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A Submersible Diving System for Science

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ABSTRACT

As a result of the inventive ambitions of Edwin A. Link, Trustee and Vice President of Harbor Branch Foundation, Inc., a unique observation submersible with diver lock-in/lock-out capabilities has been developed. A second generation submersible christened the JOHNSON-SEA-LINK II in January 1976, it exhibits the characteristics of versatility, simplicity, safety, fast turn around between missions, ease of operation and comparatively low cost.

Framework, pressure hull, mechanical, electrical and pneumatic controls, as well as life support equipment, are divided into separate modular sub-systems. In all cases the removal of a module or a system for routine maintenance or repair is accomplished in minutes. Overlapping, cross-connecting or unitizing between systems has been avoided. The use of off the shelf components, when possible, and standardization of hardware helps to satisfy the five requisites. Extensive human engineering has provided a top to bottom, left to right logic to all control functions.

The objective of the submersible JOHNSON-SEA-LINK II is to provide the scientific staff of Harbor Branch Foundation, Inc. with a sophisticated oceanographic tool that will be operational 365 days a year. This paper discusses how that objective was met.

References and illustrations at end of paper

INTRODUCTION

The drive to preserve and improve our environment and the need to deal with the pollution problems created by prolific industrial technology are two of the major issues facing the United States today. Deterioration of the environment either real or within the realm of real possibility has generated concern and demand by a public that is growing increasingly aware of the threats. If it is accepted that the rivers and streams of the nation act, in part, as sinks, then it stands to reason the oceans are the ultimate sink, the final receptacle for the nation's unrecovered, untreated and unwanted waste and byproducts. What effect has it had, what are the capacities of these great bodies of water? Consider the importance attached to these questions by the Biological Oceanographers concerned with the oceanic eco-system. To measure the quantity of life and catalog the variety of life in the water column and on the ocean floor, there must be a base line with which to compare it. Since the eco-system can be rapidly altered by the introduction of an unnatural substance, sampling and observation must be by highly mobile means. The problems associated with the procurement of accurate in situ biological and physiological sub-surface data is well documented. It follows then that an important aspect of the requirements of the oceanographer and scientist is a means of rapid in situ investigation. Often the use of manned submersibles can offer many advantages for a quick and relatively inexpensive method of obtaining the much needed information.

OBJECTIVE

The Harbor Branch Foundation, Inc. has addressed this problem with the development of a system consisting of the Research Vessel JOHNSON and the deep diving scientific submersibles, JOHNSON-SEA-LINK I and II. The system design required a careful analysis of the objectives of the scientists and operating staff of the Foundation. Classical cost effective calculations were made along with typical engineering feasibility studies. To meet the goal with minimum compromise, the system was subdivided into eight major sub-systems, 1) structural framework, 2) acrylic pilot sphere, 3) divers compartment, 4) propulsion, 5) breathing gas and compressed air storage, 6) electrical energy sources, 7) life support systems and 8) instrumentation array. A description of the submersibles major sub-systems is given below. A complete description of the Research Vessel JOHNSON is contained in reference 1.

FRAME SYSTEM

A light-weight tubular aluminum exoskeletal framing system was adopted. In addition to the strength to weight advantage, the tubular frame concept lends itself to functions other than structural.

A system of controlled flooding of two tubular frame members provides a portion of the ballasting needed to offset diver weight during egress. The main buoyancy tanks also contain the variable buoyancy trim tankage which doubles as formidable collision barriers to the manned compartments.

The three major components of the submersible, are, the pilot sphere, divers compartment and mixed gas sphere. All three are nested within the protective frame in a manner which provides maximum access to each component for inspection and maintenance. The strongback, used for lifting purposes, is located on the centerline over the diver chamber. Un-bolting the strongback provides easy access to the three major components for quick removal or replacement. Attachment points for compressed air and mixed gas cylinders, navigational instrumentation and scientific research equipment are strategically located to provide interchangeability, accessability and ease of calibration or repair. A more detailed description of this unique frame system pertaining to materials specification and manufacturing procedures is contained in reference 2.

ACRYLIC PILOT SPHERE

The success of cyclic and implosion tests of acrylic pressure hulls has been well documented by the United States Navy's NEMO program, references 3 and 4.

The conceptual design of the submersible JOHNSON-SEA-LINK I included a spherical acrylic pressure hull with a 1000 foot seawater operational depth requirement. The original NEMO pressure hull had an operational depth limited to 600 feet. With modifications, it was possible to take advantage of the data generated in the NEMO program to design an acrylic sphere capable of a 1000 foot seawater operational depth. The modification consisted of increasing the nominal thickness of the 66" OD NEMO hull from 2.5 to 4 inches and replacing the thin steel polar penetration closures with thick aluminum plugs. Validation rationale of this modification for certification is contained in reference five. The acrylic sphere of JOHNSON-SEA-LINK I is a model of success, having logged over 200,000 foot hours of operation.

The decision to design a second generation JOHNSON-SEA-LINK submersible with a 2000 foot capability dictated an additional modification to the acrylic sphere. This modification consisted of inserting polycarbonate plastic gaskets between the rigid aluminum closures and the more flexible plastic hull. Improvement in acrylic fabrication technique provided fewer dimensional variations enhancing the overall quality of the completed hull. A complete account of the acrylic hull development for the NEMO and JOHNSON-SEA-LINK class submersibles is contained in reference six.

Employing a clear spherical hull with

unlimited panoramic visibility is a highly desirable feature for the scientific community. Such a feature is found on the JOHNSON-SEA-LINK class submersibles.

DIVERS COMPARTMENT

The aluminum diving chamber provides a comfortable 72 cubic feet of space for two working divers or two scientist observers.

A 6" viewport located on the forward hemisphere of the chamber affords visual communication with the occupants of the acrylic pilot's sphere. Two 10" viewports located in the port and starboard side-walls offer an excellent view of the surrounding sea floor and water column.

The bottom entry manway is fitted with two hatches. An outer hatch seals against water pressure during normal missions while an inner hatch seals against internal gas pressure during the decompression phase of a diver lock-out/lock-in mission. The chamber is also fitted with a two way medical lock enabling the transfer of materials and supplies during divers decompression. For extended periods of decompression, a flange welded to the manway enables mating of the chamber to a more spacious facility on board the support vessel. By transferring divers to a deck decompression facility, the submersible is free to continue the mission.

The divers compartment is independent and is equipped with its own atmospheric control system, emergency life support, communications and buoyancy override controls for surfacing the submersible in emergencies. Reference two contains additional information and data.

PROPULSION SYSTEM

The ideal propulsion system should exhibit good efficiency, be reasonably light in weight, reversible, have variable speed control, high reliability and be corrosion resistant and pressure proof at operational depths. In any practical system, however, some of these requirements may have to be compromised to achieve others.

Positive control of propeller speed is necessary when maneuvering or hovering. Reliable DC motor speed control is often difficult to achieve. Output shaft speeds in the range of 100 to 600 RPM is required for reasonable propeller efficiency and good control. But the addition of a motor controller introduces some extreme penalties, not the least of which is size and weight.

Speed controllers either of the resistant or electronic type are inherently noisy electronically, or waste valuable battery power in the lower speed ranges. Due to the sensitivity of some variable DC motor controllers, they become a maintenance problem when installed in an environemnt generally associated with submersible operations.

For submersibles operating at depths below 600 feet seawater, individual outboard thrusters and propulsion motors are desirable to avoid the problem of sealing a shaft passing through the pressure hull of the vehicle.

The obvious solution is to employ multiple low horse power thrusters that can be switched on and off independently for speed control. Further, if the thrusters are strategically placed on the submersible they can serve as an alternate means of maneuvering in the event of steering control failure. Last, but not least, failure of one or two of the thrusters during a mission would not necessarily be cause for abortion.

Propulsion motors designed for use in highly corrosive ambient seawater dictate a pressure proof housing constructed of resistant materials. Stainless steel, monel metals and copper nickel alloys are the most common. For the JOHNSON-SEA-LINK class submersibles, corrosion resistant aluminum alloys were selected for the fabrication of the pressure proof housing. Compared to aluminum, the commonly accepted metals are heavy and costly. Also, aluminum is readily available, is machinable and weldable, and can be anodized, providing an excellent dielectric in areas of electrical penetration, control relays and fuses.

The propulsion motor housing is constructed of 6061-T6 aluminum 6" OD by ½" wall tubing. The end closure that also serves as the relay mounting surface and electrical penetration block is machined from 3/4" 6061-T6 aluminum plate. The end closure containing thrust bearings and shaft seal is cast from 356-T6 aluminum in a conical configuration with the small end of the cone matching the geometry of the propeller hub. This small end is machined parallel to the propeller axis providing a mounting base for the Kort nozzle spider.

Reliability, to a great extent, depends on the effectiveness of the rotating propeller shaft seal. If seawater leaks past the seal, the motor will quickly fail. Also, considerable heat is built up within the motors pressure proof housing and seawater in small quantities may be sucked or aspirated into the motor during cool down, with consequent shortening of motor life. Owing to the excellent conduction properties of aluminum, heat build up within the pressure housing is held within limits. Aspirating and subsequent seawater intrusion during cool down of the motor does not occur.

A custom 14" diameter x 16" pitch four blade propeller turning at 500 RPM produced the thrust that ideally matched the multiple propulsion motor concept. A 28 VDC permanent magnet motor rated 1¼ HP @ 3200 RPM was selected. A 6.4 to 1 shaft speed reduction is accomplished through a planetary gear system.

Due to the low rubbing speeds produced by the slow turning 1" propeller shaft, sealing of the shaft presented no problems. Double "O" rings set into a 17-4 precipitation hardened stainless steel shaft bushing has been demonstrated to be extremely reliable by hundreds of hours of weep free service. Also, some of the success of preventing aspiration must be attributed to the effectiveness of this simple o-ring shaft seal.

A Kort nozzle effectively protects divers and swimmers from injury and enhances the efficiency of the propulsion motor.

Physical data and test results for the propulsion units are:

Air Weight	72 lbs.
Buoyancy	-41 lbs.
Voltage DC	28
Amperes	38
Static Thrust	120 lbs.

GAS STORAGE SYSTEMS

The total capacity of the submersibles compressed gas storage system is 5158 standard cubic feet. For practical purposes, the system is divided into four sub-systems identified as oxygen storage, divers mixed gas storage, auxiliary divers mixed gas storage and air storage. The composition and volume of gas to be carried in each of the sub-systems is mission dependent and is changed to meet the requirements of each planned operation. All high pressure gas storage vessels are located outside of the manned pressure hulls and are equipped with pressure relief devices and shut off valves.

The oxygen storage sub-system is divided into two separate and redundant O_2 supply systems. Each system consists of one standard T-cylinder providing 330 SCF of O_2 at a pressure of 2640 psi. A total of 660 SCF of O_2 is available providing 825 man hours of metabolic oxygen make up at one atmosphere.

The divers mixed gas is stored in a 38" OD aluminum sphere at 1900 psi providing 1769 SCF of pressurization and breathing gas to the submersibles diving chamber.

The divers auxiliary mixed gas subsystems consists of five standard T-cylinders piped in series affording 1425 SCF of pressurization and breathing gas at a storage pressure of 2640 psi. Depending on the depth of the planned diving mission, gas stored in the auxiliary system is held in reserve or used to support divers on open circuit breathing equipment.

Compressed air, used primarily for pressurization of ballast and buoyancy tanks, is stored in four standard T-cylinders providing a total of 1308 SCF of air at 2640 psi. For reliability, the air subsystem is also divided into two redundant systems. For safety, the regulation and distribution of the stored gases are controlled from the one atmosphere pilot's compartment of the submersible.

Emphasis were placed on the selection of compatible materials and hardware used in the control and distribution manifolds of each gas supply system. 304 Ostenetic stainless steel tube meeting ASTM specification A269 is used for high pressure gas transmission. Where gas velocities may be high, and in all oxygen systems, the bend radi of transmission tubing is held to less than 90^o. Pipe threads, 90^o elbow fittings, and valves that offer restrictions to the smooth transmission of high pressure gas were avoided. Fast acting valves that could induce adiabatic compression were eliminated from use in the more critical oxygen system.

Without exception, all high pressure gas transmission lines penetrating into the pressure hull of the submersible are fitted with manually operated shut off valves mounted on the hull at point of entry. High pressure or regulated pressure transmission lines exiting from the hull are fitted with one way check valves on the hull at point of exit.

The capacity and versatility of the

high pressure gas storage systems of the JOHNSON-SEA-LINK make possible diver lock-out and support activities to depths of 1000 feet and observations missions, not including diver activities, to depths of 2000 feet.

ELECTRICAL POWER SOURCE

One hundred and ninety two thousand watt hours of power at an amplitude of 14 and 28 volts DC is supplied by the main battery of the JOHNSON-SEA-LINK. The battery is made up of 14 two volt cells rated 1142 amperes at a six hour rate. The fourteen cells are contained as a unit in an oil filled and pressure balanced pod located external to the pressure hulls. To provide make up oil and compensate for temperature and pressure differentials, two five gallon flexible neoprene reservoirs are piped into the battery pod. Hydrogen gas pressure generated during battery recharging and to a lesser extent, during discharge, is vented through a spring balanced, dome loading pressure release valve designed by the Engineering staff of Harbor Branch Foundation, Inc. A sealed plexiglass cover provides easy visual inspection of the battery. Air weight of the assembly is 3300 lbs. with a water displacement of 1100 lbs. In an emergency, the assembly can be jettisoned providing the submersible with 2200 lbs. of positive buoyancy. All electrical conductors and battery condition monitors penetrating the pod are of the breakaway type. In the event the pod is jettisoned, all vital electrical circuits are transferred to the emergency battery.

Nine thousand six hundred watt hours at an amplitude of twenty four volts is available from the emergency battery. This system consists of two twelve volt lead acid aircraft batteries rated forty amperes at a ten hour rate. The primary purpose of the emergency system is to supply power for life support and communications equipment. The construction of the emergency battery pod is not unlike the main battery except it is not jettisonable. In addition to the main battery and emergency battery a nicad back up battery for life support equipment is located within the pressure hull. The electrical storage system of the JOHNSON-SEA-LINK is designed to supply sufficient power for an average ten hour mission and 120 additional hours of life support for a crew of four.

LIFE SUPPORT SYSTEMS

A prime consideration in the design and construction of a submersible that is to be manned and operated in a closed environment is the assurance of an acceptable life support system for the occupants. Provisions for metabolic oxygen replenishment and carbon dioxide removal are only the cornerstones of a pyramid of problems to be solved. The list of requirements and acceptable compromise become broad and complicated as the sophistication and mission capability of the submersible is advanced.

Use of off the shelf equipment is very desirable but available space and hull configuration often place severe limitations on the selection of life support equipment. The shape and bulk of commercially available CO_2 scrubbing systems excluded them for use in the spherical hull of the JOHNSON-SEA-LINK submersible.

Baralyme, soda lime and lithium hydroxide were the three CO_2 absorbing chemicals considered for use. Baralyme is less caustic and not as susceptible to dusting or caking, and is more desirable from the creature comfort viewpoint. However, baralyme becomes very inefficient at temperatures below 62^oF. Soda lime and lithium hydroxide exhibit good efficiency at the lower temperatures but can produce extreme discomfort due to their caustic nature if it becomes necessary for the submersible crew to change the chemical in the confines of the submersible.

The obvious solution then is to provide a carbon dioxide removal system that can safely employ the more efficient chemicals but not require servicing during over-extended missions.

Through a program of intense investigation and testing, a CO_2 scrubbing system was developed by the Research and Development staff of the Harbor Branch Foundation that met the requirements. The system has demonstrated excellent reliability and more closely matches the interior hull configuration. The CO_2 contaminated atmosphere of the submersible is diffused through the absorbent bed at the rate of once every two minutes. Charged with soda lime or lithium hydroxide an absorption and retention capacity of 16 man hours at 62^oF insures continued safe operation on extended missions. This CO_2 scrubbing system is employed in the diving chamber and pilot's sphere of the submersible, In the interest of safety, a magnetically coupled pressure and explosion proof blower was used to circulate the breathing gas through the scrubber. The scrubbing system in both the pilot sphere and dive chamber are filled with soda lime before each mission affording a minimum of 16 man hours each of CO_2 absorbency. For emergency use, a 240 man hour supply of lithium hydroxide is stored in each compartment in premeasured containers. A total of 20 man days supply of metabolic oxygen and CO_2 absorbent is maintained on board the submersible at all times.

Environmental contamination by emmission of smoke and toxic gases from fire or whole flooding of a compartment are emergencies than can arise and therefore must be considered.

The best possible solution is to supply each occupant with a self-contained closed circuit breathing apparatus. The Bio-Marine CCR-1000 closed cycle rebreather was adopted as the primary diving equipment by the Harbor Branch Foundation, Inc. It was therefore logical to employ this unit as the emergency life support equipment for the JOHNSON-SEA-LINK class submersibles. Again, size and configuration of the pressure hulls prevented the installation of the units as designed for diver use. Through close cooperation by the Engineering staff of Bio-Marine Industries, the standard rebreather was redesigned for compactness, versatility, and acceptable configuration. This approach to emergency life support offers many advantages over other open circuit systems. The full face mask and breast mounted breathing diaphragm can be disconnected from the rest of the unit and serves as a personal escape system much as the famed "Stanky" hood. Since there are no exhaust gases emitted from the closed cycle system, the potentially hazardous elevation of compartment pressure is avoided.

Two modes of operation, automatic and manual, assure system reliability. In the automatic mode, the partial pressure of oxygen is maintained at $\pm$ 10% of set point regardless of ambient pressure. Diluting gas is pre-selected from any one of the submersibles gas storage systems. Electrical power for automatic mode operation is supplied to the system from the submersibles main battery or emergency battery. In the event of total power failure, the system can be switched to an internal back-up battery that will afford a minimum of 10 hours continuous, unattended operation. Electrical power is not required for the manual mode operation. The oxygen partial pressure set point meter is driven by the galvanic action of the oxygen sensors. The operator need only maintain the desired oxygen set point by manually adding oxygen as it is consumed. Observing the set point meter about once every 15 minutes is sufficient.

Fire drills, simulated flooding and casuality exercises have demonstrated the closed circuit rebreather system to be a major advancement in emergency life support technology.

INSTRUMENTATION ARRAY

Submersible capabilities and mission requirements dictate the degree of instrument sophistication. The JOHNSON-SEA-LINK class submersibles are associated with the procurement of in situ biological and physiological data. It is expected that missions may be extended, or pre-planned transects will be diverted in the interest of data collection. To provide the highest degree of safety and lend maximum mission versatility to the crew and scientists, accuracy and fidelity were considered primary prerequisites in the selection of equipment.

Transient instrumentation and equipment such as recording C.S.T.D.'s, manipulators, bottom coring devices, strobes and cameras are mission dependent and are changed accordingly.

Table 1 is a list of "fixed" instrumentation that is permanently installed on the submersible.

SUMMARY

Due to the broad spectrum of engineering disciplines required to assemble a sophisticated submersible for science such as the JOHNSON-SEA-LINK class, it is impossible to address any one discipline and subsequent application in detail. The objective of this paper is to present sufficient data to the reader that demonstrate the problems of design confronted and solved by the Engineering staff of Harbor Branch Foundation, Inc.

Due to the complexity of the design and manufacturing techniques of some of the major components of the submersible, a liberal roster of reference material is included for comprehensive study.

ACKNOWLEDGEMENTS

The framework for the submersible JOHNSON-SEA-LINK II was constructed at the Harbor Branch Foundation, Inc. facility in Fort Pierce, Florida. Reference 2 describes an identical frame manufactured by the Aluminum Company of America for this Foundation's first submersible

JOHNSON-SEA-LINK I.

The diving chambers of the submersibles JOHNSON-SEA-LINK I and II were manufactured by the Aluminum Company of America. The chambers are identical except the hemispheres, medical locks and forward view port of number II were electron beam welded by General Electric at their Pennsylvania facility.

REFERENCES

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Table 1

<u>Surface Communications To Support Vessel And U. S. Coast Guard</u>

Primary...............Motorola F.M. Transceiver-Mocom-35
2 Channel - 15 Watt - Vessel's Battery

Secondary.............Motorola F.M. Transceiver - HT 220
2 Channel - 5 Watts - Internal Batteries

<u>Internal Communications to Divers Compartment and Divers</u>

First Primary.........Helle Divers Intercom - Mod.-10
2 Channel - 2 Watt - Vessel's Battery

Second Primary........Harbor Branch Foundation, Inc. Noise Cancelling 2 Way Intercom

Secondary.............LuBell Laboratories, Inc. Mod. GD-18 Address Amplifier With Underwater Loudspeaker

Back-Up...............Hand Held Sound Power Telephone

<u>Underwater Communications to Support Vessel and Sister Submersible</u>

Primary...............Straza Underwater Telephone - ATM-504A
500 Watt - Vessel's Battery

<u>Navigation and Obstacle Avoidance</u>

Sonar.................Straza Mod. 500 CTFM Scanning 1,500 Yard Range

Navigation............Sperry Doppler Sonar Navigation System Mod. SRD-101

<u>Position Location and Submersible Tracking</u>

Sonar Transponder.....Straza Mod. 7030 - Support Vessel Mounted. Responds to Interrogation From Submersible.

Sonar Transponder.....Vickers - Submersible Mounted. Responds to Interrogation From Support Vessel

Transmitter...........Straza Mod. 7050A - Submersible Mounted. Continuous Transmitting 9 and 45 KHZ @ One Pulse Per Second

Transmitter..........Straza Mod. 7050B - Submersible Mounted. Continuous Transmitting 37 KHZ @ One Pulse Per Second.

Transmitter..........Helle Mod. 2460/1113 - Submersible Mounted. Continuous Transmitting 37 KHZ - 20 Watt

Fathometer...........Heath Mod. M1-101. 0 to 600 Feet

Messenger Buoy........Harbor Branch Foundation, Inc. Releasible Submersible Mounted.

Flasher..............Pelagic Electronics, Inc. Mod. 4133. Xenon Beacon.

Aerial Signal.........Harbor Branch Foundation, Inc. 37 MM Parachute Flare. Submersible Mounted Through Hull Ejection.

Underwater Illumination........Birns and Sawyer Lamps. Two Each Mod. 5562. Two Each Mod. 5565.

Atmospheric Control and Monitoring

Cooling and Dehumidification....Harbor Branch Foundation, Inc. Externally Mounted Chilled Water Circulating - Pilot's Sphere Only.

CO_2 Analyzer Primary............Beckman Minos A.C.D.M. Continuous Monitoring

CO_2 Analyzer Secondary...........Bendix Gastec, Manually Operated

Oxygen Analyzer Primary............Beckman Minos A.O.M. 6602, Continuous Monitoring

Oxygen Analyzer Secondary...........Bio-Marine Mod. OA222, Continuous Monitoring

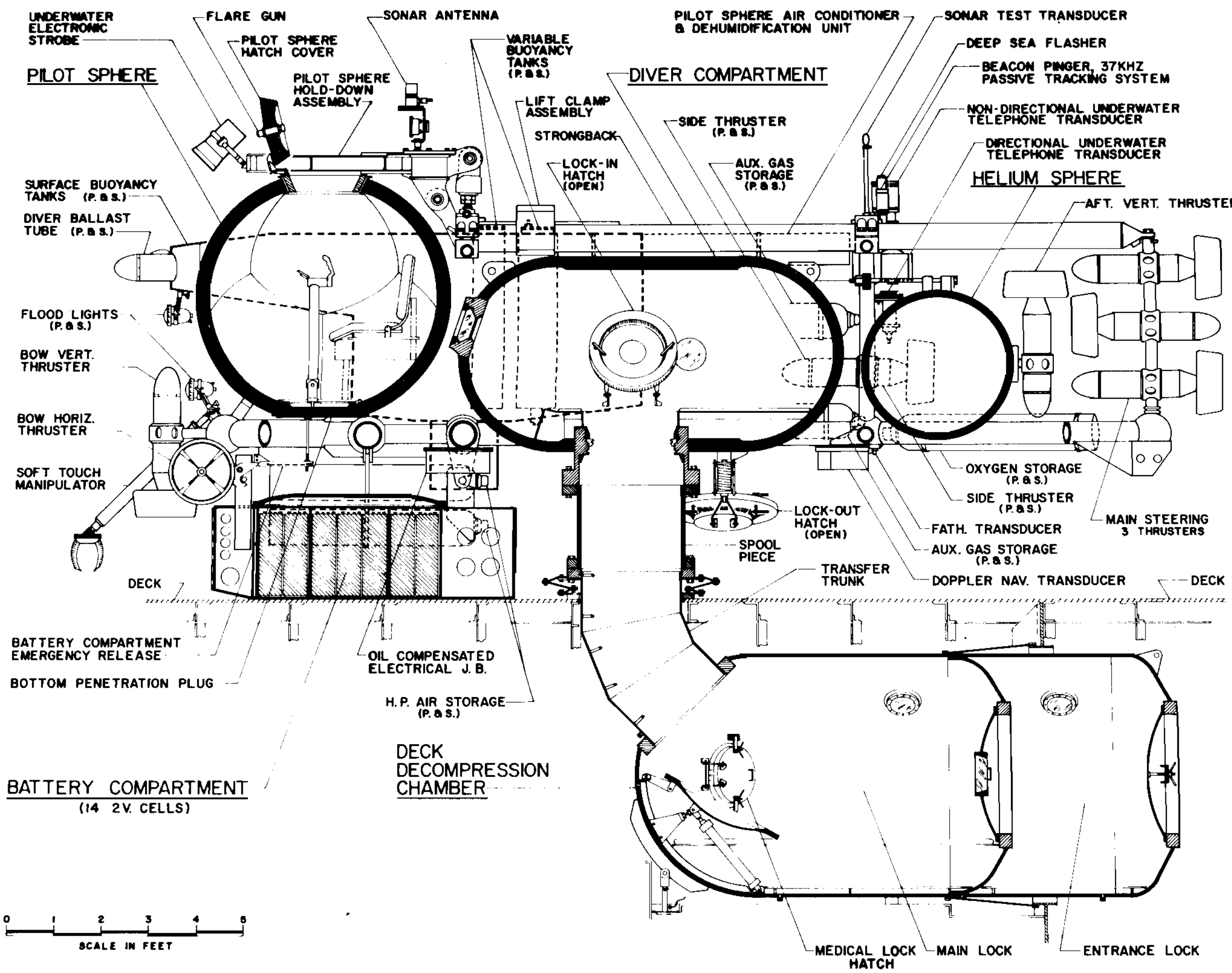

FIG. 1 - INBOARD PROFILE - JOHNSON-SEA-LINK II SUBMERSIBLE & DECK DECOMPRESSION CHAMBER.