MAILED
NOV 22 1934

To: Library L.M.A.L.
543

TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 510

THE CALCULATED EFFECT OF TRAILING-EDGE FLAPS ON THE TAKE-OFF OF FLYING BOATS

By J. B. Parkinson and J. W. Bell
Langley Memorial Aeronautical Laboratory

Washington
November 1934

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE NO. 510

THE CALCULATED EFFECT OF TRAILING-EDGE FLAPS ON THE TAKE-OFF OF FLYING BOATS

By J. B. Parkinson and J. W. Bell

SUMMARY

The results of take-off calculations are given for an application of simple trailing-edge flaps to two hypothetical flying boats, one having medium wing and power loadings and consequently considerable excess of thrust over total resistance during the take-off run, the other having high wing and power loadings and a very low excess thrust.

For these seaplanes the effect of downward flap settings was: (1) to increase the total resistance below the stalling speed, (2) to decrease the get-away speed, (3) to improve the take-off performance of the seaplane having considerable excess thrust, and (4) to hinder the take-off of the seaplane having low excess thrust. It is indicated that flaps would allow a decrease in the high angles of wing setting necessary with most seaplanes, provided that the excess thrust is not too low.

INTRODUCTION

There are two ways in which a high-lift device might shorten the take-off of a seaplane; first, by decreasing the water speed at which the craft is air-borne and, second, by lowering the combined air and water resistance. A decrease in get-away speed is highly desirable provided that there is not a compensating loss in net accelerating force at other stages of the take-off. For seaplanes the latter effect requires a consideration of factors not met with in the case of land craft.

During the take-off of a seaplane, the lift-drag ratio of the wing is, under most conditions, greater than the corresponding load-resistance ratio of the hull or float. It would then be expected that the use of a high-lift device to transfer additional load from the hull to the wings would result in a reduction in the combined air and water resistance and a shorter take-off. An increase in lift coefficient is accomplished by high-lift devices, however, only with a decrease in lift-drag ratio; moreover, a reduction of the load on the water at planing speeds tends to decrease the load-resistance ratio of the hull. These characteristics of wings and hulls make it necessary to calculate the total resistance of any combination at various speeds in order to predict the effect of a given increase in lift coefficient.

The results of complete-method tests of hulls as made in the N.A.C.A. tank, together with suitable force coefficients for the aerodynamic surfaces, make possible a direct calculation for a study of high-lift devices used with the hulls for which data are available. This paper presents the results of such an investigation made for simple trailing-edge flaps in conjunction with two N.A.C.A. hull forms.

CALCULATIONS

Assumptions.- Two hypothetical flying boats were assumed having characteristics such that the effects of the flaps could be investigated for both normal and low excess thrust during the take-off. Their characteristics are:

	Seaplane A	Seaplane B
Gross load, lb.	15,000	20,000
Wing area, sq.ft.	1,000	1,000
Total horsepower	1,000	1,000
Hull, N.A.C.A. model	11-A	35
Beam of hull, ft.	8.07	7.38
Length of hull (excluding tail extension), ft.	36.1	45.4
Parasite drag coefficient (excluding hull)	0.05	0.02

Seaplane A would be similar to the "patrol bomber" type of the U. S. Navy. It has medium wing and power loadings, a conventional hull, and a low top speed. Seaplane B is designed for higher speed and has heavy wing and power loadings, low parasite drag, and a heavily loaded hull of the pointed-step type.

Data and methods.- The N.A.C.A.-M6 airfoil was assumed for both seaplanes. The characteristics of the wing were derived from tests on that airfoil made in the variable-density wind tunnel and described in reference 1. In those tests, the trailing edge was pivoted at 20 percent of the chord and the flaps thus formed extended over the entire span. The data are stated to be correct for an effective aspect ratio of 7.32 and this value, considering ground effect, is reasonable for this type of seaplane. The variations of the lift and drag coefficients of the wing with downward flap settings are shown in figure 1. With the flap down 5°, this airfoil is approximately equivalent to the normal Clark Y section and as such is used as the basis for comparison.

The water resistance of the hulls was obtained from the nondimensional data derived from towing tests in the N.A.C.A. tank and presented in references 2 and 3. The resistance coefficients in these references represent the minimum values found by plotting resistance against trim angle for each load at a succession of chosen speeds. Consequently their use in the calculations is equivalent to assuming that the hull is operating at its most favorable angle of trim throughout the take-off. Their application to a take-off calculation is described in detail in reference 4 and is illustrated by a typical calculation in the appendix to this note.

The thrust curves were calculated from the propeller data of reference 5 using blade settings that give high efficiency at cruising speeds. The time and run required to take off were determined from the net accelerating force as described in reference 4.

Conditions investigated.- The flap settings used were 5°, 10°, and 25°, the latter being the maximum for which test data are given in reference 1. Take-off calculations at these flap settings were made for the following conditions:

Case I. Using for each flap setting the wing setting that gave minimum total resistance at 85 percent of the corresponding stalling speed. Previous calculations in which plain wings were considered had shown that this wing setting generally gives minimum total resistance at lower speeds. Its derivation is illustrated in reference 4 and in the appendix to this note.

Case II. Using for all flap settings a high wing setting corresponding to that found by the preceding method for the 5° flap setting (plain wing).

Case III. Using for all flap settings a low wing setting that would give the hulls a less unfavorable "nose-down" attitude in flight. Its value was arbitrarily chosen as 4° corresponding to that found to give minimum total resistance for the 25° flap setting on seaplane A. This case was not calculated in detail for seaplane B because of the low excess thrust existing.

RESULTS AND DISCUSSION

Wing setting for minimum resistance.- The air drag, total resistance, and thrust as calculated for Case I are plotted against speed in figures 2 and 3 for seaplanes A and B, respectively. The water resistance is less with the flaps down because more of the total load is carried by the wing. The air drag, however, is increased more than the water resistance is decreased with the result that the total air-plus-water resistance is higher.

The effect of the flaps at the first hump, or critical speed, is negligible for the "dead-calm" condition assumed. Their effect at this point would probably be greater when the take-off is made into a wind such as is usually encountered in service.

A reduction in get-away speed is an important factor in shortening the take-off, particularly since the slope of the thrust curve in each case tends to decrease the net accelerating force as the speed is increased. For Case I, the ability of the flaps to bring about this reduction in get-away speed is not fully utilized because the wing settings for minimum resistance rapidly decrease with increase in flap setting. Since in these calculations the hull is assumed to remain at its best trim angle, the lift coefficient near the get-away speed shows but a small net increase. Case I is therefore of minor interest where the excess thrust is sufficient to allow deviations from the wing setting giving minimum total resistance.

The wing settings obtained and the time and run necessary to take off when they are used are given in the following table:

Flap setting, deg.	Seaplane A			Seaplane B		
	Wing setting, deg.	Take-off time, sec.	Take-off run, ft.	Wing setting, deg.	Take-off time sec.	Take-off run, ft.
5	8.7	43	2800	6.6	122	9200
10	7.7	42	2700	5.2	125	9400
25	4.0	45	3000	1.2	-	-

Hence, for seaplane A, where the reserve thrust or net accelerating force is considerable, the flaps have little effect; for seaplane B, where the reserve thrust is small, a flap deflection as high as 25° would almost entirely prevent a take-off.

<u>High wing setting</u>.- Figures 4 and 5 show the take-off curves calculated for Case II for seaplanes A and B, respectively. The wing setting used for seaplane A was 8.7° and for seaplane B was 6.6°. In this case the higher lift given by the flaps was utilized in reducing the get-away speeds. At the same time the total resistance is generally higher because the wing with flaps down is not operating at its best setting.

From these two figures it is seen that the effectiveness of the flaps is dependent upon the excess thrust available. For seaplane A this excess is great enough that the effect of the increased total resistance is not serious in view of the large reduction in get-away speed attained. For seaplane B, however, the corresponding increase caused by the 25° flap setting brings the total resistance so close to the thrust at 100 f.p.s. that a take-off would be almost impossible.

The time and run computed from the excess thrust of figures 4 and 5 are as follows:

Flap setting, deg.	Seaplane A		Seaplane B	
	Wing setting 8.7°		Wing setting 6 6°	
	Take-off time, sec.	Take-off run, ft.	Take-off time, sec.	Take-off run, ft.
5	43	2800	122	9200
10	40	2600	120	8900
25	36	2100	-	-

It is seen that where there is considerable reserve thrust the flaps are useful in shortening the take-off; that in heavily loaded machines like seaplane B they would be slightly helpful only at low flap settings.

Case II applies to most large seaplanes whose wing settings are usually comparable with those used in the calculations and whose take-offs are relatively long.

Low wing setting.- The curves of figure 6 show the effect on total resistance and reserve thrust when the wing of seaplane A is arbitrarily lowered to secure a more favorable attitude of the hull in flight. In this case, the wing was set at 4° which is the setting for minimum resistance at 85 percent of the stalling speed with the flaps down 25°.

It will be seen that the get-away speeds for the 5° and 10° flap settings are very high as a result of the lower angle of attack at which the wing must operate to keep the hull at its best trim angle. Depressing the flaps to 25° is obviously necessary for a good take-off in spite of the higher total resistance below the stalling speed.

The time and run of take-off compare in this case as follows:

Flap setting, deg.	Take-off time, sec.	Take-off run, ft.
5	90	8200
10	61	4800
25	45	3000

Case III suggests an important use for flaps which in some instances would allow a large deviation from the wing settings commonly found in seaplanes. As the minimum air drag of floats and hulls usually occurs in the wind tunnel when the forebody keel is nearly parallel to the relative wind, an increase in top speed might sometimes result from the addition of flaps in conjunction with a low angle of the wing relative to the hull.

General comments.- The get-away speeds in all the calculations presented were found by assuming the hulls to run at their best trim angles until the load is entirely air-borne. Actually, of course, the performance at speeds above the stalling speed is more or less uncertain. After this point the airplane may be flown off or pulled off sharply depending on the form of the hull, the preference of the pilot, and the excess power available. It is possible to change the time and run considerably by varying the take-off procedure. Because a theoretical analysis of a full or partial pull-up would be difficult and perhaps misleading, it is believed that the method used in these calculations is the most satisfactory one for the examples presented.

An examination of the available wind-tunnel data indicates that other familiar high-lift devices of the trailing-edge type would have similar effects on the take-off of seaplanes A and B. The large number of such devices and the scarcity of data obtained at Reynolds Numbers corresponding to the full-sized machines preclude a detailed investigation of their effects in this study.

The cases investigated show some trends and illustrate the application of complete tank data to any specific problem. Because of the large number of variables involved, however, the desirability of incorporating high-lift devices in a seaplane as an aid to take-off must be determined individually for the arrangement under consideration.

CONCLUSIONS

The information obtained from the limited number of calculations performed, while not applicable to a wide range of conditions, is of value as a starting point for the further study of a specific design. It may be summarized as follows:

1. Below the stalling speed, the flaps generally increased the total resistance. An exception is noted in the case where the plain wing (flap setting 5°) is operating considerably below its setting for minimum total resistance (fig. 6). The increase in total resistance is caused by the additional air drag produced by the flaps which more than counteracts the decrease in water resistance due to the reduction of load on the water.

2. For a given wing setting, the flaps gave a reduction in take-off time and run for the seaplane with medium power loading. The excess thrust is large enough that the reduction in get-away speed is not compensated for by the increase in total resistance below the stalling speed. For the heavily loaded seaplane where a small increase in total resistance causes a large reduction in net accelerating force, high flap settings would entirely prevent a take-off under the conditions assumed.

3. In the case of the medium-loaded seaplane, the use of flaps would allow a large reduction in the angle of wing setting to give the hull a more favorable flight angle. It is apparent that the permissible deviation from the wing setting giving minimum total resistance throughout the greater part of the take-off depends upon the amount of excess thrust available for acceleration of the machine.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., October 25, 1934.

APPENDIX

Example of Take-Off Calculation

The method of obtaining take-off performance by the use of complete tank-test data for the assumed hull is illustrated by the following detailed calculations for seaplane A with the trailing-edge flaps set at 5°.

The lift and drag coefficients of the wing are taken from the curves of figure 1. The hull is assumed to be at its optimum trim angle at each stage of the take-off, its water characteristics for this condition being taken from reference 2. The take-off is assumed to be made in a dead calm.

The nondimensional coefficients used for the water characteristics are:

Speed coefficient, $C_V = \frac{V}{\sqrt{gb}}$

Resistance coefficient, $C_R = \frac{R}{wb^3}$

Load coefficient, $C_\Delta = \frac{\Delta}{wb^3}$

where V is the forward speed, f.p.s.

g, the acceleration due to gravity, 32.2 ft./sec.^{2}

b, the beam of the hull, ft.

R, the air-plus-water resistance of the hull, lb.

Δ, the load on the water, lb.

w, the weight density of the water (64 lb. per cu.ft. for sea water)

For this example, the beam is 8.07 ft. The coefficients then become:

$$C_V = \frac{V}{\sqrt{32.2 \times 8.07}} = \frac{V}{16.1}$$

$$C_R = \frac{R}{64 \times 8.07^3} = \frac{R}{33650}$$

$$C_\Delta = \frac{\Delta}{64 \times 8.07^3} = \frac{\Delta}{33650}$$

Best Wing Setting

The angle of wing setting is chosen which gives minimum total resistance at 85 percent of the stalling speed. In this case, the stalling speed is 94.5 feet per second; 85 percent of this speed is 80.3 feet per second which corresponds to a C_V of 4.99. The calculation by which the optimum wing setting is found is shown in the following table.

α, deg.	6	8	10	12	14	16
C_L	0.710	0.860	0.990	1.125	1.250	1.345
L, lb.	5,410	6,560	7,550	8,570	9,530	10,270
Δ, lb.	9,590	8,440	7,450	6,430	5,470	4,730
C_Δ	.285	.250	.221	.191	.163	.140
C_R	.0565	.0510	.0463	.0420	.0377	.0345
R, lb.	1,900	1,720	1,560	1,415	1,270	1,160
C_D	.0846	.0965	.112	.128	.147	.168
D, lb.	650	740	855	975	1,120	1,280
R + D, lb.	2,550	2,460	2,415	2,390	2,390	2,440
τ_o, deg.	4.7	4.6	4.5	4.4	4.3	4.2
i, deg.	1.3	3.4	5.5	7.6	9.7	11.8

In this table,

α is angle of attack and is used as the independent variable.

C_L is obtained from figure 1 for a flap setting of 5°.

L, the wing lift is obtained from

$$L = C_L S_W \frac{\rho V^2}{2} = 7,630 C_L$$

$$\Delta = 15,000 - L$$

$$C_\Delta = \frac{\Delta}{33650}$$

C_R is used for the appropriate C_Δ from a cross-plot of figure 9, reference 2 at $C_V = 4.99$.

$$R = 33,650 C_R$$

$$C_D = C_{D_W} + C_{D_P},$$

where C_{D_W} is the drag coefficient of the wing obtained from figure 1 for a flap setting of 5°.

C_{D_P}, the assumed parasite drag coefficient = 0.05.

D, the air drag is obtained from

$$D = C_D S_W \frac{\rho V^2}{2} = 7,630 C_D$$

R + D is the total resistance.

τ_o is the trim angle for minimum water resistance obtained from figure 11, reference 2 at $C_V = 4.99$ and for the appriate C_Δ.

i is the angle of wing setting $= \alpha - \tau_o$.

The value of R + D was plotted against i and the minimum total resistance was found to occur at a wing setting of about 8.7°. This value is used in the following calculation.

Total Resistance

In order to obtain the variation of total resistance during the take-off, the water resistance and air drag are calculated for a number of speeds as shown in table I. The work is complicated by the fact that τ_o, the best trim angle for the hull, depends on C_Δ, the load coefficient, which in turn depends on τ_o. A preliminary calculation of C_Δ is necessary to obtain the correct τ_o as shown by the "first approximation" of the table.

In this table,

C_V is taken as the independent variable.

$V = C_V \times 16.1.$

τ_o in the first approximation is read from the mean curve in figure 11, reference 2, at the corresponding value of C_V.

$\alpha = \tau_o + i.$

C_L is obtained from figure 1 for a flap setting of 5° at the corresponding value of α.

$L = C_L S_W \frac{\rho V^2}{2} = 1.185 C_L V^2.$

$\Delta = 15{,}000 - L.$

$C_\Delta = \frac{\Delta}{33650}.$

τ_o in the second approximation is obtained from either figure 4 or figure 5, reference 2, by interpolating for C_Δ between the constant C_Δ curves at the corresponding value of C_V.

α, C_L, L, Δ, and C_Δ in the second approximation are obtained as in the first approximation.

C_R is determined from figure 10, reference 2, for C_Δ and the corresponding C_V.

$R = 33,650\ C_R$

$C_D = C_{D_W} + C_{D_P}$, where

C_{D_W} is the drag coefficient of the wing determined from figure 1 for a flap setting of 5°

C_{D_P}, the assumed parasite drag coefficient = 0.05

$D = 1.185\ C_D\ V^2$

$R + D$ is the total resistance.

Get-Away Speed

The get-away speed given in the last column of table I is determined by plotting Δ, the load on the water, against the corresponding speed for several speeds near the end of the take-off run and extrapolating for the speed at which the load on the water becomes zero.

REFERENCES

1. Higgins, George J., and Jacobs, Eastman N.: The Effect of a Flap and Ailerons on the N.A.C.A.-M6 Airfoil Section. T.R. No. 260, N.A.C.A., 1927.

2. Parkinson, John B.: A Complete Tank Test of a Model of a Flying-Boat Hull - N.A.C.A. Model No. 11-A. T.N. No. 470, N.A.C.A., 1933.

3. Shoemaker, James M., and Bell, Joe W.: Complete Tank Tests of Two Flying-Boat Hulls with Pointed Steps - N.A.C.A. Models 22-A and 35. T.N. No. 504, N.A.C.A., 1934.

4. Shoemaker, James M., and Parkinson, John B.: A Complete Tank Test of a Model of a Flying-Boat Hull - N.A.C.A. Model No. 11. T.N. No. 464, N.A.C.A., 1933.

5. Hartman, Edwin P.: Working Charts for the Determination of Propeller Thrust at Various Air Speeds. T.R. No. 481, N.A.C.A., 1934.

TABLE I. Resistance Calculation for Seaplane A, Flaps Set at 5°

C_V	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.5	4.0	4.5	5.0	5.5	6.0	Get-away
V, f.p.s.	19.3	22.5	25.8	28.9	32.2	35.4	38.6	41.9	45.1	48.3	56.4	64.4	72.5	80.5	88.5	96.6	106
[1]τ_o, deg.	4.8	5.7	6.6	7.0	7.1	7.1	7.0	6.9	6.7	6.4	5.5	4.9	4.6	4.4	4.3	4.2	
[1]α, deg.	13.5	14.4	15.3	15.7	15.8	15.8	15.7	15.6	15.4	15.1	14.2	13.6	13.3	13.1	13.0	12.9	
[1]C_L	1.220	1.270	1.315	1.335	1.340	1.340	1.335	1.330	1.320	1.305	1.260	1.230	1.205	1.195	1.190	1.180	
[1]L, lb.	540	760	1040	1320	1650	1990	2360	2770	3180	3600	4740	6050	7500	9200	11070	13040	
[1]Δ, lb.	14460	14240	13960	13680	13350	13010	12640	12230	11820	11400	10260	8950	7500	5800	3930	1960	
[1]C_Δ	.430	.423	.415	.406	.397	.386	.376	.363	.351	.339	.305	.266	.223	.172	.117	.058	
τ_o, deg.	5.0	6.1	6.9	7.4	7.6	7.5	7.3	7.0	6.7	6.4	5.3	4.8	4.5	4.3	4.1	3.8	
α, deg.	13.7	14.8	15.6	16.1	16.3	16.2	16.0	15.7	15.4	15.1	14.0	13.5	13.2	13.0	12.8	12.5	12.0
C_L	1.230	1.290	1.330	1.350	1.360	1.355	1.345	1.335	1.320	1.305	1.250	1.220	1.200	1.190	1.175	1.115	1.126
L, lb.	545	775	1050	1340	1670	2015	2380	2780	3180	3600	4700	6000	7460	9160	10920	12770	15000
Δ, lb.	14455	14225	13950	13660	13330	12985	12620	12220	11820	11400	10300	9000	7540	5840	4080	2230	0
C_Δ	.429	.423	.415	.405	.396	.386	.375	.363	.351	.339	.306	.267	.224	.173	.121	.066	0
C_R	.0490	.0544	.0575	.0616	.0672	.0700	.0690	.0655	.0610	.0573	.0513	.0465	.0435	.0394	.0360	.0300	0
R, lb.	1650	1830	1940	2075	2260	2355	2320	2200	2050	1930	1730	1565	1460	1325	1210	1010	0
C_D	.1440	.1550	.1635	.1690	.1715	.1700	.1680	.1645	.1610	.1580	.1465	.1420	.1390	.1375	.1355	.1330	.1285
D, lb.	65	95	130	165	210	250	300	340	390	435	550	695	865	1060	1260	1470	1710
R+D, lb.	1715	1925	2070	2240	2470	2605	2620	2540	2440	2365	2280	2260	2325	2385	2470	2480	1710

[1] First approximation.

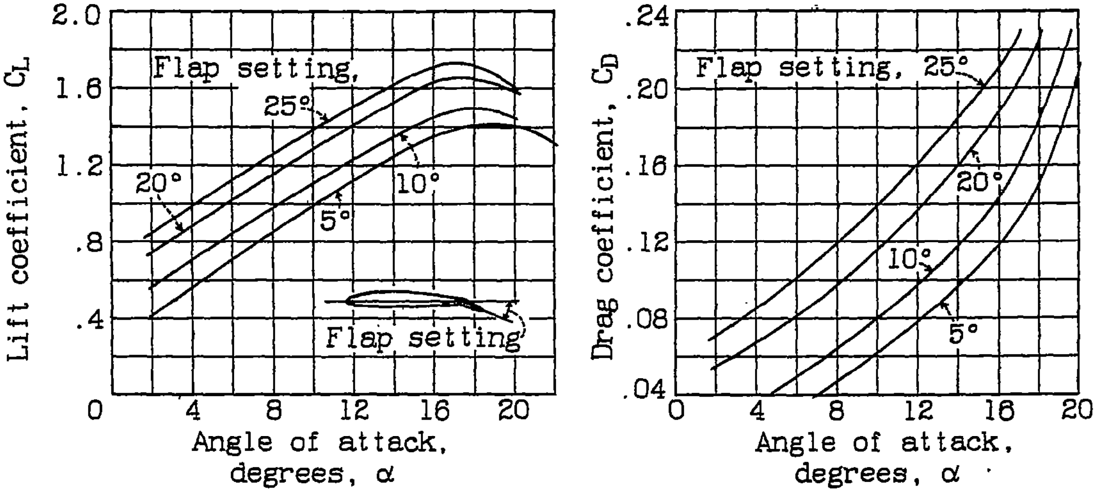

Figure 1.- Lift and drag coefficients for the N.A.C.A.-M6 airfoil section with 20 percent chord flaps.

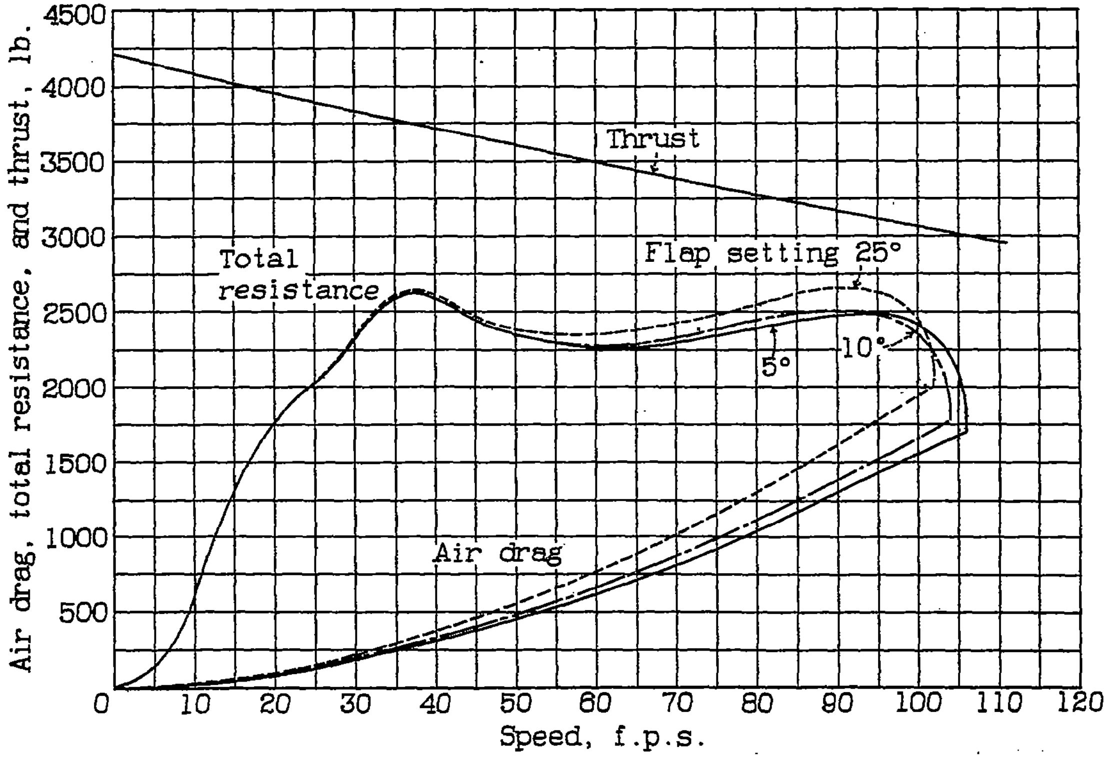

Figure 2.- Effect of flaps on the take-off resistance of seaplane A, using, for each flap setting, the wing setting giving minimum total resistance.

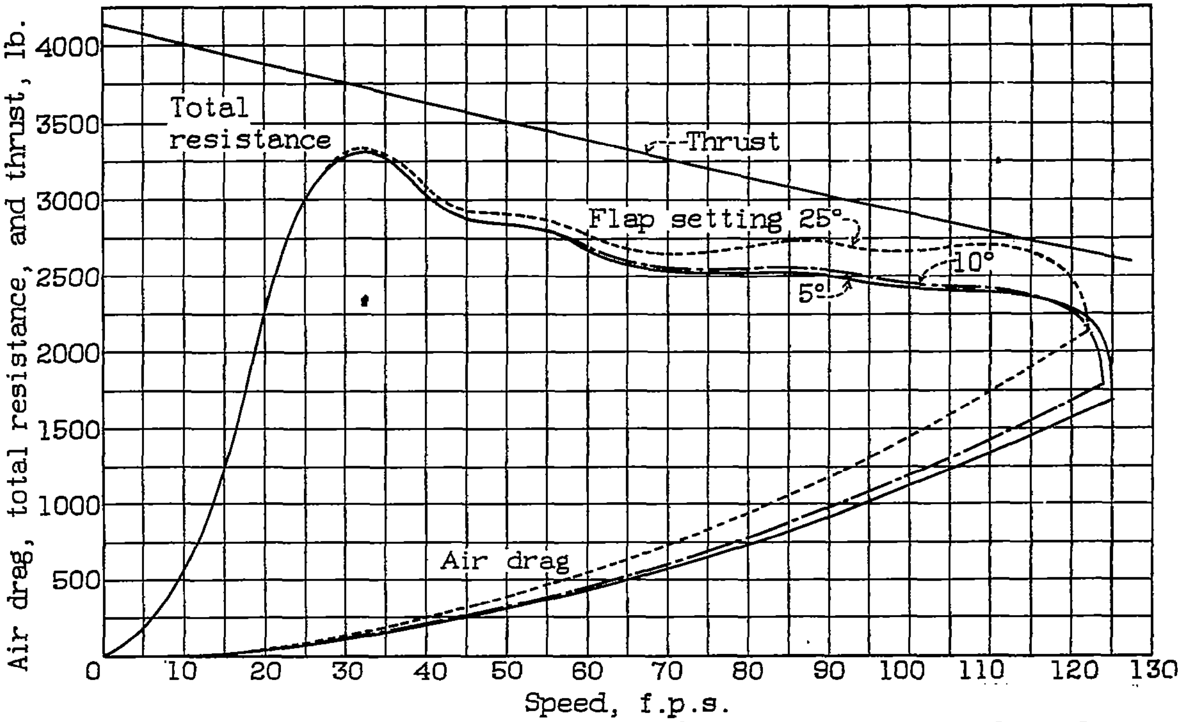

Figure 3.- Effect of flaps on the take-off resistance of seaplane B, using, for each flap setting, the wing setting giving minimum total resistance.

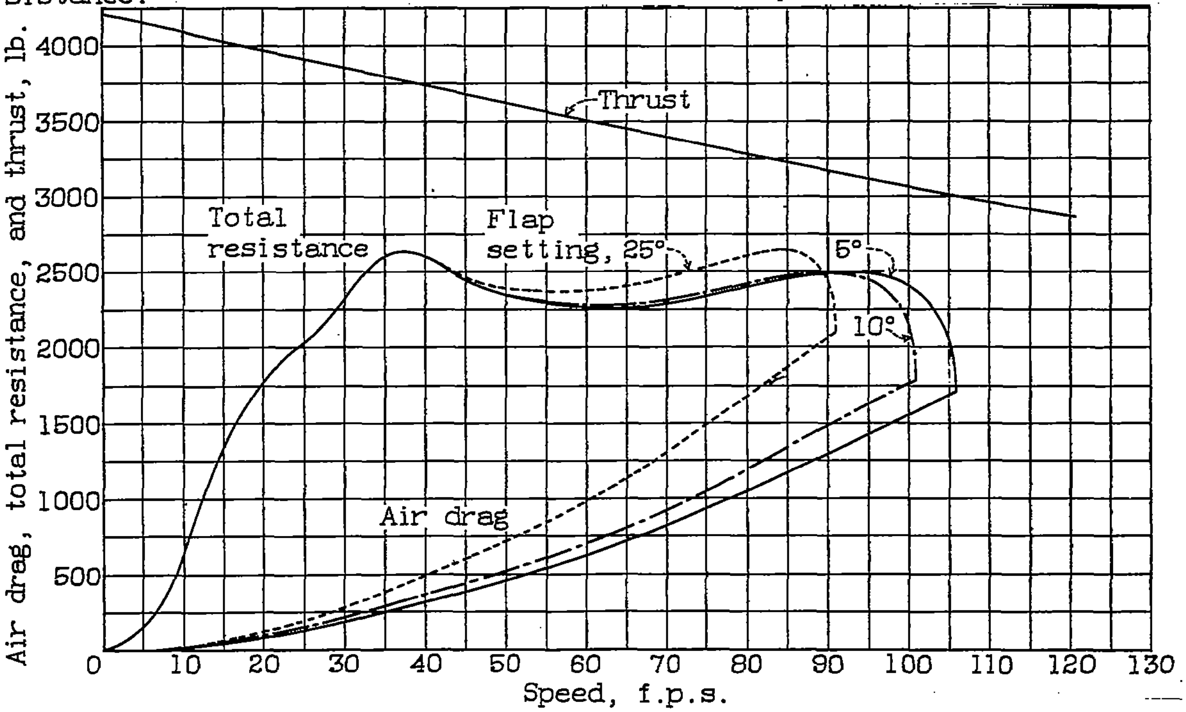

Figure 4.-Effect of flaps on the take-off resistance of seaplane A using a wing setting of 8.7°.

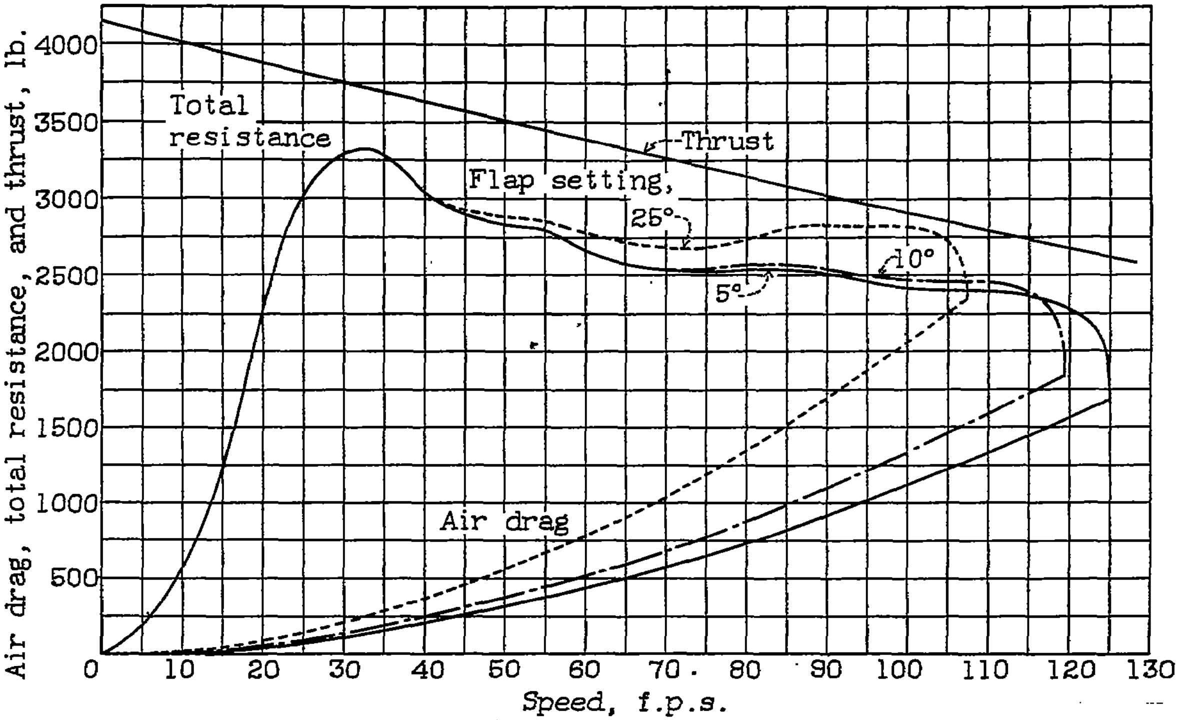

Figure 5.-Effect of flaps on the take-off resistance of seaplane B using a wing setting of 6.6°.

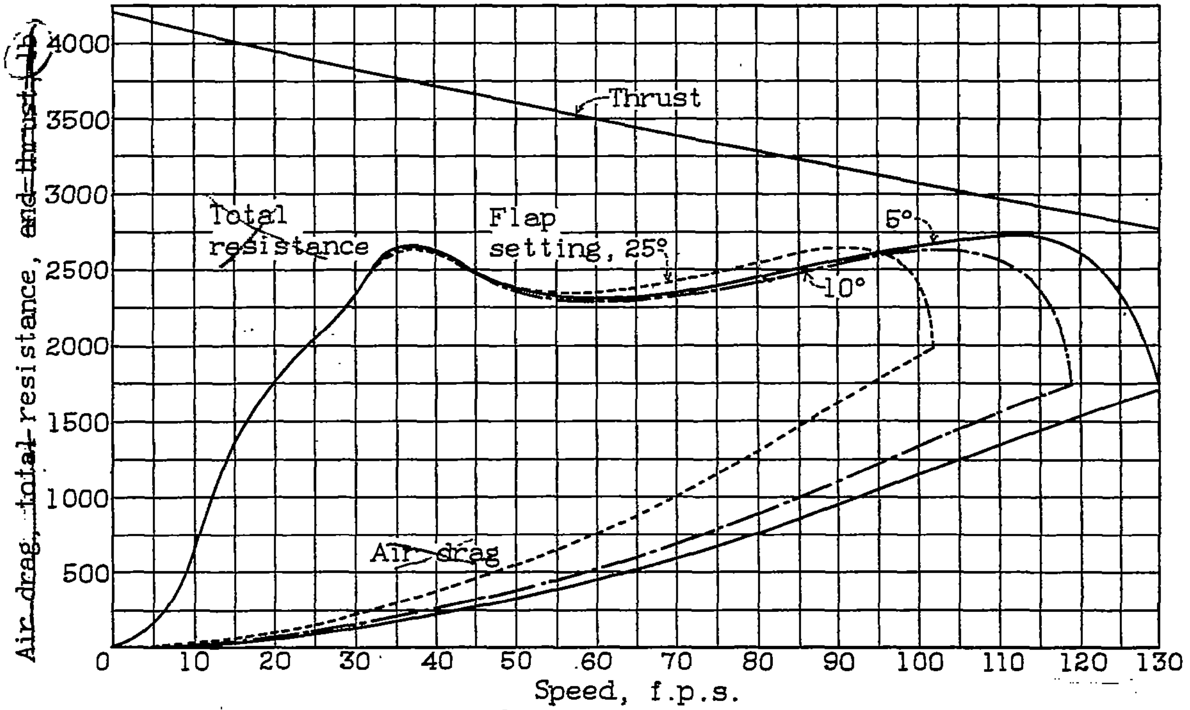

Figure 6.-Effect of flaps on ~~the~~ take-off ~~resistance of seaplane~~ A using ~~a wing setting of 4°~~.