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HULLS FOR LARGE SEAPLANES.

By Giulio Magaldi.

From "La Technique Aeronautique," October 15, 1924.

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TECHNICAL MEMORANDUM NO. 295.

HULLS FOR LARGE SEAPLANES.*

By Giulio Magaldi.

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a) By decreasing the length.

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c) By using stronger materials.

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* Communication presented to the "Société Francaise de Navigation Aérienne" by G. Delanghe, Engineer of Arts and Manufactures and Professor at the "Ecole Supérieure d'Aéronautique."
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Introduction

The calculation of hulls for seaplanes of successively increasing weight does not, at first thought, appear difficult. The first idea occurring to the mind is that the seaplanes can remain geometrically similar in every respect.

In reality, the principle of similitude is not applicable to the hulls the designing of which increases in difficulty with increasing size of the seaplanes. In order to formulate, at least in a general way, the basic principles of the calculation, we must first summarize the essential characteristics of a hull with reference to its gradual enlargement. In this study, we will disregard hulls with wing stubs, as being inapplicable to large seaplanes.

I. Impossibility of Employing a Ratio of Similitude in Terms of the Ratio of the Weights of Seaplanes.

Let us first consider why it is not possible to determine the proportions of a hull by simply employing the ratio of geometric similitude. What is, in fact, this ratio of similitude?

1. Let us assume that $\lambda = r^{1/2}$.- If, in order to satisfy the eye, we try to retain, for all the parts of a new airplane, including the hull, geometrical forms similar to those of the seaplane type, without changing the load per unit area, it is evident that, the ratio of the weights being r, the supporting surfaces must also be in the same ratio r, so that the ratio of similitude will be $r^{1/2}$.

A similar process becomes impracticable, as soon as the weight of the seaplane is much increased. We know, in fact, that in this case, the weight of the hull increases with $r^{3/2}$, while the lift of the seaplane increases with r. The percentage of the weight of the hull increases therefore with $r^{1/2}$ and consequently quickly acquires prohibitive values, even after taking into account possible savings in weight in the different parts of the structure.

Moreover, the buoyant force of the water exerted on the submerged portion must, when the seaplane is at rest, equal the total weight. It is therefore not possible for the draft of the water and air against the flotation surface to increase in the desired ratio by the law of similitude (respectively $r^{1/2}$ and r), unless the volume of the hull increases with $r^{3/2}$, instead of r. This results in an increasing disproportion between the portions of the hull above and below the water.

2. Let us assume that $\lambda = r^{1/3}$.- We can then take $r^{1/3}$ as the ratio of linear similitude for the hull. We can thus eliminate

the difficulties arising from the buoyancy. At the same time we can obtain an aerodynamic gain from the fact that the master section increases with $r^{2/3}$ and not with r.

But the adoption of $r^{1/3}$ as the ratio of similitude leads to an inadmissible result. In this case the bottom surface of the hull increases only with $r^{2/3}$, while both theory and practice demonstrate that this surface must remain in an almost constant ratio to the total weight of the seaplane, i.e., that it must vary with r.

II. Seaplane Load Index C_i.

It may be assumed that the shapes of seaplane hulls do not differ greatly. Their surface areas are therefore proportional to the square of any linear dimension, especially of the width of the bottom at the step. This is the reason for the present practice, which consists in taking the ratio of the weight of the whole seaplane to the square of the width of the step. The ratio thus obtained will be called the "seaplane load index."

Confining ourselves for the moment to seaplanes with a central hull, we observe that this index varies slightly, according to the characteristics and dimensions of the seaplanes. While some constructors, especially in other countries, have adopted indexes in the vicinity of 900, some of the best Italian constructors have adopted higher values, up to nearly 1300, as given in the following table:

Seaplane	Wt. in kg W	Width at step (m)	l^2	W/l^2
L. 1	1,700	1.15	1.32	1,285
M. 5	990	0.92	0.85	1,170
M. 9	1,800	1.20	1.44	1,250
S. 8	1,400	1.09	1.18	1,190
S.13	1,350	1.08	1.16	1,160
S. 9	1,800	1.23	1.51	1,190
S.16 bis	2,350	1.35	1.82	1,290

What should be the relative index for the hulls of large seaplanes? Manifestly, it should vary only within narrow limits.

In fact, among the various elements affecting the hydrodynamic action of the hull, the shape and curve of the bottom are subject to only slight variations. The same is true of the angle of attack which, during the period of navigation, generally has a value of only a few degrees. The same is also true of the speed corresponding to each phase and especially of the taxying speed, which is limited by reasons of safety, principally on rough water.

Colonel Guidoni, moreover, on the basis of mechanical similitude enunciated the same principle, in an analogous form, in an article on "The hydroplane surface of seaplane hulls."*

1. Increase of seaplane load index with increase in weight of seaplane.- The foregoing considerations do not establish the absolute constancy of the index of seaplane load, but only its slight

* "Les voies de la Mer et de l'Air," 1919, No. 16.

variability. In other words, we must expect a slight increase of the index with an increase in the total weight, for different reasons:

a) First, any increase in the dimensions of the hull diminishes the ratio between the lateral submerged surface (the resistance of which is absolutely parasitical) and the total submerged surface, for each speed.

b) Secondly, on rough water the braking and lifting effects decrease as the weight of the seaplane is increased.

c) Lastly, the inertia moments of a seaplane increase more rapidly than its total weight and thus further diminish the angular accelerations which impair good hydroplaning.

We will, therefore, assume that the width of the step increases a little less rapidly than the square root of the total load.

2. Empirical formula for seaplane load index.- An empirical formula, employed by many constructors, gives for this quantity the value (in meters):

$$l = k \left(\frac{W}{1000}\right)^{\frac{1}{2.3}} \qquad (1)$$

in which W is the total weight in kg and k is a coefficient slightly larger than unity, or even practically equal to unity.

Assuming that $k = 1$, we obtain for the index of seaplane load, the expression

$$C_i = \frac{W}{l^2} = 1000^{\frac{2}{2.3}} W^{\frac{0.3}{2.3}} \qquad (2)$$

which reveals a slight increase of C_i with W, in conformity with

the foregoing considerations.

For $W = 10000$ kg (22046 lb.), formula (2) would give C_i = about 1300, while it would give $C_i = 1620$ for $W = 40000$ kg (88185 lb.).

For hulls with V-shaped bottoms, some increase in width is allowable and, consequently, a diminution of the seaplane load, in order to compensate the transverse inclination of the hydroplane surface.

III. Draft and Length at Water Line.

1. Draft and means of increasing it.- If the hydroplane surface of the bottom of the hull varied directly as W, the mean draft, defined as the ratio between the volume submerged and the area of flotation, would remain constant when W varies, because, for most of the shapes of hulls, it may be assumed that the hydroplane surface remains proportional to the area of flotation.

The constancy of the mean drag has its disadvantages. It entails, in fact, for increasing lengths of the hull, a continually decreasing inclination of the keel and, in particular, a gradual diminution of the angle δ with the water line (Fig. 1). It is important for the prows to have sloping bottoms, in order to improve their taxying qualities, especially on rough water, but this advantage decreases as the dimensions increase. The prow can easily be given a more elongated shape (Fig. 2).

The constancy of the mean draft further entails a gradual diminution of the mean angle of attack of the hydroplane surface, which

lessens the dynamic lift. This finally leads to a too small height of structure and consequently, as we shall soon see, to an excess in weight.

It is therefore important, for large seaplanes, to increase the mean draft and, more especially, the maximum draft of the hulls, with the aid of suitable devices.

The first increase in draft is directly due to the fact, already mentioned, that the width of the step increases less rapidly than the square root of W. If it is further assumed that the length w of the area of flotation varies as the width w, it is necessary in order to reestablish the displacement, to further increase the mean draft. It is easily demonstrated, in this event, that the mean draft varies proportionally to the seaplane load index C_i.

2.- Length at water line and reasons for decreasing it.- We have just assumed the constancy of the ratio $l:w$. For large seaplanes, it is really better to reduce this ratio gradually, both for structural reasons, which we shall discuss, and in order to increase the angle of attack of the bottom. This relative shortening of the length may, however, give occasion for a few objections, which we will consider first of all.

a) We have said it is necessary to elongate the prows for taxying on rough water and for alighting after a dive. Would it therefore be disadvantageous, from this point of view, to shorten the hull? We have considered this question and found that large sea-

planes profit by their greater inertia. Moreover, it is always possible to have sloping prows, as shown in Fig. 2.

b) For a given seaplane, can a reduction in the hydroplane surface, due to the simultaneous reduction of w and l, greatly increase the maximum drag in the water?

Experience with actual seaplanes demonstrates that the "optimum" area of the hydroplane surface, as defined by Colonel Guidoni in the article already referred to, increases less rapidly than the weight of the seaplanes. It is known, moreover, that the maximum resistance varies slightly when the hydroplane surface area departs a little from the "optimum" value. The longitudinal contraction, or reduction of the ratio $l : w$, is possible, therefore, so long as the hydroplane surface area has nearly its "optimum" value.

If it be desired to further reduce the ratio $l : w$, it would only be necessary to change, not the length l_1, between the step and the bow, but the supplementary length l_2 between the step and the stern, which does not affect the hydroplane surface and whose effect on the maximum resistance is small, at least so long as the reduction is not excessive.

c) Can the shortening of the flotation surface impair the longitudinal stability of the seaplane on the water? It is easily demonstrated that the longitudinal stability tends to increase rapidly with the weight W.

In fact, while the volume V of the submerged portion of the hull varies with the ratio of the total weights, the distance h

between the center of buoyancy and the center of gravity may be considered proportional to $r^{1/2}$. If R designates the longitudinal metacentric radius, R-h is positive, even for small seaplanes, which are ordinarily stable longitudinally. Therefore it will only be necessary for R to vary also with $r^{1/2}$, for the metacentric height R-h to follow the same law.

Now $R = I/V$, I being the moment of the longitudinal inertia of the flotation area proportional to the fourth power of the ratio of linear similitude. Since V is proportional to r, R will vary with $r^{1/2}$; if R V or I varies with $r^{3/2}$, i.e., if the linear dimensions vary with $r^{3/8}$. However, since the exponent 3/8 is not only less than 1/2 (to which a constant hydroplane index would correspond) but also less than 1/2.3, the exponent of formula (1), the length will vary less rapidly even than $r^{1/2.3}$, while rendering possible the gradual increase of R-h.

IV. Structural Considerations.

It is known that for large airplanes, the principal danger to be avoided is the increasing of the ratio of the dead load to the full load. A similar difficulty is encountered in connection with seaplane hulls, which must:

a) Have the necessary naval and hydroplane characteristics;

b) Have a weight below a certain fraction of the dead load;

c) Have as low an aerodynamic resistance as possible.

1. Shape of bottom.- The necessity of improving the hulls and diminishing the risks of injury to their bottoms has led construct-

ors to seek better shapes than the flat bottoms of small seaplanes. The present popular type is the one with a very open V-shaped bottom, like the English and American seaplanes (Fig. 3). Other models, like the Siai (Fig. 4), have an arched cross-section, in order to reduce the angle formed with the water by the lateral borders of the bottom.

Other constructors seek to eliminate the keel line by adopting a curved cross-section, like the Nieuport (Fig. 5), which eliminates, while taxying and taking off, the difficulties inherent in sharp-edged bottoms.

Some of the Dornier seaplane hulls have a drop in the cross-section (Fig. 6) designed to localize the greatest pressures on a central salient. Though advantageous in some respects, this type creates, in the most stressed portions of the bottom, two discontinuities which impair the regular flow of the fluid filaments and produce phenomena similar to those of streams issuing from rectangular orifices.

For large seaplanes, we believe the best hull is a rational compromise between the different shapes mentioned, as indicated by Fig. 7 (a and b). It is, in fact, obvious that a sharp keel cannot support a large total load, because of the enormous hydrodynamic pressures exerted on it while taxying. Nieuport, and more especially, Dornier, sought to avoid this disadvantage by employing the curvilinear cross-section bc of Fig. 5 or the rectilinear portion of Fig. 6, narrow enough, however, to afford sufficient

strength. This rectilinear portion provides a well-defined hydroplaning surface up to the instant of taking off.

2. Utility of a second step.- The second step (which may, in the future, be followed by a third) also helps to localize the shocks which, in alighting with the tail down, are particularly violent in a well-defined and reinforced region. What has been said concerning the utility of a V cross-section for the first step might be repeated for the second step. This cross-section could be like Fig. 7, or even have a sharp keel, which would offer no disadvantage, since the second step is normally submerged while taxying.

3. Means of reducing structural weight of hull.- The central portion of the hull is ordinarily attached to the wings. It behaves, therefore, like a girder secured in the middle and free at both ends. The greatest stresses are produced at the ends, by alighting on the prow or on the tail, shocks from waves, etc. We will disregard the "flying-boat" type in which the hull carries the tail unit, since the stresses caused by the elevator and rudder are small in comparison with those due to the water and, moreover, attain their maximum strength only during flight.

From the viewpoint of strength, the means of lightening the structure can only be the following:

a) Decreasing the length of the hull;

b) Increasing the height of the maximum section;

c) Using stronger materials.

a) Decreasing the length of the hull.- As regards this point, we have seen that not only the length and the width increase less rapidly than $W^{1/2}$, but also that the ratio $l:w$ can be gradually reduced, especially on the length l_2 of the rear portion. This causes a relative reduction of the moments acting on the extremities. The stresses themselves can be reduced by adopting a suitably designed V-shaped bottom. They can be localized by employing a second and even a third step, which will render it possible to withstand stresses approaching the limit of elasticity and also to save weight.

b) Increasing the height of the maximum section.- The maximum section is located at the step and its height H is the sum of the height H_1, above water, and H_2, below water. It is obviously desirable, from the viewpoint of strength, for the height H to have the maximum value compatible with the proportions of the hull and also for it to be as nearly as possible proportional to $W^{1/2}$.

Now, the height H_1, of the portion above water, will normally vary less rapidly than $W^{1/2}$, in order to avoid too great a drift surface and a too extensive covering.

On the other hand, the mean submerged portion i_m increases, as we have already seen, with the seaplane load index. Since the height H_2, of the portion under water, is practically proportional to i_m, it will vary almost the same as W.

Moreover, the maximum draft H_2 can be still further increased by substituting, instead of the flat bottom suitable for small sea-

planes, the increasingly sharp V-shaped bottoms required for large seaplanes.

Here the cross-section shown in Fig. 7 has another advantage. It enables the distribution of a considerable portion of the strengthening material in the rectilinear portion of the base, i.e., at maximum distance from the neutral axis, which the V cross-sections do not permit in an equally advantageous degree.

c) Using stronger materials.- The thorough discussion of this question does not come within the scope of the present article. We will limit ourselves to showing the effect of the gradual enlargement of the hull on its weight and on the choice of the most suitable material.

The replacement of wood by light alloys is possible when the dimensions of the hull are not too small, provided it does not lead to the employment of too thin sheet and section metal, incapable of withstanding local stresses and unsuitable for riveting.

For seaplanes of more than ten tons (larger than any now existing), it will be possible to employ very strong steels, especially because of their resistance to corrosion and to molecular changes, as also because of the high ratio between their elastic limit and their breaking strength. Special steels may be substituted for the light alloys in a number of pieces always increasing with the volume, beginning with the longitudinal members most remote from the neutral axis and continuing with the covering of the bottom. There would remain to be made of light alloys the covering of the portion

above water and, in general, wherever it is desired to combine a large moment of inertia with a high specific strength, in order to avoid local yielding.

In general, at least for a relatively abnormal reduction of the height H, the weight of the hull or hulls represents about 12% of the total weight of the seaplane, as given by the best writers, like Colonel Guidoni and Professor Boutiron.

4. Reducing the aerodynamic resistance by reducing the maximum section.- It now remains for us to consider the problem of reducing the aerodynamic resistance of the hulls.

In reality, the area of the maximum section of the hull varies less rapidly than the weight W of the seaplane and the width of the step (which coincides with the maximum width or is in any case proportional to it) varies a little less rapidly than $W^{1/2}$, as we have already mentioned.

On the other hand, let us consider the mean height H_m, which differs from the maximum height H previously considered. H_m is the sum of two terms: h_m, the mean height of the portion above water, and h_n, the mean draft at the master section, which must not be confounded with i_m, the mean immersion of the entire hull. We are going to show that h_m and h_n both increase less rapidly than $W^{1/2}$, so that the area of the maximum section really varies less rapidly than W.

a) Effect of mean draft h_n.- We have already seen that, in order to vary the maximum immersion H_2 almost as rapidly as $W^{1/2}$,

we must give increasingly sharper V cross-sections to the bottom of the maximum section. It is therefore natural that the mean immersion h_n should not vary proportionally to the maximum immersion H_2, nor, still less, to $W^{1/2}$.

b) Effect of mean height h_m of part above water.- The portion above water must:

a) Provide a sufficient flotation reserve;

b) Afford sufficient space for the crew, fuel and merchandise;

c) Support the covering.

The first two conditions require the existence of a sufficient capacity C, whose variation can be, at the maximum, equal to that of W. In reality, good water-tight compartments and the possibility of storing a portion of the load in the wings render possible, in increasingly large seaplanes, a gradual reduction of the ratio C : W.

We have already seen that H_1 must vary practically the same as $W^{1/2}$. It is only necessary for the product of the length l_m times the mean width w_m of the portion above water to vary also with $W^{1/2}$ at most.

Now l_m cannot remain constant and increases a little more slowly than the width of the step. Lastly, w_m remains nearly constant. This constancy of the width w_m of the portion above water necessitates a discontinuity between the portions above and below the surface of the water, as found on English seaplanes and on the four-engine Besson or as proposed by Mr. Boutiron in his seaplane course at the "Ecole Superieure d'Aeronautique" (Fig. 9). We are

thus led to a section like the one in Fig. 10, in which the mean height h_m is considerably less than H_1.

In short, as the dimensions of a seaplane are increased, the ratios $H_1 : h_m$ and $H_2 : h_n$ increase and enable an increasingly large relative reduction in the master section.

V. Proportions to be Given to Twin Hulls.

If, instead of a single hull, two hulls are employed, after the manner of a catamaran, we are led to inquire how to proportion these two hulls with respect to the single hull.

We will let G_2 represent one of the twin hulls, with a displacement $W/2$, and G_1 the single hull, with a displacement W.

1. Possible solutions.- There are two extreme solutions to be considered:

A) We may calculate the hull G_2, as if it were used alone with a seaplane weighing $W/2$, in accordance with the rules previously mentioned. Under these conditions, the hull G_2 may be a little lighter than half of G_1, but it will have a maximum section a little larger than half of G_1. Furthermore, since G_2 is really used with a seaplane weighing W and not $W/2$, it will be a little short and therefore not so good from a nautical viewpoint.

B) We may calculate G_2 as if it were as long and as high as G_1 but only half as wide, as if it had been obtained by an exact longitudinal division of G_1 into halves. The maximum section, the interior capacity, etc., are then reduced one-half, but the nau-

tical qualities have not been impaired. On the other hand, the weight has been increased, as likewise the maximum resistance to motion through the water, principally by reason of the total submerged surface area. On the whole, the second solution appears to be the more satisfactory one.

2. Comparison with single-hull solution.- The single hull has the undeniable advantage of simplicity of construction and of connection with the wings. It is less expensive and also serves as a fuselage (flying boat). But any comparison limited to the hulls alone, without considering their relation with the wings, may lead to a wrong conclusion.

We know, in fact, that one of the methods for lightening the framework of large airplanes consists in distributing, as far as possible, the load along the wings and in avoiding its concentration at the center. Mr. Magaldi discussed this method in a communication to the Italian Naval College of Mechanical Engineers on "The Problem of Airplanes of Large Tonnage" (See "Marina Italiana" May-June, 1923). Now the hulls, which represent a considerable portion of the total weight, especially if they contain a part or the whole of the useful load, must evidently be attached to the wing laterally, to a certain distance from the plane of symmetry of the seaplane, in order to diminish the fatigue of the wings.

It is true, that in this case, it will be necessary to provide a fuselage to carry the crew and support the tail unit, but the resulting additional weight and aerodynamic drag can be almost exact-

ly compensated by corresponding reductions in the two hulls thus freed from the tail unit, controls, etc.

On the other hand, a large seaplane with a central hull can hardly dispense with a fuselage, even if it takes the form of a superstructure of the hull, as in Dornier's "Dolphin," some "Junkers," the four-engine "Besson," etc.

Hence, in practice, any saving in weight obtained with a single hull will certainly be less than the saving in the weight of the wings due to the employment of two floats at some distance from the plane of symmetry of the seaplane. Furthermore, the employment of two hulls improves the visibility, especially downward, and eliminates the floats under the wing tips.

Twin hulls are particularly advantageous for large monoplanes with cantilever wings or with semi-cantilever wings supported by struts. On account of the large span, the distribution of the load, and especially of the hulls, outside the plane of symmetry is of great advantage, especially for the cantilever type.

The semi-cantilever type, with struts, is lighter and enables the employment of wings of less thickness and greater aerodynamic efficiency. It is obvious that the shorter the struts, the lighter and stronger they will be. Now, these struts can rest only on the sides of the hulls. Hence, the farther apart the hulls are, the smaller and lighter the struts can be (Fig. 10).

In brief, the central hull, due to its simplicity and excellent behavior on the water, can be used advantageously on multiplanes,

which have a small span in comparison with monoplanes and which, of themselves, constitute girders of sufficient height not to require struts resting on the hull. On monoplanes, however, especially of the strut type, the total saving in the weight of the wings effected by employing two hulls is so great as to leave no occasion for hesitation.

In seaplanes of large tonnage, every lightening, however slight, is of importance in combating the relative weight increase of the wings, otherwise prohibitive. Consequently, the concentration, in the axis, of the weight of the hull is illogical, especially as the volume of the two separate hulls guarantees excellent nautical qualities.

Engineer Magaldi is confident that the tonnage of airplanes will increase rapidly, together with improvements in quality, in spite of technical difficulties.

He does not believe, therefore, that he has wasted his time in discussing the various aspects of the fundamental question of seaplane hulls and in trying to find out how to direct their evolution toward the employment of increasingly large volumes.

Translation by Dwight M. Miner,
National Advisory Committee
for Aeronautics.

Fig.1

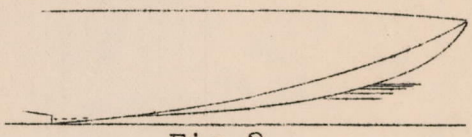

Fig.2

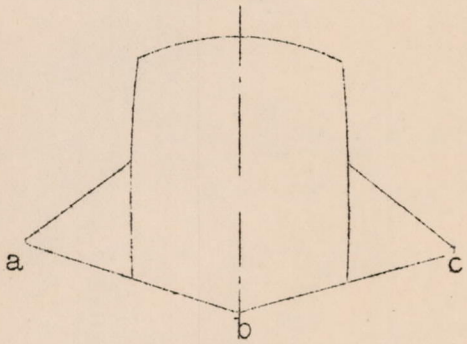

Fig.3

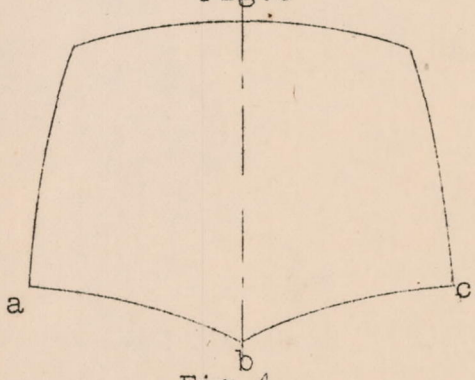

Fig.4

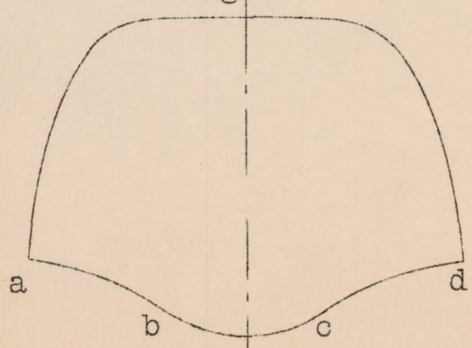

Fig.5

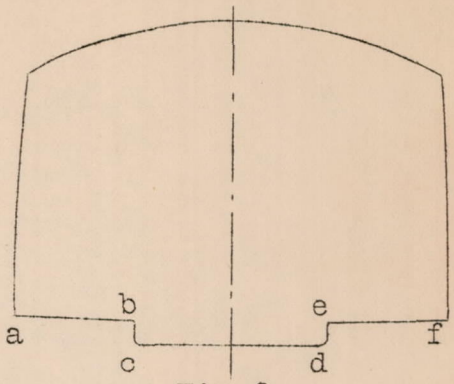

Fig.6

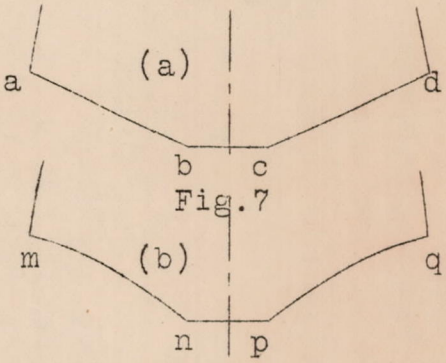

Fig.7

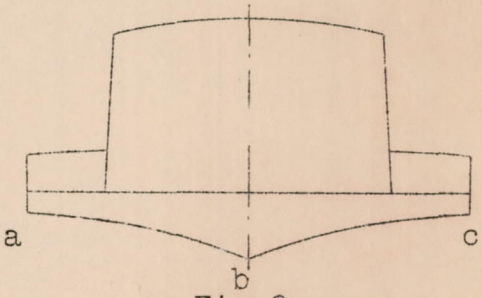

Fig.8

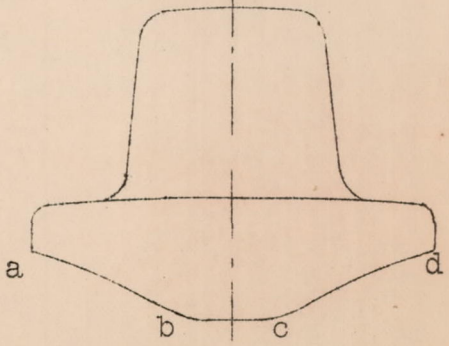

Fig.9

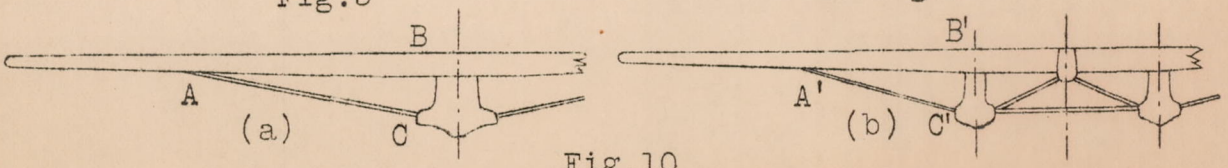

Fig.10