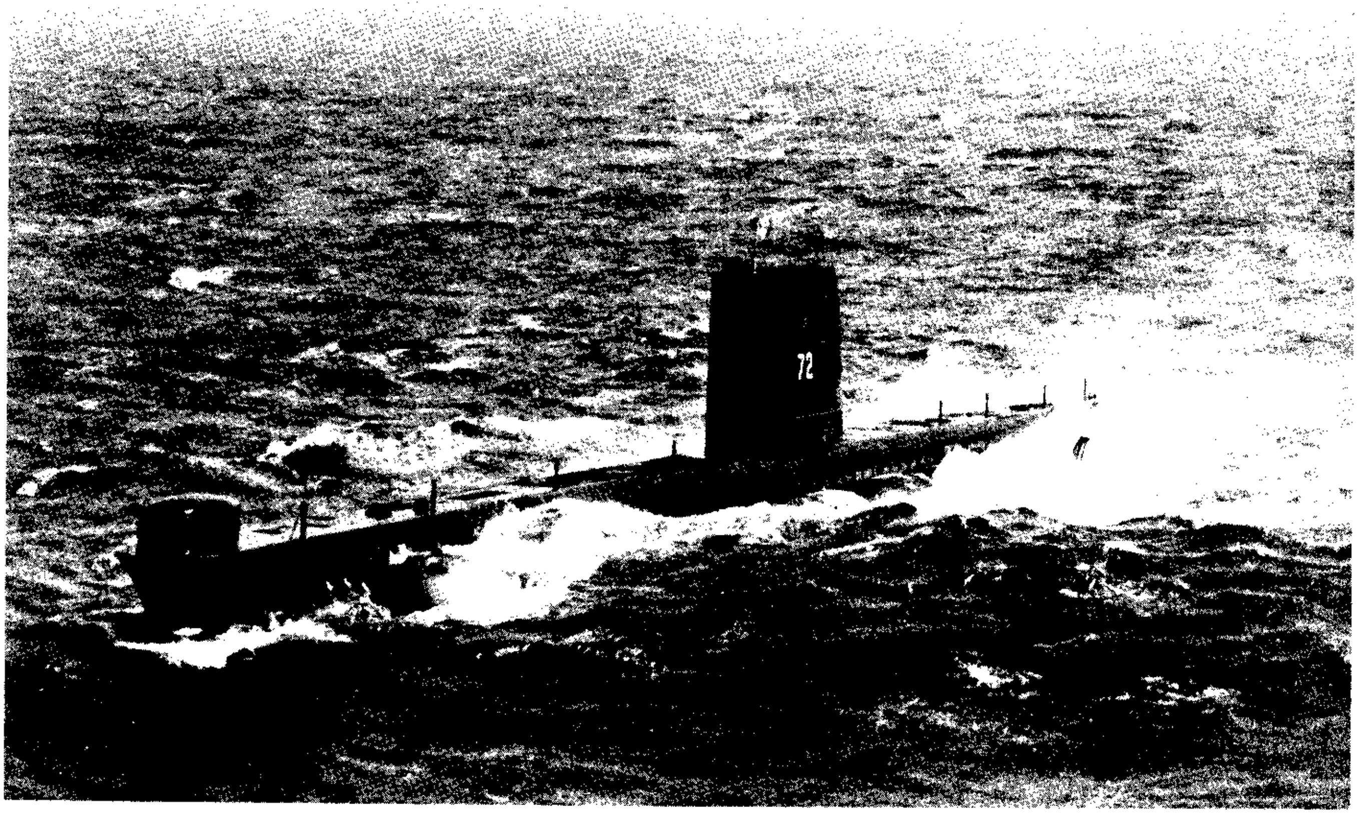
C.F. 'O' CLASS SUBMARINES



TRAINING NOTEBOOK

SUBMARINE PRINCIPLES

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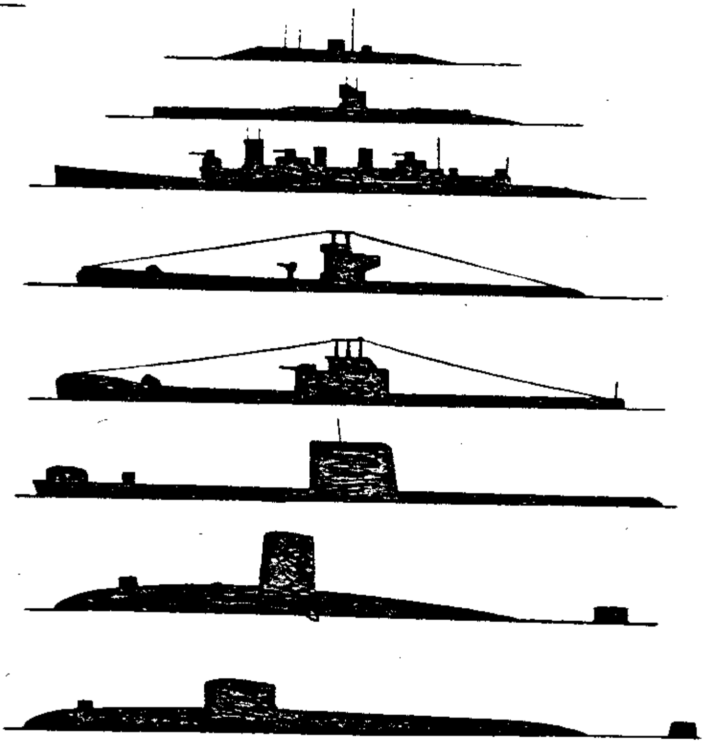
SEE HOW THEY GROW



Class	Date	No. built	Length feet	Surface Displacement tons	Propulsion	Armament	Crew
Holland	1901	5	63	105	Petrol electric	1-14" tube	7
E	1913	15	181		Diesel electric	5-18" tubes 1-12 pdr.	30
K	1917	13	338	1780	Steam electric	8-18" tubes 2- 4" guns 1- 3" AA gun	60
S	1932/ 1945	62	217	1090	Diesel/electric	6-21" tubes 1- 4" gun 1-20mm gun	44
A	1945	16	281	1200	Diesel/electric	10-21" tubes 1-4" gun 1-20mm gun	60
Porpoise & Oberon	1958	21	295	2000	Diesel/electric	8-21" tubes	68
Dreadnought	1960	1	265	3000	Nuclear	21" tubes	88
Valiant	1966 onwards		265	3500	Nuclear	21" tubes	88
Resolution	1968	4	425	over 7000	Nuclear	21" tubes 16 Polaris missiles	129 (each crew)

DEVELOPMENT OF SUBMARINES

Over the years. the development of submarines shows a steady growth in size, development, crew number and torpedoes carried. a fantastic development in complexity and an equally fantastic rise in cost. Not all the developments have been eminently practica and a high price has had to be paid for some steps in progress.

THE SUBMARINE SERVICE

Historical Introduction

The 'O' class submarines are not the first such craft to serve in the C.A.F.

The story of the first C.A.F. submarines is highly colourful. At the outbreak of the First World War, the Government of British Columbia, concerned over the lack of defence on the Pacific Coast, secretly purchased two submarines which were built in Seattle. Independent crews were found, mainly from ex-R.N. officers and men residing in Canada, and on 4 August, 1914 the two submarines were handed over in return for a cheque for $1,150,000. Three days later, the Federal Government ratified the purchase of the submarines which were accepted into the R.C.N. as CC1 and CC2. These two ships remained in service on both East and West coasts until 1920 when they were paid off to scrap.

Two 'H' class submarines, built in the United States, were given to Canada in 1919 and served in the R.C.N. until 1922. These submarines were two of the many of this class that were built both in Canada and the United States during the First World War. In 1914 a Contract to an American Shipyard had been let for the construction of 'H' class submarines; at the outbreak of war, the neutrality of the United States prevented the submarines being built in that country, so, construction was sub-contracted to Canadian Vickers in Montreal.

There was no further Canadian Submarine activity until 1945 when two German U-boats, which had surrendered to R.C.N. ships, were commissioned for trials and evaluation purposes. These were the U 190 and U 889; the former was in use until 1947 when she was sunk in local areas; the latter, U 889, was turned over to the U.S.N.

In 1961, the USS BURRFISH, was turned over to and commissioned into the RCN as HMCS GRILSE. Her purpose to provide target facilities for ASW units on the Pacific Coast.

LIST OF SUBMARINES IN THE ROYAL CANADIAN NAVY

HMC Submarine CC-1

Assembled 1913 at Seattle, Washington, as IQUIQUE.
Purchased by the Government of British Columbia and transferred to the RCN.
Commissioned 6 August, 1914.
Paid off 13 December, 1918.
Sold for scrap 1920.

HMC Submarine CC-2

Assembled 1913 at Seattle, Washington as ANTOFAGASTA.
Purchased by the Government of British Columbia and transferred to the RCN.
Commissioned 6 August, 1914.
Paid off 13 December, 1918.
Sold for scrap 1920.

HMC Submarine CH-14

Built for the Royal Navy at Quincy, Massachusetts, 1916.
Transferred to the RCN and commissioned 3 March, 1921.
Paid off 30 June, 1922.
Broken up in 1929.

HMC Submarine CH-15

Built for the Royal Navy at Quincy, Massachusetts, 1916.
Transferred to the RCN and commissioned 3 March, 1921.
Paid off 30 June, 1922.
Broken up in 1929.

HMC Submarine U-190

Built 1942 at Bremen, Germany.
Surrendered to HMC Ships VICTORIAVILLE and THORLOCK off Newfoundland 12 May, 1945.
Commissioned 19 May, 1945.
Paid off 24 July, 1947.
Deliberately sunk off Nova Scotia coast 21 October, 1947.

HMC Submarine U-889

Built at Bremen, Germany in 1943.
Surrendered to HMC Ships OSHAWA, ROCKCLIFFE, DUNVEGAN and SASKATOON, off Nova Scotia, 10 May, 1945.
Commissioned 14 May, 1945.
Paid off and transferred to US Navy, 12 January, 1946 at Portsmouth, New Hampshire.

Oberon Class Introduction

At the end of World War II British Submarines consisted of three classes:

'S' Class - Designed and built during the war.

'T' Class - Designed and built during the war.

'A' Class - Designed during but built after the war.

The Admiralty realised in late 1944, when the Germans produced the Type XXI Series U-boat that we were falling behind in S/M design. The Type XXI Series was a large, Snort fitted, fast conventional S/M with a good torpedo payload.

Our first equivalent to the Type XXI was the 'T' Conversion which was a 'T' boat with an additional battery section, adding 15 ft. to the overall length of the boat. Although this porduced a good result, and 'T' Conversions are still among the best conventional S/Ms in the world, it soon became apparent that a new class would have to be designed. Because of their age the life of the 'T' conversions was necessarily limited.

The design produced by the Admiralty was the PORPOISE Class. They are large, fast, quiet, conventionally powered submarines, i.e., non nuclear. Long ranged and with much improved habitability they are capable of extended detached patrols. Fitted with semi-automatic torpedo reloading and enormous torpedo carrying capacity, they have proved to be formidable ships.

As designs of equipment have advanced so have submarines, and improved, PORPOISE Class, called the OBERON Class, have been produced. The OBERONS are in every essential aspect the same as the PORPOISEs, but have incorporated in their design the advances made in modern technology during the 1960's.

The Nuclear S/M remains in a class by itself, but while there remains a need for conventional S/M's, the PORPOISE and OBERON Class fulfil this need. They are beyond question the finest conventional boats in the world.

In the summer of 1954, due to the increase in Canadian anti-submarine involvement, it was decided to support the Royal Navy Submarine service by loaning 180 officers and men to serve in Royal Navy submarines. These people were trained by the RN and served in RN submarines throughout the world.

The Sixth Submarine Squadron was formed in Canada at Halifax during the latter part of 1954 with two RN submarines, a third was to follow in the early part of 1955. This squadron was used as "Mechanical Mice" for the newly commissioned "DDEs".

During the years from 1954 until the early part of 1960's the RN "A" Class Submarines with some RCN personnel served in the Sixth Squadron, however it became increasingly obvious that the Canadian Navy had a requirement for submarines. It was then decided to purchase three Oberon Class Submarines, modify them to Canadian standards and establish an all Canadian Squadron based in Halifax. Thus the 1st Canadian Submarine Squadron was formed.

Purchase of the 'O' Class

The Minister of National Defence approved the acquisition of three Royal Navy Oberon class submarines on 11 April 1962. Following negotiations with the Royal Navy, Treasury Board approval was acquired in December, 1963 and the construction contract was given H.M. Dockyard, Chatham.

Commissioning dates of the submarines, designated 'O' Class Submarines in Canada were:

HMCS OJIBWA ---------------------- 23 September 1965
HMCS ONONDAGA -------------------- 22 June 1967
HMCS OKANAGAN -------------------- 22 June 1968

The dimensions and general details are as follows:

Length overall	295 ft. 3 in.
Length of Pressure hull	241 ft.
Breadth (external hull)	26 ft. 6 in.
Breadth (pressure hull)	17 ft. 9 in.
Surface displacement	2196 tons
Standard displacement	1526 tons
Submerged displacement	2417 tons
Oil fuel carried (internal)	10.44 tons
Oil fuel carried (external)	370 tons
No. of cells in battery	448
Surface B.H.P. of generating engines	3680
Complement (officers and men) approx.	62 (64 OJIBWA)

The submarine is the only unit of the fleet capable of sinking a major war vessel. True, it cannot shoot down an aeroplane, but there is no need - the aeroplane just cannot find the modern submarine. You can be justly proud of joining this specialised force, which will be the backbone of the future Navy, and feeling better than the rest. (A feeling based on thorough training and sureness of purpose.)

Submarine Pay

Special service allowance (Submarine Allowance) is paid to all personnel serving in the Submarine Service. You become eligible for Submarine Allowance while under training at the following rates:

Pte	$60.00 per month
Cpl & above	$80.00 per month

When posted to an operational Submarine on completion of basic S/M course this allowance remains the same. On successful completion of the seven month qualification programme, you will receive your Dolphin from the Commanding Officer and be "Qualified" in Submarines. Your Submarine Allowance will increase to the following rates:

Pte	$90.00
Cpl & above	$120.00

Submarine Pay is not danger money....it is a reward for the higher standard of skill and reliability required of submariners. When you have "Qualified", be sure and earn it.

Types of Submarine in Service

There are two types of submarine in current service - the "O" Class and USN Tench Class.

They are represented by RAINBOW (Tench Class) and three OBERON Class boats. They are "Conventional " in that in many ways, particularly mechanical, they differ little from earlier classes of submarine. They have diesel electric propulsion, in which their two diesel engines drive generators which in turn power the electric propulsion motors or store energy in the battery. Their main weapon is the torpedo. They also have mine laying capability.

The "O" class submarines are the best of their kind in the world. They are fast underwater, carry a large torpedo armament, are very quiet when submerged and hence not easily detected. Their standard crew comprises 7 officers and 55 ratings and they can remain at sea for at least six weeks. They need to surface or snorkel periodically to recharge their batteries, although they have a comparatively long submerged endurance at low speed starting with a fully charged battery.

In war the tasks of submarines are sinking enemy submarines and ships, minelaying and special operations, such as landing agents on enemy coasts or photographic reconnaissance.

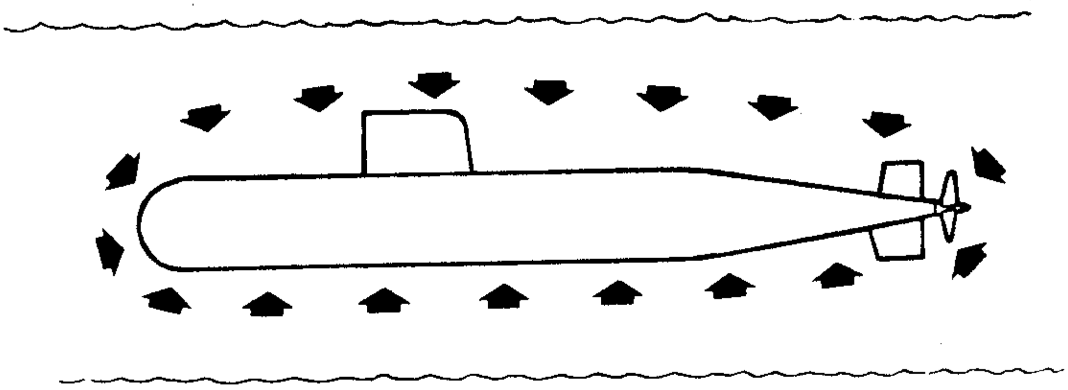
The Basic Requirement

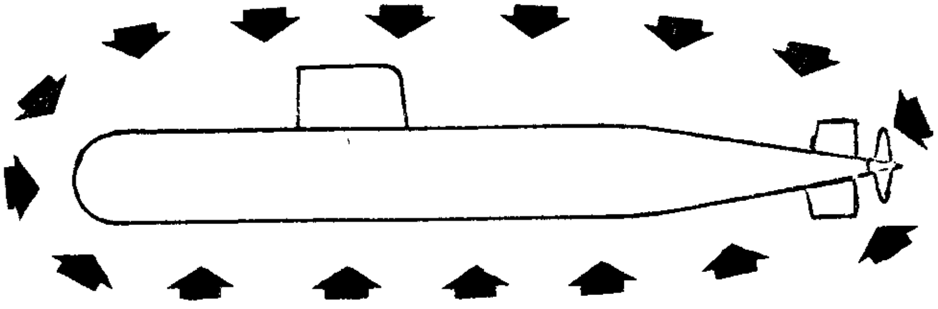
A submarine is a warship which must be capable of taking on and beating any likely opponent, whether submarine or surface vessel. In general, after leaving harbour, the submarine will dive, and carry out a dived transit to its patrol area, where it will remain dived until returning home in a similar manner. It must be capable of diving and surfacing quickly and safely, and able to manoeuvre both on the surface and submerged. The pressure hull of the submarine must be capable of withstanding the pressure of the sea down to its operating limit (and beyond) to protect the crew and equipment.

The submarine must provide living facilities and stores to enable the crew to stay on patrol for long periods and similarly carry adequate supplies of fuel, equipment spares, etc. It must be able to discharge its weapons on the surface, at periscope depth or deep, and operate to the maximum possible depth whenever necessary. To do this effectively it needs communications, sonar, navigational and weapons systems all crammed into a hull which must be as small as possible.

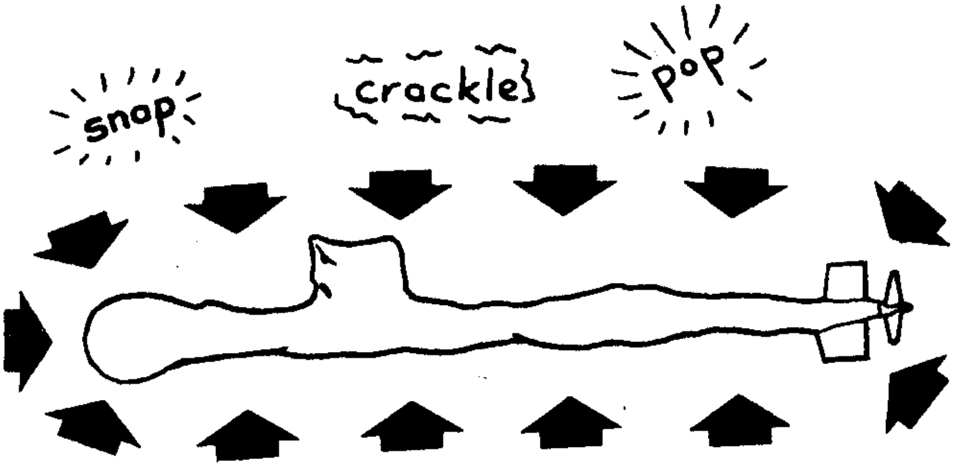
Sea Pressure

Sea pressure increases with depth. At 100 feet the pressure is about 47 pounds per square inch (in future we will use the abbreviation psi), at 200 feet about 94 psi. It is sufficiently accurate to say that the pressure in psi is equal to half the depth in feet. Thus at 600 feet the pressure is about 300 psi and the force on each side of a biscuit tin at this depth would be about 20 tons.

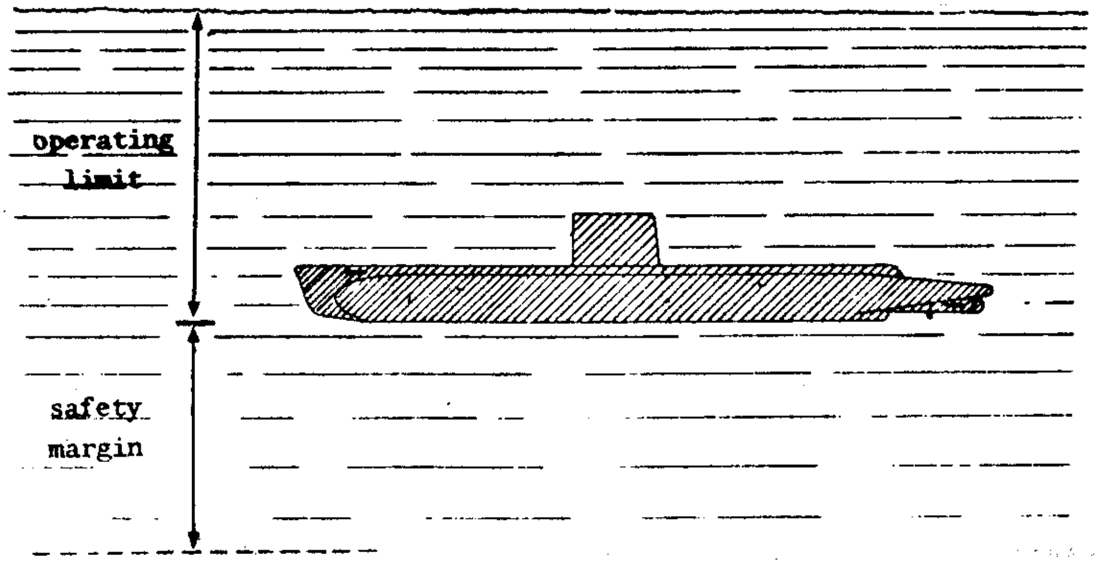




The pressure acts on a submerged hull from all directions. As the submarine continues to go deeper, a point will eventually be reached where the pressure is too great for the strength of the hull and the submarine would then be crushed.



A submarine is therefore designed so that its hull can withstand as much external pressure as possible. The stronger the hull, the deeper the submarine can go. A large safety margin is provided - the hull can withstand 70% more pressure than the normal maximum diving depth, i.e. a hull designed to go down to 500 feet would safely stand up to pressures down to 850 feet.



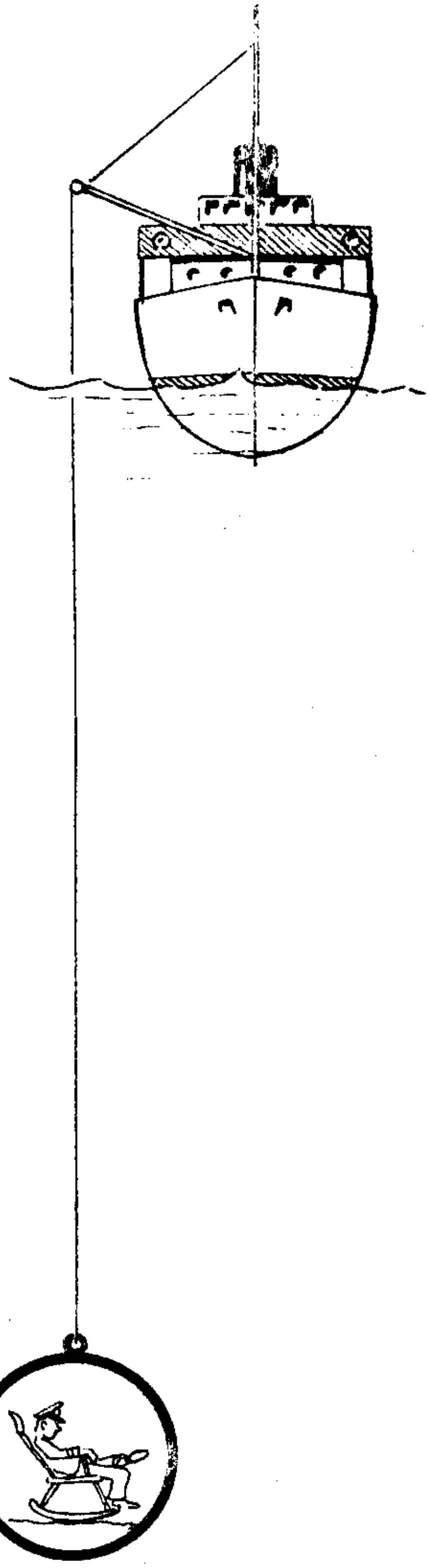
Best Hull Shape

The ideal shape for withstanding external pressure is spherical. Pressure acts uniformly around the surface, and the strength is equal at all points, so that a sphere is the most difficult shape to crush. This principle is employed in deep submergence vehicles such as bathyscapes. These have gone down to the floors of the deepest oceans. In the Marianna's Trench (Challenger Deep), the deepest recorded depth is 37,800 feet, where the pressure would be nearly 18,000 psi or 8 tons per square inch.

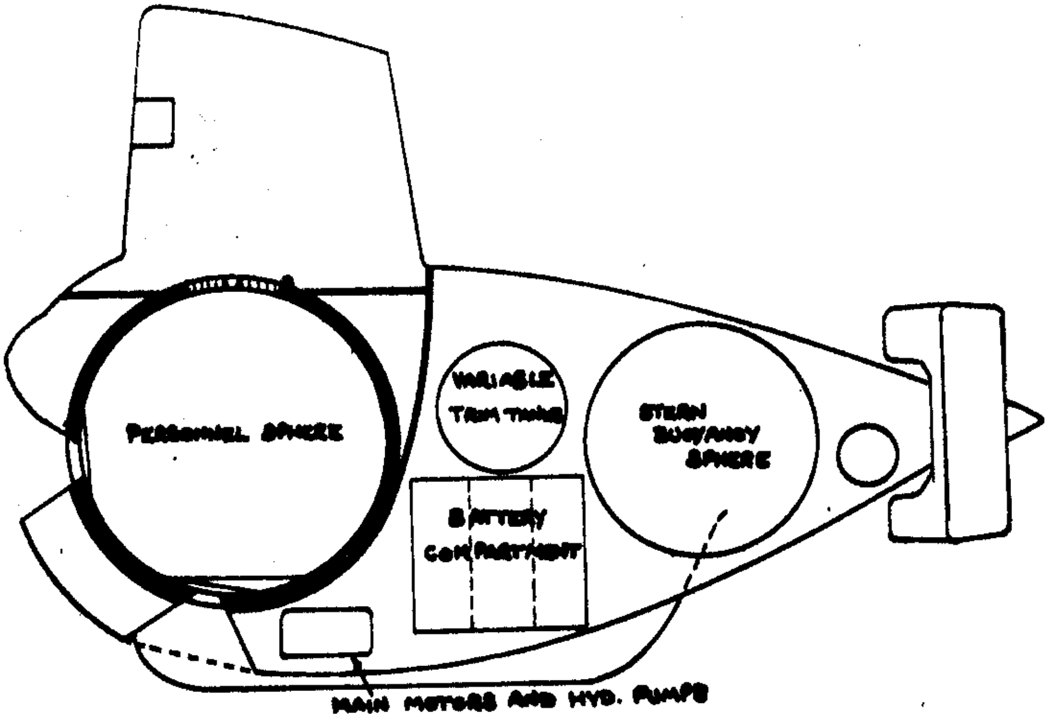
Such hulls are about six inches thick and relatively small (about six feet diameter) and can only move slowly. They would have little fighting value - even if they could find the enemy with their limited field of view. They could not carry much armament or stay submerged for long. For research purposes, more and more deep submergence vehicles are taking the water, and it is possible that in the course of time military submarines will be able to operate at the same depths.

To enable an adequate crew to live and work in a fully-equipped pressure hull, a sphere would be so large as to be impracticable from the point of view of sea-going qualities and manoeuvrability.

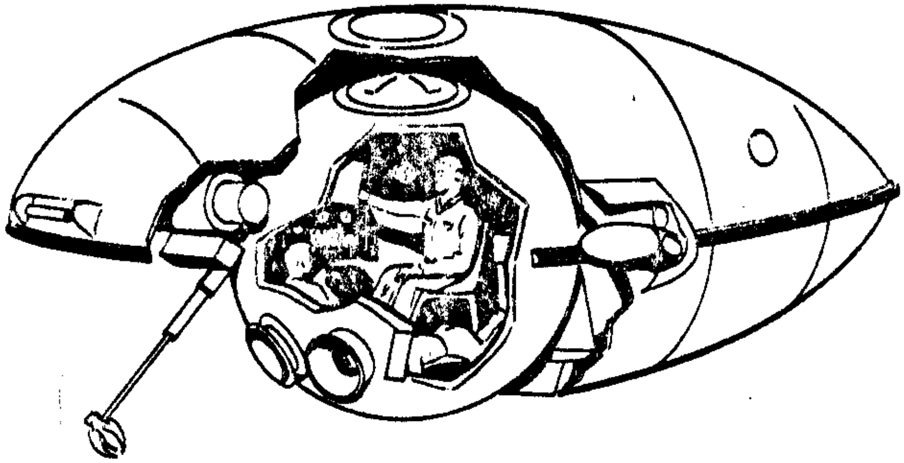
The best practical shape is a cylinder with domed ends. By fitting internal frames and bulkheads, the strength of the hull is increased against pressure tending to crush it in the middle.

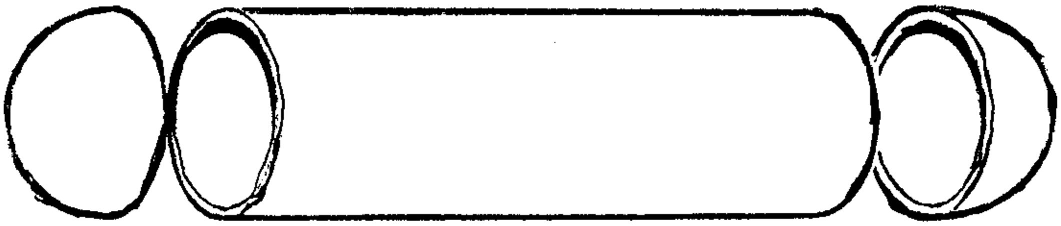


Alvin

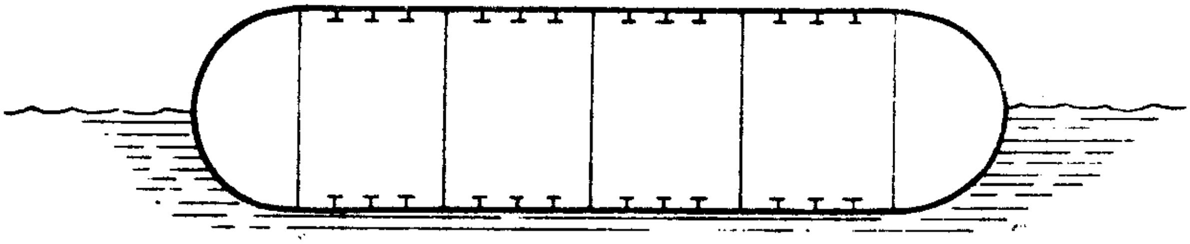


Deepstar 4000

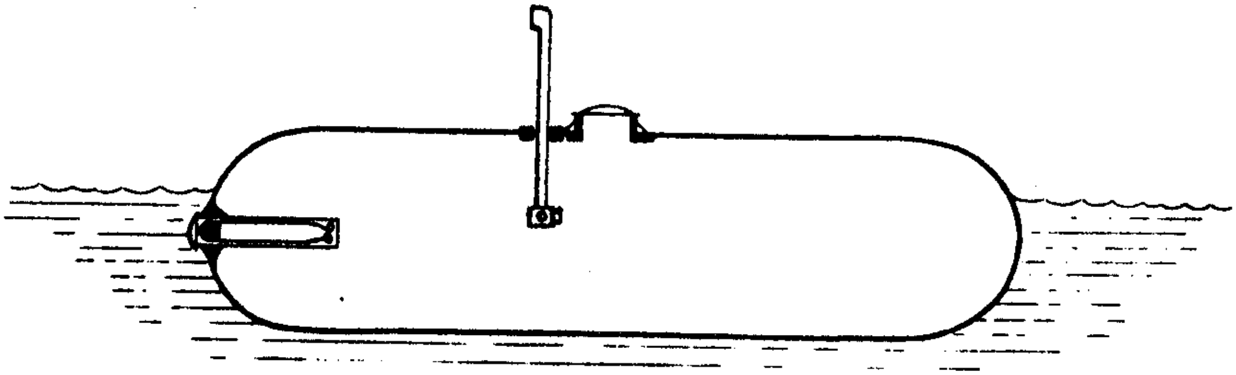




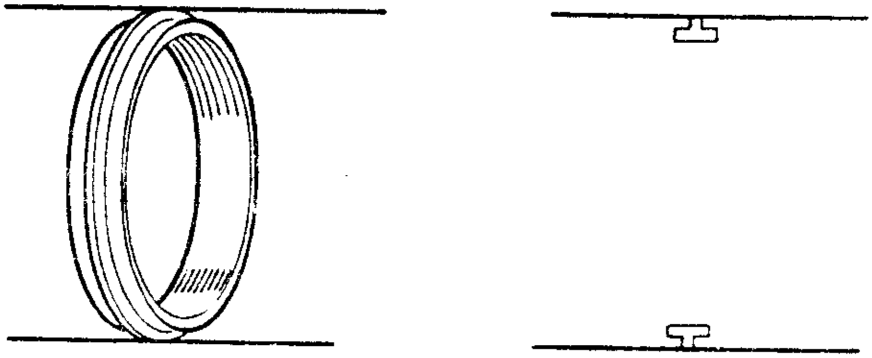
Basic Pressure Hull



The Strengthened Hull

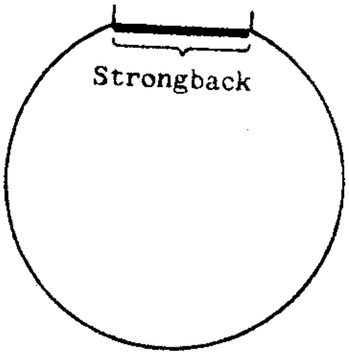


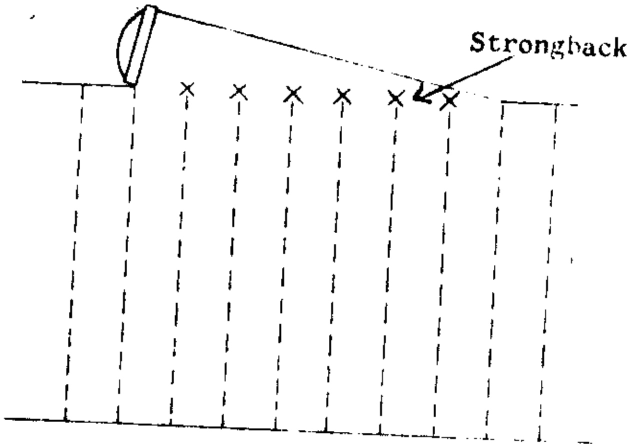
Strengthening of Hull Openings



A Typical T - Frame

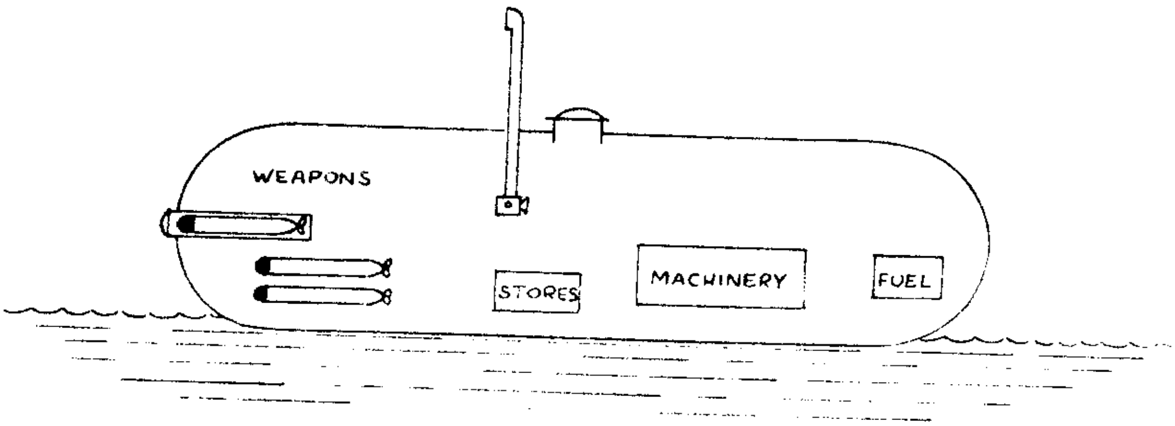
It is necessary to cut various holes in the pressure hull - hatches for entry and exit, passages for pipes, spindles, cables, propeller shafts, torpedo tubes, periscopes, masts and so on. All these holes tend to weaken the hull, so that the original strength must be restored by heavier plating around each hull opening or by extra frames. In some of the larger openings where frames have been interrupted, portable sections of the frames (called strongbacks) are fitted into place after the hatch is shut.



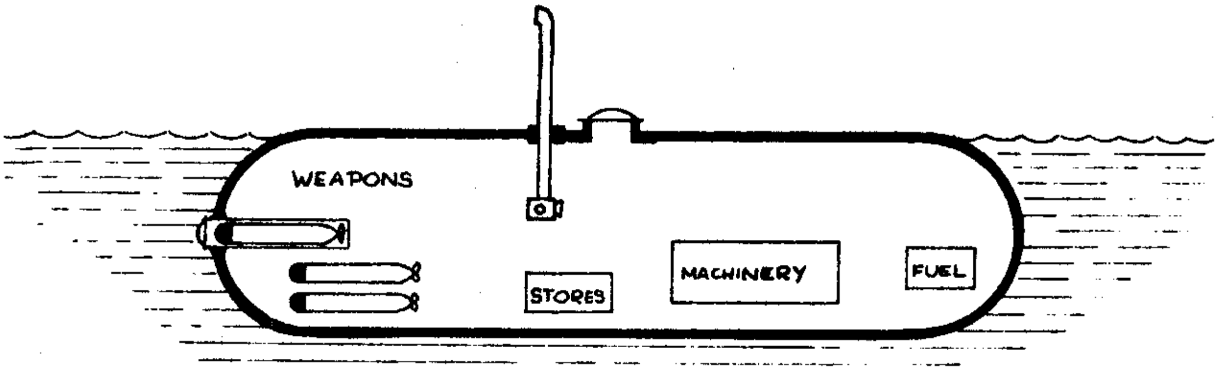


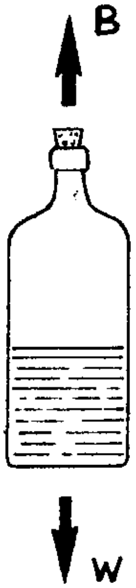
Where pipes pass through the hull, a hull valve is fitted, so that shutting the valve brings the hull back to full strength. In building or refit these hull valves are tested to full diving depth. It would be possible to make a submarine pressure hull of thick and strong steel to stand up to any pressure, but it might not then float. Although light alloys are used in bathyscapes etc., they are more expensive than steel, difficult to weld and attacked chemically by sea water. Plastic materials may come into wider use, but at present and in the immediate future, the normal building material is high strength steel.

The submarine must be able to float, but at the same time it must not be too buoyant or it will be impossible to make it dive. (Think of trying to force an inflated beach ball under water.)

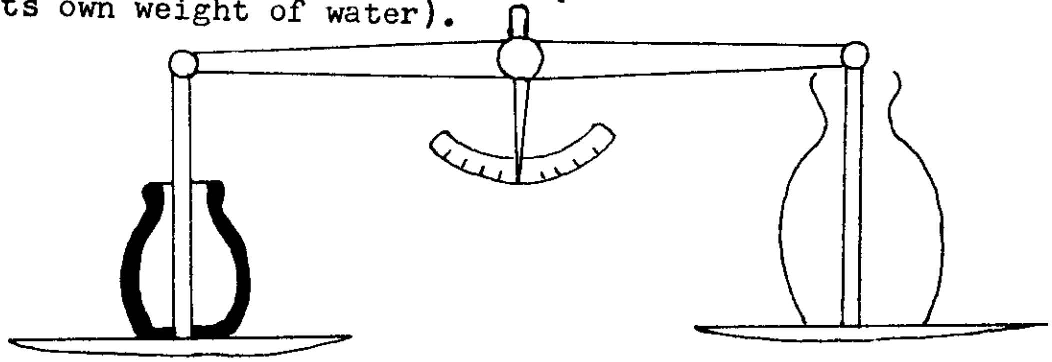


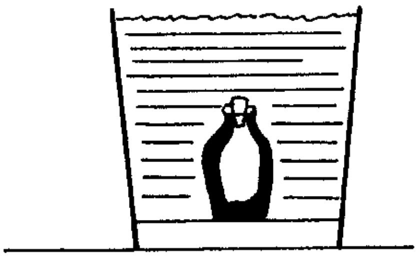
Buoyancy and Displacement

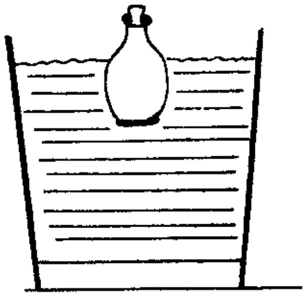




Any Child soon learns in his bath that some things float and some sink. The force which keeps an object afloat is called buoyancy, and it acts in opposition to the weight of the object. We are told that some time B.C., a Greek called Archimedes made an interesting discovery in his bath. What he had discovered was the basic principle that a body in water experiences an upthrust equal to the weight of water it displaces. We can see straight away that the important factor is not weight, but the relationship between weight and volume. A body with a heavy weight and small volume sinks like a stone, (i.e. it does not displace enough water to balance its own weight). A light body with a large volume floats high out of the water, (i.e. it does not sink far before it has displaced its own weight of water).

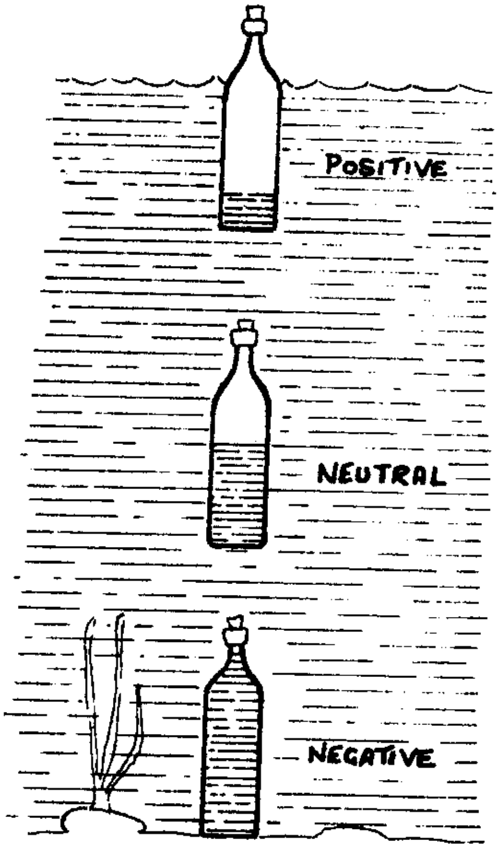






Some bodies find a balance between weight and upthrust just as they are totally submerged, or even below the surface. Such a body will definitely sink with a little added weight, or stay afloat with a little added upthrust.

A body which floats is said to have positive buoyancy. A body which sinks is said to have negative buoyancy. A body which remains completely immersed without either rising to the surface or sinking is said to have neutral buoyancy. This is what we must achieve in a submerged submarine. It is possible to alter the buoyancy of a body without changing its shape, (i.e. altering its volume). For a body floating in water, the easiest way to control buoyancy is to alter the weight by taking in water or pushing it out. As the weight of a given volume of sea water varies slightly with temperature, depth and salinity, maintaining neutral buoyancy needs constant weight adjustments.



Displacement

The size of a war ship is measured by the amount of water it displaces (displacement). We have seen that an object sinks until it displaces an equal weight of water, so that a displacement of 3000 tons means that the actual weight is 3000 tons. This will, of course, vary with the weight of fuel, stores, crew etc. on board. It is easy to see that a submarine has two displacements - one when floating normally on the surface, when the volume of water is displaced by about the lower 4/5 of the hull, the other when fully submerged. The submerged displacement is usually about 20% more than the surface displacement.

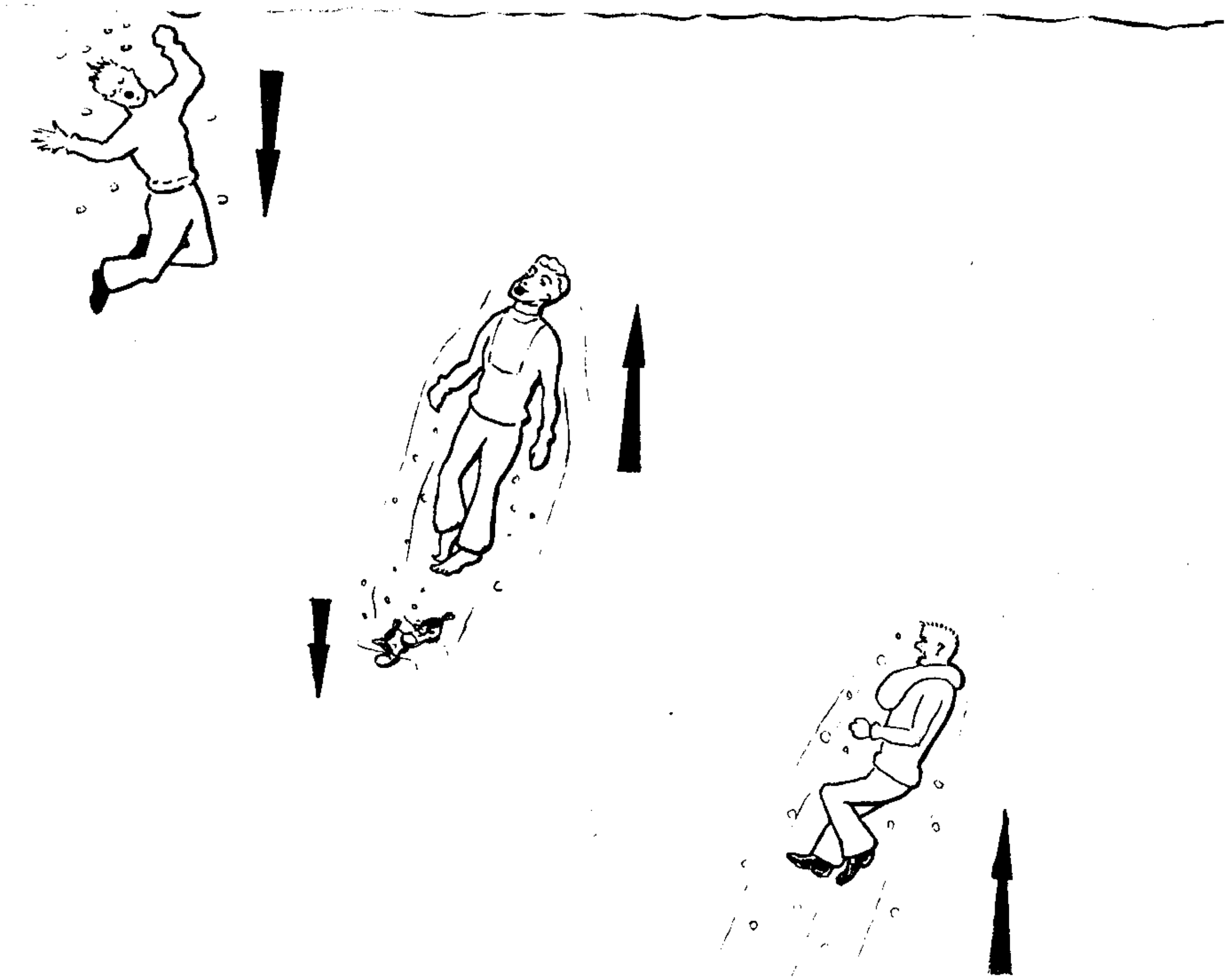
Example

A sailor wearing sea boots and a deflated life jacket falls overboard and sinks. His weight is greater than his displacement. He can save himself in two ways:

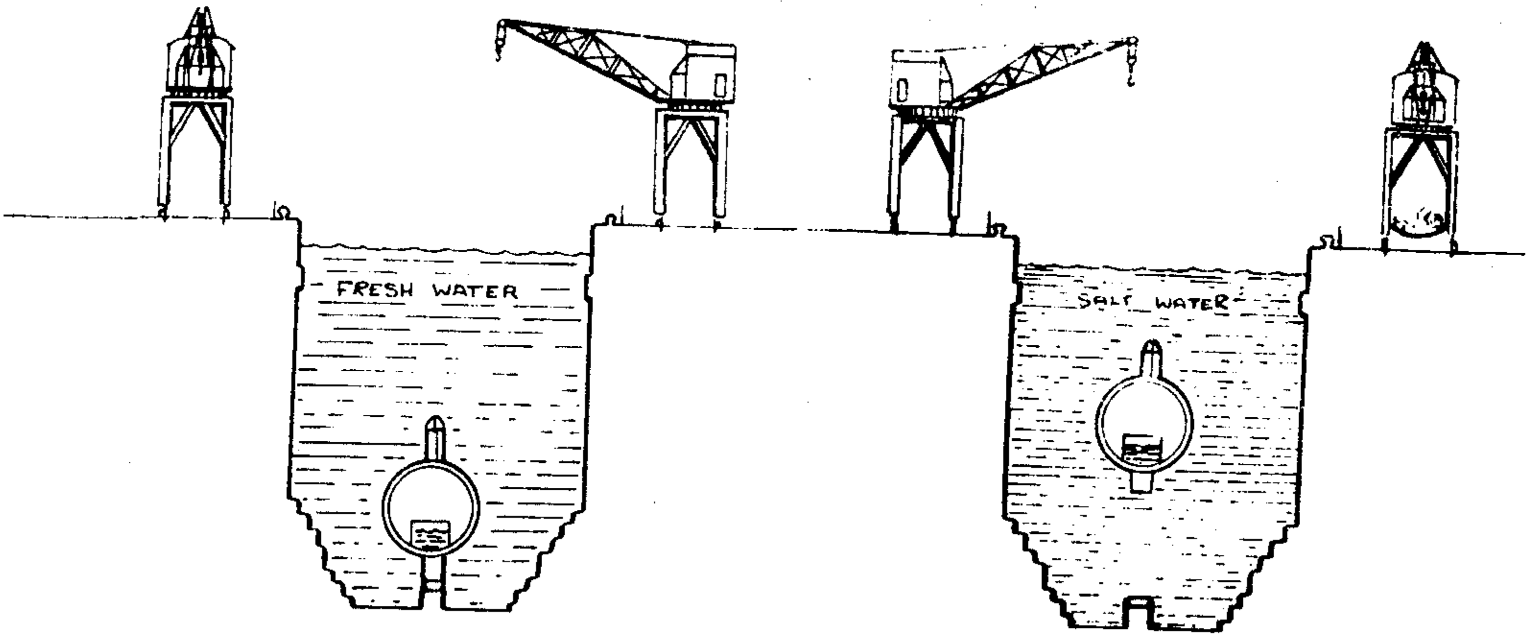
a. He can kick off his boots and reduce his weight, so that he can rise to the surface.

b. He can inflate his life jacket and increase his displacement, so that he again rises to the surface.

He can, of course do both things to come up more quickly.



Fred says: Always wear your life-jacket when working on the casing at sea.



Some More Complicated Factors Affecting Buoyancy

Variation in density of sea water

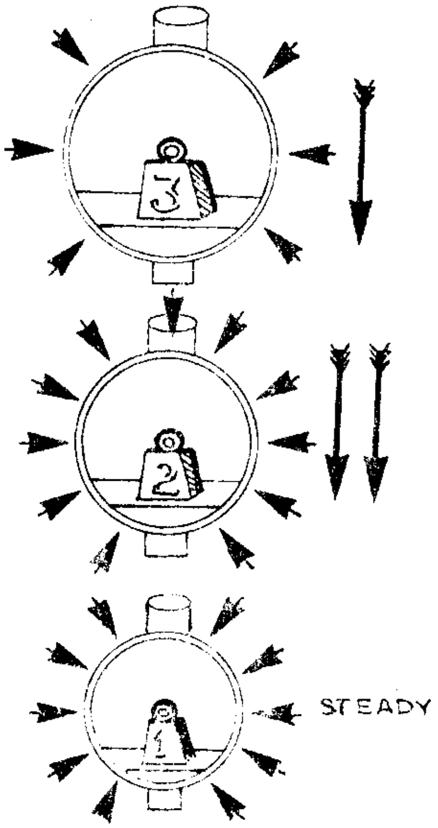
The weight of a given volume of sea water (density) is not constant. A gallon of sea water weighs about 10 lb. (A gallon of diesel fuel weighs about 8½ lb.) A cubic food of sea water weighs about 64 lb. (compared with 62 lb. for distilled water). The exact density depends on the amount of salts dissolved in the water (salinity), the temperature (warmer water is less dense) and to a slight degree on the depth.

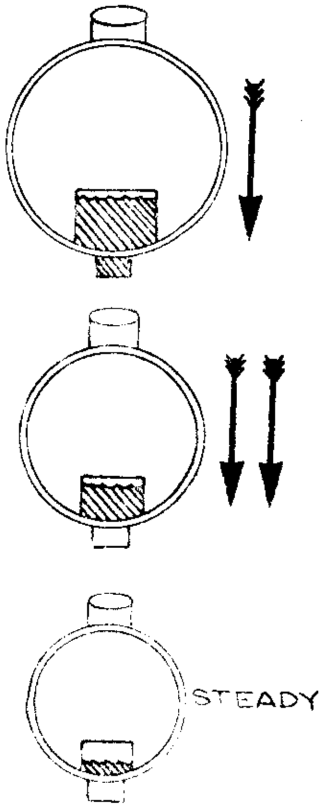
The density of sea water varies from place to place (e.g. low in the Baltic, high in the Mediterranean, low where large rivers run into the sea). Very simply, the "fresher" the salt water the less dense it is and the less weight it will support. A dived submarine running into a patch of "fresher" (less dense) water would become "heavy" or negatively buoyant and would have to be lightened if it was to retain neutral buoyancy. On the other hand, a submarine entering "saltier" (more dense) water would become "light" or positively buoyant and would have to be increased in weight to regain neutral buoyancy. Sometimes, if the change in density is great, drastic and quick action is required.

Compressibility

As the submarine goes deeper, the pressure increases and the hull contracts slightly, so that it displaces less water. This effect cannot be appreciated from inside the submarine, but the imperceptible decrease in volume has a very noticeable effect on buoyancy. As the hull displaces less water, its buoyancy decreases. As its weight is not altered, it will therefore sink.

Because of compressibility, a neutrally buoyant pressure hull will become more and more negatively buoyant as it goes deeper. Similarly, a neutral buoyancy obtained deep will become a positibe buoyancy on going shallow. Thus, changes in depth must be accompanied by changes in weight to offset the effects of compressibility. A little thought will show that this involves reducing weight when going deeper and adding weight when coming up. In one case it is necessary to prevent the submarine sinking deeper and deeper, and in the other to avoid breaking surface.

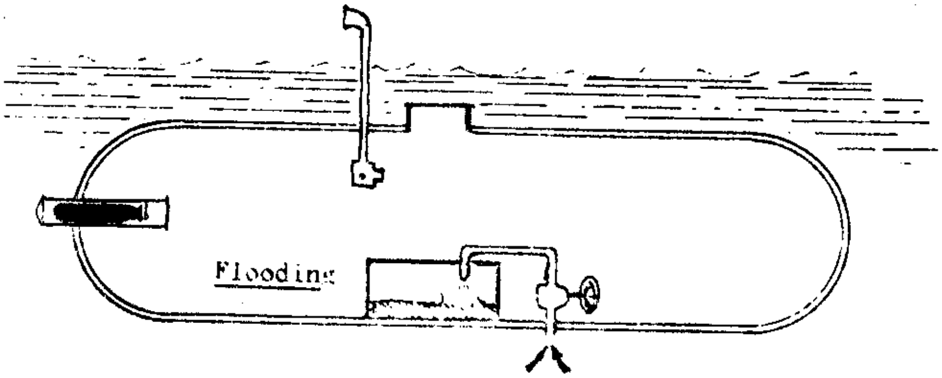


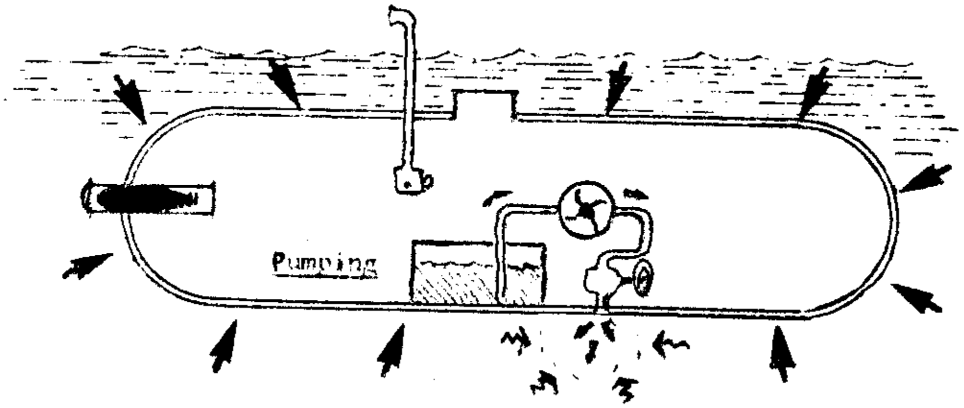


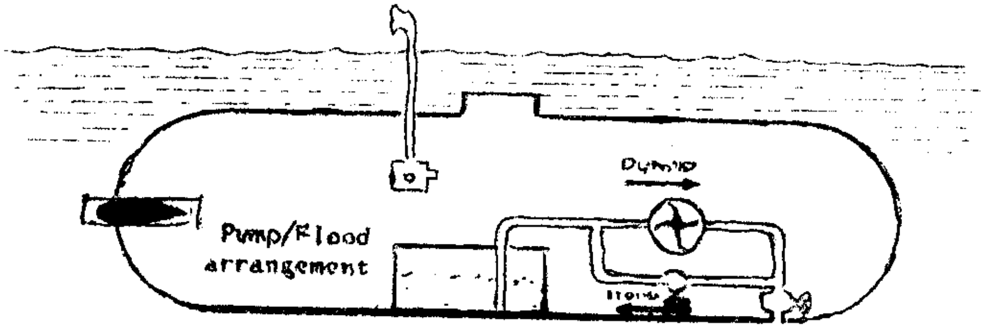
Stability

We have so far considered how the pressure hull can achieve neutral buoyancy. At this point it is balanced, with the upthrust just equal and opposite to the weight, but like many balancing acts, it is unstable. A small force in the wrong direction will cause it to take up a new, and probably very inconvenient position.

Any floating vessel, particularly cylindrical, has a tendency to roll. As the sea can impart regular impulses, the roll can soon become unpleasant or dangerous. As in most ships, the submarine obtains lateral stability by way of its construction. A heavy keel is fitted to the bottom of the hull, heavy equipment and machinery is placed as low in the hull as possible, and heavy weight high up is avoided. This makes the submarine stable.







Trimming

The process of trimming covers two functions. Firstly, the adjustment of bodily weight to achieve neutral buoyancy, and secondly the adjustment of fore and aft weight so that the submarine remains level.

a. Adjustment of bodily weight. This is done to compensate for changes in buoyancy and also to make the submarine as nearly as possible neutrally buoyant before going to sea. It is carried out by admitting water to tanks near the centre of the submarine, or by pumping water from these tanks to sea. There are known as compensating tanks. Getting water into the tanks is easily done by opening a hull valve and allowing the water to flood in through a pipe and valves to the tanks. Pumping it out again requires a powerful pump, but the same system and valves can be used.

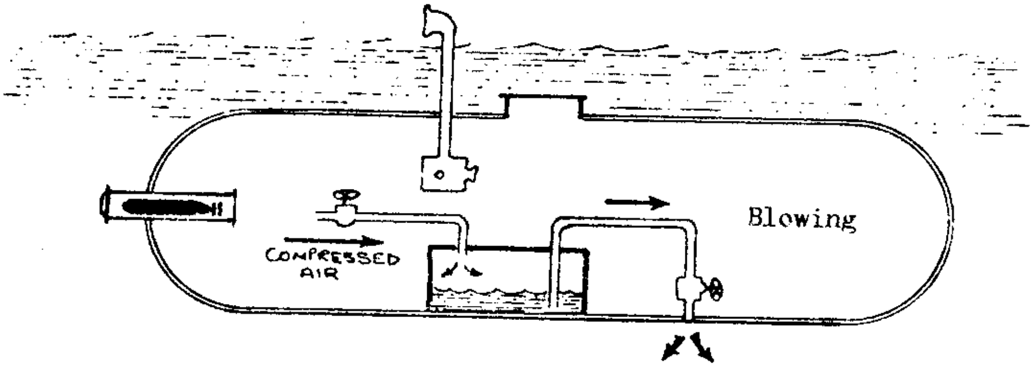
There are a number of important points to notice about this system:

(i) The pump must be able to force water out against the pressure of the sea, which can be very great at depth.

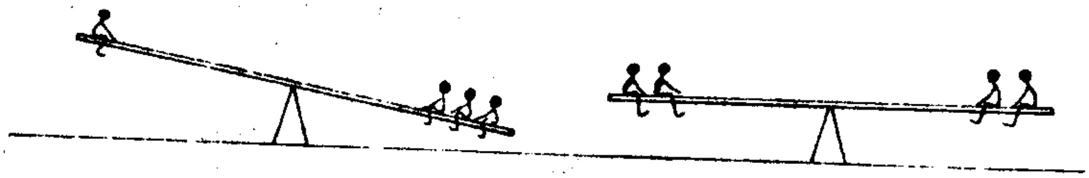
(ii) The pump must be capable of sucking water out of the tank.

(iii) The pipes must be led to the bottom of the tanks, so that all the water can be sucked out. The same pipe can be used for flooding and pumping. The same hull valve can be used for both purposes.

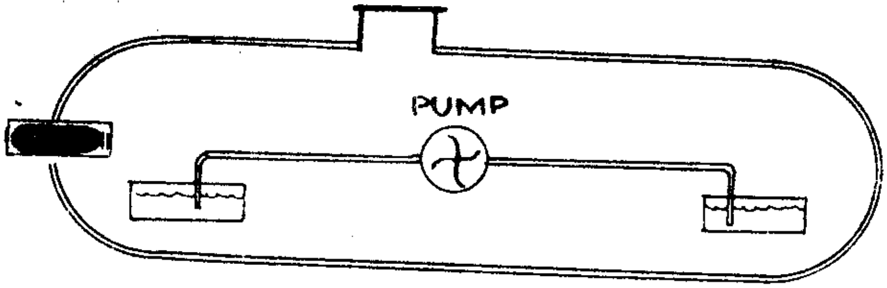
(iv) Another method of forcing water out of some tanks used in adjusting for trim, is by blowing HP air into the tops of the tanks. To do this the air pressure must be greater than sea pressure outside and the tanks tested to full diving depth. Some tanks can be blown or pumped and others only pumped.



b. Adjustment of Fore and Aft trim. If a weight is moved from the after end of a dived neutrally buoyant submarine to the for'd end, the bows will tilt downwards, and continue to do so until the weight is moved back again, and the balance restored. This is the second function of trimming.



One way to correct errors in fore and aft trim would be to move a compensating weight (for example, the crew) towards the high end. This of course is not convenient. The method used is to provide a tank at each end of the submarine, with a pipe connecting them, and a pump in the middle. These are known as Trim Tanks, and water can be transferred from one end to the other without pumping any out or flooding any in. The fore and aft trim, or trim angle can then be corrected without any change in the bodily weight of the submarine.



If the end tanks and an amidship tank are connected to the same pipes, pump and hull valve, we have a three tank system which is capable of performing both the functions of trimming.

c. Summary

Trimming is:

(i) The adjustment of bodily weight to give neutral buoyancy.

(ii) The adjustment of fore and aft trim to keep the submarine level. Bodily weight is normally adjusted by pumping out of or flooding into the amidships tanks. Fore and aft trim is normally adjusted by pumping water from for'd to aft or vice versa.

Putting on a Trim

The trim of a submarine needs frequent adjustment. Before leaving harbour, the Trimming Officer must calculate the likely effect of all the stores, fuel and armament which have been taken on. The effect depends on the actual weight and the position in the submarine. The larger the weight or the nearer the ends, the greater the effect. The amount of water in the trim and compensating tanks is adjusted accordingly. This process is known as "putting on a trim".

Catching a Trim

When the submarine dives, it is unlikely that the exact trim has been calculated, and adjustments to the trim are necessary. The nearer the calculated trim is to the actual trim the better, of course. The final process of adjustment by altering the amount of water in the tanks is called "catching a trim".

Thereafter, throughout the patrol, continuous changes must be made to allow for stores, water and fuel used, torpedoes fired etc., and water leaking in and collecting in the bilges. At the same time the effects of compressibility and changes in water density must be allowed for. Keeping the submarine correctly trimmed is an important part of the O.O.W.'s duties, for loss of trim at the wrong moment would be inconvenient or even dangerous.

The Basic Trim System

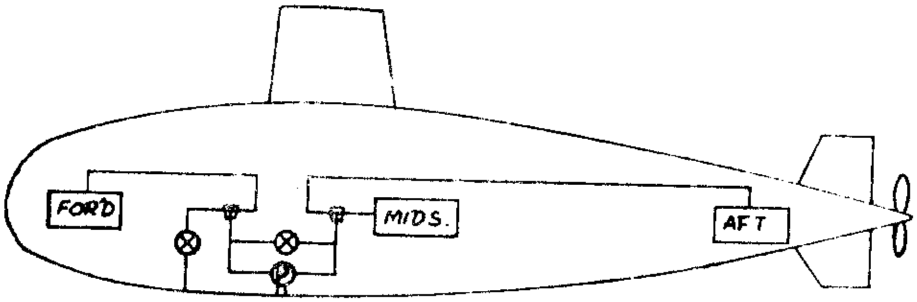
A diagram of the basic trim system is shown below. The Trimming Trainer shows how the system can do the following tasks:

a. Flood from sea

b. Blow to sea

c. Pump to sea

d. Pump forward to aft (or aft to forward by reversing the pump)



BASIC 3-TANK SYSTEM

Instrumentation

It is not possible to see from inside the submarine whether it is floating level or not, nor is it possible to see how much water is in the tanks. The following instruments are therefore fitted:

a. Trim angle indicators, which are in the simplest form spirit levels. These indicate both for-and-aft and athwartships trim.

b. Contents gauges, which show the quantity of water in the tanks (in gallons).

c. Flowmeters to show the quantity of water flooded in, pumped out or pumped from one end to the other.

Besides these instruments the Trimming Officer will use his experience ("feel") to make adjustments quickly and correctly (just as a motorist does not need to keep looking at his instrument panel).

Athwartships Trim

Small lists can be corrected by pumping water from a tank on one side and flooding water into a tank on the other. This problem is much simpler than that of maintaining for and aft trim, which you will see later has a considerable effect on controlling the motion of the submarine through the water.

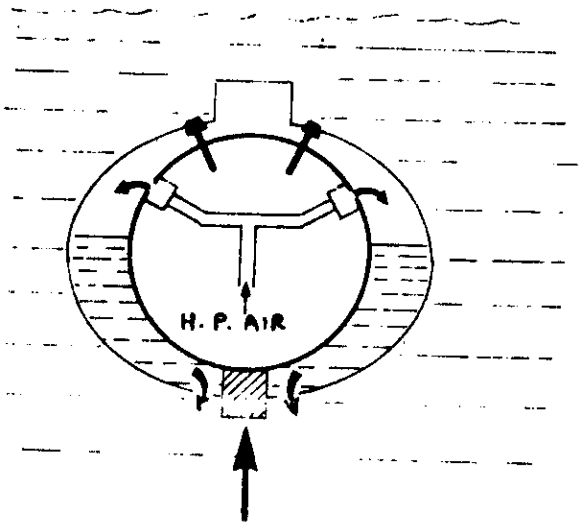
Ballast Tanks and Casing

So far we have reached a pressure hull which can achieve positive, negative or neutral buoyancy and be trimmed correctly. For a practical war vessel some means of obtaining large and rapid changes in buoyancy is needed for diving and surfacing.

This is done by fitting large tanks with provision for rapid filling and rapid emptying. There is no need for these tanks to be inside the pressure hull. They are normally left open to the sea at the bottom, so that internal and external sea pressures are equal. These tanks are known as main ballast tanks, and in addition they transform the pressure hull from an awkward cylinder to a streamlined shape for good underwater performance. As the tanks are outside the pressure hull, they increase the displacement. When they are full, the weight of water inside is equal to the weight of water they displace, so that there is no change in buoyancy. If the water is forced out, the submarine will have a large positive buoyancy and will rise quickly. Similarly, allowing the tanks to fill with water will enable the submarine to lose positive buoyancy and hence submerge quickly.

Let us now look at the practical arrangements. There is no need for the tanks to encircle the pressure hull - in fact this would be a disadvantage in many ways. They can thus be 'blisters' along the side. As there is a need for external fuel tanks as well, it is convenient to make the outer skin a continuous covering. This gives a streamlined shape and any spaces not required can be "Free Flooding", i.e. have holes top and bottom to allow free movement of water or air at all times. There are good reasons for having a number of separate ballast tanks, but the principle of each is the same, and we will examine the action in cross section.

When the submarine is dived, the comparatively light plating of the tanks is not crushed, as the free flood holes at the bottom remain open to the sea. The internal and external pressures are thus equal. If high pressure air is now admitted to the tope of the tanks, the water will be forced out through the free flood holes at the bottom and the submarine will have positive buoyancy and so rise.

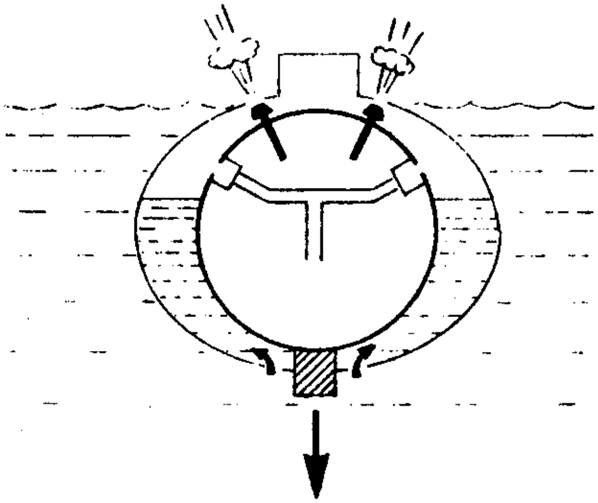


Blowing Main Ballast

Thus a high pressure air supply is needed. This must be stored in large bottles and carefully conserved, so that it is used only to achieve positive buoyancy. When the submarine breaks the surface, the conning tower hatch can be opened and a compressor (the blower) run to obtain low pressure air to continue blowing to full positive buoyancy. Each supply needs a hull valve to stop water entering the air system when the air pressure is off. There are also master valves to control the air supply to each pair of tanks.

One point to notice. Although the high pressure air supply is at several thousand psi, as soon as it enters the tanks it expands rapidly and hence the pressure drops to a few psi, so there is no need for the tanks to stand up to full HP air pressure.

A tank full of air gives positive buoyancy, but to enable the submarine to dive the water must re-enter. The top of the tank is fitted with a large valve which can be opened. The sea will then enter rapidly through the free flood holes and expel the air through the valve, known as a Main Vent. When dived, the Main Vent is shut again, so that the tanks can be blown for surfacing when required. It is obviously necessary to make sure that the Main Vents do not open accidently on the surface, or stay open when submerged. They are operated from inside the pressure hull by hydraulic pressure. When in harbour or at sea not ready for diving, large steel pins (cotters) are placed through the valve linkages to ensure that they cannot be opened accidently.



Flooding Main Ballast

Summary

For rapid submerging and surfacing, manipulating the trim tanks is inadequate. Tanks called Main Ballast tanks are fitted outside the pressure hull, and as they do not have to stand up to high pressure, they can be of light construction and used to streamline the shape. When the tanks are full, neutral buoyancy can be achieved as before. Using compressed air to blow out the water gives positive buoyancy and the submarine surfaces. To dive, the Main Vents are opened and the sea water enters through the free flood holes and expels the air. High pressure air is needed to force out the water quickly at depth to gain positive buoyancy. Full positive buoyancy can be regained by using a low pressure supply (the blower), thus conserving valuable HP air.

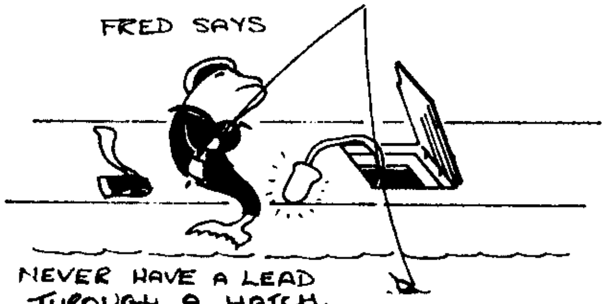
Fittings needed are free flood holes, Main Vents operated hydraulically from inside the pressure hull, and high pressure and low pressure air system hull valves. Note from the illustrations that the main ballast tanks are far from flimsy empty spaces, and must withstand bumping when the submarine is alongside.

Casing

The basic hull shape, i.e. a cylinder, as described earlier would not be very pleasant in a rough sea. Opening the hatch would be dangerous and it would not be easy to work on the upper deck. For these and other reasons the submarine is fitted with a free flooding casing and a fin. The conning tower has upper and lower hatches.

The casing provides a working deck when the submarine is on the surface and also streamlines and shelters pipes and equipment outside the pressure hull. The fin houses the structure necessary to support the periscope masts and also provides a bridge position. The submarine needs all the usual fittings of a surface ship -

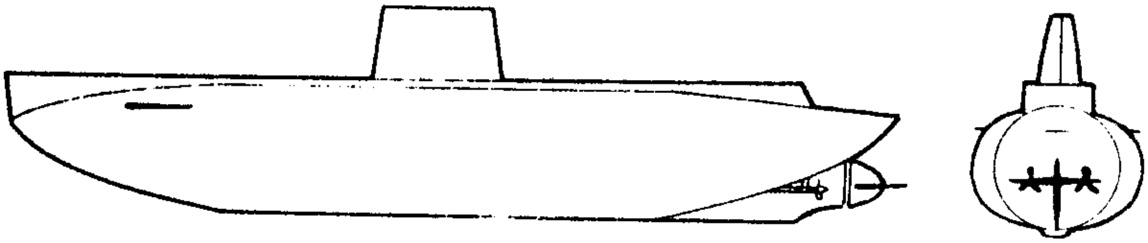
anchor, capstan, bollards, navigation lights, ensign staffs and so on. It is not intended to go into these here.



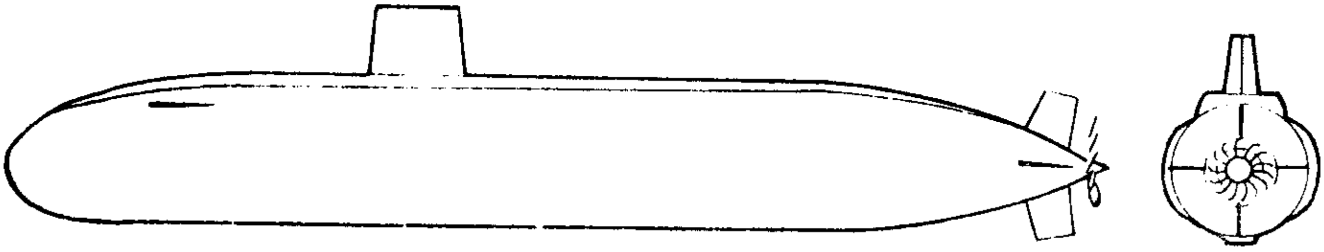
NEVER HAVE A LEAD THROUGH A HATCH.
IF YOU DO — YOU CAN'T SHUT IT!
IF IT'S ESSENTIAL, HAVE SOMETHING HANDY TO CUT IT WITH

Propulsion

Our submarine can now be surfaced, dived and trimmed, but has not yet got the means of going anywhere. A screw propeller of the normal type at the rear of the hull is used to propel the submarine. There may be two propellers with shafts and brackets protruding below the hull, or one large propeller right astern. The latter is used for nuclear-propelled submarines designed to have a high under-water speed.



The Conventional



The Nuclear

In "conventional" submarines, the propeller is driven by a shaft rotated by a large electric motor. The motor obtains its supply from a large storage battery (which even though enormous in comparison with a car battery can only be used for a limited time), or from a generator. The generator is driven by a diesel engine, which needs supplies of fuel and air.

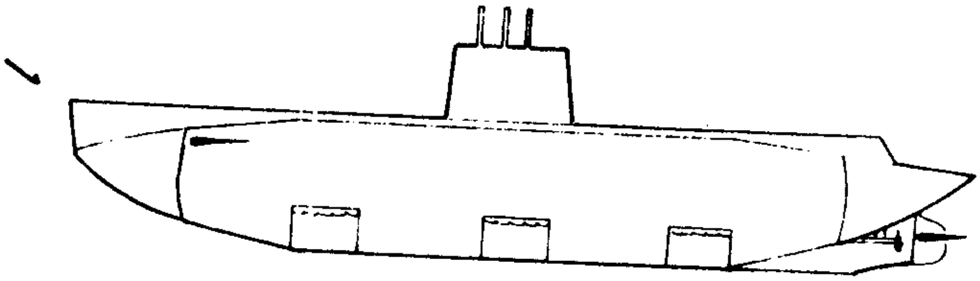
A Nuclear-powered submarine has steam turbines driven by reactor. The reactor is merely a way of heating water to get steam to turn the turbines, but has the great advantage of being completely free from reliance on an air supply, nor are fuel tanks necessary. The power obtained from a nuclear plant is much greater than that from a diesel generator, but the cost and complexity is also much greater.

Control

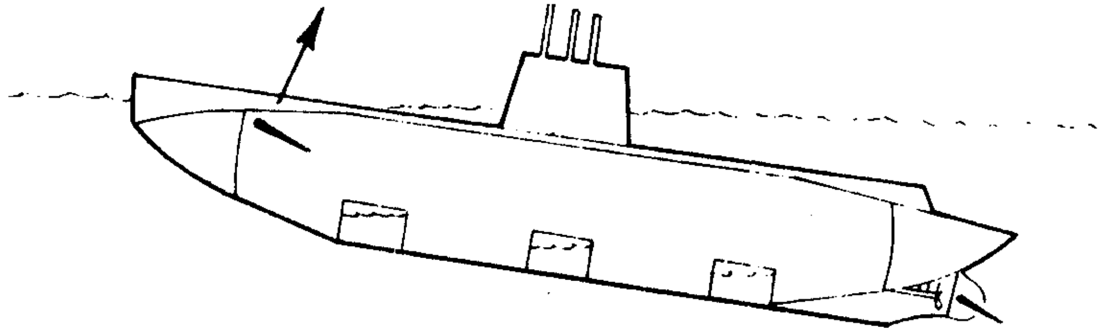
As soon as our submarine starts to move through the water, it must have a means of control. On the surface, only a vertical control is needed to keep it on a straight course, and the usual rudder suffices. This may be a balanced rudder, or in nuclear powered submarines a fin with a moving control surface.

When the submarine is dived, it must have horizontal control surfaces to assist in rising and diving, and to achieve rapid control response which could not be obtained by trimming. The horizontal control surfaces are known as hydroplanes and correspond to the aeroplane's elevators. There are two pairs of hydroplanes, one pair placed forward, usually high up on the hull, and one pair aft. Once again, there are differences between the shapes and exact arrangements in different types of submarine. The forward hydroplanes can usually be folded (or "turned in") to prevent damage alongside, the after ones do not need this because of the tapering hull.

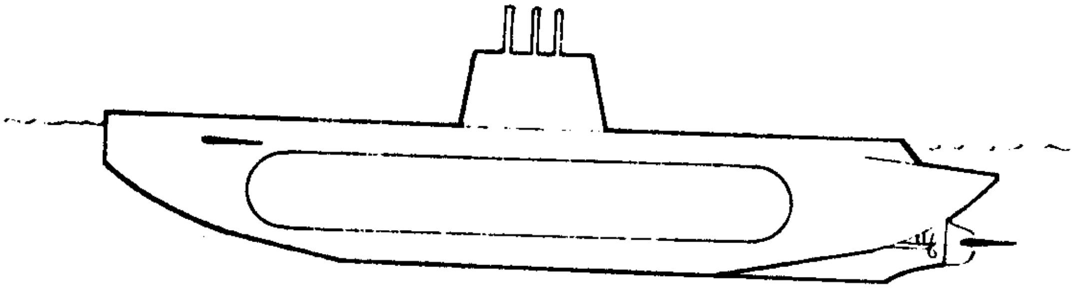
Like all control surfaces, the hydroplanes and rudder have no effect unless water is moving past them. The faster the submarine goes, the greater the effect of control surface movement, so that at higher speeds the forward hydroplanes need not be used, and movements of the after hydroplanes and rudder must not be too large or abrupt.



Submerged



Surfacing



Surfaced

It is more difficult to see that there is a complex relationship between the effects of buoyancy and control surface movement. To take a simple example, it is possible to control a submarine at high speed by the hydroplanes, and find on slowing down that control is lost because the submarine is too far out of trim. The officer on the trim and the planesmen must be aware of these effects.

The control surfaces are too large and heavy to be operated by hand. Normal movement is by hydraulic rams but emergency power is needed because of the vital nature of the control surfaces - it would not do to have the hydroplanes stuck at "hard to dive". Emergency power may be obtained from alternative hydraulic supplies, air supply or even hand pumps.

In older types of submarine, rudder, foreplanes and afterplanes were controlled separately, so that three men were needed. Considerable experience was necessary and careful co-ordination was the result of long practice. Modern submarines were a wheel mounted on a stick, similar to the control column in an aircraft. Rotating the wheel to left or right turns the submarine to port or starboard, whilst pushing the control column forward puts on dive and pulling it back puts the hydroplanes to rise. Greatly improved instrumentation reduces the skill needed by the operator, and an intelligent junior with a few hours practice can become a reasonably competent operator.

The helmsman and hydroplane operators cannot see where they are going, so that all control is by instruments. "Feel" is deceptive and is no longer a reliable guide.

Instrumentation

The following control instruments are in general use:

Instrument	Indicates
Compass	Course in degrees. The tape repeater is used for steering and is accurate to ±½ degree. The rate at which the tape moves past the lubber line is an indication of the speed of turn.
Depth gauge	Keel depth below the surface in feet. Because depth keeping at periscope depth is most important, a large scale instrument is used at shallow depths. This will indicate to ±½ foot, and once again the rate at which the pointer moves over the scale is an indication of the rate of dive or rise.
Rudder and hydroplane angle indicators	Show the actual angle put on the control surface. The effect of this will, of course depend on speed.
Trim angle indicator	Indicates the actual bow-up or bow down angle. The rate of rise or dive will depend on speed. The instrument is easier to interpret than the spirit level type.

Error Instruments

Modern control panels have instruments which show the difference between set course and depth and the actual course and depth. The scale is expanded, and the operator can keep the indicators centralised with considerable accuracy.

Modern instrumentation is easy to read, easy to follow, accurate and lag-free. Control is thus reduced from a complex skill achieved over a long period of time (like riding a bicycle along a high wire), to a simple pointer-following exercise, and whatever the old hands think, this is progress in the right direction.

More about propulsion

The plant used in a submarine must be as small as possible, i.e. have a high power/weight ratio. It must be as efficient as possible, so that the fuel and air requirements are no greater than they need be. It should also be as simple and reliable as possible. The normal methods of propulsion on the surface all require air in considerable volumes, and also a means of exhausting the products of combustion. When completely submerged, a submarine needs a propulsion system which is completely independent of connection with the atmosphere.

The possible methods are:

a. Storage batteries driving electric motors. This is also costly (A battery can cost over $600,000.00), but is silent and allows a fair combination of range and speed completely submerged.

b. Nuclear power. This is very costly, but is the only logical method of propulsion for a true submarine. There is a limit on the minimum size of plant, so that nuclear powered submarines are large. They cost about 8 times as much as a modern non-nuclear powered submarine.

Modern conventional submarines use method a. with the addition of a diesel engine and a generator. Thus we have:

The Diesel-Electric System

The diesel engine needs supplies of fuel and air; fuel is little problem, nearly 100,000 gallons is stowed in tanks and the air can be sucked in through a hatch when in harbour or at sea on the surface. (This causes a gale through the control room which may or may not be welcome.) When dived, the air must be drawn through a periscopic mast - the snorkel mast - (described later) but this can only be used to a depth of 60 ft. The diesel engine is permanently coupled to a generator, which by an arrangement of switches can supply power to various places:

a. All the generated power can be fed to charge the battery, which in principle is the same as a car battery, but has many more cells (224), giving a higher voltage (440 v) and capacity (7420 amp-hrs). However, this would mean that the submarine would have to be stopped - alright in harbour but not practical when snorkelling.

b. All the generated power is fed to the motors, thus giving a higher speed.

c. Any combination of the first two. Depending on the 'state' of the battery and the speed required, the Commanding Officer will decide how to split the power. If only one engine is available, it can still be used in any of these ways - though there will obviously be less power available for speed and/or charging.

The motors, which are the only means of turning the propellers, are DC and speed control is therefore easily obtained by varying the current supplied - be it from the batteries or generators. When dived and not snorkelling, the power must come from the batteries and there is thus the choice of a high speed for a limited time (15 knots for 1 hour) or a low speed for a long time (2 knots for 30 hours). (These figures are approximate and in any case dependent upon a fully charged battery.)

The Snorkel Mast

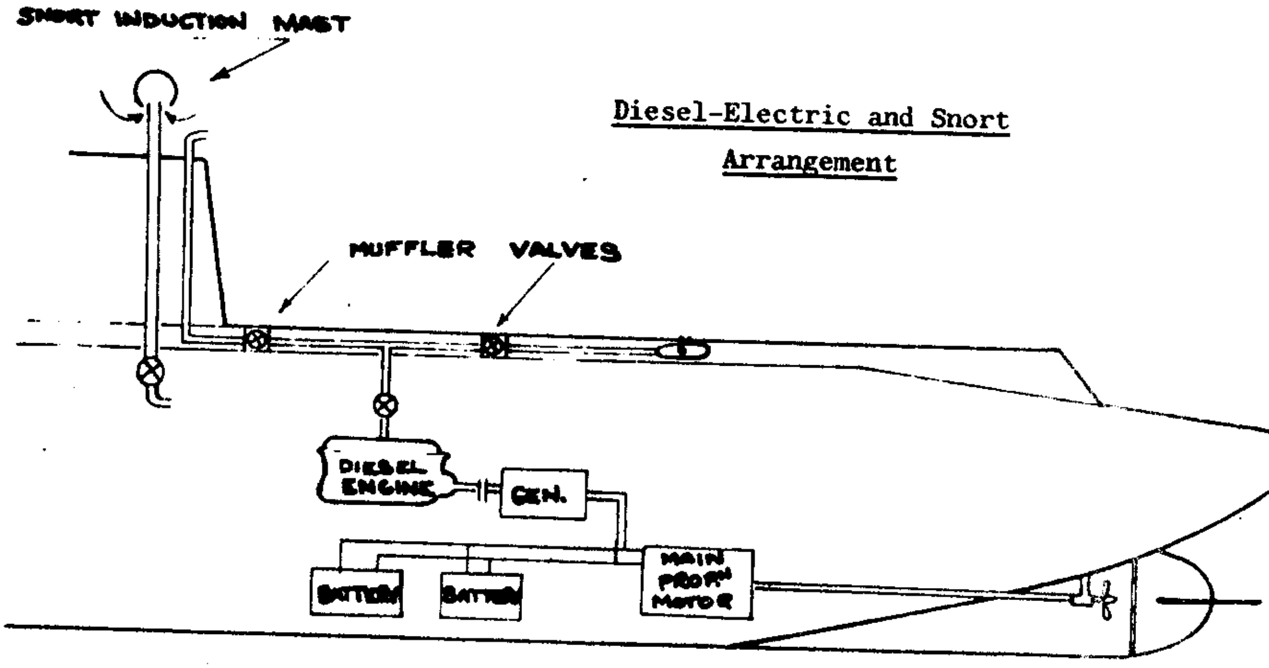
The snorkel mast is not unlike the swimmer's snorkel tube, but various precautions are needed: first, the outboard end of the mast must have some kind of float valve to seal it when temporarily 'dunked' by a wave. Second, diesel engines do not like even the small amounts of sea water which will get past the float valve (head valve), so the inboard end is led to a corner of the engine room away from the engines. Third, should the head valve stick open, a flap valve will shut off the intake thus preventing the submarine from being flooded.

Control of Propulsion

The O.O.W. in the control room or on the bridge, is in charge and will exercise control by orders such as:

"Generate both sides, 290 revolutions, float the load."

i.e. Propellers are turning at 290 rpm, and electrical output from the generators is sufficient to balance this and the remaining electrical requirements in the submarine, e.g. lighting, cooking etc.



Diesel-Electric and Snort Arrangement

The Captain issues his orders through the O.O.W. and all orders must be repeated clearly.

Control of the diesel engines is exercised at the control position at the forward end of the engine room. Here are grouped the necessary controls and instruments for starting, stopping and running the engines, and for control of important water inlet valves and snorkel valves.

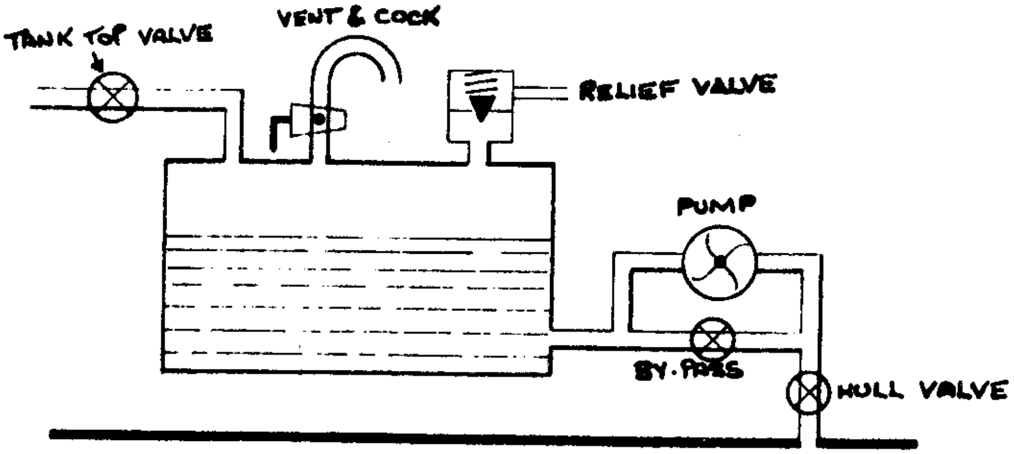
All electrical control is centralised at the main switchboard. Here the watchkeeper has the necessary controls and instrumentation to set on whatever conditions of propulsion or charging are ordered. Orders are passed over the intercom system, but because of the noise, visual order indicators are also used. Experienced Engine Room and Switchboard watchkeepers will usually know what to expect and be ready to carry out orders without delay.

Internal Tanks

Consider a completely enclosed tank connected to a water supply. When the supply valve is opened, water will rush into the tank, but as it fills up the pressure of the trapped air will rise until it equals the pressure of the water supply. No more water can then run into the tank(assuming air does not leak out or pass into the water supply system). If the water pressure is high and the tank light, the tank might buckle or even burst. To prevent this happening, a hole in the top of the tank will allow air to escape. This hole, known as a vent hole, is usually fitted with a pipe turned over at the end to prevent objects or dirt falling into the tank. The vent pipe may be fitted with a valve or cock so that it can be shut off.

With the vent valve open, the tank can be filled using even a low pressure supply. If however, the vent was left shut when the supply valve was opened, the tank might still be damaged. This can be avoided by fitting a safety valve to operate at a certain pressure. This relief valve protects the tank against excess pressure, and operates on exactly the same principle as the safety valve on a pressure cooker or boiler. In its simplest form it consists of a weight carrying plug which fits over a small hole in the lid. When the pressure rises to the level where the pressure on the area of the hole is greater than the weight of the plug, the valve will lift and release excess pressure. The operating pressure can be altered by adding or subtracting weight.

A more practical relief valve obtains its force from a spring - it can then be operative in any position, and can be adjusted to fairly accurate values by a screw. To meet the case where the pressure outside the tank may vary (i.e. sea pressure at various depths) a differential relief valve may be fitted and this will operate on the difference between external and internal pressures.



Valves and Cocks

Various types of fittings are required to control the flow of liquid in pipes. These fall into two main groups:

a. Valves These are similar to domestic taps, but considerably larger. They have handwheels which are turned clockwise to shut, anticlockwise to open, and the effort may be aided by a lever or wheel spanner. The shape of the wheel indicates to which system it is fitted.

b. Cocks These are simple devices which are shut when the handle is across the pipe, open when the handle is in line with the pipe. They can only be used in small bore piping, as they would otherwise be jammed shut by the pressure on them. They are commonly used in vent and drain pipes.

Filling and emptying Tanks

The rate (e.g. gallons per minute) at which a liquid flows through a pipe depends on the internal diameter of the pipe and the pressure difference between the ends. We considered earlier how a tank might be filled and that there are three possible methods of emptying:

a. Draining out through a pipe at the bottom of the tank.

b. Pumping out through a pipe at or near the bottom of the tank.

c. Blowing out through a pipe at or near the bottom.

Flooding

When flooding, the supply under pressure is obtained direct from the sea outside the submarine. The tank is then filled by allowing air to escape from the top of the tank and sea pressure forcing water in at the bottom to take its place.

Pumping

A tank may be emptied by pumping out, and the pump enables the tank to be emptied against a higher external pressure. At the same time the vent must be opened to allow air to enter and replace the water removed. Otherwise the pressure in the tank is reduced to a level where the external pressure might damage or collapse the tank. The only time water is pumped INTO a tank is from another tank and never direct from sea. (the pump pressure and sea pressure might be too much for the relief valves fitted)

Draining

The drain valve is opened and the liquid in the tank runs out. This will only continue if air is allowed in to replace the liquid, so that the vent valve must be opened. Draining is simple, but is slow. The tank cannot drain if the external pressure is higher than the internal pressure. It is therefore obvious that we never drain to sea.

Blowing

Compressed air is allowed to enter the top of the tank and forces the water out. The pressure can be much higher than the external pressure and so blowing may be much faster than pumping. The tank must be protected by a relief valve, but of course the vent must be shut or the compressed air will escape. When blowing is completed the valves are shut and the excess pressure in the tank released by opening the vent.

Drain, Pump or Blow?

There is no best buy. Factors to be considered are:

a. Mechanical simplicity

b. Where the liquid is going and what pressure must be overcome.

c. Speed of flow required.

d. Need to avoid noise.

e. Need to conserve high pressure air.

The Main Line and Ballast Pump

The main line is a larger bore pipe than the trim line, and is used for moving water into and out of tanks (it can also be cross-connected to the trim line.) It also provides a sea water supply for hosing down, fire fighting and so on. It can be used to pump out some of the non oily bilges. Pumping is carried out by the ballast pump. As this can run in one direction only, it is connected to the main line through a valve chest which directs the flow of water. The main line will not be dealt with in any detail here, as it does not embody any principles which have not already been dealt with. Nevertheless it is an important system and when you deal with a specific submarine system you will find that there is much more detail involved than with the trim system.

Measurement of Tank Contents

It is often necessary to know the content of a tank at any time. This can be found in various ways:

a. Gauge Glass A glass or clear plastic tube connected to the top and bottom of the tank, so that the actual level can be seen. Although simple and reliable, gauge glasses may be broken, are incorrect if the tank is tilted, and are no use if the tank is not accessible.

b. Dip Rods Like the device for checking oil level in a car sump, they are graduated rods pushed into the tank and with-drawn so that the mark made by the liquid can be checked. They are simple and reliable provided they are used only for the tank for which they were graduated. They are no use for tanks under pressure or in inaccessible places, or where frequent or continuous readings are required.

c. Electrical Contents Gauges

   (i) Smiths Gauges A float on an arm moves up and down with the liquid level, which is converted into an electrical value which can be read directly. One meter may be switched to several tanks, but each tank must have its own float arm. Does not read accurately when the tank is not level, and may be completely wrong if the float sinks, the arm jams or the electrical circuits go wrong.

   (ii) Pacetor Gauges The measuring unit in the tank consists of two concentric vertical tubes, the electrical resistance depending on how much of the space between the tubes is filled with water. In salt water these gauges tend to become inaccurate due to the formation of salt in the tank unit.

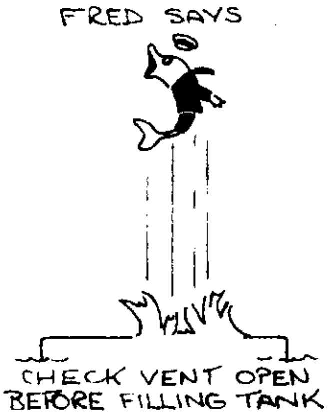
Electrical gauges have the great advantage that the meters can be grouped in a central position - in fact, where they are most convenient.

Fresh water, Sea water, Fuel, Hydraulic Fluid etc.

On the whole these principles of tanks, pipes, pumps, gauges and blowing apply whatever the liquid. In practice, while a little sea water slopping around may be acceptable, this does not apply to valuable, inflamable or toxic liquids. The practical arrangements may, therefore be considerably more complex, and operation may be more difficult than filling or emptying the bath.

Summary

Tanks may be filled using a pump, or in the case of sea water, by flooding. Vent pipes and valves (or cocks) are necessary, and for blowing, relief valves are essential to avoid the possibility of damage. Rate of flow of liquids depends on pipe bore and pressure applied. The method used for a particular purpose depends on various factors including speed, noise and expenditure of HP air supplies. Tank contents may be measured by gauge glass, dip rod or electrical indicator.



Some other Systems

Storage tanks, pipes for distribution, pumps, valves for control and shore filling connections are required for other systems. They will not be considered in any detail here, as they do not involve any new principles and are either non-vital or concern only specialist ratings.

Fresh Water	Several tanks holding about 10,000 gallons of fresh water for domestic use. Tanks connected to a main which supplies sinks, wash bowls etc. The tanks are under pressure from reduced HP air.
Distilled Water	Supplies for topping up the battery and filling the battery and engine cooling systems. The output of the distillers goes to the distilled or fresh water tanks.

Oil Fuel	A considerable volume of oil fuel is carried in a patrol submarine. The main storage tanks are outside the pressure hull, and have the same outer shape as the main ballast tanks. It is necessary to equalise the pressure in the external tanks to avoid crushing, to replace oil fuel as it is used by sea water, and to be able to prevent tell tale leaks by keeping the pressure slightly below the sea pressure when required.
Lubricating Oil	Provision of adequate supplies of lubricating oil for the diesel engines and other machinery.

Ventilation

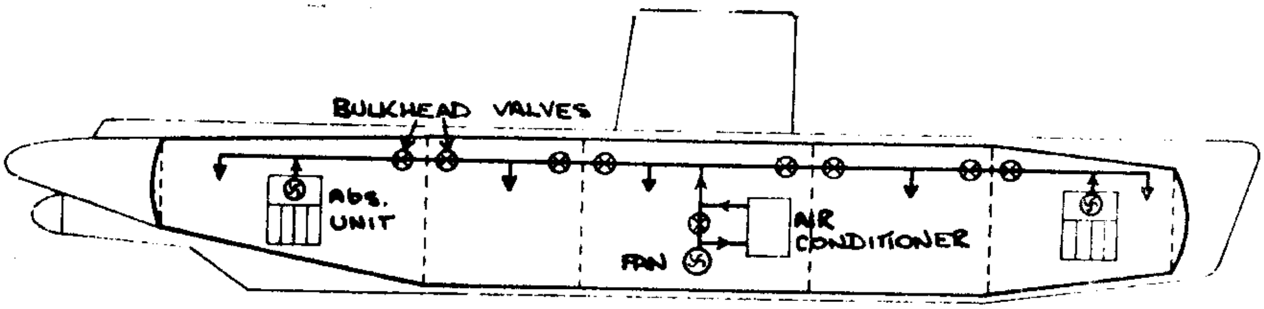
The usual ship type ventilation system of fans, trunking and louvres is used. The supply cannot be obtained from outside, so that various measures are necessary to keep the air breathable. Amongst these are:

a. Removal of explosive hydrogen from battery compartments - blown outboard in harbour or burned inboard at sea.

b. Removal of dangerous carbon monoxide by burning.

c. Provision of extra oxygen by burning oxygen candles.

d. Removal of excess carbon di-oxide by chemical absorption units.



Basic Ventilation System

In a nuclear powered submarine, which can remain dived for long periods, special provision for atmosphere control is essential. Patrol submarines, which have to surface or snorkel for battery charging at relatively frequent intervals require only arrangements that will last for a limited time. In submarines the ventilation supply is fully air-conditioned, a factor which is even more important for the correct working of some equipment than for the crew.

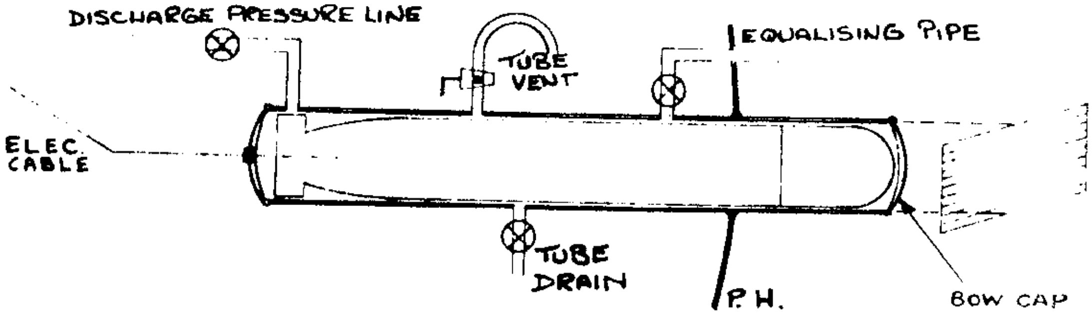
Discharge Systems

While the submarine is submerged it must be able to fire its weapons. It must also be able to discharge signal flares. With the advantage of being able to choose a convenient time it is necessary to be able to get rid of gash, sewage and bilge water. All these involve getting material from inside the pressure hull to the sea without letting water in and without betraying the submarine's position by bubbles or floating traces. Liquids are easily dealt with. They can be collected in tanks, and then pumped or blown to sea as necessary. This normally done at night if possible. There is nothing unusual about the tanks, pipes and valves of these disposal systems. Solid objects are more difficult. They require much larger holes in the pressure hull, and weapons must be available to fire at any time.

Torpedo Tubes

These are horizontal tubes into which the torpedo fits. At one end is the bow cap which is normally kept shut (it is called the stern cap for tubes fitted aft). At the other is the rear door, which can be opened to load the torpedo from the torpedo space, or to withdraw it for maintenance or replacement. This will also be kept shut unless there is a definite need for it to be open. A tally is used to indicate the state of the tube, i.e. loaded or not, dry or flooded. The tube is normally dry.

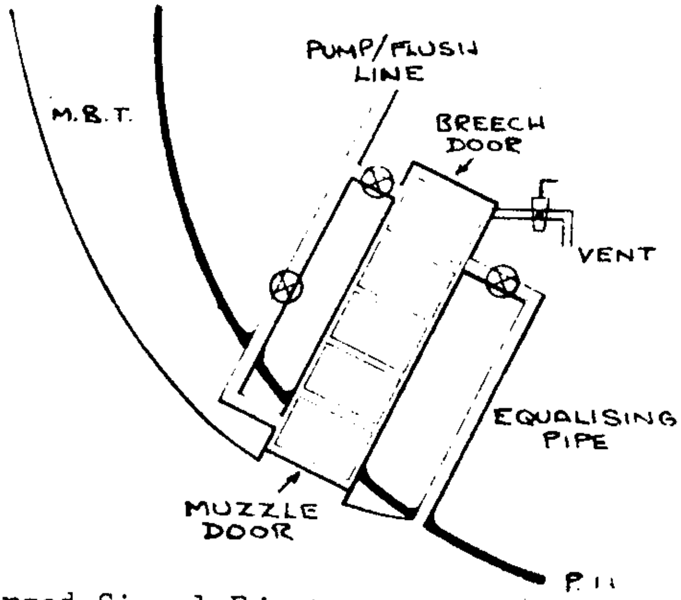
To fire a torpedo the tube is flooded. The bow/stern cap is then opened (this cannot be done unless the pressure in the tube is roughly equal to the sea pressure outside, and valves are fitted to enable this to be done). The torpedo is discharged by being pushed out of the tube of air or water pressure, although some types can swim out. After discharge the bow/stern cap is then shut an the tube drained down. It would obviously be disasterous if the rear door were open at the same time as the bow cap. To prevent this a mechanical interlock makes it impossible to open one door when the other is open. As an added precaution a small hole can be opened in the rear door and checked unobstructed by poking in a reamer - a jet of water indicates that the tube is flooded.



Garbage Ejectors

Garbage is collected into bags which are soaked in the ejector tube to ensure that they will sink. This avoids a tell-tale trail of floating gash on the surface. Cans are squashed.

When the ejector is clear of water the breech door is opened. The gash bags are inserted, and the breech door is shut. The ejector barrel is flooded from sea and pressure equalised. The muzzle door is then opened and gash bags are flushed out with water pumped from the Main Line. On completion of flushing the muzzle door is shut, water is pumped from the ejector barrel and the cycle can be commenced again.

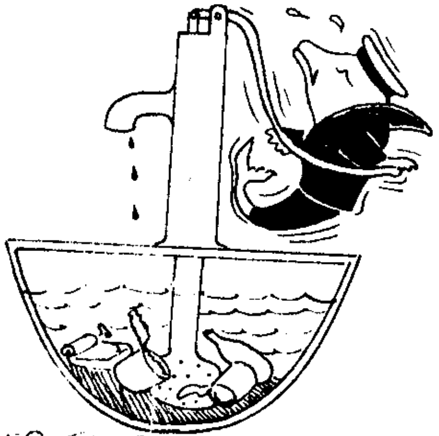


GARBAGE EJECTOR

Submerged Signal Ejectors

These are also vertical tubes, this time leading out of the upper side of the pressure hull. Smoke candles and coloured flares for signal purposes are loaded from below. To discharge the signal (or message container) the tube is flooded, and the pressure equalised, the upper door opened, the cannister ejected by air pressure and the upper door shut. Once again interlocks make sure that both doors cannot be opened together, (a 6 inch hole at 500 feet lets in water at the rate of 280 gallons per second).

FRED SAYS



KEEP THE BILGES CLEAR OF GASH -- IT CHOKES PUMP SUCTION STRAINERS

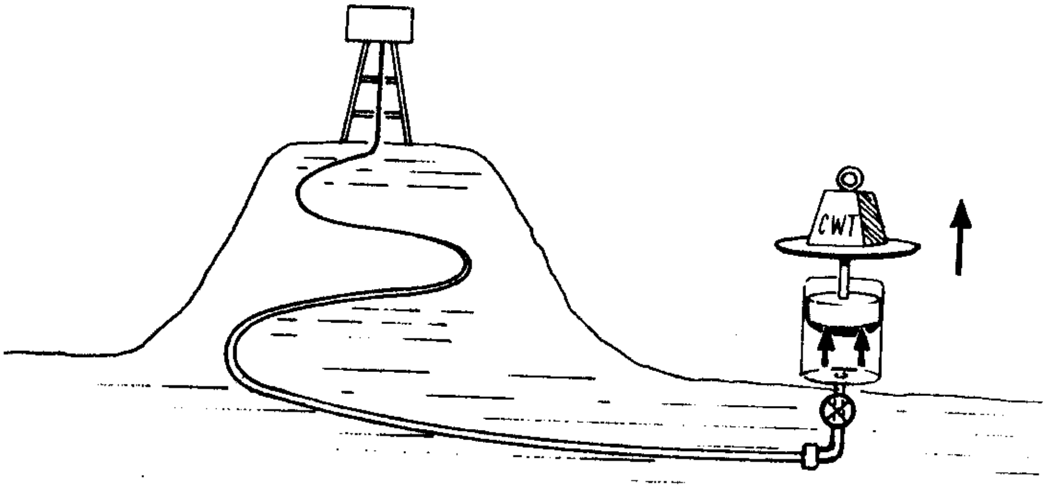
FRED SAYS

DONT WASTE FRESH WATER

Hydraulic Systems

Hydraulic systems, as a means of transmitting power are familiar in daily life. Cars have hydraulically operated brakes, garages use hydraulic jacks and lifts, and the shovels of mechanical diggers and bulldozers are hydraulically operated.

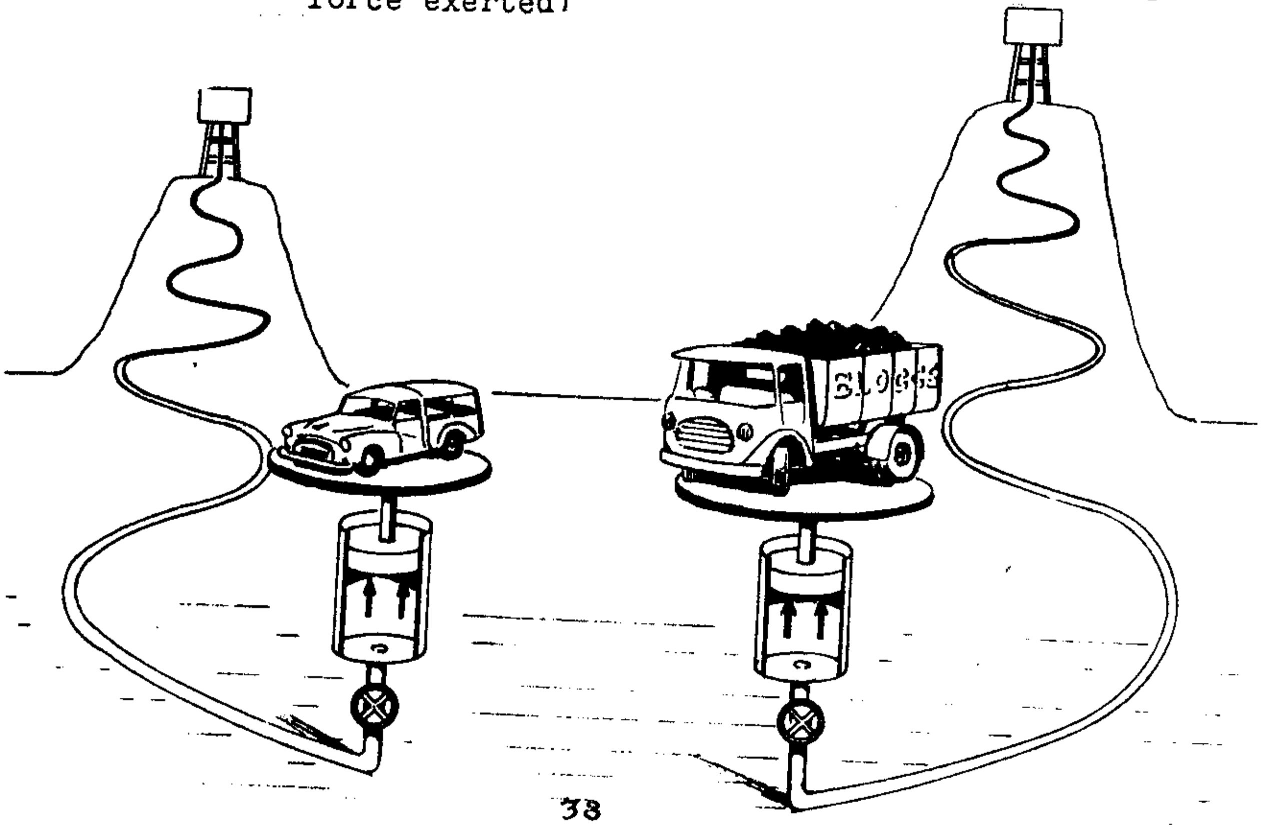
We have seen that water pressure increases with depth. Similarly, a water tower on top of a hill will give a good head of pressure at the bottom of the hill, and this pressure could be used to raise a piston in a cylinder.

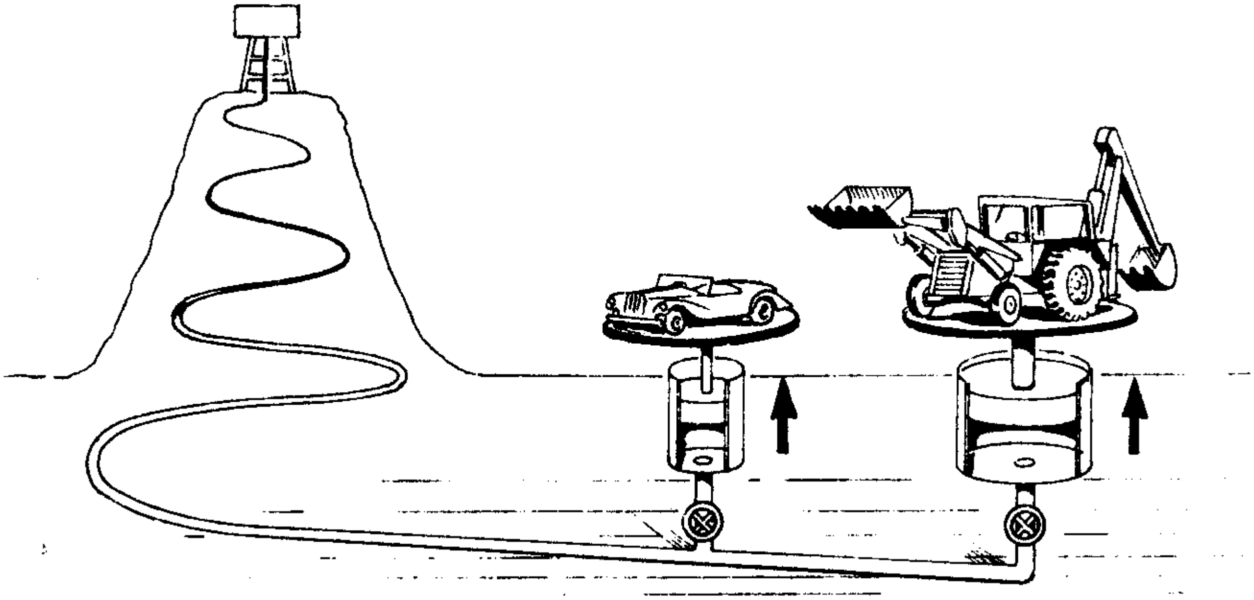


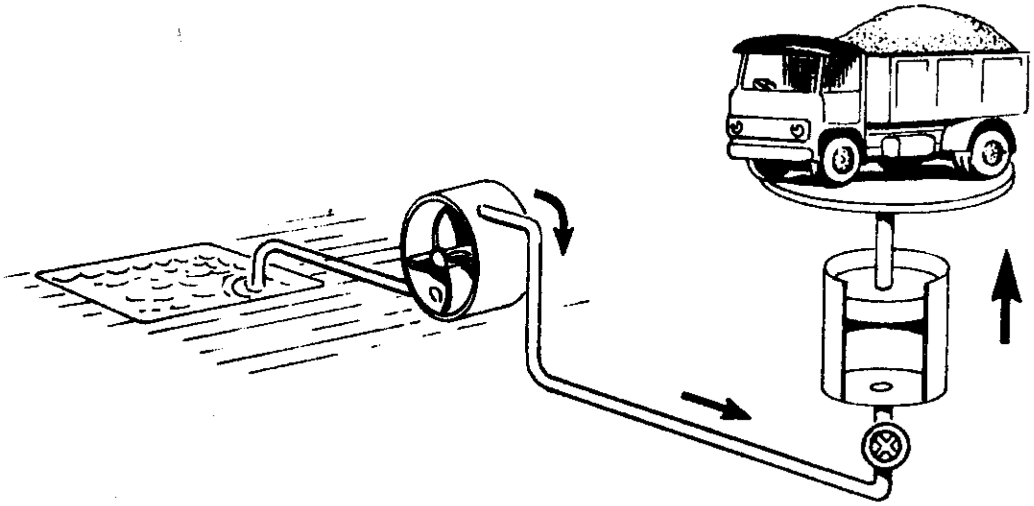
The amount of work the piston can to depends on two things:

a. Water pressure beneath piston (determined by height of tower).

b. Area of piston (the larger the area, the larger the force exerted)







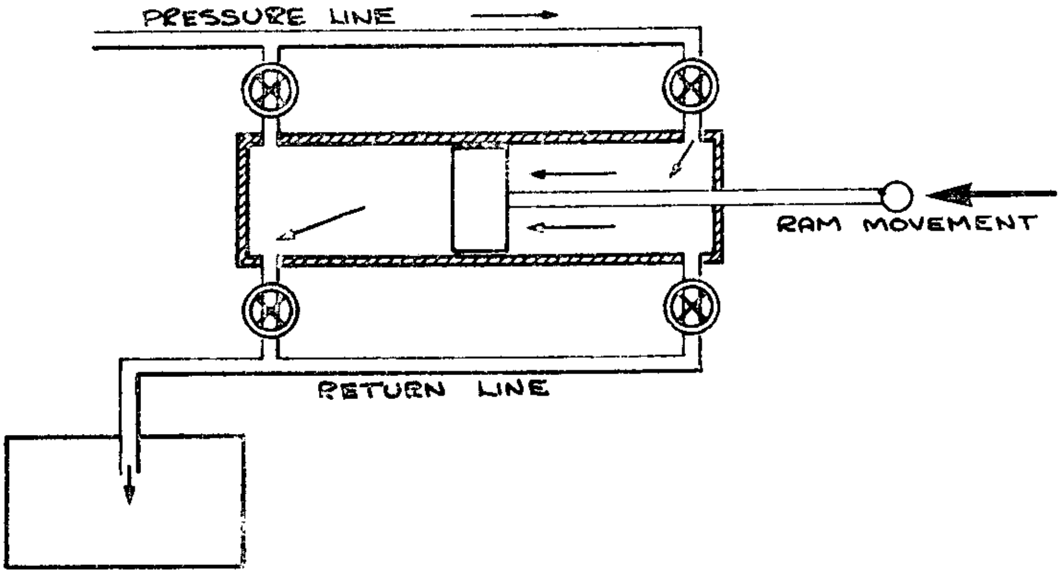
Instead of a high tower, a pump may be used to provide the required pressure. In a submarine hydraulic system, a pump takes the place of the tower and a special mineral oil is used instead of water, since it prevents corrosion and is self-lubricating. The system is operated at high pressure so that piston area can be reduced.

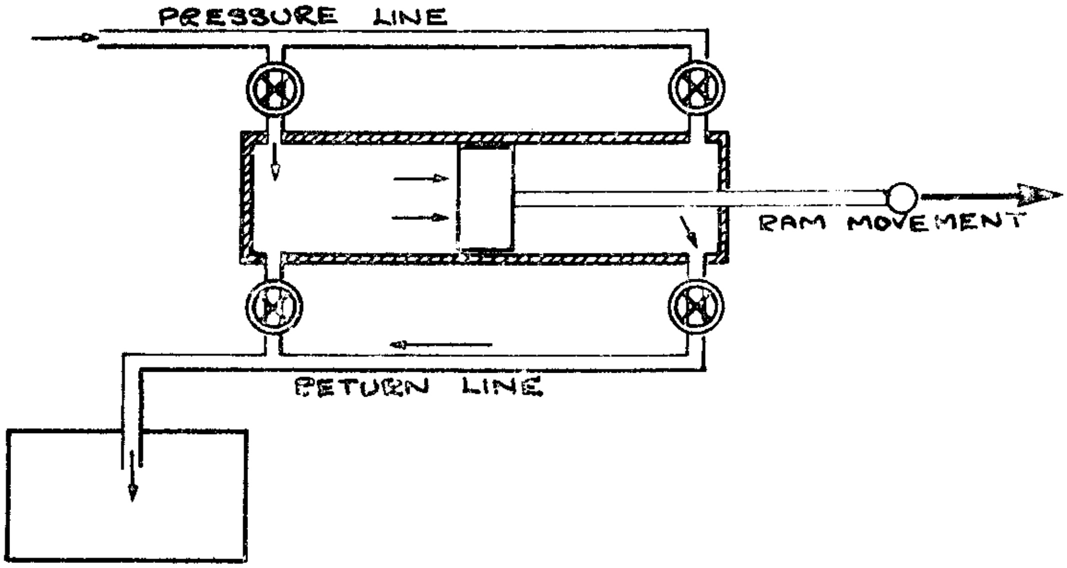
Hydraulic power is the best choice for the heaviest and most vital tasks such as moving the rudder and hydroplanes, operating the main vents and raising periscopes and masts. It is powerful, silent and reliable. The principle of operation of these items is that they are connected by rods to pistons which move in cylinders. The bigger the piston the more powerful it is. By admitting oil under pressure to one end of the cylinder or the other, the piston can be made to move in the required direction.

The Pressure and Return lines

As there are many hydraulically operated devices in a submarine, it is convenient to run a supply pipe (known as the pressure line) along the length of the submarine.

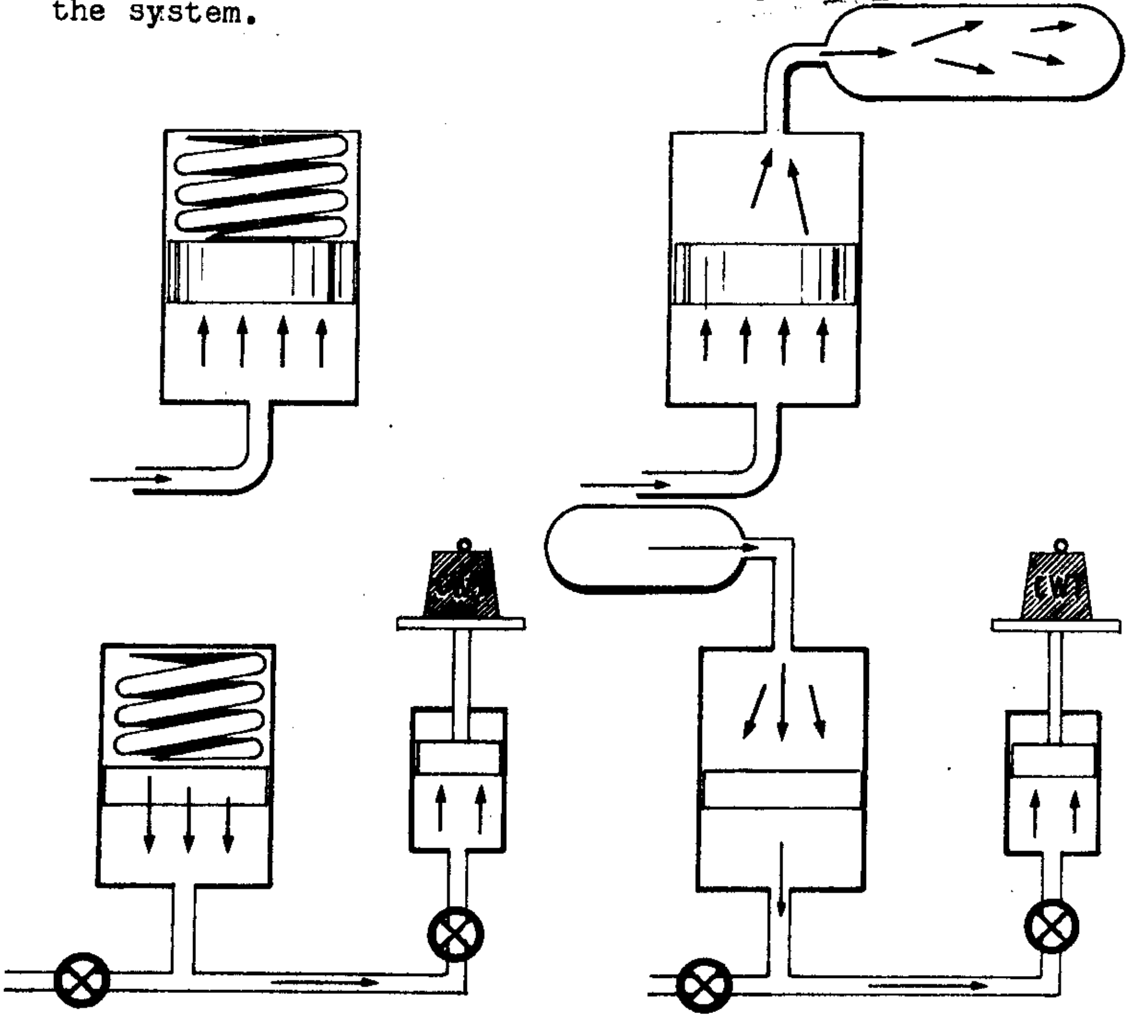
If oil under pressure is admitted to one side of a piston in a cylinder, the oil on the other side of the piston must be allowed to escape from the cylinder, otherwise since liquids cannot be compressed, the piston cannot move. This escaping oil, which is not under pressure, is collected in another pipe running the length of the submarine, called the return line, which returns it to a tank.





The Pump and Accumulator

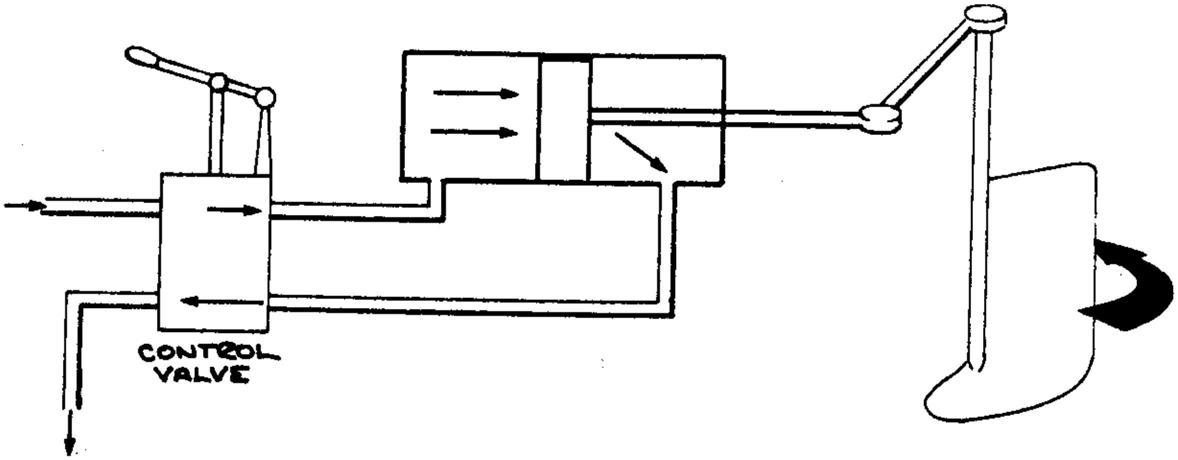
To maintain a supply of oil under pressure in the pressure line, a pump and pressure reservoir called an accumulator are provided. The pressure reservoir is a large cylinder with oil at the bottom and compressed air at the top. The oil and air are separated by a piston which is pushed upwards by oil from the pump and which moves downwards when oil is taken from the pressure line to operate hydraulic equipment. A spring on top of the piston would do just as well as the compressed air but for larger accumulators air is more convenient. The accumulators are used to provide a store o oil under pressure, and to prevent rapid fluctuations of pressure in the system.

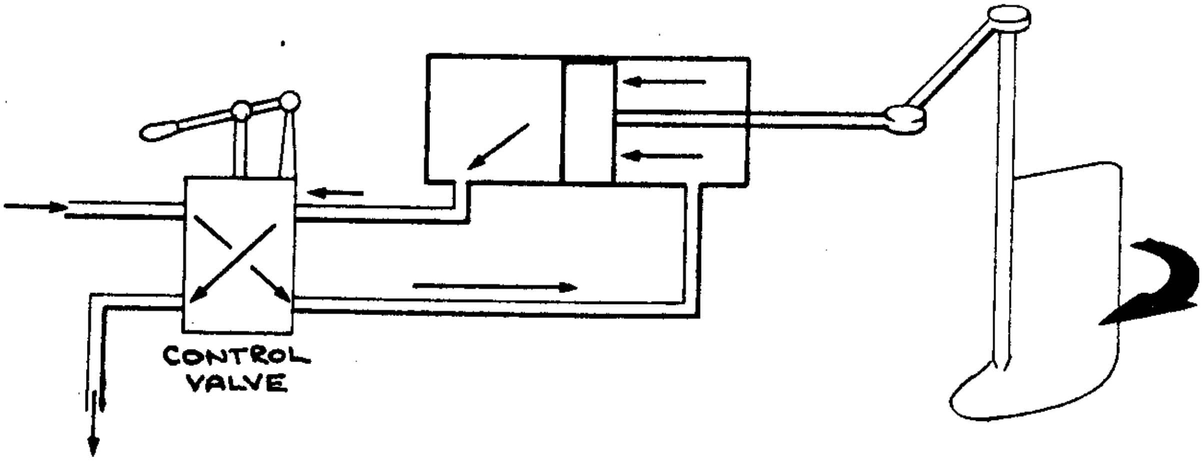


They are connected to the pressure line and there are also small spring loaded accumulators, but these will be described later. If the pump is made to suck oil from the tank, this completes the circuit from tank to pump, pump to accumulator, accumulator via the pressure line to the hydraulic cylinders, cylinders to return line, and return line back to the tank. The pump is started when the accumulator is nearly empty, indicated by falling pressure in the system. As the pump is electrically driven, the starting and stopping can be automatically controlled by pressure switches. Typical working pressure is 2,500 psi.

Control of Hydraulic Power

Control of the movements of the various pistons could be arranged by opening and shutting valves between the pressure line and the cylinders and between the cylinders and the return line each time we wanted to move them, but it is simpler to use a single control valve operated by a handwheel or lever. This is so arranged that when it is pushed in one direction, oil under pressure is admitted to one end of the cylinder and spent oil is exhausted from the other end to the return line. When the valve is returned to its middle position, both ends of the cylinder are shut off, and when it is pushed in the opposite direction, the reverse happens and the piston moves the other way.



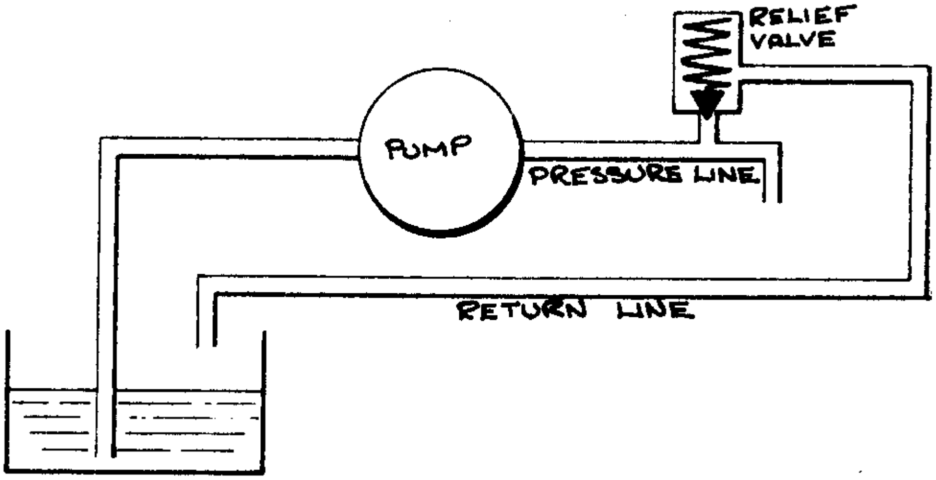


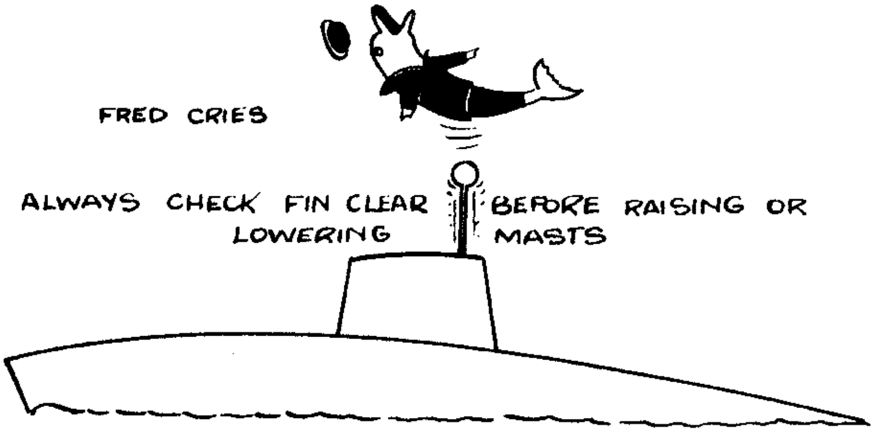
There is no need for the control valve to be situated near to the equipment it is controlling, so it can be placed almost anywhere in the submarine, and remote control of equipment is a simple matter. For example, the piston which moves the rudder is operated by a control valve in the control room.

Some remotely controlled equipment has an electrically operated control valve, in which a small pilot valve is opened or shut electrically and takes the place of the handwheel or lever.

Relief Valves

To prevent damage to the system, relief valves are fitted which allow fluid to flow direct from the pressure line to the return line. These are fitted near the pump and set to operate at an upper limit. To enable equipment to be worked on, it must be possible to shut off the supply and then relieve the pressure before breaking the pressure line or opening equipment.

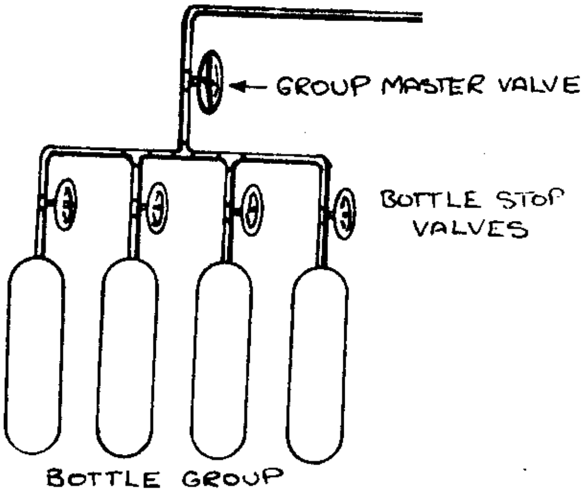


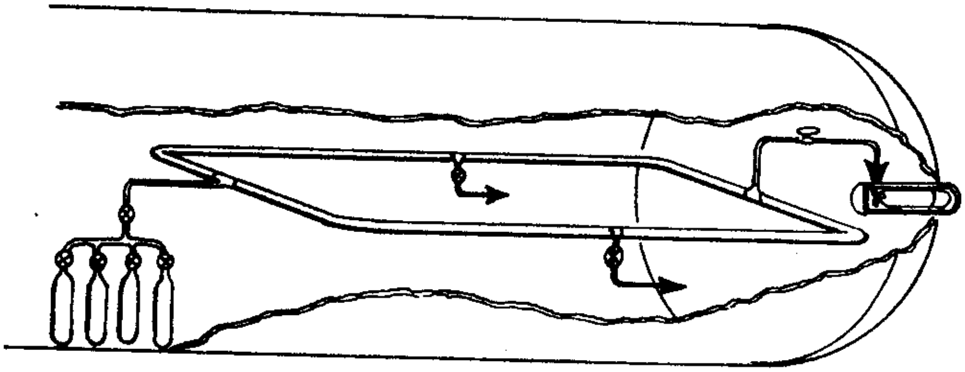


Compressed Air Systems

High Pressure Air

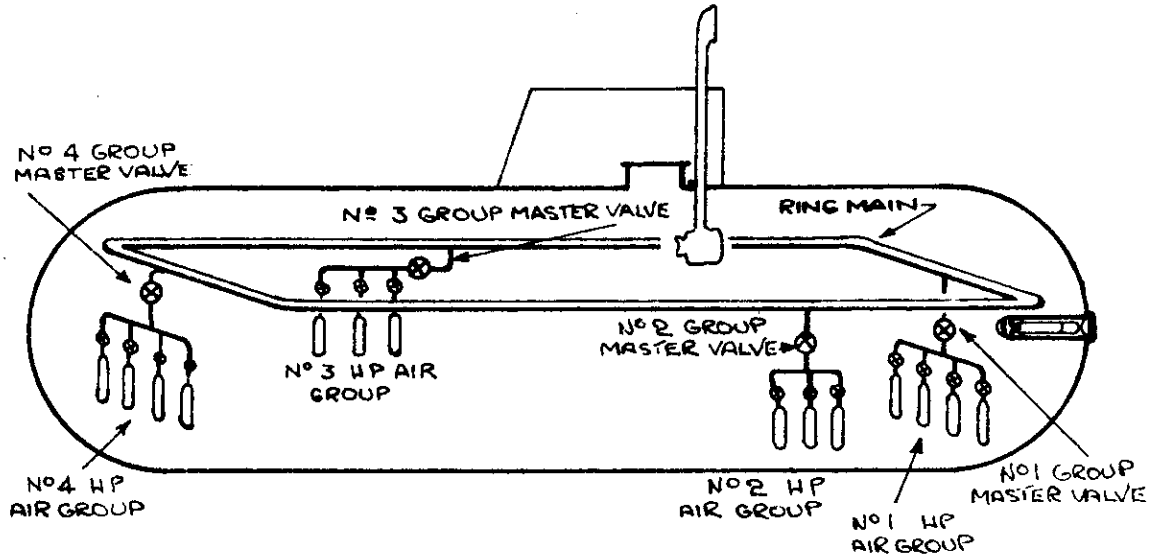
Compressing air is a method of storing energy until it is needed. The stored energy depends on the volume and pressure of the air, so that to avoid too large a storage capacity, a very high pressure of about 4000 psi is used. The air is stored in large cylinders known as bottles, which are arranged in groups at convenient points. The high pressure (HP) air is led from the bottle groups through a pipe system to wherever it is needed, (see diagram on next page).



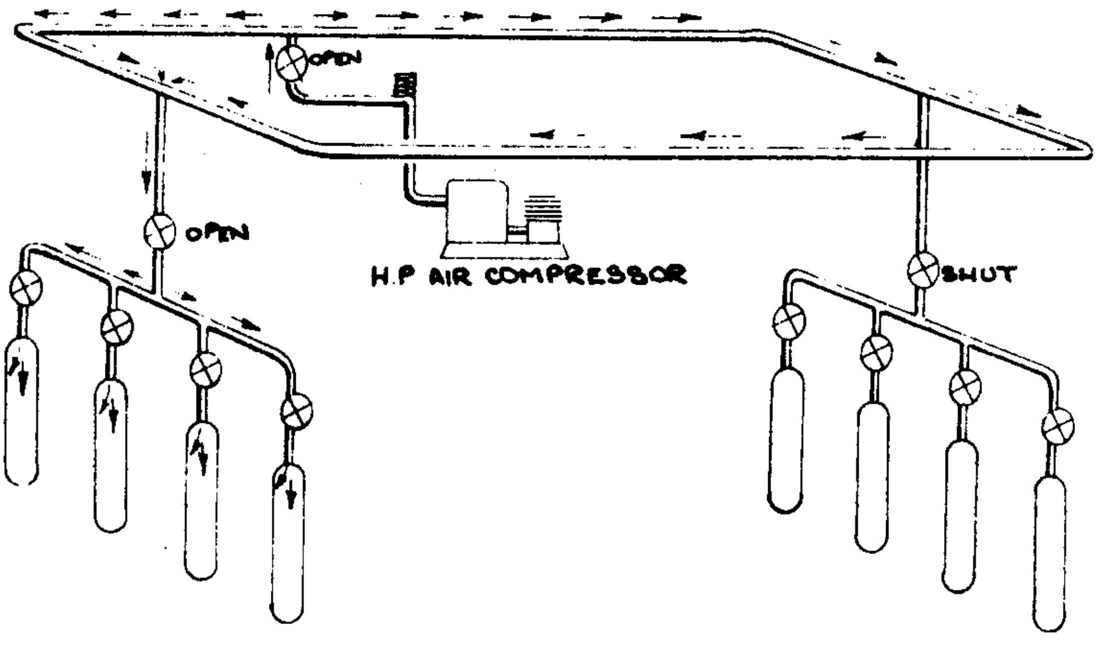


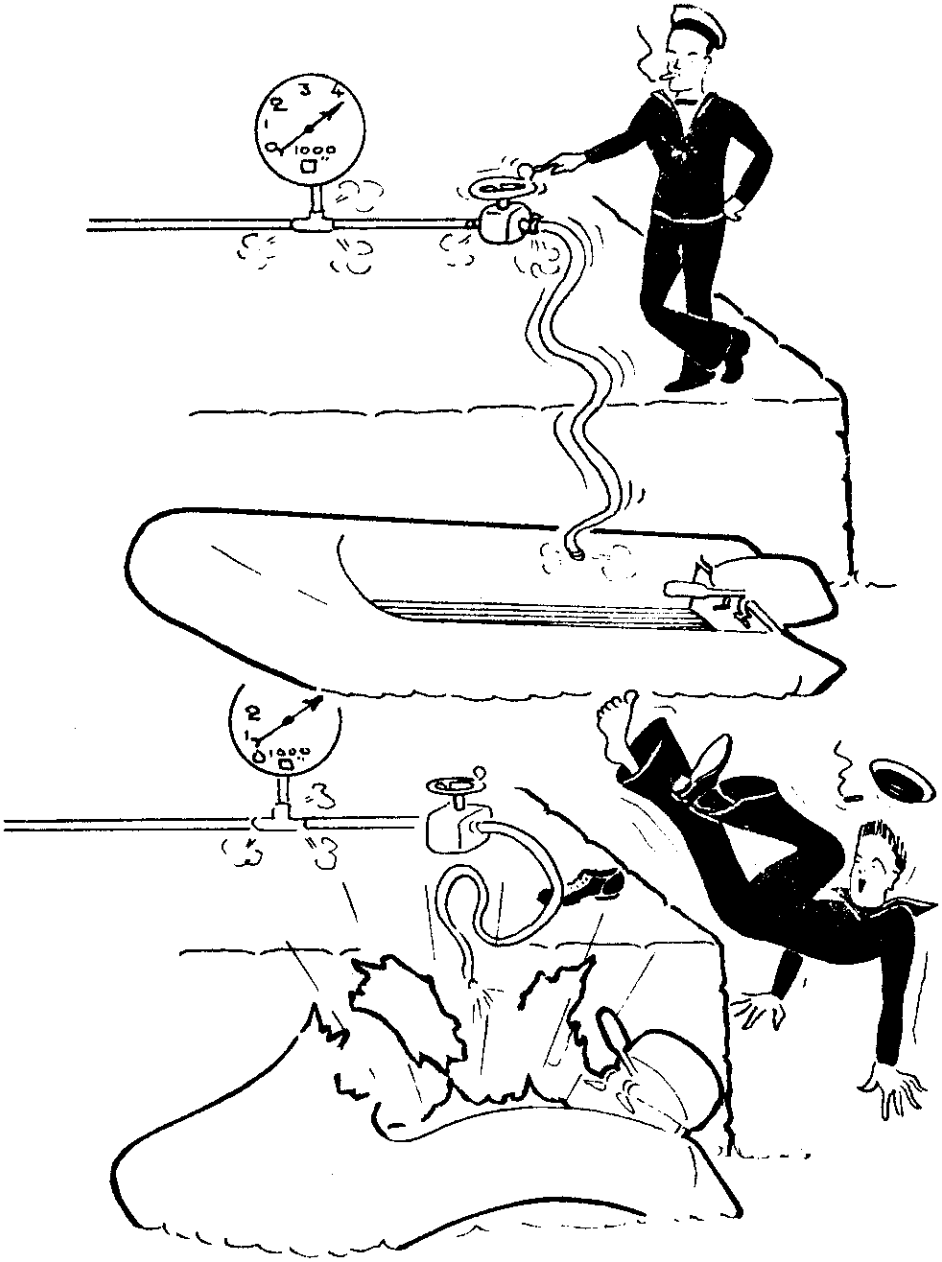
HP air is used for such operations as blowing main ballast tanks, blowing other tanks, firing torpedoes, operating signal ejectors, turning over diesel engines. Pressure reducing valves are used to reduce the pressure from 4000 psi to that required for a particular function. As the air in the bottle groups is used up it is replaced by running compressors. These are run when the submarine is on the surface or snorkelling as they take their air from outside the submarine. Like the battery, the bottle groups are kept topped up as far as possible.

To allow any piece of equipment to be operated from any bottle group, to shut off empty bottles and to isolate damage, a ring system is installed. Each bottle has a stop valve which can be used to isolate it from other bottles in the group. Each bottle group is connected by way of a group master valve to the "ring main" led around the inside of the submarine. Thus any bottle group can be isolated from the ring main. From the HP air line there are separate connections to each piece of equipment using HP air. In each case the necessary control valves are fitted.



The compressor air discharge pipe is connected to the ring main, so that any bottle group can be charged by opening the appropriate group master valve and bottle stop valves. The compressor is fitted with relief valves so that the bottles cannot be overcharged.

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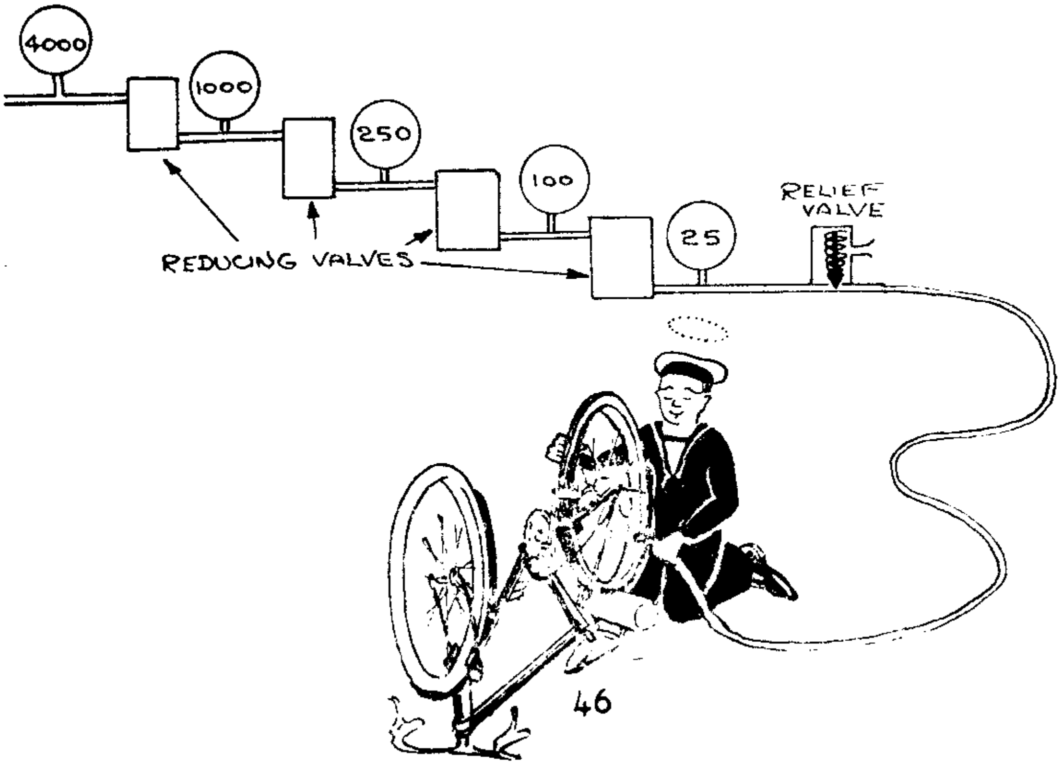

4000
1000
250
100
25
RELIEF VALVE
REDUCING VALVES

Reducing Valves

Air at 4000 psi expands violently when released into a tank or other piece of equipment. Reduced to normal pressure it expands to about 270 times its compressed volume, so that to blow a large volume such as a main ballast tank, or to operate powerful equipment, it is used direct.

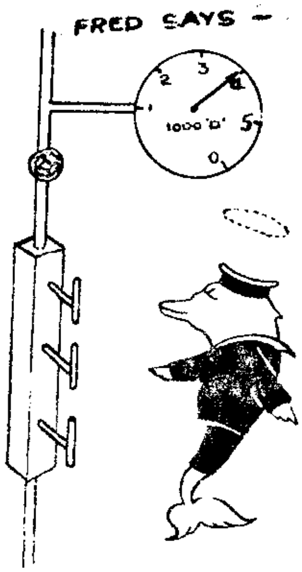
For many purposes a much lower pressure is required, and direct HP air would be dangerous. In these cases, the air is passed through pressure reducing valves which can be used to obtain any required value. Reducing valves are automatic in their operation but can be adjusted.

Low Pressure Air

HP air is a precious commodity. Even when the compressor can be run the charging process is slow. HP air is vital for the safety and operation of the submarine and must be conserved as much as possible. When main ballast tanks are blown, it is not necessary to blow out all the water in the tanks to bring the submarine to the surface. If about one third of each tank is emptied the submarine will float with the conning tower hatch far enough above water to be opened safely. (Surfacing is, of course, assisted by the use of the hydroplanes if the submarine has forward motion).

As soon as the conning tower hatch can be opened, air can be forced straight into the tanks by a low pressure blower. This is similar to a large ventilation fan. Thus, full positive buoyancy can be regained by running the LP blower for 15 or 20 minutes, and no more HP air than necessary is used up.

The low pressure air is led the length of the submarine by a single pipe system with appropriate valves to the main ballast tanks.



"ALWAYS BLOW MAIN BALLAST TANKS AT FULL PRESSURE"

Power at a Distance

A very common requirement in submarines is to operate equipment from a central position, or equipment outside the pressure hull from inside the pressure hull. There are various methods of remote control, and like many other things the choice may be a compromise.

Method of transmitting power	Comments
Mechanical - rod linkages, shafts, screws, gears, ropes and sleeves.	Simple, reliable, may be noisy. Usually heavy, may be slow. Too clumsy for many uses. Backlash.
Pneumatic - pump, pipe, air ram.	Fairly simple. For large effort pressure must be high or pipes bulky. Air supply in a submarine is limited, but as HP air is available, it may be used as emergency power supply.
Hydraulic - pump, pipe, ram or motor.	Rotary motion as well as linear motion feasible. Efficient, not too complicated quiet, can do the heaviest tasks.
Electrical - generator or battery, cables, motor or relay.	Rotary or linear motion. Needs most maintenance. Most expensive. Has the greatest possibility of control by switching, including automatic devices. Connecting system easier than pipework.
Hydraulic	Often works when all else fails.

The Submarine As A Warship

The battleship used to be judged in terms of its performance as a gun platform. The submarine has to be much more versatile, and in modern parlance we are much more concerned with the overall performance of the weapon system. The submarine vehicle itself is only part of this, and no matter how well it performs, the other parts of the system are equally vital.

Let us consider the war-time tasks of a submarine. One group of tasks, like landing special operations parties, watching the enemy, carrying vital stores and so on, depend entirely on the submarine's ability to hide itself below the surface of the sea. The submarine is vulnerable in shallow water, and many writers consider that the use of submarines for cloak and dagger or pinpricking operations is unnecessarily hazarding a valuable major war vessel. Nevertheless, there have been many examples of submarines landing agents, special parties and V.I.P.s, landing saboteurs and commandos, attacking targets ashore, watching enemy coast lines and harbours, acting as navigational beacons.

The other tasks depend entirely on the submarine's ability to sink enemy ships, coming within range and escaping again regardless of sea and air protection. The submarine can also sink enemy submarines, operating on its own or with friendly surface forces.

What does the effective submarine weapon system need?

Mobility	The ability to approach the enemy, get into a favourable position, attack and escape to fight again another day. The submarine must be fast, quiet and manoeuverable. It must be able to stay on patrol without constant replenishment, and it must be able to stay in top fighting trim. The deeper the submarine can go the bigger the volume of sea it can hide in.
Fire Power	The principal weapon of the submarine is the torpedo. The faster and longer the range of the torpedo the better, but it must not warn the target of its coming. The weapon should be capable of discharge down to maximum operating depth. Adequate replacements must be carried, although the torpedo is heavy and bulky (and expensive.)
Fire Control	Hitting the target cannot be left to luck. The correct course, depth and speed of the torpedo must be computed. This involves navigating the submarine under water, finding out where the enemy is, who he is and what he is doing, and communicating with controlling or supporting forces.
Survival	The enemy is not going to take being torpedoed very lightly. The submarine must live to fight again another day, which means beating off counter-attack, evading enemy forces, decoying homing torpedoes or just getting the hell out of it.
Training	The best weapon system in the world is no use in the hands of an untrained team. The submarine is part of the system, and if you open the wrong valve, lose the trim, press the wrong switch or just do not know the right thing to do, all may come to naught. Basic training, continuation training, team training, exercises, all lead up to one thing - an ability to use the weapon system to the full extent of its capability whenevery the situation requires it.

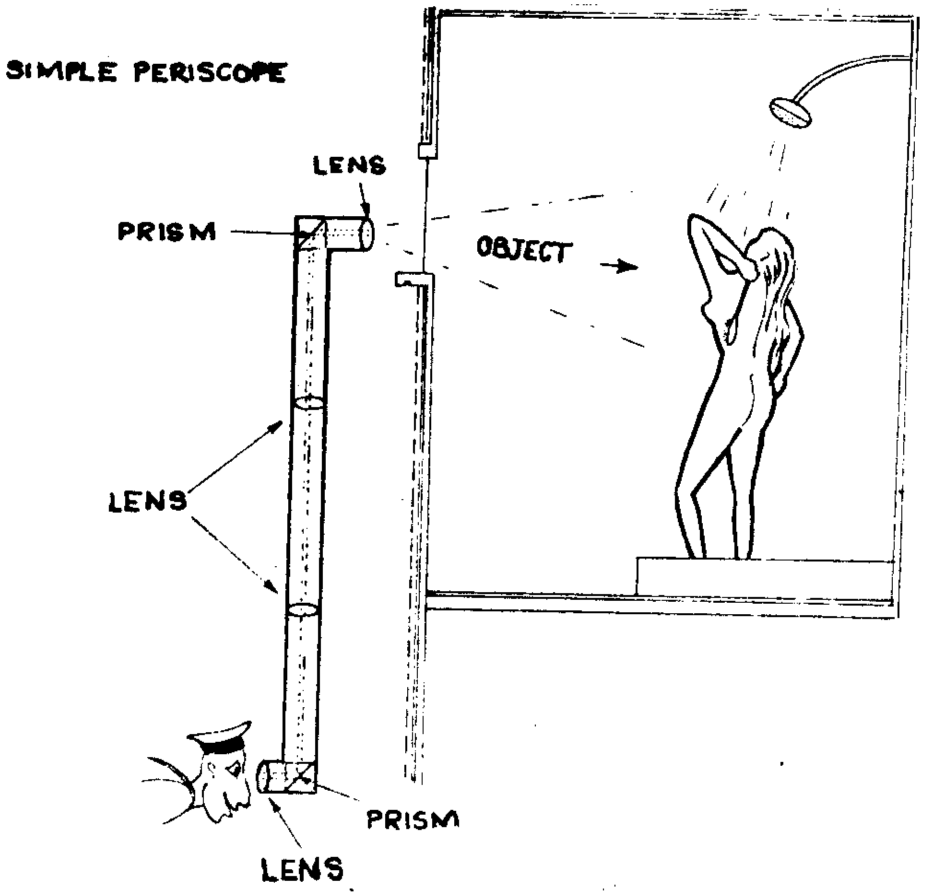
Sensors

This is the "in" word for devices which collect the information we need to know about the enemy. Intelligence may help us to find and identify him, but we want to confirm this and finally know where he is, what he is, what he is doing and how he is using his equipment. Whatever the sensor, there is always a process of search, location, identification and assessment (or classification).

Periscopes

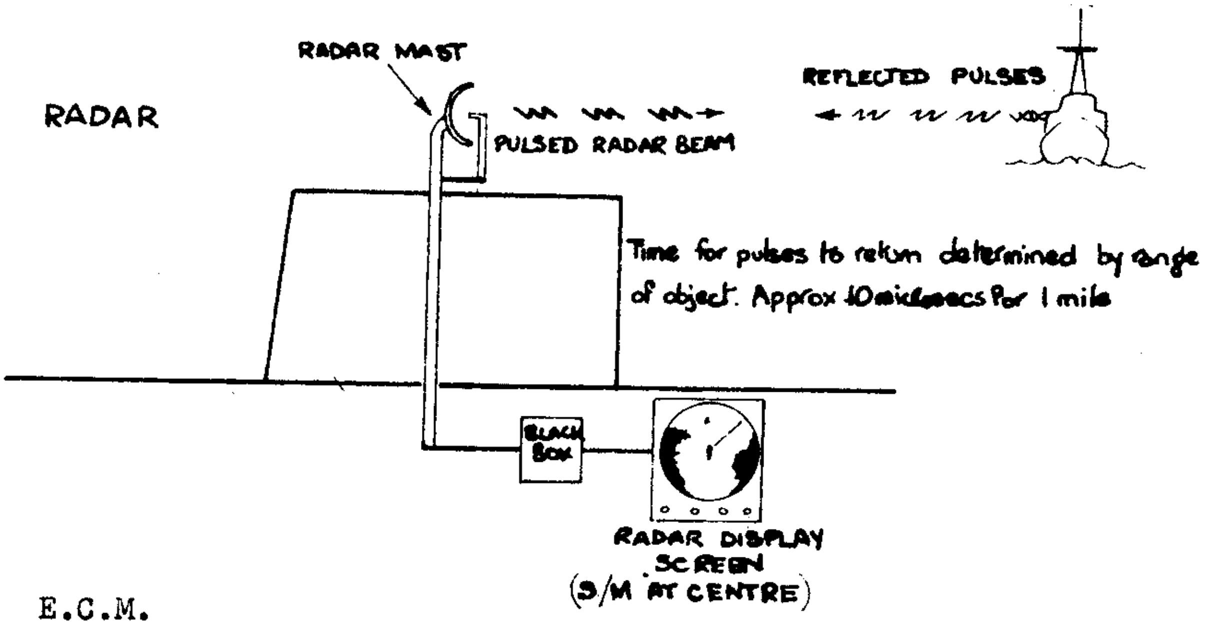
Periscopes are optical systems normally housed in the fin. the periscope tube can be hoisted so that only a small part is exposed above the water, and in favourable conditions this will not be detected by lookouts or radar. There are two periscopes - the search periscope and the attack periscope. The search periscope is binocular, magnifies the target 1½x or 6x as required and carries a small radar aerial. It is used for normal lookout purposes when at periscope depth, and continuously when snorkelling. The attack periscope is much smaller in diameter at its upper end. This makes it more difficult to see, produces less wake, and presents a smaller radar target. It is monocular and also magnifies 1½x or 6x as required.

The Commanding Officer is normally the only person who looks through the periscope during an attack. Keeping the periscope raised for the minimum time possible, he can sight an enemy vessel, obtain its bearing accurately, and can assess the range accurately, especially if he can identify the target and knows the height of the mast or funnel. He can estimate its course visually, and estimate speed from how far the target moves in a given time.



Radar

Radar can be used to search for targets and obtain their ranges and bearings. It does, however, give away the presence of the submarine with almost the first transmitted pulse and so is not favoured for attacking.



E.C.M.

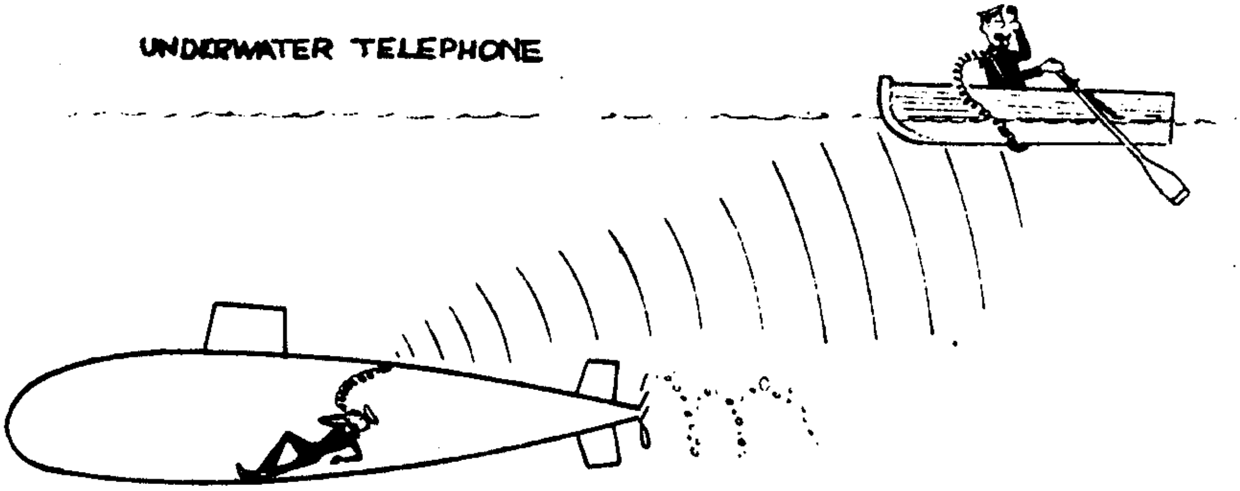
This is the device used to detect and identify the radar transmissions of enemy ships or aircraft. It can be used at any time the submarine is on the surface or at periscope depth, and watch is always kept on it if the submarine is snorkelling to give warning of the presence of aircraft in particular.

Communications

There are several aerials that can be used for receiving signals in a submarine, both on the surface and submerged. When dived they can normally only be received at periscope depth. Submarines listen for signals from shore stations at set times of the day on a special frequency known as the "Submarine Broadcast". Signals can be transmitted by the submarine only on the surface or at periscope depth. However by transmitting, the submarine immediately gives away its position. This does not matter so much in peacetime but in war transmissions are kept to an absolute minimum.

Underwater Telephone

Radio waves travel only a few feet under water, but sound waves travel for long distances. It is possible to transmit voice clearly over a limited distance. (You will hear an example of this and note that it is easier to hear than to understand.) However it could give away the submarine's position, as the enemy might pick up the noise at a considerable distance, without understanding what is said.



Data Processing

All this information flows from the equipment operators to the computing devices in the control room. This is less and less the C.O.'s head, as in the past, and more and more the associated complex electronic equipment. The processing of this information to enable the right decision to be made is called data processing - drawing on a plot, working out a course and speed, ticking off possibilities.

What happens when nothing can be seen through the periscope because it is dark or visibility is bad, and the Captain judges it prudent not to use radar? Does the submarine stumble about and lash out like a blindfold boxer? No. We have left the most important sensor of all to the end.

Sonar

We have said that sound waves travel well in the sea. An indication of this is given by the way in which scientists investigate the nature of the ocean floor, exploding charges and listenting to them many miles away. These sounds are often picked up thousands of miles away, just as the vibrations of earthquakes are detected after their passage through the earth's crust.

Sonar was known for many years as asdic, but the new word was devised to indicate that the method is the sound analogy to radar. There are two forms - passive and active. Passive sonar sets listen for noises which are then presented to the operator visually or through earphones. The operator must try to classify the source of the sound using his training and experience. Obviously the passive sonar set can only detect objects which make a noise. It is confused by the noises of the sea, possibly by fish noises and by the noise produced by the submarine in which it is fitted (which may be enough at speed to drown all incoming sounds).

Active sonar operates by transmitting a pulse of sound through the water. If it strikes a reflecting surface an echo comes back. This can be displayed in various ways, but once again the operator must decide whether he has an echo from a submarine, or from one of many other reflectors ranging from whales to mere changes of water density.

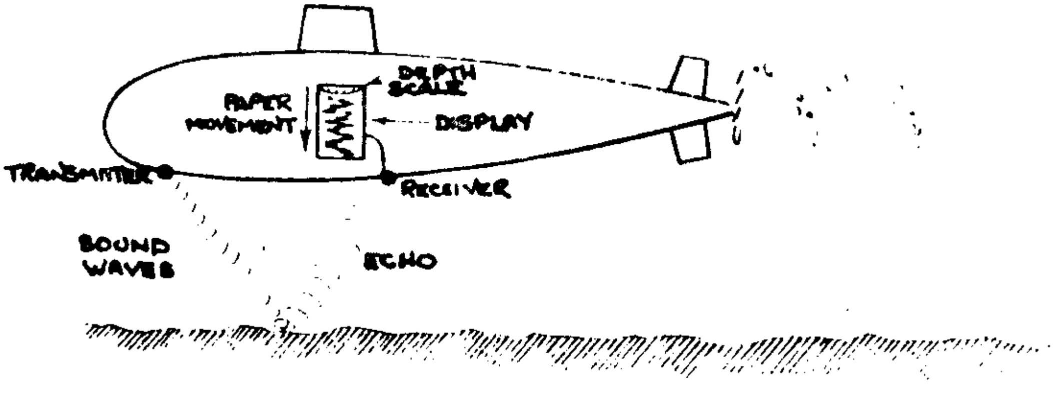
Both passive and active sonar can provide detection and bearing, but only active sonar provides a range directly. The submarine can, of course, detect the active sonar transmissions of surface vessels or submarines and can make good use of them.

The information obtained from sonar is befogged by the fact that the sound path is distorted by the variations in water density. Sometimes the sound will be bent downwards and lost, or reflected from layers and lost, so that detection ranges are short. At other times the sound will travel phenomenal distances in ducts or channels. The submarine has to work out what is happening - whether there is nothing else in the vicinity or the sound path is distorted, or whether the sounds heard are freakishly coming from many miles away. That is why a submarine has to keep a constant check on the water conditions of the area in which it is operating.

A submarine is fitted with various sonar sets, each of which can do something better than other types. The total information is processed and sifted to give the most accurate assessment of the enemy and his activities. Without sonar the submerged submarine is blind. During the last war the submarine was used as a surface vessel which had the ability to submerge; present tactics lead more and more to operating at depth with the sonar sets as the primary source of information.

Navigation

The submarine must be able to proceed from A to B and arrive at the right place at the right time. It thus needs the normal navigational facilities of a surface vessel - gyro compass, log, radar, radio fixing aids, echo sounder and plotting table with chart and book stowages.



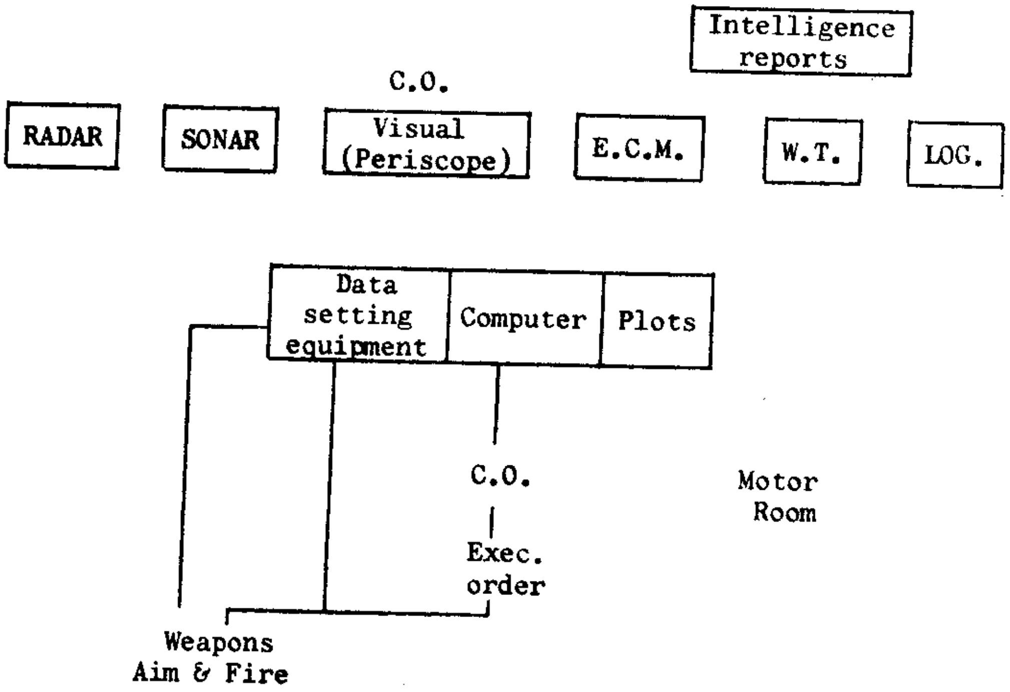
Astronomical sights can be taken in the usual way when on the surface, and through the periscope when dived at periscope depth. When the submarine is dived below periscope depth it proceeds by dead reckoning, with an allowance for tidal effect. The echo sounder can be used to check on sea bottom contours, but again might give away the presence of the submarine.

Fire Control

During an attack, information may be gained by the periscope, radar, communications and sonar room. This information is processed in the Control Room and used to decide what the enemy is, what his performance is and hence his possible actions, his course and speed and if he is a submarine, his depth. There will, of course, be useless or misleading information which must be rejected, different pieces of information which must be added together and even contradictory information about the same thing. All this calls for skill and training.

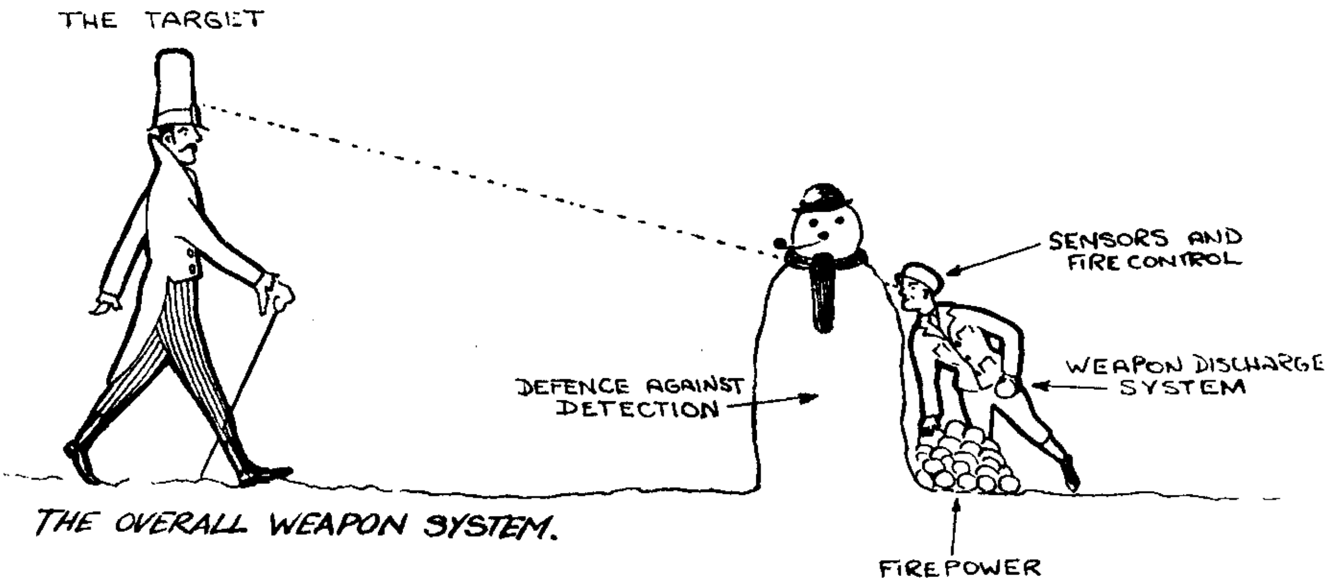
The torpedo tubes are fixed in the submarine so that the submarine must be pointed in the right direction for a certain firing solution. The actual course to steer, and running speed and depth can be set on the torpedo before it leaves the tube. Modern torpedoes may be given corrective guidance by signals passed along a wire, or may home on the target using a miniature passive or active sonar set.

The correct settings take into account the target's relative position, course, speed and depth. Pre-set torpedoes may miss the target because of errors in estimating these values, errors in feeding the information into the computers, drill errors,

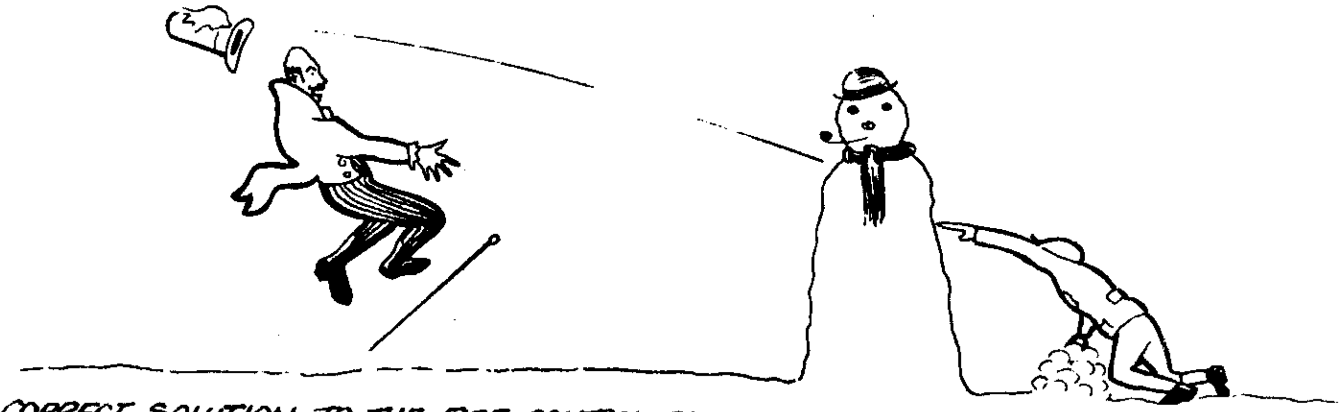


erratic performance of the torpedo or because the enemy changes course, speed or depth while the torpedo travels towards him. For these reasons guided torpedoes give a much higher chance of a hit and in practice pre-set torpedoes are fired in salvoes to "spread" them and thus increase the chances of hitting.

The earlier types of fire control computer are electromechanical, but more modern systems are entirely electronic. They produce the information necessary to get the torpedo into the same position as the target at some future point in time, or with guided torpedoes, produce the guidance information. All in all, the problem is similar to firing a guided missile at an aeroplane.



THE OVERALL WEAPON SYSTEM.



CORRECT SOLUTION TO THE FIRE CONTROL PROBLEM AND THE RESULT OF ADEQUATE TRAINING:.

"HE WHO FIGHTS AND RUNS AWAY"

The Crew

Our considerations have been concentrated on nuts and bolts, systems and equipment. The submarine cannot be any better than the maintainers who keep it running and the equipment in top line working order, or the users who operate it as a weapon of war.

A modern aeroplane is a highly automated and complex weapon system. The pilot and observer largely monitor the performance of the equipment, think originally if necessary (which computers cannot do) and get the machine back on the ground in one piece. If it becomes unserviceable it stays on the ground, or if failure occurs in the air it comes home again. In some cases a thousand man hours of maintenance is needed for every hour in the air. A highly skilled ground crew and extensive facilities are necessary.

A fully automated submarine would be an attractive proposition. Nevertheless, to stay at sea for weeks on end it would need to take its maintainers with it. There are many things which the human operator can do which a machine cannot do, so to avoid over-complication and even more maintainers, operators are necessary. There must be sufficient crew to operate the submarine continuously, day in, day out for weeks on end.

It is not intended to consider the crew in detail. From the diagrams you can see who is doing what at various times. It is worth noting that a submarine has less than half the crew of a surface ship of similar size.