MANNED SUBMERSIBLES, SHALLOW WATER

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doi:10.1006/rwos.2001.0301

Introduction

Early man's insatiable curiosity to look beneath the surface of the sea in search of natural treasures that were useful in a primitive, comfortless mode of living were a true test of his limits of endurance. The fragile vehicle of the human body quickly discovered that most of the sea's depths were unapproachable without some form of protection against the destructive hostilities of the ocean.

Modern technology has paved the way for man to conquer the hostile marine environment by creating a host of manned undersea vehicles. Called submersibles, these small engineering marvels carry out missions of science, exploration, and engineering. The ability to conduct science and other operations under the sea rather than from the surface has stimulated the submersible builder/operator to further develop the specialized tools and instruments which provide humans with the opportunity to be present and perform tasks in relative comfort in ocean bottom locations that would otherwise be destructive to human life.

Over the past fifty years a depth of 1000 m has surfaced as the transition point for shallow vs deep water manned submersibles. During the prior 100 years any device that enabled man to explore the ocean depths beyond breath-holding capabilities would have been considered deep.

History

While it is difficult to pinpoint the advent of the first submersible it is thought that in 1620 Cornelius van Drebel constructed a vehicle under contract to King James I of England. It was operated by 12 rowers with leather sleeves, waterproofing the oar ports. It is said that the craft navigated the Thames River for several hours at a depth of 4 m and carried a secret substance that purified the air, perhaps soda lime?

In 1707, Dr Edmund Halley built a diving bell with a 'lock-out' capability. It had glass ports above to provide light, provisions for replenishing its air, and crude umbilical-supplied diving helmets which permitted divers to walk around outside. In 1776, Dr David Bushnell built and navigated the first submarine employed in war-like operations. Bushnell's Turtle was built of wood, egg-shaped with a conning tower on top and propelled horizontally and vertically by a primitive form of screw propeller after flooding a tank which allowed it to submerge.

In the early 1800s, Robert Fulton, inventor of the steamship, built two iron-formed copper-clad submarines, *Nautilus* and *Mute*. Both vehicles carried out successful tests, but were never used operationally.

The first 'modern submersible' was Simon Lake's *Argonaut I*, a small vehicle with wheels and a bottom hatch that could be opened after the interior was pressurized to ambient. While there are numerous other early submarines, the manned submersible did not emerge as a useful and functional means of accomplishing underwater work until the early 1960s.

It was during this same period of time that the French-built *Soucoupe*, sometimes referred to as the 'diving saucer', came into being. Made famous by Jacques Cousteau on his weekly television series, the *Soucoupe* is credited with introducing the general population to underwater science. Launched in 1959, the diving saucer was able to dive to 350 m.

The *USS Thresher* tragedy in 1963 appears to have spurred a movement among several large corporations such as General Motors (Deep Ocean Work Boat, DOWB), General Dynamics (*Star I, II, III, Sea Cliff*, and *Turtle*), Westinghouse (*Deepstar 2000, 4000*), and General Mills (*Alvin*), along with numerous other start-up companies formed solely to manufacture submersibles. Perry Submarine Builders, a Florida-based company, started manufacturing small shallow-water, three-person submersibles in 1962, and continued until 1980 (**Figures 1** and **2**). International Hydrodynamics Ltd (based in Vancouver, BC, Canada) commenced building the Pisces series of submersibles in 1962. The pressure hull material in the 1960s was for the most part steel with one or more view ports. The operating depth ranged from 30 m to 600 m, which was considered very deep for a free-swimming, untethered vehicle.

The US Navy began design work on *Deep Jeep* in 1960 and after 4 years of trials and tribulations it was commissioned with a design depth of 609 m. A two-person vehicle, *Deep Jeep* included many features incorporated in today's submersibles, such as a dropable battery pod, electric propulsion motors that operate in silicone oil-filled housings, and

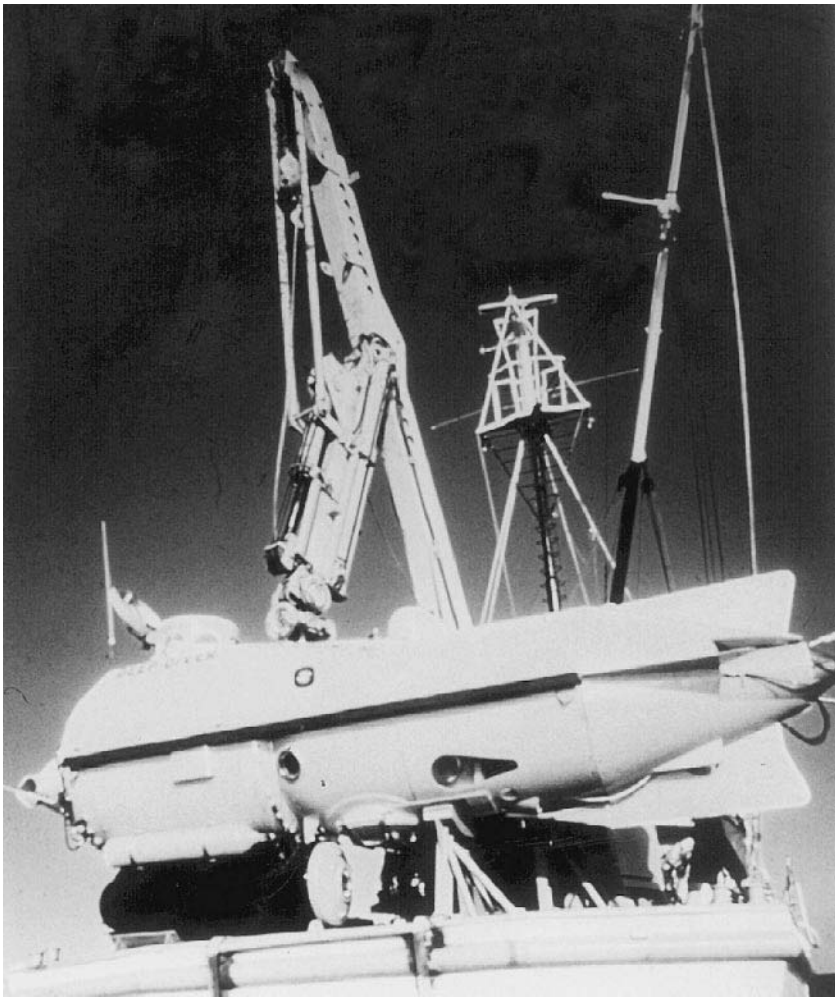

Figure 1 Perry-Link *Deep Diver*, 1967. Owned by Harbor Branch Oceanographic Institution. Length 6.7 m, beam 1.5 m, height 2.6 m, weight 7485 kg, crew 1, observers 2, duration 3–5 hours.

shaped resin blocks filled with glass micro-balloons used to create buoyancy. *Deep Jeep* was eventually transferred to the Scripps Institution of Oceanography in 1966 after a stint searching for a lost 'H' bomb off Palomares, Spain. Unfortunately, *Deep Jeep* was never placed into service as a scientific submersible due to a lack of funding. The missing bomb was actually found by another vehicle, *Alvin. Alvin* did get funding and proved to be useful as a scientific tool.

The Nekton series of small two-person submersibles appeared in 1968, 1970, and 1971. The *Alpha, Beta*, and *Gamma* were the brainchildren of Doug Privitt, who started building small submersibles for recreation in the 1950s. The Nektons had a depth capability of 304 m. The tiny submersibles conducted hundreds of dives for scientific purposes as well as for military and oilfield customers. In 1982, the *Nekton Delta*, a slightly larger submersible with a depth rating of 365 m was unveiled and is still operating today with well over 3000 dives logged.

A few of the submersibles were designed with a diver 'lock-out' capability. The first modern vehicle was the Perry-Link 'Deep Diver' built in 1967 and able to dive to 366 m. This feature enabled a separate compartment carrying divers to be pressurized internally to the same depth as outside, thus allowing the occupants to open a hatch and exit where they could perform various tasks while under the supervision of the pilots. Once the work was completed, the divers would re-enter the diving compartment, closing the outer and inner hatches; thereby maintaining the bottom depth until reaching the surface, where they could decompress either by remaining in the compartment or transferring into a larger, more comfortable decompression chamber via a transfer trunk.

Figure 2 Perry PC 1204 *Clelia*, 1976. Owned and operated by Harbor Branch Oceanographic Institution. Length 6.7 m, beam 2.4 m, height 2.4 m, weight 8160 kg, crew 1, observers 2, duration 3–5 hours.

Acrylic plastic was tested for the first time as a new material for pressure hulls in 1966 by the US Navy. The *Hikino*, a unique submersible that incorporated a 142 cm diameter and a 0.635 cm thick hull, was only able to dive to 6 m. This experimental vehicle was used to gain experience with plastic hulls, which eventually led to the development of *Kumukahi, Nemo* (Naval Experimental Manned Observatory), *Makakai*, and *Johnson-Sea-Link*.

The *Kumukahi*, launched in 1969, incorporated a unique 135 cm acrylic plastic sphere formed in four sections. It was 3.175 cm thick and could dive to 92 m.

The *Nemo*, launched in 1970, and *Makakai*, launched in 1971, both utilized spheres made of 12 curved pentagons formed from a 6.35 cm flat sheet of Plexiglas$^{\text{TM}}$. The pentagons were bonded together to make one large sphere capable of diving to 183 m.

The *Johnson-Sea-Link*, designed by Edwin Link and built by Aluminum Company of America (ALCOA), utilized a *Nemo*-style Plexiglas$^{\text{TM}}$ sphere, 167.64 cm in diameter, 10.16 cm thick, and made of 12 curved pentagons formed from flat sheet and bonded together. This new thicker hull had an operational depth of 304 m.

Present Day Submersibles

The submersibles currently in use today are for the most part classified as either shallow-water or deep-water vehicles, the discriminating depth being approximately 1000 m. This is where the practicality of using compressed gases for ballasting becomes impractical. The deeper diving vehicles utilize various drop weight methods; most use two sets of weights (usually scrap steel cut into uniform blocks). One set of weights is released upon reaching the bottom, allowing the vehicle to maneuver, travel, and perform tasks in a neutral condition. The other set of weights is dropped to make the vehicle buoyant, which carries it back to the surface once the dive is complete.

The shallow vehicles use their thrusters and/or water ballast to descend to the bottom and some of the more sophisticated submersibles have variable ballast systems which allow the pilot to achieve a neutral condition by varying the water level in a pressure tank.

One advantage of the shallow vehicles is that the view ports (commonly called windows) can be much larger both in size and numbers, and where an acrylic plastic sphere is used the entire hull becomes a window.

Since the late 1960s and early 1970s acrylic plastic pressure hulls have emerged as an ideal engineering solution to create a strong, transparent, corrosion-resistant, nonmagnetic pressure hull. The limiting factor of the acrylic sphere is its ability to resist implosion from external pressure at great depths. Its strength comes from the shape and wall thickness. Therefore, the greater the depth the operator aims to reach, the thicker the sphere must be, which results in a hull that is much too heavy to be practical for use on a small submersible designed to go deeper than 1000 m.

These shallow-water submersibles, once quite numerous because of their usefulness in the offshore oilfield industry, are now limited to a few operators and mostly used for scientific investigations.

The *Johnson-Sea-Links* (J-S-Ls) stand out as two of the most advanced manned submersibles (**Figure 3**). *J-S-L I*, commissioned by the Smithsonian Institution in January 1971, was named for designer and donors Edwin A. Link and J. Seward Johnson.

Edwin Link, responsible for the submersible's unique design and noted for his inventions in the aviation field, turned his energies to solving the problems of undersea diving, a technology then still in its infancy. One of his objectives was to carry out scientific work under water for lengthy periods.

The *Johnson-Sea-Link* was the most sophisticated diving craft he had created for this purpose, and it promised to be one of the most effective of the new generation of small submersible vehicles that were being built to penetrate the shallow depths of the continental shelf (183 m or 100 fathoms).

Originally designed for a depth of 304 m, the vessel's unique features include a two-person transparent acrylic sphere, 1.82 m in diameter and 10.16 cm thick, that provides panoramic underwater visibility to a pilot and a scientist/observer. Behind the sphere, there is a separate 2.4 m long cylindrical, welded, aluminum alloy lock-out/lock-in compartment that will enable scientists to exit from its bottom and collect specimens of undersea flora and fauna. The acrylic sphere and the aluminum cylinder are enclosed within a simple jointed aluminum tubular frame, a configuration that makes the vessel resemble a helicopter rather than a conventionally shaped submarine. Attached to the frame are the vessel's ballast tanks, thrusters, compressed air, mixed gas flasks, and battery pod.

The aluminum alloy parts of the submersible, lightweight and strong, along with the acrylic capsule which was patterned after the prototype used by the US Navy on the *Nemo*, had extraordinary advantages over traditional materials like steel. They were most of all immune to the corrosive effects of sea water.

The emphasis in engineering of the submersible was on safety. Switches, connectors, and all operating gear were especially designed to avoid possible safety hazards. The rear diving compartment allows one diver to exit for scientific collections while tethered for communications and breathing air supply, while the other diver/tender remains inside as a safety backup. Once the dive is completed and the submersible is recovered by a special deck-mounted crane on the support ship, the divers can transfer into a larger decompression chamber via a transfer trunk which is bolted to the lock-out/lock-in compartment.

Now, 30 years later, the *Johnson-Sea-Links* with a 904 m depth rating, remain state of the art underwater vehicles. Sophisticated hydraulic manipulators work in conjunction with a rotating bin collection platform which allow 12 separate locations to be sampled and simultaneously documented by digital

Figure 3 *Johnson-Sea-Link I* and *II*, 1971 and 1976. Owned and operated by Harbor Branch Oceanographic Institution. Length 7.2 m, beam 2.5 m, height 3.1 m, weight 10 400 kg, crew 2, observers 2, duration 3–5 hours.

color video cameras mounted on electric pan and tilt mechanisms and aimed with lasers. Illumination is provided by a variety of underwater lighting systems utilizing zenon arc lamps, metal halide, and halogen bulbs. Acoustic beacons provide real time position and depth information to shipboard computer tracking systems that not only show the submersible's position on the bottom, but also its relationship to the ship in latitude and longitude via the satellite-based global positioning system (GPS). The lock-out/lock-in compartment is now utilized as an observation and instrumentation compartment, which remains at one atmosphere.

Today's shallow-water submersibles (average dive 3–5 h) require a support vessel to provide the necessities that are not available due to their relatively small size. The batteries must be charged, compressed air and oxygen flasks must be replenished. Carbon dioxide removal material, usually soda lime or lithium hydroxide, is also replenished so as to provide maximum life support in case of trouble. Most submersibles today carry 5 days of life support, which allows time to effect a rescue should it become necessary.

The support vessel also must have a launch/recovery system capable of safely handling the submersible in all sea conditions. Over the last 30 years, the highly trained crews that operate the ship's handling systems and the submersibles, have virtually made the shallow-water submersibles an everyday scientific tool where the laboratory becomes the ocean bottom.

Operations

The two *Johnson-Sea-Links* have accumulated over 8000 dives for science, engineering, archaeology, and training purposes since 1971. They have developed into highly sophisticated science tools. Literally thousands of new species of marine life have been photographed, documented by video camera and collected without disturbing the surrounding habitat. Behavioral studies of fish, marine mammals and invertebrates as well as sampling of the water column and bottom areas for chemical analysis and geological studies are everyday tasks for the submersibles. In addition, numerous historical shipwrecks from galleons to warships like the *USS Monitor* have been explored and documented, preserving their legacy for future generations.

Johnson-Sea-Links I and *II* (J-S-Ls) were pressed into service to assist in locating, identifying, and ultimately recovering many key pieces of the ill-fated Space Shuttle Challenger. This disaster, viewed by the world via television, added a new dimension to the J-S-Ls' capabilities. Previously only known for their pioneering efforts in marine science, they proved to be valuable assets in the search and recovery operation. The J-S-Ls completed a total of 109 dives, including mapping a large area of the right solid rocket booster debris at a depth of 365 m. The vehicles proved their worth throughout the operation by consistently performing beyond expectations. They were launched and recovered easily and quickly. They could work on several contacts per day, taking NASA engineers to the wreckage for first-hand detailed examination of debris while video cameras recorded what was being seen and said. Significant pieces were rigged with lifting bridles for recovery. The autonomous operation of the J-S-Ls, a dedicated support vessel, and highly trained operations personnel made for a successful conclusion to an operation that had a significant impact on the future of the US Space Program.

Summary

There is no question that the manned submersible has earned its place in history. Much of what are now cataloged as new species were discovered in the last 30 years with the aid of submersibles. The ability to conduct marine science experiments *in situ* led to the development of intricate precision instruments, sampling devices for delicate invertebrates and gelatinous organisms that previously were only seen in blobs or pieces due to the primitive methods used to collect them.

While some suggest that remotely operated vehicles (ROVs) could, and have replaced the manned submersible, in reality they are complementary. There is no substitute for the autonomous, highly maneuverable submersible that can approach and collect without contact delicate zooplankton, while observing behavior and measuring the levels of bioluminescence, or probing brine pools and cold seep regions in the Gulf of Mexico for specialized collections of biological, geological, and geochemical samples. Tubeworms are routinely marked for growth rate studies and collected individually, along with other biological species that thrive in these chemosynthetic communities. Sediments and methane ice (gas hydrates) are also selectively retrieved for later analysis.

Some new vehicles are still being produced, but have limited payloads, which restricts them to specific tasks such as underwater camera platforms or observation. Some are easily transportable but are small and restricted to one occupant; they can be carried by smaller support vessels and are more economical to operate. Man's desire to explore the lakes, oceans, and seas has not diminished. New technology will only enable, not reduce, the need for man's presence in these hostile environments.

See also

Deep Submergence, Science of. Manned Submersibles, Deep Water. Remotely Operated Vehicles (ROVs).

Further Reading

Askew TM (1980) *JOHNSON-SEA-LINK Operations Manual*. Fort Pierce: Harbor Branch Foundation.

Busby F (1976, 1981) *Undersea Vechicles Directory*. Arlington: Busby & Associates.

Forman WR (1968) *KUMUKAHI Design and Operations Manual*. Makapuu, HI: Oceanic Institute.

Forman W (1999) *The History of American Deep Submersible Operations*. Flagstaff, AZ: Best Publishing Co.

Link MC (1973) *Windows in the Sea*. Washington, DC: Smithsonian Institute Press.

Stachiw JD (1986) *The Origins of Acrylic Plastic Submersibles*. American Society of Mechanical Engineers, Asme Paper 86-WA/HH-5.

Van Hoek S and Link MC (1993) *From Sky to Sea; A Story of Ed Link*. Flagstaff, AZ: Best Publishing Co.

MARICULTURE DISEASES AND HEALTH

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doi:10.1006/rwos.2001.0484

Introduction

As with all forms of intensive culture where a single species is reared at high population densities, infectious disease agents are able to transmit easily between host individuals and large economic losses can result from disease outbreaks. Husbandry methods are designed to minimize these losses by employing a variety of strategies, but central to all of these is providing the cultured animal with an optimal environment that does not jeopardize the animal's health and well-being. All animals have innate and acquired defenses against infectious agents and when environmental conditions are good for the host, these defense mechanisms will provide protection against most infections. However, animals under stress have less energy available to combat infections and are therefore more prone to disease. Although some facilities on a farm may be able to exclude the entry of pathogens, for example hatcheries with disinfected water supplies, it is impossible to exclude pathogens in an open marine situation. Under these conditions, stress management is paramount in maintaining the health of cultured animals. Even then, because of the close proximity of individuals in a farm, if certain pathogens do gain entry they are able to spread and multiply extremely rapidly and such massive infectious burdens can overcome the defenses of even healthy animals. In such cases some form of treatment, or even better, prophylaxis, is required to prevent crippling losses. This article describes some of the management strategies available to fish and shellfish farmers in avoiding or reducing the losses from infectious diseases and some of the prophylactic measures and treatments. The most important diseases encountered in mariculture are summarized in **Table 1**.

Health Management

Facility Design

Farms and husbandry practices can be designed in such a way as to avoid the introduction of pathogens and to restrict their spread within a farm in a variety of ways.

Isolate the hatchery Infectious agents can be excluded from hatcheries by disinfecting the incoming water using filters, ultraviolet lamps or ozone treatments. It is also important not to introduce infections from other parts of the farm that may be contaminated. The hatchery then should stand apart and strict hygiene standards applied to equipment and personnel entering the hatchery. Some diseases cause major mortalities in young fry while older fish are more resistant. For example, infectious pancreatic necrosis virus (IPNV) causes mass mortality in halibut fry, but juveniles are much more resistant. It is vitally important therefore, to exclude the entry of IPNV into the halibut hatchery and as this virus has a widespread distribution in the marine environment, disinfection of the water supply may be necessary.

Hygiene practice Limiting the spread of disease agents on a farm include having hand nets for each