PREFACE.

SO much has been done of late towards developing the submarine vessel, that it appears that at present we are not very far from the practical solution of this interesting problem. Many engineers, as well as naval men and business people and others, must be interested in this matter, but as yet no work on this subject has appeared by which people, without spending too much time upon it, may be able to form an idea of what has already been done in this line, how the matter stands at the present moment, and what may probably be done in the future. It is the object of this little book to supply this want, and this, together with the interest I feel for this problem, must be my excuse for venturing to write on so difficult a subject.

The book has been divided into three chapters, viz.:—

I. *The strategical value of submarine boats;* in which chapter I endeavour to show what part such boats may play in future wars, if properly developed.

II. *The history and development of submarine boats;* where I have collected all the material it has been possible for me to get access to.

III. *The construction of submarine boats;* where I have given a detailed description of how I think such boats ought to be constructed, and which principles ought to be the guiding ones. Special attention has been paid to previous experiences, and the conclusions arrived at are the result of very careful study and calculations. In fact, the design, as described in its main features, is one worked out in the course of three years, while I studied Naval Architecture at the Royal Naval College in Greenwich. The design must, however, be regarded merely as an illustration.

I have to acknowledge the assistance received in collecting the historical part of my work from Mr. Nordenfelt's paper read before the United Service Institution last year.

I also acknowledge the information got from the work of Admiral Paris, 'L'Art Naval en 1867;' from Admiral Porter's work, 'The Naval History

of the Civil War,' and from the excellent paper, 'Mittheilungen aus dem Gebiete des Seewesens.'

I have, as far as possible, throughout the book mentioned the sources from which information has been drawn.

It is unavoidable that in a work like the present errors should creep in, especially as regards the historical part. I shall be thankful for any corrections that may be made, and for all information which will make this work appear in a more complete form in an eventual second edition.

G. W. HOVGAARD.

Copenhagen, June 1887

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SUBMARINE BOATS.

CHAPTER I.

THE STRATEGICAL VALUE OF SUBMARINE BOATS.

WE have endeavoured to make our war vessels strong enough, and we have failed. They are neither strong enough to resist the guns, the ram, nor the torpedoes.

There has therefore of late been a growing tendency among the leading naval officers and constructors to build smaller, faster, and better subdivided vessels, with less armour, comparatively small but powerful and quick-firing guns, and many torpedoes. But in spite of this it must be admitted that the big vessels armed with powerful artillery and properly protected will, with their high speed and sea-going qualities, always be more powerful than any other vessels. If the two classes of ships are combined to form a fleet, where the small swift vessels, such as those of the *Archer* and *Grasshopper* class, play a similar part as the cavalry does on shore, they form the most powerful combination known at present, at least in the open sea.

It is quite impossible to take up the battle against such a fleet with any chance of success, if not nearly even in strength, other things being equal.

But if by some means we could get at the vital parts of the big vessels through the unprotected bottoms, and with little chance of oneself being destroyed, who can doubt the result?

This is what has been attempted by both passive mines and torpedoes, but while the former are necessarily very limited in application, and not difficult to destroy or counteract, the latter have the drawback, that they must always be fired from some visible vessel or boat; and it is a great question, who gets the worst of it, the ship or the torpedo-boat. For it is often known when to expect an attack, from whence it comes, and under what circumstances. The ships may be very efficiently protected by nets, and the best of all existing torpedoes, the Whitehead, can hardly be said to be very reliable, when fired at even a moderate distance.

It has been found necessary to increase the size of torpedo-boats, in order to enable them to follow the great sea-going squadrons, but this has made them better targets for machine gun fire, and the

attempts which have consequently been made to protect the boats by light armour, have been accompanied by a still greater development of the machine gun. It is not difficult to foresee that, as in the case of the big ironclads, the gun will win the race.

An attack with a torpedo-boat, every one must admit, is nothing less than an act of self-devotion, and although there is no doubt that every country can find as many naval officers as they want, as well as engineers, stokers and sailors, who would with pleasure undertake the task of making a desperate attack; still we will always if possible rather avoid the losses of boats and men, however heroically these losses may have been brought about; and if we can construct an indestructible torpedo-boat, why not do so?

Hence the numerous attempts which have been made from time to time, and more especially during the last few years, to construct submarine vessels practically useful in time of war, and great strides have already been made towards the solution, although it cannot be said that the problem has always fallen into the best hands, or to have had a really fair trial till lately.

Before considering in detail the difficulties connected with the construction and use of submarine boats, let us make certain moderate assumptions, as to what may be expected from them, and on this basis let us try to draw some conclusions as regards their use as war-vessels.

Suppose then, that we have succeeded in constructing a vessel which will move on the surface of the water, something like the *Polyphemus* when stripped of her upper light structure, and suppose that she can dive down at any moment and continue her course under water for some considerable time at moderate speed, say in 12 to 24 hours at 6 to 8 knots.

Let us also assume that she can stay under the water, say, rest at the bottom for several days, if needed; and that she can do all this with perfect safety and facility.

Let us also grant her tolerably high speed, when moving along the surface, awash; ordinary manœuvring power in the horizontal direction, whether submerged or not, and the power of moving safely upwards or downwards at will.

As regards the navigation, let us imagine that going under water is like going in a very dense fog, so that it will be necessary, when making an attack, to go up to the surface now and then, in order to correct the course. In other words she is not to be a purely "submarine" boat, but much more a "diving" boat. Indeed the term "submarine boat," which has now taken root, appears to

be very misleading, as properly speaking no such boat has ever been built, and it has no doubt contributed to frighten people from the whole idea.

A boat fulfilling the above conditions will be eminently adapted for the defence of sea-ports; in fact it is difficult to imagine how men-of-war can at all attack ports defended in this way. The mere knowledge of the existence of such boats about a place, must prevent any prudent commander from approaching it; for neither his speed, or his machine guns, or torpedo-hunters, can prevent the submarine boat from an attack, if a bombardment or a blockade is to be carried out effectively. This was demonstrated by the fate of the *Housatonic* off Charleston duing the Civil War.

Even in broad daylight such boats must be considered a far more dangerous enemy than ordinary torpedo-boats at night, for they have only just to peep up now and then, and no one can tell where the small conning-tower or cupola, which is all they need show, will turn up next time, to be visible perhaps for a few seconds only.

It may be objected that submarine vessels, if they are to attack by means of Whitehead torpedoes, are no better off as regards penetrating the torpedo-nets than ordinary torpedo-boats. But on the other hand, it must be admitted that the submarine vessel may succeed in destroying the net, before firing the torpedo, more easily than an ordinary torpedo-boat could do it, for which it is an absolute necessity to get away as soon as detected. Further, we may imagine spar-torpedoes to be used with success in spite of the nets; or if circumstances permit, passive mines may be dropped underneath the vessel, and even ramming may be used in case of light-built vessels.

It is indeed very likely that the Whitehead torpedo will be abandoned in its present form as a weapon in submarine vessels, after being thoroughly tried and experimented upon, for the recent experiments made in France and England on the effect of explosions on modern ships' bottoms, seem to show these to be much stronger and more effective than had generally been anticipated, and the same may be said as regards the protection afforded by Bullivant's torpedo-nets.

Speaking on ordinary torpedo-boats as compared to submarine boats,* Major-General Hardinge Steward, R.E., says:—

"It is all very well to say that you can do a great deal of business with an ordinary torpedo-boat, that runs 20 knots, or even with the second class boats, but unfortunately we have not got

* United Service Institution. Discussion on Nordenfelt's paper on "Submarine Boats."

enough of these boats. If under fairly favourable circumstances you are going to attack vessels lying in the offing a few miles from the entrance of a port, you must expect a loss of 30 per cent. of the boats you use, and even then you run the chance of being beaten off. But as a member of the Council of the Naval and Volunteer Defence Association, I have to consider with others the defence of commercial harbours, and I have also to deal with the defence of Colonial ports. I am in a position to state that many of our ports do not possess even the proportion of boats that is to go to the bottom. It comes to this, that if you want to economically defend a port, it is better to have a boat that does not show at all.

"Then, another thing one must remember, and that is, that the moral effect of a submarine boat would be enormous. I am perfectly certain, that foreign war-vessels would not lie off a port to intercept outward and homeward bound vessels, if they knew that there was a submarine vessel inside, that could come out without being seen. I certainly think that 10,000*l.* would be very well spent in providing a vessel of this class."

Although the chances may be very small at the present moment for an attack upon any of England's sea-ports, still it is certainly a possibility, which cannot be and is not left out of consideration. The possibility being small, it is only natural that the expenses should be small also, and it is evident that submarine boats will be much cheaper than forts, or men-of-war and ordinary torpedo-boats, and they will moreover be much more efficient, if only by their moral effect. The bigger and more powerful vessels are, the less they can afford to be sent to the bottom. In the colonies the chances for an attack on open towns are much greater, and will no doubt be carried out by any enterprising enemy. Not only may the narrow entrances to ports and rivers be defended in this way, but great inlets and passages such as the Strait of Gibraltar and Bosporus, certain parts of the Channel, the Sound, and the Storebelt, and many others may also be made quite unsafe to pass by means of these boats. At night such waters would become very dangerous traps for big vessels.

Great transports of troops will become a very precarious matter, and it is not difficult to foresee the panic that would arise on board a transport steamer, in case such a boat were even suspected to be near. Submarine boats will moreover be particularly adapted for running blockades as despatch vessels.

Whether submarine boats can be constructed, which can follow the sea-going fleets, or be carried on board of big vessels like our present second class

boats, is of course difficult to tell. The former problem will perhaps be more readily solved than the latter, for, as will be shown later on, small size is a very great obstacle in such a boat, but one that may be overcome.

What then will be the result of the extended application of such boats in the above suggested directions?

The safety of otherwise defenceless commercial sea-ports will be immensely increased. Blockades cannot be carried out effectively.

The value of thick armour, heavy ordnance, and big sized vessels will under certain circumstances be diminished.

The sea will more than ever form a barrier, difficult and dangerous to pass for an army.

As the submarine boat is at present, it is essentially a weapon of defence, but a very powerful one. However much it may be developed, even if it becomes a weapon of offence as well as of defence, still it will always be of advantage to such powers as England and Denmark, who depend for their existence to a great extent on their insular position.

It has often been stated that it is unfair to use such means as submarine boats, and even that it would be a cowardly way of fighting. No doubt, it is far better and nobler to meet one's enemy openly, face to face, and no one will deny that it is unfair to strike an enemy without his being able to see you or hurt you, but it is doubtful whether an act which requires the highest degree of cool courage and ability, can properly be called a cowardly one.

It must also be remembered that underwater attacks are, after all, made in several other ways at present, and that it is only one out of the many horrible things that take place in warfare. Is an ambush fair? Is it fair to use mines for the defence or attack of a fortress?

But one of the most horrible things in war is undoubtedly the bombardment of towns, open or fortified, whereby even women and children become exposed to the fire of the enemy, and the results of art, science, and industry are recklessly destroyed, while the enemy perhaps lies at a safe distance, thoroughly enjoying the useful practice of shelling a town in the most scientific manner.

The merciless projectiles, which bring death and destruction to every one and everywhere, are certainly as cruel and unfair as the submarine torpedo-vessel which may try to defend such a town against an otherwise invulnerable enemy.

That even open towns will be attacked in time of war is unfortunately very probable, if one is to judge from the views expressed from time to time by various leading naval authorities throughout the world.

To defend all sea-port towns effectively by means of forts and armoured vessels is next to an impossibility, but the submarine boat, if properly developed, affords a cheap and powerful weapon against the excesses of modern warfare.

CHAPTER II.

THE HISTORY AND DEVELOPMENT OF SUBMARINE BOATS.

ALTHOUGH it is nearly three centuries since the first submarine torpedo-boat was built, the problem has until lately remained practically unsolved.

This seems very strange, for the idea is forcibly suggested to us in nature by the fishes, and the usefulness of such boats is vividly brought before us through the fact that the most vulnerable part of a vessel is below the water, which moreover affords a natural protection to the submarine boat. A great many attempts have indeed been made, and one of the reasons why they have failed is, probably, that they have been made at different times by different persons, who acted to a great extent independent of previous experiences, guided only by theoretical ideas, which do not appear to have been always quite sound.

In many cases the failure was brought about through want of means for carrying on the experiments beyond the first necessarily imperfect stage. The great development which has taken place in

all branches of engineering, has quickly brought us much nearer to the solution.

In this chapter will be described all the submarine vessels built hitherto, as far as it has been possible to gather any information about them. Especially will the results of the experiments be described; for it is clear that only by experiments is it possible to approach a problem so difficult and essentially practical as that of free motion in a fluid.

The first boat on record* was constructed in the beginning of the 17th century, during the reign of James I., by a Dutchman, *Drebbell.* It was tried on the Thames, but no particulars are known about it.

In 1774 a submarine boat was designed by an Englishman, *Day;* but it went down with him in Plymouth Harbour, and was only found a long time afterwards.

About the same time a submarine boat was built by an American, *David Bushnell,* born in Saybrook (now Westbrook) in Maine. He called it a "diving boat"; it was built of wood and shaped like two turtle shells stuck together, so that the deck was highly curved. It was propelled by a screw, worked by hand, and another screw was to give vertical motion. Water might be pumped in and out by means of a pump, worked by the foot, and a gauge indicated the immersion. It carried

* 'Mittheilungen aus dem Gebiete des Seewesens.'

200 lbs. of detachable ballast. The boat must have been very small, for the one man, who was to work it, had only air sufficient for half an hour.

The boat was built for destroying British ships of war during the War of Independence, by mines of gunpowder, which were to be fixed to the bottoms of vessels, and exploded automatically, after the lapse of a certain time, by means of clockwork. The mines contained 150 lbs. of gunpowder.

This boat did not do any service, which, of course, cannot be wondered at on account of its small size, but it is interesting to see how, after all, the later boats are built on quite the same principles, the improvements that have taken place being mostly due to the general progress of engineering.

About the year 1800, *Robert Fulton*, the famous American engineer, taking up the idea of Bushnell, proposed to General Bonaparte, who was then Consul, to construct a submarine vessel. Bonaparte supplied him with the necessary means, and the boat was tried during the summer of 1801 in Havre and Brest. At the first trial, Fulton went down to a depth of 25 feet, where he remained for one hour; then he went down with three persons to the same depth, where he remained four hours. Compressed air was used for respiration. Fulton succeeded in propelling the boat through long distances under water, and in any desired direction. He also attached a torpedo containing gunpowder to the bottom of a vessel lying in Brest, and blew it up in the presence of Admiral Villarez and many spectators.

The boat has been thus described in 'The British Navy,' by Sir Thomas Brassey: "Robert Fulton's 'plunging boat' was something similar to that of Bushnell, and was called by him the *Nautilus*. Propulsion and steering were provided for by the movement of two horizontal and parallel screws. The boat could be made to sink or rise in the floating medium, by working a vertical screw. The torpedo consisted of a copper case capable of containing from 80 to 100 lbs. of gunpowder. To this was attached a gun-lock, which could be fired at any given moment. The lock was in connection with a line sixty feet long, led through a block secured to the side of the boat. To attack and blow up an enemy's vessel this line was bent to a kind of harpoon. The boat was then directed towards the ship attacked, and, when near enough, the harpoon was launched so as to stick in the hull of the enemy. At the expiration of an interval of time previously resolved on, which was measured by a clockwork arrangement, the lock was set in action and the explosion took place. The torpedo was arranged so as to be sunk twelve or fourteen feet below the surface of the water, and when so used was fitted with a catch, which could be freed on the slightest shock and so cause an explosion."

Fulton proposed to attack the English war-vessels cruising outside Brest harbour, but in vain; the French Government refused to supply him with further means. Further experiments are said to have been made by Fulton in England and America later on, but without result.

In 1821 a boat was built on the Thames by a *Mr. Johnson*, but turned out a failure.

For many years the problem remained now untouched, until the construction of ironclads revived the idea.

During the Sleswig-Holstein war, 1849, a submarine boat was constructed in Kiel,* by a non-commissioned officer of the Bavarian Artillery, named *Bauer*. It was intended for blowing up the Danish ships of war lying at Sundeved. This boat was small, and was propelled by a screw aft. At the fore end was a sort of tube with round windows and a hatch to permit the entrance and the egress of the crew. Attached to this were india-rubber gloves, with which the person manœuvring the boat might fix the torpedo under the enemy's vessel. The ignition of the charge was effected by a voltaic battery. The sides were formed of cast-iron plate, but these as well as the pumps seem to have been deficient in strength. On February 1st, 1851, the boat was tried experimentally and

* Sir Thomas Brassey, 'The British Navy.'

failed, it was made to go down, but could not be raised again. The vessel was never taken into use.

At the beginning of the Civil War in America, the Federals tried to produce a submarine torpedo-boat. A Frenchman undertook to construct the boat, and received 10,000*l.* when it was finished, with promise of 5000*l.* more for every successful attack made with the boat. But when the trial was to come off, the designer had disappeared, and the matter was dropped.

The Confederates, however, built several such boats, some of which were to go awash only, others to be "diving boats" as well. Thus the torpedo-boat which tried to blow up the *Ironsides* was really only a surface boat going awash, while the boat that succeeded in blowing up the *Housatonic*, a fine new vessel of 1240 tons displacement, was a submarine boat. It was built of boiler plates, and propelled by hand by eight men at a maximum speed of four knots. The air space is said to have been sufficient for the crew of nine men for two hours. Two side rudders were used for sinking and raising the boat, when in motion; when not moving, the vertical motion was produced by pumping water in and out.

The Confederates had to pay heavily for their experiences with this boat, and the final success must be ascribed more to their perseverance and reckless courage, than to the properties of the boat. Indeed the boat was destroyed along with its enemy.

On one of the first trial trips the boat sank, unknown for what reason, and the eight men were drowned, but the officer, Lieutenant Payne, was saved. The boat was taken up, and Lieutenant Payne offered at once to try again; he got easily a fresh crew, but one night, off Fort Sumpter, the boat capsized, and only Lieutenant Payne and three men escaped.

The boat was again got up, and one of the constructors of the boat, a Mr. Aunley, made a trip with it. It sank and all hands were lost.

The boat was taken up for the third time, and Lieutenant Dixon, who made the attack with it on the *Housatonic*, got command of it. He had no difficulty in getting another crew.

The following account is given of the attacks on the *Ironsides* and *Housatonic* by Admiral David Porter, U.S.N., in his work, 'The Naval History of the Civil War,' 1887:—

"During the operations before Charleston there was no vessel in the fleet so heartily dreaded by the Confederates as the *Ironsides*. Her well drilled crew and expert gunners made her anything but welcome, when she brought her broadside to bear upon any of the forts. Several attempts were made to destroy her with torpedoes, but without effect.

On the night of the 5th October, 1863, however, they very nearly succeeded.

"An ingenious torpedo-boat—for the day—was fitted out at Charleston, and placed in charge of Lieutenant W. T. Glassell of the Confederate Navy, with orders to operate against and destroy as many of the ironclads as possible. Glassell was assisted by Captain Theodore Stoney as first officer, J. H. Toombs, engineer, and Charles Scemps and Joseph Ables as assistants. The vessel belonged to a class known as *Davids*, and was shaped like a cigar, being supplied with a small engine and propeller, and was of the following dimensions:—Length, 50 feet; beam (or diameter), 9 feet. For offence a torpedo was carried at the end of a stout spar, extending some 15 feet ahead of the sharp bow.

"When the attempted destruction of the *Ironsides* occurred, that vessel was anchored off Morris Island, and the time, 9.15 P.M., was one at which a ship's deck is apt to be deserted except by the look-outs. A small object on the dark water, close at hand, was suddenly discovered by the sentinels and hailed by them and the officer of the deck, Acting Ensign, C. W. Howard. No response being made, the officer ordered the sentries to fire into the object. The sentries delivered their fire, and simultaneously, the ship received a severe shock from the explosion of a torpedo, which threw a large column of water into the air, whence it descended upon the spar-deck, and into the engine-room. Acting Ensign Howard was mortally wounded by a shot from the torpedo-boat, dying five days later. The proximity of the *David*, and the limited target presented by its only visible part—a hatch ten feet by two—precluded the use of great guns upon it; but a brisk musket fire was kept up on it by the marines, until it drifted out of sight. Two of the Monitors soon came under the stern of the *Ironsides* in pursuit of this new device of the enemy, but, although two boats were lowered to assist in the search, nothing was seen.

"Fortunately, no damage to the *Ironsides* resulted from this explosion, and her salvation was, no doubt, due to a miscalculation of the distance of the torpedo from the hull. Lieutenant Glassell was afterwards picked up by a coal schooner, and stated that the explosion had swamped the torpedo-boat, and that he and the two officers with him had been obliged to leave her and swim for their lives.

"Here was a new danger for the fleet to contend with, and even more than the customary watchfulness would have to be observed. The North, with all its resources, had not then developed a torpedo-boat (nor are we yet, in 1886, possessed of an efficient one), while the fleet at Charleston should have been supplied with at least twenty of them! They would have removed all obstructions faster than any energetic enemy could have put them down, and the way to Charleston would have been open to the fleet.

"The Confederates, however, did not drop the idea of such submarine or surface-boats, and fitted out another *David* after the plan, with improvements, of the one that had attempted to blow up the *Ironsides*. The first attempt was such a complete failure, that the Federal officers on the outside blockade had grown somewhat careless.

"As early as January 14, 1864, the Navy Department had written to Rear-Admiral Dahlgren, who was in command of the South Atlantic Squadron off Charleston, informing him that it had received notice that the Confederates had on foot a plan to blow up his fleet, and that it considered it of sufficient importance to notify him of it. Dahlgren, however, did not think that such a plan would be carried out against the vessels blockading outside of the harbour, but only against the ironclads on the inside, but, at the same time, thought it advisable to give notice to the officers on the outer blockade, so that they might be on their guard. Notwithstanding these precautions, the Confederates managed to get one of the torpedo-boats over the bar, and on the night of the 17th February the fine new ship *Housatonic*, while lying at anchor off

Charleston, in a most convenient position to be attacked by torpedo-boats, was destroyed under the following circumstances.

"At about 8.45 P.M., the officer of the deck on board the *Housatonic*, Acting Master F. K. Crosby, discovered something in the water, about one hundred yards away, moving towards the ship. All the officers in the squadron had been informed of the character of the *Davids*, and what they looked like on the water. The commander-in-chief had had printed full descriptions of these infernal machines, and directions as to the best manner of avoiding them. He had attached more importance to torpedoes than persons generally did at that time, and considered that they constituted the most formidable difficulties in the way of getting to Charleston. He felt that the whole line of blockade would probably be attacked with these cheap, convenient, and formidable weapons, and that officers should adopt every means to guard against them.

"When this machine was first seen by the officer of the deck, it had the appearance of a plank moving along on the water. It came directly towards the ship, and within two minutes of the time it was first sighted, was alongside. The chain was slipped, the engine backed, and all hands called to quarters. But it was too late—the torpedo struck the *Housatonic* just forward of the main mast on

the starboard side, in a line with the magazine. The man who steered her knew where the vulnerable spots of the steamer were, and he did his work well. As the after pivot-gun was pivoted to port, it was found impossible to bring a gun to bear on the daring intruder, while those on board of her were coolly making their arrangements to knock a hole in the ship's bottom, for the *David* lay alongside a full minute. When the explosion took place, the ship trembled all over, as if by the shock of an earthquake, and seemed to be lifted out of the water, and then sank stern foremost, heeling to port as she went down.

"It must have been a large hole in the bottom that could sink her so rapidly. There was, of course, great consternation on board at this unlooked-for event, for there is nothing more appalling than to have a torpedo exploded under a ship's bottom. A hundred pounds of powder on a pole is enough to blow the bottom through the heaviest ironclad—how destructive must it have been then to a wooden vessel! Most of the crew flew up the rigging for safety, and all order was at an end on board the *Housatonic*. Her captain (Pickering) was stunned and somewhat bruised by the concussion, and the order of the day was 'sauve qui peut.' A boat was despatched to the *Canandaigua* not far off, and that vessel at once responded to the request for help, and succeeded in rescuing the greater part of the crew.

"Strange to say, the *David* was not seen after the explosion, and was supposed to have slipped away in the confusion, but when the *Housatonic* was inspected by divers, the torpedo-boat was found sticking in the hole she had made, having been drawn in by the rush of water, and all her crew were found dead in her. It was a reckless adventure these men had engaged in, and one in which they could scarcely have hoped to succeed. They had tried it once before inside the harbour, and some of the crew had been blown overboard. How could they hope to succeed on the outside, where the sea might be rough, when the speed of the *David* was not over five knots, and when they might be driven out to sea? Reckless as it might be, it was the most sublime patriotism, and showed the length to which men could be urged on behalf of a cause, for which they were willing to give their lives and all they held most dear.

"Torpedo practice was at that time cried down by humanitarians, but the use of it in war was perfectly legitimate. What was considered un-Christian warfare then, is now resorted to by all nations, only in more destructive shapes. The torpedo which was so successfully used by the Confederates was a very primitive arrangement. It has been so im-

proved and enlarged in destructive ability that it bids fair to become a great factor in keeping the peace throughout the world; and those nations which have built great ironclad fleets, with which to dominate weaker nations, may well stop to consider whether it is worth while to extend the system, in view of the advances made by the locomotive torpedo, which will likely put the smaller nations more on a par with the stronger ones."

The success of the Confederates again drew the attention of the Federals to the idea of submarine boats,* and already, in October 1864, experiments were made on the Hudson river with a boat, the *Stromboli*, built in Fairhaven, and designed by Chief-constructor Wood. The results of the experiments were so satisfactory that the Congress is said at that time to have intended the construction of twenty such boats.

The boat was built of wood, and was 75 feet long, 20 broad, and 7 deep. It was not properly speaking a submarine or even a "diving boat," but by letting in water it was immersed until the deck was under water, and only a sort of conning-tower, a funnel and a ventilator projected about 3 feet above the surface. The *Stromboli* was propelled by a steam engine, which at 50 revolutions gave the vessel a speed of 10 miles an hour. The torpedo

* 'Mittheilungen aus dem Gebiete des Seewesens.'

was fitted as a 30-foot outrigger, containing up to 200 lbs. of gunpowder. The ignition of the mine was effected by electricity.

On the 26th of November, 1864, we find the *Stromboli*, under command of John L. Lay, assistant engineer, on the way to Hampton Roads, where he was to attack the Confederate ironclads. He arrived there safely on the 6th of December. Nothing is, however, known of its further proceedings.

During the same period, experiments were made in France with a submarine vessel, *Le Plongeur*.* It was designed as early as 1858 by M. Burgeois, then capitaine de vaisseau, and M. Brun, ingénieur de la marine, and many experiments were made with it at Rochefort, by M. Doré, then lieutenant de vaisseau. See Plate I. Fig. 1.

The vessel was about 140 feet long by 20 broad and 10 deep. The propelling force was compressed air, stored up in a number of reservoirs.

The outside plating was $\frac{1}{2}$ inch near the keel and $\frac{3}{8}$ inch in the rest of the vessel.

On the top of the ship was a superstructure with a hollow to take a detachable boat. In the aft end of this superstructure was a hatch, used when in harbour, and before this a conning-tower, which consisted of a cylinder 4–5 feet high, with a lid on the

* 'L'Art Naval en 1867,' par L'Amiral Paris.

top, which afforded the only exit when on the surface. In the upper part of the conning-tower were eight glasses, protected by iron plates pierced with four holes for each glass. Speaking tubes led to the different parts of the ship.

Before the conning-tower was fitted a regulating cylinder, which by the motion of a piston should take in or expel water, and thus alter the displacement at will within some cubic feet.

The pressure inside the vessel should always exceed the outside pressure, and the excess of air was expelled through a special valve into a sort of box, which was perforated with holes through which the air might escape. Special means were provided for emptying this box of water before opening the valve, which was very much like an ordinary stop-valve in a steam-engine. *Le Plongeur* was never under more than one atmosphere's pressure, i. e. 33 feet below the surface of the water. When the ship ascended quickly, and the air escaped through the said valve, a dense fog was created inside the vessel, which caused a deal of annoyance.

At first it was intended, in case of emergency, to escape through simple holes closed by lids, and placed in the top of the vessel, but M. Brun proposed to fit a detachable boat. The size of this boat was 25 × 6 × $3\frac{1}{2}$ feet.

It should be able to take 12 men. In the bottom were two holes which corresponded with two holes in the hollow of the superstructure; the holes were surrounded by packings, and the boat was pressed down on them by means of screw-bolts. There were three such screw-bolts. Several experiments were made with the detachable boat, but only when near the surface; they had no leakage whatever due to this arrangement.

Forward of the detachable boat was another regulating cylinder and a sort of skylight.

The vessel was divided in watertight compartments by two longitudinal and five transverse bulkheads; of these the end and side compartments could be filled with water in order to make the vessel descend.

The air-reservoirs were at that time very difficult to manufacture, although they were only to stand a pressure of twelve atmospheres; at this pressure they would lose one atmosphere in the first 24 hours. There were twenty-three of these cylinders, three of them for reserve. The total capacity of the reservoirs was 147 cubic metres. The energy stored up in them was 66 horses in one hour.

In order to move in a vertical direction water had to be pumped in and out. It was, however, found to be very difficult to stop the boat in time when descending. The bulkheads inclosing the compartments which were to hold the water, were

not air-tight, so that when compressed air was let in to expel the water, it escaped into the interior of the boat, and they had to apply a great general pressure throughout the boat to effectuate the expulsion of water and the ascension to the surface.

To overcome this difficulty some of the air-cylinders were used instead of the compartments for holding the water. A part of the great reserve buoyancy was taken away by putting more weight into the vessel, changing the iron ballast for lead, which took up less room. A system of pipes allowed of the trim being altered by blowing water from one compartment to the other.

A special donkey pump was fitted for pumping water, it was worked by compressed air or by hand, but it was found that the men could not stand the work more than about three or four minutes.

A very complicated system of pipes put all the air-reservoirs in communication with the various compartments, and with the machinery.

The engine was built in Rochefort, and developed 80 horse-power when working with air at twelve atmospheres; it was designed by M. Brun, and was of a peculiar construction. It always worked well.

The vertical rudder was fitted as usual.

There were two horizontal rudders turned by one spindle; they were very difficult to turn, because the leverage was small, the space aft being very limited. The subsequent experiments showed that it was necessary to improve the rudder mechanism, and to increase the area of the rudders *as they were found to afford the best means of keeping a certain depth.*

The compasses were found to be sufficiently reliable for ordinary navigation, *but if the vessel was to make an attack, it would be necessary to emerge from time to time in order to correct the course.*

The manometers showed the depth with considerable accuracy, as might have been expected.

A mercury-differenciometer showed the longitudinal inclinations, and it was found quite indispensable to have such an exact instrument, because the least difference in the distribution of weight would incline the vessel enough to produce sensible variations in depth, even if the inclinations were very small in themselves.

The transverse stability was quite sufficient.

Provisions were carried for 12 men in 48 hours.

The watertight floor in the centre compartments formed the real bottom of the boat, the outside bottom was only light plating, inside which the water might circulate. In this space, between the inner and outer bottom, were suspended a number of old shot, which might be let go, one by one.

The total displacement of the vessel was about 200 tons.

The greatest difficulty was the regulation of the motion in a vertical sense. Operations commenced by closing all openings, and then water was let into the two air-reservoirs and into the watertight compartments, until only the top of the conning-tower was above the surface. It was found to be pretty easy to go like this, awash, along the surface of the sea. It was expected that the depth of immersion could be determined by small changes in displacement, namely, by using the pistons in the regulating cylinders, but the experiments showed this to be quite impossible, and the vessel would often touch the bottom even on 30 feet depth before the motion could be changed. When striking tolerably hard bottom, such as sand, the vessel would rebound like an indiarubber elastic ball. Thus *Le Plongeur* would advance, striking alternately the bottom and remounting to the surface. It was more by the indications of the manometers than by the shock that they learned when the bottom was touched. This phenomenon is not difficult to understand, considering that the velocity up and downwards was always very small, and the impulse is measured by the product of the mass of the vessel into this velocity, which product must be much smaller than for instance the weight of the vessel.

The horizontal rudders and the regulating cylinders acted much too slowly. Most frequently they had to resort to the donkey-pump or to air-pressure to expel water, but then the ascension would take place very violently, and when at the surface, the vessel would be found to have a buoyancy of several cubic metres.

A vertical screw was therefore fitted to regulate the motion up and down; it was worked by hand. In this way the equilibrium under water was kept, but only for a very short time.

The result of the experiments was that it was possible to make a submarine boat slide along the bottom in the way described above, and also to move steadily awash.

A model of *Le Plongeur* was shown at the Paris Exhibition in 1867. This model is now to be seen in the Naval Museum in the Louvre. It does not appear that the authorities have been satisfied with the attained results, for nothing has been later heard of *Le Plongeur*.

Russia is perhaps the country where most has been done for developing the submarine boat. In 1868 such a boat was run on the Neva, off Mr. Winan's railway works. It was of the so-called *Alexandrofsky* type, and was propelled by compressed air. It descended several times, but did not seem to satisfy the authorities.

Several other types were tried in Russia, one after the other. Nothing much is known about

them, except that they cost a great deal of money. Thus, one of these boats is said to have cost 60,000*l*. It was lost in Transund Roads.

Also in the States were several such boats built at that period. One of them was tried on the Michigan Lake, and remained four hours under water, but no further notice was taken of it. The same fate befel another American inventor, Villeroi. His boat was built of iron, and was some 30–40 feet long. The most interesting point about it was that the air was kept pure by chemical means. The trial took place in Newcastle, Delaware, and the inventor remained on the bed of the river with eight men for fully five hours.

Mr. Garrett, of Liverpool, is said to have constructed two submarine boats. The first was found too small, and a larger one—the *Resurgam*—was designed in 1876, which was built at Messrs. Cochrane's, of Liverpool. It was 45 feet long, and was shaped like a cylinder, with conical ends. It had central rudders and displacement pistons. A number of interesting experiments are said to have been made with this boat, which was at last lost off the Welsh coast. These boats probably form the basis for the construction of the first Nordenfelt boat.

In 1882 a submarine boat was built and tried in St. Petersburg, by some described as of the *Bjevalsky* type, by others said to have been constructed by *Szevetzky*, and by others, again, it has been stated that it was built in Paris by *Goubet*, and was one of the first of his boats, and that the Russian Government had bought fifty such boats in 1883!

However, the boat was 20 feet long, and of 2½ tons displacement. It was shaped like a cigar, and was propelled by a screw worked by four men by foot. In the middle of the boat was a cupola of glass, from which the boat was manœuvred. The speed was 3½ knots. In general the cupola was above the water. Weights could be moved in a fore and aft direction along an iron rod, so as to give any desired inclination to the boat. In a reservoir was compressed air for twenty-four hours, and chemical means were used for purifying the air. Torpedoes with indiarubber suckers were used, and they were fired by electricity.

The later Goubet boat (see Fig. 2, Plate I.) has been described in 'Annales Industrielles,' and subsequently in 'Engineering,' Nov. 20th, 1885, from where the present account has been taken. It is about 2 tons of displacement, and the principal dimensions are 16 feet 5 inches long by 5 feet 10 inches deep by 3 feet 3½ inches beam. Its shape gives it a very great stability, both transversely and longitudinally, which is indispensable in so small a boat, where the least motion of the

men inside must disturb the equilibrium. In the top of the boat is a hatch, which is covered by a dome secured by hinges and bolts, a joint being made by the edges taking into a recess lined with indiarubber. There are seven glazed openings in the hull (the glass is ½ inch thick)—one forward, one aft, two on each side, and one at the upper part. Outside the boat, at the stern, is placed a torpedo, containing 110 lbs. of dynamite or other explosive. This is fastened by a catch-joint, which can be opened at the desired moment, and the mine is fired by electricity.

Inside is a reservoir for compressed air, which also serves as a seat for the two men who are to work the boat. Further, there are the propelling arrangements, consisting of electric accumulators, an electric motor, and oars, which are to be used if the motor breaks down or the accumulators become exhausted.

When they want to dive, the hatch is closed, a cock is opened to permit the compressed air to flow into the boat. The air has to pass through the two water reservoirs, *h* and *h* on the drawing, by the pipe *f*, in order to become saturated with humidity. An air-pump is put in action to expel the vitiated air. The man then starts the boat at the line of flotation marked in the drawing, while the officer directs its course by means of the screw-propeller which is movable with respect to the boat, having a jointed coupling. When near the enemy water is let into the reservoirs, *h* and *h*, until the desired depth has been attained. When it has arrived under the hostile ship, which may be seen through the upper window of the dome, the torpedo is cast off to ascend by its flotative power, and attach itself to the vessel by means of a ring of spikes which it carries at its upper part. This done, the boat withdraws, paying out the conductor until a safe distance has been gained. The torpedo is then exploded.

A double-acting pump serves to maintain the longitudinal equilibrium automatically. The mechanism which controls this pump is very ingenious, and consists of a pendulum which, by its inclination one way or the other, caused by alterations in trim, throws the pump into gear with an electric motor to pump water between the extreme reservoirs, A and A′, in such a way as to destroy the existing inclination of the boat.

For the safety of the crew there is fitted an explosive signal Z, which is let go in case of accident. It ascends to the surface, and a fuse explodes. It may also carry a telephone wire if desired.

A large weight X is placed at the bottom of the boat, secured by a steel screw, which engages with

a nut let into the body of the weight. When the bolt is turned, it withdraws itself from the nut, and the weight, which is otherwise free, will drop off. Thus the buoyancy of the boat may be quickly increased in case of emergency.

The buoyancy of the boat, when in the surface condition, is 860 lbs.; this weight is partly made up of the crew and partly by water introduced in the reservoirs.

The air for respiration is compressed to 50 atmospheres, and reckoning a supply of 20 cubic feet per hour per man, there is sufficient for two men for ten hours. 20 cubic feet is however rather scanty; but then 1500 lbs. of caustic potash, distributed throughout the boat, serves to absorb a part of the carbonic acid produced by exhalation. A little free chlorine destroys the organic matter that may be suspended in the air.

The motor, which is a Siemens machine, develops at full speed a power sufficient to drive the vessel at five knots an hour.

The weak point of this otherwise beautiful construction is the arrangement of the torpedo, for it is indeed difficult to see how it will at all be possible to attach the mine to a vessel with iron bottom, even if the vessel is at anchor in still water.

It does not appear that much has been done to ensure the keeping of a certain depth of immersion, but possibly the inventor has not found any difficulties in this respect during his experiments, his boat being so stable.

It has not been possible to obtain any record of the experiments made with this boat.

Of late experiments have been made in New York with a submarine boat called *The Peacemaker*, designed by the American *Professor Tuck*. Its principal dimensions are 30 feet by 8 feet 6 inches by 7 feet depth. Displacement 20 tons. Thickness of shell plating is $\frac{3}{8}$ inch. It is shaped like two boats stuck together, and it has so much lead ballast, that only a small cupola or look-out tower projects above the water. Vertical motion is produced by letting in water and pushing it out again by means of compressed air.

The vessel has two horizontal rudders, one on each side, and an ordinary rudder aft.

The mines, it is said, are proposed to be attached to the enemy's ship by means of electro-magnets.

The crew consists of one officer and one engineer. Originally this boat was propelled by electric accumulators and motors, but as they did not answer, they were taken out of the boat and replaced by a 14 H.P. Westinghouse engine, with Honigmann's natron boiler. With this new machinery the boat is said to have made 8 knots; and it is stated that a charge of 1500 lbs. of caustic soda of 95 per cent. saturation will propel the boat for 5 hours. It remained for 7 minutes on a depth of about 40 feet, in which time it ran through a distance of 1·5 mile, and passed underneath the bottoms of two steamers, which were also under way.

Mr. Waddington, of Seacombe, near Liverpool, has made a great number of experiments with a submarine boat, the *Porpoise*, which is 37 feet long by 6 feet 6 inches diameter. It is propelled by electricity, and carries forty-five of the Electric Storage Co.'s cells, said to be sufficient for running a distance of 250 miles at moderate speed. At full speed, 8 knots, they will last 10 hours. The capacity of the accumulators is 660 ampère-hours. The maximum current taken by the motor was 66 ampères; the electromotive force being 90 volts, we get a horse-power of 7·96, and the efficiency of the motor is 81 per cent.

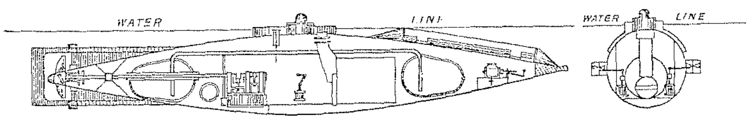
Two horizontal rudders are fitted at the middle of the boat, so that they do not incline the vessel, but only force her up and down. Propellers to produce vertical motion when not under way are fitted besides.

Compressed air is carried in two compartments at the ends. There is sufficient air for two men for six hours. This boat is intended for being carried on board of big men-of-war.

*The Nordenfelt Boats.**—The first of these was built at Stockholm some years ago, and it was in several respects a great step forward. It has been thus described by Mr. Nordenfelt:—

The boat is of cigar shape (see Fig. 1). Its length is 64 feet, and diameter 9 feet. The plates are amidships $\frac{5}{8}$ inch thick and at the ends $\frac{3}{8}$ inch.

FIG. 1.



The framing consists of angles 3 inches by 3 inches by $\frac{3}{8}$ inch placed thwartships 3 feet apart.

The conning-tower, 12 inches high, is fitted with a cover, which can be easily swung round upon a pivot to give easy ingress or egress to the three men who form the crew. The cover has a glass cupola protected by a shield.

The sponsons on either side form wells for the protection of two propellers, so placed as to give their effect in a vertical direction.

The boat, which is always kept horizontal, and always buoyant, is by means of these propellers submerged, and held at any desired depth or permitted to ascend to the surface. Mr. Nordenfelt lays particular stress on the fact that the boat is submerged *only* by the mechanical power supplied by these propellers.

* 'Journal of the Royal United Service Inst.,' 1886, and various other sources.

In the stern is a four-bladed propeller, 5 feet in diameter.

The rudder for port or starboard steering is placed aft of this propeller.

In the bow on either side are balanced rudders on one and the same axle. These rudders are always maintained in the horizontal position by a weight attached to an arm fixed at right angles to the rudder axle. Thus when for instance the boat takes up any position pointing downwards, it will be at an angle to the rudders, which will then tend to force the boat up again into a horizontal position.

The boat is calculated to withstand a pressure of 100 feet head of water, but it is by no means the intention wilfully to descend to such a depth.

The machinery in the boat is driven by steam, and consists first, of a main driving-engine, which is compound surface-condensing; secondly, of two small engines, which are used to drive the blower when on the surface, and to drive the vertical propellers when under water.

On the surface the steam is derived from an ordinary marine boiler; but when the boat is submerged, steam is supplied by means of the heat which has been reservoired in water, whilst the boat was on the surface. The hot water is carried in two tanks as well as in the boiler, and amounts to about 8 tons.

Amongst the various appliances of the boat is an apparatus which automatically stops the vertical propellers when the boat has arrived at a given depth, and which starts them again as soon as the boat rises from that depth.

It consists of a valve, which controls the steam supply to the small 6 horse-power engine which works the vertical propellers; this valve is held open by a weight adjustable on a lever; the piston of the valve is also in direct communication with the sea. When now a depth is reached at which the pressure in the sea is greater than the pressure of the weight, the valve closes, the engines stop, and the buoyancy raises the boat until the outside pressure diminishes, when the weight again opens the valve. Thus the depth of immersion is regulated.

Besides powerful pumping powers, the boat can be lightened by blowing out the 8 tons of hot water.

The boat contains sufficient air-space in itself, so that no extra appliances are needed for this reason.

The crew can very quickly get outside the boat by swinging off the conning-tower lid, which can be done, even if the boat be touching the bottom

at any depth not exceeding that at which the men could not in any case live outside by reason of too great a pressure of water.

The boat is armed with one of Mr. Nordenfelt's controllable torpedoes and one Whitehead torpedo to be ejected from a tube, to be placed outside on the bow of the boat. It was also intended that a single-barrelled Nordenfelt gun should be carried in front of the conning-tower, to be fired by the captain of the boat.

The engines will at full power indicate 100 horse-power, and then drive the boat at nine knots. The distance travelled on the surface without recoaling is 150 miles.

A cold-water tank is fitted at the centre of the boat, it holds about four tons of water, used for regulating the buoyancy.

In the surface condition the top of the boat is about 3 feet above the water, and when going to dive, the water in the cistern is brought up to a temperature corresponding to 150 lbs. pressure, the ash-pit and fire-door are then closed, the funnel, which is telescopic, is withdrawn, and the horizontal propellers are started. The heated water will now be able to give off steam sufficient for a run up to 16 miles at a speed of 3 miles per hour. At the end of such a run the pressure in the cistern is still about 20 lbs.

In September 1885 this boat was shown to delegates from most of the civilised nations. The experiments took place in the Sound of Landskrona.

The following were the results of these experiments:—

The boat was in the course of 3 hours closed up, and moved about with the cupola above the surface; its speed varying, but not higher than 4 knots. The boat was during this experiment immersed and raised again several times, remaining on the same spot. Last time it was down 5 minutes, and touched the bottom. These were the experiments of the first day. The boat could not move along under the water, as the horizontal rudders had been damaged when being towed out of Landskrona Harbour.

The next day the boat had a run in its light surface condition, working as an ordinary steam-vessel. It ran through a distance of 16 miles with a speed which was estimated at about 5 knots. The boiler leaked, so that the full power could not be attained.

During the last day's experiments the boat moved for 3 minutes under the water at slow speed. It was several other times immersed, but only three-quarters of a minute at a time. The whole experiment lasted 25 minutes. Unfortunately the stoker had been wounded by some

accident. The weather was very unfavourable the first day, so that, on the whole, the performance at these experiments is hardly a fair measure of what the boat can do.

The great advantage of this boat compared to others lies in its use of steam for under-water propulsion, for it must be admitted that, whatever drawbacks may otherwise follow this system, it is simple, and does not require any special knowledge beyond what is possessed by every marine engineer.

Mr. Nordenfelt says:—"By using water as the means of storing up energy, I am in possession of a reservoir which can never get out of order, and which can be replaced at any hour in any part of the world, and without any extraneous assistance from shore or other ships."

As regards blowing out water of the boiler and cistern to produce a sudden force of buoyancy, it ought to be remembered that it would strain them very considerably, and that if the boat should have descended to great depths, the outside pressure may become so great, that only a portion of the water can be expelled, or perhaps the water will even enter the boiler instead of being blown out.

Already in the beginning of the year 1886 this boat was bought by the Greek Government, and in April trials took place in the Bay of Salamis, which were very satisfactory.

It should be added that the boat has shown itself to be an exceedingly good sea-boat.

Nordenfelt's Boats for Turkey.—Shortly after the first boat had been bought by Greece, Turkey ordered two new submarine boats from Mr. Nordenfelt. In the beginning of 1887 these boats were tried at Constantinople, where several successful runs were undertaken, both on the surface and under the water.

Fig. 3, Plate I., shows their construction and general arrangement.

These boats* are 100 feet long, and of 12 feet diameter. Displacement, 160 tons. Speed, on measured mile, 12 knots; distance travelled without recoaling, 100 miles; depth to which it can safely descend, about 50 feet.

The engines are of the surface-condensing compound marine type, and will at a pressure of 100 lbs. of steam indicate 250 horse-power.

The boiler is of the ordinary marine return tube type, having two furnaces of about 750 square feet of heating surface.

The hot-water cistern is rhomboidal, with spherical ends.

Both boiler and cistern are made for a working pressure of 150 lbs. per square inch. Two fish

* 'Journal of the Royal United Service Institution.'

torpedoes, 14 feet long, are carried outside on the bow, and are discharged mechanically.

The sinking apparatus consists of two vertical propellers, driven by two engines, which each indicate 6 horse-power. Two main cold-water cisterns placed at each end, and containing 15 tons of water each, serve to regulate the trim and buoyancy, while one containing 7 tons at the centre serves alone to regulate the buoyancy. Eight tons of coal are carried. The crew consists of 6 men. With coal in the bunkers only, this boat can keep the sea for five days or more.

Mr. Nordenfelt's latest boat has been built by the Barrow Shipbuilding Company; the machinery is built by Messrs. Plenty and Sons, in Newbury. The vessel is designed by Mr. Garrett.

The principal dimensions are:—Length 125 feet and diameter 12 feet. Displacement, fully immersed, 230 tons; in light surface condition, 160 tons.

The engines, which are especially designed for using steam at varying pressures, will indicate 1000 horse-power when working with steam at a pressure of 150 lbs. The boat is at that power guaranteed a speed of 15 knots. When going under water her speed will be 5 knots.

Several auxiliary engines are fitted for steering, pumping, &c.

The crew consists of 9 men, all told.

The minimum metacentric height is 4 inches.

The boat carries 35 tons of cold water in her tanks, and 27 tons of hot water in her boilers. These latter are expected to store sufficient heat for a run of 20 knots under water; they may be blown out in less than 5 minutes.

The coal bunkers hold 8 tons of coal, which at a speed of 8 to 9 knots are expected to drive the boat through a distance of 1000 miles; 20 tons may be carried additionally in the cold water tanks.

Two horizontal propellers, one forward and one aft, keep the vessel submerged, and overcome the retained force of buoyancy = 500 lbs.

There are four horizontal rudders or fins, two forward and two aft.

There are two conning-towers, 2 feet 6 inches diameter, and of 1-inch steel.

The armament consists of two torpedo tubes in the bow, and two Nordenfelt machine guns.

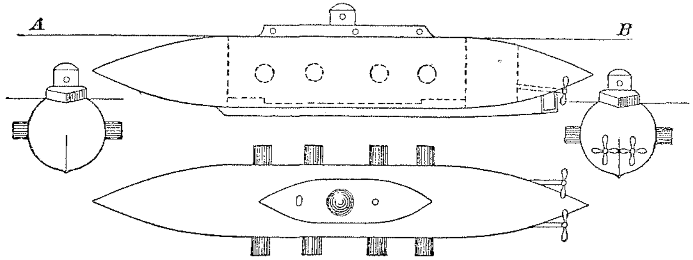
The bottom plating is about half an inch thick, while the turtle deck is one inch.

At the end of May 1887 a preliminary trial took place in Southampton Water, in presence of several authorities. The boat made a run hermetically sealed, with the conning-towers awash, at a speed of about 5 knots. She was almost invisible at a distance of a few hundred yards, being painted

with neutral tint. Next she lighted her fires, got up steam to about 100 lbs. pressure, and made a run to Calshot Castle and back at a speed of 14 to 15 knots. At future trials her sinking power and performance under water, as well as her maximum speed, will be tested.

A new submarine boat, the *Nautilus*, which was designed by *Mr. Andrew Campbell*, and constructed by him, together with Messrs. Edward Wolesley and C. E. Lyon, has been thus described in 'Engineering':—

FIG. 2.



The boat is about 60 feet long, is of circular section and has amidships a diameter of 8 feet. It is pointed at both ends like a cigar and has on the top a superstructure, on the middle of which is a conning-tower with four lenses of glass. The hatch for access to the vessel is placed on the superstructure.

The displacement when fully immersed is equal to 50 tons. The motion in a vertical sense is effected by altering the displacement; to this end four cylinders opening out to the sea are fitted on each side, and the motion of these can vary the displacement within one ton. They work through glands in the side of the ship.

The boat is built of $\frac{5}{16}$ inch Siemens-Martin steel plates; the frames are $3 \times 3 \times \frac{1}{2}$ inch and are 1 foot 9 inches apart. It is to stand the pressure of 50 feet depth. It is driven by two screws by two electric motors of the Edison-Hopkinson type; they develop up to 45 horse-power. In the central part of the boat are 180 accumulators, of the Elwell-Parker construction, arranged symmetrically. Each of these accumulators is said to store an energy of four horse-power-hours.

The two big motors also drive a pump and work the eight displacement cylinders. The speed of the vessel is estimated at eight knots by full power, and then the machines run at 750 revolutions. The store of electricity is sufficient for ten hours.

Two rudders, one horizontal and one vertical, serve for steering the boat in all directions. In the middle part of the boat is sufficient room for six persons. The air contained in the boat is sufficient for six men for two hours, but compressed

air is carried besides, and it is intended to construct an apparatus by which the air may be renewed throughout the boat very quickly, as soon as it comes to the surface.

The fully equipped boat projects only 10 inches above the water.

The armament consists of two impulse tubes for Whitehead torpedoes.

The boat was tried in West India Docks, in the presence of several authorities. It stayed for some time at the bottom of the dock, and a short trial took place.

Several experimental submarine boats have been built by *Mr. John P. Holland* of New York.* The first of these was built in 1877. The experiments with it showed the advantage of keeping a certain amount of reserve buoyancy when diving, and of being able to dive quickly.

The second boat was built in 1879, and proved the desirability of employing pneumatic guns for throwing torpedoes over as well as under the water, and also the importance of speed, handiness, and independence of station. About forty running dives were made with this boat, its longest time of submergence being two hours and a half. The time of confinement was limited by the amount of fresh air contained in the boat.

* Letter to 'Engineering,' from the inventor.

The third boat, a 16-inch working model, was built to test a new apparatus for steering in a straight line under water, and also to test the efficiency of a new projectile torpedo and a new motor. The new steering gear is said to have acted perfectly.

The fourth and last boat is 50 feet long and 8 feet diameter. Its chief weapon is a 9-inch pneumatic gun, firing projectiles, weighing 120 lbs., at 150 yards over the surface of the water and 40 yards in a straight line under water. A camera lucida is used at intervals to ascertain the course; it is placed on a telescopic tube projecting above the water. It is especially used for aiming.

The inventor says :—

"Towing, spar, locomotive, countermining, or projectile torpedoes can be employed with equal facility, although projectiles are preferred. Stationary mines can be planted, removed or destroyed, and the most thoroughly defended harbour may be entered without risk by this boat, and her three tons of projectile torpedoes disposed of to the greatest advantage."

He further states that the new pneumatic gun can have a mean firing pressure of 8000 lbs. per square inch, this pressure being raised in a moment from an initial of 2000 lbs.

CHAPTER III.

THE CONSTRUCTION OF SUBMARINE BOATS.

THE clearest way of showing the ideas and principles which ought to be the guiding ones in such a construction, is to simply describe in detail a complete design, all along giving the reasoning why such or such an arrangement has been adopted. This will illustrate the many practical difficulties of the problem, and will in the most positive way answer the numerous questions which naturally occur to every one who takes the trouble to think over the matter.

Before describing the details of the design, it will be well to sketch out its main features, of which the accompanying sketch (Fig. 5, Plate II.) is an illustration.

The essential point of this vessel is that it is able to dive down at any time, and continue its course under water for a considerable distance. This is attained by giving the vessel two different modes of propulsion, namely, steam and electricity. The steam-power enables it to move along the surface of the water, just as would do most of our modern men-of-war, if we take away their light upper part. When the vessel dives down, the electric motors are thrown into gear, and thus she may go on under the water, as long as there is any electricity in her electric storage-cells. The cells may be re-filled by using the ship's own steam-engine as motor, and the electric machines as dynamos.

The transverse section is throughout the vessel an oval with its greatest axis horizontal. This shape has been adopted partly because it is favourable as regards strength, on account of the curved surface, and partly because it gives small draught of water. The vertical axis has been made just big enough to give the necessary head-room, and thus reduce the depth to a minimum; and the breadth is what is required to give the desired displacement and room on the floor for the various fittings. The longitudinal shape is, indeed, very unfavourable for propulsion, when in the surface condition, which must be regarded as the most important in this respect; but it has to be contended with in view of the other requirements, as explained further on.

The vertical motion is given by two screws placed amidships off the centre of buoyancy. Horizontal rudders serve to maintain the equilibrium, when at the desired depth.

The armament consists of two fixed Whitehead

torpedo tubes and one outrigger torpedo, all fitted in the stem, and two Whitehead torpedo tubes, one on each side, in the steering room.

On the top of the vessel is a superstructure forming part of the hull; it serves to give sufficient depth for the telescopic funnels and the ventilator, and for a detachable boat. By this superstructure greater freeboard is also gained when on the surface, corresponding to a given amount of reserve buoyancy.

In order to facilitate the navigation of the vessel when on the surface, a platform, which otherwise rests on the superstructure, is raised up well clear of the water.

In the bottom is a big water-ballast tank, and detachable weights are fitted as a sort of bilge keels, which will also serve to support the vessel when it is resting on the bottom, and thus prevent it from heeling.

GENERAL STATEMENT OF WEIGHTS.

Hull	410 tons.
Engines, boilers, and spare gear ..	100 „
Coal	40 „
Electric machinery and accumulators	60 „
Water ballast	60 „
Detachable ballast	20 „
Stores and internal fittings	50 „
Total displacement	740 tons.

The details of the design may properly be described under the following heads:—

1. The strength and construction, shape and stability.

2. The propulsion and the pumping power.

3. The steering and navigation.

4. The armament.

5. The air-supply and the accommodation of officers and crew.

6. Special fittings.

1. *The Strength and Construction, Shape and Stability.*

Inasmuch as it is impossible to provide sufficient strength to resist the pressure of the water at any depth, there must for every boat be a limiting depth, beyond which she must not go; in the same way as a bridge has a limiting load.

The boat must, therefore, either be used only in water the depth of which is within the limit, or it must be under such perfect control, that will justify going in waters of a greater depth.

This may at first sight appear to put a too great restriction on the freedom of the boat; but as will be shown, it is quite possible to construct a boat strong enough to resist the pressure even at depths of fifty fathoms and more. It must, however, be

understood, that the boat is not supposed to go down voluntarily to such great depths; in fact, it will never be necessary to go deeper than required to clear the keel of a big ship, i.e. about 5–6 fathoms, or a pressure of one or one-and-a-half atmosphere. On the other hand, no one can deny the possibility of such vessels being forced down to greater depths against their will, as, for instance, in case of a sudden leak, bad management, or other unforeseen circumstances.

The submarine vessel must necessarily be prepared for all such contingencies; and there must also be means of escape for the crew, for the vessel may sink to the bottom, without being able to get up again, if, for instance, the machinery and pumps break down.

Now great strength means great weight of hull; in the present design a hull percentage of 56 per cent. was arrived at, using best mild steel; but, as will appear on consideration, there is plenty of weight, but little room available in such vessels.

That this is so, may be readily seen by making an imaginary experiment. Take, for instance, the *Inflexible*, and keeping her water displacement unaltered, imagine that she is cut over at the water line, and that everything now above the water is to be stowed down below the load water-line. It is clear, that to get room for all these things would be a very difficult task, and the weight would have to be disposed of in form of ballast or shell-plating, if there was to be any living space left at all.

Suppose we want to design a boat for service in the Channel, the seaports all round England and in the Baltic, then fifty fathoms would be about all they will encounter in the greater part of those waters.

Let us then examine what will be the requirements of the structural arrangements in this case. Fifty fathoms = 300 feet of water gives a pressure of about 19,200 lbs. per square-foot or $8\frac{1}{2}$ tons.

It must be remembered that fifty fathoms is taken as an extreme hypothetical figure, and we are, therefore, justified in making a theoretical estimate of the scantlings, in which we assume the best possible conditions to be given as regards the goodness of the material, its application and treatment.

In order to be on the safe side, the strength of plating and frames is everywhere calculated as if they had no curvature.

The frames are put as close together as they can conveniently be worked, say 18 inches, in order to provide not only great local strength but also general stiffness.

Although a cellular system might appear very desirable as regards both stiffness and strength, it

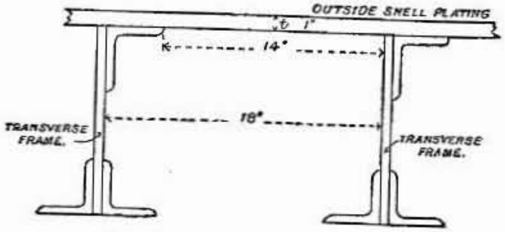
will take up too much room, and it will be impracticable to work the frames and longitudinals very close, so that this system would carry with it an enormous thickness of shell-plating. It is, however, necessary to build a water-ballast tank in the bottom, in order to have command over the displacement, and since it is to have great depth, and the plating in the bottom must in any case have great thickness for local strength, this tank is built on the ordinary cellular system, generally used in such constructions.

But elsewhere in the ship a frame spacing of 18 inches is adopted, and it now remains to be found what the thickness of the plating must be between the frames, next, what must be the scantlings of the frames to support the plating, and finally, what must be the system and dimensions of pillars, stringers, and bulkheads, which are to form the ultimate struts intended to carry the enormous compressive forces, acting on the outside plating, when the vessel is deeply submerged. Fig. 4, Pl. II.

First as to the plating (see Fig. 3): take a strip, 1 foot wide, and let us assume that no support whatever is given to it by the adjacent material. Let the width of the flange of the outer frame angle be 3 inches, then we have an unsupported length of the strip, 14 inches. Assume the proof stress of the material to be 10 tons per square inch. The load is already given to be $8 \cdot 5$ tons per square foot.

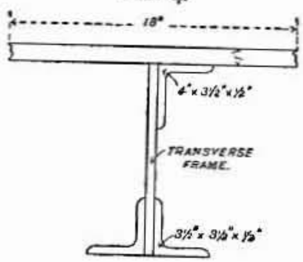
Calculating the stress set up by bending this strip, we arrive at a thickness of the plating of about 1 inch.

FIG. 3.



Now as to the frames (see Fig. 4): let us assume a certain frame which can conveniently be worked,

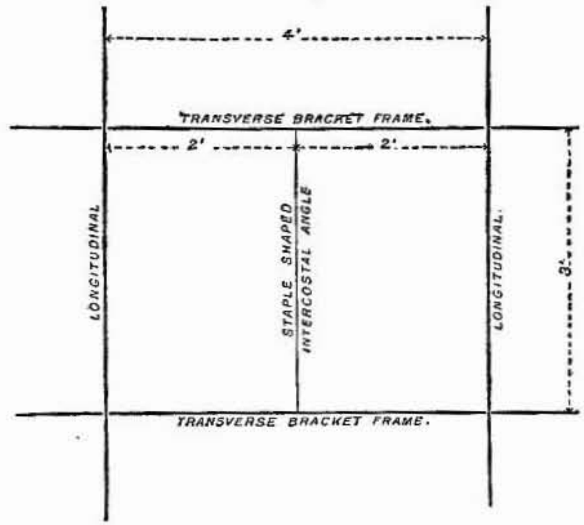
FIG. 4.



say 12 inches deep plate with angles inside and outside of the dimensions shown on sketch; it then remains to find what may be the greatest unsupported length of such a frame, i. e. what must be the spacing of our longitudinals, which are to run inside the frames, and distribute the strains from bulkhead to bulkhead, and to the system of pillars.

The frame has all along to carry a strip of plating, 18 inches wide, and we assume also here, that there is no support given to this strip by the adjacent frames and strips. Thus, the load on the frame will be $1 \cdot 5 \times 8 \cdot 5 = 12 \cdot 75$ tons per foot run. We assume the frame to be straight, and the load to be uniformly distributed. Taking proof

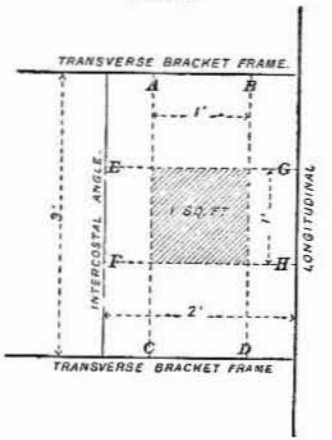
FIG. 5.



stress to be 10 tons, it would be found, that on these assumptions we may have a length of unsupported frame up to $6\frac{1}{2}$ feet.

It has already been stated, that the shape of the vessel is oval in section, and the reasons for this have been given. This shape is not the best as regards general strength, the cylindrical shape being better in this respect, but, on the other hand, it lends itself readily to pillaring. Suppose we take 8 feet head-room, 3 feet deep water-ballast tank and 1 foot frame; this will give us a depth of the vessel equal 12 feet, and let the maximum breadth be 22 feet. It will hardly be advisable to make her broader, as we should then get a very flat top and sharp corners at the bilges.

FIG. 6.



It will, of course, be most efficient to place the struts at right angles to the surface we want to support, but it is on the other hand unpractical to have sloping pillars as these take up too much

room. Near the middle line both these conditions may be satisfied, and therefore two rows of vertical pillars are placed, one on each side, and not more than 6·5 feet apart. In the sides at about mid-height we may conveniently give the support the form of a very deep stringer plate or shelf. Finally some sloping pillars support the upper bilge, if this term may be allowed, while the lower bilges are sufficiently supported by the side of the ballast tank. These pillars are connected to the edges of the side stringers, thus supporting these, should they tend to bulge.

All pillars ought to rest on longitudinals, running inside the frames, but not worked intercostally, on account of the close spacing.

The diameter of the pillars must be calculated with a very large factor of safety, say 10, and the load on each must be taken to be equal to the water pressure, acting on the area inclosed between any four pillars in the neighbourhood. To save room the pillars ought to be solid. In fact, everything must be done to save room on the deck, for it must be remembered, that on this one deck we want to place everything, that is in an ordinary vessel of the same size placed on two decks and a hold. It was found that many of the pillars would have to be 6 inches in diameter.

The water-ballast tank (see Fig. 5) may be built in quite the usual way. Let it be 3 feet deep amidships, transverse frames 3 feet apart and the longitudinals about 4 feet apart. We cannot very well work the tank closer, but even with this arrangement, it is evident that 1 inch plating will be incapable of resisting the assumed maximum pressure. It will be found that only by running extra longitudinal angles and increasing the thickness of the bottom plating to nearly $1\frac{1}{2}$ inches, is it possible to resist the maximum pressure. These extra angles may be staple-shaped, and worked intercostally from transverse frame to transverse frame.

It will be well to show the way in which this approximate strength calculation has been performed. The method adopted, although not strictly correct, is decidedly on the safe side. (See Fig. 6.)

Consider one of the unsupported rectangles of plating 3×2 feet, and take the centre square foot as forming part first of the 3 feet long longitudinal strip, A B D C, and next of the 2 feet long transverse strip, E G H F. In each case calculate the maximum load per square foot uniformly distributed, which the strip will carry considered as a beam 1 foot wide and $1\frac{1}{2}$ inches in thickness, and of mild steel. In so doing we assume that the stresses at right angles do not interfere with each other; and we neglect the support given by the four corner pieces, and the

reduction in dimension due to the width of the flanges of the angles. It will be found that on these assumptions we get a maximum load carried for the 3-foot strip of $3 \cdot 33$ tons, and for the 2-foot strip of $6 \cdot 49$ tons per square foot, the sum of which is much more than is required.

By thus almost armouring the bottom, we gain great local strength, which is of extreme importance in view of the fatal consequences of even a small leak, when deeply submerged. It will now be possible to bump on the bottom of the sea without great risk as long as the bottom is not too hard.

As regards the transverse bulkheads, a thickness of $\frac{1}{2}$ inch will be sufficient, if properly supported by deep angles. The distribution and number of such bulkheads is seen from the sketch.

No longitudinal bulkhead is introduced except in the boiler-room, where it will be desirable to separate the two boilers on account of the forced draught.

The stem ought to be exceptionally strong, for even if ramming may be regarded as too hazardous for such a vessel, collisions are not unlikely to occur in a boat of this type. The stem should therefore be one big solid steel casting, so as to admit of a most efficient connection to the adjacent plates. These plates ought to be stronger than the ordinary outside plating, say 2 inch.

The stern will necessarily be a very complicated construction like that of the Whitehead torpedo. It has to give support for the bearings and pintles of the horizontal and vertical rudders, and at the same time it must protect them. The reasons why it is preferable to place all rudders aft will be discussed further on.

The construction adopted to suit the great requirements as to strength has now been described in its main features. Something remains to be said on *the shape.*

The transverse midship section has already been settled upon, and it is natural to keep this type of section right through, in order to get tolerably clean lines.

Fig. 4, Plate II., shows a section of same shape and dimensions as the midship section as far as the lower part of the vessel is concerned, but taken through the superstructure in order to show this, and the way the detachable boat is housed.

It has been found through several preliminary designs that if the vessel is to fulfil the above-stated conditions as to strength, coal endurance, and living space, and especially if it is to have both electric and steam power, and a tolerably good speed, it cannot very well be smaller than 7–800 tons, and this gives a length of 140 feet approximately, taking a reasonable block co-efficient.

As to the shape, the vessel ought to have fuller lines forward than aft for the following reason :—

The steering qualities of such a vessel are a most essential matter, for it must be borne in mind that even small variations in the steering in a vertical direction will very soon result in considerable changes of draught, or rather depth of immersion. Contrary to variations in a horizontal sense, to starboard or port, which are as a rule, when keeping a course, of no consequence if within a few fathoms, a similar variation in a vertical sense, i.e. in draught, may become a very critical matter, as any sailor will admit, if he is asked whether he would like to be on board a ship whose draught was variable beyond his control with several fathoms.

Everything must therefore be done to give good steering, by which is meant, not a vessel which will turn round and round willingly as soon as you give her a little helm, without your hardly being able to stop her motion, but a ship which has a tendency to keep the course on which she is at any given instant. The two cases are in a way analogous to stable and unstable equilibrium.

To obtain such a ship we must do what we do with a rocket, and what nature has done with the birds and the fishes—we must give it a heavy forebody and a long, light, and broad after-body and tail. In other words, give her a full entrance, a long fine run, and big horizontal rudders.

This point may be investigated approximately by comparing the position of the centre of gravity of the ship and that of the area of a horizontal section through the axis of the boat. It is not therefore given that the vessel will be steady steering because the latter centre of gravity lies aft of the former, but the more aft it lies the more stable will be the motion of the vessel in a vertical sense.

As regards the *stability*, we must consider this property separately for each of the conditions under which the vessel may have to work. It becomes therefore necessary first to make clear what these conditions are.

It has been said above that the boat was a "diving boat," which means that under ordinary circumstances she will have a greater or smaller amount of surplus buoyancy, and only when she is going to dive will her displacement weight be about equal to that of the water displaced when fully immersed. We may therefore speak of a total displacement or immersed condition, and a light displacement or surface condition. As this design worked out, it was found that the greatest possible variation in displacement was about 80 tons, but of these 20 tons are applied as detachable ballast, and some 20 tons must be carried as ballast in the

extreme end tanks, in order to be able to regulate the trim of the vessel when disturbed by consumption of coal or the like.

Thus, only 40 tons are left. When the first 17 or 20 tons are pumped out, the superstructure will be well above the surface, and a further increase of buoyancy will only very slowly increase the freeboard, although it may increase the stability somewhat.

It is therefore supposed that the ordinary light condition, that which she would use in time of war, when it is important to be able to dive down quickly, is with about 20 tons of reserve buoyancy, i.e. the superstructure well out of the water. The volume of the superstructure displaces really 17 tons of water.

In the immersed condition she is absolutely stable all round, and her stability is the same as that of a pendulum 1·07 foot long and of 740 tons weight—1·07 foot is, namely, the distance between her centre of gravity and her centre of buoyancy, which in a fully submerged body coincides with the metacentre.

In the surface condition also she is absolutely stable all round. The metacentric height is 1·4 foot transversely, and 3 feet longitudinally. If the vessel were made to float with her bottom upwards, she would have a metacentric height of 0·4 foot, but then the centre of gravity will be 0·75 foot above the centre of buoyancy, taking account also of the shift of water-ballast; so that the metacentric height will in this condition be negative, i.e. it is a position of unstable equilibrium.

These perfect conditions of stability are mainly due to the exceedingly low position of the centre of gravity, which, when fully immersed, lies 0·77 foot below the central axis of the ship, but it is also partly due to the existence of the superstructure.

The motions of this vessel would be very easy, on account of the small metacentric height, both transversely and longitudinally, and the great radius of gyration. The movements would never become large, and would soon be extinguished, on account of the great resistance offered by the flat shape, the big rudders, and the bilge keels.

A few words may here be said on the resistance to propulsion of such vessels.

When submerged completely the skin surface will ordinarily be somewhat greater than in surface vessels of the same displacement, because we have to add the area of the upper part of the vessel to the wetted surface when floating on the water like other vessels. On the other hand, when the vessel is submerged to a considerable depth, there will be none or very little wave-making on the surface of the water.

This means that the submarine vessel will be more difficult to drive through the water at low speeds than would be a corresponding surface vessel at the same speed. For at low speeds, i.e. up to 7–8 knots for a vessel of size as the present, the skin friction forms the greater part of the total resistance.

At high speeds, i.e. above 10–12 knots, the wave-making resistance becomes predominant, and here the submarine vessel will perform as well or even better than the surface vessel.

In fact, if ever exceedingly high speeds are to be obtained in vessels driven through the water, and if ever the present great difficulties in under-water propulsion are overcome, it will be by means of submarine vessels that it is accomplished.

The performance under water has, however, but small importance for the "diving boat"; it is far more essential that she should be well adapted for going on the surface, as regards resistance of propulsion, as this will be the rule and the diving only an exception.

The shape adopted for this design is certainly not one favourable to speed along the surface, but on the other hand much is gained in strength, steering qualities, and reduced draught of water.

2. The Propulsion and the Pumping Power.

What we want in submarine vessels is a substance or mixture, which fulfils the following conditions :—

It must burn or produce heat without access of air.

It must have about the same heating-power as coal.

It must not be too expensive.

It must not corrode the boiler too quickly.

Whoever finds such a substance will have brought the problem a great step forward.

It is natural to think of substances rich in oxygen which might be mixed with coal; but, unfortunately, all such substances, such as chlorate of potash and saltpetre, are too expensive.

It has, indeed, been tried by a Frenchman, Docteur Payerne, and his boiler is described in 'L'Art Naval en 1867.' He used for combustion, balls of wood, filled with an azotate, probably saltpetre. He had first tried other combinations even some containing sulphur, but the corrosion of the boilers made him soon abandon them. He also intended to use the energy of the gases developed by combustion, as is done by gunpowder, but he had to give it up, because cylinders and valves corroded very quickly. He therefore had to use

the combustion in the usual way, applying the heat for generating steam. The smoke escaped into the water through a special valve.

Another idea, which naturally suggests itself, is to use a substance which burns when mixed with water, but here also the substances of this kind which we know are much too expensive. Possibly Honigmann's natron-boiler fulfils the above conditions.

Let us examine whether we may use any other ways of storing up energy, and see how they compare with coal.

Le Plongeur used compressed air. Let us take one of the most perfect ways of storing compressed air that we know of, namely, the reservoir of a Whitehead torpedo. If the capacity is 5 cubic feet, and the pressure 70 atmospheres, the energy stored will not exceed 3200 thermal units; but one pound of coal contains more than 14,000 thermal units, so that both as regards room, weight, and expense, compressed air is objectionable; for the same volume will hold more than 200 lbs. of coal, the air contained weighs about 30 lbs., and the expense in compressing the air is enormous.

Another way in which energy is often stored up is by means of steel springs. Imagine a steel spring of rectangular section and of best kind bent like a watch-spring, then the weight required to supply 1 horse-power during one hour will be 9 tons; so that this method is quite out of question.

In Nordenfelt's boats hot water is used for storing up energy. It has been stated that 8 tons of heated water sufficed for driving the boat, the small one, through a distance of 16 miles and at a rate of 3 miles an hour, so that the run must have taken about five hours. We need not consider through what distance 8 tons of coal would carry the boat on the surface; but this method certainly compares better with coal than any of those mentioned above.

Finally, we may store energy by means of electric accumulators. As in case of many other inventions, people expected too much of the accumulators to begin with, and the consequent disappointment brought them in such miscredit, that it is only during the last few years that they have commenced to regain people's confidence. This must also be ascribed to the fact that through many small, and apparently unimportant improvements, the accumulators have gradually advanced and become more durable, efficient, and cheap.

This confidence is best proved by the last year's sale of accumulators, which amounts to 60,000*l.*

The principal objections which may be made against accumulators or storage cells, as they are now usually called, are the loss of energy by leakage, their great first cost, and their depreciation.

The efficiency of cells may be taken to be about 70 per cent., i.e. if you use 100 horse-power to charge them, you will not get more than 70 horse-power out of them.

Good accumulators will store 22 to 23 horse-power per hour per ton weight, so that 8 tons of cells will contain 36 horse-power in five hours, which would drive the small Nordenfelt boat at much more than 3 knots.

It will be advantageous to have a great number of cells, in order to get a powerful current without exerting them too much. For if high efficiency is to be obtained there must be a reasonable rate of discharge. Mr. Reckenzaun says:*—

"An accumulator is just like a horse, if you give the horse its regular easy work to do, then he will go along at a constant rate all day long; give him too great a load, then he will gradually lose in speed until he comes to a standstill; allow him to "blow" for a quarter of an hour occasionally, and he will get along with the great load at a good rate during the regular intervals. But if we take the time as well as the energy into consideration, then we find that the steady easy work will turn out

* 'Electrical Review.'

more efficient than the great exertion with intermittent rest."

Electricity does not, however, carry a ship far, as is easily seen from the proportion between weight and power, and it can therefore only be used for underwater propulsion.

It must be admitted that steam is more reliable than electricity, but on the other hand heat will leak out of hot-water reservoirs much faster than electricity out of accumulators. We can use the electric energy a fortnight after it has been stored up, the energy contained in the heated water must be used at once. We may easily imagine circumstances under which it would be desirable for a submarine vessel to stay under water, say rest at the bottom, for several hours or a whole day, and then the vessel carrying accumulators is able to go on at once, while the vessel depending on hot water is, to begin with, quite helpless. This is, as the accumulators are at present, the main point in their favour, as compared to hot water for underwater propulsion.

In the present design a combination of steam and electricity is used; namely, steam-power only in the surface condition and electric power only in the immersed condition.

The propulsion on the surface has been considered the most important, and therefore greatest

power and weight of machinery has been given to the steam propulsion, and in order to extend the radius of action, a considerable amount of coal is carried.

Thus the steam engine is to indicate 1400 horse-power in 18 to 19 hours, which would give a distance steamed of about 250 knots, the speed being estimated at between 15 and 16 knots an hour. With reduced speed, say 10 knots, we may expect a distance steamed of about 900 knots.

The electric motors, on the other hand, will give out 120 horse-power on the shaft for 6 hours, and with a speed of 7 knots we get thus a distance of 42 knots. It must be remembered that 120 horse-power on the shaft will correspond to about 140 indicated horse-power in a steam engine.

The steam is to be generated in two boilers of the torpedo-boat boiler type, each to develop 700 horse-power.

The engine is an ordinary compound steam engine, running at 200 revolutions per minute. The screw propeller is placed aft of all the rudders, and is partly protected, as shown in the sketch, by the rudder framing.

Each boiler has a separate funnel and a separate stokehold and fan, so that they are quite independent of each other. The air is drawn from a big ventilator through a passage in the boiler room and then distributed to the two stokeholds. Both the ventilator and the funnels are telescopic, and are to be withdrawn before diving; water-tight lids are then placed on top of all the openings. The ventilator serves as the only hatch when the ship is under way. Before diving, the furnaces must also be closed perfectly air-tight, to prevent smoke from entering the stokehold.

The coal bunkers are to take 40 tons of coal; they are placed in the neighbourhood of the centre of gravity of the vessel, so as to cause as little disturbance in the trim as possible.

The electric power is given off by four motors of the Reckenzaun type, and as they ought to go with a great number of revolutions for efficiency and room, the motion must be geared down about seven times. The revolutions of the screw at 7 knots will be about 90 per minute; and the speed of electric machines should not exceed 650 revolutions per minute on board a ship, in order to avoid excessive vibrations and gyrostatic action.

The electricity is drawn from a great number of cells, the nature and size of which may be best settled upon by thorough experiments while building the ship. When the cells are exhausted, they are refilled by means of the ship's own steam engine, which is made to drive the motors in the reverse direction, as dynamos; the screw propeller

is thrown out of gear during this process. That this is possible is one of the great advantages of combining steam and electricity in one vessel. The only condition is that the machines must have a constant magnetic field, in order to charge the accumulators conveniently.

The cells must be stowed on shelves in such a way that each one of them is easily accessible. To fulfil this condition is very difficult, for it will be found that much room is required; and this indeed puts the limit to the number of cells that can be carried, and not their weight, as one might be apt to think at first sight. The accumulator room must be especially protected against the corrosive effect of the acid which may be splashed about, and particular precautions must be taken to prevent any acid from finding its way into the tank or the bilges.

To the use of accumulators on board ship is objected, that they are too delicate, and that they get easily out of order. It must, however, be noticed that accumulators are known to have been performing general domestic electric lighting for more than two years without ever getting out of order. Moreover, they have been much improved of late, especially as regards their conservation and more practical construction, and we may be justified in expecting still better results from them in the future. As it is, there is no doubt they must be very carefully looked after when on board ship.

The reason why it has been proposed to distribute the power among four motors is, that they stow better in the narrow, flat part of the ship, where they must necessarily be placed, since they must be aft of the steam engine in order to make this independent. Further, the armatures of small machines are more readily drawn out and handled than those of big ones. In case of a break-down of one or two of them, it is still possible to propel the vessel by means of the rest.

The pumping power must be very considerable in a submarine vessel, for not only may the safety of the ship depend upon it in case of a leak, but it may often be desirable to undertake great changes of displacement tolerably quickly.

The following pumps must be found on board :—
As many Downton's or other hand pumps as can be worked by the hand power available on board; in the present design four.

At least one powerful independent steam pump, and several Friedman's Ejectors.

The circulating pump must have a separate bilge-suction.

But the steam pumps can only be used when on the surface, and it is therefore necessary to fit several other pumps worked by electricity, and, in

order to drive them, the available motors may be used. Thus the motor driving the horizontal propellers may be used for pumping when near the surface: it will develop about 12 horse-power, and may thus pump out a great amount of water so long as the head is small. But should the vessel, in spite of all, get down to very great depths, it will be necessary to use pumps with smaller cylinders, but of greater power, in order to force the water out against the enormous head. For this purpose the four motors may be used, which are otherwise used for propulsion.

The vertical motion is, however, not to be brought about by pumping in and out water, for even if experience did not now tell us that this method is unpractical, it may be readily seen by considering that enormous forces are soon set up in this way, forces that would drive the vessel with a speed of many knots, if they acted aft in the same way as does the thrust of a propeller. One or two tons, for instance, are soon pumped out. But, in spite of this, the motion will be very small to begin with, partly on account of the great resistance to lateral motion, and partly because the vessel has not time to acquire any considerable velocity.

But when finally some velocity has been got up, and the vessel commences sensibly to rise or sink, it will take much longer before it can be stopped again, and thus undue vibrations are produced, which may be fatal to the safety of the ship.

The vertical motion ought therefore to be produced by means of a force which can be not only destroyed but also reversed almost instantaneously; and not like the forces of buoyancy, require as long time to be destroyed as was required to produce them, and again as much time to be reversed.

This is the reason why propellers are preferable to alterations in displacement. They ought to be placed near the centre of gravity of the ship, so as not to influence the trim, and one on each side; not in sponsons which may be easily knocked off, but in cylindrical wells, built in the side of the vessel as shown in Fig. 5, Plate II.

It would, so far, be simpler to use one propeller instead of two, were it not, that if one is used, it must be placed amidships, and it will here work with greater friction on account of the long well, and it will take up much valuable room.

The two propellers ought to go exactly at the same speed, so as not to produce any heeling, and this may be attained by putting them in mechanical connection with each other.

Mr. Waddington is said to produce vertical motion by two horizontal rudders, one on each side. In this way an upwards and downwards force may be produced, and if the rudders are

placed near the centre of gravity of the ship, no sensible change of trim will be set up; but the rudders can only be used when the vessel is in motion, and they are in a very exposed position.

In order to be able to produce a sudden and powerful force of buoyancy, in case of emergency, a considerable weight ought to be available as detachable ballast. This may conveniently be worked as a bilge-keel, if possible in such a way that it does not increase the draught, but that it will serve as supports, if the ship is to rest on the bottom of the sea.

This ballast ought to be fitted in several pieces, and great care should be taken to make sure that they do not fail when being disconnected.

The Steering and Navigation.

These are two very difficult points, of which the latter cannot at present be solved in a quite satisfactory way, as far as submarine navigation is concerned. The steering is, so to speak, to take place in three dimensions and within tolerably narrow limits. Navigation under water is like navigation in a fog of the worst description.

In the earlier vessels of this kind, it was found especially difficult to keep the desired depth of immersion.

When submerged, the usual state of things will be that the vessel is moving along at a certain depth, only now and then going up to the surface in order to have a look, and then diving down again to the same depth.

Now, the motion up and down ought to take place by means of the horizontal propellers only, for reasons already stated above.

It will be a good plan to keep a little reserve buoyancy when diving, and, like Mr. Nordenfelt, to overcome this by always keeping the horizontal propellers going. This will not only add considerably to the feeling of safety, but will really provide a margin for unforeseen accidents. The desired depth must be kept by the combined action of the rudders and the propellers; the former keep the vessel strictly horizontal, the latter move it up- and downwards, according to circumstances, just as in the Nordenfelt boats. Instead of placing the rudders forward, as in Mr. Nordenfelt's vessels, it is proposed to place them aft, for reasons stated above, and to work them indirectly by a pendulum mechanism through an electric motor. The action of this instrument should be that, as soon as the vessel becomes inclined longitudinally one way or the other, an electric motor will at once be set to work to turn the horizontal rudders, so as to destroy the inclination. This apparatus is seen to work quite independent of the depth of immersion of the vessel, and is only acted upon by its inclination.

Now, such inclination may be brought about by a cause which gives it a permanent character, such as, for instance, the moving about of weights in a fore and aft direction; and although the rudders may soon bring the vessel back again to its horizontal position, still the trim will again be changed through the action of the moved weight, and so on, as long as something is not done to restore equilibrium. An electric motor should therefore pump water from one end tank to the other in such a way as to assist the rudders, this motor being in connection with the pendulum mechanism, and set in motion and reversed by this.

The pump should not be very powerful, but only so great that if the vessel makes several *subsequent* vibrations in the above described manner, the water, which is each time pumped from one end of the vessel to the other, will finally quite destroy the moment to change trim.

The horizontal rudders are placed one on each side of the screw shaft, they are turned by the same shaft, and are very large. The centre of gravity of these rudders ought to be brought as far aft as possible, so as to give greater leverage, and to make the steering of the vessel steady. The area of the rudder is in this design 106 square feet; and it has been given the shape of a fish-tail to bring its centre of gravity well aft. By giving the rudder this shape we obtain a good protection of the screw by the framing, which is to surround and protect the rudder.

It may be of interest to see the result of a man walking from one end of the vessel to the other. Let the man weigh 160 lbs., it will then be found that with the longitudinal metacentric height of about one foot he will incline the vessel $\frac{3}{4}$ of a degree. If the vessel is moving at 8 knots an hour, this inclination, if allowed to exist, will cause a change of depth of immersion at a rate of about 9 feet per minute; a change which could not be put up with. On the other hand, the enormous horizontal rudders will only need being carried at a very small angle during a short time to place the vessel horizontal, and 150 lbs. of water pumped between the end tanks will put an end to the disturbance.

A similar principle to that used for the horizontal rudder ought to be applied in connection with the two horizontal screws. Their motion must be regulated by means of a piston, acted upon by the pressure of the water outside, and vibrating about a given position, determined by the load on a lever acting on the piston rod. Like in Mr. Nordenfelt's mechanism, the motion of the piston rod is used to govern the motor, which is here electric, and thus the speed of the horizontal propellers may be increased or diminished, or perhaps they may be stopped, and the motion reversed, according to

circumstances. When the piston is in the desired position, i. e. when the vessel is at the desired depth, the screws are working slowly downwards, thus balancing the upward force of spare buoyancy. This instrument is seen to be only acted upon by the depth of immersion of the vessel, and if placed amidships, it is quite independent of the inclinations.

If, however, the cause of the vessel's sinking or rising is of a permanent nature, such as, for instance, water entering the vessel through a leakage, or the vessel getting into water of different density (the difference in displacement in salt and fresh water is for this ship about 12 tons), this apparatus is not in itself sufficient. It becomes therefore necessary to go one step further, and arrange it so that the cause of disturbance is also finally destroyed. It is therefore proposed to put the piston rod in connection with an electric motor, making this work a pump, to pump water in or out of the vessel, according to circumstances.

The action of the pump must not be too violent, but only enough to destroy the cause of disturbance within a reasonable time.

Both this pump and the pump for trim will thus always be in action, as soon as the vessel is beyond its correct depth of immersion, or is inclined to the horizon.

By using this method of destroying permanent causes of disturbance there will be no danger of too great action, for the pumps may be readily regulated to pump less water, and, moreover, the action of the rudders and screws will be so quick, that the vessel will be brought back again to its correct position long before any considerable amount of water can be pumped about. It is only when the ship is time after time going out of position and in the same manner that the intermittent action of the pumps will, when summed up, be of any consequence.

As regards the navigation under water, it must be effected mainly by means of the compass, which, when properly compensated for the local attraction, will be sufficiently good to keep a certain course, found by observation at the surface.

The speed may be indicated by the excellent instrument lately invented by Captain Rung, of Copenhagen; it shows the speed at any instant, and only necessitates a small tube to be stuck out from the ship's bilge.

In the top of the superstructure are fitted two conning towers, from which look-out may be kept without exposing any other part of the vessel to the enemy. The steering in horizontal direction is effected by means of an ordinary vertical rudder, placed aft, and well protected by forged iron bars. It is placed underneath the horizontal rudders, so

as to be well protected against collisions, &c., and well immersed when the vessel is moving along the surface, and possibly lifting her tail out of the water in pitching. It does not otherwise present any feature of interest. Its area is 38 square feet.

When in the surface condition, the navigation should take place from a platform or bridge deck, which, when the vessel is submerged, rests on the superstructure, round about the detachable boat, but may be lifted up to a height of nearly 12 feet above the water, along with the funnels and the ventilator.

4. *The Armament.*

If it were possible to construct the bow of the vessel thus, that it could ram the bottom of other vessels without taking any damage herself, this would make the submarine boat a still more dangerous enemy. Whether this is possible cannot be determined except by experiments. In that case the stem ought to be so bluff as to make sure not to stick in the hole she had herself made in the enemy.

As it is, however, it is safer to contend with the use of torpedoes; but the stem ought, all the same, to be made as strong as possible.

This vessel is armed with four fixed torpedo-tubes, of which two are fitted in the stem to fire right ahead, and two are fitted in the steering room, one on each side, to fire athwartship; further, with one outrigger torpedo, which is placed on the end of two telescopic steel tubes, that are to be pushed out for attack by means of compressed air. The outrigger is again withdrawn by means of a chain. A great number of air-accumulators are fitted in the torpedo-room, from which the compressed air necessary to work the torpedoes is drawn.

Suppose the enemy's vessel is lying at anchor. Before the submarine vessel comes within sight of the enemy, whose position is supposed to be known, the funnels and the ventilator, together with the platform deck, are lowered down, and all the openings closed by watertight lids. The ship goes on awash, until she is so near that there is a danger of being discovered; then she dives down, but, according to circumstances, she must go up to the surface now and then, in order to correct her course; however, she only need show the small conning-towers. Judging from the difficulty with which, for instance, a buoy is kept in sight, even in fine weather, it seems very unlikely that such small objects as these conning-towers should be detected before the submarine vessel is near enough to go straight for the enemy under water. With the compass, she is not altogether without guidance as regards direction, as she will be able

to keep any given course, once determined, just as well as a ship on the surface.

If the water is quite clear, and in ordinary daylight, it will, according to divers, be quite possible to see a ship's bottom as a large dark mass even at a distance of several hundred feet. If once the bottom of the enemy's vessel is seen, the torpedoes are fired against it, one at a time, so as to destroy the net, if possible, by means of the first torpedo. If these fail, she may still try to apply the outrigger torpedo.

At night it will be a mere matter of luck, if such a vessel is discovered in time, as was proved in the case of the *Housatonic*, but then the torpedoes must be fired when at the surface, in order to obtain the direction.

5. *The Air Supply and the Accommodation of Officers and Crew.*

The air supply is to be stored up in a large number of hollow steel cylinders, of the type now used for the storage of compressed air for filling the Whitehead torpedo. Each of these cylinders takes 15 cubic feet of air at 70 atmospheres; they are tested to 150 atmospheres. A total of 36,700 cubic feet at normal atmospheric pressure may be carried in this way. This enormous supply of air is to be used for the torpedoes, and for respiration when submerged. According to the experiences from Mr. Nordenfelt's boats, the fresh air which is in the vessel to start with will go much further than one would imagine. If, however, the vessel is to wait for some time under the water, an extra supply of air will be needed.

By experiments it will be possible to decide whether it is not cheaper and more practical to procure the fresh air by chemical means; at any rate, it appears to be so in theory.

Oxygen may be produced directly by heating a mixture of chlorate of potash and black oxide of manganese. A small quantity of these substances mixed together, and heated by an ordinary spirit lamp, will produce enormous quantities of oxygen, and it only remains to purify the air by extracting the carbonic acid produced by respiration. This may be done by pumping the air through dry lime. A little chlorine is always developed along with the oxygen in the above process, but this will probably help to destroy the injurious organic matters which may be suspended in the air.

The great advantage of this method is clearly seen from the fact that a man uses only 4·5 cubic feet of oxygen per hour; but that if we want to keep the air tolerably pure by ventilation, such as is done in dwellings for instance (i.e. to keep the percentage of carbonic acid at less than about

0·06), more than 2000 cubic feet per head per hour is required.* The total complement of men and officers will be at least twenty, so that if really fresh air were to be provided by ventilation alone, the whole store of air carried in the accumulators would not be sufficient for one hour.

On the other hand, the amount of oxygen actually consumed may be got out of a few pounds of the chemical mixture.

Two officers and two engineers have their cabins in the steering room; the rest of the men must find room for their hammocks in the same compartment, if it is possible, for here the ventilation is best.

The ventilating shaft is a cylindrical tube, 4 feet in diameter, made of thin plating in two pieces, like the parts of a telescope. It is to be worked up and down, either by steel wire rope pulleys or by some other mechanical method. If otherwise found convenient, the bridge deck may be attached to the lower part of the funnels and ventilators, which then have to move together, but it may be that this will make the closing of the openings more difficult, and it puts a restriction to the height of the bridge deck.

A separate fan must be fitted to distribute the

* 'Air, its Relations to Life,' by Walter Noel Hartley, 1876.

fresh air to all the various compartments of the ship.

Electric light ought to be fitted everywhere in the vessel, as well as in the detachable boat, which will have its own accumulators for that purpose.

Not too much care can be given to the important question of the accommodation of officers and crew, which, as will be admitted by every naval man, plays so considerable a part in the fighting efficiency of a vessel. Even if the utmost is done in this respect, the living space will always be small in submarine vessels.

6. *Special Fittings.*

If, in spite of all precautions, the ship should sink to the bottom, without being able to get up again by its own means, as might happen by a breakdown of the motors or pumps, or in the case of a great leakage, it must be possible for the crew to escape. This is the reason why a detachable boat ought to be fitted. In the present design it has been placed in the top of the ship, in a hollow built down into the superstructure. The superstructure extends for a length of 32 feet, and has a height above the top of the ship of 2 feet 3 inches. Thereby we gain headroom underneath the boat in the steering room. The detachable boat is designed to stand the same pressures as

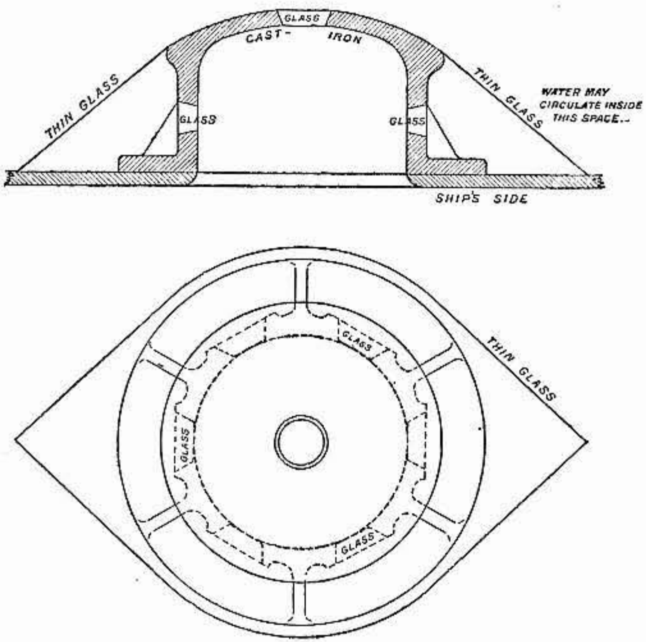
the vessel itself; it rests on a saddle-shaped packing, against which it is tightly pressed down by means of a number of clips.

Inside this packing is a circular door in the boat, and a corresponding and smaller one in the ship, arranged in such a way that it is possible to get up into the boat, close the lower lid in the ship, and then the lid in the boat. This done, all the handles on the clips are turned. The water will probably now enter the space inside the packing, and if not, it may be made to do so through a small pipe leading from the outside to this space, and provided with a stopcock. The boat will now have a certain buoyancy, but will hang on in two main clips, placed one at each end of the detachable boat, and in mechanical connection with each other, so that they can only be let go both at the same time, thereby preventing jamming. When these clips are opened, the boat will ascend to the surface. Communication with the vessel, if somebody should be left behind, may be kept up by telephonic connections.

When the boat comes to the surface, the doors in the upper part are opened. This boat is essentially the same as that in *Le Plongeur.*

Two "conning-towers" or look-out stations are placed in the superstructure forward of the boat, and on the sides of the ventilator. They are watertight compartments, six feet deep, with small towers projecting beyond the superstructure. The construction of these latter is shown in Fig. 7. The glasses are only three inches high, and consist of segments fitted into a cast-iron frame in such a way

FIG. 7.



that the greater the pressure, the greater the watertightness will be. The whole tower is surrounded by a thin glass shade, inside which the

water may circulate; it serves to prevent churning of the water when the vessel is moving along. Watertight sliding doors must be fitted in the top of the conning-towers, to be closed in case of accident.

Glass prisms may be fitted all over the ship, so as to admit the daylight everywhere.

The superstructure is surrounded by light plating, inside which the water may circulate. This is to prevent churning and breaking of the water, and to permit stowing various gear inside, such as anchors, hawsers, davits, collapsing boats, etc.

The anchors are worked by a steam winch, placed in the steering-room; the cables will have to be shackled out when not in use, in order to allow the hawse-pipes to be closed watertight.

Manometers must be fitted, showing the exact depth of immersion.

The design, such as it has here been described, must be taken merely as an illustration of the principles on which a submarine vessel ought to be designed, and as a practical way of pointing out where the difficulties lie in solving the problem. By making the vessel so large, I only mean to advocate size as the only way of fulfilling the claims to speed, strength, safety, and comfort, which may justly be made to this sort of vessels by those who are to use them. What more especially brings up the size is the fitting of two different modes of propulsion. The cost of such a vessel would be about 50,000*l.*, including the expense of the unavoidable great number of experiments.

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