CHAPTER LXVII.

THE SUBMARINE AND ITS WORK.

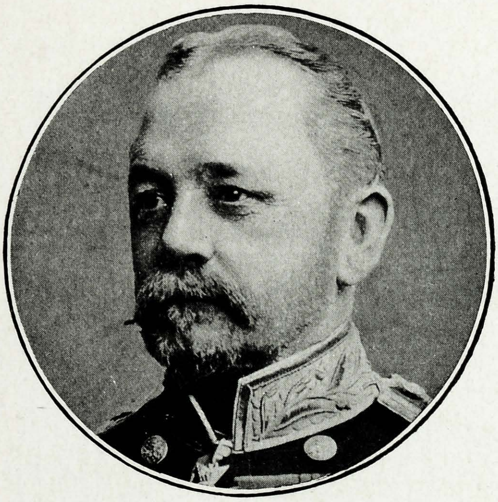
Influence on Naval Work of Surface Ships—The German Submarine Blockade—The Sinking of the Lusitania—The Evolution of the Submarine Boat—Underwater Boats in Eighteenth-Century Wars—The Development of the Submarine Fleets of Great Britain, Germany, Austria, France, and Italy—Relative Strength of Combatant Flotillas—The Armament of Submarine Boats, Torpedoes and Guns—Repair Ships for Underwater Boats—The Tactical Work of the Submarine as Influenced by Design—Oil or Turbine Machinery—Increased Speed—How a Boat Dives—How the Periscope is Used—Radius of Action of German Boats.

BEFORE the Great War the general public of all countries had learned little of the performances of submarine boats, and less of their design and construction. That such craft were shaped like a cigar, could dive, and be propelled under water while the officer in command was able to view objects on the surface through something called a periscope, and that a torpedo could be fired at any ship or object afloat, was about all that the ordinary reader knew. He occasionally heard of breakdowns, of submarines being run down by surface ships, and even of boats, when diving, digging their noses into the bed of the ocean. It is not wonderful, then, that when war came, involving the nations most earnest in the pursuit of scientific methods, there should be uncertainty and doubt as to the value of under-water craft.

Even among naval tacticians of all nations there was a wide divergence of opinion. Most of them knew something of the mechanism ; a few had knowledge of the part played by the new vessels in recent naval manœuvres. Yet there was still wide variance in views as to the value of the ships and as to whether they were best suited for the strategy and tactics to be pursued in war by the great, or by the secondary, Powers. It was soon made clear by the test of war that the submarine boat justified her place among the ships of all nations, great and small, and that the mightiest of the ships of the line must not despise these lurking yet watchful foes.

The acceptance of the evidence as establishing the right of the submarine boat to a place in every fleet must not be stretched to mean that this type of vessel at once did all that was predicted for it. The chief successes of our enemies' submarines during the earlier phases at any rate of the war were against unarmed merchant vessels ; but these were generally achieved by violation of accepted rules of warfare. It remains to be seen to what extent laws and customs affecting non-belligerent ships, which carry no contraband of war, are to be abrogated, or how they are to be enforced.

As regards the purely military achievements of underwater craft, it was inevitable that they should be measured by the standard set up by Admiral Sir Percy Scott, Bart., as war broke out within two months of the publication in *The Times* of his famous pronouncement that the submarine boat superseded all other craft except light cruisers and aeroplanes. The main



[Lafayette.

ADMIRAL SIR PERCY SCOTT, Bart.

[Elliott & Fry.

CAPT. S. S. HALL, C.B.,
Chief of the Submarine Department at the Admiralty.

points in Sir Percy Scott's argument were as follows :

> The introduction of the vessels that swim under water has, in my opinion, entirely done away with the utility of the ships that swim on the top of the water.
>
> The submarine causes to disappear three out of five of the functions, defensive and offensive, of a vessel of war—*i.e.*, port bombardment, blockade, and convoy of a landing party, or the prevention of all three—as no man of-war will dare to come even within sight of a coast that is adequately protected by submarines.
>
> The fourth function of a battleship is to attack an enemy's fleet, but there will be no fleet to attack, as it will not be safe for a fleet to put to sea.
>
> The fifth function is to attack enemy's commerce or to prevent attack on our own.
>
> If by submarines we close egress from the North Sea and Mediterranean, it is difficult to see how our commerce can be much interfered with.
>
> Submarines and aeroplanes have entirely revolutionized naval warfare, no fleet can hide itself from the aeroplane eye, and the submarine can deliver a deadly attack even in broad daylight.
>
> Naval officers of the future will therefore live either above the sea or under it. It will be a Navy of youth, for we shall require nothing but boldness and daring.
>
> Not only is the open sea unsafe. . . . With a flotilla of submarines . . . I would undertake to get . . . into any harbour, and sink or materially damage all the ships in that harbour.
>
> What we require is an enormous fleet of submarines, airships and aeroplanes, and a few fast cruisers, provided we can find a place to keep them in safety during war time.
>
> In my opinion, as the motor-vehicle has driven the horse from the road, so has the submarine driven the battleship from the sea.

Let us examine Sir Percy's enunciation of the offensive functions of a vessel of war as practised by the British surface ships to ascertain how these were influenced by the enemies' submarine boats. But observation on these points should be prefaced with the remark that the personal equation in submarine warfare is as important as, if not more so than, in any naval operations.

The offensive functions of a fleet as stated by Sir Percy are: (1) To bombard an enemy's ports: we had the repeated bombardment of the coast of Flanders in German occupation and of the Dardanelles; (2) to blockade an enemy: we contained the enemies' main fleets in the North and Adriatic Seas, although beset by their submarines; (3) to convoy a landing party: we sent across all the oceans greater convoys than in any previous war in the world's history; (4) to attack the enemy's fleet: that was done whenever the enemies' fleets put to sea, even when they sought to decoy us into the submarine and mine zones; and (5) to attack the enemy's commerce: early in the war we swept all seas clear of the enemies' merchant shipping and prevented the entrance of ships into the enemies' ports. All this was achieved despite the fact that Germany used her submarines to the best of her ability.

Conversely let us consider how the enemies' submarines in the first months of war affected the work of our surface ships, whose safety on the open sea was to be endangered, and even whose retention in harbour was to be hazardous because of submarines.

(1) To attack ships that come to bombard ports: submarines were repeatedly used by Germans during the bombardment of the coast of Flanders, and the most notable, if not the only achievement, was the sinking on October 31, 1914, of the old unprotected cruiser Hermes when acting as a seaplane-carrying ship.

(2) To render blockade impossible: Germany

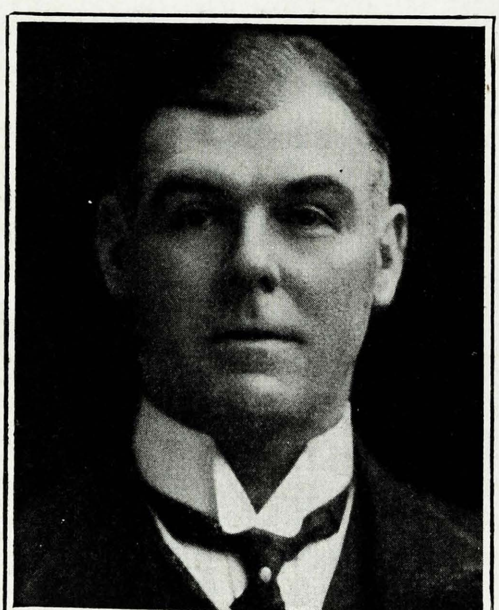
was unable to get direct supplies, and although some of our older ships on patrol were sunk, the limitation of imports to Germany continued effectively.

(3) To attack ships convoying a landing party: no success attended German submarines, although the opportunities were great, as our transports and convoys were unsurpassed in history in their numbers and the length of their voyages. On the other hand, our E14 and E11 did good service against transports and supply ships in the Sea of Marmara.

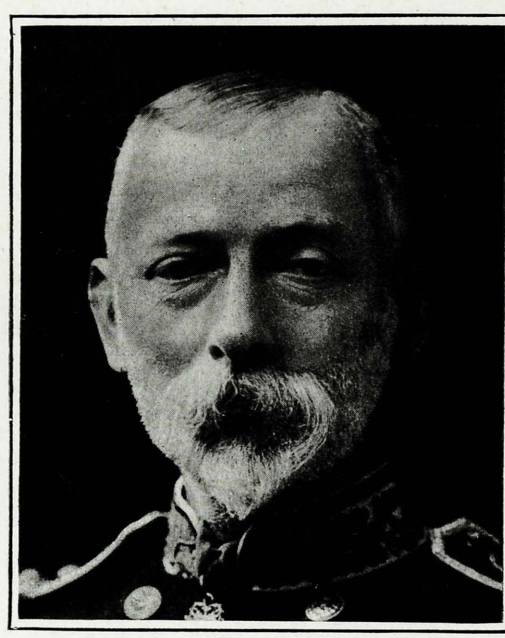
(4) To attack the enemy's fleet: Sir Percy's view was that there would be no fleet to attack as it would not be safe for a fleet to put to sea. Our Grand Fleet—the greatest ever gathered together—remained on watch and guard in the open sea without molestation, the rare attacks on the fleet by submarines resulting in the destruction of such vessels. It is true that many of our warships were sunk when patrolling separately, and that the Aboukir, Cressy and Hogue were sunk when together; but the great majority, practically all the warships, thus sunk were steaming at low speeds and under circumstances favourable for the German submarines.

The British submarine boats, on the other hand, played a different part, but they have scarcely met Sir Percy's ideal: "With a flotilla of submarines . . . I could undertake to get . . . into any harbour and sink or materially damage all the ships in that harbour." The nearest approach to this was the "scooping" movement which resulted in the battle of the Bight of Heligoland on August 28, 1914. The submarine's part was most interesting. Success was due in the first instance to the information brought to the Admiral by the submarine officer, who showed—to quote the First Lord of the Admiralty—"extraordinary daring and enterprise in penetrating the enemy's waters." In addition to this the submarines behaved splendidly in the action itself and were afterwards instrumental in saving life. According to Commodore Keyes,* in his dispatch of October 17, 1914, E6, E7 and E8 "exposed themselves with the object of inducing the enemy to chase them to the westward." On approaching Heligoland the visibility, which had been very good to seaward, reduced to 5,000 to 6,000 yards, and this prevented the submarines from closing with the enemy's cruisers to within torpedo range, especially owing to the anxieties and responsibilities of the commanding officers of submarines, who handled their vessels with coolness and judgment in an area which was necessarily occupied by friends as well as foes. The Commodore added that "low visibility and calm seas are the most unfavourable conditions

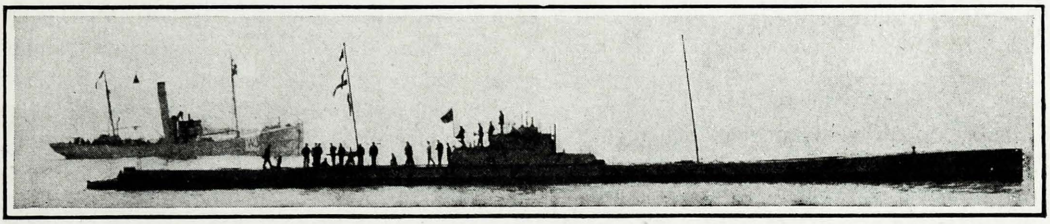
* Commodore Keyes' portrait appears in Vol. II., page 12.



COMMANDER SIR TREVOR DAWSON,
Who 14 years ago predicted use of submarines against British merchantmen.



ENGINEER VICE-ADMIRAL
SIR HENRY J. ORAM, K.C.B.,
Engineer-in-Chief of the Navy.



THE GERMAN "PIRATES" AT WORK.

The "U28" holding up the Dutch Liner "Battavier 5" in the North Sea. The ship was seized and taken as a prize to Zeebrugge.

under which submarines can operate." They did their work satisfactorily as "decoys" and the end was satisfactory, as reviewed in Vol. II., page 8. Our submarine E11 penetrated into Constantinople and torpedoed a troop ship in May, 1915.

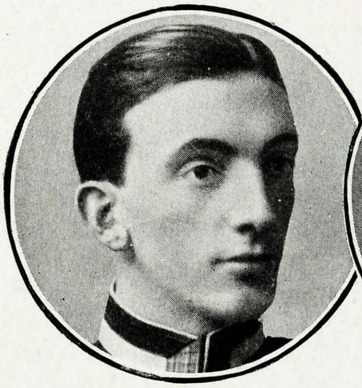
And this brings us to the fifth function of the warship as enumerated by Sir Percy Scott—commerce destruction. He did not seem to anticipate that submarines would attack merchant ships. Submarines "in being" were to render impossible the existence on the high seas of warships to attack commerce: that was a weakness in his "thesis" which Lord Sydenham exposed. And yet the idea of a submarine attack on commerce was not new. Commander Sir Trevor Dawson, who has done so much for the development of the British submarine boat as for all our munitions of war, predicted as long ago as 1901 the use of submarine boats against merchant vessels. In a lecture to the Institution of Mechanical Engineers in that year he said:

"Attacks would be made on our fleet in much the same way as the bands of Boers are making guerilla attacks on our regular army in the Transvaal. Of the continuous stream of ships passing up and down the English Channel—the busiest steamship track on the globe—quite 90 per cent. are British vessels and upon them our mercantile greatness depends. . . . Submarine boats have sufficient speed and radius of action to place themselves in the trade routes before the darkness gives place to day, and they would be capable of doing almost incalculable destruction against unsuspecting and defenceless victims. The same applies to the Mediterranean and other of our ocean highways within the danger zone of the submarine. The submarine boat has thus increased the value of the mechanical torpedo tenfold.'

This is a true picture of what actually happened, although drawn thirteen years before the Great War. From the commencement of hostilities the Germans used their submarine boats with the view of reducing as far as possible the preponderance of our naval force. First contact was on August 9, when one of our cruiser squadrons met with German submarines, and one—U15—was sunk by H.M.S. Birmingham without any damage being done to our ships. But it is not proposed in this chapter to review in chronological order the operations of submarines in the war; it is preferable to take the incidents as illustrations of the efficiency, limitations and probable developments of this type of war craft.

That the Germans were dissatisfied with the extent of their success in reducing our naval superiority in contrast with the increase in the "silent pressure" of our Grand Fleet upon importations into Germany of the necessaries of life and warfare is established, first by the new policy begun in October, 1914, when German submarines were ordered to sink British merchant ships, and second by the declaration of the so-called submarine blockade of Britain from February 28, 1915.

The submarine blockade, characterised by the Prime Minister as a "campaign of piracy and pillage," violated international law in several respects. Ships were sunk irrespective of their nationality or destination or cargo—contraband or otherwise. International law as well as usage ordains that any merchant ship may be searched, her papers examined, and, provided she has no contraband on board, she must be liberated. Otherwise she can be captured and brought into port, and her assumed infringement of law adjudicated upon by a prize court. While Britain and her Allies scrupulously followed this course, German submarines sank at sight, when able, any ship which crossed their way, sometimes without warning. Occasionally the courtesies of war were shown, to the credit of the officers but not of the system. Under the more humane circumstances ten minutes' grace was given to allow passengers and crew to take to the boats. Only in rare cases were neutral vessels allowed to escape, and equally seldom were the lifeboats towed to port or to within rowing distance of land. On the other hand, there were proved cases of shells being fired at men in the boats trying to



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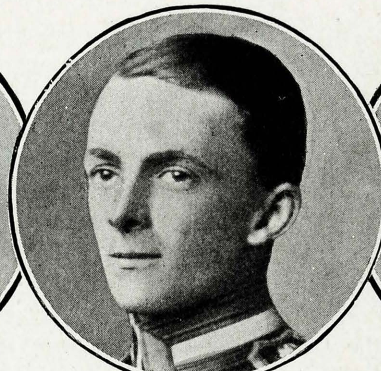
LIEUT. W. R. SCHOFIELD ("C29").



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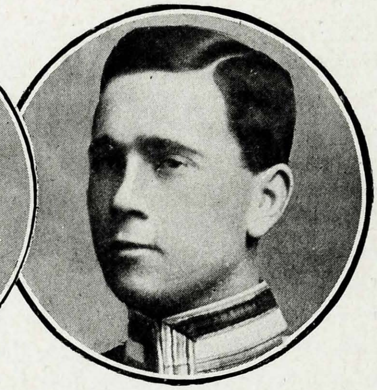
LIEUT. B. A. BEAL ("B1").



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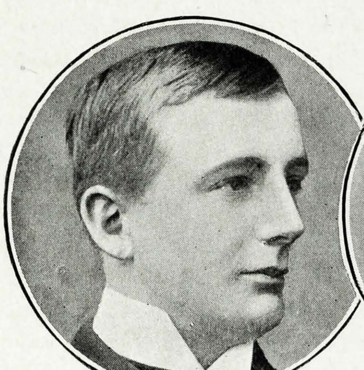
COM. C. P. TALBOT ("E6").

rescue their comrades struggling in the water One of several such cases was associated with the sinking on the Dogger Bank of the trawler St. Lawrence on April 22, 1915.

The German Navy's career of lawlessness culminated on May 7, 1915, in the sinking of the Cunard Liner Lusitania some miles south-west of the Old Head of Kinsale. She was one of the largest and finest of the world's liners—785 feet long and of 32,500 tons gross. She was certainly the fastest of merchant ships, her speed being 26 knots. She left New York an unarmed liner in the ordinary routine of her mail and passenger service, having on board 292 first, 602 second, and 361 third-class passengers, many of them citizens of the United States of America and of other neutral countries, and 651 of a crew—1,906 persons all told, men, women, and children. Warnings by advertisement and communications to individual passengers had been given, in some cases by German officials, that it was the intention of the Germans to waylay the ship by submarines and sink her by torpedoes. The ship sailed as usual, the view entertained being that the realization of the aim would be too great a crime even for the Germans to commit. But the enemy carried out their purpose in all its wickedness, and of the great population on board 1,134 were killed by the explosion or were drowned, notwithstanding every possible effort to save them: the submarine boat was not seen after the disaster.

At the coroner's inquest on some of the victims, Captain Turner of the Aquitania, who was in command of the Lusitania on this voyage, gave evidence which enabled a clear idea to be formed of the sequence of events. On approaching the Irish coast he received, by wireless message from the Admiralty, warning of the presence of German submarines off the Irish coast, and of the sinking of the schooner Earl of Lathom on Thursday, May 6, along with certain instructions, which he said he carried out "to the best of my ability." There were double look-outs keeping special watch for submarines. No submarine was seen. A zig-zag course was not steered. The speed had been reduced to eighteen knots so that the



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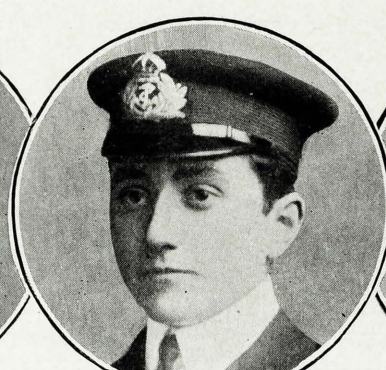
LIEUT. R. K. C. POPE ("C38").



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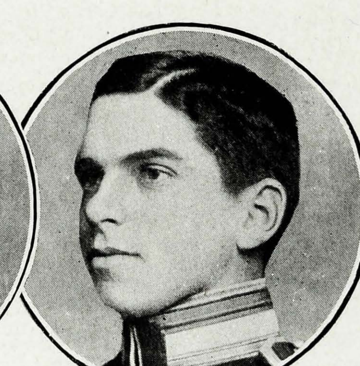
LIEUT. D. M. FELL ("A12").



Russell.

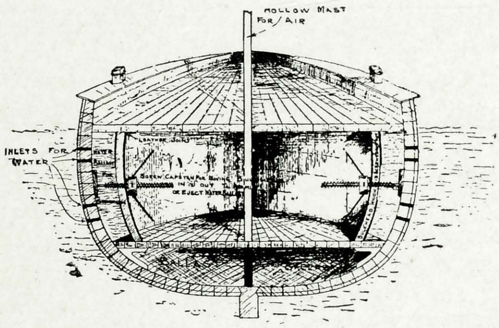
LIEUT-COM. R. R. TURNER ("D3").

vessel would not arrive at the Mersey Bar before the tide permitted her to cross. No warning whatever was given by the submarine. At about a quarter past two, when he was on the port side of the lower bridge, the second officer called from the starboard side of the bridge, "There is a torpedo." Captain Turner ran to the side and saw the wake of it. The torpedo was almost on the surface. When it struck he heard the explosion, and "smoke and steam went up between the third and fourth funnels, and there was a slight shock to the ship." Immediately after the explosion there was another report, but possibly that may have been an indirect explosion. The torpedo probably struck at either No. 3 or 4 boiler-room; it may be that the explosion rent the bulkhead between them, causing havoc to the twelve boilers and the steam-pipes. The second indirect explosion was probably the bursting of the main steam-pipe. The turbines, whether affected or not, were "out of commission"; there was no steam to reverse them, so that the ship had still her momentum up to the time she sank, which, according to the stopping of the captain's watch, was at 2 hours 26¼ minutes, or less than fifteen minutes from the explosion. The way on the ship, and the list to starboard prevented the crew from getting all boats promptly launched; but according to the captain, all was calm and all his orders were carried out. The ship sank under him when he was on the bridge; he was picked up two or three hours afterwards.

The cruel and treacherous procedure of the German submarine warfare on many occasions "gives furiously to think" respecting the predictions of the inhumanity of this system of waging war. Admiral Mahan, at The Hague Conference of 1899, called the submarine boats "inhuman and cruel." When Fulton, an American artist who developed the engineering faculty, about the year 1800 achieved a sufficient measure of practical success with a boat manually propelled under water on the River Seine and in Brest Harbour, the Maritime Prefect of the port refused to allow it to be used in an attack upon English frigates lying off Brest because this manner of making war on the enemy would be visited with such reprobation that the persons who should have waged it and should have failed would be hanged. The French Minister of Marine of the day—Admiral Pleville le Belly—declared that his conscience would not allow him to have recourse to so terrible an invention. "Cold-shouldered" by all, Fulton came to London in 1804, and Pitt, then Prime Minister, appointed a Commission to consider the proposals. The First Lord of the Admiralty—Admiral Earl St. Vincent—recognized the "tremendous possibilities of these inventions, but openly opposed them in emphatic language." He criticised Pitt for his encouragement of this new method of conducting warfare, "which those who commanded the seas did not want, and which, if successful, would deprive them of it."

THE EVOLUTION OF THE SUBMARINE BOAT.

The submarine boat is the product of centuries of experiment. Its principles were evolved as the result of trial and error. The early workers established the governing principles, but they failed in attaining reliability because they had not the advantage of those advances in collateral branches of science which so greatly assisted the modern workers. The

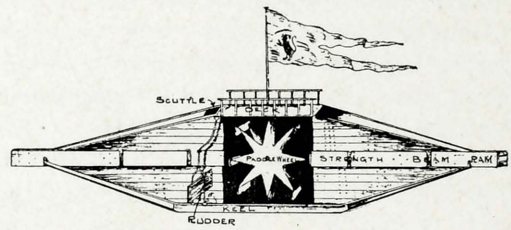


submarine boat was not a practical success until the oil internal combustion engine was perfected, the storage of electricity made practicable within reasonable limits of weight, the Whitehead torpedo improved in power and range, the hydroplane introduced for diving and for keeping the vessel on an even keel under the surface, and lastly, constructional materials evolved to give strength of hull with lightness. And yet underwater craft were used in three wars of the past century—against the British fleet in the American War of Independence in 1812, against the Danish blockading fleet off the German coast in 1850, and against the Federal ships in the American Civil War in 1862–4. In this last alone was there any pronounced success—one ship was sunk and three others injured.

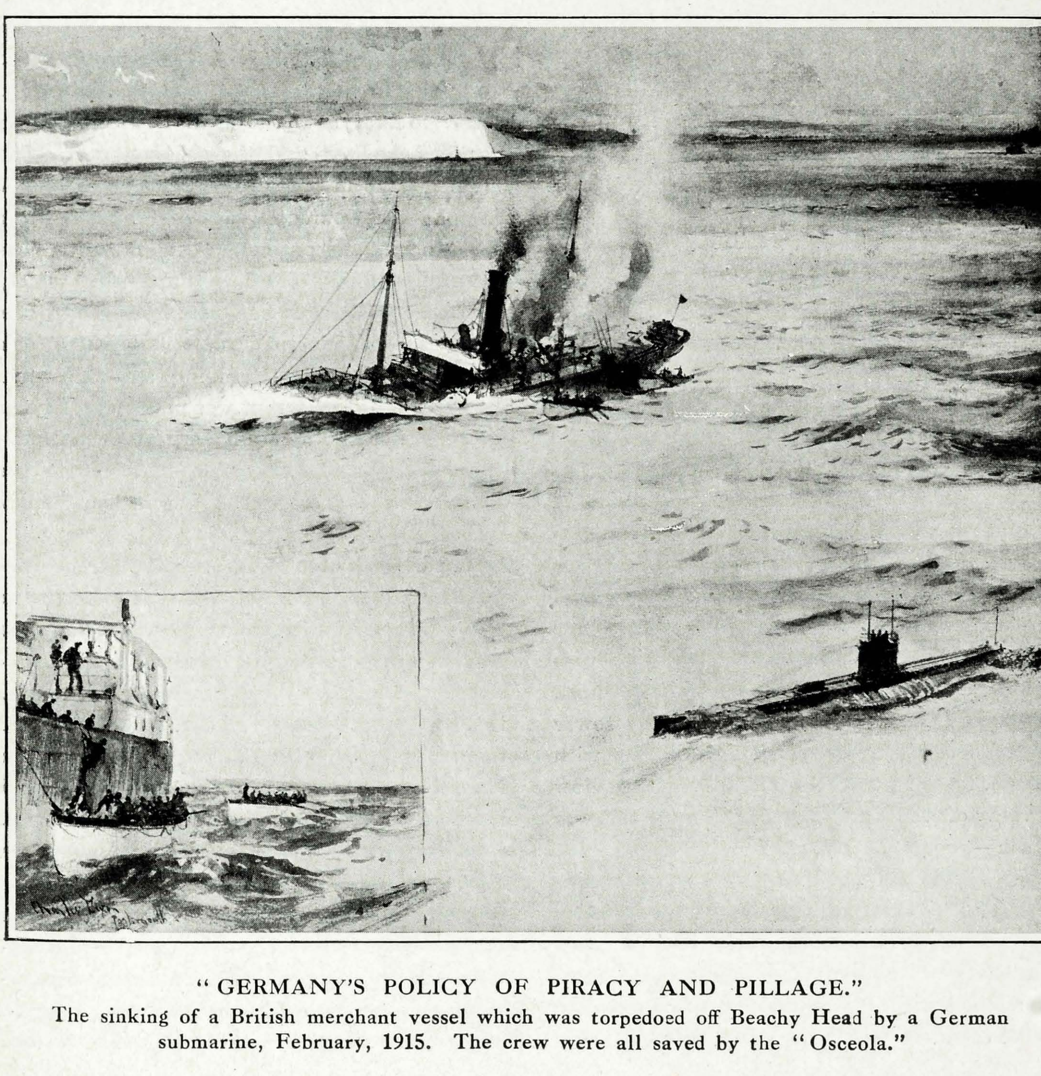
The first known invention of a submarine boat was by William Bourne and was described in a publication of date 1578. As in the modern boat, water ballast was used for ensuring immersion. The vessel was practically a covered-in barge, the outer shell was pierced with small holes, and parallel to each side there was an interior division-wall working in leather-lined grooves. This latter was moved towards, or from, the outer shell by screws and a capstan, exactly in the same way as the top part of a letter-copying press is worked against the bottom part. As the inner wall moved from the outer shell, water entered through the small holes, and as the division-wall was forced back, the water was expelled through the apertures. Thus the boat sank or rose. Air supply was admitted through a hollow mast. A sketch to illustrate this boat is given on page 86.

The first known underwater boat actually tried was by a Dutch physician, Cornelius van Drebbele. His boat in 1620 made the voyage just awash from Westminster to Greenwich along with the current. The vessel was weighted down with ballast and propelled by twelve oars projected through holes in the side and kept watertight by leather lining. It was said that he had a "quintessence" for renewing the air.

The first mechanically propelled boat was that of a Frenchman named de Son, which he



built at Rotterdam in 1653. It was 72 feet long and was tapered towards a point at both ends. Centrally placed, internally, but open to the sea at the bottom, was a paddle-wheel, which, driven by clockwork, was to propel the boat from Rotterdam to London in a day.

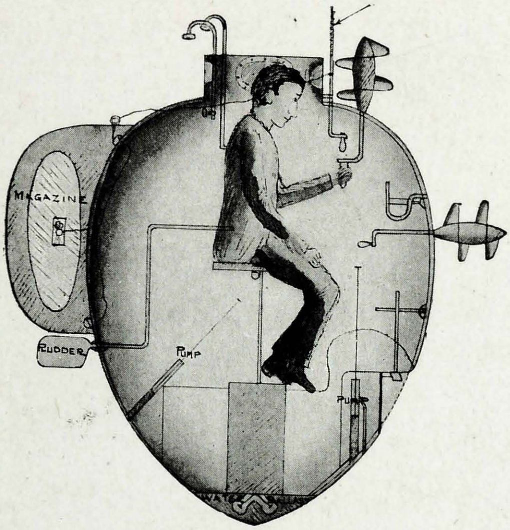


"GERMANY'S POLICY OF PIRACY AND PILLAGE."

The sinking of a British merchant vessel which was torpedoed off Beachy Head by a German submarine, February, 1915. The crew were all saved by the "Osceola."

The wheel is shown in the sketch on page 87, with the side cover removed. Unfortunately, although the wheel worked well in air, it was not powerful enough to move the vessel in the water.

The next interesting test was on the Thames. One Symons covered in an ordinary open, wooden, oar-propelled boat, and fitted it with a number of leather bottles having openings through the bottom of the boat. When the necks were untied water filled the bottles and sank the boat to the "awash" position; to cause the vessel to rise the water was squeezed out of the bottles and the necks retied. This



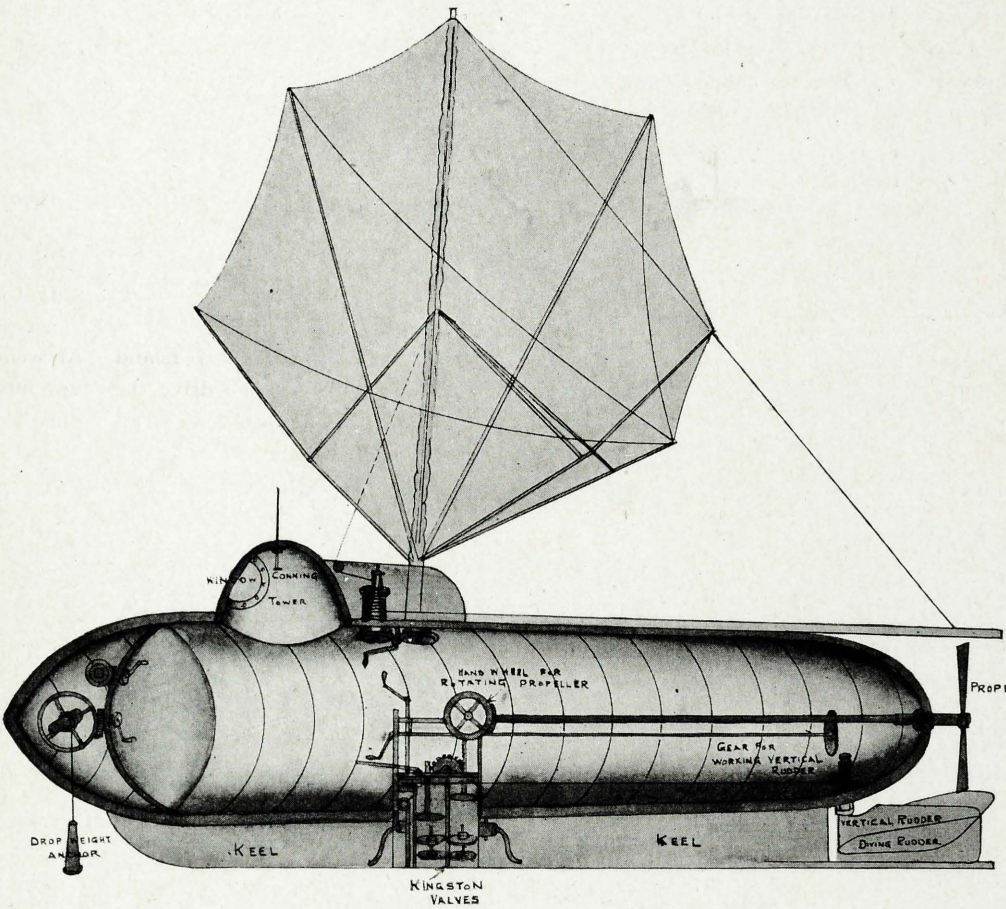
arrangement has its counterpart in the modern submarine boat; tanks replace bottles, valves are substituted for the tying of the necks, and compressed air drives out the water when the vessel is to rise.

The War of Independence, quickening the ingenuity of the Americans, brought a submarine into action for the first time. It was a most ingenious invention by David Bushnell, who had been educated at Yale College (now University). A sketch through the centre is reproduced above. It was strongly built, egg-shaped in section, with a conning tower in the form of a brass cover like a top hat with a brim, to assist towards stability and to allow a view of the surface when the vessel was awash—two anticipations of later designs. A third was the use of a gunpowder charge to explode under water. For descent there was a water-ballast tank in the bottom, with controlling valves, and for ascent two foot-operated pumps for ejecting the water. For ahead or astern, and vertical or diving, movements there were separate hand-turned screws. With scuttles to admit light, compass, instrument to indicate depth of immersion, and ventilator, the ship was well "found." Again, there was a rudder, the stock of which the operator, while seated, worked with the sway of his body. Indeed, the operator required all his wits to accomplish movements by each hand, each foot, and the sway of his body. The magazine, containing 150 lb. of gunpowder, was saddled to the side and connected to a screw at the side of the conning tower.

When the boat got alongside the vessel to be sunk the operator drove the screw into the bottom of the enemy's ship, released the magazine, which, with the travel of the current, got alongside the ship, and then by clock mechanism operating hammer and percussion cap the explosion was effected. The first attempt was made in a preliminary encounter prior to the war in 1776 against H.M.S. Eagle—a 64-gun frigate—off Plateau Island. All went well until the attempt to drive the screw into the hull, but as the latter was copper-sheathed two tries failed, and the submarine had to return to safety. In the dawn the conning tower exposed the boat, and the occupant unsaddled his magazine in order to increase the speed of escape. The pursuers, fearing disaster from this move, discontinued the pursuit. The magazine exploded. The submarine safely returned. Two further attempts with this submarine failed and Bushnell desisted from further experiment, receiving a commission. In 1812 another attempt was made by a similar boat against H.M.S. Ramillies, but in this case the screw for attaching the explosive to the hull broke. That ended submarine attack during the war.

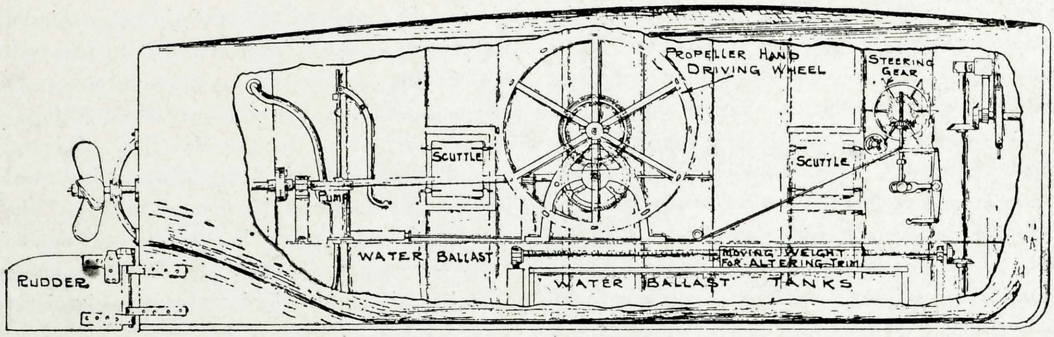
Fulton, to whose work general reference has been made, was a pacifist. He desired to make the existence of navies impossible, and to this end entered upon the invention of explosives. Britain's naval strength encouraged him to look to Napoleon for encouragement, and his submarine boat Nautilus, illustrated on the opposite page, may be said to have marked the beginning of the practicable submarine boat. Launched in 1801, she was first worked on the Seine. She was 21 feet 4 inches long, 7 feet in diameter, designed with a strength to enable her to dive to a depth of 25 feet, being constructed of copper with iron frames. Submergence was achieved by the admission of water into tanks through Kingston valves;

she had pumps for expelling it in order to rise again in the water. Aft she had inclined planes to control the vessel when being submerged or raised. She carried a mast and sails, which were collapsible like an umbrella, so that the mast could be folded down on the deck like those of present-day submarines for Marconi wireless telegraphy and signalling. She had a two-bladed propeller, rotated by a hand-wheel, gearing being interposed to ensure high revolutions for propulsion on the surface or submerged. A vertical rudder served for the steering of the boat. Projecting through a spherical conning tower, with a thick glass scuttle for observation, was a spike for driving into the bottom of the hull of a ship. This spike had a hole in it for the purpose of securing the line to the copper powder-magazine, somewhat after the style of the Bushnell system. There was also a large glass scuttle on the top of the boat to admit light to the interior.



The vessel was easily submerged, and the Seine current enabled her to proceed a considerable distance during eight minutes' submergence. More trials were made at Brest, where she remained below the water for an hour. She covered 500 yards in seven minutes when under water, and returned to the point of starting. As a test an old schooner was blown up by a "magazine" with 20 lbs. of gunpowder towed by the Nautilus. This was the first case of a ship being blown up in Europe by a submarine explosion. Fulton got no encouragement either in France or England, and returned to America in 1806, where he did good service in developing steam navigation.

Germany's first essay was with a boat $26\frac{1}{2}$ ft. long and of $38\frac{1}{2}$ tons displacement, built in 1850 from the designs of a Bavarian artilleryman—Corporal William Bauer—and intended to act secretly against the Danish blockading fleet. This vessel, Le Plongeur Marin, was like the ship-shaped caissons now used at docks, with a hand-worked propeller and rudder at one end. While water was used for immersion, as by Fulton, with the necessary ejection pumps, Bauer had a weight movable fore and aft to alter the inclination or longitudinal trim and thus facilitate diving or emergence. This weight was moved by worm gearing actuated by a hand wheel. On the hatchway, through which the crew entered



and left the boat, there were "gloves" to enable the explosive to be attached to the enemy's ship, and the explosion was effected by a primary battery. A successful feint was made from Kiel, and the moral effect on the Danish warships' crews caused them to withdraw; but structural weakness ultimately caused the water to enter the boat. The air in the interior, being compressed, caused the hatch to blow out, and fortunately Bauer and his two of a crew were shot up to the surface. The sunken vessel was discovered in 1887, and is now, or was until lately, in one of the Berlin museums. Bauer lost prestige in Germany, tried experiments in St. Petersburg, London, and elsewhere, building many boats; he contributed much towards knowledge of submarine boats, but did not achieve final success. He was pensioned by Germany, and has a monument to his perseverance and resource at Munich.

When the American Civil War broke out the Northerners had powerful warships, and against these "Goliaths" the Southern States built submersible boats, which they called "Davids." Some of these were mechanically propelled, having a boiler and a single cylinder horizontal engine driving a propeller through gearing: in others men worked the crank shaft, They were sunk until the top was awash, the funnel only showing, but even this could be telescoped so that little of it could be seen. The 54 ft. long boats, of cylindrical form amidships with conical ends, carried at the bow a spar having a copper case containing 134 lbs. of gunpowder with chemical fuse. This is one of the earliest instances, if not the first, of a spar torpedo. Off Charlestown one of these submarine boats attacked the Ironside, and the quartermaster hailed the unrecognisable object; the reply was a volley of musketry from the submarine hatch, a Federal officer being killed. The submarine kept on its way; its gunpowder exploded, but as it was too near the surface little damage was done to the Ironside. The David was swamped, and the lieutenant and the two members of the crew were picked up by a schooner.

In future boats the spar was given a downward inclination to ensure greater immersion to the "torpedo." Such a boat, with the screw propelled or rotated by eight men working cranks on the screw shaft, succeeded in February, 1864, in sinking in shallow water the new wooden ship Houstanic, the propeller of which, fouling the spar caused the explosion of the charge. The submarine was lost with all hands. This boat had hydroplanes on each side forward to assist in immersion and to keep the bow low. In April of the same year the Minnesota was injured off Newport News by a steam David, and in March the Memphis was attacked in North Elisto River. The measure of "liveliness" due to the Davids kept the Federal fleet on the move, especially at night.

Nearly fifty years elapsed before a submarine boat was again used in war. In the intervening years great changes were made, not only to improve the mobility of the ships and the facility in diving under, and emergence to, the surface, but especially in the weapons of destruction they carried. The noted gun expert, Nordenfelt, took up the proposals and experience of a Liverpool curate, Garrett, who achieved much success with a 14 ft. steam boat. In the next ten years Nordenfelt built several steam vessels—one of 125 ft. in length, of 230 tons displacement submerged, and with steam machinery of 1,300 indicated horse power to give a speed of 14 knots, made a great sensation at the 1887 Jubilee Naval Review at Spithead. From this time forward the British adopted a waiting and watching attitude. France was stimulated by Nordenfelt's success and continued experiments almost unceasingly. Spain worked at the problem for a time from

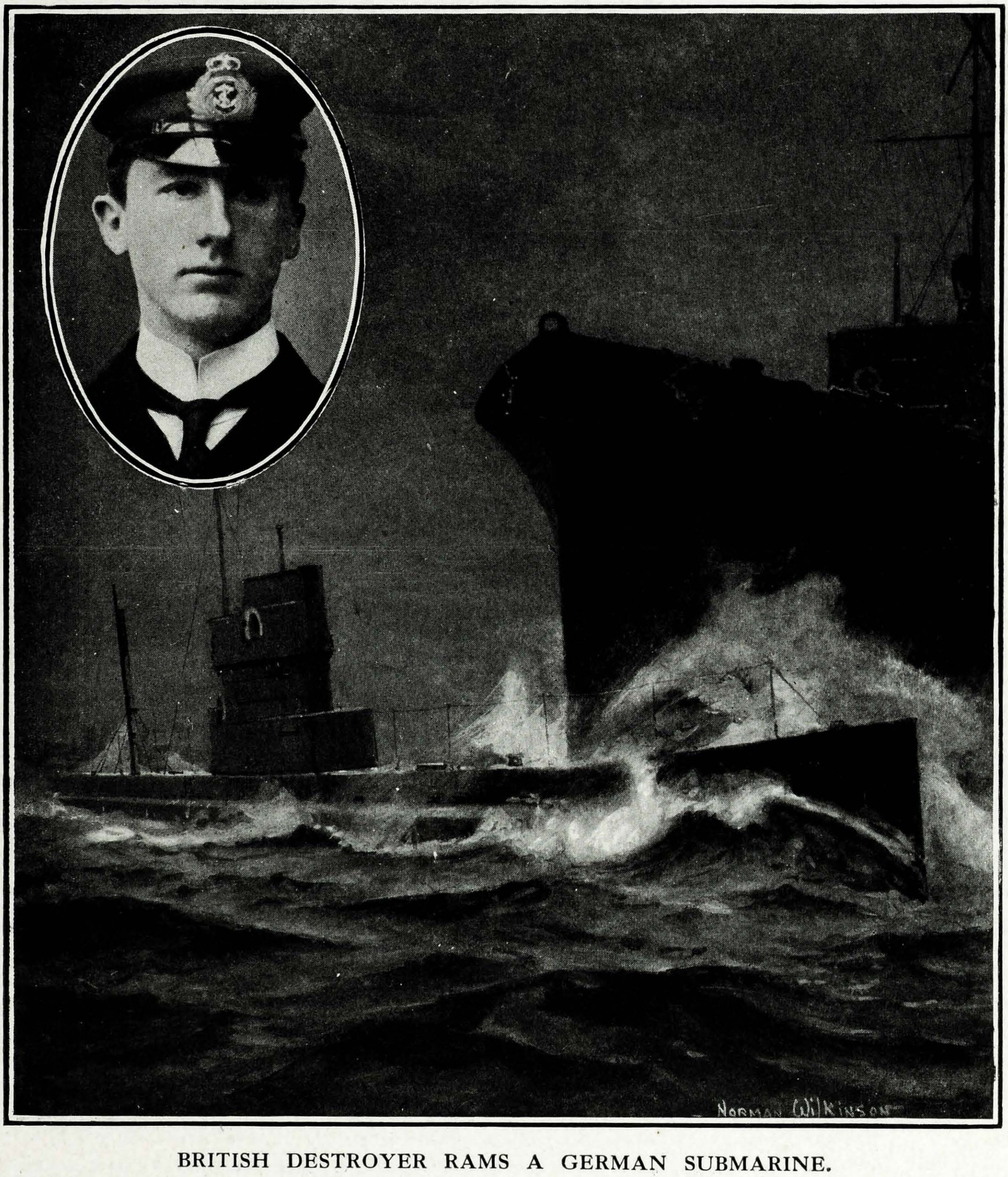
SINKING OF THE GERMAN DESTROYER "S126."

Submarine "E9" (Lieutenant Max K. Horton inset) torpedoes the German destroyer in the mouth of the Ems, October, 1914.

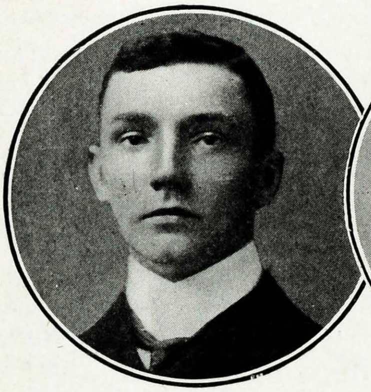
1860, Russia began again in 1876 and America in 1893, but it is not proposed here to review all the stages in the process of evolution ; that is completely and admirably done in the book on Submarine Boats, Mines and Torpedoes, by Captain M. F. Sueter, R.N., who himself did much towards perfecting such weapons, and has done even more in bringing aircraft to their present high state of utility.

France was most consistent and confident in adherence to the idea of underwater warfare. Most of the early notable boats were pure submarines and were electrically propelled. Others had steam machinery. Then separate machinery was introduced for surface and for submerged propulsion, steam engines being used on the surface and electric motors under the surface, run by electric storage batteries, the motor being also an electric generator, which, when driven by the steam engine on the surface, recharged the batteries at will. Holland, in the United States, proved the efficiency of gasolene or petrol engines, which took the place of steam engines in later boats.

This use of the oil engine was probably the departure having the most far-reaching effect during the past fifty years. Steam machinery

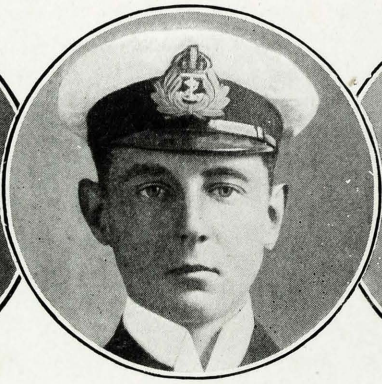


BRITISH DESTROYER RAMS A GERMAN SUBMARINE.
A German submarine rammed and sunk by the destroyer "Badger" (Commander Charles Fremantle) off the Dutch Coast, October, 1914. Inset : Commander Fremantle.



[Russell.

LIEUT.-COM. R. C. HALAHAN ("D67").



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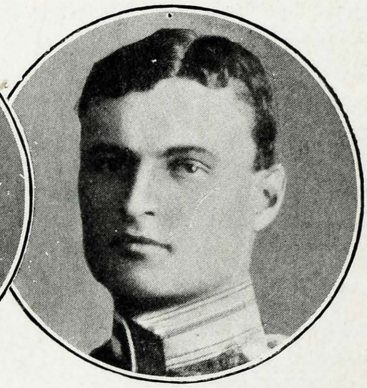
LIEUT. C. H. VARLEY ("A10").



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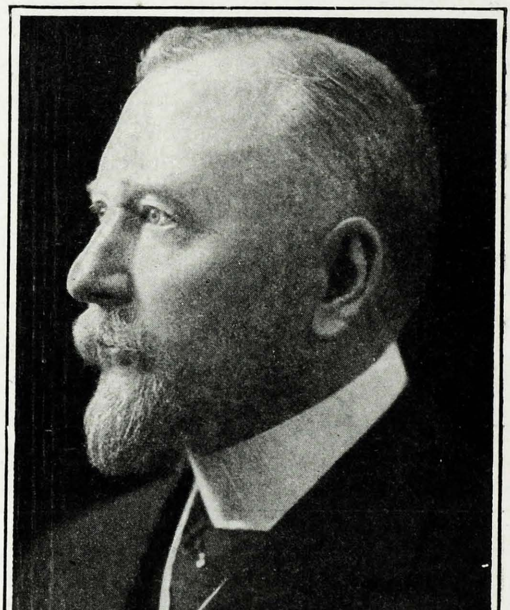
LIEUT. A. POLAND ("C30").

was found in early years not only heavy, but in some cases involved almost insufferable temperatures and increased the time required for diving. The oil engine, when petrol was used, involved danger owing to the possibility of ignition, and when paraffin or petroleum was used in the ordinary system requiring ignition there was still danger and irregularity. The Diesel engine changed all this, and was adopted for submarines first by the French soon after the 1900 Paris Exhibition, where the Diesel oil system was shown at work. The influences of these changes we shall review when we come to consider the tactical work of the submarine as influenced by design.

The British Admiralty ordered their first submarine boat in 1900. After careful consideration of the results of all types they decided to adopt the Holland design of vessel then in use in the U.S. Navy. The American company, which had supported Mr. J. P. Holland, of Paterson, New Jersey, in all his experiments, dating from those with a man-propelled boat in 1875, entered into an agreement with the Vickers company, with Admiralty consent, for the construction of five boats, and from that time, until shortly before the war all British submarines were built at Vickers' works at Barrow-in-Furness, under the direction of Mr. James McKechnie. The result has been most satisfactory, this firm having a great reputation for the ingenuity and enterprise exercised for the improvement of all munitions.

Great developments have been made in British vessels of the class alike in form, offensive power, safety, speed and endurance. Inventions by which these improvements have been effected have been kept secret, and Messrs. Vickers were precluded from building for any unallied navy. An important contributory cause was the great range and variety of experiments carried out by the company, not only in respect of machinery, but in models at their experimental tank at St. Albans. Mr. T. G. Owens Thurston, the naval constructor of the company, has contributed largely to the valuable work by the company for the development not only of the submarine boat and every type of warship, but of means for combating the attack by the newer weapons and craft.

The five boats first built for the British Navy embodied Holland's latest ideas. He had for years adopted the gasolene or petrol engine for propelling the vessel on the surface and for driving an electric motor generator for re-charging, when necessary, electric storage batteries which supplied current to the motor



MR. JAMES McKECHNIE,
Director of Vickers Works, where nearly 100 submarines have been built.

generator for propulsion when the boat was submerged. This was the type of machinery fitted in the first British vessels. They were 63 ft. 10 in. long over all, 11 ft. 9 in. beam, and of 120 tons displacement submerged, and were constructed to stand the external water pressure due to submergence to a depth of 100 ft. The torpedo firing tube was at the bow, and three torpedoes were carried. The 160 horse-power engines gave a speed of 7·4 knots on the surface, and the 75 horse-power electric motor 5 knots when the boat was submerged. The vessels had a radius of action of about 250 miles and could work for four hours submerged. They dived like a porpoise, not on an even keel, and each vessel had two horizontal rudders to effect this purpose, as well as two vertical rudders for steering the boat. The conning tower was 32 in. in diameter, and there was a deck 31 ft. long. The view of one of these boats on the beach, on page 101, suggests the whale-like form.

The trials and working of the five boats separately, and in manœuvres with surface craft, yielded valuable data for guidance in designs of future craft, the building of which was justified by the success of these pioneers. The next vessels, known as the "A" class, were 100 ft. long and of 200 tons displacement. At this time foreign Governments had serious difficulties with the submergence of such large vessels, and the ready and complete success of the "A" boats was particularly gratifying to all concerned. Although the A1 was sunk when diving under the Berwick Castle on March 18, 1904, owing probably to a mistake in taking "bearings," that was "an act of God" and not due to mechanical deficiencies. The early "A" boats had Wolseley 16-cylinder engines of 400 h.p. for surface propulsion, giving 11 knots speed; while submerged the rate was 6 knots. The particulars of successive boats, so far as published, are tabulated on this page.

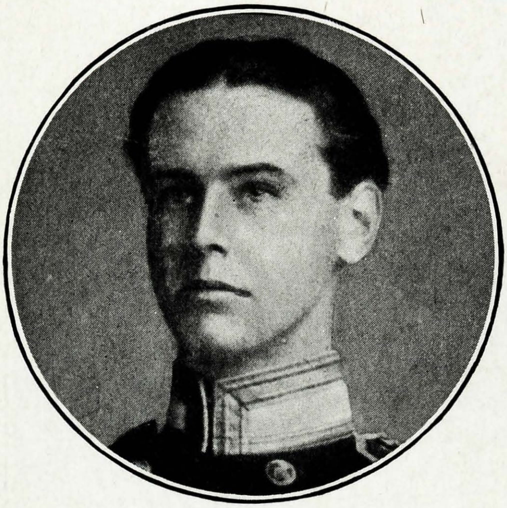
Apart altogether from the increase in size, power and speed, improvements were made in successive vessels. In the "D" Class twin engines and propellers were introduced, adding to reliability and speed. Two periscopes were adopted—one for the captain's use for navigation, the other for that of a look-out to sweep the ocean continuously. Electric gear, too, was adopted for operating the rudders. In the "E" boats not only was the number of torpedo tubes increased, but guns were fitted on disappearing mountings. The number of spare torpedoes carried was greater. The radius of action was greatly augmented. It was not until 1911 that Germany introduced guns.

But perhaps the improvement of greatest significance was the introduction of the Vickers' heavy-oil engine. The use of the petrol engine in motor cars has made the public familiar with the element of danger from fire with petrol. An outbreak would be more serious in its consequences in a boat, especially where there are only comparatively narrow openings for egress, as in a submarine boat. The heavy-oil engine enabled fuel oil of a higher flash-point to be used, so that there was less liability to ignition of the supply. Later, when considering the influence of design on tactics, we shall explain the significance of these and other engine developments. The success of the British submarine was, in a great measure, due to engineering, and in this connexion a reference ought to be made to the ingenuity and enterprise which was displayed not only directly in all naval work, but by the stimulation of his staff, by Engineer Vice-Admiral Sir Henry Oram, K.C.B., the Engineer-in-Chief of the Navy. For something like thirty years at the Admiralty, he exercised a powerful influence in the prosecution of the enormous advances made in naval engineering for surface vessels, which disclosed itself not only in the enormous speed realized by large ships and torpedo boat destroyers, but by the remarkable immunity from breakdowns in peace service and during

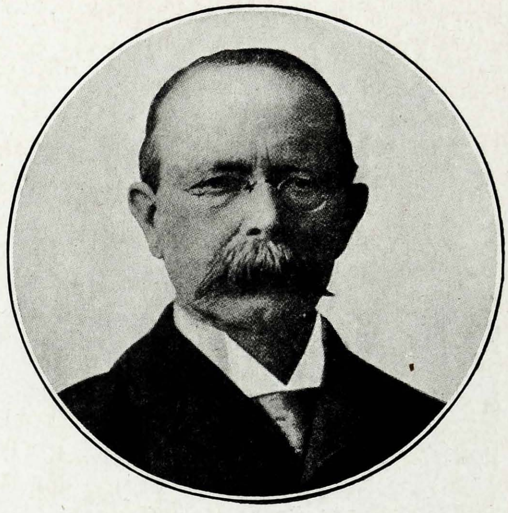
PARTICULARS OF BRITISH SUBMARINE BOATS.

—	1–5	Early A.	Later A.	B.	C.	D.	E.
Date laid down	1901	1902	1904	1905	1906	1908	1910
Length over all	63 ft. 10 in.	100 ft.	100 ft.	142 ft.	142 ft.	160 ft.	176 ft.
Beam	11 ft. 9 in.	11 ft. 9 in.	12 ft. 8 in.	13 ft. 6 in.	13 ft. 6 in.	20 ft. 6 in.	22 ft. 6 in.
Displacement (submerged) ...	120 tons	200 tons	200 tons	313 tons	313 tons	600 tons	800 tons
H.P. for surface navigation ...	160 H.P.	400 H.P.	600 H.P.	600 H.P.	600 H.P.	1200 H.P.	1600 H.P.
Surface speed	7·4 knots	11 knots	11·5 knots	12 knots	12 knots	14 knots	15 knots
Submerged speed	5 knots	6 knots	6 knots	6½ knots	8 knots	9 knots	10 knots

(The particulars are partly from the Navy Estimates; partly from the Navy Annual.)



LIEUT.-COM. E. C. BOYLE
(Submarine "E14").



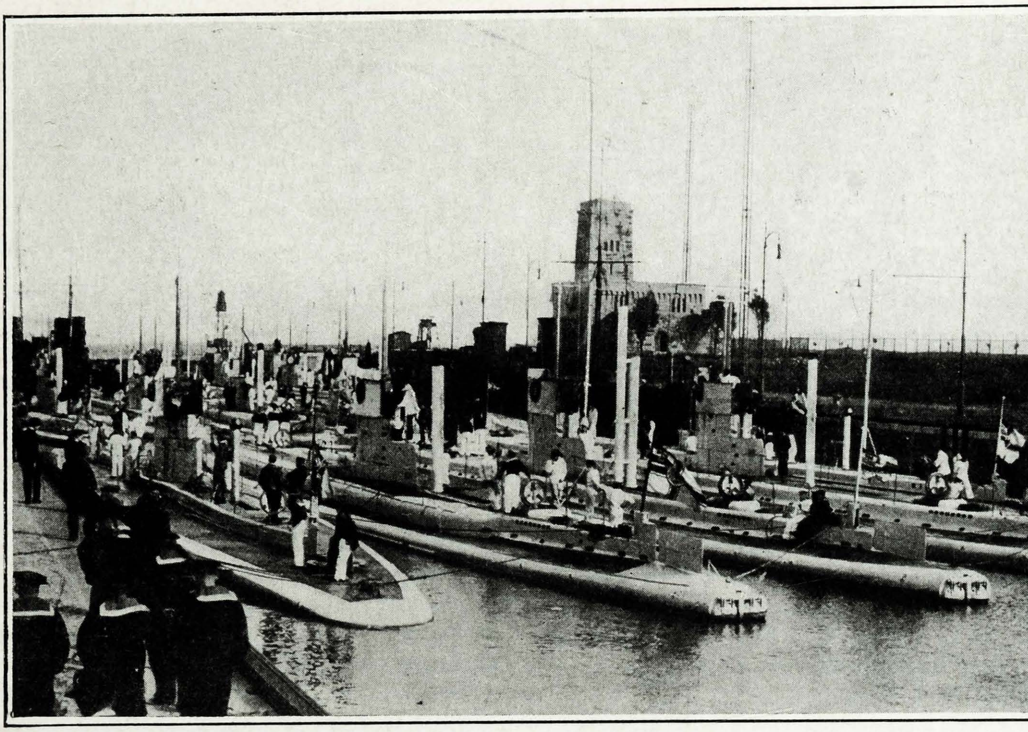
J. P. HOLLAND,
The inventor of the Holland submarine.

the war. Sir Henry was for long Deputy Engineer-in-Chief and became Engineer-in-Chief in 1906.

We may now similarly review the progress of contemporaneous submarine building in Germany. At the time Nordenfelt was working with submarines in England, Germany ordered two boats of the class to be built respectively at Kiel and Dantzig. These, built in 1890, were 114 ft. 4 in. long and of 215 tons displacement on the surface. They had steam machinery. The speed was 11 knots on the surface and 4½ knots submerged. Germany's next boat followed French lines; this craft, 47 ft. long, depended exclusively on electric storage accumulators and a motor for propulsion. The speed was 6 knots on the surface and 4 knots submerged and the radius of action and reliability were low. They next purchased plans from a French officer, whose proposals had been declined by the authorities at Paris. The boat which resulted, built by Krupp at Kiel, was 116 ft. 8 in. long and of 180 tons displacement on the surface. The petrol engine for propulsion was of 200 h.p. and gave a speed of 11 knots on the surface, and the electric motor gave 8 knots submerged. The storage batteries sufficed for three hours' running. Five minutes were required to dive. The two periscopes fitted had each a field of 50 degrees and could be trained in azimuth by electric motors; they had a special erector fitted for

PARTICULARS OF GERMAN SUBMARINE BOATS.

—	"U1"	"U2" to "U8"	"U9" to "U12"	"U13" to "U20"	"U21" to "U32"	"U33" to "U38"
Date of commencement ...	1903	1906–1907	1908	1909–1910	1911–1912	1913
Length	182 ft. 3 in.	141 ft. 8 in.	Slightly larger than the U2 boats.	—	213 ft. 3 in.	214 ft.
Breadth	11 ft. 10 in.	12 ft. 4 in.		—	20 ft.	20 ft.
Draught	9 ft. 2 in.	9 ft. 8 in.		—	11 ft. 10 in.	14 ft.
Displacement on the surface ...	185 tons	237 tons		450 tons	650 tons	675 tons
Displacement when submerged	240 tons	300 tons		550 tons	800 tons	835 tons
Power of oil-fuel surface engines	400 h.p.	600 h.p.		1,200 h.p.	1,800 h.p.	4,000 h.p.
Power of electric under-water motors	240 h.p.	320 h.p.		600 h.p.	800 h.p.	—
Maximum speed on surface ...	11 knots	12 knots		15 knots	16 knots	18 knots
Maximum speed submerged ...	8 knots	8·5 knots		9 knots	10 knots	10 knots
Radius of action on surface ...	—	1,200 miles at 9 knots		—	1,500 miles at 12 knots	2,000 at full speed, 6,000 10 knots
Radius of action submerged ...	—	50 miles at 9 knots		—	70 miles at 6 knots	95 miles at 4 knots
Armament	One torpedo tube	Two tubes	Two tubes	Two or three tubes	Four tubes	Four tubes
	Three 17·7 in. torpedoes	Four 17·7 in. torpedoes	Four 17·7 in. torpedoes	Four or six torpedoes, one 1·456 in. gun	Eight 19·6 in. torpedoes, two 3·464 in. guns	Eight 19·6 in. torpedoes, two 3·464 in. guns



GERMAN SUBMARINES OF THE "U" TYPE AT WILHELMSHAVEN.

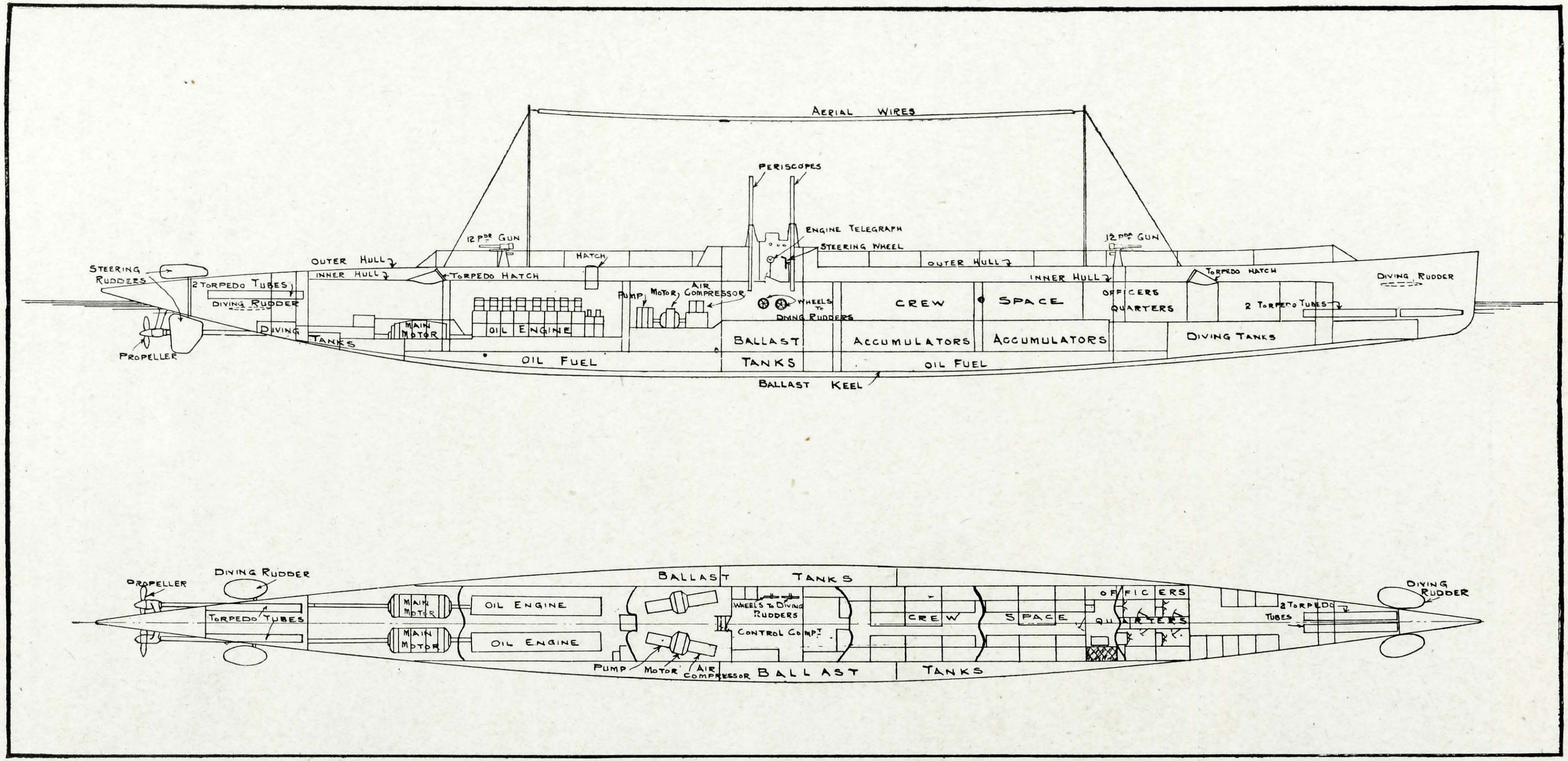
giving the observer an upright image during rotation.

From these beginnings date Germany's submarine policy. Krupp built the first boat in 1906. Like all Germany's boats it was designated by a U, meaning "Unterseebote," and a number—thus, U1. In its characteristics it resembled our "A" boats, Germany being a close student of our naval shipbuilding.

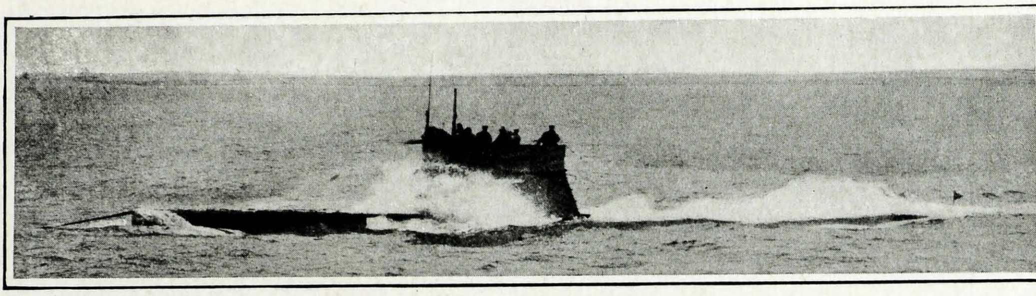
M. Laubeuf, the well-known French designer of submarine boats, at a meeting of the French Society of Civil Engineers on March 26, gave particulars of German submarine boats, and a table comparable with that of the British boats, already given, is reproduced on page 95; the particulars of U33 to U38 are from another equally reliable source.

Germany, entering upon submarine boat building late in the day, profited by the experience of others; boats were ordered from some Continental builders outside Germany in order to find out what was being done elsewhere. But once she had evolved her policy, the "frightfulness" of which has been revealed to all during the war, she pursued her preparations with the same calculated haste as characterized her in all other departments of war-material construction. In the summer of 1907 she had only one submarine in service and seven in course of construction. The sum set apart for submarine construction in the 1907 Budget was £250,000. It increased rapidly, amounting to £350,000 in the Budget for 1908; to £500,000 in that for 1909; to £750,000 in each of those for 1910, 1911 and 1912; to £1,000,000 in that for 1913; and to £950,000 in that for 1914; but there can be no doubt that after the war began an immensely greater sum was devoted to submarine boats.

Sketches of one of the latest German submarine boats are reproduced opposite, one—the upper sketch—shows the arrangement of the interior from the bow to the stern, the other is a plan. In the bow of the boat there are installed two torpedo tubes, so that double torpedo discharge can be effected at an opportune moment. The tanks in the way of these tubes are appropriated for either water ballast or compensating tanks. Strong transverse bulkheads enclose all the forward part of the torpedo tubes and provide an amount of protection in the event of collision. The compartment abaft the collision bulkhead serves for working the torpedoes, loading or adjusting them, and this space is also available for carrying spare torpedoes. The anchor and windlass gear are usually fitted in this room. Below the deck the space is utilized for diving tanks. In the next compartment are the living quarters for officers, comprising cabins, with the usual arrangements of beds, etc., for the comfort of those who may be required to



PLANS OF A GERMAN SUBMARINE.



ON DUTY.

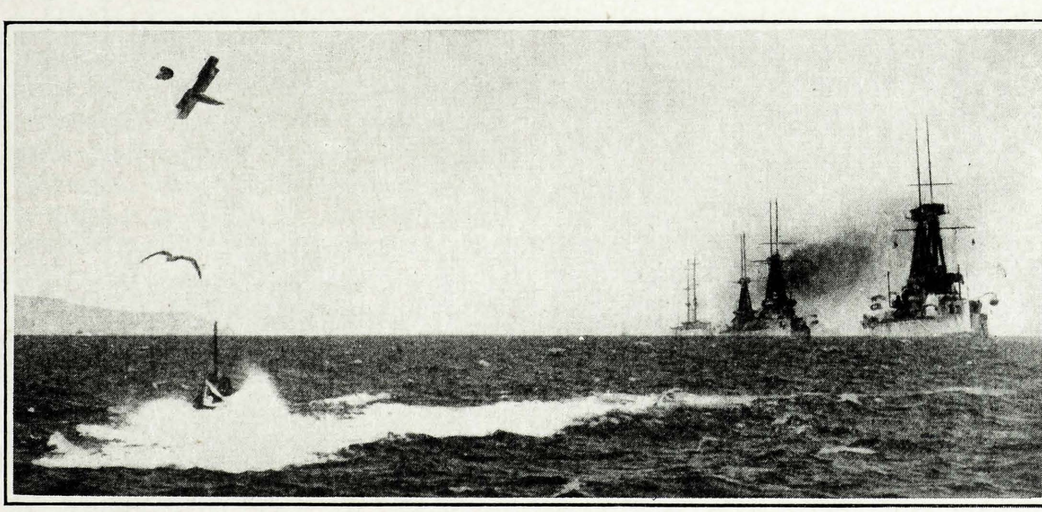
A British submarine, which is cleared of deck hamper, is ready to dive at a moment's notice.

remain at sea for long periods. The next space is allotted to the crew, each member of which is provided with a folding bed, lockers, etc. Below the deck the electric storage accumulators are stowed, and the space below this again is used for oil fuel.

The next division of the boat may be termed the Control Compartment, and in it are placed all the principal elements of control, such as periscopes, conning tower, diving and steering wheel gears, recorders, indicators, communications, etc. The objects projected by the periscopes are observable from inside the boat, so that, when the access hatch to the conning tower is closed down, operations while submerged are carried on from inside the boat proper. Below the deck ballast water tanks are arranged. In this division, too, auxiliary machinery, comprising pumps and compressors with their driving motors, are situated. In the next compartment the main propelling engines of the heavy-oil type are installed. They work twin screws. Oil fuel and lubricating oil are carried in the tanks underneath the engine seating. Immediately abaft the engine room is the main electric motor compartment, in which space are the electric motors for propelling the boat when submerged. At the extreme aft end two torpedo tubes are installed of the same pattern as those at the bow.

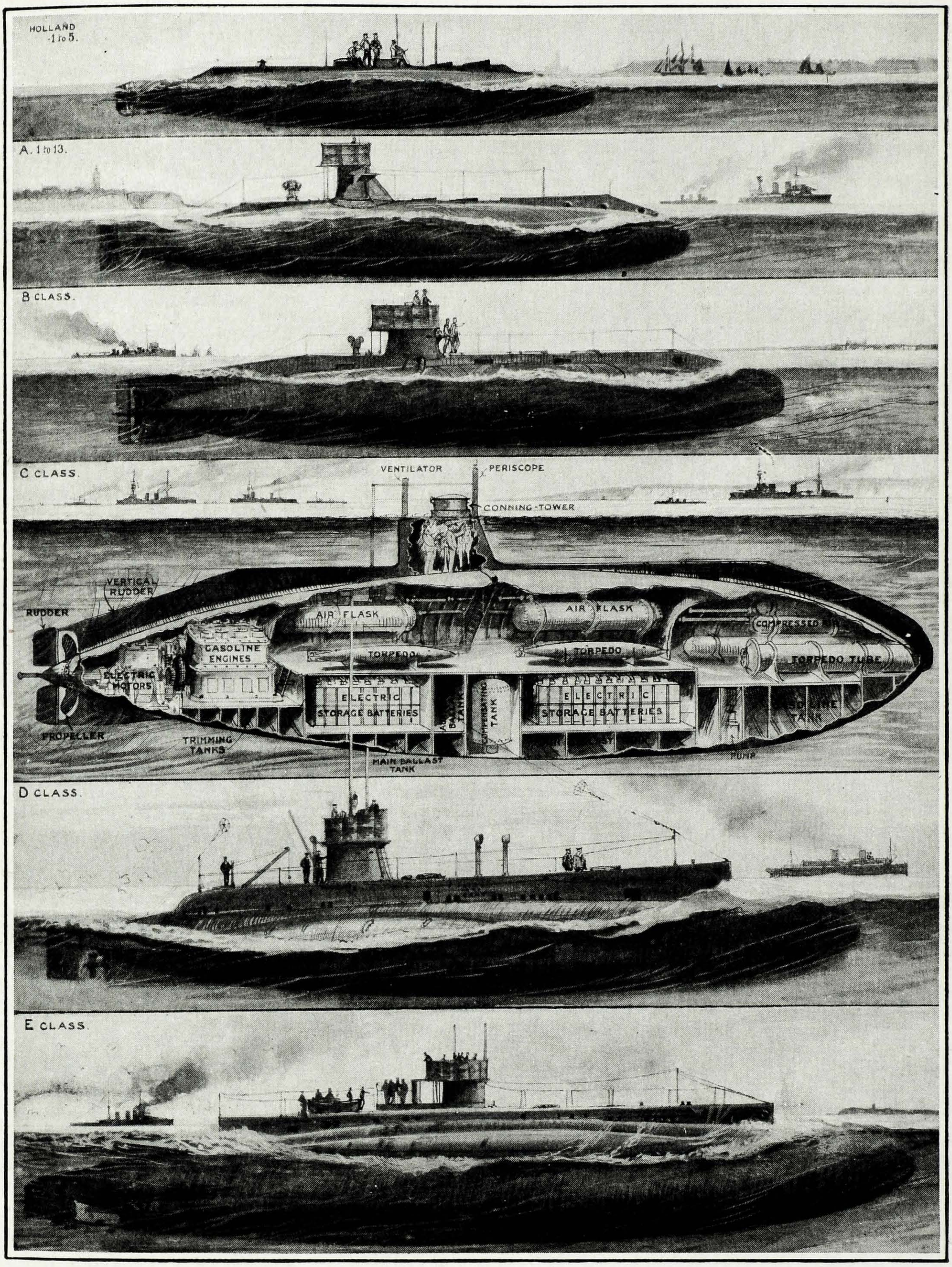
Two 12-pounder guns are placed on the top, having practically an all-round fire. These guns fold down within the superstructure, as will be described later. For diving or submerged running there are control-diving rudders ; those at the bow fold inboard when not required. A vessel of this type may safely submerge to a depth of 150 ft. and come to surface in a few seconds by air-blowing arrangements for expelling the water ballast, or by her pumping gear. The bulk of the water ballast is carried between the inner and outer hulls.

The Austrian submarine boats, few in number and of small dimensions, are for the most part of Krupp origin, and one of these—U5—it will be remembered, sank the old French cruiser Leon Gambetta in full moonlight early in the morning of April 27, 1915, when she was



BY SEA AND AIR.

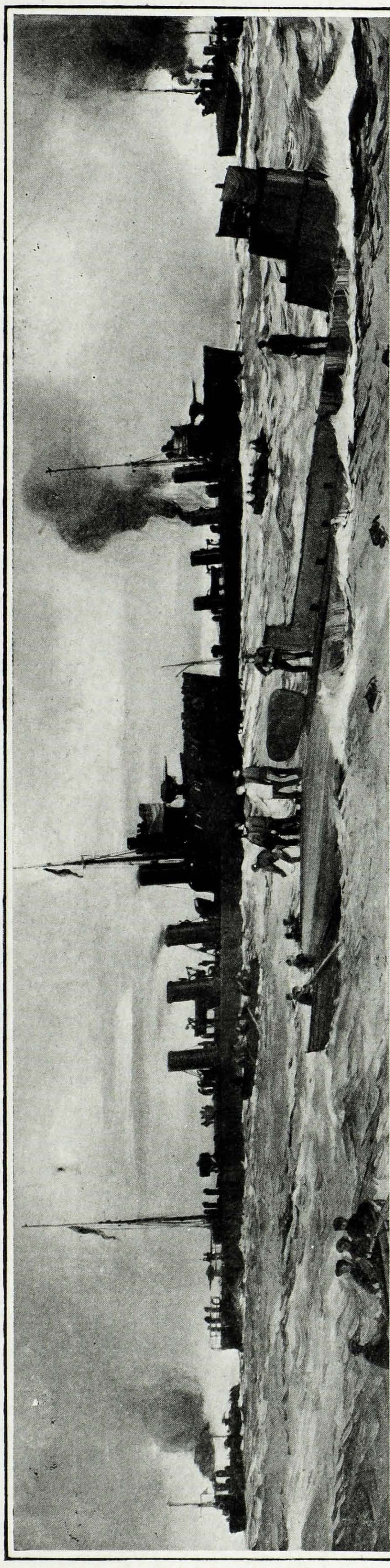
British warships, submarine and seaplane ; sea gulls on one occasion revealed the presence of a German submarine boat.



PROGRESS OF SUBMARINE CRAFT: HOLLAND TO "E."

patrolling at low speed at the entrance to the Otranto Straits. The sea was calm, but there was great loss of life.

The French contributed more than other belligerents to the solution of submarine propulsion, especially in the early days. They have tried every known system of machinery. In a 420-ton boat, Le Plongeur, built in 1858, with a spar torpedo explosive charge, like that used in the American Davids, they adopted compressed air, which was stored in steel reservoirs, for driving the propelling engines. This boat failed because an even keel, when submerged, could not be maintained. The next notable boat was the Goubet I., only 16½ ft. long and of 11 tons weight; she could thus be lifted upon a warship. She depended solely on electric motors for propulsion and had a speed of 4 to 5 knots



SINKING OF THE "U8" OFF DOVER, MARCH 4, 1915.

The last plunge of the German submarine after being attacked by British destroyers—The rescue of the officers and crew by the boats of the British vessels.

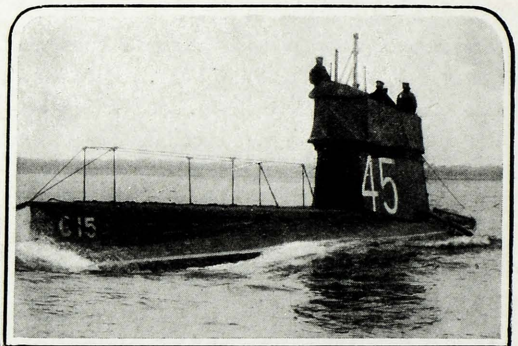
on the surface. She carried two locomotive torpedoes in "collars" on the outside. This boat was purchased by Brazil for £10,000, and a larger vessel of the same class was built for France. The experiments made with her yielded valuable data for guidance in later boats, and Goubet himself, by his experiments, gave a great impetus to other workers. The French authorities continued to encourage scientists, and many types were produced. An invitation in 1896 for competitive designs for a boat not exceeding 200 tons displacement brought designs from twenty-nine persons, one of the most prominent being probably M. Laubeuf, and his vessel, the Narval, marked a great advance. She was 111½ ft. long and of 168 tons displacement submerged. The hull had a double skin, and water freely circulated between the two skins, increasing protection against gun attack. The space, too, was used for water ballast to decrease the buoyancy before submergence and to compensate for the weight lost owing to the consumption of fuel, etc. Laubeuf, adopting Holland's practice, used a different system of machinery for surface and submerged propulsion, but had not the courage of the American designer to use petrol or gasolene engines for the former. Instead the boat had an oil-fired tubular boiler and 250 h.p. triple-expansion engines. A new departure was made in having hydroplanes to increase control in diving, in order that the sulphuric acid would not be spilled from the electric accumulators—which was for long a source of trouble in nearly all boats. Latterly the batteries were entirely closed in. The Morse and the Gustave Zédé were the other competing boats and were electrically propelled. The chief disadvantage of the Laubeuf boat was that, owing to the steam machinery, 20 minutes were occupied in submerging her.

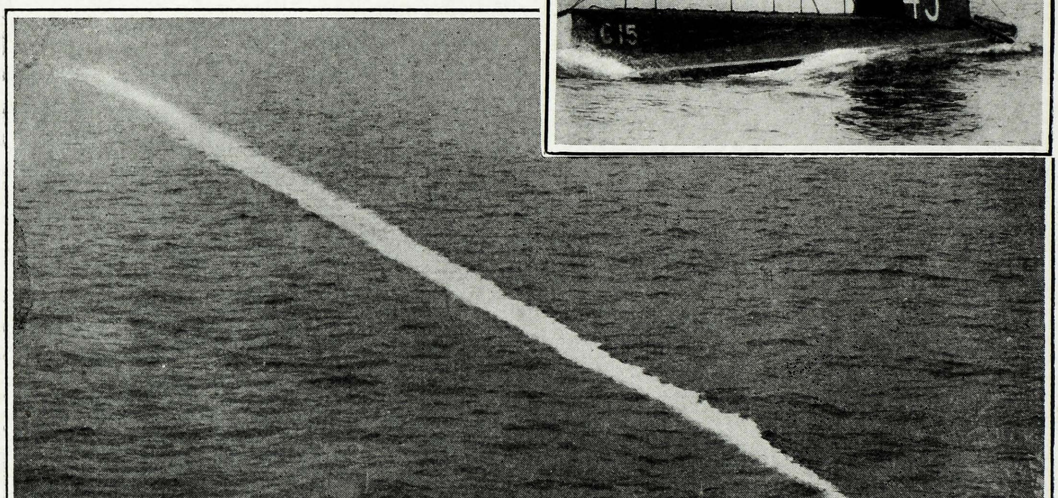
Then came full recognition in France of the idea that in view of the collective naval power of the then Triple Alliance, as compared with the French fleet, a submarine navy could alone regain the balance. *Le Matin* raised a sum of £12,000 by public subscriptions, and two electric submarines were built. From this time forward there was great activity, and twenty boats were provided for in the Budget of 1901—the year when Britain began submarine building. These were all practically alike, designed by Romazatti, and were known as the Naiade class. They were 77 ft. long, and of 68 tons displacement on the surface. Most of these boats were modified during construction, and many were fitted with benzoline engines, but these did not prove successful. There was later a return to varied types of craft, and it is not possible, within reasonable limits of space, to give particulars of all, but a table may here be given showing representative types for comparison with the main features of the British and German vessels.

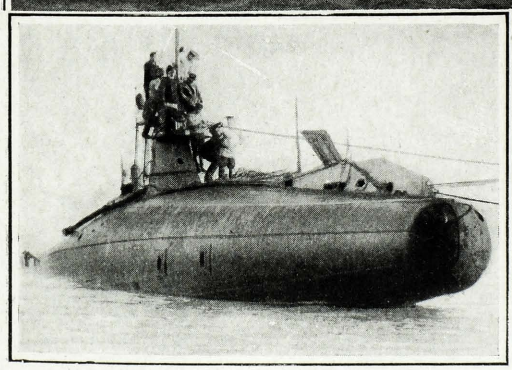
REPRESENTATIVE TYPES OF FRENCH SUBMARINE VESSELS.

Year.	1901.	1904.	1907–1912.	1913.
Name	Naiade	Aigrette	Pluviose Class	Gustave Zédé Class
Length	77 ft.	117 ft. 6 in.	160 ft.	239 ft. 6 in.
Breadth	7 ft. 6 in.	12 ft. 9 in.	16 ft. 4 in.	19 ft. 8 in.
Depth	7 ft. 11 in.	8 ft. 4 in.	13 ft. 6 in.	14 ft. 4 in.
Displacement surface	68 tons	175 tons	398 tons	787 tons
Displacement submerged ...	—	220 tons	—	1,000 tons
H.P.	60	200	700	4,000
Speed on surface	8	10·5	12·5	20
Speed submerged...	5	7·5	7·75	10

The Aigrette, of which several were built, resembled the Laubeuf type, but instead of having a double hull, they had an inner longitudinal bulkhead along the sides only. The absence of the double skin over the top, it was considered, reduced the draught and improved the seaworthiness. Moreover, they had Diesel heavy oil engines, which had been exhibited by German firms at the 1900 Paris Exhibition. France had to purchase six sets before they could get drawings. This class of ship only took from four to five minutes to dive, a great improvement on the twenty minutes of the earlier boats. Some of the later vessels have water-tube "express" boilers and steam turbines, working through gearing on twin screws. Messrs. Schneider have done valuable work, not only in building French submarines, but in the improving of all features of design. The Laubeuf type of submarine is constructed in this country by Sir W. G. Armstrong, Whitworth & Co., Ltd., Elswick.

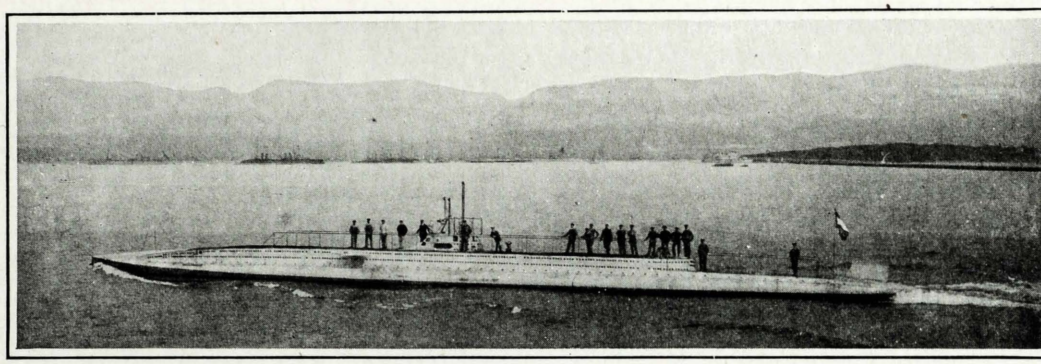






ABOVE AND BELOW THE SURFACE.

Full speed on the surface of the water; wake effect on the water of a torpedo fired from a submerged submarine; and a vessel out of water.



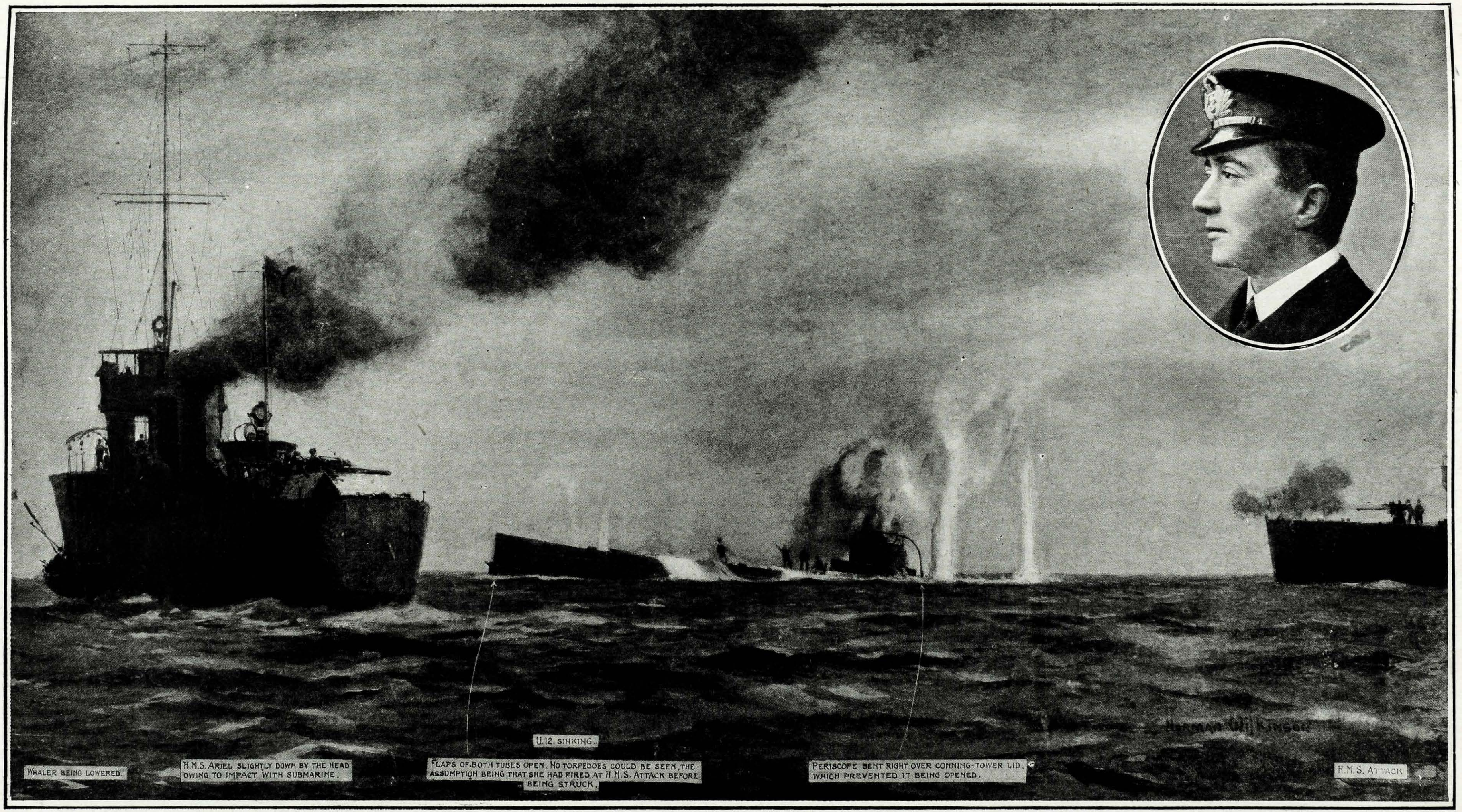
THE FRENCH SUBMARINE "DELPHIN."

The Russians were eager to try submarines in the war against Japan, but although several, including some of the Lake type, were sent to the Far East, there is no record of war service. An electrically propelled boat of 60 tons was sent across the Siberian Railway. Her armament consisted of two 18-in. locomotive torpedoes suspended in drop collars, a system invented by Drzewiecki, who designed many of Russia's earliest boats. This boat, however, was not completed at Vladivostok in time to take part in the war. There was another vessel sent to Port Arthur, but she took no part in the war. This vessel, built in 1905, was of 200 tons displacement submerged, and had petrol engines, which gave her a surface speed of 11 knots. When being tested at Cronstadt, the Kingston valves fitted to admit water for submergence were opened when the conning-tower hatch was not closed. As the boat sank, water flowed into the hull, with the result that an officer and 23 men were lost. Many of the latter were on board for instructional purposes. This was the earliest disaster of great magnitude, and perhaps raised doubts as to whether such boats would ever be safe. In 1904 the Russians adopted the Holland type, which in Russia is known as the Biriliff type, from the Holland works there. Ships of other designs were also built, and, as with the other European nations, there was a steady advance in size and power, a few of the later ships being of 500 tons displacement, with oil engines to give a surface speed of 13 knots.

The Laurenti type of submarine boats was adopted by Italy, and many nations had one or more vessels of the same class. It has many valuable qualities. Signor Laurenti introduced the principle of two hulls, the outer of a form to give the highest propulsive efficiency and reserve buoyancy on the surface, with the minimum of draught, and the inner to minimize the internal cubic capacity while ensuring satisfactory conditions when submerged. The double skin, which is braced with stays to ensure the maximum of structural strength,

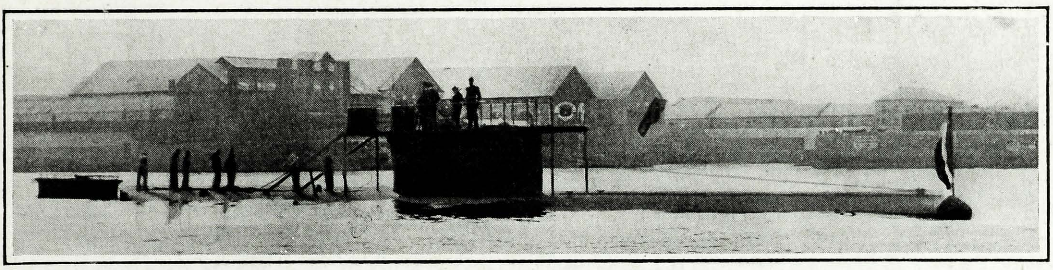
M. LAUBEUF,
The Designer of French Submarine Boats.

CAESAR LAURENTI,
Designer of Italian Submarine Boats.



THE SINKING OF A GERMAN PIRATE SUBMARINE BY A BRITISH DESTROYER, MARCH 10, 1915.

The German submarine "U12," which was rammed and sunk by the H.M.S. "Ariel" (Lieutenant-Commander James V. Creagh). The H.M.S. "Ariel" is seen on the left, slightly down by the head, owing to impact with the submarine. The periscope of the "U12," which was bent right over, prevented the conning-tower lid being opened. The boat on the right is the H.M.S. "Attack." Inset is Lieut.-Com. Creagh.



THE FRENCH SUBMARINE "OPALE."

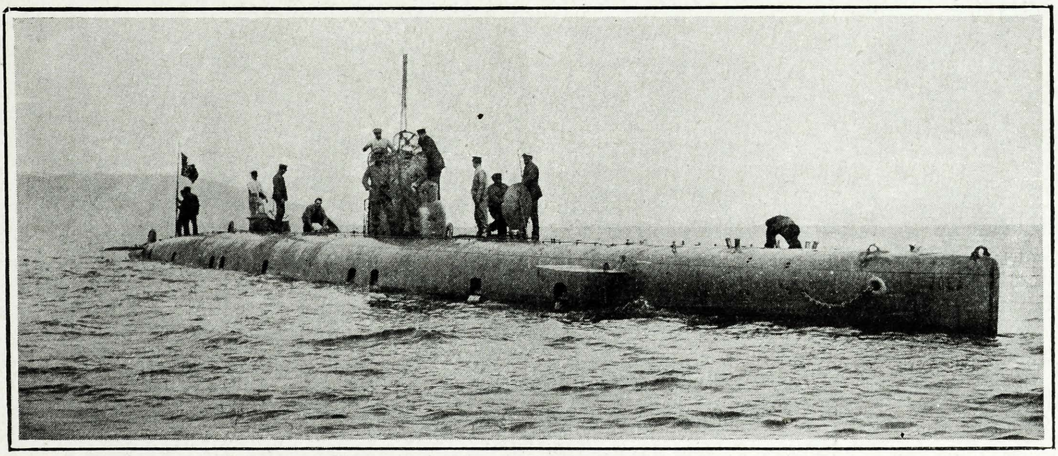
is confined largely to the central part, and the space between the two skins, up to the water line on surface displacement, is utilized to form water-ballast tanks for submergence. Kingston valves are fitted at the turn of bilge on each side for the flooding of the compartments, and the structure is made sufficiently strong to enable the water to be pumped out without danger of collapse due to the pressure of the sea water on the outer skin. Compressed air can be, and normally is, used for expelling the water when the boat is to return to the surface. Hydroplanes are fitted for diving. Over the central part of the ship there is a double decking, with lattice bracing, and valves are fitted on each side above the water-line, through which water enters and leaves respectively for the submergence or emergence of the vessel, which is effected on an even keel. This double decking extends practically from bow to stern. Vertical bulkheads divide the hull into several compartments. While the German boats have generally a sheer at the forward end, and the French boat a downward curve, the Laurenti boat has the top level right to the stem.

Beginning with vessels of 120 ft. long in 1906, the size of Italian boats had advanced to 148 ft. in length, with a speed of 16 knots on the surface, and 9 knots when submerged ; but it is understood that a Laurenti type of boat being built in Italy for Germany was completed after the outbreak of the war, and added to the Italian Navy. This was of U33 class, 835 tons displacement submerged, while the Fiat engines of 4,000 h.p. gave a speed on the surface of 20 knots. The Fiat San Georgio companies contributed greatly to the success of submarine boats. The Laurenti type is built in this country by the Scotts' Shipbuilding & Engineering Co., Ltd., Greenock.

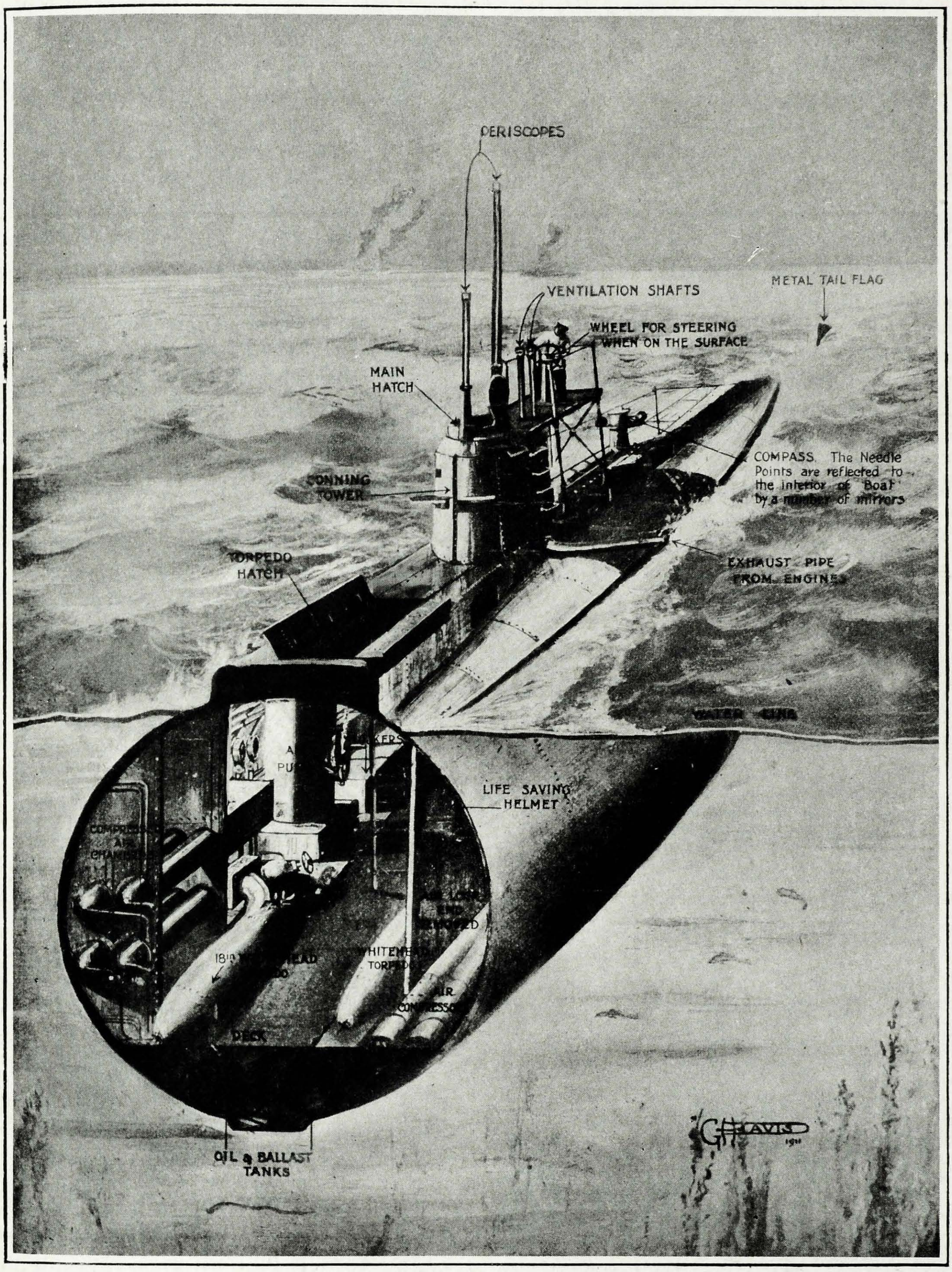
As to the strength of the submarine fleets of the Powers, we give in the table on p. 106 the numbers of the principal Powers as given in a British Government report, issued a few months before the war. We have arranged these according to the year of completion, as this affords some indication of the size, speed, radius of action, and power.

There is also shown the number of boats building in April, 1914. There is room for doubt as to whether the figure given for Germany—14—is not greatly understated. In any case, it is known that many new boats were completed after the outbreak of war, and many more were laid down.

The manufacture of the machinery takes the



AN ITALIAN SUBMARINE.
Ready to dive.



A SUBMARINE SHOWN IN SECTION.

The above illustrates the interior of a submarine, showing under the water the oil and ballast tanks, the deck tanks for compressed air, two 18-in. Whitehead torpedoes, compressed air chambers, and air pump; and above the water-line the periscopes, the torpedo hatch, conning tower, main hatch, ventilation shafts, and wheel for steering when on the surface.

longest time, not only because of its intricacy, but because of its construction, and experienced workers must be employed for this work, as well as for the building of the hull. Germany had an advantage, as the Diesel engine was more favoured in Germany than elsewhere, probably because of the relative scarcity of good steam coal and its higher price. More firms were engaged upon its construction, and thus it was easier to increase suddenly the output.

But even so, it is doubtful if a submarine could be completed in Germany under seven or eight months, and thus the "Submarine blockade" may have been timed to begin on February 18 because there were then becoming available submarine boats laid down before and at the commencement of the war. The Germans probably laid down a great many boats at once, and from April, 1915, onward there was a steadily increasing augmentation of the submarine fleet. A greater difficulty was the training of officers and men for a great accession to numbers of boats.

The Armament of Submarines.

The principal weapon of all submarine boats is the torpedo. There are many types, but here we are only concerned with those used in submarine boats. The generic type is that invented by the English engineer, Mr. Robert Whitehead, when engaged as the manager of a factory at Fiume. The Germans adopt the Schwartzkopf, and the Americans have the Bliss-Leavitt, in which an important difference is the use of turbines of the Curtis type for propelling the torpedo, but with compressed air instead of steam, as in surface craft.

The Whitehead torpedo originated in the mind of an Austrian naval officer, Captain Lupuis, who, as the result of a series of experiments, evolved a floating weapon which had, at the forward end, a charge of gunpowder, to be automatically fired by a piston detonator on contact with the enemy's ship. The propulsion of the weapon was to be achieved by the use of clockwork, while the vessel was guided along or near the surface of the water from a fixed base by means of lines or ropes. The idea was acceptable, but the method of propulsion and guidance precluded complete success from the practical point of view. Captain Lupuis recognized that success depended upon the torpedo being entirely independent of outside aid after being sent on its trip, and he was fortunate in securing the cooperation of such an ingenious engineer as Whitehead to devise the mechanism not only for self-propulsion and steering, but ultimately also for the maintenance of the depth within predetermined limits, and for securing safety before the torpedo entered the water, and certainty of explosion only when the object to be destroyed was struck. The first Whitehead torpedo was a pronounced success. It was of steel, was 14 in. in diameter, and weighed 300 lbs. It carried a charge of 18 lbs. of dynamite, and the engine was driven by air, stored at a pressure of 700 lbs. in a chamber made of ordinary boiler plate. The speed was six knots, but the range was very small.

Submarines of Belligerent Fleets shortly before the Beginning of the War.

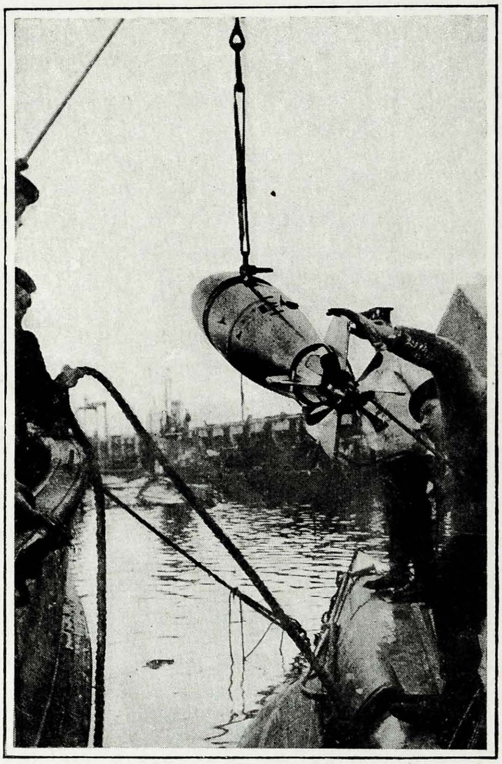
Year of Completion.	Great Britain.	France.	Russia.	Italy.	Germany.	Austria.
1905 or earlier	9	7	—	2	—	—
1906	12	2	11	1	1	—
1907	7	6	3	1	—	—
1908	6	10	4	3	1	4
1909	16	6	1	—	2	2
1910	8	2	5	—	4	—
1911	3	7	—	2	4	—
1912	3	10	—	3	6	—
1913	5	—	1	6	6	—
Building April, 1914 ...	27*	26	18	2	14†	9
	96*	76	43	20	38†	15
	235				53	

* Exclusive of two Australian boats.
† Exclusive of one Norwegian boat building in Germany, absorbed into the German Fleet.

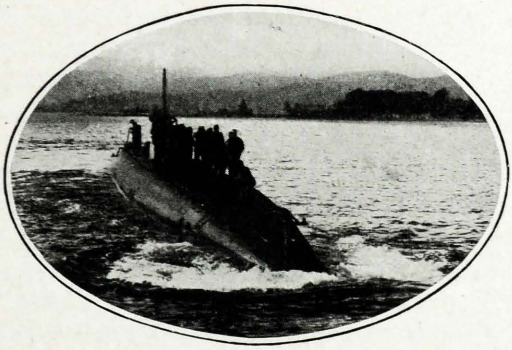
In this first instrument there was no attempt to introduce mechanism for maintaining the depth of the torpedo below the surface at a predetermined level. That came in 1868, as the result of very careful experiments. By this time, too, it was discovered that guncotton was preferable to dynamite, and the power of the propelling motor was increased so that the speed was maintained at 8½ knots for 200 yards or at 7½ knots for 600 yards. It was a torpedo 14 in. in diameter, with these characteristics, which demonstrated in tests before a British Admiralty Committee the potentialities of the Whitehead torpedo, the secret and right of manufacture of which were then bought for £1,500. From this time forward many improvements were made. By 1876 the speed had been increased to 18 knots for a distance of 600 yards, and the charge of guncotton in the warhead was advanced to 26 lbs. In 1884 the speed had gone up to 24 knots at 1,000 yards range, and by 1889 to 29 knots for the same range, while the charge was 200 lbs. of guncotton. The greater speed was largely a result not only of the increase in size (the torpedoes having become of 18 in. diameter), but of augmentation in the power of the propelling engines—manufactured to work with compressed air—and also of the introduction of twin three-bladed propellers. The most recent advance has been a consequence of heating the air used in the propelling engine. Now the torpedoes of 21 in. diameter are capable of achieving a speed of almost 45 knots for the first 1,000 yards of the course, reduced to 40 knots at 1,500 yards, and 38 knots at 2,000 yards, while the range has gone up to over 4,000 yards, the speed at that distance from the point of discharge being 28 knots. It will be understood that the reduction in speed is consequent on the use of the compressed air causing a reduction in the pressure, which, when the torpedo first leaves the submarine, is as high as 2,250 lbs. per sq. in. The normal explosive charge is about 330 lbs. of guncotton.

The torpedo of the present day has a diameter of 21 in. Its form has been evolved from Nature. The earlier torpedoes were made with a fine entry, but tests showed that a bluff head, following the lines of the fish, reduced the resistance to passage through the water. The torpedo, however, at the after end tapers away to a fine point, round which a tail-piece carries the propellers, etc. The shell is built up in sections, and non-corrosive metal is used not only for the outer skin, but, as far as possible, for the internal mechanism, so that there may be little or no deterioration during storage. There are five main sections from bow to stern. First, that containing the charge and the mechanism for exploding it on contact with the ship; second, the chamber for the storage of the compressed air for driving the propelling machinery; third, the chamber in which is enclosed the balancing gear, to ensure that the torpedo will travel without variation at a given distance from the surface of the water; fourth, the engine room; and fifth, the buoyancy chamber. There are variations in the length of the air chamber, in order to increase the explosive warhead. It is possible that the great damage done to some of our larger ships by German submarines, and the short period which elapsed before they sank, were due to the use in this way of an excessively large volume of explosive compound, as well as to its particular composition. This increase of explosive charge is, it is true, at the expense of the range, as the reduction in the size of the air chamber lessens the time which the propeller engine can be run. This shortening of the range, however, carries little disadvantage when the vessels to be attacked are unarmed merchantmen, as the submarine boat can risk much against an unarmed vessel by getting close to her. It is possible, further, that the German submarines use two different types of torpedoes, one for short range, to attack defenceless vessels, and the other for long range, to attack warships.

In connexion with the warhead it will be understood that it is of the highest importance that there should be no detonation of the charge until the torpedo has actually struck the object to be destroyed. Thus safety has to be ensured during the loading of the torpedo into the tube, out of which it has to be fired from the submarine, and, further, it must be provided that contact with any light object during its transit should not cause detonation. Where tubes are fired from the decks of vessels, as in the case of torpedo-boat destroyers, there is a further precautionary measure to ensure that there will be no possibility of the explosion of the charge when the torpedo first strikes the water. The striker



TORPEDO BEING LOWERED ON BOARD A SUBMARINE.



AN ITALIAN TORPEDO BOAT DIVING.

serves as a simple hammer, usually igniting fulminate of mercury, which in its turn acts on a primer charge of dry guncotton enclosed in a tube to the rear of the striker, and this in turn explodes the main charge. The striker, to begin with, has a pin which keeps it in position until the torpedo is comfortably placed in the tube from which it is to be ejected; this pin is then removed. Next the striker is gently moved to a position where it is free to be driven into the detonating tube by the working of a fan rotating by the movement of the torpedo through the water. In order that the blow on the ship may be a direct and not a glancing one, there are mounted "projections" or "whiskers" on the point, so that should the torpedo strike the vessel at an acute angle it will incline almost to right angles at the moment of impact. The precaution against explosion due to contact with a light object floating in the water is the provision of a pin through the primer, which, however, is broken or sheared when a heavy object, such as a ship, is struck. This last shearing is done by the primer receding with the great force of impact into its tube to detonate the fulminate of mercury.

The balancing of the torpedo horizontally at a predetermined depth under the water surface was long maintained as a great secret, but this is no longer the case. It is a simple contrivance, consisting of a valve on the outer surface of the torpedo. This recedes into the interior when too great a depth is attained, this action of the valve being consequent upon the increase in the hydrostatic pressure, due to the increased depth at which the torpedo is running. Conversely, if the torpedo rises above the predetermined level, the reduction in the hydrostatic pressure causes the valve to lift. The depth under the surface at which the torpedo is to travel is fixed by the setting of a spring on the valve spindle; the degree of compression of the spring determines the increase or decrease of hydrostatic pressure necessary to operate the balancing mechanism. The valve is connected to a vertical lever held in a truly vertical position by a pendulum weight, which is free to rock. To this is pivoted a bell-crank lever, the outer end of which is connected to the horizontal rudder, while at an intermediate position there is a connexion to the hydrostatic valve. When the valve moves, due to the torpedo running deeper in the water and consequent increase in hydrostatic pressure, the bell-crank lever is thrown with its top end towards the stern, and thus it operates the horizontal rudders used for deflecting the vessel downwards. If, on the other hand, the torpedo tends to rise to the surface, the valve moves outwards, the lever is drawn towards the bow, moving the bell-crank lever and the horizontal rudders in the opposite direction, to ensure that the torpedo will take a downward course until the required level of progression is reached again.

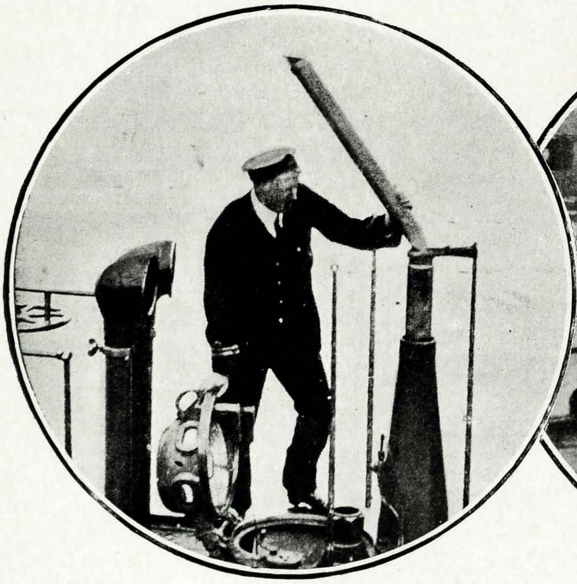
The propelling engines were, until recently, always of the piston type, the cylinders being set radially, and these worked most satisfactorily and at exceptionally high speed—over 2,000 revolutions per minute. Great success has been achieved in reducing the weight for a given power, the later torpedoes having engines giving more than 1 h.p. per lb. of weight. The Americans in their air turbines claim to get 1 h.p. per ½ lb. Provision, of course, is made to ensure the minimum of leakage from the air chamber to the engine. The air is charged into the air chamber before the torpedo is placed in the tube, from air-compressing plant. As it is not desirable that the engine within the torpedo should start running before the torpedo has got some distance away from the ship, arrangements are made to delay the admission of air to the propelling engine. As the torpedo leaves the tube a projection on it acts automatically to lift the valve admitting air to the engine, but there is an ingenious obstruction, a "delay action" valve, to the passage of the air. This obstruction is removed by the action of a tripper, which is thrown over by the torpedo striking the water. Then only can the engine begin running, and thus there is obviated all possibility of the torpedo when not in the water being injured by the immense speed of the propellers—2,000 revolutions per minute in water, but enormously greater in air.

The Servo motor was introduced in 1876 to increase the power of the rudders. The Servo motor acts in the same way as the steering engine in magnifying the power of the helmsman on surface craft. In 1899 there was introduced a further improvement in connexion with the automatic steering apparatus, consisting of the application of a gyroscope, by means of which the causes of erratic running—deflection of the torpedo on entering the water, dents (particularly in the tail), variation in the speed of the propellers, or imperfect balancing—are nullified. The gyroscope is simply a heavy flywheel supported on gimbals with very fine points, giving it a very delicate suspension, so that friction is practically non-existent. The wheel is set spinning by a powerful spring as the torpedo leaves the tube, and it continues rotating at 20,000 revolutions per minute. Thus it is given a directive force maintaining in a true line the axis of the wheel, which is coincident with the longitudinal axis of the torpedo. Notwithstanding any change in the direction of the torpedo the axis on which the gyroscope revolves remains constant by reason of the velocity of the wheel. At the point of suspension of the gimbals there is a vertical rod connected to the valve working the air cylinders actuating the vertical steering rudders. Thus any change in the relative axes of the gyroscope and the torpedo causes the air motor to move the vertical rudders until both axes again coincide.

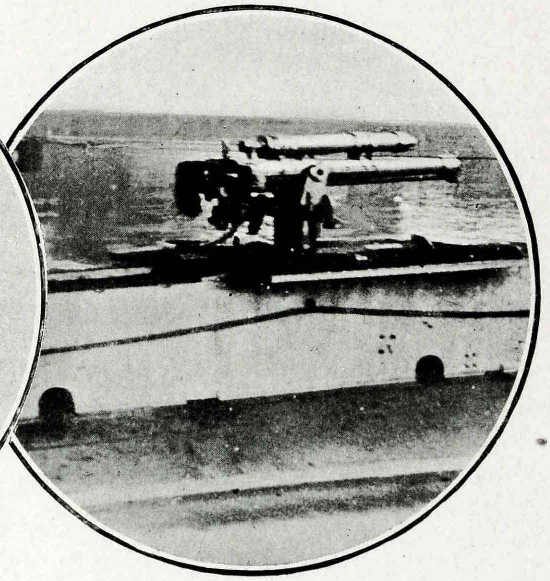
The buoyancy chamber, which is the sternmost of all the compartments, serves the purpose of giving the necessary buoyancy to the torpedo. The propellers are mounted on what is termed the "tail piece," which forms a continuation of the buoyancy chamber. This tail supports two propellers, the vertical rudders, the horizontal rudders worked by the balancing mechanism, and the fins worked by the gyroscope. The whole of the units are protected by a framing. The propellers and rudders are well shown in the view of a torpedo on page 107.

It may be added that mechanism is fitted so that the torpedo can be brought to rest at a predetermined distance in practice firing, and that arrangements are made so that if the torpedo fails to reach its billet it will sink.

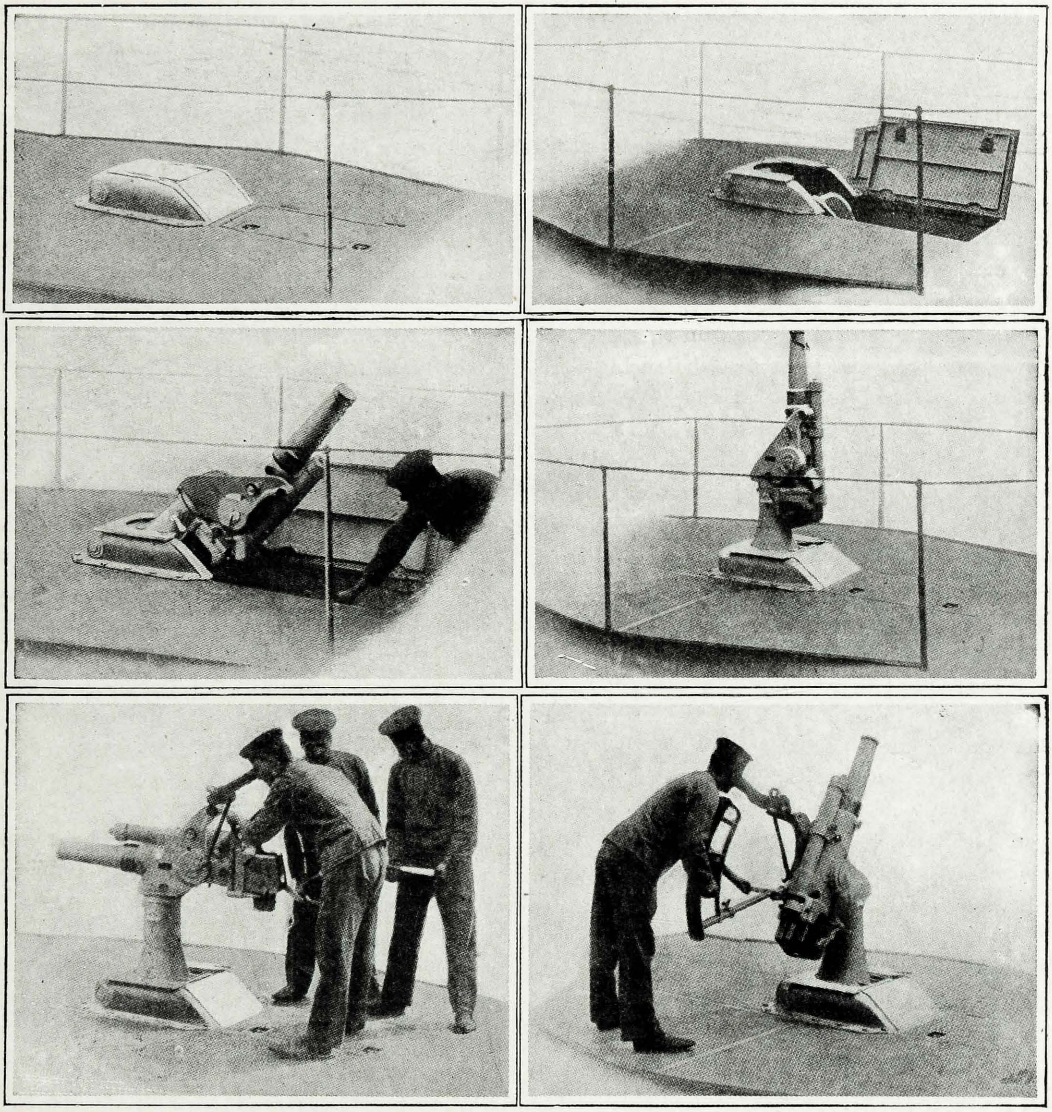
As regards the guns fitted on board submarine boats, Britain was the first to apply this form of armament, and the Germans, immediately on hearing of this procedure, took steps to arm their later vessels. Their guns, which are of 2·95-in. bore, are mounted so that they can be lowered into a recess in the deck of the vessel—as shown in the longitudinal section of a typical German submarine boat on page 97—between the upper deck and the inner hull. The gun arrangement is illustrated in six views on page 110. Fig. 1 shows the cavity for the gun entirely closed, while Fig. 2 shows it open, and the first movement in connexion with the raising of the gun. For the raising and lowering of the gun the lower part of the mounting turns in a bearing contained in the



THE EYE OF THE SUBMARINE.
Removing the periscope.



ON SUBMARINE "D4."
Quick-firing guns.



ON A GERMAN SUBMARINE.

A 3·7-cm. (1·456-in.) gun fitted on a fixed pivot mounting, having a total weight of 365 kg. (584 lb.). It is carried on top of the fixed mounting in a cylindrical cradle, in which it slides backwards and forwards when in action. *(By courtesy of "Engineering.")*

forward part of the fixed foundation seen in Fig. 2. A spring buffer raises the gun automatically into a vertical position. Fig. 3 shows the gun in the process of rising. When the gun has been brought to the vertical position, it is held fast by spring catches, which come into play immediately it reaches the position shown in Fig. 4. These spring catches have to be disengaged when it is desired to rehouse the gun for submarine navigation. When raised to the highest position, sights and shoulder rests have to be fitted, and with these the gun is rotated and elevated. It is stated that the gun may be raised and got into position for training in twenty seconds, and that it can be stowed away in a corresponding time.

As to the gun itself, it is fitted with a wedge breech block, which moves vertically instead of laterally—as with most of the Krupp guns for other purposes. The cradle is cylindrical, surrounding the gun tube itself, and having the usual trunnions in the brackets of the gun supports. The recoil cylinder and the run-out springs are shown in several of the views. The pedestal carries on the top a pivot bearing. The various views show the range through which the gun can be elevated. It will be seen that it can be used against air craft. The total weight of the gun, as illustrated, is 1,895 lbs., and it fires a projectile of 12¾ lbs. The penetrating power cannot be great, so that success can have been achieved in attack even on merchant ships only at very close range.

In nearly every fleet there are parent ships auxiliary to the submarine fleet and to serve as floating bases, having spare parts and stores, including torpedoes and machine tools for the carrying out of small repairs.

Several navies have combined a salvage and docking ship in one, and such a vessel is self-propelled and forms itself the parent ship to the fleet. One of these salvage ships is illustrated on page 112. The hull itself is formed with two side walls, having an entrance at the bow, while the extensive upper works are fitted with lifting gear, so as to raise by tackle the submarine from the bottom of the sea, in order that the vessel may be slung between the two walls of the ship, and conveyed to a port of repair. Alternatively, a floating submarine may be hauled through the bow opening between the side walls for the purpose of having the outer hull fittings repaired or painted. It will be seen that the ship is in every respect a sea-going craft, fitted with wireless telegraphy. The submarine is shown being drawn between the two side walls. There is a double bottom, so that when the water is pumped out of the two side walls of the ship, the bottom is above water level, the whole of the hull of the submarine being exposed.

The Germans have adopted many systems of meeting possible disaster. In order to enable the vessel to remain submerged for a prolonged period, either between the surface of the water and the bottom of the sea, or at the bottom of the sea, they have introduced a system of purifying the air. The vitiated air is circulated by fans through a row of cartridges filled with potash, to absorb the carbonic acid and the moisture, etc. The purified air leaving the cartridges has oxygen added to it from special reservoirs. Separate small cartridges of the same character are supplied to each man, so that in emergency—for instance, when fumes arise through the overturning or spilling of the contents of the accumulator batteries—the men may put the cartridges before their mouths and inhale purified air. Air-purifying vessels with tubes are also supplied to the men, so that they may exhale or inhale through the tubes. Corresponding means are adopted in practically all submarines in order to overcome the effects to which we have referred, but in the British practice it has been found that by isolating the accumulators in separate compartments there is little chance of such fumes finding their way into the inhabited compartments of the ship, so that here, as in other respects, the principle has been adopted of meeting contingencies before they arise, rather than of devising means for counteracting the dangerous effects of such contingencies.

The Tactical Work of the Submarine as Influenced by Design.

Such success as the submarine boat has achieved is due to the quality of invisibility which it possesses rather than to what might be termed the capacity for direct frontal attack. The handicaps imposed on the submarine are its vulnerability to attack by ramming or by gun power, its low speed relative to that of torpedo-boat destroyers and cruisers, the insufficiency of its gun power and the relatively short range of the torpedo, its inability to fire the torpedoes at all arcs of training, and its comparatively wide turning circle. The fact that British merchant ships of comparatively low speed have been able to escape from German submarines, and that at least one merchant ship rammed a submarine, is proof of these latter two disabilities. The case of the Thordis, which rammed a submarine on March 4—for which the captain and crew were honoured, the former being made a lieutenant of the Naval Reserve, and, along with his crew, getting a large monetary reward—should be encouraging for others. There are many other cases which show that difficulties due to slow manœuvring beset submarines.

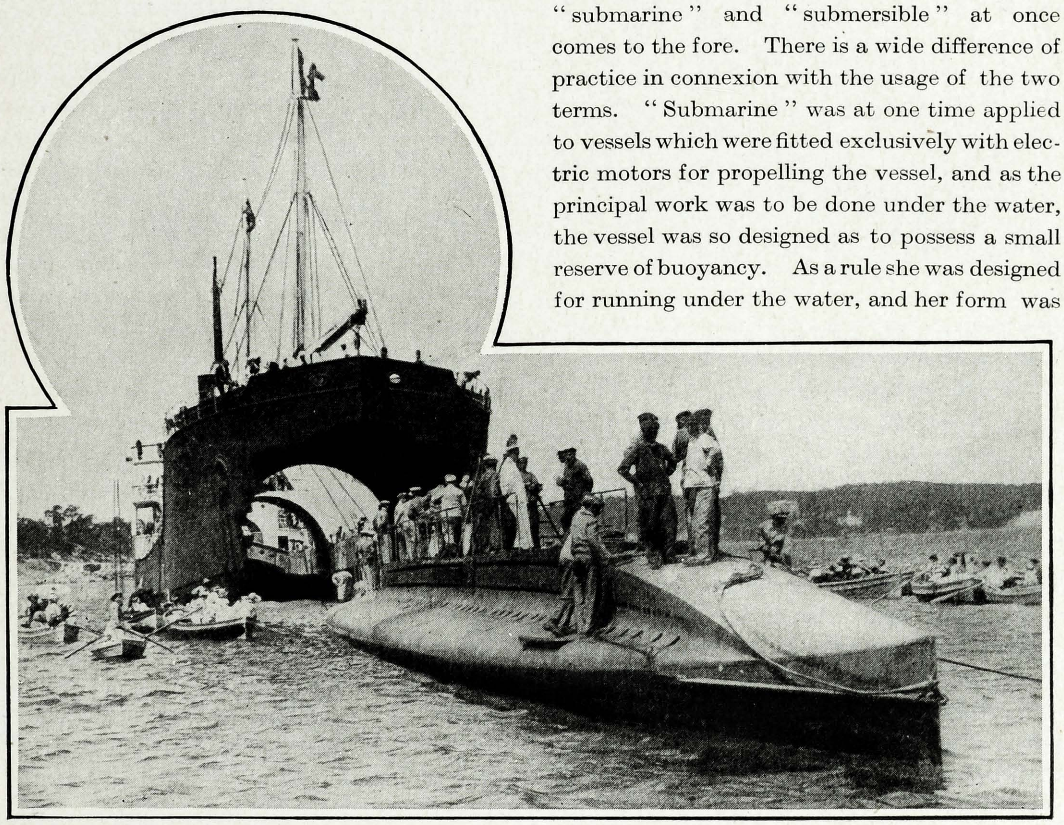
The submarine has often been regarded as an under-sea torpedo-boat, but its deficiency in speed is much against its utility for attacking warships on the surface. Many destroyers during the war attained speeds of over thirty knots, some of them as much as thirty-five knots. They manœuvred very easily, and proved in many cases capable of ramming submarines. A notable instance was that of the Badger, which on October 25 accounted for one of the German submarines, whilst the Garry, on the 23rd, rammed the U18 off the north coast of Scotland, saving all the crew except one, who remained on board to open the Kingston valve, in order to ensure that the vessel would sink. H.M. Destroyer Ariel also bagged U12 on March 10, all officers and crew being taken prisoners. A destroyer steaming at 32 knots approaches a submarine at 54 ft. per second, and should the submarine be travelling on the surface, with her masts and other gear in position for surface navigation, the time taken to dive cannot be short of a minute, even presuming that no attempt is made to lower the mast and make everything on deck secure. It is therefore obvious that the submarine is at a great disadvantage.

As regards comparison with light cruisers, the case is nearly as pronounced as with torpedo-boat destroyers, and the success of the Birmingham in sinking U15 on August 8 was due to the difference in speed. As regards the range of the torpedo, the war has shown that the gun, by reason of the efficiency of control and aiming, is capable of accurate hitting at a much greater range, so that the submarine, even when present, has had little chance of being effective in fleet actions. The velocity of the present-day torpedo enables it to reach an object at 6,500 yards in about four minutes, but a projectile from a 12-in. 50-calibre gun can travel that distance in nine seconds. In an open fight it would be possible to aim and fire a 12-in. gun at a submarine after her torpedo had been discharged and before it reached its billet. Vice-Admiral Beatty, in his dispatch on the fight in the Bight of Heligoland, stated :

> I did not lose sight of the risks of submarines and a possible sortie in force from the enemy's base, especially in view of the mist to the south-east. Our high speed, however, made submarine attack difficult, and the smoothness of the sea made their detection comparatively easy. I considered that we were powerful enough to deal with any sortie except by battle squadron, which was unlikely to come out in time, provided our stroke was sufficiently rapid.

In this connexion the photograph which we reproduce on page 101, showing the wake of a torpedo, due to the exhaust of air after it has operated the propeller, indicates that under certain conditions the presence of a submarine and the advance of a torpedo can be detected. In the actual fight in the Bight of Heligoland a German submarine attacked the Queen Mary, but this mighty cruiser managed by rapid steering to elude the torpedo.

The question whether a submarine can be built to achieve a high speed involves the form of hull and the type of machinery. Dealing first with the former, the subject of the titles "submarine" and "submersible" at once comes to the fore. There is a wide difference of practice in connexion with the usage of the two terms. "Submarine" was at one time applied to vessels which were fitted exclusively with electric motors for propelling the vessel, and as the principal work was to be done under the water, the vessel was so designed as to possess a small reserve of buoyancy. As a rule she was designed for running under the water, and her form was



A REPAIR SHIP FOR SUBMARINES.

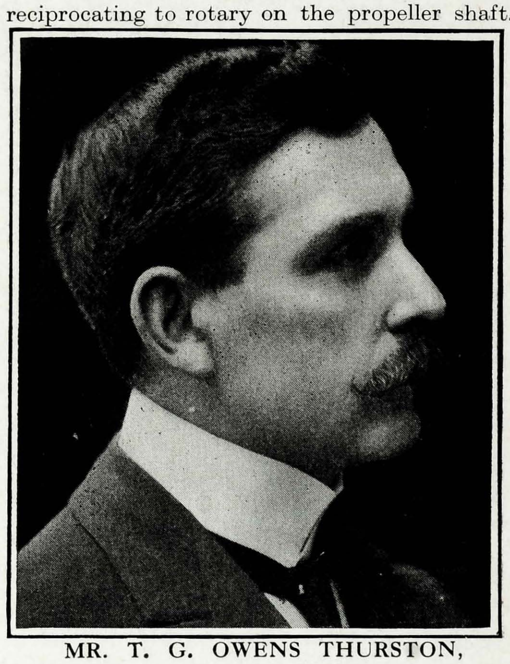
This vessel, which is used for carrying submarines across the seas, can also be used as a floating dock for repairs.

arranged to comply with this condition. Thus, the section was circular, and she had a straight line axis. The term "submersible" may be applied to a vessel possessing a large reserve of buoyancy, and designed for improved surface conditions, for fairly high speed, and for keeping the sea. Thus the form appertained more to that of the torpedo boat or surface vessel, so far as the outside lines were concerned. But there was introduced an inner hull, not only to increase the resistance to hydrostatic pressure when immersed at a great depth, but to provide between the two hulls water-ballast tanks for the introduction of water in order to reduce the high reserve of buoyancy to enable the ship to dive. The difference is pretty much one as to the amount of surface reserve buoyancy, and with this proviso the term "submarine" may be accepted as covering all types of under-water craft.

The tendency, however, must be towards the adoption of the same lines as surface craft, if high speed on the surface is to be realized, but this form is not conducive to a great speed when submerged. Modification, however, has to be made at the bow and stern in order to accommodate the torpedo launching tubes, and in this way there is introduced something very bluff and round-ended, quite opposite to the knife-like edge of the high-speed surface vessel. The torpedo armament provisions thus limit the speed to some extent. The desideratum is towards high speed on the surface even at the expense of speed submerged, and for the latter 8 to 10 knots may be regarded as reasonably satisfactory, with a fairly good radius of action; that is to say, with batteries sufficient for four or five hours' propulsion under the water. The acceptance of this condition is encouraged by the great weight of the electrical installation for propulsion under water. Normally the electric power in a submarine boat is only from half to a quarter that of the oil engines used for surface propulsion, but the weight of the electric motors, batteries, cables, switches, and other gear is practically twice that of the oil engines, exclusive of fuel, which necessarily varies according to the radius of action on the surface desired. If it were desired to get 18 knots under the surface as well as on the surface, the vessels would require to be quite 20 per cent. larger in displacement tonnage.

For surface propulsion the oil engine holds the field for the present. In some of the earlier power-propelled boats a steam boiler and reciprocating engines were adopted, but they were not favourably looked upon. Electricity and compressed air were also used for small craft. The introduction of the internal combustion engine in the Holland boat gave a great impetus to the use of oil engines. At first petrol or gasoline were used, pretty much as in the motor-car, but the petrol gives off inflammable vapours at atmospheric temperature, and was thus very dangerous. Paraffin engines superseded the petrol, but there was the disadvantage that while petrol, if it fell into the bilges, evaporated, paraffin lay about, and, as it ignited at a very low temperature, it also was a source of danger if naked lights were anywhere near. Engines using heavy oil were next introduced, and proved most acceptable, the heavy oil having a flash point three times that of paraffin (or from 200 to 250 deg. F.), so that the danger of fire and explosions was almost eliminated.

The oil engine is preferable to steam because there is less loss in the conversion of heat into work. In the case of the steam machinery only 13 per cent. of the heat stored in the fuel is converted into work, whereas in the case of the oil engine the percentage is between 35 per cent. and 40 per cent. The impulse given within an oil engine cylinder is due to the explosion or combustion of oil vapour above the piston, which is thus driven downwards, and by suitable mechanism the motion is converted from reciprocating to rotary on the propeller shaft.



MR. T. G. OWENS THURSTON,
Naval Constructor of the Vickers Company.

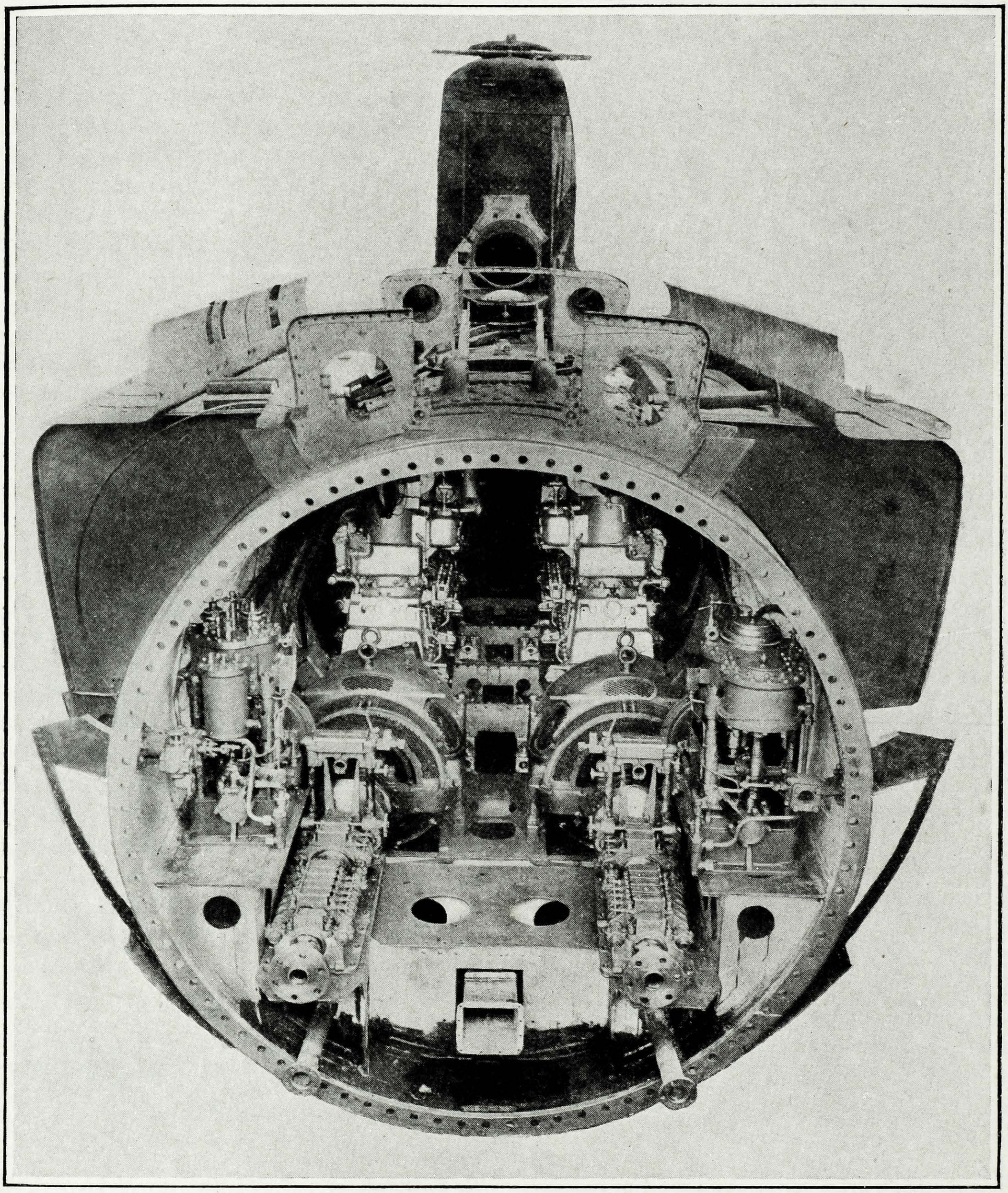
In earlier heavy oil engines the ignition of the oil was effected by flash or other separate agency. A noted German chemist, the late Dr. Diesel, modified this, and it was largely as a consequence that the use of heavy oil became possible in engines of suitable power and weight for submarine propulsion. When air is compressed it becomes heated, as can easily be tested by the use of a tyre pump. He therefore introduced the principle of compressing the air for the cylinder to a pressure of about 500 lbs. per sq. in.; this raised its temperature to about 1,500 deg. F. It is only necessary then to spray oil into the cylinder with highly-compressed air in order to ensure combustion; there is no need for separate ignition with its attendant disadvantages. As only air is contained above the piston at the full height of its stroke, there can be no premature ignition with serious troubles accruing. The impulse to the piston is more gradual because of the gradual combustion of the charge, and consequently there is less variation in stress on the working parts and bearings. The oil engine, as at present designed, is undoubtedly heavier than steam turbine installations in high-speed vessels. A fair figure for the oil engine would be 90 lbs. per horse-power, and for corresponding machinery of the steam turbine type 45 lbs. per horse-power. One pound of oil, however, used in the oil engine gives more than double the power developed by the steam turbine, the consumption of oil being about ½-lb. per horse-power in the oil engine, while for the steam turbine installation at full power the consumption of oil in the boiler is about 1·4 lb. per horse-power, and more at small power. To ensure the same radius of action, it follows that there must be carried in the steam-propelled boat nearly thrice the fuel necessary in an oil-engine propelled ship.

An interesting departure was made, prior to the outbreak of the war, in the adoption of turbines instead of oil engines for driving submarine boats on the surface, the turbines being used when desired, as in the case of the oil engine, for generating electricity to recharge storage batteries. This change, because of its potentialities is regarded as of great importance. Four turbine-driven submarine boats have been built for the French Navy. Two are of about 900 tons displacement, and the turbine engines, driving twin-screws through gearing, are to be collectively of 4,000 s.h.p.; the two others are slightly larger, and of 5,000 s.h.p. The weight of the turbine installation is said to be 60 per cent. of that of the oil engine.

The difficulty experienced in the early steam-driven submarines was that the closing down of the boiler occupied a comparatively long time; but with the modern "express" water-tube boilers of rapid evaporative quality, using oil fuel, the volume of steam or water in the boiler at any time is very small, and the supply of fuel to the furnace can be instantly cut off, so that the time taken to damp down may not be much greater than that taken at present to change over from oil-engine drive to electric drive, and otherwise to prepare the vessel for diving. The question, too, of heat may be overcome by insulation. There may, however, be greater difficulty in raising full pressure of steam in the boilers when the submarine boat returns to the surface.

Steam machinery may require more numerous and larger hull openings, and more top hamper, such as funnels, air-intakes, etc., will be necessitated, since a larger volume of air is required. Special gear will have to be devised for closing these apertures rapidly and effectively.

The subject of closing down and diving is one requiring the greatest experience in order to secure safety and rapidity. In ordinary practice submarines dive with a reserve of buoyancy, varying according to the design of the particular boat. This change in buoyancy from the surface to the submerged condition is effected by the filling with water of certain compartments. When the boat has reached a predetermined stage, so far as the degree of buoyancy is concerned, if she is not under way the electric motors are set in operation to give a forward movement, when, by the use of horizontal planes, the ship dives, the angle varying with the length of the ship, its speed and the area and angle of the planes. These planes, which are well seen in the illustration on page 117 and are controlled from inside the boat, may be placed at an angle with the direction of flow of the water, the result being a perpendicular thrust sufficient to overcome the pre-arranged reserve buoyancy. So long as the boat travels with the planes set at an angle to the horizontal the downward thrust remains effective, and the boat is able, under submerged control, to dive or rise as the angle of the planes is increased or decreased, the whole being a balance of forces at all times. For the same reason it is necessary for the vessel, even when submerged on an even keel, to keep moving, in



INTERIOR OF A GERMAN SUBMARINE

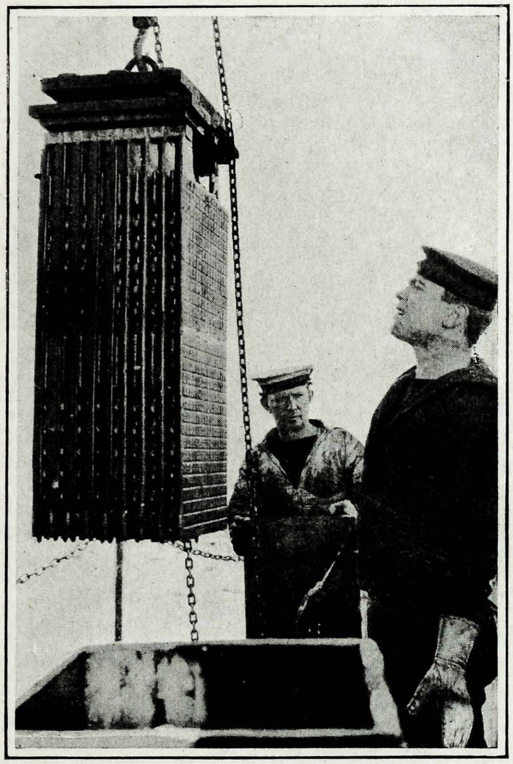
Showing the two internal combustion engines for driving the twin propellers on the surface, and the motor-generators for submerged propulsion.

order that the planes may operate to bring about the balancing of forces, and thus prevent the vessel rising to the surface.

The stability is a matter of great importance, but there exists a wide difference of opinion among authorities as to what amount should be given. A submarine can have too much as well as too little, and the most successful design is that which gives best results at sea in all weathers on the surface, and at the same time is quite satisfactory in a submerged condition. As to the seaworthiness of British boats there can be no two opinions. In one of his official dispatches Commodore Keyes wrote:

> During the exceptionally heavy westerly gales which prevailed between September 14 and 21, 1914, the position of the submarines on a lee shore within a few miles of the enemy's coast was an unpleasant one. The short steep seas which accompanied the westerly gales in the Heligoland Bight made it difficult to keep the conning tower hatches open. There was no rest to be obtained, and even when cruising at a depth of 60 ft. the submarines were rolling considerably and pumping, *i.e.*, vertically moving, about 20 ft.

Perhaps the best method of describing the mechanism for submerging the ship will be to



SUBMARINE ACCUMULATOR.
The electric storage battery leaving charging vat. The sailor is wearing india-rubber gloves.

follow the successive operations, beginning when the ship is cruising on the surface of the water with her deck and bridge showing, all hatches being open, wireless masts up, ventilators in place, etc. All gear would have to be stowed before diving. In war the chances are that the minimum amount of work would be left to be done. In the danger zone only the conning tower would be left open. allowing air to enter for the engines, all other arrangements being made for instant diving. Then three warning bells are sounded, one for the closing down of the conning tower, another for the stopping of the main propelling engines, and the third for all hands to proceed to their respective definite stations, where, as a rule, they remain during the complete watch, there being the minimum of movement while running submerged. Even when everything has to be stowed, two minutes suffice for the diving. If the vessel were running awash, with only the conning-tower hatch visible, the boat would dive, with the help of the hydroplanes, in half a minute. If running on the motors the vessel would disappear almost instantly. Various stages in diving are illustrated on pages 118 and 119.

Then all movement and action is controlled with the help of the periscope, which is a tube, varying from 3 in. to 6 in. in diameter, which can be telescoped to a height of from 15 ft. to 17 ft., and even in some cases 20 ft. At the top there are prismatic lenses or prisms, through which the rays of light enter, and are reflected downwards to a corresponding lens at the base. In some cases the tube contains magnifying lenses, the degree of magnification being in some cases five to six times the actual size. The periscope can be turned through a complete circle without the captain taking his eye from the eye-piece. In order also to enable him to concentrate his visual faculties, the periscope is usually telescoped upwards or downwards by a small motor at will. To ensure freedom from moisture, and therefore cloudy vision, the air in the periscope tube can be passed through a drying medium, such as calcium chloride, returning again to the periscope automatically. The periscope lens seen by the captain is usually graded so that the captain can estimate approximately the range. In nearly all boats now there are two periscopes, one used by the captain for guiding the ship and discharging the torpedo ahead or astern, and the other for the look out, to sweep the horizon continually in search of enemy craft. This instrument has undoubtedly proved of enormous advantage, but the task of observation imposed has been fitly and graphically described by Admiral Bacon, who in a letter to *The Times* said :

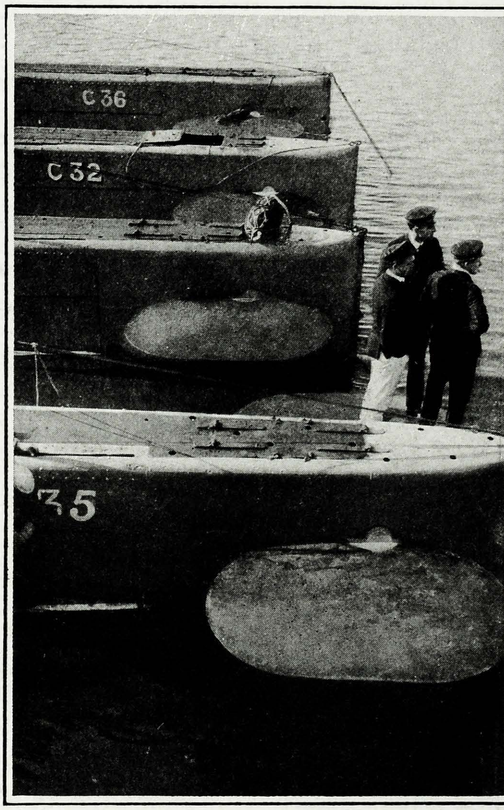
> If any of your readers wishes to appreciate some of the difficulties of submarine work, let him sit down under a chart of the Channel suspended from the ceiling let him punch a hole through it, and above the hole place a piece of looking glass inclined at 45 degrees. Let him further imagine his chair and glass moving sideways as the effect of tide. Let him occasionally fill the room with steam to represent mist. Let him finally crumple the chart in ridges to represent the waves, and then try to carry out some of the manœuvres which look so simple when the chart is spread out on a table and looked down upon in the quiet solitude of a well-lit study.

With the periscope splendid work was done by the commanding officers of submarine boats. Commander Max Kennedy Horton gained his promotion by sinking the German torpedo boat destroyer S126 running at a high speed off the Ems River on October 6, and with the same submarine, E9, he had on September 13 sunk the Hela, so that it will be obvious that, with smart officers, the periscope fulfils the requirements.

As to the depth and length of time of submergence, most of the vessels are designed to withstand a hydrostatic pressure due to immersion to a depth of 200 ft. below the surface, which is equal to about 90 lb. per sq. in. Indeed, in some cases the vessels have actually sunk on an even keel when suddenly approached by the enemy, without even using the diving rudders. On one occasion an officer who had achieved this feat when asked how he got on when resting on the bottom replied : " I did fine ; we played auction bridge all the time, and I made 4s. 11½d." Contrast this with statements in a semi-officially published interview with the captain of one of the German submarines, Commander Hansen. He is reported to have said :

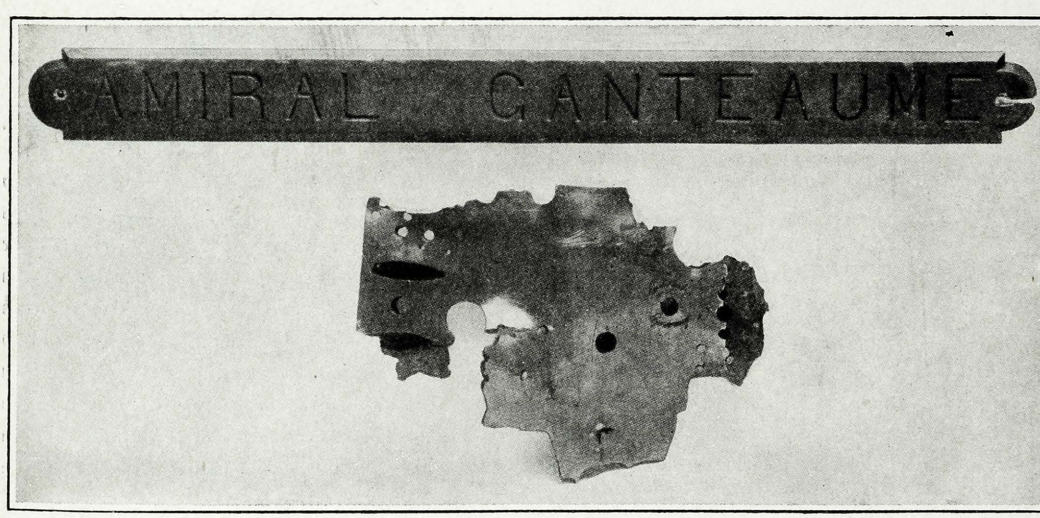
It is fearfully trying on the nerves. Every man does not stand it. . . . When running under sea there is a death-like silence in the boats as the electric machinery is noiseless. It is not unusual to hear the propeller of a ship passing over or near us. We steer entirely by chart and compass. As the air heats it gets poor, and mixed with the odour of oil from the machinery. The atmosphere becomes fearful. An overpowering sleepiness often attacks new men, and one requires the utmost will power to remain awake. I have had men who did not eat during the first three days out because they did not want to lose that amount of time from sleep. Day after day spent in such cramped quarters, where there is hardly any room to stretch your legs, and constantly on the alert, is a tremendous strain on the nerves.

I have sat or stood eight hours on end with my eyes glued on the periscope, and peered into the brilliant glass until my eyes and head ached. When the crew is worn out we see a good sleep and rest under the water. The boat often is rocking gently with a movement something like a cradle. Before ascending, I always order silence for several minutes in order to determine by hearing, through the shell-like sides of the submarine, whether there are any propellers in the vicinity.



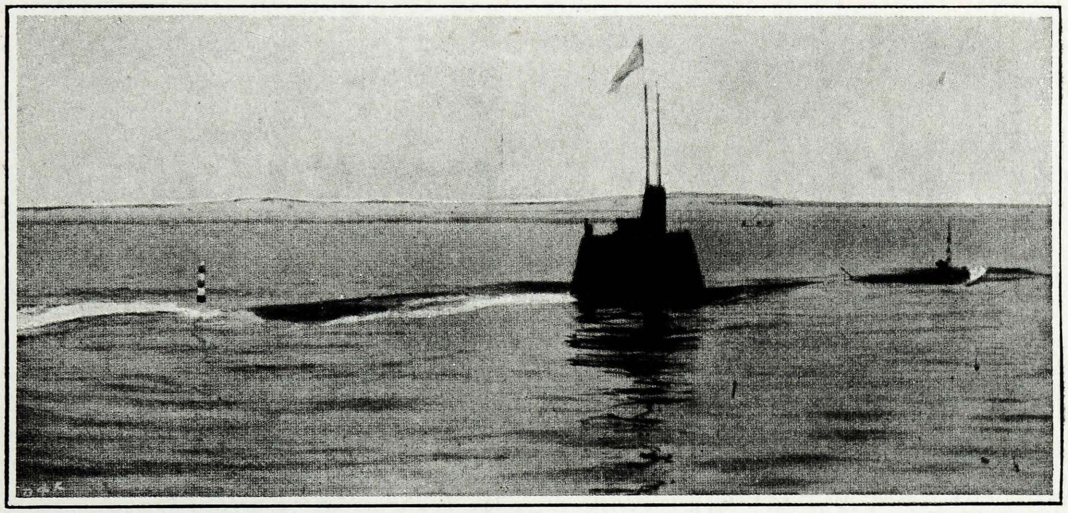
THE PLANES OF THE SUBMARINE.
Horizontal rudders which regulate the angle of descent and ascent.

Steering may be done by the gyroscopic compass, the wheel of which runs at something

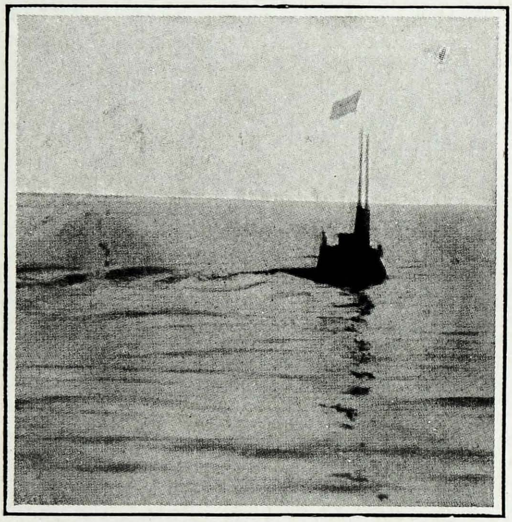


ON A TORPEDOED PASSENGER STEAMER.

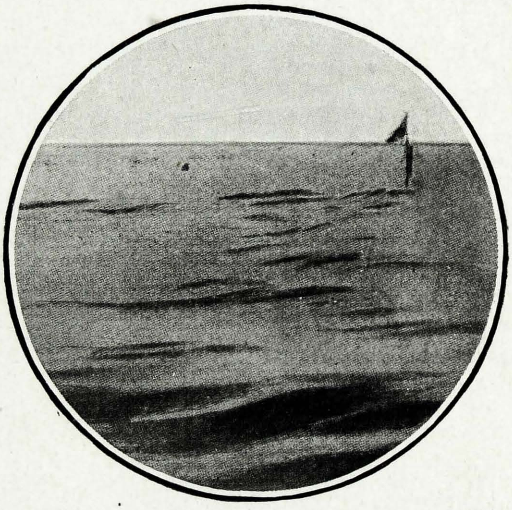
While on a passage on October 26, 1914, from Ostend to Havre, the passenger steamer "Amiral Ganteaume," with 2,000 unarmed Belgian refugees on board, including a large proportion of women and children, was torpedoed by the Germans without warning. The above illustration shows a portion of a German torpedo found on the steamer after she was struck, which proves the German method of attack



First stage: Angle ½ degree.



Third stage: Angle 2 degrees.



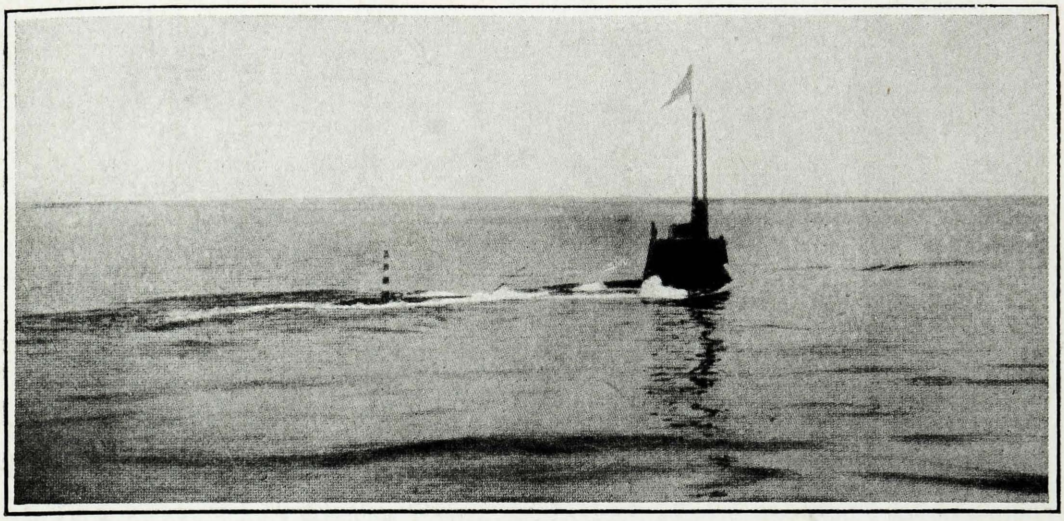
Fourth stage: Angle 1¼ degrees.

SUBMARINE BOAT

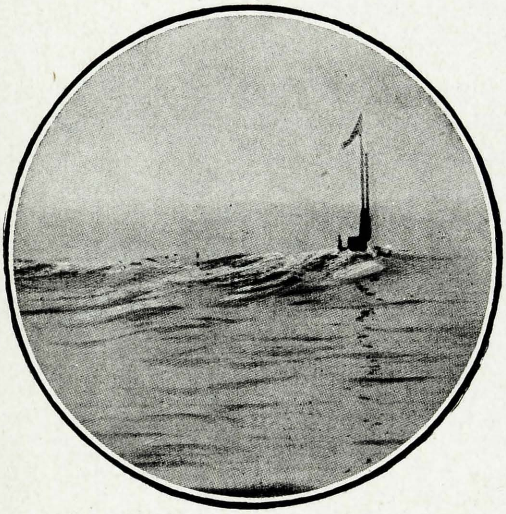
approaching 20,000 revolutions per minute. One of the finest performances submerged was that of B11 (Lieutenant Holbrook), who penetrated the Dardanelles, diving under the mines, and seriously injured the Turkish battleship Messudijeh early in February. He succeeded in escaping in the same way. In the same waters the exploit of E14 (Lieutenant Commander E. Courtney Boyle) in the sinking of the Turkish gunboats and a Turkish transport in the Dardanelles is notable.

But the most interesting work when submerged is the firing of the torpedoes. In the submarine the cap or shutter which forms the outboard closure for the tubes is protected by a heavy steel stem. The cap is hinged to rise upwards by mechanism within the ship. The breech block is rotated and swung to right or left, the torpedo being supported while being run into the tube on tackle overhead. The breech is closed, and then the torpedo is discharged by the captain in the central control station at the required moment by compressed air. As soon as the torpedo has left the tube, water rushes into it and compensates for any loss of weight at the bow which might affect the trim of the boat. The cap is closed, by turning one or other lever at the top, and the water is forced by air into compensating tanks until the tube is quite empty. The next torpedo is then loaded into the tube.

The later German submarines have a radius of action of close upon 2,000 miles at 16 to 18

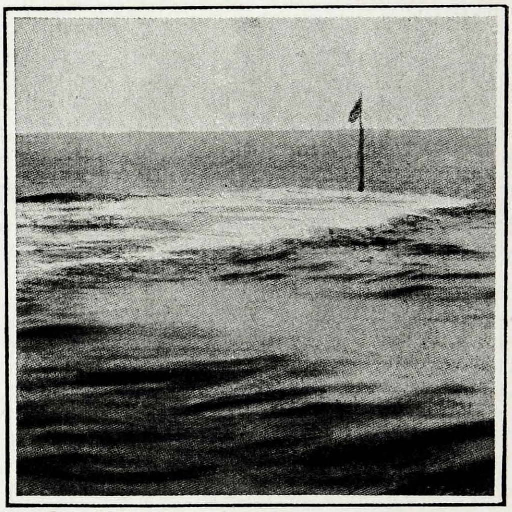


Second stage: Angle $1\frac{1}{4}$ degrees.



Completion of the dive.

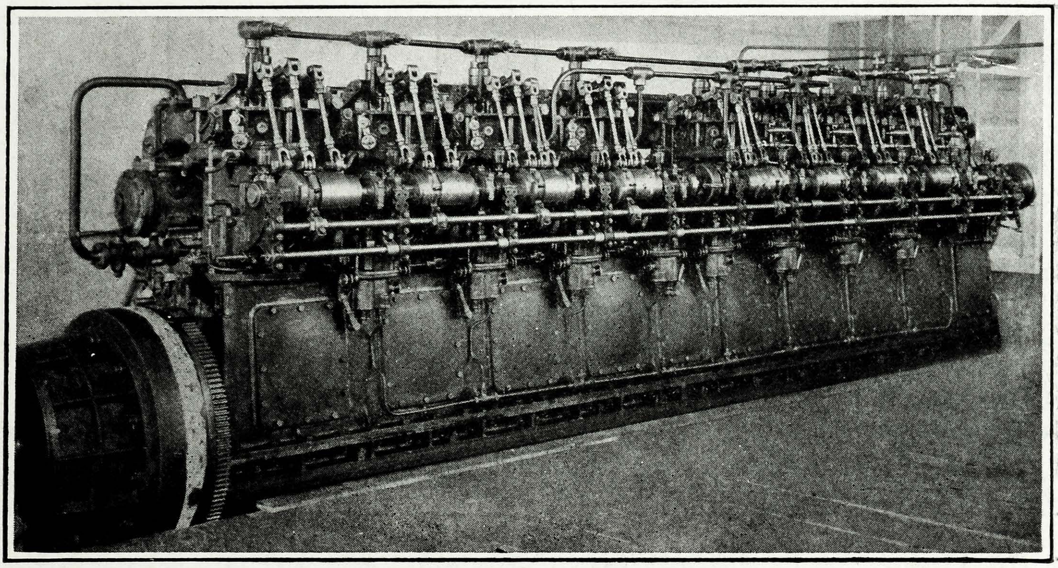
STAGES IN DIVING



Running submerged.

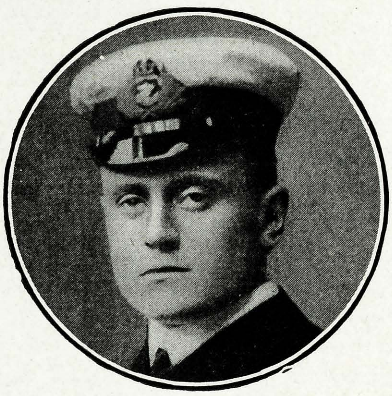
(By courtesy of "Engineering.")

knots speed. But the tactics of the submarine rarely demand this radius at this speed, because if danger besets them they have only to disappear to a sufficient depth in order to elude the enemy, at all events for the time being. Consequently their cruising is probably done at a low speed, and some of the vessels are quite capable of doing 4,000 or 5,000 miles at such low speeds. Moreover, the nominal radius of action can be increased if, as is probable, the ships leave their base in the awash condition, showing only their conning towers. This is an advantage from the point of view of invisibility and safety, and is, further, conducive to rapid disappearance under the surface. In such condition their ballast tanks require to be partially filled, and when operations are to be carried out in waters distant from the German base, there is no reason why fuel oil should not be used in these ballast compartments instead of water, the fuel oil for the first part of a prolonged cruise being pumped from these tanks for use in the engine. When the oil in such tanks has been used, water can be pumped in to ensure the required degree of immersion. The vessel, having reached her station, to await the passage of her prey, need use little fuel oil, as she may remain in any condition, with the deck above water, or in the awash state in a stationary position, or with only a sufficient way on to ensure rapid submergence if on the surface, while if submerged she need only keep way on to make the diving rudder overcome the influences of the reserve of



ON BOARD A FRENCH SUBMARINE.
A petrol motor of 360 horse-power.

buoyancy. The electric storage batteries in the later ships are supposed to give a radius submerged of about 100 miles at 4 knots, which would be quite sufficient to enable the boat to get out of the visible range of attack by torpedo-boat destroyers or other craft. But, when convenient, the main propelling Diesel engines are used to re-charge the storage batteries by the working of the motor generator. In the case of all German boats, particularly those of the earlier and smaller class, the effective radius down the Channel was increased by the capture in November of Zeebrugge, which was subsequently used as a base. A glance at the map will show that Zeebrugge is much nearer the track of ships in the Channel than the bases within Heligoland. Calais would be still more effective.



[Russell.

LIEUT.-COM. M. E. NASMITH ("E11").