THE SEABED OPERATIONS VESSEL

BY

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Background

Some years ago the Naval Staff could foresee the need to replace the Royal Navy's ageing diving tender H.M.S. *Reclaim* and also to provide a seagoing platform for the developed Naval Saturation Diving System. It was not until early 1975 that an operational requirement could be firmly identified and initial steps taken toward the conception of the Seabed Operations Vessel (SOV), an artist's impression of which is shown in FIG. 1.

During 1975, a Staff Target was put together and it was finally approved as NSR 7003 in 1976. Feasibility studies, started in late 1975, were continued through to mid 1976 when the basis for the design now being described was chosen from six possible options.

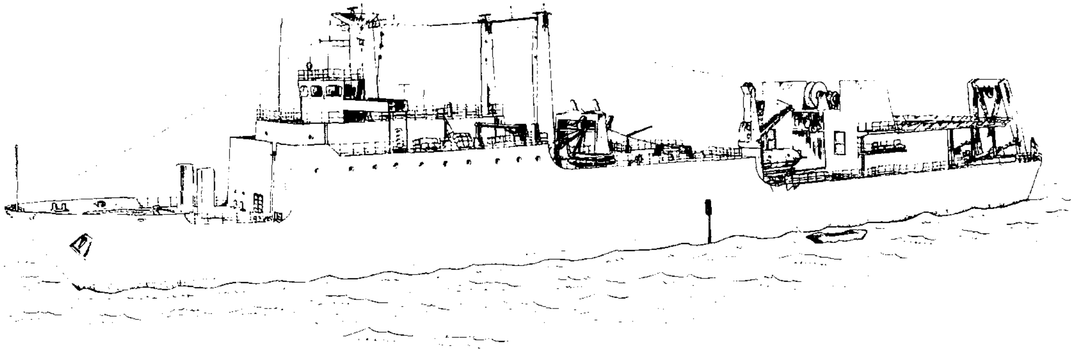


FIG. 1—ARTIST'S IMPRESSION OF THE SEABED OPERATIONS VESSEL

Role and Design Parameters

The SOV's main role as envisaged by the Naval Staff is to deploy and support the R.N. Saturation Diving System to a depth of 300 m and an unmanned submersible for search and inspection to greater depths. To avoid the difficulties and time delays of laying multi-point moorings in the operating depths considered, a Dynamic Positioning (DP) system to hold the ship stationary with respect to the bottom was specified.

To enable the SOV to operate in most weather conditions in the region of the British Isles, 50–60-knot winds, sea state 5, and a 3-knot current were specified as the maximum operational environment for design purposes.

To ensure the safety of divers and reduce the design risk in a one-off ship to a minimum, great emphasis was placed on selecting proven equipment for the ship and in duplicating systems as necessary to achieve a uniformly high standard of reliability. Commercial standards have been used in the design except where it was found more cost effective to go to R.N. standards.

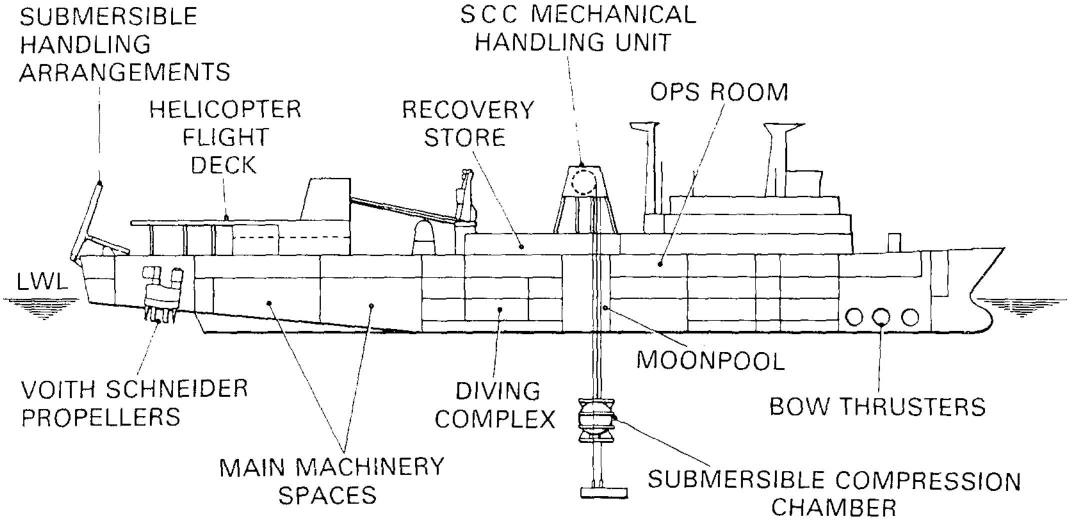


FIG. 2—SEABED OPERATIONS VESSEL—GENERAL PARTICULARS

Description of the Ship

The SOV which has evolved is large, measuring 134 m overall, 18 m in beam and displacing approximately 7200 tonnes. After a brief description of the general arrangement shown in FIG. 2, the major systems will be discussed in greater detail.

The distinctive feature in the forward end of the ship is the three bow thrusters which, together with the Voith Schneider propellers aft, allow the ship to maintain position relative to a fixed point on the ocean floor without using moorings.

Aft of the bow thrusters and forward of the operations room is an area mainly given over to accommodation for up to 185 personnel. A Royal Navy crew has been specified, and therefore accommodation specifications reflect the latest R.N. standards.

The central section of the ship houses the operations room and the R.N. Saturation Diving System which includes all the equipment required to support the divers in the centrally located compression chambers. The mechanical handling gear and moon pool allow divers under pressure to be transferred to the seabed in the Submersible Compression Chamber (SCC).

Immediately aft of the Diving Complex on No. 1 deck is the recovery deck with its crane, winch, and other equipment for lifting heavy objects from the seabed. It is envisaged that a heavy duty winch will be used to lift objects to a point just below the keel where the conventional 25-ton crane will take over and lift them onto the deck. Large objects will be stowed on the deck and relatively small items of complex hardware will be stowed and inspected in the Recovery Store. The store will be fitted with special ventilation, spraying, and other facilities.

Below the recovery deck is a salvage gear store and below this the Brown Brothers designed controlled passive tank stabilizer, installed to reduce rolling at slow speeds and during dynamic positioning. The moon pool, diving complex, and recovery deck are located amidships (where motion is least) to ease launching and recovery of the SCC, lifting items from the seabed, and keeping ropes and wires as far from the various thrusters as possible.

The after end of the ship below the weather deck houses the switchboards, main machinery, and Voith Schneider propellers. The weather deck is dominated by the Sea King helicopter landing and refuelling facilities and the large A-frame. The A-frame can initially be used to launch and recover the unmanned search submersible, but has been designed so that later in the ship's life it can carry a larger manned submersible which may be fitted with a diver lock-out capability. For this reason, a clear passage has been left between the funnels to allow the manned submersible to move forward to the diving complex to transfer divers under compression.

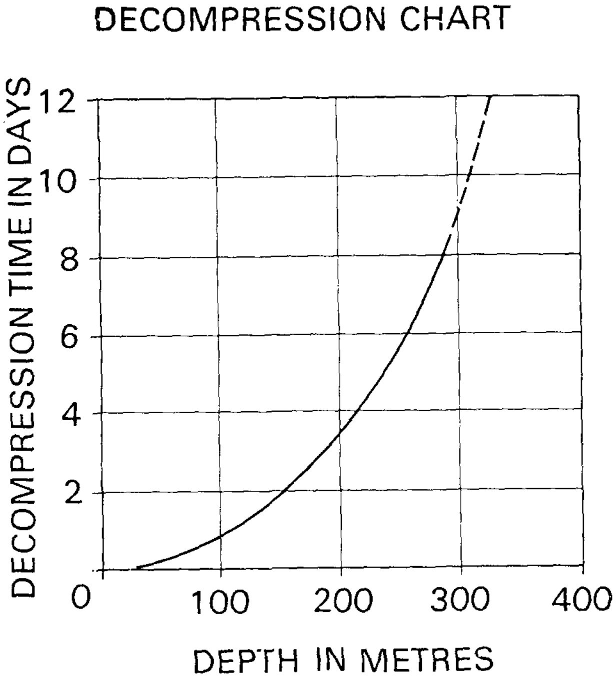


FIG. 3—DECOMPRESSION CHART

Saturation Diving System

Saturation diving has been developed in the last decade commercially and militarily to increase free-swimming diver's effective bottom time as diving depths increased. To avoid the necessity for the majority of each dive being taken up with gradual decompression, the divers are pre-compressed on board to the required depth in compression chambers. On arrival at the site, compressed divers are lowered to the seabed in a SCC. Once under pressure, divers will make repeated trips to the bottom in the SCC returning to the compression chamber after each trip to recuperate. After the work is completed, divers will be gradually decompressed on board perhaps during the trip back to base. FIG. 3 shows how decompression times increase dramatically with depth.

FIG. 4 illustrates the saturation diving system as it will be sited on board the SOV. It comprises:

(*a*) compression chambers in which several divers (to a maximum of twelve) can live under pressure for a number of weeks;

(*b*) a submersible compression chamber which can transfer up to three pressurized divers to the seabed via a hole in the ship (moon pool) and recover them still under pressure at the completion of their work;

(*c*) the machinery associated with the life support of divers when they are in the compression chambers and when they are working on the bottom. This includes such items as correct breathing mixtures, food, waste removal, and atmosphere conditioning.

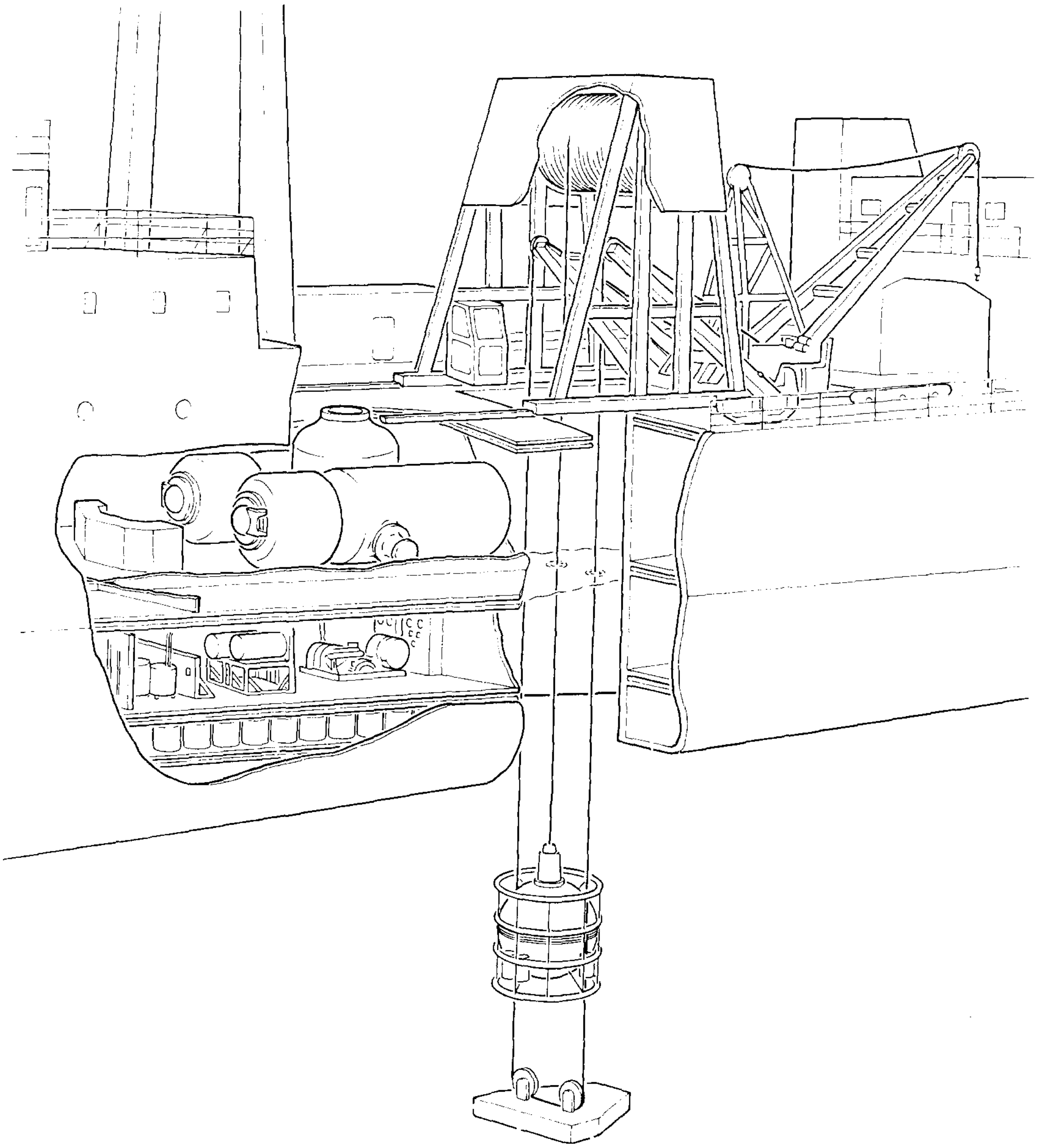


FIG. 4—SATURATION DIVING SYSTEM

The manned submersible which may be retrofitted to the SOV, if fitted with diver lock-out facilities, will operate on the same principle as the SCC, mating with the compression chambers and carrying pressurized divers to the seabed in a self-propelled vehicle that is launched and recovered over the stern. The details of this system have not yet been finalized.

Search

To achieve its objective of finding and inspecting/recovering objects on the seabed, the SOV is extensively equipped with sensors to carry out detailed search of suspected areas. On discovery of the object, the ship will be dynamically positioned to enable the SCC to be deployed. Raw data from the sensors is analysed by computers to provide appropriate position indication and control signals for thrusters.

The Integrated Navigation System, based on a GEC 4070 computer, will maintain up-to-date geographic position with real time inputs from the various navigational aids shown in FIG. 5. Any other sources of data such as sun sights, etc. can also be fed in manually to update the position. Positional accuracies

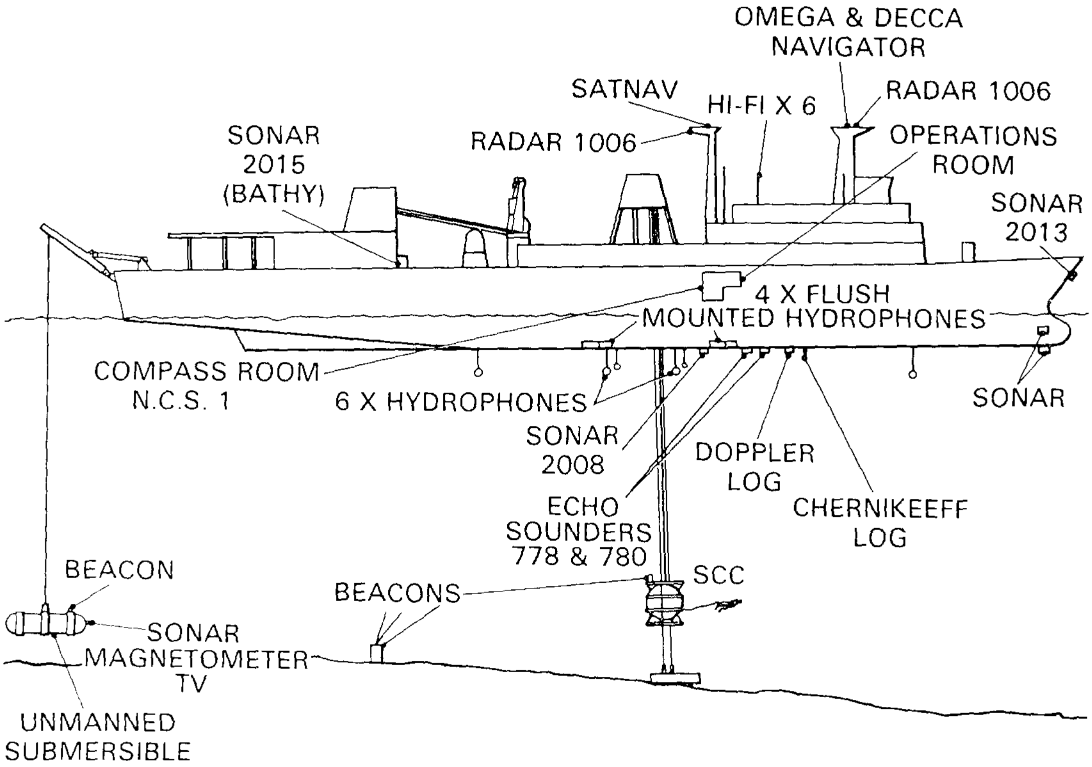


FIG. 5—SEARCH AND DP SENSORS

using navigational sensors range from about 8 km with OMEGA world wide to about 5 m on HIFIX 6.

Once in the search area, it will usually be more practical to maintain accurate relative position to some point on the seabed by using acoustic beacons on the bottom and ship-mounted hydrophones shown in FIG. 5. Shown in TABLE I is the dependency of the equipment to be used in the relative modes on the water depth. In depths below about 200 m, the unmanned submersible will be used. Hull and stalk-mounted hydrophones, with beacons on the submersible and on the bottom, will be used to track the submersible and to position objects found. Accuracies in depths over 200 m are expected to be of the order of 1 per cent. of water depth.

TABLE I—*Search modes*

Role	*Equipment*	*Remarks*
Geographic Positioning	OMEGA SAT NAV DECCA NAV HIFIX 6	World-wide: accuracy 4–8 km World-wide: accuracy 50–100 m (single fix) 100 miles from station: accuracy 5 m
Relative Positioning Close Area Search 1. 0–200 m depth	Sonar Beacons (Transponders) Hydrophones (Stalk) Geographic Pos. Equipment	Search Sonar for larger objects
2. 200–600 m depth	Submersible (with Responder) Beacons (Transponders) Hydrophones (Stalk) Geographic Pos. Equipment	
3. 600–3000 m depth	Submersible (with Responder) Beacons (Transponders) Flush SB Hydrophones Geographic Pos. Equipment	Single array only required
4. 3000 m and deeper	Submersible (with Responder and High-power Directional Beacon) Beacons (Transponders) Flush SB Hydrophones	Distributed array required

The submersible may be fitted with forward and with side scan sonar, upward and downward echo sounders, TV cameras, stereoscopic camera, and magnetometer for the inspection and classification of objects found during the search.

Information from the various search and inspection sensors is displayed in the operations room to monitor search patterns and establish whether a closer diver inspection is required.

Dynamic Positioning (DP)

If the search results in the location of a contact of particular interest in depths less than 300 m, the Captain may wish to deploy his divers in the SCC for a closer inspection and possible retrieval.

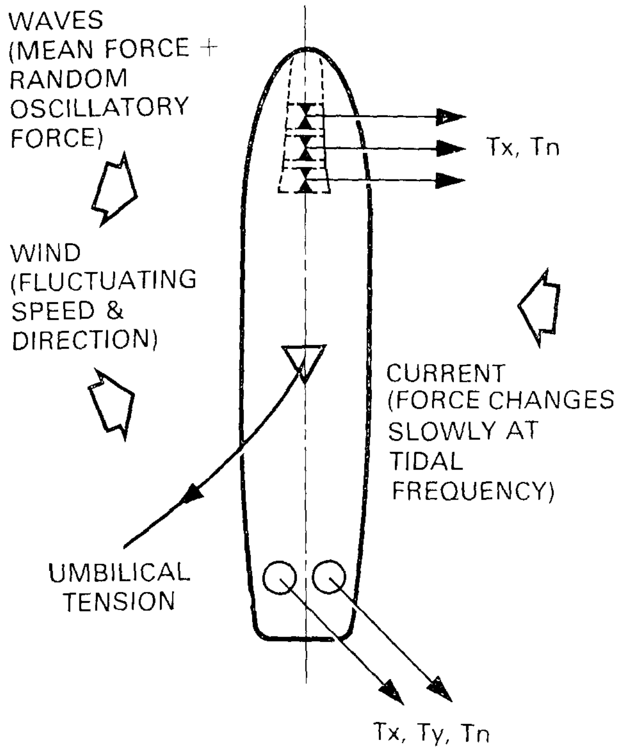


FIG. 6—BALANCE OF FORCES ON THE HULL

T_x = Lateral thrust (Bow Thrusters and Voith Schneider)

T_y = Longitudinal thrust (Voith Schneider)

T_n = Turning moment (Combination of BT and VS)

In order that the divers (who are attached to the SCC by their own life support umbilicals) are within range of the object, the SOV must maintain a very accurate position relative to it while lowering the sinker weight and SCC guide wires attached to it. Once the sinker weight is in position and the SCC with its divers has been lowered, the chamber must not be allowed to tilt too far or the divers may be endangered. Both these requirements dictate that the dynamic positioning system is accurate and reliable.

Adequate redundancy has had to be built into DP thrusters to ensure diver safety in the event of failure. To achieve this, the bow and stern thrusters have been sized so that if one unit at either the bow or stern were to fail, the remaining units could hold the ship in design environmental conditions while divers were recovered.

Forces to which the ship has to respond during DP are shown in FIG. 6, the main components being wind and current. Waves contribute a small mean force combined with cyclic surge and sway components causing the ship to oscillate about a mean position. Fortunately this oscillatory motion is within acceptable limits and can be ignored. The forces imposed by the umbilical tension are steady and small enough to be neglected. The most significant force fluctuation is caused by gusting of the wind and the system must respond rapidly to react to this.

The system developed to achieve DP is shown in FIG. 7. The basic closed loop takes in position and heading error signals, computes the required corrective thrust, and converts these into thrust demand signals. There are, however, three main complications:

(*a*) The wave induced oscillations mentioned above act as noise and must be filtered out using a wave filter.

(*b*) In order to stabilize a system with such long time constants, response of the main loop must necessarily be very slow. In order to react to wind gusts, a feed forward system is employed to modify derived thrust.

Suitably processed anemometer signals are added to the main thrust demand signal after the wave filter.

(*c*) It is considered that wind gusts could occur which would place the ship in a beam-to-weather heading where she might have difficulty holding position. In this case, recovery of heading is automatically given priority so that the ship swings to a more favourable heading before thrusting back into position at the expense of some downwind drift.

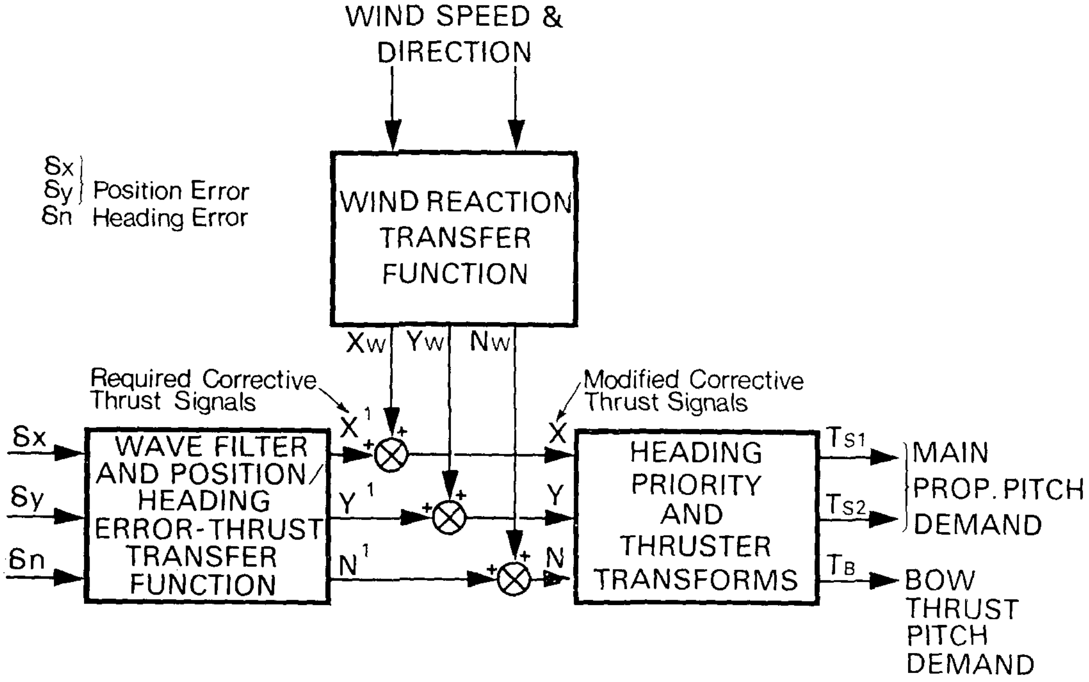


FIG. 7—THRUSTER DEMAND COMPUTATION AND POSITION/HEADING ERROR SIGNALS

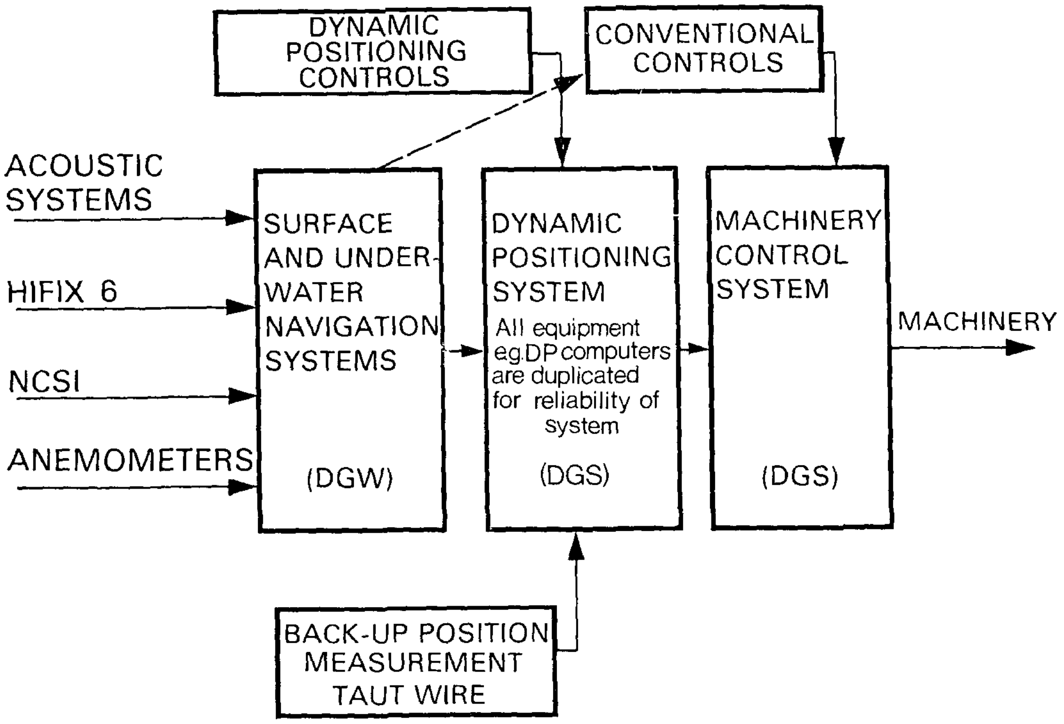


FIG. 8—PROPULSION CONTROL SYSTEM

To improve the position-keeping reliability, the acoustic and navigational positioning systems are backed up by a mechanical taut-wire system which is deployed when the SCC is lowered. The system consists of an anchored wire tensioned over a boom. By measuring wire inclination to the vertical in two planes and knowing the water depth, positioning error signals can be derived. While this method suffers from the effect of current drag on the wire, it can be corrected by an occasional acoustic fix and take over temporarily in emergency.

Control Interfaces

FIG. 8 shows the various components of the ship control system. Signals are fed to the DP computer from the various surface and underwater sensors and the output provides thruster demand to the machinery control system. These demand signals form an alternative input to the conventional bridge control. The Command can override DP control inputs in emergencies; however, this would be a very unlikely event as in manual control it would be difficult to avoid endangering divers.

For reliability, all diver-associated control systems such as DP are duplicated with automatic changeover. For this reason, the two GEC 4070 DP computers are programmed to carry out all necessary position-fixing calculations independently, although they can, if required, read ship's position from the surface and underwater navigation computer. This may be done in reversionary mode or to enable the DP system to be used to assist ship control during slow-speed search operations. In this mode, the ship is controlled from the operations room where particular search patterns can be fed in depending on requirements.

For high-speed search, control reverts to the bridge where two modes are available—manual steering or autopilot. These modes are conventional except that turning moment is achieved by vectoring the Voith-Schneider propellers' thrust rather than by the use of rudders.

The navigation systems used for searching have the ability to produce

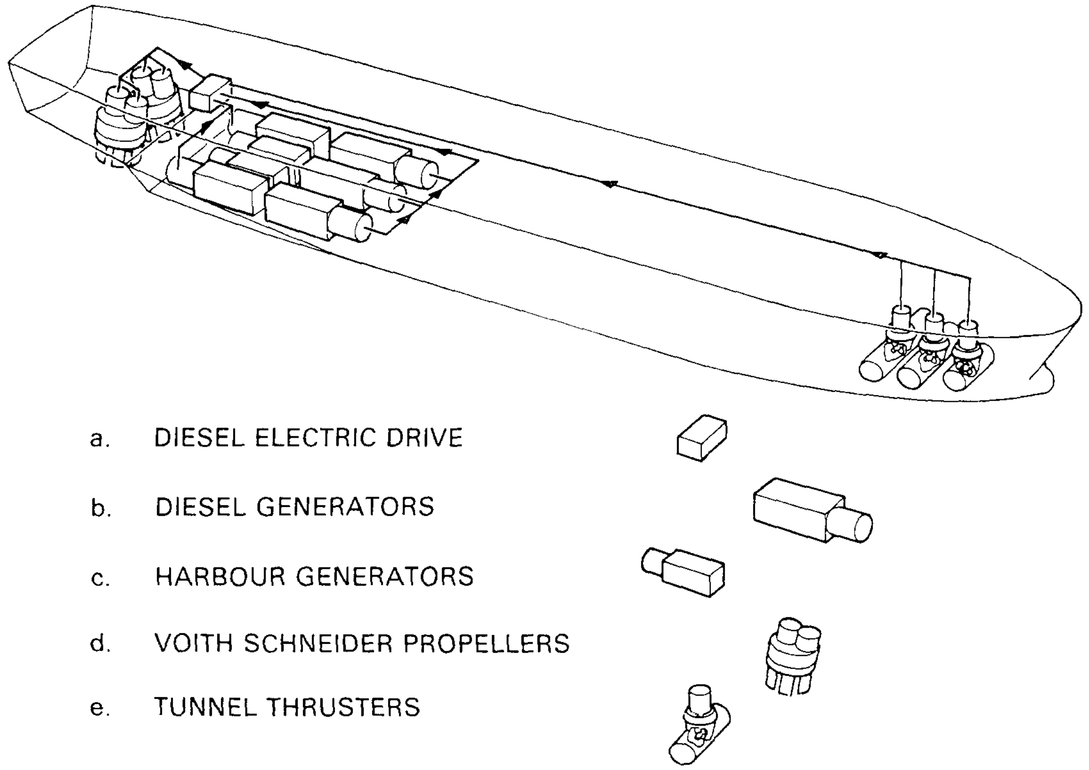
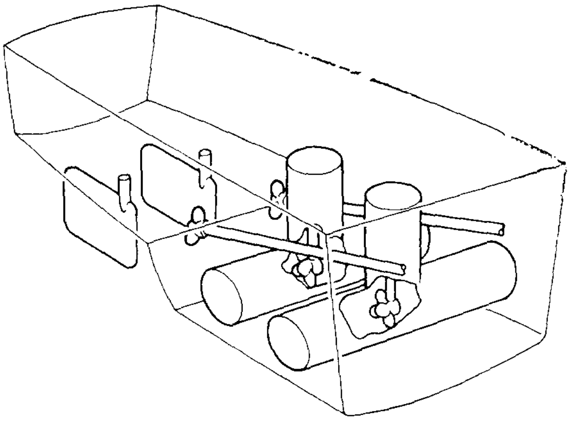
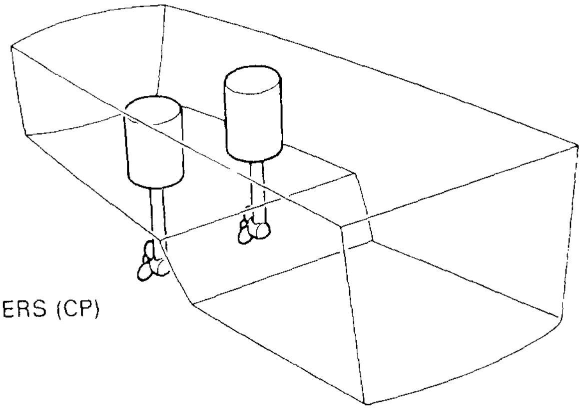


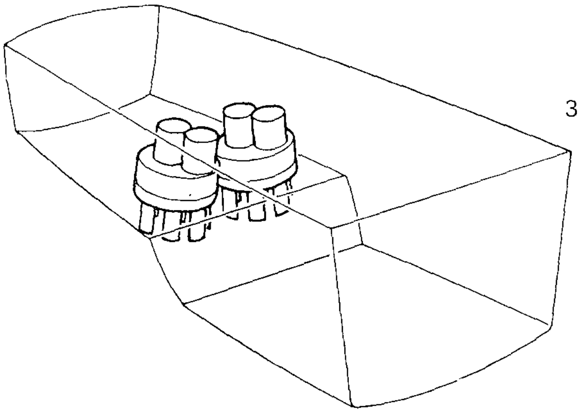
FIG. 9—MACHINERY FIT



1. C.P. PROPELLER + THRUSTERS + RUDDERS



2. ROTATABLE THRUSTERS (CP)



3. VOITH SCHNEIDER CYCLOIDAL PROPELLERS

FIG. 10—STERN PROPULSOR OPTIONS

distance-off-track signals and the possibility of using these to control the autopilot to give automatic track following are being investigated.

Main Propulsion

The physical distribution of high-power thrusters at both ends of the ship and severe constraints in the siting of machinery spaces dictated a very flexible power distribution system, shown in FIG. 9. The further requirement of proven reliability and high availability led to the selection of a diesel-electric system the elements of which are now described in turn.

Stern Thrusters

To achieve the requirements of high cruise speed, good low-speed characteristics, reliability, and variable direction thrust at the stern at the powers required, the main options were those shown in FIG. 10:

(*a*) *CP propellers combined with athwartships thrusters.* A well-proven combination used in current DP drill ships, but the system takes up considerable ship length.

(*b*) *Rotatable CP thrusters.* They have good efficiency but have not been used in the DP role in the size required.

(*c*) *Cycloidal propellers.* They have the lowest efficiency of the three options but have proven DP experience, excellent slow-speed characteristics, and fit neatly into the available space.

The selected Voith Schneider propellers are arranged side by side in the stern as shown in FIG. 11. They are angled inwards at about 10° to the horizontal to reduce the slamming effects on the large flat shallow stern. Each unit is driven by two 1·25 MW two-speed electric motors via fluid couplings. The low-speed range of the motor is included to avoid blade bearing wear which can occur at low powers in the high-speed range. Each unit weighs about 64 tonnes and the blade mechanism rotates at a constant speed.

The principle of operation of the Voith Schneider, illustrated in FIG. 12, is similar to that of a dolphins tail. By simple mechanical linkages, the pitch of each blade fitted on the periphery of a rotating hub is reversed as the assembly rotates so providing thrust in the same direction. Magnitude and direction of thrust is determined by the displacement of the control rod from the central position.

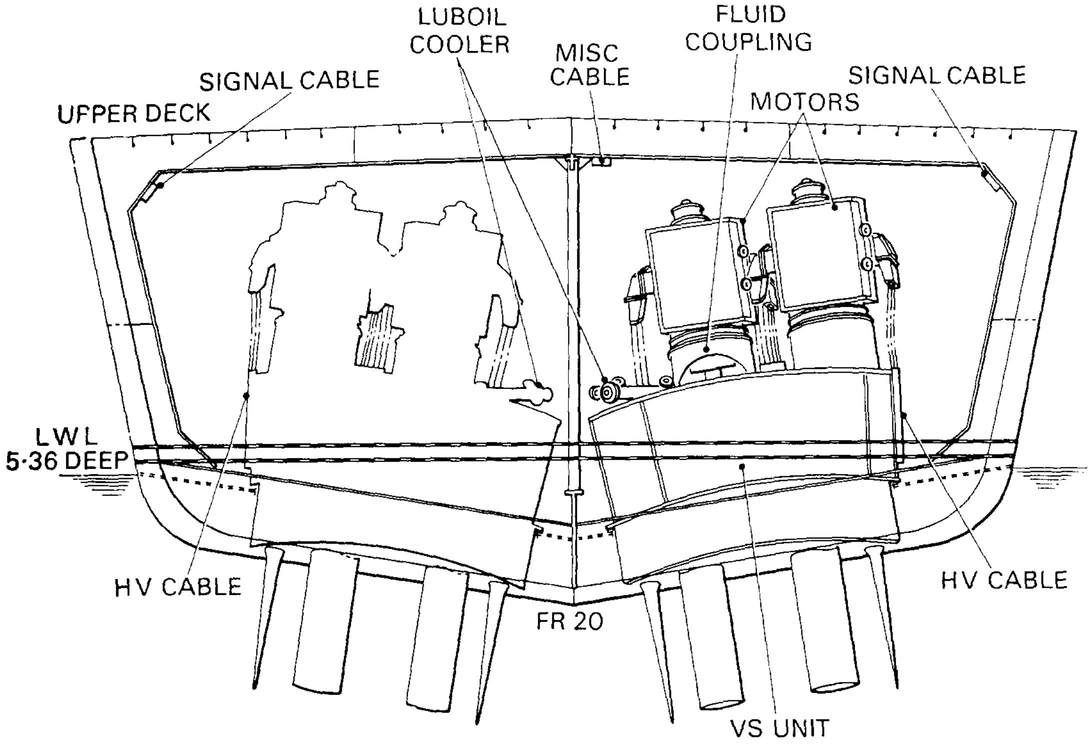
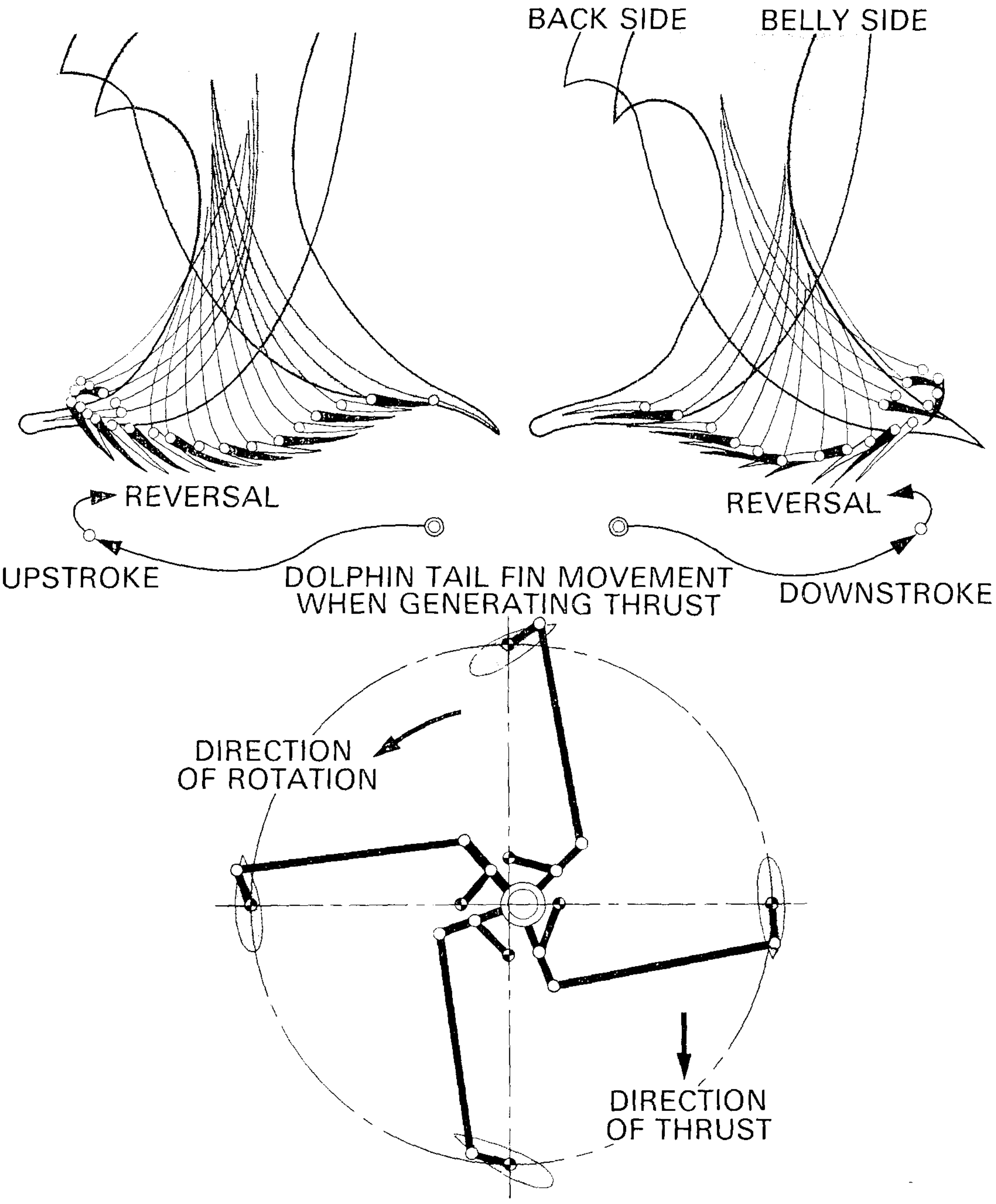


FIG. 11—SOV VOITH SCHNEIDER PROPELLER ARRANGEMENT

Bow Thrusters

Tunnel thrusters have been chosen to provide lateral thrust in the bow as they are very well proven in DP drill ships and they fit into the SOV's bow form. Retractable thrusters were considered for the duty as they have better thrust characteristics in a current and provide a smoother hull shape when retracted. It was considered, however, after investigation that the advantages did not warrant the very much higher cost combined with the difficulties in construction of a suitably strong closing plate.



AMPLITUDE AND PHASE RELATIONSHIP DETERMINE MAGNITUDE AND DIRECTION OF THRUST — ACCORDING TO NATURE'S IDEALS

FIG. 12—VOITH SCHNEIDER—PRINCIPLE OF OPERATION

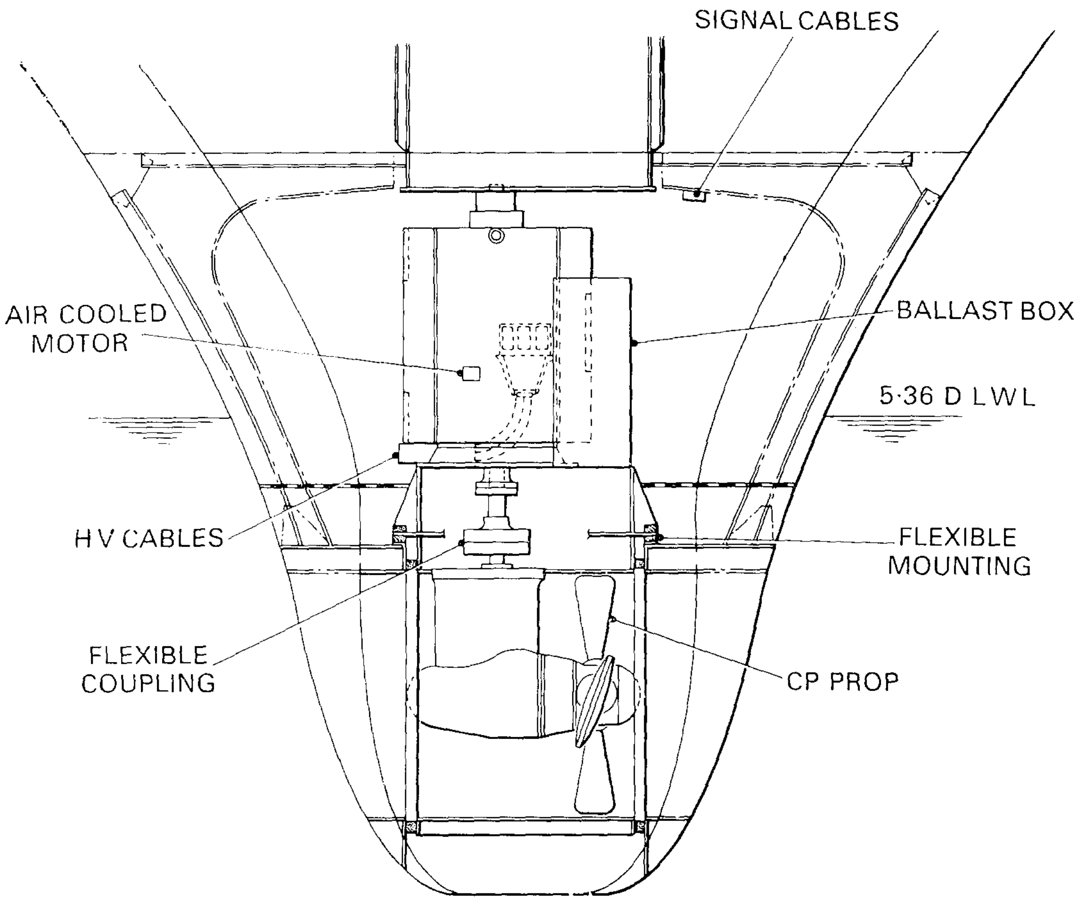


FIG. 13—BOW THRUSTERS

FIG. 13 gives a good idea of the layout in the rather narrow bow shape. The motor is air cooled and the whole unit is flexibly mounted to reduce noise levels in the accommodation area directly aft of the bow thruster compartment.

Main Generators

The number and sizing of main generators was based on the requirement to meet expected maximum power load in DP with one unit standby and one unit under maintenance.

TABLE II—*Main diesel a.c. generating sets*

Engine		Ruston
Type		16RK3CZ
Continuous Electrical Output		2520 kW
Overall Dimensions	Length	9·84 m
	Width	2·97 m
	Height	3·20 m
Weight of Set		39 tonnes
Cost of engine		159 000 (£1978)
Top Overhaul		10 000 and 20 000 hours
Complete Overhaul		30 000 hours

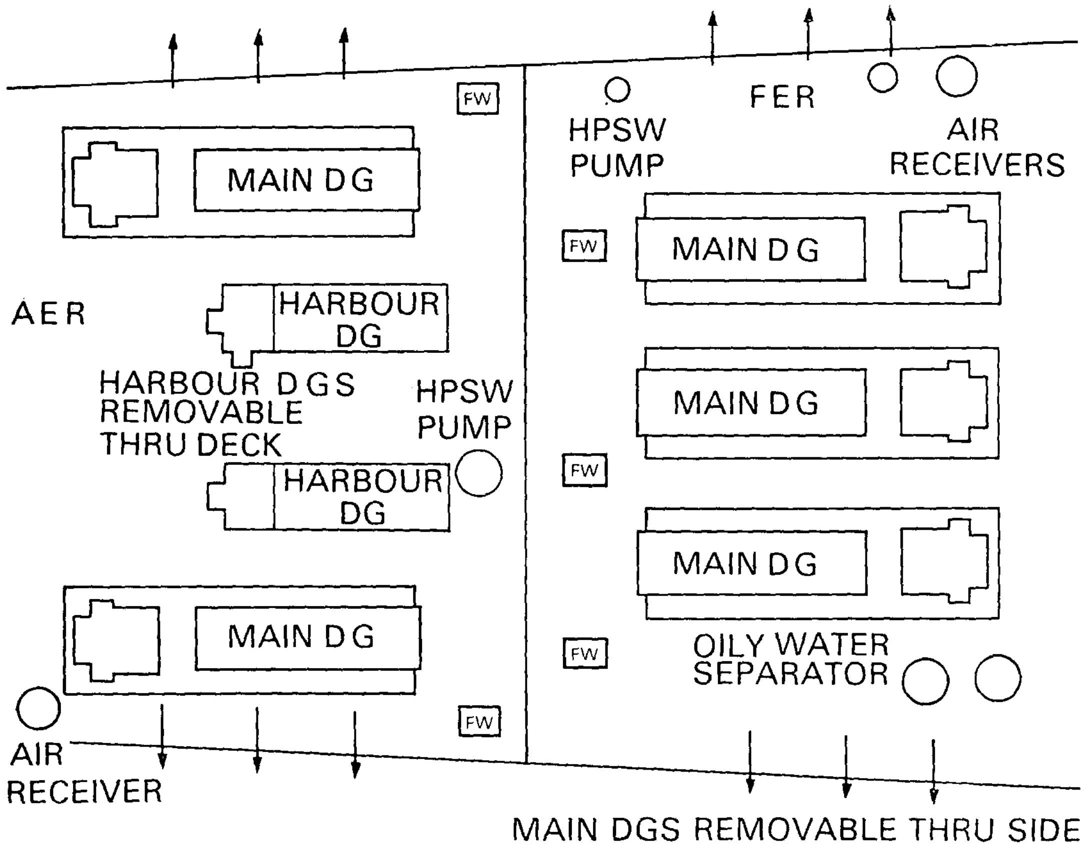


FIG. 14—LAYOUT OF GENERATING SETS

In the worst anticipated situation of heading change during DP in design conditions, the latest power estimate gives a propulsive power requirement of 7·6 MW which can be met by three generators. This led to the selection of five main generating sets rated at 2·5 MW each.

The engine selected for prime mover duties from other possible contenders in the 2·5 MW range is the Ruston 16RK3CZ. The main factors that decided in favour of this engine included that it was British designed and built, it was already at sea with the R.N. in its 12-cylinder version in the OPVs, and it was the cheapest. The chief features of the engine are given in TABLE II.

The main generators and harbour sets are arranged in two engine rooms as shown in FIG. 14.

Generation and Power Distribution System

Having decided on a diesel-electric propulsion scheme, the characteristics of the generated power needed investigating. TABLE III shows the various options available and a few of the major advantages and disadvantages. The major factor that decided against the d.c./d.c. system was the size and complexity of d.c. machines and their control equipment in relation to the limited space available in the SOV. The conversion equipment needed in the a.c./d.c. system would cause severe wave form distortion and signal interference which the SOV could ill afford with its sensitive DP control equipment.

While the problems posed by these systems could be overcome, it was decided to opt for an a.c./a.c. fixed-speed system taking advantage of the well-proven CP thrusters available on the market. It is interesting to note that most system designers of large DP ships, such as the PELICAN Class of drill ships, have come to the same conclusions.

The arrangement of the power distribution is shown in FIG. 15. Because of the very high generating capacity and corresponding high system fault level of

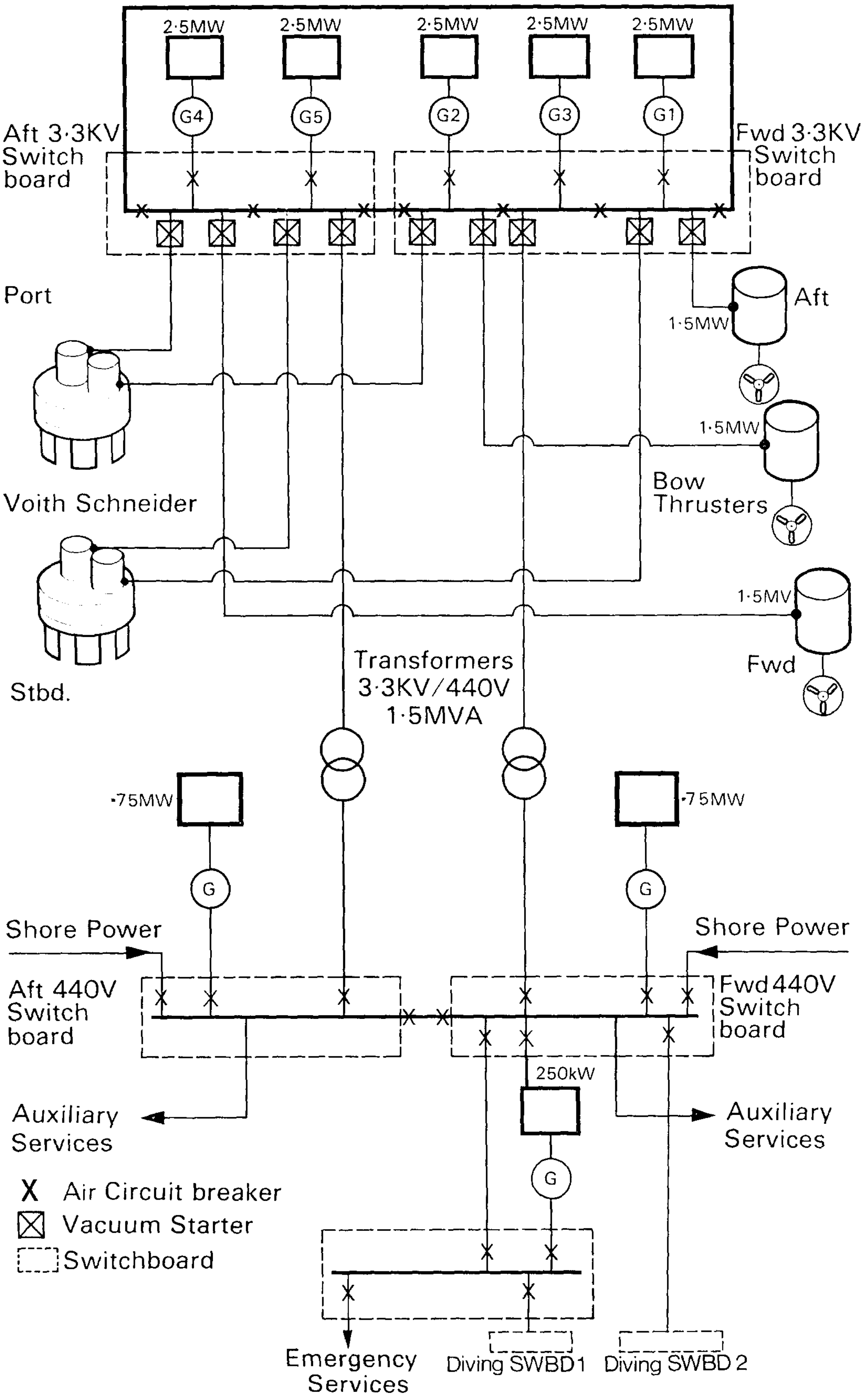


FIG. 15—DIESEL ELECTRIC PROPULSION SYSTEM

250 MVA, roughly ten times that of the normal frigate, it was decided to use a high voltage system. 3·3 kV was chosen due to the availability of suitable switch gear. Medium voltage of 440 V, 3-phase, 60 Hz for auxiliary services is provided via two 1·5 MVA transformers from the high-voltage system or directly from two 750 kW harbour generators.

For integrity of supply, the high and the medium voltage systems have been divided into forward and after switchboards. The high voltage switchboards are also connected to form a ring with five sections, a failure of any one resulting in that section being automatically isolated, the system will normally be operated with two or three generators in parallel increasing to four only when operational requirements dictate a reduction in generating redundancy.

The rather high emergency generator power results from the need to hoist the SCC using the electro-hydraulic mechanical handling gear.

The propulsion system is designed to be controlled by one watchkeeper in a MCR immediately above the forward engine room. It is expected that he will normally be assisted by one roundsman and, during DP operations, a second watchkeeper with special responsibility for switchboard re-configuration in the event of emergencies would be closed up.

TABLE III—*Power system options*

Power generation	*Propulsor drive*	*Propulsor type*	*Advantages*	*Disadvantages*
d.c.	d.c. (variable speed)	Fixed pitch	Already used in R.N. All control mechanisms inboard. High efficiency, low noise especially at low power levels. Cheaper and quieter propulsors.	Larger size. Weight of d.c. machines. Complex control equipment. Response rate poor compared to d.c./a.c. or a.c./a.c. Does not readily provide auxiliary power 440 V, 60 Hz.
a.c. (fixed speed)	d.c. (variable speed)	Fixed pitch	Efficiency and cost of fixed-pitch propulsors.	Requirement for conversion equipment, and heavy propulsion motors.
a.c. (variable speed)	a.c. (variable speed)	Fixed pitch	Most efficient overall electric system.	Speed range limited dependent on prime mover. No independent speed control of two or more propulsors from one prime mover. Auxiliary a.c. power cannot be provided from variable frequency main generators.
a.c. (fixed speed)	a.c. (fixed speed)	Variable pitch	Most versatile arrangement. a.c. power can be guaranteed at most economic voltage up to about 11 kV. Wider choice of prime movers. Readily provides a.c. auxiliary power.	Requires more expensive CP propellers.

Auxiliary Systems

The auxiliary systems generally reflect current R.N. practice. Because of the less stringent requirements in areas such as shock and the many special features of the SOV, every effort has been made to select equipment on a basis of through-life cost effectiveness taking into account basic cost, spares support, duty, etc. in deciding whether to specify commercial or R.N. standards.

The distilling arrangements are, perhaps, slightly novel for the R.N. as the plants will be run on diesel engine waste heat. The ship will not have any auxiliary boilers and all heating will be done electrically.

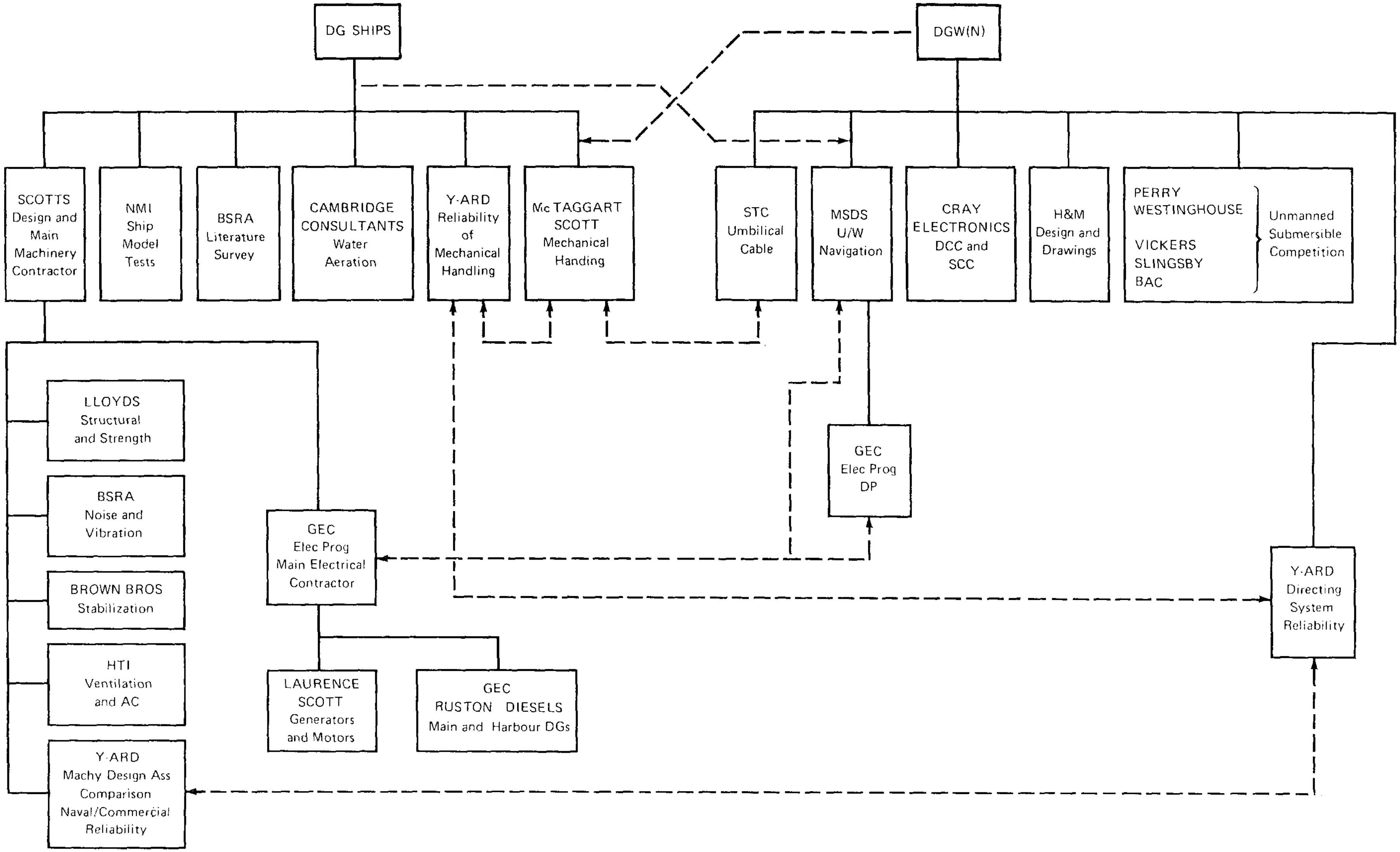


FIG. 16—DESIGN DEVELOPMENT CONTRACTORS

Maintenance and Support

Discussions have taken place already with concerned authorities such as DFM and CED with respect to maintenance and support aspects of the SOV. It has been decided that generators will normally be maintained *in situ* and studies are in progress to ensure that suitable maintenance envelopes and handling equipment is called up by the specifications. In case the diesel engines have to be removed from the ship, care has been taken to keep the ship's side in way of them relatively free of interference. Other auxiliary equipment whose components are too big to be removed through normal openings will have designated removal routes with portable plates being arranged as required.

The large quantity of non-R.N. standard equipment aboard the SOV has dictated that support aspects be considered very early to avoid problems when she joins the Fleet. Because she will be a one-off ship, the expense of full 'Type A' support is considered excessive and it is expected that she will have the modified 'Type B'. This will reduce the degree of special cataloguing effort and hopefully will allow support arrangements to be completed before the ship is accepted.

Design Development

The various sections of the SOV design have been developed under the general direction of D.G.Ships and D.G.W.(N) by a variety of main and sub-contractors as shown in FIG. 16. The areas of joint D.G.Ships/D.G.W.(N) interest are shown by dotted lines.

The management of the rather complex array of contractors by a small group of D.G.Ships personnel and an even smaller D.G.W.(N) contingent has not been easy. There have been the normal quota of problems and delays resulting in a programme slippage of about a year.