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TECHNICAL DETAILS IN THE STRUCTURAL DEVELOPMENT OF ROHRBACH SEAPLANES

By Gotthold Mathias and Adolf Holzapfel

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TECHNICAL DETAILS IN THE STRUCTURAL DEVELOPMENT OF ROHRBACH SEAPLANES.*

By Gotthold Mathias and Adolf Holzapfel.

The recent trial flights and acceptance tests of the Rohrbach "Romar," the largest seaplane in the world, have yielded results fully confirming the principles followed in its development. Its take-off weight of 19,000 kg (41,888 lb.), its beating the world record for raising the greatest useful load to 2000 m (6562 ft.) by almost 2500 kg (5511 lb.) and its remarkable showing in the seaworthiness tests are the results of intelligent researches, the guiding principles of which are briefly set forth in the present article.

The Wing

The development of a large airplane necessitates a gradual increase in the wing loading. The requirements for certain good flight performances constitute the determining factor. With a constant engine power these requirements are satisfied by the mutual balancing of the three principal variables: wing loading, structural weight and aspect ratio (here considered as the ratio of the square of the span to the wing area). For cer-

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*"Technische Besonderheiten in der baulichen Entwicklung der Rohrbach-Flugboote," from Zeitschrift für Flugtechnik und Motorluftschiffahrt, July 15, 1929, pp. 334-338.

tain safety requirements any increase in the wing loading increases the weight of certain structural parts, but the weight of the whole structure is not raised at first, due to the relatively smaller size of the wing. On the other hand, any increase in the aspect ratio, for the same perimeter, increases the weight of the wing structure. The effect of this measure on the flight performances, however, depends largely on its aerodynamic consequences. For every wing loading there can be found the best aspect ratio, whose aerodynamic advantages offset the increase in the weight of the wing structure. By determining the two variable ratios, wing loading to structural weight and structural weight to aspect ratio, for certain good flight performances one obtains the best fundamentally inseparable combination of correct wing loading and correct aspect ratio. These are not at all synonymous with high wing loading and large aspect ratio in the ordinary sense. With good climbing and distance performances the values of both are inversely proportional to the ratio of the weight of the cell to the total weight of the airplane (Fig. 1). Thus the endeavor to obtain a light wing with a favorable aspect ratio led to the choice of a strongly tapered cantilever wing (Fig. 2) as first used on the "Robbe II" and, after being found satisfactory, now also on the "Romar" (Figs. 3-4).

This type of wing foregoes the aerodynamically best lift distribution along the span in favor of greater static advantages.

The effect of a slight deviation from the elliptical lift distribution on the induced drag is relatively unimportant and, with increasing aspect ratio, grows continually less important. The lower limiting case of parabolic distribution is accompanied by an increase of the induced drag in the ratio of 9 : 8, hence not more than a reduction of the aspect ratio from 9 to 8. The Rohrbach wing contour is still far from this limiting value.

The static advantages, on the contrary, are of two kinds:

1. The "under-elliptic" distribution reduces the load on the outer portions of the wing, especially at high lift values, so that these portions can have a lighter structure than with an elliptical distribution.

2. Girder dimensions increasing proportionally with the chord afford the best strength utilization of the whole girder structure. A cantilever rectangular or slightly tapered wing, on the contrary, must be considerably heavier in the middle portion, due to the small thickness of the girder for withstanding the bending moments, and at the tips, due to the poor utilization of the bonds to be dimensioned with respect to their holding strength.

The principal advantage of a strongly tapered cantilever wing is therefore, especially on large airplanes, a considerable saving in the structural weight. This saving is further increased by the drawing in of the air force and gravity resultants of the wing-halves toward the middle of the airplane, which is particularly effective at large lift values (in levelling off and in vertical gusts) and with respect to the stresses produced in the girders by take-off and landing shocks.* The latter consideration assumes special importance in the endeavor after the greatest possible seaworthiness.

The Hull

Due to the small seaworthiness requirements for the hulls of former seaplane types, flat-bottomed hulls with keels had certain advantages. They were structurally simpler, had when rightly constructed, good starting characteristics in quiet water and, with the exercise of a little skill, could take off and alight safely on moderately rough water.

In alighting on very rough water, however, the flat bottom does not afford the adequate safety which must now be unconditionally required as the result of practical experience. Even with very great reliability of the power plant, the necessity of this requirement could not be permanently ignored. A corresponding reinforcement of the bottom would soon increase the structural weight beyond measure. As already mentioned, the creation of a satisfactory large airplane would not only increase the wing loading but also the landing speed. The resulting stress increments would soon get beyond control and bring the further development of seaworthy flying boats to a halt.

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*See N.A.C.A. Technical Report No. 150: "General Biplane Theory," by Max M. Munk (1922), and L'Aeronautique, 1928, p.100 ff.

A necessary condition for the development of a large seaworthy flying boat was therefore the creation of a sharp-bottomed hull (Figs. 5-6). In the comprehensive towing tests of flat-bottomed models (for comparison) and of a considerable number of models with V-shaped bottoms, the strength and dynamic lift of the sharp-bottomed hulls were found to be fully equal to those of hulls with flat or slightly V-shaped bottoms (Fig. 6). The practical result of this combination of the advantages of flat and V-bottomed hulls is strikingly shown in the excellent take-off characteristics of the Rohrbach seaplanes, especially of the "Romar."

Even the ground plan was determined by the requirement of the greatest possible seaworthiness. Hence the width of the hull was held at the lower limit of the dimensions required for utility and convenience. This produced a slender ground plan, which combines great seaworthiness and aerodynamic excellence and thus greatly increases the commercial value and safety.

Lateral Floats

The slender shape of the hull necessitates the use of auxiliary floats for preserving the floating stability with respect to the longitudinal axis. On the Rohrbach seaplanes these floats are located at a moderate distance from the hull and a little higher than the bottom of the hull. This arrangement prevents the floats in taking off and alighting from having the effect of lateral extensions of the hull and thus interfering with the gradual damping of the shocks. Their position also enables them to exert a powerful dynamic lift in taking off. As soon as the hull has risen on its step, the floats leave the water, thus diminishing their drag. The deeper the hull is submerged due to heavy loading, the greater the static and dynamic lift afforded by the floats in taking off. They are especially valuable in helping the seaplane past its critical speed (Fig. 7). This explains why the narrow Rohrbach seaplanes, even when very heavily loaded, rise on their step remarkably quick, so that, despite a greater wing loading, their take-off time for the same weight per horsepower is no longer than that of seaplanes with wider flat-bottomed hulls.

In alighting, the hull enters the water first. Due to its V-shaped bottom, the shock is very slight. Only when the speed is further reduced, do the similarly shaped floats gradually submerge. Severe local stresses of the wing, due to heavy shocks from the floats, are thus avoided.

If a float or its supports are damaged, there are two provisions to lessen the tipping of the seaplane:

a) The floats, like the hull (Fig. 8), are divided into several water-tight compartments, so that, in the event of a leak, only a portion of the lift is lost.

b) If a float should be entirely removed, the wing tip would dip into the water. In anticipation of such an event, the wing spars of the "Romar" on the outer side of the lateral engines have the form of water-tight box girders. These have sufficient buoyancy to prevent the seaplane from capsizing. The seaworthiness tests of the "Romar" demonstrated the utility of this device.

Power Plant

One of the most important conditions for good flight performances, especially while taking off and climbing, is the least possible disturbance of the air flow on the upper side of the wing. Any obstacle on or near it causes a premature separation of the boundary layer from the wing, thereby increasing the drag and decreasing the lift generally over quite a large portion of the wing. It is therefore important, especially in the case of high-wing loading, to keep the engines at some distance from the upper side of the wing. On land airplanes with lateral engines, this consideration leads to the suspension of the engines underneath the wing, where their disturbing effect is relatively small (Rohrbach "Roland"). This arrangement is not practicable, however, on large seaplanes, because it brings the propeller too near the water (Fig. 9). Hence it is necessary to locate the closely associated engine-propeller aggregation far enough above the wing to reduce the lift disturbance as much as possible (Fig. 10). The distance varies somewhat, according to the position of the engines in the ground plan and the size and shape of the engine housings. The favorable effect of increasing this distance has been demonstrated by both model and flight tests. The supporting framework, when correctly constructed with streamlined cross sections, disturbs the air flow on the upper side of the wing so little and over such a small area as to have but little effect on the induced drag of the wing. In any case the combined retarding effect is far less than the retarding effect of engine housings joined directly to the upper side of the wing.

The Rohrbach arrangement has the further advantage of enabling the use of pusher propellers without cutting away the trailing edge of the wing, which latter has a very detrimental effect on the lift and on the lift-drag ratio. The nature of the inflow with which the propeller must work in such a cutaway considerably impairs the reliability and length of life of both propeller and engine.

In opposition to the above-mentioned advantages, the often raised objection of the inaccessibility of the engines during flight should serve principally as an incentive to the creation of high-grade reliable engines. This objection does not apply to the special fundamental principle involved in the Rohrbach arrangement, since the installation of the engines, in the present status of seaplane construction, does not enable complete attendance of the engines during flight. Only this complete attendance can be of decisive effect on the reliability of the power plant.

Taxying, Take-Off and Flight Characteristics

The application of the principles here involved, as finally given expression in the "Romar," has been entirely successful in the resultant taxying, take-off and flight characteristics. The maneuverability on the water is greatly improved by the V-shaped bottom of the hull, which prevents the drifting of the seaplane in a side wind. This fact, in conjunction with the strongly stabilizing effect of the lateral floats, enables the seaplane to follow any desired course even with a very strong side wind. With the aid of the lateral engines, turns can be made in a very small space. Even with one of the lateral engines stopped, it is generally not difficult to hold to the course in taxying. In case of need, the maneuverability can be adequately supplemented by a water rudder. Taxying on the water is possible for any desired length of time, even in hot weather and with a fair wind, since the cooling of the engines is assured by an auxiliary sea-water radiator.

The chief advantages of the V-bottomed hull are exhibited in the take-off characteristics. The beginning of the take-off process has already been referred to in the section on Lateral Floats. After the hull has risen on its step, the speed is greatly accelerated as a result of the rapidly diminishing water resistance (Fig. 7), and the seaplane finally takes off easily and smoothly. The instant of the take-off can be largely determined by the pilot. The necessity of a long preliminary run to acquire sufficient wing lift is obviated by the design of the bottom of the hull. The wave shocks in taking off and in alighting are greatly reduced. No failure of a tension member in the forward part of the hull (a common occurrence in flat-bottomed hulls) has yet occurred in Rohrbach V-bottomed hulls.

Large vertical control surfaces with a well-balanced rudder (Fig. 3) assure good directional stability, even when one of the side engines is dead. Since the elevated position of the horizontal tail surfaces frees the larger portion of the rudder from interference, even at large angles of attack, it is not only possible to continue straight flight, but even to turn against the engine which is still running.

Rolling stability is fully attained by the large dihedral of the wing, despite the elevated position of the engines. The action of the ailerons is especially favored by the peculiar location of the center of gravity of each half-wing, due to the strong taper. Even in stalled flight, the tapered wings have proved at least as favorable as any other shape. The longitudinal or pitching stability is excellent. The balanced elevator was made very large for taking off from and alighting on rough water.

The opinion has often been expressed that elevating the engines would unfavorably affect the trim when the speed is reduced. This idea is wholly wrong. With a correctly dimensioned horizontal stabilizer any change in the moment of the propeller thrust would be offset by a corresponding change in the stabilizer moment resulting from the change in the dynamic pressure of the propeller slipstream. The degree of this balancing of moments is simply a question of the correct calculation of the longitudinal stability. For the smallest possible variation in load in the whole speed range, the elevated position of the engines is even more favorable than if they were located at the center of gravity of the airplane. Extensive flight tests have confirmed this line of reasoning, so that the above-mentioned objection can be regarded as fully answered.

Flight Performances

The most important characteristics of a seaplane designed for long flights are great seaworthiness, the best take-off characteristics, the most favorable load ratio and high cruising speed.

As already stated, the Rohrbach seaplanes have been developed with an eye to the best possible fulfillment of these four requirements. Good starting characteristics are necessary in order to enable the carrying of an adequate fuel supply without too greatly reducing the useful load. High speed and small fuel consumption are necessary in order to diminish the effect of the weather on the distance flown and to pass quickly through small regions of unfavorable winds.

The wing loading and aspect ratio of the Rohrbach seaplanes are of decisive importance for the fulfillment of these requirements. Their wing loading enables good speed in the range of economical flight with the best lift-drag ratio and with great reserve speed. The aspect ratio, in conjunction with the shape of the hull, affords good take-off ability and high overloading capacity in taking off with a full fuel supply. The aerodynamic perfection of all the supporting parts, the slender hull, the V-shaped floats, elevated engines, etc., also reduce the structural drag to a minimum, so that the lift-drag ratio and the power required to maintain horizontal flight attain remarkably favorable values and enable long nonstop flights. Moreover, the propellers are carefully adapted to the particular seaplane of which they are to be regarded as essential and integral parts. Hence they enable the maximum efficiency both in taking off and at subsequently reduced speed.

The ability to overload for the take-off enables the carrying of a relatively heavy useful load and sufficient fuel for long nonstop flights. The Rohrbach "Romar" has already shown that the right course is being pursued and will lead to further favorable results.

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

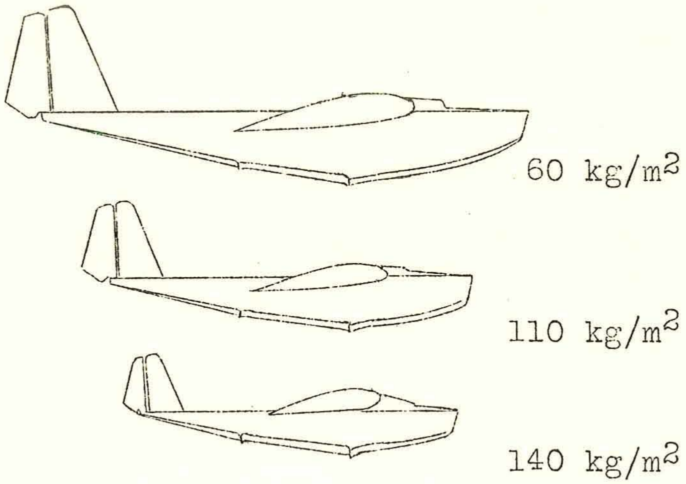

Fig.1 Effect of wing loading on wing area with different space requirements for the same flying weight.

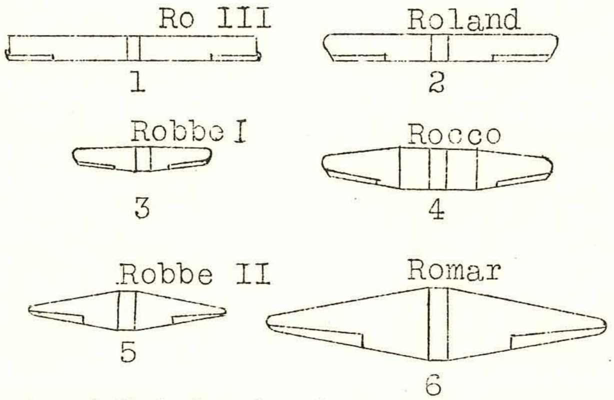

Fig.2 Development of Rohrbach wing contour to a tapered shape, Nos.2-4 being semicantilever.

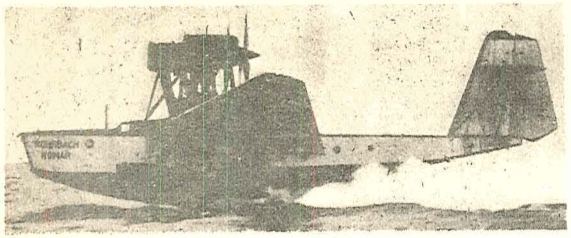

Fig.3 The "Romar" taking off

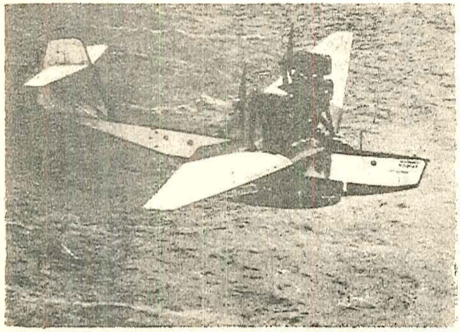

Fig.4 The "Romar" in flight

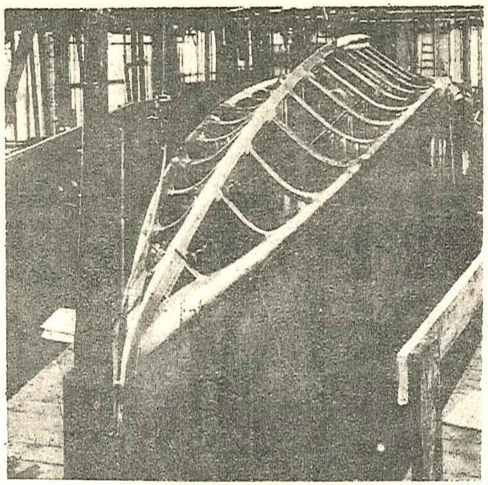

Fig.5 Keel-bottomed hull of Rohrbach "Robbe I"

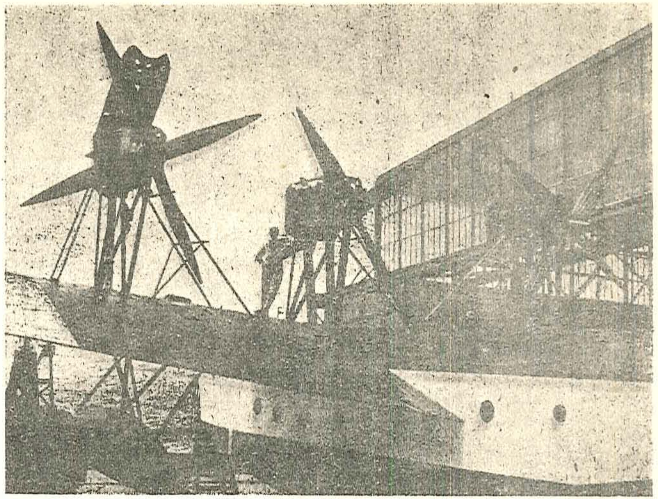

Fig.10 The "Romar" showing location of power plant.

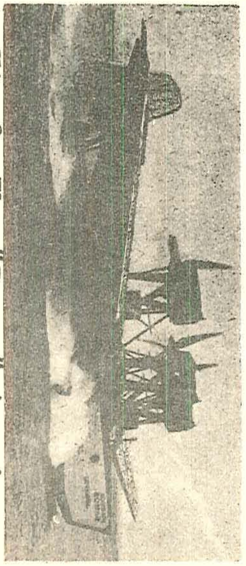

Fig.9 The "Romar" taxying

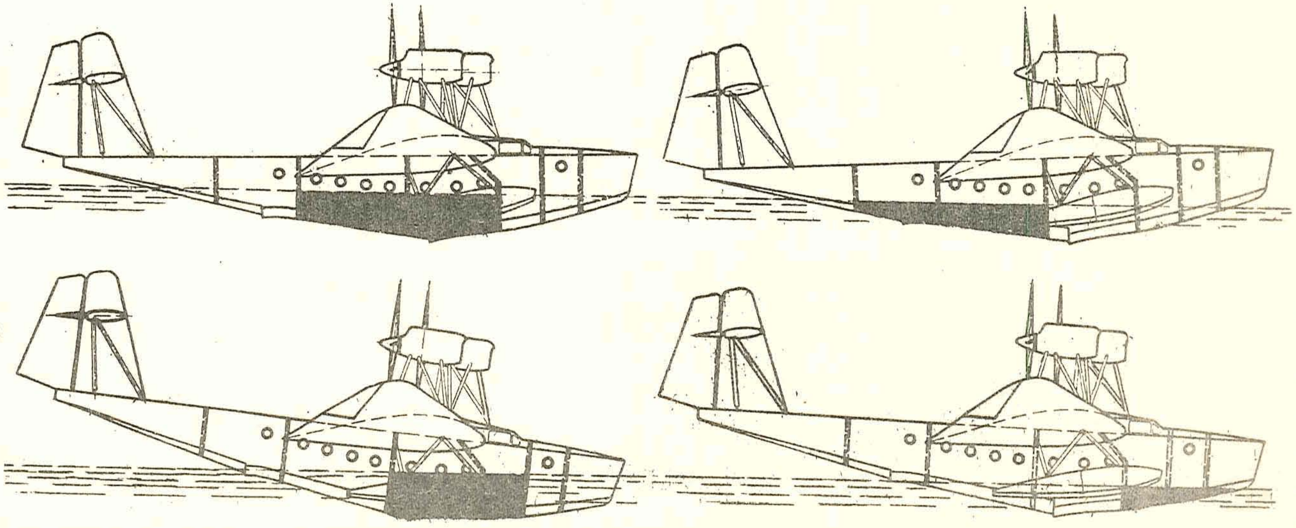

Fig.8 Division of hull of "Romar" into water-tight compartments and effect, of filling one or more compartments, on the trim.

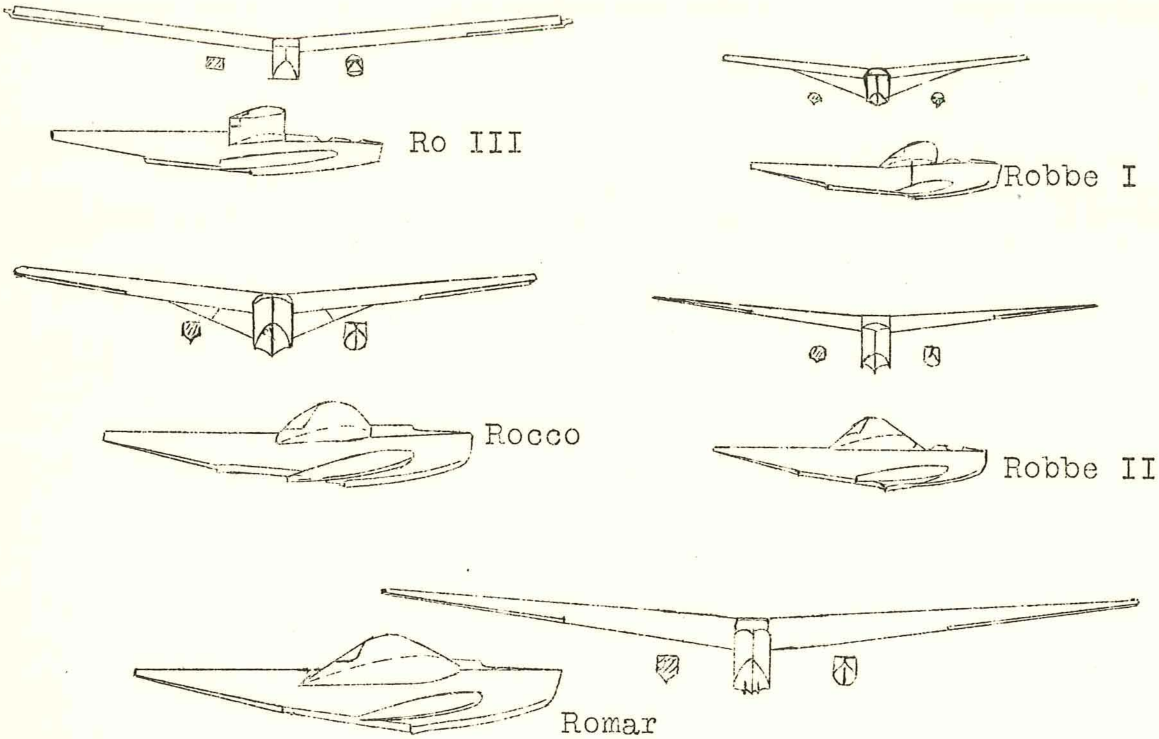

Fig.6 Development of Rohrbach hulls from the flat bottom of the"Ro III" to the sharp V-bottom of the"Romar".

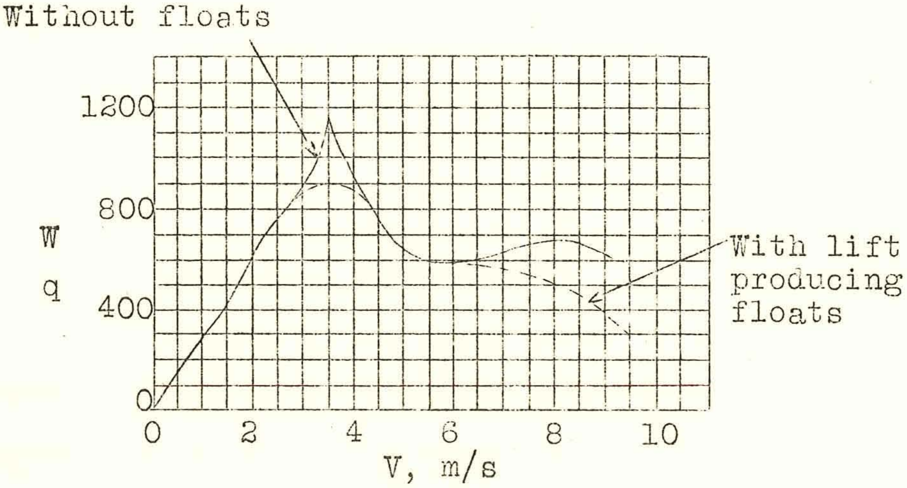

Fig.7 Resistance of water to the model, with and without lateral floats, plotted against the velocity.