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“On Torpedo-Boats and Light Yachts for High Speed Steam Navigation.”

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THE services for which torpedo-boats and steam-yachts are required render it imperative that they should be capable of attaining high speeds, that they should work silently, and that they should be of limited dimensions. They must also possess great propelling power in proportion to their total weight or displacement; that is to say, whilst the propelling power must be ample, the displacement must be reduced to a minimum. It will be expedient to examine how the two conditions of lightness and sufficient power may best be attained, and what practical means have hitherto been adopted for giving effect to them. For this purpose the total weight or displacement of a vessel may be conveniently divided into three components: 1st. The structural hull, as defined by the late Mr. Froude; 2nd. The propelling machinery and apparatus; 3rd. The load.

The third of these, the load, is comparatively insignificant. In torpedo-boats the load consists of torpedoes and the fighting gear; in steam-yachts, the cabin fittings. The first component, the hull, depends practically on the second, and it cannot safely be made less in weight than a certain fraction, well defined, of the sum of the two other components. Most progress is to be hoped, therefore, from the treatment of the second component, and in reducing the weight of the propelling machinery and apparatus, the weight of the hull, too, may be reduced.

The general conditions on which the reduction of the weight and the volume of the propelling machinery and apparatus is dependent, may be briefly summarised as follows:—Rapid combustion of fuel, subdivided flue-way, in order to multiply the heating surface; high steam-pressure, and high speed of engine—speed of

revolution as well as of piston, particularly the former as the more important of the two. Such are the characteristic features of the locomotive engine, in which they were first developed, and it may be useful to sketch the progress of the locomotive as the embodiment of extreme lightness and concentration of power.

The earliest locomotives, used for working coal-trains on tramways, were little more than reflections of the ordinary practice of the stationary engines of the time, in which the element of weight was not in itself objectionable. The fires were urged simply by the natural draught of the chimney, assisted occasionally by the exhaust steam turned into the chimney; and the heating surface consisted of the iron-plate furnace and the iron flue. Under these circumstances, from 30 lbs. to 40 lbs. of coal were consumed per square foot of fire-grate per hour, whilst the quantity of water evaporated per lb. of coal did not amount to more than from $3\frac{1}{2}$ lbs. to 4 lbs., and the pressure of steam in the boiler did not probably exceed 15 lbs. or 20 lbs. per square inch. Suffice it to state, in addition, that in the course of improvement the current of hot gases was subdivided, by the multitubular flue, into numerous streams enclosed within extensively developed surfaces, as initiated in the historic "Rocket" locomotive. But the draught, and consequently the rate of combustion of the fuel, were vastly accelerated by the introduction of the blast-pipe for directing the exhaust steam up the chimney, insomuch that from 50 lbs. to 100 lbs., and even still higher rates of combustion of fuel per square foot of fire-grate are now practised; that higher pressures have been adopted, augmented progressively from 50 lbs. to 140 lbs. per square inch; and that the cylinders have universally been connected directly to the driving- or crank-axle, making from two hundred to two hundred and fifty revolutions per minute, with speeds of piston of from 600 to 1,000 feet per minute.

With such a practical example of combined lightness and power, it followed naturally that much of what had been matured in the practice of the locomotive on railways was adopted for the propulsion of high-speed vessels of limited dimensions on water. But there are at the same time important differences in the circumstances of the two cases under which the engines work. In water, the engines are required to put forth their full power continuously for long periods, for there is nothing corresponding to a level road or a bank sloping downwards, after an ascent on an incline, to relieve the stress. Full power is unremittingly required to keep up full speed, whilst the water ever assumes the form of an

inclined plane upward. Boiler power is, under such circumstances, continually tasked to its utmost capacity, and a larger boiler is required for cylinders of given dimensions than is necessary under the circumstances of railway traction. Moreover, for surface-condensing engines, from which the soft water of condensation is returned to the boiler, a greater proportion of steam-room is necessary. The bearing surfaces of the engines, likewise, are required to be larger, in order to keep the working parts cool.

In the swift American river-boats high-pressure steam is used, either with or without condensation, whilst the fires are forced by means of a fan-blast or a blow-pipe in the chimney. But the high speeds of which they are capable have, for the most part, been effected with great dimensions; for, with large paddle-wheels and long strokes, their engines are necessarily heavy and bulky, and although a considerable speed of piston is attained in virtue of the long stroke, a high speed of revolution is impracticable.

The large space occupied by paddle-engines, and the great weight involved in their construction, were partially reduced by the introduction of oscillating cylinders, though here a difficulty was encountered in employing steam of high pressure; and with relatively low pressure and low speed of pistons, cylinders of large capacity were unavoidable. Many swift paddle-steamers have been built with oscillating cylinders, and they are beautiful structures of their kind; but the cylinders are so large as to occupy nearly all the mid-ship sectional area of the vessel. To make way for higher pressures with paddle-engines, many constructors have returned to fixed cylinders, with connecting-rods; but when such engines are, for the sake of length, placed in an inclined position within a vessel, they are open to the objection of occupying considerable room, besides the fundamental objection of heaviness in comparison to the work that can be done with them.

When the screw came to the front as a rival to the paddle, a new opening was made for augmenting the speed of marine engines, although at first the opportunity was not embraced, seeing that intermediate gearing was employed to bring up the speed of revolution of the screw, whilst the speed of the engine remained relatively low. But the reducing gear was ultimately suppressed, and the screw was driven direct by the engines, which were connected to the screw-shaft; and compact engines of quick revolution, with high speed of pistons, worked under high pressures, were brought into successful operation.

Under the stress of competition, the demand for economy of the space occupied by the boiler and the coals was keenly felt, most

of all for long voyages, for which the first ocean vessels working at high pressure were built. Besides, the higher the pressure, the smaller may be the boiler, at least so far as the steam-room may be proportioned; and there does not appear to be in use at present better boilers than those of the locomotive type, which are light and trustworthy, for the service of torpedo-boats and steam-yachts. It is to be noted, nevertheless, that a limit is imposed on the degree of pressure that may be available, by the limit of temperature of the steam, which increases with the pressure at which an engine can be worked.

The Herreshoff boiler claims some notice, as it is light, and is of small capacity, containing designedly but a limited quantity of water, in itself conducive to safety. This boiler consists of little else than a coil, by which the water-supply is connected with the steam-pipe and separator. The feed-water, introduced at the top, falls by gravitation, and its fall is accelerated by the stream of steam disengaged in the course of its passage downwards,—by the only way out, in fact. The boiler appears, at first sight, to promise good results. But so even a balance is required between the fire and the feed-water that the boiler is not likely to be maintained, even for a short time, in the most favourable conditions for work; and should the supply of water fall short of the normal quantity, the steam would be highly superheated, and the engines would be seriously damaged. By an excess of water-supply, on the contrary, the heat of the fire would be taken up, without the performance of useful work, and with a corresponding loss of economy. But the question remains, What are the merits of the Herreshoff boiler, under the best conditions that can be maintained, with a small excess of feed-water?

For the purpose of forcing the draught of marine boilers, the fan appears to be the most convenient instrument. Fans have occasionally been set to work in the flues, operating by suction on the products of combustion after they have left the boiler; but they could not last long there, exposed to high temperatures. The Author prefers to stimulate the draught by forcing air into the stokehole. By this means, a better action is maintained, whilst at the same time the stokehole is kept moderately cool. He devised the fan-blast in this form for the boilers of the yacht "Gitana," built by him in 1876, and it has been found to work efficiently. The pressure of the blast used for the boilers of the "Gitana" and other boats of its class is measured by a column of water, from 3 inches to 6 inches high. The greater part of the pressure is exerted in overcoming the resistance of the flue-tubes of the boiler.

The degree of blast-pressure that may safely be employed depends very much on the length and the diameter of the tubes, as well as upon the width of the water-interspaces between them. If large flue-tubes were used in a boiler, the Author is of opinion that the limits of safety might easily be exceeded; and although the maintenance of a plenum in the stokehole is satisfactory in operation, he feels that it must be employed with caution, particularly in its application to boilers having small firegrates and large sectional area of flue-ways. The risk of damage would, of course, be greatly increased by internal deposits.

In using steam of high-pressure, the compound engine is generally adopted, for stationary as well as for marine propulsion; though in locomotive practice the cylinders, as yet, have but rarely been compounded. There are three advantages attendant on the employment of compound engines compared with single-cylinder engines—a more nearly uniform distribution of pressure during the stroke of the piston, accompanied by a better distribution of tangential pressure on the crank-pins; a diminished range of temperature in each cylinder, and comparative simplicity of valve-gear. A relatively high speed of engine may be taken as favourable for economy of steam, in consequence of the smaller area of cooling surface in the cylinders of high-speed engines than in those of low-speed engines, exerting equal power; as well as of the smaller circumferential passages for accidental leakage of steam about the pistons and the valves.

The proportion of expansion to which steam should be worked in compound engines, for the purpose of attaining the greatest economy of steam and fuel, was made the subject of many carefully-conducted experiments on the compound engines of the U.S. revenue steamer "Rush," in which the cylinders were thoroughly steam-jacketed with steam of 82 lbs. per square inch initial pressure. The most economical ratio of total expansion was found to be 6·22; and on board the "Dexter," where the engines had single cylinders without any steam jackets, the best ratio of expansion was $3\frac{1}{2}$.¹

Having considered, in general terms, the conditions necessary for light propelling machinery, the Author will now examine the relative weight and form of hull best adapted for carrying the load and the machinery. The weight of the hull depends principally, as already stated, upon the gross amount of weight to be carried. It is not much affected, within moderate

¹ Vide Minutes of Proceedings Inst. C.E., 1874-75, vol. lxi., p. 296.

limits of variation, by the proportions of the hull; but when the proportion of the length to the depth is increased, the weight of material necessary to secure sufficient longitudinal strength is inevitably also increased.

The shape of hull that should be adopted is the result of the most suitable compromise between several requirements, each of which, taken separately, dictates unfortunately a special form differing from the other forms. Speed is, for torpedo-boats, a requirement of the first importance. The next is handiness, and this demands that the length should be shortened as much as is practicable. The element of frictional skin-resistance of the submerged surface of the hull should be reduced as much as possible. For this object, by cambering the keel, the area of the immersed surface and that of the dead wood is much lessened. The handiness of the vessel for turning is, at the same time, increased by diminishing the depth at the ends.

To augment the stability, the width of the deck may be increased considerably beyond the width measured at the water line. The increase of bulk thus effected augments the righting force, when any considerable inclination of the vessel from the vertical is reached, without impairing the speed. The freeboard, also, must be such that the angle at which stability vanishes is very large, so that there may not be any danger of capsizing. The suddenness with which waves are encountered when the vessel is in rapid motion requires that the form of the bows of the boat above water be not too bluff, otherwise the shocks which are sustained may endanger the structure. Nevertheless, considerable bulk must be maintained in the bows, in order to lift the forward part of the vessel. This lifting is greatly facilitated by making the ends light, and concentrating the load, as far as may be, about the centre of the vessel.

To illustrate the form of hull employed for the torpedo-boats, the diagram, Fig. 8, Plate 4, has been prepared. It shows the distribution of displacement with regard to the lengths of the boats, by a curve—one for each boat—of which the vertical ordinates represent the corresponding areas of immersed section in the length of the vessel represented by the base line. A curve constructed in this way, taken from H.M.S. “Iris,” is added. It is of further interest, on account of the great care bestowed on the design of this vessel, the hull of which is no doubt excellently formed for the service for which the vessel is intended.

By this diagram it may be seen that the bow lines of the “Iris” are finer than those of many of the vessels constructed by the

Author's firm. Change of trim, however, and the modification of the immersed form when the vessel is at full speed, may reverse the contrast. In the case of the "Iris," the effect of high speed is to augment the immersed sections near the bows, whilst in the torpedo-boats, at full speed, the effect is to lessen the immersion of the corresponding sections. The curves shown in the diagram are calculated for the vessels as at rest. They afford a good idea of the form.

The most favourable position for the propeller for high speeds, is astern of the rudder; but, as little loss of speed is entailed by reversing the relative positions of the rudder and the screw, and as the steering qualities are improved by so doing, it is frequently preferred to place the screw in advance of the rudder, although the effect of the transposition is somewhat to increase the length and the weight of the boat at the stern. The question of immersion of the propeller is also important; but it is not easy of estimation in vessels of high speed relative to their size, as the change of trim involved by high speed frequently provides sufficient immersion, although when the vessel is at rest, immersion may not be complete. If the propeller breaks the surface of the water while in action, the air drawn down, in consequence, causes a greater loss than might be expected. Experiments were lately made by the Author on a model propeller, the performance of which was carefully noted, both when it was totally immersed and when it was working under such a state of immersion that it just broke the surface. In the first case, the useful effect was equal to about seven-tenths of the power expended, and the action was perfectly steady and easily recorded. In the second case, however, the condition of working varied so much that it was only with difficulty that the efficiency could be ascertained, and no precise value for the efficiency could be given, except in so far that a considerable loss was proved, for it did not appear that the efficiency exceeded five-tenths of the power expended.

For small vessels, it does not seem worth while to discuss the question of using one propeller or two propellers, as twin engines would involve so many duplicate pieces, that they could only be employed where the advantages to be derived from their use would be very great. For large vessels, they seem to be most desirable.

The relative position of vessels in motion, in the system of waves caused by and surrounding them, is of great interest, as it throws light on the cause of the low rate at which the resistance of hulls increases at relatively high speeds. It was ascertained

by Mr. Bramwell in experimenting with the "Miranda"¹ that a wave crest, situated near the stem at ordinary speeds, moved gradually towards the centre of the vessel as the speed was increased to the maximum attained by the vessel. Mr. R. E. Froude has found that this wave crest is the foremost in the system, and that the advance of a vessel upon this crest has the effect of diminishing the wave slope which is opposed to the vessel's motion.

The Author will now describe three boats built by his firm:—1, The yacht "Gitana," for the Baroness Adolphe Rothschild, for excursions on Lake Lemman; 2, a first-class torpedo-boat, for the English Government, very similar to the "Lightning," the earliest boat of the class; 3, a second-class torpedo-boat, smaller than the preceding, many of which have been constructed for the English Government.

THE YACHT "GITANA." (Plate 2, Figs. 1 and 2.)

The length of the hull at the water-line is 86 feet, and the extreme length is 90 feet; the breadth of beam at the water-line is 10 feet 6 inches, and the extreme beam is 13 feet 2 inches. The draught of water is 4 feet aft, and 1 foot 1½ inch forward. The displacement is about 29 tons.

The engines are compound, condensing by injection, with an intermediate receiver. There are three cylinders, comprising a 13½-inch high-pressure cylinder, and two 15-inch low-pressure cylinders, with a stroke of 16 inches, working on three cranks placed at equal angles. The air-pump is 23 inches in diameter, with a stroke of 3 inches, and is worked by levers from the high-pressure cylinder. The feed-pump is double-acting, 2¾ inches in diameter, and is worked directly by a steam-cylinder, with a stroke of 7 inches. There is, in addition, a Giffard injector of 5 millimetres. The fan for blowing the fire is 3½ feet in diameter, and is driven directly from a 5-inch steam-cylinder, with a stroke of 3 inches, making about nine hundred revolutions per minute.

The propeller (Thornycroft's patent) is a screw of three blades, 5¼ feet in diameter, with a pitch of 8½ feet; it is placed abaft the rudder.

The boiler is of the locomotive type, having a working pressure

¹ *Vide* Transactions of the Institution of Naval Architects, vol. xiii. (1872), page 269.

of 120 lbs. per square inch. The fire-grate has an area of 16·2 square feet. There are one hundred and ninety-seven flue-tubes, each $1\frac{3}{4}$ inch in diameter externally, and 8 feet $0\frac{1}{2}$ inch long. The heating surface of the fire-box is 52 square feet, and of the tubes 653 square feet, together 705 square feet of heating surface.

The slide-valves are so arranged as to cut off steam earlier in the stroke of the low-pressure cylinders than in that of the high-pressure cylinder, in order to equalise, as nearly as possible, the work between the three cylinders.

The framing of the main engine consists of small steel columns, directly connecting the cylinders with the bedplate, and placed as near to the main bearings as practicable. These columns are braced together near the centre of their length, and are only adapted to resist vertical forces. The framing depends for transverse stability on its connection with the hull, to which the cylinders, and the lower ends of the guide-bars, are fastened by stays.

For securing lightness of moving parts, the pistons are of wrought-steel; the piston-rods and connecting-rods are also of steel, the piston-rods being bored out. The cranks, the crank-pins, and the lower halves of the connecting-rods, are balanced by cast-iron balance-weights, secured to the cranks by steel bolts.

The proportions of the blowing engine are unusual, a great length of bearings having been given. The combined length of the main bearings is 18 inches, their diameter being 2 inches; whilst the diameter of the steam-cylinder is only 5 inches. The crank-pin is 4 inches long by 2 inches in diameter. The disk of the fan revolves within the engine-room, without any external casing. It takes air in at one side only, from a large tube leading from the deck, and delivers it all round the circumference of the disk, without inconvenience. The shaft of this engine is fitted with thrust-collars to resist the unbalanced pressure of the air on the disk. Engines of this pattern have been worked at a speed of seventeen hundred revolutions per minute, or fifty-six strokes per second, without damage.

In estimating the effects of rapid change in the direction of stress on the journals of engines working at high speed, the Author is of opinion that sufficient importance has not, in general, been attached to the fact that the lubricant has to sustain the pressure for but a very short time in one direction. This he considers is the principal reason why high-speed engines have so much less wear and tear than many persons appear to expect. It is, nevertheless, most important that correct adjustment should be maintained in order to secure good working results.

FIRST-CLASS TORPEDO-BOAT (Plates 2, 3 and 4).

This boat is 87 feet in length, with a breadth of beam of $10\frac{1}{2}$ feet. The draught is 1 foot 6 inches forward, and 5 feet 2 inches aft, with a displacement of 32·4 tons. The engines are compound, with an intermediate receiver, having a $12\frac{3}{4}$ -inch high-pressure cylinder, and a low-pressure cylinder $20\frac{7}{8}$ inches in diameter, with a stroke of 12 inches. The cranks are at right angles. The air-pump is worked by levers from the high-pressure cylinder, as in the engines of the "Gitana," making, of course, the same number of strokes per minute as the engines. The condensing water is forced through the condenser by a centrifugal pump, with an auxiliary engine, assisted by a special form of grating, which, by means of gradually expanding openings, converts the external relative velocity of the water into pressure. The thrust-block is secured to the bedplate of the engine by two stays, one attached to each side, and level with the centre of the shaft: thus preventing any tendency to throw undue thrust on the lower half. The slide-valves of the engines (Plate 4) are balanced by being placed under bridges, which are made with recesses corresponding to the ports in the cylinders, as used by Mr. Wilson, of Patricroft. In order to obviate the difficulty caused by the varying deflection under varying pressures, each bridge is in section like a bowstring girder, the bow not being attached, however, to the string except at the ends; and, by connecting the intermediate space with the exhaust, the flat surface is little distorted by pressure, and does not partake of any deflection affecting the bow. This construction of Mr. Wilson's valve is due to Mr. J. Donaldson, M. Inst. C.E., and appears to answer its purpose well.

The packing rings of the pistons are of Perkins metal, four in each piston, in separate grooves. They are found to work much more quietly than the single wide rings usually adopted in marine engines.

The fan engine (Plate 4) is similar to the one employed in the "Gitana." Two feed-pumps are worked by a cast-iron four-thread worm on the engine shaft, geared into a suitable wheel of phosphor-bronze secured to a steel shaft, having cranks at the ends, to each of which a feed-pump is connected. The ratio of the gearing in the worm and wheel is as 4 to 15. The feed-pumps are 4 inches in diameter, with a 3-inch stroke. The engine-room also contains a bilge-pump, which is worked from the feed-pump shaft; and an air-compressing pump, with a separate engine, for

charging torpedoes. A donkey pump is fitted in the stokehole, by which the boiler can be supplied when the main engines are at rest.

The propeller is constructed with three blades, and is placed forward of the rudder. It is 4 feet 6 inches in diameter, and has a pitch of 6 feet.

The boiler (Plate 4) is of the locomotive type, and has a total heating surface of 620 square feet, of which 56 square feet are contributed by the fire-box surface. The area of the fire-grate is 18·4 square feet. The outer shell is 4 feet 5 inches in diameter, and 12 feet 6 inches long. It contains two hundred and five tubes 6 feet long, measured over the tube plates, and $1\frac{3}{4}$ inch in external diameter. The working pressure is 120 lbs.

An important feature in the boiler is the fire-box. In the boilers of the smaller type of torpedo-boats, the roofs of the fire-boxes are stayed with ordinary longitudinal beams; but in the boilers of the larger type, where the fire-grate amounts to more than 18 square feet in area, the roof of the fire-box is stayed directly to the outer shell of the boiler, made flat for a width equal to that of the top of the fire-box, to which it is connected by vertical stays. By this mode of construction, there is the advantage of adding slightly to the steam-room, but this alone scarcely balances the extra weight of material used in construction. It is, however, more convenient for staying than the radial system when the outer shell is cylindrical over the fire-box; and there is more elasticity, to take up any unequal expansion between the fire-box and the shell. The shells of the boilers are mostly of steel. In the earlier boats, the fire-boxes were of copper; but in the boats built for the English Admiralty, the fire-box has been constructed of iron, as the boilers are liable to be fed with salt water. At the same time, iron fire-boxes possess greater strength than those of copper.

In order to extinguish the fire, in cases when it must be extinguished and cannot be drawn, a rose with an ejector is fitted, in constant communication with the sea, by admitting steam to which the fire may be extinguished in a very short time.

Provision is also made, by self-closing ashpit-doors, for preventing the return of vapour to the stokehole. A passage to the deck is also provided to facilitate the escape of the steam discharged in the event of a tube giving way.

Experiments were made at Portsmouth to ascertain the performance of the boilers of the first-class torpedo-boats, the results of which are given in the annexed Table I.

TABLE I.—BOILER TRIALS, FIRST-CLASS TORPEDO-BOAT No. 3.

Air-pressure in stokehole . . . inches	2	3	4	6
„ ash-pit . . . „	1·47	2·29	3·26	5·25
„ furnace . . . „	1·35	1·87	3·0	4·33
Temperature, feed-water . . . Fahr.	53·5	57	54	56
„ funnel „	1,073	1,192	1,260	1,444
Steam pressure (above atmosphere) lbs.	117	117	115	115
Coal consumed per hour . . . lbs.	925	1,177	1,472	1,815
„ „ per square foot of fire-grate . . lbs.	49	62	78	96
Water evaporated per hour . . lbs.	6,530	7,770	9,320	10,840
„ per lb. of coal . . . lbs.	7·06	6·6	6·33	5·97
Evaporation per lb. of coal reduced to equivalent at 212° F. from 100° . . }	7·61	7·08	6·81	6·41
Evaporation per hour per square foot of heating surface }	10·8	12·9	15·5	18·0
Coal used, Nixon's Navigation.				
Ashes, 9 per cent.	H. M.	H. M.	H. M.	H. M.
Duration of experiment	2 0	2 7	1 39	1 27

The influence of the pressure of air employed on the rate of evaporation and of combustion, and on the temperature of the gases leaving the boiler, is clearly manifested. The measurements of the pressure in the stokehole, ashpit, and fire-box, show that of the initial pressure, the resistance of the tubes accounts for about seven-tenths of the whole, the resistance of the fire and fire-bars being only about one-tenth. The loss on entering the ash-pit appears too large, and the indicated deficiency of pressure under the bars is perhaps partly due to the comparatively high velocity of the air at this part of its transit. The pressure in the funnel, as measured, was sensibly equal to atmospheric pressure. The evaporative duty of the fuel in this boiler varies from 6·4 lbs. of water, evaporated with 6 inches of air-pressure, to 7·6 lbs. with 2 inches, when reduced to the equivalent for feed-water of 100° evaporated at 212°; and as the consumption of fuel per square foot of fire-grate was 49 lbs. per hour with only 2 inches of air-pressure, the results would have been of greater interest had lower pressure of air also been tried. The boiler, even at half-engine power, is worked too hard to give high duty; but to obtain the highest speed, when coal has only to be carried for a short distance, it is necessary to work the boiler above its economical rate of evaporation. If it were intended to carry a supply of coal for

great distances, no doubt more heating surface should be provided for a given power. The boiler made by Messrs. Clayton and Shuttleworth, and tried at Cardiff, evaporated (equivalent from and at 212° Fahrenheit) 11·8 lbs. of water per lb. of fuel, and gave the highest duty at that trial;¹ but the evaporation per square foot of heating surface per hour was only 2·2 lbs., whereas the boiler tried at Portsmouth evaporated 18·0 lbs. (equivalent at 212°) per square foot of surface per hour, being fully eight times as much.

Amidships, the deck is raised, so as to give room to work the fire and the engines, the depth of the vessel otherwise not being sufficient for this purpose. On either side of this raised deck, the torpedo-davits are fixed, and the torpedoes are so carried as to hang within the width of the boat, for security. Air for the fire is taken in at a cowl, situated just astern of the after bulkhead of the engine-room, against which may be seen the disk of the blowing fan.

The deck forward is much rounded, so that any water that may come on board can run off with facility. The stepped section amidships partially gives the same result. It affords much better foothold than the rounded surface, which is very necessary for the men at this place.

The stern-frame extends considerably below the rest of the vessel, and carries the rudder abaft the screw. This frame is a Bessemer-steel forging, carefully shaped to a long elliptical outline in horizontal section, parallel, of course, to the direction of its intended motion through the water, in order to reduce, as far as possible, its resistance. The boat is fitted with a bilge suction-pipe to each of the principal compartments. Indexes on deck show what communicating valves are open. In the section, Plate 4, Fig. 3, it will be observed that the boiler is placed lower at the forward end than at the fire-box end. The boilers, however, assume a horizontal position when the boats are at full speed, in consequence of the change of trim. This change amounts to about 3 feet 10 inches in 100 feet, according to the results of experiments on the "Miranda." By Mr. Froude's model of the "Lightning," at a speed corresponding to 19½ knots, it was shown that the vessel inclined 3 feet 5 inches in the same length, 100 feet; an inclination which does not differ much from that of the "Miranda."

¹ *Vide Minutes of Proceedings Inst. C.E., vol. xlv., p. 264.*

SECOND-CLASS TORPEDO-BOAT (Plates 3 and 5).

This boat is 60 feet in length, with a beam of $7\frac{1}{2}$ feet. The draught is $12\frac{1}{2}$ inches forward, and 3 feet 4 inches aft. The displacement is 10·6 tons.

The engines are compound, surface-condensing, and work up to about 112 indicated HP. The cylinders are 7 inches and 11 inches respectively in diameter, with a stroke of 8 inches. The air-pump, operated by levers, is 7 inches in diameter, with a stroke of 2 inches. Two feed-pumps are worked by worm and wheel, as described for the first-class boats.

The circulation of the water in the condenser is effected entirely by an apparatus, by which the external motion of the water when the boat is moving is utilized. An ejector is also fitted for removing air from the water-space of the condenser, which is partly above the load water-line. By this apparatus sufficient circulation can be maintained, when the boat is at rest, to condense any steam that may be required to be condensed in order to prevent its escaping into the air.

A small engine is used for blowing the fires, the same as described for the first-class boats; but it is made to drive two pumps, which can be connected when required.

The boiler is of the locomotive type, and has a total heating surface of 198 square feet, of which 22 square feet are supplied by the fire-box surface. The area of the fire-grate is 6·3 square feet. The outer shell is 3 feet 1 inch in diameter, 7 feet 7 inches in length, and contains one hundred and twelve solid-drawn brass tubes, $48\frac{1}{2}$ inches long, and $1\frac{1}{2}$ inch in external diameter. The working pressure is 120 lbs.

Fig. 1, Plate 5, represents the sheer draught of the boat, with a "Whitehead" torpedo in davits, as carried. The boat is also seen in plan in Fig. 2, and in section in Fig. 3. It is divided into six watertight compartments, and is subdivided up to a level considerably above the water-line, by half bulkheads. The vessel is steered from forward. The conning shield over the steering wheel is of 4-inch steel plates on the forward side.

Figs. 4, 5, and 6 represent the second-class torpedo-boat in cross-section, and are intended to illustrate its stability. Fig. 4 shows the inclination due to the absence of one torpedo when the unbalanced weight of the other inclines the boat to about $5\frac{1}{4}^{\circ}$. Fig. 5 shows the boat inclined until the righting force has become a maximum, which happens at about 42° . Fig. 6 gives

a section of the same boat heeled over until the stability is just vanishing, when the angle is about 79° . This angle comprises a large range of stability, which is favourable to the safety of the boat.

The boiler and engines being, in the second-class torpedo-boats, contained in one compartment, there is some advantage in point of simplicity over the larger type. But this disposition involves so large a compartment as would endanger the boat if it were filled with water. It has therefore been decided to separate the engine from the boiler by a bulkhead, in the new boats of this class now being built. Any one compartment in these boats may become flooded, and yet an ample degree of buoyancy would remain.

These boats are designed to be carried on board ship, and they require to be slung overboard complete and ready for use. This condition involves their being subjected to considerable stresses. To illustrate the effect of their being thus suspended the data for the curves, Figs. 9 and 10, have been calculated. In these diagrams, the weight of the vessel is represented in amount and distribution by the area contained between the base line X Y, which also represents the length of the vessel, and the curve lines W W W. The points of support, when suspended, correspond to the points P_1 P_1 in the diagram; and for simplicity the vertical components only of the forces acting through these points in this case are at first taken. The bending moment at any section of the hull is represented by the distance of the line M M M from the base X Y, the shearing forces being, in the same way, represented by the distance of the line S S S from the same base-line. When the oblique forces are considered, and the slings take the lines 1, 1, or 2, 2, the bending moments for sections between P and P_1 will be increased, as shown by the line M_1 or the line M_2 . The height of the line R R R represents, on the same scale as that of the bending moments, the moment of resistance of any section of the hull. This line is calculated on the assumption that the maximum stress on the material is to be equal to 14,000 lbs. to the square inch.

The curves M and S S, in the diagram, Fig. 10, represent the bending moments and shearing forces to which the hull is subjected when floating in still water, where the area between the line B B and the base-line represents the supporting force, or displacement. The line L L represents the curve of loads, or difference between the curve of weight W W and the curve of displacement B B at any point. The ordinates for the line B B and M M being

drawn to the same scale, it is evident that the greatest stress to which the boat is subjected on being lifted, is only a small part of its ultimate power of resistance: the maximum stress on the material being about 7,000 lbs., or 3·14 tons per square inch.

CONCLUSION.

A few examples of the weight of hulls in percentage of displacement, taken principally from sea-going vessels, with the coefficient of fineness of form, are given in Table II. By comparing the hulls built by the Author's firm it will be seen that the weight has not been unduly reduced; for although they are lighter, their relatively short lengths afford great advantage for relative strength.

TABLE II.—PROPORTIONATE WEIGHT OF HULLS.

Name of Vessel.	Percentage of Displacement.		Coefficient of Fineness.
	Weight of Hull.	Weight Carried.	Immersed Volume Midship Section × Length.
Circular ironclads . .	Per cent. 20 to 22	Per cent. 78 to 80	0·780
Iron merchant ships . .	30 „ 35	65 „ 70	..
H.M.S. Bellerophon . .	49	51	0·698
H.M.S. Inconstant . .	51	49	0·614
H.M.S. Devastation . .	31	69	0·766
H.M.S. Iris	32	68	0·548
H.M.S. Inflexible . .	34	66	0·721
Lightning torpedo-boat	33	67	0·601
First-class do. . . .	33	67	0·583
Do. do. with ram bow	33	67	0·552
Second-class torpedo-boat	30	75	0·591
Miranda (yacht) . . .	35	65	0·561
Gitana (yacht)	33	67	0·662

A selection of practical instances is given in Table III. to show by contrast the progress that has been made in concentrating power in a small compass, and at the same time reducing the weight of the machinery and of the boilers. The quantities in the seventh column of the Table—cylinder capacity per indicated HP.—are deduced by dividing half the volume swept by the pistons in one revolution by the indicated HP. They are approximate measures

of performance relatively to the bulk and weight of the engine, irrespective of the boilers.

TABLE III.—RELATIVE PERFORMANCE AND WEIGHT of STEAM VESSELS, and LOCOMOTIVES.

Date.	Name of Vessel.	Fuel per Square Foot of Fire-grate per Hour.	Boiler pressure.	Revolutions per Minute.	Speed of Piston in Feet per Minute.	Indicated HP.	Cubic Inches of Cylinder per Indicated HP.	Weight of Propelling Machinery, including Boilers with Water.		Heating Surface per Indicated HP.	Indicated HP. per Foot of Fire-grate.
								Per Indicated HP.	Per Cub. Inch of Cylinder.		
		Lbs.	Lbs.					Lbs.	Lbs.		
1855	{ City of Boston and City of New York }	..	35	20·0	480	1800	402·0	606·0	1·50	..	..
1857	Persia . . .	..	25	15·0	360	4950	457·0	498·0	1·08	..	..
1861	{ Holyhead mail-boats }	..	..	22·0	286	4751	248·0	318·0	1·34	..	..
1878	H.M.S. Inflexible	21·0	61	73·2	585	8483	185·0	420·0	2·26	..	..
1829	Rocket, locomotive	36·0	..	143·0	393	22	73·0	286·0	3·98	..	..
	Modern locomotive	80·0	120	240·0	880	..	..	..	9·80	..	..
1872	Miranda (yacht)	..	120	600·0	800	64	6·3	62·8	10·00	1·84	16·2
1876	Gitana (yacht).	138·0	120	320·0	850	460	17·3	43·5	2·52	1·53	28·4
1877	{ First-class torpedo-boats }	100·0	120	440·0	880	455	12·0	57·7	4·80	1·33	23·4
	Lightning class	60·0	120	600·0	800	108	9·9	81·6	8·26	1·82	16·6
1879	{ Second - class torpedo-boats. }	78·5	130	650·0	866	150	9·1	66·5	7·27	1·66	23·1

Table IV. contains some additional comparative results of the performance of large steam vessels of the Navy, and the yachts and torpedo-boats before described.

On comparing the contents of the Tables III. and IV., it appears that the "Gitana" presents the lightest machinery in proportion to indicated HP., weighing only 43½ lbs. per indicated HP., or a little over one-eighth of the machinery of the Holyhead mail-boats, and only one-fourteenth of that of the American paddle river-boats, the "City of Boston" and the "City of New York" Correspondingly, the volume of cylinder per indicated HP. of the "Gitana" is but one-fourteenth of that of the Holyhead boats, and only one-twenty-third of that of the American boats. In this respect, the "Miranda" excels even the "Gitana," having only 6·3 cubic inches of cylinder capacity per indicated HP., or little over one-third of that of the "Gitana."

The consumption of fuel in the torpedo-boats has been approxi

TABLE IV.—RELATIVE DISPLACEMENT AND PERFORMANCE OF STEAM VESSELS.

Name of Vessel.	Date.	Length on W.L.	Displacement.	Indicated HP.	Speed in Knots per Hour.	$V \propto D^2$ I. HP.	Blast in Inches of Water.	Revolutions per Minute.	Steam Pressure in Boiler.	Receiver.	Vacuum in Condenser.	Fuel per Indicated HP. about.
		Fet. Ins.	Tons.	I. HP.	Knots.	Constant.	Inches.	Turns.	Lbs.	Lbs.	Inches.	Lbs.
Miranda	1872	45 6	3.7	64	16.20	160.0	..	600.0	120.0	..	..	..
Gitana	1876	86 0	29.0	460	20.75	183.0	4 to 6	320.0	120.0	..	..	..
First-class torpedo-boat No. 1)	1877	81 0	28.7	400	18.55	150.0	..	350.0	120.0	35.0	25.25	..
" " 6	1879	83 9	32.43	425	20.00	191.5	5	420.0	120.0	33.0	25.0	3.92 ¹
" " 10	1880	88 3	29.73	460	22.01	223.0	5	438.0	123 0	36 0	24.5	..
" " 10	1880	88 3	32.5	469	21.756	221.0	5½	443.0	133.8	40.5	23.8	..
Second-class torpedo-boat	1879	58 4	10.6	108	16.51	181.0	3½	600.0	120.0	38.0	24.5	3.51 ²
" "	1880	60 10	10.9	150	17.645	180.0	3	653.0	131.0	41.3	22.4	..
H.M.S. Inconstant . .	1869	339 0	5,328.0	7,361	16.513	186.0	..	71.5	30.4	..	25.3	3.25
H.M.S. Inflexible . .	1878	324 0	9,515.0	8,483	14.74	169.0	..	73.26	61.0	..	26.5	2.06
H.M.S. Iris	1878	301 6	3,290.0	7,556	18.573	189.0	..	97.2	65.0	..	2.7	2.75

¹ The consumption 3.92 lbs. took place with a first-class torpedo-boat, when indicating 340 indicated HP.² The consumption 3.51 lbs. took place with a second-class torpedo-boat, when indicating 112 indicated HP.

mately measured, and is about 3·9 lbs. per indicated HP. for the first-class boats when developing 340 indicated HP., and 3·5 lbs. for the second-class boats at 112 indicated HP.

From the last column of Table I. it appears that from 1 square foot of fire-grate 28·4 indicated HP. were developed in the "Gitana"; whilst, in the last column but one, 1 indicated HP. was developed for 1·33 square foot of heating surface, in the first-class torpedo-boats.

With regard to the relative consumption of fuel for each indicated HP., it is apparent that the lighter machinery consumes more than the heavier machinery. But the excess of consumption is due, not to comparative lightness, but to the fact that the boilers are proportionately overworked, as is clearly proved by the high rates of consumption of fuel per square foot of fire-grate. The ratio of expansion used in the torpedo-boat engines seems, perhaps, less than desirable, but the gain from expanding more than five times with the pressure used, would be very limited, whilst the weight of engines would be materially increased.

In comparing, in Table IV., the performance of small vessels with large ones, the common formula $\frac{V^3 D^{\frac{3}{2}}}{I. HP.} = C$, is convenient and

suitable; for if similarly formed vessels of different dimensions are propelled at what Mr. Froude has called "corresponding speeds" (speeds proportioned to the square root of their linear dimensions), the power required varies in such a manner as to give a constant value to this fraction, if the effect of the different proportion of surface-friction to the whole resistance may be neglected in the comparison; and, as the increased proportion of surface-friction in small vessels has the effect of reducing the value of the constant C, this formula cannot be supposed to favour the particular kind of craft under discussion. The high value obtained by No. 10 torpedo-boat, Table IV., is worthy of remark; but it should be noted that this boat had the advantage over others of its class, that no bilge keels were fitted, and the stern frame did not extend below the propeller boss.

In conclusion, the Author has the pleasure to acknowledge the careful assistance rendered by Mr. S. Barnaby, Assoc. M. Inst. C.E. He is also indebted to Mr. W. H. White's excellent book¹ for part of the materials in Table II.

The Paper is illustrated by a series of diagrams, from which Plates 2, 3, 4 and 5 have been prepared.

¹ *Vide* "A Manual of Naval Architecture." 8vo. London, 1877.

FIRST CLASS TORPEDO BOAT.
Scale: $\frac{1}{8}$ Inch = 1 Foot.

ON TORPEDO BOATS AND LIGHT YACHTS,
FOR HIGH SPEED STEAM NAVIGATION.

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.

Fig. 5.

ENGINES OF SECOND CLASS TORPEDO BOATS.

Scale: $\frac{1}{16}$ Inch = 1 Foot.

ENGINES OF FIRST CLASS TORPEDO BOATS.

Fig. 2.

FAN ENGINE.

F A N .

Fig. 4.

Scale: $7/8$ Inch. = 1 Foot.

Fig. 6.

Scale: $\frac{1}{4}$ Inch. = 1 Foot.

[illegible]

Fig. 7.

Fig. 1.

Fig. 2.

Fig. 3.

GENERAL ARRANGEMENT OF SECOND CLASS TORPEDO BOATS.
Scale $\frac{1}{8}$ Inch = 1 Foot.

CURVES OF SHEARING FORCES AND BENDING MOMENTS WHEN AFLOAT.

Scales of Curves, Figs 9 and 10.
Base Line, $\frac{1}{10}$ Inch = 1 Foot.
WW, BB, LL, $\frac{1}{5}$ square Inch = 100 lbs.
MM, RR, 0.5 Inch = 1 Foot-Ton.
SS, $\frac{1}{5}$ Inch = 1 Ton.

SECOND CLASS BOAT.
CURVES OF SHEARING FORCES AND BENDING MOMENTS
WHEN SUSPENDED.

Fig. 4.

Fig. 5.

SECOND CLASS BOAT. CURVE OF STABILITY.

Fig. 7.

Fig. 8.

CURVE OF AREAS OF IMMERSED TRANSVERSE SECTIONS.

First Class Torpedo Boat ---
Second Class Torpedo Boats ---
H.M.S. 'Iris' ---

Fig. 6.