be that cavitation at the propellers permits the escape of dissolved gases into the water vapor cavity. When the vapor collapses, a microscopic gas bubble remains which requires a finite time to redissolve.

UCDWR made studies of the wakes of surface vessels and of submarines on the surface and at various depths, to determine their "target strength" and the rate at which the wake strength diminishes. The results of these experiments have tended to discount some of the early ideas of their acoustic characteristics. For one thing it was established that the echoes from the wakes of submerged submarines are very weak compared to those from a submarine on the surface, and virtually disappear below 100 feet. Furthermore, there is no evidence to indicate that the wakes of surface vessels can be detected acoustically for more than about one-half hour after the passage of the vessel (Figure 3.17).

It was found that the target strengths of surface vessels' wakes increase with the size and speed of the vessel and with the frequency and ping length employed. Wake echoes are strongest not immediately astern of the vessel, but about one minute after the passage of the vessel. This is attributed to the vertical and horizontal spreading of the wake and the loss of the larger bubbles that rise to the surface.

Studies were made with several types of surface vessels to determine the screening effect of the wake on the sound from the vessel, as well as when using other sound sources. These indicated that the screening effect increased with ship speed and frequency.

The rather fragmentary results of this program provided information for operational doctrine and for the design and use of noisemakers. It should be kept in mind that the acoustic properties of wakes, particularly those of absorption and scattering, are basically identical with those involved in abnormal absorption and reverberation, and therefore form related topics.



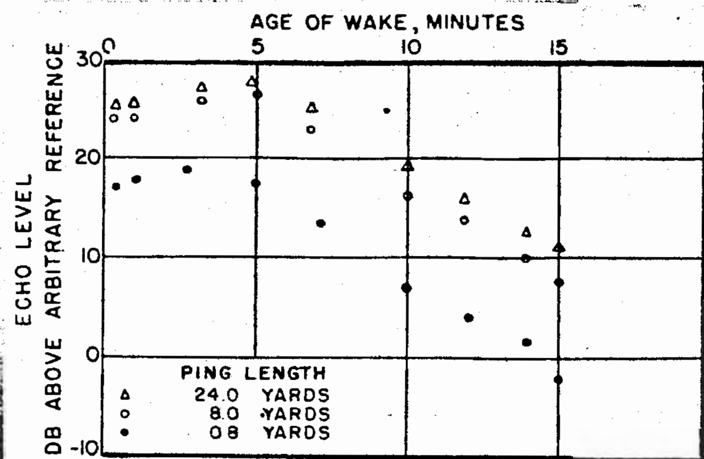


FIGURE 3.17.
THE STRENGTH OF THE ECHO FROM A WAKE DEPENDS UPON THE AGE OF THE WAKE AND THE PING LENGTH.

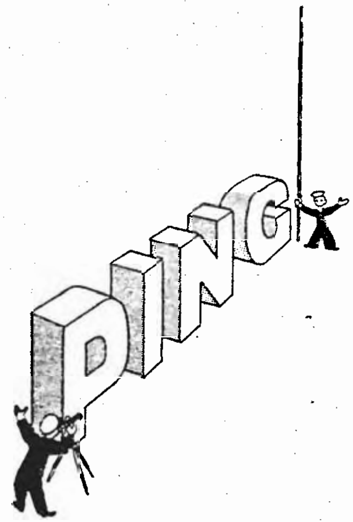
VII. studies of sound recognition

(See File Nos. 01.35, 01.41, 01.42)

In the preceding pages all but one of the factors involved in listening and echo ranging have been surveyed. The remaining one, namely, the detection or identification of a signal or echo, depends in part upon the equipment and method of portrayal, but is essentially a psychological problem, as it is the sonar operator who must recognize the wanted signal. The recognition differential is a measure of the operator's ability to detect a wanted signal in the presence of background. It is usually expressed in decibels above the background, and the numerical values will depend on the frequency band widths used as well as upon the type of background and signal. As the wanted signal can be heard at all times if sufficiently loud, and not at all if too faint, it is customary to use the 50 per cent recognition differential, namely, the difference in levels when the wanted signal is detected 50 per cent of the time. Information on recognition differentials and factors governing them is essential to the prediction of maximum listening and echo ranges. In most of the work only aural detection was studied, but it is obvious that similar problems relate to the chemical recorder, CRO presentation, etc., that in any of these devices there is an optimum method of presentation, and that this must be established before the relative merits of the different methods of portrayal can be determined. Even with existing gear it is possible to establish optimal operating procedures for different situations, such as the choice of ping length in echo ranging, choice of filter band widths, etc.

The research program was concerned with both listening and echo-ranging problems. The listening phases involved the study of high-fidelity recordings of the sound from various types of vessels and their detection against recordings of background noises, including ambient noise and self-noise of many kinds (Figure 3.18). The echo-ranging studies involved matching of recorded echoes taken with different ping lengths and on submarines at different aspects and presented to observers against reverberation and background noises of different types. The materials for these studies were collected with the assistance of other groups in the Laboratory, and, whenever possible, methods of measuring and reporting data were made consistent with those in use in other parts of UCDWR and at other laboratories. The complexities arising from the study of realistic sounds and the lack of adequate psychophysical information about the response of the ear made it necessary to undertake a certain amount of purely fundamental research. The need for information on recognition was felt early in the war but it was not until the summer of 1944 that an intensive program was initiated. As a consequence this phase of research was not advanced as far as the others that affect sonar ranges.

It was obvious early in the program that wide-band measurements of ship sounds and noise were not valid measures of their detectability and masking properties. The ear has a remarkable ability to select one frequency and disregard others. Hence, if a ship produces a single-frequency tone, it may be this that the ear selects and can hear at the longest range. To make valid estimates of the range of detection of individual vessels it is necessary to have a sound spectrum for the source and for the masking noise. This is of course impossible with enemy vessels but has emphasized the care needed in the measurement and analysis of sound data from our own vessels and, in particular, in the "quieting" of submarines, because of the fact that a narrow band of frequencies may be the significant listening sound but will contribute little or nothing to the wide-band level.



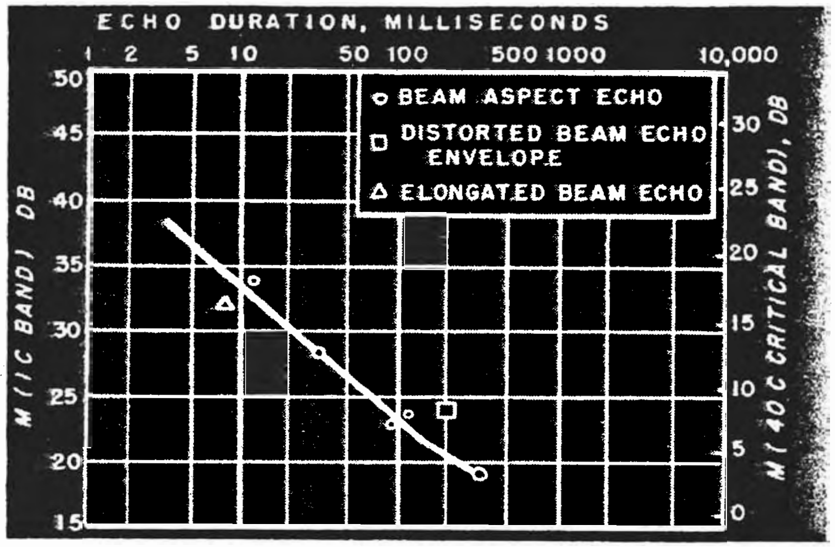
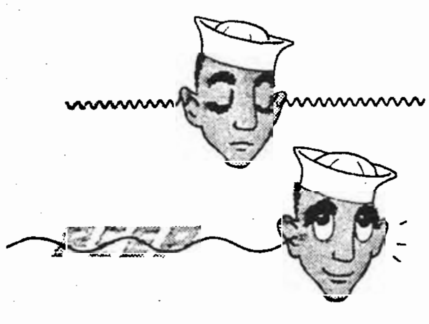
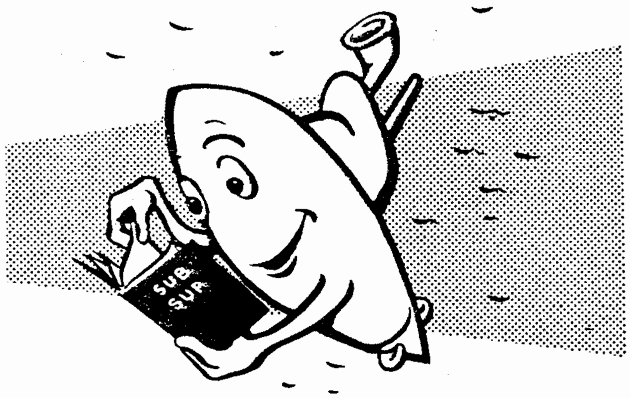


FIGURE 3.18.
THE RECOGNITION DIFFERENTIAL DECREASES WITH INCREASING PING LENGTH.

The study of echoes against noise and reverberation is complicated by the large number of variables. It was necessary to study different ping lengths, different target aspects, and in the case of reverberation, the effects of doppler. Reverberation is not constant with time as is background noise but fluctuates and decreases following each ping and differs in details from ping to ping. The general results obtained indicate that the recognition differential decreases with increasing ping length and is smaller for beam than for quarter echoes. The effect of doppler is virtually independent of ping length but reduces the recognition differential slightly more for down-doppler than for up-doppler. It has been found that the ear tends to smooth out the momentary fluctuations in reverberation, and this result raises questions as to the manner in which the reverberation and echo should be presented to the ear.



The results of these investigations had immediate application to prediction of listening and echo ranges, but a great deal more fundamental testing must be completed before it will be possible to evaluate different methods of portrayal and develop equipment designed to increase the effectiveness and efficiency of the sonar operator.



E. INTEGRATION OF RESULTS

(See File Nos. 01.911, 01.913, 01.921, 01.922, 91.80, 100.00)

As has been emphasized repeatedly in this chapter, the underlying purpose of most of the research program was to evaluate the numerous factors affecting sonar ranges and to develop means for predicting maximum ranges from the known or easily measured variables. The latter phase was kept in the forefront, sometimes to the detriment of the scientific aspects, by the urgent demands for better and easier means of prediction.

The prediction of echo ranges was first proposed early in the life of the Laboratory, and in the spring of 1942, in cooperation with WHOI and CUDWR, a manual was prepared for printing and distribution by BuShips. This was intended for surface vessels, and predictions were based on the temperature conditions alone. Simultaneously the first Sonar Range Charts were prepared (see below). In the years that followed, as information and understanding increased, it was possible to revise and improve the methods of echo-range prediction and sonar charts for both surface vessels and submarines. The steady progress of research rendered such publications obsolete almost as soon as they were issued, and it is desirable that a more careful analysis of data available be made the basis of revision of those now-outdated manuals. Methods for predicting listening ranges were also developed and revised several times.

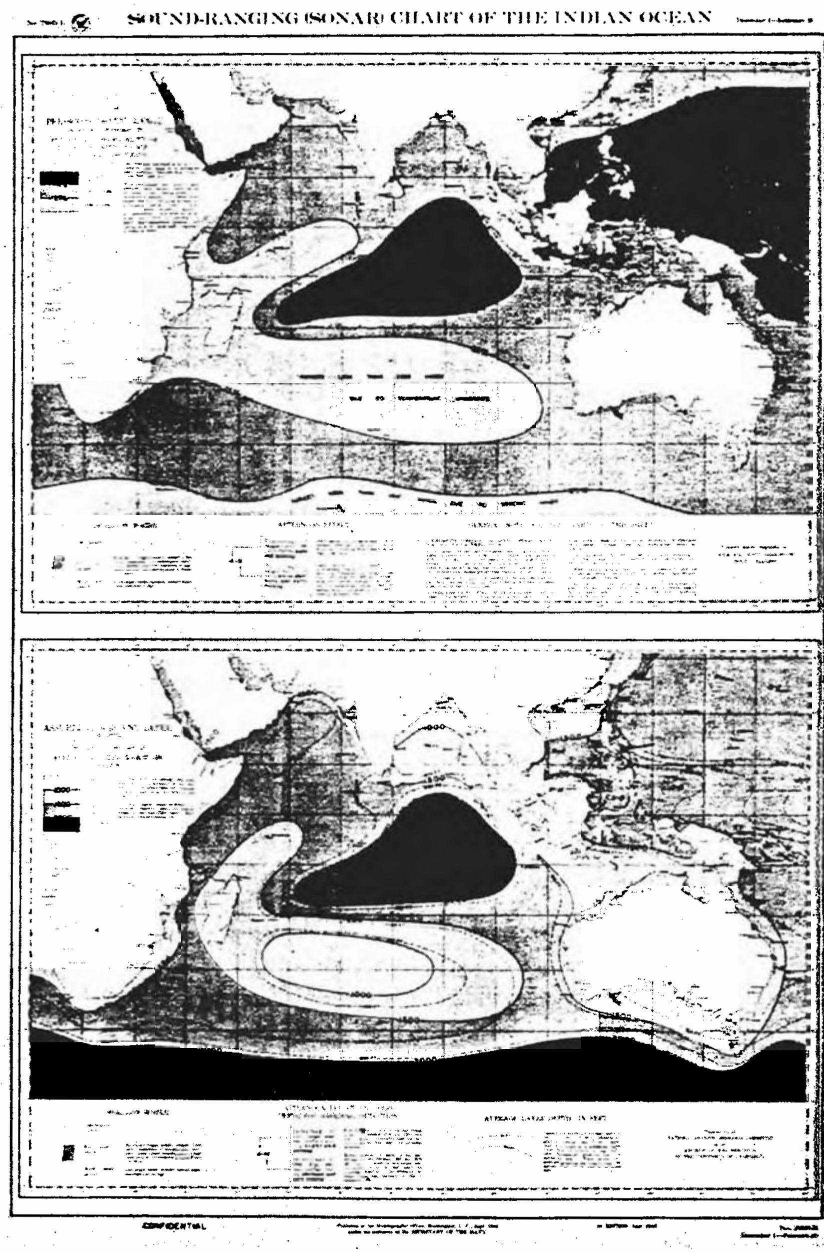
Three types of material other than the prediction manuals were prepared for official Navy publication. These were: Sound-Ranging (Sonar) Charts, Bottom Sediment Charts, and the Submarine Supplements to the Sailing Directions.

All three of these involve the interpretation of known oceanographic data in terms of sonar conditions. Sonar Charts were finally based on temperature conditions, climatic winds (as a measure of sea state), and in shallow water on the type of bottom. A set of three was prepared each six months so that they covered both winter and summer seasons in the North and South Pacific and Indian Oceans. Bottom Sediment Charts were based on topography and bottom character alone, but were subdivided into areas of different acoustic effects. The Submarine Supplements to the Sailing Directions for the areas of the Western Pacific included data additional to those on the Sonar Charts and also information regarding conditions affecting diving and the subsurface navigation of submarines. The number of items prepared by UCDWR or in cooperation with other activities can be seen in Appendix A (Figure 3.19).

In addition to the prediction manuals, the Sonar Data Division has contributed to official publications by preparing textbook and explanatory material on subsurface conditions and underwater sound. Such publications were prepared in cooperation with the Publications Division. The essence of the scientific results has been incorporated in the Summary Technical Reports of which one volume, "Principles and Applications of Underwater Sound," was entirely prepared by the Sonar Data Division. Quantitative information on the topics discussed can be obtained readily from such publications.

FIGURE 3.19

EXAMPLES OF THE SONAR CHARTS AND THE SUBMARINE SUPPLEMENTS TO THE SAILING DIRECTIONS, PREPARED BY THE SONAR DATA DIVISION IN COOPERATION WITH OTHER ACTIVITIES FOR OFFICIAL NAVY PUBLICATION.



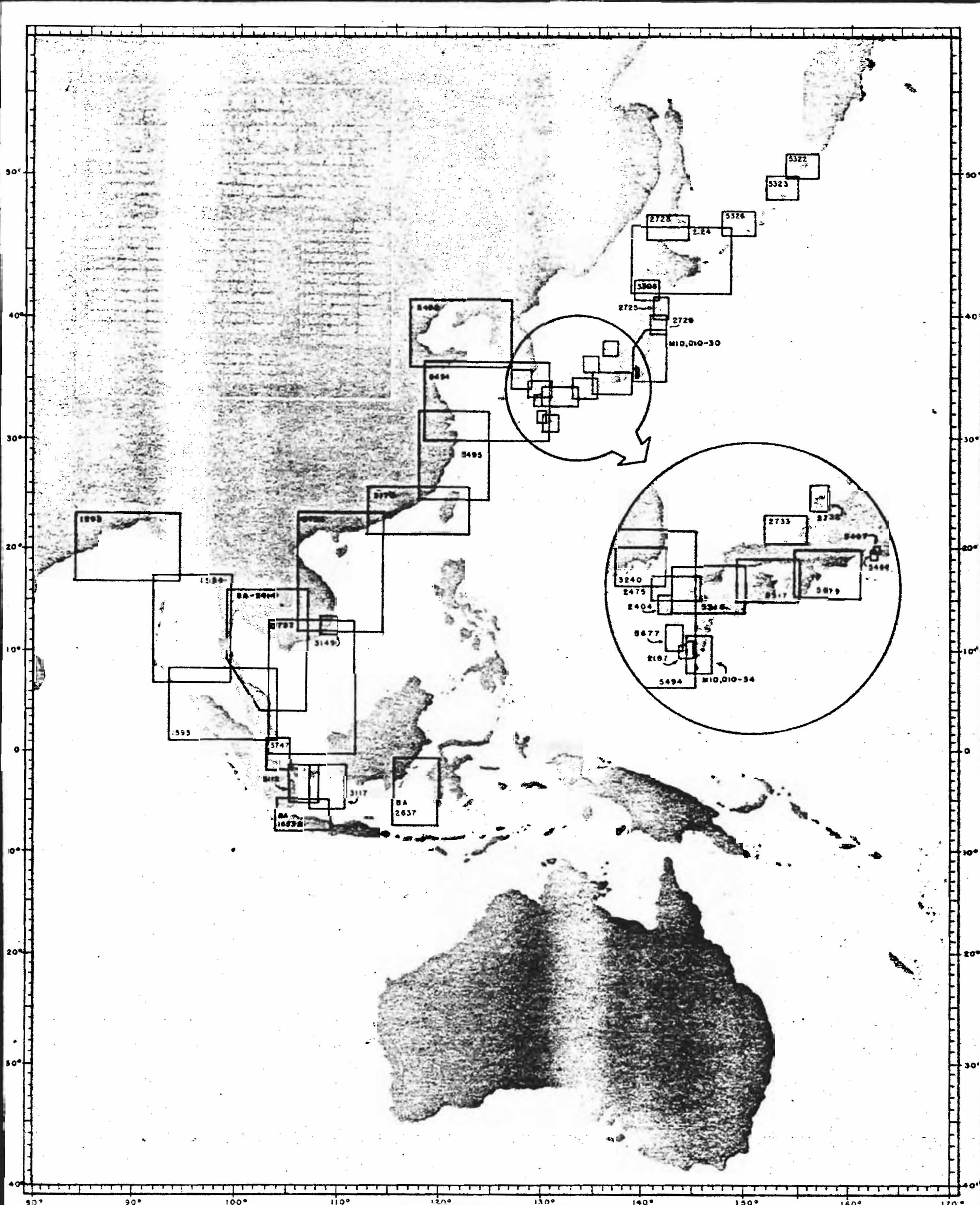
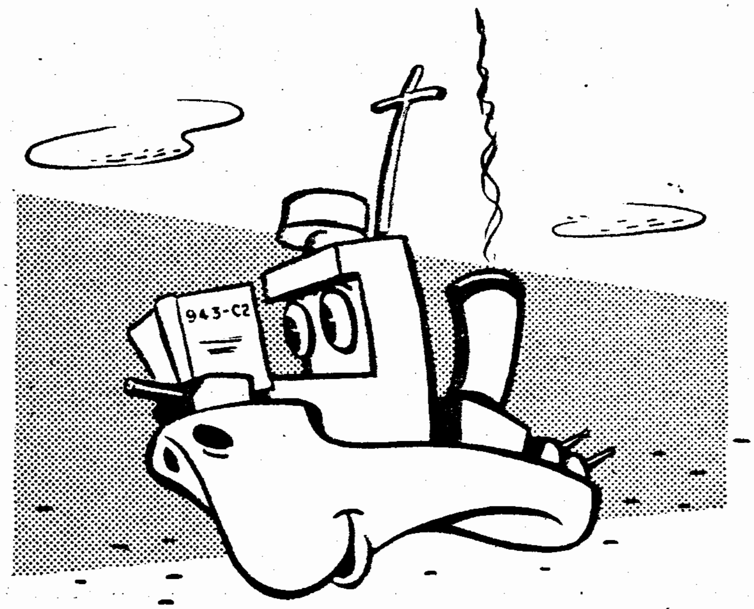


FIGURE 3.20. INDEX MAP OF AREAS FOR WHICH BOTTOM SEDIMENT CHARTS WERE PREPARED AND PUBLISHED.

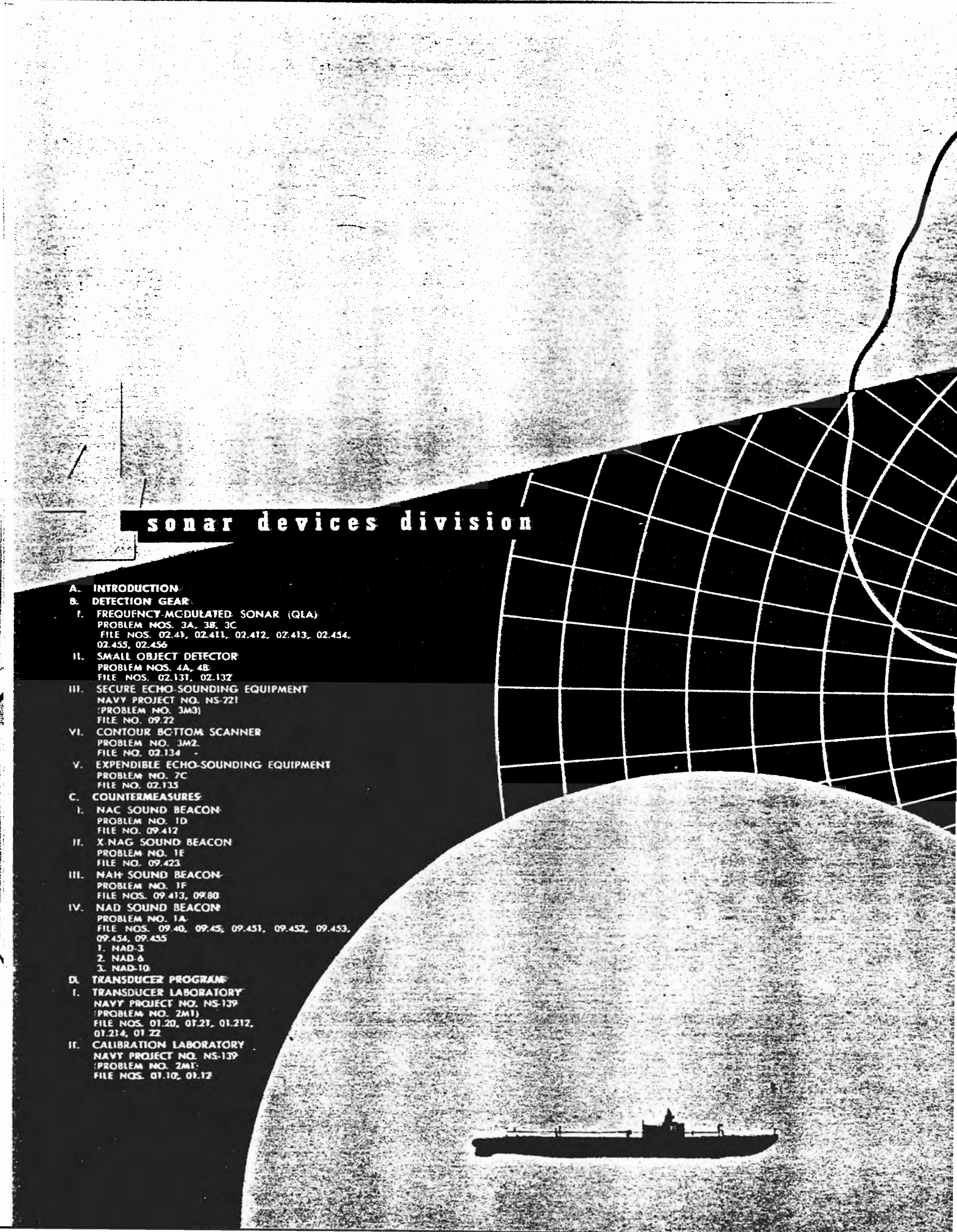


F. RECOMMENDATIONS

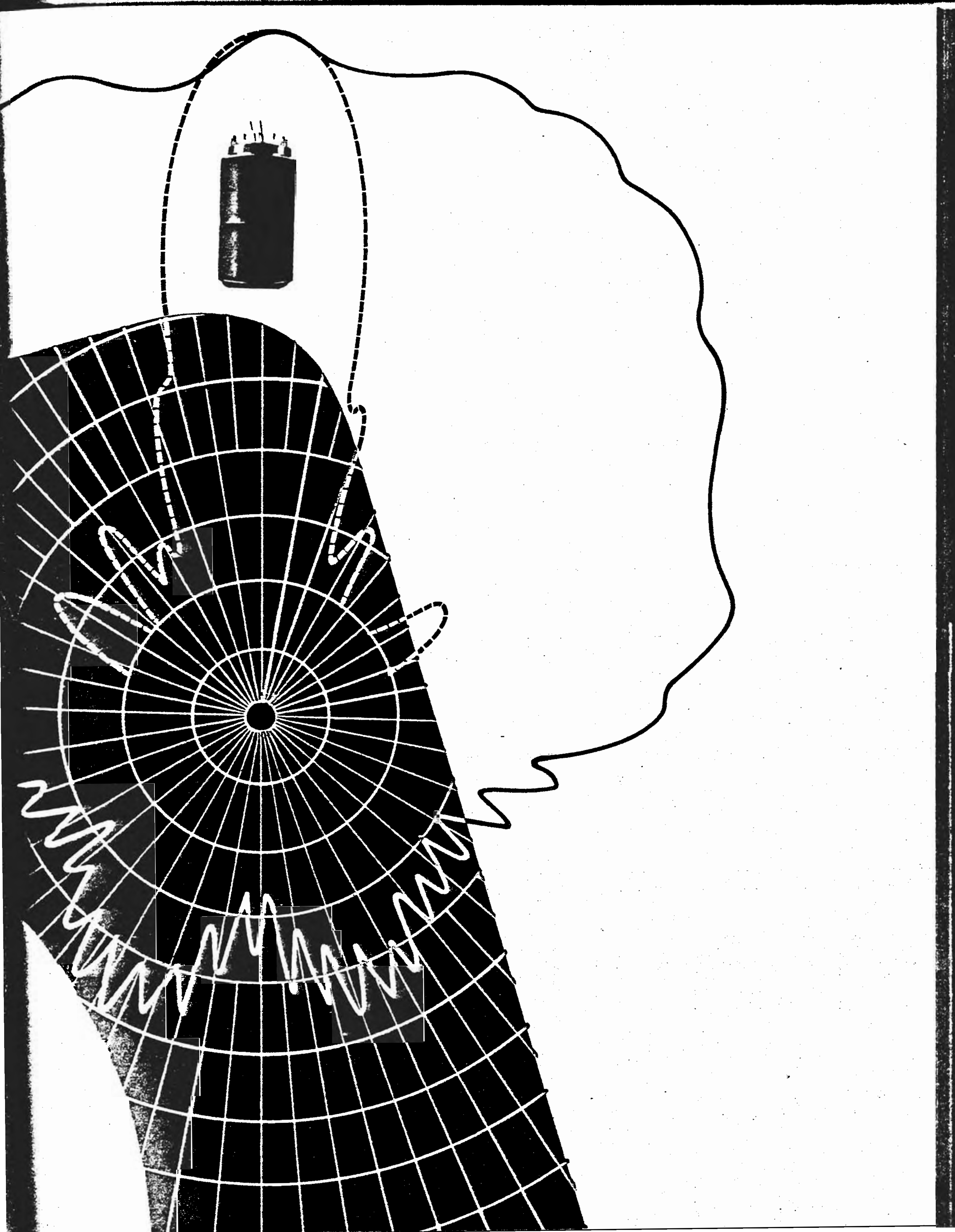
The repeated statement that the work of the Sonar Data Division had applications to operational procedures and to engineering-design problems indicates the close contact maintained with other activities. This had both good and bad features. Under the emergency character of the program, when specific questions required immediate attention the contact with the operating forces and the engineers was stimulating and helpful. On the other hand, answers had to be given before the necessary information was available or thoroughly digested; and, under pressure, there was a tendency to skip from one problem to another before conclusive results could be obtained. Although unfortunate, these conditions were normal for wartime operation and, taking them into consideration, it is felt that fundamental research made notable contributions of immediate application as well as establishing a firm foundation for continued research.

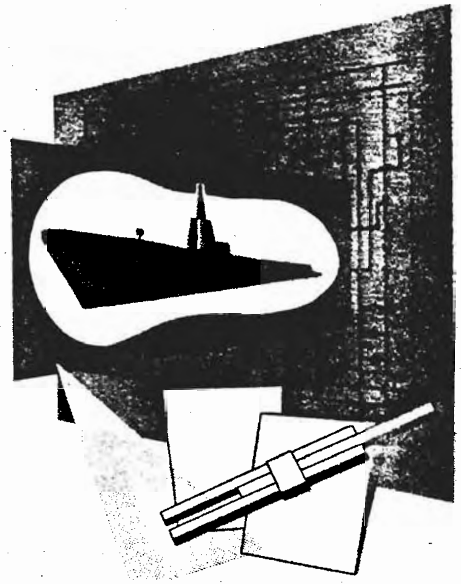
Fundamental understanding of the physics of sound in the sea is essential to the proper design and operation of sound gear. New developments should make full use of such information, and this has not been possible during the emergency. The activities of the Sonar Data Division were largely devoted to answering questions that existed in the minds of the engineers and operating personnel at the time the Laboratory was established. The urgency of these questions did not permit the group to carry out its real function, namely, to search for new techniques and ideas and provide a source of information from which the designers could have drawn when a new type of device, operating on original principles, was under consideration. Such research cannot be done adequately during a wartime emergency, when lack of both facilities and trained personnel contribute to the difficulties. An extensive period is needed to build up the required experimental equipment and to train personnel in the special problems and techniques of underwater sound; in 1941 there was a dearth of both.

A fundamental research program established on a long-term basis is essential to overcome the deficiencies of an emergency program. Besides affording time and opportunity to conduct original research under favorable working conditions, such a program would provide a pool of trained workers and up-to-date equipment. It is not suggested that this program should be without contact with design engineers and operating forces, because such contact is stimulating to all concerned, but rather that the research program should not be dominated by demands for specific and urgently-needed pieces of information.



sonar devices division





A. INTRODUCTION

It was not originally intended that UCDWR would engage in development work, but it was inevitable that ideas on devices would emerge from the minds of the technical men recruited for the Laboratory. Since ideas are not exportable commodities, work began on several development projects in the first few months of operation. With the onset of war and the consequent increase in obligations of all the contractors of Division 6, NDRC, it was even more impractical to transfer such ideas to other laboratories for further engineering development.

Although the various subdivisions of the work of the Sonar Devices Division are discussed individually in this chapter, a number of significant generalities may be noted. During the first year of work, and with the inadequate liaison of those days, contributions to the Navy by this Division were of minor importance. It was a useful year, however, because the technical staff of the Division gained much experience in underwater sound, and began the study of frequency-modulated sonar systems (FM sonar) and practice targets. Although the practice targets were really training devices and are reported in Chapter Five under the Training Aids Division, the development was actually carried out by engineers of the Sonar Devices Division. Since this device utilized the echo-repeater principle, the techniques developed were found to be of great value in the work done later on the NAD beacons.

Because transducers play an essential role in all underwater sound work, and because great difficulty was encountered in procuring them, one of the first activities set up in this Division was the Transducer Laboratory. Wartime expediency suggested that San Diego concentrate its efforts on piezoelectric transducers while the Harvard Underwater Sound Laboratory and Columbia University Division of War Research concentrated on magnetostriction transducers. This division worked very well, although as a long-term measure such restriction is undesirable; for example, on a number of occasions, UCDWR found it necessary to design and construct magnetostriction units. The facility of having transducer designers working directly with electronic designers was one of the most valuable aspects of the Sonar Devices Division's operation.

A Calibration Laboratory was established as a necessary adjunct, first to the Transducer Laboratory and later to the whole organization. During all of its existence, and despite difficulty because of lack of special electronic equipment, the Calibration Laboratory produced work which was usually of a quality comparable with that done by the Underwater Sound Reference Laboratory. The accomplishments of both the Devices Division and the Data Division would have been impossible without this service.

A number of projects were carried through the summer of 1943 when successes against the submarine in the Atlantic and a comparative freedom from this menace in the Pacific suggested a concentration of effort toward aiding our own submarines. In particular, the fledgling prosubmarine countermeasure program was allowed to expand considerably, and because of its demands for unusual transducers, the Transducer Laboratory also grew. Work was begun on a secure echo sounder (SESE) which would enable submarines to take soundings in shallow water without making enough noise to reveal their presence to the enemy. The need for a mine-detecting device by which our submarines could transit Japanese mine fields in order to close with enemy shipping was particularly urgent, and the demonstrated ability of FM sonar to detect small objects suggested that it might be very useful for this purpose. Development work on FM sonar was therefore largely stopped and the full time of that group was devoted to engineering it into a model (Navy Model QLA) for installation on Fleet-type submarines. Following British experience, and as another possible solution to the problem, work was also begun on a pulse-type sonar (SOD). Early in 1944 several of these phases of prosubmarine work were showing promise, and through the good cooperation of Submarine Squadron 45, then based in San Diego, preliminary operational tests had begun.

A new phase began in the spring of 1944 when several staff members were invited by the Commander Submarines, Pacific Fleet, to come to Pearl Harbor to make further operational tests and demonstrations of UCDWR gear in that area. This joint work with the Fleet continued actively until the end of the war. For nearly a year UCDWR maintained men from the Sonar Devices Division in the Pacific area in connection with both the FM sonar (QLA) and the NAC and NAD beacon projects. This was of great value both to the Navy in giving them trained men to help their officers, and also to UCDWR in suggesting improvements in the gear as a result of combat experiences.

After V(J) Day active work was carried on in most of the projects in hand in order to bring them to a convenient state for termination or for transfer to NEL. With the gradual cessation of active development work, more and more time was devoted to the writing of final technical reports.

Several of the devices developed by this Division were manufactured in quantity for Navy use. Some idea of this can be gained from Figure 4.1 which shows the dollar value of the production of such equipment. With minor exceptions, all of this was done by Navy contract with outside manufacturers; only very small quantities of individual devices were made by the UCDWR shops. In all outside work, Laboratory engineers acted as consultants, advisers, and frequently expediters.

The following sections contain brief descriptions of the principal devices on which work was done. Needless to say, many other pieces of equipment were developed but are not discussed because of the minor nature of the work or the unsuccessful outcome of the effort. The bibliography in Appendix A, however, gives a complete list of reports and memoranda on all devices produced by the Sonar Devices Division.

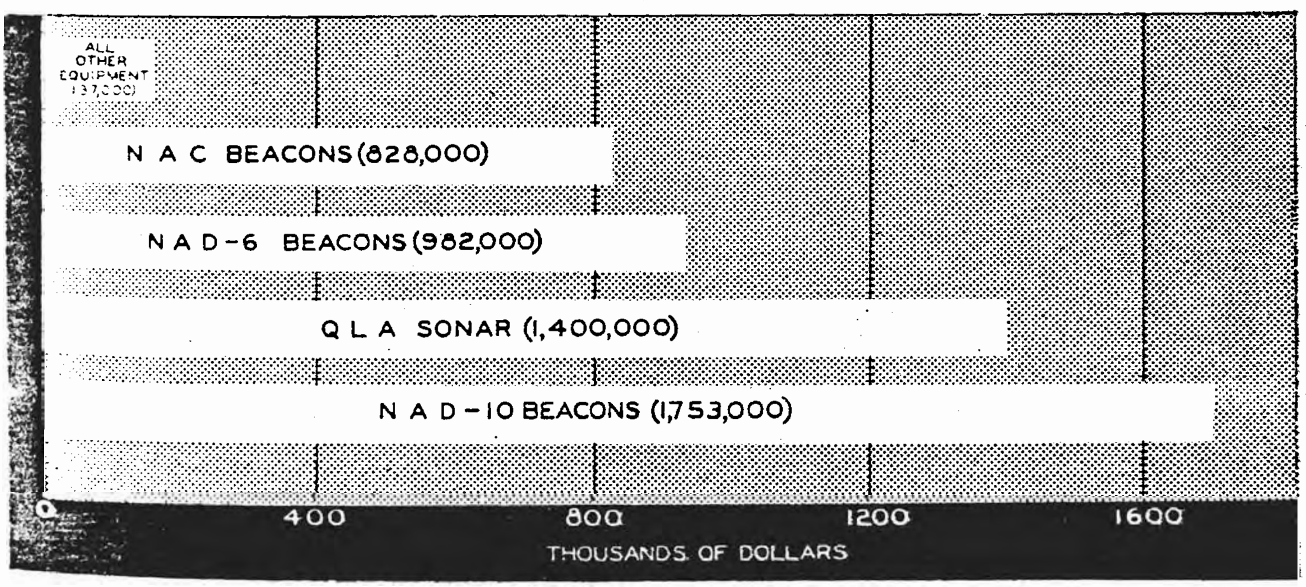
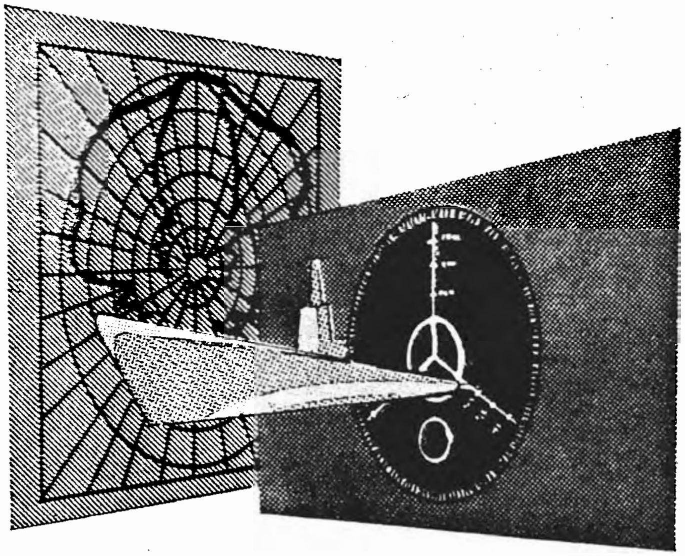


FIGURE 4.1.

A GRAPHIC REPRESENTATION OF THE MONEYS EXPENDED, LARGELY THROUGH NAVY CONTRACT WITH COMMERCIAL MANUFACTURERS, ON EQUIPMENT DEVELOPED BY THE SONAR DEVICES DIVISION. WITH VERY FEW EXCEPTIONS, UCDWR LIMITED ITS MANUFACTURE TO NECESSARY PILOT AND TEST MODELS.



B. DETECTION GEAR

I. frequency-modulated sonar

(See File Nos. 02.41, 02.411, C2.412, 02.413, 02.454, 02.455, 02.456—especially 02.454)

The development of frequency-modulated sonar systems was one of the major efforts of the Division. The examination of a system transmitting continuous sound energy whose frequency was varied periodically between fixed limits began in the first few months of the Laboratory's operation. This device, which bore the name "Echoscope," detected the continuously-returning echo by beating it with a sample of the outgoing signal. Clearly, if the travel time of sound to and from a target is less than the period of the frequency sawtooth, the returning echo on being mixed with the outgoing signal will produce a beat-note whose frequency is a measure of the range of the target. In the echoscope, provision was made for adjusting the sawtooth interval so that the beat-note arising from a specific target could be centered on a sharp filter which would pass a signal only if its frequency was half the difference between the extreme frequency limits. Thus, on sweeping between 36 and 48 kilocycles, the sawtooth interval was adjusted so that the echo beat-note corresponded to six kilocycles.

First tests were made on this device in the early spring of 1942, and its behavior was found to be almost identical with expectations. Progress was seriously handicapped by lack of adequate transducers, and it was not until nearly two years later that suitable transducers specifically designed for this purpose were available. The wide-frequency characteristic and the need for high efficiency required many months of careful research on the part of the Transducer Laboratory before engineering design data could be formulated. However, these early tests with the echoscope demonstrated the feasibility of the scheme and its inherent high degree of accuracy of range determination. The falsifying effect of doppler on range accuracy was also clearly understood, and methods were subsequently devised for eliminating this error and employing it usefully to measure range rate.

Some work was attempted along the line of utilizing the Mason supersonic prism in connection with the echoscope method, and for a few days in 1942 a rudimentary scanning system was in operation. A great many difficulties in this scanning arrangement were recognized, however, and further work on it was abandoned.

In the fall of 1942, an effort was made to adapt these principles to improve the accuracy of fire control of the Mark 20 mousetrap ahead-thrown weapon. It was possible in this design, called "Subsight," to make use of the doppler effect to correct for the relative motion between target and attacking vessel. Subsequent tests of subsight at New London demonstrated that improved methods of conning for forward-thrown attacks had borne such fruit that the need for a device like subsight was less marked than it had been earlier.

It was pointed out that the echoscope principle could be applied to any filter whose center frequency lay between the extremes of the frequency sweep just as well as to one centered midway between such limits, and this suggested the constructing of a device containing a large number of separate filters whose outputs were scanned by an electronic switch. In this way the sharp range focus of the echoscope could be distributed over much wider range limits. Development on this device, which was later known as FM sonar, became active early in 1943, and by February of that year a scanning system in which range was plotted rectangularly against azimuth on the face of a cathode-ray tube was in operation in San Diego Harbor. This first FM sonar had ten filters giving rise to ten range channels. The positioning of the spot on the axis was accomplished by means of a linear potentiometer.

Because of the difficulties of constructing a large number of very sharp filters, a parallel development was started by UCDWR and by the Western Electric Company under subcontract with the University (see Chapter Six, Section E, II), to develop a mechanical filter system analogous to the light-valve used in the motion picture industry. This progressed to a satisfactory conclusion with the construction of a 100-channel light-valve and fluorescent screen and plotting board by the Western Electric Company. However, by the spring of 1944, progress in the purely electronic FM sonar was such that the demands made by the Commander Submarines, Pacific Fleet, for engineering and procurement caused a temporary cessation of the work on the multi-string light-valve.

After the successful operation of the 10-channel FM sonar, a 20-channel unit was built in which the information was plotted on the screen of a cathode-ray tube as is done in the radar plan position indicator (PPI). The angular position of the spot is determined by a sine potentiometer connected to the transducer shaft. This system was given many operational tests during the summer, and in all ways behaved as expected. Two arrangements of transducers were tried: one in which sound was radiated in all directions and the directional hydrophone scanned continuously through 360 degrees, and one in which sound was radiated through only about 80 degrees and both transmitting and receiving transducers rotated together. The latter method was found to be more economical of power and later became a standard arrangement. Several tests of FM sonar were made on the USS SEMMES during the following winter and suffered the usual casualties of tests on incompletely-developed equipment. During this time the first of the especially designed transducers had become available, and experience gained in the cold waters of a New London winter proved very helpful to the transducer designers accustomed to the warmer water near San Diego.

At the suggestion of the Commanding Officer of Submarine Squadron 45, then based in San Diego, an engineering prototype of FM sonar was designed, built, and installed on the USS SPADEFISH (SS-411) in the spring of 1944. Several UCDWR engineers met this boat in Pearl Harbor during the summer and conducted exercises and demonstrations before interested officers of ComSubsPac and ComSubsTrainPac. Primary interest was expressed in the usefulness of this equipment in mine detection. Experience with the echoscope and early models of FM sonar had demonstrated such ability, and in the much more favorable conditions around the Hawaiian Islands, the SPADEFISH's equipment was able to detect moored mines to distances of 450 yards.

Concurrently with the above introduction of FM sonar into the submarine service, and at the request of an officer attached to the staff of the Commander Service Squadron Six, a laboratory model of the equipment with two UCDWR engineers was taken to the Mediterranean Theatre where several tests were made near Palermo and Salerno during the summer of 1944. Mines were detected at about the same ranges encountered off Oahu. This experience proved very valuable when, after V(J) Day, installations were made on two vessels of the YMS class.

Henceforth the activities of the FM sonar group were entirely devoted to further improvements and general engineering of the system, together with the superintending of manufacture and installation of units on Fleet-type submarines. Although UCDWR made a small number of units, the quantity manufacturing was done under subcontracts with the Western Electric Company. By the time the war had ended, a total of 48 systems (given the Navy code letters QLA) had been constructed, 21 of which had seen service on war patrols. The detecting of mines by QLA gear was found to be principally influenced by bottom and surface reverberation as well as thermal down-bending. This is best shown by the excellent performance of QLA on war patrol and in training exercises off Guam and Saipan where ranges of 1000 yards on three-foot-diameter moored mines were frequently experienced. By the time most of the QLA units were under manufacture, a successful and thoroughly rugged transducer had been achieved. The final QLA system operates between the frequency limits of 36 and 48 kilocycles, and the PPI range dial has scales of 300 feet and 300, 600, 1200, and 3000 yards. Range accuracy on this model is about three per cent and bearing resolution about three degrees. The doppler range error is about two per cent for each knot of relative range rate; however, since the particular circumstance of use for this equipment was in searching for stationary objects from a submerged submarine, this error was not significant. As can be seen in the schematic diagram of Figure 4.2, there are 20 filters, each 75 cycles wide, which feed the intensity axis of the cathode-ray tube, and a loudspeaker which also serves to carry an audible sound of the targets. This combination of visual and audible presentation has been found to be of greatest value in identifying targets.

In order to arrange QLA equipment conveniently in the very crowded confines of a submarine, it is broken up into three units: (1) The conning tower unit, Figure 4.3(a). This consists of a cabinet carrying the cathode-ray tube and all controls, and a loudspeaker. (2) The main stack. This, consisting of transmitter, analyzers, and receiver, is mounted in the forward torpedo room and requires no attention; it is broken down in convenient sizes for passing through a hatch and is shown mounted in Figure 4.3(b). (3) The transducer, reversing mechanism, and sine-potentiometer assembly. A transducer schematically represented in Figure 4.2 is shown in a topside mounting in Figure 4.3(c). At the bottom of this shaft and inside the forward torpedo room is the thyratron reversing mechanism for automatic scanning and the sine potentiometer for rotating the spot on the CRO in synchronism with the transducer.

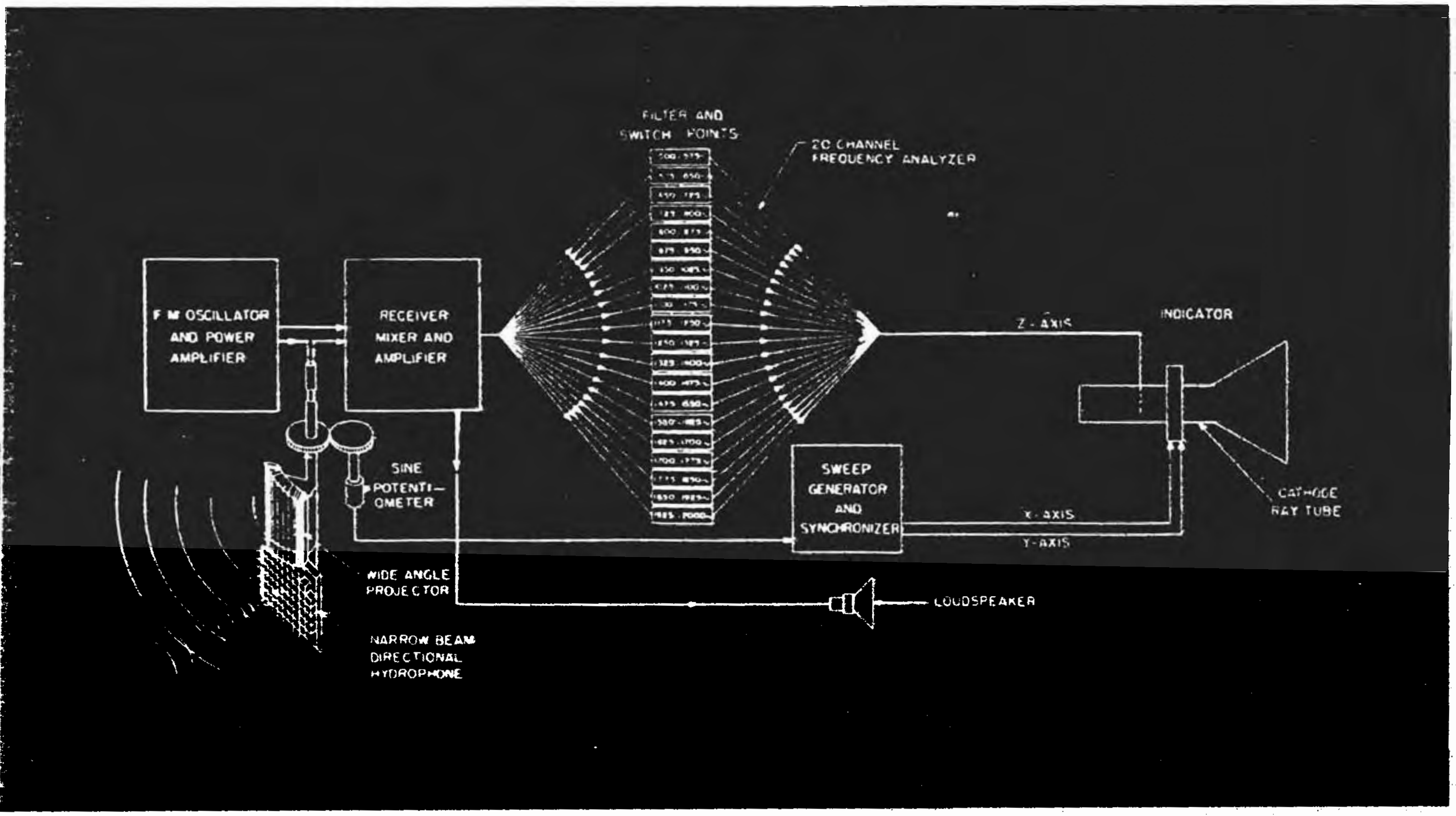


FIGURE 4.2.

A SCHEMATIC BLOCK DIAGRAM OF THE QLA SONAR (FM SONAR) EQUIPMENT. THE COMBINATION PROJECTOR AND HYDROPHONE IN THE LOWER LEFT-HAND CORNER IS FED FROM A FREQUENCY-MODULATED OSCILLATOR AND THE RECEIVED SIGNAL IS MIXED WITH THE OUTGOING PULSE. THE FREQUENCY DIFFERENCE IS ANALYZED BY 20 CHANNELS WHICH ARE SCANNED BY AN ELECTRONIC SWITCH. THE OUTPUT OF THESE 20 CHANNELS IS APPLIED TO THE INTENSITY MODULATION OF A CATHODE-RAY OSCILLOSCOPE. THE RADIAL AND ANGULAR POSITIONS OF THE SPOT REPRESENTING AN ECHO ARE PROPORTIONAL TO THE RANGE AND BEARING OF THE TARGET. THE UNANALYZED SIGNAL IS APPLIED TO A LOUDSPEAKER WHICH AIDS IN THE IDENTIFICATION OF THE TARGET.

(c) A TOPSIDE-MOUNTED QLA TRANSDUCER.

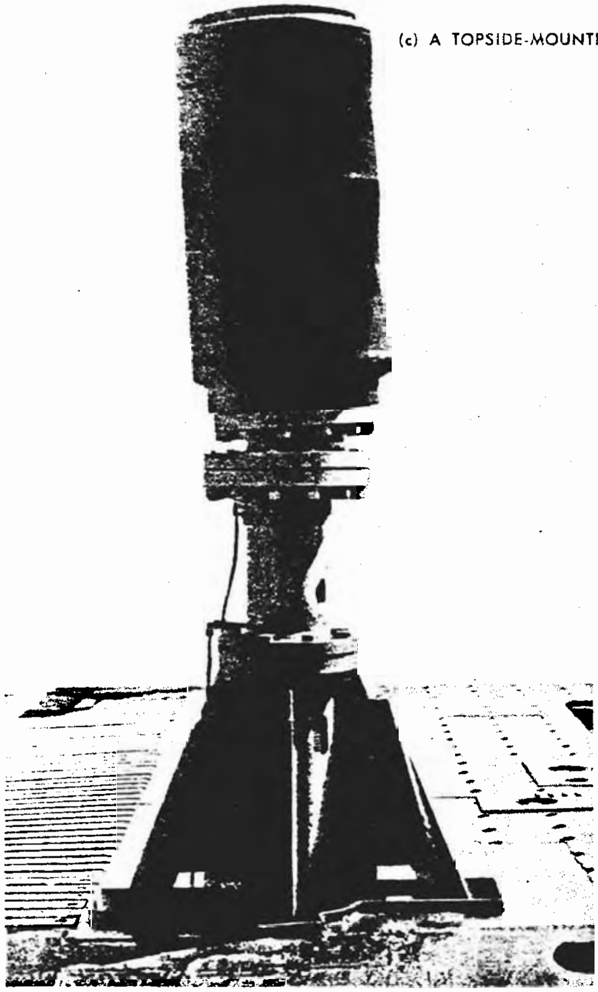
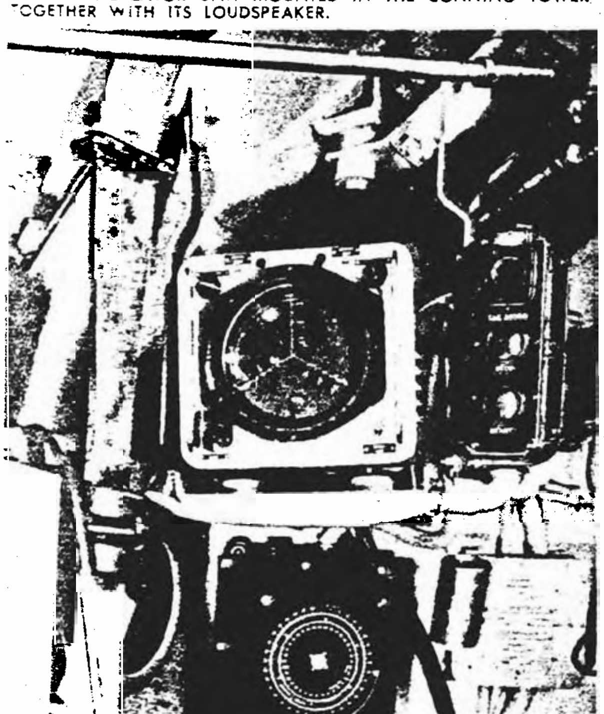
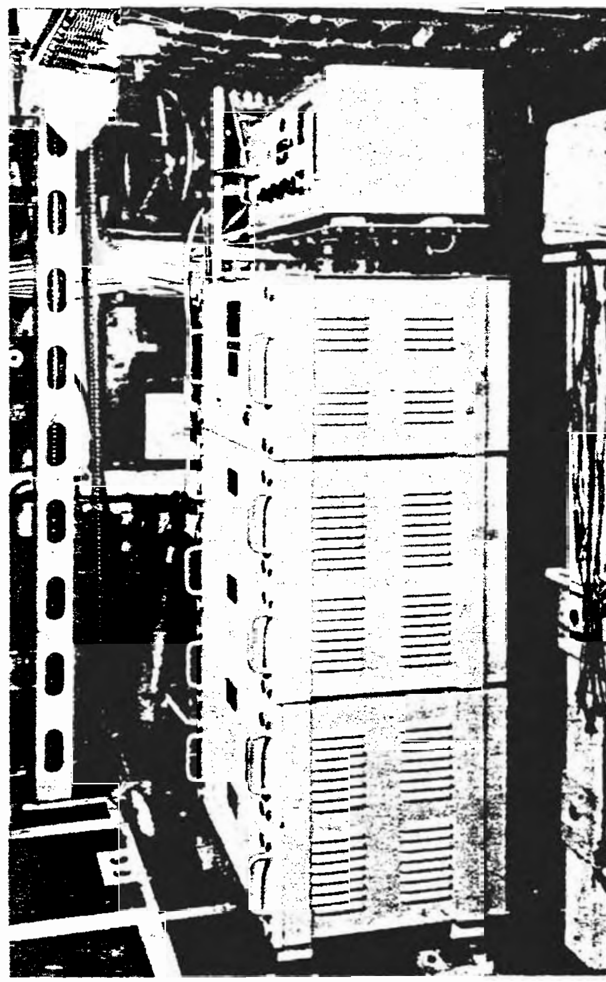


FIGURE 4.3.
A TYPICAL QLA INSTALLATION ABOARD A FLEET-TYPE SUBMARINE
(a) THE INDICATOR UNIT MOUNTED IN THE CONNING TOWER TOGETHER WITH ITS LOUDSPEAKER.

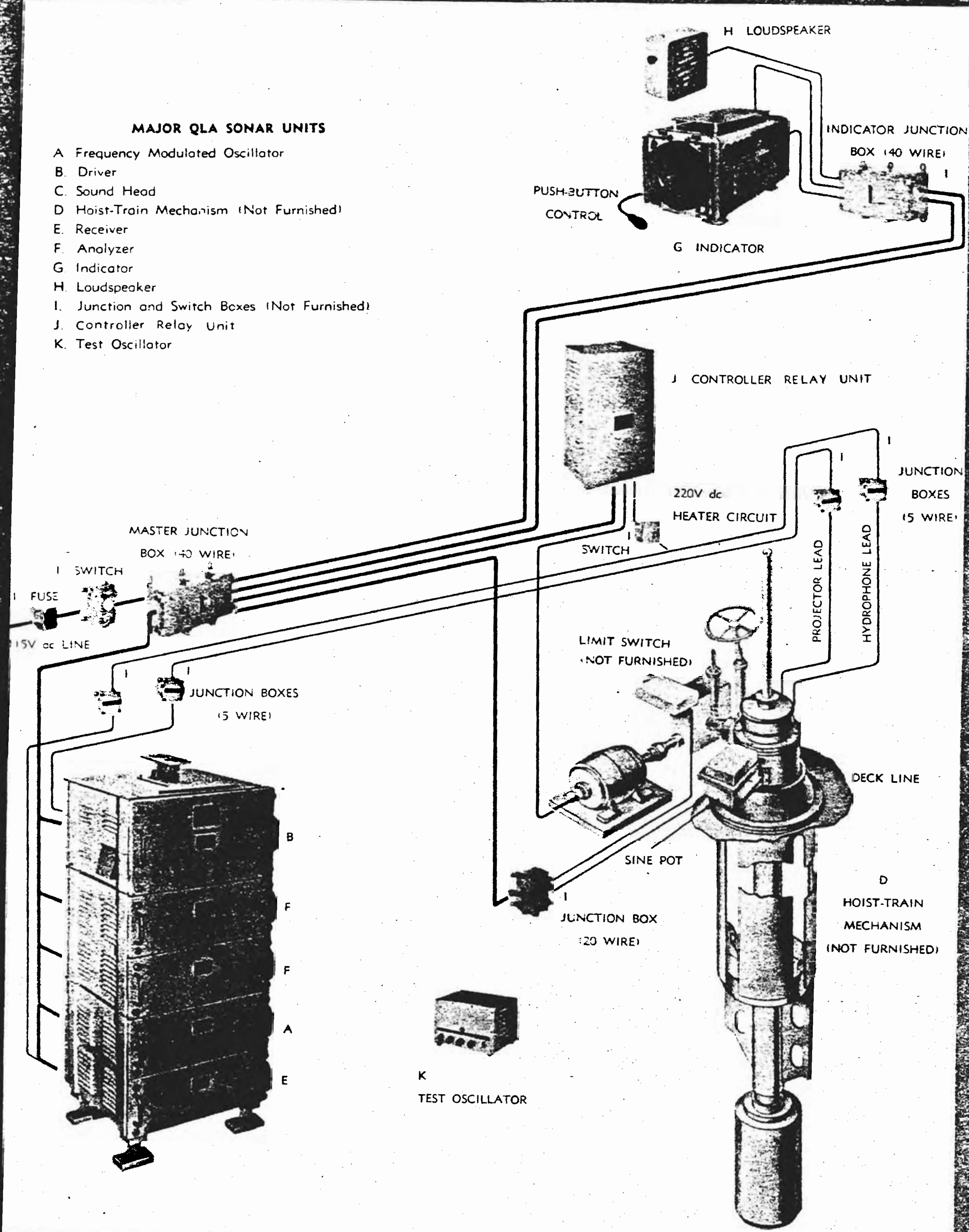




(b) THE ELECTRONIC STACK IN THE FORWARD TORPEDO ROOM.

MAJOR QLA SONAR UNITS

A. Frequency Modulated Oscillator
B. Driver
C. Sound Head
D. Hoist-Train Mechanism (Not Furnished)
E. Receiver
F. Analyzer
G. Indicator
H. Loudspeaker
I. Junction and Switch Boxes (Not Furnished)
J. Controller Relay Unit
K. Test Oscillator



Schematic diagram for these arrangements within a ship is shown in Figure 4.4. Provision is made in this model for automatic search throughout the whole horizon or for sector scanning, which has proven valuable in making a transit of a mine field.

The commendation in the frontispiece indicates the role which this equipment has played. Because of the urgency of the program, it was necessary for the QLA group to expand its activities into the field of material training, and 87 officers and men were given courses in operation and general maintenance and trouble shooting for this equipment. In addition, work was initiated on a variety of training items as a program of assistance to the Fleet Sonar School, San Diego, and a film on the theory of operation of QLA sonar was made with the help of the Hugh Harmon Studios.

FIGURE 4.4.
A DIAGRAM OF THE COMPLETE QLA SONAR SYSTEM AS MOUNTED ABOARD A FLEET-TYPE SUBMARINE. THIS SPECIFIC ILLUSTRATION REFERS TO A BOTTOM-MOUNTED TRANSDUCER WHICH CAN BE RETRACTED INTO A SEACHEST.

II. small object detector

(See File Nos. 02.131, 02.132)

As a part of the general program of Division 6, NDRC, UCDWR was asked to carry out evaluation tests of various pieces of gear designed for the detection of small objects, specifically, mines. For these purposes, a mine is considered as a sphere three feet in diameter, suspended somewhere between the bottom and the surface. Work along these lines is of course applicable to any other object of similar acoustic dimensions, such as human torpedoes and other subsurface sneak craft.

In the summer of 1944 after examining pieces of British gear represented by the 135 ASDIC and the 150 ASDIC, UCDWR was informed by Dr. H. F. Willis, of His Majesty's Anti-Submarine Experimental Establishment, Fairlie, of recent British experience with this type of equipment. The performance figures quoted by Dr. Willis were somewhat greater than any encountered by American observers at that time, so it was considered desirable to construct as nearly as possible an American replica of the latest British equipment. This model came to be known as the Small Object Detector (SOD), and had the following characteristics: The pulse length was considerably shorter than ordinarily used in antisubmarine work; the power output was large (the shortness of the pulse length made it difficult to secure an accurate measurement of the power radiated); the indication was audible and, by means of a chemical recorder, the receiver embodied the British subtractive circuit which favors pulses of a specific length over noise and reverberation. The projector was a unit constructed locally, using ADP crystals, and the receiver was especially built to accept the very wide band of frequencies demanded by the shorter pulses.

Experiments on bottom reverberation in shallow water conducted by the Sonar Data Division had indicated that, at least for pulses as short as one-third millisecond, bottom reverberation decreased with pulse length. Consequently, pulses of a fraction of a millisecond were used in all of this work.

One complete model of this gear underwent performance tests in the spring of 1945 and demonstrated its ability to detect three-foot spheres at ranges of the order of twice those encountered by other equipments in the very unfavorable conditions prevailing in San Diego Harbor. Sea tests in deeper water gave ranges of the order of 800 or 900 yards when the device was mounted on a small surface vessel. This model was later mounted on the USS FLYING FISH (SS-229) for further tests during April and May 1945. In these later evaluations and in competition with other mine-detecting gear, the SOD equipment gave, on nearly all occasions, maximum ranges in excess of 1500 yards.

At the request of the Commanding Officer of the USS FLYING FISH, the SOD equipment was left aboard and taken on war patrol. As far as UCDWR knows, however, it was not used because of the satisfactory performance of the QLA gear also mounted on the boat. The unit on the FLYING FISH is shown schematically in Figure 4.5. It will be noted that it consists essentially of four parts: The special ADP transducer which is mounted topside and is also shown in Figure 4.6(a); the transmitter cabinets which were mounted in the forward torpedo room and are shown in Figure 4.6(b); and the receiver and range recorder mounted in the conning tower and shown in Figure 4.6(c). The recorder is a standard Sangamo antisubmarine range recorder which has been stripped of all superfluous appurtenances.

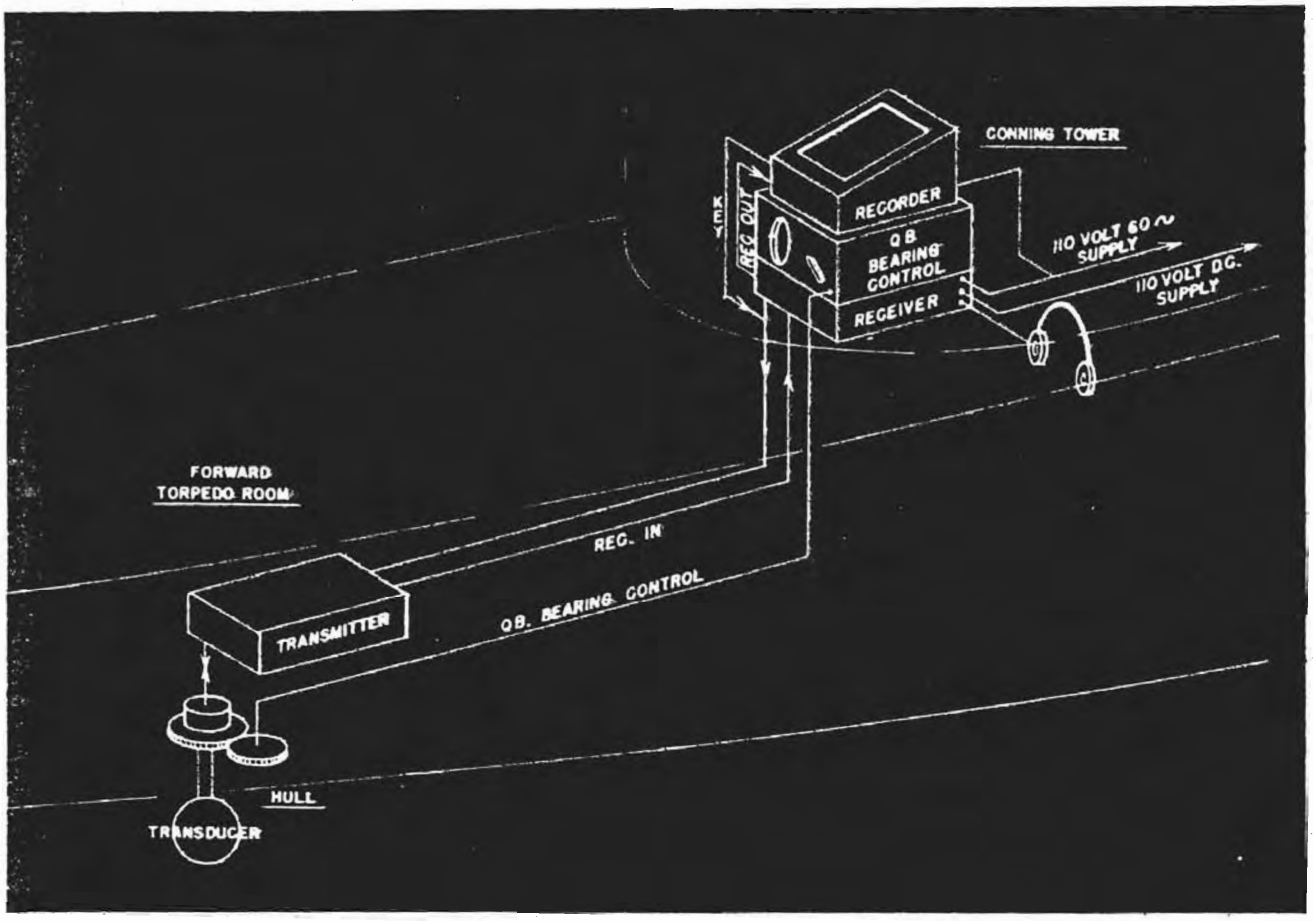
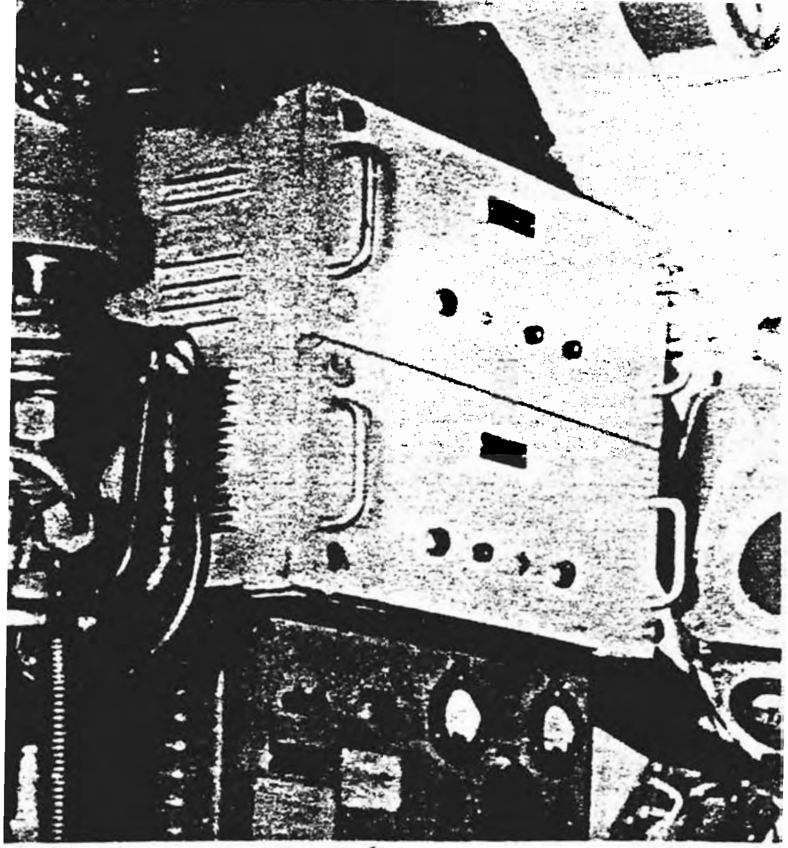


FIGURE 4.5.
A BLOCK DIAGRAM OF ONE INSTALLATION OF THE SOD EQUIPMENT ON A FLEET-TYPE SUBMARINE. IN THIS THE TRAINING WAS DONE BY THE QB SECTION OF THE WCA, AND BOTH THE RECEIVER AND THE RECORDER WERE MOUNTED IN THE CONNING TOWER WITH THE TRANSMITTER IN THE FORWARD TORPEDO ROOM AND THE TRANSDUCER MOUNTED ON ONE OF THE STANDARD SHAFTS.

No further work was done on this model after the departure of the FLYING FISH, and the remaining effort was largely devoted to development of a bearing recorder which presented bearing information simultaneously with range information on the same piece of recording paper. Before the cessation of active work on this project, the bearing recorder development had been reduced to a working model.

Simultaneously with this latter development, tests were made on a unit working at 90 kilocycles instead of 24 kilocycles, and employing a beam narrow in azimuth but broad in elevation so that contact with a mine could be retained even under adverse sea conditions. This gear, as would be expected, showed smaller maximum ranges than did the 24 kilocycle equipment, but, despite its higher frequency, it compared favorably with such equipment. This was undoubtedly due to the very short pulse length permitted by the higher frequency. Although this work did not result in the devising of a piece of service equipment, it demonstrated the extreme value of ultra-short pulses and indicated the compensations which must be made in the other portions of the equipment for such pulses, including a very wide pass band in the receiver, a very high peak power, and the use of the subtraction circuit. This and similar work should serve as a basis for future developments in the field of small object detection.

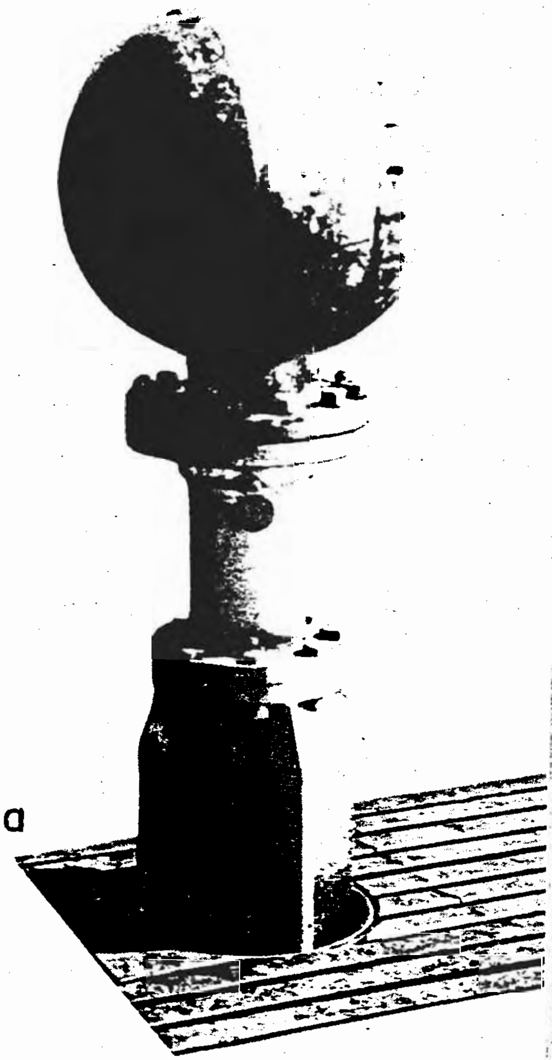


b

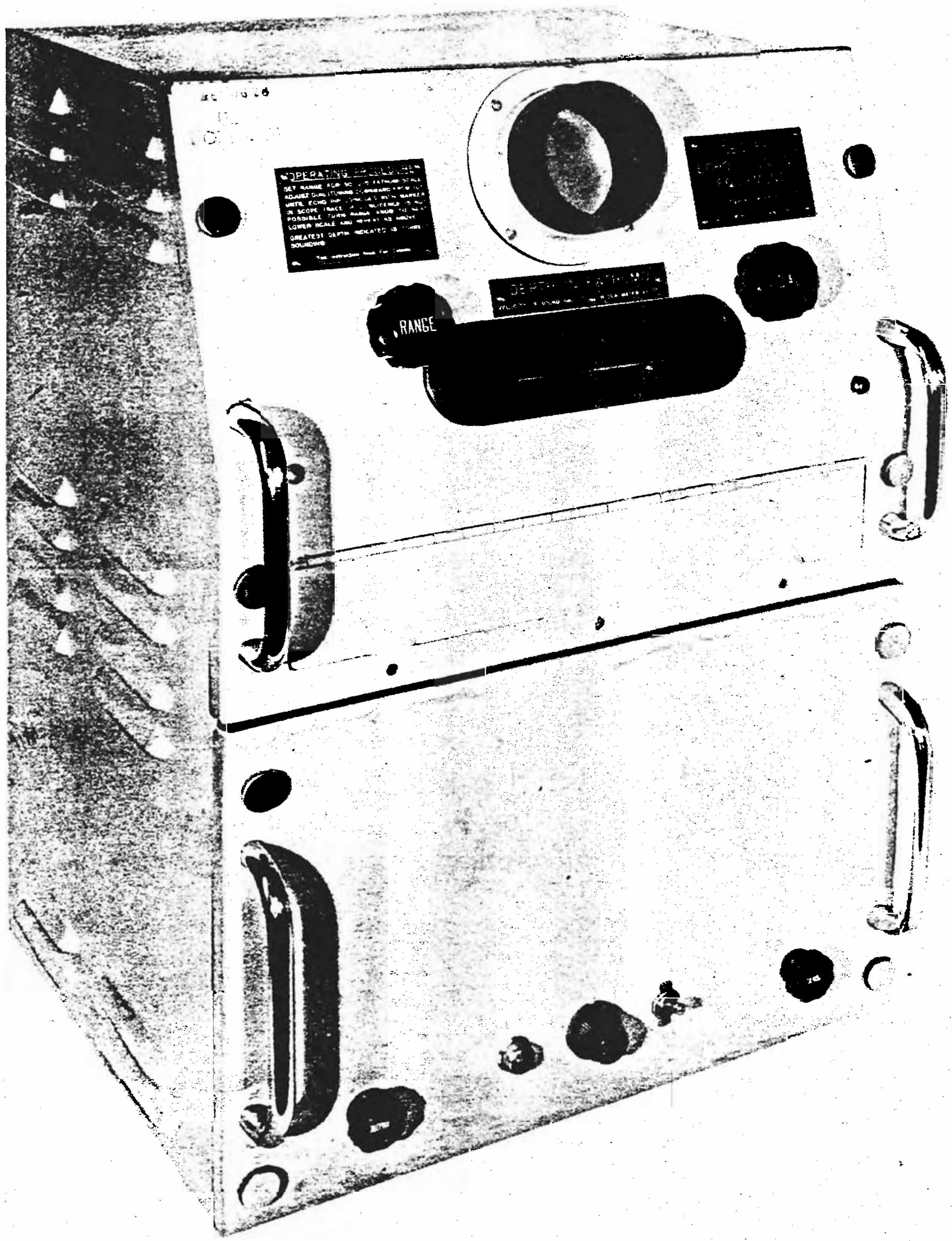
FIGURE 4.6.

VIEWS OF THE INSTALLATION OF SOD ABOARD THE USS FLYING FISH. (a) THE TRANSDUCER ON A TOPSIDE MOUNT. (b) THE RECORDER AND RECEIVER ABOVE AND BELOW THE QD TRAINING PANEL. (c) THE SOD TRANSMITTER MOUNTED ABOVE THE QC DRIVER IN THE FORWARD TORPEDO ROOM.

c



a


RANGE

III. secure echo-sounding equipment

(See File No. 09.22)

As United States submarines penetrated into the shallower waters surrounding the Japanese Empire, the need for sounding equipment which would not betray the submarine's presence to the enemy was keenly realized. UCDWR undertook, first, an analysis of the requirements to be satisfied by such a device, and secondly, the development of equipment embodying specifications resulting from this study.

It was demonstrated that there was no noticeable difference in the recognition of short pulses of water noise whose mean frequency lay in the high-frequency band (80 kilocycles) from that of equally short pulses of pure tones in the same frequency band. It had originally been thought that against a background of water noise, pulses of this noise would be less distinguishable, but tests made in the Recording Laboratory and also at sea showed that any such difference was not of practical significance. It was also demonstrated that pulses of extremely small peak power were capable of sounding to a depth of 100 fathoms, the depth considered adequate by the Submarine Force.

A model of the Secure Echo-Sounding Equipment (SESE) was built and installed on the USS SPADEFISH in the spring of 1944 for evaluation tests with the Fleet in the Pacific. This completed gear is shown in Figure 4.7, where it will be seen that a small (three-inch) cathode-ray oscilloscope was used as an indicator. The rest of the equipment consisted of a dual transducer (projector and receiver) mounted in the keel of the submarine (because of the very short time that was involved, it was not considered practical to use one transducer for the purpose). The two units were identical and were constructed of Y-cut Rochelle salt. Every effort was made to keep the operating procedure as simple as possible and the oscilloscope indication was arranged like the Type A indication in radar. In other words, the returning echo appeared as a "pip" which was lined up with a "notch" by means of the knob labeled "Dial." The pointer on the "Depth in Fathoms" scale then read the correct depth.

There are four range scales provided: 1 to 3.5 fathoms, 3 to 10.5 fathoms, 10 to 35 fathoms, and 30 to 105 fathoms. Four units of SESE were installed on Fleet-type submarines (USS SPADEFISH (SS-411), USS SPOT (SS-413), USS FLYING FISH (SS-229), and USS STICKLEBACK (SS-415)) and were used continuously on many war patrols. Figure 4.8 shows a typical installation in the conning tower.

FIGURE 4.7.
THE SECURE ECHO-SOUNDING EQUIPMENT. THIS CABINET CONTAINS THE ENTIRE UNIT WITH THE EXCEPTION OF THE PAIR OF COLUMN-MOUNTED TRANSDUCERS. IN NORMAL OPERATION, ONLY THE TWO DIALS ON THE SLOPING PART OF THE DEVICE ARE USED. THE RANGE DIAL SELECTS THE PARTICULAR SCALE, AND THE OTHER ONE MARKED "DIAL" MOVES THE CURSOR ON THE DEPTH-IN-FATHOMS SCALE IN SUCH A WAY AS TO BRING THE ECHO PIP ON THE CATHODE-RAY SCREEN INTO COINCIDENCE WITH A NOTCH.

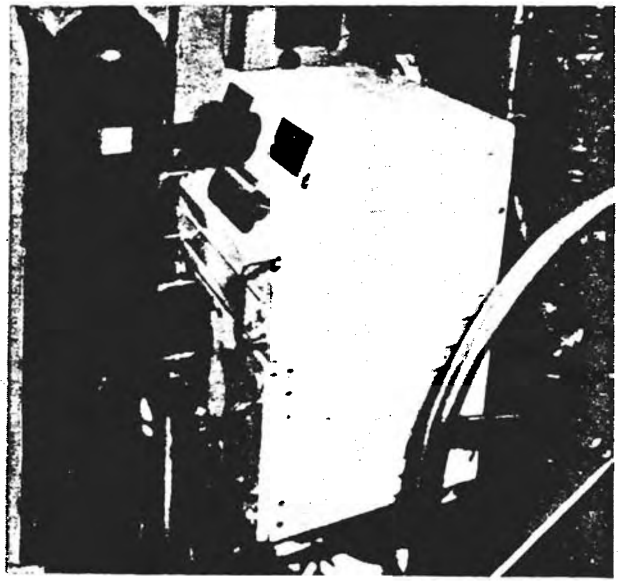
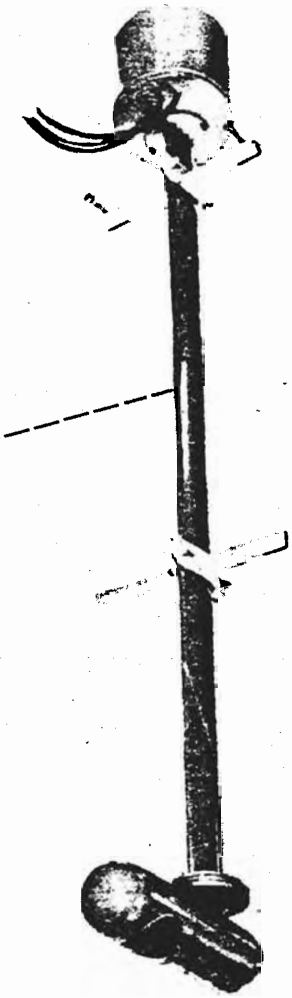


FIGURE 4.8.
A TYPICAL INSTALLATION OF SESE IN THE CONNING TOWER OF A FLEET-TYPE SUBMARINE.

FIGURE 4.10.

(a) A PHOTOGRAPH OF THE COMPLETE ELECTRONIC CABINET OF THE CONTOUR BOTTOM SCANNER (BATTERY-OPERATED MODEL). IT IS TO BE NOTICED THAT THERE ARE NO OPERATING CONTROLS ON THIS UNIT. THE USUAL CATHODE-RAY "CENTERING," "ON," AND "FOCUSING" CONTROLS ARE, HOWEVER, AVAILABLE.



(b) THE LIGHTWEIGHT OVERSIDE EQUIPMENT OF THE CONTOUR BOTTOM SCANNER. THE BOX AT THE TOP CONTAINS A MOTOR WHICH FURNISHES THE POWER FOR THE MOTION OF THE TRANSDUCER. IT ALSO CONTAINS A SINE POTENTIOMETER FOR PASSING ON ANGULAR INFORMATION TO THE MAIN CABINET. AT THE LOWER END OF THE STREAMLINED STRUT IS THE SMALL HIGH-FREQUENCY TRANSDUCER.

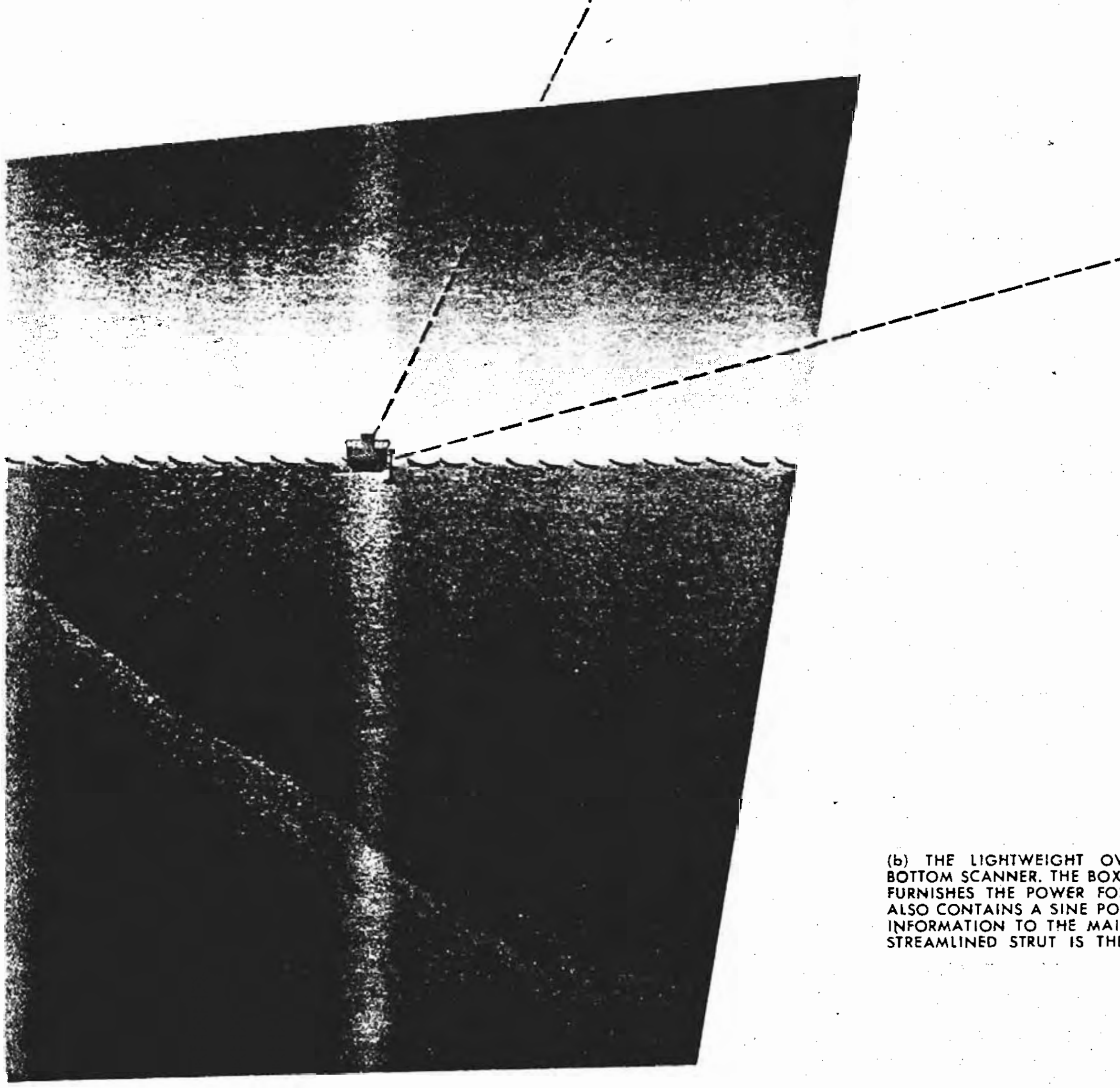


FIGURE 4.9.

A DIAGRAM SHOWING THE RELATIONSHIP BETWEEN THE DISPLAY ON THE FACE OF THE CATHODE-RAY TUBE OF THE BOTTOM SCANNER IN THE UPPER LEFT-HAND CORNER AND THE ACTUAL BOTTOM CONTOUR AS SHOWN IN THE LOWER PORTION OF THE DRAWING. THE OVERSIDE MOUNTING IS HERE SHOWN IN THE UPPER RIGHT-HAND CORNER AND ALSO LOCATED ON THE SHIP IN THE LOWER PICTURE.

IV. contour bottom scanner

(See File No. 02.134)

In the fall of 1944, the Hydrographic Office invited the Laboratory to consider the application of sonar methods to hydrographic problems. Specifically, a means of expediting the tedious process of wire-dragging in the water depths of channels and roadsteads was desired. A device, known as the Contour Bottom Scanner (CBS), essentially a scanning fathometer, was built by the Laboratory, and, after a period of tests, was engineered into a portable battery-operated device which can be mounted on any craft, as shown in the schematic diagram of Figure 4.9. It consists of an overside transducer mount (also shown in Figure 4.10(a)) together with a small cabinet carrying all the electronic gear and indicator, as shown in Figure 4.10(b). In the bottom of the transducer mount is a rotating section, carrying a small transducer, which is simply an array of ADP crystals cycle-welded to a thick rubber diaphragm and so arranged that it can be rotated back and forth through an angle of approximately 130 degrees athwartship.

The electronic unit generates very short pulses at a frequency of 80 kilocycles at a fixed and rapid rate. These pulses on reaching the bottom are reflected and brighten the cathode-ray screen at a radial distance which is proportional to the slant depth. Since the cathode-ray screen is of a persistent type, it draws a contour of the bottom immediately below the ship as it swings back and forth. The ability of such a rapid method to outline sharp irregularities in water has been demonstrated, and several photographs in Figure 4.11 show the results obtained near San Diego. For the original purpose the maximum depth given on the screen was set at 100 feet, but as this report is being written, the portable model of CBS is being taken to Bikini Atoll to take part in the CROSSROADS Project. Since the average water depth at Bikini is of the order of 30 fathoms, the range scale of the device has been extended to 200 feet.

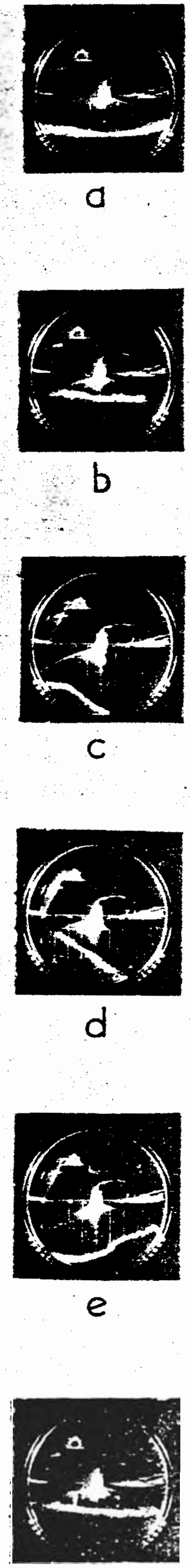


FIGURE 4.11.
PRESENTATION BY THE CONTOUR BOTTOM SCANNER OF:

(a) GENERALLY LEVEL SAND AND MUD BOTTOM AT ABOUT 40 TO 60 FEET DEEP.

(b) GENERALLY LEVEL ROCKY BOTTOM AT ABOUT 25 TO 35 FEET DEEP.

(c) SIDE OF SUBMARINE CANYON SHOWING DEPTHS FROM 40 TO 100 FEET.

(d) STEEP UNIFORMLY SLOPING WALL OF SUBMARINE CANYON.

(e) IRREGULAR WALL OF SUBMARINE CANYON.

(f) GENERALLY LEVEL BOTTOM WITH BODY OF KELP.

FIGURE 4.12. A CUT-AWAY PHOTOGRAPH OF THE EXPENDIBLE ECHO-SOUNDING EQUIPMENT. THE COLLAPSIBLE ANTENNA IS SEEN AT THE TOP SURROUNDED BY THE PARACHUTE CASE. IN THE LONG CYLINDRICAL TUBE ARE THE VARIOUS STAGES OF THE ELECTRONIC GEAR, AND HANGING BELOW THE WHOLE UNIT IS THE TRANSDUCER WHICH IS RELEASED ON IMPACT WITH THE WATER.

V. expendible echo-sounding equipment

(See File No. 02.135)

To fill the need for equipment to make soundings in the shallow water close to an enemy's shore, UCDWR assisted NEL in developing the Expendible Echo-Sounding Equipment, which was a modification of the expendible radio sono buoy developed by the Columbia University Division of War Research. This buoy consisted of a cylinder carrying a small parachute and a radio antenna. Inside the cylinder were stowed a hydrophone and sonic amplifying equipment coupled to a frequency-modulated radio transmitter. The device was designed to be launched from blimps or oircraft and, on striking water, to release its hydrophone on a length of cable and transmit by radio any sounds which it detected in the water.

UCDWR modified this by replacing the hydrophone and amplifier with a lead line and self-locking mechanism coupled to a potentiometer which thereby controlled the frequency of the radio transmission. This frequency then became a measure of the length of lead line paid out and therefore, presumably, of the depth of the water.

Recognizing certain inherent difficulties in this type of mechanism, another modification, which was later called the Navy Model CXKD Equipment, was devised. In this a small transducer was released on a short length of cable when the buoy struck the water, and suitable modifications were made in the electronic circuits so that this became a pulsed echo-sounding system and both the outgoing ping and returning echo were transmitted over the radio link. This required a cathode-ray oscilloscope for measurement purposes in the aircraft, and later a very compact CRO, using a one-inch tube, was designed for this service. The transducer consisted of a small array of ADP crystals, cycle-welded to a rubber sound window and operated at 115 kc. Pulses are emitted at a constant rate, and depths of water between five and 70 feet can be measured with an accuracy of seven per cent. Figure 4.12 shows the complete CXKD and Figure 4.13, a schematic diagram of its use. Inasmuch as the carrier frequencies of the buoys can be set to different values and identified by the color of the parachutes, it was intended that the actual spotting of the buoys would be done by aerial photography.

It was suggested by the Underwater Demolition Teams (UDT) of the Amphibious Forces that the CXKD could be used in another way which seemed to possess considerable advantage over the airborne method. This proposal was to attach a CXKD to the paddleboards used by the UDT. In this way a plot could be made of the bottom depths on the control ship and the positions of the paddleboards determined by radar. At the close of hostilities UCDWR was engaged in the construction of a number of these for pending action against Japan.

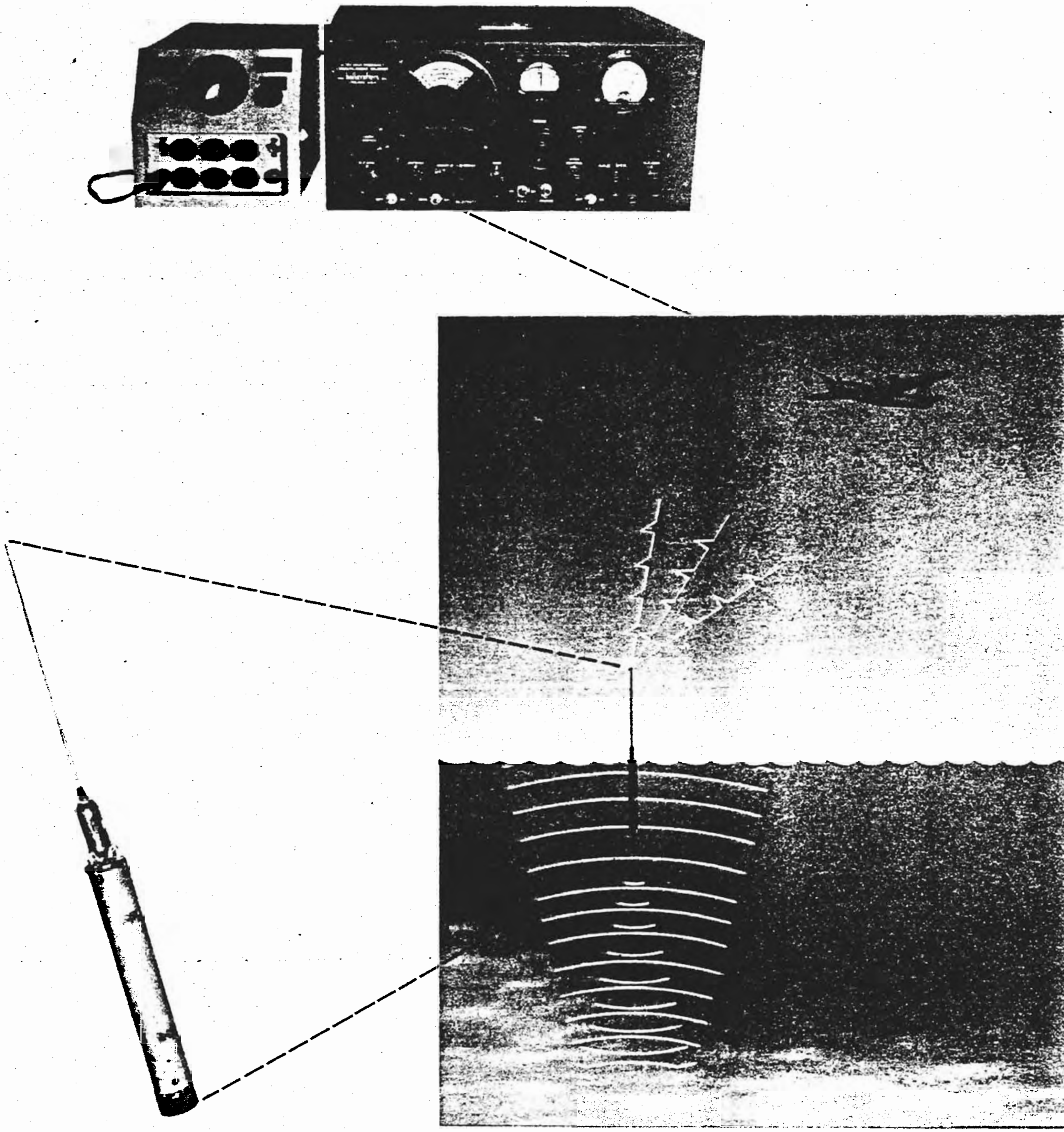


FIGURE 4.13.

A DIAGRAM OF THE USE OF THE EXPENDIBLE ECHO SOUNDER. THE UNIT IN THE WATER IS SOUNDING FOR THE BOTTOM AND RELAYING ITS INFORMATION TO THE PLANE

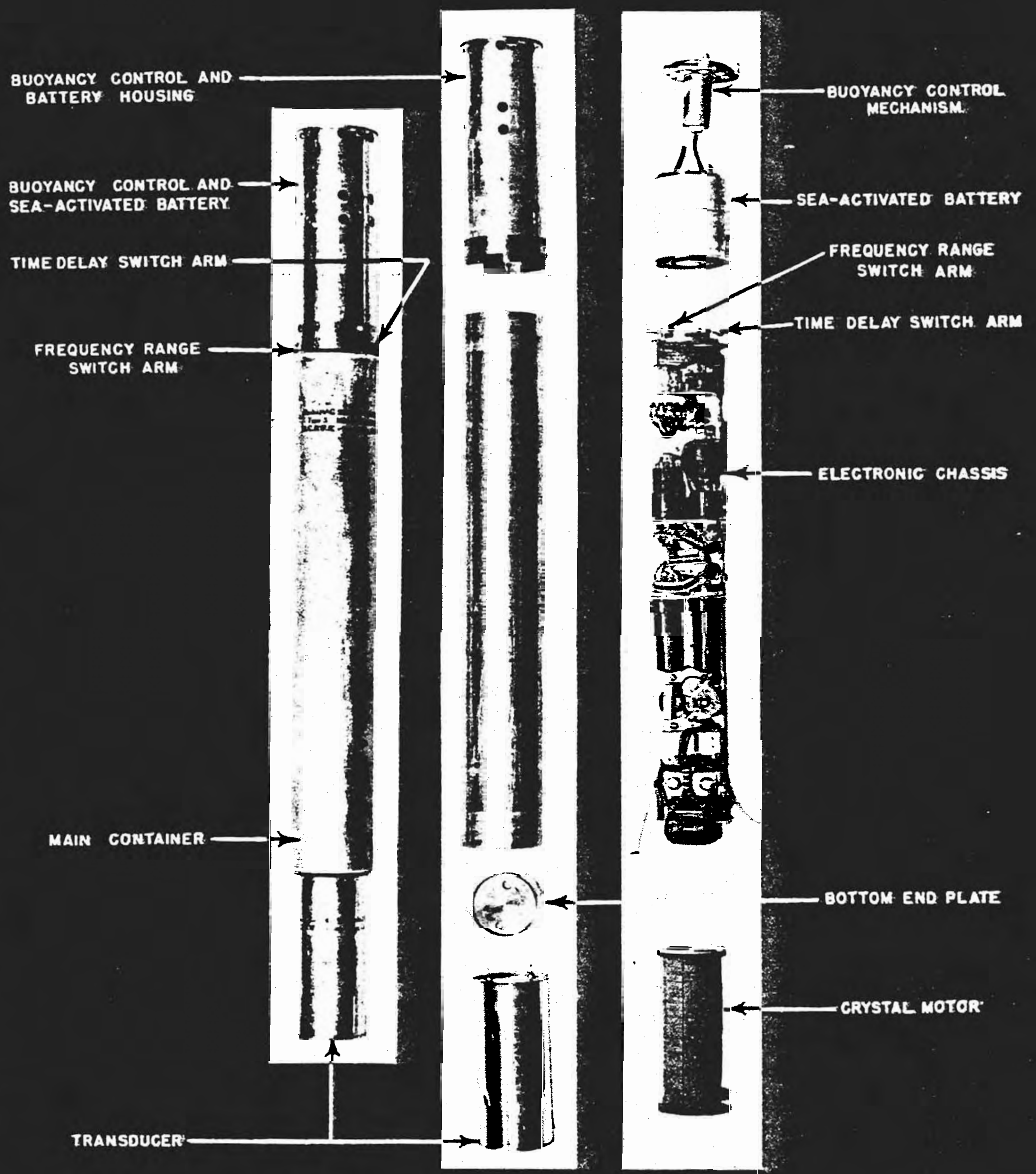
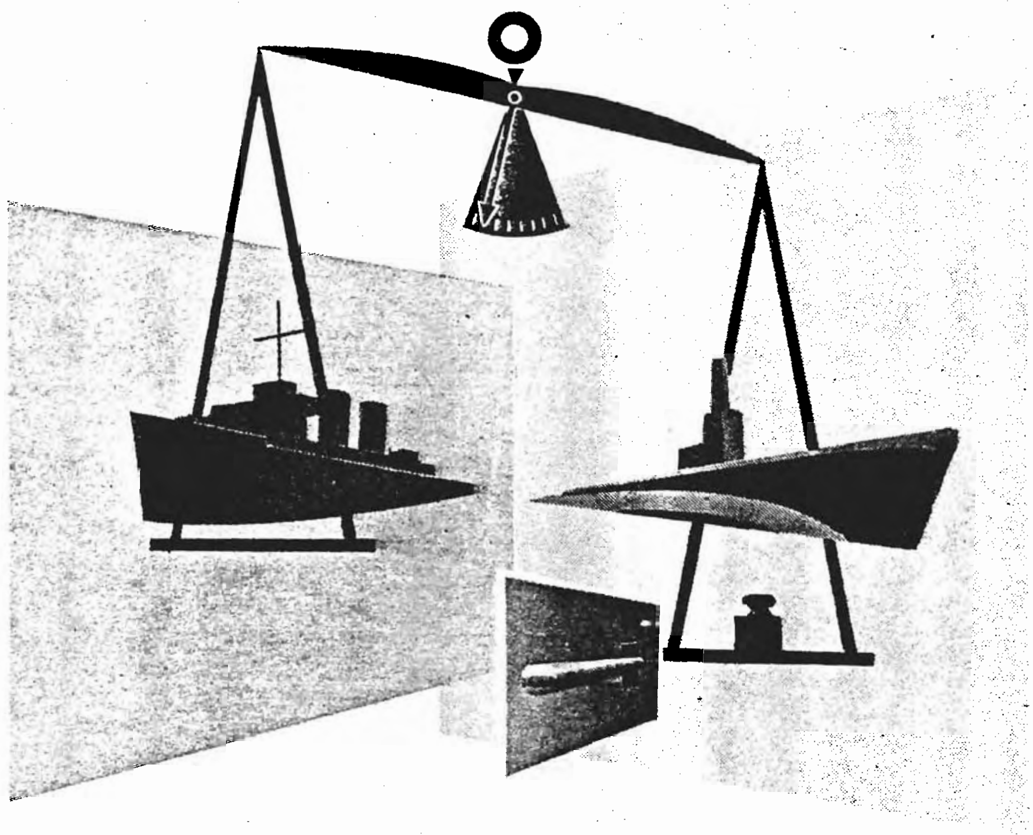


FIGURE 4.14. A COMPLETE NAC SOUND BEACON, ALSO SHOWN DISASSEMBLED.



C. COUNTERMEASURES

I. nac sound beacon

(See File No. 09.412)

In order to aid submarines in breaking sonar contact established by enemy antisubmarine vessels, UCDWR devised the Navy Model NAC sound beacon, an expendible device for release through the signal tube of a submarine. It is so designed that on being released at depths less than 600 feet, it seeks a depth of 50 feet and by means of a buoyancy control holds this depth for a period of about 15 minutes. It carries a sea-water-activated cell as a source of electric power which supplies energy to an electronic circuit connected to a crystal transducer. This causes it to emit sounds in a number of supersonic bands. The frequency of these sounds is swept at a rate of about four cycles per second across one of three bands (15-19, 17-22½, 21½-27½ kilocycles). A selector switch enables the operator to select the band in which the enemy is echo ranging, while another control permits him to set a time clock which delays the emission of sound by as much as ten minutes.

Tests under simulated operating conditions indicate that one beacon will not, in general, suffice to break sound contact; several are needed, and their proper disposition relative to the enemy vessel and the subsequent maneuvering of the submarine are important factors. Figure 4.14 shows the commercial model of the NAC sound beacon, the buoyancy control and sea battery being housed in the perforated structure at the top, the electronic gear in the central position, and the Rochelle salt transducer at the bottom.

The Navy Department contracted for over 10,000 units of this device (Contract NXsr-60065 with the Sound Equipment Corporation, Glendale, California, for 5450 units, and Contract N5sr-10525 with the Warwick Manufacturing Company, Chicago, for 5000 units), and over 4000 were delivered to the Submarine Force prior to the end of the war. During the last six months of hostilities, the NAC beacon was used very successfully.

II. x-nag beacon

(See File No. 09.423)

The NAC beacon provides jamming in the supersonic region and is of little use against attacks based purely on listening. UCDWR therefore developed a companion to the NAC which would provide for jamming in the sonic region. This unit did not pass beyond the experimental stage but was tentatively given the Navy Model Number X-NAG shown in Figure 4.15. In general operating characteristics, it is similar to the NAC sound beacon but generates its sound mechanically. There are actually two sources of sound, one an electronic "horn" similar to an automobile horn whose oscillations are controlled by a gas tube, and the other a motor-driven rotor which carries rotating hammers up and over inclined ramps so that these hammers beat on the hull of the unit. In the present stage of development, a good operator can hear a submarine through the noise of the X-NAG, but the maximum range of contact is considerably reduced and the general confusion does not permit well-developed attacks.

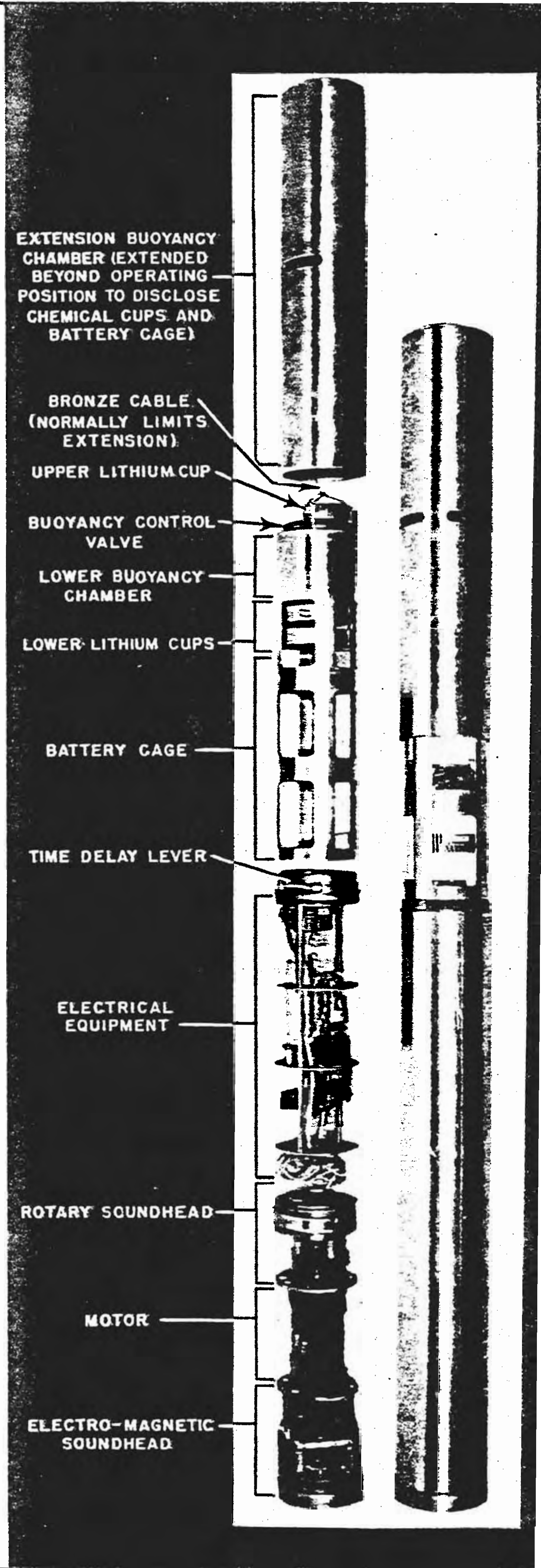
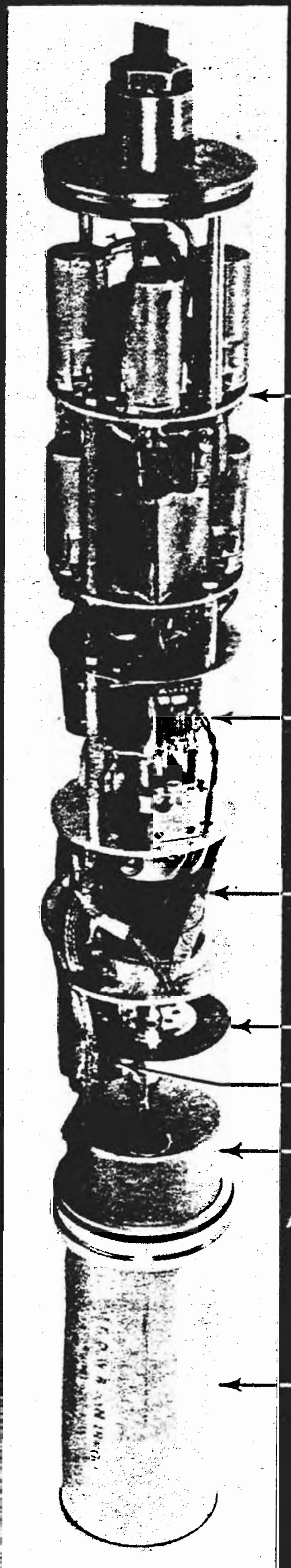


FIGURE 4.15.
A COMPLETE X-NAG SOUND BEACON, ALSO SHOWN DISASSEMBLED.



III. nah sound beacon

(See File Nos. 09.413, 09.80)

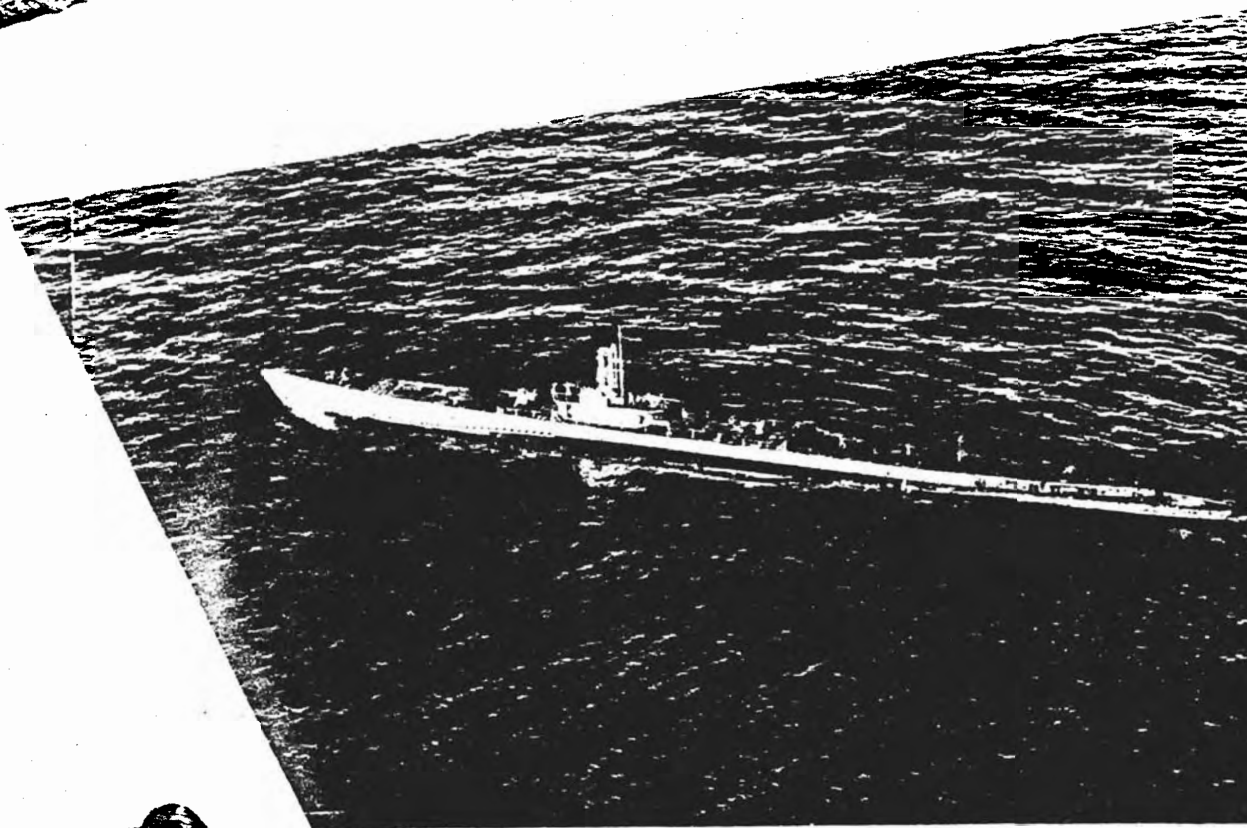
A number of basic faults in the NAC sound beacon were recognized by UCDWR, and in an endeavor to correct them, the NAH beacon was developed. The NAC beacon, in sweeping through a wide band of frequencies, radiates considerable power which is wasted on an enemy echo ranging on a single frequency. In addition, the operating frequency must be set to correspond to the enemy's frequency. If this is done wrongly or if the enemy changes frequency, the device loses its value. These difficulties can be overcome with a sound beacon which transmits all its energy at a single frequency and which automatically sets that frequency to agree with the enemy's echo-ranging equipment. The NAH beacon accomplishes this by recording the enemy's ping on a magnetic disk and using this recorded signal to establish the frequency of an amplifier which then re-transmits it through a crystal transducer. Figure 4.16 shows the internal arrangement of the NAH beacon. At one end may be seen the transducer sealed in an ordinary "tin" can; immediately below it is the motor-driven recording unit in which the magnetic material is in the form of a thin disk. The unit is arranged to stop the continuous transmission every 15 seconds so that if the enemy changes his frequency, it may be re-established in the beacon. Because the transducer covers the band 15-35 kilocycles, the beacon is capable of jamming a single-frequency echo-ranging system within these limits.

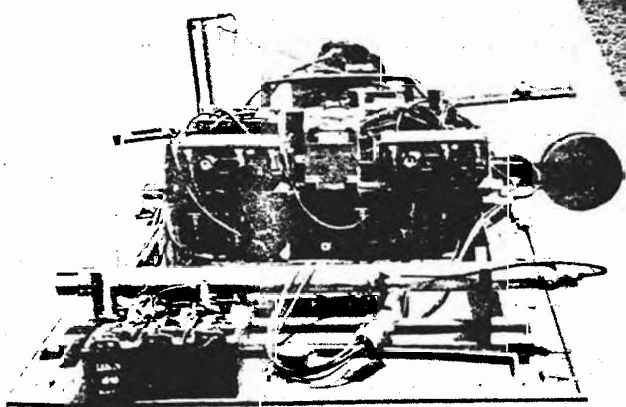
At the time of writing this report, work on the NAH beacon is not entirely complete but is being carried on by the Navy Electronics Laboratory.

FIGURE 4.16.
AN EXPERIMENTAL VERSION OF THE NAH BEACON.

IV. nad sound beacons

(See File Nos. 09.40, 09.45, 09.451, 09.452, 09.453, 09.454, 09.455)





1. nad-3 sound beacon

(See especially 09.451)

All the sound beacons described above remain stationary in the water once they are ejected from the submarine. The NAD-3 is the smallest of a group of self-propelled devices whose purpose is to simulate the self-noise of a submarine and are, therefore, true decoys rather than jammers. The NAD-3 proved to be the most difficult of these units to develop, because it had to be small enough to be ejected through the signal ejection gun of the submarine, and at the same time contain all the machinery necessary to drive and furnish course and depth control and make the necessary noises. Although this work is not entirely complete at the time of writing this report, it is being carried on as a continuing project in the Navy Electronics Laboratory and has reached a stage of development in which only trivial changes are expected.

The external appearance of the beacon as well as its appearance with the hull removed is shown in Figure 4.17. It should be noted that the beacon is being driven by a tractor propeller and that it carries course and depth control planes at its stern. The unit derives its power from an Edison-type battery mounted amidships and housed in a plastic case with the electrolyte separate from the electrodes. The battery is activated by breaking a partition so that the electrolyte may flow into the electrode section. The propeller is driven from a small motor in the forward end of the body and, in order to clear the submarine, will travel at high speed for a predetermined time. At the end of this time the unit slows down to a speed of about three knots and follows a course which has been set by means of a flush dial on the hull of the unit. The course is controlled by a small gyro which may be seen near the stern. Depth is controlled by a bellows and pendulum arrangement in the tail assembly. Another motor just forward of the battery drives, through an appropriate series of gears, a pair of rotary hammers which communicate their energy into the hull through striking pins. One of these series of hammers produces a gear whine and the other a propeller-beat simulation.

This beacon provides a moderately good imitation of a submarine making 120 turns at periscope depth and will maintain an operating depth of 50 feet after ejection from any depth less than 600 feet, traveling at a speed of 2½ knots for approximately 20 minutes. At the end of its useful life it sinks.

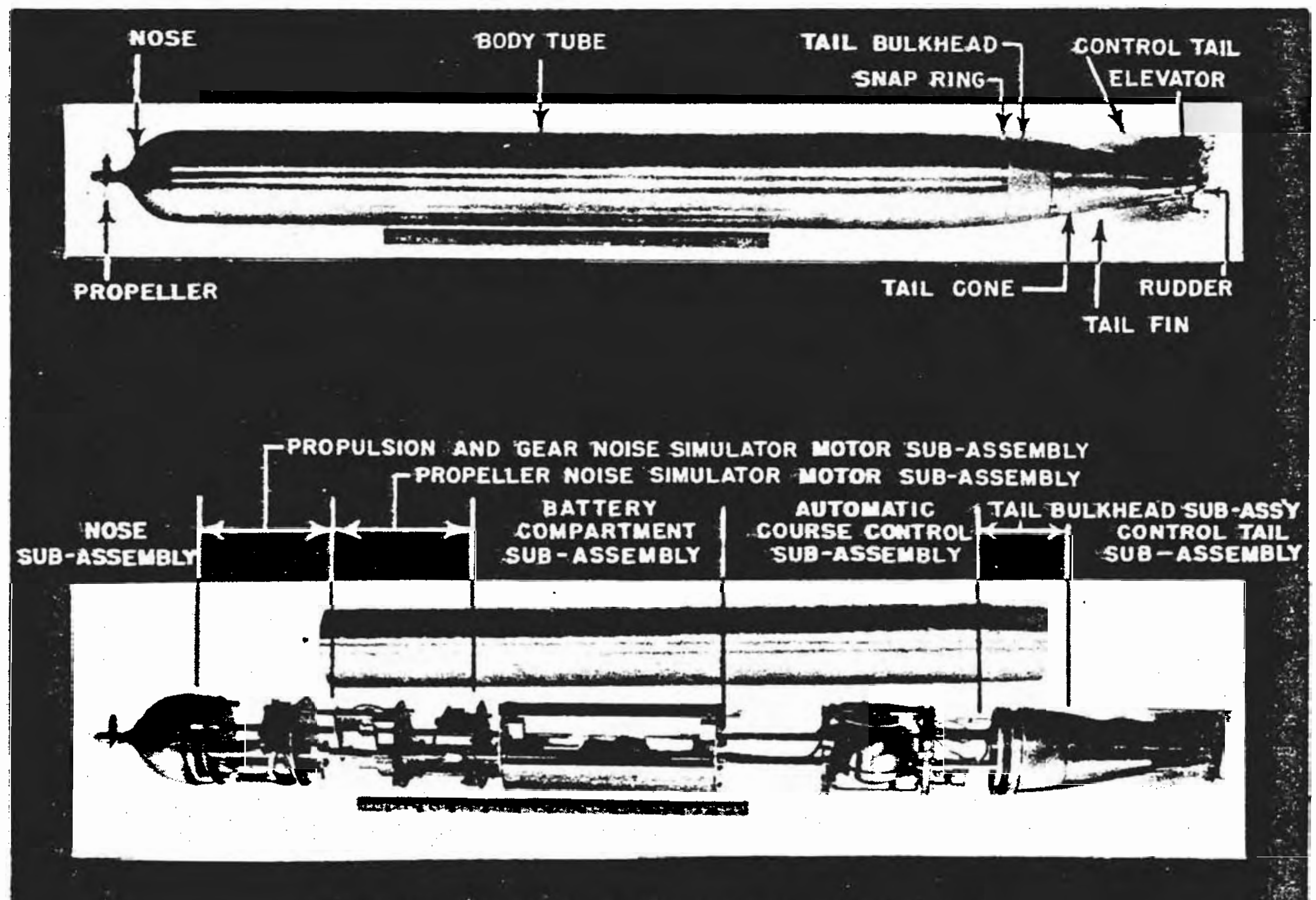


FIGURE 4.17. A COMPLETE NAD-3 BEACON. ALSO SHOWN DISASSEMBLED.

2. nad-6 sound beacon

(See especially File No. 09.452)

The NAD-6 sound beacon, as shown in Figures 4.18 and 4.19, is a self-propelled submarine decoy designed to be launched under its own power from a 21-inch torpedo tube. The need for a device of this type was so urgent that it did not seem feasible to install special ejection tubes for it in submarines, and consequently both the NAD-6 and the NAD-10 were arranged to swim out of the standard torpedo tube. This allowed the designers much more flexibility in the treatment of the exterior of the body and therefore materially speeded up the development work. The NAD-6 (so-called because its main body is six inches in diameter) produces noises characteristic of a submarine making 120 turns, and in addition returns echoes to any echo-ranging gear operating between 15-30 kilocycles. It derives its power from a sea-water-activated battery located in the nose, which drives the main propulsion motor in the stern and the simulator motor located just aft of the battery. Traveling at a speed of four knots, the beacon has an operating life of about 20 minutes. Both course and operating depth may be set prior to its launching by means of flush dials on the hull. The noisemaker is mechanical and consists of a series of motor-driven gears which bear on two sets of pressure pads, driving them against the hull. The characteristics of these pads and the gears behind them are such that one set simulates gear whine and the other propeller cavitation.

In general, maximum ranges of echo detection of a NAD-6 beacon are approximately the same as those of a Fleet-type submarine. The Navy Department contracted with the Bendix Aviation Corporation, North Hollywood, California (Contract NXsr-87757), for the production of 500 units of the NAD-6. At the request of the Navy, UCDWR undertook the proof checking of a certain number of these beacons and was assisted by personnel assigned from the Submarine Force for instruction in beacon technique. In addition, at the request of the Commander Submarine Training Command, Pacific Fleet, engineers from UCDWR set up and operated a beacon shop in Pearl Harbor, where beacons were bench-checked and made ready for sea trials, and cooperated with the officers of ComSubsTrainPac in the formulation of Fleet doctrine. A number of the NAD-6 beacons were taken on war patrol before the cessation of hostilities.

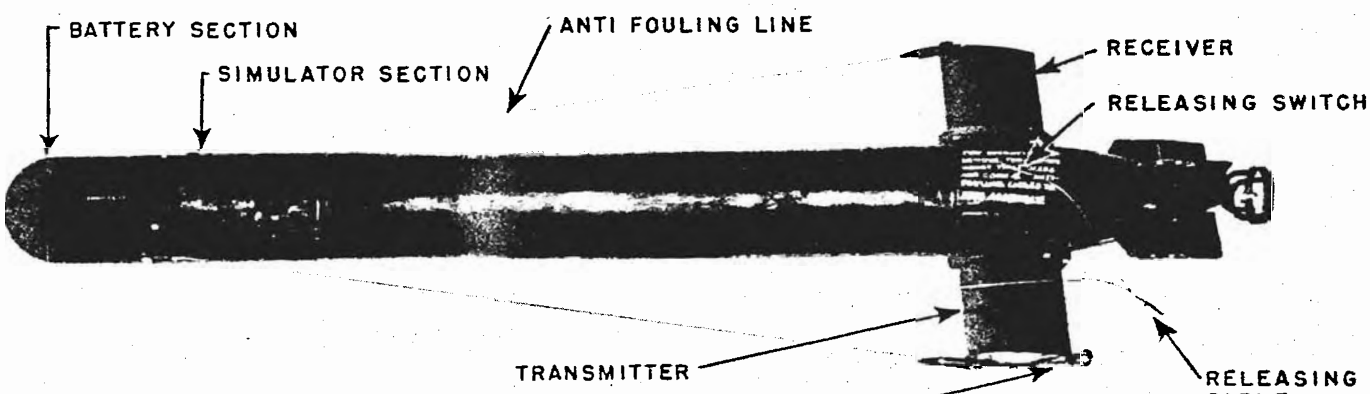


FIGURE 4.18. THE NAD-6 SOUND BEACON.

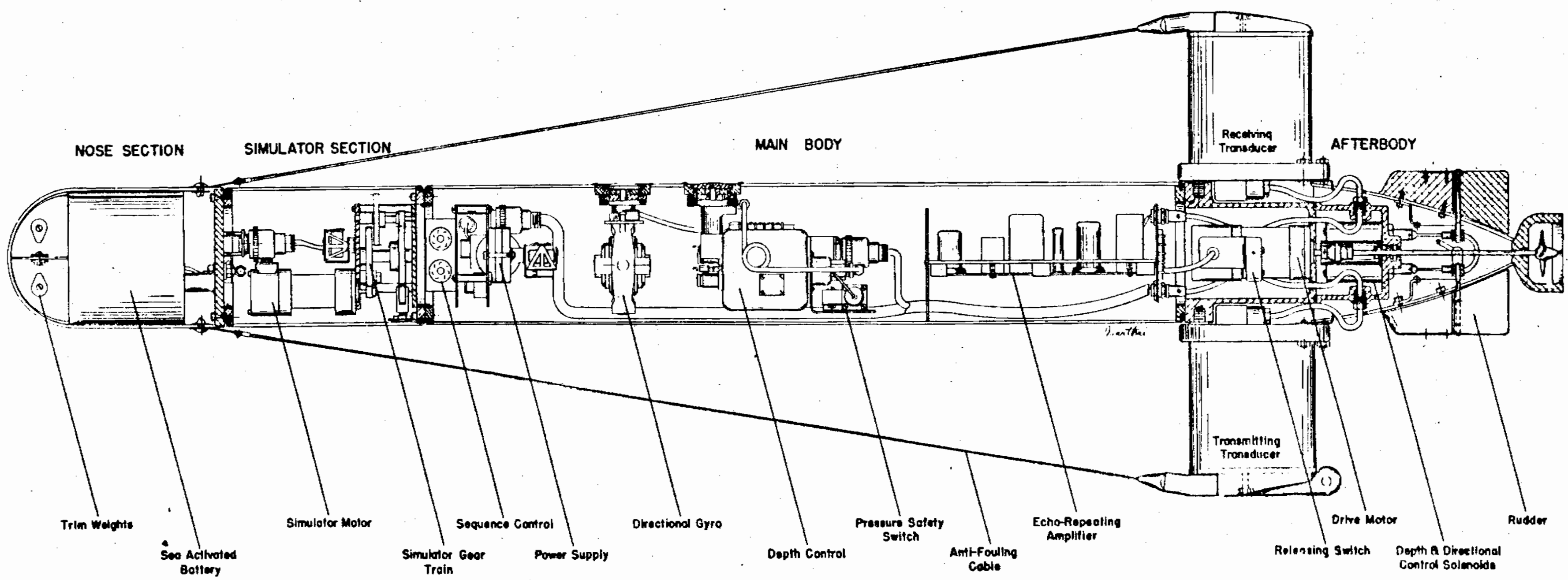


FIGURE 4.19.
A CROSS-SECTION OF THE NAD-6 SOUND BEACON.

3. nad-10 sound beacon

(See especially File No. 09.453)

As another aspect of the urgency of the NAD program, it was considered advisable to carry on a second development simultaneously with that of the NAD-6. This procedure was suggested because of the existence in Navy storage of a sizable number of torpedo-like bodies, accumulated during the course of work on another project which had been abandoned. UCDWR undertook to modify these bodies to serve as submarine simulators. The device resulting from this modification, which ultimately became known as the NAD-10, is shown in Figures 4.20 and 4.21. Like the NAD-6, it derives its name from the fact that the main body is ten inches in diameter. The larger size of this body allowed still more flexibility in design. The various problems which resulted from the fact that the original body was not entirely suitable for this different purpose, so far as propulsion was concerned, caused the development work on the NAD-6 and NAD-10 to be finished at approximately the same time.

Despite the original hope, the NAD-10 was not a simply-made modification, and the differences between the NAD-6 and NAD-10 ultimately became performance differences. The larger size body permitted a number of additional features to be added to the NAD-10. The self-noise simulation is generated by an electronic circuit and applied to a magnetostriction transducer, located outside the body as can be seen in Figure 4.21. The simulation provided in this manner is considerably more realistic than that of the mechanical noisemaker of the NAD-6. Moreover, it is a very easy matter to alter the characteristics of the noises so generated. Potentiometers are provided on the electronic chassis inside the body which enable the operator to change the effective propeller beat, gear whine frequency, and gear whine intensity. The echo repeater used is essentially the same as that on the NAD-6, but uses a different set of transducers; the receiving transducers are located in the nose and the transmitting transducers amidships. Provision is also made for two different speeds of propulsion: a high speed of about seven knots, which carries the unit clear of the submarine, and a low speed of about four knots for the rest of its run. It was planned to use a 12-volt storage battery, but the upkeep on this presented serious difficulties and a battery-breaking mechanism was designed for later versions of the NAD-10 for use with an Edison-type cell. This type of cell carries the electrodes and electrolyte in separate compartments so that it requires no upkeep. Immediately before firing the unit, a partition in the cell is broken and the electrolyte flows into the plate compartment, as in the case of the battery used in the NAD-3.

The Navy Department contracted with the American Type Founders, Elizabeth, New Jersey (Contract NXsr-84987), for the production of 500 units of the NAD-10. At the Navy's request, UCDWR undertook the proof checking of a certain number of these and in addition gave instructions in beacon technique to various personnel assigned by the Submarine Force. Engineers from UCDWR included the NAD-10 as well as the NAD-6 in their Pearl Harbor activities. A number of these beacons were taken on war patrol before the cessation of hostilities.

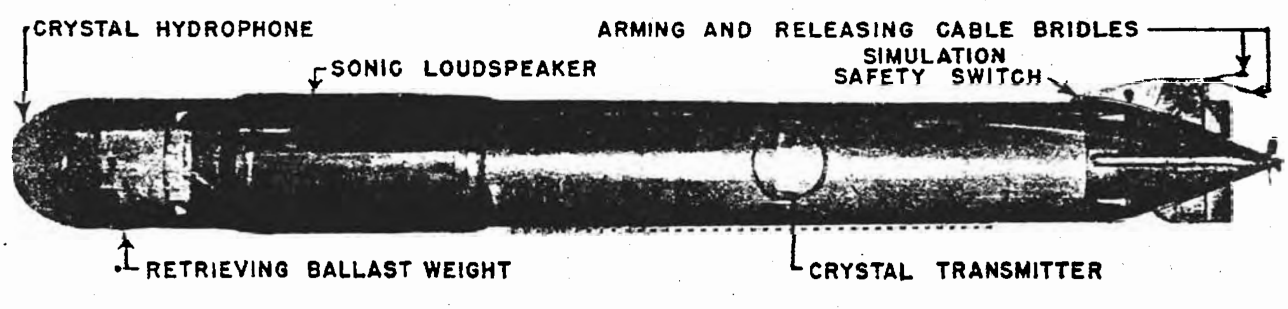
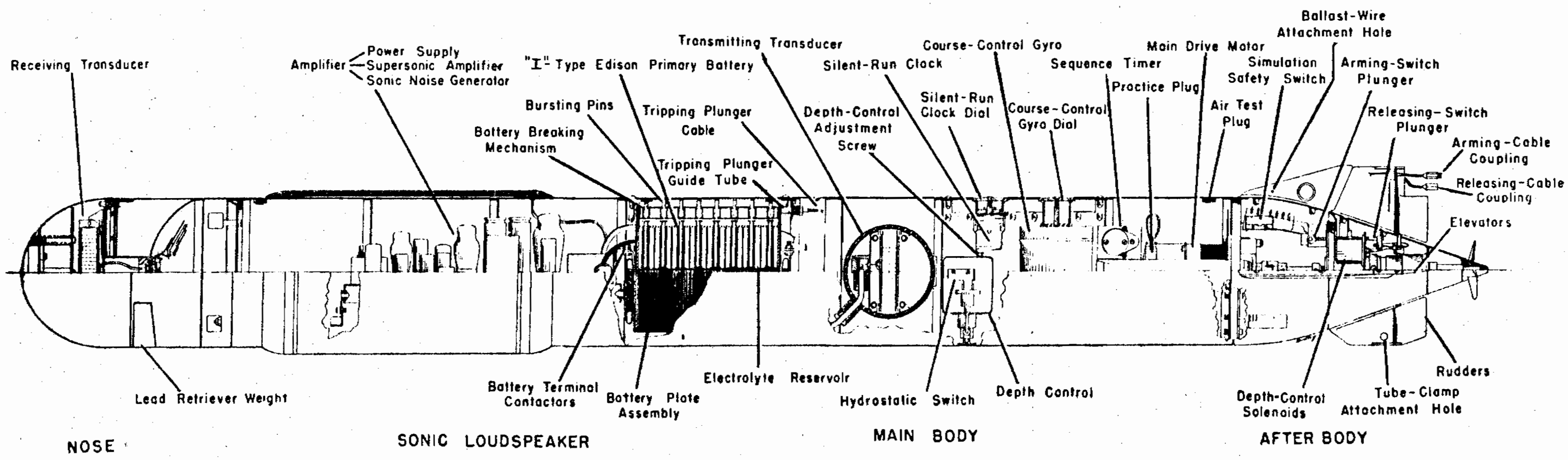
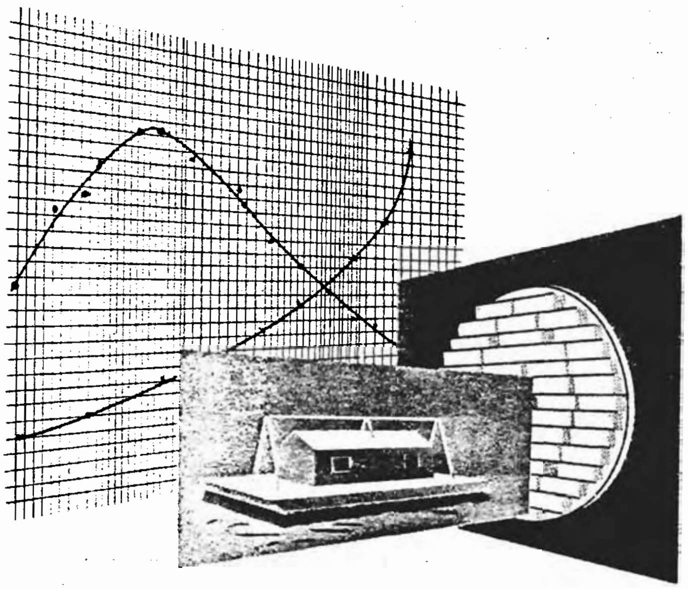


FIGURE 4.21. A PHOTOGRAH OF THE NAD-10 SOUND BEACON.

FIGURE 4.20.
A CROSS-SECTION OF THE NAD-10 SOUND BEACON.





D. TRANSDUCER PROGRAM

1. transducer laboratory

(See File Nos. 01.20, 01.21, 01.212, 01.214, 01.22, especially 01.22)

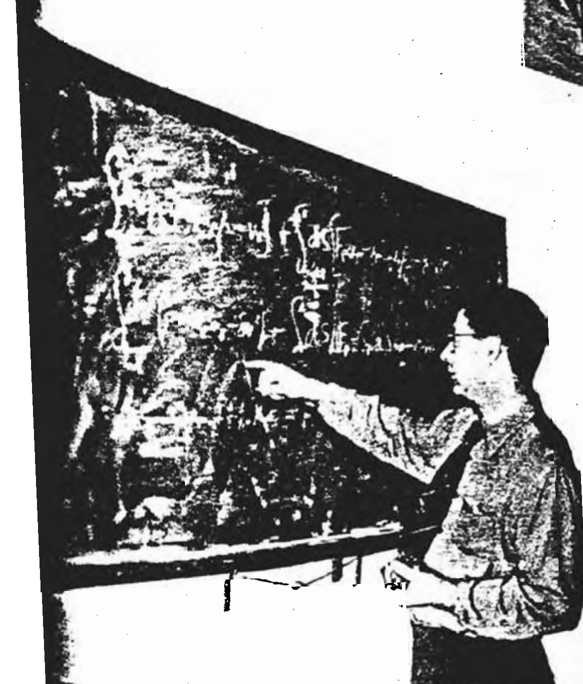
Shortly after the establishment of the Laboratory, a small group was assembled to make scientific studies of X-cut Rochelle salt. Its primary purpose was to ascertain whether the dependence of properties of X-cut Rochelle salt on temperature and electric field strength was sufficiently marked to eliminate it from serious consideration as a transducer material. This group served as the nucleus of the Transducer Laboratory, which was established to undertake engineering work in connection with transducer design and to continue fundamental studies on the properties of piezoelectric crystals. The Transducer Laboratory designed and built nearly all the transducers used by the Sonar Data Division and, in close association with the electronic designers of the Sonar Devices Division, designed all other transducers used in UCDWR developments. Its growth was gradual but steady, and by the end of the experimental program, it had collected sufficient equipment to build a very large variety of transducers. It bought its crystalline material from either the Brush Development Company, or, occasionally, the Western Electric Company, in the form of cut crystal plates, which were sawed and machined to whatever size was required for each particular design. Fortunately, the storage of crystals and the fabrication of transducers did not require air-conditioning in San Diego.

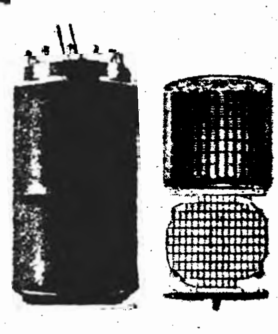
The Transducer Laboratory was gradually provided with the tools it needed for its increasing activities. A bandsaw and a high-speed vertical mill equipped with a vacuum chuck were used for the cutting and final machining of crystals. A large variety of pneumatic presses were built and used to apply pressure to crystal arrays during glueing operations. Several thermostatically controlled ovens, one of which maintained the atmosphere at a controlled humidity, were used in curing glued joints. A dehydrating tower was designed and built that was capable of dehydrating and storing 30 gallons of castor oil under vacuum and so arranged that oil could be pumped from it under pressure to another vacuum chamber so the transducers could be vacuum-dried and filled with dehydrated castor oil at an oil pressure several pounds above atmospheric without air ever coming into contact with the crystals. Before the end of the Contract, the molding of rubber and plastic parts for transducers had begun and a steam autoclave was added. At all times the Transducer Shop was under-equipped, however, and, despite efforts to maintain adequate stocks on hand, undesirable delays were often incurred because of difficulties in procuring crystals, rubber sound windows, castings, and other essential parts.

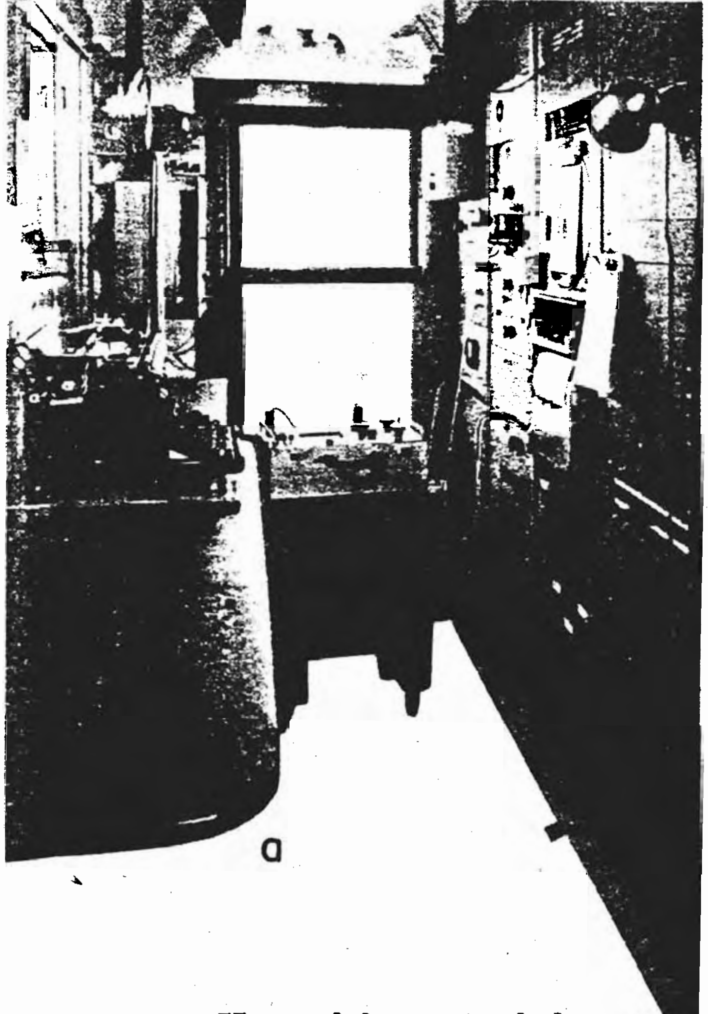
In the fall of 1943 with the increased need for transducers of unusual characteristics, a number of competent theoretical and experimental physicists were diverted from other work and asked to concern themselves with the over-all transducer problem. This group made very definite progress in the general formulation of the theoretical and practical aspects of transducer engineering. The enormously complicated theoretical design problems were largely resolved into a set of design principles from which reasonably accurate predictions of transducer performance could be made. Several ingenious shortcuts were devised. It was shown that under certain conditions electrical circuits could be constructed whose electrical performance was analogous to that of a transducer; consequently, electrical measurements made on such circuits took the place of laborious calculations. The problem of transducer engineering is mainly that of devising an equivalent electrical circuit for the transducer and, by calculations made as indicated above or by other means, predicting the performance of the transducer; or, conversely, predicting the design features necessary to attain a given performance. The concoction of such an equivalent circuit is in itself a difficult matter, for to include all the sources of energy dissipation, the finite size of crystal blocks, etc., is very difficult.

One of the principal contributions of the Transducer Laboratory was to emphasize the necessity of considering the transducer as an integral part of the entire system rather than as a separate unit. The transducer reacts on the electronic circuit in a way that the average electronic engineer finds difficult to realize, and a close liaison between electronic and transducer engineers is therefore essential in the development of sonar systems.

The entire subject of transducer engineering in the stage of development which it had reached under UCDWR auspices has been collected in a volume, "The Design and Construction of Synthetic Crystal Transducers," one of the volumes of the Summary Technical Reports of Division 6, NDRC. During the closing months of the Contract, the efforts of the research group of the Transducer Laboratory were very largely directed towards the compilation of this book.







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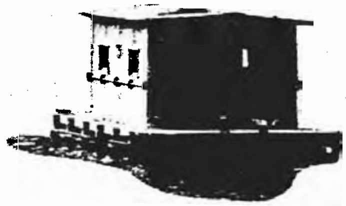


II. calibration laboratory

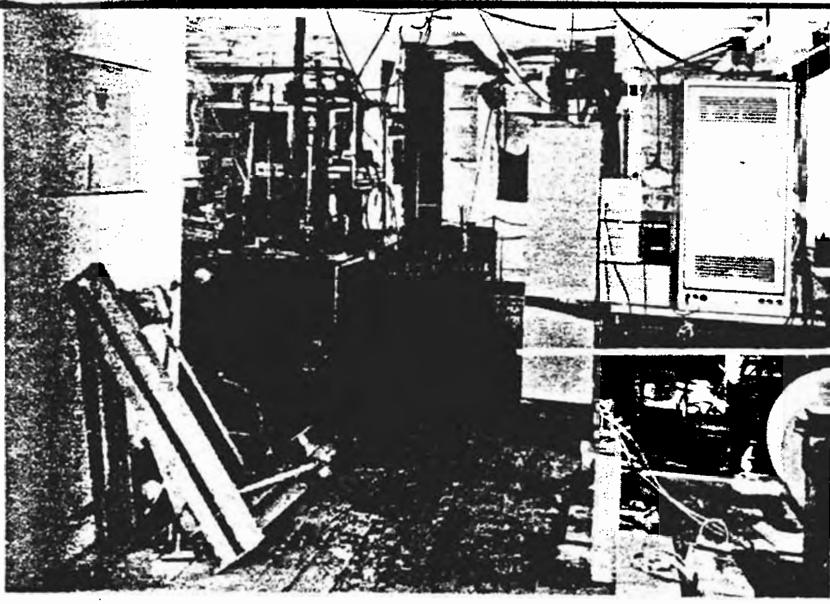
(See File Nos. 01.10, 01.12)

For a laboratory engaged in sonar research and development, facilities and personnel for calibrating transducers are clearly essential. The Calibration Laboratory was originally set up in what came to be known as the Sonar Data Division, but with the establishment of the Transducer Laboratory, it was transferred to the Sonar Devices Division and worked very closely with the Transducer Laboratory. Although it served the entire organization, the transducer engineers were its best customers.

In the spring of 1942 the Calibration Group's facilities consisted of a small barge located at the Section Base in San Diego Harbor, and its equipment was all "home-made." As the amount of work which the group was called upon to do increased and as its scope broadened, the need for a new location where interruptions caused by noise and traffic would be fewer became imperative. A survey was made of the various bodies of water located in San Diego County, and after careful consideration Sweetwater Lake, owned by the California Water and Telephone Company, was selected as an almost ideal spot. Near the dam of this large artificial lake is an area about 1000 feet wide where the water is 50 to 60 feet deep. On the shore adjoining this area was a small but sturdy house and barn. The house was converted into a laboratory and all the calibration equipment shown in Figure 4.22 (a) was located therein. A small barge was moved to the Lake and considerably altered to make the handling of transducers more convenient. Transmission lines between the barge and the shore station were run under water and the barn was converted into a machine shop for maintenance and for the construction of brackets, etc., needed daily.

Because the Sweetwater Testing Station was located about 17 miles from the Laboratory, it had to function very much as an autonomous unit. The limited floor space available, however, required the group engaged in the calculations necessary for putting the calibration data in a useful form to remain at the main Laboratory. This was recognized as an inefficient, though unavoidable, arrangement.

As the work at Sweetwater increased, Barge 4, located at the end of the UCDWR pier, was employed as a second calibration station. The equipment installed on Barge 4 was generally as accurate as that at Sweetwater, and an attempt was made to duplicate facilities in the two stations. Figures 4.22 (b) and 4.22 (c) show interior and exterior



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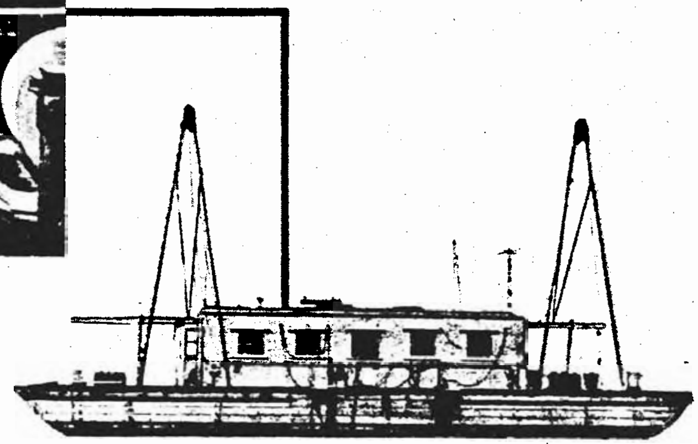

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FIGURE 4.22.

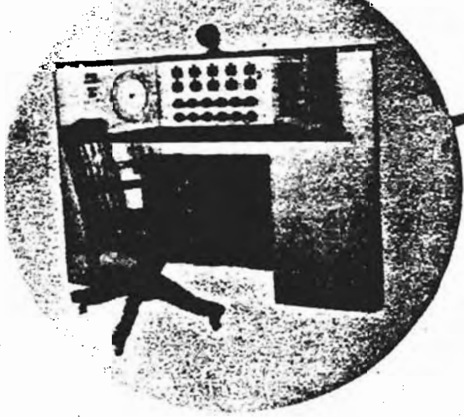
VARIOUS VIEWS OF THE CALIBRATION STATIONS AT SWEETWATER LAKE AND ON BARGE 4 IN SAN DIEGO HARBOR. (a) THE OPERATING PANELS AT THE SWEETWATER STATION. THE CORE AND LINEAR RECORDERS MAY BE SEEN ON THE THIRD PANEL FROM THE WINDOW. (b) INTERIOR OF BARGE 4. A REAR VIEW OF THE OPERATING PANELS MAY BE SEEN AT THE RIGHT AND THE TEMPERATURE-CONTROLLED ACOUSTIC TANK WITH A NUMBER OF QLA TRANSDUCERS MAY BE SEEN TO THE LEFT. (c) EXTERIOR VIEW OF BARGE 4. THE TWO A-FRAMES ARE USED FOR LIFTING THE ENTIRE TRAINING COLUMN FROM EACH OF TWO CARRIAGES WHICH MAY BE SEEN AMIDSHIPS. THESE CARRIAGES RUN ON REELS AND PERMIT A LARGE SEPARATION TO BE USED. (d) VIEW OF THE SWEETWATER STATION SHOWING THE TWO BUILDINGS ON THE SHORE, WITH A CONCRETE PATH LEADING DIRECTLY INTO THE WATER SO THAT HEAVY UNITS CAN BE LOADED ONTO THE TRANSPORTATION BARGE, AND THE NEW LARGE CALIBRATION BARGE WHICH IS SITUATED FURTHER OUT IN THE LAKE.

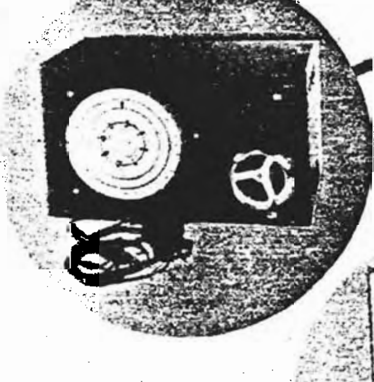
views of this station. Some special items of equipment of greater day-to-day use in connection with transducer design were also installed on the Barge; for example, a special impedance bridge and an acoustic tank purchased from the Bell Telephone Laboratories which was set up so that its temperature could be varied over a wide range. This was necessary in San Diego because the temperature excursion of the local waters is limited. During the war, despite the very heavy load on these facilities, it was possible to make calibrations as accurate as those made at any station in the country; indeed in many ways the natural facilities at Sweetwater Lake, with its depth and quietness, were superior to those found elsewhere.

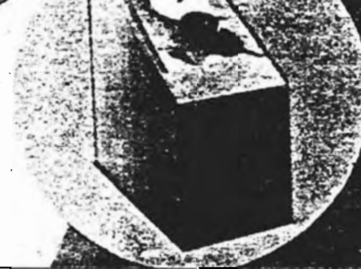
As experience in the science of calibration grew, certain shortcomings of the equipment were recognized, and in the summer of 1945, new primary oscillators were ordered for both stations and plans were drawn for a new barge and new hoist-train equipment at the Sweetwater Station. The original barge had not been constructed with calibration in mind and it was impossible therefore to get adequate separation between transducers; moreover, it sometimes tipped precariously when heavy transducers or other equipment were placed off-center. The greater depth at Sweetwater Lake permitted work at greater separations than was possible at most other calibration stations, and this is of course essential to reach the plane-wave field of the transducer in the calibration. The new barge was designed particularly to give separations up to about 50 feet and with such a high degree of stability that transducers weighing more than 1000 pounds could be placed at any point on it without causing it to tip seriously. At the time of writing this report, this barge had been completed and fulfilled specifications in every respect. It is shown in the view of Sweetwater Station in Figure 4.22 (d). The new hoist-train gear was designed from the beginning as a precision unit and every effort was made to reduce back-lash to a minimum by means of ingenious lash-lock mechanisms. Construction of this unit guaranteed the transference to NEL of a calibration station of the highest order of precision possible at the present stage of the art.

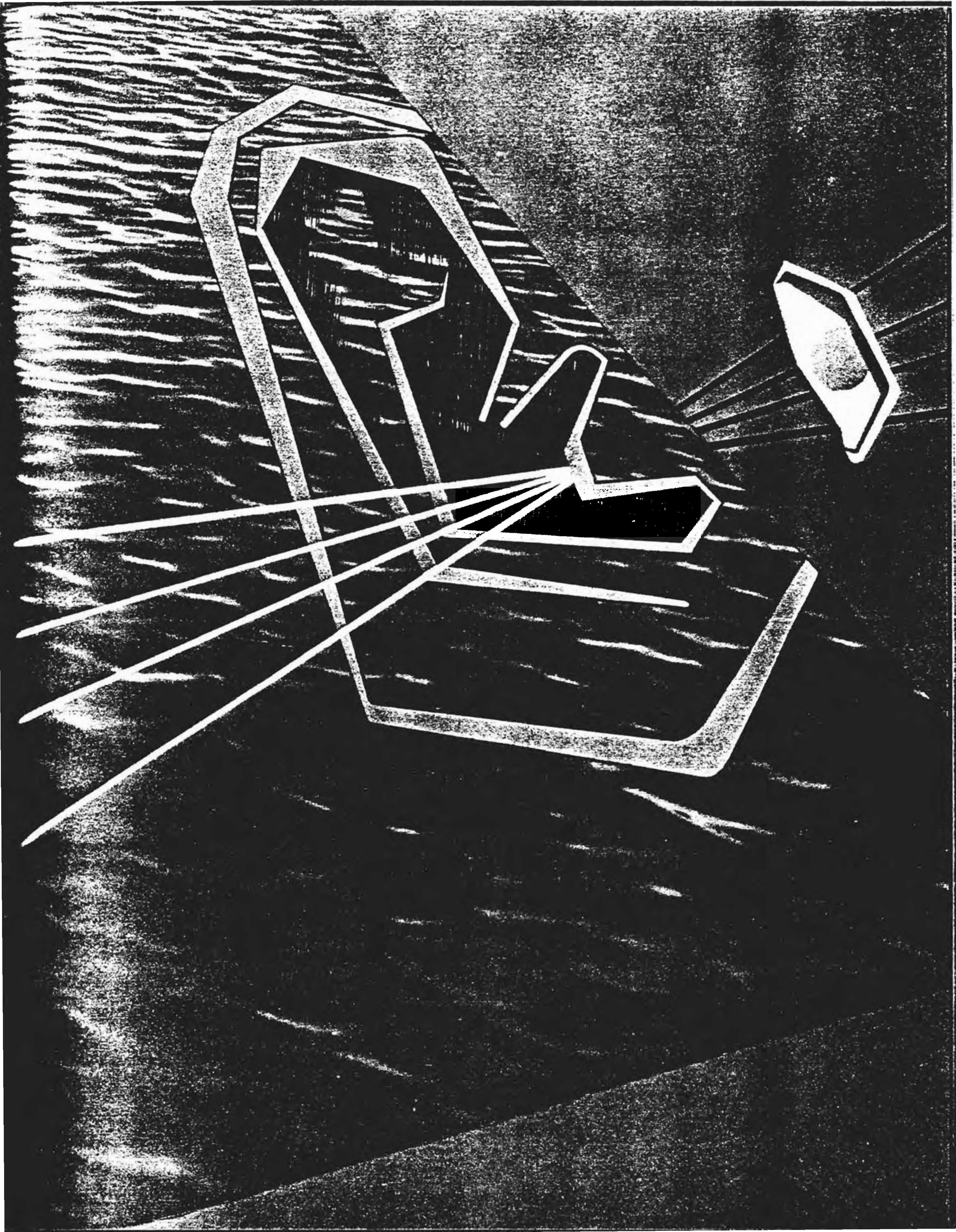
It may be added that the Sweetwater Station proved itself to be of value in ways other than those connected with calibration. For example, an area of water of from 300 to 700 yards, extending away from the barge, has a flat mud-covered bottom at a nearly consistent depth of about 50 feet; many studies of completed devices have been made in this area unhampered by rough seas.

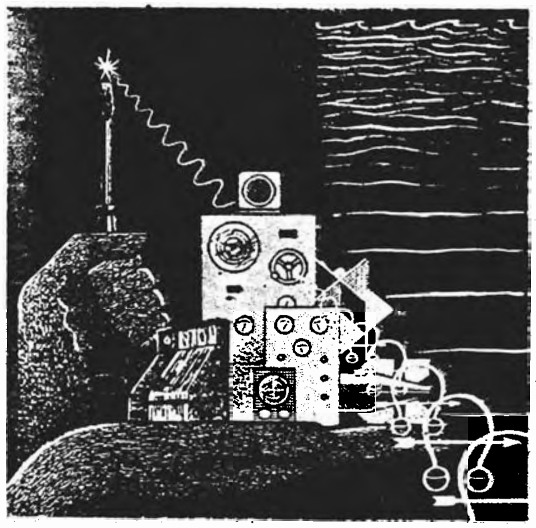
5 training aids division











A. INTRODUCTION

In 1941 the field of sonar training was in the early stages of growth. The two Sonar Schools were new and very small, and no comprehensive system for selecting and instructing recruits had been developed. When our entry into the war confronted the Navy with the necessity for enormous and rapid expansion, serious problems immediately arose, the solution of which was made more difficult by the inadequacy of the facilities available and the lack of experience in sonar training. The major problems were:

1. The need for careful selection of recruits. Only men with certain definite qualifications can be developed into sonar operators.

2. The need for a comprehensive training program with adequate manuals, visual aids, examinations, scoring methods, etc.

3. The need for properly trained teachers.

4. The need for mechanical training devices which would simulate sea conditions. This was of great importance because surface ships and target submarines were not available for the sea training of large numbers of sonar recruits.

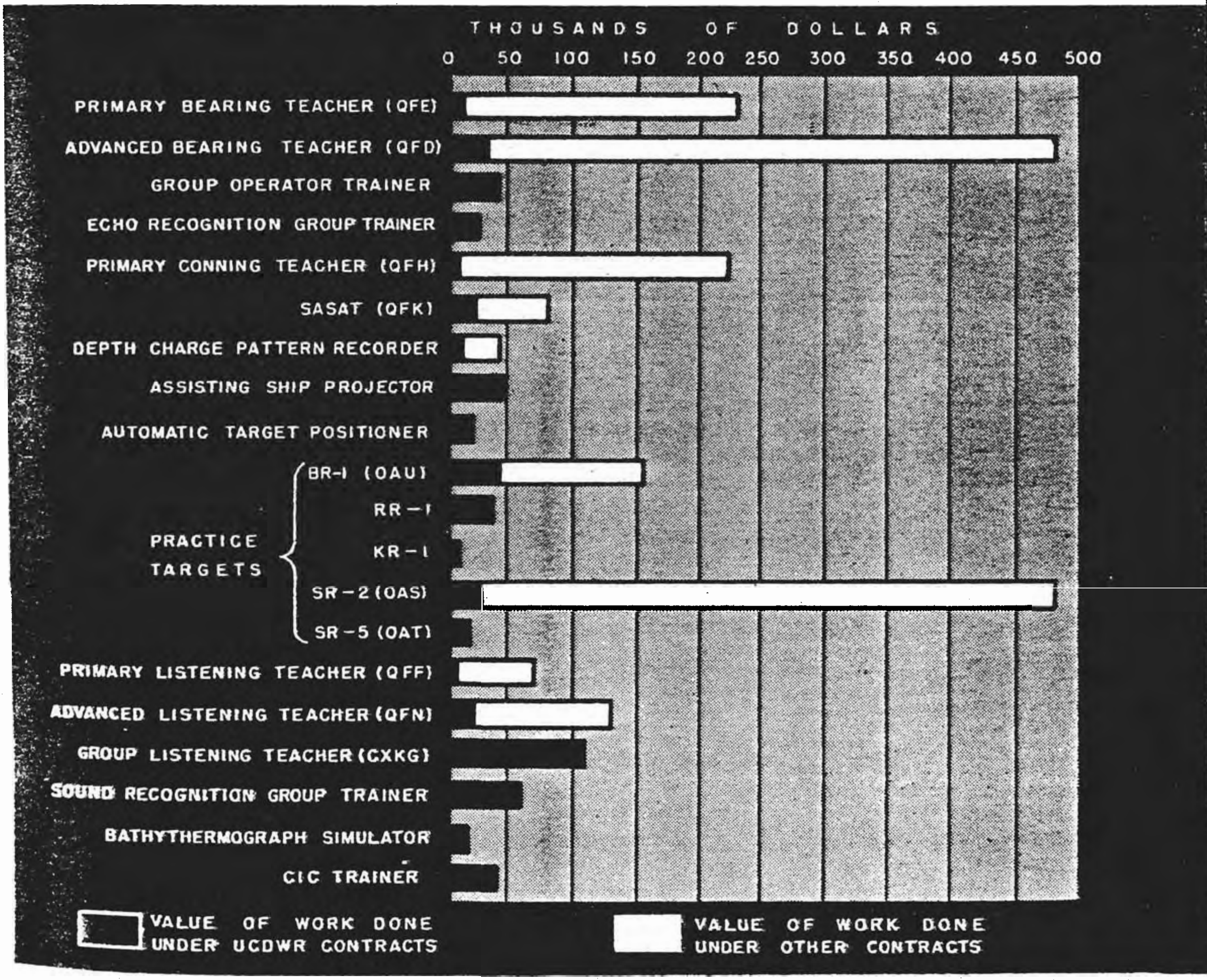
To help the Navy to solve these major problems and countless minor ones which arose, the scope of OSRD's submarine detection assignment was enlarged in January 1942 to include active participation in the selection and training of sound operators both at San Diego and at Key West. To carry out this enlargement, Division 6 of NDRC assigned a project to UCDWR, and an Assistant Director was placed in charge of the Training Aids Division. Civilian staffs, including psychologists, engineers, and teachers, were assembled, and techniques and special apparatus developed. The appointment during the spring of 1942 of the Chairman of the Selection and Training Committee, Division 6, NDRC, as Director of the Laboratory emphasized this aspect of UCDWR's activity and stimulated liaison between the Laboratory and sonar training activities. As one of the first steps in this participation, four men of the staff were assigned to the U. S. Fleet Sonar School, San Diego (then West Coast Sound School), to take the regular course of training for sound operators. Their firsthand experience of the actual problems of sound ranging and of antisubmarine tactics in general was invaluable in carrying on the work of the Division, and gave it a lively and direct interest in the subject. The scores achieved by them in their training course (the final grades of the four men were among the five highest grades in the course) assured the Navy of their competence and strengthened the bonds between the Navy and UCDWR.

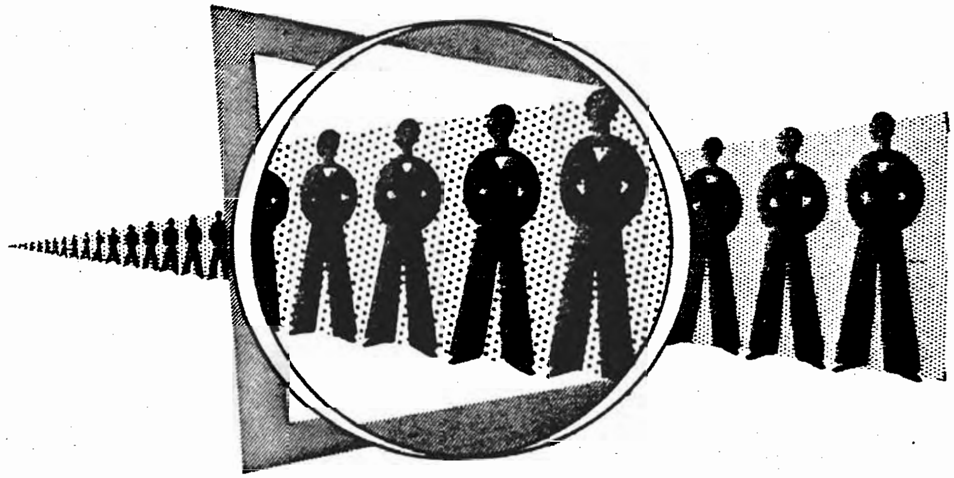
The work of the Training Aids Division fell naturally into two categories: instructional and mechanical. The first of these included selection tests, printed and photographed classroom materials, tests for progress and training, arrangement of curricula, correlation studies to validate and improve training programs and examinations, general assistance to the Sonar Schools in their training problems, and the furnishing of instructor personnel to perform specific jobs at the Schools and the naval bases.

The second category embraced mechanical devices constructed to fill specific wants in the training program. These devices provided improved training, helped relieve the acute instructor shortage, acted as substitutes for sea training, and more effectively screened the personnel being trained. Some 25 such devices, both major and minor, were designed and constructed. Worthy of special mention are the several "group trainers" which allowed groups of as many as 20 students to receive practical instruction simultaneously from one instructor. Many of these training devices were manufactured in quantity, some by UCDWR alone, and many more through direct Navy contract with manufacturers. Figure 5.1 shows the approximate value of equipment produced from Training Aids Division designs.

The specific projects covered by the program of the Training Aids Division are listed in detail in the file outline in Appendix A.

FIGURE 5.1.
APPROXIMATE VALUE OF EQUIPMENT PRODUCED FROM TRAINING AIDS DIVISION DESIGNS





B. INSTRUCTIONAL ASSISTANCE

I. selection and psychological studies

1. selection of sonar operators

(See File Nos. 91.00, 91.10, 91.11)

The first operator selection test was put together by the Selection and Training Committee in January 1942 and administered on a trial basis to 109 men at San Diego and 92 men at Key West. This test consisted of five components:

a. The Otis Mental Ability Test (Intelligence)
b. The Bennett Mechanical Comprehension Test, Form AA
c. The Seashore Sense of Pitch Test, First Edition
d. The Seashore Sense of Intensity Test, First Edition
e. The Seashore Tonal Memory Test, First Edition

The pressure to obtain men was so great at that time that the tests had to be used as a selection screen before the completion of adequate psychological studies of their validity for that purpose. It was reassuring to find that this use of the test was thoroughly justified by the validity studies when completed.

In order to simplify the job of the selection officers, after this first administration it was decided to use the Navy General Classification Test (GCT) instead of the Otis Mental Ability Test. With this change the selection test consisted of two screens: the first was the intelligence test, from which were accepted only those men who could secure a better-than-average score; the second screen, applied to those men selected by the first one, was the average of the scores on the mechanical comprehension test and the Seashore tonal tests. The lowest third of the once-screened candidates were rejected by the second screen. UCDWR had little to do with the setting up of the original battery, but in March 1942, coincident with the acceptance of the test battery given above, it was arranged for the resident psychologist at San Diego (and his aides) to travel the circuit of the naval training stations, meeting the selection officers, demonstrating the selection procedure, inspecting the equipment and test locations, and following through with continuous assistance to see that the difficulties of administration were overcome and that the screening procedure was carried out as accurately as possible. During 1942 and 1943, this contact with the training stations was continued. The personnel of the Laboratory therefore took over in large measure the responsibility for application of the selection tests.

The original battery of tests was used with only minor changes until the spring of 1944. Several important defects were discovered in the interval, and to remedy them UCDWR developed a new two-screen selection procedure, wherein the first screen was formed by the general and special intelligence tests and the second screen was restricted to a new pitch test. This pitch test was a completely new one developed by intensive research at UCDWR. It consisted, like the Seashore tests, of phonograph recordings, but with many modifications that made for ease and accuracy of administration and improved its validity as a selection device. The references given in Appendix A should be consulted for the details.

The final selection battery, used till the end of the war, consisted of the following:

a. Navy General Classification Test (general intelligence)
b. Navy Reading Test (comprehension of technical reading)
c. Navy Arithmetic Test (arithmetical reasoning)

d. Navy Mechanical Aptitude Test (mechanical comprehension and visualization)
e. New UCDWR Pitch Memory Test.

A candidate had to make a better-than-average score on three out of the first four (the first "screen") and a better-than-average score on the pitch memory test (the second "screen") to be accepted. The new selection battery was approved by the Navy's Bureau of Personnel in May 1944 and was instituted by directive to the various naval training centers where selection was carried on. Approximately 10,000 men in all took the selection tests, either first or second batteries, and the accumulated scores form a large and valuable collection of psychological data.

2. selection of sonar maintenance men

(See File No. 91.11)

It was evident very early that the cause of many of the poor results with sonar equipment was maladjustment of the equipment, and though the operator might be well trained in attack procedure, he frequently did not know when his equipment was out of order. The Navy, therefore, decided to train about one-third of the operators to make repairs and adjustments, assuming that a ship with three or more sonarmen would then have at least one man who could take care of the upkeep.

At the start of this training program about one-third of the top graduates from each operator class were selected to take the ten weeks course in sonar maintenance. It was soon realized, however, that the top third of the operator classes was not the best source of candidates for maintenance instruction. Many an expert operator with a fine ear and good operator skill found it impossible to understand the electronic principles of sonar equipment and was promptly dropped. On the other hand, many a man with only mediocre operating ability ended in the top rank of the maintenance class. As a substitute for arbitrary selection of the top third, a composite selection plan was designed by UCDWR, using each of the following tests:

a. Navy GCT
b. Navy Arithmetic Test
c. Bennett Mechanical Comprehension Test
d. Education Background (units of education in mathematics and science in high school or college)
e. Average Grade on three operator written examinations

These tests were administered to all operator graduates. The predictive value of each one of the five proved to be nearly the same and accordingly the five scores were merely averaged together and the men in the upper third taken. This new selection plan for maintenance candidates was installed in December 1942 at the Fleet Sonar School, San Diego, and was administered by UCDWR psychologists throughout the war. Somewhat later a similar plan was established at the Fleet Sonar School, Key West.

3. selection of sonar officers

(See File No. 91.12)

Early in 1943 it became evident that a selection procedure was also needed for screening prospective Sonar Officers. Their training was very brief and it seemed that a considerable increase in their efficiency might result from the application of a good selection test. The attempt to set up such a test proved to be the most difficult task the UCDWR psychologists were asked to undertake. The wide variety of aptitudes needed, the rapid changes in sonar doctrines and the resulting changes in these aptitudes, the far from objective grading methods during the course, and, most of all, the other qualifications—"officer-like qualities"—that were expected of prospective officers, and that are really irrelevant to skill in sonar operation, all conspired to make a statistically reliable selection scheme most difficult to construct. Some progress was made, however, particularly in the direction of more consistent grading of performance during the course, and by the summer of 1944 a selection test was made up that looked very promising. By this time, however, the number of Sonar Officer candidates had fallen off greatly and the real need for a selection program had passed. One desirable step, however, was taken very early: at UCDWR's suggestion, the Bureau of Personnel ordered that the operator's selection test be applied to all officer candidates. This test served at least to get rid of pitch-deaf candidates.

4. psychological studies

(See File Nos. 91.11, 91.14 especially)

A large number of validation studies were made on each training device produced by UCDWR. There were also surveys of special aptitudes such as doppler perception, etc. A complete list of the reports submitted to cover these studies will be found in the bibliography of Appendix A of this volume.

II. navy training assistance

(See File Nos. 91.14, 91.50 especially)

Because of the very rapid development of the training program and the introduction of numerous training devices, UCDWR was called upon to provide assistance at the Schools and at various remote bases. This assistance took many forms: (1) When a training device was installed, technical advice was given to Navy maintenance men in its operation and upkeep. (2) At the same time, the Navy instructional staff was coached in the most effective methods for using the device in training, and frequently complete training programs were organized. At times UCDWR men acted as instructors for considerable periods. (3) Surveys of the effectiveness of these training programs were often made and new methods and materials introduced where necessary. (4) Courses of lectures on various technical subjects were given. (5) A comprehensive study of the effectiveness of ahead-thrown weapons was made and assistance rendered at sea in training personnel on shake-down ships in the proper use of ahead-thrown weapons from both a tactical and an ordnance angle.

As an illustration of the diversity of these activities it should be mentioned that at one time (15 January 1944) the UCDWR Training Aids Division had 42 men on assignment to various naval activities. Of these, seven men were in San Diego; seven at the Fleet Sonar School, San Diego; eight men at the Fleet Sonar School, Key West; twelve at the Submarine School, New London, and six more in scattered berths from Pearl Harbor to Bermuda. One of these latter, James M. Snodgrass, served for 23 months on the staff of the Commander Destroyers, United States Pacific Fleet, assisting in antisubmarine warfare training and technical problems. For his services he was authorized by the Commander-in-Chief United States Pacific Fleet to wear the Asiatic-Pacific Area Campaign Ribbon.

III. the bathythermograph training program

(See File No. 91.80)

1. introduction

The activities of UCDWR in connection with bathythermograph training fell into two general categories: (a) the analysis of oceanographic and sound transmission data and the presentation of this information by means of charts and manuals, and (b) providing Field Engineer-Instructors (Pilot Instructors) to familiarize Navy personnel with the effects of water conditions and related factors on the performance and operational use of sonar equipment and on the submerged operation of submarines.

2. preparation of charts and manuals

The preparation of Sound Ranging (Sonar) Charts, Bottom Sediment Charts, and Submarine Supplements to the Sailing Directions is described in Chapter Three. Bureau of Ships manuals and training aids are more or less arbitrarily placed here under the Training Aids Division, though the preparation of these publications intimately concerned the Sonar Data Division as well.

In March 1943, the Coordinator of Research and Development (SONRD) requested NDRC to assist the Bureau of Ships in the preparation of manuals relating to the use of the bathythermograph and the interpretation of bathythermograms in terms of sonar conditions and the buoyancy control of submarines. Manuals prepared under this request were the joint effort of Columbia University Division of War Research, Woods Hole Oceanographic Institution, the Bureau of Ships, and UCDWR. The completed manuals are listed in Appendix A.

In May 1944, SONRD requested that NDRC establish an expanding training program involving both the development of additional training aids and manuals and the assignment of specialist instructors to various Navy activities under Navy Project NS-308. Under this program, a special bathythermograph training group was established at UCDWR. Writers and artists undertook the preparation of official Bureau of Ships manuals and training aids, while a group of scientists was recruited and trained as Field Engineer-Instructors. The bathythermograph training aids group prepared a rather wide variety of material under this project, including official NavShips manuals, posters, and films for submarines, surface vessels and harbor defense

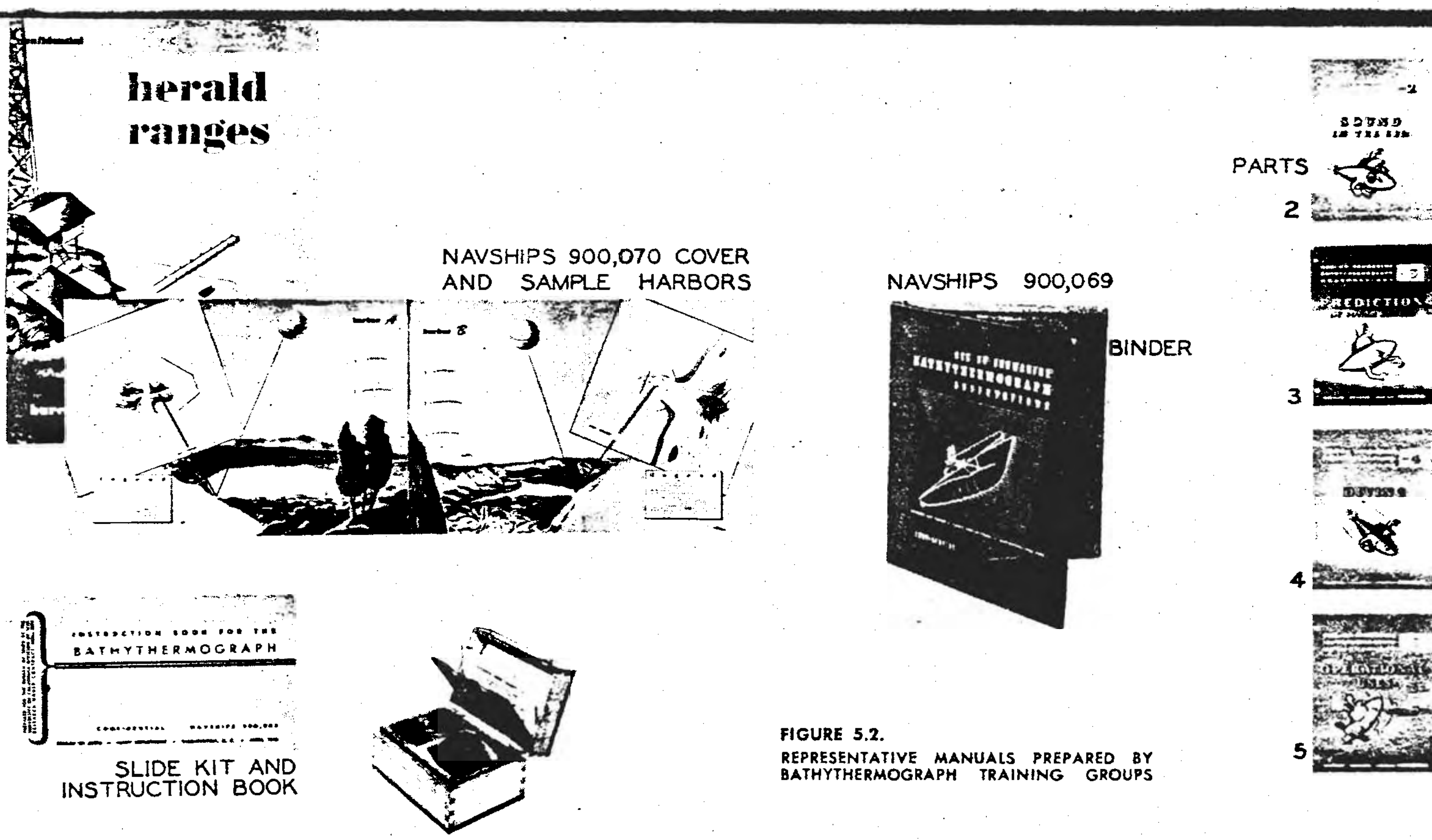


FIGURE 5.2.
REPRESENTATIVE MANUALS PREPARED BY BATHYTHERMOGRAPH TRAINING GROUPS

activities. The manuals prepared by this group are listed in Appendix A; Figure 5.2 shows a number of manuals representative of the work of the group.

3. field instruction

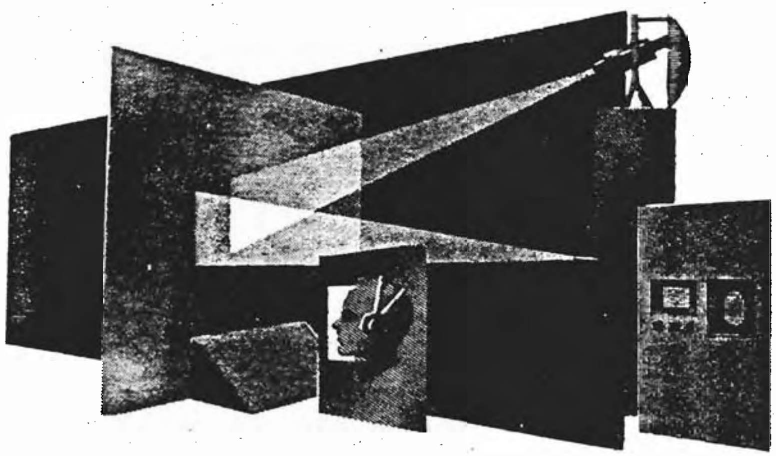
For the Submarine Force:

Since the first experiments with bathythermographs on board submarines in 1941, the personnel at Woods Hole Oceanographic Institution had maintained close liaison with submarine operating forces, particularly on the East Coast. During 1943 and early 1944, representatives of WHOI visited activities on the Pacific Coast and in the Pacific. Following the request of SONRD in May 1944, these services were expanded and UCDWR trained three civilian specialists for this work. As a consequence, a UCDWR BT technician was stationed in Pearl Harbor from November 1944 until September 1945. In addition, from October 1944 until September 1945, a Field Engineer-Instructor was attached to ComSubsPacSubAd, NYMI, and part of this time an additional instructor was attached to ComSubRon 45 and the Fleet Sonar School, San Diego. The duties of these specialist instructors included research on various subjects concerning the effects of water conditions on submarine operations, the preparation of special materials on areas to be visited during war patrols, instruction on shipboard and at training centers in the interpretation of submarine BT data, and expediting the issuance of charts and manuals.

For A/S Forces:

The request of SONRD in May 1944 indicated immediate need for assignment of one or more experienced members of the Laboratory staff to assist in the surface vessel bathythermograph instruction program in the Atlantic area, and the procurement and training of additional civilian instructors for assignment to Fleet activities concerned with antisubmarine warfare. Accordingly, one member of the Laboratory staff was assigned to the Bureau of Ships and the Eighth Fleet from June to September 1944, and another to the Bureau and LantASWUnit, COTClant, from June to December 1944. In addition, three civilian scientists were employed and trained. Two of these men were assigned to COTCPac in December 1944, and the third man in March 1945. They were attached to COTCPac, San Diego; Pre-Commissioning Training Center, San Francisco; and COTCPac, SubordCom, Seattle. These three men remained on duty until their work was transferred to the Navy in September 1945.

The duties of the surface Field Engineer-Instructors included instruction on shipboard and at ASW training centers on the interpretation of bathythermograph data and the effects of water conditions on sonar performance and tactics, the expediting of charts, manuals, and bathythermograph equipment to ships of the Fleet, and the collection of information on the operational performance of sonar gear under varying water conditions.



C. TRAINING DEVICES

As the program for training large groups of sonar operators, Sonar Officers, and submarine personnel developed, it became rapidly and increasingly apparent that much of the training heretofore carried on at sea would have to be done on shore. The number of vessels available for training at sea was hopelessly inadequate. Shore installations of devices which simulated operating conditions at sea were essential and UCDWR was called upon to undertake their development as the need for them arose. They may be divided into four groups according to function (many minor devices developed by UCDWR are not mentioned here but are completely referenced in the bibliography of Appendix A):

Devices for training surface ship sonar personnel:

1. Primary Bearing Teacher (QFE)
2. Advanced Bearing Teacher (QFD)
3. Group Operator Trainer (GOT)
4. Echo Recognition Group Trainer (ERGT)
5. Primary Conning Teacher (QFH)

I. classification of devices

Devices for antisubmarine team training:

1. Assisting Ship Projector
2. Depth Charge Pattern Recorder
3. Shipboard Antisubmarine Attack Teacher, A
   Shipboard Antisubmarine Attack Teacher, B
4. Automatic Target Positioner
5. Practice Targets

Devices for training submarine sonar personnel:

1. Primary Listening Teacher (QFF)
2. Advanced Listening Teacher
3. Group Listening Teacher (CXKG and CXKG-1)
4. Sound Recognition Group Trainer (SRGT)
5. Submarine Bathythermograph Simulator (BTS)
6. Submarine Barometer Simulator
7. Submarine Bathythermograph Classroom Demonstrator

Special Devices:

1. Tactical (Combat Information Center) Trainer

II. devices for training surface ship sonar personnel

1. primary bearing teacher (QFE)

(See File No. 91.211)

This device is a single-student trainer, shown in Figure 5.3, designed to give practice in the elementary manipulations required of a sonar operator in searching for and holding contact on a submarine target. It produces sounds which simulate echoes and reverberations and an approximation of doppler. The student listens to these sounds through headphones, and by means of a handwheel simulates training a projector across the target. He is required to report, in the proper manner, contact bearing, cut-ons, center bearings, bearing drift, and doppler. By means of the primary bearing teacher correct operational habits can be developed before the student goes on to more advanced training.

The device consists of a box measuring 11½x10½x 7½ inches, housing two electronic audio oscillators with a small motor for keying them alternately. These produce tones in the student's headphones which represent echo and reverberation respectively. On the student's side of the box is a handwheel and a bearing indicator which shows the angle of train. On the instructor's side is a bearing indicator which shows the bearing of the target as well as the train-angle of the simulated projector. Means are provided on the instructor's side for controlling the fictitious ship's course and the angular position of the fictitious submarine. The instructor can also alter the frequency of the echo oscillator to simulate changes in doppler. The apparent range of the submarine stays fixed at 800 yards. Echoes are heard when the simulated projector is trained within 10 degrees of the target.

Work on the primary bearing teacher was begun in June 1942. Twenty units were built by UCDWR and a total of 607 units were supplied to the Navy on Contract NXs-17438 with the Bell Sound Systems, Inc., Columbus, Ohio.

2. advanced bearing teacher (QFD)

(See File No. 91.212)

This device was developed several months before the primary bearing teacher, but in the training program the student is assigned to the primary teacher first. The advanced bearing teacher presents conditions more closely resembling those of actual operation of echo-ranging equipment at sea. The student's side is similar in nearly all respects to the older types of QC sonar stacks. Either long or short standard keying interval can be used; realistic sounds characteristic of operating QC gear are produced—ping, echo, reverberation, and water noise; the echo follows the outgoing signal at an interval corresponding to the range; strongest echoes are heard when the sound beam is trained directly on the target; the echo strength increases as the range becomes shorter; the training handwheel is of the same size and has approximately the same friction and moment of inertia as the one on QC gear; and Doppler effect appropriate to the target aspect is automatically introduced.

The device is housed in a metal cabinet 48 inches high, 22 inches wide, and 14¾ inches deep, with a loudspeaker mounted on top. On the student's side, Figure 5.4, are the training handwheel and a bearing indicator with true-bearing dial, relative-bearing dial, and a bug-ring dial showing the angle of train. There are also a short- and long-range keying switch and a gain control. On the instructor's side is a similar bearing indicator, a crank for altering the attacking ship's course and knobs for

FIGURE 5.3. PRIMARY BEARING TEACHER (QFE)

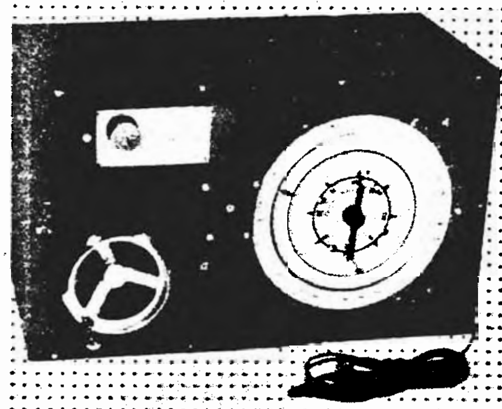


FIGURE 5.4. ADVANCED BEARING TEACHER (QFD), STUDENT'S SIDE

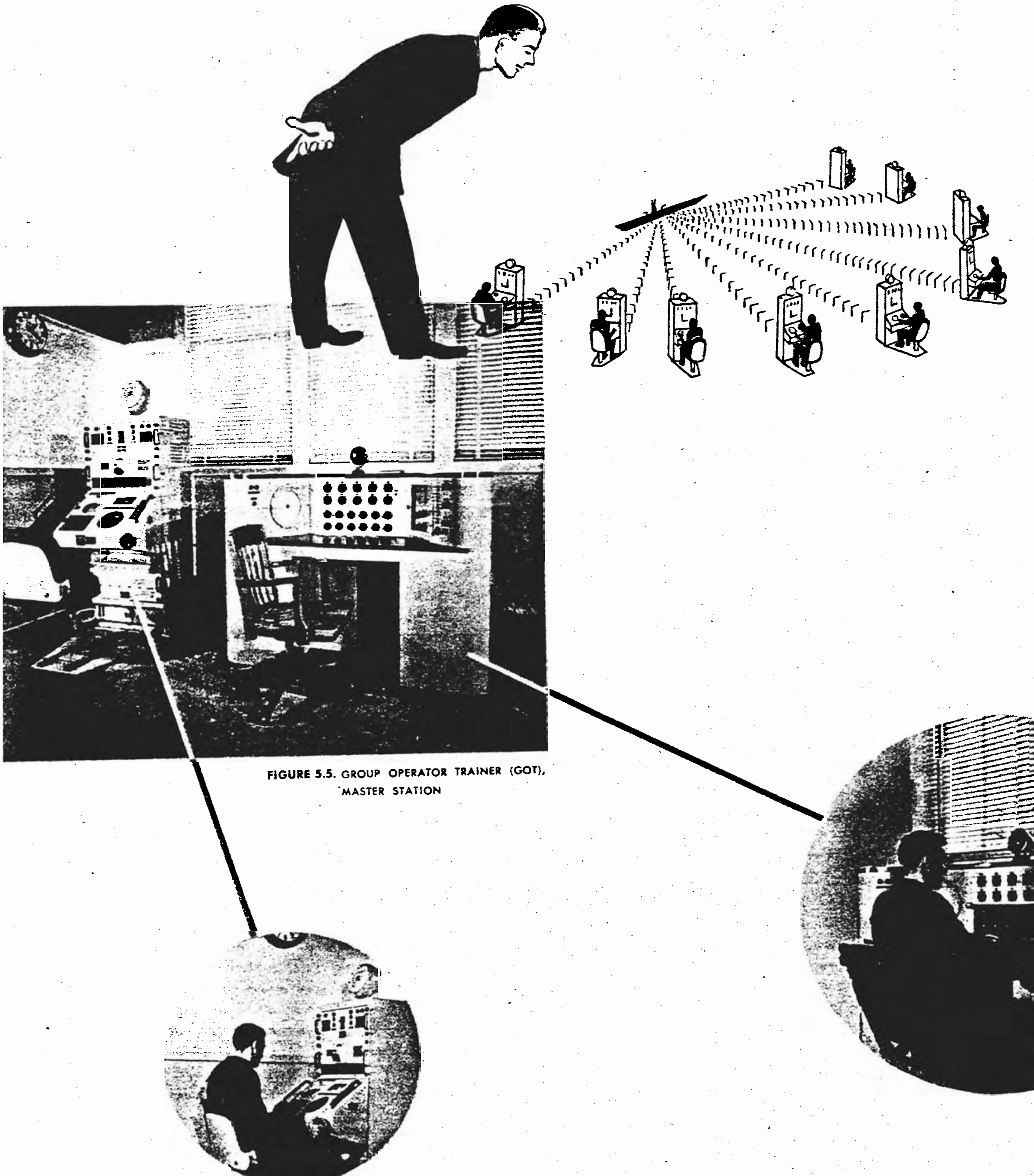


FIGURE 5.5. GROUP OPERATOR TRAINER (GOT), MASTER STATION

controlling signal-to-echo ratio, water-noise amplitude, echo frequency and reverberation. The problem begins with the submarine at a range of 2300 yards and with a target width of 7½ degrees. The attack can be allowed to develop automatically or it can be modified as desired by the instructor. If he wishes to introduce more of the distractions and difficulties which confront the operator at sea, he can alter one or more of the following features of the problem: (1) pitch of the echo with respect to reverberation, (2) loudness of echo with respect to reverberation, (3) rate at which reverberation fades, (4) loudness of water noise, (5) heading of attacking ship, (6) bearing of submarine. The problem runs for about eleven minutes and ends with the attacking ship passing about 150 yards ahead of the submarine and with a target width of 24 degrees.

Work was begun on the advanced bearing teacher early in 1942. Six units were built by UCDWR and 164 on Navy Contract NXs-12758 with the Radio Corporation of America (Victor Division), Los Angeles, California.

3. group operator trainer (GOT)

(See File No. 91.213)

As the classes of sonar students increased in size, the allowance of advanced bearing teachers became inadequate, and the demands made upon the instructional staff by these single-student trainers became prohibitive. In consequence, UCDWR was requested to develop a group trainer to enable one instructor to handle as many as ten students at a time. This purpose is achieved in the group operator trainer by means of a master station or problem generator for the instructor and ten student stations, each of the latter being installed in a separate booth.

Every effort was made to produce the maximum of realism. The student stations are standard QGB or QJB sonar stacks. By an advance in the technique employed in the advanced bearing teacher, the sound effects have been made to simulate more closely those heard in actual operation at sea. There are six problems grouped in pairs, each pair consisting of attack and reattack. Any problem can be selected at will by the instructor by means of an adjustment at the master station, but once a problem has begun, it carries through automatically so far as the relative movements of the simulated surface ship and submarine and the Doppler effect appropriate to the various target aspects are concerned. The simulated surface ship is "conned" correctly throughout the attack and reattack, so that the operator is not bothered by faulty maneuvering. The difficulties and distractions so frequently met during an attack at sea can be introduced at will by the instructor, who, by means of various controls at the master station, can produce more difficult problems than will result if the problem is allowed to proceed automatically. The following changes can be introduced: (1) change in length and volume of reverberations, (2) change in volume of water noise, (3) introduction of propeller beats, (4) introduction of FXR interference, (5) wake interference at various ranges and volume, (6) changes in echo volume, (7) changes in the apparent depth of the target and consequent change in the range at which loss of contact occurs.

The master station, as can be seen in Figure 5.5, consists of a console equipped with three panels. On the left-hand panel is a bearing indicator which shows the true center bearing of the target submarine. On the center panel, ten small identical dials register the angle of train of the various student projectors. By an intercommunication system the instructor can coach each student as necessary. Below the bearing dials are the various knobs by means of which the changes mentioned in the preceding paragraph are introduced. On the right-hand panel are contral buttons for the intercommunication system. Two units were built by UCDWR. One was installed at Fleet Sonar School, Key West, and one at the Fleet Sonar School, San Diego.

4. echo recognition group trainer (ERGT)

(See File No. 91.216)

This equipment was developed for the purpose of giving Sonar Officers and operators more intensive training in the recognition of target echoes than was provided by the various trainers described above. Specifically, it was designed to improve the students' ability in (1) doppler judgment, including degree of doppler, (2) distinction between wake and submarine echoes, (3) detection of faint submarine echoes, (4) identification of cut-ons and (5) proper reporting of judgments made during an attack. It was also designed to furnish a printed record of the students' decisions as an aid to proper grading. The sound effects produced by the echo

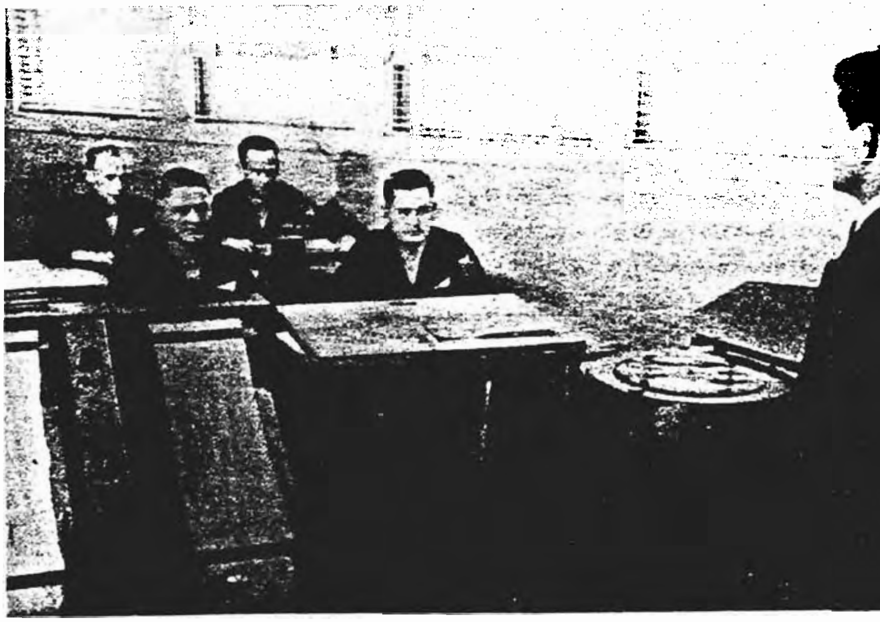
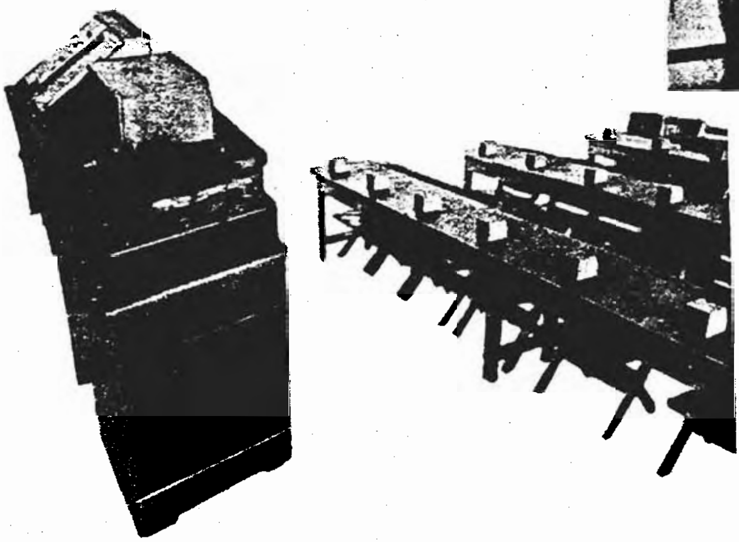


FIGURE 5.6. ECHO RECOGNITION GROUP TRAINER (20 STATION)



recognition group trainer are playbacks of actual sea recordings interspersed with related lectures so that the maximum degree of realism is obtained.

The equipment consists of a phonograph, a monitor recorder, and twenty student station keys. A student station key is a small box, on the front of which is a handle and a translucent window. By means of the handle a light spot behind the window can be moved to various labelled positions. These labels are (1) no echo, (2) doppler low, (3) doppler high, (4) no doppler, (5) slight doppler, (6) marked doppler, (7) submarine contact, (8) non-submarine contact. During the presentation of a recording, each student registers his judgment by moving his handle to the appropriate position. These movements are all recorded simultaneously on the instructor's monitor recorder on chemical recorder paper which moves at constant speed beneath styluses actuated by the student station keys. Each key controls three adjacent styluses, and the recorded marks are different combinations of broken and continuous lines. The instructor also moves a recording key during the presentation, and at the end of the selection, by a predetermined code, compares the students' records with his own.

For use at advanced bases albums of recordings were prepared, together with instructional manuals and mimeographed forms to be marked in pencil by the students in lieu of the keys and recorder. Twenty such kits were issued.

Model I of ERGT had only 15 student stations and was inadequate to handle the full class. Therefore Model II was built with 20 stations. One unit, shown in Figure 5.6, was installed at Fleet Sonar School, Key West, and one at Fleet Sonar School, San Diego.

5. primary conning teacher (QFH)

(See File No. 91.222)

This device differs in nature and purpose from the four described above; it is intended principally to provide preliminary practice to student officers in dealing with the relative-movement problems that exist in an antisubmarine attack. No sounds are produced.

The device is housed in a sheet-metal box 19 inches long, 12 inches wide, and 16 inches high, shown in Figure 5.7. At each end is a circular translucent screen. The student's screen is marked with radial lines for bearing and circular lines for range (maximum 2000 yards). The student, viewing this screen, imagines his own ship to be at the center. A small light spot, which appears on the screen intermittently, represents the submarine target. The frequency with which the spot appears corresponds approximately to that at which the information could be expected from a good sonar operator. Surface ship speed and rudder controls are installed on the student's panel and submarine controls on the instructor's panel. These, in combination, control the course and speed of the light spot. The center of the screen is imagined to represent the surface ship on the student's side, and the submarine on the instructor's side. The movement of the light spot is therefore relative movement. The instructor's screen has no circular range lines. The speed controls simulate 0 to 20 knots for the surface ship and 0 to 10 knots for the submarine. Appropriate rudder lag and turning circles are automatic in the rudder controls.

A problem is started by moving the light spot to any desired starting position. The instructor may then, in the simplest case, set a straight course at fixed speed for the submarine and so announce to the student, or he may, without informing the student, maneuver at will within the limitations of a submarine during the attack. The student, by means of his speed and rudder controls, attempts to conn the attack successfully. A firing button is provided which can be set, with appropriate dead time, for either depth-charge or ahead-thrown attacks. Suitable templates are supplied for scoring.

Five units of the primary conning teacher were built by UCDWR. Subsequently the Navy contracted (Contract NXs-29059) with the Sangamo Electric Company, Springfield, Illinois, for 100 units. In order to make use of a number of parts of other devices already being manufactured, Sangamo altered many details of the UCDWR model but produced a unit of the same general appearance and method of operation. The Sangamo model has the Navy designation QFH Sound Training Equipment.

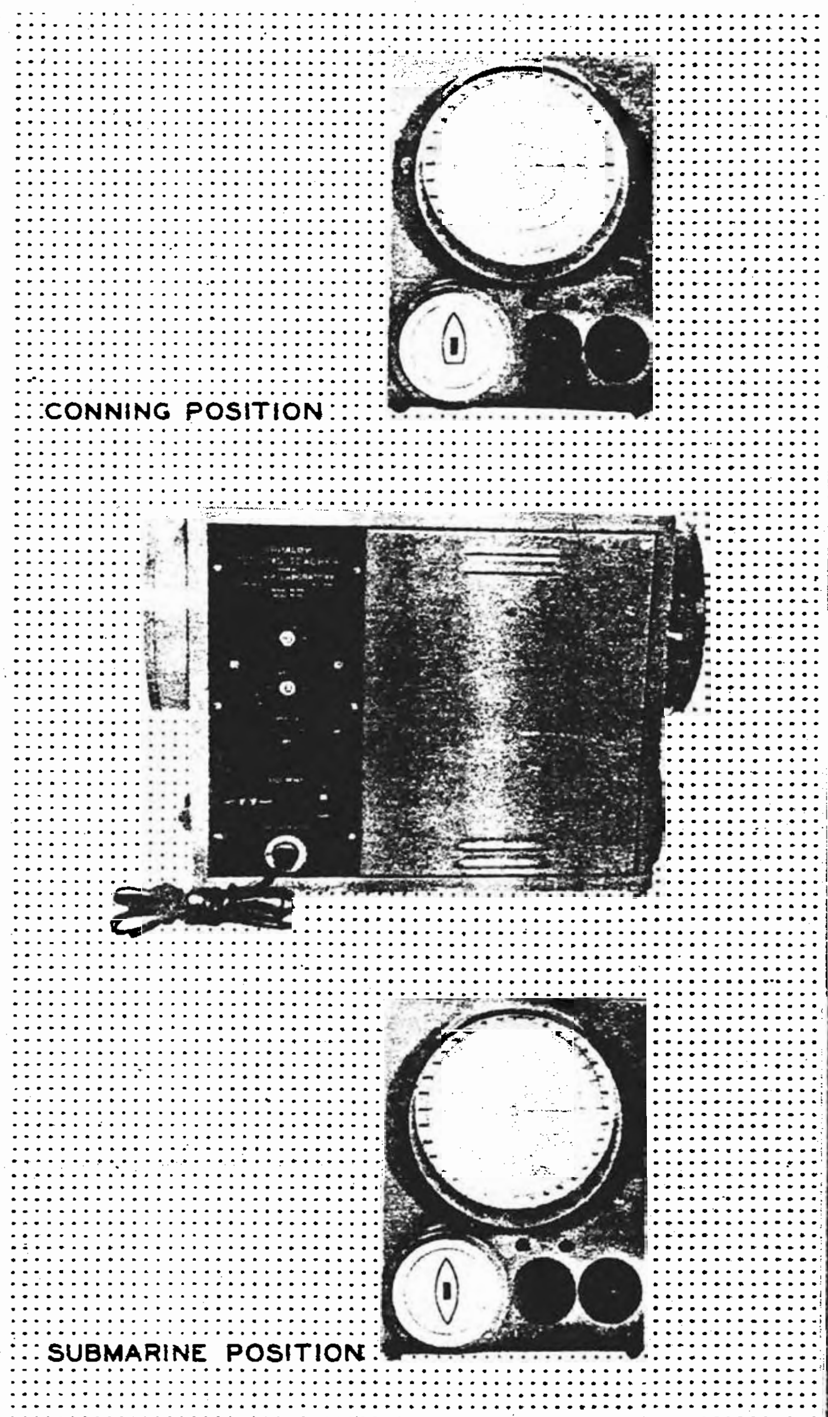


FIGURE 5.7. PRIMARY CONNING TEACHER (QFH)

III. devices for antisubmarine team training

These devices, with the exception of the Assisting Ship Projector, cannot be classified as shore installations which simulate sea conditions, as can the other devices herein described. Each, however, fulfilled a specific need in the over-all training program.

1. assisting ship projector

(See File No. 91.239)

In the antisubmarine attack known as an assisted ship attack or creeping attack, two surface vessels take part. One, the directing ship, echo ranges on the target submarine from a convenient position within easy sound range and directs the other, the attacking ship, by voice radio into a proper position to drop depth charges. The sonar gear of the attacking ship is secured during this operation. To direct such an attack requires, on the directing ship's dead reckoning tracer, a simultaneous plot of the submarine's course from sonar information and the attacking ship's course from radar information.

In order to train antisubmarine attack teams ashore in the routine of conducting an assisted ship attack, an attack teacher is used. The ship and submarine images projected onto the screen represent the directing ship and the target, and sonar ranges and bearings are reported to the plotters in the usual manner. The assisting ship projector, the name of which is a misnomer, was designed to project onto the attack-teacher screen the image

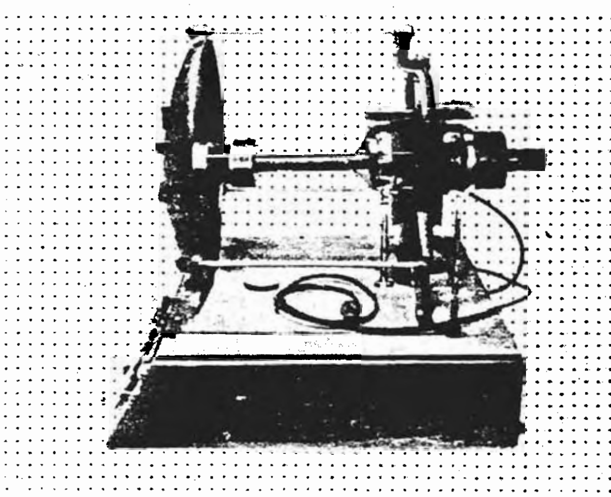


FIGURE 5.8. ASSISTING SHIP PROJECTOR

of a second surface ship representing the attacking ship, and to move the image across the screen at appropriate courses and speeds as directed. A range measuring line, centered on the ship and adjustable in azimuth, is also projected onto the screen. By means of this range line, ranges and bearings of the attacking ship, in simulation of the radar information used at sea, are reported to the plotters. The device can also be used as a problem generator with any suitable system.

The assisting ship projector, which is shown in Figure 5.8, consists of an optical projector mounted in gimbals in such a manner that it can be swung both vertically and horizontally (moving the images across the screen in any desired direction), and a control cabinet upon which the projector assembly is mounted. Inside the control cabinet are the mechanisms which swing the projector, and on the front panel are four control knobs with appropriate indicating dials. These knobs control the course and speed of the ship's image and the position of the range line image.

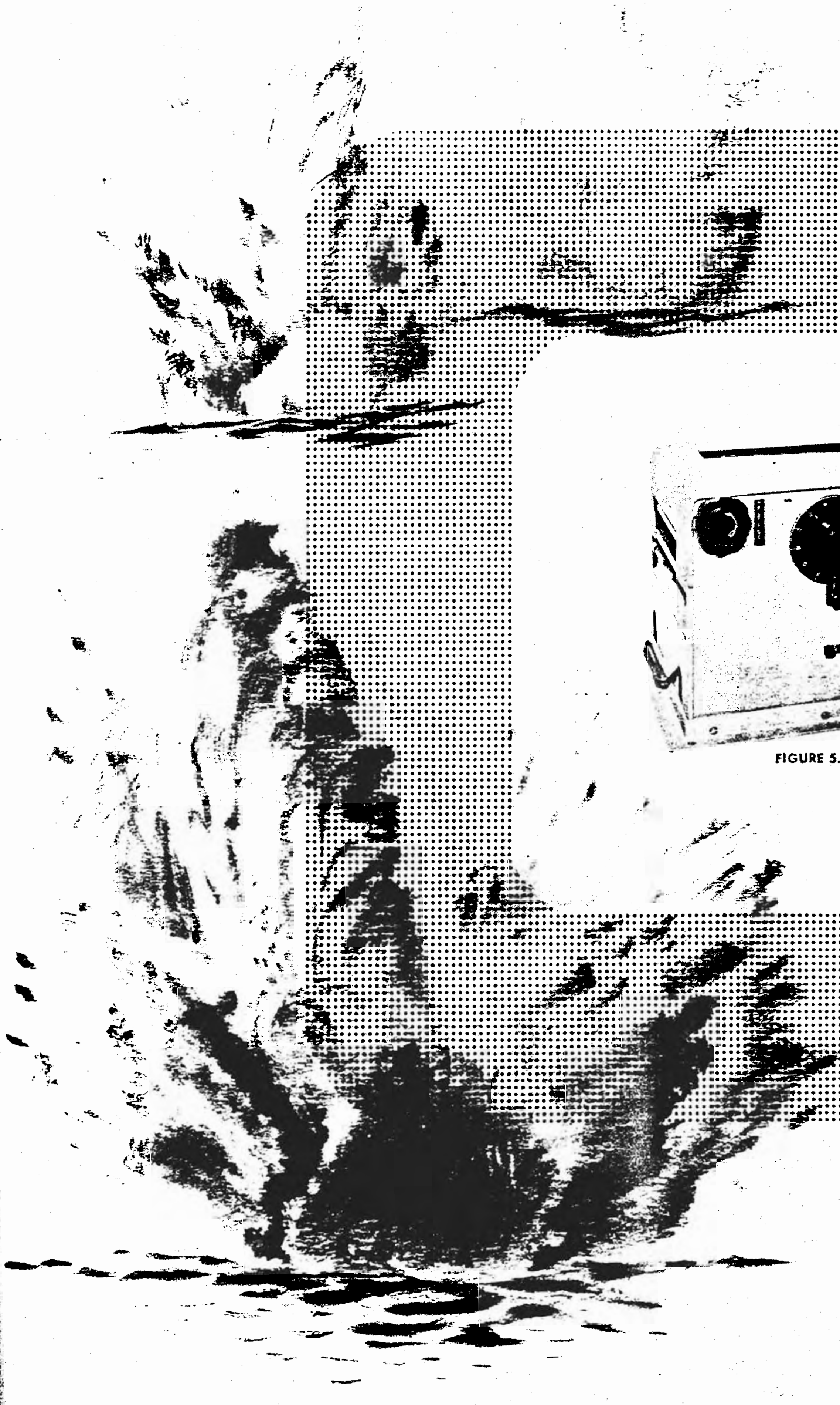
Two units were built by UCDWR and were delivered to the Fleet Sonar School, San Diego, at the end of 1945. The upper portion of the device is the projector for the Antisubmarine Search Trainer built by J. H. Keeney and Company Inc., Chicago, Illinois, and modified by UCDWR.

2. depth charge pattern recorder

(See File No. 91.232)

This device was developed for the purpose of analyzing depth charge practice attacks on equipment known as the depth charge driller. The latter is a shore-based arrangement of K-guns and depth charge racks which simulates a shipboard installation. In practice attacks the K-guns are fired and the rack releases tripped in predetermined sequence so as to simulate laying a given pattern. The depth charge pattern recorder is electrically connected to the K-guns and rack releases in such a manner that a record is made of the actual pattern. In scoring the success of the attack this record is compared with the intended pattern.

The device, shown in Figure 5.9, consists of a metal box approximotely 18 inches long, 10 inches wide and 11½ inches high, inside which, standing ver-



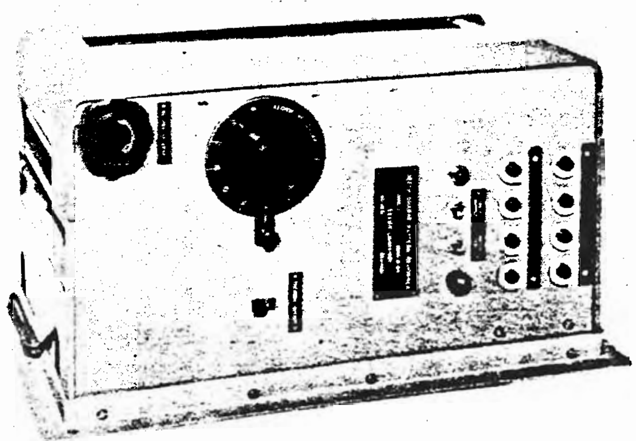


FIGURE 5.9. DEPTH CHARGE PATTERN RECORDER

tically, are eight solenoid-operated electric punches. Above these is a paper strip so arranged on rollers at each end that it can be moved horizontally above the punches. Means are provided for connecting each punch electrically to a K-gun, and for adjusting the punches horizontally so that their positions conform to the layout of the K-guns and racks. The paper strip can be made to move at a speed proportional to the speed of the simulated A/S vessel. The firing of a K-gun or tripping of a rack release permits an electric current to pass through the corresponding solenoid. This activates the punch within the solenoid, forcing it upward to punch a hole in the moving paper strip. At the end of the attack the arrangement of these holes represents the depth charge pattern simulated. Five depth charge pattern recorders were built by UCDWR, and various parts for 26 more were procured for the Navy from Los Angeles firms and assembled by UCDWR.

FIGURE 5.10. SHIPBOARD ANTISUBMARINE ATTACK TEACHER (SASAT A), (QFK)

3. shipboard antisubmarine attack teacher (SASAT A) (QFK)

(See File No. 91.234)

The need for this device arose from the fact that a sound operator at sea has very little opportunity to work at his trade. He graduates from Sonar School with his ability at the peak of intensive training, and may spend six months or more at sea without hearing an echo. The same is true of other members of an antisubmarine attack team. A shipboard device, therefore, was needed which would permit simulated antisubmarine drills to be held in the absence of practice targets.

SASAT A is a portable device, shown in Figure 5.10, which can be connected to standard sonar gear without interfering with its regular operation. It injects an echo into the sonar stack of such a character and at such a time as to simulate the echo that would have been received from a target submarine. By means of controls on the panel of the device, the instructor can place the simulated submarine at any bearing and change the bearing to indicate bearing drift. He can control the elapsed time between the outgoing signal from the stack and the echo by means of a range dial which in turn is controlled by a range-rate dial. This results in a realistic slope of the recorder trace. He can control the echo length to provide bow, beam, quarter, or stern traces, and, by changing the pitch of the echo, can simulate doppler. An endless variety of the problems incident to an antisubmarine attack can thus be simulated.

Thirty units were built by UCDWR and 100 were procured by the Navy under Contract NXs-30773 with the Stoddart Aircraft Radio Corporation, Los Angeles, California.

In an effort to design a completely automatic attack teacher, one of the Division's groups worked for a considerable period, at relatively low priority, on SASAT B. Certain progress was made toward the solution of the various problems presented by a completely automatic trainer, permitting freedom of maneuvering to the ship and providing an accurate record of the positions of the ship and synthetic target, but the device did not reach the stage of service tests and evaluation before personnel were diverted to more urgent assignments.

4. automatic target positioner for dead reckoning tracer

(See File No. 85.00)

The automatic target positioner, Model I, is not a training device at all, although its development grew out of experience with a somewhat similar instrument designed for use in a CIC training program.

Model I is an experimental model of a device designed for installation aboard ships. It is intended to be installed in and become a part of the Arma dead reckoning tracer, and its purpose is to facilitate plotting of targets. Plotting is done by means of a light spot, representing the target, which responds automatically to range and bearing information fed into it from radar. The target light, with the mechanism which moves it to the desired positions, is housed in a frame which fits into the DRT table beneath the glass plotting surface, as can be seen in Figure 5.11. The own-ship light spot is the origin relative to which the target light spot is positioned. The light spot responds so rapidly to radar information that a continuous plot of twelve targets per minute can be carried on, and the errors incident to hand plotting with a drafting machine are eliminated.

The complete device consists of the following components: (1) a range and a bearing transmitter designed to be connected directly to an SG radar so as to feed ranges and bearings of selected targets into the positioning mechanism automatically; (2) a power and amplifier unit; (3) the target light, positioner, and its supporting mechanism installed in a frame to fit into the DRT table; (4) a non-obscurable own-ship light with a special focusing reflector to be substituted for the standard own-ship light in the DRT; (5) a system of "ready" and "release" lights, a stop clock, and associated control push buttons; (6) a range scale selector for bringing the DRT and ATP scales into agreement.

Model II of this device is still under development at the time of writing. Some such device is an obvious necessity for the CIC Trainer and it can be foreseen that the ultimate DRT will include rapid target plotting as a matter of course.

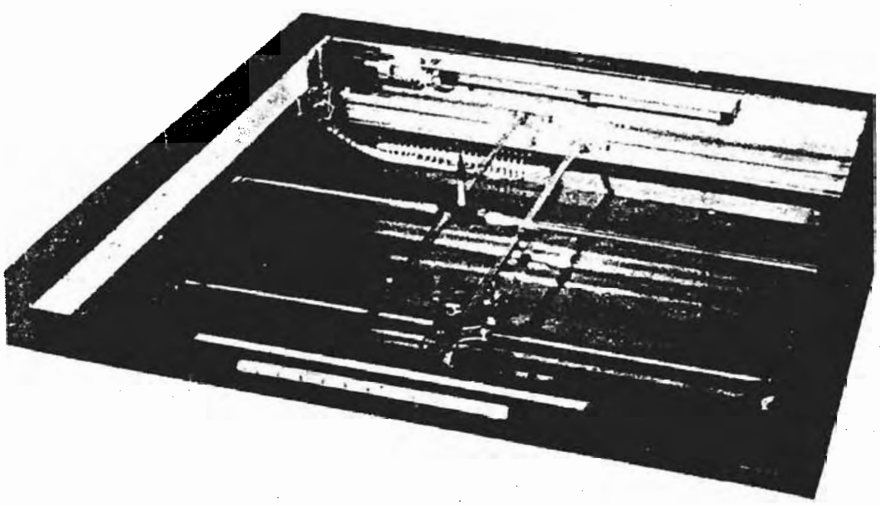
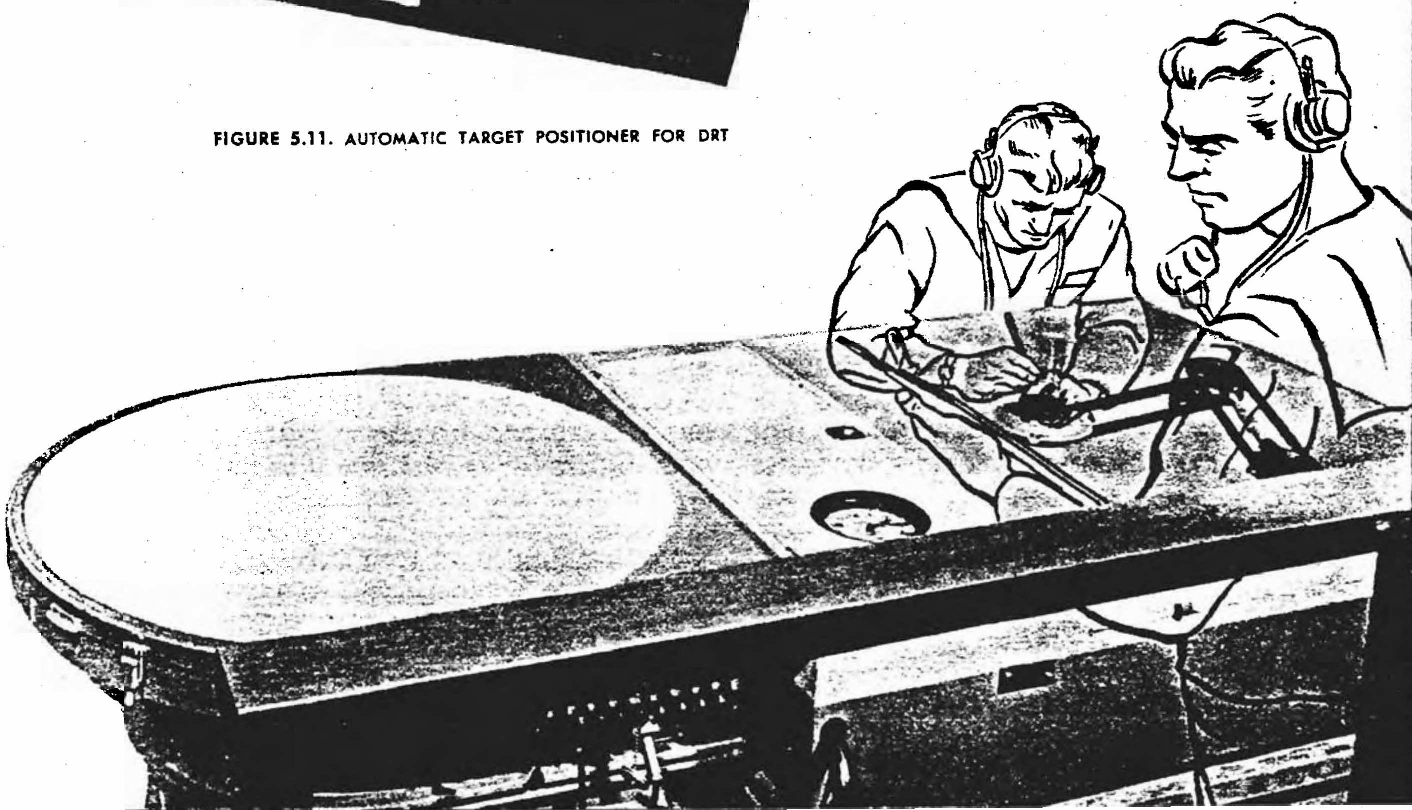
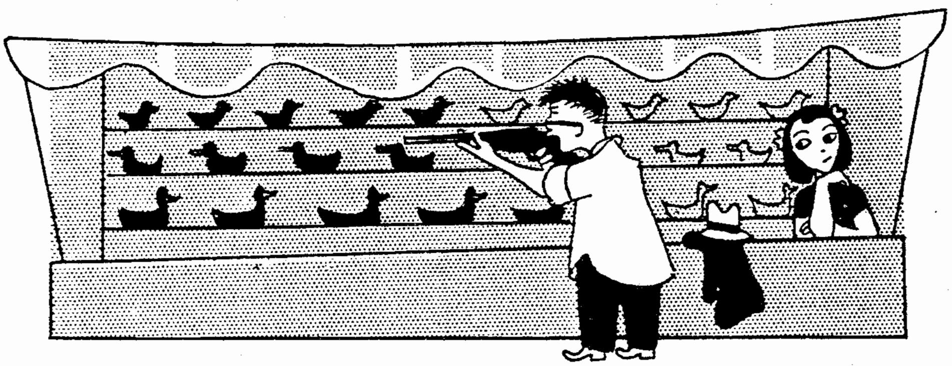


FIGURE 5.11. AUTOMATIC TARGET POSITIONER FOR DRT





5. practice targets

(See File No. 91.236)

The serious lack of submarines for sea training of A/S teams created the need for targets which would simulate submarines for echo-ranging purposes. In 1942, UCDWR developed the practice target to fill this need. All types of targets are equipped with a receiving transducer (hydrophone), an amplifier, and a transmitting transducer (projector). The signal from the echo-ranging vessel is picked up by the hydrophone, amplified and returned by the projector as a simulated echo. Several types of targets for different uses were developed and are described below.

RR-1 Raft Type. In the first target to be built, the transducers were fastened ten feet apart beneath a 15-ft. plank so that they were submerged to a depth of six feet, and the plank was towed by a small vessel. Cables from the transducers were taped to the tow line and led to the amplifier which was carried aboard the towing vessel. Thirty-one units of this type, shown in Figure 5.12, were built by UCDWR.

KR-1 Keel Type. The success of the RR-1 led to the development of the KR-1 in which the transducers were mounted beneath the keel of a surf boat, as shown in Figure 5.13. Six units of this type were built by UCDWR.

BR-1 Buoy Type (Navy OAU). The two types of target mentioned above had certain shortcomings: the transducers were shallow, and the ranges in consequence were short; the small vessels could not operate satisfactorily in rough seas; the presence of the small vessel prevented the attacking ship from maneuvering freely in the neighborhood of the target. The first attempt to overcome these drawbacks resulted in the BR-1. This, as shown in Figure 5.14, consisted of a 50-gallon steel barrel housing the amplifier, power supply, and two 6-volt storage batteries. The transducers, mounted at either end of a ten-foot pipe, were suspended beneath the buoy on a cable at a depth of approximately 50 feet. This target merely drifted and did not simulate a submarine in motion, but it presented only a very small hazard to the maneuvering ship, and it could be carried on deck and put overboard in the operating area. It was useful for primary training. Thirty-nine units were built by UCDWR and 83 by the Western Electric Company (ERPD), Hollywood, California, on direct Navy Contract NXs-30776.

SR-2 Towed Submerged Type (Navy OAS). It had been recognized during the development of the targets described above that the eventual practice target should be a towed, submerged body which would closely simulate a submarine. The SR-2 complies with these requirements. As shown in Figure 5.15, it consists of a 330-pound torpedo-like body carrying the two transducers in the tail structure, and the amplifier inside. The towing cable has an insulated electrical conductor in its core which connects the transducers and amplifier to a power supply and control unit aboard the towing vessel. The target floats when stationary, but, when towed at three to six knots on 1200 feet of cable, submerges to a depth of 60 to 90 feet. The control unit contains a gain control and a depth indicator. Sixteen units were built by UCDWR and 163 under Navy Contract NXs-28612 with the Western Electric Company (ERPD), Hollywood, California.

SR-5 Towed Submerged Type (Navy OAT). The SR-2 is somewhat heavy for convenient handling, so the SR-5, shown in Figure 5.16, was developed to overcome this drawback. The body is a hollow wing-like structure resembling a ray (fish). The total weight is approximately 100 pounds, and its performance is almost identical to the SR-2. Sixteen units were built by UCDWR.

practice targets

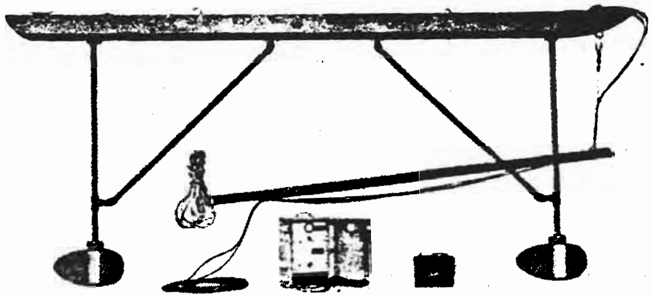


FIGURE 5.12. PRACTICE TARGET—RAFT TYPE (RR-1)

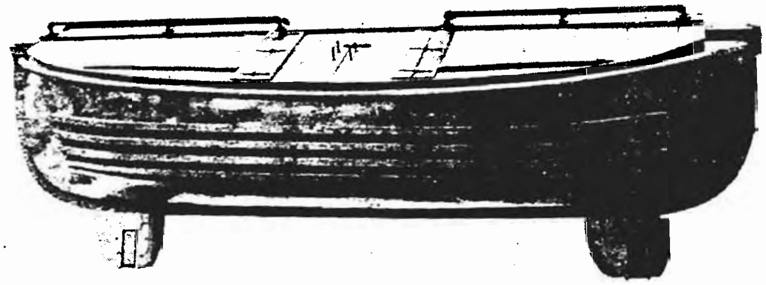


FIGURE 5.13. PRACTICE TARGET—KEEL TYPE (KR-1)

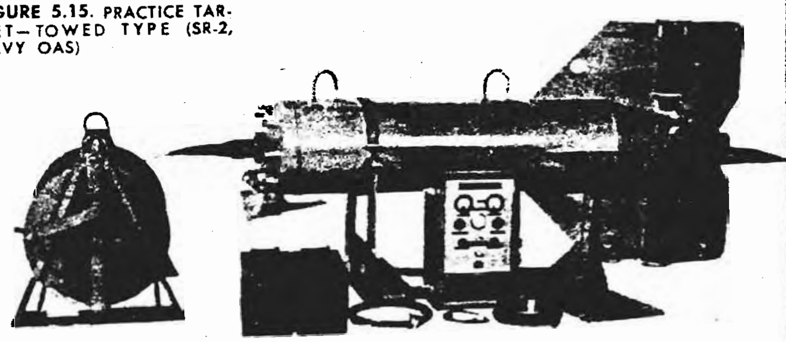


FIGURE 5.15. PRACTICE TARGET—TOWED TYPE (SR-2, NAVY OAS)

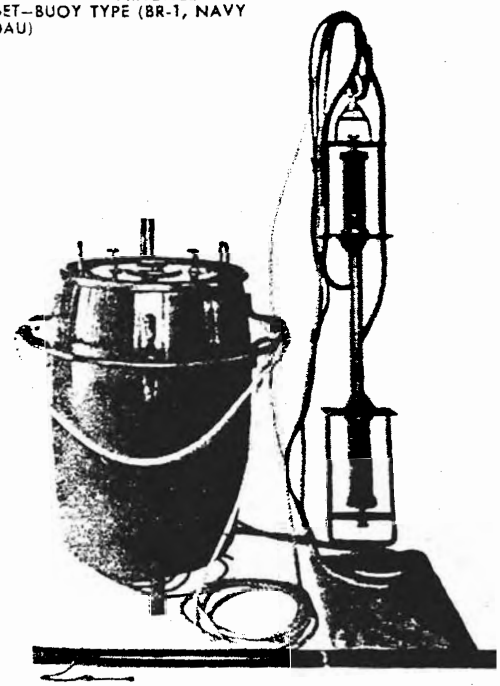


FIGURE 5.14. PRACTICE TARGET—BUOY TYPE (BR-1, NAVY OAU)

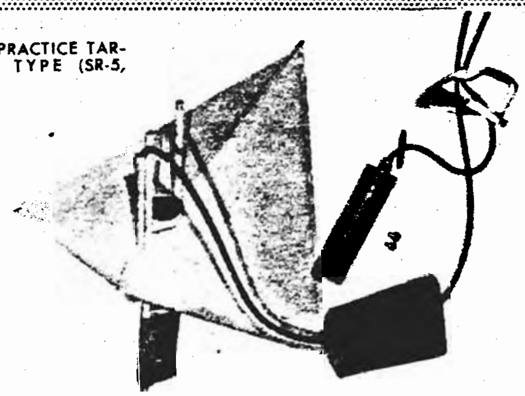


FIGURE 5.16. PRACTICE TARGET—TOWED TYPE (SR-5, NAVY OAT)

IV. devices for training submarine sonar personnel

The first four devices in this group were designed to perform functions in the submarine training program very similar to the functions performed by four devices already described for use in surface sonar training, namely, the primary bearing teacher, advanced bearing teacher, group operator trainer, and echo recognition group trainer. The corresponding devices in the two groups closely resemble each other, the important difference being the emphasis on listening, as distinguished from echo ranging, in the submarine training devices. The two other devices described in this section meet training problems peculiar to submarines.

1. primary listening teacher (OFF)

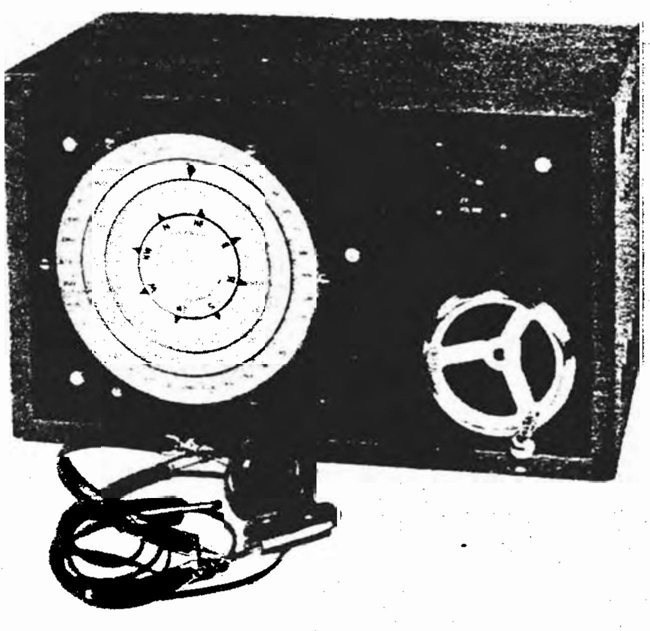
(See File No. 91.241)

This device closely resembled the primary bearing teacher shown in Figure 5.3, the essential difference being that screw noises are simulated instead of echoes. Its purpose is to provide submarine sonar operators with primary training in the routine of locating a surface ship by listening for screw noises, locating the center bearing by noting the reduction of sound intensity at each side, following a moving target, counting propeller beats (making these determinations in the presence of varying amounts of water noise), and reporting the results properly.

The device (see Figure 5.17) is housed in a box similar in size to the primary bearing teacher. The student's panel is equipped with a training handwheel, a bearing indicator which shows the angle of train of the simulated projector, a volume control, and headphones. On the instructor's panel is a bearing indicator which shows the bearing of the surface ship from the submarine, a crank by means of which the surface ship can apparently be swung around the submarine, a handwheel with which the course of the simulated submarine can be changed, a volume control for water noise, one for propeller sound, a control for revolution rate of propeller beats, and headphones.

Ten units were built by UCDWR and 152 by Bell Sound Systems, Inc., Columbus, Ohio, under Navy Contracts NXs-18748 and NXs-43410.

FIGURE 5.17. PRIMARY LISTENING TEACHER, STUDENT'S POSITION



2. advanced listening teacher

(See File No. 91.242)

This is a device for advanced training of submarine sonar operators in the operation and tactical use of JK listening gear. Its counterpart in the surface ship training program is the advanced bearing teacher. Every effort has been made to simulate sea conditions as realistically as possible. The cabinet, shown in Figure 5.18, closely resembles a WEB stack. It is equipped, on the student's side, with normal JK controls for training the projector, tuning the receiver, and adjusting the gain control and filters. There is also a bearing indicator which shows the heading of the submarine and the angle of train of the JK head. The water noise and propeller beats of a submarine under way and the propeller beats and echo-ranging signals of two surface ship targets are realistically simulated. The student locates and tracks the targets in a manner similar to that employed at sea, while the instructor controls the problem from the opposite side of the cabinet. On the instructor's side is a viewing screen representing an ocean area 8000 yards square with the submarine at the center. On it is a fixed bearing dial, with north at the top, inside which rotates a bug ring, the bug indicating the bearing toward which the JK head is trained by the student. Inside the bug ring is a relative bearing card, in the center of which the submarine image is printed. The heading of the submarine, as shown by this image and by the student's bearing indicator, is controlled by the instructor. The respective points of intersection of two pairs of colored lines (red and blue), which cross at right angles, depict the location of the simulated surface target ships. A bearing-and-range line overlies the chart and may be rotated about the center of the submarine image by the instructor to determine bearings and ranges of the targets.

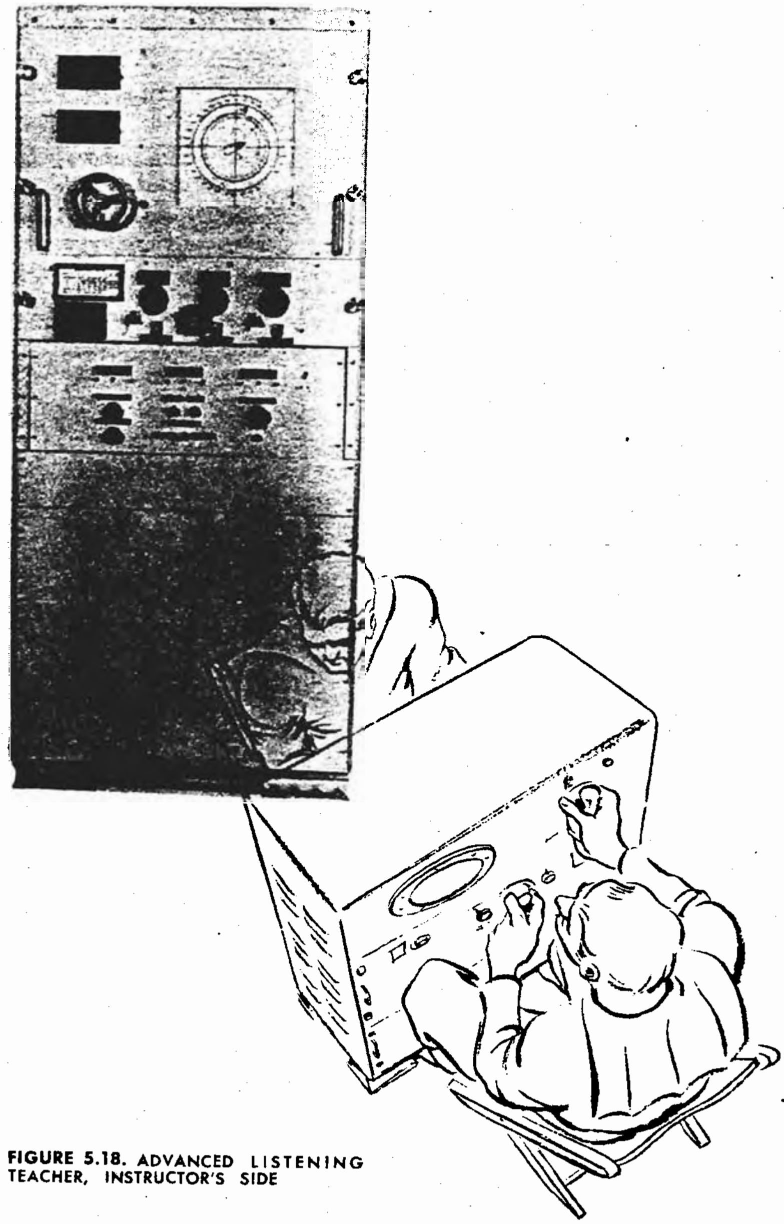
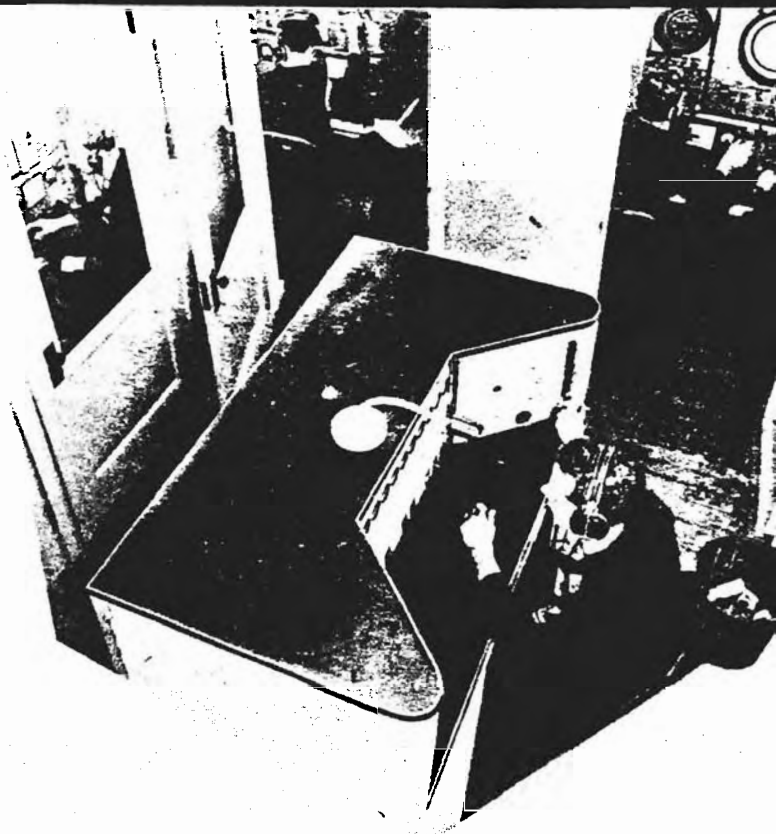


FIGURE 5.18. ADVANCED LISTENING TEACHER, INSTRUCTOR'S SIDE

The instructor controls the course and speed of the submarine and the two surface ships. It will be noted that, because the submarine image does not move from its position in the center of the screen, the movements of the targets represent relative movement. Any selected setting of the submarine speed control knob automatically produces water noise and propeller beats appropriate to that speed. The loudness of the water noises and propeller beats may be manually reduced by the instructor, however, if desired, as in the case of beginning students who have difficulty identifying the targets because of this interference. The targets' propeller speeds are automatically regulated by the setting of the target speed control knob, but the type of propeller beats (type of ship being simulated) is controlled by two knobs, one for each target, with which five types may be selected for each target ship. The water noises and propeller beats of a target can be heard when the JK head is trained on the target, and undergo attenuation when the head is trained off. They grow louder as the range shortens. The instructor also controls the echo-ranging effects from the target.

Three units were built by UCDWR and 62 by Radio Corporation of America (Victor Division), Comden, N. J., under Navy Contract NXsr-86288.



3. group listening teacher (CXKG and (CXKG-1)

(See File No. 91.247)

The conditions which made necessary the development of a group trainer for surface ship sonar students also obtained in the submarine sonar training program, and the group listening teacher, which resembles the group operator trainer, was designed to solve the same sort of problem. As in the latter device, there is a master station or problem generator, shown in Figure 5.19, and ten student stations, and each student station is a standard sonar stack of a type in current use in the submarine service. There are three such types, and because they differ considerably it is essential that each student receive training on all three. For this reason the complete group listening teacher actually consists of three separate installations: (1) a problem generator and five double WCA stacks; (2) a problem generator and ten JT stacks; (3) a problem generator and 10 WFA stacks.

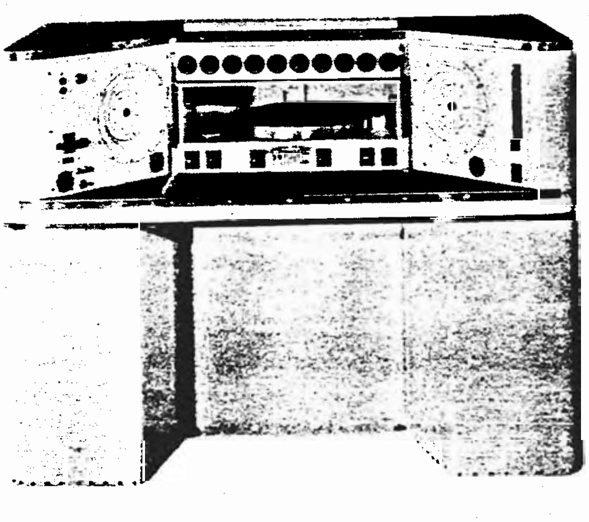


FIGURE 5.19. GROUP LISTENING TEACHER (CXKG)—MASTER STATION

The problem generators are quite similar in all three installations. They generate sounds which simulate two surface ships and the submarine, i.e., water noises, propeller beats, echo-ranging signals, torpedo explosion, etc. There are three 20-minute problems which can be selected at will by the instructor. Two of these simulate attacks by the submarine on the surface ships in which torpedoes are fired at the end of a successful run, and the third simulates an attack on the submarine by the surface ships in which the submarine maneuvers successfully to escape. When a problem has been started, it progresses automatically, with appropriate sound effects introduced, without any manipulations by the instructor. However, if the instructor desires to complicate the situation, in order to train the students in overcoming the further distractions which may occur at sea, he can manually introduce: (1) changes in frequency and interval of surface-ship echo-ranging signals, (2) changes in the type of propeller beats of either surface ship, (3) changes in the submarine's water noises. The instructor's console is equipped with bearing indicators to show the true bearing of each of the two surface ships from the submarine, and with ten small bearing dials to indicate the angle of train of the students' projectors. There is also an intercommunication system through which the instructor can coach the students.

4. sound recognition group trainer (SRGT)

(See File No. 91.246)

This equipment fulfills the same purpose in the submarine sonar training program as the echo recognition group trainer in the surface ship program, namely, to give sonar operators intensive training in sound recognition and to furnish a printed record of the students' decisions as an aid to proper grading. As in the echo recognition group trainer, the sound effects are playbacks of actual sea recordings. Propeller beats of a wide variety of ships at various speeds, echo-ranging signals from surface ships, water and screw noises from own-submarine, and sundry other sound effects frequently heard over submarine listening gear have been recorded and classified. They have been divided into groups, each of which gives the student practice in some problem of target identification.

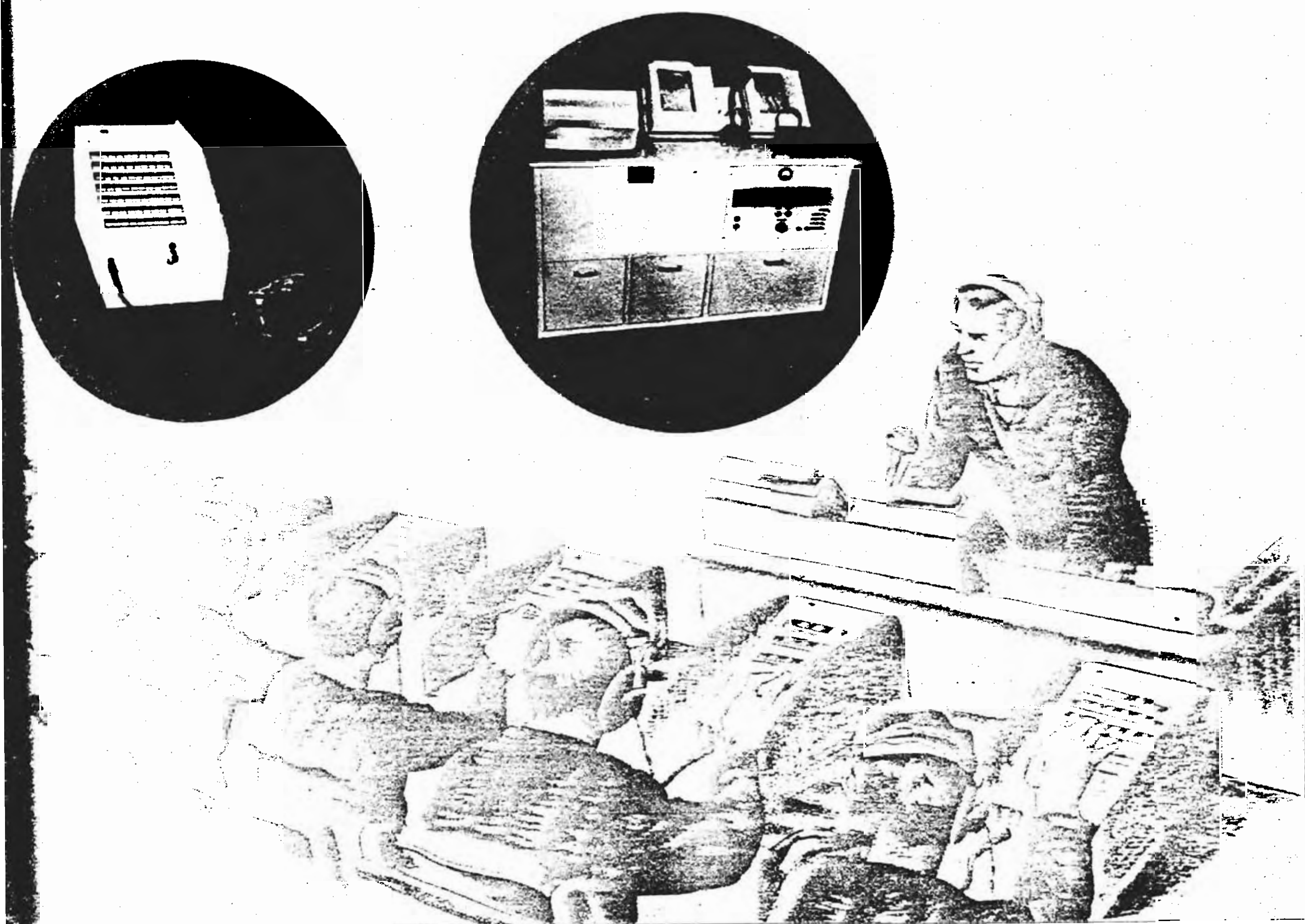
The instructor's station, shown in Figure 5.20, is a cabinet which houses the phonograph and on top of which are two monitor recorders. Each student station is equipped with a small sheet-metal box with a sloping top on which are 70 push buttons with code numbers, as can be seen in Figure 5.21. When a button is pushed, the code number is printed on the moving paper strip in one of the monitor recorders. Each of the latter accommodates eleven columns of figures, ten for the students and one for the instructor, whose station is also equipped with push buttons. The complete installation has 20 student stations.

The student listens over headphones and records his judgment by pushing the appropriate button, following a code arranged before the lesson begins. The instructor, by watching the printed record, is able to coach the students, and the record forms a ready means for grading. The instructor's voice comes to the students over the headphone circuit.

Three units were built and installed by UCDWR, two at the Fleet Sonar School, San Diego, and one at the Submarine School, New London.

FIGURE 5.21. SOUND RECOGNITION, GROUP TRAINER (SRGT)—STUDENT'S STATION

FIGURE 5.20. SOUND RECOGNITION GROUP TRAINER (SRGT)—INSTRUCTOR'S STATION



5. submarine bathythermograph simulator (BTS)

(See File No. 91.248)

This device is an adjunct to an Askania diving trainer and the need for it arose because of the following conditions: the Askania diving trainer is an elaborate mock-up of the control room of a submarine by means of which personnel are trained in the techniques of diving procedure. Various factors such as speed, plane positions, quantity and disposition of ballast, etc., are automatically simulated, but the important factor of change in water density can be introduced only manually, and to do so requires the close attention of the instructor. The submarine bathythermograph simulator was developed for the purpose of introducing the density factor automatically, and in doing so it simulates sea conditions much more closely than could be done by using the manual controls. It also traces on a bathythermograph card the depth-temperature pattern being followed.

FIGURE 5.22. SUBMARINE BATHYTHERMOGRAPH SIMULATOR (BTS)

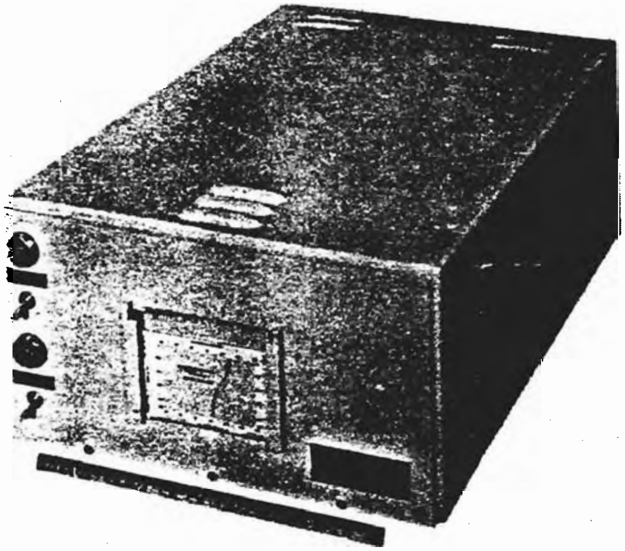
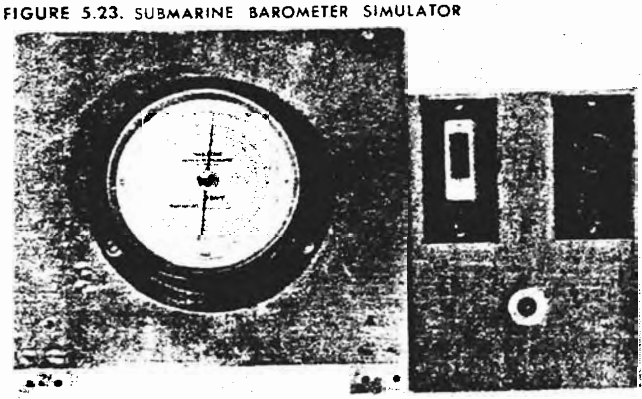


FIGURE 5.23. SUBMARINE BAROMETER SIMULATOR



The BTS, shown in Figure 5.22, consists of a control cabinet and a mock-up of a submarine bathythermograph. In operating the device, a master bathythermograph card is inserted into a window in the front panel of the control cabinet. This card is one of an assortment of prepared cards covering representative depth-temperature conditions. Inside the cabinet a light spot is focused on the back of the card and reflected back into a photo-electric cell mounted on a movable carriage. The mechanism is so designed that as the depth of the submarine simulated by the trainer increases, the photocell follows the contour of the temperature trace on the card and, through selsyns, turns the density control shaft on the trainer. At the same time it actuates the bathythermograph mock-up in such a manner as to trace on the latter's card a depth-temperature pattern similar to that on the master card.

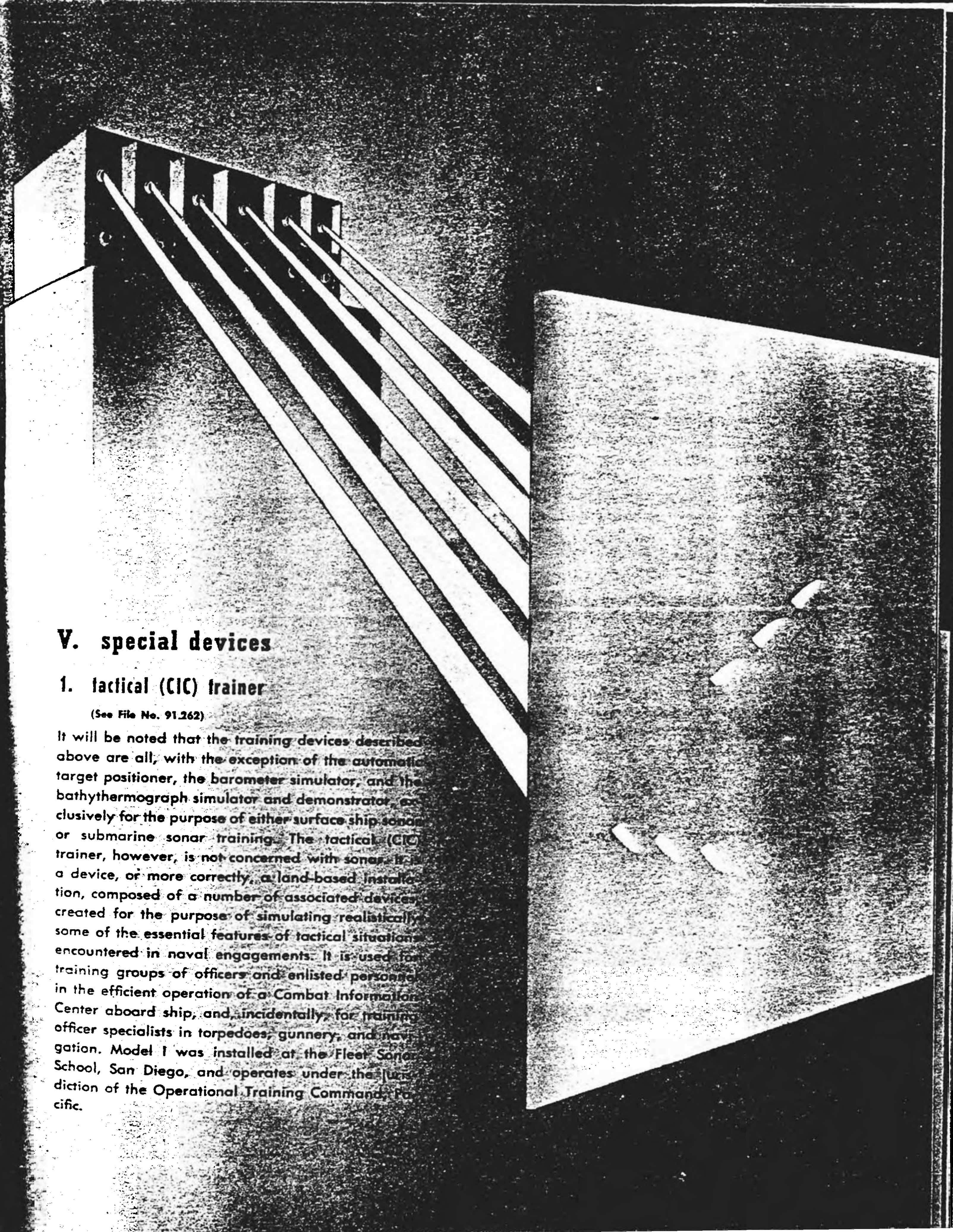
One unit of this device was built by UCDWR and installed at Submarine Squadron 45, stationed at that time in San Diego.

6. submarine barometer simulator

(See File No. 91.249)

This device (see Figure 5.23) is also an adjunct to the Askania diving trainer, which, as previously mentioned, is a mock-up of the control room of a submarine and is used to train submarine personnel in diving procedures. On an actual submarine the internal air pressure is increased slightly just before submergence to prove that all openings to the outside atmosphere are closed. If pressure, as indicated by a barometer, fails to build up, the diving officer is warned that conditions are unsafe for diving. The Askania trainer had nothing to simulate a barometer, hence the need for this device, which consists of a standard Navy aneroid barometer with an electrical actuating mechanism substituted for the pressure-operated mechanism. There is also a control panel. When the diving alarm push button is actuated, the barometer needle moves to normal pressure indication (usually 29.6 inches of mercury); a time delay mechanism is started (if the pressure indicator switch is on); and after a suitable interval the needle moves up to indicate 0.3 inches increase of pressure. If the instructor desires to show a condition unsafe for diving he leaves the pressure indicator switch in the "off" position.

One unit of this device was built by UCDWR and installed at Submarine Squadron 45, then in San Diego.



V. special devices

1. tactical (CIC) trainer

(See File No. 91.262)

It will be noted that the training devices described above are all, with the exception of the automatic target positioner, the barometer simulator, and the bathythermograph simulator and demonstrator, exclusively for the purpose of either surface ship sonar or submarine sonar training. The tactical (CIC) trainer, however, is not concerned with sonar. It is a device, or more correctly, a land-based installation, composed of a number of associated devices, created for the purpose of simulating realistically some of the essential features of tactical situations encountered in naval engagements. It is used for training groups of officers and enlisted personnel in the efficient operation of a Combat Information Center aboard ship, and, incidentally, for training officer specialists in torpedoes, gunnery, and navigation. Model I was installed at the Fleet Sonar School, San Diego, and operates under the jurisdiction of the Operational Training Command, Pacific.

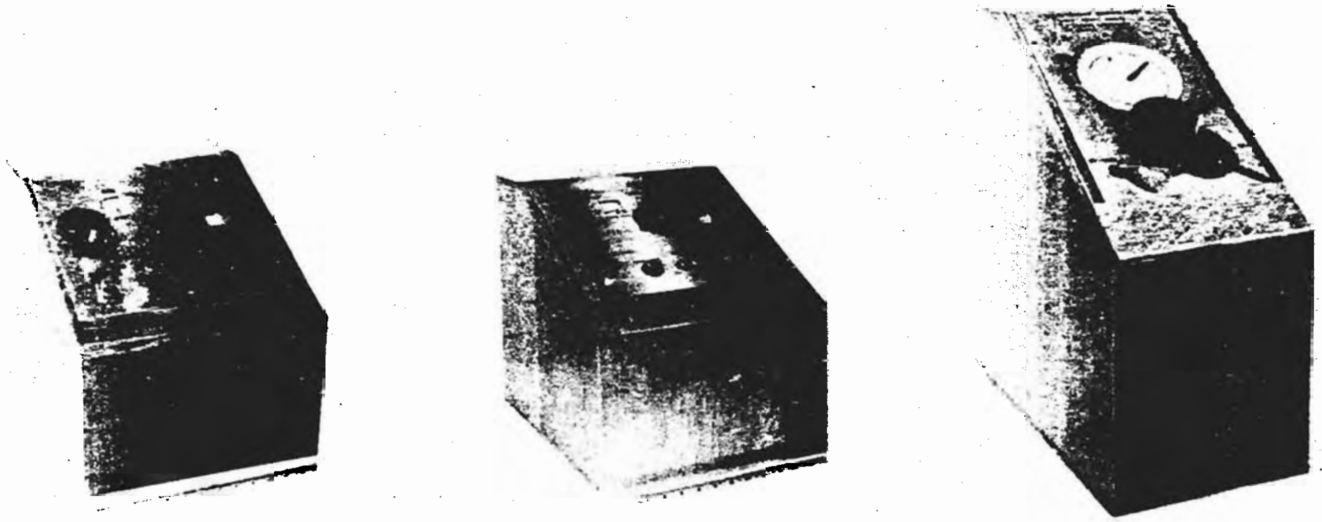
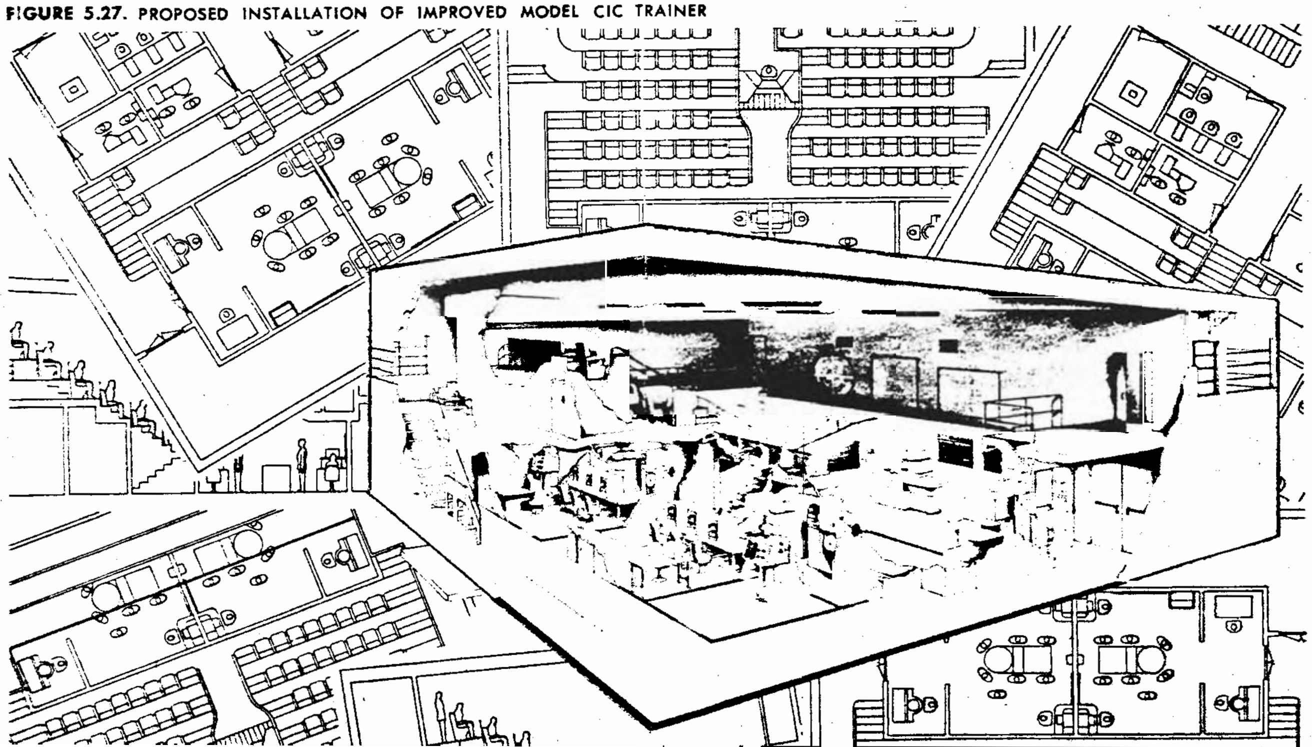


FIGURE 5.26. TACTICAL (CIC) TRAINER—CONTROL UNITS

Model I has eight optical projectors, shown in Figure 5.24, and a viewing screen, representing an ocean area 36 miles square, on which the images from these projectors appear. Six images simulate surface ships and associated gunfire, and two simulate torpedoes. The guns on each ship are represented by a small rectangular image which indicates the direction in which the guns are trained. When the gun is fired, this image lengthens at an appropriate rate to simulate gunfire (two such gunfire images are shown in Figure 5.25). The two torpedoes are represented by small circular images, and either torpedo may be assigned to any surface ship. Before firing, the torpedo image is superimposed upon the ship image and travels with it. When the torpedo is fired, it moves off at the course and speed selected. Each ship projector is electrically connected to its own conning unit by means of which the maneuvers of the image on the screen are controlled, and each of the two torpedo projectors is similarly connected to a torpedo control unit. The guns on each ship are trained and fired by means of a separate gunfire unit connected to each ship projector. A conning unit, torpedo control unit, and a ship projector are shown in Figure 5.26. The range and bearing indicators of either of two standard radar installations may be associated with any of the ships. They function normally and view the other ships as targets. The installation is so arranged that standard plotting devices, such as the DRT, can be used.

An improved model for use at larger training activities is in the process of design, and a proposed installation is shown in Figure 5.27.

FIGURE 5.27. PROPOSED INSTALLATION OF IMPROVED MODEL CIC TRAINER



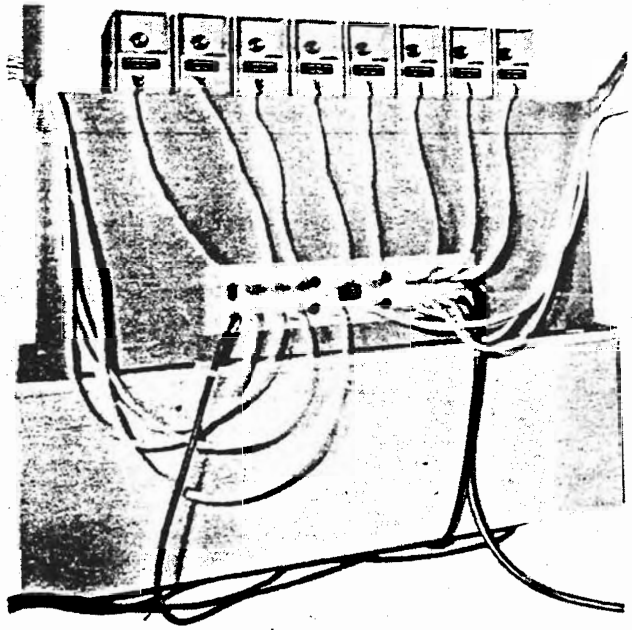


FIGURE 5.24. TACTICAL (CIC) TRAINER—PROJECTOR BANK

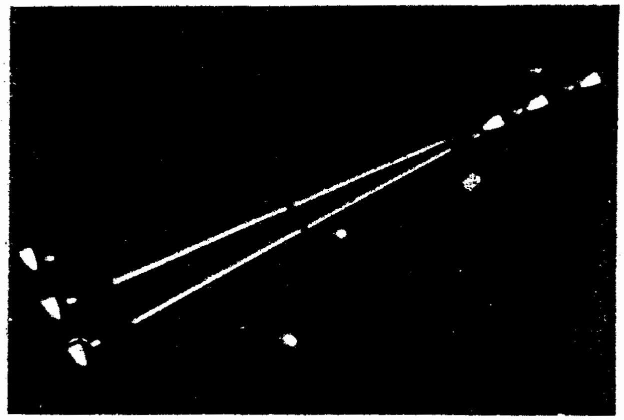


FIGURE 5.25. TWO GUNFIRE IMAGES ON CIC SCREEN

VI. miscellaneous training aids

These took many forms and were supplied not only to the Sonar Schools but also to Fleet units engaged in training at sea and often to combat forces. They contributed materially to the effectiveness of the instruction, made the instructor's job an easier one, and increased the number of students that one instructor could handle efficiently at a time. These aids were not only actual mechanical devices, but, profiting by industrial experience in visual education, also motion picture films, slide films, and display material. These films formed part of the sonar curriculum at the Schools and were of great value in refresher training with the Fleet and at advanced bases. The Laboratory made slide films which dealt chiefly with newer types of auxiliary equipment such as the bathythermograph and radio sono buoy. An extensive library of lantern slides was also built up which helped the Schools' curricula materially, and charts and animated demonstrators were built to demonstrate surface vessel and submarine maneuvers.

Visual aids of this sort were supplemented by auditory ones. The recording facilities of the Laboratory produced a wide variety of recordings for both training and experimental purposes. Lectures were sometimes recorded at one School and sent to another. They were also played back to the original instructor as a means of improving his technique. Recordings of sea echoes and ship sounds formed the basis of the training in echo and sound recognition, and an extensive program was carried on to build a "library" of recordings of representative echoes and ship sounds. These were later edited and assembled in graded series adapted for use both by the Sonar Schools and at advanced bases. About 400 records were made for training purposes out of the materials available, and over 1000 experimental recordings of one sort or another. About 600 master records are now available from which pressings can be made upon request. A complete catalog was kept and transferred to NEL.