G&S FEATURE

EXPLORING THE DEEP OCEANS

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The mean depth of all the oceans, which cover two-thirds of the Earth's surface, is 3771 m; the deepest depth so far plumbed is 10912 m in the Marianas Trench.

The waters around the United Kingdom are mainly within the depth of the Continental shelf—generally acknowledged to be shallower than 200 m. These waters constitute only a very small percentage of the total, notwithstanding the potential economic value of Britain's share of the North Sea gas and oil reserves—estimated at thousands of millions of pounds.

Even the most conservative engineer would acknowledge that the ocean-engineering achievements of the last decade have solved many of the apparently unsurmountable shallow-water engineering problems of the 1940–50 era. Useful work using structures, habitats, production facilities and divers to the limits of the Continental shelf is now an everyday occurrence. Off the shelf, the technology is in its infancy; we advance down the Continental slope at an apparent snail's pace, the majority of oceanographers still perpetuating the classical tools of Wyville Thomson and John Murray of *Challenger* fame. Such sampling of the sea bed from a distance of 4000 m overhead can be conclusively verified only by successive sampling plus statistical techniques. Recently, remotely controlled photographic and television cameras have increased the data rate; but what is really required is the ability for man to penetrate these depths at will.

Sir John Ross was one of the earliest explorers of the deep ocean; he assembled enormous lengths of rope in order to sound a depth of 4877 m in 1840 in the South Atlantic; he also invented a bottom-sampling device. Submarine cable engineers at the time of the early Atlantic cables (1857–58, 1865–66) secured the services of naval vessels from both sides of the Atlantic to survey possible cable routes. These surveys were carried out by lowering a weight on hemp line, each sounding occupying several hours. In the deep ocean the observations were spaced 20 n.m. apart. This procedure was greatly speeded up by Lord Kelvin in 1872 when he replaced the hemp rope with piano wire. Sounding machines of this type were in general use until the advent of the echo sounder.

Seabed and water-column sampling devices for geological, biological and physical oceanographic purposes were developed from 1873 onwards, when HMS *Challenger* sailed on the first deep-sea oceanographic expedition. For many years the basic technique remained unchanged: an inspired remote sample from the sea surface. It is truly amazing that such scanty data yielded so much fundamental understanding of the deep oceans.

With the advent of electronics in the deep ocean, the basic lower/raise technique is still paramount, with variations on the theme being provided by 'free-fall' or 'pop-up' devices.

Acoustics have become a major tool in exploring the deep oceans, but once again the techniques are sea-surface oriented.

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Without doubt, the data rate and quantity of available data have multiplied a thousandfold, but even so there are still requirements for more refined, accurate and repeatable data to fill in the many gaps in our knowledge. The only way to fulfil these requirements is for man to explore personally.

The advocates of unmanned exploration of the Moon have been remarkably subdued since the Apollo landings; the additional complications of landing human beings have proved of inestimable value. Similar considerations apply to manned versus unmanned exploration of the deep ocean. The engineering problems of manned deep-ocean exploration are as formidable as those of outer-space exploration; in the spheres of pressure engineering and life support they are more formidable. The pressure change in travelling to the Moon is 1 atm; a similar change takes place at a depth of 10 m in the ocean!

It was not until 1930 that man first explored the fringe of the deep ocean. Roberto Galeazzi reached a depth of 213 m in his 'butoscopic turret', a steel canister with a bulbous top encircled by 12 ports and lowered from the surface. Also in 1930 William Beebe and Otis Barton reached 305 m in a steel ball which they called a bathysphere. The sphere had an entrance hatch 38 cm in diameter and four fused-quartz windows. Electric power was supplied down a cable independent from the hoist cable. On their first dive 4·5 m of electric cable extruded into the sphere owing to the differential pressure across the stuffing box, a problem still encountered today by the unitiated. In September 1932, Beebe and Barton reached 518 m, followed in 1934 by 923 m, the limit of their cable. Barton went on to achieve 1372 m in 1950 in a modified design which he called a benthoscope.

The strength of steels used in the construction of spheres was such that the weight/displacement ratio was always greater than one, i.e. the spheres were negatively buoyant; and consequently the achievable depth was limited by the weight that could be supported on the end of the hoist. This problem was neatly solved by Auguste Piccard, who achieved a positive buoyancy by suspending his pressure sphere with a weight/displacement ratio of 2 beneath an envelope filled with petrol, a fluid much lighter than water and almost incompressible. Gone was the lowering cable, submerging being achieved by temporarily destroying the positive buoyancy of the sphere/petrol combination by adding water and iron shot. On reaching the ocean floor, ascent was achieved by dumping the iron shot to make the vessel positively buoyant again.

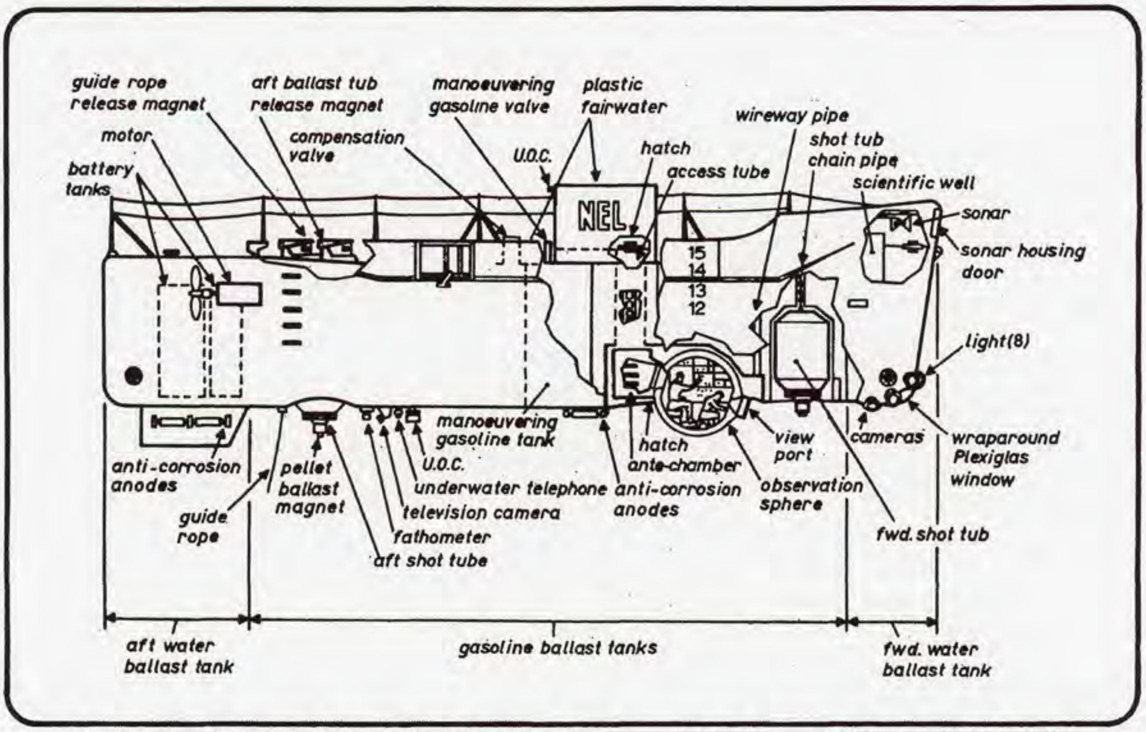
Piccard had started to build a vessel using these principles before the start of the Second World War, and had actually cast the pressure sphere when the work was stopped. After the war, the vessel was completed in 1948 and taken to the coast of West Africa, where, after an unmanned dive to 1402 m the envelope containing the petrol was so badly damaged by surface buffeting that any further attempts had to be temporarily abandoned. A new vessel was designed in conjunction with the French Navy, but progress was so slow that Piccard broke away and achieved financial backing to build a third boat, which he called *Trieste*. After a series of comparatively shallow dives, 3168 m was achieved in September 1953 off Naples. This depth was passed by the French Navy boat on the 1st February 1954, when 4099 m was reached. In 1958, the US Navy purchased *Trieste* and fitted a new pressure sphere which enabled it to reach the greatest known depth, 10912 m, on the 23rd January 1960.

None of the early bathyscaphs had any propulsive or manoeuvring power; they were little more than underwater lifts with human observation facilities. However, at last man was observing the deep ocean at first hand. New data were collected on each dive, old theories were destroyed, and confirmation of life at great depth was obtained.

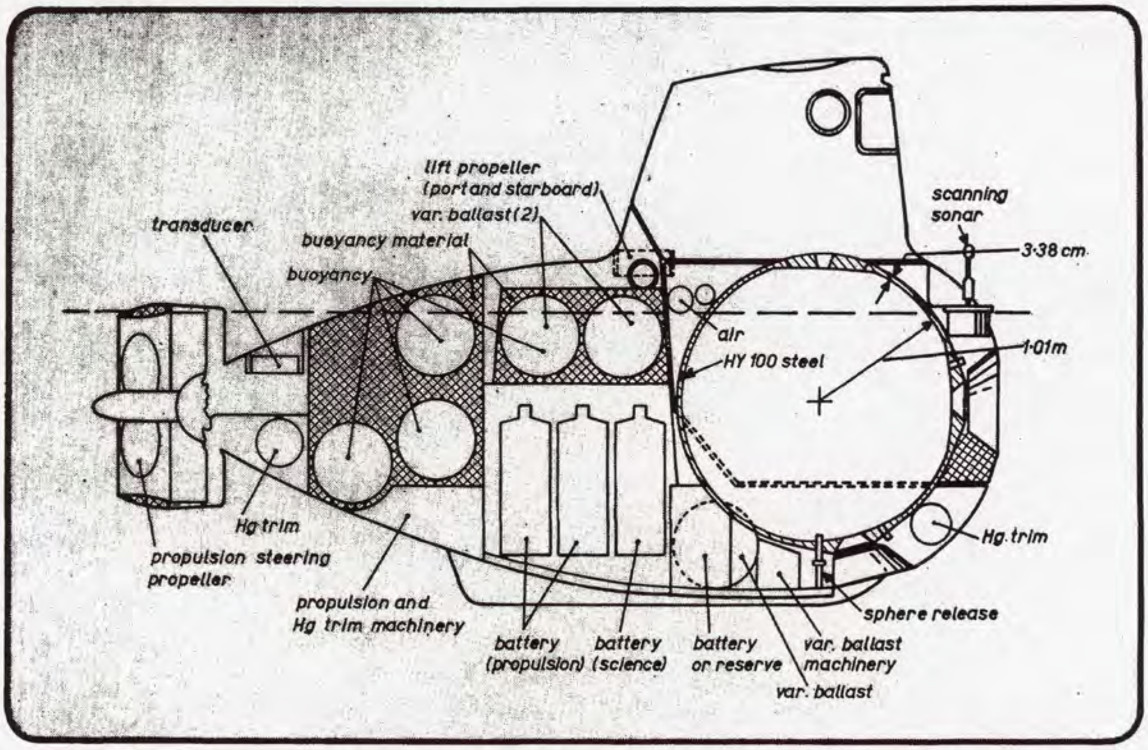
Bathyscaphs are unwieldy beasts to handle on the surface, and present enormous logistic and engineering problems. The current version of *Trieste* (Fig. 1) is transported to the dive site in a self-propelled floating dock.

At the shallow end of the scale, a further new type of vessel for ocean exploration was evolving during the 1960s: the submersible, the first of which was the diving 'saucer' *Denise*, built in 1959 by Jacques Cousteau. The pressure hull consisted of two 2 m-diameter ellipsoids welded together. An unloaded weight/displacement ratio of 0·7 was achieved by limiting the maximum diving depth to 330 m, thus restricting the pressure-hull thickness and ultimately its weight. No additional buoyancy material was required, the inherent positive buoyancy being destroyed on diving by loading droppable ballast.

Another vessel of this type is *Alvin* (Fig. 2), which originally had a pressure hull with a weight/displacement ratio of 0·7



1 **The current version of *Trieste*, the bathyscaph that descended to the greatest known depth in 1960**

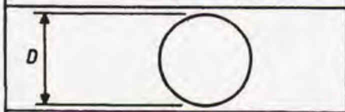
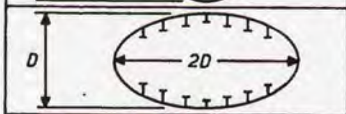
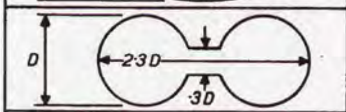
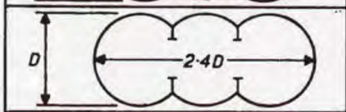
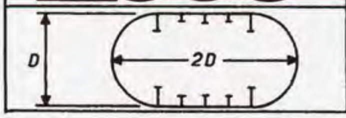


2 ***Alvin*** **submersible, developed by the US Office of Naval Research; in an improved version, it will be capable of dives down to 3050 m**

constructed of HY 100 steel, which gave it a maximum diving depth of 1830m; the hull is now being replaced with a titanium one, which will increase her depth to 3050 m. Additional buoyancy to that provided by the sphere itself is carried in two forms in the outer free-flooding exostructure; the first is of a permanent nature, consisting of syntactic foam, while the other is of a variable nature, and disposes of the need to carry droppable ballast; oil is pumped from aluminium spheres to collapsible bags to increase buoyancy. Mercury trim tanks are used to tilt the boat for a spiral descent and ascent.

Most submersibles for use off the continental shelf use this type operation. The greatest depth achieved so far by this type of boat is 2532 m by *Deep Quest* in February 1968. *Aluminaut* has a 4570 m potential, but has not gone deeper than 1980 m. This vessel is unique in that it has a buoyant cylindrical hull fabricated from 11 aluminium cylindrical forgings and two hemispherical endcaps, all bolted together.

Hull shape and material are the two main constraints on the designer, given an operating specification. Possible shapes of the pressure hull for a particular vessel with a 1830 m maximum operating depth and a 2745 m collapse depth are shown in Fig. 3. The sphere is theoretically the best shape from the weight/displacement-ratio aspect, but there are practical difficulties in achieving the perfect sphere; the sphericity should

shape	weight/displacement ratio		
	Hy-100 steel	Hy-140 steel	Hy-110 titanium
	0·47	0·39	0·28
	0·49	0·40	0·29
	0·49	0·41	0·30
	0·51	0·42	0·30
	0·52	0·43	0·31

3 Possible shapes of pressure hull for a vessel with a 1830 m maximum operating depth and a 2745 m collapse depth

not depart by more than 2–3% of the shell thickness. Assuming a weight/displacement ratio of 0·5 or less, the material to be used for a given depth can be obtained from Fig. 4.

Having achieved a good weight/displacement ratio, the designer does not want to waste too much of it by loading heavy equipment into the pressure hull; consequently, as much as possible is placed outside in pressure-balanced or pressure-tight containers. This approach immediately introduces problems with electrical penetrations; no other single item in deep-ocean exploration has caused so much frustration and annoyance as the electrical wiring of submersibles.

Other problems in the electrical field are the nonavailability of a cheap high-density battery. Most submersibles use simple lead–acid batteries, but fuel cells have been proposed for some applications. Subsurface communication is far from reliable. Acoustic propagation is the only means available for distances greater than 100m, but even this suffers from multipath interference and vagaries of the medium caused by thermoclines. Subsurface navigation also has its problems as acoustic navigational devices are mostly used; inertial systems are possible, but the cost is extremely high.

Perhaps the biggest engineering problem in the use of submersibles to explore the deep ocean is the question of penetrating the air–sea interface. With a few exceptions, submersibles are transported to their dive site on a mother ship and then launched by methods ranging from a simple derrick to sophisticated lifts arranged between the hulls of a catamaran vessel. None of the present systems is ideal, and none can be used in all weathers; the best solution appears to be to use a large submarine as the mother ship carrying the submersible 'piggyback'; such a system can be made independent of weather, but introduces additional engineering problems on subsurface mating.

In the last 3–4 years, the diver has received great attention as a possible means to explore the deep ocean. If such a suggestion had been made ten years ago, it would have been treated as little more than science fiction. Diving to the limits of the Continental shelf is now commonplace, and a depth of 600m is within our grasp. If in the next decade we maintain the progress made in the last, we will be working at 1500m within the foreseeable future.

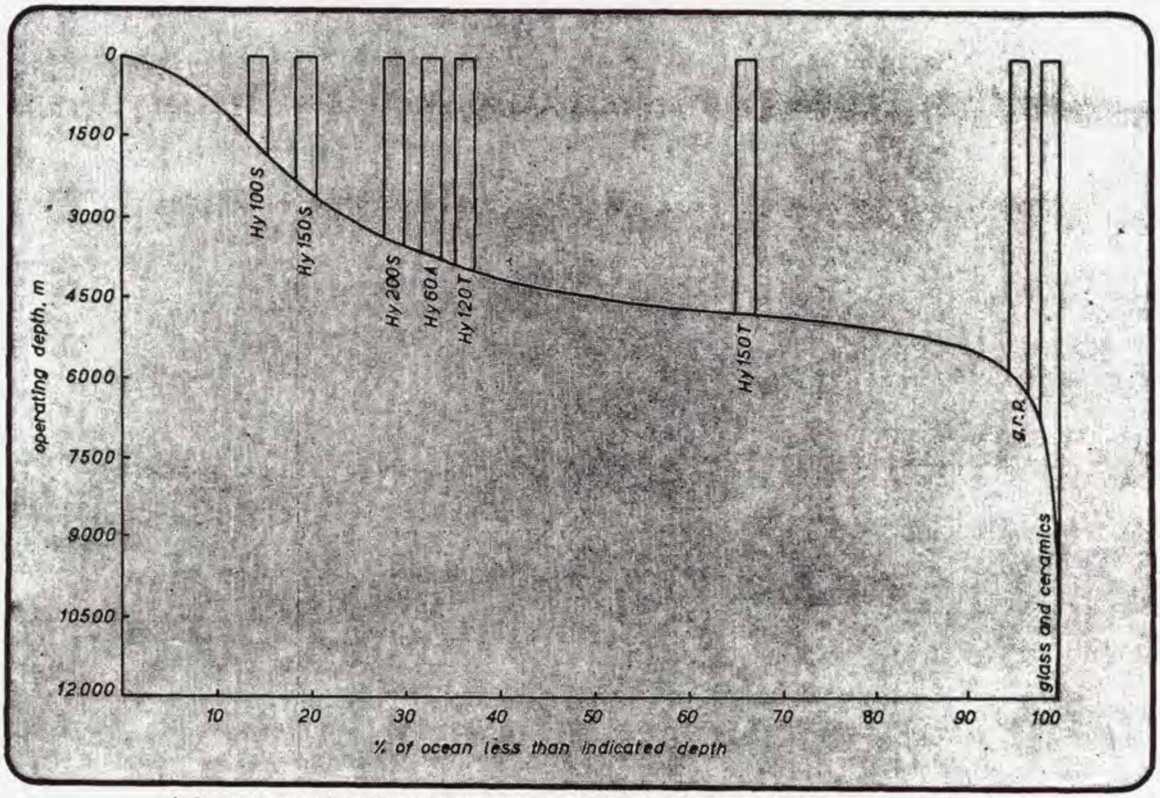
Achieving these great depths is made possible by first replacing the nitrogen in the diver's breathing mixture with helium, so that he does not suffer from nitrogen narcosis, and then keeping him under pressure until his bloodstream and tissues can absorb no more gas; in this state he is termed 'saturated'. At this stage, the diver can stay at depth for very long periods without increasing the time to decompress on returning to the surface.

Supporting a diver in the saturated mode has brought with it some unusual engineering problems. Apart from the obvious problems of gas handling and storage, the use of helium means that the divers lose their body heat at a rate seven times faster than normal, and their speech becomes unintelligible. Both problems are under temporary control, but the ideal engineering solution of keeping the diver warm has not yet been found.

In a saturated diving system, the diver is pressurised in a chamber aboard ship and lowered to his worksite in a sealed capsule; the capsule is opened when the external and internal pressures are equal; the diver carries out the task, returns to the capsule and seals it, transfers to the ship's deck chamber (still under working-depth pressure) and there decompresses. Obviously, the deck decompression chambers must be designed for the full working pressure, and similar problems are encountered as with submersibles, including the launching arrangements of the sealed capsule.

One of the most attractive methods for exploring the shallow end of the spectrum is the combination of saturated diving from a submersible. 'Locking out' a diver at 300m depth is shortly to be attempted.

There are many challenging engineering problems to be solved in deep-ocean exploration, covering a wide range of specialities, but before any individual attempts are made to solve them any prospective proponents have first of all to come to terms with the ocean; it is a punishing environment to both man and his equipment.



4 Assessment of material to be used for given depths; a spherical pressure hull is assumed with a weight/displacement ratio of 0·5 or less