U.K. NUCLEAR SUBMARINES

THE DEVELOPMENT OF THE OVERALL DESIGN

BY

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(*Sea Systems Controllerate*)

Background

The Admiralty had became aware of the potential of nuclear power for warship propulsion by the time the second world war ended. The Controller of the Navy submitted a paper to the Sea Lords in which the following reference to it was made:

> All this [nuclear] research and development covers a vast field and many years may pass before the new Navy will emerge. But I believe that it will emerge and the change from the present to the future will be as great as the change from sail to steam.

Due to a lack of facilities and trained personnel it was impossible to institute anything more than the sketchiest investigations before 1950, when preliminary studies for a nuclear submarine were carried out by the Admiralty in association with Metropolitan Vickers. For the original design the Atomic Energy Research Establishment at Harwell proposed an enriched Uranium thermal reactor, graphite moderated and helium cooled. It was planned that the submarine would have a surfaced displacement of about 2500 tons, with twin shafts and 20 000 s.h.p giving an underwater speed of about 25 knots.

In 1951 a more detailed investigation showed that the reactor would be much bigger than at first thought. The submarine would have a surfaced displacement of about 3400 tons and an estimated speed of only 22 knots. Further study revealed that once proper allowance was made for factors such as the need to operate in a highly manoueuvrable vehicle and to withstand underwater explosion, then the overall size had increased to 4500 tons at 20 knots. The pressure hull diamater had increased from 25 feet in the original concept up to 31 feet. It was concluded that this type of reactor was unsuitable for use in a naval environment.

In 1953 Naval Staff Requirements emphasized the relative importance of endurance rather than speed. This confirmed the thermal reactor as a strong candidate, and two types were studied at Harwell. One was water moderated and cooled, and the other liquid metal cooled. At that time the preference of the Engineer-in-Chief was for the liquid metal cooled type.

By 1953 an important stage had been reached in the American nuclear programme. Admiral Rickover and a group of specialist officers had been working on the feasibility of a nuclear submarine plant since 1947. The pressurized water reactor prototype plant went critical in March 1953. The construction of U.S.S. *Nautilus* had been authorized in 1951 and she was commissioned in September 1954.

It was not until 1955 that there were more visible signs of progress in the U.K. The Naval Staff recommended that the initial project should be the design of a nuclear propulsion plant of approximately 15 000 to 20 000 s.h.p. suitable for a submersible, with a view to the development of a larger plant suitable for an aircraft carrier. The system chosen was a pressurized water reactor, mainly for reasons of compactness. The decision to proceed with a submarine plant first was based on the following points:

(*a*) The outstanding operational advantages of applying nuclear propulsion to a submarine rather than a surface vessel.

(*b*) The only naval reactors then thought feasible required highly-enriched uranium. A submarine plant would need less of this than any major surface warship.

(*c*) It would be quicker and cheaper to get a nuclear plant to sea in a submarine than in a major surface warship.

(*d*) The development of a submarine plant best suited the current plans for new construction.

The military arguments in favour of nuclear propulsion for a submarine were seen as follows:

(*a*) It would permit a major operational development over present conventional submarines by giving hitherto unheard-of submerged endurance and, when needed, speed.

(*b*) It could lead to submersible warships with all the tactical advantages of concealment and surprise combined with great endurance.

(*c*) It would provide first hand experience of nuclear submarines to assist the preparation of countermeasures.

(*d*) As a long-term development the tactical advantages of nuclear submarines could be combined with fitting of ballistic missiles.

The draft Naval Staff Requirements for the first British nuclear propelled submarine were discussed late in 1956. Then in 1957 a series of important events took place. The first of these was a February visit to America by the Minister of Defence during which the United States offered to release information on nuclear propulsion for ships. In March the name of *Dreadnought* was approved for the first British nuclear submarine; 'Vulcan' and 'Thunder' were close seconds. By May 1957 contracts had been placed with

Vickers-Armstrongs for the prototype plant and for the hull and machinery of *Dreadnought*. The propulsion machinery was at the time to be identical to the prototype plant except as might be otherwise approved by the Engineer-in-Chief. In June exchanges took place between British and American technical teams. In October U.S.S. *Nautilus* arrived at Portland in Dorset, and both the First Sea Lord and the Minister of Defence sailed in her for five hours. On October 4th the Soviet Union launched their first satellite into orbit, followed by a second on November 3rd. In November the 'Neptune' reactor at Harwell for the zero energy physics experiments went critical, and in Bath the Dreadnought Project Team was assembled.

As a result of a meeting in October 1957 between the British Prime Minister and the President of the United States, an agreement (the Westinghouse Agreement) was made in January 1958 to purchase a complete American nuclear propulsion plant for H.M.S. *Dreadnought*.

Prior to this a series of design studies for nuclear submarines had been carried out by the Director of Naval Construction since about 1955. These designs were all based on the British design of nuclear plant. Consideration was given to many arrangements and machinery configurations in order to reduce noise and shielding weight, and to minimize overall weight and space requirements; an early example is shown in FIG. 1. Direct geared drive

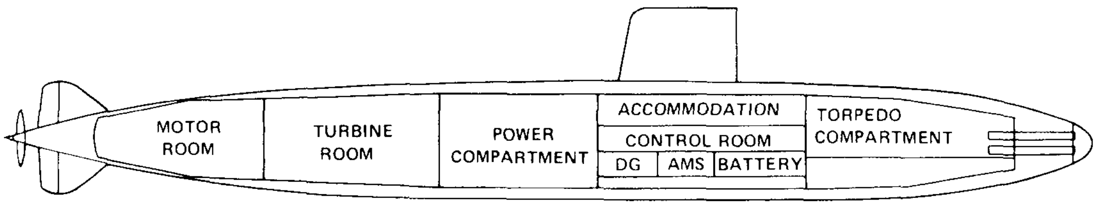

FIG. 1—A PRE-'DREADNOUGHT' BRITISH DESIGN FOR A NUCLEAR SUBMARINE

Surfaced displacement: 4500 tons
Length overall: 320 feet
Maximum beam: 35 feet
Pressure hull diameter: 28 feet

together with a 'creep' electric motor was chosen in preference to turbo-electric drive. The reactor was to be located midships primarily to minimize any difficulties resulting from an increase in weight. By 1957 the design studies had reached a stage of considerable detail. The preferred option had a submerged displacement of 4500 tonnes (compared with *Dreadnought*'s final figure of about 4000 tonnes) and incorporated many advanced design features for the machinery that were not to be seen until *Valiant*. The design was already considerably larger than the American *Skipjack* design, due primarily to the large new bow sonar array, an increased weapons outfit, the greater power of the British machinery, noise reduction features, and improved reactor containment standards. By the end of 1957 a further increase in size of the design was inevitable since the design margin had been consumed due to increases in the weight of the propulsion and auxiliary machinery, and the need to re-design the pressure hull structure in way of the transitions.

H.M.S 'Dreadnought'

The Dreadnought Project Team (DPT) was set up in 1957 to provide the firm cohesive direction that was considered at that time to be lacking on both the Admiralty and contractual side. The first Technical Chief Executive was Rowland Baker (later to be knighted) who was responsible for the overall design and production of H.M.S. *Dreadnought*, including its propulsion machinery and the prototype shore-based installation at Dounreay.

After the Westinghouse Agreement the decisions as to which U.S. submarine plant to purchase and the configuration of the remainder of the submarine needed to be made quickly in order to meet the programme. The choice of machinery was between that of U.S.S. *Skate* and *Skipjack*. The *Skipjack* machinery was selected due to the broad similarities to the U.K. plant in size, power, and being single-screw. This meant that much of the U.K.'s own submarine design could be retained and would thus minimize any delay to the programme.

In March 1958 the Admiralty Board confirmed that the development of the Dounreay shore-based prototype reactor for the first all-British nuclear submarine would continue. One of the reasons for buying the American plant had been that the design and test data would enable the U.K. to proceed with greater confidence with its own designs for subsequent classes.

By the spring of 1960 the number of modifications requested that involved changes in the design of *Dreadnought* was causing some concern. The Technical Chief Executive instructed Vickers-Armstrongs that no change or alteration, affecting equipment under manufacture or any drawing or specification already approved, was to be made without his personal agreement. It was added that this would only be given in exceptional circumstances!

H.M.S. *Dreadnought* was accepted, on programme, in April 1963.

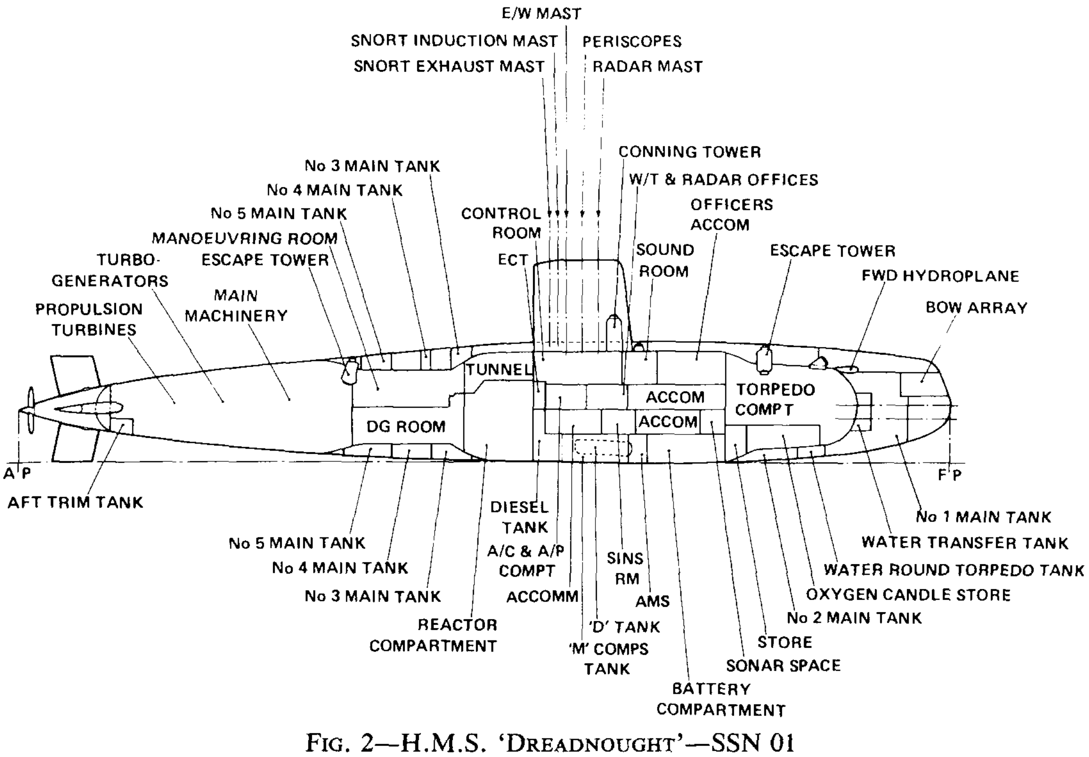

FIG. 2—H.M.S. 'DREADNOUGHT'—SSN 01

The final design (FIG. 2) had a submerged displacement of about 4000 tonnes (surfaced 3550 tonnes). The hull form was of British design, though the after end geometry was very closely constrained to match that of *Skipjack*. Forward of the reactor compartment the design and layout, although influenced by U.S.N. thinking, was entirely of British design and largely used British equipment. The design was greatly assisted by the detailed weight data, drawings, and technical specifications provided by the Americans. The design of *Dreadnought* differs from *Skipjack* in the following important respects:—

(*a*) *Pressure Hull*. The diving depth of the British design studies was reduced to match that of *Skipjack*'s machinery and auxiliaries. In place of *Skipjack*'s flat bulkheads, the pressure hull is ended by torispherical domes (i.e. somewhat flattened hemispheres) in order to reduce the stress concentrations at the intersection with the cylindrical portion of the hull and also between the bulkhead and torpedo tubes. Detailed analysis of the cylinder/cone transitions in *Skipjack* revealed that the longitudinal bending stresses were undesirably high when related to the current philosophy on fatigue. The stresses at the converging transition were reduced by the use of a spherical section. At the diverging transition a bulkhead would have had a beneficial effect but the internal arrangement precluded this option and it was necessary to use a combination of an external bulkhead and some shell reinforcement. The pressure hull material was a new British high yield steel, QT35. It was recommended that careful hull and crack detection surveys should be carried out at the submarine's first refit.

(*b*) *Hydrodynamics*. The bridge fin was sited further aft in *Dreadnought*. Its position was determined largely by the internal arrangement which followed previous U.K. practice but it served also to minimize the transient behaviour experienced whilst manoeuvring at high speed.

The decision on the location of the bridge fin was also associated with the preference to site the forward hydroplanes well forward in the superstructure casing. This improved control at slow speed (particularly at periscope depth), was more effective for recovery in an emergency, and had the advantage of allowing the bridge fin to be smaller, hence reducing resistance and snap roll. The disadvantage of siting the hydroplanes well forward was the self noise created at the bow sonar. It was decided to tackle the self noise problem by careful detailed design of the forward hydroplanes and close attention to other features such as the torpedo tube bow shutters.

To match the American machinery several British propellers were designed. The purpose of these was to obtain full-size data that would benefit future single-screw submarine designs.

(*c*) *Weapon Sensor Fit*. H.M.S. *Dreadnought* was designed to carry a greater outfit of torpedoes than *Skipjack* and had six torpedo tubes. The means of weapon launch was the newly developed water ram discharge gear, which was capable of discharging torpedoes at a considerably greater depth than previously possible. The principal sensor was the new active/passive bow sonar. This was a very large conformal array dominating the design of the forward end of the submarine. After considerable debate the configuration chosen sited the array above the axis, with the torpedo tubes underneath.

Valiant Class

H.M.S. *Dreadnought* was followed by H.M.S. *Valiant* (SSN 02) and H.M.S. *Warspite* (SSN 03). Ordering commenced in August 1960, *Valiant* entered service in July 1966 and was followed nine months later by *Warspite*. The basic concept for this design was to use the forward end of *Dreadnought* together with the British nuclear machinery based on the Dounreay Submarine Prototype. A complete re-design could have resulted in a smaller submarine but this was ruled out by the need to complete the submarines as soon as possible.

The Naval Staff Requirements were similarly constrained. The significant additions to those for *Dreadnought* were as follows:

(*a*) More explicit reactor safety requirements.

(*b*) 75% increase in diesel fuel.

(*c*) 50% increase in communications fit.

(*d*) Forward hydroplanes to be moved away from the main bow sonar array to reduce self noise.

(*e*) A small increase in diving depth back to that for the original U.K. design studies.

(*f*) A secondary means of propulsion to be fitted independent of the main propulsion system. This was to be retracted into the streamline hull form when not in use.

(*g*) Sound insulation against sonar noise to be fitted in the control/accommodation block.

(*h*) Reduced machinery noise.

The trials with *Dreadnought* had shown the need for an improvement in noise performance of her SKIPJACK machinery. Therefore many of the original U.K. design features were introduced in the VALIANT Class to meet the required operational roles:

The listening or ultra-quiet role: this was achieved using turbo-electric drive independent of the gearbox. A lower speed could be achieved using the batteries.

Task group or convoy role at optimum depth using sonar: this was achieved by resiliently mounting the main turbines and gearbox. The mounting system was operable up to about half power.

High speed for interception, evasion or transit: mounting system locked.

A simple joining of *Dreadnought*'s forward end and the British machinery design would have resulted in a submarine with a submerged displacement of 4600 tonnes compared with *Dreadnought*'s 4000 tonnes. This was principally due to the higher design power, the noise reduction features and some duplication of equipments in the two parts of the vessel. The resulting design would however, if left unmodified, have been deficient in stability and reserve of buoyancy and would have had an unacceptable surfaced trim by the bow. There would also have been insufficient internal space for the improved communications and sonar fit required.

These deficiencies were overcome by lengthening both the forward compartment and the control/accommodation block, and by siting the forward trim tank, torpedo overflow tank and water round torpedo tank inside the

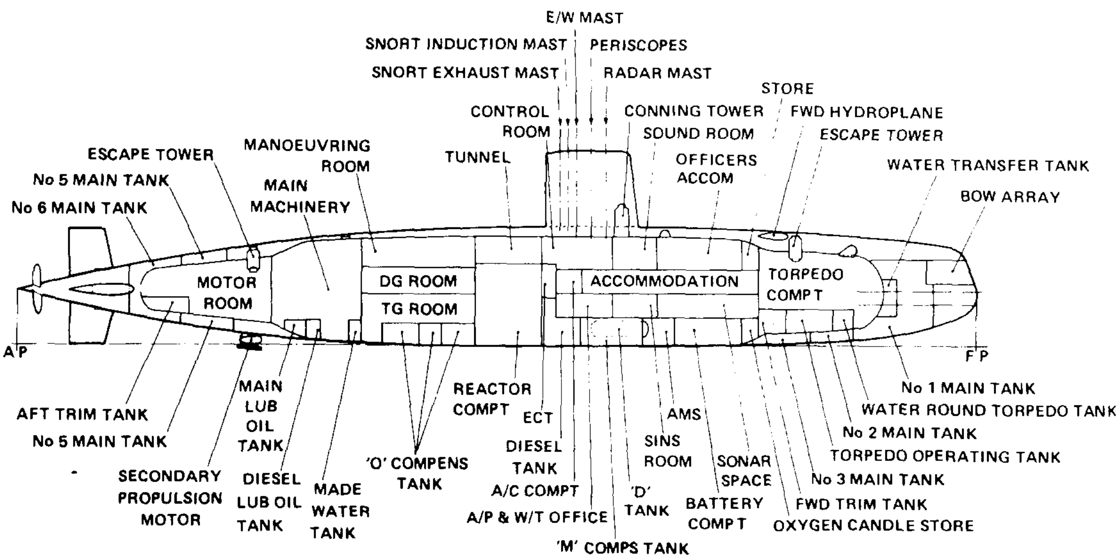

FIG. 3—H.M.S. 'VALIANT'—SSN 02

pressure hull. The re-siting of these tanks also allowed them to be 'soft', ie they were not designed to withstand the full diving depth pressure as in *Dreadnought.*

The core of the nuclear reactor (Core A) was essentially the same as that for the American plant in *Dreadnought* and it had been intended to make no other major modifications to the Dounreay Prototype design. In the event, however, several changes were made as a result of the Americans' experience. These are described in Sir Ted Horlick's paper of 1982[1].

The final design of *Valiant* (FIG. 3) had a submerged displacement of about 4850 tonnes (surfaced 4300 tonnes). This confirmed the results of the studies carried out in 1957 for an all-British SSN.

TABLE 1-*Summary of Submarine Particulars*

	SSN 01	*SSN 02*	*SSBN 01*	*SSN 07*	*SSN 13*
Length Overall, metres	81·0	86·9	129·5	82·9	85·4
Maximum Pressure Hull Diameter, metres	9·8	10·1	10·1	9·8	9·8
Displacements, tonnes:					
Surfaced	3550	4300	7750	4400	4650
Submerged	4000	4850	8550	4950	5200
Form	4450	5300	9550	5450	5700
Percentage Reserve of Buoyancy:					
Internal	—	—	1½	2	2
Total	13	13	10	13	12
Permanent Accommodation	84	90	127	97	98
Type of Reactor Core	A	A	A	B	Z
Torpedo Tubes	6	6	6	5	5

Repeat Valiant Class

The Repeat VALIANT Class consists of the submarines H.M.S. *Churchill, Conqueror,* and *Courageous* (SSNs 04 to 06). *Churchill* was ordered in October 1965 and *Courageous* was accepted into service in November 1971. The two stages of the VALIANT Class production were separated by the building of the four SSBNs of the British naval deterrent force. The major particulars are the same for both parts of the VALIANT Class and no significant alteration was made to the internal arrangement. The only changes in the Naval Staff Requirement were a further improvement to the communications fit and the ability to stow and fire the new Mk. 24 Mod. O torpedo 'Tigerfish', (which did not in fact enter service until 1974). It was possible to accommodate both of these improvements within the *Valiant* design.

During the build of H.M.S. *Churchill* there was considerable concern about the adequacy of the pressure hull steel, QT 35. This was caused by the results of the *Dreadnought* hull survey which revealed cracking in the frame/plate welds and some laminar tearing in the plate iteslf. As a result of this investigation the next submarines to be built used the American HY80 steel, pending the development of a new British material. Revised welding details and practices were adopted, a series of regular hull surveys was instituted for all QT35 submarines to monitor crack growth, and a fracture mechanics study was carried out to help formulate a repair policy.

Resolution Class SSBNs

The agreement to purchase the Polaris missile system from the United States was approved in April 1963. The four Polaris submarines that form the British naval deterrent force were all ordered in 1963 and accepted into service between 1967 and the end of 1969.

The Polaris portion of the submarine was to follow the arrangements in the American submarines as closely as possible. The rest of the design was to be as similar as practicable to *Valiant*. The main propulsion plant, torpedo tube and bow sonar arrangements were the same as in *Valiant*, but the Polaris system did have a considerable effect on other aspects of the equipment and arrangement as follows:

(*a*) Requirement for improved control at slow speeds.
(*b*) Incorporation of a 'hover' system.
(*c*) Uprated turbo-generators to meet the increased electrical load.
(*d*) Missile compensation system.
(*e*) Much improved communications and navigation fit.
(*f*) Large increase in complement and higher standards of accommodation and facilities.

Due to the constraint placed on any changes to the fore and after ends it was not possible to provide an adequate reserve of buoyancy with external ballast tanks alone. Additional main ballast tank capacity was provided by 'hard' tanks within the pressure hull, though the final reserve of buoyancy was still to a lower standard than for the SSNs.

The final design had a submerged displacement of about 8550 tonnes (surfaced 7750 tonnes). The additional length over *Valiant* was 43 metres of which only about a half was directly attributable to the missile compartment. The remainder was required for all the other associated changes.

Swiftsure Class

The design of the SWIFTSURE Class was undertaken through the mid-1960s at the time the early VALIANT Class submarines were entering service. The first of the class, SSN 07, was ordered in November 1967 and entered service in May 1973. The sixth and last of the class entered service in May 1981.

By comparison with the United States SSN593 Class, the VALIANT Class had been large, slow, and lacking in diving depth. The sensor and weapons outfit of the VALIANT Class was in general retained for the SWIFTSURE Class, and the aim was to improve the overall submarine effectiveness by improvement in the characteristics of the platform. The major improvements required were:

(*a*) Significant increase in the diving depth.
(*b*) Higher maximum speed.
(*c*) Reduction in both the radiated and self noise levels.
(*d*) Improvements in submarine safety.
(*e*) Increase in the operational seawater density range.
(*f*) Improved accessibility for maintenance and reliability of the main machinery.

Increased Diving Depth

The original aim was to about double the diving depth of the VALIANT Class, but eventually this target had to be reduced due to weight considerations and the requirement to restrict the size of the submarine. In order to minimize the weight of the pressure hull it was made as nearly cylindrical as possible along its length. This configuration also avoided the high stresses at the changes of section which had been a cause of concern in both the *Dreadnought* and *Valiant* designs. A new British submarine steel (NQI) was used that was considerably tougher and cleaner than QT 35.

Higher Maximum Speed

Development of the propulsion plant for the SWIFTSURE Class, in particular the new reactor core (Core B), provided an increased maximum power. To take full advantage of this the aim was to restrict the form displacement of the submarine and to reduce the resistance due to the appendages.

The submarine's form displacement was restricted in two ways. First by scrutinizing the weight and space requirements within the pressure hull envelope and secondly by reducing the volume requirements external to the hull. Within the pressure hull the most notable savings were in the space allocated to weapon storage, for only a minor reduction in the number of weapon reloads, and the re-design and rationalization of the machinery arrangements. The volume external to the pressure hull was reduced primarily by cutting the external main ballast tank capacity to 10% of the surfaced displacement. A further 3% reserve of buoyancy was provided by internal 'soft' tanks utilizing space that would otherwise have been unusable.

A notable reduction in the resistance was achieved by reducing the height of the bridge fin. This necessitated a reduction of 13% in periscope depth. In order to ensure good control at periscope depth the forward hydroplanes were moved from high up in the forward superstructure casing, as in *Valiant*, to a position on the submarine axis just aft of the bow sonar. In this position the hydroplanes have maximum effectiveness, which allows their size to be reduced and leads to a further reduction in resistance. The forward hydroplanes are retractable and, although this does provide a further reduction in resistance, the main objective was to reduce the self noise effect on the bow sonar.

A feature of major significance in the *Swiftsure* design is the very full after end, having a tail-cone angle of 45° compared with less than 30° in *Valiant*. At the time of the design this feature was thought to increase propulsive efficiency; current thinking, however, is that the benefit is marginal. The fuller aft end does provide valuable buoyancy to support the revised machinery and new propulsor, and it also gives improved access for maintenance in the Main Machinery Compartment.

Reduced Radiated and Self Noise

In order to reduce the self noise at the bow sonar position the following measures were taken:

(*a*) Fitting of retractable forward hydroplanes. This permits their location on the submarine axis which is hydrodynamically more effective. At low speed the forward hydroplanes are essential for providing adequate depth control. At medium speeds the hydroplanes are not needed for control and can be retracted. At higher speeds they are usually deployed again for safety reasons.

(*b*) Siting the bow sonar array in the 'chin' position, thereby reducing noise due to surface reflection.

(*c*) Applying acoustic treatments to the pressure hull and external structure.

(*d*) Fitting a GRP dome over the bow sonar array to reduce the hydrodynamic noise that predominates at higher submarine speeds.

In order to reduce the radiated noise levels the following changes were made:

(*a*) Improved raft mounting of the main propulsion and generating machinery, with isolation retained up to full power. The main machinery raft carries the main turbines and turbo-generators together with their common condensers and the gearbox. Mounting the condensers results in the need for large mechanical flexible couplings in the main circulating sea water system. The main circulating water is supplied through scoops in the leading edges of the stabilizer fins which allow operation up to medium speeds without running the main circulating pumps.

(*b*) Re-design and noise testing of auxiliary machinery. Many auxiliary machines which were known to be noise offenders were completely re-designed and/or fitted with improved mounting arrangements.

(*c*) A reduction in the maximum shaft r.p.m. and the fitting of a pump jet. This followed a successful trials fit in one of the Repeat VALIANT Class submarines.

Improved Submarine Safety

Following the loss of U.S.S. *Thresher*, DPT set up a Submarine Safety Working Party in 1964 to review thoroughly submarine design, construction, and operation.

The increase in diving depth of the SWIFTSURE Class necessitated a re-design of many systems and equipments. It was possible to include many of the recommendations of the first Working Party report as follows:

(*a*) Review of system design, fabrication methods, and quality assurance.

(*b*) Reduction in the number and extent of systems open to the sea at depth. This led to a 'soft' trim system and the use of a low pressure freshwater cooling system for all auxiliaries, supplied from seawater/freshwater coolers.

(*c*) Greatly increased emergency blow rates for main ballast tanks.

(*d*) Hull valves larger than a certain size to be power-operated.

(*e*) Revised hull valve design and testing procedures.

(*f*) Use of a floating vehicle for shock testing equipments and fittings.

(*g*) Installation of three types of flood alarm. A burst pipe warning system activated by a pressure differential was installed on critical systems (but subsequently dropped due to unreliability), a simple float switch was installed low down in each compartment, and manually operated alarms were fitted.

(*h*) Provision of guidelines to the submarine operators on safe combinations of speed, depth, and hydroplane angle in the form of a Manoeuvring Limitation Diagram. This is based on an assessment of the submarine's ability to recover from a flooding or jammed hydroplane accident.

Main Machinery

Although the main machinery is a development of that in the VALIANT Class, the final design represents a major improvement. The new Core B provides greater power and in addition it has an increased life. The raft mounting of the complete secondary machinery, the integration of the main turbine and turbo-generator condensers, and the considerable reduction in maximum shaft r.p.m. necessitated a complete re-design. These changes and the elimination of the Ward-Leonard electric drive aft of the gearbox reduced the length of the main machinery and improved accessibility.

Another change was the decision to make better use of the reactor tunnel. The tunnel was enlarged to occupy some of the reactor compartment volume that was not usable and the resulting space was renamed the Reactor Services Compartment. The consequent reduced volume of the Reactor Compartment meant that the over-pressure to be contained in the event of a reactor accident would have been excessive. Whereas previous designs had 'hard' tunnels, in order to reduce this over-pressure the Reactor Services Compartment was designed as a 'soft' structure. To contain a rector accident, whilst also providing access through the Reactor Services Compartment in normal operation, an airlock was provided at each end.

Weapon/Sensor Fit

The weapon/sensor fit of the SWIFTSURE Class was essentially the same as in the VALIANT Class but some fundamental re-arrangement took place in order to improve performance. The main change was the decision to position the bow sonar array in the 'chin' position so as to reduce surface reflection. In order to accommodate this arrangement the torpedo tubes (reduced to five) had to be angled and the weapon stowage compartment sited further aft. The difficulties associated with embarking weapons were considered to be outweighed by the operational advantages of this arrangement.

Two further improvements were made:

(*a*) Addition of port and starboard hull-mounted sonar arrays—flank arrays—to improve coverage of the beam.

(*b*) Introduction of a computer-based tactical data handling system.

With all the improved characteristics over the VALIANT Class both weight and space were at a premium. The increase in diving depth meant that the design was weight-limited rather than space-limited as in previous designs. A vigorous exercise was carried out to reduce weight and a more effective weight control organization was set up in both DPT and the shipbuilder. The final design (FIG. 4) had a submerged displacement of about 4950 tonnes (surfaced 4400 tonnes), which was only about 100 tonnes greater than *Valiant*.

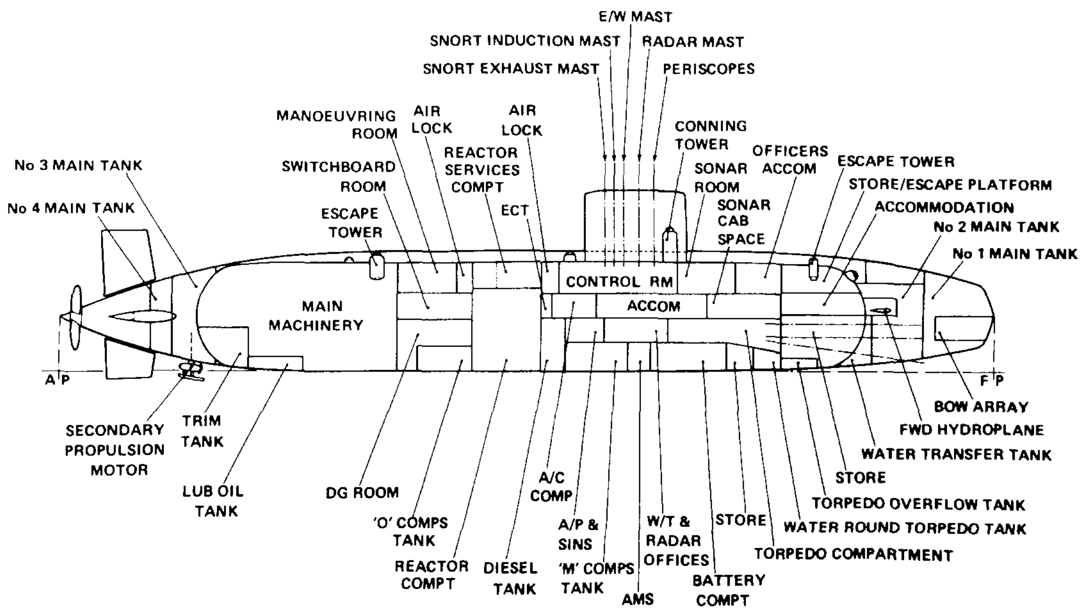

FIG. 4—H.M.S. 'SWIFTSURE'—SSN 07

Trafalgar Class

TRAFALGAR is the class of nuclear submarine currently under construction and was originally referred to as the Modified SWIFTSURE Class. The first of this class is SSN13 which was launched in July 1981. The design was derived directly from that of the SWIFTSURE Class and many of the improvements have been selected so as to be capable of being retrofitted in the SWIFTSURE Class and even earlier submarines.

Studies into the operational effectiveness of diving depth showed that an increase over the diving depth capability of SWIFTSURE gave only small benefits and so no change was made. The reactor plant and main machinery in the TRAFALGAR Class are essentially the same as for SWIFTSURE and therefore the achievement of an acceptable maximum speed depended on the ability to limit the increase in overall size of the submarine. The most significant improvement to the nuclear plant was the new core (Core Z) for which a major design aim was to further increase core life.

Noise Reduction

Many lessons have been learnt from each completed boat of the SWIFTSURE Class. Improvements in noise reduction have been gained with each boat by attention to design detail and the TRAFALGAR Class reflects the aggregate of these measures and some necessary design changes.

During the early development of the design, so much emphasis was placed on noise reduction in the Main Machinery Space that it was decided to mount everything in that space—not only the entire main and auxiliary machinery but even auxiliary tanks—on a massive raft. This raft was then to be mounted, not from the pressure hull (as was the case with the smaller raft in the SWIFTSURE design), but from the main transverse bulkheads at each end of the compartment. A further advantage of this arrangement was the potentially improved performance under shock. The development of this feature (known as the Bulkhead Mounted Raft) continued up to the point of starting to fabricate a prototype raft. It became clear however that this approach placed far too much emphasis on just one characteristic of noise reduction. The difficulties of construction and the overall increase in the size of the submarine resulting from this and the other noise reduction and weapon/sensor features being proposed would have resulted in a considerable growth in cost and size, and a reduction in submarine speed of up to 2 knots. Because of this and the technical risks it was decided that the investment was too great and the design was stopped.

The new approach adopted to the design was to walk, rather than leap, forward from the SWIFTSURE Class and to build on its successes. A principle of minimum change was adopted unless there was a good and thoroughly substantiated reason for change. The following improvements were included:

(*a*) Development of the mounts for the main machinery hull-mounted raft.

(*b*) Addition of several smaller auxiliary rafts.

(*c*) Evolutionary improvement in the design of pump jet.

(*d*) Critical review of system design and isolation e.g. ventilation.

(*e*) Improved acoustic hull coatings.

Weapon/Sensor Fit

The improvements to the weapons and sensors have been constrained by the need to remain as nearly as possible within the SWIFTSURE configuration. The new fit does however provide some very significant and long-awaited improvements to the total effectiveness of the submarine:

(*a*) Provision of an integrated command complex.

(*b*) Modified bow sonar with complete re-design of the processing, and incorporating computer-assisted data handling.
(*c*) Provision of towed sonar array.
(*d*) Improved computer-based Action Information Organization (AIO) with integrated Fire Control system.
(*e*) Provision for the Mk 24 Mod 1 torpedo which has reduced noise, increased range and an anti surface ship capability.
(*f*) Provision for R.N. Sub-Harpoon—a medium-range subsonic salvo missile for use against surface ships.

The introduction of these improvements to the platform characteristics and the weapons fit has increased both the weight and space demands. Although the SWIFTSURE Class had a margin to accommodate improvements it has been necessary to lengthen the base design by several frame bays. This has resulted in the TRAFALGAR Class (FIG. 5) having a submerged displacement of about 5200 tonnes (surfaced 4650 tonnes). The resulting reduction in maximum speed compared with SWIFTSURE is only about half a knot.

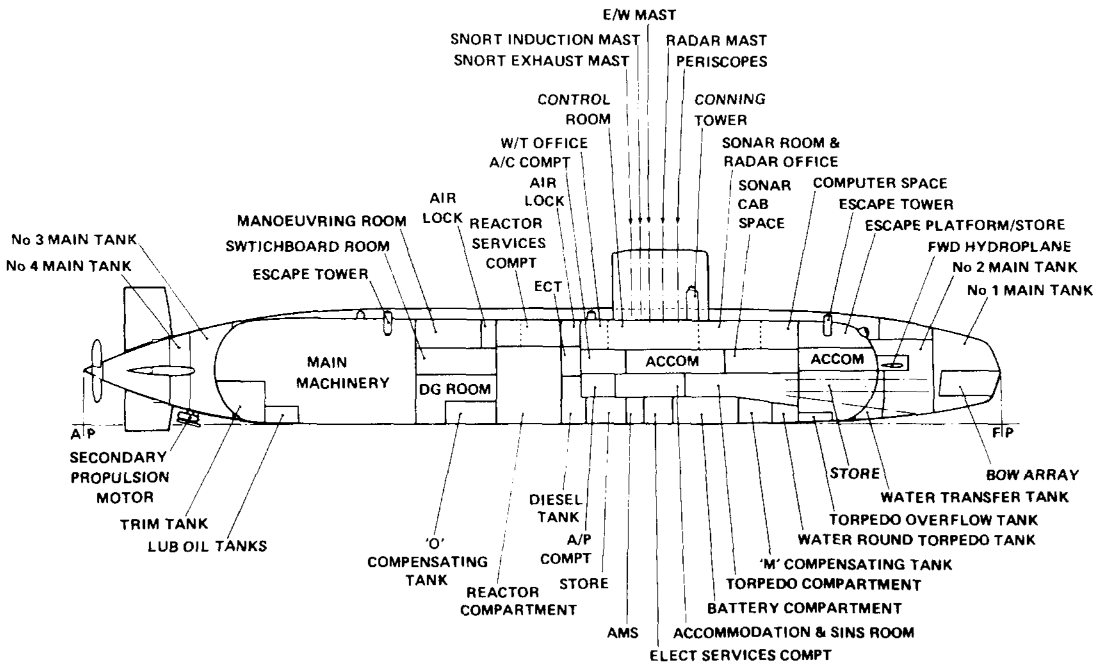

FIG. 5—H.M.S. 'TRAFALGAR'—SSN 13

Conclusion

In the 1950s the advent of the nuclear submarine was seen as the greatest advance in warships since the supersession of sail by steam. H.M.S. *Dreadnought* had the direct advantages associated with nuclear propulsion but was a great deal noiser than conventional submarines and relied largely on Second World War weapons. Her top speed was disappointingly low and she had only a modest increase in diving depth over previous submarines.

Since H.M.S. *Dreadnought*, improvements have been made in every aspect of submarine performance. Some of these have been radical, such as the use of a new propulsor, main machinery rafts, a significant increase in diving depth, and the introduction of a new weapon system. Many improvements have been less dramatic individually but have provided major advances over a span of many years. These include the development of the reactor core for increased power and longer life, and the continuing attention paid to noise reduction through detailed re-design and testing. All these improvements mean that submarines of the TRAFALGAR Class will have an operational effectiveness far superior to that of *Dreadnought*.

Currently there are planned to be seven submarines of the TRAFALGAR Class. There then will be a pause in SSN construction whilst the new SSBNs are being built. The next class of SSN will therefore be able to benefit from developments in hull, machinery and weapons introduced for the new SSBNs. However in view of the large cost and timescale of such developments they could also act as constraints on the design options available. It will be necessary to reassess the balance of requirements for speed, diving depth, complement, weapons, sensors, and standards (noise, shock, accommodation, safety, availability etc), and only by doing this will it be possible to continue to develop the operational capabilities of nuclear submarines within an acceptable cost.

Reference

1. Horlick, E. J.: Submarine Propulsion in the Royal Navy, *Journal of Naval Engineering*, vol. 27, no. 1 June 1982, pp. 1–22.