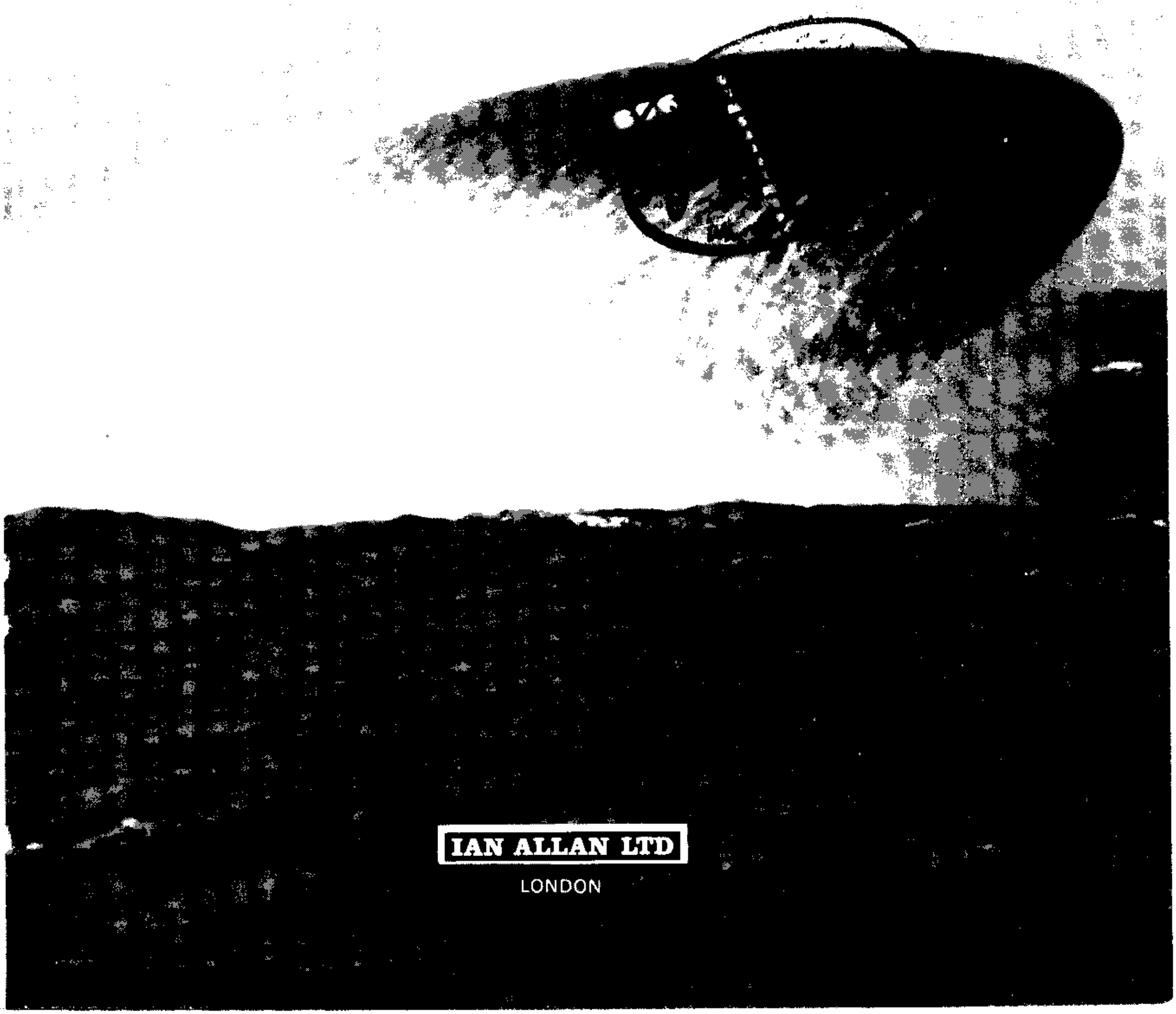
SUBMARINE

The capital ship of today

John Marriott



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John Marriott

Contents

Preface

The object of this book is twofold: firstly to explain in semi-technical terms how submarines and their weapons function and are used; secondly, to discuss the many types of submarines to be found in all the major navies of the world today and the purposes for which they are operated.

Modern submarines are extremely complex, and modern submariners must possess a great deal of highly technical knowledge. This book is not for them, except perhaps as a reference book about other navies. It is however for persons who are interested in the undersea world and the men who sail in it, but are themselves not qualified engineers or electronics experts.

The book is as up-to-date as possible at the time of writing, but more submarines are being built almost weekly and there may be new classes of submarines appearing, and perhaps more important, new weapons and sensors being developed. Basic principles, however, do not change with such bewildering rapidity.

Right:
The nuclear-propelled attack submarine USS *San Francisco* (SSN-711).

1 The Modern Submarine

The idea of ships concealing themselves by getting beneath the surface of the sea is centuries old. It is even said that Alexander the Great used some form of submersible in the siege of Tyre in 332BC. However, the concept seemed to lapse, for it is not until the 16th century that submersibles were heard of again, although even then they were more akin to the present commercial submersibles, which are used for recovering objects from the seabed, working on oil rigs and so forth.

The Beginning

The first recorded use of a submersible for military purposes was in 1776 when an American named Bushnell produced a craft, the *Turtle*, made of metal, with an explosive charge attached and manned by one man. It was driven by a hand-operated propeller, and the idea was to con it, well trimmed down, on the surface to alongside a target ship, with the one operator peering out through scuttles just above the surface of the water, and winding away on a handle to rotate the propeller. When in position the craft was sunk by flooding a tank in its bottom. The intrepid operator then emerged, removed the explosive charge from the submersible and attached it by screws to the wooden hull of his target. The charge was presumably operated by a time fuse, whilst the operator re-entered the submersible and made his getaway as best he could, furiously winding his handle.

The American War of Independence was in progress at the time and *Turtle* was designed as a means of attack on the blockading British ships. The new vessel did in fact make one attack on HMS *Eagle*, a 64-gun ship, at anchor off Staten Island in New York harbour. *Turtle*, with its inventor on board, was towed into a position near the *Eagle*, by two rowing boats, and successfully carried out the operation until the moment came to screw the charge on to the ship's bottom: to Bushnell's horror he found that the ship had a copper sheathing to its bottom and the screws would not penetrate it. Later he made two other attempts on ships in the Hudson River without success, except perhaps as being the first man to attempt an underwater attack.

Towards the end of the century, the well-known American engineer Fulton entered the field with another invention. The US government was not interested in his proposals, but in 1802 Napoleon granted Fulton sufficient money to proceed with his ideas, and in Paris he built a submarine called the *Nautilus*. Its hull was similar in shape to the tear-drop shape now much in use today, but the craft was small, less than 20ft in length, and had a crew of three. It was propelled submerged by a Bushnell-type winding handle driving one propeller, but on the surface a small collapsible mast complete with sails was raised and *Nautilus* turned into a sailing ship. One external explosive charge was carried, but how this was to be attached to a ship's hull is not explained. The French kindly lent Fulton an old hulk and he succeeded in blowing it up. *Nautilus* had a reasonable endurance and on one occasion remained submerged for five hours with the crew on board.

Eventually, though, the French decided not to proceed with the project as they considered such warfare dishonourable. Fulton went to England and succeeded in getting his invention examined by a government committee, of which the Prime Minister, Pitt, was a member. Pitt was apparently enthusiastic about it, but the First Lord of the Admiralty, Earl St Vincent, successfully squashed it when he made his famous statement 'Pitt is the greatest fool that ever existed to encourage a mode of war which those who command the sea do not want and which, if successful, will deprive them of it'. From then on, for nearly a century, it was official Royal Naval policy that any form of underwater warfare was 'not quite cricket' and was to be discouraged.

Other nations were not quite so naïve (or perhaps did not play cricket) and further inventions appeared. Among these was the spar torpedo, an explosive charge on the end of a long spar sticking out from a submarine. Intrepid submariners manoeuvred the submarine so as to place the charge, still on its spar, against the bottom of the target ship and then explode it. The spar, however, was not very long and the submarine was almost in as great a danger as the target.

In the American Civil War, the Confederates attempted to use the spar torpedo attached to a submarine against the Federal blockading ships. At least four attacks were made but the results were not very successful; one new steam wooden sloop was sunk, but the attacking submarine was also sunk in the explosion. An ironclad and another vessel were damaged, but that seems to be the total of casualties.

As the years went by quite a few inventors produced a variety of ideas, some of which came to fruition, including a steam-powered craft designed by an Englishman called Garrett. When the boat submerged, the furnaces were extinguished, but for a short time left a full head of steam in the boiler which was used to propel the craft submerged.

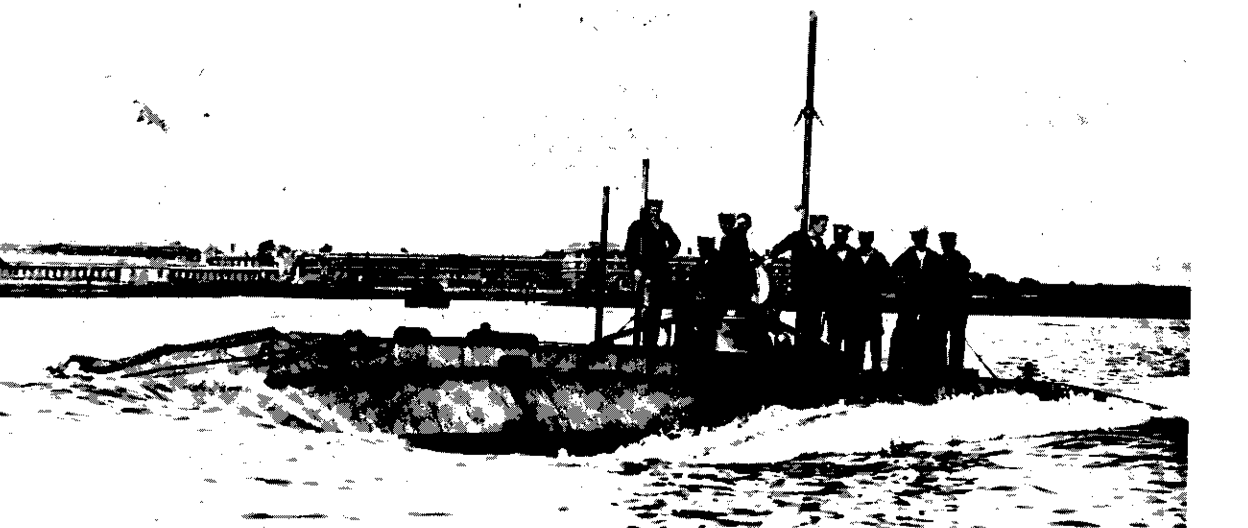
The early Whitehead torpedoes showed that electric motors powered by batteries were a possibility for submerged boats, and the design was quickly followed up, but the Royal Navy stuck to its principles and showed no interest in submarines. The French had more foresight and actually funded the development of one or two electric submarines. In America, the government ran a competition for the development of a submarine, which was won by a Mr Holland who had been working on submarine designs for some years. His vessel was propelled by steam on the surface and by batteries and electric motors submerged, the batteries being charged by the steam plant when on the surface. Holland's boat also carried for the first time a propelled torpedo made by Whitehead. Named the *Plunger*, the vessel was laid down in 1897, but, soon after, it was realised that the heat given out by the steam boiler when submerged would make the interior of the boat too hot. Work on it was therefore stopped.

However, Holland, at his own expense, produced another design. Instead of steam propulsion he used a petrol internal combustion engine, which, of course, also charged the batteries. Named *Holland*, it was, in fact, the only reasonably successful submarine produced by any nation until that time. Displacing 105 tons, its petrol engine drove the boat at 8.5kt on the surface, and the electric propulsion at 7kt when submerged, but only for up to 24 miles. Its main rival was the French *Norval* of 108 tons with steam propulsion and batteries with motors, giving 11kt on the surface and 8kt for 25 miles submerged. It had four torpedo launchers.

By the end of the 19th century six navies had submarines. France was in the lead and was building fast. The USA had two boats, one of which was the *Holland*, the most advanced of them all. Britain had none, but the Admiralty began to realise that it was being left behind and, because it had done no development work, decided to buy a design from abroad. It therefore bought the design of the *Holland* type, and ordered five boats from Vickers. The very first British-built submarines were only 63ft long with a displacement of 120 tons and carried a crew of two officers and seven ratings. They were driven by a four-cylinder petrol engine on the surface and by an electric motor when submerged.

The 'Inspecting Captain of Submarine Boats' — a new naval post — energetically started increasing the numbers of the 'Holland' class, but they were still intended purely as defensive weapons. About 10 a year were being built in the UK and shortly afterwards their role was extended from that of defending major ports to defending the entire East Coast.

In 1907, Britain finally broke away from the basic 'Holland' design with a British designed 'D' class. They were of 500 tons and driven by diesel engines instead of petrol, and were capable of remaining submerged the whole of the daylight hours. It was soon realised that here were vessels which could be used both defensively and offensively. Sizes were increased and by 1914 Britain had its 'Nautilus' (again) class of 1,270 tons



with an endurance of 5,000nm, two torpedo tubes (one forward and one aft), one 12pd gun, 17kt on the surface and 10kt submerged. Meanwhile the Germans had not been idle and decided to go for a large 'overseas' submarine of more than 500 tons from the start. By the beginning of World War 1 they had ordered 42 large submarines, of which 29 were in service when the war started — twice as many large submarines built or building as the British.

The French also went for large submarines, but they were not so successful as the British and Germans, and used their craft purely for defensive purposes. American submarine construction lagged well behind that of the Europeans and by 1914 they were relegated to fourth place in the submarine stakes.

Today

This is no place to discuss the submarine campaigns of two world wars, but as is well known, submarines developed apace, becoming larger, faster and deeper diving. The German U-boat campaign very nearly brought the Allies to their knees in both wars and showed convincingly to the whole world the inestimable value of the submarine to any maritime power; even the advent of sonar in World War 2 did little to diminish their worth. Of recent years we have seen the tremendous strides made by submarines to avoid sonar detection, which have probably outdistanced the efforts made by the sonar manufacturers to improve their sensors.

Perhaps we should now look at where we stand today in the modern submarine world. There are basically three main types of submarines. Top of the list comes the Ballistic Missile Nuclear Submarine (SSBN), of which there are 117 in service: 66 are Soviet, 38 American, six French, four British and two Chinese. They are the largest types of submarines built, most averaging 3,000 to 9,000 tons, but with two *very* large types — the Soviet 'Typhoon' class of 30,000 tons and the US 'Ohio' class of 18,200 tons. (The tonnage is the displacement when the submarine is fully submerged and throughout this book when submarine tonnage is mentioned it refers to submerged tonnage.) SSBNs, in a sense, are purely strategic missile launchers, but they can be used in the normal attack role if required. They are nearly all capable of 24kt or more submerged.

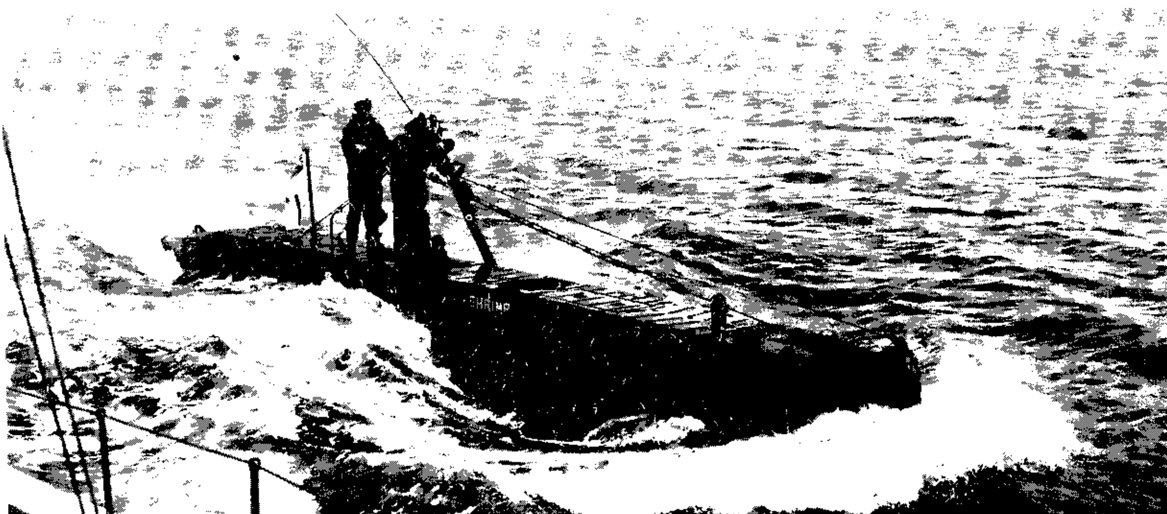
Next in size comes the Nuclear Attack (Fleet) Submarine (SSN). The Americans call these 'attack' submarines; the British and French 'Fleet' submarines, presumably because they are fast enough to be able to operate with the fleet at sea. The nomenclature 'attack' is however more descriptive and will be used in this book.

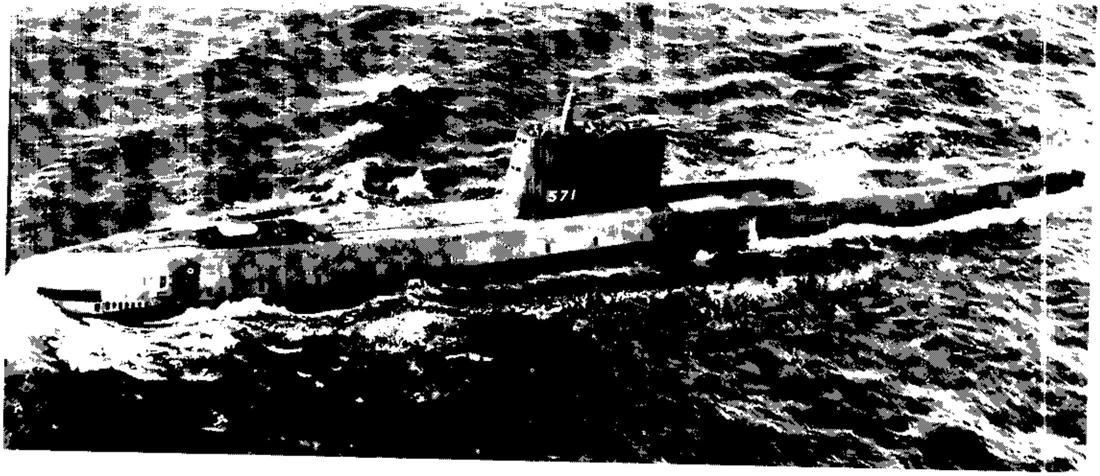
In the USSR, many of the nuclear attack submarines are fitted with submarine-launched guided missiles for anti-ship use, and NATO has christened them SSGNs. The USSR has 127 SSNs and SSGNs, NATO 115, of which 96 are American, 17 British and two French. However, the building of these very useful craft is proceeding at a steady rate — in the Soviet Union, at an accelerated rate — thus these figures will soon be out of date. For example, Britain is to build three more SSNs in the next few years and France four more. SSNs are normally between 4,000 and 7,000 tons, although the French ones are considerably smaller, whilst the Soviets are now building the 'Oscar' class SSGNs of 18,000 tons.

The third main type of submarine is the 'conventional', so called because it uses conven-

Below left:
An early Royal Navy submarine of the 'Holland' type.

Below:
One of the Royal Navy's early midget submarines, photographed in 1957.

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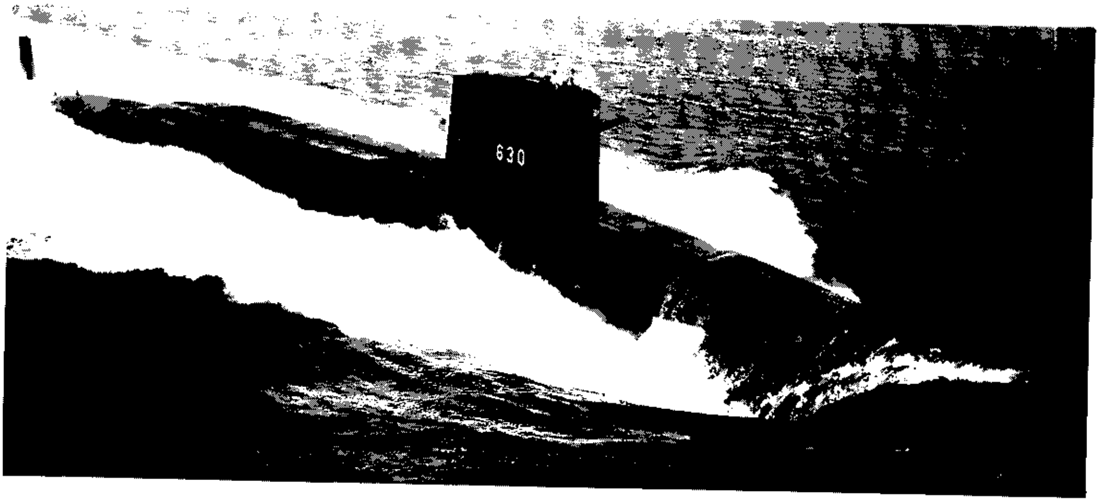
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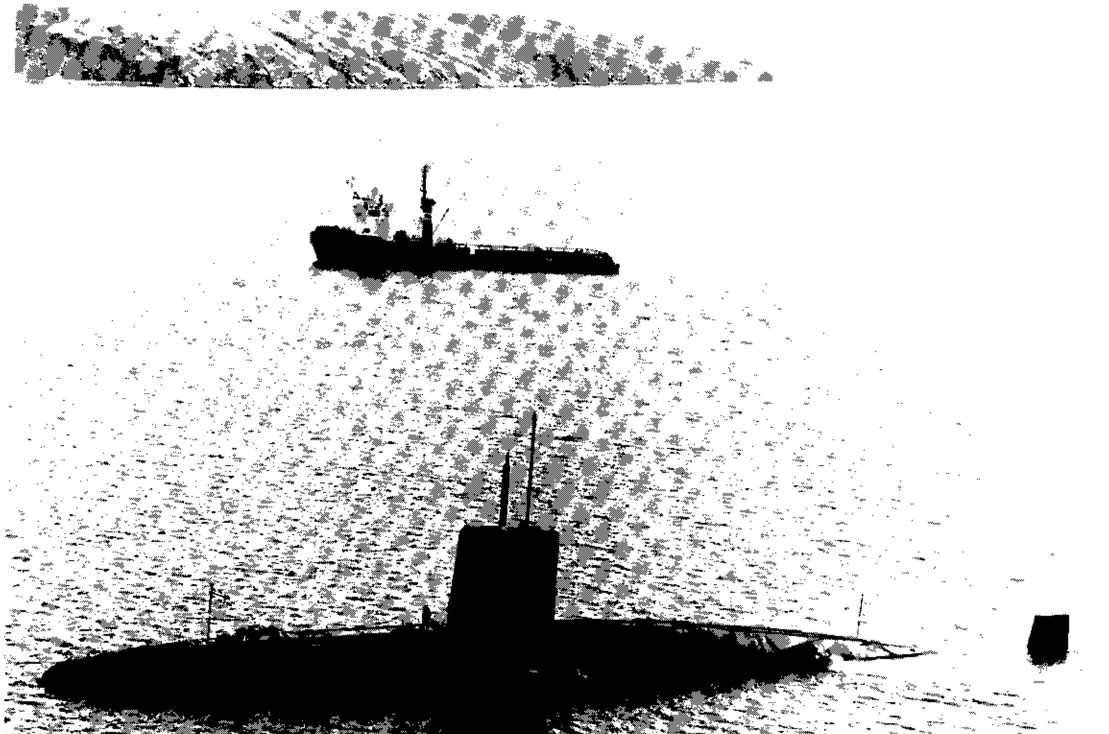
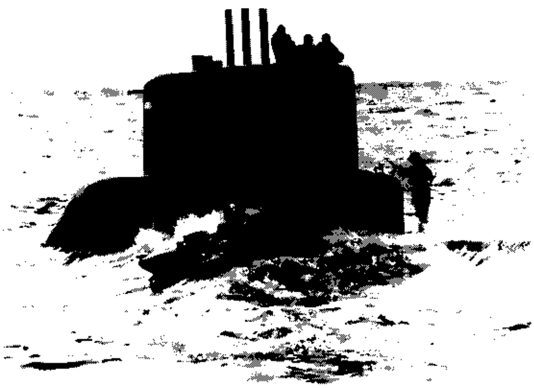




Top left:
The USS *Nautilus.* An SSN, *Nautilus* was the US Navy's first nuclear-powered submarine.

Left:
The USS *John C. Calhoun.* An SSBN of the 'Lafayette' class, she displaces 8,250 tons submerged.

Bottom left:
The nuclear-powered fleet submarine HMS *Courageous* in San Carlos Water off the Falkland Sound. *Courageous* was one of six RN submarines to take part in the 1982 campaign.

Above:
The German submarine *U12,* one of the Type 205s of 450 tons submerged. It is possible to see how small the type is by the size of the inflatable dinghy alongside.

tional diesel-electric propulsion, as opposed to nuclear. Conventionals are generally denoted by the letters SS (standing for submarine), but some nations refer to them as Patrol Submarines. They can vary considerably in size from some 3,000 tons down to about 400 tons. There is nevertheless a fairly clear dividing line between ocean-going conventionals with a good endurance, mostly of 1,600 tons upwards, and the smaller submarines which are not really intended for deep ocean work, but could be used as such if necessary. The latter are more for coastal and narrow water patrols, clandestine work and reconnaissance. They are also particularly valuable in shallow water.

There are no less than 567 conventional submarines in the world today, some still being built. Out of these, China has 112, the USSR 223, West Germany 26, France 14, North Korea 19 and Britain 16. The US has stopped building conventional submarines altogether, but has three old ones left. France too has announced that it will build no more, but has quite a few still in commission. Britain is to maintain its fleet of conventionals and has recently ordered the first of a new type — the Type 2400 — to replace its existing 'Oberons' and 'Porpoises', but whether all 16 of them will be replaced is doubtful.

Costs

The cost of building a submarine is difficult to ascertain, as many governments are disinclined to publish the enormous sums involved. However, this is not always the case and it is occasionally possible to obtain some fairly accurate figures. The latest American SSBN, the *Ohio*, cost about $1,000 million; this includes the missiles, which are of course the very expensive long range Trident C4, as opposed to the cheaper Polaris/Poseidon missiles at present carried by other American and British SSBNs. The projected British Trident-carrying submarines are estimated to be going to cost £1,870 million each including 16 missiles, which will be of the newer Trident D5 type, and this alone adds about £570 million. The figures have been projected ahead for 15 years and allow for inflation, but the estimate was made when the sterling-dollar exchange rate was $1.78 to the £. At present the figure is around $1.40. Who can tell what may happen in the next 15 years?

The cost of a nuclear SSN varies considerably. For example, the 'Los Angeles' class is now costing about £353 million per submarine, but the next British SSN to be built is estimated at only £175 million by the time it is completed in 1986. This includes all the equipment and weapons.

Conventionals come somewhat cheaper, but even so are by no means inexpensive. Britain's latest ocean-going conventional, the first of the Type 2400s (*Upholder*), which commenced building in 1984, will cost about £100 million, but subsequent ones are expected to be slightly less.

Submarines in the Major Navies of the World

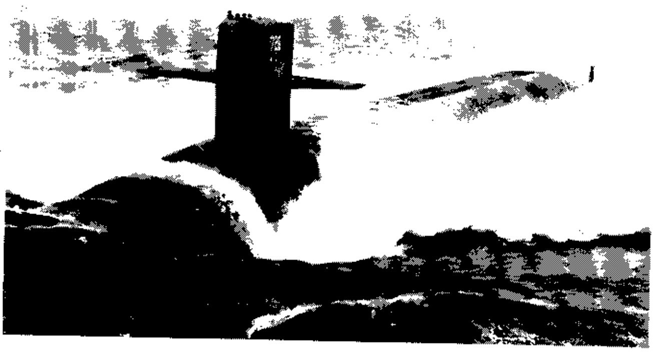
A breakdown of the world's submarines is listed at the end of this book. Tables cannot tell all the story, so let us look now at the submarines in the major navies. The Soviet Navy has such an incredible number of submarines that it has a chapter all to itself — Chapter 11.

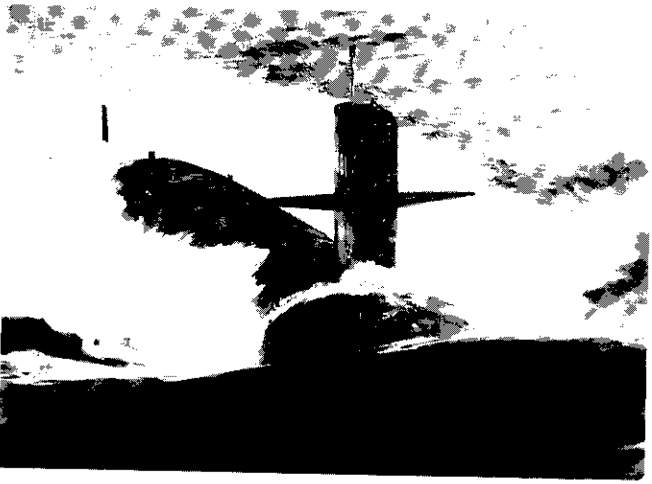
USA

SSBNs

Next to the USSR, the United States has the largest submarine fleet. The Americans put great faith in the submarine launched ballistic missile as a second strike weapon and have amassed a considerable number of these highly expensive craft.

After much experimental work in submarines with large, unwieldy, primarily land-based missiles, such as Regulus, Triton and Jupiter, all of which would have required very large submarines



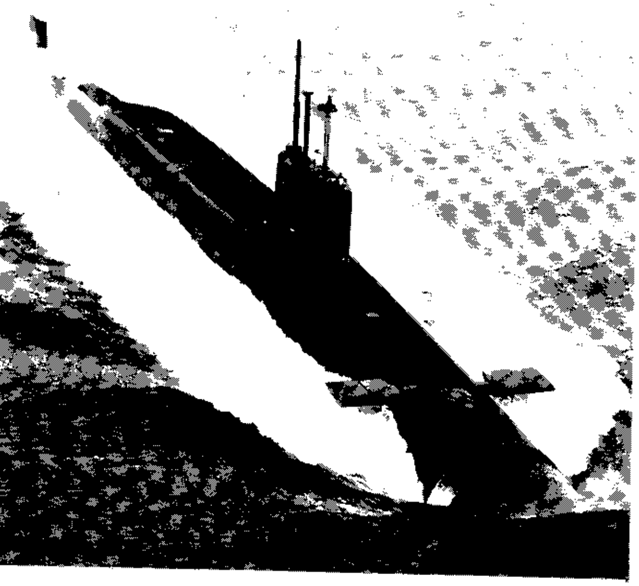


to carry them, US naval opinion turned towards smaller submarines but more of them, each with 16 missiles. Opinion was considerably helped by the fact that such a missile then under development, named Polaris, appeared viable and would soon complete development. After a number of trial firings from surface ships, the first Polaris submarine was commissioned on 30 December 1959 and fired the first Polaris A1 missile on 20 July 1960. A1 had a range of 1,200nm and a warhead with a yield of 700-800kT.

It was soon replaced by Polaris A2, with a range of 1,500nm, which first flew in November 1960. The operational requirement was quickly amended to a missile with a range of 2,500nm and the Polaris A3 was produced. The A3 was first fired from a submarine in 1963. It is the A3 that Britain now uses, but it has undergone a number of improvements, and its range has been increased to 2,880nm.

Staff requirements increased again and after numerous discussions and fresh proposals, the Poseidon C3 was announced and was first fired from an American submarine on 24 August 1970. Poseidon was a great improvement on the Polaris A3, principally by having 14 MIRVs (Multiple Independently Targeted Re-entry Vehicle) as opposed to the original Polaris A3's three MRVs (Multiple Re-entry Vehicle).

A total of 31 US SSBNs were converted to carry Poseidon. Meanwhile, McNamara, the US Secretary of Defense, had ordered a new study of all future US strategic offensive forces, and out of this came a requirement for a missile with a much longer range and improved accuracy. This was Trident (C4), and 10 SSBNs were converted to



Top left:
The latest SSBNs of the US Navy displace 18,700 tons submerged. Seen here is the lead ship of the class — the USS *Ohio*.

Centre left:
The USS *Batfish*, a 'Sturgeon' class SSN fitted with the Harpoon submarine-launched anti-ship missile, SUBROC and four 21in torpedo tubes. Her maximum submerged speed is 30kt.

Left:
HMS *Revenge* is one of four British SSBNs. Although she appears to be diving, in fact she is not because some members of the crew can be seen on the bridge.

Top right:
HMS *Superb* leaving the Royal Navy's submarine base at Faslane in Scotland. She was the ninth 'Fleet' (Attack) submarine to be built in the UK. She displaces 4,500 tons submerged and has a maximum underwater speed of 30kt.

carry the missile; they are now at sea. However, Trident 2 (D5) with an even longer range was being developed. It turned out to be too large to fit into existing Polaris/Poseidon submarines and so a new class of submarine had to be built to carry it. Known now as the 'Ohio' class, two are already at sea, and a further three are ordered and 14 more projected. At present the 'Ohios' will carry the Trident (C4) as the D5 has not yet completed development, but they carry 24 of them instead of the 12 or 16 with which all US SSBNs had been fitted. Britain has also decided to operate the Trident (D5).

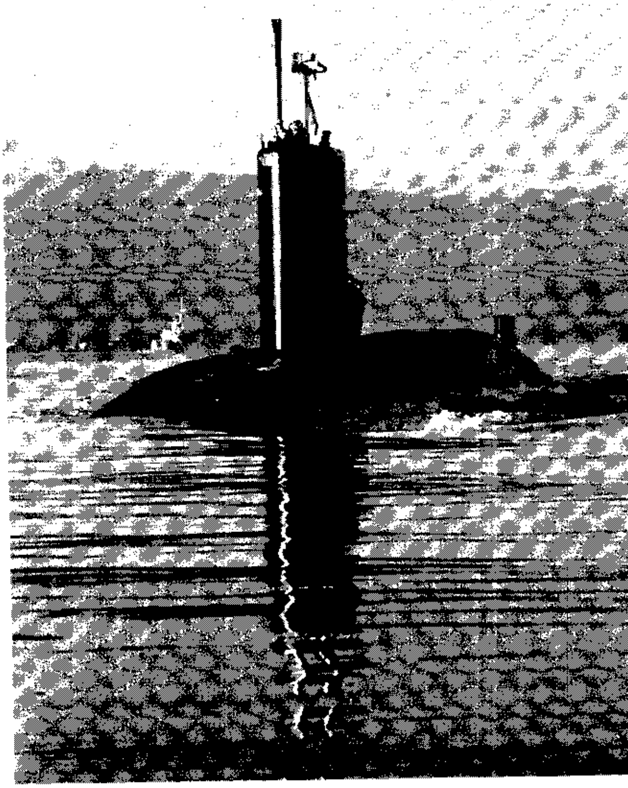
SSNs
The USA's 96 SSNs (100 are planned) range from the 'Skate' class, launched in 1954-55, to the latest 'Los Angeles' class of which some 24 have been launched since 1974 and more are following. They all have between four and eight torpedo tubes for 21in torpedoes. The 'Los Angeles' class vessels, unusually, have four tubes mounted amidships, two protruding out of each side of the hull. American SSNs vary between 2,500 tons for the old 'Skate' class to 6,900 tons for the 'Los Angeles' class, and all have submerged speeds of over 25kt.

UK

SSBNs
The UK has four SSBNs of the 'Resolution' class, each armed with 16 Polaris A3 missiles. They have a submerged tonnage of 8,400 tons, a maximum submerged speed of 25kt, and are to be replaced in the early 1990s with four new submarines carrying the Trident D5 missiles. It was announced in April 1986 that the first of these, HMS *Vanguard*, is to be built by Vickers. Considerable controversy exists in the UK as to whether or not the country can afford the enormous cost of the missiles and the new submarines. Britain's policy is to keep one SSBN on patrol at all times.

SSNs
Britain has, or will shortly have, 17 SSNs in service and is building about one more each year. They vary between 4,500 and 4,900 tons, with underwater speeds of around 30kt, and are armed with five or six torpedo tubes for 21in torpedoes.

SS
The present complement of conventional submarines is 16 with one more of the Type 2400 class building. As more of this class are built, the somewhat aged 'Oberon' and 'Porpoise' classes will be phased out. What the total complement of conventionals is likely to be has not been announced, but it is unlikely to be more than 12 at the outside.

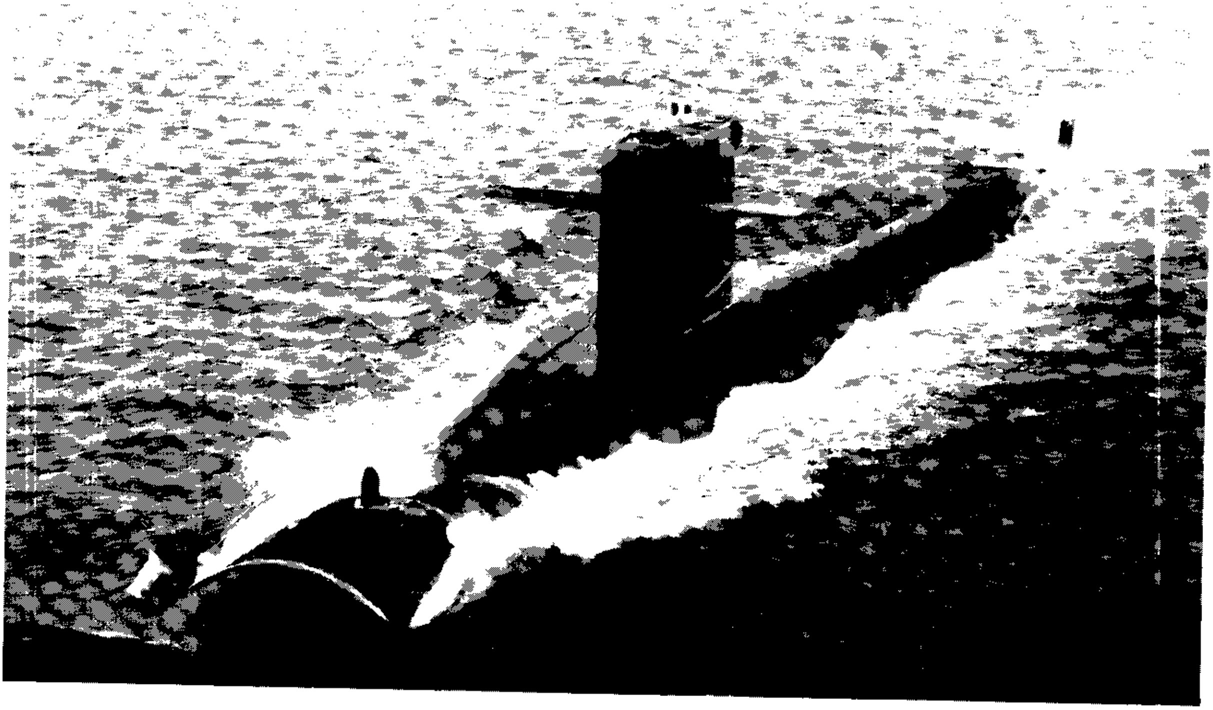
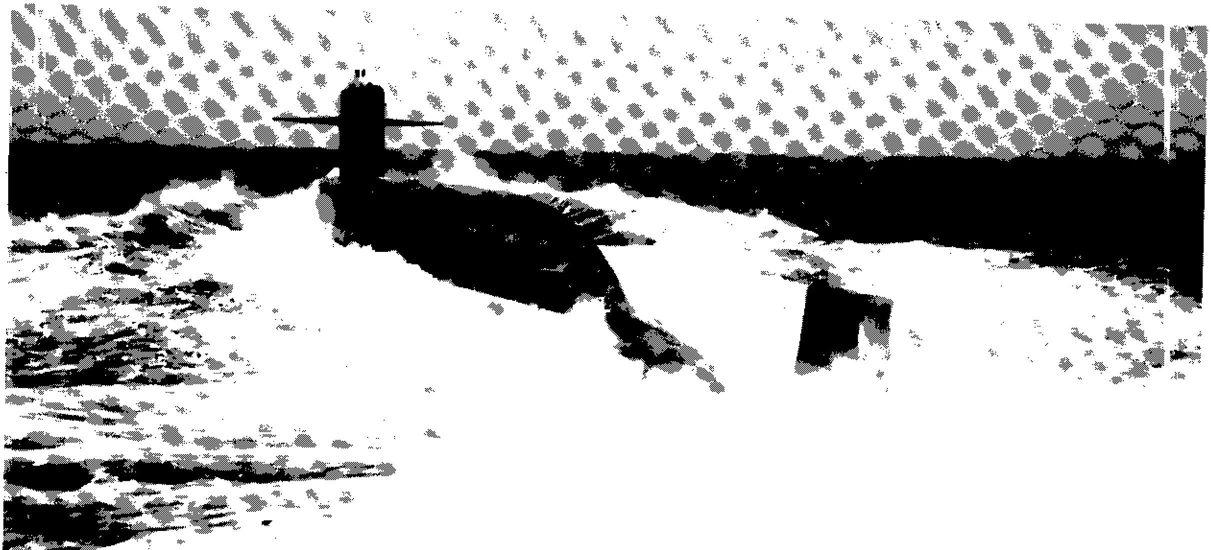


France

SSBNs
France has six SSBNs: the first, *Le Redoutable*, entered service in 1971 and the fifth, *Le Tonnant*, in May 1980, and *L'Inflexible*, is just completing. France intends in future to keep three of them always on patrol, and for this would seem to need six submarines, but after experience has been gained it is hoping to pay off *Le Redoutable* and endeavour to keep three on patrol with a total of only five submarines. The submarines are slightly larger than the British ones (8,940 tons), but carry the same number of missiles — 16. The missiles and their nuclear warheads are entirely of French manufacture.

The French call their ballistic missile submarines SNLEs instead of SSBNs and the entire nuclear submarine ballistic missile force is known as the 'Force de Dissuasion', a descriptive and sensible title.

SSNs
The French only comparatively recently decided to operate nuclear attack submarines. Five SSNs have been ordered, and although only two are so far in service, all should be in service by 1990.


They are of the Type SNA72 and are considerably smaller than similar American or British submarines, displacing only 2,670 tons submerged as compared with modern British and American craft which are all over 4,500 tons. Apart from the usual torpedoes, they are also to be armed with the Aerospatiale Exocet SM39 anti-ship missile when it comes into service. A new class of five Fleet submarines is to be ordered in due course.

SS

France has three classes of conventional submarines: the 'Agosta' class of four boats, the 'Daphne' class of nine boats and the older 'Narwal' class of four boats. The 'Agostas' and 'Daphnes' are small (around 1,400 tons submerged), but the 'Narwals' have a submerged tonnage of 1,930.

France has exported 'Agostas' to Spain and Pakistan, and 'Daphnes' to South Africa, Portugal and Spain. The Spanish ones are being built in their own yards.

West Germany

SS

The West Germans have concentrated on small conventional submarines, partly because after the war they were not allowed to build large ones, and partly because their major operational areas are in the shallow Baltic and North Sea where large submarines could not operate satisfactorily. The German submarine fleet consists of 18 Type 206s of 498 tons submerged and eight of the older Type 205s of 450 tons.

West Germany is very progressive in its submarine construction and has sold many craft abroad, including much bigger ones. Thyssen, for example, has produced the TR1700 which displaces 2,300 tons submerged, with six on order for Argentina. West Germany is also experimenting with air independent propulsion systems and hopes to produce a new Type 208 submarine in the 1990s which, although propelled by diesels, will never have to snort or surface.

Above left:
Two views of the French SSBN *L'Inflexible*. One shows the fore end and the other the after end. The two flat surfaces protruding from the conning tower are the forward hydroplanes.

Right:
SNLE *Le Redoutable*, one of France's six SSBNs, displacing 3,940 tons submerged.

Left:
The French SSN *Rubis*. Six of the class have been ordered but only two were in commission in 1985. Displacing only 2,670 tons they are the smallest SSNs to be built.

Netherlands

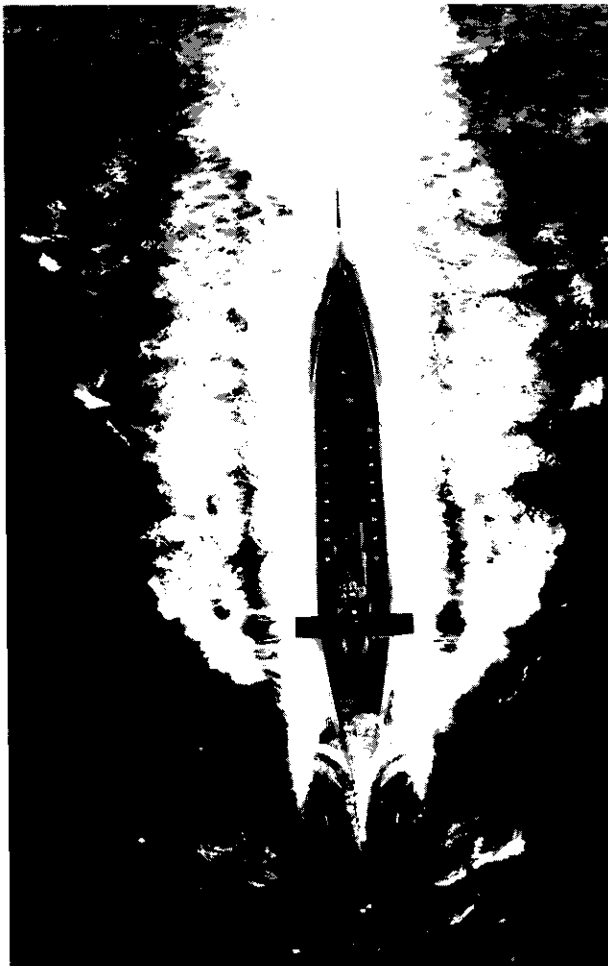
SS

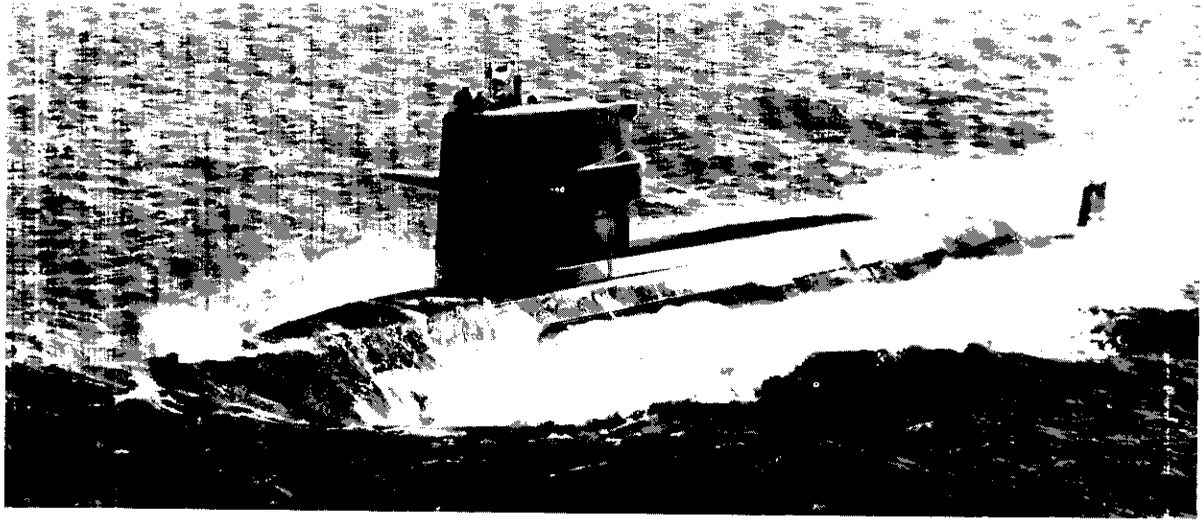
Like the West Germans, the Dutch have also concentrated on conventional submarines, but of real ocean-going size. Their latest class is the 'Walrus' of which four will be built eventually. Two are nearly completed and are expected to commission in 1986. They will displace 2,800 tons submerged and achieve 20kt dived.

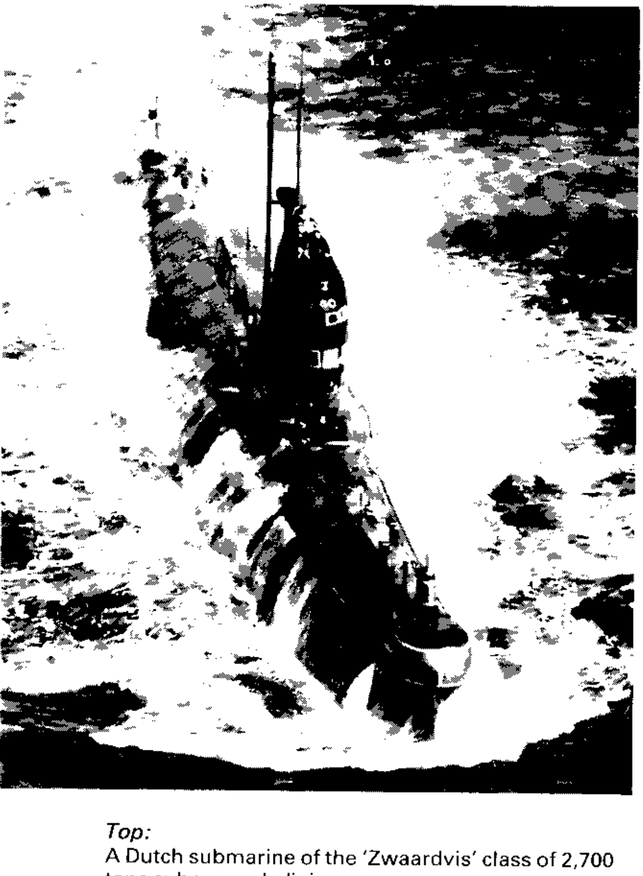
Italy

SS

Italy is maintaining its reputation as a submarine builder with eight submarines, all conventional and all built by Italcantiere. Four are of the 'Sauro' class and entered service within the last five years: they are primarily for service in the Mediterranean, displacing 1,623 tons submerged, and, like the Dutch vessels, their maximum underwater speed is 20kt. The other four comprise the 'Toti' class and are very much smaller, only displacing 582 tons submerged. Italy also has two 2,700-ton







submarines of the US 'Tang' class, transferred to it by the Americans between 1952 and 1959.

Most other countries, whether NATO members or not, buy their submarines from abroad, although some of them have manufacturing facilities and buy only the design, to be manufactured by their own shipbuilders. Denmark, however, has built a few small submarines to its own design.

Outside NATO there are three major countries (apart from the USSR) which have thriving submarine design and building facilities: Sweden, China and Japan. Yugoslavia also has built six small submarines since 1957.

Sweden

SS

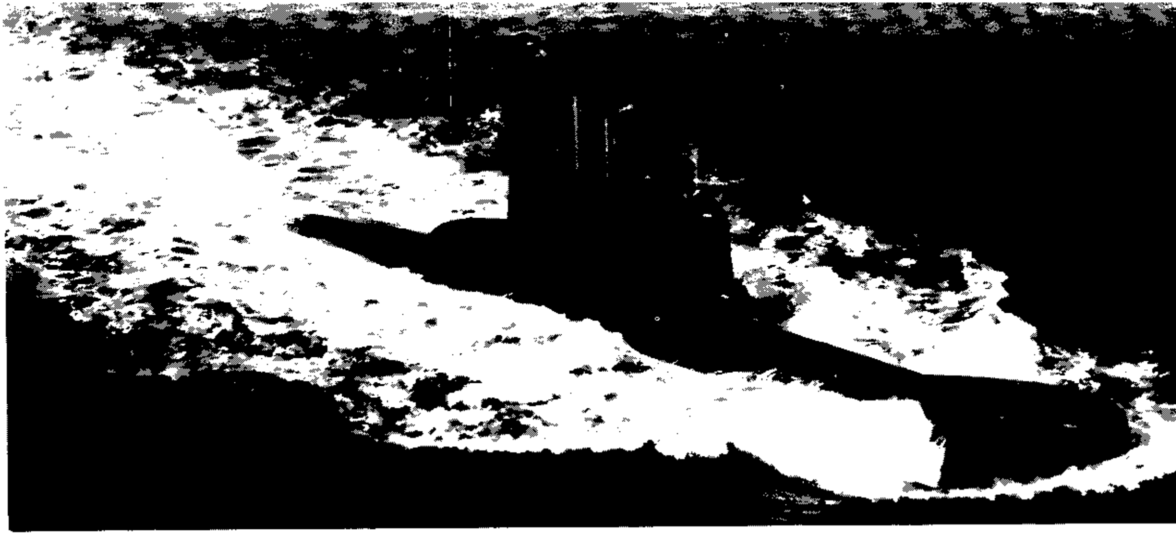
The Swedish Navy is very submarine-minded. All Swedish submarines are of conventional type and are built by Kockums, with considerable help given by Karlskrona Dockyard. The latest class is the 'Vastergötland' of four submarines, but none has yet been launched. Kockums is building the midship section and carrying out the final assembly, whilst Karlskrona is building the bow and stern sections. They will displace 1,140 tons submerged with a maximum submerged speed of 20kt.

In addition, Sweden has three 'Nacken' class

Top:
A Dutch submarine of the 'Zwaardvis' class of 2,700 tons submerged, diving.

Above:
A Soviet 'Foxtrot' class submarine seen on patrol. 'Foxtrots' have been sold to Cuba, Libya and India.

Right:
HMAS *Oxley*, a Royal Australian Navy 'Oberon' class submarine built in the UK.



Above:
An Israeli 500-ton conventional submarine built by Vickers to a German (IKL) design.

vessels commissioned in 1980-81, and five 'Sjoormen' class commissioned in 1968, all home built. Both types are around 1,200 to 1,400 tons submerged.

China

SSBN
Unfortunately very little is known about Chinese submarines. They are believed to have built two SSBNs of the 'XIA' class and are expected to build more. The class will carry 14 to 16 Chinese-built nuclear ballistic missiles with a reported range of 1,800nm; some test firings are known to have been carried out.

A diesel-propelled strategic missile submarine, appearing to have three launch tubes in the conning tower has been sighted, and this may be an experimental prototype.

SSN
The Chinese are supposed to have built no less than 76 'Han' class SSNs of around 5,000 tons submerged. They were the first nuclear craft to be built in China and construction apparently began about 1971. They were reported by the Chinese press to have taken part in exercises in late 1980 or early 1981. Details of their armament are not known.

SSN
There are some 100 conventional submarines in the Chinese Navy. They are of the Soviet 'Romeo' and 'Whiskey' design and some were obtained from the USSR, but most are copies built in China.

Japan

SS
The Japanese submarines are all conventional. There are three classes — 'Aroschio' (two boats), 'Ususchio' (seven boats) and 'Yuuschio' (nine boats). All are of about 2,500 tons, double hulled and capable of 18-20kt submerged. The oldest vessels are the 'Aroschios', launched in 1967-68, and they are now being faded out. All were built in Japan by Kawasaki and Mitsubishi.

Markets
With some 31 countries buying submarines from abroad, it will be seen that there is potentially an enormous market for submarine builders, particularly those that can design and build relatively small, not too sophisticated boats. The building yards are well aware of this and their salesmen will be found throughout the maritime world.

2 Submarine Roles

The Ballistic Missile Submarine (SSBN)

In NATO the role of the ballistic missile submarine is to deter an enemy from the use of strategic nuclear missiles of any sort. The modern theory is that should the Soviets launch a nuclear strike against the USA, it would probably be launched at the strategic nuclear weapons silos on land and might conceivably knock them all out. If this did occur, it would prevent the USA from launching a second strike against the USSR were it not for the SSBNs. Similarly pre-emptive nuclear strikes against Britain and France would be replied to by British and French SSBNs.

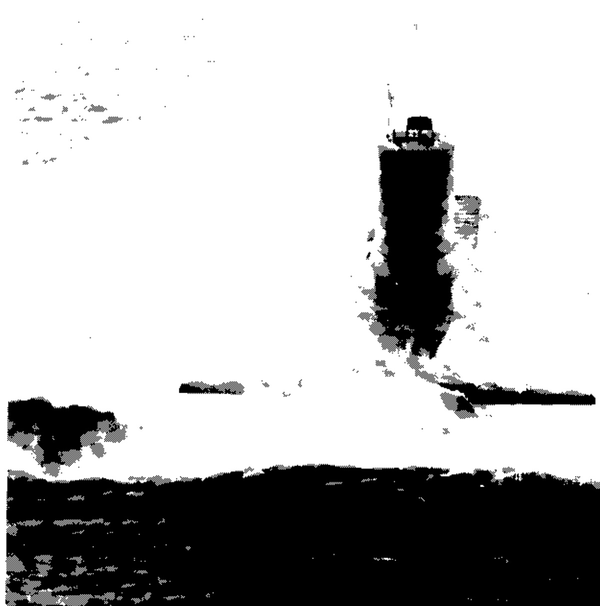
To guard against a completely unexpected Soviet nuclear strike, the USA, Britain and France all keep some SSBNs at sea in peacetime, day in, day out, year in, year out. How many deterrent submarines are on patrol at once is kept secret: America has 34 SSBNs, Britain has four and France has six. Britain makes no secret of the fact that it always keeps one SSBN on patrol, and France has announced that it will keep three on patrol. Working on these figures it seems reasonable to guess that the USA could keep between seven and 17 on patrol. However, even if it is only seven, it would mean that the USA has over 100 missiles targeted on the USSR at all times, and most missiles carry between eight and 14 warheads, each having the equivalent power of between 50 and 200kT of TNT.

The first nuclear weapon ever used (on Hiroshima) was only of 20kT, but the damage done was colossal. Out of a population of 300,000, 78,000 were killed, 84,000 were seriously wounded, and 124,000 were badly shocked or slightly injured. Numerous others suffered radiation sickness and many of them have since died of the effects. It is obvious, therefore, when the smallest nuclear warhead in the American armoury is of 50kT, that seven American SSBNs alone have the power of inflicting unacceptable damage to the Soviet Union. Even Britain's one submarine with 16 missiles and at least 32 warheads, and France's three submarines with 48 missiles all carrying 1mT warheads, would devastate an enormous area of the USSR. The Soviets must feel that to start a nuclear exchange by bombing either the US, or Britain, or France would be sheer suicide. Further they cannot be certain that a nuclear strike on other European countries would not provoke a British, French or US response.

It is the SSBN deterrent which NATO hopes will always be sufficient to prevent any nuclear strike by the Soviet Union. Of course, the USSR has nearly 70 SSBNs itself and they similarly constitute an enormous deterrent to any nuclear adventure on the part of NATO.

What then is the exact role of the SSBN in peace and war? In peace the SSBN's duty is to patrol the high seas, always ready to unleash its deadly missiles. Each patrol lasts some six to eight weeks and every man on board knows that at any time he may be called upon to carry out his task, however small it may be, to ensure that the missiles are correctly launched.

All Western SSBNs have two crews, one on patrol and the other resting or on refresher courses and training at the SSBN's base. The patrols are turned over at sea so that there is never a moment when the nuclear deterrent guard is dropped. On patrol, the submarines do not remain stationary but move along their patrol line very slowly (3-4kt) to ensure that they make as little noise as possible



Above:
Missile hatches on board the USS *Sam Rayburn*, a 'Lafayette' class SSBN. Sixteen missiles are carried in this class.

Below:
The British SSBN *Resolution* bows-on.

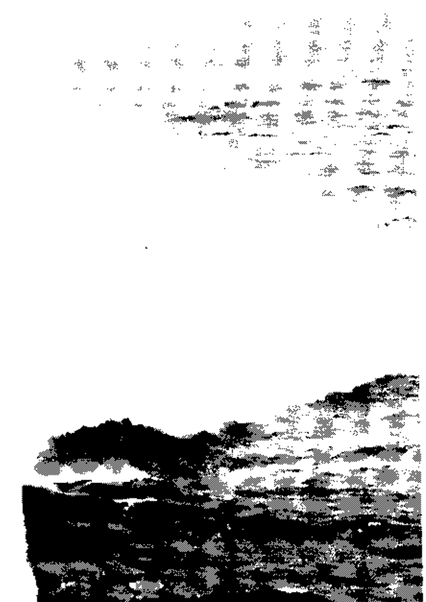
Below right:
The commanding officer of a British SSBN takes a very rare look through the periscope.

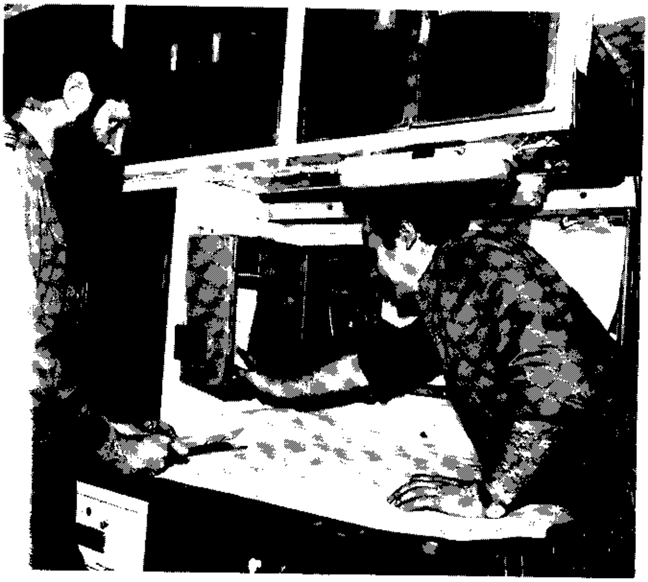
in case an enemy submarine is listening. Where the patrol lines are is never disclosed and even the crew on board have no idea where they are. All that we do know is that as missile ranges are improved, the farther away from the Soviet coastline can be the patrols. Trident missiles now have ranges of up to 5,000nm, and the distance between the East Coast of America and Moscow and many other Soviet cities is between 4,000 and 5,000nm, so the Trident submarines need not patrol very far out to sea. By the same token, the distance from the Soviet naval base at Murmansk to New York is about the same, so the Soviets with their newest submarine-launched ballistic missile (the SS-N-20, which has about the same range as the Trident), can patrol just off their base and still threaten the USA's most famous city.

However, in spite of all this, NATO still has a problem. Normally British and French submarines patrol in the Atlantic only, and many of the Soviet Union's major cities and military bases are still outside the range of missiles launched in the Atlantic, so the USA keeps SSBNs patrolling in the Pacific. It would not be surprising also to find some American SSBNs in the Indian Ocean to cover the southern part of central Russia. Therefore, with only seven SSBNs on patrol the American nuclear force is well stretched.

SSBNs are given the positions of their targets before they leave harbour — indeed all the major Soviet targets have been long decided upon and their positions entered into computers on board the submarines. Targets can be changed during a patrol by signal from the shore.

The submarines dive soon after leaving harbour and proceed to their patrol positions; they remain





Left:
Two officers on board a British SSBN removing the authentification codes from their safe in order to determine whether a firing signal just received is genuine or not.

dived throughout the entire six- to eight-week patrol period. They certainly, however, come up to periscope depth at intervals to expose their satellite receiving antennas, but again in theory they never transmit to the shore. If necessary they can receive signals from the shore without exposing anything.

Chapter 13 gives some idea of what it is like to be cooped up in a submarine over long periods, but the boredom is relieved from time to time by exercising the launching of missiles, when all the launching procedure is followed, except of course the actual launch.

SSBNs are also fitted with torpedo tubes. In wartime, torpedoes might well be used against a shadowing submarine; in addition, when all missiles have been expended, it enables the SSBN to act as an SSN, should the war still be continuing. Torpedo attacks are therefore also exercised, again without actually firing the torpedoes.

Missile Launch Procedure

The very greatest care is taken to avoid the launching of a nuclear missile by mistake, or because of false orders passed by signal to a submarine by the enemy in order to justify a vast nuclear bombardment of the West. The launch procedure relies on numerous checks, double keys and highly secret methods of authenticating signals. The following is as much of the British procedure that is allowed to be published; it is probable that similar procedures exist in the American and French systems.

The start of a missile launch sequence is the receipt in the radio office of a signal from the shore, prefixed FLASH, the highest degree of priority. The operator on watch, on seeing it, announces over the main public address system, 'There is a FLASH message for us'. A few moments later, when he has had time to scrutinise the message, he will add, 'the FLASH message is a firing message'. The Officer of the Watch then orders 'Action Stations Missiles' and the crew proceed to their assigned stations.

The FLASH message contains a group of codes, which are not decoded in the radio office but are handed to two officers specially detailed for the job of decoding, usually the Executive Officer and the Weapons Engineer Officer (WEO). The codes contain the authorisation for the message and will ensure that if it is a bogus signal, perhaps originated by the enemy or a third party, it will be recognised as such. The two officers check the authorisation with certain data held in separate safes, to which only they have access, and then report to the Captain.

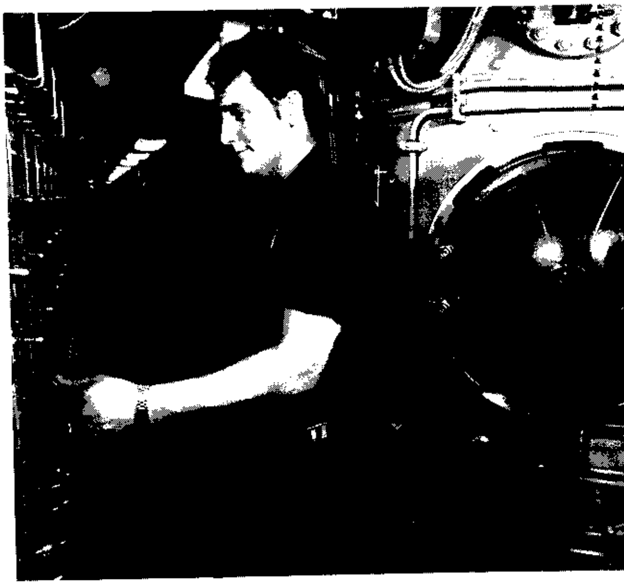
Up to this point, nobody on board knows whether it is an exercise or the real thing, but the cross checking by the two officers will indicate which it is.

Assuming that it is an exercise, the order is then passed to 'set condition XYZ, for weapons system readiness test'. Everything is carried out as realistically as possible, even to adjusting the submarine's depth, attitude, course and speed to suit a missile launch. In the missile compartment, the Assistant WEO and his technical staff prepare the missiles for launch, whilst the WEO and his team at the missile control centre, programme the numerous computers for the launch sequence. The Captain takes out of a safe two boxes of missile arming keys and passes them to an officer who takes them to the Assistant WEO in the missile compartment. There is one key to each missile tube, and until the tubes are unlocked, the missile launching system cannot function.

Meanwhile, the WEO and his Assistant receive a large number of verbal reports and watch the electronic indicators showing the readiness conditions of each tube. The WEO unlocks two small safes fitted with combination locks. In one of the safes is a black trigger assembly, which is used for exercise firings, and in the other is a similar red trigger assembly, which is used for actual launch. Both assemblies are on flexible leads and the WEO places the appropriate trigger close to his hand.

Finally, the Assistant WEO reports 'Launchers ready condition XYZ'. The WEO checks his own displays and satisfies himself that all is indeed

Right:
Checking the missile system on board the USS *John Adams*. A missle tube can be seen behind the enlisted man.



ready, and then passes a message to the Captain: 'Missiles in XYZ'. The Captain takes a key on a chain hung round his neck and places it in a keyhole in the Missile Readiness Panel, but does not turn it — the key is the only one of its kind and is kept permanently round the Captain's neck. The Captain then passes a message on the main public address system, 'WEO from Captain. You have my permission to fire.' On another internal circuit the Executive Officer calls the WEO and says, 'You have the Captain's permission to fire.' Once these two messages have been passed, the Captain turns his key which completes the firing circuit, and lights up green firing lamps in the Control Room and the Missile Control Centre. The WEO presses the appropriate trigger. If it is a real live firing the missiles are then launched automatically in succession. If it is merely a practice, various circuits are made and the missile 'fire' lights show, but of course no actual launchings take place.

The geographical launching position is taken from the submarine's navigational system and is automatically fed to the missiles, whilst the positions of the targets have already been fed to the missiles' guidance computers. It would probably take half an hour from receipt of the firing signals from the shore until the missiles are launched.

Polaris and Poseidon missiles have two-stage motors to propel them, Trident missiles have three. The following refers to Polaris and Poseidon. On emerging from the submarine the first stage motor ignites and serves to take the missile through the water and up into the atmosphere. On breaking surface the missile guidance computer is initiated and starts controlling the missile on its way. Having completed its job, the first stage separates from the missile and falls into the sea. Meanwhile the second stage motor has ignited and continues to propel the missile. Shortly afterwards, the nose fairing separates and is jettisoned into the sea, and finally the re-entry body is ejected. This takes place when the guidance computer calculates that the missile has reached a point from where the re-entry body can continue unpropelled in a normal ballistic trajectory to take it to the target, but of course warheads may be dropped off on other targets as it descends.

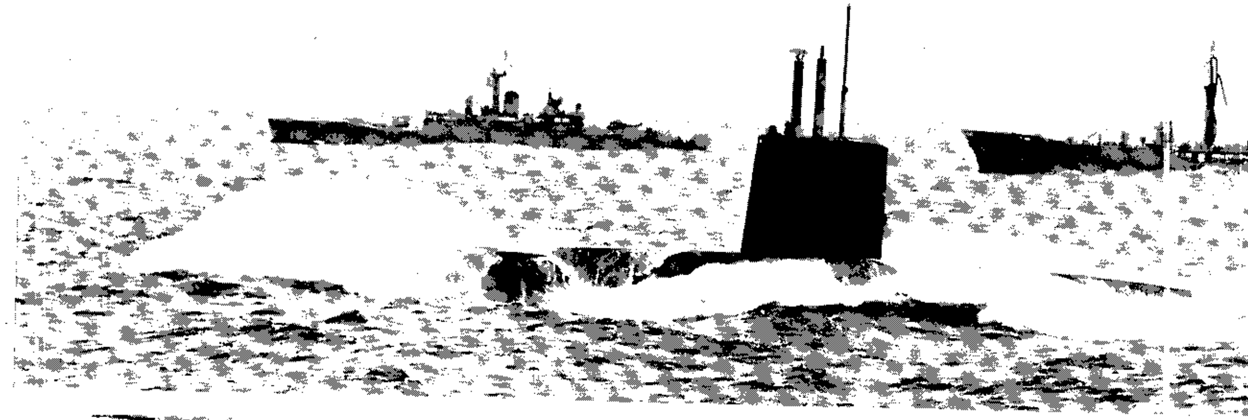
Submarine launched ballistic missiles were originally not very accurate, hence they were all aimed at large targets, such as cities. However, accuracy has improved so much in recent years that they can now be used on much smaller targets, such as missile silos (latest Trident missiles are reported to have a CEP — circle of equal probability — of 250m). It may well be that the second strike concept could be altered from attacks on cities to attacks on missile sites to prevent a third strike.

The Nuclear Attack Submarine (SSN)

The primary role of the SSN is to hunt and attack enemy submarines, and in particular enemy SSBNs. For this they are provided with the best possible sonars and underwater weapons, which, against other submarines, are usually torpedoes. Their secondary role is to attack surface craft. Up to date this has been carried out by means of torpedoes, a recent classic example being the attack on the Argentine cruiser *General Belgrano* by the British SSN *Conqueror*. In future, attacks will probably be made by submarine launched anti-ship missiles.

Given the vastness of the oceans, which cover 70% of the surface of the world, it is obviously ridiculous to send an SSN to sea to look for an enemy SSBN or other submarine. Some indication of the possible whereabouts of enemy submarines must be made available to the SSN.

NATO is perhaps fortunate that the Soviets have to transit fairly narrow channels to reach the operating areas in the open ocean. To reach the Atlantic, for example, Soviet submarines must pass between the Arctic ice and Iceland, or between Iceland and the Faroes, or between the Faroes and the UK. There is also the English Channel route, but this is so crowded and so shallow that it is a highly unlikely route for Soviet



submarines. There are similar restrictions into the Pacific from Soviet bases in Eastern Russia, and from their bases in the Black Sea into the Mediterranean.

One way therefore of finding Soviet submarines is for allied submarines to patrol these gaps, or choke points. For this the SSN, with its speed comparable or superior to that of the Soviet SSBNs, is ideal. It must however be pointed out that, with the new types of strategic nuclear weapons and the new type of SSBNs, it is possible for the Soviets to launch their submarine-borne nuclear missiles on America or Europe without passing through any of these gaps.

Another obvious place to find enemy attack submarines is in the vicinity of important allied surface targets. These may be convoys, task forces or highly valuable ships such as aircraft carriers. Such targets are very attractive to enemy submarines of both the SSN and SS types, and therefore constitute one obvious place in which to deploy friendly submarines. It is, for example, possible for a convoy or task force to have with it one or more SSNs. They would remain continuously submerged and can be stationed by the Officer in Tactical Command in the direction in which he thinks enemy submarines might attack. Alternatively, they can be stationed beneath the convoy/task force and directed out to attack when a distant submarine contact is made by other means, perhaps an aircraft.

There are, however, problems. The noise made by the ships of the convoy/task force means that the noise made by an attacking submarine may not be heard by the SSN under the force until it is too late. Equally though, the attacking submarine may not know that there is an opposing submarine under the force at all, at least until it is well clear of the surface ships.

There are of course many roles for which SSNs can be used. Admiral Sir John Woodward, of Falklands fame, and later Flag Officer of all British submarines, listed their possible roles as follows:

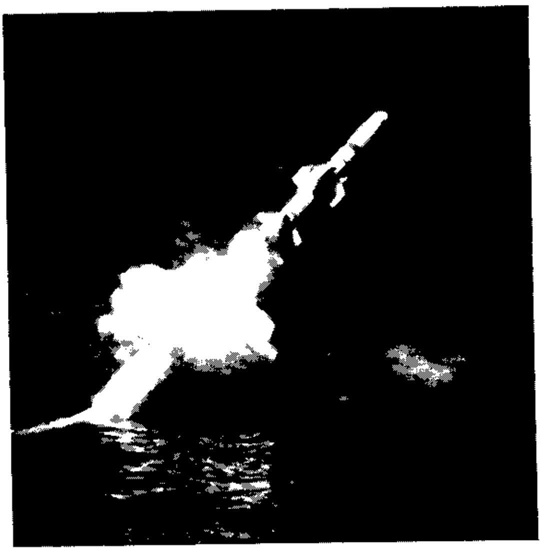
a Protection of sea lines of communications, including support of convoys and maritime task groups.
b Barrier or choke point operations.
c Mining.
d Special Forces operations.
e Surveillance.
f Forward defence.
g Deterrent support.
h Anti-surface vessel warfare.

The final role quoted is of course still highly important, but SSNs are fitted with torpedoes primarily designed for use against other submarines. For a number of reasons, such torpedoes are not very satisfactory for use against surface ships. However, as already mentioned, with the coming into service of the submarine launched anti-ship missile, whose range is greater than that of the torpedo, the majority of attacks will no longer be by torpedo.

Finally, the high speed of SSNs is a great advantage whilst actually carrying out an attack against a fast nuclear. It also means that the times taken to get out to, and return from, the patrol area are very much shortened, which in the long run means that the size of a submarine fleet can be reduced.

Above:
One role of a modern SSN is the support of convoys and task groups. This is the nuclear-powered fleet submarine, HMS *Warspite,* seen in the Indian Ocean in 1974, in company with a frigate and a Royal Fleet Auxiliary tanker. Normally the submarine would be a little less conspicuous!

Left:
HMS *Conqueror,* a 'Churchill' class SSM with six 21in torpedo tubes. It was this submarine which sank the Argentine cruiser *General Belgrano.*



Above:
The submarine manoeuvres to attack.
(Watchkeepers on the planes and rudder on board the USS *La Jolla,* a nuclear-powered attack submarine of the 'Los Angeles' class.)

Left:
Missile fired.
(A McDonnell-Douglas Harpoon anti-ship missile breaks the surface after being launched from a submarine. Britain has bought the missile for use by its submarines.)

Below:
Target destroyed.
(In this case the old RN frigate HMS *Rapid,* sunk in 1981 by torpedoes fired by HMS *Onyx.)*

Typical Sequence of Events of an SSN Attack

The following shows, in an abbreviated form, a typical sequence of events of an SSN fulfilling two of its main roles — attacking another submarine and attacking a surface craft.

Event	*Remarks*
Signal received from shore operating authority: 'Enemy submarine located in position . . ., course . . . speed. . . . Search and destroy. She may be accompanied by surface ships'.	
Navigator recommends course to intercept. Captain orders new course and speed: 'Steer 040. Revolutions for 16kt'.	Sonar commences listening watch on passive equipment.
Captain to Weapons Engineer Officer (WEO): 'Bring all tubes to the action state'.	The torpedo tubes are got ready in the weapons compartment.
Sonar operator to Officer of Watch: 'Contact bearing 035°'. OOW reports to Captain.	No range can be given as yet as the sonar is not in active mode.
First Lieutenant over main public address broadcast system: 'Assume ultra quiet state'.	Certain machinery configurations are made to ensure less noise. Crew move silently about their business.
Captain to control room and sonar: 'Start tracking'.	Sonar commences passing bearings to the Tactical System. Boat is manoeuvred to enable computer to work out range.
Captain orders: '10 down. Keep 260ft'.	The Captain is selecting the best depth to suit sonar conditions.
Navigator (who is also the operations officer) to Captain: 'Computer makes enemy's course 210, speed 18, range 20,000yd.'	The computer has worked out from the series of bearings the enemy's course, speed and range.
OOW on main broadcast: 'Watch stand to'.	SSNs have a large enough crew to carry out an attack using one watch only. Conventionals would go to Action Stations, which would involve everybody.
Attack Co-ordinator at Tactical Table to Captain: 'We are in a firing position, Sir'.	
Captain to WEO: 'Proceed with firing sequence'.	The firing sequence is controlled by the computer after initial order to Fire.
WEO then passes orders to the tubes crew in the weapon compartment at the fore end of the boat, such as: 'Tubes to readiness'; 'Open bow caps'; 'Firing drill'.	Opening the bow caps will allow sea water to enter the tubes. The firing drill ensures that the correct tubes to use have been inserted in the fire control system.
WEO to the fire control team' 'Fire'.	The fire control team is in the control room. The computer shows the right moment to fire the torpedoes and controls the firing sequence. On the order Fire, an operator presses a button which starts the firing sequence. Not all the torpedoes would be fired, in this case probably only two. The wire guided torpedoes are guided by a computer under the supervision of a fire control operator, who also switches each torpedo to self homing when they have acquired the target.

Sonar to Captain: 'Target achieved, Sir'.

The sound of the explosions can be heard in the control room if the target is close enough. If it is too far away, the sonar operator will hear it.

Tactical System Officer to Captain: 'There appears to be a group of "skimmers" behind that submarine'.

The sonar operator has heard the noise of surface ships and has started tracking them, passing the bearings to the Tactical System.

Captain to Control Room: 'We will attack by Sub-Harpoon. I am going to have a look at them. 10 up, keep 70ft. Up periscope'.

The Captain decides to attack the largest ship, using the Sub-Harpoon anti-ship missile fired from a torpedo tube. He decides to look at the ships, both to confirm that they are hostile and to try and identify the largest ship. Sub-Harpoon can be fired on sonar bearings or by use of the periscope.

Captain to control room: 'Down periscope. A carrier and three or four escorts. I am going to attack the carrier'.

Captain to Sonar: 'One ship is a carrier, can you pick her out?'

Sonar to Captain: 'Afraid not, Sir, there are too many contacts to be definite'.

Captain to control room: 'I am going to attack by periscope'.

The Captain will take a number of quick looks through the periscope and each time he is on the carrier he will press a button which will transmit the bearing of the carrier to the tactical system. Similarly he will take ranges of the target. He also calls out to the control room so that they can record the bearings and ranges.

Captain to control room: 'Bearing is . . . that'. 'Range is . . . that'.

The bearings and ranges when he calls 'that' are read off indicators in the control room.

Captain to WEO: 'Fire when ready'.

WEO to Captain: 'Missile fired, sir'.

Only one missile is being fired and the WEO will press the firing button when he is satisfied that he has enough information about the target's position, course and speed.

Captain to control room: 'Up periscope'.

The Captain looks to see if the target is hit. Alternatively he may rely on the sonar to tell him if an explosion has occurred.

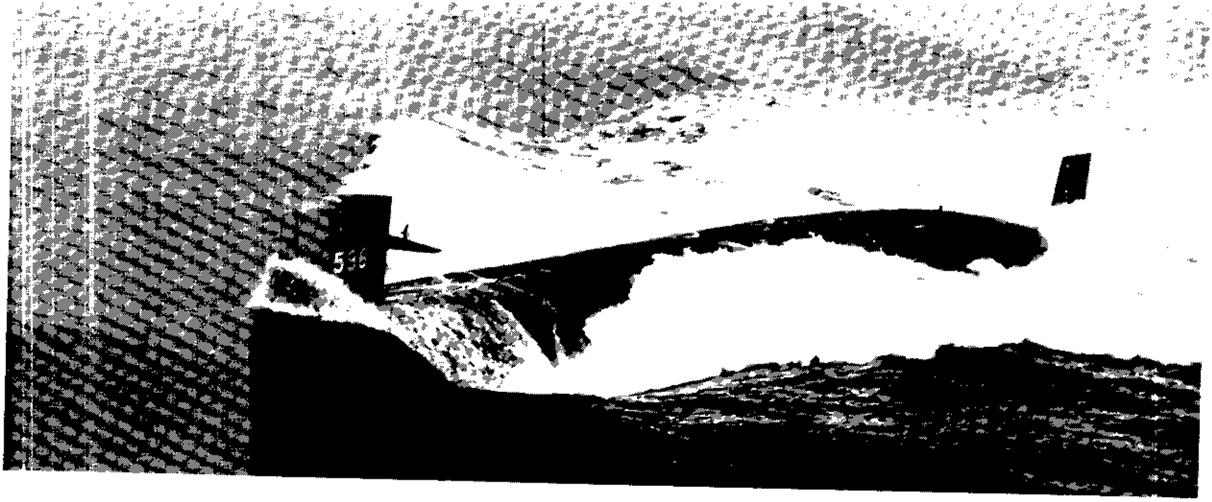
Captain to control room: 'Down periscope. We've got him. Steer 180. 10 down. Keep 400ft. Revolutions for 20kt'.

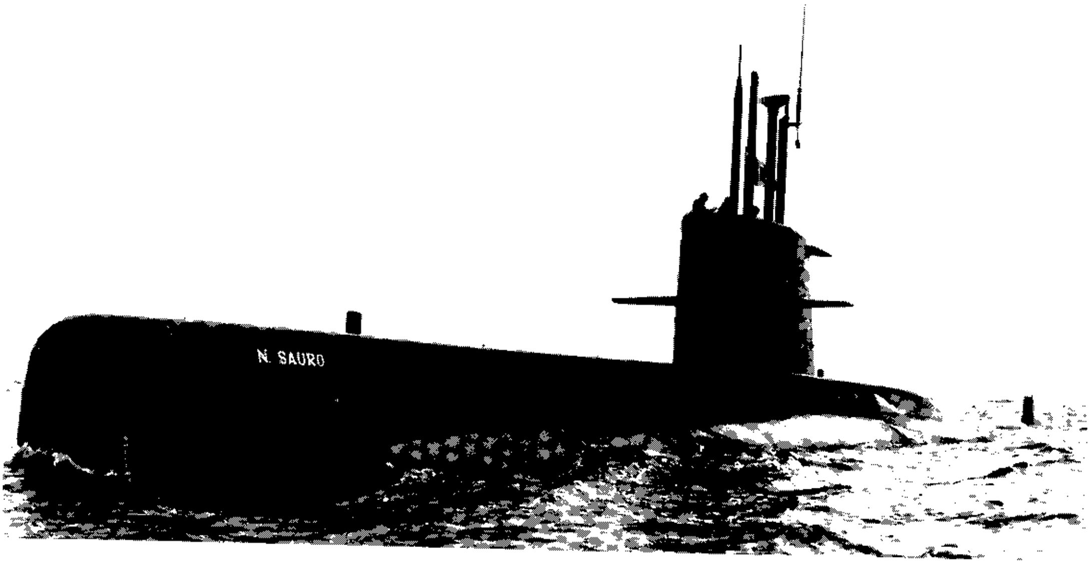
Captain on main broadcast: 'Clear the datum'.

This means, 'Let's get out of here'.

Captain to Marine Engineer Officer: 'Bring the plant to full power'.

The Captain cons the boat on to the best course to clear the area and goes deep in case of counter-attack. As soon as he can, he will increase to full speed. Quietness is now no longer necessary. It is doubtful if any surface ship will be able to catch him, but attack by helicopter or fixed wing aircraft is possible.

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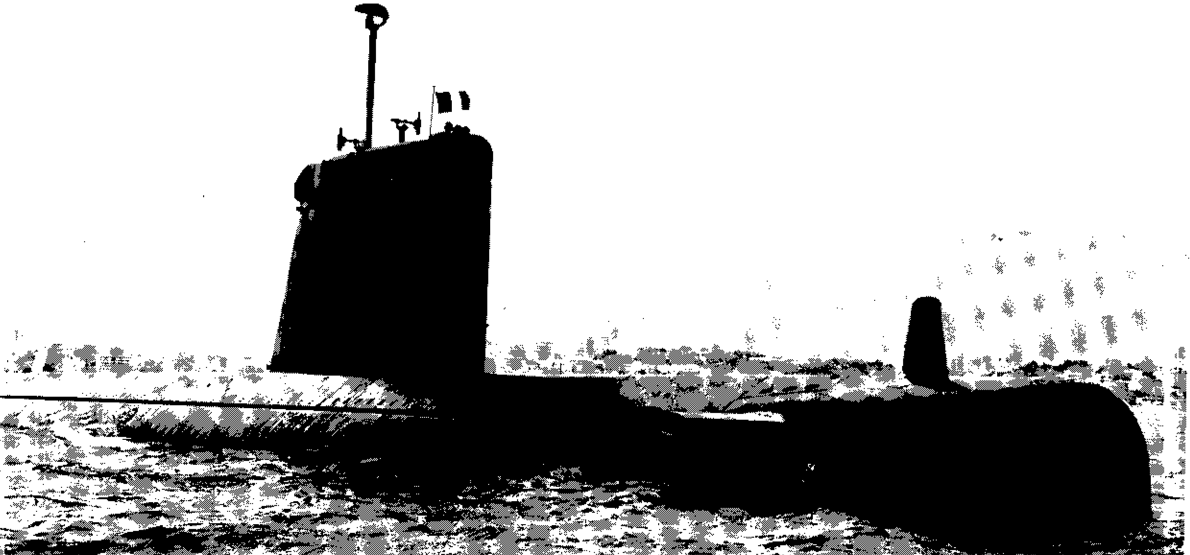


The Conventional Submarine (SS)

Conventionals can carry out most of the roles mentioned for SSNs, but for some of them with a diminished capability. However, they are undoubtedly very useful craft. They are considerably cheaper to build and operate than nuclears, but of course as yet they do not have the submerged endurance of the latter, neither are they so fast. This lack of speed in a conventional can be a very limiting factor, as is also the fact that they have to raise their snorkels every so often to suck in the air required by the diesels when charging the batteries. A snorkel can be detected by radar, thus during the period it is raised, the submarine can be said to be at risk. This risk period (often known as the indiscretion period) is normally expressed as a percentage of the total time submerged: a typical figure might be 7%. A submarine must always bear in mind that having snorted, it may have been detected by an aircraft or ship's radar, so it is undesirable to snort again for some time in case the detecting craft is still in the vicinity.

In fact, most conventional submarines can go for quite a long time without snorting at all. For an average ocean-going conventional submarine, the cruising range submerged at economical speed (about 5kt) before having to snort can be as much as 500 miles, or 100 hours, but on completion the submarine would have to snort for seven hours to recharge its batteries fully.

Compare this with a nuclear submarine. It can virtually choose what submerged speed it likes on passage, but in order not to make too much noise would probably restrict it to 10kt, so its time on passage to, say, its patrol area could be half that of a conventional. Further, it would be able to proceed at its full speed of, say, 30kt immediately on arrival on patrol for as long as it wished, as opposed to the conventional whose time at full speed, without being at risk by snorting, would be severely limited by the capacity of its batteries.

Another point about speed is that on a barrier patrol, with perhaps only a few submarines available, the first information the submarines would get of an approaching hostile submarine might come from intelligence or from a detection by a maritime patrol aircraft, patrolling some distance in advance, ie towards the likely approach route of the enemy. The aircraft report might show that the hostile submarine was making for one end of the barrier, and it might be that the nearest friendly submarine was at a considerable distance off the hostile's track. High speed would then be essential to make an interception.

It follows that if only conventional submarines were used on a patrol line, it would require many more submarines than if nuclears had been used. In addition it might be necessary to put the aircraft patrols farther from the submarines, in order to give earlier warning. The earlier the warning, however, the more chances there are of the hostile making evasive alterations of course. Yet again, if the aircraft were able to track the hostile all the way, the patrol submarines should have no difficulty in getting into a position where their own sonars could detect the intruder.

Conventionals are often used in conjunction with nuclears on barrier patrols for a number of reasons. Their battery-driven electric motors are quieter than the steam turbines on the nuclears. They have smaller and narrower hulls which are more difficult for active sonar to detect than the larger, somewhat bulbous hulls of nuclears and, as mentioned, they are cheaper to operate.

Conventional submarines would not be used to accompany convoys or task forces, because they would be unable to keep up with them, but they might be used to patrol convoy lanes in dangerous areas. Assuming that they are able to expose their snorkels (without undue risk) reasonably frequently, a conventional's endurance might be as much as 9,000nm. The figure is largely governed by the amount of fuel that can be carried.

Conventionals are not so strongly constructed as nuclears and are thus unable to carry out really deep dives. For example, the US 'Los Angeles' class of SSNs has an operational diving depth of 450m, whilst the British conventionals of the 'Oberon' class can only achieve 350m. In both cases, however, this does not mean that they could not go deeper in an emergency. In fact nuclears could probably go down to 1,000m without collapsing. The figure for conventionals would be considerably less.

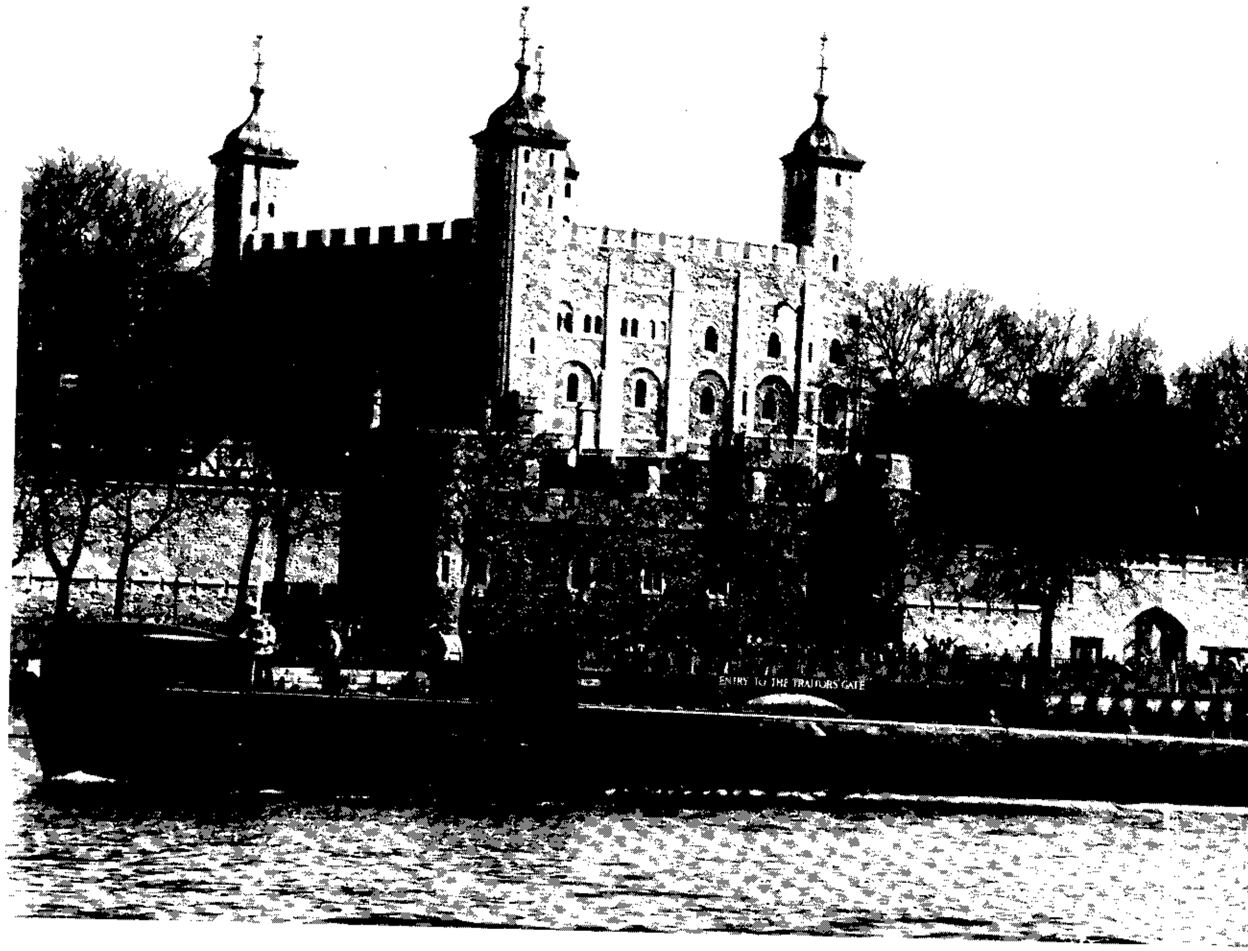
Top left:
The USS *Barb*, one of the 'Thresher' class of SSN, seen diving.

Centre left:
The conventional submarine *Sauro*, nameship of four submarines of 1,500 tons built by Italcantieri for the Italian Navy.

Left:
A French conventional submarine of the 'Agosta' class. She displaces 1,726 tons submerged and has a maximum submerged speed of 20kt.

Small Submarines

Many nations do not have large conventional submarines of, say, 1,600 tons or more, capable of operating in the wide ocean, with high endurance and good sea-keeping qualities. A great deal depends upon the depth of water in which they are



likely to operate, the tasks they are likely to have to perform, and of course the amount of money available. Small submarines vary between about 430 tons and about 1,200 tons. The leading operator is West Germany which has eight conventionals of the '205' class, displacing 450 tons submerged, and 16 of the '206' class, displacing 480 tons. It has also sold similar sized submarines to Norway, Greece and Ecuador.

Although so small, these submarines manage to pack in quite a considerable torpedo armament, most having at least eight full size (21in) torpedoes. The submarines are primarily for use in enclosed and shallow waters, such as the Baltic and Norwegian Fjords. They are ideal for coastal patrols and to lie in wait in entrances to ports or other strategic points. They can be used for clandestine reconnaissance or to land spies or saboteurs and for minelaying. They carry crews of around 22 men.

These 500-ton submarines are at the lower end of the normal submarine scale, but there are many nations which use medium size submarines of between 1,000 and 1,600 tons, most of them German-built.

Above:
HMS *Osiris*, a British conventional submarine of the 'Oberon' class (2,450 tons submerged, maximum speed submerged 17kt), seen here arriving in the Pool of London in April 1984. Note that the forward planes are folded when not in use.

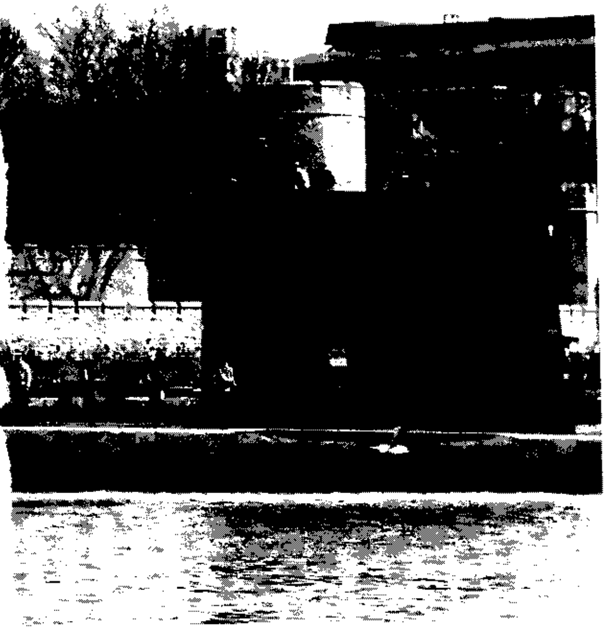
Right:
A German submarine of the '206' class. These are small conventional submarines of 498 tons submerged.

Midget Submarines

Finally we come to midget submarines. Although not included in the list of modern submarines in Chapter 1, these submarines played a very important role in World War 2 and it seems possible that they might be of use in any future conflict, particularly a somewhat limited one. In spite of this they have been badly neglected since the war.

There is no official definition of what constitutes a midget submarine, and the term pocket submarine has also come into use, meaning a very small submarine, which tends to complicate matters, However, a midget is generally taken to be the smallest possible type of submarine, capable of holding a crew of not more than about four, whilst a pocket submarine is somewhat larger — certainly over 100 tons — and with a crew of five or more.

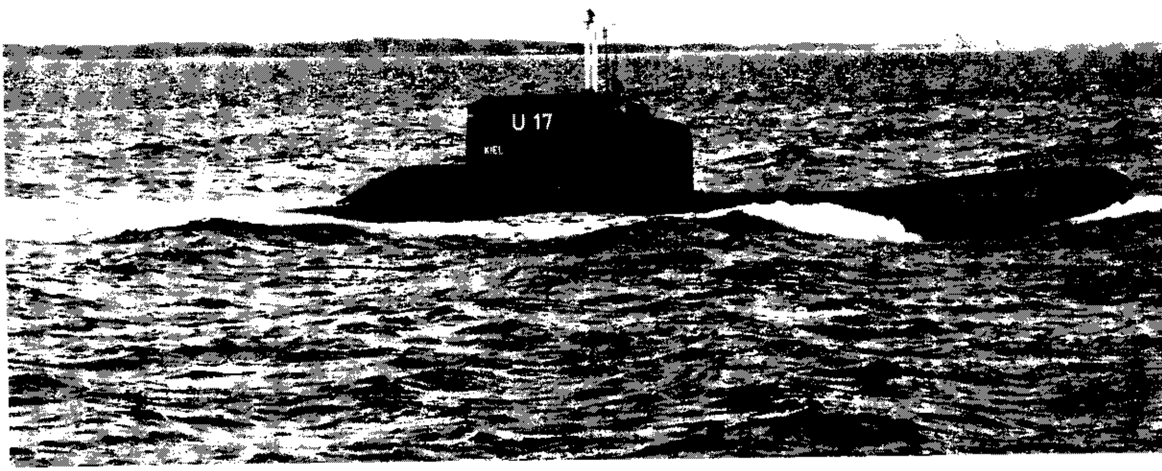
In World War 2, the Germans, Japanese, Italians and the British all used midget vessels. The Germans had by far the largest number, 971; the Japanese had 391, the Italians 26 and the British 23. The Japanese used their craft for attacking warships in harbour, including the famous air and submarine attack on Pearl Harbour. The Italians had few successes, although they had planned to attack the British base at Freetown in West Africa and more ambitiously, New York harbour: the Freetown operation was abandoned as being too difficult and the Italians capitulated before the New York attack had been attempted.

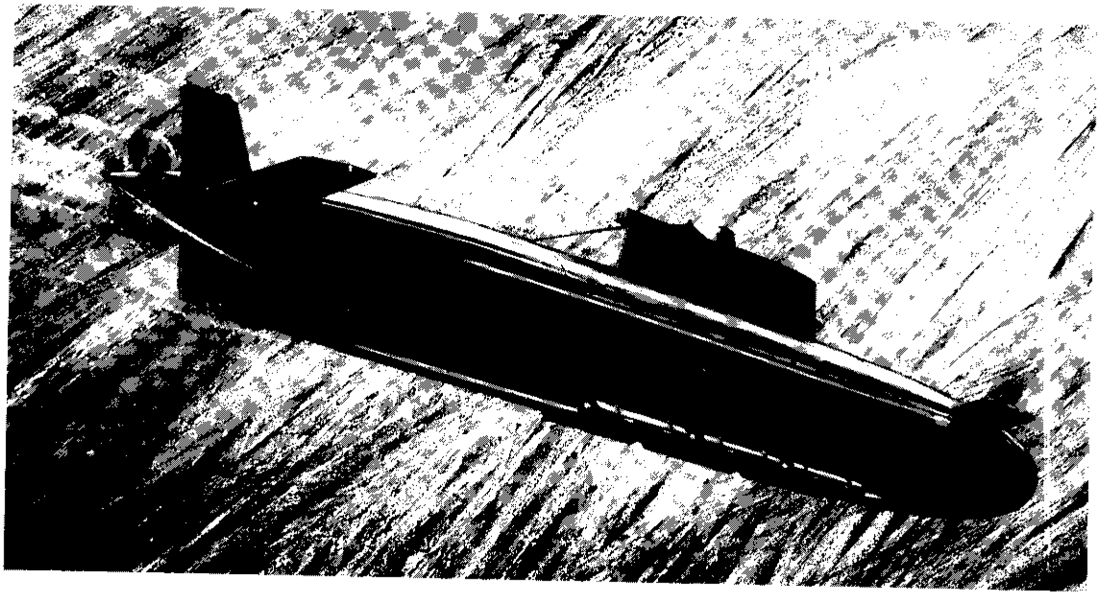


The Germans used their midgets in massed attacks on shipping in the Channel and North Sea, but had little success. Although they did not sink many ships in their operating area — the North Sea — the 14.7-ton 'Seehund' class constituted an annoying threat to allied shipping towards the end of the war.

The British 'X' craft succeeded in putting the German battleship *Tirpitz* out of action in Kaa Fjord in Norway on 22 September 1943; *Tirpitz* remained out of action until March 1944, and was finally sunk by RAF bombs on 12 November 1944 at Tromso.

Although midget submarine operations were highly dangerous and, because of their limited





endurance, they had to be towed by other submarines to the scene of action, there is no doubt that they achieved some significant success, which makes it all the more strange that so few midgets have been built for military purposes since the end of the war, particularly as quite a number of commercial midgets have been built for underwater operations in connection with oil exploration.

Yugoslavia has built a few two-man midgets and has sold two of them to Libya, and North Korea is reported to have some sort of 'X' craft. The UK has no requirement for them, but Vickers of the UK has designed the most sophisticated and ambitious midget — or rather pocket — submarine yet seen, called *Piranha*. Vickers has spent some time on the design, but so far has not sold it to any country.

Piranha is a 26.6m long, 150-ton submarine with a submerged and surface speed of 9kt and a crew of seven, but with room to carry up to 10 passengers, Commandos or Frogmen. Her operating depth is 100m and she can carry six ground mines or alternatively two 'chariots', which are two-man diver transport vehicles. The men take with them limpet mines or explosive charges to lay beneath ships' hulls. Access to and from the submarine when submerged is by two divers' lock-outs, one for the crew and the other for the Commandos or Frogmen.

Piranha is a conventional submarine in all respects except that it is much smaller than is normal. It can be directly driven by its diesel when snorting or on the surface, and has a motor generator by which it is driven when submerged, and can also be driven by it when on the surface.

Above:
Artist's impression of the Vickers-designed pocket submarine *Piranha*. So far the design has not been sold. She displaces 136 tons and can carry a crew of seven and 10 Commandos.

Vickers claims that *Piranha* is very quiet submerged and highly manoeuvrable, difficult to detect by sonar (because of its small size), and very suitable for shallow water operation. Another point in *Piranha's* favour is that it has an excellent endurance for so small a craft — 1,870nm continuous snorting and capable of 4kt for 70nm when fully submerged.

The role of midgets would undoubtedly be clandestine attacks on warships at anchor or alongside in harbour. They could also be used for the destruction of floating docks and wharfs and for the landing of spies or saboteurs, clandestine reconnaissance and minelaying.

Whether there would be any call for such operations in a modern East/West war is uncertain because the Soviet naval bases are mostly a very long way from NATO bases, and to get the midgets into the operational areas would be a major task. However, the Soviets have apparently recently deployed a number of small or even midget submarines in the Baltic, particularly in the Swedish archipelago. Quite what they have been doing there is not clear, but probably they have been practising carrying out some form of surveillance, or underwater charting, with the possibility of bottling up the Swedish Fleet in the event of hostilities. Occasionally Soviet submarines have also been detected in the Norwegian fjords.

3 Submarine Design and Construction

In World War 2 submarines needed to spend a high proportion of their time on the surface. They also had to be designed to cope with rough weather likely to be found on the surface. Thus they had long hulls, which were able to make passages in rough weather, and were conducive to high surface speed but not to high submerged speed. In the Atlantic in World War 2 the German U-boats frequently attacked on the surface in 'Wolf Packs', which emphasised the need for designs with high surface speed.

Today the pendulum has swung. Submarines spend little time on the surface and most are designed for higher underwater speed than that attainable on the surface. As a result the shape of their hulls has changed. It has been found that the relatively short, bulbous nose type, tapering to a narrow end aft (the 'tear-drop' shape) is a better form of streamlining when submerged. The reason is that the length to diameter ratio is smaller and this reduces the hull surface presented to the sea and thus the skin friction. This in turn means higher underwater speed for a given power.

Fundamental to the operation of any submarine are the ballast tanks which provide the means for it to submerge and to surface again. In modern single hull boats the ballast tanks are usually situated forward and aft in the free flooding space between the pressure hull and the casing. In double hull boats the ballast tanks are placed between the inner and the outer hulls.

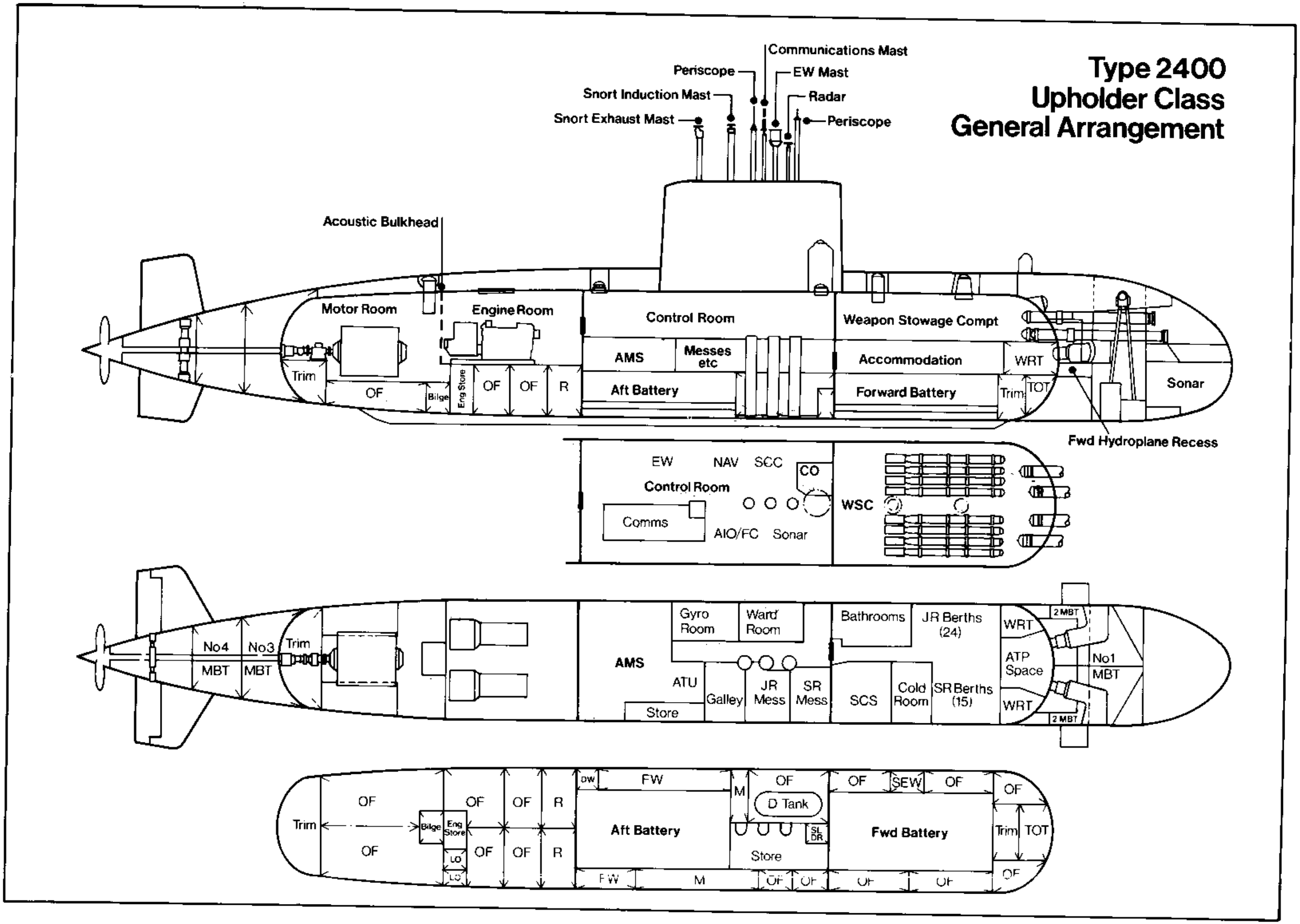
Submarines are built of a pressure hull strong enough to withstand the pressure of a sea down to (sometimes) considerable depths. In addition to the pressure hull there is an outer casing, which forms a deck on which to walk when on the surface and to get access to the outside of the submarine — for example, for boats coming alongside and for mooring to jetties. The casing normally extends forward and aft of the pressure hull and in the space formed between the casing and the ends of the pressure hull are compartments. The forward one usually contains a sonar transducer, the ballast tanks and the torpedo tubes. The anchor and cable are also stowed there. The after compartment contains the propeller shaft, the remaining ballast tanks and the rudder controls. The whole of the casing and the two compartments formed by it are open to the sea, so the casing does not need to be anything like as strong as the pressure hull; holes to enable the water to enter and drain out are of course essential, but they do constitute a significant drag on the craft's underwater speed.

From the strength point of view, an ideal pressure hull would be a sphere, and indeed very deep-diving experimental and oceanological submersibles are built to this shape. However, a submarine has to move through the water and a sphere would be impracticable, so instead the pressure hull is made tubular in shape and is built round a series of concentric frames. Construction of the pressure hull is a very specialised business and is done by making small sections of it at a time, in the shape of circular rings. Usually five or six of these rings, called 'hoops' by constructors, are first welded together to form a short tube, perhaps 3m long. More sets of hoops are then built on until an entire section of a pressure hull has been completed. Towards the ends of a complete pressure hull its diameter is reduced and finally each end of the hull is closed by toroidal or hemispherical cones.

On top of the pressure hull, and forming part of it, is welded the conning tower; the navigating bridge, for surface use, is on top of that. Around the conning tower is built the fin. It has an oval cross section and through it pass the periscopes and the masts. It is free flooding, but water is prevented from entering the conning tower by a hatch at the top of it, and it is the duty of the last man off the bridge before diving to make sure that it is securely shut.

Of course various holes have to be left in the pressure hull for escape and access hatches. There is a large access hatch forward through which torpedoes are lowered into the torpedo compartment. One torpedo is loaded from there into each tube and the remainder are stowed in the torpedo compartment as spares. In addition, in a SSBN the missile tubes must penetrate the pressure hull. They are fitted with hatches on top of them to prevent water entry. The hatches are opened from inside the submarine before the missiles are fired, leaving a thin diaphragm at the top of the tubes, which the missiles penetrate when fired and the sea pours in and replaces the missile.

Type 2400 Upholder Class General Arrangement



At the bottom of the pressure hull in submarines which may have to lie on the sea floor (usually conventionals only), is a ballast keel running the whole length of the pressure hull. In the keel are a number of compartments, some open to the sea, others enclosed. In the free flood sections are put lead weights which can be removed (a dockyard job) if, for example, some additional heavy equipment is subsequently fitted. All submarines also carry other ballast in the bottom of the hull for stability purposes.

All the above is assuming that there is only one pressure hull, but not all submarines have only one. Double hull boats are occasionally found in various European designs, and the Dutch even have one class with triple pressure hulls. The space between pressure hulls is often used for ballast and oil tanks.

The steel used in British and American submarines is called High Yield 80 (HY80). Steel has gradually been improved throughout the years and each new type is given a new high yield number, thus we get HY80 which is extremely strong. The Americans have now developed an even stronger steel, known as HY100. It is in service, but is not extensively used at present.

Inside the pressure hull there may be one or more decks. In addition the submarine may be divided into a number of pressure tight compartments, each being divided from the next by a watertight bulkhead. British and American nuclear submarines have two pressure tight bulkheads: one shuts off the fore end, the other the after, thus making two watertight compartments. From these compartments there extends upwards an escape tower. The principle is that, provided only one of the compartments is flooded, the remaining crew can move into the other and escape one by one up the tower and into the sea, and thence to the surface.

Alternatively, external rescue methods may be used, such as the Deep Submergence Rescue Vehicle (DSRV), or a diving bell. Either could mate with the usable escape tower and the crew could pass from the stricken submarine to the rescue vessel, all at atmospheric pressure.

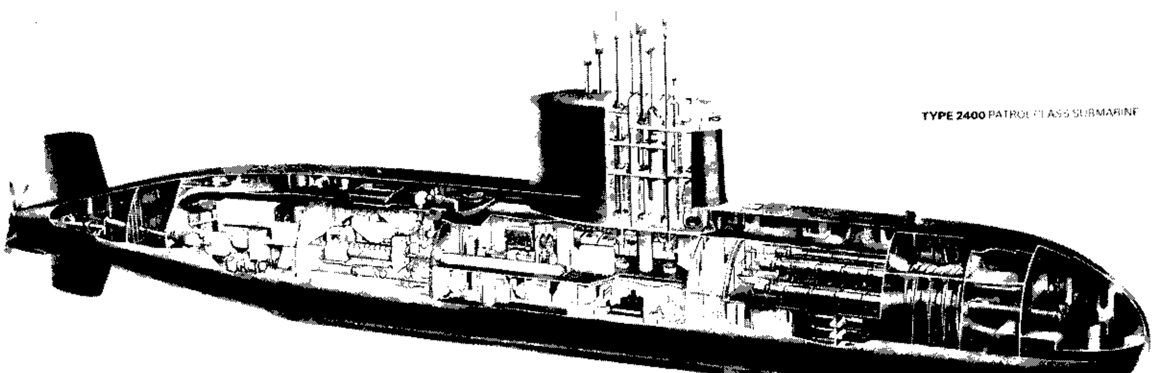
Diameters of pressure hulls in the West vary from about 8m for a 2,000-ton conventional to somethin just over 10m for SSBNs: French SNLEs are 10.6m, most US and all British SSBNs 10.1m. The USSR's enormous *Typhoon* SSBN has a pressure hull with a reputed diameter of 22.9m, and the US counterpart, the 'Ohio' class SSBNs, 12.8m. Length of pressure hulls are about two-thirds the overall length of the submarine, overall lengths varying from about 90m for a 2,000-ton conventional to 129m (approx) for the US, British and French SSBNs. The USSR *Typhoon* and the American *Ohio* are, despite widely differing pressure hull methods, almost exactly the same length at 170m, about the same as the US 'Spruance' class destroyers.

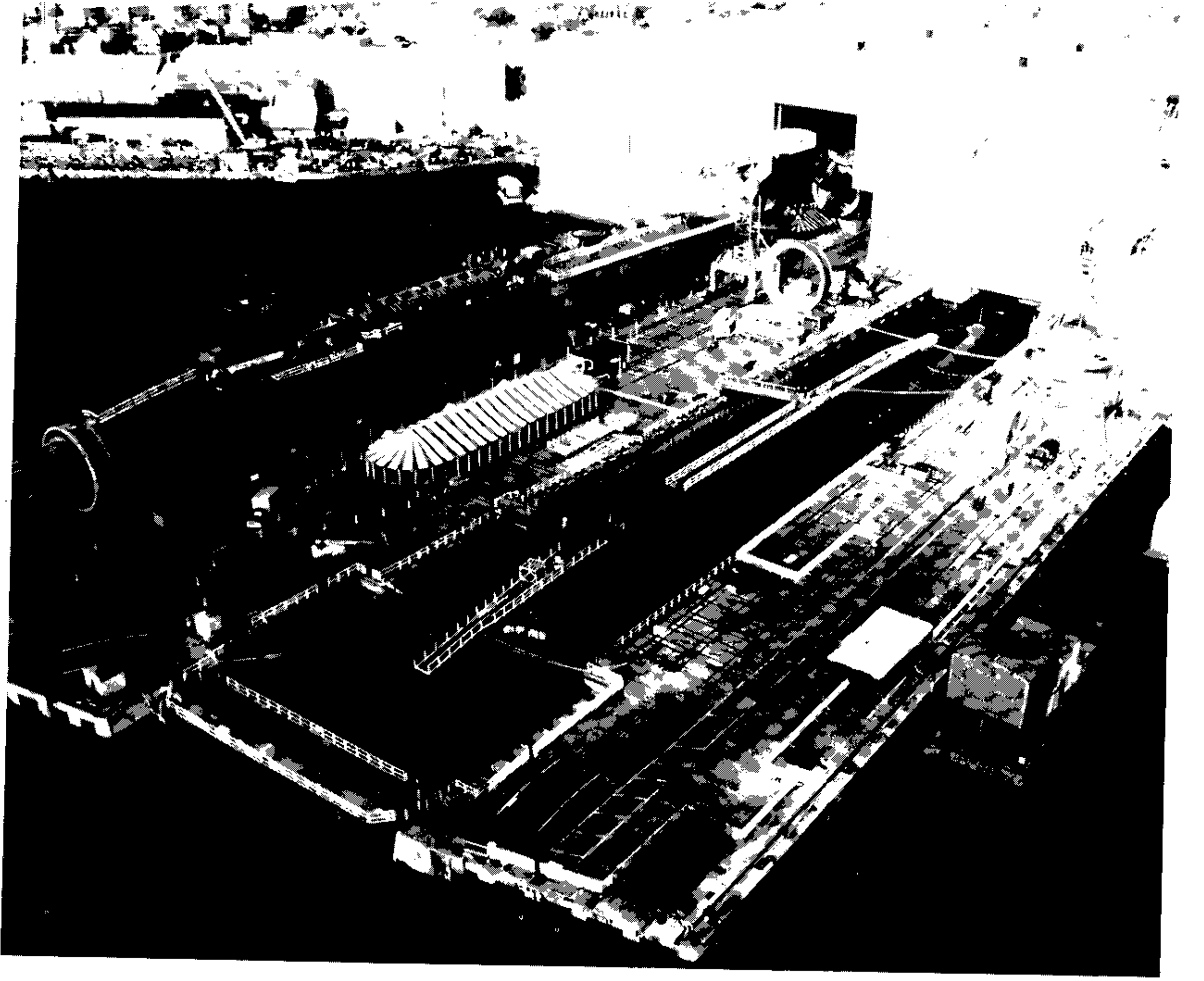
The draft of a submarine depends very much on whether it has to carry strategic nuclear missiles. These are carried in vertical tubes, the tops of which are level with the top of the pressure hull, so the longer the missile, the greater must be the draft. The US *Ohio*, for example, built to carry the Trident missile (length 10.36m) has a draft of 10.9m, whilst other US SSBNs (mostly Poseidon missiles also 10.36m long) have a draft of 9.6m, but many of them are being converted to carry Trident. British SSBNs built to carry Polaris (length 9.55m) have a draft of 9.1m and the French SNLEs (which carry the French MSBS M20 missile, 10.4m long) have a draft of 10m. Although in some cases the missiles are longer than the draft, it must not be forgotten than draft is measured from the waterline when on the surface down to the lowest point in the bottom of the boat, and a considerable portion of the pressure hull extends above this waterline.

SSNs have no such problem and their drafts can be less. They vary from 6.6m in the French

Left:
General arrangement of Britain's latest conventional submarine, the Type 2400.

Below:
Cutaway of the Type 2400 patrol submarine.





SNA72s to 8.2m in the British and American SSNs, although the new 'Los Angeles' class vessels have a draft of 9.9m, possibly so that they could be converted to SSBNs should it ever be required.

SSBN Designs

SSBNs are always larger than other types of submarines because they have to carry the very heavy nuclear missiles: one Trident C4, for example, weighs 29,500kg. The missiles are stowed in their vertical launch tubes in the missile compartment, which in all SSBNs except the 'Ohio' class and the Soviet 'Typhoon' class is abaft the fin which is therefore in the fore part of the vessel. In the two exceptions the fin is much farther aft to leave room forward for the 24 missiles in *Ohio* and the 20 in *Typhoon*.

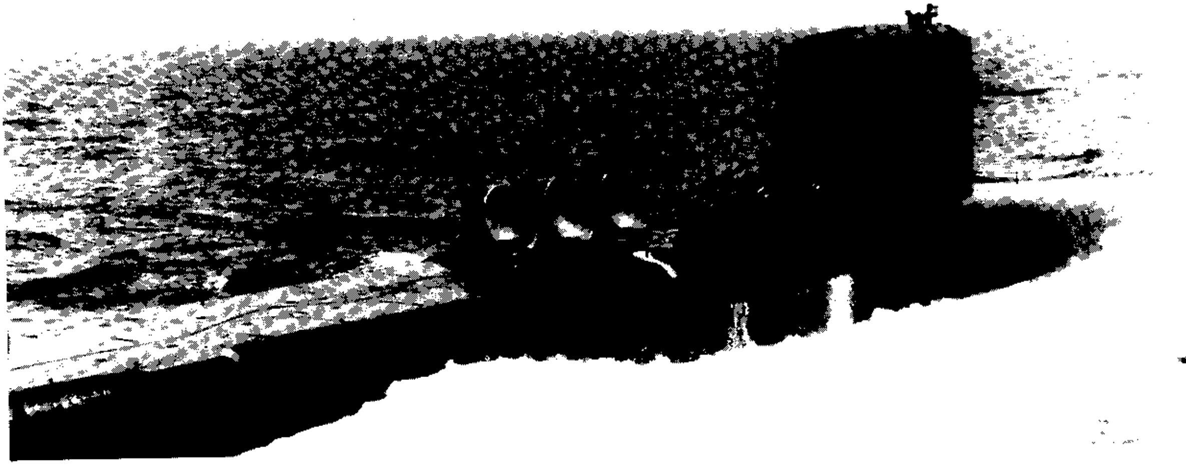
SSBNs have a special trim problem when they launch their nuclear missiles. If the tremendous missile weight was suddenly released from the submarine, it would pop up to the surface in no time unless compensating weight was added. What

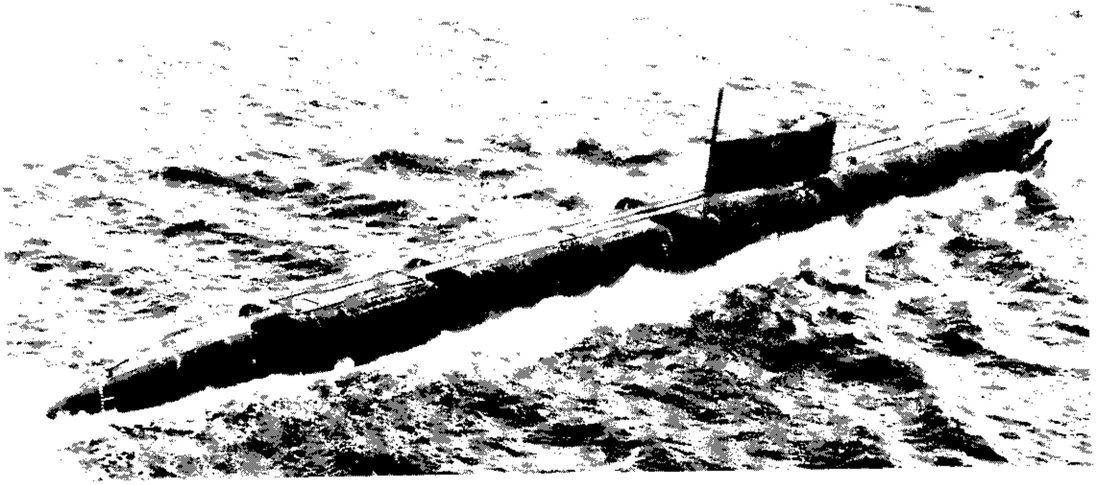
Above:
US nuclear ballistic missile submarines building at the electric boat division of the General Dynamics Corporation yard at Groton, Connecticut. The *Ohio* can be seen in the foreground (in dock) and the *Michigan* (No 727) on the pier. The hoop between the two is the start of the pressure hull of a third 'Ohio' class SSBN.

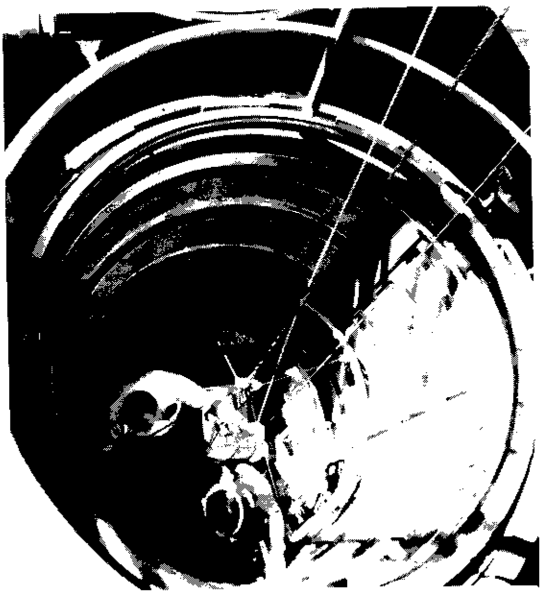
Top right:
An American SSBN under way with some of the Poseidon missile tube doors open.

Centre right:
A Soviet 'Echo II' class submarine. Note the eight hatches for nuclear cruise missiles.

Right:
The interior of a missile launch tube with men at work in it.







happens is that initially the air pressure inside the tube is increased until it is the same as the water pressure on the tube hatches to enable the hatches to be opened. Just inside the hatches each tube is covered by a membrane which keeps the water out, but which is burst by the missile firing. As soon as the missile leaves the tube the water enters and fills the tube. In fact the water is heavier than the missile so the submarine should tend to go deeper. To compensate for this there is a Missile Compensating System which blows out the difference between the weight of the water in the tubes and the weight of the missiles launched into a secondary ballast tank which can then be pumped out.

A similar process occurs in all submarines when they fire their torpedoes, with special trim tanks provided to adjust weights. The object in both cases is not only to keep the submarine in trim, but to keep it at a constant depth.

The maximum depth at which a submarine is required to be able to operate is laid down by a

Staff Requirement, and the submarine designer builds his submarine to satisfy it. However, it is not unknown for a submarine diving in an emergency to go down too quickly and inadvertently go below the specified depth, so the designer leaves a good margin to allow for this. When the depth is such that the pressure of the water gets too great for a particular submarine, the pressure hull will start to buckle and eventually the hull will implode or explode. Such a depth is known as the collapse depth and is invariably kept secret.

Other Submarine Designs

Whilst the general principle of submarine designs is roughly the same in all navies, there are one or two main differences, primarily caused by the means of escape in use in the navy concerned.

The West Germans, for example, have had various internal changes to the design of the pressure hulls. At one time they thought it advisable to divide up their submarines into a number of pressure tight compartments in order to contain general flooding. However, such an arrangement might mean that men could be trapped in a number of compartments and would be unable to reach an escape tower unless they had access to a compartment in which such a tower was situated. It was obviously impracticable to fit each compartment with escape towers.

Recently the West Germans have changed their minds and in some export versions of the '209' class a rescue sphere is permanently attached to the submarine. The boat is divided into the normal two pressure-tight compartments by a bulkhead, roughly in the centre of the pressure hull. Each compartment has an escape tower which join together at the top, thus giving access to the rescue sphere from either or both compartments. When all the escapees are in the sphere it is released and floats to the surface where it becomes a form of lifeboat. It is a once-only system and the sphere is large enough to hold all the crew which in the small '209' class number only 22.

Some navies have no pressure tight compartments and leave the crew to move freely about the entire submarine. Only one escape tower is fitted and reliance is placed on external assistance, either by a DSRV (Deep Submergence Rescue Vessel) mating with the escape tower, or by a diving bell being lowered on top of the tower. The system is presumably only of use if the submarine has sunk, not by being holed or flooded in any way, but because of loss of power.

Endurance

The designer of conventional submarines is always much concerned with endurance and underwater speed. There is constant demand from sea-going officers to increase the underwater endurance to something approaching the unlimited endurance of the nuclear.

The only way to do this is to find or develop an

engine (whether it be used for charging batteries or for actual propulsion) which can function without air, or to be more specific, without oxygen. The fuel cell has often been quoted, but this still requires a supply of oxygen. A combination of fuel cells and batteries has been suggested, but lack of space would make this difficult. Any form of propulsion completely air-independent seems as far off as ever, so the designer is faced with improving the batteries so that they do not need charging so frequently. This would obviate the submariner's great fear — exposing the snorkel which he knows full well can be detected from the air by radar.

Batteries have been improved tremendously over the last decade. It is now not uncommon, for example, for conventional submarines to stay fully submerged for three or more days without the use of the snorkel, always assuming that they do not have to use high speed for any length of time, and also assuming that the use of all other electrical equipment in the submarine is reduced to the absolute minimum. This latter is not easy. Sonar, for example, consumes a great deal of electrical power, and what captain would be happy without the use of his sonar? The present situation is that high speed breaks of 25kt or so submerged are possible, but are limited to no more than about one hour before re-charging becomes necessary.

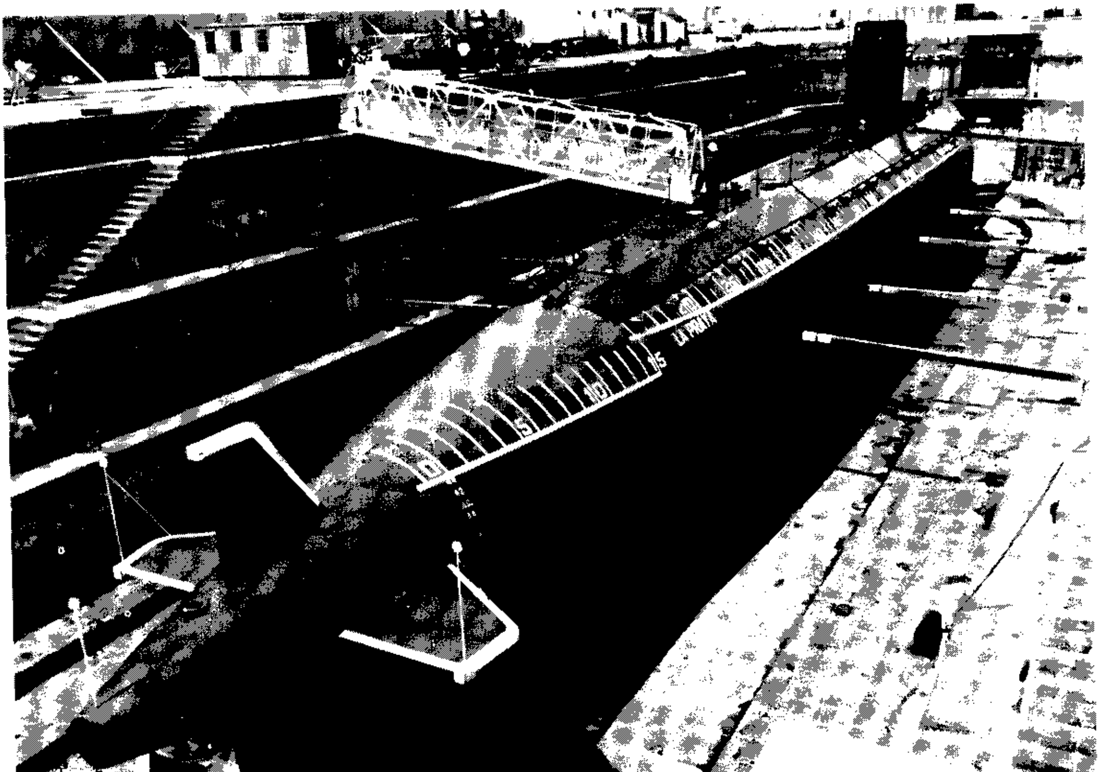
Whatever way one looks at it, sooner or later the conventional submarine must expose a snorkel. With this in view, perhaps it would be better to redouble research efforts into means of rendering the snorkel undetectable by radar.

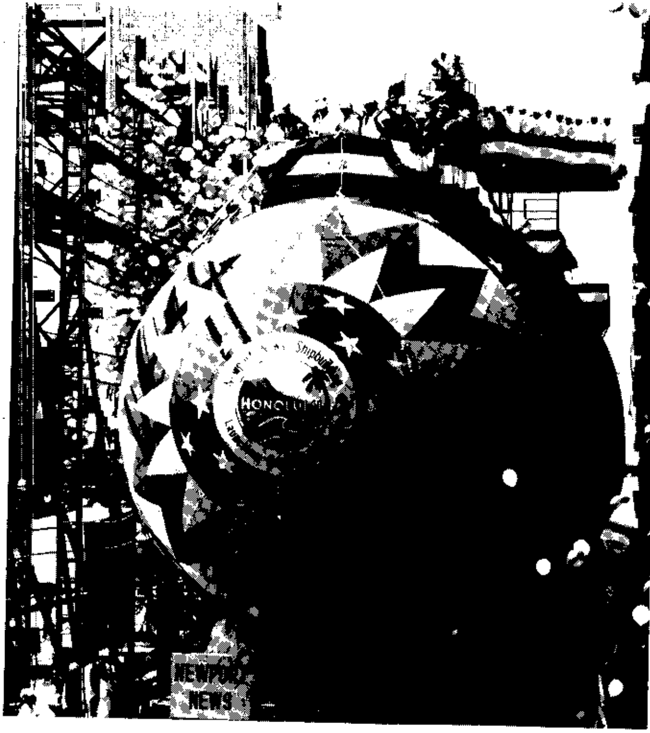
Below left:
The French submarine *Beveziers*, one of the 'Agosta' class. The draught of the vessel can be appreciated fully in this bow view.

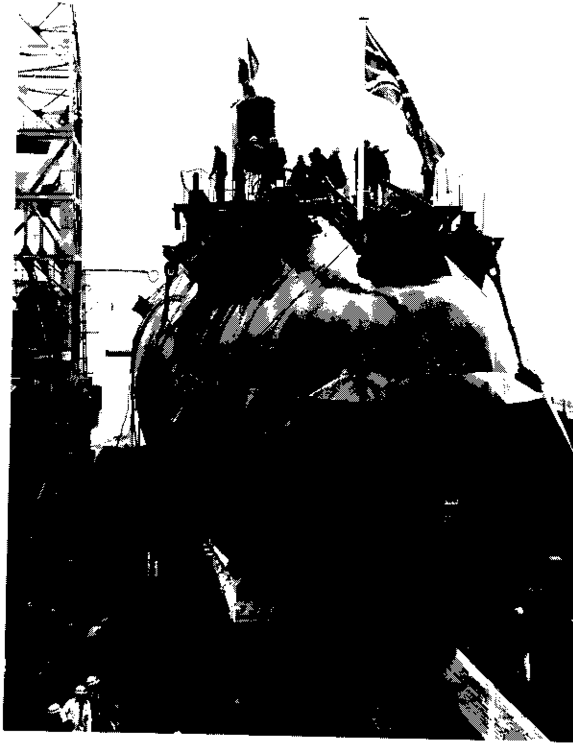
Below:
A stern view of the same class of French conventional submarine showing the long narrow hull which is a feature of this class.

Control

The control surfaces in a submarine are the hydroplanes and the rudder. There are two sets of hydroplanes, one forward and one right aft. Usually the forward planes protrude from the hull and are mounted well forward; they can either be retracted or folded back against the hull when not in use. Some submarines, however, have their forward hydroplanes mounted either side of the fin. The after hydroplanes are attached to two horizontal stabilisers on either side of the after part of the hull and they extend beyond the widest part of the submarine. They cannot be retracted or folded. Provided the boat is proceeding at a moderate speed, the control of depth can be exercised by the after hydroplanes alone. The forward planes are however necessary for control







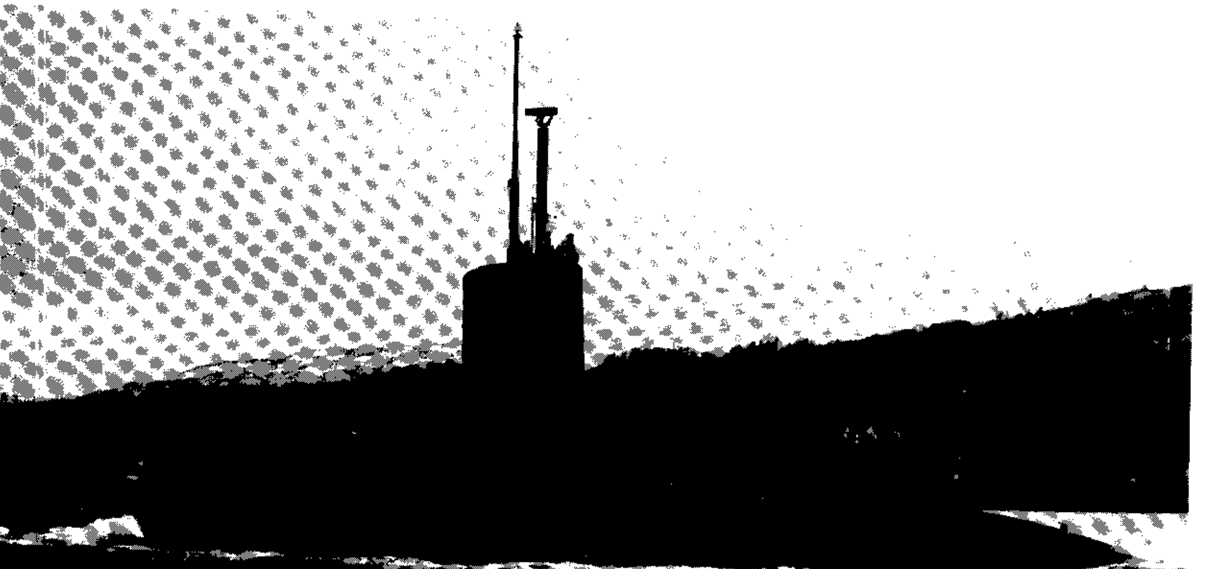
at slow speed and at periscope depth in rough weather. A curious feature is that at very slow speed the hydroplanes have to be used in reverse, ie when set to dive, the boat in fact will tend to rise and vice versa.

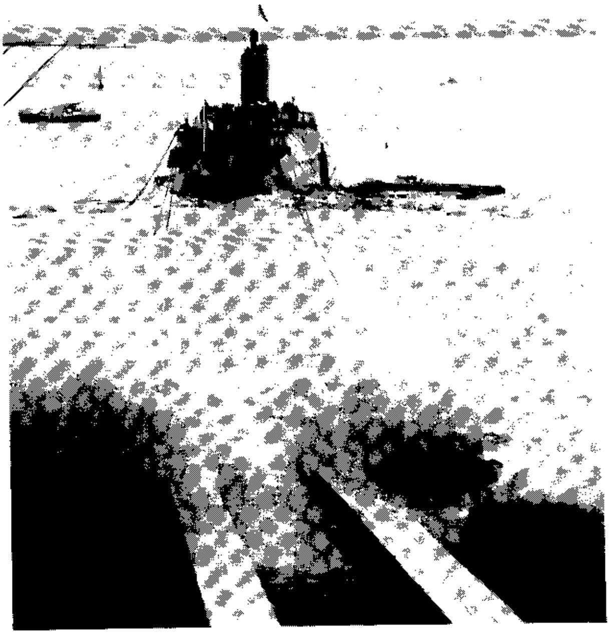
Some navies, notably the Swedish, have their hydroplanes and rudder control surfaces shaped like an X and mounted aft; they can then control the boat in both the horizontal and vertical planes, the control being exercised by a sort of joystick. Normal submarine controls consist of two wheels, placed side by side and manned by two planesmen. One is for the forward hydroplanes and the other for the after ones. The wheels are not unlike car

Above left:
The launch of the 'Los Angeles' class SSN USS *Honolulu* on 24 September 1983.

Above and above right:
The launch of HMS *Tireless* — a 'T' class SSN — at Vickers' Barrow-in-Furness yard in the UK.

Below and below right:
Two SSNs compared — the Royal Navy's HMS *Churchill* and the USS *Los Angeles* on her initial trials, Note that the Americans place the forward hydroplanes protruding from the conning tower, whilst the British have them protruding from the hull.





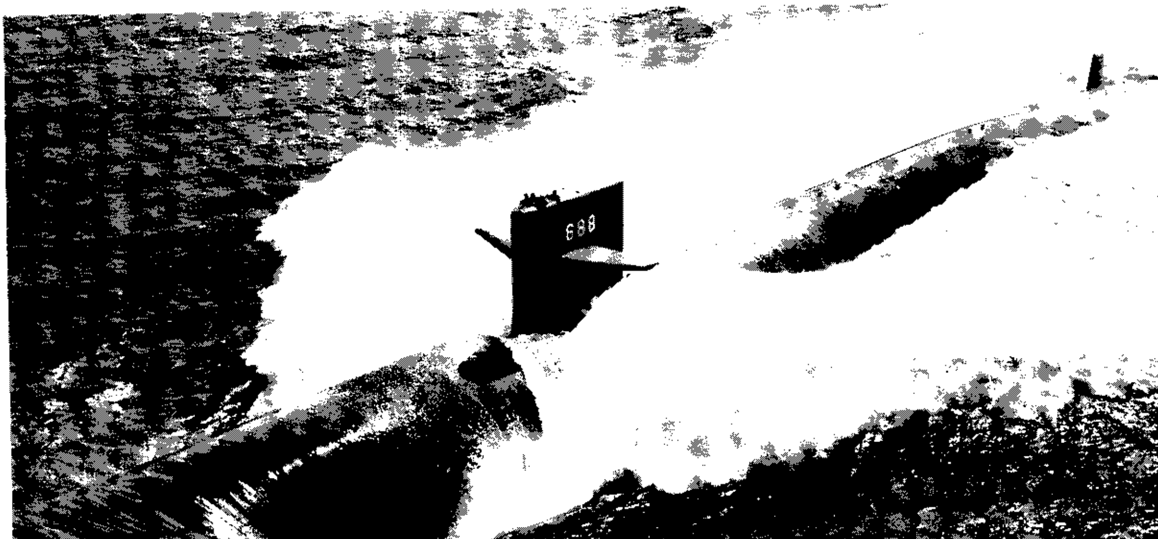
steering wheels, but have no upper and lower rims to them. To operate the hydroplanes the whole wheel is pushed forward to cause the submarine to dive deeper, and pulled back to level off or cause the submarine to rise. An automatic pilot can be connected up and it acts in much the same way as does a similar device in an aircraft, keeping the boat level and on the correct course.

A submarine, particularly a small one, can change depth by hundreds of feet in less than a minute and with trim angles no greater than 20° to 30°. In the horizontal plane a small submarine can achieve a tactical diameter of less than four times its own length. Violent manoeuvres such as these may be invaluable when avoiding torpedoes or depth charge attack and when attacking another submarine.

SSBNs are not so manoeuvrable, owing to their size, and they must rely more on high speed to escape attack. In addition, nuclear submarines have other problems all of their own. One is, in order to satisfy standard safety measures, the reactor and all its shielding should be placed as far distant from the crew as possible, and this suggests that it should be as far aft as possible. Because of its weight, this is not possible and it has to be sited amidships. This puts it right amongst the crew — so it has to be particularly well shielded — and right across the access from one end of the submarine to the other. It is so large it stretches right across the inside of the pressure hull, so the problem is overcome by building a tunnel right through the reactor compartment, on top of it. The doors at each end of the tunnel are not allowed to both be open at the same time, and of course the whole arrangement adds weight.

Another problem is that a nuclear plant produces saturated steam, and not the superheated steam common in surface ship engines. As a result, the turbines, condensers and the secondary machinery have to be larger than in craft using superheated steam. The nuclear plant also uses a considerable amount of electricity, necessitating a number of turbo alternators, again more weight.

Finally, of course, nuclear submarines are proverbially noisy at speed. A great deal has been done to quieten them, such as mounting all moving parts on resilient mounts, using non-cavitating propellers and so forth, and some success has been achieved. The result is that the old adage that conventional submarines are much quieter than nuclears has now become only marginally true. However, conventional submarines are at least cheaper to build and operate.



4 Propulsion

There are at present only two methods used to propel submarines through water: by diesel-electric drive and by steam generated by a nuclear reactor.

Nuclear Propulsion

As is well known, the prime method of propelling a nuclear submarine is by steam, in exactly the same way as for many years surface craft were propelled by steam, firstly using reciprocating engines and later using turbines. In surface craft the steam was produced in a boiler in which water was heated, originally by burning coal and latterly by burning oil fuel. A nuclear submarine is little different, except that its steam is produced by heat from a nuclear reactor.

The Reactor

A submarine reactor uses atomic energy to heat water in a steam generator (boiler). The steam produced is then used to drive the main turbine which in turn is connected through gears to the submarine's propeller by means of a propeller shaft.

The reactor consists of a large number of uranium coated plates. When two such plates are placed facing each other a bombardment of neutrons is set up between them. This has the effect of splitting the uranium atoms which produces intense heat. The whole process is known as nuclear fission.

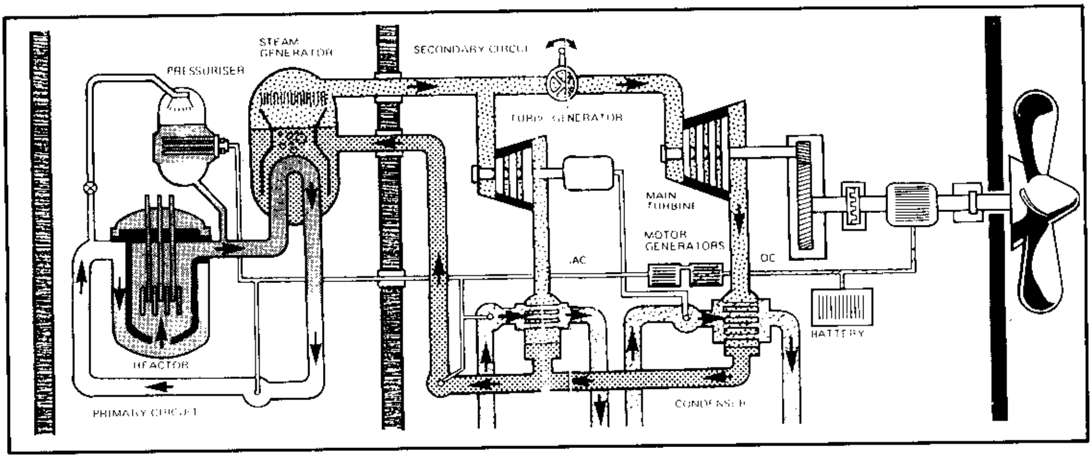
To control the nuclear reaction, and thus the heat produced, other shielding plates known as control rods are inserted between the uranium plates. In fact there are not just two plates facing each other, but a number of plates are bunched together, and the control rods are inserted between bunches of uranium plates. When the rods are fully inserted they form a complete barrier between the 'bunches' of plates and no bombardment by neutrons can take place. However, if the rods are slowly withdrawn (usually upwards) and the plates gradually become exposed to one another, a bombardment starts between the exposed portions of the plates. As the rods are further withdrawn, the reaction becomes more active: maximum heat is produced when the rods are fully withdrawn. Thus the heat generated in the reactor is a direct function of the position of the control rods between the bunches of uranium plates. The hot water generated in the reactor is pumped through coiled pipes in the steam generator, the remainder of the inside of the generator being filled with water. The heat in the pipes warms up the water in the same way as does an immersion heater in an ordinary domestic boiler, until it boils and steam is formed.

The heat in the reactor is far greater than the heat in the steam generator and would soon boil the water in the pipes leading to the steam generator. This is obviously undesirable, so a device called a pressuriser is used to prevent the water in the reactor boiling, but at the same time allowing it to pass on as much heat as possible to the steam generator. The pressuriser creates a bubble of steam in the top of the pressuriser's cylinder. This exerts pressure on the water in the reactor, which in turn prevents it boiling, because water under pressure boils at a much higher temperature. The greater the pressure on the water in the reactor, the higher will be the temperature at which it will boil, so the pressure in the reactor is kept very high, around 3,000lb/sq in.

The reactor, the steam generator, the pressuriser and their associated pipes are known as the primary circuit, and they are all kept in one compartment which is heavily shielded from the rest of the submarine to avoid any radiation leaks.

The Secondary Circuit

What happens to the steam after it leaves the primary circuit of the reactor until it returns to it as water constitutes the secondary circuit. Starting from the steam generator, steam is led away by pipes, through a control valve, to the main turbine which it drives in the normal way. Before it reaches the control valve, however, some of it is tapped off to drive a turbo generator which generates all the electrical energy, at various voltages, required in the submarine. The major portion of the steam, after passing through the main turbine, is passed through a sea water cooled condenser which turns it back into water, and from there it is passed back into the steam generator as



Above:
A typical submarine nuclear propulsion power plant.

cool water. On the same principle, the steam used to drive the turbo generator is condensed and joins the water returning to the steam generator. Thus we get a complete closed circuit loop of steam and water.

Changes of Speed
Now let us look at what happens when speed changes are made. For example, suppose the boat is being driven ahead at half speed and the captain suddenly orders full speed ahead. The control valve is opened up to allow more steam into the turbine. As this steam is drawn off the steam generator, the water level in the generator will go down, so more water will have to be pumped in to level it up. The new water, however, will be cool and will tend to lower the temperature in the generator. But *more* steam is required because of the higher speed, so the reactor must be made to produce more heat. This is done by raising the control rods to allow larger surfaces of the uranium plates to bombard each other. The control rods are operated by one man whose main job is to see that the temperature in the reactor remains constant. He has various gauges and as he sees the temperature tending to drop due to the higher speed, he electrically operates the control rods, raising them until the temperature comes back to normal. Thus, with frequently varying speed, which does not happen very often, he is kept busy raising and lowering the control rods.

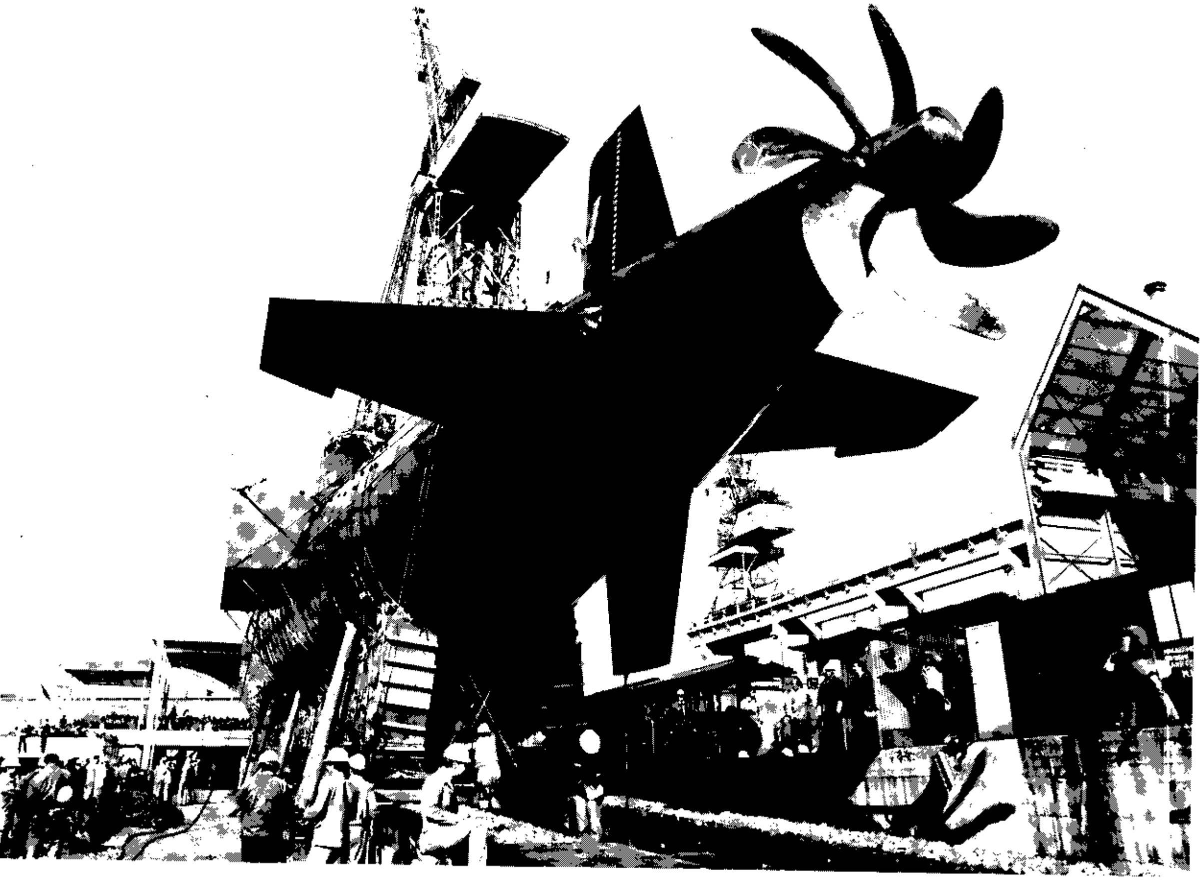
On reaching harbour, the reactor can be shut down. This is done by slowly lowering the control rods until the flow of neutrons between the uranium plates is stopped altogether. Similarly, on preparing for sea, the control rods have to be slowly raised until the reactor is once more in a working state — a position known as 'going critical'. The process of raising the control rods up to the critical state takes some time.

When a reactor is shut down, the water cools and shrinks. On going to sea, more water has to be pumped in. Thus when the reactor is back in full working order the water is hot and has expanded, so the excess water has to be pumped out into the sea. This is done when well clear of the land as the water might be radioactive, but the amount is very small and is soon dissipated into the vast oceans of the world and does no harm. Similarly, reactors sometimes accidentally shut down whilst at sea and the same process takes place.

Fuelling
The plates in the reactor slowly lose their uranium coatings and eventually refuelling has to take place. In peacetime it occurs about once every five years. To refuel, the entire reactor has to be taken out of the submarine. This is a lengthy process lasting four to five months and involves cutting a hole in the pressure hull, lifting the reactor out and replacing it by a new one: the lifting crane and all the personnel on the job have to be screened from the reactor.

Noise Suppression
One of the main problems in a modern submarine is to prevent it making any significant noise when dived; nuclear submarines tend to be particularly noisy, especially when they are proceeding at speed.

The propulsive machinery and the propeller are two of the main sources of noise. Whilst the machinery inside the pressure hull can be made as quiet as possible — by mounting it on rubber pads so that the noise is not transmitted to the pressure hull — the propeller is not inside the pressure hull. By its very nature it is bound to thresh around in the water and a large part of the noise it makes is caused by drops of water falling off its blades — a



process called cavitation. A considerable amount of this noise can be cured by the design of the propeller — bending the tips of the blades over and inwards is one method — but development work is still being carried out in reduction of noise.

Most nuclear submarines, and modern conventional ones too, now have only one large propeller, instead of the customary two. These monster propellers, specially designed to reduce cavitation, need only rotate slowly to drive the boat at a reasonable speed, and provided they are kept slow, they make little noise. However, at high speeds,they can be detected at great distances.

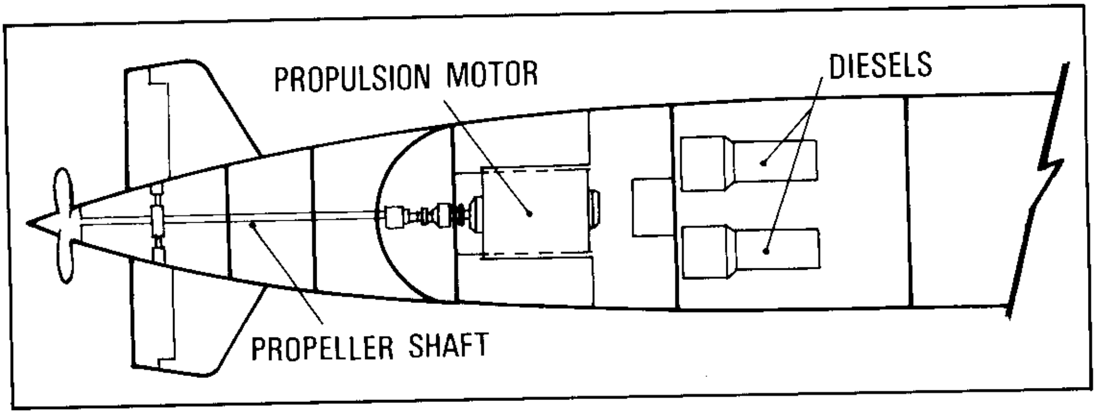
One modern idea to reduce noise is to fit a shroud over the entire propeller and to rotate the latter by means of water jets. The system is known as a propulsor and is said to be considerably quieter than any other form of propeller yet designed, but it is not yet generally at sea.

Diesel-Electric Propulsion

The so-called 'conventional' submarine uses electric motors to rotate the propeller at all times whether on the surface or submerged. To provide power for these motors, batteries are used, but they of course have to be charged and for this purpose two or more diesel generators are provided. Most modern conventionals have one propeller only and one electric motor, but possibly with a twin armature. A final electric drive is used because it is quieter than a direct diesel drive and in fact conventional submarines, when operating on batteries only, are quieter than nuclears. It is possible by the use of slow running, for large propellers to have direct shaft drive instead of having to go through a gearbox, and this reduces the noise considerably.

The diesels are of various makes, although perhaps Pielstick and MTU types are the most common. Their bhp varies with the size of the boat, but large conventionals of 2,000 tons or more would probably have two 16-cylinder vee-type diesels of at least 1,500bhp.

Control of the speed of the boat is normally effected by altering the voltage supplied to the armatures of the propulsion motor. The batteries are normally run in parallel, but for higher speeds they can be put in series, and if more than a single armature motor is being used, these too can be put in series.



Above:
A typical conventional propulsion arrangement. The propeller is rotated by an electric motor to which electric power is supplied from the batteries, not shown here, but situated low down in the submarine usually farther forward. The diesels are used to charge the batteries, but as they need oxygen, charging can only be carried out when on the surface or when snorting.

Left:
The stern of the Italian submarine *Leonardo da Vinci*. The peculiar curved blades of the propeller are designed to ensure that the propeller makes as little noise as possible in the water.

Batteries
There is great competition between battery manufacturers in Germany, Sweden and the UK to produce batteries with a much higher capacity without increasing the weight and size. Indeed, batteries have been greatly improved over the last decade. Lead-acid batteries are generally used and stowed as low in the boat as possible, because their heavy weight gives the boat better stability. The overall size of the battery is another important factor since space is always at a premium in a submarine. The average life of a battery is about five years, although the German Navy has some batteries which have been in use for seven years, but battery life is very dependent upon maintenance.

Batteries can be re-charged when on the surface or when submerged by use of the snort system which sucks fresh air into the boat. To charge, the charge current must always exceed the current given by the batteries to drive the propulsion motor. Thus if the submarine is proceeding at a fast speed all that can be done is to 'trickle charge', in other words ensure that the charging current equals that being produced by the batteries. It follows that when it is essential to charge the batteries, the submarine will be very restricted in speed, both on the surface and submerged.

Britain's new Type 2400 conventional submarines, being built by Vickers, can be regarded as reflecting the latest state of the art in propulsion. The submarines will have two Paxman Ventura diesels of 1,350kW each, and one twin-armature motor of 4,000kW. The batteries will be of the lead-acid type and will consist of 240 cells, the whole battery weighing 270 tonnes. The propulsion motor can have its two armatures connected in parallel or in series, as of course can the batteries. These systems will enable maximum speeds of 12kt surfaced and 20kt plus submerged.

Fuel
Unlike nuclear submarines, conventionals must carry diesel fuel. This is stowed in tanks which are situated outside the pressure hull, adjacent to the main ballast tanks, but unlike the ballast tanks the fuel tanks are not open to the sea. However, water and fuel can be stored in the same tank if necessary, as they do not mix and the fuel floats on top of the water.

The Snorkel
The snorkel, or snort as it is generally known, is a pipe about 14in in diameter, which is raised above the surface of the sea to get fresh air into conventional submarines to enable the diesels to be run. There is also a second pipe which can be raised and lowered to carry the exhaust gases out of the submarine. The top of the pipe is kept just below the surface of the water so that the gases are discharged into the water. The snort mast itself is about the same height as the periscope, so it follows that submarines snorting must be at periscope depth. To prevent water, which might lap into the top of the snort, from entering into the boat, a float valve in the snort tube shuts momentarily.

5 Diving and Surfacing

غوطه‌ور شدن (شیرجه زدن)   روی سطح آمدن

Underwater Dynamics

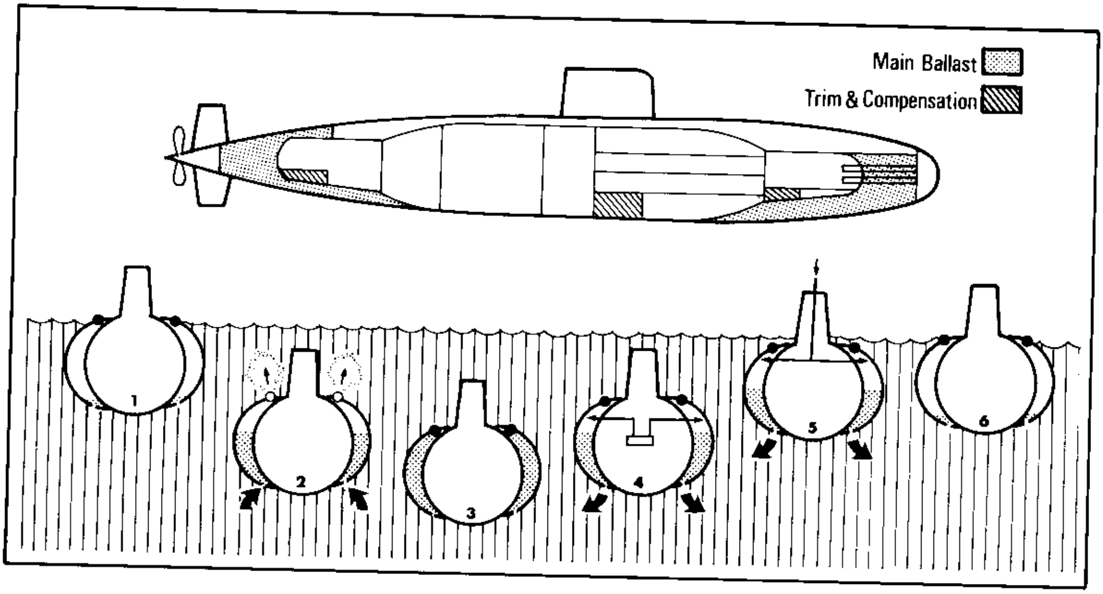
In a ship the centre of gravity (G) is normally above the centre of buoyancy (B), but in a submarine totally submerged, B is naturally higher than G. In order to attain submerged neutral buoyancy (when the boat neither tends to rise or sink) the buoyancy of the submarine must be equal to its weight. To ensure this, submarines are fitted with ballast tanks open to the sea. Under surface conditions the pressure of the air inside the ballast tanks is equal to that of the sea, and no water enters the tanks. To allow water to enter the tanks, the air is allowed to escape and the water replaces it, the weight of water causing the submarine to submerge. Final adjustment to achieve buoyancy, and also to ensure that the submarine is perfectly level and with no list, is made by entering or expelling water from small 'trim' tanks situated inside the pressure hull.

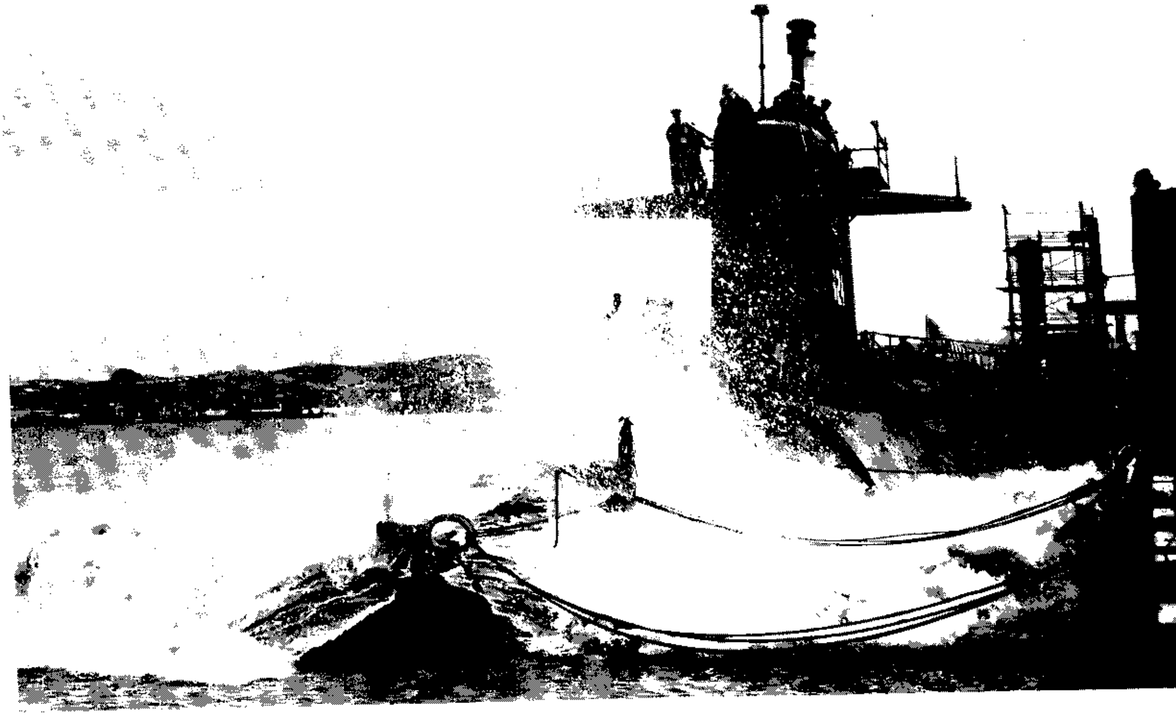
Submarine ballast tanks are usually situated outside the pressure hull. In modern single-hull boats they are normally fitted at the bow and stern, while in twin-hull boats they are between the inner and outer hulls. Some older boats have 'saddle tanks' on either side of the outside of the pressure hull.

In a typical single-hull boat the casing extends beyond the ends of the pressure hull, leaving a free flooding space forward and aft in which the ballast tanks are fitted. There are usually two small tanks inside the pressure hull, which are used for trimming, and also other tanks for filling with water to compensate for the loss of weight when missiles or torpedoes are launched. All ballast tanks are open to the sea at their bottoms.

Diving

To dive the submarine, the bridge staff clear the bridge, taking with them all portable equipment, signal books and other papers. When all the personnal have entered the submarine a watertight hatch in the conning tower is closed and firmly latched, and the captain gives the order to dive and also probably orders half ahead. The hydroplanes are put to 'dive'. The normal position of the hydroplanes is horizontal, but when set to dive they are turned so that the two forward ones slope downwards and the two after ones slope upwards. This in itself is not sufficient to dive the boat, although it is a very good method of changing depth once the boat is fully submerged. To get below the surface of the sea it is necessary to flood





Above:
Testing a ballast tank's blow system on board an American SSBN.

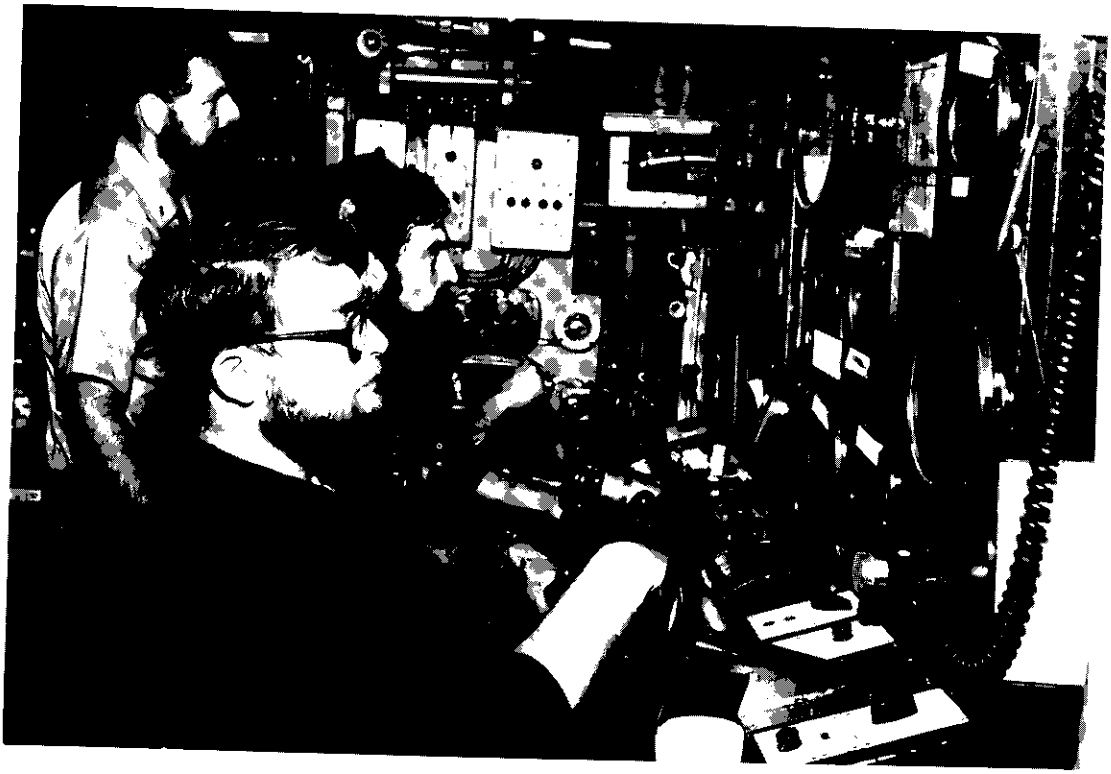
Left:
Diving and Surfacing
1 On the surface the main ballast tanks are filled with air, giving the submarine positive and stable buoyancy.
2 When the main vents at the top of the ballast tanks are opened for diving, sea water enters through the 'free flood' holes in the bottom of the main ballast tanks forcing the air out through the open vents. The submarine is thus forced down in the water.
3 When the submarine is fully below the surface and the main ballast tanks are full of water it should be neutrally buoyant and the main vents are shut.
4 To restore positive buoyancy so that the submarine can float stably on the surface, high pressure air at 4,000lb/sq in is blown into the top of the tank forcing the water out of the free flood holes in the bottom.
5 Once the submarine has surfaced and is free to draw in fresh air through the conning tower, it is possible to save using high pressure compressed air by slightly compressing normal air with a low pressure compressor.
6 This low pressure compressed air can then be used to complete the 'blowing out' of the ballast tanks in order to achieve full buoyancy.

Normal diving and surfacing evolutions are carried out using a combination of appropriate hydroplane deflections with the submarine moving forward, aided by the changing buoyancy state as the main ballast tanks fill and empty.

the main ballast tanks. They are already open to the water, but it will not rise in the tanks because the pressure of the air on top of the water will prevent it. This pressure is therefore released by opening the vents at the top of the tanks. When the tanks are sufficiently full, the vents are shut and the boat, now negatively buoyant, sinks. To control the depth, the hydroplanes are used, and it is possible to level the boat off at the required depth, and for the depth to be maintained, provided the boat is 'in trim'.

Trimming is done by pumping water to and from small tanks inside the pressure hull. On going to sea, and after any major changes of weight in the submarine, it is necessary to 'catch a trim'. By this is meant that the boat has to be balanced so that it is neutrally buoyant and level when proceeding ahead at a very low speed. In theory therefore, when the boat has reached the required depth and is proceeding at only a knot or two, it should not sink farther or rise and should remain horizontal when the hydroplanes are put to the horizontal position. In practice this is not usually the case as the density of the water may not be the same as it was in the position where the trim was originally caught, and there may have been other small changes on board; perhaps the drinking water was diminished or there may be additional water in the bilges.

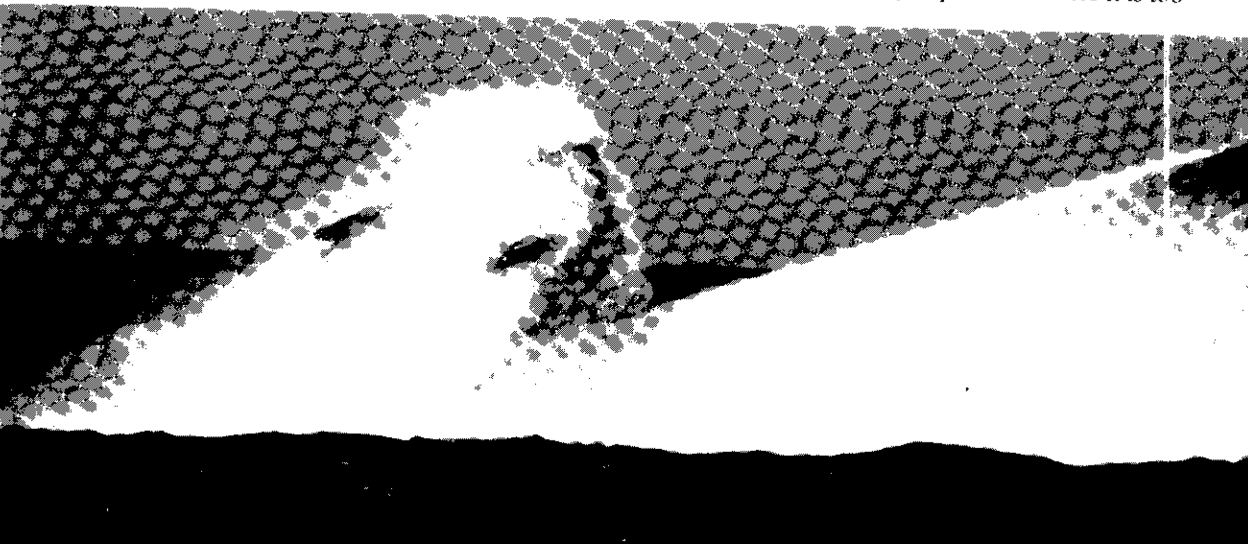
It is normal therefore to remain at periscope depth until the re-trimming has taken place. However, at periscope depth the submarine is near



enough to the surface to feel the effect of the waves, so it is sometimes necessary to go deeper until no wave motion is felt.

Normally it takes a medium size conventional submarine about 1½ minutes to dive. Nuclear submarines, being much larger, take up to seven minutes. However, some submarines can dive much faster by the help of a quick flooding tank under the keel of the boat, known in the Royal Navy as Q tank (Q for Quick). It can hold up to four tons of water dependent upon the size of the submarine. It is not open to the sea, like the ballast tanks, and water inlet is controlled by Kingston valves operated from the control room. The tank is kept flooded when on the surface if a 'crash' dive may have to be made. With the extra weight of water, when the main ballast tanks are flooded the boat will sink much faster. At other times on the surface the quick dive tank is empty.

After diving, the tank is emptied and can always be rapidly refilled, even from dived, if it is desired to make a rapid descent to avoid detection, for example after carrying out an attack. Nuclear submarines do not carry a quick tank since it is too



Left:
The helmsman, and forward and after planesmen during a deep dive on board the US submarine *Grayback.*

dangerous to 'crash' dive such a large craft.

Modern submarines can dive to great depths. Two figures are usually quoted, the diving depth and the collapse depth. The latter is considerably deeper than the diving depth and is kept a close secret. The diving depth is that to which the submarine is actually tested: the ill-fated *Thresher's* test depth was 600ft (200m approx) and it was diving to this depth when lost. The present 'Los Angeles' class of US SSNs has a diving depth of 1,475ft (450m), but strangely the US latest SSBNs, the 'Ohio' class, have a diving depth of only 985ft (300m). Below the diving depth the first thing that will occur is that fittings and pipes on board the submarine begin to give way. As the submarine goes deeper the enormous pressure on it will begin to pull the craft apart, further rupturing pipes and fittings and even the hull. Water starts flooding in and all efforts to bring it up become of no avail, until finally the whole pressure hull collapses.

Submarines only dive below their diving depth in emergencies, but the captain will know when he is reaching a dangerous depth by the initial fracturing of pipes, etc, and he will at once come up to a safer depth.

Surfacing

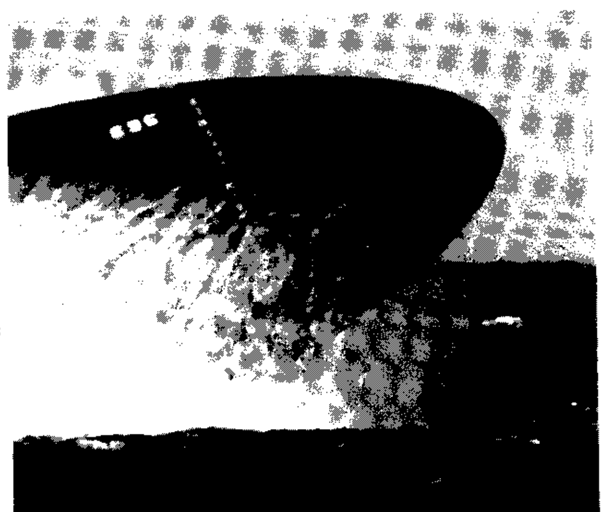
To surface, the water from the ballast tanks must be pumped out. The vents are already shut, so it is necessary to apply pressure at the top of the tanks and force the water out through the openings at the bottom. This is done by high pressure (HP) air which is blown into the tanks: as the water is being forced out, the submarine continues to go ahead with the hydroplanes angled to force the bows up. HP air is stowed in a submarine in bottles and, since there is a limit to the number of bottles that can be carried, is used very sparingly. It has other uses than blowing the main ballast tanks; firing torpedoes is one example.

As soon as the submarine reaches the surface and the conning tower hatch is opened, the HP air blower is stopped and separate air pumps (sometimes known as low pressure blowers) take over clearing the water from the ballast tanks, until the submarine is fully surfaced, an operation which may take all of five minutes. Meanwhile the HP air bottles are recharged by means of an air compressor.

Before surfacing, it is vital to make quite sure that there are no ships around which might be a hazard. In war it is also necessary to ensure that there are no hostile ships or aircraft close enough to be able to attack. Submarines therefore have a NATO standardised procedure for surfacing. They come up to 180ft depth and stop or proceed very, very slowly whilst carrying out a passive, all-round sonar search by listening on their hydrophones. If nothing is detected, or if any detection is too far away to constitute a risk, the submarine slowly comes up to periscope depth. The periscope is then raised and a careful visual all-round search is made. If all is clear, the submarine surfaces. In war, the main danger is likely to be enemy aircraft, so the first mast to be raised is the ESM, or Warner, mast. This carries a radar search receiver and looks for enemy radar transmissions. The search receiver will pick up a radar signal long before the radar in the hostile craft can detect the mast. Not until the captain is satisfied that there are no hostile craft within radar range does he raise the periscope. The Warner mast has only a small receiver on it and it is not easy for aircraft to detect it by radar, particularly if the weather is choppy.

One would think that with all these precautions there could be no danger of surfacing under a ship, in peacetime at least. However, on at least one occasion a submarine captain has raised his periscope to find a sailing craft, usually a yacht, far too close for comfort and has had to go deep. Sailing craft normally have no engines or machinery running and even a careful passive sonar search can fail to detect them.

Surfacing used to be one of the most dangerous manoeuvres for submarines both in peace and in war, but nowadays with modern highly sophisticated sensors and a careful, laid down procedure any danger is minimal.



Left:
Like a whale, the USS *Birmingham,* an SSBN, surfaces.

6 Submarine Weapons

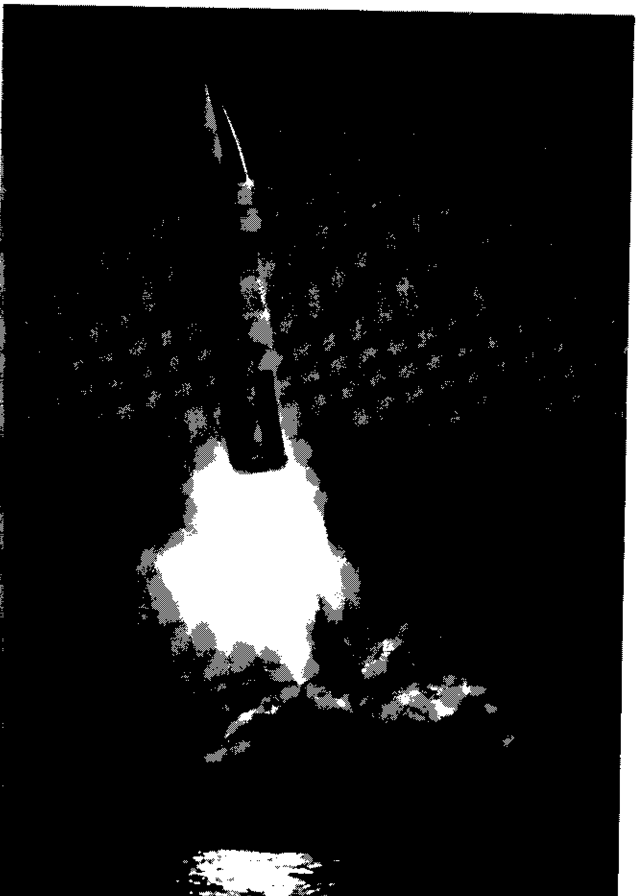
SLBM Method of Operation

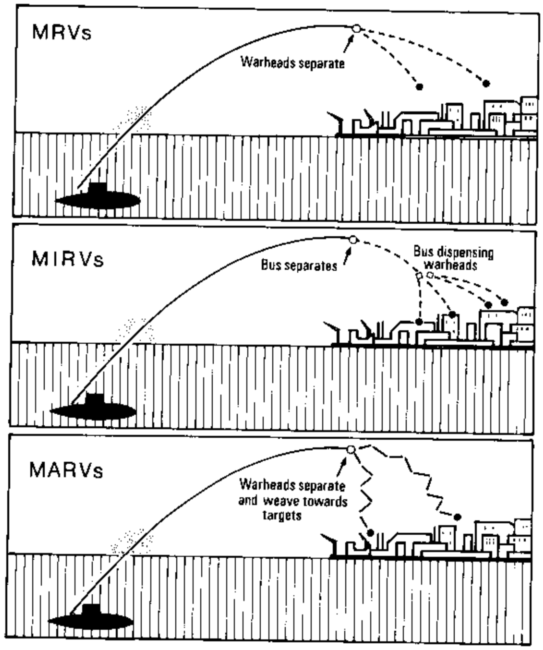
SLBMs all work on roughly the same principle. Their guidance during the powered flight is by inertial navigation. They are given the exact geographical position of their starting point and the exact position of their target(s). The inertial navigation system calculates the course to steer, and the moment when powered flight should cease and they should go into an unpowered ballistic trajectory to hit the target. Should the missile stray off course, the system can steer it back again, but once it has gone into a ballistic trajectory it cannot be further controlled in course.

The missiles are lifted out of their vertical launch tubes by an expanding gas and when they reach the surface of the sea the first stage motor ignites to boost the missile into flight. It burns out after a short time and is jettisoned. A second stage motor immediately ignites and this continues to power the missile until the calculated separation from the missile, which then proceeds, without propulsion, as a re-entry vehicle on a ballistic trajectory.

In the Trident system there are three stage motors instead of two because the missile is heavier than Polaris, Poseidon and MSBS. In addition, because Trident has such a long range, it can automatically take a star fix during its powered flight and update the inertial system. Of course the entire system depends upon the submarine knowing its position extremely accurately at the moment of launch.

Strategic missiles of this type are not as accurate as missiles designed as first strike weapons, ie, to take out the enemy's ballistic missiles before they





Above:
Types of ballistic missile.

Left:
A Polaris A3 missile is launched.

can be launched. For this reason they are normally targeted on large targets, such as cities or industrial complexes. Even so they have a CEP of 500m and it is actually hoped to improve this by various forms of terminal homing, including optical guidance using TV cameras. Polaris, which is not as accurate as Trident, could easily use MRVs, which would drop in different parts of a city and create unbelievable havoc over a large area.

The new Trident D5 missile, which Britain is to buy instead of the existing C4, and which will be retro-fitted in the American 'Ohio' class of SSBN, will have an even longer range than the C4, and will embody new methods of updating the inertial system (one possibility is fixing itself by the new GPS satellite fixing system which will shortly come into service). It is also hoped to improve terminal guidance so that the missile actually homes itself on to the desired target.

The following table gives a picture of the strategic ballistic missiles in use, or coming into use, in the world's submarines.

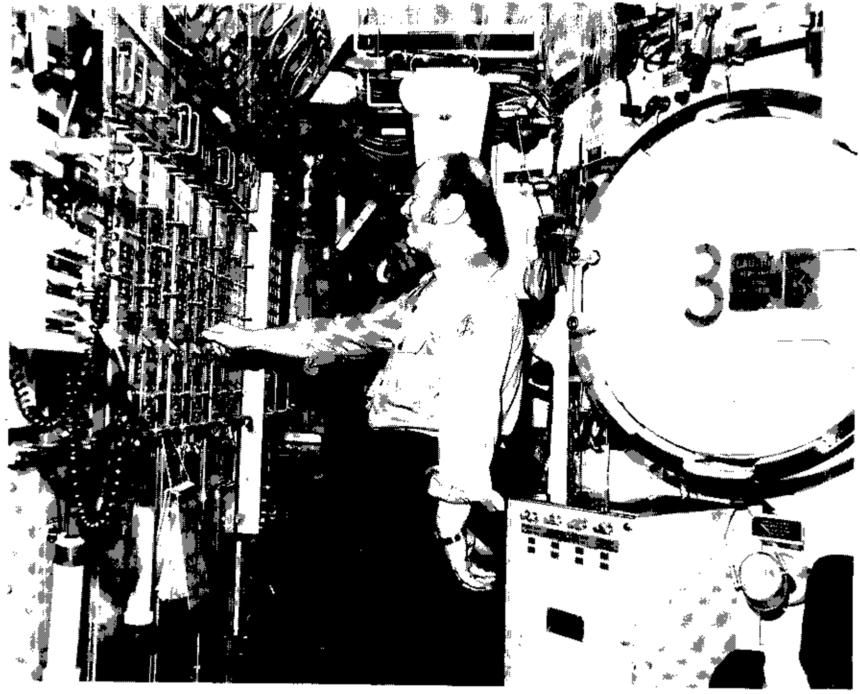
Submarine Launched Ballistic Missiles

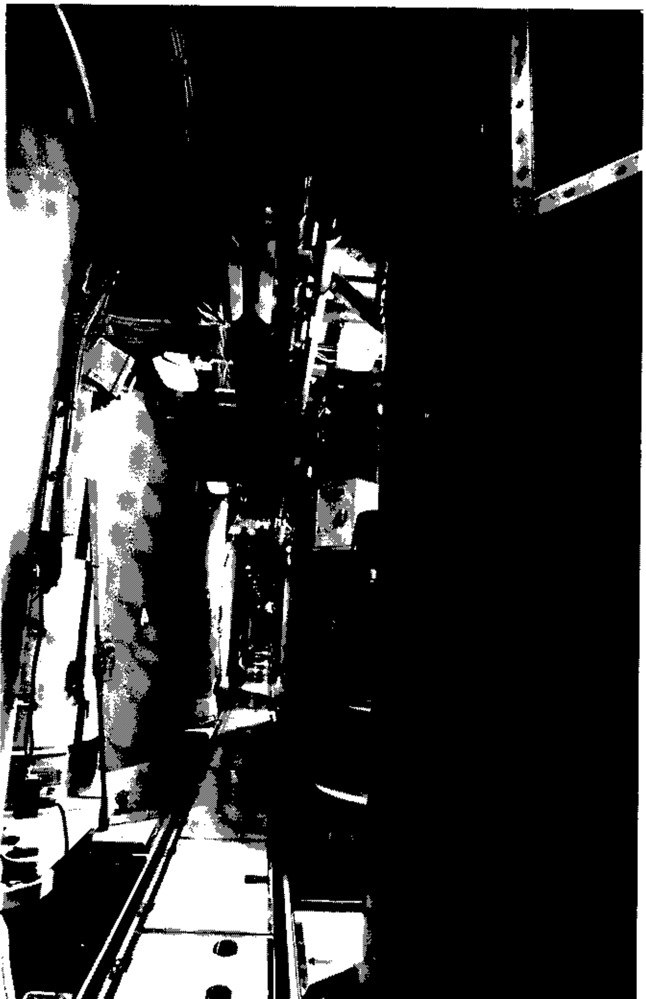
Missile	*Vessels fitted*	*Launchers in each submarine*	*Warheads*	*Range*
NATO				
Polaris A3	4 British	16	3 MRVS of 200kT each	2,880nm
Poseidon C3	19 US	16	Up to 14 MIRVs of 50kT each	2,880nm
Trident I C4	17 US	12 (except for 5 'Ohio' class which carry 24)	8 MIRVs of 100kT each or fewer MARVs	5,000nm
Trident II C5	Under development. Will be bought by the British. Longer range with same payload as the C4 or similar range with a heavier payload.			
MSBS 20	6 French	16	One of 1MT	2,200nm
MSBS M4	Under development to replace the M20			3,000nm
USSR				
SS-N-5	12 'Golf II' (Conventional)	3	One of 800kT	900nm
	7 'Hotel II' and 'III'	3	One of 800kT	900nm
SS-N-6	25 'Yankee I'	16	One of 1MT; later versions have 2 MRVs	1,300nm
SS-N-7	1 'Yankee II' (for trials)	12	MRVs or MIRVs	2,000nm
SS-N-8	18 'Delta I' and	12 in 'Delta I'	One of 1MT	4,200nm
	4 'Delta II'	16 in 'Delta II'	One of 1MT	
SS-N-18	13 'Delta III'	16	MRVs	5,200nm
SS-NX-20	1 'Typhoon'; 1 more building	20	MIRVs	4,500nm; believed to use solid fuel

Note:
MRVs (Multiple Re-entry Vehicles) are nuclear warheads which are dispersed more or less randomly on separation from the missile.

MIRVs (Multiple Independently Targeted Re-entry Vehicles) are nuclear warheads which are contained in a 'bus'. The 'bus' separates from the missile and continues on a ballistic trajectory towards the ground. The 'bus' contains up to 10 separate warheads and it can alter course in space. At the appropriate moment, each warhead is ejected according to instructions given it by an onboard computer; thus each warhead can be dispersed to a different target. The 'bus' can also eject a number of decoys to confuse the enemy's anti-ballistic missiles (ABMS).

MARVs are MRVs which can weave on their downward path to make them more difficult for an ABM to intercept.





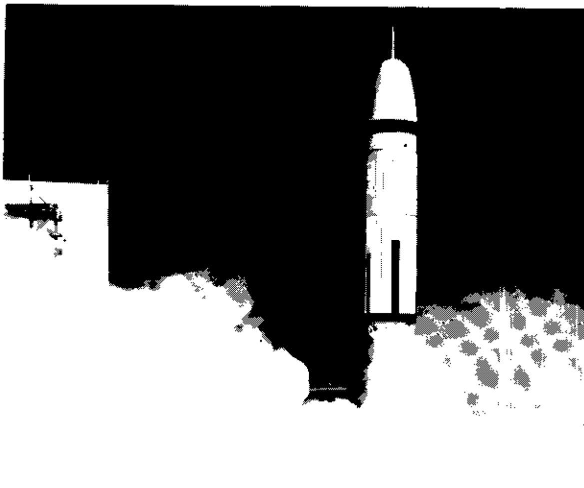
Above left:
Carrying out checks in the missile compartment of a British SSBN. One of the Polaris missile tubes can be seen on the right.

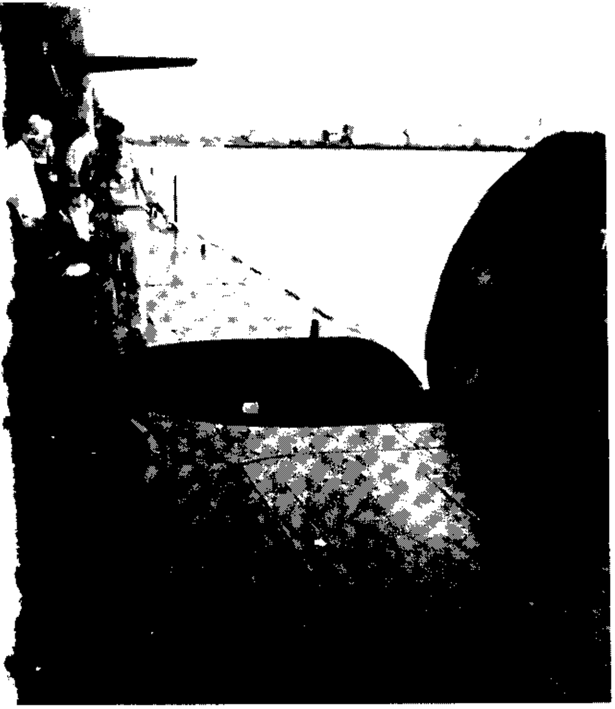
Above right:
Open missile launch tubes on a US SSBN.

Left:
The ballistic missile compartment on board the SSBN USS *Ohio*.

Below:
First launch of the Trident missile, at Cape Canaveral. The missile was launched from a flat pad.

Right:
A Poseidon is launched from the USS *James Madison*.





Cruise Missiles

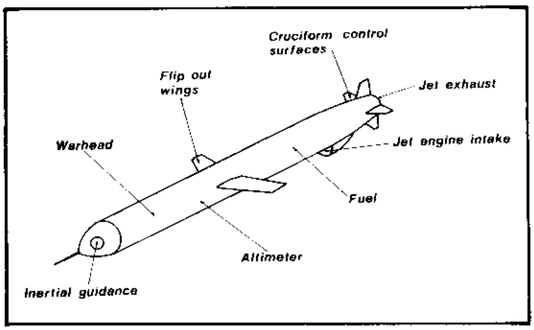
All American SSNs are to be fitted with General Dynamics Tomahawk cruise missiles with a considerably extended range in place of the Sub-Harpoon. Tomahawk will be launched from the torpedo tubes, and submarines can carry two versions, one for anti-ship use with a range of 244nm, and the other with a range of 1,355nm for use against land targets. In both versions either nuclear or HE warheads can be used.

To attack targets on land, a guidance system called TERCOM (Terrain Contour Matching) is used coupled with inertial navigation. The latter takes the missile to a predetermined point on the coast-line, and from there on compares the contours of the ground with a contour map held in the missile's computer. This enables a continuous appraisal of position and any course corrections necessary can be made. The system sounds difficult, but is similar to the ground launched cruise missile, and many trials of SLCMs have been carried out in the USA with outstanding success.

The anti-ship version of Tomahawk uses a specially modified version of the active radar guidance system found in the normal Harpoon missile. It enables the missile to be launched in the general direction of the target, using inertial navigation, and at a pre-set distance from the target the radar is activated, searches for and acquires the target and guides the missile to hit. In this respect it is very similar to Harpoon, but presumably the radar has a much wider arc of search. The anti-ship version can also be fitted in surface ships.

Both versions in submarines are contained in a stainless steel canister which is loaded into the torpedo tube. On launch the canister and the missile are ejected, the canister is separated from

Below:
A typical cruise missile exemplified by Tomahawk. The missile is powered by a small air-breathing jet engine which gives long endurance at high subsonic speeds.



the missile and a boost motor propels the missile through the water and up to the surface. Once in the air, the boost motor is jettisoned and a turbofan cruise motor keeps the missile in flight until the end of its mission. Cruising speed is 479kt and the missile flies very low to avoid detection by enemy radars. The anti-ship version of Tomahawk is being fitted in some 70 US nuclear attack submarines, but how many have been fitted so far is not known.

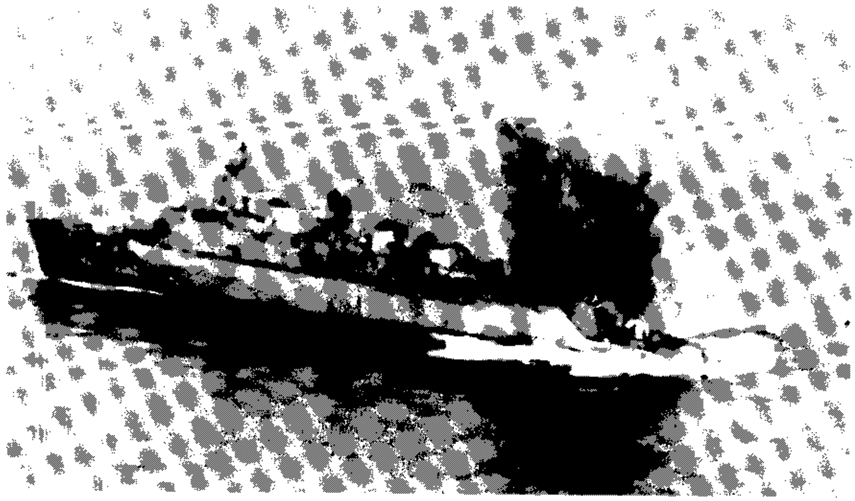
The Soviet Navy has at least two SLCMs but their ranges are only about 60nm and they are purely anti-ship and cannot be used against land targets.

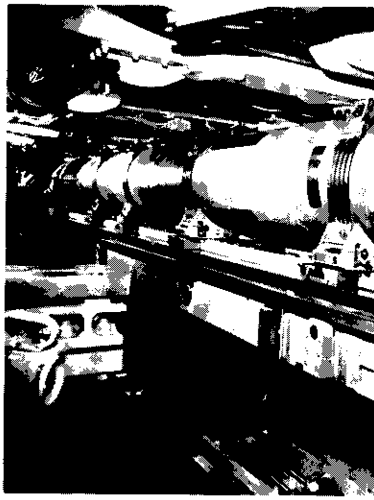
Torpedoes

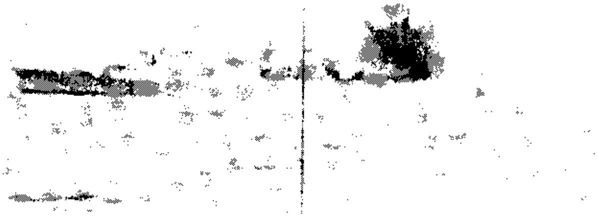
It will be appreciated that strategic ballistic and cruise missiles are not really naval weapons. The real naval weapon of the submarine is and has always been the torpedo, although it is likely that the tactical submarine-launched anti-ship missile, now being generally fitted, may replace it.

All nuclear attack submarines carry torpedoes. The number of torpedo tubes fitted varies somewhat, but in general the figure is between four and six. The latest US 'Los Angeles' class has four tubes, the British 'Swiftsure' class has five, whilst the older 'Valiant' and 'Churchill' classes have six. Up to 26 reload torpedoes can be carried in some classes, but the new French 'SNA72' class vessels can carry only 10 because the submarines themselves are smaller than the British or American.

All torpedoes are 21in (533mm) in diameter. The British, French and Americans use wire guided torpedoes; the British Marconi Mk 24







Above left:
A patrol aircraft's view of the Tigerfish torpedo striking the hulk of the decommissioned destroyer HMS *Devonshire* in 1984.

Left:
A distant shot of the Tigerfish hitting HMS *Devonshire*, taken through the periscope of the fleet submarine HMS *Splendid* in 1984.

Above:
A Mk 48 torpedo in the torpedo room of the USS *Ohio*.

Right:
A Mk 48 torpedo is lowered into the torpedo room on board a US SSBN.

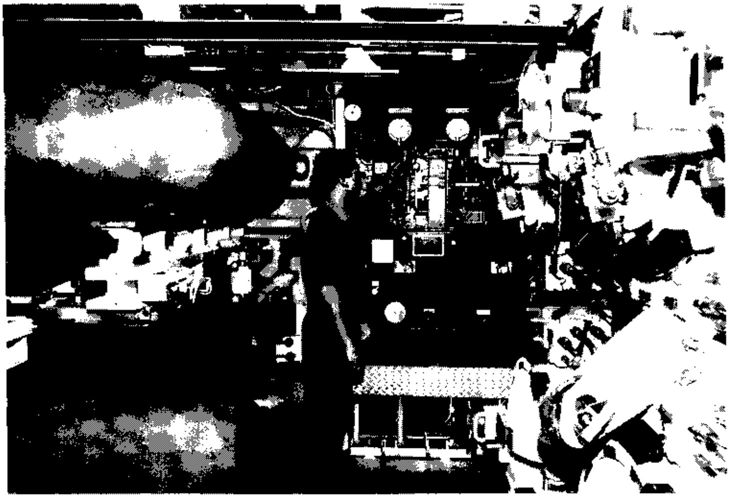
Above right:
Checking instruments in the torpedo storage area on board a British SSBN. Six torpedoes are carried in six torpedo tubes; these torpedoes are spares.

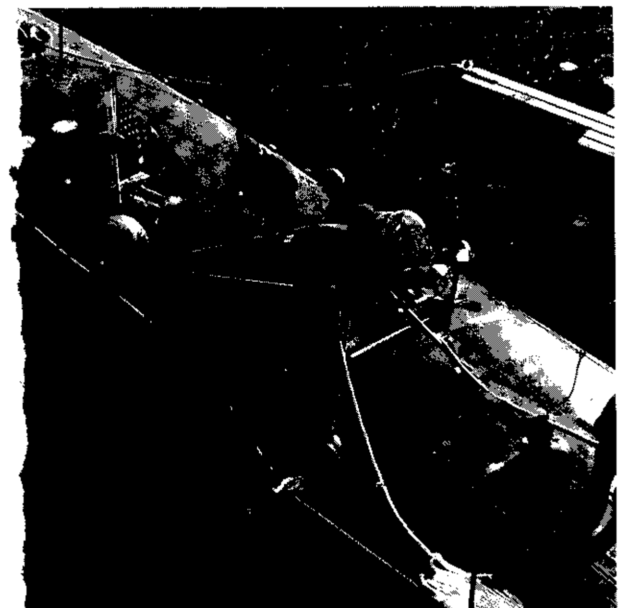
(known as Tigerfish), the Americans the Gould Mk 48, and the French the F17P.

The Mk 24 (Tigerfish) is 6.46m long and weighs 1,550kg. Its maximum speed is 50kt and its range is reported to be about 10nm. Electrically driven, it has contra-rotating propellers and two speeds — high and low. The high speed is used for its initial run to the vicinity of the target and the operator can switch it to low speed, by a signal down the wire, when it goes into the search mode.

On being launched, the wire is played out both from the submarine and from the torpedo. The submarine's computer has the position of the target and steers the torpedo towards it. On arrival in the target's vicinity, the torpedo is put into the search mode and it then carries out a computerised, pre-programmed search. During the final homing run the torpedo's computer interprets the data from the homing sonar (which can be active or passive) and calculates and orders the appropriate course to be steered, although the operator onboard the submarine can override the torpedo's computer and alter the course of the torpedo to miss if for some reason it is necessary to abort the attack (eg the target suddenly proves to be friendly).

Tigerfish has had a number of modifications made to it. One has been to improve the torpedo's homing capability on surface targets when coming up from deep. The torpedo is optimised for attack against submarines, since this is the main target of an attack submarine. It is unfortunate that the same torpedo has to be used against ships where it is not quite so effective, but it would be impossible to carry two different types of the same torpedo.





Tigerfish's range, although a great deal longer than previous British torpedoes, is too short for modern warfare, so a relacement, called Spearfish, is under development by Marconi Underwater Systems. It is to have a greatly increased range (said to be possibly as much as 35nm), a higher speed of 70kt and a deeper diving capability.

The American Mk 48 is 5.8m long (about 0.7m shorter than the British torpedo, which facilitates handling). It weighs 1,600kg (slightly heavier than Tigerfish), has a maximum speed of 55kt, and its maximum range is stated to be 19nm. Like Tigerfish there have been a number of modifications to it, the latest being the ADCAP improvement programme started in 1979. It includes a new guidance system by Hughes, to enable it to deal more effectively with the fast deep-diving submarine. It is able to run deeper and makes less noise than the original torpedo. ADCAP also includes better shallow water performance, and better performance under ice.

against doppler targets, in strong thermal gradients and in high sea states. A higher powered active sonar is fitted which will enable the torpedo to search a greater volume of the sea. The sonar array is electronically steered, reducing the need for the torpedo to manoeuvre whilst searching.

Unlike the electrically driven Tigerfish, the Mk 48 is driven by a 500hp six-cylinder two-stroke swashplate engine using Otto fuel, which is a nitrogen-based fuel enriched by an oxidiser that allows the engine to operate independently of outside air. The ADCAP modification has run into some trouble with the Oto fuelled engine, and the modification is not yet in service.

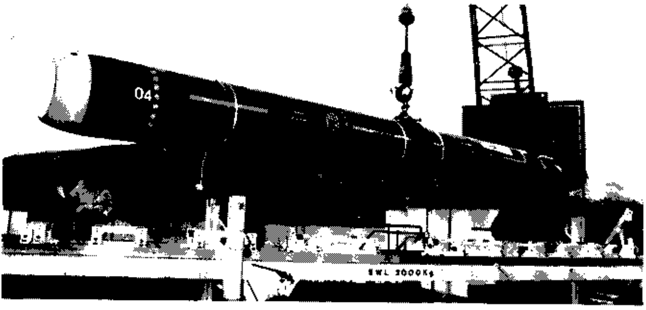
The French use the F17P wire-guided torpedo with a sonar homing system. The weapon is normally launched in the wire-guided mode, but it can be launched in the 'automatic' mode which means it has no wire guidance. It is 5.620m long and weighs 1,320kg. Maximum speed is 35kt and maximum depth 500m. It carries an explosive charge of 250kg. Its range is not disclosed, but it is probably about 10nm. Propulsion is electric.

Nearly all submarines launch torpedoes from bow tubes, but the Americans, in their latest class of SSN, the 'Los Angeles' class, have gone in for a different arrangement. The vessels have four 21in torpedo tubes mounted on either side of the hull roughly amidships. This is because the greater part of the space in the bows is taken by by the large BQQ-5 sonar dome which contains transducers for the active element of the sonar. From SSN-719 onwards there will be 12 Tomahawk launchers in each submarine, mounted in the space between the BQQ-5 dome and the fore end of the pressure hull, in special launch tubes and not torpedo tubes.

Soviet Submarine Torpedoes

Few details of Soviet torpedoes are known. Most of them are 21in as used in the West, and it appears that they can carry either nuclear or conventional warheads. When the Soviet 'Whiskey' class submarine ran aground in Sweden, the Swedes estimated that the torpedo nuclear warheads onboard would have a yield of 15kT.

Torpedo propulsion is by steam or electric



Left:
Spearfish, the new British heavyweight torpedo by Marconi Underwater Systems. It is reputed to be able to achieve a speed of 70kt.

Below:
The AN/BQQ-5 sonar room on board a 'Los Angeles' class nuclear attack submarine.

Right:
The submarine-to-surface Harpoon missile being lowered below in a US attack submarine.

motors. They are either straight or pattern running with acoustic homing: wire guidance does not yet seem to have been introduced.

Whilst the Soviets have dual purpose warheads (anti-submarine and anti-ship) they also are said to have designed torpedoes for anti-ship use only, and some specifically for anti-submarine use.

Submarine Launched Tactical Missiles

A weapon which is coming more and more into use in NATO submarines, and which is also in use in Soviet submarines, is the submarine launched anti-ship missile.

In NATO are two main types of missile which have been adapted for submarine use — the US McDonnell Douglas Harpoon and the French Aerospatiale Exocet SM39. Both are basically the normal ship-to-ship missile; Harpoon has a range of 60nm and Exocet 26nm. The British are fitting the Sub-Harpoon in an increasing number of SSNs, and the US 'Los Angeles' class will also have it. The missile is 21ft long and is launched from a torpedo tube in an expendable capsule; this rises to the surface and is disconnected when the missile's engine ignites, its fins extend and it takes off, assuming a similar flight path to that when it is launched from a surface ship. The new class of SSN in France — the SNA72 — will carry the Exocet SM39, similarly enclosed in a capsule and launched from a torpedo tube.

The Soviet Navy has three submarine launched missiles, the SS-N-7 (NATO code name 'Siren'), the SS-N-9 and the SS-N-19, with yet another under development — the SS-N-21. The SS-N-7 was the Soviets' first underwater launched anti-ship missile and has a range of 30 to 35nm. It is a radar homer and can carry nuclear or conventional warheads. It is fitted in the SSN 'Charlie I' class, and the SSGN 'Charlie II' class, although some of this latter class have got the SS-N-9.

The SS-N-9 can be launched from surface ships or submarines and has a range of 60nm, but mid-course guidance is required for maximum range. It is slowly replacing the SS-N-7 and may be fitted in the one 'Papa' class submarine so far built.

The SS-N-19, so far as is known is only fitted in the 25,000-ton 'Kirov' class of battle cruiser and the large SSGNs of the 'Oscar' class. Each of the 'Oscars' is to carry 24 missiles reported to have a range of over 250nm.

A feature of Soviet underwater cruise missiles is that, unlike those in NATO, they are carried in special tubes mounted on top of the pressure hull. The tubes lie flush with the upper deck and are raised to an angle of about 40° before firing from submerged. In the British and American systems at least one torpedo tube may have to be kept loaded with an anti-ship missile to the detriment of the submarine's anti-submarine capability.

Missile Carrying Depth Charge

There is one other ASW weapon carried in American and Soviet submarines. It is an underwater launched missile which rises to the surface and then flies like a missile, until over the target, when it drops a nuclear depth charge or bomb. Called SUBROC by the Americans, it is launched from a normal torpedo tube by conventional means, and, after a short underwater path (which need not be in the direction of the target) it rises to the surface and takes off, proceeding through the air like a missile and steering itself in the direction of the target by inertial means. On reaching the target area, a nuclear depth bomb is dropped and follows a ballistic trajectory to the point where it enters the water. It then sinks and is self detonated at a predetermined depth.

The lethal range is a matter of conjecture. The nuclear bomb is equivalent to 1kT of TNT and if it explodes below the target would probably destroy the target's pressure hull at ranges up to 2km, but the pressure wave caused by the explosion might put the enemy submarine out of action at much greater ranges by blowing all internal fittings off their seatings and generally causing havoc inside the submarine. Explosions above the target have a much shorter lethal range. The actual range of the SUBROC missile has never been officially published, but it is believed to be 35 to 40nm. The weapon is fitted in quite a number of SSNs.

SUBROC has the advantage of not giving away the position of the launching submarine, but it is not sufficiently accurate to carry a conventional warhead, nor was it designed to carry a homing torpedo, as do the similar ship launched weapons — ASROC and Ikara. As the first use of a nuclear weapon, even under the sea, will for NATO probably not be possible, a nuclear-only weapon is of little value in the opening stages of a conflict, so a new system is under development in the USA, called the stand-off ASW weapon (SAW). It is similar to SUBROC, but can be launched both by submarines and by ships, the latter by vertical launch. It can carry the Mk 46 ASW homing torpedo or the new Advanced Lightweight Torpedo under development, or, if necessary, a nuclear depth bomb. Its range is presumably of the same order as SUBROC.

The Soviet equivalent to SUBROC is the SS-N-15. It carries a nuclear warhead but whether this is dropped, or the whole missile dives into the sea, is not clear. It is reputed to have a range of 20nm. Like the Americans, but a little earlier, the Soviets evidently realised that any future war may not necessarily go nuclear, so they have developed the SS-N-15 to carry a homing torpedo which is parachute dropped from the missile near the target. The missile is launched from a tube which is said to be larger than the normal 21in torpedo tube. It is fitted in the 'Oscar', 'Papa' and 'Charlie' class submarines.

Conventional Submarines

The weapons carried by conventional submarines are similar to those carried by nuclears. Some conventionals are fitted with the latest wire guided torpedoes and the submarine launched missile. Whilst the torpedoes in use by SSNs have been mentioned, the West Germans have developed a very fine wire guided torpedo for their conventional submarines. Called the SUT, it is now coming into service; a version of it, the SST4, is being exported. Made by AEG Telefunken, the SUT is a development of the well-known Seal and Seeschlanger German torpedoes. It is a dual purpose weapon for use against surface craft or submarines, is electrically propelled and has active/passive acoustic homing. No performance details of it have been released but it is said to be 'long range'.

Whitehead Moto Fides of Italy is also in production with its A184 submarine or surface-launched, wire-guided torpedo, whose range is

stated to be greater than 14km (7.4nm). How much greater is not stated, but it is doubtful if it has a range approaching that of the American and British submarine launched torpedoes.

Other Weapon Systems

Two other weapon systems must be mentioned. Many conventional submarines are capable of laying mines which are discharged through the torpedo tubes. When on a minelaying mission therefore, the submarine is unlikely to carry its full complement of torpedoes.

The other system was developed by Vickers of the UK and is called SLAM. It consists of six Short Blowpipe missile launchers mounted on the fin and is for defence against helicopters when on the surface. It is remotely controlled from the control room using radar or thermal imager sensors. It was intended for the British 'Oberon' class but has not been generally fitted, neither is it destined for the new Type 2400s at present. It has however been sold abroad and at least one foreign navy has fitted its submarines with the system.

Command and Control Systems

Submarines need Command and Control systems just as much as surface ships. Usually the action information system is combined with the fire control system, the latter being the system for aiming the torpedoes and/or the undersea guided weapon (USGW).

SSBNs' fire control systems for launching their strategic missiles are entirely separate and are highly classified, so no information on them is available. However, SSBNs also carry torpedoes for use once their ballistic missiles have been launched, or, if for some reason they are deployed in the hunter killer role. Thus they must carry the same type of fire control system as any other attack submarine.

Similarly there is very little to choose between a conventional's control system and that of an SSN. Various new types of fire control systems are however being produced to take account of the new long range wire-guided torpedoes and also the underwater launched missile.

To obtain the maximum amount of information, virtually every type of sensor fitted in the submarine feeds into a central computer which sifts and analyses the detections and displays them on a tactical display. Sensors can include any or all of the following.

Underwater

Sonars, both active and passive and including towed arrays
Sonar path predictors
Bathythermographs
Sonar intercept receivers
Underwater telephones

Above Water

Radar
ESM Receivers
Infra-red sensors (thermal imagers)
Periscopes
Laser rangefinder
Image intensifier fitted in a periscope
Low light TV
Radio communications with both the shore and co-operating aircraft

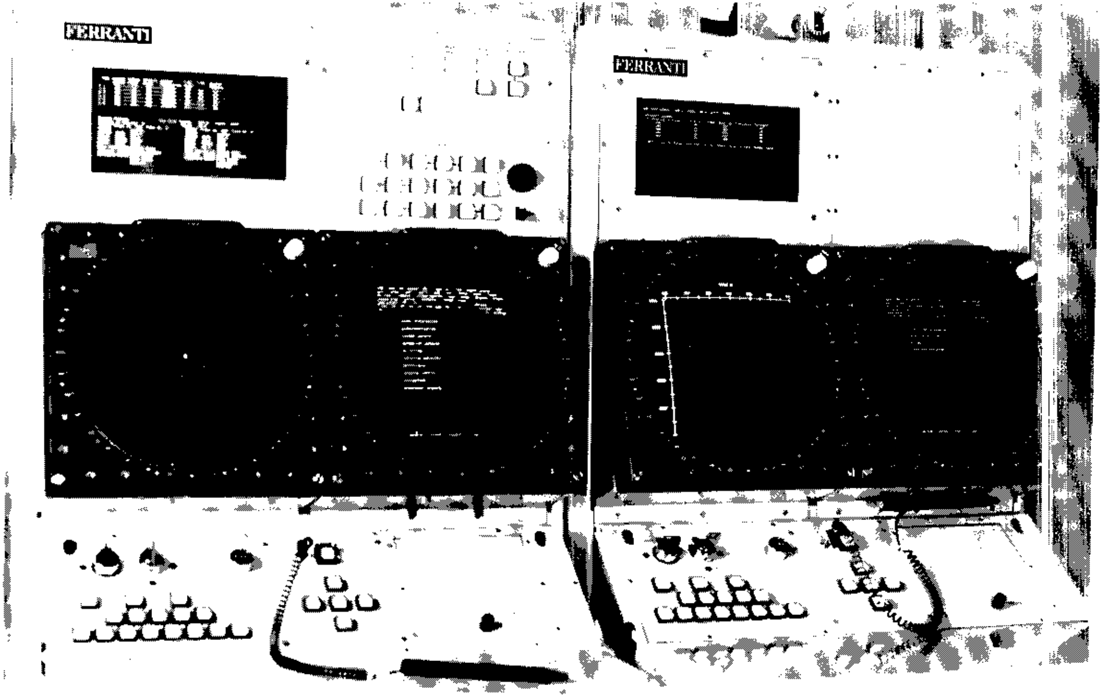
As passive sonar is used more frequently than active, arrangements have to be made to plot the tracks of targets and from these deduce their ranges. Thus the main tactical computer display should show target submarine tracks as well as their range, course and speed.

Fire Control

The job of the fire control system is to provide the command with the target's course and speed, and

Left:
A weapons readiness test in the missile control compartment of a British SSBN. The weapons engineer officer (WEO) in the foreground can be seen holding the trigger which would fire the missiles.

Right:
The missile launch operating panels on board the SSBN USS *Lafayette.*



its anticipated position when the submarine's weapon strike takes place. Since both the course and speed of the target may vary during the course of the run of the torpedo, the latter is fitted with its own computer which can originate a predetermined search pattern. In addition, the torpedo is fitted with an active and a passive sonar homing device, which once the torpedo had found the target should accurately home it to hit. Of course, one of the big advantages of wire guidance is that the torpedo's course can be altered by command from the launching vessel to take account of any changes made by the enemy during the torpedo's run. One other job for the fire control computer therefore is to display the position of the torpedo as well as that of the target. Assuming a maximum torpedo range of, say, 20nm and a maximum torpedo speed of 55kt, the time taken for the torpedo to reach the target area will be anything up to 22 minutes, ample time for the target to make a number of alterations of course.

If a USGW is to be launched, the fire control problem is not so great. The submarine should be able to get a fairly good estimate of the range of the surface target even though only using passive sonar, and be able to predict its course and speed. The missile has to have its starting position and the estimated position of the enemy ship on impact fed into its intertial navigation system, together with the moment at which its radar should open up. The problem is however simplified by the fact that the speed of the missile is so much greater than that of a torpedo. Of course the actual distance of the target at the moment of firing may also be greater, say up to 60nm, but the missile's active radar has quite a large arc of search and so should be able to take care of any alteration of target course, which in any case is unlikely to be made before the oncoming missile is detected, which may well be only a minute or so before impact.

Above:
An action information and fire control system for conventional submarines developed by Ferranti and known as KAFS.

The Americans, with SUBROC, have one other problem. The point at which the nuclear depth bomb must be released in order to get the bomb as near as possible to the target has to be predicted. In addition, the missile has to commence its airborne run absolutely level for its inertial system to be set. An additional computer is therefore carried to perform these two functions.

There are a number of submarine command and control systems on the market, of which perhaps the best known is the US system made by Singer Librascope Division and known as FCS Mk 113 Mod 8. It is the standard system in use in many American SSNs. In the UK the comparable system is the Vickers TIOS-E, which uses Ferranti computers and a Gresham Lion fire control system. Furthermore, a new company formed by Gresham and the CAP Group (specialists in software) is developing a new tactical system for future submarines. Ferranti also makes a tactical system, called KAFS, which has been operational in some British submarines for some years, but has only recently been released for export.

7 Submarine Sensors

Whilst undoubtedly sonar is the main sensor of any submarine, there are a number of others. Perhaps the most important is the Periscope, followed by Electronic Support Measures (ESM), and Radar. Then there are a number of devices, principally for seeing in the dark, such as Thermal Imagers, Image Intensification, and Television. Finally there is a radio communication intercept facility and often a Laser Rangefinder. All of these except sonar are for use above the surface of the sea; in other words the sensor must be exposed. It follows that a modern submarine must have a large number of telescopic masts which can be raised above the surface when required and lowered again when not required. To use any of the sensors therefore, the submarine must be at periscope depth.

A modern conventional or SSN will probably have up to seven masts, any of which can be made to protrude from the top of the fin. They are as follows:

(a) A snort induction mast (not a sensor)
(b) A snort exhaust mast (not a sensor)
(c) A search periscope
(d) An attack periscope
(e) A communications mast (not a sensor)
(f) An ESM mast
(g) A radar mast
(h) A satellite communications receiver mast (not a sensor)

In fact, although many modern submarines do have as many as seven masts, normally it is possible to combine some of the systems on one mast or periscope. For example, the ESM antenna may be fitted on the periscope or the communications mast, and the thermal imager is often combined with one of the periscopes.

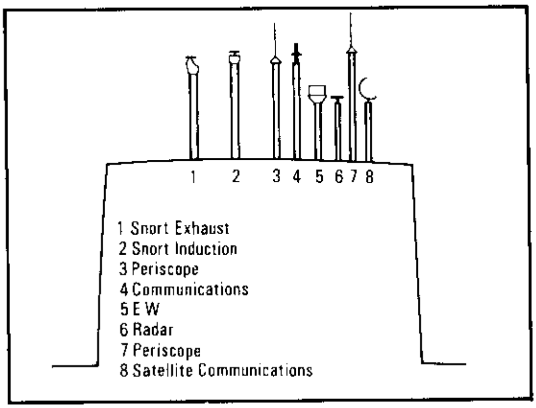
Let us look at all the sensors in turn and discuss their function and value, starting with by far the most important — sonar.

Sonar

It would be nice to report that NATO had at least made a real breakthrough in submarine sonar detection of other submarines, but alas such is not the case, nor is it likely to be in the forseeable future. The laws of physics still apply and it is just not possible materially to increase the maximum range an underwater object can be detected by sonar. Sound is still attenuated by water, the sea is still full of a thousand and one minute noises, and there are still thermoclines and temperature layers, all of which do not help sonar detection, although the last one — temperature layers — can increase ranges considerably if the sonar sensor happens to be in the same temperature duct as the target submarine.

However, this certainly does not mean that there have been no new developments in sonars. Scientists and engineers have been working hard on the difficult task of recognising the acoustic noises made by a submarine from all the other noises in the sea, and analysing the returning echo from a submarine. In addition, great improvements have been made in recognising non-sub echoes of rocks, wrecks, fish and whales. More important perhaps in the submarine world, where passive sonar is used a great deal more than active, is the ability to recognise and analyse the sounds made by a submarine proceeding through the water and the sounds made by its engines and ancillary machinery. It is now possible to keep a record of the types of noises made by different classes of submarines, and to store them in a computer library.

Below:
A typical mast arrangement.

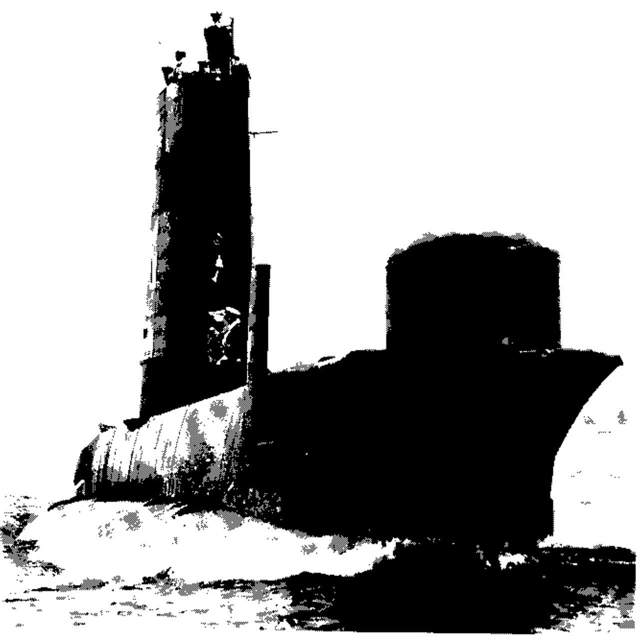


Behaviour of Sound Waves

We now know a great deal more about the behaviour of sound waves under water. The principles of thermoclines and temperature ducts have long been understood, and the use of bathythermographs to determine where they exist is commonplace. Less well known, however, is the manner in which sound waves can be reflected or refracted upwards by the increase of water density with depth, until they reach the surface where they are reflected back again to the denser water where, once more, they are bent up again, and so on. This effect gives rise to what are known as 'convergence zones' near the surface, where the sound waves are strong over a small area, with gaps of many kilometres between them where they are non-existent. Other phenomena include active sonar waves being reflected off the bottom of the sea bed and returning to the surface many kilometres away (23km with a sea bed at a depth of 5,000m); this is known as 'bottom bounce'. Similarly, sound emitted at great depth can travel upwards to the surface and be refracted back and carry on travelling on this up and down path for a considerable distance.

Limiting the distance travelled by sound is the fact that sound is absorbed in water in proportion to the distance it travels, and also in proportion to the frequency of the sounds; the lower the frequency, the less the absorption.

By predicting these various acoustic features — and sound path predictors now exist — it is possible to take advantage of them. For example, modern long range active sonars tend to be of very low frequency. Similarly, the low frequency sounds emitted by submarines will be picked up farther away than will high frequency sounds. Thus submarine designers pay particular attention to suppressing low frequency sounds in the machinery inside the boat.



Towed Arrays

Undoubtedly, the most reliable method of detecting the noises made by a submarine is by an array of hydrophones (passive sonar) towed well astern of a ship or submarine — the towed array. The array consists of a line of hydrophones, one behind the other stretching for about 200m and towed by a cable, which also carries electrical wires, which is anything up to 1,000m long and is neutrally buoyant so that it does not sink to the sea bed if the towing vehicle should stop. Such an array achieves a much larger receiving aperture than would be possible if it was arranged round the hull of the towing vehicle, and it can be towed at a selected depth dependent upon the previously ascertained sonar conditions. Passive sonars can detect submarines at very much greater ranges than can active sonar (pinging), because with the latter, the sound has to travel to the target and back again.

A towed array's hydrophones cannot distinguish from which side the sound is coming, but it can determine bearings or their reciprocal, and after a few have been plotted by a computer, the actual direction of the target will become obvious. The array is well away from the noises generated by the towing vehicle's own propeller and this helps it to pick up the sometimes very faint noises made by a submarine. However, its own motion through the water generates noise which increases with speed. Ideally it should be towed at a very slow speed, and it need not necessarily be towed by a combatant vehicle at all; but in general it is only fitted in submarines and some surface ships.

Submarine Towed Arrays

Submarine towed arrays originated in America and the US Navy used to designate them by a particular type number. For example, the designation for the towed array specifically designed for use by SSBNs, and by some SSNs, was known as the AN/BQR-15. However, today towed arrays form part of a complete sonar system, thus we find that in the latest SSNs — the 'Los Angeles' class — that there is one sonar

Left:
An older type of conventional submarine, HMS *Sealion*. The sonar dome on the bow has now been placed below decks in newer submarines and no longer protrudes.

system only, known as the AN/BQQ-5 and that it includes a towed array. Similarly in the latest SSBNs — the 'Ohio' class — there is the AN/BQQ-6 which also includes a towed array.

The original towed array in US submarines was fitted to be towed from a fixed point on the hull of the submarine. This must have been very awkward as presumably it had to be slipped and picked up by a tug, or similar type of ship, before entering harbour, and reconnected on going to sea. Now, however, the US towed arrays are recovered and streamed by the submarine itself and are stowed in recesses down either side of the hull but outside it. The towing cable is believed to be coiled down inside one of the ballast tanks.

Britain reveals little information on submarine sonars, but British submarines are known to use towed arrays. There appear to be two types, the Type 2024 which was procured from America and the Type 2026 which was developed by Marconi Avionics and is fitted in some, but not all, RN submarines.

France is reported to have a surface craft towed array under development; however no mention has yet been made of a towed array for submarines, but with the advent of France's new SSNs it is bound to come. In 1983 the US Government stated that the new Soviet 'Victor III' class of submarines can tow an acoustic array from the top of a vertical fin.

As there is more information available on the US BQQ-5 towed array for submarines than on any other, perhaps a brief description of it will show roughly what form other navies' arrays will take. The array itself consists of some 600 hydrophones 0.3m apart strung one behind the other. This makes the array about 200m long, and it is reported to be 82.5mm in diameter. The array is towed by a cable 800m long and 5mm in diameter. The cable and the array are neutrally buoyant and the drop with the towing vehicle proceeding at only 2kt is said to be about 15m.

Ranging

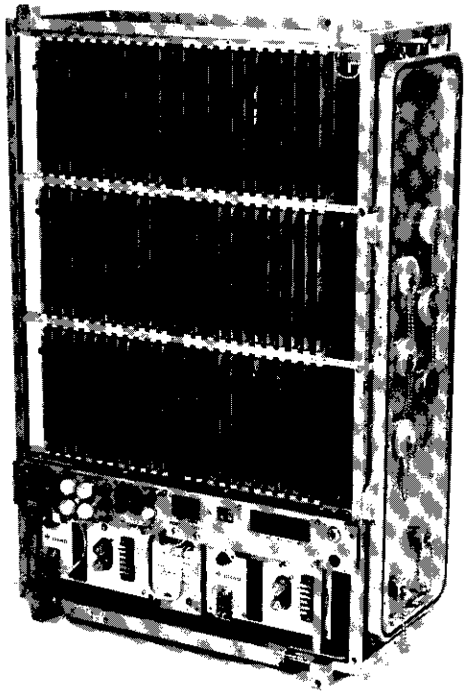
Whilst passive sonar arrays are excellent for initial detection, it is vital to obtain the range of the target if any form of weapon is to be fired at it. Of course range can be obtained by using an active sonar, but this is likely to give away one's presence to the hostile submarine, the one thing any submariner intent on making an attack wants to avoid. Considerable thought has therefore gone into ranging by passive means and it has now become possible to obtain reasonably accurate ranges without having to transmit a sonar signal at all.

There are various methods. One is for the submarine's hull-mounted passive sonar and the towed array to take bearings of the sound source. With the reasonably long baseline formed by both the towing vehicle and the towed array working together, the bearings should cut at a distant point and a computer can then determine the range by trigonometry. Another method is to take and time a series of bearings. Given an estimate of the target's speed, a computer can work out the course of the target and calculate its range. Such a system is used in a new passive sonar recently unveiled by Ferranti of the UK. By plotting the bearings against time, a course of the target together with its range can be shown on a vertical display.

Yet another method is the Sperry (USA) Micropuff system. Here there are three hydrophones, mounted as far apart as possible, along each side of the submarine's hull. The sound waves emanating from the target arrive first at the hydrophone nearest to it, then at the middle hydrophone and finally at the one which is farthest away. If the time of arrival at each point is accurately measured, and the distances between the hydrophones are known, simple geometry can then calculate the target's range from the centre hydrophone. In all these methods the range may not be very accurate, hence the necessity for a homing torpedo.

Towed arrays have undoubtedly helped in the

Right:
The Plessey Marine 2020 submarine sonar which is currently being fitted to some RN 'Trafalgar' class submarines.



Above left:
The French submarine sonar 'Eledone' display console.

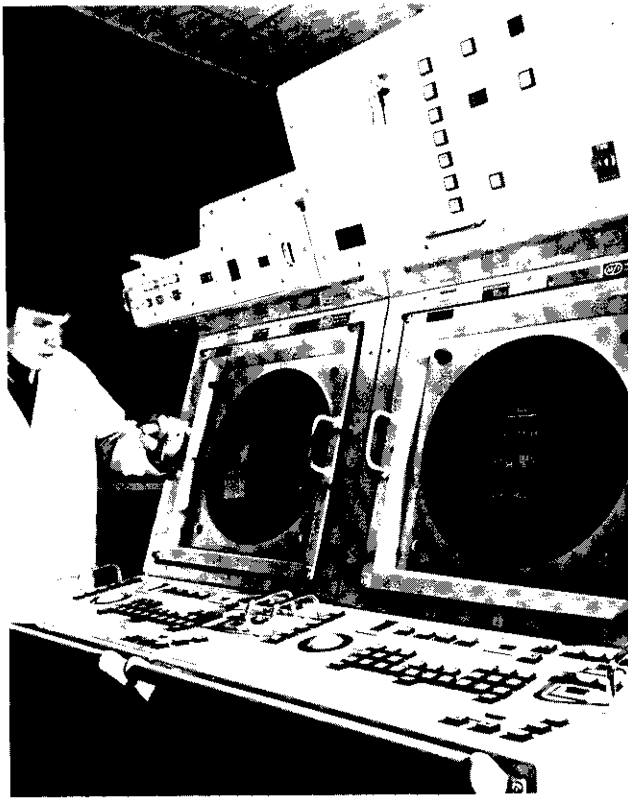
Left:
The data processing cabinet of the Thomson-CSF 'Eledone' sonar.

detection of submarines and they are constantly being improved. Now that sonar processors have become digital, as opposed to analogue, signal processing is so sophisticated that an analysis of the echo, or the received sound, can not only enable target submarines to be picked out from other extraneous underwater sounds or echoes, but has also made it possible to identify, within limits, the type of submarine detected.

Typical Sonar System

Whilst towed arrays are rapidly becoming all important, submarines do of course have other types of sonars. A typical attack submarine system might consist of the following.

- A passive sonar system on board the craft itself. Sometimes the receiving hydrophones are arranged round the hull, starting usually about



Above:
Operating the main sonar of the US SSBN *Ulysses B. Grant.*

Above right:
A Ferranti engineer carrying out final commissioning tests on the display console of the sonar equipment for the Royal Navy's latest attack submarines.

half way along the hull on one side, round the bow to half way round the hull on the other. The object is to keep the hydrophones as far away from the propeller as possible to minimise the reception of the noise it makes. Sometimes, however, the hydrophones are arranged in columns round a circular array protruding from the hull.

- An active sonar with the transducers for it mounted in a large dome either on top of the bow or below it. Alternatively the transducers may be mounted inside the bow itself. Low frequency sonars are extensively used nowadays as the sound waves they produce penetrate farther through the sea; consequently the transducers may be large and the domes in which they are housed verging on the enormous.
- An intercept sonar receiver or receivers. These listen for enemy transmissions and record them for analysis, at the same time taking bearings of them.
- A towed array.
- A number of computers and displays, the most important of which, to a submarine, is the all round display showing the detections made by the passive sonar (including the towed array). Targets can be labelled with their course and speed, or these details can be shown separately on another display.
- An underwater telephone for communication with other submarines or surface ships.

A Typical Submarine Sonar Outfit

Few nations release full details of their submarine sonars, but Thomson CSF of France has recently produced a new modular sonar system for submarines, known as Eledone, and the company's marketing overseas has given a reasonably full description of it. Since it is probably the best explanation of a modern submarine sonar available, it is reproduced here in a shortened form.

The Eledone Sonar

Eledone integrates all the main functions of a modern sonar on board submarines, as follows:

- Panoramic search in the passive listening mode, coupled with automatic tracking and processing of up to 12 simultaneous targets.
- Ranging by directive sonar transmissions, the returning echoes being received by the passive listening receiver.
- Full 360° interception of enemy sonar transmissions, with automatic detection and storage of the analysis results.
- Additional signal processing capable of being associated with each of the above functions, to give enhanced performance in specific areas, such as discriminating capability, spectral analysis, sound-field plots, etc.
- Processing the data from the different sensors for a tactical situation display.
- Fire control for torpedo launching and guidance.

The whole equipment is built on a modular concept so that navies wishing to confine themselves to the passive listening function, for example, need only select the corresponding modules and will consequently have a system that is easy to install. Alternatively, on board medium or large submarines it will be possible not only to install the major functions, but also to duplicate them and to equip the system with a second operator's console. The latter can then be used for attack purposes in complex tactical situations that may require two operators.

The Passive Sonar

The passive sonar consists of a circular array of 32 or 68 columns of hydrophones, and its diameter can be adapted to the submarine's dimensions. A total of 128 preset panoramic channels for all the versions are formed on the basis of this array, enabling a single electronic package to be used for each version.

There are simultaneous tracking channels for four to 12 targets with a direction-finding capability accurate to within one-tenth of a degree. A directional audio channel is preset separately. This channel is always useful to assist in unambiguous target classification thanks to good frequency-wise selection flexibility. The transducer and signal processor are very sensitive giving greatly extended detection ranges, the improvement over equipment designed in the 1960s being better than 10 decibels.

The Active Sonar

The active sonar facility is often considered to be the least important for a submarine, generally required to exercise maximum stealth. Consequently the Eledone system is a simple and low cost one. It has an unsophisticated transmitter with directional transmitting arrays, but its performance is good, thanks to the reception being by the passive array and the listening circuits. It is primarily used to obtain a snap range of a target detected only by the passive sonar.

Interception Equipment

Interception of enemy sonar signals is often vital to a submariner. It may well be that it is the first indication of the presence of an enemy surface ship, submarine or helicopter with dipping sonar. It is of course necessary to recognise the type of sonar intercepted and to be able to say from what type of craft the transmission emanated. A store of known sonar signals is therefore kept in the submarine and a computer will consult it when an interception is made and will indicate the platform from which it probably emanated. As it is possible to intercept a sonar transmission at a much greater range than the transmitting vehicle can obtain an echo, an intercept receiver is a very useful warning device to enable the submarine to take evasive action. The Eledone intercept receiver is a 360° system and has an automatically triggered device which sounds an alarm when an intercept is made. Direction finding is embodied. The equipment also feeds the detections made into a store so that they can be subsequently analysed.

Displays

The main display console employs a coloured cathode ray tube, and different colours distinguish by which mode any information is obtained, eg active detection symbols might be coloured green, passive ones red, intercepted sonar signals blue, and so on. The console can be supplemented by a graphic recorder or a television screen so as to capitalise on the immense advantages offered by a 'waterfall' type display in passive detection.

A feature of the Eledone system is that the images corresponding to the different functional modes are correlated. For instance, passive listening targets may not correspond with sonar interceptions or vice versa; in addition, the fact that two images obtained by different modes are superimposed on the display makes instant classification of the targets possible. Another example is that if the intercept equipment detects a sonar transmission, but the passive listening sonar does not detect any water noises, such as might be made by a ship or submarine on the same bearing, it is a fair assumption that the intercepted sonar is a dipping sonar deployed by a helicopter.

Finally, the system has a built-in test system which not only locates a malfunction but evaluates it and causes an indicator lamp to glow on the faulty printed circuit boards involved. They can then be replaced without further adjustment.

Eledone's main sonar function can be supplemented with the following items:

- A bathycelerimeter which gives an extremely accurate measurement of the speed of sound in sea water as a function of the submarine's depth.
- A sound-field plotter to display the sound beams and thus ensure proper utilisation of the acoustic coverage dependent upon propagation conditions.
- A compact, acoustic underwater telephone for communication between submarines and surface craft.
- An acoustic distress beacon to enable searching craft to find the stricken submarine in the event of an accident.

Eledone can be operated by one man, thus reducing the size of the crew carried in a submarine.

Over 20 Eledone systems have been ordered by five European navies.

Submarine sonars are constantly being improved, but major advances are always kept secret for as long as possible. With the advent of the micro-chip, data processing and the analysis of underwater sounds becomes easier and takes less time. Towing cables for towed arrays should soon be made smaller in diameter and lighter, by the use of fibre optics instead of electric cables.

There is no reason why the sonar transmitter and receiver of an active system should be co-located. They are already separated by some distance apart with the transmitter on board a ship or submarine and the receiver at the end of a towed array. This enables the receiver to be placed at a different depth to the transmitter. Carrying this even farther, the transmitter and the receiver need not even be on or near the same platform. They could be stationed a long distance apart, with the echo being received by oblique reflection from the target. Again, it might be possible for the transmitter to be deployed from a helicopter whilst the attacking submarine receives the echoes from the target caused by the transmitted waves impinging on it. The target will naturally try to close the transmitting sonar, thinking it to be an enemy submarine, whilst the attacking submarine, remaining completely silent as far as its sonar is concerned, stalks the target quite unbeknown to those on board it.

These are but a few of the potential developments of the future, and they may be in operation much sooner than many suspect.

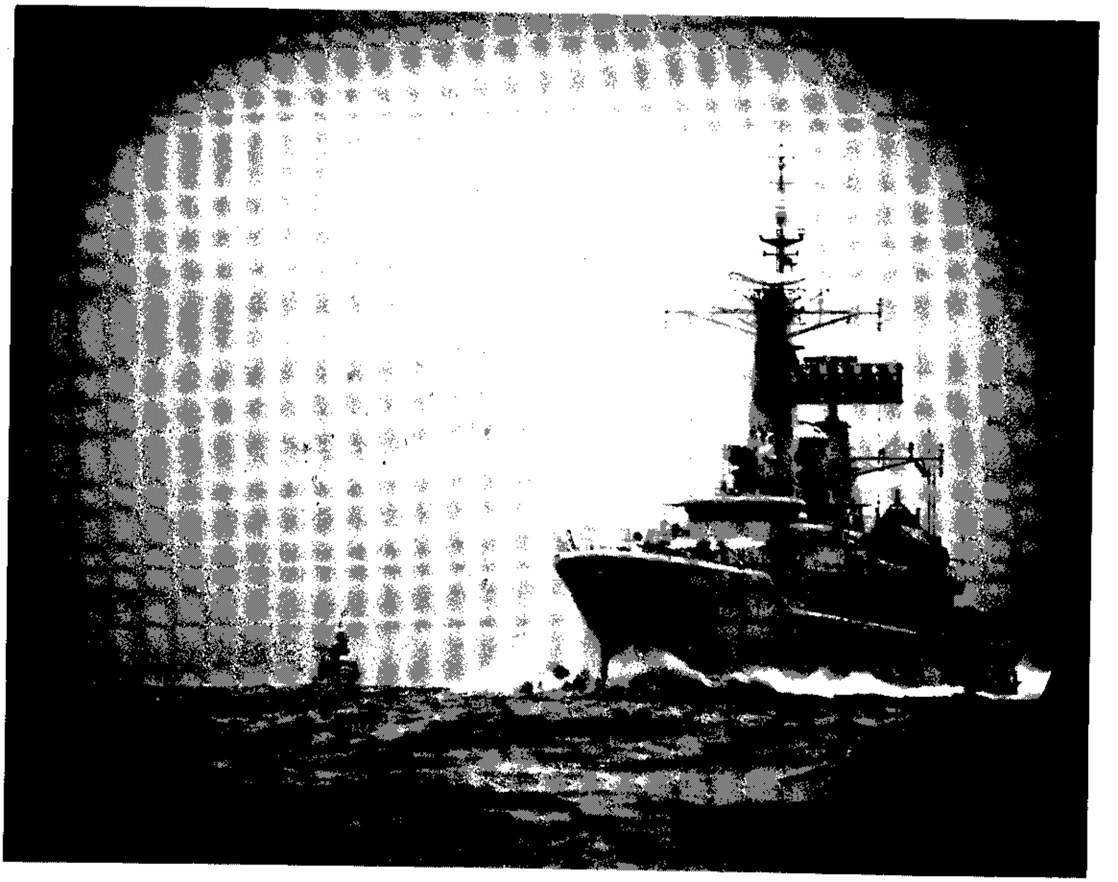
Periscopes

So much for underwater sensing. Now let us look at the submarine's traditional sensor for detecting and (perhaps more important) identifying ships and aircraft, the periscope.

All submarines have two periscopes, the Search and the Attack, but it is possible to combine them into one periscope standard. Periscopes are basically tubes with a lens at the top and a viewing device at the bottom in the control room. The viewing device may be of the binocular type or monocular, and various focusing controls are situated adjacent to it. In some cases viewing can be remoted to a display in the control room.

The search periscope has a wide angle field of view and the operator can tilt it to view the sky or the sea, or it may have a wide enough field of vertical view to see both at the same time. It can be rotated by two horizontal handles protruding from either side of the base of the periscope. The handles are normally folded up to lie alongside the

Right:
On board the SSBN USS *Ohio*. The officer of the watch looks through the search periscope.



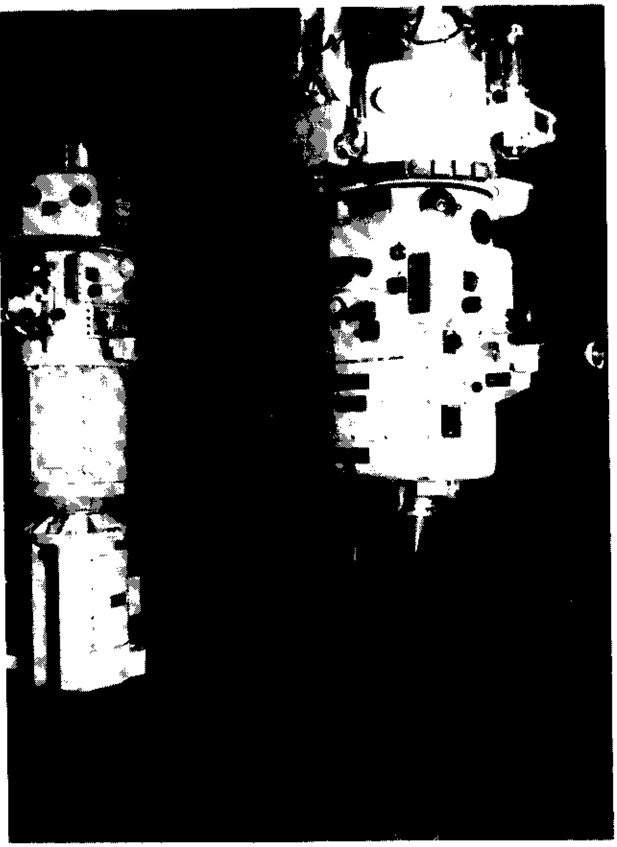
periscope when it is lowered to its down position. The operator can press a button on one of the handles and an electric motor will help rotate the periscope. Alternatively, he can connect a more powerful motor which can rotate the periscope through a 360° search without manual assistance. This is very useful if a remote viewing display is fitted, and avoids an operator having to walk round, looking through the viewer all the time.

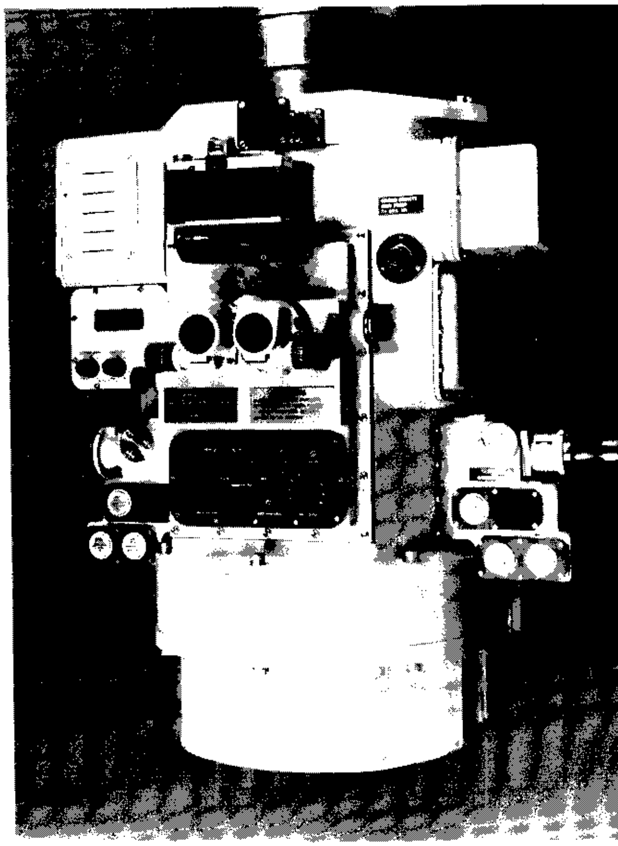
Periscopes can have a window at the top and the eyepiece at the bottom heated, and there are facilities for desiccation. In addition there are a number of other devices which can be embodied in the periscope. These include an ESM antenna; an active receiver antenna for the interception of enemy radio communications; and a still camera with up to 250 frames per film on which the time and bearing are injected and printed.

On the optronic side, an image intensifier can be fitted, giving improved vision at night to near starlight conditions with a high resolution. Alternatively a thermal imager can be fitted. It can be viewed from the eyepiece, or relayed to a remote monitor and/or a video tape recorder. It gives the periscope a day or night capability and enhanced detection and identification in haze, mist or sun glare conditions. A 16mm TV camera can be fitted in the control room to relay the optical or image-intensified picture to a remote monitor or video tape recorder with provision for alpha-numeric insertion of data. The bearing on which the periscope is trained can be displayed in one of the eyepieces, as well as remotely. Finally, sights of heavenly bodies can be taken through the periscope which is fitted with a sextant and an artificial horizon.

The attack periscope can have most of the additions listed for the search periscope, but not the sextant and artificial horizon. In addition, however, it can have a laser rangefinder fitted with an accuracy of ±10m. Its line of sight is usually stabilised and range is displayed in the eyepiece or can be transmitted to the fire control system.

It will be seen that by fitting some of the additional sensors in the search periscope and others in the attack, it is possible to carry a large number of sensors and only a few masts. However, periscopes are getting so many bits and pieces hung on them that Barr & Stroud Ltd, the British firm that supplies periscopes to more than nine





Above left:
The 'Leander' class frigate *Diomede* (F16) seen from HMS *Onyx*.

Above:
Barr & Stroud attack and search periscopes in an RN submarine.

Above right:
A Barr & Stroud attack periscope fitted with thermal imaging. Barr & Stroud makes all British periscopes and a great many foreign ones as well.

foreign navies, has developed an optronic pod which gathers together all the additional sensors into one small pod which can be fitted on top of a periscope or on a separate mast. It contains:

- A radio communication intercept facility
- An ESM capability
- An integrated day and night thermal imaging facility, capable of searching rapidly for air and surface threats and relating them to ESM threats.
- Television

The prime purpose of the pod is to provide improved all-round watchkeeping and target acquisition facilities in intercepting radio and radar, and in day and night viewing at rotational speeds, decided upon by the operator. Data transmission from the sensors down to the displays in the control room is provided and the thermal imager has a 90° overhead coverage as well as the 360° in azimuth. The pod can be programmed to search the complete hemisphere automatically. Such a mode of operation ensures that the search is methodical and that no sector is either omitted or covered twice. During the search, a thermal picture can be recorded for subsequent evaluation. Speed and pattern of search can be changed to suit operational circumstances.

ESM

ESM equipment embodied in periscopes, as mentioned above, can also be supplied for fitting on masts; indeed, it is more common to have a separate mast. A submarine on patrol can anticipate maritime patrol aircraft, helicopters and surface ships as well as submarines. The air and surface craft are likely to use radar to try and detect anything a submarine might show above the surface. However, with ESM the submarine should be able to detect the radar transmission at a considerably longer range than the radar itself can detect the submarine's masts. Unfortunately, detection is not enough, because the submarine must know whether it has detected an enemy or a friendly radar. It is also necessary for the submarine to know what type of radar it has detected, and if possible what type of craft it emanated from. To do this, submarines, like surface ships, are provided with a computer library giving the parameters of all known radars, both hostile and friendly and both military and civil. To enter the library it is first necessary to collect all possible parameters of the intercepted radar. These include such things as frequency, pulse repetition rate, sweep rate, pulse length and so on. A modern ESM suite takes less than two seconds to do this and to present the answers to the operator. They would also automatically be fed into the library. The computer library's first action is to identify if the radar is hostile and, if so, to initiate an alarm signal to warn the submarine. Less than a second later it will display as many of the radar's parameters as possible and the type of platform from which it emanates. It will also show a 'confidence' factor and a rough bearing of the transmission.

Before exposing anything else in possibly hostile waters, the normal procedure is first to carry out an all-round ESM search. Most ESM equipments are all-round looking and no rotation of the antenna is necessary. If an apparently hostile radar transmission is detected, the mast is withdrawn immediately, and if the signal is strong, indicating that it emanates from somewhere quite close, the submarine may also go deep.

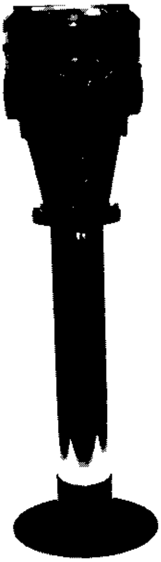
The normal type of display will indicate the direction of the intercepted radar, so that the submarine will have some idea of the direction in which it should *not* try to make a get-away.

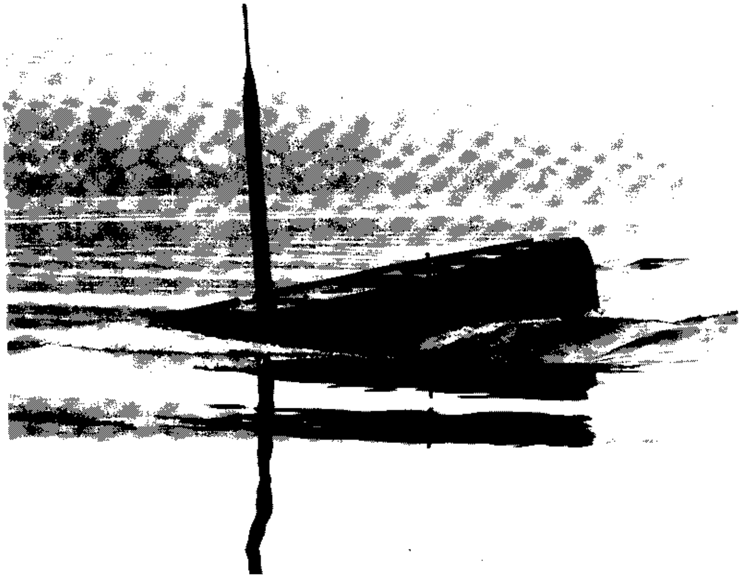
ESM in a submarine is also used to gather electronic intelligence (ELINT). For example, a submarine or submarines could be deployed off an enemy coast to gather intelligence of, say, a coastal radar, always bearing in mind that the submarine should be able to detect the radar transmission at a greater distance than the transmission can detect the ESM mast. All possible intelligence is gathered and forwarded to the appropriate authorities on return to harbour. It forms one of the ways of compiling the library.

Radar

Nearly all submarines carry radar with the antenna mounted on a separate mast. The antenna itself is probably a rotatable and quite small horn type and will detect surface ships and low flying aircraft. Radar of course is a two-edged sword. It may tell the submarine the bearing and range of an aircraft, helicopter or ship, but it will not indicate whether the craft detected is hostile or not, although IFF can be fitted. What it does do is to advertise the submarine's presence to any aircraft or ship's ESM

Below:
The captain of a German submarine takes a look through the periscope to see if all is clear for surfacing.





receiver, and such a craft might have remained blissfully ignorant of the submarine's presence. Submarines therefore tend to rely more on their ESM equipment than on their radars.

Optronics
As we have already seen, optronics can include image intensifiers, thermal imaging and devices to enhance plain vision, such as television. The main feature of optronic equipment is that none of it makes any emission which could be detected by the enemy. The one exception is the laser rangefinder, but its transmission to obtain a range is so short that it is unlikely to be intercepted; even if it is, it is doubtful whether the enemy could make much use of it.

Probably the best of the above-water devices is the thermal imager because it affords a method of recognition by silhouette, which none of the other devices does. It works on the principle of detecting the infra-red emissions given off by any object whose temperature is above absolute zero, and so well does it do it that it can display a complete picture of the sea and any ships on it. It will also show aircraft up to an elevation of 90°. The picture is similar to a black and white television image, but not so detailed and generally little more than the outline of a ship or aircraft can be seen. Darkness makes no difference, but its performance is degraded in mist or heavy rain or snow, and it is of little value in fog. Not all submarines are yet fitted with it, but it is being constantly improved and it will not be long before it becomes a standard fitting in conventional and nuclear attack submarines. SSBNs, which seldom, if ever, expose anything above the surface, may not all be fitted.

Above left:
An ESM antenna manufactured by Racal of the UK for various types of submarines.

Above:
A conventional submarine diving, showing the attack periscope.

Summary
Submarine sensors have improved greatly from the rudimentary equipments used in World War 2. Sonar has been considerably improved, image intensifiers and thermal imagers were unknown in the 1940s, and periscopes are now very much more sophisticated. The trouble is that improvements have also been made in submarine detection devices. Modern maritime patrol aircraft, for example, now have highly sensitive radars, capable of detecting the smallest submarine mast in all but the roughest seas. Ships and helicopter sonars are good, but not always perfect. Similarly ESM in aircraft and ships is excellent, but submariners know it and avoid the use of radar as far as possible.

On the whole it is generally agreed that the submarine still has the edge over the anti-submarine ships and aircraft. The greatest danger to a submarine is still the maritime patrol aircraft and the helicopter whose presence the submarine cannot detect from submerged unless it shows a mast or periscope. However, even this may change as there are persistent rumours that scientists may have found a method of hearing an aircraft's engine noise whilst fully submerged. They are still rumours, but it is an obvious line of development well worth pursuing.

8 Anti-Submarine Weapons

Since this book is about submarines, it follows that anti-submarine weapons must be looked at from the point of view of what the submariners may have to face in the enemy's efforts to destroy them. The first problem in anti-submarine warfare is to find a target. The oceans cover 70% of the earth's surface and to locate one relatively small submarine in such a vast expanse of sea is no mean task. One SSN sent out to look for and destroy any enemy SSBNs it could discover, would be a waste of time; the chances of coming across even one are remote — unless, and this is the vital point, the hostile submarine can be found by other means which have greater possibilities of finding submarines over far wider areas.

With this in view both the US and the USSR have established enormous fixed underwater listening sonar installations, or chains, in stretches of the oceans in which the other side's submarines are most likely to be found. These are near choke transit points, off enemy coasts and ports and in well-known shipping areas, for example the route between western Europe and the Americas. In addition, a certain amount of reliance is placed on the long range patrolling anti-submarine aircraft and on satellite detection. The Americans also have a number of mobile underwater sonar arrays towed by ships and some laid by aircraft, but they are unlikely to be far from a friendly coast line.

Air patrols, even given far more ASW aircraft than either NATO or the Warsaw Pact possess, are, at best, a very hit and miss system of finding submarines, observing that a nuclear submarine need never surface or even expose any mast, snort or periscope above the surface. Of course, aircraft can lay sonobuoys, but even then the area searched by any one aircraft by this means is a minute fraction of the oceans. There are other detection devices used by aircraft, such as the Magnetic Anomaly Detector (MAD) which detects the disturbance made to the earth's magnetic field by the presence of a submarine. Again, such a device has only a short range and is virtually useless unless the enemy submarine has been previously located by other means so that the aircraft has some idea as to where to look.

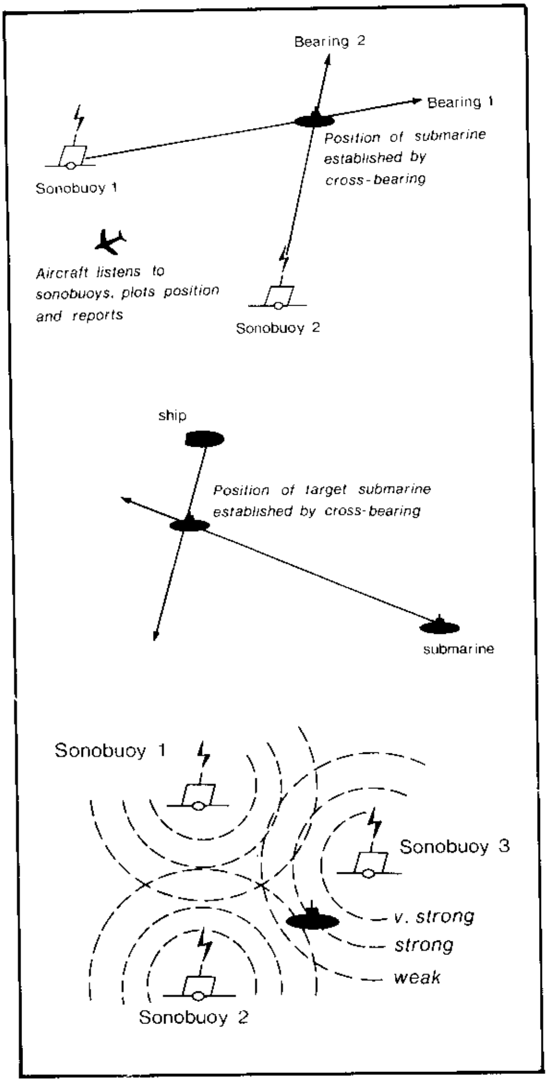
The chances of an aircraft catching submarines on the surface, or even with a periscope, mast or snort protruding above the water, are extremely limited, and only likely with conventional submarines. However, the fact that aircraft carry highly efficient radars does tend to inhibit submarines from using their periscopes, radars and snorts, and certain circumstances their radio communications.

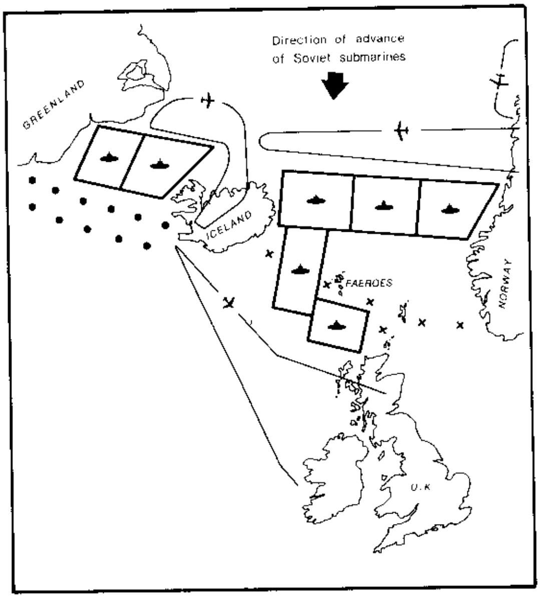
Detection of submarines by satellite is an unknown factor. From time to time there are reports of satellites detecting submarines by infra-red sensors, due to the fact that nuclear submarines tend to heat the sea near them by their nuclear discharge. There are also reports of trials of detecting a submerged submarine by laser beams from satellites, but there is little firm information of successful detections being made. However, satellites do serve in preventing submarines surfacing or using any apparatus which requires something to be raised above the surface of the sea.

This leaves us with the fixed underwater sonar installations. The main American system is known as SOSUS. It consists of immense arrays of hydrophones secured to structures embedded in the ocean floor and connected to a controlling shore station by wire or radio. The Americans also have another system called SURTASS (Surveillance Towed Array Sensor System). This consists of mobile hydrophone arrays of great length towed by specially fitted ships or tugs. There is apparently one or more systems on each of the North American coasts, controlled by a shore station on each coast. It is unlikely that either side know the capabilities and exact locations of the other's installations, but both know full well that they rely on detecting and tracking submarines by the noise they make. Both are busily developing quieter and quieter submarines, but water noise can only be reduced by using slow speed, which perhaps may inhibit submarine commanders using the speed for which their craft are designed.

Neither side has ever admitted the success or failure of its fixed sonar installations, but it is obvious that some success must be achieved, or the two sides would never continue spending the vast amount of money required to improve and maintain their installations.

There are two other procedures which might

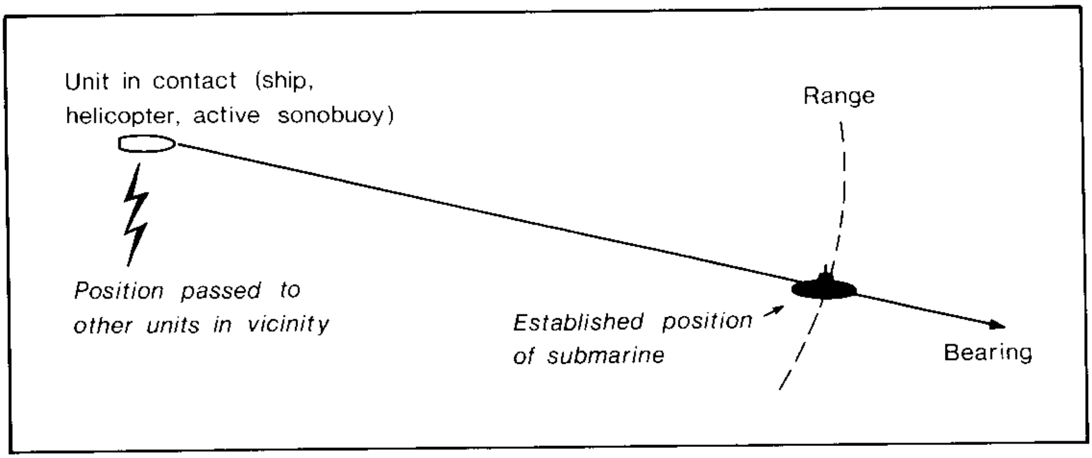


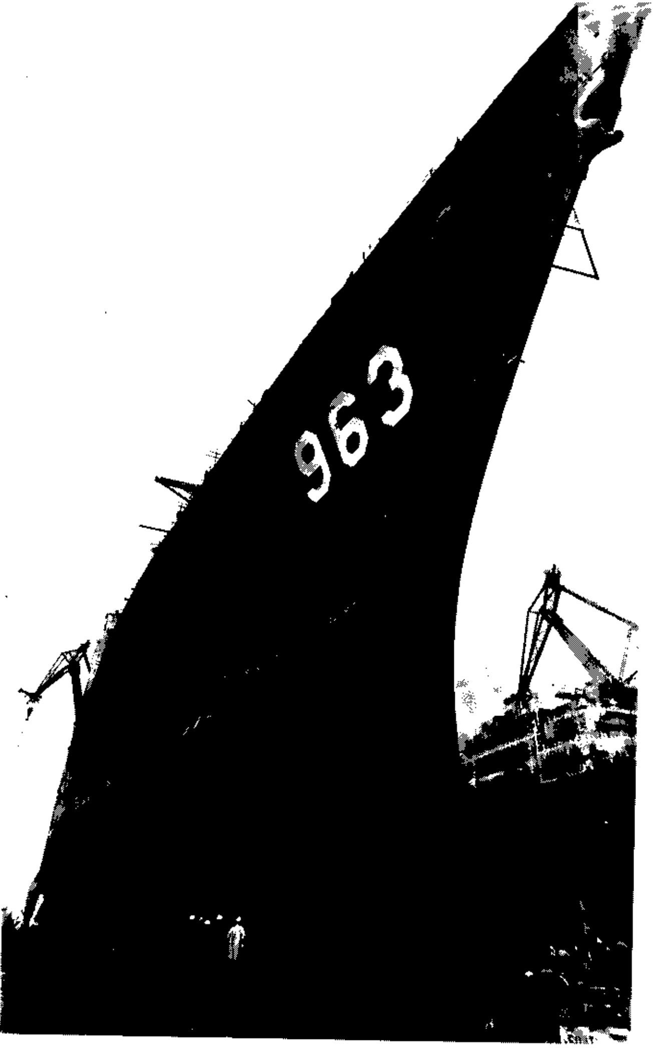


Above:
NATO ASW barrier: a Soviet view. This plan is adapted from one published in the Soviet press. Crosses represent the SOSUS arrays and the small circles represent a NATO anti-submarine minefield. NATO submarines and aircraft on patrol are indicated by drawings.

Left:
Acoustic localisation: Passive sonar.

Below:
Acoustic localisation: Active sonar.





Left:
The bow of the US destroyer *Spruance* showing the large sonar dome.

Right:
A Difar sonobuoy on board a maritime patrol aircraft. Sonobuoys are widely deployed by MPAs for the detection of submarines.

Far right:
Stonefish, a modern British anti-ship and anti-submarine mine made by Marconi, about to be loaded into an aircraft. The mine can be actuated by acoustic, magnetic or pressure systems.

help the detection of a hostile submarine. The first is to detect it the moment it leaves harbour and to continue to track it for as long as possible, calling up other friendly submarines to take over the tracking when forced to return to base. This means maintaining a patrol of submarines off the enemy's base — a difficult and dangerous task, even in peacetime, and easily countered by a number of submarines leaving the base at the same time and splitting up as soon as they get outside. It is most unlikely that there would be enough submarines patrolling off the base to enable all the exiting submarines to be followed. In wartime such a patrol would probably not be feasible. In any case, tracking a submarine over a long period is by no means an easy task. The hunted submarine may well be able to detect and pin-point the hunter, and a wily submarine commanding officer may be able to throw it off the scent by rapid manoeuvring and by the launching of decoys to distract the hunter's sonar operators.

The other way is to wait for the 'enemy' submarine to commit some hostile act, such as attacking a ship or ships. It is true that with modern stand off anti-ship missiles, the attacking submarine may not be very near to its victim, but if torpedoes are used, it is possible to determine the direction from which they were fired, and to establish a datum position from which to start a search, accurate to perhaps a maximum of 40nm.

ASW Weapons

Mines

Even if a submarine has not been detected, there is one weapon which it may encounter at any time — the submarine mine. One type, made by the Italian company Whitehead Moto Fides, has a string of explosive charges stretching from the moored mine to the sinker. It only requires a submarine to touch the 'string' to explode one mine. This in turn explodes the others, on the counter-mining principle, so that there are a whole host of explosions at different depths. It is efficient down to 300m, but some nuclear submarines can dive much deeper than this.

The Americans have an even more ingenous device, known as Captor. It consists of an active and passive sonar contained in a submerged capsule to which is attached a Mk 46 homing torpedo. It is laid as deep as required, but its maximum depth is not disclosed. The mine's sonar initially detects the submarine by passive means, and, when the submarine gets closer, automatically switches on its active sonar and gets the target's range, from which a computer calculates the optimum moment to fire the torpedo. The torpedo searches for the submarine with its own passive sonar and finally locks on to it and guides itself to hit.

Between these two types of mine there is a whole host of submarine mines, but few are effective in really deep water, so far as is known. Similarly, it is not known exactly what submarine mines are used by the Soviet Navy, but it seems probable that their mines are very similar to those

of NATO. The Soviets are reputed to have a mine very similar to the US Captor, fitted with passive sonar detection, capable of being laid in depths up to 910m, and like Captor able to fire a homing torpedo. The Soviets are very mine conscious, more so apparently than are the NATO nations, and are reported to have a stock of between 300,000 and 400,000 mines of all types, which is certainly a larger stock than that held by the US Navy.

In mid-Atlantic the sea depth can be as much as 2,000 fathoms (4,000m) or more, and so submarine minelaying is probably impracticable. In the Greenland-Iceland gap and in the Iceland-Faroes gap, depths of 200 to 300 fathoms (400m to 600m) are common, and submarine minelaying is certainly possible here. In general, mines are most valuable in shallow water when ordinary ground mines might well be set off by submarines. In deeper water, such as in the gaps mentioned above, moored mines would have to be used, and if magnetic or pressure mines are used, can be set off by the mere close presence of a submarine. Submarine minefields can also act as a deterrent to enemy submarines and channel them through areas which the opposite side may patrol with submarines and aircraft as heavily as possible.

Possible Sequence of Events

The ideal type of craft for use in anti-submarine warfare is unquestionably another submarine and the obvious weapon for it to use is the torpedo. Submarines have much better sonar facilities than do surface craft and have the capability of being able to vary their depth at will to take advantage of temperature layers in the sea.

If we postulate a tactical situation when there are both aircraft and submarines patrolling a gap through which hostile submarines must pass to reach their operating area, the anti-submarine sequence of events might be as follows:

1 Fixed underwater sonar installation detects a presumably hostile submarine. The detection is signalled to aircraft and submarines on patrol. An aircraft makes for the likely track of the submarine and starts laying sonobuoys. Let us assume that some of the sonobuoys gain contact and the aircraft starts tracking the submarine by laying more sonobuoys in its path.

2 The aircraft signals the hostile submarine's position, course and speed to its shore control and the signal is repeated to the submarines on patrol by the submarine VLF broadcast. The aircraft and the appropriate submarines establish voice communication. One submarine, we will assume, gains sonar contact with the hostile submarine and starts to track it, using passive sonar. It will be noted that, as yet, the hostile submarine probably has no idea that it has been detected.

3 Meanwhile the attacking submarine manoeuvres, using as slow a speed as possible, to get into a position to launch one or more torpedoes.

4 The torpedo (or maybe more than one torpedo) is launched and proceeds at high speed towards its target, being wire guided by the launching submarine. Eventually the torpedo's own sonar equipment detects the target and it starts to home itself.

5 The target submarine is unlikely to have received any indication that it is under attack until the torpedo is nearing the end of its run, when the submarine's passive sonar may detect the torpedo's noise. At about the same time the torpedo may open up its active sonar: the target submarine will certainly hear this and take avoiding action, but the torpedo's own active sonar should have locked on the target and will track it, even though evasive manoeuvres are being employed.

6 The torpedo hits and its 200-250kg warhead explodes.

Torpedoes

This sequence sounds very simple from the attacking submarine's point of view, but there are snags; firstly in the design of the torpedo. High speed is of course a vital attribute (the Soviet 'Alphas' are reported to be able to attain 45kt submerged), but the faster a torpedo is designed to go, the more space and weight is taken up by the engine and the fuel, or the larger will be the battery. This means that the warhead's explosive charge will have to be reduced or the torpedo will become unacceptably large. With modern submarines using very tough steel plating and fitted with double hulls, the warhead must be as large as possible. Present warheads contain about 200-250kg of explosive, and certainly no reduction of explosive could be considered, rather the reverse.

Endurance is also a problem because, if the torpedo misses on its first run, it is programmed to turn round and carry out a search; this means it may have to run considerably farther than the straight line distance to the target. Similarly, if the target turns away at high speed, the torpedo may have a long stern chase.

The initial wire control from the launching submarine must be accurate enough to place the torpedo within homing range of the target, which may not be very great.

Apart from the design of the weapon itself, tactics can play a major role. The hunted submarine, in addition to evasive manoeuvring, can probably release a false target, ie something which will produce a stronger echo to the torpedo's sonar than the target itself.

The homing equipment in the torpedo must be capable of not only searching in azimuth, but also in elevation: the target may well try to outwit the torpedo by rapid changes in depth.

Lightweight Anti-Submarine Torpedoes

In addition to the submarine torpedo, which is 21in (533mm) in diameter and weighs about 1,600kg, and is commonly referred to as the heavyweight torpedo, a much smaller and lighter torpedo has been developed, primarily for launch by helicopters or maritime patrol aircraft, but also capable of being launched from deck tubes on board surface vessels and by missiles.

The present lightweight torpedo in service in many Western navies is the US (Honeywell) Mk 46, but Britain (Marconi) has produced a new, much more advanced one, called Stingray. It is just coming into service in the British Navy, and Marconi hopes to sell it overseas. In the States, Honeywell is developing, what at present is known as the Advanced Lightweight Torpedo (ALWS), but is to get the US designation of the Mk 50.

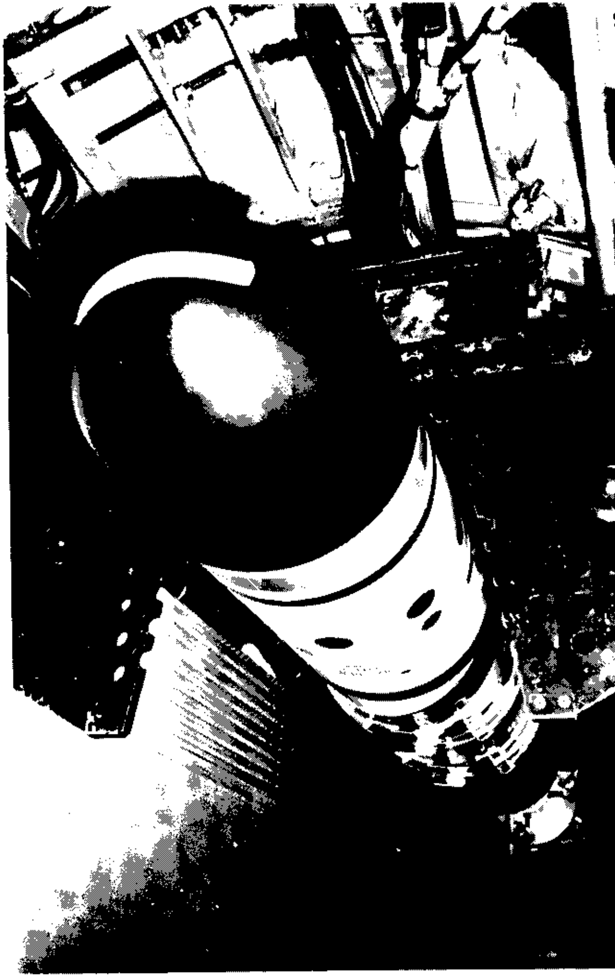
Lightweight torpedoes are around the 12-14in (305-356mm) in diameter and weigh something under 300kg, so it can be seen that they can only carry small warheads. In fact the average lightweight torpedo will probably only have a warhead containing not more than about 50kg of high explosive this is hardly likely to have much effect on a strongly built, double hulled submarine. However, both Marconi and Honeywell have produced warheads of about this size which, provided they hit the target's hull at right angles, will project a plug of molten metal into the pressure hull of a double hulled submarine, or through it in single hull boats. The head-on 90° approach adds complications to the homing system, but Marconi has overcome this by producing a highly sophisticated homing system with its own onboard computer; presumably the US ALWT will have a similar system.

There are three Western missile-launched torpedoes and one Soviet. America has ASROC, Britain Ikara (which was developed in Australia), and France Malafon. All work on roughly the same principle. When the target has been located, the missile, with torpedo attached, is launched in the direction of the target and, in the case of Ikara and Malafon, the torpedo is released by radio command from the ship when the missile is deemed to be within torpedo range of the target.

In ASROC's case, the release is made at a predetermined position. The torpedo descends by parachute, and on entering the water starts its engine and activates the homing system which should bring it into contact with the target. The distance the missile flies before releasing the torpedo is not officially disclosed, but ASROC's range has been estimated at 5-10km and Ikara at 20km. Malafon is probably somewhere between the two. The Soviet system, called by NATO SS-N-14 ('Silex'), is very similar, but its missile range is estimated by some analysts to be as much as 30nm.

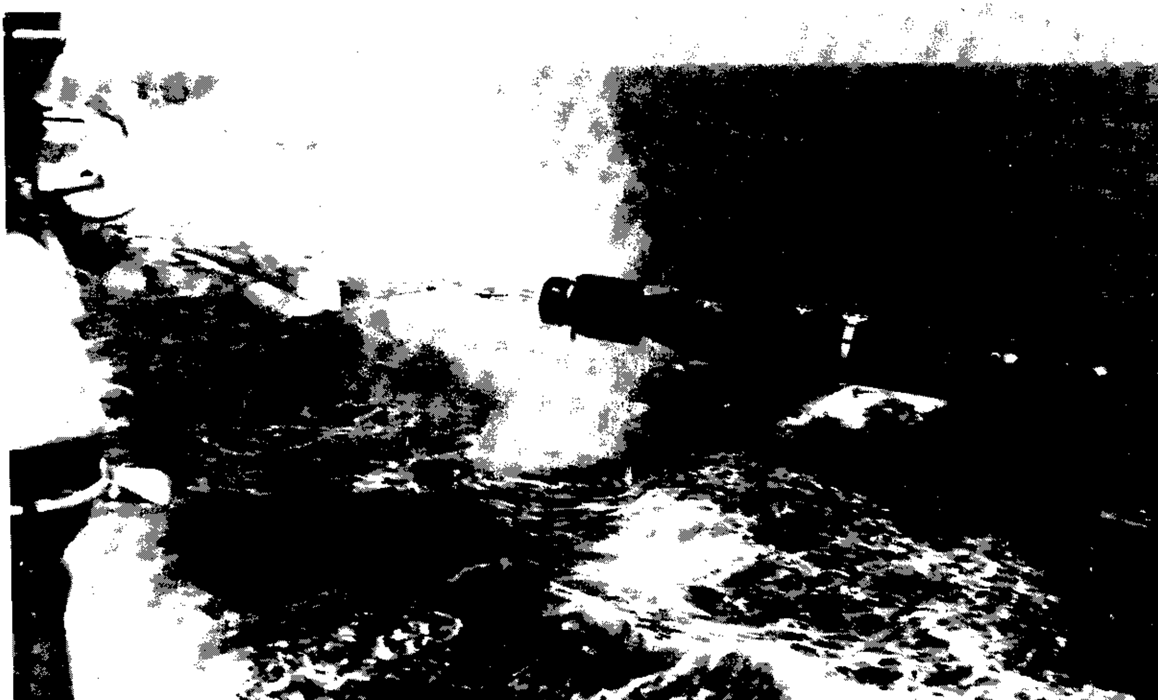
Apart from the lightweight torpedoes already mentioned, Italy has the Whitehead Moto Fides A244 and Sweden has the FFV Type 41. Very little is known about Soviet torpedoes, but it is known that there are lightweight ones of 16in (406mm) diameter which are carried by some ASW frigates.

Most Western ships also carry lightweight ASW torpedoes, launched from deck mounted tubes. Ranges of such torpedoes are not divulged, but are probably not more than 10,000m which means that they are for use against submarines which are probably already committed to an attack.



Right:
Stingray suspended in a bomb bay ready for launch from a Nimrod aircraft.

Below:
The British (Marconi) Stingray ASW torpedo launched from a surface ship for trials.



Depth Charges

Although somewhat outdated by homing torpedoes, depth charges are still in use in a number of older ships in NATO navies. Instead of being rolled over the stern as in World War 2, they are now launched by rocket or mortar launcher. They are usually thrown ahead of the ship, but are also capable of being thrown in any direction. The old launchers of the Hedgehog and Limbo type are still in use in older ships, but a much more modern rocket projector with a range of up to 3km has been produced in Sweden by Bofors; a number of Western ships are fitted with it.

The USSR, on the other hand, still sets great store by depth charges, perhaps because its lightweight torpedoes have not proved satisfactory. The average Soviet ship's complement of rocket depth charge throwers, known as RBUs (Roketnaya Bombometnaya Ustanovka), varies from two to four eight-barrelled mountings; 16-barrelled launchers are however also fitted in some ships. The launchers can throw depth charges over distances varying from 1,000m to 6,000m and have warheads weighing 21-57kg. Nearly all the Soviet ships of frigate size and above carry depth charges, including aircraft carriers. It is difficult to understand the philosophy behind the latter, as by the time a submarine has got to within 6,000m of a carrier it should certainly have completed its attack. However, the Soviets seem to have revised their thinking; because the 'Kiev' and 'Moskva' classes of carrier have been fitted with twin missile launchers (known in NATO as the SUW-N-1) which carry a nuclear depth bomb to a distance of 16nm.

Depth charges are also launched by aircraft. Most nations' long-range maritime patrol aircraft can carry them, but as the aircraft also carry lightweight homing torpedoes, they tend to use them instead of depth charges.

The Effect of Nuclear Underwater Explosions

As virtually any torpedo, mine or depth charge can be fitted with a nuclear warhead, perhaps it would be as well to examine the effect of a nuclear explosion on a submarine. It is thought in many circles that it is possible that any future nuclear war might be confined to the war at sea. The probably wishful thinking behind this is that with the sea being very sparsely populated by human beings, nuclear explosions would not be so devastating as

Below:
A Soviet 'Hormone' Ka-25 anti-submarine helicopter in flight.

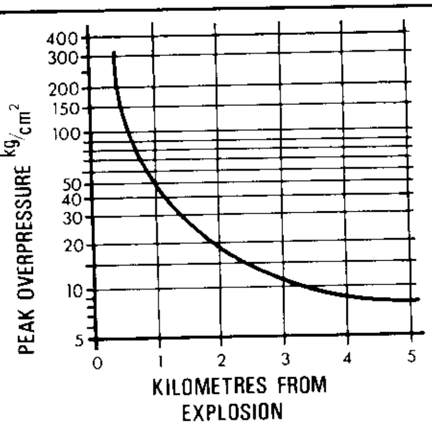
on land. Let us therefore look at how an underwater explosion whether nuclear of high explosive would affect a submarine. The following is taken from a paper read to the Royal Institution of Naval Architects in 1983 by Mr R. J. Daniel who at that time was the Managing Director of Warship Building in British Shipbuilders.

'The depth at which an explosion occurs is clearly important. The explosion bubble migrates upwards as it expands. Due to its energy, the bubble over-expands and is then collapsed to produce a second positive pressure pulse and a second expansion phase and upward migration, finally to vent at the surface. An explosion deep beneath a vehicle could result in greater damage from the second positive pulse than from the first, because of bubble migration.

'A conventional explosion under water generates a sharp-fronted shock wave of some milliseconds duration. Nuclear weapons generate higher presures of much longer duration. It has been stated that a 2.5kT TNT equivalent weapon detonated at a depth of 100ft would destroy a submarine submerged at a depth of 200ft at a distance of 2,000ft. A 10kT equivalent weapon would destroy a submarine at operating depth at a distance of 5,000-6,000ft. Overpressures, less than those to cause hull rupture, can cause serious damage to installed equipments by virtue of the shock and displacement of the hull. The displacement is the cause of the shock acceleration and subsequent deceleration experienced by machinery, equipment, armament and personnel, reaching considerable magnitude. An indication of the overpressure due to 1kT equivalent charge is shown in the accompanying graph.

'The damaging effect of an underwater explosion on a submarine's pressure hull depends on the magnitude of the overpressure along the front of the shock wave formed when the charge is exploded, the depth at which it is exploded, its duration, the distance to the submarine, and the reserve of strength of the hull. This reserve of strength is determined by the difference between the collapse depth of the hull and the depth at which the submarine is submerged at the time of the explosion. The deeper the submarine is, the less overpressure its hull can stand, but, of course, the deeper the submarine is, the more difficult it is to detect and the more difficult to attack successfully, especially if the submarine is alerted.

'Equipment and systems essential to the operation of a submarine are secured by means of resilient mountings designed to reduce the acceleration due to shock loading to acceptable levels. Mountings are also designed to reduce transmitted noise.'



1 Kiloton Equivalent Charge – Overpressure/Distance

Above:
Overpressure on a submarine of a 1kT nuclear explosion.

It will be seen from the graph that even at 5km from the centre of the explosion of a 1kT explosion at depth there is still a strong overpressure of about 8kg/sq cm. It is virtually impossible to calculate any safe distance a submarine should be from an underwater nuclear explosion, because, quite apart from the size of the explosion which of course the attacked submarine has no means of knowing, so much depends on the depth of the submarine and the depth of the explosion.

Observing, however, that nuclear depth charges and submarine mines may well have nuclear warheads with an equivalent of 20kT, it would appear that the radius at which the target submarine would be rendered inoperable, but not perhaps sunk, would be something over 10km. The lightweight torpedo would carry much smaller nuclear charges, probably of only 1kT. This might destroy a submarine's pressure hull at ranges up to 2km, but might well put a submarine out of action at ranges up to 5km. However, opinions on lethal ranges differ considerably: for example in some books of reference the 1kT SUBROC is said to be lethal to submarines at ranges from 5-8km. However, homing torpedoes are considered to be more accurate than depth charges.

Up to now it has generally been accepted that in any future conflict, the submariners would have a considerable advantage over the anti-submariners, but the pendulum is swinging and it may be that before long this will not always be the case — although the lone SSBN, securely hidden in the vastness of the oceans, will still be very difficult to find.

9 Submarine Communications

Whilst communication with submerged submarines of all types is always required, undoubtedly the most vital form of communication is that authorising a ballistic missile submarine to launch its missiles at an enemy target. No submarine commander has the authority to launch strategic nuclear missiles without a final message from the shore. It follows that an enemy will do all in his power to prevent such a message getting through.

Shore-to-Submarine

The primary method of passing information and instructions to submarines is by the use of very low radio frequencies (VLF). The VLF band officially stretches from 2kHz to 30kHz, but for messages to submarines, normally the lower half of this band is used, because the lower the frequency (and the longer the wavelength) the more the radio waves will penetrate beneath the surface of the sea. Submarines can thus receive them without the necessity of surfacing; however, even then, they may have to come up to periscope depths if they are some distance away from the transmitter. Both NATO and the Warsaw Pact have a number of VLF shore transmitting stations and messages from shore commands are routed through them, usually using the nearest station to the estimated position of the submarine.

These shore stations have very large antennas and use considerable power. Whilst some of their localities are well known, there are others which are kept as secret as possible, but it is comparatively simple for any observer to recognise a VLF station by the size of the antenna system, which it is virtually impossible to hide. There are known to be at least six VLF stations in the USA, one or two in the UK, at least one in France and one in northwest Australia. Doubtless the USSR also has as many.

Since it seems probable that the locality of the stations on both sides must be known, they obviously constitute prime targets for enemy action. Further, as any future nuclear war is likely to involve ballistic nuclear submarines (SSBNs) in the very early stages, the enemy will be certain to try and put its opponent's communications out of action before war actually breaks out. The most likely form of enemy action would be sabotage, not necessarily blowing up the antennas, but by the more subtle means of cutting power supplies, feeder cables and the like, or even immobilising the radio stations' crews by chemical warfare. One certain indication of a coming nuclear war might be the destruction of a VLF station's capability.

A submarine receives VLF signals in a number of ways. For reception at shallow depths, submarines are fitted with fixed loop antennas usually mounted on the fin. If it is too dangerous to remain at a shallow depth it is possible to release a tethered buoy, also carrying a loop antenna. The buoy is towed by the submarine at slow speed and passes the received signal down the towing wire to the submarine's radio receiver. Even a small buoy, however, or rather its loop antenna, can be detected by radar, thus there is a certain amount of risk in exposing it, and in general, as far as possible, buoys are kept just below the surface of the sea where reception is only marginally impaired.

An alternative method, for use when deep-diving, is to stream a wire antenna which is made to float just below the surface of the sea. The antenna is long and is inconvenient if the submarine has to manoeuvre and/or use high submerged speed.

Submerged VLF reception depends very much on radio propagation conditions, but reception when submerged up to 5,000 miles from the shore station has been known.

The TACAMO Project

The possibility of the shore stations being immobilised by enemy action has not been ignored by NATO, nor has also the possibility of the shore-based headquarters of the high command becoming untenable. Thus the Americans have a number of large shore-based aircraft fitted as command posts. In addition they have some 13 EC-130C TACAMO aircraft fitted to broadcast on VLF using long trailing antennas. The aircraft can patrol in suitable locations to ensure that their VLF signals can be heard by selected SSBNs. The flying command posts pass the messages intended for the submarines to the appropriate aircraft by normal radio and they then re-broadcast them on

VLF. It has been reported that these aircraft's antennas can be as long as four miles and that they transmit on 200kW of power.

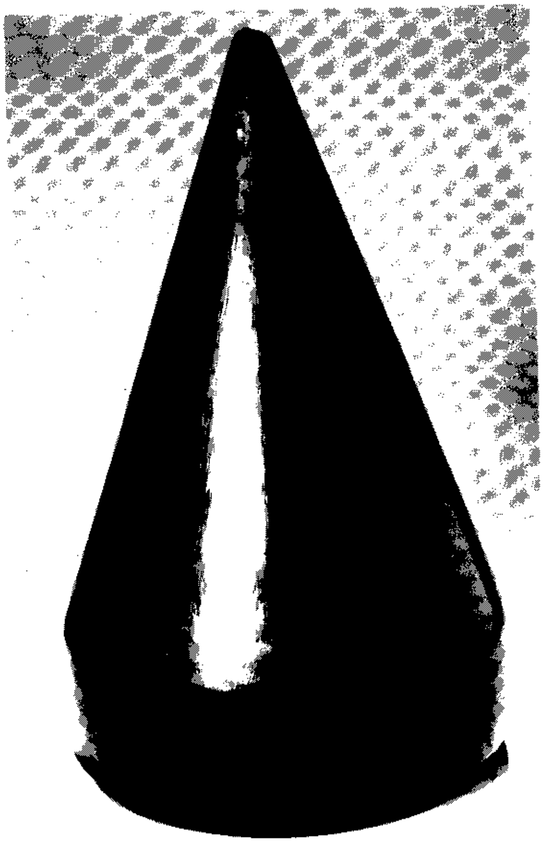
ELF

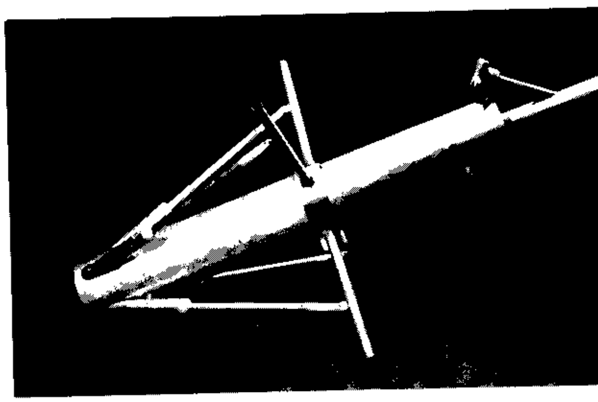
The Americans have taken submerged communications a step further by going to ELF (Extremely Low Frequencies). The exact frequencies used have not been disclosed, but it is believed that they are less than 100Hz. The first ELF station was built in Wisconsin and consists of two 14-mile long antennas strung from tall masts in the form of a cross and fed by a 1kVA transmitter. The ends of each antenna are grounded and the whole system forms two enormous crossed loops with current flowing from the transmitter along the wires, through the earth and back to the transmitter through the earth. Only 2W of power are radiated and a vertically polarised wave is produced between the ionosphere and the surface of the earth. When the wave crosses the sea, it is tilted and a horizontal component is produced, with little attenuation in sea water, and can be received by submarines at great depths. The submarine has to tow a long wire antenna astern of it.

The Wisconsin site has been in use for test purposes for over 10 years, but has now been further developed into a permament communication centre. A second ELF station has been built in Michigan with two parallel antennas, crossed by a third and all buried into the rock formation of the ground to a depth of 3-6ft.

Data transmission is used, but the data rate is extremely slow at only about three characters every 15 minutes. Thus a three-letter code has been devised, partly for security but mainly to shorten the message. The signals passed on it are very short, perhaps just one three-letter group, to indicate to the submarine to rise to periscope depth and stand by for a longer VLF signal in the normal way, or to expose its satellite receiver antenna for a COMSAT signal. However, by the fact that a second station has now been built, and the Wisconsin facility improved, it would appear that it is now the intention to use the ELF system for more lengthy operational signals to SSBNs and to SSNs, and to accept the fact that the signal may take some hours to get through.

ELF can provide reliable communications up to 1,000 miles from the transmitter. It is virtually impossible to jam and, with the antenna buried in the ground, as in the Michigan site, the





Above:
The Plessey Marine Submarine Conical Log Sprial (CLSU) antenna for conventional communications mast installations. The CLSU antenna is an active transmit/receive unit operating over a broad band ranging from VHF through UHF to SHF using a single antenna element.

Right:
The Plessey Marine Emergency Turnstile antenna (CLSE), for attachment to the submarine bridge flagstaff bracket, provides an alternative UHF transmit/receive facility when operating on the surface.

transmitting station is not so obvious and thus more difficult to destroy. The object of the system is to enable submarines to keep at a safe depth for much longer periods.

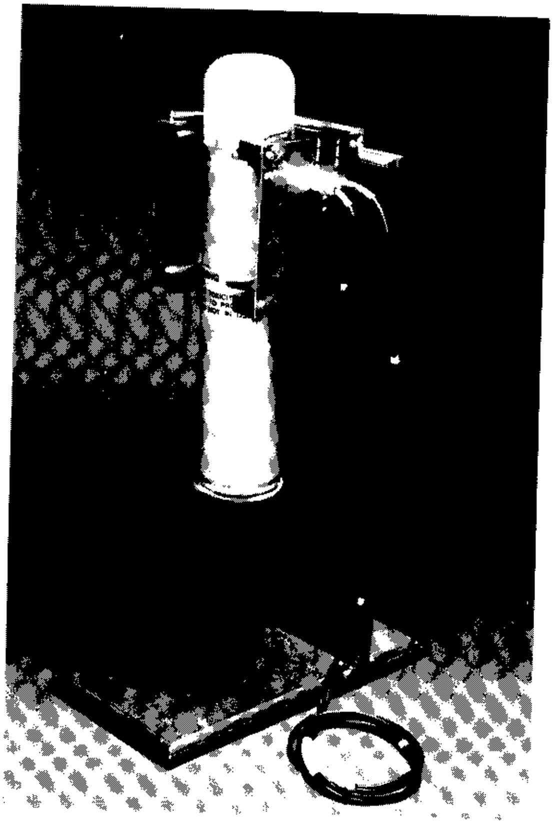
Satellite Communications

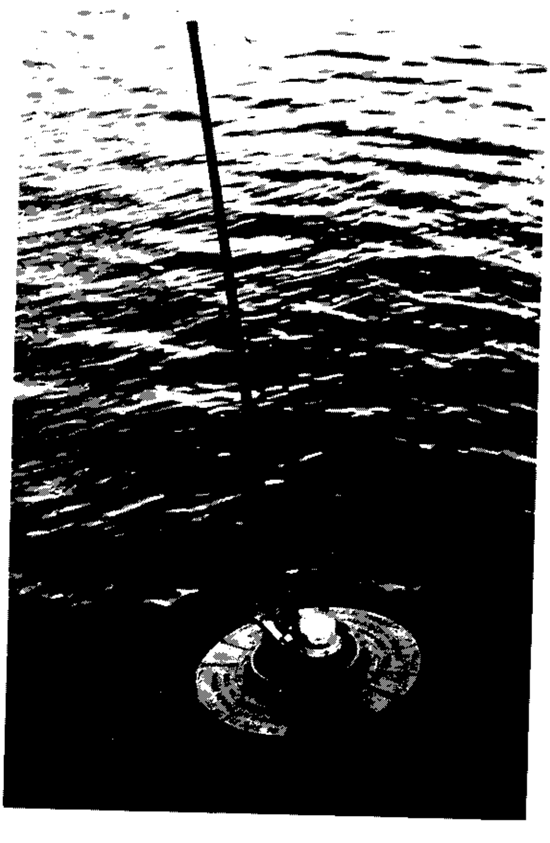
Another form of communication which has come to the fore in recent years is via communication satellites. The US has its FLTSATCOM system with four geostationary satellites at 100° West, 23° West, 72° East and 172° East longitudes. They cover a large part of the world between 70° North and 70° South. Submarines are allocated one channel in the system, but it is also possible to have one channel on a commercial satellite system.

Unlike VLF, submarine satellite communications are two-way; in other words they receive the signals via the satellite and can also transmit signals to the shore also via the satellite. Frequencies used are UHF. The normal practice is for the command operational authority to route signals for any of its submarines via the satellite where they are stored, in order of priority. They are then broadcast by the satellite at set times during the 24 hours and are usually repeated up to four times, in the hope that the addressed submarines will be able to raise their antennas at least on one of the occasions. The set times of the satellite broadcasts are of course known to them and all submarines endeavour to come to periscope depth at these times and raise their communications mast. Alternatively, a submarine having got itself into a position where enemy detection is unlikely, will raise its satellite antenna and request the satellite to pass all messages awaiting the submarine in its store.

The broadcast is known as the Submarine Satellite Information Exchange System (SSIXS). It is American-controlled, but will, on request, broadcast messages for NATO submarines.

Submarine satellite antennas are usually carried on top of a special retractable mast, known as the wireless or communications mast. It is but one of the numerous antennas and periscopes which protrude above the conning tower. The actual antenna itself is very small and inconspicuous. The British use a small rod type antenna, not much larger than a thick pencil, whilst the Americans use a small dish type antenna of about 8in diameter which has to be pointed at the satellite. However, unlike the VLF antennas, the satellite antenna must be completely clear of the water. The same antenna in British submarines is used for communication on UHF with aircraft.





Above:
Transfer of personnel to the British SSN *Sceptre*, one of the 'Swiftsure' class. Such an operation could be considered a form of communication, but one that can only be carried out in reasonably calm weather.

Left:
Two types of expendable submarine communications buoy.

Submarine-to-Shore Communications

As we have already seen, one method for submarines to communicate with the shore is via a satellite. However, it is an unfortunate fact that for any form of shore communications, a submarine must expose an antenna of one sort or another. In these days of modern high definition airborne radar found in maritime patrol aircraft, this places the submarine at risk of being detected.

HF Communications

For HF communications, submarines use a whip antenna mounted on top of the communications mast, which is raised and lowered when required in the same way as are the periscopes. The whip antenna must be well above the surface of the sea and is even more vulnerable to detection by enemy radar than is the satellite antenna.

The main objection to the use of HF, however, is its vulnerability to DF (direction finding) by enemy shore (or ship) stations. In World War 2 German submarines used HF a great deal and the allied shore DF stations had little difficulty in pin-pointing their positions.

The normal practice with HF from ships at sea is for them to call an appropriate shore station. Two-way communication is then established and any messages from the ship are then passed using radio teletype. If the station called does not hear the call, any other allied ship-to-shore station may accept it and receive the messages. That station is then responsible for passing on the messages to the addressees. Whilst it is relatively easy for submarines to get rid of their messages in this way, it may entail quite lengthy transmissions, particularly if the initial call is not immediately answered and has to be repeated. Thus an efficient enemy DF network is a great deterrent to the use of HF.

Why, one might ask, is it then retained? The answer is that it is an effective back-up system for use if other systems are jammed or put out of action (communication satellites, for example, might well be destroyed). HF itself is not easy to jam since the jamming signal would have to be directed at the receiving station, and there are so many of them scattered round the world that it would be difficult to jam all of them. Further, whilst in World War 2 the use of HF was often followed by retaliatory enemy action, nowadays with nuclear submarines capable of 30kt or more, they could soon get away from the locality in which they made an HF signal, and by the time the enemy had taken offensive action, could be some considerable distance from the DF fix and lying quietly in very deep water. The use of HF these days by, anyhow, nuclear submarines is not therefore perhaps so dangerous as it was 40 years ago. For all that, it is used sparingly.

Communications with Aircraft

Attack submarines, whether nuclear or conventional, will probably need to communicate with co-operating aircraft when hunting enemy submarines or surface ships. Submarines are therefore fitted with small UHF and VHF antennas on the top of the communications mast. Since the aircraft does not know when the submarines will be able to expose this mast, the initial contact with the aircraft would probably be made by one or more of the submarines by UHF. Thereafter reports by the aircraft can be passed direct to the appropriate submarines by this means. Similarly, UHF is used between submarines and any co-operating ships.

Since it may be difficult for submarines to expose their communications mast too often, they carry a number of expendable communications buoys. These are fitted with a tape recorder, a VHF or UHF transmitter and a whip antenna. A submarine wishing to communicate with a friendly aircraft makes a recording of the message on tape either in voice or on teletype, inserts the tape in the recorder in the communications buoy and discharges it to the surface, whilst still submerged, through the standard signal ejector, normally used to discharge smoke canisters. The buoy can be set to transmit the message on reaching the surface, after a delay of at least a few minutes to give the submarine time to get clear of the position. It broadcasts the message, repeating it continously until an aircraft (or ship) receives it, when the aircraft/ship will transmit a specially coded message to order it to cease transmitting. The buoy then scuttles itself. Alternatively, the buoy's transmitter can be set to operate for a certain period of time and then sink itself. The submarine, of course, does not know whether its message has been received, but it could include in the message instructions to acknowledge its receipt on the VLF or satellite broadcast.

British expendable communication buoys are made by Plessey Marine and in the US by Spartan. Another buoy, also made by Spartan in conjunction with Sanders Associates and called the Air Transportable Acoustic Communication Buoy, is also expendable, but is used for communication from ships or aircraft to submarines and vice versa. It can receive UHF radio signals from aircraft or ships, convert them into sonar signals and transmit them through the water to the submarine. It can also receive sonic signals from the submarine, convert them into radio signals and transmit them to a ship or aircraft on UHF. The buoy is normally air-launched, like a sonobuoy: in fact in size and shape it is very similar to the DS Difar Sonobuoy, also made by Spartan/Sanders amongst many others.

Summary of Submarine Communications

Type	*Methods Used*	*Antenna used by Submarine*	*Range*	*Remarks*
From shore	HF from powerful shore stations	Loop on hull/ towed buoy with loop on it/towed floating cable	Up to 5,000 miles	Submarine must be at periscope depth/ submarine can be deep/submarine can be deep
	VLF from specialised aircraft	Loop on hull/ towed buoy with loop on it/towed floating cable	Probably no more than 1,000 miles	As HF
	ELF from specialised shore stations	Towed underwater wire antenna	Many thousands of miles	Submarine can be deep
	via COMSATS	Small rod on periscope or mast	World-wide	Submarine must be at periscope depth and expose antenna
From ships	UHF or VHF	Small rod on periscope on mast	Horizon, probably no more than 10 miles	Submarine must be at periscope depth and expose antenna
From ships and other submarines	UW telephone	Transducer	A few miles	Range depends on sonar conditions
From aircraft	UHF or VHF	Small rod on periscope or mast	Horizon	Range depends on height of aircraft

Apart from these sophisticated tactical buoys, most submarines carry a buoy attached to the submarine by a telephone cable which will transmit a distress call on HF. It is hoped that any rescue ships will fix the buoy by DF and radar, pick it up and be able to talk to the stranded crew over the telephone line.

Underwater Telephone

Nearly all submarines are fitted with an underwater telephone system. They work on the sonar principle using a carrier frequency of around 10kHz or less and a power of around 100W. Underwater telephones are continually being improved and some of them carry digital transmissions as well as voice. It is not easy to transmit continuous sonar signals through the water and nearly all underwater telephones are very limited in range, probably to no more than a few miles. Surface ships are also fitted with similar telephones and they can be of considerable tactical use when, for example, a submarine is accompanying a convoy or a task force submerged. Orders to it can be passed quite freely, although voice coding can be used if desired, and the submarine can report any contacts gained to the surface craft.

There is undoubtedly a requirement for much longer range underwater telephones, but so far, NATO does not seem capable of producing one. This is odd, because the Soviets seem to have mastered the art and are believed to be able to communicate under water over much longer distances than can NATO ships and submarines, even to over 100 miles. However, it is doubtful whether the Soviets can guarantee long distance underwater communications because, as with sonar, so much depends upon the temperature layers in the water.

The table below gives a summary of the methods used by submarines for external communications. Whilst communications to submarines from the shore are reasonably satisfactory, in the opposite direction, reliable communications can only be achieved by exposing an antenna, and this, when faced by a sophisticated enemy, must always be regarded as a risk.

Via buoys	UW telephone to buoy. Radio transmission to and from buoy to aircraft or ships	Transducer	A few miles to buoy, but aircraft or ships up to horizon range from buoy	New development from America. Ship or aircraft transmits on UHF to buoy which relays to submarine on sonar frequenices
To shore	via COMSATS	Small rod on periscope or mast	World-wide	Submarine must be at periscope depth and expose antenna
	HF	Whip on mast	World-wide	As above but transmission could be DF'd
To ships	UHF or VHF	Small rod on periscope or mast	Horizon, probably no more than 10 miles	Submarine must be at periscope depth and expose antenna
To other submarines	UW telephone	Transducer	A few miles	
To aircraft	UHF or VHF	Small rod on periscope or mast	Horizon	Range depends upon height of aircraft
Via buoys	Recorded tape	—	Horizon	Buoy transmits on UHF or VHF to aircraft or ships

10 Navigation

Submarines have a very difficult navigational problem. SSBNs need extreme accuracy, because whether or not their long range nuclear missiles hit the scheduled targets depends upon the submarine knowing its exact geographical position at the moment of firing. Even other operational submarines need to know their positions to within 1nm. For firing underwater launched tactical missiles — in co-operation with other ships, submariners or aircraft — the accuracy required is in the region of 140m.

Coupled with these stringent figures, the submarines have to navigate with the very minimum exposure of any radio antennas or the periscope. Submarine navigation is no easy task, thus vessels carry a number of different navigational systems and can 'average out' the position they obtain to get as true an actual position as possible.

The navigational equipment carried by all modern submarines consists of:

- A sextant mounted on the top of the periscope and used for taking sights of heavenly bodies, using an artificial horizon.
- Satellite navigation receivers.
- Inertial navigation.
- Decca or Loran navigational radio aids.
- Omega receivers to receive the VLF long range Omega hyperbolic system.
- Echo sounders for bottom contour navigation.

The Sextant

This is normally fitted at the top of the attack periscope and an artificial horizon is created by means of a gyro and a pendulum. The sextant is controlled remotely so that the periscope officer can bring the heavenly body down to the artificial horizon and read off its angle of elevation in the normal way. Only bright objects can be used, such as planets or the sun or moon. Normally the body is tracked for, say, two minutes and the average angle over that period is worked out and entered into a computer.

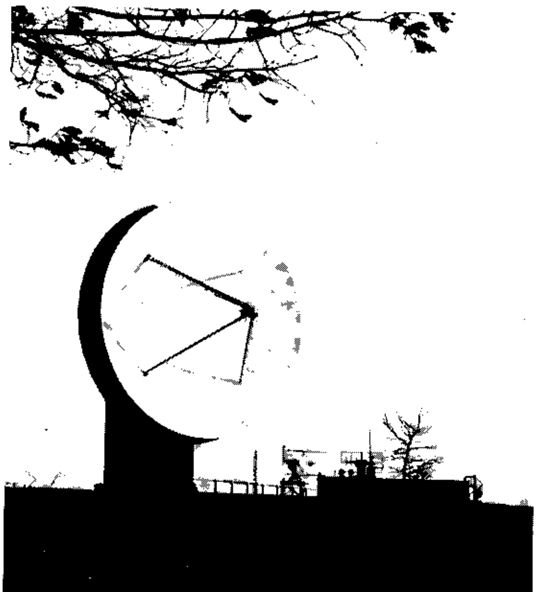
It is obviously best to take two heavenly bodies at, or nearly at, the same time, but this is not always possible and two position lines have to be obtained using the same body in the 'running fix' method.

One might think that the use of astronomic navigation is somewhat out of date in these days of sophisticated methods of electronic means of fixing, but always at the back of a nuclear missile submariner's mind is that his is a second strike weapon, and the first strike by the enemy might well put all the electronic systems out of order. So important is astro navigation that British submarines now have to spend three days a month using it only. An astronomic fix should be accurate to within ½nm.

Satellite Navigation

The satellite system in operation today is known as the US Navy's Navigation Satellite System (NNSS), or more often 'Transit'. Developed initially for SSBNs for updating their inertial navigation system, NNSS was declassified in 1967 and is now used by naval and merchant ships of all nationalities worldwide.

The system currently consists of five satellites orbiting the earth in 955km (600 miles) high polar orbit, each orbit taking about 107 minutes. The satellites form a 'birdcage' about the earth. The latter revolves within this stationary cage so that every point on the earth 'sees' each satellite at least



once every 24 hours. The system's basic weakness is that it does not give continuous position fixes, so some form of dead reckoning is required between the passes. It should be noted that it is possible to predict very accurately when a satellite will be available and hence plan one's navigation accordingly.

To obtain a fix the hyperbolic principle is again used; the difference in range of the submarine from two positions of the satellite is measured, thus giving a line of hyperboloid whose foci are the two positions. The process is repeated many times from the same satellite. A built-in processor then combines all of the position lines to provide a position relative to the satellite.

The satellite transmits its position by radio in the form of orbital parameters (ephemeris) and precise time. Doppler shift on the received radio signal, caused by the satellite's high velocity, is used to obtain range differences. The submarine's motion and earth rotation are also taken into account. Because of the large amount of data involved in a satellite fix, a micro-computer is required. Inputs from the inertial navigation system provide the computer with dead reckoning parameters which are combined with the satellite's orbital data and the doppler range measurements to produce a satellite fix. The fix is then used to update the dead reckoning as given by the inertial system. The operation requires no intervention on the part of the navigator, once the initial input of time and approximate position have been inserted at the beginning of the voyage.

Below left:
A Transit satellite tracking antenna.

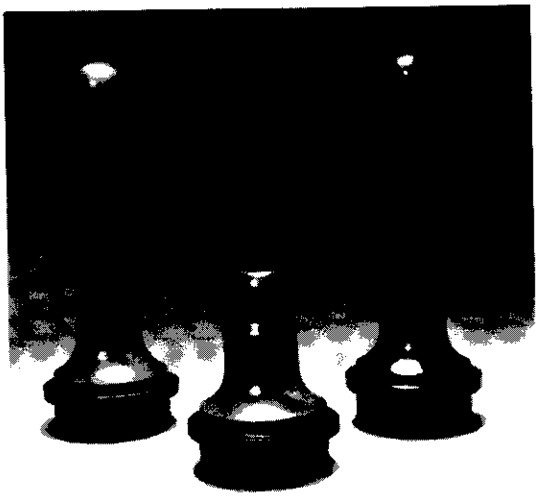
Below right:
A French Transit satellite receiver.

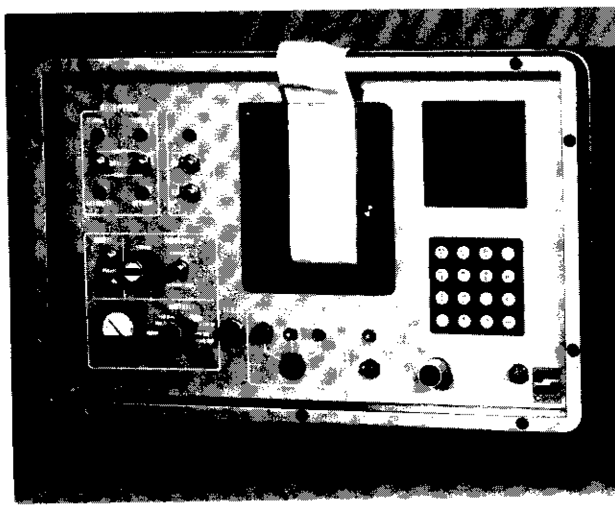
Below:
Examples of submarine antennae made by Plessey Marine. The longer ones are used for reception of navigation satellite signals.

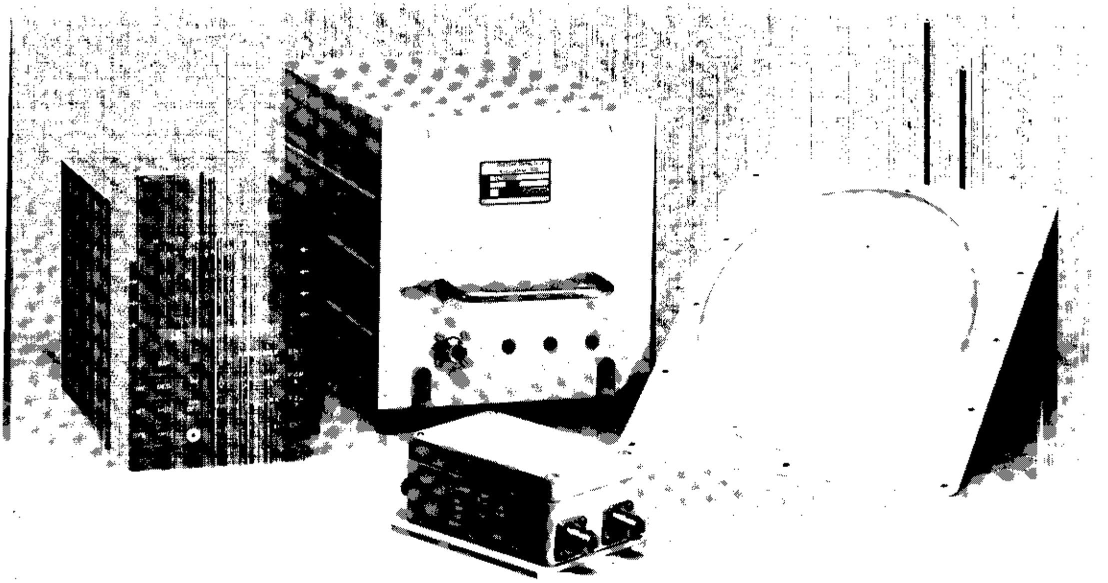
So that the satellite shall always know its own position and orbital path, it is tracked by a number of stations on earth which feed their information, via a computer, to an injection station. This station transmits to the satellite its own ephemeris as calculated on earth, and this is fed into the satellite's 'memory' and stored there, being updated by each successive transmission, usually every 12 hours.

Every two minutes the satellite transmits a burst of information containing its ephemeris that applies to that exact two-minute duration. A digital marker is placed in the message, timed to occur at each exact even minute. This marker is used to synchronise the submarine's receiver. Each satellite is within horizon-to-horizon range of an observer on earth for a maximum of 18 minutes, and during this period the satellite will transmit up to nine bursts of information, each of two minutes' duration. Normally a minimum of three separate transmissions are required in order to obtain a fix. From the information received, the submarine's computer can work out the position of the satellite at the beginning and end of each transmission. Meanwhile the receiver measures the Doppler shift. This is integrated with time and so the range difference between the two satellite positions is obtained.

To enable the receiver to measure the doppler shift, the satellite transmits two highly stable radio frequency carriers on 150MHz and 400MHz. The receiver is fitted with a local oscillator which beats against both frequencies, and a mean doppler shift, corrected for errors due to ionospheric refraction, is obtained.







Operation

The submarine equipment consists of the receiver, capable of receiving both frequencies, a micro-computer and display or print-out equipment. The antenna is a small VHF vertical rod, normally mounted on top of the wireless mast. Other VHF antennas are available if required — perhaps one on the search periscope and another one on the wireless mast. When the satellite appears over the horizon, the receiver acquires it automatically and synchronises itself, indicating that this has been done on the display.

The degree of accuracy obtainable is theoretically better than 100m, but this assumes accurate knowledge of the craft's speed. Submariners usually assume satellite navigation accuracy to be of the order of ½nm.

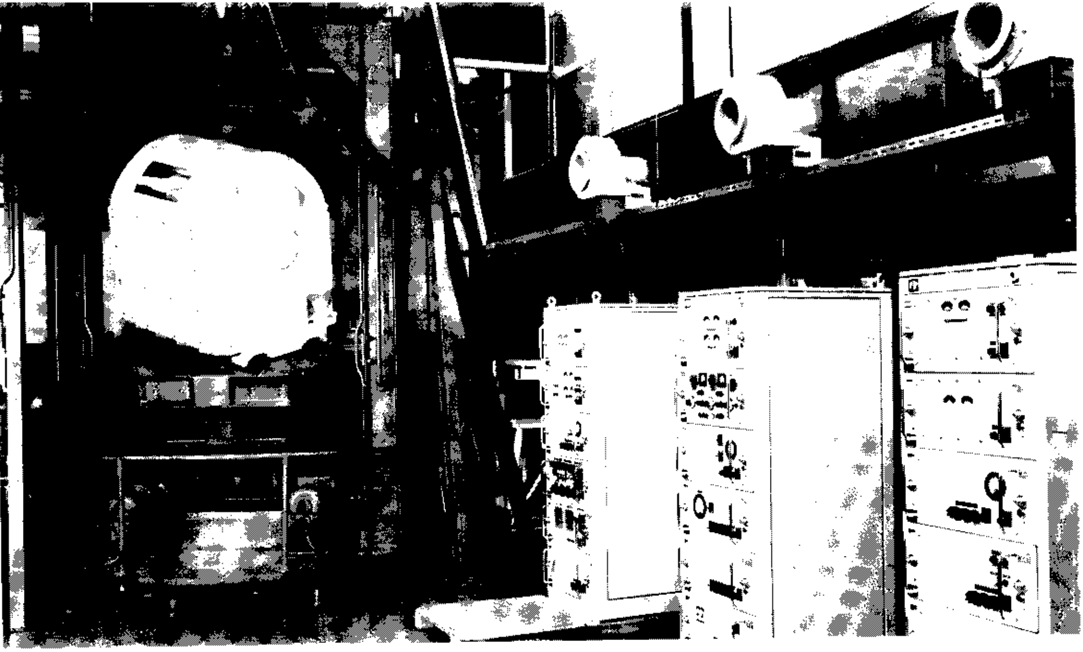
As we have seen, a satellite will be above the horizon for a maximum of 18 minutes, but a submarine tries to obtain its fix during the portion of the satellite's orbit when it is nearest to the submarine, as this makes for greater accuracy. To enable it to do this Magnavox, of the USA, the world's largest manufacturer of Satnav receiving equipment, has developed a special computer program which will work out the exact moment when the antenna should be raised and will indicate to the control room when to press the button to raise the mast.

NAVSTAR

Obviously, with only five satellites in orbit there is not always one immediately available for fixing. Whilst this might be acceptable to surface ships, it is often by no means acceptable to submarines, particularly SSBNs. Nuclear submarines with their high speeds can move a considerable distance between successive satellite passes. For this reason a new satellite system is to be introduced, known as the NAVSTAR Global Positioning System (GPS). It is under development in the USA and trials have already started. Eventually there will be 18 satellites in circular orbit at a height of 10,000nm. Their orbital planes will be at 63° inclination to the equator to provide global coverage. This will mean that at any one time there will be five satellites above the horizon. Four will be needed to get an accurate fix, three for actual fixing and one for synchronisation.

The satellites will be tracked, controlled and monitored by a master control centre at Fortuna Air Force Station in North Dakota, and there will be four tracking stations at Guam, Hawaii, Alaska and in California.

GPS will work on a different principle to the present system. Instead of fixing by taking two positions of one satellite, the navigator will measure the actual range of three satellites, which will produce three range arcs on which the submarine could be situated. Where the three intersect will be its true position. The dead period between the fixes will be completely eliminated and submarines, aircraft and ships will be able to fix themselves continuously throughout the 24 hours. Taken to its logical conclusion this should make Omega, Decca, Loran and other hyperbolic systems obsolete, but submarines will still be constricted in the times at which they consider it safe to expose an antenna and will probably still need inertial navigation and a method of updating it when submerged.



Above left:
A NAVSTAR (GPS) receiver manufactured by Crouzet of France.

Above:
A Sperry Ship's Inertial Navigation System (SINS) on test.

Below:
The navigation centre on board a British SSBN. The inertial navigation system is housed here.

The satellites are being built by the Collins Division of Rockwell International, the control equipment by General Dynamics. The user equipment will be built by a number of manufacturers. The new system should be available from late 1987 onwards.

Inertial Navigation
Inertial navigation is an accurate method of computing a submarine's position by dead

reckoning. In simple language, it relies upon a platform, stabilised by gyros in three dimensions, coupled to accelerometers. These devices are based upon the principle that when a moving body accelerates, it leaves any free moving weight inside it behind. The force required to bring this weight back to its original position is a function of the distance the body has moved. If accelerometers are mounted in the north/south plane and in the east/west plane, the movement north or south and east or west is measured, and by integration the actual direction of the movement can be ascertained, together with the speed and direction covered.

Even if the gyro compass measures an accurate heading, a current may cause the submarine to drift, and in fact the course and speed made good may differ considerably from that measured by the compass and the log. Accelerometers, however, measure the submarine's actual displacement from a given starting point, thus they show the course and speed made good. In fact an inertial system will display the submarine's position continuously and, very often, will also show the difference between the course and speed made good and that shown by the compass and the log.

In view of this, it might be thought that no other form of navigational system is necessary, but unfortunately inertial systems do suffer from errors, particularly when used over a long period. Thus they require updating at fairly frequent intervals. For this, satellite navigation and other methods of position fixing, as shown below, are used.

Radio Navaids

The two most common radio navaids used by submarines are Decca and Loran and are the same aids used by surface craft. Decca is used by British submarines for fixing in coastal waters and Loran by American submarines to update their inertial systems. Both Decca and Loran are hyperbolic systems. Decca works on medium frequencies and Loran C (the latest system) on 90-100kHz. Both require the submarine to expose an antenna. Loran C covers the North Atlantic, North Pacific, Mediterranean and the Norwegian Sea. There is also coverage of the east and west coasts of the North American continent and an area around the Hawaiian Islands.

Omega

Of more interest to submariners is Omega. The system uses very low frequencies between 10 and 14kHz and covers virtually the entire world. Like Decca and Loran it too works on the hyperbolic principle. It is possible to receive the VLF waves when submerged, but dependent upon the distance the submarine is from appropriate Omega stations, it will probably be necessary to come to periscope depth, which may not be desirable or possible at times. The normal Omega antenna is a loop secured to the top of the fin, but if the submarine has to remain deep it is possible to send up a buoy with a similar loop attached or alternatively trail a floating wire on the surface (the same antennas are used for the reception of VLF teletype for normal communications).

The Omega chain consists of eight VLF stations situated in Norway, the USA, Liberia, Argentina, La Reunion (off Madagascar), Japan and Australia. Like any hyperbolic system, the navigator measures the difference in time of arrival of signals from at least two pairs of stations, using the phase difference technique. Because of the very long wavelength all stations have immense antennas and are easily recognisable and would form tempting targets in war. Only one station transmits on a given frequency at a time, and the pulse from each station differs slightly in length to aid recognition at the receiver. Highly accurate atomic clocks are used to synchronise the times of transmission from each station.

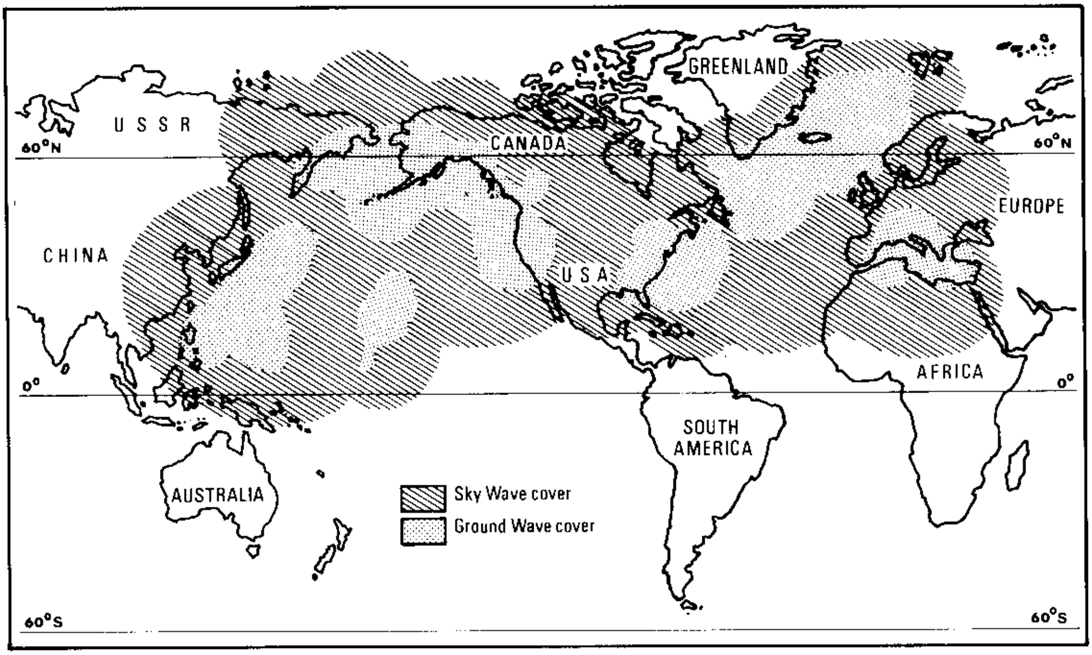
Submarines use Omega primarily to update their inertial systems between satellite fixes. Omega's accuracy depends very much on the distance of the submarine from the Omega stations used. Under stable atmospheric conditions, and provided the Omega stations used are not more than 2,000 miles away, it is feasible to expect an accuracy of 1nm by day and 2nm by night, which, by itself, is not good enough for an SSBN.

Ideally, to keep the inertial system properly updated a satellite fix should be taken about once an hour, which will not be possible until the new NAVSTAR system is in operation. Even then, it might well be too dangerous for a submarine to expose the small VHF rod to receive the satellite's transmissions, so some other method of updating must be used, possibly the Bottom Contour system mentioned below.

In the meantime Magnavox has produced a combined Satellite/Omega system, particularly designed for updating the dead reckoning between satellite fixes and for providing an accurate distance run. Whilst the principle of using the two systems remains the same, by combining them the navigator's task is greatly simplified.

Bottom Contour Navigation

Of the equipment mentioned at the beginning of this chapter only the echo sounder has not been explained. This is used to measure the depth of water by transmitting sonar pulses down to the bottom and noting the time between the transmission of a pulse and the time its echo returns, like



Above:
Loran C radio navigation aid coverage.

any other active sonar set. From this, of course, it is possible to measure the depth very accurately.

Almost the whole of the sea bottom of the North Atlantic has been surveyed over the last decade and very accurate contour maps have been drawn showing the various depths down to 2,500 fathoms. The maps, naturally, are highly classified, but there is little doubt that the Soviet union has drawn similar maps.

A submarine can run a line of soundings over a period of time, plot them on transparent overlays, fit the overlays to the contour lines on the appropriate map, and so obtain its position. In this case the sonar transmission is beamed downwards and the chances of it being intercepted are not very great; even so, the transmissions are usually limited to just one 'ping' at a time.

Navigation by bottom contour is used if it is necessary to stay deep and expose nothing above the surface, or if electronic methods are unusable due to enemy action. The system is surprisingly accurate: in areas where the depths vary greatly, and numerous and definite contours can be drawn, the accuracy is comparable to astro fixing (ie within ½nm). It is used quite frequently in peacetime in order to practise it.

From the above it will be seen that no one system is 100% accurate, with the possible exception of astro navigation, which might not always be available. It is customary therefore for the navigator to plot the various positions obtained by the different means available and to decide upon a mean position, but at the same time to produce a mean maximum error figure. This depends upon a large number of factors: perhaps the submarine is a long way from the Omega or Loran stations used, perhaps bad weather or the danger of exposing a small antenna has meant that no satellite fix has been possible for a long time, or it may not have been safe to put a periscope up to obtain an astro fix. The inertial system may not have been updated for hours and so on. All this has to be taken into account and often no more than a 'guesstimate' of the true position can be made.

SSBNs have similar but more accurate equipment. For example they have two inertial systems which can be compared one against the other, and if necessary a mean inertial navigation position taken.

Finally, the Sperry company of the USA is working on a new complete navigational system for the Trident-carrying SSBNs under a 10-year contract worth about $800 million, which is some indication of the importance given to accurate position fixing for SSBNs. There are many sub-contractors, and it will undoubtedly place great reliance on the NAVSTAR system when it comes into use. The longer the range of a ballistic missile, the greater is the necessity for a highly accurate starting point, and Trident has a very long range indeed.

11 Soviet Submarines

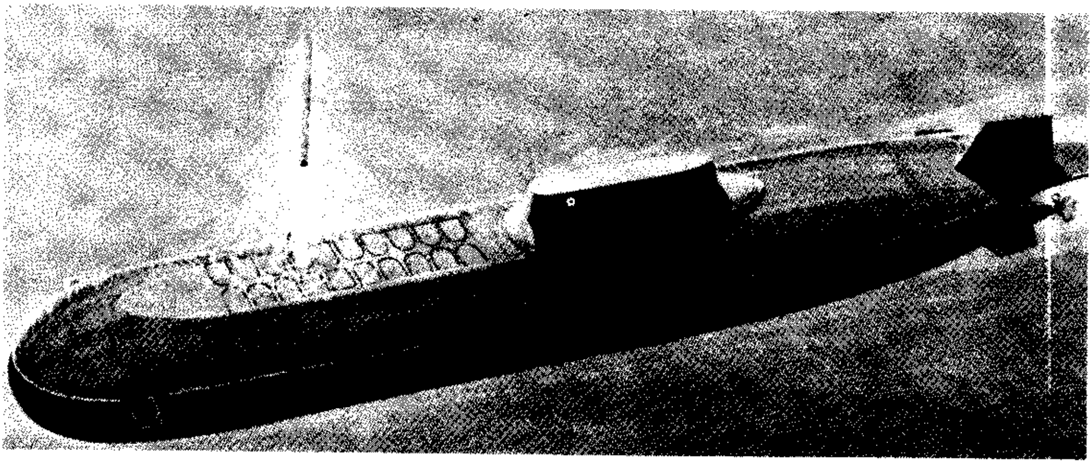
A glance at the Summary to the Appendix at the end of this book will show the immense submarine fleet that the Soviets have managed to amass — 66 SSBNs, 15 SSBs, 127 SSNs and SSGNs and 223 conventional diesel driven craft. It is difficult for us in the West to understand why such huge numbers are required, but it must not be forgotten that:

- The USSR has two large coastlines to patrol and has to deploy SSBNs in both the Atlantic and the Pacific (and possibly also the Indian Ocean) with missiles targeted on the USA, China, the UK and the rest of Europe. These four different target areas might well account for the fact that the Soviets have some 30 more SSBNs than do the Americans, but only 20 more than the combined strength of the USA, France and the UK. Whilst on comparisons, it is worth noting that the USSR can deploy 842 Submarine Launched Ballistic Missiles (SLBMs) and NATO (US, France and UK) can deploy 736.
- Not all the Soviet SSBNs are modern and a few missiles have a very limited range.
- SSGNs nearly all deploy medium range cruise missiles, primarily for anti-ship use, a concept only recently adopted by NATO.
- The figures take into account many Soviet submarines by no means in their first youth, some of which might not even be seaworthy.

However, all this may be wishful thinking as there is no doubt that the Soviet submarine building programme is proceeding steadily, and it would appear that in time the older submarines will be replaced by more modern ones. Let us therefore look at the types of Soviet submarines in service or about to enter service, paying particular attention to the more modern ones.

SSBNs

Pride of place amongst the Soviet SSBNs must be given to the largest submarine in the world — the 'Typhoon' class. There are conflicting reports about this new class of nuclear submarine, primarily because only one submarine — *Typhoon* — is in commission, although a second one is known to be building. One point on which the commentators agree is that the submarines are enormous and are thought to displace 26-30,000 tons submerged. Their length is estimated as 170m, beam at 22.9m and draft at around 14m. Opinions, however, differ over their design. Some analysts think that they have two parallel pressure hulls with an overall outside hull or casing. It is known that they have 20 missile hatches placed



forward of the fin in pairs. One school of thought is that the missiles are placed on end, with 10 in each pressure hull. Another suggestion is that the missiles are between the two pressure hulls.

The design has a low length-to-beam ratio of about 7:1 compared with 13:1 of previous Soviet submarines. In other words it is short and fat. Another feature of it is that the fin (or sail as the Americans call it) is placed well aft to allow room for the missiles forward of it and is much lower than usual. Various reasons have been advanced for its low height, but the most probable is that it has been shortened to enable the submarine to operate under ice, and to break through to allow the missiles to be launched, without ice damaging the fin. The type is thought to have two nuclear reactors, twin turbines and two propellers, giving a maximum speed of 24kt submerged.

The most interesting feature of the 'Typhoons', however, is their missiles. They are equipped with the new SS-N-20 ballistic missile which is replacing the present SS-N-18. The new missile is reputed to be slightly longer than the N-18 which is 14.1m long (the US Trident C4 is 10.38m long). The N-20 may have up to nine RVs, which is two more than the N-18 has, and an estimated maximum range of 5,060nm (Trident C4's range is 4,512nm; the new new D5 will have a range of about 6,000nm).

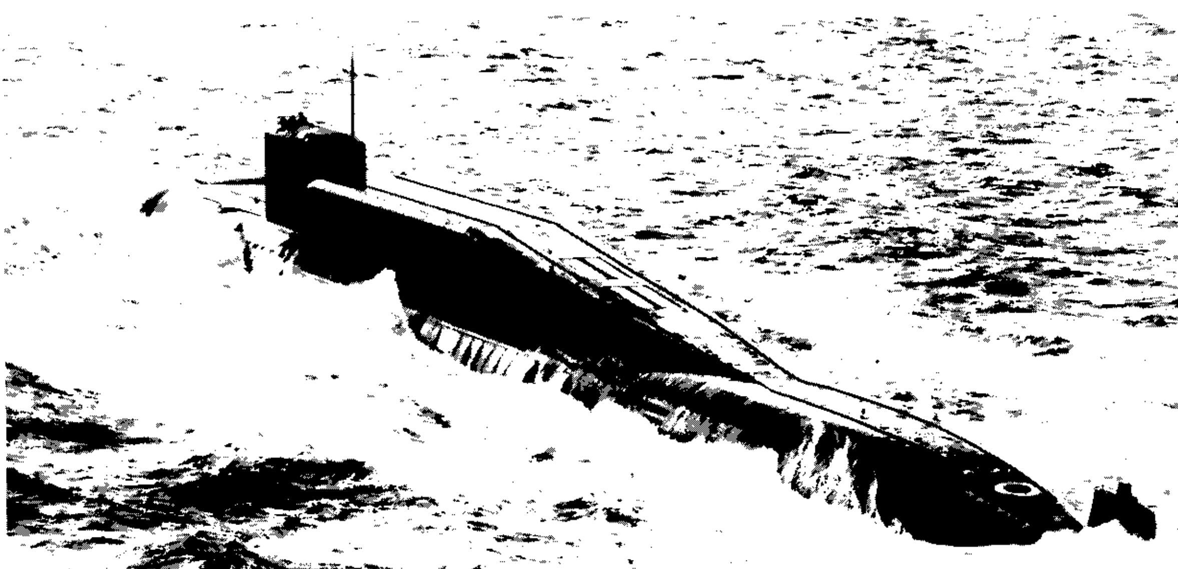
Below left:
Artist's impression of the Soviet 'Typhoon' class, the largest submarine in the world, reputed to be at 26,000-30,000 tonnes.

Below:
A Soviet 'Delta III' class submarine. Note the built-up casing to cover the SS-N-18 nuclear missiles. The Soviets have 15 of this class.

Because of the 'Typhoon's' large size, some observers consider that a reload of 20 missiles is also carried, but this seems unlikely. Other points about the 'Typhoon' class vessels are that they almost undoubtedly have double hulls, although previous Soviet submarines have had single hulls. It is possible that the outer hull is no more than a casing, but judging by their weight it is more likely to be a strong thick hull with ample space between it and the inner pressure hull. This would account for such a large submarine. If this is not the case it is difficult to understand why the Soviets required such a large vessel. The much smaller 'Delta III' class carries 16 SS-N-18 missiles with a range of 4,300nm, almost as long a range as the SS-N-20. Since the latter is reported to be only slightly longer than the N-18s, it would appear that they could have been embarked on the 'Delta IIIs' in place of the N-18s, accepting the fact that only 16 could be carried instead of 20. So why go to the expense of building a new class so much larger? No valid explanation has been advanced by Western analysts so far. . . .

The 'Typhoons' would seem to have everything against them. They form large targets for enemy sonar, they are not particularly quiet, they are not very fast — nothing like as fast as Western SSNs — they must have a large magnetic signature easily detectable by airborne MAD or ocean laid magnetometers, they must require a large crew, they are not very manoeuvrable and they are expensive: the loss of only one would be equivalent to the loss of two smaller SSBNs. But, and it is a very big but, their double hull may go a long way towards preventing unacceptable damage by torpedoes.

With their very long-range missiles, it seems likely that they would be deployed in the Barents Sea, right on the USSR's doorstep, and still be



able to cover the whole of North America's industrial zone and military bases.

Apart from the 'Typhoons', the latest type of Soviet SSBN is the 'Delta III' of which there are 14, and one building. These too are large submarines, displacing 11,000 tons submerged (some authorities put the figure at 13,250 tons). Like the 'Typhoons' they have two reactors and two propellers, giving a maximum submerged speed of 24kt. Unlike the 'Typhoons', their fins are mounted well forward, leaving plenty of space for the missiles abaft them, but their shape is somewhat peculiar in that they have a very high casing to cover the missile compartment, so high that their fins extend only a few feet above the casing. Like the 'Typhoons' this may be to enable them to operate under the ice.

Their SS-N-18 nuclear missiles have three versions:

- Mod 1: 3,500nm range with three MIRVs.
- Mod 2: 4,300nm range with only one RV.
- Mod 3: 3,500nm range with only one RV.

The first of the 'Delta IIIs' entered service in 1976, but the missile did not become operational until 1979. It is not known which submarines carry which modification of missile.

The predecessors to the 'Delta IIIs' were the 'Delta IIs', of which only four were built. They are really enlarged 'Delta Is'. The latter displace 10,000 tons submerged and 18 were built. Both the 'Delta Is' and 'IIs' carry the SS-N-8 missile which is believed to have a range of between 4,200 and 4,900nm. The 'Delta Is' carry 12 missiles each and the 'Delta IIs' 16. All the 'Deltas' have a maximum submerged speed of 24-25kt. 'Delta Is' were completed between 1972 and 1977, 'Delta IIs' between 1974 and 1976, and 'Delta IIIs' between 1979 and 1982.

This brings us to the 'Yankee' class (9,300 tons submerged) of which 34 were built at a very rapid pace between 1970 and 1974. However, as a result of the SALT 1 agreement, nine 'Yankees' had their missile tubes removed and have been converted to SSNs, leaving 25 still fitted as SSBNs. The types of missile carried varies. Some carry 16 SS-N-6 Mod 1s, some have 16 SS-N-6 Mod 3s and one has 12 SS-N-17s. The N-6 Mod 1s have a range of 1,300nm and one RV, the N-6 Mod 3 has a range of 1,800nm and two MIRVs, whilst the N-17 is a much more modern missile, with a range of 2,400nm and only one RV. The early N-6s are somewhat similar to the US Polaris A2 and first appeared soon after the Americans started deploying the A2.

The final SSBN class is in fact divided into two, the 'Hotel IIs' and the 'Hotel IIIs', but only one 'Hotel III' was built after five 'Hotel IIs'. The hulls of both classes are the same and displace 6,000 tons submerged. 'Hotel IIs' have only three missiles of the SS-N-5 type and the one 'Hotel III' has six of the SS-N-8 type. The N-5s are obsolescent because of their short range (850nm).

One other missile is believed to be under development. Known to NATO as the SS-N-23, it is probably designed to replace the SS-N-18 in the 'Delta III' class and will undoubtedly have multiple RVs with improved accuracy. No range figures are available, but it is likely to have a range of about 6,000nm to match the Trident D5. It is unlikely to enter service before mid-1986.

The total of Soviet SSBNs is 68, but the three 'Hotel IIs', although apparently still in commission, must be considered obsolescent, so the number of operational SSBNs comes to 65.

SSBs

In addition to the SSBNs, the Soviets have 15 ballistic missile submarines, but they are not nuclear propelled. They are all of the 'Golf' class: 13 'Golf IIs', one 'Golf III' and one 'Golf V'.

Below:
A Soviet 'Yankee'-class SSBN submarine on the surface. The Yankee was the Soviet Union's first modern SLBM submarine. Almost 70 similar Yankee/ Delta submarines have been completed since 1967.

Soviet SSBNs

Class	*Submarines in commission*	*Max Submerged speed (kt)*	*Missiles carried*	*RVs*	*Missile range (nm)*	*Remarks*
'Typhoon'	2	24.7	20 SS-N-20	6-12	4,500	No of RVs is not certain
'Delta III'	14	24	16 SS-N-18			
			Mod 1	3	3,550	Not certain which type of Mod is fitted in which submarine
			Mod 2	1	4,300	
			Mod 3	7	3,500	
'Delta II'	4	26	16 SS-N-8			
			Mod 1	1	4,200	The one RV is reported to have an 8MT warhead
			Mod 2	1	4,900	
'Delta I'	18	26	12 SS-N-8			
			Mod 1	1	4,200	As 'Delta II'
			Mod 2	1	4,900	
'Yankee I'	25	28	16 SS-N-6			
			Mod 1	1	1,300	Not certain how many Mod 1 missiles and how many Mod 3
			Mod 3	1	1,800	
'Yankee II'	1	28	12 SS-N-17	1	2,400	
'Hotel II'	3	26	3 SS-N-5	1	850	Obsolescent
'Hotel III'	1	26	6 SS-N-8			
			Mod 1	1	4,200	

Soviet SSBs

Class	*Submarines in commission*	*Max Submerged speed (kt)*	*Missiles carried*	*RVs*	*Missile range (nm)*	*Remarks*
'Golf II'	13	14	3 SS-N-5	1	850	
'Golf III'	1	14	6 SS-N-8	1	4,200	
'Golf V'	1	14	—	—	—	Used for trials of the SS-NX-23

'Golf IIs' carry three SS-N-5 missiles mounted in the fin which is therefore very large. The missiles having such a short range are regarded more as theatre weapons as opposed to strategic. Half the 'Golf IIs' are stationed in the Atlantic and the other half in the Pacific. The one 'Golf III' was converted to carry the SS-N-8 missile; why is a mystery. The 'Golf V' is believed to be carrying out trials of new missiles.

The 'Golfs' displace 3,000 tons submerged and are diesel-electric driven with three shafts. They have a maximum submerged speed of 14kt, but can achieve 17kt on the surface.

SSGNs

We now come to the cruise missile submarines, labelled SSGNs by NATO. The US Navy experimented with cruise missile submarines as long ago as 1949 with the missiles launched from their own tubes. However, the programme was abandoned in 1965, only to be re-started in the same year, but with the cruise missiles launched through torpedo tubes.

The USSR first placed cruise missiles on board submarines in 1958 when some 'Whiskey' class conventional submarines were fitted with SS-N-3s (the old 'Shaddock'). The missiles had a range of some 200nm and the submarine had to surface to launch them. Later other submarines were also fitted with the same missile, but it still had to be launched from the surface. However, the second Soviet cruise missile programme finally took off about 1970. Eleven 'Charlie Is' were fitted with eight SS-N-7 missiles with a maximum range of 35 miles and which could be launched submerged. Although called cruise missiles, they were in fact the forerunners of what is now called (in the West anyway) the tactical submarine-launched anti-ship missile, such as Sub-Harpoon and Exocet SM39.

The 'Charlie I' class vessels are nuclear attack submarines (SSNs) with a maximum submerged speed of 28kt (although they have to go considerably slower when actually launching their missiles), and the fact that attack submarines could now launch an anti-ship weapon with a range much greater than the torpedo caused a number of tactical headaches in the West. Until then ASW screens were stationed around the larger ships in a force at ranges to match those of the then existing torpedoes, perhaps, only 5,000m. Suddenly it was necessary to endeavour to detect hostile submarines outside their missile firing range. This involved far more use of helicopters with dipping sonars, and long range maritime patrol aircraft patrolling some 100nm or more from the main body. Further missile attacks could be made from abaft the beam, or even right astern which had not been possible with the then slow and relatively short range torpedo.

The Soviets followed with their SS-N-9 cruise missiles with a range of 70nm fitted in each of the six 'Charlie IIs' and 10 missiles in the one 'Papa' class vessel.

Then came an entirely new type of Soviet missile, the SS-N-19, with a range of 270nm-plus, together with a revolutionary type of attack submarine, the 'Oscar' class, of which it is expected eight will be built; at present there are only two. The 'Oscars' are very large SSGNs (14,000 tons submerged) and carry 24 angled tubes for the SS-N-19. They are nuclear propelled with two reactors and have a supposed maximum speed of 35kt. The missiles are in two banks of 12 either side and fixed in elevation at an angle of approximately 40°.

There is also thought to be a new submarine (torpedo-tube) launched cruise missile under development, known as the SS-NX-21. It appears to be similar to the US Tomahawk and capable of use against land or sea targets. Its range is not known.

All the SSGNs carry at least six 21in torpedo tubes ('Oscars' have eight) and all the submarines have high submerged speeds, so that they can be used in the SSN role for attacking other submarines or even torpedo attacks on surface ships. All of them, from the 'Charlie I' class onwards, also have the SS-N-15, an anti-submarine weapon similar to the American SUBROC. It is launched from a torpedo tube, rises to the surface and then flies to the vicinity of the target where it drops a depth bomb (which could be nuclear). Its maximum range is about 15nm.

There are older SSGNs — 29 'Echo II' class — but they carry only the elderly SS-N-3 type of missile and have a maximum submerged speed of 25kt. There is also the 'Juliet' class of 16 SSGs. They are diesel-electric propelled and they use the same type of missile. Both types have to surface to launch.

The Value of Cruise Missiles

As mentioned above, the advent of submarine-launched cruise missiles forced NATO to shift the ASW screens of important targets farther out, to some 70-100nm from the main body, to what has become known as the 'outer zone'. Of course, the Soviets have a very large number of SSNs and conventional submarines which might be deployed, together with the SSGNs, in the 'inner zone'. It follows that shifting the ASW screen farther out is by no means the complete solution, because there are still the close range attackers to be reckoned with. Thus the old World War 2 ASW screens cannot be completely forgotten, the only difference being that modern torpedoes have ranges up to 20km, so the inner zone may have to extend out as far as this.

There are also problems for the attackers. Even with a submarine-launched 70nm range missile, it is very difficult to pick out the actual target required. In principle, the submarine detects the target by passive sonar, not very accurate at the best of times, and by the occasional raising of the radar mast, but a submarine's radar would not detect a target, even one as big as an aircraft carrier, at 70nm. A more likely detection range would be some 20-30nm.

This problem has been realised by the Italians who have developed an Otomat missile (with Matra of France) which can be guided in flight by the use of a helicopter, to gain target position by its

Above left:
A Soviet 'Echo II' class submarine. 'Echo IIs' displace 5,800 tons submerged.

Above:
A Soviet 'Victor' class attack submarine. Nuclear propelled, these submarines have a maximum underwater speed of 32kt.

radar. The US Sub-Harpoon has no method of guidance from an external source in flight, and relies upon its own active radar to pick out the target. It would not appear to be difficult to deceive it. The Soviet 70nm range cruise missiles are presumably the same, but it is possible they have some form of mid-course guidance provided by a helicopter, although how the helicopter hopes to survive in the presence of an enemy carrier or even enemy surface ships with modern ship-to-air missiles is difficult to discern.

In addition, if a submarine is relying on its passive sonar to detect the enemy, how can it be certain that the sounds it hears really do emanate from the particular force it wants to attack, or even more difficult, from the particular ship it intends to sink? ESM might help, particularly when trying to pick out a carrier, as such ships use their radar and radio nearly all the time to control their aircraft; however, use of ESM means exposing yet another mast.

All this means that submarine commanding officers will want to get close enough to their targets to identify them positively before launching an anti-ship missile, and we may find that successful air patrols in the other zone are able to keep submarines from raising their radar or ESM masts. That in turn may well mean that, in spite of long range missiles, attacks may still be made in the inner zone.

When it comes to the 'Oscars' with their 270nm range cruise missiles, launching them so far away from their target does not appear very likely. On the other hand, the Americans are proposing to arm their submarines with the Tomahawk anti-ship cruise missile with a maximum range of 244nm and the same remarks must apply to them. The missiles are said to have a guidance system similar to the Sub-Harpoon, but greatly improved and modified. This may mean that the missile will have a better active radar on board with wider arcs of search, or it may be that some method of external updating of the missiles' inertial navigation system is to be fitted.

None of these remarks applies to the longer range cruise missiles which are designed to attack land targets. They are launched to cross the coastline at a certain point and thereafter guide themselves over the land by comparison of the country overflown with contour maps held in the computer onboard — what the Americans call the Tercom system.

SSNs

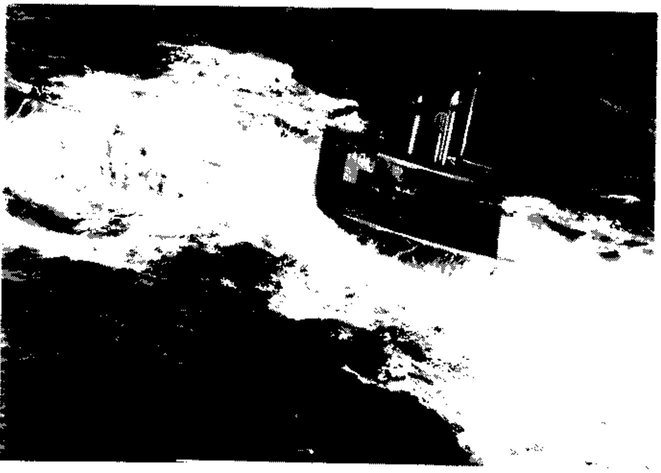
We now come to the nuclear submarines (SSN) primarily armed with torpedoes and commonly known as Fleet or Attack submarines. The most interesting are the 'Alfas". The first one was laid down as long ago as the mid-1960s as an experimental trials craft. The trials were not very successful and it was subsequently scrapped. However, armed with the lessons learnt, the Soviet started service production in 1979 and so far have built seven of them with, it is believed, more to come. The class is distinguished because, if the Soviets are to be believed, they are the fastest submarines in the world, achieving a maximum submerged speed of 42-45kt. Displacing 3,800 tons submerged and with a length of only 79.3m, they are very manoeuvrable and undoubtedly constitute a serious threat to NATO navies. They are armed with six 21in torpedoes and the SS-N-16, the successor to the SS-N-15 ASW weapon which we have already met. There does not appear to be much difference between the N-15 and the N-16 except that the latter probably has a homing torpedo instead of a depth bomb. Its range is also said to have been improved to 25nm.

'Alfas' are reported to have titanium hulls. Titanium is much stronger and lighter than any known type of steel, but is very difficult to work with when building: welding for example is by no means an easy matter with titanium. It may however mean that the 'Alfas' operating diving depth is very much deeper than the average SSN or SSBN. Some reports put it at 600m instead of the normal operational depth for an SSN of 400m. An advanced reactor, using a liquid metal rather than water is said to be fitted and the controls are believed to be highly automated, reducing the crew to only 45 men (the average crew of US and British SSNs is around 130 men). 'Alfas' are reputed to be noisy, particularly at high speeds.

Some authorities argue that the use of titanium in a submarine hull would give increased diving depth or increased speed, but not both. They say that even with the new type of reactor giving a higher output, to use this to increase the speed would require much heavier turbines, but this does not seem to be the case as the 'Alfas" displacement weight is in fact smaller than most other Soviet (and Western) SSNs. The argument runs that the speed may have been increased marginally to, say, 35kt using very slightly heavier turbines, but that their diving depths are still much the same as other SSNs, around 400m.

Other Soviet SSNs are all much longer than the 'Alfas', being over 100m, and displace between 5,000 and 6,000 tons submerged. They consist of:

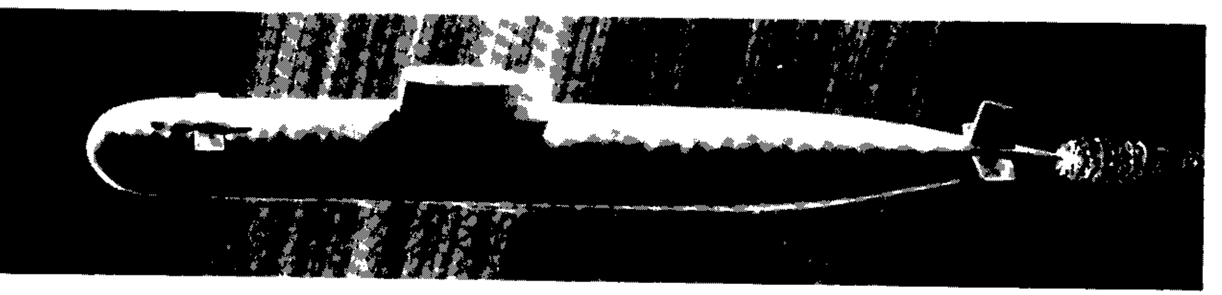
- Eight (some authorities say 16) 'Victor IIIs' with more building, first one completed 1978; 5,800 tons and 25kt submerged, eight torpedo tubes and the SS-N-15 or N-16, diving depth 400m.



Left:
A 'Tango' class patrol submarine photographed from an RAF Nimrod aircraft in the North Sea, during a Soviet Navy exercise in April 1984.

Right:
HMS *Aurora* in company with a Soviet diesel submarine of the 'Foxtrot' class. This photograph was taken as *Aurora* passed through the Mediterranean on her way home after a deployment to the Far East.

Below:
Artist's impression of one of the Soviets' newest submarines, the 'Mike' class SSN.



- Seven 'Victor IIs' completed 1972-78; 5,800 tons and 31kt submerged, six torpedo tubes, SS-N-15.
- 16 'Victor Is' completed 1967-74; 5,100 tons and 32kt submerged, eight torpedo tubes, SS-N-15.
- Five 'Echos' (converted from SSBNs 1970-74); 5,200 tons and 25kt submerged, eight torpedo tubes, SS-N-15.
- 13 'Novembers' completed 1959-64; 5,300 tons and 30kt submerged, eight torpedo tubes and four smaller ASW torpedo tubes.

New SSNs

Since this book was started, information has been received of two new types of Soviet SSNs, thought to be now carrying out trials. The first, believed to herald a new class which NATO has named the 'Sierra', was launched in January 1983. The class will apparently be the successor to the 'Victor IIIs'. Little is known about them, but they will presumably carry the SS-N-16 and up to eight torpedo tubes. They will have a slightly higher speed than the 30kt submerged of the 'Victor IIIs' and are reported to displace 6,000 tons submerged.

The other submarine is the 'Mike' and is also a nuclear attack craft. The first was launched in May 1983 and apparently displaces 9,700 tons submerged although it is reported to be the same length as the 'Sierra' class — 110m.

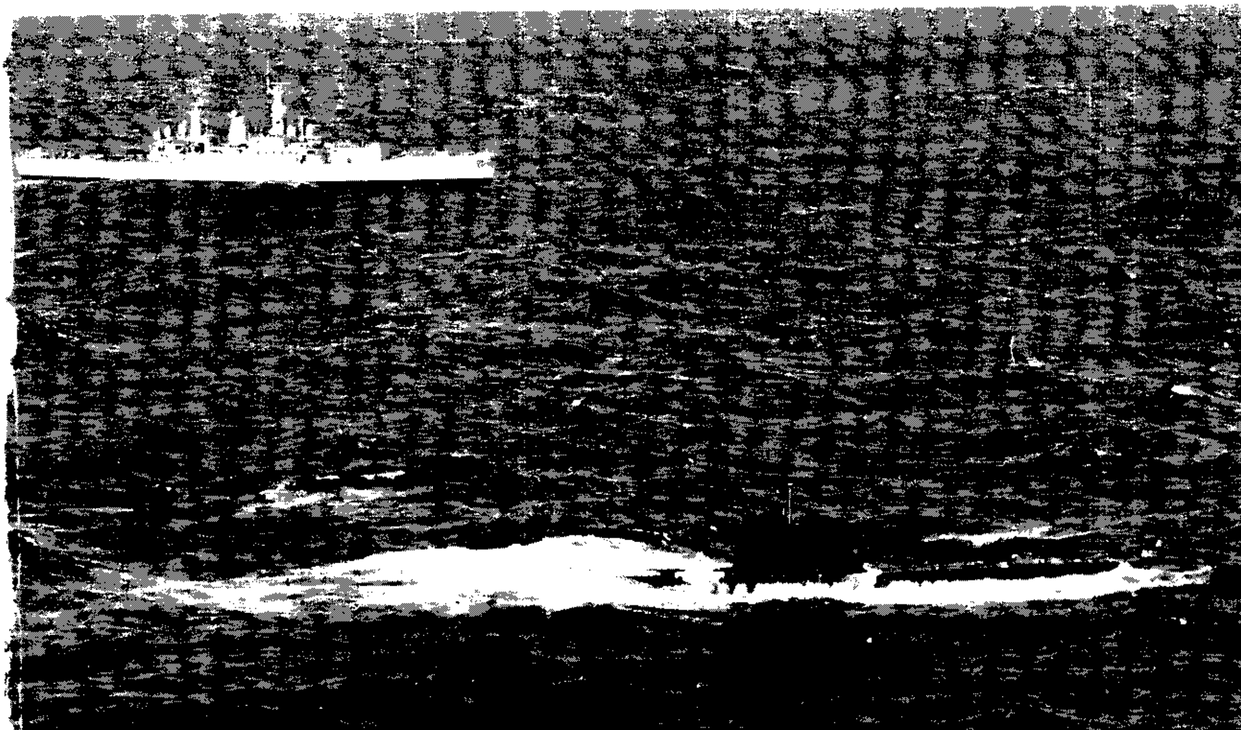
It has also emerged that all new Soviet submarines have a coating of anechoic paint which not only restricts their sonar echoing properties when detected by an active sonar, but absorbs any machinery noises from inside the submarine. One report states that the coating will reduce NATO's capability by 75%, but this may refer to active sonar capability only. There is still the noise made by a submarine passing through the water and the cavitation noises of the propeller.

Conventional Submarines (Diesel-electric)

The newest Soviet conventional submarines are the 'Kilo' class. They are still being built and only four have so far been completed. There is nothing particularly novel about them. They displace 3,500 tons submerged which makes them slightly larger than most ocean-going conventionals. Their submerged speed is 16kt and they carry eight torpedo tubes. Their two main claims to fame are that they appear to be the first new conventionals to be built in the Soviet Union for 10 years and secondly that their shape is more like the 'tear-drop' shape much used in the West, whereas previous Soviet conventionals have been long and thin.

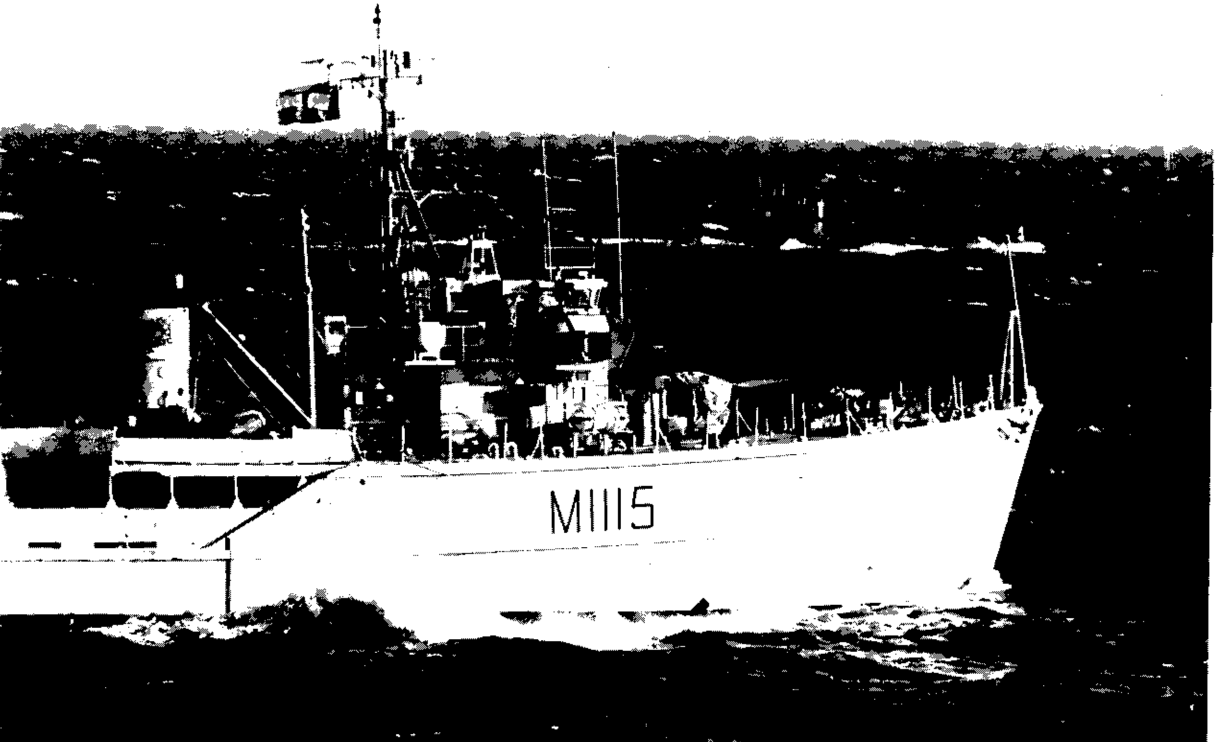
Their immediate predecessors were the 'Tango' class of which some 20 have been built and more are on the way. These displace 3,200 tons submerged, have a submerged speed of 16kt and carry eight torpedo tubes.

Western observers find it difficult to understand why the new 'Kilo' class was started whilst the 'Tangos' are still being built. There seems little to choose between the two types, except that the 'Tangos' are slightly longer. The 'Tangos' are the replacements for the well-known 'Foxtrot' class



Above:
A Soviet 'Zulu' class submarine about the same size as the British 'Oberons'. 'Zulus' were built in the 1950s and are now obsolescent.

Below:
A Soviet 'Whiskey' class submarine in the English Channel being shadowed by HRH The Prince of Wales commanding HMS *Bronington.*



and are about the same length. It seems probable therefore that the 'Kilos' are to be the replacements for the 'Whiskey' and 'Romeo' classes which are smaller.

The remaining Soviet conventionals are considerably older, although many of them are still in service, but will be replaced before long. They comprise:

- 80 'Foxtrots', 2,400 tons and 15.5kt submerged, eight torpedo and four smaller ASW tubes. 'Foxtrots' have been sold to Cuba, India and Libya.
- 10 'Romeos', medium range, 1,700 tons and 13kt submerged, eight torpedo tubes. Two 'Romeos' were transferred to Bulgaria, six to Egypt and one to Algeria.
- Four 'Quebecs', coastal craft with closed-cycle diesels, 540 tons and 16kt submerged. All that is left of a class of 30. Probably used for training.
- 10 'Zulu IVs', 2,300 tons and 16kt submerged, 10 torpedo tubes. Only four in service, remainder in reserve.
- 50 'Whiskeys', 1,350 tons and 13.5kt submerged, six torpedo tubes (two mounted aft). Some 75 others are in reserve. In addition at least 30 have been transferred or sold abroad. It will be remembered that it was a Soviet 'Whiskey' which stranded itself off Karlskrona in Sweden a few years ago.

Soviet Efficiency

Finally we come to the all important question — how efficient are Soviet submarines? This can be divided into four disciplines:

- How efficient are the crews?
- How efficient are the submarine equipments?
- How efficient are the sensors and weapons?
- How efficient are the tactics employed?

As can be imagined, it is quite impossible to give straight answers to these questions. All that can be done is to take a brief look at any indications there may be.

The Crews

75% of Soviet ratings are conscripts, serving for two or three years. By the nature of things, conscripts on short service are seldom as efficient as career men who have volunteered for long term engagements. However there is no evidence to suppose that Soviet submarine crews are not as efficient as their counterparts in NATO, but they may not have quite the dedication and the intensive training. This is underlined by the very large number of submariners that the Soviets have to train and by the fact that quite a proportion of a Soviet rating's time is taken up by political indoctrination and constant lectures on the communist creed, a burden that submarine ratings in the West do not have to bear, leaving them more time for technical training.

Submariners have to be highly qualified and trained to use their initiative without orders from above. The Soviet armed forces work very much to the rule book and there is little room for individual enterprise. In NATO submarines, nearly every man in the crew is trained to perform duties other than his own specialisation, and in the event of sickness or casualties there is nearly always somebody equally capable of stepping into another man's shoes. This may be equally true of Soviet submarine crews, but it would be foreign to the normal training in their services.

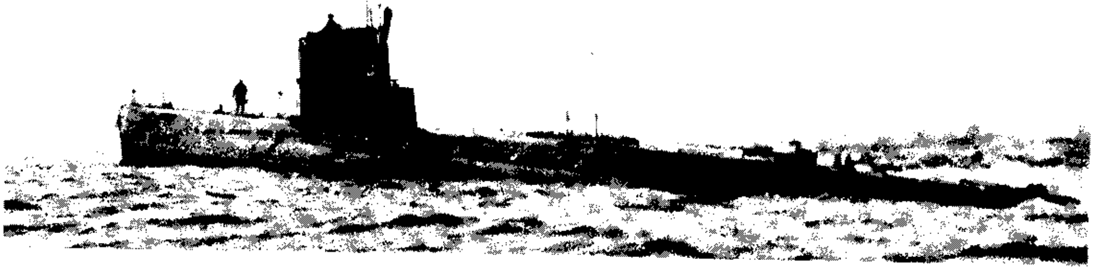
Little is known about the efficiency of the officers, who are not conscripts, but the antics of the 'Whiskey' submarine, which managed to strand itself off the Swedish coast, did not improve the image of its Commanding Officer and Navigator. The Soviets themselves announced that it ran aground due to the failure of some navigational instruments. If this is true it would lend more credence to the Western view that Soviet equipments are not very reliable.

Equipments

Equipments in Soviet submarines appear to be based very much on those used in the West (some might say copied), but it is often thought that Soviet equipments (not necessarily in submarines) are inclined to fail when they are most needed, possibly due to poor maintenance. There have been a number of cases in recent years of Soviet submarines breaking down, or catching fire at sea and having to be towed home, something which seldom happens in the Western submarine world. These breakdowns are those which NATO has had the luck to observe, but there may be others of which no information has leaked out. In addition, of course, it is not known how many submarines have been lost at sea by accident as the Soviets never announce any losses.

Sensors and Weapons

It is generally thought, even in the Soviet Navy, that NATO submarine sonars, both active and passive, are more efficient than those of the Soviets. In addition, Western submarines do their best to avoid transmitting ev[illegible] sonar pulse on their active sonars, for fear of detection. The same is not apparently true of Soviet submarines, which are thought to use active sonar much more than do NATO submarines. They also appear to use their radios more.



As regards weapons, the Soviets and NATO ones show remarkable similarity, but how well the Soviet weapons work is something which is shrouded in mystery until a shooting war breaks out. Since both sides sincerely hope that such an event will never happen, neither side may ever know how effective their weapons would have been.

Tactics

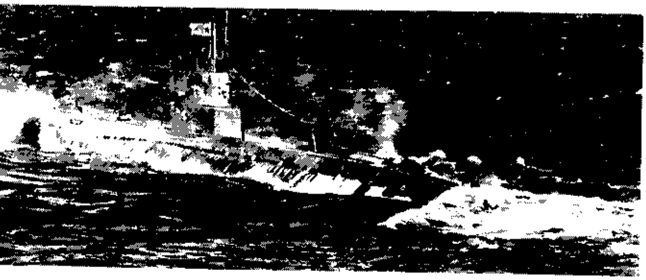
The Soviets exercise strict control of their submarines at sea from shore headquarters. They also believe in simultaneous massed air and submarine attacks. This is difficult to achieve and may lead to as much confusion amongst the attackers as amongst the defenders. It certainly leads to a great deal of radio traffic, which, if jammed, might lead to even greater confusion.

The Soviets seem not to attach so much importance to radio silence at sea as does NATO and particularly NATO submarines. The German U-boats did much the same thing in World War 2 when their Wolf Pack tactics for submarines required many transmissions from the U-boats, allowing the Allied shore DF stations to establish the positions of many enemy submarines without difficulty, and also considerably helped the Allied surface ASW ships. On the other hand, a well co-ordinated air and submarine attack on, say, a Carrier Task Group, might well be devastating.

In submarine versus submarine tactics, the problem is much the same for both sides — the opposing submarine must first be located. To find, say, SSBNs it is necessary to establish patrols outside their bases or at choke points through which they must pass. It is possible that, knowing that the choke points would be well patrolled by NATO, the Soviets might consider escorting their SSBNs through them with SSNs, to beat off any submarine attacks or create diversions. However, it is possible that in the future, when 6,000nm submarine-launched missiles are deployed on board more Soviet SSBNs, there will be no necessity to send SSBNs to traverse the Iceland-UK gaps, although it may well still be necessary to send SSNs and conventionals through to attack shipping in the Atlantic.

To conclude, there is no doubt that Soviet submarines constitute a formidable threat to NATO. However, if the SSBNs, which after all are merely concealed mobile strategic missile launchers, and as such play no part in a conventional war at sea, are discounted, then the Soviet numerical superiority over NATO SSNs and SSs is about 2 : 1; but the Soviets are obliged to keep a considerable number of submarines in the Pacific, and they would not materially affect a European conflagration.

A formidable threat — yes. Insurmountable — no.



Top:
A 'Whiskey' class submarine ashore in Swedish territorial waters.

Left:
The Soviet 'Whiskey' class submarine *U137* finally makes her departure from Swedish waters.

Below:
U137 leaving Swedish waters with a 'Kildin' class destroyer standing by.

12 Submarine Accidents

Peacetime accidents in which submarines are lost are now fortunately few and far between. They reached their peak in the 1920s when no less than 26 submarines, world-wide, were accidently sunk in nine years. The figure has been greatly reduced since and between 1960 and 1980 only eight submarines were known to be lost: the figure since then is even lower, but there have been no figures available for Soviet submarines since 1960.

There are two main reasons for this reduction. Firstly, much more attention has been paid to the safety of submarines, and secondly, NATO has instituted a NATO-wide system for organising search and rescue operations for submarines in distress. Briefly it is a system requiring submarines to report to their operational authority what they are doing at routine times. If any report fails to arrive, a NATO-wide emergency is declared and various planned procedures are activated.

The SUBSUNK System

All submarines on passage are required to make a SUBCHECK report (SUBCHECK being the first word of the message) whether they dive or not. The intervals at which such reports are made is decided by the operating authority, and usually varies between 18 hours for submarines immediately after a refit or period in dockyard hands, to 36 hours which is the interval normally used; but often, in deep water, no SUBCHECKs are normally required.

Before proceeding to sea, submarines issue a SUBNOTE on which they state the time by which an operating authority should have received a surfacing signal after a dive. Diving signals are not necessarily sent for every dive, since on exercises the submarines may be diving and surfacing very frequently. The time indicated in the SUBNOTE therefore is the time the submarine will surface at the end of the exercise or a passage. If a SUBCHECK or a surfacing signal is not received by the time it is due, the operating authority can issue a COMCHECK signal, meaning 'establish communication with me forthwith', to make sure that nothing has gone wrong with the communications (also perhaps to jog the commanding officer's memory). If no reply is received to this for one hour, or the normal surfacing signal is one hour overdue, the operating authority (or indeed any ship or authority) may issue a SUBLOOK signal, or even a SUBMISS signal (see below) if there is reason to believe that an accident has taken place.

Five hours then elapse, during which time all local authorities can initiate searches and ships keep a particularly sharp look out, on radar, for the missing submarine. If it still has not been located after five hours, or earlier if he considers it necessary, the operating authority issues a SUBMISS signal. This indicates that something is definitely wrong and that either the submarine cannot surface or has suffered a complete breakdown of communications.

Finally, if positive information is received that a submarine has sunk, or so much time has elapsed that there can be no other explanation, a SUBSUNK signal is issued. It is normally issued by the operating authority, but may be sent by anybody who has received positive information of a sinking. It is the executive order to start all possible rescue efforts and includes the use of the American Deep Submergence Rescue Vessel (DSRV).

The Americans have kindly offered the use of this craft to NATO should it be required in any emergency. In fact preparations of the DSRV are started on receipt of the SUBMISS signal: the SUBSUNK signal constitutes a definite request for it to be flown to the nearest airfield to the disaster area. It is fully described below.

Escape Methods

In depths down to 180m (600ft) it is possible to make individual escapes from submarines. At greater depths this is not possible and it is essential to send a specially designed rescue submarine to 'mate' with the stricken submarine, the crew of which then enter the rescue vehicle at normal atmospheric pressure (or nearly so). National escape methods vary, although many NATO nations have now adopted the system developed by the British. The Americans however rely on an outside source to rescue the crew, even at depths less than 180m. Some nations still use the free ascent method, which the British discarded over 10 years ago. In this system, the man wears no special escape equipment except a life jacket. He breathes in as much pure air as possible through a built-in breathing system (BIBS) in the escape chamber. Then the escape tower, with him inside it, is slowly flooded until the hatch opens and the man goes out, breathing out as he goes until he reaches the surface.

British and American Concepts

Before going on to describe the British system, it is necessary to examine the difference in philosophy between the British and the Americans. The British feel, rightly or wrongly, that if a submarine cannot surface it is because it has been holed and a large amount of water taken on board. They analysed all their peacetime disasters in recent years and found that nearly all occurred in waters of the continental shelf depth of less than 180m. There are two reasons for this: firstly, in peacetime, submarines exercise close to the land, rather than in mid-ocean, and secondly, there are more hazards, risk of collision, etc, close to the shore. They therefore concentrated on relatively shallow water escapes.

The Americans, on the other hand, with far more experience of nuclear and deep-diving submarines, feel that disasters could occur with the pressure hull still intact and no water in the submarine. Nuclear submarines are extremely strong and, whilst no collapse depths for them have ever been quoted, it is likely to be in terms of over 1,000m, instead of the few hundred likely in conventional submarines. SSBNs and SSNs are designed to remain submerged for days on end, and it is perfectly possible for crews to remain alive for periods long enough for the rescue craft to arrive, provided the pressure hull has remained intact and electrical power is still available. Without electrical power the crew could still remain alive for 48 hours. A further point is that with US SSBNs (and SSNs) operating in the deep oceans, the US has been forced to think in terms of rescue outside the continental shelf. Britain also has SSBNs and SSNs, but for the present it relies on help from the US should one of them get into trouble in deep water.

The British Escape System

Every RN submarine is fitted with two escape compartments, one forward and one aft. From the escape compartments run two towers (one for each compartment) large enough to hold one man. The towers run vertically upwards to hatches in the pressure hull. They can be flooded up from the sea by means of a valve controlled in the escape compartment and are similarly capable of being blown down. Flooding can also be achieved by means of a valve situated inside the tower itself, but this is only used by the last man to escape. The hatches on top of the towers lift when the pressure inside them equals that of the sea outside.

Escapers are enclosed in a special suit, and sufficient suits are provided for every man in the crew, plus a number of spares. The suit consists of an inflatable quilt which is filled from a small CO_2 cylinder stitched to it. In addition there is a buoyancy life jacket built into the suit and this is inflated from an air supply in the submarine. Over the man's head is a hood: in fact there are three hoods, an inner waterproof helmet, an insulating hood which is an extension of the suit, and an outer hood which is fitted with a viewing panel. Insulating mittens are stowed in a rip-open pocket of the suit, and a water activated light is also fitted.

The escape procedure is simple. The escaper, wearing the suit and hood, enters the escape tower and plugs his life jacket into an air outlet in the tower by a connector in the left cuff of the suit. The air outlet is supplied with pure air from the submarine's air storage cylinders, and, as the life jacket fills, it inflates; when the pressure has built up, a relief valve opens. This valve exhausts into the hood which is thus kept fully inflated against the pressure which will build up in the tower when it floods up.

The bottom of the hood is open, but as the pressure difference between the hood and the tower is so slight, there is little wastage of air out of the hood, and indeed it provides a safe and comfortable air lock from which the man can breathe.

When the escaper is ready he gives a signal and the tower is flooded up by opening a valve in the submarine. The water gradually rises and, when equalisation of pressure occurs, the hatch flies open and the man, who is very buoyant, shoots up to the surface. His sleeve connection to the air outlet automatically disconnects and seals, whilst the air outlet also automatically closes. As soon as he has gone, the escape hatch is closed from inside the submarine, and the tower blown down by compressed air from the submarine's normal supply. The next man then enters and the cycle is repeated.

To keep the escape as short as possible the pressure in the tower (ie the flooding) is arranged so that it doubles every four seconds and at 150m will equalise with the sea pressure in 16 seconds. No harmful effects of this rapid increase in pressure have resulted and in fact it has been found that the rate could be doubled without harm.

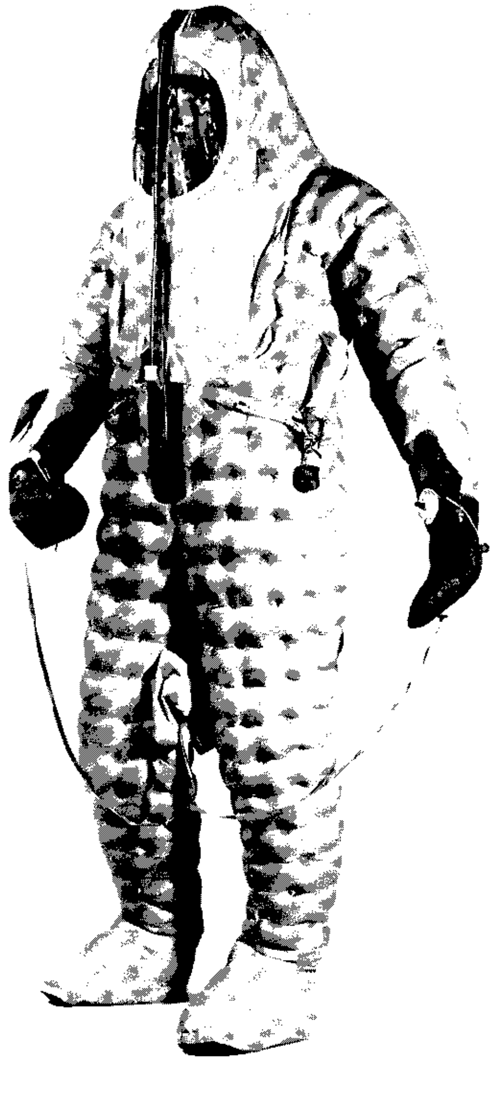
The man, of course, ascends to the surface with no stops for decompression, and trials were carried out to see at what speed this could be accomplished without causing the 'bends'. A 'bend' after an exposure of 50 seconds showed the limit, and it was decided to set an ascent rate of 8.5ft per second. Although air is used, nitrogen narcosis down to 150m was found to be only slight, and oxygen poisoning was not experienced in any of the tests.

During the ascent the hood pressure remains the same as the sea around it because of the open bottom. The escaper breathes normally all the way up so that his lungs always contain air at or very near ambient pressure. The likelihood of lung damage is very slight and the whole escape is so simple and easy that during the initial trials many inexperienced men requested to do it again.

The system works extremely well and there have been no cases of panic (as might be expected when a man is enclosed in a small chamber all by himself). Untrained men take easily to it and there has only been one case of the bends, and that was due to the man (an officer) making repeated escapes during trials. In addition there have been a few cases of ruptured eardrums, but with no serious results. The system, however, has never been used in the case of a real accident, but the RN submarine service has complete faith in it. Although 180m has been set as the maximum depth, it is thought that escapes down to 230m and perhaps deeper would be possible, although some casualties might be expected at the greater depths.

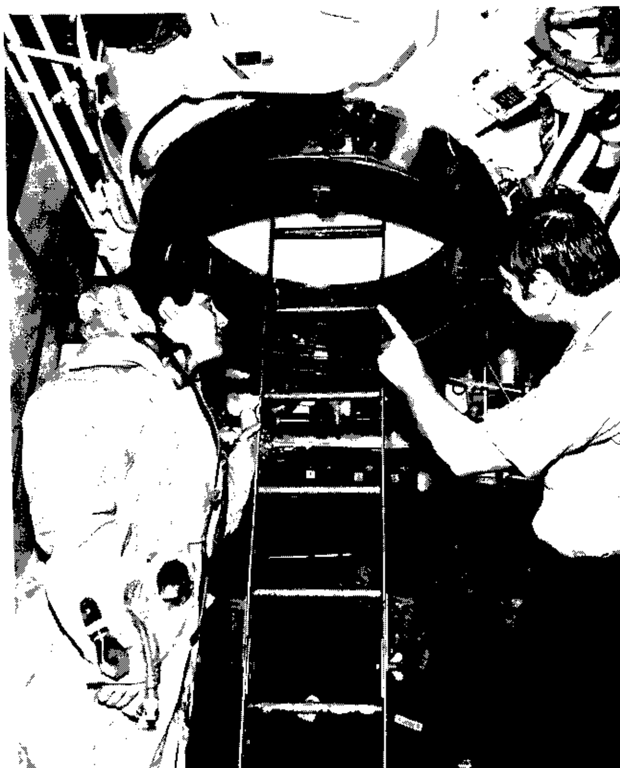
Location of Submarines

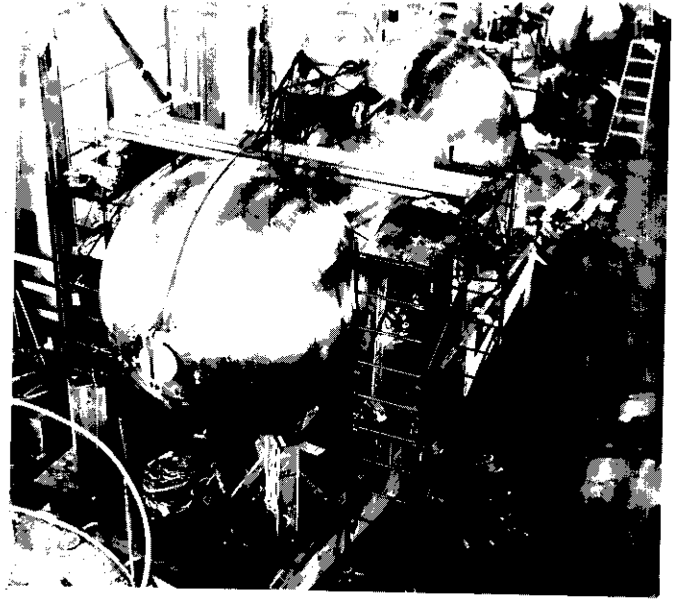
It is of course essential that the escaper should be picked out of the water on surfacing without delay, hence, although no external means of rescue is proposed by the RN (except in very deep water), there is always the necessity for any submarine not relying on a DSRV to be found. Most submarines are therefore equipped with Submarine Indicator buoys. Two are normally carried, one forward and one aft, and are on a wire which can be reeled out



Left:
A submarine escape and survival suit. Invented by the British, the suit has been adopted for use by a number of NATO countries.

Below:
A trainee being given detailed instruction on escape techniques.

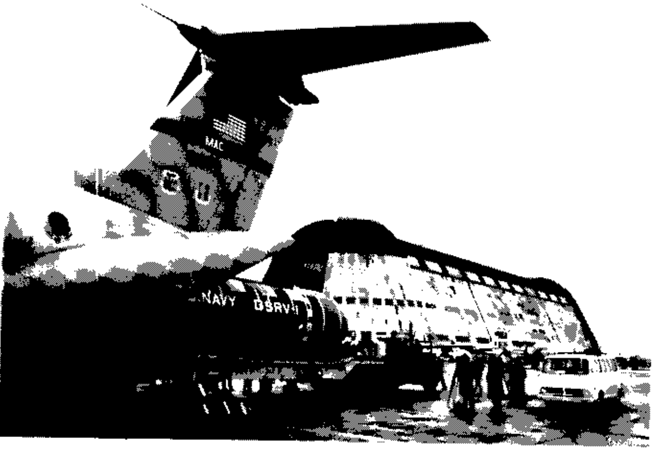




from the submarine. The buoys contain HF and UHF transmitters, a keying unit and a light flasher unit. There is normally a hinged antenna on top of the buoy which automatically erects itself on the buoy reaching the surface. Power is provided by batteries which should last for about 22 hours.

The keying unit feeds the HF transmitter with the code number of the submarine, followed by the words SOS and SUBSUNK in Morse. This in turn is followed by a steady note of 30 seconds for DF purposes. The whole cycle is repeated twice every 10 minutes.

The UHF transmission is a steady signal, tone modulated every half second, every two to three seconds. It is intended for DF purposes only and enables searching aircraft to home using their normal UHF homing equipment. The HF transmitter operates on a distress frequency of 4.3MHz and has a range of 30 miles at sea level. The UHF transmitter is on 243MHz and its range is

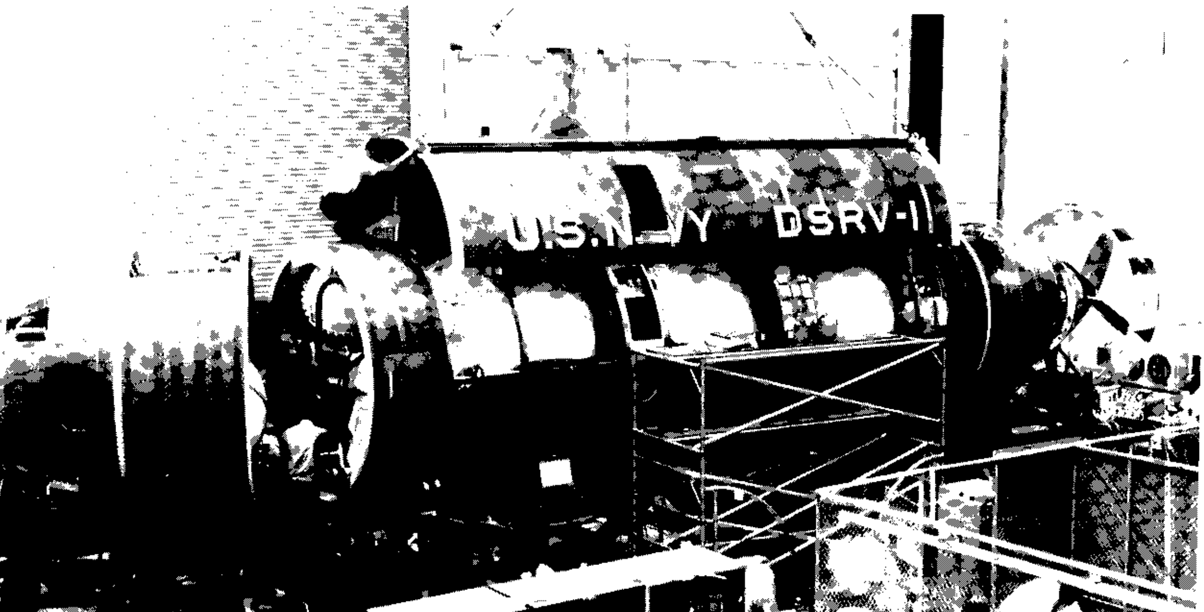


Top:
The pressure capsules which fit inside the DSRV. The vehicle will hold 24 men.

Left:
The DSRV can be carried by large transport aircraft. DSRV-1 is shown here being loaded on to a C-141A Starlifter aircraft.

Below:
Assembling the DSRV at the Lockheed Missile & Space Co's yard. The pressure capsules can be seen below the outer casing.

Below right:
The DSRV under water.



approximately 20nm, but is dependent upon the search aircraft's height. Finally, there is a flashing light which flashes a white light in synchronisation with the UHF transmission, eg half a second on and two to three seconds off.

The American Rescue System

As already mentioned, American thoughts have always been more centred on rescue from outside and they developed the McCann Rescue Chamber which is still in use. It is a large bell-like object with the bottom open to the sea, but with air supplied to the top portion of the bell through a pipe from an attendant surface ship. The bell is placed over the submarine's escape hatch and the water in its lower half pumped out into two adjacent ballast tanks. The submarine's hatch is then opened, pressure equalised by venting air from the bell and the survivors transferred into its upper compartment. Eight men can be taken into the bell at a time, thus it has to make many dives to rescue a whole crew. Further, its maximum depth is limited to 260m and it is an unwieldy object, difficult to handle in rough weather. The best known use of the McCann Chamber was in 1937 when 13 men were rescued by it from the US submarine *Squalus* which had sunk in 73m off the coast of New Hampshire.

DSRVs

It was soon realised that with the great depths to which nuclear submarines can dive, something more sophisticated was required. The Americans therefore developed the Deep Submergence Rescue Vehicle (DSRV). The original intention was to build six, and station them round the coasts of the USA and overseas so that there would always be one in the vicinity of the main submarine operating areas. Owing to shortage of funds this programme was cut heavily and only two DSRVs have so far been built, both by Lockheed.

A DSRV's outer hull is 15.24m long and 2.5m in diameter. It is constructed of formed glass fibre reinforced plastic with titanium and aluminium framing. Within the outer hull there is a pressure capsule consisting of three interconnected spheres, each 2.28m in outside diameter. The whole capsule provides 'hotel' space at normal atmospheric pressure for personnel and control equipment. Under the middle sphere is a hemispherical protrusion, known as the 'mating' skirt which seals over the disabled submarine's hatch. The vehicle is designed to operate in depths down to 1,524m, and it has the strength to withstand the water pressure at this depth combined with the lightness for air transportability. The capsule is built of a new high yield strength steel, known as HY140.

Twenty-four passengers and three crewmen can be accommodated, and for propulsion there is a conventional stern propeller in a movable control shroud and four ducted thrusters. The propeller is used for forward propulsion, whilst the ducted thrusters, two forward and two aft, provide lateral manoeuvrability to enable the DSRV to hover over the disabled submarine during mating operations. The vehicle can hover in underwater currents of up to 1kt and can mate with a submarine lying at an angle of as much as 45° from the horizontal. Power is provided by silver zinc batteries and the vehicle has a submerged endurance of eight hours, plus a reserve for emergencies.

Finally, an external mechanical arm is fitted, controlled from inside the vehicle. It is intended for use to clear away debris or cables over the submarine's escape hatch.

A sophisticated sensor and navigation package is carried to permit the vehicle to work effectively in the deep ocean where sunlight is limited to the first 300m and where electronic signals are greatly affected by water density, temperature and salinity. The vehicle's primary means of locating a disabled submarine is by listening on directional hydrophones. Every US submarine is equipped with an emergency acoustic transmitter and the DSRV will pick up their transmissions and home on to them.

In addition, no less than six different sensors are fitted as follows:

- Horizontal sonar to detect objects ahead of the DSRV.
- Short range sonar to outline objects directly beneath the DSRV's mating skirt and thus assist the mating on to the submarine's hatch.
- Vertical sonar to measure the height of detected objects.
- Interrogation sonar to interrogate transponders fitted in other vessels or on beacons.
- Altitude/depth sonar to indicate the vehicle's depth below the surface and altitude above the sea bottom.
- Doppler sonar to determine the horizontal movement of the vehicle over the sea floor.

Other devices carried are a sound velocimeter which measures the speed of sound in water to enable sonars to be calibrated during a mission, and a tracking transponder which continually broadcasts an acoustic signal to enable a surface ship or mother submarine to keep track of the vehicle.

Complementing the sonars is the optical system which consists of six TV cameras (one in the bows, one under the skirt, two mounted on top of the vehicle and two mounted below it), a 35mm still camera, external flood and strobe lights, and direct viewing ports in the forward and middle spheres.

Navigation is by an inertial navigation system, the Doppler sonar mentioned above, and by ranging on bottom transponders laid by surface ships. The sensors and navigation equipment all feed into a central computer, which processes the information and displays it to the two pilots. The controls are simplified as far as possible and one operator, seated at an integrated control and display console, can control all the vehicle's movements by one knob.

Rescue Operations

DSRVs are employed as follows. The vehicles are based near airfields from which C-141 or C-5 aircraft can operate. On receipt of a SUBMISS signal the nearest DSRV and support equipment is got ready and one or two aircraft are prepared. If a SUBSUNK signal is received the aircraft with the DSRV on board and a second aircraft with the support equipment are at once flown to the airfield nearest to the scene of the disaster. Alternatively, if the accident took place off the coast of America the equipment may be sent by road or rail.

Meanwhile, a specially adapted (mother) submarine will have been ordered to the nearest port, or if a suitable submarine is not available, a submarine rescue ship (ASR) will be sent. The DSRV will be loaded on to the back of the mother submarine (or into the ASR) and will be taken out to the disaster area. On arrival the DSRV will detach itself, or be lowered into the water by the ASR, and will then proceed direct to mate with the sunken submarine. Alternatively, if it has not been located, the DSRV will have to search.

By use of its mechanical arm the DSRV will clear any debris from the submarine's hatch and then, using its four thrusters, will attach its rescue skirt to the escape hatch, pump the skirt dry, equalise the pressure between itself and the submarine, open the hatches and commence transferring the crew. When 24 men have been embarked the DSRV will proceed to the mother submarine, mate with it and transfer the passengers to it. If an ASR is used, the DSRV will have to be recovered by it, or possibly surface near it and transfer the men. The procedure is then repeated until the whole crew has been rescued, a process which might take as long as 17 hours to rescue a complete crew of, say, 130 men.

Submarine Rescue Ships

The Americans originally intended to build a number of ASRs to transport the DSRVs and act as control ships. In the event only two were built — the *Pigeon* and the *Ortelan*. They are catamarans consisting of two 250ft (76.2m) hulls with a 34ft (10.35m) wide space between them. The ships displace 3,411 tons and are fitted with sophisticated command and control arrangements and a helicopter landing deck.

The DSRVs are carried in cradles on the main deck. To launch, the cradle is moved on to a central lift between the hulls and it is then lowered down to a depth of 35m below the surface. The DSRV is then unlocked from the cradle and, using its thrusters and stern propeller, rises off the cradle and backs away from the lift. On return the DSRV manoeuvres itself on to the cradle and, when in position, a controller on board the ASR locks it on and raises the lift.

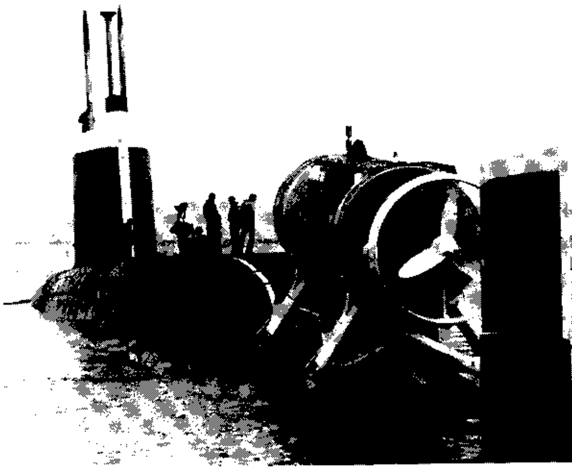
All rescue operations are controlled from a rescue control centre which is in effect an operations room full of radar and sonar displays. Underwater targets are tracked by an interrogating sonar which triggers off the transducers in the DSRV, the disabled submarine and the navigational beacons. It is combined with a computer which computes the positions of the objects detected and displays them to the Command. The ASRs also carry a McCann Rescue Chamber and deep diving equipment. Although useful, ASRs are not essential, as the DSRVs can be controlled by the mother submarine. The Americans originally intended to convert a large number of SSNs to carry the DSRV, but very few have in fact been converted.

The conversion merely provides 'hard points' near the after hatch and a few other fittings to enable the submarine to support the DSRV. When the DSRV is embarked, it brings with it a kit of equipment for its own support. The kit includes the pylons on which it rests the mother submarine, a hook-up assembly to pull the DSRV on to the pylons, a TV camera for installation on the deck of the mother submarine to monitor 'take-offs' and 'landings', an acoustic transponder, and finally battery charging and water ballast re-supply units.

The Swedish Navy also has a rescue submarine, developed by Kockums in conjunction with the French company Comex. It can dive to 400m (the maximum depth in the Baltic). Known as the URF, it is 13.5m long and displaces 49 tons. A crew of three is carried plus two divers who can leave the submarine via a diver's lock-out position. The craft is towed to the scene of a submarine disaster and mates with the stricken submarine's rescue hatch, in the same way as does a DSRV. The crew of the disabled submarine transfer in batches of 25 at a time. The rescue submarine is also used for commercial work.

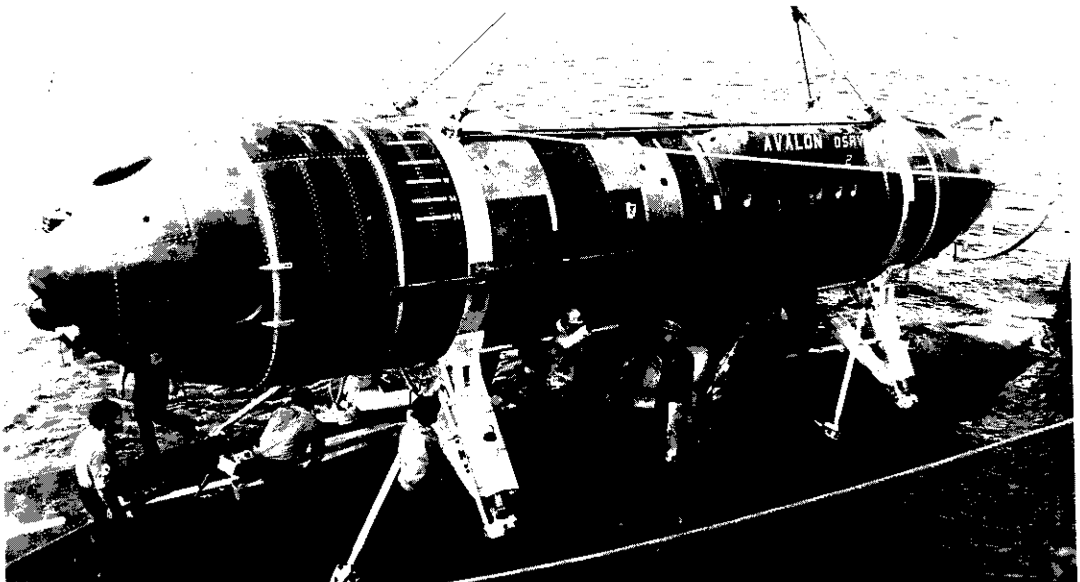
Anglo-US Trial

Britain showed great interest in the DSRV from the start, but regretfully decided it could not afford one for itself. With great generosity the US offered the use of its DSRVs should an emergency arise in European waters. Britain at once started modifying its submarines to give them the facility for rescue by DSRV and also decided to modify all four of its SSBNs to enable them to carry a DSRV and act as mother ship. Finally, it was decided to carry out a test to see how long it would take for a DSRV to be flown from America to effect a 'rescue' from a British submarine lying on the



Below:
Trials of DSRV-2 (*Avalon*) were carried out in the UK. *Avalon* is seen being secured to *Repulse*, the British SSBN acting as mother ship.

Right:
Avalon attached to *Repulse*.



bottom in the Clyde area of Scotland. The test took place between 29 April and 14 May 1979.

HMS *Odin*, one of the conventional 'Oberons' was chosen to play the part of the sunken submarine and HMS *Repulse*, one of Britain's four SSBNs, was selected to act as the mother ship. The DSRV, unofficially named *Avalon*, together with its land transport vehicle, was loaded into a US Air Force C-5 Galaxy, and the associated equipment was placed on board a USAF C-14 Starlifter. Both aircraft then flew direct to Glasgow civil airport in Scotland, landing just after midnight. Within three hours the DSRV was on the road, on its special transporter, for Faslane, the RN's submarine base, some 25 miles from the airport. On arrival *Avalon* was hoisted on to the after casing of *Repulse*. Meanwhile *Odin* dived and bottomed in a position 120 miles off the Isle of Arran, and lay there, simulating a submarine unable to surface. The time between the initial request for help until *Avalon* was loaded on board *Repulse* and it was ready to sail, was 47 hours. *Repulse* made the voyage to the vicinity of *Odin* on the surface at 17kt as the weather was good. No damage to *Avalon* resulted, but it was pointed out that a much lower speed would have been necessary had the passage been made submerged. On nearing *Odin*, *Repulse* dived to 70m and launched the DSRV.

Over a period of five days *Avalon* carried out seven dives, successfully completed four matings with *Odin* and carried out a number of successful transfers of personnel. A commercial submersible, belonging to British Oceanics, also carried out trials of mating with *Odin* and transferred stores and personnel, although of course the small submersible could only hold a few men at a time, as compared with *Avalon's* 24. The submersible also successfully managed to mate on its side.

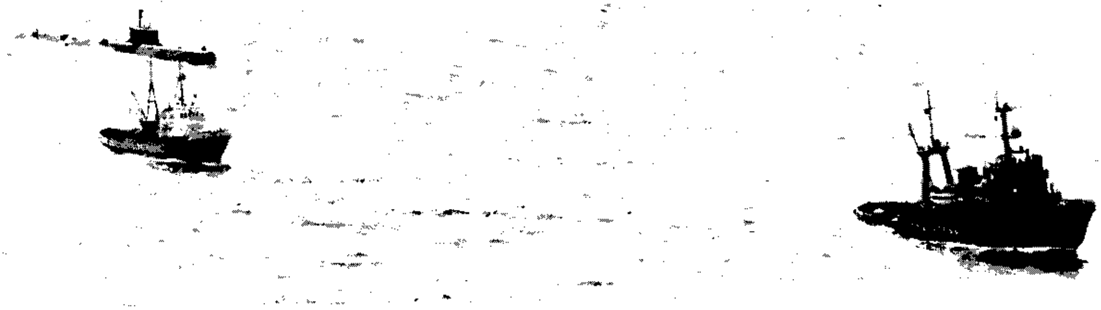
The trials proved that a rescue using an American-based DSRV was possible, but that at least 50 hours would elapse between the disaster occurring and the arrival of the rescue vehicle. However, the trials also demonstrated that in the meantime a commercial submersible could be used to supply the stricken submarine with additional life support stores and equipment.

Atmosphere Onboard a Sunken Submarine

The atmosphere in the escape compartments is all important, particularly with a large number of men crowded into the comparatively small space. Special monitoring equipment is provided in both escape compartments and the atmosphere is carefully monitored all the time whilst awaiting rescue. The most critical factor is the level of the carbon dioxide gas (CO_2) in the compartment which must be kept within 2.5% limit until just

prior to escape, and this may require more CO_2 absorbers than have been provided if the waiting period is very long. Thus life support stores (principally oxygen candles and canisters of carbon dioxide absorbent) are critical to survival. It is these stores which it is hoped small commercial submersibles will be able to 'post' into the stricken submarine.

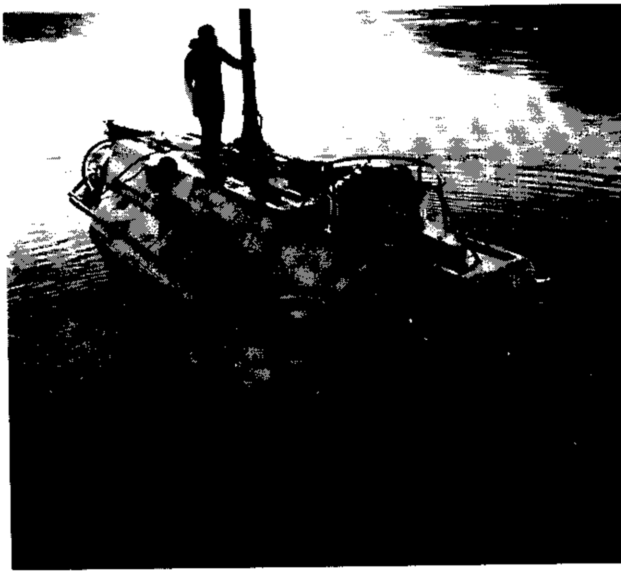
There is another problem which might occur should the submarine be disabled because of partial flooding. If this has occurred the air pressure inside the submarine is likely to be raised to some level dependent upon the time the pressure-proof bulkhead doors were shut. Since escapes are usually delayed until it is certain that some rescue craft are nearby, it is possible that the men in the non-flooded part of the submarine may have to wait under pressure for some time before attempting to escape. The level and duration of this pre-exposure to pressure has the effect of reducing the depth from which a successful escape can be made. Under this pre-exposure pressure, the pressure of gas being absorbed in human tissue is virtually complete after some hours, and a wait of some hours may well be necessary. When additional gas is absorbed during the pressurisation of the escape tower which takes place during an escape, the combined effect of this and the gas already absorbed in the tissues can lead to decompression sickness and 'the bends'. At greater depth such 'bends' tend to affect the brain and the central nervous system and are even more



Above:
A Soviet 'Echo' class submarine had to surface in June 1984 after apparently fouling its propellers in wires some 500 miles north-northeast of Saxa Vord in the Shetlands. This photograph taken by an RAF Nimrod from Kinloss shows the submarine being towed by the 'Purga' class tug *Vilnis*, with a second vessel in attendance.

Left:
A DSRV on the surface, securing to a research vessel.

Right:
A civilian submersible with a diver's lockout position and a mating skirt which can be used to 'post' stores to a stricken submarine pending the arrival of a DSRV.



dangerous than the normal limb 'bends'. The problem has not been completely solved and experimental work is still being carried out, but it has been possible to provide some predicted figures to show the maximum escape depth against the pre-pressurisation that may have been received. It is possible that remedies may be found by using decompression stops when rising through the water, or by using an enriched oxygen mixture for the hood inflation system. It is emphasised however that there will be no pre-pressurisation time unless the submarine has taken in a lot of water.

Accidents

Fortunately there has only been one nuclear submarine lost by accident — the USS *Thresher* which sank carrying all 129-man crew with it on 10 April 1963. *Thresher* had just completed a refit and was carrying out diving trials down to its operational diving depth, believed to be 122m. After some preliminary shallow dives on the early morning of 10 April, *Thresher* informed its attendant surface vessel, the USS *Skylark*, that it was about to dive to the 'test depth'. A few minutes later it reported by underwater telephone that it was at 400ft (122m) and was checking for leaks. Shortly afterwards *Thresher* reported that it was having some minor trouble. This was followed by the report 'Have positive up angle. Attempting to blow'. All further contact with *Thresher* was then lost.

The subsequent Court of Enquiry report stated that investigators thought it likely that a fault in the piping system, probably in the engine room, had developed and that this led to a violent spray of sea water into the pressure hull and progressive flooding. They added that the water probably affected electrical circuits and caused loss of power. As a result *Thresher* began to sink and within moments had exceeded its collapse depth.

The submarine came to rest on the sea floor 8,400ft (2,552m) below the surface. Its remains were subsequently found by the bathyscaphe *Trieste*, the world's deepest diving oceanographic research submersible.

It was the *Thresher* incident which caused the Americans to opt for the DSRV method. However, even if a DSRV had been available at the time, it would not have been effective since the sinking was presumably due to the additional weight of water which entered the submarine, and it sank so fast, in such deep water, that any form of outside rescue would have been impossible.

Today, the risk of accidents in peacetime has been almost eliminated, but of course there is always the unexpected; it is a risk, small though it may be, that submariners have learned to accept.

13 Life On board

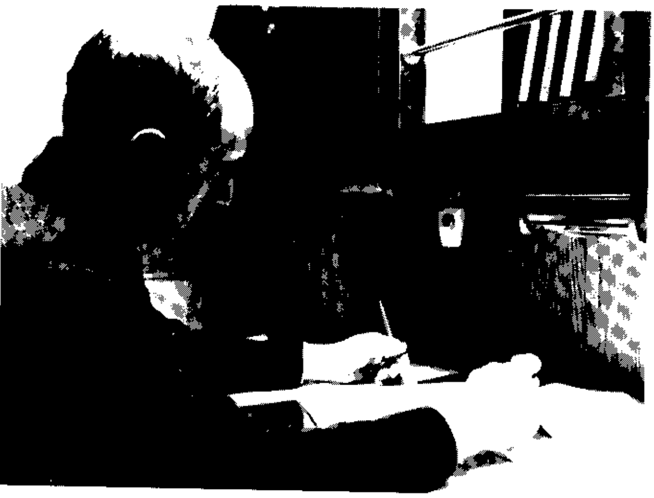
Life on board any submarine could never be said to be comfortable, but of course the larger the submarine the less uncomfortable it becomes. The largest submarine is the SSBN, so perhaps it would be advisable to discuss this fairly fully and then to note how the SSNs and conventionals differ.

Before life on board can be fully understood it is necessary to know how a submarine is divided up, and for this description a British SSBN will be used, largely because it is very similar to both the American and French SSBN — in fact it was based on an earlier American design. It must be realised however that all SSBNs differ slightly, not only between classes, but also amongst boats of the same class. For example, not all SSBNs carry their missiles abaft the fin, some have the fin much farther aft and the missile compartment occupies a large amount of the forward part of the submarine.

A typical SSBN is single-hulled, and the casing, which is not watertight, curves round the forward end of the pressure hull. Between it and the hull itself is a free flooding compartment which contains a large sonar transducer, which curls round the bows like a horseshoe, and a number of ballast tanks. The six torpedo tubes pass through this compartment and holes in the casing, but their inboard ends are in the next compartment, known as the torpedo compartment. This is large and on two levels. The spare torpedoes are stowed on the lower level, and the upper level is used for handling the torpedoes when they are loaded on board, and to allow space for striking down the spares and for loading the tubes. The upper of the two spaces has room to accommodate camp beds for any passengers, or additions to the crew. At the rear end of the compartment is a watertight door, which, should any water enter the fore end, will prevent it getting into the rest of the submarine, or alternatively will prevent any water which has entered the rest of the submarine from entering the compartment. It therefore forms an escape compartment.

Abaft the torpedo compartment there are three horizontal decks and divided between these decks are the sonar, radio and radar rooms; officers' and ratings' accommodation; and the senior and junior rates' dining halls and lounges. Underneath the lot are the main batteries.

Moving aft, we find on the top deck, the control room. It is immediately below the fin and leading out of it is a vertical ladder to the bridge, running up the conning tower, whilst just abaft it is the navigation centre. On the next two decks down is more accommodation. All the officers are on the deck immediately below the control room, so that they may have quick access to it. There is a passageway leading to the wardroom with cabins either side of it. The cabins are small. The Captain has one to himself measuring about 6ft by 6ft 6in. In it are a fold-up bunk, a desk, an upright chair and a fold-away basin. There is also a small wardrobe — actually more like a locker — and a book shelf, plus numerous telephones and instruments. There are two double cabins, occupied by the Executive Officer and the Senior Marine Engineer Officer in one, and the Weapons Engineer Officer and the Deputy Marine Engineer in the other, but the actual arrangement may vary from submarine to submarine. Three more cabins complete the officers' accommodation: one holds six officers, another five, and the third six, making the total officer accommodation 22 berths. This



Left:
The captain of a French SNLE (SSBN) in his cabin.

usually leaves about two or three spare berths for officers under training.

The wardroom is a fair-sized carpeted room stretching right across the submarine. It is pleasantly panelled, and furnished with a small bar and pantry, two long dining tables, and padded seating nearly all round, covered in a chintz. There are also dining chairs and there may also be one small armchair.

The ratings all sleep in bunks. Most of them are in small alcoves off the passageways. A pull curtain gives each occupant a certain amount of privacy from passers-by; there is a reading lamp over each bunk and a small locker for clothes with only room for a spare pair of trousers and a few shirts. Senior rates sleep in bunks in so-called cabins holding up to eight persons. Ample washrooms, showers and lavatories are provided.

The main mess hall is fitted with a number of tables, and a cafeteria system of serving food is used. The senior rates have a separate mess which is very similar to the wardroom but larger as there are some 70 senior rates, although no more than two-thirds feed at the same time. There is a padded seat covered in chintz running round nearly all the walls of the mess; upturned beer barrels, also covered in chintz, are used for chairs. There is a small bar at one end where drinks may be bought, and each man notes what he has bought on a pad. All types of drinks are served in harbour, but only beer and wine at sea.

Continuing our tour of the submarine, let us have another look at the control room. At one end are the planesmen positions with hand controls for the rudder, hydroplanes and speed. These are manned during manoeuvres, but normally they are controlled by a computer. Comfortable chairs are provided for the operators, and the captain has a fold-away seat from which he can supervise matters. One side of the room is devoted to the control of the submarine itself, whilst the other side is devoted to fighting the submarine and has the action information system stretched along it, and the torpedo fire control equipment and various other weapons controls, including one for the Sub-Harpoon. In the middle of the control room are the two periscopes, one for search and one for close range action, together with the controls for raising and lowering them. Also situated at the back of the control room are the controls for raising and lowering all the other masts with which the submarine is equipped. Leading off the control room in the after direction is the navigation centre which, amongst other items, contains the ship's inertial navigation system.

Farther aft again is the missile compartment, holding 16 missiles in their vertical tube containers, and adjacent to it is the missile control centre which contains not only the controls but the missile guidance computers as well. In this room will be found the devices for feeding into the missiles' navigation systems the positions of the possible targets which are to be attacked when ordered. Some 100 target positions are prepared in a headquarters ashore and placed on computer tape. The tape is hand carried to the submarines and fed into the appropriate computers. Before each patrol a number of the targets are selected as the ones for that particular patrol, the others are blanked off from the missile. A firing signal will tell the submarine to launch so many missiles at the designated targets, which are not named, but merely given an identification letter or number. Thus nobody on board the submarine, not even the Captain, has any knowledge of either the position, name or type of targets being fired at.

The designated targets can be changed whilst on patrol by signal, which merely says for target 'X' substitute target 'Y'. No names or positions are ever stated.

Between the missile tubes are often found the bicycle and rowing exercise devices. It seems an odd space in which to stow them, but there is literally nowhere else suitable.

Immediately abaft the missile compartment is the auxiliary machinery compartment and abaft that is the reactor. The latter is heavily shielded to prevent any nuclear radiation escaping, and because it stretches right across the submarine, access through it is provided by a tunnel on top of it. This too is heavily shielded and has a door at either end, one of which must be kept closed at all times. There are tell-tales to show if either door is open and an inter-lock to prevent opening one

Right:
The wardroom of a French SNLE.

door if the opposite door is already opened.

The last compartment is the marine machinery compartment containing the steam turbine, alternators for charging the batteries, with beyond them the actual electric motors for driving the propeller shaft. This compartment forms another escape compartment and there is a watertight door leading to it and a vertical escape tower leading up through the pressure hull, similar to the forward escape tower.

Day-to-day Life on Board

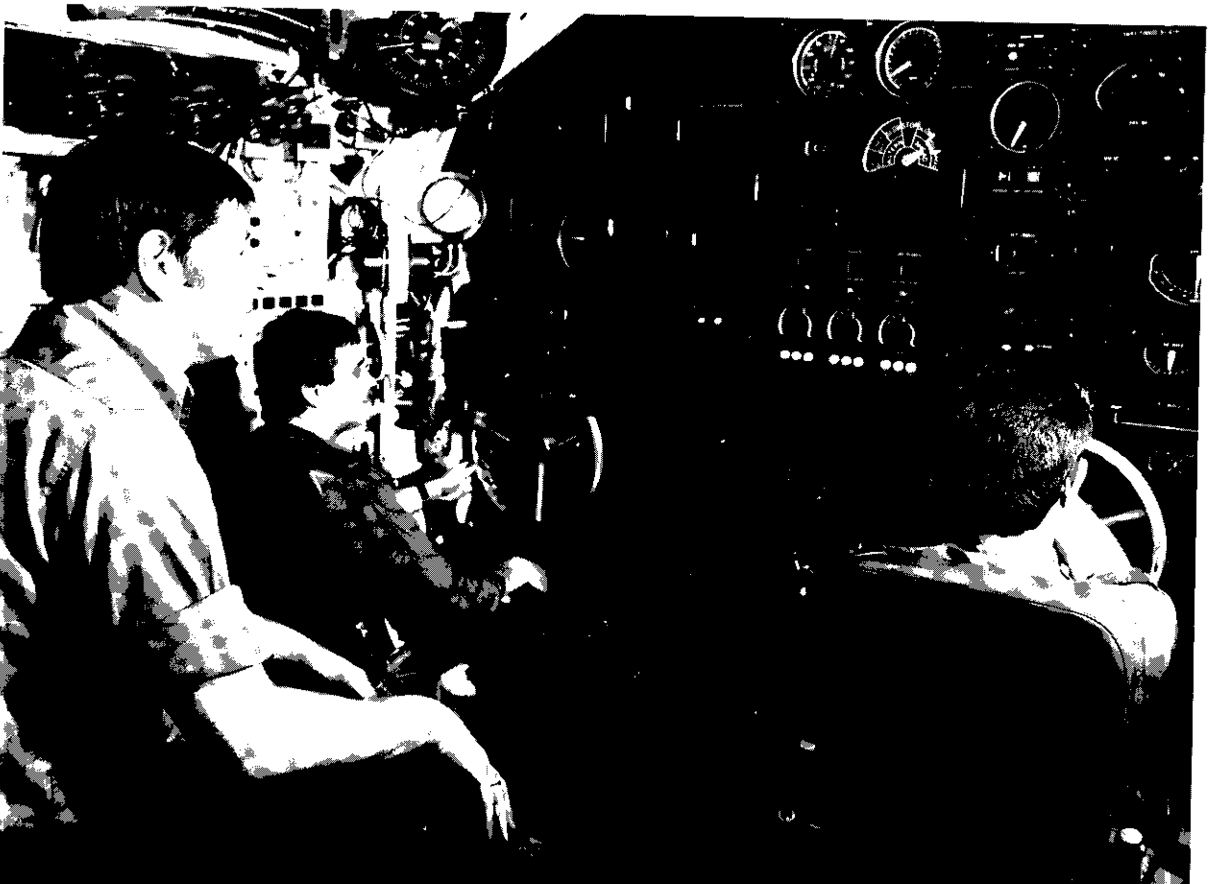
Coming now to the day-to-day life on board and perhaps this is best explained by following the life of the crew from the moment they join the submarine until they get ashore again. SSBNs have two crews, in the Royal Navy known as the port and starboard crews.

About three weeks before the patrol is due to begin, the new crew (which up to then has been the relief crew) joins the submarine. Most of them will have been on the crew's previous patrol of the same submarine which probably ended some three to four months before, but there are always some changes in personnel. In addition there may be some trainees on board.

The first two weeks on board are spent finishing off any maintenance work, storing the boat with the vast amount of provisions required for 60 days at sea, and in general preparing for sea. The crew works hard but follows normal set working hours, usually from 08.00hrs to 16.00hrs, although towards the end of the provisioning period they may have to work longer — but the married ones will always be able to get home at night.

About 10 days before the patrol proper is due to start they go to sea and carry out exercises and drills. The submarine is dived and surfaced, all the equipment is tested and they often carry out tactical exercises against another submarine. The latter may play the role of a shadowing submarine. All the manoeuvres designed to shake off a shadower are practised, practice torpedo attacks may be made on the 'enemy' submarine, and various emergency drills are tested. At the end of this period, which may last about a week, the submarine returns to its base and embarks any nuclear missiles which had been landed on return from the previous patrol.

Finally, the day arrives when the crew have to kiss the wives, children or girl-friends good-bye. A poignant moment this, particularly for the wives, as rightly or wrongly they always feel that there is an element of danger in going to sea in a nuclear submarine. The wives usually congregate at some vantage point to wave farewell, but the submarine



soon fades into the distance and they must go back to their homes and settle down to their, perhaps, lonely lives. Wives say that the time they miss their husbands most is in the evenings when there is nobody with whom to discuss the day's events.

Much has been written about the lonely wives of ballistic missile submariners, and both the Americans and the British have gone to great lengths to help them. Welfare organisations have been set up to look after them, and entertainments and excursions arranged. In fact they are not much worse off than any naval wives. Other submarines and surface ships go away for long periods and naval wives are used to separations; some say that it is the secret of the success of most naval marriages. The main difference between the ordinary naval wife and the wife of a nuclear submariner is that the former can always communicate with her husband, whilst the latter cannot do so by letter for the period of a patrol. There is however a system of allowing the wives to send messages to their husbands by normal naval radio communications.

In the Royal Navy, messages are limited to a maximum of 40 words and may be sent once a week. They can be originated by any close relative or live-in girl-friend. In the US Navy a similar system prevails, but the messages are limited to 20 words and may only be sent once every two weeks. The messages, known as 'Familygrams' in the Royal Navy, are meant to encourage the men at sea, to tell them that all is well at home and to give them items of good news. Bad news is discouraged, as it is essential to keep up the men's morale. In some cases bad news may have to be sent, but each message is scrutinised at the base before transmission, partly on security grounds and partly to make sure that no discouraging message is sent. If a message contains bad news, it is usually taken out and an official signal is sent to the man's commanding officer to ask him to break the bad news personally to the man, and to leave it to his discretion as to when he does so. The Captain may well decide that nothing would be gained by, for example, telling a man that his wife had gone to hospital with a serious illness, until towards the end of the patrol. After all there is always the chance that she might have recovered by then, and there seems little point in the man worrying for weeks on end when there is nothing he can do about it.

Apart from messages being seen at the base before they are transmitted, the Captain of the submarine sees all 'familygrams' before they are sent to the individual in a sealed envelope. All messages are also seen by the radio operator on watch as they arrive in plain language. The men understand this and are not worried by it. The radio operators are told that on no account may they discuss the contents of any private message with the recipient or with anyone else. In any case they would not dream of doing so.

As the submarine slowly steams out to sea, its crew falls into the daily routine at sea. It is difficult to describe what each man does all day. The officers will be determined to make the patrol as interesting as possible and hardly a day goes by (except Saturdays and Sundays) when some form of drill or exercise is not carried out. These vary tremendously: one morning might be devoted to preparing the torpedoes and going through the motions of launching them against an imaginary target, another half day might be spent in preparing the missiles for launch. An imaginary fire on board might exercise the fire-fighting crews, an equally imaginary injury might be sustained by a selected man, who would then have to be stretcher-lifted to the sick bay where the doctor might decide that an operation is necessary. All the preparations would be made up until the anaesthetic is about to be given, and there are always exercises devised by the shore control which initiates them by sending a signal to the submarine, care being taken to make quite sure that it is marked for exercise only.

Most of the crew work in watches, usually in the

Above:
Officers at lunch on board HMS *Renown*, one of Britain's four SSBNs. Note the sandals worn by one officer: this type of footgear is often worn on British submarines.

Left:
Two planesmen keep HMS *Renown* — a British SSBN — at the correct depth, under the watchful eye of the ship control officer of the watch.

three-watch system — four hours on and eight hours off. Of the officers, only the Captain, the Executive Officer and the Senior Marine Engineer Officer do not keep watch. Even the doctor and the supply officer take their turns on handling the hydroplanes.

A great deal of entertainment is provided: a new film is shown every day, one perhaps in the wardroom to the officers, another film to the senior rates and a third to the junior rates. Thus there may well be three different films shown every night, which means that before going to sea some 60 different films have to be embarked. The films are so modern that they are sometimes screened on board before they are shown in the cinemas at home. In addition, tapes of well-known television programmes (mostly football matches) are frequently shown.

For all that, each man has plenty of spare time which can hang heavily on his shoulders. Many read a lot and there is a library on board. Tastes vary but some men prefer the heavier books which are perhaps too lengthy or perhaps too difficult to read at home with the interruptions of family life. Hobbies abound and range from basket-work to correspondence courses. Some learn languages, and some try their hand at writing articles or novels. Perhaps the majority use the time to study for the exams they have to take for professional advancement in the Navy.

Most of these occupations are however just signs of boredom. One must not forget that in normal life at home a man changes his environment at least once a day. He goes from home to his place of work and goes home again in the evening. He probably meets new faces every day and he has someone to listen to his moans and worries in the evening, or to congratulate him when he has done some job well. His life, however dull he thinks it is, does at least have some variety in it. Not so in an SSBN — every face on board is seen daily, there is never any change of scenery, no friends to be entertained, no one to go home to.

It is often said of submariners that two months away on patrol is not so very different to life in a surface ship, which may well be away from its base for two or more months. In fact there is a world of difference. The surface ship man often gets the chance of a 'run ashore', not perhaps in his home port, but at least it affords a change of scene and the chance of meeting people other than the ones he sees every day. At sea he can often sun-bathe, and even to watch the sea going by is quite relaxing. Where the two forms of life are very comparable is for the wives. Both surface ships and submarine wives have been left alone, but in a sense the submarine wife has nothing to be jealous about. Her husband is not 'enjoying' himself, not meeting other women; in fact she is having a much better time than he is!

Submarine officers and men are often asked 'but what do you do all day on a 60-day patrol?' It is a difficult question to answer even in normal every-day life on shore, but twice as difficult when cooped up in a submarine. However, for what it is worth, here are two accounts of daily lives on patrol; one from a Captain of a SSBN and the other from a senior rating.

The Captain

'It is difficult to know when I start my day because I am often called numerous times during the night.

For one thing, all important signals received are brought to me on receipt and you would be amazed at the large number of signals that are received. The most important ones give the positions, course and speed of all ships and submarines which are likely to approach or pass through my patrol area. Each signal may mean a consultation with the Navigation Officer as to whether we should alter our course and speed to make sure that they pass so far from us that they could not possibly detect us. In addition to signals, there are very few nights when I am not called by the Officer of the Watch, usually because the sonar has picked up the sound of a ship, and sometimes a submarine, passing close to us. This may mean immediate action, either to dive deeper or alter course well away from the course of the sound. My orders are to take all possible steps to avoid detection by both friendly or potentially hostile craft.

'However, I will start my day from when I officially get up in the morning. I always sleep in my pyjamas and I get out of my bunk at about 08.00, shower, shave and dress and then go to the Control Room to get a report from the OOW as to what the situation is and what has happened during the night, which I probably know about anyway. I then visit the radio office and look through all the signals received during the night, even though I may have seen most of them before. This is followed by a quick walk round the operational parts of the boat, probably the sound room (sonar office), the navigation centre, the action information organisation and the ship control areas, such as the plane controls, and I check the course and speed. I also take in the missile control centre to

Above right:
The supply officer of a British SSBN in his cabin, which he shares with four other junior officers.

Left:
The Royal Navy nuclear-powered Fleet submarine HMS *Warspite* seen in San Carlos Water alongside the forward repair ship *Bar Protector* in March 1984, when she made a short visit to collect stores and mail. *Bar Protector* is one of a number of ships taken up from trade for service in the South Atlantic, and is used primarily as a forward support ship. HMS *Warspite* hit the headlines on her previous patrol to the South Atlantic in 1983, when her 112-day patrol was at the time the longest ever made by a Royal Navy nuclear-powered submarine.

Right:
Living space always is at a premium on board a submarine. This photograph of a junior rating on board a British SSBN shows the bunks one above the other and the small cupboard space provided for each man.

have a word with the two men on watch there. All this does not take me very long and I probably get back to my cabin for breakfast around 08.45. After breakfast I generally deal with my paperwork, of which there is always plenty. Later in the morning I play my part in any exercises or drills which we have arranged, or if the drill does not require my presence I go and watch it to see that everybody is doing their job to my satisfaction.

'Lunch is at 12.00 and before then I usually wander into the wardroom to talk to my officers and possibly have a glass of beer. This is very useful to me as it is the one time when most of the officers are present and I encourage officers to put forward suggestions and we discuss them. I lunch in the wardroom which is a help-yourself type of meal.

'The period after lunch is traditionally a rest time in submarines and most off-watch men get their heads down for an hour or so, including me. After that I write a chapter or so of my book (I am writing a novel which has absolutely nothing to do with the Navy). During the dog watches (16.00 to 20.00) further exercises and drills are carried out, which may or may not require my presence. Supper in the wardroom is served from 18.30 onwards. Officers' watches change at 19.00, so those about to go on watch eat at 18.30 and those coming off watch at about 19.30. After supper a film is usually shown and I normally attend. It ends by about 21.45 and I then go back to my cabin and maybe discuss the next day's exercises and drills with the officers concerned, or I continue writing my book until about 23.00 when I carry out my final rounds of the day, following much the same route as I do in the mornings, and I get to bed around 00.30. In addition, at any hour of the day or night there may arrive from our operating authority on shore, a signal ordering us to carry out a missile firing drill which requires the participation of practically everybody on board.

'It is not a particularly full day and I have plenty of spare time, most of which I spend on my novel: what I shall do when I have finished it, I don't know; start another I suppose, but that will depend on whether the first is accepted by a publisher. In any case, I expect to get another job soon, probably as a staff officer on shore.'

The Captain was very open about his job, and apparently regarded it as purely routine. The fact that he may one day be responsible for causing terrible destruction and the loss of thousands of lives does not seem to worry him. As he points out, firstly he is only a link in a very long chain. The decision to launch nuclear weapons has already been taken by the politicians and if any guilt is involved, it is they who must bear it, not him. Secondly, if he is ever ordered to pull the trigger, he and all his crew will know that somebody, somewhere has already attacked NATO with nuclear weapons, and for all he knows his wife and family may already be dead. He also pointed out that, in fact, it is not his finger on the trigger, but that of his Principal Weapons Engineer Officer (PWEO). But, he added, it made no difference anyway, since the whole operation was a combined effort by the entire crew. The PWEO when asked what he thought about it, took the same line as his Captain. Although he did actually pull the trigger, it could equally well have been done by a computer. Both pointed out that neither they, nor anybody else on board, knew on what targets their missiles were targeted. They could be aimed at cities or nuclear weapon silos on land.

Captains of British SSBNs are of commander rank and their basic pay is £20,700 a year (in which £1 a day for being in command is included). In addition they get, like all submariners, submarine pay. This varies with rank from about £3 a day for a rating to £5.15 for the captain. In all then, the captain gets about £22,000 a year.

The Rating

'I am a Petty Officer of the radio operator branch and I have six radio operators under me. Two of them are always on watch. They are responsible for tuning the receivers (and transmitters when used) to the designated frequencies and for manning the radio teletypes on which incoming messages are received. They simply tear the messages off the teletype roll, note their time of receipt and file them for distribution to the officers concerned. My job is to ensure that they carry out their job efficiently and this includes making sure that they set watch on the correct frequencies at the scheduled times for the reception of broadcasts from the shore. I also supervise satellite communications when they take place. I always get called if any emergency should arise. For example, if we received a FLASH message (the NATO word denoting the highest possible degree of priority) I would be informed at once and I would probably take it to the Captain myself. In addition the fact that a FLASH message had been received would be broadcast over the ship's intercom by the radio operator who received it.

'My job could hardly be called onerous, so I am roped in to form one of the watchkeeping team on the hydroplanes. Even so I have plenty of time on my hands and I spend a lot of it studying for my advancement to chief petty officer. I have another 12 years to do in the Navy and I shall probably go on doing the same job, with occasional spells ashore as an instructor. I do get bored at times and I would not object to transferring to an SSN because life on board one of them is much more varied, particularly for the head of the Radio Department, but then I remember that in my present job I get three weeks' leave after every patrol, whilst on board an SSN I would not get nearly so much, nor would I know when I would get it. One of the troubles for radio operators is that it is not a trade of much use to any civilian employer, but I am not worrying about that yet.'

I also spoke to a much more junior rating. He volunteered for submarines and was very happy serving in a conventional. One day, without warning, he was told he was to be drafted to an SSBN. He disliked the idea intensely and asked to see his Commanding Officer to get his draft changed, but to no avail. He has now served for a year in an SSBN and has found that he enjoys it very much. He has a pleasant married quarter near the base in Scotland and he and his young wife are perfectly contented, but like the Petty Officer, he has no hobby and not a great deal of ambition.

After prolonged discussions with many officers and men, it became apparent that SSBN life suits two different types of men. First comes the man who is ambitious and is determined to better himself, either inside the Navy or in civilian life when he retires, and many are in the Navy for only short-service engagements. He welcomes long periods of enforced leisure to enable him to get on with his studies, either for advancement in the Navy or to fit himself for a good civilian job. He will want a change from SSBNs before long in order to broaden his outlook and might be sent back into general service.

Then there is the man (or maybe his wife) who likes an orderly life, a regular routine and long periods of leave. He may be an older man, who is not particularly ambitious and welcomes periods of relative inactivity which he fills by working with his hands, doing basket-work, rug-making, knitting and the like, or by reading, usually novels. He welcomes the extra pay and is content to go on like that for many years. He might even resent a change.

Dress At Sea

Strict uniform regulations are seldom followed by submariners. Exactly how much they can be relaxed is a matter for the Captain to decide. Most RN officers wear their white uniform shirts (which incidentally are specially treated to make them both fire and nuclear radiation proof) with their badges of rank on the shoulders, together with normal uniform trousers. Other navies wear their own rigs — the Americans, both officers and men, wear coveralls, for example. Boots or leather shoes are discouraged because heavy footfalls can be heard outside the submarine by listening enemy submarines. In the RN, officers and men wear rubber-soled sandals, similar to those worn on a beach. Again in the RN, officers 'dress' for dinner by putting on a tropical white shirt, cummerbund and uniform blue trousers.

British ratings wear the normal navy blue working dress of trousers and an open neck shirt. Caps are not often worn, for after all the men are not out of doors.

The Value of Silence

Considerable store is set in keeping the submarine as silent as possible. Footfalls have already been mentioned, but great care is also taken to avoid dropping objects which may clatter against other metal work. Anyone dropping a spanner on the metal deck, for example, may well find himself in front of the Captain, not so much for punishment, but more to find out how it happened and how to prevent it happening again.

Modern submarines have special sound-proof tiles over the outside of their steel hulls. These do indeed deaden noise from within and they also act as poor sound reflectors against an enemy sonar active transmissions. Another source of sound is the human voice: whilst submariners do not go so far as to whisper, a loud command is never heard. The boat's intercom is comparatively loud, but nothing like as loud as a surface ship's. Films and TV programmes do not have to be run quietly.

Passage of Time

In a submarine which never surfaces, it is impossible to tell whether it is night or day outside, but everything possible is done to keep the days and nights completely separated. For example, at night the lights are dimmed, partly to allow people to sleep, but also to give the impression of night time. Similarly meals reflect the time of day, cereal or eggs for breakfast for instance. Saturdays and Sundays are treated as holidays and the Captain holds a church service every Sunday (there is even a harmonium on board). Submariners basically are by no means anti-religion, but the church services are very poorly attended.

Food

The food in SSBNs is generally superb, with plenty of choice. An accompanying table shows the weekly menu which is published at the beginning of each week in RN SSBNs. A duty chef stays up all night to bake fresh bread for the next day. There are a number of deep-freezers on board, and vegetables, albeit frozen ones, are featured strongly. The officers eat the same food as the men. Good though the food is, many members of the crew ration themselves, sometimes quite severely, as with the lack of exercise there is a

Above:
Lunch being prepared in the galley of a British nuclear submarine. Officers and ratings all eat the same food.

Below:
The enlisted men's mess on board the USS *Ohio*, lead ship of the 'Ohio' class.

tendency to put on weight, in spite of the exercise bicycle and rowing machine. Each man gets three bottles of beer a day free: this replaces the old rum ration which died a much mourned death some years ago.

Health

British SSBNs carry a doctor. His main function is to ensure that constant monitoring for nuclear radiation is carried out. This is highly important as any leak from the reactor might spread throughout the boat and, as is well known, radiation sickness can not only be a killer at the time, but may affect the lives of the whole crew many years later. So far radiation from the reactor has not proved a problem, in fact the crew is subject to less radiation on board the submarine than they would be in front of their TV set at home, but problems can occur and constant monitoring is the only answer.

Apart from that, the doctor is there to ensure that the crew keep themselves healthy as far as possible. He ensures that the food provides a well-balanced diet as possible and he must be alert to prevent any contagious illness spreading. There can be no question of sending a man to hospital or of isolating him. Surprisingly, however, the health of most crews on long periods remains reasonably good, in spite of the lack of sunshine. The doctor is very much on his own: in fact he must be a surgeon, a general practitioner, a dentist, a

Typical Menu for a Week in an SSBN (British)

Breakfast	Lunch	Supper
MONDAY 11 June		
Standard & Saute Kidney	Spring Rolls Beefburger Roll Cold Meant Selection Chips Spaghetti	Baked Gammon & Peach Sauce Irish Stew Haggis Boiled & Creamed Potatoes Carrots & Turnip Manchester Tart
TUESDAY 12 June		
Standard & Kippers	Mince & Onion Pie Fish Cakes Cold Meat Selection Chips Processed Peas	Roast Beef & Yorkshire Pudding Chicken & Veg Pie Pork Chop & Apple Sauce Oxtails Roast & Boiled Potatoes Cabbage & Mixed Veg Fruit Flan & Cream
WEDNESDAY 13 June		
Standard & Scrambled Egg	Oggies (Cornish Pasties) Lamb Chop & Egg Cold Meat Selection Chips BITS (Beans in Tins)	Roast Pork Braised Beef Slice Liver Casserole Roast & Boiled Potatoes Green Beans & Cauliflower Black Cap Pudding
THURSDAY 14 June		
Standard & Fish Fingers	Gammon Steak & Pineapple Cheese Flan Cold Meat Selection Chips Garden Peas	Roast Lamb Steak & Kidney Pie Stuffed Hearts Roast & Creamed Potatoes Carrots & Sprouts Apple Crumble
FRIDAY 15 June		
Standard & Black Pudding	Poached Cod Harbour Cotters Cold Meat Selection Chips Mushy Peas	Boiled Silverside Chilli Con Carne Pork Chop Boiled & Creamed Potatoes Carrots & Butterbeans (Sauce) Chocolate Sponge
SATURDAY 16 June		
Standard & Poached Egg	Hot Dogs Sweet & Sour Cod Balls Cold Meat Selection Chips	Striploin Steak Rump Steak Salmon Steak Chips Sweetcorn Peas Fresh Fruit
SUNDAY 17 June		
Standard & Mushrooms	Beef Lamb Chicken Roast & Boiled Potatoes Brussels Sprouts & Cauliflower Jellied Fruit	Prawn Curry Chicken Chop Suey Pizza Chips BITS Cheese Board

dietician, a nuclear expert, and to crown it all he keeps watch on the hydroplane controls, like anybody else on board who does not have set duties which occupy him most of the time.

Finally, the doctor is also responsible that the air breathed in the submarine is free of all noxious gases. He has a small laboratory in which to carry out any tests necessary.

Air Purification

This brings us to the methods of ensuring that the air is safe to breath. A normal atmosphere contains mostly nitrogen, 21% oxygen, and very small percentages of argon, carbon dioxide and other gases. When a man breathes he takes in all these gases, but when he breathes out his breath is almost pure carbon dioxide (CO_2). Carbon dioxide is a poisonous gas, but when it is breathed into a normal atmosphere it quickly mingles with the air and no harm results. When it is breathed out in the confined space of a submarine, it will build up until the boat is so full of CO_2 that life is endangered, so it has to be absorbed. At the same time the man is absorbing oxygen from the air, but oxygen is fundamental to life, so the oxygen cannot be taken out of the air unless it is replaced. In addition, cooking, smoking and battery charging produce other gases and vapours which tend to degrade the atmosphere, and as long exposure to them would be harmful to the crew, these too have to be absorbed. However, getting rid of the CO_2 is by far the most important.

This can be done in a number of ways. The simplest method is to pass air taken from the inside of the submarine through canisters containing soda lime which absorbs the CO_2 element. Such a system is used in conventional submarines, but nuclear submarines with their requirement for much longer periods whilst no fresh air can be admitted, use a more complicated process, known as the Monothanolamine CO_2 absorbtion unit (MEA). This contains an organic chemical and is widely used for absorbing CO_2 in other walks of life. British nuclear submarines have two units plus four oxygen generators in the fore end, with the main purification unit in the auxiliary machinery space aft. It is similar to the forward unit but larger and also contains the cooling unit for the general air conditioning systems.

Oxygen can be produced in a number of ways. In a small submarine it is produced by what are known as oxygen candles. These are small sticks made of a mixture of sodium chlorate and potassium chloride which are lit like a candle and burned in a controlled manner inside a container, known as the oxygen generator. Nuclear submarines use a system of water electrolysis. Briefly, the process consists of dividing water (H_2O) into

Top:
Checking for possible radioactive contamination in the health physics laboratory of a British nuclear submarine. Frequent checks are made.

Above:
A crewman logs equipment gauge readings on board an SSN of the US Navy.

its basic components — hydrogen (H_2) and oxygen (O). The chemical separation process is long and complicated, but the end result is that pure oxygen is extracted and fed into the submarine's normal ventilation system, and the hydrogen is discharged overboard.

The result of these processes is that the air breathed, even after months of being submerged with no fresh air entering the submarine, has no effect on the men's health at all; smoking is permitted at most times of the day.

American SSBNs

Most of the above is written from the British point of view. Life on board an American SSBN is very similar, which is not surprising considering that the British based their way of life on that used by their American counterparts. US SSBNs were the first to be placed in service, although the Soviets had some conventional submarines fitted with nuclear strategic missiles somewhat earlier. There are however some minor differences between the American way of life on board SSBNs and that of the British, most of which are conditioned by the fact that the US has many more submarines than do the British (or the French, for that matter).

The Americans have seven submarine bases in America, instead of just the one used by the Royal Navy. There is also one American overseas base for SSBNs at Holy Loch in Scotland, not far from the British submarine base at Faslane. US submarine bases are as follows. On the west coast there are four. New London, Connecticut has the older SSBNs and some SSNs based there. Norfolk, Virginia is of course a main fleet base, but also has a number of SSNs stationed there. Farther south there is a main submarine operating base at Kings Bay, Georgia, but the shore accommodation and married quarters for it are at Charleston, South Carolina which is some 100 miles farther north. At Kings Bay are based submarines fitted with the Trident I missile, which used to be based on Rota in Spain, whilst from December 1989 there will also be some 10 'Ohio' class vessels with Trident II missiles (the D5). Their crews will live at Kings Bay, not at Charleston.

On the west coast, in the north, Bangor, Washington, which will have eight 'Ohios' based there, but at present there are only five, the remainder not yet being completed. They will initially carry Trident I missiles, but will eventually convert to Trident II. At Pearl Harbor in Hawaii there is a small SSN base and at San Diego, California (at Point Loma) there is another SSN base.

Finally, one SSBN squadron (about 14 submarines) is based on Holy Loch, Scotland, but normally a number of the submarines are back in the US, refitting. It is not really a base, but there is a depot ship there and an accommodation vessel. All the submarine servicing is carried out by the depot ship workshops. The crews of SSBNs operating from there, on their return from patrol, are flown all the way back to New London in the US for their rest and leave periods, and similarly the relief crews are flown from New London to Holy Loch to take over from the returning crews. They do this immediately the returning submarine gets alongside the depot ship. Incidentally, the Americans call the SSBNs' two crews Blue and Gold.

American SSBNs are slightly more luxurious and comfortable than are the British and French, and the 'Ohios' are the last word in comfort and space. American SSBN officers are housed in two or three-berth cabins, not the multi-berth cabins found in some British submarines. The Captain, naturally, gets a cabin to himself, and the Executive Officer may or may not also get one, but he may have to share if there are supernumerary officers on board. Alcohol is, as is well known, never permitted on board any US warship. Senior enlisted men are in less cramped quarters than are their counterparts in British and French submarines. The senior rates feed with the rest of the enlisted men, but have their own separate lounge.

Watchkeeping is on the three-watch basis of six hours on and 12 hours off, but the officers and some senior rates are in four watches.

The holding of a church service on Sundays is not obligatory, as it is in British SSBNs, but most Captains hold a voluntary service which, like the British, is not well attended.

Food is reputedly very good, but most men tend to diet themselves. Exercise machines are provided, including the latest computer bicycle on which can be set the additional tension of climbing an imaginary hill.

US naval pay is generally much higher than in the Royal Navy, and submariners receive rather more bonuses than do their British counterparts. The Captain of a USS SSBN (normally a Commander) gets about £40,000 a year, as compared to the £22,000 received by his British counterpart. Both salaries include submarine pay, command allowance and often nuclear qualification pay. Enlisted men are correspondingly higher paid.

Doctors are not carried in all US SSBNs, but there is always an 'individual duty hospital corpsman' on board. Such men are specially trained for responsible individual posts and, like the doctor in British submarines, is responsible for the health of the crew.

US SSBN patrols are about the same length as in the Royal Navy, but, surprisingly, it is not unknown for a patrol to be interrupted for a short port visit to allow the crew to stretch their legs. Ports visited are not necessarily those in the USA, but maybe ports reasonably adjacent to their patrol areas.

Most enlisted men serve from two to four years in SSBNs, and the officers up to three years. Commanding Officers serve 2½ or perhaps three years. Patrols average two a year, compared to the British three.

There is no shortage of volunteers for the US submarine service. It is regarded as an elite corps and both officers and men take a great pride in belonging to it. However, the nuclear qualified officers are much in demand by industry, as they are so highly trained in all scientific matters. As a result they are difficult to retain in the Service, even though offered special bonuses to stay on.

Life on Board an SSN

SSNs are built to very much the same design as are SSBNs, the major difference being that they are smaller because they do not have to carry 16 or more large missiles, and they carry about 120 men instead of the 150 carried by an SSBN. The accommodation for both officers and men is also very similar but about two-thirds the size. The officers' cabins all lead directly off the wardroom, except for the Commanding Officer's cabin. The cabins hold four or eight officers and are very cramped. The ratings sleep in bunks dotted around the submarine in virtually any position that can be found for them.

Whilst SSNs can be sent on long patrols of up to 60 days, and a 90-day patrol is not unknown, normally they go to sea for not much more than 14 days at a time and do not necessarily return to the port from which they sailed. The crew's life is much more varied and considerably more interesting, because they are probably taking part in national or NATO exercises when at sea in peacetime. There is always a thrill in detecting another submarine, even if it is just playing the part of an enemy, and unlike SSBNs in peace, the SSNs frequently carry out mock attacks. Further, when on patrol, the object is to find a potentially hostile submarine and track it, unlike the SSBN which does its best to avoid any other ship or submarine.

One Commanding Officer I spoke to said that he really enjoyed life in an SSN, but simply could not imagine enjoying life in an SSBN.

From the officers' point of view much depends upon the individual's temperament. The placid man with no great ambition would be quite at home on a 60-day patrol in an SSBN, but the active man, very keen on his job, would be better suited to an SSN.

From the ratings' point of view the difference between the two types of submarines is not great.

After all, if your job is, say, in the machinery compartment, it does not make a whole lot of difference whether you are on an exercise or on a patrol against no opposition as in an SSBN. On the other hand, many ratings prefer SSNs because of the shorter time away from home, the occasional visits to other ports and the variety of life.

Life on Board a Conventional Submarine

Life in a conventional submarine is similar to that in an SSN, but the patrols are probably shorter; although the modern conventional has great endurance and can carry out long patrols, it of course has to snort from time to time. From the crew's point of view snorting does make some variety because fresh air can be breathed for a change, though this makes little difference with the modern air purification equipments now in use. Also at persicope (snort) depth there may be some motion on board if the sea is rough.

Conventionals are also often used as targets for surface ships and helicopters to exercise their anti-submarine capabilities, and such exercises always add an interest for the submarine crews.

There is more chance of carrying out some shallow water work in conventionals than in nuclears, which avoid shallow water. This might result in patrols off potential enemy coasts, landing Commandos for exercises, bottoming and lying silent, which nuclears do not do. Minelaying might also be exercised and attacks against surface vessels for exercise are frequently carried out. All this adds an edge to life which nuclear submariners, particularly the SSBN submariners, miss.

Another point about conventionals is that they offer the opportunity for more junior officers to get command of their own submarines, and for the other young officers and ratings to be given more responsible jobs than in the nuclears.

Conventionals play a very important role in the Royal Navy and will continue to do so, in spite of the fact that the US and France do not agree, as they are no longer going to build them. Of course in a great many navies they are the only type of submarine, and are perhaps vital to such navies' strategy and tactics.

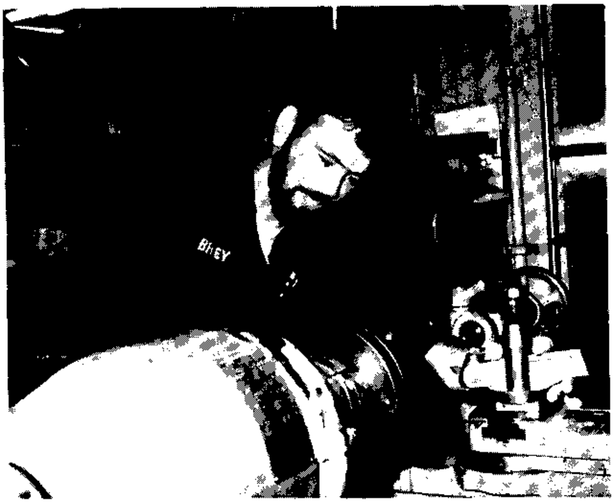
The Submariner

Life on board a submarine has an element of risk about it, albeit very slight nowadays, but the submariner accepts this and the world's navies seldom lack for volunteers. Why is this? Perhaps because every officer and man performs highly responsible jobs on which depends not only his own life but the lives of his shipmates. Individual responsibility in submarines is at a far higher level than in surface ships, and there is nothing like responsibility to make a man feel he is doing a worthwhile job.

In addition there is the fascination of submarine warfare. To most of us, whether we go to sea in submarines or not, there is something peculiarly exciting about the thought of two adversaries manoeuvring in the depths of the ocean, trying to outwit each other. It is a real game of cat and mouse with enormous stakes. It is not difficult to understand why it attracts men.

Much more difficult to understand are those who volunteer for the strategic nuclear submarine. Not for them the tactical games played in peacetime to prepare for war, nor the prospect of bringing their training to fruition in war. All they can look forward to are endless long patrols in peace, coupled with the very remotest prospect of launching their nuclear missiles. In war, if the time should ever come to launch their missiles in anger, they will never know the exhilaration of having fought a battle and won. There will have been no battle and the launching of the missiles is a confession of failure. Not only that, they also know that there may now never be a homecoming for them, since no homes may still exist.

We are fortunate indeed that in the three nuclear navies in the West, men do volunteer for such work — we should be grateful to them that they do, otherwise the nuclear deterrent, which has kept the peace of the world for so long, would cease to exist.



Above:
A machinist's mate first class working in the machinery space on board an SSBN of the USN.

Left:
Junior ratings playing Ludo (called 'Uckers' in the Royal Navy).

Submarines of the World

Country	Number & type	Class	Builder	Submerged tonnage	Max speed (submerged)	Remarks
Albania	3 SS	'Whiskey'	USSR	1,350	14kt	Transferred from the USSR
Algeria	2 SS	'Romeo'	USSR	1,800	16kt	Lent by USSR to train Algerian Navy in ASW
Argentina	6 SS	'TRT 1700'	Thyssen (W Germany)	2,300	25kt	Two delivered, one of first batch still building. Three more recently ordered. Some will build in Argentina. Designed in Germany, built in Argentina
	2 SS	'Salta'	HDW (W Germany)	1,200	22kt	
Australia	6 SS	'Oberon'	Scotts (UK)	2,410	17kt	Acquired from UK some years ago. Now being modernised
Brazil	3 SS	'Oberon'	Vickers (UK)	2,410	17kt	Built specially for Brazil
	2 SS	'Guppy III'	USA	2,450	16kt	Sold by USA
	2 SS	'Guppy II'	USA	2,420	15kt	Sold by USA
	3 SS	'209'	HDW (W Germany)	1,440	21.5kt	Building. First in Germany, other two in Brazil
Bulgaria	2 SS	'Romeo'	USSR	1,800	16kt	Transferred from USSR
Canada	3 SS	'Oberon'	Chatham Dockyard	2,410	17kt	Sold by the UK
Chile	2 SS	'209'	HDW (W Germany)	1,390	21.5kt	Sold by W Germany
	2 SS	'Oberon'	Scott-Lithgow (UK)	2,410	17kt	Sold by UK
China	2 SSBN	'XIA'	China	8,000	22kt?	A further four planned
	1 SSBN	'Golf'	China	2,800	14kt	Similar to Soviet 'Golf' class. May have been lost when launching its first nuclear missile
	76 SSN	'Han'	China	5,000?	?	Two are known to have been built and four more planned
	2 SS	'Ming'	China	1,900	?	First believed to have been laid down in 1971-72
	94 SS	'Romeo'	USSR & China	1,800	13kt	First one built in USSR remainder in China. The Chinese have transferred eight to Egypt and N Korea
	16 SS	'Whiskey'	China	1,250	14kt	Some are now unfit to dive
Colombia	2 SS	'209'	HDW (W Germany)	1,285	22kt	Commissioned 1975
	2 SS	'SX506'	Cosmos (Italy)	70	6kt	Holds five men only
Cuba	2 SS	'Foxtrot'	USSR	2,500	16kt	Transferred from USSR
	1 SS	'Whiskey'	USSR	1,350	14kt	Transferred from USSR
Denmark	2 SS	'Nahrvalen'	Royal Dockyard Copenhagen	450	17kt	Coastal submarine. Similar to German '205s'
	3 SS	'Delfinen'	Royal Dockyard Copenhagen	642	16kt	Obsolescent
	3 SS	?	?	?	?	Denmark is reputed to be about to order three small submarines from either Sweden or Germany
Ecuador	2 SS	'209'	HDW (W Germany)	1,390	21.5kt	These two boats have been in commission since 1977-78

Submarines of the World — *Continued*

Country	Number & type	Class	Builder	Submerged tonnage	Max speed (submerged)	Remarks
Egypt	9 SS	'Romeo'	USSR & China	1,800	14kt	Three of these were transferred from China, remainder from USSR. Unlikely that all are in commission
	4 SS	'Whiskey'	USSR	1,350	14kt	Two at least are non-operational
France	6 SSBN	'SNLE'	Cherbourg (France)	8,940	25kt	Five in commission, the sixth will commission early in 1985
	2 SSN	'SNA72'	Cherbourg	2,670	26kt	Six have been ordered with two more to follow. Only two are yet in service
	4 SS	'Agosta'	Cherbourg	1,725	20kt	Four designs sold to Spain and two are being built for Pakistan
	6 SS	'Daphne'	Various naval dockyards	1,638	16kt	S Africa, Pakistan, Portugal and Spain have all bought 'Daphnes'
	4 SS	'Narval'	Various naval dockyards	1,635	18kt	Based on the German Type XXI. France does not intend to build any more conventional submarines
Germany	18 SS	'206'	HDW & Rheinstahl (W Germany)	498	17kt	Crew of 22
	8 SS	'205'	HDW	450	17kt	Crew of 22
Greece	8 SS	'209'	HDW (W Germany)	1,210	21.5kt	Latest four boats are slightly larger
	1 SS	'Guppy III'	USA	2,450	15kt	Transferred from USA
	1 SS	'Guppy IIA'	USA	2,445	15kt	Sold by USA as a training boat
India	0 SS	'209'	HDW (W Germany) Mazagon (India)	1,680	22kt	Two boats to be built in Germany and two in India
	8 SS	'Foxtrot'	USSR	2,400	18kt	Eight have been bought and four more believed to have been ordered. All of new construction
Indonesia	2 SS	'209'	HDW (W Germany)	1,390	21.5kt	Commissioned in 1981
Israel	3 SS	'206'	Vickers (UK)	600	12kt	Built by Vickers to an IKL (W Germany) design
Italy	4 SS	'Sauro'	Italcantiere	1,631	20kt	Two more ordered in 1983. They will be slightly larger and may be armed with ULGW
	4 SS	'Toti'	Italcantiere	582	15kt	Crew of 26
	2 SS	'Tang'	USA	2,700	16kt	Transferred from USA
Japan	2 SS	'Aseshio'	Kawasaki & Mitsubishi	2,450	18kt	Obsolescent. Double hulled
	7 SS	'Uzushio'	Kasasaki & Mitsubishi	2,430	20kt	Double hulled
	8 SS	'Yuushio'	Kawasaki & Mitsubishi	?	20kt	Enlarged version of 'Usushio' class, with deeper diving depth. One more on order
Korea (North)	15 SS	'Romeo'	Chinese & N Korean yards	1,800	14kt	Some were transferred from China, others built in N Korea
	4 SS	'Whiskey'	USSR	1,350	14kt	Transferred from USSR
	12-14	X-craft	?	?	?	Reported to be in commission
Korea (South)	?	?	?	?	?	Reported to be building a number of small submarines or X-craft
Libya	6 SS	'Foxtrot'	USSR	2,400	12kt	Transferred from USSR
	2 SS	'Mala'	Yugoslavia	?	?	Two-man submersibles
Netherlands	2 SS	'Walrus'	Rotterdam Droogdok	2,800	20kt	Four more will be built in the next four years. First two not yet in service
	2 SS	'Zwaardvis'	Rotterdam Droogdok	2,640	20kt	Commissioned 1972
	2 SS	'Potvis'	Wilton-Fijenoord	1,830	12 kt	Triple hulls
	2 SS	'Dolfijn'	Rotterdam Droogdok	1,830	12kt	Triple hulls

Submarines of the World — *Continued*

Country	*Number & type*	*Class*	*Builder*	*Submerged tonnage*	*Max speed (submerged)*	*Remarks*
Norway	14 SS	'209'	Rheinstahl (W Germany)	436	12kt	Commissioned between 1964 and 1967
	6 SS	'210'	Thyssen (W Germany)	1,300	23kt	Six ordered from Thyssen in September 1983
Pakistan	2 SS	'Agosta'	Dubigeon (France)	1,450	20kt	Originally intended for S Africa but sold to Pakistan when arms sales to S Africa were banned
	4 SS	'Daphne'	Various French yards	1,043	15.5kt	'Daphne' class design but modified internally to suit Pakistan
Peru	2 SS	'Guppy IA'	USA	2,440	15kt	Bought from USA
	4 SS	'Abtao'	USA	1,400	10kt	Commissioned 1954-57. Old US 'Mackerel' class
	6 SS	'209'	HDW (W Germany)	1,290	21kt	Commissioned 1974-83
Poland	4 SS	'Whiskey'	USSR	1,350	14kt	Transferred from USSR
Portugal	3 SS	'Daphne'	Dubigeon (France)	1,043	15kt	Commissioned 1967-69
South Africa	3 SS	'Daphne'	Dubigeon (France)	1,043	15kt	Commissioned 1970-71
Spain	4 SS	'Agosta'	Bazan	1,725	20kt	French design, built in Spain
	4 SS	'Daphne'	Bazan	1,043	15kt	French design, built in Spain
	2 SS	'Guppy IIA'	USA	2,445	14kt	Transferred by USA
Sweden	4 SS	'Draken'	Kockums	1,110	20kt	Undergoing modernisation
	5 SS	'Sjöormen'	Kockums	1,400	20kt	Two decks
	3 SS	'Nacken'	Kockums	1,125	20kt	Commissioned 1980-81
	0 SS	'Vastergotland'	Kockums	1,140	17kt	Building. Commissioning 1987-89
Taiwan	2 SS	'Guppy II'	USA	2,420	20kt	Transferred from USA
	0 SS	'Zwaardvis'	Wilton-Fijenoors	?	?	Two ordered
Turkey	7 SS	'Guppy IIA/IA'	USA	2,440	17kt	Transferred from USA
	2 SS	'Guppy III'	USA	2,450	17kt	Transferred from USA
	2 SS	'Tang'	USA	2,700	16kt	Transferred from USA
	6 SS	'209'	HWD (W Germany)	1,185	22kt	Six more planned. Of the first six, three will be built in Turkey
UK	4 SSBN	'Resolution'	Vickers	8,400	25kt	To be replaced by Trident carrying submarines
	6 SSN	'Trafalgar'	Vickers	4,500	32kt	Two in service. Four more building
	6 SSN	'Swiftsure'	Vickers	4,500	?	Completed 1973-81
	2 SSN	'Valiant'	Vickers	4,900	28kt	'Valiant' and 'Churchill' classes are almost identical
	3 SSN	'Churchill'	Vickers & Cammell Laird	4,900	29kt	A submarine of the 'Churchill' class, the *Conqueror*, sank the Argentine cruiser *General Belgrano*
	1 SS	'Upholder'	Vickers	2,400	20kt	The Type 2400 class. More to follow at rate of about one a year
	13 SS	'Oberon'	Various UK yards	2,450	17kt	Will be faded out as the 'Upholder' class come into service
	3 SS	'Porpoise'	Cammell-Laird & Scotts	2,450	17kt	The two 'Porpoises' were the forerunners of the 'Oberons'. Will also be faded out
USA	5 SSBN	'Ohio'	General Dynamics (GD)	18,700	?	Four more building and 14 to 20 more projected
	31 SSBN	'Franklin & Lafayette'	GD & other yards	7,280	30kt	The two classes are virtually identical. 12 have been converted to carry Trident missiles
	22 SSN	'Los Angeles'	GD & Newport News	6,900	30kt+	10 more building. Eight more ordered
	1 SSN	'Narwhal'	GD	5,300	30kt+	Prototype
	37 SSN	'Sturgeon'	GD & other yards	4,640	30kt+	Largest group of nuclear submarines of one design, but will be overtaken by 'Los Angeles' class
	4 SSN	'Ethel Allen'	Newport News & one by DG	7,800	30kt	Original designed as SSBNs

Submarines of the World — *Continued*

Country	*Number & type*	*Class*	*Builder*	*Submerged tonnage*	*Max speed (submerged)*	*Remarks*
	3 SSN	'George Washington'	Newport News & one by GD	6,888	31kt	First ballistic missile submarines. Missiles subsequently removed
	13 SSN	'Thresher'	Various yards	Vary between 4,242 & 4,470	30kt+	*Thresher* lost in April 1963
	1 SSN	'Tullibee'	GD	2,640	20kt+	Early experimental submarine
	5 SSN	'Skipjack'	Various yards	3,513	30kt+	Commissioned 20 years ago
	1 SSN	'Triton'	GD	6,670	20kt+	Laid up
	4 SSN	'Skate'	Various yards	2,500 (approx)	25kt+	Obsolescent
	1 SSN	'Seawolf'	GD	4,200	20kt+	Used for research work
	1 SSN	'Nautilus'	GD	4,040	20kt+	World's first nuclear propelled vessel. Not in commission
	3 SS	'Barbel'	Various yards	2,894	21kt	Commissioned in 1959. The last US conventional submarine built
USSR	2 SSBN	'Typhoon'		30,000	24kt?	The largest submarines ever built. More are expected to follow
	14 SSBN	'Delta III'		11,000	24kt	At least one more being built
	4 SSBN	'Delta II'		11,000	26kt	A larger edition of 'Delta Is'
	18 SSBN	'Delta I'		10,000	26kt	Improved 'Yankees'
	24 SSBN or SSN	'Yankee'		9,300	28kt	10 have had their missile tubes removed and may be converting to SSNs
	4 SSBN	'Hotel'		5,500	26kt	Over 20 years old. Consist of three 'Hotel II' and one 'Hotel III'. Little difference between them
	15 SSB	'Golf'		3,000-3,500	15kt	Diesel-electric basllistic missile submarines. 13 are 'Golf IIs', one 'Golf V' and one 'Golf III'
	2 SSGN	'Oscar'		14,000	30kt	Presumably more to follow. Called SSGNs because they carry cruise missiles with a range of over 300nm
	1 SSGN	'Papa'		7,000	35kt+	Like 'Oscars' carry cruise missiles, but with a range of only 70nm
	6 SSGN	'Charlie II'		5,500	25kt	Carry anti-ship missiles
	11 SSGN	'Charlie I'		5,000	28kt	Carry anti-ship missiles
	29 SSGN	'Echo II'		5,300	25kt	Carry older anti-ship missiles with ranges up to 70nm. Some carry more modern missiles with ranges up to 200nm
	16 SSG	'Juliett'		3,500	14kt	Diesel-electric propulsion. Some carry the 'Shaddock' missile with a range up to 200nm
	2 SSG	'Whiskey'		1,500	12kt	Carry 'Shaddock' missiles
	1 SSN	'Mike'		9,700	?	Launched May 1983. Presumably first of a new class
	1 SSN	'Sierra'		6,500	32kt+	Launched January 1983. Presumably first of a new class
	6 SSN	'Alpha'		3,800	42kt+	Fastest submarine afloat
	10 SSN	'Yankee'		9,300	30kt	May have been converted from the 'Yankee' SSBNs mentioned above
	18 SSN	'Victor III'		6,000	30kt	Improved 'Victor II' class
	7 SSN	'Victor II'		5,800	31kt	Enlarged 'Victor Is'
	16 SSN	'Victor I'		5,200	32kt	First one laid down 1967-68
	5 SSN	'Echo I'		5,200	28kt	Completed 1960-62
	12 SSN	'November'		5,000	30kt	Entered service 1958-63
	5 SS	'Kilo'		2,200	16kt	Conventional submarines. More being built
	18 SS	'Tango'		3,700	16kt	May be fitted with SS-N-15 missile-launched torpedo. More being built
	3 SS	'Modified Golf I'		3,000	14kt	Missiles removed. May be used as command & control craft
	60 SS	'Foxtrot'		2,500	16kt	Widely deployed and sold abroad to Cuba, India and Libya
	5 SS	'Zulu IV'		2,300	16kt	Four are in reserve
	10 SS	'Romeo'		1,800	14kt	Improved 'Whiskeys'
	125 SS	'Whiskey'		1,350	14kt	75 are in reserve
	1 SS	'Whiskey' ('Canvas Bag')		1,350	14kt	Similar to 'Whiskeys' but with an improved radar. Used as radar pickets
	6 SS	Various old craft				Used as research or rescue submarines and as targets
Venezuela	1 SS	'Guppy II'	USA	2,420	15kt	Transferred from USA
	2 SS	'209'	HDW (W Germany)	1,450	22kt	Commissioned 1976-77

Note: All Soviet submarines built in USSR naval yards

Submarines of the World — *Continued*

Country	*Number & type*	*Class*	*Builder*	*Submerged tonnage*	*Max speed (submerged)*	*Remarks*
Yugoslavia	2 SS	'Sutjeska'	Uljanik Shipyard	945	9kt	The first submarines to be built in Yugoslavia. Commissioned 1960-62
	2 SS	'Heroj'	Uljanik and S&DE, Split	1,070	10kt	Have Soviet electronics and armament
	3 SS	'Sava'	S&DE, Split	950	16kt	Have Soviet electronics and armament
	? X-craft	?	?	?	?	Two-man submarines. Two also sold to Lybia

Summary

Country	*SSBNs*	*SSGNs and SSNs*	*SS*	*Total*
USA	38	96	3	137
USSR	66 + 15 SSBs	127	223*	431†
UK	4	17	16	37
France	6	2	14	22
China	2	76	112‡	190§
Other Nations	–	–	189	189
Total number of World submarines				1,006

* Including 75 in reserve; † including about 70 in reserve;
‡ including 16 in reserve; § includes 16 in reserve.
Note: The total number of World Submarines includes all those in reserve

Comparison Between NATO and Warsaw Pact

Type of Submarine	*NATO*	*Warsaw Pact*
SSBNs	48	66
SSGNs and SSNs	115	127
SS	142	227*
Total	305	420

* Includes about 90 in reserve