Design of Floats for Hydro-Aeroplanes—I*

Giving the Results of Tank Experiments with Various Models

By G. H. Millar, B.A.

THIS paper is founded on a series of experiments made by Mr. G. S. Baker and the author at the William Froude National Tank, at the instance of the Advisory Committee for Aeronautics. The work consisted of designing and running a large number of models of hydro-aeroplane floats, some of which have been subsequently built to. The special apparatus employed and methods of experiments are described in the Appendix, while the complete results are included in the Official Aeronautical Reports for 1912-13 and 1913-14. It should be borne in mind that the statements here made, and conclusions arrived at, are founded mainly on these model experiments, while many details can only be decided as the result of experience with actual machines.

Hydro-aeroplanes may be divided, broadly, into two classes: (1) Those in which the machine follows the same general lines as a land machine, with floats substituted for the landing-gear; (2) those in which the fuselage is in the form of a boat containing the crew, and sometimes the engine. The term "hydro-aeroplane" is usually confined to machines of the first class, those of the second being termed "flying boats." These two classes are being

floats, which, of course, requires that the tail float shall take some of the load at rest. This also makes the machine float more steadily in a short sea, and allows an underwater rudder to be used to assist maneuvering on the water at low speeds. In any case the load on the tail float is small, and its design of no particular moment. Considering the main floats, the general balance of

origin, and to pass through the point $P(V, W)$. The ordinate at any speed v (less than V) is, of course, $\left(\frac{v}{V}\right)^2 W$.

Now it will be seen that the lift is comparatively small until a high speed has been attained; at half speed it will be only one-quarter of the dead-weight of the machine. But even this speed is a very high one for the length of the float, and consequently for a float not designed on hydroplane principles the resistance and wave-making will become enormous before the air lift becomes appreciably great, and the machine will never reach its flying speed, unless with a strong head wind.

It may here be well to consider the principles on which hydroplane design is based. Any normal form of vessel will rise and skim along the surface of the water if she is towed fast enough. But in the case of a ship designed for low speeds, the speed at which she begins to rise is a very high one, and up to this point wave-making and resistance will increase to a prohibitive extent.¹

Now, a hydroplane is so designed that when a high speed is attained the normal pressure of the water on

Fig. 1.

Fig. 5. RESISTANCE CURVE FOR FLAT PLATE, 6" WIDE, AT 6° P=4.86 LBS. AT ALL SPEEDS.

developed side by side; in some cases both are built by the same manufacturers. The second class is specially popular in America. It is as yet too early to say which will ultimately prove the more useful, but possibly both types will persist, each for its own purpose. This paper is mainly concerned with the first class, the hydro-aeroplane proper, although most of the conclusions come to are applicable also to the "flying boat." At first sight, the latter may appear to be the more seaworthy device; but with a large open cock-pit it is exposed to great risk of swamping. The Curtiss flying boats are fitted with water-tight bulkheads, and have a very large total buoyancy (usually four and a half times the weight of the machine), but this necessitates a large boat, which even then cannot altogether take the place of the fuselage of the land machine, especially if the engine is carried overhead.

Turning now to the hydro-aeroplane proper, the machine may be supported either (a) by a single broad main float, with small subsidiary wing floats, or (b) by a pair of floats side by side at a suitable distance apart. In either case a small tail float is usually fitted, which may rest on the water at the lowest speeds, or may be clear of it even when the machine is at rest, and only relied on to prevent the tail of the machine dipping if it is thrown backward by a sudden gust of wind. It is, however, usually preferred to have the center of gravity of the whole machine aft of the center of buoyancy of the

opinion seems to be decidedly in favor of twin floats. With a single float the lateral stability (on the water) is small, unless the float is unduly broad for its length, and wing floats become essential. On the other hand a pair of floats placed too far apart may cause a severe slewing strain if one becomes more deeply immersed than the other. As regards efficiency, experimental results show that if a pair of floats be replaced by a single one of similar design but double the breadth, much the same results will be obtained, although the water disturbance is more noticeable. The performance of twin floats is not appreciably affected by their distance apart, provided that the gap is not less than the breadth of either float. It is generally agreed that the total buoyancy of the floats should be at least twice the dead-weight of the machine, and water-tight bulkheads are frequently fitted. These incidentally prevent any water that may leak in from flowing from end to end of the float when in the air. The air resistance of the floats must be taken into consideration, and their construction is a matter of some difficulty, great strength being required with a light weight.

The design of hydro-aeroplane floats is naturally very closely allied to that of hydroplane boats, though with some important differences. Since the lift of the aerofoils increases continuously with the speed, and ultimately becomes equal to the weight of the whole machine, it might be thought that any fine lined ship-shaped form would be suitable for a float, but this is not the case. Fig. 1 shows the curve of lift for an aeroplane of "W" pounds total dead-weight designed to leave the water at a speed of V foot-seconds, it being assumed that the angle of attack is constant throughout. This curve is simply a parabola described to touch the axis Ox at the

the hull shall have a large vertical component, which raises the boat and so decreases her displacement, and, consequently, the wave-making. The simplest way of attaining this result is to provide the boat with a flat bottom, which, at high speeds, shall have an inclination of about 5 degrees to the horizontal, in a fore-and-aft direction.

Figs. 2, 3 and 4, on this page, show the results of some experiments made on flat plates at the William Froude Tank. The plates were 1 foot wide, and were towed on the surface of the water at a series of small angles, and at speeds of 600 feet, 800 feet, 1,000 feet, and 1,200 feet per minute. The immersion was also varied independently, and the vertical force P and horizontal force R on the plate were measured. In the figures, V is the speed in feet per second, and A the area of plate immersed in square feet. The plate being 1 foot wide, the number denoting this area also denotes the length of plate immersed and the ratio $\frac{\text{length immersed}}{\text{breadth}}$, which is the inverse of the aspect ratio. These results cannot be taken to be very exact, as there was a considerable variation

of $\frac{P}{AV^2}$ and $\frac{R}{AV^2}$ with speed, although an uncertain one. This may have been due to two causes—to the variation with speed of the actual area immersed for a given value of A (which was the area immersed when the

¹ In the case of a mercantile form model run at the William Froude Tank, for a ship 400 feet long, the E. H. P. required at 14.8 knots was 4,115, and at 16.5 knots was 10,900, the resistance increasing as the sixteenth power of the speed between these points.

* Paper read at the joint meeting of the Institution of Naval Architects, the Institution of Engineers and Shipbuilders in Scotland, and the North-East Coast Institution of Engineers and Shipbuilders, at Newcastle-on-Tyne. Reproduced from *Engineering*.

plate was at rest at the same angle and height); or to errors in estimating the position of the center of pressure, which could not be directly measured with the apparatus then in use.

Fig. 3 shows that the efficiency of such a plate increases with increase of aspect ratio, but that the effect is not a very marked one, over the range here considered. At large aspect ratios the efficiency seems to increase considerably, and, with single-plane floats at high speeds and small loads, efficiencies of as much as 10.5% have been obtained, although this was perhaps a little too high. With a plate of an aerofoil section and an aspect ratio 6 : 1, having its chord at 4½ degrees, and its leading edge

that the plate scoops out a hollow in the water, which does not fill up until some way astern of it. The water which passes underneath the plate issues at the back in a smooth stream, which at first follows the direction of the plate, but gradually turns upward again. From the crests of the bow diverging waves the surface slopes down to this smooth region, meeting it in a well-defined line. At the points *K*, *K* two converging waves appear to leave the inner walls of the diverging waves, and these meet to form a curious "fan" of partly broken water. At the after end of the "fan" another diverging system starts with a smaller one inside it. This system is really a continuation of the converging waves which cross at the "fan."

Type 1 wave will go clear of the sides, type 2 will just do so, but type 3 will force a thin film of water up the side of the float, which will add very considerably to the resistance. Again, where the wave is of type 1, the sides may be flared considerably, without touching the wave, and where the wave is of type 3 they must "tumble home" from the bottom to clear it. With a vertical-sided and flat-bottomed float thin filmy waves will always rise against the side of the float at a moderate speed, which will gradually move aft as the speed increases till they leave it altogether. The sketch in Fig. 10, below, shows their appearance when the speed is reached at which they start to leave the float. These clinging waves may, however, be thrown clear of the sides by the use of bilge-planes (better known, perhaps, by the facetious title of "mud-guards").

The waves set up by our elementary plate will not be affected if we build up a boat form upon it, provided that the total load is the same, and that no part of the boat except that formed by the plate touches or comes very near to the surface of the water. In particular, it may be observed that by forming a step at the back edge of the plate we may build on a tail to the boat aft of this point, which will be completely clear of the water at a certain speed. To make the sides of the boat clear of the waves at the lowest possible speed, they should have increasing tumble-home toward the after end, while they may be flared a little at the forward end. The use of tumble-home on the after part of the sides is, however, not without its objections in the case of a hydro-aeroplane float, as it tends to throw the water up when turning. We have so far considered a boat or float having only a single "planing" surface. We may, however, have any number of such surfaces separated by steps. Each plane

just above the water surface, an efficiency of 11.8% was obtained.

Fig. 5, above, is deduced from Figs. 2, 3 and 4, by calculation, and shows the resistance of a plate 6 inches wide at a constant angle of 6 degrees and a constant load of 4.86 pounds at speeds of 10 feet to 18 feet per second. It will be seen that the resistance actually falls as the speed increases over this range. The curve cannot be extended down toward zero speed from the experimental results, but it will be obvious that at a very small speed a very great length of the plate must be immersed to support any load; hence the curve, if produced toward zero speed, must be of the nature shown by the dotted line—i. e., asymptotic to the axis of resistance.

Fig. 6 shows the general appearance of the curve of resistance to a base of speed for a hydroplane (having a constant load). It will be seen that at the point *P* the rate of increase of resistance rapidly falls off. This is the point at which the boat commences to rise in the water, and after this the resistance only increases very slowly. In the case of a hydro-aeroplane float running at a constant angle the load is constantly decreasing; the load at a speed *v* is $W \left(1 - \frac{v^2}{V^2}\right)$, where *V* is the speed at which

the machine begins to fly and *W* the dead-load. Hence, the curve of resistance to a speed base takes the form shown in Fig. 7, having a "hump" (which may be sharp and peaky or flat and spread out) at the point where the float begins to rise in the water, and afterwards falling off rapidly till at the flying speed it denotes the air resistance of the float. In the same figure, curve "A" denotes the resistance the float would have if constantly kept at the same vertical height and prevented from rising; curve "B" denotes the resistance of a flat plate carrying the same load as the float. The curve for the actual float tends to follow curve *A* at moderate speeds and curve *B* at planing speeds, the hump representing the intermediate stage when the float is rising sharply in the water.

The problem of designing a hydroplane that shall have a small resistance at a planing speed is a comparatively simple one. But the requirements for such speeds differ considerably from those for low resistance at moderate speeds. As a matter of fact, at speeds up to the "hump" speed any hydroplane is a very bad boat. Consider first the requirements at planing speed. Fig. 8, above, shows the wave system generated by a flat plate towed along the surface at a high speed and small angle (6 degrees), the fore end of the plate overhanging. It will be observed

The whole system is merely an extreme case of that of an ordinary high-speed ship, where the "fan" occurs as a region of high-pressure under the after end of the ship. The diverging system aft of the fan corresponds to the ordinary stern diverging system. In a high-speed destroyer, the "fan" may sometimes be seen clear of the stern. If it is just underneath the stern, the space bounded by the diverging waves aft of it will appear as a plateau of broken water.

Fig. 9 shows a transverse section of the plate and the bow diverging wave. The latter will change from type 1 to type 2, and from type 2 to type 3, if the speed be decreased, or the depth of immersion of the element is increased, and the same gradual change occurs as we go aft along the plate. That is to say, the inner wall of the wave becomes steeper and more convex up to the point where the crest has its maximum height. Now, suppose the plate to form the bottom of a float with vertical sides.

will then set up its own system of waves, and the diverging crests from one plane may even cross the crests from the plane ahead of it.

It is not difficult to design a float which shall have a good efficiency at "planing" speeds. But this is not nearly so important as the behavior of the float at lower speeds. From a resistance point of view, the important range of speed is that up to the "hump" on the resistance curve, during which it must be considered as a displacement boat.

The essentials for good "planing" are:

1. Considerable overhang at the forward end with short immersed length and suitably-shaped bottom.
 2. That the water should leave the bottom of the boat on a sharp edge both at the stern and at the sides.
- For a fast displacement boat we require:
1. A fine curve of sectional areas, and consequently great length with small beam, or light draught.

* This is the value of the ratio $\frac{P}{h}$.

2. No sharp corners or edges in contact with the water; they produce eddy-making, and consequent waste of power.

3. Smallest possible wetted surface to reduce surface friction. This is not so important as condition 1, except at very low speeds.

We have, therefore, to try and satisfy two sets of conditions which are in some respects antagonistic.

First, as regards length. At speeds below the "hump," increase of length and decrease of breadth produce considerable improvement. At "planing" speeds they are slightly detrimental, and will probably cause the "hump" to come at a slightly higher speed, but in the case of a stepped float this may be partially counteracted by the fact that the narrower float will require less air at the steps. On the whole, a float can always be improved by increasing the ratio of length to breadth up to an excessive limit. From a practical standpoint, very long floats are highly undesirable; a good float can be got out on a length to breadth ratio of about $5\frac{1}{2}$ to 1, and in the author's opinion a ratio of about 6 to 1 should not be exceeded, although a good many floats have a ratio of 7 to 1 or more.

It has been seen that for a flat plate the most efficient angle is 4 degrees, and for a float having a flat planing surface the best results would be obtained with the surface at the same angle. In practice, however, it is better to design the floats to run at a slightly greater angle, so as to give a greater margin of safety when alighting. In the series run at the William Froude Tank, the normal running angle was taken to be 6 degrees for the forward or main planing surface, or in the case of a cambered surface the mean angle was 6 degrees. The model floats were made to a scale of $\frac{1}{50}$ for a machine of 2,200 pounds weight designed to leave the water at a speed of 67 foot-seconds in a calm. For convenience, these figures will be taken as the standard for the rest of the paper.

It might be thought that the pilot would be able to run the machine on the water at any angle he desired, just as he can in the air; as a matter of fact, the water forces on the float may introduce very large trimming moments, quite outside the pilot's range of control. The magnitudes of the moments brought into play are therefore a very important part of the design. Suppose that for a given float, or pair of floats, running at a given angle and speed, the reaction of the water on the floats is represented by vertical and horizontal components P , R pounds, and a moment of M foot-pounds, about some point O ; these quantities can be determined from model experiments. Let G be the center of gravity of the whole machine (including the floats), and let the horizontal and vertical co-ordinates of G relative to O be (g, h) feet. Let T be the thrust of the propeller, and l the distance of its line of action from G .

Also let the force on the elevator and tail-plane be E pounds acting in a line distant e from G , and let S be the resultant resistance of the machine (apart from the floats) acting in a line distant s from G .

Then for angular equilibrium we have, with the convention of signs shown in Fig. 11:

$$Ee + Tl - Ss = M + Pg - Rh,$$

the trimming moment being reckoned positive when it tends to depress the tail of the machine. The expression $Tl - Ss$ is usually very small; for a machine of the weight considered, at a speed of from 30 to 40 foot-seconds, it will probably not exceed 150 foot-pounds at the most; and a calculation of the elevator control (Ee) for a specific machine of this weight gave the following maximum values:

Speed, ft. secs.	10	20	30	40	50	60
Control, ft.-lb.	68	272	632	1088	1700	2528

We can therefore calculate the limits within which the moment $M_g \equiv M + Pg - Rh$ must be kept if the machine is to be run at its designed angle, although these limits may be exceeded momentarily.

The value of M_g at any speed and angle is, of course, very largely dependent upon the position of the floats relative to G —that is, on the value of g, h . For the machine considered G is at a height of about 6.3 ft. above the bottom of the floats, so that the part of $M - Rh$ due to resistance is of some importance. Now the height of G , and, therefore, the value of h , will be decided on in the early stages of the design. We therefore require a simple means of determining the most suitable value of g . One method of doing so is as follows:—The values of M , P , R , referred to a definite point O , are determined from model experiments for a range of speeds and angles and the value of h is decided on. Consider, first, the case in which the angle is constant (say 6 deg.) and the speed varies. Then $M_g = M - Rh - (-Pg)$.

On a base of speed plot the values of $-Pg$ ft.-lb. for $g = 1, 2, \dots$, of $-Pg$ ft.-lb. (Figs. 21, 24, and 26, next issue) The result is an inverted parabola, which, by distorting the abscissa scale, can be reduced to a straight line. Pg will now for every value of g be represented by a straight line, all such straight lines radiating from a point in the base line. At the distorted abscissa points erect ordinates denoting the values of $M - Rh$ and join up the ends of these ordinates to form an open polygon. Then, taking any desired value of g , the value of M_g is given by the

distance from the corresponding Pg line to the polygon curve, being positive if measured upwards, and negative if measured downwards. We can thus see by inspection the effect on the moments of altering the value of g .

We also require cross-curves showing the value of the moments at constant speed and varying angle, which will show us what change of trim (if any) is likely to take place at any speed. Similar diagrams can be prepared for this case. In the model apparatus used at the William Froude Tank the value of M as read is only strictly correct at 6 deg. inclination of float. At any other angle (6 deg. + θ deg.) the true moment is $M \cos \theta$, while, whatever the angle, P and R are always measured vertically and horizontally.

Hence (see Fig. 12) the moment is now—

$$M_g \equiv M \cos \theta + P(g \cos \theta + h \sin \theta) - R(h \cos \theta - g \sin \theta),$$

which may be written:—

$$M \cos \theta + h(P \sin \theta - R \cos \theta) - [-g(P \cos \theta + R \sin \theta)].$$

We now plot $-g(P \cos \theta + R \sin \theta)$ ft.-lb. to a base of angle for $g = 1$, and distort the abscissa scale to make it a straight line; then plot $M \cos \theta + h(P \sin \theta - R \cos \theta)$ at the new abscissa points, and proceed as before (see Figs. 22 and 23). In this case, θ being small, a rough approximation may be obtained by plotting $-P$ instead of $-(P \cos \theta + R \sin \theta)$ and $M - Rh$ instead of $M \cos \theta + h(P \sin \theta - R \cos \theta)$, and spacing the ordinates at any convenient distance apart. If the variations of P with angle be also neglected, we get a straight line parallel to the base.

We require some point of reference for the horizontal position of the C.G., and the most convenient one is the position of the center of buoyancy of the float when fully loaded and inclined at the standard angle of 6 deg. The value of g to bring this point vertically under the C.G. is then calculated, and the corresponding line drawn on the moment diagram. We can then readily see the effect of placing G at any desired distance aft of the C.B.

It is now proposed to consider some float design in detail. Fig. 13, above, shows a type of float that has been more widely employed than any other. It is simple to construct, and has given good service in practice. It has a rectangular water-line at all speeds, and therefore should have fine bow-lines; but, as usually made, the curve of areas is not particularly fine forward. This is, however, partially compensated for at moderate speeds by the large amount of lifting surface, which causes the float to start rising in the water at quite low speeds.

Cling waves form against the sides, and do not leave them until rather a high speed is attained. The long overhang required forward makes the float very stable at small angles, but otherwise is so much wasted length. Such a float naturally tends to "slam" badly in a short chop. Floats of this type are sometimes fined at the forward end by pinching in the sides.

Figs. 14 and 15 show two floats of a very different type that were included in the series of floats evolved at the William Froude Tank. Of these, type 3 (Fig. 15) is the better, its flat under surface being all at the most efficient angle. Both these have tail appendages, which leave the water completely before the hump speed is reached if the floats are maintained at an angle of 5 deg. to 6 deg.

(To be concluded)

Corrosion of Condenser Tubes

IN many places the destruction of condenser tubes through pitting or corrosion results in considerable expense. An article by Mr. E. Bate in the *General Electric Review* deals at some length with causes leading to the pitting and corrosion of condenser tubes. These causes may be briefly stated thus: Stray currents from earthed systems, galvanic currents between the dissimilar metals of which the condenser is constructed, galvanic currents due to deposits of active material inside the tubes, use of unsuitable mixture for the material of the tubes. The increasing use of negative boosters on earthed systems prevents the first-mentioned point from being of serious importance. Regarding the second point, the alloy of which the tubes are usually composed is electro-negative to the cast iron casing, so that no corrosion of the tubes could be caused by these currents. That the third cause is responsible for the greater majority of tube failures is borne out by the fact that 96 per cent of the tubes examined by the author were pitted in the lower half, where, of course, all internal deposits would collect. It is suggested that in cases where the circulating water is drawn through a long line of cast iron piping, oxide of iron and carbon may be deposited in the condenser tubes, thus giving rise to injurious electrolytic action. The author is of opinion that, once local corrosion has commenced, it cannot practically be stopped. A suggested method of preventing this deleterious deposit in the condenser tubes is to treat the interior of the cast iron piping so

* The effect of neglecting this is to decrease the moment numerically at angles below 6 degrees, and to increase it numerically at angles above 6 degrees.

as to prevent corrosion, and to keep the intake pipes as short as possible.

Fog Signals by Wireless

IN the Firth of Clyde, in Scotland, several fog signal stations have been established which are operated entirely by wireless currents sent from a distant station, and require no attention other than the periodic replenishment of the necessary supplies. The signal is in the form of a gas gun in which a charge of acetylene gas air is fired at regulated intervals so that it identifies itself. The gas admission and ignition is quite automatic, and once the gas is turned on the cycle of operations proceeds regularly. All that is required is to control the gas valve electrically, so that it can be turned on in time of fog. The needle valve used for the purpose is actuated by two electromagnets, one for opening and the other for closing. These are controlled by a relay working in conjunction with a special form of coherer, which receives the signals through a jigger transformer. The principal feature of the apparatus is the selective synchronizer, by which the apparatus only responds to a particular signal, different signals being employed for the turning on and turning off circuits. A 14-foot receiving aerial of the wires is used, and the transmitting apparatus is of the simplest character, embodying synchronizers of similar nature to the receiving synchronizers for giving the correct signals.

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