CONVERSION OF TWO-MAN SUBMERSIBLE FOR SHALLOW DEPTH OCEANOGRAPHIC RESEARCH: PHASE II-POTENTIAL UTILIZATION, INSTRUMENTATION STUDY

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THESIS

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ABSTRACT

A multi-phase project directed toward determining the suitability of a two-man, shallow depth submersible in oceanographic research is in progress at the Naval Postgraduate School. This thesis, Phase II of the project, addresses the instrumentation and potential oceanographic use of the craft. Based on previous submersible and habitat oceanographic operations, projected utilization of the craft, Sea Otter, has been specified for applications in biology, geology, acoustics, chemistry, and physical oceanography.

Modifications recommended to amplify Sea Otter's research potential include addition of an equipment brow and a manipulator as well as substitution of fiberglass units for the steel ballast tanks. Designs for the brow and manipulator are proposed. Equipment packages are suggested which will fulfill requirements of the stated applications. Proposed modifications and equipment meet several restrictive criteria including weight, cost, power, availability and Navy certification criteria.

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I. INTRODUCTION

A. BACKGROUND

A small, shallow diving, two-man sports submersible has been obtained by the Naval Postgraduate School for use as a training aid in Ocean Engineering. The presence of the craft, named Sea Otter, at Monterey has focused attention on the usefulness of small submersibles in oceanographic research.

The worthiness of submersibles in oceanography has been addressed recently at the Naval Postgraduate School by J. F. King [1]. King examined the various national programs to determine which data collection missions require the unique capabilities of a submersible. A conclusion of King's thesis was that the cost factor in most submersible programs was a severe limiting factor which lead to reduced submersible utilization. Another conclusion stated that the submersible has unique work capabilities and are essential to attain national goals in the ocean. The goals described were security oriented. Regarding a submersible's application to oceanography, King is pessimistic.

The approach taken by King is consistent and not unlike a general trend in the oceanography community in that research and expenditures have been directed to all purpose, extremely deep diving, ultra sophisticated submersibles. There is no question that deep ocean research is worthwhile. The development of the deep diving submersibles to the exclusion of submersibles with shallow capabilities is

questionable however. There is a considerable area of the ocean which can be reached by shallow diving submersibles which require less support and cost much less to design, build and maintain. Operating one of the large, ultra sophisticated submersibles in shallow water is wasteful in two ways. Just a small portion of the sub's capabilities are utilized and secondly, the sub is not available to do deep work elsewhere. A submersible designed for shallow water work can be considerably less sophisticated and therefore costs are reduced due to the reduced pressures which will be encountered.

LCDRs V. K. Nield and T. J. Rowley are responsible for the presence of Sea Otter at the Naval Postgraduate School. They noticed the craft at the Tiburon Marine Laboratory, U. S. Fish and Wildlife Service and recognized in the craft a unique opportunity to develop an efficient oceanographic research vessel. Table I lists the current specifications of Sea Otter.

The cost entailed in operating Sea Otter has been projected at $2210 per year [2]. This figure is based on operating in Monterey Bay at a frequency of three six-hour dives per week, forty weeks per year. Table II compares Sea Otter's cost with other submersibles (deep diving craft) conducting oceanographic tasks. Sea Otter's yearly cost compares favorably with the daily costs required to operate these deep diving craft.

TABLE I

SEA OTTER* SPECIFICATIONS

HULL CONSTRUCTION: Pressure hull constructed of medium carbon steel, fabricated to ASME and Navy combatant submarine specifications for welding and materials. Ballast tanks bolted-on and exterior to pressure hull.**

LENGTH: 13 feet.

BEAM: 4 feet 2 inches (with ballast tanks installed).

HEIGHT: 4 feet 9 inches.

SPEED: 2 knots (cruise).

RANGE: 12 to 16 miles.

WEIGHT: 2,300 pounds.

PAYLOAD: 105 pounds (assumes two 200-pound occupants-one operator forward and one passenger aft). The fact that the ballast tanks are bolted-on and hence removeable allows for modification to permit increased payload and stability. The replacement of the steel ballast tanks with fiberglass will reduct weight by 105 pounds and increase the stability of the craft.

POWER SOURCE: Four 6-volt heavy duty, rechargeable lead acid batteries connectable for series or parallel operation.

(a) All gauges, compressor motor, air recirculation system operate on 12 volts.

(b) The 3 horsepower electric propulsion motor operates on 12 or 24 volts for speed control, directly driving a conventional propeller shaft arrangement.

OPERATIONAL CONTROLS:

(a) Stick operating diving planes for diving and surfacing.

(b) Lever for rudder control.

PRESSURE SYSTEM:

(a) Low pressure 150 psi system - used for normal blowing of the 4 main ballast tanks and trim tank control, which can be regenerated with air compressor.

(b) High pressure 2200 psi system for emergency use when low pressure system is depleted.

ENVIRONMENTAL CONTROL: Air recirculation system utilizing CO_2 absorption unit and make-up oxygen, giving a 6 hour fresh air supply.

METHOD OF SURFACING:

(a) Under power of propulsion unit, using bow planes.

(b) Blowing of ballast tanks with high or low pressure air.

(c) Blowing trim tank.

(d) Releasing 35-pound droppable lead keel.

VISIBILITY: 360 degrees horizontally through 1-inch thick acrylic conning tower windows.

* Originally marketed as AMERSUB Model 300. This model was also widely known as the "sportsman".

**SEA OTTER was the only AMERSUB Model 300 sold with the unique feature of bolted-on ballast tanks. All other models sold were constructed with weld-on ballast tanks.

TABLE II

RANGE OF COST OF A SUBMERSIBLE LEASE

NAME OF VESSEL	COST OF DIVE			APPROXIMATE DAILY LEASE RATE	DEPTH CAPA-BILITY (FT.)
	HIGH	LOW	MEAN		
Deepstar 4000	$13,100	$ 3,145	$ 7,720	$ 5,000	4,000
Aluminaut	19,760	11,800	14,550	2,500-16,000	15,000
Star III	9,680	4,720	7,040	2,500-4,500	2,000
Star II			2,500	2,000-2,500	1,200
PC 3B	1,910	667	1,110	400	600
Pisces	2,800	2,240	2,450		1,800

Sea Otter's reduced weight (2300 lbs.) permits towing on a small trailer and operation from the sixty-three foot surface craft available at the Naval Postgraduate School. A simple convertable A-frame device can be built to hoist Sea Otter into and out of the ocean from the deck of this craft. On hand materials and personnel can be used for the task, further reducing costs entailed in Sea Otter operations.

Considerable advantage has been taken of the similarity between Sea Otter and Nekton craft. The experience in the operation of the Nekton submersibles as explained by one of its developers, Mr. Douglas N. Privitt, has provided an essential experience base upon which much of Sea Otter's operating concept is modeled.

The substitution of a TV camera, a Nansen cast, or other surface controlled mechanism is often proposed as an acceptable substitute for submersible data collection. Mackenzie [3] stated that the advantages of manned submersibles for gathering data include the capability of observing instrumentation during measurements, mounting multiple equipments with short cables, and controlling the proximity of the sea floor. Surface controlled devices cannot provide as much assurance of correct equipment operation that is available when an operator observes data collecting equipment. Should there be a malfunction in data collecting equipment, an observer can usually pin-point the problem more effectively because he can see where the operation begins to fail. In-situ collection coupled with observation removes doubts which otherwise can only be statistically eliminated.

A bonus obtained in operating a submersible is the increased capability to recover lost objects at sea. An expensive alfa meter ($2900) now lies on a mound in 300 feet of water in Monterey Bay. The location is known to a sufficient degree to suggest that a submersible can find the unit. There is no way to find this unit from the surface with any vehicle whose operating costs are less than the cost of the alpha meter itself. Based on the known position, Sea Otter's excellent visibility, and the minimum support required there is reason to be confident about recovering the alfa meter at a minimum expense. Other examples of submersible contributions to salvage operations are easily brought to mind; the Palomares operation in recovering the A-bomb or the recovery of the submersible Alvin are two. The advantage of using submersibles in each case is based on the ability to place at the scene an individual who can choose the correct means to accomplish his task.

The possibility of applying the advantages of a submersible to shallow depth operations was foreseen by LCDRS Nield and Rowley. Having obtained a small submersible from Tiburon Marine Laboratory, they set out to investigate Navy certification procedures applicable to Sea Otter, and renovate the submersible to Navy certification specifications. It became apparent that the completion of this entire task was not possible in the time available. Convinced of the worthiness of Sea Otter, a multi-phase project directed toward accomplishment of the following long range objectives was formulated:

(1) to provide the Naval Postgraduate School with a safe, inexpensive, easily maintained, shallow depty (300 ft.), two-man research submersible that is certified for Navy use.

(2) To assist in the development of Navy certification criteria for simple, unsophisticated shallow depth submersibles.

(3) To promote and coordinate the accumulation of substantial submersible technology at the Naval Postgraduate School for long range oceanographic applications.

A four-phase project was outlined to achieve these objectives. There is no requirement that four phases are necessary or will be sufficient to complete the task. Each portion of the project addressed so far has been underestimated. In view of the extent of the problems discovered, it was recommended that teams of students rather than individuals undertake the latter two phases of the project. By so doing a continuous cross check and verification of steps could be made by team members.

From the knowledge of the project at the time, the following division of work was developed:

Phase I - Hull Certification.

a. Initiate overall programs.

b. Accomplish all work required for completion of certification checklists in the NAVSHIPS Presurvey Outline Booklet pertinent to the basic pressure envelope, except windows.

Phase II - Potential Utilization, Instrumentation Study

a. Conduct a comprehensive study of the potential uses of the vehicle by the Naval Postgraduate School.

b. Determine general power and payload capabilities, considering propulsion, ballast, navigation, communication, and life support requirements.

Phase III - Systems Installation, Outfitting

a. Redesign all remaining systems, considering certification.

b. Repair existing components as required.

c. Procure and install all operational system components.

d. Obtain and install basic instrumentation.

e. Test all systems.

f. Conduct surfaced and submerged stability tests.

g. Complete pertinent sections of certification checklist, including any remaining from Phase I.

Phase IV - Operation and Support, Total Certification

a. Complete any work remaining from Phase III.

b. Develop administrative procedures in accordance with certification requirements including logistics, maintenance, and surveillance.

c. Develop operational procedures and expertise; train pilots and support personnel, and outfit support vessel.

d. Effect total certification of the system.

B. PURPOSE

The purpose of this thesis is to fulfill Phase II - The Potential Utilization and Instrumentation Study. The timing of this portion of the project is designed to identify areas of redesign and adaptation of the hull prior to installation of life support and operating systems and at the same time provide some motivation to continue the project.

Phase I of the project is completed and the hull of Sea Otter is certifiable safe for the use intended. Oceanography Department personnel currently involved in the overall Sea Otter project are optimistic about potential Navy certification and the contribution Sea Otter can make to Oceanographic research. It would be premature to suggest operating the craft at this time. The hull meets certification criteria. The entire system, including hull and appurtanenences, life support items, and operators, does not yet meet appropriate criteria. When the several phases of the Sea Otter project are completed satisfactorily, a recommendation and request to operate Sea Otter will be in order.

II. OCEANOGRAPHIC APPLICATIONS OF SEA OTTER

A. APPROACH

A detailed review of submersible oceanographic operations was conducted in order to estimate the usefullness of Sea Otter as an oceanographic platform. Especially valuable and informative were the Naval Electronics Laboratories' Deep Submergence Logs [4,5,6,7] as well as SEALAB [8] reports. While reviewing the reports on submersible operations, notes were taken describing any operation undertaken or attempted which could have a direct or indirect application to Sea Otter. Operations such as coring, recovery of very large samples, diver lock-out, etc. which obviously had no application to a small, shallow depth submersible were considered only to the extent that the operation could be modified or scaled down. Detailed lists of operations which could apply to Sea Otter were compiled and broken down into specialty areas of biology, geology, chemistry, physical oceanography, and acoustics.

This compilation of tasks was mimeographed and distributed to various academic departments at the Naval Postgraduate School with a request for comment on required equipment and the general concept. The purpose of the distribution was twofold. First, it was hoped that feedback from the memorandum would identify immediate applications of Sea Otter. Secondly, the memorandum informed the recipients of Sea Otter's presence and potential.

Response to the memorandum was favorable though sparse. One comment indicated that the lists presented could conceivably cover all currently known applications of a small submersible but that state of the art advancements would augment this list at a rate dictated by the collective imagination of the oceanographic community.

Portions of the data suggested here for collection by a submersible might also be collected by a diver or divers. Three hundred feet is not an impossible depth to reach by SCUBA, however, the diver has many limitations. He may be affected by cold; he is severely time limited (beyond 25 minutes at 100 feet, the diver must consider decompression stops [12]), repetitive dive restrictions apply on successive dives; the diver can carry only one or two sensors with little cross-check or verifying ability; and he is biased in his evaluation of any situation. The operator in a submersible would have more time; would be comfortably warm; would not have to decompress or wait to resubmerge and would have a multitude of sensors to define the situation; the result is increased reliability and little bias. The submersible would also have the facility to record measurements, permitting later analysis and correlation.

A similar comparison can be made between submersibles and remote devices controlled by a surface ship. The presence in-situ of an individual within the submersible comprises a significant advantage over the relatively blind operation of devices managed from a surface vessel. Surface

controlled sensors generally must use more sophisticated instrumentation to compensate for the absence of an operator-observer on the scene. The cable connecting the sensor and the surface vessel projects the surface craft's motion into the collecting operation and injects a foreign noise into the environment. Submersibles operate without such a tether and generate a limited amount of noise which can be controlled by securing selected equipment. Real time identification, selection and collection of data is possible in a submersible. This theme is further amplified as it applies to particular instances in later paragraphs.

B. APPLICATIONS

Sea Otter and other small submersibles are particularly valuable in descriptive disciplines such as biology and geology. The specific application of Sea Otter to these disciplines centers on the excellent visability afforded observers. This is amplified further in the next section. In any research endeavor submersibles can provide a selectivity in sample measurement and collection in an immediate time frame. The data collected can be applied to augment or confirm previously collected information. The accurate data provided by a small submersible relys on the submersible's ability to deliver an observer to the study area, provide lighting for observation and photography and select the optimum position for recording desired information.

The redundant sensors recommended for Sea Otter provide an ability to verify each sensor's accuracy, reliability and

determine calibration drift as applicable. Back-up and prototype navigation systems, if installed in Sea Otter, could provide considerable assistance in improving navigation systems currently in use. The "fortune cookie" navigation system [9], for example, proved somewhat effective in the Thresher salvage operations. As the name implies, the system was not foolproof. The system entails surface placement of numbered navigation aids in a predetermined grid. Improvement of the system from marker design through surface handling and sowing to bottom deployment can be assisted by a small submersible.

The depth confines of Sea Otter includes most of the engineering projects on the continental shelf. For example, most oil rigs and other mining operations are located in less than three hundred feet of water.

1. Biology

The Biologist is interested in observing and studying organisms in-situ and correlating the life pattern of those organisms to the structure of the water column, the bottom, and to neighboring organisms. To this end, he would be interested in observing and collecting plankton and nutrients, bottom dwellers, sealife specimens, deep scattering layer organisms, bio-luminescence, and coral formations. In order to fully understand the nature of an organisms existence, several minimum parameters would need recording to match against the organism studied. These are temperature, salinity, pressure and oxygen.

A more complete understanding of the commercial fish population can be reached with the knowledge gained by in-situ observation and sampling. Marine harvest techniques for catching bottom dwellers as well as free swimmers can be improved through better understanding of the catch gained by observation in-situ. Observation and study of operating net systems is not recommended, however, due to the inherent danger of tangling the submersible in the net. The sparse light available at depth would require a submersible to position itself too close to the net for safe operation.

The interaction of fish and their environment is observable in-situ from a submersible. Some adjustment is required to data observed in-situ since submersibles attract fish [8]. To eliminate the effect of its presence, the submersible can alternate its illumination by taking "light looks" [5], the submersible remains in a darkened condition for the most part, infrequently illuminating the surrounding water for a quick look or photograph to be later analyzed. In this manner the observer eliminates the effect of an unnatural source of light in the area under observation.

Ecology studies are a variation of the fish behavior study described above, with emphasis on groupings rather than individuals. The continuing nature of the subject requires regular and persistent examination of organisms in a restricted area, a task particularly suited to a small submersible.

With the numerous ocean engineering projects taking place in support of oil exploration, recreation, an off-shore aquaduct, harbor construction and the like, the knowledge of how marine organisms will react to new structures in their regime is required information. A small submersible can return to a given position underwater at frequent intervals to determine just what changes have taken place in the numbers or kinds of inhabitants. The depth capabilities of Sea Otter would be sufficient to contribute knowledge in each of the examples cited above.

SEALAB [8] scientists noted a different grouping of organisms favored the shadow zone of their habitat than the group which congregated in the more lighted, surrounding areas. Elaboration on this theme can be effected by placing test structures on the bottom for study or by observing fish patterns around wrecks or outcroppings.

In Monterey Bay where discussion of sewage outfall lines is an everyday occurrence, knowledge of how the bottom dwellers will react to an outfall line is important. It is known that the bottom fishes do not generally swim over a low barrier but try to go around it. With the installation of an outfall line, fish may be shunted into deeper water or over bottom configurations they don't favor. They are thereby corralled or excluded from an area. The knowledge of how this phenomena affects the local inhabitants could lead to modification of design or placement of any low profile bottom structure.

The immediate effect of introducing pollution can be observed from a submersible. A significant advantage of using a submersible in this instance, rather than divers, is that the operators of a submersible will not be immersed in the pollutant. With a multi-sensor package on the submersible, pollution in the form of heat, chemicals or bacteria can be gauged completely by collecting samples and recording pertinent data. The ability to collect the data at the location where the effects of pollution are observed is inherent in a submersible's capabilities.

Fouling is most often studied by immersing test articles in the water and removing them at selected times to measure amounts and types of fouling. This method can be effectively augmented and verified with concurrent observation in-situ. An observer can obtain an expanded view of the water column supporting the fouling mechanism by collecting additional data with the multiple sensors available at hand. Progress of fouling can be monitored without disturbing the fouling organisms by removing them from the water.

The ability of a submersible to provide excellent visability for long periods of time in-situ and to return to the same locality on a regular basis permits a long term cataloging of organisms. The ability to return regularly to the same locale permits time phased observation in excess of the submersible's operating limits. Continued observation matched against observed organism changes can lead to a

better understanding of biological reaction to changes in the underwater regime.

2. Biological Instrumentation

To implement the biological studies described above, several sensors will be required. These include:

Manipulator (specimen collector)

Sample bag

Lights

Cameras

Thermometer

Salinity Sensor

Light Measuring Device

Plankton net

Pressure sensor.

It is quite possible to configure Sea Otter with each of the sensors mentioned. The observation station is of course already installed. Whether all of the sensors mentioned above can be mounted and used concurrently is considered later.

3. Geology

To accurately describe the make-up and origin of the soils found on the sea floor, samples must be selected, collected and analyzed and the information gained from the sample should be augmented and verified by in-situ testing.

An important consideration in any geological study is accurate location of the observation platform. Navigation systems are generally not able to provide the accuracy required in deep submersibles due to refraction of sound waves

and underwater current displacement. Shallow depth operation will mitigate this disadvantage. Navigation equipment planned for Sea Otter will be in the form of a pinger locator, an aircraft type gyrocompass, a magnetic compass and a timer.

In the normal pursuit of knowledge of the sea floor, samples are usually collected from a surface vessel and returned to the lab for study. Due to distortion, drying and pressure variation, it is not always possible to obtain the accuracy required to determine the true nature of the sample. According to Ciani [10], in-situ testing will provide the most accurate information on soil characteristics. The in-situ measuring devices should measure:

- Bearing Strength
- Shear Strength
- Consolidation
- Index Properties (density, void ratio, grain size, etc.)
- Sediment Thickness
- Compaction Characteristics
- Slope Stability
- Penetration Resistance

Ciani further noted that turbidity and settlement is observable from a submersible. A submersibles contribution to augment and support knowledge of the sea floor gained by other means can be invaluable in that in-situ data can confirm previous knowledge or provide accurate data whereby laboratory work can be adjusted.

The ability of a submersible to position itself on a given spot and orient a measuring device properly for collecting data is often a decided advantage over surface controlled mechanisms. The advantage of observing the sensor position removes any doubt of equipment malfunction. Sensors can be smaller, less sophisticated and concurrently more reliable.

Near floor sample collection by sample bottles as well as a manipulator scoop can contribute to knowledge of suspended sediments and general sedimentation studies. The ability of the submersible to avoid disturbing the regime through observation and control of its movement is preferred to remotely controlled devices.

In-situ observation will identify many objects not discernable by fathometers. The spreading of a fathometer's sound beam restricts its view of the bottom and limits the detail recorded. Visual observation can identify negative slopes, cracks, rubble, caves and discontinuities not observable from the surface. Roughness can be observed and recorded by camera or by measurement. This phenomena can be measured by surface mounted stereo camera, however, the camera doesn't have the ability to select and collect a sample of the area under study. The control and operation of a camera from the surface is a difficult and sometimes expensive task. The camera's position relative to the sea floor is difficult to control. Ship movement as well as bottom irregularities combine to exaggerate the problem.

The operation of a TV camera at depth resolves this problem to an extent but you must accept less detail in the pictures received. Color contrast, depth perception, and range resolution are lacking in current television systems [10]. A camera operated in-situ can be positioned properly in range, light requirements can be adjusted as required and the record obtained can be observed, confirmed and augmented by the operator.

Sea Otter can confirm bathymetry and identify major features of the bottom, i.e., scarps, canyons, troughs, ridges, fissures, banks, depressions, gullies, land slides and mud flows. The gross scale of these features is not always easily observed by submersibles due to limitations in visability underwater. However, small scale phenomena incident to these features are observed and samples can be taken for later study. Land slides or mud slides can be confidently recorded if observed in-situ.

Small submersibles can operate equipment to measure the acoustic properties of sea-floor sediments. According to Hamilton <u>et</u> <u>al</u>. [11], the study of acoustic properties of sea-floor sediments and determination of acoustic models of the sea floor requires in-situ study which can best be accomplished using submersibles; these measurements would include the velocity and attenuation of compressional (sound) waves, and the velocity of shear waves in deep-water sediments. Computation of elastic and visco-elastic constants and the application of these measurements and

studies to acoustic models of the sea floor, is then possible. The foregoing description of an on-going study lead to these recommendations:

(1) Continue to measure and study the least known acoustic properties of marine sediments: The attenuation of compressional (sound) waves, the velocities of shear waves, and elastic and viscoelastic constants.

(2) Emphasize in-situ measurements from submersibles and by diving, because it is impossible to create artificial high-porosity sediments in the laboratory which duplicate those in the sea floor, and the wavelengths of low-frequency sound waves are too great for measurements of attenuation in core samples.

(3) Devote further study to the subject of appropriate acoustic models of the sea floor, especially of the role of rigidity and shear waves in the absorption of sound at sediment-layer boundaries.

According to Dr. R. O. Andrews, (private conversation) the equipment required to pursue the investigations recommended are currently available at the Naval Postgraduate School. Dr. Andrews stated that a Visco-elastometer developed by Dr. O. B. Wilson, is being modified to reduce its size and for more extensive application in Monterey Bay. Dr. Wilson (private conversation) stated that he is anxious to test this equipment in-situ and match its data against in-situ Stoneley wave data. The immediate purpose of these efforts is a necessity to determine the relation between the lab and empirical measurements.

The final configuration, weight and power requirements of the equipment for measuring the acoustic characteristics described are not known. Preliminary estimates suggest that the entire installation of the viscoelastometer can be installed on Sea Otter. Unfortunately, few auxiliary sensors can accompany the equipment since it weighs nearly eighty pounds. Subsequent generations of this equipment, according to Dr. Wilson, will be designed with a small submersible in mind thus favoring lighter weight components and DC power.

4. <u>Geological Instrumentation</u>

The following sensors are required to implement studies of geological phenomena.

Observation Station

Manipulator

Sample Bag

Temperature Probe

Thermometer Array

Sample Bottles

Photographic Equipment

Inclinometer

Pressure Sensor

Lights

Vane Shear Mechanism

Pinger (for position fixing)

Acoustic Devices

Most of the equipment noted can be concurrently located on board Sea Otter. Acoustic devices, vane shear mechanisms, and other soil characteristics measuring devices not mentioned are available at the Naval Postgraduate School; however, extensive modification of this equipment for use in-situ is required prior to installation on any submersible.

5. Chemistry

The usual method of identifying chemical constituents in sea water is to collect a sample using a Nansen cast or similar mechanism. The sample is then removed to a laboratory for analysis. Replacement of the Nansen cast by submersible operations is not in order since a Nansen cast is relatively quick and inexpensive. A disadvantage of using this technique is that interesting phenomena are identified sometime after the collecting operation has been concluded. Should more information be desired about this pehnomena there is some doubt whether it can be obtained due to the difficulties in navigation and positioning of a surface craft. A submersible has the capability to identify anomalies in-situ and collect samples at that point for verification and more extensive study later.

Whether a sample is collected with a Nansen cast or collected by a submersible, similar analysis is usually conducted to identify nitrogen, oxygen, phosphate, silicate, pH, trace elements, hydrogen ion concentrations, dissolved gases such as hydrogen sulfide, and carbon dioxide, and oxydation-reduction potential.

A small submersible can collect samples from the sea floor to the surface in relatively small increments. Surface tended devices used to collect near bottom water samples are limited in the depth accuracy at which samples are taken, in the number of adjacent samples which can be collected and have little hope of returning to the same location for additional information. A pinger, flag or a sensor left at the scene can be relocated by submersible for subsequent sampling operations. Small scale phenomena can be identified by stacking sample bottles no further apart than their own diameter. Correct sample selection and collection is immediately verified as observed.

6. Chemistry Instrumentation

The following sensors are required to implement study of the chemical phenomena described.

Sample Bottles

Temperature Sensor

Pressure Sensor

Camera

Salinometer

Lights

Observation Station

7. Acoustics

The submersible's contribution to acoustics research is keyed to the craft's ability to select a location and operate sound measuring equipment. Small non-sophisticated submersibles such as Sea Otter have a welcome advantage in acoustics measurements by making themselves extremely quiet.

They are not tethered so that no noise is generated by a supporting cable. The equipment required for life support are few and their acoustic structure can be defined and accounted for in a sound survey.

By selectively positioning a submersible, measurement can be made of reflection, scattering, sound velocity, sediment transmission and noise level. Submersibles provide the capability to identify and relate noises to sources by placing a qualified observer near the source.

8. Acoustics Instrumentation

To implement acoustics research the following equipment is required:

Observation Station

Sound Measuring Set

Pressure Sensor

Temperature Sensor

Lights

Water Bottles

Camera

Note: Sound transmission in sediment was discussed in the Geology Section.

9. Physical Oceanography

Submersible support of physical oceanography is keyed to the ability to select and position at a specific location a sufficient number of sensors to accurately describe the phenomenon being studied. The complete description at a location might include measurements of temperature, currents,

ambient light, optical properties, bathymetry and density.

Complete understanding of the physical phenomena in an area would include correlation of these items. The multi-sensor approach of a submersible is considered sufficient to conduct the measurements indicated and match the data against depth, water mass, time and location.

A submersible can place, monitor and recover oceanographic sensors with considerably more certainty than remote systems. The ability to handle equipment external to the craft is utilized to place measuring devices, retire to permit unhampered measurement of data, and retrieval of data and equipment. A small submersible is capable of choosing representative locations on the sea floor from which to monitor water movement and at the same time record pressure variations induced by wave action. Continuous measurements of pressure versus temperature will be possible in Sea Otter.

Recent investigations have found considerable variation of temperature and salinity micro-structure and turbulence. Sea Otter can provide a suitable platform for the instrumentation utilized to measure these variations. Hot film anemometers used for turbulence measurements require a mean flow of fluid past the sensor to operate. Sea Otter can provide the mounting platform for this sensor as well as a measured mean motion. The submersible can collect horizontal variations of temperature concurrently with turbulence

measurements while cruising at a selected depth in a given direction. Vertical temperature variations can be gauged by operating the ballast systems of Sea Otter to force the motion desired. Although optimum procedures for collecting specific data requires additional testing, Sea Otter appears to offer a realistic potential in this area of research.

10. Physical Oceanography Instrumentation

Physical oceanography measurements can be collected through the use of the following sensors:

Observation Station

Temperature Sensor

Pressure Sensor

Lights

Current Measuring Devices

Water Bottles

Camera

Manipulator (to position sensors)

Salinometer

All of the equipment listed above can be concurrently located on board Sea Otter.

III. SEA OTTER INSTRUMENTATION PACKAGE

The several criteria for selection of an individual piece of equipment for installation in Sea Otter are: power required, weight, volume size, cost, depth capability, temperature limits, number of conductors, stability and accuracy, availability, and interchangeability. While equipment lists are proposed for each specific task, it is not intended to strictly define which equipment could or could not be used. The purpose is to describe a representative package which can be effectively utilized aboard Sea Otter. In actual use, considerable variation from the proposed packages is expected and desired.

A. GENERAL CRITERIA

1. Power

Sea Otter has lead acid battery power with power take-off available at 6, 12 and 24 volts. Since any drain on this power by auxiliary equipment reduces power available to the propulsion motor, every effort has been made to prescribe equipment with built-in power sources.

2. Weight and Volume

Minimum weight and volume (size) requirements are self evident. The small size of Sea Otter requires miniturization to as great an extent as possible. To provide for increased payload and stability it is recommended that the steel ballast tanks be replaced with ones fabricated of fiberglass.

Mr. Gordon Gulbranson (private conversation), of the Naval Postgraduate School model fabricating shop, outlined the considerations entailed in the fabrication of fiberglass units. The original ballast tanks and Sea Otter should be used as forms for the fiberglass tanks. By so doing costs would be reduced by eliminating the need for forms, the ultimate fit would be better since the tanks would be assembled in place, and time required for the project would be reduced. The weight saved by replacing the metal ballast tanks with the .25 in. thick fiberglass is outlined below. As a comparison for gauging the thickness of the fiberglass recommended, it should be noted that small boat hulls constructed of fiberglass vary in thickness from .187 to .25 inches.

TABLE III

BALLAST TANK WEIGHT CONSIDERATIONS

TANK	SURFACE AREA (SQ. IN.)	VOLUME OF FIBERGLASS (CU. IN.)	WEIGHT (LBS.)		
			STEEL	FIBERGLASS	DIFFERENCE
Fwd	2926	732	65	39	26
Aft	3468	867	73.5	47	26.5
				TOTAL	52.5

The resultant 105 pounds is an important gain in payload and represents the gain over replacing four tanks, two forward tanks and two aft tanks. Without this modification any consideration of an equipment package installation on

Sea Otter is extremely limited due to a reduced payload of approximately 40 lbs.

3. Depth Capability

Each external piece of equipment considered must have an operating depth range in excess of 300 ft., the maximum operating depth of Sea Otter.

4. Temperature Limit

The expected temperature range of the water to be explored determines the specific range desired, -5° to $50^{\circ}C$. Most equipment considered has temperature limits in this range.

5. Number of Conductors

Conductors in this sense pertains to the number of individual wires which must penetrate the hull to transmit sensor measurements to the recording and read-out equipment. Rather than have the number of hull penetrations available determine the number of sensors which could be used, the sensors desired for each package was determined. The number of penetrators recommended accommodates the highest number of conductors required.

6. Stability and Accuracy

In a case where two similar pieces of equipment were considered, both having similar physical characteristics, the one having displayed the most accurate and consistent data was selected.

7. Interchangeability

An effort was made to avoid dedicating any particular piece of equipment to Sea Otter. This effort has been

successful in all cases except with navigation and communication equipment. In these instances, less than one hundred per cent interchangeability is accepted with the understanding that each system used can, in fact, be removed and utilized elsewhere but considerable work is entailed in such removal.

8. Cost

Cost is an over riding consideration in every determination since a basic tenet of the Sea Otter concept is to provide a versatile yet inexpensive tool for use in oceanographic research. Instruments available at the Naval Postgraduate School are recommended whenever possible.

9. Availability

As it turned out, most other considerations were mitigated in lieu of availability. Most of the equipment recommended is available at the Naval Postgraduate School. In other cases, acceptable substitutes can be fabricated utilizing Naval Postgraduate School facilities.

B. NAVIGATION AND COMMUNICATIONS

Navigation and communication equipment are considered together because they complement each other and share the distinction of being required regardless of the investigation being undertaken. The navigation and communications package proposed includes the following items:

Lights

Gyrocompass, power supply (surplus)

Magnetic Compass

Acoustic Locator (Pinger)

Echo Sounder

Elapsed time clock

Underwater Telephone

Surface Transceiver

1. Lights

The lights recommended for use in Sea Otter are manufactured to order by Nekton, Inc. These low cost lights have been used extensively at 1000 feet, are interchangeable and provide excellent illumination. The specifications and dimensions of the lights are listed on Figure 1.

The number of lights required on any particular dive depends on the objectives of the dive. In most general operations lights would be required as follows:

LOCATION	NO.	VIEW ILLUMINATED
Forward - Hatch bracket	2	Forward 120°
Manipulator	1	Manipulator operation
Aft - Hatch bracket	2	Aft 120°
Amidships	2	90° either side
TOTAL	7	
TOTAL WEIGHT (Wet)	28 oz.	

Individual switches for each light are recommended to conserve power as well as to minimize the disturbance of light on the environment. It is also recommended that the lights be semi-permanently mounted and provided separate hull penetrations at their location.

2. Gyrocompass and Magnetic Compass

An aircraft gyrocompass is available from surplus. An appropriate power adapter (inverter) to Sea Otter's 24

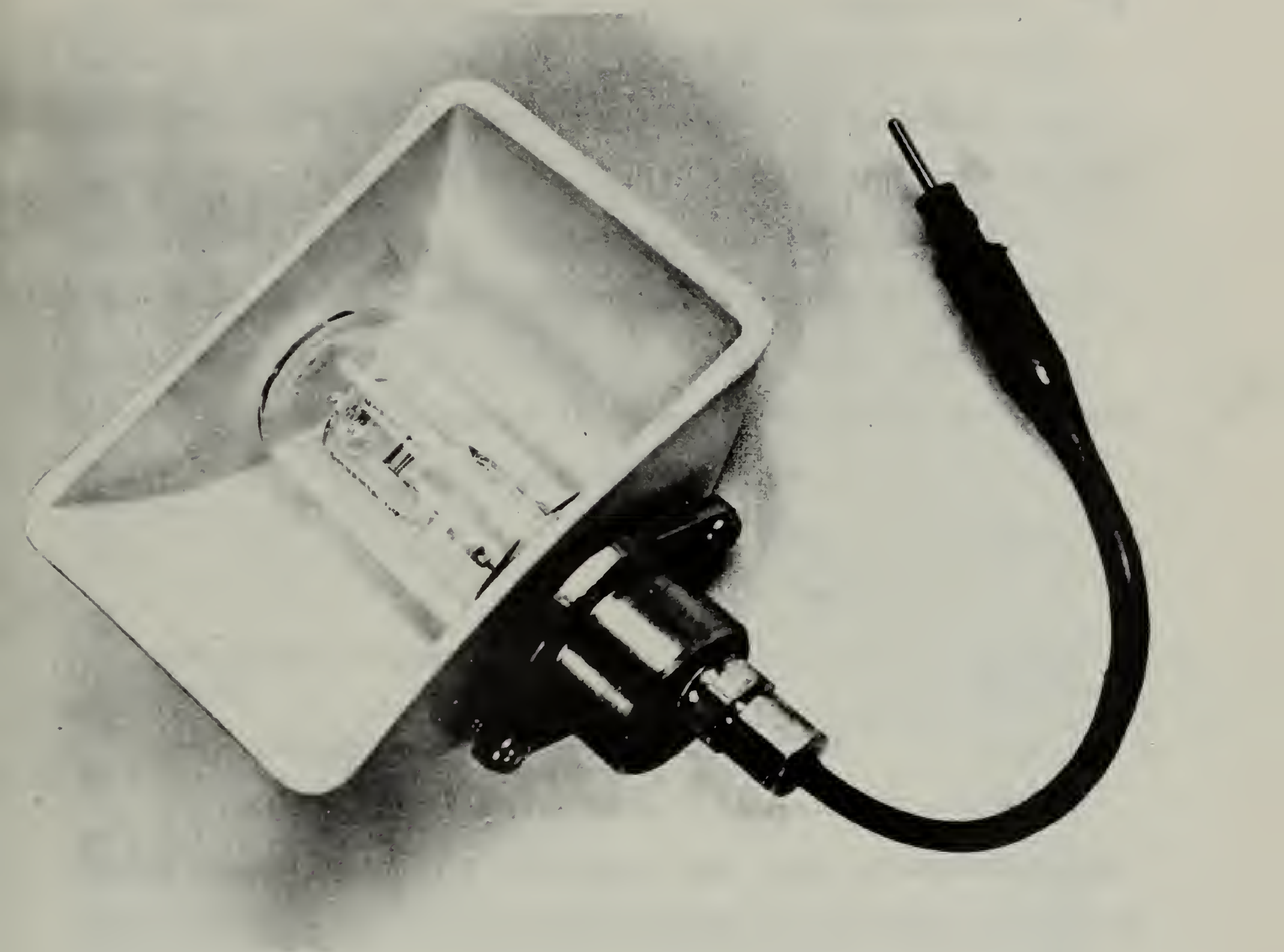


Figure 1. Underwater Lights

Underwater Light
Nekton Inc.

Bulb:	GE or Sylvania (FCS) Tungston Halogen lamp
Lumens:	4,500
Life (hrs):	50
Power:	24V/150 watts
Dimensions (in):	3.25 x 1.5 x 3.75
Weight (lbs):	
Air	.4
Water	.25
Cost:	$50.00

volt system is required and is available commercially. The magnetic compass is required only to align the gyro when it is initially turned on. The recommended procedure used successfully by Nekton craft (private conversation with Mr. Douglass Privitt) is to maneuver to one known accurate heading on the magnetic compass and when the gyro is up to speed, uncage it on this heading. Subsequent maneuvers ignore magnetic compass headings and rely on the gyrocompass.

COMPASS WEIGHT DATA

	WEIGHT (LBS.)		COST
	DRY	WET	
Gyrocompass w/power supply	8		($100) Surplus
Magnetic compass	.4	0	$20

The magnetic compass should be mounted over the diving plane terminal to minimize the craft's magnetic disturbance. The gyrocompass would best be utilized if mounted amidships, center line and facing aft. This placement is necessary to permit operation of the manipulator in the forward cone area of the craft.

3. Acoustic Locator

Selection of an acceptable acoustic location device was simplified since an ideal pinger-locator system is available at the Naval Postgraduate School. The Beacon-Pinger locator device adds little weight to the submersible when submerged. Location of the device is affected from a surface craft by immersing the antenna provided in the water and rotating same until the strongest signal is obtained (Fig. 2).

Figure 2. Pinger/Locator

Beacon-Pinger Locator
Interocean Systems Model B-910

Signal (KHZ):	12-27-37	Dimensions (in):	7.5 x 5.5 x 11.5
Range (mi):	4+	Power:	Internal 12V battery
Weight (lbs):		Accuracy:	$\pm$ 5°
Air	4	Cost:	$925.00
Water	Neutral		

Considering the desirability of having nothing obstructing or interfering with the pinger's signal, the best position for it would be on one of the conning tower hatches. The after hatch is recommended. No hull penetration is required.

4. Echo Sounder

The Oceanography Department of the Naval Postgraduate School has been operating a small fathometer which is easily adaptable to Sea Otter (Fig. 3). Positioning of the transducer to eliminate masking by the craft's hull as well as to minimize the chance of fouling on lines and kelp is best affected on the underside of the after-cone section of Sea Otter. The transducer should be modified by replacing the 0.75 in. mounting shaft with a shorter unit. This would permit a cleaner installation on Sea Otter.

5. Elapsed Time Clock

There are numerous acceptable time pieces available for use in Sea Otter. The selection of any particular one is best left to the research team conducting a submersible operation.

6. Underwater Telephone

The smallest, lightest underwater telephone that was located is built and distributed by Nekton, Inc. The unit has been successfully operated at 1000 ft. and is compatible with standard underwater telephones. A pair of these telephones (Figs. 4, 5) would provide communications between Sea Otter and a surface support craft. The surface mounted unit

Figure 3. Echo Sounder

Apelco Fathometer

	Readout	Transducer
Dimensions (in):	10.5 x 6.25 x 5.5	4 x 5
Weight (lbs):		
Air	7	3.6
Water	7	1.6
Conductors: 2		
Power Required: 12V		
Cost: Unknown		

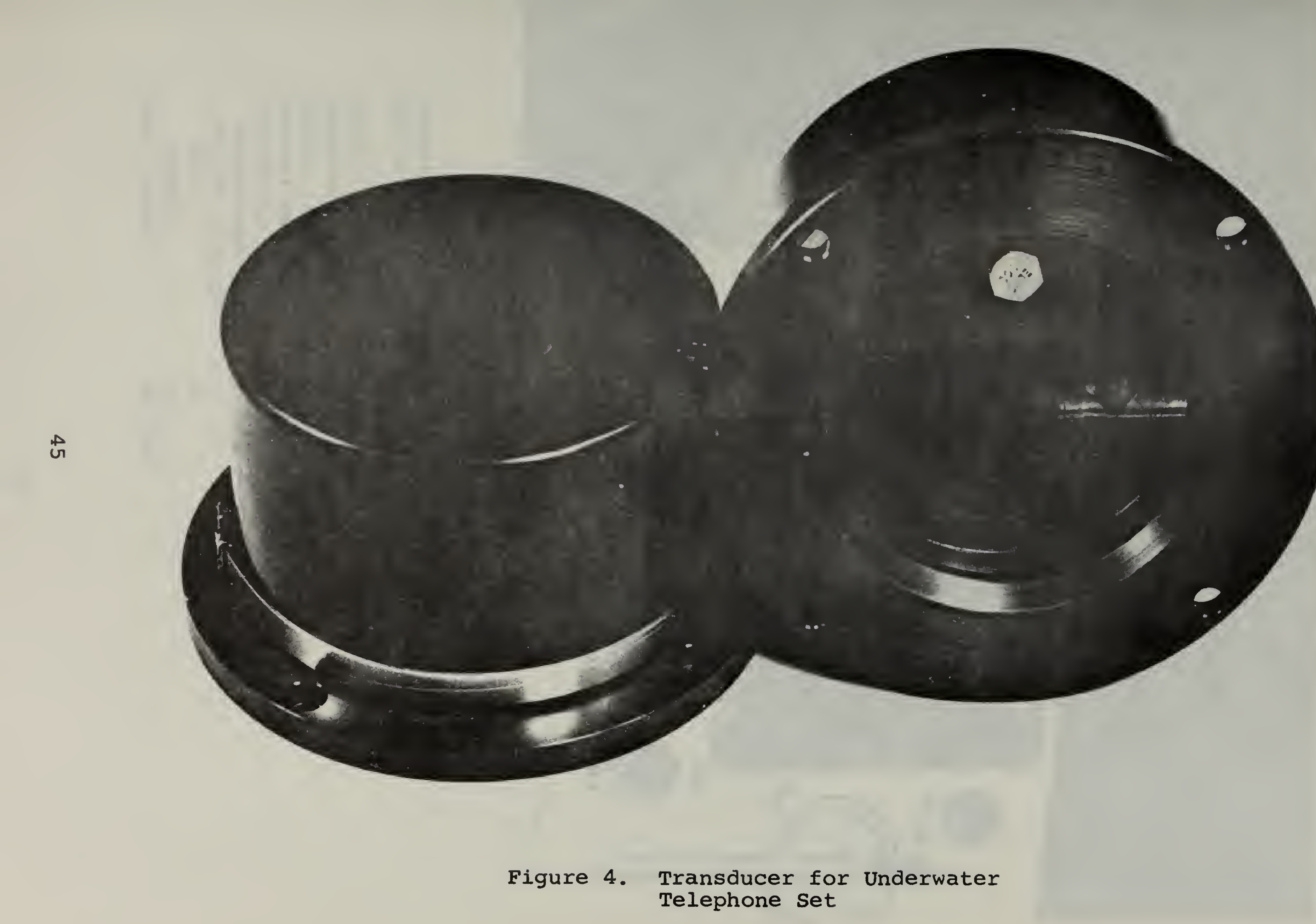


Figure 4. Transducer for Underwater Telephone Set

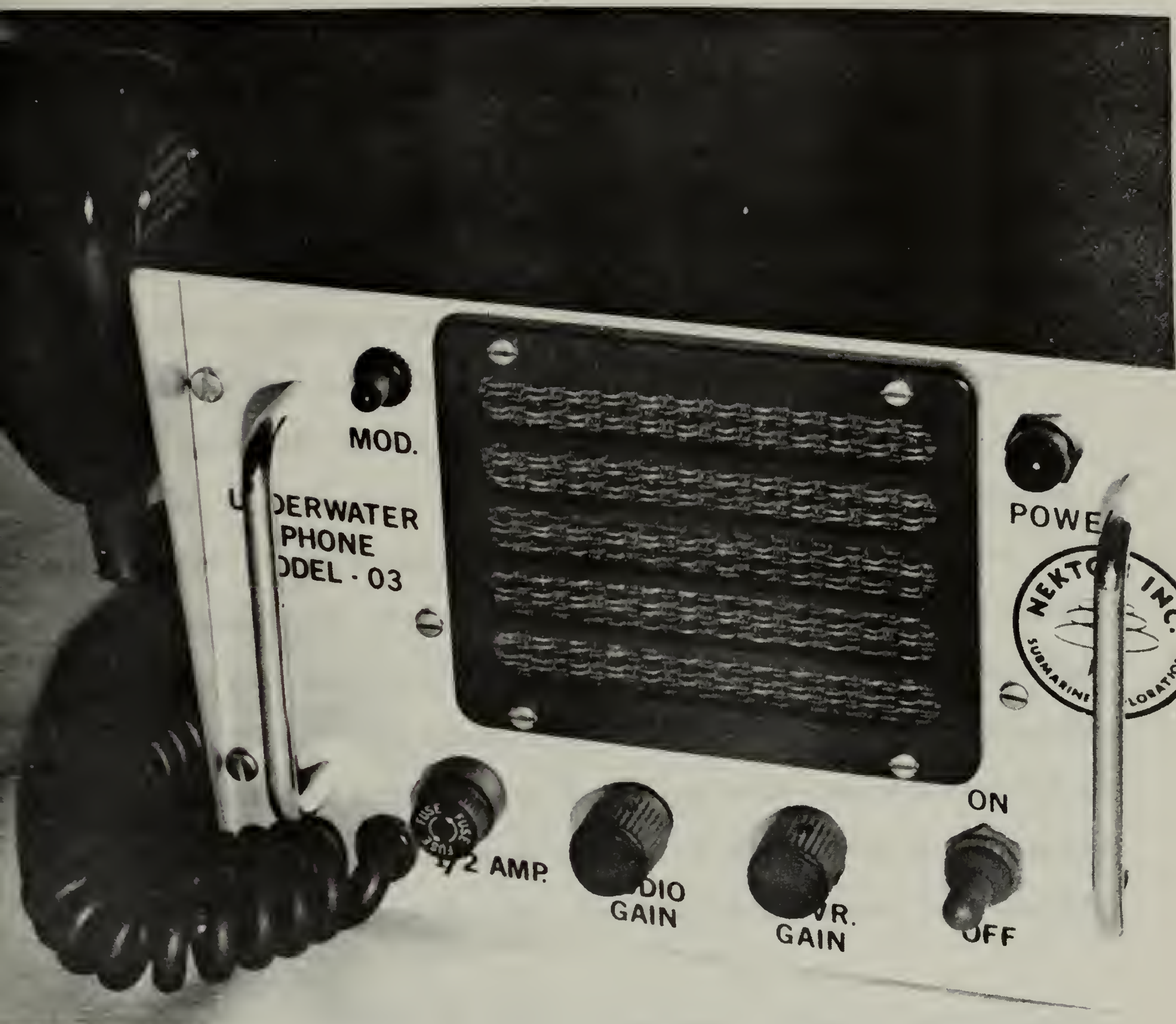


Figure 5. Underwater Telephone Set

Underwater telephone set
Nekton, Inc.

Power:	24V
Frequency (KHZ):	8.3 to 10.7
Weight (air):	7 lbs.
Dimensions (in):	9 x 6-1/4 x 5-3/4
Transducer	
Dimensions (in):	5-1/2 x 3
Weight (lbs.):	
Air	4
Water	2.2
Cost (each):	$1,500

would be completely portable while the Sea Otter mounting would be a semi-permanent one. The recommended location is on the after cone to the right of centerline about six inches from the aft conning tower.

7. Surface CB Transceiver

Surface communications are considered an important liaison and safety feature. Commercially available units are available ready made and in kit form at a price of about $100. An acceptable CB antenna (Fig. 6) is produced by Nekton Inc. and is encapsulated in a synthetic compound to protect it from corrosion. The recommended location for the antenna is on the after hatch cover. Penetration through the hatch cover at the point of attachment constitutes both mounting bracket and conductor connection for the transceiver.

An ideal alternative to using a CB transceiver is to use walkie-talkies. Such a system is available at the Naval Postgraduate School and would take up less space and weight than a CB unit.

The location of the transducer, pinger-locator and CB antenna is shown in Figure 7. The photograph is of one of the Nekton boats. Table IV lists the entire navigation-communications package.

C. BIOLOGY INSTRUMENTATION PACKAGE

A most beneficial capability of Sea Otter in biological research is its 360° view. A considerable amount of biological research can be accomplished with little additional equipment.

Figure 6. Surface CB Antenna

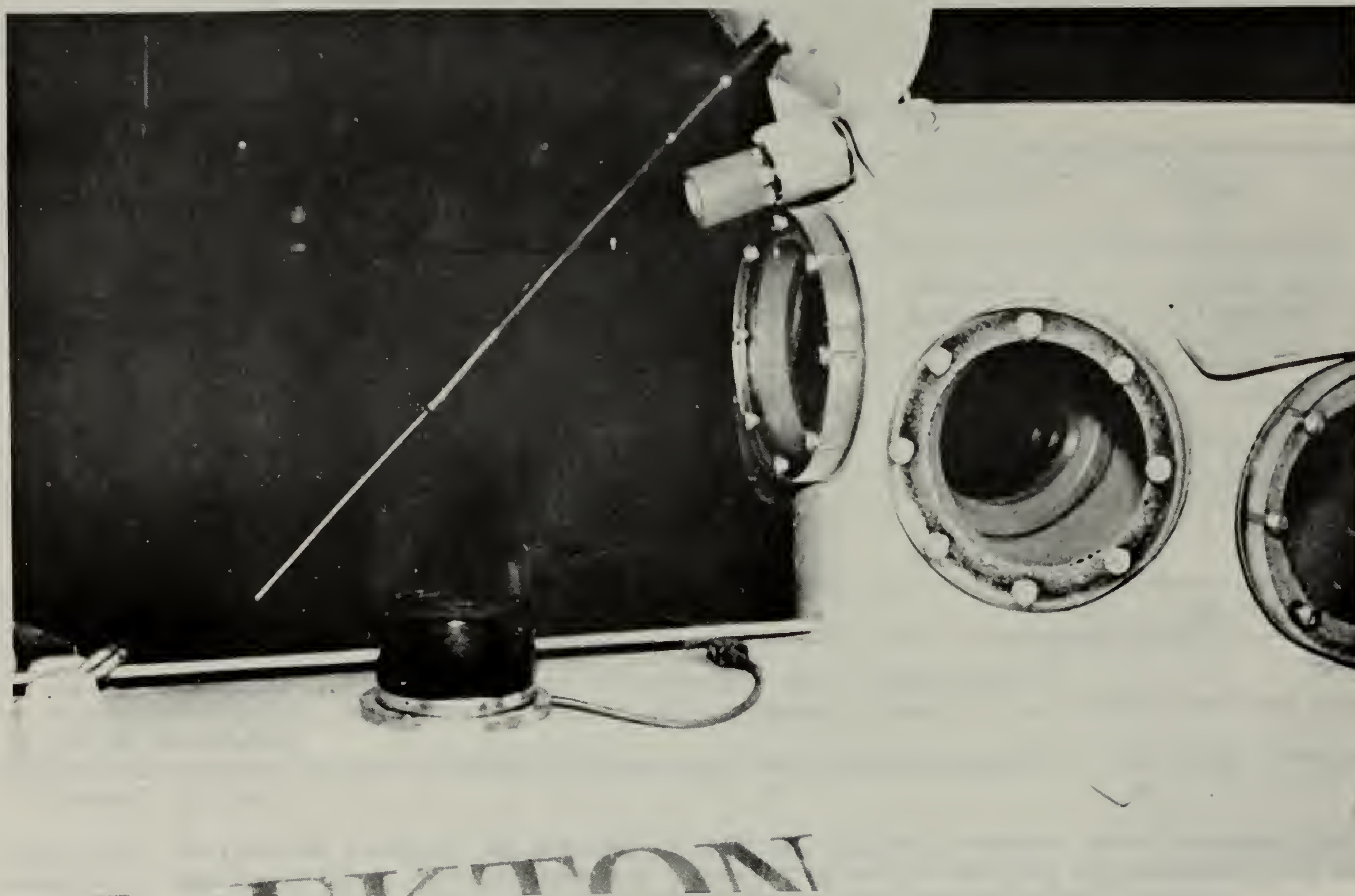


Figure 7. Location of Transducer, Pinger-Locator, CB Antenna (Nekton pictured)

TABLE IV

NAVIGATION-COMMUNICATIONS PACKAGE

SENSOR	WEIGHT (LBS.) AIR	WEIGHT (LBS.) WATER	CONDUCTORS	POWER	LOCATION	COST
Lights (7)	2.52	1.75	0	24V	Various	$ 350.00 (7)
Pinger-Locator	4		0	24V	After Hatch	925.00
Echo Sounder	10.6	8	2	12V	After Cone	
Underwater Telephone	11	8.8	(fixed)*	24V	After Cone	3,000.00 (2)
CB Trans-ceiver***	4	4	(fixed)	24V	After Hatch	100.00
Gyrocompass	3	3	0	24V	Amidships	Surplus
Magnetic Compass	.7	0	0	None	Diving Plane Terminal	20.00
TOTAL	35.82	25.55	3			$4,395.00**

* Permanent installation, requires no separate hull penetrator.

** Total cost of all equipment. Deducting equipment presently available reduces total price to $3,450.

*** Walkie-talkies are an acceptable substitute and are available at the Naval Postgraduate School (2 lbs.).

A modified navigation package consisting of lights, pinger-locator, echo sounder, underwater telephone, walkie-talkie, gyrocompass and magnetic compass will be recommended for use with other equipment packages. The payload consideration for the modified package is:

WEIGHT (LBS.) CONDUCTORS: 3 COST: $4,295.00
Air - 33.82
Water - 23.55

1. Manipulator

The manipulator (see section on general support equipment) recommended for use on Sea Otter is capable of retrieving most slowly moving organisms. With cunning, patience and some agility, fish can also be captured with the manipulator. A sample bag located near the manipulator will provide stowage for collected samples. The viewport incident to the manipulator provides an observation port whereby the bottom can be studied.

2. Lights

The lights provided for navigation double effectively for observing objects in deeper water. The selective switching of lights on and off provides a means to observe the in-situ population without disturbing the regime.

3. Temperature

The temperature sensor recommended for use of Sea Otter is distributed by Hydro Products. Several thermistor temperature probes are available at the Naval Postgraduate School as well as the readout mechanism (Fig. 8). An important capability of the Hydro Products equipment is its compatability with the Rustrak strip recorder (Fig. 9). Several thermistor probes can be utilized by providing a switching mechanism or by selectively plugging in the sensor desired. Redundant temperature readings can be provided by fixing a standard thermometer to the inside of a hatch support bracket. Visual observation of this thermometer is possible through the plexiglass observation ports. By

Figure 8. Temperature Sensor

Portable Remote Hydrotemp
Hydro Products

Range:	0 - 40°C
Linearity:	$\pm$ 2%
Conductors:	2
Max. Error:	$\pm$ 5%

	Sensor	Module
Weight (oz):	2	12
Dimensions (in):	3.1 x .75	5.4 x 3.6 x 3.7
Power:	Battery	
Cost:	$258.50	

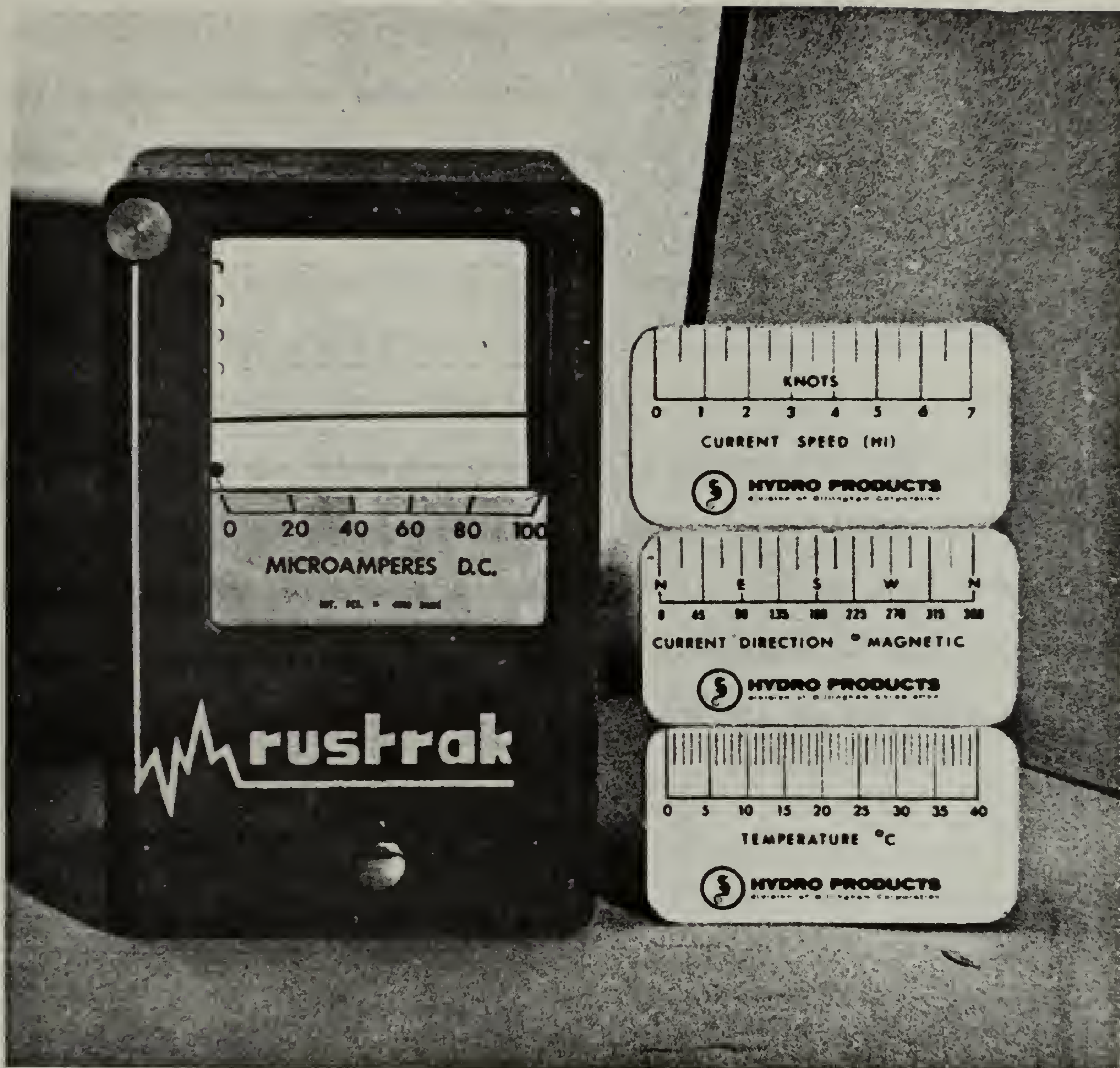


Figure 9. Rustrak Recorder

Rustrak Automatic Chart Recorder
(Continuous, distortion free line on pressure sensitive paper)

Dimensions (in):	5.63 x 3.63 x 3.5
Weight (lbs):	3.5
Power:	Battery
Cost:	$135.00
Power:	0.6W at 24-28 V DC

providing a calibrated (pressure and temperature) thermometer at this stage, regular readings of a known accurate thermometer can be used to verify or correct data recorded automatically via the Hydro Products unit.

4. Pressure

The recommended pressure sensor is distributed by Hydro Products and is also available at the Naval Postgraduate School (Fig. 10). The unit is compatible with the Rustrak recorder thereby permitting permanent and continuous recording of depth information. Redundancy is provided by a depth gauge permanently installed in Sea Otter. These sensors can both be calibrated for temperature and pressure variation. The benefit to the researcher is an accurate and verifyable record.

5. Cameras

Photographic equipment, both still and motion, is available at the Naval Postgraduate School. The numerous equipment available represents both private and government owned instruments varying in weight from several ounces to several pounds. No effort was made to catalog this equipment beyond determining that most could be used inside Sea Otter coupled with a strobe lighting system or with lights recommended for installation on Sea Otter.

External mounting of photographic equipment was considered and found to be beyond the capabilities of Sea Otter. Several reasons suggested that external photographic equipment would not be efficiently utilized. Pan and tilt

Figure 10. Remote Depth Gauge

Portable remote depth gauge
Hydro Products

	Sensor	Readout
Model:	404	402
Pressure Range:	0-500 psi	0-500 psi
Maximum depth (ft):	2000	2000
Static Error:	1.5% full scale	$\pm$2% full scale
Power Range:	0.5 watts (battery)	
Conductors:	3	3
Dimensions (in):	7 x 3	5.5 x 3.6 x 4
Weight (lbs):		
Air	3	1
Water	2	N/A
Cost:	$550.00	$185.00

mechanisms considered for use on Sea Otter in conjunction with the photographic equipment turned out to be too heavy. Permanently mounted external photography equipment relys on aiming Sea Otter. Sea Otter has neither the power nor the control surfaces required to hold position or train effectively after a selected subject. Finally, the limit of the lighting available matched with the 360° visibility out of Sea Otter suggests that sufficient photographic recordings can be made from within the craft.

6. Salinometer

Industrial Instruments manufactured the salinometer recommended for use on Sea Otter (Fig. 11). The instrument is present at the Naval Postgraduate School and provides conductivity, salinity and temperature readings. No particular position is recommended for the Salinometer. Particular studies will dictate the best position for collecting the desired data.

7. Plankton Net

A proposed use of Sea Otter is to select and collect organisms with a plankton net secured to the equipment brow. Opening and closing of the net can be affected by use of a solenoid tripped gate or mechanically by operating the net with the sample bag control mechanism.

The Biology package is listed in Table V.

D. GEOLOGY INSTRUMENT PACKAGE

Equipment required to conduct the geology research outlined previously is in all cases available at the Naval

Figure 11. Salinometer

Electrodeless Salinometer
Industrial Instruments Inc.

Power: Battery

	Readout	Transducer
Cost: $975.00		
Weight (lbs):		
Air	11	5
Water	--	4
Dimensions (in):	6 x 7 x 9	4 x 2

	Range	Corrected
Salinity:	0-40% ± 0.3%	± 0.05%
Temperature:	0-40°C ± 0.5°C	± 0.05°C
Conductivity:	0-60 mmhos/cm	± 0.05 mmhos/cm

TABLE V

BIOLOGY INSTRUMENT PACKAGE

SENSOR	WEIGHT (LBS.)		CONDUCTORS	POWER	LOCATION	COST
	AIR	WATER				
Manipulator	3	2	--	--	Port Fwd Cone	$ 0
Sample Bag	1	.5			Inside	--*
Cameras	Various		0	Battery	Various	--*
Temperature	.87	.81	2	Battery	Various	258.00*
Rustrak Recorder	3.5	3.5	N/A	Battery	Inside	135.00*
Salinity	15	13	6	Battery	Various	975.00*
Depth Sensor	4	3	3	Battery	Various	735.00*
TOTAL	27.37	22.81	11			$2,103.00

*Items available at the Naval Postgraduate School.

With the modified navigation package consisting of the pinger-locator, echo sounder, lights, underwater telephone, gyrocompass, magnetic compass and walkie-talkie (Table IV), total payload becomes:

	61.19	46.36	14			$6,398.00

Postgraduate School. Several of the instruments, however, are not currently configured for use in-situ. These include acoustic devices, the vane-shear apparatus and other soil characteristic mechanisms. The visco-elastometer currently in operation at the Naval Postgraduate School is exceptionally heavy in its present configuration. Modifications in size and weight are planned for further models of the visco-elastometer as well as conversion to as great an extent as possible to DC power. The inclusion of the vane-shear mechanism and the visco-elastometer will significantly enhance the oceanographic capability of Sea Otter.

Some sensors utilized in geology research are common to the biology or navigation package. This equipment is the manipulator, sample bag, temperature sensor, cameras, lights, pressure sensor, and pinger-locator. The equipment will not be again described in this section although they will be included in the tabulation of the geology package.

1. Temperature Probe

A temperature probe is needed to measure temperatures at various levels in sediment. The sensor consists of a rigid tube containing one to several thermistors at given separations along the tube length. One temperature probe available at the Naval Postgraduate School is used in conjunction with the Physics Department's visco-elastometer. Modification of this particular probe for use in Sea Otter is not considered worthwhile since the construction of an acceptable device compatable with the Hydro Products temperature recording system (Fig. 8) is possible with on-hand

materials. The probe would be utilized in conjunction with Sea Otter's manipulator. Manipulator placement insures proper orientation of the probe within view of the operator. The manipulator also allows the operator to feel the probe into position which will reduce damage to the probe. Expected weight of the probe will be of the same order as the temperature sensor previously described.

2. Sample Bottles

Two different types of sample bottles are available for use on Sea Otter. Fjarlie bottles (Fig. 12) have been used effectively in submersible applications. The characteristic of the Fjarlie bottle which recommends it to submersibles is that it can be rigidly mounted and the spring loaded end caps can be tripped by solenoid. Removal of the thermometer rack is recommended in most configurations accompanied by modification of the tripping mechanism to eliminate any possibility of snagging.

Bottles with wider possible application to Sea Otter due to their low weight are the Van Dorn type PVC units available at the Naval Postgraduate School (Fig. 13). These units are also adaptable to solenoid operation. The equipment brow proposed for Sea Otter is designed with cross member spacing of twelve inches to facilitate attachment of sample bottles.

Solenoids are available commercially; however, Professor Tucker (private conversation) has found that a more effective and longer lasting solenoid can be manufactured

Figure 12. Fjarlie Bottle

Weight (lbs):	
Air	10
Water	8
Dimensions (in):	18 x 5
Capacity (ltr):	1.3

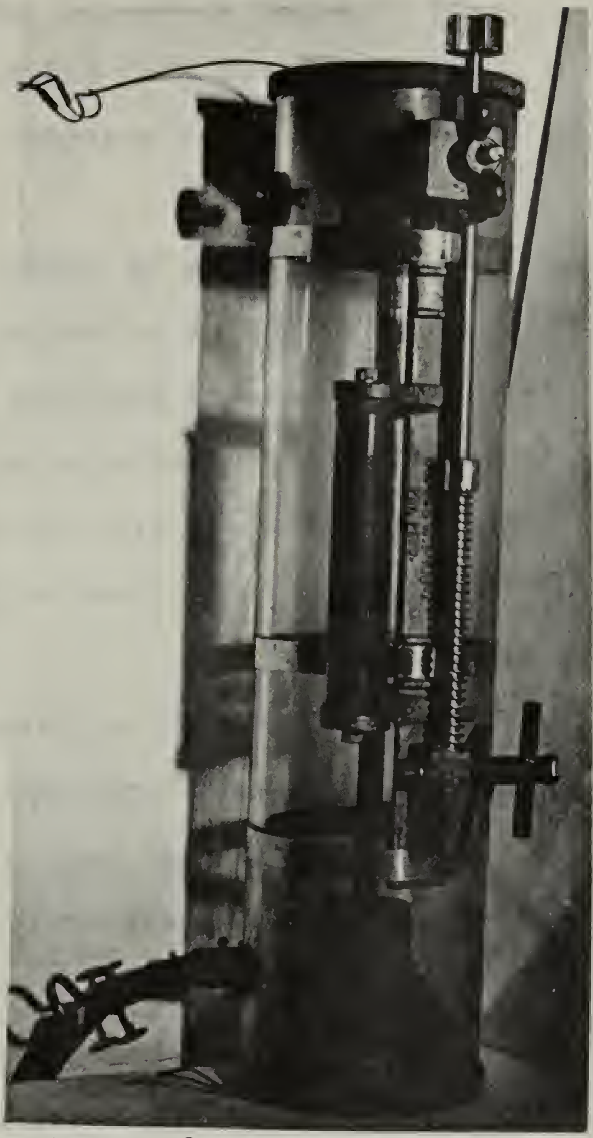


Figure 13. Van Dorn Bottle

PVC Plastic
Models Available:

Capacity (ltr)	Dimensions (in)	Weight (lbs)
2	4 I.D. 12 Long	6
3	4 I.D. 18 Long	7
6	4 I.D. 32 Long	9
9	5 I.D. 31 Long	14

Clear Plastic

Capacity (ltr)	Dimensions (in)	Weight (lbs)
3	4 I.D. 18 Long	6
6	4 I.D. 30 Long	8

locally of stainless steel. The advantage would be to tailor the solenoid to the specific task thus reducing weight, and more importantly, reducing power required.

3. Inclinometer

The use of the entire craft as an inclinometer is recommended. The keel of Sea Otter is an effective base line and a line with a weight attached inside the hull will indicate slopes effectively and accurately. Attachment of a similar line to the manipulator will serve the same purpose for measuring small scale slopes. The line providing the vertical reference.

Light weight clinometers are also available commercially. A small (3 x 6 in.) plastic framed unit weighing six ounces provides readings in two degree increments. A larger model (1 lb., 2 x 6 in.) is available which provides readings in one degree increments. Estimated prices of the two inclinometers averages forty-five dollars [13].

The geology instrumentation package is listed in Table VI.

E. CHEMISTRY INSTRUMENTATION PACKAGE

The sample bottles, temperature sensor, pressure salinity sensor, lights and observation station required for chemical research have been previously described. An additional sensor which may prove worthwhile is a pH recorder. Several commercial concerns offer pH meters for use in-situ. Most of these sensors on the market at this time, however, share a common failing in that they do not predictably react to

TABLE VI

GEOLOGY INSTRUMENTATION PACKAGE

SENSOR	WEIGHT (LBS.)		CONDUCTORS	POWER	LOCATION	COST
	AIR	WATER				
Manipulator	3	2	N/A	N/A	Fwd. Cone	--
Sample Bag	1	.7	N/A	N/A	Fwd. Cone	--
Temperature	.87	.81	2	Battery	Various	$ 258.00*
Cameras	--	--	0	N/A	Inside	--*
Depth	4	3	3	Battery	Various	735.00*
Temperature Probe	4.2	3.2	2	Battery	Manipulator	--*
Sample Bottle (2--plastic)	12	10	3 (solenoids)	12 Volt	Equipment Brow	190.00*
Rustrak Recorder	3.5	3.5		Battery	Inside	135.00*
Inclinometer	0	0	0	0	Inside	0
TOTAL	28.51	23.21	10			$1,668.00

* Items available at the Naval Postgraduate School.

With the modified navigation package consisting of the pinger-locator, echo sounder, lights, underwater telephone, gyrocompass, magnetic compass and walkie-talkie (Table IV), total payload becomes:

	AIR	WATER	CONDUCTORS	COST
	62.39	57.03	13	$5,963.00

pressure changes. These units are little more than a common lab pH meter with the probes encapsulated for use in-situ. Such a unit can be developed locally but considerable testing would be required to produce a sensor which can be calibrated to the pressure fluctuations expected. Development of a lab sensor would require the use of an inverter to adapt to the DC power available on Sea Otter. Solid state inverters are available commercially and vary considerably in output and price. A particularly steady inverter (less than 2% variation in frequency) which costs about one hundred dollars and weighs twenty-nine pounds is available commercially. A less costly unit ($40.00) weighing eight pounds is also available but this unit does not provide as steady a source of power.

Until a suitable installation can be developed or purchased, sample bottles can provide a means whereby water is collected and delivered to the lab for determination of pH.

Table VII lists the proposed chemistry instrumentation package.

F. ACOUSTIC INSTRUMENTATION PACKAGE

A light weight system for collecting underwater sound signals has been suggested by Prof. H. Medwin of the Physics Department (private conversation). The proposed system consists of a hydrophone, a pre-amplifier and a two channel magnetic tape recorder. Components of the equipment recommended have been used recently by various members of the Physics Department. The solid-state pre-amplifier weighs

TABLE VII

CHEMISTRY INSTRUMENTATION PACKAGE

SENSOR	WEIGHT (LBS.)		CONDUCTORS	POWER	LOCATOR	COST
	AIR	WATER				
Sample Bottles (2-plastic)	12	10	3 (solenoids)	12 V	Equipment Brow	$ 190.00*
Temperature	.87	.81	2	Battery	Various	258.00*
Depth	4	3	3	Battery	Various	735.00*
Salinity	15	12	6	Battery	Various	975.00*
Rustrak Recorder	3.5	3.5	0	Battery	Inside	135.00
TOTAL	35.37	30.31	14			$2,293.00

* Items available at the Naval Postgraduate School.

With the modified navigation package consisting of a pinger-locator, echo sounder, lights, underwater telephone, magnetic compass, and walkie-talkies (Table IX), total payload will become:

	69.19	53.86	17			$6,588.00

approximately two pounds. This system provides a capability to record in-situ sound on one channel with appropriate voice annotation on the second channel of the tape recorder. Analysis of collected information is conducted later in the laboratory. Weight considerations preclude any real time analysis in-situ.

Prof. Medwin pointed out that the distance of the hydrophone from Sea Otter's hull should vary according to the frequency of the sound wave under study. Sound rebounding from Sea Otter can distort the signal being recorded if the wave length of the signal and the distance of the hydrophone from Sea Otter coincide. Several wave lengths separation is recommended. Low frequency sounds with their long wave lengths would require hydrophone placement at a considerable distance from Sea Otter. A boom affair to accomplish this would be both unwieldy and unsafe. Sea Otter's ability to handle items externally with the manipulator will permit placement of a hydrophone on the sea-floor, retiring to an acceptable distance while paying out a transmission line and then, recording the sound signal. Recovery is easily affected with the same manipulator device. Some consideration would be made for the stowage, payout, retrieval and re-stowage of the transmission line required for this operation.

Table VIII lists the proposed acoustic instrument package for Sea Otter.

TABLE VIII

ACOUSTICS INSTRUMENT PACKAGE

SENSOR	WEIGHT (LBS.)		CONDUCTORS	POWER	LOCATION	COST
	AIR	WATER				
Manipulator	3	2		--	Fwd.	*
Rustrak Recorder	3.5	3.5		Battery	Inside	$ 135.00*
Temperature	.87	.81	2	Battery	Various	258.00*
Salinity	15	13	6	Battery	Various	975.00*
Cameras			0	N/A	Inside	*
Depth	4	3	3	Battery	Various	735.00*
Sample Bottle (2-plastic)	12	10	3 (solenoid)	12 Volt	Equipment Brow	190.00*
Sound Taping Set	5	4.5	2	Battery	Various	Unknown
TOTAL	43.47	36.81	16			$2,293.00

* Items available at the Naval Postgraduate School.

With the modified navigation package consisting of the pinger-locator, echo sounder, underwater telephone, lights, gyrocompass, magnetic compass and walkie-talkie (Table IV), total payload becomes:

	77.19	60.36	19	$6,588.00

G. PHYSICAL OCEANOGRAPHY INSTRUMENTATION PACKAGE

Many of the instruments which will contribute to the knowledge of physical oceanography have already been discussed. These include temperature sensors, pressure sensors, lights, water bottles, camera, manipulator and salinometer.

A class of instrument which has extensive application in physical oceanography is the current measuring device. Both ducted and Savonious type current meters are available at the Naval Postgraduate School.

The Savonius rotor current measuring system which is recommended for Sea Otter is described in Fig. 14. This device is compatible with the Rustrak strip recorder so that continuous readings can be recorded. The mass of Sea Otter will influence the magnetic current direction portion of current measuring equipment. The direction will have to be deduced from visual observation of a vane or by positioning a current direction measuring device on the sea floor, retiring from the area to permit the devices uninfluenced measurement of current data, followed by a return to the area to retrieve the device.

An alternative available current measuring device is distributed by Marine Advisors. This current speed system is available with several different size ducted sensors (Fig. 15). These sensors are also compatible with the Rustrak strip recorder. The combination of the Savonius rotor, ducted rotor and streamers should provide an acceptable current measuring system.

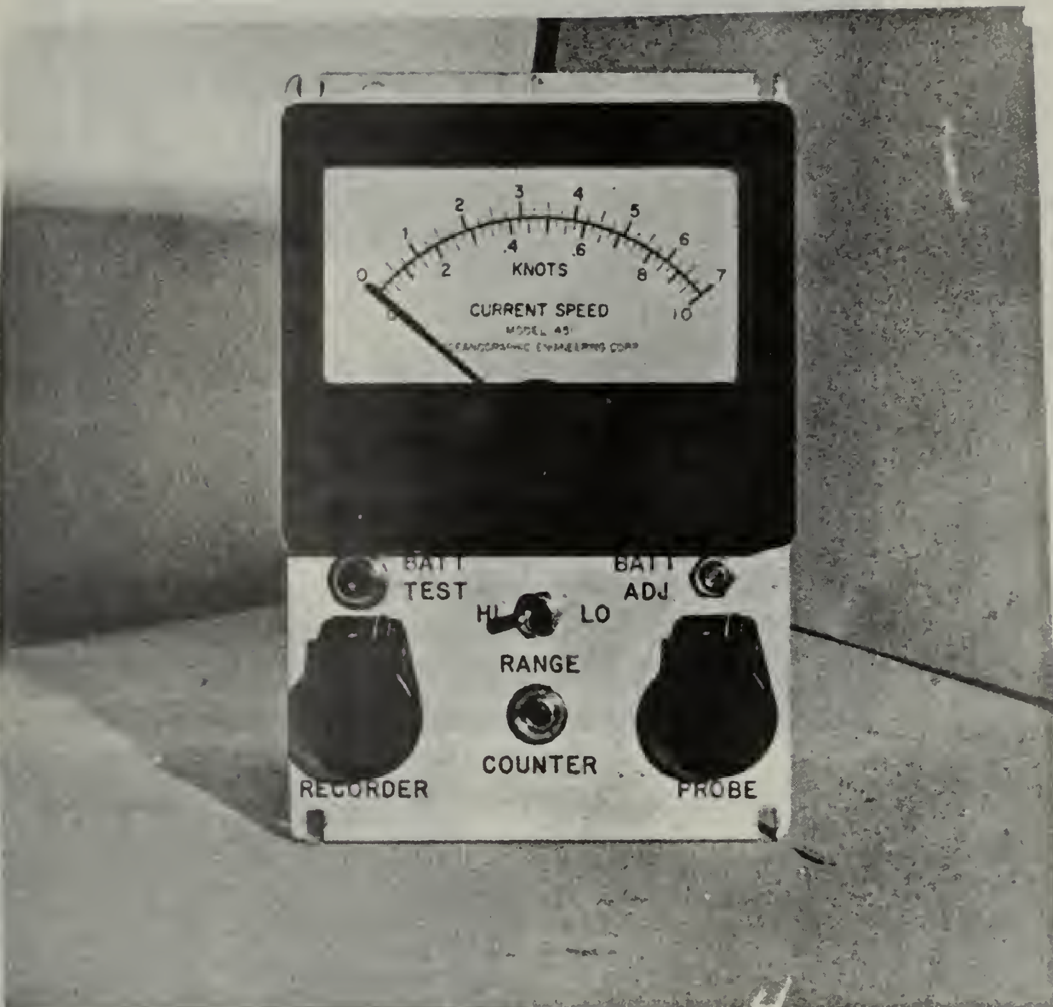
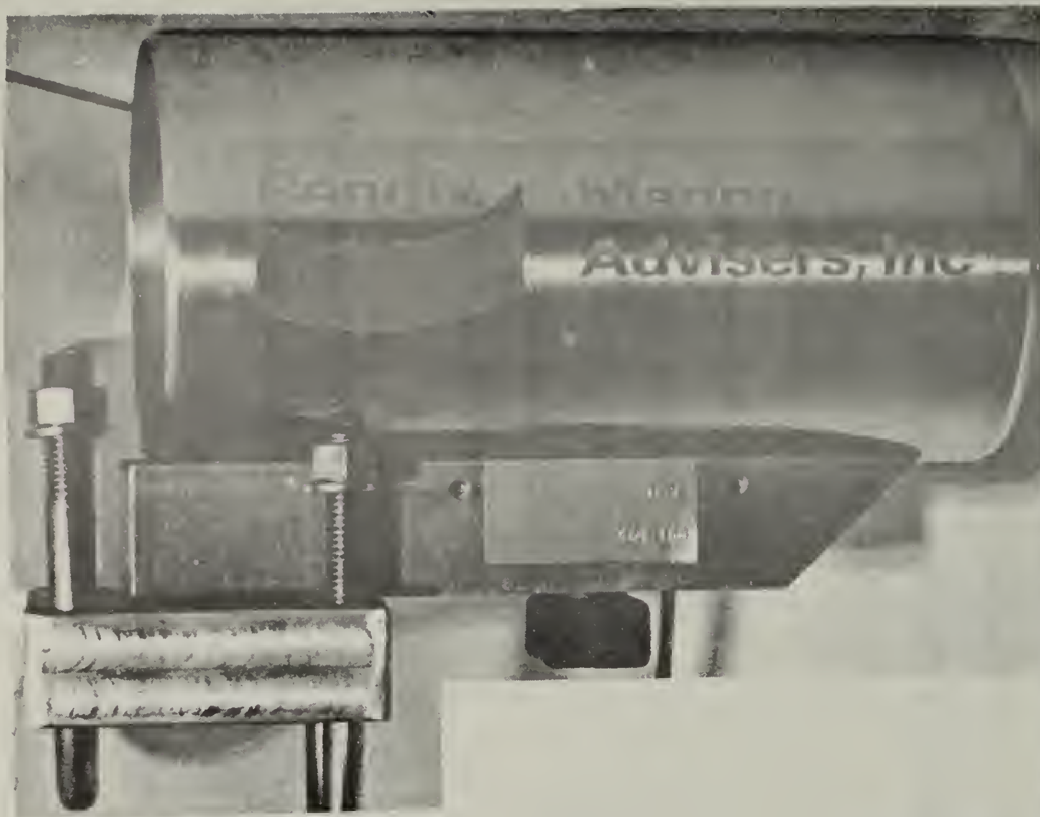


Figure 14. Hydro Products Current Measuring Readout

Current Speed Meter System
Hydro Products Models 460, 465A

Range:	.05 to 7.0 kts.
Scales:	Low 0 - 1 kt.
	High 0 - 7 kts.
Accuracy:	± 3% of reading
Depth:	To 40,000 ft.
Power:	Battery
Transducer:	Savonius rotor
Cost:	
Sensor	$395.00
Module	320.00
	$775.00



	Readout	Transducer
Accuracy:	± 2% full scale	± 2%
Range:	0-2; 0-10 kts.	0-10 kts.
Power:	Battery	Battery
Connectors:	2	2
Dimensions (in):	9 x 10 x 5	8 x 4
Weight (lbs.):		
Air	7	7
Water	-	6
Cost:	$395.00	$395.00

Figure 15. Ducted Current Measuring Device and Readout

Table IX lists the physical oceanography instrumentation package proposed for Sea Otter. Table X illustrates the breakdown of all the various equipment available and their various applications. The representative loadouts proposed for the various specific tasks should be modified for particular purposes. The addition of a compact tape recorder, for instance, would provide a convenient method for logging each research operation.

H. TOTAL PACKAGE COST

Table X indicates the equipment available at the Naval Postgraduate School, the equipment which can be manufactured locally, and the equipment which has yet to be obtained. In order that each package recommended can be utilized on board Sea Otter, this equipment must be purchased:

Underwater lights (7)	$ 350.00
Gyrocompass	surplus
Inverter for Gyrocompass	100.00
Magnetic Compass	20.00
Underwater Telephone (2)	3,000.00
Citizens Band Transceiver	100.00
Hull Penetrators	170.00
	$3,740.00

The acquisition of these items coupled with the equipment presently available at the Naval Postgraduate School will provide a considerable submersible oceanographic research capability. The purchase of the CB transceiver can be delayed while using available walkie-talkies for surface

TABLE IX

PHYSICAL OCEANOGRAPHY INSTRUMENT PACKAGE

SENSOR	WEIGHT (LBS.) AIR	WEIGHT (LBS.) WATER	CONDUCTORS	POWER	LOCATION	COST
Temperature	.87	.81	2	Battery	Various	$ 258.00*
Pressure	4	3	3	Battery	Various	735.00*
Sample Bottles	12	10	3	12 Volt	Equipment Brow	190.00*
Cameras	--	--	--	--	Inside	
Rustrak Recorder	3.5	3.5	0	Battery	Inside	135.00
Manipulator	3	2	N/A	N/A		
Salinometer	15	13	6	Battery	Various	975.00*
Current Meter (Savonus)	10	2.5	2			715.00*
Current Meter (Ducted)	8.5	7.5	2			395.00*
TOTAL	56.87	42.31	18			$3,403.00

* Items available at the Naval Postgraduate School.

With a navigation package consisting of a pinger-locator, echo sounder, lights, underwater telephone, gyrocompass, magnetic compass, and walkie-talkie (Table IV), total payload becomes:

	90.69	65.86	21	$7,698.00

TABLE X

EQUIPMENT COMPILATION

SENSOR	Manipulator	Sample Bag	Lights (7)	Cameras	Temperature	Salinity	Temp. Probe	Plankton Net	Depth	Sample Bottles (2)	Inclinometer	Vane Shear Mech.	Visco-Elastometer	Current (Savonius)	Sound Tape Set	Current (Ducted)	Wave Recorder	Strip Recorder	Gyrocompass	Magnetic Compass	Echo Sounder	Underwater Phone	CB Transceiver	Pinger	Walkie-Talkie	Total Conductors	PACKAGE WEIGHT (LBS.) AIR	PACKAGE WEIGHT (LBS.) WATER
Dry Weight (lbs)	3	1	2.5	-	.87	15	1	Var	4	14	0	UK	80	20	5	7	UK	3.5	3	.7	10.6	11	4	4	2			
Wet Weight (lbs)	2	.7	1.7	-	.81	13	.85	Var	3	10	0	UK	78	5	4.5	6	UK	3.5	3	0	8	8.8	4	0	NA			
Connectors	0	0	0	-	2	6	2	0	3	3	0	2	2	2	2	2	2	0	0	0	2	0	0	0	0			
Manufacture in House	X	X					X				X																	
Available in House				X	X	X		X	X	X		X	X	X	X	X	X	X			X			X	X			
External Purchase			X																X	X		X	X					
Package																												
Navigation			*																*	*	*	*	*	*		3	35.82	25.5
Biology	*	*	*	*	*	*		*	*									*								11	27.37	22.8
Geology	*	*	*	*	*	*	*		*	*	*	*						*								10	28.57	23.2
Acoustics	*			*	*				*						*			*								16	43.37	36.8
Phy. Ocn.	*		*	*	*	*			*				*			*	*	*								18	56.87	42.3
Chemistry			*		*	*			*	*																14	35.37	30.3

communications. The installation of underwater communications equipment in Sea Otter is essential to the certification of the craft [14].

IV. GENERAL SUPPORT EQUIPMENT

A. MANIPULATOR

Manipulators have undergone considerable evolution recently due to the requirements of several organizations. Any manipulator considered must have sufficient power for its intended tasks as well as sufficient movement through as many as eight degrees of motion (in, out, left, right, up, down and rotation left and right). The manipulators reviewed for this thesis can be broken down into several categories.

Hydraulic

Electrical

Mechanical

Combinations of the above.

Controls for each of these manipulators vary markedly from extremely simple mechanical devices to systems with integrated circuits and feed back systems requiring considerable space and power.

1. Sea Otter Restrictions

Sea Otter offers many restrictions to "off the shelf" manipulators in use today. The craft is extremely small and has little power to spare for auxiliary systems. A basic tenet of the Sea Otter project is to minimize cost which further eliminates from consideration all but a few manipulators.

The cramped quarters of Sea Otter offer an interesting problem in choosing a mounting position for a manipulator.

The battery cases obstruct much of the cylindrical portion of the craft where the maximum amount of space is available. At the same time this main body area has an external conflict in the ballast tanks. These considerations suggest that the most logical position for the manipulator be in the forward cone area.

Extenuating considerations with the manipulator is the necessity of having a viewport and a light adjacent to the device. A viewport is necessary to monitor operation of the manipulator. Consequently one must find room for installations of both manipulator and viewport in an already restricted area. Lighting is necessary in the same location to permit operation at the extreme depth limits of Sea Otter's capability.

Additionally, the entire installation, wherever it is located, must be designed so that the mechanism does not constitute a hazard by snagging anything which could impede or hold the craft.

2. Manipulator Design

Most of the manipulators reviewed were not considered feasible for installation in Sea Otter due to the weight and power required. The design recommended is a mechanical implement used successfully in the Nekton submersibles. It consists of two concentric stainless steel tubes which penetrate the hull through a flexible fitting. The design provides eight degrees freedom in movement, utilizes manual power, and is extremely light.

A significant advantage in this design is that it carries no patent and its developer, Mr. Douglass N. Privitt, of Nekton Incorporated, both recommends its use and has provided invaluable assistance and suggestions for reproducing the design (Figures 16, 17).

3. <u>Design Criteria</u>

Liaison with the Naval Postgraduate School machine shop indicates that the entire manipulator mechanism can be manufactured locally. The final design submitted for the manipulator is an amalgamation of Mr. Privitt's suggestions and those suggestions made by personnel at the Naval Postgraduate School machine shop reflecting materials available and mechanical competence.

In order that space and stress considerations can be minimized it is recommended that the manipulator and its adjacent viewport be mounted on the same base plate. This eliminates the necessity of cutting adjacent holes in the hull and welding separate inserts into these holes.

A-36 type steel should be used for the base plate since that is the material of Sea Otter's hull. The viewport is completed by mounting a six inch diameter by one inch thick plexiglass disk as indicated.

The manipulator itself consists of two concentric stainless steel tubes having handles and grapples for handling material underwater. Additional motion is built into the system by passing these two rods through a flexible fitting at Sea Otter's hull. This flexible fitting is a billiard

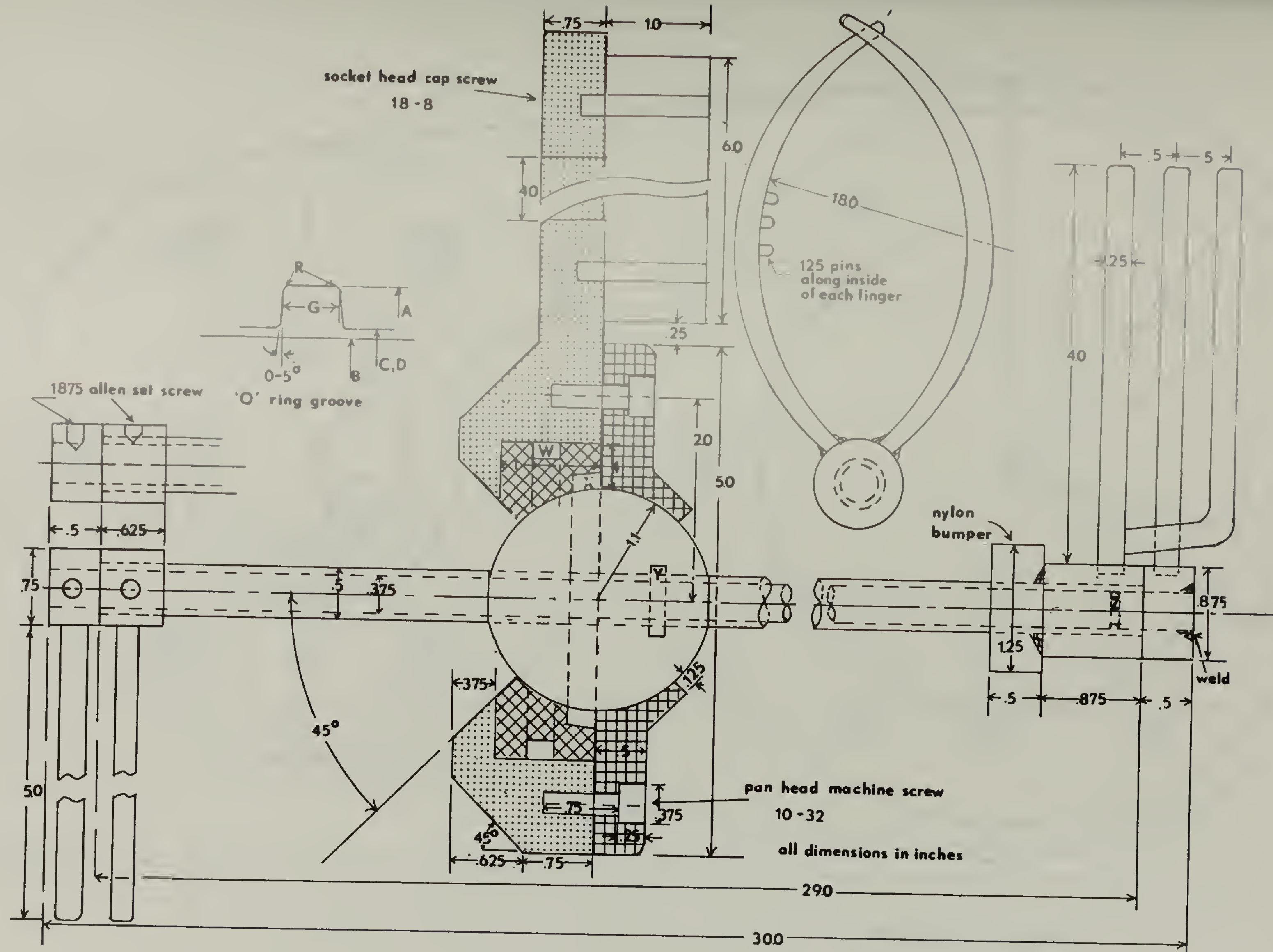


Figure 16. Manipulator

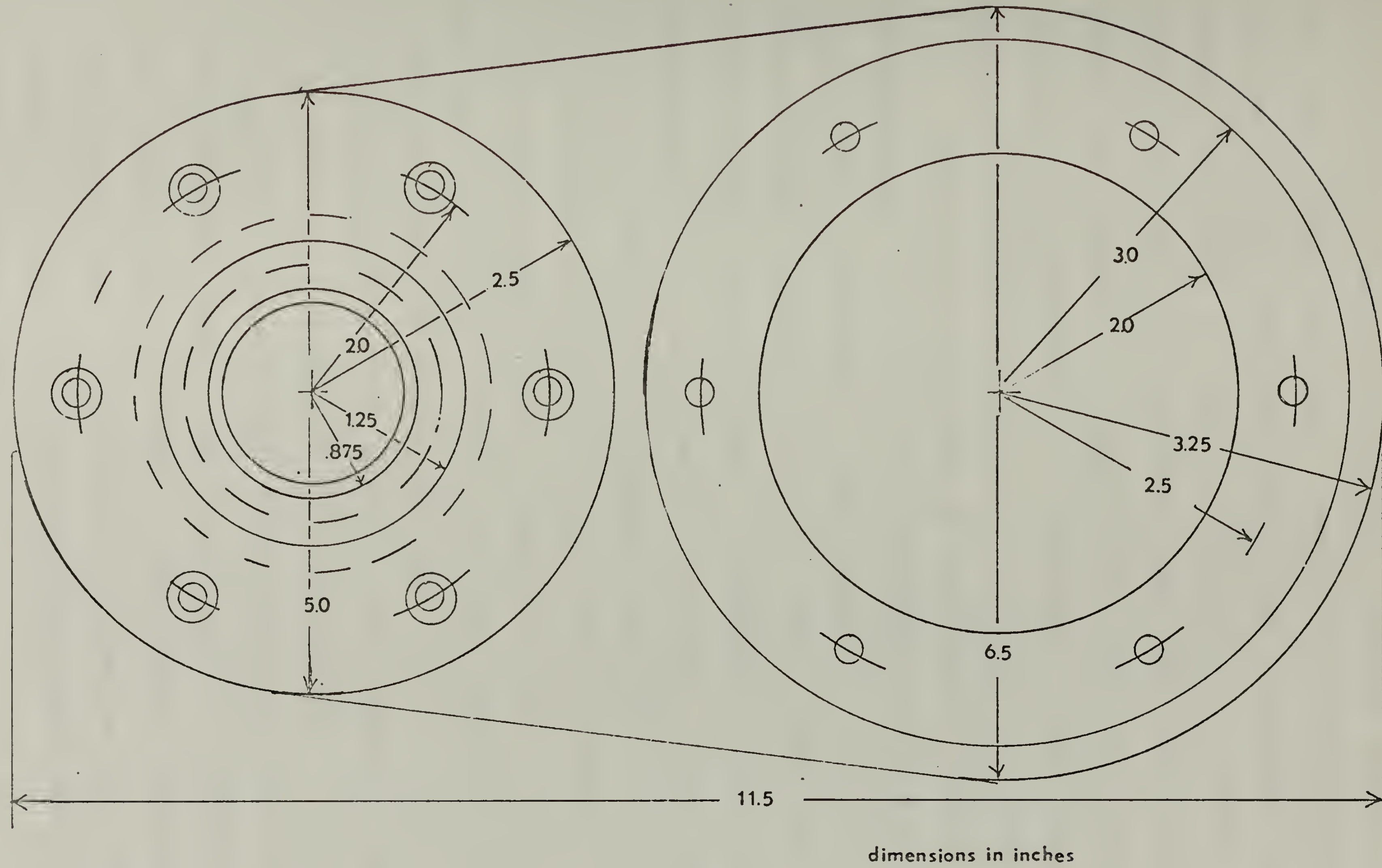


Figure 17. Manipulator, Hull Insert

ball drilled to permit longitudinal movement of the stainless steel tubes. The ball is sandwiched between a stainless steel 'donut' and plate which forms a pressure fitting through the use of 'O' rings. An attempt was made to replace the inner solid stainless steel rod with a lighter weight tube, however, the requirements of an 'O' ring made this approach impossible. 'O' rings used in the manipulator design as well as later designs are described in Table XI.

Several notes provided by Mr. Privitt (private communication) reflecting his experience with this particular manipulator are important to keep in mind. A maximum of ninety degrees movement of the ball joint, forty-five degrees either side of normal, is permitted. Sufficient bearing surface is otherwise not provided. A nylon bumper should be provided on the outboard side of the arm to protect the ball. A single 'O' ring in each location is sufficient to seal the unit. Doubling up the 'O' rings does not provide additional safety. In fact, pressure builds up between adjacent 'O' rings and causes one to blow out. Screws prescribed for the design are all stainless steel. It is further recommended that a guard should be constructed to shield the device against a glancing blow from forward. This guard will complete the installation and should surround the manipulator-viewport installation. The guard should be at least .25 in. thick, and enclose the light (Figure 1). Figure 25 shows the Nekton manipulator with adjacent light and guard.

TABLE XI

'0' RING SPECIFICATIONS*

POSITION KEY	W	X	Y	Z	SAMPLE BAG HOIST	BROW RELEASE
Size	335	330	112	011	011	011
Inside Diameter	2.725	2.100	.487	.301	.301	.301
Cross Section	.210	.210	.103	.070	.070	.070
Mean Outside Diameter	3.145	2.520	.693	.441	.441	.441
A Gland Groove	3.120	2.495	.676	.422	.422	.422
B Rod OD	2.748	2.123	.498	.310	.310	.310
C Male Gland OD	3.117	2.492	.674	.420	.420	.420
D Female Gland Bore	2.751	2.126	.500	.312	.312	.312
W Cross Section	3/16	3/16	3/32	3/32	3/32	3/32
L Gland Depth	.186 to .188	.186 to .188	.089 to .091	.089 to .091	.089 to .091	.089 to .091
G Groove Width	.281	.281	.141	.141	.141	.141
R Groove Radius	.020 to .030	.020 to .030	.005 to .015	.005 to .015	.005 to .015	.005 to .015

*Parker '0' Ring Handbook
Parker Seal Company, Culver City, Col.

Figure 18. Nekton Manipulator Arrangement

4. Manipulator Placement

The recommended position for the manipulator is on the port side of the forward cone below the centerline and three inches forward of the cylindrical portion of the craft. The oxygen tank and ballast bottles must be relocated to the opposite side of the craft from their present position in order to accommodate the proposed location. The reason for the port side placement is to favor right handed operators. The viewport should be closest to the operator. The light should be placed between the viewport and the manipulator. In this position the operator can lean forward from a sitting position and grasp the manipulator while peering out the viewport. The unit can be reached by sitting on the trim tank and bending forward over the battery cases. This position can be eased somewhat by replacing the battery cases by smaller units or by installing permanent battery boxes. The latter solution is recommended to reduce weight.

5. Complementary Equipment

A sample bag should be provided close to the manipulator in order that maximum use can be made of the device. This is effected by placing a winch mechanism on Sea Otter to lower the sample bag for filling, as well as to close and raise the bag for stowage when collecting operations are complete (Fig. 19). Manual operation of the mechanism is possible from within Sea Otter. The device used on Nekton is included as a guide for construction (Fig. 20). The sample bag is an ordinary canvass container with drain holes

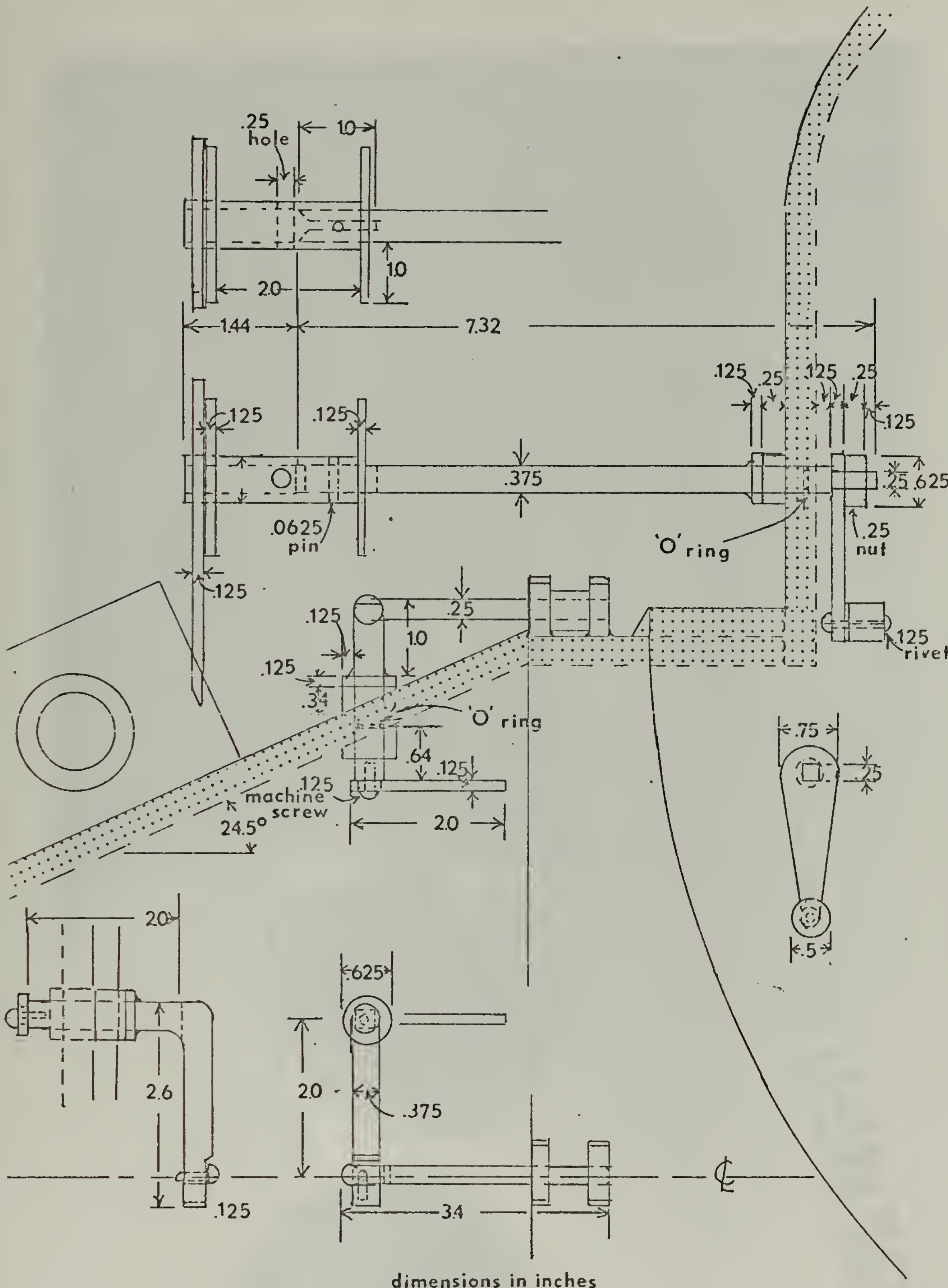


Figure 19. Sample Bag Control Mechanism and Equipment Brow Toggle Fastener

Figure 20. Nekton Sample Bag Mechanism

in the bottom and a hinged opening which opens automatically when released and closes when the bag is retrieved.

B. EQUIPMENT BROW

In order to expand the utilization of Sea Otter by providing a mounting area for sample bottles and other sensors, installation of a convertible equipment brow is recommended. Several considerations are indicated when contemplating such a device. The brow will add weight and at the same time provide a space to mount buoyancy units. Stability is a consideration although the installation recommended will balance itself. Consideration of stability will still be required, however, when mounting sensors on the brow. Attachment to Sea Otter must be such that installation and removal is easily accomplished. Facility of removal underwater from inside by the operators is a safety feature which must be incorporated in the design. The size and shape of the brow required should be influenced by the equipment intended to be used thereon and the overall design should not be so bulky or have so many protrusions that the hydrodynamic shape of Sea Otter is adversely affected.

1. Weight Considerations

Stainless steel fabrication of the equipment brow is recommended. The material and expertise necessary is available at the Naval Postgraduate School. The brow design (Fig. 21) proposed for Sea Otter requires about thirty-seven feet of tubing. A separate brow is proposed for each side of Sea Otter. Design of the port side unit is just the

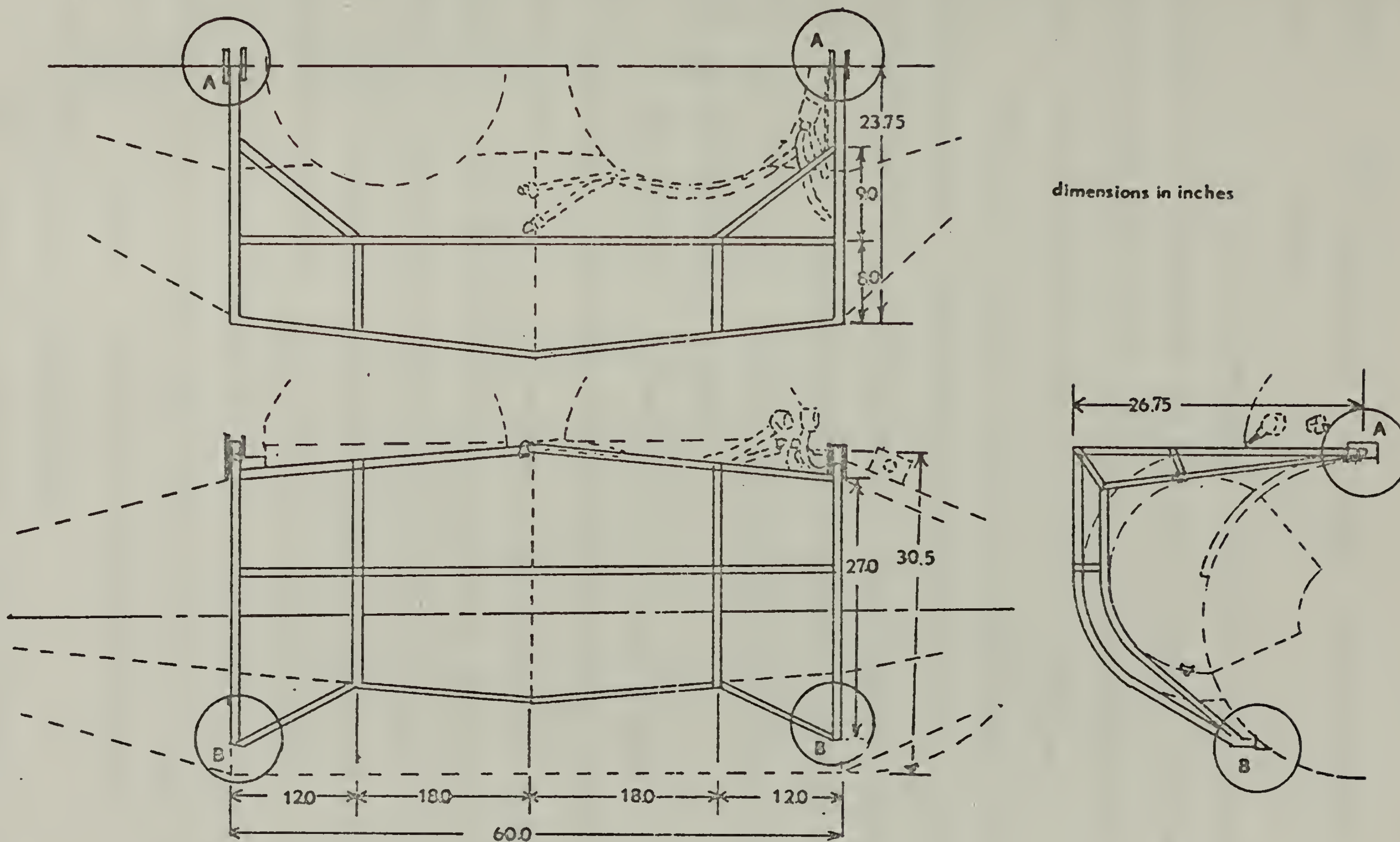


Figure 21. Equipment Brow

opposite of that depicted in Fig. 21. Weight considerations are:

Tubing	Wall Thickness	lbs./ft.	(X) 37.35 ft.	(X)2
.5 in.	.028	.141	5.3 lbs.	10.6 lbs.

It must be remembered, however, that the brow can be utilized as a mounting for buoyancy units. For each cubic foot of syntactic foam (34 lbs/ft.^{3}) attached, half on each brow, a thirty pound buoyant force is obtained.

Buoyant material should be added above the center-line to maintain and improve stability. It is recommended that any syntactic foam added to Sea Otter be fabricated to wedge between the equipment brow and the ballast tanks. This procedure will insure minimum disruption of view as well as hydrodynamic shape.

The weights quoted above are dry weights. Consideration has been given to sealing each of the tubular members of the brow to provide buoyancy and reduce the submerged weight. The limited buoyancy gained by sealing each brow member is offset by the increased weight required to make the brow strong and reliable enough in the face of repeated collisions with the support craft and the bottom. Therefore, it is recommended that each tube have sufficient penetrations to permit free flow of water so that they will not have to support hydrostatic pressure forces.

2. Installation and Removal

The operators of Sea Otter must be able to jettison the equipment brow and everything attached to it should

something become entangled underwater. This capability is provided Sea Otter by mounting the equipment brow on swival attachments on the underside of the craft and by securing the upper portion of both brows by toggle pins which can be operated from within Sea Otter.

Installation and removal of the brow is affected by operating the toggle pin which locks the brow to centerline channels adjacent to the forward and aft cone of Sea Otter (Fig. 22). The swival mounting (Detail B, Fig. 22) was derived from reference 15. By rotating the control lever ninety degrees the toggle pins locking the brow are removed permitting the weight of the brow and installed instruments to rotate away from and fall clear of Sea Otter. Care must be taken to attach all electrical connectors in quick disconnect blocks and oriented normal to the motion of the jettisoned brow so that the electrical connections will not tether the brow to Sea Otter.

3. Intended Use

The design proposed has incorporated member spacing which will permit installation of sample bottles, or other sensors at a variety of locations. Compensating buoyancy units can be fabricated in block form to be attached to the outside of the brow or formed in such a way as to be wedged between the brow and the ballast tank. The latter method is recommended to minimize the obstruction of the view and reduce the hydrodynamic impact of any additional shape.

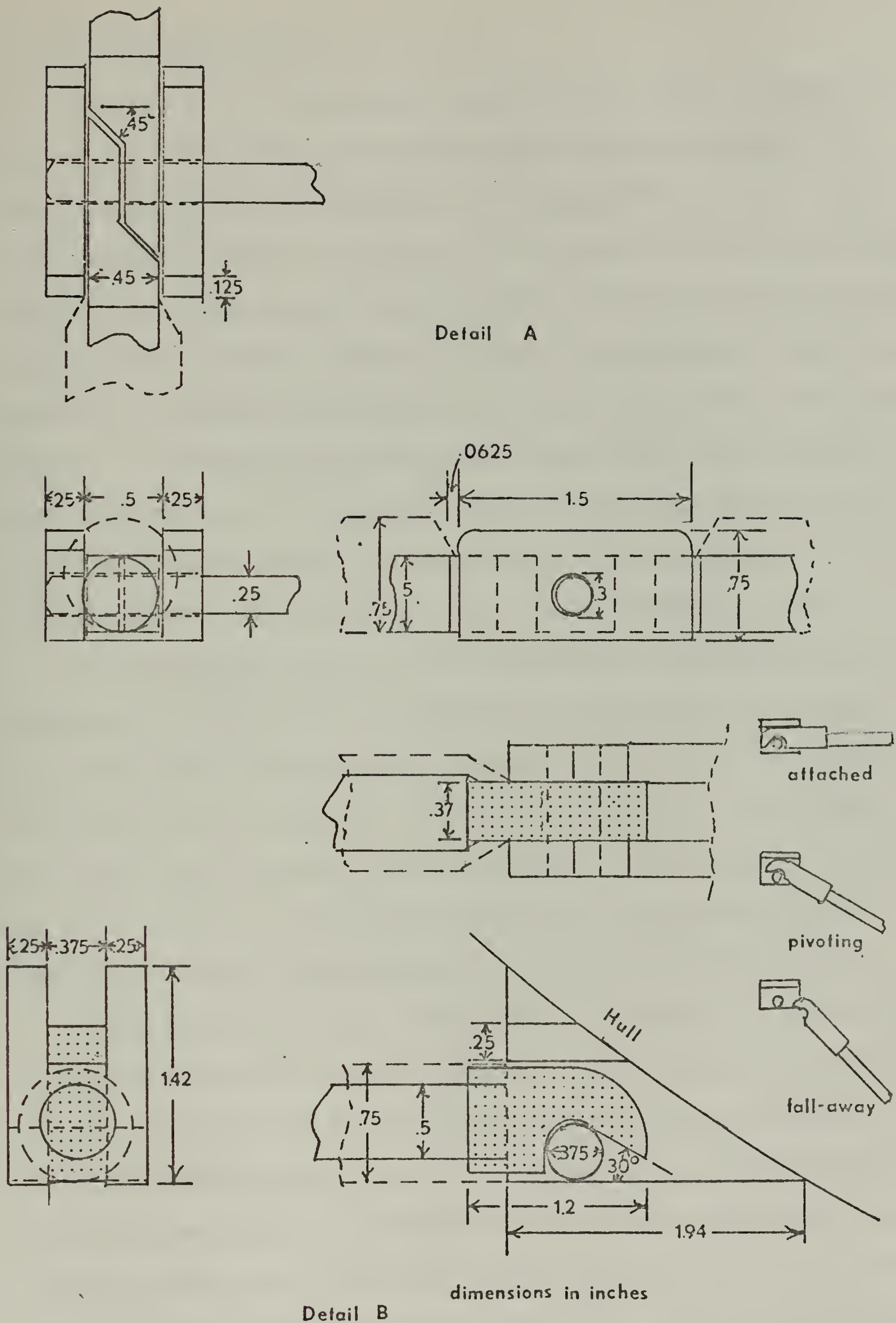


Figure 22. Equipment Brow Mounting Device

C. HULL PENETRATORS

Several hull penetrators must be provided in order to transmit collected information from installed sensors to the readout/recording apparatus on board Sea Otter. Considerations leading to selection of a particular penetrator include availability, load capacity, number of contacts and reliability. Prof. Tucker (private conversation) again provided the needed experience and logic to pin down the proper device. A commercially available unit with four contacts and constructed of stainless steel is recommended to fulfill the known requirements of Sea Otter. The bulkhead connector recommended is available for less than twenty dollars.

The amperage rating of the penetrator (Designated XSG 4BCL-P) is sufficient to handle any known load projected for Sea Otter and each unit incorporates a pigtail which will facilitate internal hookup and minimize the cluster of loose wires inside the submersible. One caution suggested by Prof. Tucker is that on purchase of the penetrators, spares and dummy plugs should be obtained concurrently.

Four penetrators are initially recommended. The sixteen circuits provided will accommodate every proposed load-out except the physical oceanography package which requires eighteen connectors. In this instance one redundant sensor can be eliminated to reduce the connectors required. Penetrators should be installed on the after conning tower with ninety degree spacing between each unit. Half inch tapped holes currently installed at forty-five and three hundred

fifteen degrees from centerline and three inches above the main body of Sea Otter should be enlarged to accommodate two of the penetrators. The other two penetrators should be installed on the back portion of the same conning tower.

Total projected cost for eight penetrators (one hundred per cent spares), stainless washers and sleeves and sixteen dummy connectors (for unused external contacts), would be about one hundred-seventy dollars. The penetrators recommended have extended applications in oceanographic research and can be suitably employed external to the Sea Otter package.

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V. STATIC ANALYSIS

A complete and accurate static analysis of Sea Otter configured with the several scientific packages proposed in this paper requires, as a starting point, the waterborn center of gravity of the craft. This information is not available at present and cannot be determined until Sea Otter is reassembled and tested in the water. Since Sea Otter is unique in its ballast tank configuration, knowledge of the center of gravity in another AMERSUB 300 will provide little more than a guess at the information desired. In order to proceed with a determination of what the addition of specific equipment will do to Sea Otter's stability an assumed center of gravity will be stipulated and all measurements will be taken from this point. In Figure 24 the assumed center of gravity has been indicated by ⊗. Should this assumed figure be found incorrect by later testing, the results of the following determination can be easily adjusted to the correct center of gravity.

A. ANALYSIS PROCEDURE

A method of vector bookkeeping has been developed in order that the effect of adding several sensors to Sea Otter can be controlled and coordinated. Equipment location fore or aft, left or right of the assumed center of gravity will be measured and multiplied against the particular sensor's weight. This figure will be positive if the mounted position of the sensor is either forward or to the right of

⊗, negative otherwise. An algebraic summation can then be kept on the net affect of adding several items to the craft.

The procedure will be demonstrated for the installation of the biology package and a navigation package. No attempt will be made to analyze each package proposed since the actual use of any particular package without modification is considered unlikely.

Table XII outlines the analysis and approach herein described. Measurement of the sensor location relative to ⊗ have been taken directly from the scale on Figure 24.

The analysis proposed does not include the effect of the recommended change in the ballast tanks. This change will have the desirable effect of lowering the center of gravity and will result in a more stable craft.

As long as the total weight of the equipment package is less than the maximum payload of Sea Otter (approximately 100 lbs.) and the resulting net moment is small, final trim can be accomplished with appropriate positioning within the craft of one pound lead weights. In the example shown in Table XII, lead weights must be added to make up the difference between the payload and the seventy-three pounds of equipment installed.

B. SURFACE STABILITY

Sea Otter's surface configuration is such that only the two conning towers are clear of the water. Since nearly all equipment and sensors added to Sea Otter will remain submerged, stability considerations for submerged operation pertain.

TABLE XII

STATIC ANALYSIS WORKSHEET

ITEM/SENSOR	WEIGHT (LBS.) (WATER)	LOCATION + FORE/AFT	LOCATION − FORE/AFT	LOCATION + RIGHT/LEFT	LOCATION − RIGHT/LEFT	MOMENT	NET MOMENT	MOMENT	NET MOMENT
Navigation Equipment									
1. Lights (1)	1.75	2		.5		+3.50	+ 3.5	+ .87	+ .87
2. (2)		2			.5	+3.50	+ 7.0	− .87	0
3. (3)		3.25			.7	+5.68	+12.68	+ 1.22	+ .35
4. (4)			2.25	.5		−3.98	+ 8.75	+ .87	+ 1.22
5. (5)			2.25		.5	−3.93	+ 4.82	− .87	+ .35
6. (6)		0		.6		0	+ 4.82	+ 1.05	+ 1.40
7. (7)	1.75	0			.6	0	+ 4.82	− 1.05	+ .35
8. Pinger	1.75		1.7	.7		−2.97	+ 1.85	+ 1.22	+ 1.57
9. Echo Sounder	7		.15		1.1	−1.05	+ .80	− 7.7	− 6.13
10. Transducer	1.6		3.5	.5		−5.6	− 4.8	+ .8	− 5.33
11. Underwater Telephone	7		.2	1.1		−1.4	− 6.2	+ 7.7	+ 2.37
12. Transducer	2.2		3.	.3		−6.6	−12.8	+ .66	+ 3.03
13. Walkie Talkie	2		0	0		0	−12.8	0	+ 3.03
14. Gyrocompass	3		0	0		0	−12.8	0	+ 3.03
15. Magnetic Compass	0		0	0		0	−12.8	0	+ 3.03
16. Equipment Brow	10.5		0	0		0	−12.8	0	+ 3.03
TOTAL	47.30								

TABLE XII

STATIC ANALYSIS WORKSHEET (continued)

ITEM/SENSOR	WEIGHT (LBS.) (WATER)	LOCATION FORE/AFT +	LOCATION FORE/AFT −	LOCATION RIGHT/LEFT +	LOCATION RIGHT/LEFT −	MOMENT	NET MOMENT	MOMENT	NET MOMENT
Balance	47.30						-12.8		+ 3.03
Biology Equipment									
17. Manipulator	2	3.25			.7	+6.5	- 6.3	-1.4	+ 1.63
18. Sample Bag	.5	3.25			.7	+1.62	- 4.68	- .35	+ 1.28
19. Camera	1	0			0	0	- 4.68	0	+ 1.28
20. Temperature	.75		.7		1.1	- .52	- 5.20	- .82	+ .46
21. Probe	.13	2.4		1.9		+ .31	- 4.89	+ .24	+ .70
22. Salinity	11.		.3		+ .65	+ 3.3	- 1.59	-7.15	- 6.45
23. Probe	4.	2.4		1.9		+ 7.6	+ 6.01	+7.6	+ 1.15
24. Rustrak Recorder	3.5		1.3		1.	- 4.5	+ 1.51	-3.5	- 2.35
25. Depth	1.	2.1		1.1		+ 2.1	+ 3.61	+1.1	- 1.25
26. Probe	2.		1.8	.6		- 3.61	0	+1.2	- 0.05*
TOTAL	73.22								

*Essentially no net moment

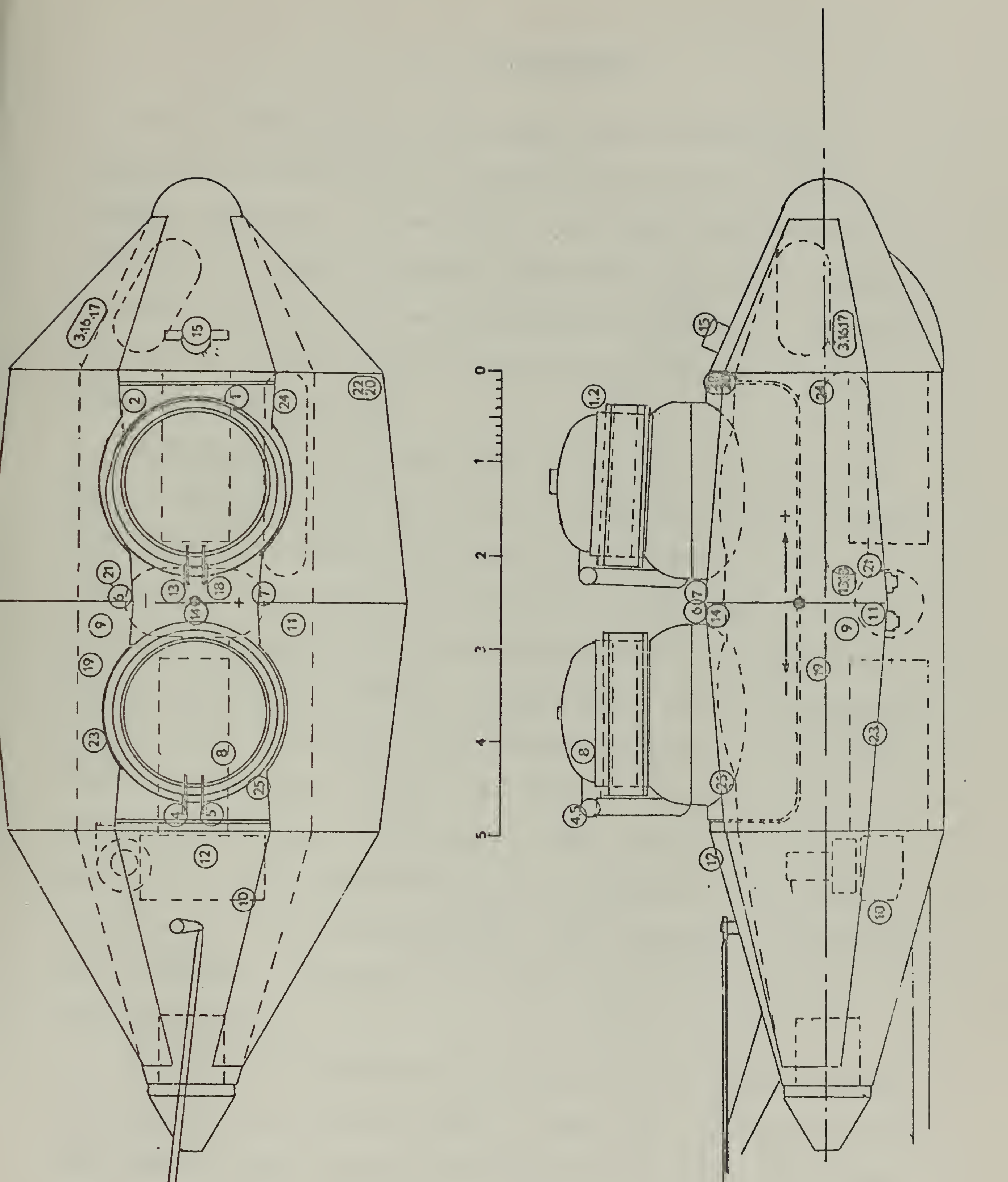

Figure 23. Static Analysis Diagram

VI. CONCLUSIONS

Small submersibles have unique and to some extent, unexploited capabilities to provide support for oceanographic research. In Sea Otter, the Naval Postgraduate School has a small, two-man, submersible which can provide a sensor platform from which extensive data can be selected, collected, and correlated with previously collected data and laboratory analysis.

Previous work with Sea Otter has shown that potential Navy certification of the craft is possible within a reasonable time if interest and support is expended in that direction. The general conclusion of this thesis is that with limited funding Sea Otter can provide a desirable and unique platform for several oceanographic research endeavors. Funding for the equipment recommended should not be charged wholly to Sea Otter, but to the general support of the entire Oceanography Department. Each sensor can, and should be, used independently or in conjunction with other equipment in other installations. The concept of dedicating any particular equipment to Sea Otter has been avoided wherever possible.

Provision of a research capability in Sea Otter depends on replacing the present ballast tanks with fibreglass units. The hundred pound payload provided by this modification permits a loadout of sufficient equipment to make pursuing the project worthwhile.

The several general support equipment recommended for inclusion in Sea Otter represent an attempt to expand the already considerable payload of the craft by providing space to mount buoyancy units as well as to provide additional external mounting locations for the several sensors available at the Naval Postgraduate School.

The potential benefit gained by completing the certification of Sea Otter, which will at the same time bring the craft to operational status, extends beyond the Oceanography Department. Ongoing projects in other departments of the Naval Postgraduate School require in-situ verification of laboratory data recently developed. Equipment developed for use in Sea Otter can find expanded use throughout the field of Oceanography, possibly in the larger, more expensive, deeper diving submersibles. Finally, the procedures developed for Navy certification of civilian designed and constructed submersibles can provide guidelines for the civilian submarine building community. Civilian built submersibles incorporating Navy procedures and requirements can be certified for use by government personnel. Not only will this situation provide additional craft for use by government laboratories, but will also provide incentive to build certifiable submarines by providing an expanded user population.

The direct and indirect benefits gained by completing the multiphased project directed toward certifying Sea Otter and then operating the craft suggest that continuing the project is worthwhile.

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3. ABSTRACT

A multi-phase project directed toward determining the suitability of a two-man, shallow depth submersible in oceanographic research is in progress at the Naval Postgraduate School. This thesis, Phase II of the project, addresses the instrumentation and potential oceanographic use of the craft. Based on previous submersible and habitat oceanographic operations, projected utilization of the craft, Sea Otter, has been specified for applications in biology, geology, acoustics, chemistry, and physical oceanography.

Modifications recommended to amplify Sea Otter's research potential include addition of an equipment brow and a manipulator as well as substitution of fiberglass units for the steel ballast tanks. Designs for the brow and manipulator are proposed. Equipment packages are suggested which will fulfill requirements of the stated applications. Proposed modifications and equipment meet several restrictive criteria including weight, cost, power, availability and Navy certification criteria.

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Oceanographic research						
Underwater equipment						
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