Underwater Operations with Submersibles

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ON

UNDERWATER OPERATIONS WITH SUBMERSIBLES

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SUMMARY

Submersibles have been used commercially, largely in the USA, for about 15 years. Developments made in recent years have extended their successful operation to exposed sea areas. In many conditions, submersibles are now competing successfully with diving systems and have replaced divers for many tasks.

This paper describes the development work carried out by Vickers Limited Shipbuilding Group and Vickers Oceanics Limited in this sphere. Considerable attention has been given to developing a system for the launch and recovery of submersibles, suitable for sea states 5 to 6, and to developing specialised work equipments and to combined operations with divers and submersibles. In this paper the future of underwater vehicles is also discussed.

UNDERWATER OPERATIONS WITH SUBMERSIBLES

The concept of submersibles, like that of aircraft, is very old and historians have eagerly recorded the facts in many publications. Perhaps one of the best records of submersible development is 'A Pictorial History of Oceanographic Submersibles' by James B Sweeney.

The greatest impetus to technical development has, of course, been in the naval application of submarines in the two World Wars. In recent times, the rôle of the naval submarine has been dramatically changed by the introduction of the nuclear power plant. This is still, however, a luxury of certain marine powers, but so great is the value of nuclear power in underwater operations that we must expect its wider application, in both military and civil fields, in the next decade. The wheel of fortune has turned full circle and there is now a growing need for submersible vehicles to be exploited commercially in a way which was not feasible in the past.

The author's Company has been in the forefront of submarine development since the Holland Boats were first introduced. It has been involved in most, if not all, of the developments of the naval submarine for the Royal Navy, since that time. All of us would recognise that the best development projects stem from solving problems as they arise and, accordingly, we have felt obliged to keep abreast of underwater technology by a more direct involvement in operations than has hitherto been the case.

It was noted that a considerable number of submersibles had been constructed in the USA by a wide spectrum of organisations ranging from Aerospace Companies to Oceanographic Institutes and down to enthusiastic, if sometimes misguided, amateurs. There seemed to be a degree of individual achievement in each of these projects but none of the vehicles was reported to be operating economically. In reaching a conclusion about the submersible vehicle one must first look at what it was intended to replace, namely divers.

Diving Technology

Diving, taking into account the progress made in the last ten years, is an effective if not an efficient operation primarily because most underwater installations are presently designed to suit diver limitations. Much money has been spent, particularly in the USA and in France, in developing deep-diving operational systems. Experimental deep-diving and safety work in the UK has led to diving tables and procedures which are now widely used. Development work on shore-based complexes, underwater habitats, mixed gas equipment and diver heating is establishing man's ability to exist and work routinely at pressures of over 300 lbf/in^2, ie approximately 200 metres deep. In July of this year, Oceaneering International Inc announced the first contract for a service to 300 metres in the North Sea.

Simulated diving cycles have been carried out in shore facilities at pressures corresponding to depths of 500 metres and in some actual working situations of about 300 metres. However effective these demonstrations might seem to be, the offshore industry is really interested in the accomplishment of useful engineering and maintenance tasks at these depths. Here we encounter the real difficulties of the environment. Diving to 50 metres and performing light tasks at that depth is well within the capabilities of the average diver working under supervision with simple equipment. Even modest increases in the operating depth quickly escalate the physiological problems of supporting a man in the sea, and this is reflected in increasing complications in the systems which are required to support him. In depths up to 120 metres, engineering tasks can be done by first class divers working with first class equipment. Depths of 200 metres have been reached, but little in the way of effective work has yet been reported.

When divers work at depths greater than 70 metres, it is necessary to use mixed gases, the helium content increasing with the depth. Apart from the expense, there are additional technical problems such as heat loss and speech distortion. Helium is a good conductor of heat and it readily penetrates insulating materials with the result that there is the serious problem of conserving the heat of a diver's body in cold water. Firstly, it is necessary to heat the atmosphere he breathes, then the diver's body. Electrical heating can be somewhat dangerous in a sea-water environment and the alternative is to circulate warm water. Both systems involve umbilicals and there are problems of delicate temperature control. As helium is expensive, the mixed-gas atmosphere should be recovered, but the scrubbing and recovery plant is cumbersome and expensive. The result is that for deep-diving, especially by saturation methods, the capital cost of plant is high.

In addition, the power capability of man is very limited in civil engineering terms and he has limited strength for moving about and combating underwater currents. As we provide to him the 'assistance' for breathing, heating, and for powered tools, his power is effectively reduced. The support plant and umbilicals seriously reduce his mobility and working capability, eventually destroying the main advantage which the diver otherwise has over the submersible. Man at depth is not at his most intelligent and bone necrosis is giving rise to industrial claims for physical damage.

The diver's need for powered tooling leads to further operational difficulties, with power leads from the surface or the technical complications of power sources which can run unattended underwater. In view of the logistics, handling and, as yet, unsolved physiological problems of diving, we directed our attention about six years ago towards alternative methods of performing underwater tasks, which would have great scope for development in the future.

Submersibles

A world-wide survey was made of existing submersibles and it was evident that, although a good deal of attention had been given to the technicalities of submersible design, they had not been designed for commercial exploitation.

In 1967 we analysed, in some detail, the reasons for this situation and how it could best be corrected.

Depth capabilities ranged from continental shelf types, with typical diving depths of 200 metres, to the Bathy-Scarph with a depth capability greater than 10 000 metres, adequate for diving in the Mariana Trench, the deepest known area in the world oceans. The costs of individual submersibles ranged between the few millions of dollars typical of the products of Aerospace Industry down to the relatively inexpensive versions of the amateur.

High capital costs of those produced by the Aerospace companies and low reliability or limited capability of the less expensive units, coupled with the absence of suitable launching and recovery systems, seemed to be the major reasons for their unsuccessful application in a commercial setting.

A comprehensive selection of types of underwater vehicle is given in Fig 1. Some do not yet exist, but in most cases there are one or two examples in operation. These can be divided, broadly, into the following groups:

Manned or unmanned

Tethered or untethered

Bottom traction or water jet propulsion

With such a diverse array of units and a low market profile for any in particular, there seemed little virtue in starting afresh to design a new submersible. Two existing types of submersible stood out as practical possibilities for building into operating systems and these are described in the following text.

Pisces Submersible

The Pisces submersible developed by International Hydrodynamics of Vancouver is suitable for deep-diving applications, and 5 units have now been built with operating depths ranging from 600 metres to 2000 metres.

Fig 2 shows the arrangement of a Pisces-type Submersible. It comprises a Main Sphere of 80in. diameter and a Machinery Sphere of 60in. diameter. Between the two spheres is situated a battery of the lead-acid type which is immersed in oil and is pressure-compensated. The submersible is propelled by two propeller units driven by oil-filled electric motors, which are also pressure-compensated.

The buoyancy control system comprises an oil reservoir, situated in the Machinery Sphere, and a pump which can pump the oil to and from flexible bags amidships, or, for trim control, to the trim spheres at the bow. Additional buoyancy, when on the surface at launch or recovery, and increased lifting ability when submerged are provided for by midships ballast tanks which are filled with compressed air to displace the water, or flooded completely when neutral buoyancy is required.

Tooling, in the form of manipulators or hydraulically-powered saws, spanners, grinding wheels or cable cutters is arranged at the fore-end, within the field of view of the operators. The work area is illuminated by high-powered thallium iodide lights. A simple Fish Finding Scanning Sonar serves for collision avoidance, but by suitable modification its performance can be improved to the extent that it can also locate targets for investigation. Underwater telephones are provided for communication with the surface and a transponder is fitted to enable the submersible to be tracked from the surface. An echo-sounder records the position of the submersible relative to the bottom and the surface.

This type of submersible has been successfully used in the field for operations down to 1000 metres.

PC Submersible

The PC-15 Submersible designed and built by Perry Oceanographics of Florida, is a Diver Lockout Unit suitable for 400 metres operating depth; the essential features are shown in Fig 3. It comprises a cylindrical hull with two compartments which are inter-connected by a pressure-resistant and watertight hatch. The forward compartment is dry and carries the pilot and a diving supervisor. The after compartment carries the two divers. This compartment can be pressurised by a gas mixture appropriate to the operating depth, enabling the two divers to open the hatch and emerge onto the sea floor. The divers are connected to the submersible by an umbilical, which provides their power, communications and gases, and also acts as a safety link to prevent them taking excursions to the surface or losing contact. On completion of a mission, they return into the submersible, close and lock the hatch and are brought to the surface, where they are transferred under pressure into a deck decompression chamber. If saturation diving is being undertaken, they can be held at pressure for several days, or even a few weeks, during which they can transfer to and from the submersible to spend daily work periods on the sea floor.

The Diving Supervisor is able to observe the behaviour of the divers whilst in the submersible or deck decompression chamber, and controls the gas systems throughout the dive.

This submersible is fitted with an acrylic window, giving the pilot and observers a wide angle of visibility. The batteries are carried in the twin pods on the bottom of the submersible. Propulsion is provided by a single screw, and transverse propulsion units provide lateral or turning movements. Forward planes are also fitted for 'flying' off the bottom.

Underwater Operations

With the prospect of a developing market for underwater services, in the forthcoming decade, it was decided to put together a range of complete systems, based on these submersibles, capable of providing a submersible service in sea conditions of at least sea state 4 (12/15ft waves). Other known systems of handling were not capable of safe working in greater than sea state 2.

Sea conditions in the waters around the UK are significantly worse than anywhere else in the world that has seen diver and submersible operations, thus it was essential to develop a handling system such that a submersible weighing up to 20 tons could be launched and recovered in perfect safety under these conditions. A small stern trawler was purchased and converted into a submersible support ship, including the fitting of a 12 ton handling system (Fig 4). Development trials were carried out over many months of operations, using a dummy submersible, until satisfactory performance of the equipment and the launching and recovery procedures was obtained. Sea trials with a Pisces Submersible were then undertaken.

This unit has now been in service for 4 years, during which time it has built up a satisfactory market in Torpedo Recovery for the Ministry of Defence (Navy), in relatively protected water ways with surface conditions up to sea state 4. The operating techniques and tool kits for such operations have also been built up as a result of experience over this time. However, the support ship, which is 125ft length, was found to be inadequate for work in open seas, such as the North Sea, and it was decided to improve the capability by the acquisition of a larger ship carrying two submersibles (Fig 5). The latter unit has now been in service for 1 year, largely on cable burial and pipeline surveys, and has satisfactorily operated the submersibles in conditions up to sea state 6. This unit will shortly be modified to take the Diver Lockout Submersible, thus providing an all round submersible and diving capability.

The total experience so far with submersible operations is that in many situations they can replace divers. In the case of United Kingdom waters, the conditions are characterised by:

(1) Average sea states and extremes of weather conditions are significantly worse than previously encountered in routine offshore operations.

(2) Strong tidal currents and turbidity.

(3) Greater water depths than previous oil extraction workings; 200 metres at present with oil-bearing potential extending to depths of 300 metres to 600 metres for future development.

(4) Low water temperature.

(5) Wide area of activity, requiring mobility of the facility.

Other areas of the world wherein oil is expected to be found, in meeting the challenge of diminishing supplies, are likely to have conditions which are equally taxing to mans' existence in the sea. Perhaps the southern coast of Australia is a comparable operating area.

Whereas it was thought that submersibles would not compete with divers in water less than 120 metres deep, it is now found that they are economically and effectively replacing divers in water as shallow as 50 metres. The reasons are simple: divers have little or no power at their elbow, quickly run out of their gas supplies and their strength, and are frequently cold and frightened. If they move on the bottom they stir up clouds of bottom sediment, and because of the limitations of their gas supplies they are unable to wait until it clears to make their next productive move.

On the other hand, the submersible presents a 'shirt sleeve' environment with a reasonable, even if still insufficient, power source at hand and, as it is capable of operating for periods of the order of 6 to 8 hours per day, it can afford to wait on the bottom until conditions improve. However, there is the technical problem of devising methods of doing work remotely from inside the pressure hull of the submersible. Because the submersible lacks flexibility, provision for tooling has to be made well in advance of meeting the problem in the field. Very often the underwater problems are not well defined and two or three alternative approaches need to be worked out and tooling provided accordingly.

Thus, we foresee that there will always be specialised tasks that divers will perform best. Submersibles will play a major part in the exploitation of the deeper and harsher areas offshore, but there is also a need for divers and submersibles to provide an integrated service. Accordingly, we have specified, and recently taken delivery of, the diver lockout submersible previously described, which is expected to improve the diver's performance by:

(1) Conserving life support facilities.

(2) Removing the fear of loneliness on the bottom.

(3) Providing additional power for tooling.

(4) Improving work times by using the submersible's freedom for search and approach to the work sites.

An attempt to quantify the comparative costs of diving methods and submersibles on a basis of operating depths is shown in Fig 6. This takes account of the productivity and capitalisation necessary in the competing systems. Broadly, as depth increases the submersible system tends to dominate the situation.

Current Applications of Submersibles

An excellent application for submersible services has been found in the field of undersea cables, which are being damaged by fishing trawls. The repeaters and repaired lengths of cables have now been buried on several Transatlantic cables out to depths beyond 2000ft. In this case, the requirements of depth, power for burying and exposure to rough water were such as to rule out diving as a competitive approach.

A further application which has been developed is the survey of gas and oil pipelines in the North Sea. A full video recording of the pipeline is obtained together with measurements of the depth of burial and accurate location information. Such records, showing defects in coatings, damage caused by trawls and anchors and displacement of saddles, are proving a boon to those responsible for the maintenance of the pipelines. In fact, requests are now being made for annual surveys to establish if there are changes in pipeline conditions due to tidal scouring. Equipment has been developed to penetrate the pipe covering for the purpose of taking cathodic potential readings.

This service is now being extended to the provision of surveys of the contours and texture of the bottom prior to the establishment of drilling platforms and pipelines. The submersible has also found application in the location and recovery of wreckage of crashed aircraft. In this case, the investigator prefers to identify wreckage and its distribution before recovery, as evidence aimed at establishing the cause of a crash. An experimental technique has been tested involving the continuous transmission of video pictures from the submersible to a command ship. This system enables experts to view the operations and to identify components from the reasonable comfort of the shore base or command ship. It, however, carries the distinct disadvantage to the submersible of some loss of mobility by having to tow a surface transmitter.

Other operations which have been undertaken include observation of fish life, the observation of trawls in use and the coring of rock samples from underwater cliffs.

Future Developments

Reference was made previously to the wide variety of vehicles which have or are being developed for undersea work. The so-called energy crisis means that there is now a greater incentive for men and machines to work, effectively, and with reliability, on the bottom. The stakes are high and expensive development can be made to pay off if productivity and reliability are achieved. There is a positive need for vehicles which can inspect the structure of platforms of both the fixed and semi-submersible type.

The direction in which future development will go is difficult to predict but certain major parameters stand out:

(1) Man has a special ability to operate and improvise in the uncertainties of this environment.

(2) An increasing level of power and endurance will be required and mono-fuels or nuclear power sources will find wider application.

(3) Umbilicals are clumsy and often dangerous, and the hydrodynamic stability of vehicles with umbilicals is an area of extreme uncertainty. Systems without them will tend to be preferred.

(4) Surface support is expensive, and very often the dominating factor in overall costs. It is often unreliable due to surface conditions. Accordingly, autonomous underwater systems will tend to be more acceptable in the future.

From this, the author concludes that we will see increasing use of underwater drilling systems followed by well-head completion and also the laying of pipelines, entirely underwater. The power requirements will be met by nuclear power and the vehicles of fixed facilities will be manned by technicians serving as much as 2/4 weeks underwater at a time.

Only well-head completion underwater is being developed seriously at this time. SEAL and Lockheed are both developing underwater work chambers combined with remote handling methods of transferring men and equipment to and from the surface. Both depend on power from the surface and accordingly rely on a surface ship which can accurately maintain station even in rough weather, presenting a problem which should not be under-estimated.

Eventually we may well see civil engineering, engineering maintenance and the surveillance and policing of our offshore investments all performed without surface ship support. A small autonomous submarine with nuclear power will provide much the same service as we are providing now with small submersibles operating from a surface ship or fixed platform.

Future Underwater Systems

MANNED		Unsupported, at sea	1	Submarine
	MOBILE	Supported, moving or fixed ship	2	Tethered powered submersible
			3	Tethered powered crawler
			3A	Tethered powered climber
			4	Tethered towed submersible
			5	Tethered towed tracked sledge
			6	Untethered submersible
			7	Untethered crawler
			8	Tethered wet vehicle
			9	Untethered wet vehicle, DPU
		Fixed ship, barge etc	10 + 16	Tethered diver (saturated)
			10A	Tethered diver (armoured suit)
			11	Untethered diver (shallow water)
			12	Tethered telechiric
	IMMOBILE	Supported (eg fixed ship, barge etc)	14	Tethered habitat
			15	Untethered habitat
			17	Tethered diving bell (diving pressure)
			18	Tethered manipulator system
			18A	Tethered tracked manipulator system
UNMANNED		Supported, moving or fixed ship	20	Tethered powered submersible
	MOBILE		21	Tethered powered crawler
			21A	Tethered powered climber
			22	Tethered towed submersible
			23	Tethered towed tracked sledge
			24	Untethered submersible
			25	Untethered crawler
		fixed ship, barge etc	26	Tethered powered submersible (fixed ship)
			27	Tethered powered submersible (fixed ship & clump anchor)
			28	Tethered telechiric
	IMMOBILE	Supported (eg fixed ship, barge etc)	30	Tethered fixed base
			31	Untethered fixed base
			32	Tethered manipulator system
			32A	Tethered tracked manipulator system

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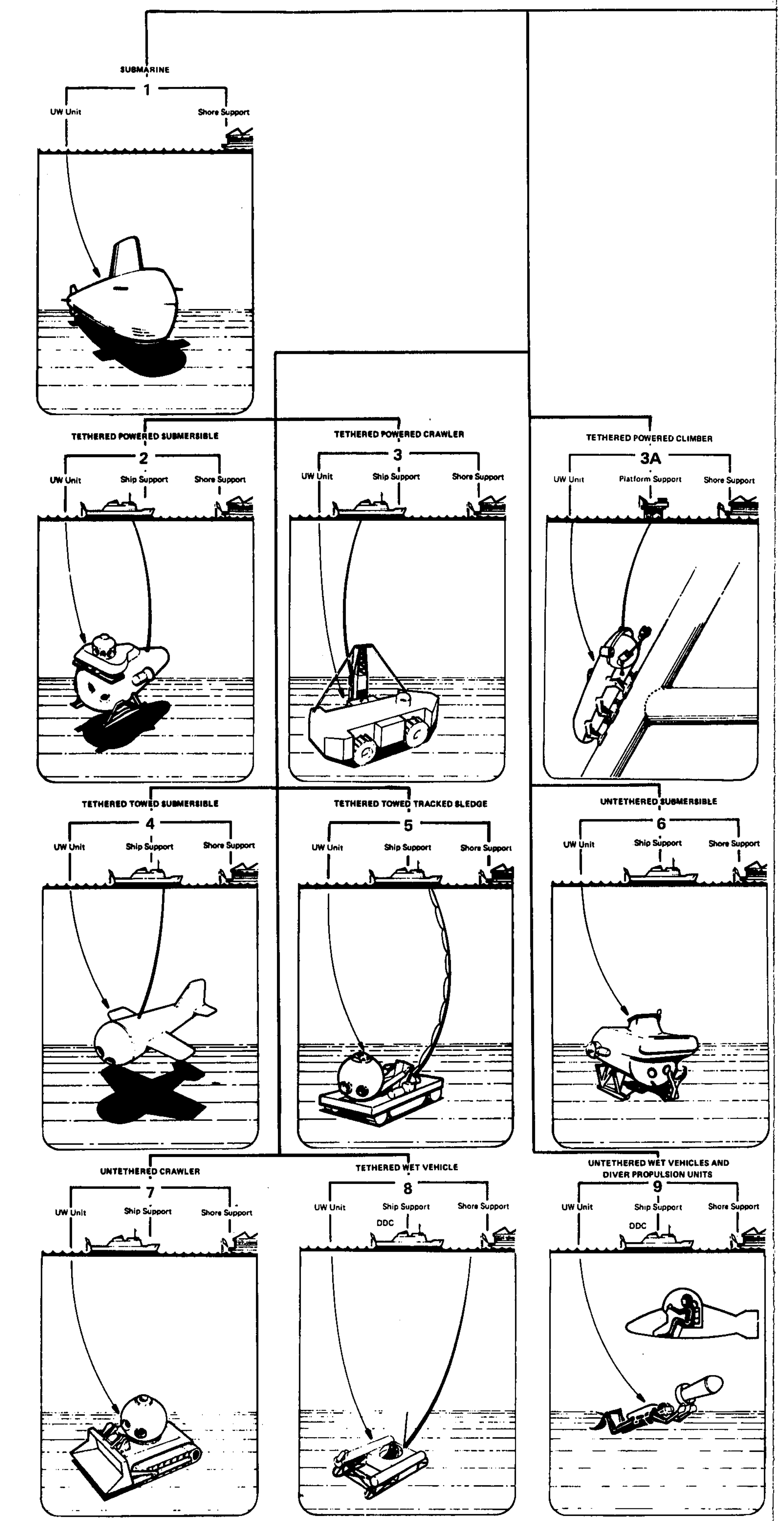
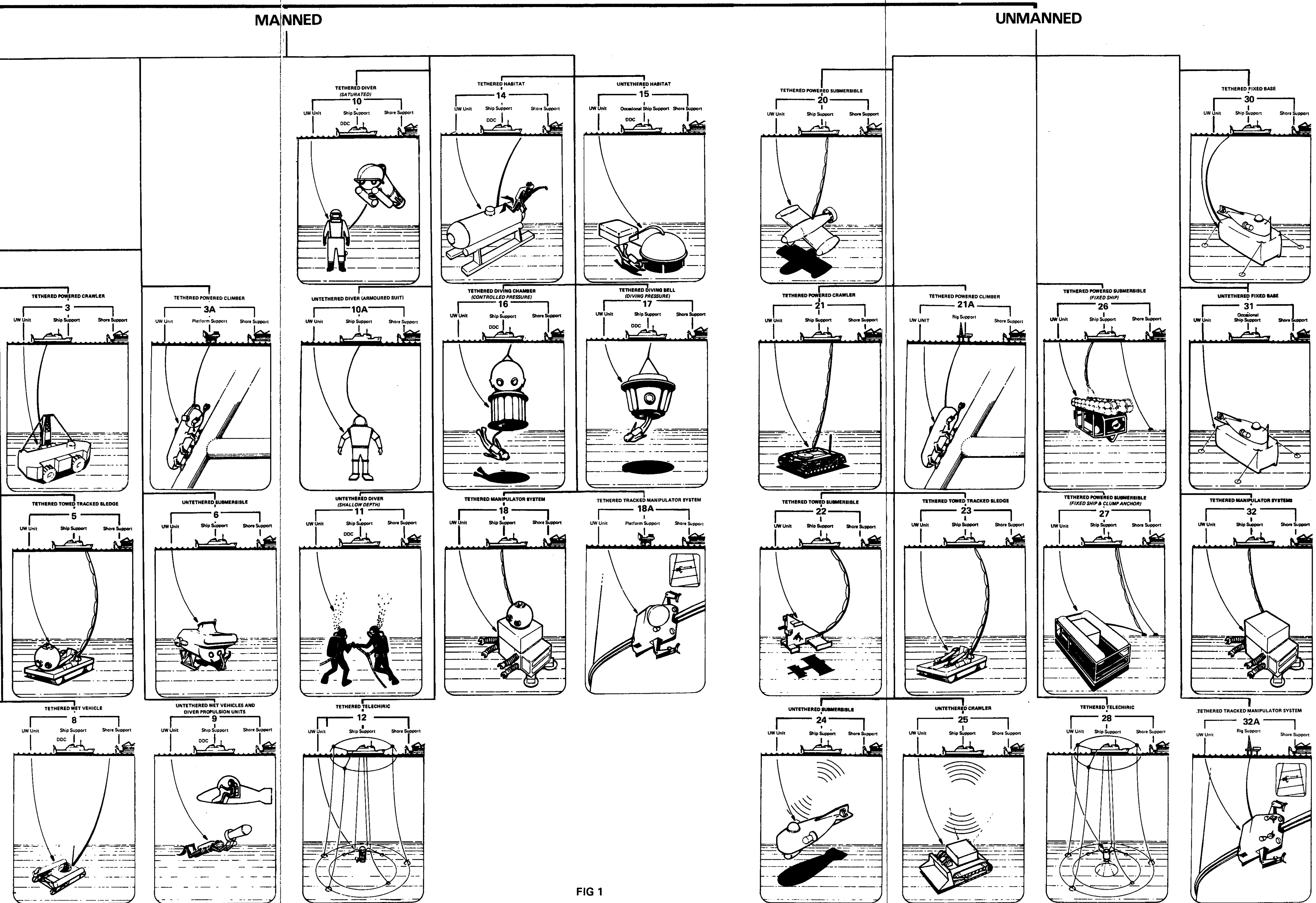
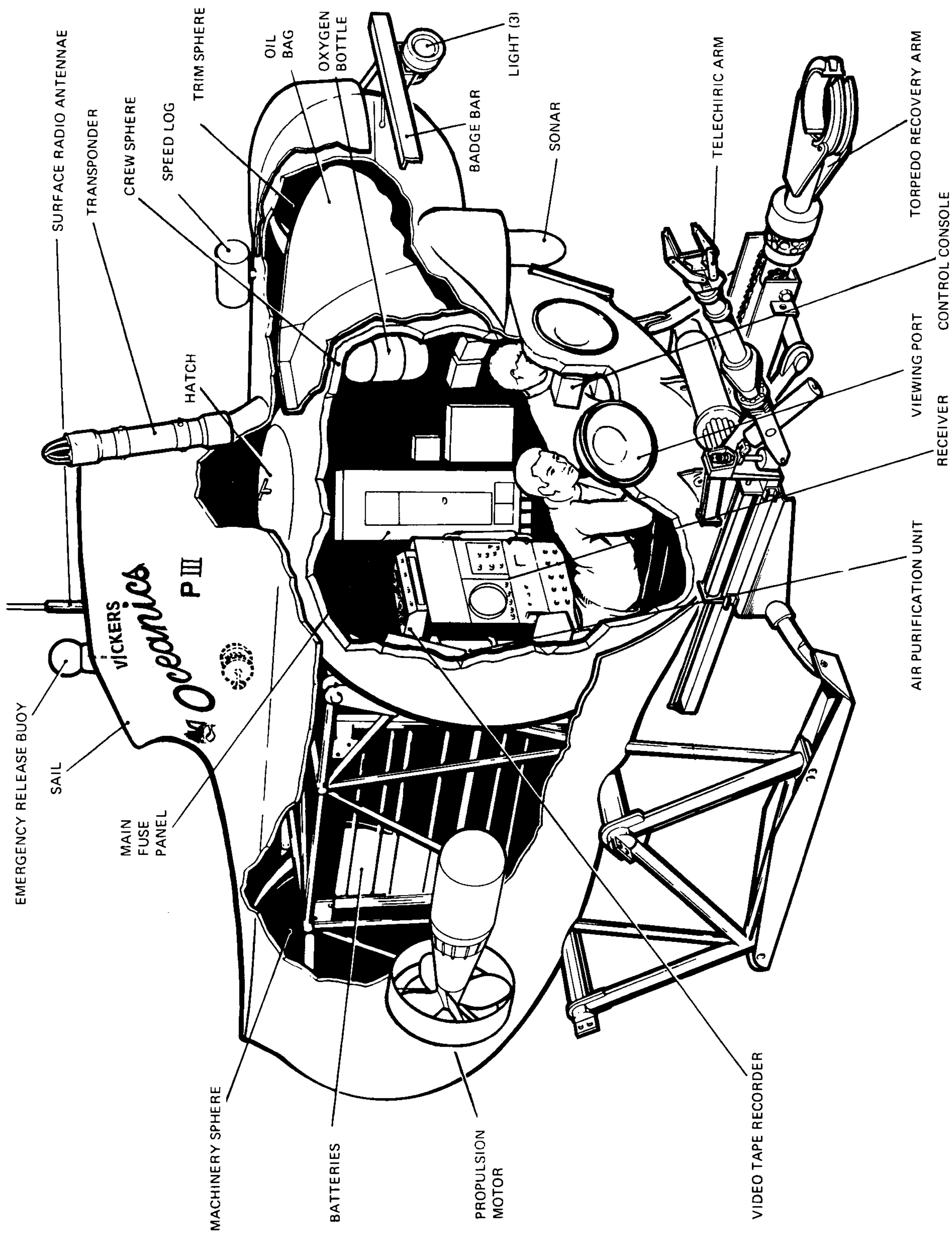


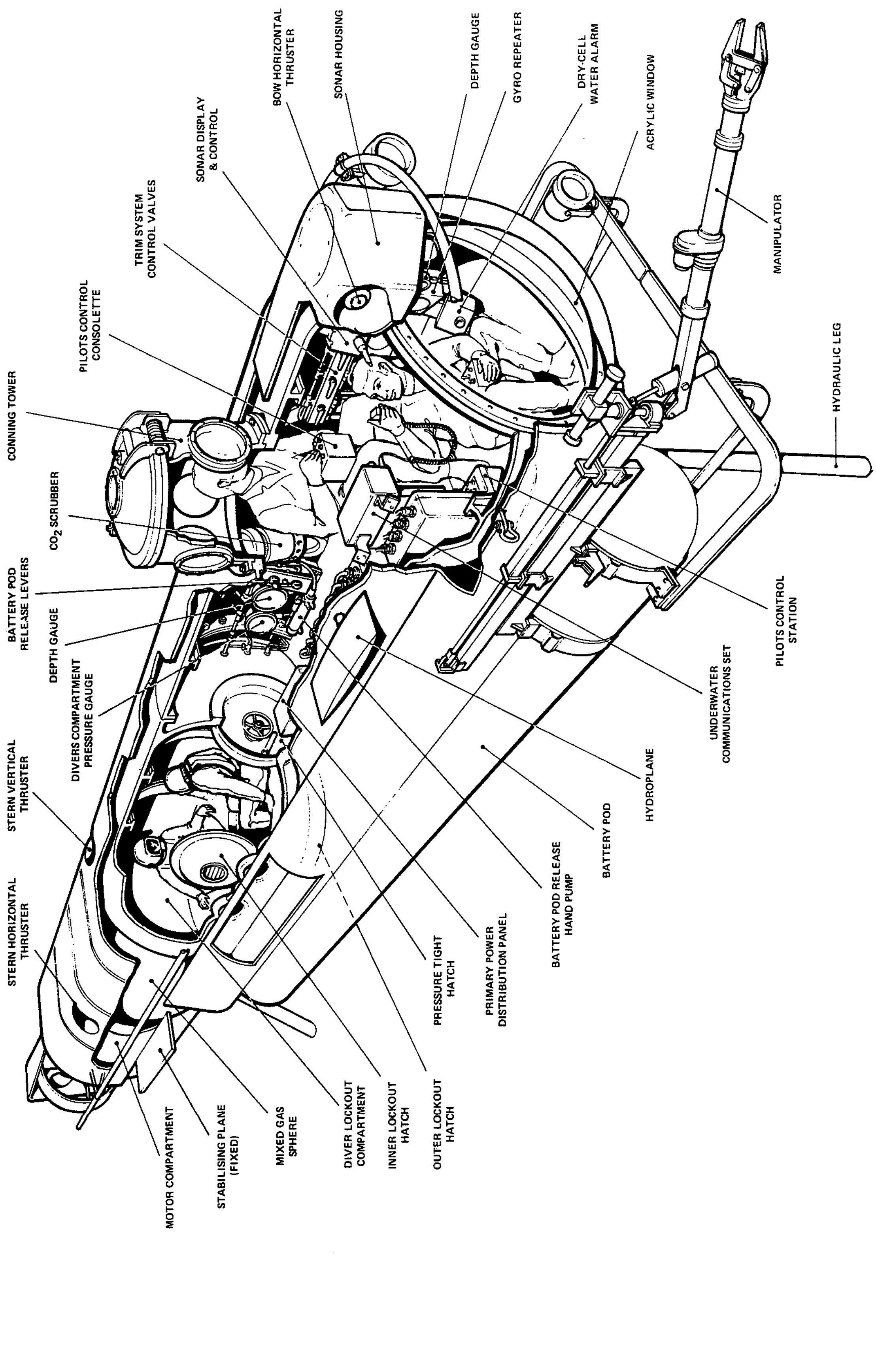


MANNED
UNMANNED
TETHERED DIVER (SATURATED) 10
UW Unit
Ship Support
DDC
Shore Support
TETHERED HABITAT 14
UW Unit
Ship Support
DDC
Shore Support
UNTETHERED HABITAT 15
UW Unit
Occasional Ship Support
DDC
Shore Support
TETHERED POWERED SUBMERSIBLE 20
UW Unit
Ship Support
Shore Support
TETHERED FIXED BASE 30
UW Unit
Ship Support
Shore Support
TETHERED POWERED CRAWLER 3
UW Unit
Ship Support
Shore Support
TETHERED POWERED CLIMBER 3A
UW Unit
Platform Support
Shore Support
UNTETHERED DIVER (ARMOURED SUIT) 10A
UW Unit
Ship Support
Shore Support
TETHERED DIVING CHAMBER (CONTROLLED PRESSURE) 16
UW Unit
Ship Support
DDC
Shore Support
TETHERED DIVING BELL (DIVING PRESSURE) 17
UW Unit
Ship Support
DDC
Shore Support
TETHERED POWERED CRAWLER 21
UW Unit
Ship Support
Shore Support
TETHERED POWERED CLIMBER 21A
UW UNIT
Rig Support
Shore Support
TETHERED POWERED SUBMERSIBLE (FIXED SHIP) 26
UW Unit
Ship Support
Shore Support
UNTETHERED FIXED BASE 31
UW Unit
Occasional Ship Support
Shore Support
TETHERED TOWED TRACKED SLEDGE 5
UW Unit
Ship Support
Shore Support
UNTETHERED SUBMERSIBLE 6
UW Unit
Ship Support
Shore Support
UNTETHERED DIVER (SHALLOW DEPTH) 11
UW Unit
Ship Support
DDC
Shore Support
TETHERED MANIPULATOR SYSTEM 18
UW Unit
Ship Support
Shore Support
TETHERED TRACKED MANIPULATOR SYSTEM 18A
UW Unit
Platform Support
Shore Support
TETHERED TOWED SUBMERSIBLE 22
UW Unit
Ship Support
Shore Support
TETHERED TOWED TRACKED SLEDGE 23
UW Unit
Ship Support
Shore Support
TETHERED POWERED SUBMERSIBLE (FIXED SHIP & CLUMP ANCHOR) 27
UW Unit
Ship Support
Shore Support
TETHERED MANIPULATOR SYSTEMS 32
UW Unit
Ship Support
Shore Support
TETHERED WET VEHICLE 8
UW Unit
Ship Support
DDC
Shore Support
UNTETHERED WET VEHICLES AND DIVER PROPULSION UNITS 9
UW Unit
Ship Support
DDC
Shore Support
TETHERED TELECHIRIC 12
UW Unit
Ship Support
Shore Support
UNTETHERED SUBMERSIBLE 24
UW Unit
Ship Support
Shore Support
UNTETHERED CRAWLER 25
UW Unit
Ship Support
Shore Support
TETHERED TELECHIRIC 28
UW Unit
Ship Support
Shore Support
TETHERED TRACKED MANIPULATOR SYSTEM 32A
UW Unit
Rig Support
Shore Support

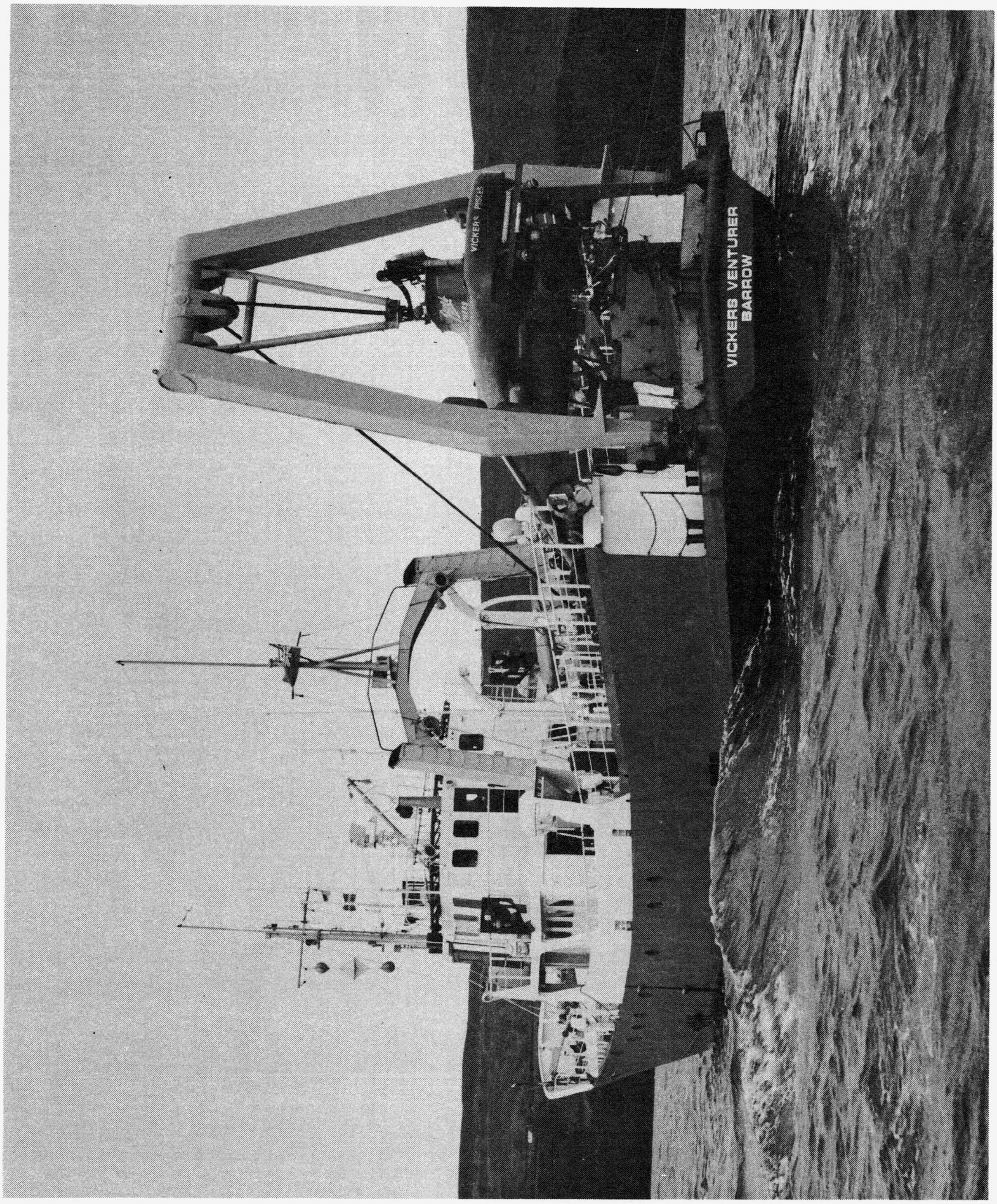
FIG 1



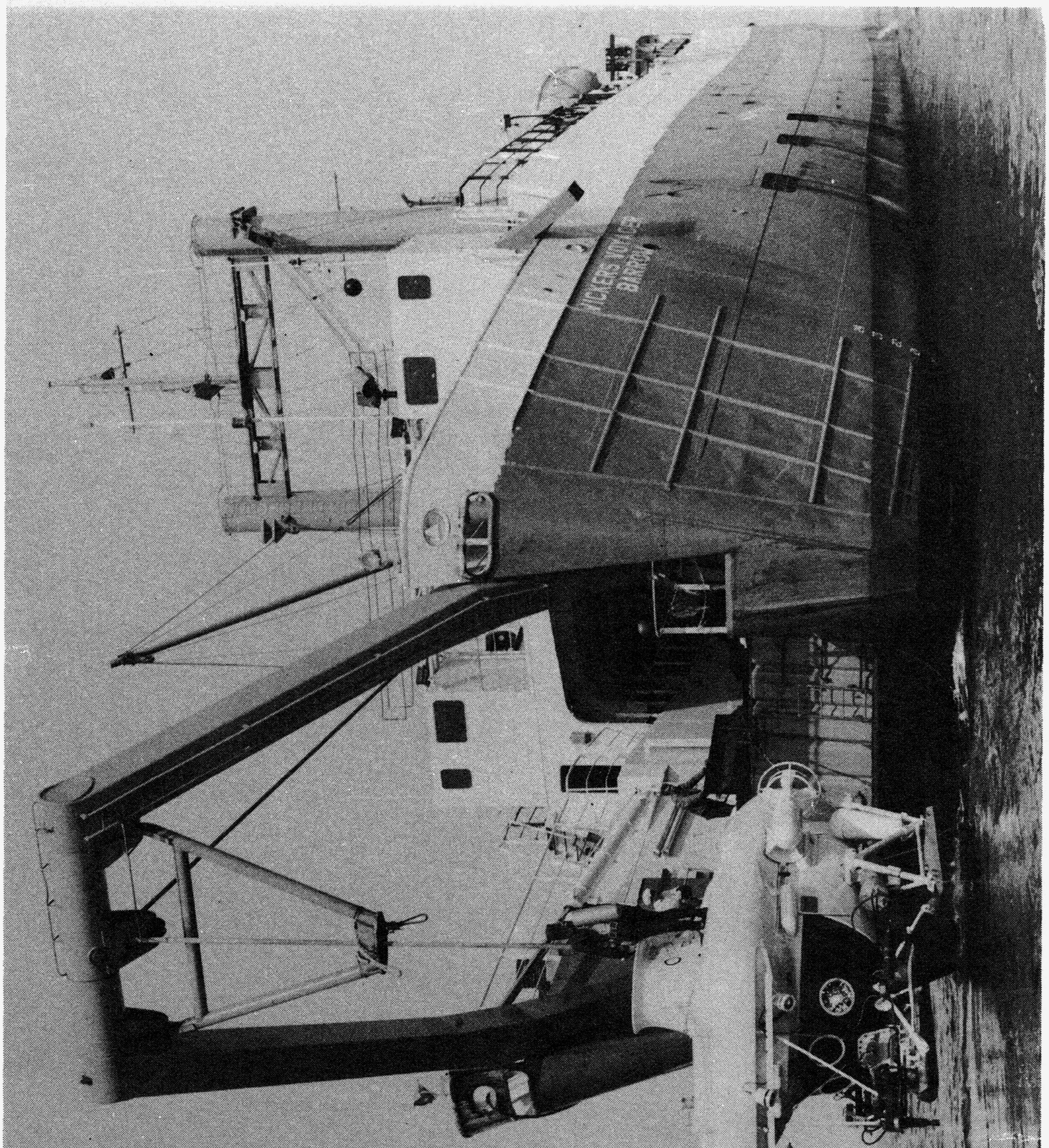
PISCES-TYPE SUBMERSIBLE **FIG 2**



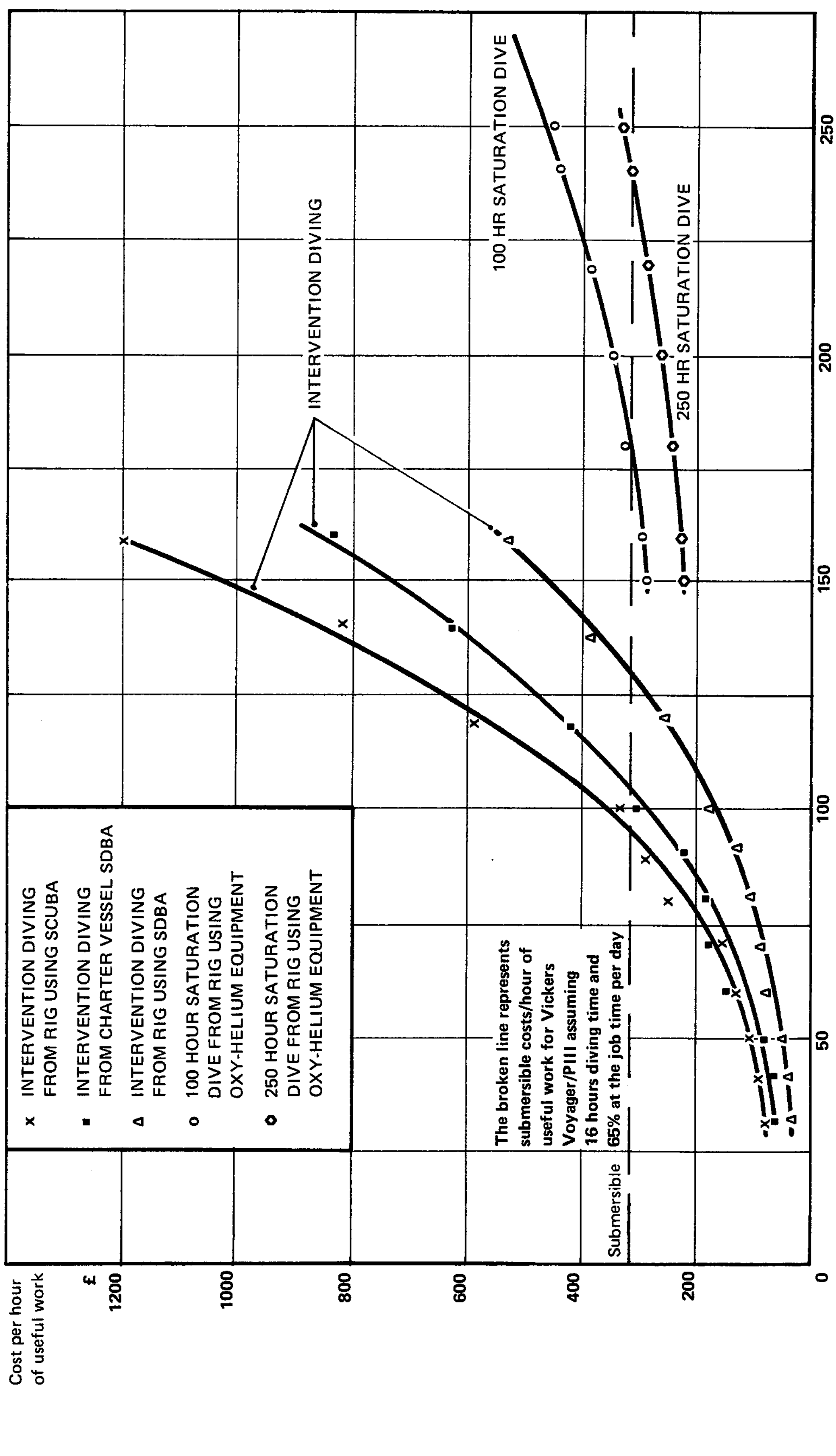
PC-15 SUBMERSIBLE **FIG 3**



SUBMERSIBLE SUPPORT SHIP VICKERS VENTURER **FIG 4**



SUBMERSIBLE SUPPORT SHIP VICKERS VOYAGER **FIG 5**



COMPARATIVE DIVING COSTS BASED ON AMERICAN RATES **FIG 6**