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HYDRODYNAMIC TESTS FOR DETERMINING THE TAKE-OFF CHARACTERISTICS OF SEAPLANES.

By R. Verduzio.

From "Rendiconti dell'Istituto Sperimentale Aeronautico," No. 4, December 15, 1922.

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HYDRODYNAMIC TESTS FOR DETERMINING THE TAKE-OFF CHARACTERISTICS OF SEAPLANES.*

By R. Verduzio.

A few years ago the writer published a graphical method for determining the flight characteristics of aircraft. This, however, concerned flight only. It is very important for the constructor to determine beforehand the possibility of the aircraft's being able to take off. If an airplane can fly, it can always take off, but with a seaplane the case is different. Here, the resistance of the water, even at low speeds, may be such as to render it impossible to take off.

For this type of aircraft, it is therefore especially important to determine the take-off characteristics. This problem has been greatly neglected by technicians and it is often only in the actual test of the completed seaplane that its inability to leave the water is discovered. In this short note there is given a new graphical method which is very simple and which appears to be the only one for the complete solution of the problem.

In the first cartesian diagram (Fig. 5) the angles of incidence of the airfoil are plotted horizontally as abscissas and L_y, the total lift of the airfoil reduced to unit velocity is plotted

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vertically. For normal angles of flight this L_y curve is a straight line V_1 V_2 V_3 V_4 .... V and on it is marked the velocity V_n of the lift for the different states of flight i_n defined by the verticals V_n A_n in which the points A_n give the angles of incidence of the airfoil i_n. It is clear that in the stages relative to the points A_n at the corresponding velocities V_n, the craft is sustained by the air and therefore the floats do not come into the question at all, being quite out of the water with the known unit resistance r_n. Diminishing the incidence i_n and at the same velocity V_n, the floats will be in the water and must supply that part of lift which is not given by the airfoil. At the incidence $-i_o$, for which $L_y = 0$ (non-supporting airfoil), the floats will carry the entire weight W of the seaplane. If we now draw a vertical line from $-i_o$ to the horizontals passing through V_n, the points of junction B_n, will give the lift of the floats due to the static buoyancy of the water and its dynamic lift. And since L_y is a straight line, all the curves of lift due to the water are also straight lines and are therefore easily plotted. It is evident that the projection normal to the ordinate forming the origin of that part of A_n B_n comprised between this and the ordinate $-i_o$, is equal to the lift 0^o V of the airfoil at the angle 0^o.

On the lines B_n A_n we have the static and dynamic lift of the floats necessary for raising the seaplane from the water at a speed V_n and incidence i. We can therefore draw up a table of the total loads on the floats at given incidences i and speeds V_n:

Table 1.

	Incidence $i^\circ = 2^\circ$				Incidence $i^\circ = 4^\circ$				Incidence $i^\circ = 6^\circ$			
Speed	V_1	V_2	V_3	V_4	V_1	V_2	V_3	V_4	V_1	V_2	V_3	V_4
Lift	C_1	C_2	C_3	C_4	C_1	C_2	C_3	C_4	C_1	C_2	C_3	C_4
Load	$C_1 V_1^2$	$C_2 V_2^2$	$C_3 V_3^2$	$C_4 V_4^2$	$C_1 V_1^2$				$C_1 V_1^2$			

From tests made in water on the floats, there are determined the groups of head resistance curves L_{xa} for different speeds V_n and different angles of incidence i, referred to those of the airfoil, each group corresponding to a given total load W_a on the floats, this load being compensated by the dynamic and static reactions of the floats. Thus by means of the L_{xa} experimental curves corresponding to the two consecutive loads W'_a, W''_a, which comprise the load $C_n V_n^2$, we read on the ordinate V_n the values of the resistances L'_{xa}, L''_{xa} (which by interpolation give L_{xan} corresponding to $C_n V_n^2$, i°), for each load $C_n V_n^2$ previously calculated and relative to a given incidence $i = 2^\circ$, 4°, 6° .... We can therefore add to our table a new line giving the values L_{xan}.

The tests for the determination of the L_{xa} curves were carried out in England and published in the English reports in 1916. In these tests the load W_a was taken as being independent of the velocity. We, however, in 1919, considered the load W_a as a function of V_n depending on the characteristics of the seaplane and assuming a form

$$W_a = a - b V_n^2$$

in which a and b are constants (Figs. 3 and 4). This introduces a slight complication in the tests and calculations, but gives perhaps a closer approximation.

The L_{xa} curves run from 0 to 0 and are maximum at a certain velocity as shown on the diagram. There is a little overlapping, but that agrees with the fact that a better resistance may often be produced by pre-existing waves.

Since the tests in the water are carried out at low speeds, the resistance of the superstructure, due to the air, cannot be measured with sufficient accuracy, and it must be remembered that the L_{xan} curves only show that part of the resistance due to the water. This difficulty is met by testing the floats (Fig. 1) in a wind tunnel and determining their head resistance. Then, by transferring this experimental diagram (Fig. 2) to the first diagram (Fig. 5) at D_1 D_2 D_3 .... we can also take into account the resistance of the air. Strictly speaking, however, we consider only the resistance for the floats when entirely out of the water. When partly immersed the resistances are slightly higher.

Now, by suitably graduating the scales of the ordinates, we can plot on the diagram of lift the L_{xan} curves corresponding to the velocity V_n of the submerged part. It is clear that these curves must pass through the points A_n. Having, however, neglected the air resistance, which, at the points A_n, is the unit resistance $r_n = A_n D_n$, at the origin we shall have a known absolute value O D and we must take as basis of the abscissas of the

L_{xan} curves, not the straight line O i, but the curve D D_n. Thus the curves G_n D_n are plotted.

The scale of the L_x curves being defined, we can plot this L_x curve for all parts of the seaplane except the floats and we shall have a curve intersecting the A_n V_n curves at the points E_n. At the different velocities V_n, these points divide the L_x curve into two zones, that of resistance due solely to the air, and that of resistance due to air and water. The latter is to the left of E_n, the floats being more or less in the water. The total resistances in this zone are obtained by plotting from L_x segments LK_n equal to FG_n, the points G_n being defined by the intersection of the ordinate FL with the G_n D_n curves. This gives the curve N_n K_n L_t of the unit resistance of the seaplane at the take-off and in flight at a velocity V_n.

Multiplying FK_n by $V_n{}^3$ we get a sheaf of curves P_n M_n. These give the power required for the take-off and for subsequent flight at velocities V_n. These curves, being a family, will be distributed according to a given law and will have a series of minima M_n which, united, give a certain curve, the importance of which will be explained.

A certain velocity V_n being obtained for the take-off, the seaplane requires a specific power of the P_n M_n curve: it rises from the water with the power P_n, while the incidence varies according to the values of i.

If we assume that the velocity varies from V_n to V_{n-1}, we shall have to pass from the P_n M_n curve to the P_{n-1} M_{n-1} and the take-off will be obtained at the power P_{n-1}. The passage from a $P_n M_n$ curve is arbitrary; we may therefore follow the M_n curve which is the curve of minimum power. Consequently this curve will indicate lift when the power is minimum, that is, at the point M, the point of intersection of the M_n curve with the curve of points P_n, actual lift occurring at velocity V_n. The point M will correspond to a velocity of lift V_m which will be called the minimum velocity of lift, since it is obtained with the minimum expenditure of power.

The M_n curve of minimum power required for lift determines, relative to the various forward speeds V_n:

a) The incidences I_n necessary for the airfoil;

b) The values of the resistances $R_n I_n$ of the substructure;

c) The values of the resistances $S_n R_n$ of the superstructure.

When the suitable incidence I of the airfoil is known, the relative incidence of the floats can be determined.

For the take-off to be possible, the $P_n M_n$ curves must indicate a lower value than the power actually available, taking into account the efficiency of the engine group. If this is not the case, the relation between the airfoil and the floats must be altered and therefore in the same L_{xa} groups we shall have to determine, as before, other values of L_{xan} to be substituted for those in the fourth line added to the table. When the possibility of take-off has been obtained, the most suitable angle or angles I_n have also been determined.

In view of the formation of the $N_n K_n S_n L_t$ curves, the minima S_n, which are determined from the curves $G_n D_n$, fall on a curve (practically a straight line) as shown on the figure; that is, they are situated on a parallel to the axis of the ordinates, or, starting from S_1, tend slightly to the left. This means that as the velocity increases, we have minimum resistance with angles which are constant or nearly so. This fact is evidently deduced also from the $P_n M_n$ curves. We may, therefore, enunciate the following general theorem: When the seaplane leaves the water following the curve of minimum power required, as the forward speed increases, the incidence of the airfoil remains constant or decreases slightly. The pilot should, therefore, provide accordingly.

This theorem is illustrated in a second cartesian diagram (Fig. 6) having as abscissas the velocities from zero to at least V_m the velocity required for the take-off. The ordinates of this diagram give the weights of the seaplane. We can now plot a curve of lift which, if the incidence I_n is constant at different velocities, will be the usual L_y curve already under consideration. But if the incidence I_n varies with the velocity V_n, the curve of lift will be the L'_y curve, derived from the usual L_y curve, and easily plotted. On this new L'_y curve we must mark the incidences I_n. The ordinate passing through the minimum velocity of lift V_m, intersects the L'_y curve at a height corresponding to the total weight W of the seaplane. The horizontal line drawn from this point of intersection indicates above L'_y the load W_a which can be supported at different velocities by the floats.

Bringing over from the first cartesian diagram the values $R_n T_n$, water resistance, and $T_n I_n$, air resistance, at velocity V_n, and multiplying by V_n^2, we shall have the points of water resistance L_{xan} and air resistance L_{xn} for the floats. These points define two curves, the first, L_{xan}, starting from the ordinate 0, and the second, L_{xn}, from the ordinate having the value $r_m V_m^2$, corresponding to the abscissa V_m, the minimum velocity take-off .

These two curves will have a certain length. To the right, the L_{xan} terminates, while the L_{xn} continues as a quadratic function of V. To the left, both continue as far as the minimum V_n of the first diagram can be determined, which, in our case is V_1 defined by the L_y curve of the wings. As to the continuation of the resistance curves to the left of min. $V_n = V_1$, we should observe that the air resistance of the flotation body, L_{xn}, may, without appreciable error, be represented by a straight line passing through the origin and reaching the first known value of L_{xn}, while for the L_{xan} curve, giving the resistance of the water for the floats, we must refer to the experimental diagrams previously mentioned. Thus, having defined the angle of incidence I_n corresponding to the minimum velocity V_1 and taking into account the fact that the I_n is constant or nearly constant, it is also assumed, for facility of maneuvering, that I_n remains constant and corresponds to I_1 relative to the minimum velocity V_1. In this case, the curve to be considered is defined for each group of experimental curves obtained in the test tank. From the second diagram we know the load for each velocity $V_a < V_1$, and we therefore know which experimental group should be chosen or how interpolated and thus we can complete the L_{xan} curve which evidently passes through the origin.

Furthermore, on the second diagram we will plot the L'_x curve of the airfoil, noting, of course, whether I_n is variable. Finally, taking the arithmetical sum of the ordinates of the three curves of resistance L_x, L_{xn}, L_{xan}, we shall have for various velocities the total values of the L_t curve during the take-off. If the whole of the L_t curve is below the T curve; representing the thrust at the propeller hub for the different velocities, the take-off is possible.

The point U, where the T and L_t curves intersect, determines the maximum velocity of the seaplane at zero altitude. The point Z, which is the maximum of L_t beyond U, determines what is called the critical velocity for the take-off. The ordinate ZV_z gives the maximum resistance for the take-off. The ordinates ΔT, gives the thrust available for increasing the velocity of the seaplane. One of these ΔT ordinates is a minimum giving the critical point Q which must be passed for the take-off to be possible. It therefore corresponds to the minimum available thrust, and if resistance increases, owing to some unforeseen cause such as high waves, T and L_t may intersect at or near this point, since, with L'_x and L_{xn} remaining constant and L_{xan} being variable, the form L_t varies a little.

Noting that ΔT is a function of the velocity V, we can write:

$$T = l(V) = \frac{d\,V}{d\,t}\,m,$$

in which m is the mass of the seaplane. This is an unknown quantity, since we do not know the displacement of water and air in the wake of the seaplane, such displacement varying with velocity. As a first approximation, however, we may take m as constant and equal to the mass proper of the seaplane multiplied by a number greater than unity, 1.2 to 1.5, for instance.

At any rate, the above relation gives:

$$t = \int m\,\frac{d\,V}{T}$$

which is the law of motion.

Translated by Paris Office,
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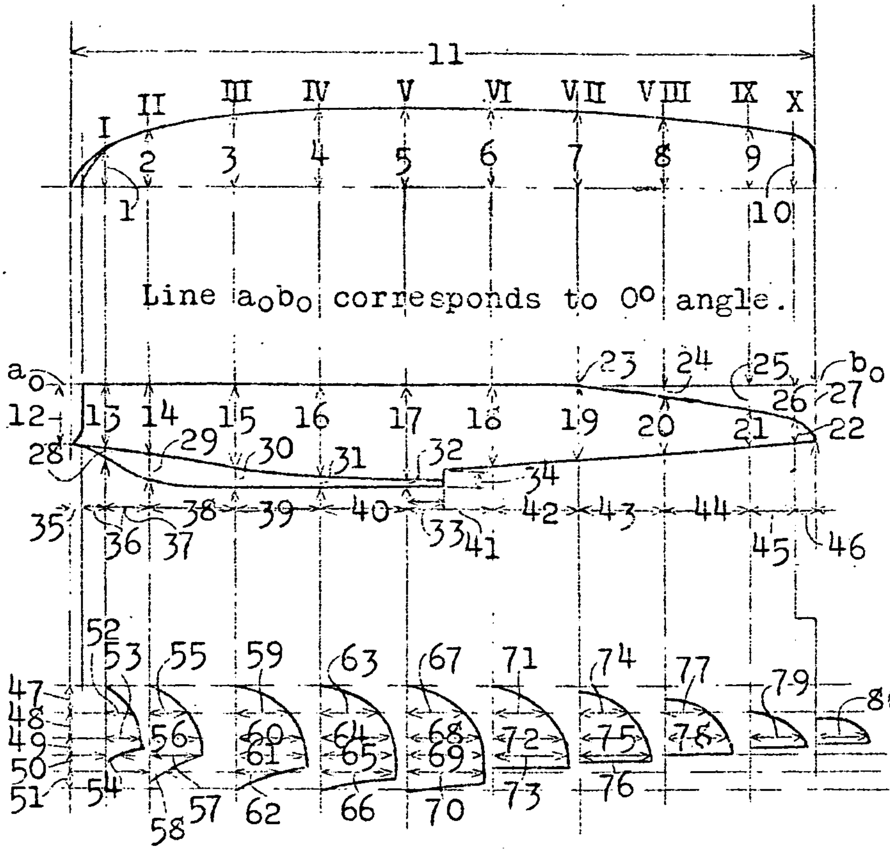
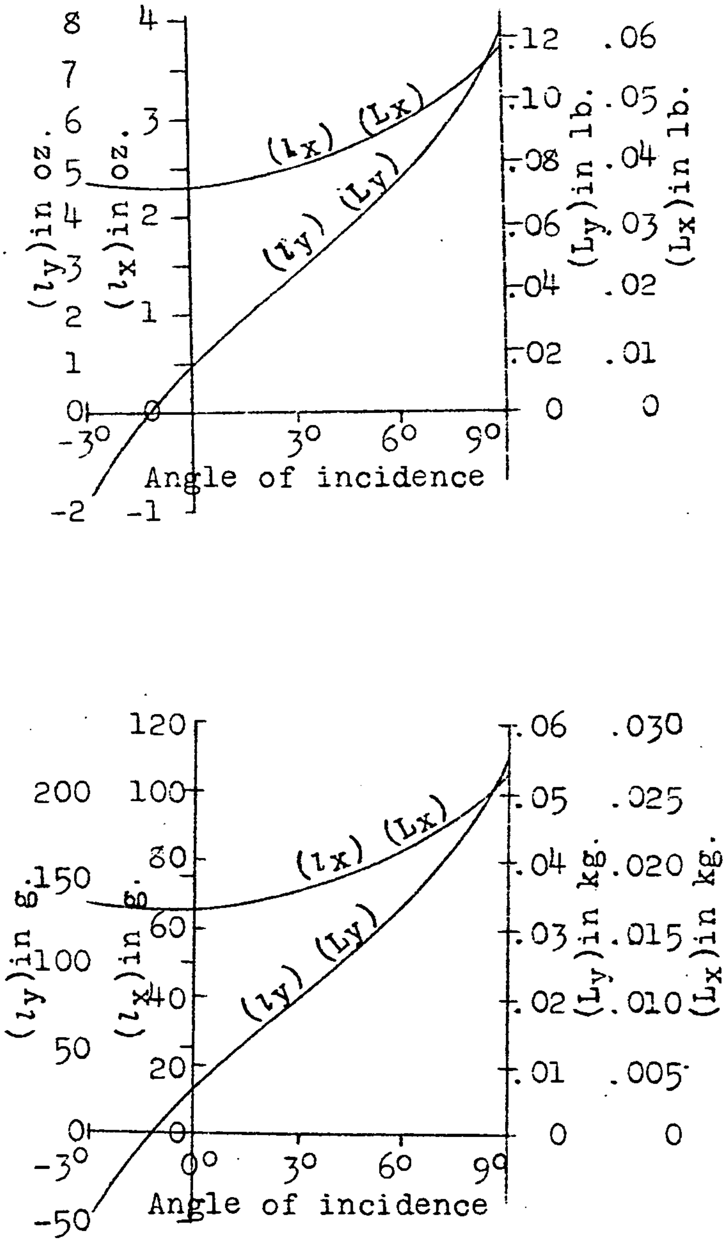


Dim.	mm	in	Dim.	mm	in	Dim.	mm	in
1	21	.83	28	5.5	.22	55	23.5	.93
2	31.5	1.24	29	16.0	.63	56	30.5	1.20
3	42.5	1.67	30	12	.47	57	31.5	1.24
4	44.5	1.75	31	6	.24	58	8.5	.33
5	46	1.81	32	4	.16	59	31.0	1.22
6	45.5	1.79	33	11	.43	60	38.5	1.52
7	44.5	1.75	34	10	.39	61	41.5	1.63
8	41	1.61	35	7	.28	62	32	1.26
9	35	1.38	36	14	.55	63	35	1.38
10	33	1.30	37	25	.98	64	42	1.65
11	426.5	16.79	38	50	1.97	65	44	1.73
12	35.5	1.40	39	50	1.97	66	44.5	1.75
13	37.6	1.48	40	50	1.97	67	34	1.34
14	40	1.57	41	50	1.97	68	43	1.69
15	48	1.89	42	50	1.97	69	44.5	1.75
16	54	2.13	43	50	1.97	70	45	1.77
17	56	2.20	44	50	1.97	71	33	1.30
18	47.5	1.87	45	25	.98	72	41.5	1.63
19	42.5	1.67	46	12.5	.49	73	44.5	1.75
20	34	1.34	47	15	.59	74	30	1.18
21	21	.83	48	15	.59	75	40	1.57
22	14	.55	49	10	.39	76	43.5	1.71
23	1.5	.06	50	10	.39	77	26.5	1.04
24	6	.24	51	10	.39	78	37.5	1.48
25	15	.59	52	17	.67	79	33	1.30
26	20	.79	53	20.5	.81	80	31.5	1.24
27	33.5	1.32	54	5	.20			

Fig.1.



Aerodynamic Drag (l_x).Model 1/20 size
" Lift (l_y).with one float.
Airspeed 40 m/sec.

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Aerodynamic Drag (L_x).Seaplane with
" Lift (L_y). one float.
Airspeed 1m/sec.

Fig.2.

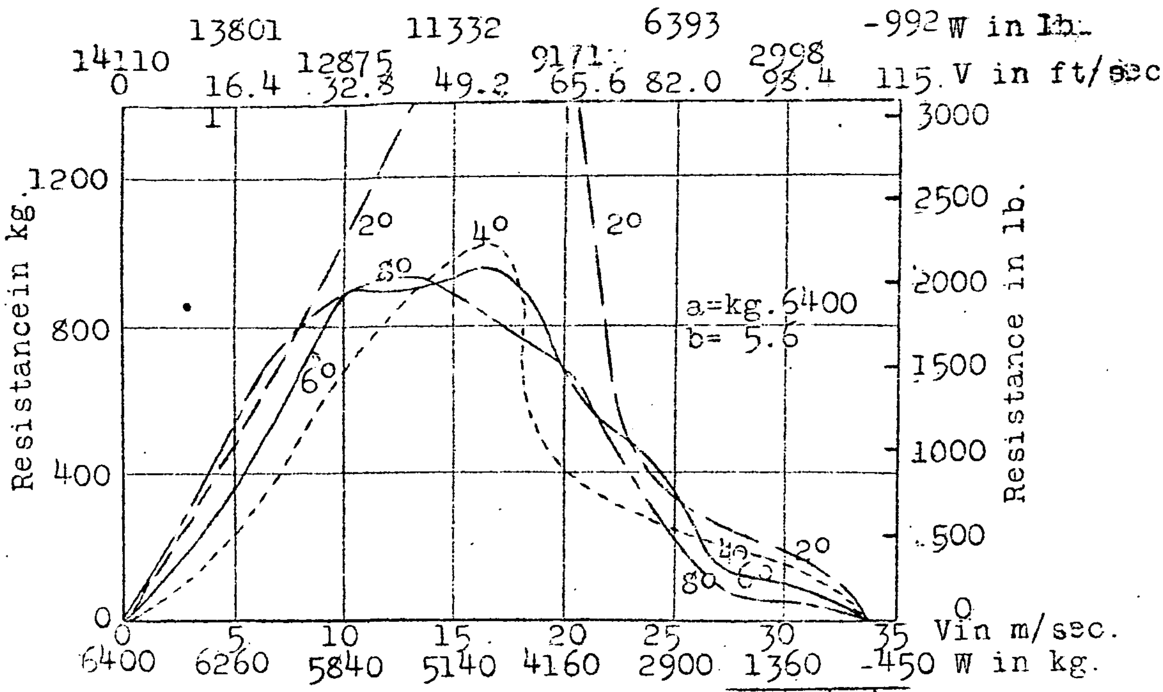


Fig. 3.

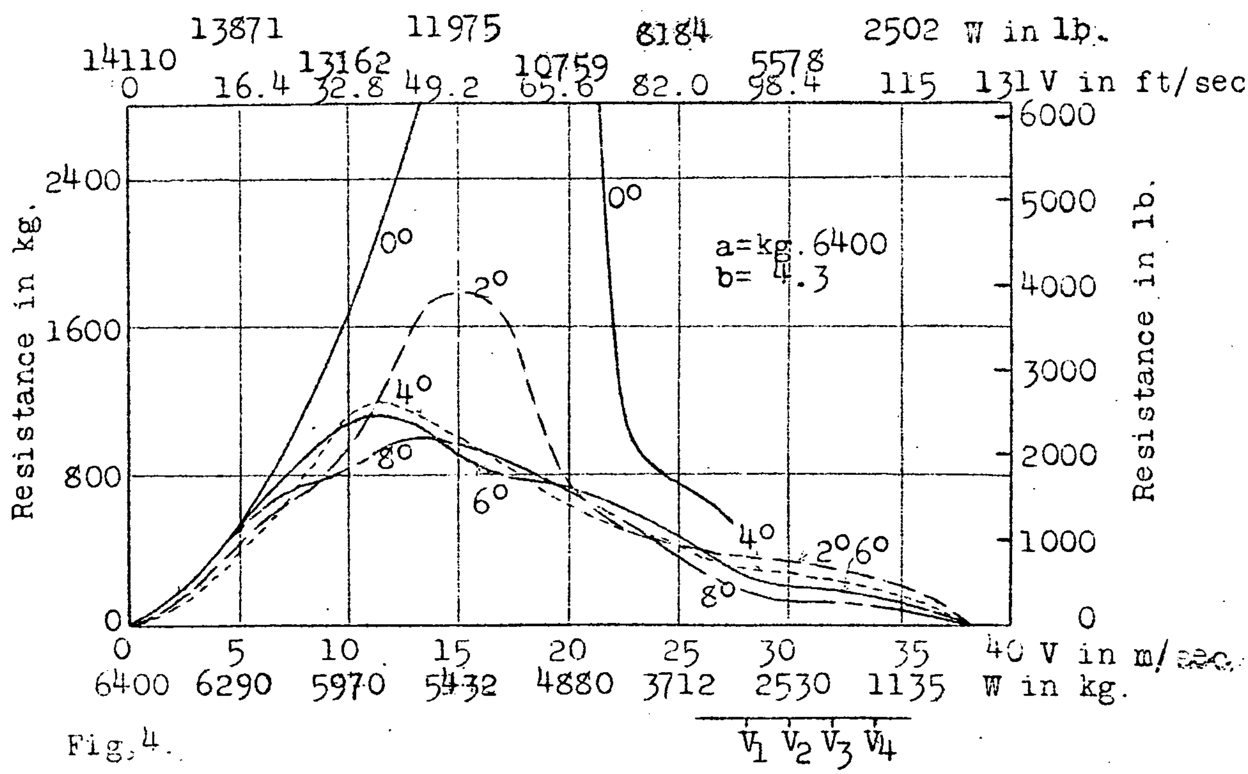
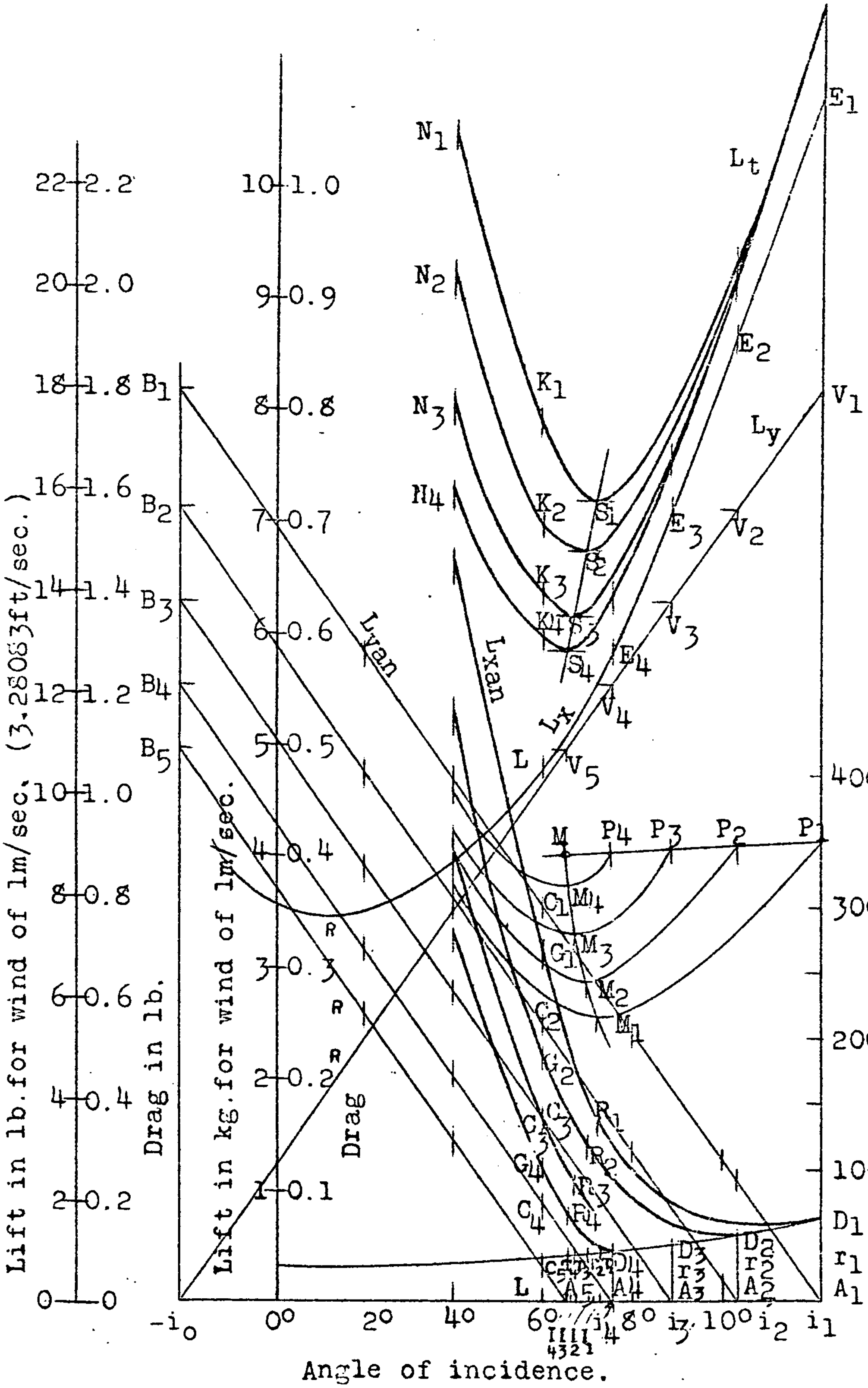


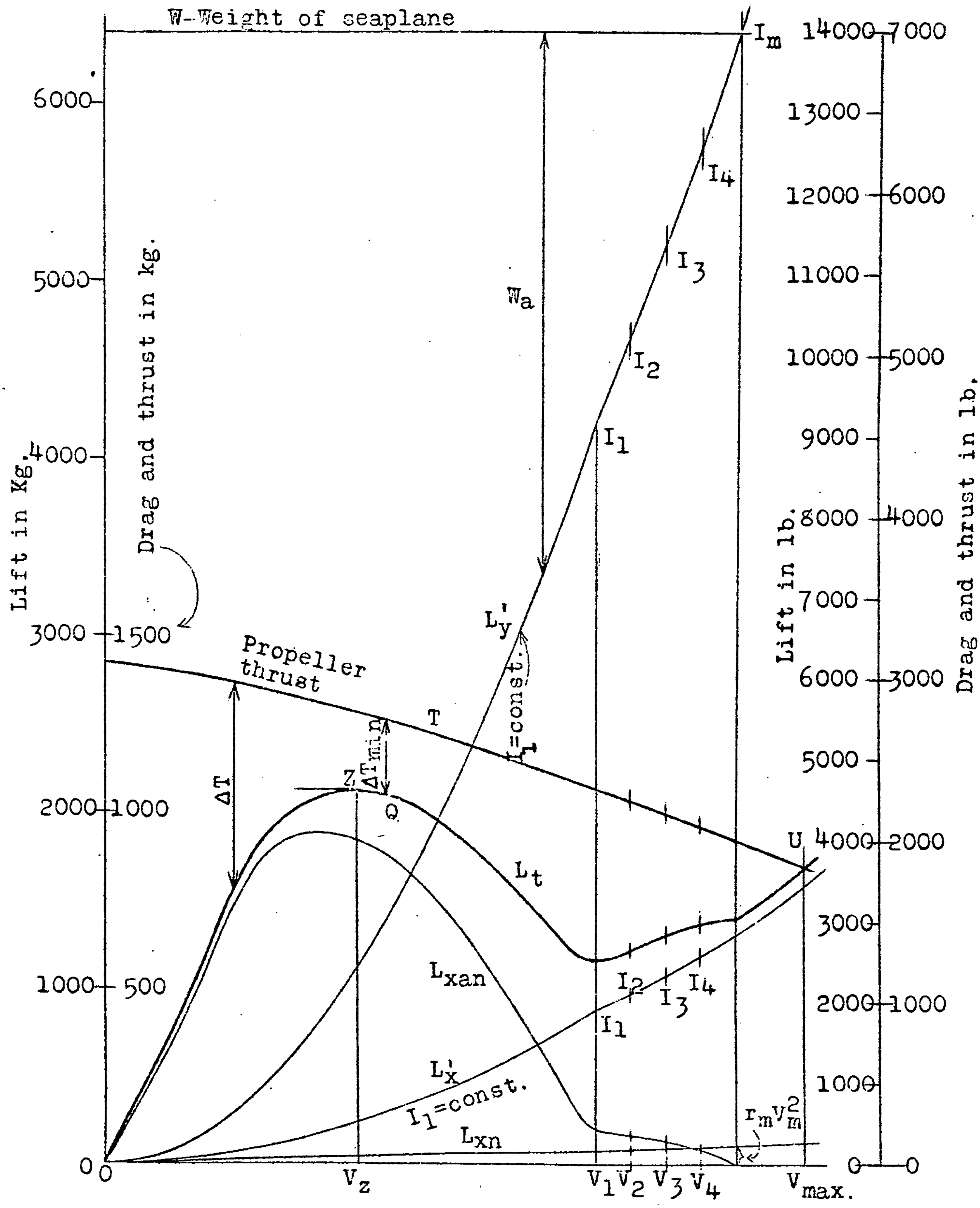
Fig. 4.

Hydrodynamic resistance in kg. of two full-size floats coupled together with an intervening space of 5m(16.4ft) at progressive speeds and for given longitudinal trims by computing the lifting effect inherent in each speed due to the characteristics of the seaplane according to the formula $W_a=a-bV^2$.



Lift in lb. for wind of 1m/sec. (3.28083ft/sec.)
Drag in lb.
Lift in kg. for wind of 1m/sec.
Drag
Horsepower
Angle of incidence.
-i0
0°
2°
4°
6°
8°
10°
i1
i2
i3
i4
Lt
Ly
Lx
Lxan
Lyan
L
400
300
200
100

Fig.5.


W-Weight of seaplane
Lift in Kg.
Drag and thrust in kg.
Lift in lb.
Drag and thrust in lb.
Propeller thrust
T
W_a
I_m
I_1
I_2
I_3
I_4
L_y'
I_1=const.
ΔT
ΔT_{min}
Z
Q
L_t
L_{xan}
L_x'
I_1=const.
L_{xn}
$r_m V_m^2$
U
0
V_z
V_1
V_2
V_3
V_4
$V_{max.}$
6000
5000
4000
3000
2000
1000
1500
1000
500
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
7000
6000
5000
4000
3000
2000
1000
0
Fig.6.