Technical Considerations in the Design, Engineering, Construction and Installation of the Poseidon Undersea Resort

By: L. Bruce Jones, President, U.S. Submarine Structures, L.L.C.

U.S. SUBMARINE STRUCTURES LLC.

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The Poseidon Undersea Resort will be the world's first sea floor resort complex and is slated to open at its initial location by early 2011.

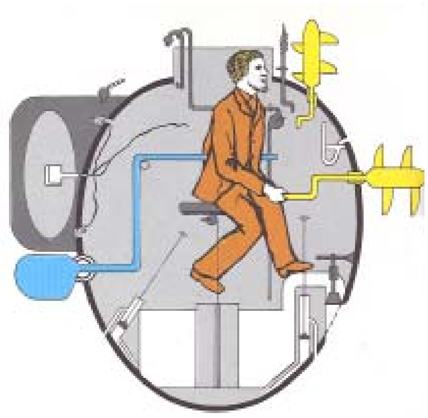
The Poseidon concept has been developed over a seven year period by L. Bruce Jones, a subsea technology specialist with 21 years of experience in the submarine industry along with a team of engineers associated with U.S. Submarines, Inc. A new company, U.S. Submarine Structures LLC, staffed by a select group of the most experienced engineers and operators in the civil submarine business, is carrying out the actual detailed design work on the resort.

While Poseidon will truly be a "world's first," in this case, the first permanent one-atmosphere sea floor habitation, there exists substantial international precedent for more complex and demanding undersea vehicles and structures. Current technology coupled with the experience of our engineers and operations staff makes the implementation of the resort a fairly simple endeavor without significant technical risk.

1. Precedent

The first evidence of an undersea vessel is based on observations made by Aristotle circa 300 B.C. of primitive diving bells used by sponge divers. Descriptions of submarines existed in the 13th century but the first confirmed primitive submarine was developed by

Engineering form view of the Poseidon Undersea Resort.



Artist's conception of the Turtle.

Cornelius Van Drebbel in 1620 and dived in the river Thames in London. However, earlier, in 1531, a diving bell with a small glass window was used in attempts to raise Caligula's pleasure galleys, which had sunk in Lake Nemi. In 1690 Edmond Halley developed the world's first well-known diving bell and by 1749 John Lethbridge was diving to 72 feet in a suit of his own creation. In 1776 David Bushnell built what is generally heralded to be the first submarine, the *Turtle*. Robert Fulton built the *Nautilus* in 1801 and in 1864 the submarine *Hunley* sank the Union 1264-ton *Housatonic* in the first example of submarine warfare. John Holland then built several more sophisticated submarines from 1870-1906, the last, the *Octopus* was 105 feet long, displaced 270 tons and could cruise at 11 knots on the surface and 10 knots submerged. It carried a crew of 15 and dove to 205 feet. Fellow American Simon Lake built several successful submarines as well and by 1914 the Germans had 29 submarines based on his designs while Britain and France had approximately 55 submarines based on modified Holland designs.

The history of submarine development during World War I & II is well known and well documented and the technical advances were extraordinary. However, those advances paled in comparison to Hyman Rickover's *Nautilus*, the first nuclear submarine that could travel underwater for over 100,000 miles pow-


The Nautilus

ered by a nuclear mass the size of a baseball. Hydrodynamic efficiency was later optimized by the Navy's *Albacore* project and the lessons applied to faster more efficient nuclear submarines. In 1960 the *Skate* completed a 36,000 mile submerged circumnavigation in 83 days. Today's subsequent attack and nuclear ballistic missile submarines are matched in technical sophistry only by the space shuttle and are the defining articles of 20th century transportation.

Also in 1960 the bathyscaphe *Trieste* manned by Don Walsh (one of Poseidon's Principal Consultants) and Jacques Piccard descended unassisted to a depth of 35,800 feet in the Mariana's Trench off Guam. They landed on the bottom just 400 feet short of the deepest spot in the ocean. At that depth, the external pressure was over 16,000 pounds per square inch. Notably, the material for the viewports was acrylic plastic, the same material used for the transparent pressure boundaries on Poseidon.

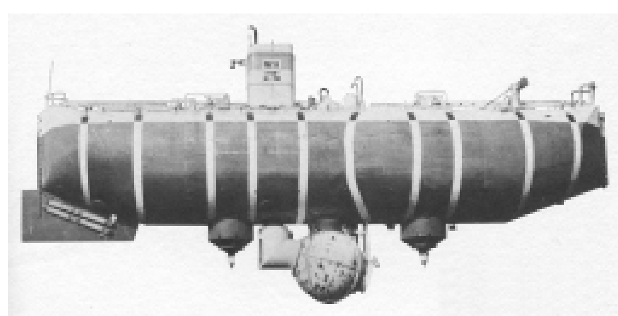
By 1960 a strong interest had developed in ambient pressure habitats and by 1963 Jacques Cousteau had designed and built the *Conshelf III* underwater habitat where he and five aquanauts spent 30 days submerged. In pursuit of the knowledge on both the physiological and the psychological effects of living at depth exposed to hydrostatic pressure, a large number of experimental habitats were built, mainly in the 1960s and 1970s and a total of 72 ambient pressure habitats have been installed to date.

Poseidon uses the techniques of submarine pressure vessel design from 1900 onward coupled with acrylic viewport design from the 1960s, well developed by 1969 and in widespread worldwide use in aquariums since 1980. A very primitive one atmosphere undersea bedroom could have been built of wood cooperage techniques with tar or pitch sealed glass viewports by the 15th century.

2. Team Experience

The core design team for U.S. Submarine Structures consists of three individuals that between them have over 60 years of submarine related experience and have been involved with over 60 submarine projects. Between them they cover all of the disciplines of design, detailed engineering, construction and operations. They have designed and built military submarines, diesel electric commercial and research submarines, deep submersibles, tourist submarines and luxury submarines. They are the most experienced group of their type in the civil submarine industry. They are supported by highly regarded technical specialists and consultants whenever necessary.

Designing the Poseidon Undersea Resort has less technical complexity than virtually any single design project the group has undertaken in the past 15 years.

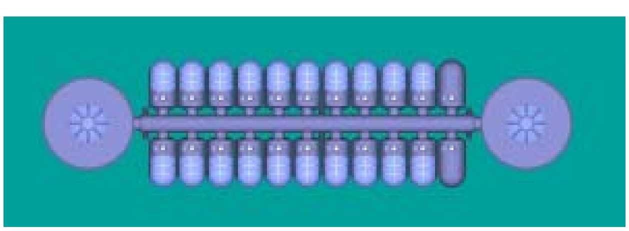

The bathyscaphe Trieste

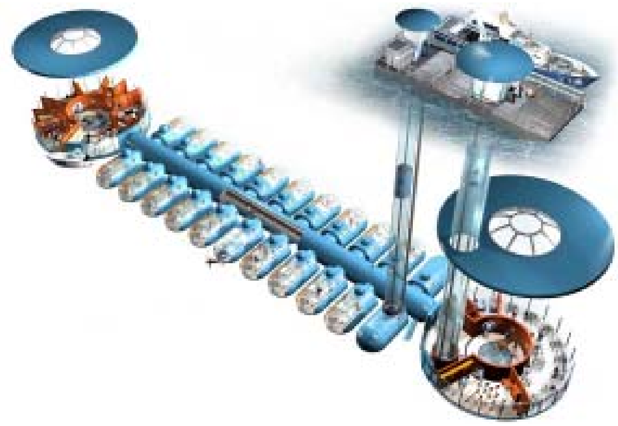
3. Design and Engineering Issues

The Poseidon Undersea Resort design went through a number of iterations before it reached its current optimum state. Initially, we looked at a structure built from conventional geometries used in submarines; spheres and cylinders with hemispherical or ellipsoidal end caps. A sphere is the most efficient structural form to obtain a minimum weight/displacement ratio and is common in very deep diving submersibles, while a right circular cylinder reinforced with frames is the most common geometry used for shallow to mid depth-range military and civil submarines. Both can be easily fitted with acrylic viewports.

The original designs had the benefit of being capable of deeper depths of emplacement, but the decision was made to develop a design for shallower water where the lighting is excellent and the marine life abundant. We looked first at structures composed entirely of transparent acrylic but there were disadvantages in form and cost. Maintaining a large external visual field for the occupant was important to dispel any possible feelings of claustrophobia, but conversely we wanted to avoid the feeling of too much exposure and a possible lack of privacy.

It took considerable time and effort to reach the current design status which is technically a hybrid that we believe to be absolutely optimum. An emplacement depth range of from 30 feet to 60 feet provides significant versatility of site location and the modular nature of the design means later expansion or the development of larger or smaller resorts is simple. Resorts with 20, 40, 80, or 120 underwater rooms can be built with ease.





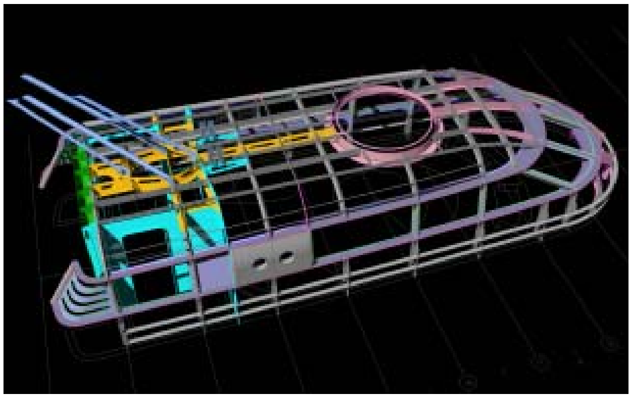
Rendering of an autonomous version of the resort

The plans for the first resort included easy shore access so that power, water, electricity and communications lines could be run to land-based infrastructure. The design then evolved into a completely autonomous unit with self-contained power generation, fresh water production, etc., so that a resort could be built offshore and accessed by boat, submarine, or helicopter.

As discussed in Section 6 below, our empirical calculations have been confirmed by finite element analysis. Each modular "pod" as well as the larger end units will be tested submerged when complete.

At U.S. Submarine Structures we'll take advantage of a new trend in large yacht construction called net part production. The design is executed with mathematical precision with 3D computer design software. The deliverables are zero tolerance cutting paths for each part of the resort, along with all required assembly information. The resort, both the interior and exterior, is then built with individual pre-cut numbered parts that are put together following a pre-determined path.

The resulting millimeter-perfect precision in construction produces excellent results as the quality control is largely built into the design process. More important is the tremendous versatility that allows assembly in



3-D drawing for net-parts construction

areas with less expensive labor or remote locations and it makes it practical to outsource complicated sub-assemblies (e.g. interiors) to dedicated specialists who can proceed in parallel. Using this system building the resort becomes an assembly process where we are free to shop worldwide for labor, equipment, materials and quality and then to bring the components to our chosen build-site for assembly.

4. Acrylic Uses & Manufacturing

Transparent polymethyl methacrylate, commonly known as acrylic plastic or by the brand name Plexiglass is by far the most common transparent boundary material used in submarines and submersibles. Its initial utilization by Auguste Piccard on the bathyscaphe *Trieste* was successful on the dive to Challenger Deep, still the world's deepest. The acrylic windows were machined as truncated cones and the material was used because unlike glass or fused quartz it deforms elastically under pressure without fracturing and as the pressure on the exterior face of the window increases the seal at the window-pressure hull interface becomes more secure.

In the 49 years since the *Trieste's* deepest dive the uses of acrylic in industry have become ubiquitous and it is the only transparent material used now in submarine construction. Today it is quite common for an entire submarine pressure hull to be composed of transparent acrylic. Examples include the 44-passenger tourist

The Triton 1000 has a transparent spherical acrylic passenger compartment

submarine Deepstar and the Triton 1000 built by U.S. Submarines, Inc.

Acrylic is a remarkable material well suited for subsea applications. It is abrasive resistant with excellent weatherability and it is optically highly transparent. The material's strength to weight ratio is equivalent to that of low carbon steel and its plasticity allows it to tolerate large stress concentrations in compression. In addition, the material's refractive index closely approximates that of seawater so that the outside surface of an acrylic window underwater effectively disappears, providing an immersive experience for the viewer.

In submarine applications acrylic windows typically have a life of 20 years or 10,000 dives.

Poseidon will have a similar acrylic-hulled submarine at Katafanga built by U.S. Submarines

Acrylic windows are widely used in aquariums worldwide. Indeed the largest acrylic aquarium panel fabricated to date measures 74 feet long by 27 feet wide and is 24 inches thick. In comparison, the acrylic windows used for the Poseidon project are less than 10 feet long, 6 feet wide and 4 inches thick.

The Poseidon Undersea Resort has been designed such that only five different acrylic geometries are necessary to build the entire resort. However, a total of 220 pieces of acrylic will have to be fabricated. While there are a number of acrylic manufacturers that could provide Poseidon's windows, the cost would be high and the major manufacturers are notorious for late deliveries and quality control issues. As a result we have decided to set-up and staff an acrylic production facility to build our own windows and to build the acrylic pressure hull components for Poseidon's submarine. We have acquired technical staff and have made arrangements for a technical support package.

5. Safety, Testing & Fabrication

When we construct a submarine the paperwork and procedures for obtaining +A1 Manned Submersible Classification from the American Bureau of Shipping are quite arduous. The result is that there has never been a serious injury or fatality to any passenger aboard an ABS classed submarine or submersible. This is remarkable considering that the tourist submarine industry carries approximately 1,500,000 passengers per year, making civil submarines statistically the safest form of transportation in the world today.

A conventional tourist submarine

Large acrylic windows are ubiquitous in the aquarium industry

However, no existing classification agency has procedures in place for the classification of a one-atmosphere underwater habitat like Poseidon. Our intention is to build the Poseidon Resort to the rigorous safety standards we apply to submarine projects and to have the standards and implementation verified by outside engineering experts that report to the insurance underwriters.

It is interesting to note that any potential accident that might be contemplated in a submarine would almost invariably be associated with the vehicle's motion and would include collisions, sub-sea entanglements or uncontrolled dives. Clearly these are not factors with a stationary and fixed sea floor resort. So, effectively, we are taking the principals, materials, techniques and structures from what has been demonstrated to be the world's safest form of transportation and utilizing them to build a fixed, shallow-water, sea floor structure that is considerably safer.

Poseidon's design specifications generally follow the requirements of such regulations as proposed in *Rules for Building and Classing Underwater Systems and Vehicles* by the ABS, the American Society of Mechanical Engineer's *Safety Standard for Pressure Vessels for Human Occupancy* as well as various bulletins of the Welding Research Council. Moreover the resort has been designed to be heavy-weather and seismic-activity resistant and will easily withstand a category five hurricane or significant earthquake event.

A testing and verification program utilizing complete finite element analysis is being used to verify predictions prior to beginning construction. Each individual pod and the larger end units of the resort will be submerged to full operating depth prior to resort assembly as part of the quality control process.

6. Transportation

Because the initial installation location is geographically isolated management has decided to transport the undersea resort to the operating location in a fully assembled condition. The resort has been designed so that individual modules can be installed or removed from the complex underwater, but for the first location the resort complex will be fabricated at a shoreside location and transported aboard a semi-submersible heavy lift ship to the operating site.

The resort, in ballasted condition is expected to weigh approximately 7,140 tons and to measure 420 feet in length by 80 feet in width and 15 feet in height.

Dockwise, an internationally well-known shipping company has 15 semi-submersible heavy lift ships in

The Dockwise company's semi-submersible heavy lift ships have remarkable transport capability various sizes with the largest being able to transport structures to 75,000 tons. A Swan class ship has been chosen as appropriate to transport Poseidon. The resort with its monocoque framework supporting the individual pods and main end units and tying those in with the central hallway structure would be rolled onto the deck of the ship and secured. Upon arrival at the site, the ship would submerge and the resort and framework would be floated off. The cost to ship the resort from the U.S. West Coast to Fiji would be approximately $2.75 million..

7. Installation & Access

Before the resort is delivered steel piling will be driven into the sea floor at suitable locations. In addition, it is likely that a covered pier will be constructed from shore out to the site of the eventual entrance elevator to the resort.

When the resort arrives on the heavy lift ship the vertical caissons that contain the elevator and access will be erected into their vertical position above the main end units. The entire resort structure will then be floated off and moved into its surface position and the resort's framework will be attached to the piles by specially fabricated steel hoops. The resort, which is only slightly positively buoyant will then be winched and/or ballasted down to the sea floor until it is in position, just above the seabed. At that time the framework will be permanently fastened to the piles and the upper portion of the piles that extend to the surface will be removed. The electrical, fluid, and communication umbilicals will be connected from the top portion of the elevator shafts to the dock and the resort will immediately become operational.

8. Maintenance

The majority of the infrastructure necessary to support the resort's operation is established on the island. Power, water, air and communications equipment will have regular servicing on established schedules and back-up equipment will be available.

Resort maintenance will be minor and can be carried out from the interior of the resort. The one exception is viewport cleaning. The acrylic viewports must be kept clean from algae and encrusting marine life. To do that U.S. Submarine's engineers have designed an automated water jet viewport cleaning system that will clean each of the viewports twice each day.

The resort was designed so that each of the individual pods can be detached from the framework underwater and brought to the surface for servicing. In reality, this would likely only happen at ten-year intervals.

9. Environmental Issues

Poseidon has been designed specifically to have a net positive impact on the environment. The resort complex itself is situated above the sea floor and does not come in contact with the bottom except at the minimal piling/sea-floor interface. The resort emits no effluents. With the exception of the viewports marine growth is free to take hold on the structure itself.
With its location above the seabed the resort will act as an artificial reef and will attract marine life to a new habitat.

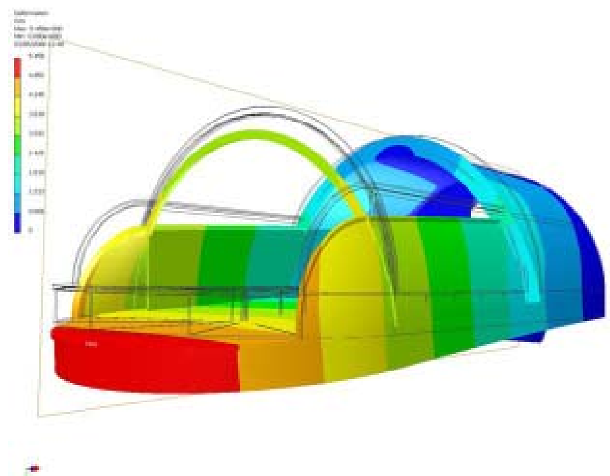
Poseidon's most important environmental effect will be to introduce thousands of people to the sub-sea world and to promote environmental stewardship, for you can only expect people to act to protect the ma-

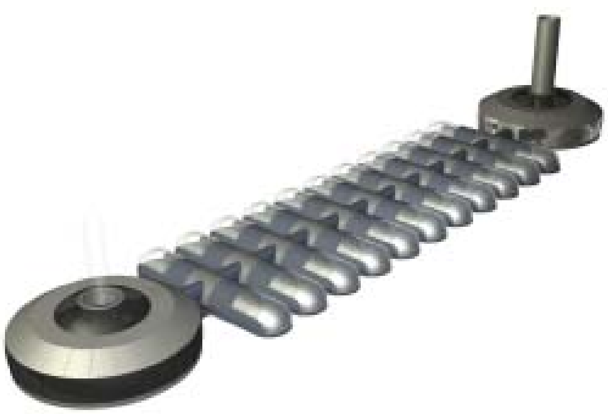
rine environment if they understand the issues and can see what they are protecting first-hand. We'll also have various naturalists in residence to provide lectures to guests.

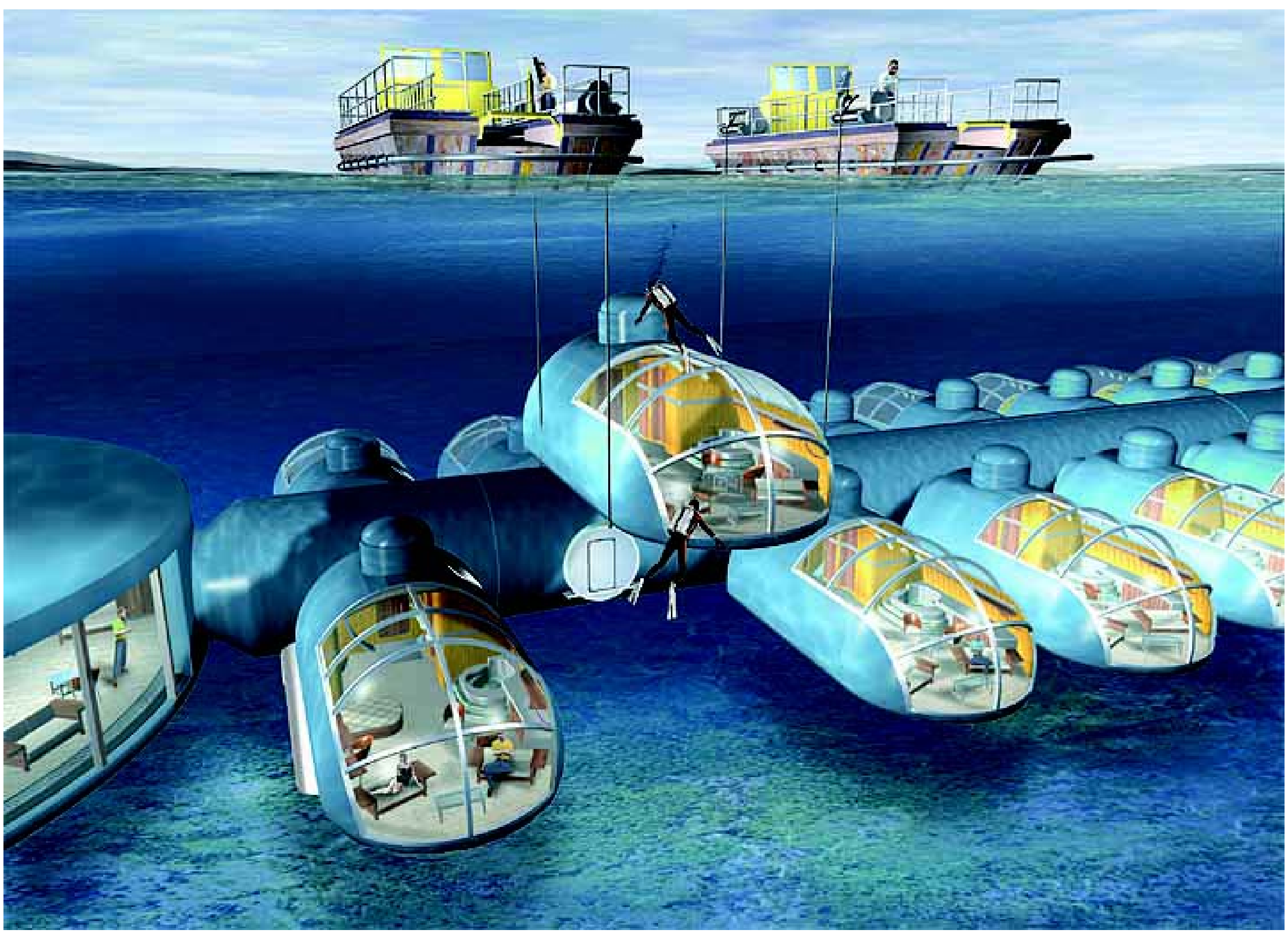
We are committed to environmental sensitivity and stewardship. The tourist submarine industry where we are very active introduces 1.5 million people to the undersea marine environment each year and we expect to continue that work with Poseidon.

10. Conclusion

The Poseidon Undersea Resort is being designed and built using well-known techniques, materials and procedures proven to be effective in subsea applications over many years. The procedures for assembly, transportation, installation and maintenance have been optimized to minimize any technical risk.







Part 2: Poseidon's Tourist Submarine Safety & Submarine Design

The Poseidon Undersea Resort will operate a new, state-of-the-art, transparent-hulled tourist submarine. A derivitive of the *Deepview 20* design the submarine will be used to take Poseidon's guests on tours of nearby coral reefs and will dive to 360 feet. We anticipate that a small group of guests will be able to enjoy cocktail dives and dinner dives as well and we also intend to offer overnight stays on the submarine at depth. The versatile design will accommodate several different configurations and will have an on-board head and galley.

Acrylic hulled tourist subs

DeepView 20: Technical Specifications

Classification:	*ABS ✠A1 Manned Submersible*	
Maximum certified depth:	*360 ft.*	*110 meters*
Test depth:	*452 ft.*	*138 meters*
Passengers:	*20*	
Crew:	*2*	
Length overall:	*42.7 ft*	*13.0 meters*
Height overall:	*18 ft.*	*5.5 meters*
Beam:	*9.8 ft.*	*3.0 meters*
Pressure hull diameter:	*7.9 ft.*	*2.4 meters*
Draft:	*8.9 ft.*	*2.7 meters*
Weight in air:	*55,000 kilograms*	
Autonomy:	*80 hours*	
Mission time:	*14 hours (14 one hour dives)*	
Maximum speed:	*4 knots*	
Electrical power:	*240VDC/24VDC*	
Forward/reverse thrust:	*1 x 35 kW (47 HP)*	
Lateral bow thrust:	*1 x 10 kW (13.4 HP)*	
Lateral stern thrust:	*1 x 10 kW (13.4 HP)*	
Vertical thrust:	*2 x 10 kW (13.4 HP)*	

Safety & Submarine Design

By: L. Bruce Jones

There are a number of important criteria useful in evaluating passenger submarine design, but the first question asked by a prospective customer is "Are they safe?"

The answer, in a word, is "Very".

Passenger submarines are designed and built under the supervision of, and in accordance with the regulations and rules established by, one of the major classification societies. The three largest classification organizations are the American Bureau of Shipping (ABS), Lloyds Register of Shipping and Bureau Veritas.

The ABS has the most experience of the three in submarine certification, having classified most of the manned submersibles built in the last several decades. It is pertinent to note that there has never been a serious injury or fatality to any passenger stemming from the operation of an ABS certified commercial or passenger submersible.

Involvement by the classification society begins with the approval of the initial design, evolves to a survey process during construction and continues with annual inspections of the submarine throughout its life.

Submersibles that meet the stringent requirements of the ABS are awarded "class" and are listed in the Record of the Society as *A1 Manned Submersible, or in the case of Lloyds Registry *100A. The * is deleted if the craft was not constructed under society supervision but was later surveyed and awarded classification.In order to retain classification, which is important as it would be virtually impossible to operate and insure a submersible without the A1 or 100A rating, the submersible undergoes a thorough annual survey that includes the detailed inspection of ten major systems. Additionally, every three years the submarine undergoes an even more stringent survey that involves pressure and hydrostatic tests, dimensional checks of the pressure hull, instrument calibration and a special test dive.

In the United States the U.S. Coast Guard will approve the submarine design and survey construction, actually duplicating work done by the ABS. The Coast Guard also stipulates requirements for the experience levels and licensing of the submersible crew, insures the existence of adequate documentation which includes operation and maintenance manuals, applicable logs, records and checklists, etc., and assures compliance with a substantial body of safety and other regulations.

Assurance of submersible safety begins with the design process. The cost to design a contemporary passenger submarine that might cost $5.0 million to build approaches, and in some cases exceeds $400,000. Literally thousands of man hours are required and hundreds of drawings are generated. Detailed calculations are required in such areas as pressure vessel stress analysis, life support systems, electrical load requirements and buoyancy and stability analysis. All materials to be used during construction must be certified and specified beforehand. The design specifications generally follow the requirements of such regulations as proposed in *Rules for Building and Classing Underwater Systems and Vehicles* by the ABS, the American Society of Mechanical Engineer's *Safety Standard for Pressure Vessels for Human Occupancy* as well as various bulletins of the Welding Research Council.

When the design is finally complete it will be exhaustively analyzed by the engineers of the regulatory agency and classification society, and those plans that are satisfactory will be approved. Once all plans have been authorized, construction may commence.

Society surveyors are on hand for the construction process. They assure the quality of the materials and the construction techniques. They monitor the welding process, implement and review extensive non destructive testing procedures, and they witness the hydrostatic testing of piping and gas storage systems and ballast tanks. Inspectors also verify the installation and testing of mechanical and electrical systems, check safety devices and examine critical dimensions. Subsequent to pressure hull completion a hydrostatic submergence or "drop" test with strain gauges is carried out to 1.25 times the design depth.

Requirements for submarine design classification include many redundant systems that can be used in the event of a primary system malfunction. These include ballast/trim, life support, propulsion and electrical systems.The ballast/trim systems of the submarine control the craft's buoyancy and insure its stability under a broad range of conditions.

The ballast system controls the submarine's ability to descend underwater, maintain depth or rise to the surface, while the trim system controls weight distribution along the length of the craft, or its angle of incline in reference to the horizontal.

Ballast and trim systems are composed of three components; 1) the "hard" or variable ballast tanks which are externally mounted and use high pressure air to control buoyancy and adjust for variations in weight distribution (trim) in the submarine. Hard ballast can also be pumped dry by an electric ballast pump. 2) Soft ballast tanks are non-pressurized and are also externally mounted and are used primarily to provide additional freeboard and stability while the submarine is on the surface. They are vented through the bottom to the water, which is displaced by the introduction of high pressure air. In an emergency the soft tanks can be "blown" full of air, causing the submarine to rise rapidly to the surface. 3) A drop-weight of one or more sections can be manually released in an emergency, dramatically lightening the submarine and causing it to surface. In some designs moveable weights are used to control trim either in conjunction with, or in substitution for, variable ballast trim procedures. A further method of surfacing is the vertical thruster system which can be actuated to propel the submarine upwards. Indeed, some submersibles are designed in such a way as to always be slightly positively buoyant, and they require the constant use of the vertical thrusters to remain submerged.

In summary, ABS certification requires that the submarine be able to surface with the largest single volume flooded, with the exception of the pressure hull. This can be accomplished by blowing or pumping the hard ballast tanks, blowing the soft tanks, releasing the dropweights or powering to the surface with thrusters.

Life support systems consist of oxygen supply and delivery, an atmosphere control mechanism and a carbon dioxide removal process. Most larger passenger submarines have one or two freon based air conditioning units that maintain cabin temperatures at 72 degrees and control humidity and remove odors. These are operated in conjunction with a scrubber system that removes the carbon dioxide to a level of 0.5% or below. Oxygen is supplied from high pressure cylinders and is automatically injected into the cabin at a rate that replaces the oxygen consumed and maintains a level of 21% by volume. In the event of a failure, a manual bypass system with flow meters and monitoring equipment are available. In addition, built in breathing sets for each person on board must have a two hour air supply. A purge compressor is used to maintain atmospheric pressure regardless of the depth of the submarine or the internal temperature. This also prevents accidental over pressure in the event of a high pressure air leak. Regulatory agencies and the certifying society require at least 72 hours of oxygen supply and carbon dioxide removal capability for an entire complement of crew and passengers.

Leisure submarines are usually powered by several externally mounted brushless DC motors or internal electro-hydraulic propulsion devices. In either case sufficient system redundance exists to allow for the propulsion of the craft in the event of a unit failure.

Electrical power is provided by either sealed lead acid traction batteries or sealed gel cell batteries. Either type are capable of providing power for the submarine for 10 to 14 operating hours per day, and can be fully recharged in an eight hour period. The batteries have a minimum useful life of 1500 deep cycle charges. Main power is either 120V or 240V DC which provides electricity for the main propulsion devices, lighting, etc. A separate 24V/12V system is used for life support systems, navigation and communication equipment. Moreover, a secondary separate 24V/12V emergency power system is also required. Sophisticated circuit breakers and power shut-off equipment are available to provide circuit isolation as necessary. The battery compartments are isolated and have their own hydrogen removal/scrubbing purge compressor/ventilation systems.

The submarines are equipped with several bilge pumps, and both active and passive fire fighting systems. The craft is in constant contact with the surface support vessel via a dual frequency underwater telephone, or when surfaced, with a VHF marine band radio.While in a brief article it is impossible to delineate all the safety features inherent in a classified contemporary passenger submarine, their pristine operating records provide a tribute to the classification societies and manufacturers. Statistically, there is no safer form of transportation.

Hawaii

Italy

Mallorca

Martinique

U.S. SUBMARINE
STRUCTURES LLC.

POSEIDON
UNDERSEA RESORTS

POSEIDON UNDERSEA RESORTS L.L.C.
Tel: 208/687-9057 ▪ Fax: 208/441-7478 ▪ E-mail: bruce@ussubmarines.com

