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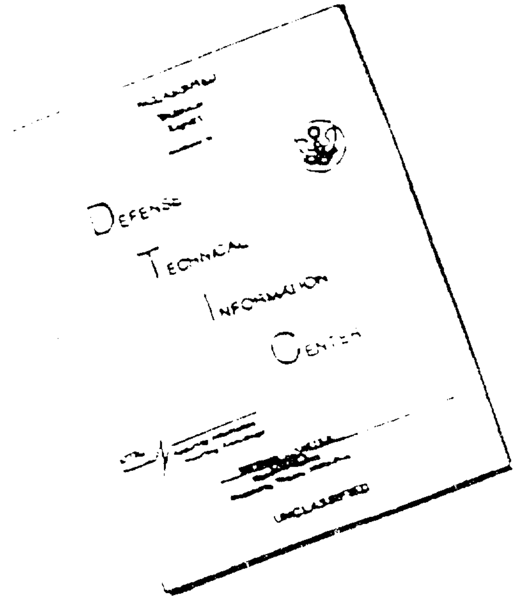

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NRL Report 6535

Project Artemis Acoustic Source
Summary Report
[Unclassified Title]

September 7, 1967

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NRL Report 6535

Project Artemis Acoustic Source Summary Report

[Unclassified Title]

A. T. McCLINTON

Propagation Branch
Sound Division

September 7, 1967

DEPARTMENT OF THE NAVY
OFFICE OF NAVAL RESEARCH

NAVAL RESEARCH LABORATORY
Washington, D.C.

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CONTENTS

ABSTRACT
[Confidential]

A directional 400-Hz source was developed for the Navy research program on undersea surveillance. The source can be operated over a 100-Hz frequency band from 350 to 450 Hz with a maximum available source level of 147 dB versus 1 dyne per square centimeter at 1 yard (dB//1 dyne/cm^2 at 1 yd). The system is installed in a converted T-2 class A-2 tanker, the major modification being a well cut through the main deck and keel approximately at midship through which the transducer array is lowered to operating depth. The system includes winches and cable-handling machinery for lowering the approximately 800,000 pound transducer array to a 1200-foot depth.

Interaction between transducer elements in the multielement array was a major problem in the system development. Although the effect of interaction was reduced, it was not completely overcome. The principal effect of the interaction was to cause excessive fatigue in transducer elements, necessitating reduction of input power to prevent transducer failure. A modified version of the element was developed which can withstand the larger displacement associated with interaction. If this element were used in the array, it is anticipated that a source level of approximately 156 dB could be obtained. This assumes that the pressure-release system required to suppress the back radiation of the array could be modified to withstand the higher acoustic intensity.

The Artemis acoustic source development was intended, first, to provide the acoustic signals for the Artemis experimental program on propagation research and signal processing development and, second, to determine the problems associated with construction and operation of an acoustic source for active undersea surveillance systems. Although an exhaustive research and development program on the acoustic sources for this kind of application was not undertaken, general recommendations concerning engineering and construction problems were obtained as a result of this program.

PROBLEM STATUS

This is a final report on the problem. Unless otherwise notified the problem will be considered closed thirty days after the issuance of this report.

AUTHORIZATION

NRL Problem S02-11
Project ONR RS 046

Manuscript submitted December 28, 1966.

PROJECT ARTEMIS ACOUSTIC SOURCE SUMMARY REPORT

[Unclassified Title]

INTRODUCTION

Prior to the inception of the ocean surveillance study program that became known as Project Artemis, an ad hoc group completed a study expedited at the request of the Office of Naval Research for a "high power, deep underwater sound source." The membership of this ad hoc group was as follows:

F. S. Andress — Undersea Warfare, Bureau of Ships (part time)

B. G. Bingham — Undersea Branch, Office of Naval Research

R. E. Faires — Transducer Branch, Naval Research Laboratory

A. T. McClinton — Electrical Applications Branch, Naval Research Laboratory

A. W. Pryce — Acoustics Branch, Office of Naval Research

The study began in April 1958.

A general set of guidelines for this source was established as follows:

Frequency range	300-1500 Hz
Power	A minimum of 1 MW acoustic power within 20 degrees of the horizontal. This narrow beam was considered to be an asset, but was not essential.
Pulse length	It was anticipated that long pulses, in the order of seconds, or continuous-wave operation would be required.
Duty cycle	20%.
Frequency stability	For long-pulse operation, frequency stability of 0.07% was required.
Depth	The possibility of submergence of the transducer to the ocean floor was desired. However, 2000 fathoms maximum would be acceptable.

It was considered virtually certain that the frequency range of interest could be covered only by a number of transducer arrays. The time scale established for this source scheduled it to be in the water by September 1959.

Proposals for systems that would meet these very general specifications were received from five manufacturers. Because of the broadness of the specifications and the experience and capabilities of the companies making the proposals, the characteristics of the systems varied markedly in all areas. Array configurations ranged from planar arrays 2λ by 10λ to cylindrical arrays 1λ in diameter by 3λ high. Some of the units required baffles in order to provide the directional characteristics, whereas others were omnidirectional in the horizontal plane, requiring no pressure release. The proposed operating frequency varied from 220 Hz with a Q of 1 to as high as 1500 Hz with a Q of 10. Operation depth varied from 6000 to 20,000 feet. Most proposals indicated that 1000 kW of acoustic power could be achieved. However, one of the proposals indicated a maximum acoustic power of 5000 kW. Similar variation in the proposals was noted in areas pertaining to the electrical and acoustical performance of the system. Although the general specifications did not indicate either a mobile or fixed installation, a few proposals did suggest that the system could be used as a fixed installation supplied by cable from the shore or from a ship. One proposal suggested a completely mobile system with the transducer supported by cable from a ship carrying the remaining components of the acoustic source. Some proposals were quite optimistic regarding the completion date and indicated that the requirement of September 1959 could be met, whereas others required up to three years to complete an acoustic source operable in the required frequency range.

Careful analysis of the five proposals, along with a review of the manufacturers' facilities and technical capabilities, indicated that it was feasible to produce a high-power low-frequency acoustic source of approximately the characteristics specified (1). However, many engineering, design, fabrication, and operational problems were apparent. Furthermore, it was evident that any one of the approaches should be supported by a back-up program of a second transducer. In addition, certain research programs were obviously necessary to support a continuing effort. The one important conclusion to note was the advantage of an omnidirectional array for the initial devices, as opposed to a directional array.

ARTEMIS REQUIREMENTS

The general requirements for the high-power acoustic source for Project Artemis were formulated in September 1958. A summary of the desired acoustic capabilities of the source were as outlined in Table 1.

Table 1
General Requirements for Acoustic Sources

Parameter	Value
Frequency	400 Hz
Power	1000 kW acoustic
Beam Pattern	
Vertical	12.5 degrees (-3 dB points)
Horizontal	20 degrees (-3 dB points)
Source Level	152 dB//1 μbar at 1 yd
Pulse Length	10 milliseconds to 60 seconds

The transducer was to have a mechanical resonant frequency, in water, of 400 Hz with a mechanical Q of 4. The main lobe of the beam pattern was to be 12-1/2 degrees between the -3-dB points in the vertical plane and 20 degrees between the -3-dB points in the horizontal plane. This provided a directivity index of 21 dB and a source level of 152 dB versus 1 dyne/cm^2 at 1 yard (dB//1 dyne/cm^2 at 1 yd). Steering of the acoustic beam was not to be required for this source.

Initially, the acoustic source was envisioned as a permanent installation with the transducer array fixed on the ocean bottom in approximately 200 fathoms of water and with the remaining components of the acoustic source (i.e., the transmitter, primary power source, and controls) installed on the beach. A schematic representation of this is shown in Fig. 1. The installation site was to have been on Eleuthera, permitting connection of the shore-based transmitter and the bottom-mounted transducer array with approximately 3 to 4 miles of underwater cable. The acoustic axis of the transducer was to be oriented in the vertical plane 5 degrees above the horizontal. The geometry of the beam pattern and location of proposed monitoring hydrophones are shown schematically in Fig. 2.

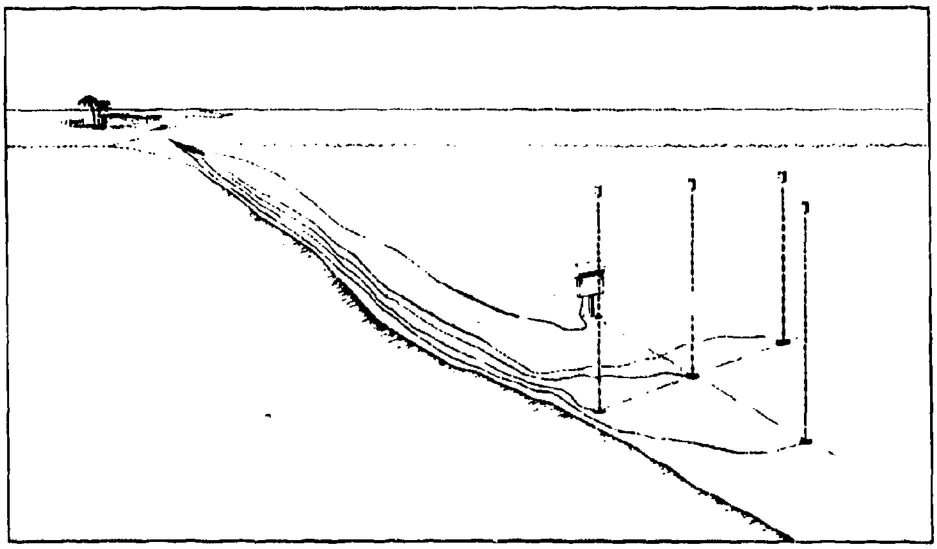

Fig. 1 - Artemis acoustic source installation (Eleuthera)

While the other facets of the Artemis program developed, changes were made in some of the requirements for the acoustic source. The first major effect on the source was a change in the installation site from Eleuthera to Plantagenet Bank, southwest of Bermuda. This site was approximately 25 miles from shore, which was believed to require an excessive cable run for transmitting an estimated 4000 kW of power to the array. Ship use versus platform use on Plantagenet Bank to house the transmitter, primary power, controls, and operating personnel was evaluated. Although the fixed platform, supported from the sea floor in 180 feet of water, was feasible and economical, a mobile platform, such as a large seagoing barge or a ship, would also be required for installation of the transducer array on the ocean bottom. Although it was desired that the

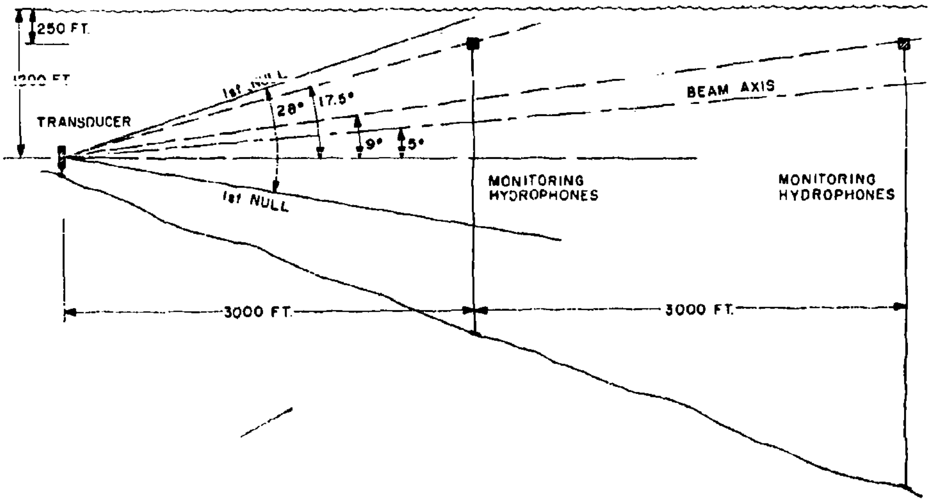

Fig. 2 - Geometry of beam pattern

final system be a fixed transducer array in 200 fathoms of water, it was recognized that considerable advantage would be realized with a mobile system. Thus, the decision was made to combine all of these requirements into one; that is, the platform, which would be suitable to make the fixed installation of the transducer array, would first be used to provide for mobile operation of the acoustic source. When this phase of the research program was completed, the array would be fixed to the ocean bottom in 200 fathoms of water on the slopes of Plantagenet Bank. Power and control would be supplied from the installing ship, moored on Plantagenet Bank. This arrangement is shown schematically in Fig. 3. Thus, one vehicle served for the mobile operation of the source, installation of the array on the ocean floor, and powering of the array as a fixed system.

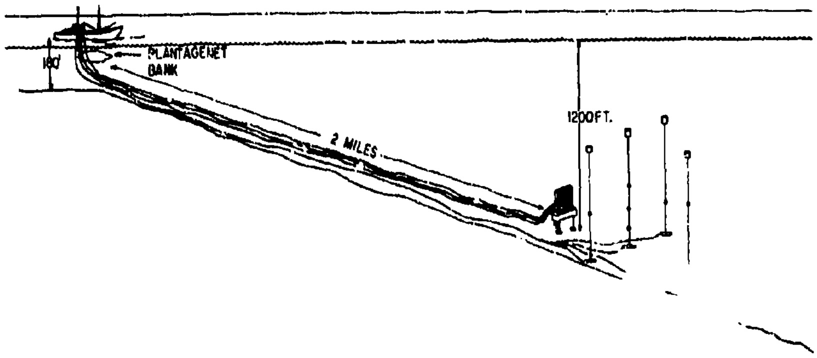

Fig. 3 - Artemis acoustic source installation (Plantagenet Bank)

The general specifications developed for the Artemis acoustic source are included as Appendixes B and C. Appendix B is the original specification based on an installation at Eleuthera. The modification to this, reflecting the change in installation site from Eleuthera to Bermuda, is shown in Appendix C. A second but more or less minor change was also made to the acoustic axis of the transmitted beam. This was changed from 5 degrees in the original specification to 11 degrees in the revision of November 1959.

SYSTEM DESIGN CONSIDERATIONS

Design problems associated with the components of the Artemis acoustic source can be divided into two general areas. These are:

1. Components which presented engineering problems once the requirements and specifications of related components were established.

2. Components which presented more basic problems because the requirements demanded a significant advance in the state of the art.

The amplifiers, source of primary power, and instrumentation fell in the first category, whereas the transducer element, transducer array, pressure release, and transducer-array handling system were in the latter. However, interaction between the system components influenced the requirements and specifications for all of these. The time schedule did not permit approaching the problems in order, first solving the problems related to the transducer and array and progressing from there to the total system specification. In order to meet the schedule, it was necessary to establish specifications for the system components based on the best engineering design data available regarding the probable characteristics of the transducer and pressure-release systems. These engineering estimates of transducer weight and performance influenced the early decision on transducer handling system, amplifier rating, source of primary power, and the characteristics of the instrumentation.

Electrical and Electronic

Several approaches, including remote nuclear power (2), were considered and evaluated for supplying power to the transducer elements. It was estimated that the transducer conversion efficiency would be approximately 25%. Adding to this the estimated losses in matching transformers and cables to the array, the required power in the band from 350 to 450 Hz was approximately 5.2 MW. Since the frequency fell in the range that could easily be generated by rotating machinery, first consideration was given to the possibility of generating this directly. However, signal-processing techniques under consideration required pseudorandom noise transmissions. Techniques were not available for generating controllable pseudorandom noise signals by rotating machinery, and it was concluded that conventional amplifiers would be required between the source of primary power and the transducer array.

Early considerations for the array indicated the possibility that it would be composed of a few high-powered transducer elements. Furthermore, the mode of operation did not dictate either electrical or mechanical steering of the acoustic beam. Therefore, a single high-powered amplifier system would meet the requirements for the source. For that reason, an amplifier of conventional design using available tubes was selected.

The source of primary power, unlike the amplifiers, was not restricted to one approach. There were several possibilities to be evaluated concerning the type of prime mover and type of energy-storage system. In making the selection of prime mover, consideration was first given to the use of energy storage between the prime mover and the amplifiers. The system of principal interest was an inertial system consisting of a flywheel on the generator shaft. Unfortunately, the long pulse length of 60 seconds made any type of energy-storage system impractical.

Because provision for energy storage was impractical, the prime mover had to provide sufficient power to drive the generator, which in turn provided a plate supply for the 5.2-MW amplifiers. Based on a reasonable efficiency for the amplifiers, a generating capacity of 8000 kW was needed.

Prime movers considered for this generator were diesel, steam turbine, and gas turbine. Because of the pulse load, it was not considered desirable to use parallel prime movers. Acceptable division of the pulse load would necessitate a major development of control systems. Thus, it was decided that a single generator and a single prime mover were desirable. This eliminated the use of a diesel prime mover because of the limited size and ratings of existing units. Although a steam turbine of the required rating could be readily provided, there was no assurance that the response time of a boiler and steam turbine would be adequate to meet the transition from an 800-kW base load to an 8000-kW full load. Either a prohibitively large boiler would have to be provided to meet the requirements, or some other form of steam accumulation would have to be provided to meet the demand for conversion from low steam rate to high steam rate.

Several gas turbine manufacturers had units commercially available having the required horsepower to drive the 8000-kW generator. Of initial concern, however, was the capability of gas turbines to meet repeated transient load demands without thermal shock damage to the turbine blades. Preliminary study indicated that suitable controls could be developed to minimize thermal shock during application and removal of the step load.

Other electrical and electronic components for the system, such as cable, matching networks, and monitoring instrumentation, were considered to be well within the state of the art. The major problem these components presented was the preparation of specifications without complete and adequate knowledge of the characteristics of the interconnected components.

Transducer and Array

Three types of transducers were developed in the Artemis program. Two of these, magnetostrictive and electromagnetic, were developed for the Artemis acoustic source. A third type, ceramic, was developed for low-power acoustic experiments to be performed early in the research program.

The directivity requirements for the acoustic source dictated the equivalent of a planar array having dimensions approximately 2-1/2λ by 4λ. Earlier studies by the ad hoc group referred to in the introduction emphasized that construction of a transducer capable of radiating 1 MW acoustic power was feasible but should be fabricated from magnetostrictive rings. This minimized the engineering problems by eliminating the pressure release required for directional arrays. Unfortunately, an omnidirectional radiator would not be a satisfactory tool for this research project because of reverberations from all directions and the lower source level. These are important items, and the omnidirectional transducer would necessitate a large reflector to provide the required directionality. Since this appeared to be far beyond the state of the art at the time, it was decided to employ the magnetostrictive rings in the form of a resonant cavity, with 10 cavities forming the complete transducer. Figure 4 shows one of these units being prepared for test in the Pacific Ocean. The transducer element is approximately 12 feet in diameter by 3 feet deep and weighs approximately 60,000 pounds. It is composed of three rings of magnetostrictive material, as shown in Fig. 5. Each nickel ring is encapsulated in epoxy resin, wound with the electrical conductor, encapsulated overall with epoxy resin, and then covered with a watertight rubber boot. Pressure-release material was then put on the outside surface of the ring and at the rear face of the element to provide the directionality required for the final array.

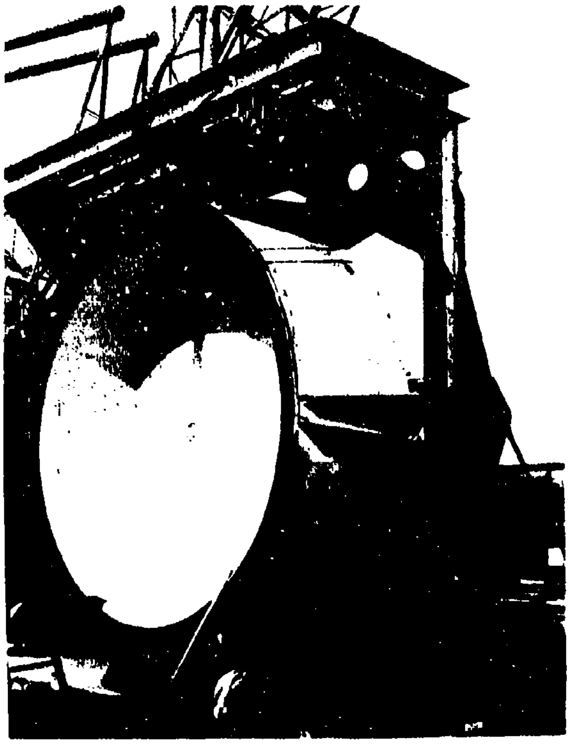

Fig. 4 - Magnetostrictive transducer element

The electromagnetic transducer is a two-mass, magnetic-field-driven element, as shown in Fig. 6. This transducer is approximately 1 foot cubed and weighs approximately 160 pounds; 1440 of these would be required for the transducer array. The internal construction of an early model of the element is shown in Fig. 7. It consists of an inner mass, the magnetic assemblies and springs, and the enclosure which is the external mass. The inner mass consists of a steel plate and the "E" section of each magnetic assembly. The external mass consists of the two end plates with the "I" laminations and the four side-plate assemblies. The side plates are of honeycomb construction to reduce

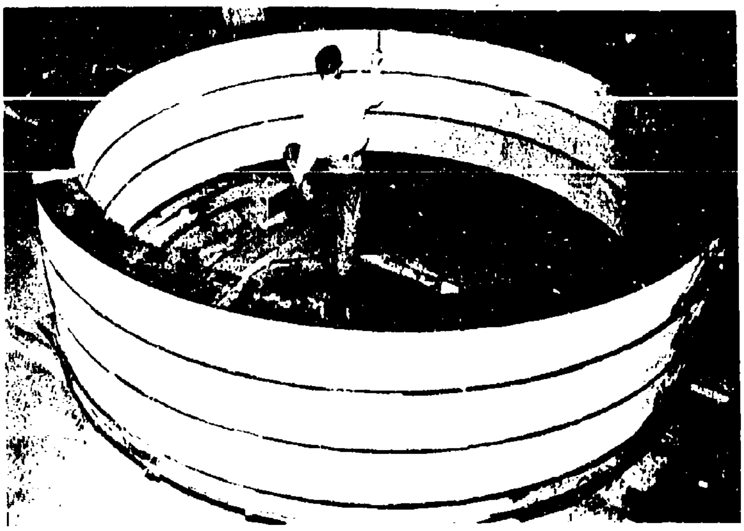

Fig. 5 - Magnetostrictive transducer rings during assembly

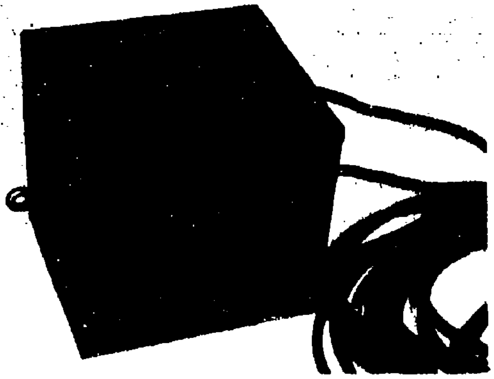

Fig. 6 - 400-Hz electromagnetic transducer

the total weight of the external mass, yet provide the necessary strength to withstand depths as great as 3000 feet.

The segmented-ring barium titanate transducer, developed as a low-power acoustic source for the early phases of the propagation research, was constructed as shown in Fig. 8. Bars of barium titanate were cemented together to form a ring resonant at 400 Hz. Directional features were not required for this transducer; therefore, four rings were assembled in a cylindrical configuration without pressure release. These rings were enclosed in an oil-filled rubber enclosure. The finished transducer, shown in Fig. 9, is approximately 7 feet in diameter by 4 feet high.

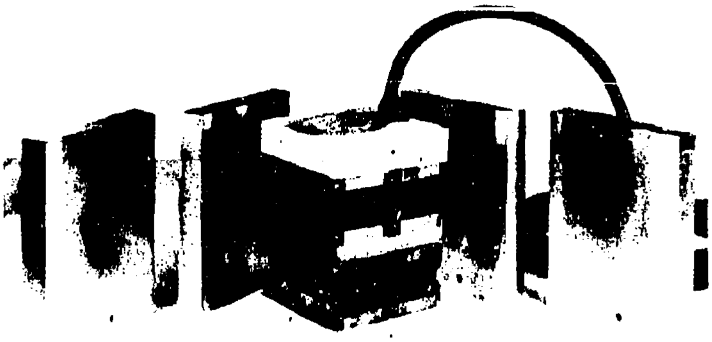

Fig. 7 - Exploded view of electromagnetic transducer element

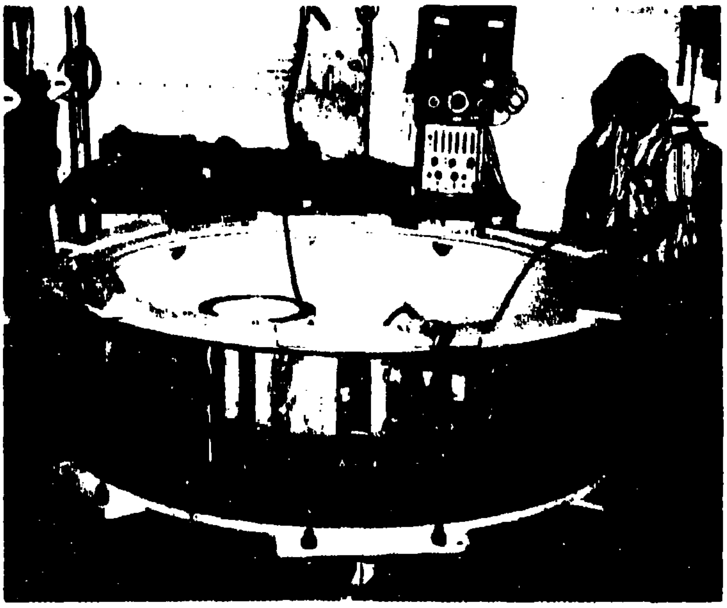

Fig. 8 - Segmented-ring barium titanate ring transducer

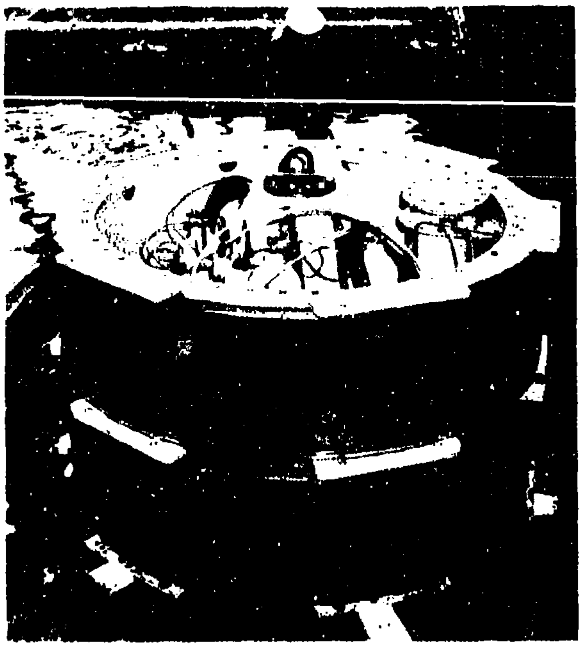

Fig. 9 - Barium titanate ring transducer assembly

Besides basic design features and the engineering problems associated with constructing these various transducer elements, a major problem was providing a test facility in which transducer elements approximately 12 feet in diameter and weighing 60,000 pounds could be tested to depths of 1200 feet. Since no government or privately owned facility was available, a seagoing barge was rented from a private contractor and outfitted for these tests. A photograph of this facility is shown in Fig. 10, with the magnetostrictive transducer element being prepared for test. A boom approximately 300 feet long was provided to support hydrophones in the far field for making acoustic measurements.

Several tests on scale models (3,4) as well as the full-size element were conducted on the magnetostrictive, resonant-cavity transducer. Although nearly the rated acoustic power was obtained from the element for a short period prior to failure, considerable difficulty was experienced, both mechanically and electrically, with this design. Since the electrical failures of the winding were apparently initiated by mechanical failure, it was evident that the major problem was fabrication of a complete transducer assembly in a manner permitting the components to operate under the large excursions associated with 400-Hz radiation. Furthermore, localized failures of the encapsulating material on the inside face of the resonant cavity indicated that the problem was also related to localized acoustic cavitation at the high radiating power. Within the time scale allowed for the investigation, it was impossible to solve all the mechanical problems. Thus, the development of this type element was terminated when it became evident that suitable methods for encapsulating the nickel rings and the electrical conductors would not be available when needed.

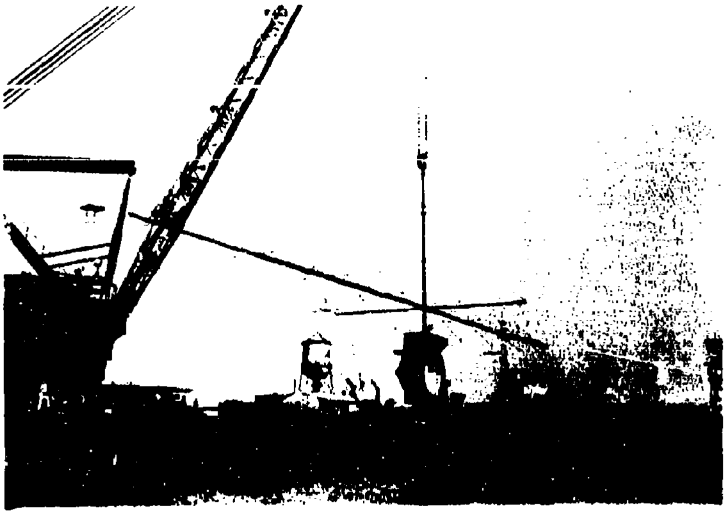

Fig. 10 - Project Artemis test facilities for 400-Hz transducer element

Fourteen elements of the electromagnetic transducer were developed during the initial program. These were tested at the Navy Underwater Sound Reference Laboratory (5) to determine their characteristics and conformance to the element specification. On the basis of testing individual elements and an array of nine elements, it was found that the transducer met the specifications and, presumably, the requirements for the acoustic source. If an array of 1440 of these elements radiated at a uniform velocity, an acoustic power in excess of 1 MW was calculated to be achievable.

Several transducers of the segmented-ring barium titanate element (6) were fabricated, tested, and installed for use in the early research program. Because of test facility limitations these elements could not be tested under conditions comparable to the operating environment. However, the experimental results in the available test facility indicated that the units would be satisfactory. Unfortunately, all these transducer elements failed after installation in the operating environment. These failures were apparently due to inadequacies in the basic design, engineering difficulties stemming from encapsulation and quality control, and abuse during installation.

On the basis of the experience gained with the three types of transducer elements and the urgency of the program, the electromagnetic transducer was accepted for the final array. This decision was based on the obvious engineering difficulties with the other transducers, and the assumption that a nearly uniform velocity distribution over the face of the 1440-element array would exist, and on the assumption that the acoustic loading on the array would be approximately unit ρc.

Twelve magnetostrictive rings prepared for the resonant-cavity transducer were modified and prepared for assembly to form a cylindrical magnetostrictive transducer 1λ in diameter by 1λ high. A photograph of a scale model of the configuration is shown in Fig. 11. This transducer is of the configuration recommended by the ad hoc group

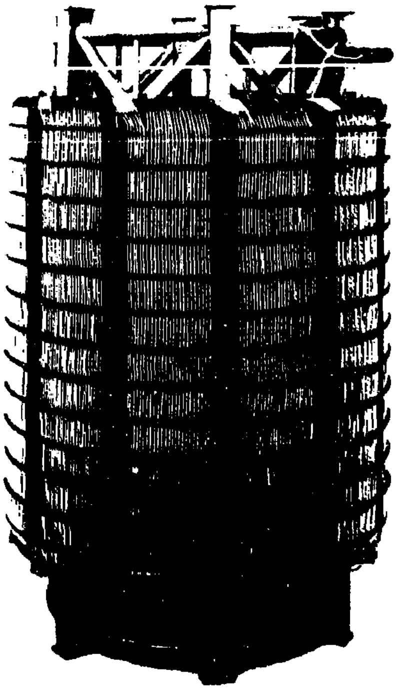

Fig. 11 - Model of magnetostrictive ring transducer

referred to in the introduction, is approximately 12 feet in diameter by 12 feet high, and weighs 160,000 pounds. Additional size and weight must be allowed for the supporting structure. The device should radiate 1000 kW acoustic power at depths to 20,000 feet or greater. Because of the limitations in directionality, the source level will be limited to 134 dB//1 dyne/cm^2 at 1 yd. If the 12 rings could be spaced to provide a longer transducer array without seriously compromising the acoustic loading, it is conceivable that the vertical directivity improvement would lead to a few decibels improvement in source level. If additional rings were added, additional power-handling capability, as well as improved vertical directivity, could be obtained.

Unfortunately, the opportunity was not available to assemble and test this array. However, it did serve as a back-up to the planar array in the event of loss during operation at sea. A proposed configuration of the structure providing element support as a replacement for the planar array is shown in Figs. 12 and 13.

It was evident early in the transducer development program that difficulties would be experienced in providing the necessary pressure release for any type of array of transducer elements. Two compliant types of construction were evaluated with the resonant-cavity devices. The first, which may be seen in Fig. 4, was a metal diaphragm which provided an air cell approximately 1/2 inch thick. Fatigue failure of the diaphragm occurred early in the measurements at low power drive. The second is shown in Fig. 14. This was a 1/2-inch-I.D. neoprene hose coiled in a spiral and inserted at the base of the resonant cavity. This, like the metal diaphragm, failed due to mechanical fatigue. There was some evidence that failure may also have resulted from localized "hot spots" generated by nonuniform acoustic pressure over the diaphragm. The third and final method of pressure release was a resonant reflector shown in Fig. 15. This reflector was made from a 4-inch-O.D., 1/8-inch-wall stainless steel tube which was flattened to the configuration shown. The tube was designed to resonate at approximately 400 Hz. Mechanical fatigue was also experienced with this reflector, with breakage occurring at the small radius of curvature (7,8). In order to minimize the stress in the material, the largest possible radius of curvature had to be used. On the other hand, the smallest radius of curvature was desired to minimize the volume of air in the pressure-release tube because the tubes had to be compensated against external pressures at the operating depth of 1200 feet. These requirements led to the "dog-bone" configuration shown in Fig. 15. An assembly of these tubes behind a module of 72 electromagnetic elements is shown in Fig. 16.

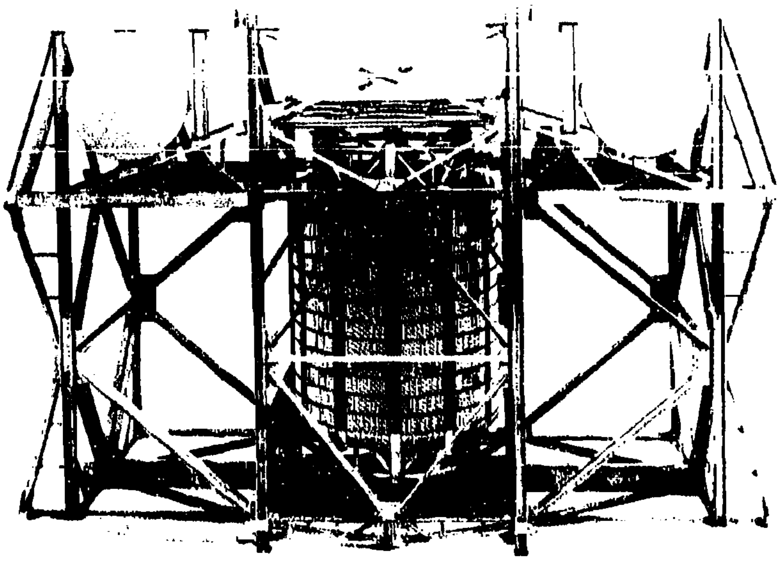

Fig. 12 - Model of magnetostrictive ring transducer and support structure

Fig. 13 - Model of magnetostrictive ring transducer and support structure, side view

Fig. 14 - Compliant tube pressure release

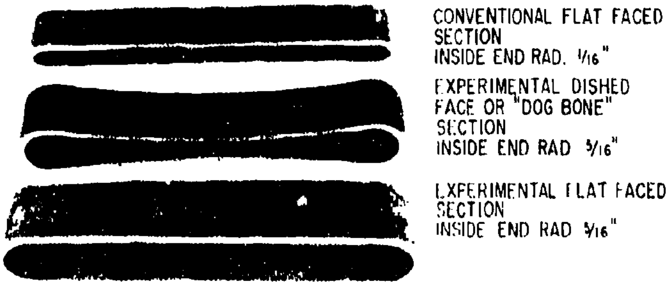

Fig. 15 - Resonant pressure-release cross sections from pressed 4-in.-O.D., 1/8-in.-wall stainless steel tubing

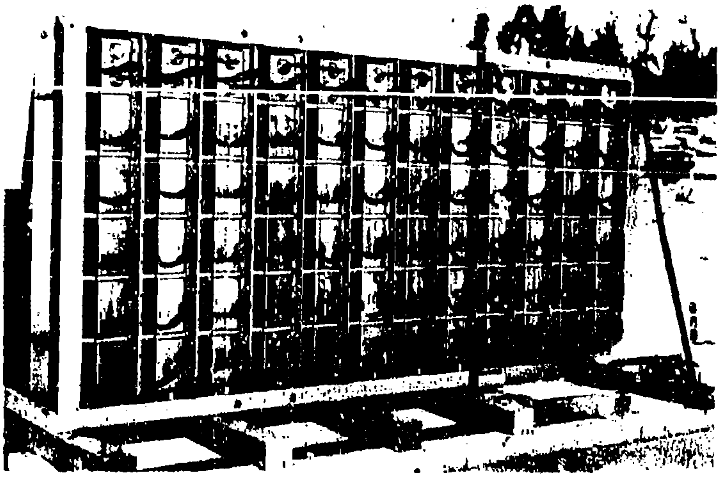

Fig. 16 - Rear view of module showing assembly of 12 resonant pressure-release tubes

Array Handling

Considerable effort was given to the problem associated with handling the transducer-array (9). There were many facets to the problems involving the mobile operation and the fixed installation, on the ocean bottom in 1200 feet of water, of a transducer array, structure, and electrical components weighing 1 million pounds. A discussion of the array structure and handling system, as finally installed in a ship, is given in the following section. Since the initial concept of the program required fixing the array structure to the ocean bottom and supplying power to it from an attending ship, engineering plans were prepared accordingly. Furthermore, modifications to the ship were made to accommodate the additional machinery required for this purpose.

The facilities required for making the fixed installation consisted of the ship facility used for the mobile operation, barge(s) or cable layers for handling three electrical cables, a mooring system, and several tugs. Figures 17 through 21 illustrate schematically the step-by-step procedure that was developed for making the fixed installation. The ship carrying the array would be placed in an eight-point moor, as shown in Fig. 17. The foundation, or base, for the array would first be lowered to the ocean floor and fixed in place with conventional deep-water drilling and cementing techniques. The array structure would next be lowered to this base, being suitably oriented and held in place by appropriate keying arrangement. The ship would be assisted in the lowering operation with a barge, serving as cable layer, as shown in Fig. 18. The barge would lay out the cables from the 1200-foot water depth up the slope of Plantagenet Bank. Meanwhile, the various cables and guide chains used in lowering the array structure to the bottom would be laid out on the ocean floor, as shown in Fig. 19. The purpose of this latter arrangement was to permit recovery of the array structure at a later date, if so desired. The final configuration showing the ship and cable tower is presented in Fig. 20. A more detailed view of the arrangement at the cable tower is shown in Fig. 21. The ship would be anchored at the base of the tower by means of the anchor chain. Neutrally buoyant electrical cables would be used to provide power over the bow of the ship to the cable-termination tower.

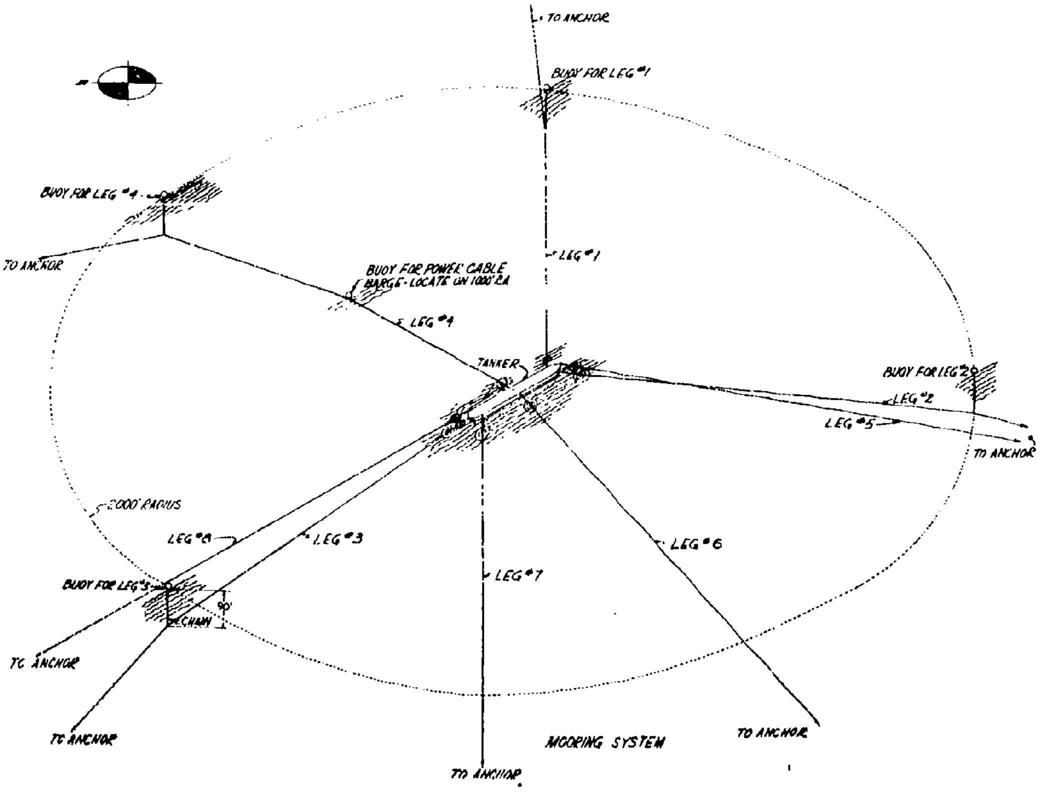

Fig. 17 - Fixed installation -- ship moor

Three electrical cables suitable for providing the power and control signal from the moored ship to the mooring tower were designed, fabricated, and tested. The three cables were identical in general construction features to that shown in Fig. 22. A center strength member was provided, around which were clustered the electrical conductors and air-filled tubes. The latter provided the buoyancy required to permit these cables to float. A similar type construction was used for the three-phase, 60-Hz cable supplying polarization power and for the two-conductor, 400-Hz cable which supplied the transducer driving current.

Ship's Heading Control and Positionkeeping

The directional properties of the source array necessitated some means for holding ship's heading during mobile operation for research experiments. Furthermore, the research experiments required that the array's geographic position be held nearly fixed to minimize doppler effect and changes in the acoustic-path geometry. A three-point moor was installed on the western slope of Plantagenet Bank to meet these requirements. Unfortunately, this deep-water moor was carried away during a severe storm before it could be used, and was never replaced. Attention was then directed to a self-contained shipboard system, since it allowed complete freedom in choice of source location for the experimental program.

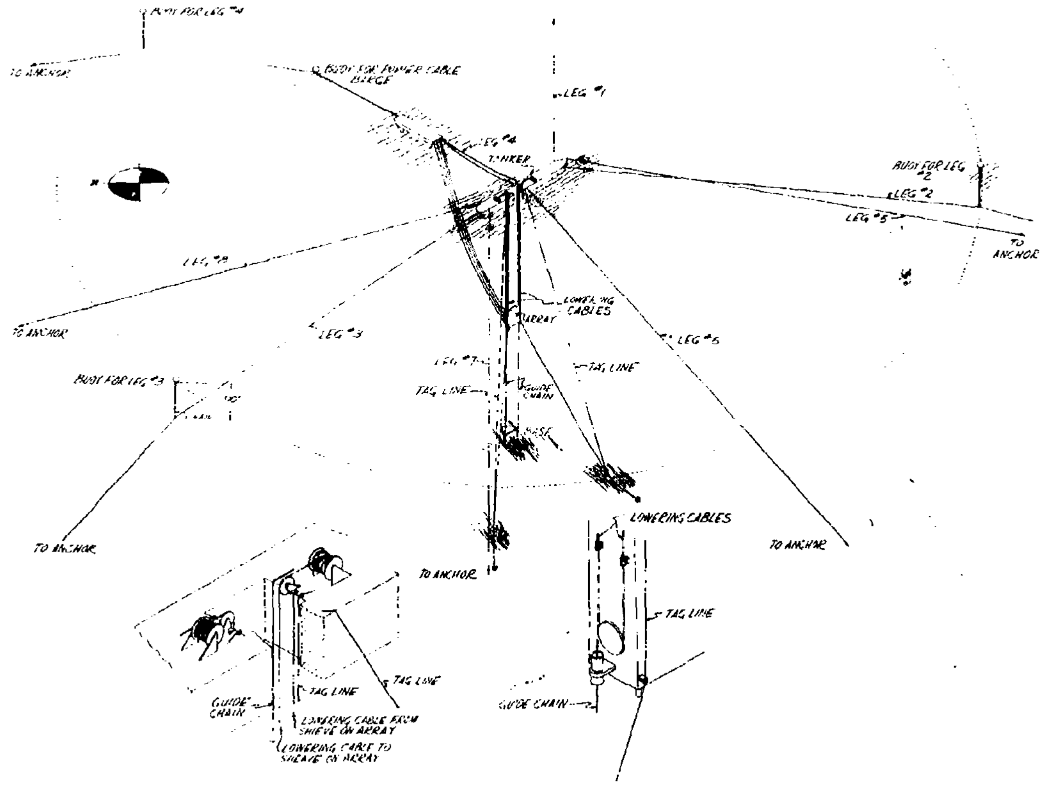

Fig. 18 - Fixed installation -- lowering array in place

Several types of heading-control devices which could be installed on the source ship were investigated (10,11). There existed in this country, and more notably in Europe, much precedent for such installations in ships; therefore, no engineering development appeared necessary. The British luxury liner *Oriana*, the World War II German cruiser *Graf Zeppelin*, the German buoy tender *Walter Körte*, and the Great Lakes bulk carrier *J. R. Sensibar* were prime examples.

Several types of maneuvering devices are used commercially for auxiliary propulsion. These include vertical-axis propellers, right-angle drive units, active rudders, and ducted propellers.

Briefly, vertical-axis propellers consist of four to six equally spaced, airfoil-shaped paddles which extend vertically downward from the circumference of a horizontal turntable affixed to a vessel's bottom. As the turntable rotates, the paddles revolve about the common center and, in addition, change pitch by rotating about their individual axes in the same manner as a helicopter rotor. Thrust direction and control are achieved by regulating blade pitch. A modern version of the vertical-axis propeller, the Voith-Schneider propeller, is one in which the blades describe a cycloid as they revolve and rotate. Hence, these propellers are sometimes referred to as cycloidal propellers. Vertical-axis propellers are usually located aft and may be either of single or twin screw configuration.

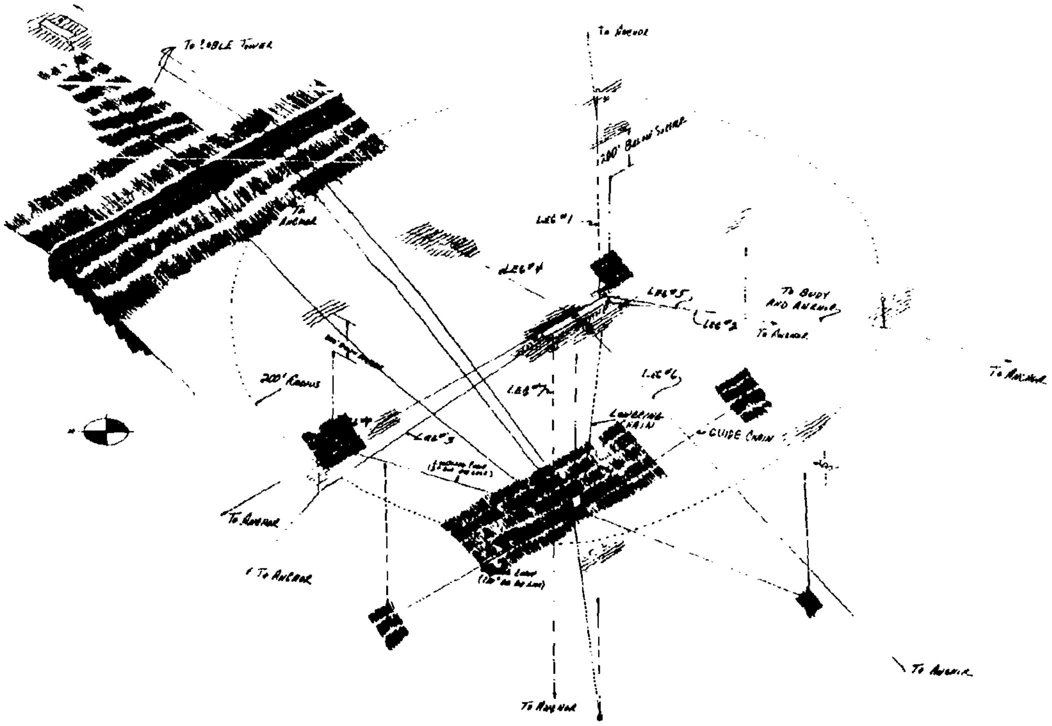

Fig. 19 - Fixed installation -- laying out cable and lowering lines

Right-angle drive units are simply overgrown outboard-motor installations in which the propulsion engine, unlike the usual pleasure outboard, is affixed to the deck of the vessel just forward of the vertical drive shaft. The propeller shaft can be swung from port to starboard to establish the desired direction of thrust. Engine speed determines the degree of thrust.

Active rudders are rudders containing a motorized propeller. The motor is mounted in line with the screw in the body of the rudder. By turning the rudder, the direction of thrust is oriented.

The ducted propeller consists of a tunnel usually containing a screw propeller of fixed or controllable pitch and of single or contra-rotating blading. Since the tunnel is fixed, thrust can be delivered only along the axis of the tunnel unless exit guide vanes are installed. This method of auxiliary propulsion generally is installed in the forefoot of a vessel and is sometimes supplemented with an active rudder in cases where heading-control response is most critical.

In larger vessels most auxiliary propulsion is for heading control at low speeds, where rudder action is sluggish and ineffectual. In such cases, the simplest and most effective installations have proven to be ducted propellers. They need not be refracted in shoal water or when not in service, are available in high power sizes, and are very simple to install in a ship's forefoot. Vertical-axis propellers can be mounted in a tunnel but are not usually used unless employed for main as well as auxiliary propulsion.

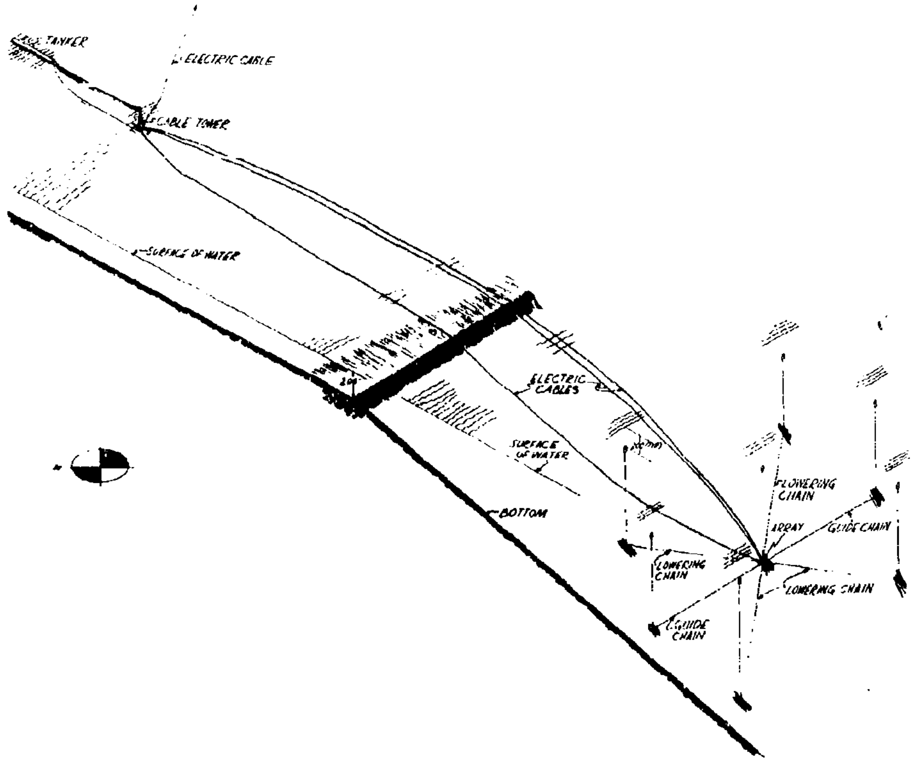

Fig. 20 - Fixed installation -- configuration of completed installation

Their configuration lends best to a specially designed vessel with a flat run. Furthermore, these propellers are not hydrodynamically as efficient in a tunnel as the axial screw and are considerably more expensive.

All of the aforementioned devices have been installed for such purposes as docking a ship, navigating a canal, or tending a buoy. However, no application had been noted where precise heading control, without being underway, was used in the open sea. Therefore, no suitable test data were available for the thrust requirements for the Artemis acoustic source ship.

Unlike the usual maneuvering problems of berthing or navigating at slow speed in relatively smooth water, the main propulsion screw and rudder would be of no value merely keeping station in Artemis project operations. Wind and wave forces would predominate and would have to be reckoned with in computing the required power. There was no time for model tests, nor would the Artemis schedule permit bollard-pull measurements at sea. Instead, a maximum swing rate was estimated from the combined forces of wind, wave, and current and equated to the smooth-water condition of determining the drag forces on a twisting vessel. In addition, twist-ship performance data for smooth-water conditions were obtained from the *J. R. Sensibar*, a vessel of comparable size. This latter vessel has in its forebody a 500-shaft-horsepower, ducted, controllable-pitch screw propeller. This propulsion application has become known as a bow thruster.

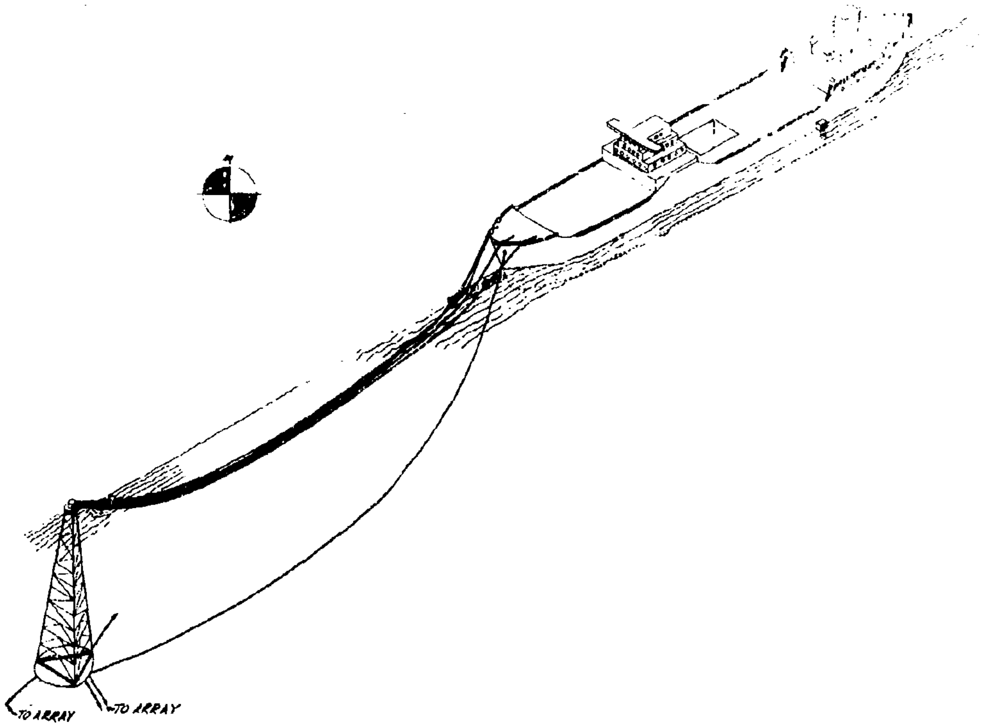

Fig. 21 - Fixed installation -- tower for mooring ship and terminating electrical cable

Fig. 22 - Neutrally buoyant instrumentation cable

As reported by the operators of the *J. R. Sensibar*, data are as follows:

Length overall	614 feet
Beam (molded)	56 feet
Draft (full load)	21 feet, 6 inches
Static thrust of blow thruster	13,600 pounds
Twist rate at bow thruster full power (sea conditions unknown)	12 degrees per minute

From this information, it was estimated that 10,000 pounds of transverse static thrust against the ship's bow or stern would be needed to twist the heading to a particular orientation and to hold it to within a few degrees of yaw in moderate weather; that is Beaufort 4.

Slow-speed applications, such as this, where propellers are properly designed to operate at high slip prove only one-third to one-half as efficient as properly designed free-running propellers. Because of kinetic energy loss from slip, only about 20 to 30 pounds of thrust can be realized per shaft horsepower. Therefore, about 500 shaft horsepower would be required to deliver the necessary 10,000 pounds of thrust.

A heading-control system met only part of the requirements for mobile operation. In addition, position control was also required in order to obtain the same acoustic propagation paths throughout an experiment. Three approaches to this were:

1. A single point deep ocean moor,
2. An ocean tug, and
3. A dynamic positioning system built into the ship along with the bow thruster.

Each of these approaches offers advantages and disadvantages. These are summarized in Table 2.

DESCRIPTION OF INSTALLED ACOUSTIC SOURCE

The acoustic source (12-15) developed in accordance with the requirements set forth is composed of all the equipment from the source of electrical power to the transducer. In addition to this, it consists of the winches, cable machinery and other pertinent equipment necessary to lower and raise a one-million-pound transducer array to and from a depth of 1200 feet and to supply the electrical power to the device at this depth. A system block diagram is shown in Fig. 23. It is to be noted that this system consists of three basic parts, as follows:

1. The fixed shipboard equipment consisting of power source, amplifier, and controls,
2. The submarine cables, and
3. The transducer array, consisting of the transducer, electrical components, controls, and instrumentation.

Table 2
Comparison of Three Methods of Ship Position Control

Method	Installation Cost	Operating Cost	Bow Thruster	Ship's Power	Operation Experience	Equipment Availability	Ability to Hold Fixed Position	Installation Time	Preparation Time on Station
Single-point deep ocean moor	Low	Lowest	Required	While paying out or hauling in line and bow thruster	With small vessel only	Available	Will swing over 1/2 mile or more radius if anchor holds	Few days of topside installation	Several hours
Ocean tug	None	Very high	Required	Bow thruster	None	Commercial tugs available. Navy tugs uncertain.	Depends on navigation aids and seamanship	None	Very small
Dynamic Positioning	High	Moderate	Not required	Maximum, approx. 25% of ship's propulsion generator	Limited and in coastal waters	Components available. System design required.	Depends on navigation aids and seamanship	Several weeks, and includes drydock work	Very small

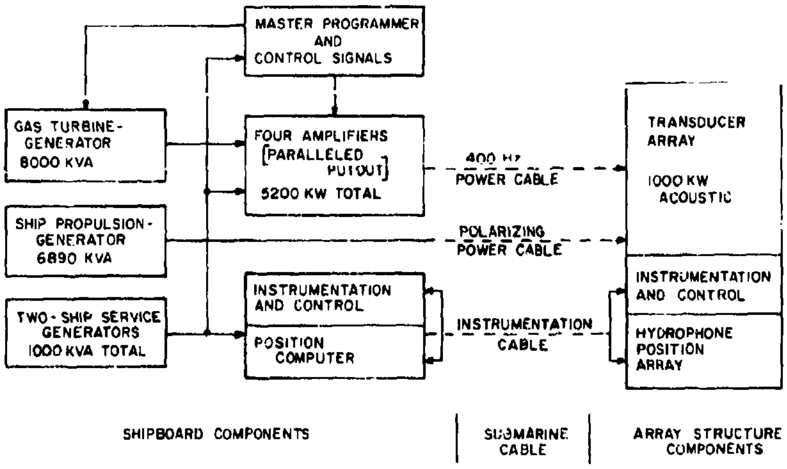

Fig. 23 - System block diagram

The class of ship selected for the installation of this equipment was a T2-SE-A2 tanker. This ship provided the necessary space for installation of the components and also afforded the structural suitability for a large center well through which the transducer array could be lowered. The location of the component parts of the project equipment is shown on the arrangement plan in Fig. 24. The gas turbine generator is located aft in what were formerly center tanks 9 and 8. The major switchgear associated with the power distribution and control center for the turbine is located in this area on a platform overlooking the gas turbine generator. This arrangement places all the power generating equipment in the after part of the ship, simplifying ease of operation, maintenance, and distribution of power.

The transducer array is handled through a well cut from the main deck to the keel in part of the area formerly used for center tanks 7 and 6. This well provides an access area 30 feet by 48 feet for stowing, lowering, and raising the array.

The electronic amplifier, project control center, and other related facilities are located forward of the array. These are in what were formerly center tanks 5 and 4. Immediately forward of these compartments is the electrical cable machinery for handling the electric submarine cables to the transducer array.

The *USNS Mission Capistrano* (T-AG 162), on which this installation was made, is shown in Fig. 25. Evident in this photograph are the helicopter platform, located forward, and a pipe rack just aft. The pipe rack is part of the equipment required for installation of the array on the bottom as a fixed source.

Electrical and Electronic

The generating capacity on the *USNS Mission Capistrano* was not adequate to meet the requirement of 8000 kW primary power for the amplifiers. Because of space considerations on the ship, as well as other factors stated in an earlier section, a gas turbine was selected as the prime mover for the electrical plant. The ship's propulsion generator

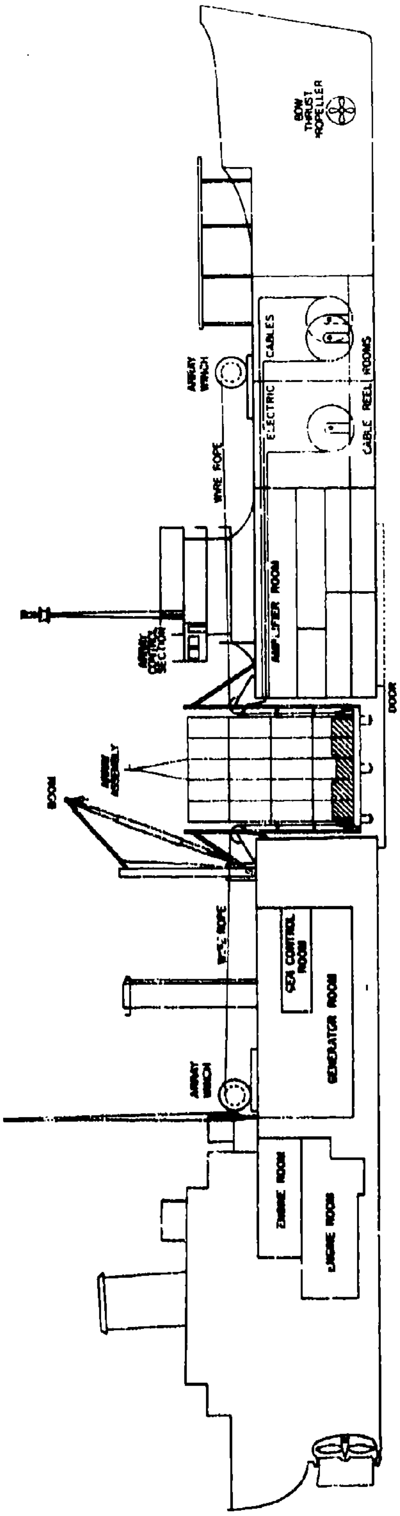

Fig. 24 - Equipment arrangement on *USNS Mission Capistrano*

Fig. 25 - *USNS Mission Capistrano*

could be used to supply some power less than the maximum rated power required by the amplifiers if certain modifications were provided to the turbine controls.

The gas turbine generator (16) which furnishes power to the electronic amplifiers is shown in the artist's conception, Fig. 26. It is rated 8000 kW at 4160, three phase, 60 Hz. Special provisions have been made in the control systems to provide precise frequency and voltage control and to minimize thermal shock on the gas turbine due to the step-load application and removal. These controls are capable of accepting a transient step application or removal of load from 800 kW base load to 8000 kW full load. Under this condition the transient-voltage variation is less than 2%, and frequency variation is less than 1%. Furthermore, the transient temperature variation of the gas turbine blades is not detrimental to turbine life.

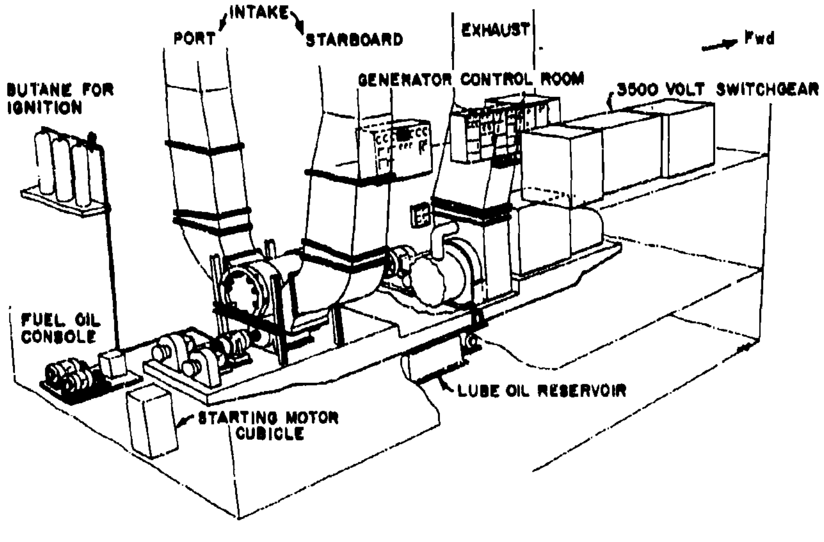

Fig. 26 - Gas turbine generator installation

Provision has also been made to supply the electronic amplifier power from the main propulsion steam turbine generator when the latter is not used for propulsion purposes. This generator is rated at 6890 kW, 3500 V, three phase, 60 Hz. A three-phase, 2000-kVA, 3500/4160-V transformer provides the proper voltage to the amplifier bus. The steam turbine governor was modified to include open-loop compensation thus minimizing the transient variation in generator speed due to step application and removal of the amplifier loads. This compensation is incorporated in the load programmer control in the amplifier room. It was originally intended that only one amplifier would be operated to full load, 1300 kW, from the steam turbine generator. However, tests demonstrated that two amplifiers could be step loaded to a total of 2210 kW, with frequency and voltage variation of the generator output no greater than ±0.2 Hz and 100 V, respectively.

The electronic amplifiers, along with switchgear, matching transformer, test load, and related instrumentation are shown in the artist's conception, Fig. 27. Four amplifiers, each rated at 1300 kW, are installed in this area. These units may be operated singly or in parallel to give a maximum power of 5200 kW. A central control panel, which permits operation and monitoring of the amplifiers and transducer array, and a master programmer for programming the time sequence of events pertaining to operation of the gas turbine generator or the steam turbine generator, amplifiers, and related instrumentation are located in this control center.

Transducer and Array

The transducer elements, which have a radiating face approximately $\lambda/12$ by $\lambda/12$, are assembled into modules of 72 elements, each arranged mechanically six elements wide by 12 elements high, or 0.5 λ wide by λ high. One module is shown in Fig. 28. Twenty of the modules are assembled on the array in four horizontal rows, each row consisting of five modules. The transducer array consists of 1440 transducer elements, associated electrical components, acoustic pressure-release system, and pressure compensation. This is mounted on an array structure that is 44-1/2 feet wide by 22-1/2 feet deep at the lower end. The radiating face is tilted backward at an 11-degree angle with the vertical. The completed array weighs 800,000 pounds. This array is shown in the raised position for servicing and maintenance in Fig. 29. Other views of the array (Figs. 30 and 31) show the cable entrances on the rear, location of the air flasks for pressure compensation of the pressure release, and a few of the tanks housing electrical components.

Electrical equipment required to match the transducer impedance to the submarine cable voltage, capacitors to compensate for the load reactance, and rectifiers to provide the dc polarization required for the transducer elements are installed in electrical component tanks on the bottom of the array structure (15). In addition, measurement and control functions are provided. Array-orientation instrumentation provides depth, azimuth, level, and cross-level information. An assembly of four hydrophones, positioned in three coordinate axes on the top of the array structure, was provided as a means for determining the location of an acoustic monitoring hydrophone relative to the array when the array was fixed to the ocean bottom. The hydrophone assembly was removed when plans for a fixed array were changed to mobile operation.

Program and Control

A master programmer, Fig. 32, is provided to gate the signal pulses to the amplifiers, provide pulses for external use as may be required, and provide control of the

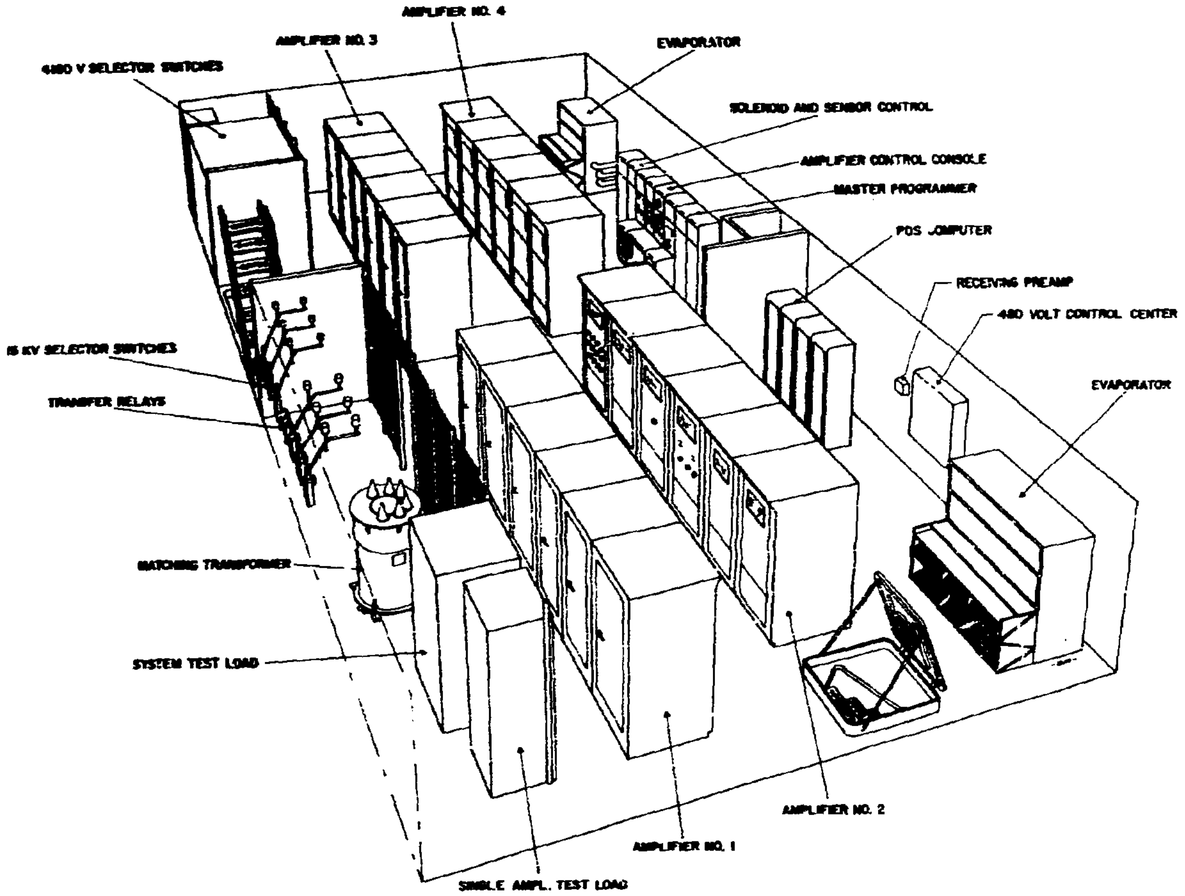

Fig. 27 - Amplifier room

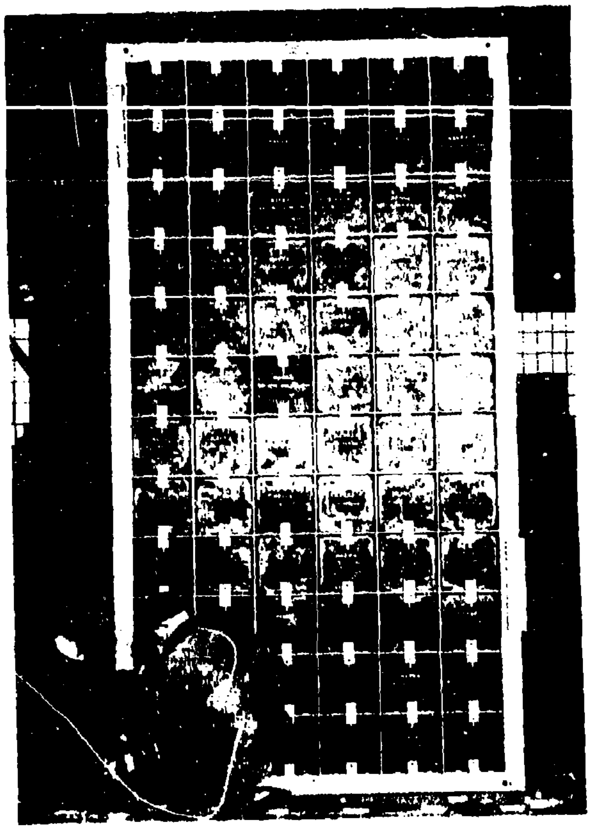

Fig. 28 - Source module 0.5λ wide by λ high containing 72 transducers

ship's propulsion generator of the gas turbine generator when either is used to supply amplifier plate power.

The programmer, shown in block diagram in Fig. 33, consists of:

1. A sta [illegible]-MHz-per-second oscillator which provides the basic clock frequency,

2. A set of three regenerative dividers which divide the output of the clock oscillator and furnish sinusoidal outputs of 100, 10, and 1 kHz,

3. A set of digital dividers which further subdivide the clock frequency furnishing pulsed outputs of 100, 10, and 1 pulses per second,

4. A WWV receiver and comparator which provide for synchronizing the local clock frequency with WWV transmissions,

5. A time generator which generates real time in the 24-hour clock systems in hours, minutes, seconds, and milliseconds, derived from the clock oscillator,

Fig. 29 - Transducer array and structure in servicing position, 2.5λ wide by 4λ high array (20 modules)

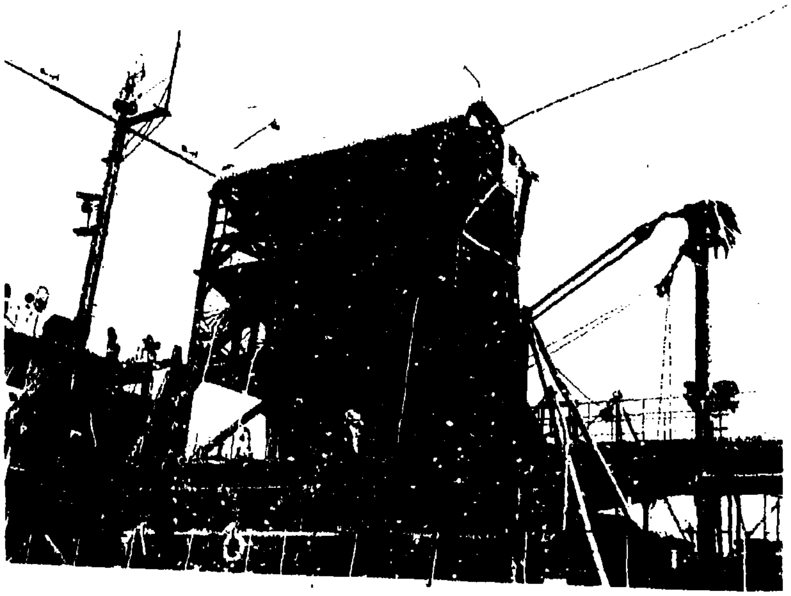

Fig. 30 - Transducer array -- rear view

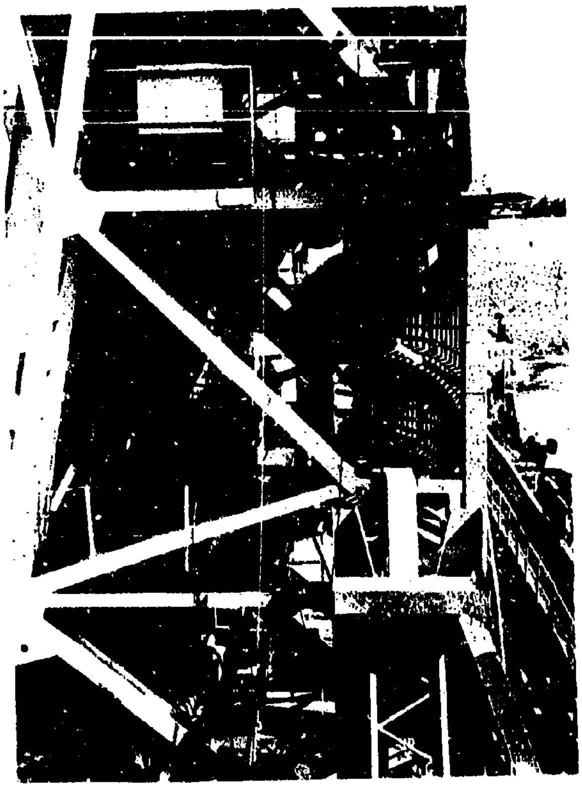

Fig. 31 - Transducer array -- arrangement of components

6. An in-line display unit which displays real time in hours, minutes, and seconds,

7. A time-storage register with visual and electrical coded output which stores and displays the time of the start of each signal pulse in hours, minutes, seconds, and milliseconds,

8. A ping-number generator with in-line visual display and electrical coded output which counts and displays in three decimal digits the number of signal pulses which have been projected in a transmission sequence,

9. A stable pushbutton controlled oscillator which provides signal frequencies variable from 1 Hz to 1 kHz in 0.5-Hz increments for continuous-wave transmissions,

10. An electronic counter which counts the output of the signal oscillator for 100 seconds and displays the count for 100 seconds with time interval generated by the master clock oscillator,

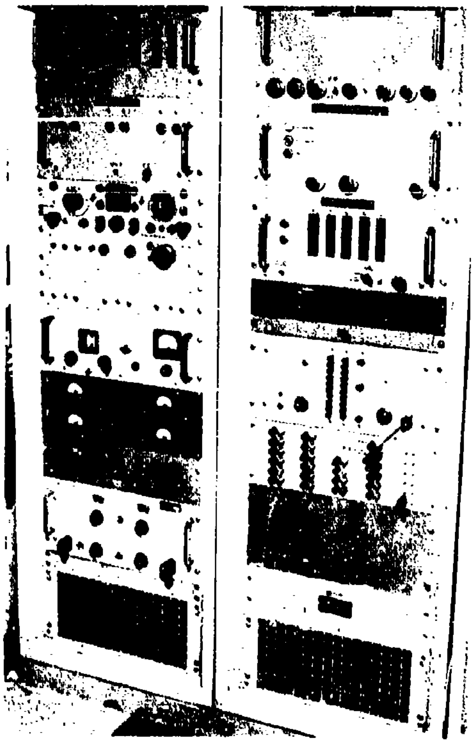

Fig. 32 - Acoustic source programmer and control

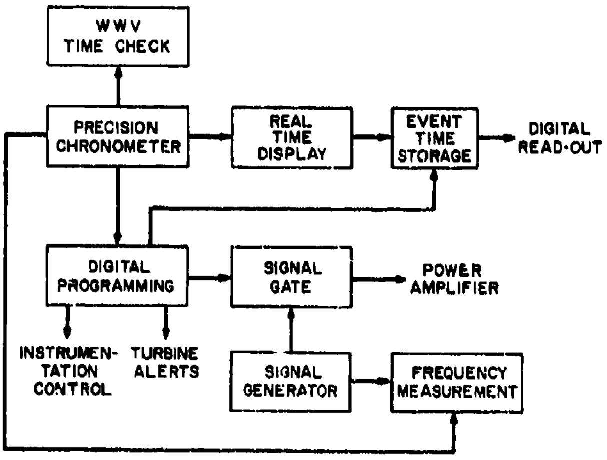

Fig. 33 - Block diagram of programmer

11. A programmer control unit consisting of a solid-state balanced signal gate, amplitude limiter, bandpass filter, and associated circuitry, and

12. A phase-lock control unit which provides for the optional use of phase-locked signal pulses.

The sequence and duration of programmed events are illustrated in Fig. 34. The cycle length of the gate of signal pulses to the amplifiers is adjustable in 0.1-second increments from 1.5 to 100 seconds, in 1-second steps from 100 to 1000 seconds, and in 10-second steps from 1000 to 9990 seconds. The pulse length is independently adjustable in 10-millisecond increments from 10 to 990 milliseconds and in 1-second increments from one to 99 seconds and continuous. Any type of signal generator may be connected to the programmer input. Within the programmer the signal is amplified, passed through the signal gate, limited to ±1.5 V, passed through a bandpass filter and through mercury-wetted relay contacts which short the signal line to ground during the interval from the opening of the signal gate to 9 seconds before the closure of the signal gate, and transformer-coupled to the input of the power amplifiers. The bandpass filter, which has a 100-Hz passband centered about 400 Hz, may be bypassed.

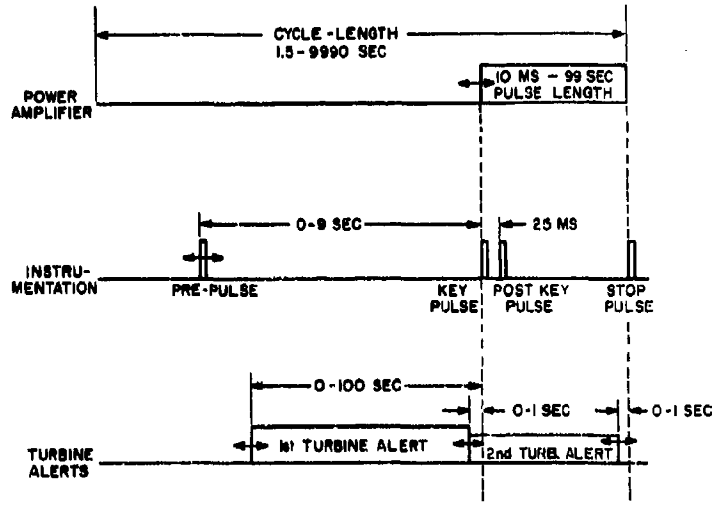

Fig. 34 - Sequence and duration of programmed events

Four positive pulses of 100 V amplitude and less than 0.1 microsecond rise time are provided for external instrumentation. These are a prepulse which can be adjusted to occur 0 to 9 seconds before the start of transmission in 1-second increments, a key pulse which occurs at the start of transmission, a postkey pulse which occurs 25 milliseconds after the start of transmission, and an end-of-transmission pulse.

Control of the gas turbine is provided by means of two mercury-wetted relay closures. The first, known as first turbine alert, can be adjusted to close 0 to 100 seconds before the start of transmission in 1-second increments. The relay opens at the time of the second turbine alert. The second relay closure, known as the second turbine alert, can be adjusted to close 0 to 1 second before the start of transmission in 0.1-second increments. This relay stays closed for an interval equal to the pulse length. When the ship's propulsion generator is used to supply plate power, the second turbine alert is used to provide open-loop compensation to the steam turbine.

Also available for programming auxiliary equipment are the 100, 10, and 1 kHz signals and pulse trains of 1 and 1000 pulses per second derived from the master oscillator. An optional mode of operation uses the phase-lock control unit. In this mode, the signal gate is opened at the first negative-going axis crossing of the signal waveform after the key pulse and closes at the time of the first negative-going axis crossing after the end of transmission pulse.

Array Handling

Prior to the selection of a shipboard installation, a number of methods had been considered for making electroacoustic tests and for lowering the structure to the ocean floor. There was no existing ocean-going barge and crane facility which could lift such a structure and lower it to a 1200-foot depth. Therefore, it was necessary to design and fabricate a facility suitable for this purpose. Consideration was being given to modifying a large ocean-going barge to accomplish this when the decision was made to use a ship-installed system. By selecting a ship of suitable beam it was possible to cut a well from the main deck through the bottom plating large enough to stow an array structure during transit, and through which the array could be lowered to the 1200-foot depth, either for test purposes under mobile operation or for the final installation as a fixed unit on the ocean bottom.

Special machinery to handle the array structure (17, 18), electrical cables (19), and facilities for stowage of the array system were developed and installed on the ship. A composite arrangement of this machinery is shown in Fig. 35. One of the two array winches is shown in Fig. 36, and one of the three electric cable machines is shown in Fig. 37. The electric cable machines permit a continuous supply of power from the amplifiers to the array without the use of slip rings or connectors. This is accomplished by means of two planetary drums mounted internal to the main drum, as shown in Fig. 37. These planetary drums carried unarmored electrical cable otherwise identical to the armored cable. One of these drums can be seen through the lightening holes cut in the end of the main drum in Fig. 37.

The two array winches were driven first by a variable-speed induction motor drive. Considerable difficulty was experienced with this type of drive, in part a result of the provision of a step speed control rather than a continuous speed control. Furthermore, the induction motors did not provide a positive control of speed, since any variation in load caused a variation in speed. Because of these difficulties, the electric drive was removed and replaced with a hydraulic drive. This drive provided continuous, positive control of speed.

The termination of the wire rope and of the electric cables at the array are shown in Fig. 38. The array is supported by two two-part lines consisting of 2-3/4-inch wire rope. The rope passes over the live sheave through a cable guide at the top of the array structure, around the sheave on the array, and up through another cable guide to the ship, where the bitter end is secured on a bitter-end sheave. A roller-path guide positioned at the center of roll supports the 2-3/4-inch wire rope at this point to minimize the translation forces imparted to the array due to ship's motion when the array is suspended

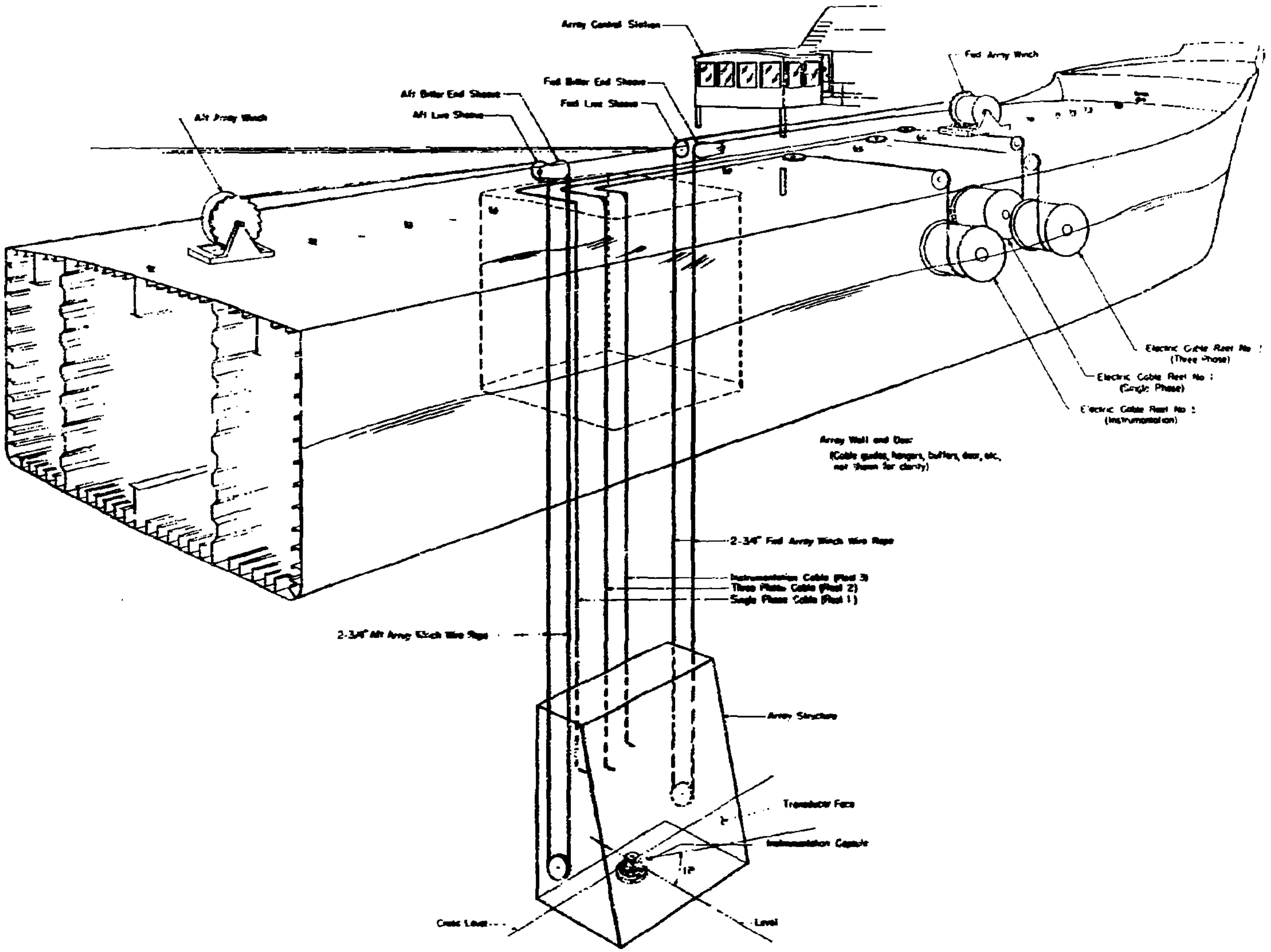

Fig. 35 - Composite arrangement -- hull, array winches, and electric cable reels

Fig. 36 - Forward array handling winch

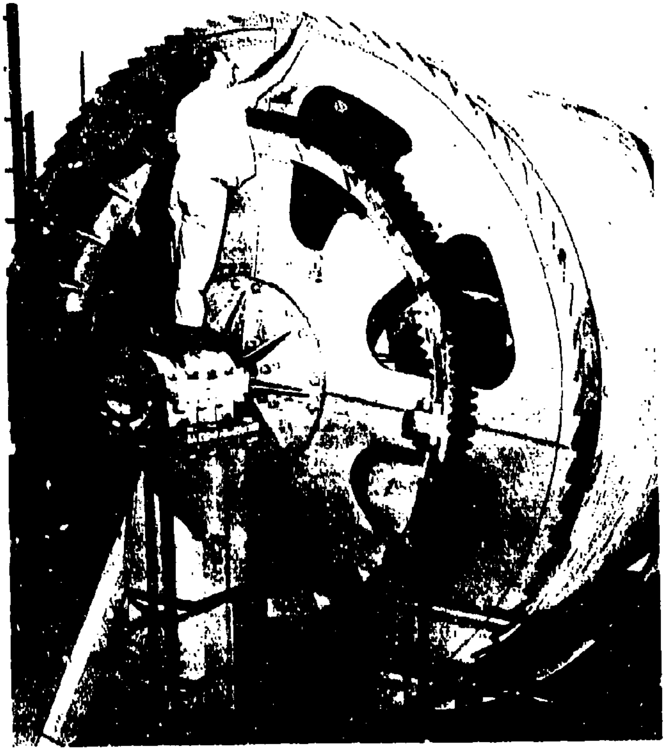

Fig. 37 - Electric cable machine

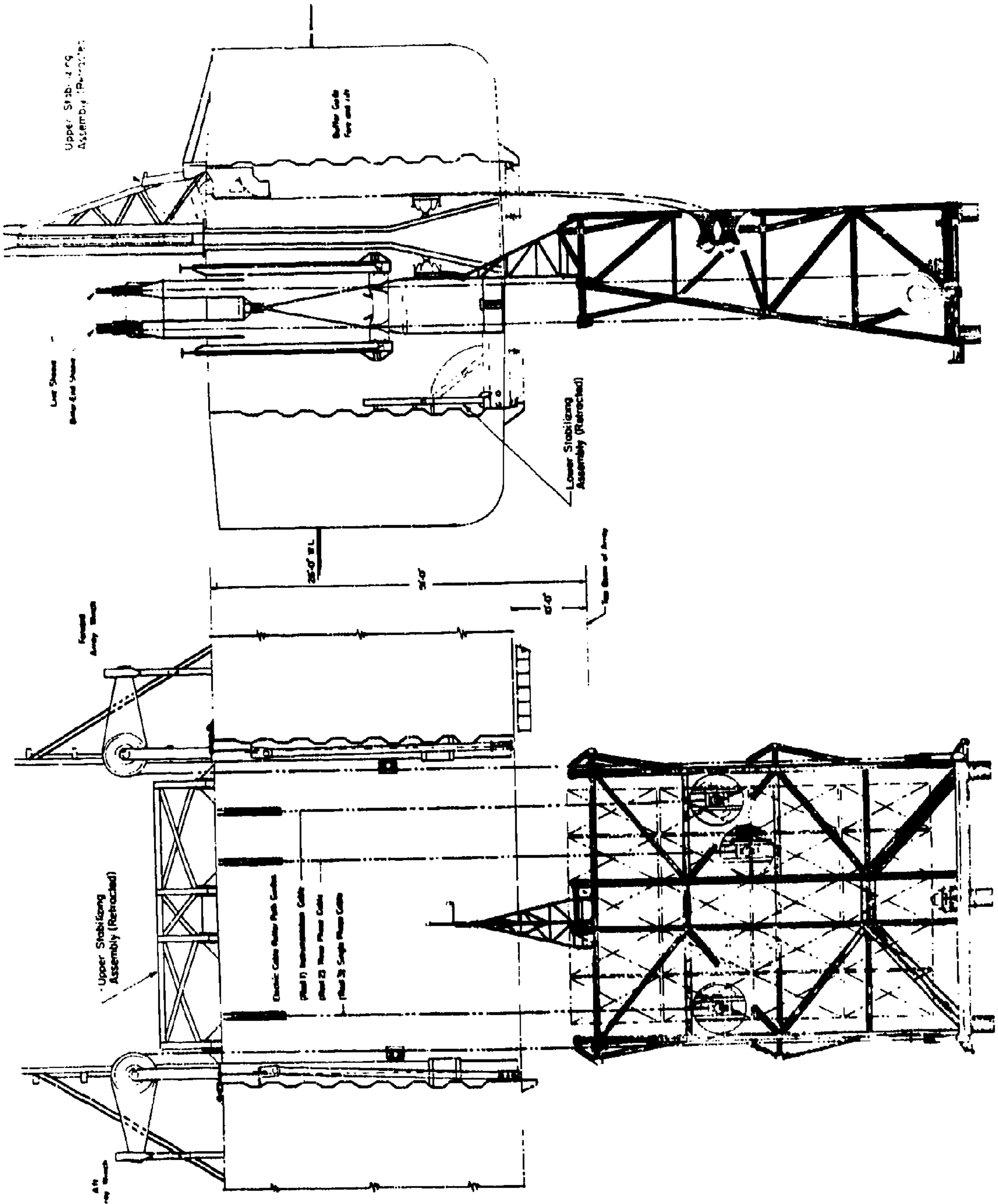

Fig. 38 - Array and array stowage system

beneath the ship. The electrical cables enter the well over roller-path guides on the port bulkhead of the array well and into the array structure on the rear face through appropriate cable bells.

The array stowage system (20), shown in Fig. 38 and 39, provides for guiding the array into the array well and for securing it while the ship is transiting between areas. The array is guided into the ship by means of six guide shoes (three forward and three aft, relative to the ship) on the array and two guide tracks located on the fore and aft bulkheads of the array well. These guide tracks consist of two sections: an upper section extending from the main deck up and is fixed to the ship, and a lower section pivoted at main deck level and extending down to near the bottom, where it is shock-mounted to minimize shock of the array structure as it enters the well. The lower end of this bottom section is flared fore and aft and athwartships to accommodate the effect of roll and pitch as the array enters the tracks. This was designed to accommodate a roll of ±8 degrees and a pitch of ±1-1/2 degrees when the array enters the guides. The array is secured in its stowed position by means of array hangers, shown in Fig. 38, and the stabilizing mechanism, shown in Fig. 39. The latter consists of an upper stabilizing assembly on the port side and two lower stabilizing assemblies on the starboard side. While in the stowed position, these stabilizing struts prevent motion of the array structure in the fore, aft, and athwartship directions. The weight of the array is carried by two array-support hangers, one located on the forward bulkhead and one on the after bulkhead of the well. Thus, the entire array structure is supported in the ship independently of the wire rope.

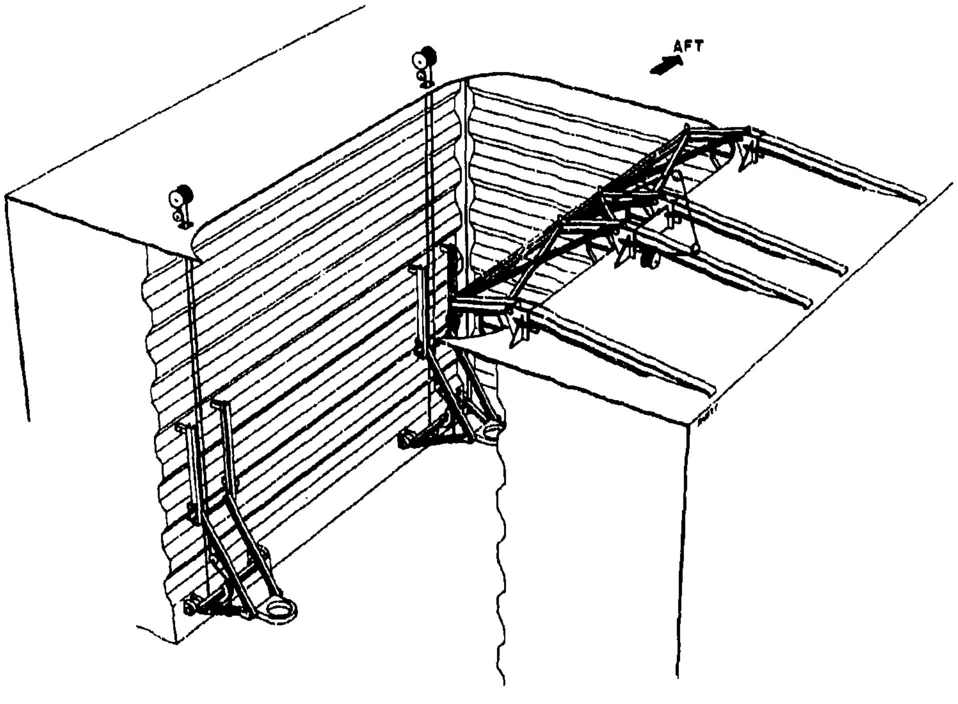

Fig. 39 - Array stabilizing mechanism in extended position

A door was provided on the bottom of the ship to close the array well when the array is in the stowed position. This door is rolled fore and aft on a pair of tracks which are located on the port and starboard sides of the ship. Wire rope passing from the forward corners of the door to the main deck and then to a winch is used to open the door. A similar arrangement of wire rope secured to the after end of the door is used to close the door. This door does not seal the well. However, it does prevent water surging into the well while the ship is underway, thus preventing damage to the components in the array. Provision has been made to use the door to support the array in an emergency due to failure or repair of the main stowage system.

A central control station is provided on the after part of the deckhouse to overlook the array well. The controls for the two array winches and the three electric cable machines are located within this array-control station. The necessary instrumentation for operating the array-handling system is provided in the panels above the controls. The station for control of the two array winches is shown in Fig. 40. This station is on the starboard side and requires one man for operation. Figure 41 shows the control station for the three electric cable machines. This is located on the port side and requires three men for operation.

Fig. 40 - Control station for array winches

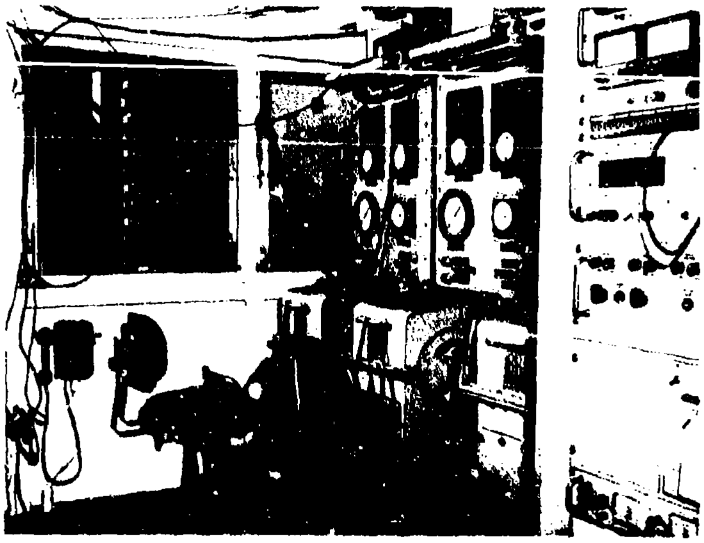

Fig. 41 - Control station for cable machinery

Ship's Heading Control and Positionkeeping

It was determined that the simplest yet most precise method for ship's heading control for this application would be a controllable-pitch propeller in an athwartship tunnel through the vessel's forefoot. Such an installation was proven commercially and was available in this country without abnormal delay. In addition, the comparatively high efficiency of this propulsion method would minimize the size and cost of the drive motor and associated electrical equipment. A 500-shaft-horsepower controllable-pitch bow thruster was selected for installation (21,22). This unit was rated by the manufacturer to deliver 13,200 pounds of static thrust.

The thruster unit consists of a controllable, reversible-pitch propeller having four blades of symmetrical cross section. The propeller is located in the vessel's forefoot in the center of a transverse tunnel (Figs. 42 and 43) midway between port and starboard support struts. A vertical drive shaft which turns the propeller through a 5-1/2-to-1 right-angle bevel gear passes through the starboard strut. It should be noted that the gear diameter and not the pitch-control mechanism in the hub limits the minimum diameter of the propeller hub design, a factor which is of great concern in propeller hydrodynamics. The port strut assembly houses both the tubing for hydraulic pitch control and the mechanical follow-up cable, described later.

Various means for powering the propeller were examined. Electrical power was selected because it was available aboard the vessel and appeared lowest in cost, operation, and maintenance. Sufficient power was not available from the ship service generators. However, the main propulsion generator was available, since the main screw was not used during thruster operation. Three single-phase, 3500/450-V transformers were installed to step down the generator voltage to 440 V for the 1800-rpm, 500-horsepower, three-phase propulsion motor.

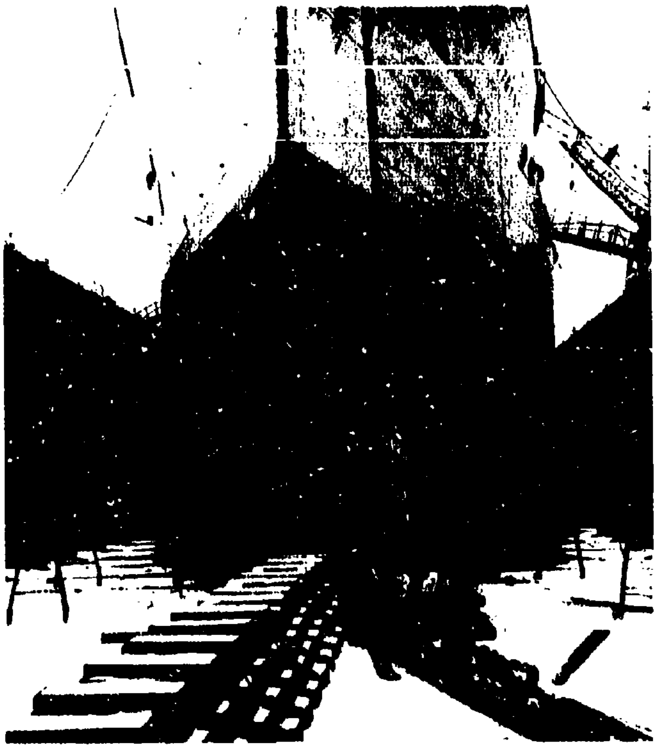

Fig. 42 - Bow thruster tunnel

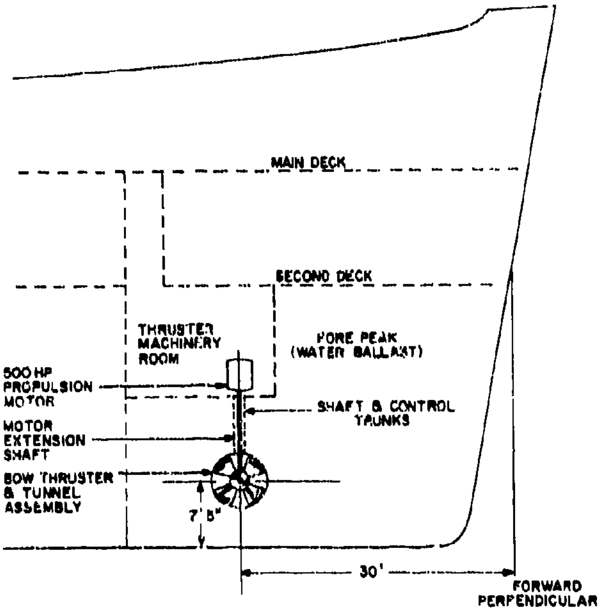

Fig. 43 - Thruster layout

A hydraulic power and pitch control unit in the thruster machinery room receives pneumatic signals from a remote-control station and hydraulically positions a pitch-setting servo and crosshead assembly, which in turn regulates the propeller pitch. A mechanical follow-up linkage provides pitch-position feedback. Maximum blade pitch for full rated thrust is regulated by positioning mechanical stops in the hydraulic pitch control unit.

To gain a maximum twisting moment, the thruster was installed in the forward peak tank as low and as far forward as practicable. Since the forepeak is used for water ballast and because of the close proximity and size of the ammunition flat just above, the latter was used for the thruster machinery space. The thruster is installed with the drive shaft in the vertical position, directly below the vertically mounted drive motor in the machinery space. The two are connected by means of an extension shaft with flexible couplings at each end. The three 3500/450-V transformers are located on the port side of the machinery space; power for them runs forward from the vessel's engine room along the main deck just below the catwalk, down to the thruster machinery space.

The mooring system installed to provide position control used as much of the existing shipboard facilities as possible to minimize cost and installation time. The principal item used was the vessel's anchor windlass, which could pay out or haul in any amount of anchoring line. A 2-inch-diameter, three-strand polypropylene rope was used for the mooring line. To stow the rope, a hydraulically driven reel was mounted forward of the midship house on the main deck, starboard side. Over 30,000 feet of rope were stowed on the reel. The rope was fair-led forward to the anchor windlass gypsy on the forecastle deck by means of swivel snatch blocks, and from there forward to another snatch block so that the gypsy would be aligned with the rope. From there the rope was led aft on the forecastle and over the side through a roller chock.

Polypropylene rope floats in water, thus presenting a reverse of the catenary described by anchor chain when a vessel is moored. Because of this buoyant tendency of the rope, between four and six shots of 1-3/8 to 1-5/8 inch stud link chain were used to back the anchor and prevent its lifting from the bottom. Between the rope and chain was a 1-3/4-inch-diameter nylon rope, several feet in length, which served as weak link. A 3000-pound LST Danforth anchor was used to complete the ground tackle. Several sections of polypropylene rope were long-spliced to form one continuous length. The normal arrangement of thimbals and shackles was used to link the sections of tackle together.

This deep-ocean anchoring system was used 28 times over a 27-month period, during which refinements were made for reasons of increased safety and improved technique. However, the basic system remained as described. Moors were attempted in water depths of 8000 to 18,000 feet. Instead of requiring an anchor line, the normal length of which would be several times the depth of water, the buoyant polypropylene line needed to be of a length only twice the depth. In spite of this, the processes of letting go and weighing were very slow, each requiring about 4 hours.

The anchor-rope reel could be rotated at any required speed and was controllable by hydraulic drive motor. The gypsy offered no rotational problems, and the rope was paid out or hauled in as fast as practicable. The rope required watercooling with a fire hose where it passed through the chock when anchoring or retrieving, and over the gypsy upon retrieving.

In order to accommodate the use of thimbals and shackles in the tackle, it was necessary to cease anchoring or weighing and stop-off the anchor line so that these obstructions could be passed around the snatch block fair-leads and gypsy. This process proved time consuming and was regarded as dangerous to the seamen involved. This method of stopping was also used to pass the anchor line aft, forward, or across the bow to the opposite side of the ship. It often was necessary to reposition the anchor line because of the varying directions of wind and sea. The bow thruster was used to maintain heading after the anchor line was finally positioned. Upon retrieving the tackle, the line had to be hauled through the chock upon forecastle. When hauling, the ship was put head to sea, and the main screw and rudder were used to lessen the strain on the anchor line. The thruster was not used during hauling, to avoid ingesting the line into it, which happened on one occasion.

During initial retrieving operations, the long polypropylene anchor line was found to have numerous kinks in the strands. This apparently resulted from the line's unlaying during lowering operation while the anchor was above bottom. As soon as the anchor and chain touched bottom, removing the line tension, the rope formed kinks on each strand. To prevent further occurrence, "anti-spin" plates were welded to the anchor flukes. These 2-foot-square steel plates apparently did not satisfactorily reduce the rotation of the anchor after letting go, and may actually have compromised the ability of the anchor to hold. It is not known if the anchor ever had held without dragging to some extent, but it is known that it offered great resistance, since the ground tackle parted several times either at the weak link or in the polypropylene line. Since the "anti-spin" plates were unsuccessful, a plaited or interwoven type of anchor line was obtained. This line was composed of eight polypropylene strands, each of which was jacketed in nylon to reduce friction burning. The strands were not laid in regular fashion. Instead, parallel-stranded pairs were mutually interwoven to preclude further unlaying and kinking.

In spite of the improvements to the anchor system, it was not satisfactory. On many occasions the anchor failed to hold, even when the chain was increased to six shots. When the anchor held, the ship would swing over such a large radius that it could not be considered "fixed" for the acoustic experiments.

The assistance of another vessel serving as a tug was tried and found fairly successful [illegible] stationkeeping. However, Navy tugs were not always available when needed, and the cost of hiring tug services was prohibitive.

The feasibility of positioning the source ship by dynamic means instead of further attempting a suitable deep-ocean moor has been investigated. Stationkeeping out of sight of land presents problems other than installing propulsion devices into a vessel. A means must be provided to identify the proper station or position. Furthermore, the installed auxiliary propulsion power must be regulated continuously, so that the ship is able to remain on or to regain station while maintaining proper heading. All of this must be accomplished without excessive hunting about position.

A study of requirements for stationkeeping established that project operations would permit a deviation of ±2 degrees from the desired heading and a drift of 1000 feet in radius from the desired position. Heading and position were to be maintained in state 5 seas with winds up to 25 knots and additive currents up to 1 knot. In addition, the system used to identify the ship's position would have to be operable in water depths from 5000 to 18,000 feet.

Using these parameters, it was concluded that a resultant force of 74,000 pounds of static propulsive thrust would be required at the vessel's transverse center of pressure. The center of pressure was calculated, from the combined natural forces upon the ship, to be just forward of the after bulkhead of the array well. The well, in turn, is centered several feet abaft the vessel's midperpendicular. The system selected for this purpose consisted of three subsystems: a position-measurement system, a control computer, and two trainable propulsion units. The specified characteristics of this system are described in the paragraphs to follow.

The absolute position of the source ship must be initially established by customary methods, either electronic or astronomical. Once this point has been established, the vessel's relative position will be determined in reference to a bottom beacon. In addition, three retractable hydrophones lowered during operation form an L-shaped array. The L is angled approximately 45 degrees to the ship's axis to maximize array dimensions. The hydrophones extend below the bottom to place the thrusters on a back lobe of the directional hydrophones. The received beacon pulses are pitch and roll compensated, processed, and fed to a special-purpose computer along with ship's gyro information. The computer outputs are thrust and heading commands to the two right-angle drive units. Monitor outputs are also provided which drive a recording PPI display and associated horizontal velocity and acceleration meters. Acoustic position errors are digitally recorded for later reference.

The presently installed bow-thruster system will not be required for heading control. Instead, two Murray and Tregurtha right-angle-drive propulsion units, one forward and one aft, will maintain both heading and position. These units are to be similar in design and will be located equidistant before and abaft the vessel's center of pressure. It is contemplated that one unit will be housed in the electrical-cable reel room and the second in the gas turbine generator room. The location of major components is to be as illustrated in Fig. 44.

The propulsion devices will be kort nozzles having fixed screws with close clearance between blade tip and shrouding nozzle. It is anticipated that 37,000 pounds of thrust will be obtained from each of the two thrusters. Drive will be accomplished by 1200-horsepower induction motors, which will be supplied from the ship's main propulsion generator at 3500 V, 60 Hz. In order to provide a capability for continuous thrust variation, an eddy-current coupling will connect the drive motors and the propulsion units.

The propulsion devices will project below the bottom of the ship and will be retractable vertically for maintenance as well as for reducing interference with navigation. Electric motors will be used to train the propellers to provide continuous control.

PERFORMANCE CHARACTERISTICS OF INSTALLED SYSTEM

Electrical and Electronic

The individual components of the 400-hz power system have been tested into resistive loads to full rating and found satisfactory (23-25). System tests of this equipment have been completed with 3900 kW of 400-Hz power into the test load. Under these conditions, it was found that the system met all the requirements.

The electrical system installed in the component tanks on the array structure has performed satisfactorily, electrically. However, mechanical difficulties were experienced in the first operation with this equipment. A pressure-compensation system is provided with these tanks to equalize the internal pressure with the external pressure as the array is lowered to depth. Due to an error in oil filling, not all of the air was removed. In the presence of air it is impossible for this pressure compensation system to maintain equalization of pressure. Upon correction of this deficiency, the entire structure

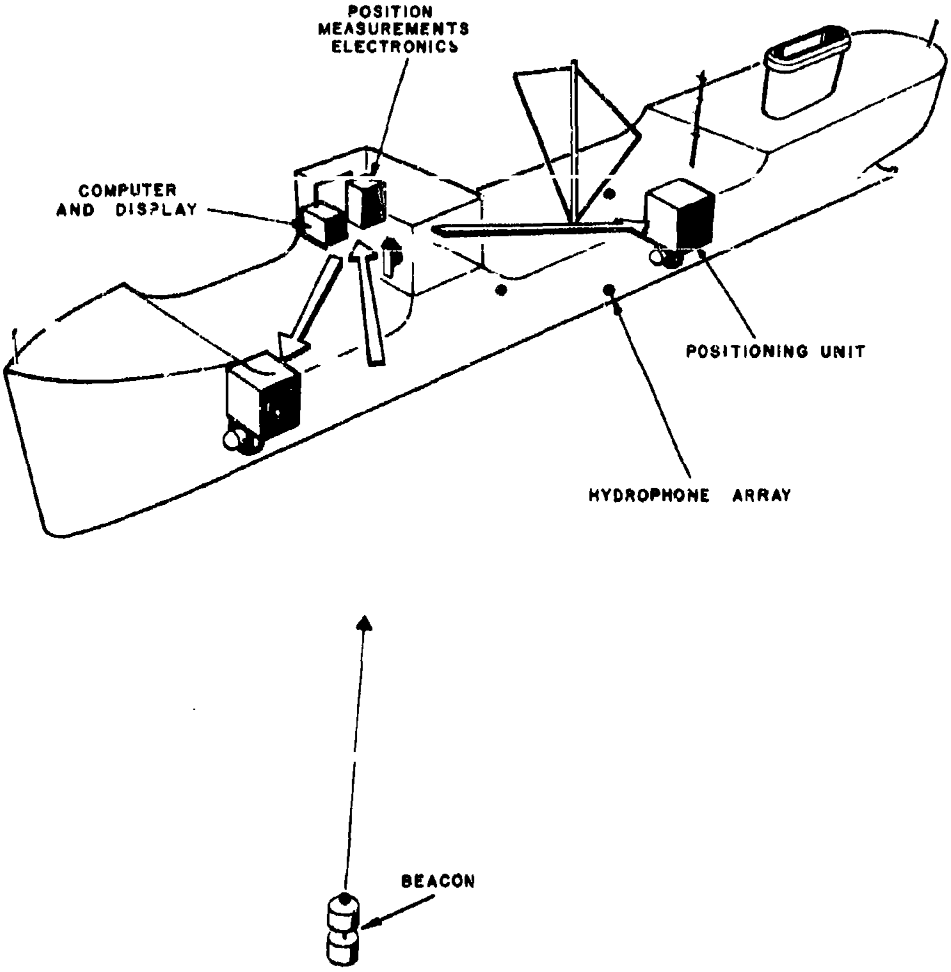

Fig. 44 - Dynamic stationkeeping system layout

has been used repeatedly to 1200 feet and found to perform satisfactorily, mechanically as well as electrically.

Transducer and Array

Experimental data have been obtained on the acoustic performance of the transducer elements and the transducer array. Tests on the elements have revealed that they meet all of the specification requirements.

The transducer array was assembled and tested in three phases. In May 1961 two transducer modules were installed on the array structure to form a 1-wavelength-square array. In September 1961 thirteen additional modules were installed, resulting in an array 2-1/2 wavelengths wide by 3 wavelengths high. The array was completed in July 1964 by the addition of the final five modules, increasing the height to 4 wavelengths. Concurrent with the addition of the final modules, the electrical connection to the transducer elements was modified from a series-parallel to an all-parallel configuration, and the air-filled tubes forming the rear acoustic baffle were replaced by tubes of an improved mechanical design.

Electroacoustic measurements with the two-module and 15-module array revealed that performance of this transducer array was affected by a velocity anomaly resulting from interaction of the transducer elements. Therefore, an experimental (26-33) and theoretical (34,35) program was established to investigate this phenomenon and develop corrective measures for the Artemis source. Because of the magnitude of the effort necessary to carry out this program with the ship-installed array, a study of interactions was conducted on a 36-element and a 144-element array. These arrays were 0.5λ by 0.5λ and λ by λ, respectively. The principal factors studied in this investigation were the mechanical bonding of the elements into subgroups and various electrical interconnections of the elements. Mechanical subassemblies of 0.25λ by 0.33λ and 0.5λ by 0.5λ were tried in the experimental investigation. Only the latter arrangement was considered in the theoretical study. Electrical connections involving series-parallel groupings of the elements, all-parallel connection, and parallel connection plus series tuning of each element were investigated experimentally and theoretically.

The results obtained from this experimental and theoretical program were used to compute the expected performance for the 2.5λ by 4λ Artemis array. The results are summarized in Figs. 45 and 46. The series-parallel, unconsolidated arrangement is used for comparative purposes on each of these two figures, since it was the original configuration chosen to interconnect the 1440 elements. The improvement in performance resulting from mechanical grouping as well as electrical interconnection is evident from these results. On the other hand, it is to be noted that the estimated source level is less than the design objective of 152 dB at 400 Hz. This reduction is a result of the following:

1. All of the effects of interaction have not been eliminated; thus, a variation in amplitude of the elements across the 1440-element array still exists in spite of the modified arrangements,

2. The acoustic loading of the array is less than unity, and

3. There is a second mode of vibration of the inner mass which is a rotary component superimposed on the linear motion of this mass, with the result that the effective spring deflection has been increased.

All of these factors contribute to the spring deflection limiting the maximum displacement available from the radiating face and, in turn, the maximum radiating power that can be obtained from the source.

It was noted from the experimental and theoretical program that the largest improvement in array performance could be achieved by using a parallel connection of all elements with individual tuning and by consolidating the elements into subgroups. There were two disadvantages to this method, however. One was the sharp reduction in allowable source level in the vicinity of 375 Hz, resulting from the second mode of vibration of the inner mass, and the cost of making this modification to the array. For these reasons, mechanical consolidation was not attempted for the full array. However, all of the elements were reconnected electrically in parallel. The 5 μF individual tuning was not

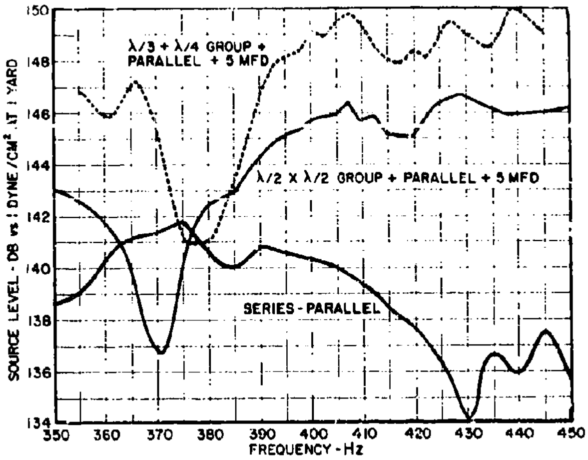

Fig. 45 - Effect of mechanical consolidation of elements on source level of Artemis array

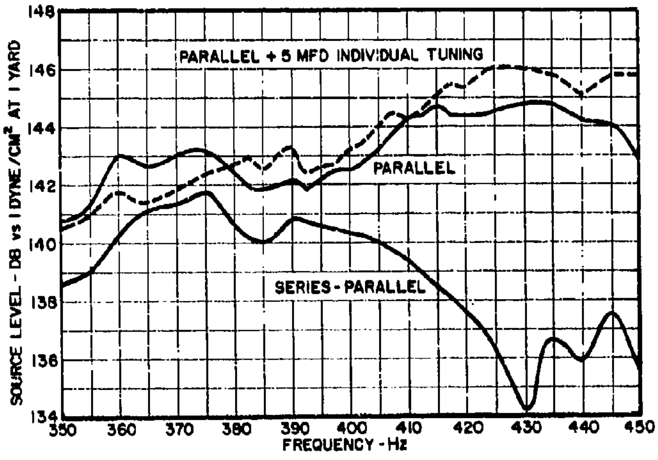

Fig. 46 - Effect of electrical connection of elements on source level of Artemis array

incorporated into this modification because of a significant reduction compromise in source level at the lower frequencies to gain a slight improvement at the upper end of the frequency band.

The impedance characteristics of the completed array are illustrated in Fig. 47. These data were obtained with the array submerged to a depth of 600 feet and with a driving current of 50 amp at frequencies from 350 to 445 Hz and 25 amp for frequencies higher than 445 Hz.

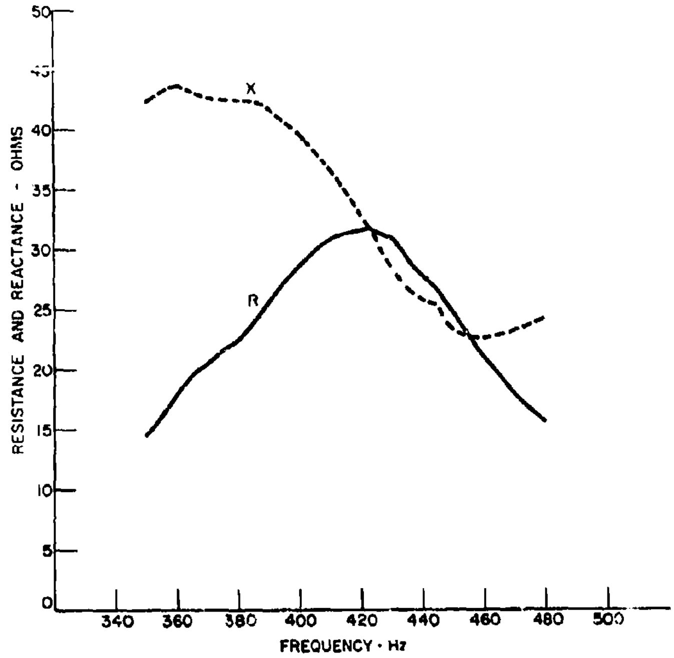

Fig. 47 - Array resistance (R) and reactance (X) characteristics

The conventional current, voltage, and power response on the acoustic axis are shown in Fig. 48. These measurements were made with a hydrophone suspended from a small boat which was tethered to the source ship at a range of 250 feet. The hydrophone range was measured acoustically. The acoustic axis was located by searching with the hydrophone in depths and azimuth for the maximum response. Signal power input to the transducer was held constant at 200 kW at all frequencies except 450 Hz, where it was reduced to 125 kW. The depth of submergence was 250 feet. The measured results are normalized to provide the response curves shown in Fig. 48.

No far-field measurements of the acoustic field on the reciprocal acoustic axis have been made; however, the pressure-relief baffle has been demonstrated to be acoustically effective on a test module. The radiation pattern of a 0.5λ square array consisting of 36 TR-11C transducer elements is illustrated in Fig. 49. This array was baffled with the same type of pressure-release tube now in use on the full array. The ratio of acoustic intensity on the acoustic axis to that on the reciprocal acoustic axis (front-to-back ratio) for this test module is plotted as a function of frequency in Fig. 50.

An approximate directivity pattern for a portion of the major lobe was obtained in a horizontal plane through the acoustic axis of the 15-module array. The hydrophone was suspended from a small boat at a range of 250 feet and was moved in depth to search for maximum response at each azimuthal angle. Azimuth was determined by a transit on the deck of the source ship. Although the range was measured acoustically, errors in azimuth could occur due to streaming of the hydrophone beneath the small boat. Results are shown in Fig. 51.

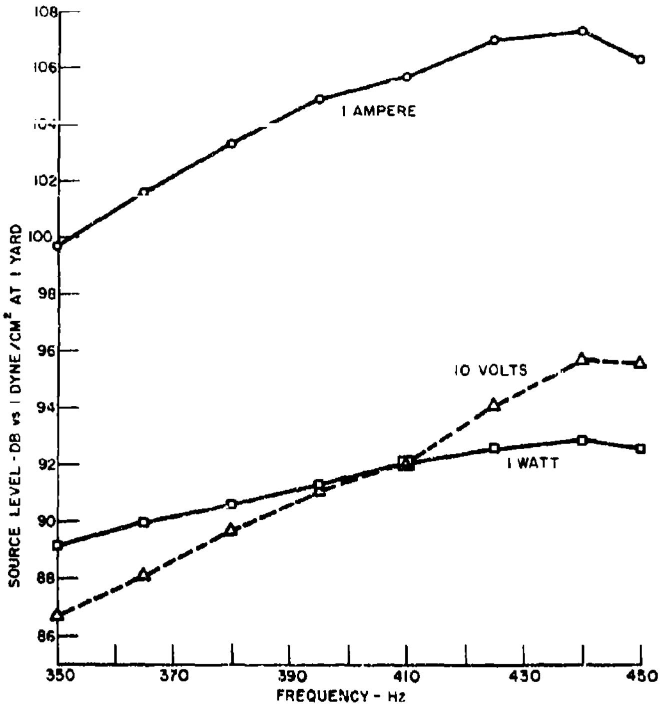

Fig. 48 - Array response characteristics

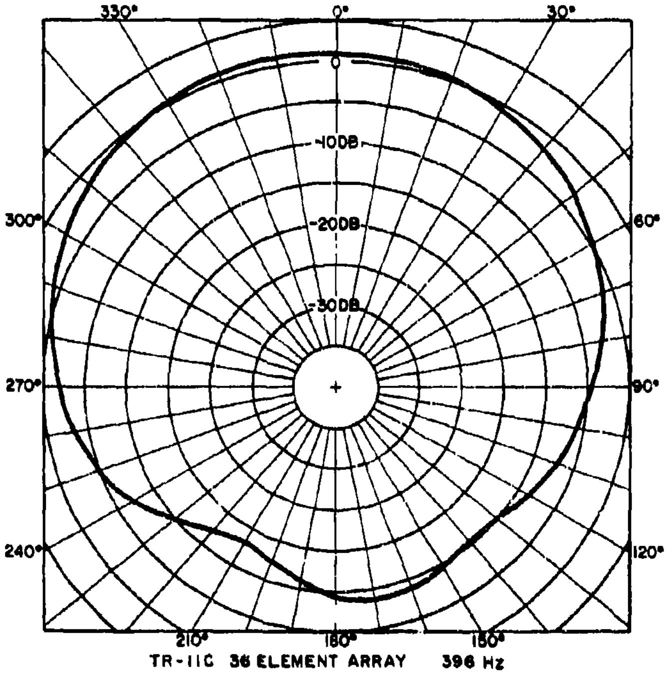

Fig. 49 - Beam pattern of 36-element 0.5λ square array

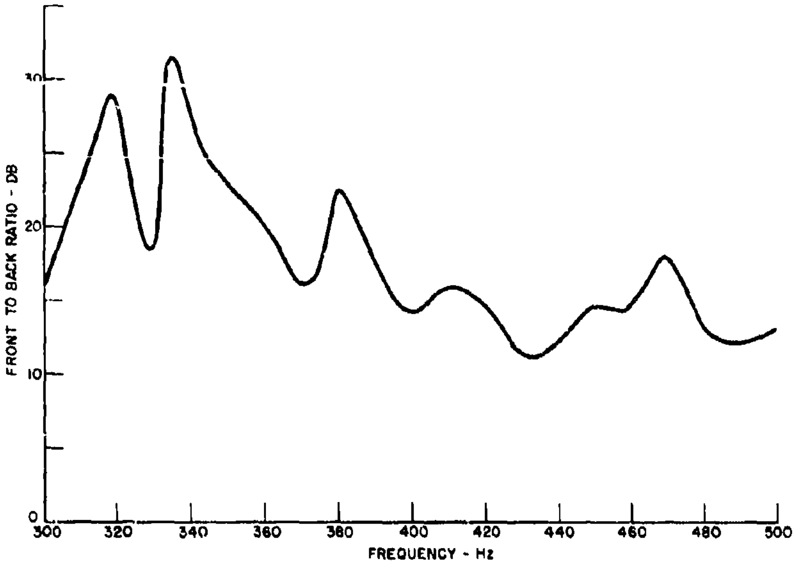

Fig. 50 - Front-to-back ratio of 36-element 0.5λ square array

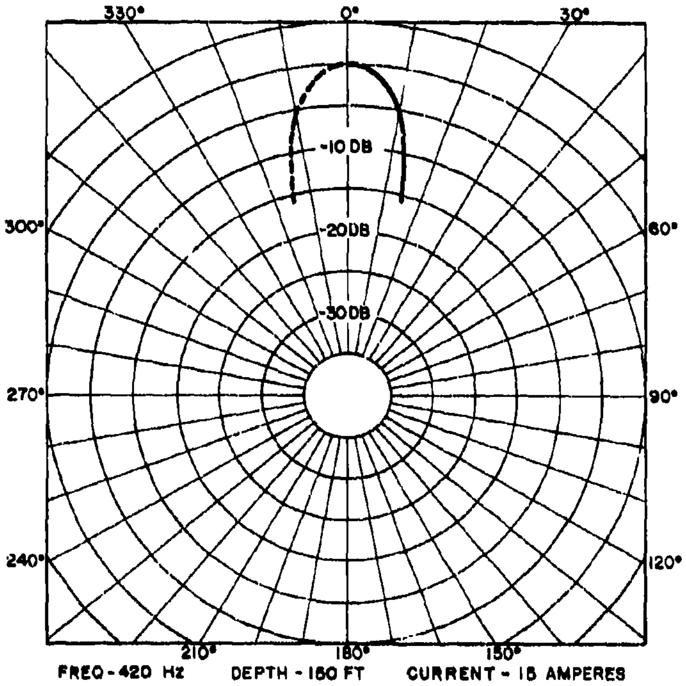

Fig. 51 - Horizontal beam pattern, 2.5λ wide by 3λ high array (15 modules)

Vertical beam patterns were obtained on the completed array using a hydrophone mounted on a 190-foot beam fixed to the array structure. This permitted precise positioning of the hydrophone range and elevation in a vertical plane through the acoustic axis of the source transducer. The amplitude and phase of the directivity pattern for 350, 400, and 450 Hz is shown in Figs. 52 and 53. Only the lower half of the main lobe and the first side lobe were obtained owing to handling limitations of the boom.

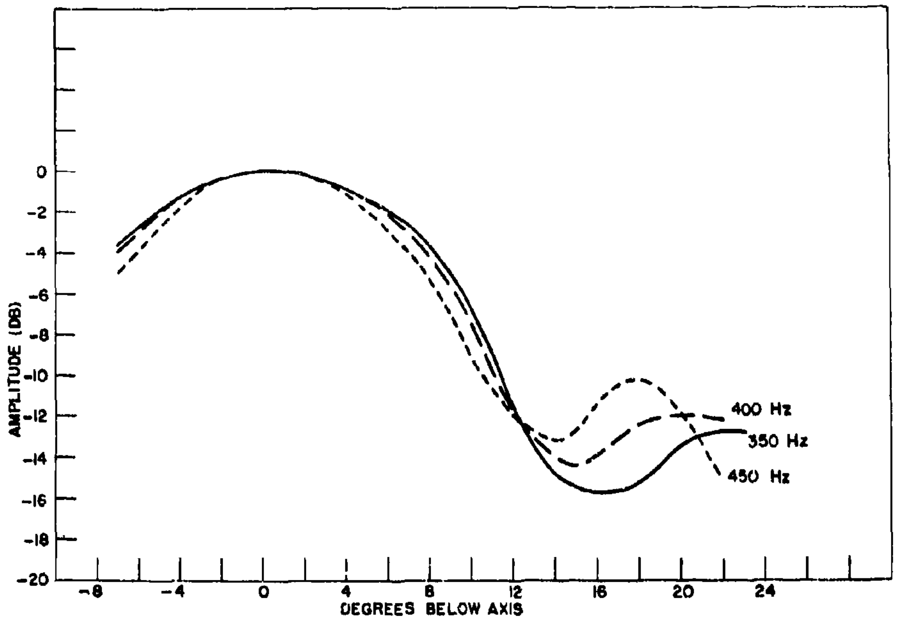

Fig. 52 - Vertical beam pattern amplitude, 2.5λ wide by 4λ high array (20 modules)

The conversion efficiency from electrical to acoustic energy for the complete transducer array was determined from the electroacoustic data used to derive the current and voltage response. The measured values of acoustic intensity and the computed directivity index at the several frequencies, along with the electrical input power, were used in these computations. The efficiency for the complete array as a function of frequency is shown in Fig. 54.

Instrumentation and techniques were developed to study the array element interaction problem by measuring the displacement of the inner mass and the radiating face of transducers mounted in the array. In the course of the experimental investigation, the displacement of approximately a 10% sample of all the elements in the array for various frequencies was obtained. The displacement values for the radiating face were used to compute an average displacement for the transducer array. An average acoustic loading ratio for the entire array has been computed from the ratio of radiating power to that power which would be radiated from a uniform velocity piston of equal size having a displacement equal to the average of the measured displacements and radiating into a unit ρcA load. The results of this analysis are presented in Fig. 55. It should be noted that

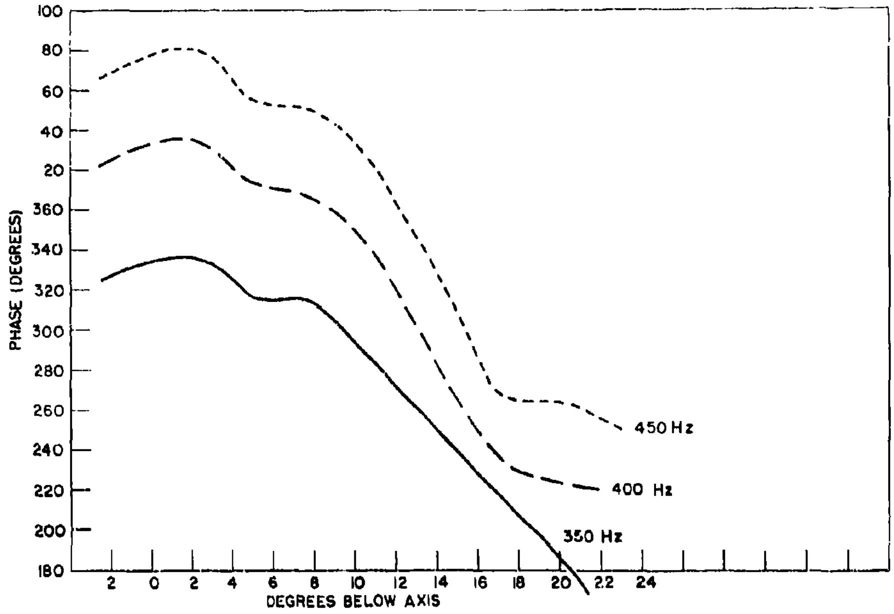

Fig. 53 - Vertical beam pattern phase, 2.5λ wide by 4λ high array (20 modules)

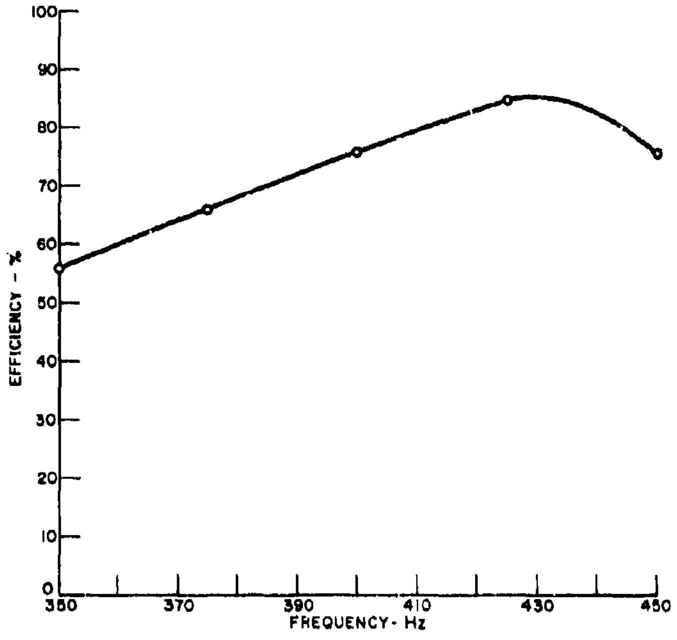

Fig. 54 - Array conversion efficiency, 2.5λ wide by 4λ high array (20 modules)

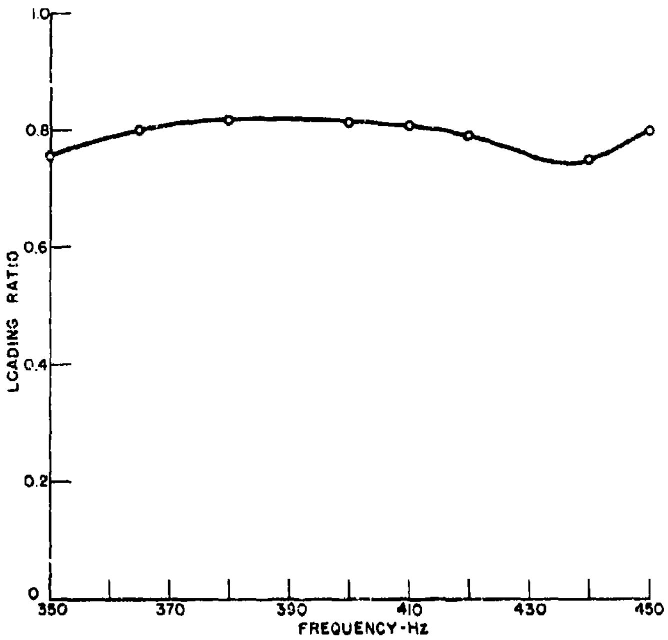

Fig. 55 - Array acoustic loading, 2.5λ wide by 4λ high array (20 modules)

the computations based on average displacement of the elements lead only to an approximation of the acoustic loading, since the elements in the array are not moving with equal amplitude and phase.

Interaction among the 1440 transducer elements in the source array became a major concern with this array. Since the element size is approximately 1/12 wavelength in water, the interaction loading predominates over the self-loading. This not only produces a nonuniform loading over the face of the array but also unloads some elements within the array. Transducer spring deflections are sensitive to the acoustic loading on the elements, and those elements having small values of load can have exceptionally large spring deflections. Since spring failure will occur due to fatigue when the element is overdriven, the interaction of the array elements has the effect of decreasing the maximum allowable power input to the array. This is true even though there are only a few elements in the array subjected to the large spring deflections.

The variation in displacement of the radiating face from element to element in the array is a function of frequency. Furthermore, the acoustic interaction of the elements causes a spatial variation in the radiation load of the array. This results in a variation in the electrical impedance. Since the elements are connected electrically in parallel, the electrical power to each of the elements will vary with the acoustic load. This variation in input power and acoustic loading produces a diversity of element displacements.

A statistical sample of spring deflections was obtained for continuous-wave signals over the operating frequency band. The distribution of outer-mass displacement observed in these measurements is plotted for six frequencies within the operating band in Fig. 56. The displacements shown in this figure are normalized to a mean displacement at each frequency. It will be noted that the uniformity of this displacement progressively deteriorates at frequencies above 430 Hz. Distribution of the spring deflections for the elements is shown in Fig. 57. It will be noted here that the deterioration in performance starts at a lower frequency. This is the result of a rotary mode of vibration associated with the inner mass of the elements. An indication of this can be seen in Fig. 58 where the spring deflection associated with the top and bottom of the inner mass relative to the outer mass is shown. It can be shown from amplitude and phase data that, for frequencies in the range of approximately 380 to 420 Hz, there are dissimilarities between the top and bottom deflections which are a result of rotary motion. This curve, shown for one element position, is in general typical of that measured for other elements in this same position or elements in other positions. The curve will differ in detail, but the general appearance and shape are unchanged.

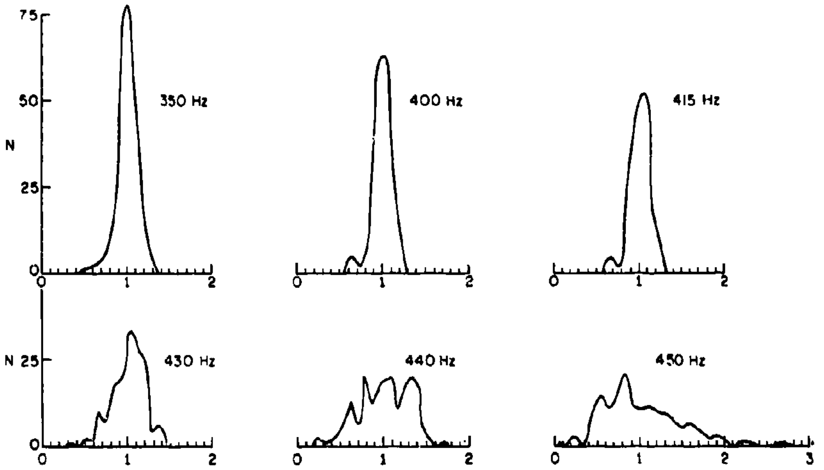

Fig. 56 - Distribution of radiating face displacement for statistical sample of elements. Distribution N is plotted relative to mean displacement in 1/1000th of an inch at each frequency. 2.5λ wide by 4λ high array (20 modules).

On the basis of these data along with a knowledge of the maximum allowable spring deflection without fatigue, the maximum allowable input power to the array, the maximum allowable input voltage to the amplifier, and the maximum available source level were determined. However, to assure reliable operation of the system a safety factor of 3 dB has been inserted to allow for the size of the statistical sample of spring deflections and to allow for the effects of transient overshoots when the signal is pulsed. This 3-dB allowance has been made in the three curves to be described in the following paragraph.

The maximum allowable input power to the array is presented in Fig. 59. The maximum allowable voltage input to the amplifier corresponding to this maximum power input curve is shown in Fig. 60. The source-level curve shown in Fig. 61 was derived from experimental measurements as previously noted. Since the transducer spring deflection is most sensitive to the effects of interaction in the vicinity of air resonance of the transducer element, a large fall-off in allowable input power is observed above approximately

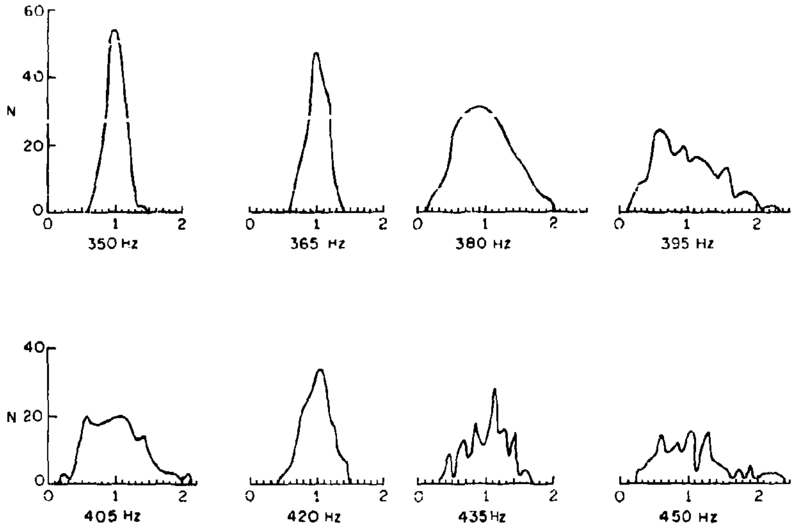

Fig. 57 - Distribution of transducer element spring deflection. Distribution N is plotted relative to mean deflection in 1/1000th of an inch at each frequency. 2.5λ wide by 4λ high array (20 modules).

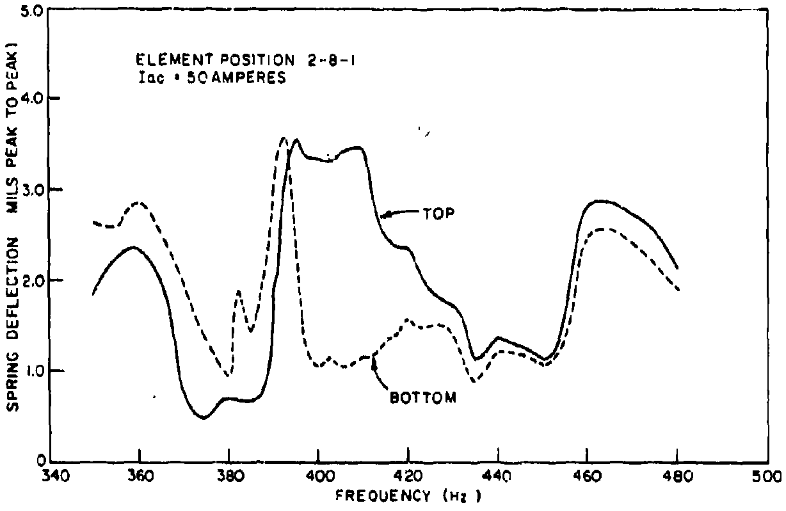

Fig. 58 - Deflection of upper and lower springs in a transducer element for constant current input

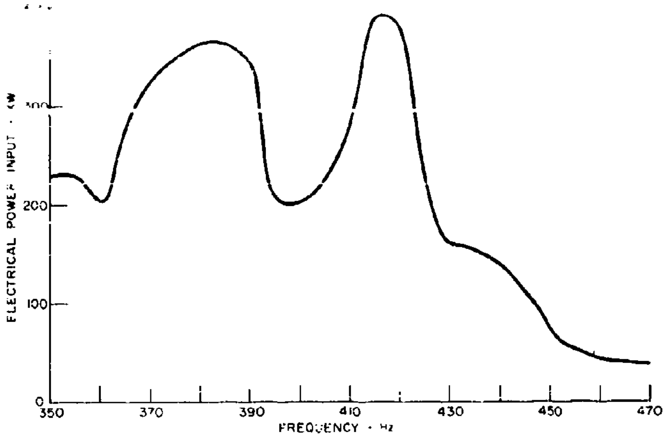

Fig. 59 - Maximum allowable single frequency sine wave power input to array, 2.5λ wide by 4λ high array (20 modules)

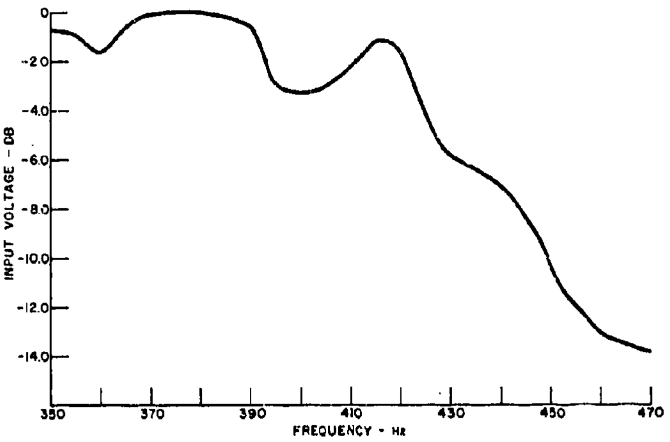

Fig. 60 - Maximum allowable single frequency sine wave input voltage to amplifier (relative), 2.5λ wide by 4λ high array (20 modules)

425 Hz. At frequencies in the vicinity of 395 Hz the spurious mode of vibration of the inner mass of the transducer element occurs. This spurious vibration increases the spring deflection without a corresponding increase in the displacement of the radiating face. Hence, allowable power is decreased in this region. The general increase in source level over the range from 350 to 430 Hz is due to the increase of allowable power as a function of frequency, the allowable intensity being proportional to the square of the frequency for a given displacement. The limits presented in Figs. 59 through 61 are for single-frequency sine-wave input signals to the amplifier. Different limits may be required for other types of signals.

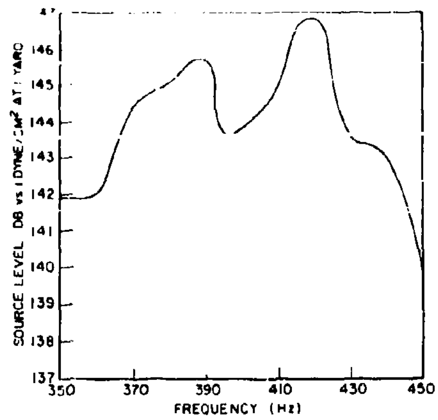

Fig. 61 - Maximum available source level, 2.5λ wide by 4λ high array (20 modules)

The transfer function and deviation from linearity are necessary to define the behavior of any system which is to be subjected to transient or modulated type signals. This is also true for acoustic sources which are to be used with some form of modulated signals in correlation studies and coherence processing techniques. The linearity of the Artemis source is presented in Fig. 62 as a system gain with relation to transducer input current. This "gain" is expressed as the ratio of the voltage amplitude output from a hydrophone placed on the acoustic axis to the voltage amplitude of input signal to the amplifier. The results are shown for 350, 400, 420, and 450 Hz. The maximum deviation from constant gain is approximately ±8% at any frequency but is approximately ±25% for both signal level and frequency. The phase relationship between hydrophone voltage and input signal is shown in Fig. 63. The phase of the hydrophone voltage has been corrected to far-field conditions and then referred to zero range.

The transfer function of the system obtained with two types of amplifier input signal, single-frequency sine-wave signals and modulated sine-wave signals, is shown in Figs. 64 and 65. The amplitude and phase data are shown for the axis of the main lobe at 7.5 and 20 degrees below the main-lobe axis. The latter corresponds to the axis of the first side lobe at 400 Hz. These data show the same deviation from constant gain as indicated previously on Figs. 62 and 63. This deviation will not introduce appreciable amplitude distortion. The phase shift presented for the on-axis data in Fig. 64 can be shown to be directly proportional to frequency. Therefore, it represents a time shift which will not cause phase distortion.

The modulated-wave signal input to the amplifier used in Figs. 64 and 65 was a coherent 180-degree, phase-modulated, 400-Hz sine-wave carrier. Phase modulation was obtained by means of a linear shift register sequence which provided a maximal length sequence from a 12-bit binary shift register using a shift rate of 100 times per second. The total sequence duration is 40.96 seconds.

The average rms current to the array was 80 amp for the single-frequency continuous wave and for the modulated sine-wave signal. However, due to the spectral spread of energy for the latter signal, about 1% of the energy is present in a four-cycle band at 350 Hz, and 4% in a four-cycle band is present at 400 Hz. In spite of this large difference

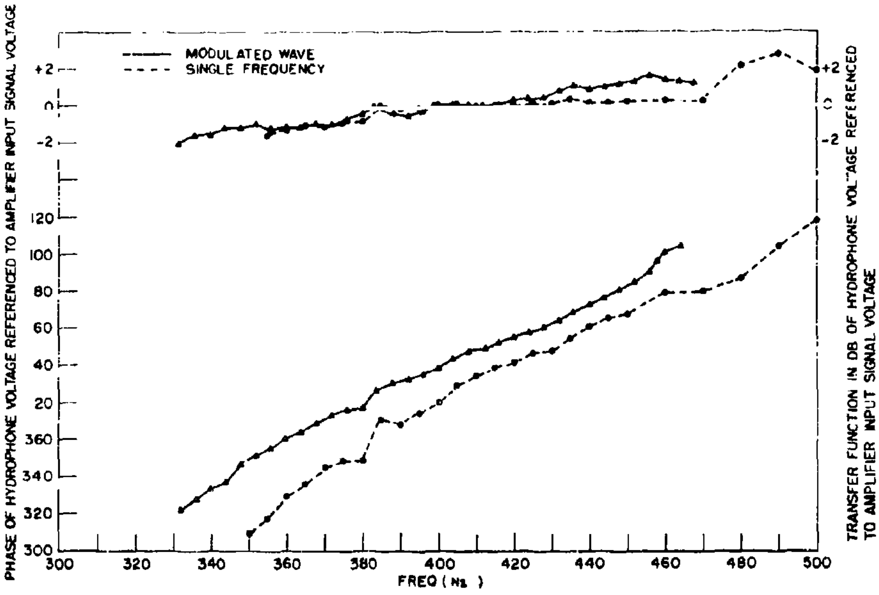

Fig. 62 - Amplitude response of the system

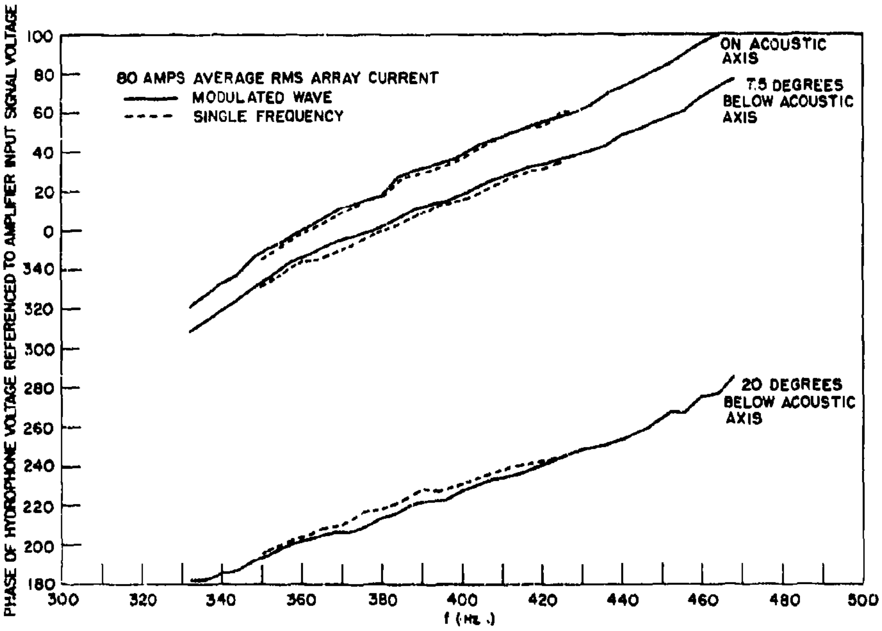

Fig. 63 - Phase response of the system

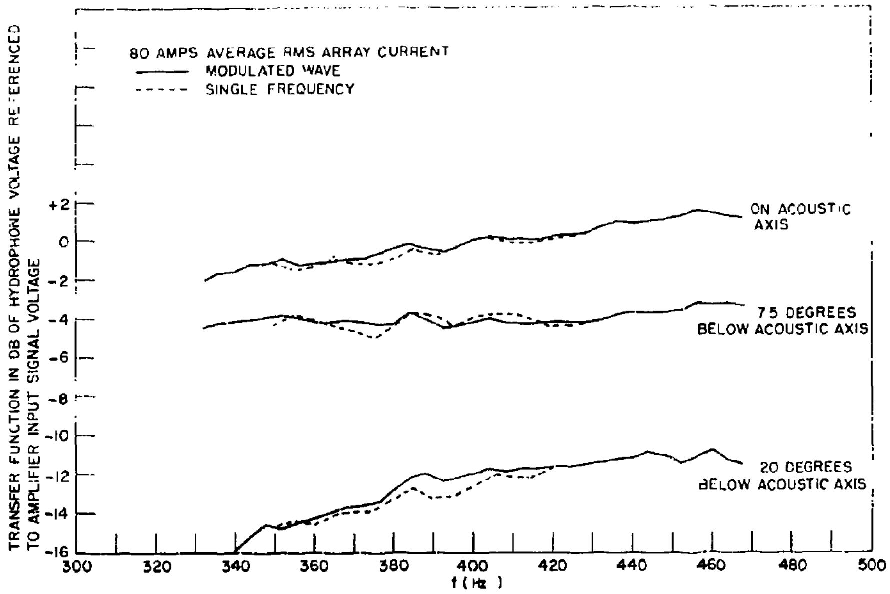

Fig. 64 - Transfer function -- amplitude

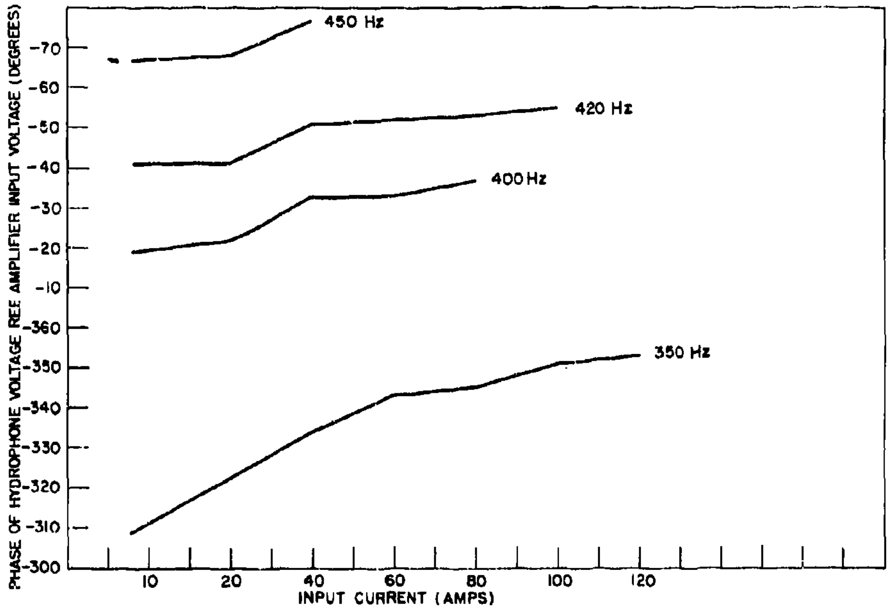

Fig. 65 - Transfer function -- phase

in equivalent signal level, there is good agreement in the shape of the amplitude and phase curves for the two signals. Reducing the current to 8 amp for the single-frequency, continuous-wave signal did not change the amplitude characteristics but did cause an approximate 25-degree shift in phase response. This is shown in Fig. 66.

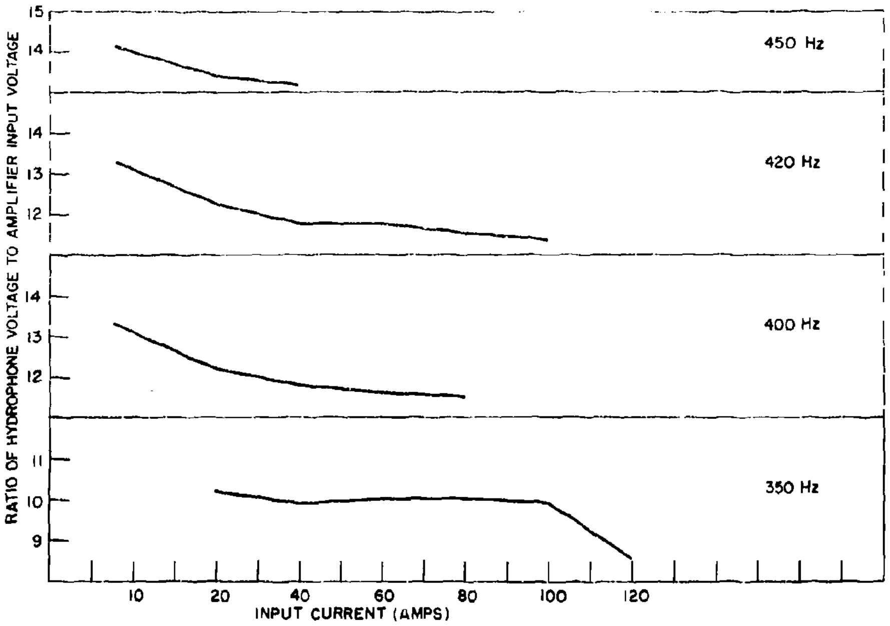

Fig. 66 - Amplitude and phase comparison for 80-amp input modulated wave and 8-amp input single frequency

The measurements indicate that the source has acceptable response characteristics, that the amplitude and phase linearity are adequate for the type of modulated signal used in the Artemis system, and that good correlation between acoustic signal and amplifier input signal should occur (36,37). This observation is limited to the characteristics of the system as viewed from the input and output terminals. On the other hand, it must be recognized that modulated-wave signals can create transient situations within such a complex system which must be considered if they influence or limit the allowable input and the available output signals. Steady-state measurements using single-frequency input signals to the amplifier have shown that the transducer array is more limited in power-handling capability at certain frequencies than at others within the operating band. On the basis of this steady-state data, it would seem reasonable to expect that the modulated-wave signals and the transient situations created by such signals would have to be recognized in establishing the maximum allowable input signal to the amplifier.

Since these steady-state data have indicated that the allowable signal level is frequency dependent, it would appear that tailoring of the energy level in the frequency spectrum for modulated-wave signals would be advantageous, since it would permit the maximum allowable average power from the array. The steady-state data referred to showed two areas where the allowable power was most sensitive to frequency. These were in bands centered at approximately 380 and 460 Hz. The limitation of the system to the dynamic situation created by modulated-wave signals may not be the same as that observed with the single-frequency sine wave, but, in the absence of data, observations were made with signals tailored to avoid at least one of these frequency-sensitive bands. There are at least four methods which can be used to tailor the type of modulated signal used in the Artemis program. These are:

1. Change the maximum bit length by change in shift register,
2. Change the minimum bit length by change in shift rate,
3. Change the center frequency, and
4. Restrict the frequency band of the input signal to the amplifier by banpass filters.

The effect of each of these methods on maximum allowable power input to the array is illustrated in Table 3. The criterion for maximum power is the allowable maximum peak-to-peak spring deflection.

Table 3

Modulation Type*	Shift Reg. Length	Modulation Rate (Hz)	Center Freq. (Hz)	Filter Bandwidth (Hz)	Allowable Power (kW)
PRS	12	100	380	350-450	262
PRS	12	100	400	350-450	182
PRS	12	100	420	350-450	229
PRS	12	100	400	350-430	232
PRS	12	80	400	350-450	257
PRS	11	50	380	350-450	268
PRS	11	50	400	350-450	342
PRS	11	50	420	350-450	307
PRS	7	100	400	350-450	245
PRN	-	wide band	400	350-450	110
PRN	-	100	400	350-450	237
FSK	11	42	400	350-450	385

*PRS = Phase reversal modulated pseudorandom signals; PRN = Pseudorandom noise signals; FSK = Frequency shift keying.

Although it is possible to make broad and generalized comments on the interrelationship of these four controllable signal parameters, there is insufficient knowledge of the transfer characteristics of each component in the system to assign quantitative values to the contribution of each parameter on maximum available power. This area is worthy of more study on all sources which are to be operated with modulated-wave signals (36).

The frequency spectrum of the radiated acoustic signal for a single-frequency continuous-wave signal into the amplifier is a measure of the system design and is of interest to other acoustic systems that might operate in the acoustic field of the source. The spectrum for this source is shown in Table 4.

Table 4
Frequency Spectrum of Radiated Acoustic Signal

Frequency (Hz)	Source Level (dB//1 dyne/cm^2 at 1 yd)	Harmonic
Gate Open — Signal to Amplifier		
60	60.4	
301	80.1	
360	90.0	
420	145.1	Fundamental
480	94.6	
540	86.3	
840	104.5	2nd
1200	64.0	
1260	94.3	3rd
1680	72.3	4th
2100	76.0	5th
2940	70.9	7th
Gate Closed — No Signal to Amplifier		
420	82.6	Fundamental
330	75.6*	

*Source assumed to be ship at range of 600 feet.

All the spectral lines observed over the frequency range from 60 to 15,000 Hz at a hydrophone on the acoustic axis of the source and at a range of 190 feet, with the array submerged to a depth of 600 feet, are listed. The upper section of the table lists the observed lines when the array was energized with 100 amp at 420 Hz. The entries at the bottom of the table are the only lines observed when the signal gate was closed. When the amplifiers are off and disconnected from the transducer array, the 420-Hz line disappears, but the 330-Hz line remains unaffected. Because of this, it is assumed that the transducer array is the source of all lines except the 330-Hz line, which is assumed to emanate from the ship. The 330-Hz line may have existed when the array was energized but was overlooked, since only the higher-level lines were recorded at that time. Although the ship's equipment causing this line could not be identified, it was found to be absent during a later measurement.

From the above discussion it follows that a multielement transducer array, made up of transducer elements much less than a wavelength in water, suffers from acoustic interaction effects created by nonuniform loading. Furthermore, it has been observed that the average acoustic loading for such an array was 0.8 or less. Thus, if nothing is or can be done to further reduce the effects of interaction and to increase the acoustic loading to unity, it is necessary to design the transducer element for displacements that recognize these two factors. Since the spring deflection is a function of the radiating-face displacement, it is necessary to design the element with a greater allowable spring deflection than that permissible for the present element used in the Artemis array. Anything that can be done to reduce or eliminate the nonrectilinear mode of vibration in the element would increase the power-handling capability.

A modified version of the Artemis transducer element has been designed, which, if substituted in the present array of elements, should radiate at least 1 MW acoustic power in the presence of the interaction and reduced acoustic loading (38-40). The redesign consists of new springs which have an allowable deflection of approximately four times that in the present springs and a rearrangement of the spring support for the internal mass to reduce the nonrectilinear mode of vibration. Tests on samples of this element indicate a 12-dB gain in source level over that shown in Fig. 61 could be achieved. It is believed that a conservative figure for an array made of this modified version of the Artemis element would be an increase in source level of approximately 9 dB over that shown in Fig. 61. Furthermore, the rotational mode of vibration causing the dip in response near 395 Hz would be eliminated.

It should be noted that problems which have not been experienced with the present source may develop in operating an acoustic source at a 156-dB level. It is known, for example, that the pressure release must be improved to meet these requirements, for the present system installed on the acoustic source will suffer from fatigue failure at source levels only slightly above the present operating level. Furthermore, there is little experience on the performance of electrical components and mechanical structures in underwater, high-intensity acoustic fields. Further attention would have to be given to at least these two problems to assure that an array of these modified versions of the Artemis transducer element could, in fact, provide a source level of 156 dB.

Array Handling

The array handling system, consisting of winches, cable machinery, instrumentation, and controls, performed satisfactorily in lowering the array to 1250-foot depths during the first test of the handling system. The system has been used repeatedly since then in lowering the array down to depths of 1200 feet. The array guide system has also performed satisfactorily throughout the operation, with ship motion as high as 10-degree roll and 3-degree pitch when the array entered the well. However, difficulty was experienced with the array-securing system during early operations. This system failed while transiting in heavy seas, leaving the guide shoes on the array and the guides on the ship as the only restraint to array movement. Eventually several of the guides failed. Fortunately, damage-control measures were adequate to prevent more serious damage. One of the damaged guides is shown in Fig. 67. The corresponding guide on the forward end of the array, which was not damaged, is shown in Fig. 68. The stabilizer was redesigned to meet the unexpectedly severe dynamic load requirements imposed by ship motion. The redesigned system, which is the one already described, has proven satisfactory to fix the array securely in the stowed position during the high sea states.

Ship's Heading Control and Positionkeeping

The bow thruster was the only part of the ship heading control and positioning system given a controlled test. Both static and dynamic performance tests of short duration were conducted on the installation. The static tests were run at dockside, the vessel being moored to piers by four lines located port and starboard, fore and aft. The mooring lines were instrumented with dynamometers which measured line pull. Static thrust of 11,250 pounds at normal rated power was attained during these tests.

In a mild sea condition, the vessel was able to twist at a constant rate of 18 degrees per minute. The mean draft at the time was 20 feet, 6 inches, several feet less than the full-load draft. From the maximum swing rate in one direction to the maximum in the other, an elapsed period of three minutes was required. On another occasion at about the same draft, with 15-knot winds, 5-foot waves, and 6-foot swells, the vessel reported ability to twist to any given heading and maintain it within 1 degree of yaw. On the matter of helmsmanship, it is reported that no special training is required to use the device for heading-keeping to within 1 degree of yaw.

Operational experience is the only information available on the characteristics of the deep-water mooring system. These results indicated that the technique and system were unsatisfactory for the source ship. The physical arrangements for handling the mooring tackle and the inability of the anchor to hold to the ocean bottom were the principal problems.

Fig. 67 - After array guide, damaged while transiting in heavy seas

Since the dynamic ship-positioning system has not been installed at the time of this writing, no performance data or operational experience can be given. Obviously, in the absence of such data, the system appears to be outstanding. Limited experience quoted with other dynamic positioning systems indicates acceptable operational characteristics. In theory it should be good, but expensive.

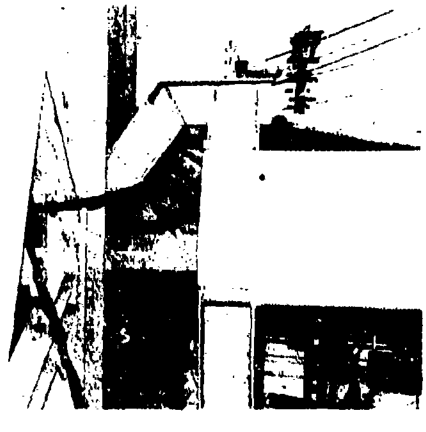

Fig. 68 - Forward array guide, undamaged

Modifications have been made to the system described in the preceding paragraphs. As a result of changes in research-experiment requirements, the transducer array for the acoustic source is not to be installed on the ocean bottom. Therefore, certain of the shipboard facilities and arrangement originally made to accommodate the requirement for fixed installation have been removed. These consist of the machinery foundation, pipe rack for the drilling rig, and the helicopter platform, all on the forward deck area. The gas turbine generator is to be removed from the ship, since the power required for the array can be supplied from the main steam turbine generator. This has resulted from the higher efficiency of the transducer element, i.e., over 50%, as opposed to the 25% originally estimated) and the reduced power-handling capability of the array resulting from the effects of interaction. The maximum power from the amplifiers for pulse operation will be restricted to approximately 2210 kW. However, this may be further reduced depending on power demands on the main steam turbine generator for stationkeeping and other electrical loads. If the elements in the array are replaced by the improved version, the source of the electrical power may not be adequate to meet the needs.

TECHNICAL CONSIDERATIONS FOR FUTURE SYSTEMS

The Artemis acoustic source development was intended, first, to provide the acoustic signal for the Artemis experimental program on propagation research and signal processing development and, second, to determine the problems associated with construction and operation of an acoustic source for active ocean-surveillance systems. This program has not included an exhaustive study of such extent and detail that generalized recommendations can be made of the engineering and construction problems of a source for any surveillance application. There are many factors which were not part of the Artemis program that influence the characteristics of the source. These, in turn, will play a major role in determining problems of engineering, construction and operation.

In the absence of such a broad study, rather than discuss only the technical facets of a source meeting the specification for the Artemis research program, technical consideration based on broad and general terms will be discussed for acoustic sources for future active surveillance systems. Factors that will influence the source design and will determine problem areas, along with a list of some of the problem areas, are summarized and discussed below.

The operating characteristics of other components in the system and operational requirements will influence engineering, design, and construction problems. These characteristics and requirements are:

1. Mobility, fixed or deployable,
2. Operating area and spatial stability,
3. Foreign or enemy countermeasures,
4. Depth, fixed or variable,
5. Directionality in the horizontal and vertical directions, beam direction and stability, steered or fixed, front-to-back ratio, and side-lobe suppression,
6. Signal characteristics, that is, frequency, bandwidth, modulation, pulse length, duty cycle,
7. Linearity of system components such as the transducer and transmitter,
8. Source level,
9. Use of source transducer in a receiving system,
10. Acceptable limitations due to weather and sea conditions,

11. Expected life,

12. Reliability, and

13. Time scale.

The above factors will influence the many technical problems, because they will determine or restrict the acceptable approaches. The principal areas where technical and management problems will be influenced are:

1. Selection of transducer type and array configuration,

2. Transducer transmitting and receiving sensitivity,

3. Problems of mechanical fatigue of transducer, pressure release, and nearby electrical and mechanical components,

4. Magnitude and limiting effect of transducer-element interaction between elements in the array and between elements and associated mechanical structure or ocean bottom,

5. Need for beam steering, mechanical or electrical,

6. Need for acoustic pressure release,

7. Need for pressure compensation of the transducer elements, pressure release, or associated electrical and mechanical components,

8. Use of a single high-power amplifier or modular construction of near correspondence in number of amplifiers and transducers,

9. Possible use of energy storage,

10. Characteristics of electrical cable,

11. Extent and type of corrosion protection,

12. Need to install a heavy structure on the ocean bottom or to handle and suspend it routinely in high sea states and wind forces,

13. Requirements for ship position and heading control,

14. Navigational needs,

15. Factors of safety to accommodate the environmental factors such as wind, sea state, ice, and temperature,

16. Extent of redundancy and/or overdesign to provide for long life and reliability,

17. Adequacy of test facilities,

18. Availability of contractor(s) with capable personnel for engineering, design and fabrication, and

19. Availability of time to complete an orderly engineering process of subjecting the component and system design to theoretical and model evaluation prior to building the finished system.

If a single item is to be selected from this list as representing the major problem area, it must be the availability of time to adequately engineer the system and components before fabrication is started. A well-planned research and development program beginning immediately on the operational and technical needs and problem areas can do much to minimize this time. After that, time will be obtained by spending more money and using more personnel in a hasty program. Unfortunately, the latter approach oftentimes results in compromises in quality.

It is difficult to select other items from the list as representing major problem areas. Such a list will change as the characteristics dictated by other system components and operational requirements change. However, a few generalizations can be made. If weight and size must be minimized, then, as frequencies go lower, the mechanical-fatigue problem will increase for a given source level. If a directional array is required for deep operation and a good front-to-back ratio is needed, pressure release will present a problem of increasing magnitude with decreasing frequency. Research on three-dimensional arrays may lead to a solution to this problem by eliminating the need for pressure release. On the other hand, this may present unacceptable compromises in response characteristics and may introduce interaction effects.

If the transducer array consists of an array of elements each a few tenths of a wavelength in size, mutual loading will predominate over self-loading. Until methods are developed to reduce the effects of loading variation on element behavior resulting from interaction, each transducer element must be overdesigned to prevent electrical and/or mechanical failure. Expressed from the standpoint of total array power, it appears that an overdesign of 6 to 8 dB is in order. This also recognizes that the average acoustic loading will probably be 0.8 rather than the 1.0 generally recognized for large arrays.

Care must be exercised to assure that the system is free of parasitic resonances in the transducer, adjacent mechanical structures, or the entire electromechanical system. The presence of these will, at minimum, introduce additional electrical or mechanical fatigue, lowering the allowable operating power if failure is to be prevented. The system and component response to modulated-wave signals must be evaluated from a point of view of both source reliability and coherent processing systems.

A discussion of potential problem areas would be incomplete without reference to the mechanical handling problems and the forces attributable to the action of waves and swells. There is very little experience in handling heavy and large structures from ships in the open ocean. However, every bit of this experience must be used by the designer if a reliable, safe system is to be engineered. Even with this information, acceptable designs must err on the side of overdesign.

The remaining technical areas where there are potential problems can be handled by good engineering practice. Shortcuts can be made or requirements incorrectly stated that can lead to operating deficiencies or low reliability. For example, amplifiers can be designed and rated for a unity power factor load, whereas the transducer load will represent a range in power factor depending on the type transducer, tuning, and frequency band of operation.

There are trade-offs that should be recognized and made in the source design. Equally important are trade-offs possible between the source and other components of an active ocean-surveillance system. Specification of system characteristics should recognize the total interrelated system problem and not be restricted to the propagation phenomena, the signal-processing needs, or operational requirements. Decisions based on one or more of these considerations can vastly complicate the technical problems in other areas. A consideration of needs from the viewpoint of the total system problem should recognize also the cost-effectiveness of various approaches. The relative cost of decibels obtained in each part of the system may be a deciding factor on component requirements.

REFERENCES

1. ONR, "Proposed Contract Program," Office of Naval Research Ad Hoc Group on High Power, Deep Underwater Sound Source Memo Report (Confidential Report) (Unpublished), Jul. 17, 1958
2. McClinton, A.T., and Cybulski, J., "Feasibility of a Remote Unattended High Power Acoustic Source," NRL Memorandum Report 1095 (Confidential Report, Unclassified Title), Aug. 1, 1960
3. Parrish, E.W., "Bendix Model DT-80 Transducer Element No. 3 and DT-80 Transducer Array No. 1," Navy Underwater Sound Reference Laboratory Calibration Report 1582 (Confidential Report), Aug. 27, 1959
4. Parrish, E.W., and Darner, C.L., "Calibration of Bendix Model DT-80 Transducer Array No. 1," Navy Underwater Sound Reference Laboratory Calibration Report 1652 (Confidential Report), Jul. 7, 1960
5. Barnes, E.A., Rayburn, E.M., "Calibration of Massa TR-11 Elements, Serials 6-14," Navy Underwater Sound Reference Laboratory Report 1641 (Confidential Report), Apr. 29, 1960
6. Liddiard, G., "Two High-Power Projectors for the Lower Audio Frequencies," U.S. Navy Journal of Underwater Acoustics (Confidential) 11:59-67 (1961)
7. Barton, A.M., "Project Artemis Fatigue Test of Pressure Release Tube," NRL Memorandum Report 1144 (Confidential Report, Unclassified Title), Jan. 11, 1961
8. Hunsicker, F.L., "Project Artemis High Power Acoustic Source, Fatigue Test of Pressure Release Tube Excited by Six Transducer Elements," NRL Memorandum Report 1211 (Confidential Report, Unclassified Title), Aug. 11, 1961
9. Nelligan, J.J., "Artemis Model Tests," David Taylor Model Basin Report C-1244 (Confidential Report), May 1961
10. Saunders, H.E., "Hydrodynamics in Ship Design," New York: Society of Naval Architects and Marine Engineers, 1957
11. Taggart, Robert, "Special Purpose Marine Propulsion Systems," American Society of Naval Engineers Journal 71:433-615 (1959)

12. McClinton, A.T., Ferris, R.H., et al., "Project Artemis High Power Acoustic Source," NRL Report 5599 (Confidential Report, Unclassified Title), Feb. 14, 1961

13. McClinton, A.T., "Project Artemis High Power Acoustic Source, Description of the Facility as Installed on the *USNS Mission Capistrano* (T-AG 162)," NRL Report 5599 Supplement, July 10, 1961

14. McClinton, A.T., "Project Artemis Acoustic Source, Description and Characteristics of the Facility as Installed on the *USNS Mission Capistrano* (T-AG 162)," NRL Memorandum Report 1299 (Confidential Report, Unclassified Title), Mar. 8, 1962

15. Bendix-Pacific, "Operation and Maintenance Instruction Manual for Project Artemis High Power Acoustic Source," (1961) consisting of the following: 8-760, "Project Artemis High Power Acoustic Source," Apr. 1961 (Confidential); 8-762, vol. 1, "Control Station Instrumentation and Sensor Sampling Instrumentation for Mobile Immersion Test," Apr. 1961 (Confidential); 8-762, vol 1, "Control Station Instrumentation System, Rev. Manual for Interim Mobile Immersion Test," 1961 (Confidential); 8-762, vol. 1, "Supplement, Appendices A Through Fa," 1961; 8-762, vol. II, "Position Determination System," Mar. 20, 1961; 8-762, vol. II, "Supplement, Position Determination System," Mar. 1961; 8-763, vol. I, "High Voltage Power Distribution System, Electrical Power and Distribution," Apr. 1961 (Confidential); 8-763, vol. II, "Amplifier Output Signal Distribution System, Electrical Power and Distribution," Apr. 1961 (Confidential); 8-763, vol. III, "Electrical Distribution System, 480 V AC, 3 Phase, 60 CPS," Apr. 1961 (Confidential); 8-763, vol. IV, "Interlock and Control System, Electrical Power and Distribution," Apr. 1961 (Confidential); 8-763, vol. V, "120 V DC Power," Apr. 1961; 8-763, "Supplement, Appendices 1-A Through 1-G, II-A Through II-L, III-A Through III-B and IV-A," 1961; 8-764, vol. I, "High Power Amplifier System," 1961 (Confidential); 8-764, vol. II, "High Power Amplifier System," 1961 (Confidential); 8-764, vol. III, "High Power Amplifier System," 1961 (Confidential); 8-764, "Supplement, Appendix A," 1961; 8-765, "Test Load Subsystem," Apr. 1961 (Confidential); 8-765, "Supplement, Appendix A," May 1961; 8-767, "Junction Box, Unit 2, and Component Tanks, Units 3-6," June 1961; 8-769, "Electric Cable System, Interim Mobile Immersion Test," May 1961 (Confidential) (Unclassified volume); 8-774, "Pressure Release System," Apr. 1961 (Confidential); 8-832, "Transducer Element Contactor Control System (Unit 41R)," June 1961 (Confidential)

16. Clark Bros., "Gas Turbine Driven Generator Instruction Manual, vol. I-V," 1960

17. NAVSHIPS, "Western Gear Electro-Hydraulic Array Winch, Le Tourneau," Instruction Manual 320-0840, May 1958

18. NAVSHIPS, "Western Gear Cargo Winch Model CWHE-100," Instruction Manual 320-0659, May 1958

19. Western Gear, "Electric Cable Winches for *USNS Mission Capistrano* (T-AG 162)," Instruction Manual, 1960

20. NRL, "Technical Manual for the Handling, Storage and Maintenance of the Array Structure Installed on the *USNS Mission Capistrano* (T-AG 162)," NRL Instruction Book 38, Apr. 12, 1963

21 Gregory, J.B., "Project Artemis, Installation of a Bow Thruster in the *USNS Mission Capistrano* (T-AG 162)," NRL Memorandum Report 1362, Oct. 2, 1962

22. Bird-Johnson, "Instruction Manual for KaMeWa Controllable Pitch Marine Propeller, 500 HP Bow Thruster," 1962

23. Clark Bros., "Final Report on Performance, Gas Turbine Driven Generator," Clark Bros. Report CE 2316, Jan. 1961

24. Lawson, W.M., Jr., "Project Artemis, Analysis of Transducer-Impedance Variations on the Amplifier Operation," NRL Memorandum Report 1066 (Confidential Report, Unclassified Title), Mar. 16, 1960

25. Lawson, W.M., Jr., "Project Artemis High Power Acoustic Source, Analysis of the Effect of Impedance on Amplifier Operation," NRL Memorandum Report 1131 (Confidential Report, Unclassified Title), Nov. 30, 1960

26. Ferris, R.H., "Project Artemis High Power Acoustic Source, Fourth Interim Report on Acoustic Performance," NRL Memorandum Report 1400 (Confidential Report, Unclassified Title), Mar. 12, 1963

27. Ferris, R.H., "Test of Project Artemis, Acoustic Source," NRL Memorandum Report 1648 (Confidential Report, Unclassified Title), Sept. 15, 1965

28. McClinton, A.T., "Project Artemis High Power Acoustic Source, Effect of Transducer Element Electrical Connection on Interaction in a Consolidated Array," NRL Memorandum Report 1323 (Confidential Report, Unclassified Title), June 4, 1962

29. McClinton, A.T., "Project Artemis Acoustic Source," NRL Memorandum Report 1458 (Confidential Report, Unclassified Title), Oct. 8, 1963

30. McClinton, A.T., and Ferris, R.H., "Project Artemis High Power Acoustic Source, Second Interim Report on Acoustic Performance," NRL Memorandum Report 1214 (Confidential Report, Unclassified Title), Sept. 19, 1961

31. McClinton, A.T., and Ferris, R.H., "Project Artemis High Power Acoustic Source, Third Interim Report on Acoustic Performance," NRL Memorandum Report 1273 (Confidential Report, Unclassified Title), Apr. 23, 1962

32. McClinton, A.T., Ferris, R.H., and Herrington, W.A., "Project Artemis High Power Acoustic Source, Interim Report on Acoustic Performance," NRL Memorandum Report 1205 (Confidential Report, Unclassified Title), Aug. 3, 1961

33. NEL, "TR-11C Array (6×6)," Navy Electronics Laboratory Transducer Calibration Data Report 1003 (Confidential Report), 1963

34. Ferris, R.H., and Baier, R.V., "Acoustic Interaction in Multielement Sonar Arrays," Office of Naval Research Proceedings, 7th Navy Science Symposium, ONR-16, vol. 2, May 1963

35. Baier, R.V., "Theoretical Interaction Computations for Transducer Arrays, Including the Effects of Several Different Types of Electrical Terminal Connections," NRL Report 6314 (Confidential Report, Unclassified Title), Oct 7, 1965

36. Ferris, R.H., and Hunsicker, F.L., "Power Limitations and Fidelity of Acoustic Sources," NRL Memorandum Report 1730 (Confidential Report, Unclassified Title), Nov. 1966

37. Ferris, R.H., and Rollins, C.R., "Final Report on Project Artemis Acoustic Source," NRL Report 6534 (Confidential Report, Unclassified Title), 1966

38. Ferris, R.H., "Project Artemis Acoustic Source, Characteristics of the Type TR-11F Transducer Element," NRL Memorandum Report 1498 (Confidential Report, Unclassified Title), Jan. 31, 1964

39. Beatty, L.G., "Tube-Facility Measurements, Massa TR-11F Transducers, Serials 3 and 4," Navy Underwater Sound Reference Laboratory Technical Memorandum 13-65 (Confidential), Oct. 8, 1965

40. Massa, "Performance Characteristics of Massa TR-11G Variable Reluctance Transducer," Massa Division Report ER6502, Feb. 10, 1965

Appendix A

CHRONOLOGICAL LOG OF SIGNIFICANT EVENTS RELATING TO PROJECT ARTEMIS ACOUSTIC SOURCE DEVELOPMENT AND TESTS

May 12, 1958	First meeting of ONR Advisory Group for High Power, Deep Underwater Sound Source (Office of Naval Research, Bureau of Ships, Naval Research Laboratory)
July 17, 1958	Report of ONR Advisory Group for High Power, Deep Underwater Sound Source
Sept. 9, 1958	NRL specification for high power sonar source
Nov. 11, 1958	Authority given to procure high power sonar source, research and development phases
Dec. 4, 1958	Hudson Laboratories, Columbia University, to establish contract with Bendix-Pacific Division, Bendix Aviation Corp., for
	Phase I - Model study, to be completed June 30, 1959
	Phase II - Design study, to be completed June 30, 1959
	Phase III - Fabrication, installation, and test
Mar. 27, 1959	NRL request to ONR for Lamont Geological Observatory contract for current survey data at 200 fathoms on Plantagenet Bank
May 21, 1959	Specification change in site of fixed installation for high power sonar source
June 4, 1959	Meeting on ship alteration and installation of project equipment, including various array support structure concepts (Naval Research Laboratory, Military Sea Transportation Service, Bureau of Ships, Bendix-Pacific)
Aug. 1959	Calibration of Bendix DT-80 10-kHz model of Artemis transducer at Navy Underwater Sound Reference Laboratory
Aug. 28, 1959	Massa transducer unit 1 received at NRL
Aug. 28, 1959	BuShips specification for T-2 tanker conversion
Sept. 9, 1959	David Taylor Model Basin study for NRL on ship motion, scroll heating, *R/V Lord Kelvin*, 110-ft sub-chaser, 1/10 scale (DTMB report C-1244 of May 1961)
Nov. 30, 1959	First tests of magnetostrictive resonant cavity transducer conducted from barge at Long Beach, California

Jan. 4, 1960	ONR request to NRL for study of feasibility of remote, unattended, high power nuclear source for Artemis (NRL Memorandum Report 1095 of Aug 1960)
Jan. 7, 1960	Avondale Marine Ways given contract for modification of *USNS Mission Capistrano*
Mar. 1960	Bendix completed redesign and construction of 10-kHz transducer, Phase I model, and shipped to the Navy Underwater Sound Reference Laboratory for tests
Mar. 1960	14 Massa transducer elements delivered
Apr. 11, 1960	DTMB model tests, installation of array (1/10 scale) (DTMB report C-1244, May 1961)
May 16, 1960	Pacific sea test of engineering model 2, transducer element, phase I
May 23, 1960	Pacific sea test of engineering model 2, transducer element, phase I
June 8, 1960	Meeting at ONR. Bendix scroll transducer development to be terminated, replaced by Massa subcontract from Hudson. Bendix to submit proposal for development of magnetostrictive transducer using rings from terminated work.
June 10, 1960	NRL specification for array module of 72 variable reluctance transducer element (revised June 30 and Aug. 19, 1960)
Sept. 10, 1960	First of Ling amplifiers shipped to New Orleans
Sept. 23, 1960	Load-matching transformer delivered to New Orleans
Oct. 3, 1960	ONR contract to Welex Electronics for field engineering personnel to man electronic equipment on *USNS Mission Capistrano*, Nonr 3326(00)
Oct. 14, 1960	Continental test load delivered to New Orleans
Oct. 26, 1960	*USNS Mission Capistrano* in drydock for completion of well, doors, and bottom doubler plates — Todd Shipyards, New Orleans
Oct. 29, 1960	Clark Bros. gas turbine generator delivered to New Orleans
Nov. 5, 1960	First set of Simplex mobile immersion cables received at Todd
Feb. 2, 1961	Array winch tests of dockside, Avondale. 436,000-lb river test completed.
Mar. 4, 1961	Array structure installation completed
Mar. 15, 1961	First two Massa modules shipped to New Orleans, installed at Todd, providing a λ wide by λ high array
Apr. 1, 1961	Gulf of Mexico tests to 1248-foot depth of array

Apr. 7, 1961	*USNS Mission Capistrano* transit from New Orleans to Norfolk, arrival April 12
Apr. 12, 1961	*USNS Mission Capistrano* arrives in Norfolk for corrections to project equipment
Apr. 25, 1961	Tests off Cape Charles City, Va., at 40-foot depth
Apr. 27, 1961	Tests in Atlantic, 300-foot depth at 36°N, 70°W, leaks in trunk and branch cables
Apr. 28, 1961	First General Electric junction box and component tanks shipped to Norfolk
May 1, 1961	*USNS Mission Capistrano* off Cape Charles City, tests to 85-foot depth
June 27, 1961- June 28, 1961	Acoustic tests of 144 element array in Chesapeake Bay without pressure release system (NRL Memo Report 1214 of Sept. 19, 1961)
Aug. 1961	Installation of four component tanks, junction box, and 13 modules; ventilation of gas turbine generator room; miscellaneous work on array handling equipment and installation of components on array structure. MSTS contract with Newport News Shipbuilding and Drydock. NRL specifications of May 15 and June 23, 1961. Source array 2.5 λ wide by 3 λ high.
Sept. 20, 1961- Oct. 16, 1961	Acoustic tests on 15-module array in Chesapeake Bay (NRL Memorandum Report 1273 of Apr. 23, 1962)
	Oct. 2, 1961 — operations in Exuma Sound, 27°35'N, 75°W, test to 400-foot depth
Mar. 29, 1962	Installation of bow thruster of Bethlehem Steel, Baltimore (NRL Memo Report 1362 of Oct. 2, 1962)
May 1962	Tests of electrical interconnection and mechanical consolidation for reducing interaction effects, Chesapeake Bay, *USS Hunting* (EAG 398), 144-element array of TR-11C and TR-11B elements (NRL Memo Report 1400 of Mar. 12, 1963)
July 1962	Tests on consolidated and unconsolidated 36-element arrays, U. S. Navy Electronics Laboratory Pen Oreille Calibration Station (NRL Memo Report 1400 of Mar. 12, 1963)
Nov. 3, 1962	Array removed from ship at Philadelphia Naval Shipyard to make ship available for other work. Component tanks 3 and 6 returned to General Electric.
Jan. 24, 1962	Tests of two designs of compliant tubes at NELPOCS, and transducer interaction experiments on 36-element array (NRL Memo Report 1458 of Oct. 8, 1963)
Mar. 21, 1963	Array installed at Philadelphia Naval Shipyard

Nov. 13, 1963- Nov. 26, 1963	NRL Transducer Calibration Platform tests of four TR-11F transducer elements (NRL Memo Report 1498 of Jan. 31, 1964)
Apr. 1964	Began installation of all remaining modules on array and transformer system to provide parallel connection of all transducer elements. Source array 2.5 λ wide by 4 λ high.
July 3, 1964	Tests of complete acoustic source in Northwest Providence Channel
July 9, 1964	NRL contract for two Massa type TR-11G transducer elements (TR-11C's with improved springs and relocated spring-inner mass assembly)

Appendix B

GENERAL SPECIFICATIONS FOR HIGH-POWER FIXED-INSTALLATION SONAR SOURCE (Nov. 6, 1958)

1. General

These specifications set forth the requirements for a high power acoustic source intended for use as a research tool in the Atlantic Ocean. The source is to be a complete system composed of transducer, transmitter, primary power source, interconnecting cable, controls, and mechanical assembly, which is an integral part of the transducer and required to fix it in place. Instrumentation is also to be installed to monitor the output of the source, Fig. B1. The installation site will be within 3 to 4 miles of shore, permitting shore installation of transmitter, primary power, controls, etc. Proven methods, techniques, and materials are desired in order to provide a reliable, long-life (minimum of 2 years) system, which can be installed by April, 1960. The general philosophy of employing more than adequate safety factors in the system design shall be followed throughout. These general requirements and detailed specifications, to follow, of the various components have been selected with the intent of minimizing the difficulties associated with design, fabrication, and installation, and to provide a highly reliable system that will serve as a research tool.

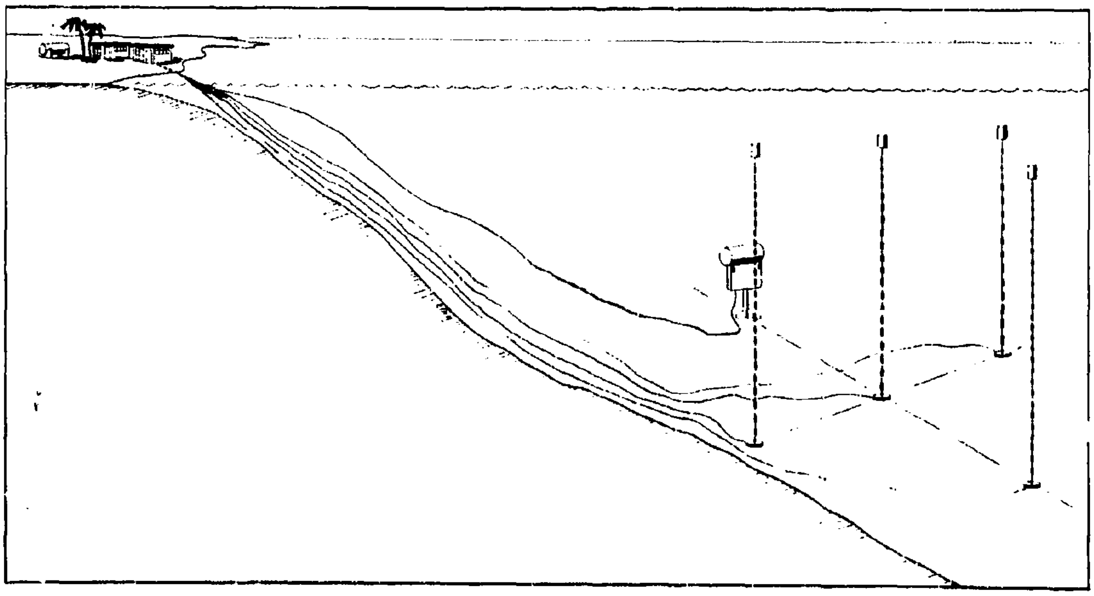

Fig. B-1 - High power sonar source -- general layout

2. Transducer

2.1 General Comment

2.1.1 Energy Conversion Method

The transducing device, which is submitted to meet the specifications listed below must be either a system which converts the energy associated with an electrical field into acoustic energy, or which converts the energy associated with a magnetic field into acoustic energy.

2.1.2 Life

The life expectancy of the transducer assembly shall be at least 2 years.

2.1.3 Reliability

The underwater parts of the transducer system shall be designed to insure high reliability for a 2-year period. High reliability is to be interpreted to mean: that no underwater part of the transducer assemblage will require repair, or that any part which, it is anticipated, will require repair can be replaced without moving the entire assembly from its bottomed site. If there are parts which, it is anticipated, will require repair, and which cannot be removed without removing the entire assembly, these parts shall be considered reliable on the basis of accepted life testing of models.

2.1.4 Recoverability

The design shall include such features as may be necessary to permit recovery of the transducer at the end of a two-year period.

2.2 Acoustic Properties

2.2.1 Frequency

The transducer shall have a mechanical resonant frequency in water of 400 Hz. If a multielement system is employed the permissible tolerance in the resonant frequency of individual elements shall be ±2.5%.

2.2.2 Mechanical Q

The maximum acceptable mechanical Q, in water, for the completely assembled transducer shall be 4.

2.2.3 Beam Pattern

a. The principal lobe of the vertical plane pattern shall be designed for 12.5 degrees between the minus 3-dB points.

b. The principal lobe of the horizontal plane pattern shall be designed for 20 degrees between the minus 3-dB points.

c. The directivity index shall be 21 dB. This value is based on the assumption of a uniform-velocity-surface rectangular radiator. This assumption does not preclude the use of nonuniform velocity surfaces, provided that the principal beam widths specified in items a and b are realized.

2.2.4 Power Output

The transducer shall be capable of radiating 1 MW of acoustic power at the resonant frequency.

2.2.5 Power Density

The acoustic power radiated shall not exceed 2 W per square centimeter of active radiating surface for a total output of 1 MW.

2.2.6 Source Level

The source level of the transducer shall be at least 152 dB relative to one microbar (dB//1 μbar).

2.2.7 Efficiency

The minimum acceptable value for the conversion efficiency shall be 25% at 400 Hz.

2.3 Electrical Properties

2.3.1 Transducer Tuning

If transducer tuning networks are employed, they shall either be accessible to permit tuning at specific frequencies, or be capable of presenting a load to the power transmitter over a bandwidth of 100 Hz, with a power factor not less than 90%.

2.3.2 Impedance

The load impedance shall be adjusted so that the maximum rms cable voltage shall not exceed 15 kV at any point on the cable when the transducer is radiating 1 MW of acoustic power. This impedance includes the effects of transducer impedance, transformers located with the transducer, and tuning networks located in the transducer.

2.3.3 Electrical Q

The electrical Q of the transducer shall be no greater than 4.

2.3.4 Polarization

If polarization of the transduction device is required, the transfer and application of polarization power shall be accomplished with a separate electrical cable to the transducer.

2.3.5 Pulse Length

The transducer shall be capable of radiating 1 MW of acoustic power for a period of 1 minute and 100 KW continuous.

2.3.6 Duty Cycle

The transducer shall be capable of radiating 1 MW pulses having a duration of 1 minute once in every 10 minutes and 100 kW continuously.

2.3.7 Beam Steering

Electrical or mechanical steering of the principal lobe in either the horizontal or vertical plane shall not be provided for this transducer.

2.4 Mechanical Assembly

2.4.1 Assembly

The transducer design shall make necessary allowances for either assembly of component parts of the transducer at the manufacturer's plant and transportation of the entire unit to a specified site, or for assembly of component parts at the site. In either case, a feasible plan for getting the transducer through the air-water interface shall be submitted, and this plan shall consider such problems as transportation of transducer from shore to site, assembly operations required at the site, and crane facilities for lifting operations.

2.4.2 Buoyancy

Buoyancy devices will probably be required to reduce the stress on the supporting cable at the time of installation. The design of these buoyancy devices and transducer assembly shall minimize the inertial and drag forces which may be encountered, as well as the static weight. Buoyancy devices shall not introduce unsymmetric distortion of the acoustic beam pattern of the transducer. Design of the system shall also provide for recovery.

2.4.3 Transducer Environment

The transducer must be fastened securely to a foundation which will provide one specific constant orientation of the transducer assembly. The foundation is to be secured to the ocean bottom where the bottom slope may be as great as 30 degrees and the water depth is 200 fathoms. The transducer assembly shall be 50 feet above the foundation surface and shall be tilted so that the acoustic beam axis is 5 degrees above the plane parallel to the ocean surface with the bearing fixed at the time of installation. Subsequent information of transducer and site characteristics may indicate that a smaller separation will be more desirable and a tilt of other than 5 degrees be selected in accordance with the site geometry, Fig. B2.

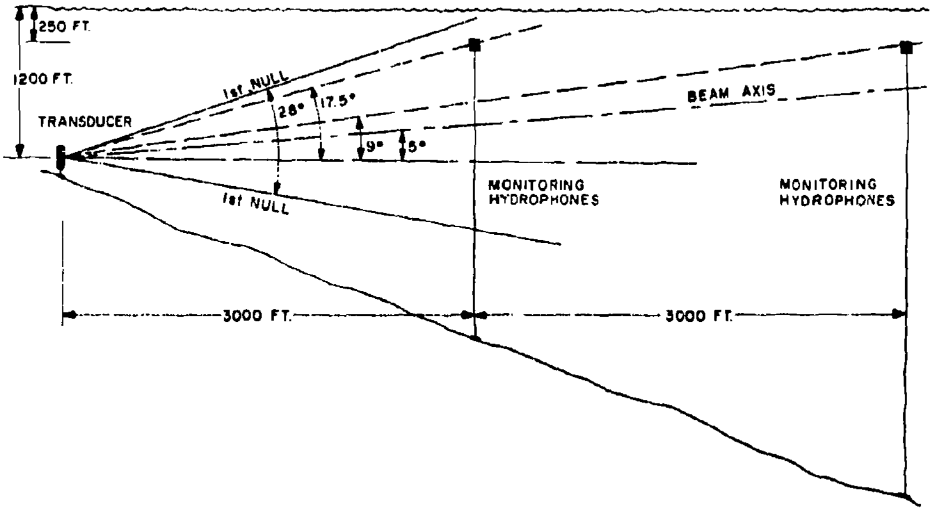

Fig. B-2 - Geometry of beam pattern

3. Power Cable

Separate conductors shall be provided for the ac power and polarizing power. These may be placed together to form one cable or separated as two cables. Concentric conductors are preferred for the polarizing current and the ac power. The following electrical and mechanical properties apply to both the ac power and polarizing power conductors and cable.

3.1 Electrical Properties

An armored submarine cable shall be used between the transducer and the transmitter, which is located on the shore. The cable shall be designed for an operating voltage of 15 kV rms between conductors and between conductors and sheath. The design of these cables shall take into consideration: (a) carrying the transducer power required for 1 MW into the water and polarizing currents, (b) dissipation of cable losses when in water, soil and air, (c) loading effects (static and dynamic) on the transmitter, and (d) minimizing earth currents and coupling with nearby signal cables. The water shall not be used as a return path in place of a conductor.

3.2 Mechanical Properties

The cable shall have adequate tensile strength to permit laying in 200 fathoms of water and to withstand the strain of the cable resting on a bottom having a slope as great as 30 degrees. Design of the cable and armor shall recognize abrasive action resulting from cable motion over the bottom from bottom currents, wave action, and sediment movement. Forces will be greatest near the shore, where the cable will cross coral bottom, and on the beach.

3.3 Entrance to Transducer Assembly

Any junction for electrical cables or junction boxes containing cable interconnections and other electrical components shall be designed to assure no leakage of salt water. These junctions shall be designed to withstand 1000 psi static test pressure. The position of the entrance of the cable into the transducer assembly shall be chosen to minimize mechanical forces which might cause motion of the transducer from the desired fixed position. This cable shall not be used as a method of anchoring the transducer in its fixed position.

4. Transmitter

4.1 Type

An electronic amplifier or amplifiers operated in parallel shall be used to supply power to the transducer and shall have adequate rating to produce 1 MW power in the water through the cable, supplied at 400 Hz. These amplifiers shall also be capable of supplying the same power to the cable and transducer in the frequency range between 350 and 450 Hz. If fixed tuning is used on the load the amplifier shall be rated to deliver this power for any variation of impedance that will occur in this frequency range. Consideration shall be given to impedance matching for the purpose of producing maximum efficiency and bandwidth for the system.

4.2 Characteristics

4.2.1 Frequency

The response shall be flat to within 0.1 dB for a single frequency input from 100 to 2000 Hz. For a noise input covering all frequencies in the band from 350 to 450 Hz the amplifier shall reproduce the spectrum of the input signal to within 1.5 dB within the frequency range from 350 to 450 Hz. These characteristics shall be measured with the test load of section 4.4.

4.2.2 Harmonic Distortion

The distortion shall be less than 5%.

4.2.3 Control Signal

Full output shall be achieved from 1 V rms input signal into a 600-ohm input impedance. The peak-to-rms ratio for the control signal shall be 1.414. Amplifier output shall be linear to within 10% for input signals from zero to 1 V for a matched resistive load.

4.2.4 Hum

Output ripple shall be at least 60 dB below rated output.

4.2.5 Input Power

Input power shall be three-phase, 60-Hz. The voltage shall be consistent with the power source of section 6.2.

4.2.6 Parallel Operation

If two or more amplifiers are operated in parallel to satisfy the power requirements, load unbalance of any amplifier from its share of the load shall not exceed 5% under static and dynamic conditions.

4.2.7 Cooling

The output stage shall be water-cooled with a suitable heat exchanger provided to permit use of salt water as a raw-water cooling medium. The amplifier cubicles shall be ventilated under pressure with a suitable fan and filtered air supply. Maximum ambient air temperature will be 35°C, and maximum salt water inlet temperature will be 30°C.

4.2.8 Metering

Instruments shall be provided on each amplifier, where easily visible from the front side of the amplifier cubicle, to indicate filament voltage and current, plate voltage and current, output volts, volt-amperes and watts, voltage of input power, and coolant temperature. Instrumentation shall also be provided to monitor the total output volt-amperes, volt-amperes reactive, watts, volts, waveform, and frequency.

4.2.9 Output Transformer

Several transformer impedance ratios shall be provided, as required, to permit operating any one amplifier or any combination of amplifiers in parallel to supply power to the transducer load. In each case, the amplifiers are to be operated at their rated power. If there are a number of amplifiers in the system, the same equal number of impedance ratios shall be provided and shall be obtained by means of suitable taps on the transformer, which shall be connected to the load bus through an adequate switching system.

4.3 Switching

Disconnect switches shall be provided for isolating each amplifier and the load from the central bus. Interlocks shall be provided to prevent operation of these switches while the amplifier is turned on.

4.4 Test Load

A water-cooled test load capable of absorbing the total combined output of the amplifiers for 10 seconds with a duty cycle of 20% shall be provided. The impedance of this load shall be the same as the transducer load seen from the input to the cable at 400 Hz and full power. A disconnect switch, interlocked with the transducer load, shall be provided for this load.

4.5 Central Control Panel

A central control panel shall be provided for remote control of all amplifiers. This center shall provide terminals for input control signal and instrumentation to monitor voltage of input power, total output volts, volt-amperes and watts, filament voltage, plate current, waveform, frequency, and coolant temperature of each amplifier. The latter three may be monitored with a suitable selector switch. Any controls and indicators required for safe operation of the equipment shall be supplied. If polarizing power is required, control and instrumentation for monitoring this shall be provided on the panel. Necessary interlocks required for safe operation shall be provided.

4.6 Protection

A protective circuit shall be supplied that will provide adequate protection to the amplifiers in the event of overload or short circuit.

5. Polarizing Requirements (applicable to transducers requiring polarization).

5.1 Isolation Networks

Necessary isolation networks between the polarizing circuit and amplifier circuit shall be supplied.

5.2 Polarizing Power

The power source shall be supplied by the contractor. This source shall operate off a 450-V, three-phase, 60-Hz supply. Input and output controls required for connecting the source into the system, as well as any monitoring and control equipment, are considered part of the power source.

6. Prime Power Source

Two sources of power shall be supplied for the system. These are as follows:

6.1 Low Power Source

A 450-V three-phase, 60-Hz source shall supply polarizing power, transmitter filament power, general instrumentation requirements, and all other power required for the facility except that provided by section 6.2.

6.2 High Power Source

A three-phase, 60-Hz source shall supply power to the rectifier for the transmitter plate supply. This source shall permit the transducer to deliver 1 MW power throughout the entire pulse, with the possible exception of the first few seconds of transient response of the prime mover governor and generator regulator. The speed of the prime mover should not decrease by more than 2% on application of full load and should recover to its steady state value in approximately 2 seconds. The generator voltage should not dip more than 12% on step application of full load and should recover to within 3% of its steady-state value within 1 second. Parallel operation of a multiple-generator source is not considered feasible for this application.

7. Source Monitoring Equipment

Instrumentation shall be provided which may be used to provide initial calibration of the source and later provide continuous monitoring of transmissions.

7.1 Calibration

Instrumentation shall be provided which will determine the in situ beam pattern and source level as a function of input power and frequency. The measurements shall be made at distances of approximately 1000 and 2000 yards. The orientation of the transducer, effective beam pattern, and its true bearing shall be determined by means of this instrumentation. A means shall be provided on the transducer to give remote indication of the orientation of the transducer in bearing and elevation.

7.2 Continuous Monitoring

Instrumentation shall be provided which can continuously monitor the source output to determine changes in the original calibration resulting from changes in transducer properties, short range propagation characteristics, or transducer orientation. This instrumentation shall also determine the absolute output of each transmission. Provisions shall be made to measure variations in relative orientation of source measuring equipment and source. This instrumentation shall be the same, or a part thereof, of that used for calibration.

8. Installation

Complete installation of the system, which will make it ready for experimental use, is required.

8.1 Foundation for Transducers

A foundation for the high power source transducer shall be constructed and installed. This foundation shall be firmly fixed to the bottom to prevent motion due to sediment movement over the expected 2-year life of the installation. The transducer assembly shall be fixed to the foundation in a manner to prevent motion of the assembly caused by ocean currents and sediment movement. (It is desired that the bearing movement of the center line of the transducer beam be restricted to less than 1 degree on both a short-time and long-time basis.)

8.2 Source

The transducer shall be transported to the site, assembled at the site, if required, and placed on the foundation (8.1). Installation shall consist of lowering it in place and fixing it to the foundation. The transducer expected beam axis shall be oriented to within ±2.5 degrees of the specified orientation.

8.3 Monitoring Equipment

The monitoring hydrophones and associated high frequency sources shall be installed to within an accuracy that permits the desired monitoring of paragraph 7.2.

8.4 Cables

The high voltage submarine cable from the transducer and the cable to each transducer and hydrophone in the monitoring system shall be laid on the bottom to the transmitter house on the beach. The routing of the power cable shall avoid existing cable installations as well as small signal cables to the high frequency source and hydrophone to prevent electrical interference with these circuits. If cooling of the power cable is not adequate in air, this cable shall be laid underground between beach and transmitter house.

8.5 Equipment and Personnel Housing

Complete, operational, and functional criteria for shore site including access to roads, building for housing equipment and personnel, and fuel storage shall be prepared. Liaison shall also be provided with the Bureau of Yards and Docks and the A. & E. Contractor, who will be responsible for these facilities. Airconditioning of laboratory space shall be specified to provide for equipment reliability. Installation of the shore-based equipment in the housing shall be the responsibility of the prime contractor for the high power sonar source.

9. System Tests

The contractor shall provide technical services during the testing of the system to perform the initial operation, aid in obtaining calibration data, and other services as necessary.

Appendix C

GENERAL SPECIFICATIONS FOR HIGH-POWER FIXED-INSTALLATION SONAR SOURCE (Original Nov. 6, 1958; Revised Nov. 19, 1959)

1. General

These specifications set forth the requirements for a high power acoustic source intended for use as a research tool in the Atlantic Ocean. The source is to be a complete system composed of transducer, transmitter, primary power source, interconnecting cable, controls, and mechanical assembly, which is an integral part of the transducer, required to fix it in place. Instrumentation is also to be installed to assist in monitoring the output of the source, Fig. C1. The installation site will be approximately 25 miles from shore, necessitating the use of a ship housing the transmitter, primary power, controls, etc., which will be moored in deep water within 2 nautical miles of the transducer array. The latter is to be mounted on the ocean bottom, in 200 fathoms depth. Proven methods, techniques, and materials are desired in order to provide a reliable, long-life (minimum of 2 years) system, which can be installed by July 1960. The general philosophy of employing more than adequate safety factors in the system design shall be followed throughout. These general requirements, and detailed specifications to follow, of the various components have been selected with the intent of minimizing the difficulties associated with design, fabrication, and installation and to provide a highly reliable system that will serve as a research tool.

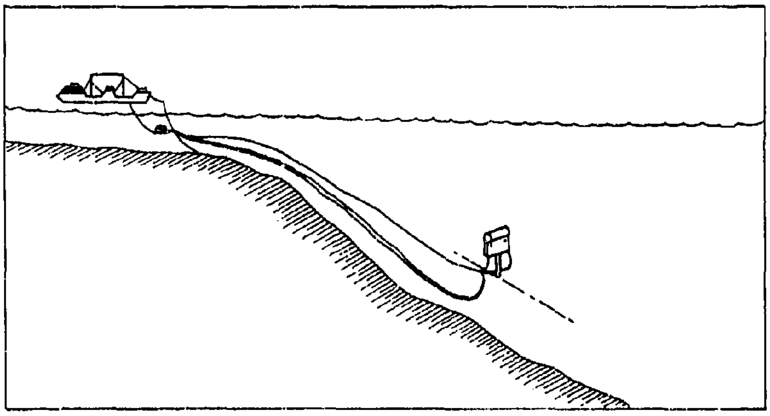

Fig. C-1 - Site geometry

2. Transducer

2.1 General Comment

2.1.1 Energy Conversion Method

The transducing device, which is submitted to meet the specifications listed below, must be either a system which converts the energy associated with an electrical field into acoustic energy, or which converts the energy associated with a magnetic field into acoustic energy.

2.1.2 Life

The life expectancy of the transducer assembly shall be at least 2 years.

2.1.3 Reliability

The underwater parts of the transducer system shall be designed to insure high reliability for a 2-year period. High reliability is to be interpreted to mean: that no underwater part of the transducer assemblage will require repair, or that any part which it is anticipated will require repair can be replaced without moving the entire assembly from its bottomed site. If there are parts which it is anticipated will require repair and which cannot be removed without removing the entire assembly, these parts shall be considered reliable on the basis of accepted life testing of models.

2.1.4 Recoverability

The design shall include features as may be necessary to permit recovery of the transducer at the end of a 2-year period.

2.2 Acoustic Properties

2.2.1 Frequency

The transducer shall have a mechanical resonant frequency in water of 400 Hz. If a multielement system is employed the permissible tolerance in the resonant frequency of individual elements shall be ±2.5%.

2.2.2 Mechanical Q

The maximum acceptable mechanical Q in water for the completely assembled transducer shall be 4.

2.2.3 Beam Pattern

a. The principal lobe of the vertical plane pattern shall be designed for 12.5 degrees between the minus 3 dB points.

b. The principal lobe of the horizontal plane pattern shall be designed for 20 degrees between the minus 3 dB points.

c. The directivity index shall be 21 dB. This value is based on the assumption of a uniform-velocity-surface rectangular radiator. This assumption does not preclude the use of nonuniform velocity surface provided that the principal beamwidths specified in 2.2.3a and 2.2.3b are realized.

2.2.4 Power Output

The transducer shall be capable of radiating 1 MW of acoustic power at the resonant frequency.

2.2.5 Power Density

The acoustic power radiated shall not exceed 2 W per square centimeter of active radiating surface for a total output of 1 MW.

2.2.6 Source Level

The source level of the transducer shall be at least 152 dB relative to one microbar at one meter (dB//1 μbar at 1 m).

2.2.7 Efficiency

The minimum acceptable value for the conversion efficiency shall be 25% at 400 Hz.

2.3 Electrical Properties

2.3.1 Transducer Tuning

If transducer tuning networks are employed, they shall either: (a) be accessible to permit tuning at specific frequencies, or (b) be capable of presenting a load to the power transmitter over a bandwidth of 100 Hz, with a power factor not less than 90%.

2.3.2 Impedance

The load impedance shall be adjusted so that the maximum rms cable voltage shall not exceed 15 kV at any point on the cable when the transducer is radiating 1 MW of acoustic power. This impedance includes the effects of transducer impedance, transformers located with the transducer, and tuning networks located in the transducer.

2.3.3 Electrical Q

The electrical Q of the transducer shall be no greater than 4.

2.3.4 Polarization

If polarization of the transduction device is required, the transfer and application of polarization power shall be accomplished with a separate electrical cable to the transducer.

2.3.5 Pulse Length

The transducer shall be capable of radiating 1 MW acoustic power for a maximum pulse length of 1 minute, and 100 kW continuously. The system shall be capable of radiating 1 MW acoustic power at pulse lengths between a minimum of 10 milliseconds to the maximum of 1 minute.

2.3.6 Duty Cycle

The transducer shall be capable of radiating 1 MW pulses having a duration ranging from 10 milliseconds to 1 minute at a maximum duty cycle of 10%. The system shall be capable of radiating the same pulse lengths on duty cycles from essentially zero to 10%.

2.3.7 Beam Steering

Electrical or mechanical steering of the principal lobe in either the horizontal or vertical plane shall not be provided for this transducer.

2.4 Mechanical Assembly

2.4.1 Assembly

The transducer design shall make necessary allowances for either assembly of component parts of the transducer at the manufacturer's plant and transportation of the entire unit to a specified site, or for assembly of component parts at the site. In either case, a feasible plan for getting the transducer through the air-water interface shall be submitted and this plan shall consider such problems as transportation of the transducer from shore to site, any assembly operations required at the site, crane facilities for lifting operations, etc.

2.4.2 Buoyancy

Buoyancy devices will probably be required to reduce the stress on the supporting cable at the time of installation. The design of these buoyancy devices and transducer assembly shall minimize the inertial and drag forces which may be encountered, as well as the static weight. Buoyancy devices shall not introduce unsymmetric distortion of the acoustic beam pattern of the transducer. Design of the system shall also provide for recovery.

2.4.3 Transducer Environment

The transducer must be fastened securely to a foundation which will provide one specific constant orientation of the transducer assembly. The foundation is to be secured to the ocean bottom where the bottom slope may be as great as 30 degrees and the water depth shall be 200 fathoms. The lowest active radiating surface of the transducer assembly shall be 50 feet above the ocean bottom, and the transducer array shall be tilted so that the acoustic beam axis is 11 degrees above the plane parallel to the ocean surface, with the bearing fixed at the time of installation. Subsequent information concerning the transducer and site characteristics may indicate that a smaller separation will be more desirable and a tilt of other than 11 degrees be selected in accordance with the site geometry, Fig. C2.

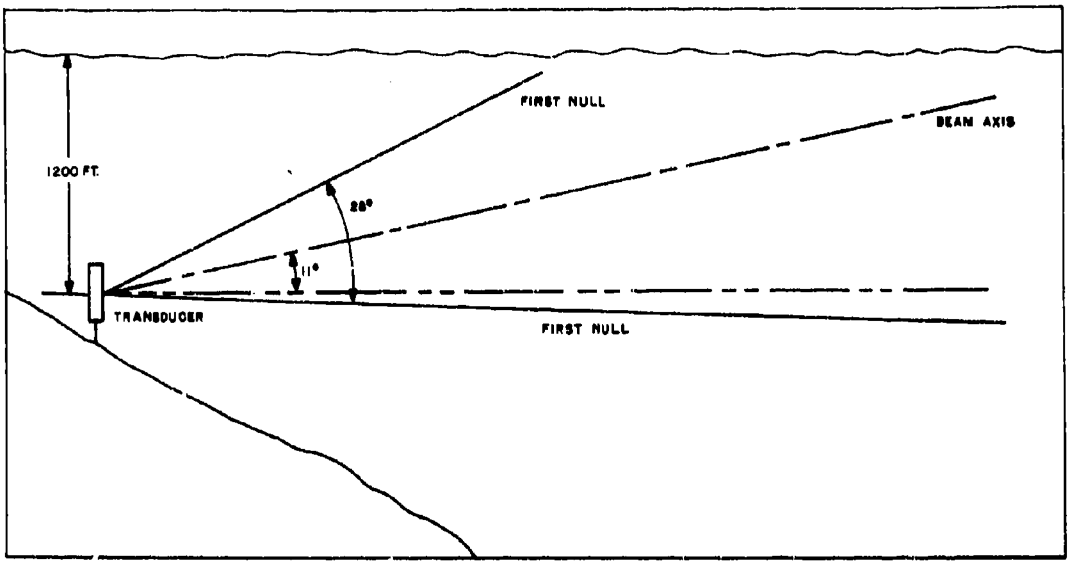

Fig. C-2 - Beam pattern geometry

3. Electrical Cables

Separate conductors shall be provided for the 400 Hz power, the polarizing power, and the instrumentation circuits. The conductors for the 400 Hz power and polarizing power may be placed together to form one cable or separate as two cables. Concentric conductors are preferred for the polarizing power and the 400 Hz power. The following electrical and mechanical properties apply to both the 400 Hz power and/or polarizing power conductors and cable.

3.1 Electrical Properties

Armored submarine cables shall be used between the transducer and the transmitter. The 400 Hz power cable shall be designed for an operating voltage of approximately 15 kV rms between conductors, and between conductors and sheath. However, if concentric conductors are used, the outer conductor shall be insulated for a minimum of 1000 V rms to sheath. These cables shall take into consideration: (a) carrying the transducer power required for 1 MW acoustic power into the water and the polarizing currents, (b) dissipation of cable losses when in water, soil, and air, (c) electrical loading effects (static and dynamic) on the transmitter, and (d) minimizing earth currents and coupling with nearby signal cables; the water shall not be used as a return path in place of a conductor.

3.2 Mechanical Properties

The cable or cables shall have adequate tensile strength to permit laying in 200 fathoms of water and to withstand the strain of the cable's resting on a bottom having a slope as great as 30 degrees. Design of the cable and armor shall recognize abrasive action resulting from cable motion over the bottom from bottom currents, wave action, and sediment movement. Forces will be greatest where the cable leaves the bottom and also where it passes onto the ship. A system shall be designed which will minimize abrasion and fatigue due to these forces. A replaceable length of cable shall be used between the sea cable termination and the ship.

3.3 Entrance to Transducer Assembly

Any junction for electrical cables or junction boxes containing cable interconnections and other electrical components shall be designed to assure no leakage of salt water. These junctions shall be designed to withstand 1000 psi static test pressure. The position of the entrance of the cable into the transducer assembly shall be chosen to minimize mechanical forces which might cause motion of the transducer from the desired fixed position or damage to the cable. This cable shall not be used as a method of anchoring the transducer in its fixed position.

4. Transmitter

4.1 Type

An electronic amplifier or amplifiers operated in parallel shall be used to supply power to the transducer and shall have an adequate rating to produce 1 MW power in the water through the cable, supplied at 400 Hz. These amplifiers shall also be capable of supplying the same power to the cable and transducer in the frequency range between 350 and 450 Hz. If fixed tuning is used on the load, the amplifier shall be rated to deliver this power for any variation of impedance that will occur in this frequency range. Consideration shall be given to impedance matching for the purpose of producing maximum efficiency and bandwidth for the system.

4.2 Characteristics

4.2.1 Frequency and Phase

The response at rated power output shall be flat to within 0.1 dB for a single frequency input from 350 to 450 Hz and shall be within 1.5 dB of the 400-Hz response from 90 to 350 Hz and from 450 to 1800 Hz. These characteristics shall be measured with the specified load. If the phase shift is not constant for all frequencies from 350 to 450 Hz, it shall be a linear function of frequency within 1/2 radian over the frequency range.

4.2.2 Harmonic Distortion

The distortion shall be less than 5%.

4.2.3 Control Signal

Full output shall be achieved from 1 V rms input signal into a 600-ohm input impedance. This input signal will be supplied to the amplifier through a bandpass filter, the frequency band of which will be 350 to 450 Hz. The peak-to-rms ratio for the control signal shall be 1.414. Amplifier output voltage shall be linear to within 10% for input signals from zero to 1 V for a matched resistive load.

4.2.4 Hum

Output ripple shall be at least 60 dB below rated output.

4.2.5 Input Power

Input power shall be three-phase, 60-Hz. The voltage shall be consistent with the power source of section 6.2.

4.2.6 Parallel Operation

If two or more amplifiers are operated in parallel to satisfy the power requirements, load unbalance of any amplifier from its share of the load shall not exceed 5% under static and dynamic conditions.

4.2.7 Cooling

The output stage shall be water-cooled with a suitable heat exchanger provided to permit use of salt water as a raw water-cooling medium. The amplifier cubicles shall be ventilated with suitable fan and filtered air supply to prevent accumulation of dust and dirt in the cubicles. Maximum ambient air temperature will be 35°C, and maximum salt water inlet temperature will be 30°C.

4.2.8 Metering

Instruments shall be provided on each amplifier, where easily visible from the front side of the amplifier cubicle, to indicate filament voltage and current, plate voltage and current, output volts, volt-amperes and watts, voltage of input power, and coolant temperature. Instrumentation shall also be provided to monitor the total output volt-amperes, volt-amperes reactive, watts, volts, waveform, and frequency.

4.2.9 Output Transformer

Several transformer impedance ratios shall be provided, as required, to permit operating any one amplifier or any combination of amplifiers in parallel to supply power to the transducer load. In each case, the amplifiers are to be operated at their rated power. If there are a number of amplifiers in the system, the same number of impedance ratios shall be provided and shall be obtained by means of suitable taps on the transformer, which shall be connected to the load bus through an adequate switching system.

4.3 Switching

Disconnect switches shall be provided for isolating each amplifier and the load from the central bus. Interlocks shall be provided to prevent operation of these switches while the amplifier is turned on.

4.4 Test Load

A water-cooled test load, capable of absorbing the total combined output of the amplifiers for 10 seconds with a duty cycle of 20% shall be provided. The impedance of this load shall be the same as the transducer load seen from the input to the cable at 400 Hz and full power. A disconnect switch interlocked with the transducer load shall be provided for this load.

4.5 Central Control Panel

A central control panel shall be provided for remote control of all amplifiers. This center shall provide terminals for input control signal and instrumentation to monitor, for each amplifier, voltage of input power, total output volts, volt-amperes, watts, filament voltage, plate current, waveform, frequency, and coolant temperature. The latter three may be monitored with a suitable selector switch. Any controls and indicators required for safe operation of the equipment shall be supplied. If polarizing power is required, control and instrumentation for monitoring this shall be provided on the panel. Necessary interlocks required for safe operation shall be provided.

4.6 Protection

A protective circuit shall be supplied that will provide adequate protection to the amplifiers in the event of overload or short circuit.

5. Polarizing Requirements (Applicable to transducers requiring polarization)

5.1 Isolation Networks

Necessary isolation networks between the polarizing circuit and amplifier circuit shall be supplied.

5.2 Polarizing Power

The power source shall be supplied by the subcontractor. This source shall operate off a 3500-V, 3-phase, 60-Hz ship supply. Input and output controls required for connecting the source into the system, as well as any monitoring and control equipment, are considered part of the power source. The rectifier for this source may be located at the ship or at the transducer, as determined from system analysis.

6. Prime Power Source

Three sources of power shall be supplied for the system.

6.1 Low Power Source

A 3500-V, 3-phase, 60-Hz source shall supply polarizing power, transmitter filament power, general instrumentation requirements, and all other power required for the facility except that provided by section 6.2. This source will be government-furnished equipment, will have the capacity necessary for the requirements, and will have voltage regulation normally available for this type and size of Navy equipment. Two 400-kW, 440-V, 3-phase auxiliary generators will also be available to supply power to part of the above loads.

6.2 High Power Source

A 3-phase, 60-Hz source shall be provided to supply power to the rectifier for the transmitter plate supply. This source shall permit the transducer to deliver 1 MW power throughout the entire pulse, with the possible exception of the first few seconds of transient response of the prime mover, governor, and generator regulator. The speed of the prime mover should not decrease by more than 2% on application of full load and should recover to its steady-state value in approximately 2 seconds. The generator voltage should not dip more than 12% on step application of full load and should recover to within 3% of its steady-state value within 1 second. Parallel operation of a multiple generator source is not considered feasible for this application.

6.3 Emergency Power Source

A 440-V, 3-phase, 60-Hz, 100-kW diesel-driven alternator complete with exciter, voltage regulator, and governor (or a suitable 120-V storage battery) will be supplied for emergency use. This equipment will be government furnished in accordance with requirements supplied by the subcontractor.

7. Source Monitoring Equipment

Instrumentation shall be provided which may be used to provide initial calibration of the source and later provide continuous monitoring of transmissions as defined in sections 7.1 and 7.2.

7.1 Calibration

Instrumentation shall be provided which will enable determination of the in situ beam pattern and source level as a function of input power and frequency. This instrumentation shall permit making these measurements at distances of approximately 1000 and 2000 feet. Orientation of transducer, effective beam pattern, and its true bearing shall be determined by means of this instrumentation. It shall be provided on the transducer to give remote indication of the orientation of the transducer in bearing and elevation and to permit accurate location of hydrophones in the space around the 400-Hz array. Orientation of the transducer in bearing and elevation (tilt) shall be determined at the time of installation. The monitoring hydrophone and recording instrumentation is not included as a requirement of this specification. However, the remote indicating system for determining location of this hydrophone shall be compatible with available hydrophones.

7.2 Continuous Monitoring

The minimum of instrumentation shall be provided at the transducer array for determining the performance of the transducer elements where these properties cannot be monitored adequately at the transmitter. This instrumentation shall consist of ac and dc polarizing-current measurements of each element of the transducer on the array structure.

8. Installation

Complete installation of the system, which will make it ready for experimental use, shall be provided. Government-furnished equipment and services for the installation (if required) will be as follows: (a) Two ships' worth of anchor Missouri class windlasses with modified wildcats to handle 2-1/2 inch die lock chain, (b) 95 shots of 2-1/2 inch die lock chain, (c) 27 shots of 1-1/4 inch die lock chain, (d) A detailed ocean bottom survey at the installation site, (e) Suitable moors for anchoring the installation vehicle above the site of transducer installation in position for supplying power to the transducer, and (f) Weather information from the staging area, on the East Coast or Gulf ports, to the installation site during the period of installation.

8.1 Foundation for Transducers

A foundation for the high power source transducer shall be designed, constructed, and installed. This foundation shall be firmly fixed to the bottom to prevent motion due to sediment movement over the expected 2-year life of the installation. The transducer assembly shall be fixed to the foundation in a manner preventing motion of the assembly caused by ocean currents and sediment movement. (It is desired that the bearing movement of the center line of the transducer beam be restricted to less than 1% on both a short-time and long-time basis.)

8.2 Transducer Array

The transducer shall be transported to the site, assembled if required, and placed on the foundation (8.1). Installation shall consist of lowering it in place and fixing it to the foundation. The transducer expected beam axis shall be oriented to within ± 1 degree in the vertical plane and ±5 degrees in the horizontal plane.

8.3 Cables

The high-voltage submarine cables from the transducer, as well as any instrumentation cable, shall be laid on the bottom to a point where the ship is moored. The routing of the power cables shall avoid existing cable installations and small signal cables to prevent electrical interference with these circuits. Cable terminations at the ship shall be designed to minimize failure from fatigue and abrasion resulting from the continuous cable movement, and shall be adapted to reasonable, convenient repair.

8.4 Shipboard Installation

A ship will be provided by the government which will be suitable for housing the primary source of power, transmitter, switchgear, controls, and cable terminal, as well as other components, and which will also be suitable to serve as a platform from which the array structure and its foundation can be lowered in place. The subcontractor shall provide complete specifications: drawings showing size, weight, and location of mechanical support, plumbing and electrical connections, technical data, performance characteristics, and such other information as may be required of each subcontractor-supplied component, instrument, or device which is part of this contract, in order that the government can select a suitable ship for the above purpose. Functional criteria, operational requirements, and technical limitations, as well as other pertinent information required in selecting a ship suitable for the platform from which the array structure can be lowered in place, shall also be provided. This information shall be made available throughout the subcontractor's planning stages and in the final engineering stage of the subcontractor's work, in an expeditious manner as requested by the government. The government will make a feasibility study of the shipboard installation, prepare contract plans for shipboard arrangement, prepare structural modification plans, conduct stability analysis, prepare detailed specifications for the ship alteration, and contract for and supervise the ship alteration and installation of the subcontractor-furnished equipment.

Installation and interconnection on the ship of the system components supplied by the subcontractor will be made in accordance with technical requirements (mechanical, electrical, hydraulic and pneumatic) which the subcontractor shall supply and in accordance with the government's general arrangement plans. The subcontractor shall provide technical assistance to the government, as requested, during installation and test of subcontractor-furnished equipment. Tests will be performed in accordance with subcontractor-furnished plans. The shipbuilder, under contract to the government for ship alteration and equipment installation, shall be responsible for conducting tests on all subcontractor-furnished equipment to demonstrate proof of installation. The subcontractor shall be responsible for the performance of the components and system meeting the requirements of this specification for a high power acoustic source. The subcontractor shall be responsible for conducting tests on all subcontractor-furnished equipment both as separate components and as a complete system, demonstrating proof of performance. All tests and test procedures to be employed by the subcontractor shall be submitted for review and approval prior to conducting the tests proposed. Government vessels, equipment, and personnel will be furnished as required during all tests. System components, as used herein, are defined to mean all major and minor subsystems, devices, instrumentation, array structure, array structure handling gear, cable support, and other assemblies which (a) are part of the acoustic source or are related to the acoustic source and supplied by the subcontractor or the government for installation on the ship, and (b) are required for the installation, operation, and maintenance of the acoustic source. Installation equipment to be provided by the subcontractor installing the array structure on the ocean bottom, subsequently not required for any recovery, is to be removed by the subcontractor upon completion of the installation. This installation equipment is not included as part of the acoustic source. Suitable equipment for mooring the ship during transducer array and foundation installation and for mooring the ship in position for supplying power to the transducer array will be designed, supplied, and installed by the government.

9. Operational Procedure

The subcontractor shall provide complete operational plans and procedures for the installation of the transducer-array-structure foundation and cable in place on the bottom. The first draft shall be available six months before the estimated installation date and the final draft three months before this date. This operational plan shall show facilities and personnel, the sequence of events during installation, time to complete each phase maximum weather conditions (sea state and wind force), point in the installation where commitment to proceed is important, procedures for securing operation during installation due to weather, tests during installation period, and any other information as may be required to assure an adequate and complete program of installation. Liaison with the government shall be provided by the subcontractor as required.

10. Technical Data

The subcontractor shall provide specifications, drawings, operating instructions, test data, test procedures, and such other information as may be required for the installation, testing, operation, maintenance, and upkeep of all subcontractor-furnished machinery and equipment.

11. Spare Parts

In addition, the subcontractor shall provide a listing of recommended spare parts considered necessary for the operation and maintenance of subcontractor-furnished equipment for 2 years.

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PROJECT ARTEMIS ACOUSTIC SOURCE SUMMARY REPORT

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
An interim report on the problem; work is continuing.

5. AUTHOR(S) *(First name, middle initial, last name)*

A. T. McClinton

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13. ABSTRACT [Confidential]

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Interaction between transducer elements in the multielement array was a major problem in the system development. Although the effect of interaction was reduced, it was not completely overcome. The principal effect of the interaction was to cause excessive fatigue in transducer elements, necessitating reduction of input power to prevent transducer failure. A modified version of the element was developed which can withstand the larger displacement associated with interaction. If this element were used in the array, it is anticipated that a source level of approximately 153 dB could be obtained. This assumes that the pressure-release system required to

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	ROLE	WT	ROLE	WT	ROLE	WT
Acoustic baffles						
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Beam pattern						
Beam steering						
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Deep-ocean anchoring						
Directivity index						
Directivity pattern						
Electromagnetic transducer						
Magnetostrictive transducer						
Segmented-ring transducer						
Element displacement						
Frequency-sensitive band						
Gain						
Heading-control devices						
Impedance characteristics						
Linearity						
Mechanical resonant frequency						
Planar array						
Position keeping						
Radiation pattern						
Spring deflections						
Transfer function						
Velocity anomaly						
Ocean surveillance						

suppress the back radiation of the array could be modified to withstand the higher acoustic intensity.

The Artemis acoustic source development was intended, first, to provide the acoustic signals for the Artemis experimental program on propagation research and signal processing development and, second, to determine the problems associated with construction and operation of an acoustic source for active undersea surveillance systems. Although an exhaustive research and development program on the acoustic sources for this kind of application was not undertaken, general recommendations concerning engineering and construction problems were obtained as a result of this program.

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2. Acoustic systems — Calibration
3. Acoustic systems — Test results

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The Artemis acoustic source development was intended, first, to provide the acoustic signals for the Artemis experimental program on propagation research and signal processing development and, second, to determine the problems associated with construction and operation of an acoustic source for active undersea surveillance systems. Although an exhaustive research and development program on the acoustic sources for this kind of application was not undertaken, general recommendations concerning engineering and construction problems were obtained as a result of this program. [Confidential Abstract]

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UNITED STATES GOVERNMENT

Memorandum

7100-016

DATE: 22 January 2004

REPLY TO ATTN OF: Burton G. Hurdle (Code 7103)

SUBJECT: REVIEW OF REF (A) FOR DECLASSIFICATION

TO: Code 1221.1

REF:
(a) "Project ARTEMIS High Power Acoustic Source", A.T. McClinton, R.H. Ferris, W.A. Herrington, Sound Div., NRL Memo Report 1205, 3 Aug 1961 (U)
(b) "Project ARTEMIS High Power Acoustic Source Second Interim Report on Acoustic Performance", A.T. McClinton and R.H. Ferris, Sound Division, NRL Memo Report 1214, 19 September 1961 (U)
(c) "Project ARTEMIS High Power Acoustic Source Third Interim Report on Acoustic Performance", A.T. McClinton, R.H. Ferris, Sound Division, NRL Memo Report 1273, 23 April 1962 (U)
(d) "Project ARETMIS High Power Acoustic Source Effect of Transducer Element Electrical Connection on Interaction in a Consolidated Array", A.T. McClinton, Sound Division, NRL Memo Report 1323, 4 June 1962 (U)
(e) "Test of Project ARTEMIS Source", R.H. Ferris, Sound Division, NRL Memo Report 1648, 15 September 1965 (U)
(f) "Power Limitations and Fidelity of Acoustic Sources", R.H. Ferris and F.L. Hunsicker, Sound Division, NRL Memo Report 1730, November 1966 (U)
(g) "Project ARTEMIS Acoustic Source Acoustic Test Procedure", R.H. Ferris and C.R. Rollins, Sound Division, NRL Memo Report 1769, 5 June 1967 (U)
(h) "Calibration of the ARTEIS Source and Receiving Array on the Mission Capistrano", M. Flato, Acoustics Div., NRL Memo Report 2712, Dec 1973 (U)
(i) "Theoretical Interaction Computations for Transducer Arrays, Including the Effects of Several Different Types of Electrical Terminal Connections", R.V. Baier, Sound Division, NRL Report 6314, 7 October 1965 (U)
(j) "Project ARTEMIS Acoustic Source Summary Report", NRL Report 6535, September 1967 (U)

1. References (a) thru (j) are a series of reports on Project ARTEMIS Reports by the Sound Division that have previously been declassified.

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

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

Burton G. Hurdle
BURTON G. HURDLE
NRL Code 7103

CONCUR:
Edward R. Franchi 1/23/2004
E.R. Franchi Date
Superintendent, Acoustics Division

CONCUR:
Tina Smallwood 1/28/04
Tina Smallwood Date
NRL Code 1221.1