MANNED SUBMERSIBLE DEVELOPMENT AT GRUMMAN

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Introduction

The exploration and exploitation of the world oceans has been greatly stimulated in recent times by the development of an ever-increasing number of manned submersible vehicles. The vehicles to date range from small, lightweight and highly maneuverable vehicles such as Alvin, Deepstar 4000 and the various Star series boats to the larger, heavier and less maneuverable vehicles such as the Aluminaut and Auguste Piccard. In addition, the bathyscaphs Trieste and Archemede have permitted manned exploration of the greatest depths. Thus, a large selection of submersibles is presently available, each more or less tailored for a specific range of mission tasks. It is interesting to note that most of the available vehicles are relatively small with a limit on the number of occupants from 2 to 4. The habitability afforded by the majority of these small submersibles is also extremely limited providing free volumes of from 35 to 60 cu ft/man. These values compare with approximately 53 cu ft/man for the Gemini spacecraft. The limited mobility afforded the occupants in the small submersibles is perhaps the major influence which dictates the small amount of submerged stay time permitted.

Within the next few years, we at Grumman anticipate an increasing need for larger, more habitable submersibles which will be capable of operating at continental shelf depths for periods of days rather than for periods of hours. Some of the benefits to be derived from this approach include:

- It provides a vehicle which can carry groups of scientists or teams for research into the research area at the same time thus permitting simultaneous observation of the same undersea phenomenon.
- Trained scientific team members need not be cross trained in boat operation in order to provide operating crew backup.
- It permits continuous submerged observation for long periods of time and in relative comfort.
- It permits observer rotation and relief in search type missions.
- It provides absolute payload capability for large amounts of internally carried equipment. This equipment can be of conventional design and need not be specially developed to fit into small irregular shaped spaces.

Recognizing the need for a large, long stay time submersible capable of providing habitability for six or more occupants, Grumman has undertaken the development of a prototype vehicle. The submersible will evolve from a design conceived by Jacques Piccard and will be similar in certain respects to Piccard's earlier mesoscaph PX-8, the "Auguste Piccard." The code name for the first prototype vehicle is PX-15. The PX-15 is being constructed in Europe, with completion of tests expected in early 1968.

The PX-15

Gulf Stream Drift Mission

The first anticipated use of the PX-15 will be to perform a submerged drift in the Gulf Stream from a point near Miami, Florida, to a point off Halifax, Nova Scotia, a distance of approximately 1450 nm. This mission was conceived by Jacques Piccard and will permit a team of scientists to remain in the depths of the Gulf Stream continuously for several weeks and achieve a comprehensive survey of day-to-day phenomenon. In addition to the scientific value of such a venture, we will derive a considerable amount of useful experience in the operational problems associated with a large submersible. The lessons learned during this mission will assist us in determining what design changes, if any, will be required for later missions.

Preliminary studies have indicated that the most suitable depth to be explored during the first drift is about 200 meters. However, from this depth it is expected that periodic excursions will be made up to 100 meters and down to 400 meters. At 200 meters depth, the temperature in the middle of the stream will be between 15° and 17°C. As the temperature of the stream increases toward the east, the drift can be controlled by monitoring the temperature changes and periodically propelling the submersible back to the desired isotherm.

The average speed of the Gulf Stream off the American shore is about 4 knots at the surface, 1.5 to 2 knots at 200 meters and 1 knot at 400 meters depth. In addition, the stream flow varies with the time of the year, providing higher speeds in May and lower speeds during October. With an average submerged depth of 200 meters, the average speed of the PX-15 is expected to be 1.5 to 2 knots for the entire trip. Thus the distance traveled per day will be between 36 and 48 nm. The anticipated mission duration will, therefore, be between 4 and 6 weeks.

Since the PX-15 will remain continuously submerged throughout the mission, it will not be able to determine its position accurately in latitude and longitude. It is essential that all data recorded during the drift be correlational with respect to depth, latitude, longitude and time. For this reason, a surface support vessel will be used to track the course of the submersible throughout its drift. The support vessel will be equipped with suitable communications and navigational equipment to permit position fixing with respect to shore installations while establishing the position of the submersible with the aid of sonic detection gear.

At the start of the mission, the PX-15 will be towed to its dive point off Miami. Self-propelling to the dive site does not appear practical in view of the limited amount of electrical energy that can be provided. A tow to port at the termination of the drift will also be required. Much of the external configuration of the vessel must, therefore, be designed to withstand the wave slap conditions resulting during the towing operations.

A primary requirement of the mission will be to permit silent, stable operation at various depths. As a result, the PX-15 has a variable buoyancy capability which will permit precise adjustment of vehicle displacement. In order to minimize the requirements on the variable buoyancy system, the PX-15 has been designed to have a bulk modulus greater than that of sea water, i.e., it will be less compressible than its surrounding environment thereby permitting the vehicle to establish any desired equilibrium depth. The compressibility characteristics of the PX-15 are such that a difference in ballast of one pound will effect a change in depth of approximately 10 feet at constant temperature. However, the actual change in ballast required to provide a predetermined change in depth is rather complex since it is affected by the change in water temperature with depth and the heat generated within the cabin by both occupants and equipment. As a result, the vehicle is not expected to arrive at a stable equilibrium depth or even a small amplitude system before one day or more after a dive has been initiated unless the variable ballast system is used actively.

Configuration

The general arrangement and the current internal arrangement of the PX-15 is presented in Figures 1 and 2. A summary of the vehicle's chief characteristics follows:

Weight	130 tons
Length	48'
Beam	13'-4" without motors; 18'-6" with motors
Height	20'
Max. Operational Depth	2000 ft.
Collapse Depth	4000 ft.
Battery Capacity	750 kwh (1000 hr. rate)
Propulsion	four 25-HP, three-phase, variable-frequency electric motors
Power Conversion . . .	two variable-frequency, solid-state inverters powering the main propulsion motors two fixed-frequency, solid-state inverters powering the propulsor pod rotational motors one fixed-frequency, solid-state inverter powering various on-board equipment
Visibility	29 viewports (placed to permit all around visibility)
Payload	5 tons minimum
Life Support	6 men for 4 weeks plus 2 weeks emergency reserve
Emergency Droppable Ballast . . .	5 tons
Max. Submerged Speed	in excess of 4 knots

The structural arrangement of the hull, shown in Figure 3, consists of a ring-stiffened cylinder with hemispherical end closures. The hull is fabricated of 1-3/8-inch thick steel plate having a yield strength of 80,000 psi. Structural rings spaced uniformly along and inside the hull provide sufficient support to the shell to permit safe operational depth to 2000 feet while maintaining a margin of safety of 2 on hull collapse. This combination of hull plating and reinforcement also provides a hull bulk modulus in excess of 400,000 psi.

In order to permit relatively easy modification of the hull for future missions, the initial design makes use of a hull mechanical joint located near the center of the hull and employs integral hull flanges which are bolted together. Low pressure sealing is provided by a conventional "O" ring seal while high pressure sealing is provided by metal to metal contact of the machined mating surfaces. This separation joint will permit future hull modifications for more advanced vehicle uses which will be discussed subsequently.

Two "soft" main ballast tanks are mechanically attached to the hull, one on each side, and provide

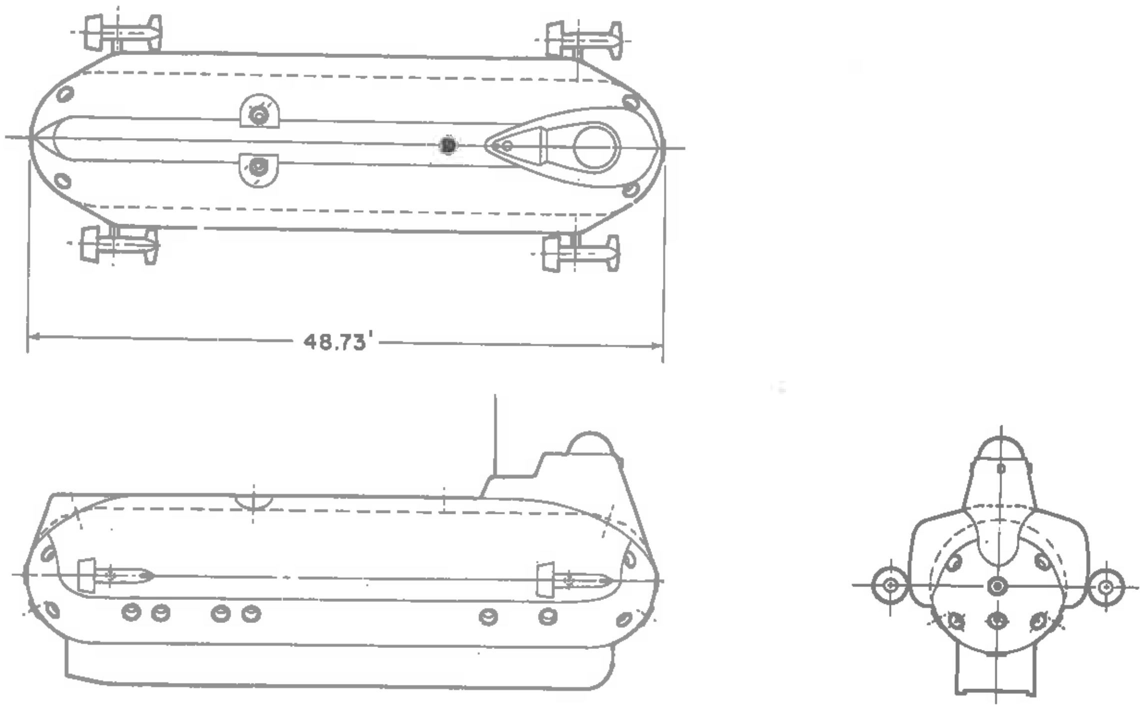

FIGURE 1. PX-15 GENERAL ARRANGEMENT

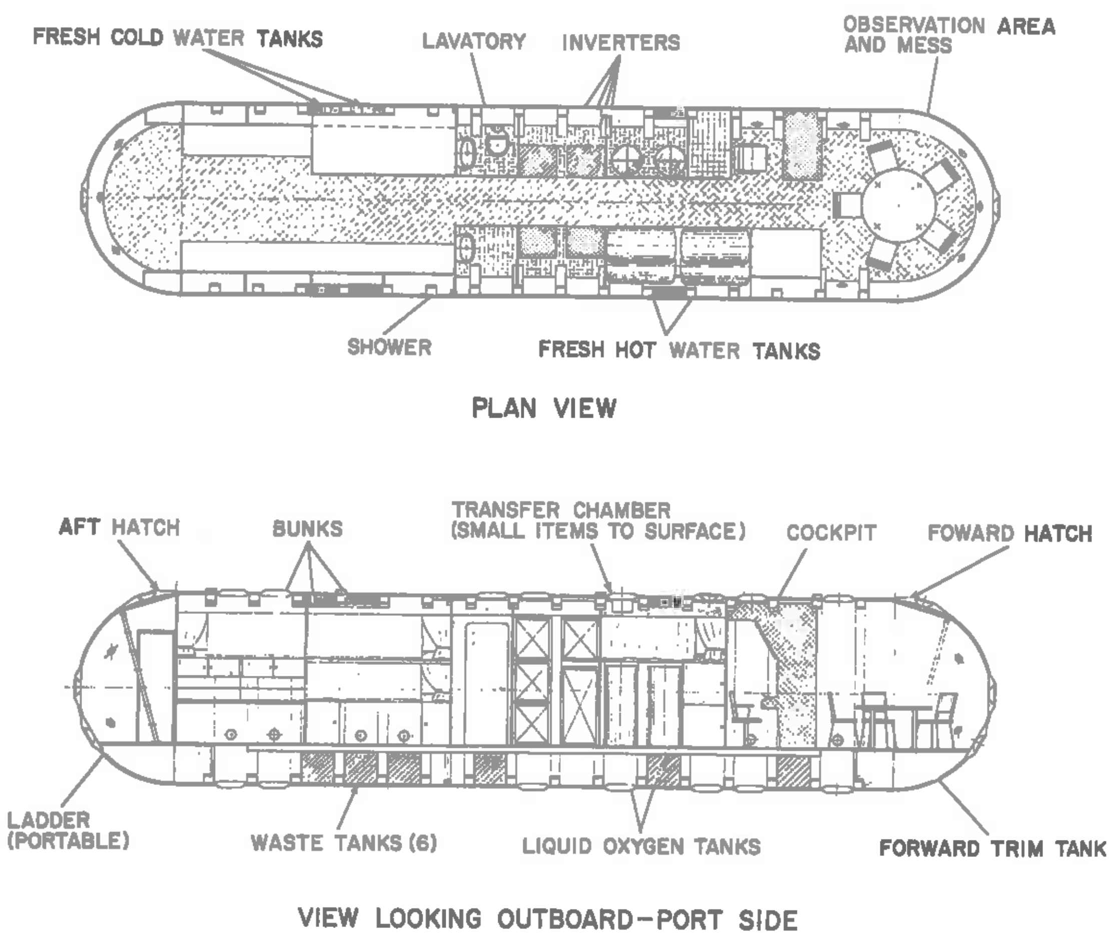

FIGURE 2. PX-15 INBOARD PROFILE

additional buoyancy to the vehicle when it is surfaced. This additional buoyancy provides adequate freeboard to permit ingress-egress through either of the vehicle's two hatches. These main ballast tank assemblies are normally completely flooded during submerged operations. Diving from the surface is accomplished by permitting water to enter these tanks from the bottom while air is vented off at the top. After surfacing, stored compressed air, carried in high-pressure tanks located in faired compartments above the main ballast tanks, is valved into the main ballast tanks at the top, blowing out the entrained water at the bottom.

Variable buoyancy control is provided by two pressure-resistant ("hard") tanks located beneath the hull in the lower keel section. The vehicle is neutrally buoyant near the surface when these tanks are half full of water. Allowing water to enter or blowing water out by compressed air provides vertical maneuvering capability for the vehicle within its operational depth limit.

Electrical power is supplied by lead-acid batteries housed in the free-flooded keel section. These batteries are pressure-compensated to sea ambient, and consist of up to 378 individual cells connected in series-parallel. They provide 168 VDC to two fixed frequency inverters which power the propulsor positioning motors and 336 VDC to two variable frequency inverters which power the main propulsion motors. In addition, the battery provides 112 VDC for exterior lighting and 28 VDC for on-board equipment. It is interesting to note that the weight of batteries carried is roughly 25% of the vehicle gross weight.

Propulsion for the PX-15 is provided by four 25-hp, AC electric motors powered from two variable-frequency, solid-state inverters. This configuration provides speed control of the vehicle and sufficient power to propel the submerged PX-15 to speeds in excess of 4 knots. In addition, the propulsion motors can be fully reversed and rotated in the vertical plane thus providing up, down and reverse thrust capability. By applying forward thrust with the motors on one side of the vehicle and reverse thrust with the motors on the other side of the vehicle, the PX-15 can make still-water turns within its own length. The degree of sophistication displayed by this propulsion system is not required for the Gulf Stream drift mission. It is incorporated into the vehicle at this time to permit study of large vehicle maneuvering requirements.

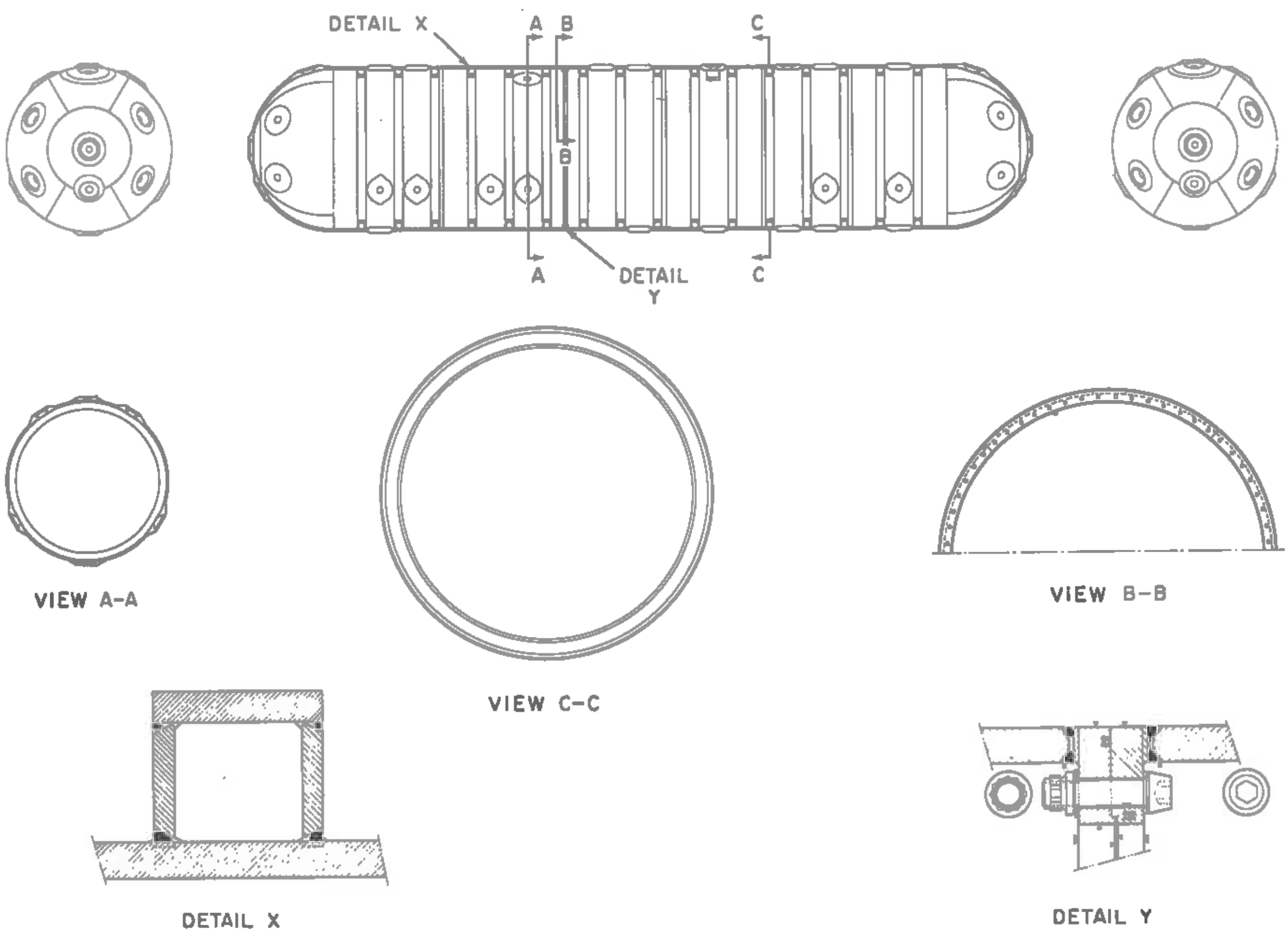

FIGURE 3. PX-15 STRUCTURAL ARRANGEMENT

Life support provisions for a mission duration of up to six weeks have presented a number of interesting problems. The design of the various life support elements is based, in part, on the metabolic requirements of the crew which are summarized in Table I. In addition to these requirements, a supply of water is required for washing and toilet facilities.

As shown in Table I, approximately 500 lbs. of oxygen will be required. Containment of this amount of gas in standard high-pressure cylinders would have resulted in an unacceptable oxygen supply system weight of 5,000 lbs. However, liquid oxygen (LOX) stored in standard containers was found to weigh only 1,000 lbs. In addition, the minimum rate of vaporization of the liquid oxygen was found to be below the minimum oxygen consumption rate for 6 crew members, thus making it ideally suited for the drift mission.

Purification of the air requires control of CO_2, odor and contaminant levels, the latter being generated by man's metabolic processes and by the equipment and materials within the hull. Lithium hydroxide is used for CO_2 absorption. In order to conserve electrical power, the LIOH will be used in panel configurations located throughout the vehicle to permit the natural convective currents within the cabin to circulate through them. These panels also contain activated charcoal for odor and certain contaminant removal. Contaminants which are not processed by the charcoal will be neutralized by an active odor removal unit which consists of a chemical absorbing section and a catalytic burner section. This burner will be activated periodically whenever the contaminants reach significant levels. Contaminant levels will be determined with "Drager" gas detector tubes. Approximately 40 different detector tubes will be available to monitor the range of anticipated gas contaminants. Since many contaminants can be toxic even in small concentrations, careful control of all equipment used in the cabin is being exercised in order to minimize the source of potentially dangerous contaminants. This passive system has been demonstrated in a 100-hour test of the PX-15 life support and waste management system*.

Table I

Life Support Requirements

PX-15

Item	W #/Man-Day	W 6 Men 42 Days # Total	Remarks
Intake:			
Food	1.23	311	Freeze dried and heated for use. 2800K Cal/day 12-40-48 diet. Food does not include water.
Water (Tot)	6.00	1,512	Potable stored.
Oxygen	2.00	504	Moderate activity levels.
Total	9.23	2,327	Total input.
Outgo:			
CO_2	2.25	567	Gaseous.
Water (A)	3.10	781	Urine.
Water (B)	2.68	676	Respiratory.
Water (C)	0.85	215	Perspiratory.
Water (D)	0.22	55	Feces (water only).
	6.85	1,727	Total Water
Feces	0.13	33	Feces (solid only).
Total	9.23	2,327	Total Output

*Grumman OSR-67-1 A Four Day Manned Test of the PX-15 Life Support System - F. J. Abeles

A considerable quantity of water will be required by the crew during the drift mission. In addition to the 1,512 lbs. of potable water indicated in Table I, an additional amount of 1,512 lbs. is provided for washing. Half of the potable water is stored in tanks which are in good thermal contact with the hull plating, thus providing cool drinking water. The remaining potable water is stored in superinsulated tanks at approximately 210° F. This water will be used in the reconstitution of freeze dried food. Stored hot water was chosen in preference to electrically heating cold water primarily on the basis of minimum weight and electrical energy. Approximately 22.5 kilowatt hours of energy would be consumed from the battery to heat the water. For a lead-acid battery, this energy is equivalent to 1,500 lbs. of battery weight. The superinsulated tanks, on the other hand, weigh 440 lbs.

Temperature and humidity control of the cabin atmosphere appears to be controllable by purely passive means. Based on a sedentary crew activity level of 400 BTU/Hr/Man and an average heat generated by cabin equipment of 680 BTU/Hr., it appears that the cabin temperature will remain between 63°F and 81° F for the expected range of sea water temperatures in the Gulf Stream without the need for cabin wall insulation. The uninsulated cabin walls will condense atmospheric moisture and maintain a relative humidity between 40 and 70 percent during the drift.

For missions in colder water, active heating and dehumidification will be used.

Future Development

The operational advantages of large payload, passenger comfort, long submerged stay time, etc. accrue to the large submersible at the expense of maneuverability. In the PX-15 the loss in maneuverability has been partly overcome through the use of relatively larger motors than are usually found on submersibles. The four 25 HP propulsors provide a power-to-weight ratio comparable to smaller vehicles now operating.

The use of larger motors results in a loss in cruise performance due to electrical power losses in conversion. As a consequence, the specific range of the PX-15 is not as high as it might be. The low specific range is not of practical significance for the PX-15's first missions -- the Gulf Stream Drift and Investigation of Large Submersible Operations and Handling. Follow-on configurations envision the use of alternate propulsion configurations which greatly improve the submersible's range and powered endurance.

Although the PX-15 embodies many advantages of a large submersible, its initial configuration will not possess several advantages which a large vehicle can provide. These are: relatively large payload-pickup capability at operating depth, and bottom-sit capability providing a stable base for payload lift and other operations with a manipulator. To provide these capabilities the following are required:

- a landing gear for bottom sitting
- a larger variable ballast capability for payload pickup
- a larger attitude trim capability for off-center payload pickup
- a manipulator
- emergency systems for ballast dump or jettisoning to ensure safe recovery in the event of abnormally high breakout forces or fouling of the manipulator or landing gear.

Future versions of the PX-15 will probably incorporate the landing gear and manipulator with their supporting systems. Grumman designs are currently on the boards as part of a design study of our follow-on vehicle -- the Grumman Submersible #1 or GSV-1. These designs are directly applicable to later versions of the PX-15 as well.

One highly desirable aspect of large submersibles is their potential for adaptation with a diver lock-out capability -- something like a mobile Sealab -- with mission durations of approximately seven days or more. We believe that the ability to send divers out on-the-spot at the time of the first visual sighting of an underwater find, and to remain on the site for extended time, will represent a significant improvement in capabilities over current systems. Grumman's follow-on vehicle, the GSV-1, will incorporate this capability.

The GSV-1

The GSV-1 is an adaptation of the PX-15 design and will provide greatly increased capabilities for undersea work. It is primarily directed toward commercial exploitation of the ocean's resources.

As previously described, the PX-15 hull is being built with a mechanically joined splice at about its mid-point. This will make it possible to use either the PX-15's forward section, or its twin, to complete the GSV-1 vehicle after its new sections have been qualified.

The GSV-1 is currently in the Preliminary Design stage. Its present configuration is shown in Figure 4. Its resemblance to the PX-15 is obvious. A characteristics summary comparison is shown in Table II.

The GSV-1 configuration incorporates a landing gear, manipulator, and diver lock-out capabilities. The landing gear is of the twin pontoon type and offers several advantages:

- It can be made self-buoyant, thereby preserving the reserve buoyancy of the hull which provides for payload lift.
- It provides tankage volume which can be partitioned and used both as a large variable

Table II

	GSV-1	PX-15
Weight	173 tons	130 tons
Length	61 ft. 9 in.	48 ft.
Beam	19 ft.	18 ft. 6 in. with motors
Height	22 ft. 10 in.	20 ft.
Maximum Operating Depth	2000 ft.	same
Collapse Depth	4000 ft.	same
Battery Capacity	> 750 kwh	750 kwh (1000 hr. rate)
Propulsion	(2) 25 hp (1) 7.5 hp steerable	(4) 25 hp
Payload	>9 tons	5 tons minimum
Life Support	3 men fwd) 2 wks 6 men aft)	6 men for 4 wks plus 2 wks emergency reservo
Emergency Droppable Ballast	5 tons	same
Max. Submerged Speed	approx. 4 kts.	> 4 kts.

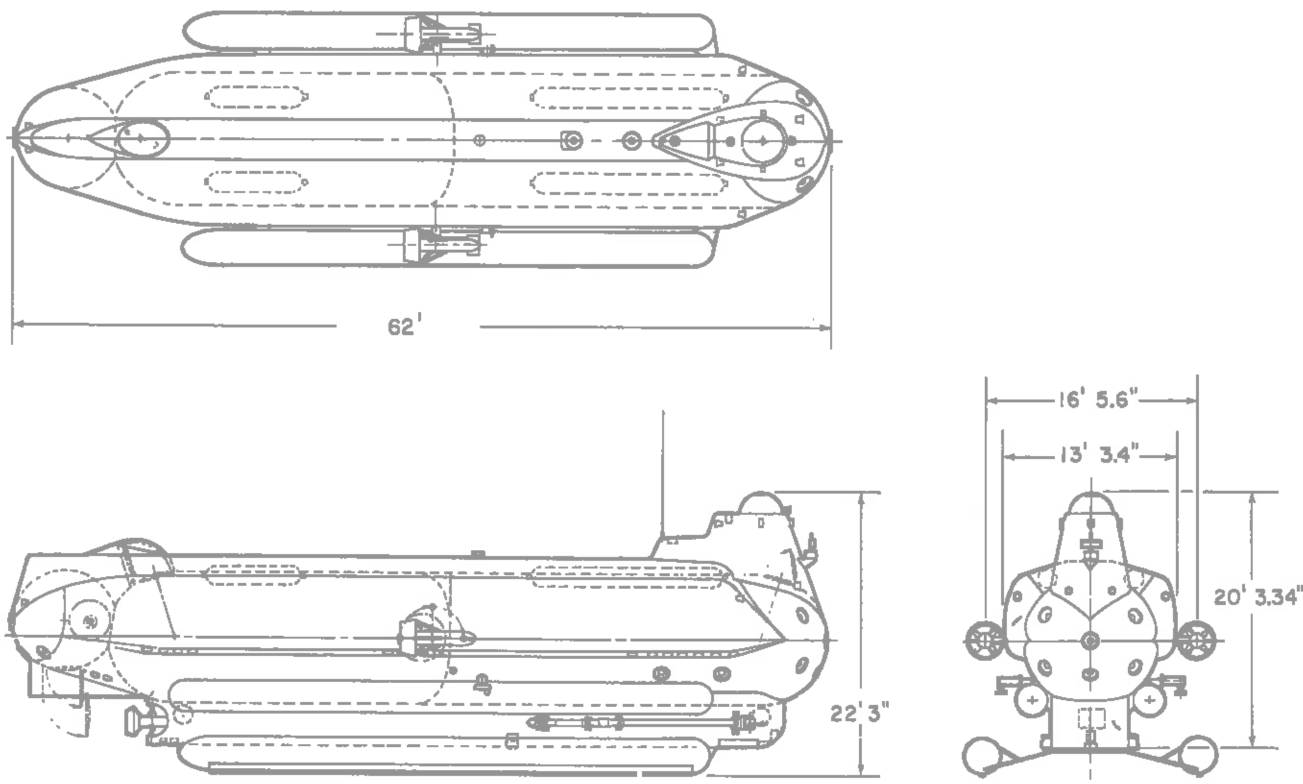

FIGURE 4. GSV-1 GENERAL ARRANGEMENT

ballast tank for payload pickup and as a variable trim tank to permit off-center payload pickup.

- It provides a stable base for using the manipulator on the bottom.
- It provides a convenient mounting place for specialized payload containers.
- It provides a low pad pressure for sitting on unconsolidated bottom soils.

The gear may present some problems with respect to bottom breakout forces. For this reason, it has been designed so that each bottom surface is a steel plate shoe weighing several thousand pounds which can be pyrotechnically released as emergency ballast. The steel plate also serves as armor for the tankage against bottom irregularities. It will also be possible to jettison the entire landing gear assembly for emergency purposes.

Consequently, the GSV-1 manipulator system can be added to the PX-15 without major retrofit.

Gross location of the manipulator is achieved by means of a swinging linkage which allows the whole mechanism to be stowed aft alongside the battery box-keel as shown in Figure 6.

Manipulator capabilities will include a 500-pound lift at a reach of 10 feet. The working envelope is shown in Figure 7.

The bottom-sit/payload pickup capability is shown in Figure 5. Depending upon the mission, a 5,000 lb. pickup or a 5,000 lb. bottom-sit can be provided by varying the internal ballast load.

The manipulator is of relatively conventional design having eight degrees of freedom. It is operated from a crew station located at the forward end of the boat. This crew station is located in the section of the boat which is obtained from the PX-15 or is a twin of the PX-15's forward section.

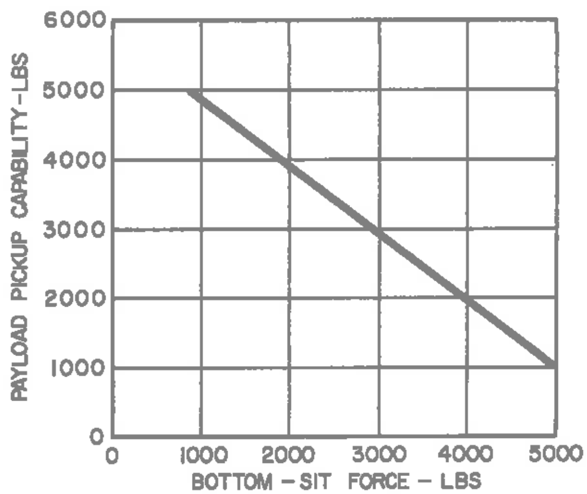

FIGURE 5. PAYLOAD PICK-UP CAPABILITY ON THE BOTTOM

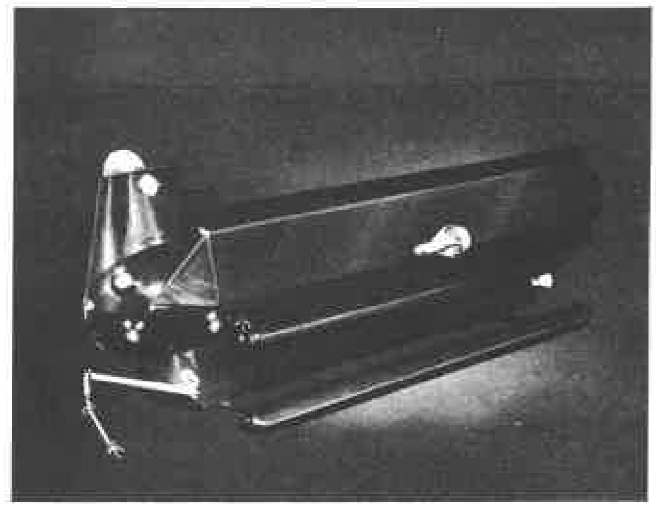

FIGURE 6. MODEL OF GSV-1

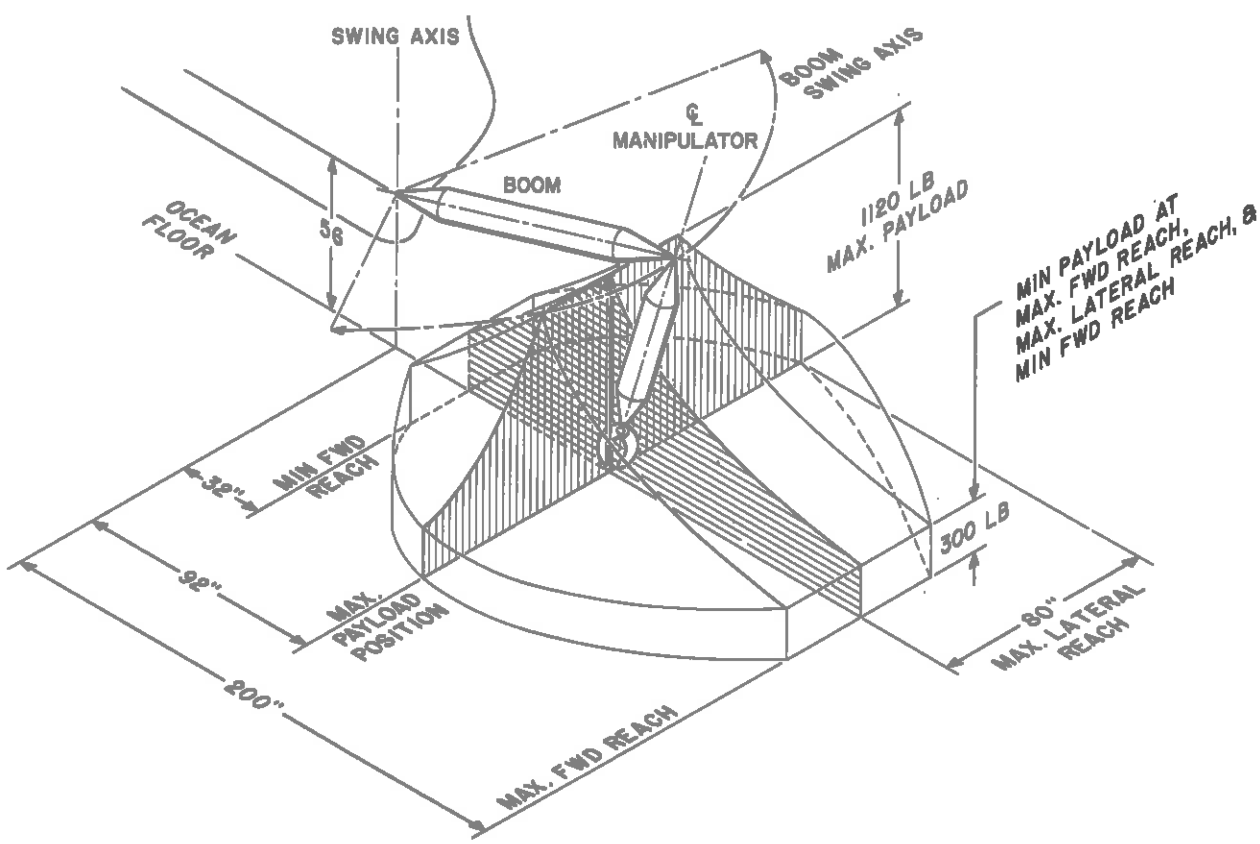

FIGURE 7. GSV-1 MANIPULATOR REACH VS PAYLOAD

GSV-1 diver operations are carried out from the aft compartments of the boat. This is shown best in the Inboard Profile, Figure 8. The GSV-1 is divided into three compartments. The forward compartment is similar to that of the PX-15. It houses the operational subsystems of the vehicle -- propulsion and maneuver, trim and depth, navigation, communications, caution and warning, etc.-- and the operating crew. It is kept at sea level pressure at all times. Life support is similar to the PX-15's.

The forward compartment is formed by a closure dome when the new aft section is spliced to the PX-15's forward section. The dome is a part of the new assembly. The second, or midsection compartment is designed for operation at either sea level pressure or at ambient water pressure for saturated diving operations. Systems will be qualified for hyperbaric operation to 1,500 feet but expendables and replaceable diver gear will be sized for 800 feet operation. This is expected to be the practical depth limit for extended dives in the early period of GSV-1 operation.

Six divers can live and work completely self-sufficient for saturated diving periods of up to seven days in the midsection compartment. Complete housekeeping and life support facilities are provided. The principal areas are identified in Figure 8.

Diver Lock-Out

Diving operations are conducted through a bottom hatch in the aft section compartment. This compartment is a separate ball eight feet in diameter -- smaller than the basic hull's 10 feet diameter -- and is mechanically joined to the basic hull. A diving compartment formed by a closure dome similar to the one forward was considered. It was rejected because of advantages to be gained from the smaller separate ball, as follows:

- Axis of the diving hatch can be vertical.
- Permits use of an overhead hatch to facilitate transfer of saturated diving personnel to a surface decompression chamber.
- Small diameter permits cleaner aft body fairing and reduced drag.
- A small diameter chamber mounted off-center provides greater diver clearance for a given landing gear length.
- A mechanically joined diving chamber can be easily reconfigured as experience is gained with diver systems or can be replaced with special purpose ball modules for such tools as coring or drilling.
- Diver egress-ingress can be monitored with direct vision view.

Diver operations could be carried on without the use of a separate, third chamber by providing a hatch in the end-bell of the hyperbaric chamber. However, this configuration would practically eliminate a particularly attractive mode of diver operations called bounce or yo-yo dive at Grumman. In a yo-yo dive, the divers are pressurized to ambient water pressure in the small ball while the remainder of the vehicle is held at one atmosphere. The divers operate outside while being monitored by a tender who is a member of the diving team and is at hyperbaric pressure in the small ball. At the conclusion of the work period -- perhaps as long as four hours -- the divers return to the ball and the diving team is decompressed to one atmosphere. At depths below several hundred feet, the divers never reach complete saturation so the decompression times -- even for several hours out -- are

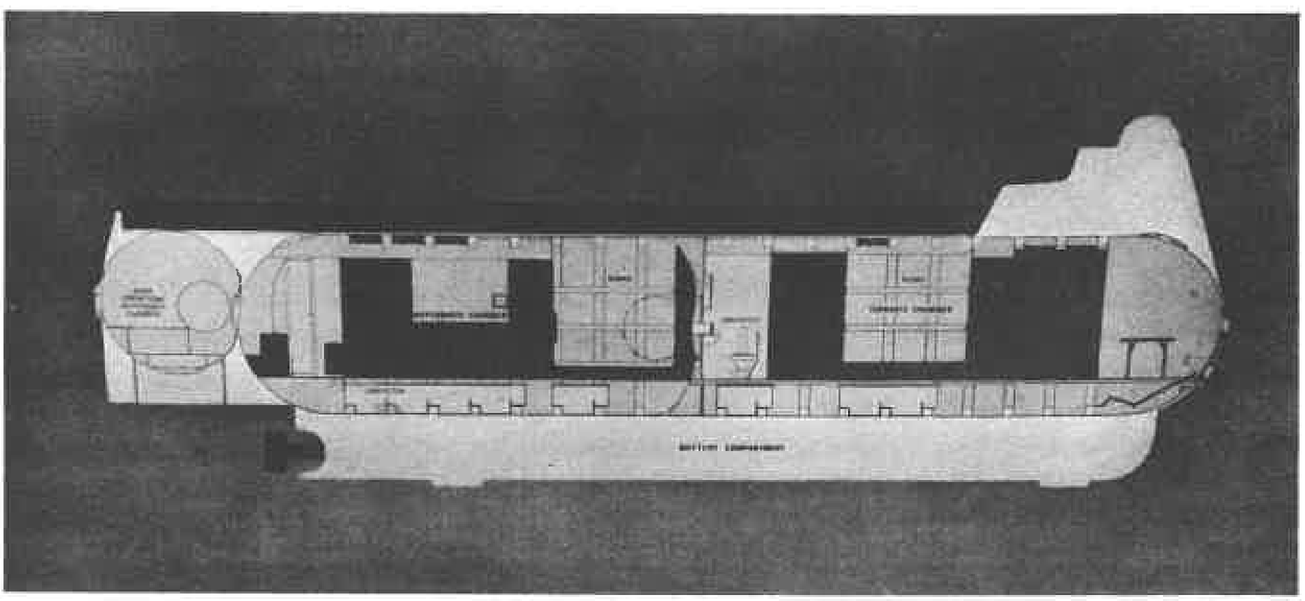

FIGURE 8. GSV-1 INBOARD PROFILE

relatively short. Preliminary Grumman studies indicate a complete turn-around from one atmosphere to ambient to one atmosphere could be made in about 8-10 hours. This appears to be a practical diver team work cycle since the men are resting during the decompression period. Furthermore, once the divers return to one atmosphere, they will rest more comfortably and be able to complete a debriefing without the complications of garbled communications in the hyperbaric helium environment.

Using the small ball for yo-yo diving conserves pressurizing gases if they are dumped upon decompression, or the energy used to recompress the gases to storage pressure. The third chamber for diving also permits several dive teams to alternate using the yo-yo technique.

A helium-oxygen environment will be used for the GSV-1 diver operations to 800 feet. Systems will be designed to withstand operating pressures to 1,500 feet but will be sized for 800 feet operation due to a projected diver limitation. The yo-yo dive technique looks sufficiently attractive that Grumman believes the forward and midsection chambers will often operate together at one atmosphere. Accordingly, a large 4-foot diameter hatch will be provided in the closure bulkhead between the forward and mid-sections to permit relatively easy passage. The interior hatch to the diving ball will have a 30-inch diameter clear opening and the bottom diving hatch will have a 36-inch clear passage to accommodate divers with equipment.

Incorporating a hyperbaric chamber and diving chamber in the GSV-1 requires changes in design approach for these chambers compared to the PX-15. No trapped air pockets can be permitted unless the equipment and structure have been designed to withstand an external pressure of about 670 psi (equivalent to ambient water pressure at 1,500 feet). Orifices for venting must be sized to limit pressure differentials during rapid pressurization. Generally, decompression will be slow for diver physiological reasons. The original PX-15 ring stiffener design, Figure 3, is a box section which is sealed after stress relief. In the GSV-1 midsection, these stiffeners must either be vented or redesigned. A T-frame design is being studied.

All systems with internal fluids at ambient cabin pressure, such as the water supply and waste management system or emergency wet cell batteries, must be vented or pressure-compensated to work in the GSV-1 aft chambers. Without special design features, it is difficult to employ common systems in such areas as water supply for chambers operating at different pressures. Common systems are possible for gas supplies where storage pressure is greater than the working pressure of either chamber. In the GSV-1, separate systems will be used for water supply, waste management, environmental control and life support. Common supplies will be used for O_2 and electrical power.

The use of separate systems has an additional advantage. It permits the aft sections of the GSV-1 to be developed as "man-rated" chambers at the working pressures of depths to 800 feet. It is possible to conduct this development on land since the pressure vessel is designed to withstand high internal pressure in order to decompress saturated divers slowly with the GSV-1 at the surface. It is anticipated that all of the hyperbaric systems development will be completed before a front end is joined. It will also be possible to check out the operations of the diver system and diver lock-out in shallow water operations before the final assembly of the GSV-1 with its front end.

Other Modifications

Other modifications to the basic PX-15 under consideration for the GSV-1 are less obvious on first inspection. These modifications are in the areas of functional subsystems performance.

One principal modification will be in the Propulsion and Maneuvering System where the substitution of an active rudder is planned using a low HP motor with a ducted propeller. This can be seen on the General Arrangement Drawing, Figure 4. The low HP motor can also be employed for low speed cruise between 1 and 2 knots offering a significant improvement in specific range -- n.mi/kw-hr. -- and powered endurance for holding position in a current. The drawing shows only two of the PX-15 25 HP motors retained for obtaining vertical thrust, fast acceleration, maximum speed and rapid in-place yaw rotations. This is planned pending results of actual PX-15 operation with the four motors and analysis of the maneuverability requirements.

The PX-15 Navigation and Guidance subsystem will be augmented in the GSV-1 to achieve capability for self-navigation near the bottom. Addition of a doppler sonar (for long-range bottom navigation) and a device for interrogating bottom emplaced transponders (for local navigation) are being considered. A forward-looking sonar will provide an obstacle avoidance capability. A digital computer and X-Y plotting board will be used to process and display data.

The PX-15 communications gear will be augmented by an intercommunications system between compartments and divers, through which surface communication can be fed. A surface buoy with R.F. handline will be added for emergency and recreational communications from the surface. Sound powered phones will be required for diver communications.

The foregoing modifications to a PX-15 type submersible -- added landing gear with payload pickup and bottom-sit capabilities, manipulator installation and capabilities for saturated and yo-yo diving from the boat at depths to 800 ft. -- represent the principal near term avenues of manned submersibles development at Grumman. The GSV-1 embodying these changes will be in development through 1968 and should be available for use in mid-1969. By 1970, we at Grumman believe that the utility and performance capabilities of the large manned submersible will have been demonstrated, leading to greater and greater demand for services.