TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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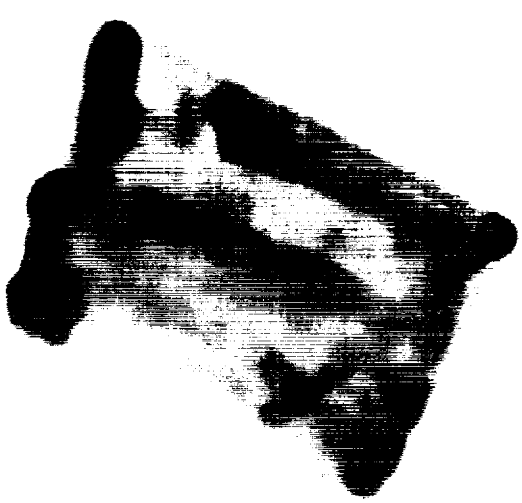

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SUMMARY

Data obtained at the N.A.C.A. tank from tests on the models of three flying-boat hulls - N.A.C.A. Models 11-A, 16, and 22 - are used to demonstrate the effect of trim angle on water resistance. A specific example is taken, and data from Model 11-A are used to show that the trim angle giving minimum water resistance will give minimum total air-plus-water resistance. Total-resistance curves for best trim angles and other angles are compared for the same example.

The effect of wind on best trim angles and upon the take-off time and run is shown by the working of an example.

The possibility of using tank data on trim angles as an aid in piloting is discussed, and an instrument for use in determining the trim angle of seaplanes under way is described. The importance of maintaining the best trim angle throughout the take-off run is indicated.

INTRODUCTION

Although the necessity of running a seaplane near the best trim angles during a take-off is generally recognized, accurate quantitative data on the effect of deviations from the best angle have not been heretofore available. The conventional hydrovane type of model test does not offer a satisfactory basis for such a study. In this type of test it is assumed that the wings remain at a constant lift coefficient regardless of the trim angle, thus involving an error in one of the fundamental variables, the load on the water. Full-scale experiments to determine the effect of trim angle upon take-off performance would require the development of suitable instruments. The procedure in such a test would be to measure the acceleration for several trim angles at a series of speeds in the take-off range. An accelerometer more sensitive than any available at present, or an accurate record of the variation of speed with time, as well as a trim-angle indicator free from the influence of longitudinal accelerations would be required.

Another method of studying the subject is furnished by the data from a complete towing test such as described in reference 1. This type of test gives the performance of the hull at all the speeds, loads, and angles within the working range; hence the effect of changes in any of the variables may be investigated. The purpose of the present paper is to apply the data obtained in such tests to a study of the effect of trim angle on seaplane take-off performance.

THE EFFECT OF TRIM ANGLE ON WATER RESISTANCE

When the water resistance of a model is plotted against trim angle for a series of loads and speeds, the resulting families of curves have the form of those in figure 1. The data used in constructing these curves were taken from references 2, 3, and 4, which give the characteristics of N.A.C.A. Models 11-A, 16, and 22, respectively. Although these three models represent a considerable disparity of form, all the curves of resistance against trim angle show the same general trend. Deviations of more than about 1° from the best trim angle result in an appreciable increase in water resistance over the minimum value.

The straight line drawn through the curves of figure 1 represents the best trim angles at the various loads, as used to cross-fair the angle against load in the construction of the curves of best angle. The line does not pass through the exact minimum of the resistance curve in each case; however, it was found that any attempt to obtain a more accurate value of the best angle caused trouble in the subsequent cross-fairing, and that better results were obtained by drawing a straight line as shown, considering the entire family of loads for a given speed.

EFFECT OF WING SETTING ON TOTAL RESISTANCE

The curves of figure 1 establish the fact that there is a definite trim angle giving the least water resistance for each speed and load. The load on the water, however, depends upon the wing lift, which in turn depends upon the angle of attack. The total resistance of an actual seaplane is made up of the water resistance and the air drag, both of which thus depend upon the angle of wing setting. The method of determining the wing setting, outlined in reference 1, consists of making this total resistance a minimum at 85 percent of the stalling speed. It was assumed that the best wing setting at this speed would give reasonably good results at other speeds. The validity of this assumption for a specific example is shown by the curves of figure 2. The calculations required to determine the variation of total resistance with the angle of wing setting are shown in detail by an example in the appendix to this note. The curves show the total resistance plotted against angle of wing setting for a series of speeds between the hump and get-away, including the one at 85 percent of the stalling speed used to determine the wing setting in the example of reference 2. It is apparent that the wing setting of 6.7° chosen as best at $0.85V_S$, gives substantially minimum resistance at the other speeds up to 95 percent of the stalling speed. At the stalling speed, however, the resistance continues to decrease with increasing angle of wing setting, indicating that the resistance is least when all of the load is air-borne.

EFFECT OF DEVIATION FROM BEST TRIM ANGLE

From the considerations of the preceding paragraph it may be shown that, for this example at least, any departure from the trim angle giving minimum water resistance must cause a corresponding increase in the total resistance. This conclusion follows from the fact that the best angle of wing setting is substantially constant throughout the take-off run, hence no compensating effect is to be expected from the action of the wing lift when the seaplane is run at other than the best trim angle.

The effect of deviations of $1\text{-}1/2^{\circ}$ and 3° above and below the best trim angle is shown quantitatively in figure 3 for the example of reference 2. The calculations involved may be followed from the example in the appendix. It is apparent from these curves that the trim should be held within about 1° of the best angle in the two critical regions to avoid serious loss of net accelerating force.

The increase of resistance in the high-speed range caused by a decrease in the trim from the best angle is considerably greater than that caused by an increase of the same magnitude. In this region the trim angle should probably not be allowed to fall more than 1/2° below the best angle. The reason for this increase in resistance is evident from the shape of the curves of figure 1 for Model 11-A at values of $C_V = 4.5$ and 6.0. The curves of resistance rise very rapidly from the minimum with decreasing angle. The time and distance of take-off for these deviations from best angle can be obtained in the usual manner; however, it is believed that the curves of total resistance show the necessity of holding the best trim angle as clearly as it would be shown by the time and run.

The effect of pulling the seaplane up to high angles near get-away may also be seen from figure 3a. This procedure obviously decreases the get-away speed, and hence tends to decrease the length of the take-off. If the pull-up is started before the stalling speed is reached, however, the increase in total resistance at speeds near stalling may more than offset the advantage obtained. Exact analysis of a pull-up does not seem to be feasible because of the uncertainties involved in estimating the aerodynamic characteristics of the seaplane running on the water. It may be concluded from the present example, however, that the seaplane should be run at the best trim angle until the stalling speed is reached, and should then be taken off as quickly as possible by applying a positive moment with the elevators.

THE EFFECT OF WIND ON THE BEST TRIM ANGLE

In actual practice a take-off is seldom made in a dead calm; consequently the curve of best trim angle for a take-off made into a head wind has more significance than one obtained from a calculation assuming no wind. The procedure involved in determining the take-off characteristics with a wind is discussed in the appendix of this note. A head wind of 25 feet per second is assumed in this calculation. The curves of total resistance with and without wind are shown in figure 4, together with the thrust curves for the two cases. The values of 1/a and V/a (where a is the acceleration and V, the speed) are plotted against speed in figures 5 and 6. The take-off time and run obtained from the areas under these curves (see reference 1) are:

	Time sec.	Distance ft.
Without wind	39.6	2,570
With 25 f.p.s. head wind	26.3	1,130

It has already been demonstrated that, without wind, the trim angle giving the least water resistance also gives the least total resistance for a seaplane design in which the wing setting has been properly chosen. The present example has been checked to find whether this characteristic still holds true with wind. The calculations are similar to those made to determine the effect of deviations from the best angle without wind, hence are not included in the appendix. They show that, within the accuracy of the test data, the angle giving least water resistance gives the least total resistance for the example with a 25-foot-per-second wind. A further check was made by determining the best angle of wing setting with wind. It was found to be almost exactly the same as the best wing setting without wind.

Figure 7 gives the variation of the best trim angle with speed, with and without a head wind. The curves show that, for this example, the effect of a 25-foot-per-second head wind is to decrease the best trim angle for a given water speed by about 1° at the hump and about 1/2° near get-away. The change in best trim angle is thus of the same order as the tolerance within which the trim angle should be held. The reduction in the length of take-off caused by the effect of wind also increases the amount of deviation from the best angle that may be tolerated; hence if the pilot holds the best trim angles for a given water speed recommended for a take-off in a calm, the resulting take-off performance with winds up to 25 feet per second (about 15 knots) will be reasonably close to the best obtainable.

NOTES ON PILOTING

An experienced seaplane pilot can probably obtain good take-off performance with a given machine by determining the trim angle from the "feel" of the acceleration. Several considerations lead to the belief, however, that the best take-off performance obtainable by this method is considerably inferior to that resulting when the best trim angles calculated from test data are held throughout the run. First, the acceleration on which the pilot has to base his estimate of the most desirable trim angle is usually small. In the example of this note, the accelerating force in the critical regions is of the order of 1,000 pounds for a 15,000-pound seaplane. The resulting acceleration is thus only about one fifteenth that of gravity, and changes in so small an acceleration are difficult to detect. Second, changing the trim angle shifts the pilot's weight in his seat, increasing further the difficulty of interpreting what he feels in terms of acceleration of the seaplane. Moreover, as the best trim angle is variable throughout the take-off run, the process of determining the correct trim at each speed would be rather laborious as well as open to possible errors in the pilot's judgment.

Although it is admitted that practical considerations prevent the pilot from adhering strictly, in every take-off, to a trim-angle curve recommended by the designer, it is believed that such curves, which may be calculated when the designer has complete test data for the hull used, would be of considerable assistance to a pilot in becoming familiar with a new type of seaplane. Practice take-offs made with the aid of an observer who could devote his attention to the air-speed meter and trim-angle indicator, would soon give the pilot the "feel" of the seaplane when it is running at the best trim angle for each speed. The resulting take-off performance should be considerably better than that obtainable by a pilot depending only upon his unaided senses.

One difficulty in this procedure arises from the lack of a satisfactory trim-angle indicator. The usual U-tube or bubble type of inclinometer is useless because it is affected by longitudinal accelerations. A forward acceleration one fifteenth that of gravity will cause the instrument to read about 4° high. A gyroscopic instrument with a sufficiently open scale would serve, but none is available at present. A graduated scale on the bow of the seaplane which the pilot can read against the horizon seems to be about the simplest solution to the problem. If it is used, some means of locating the pilot's eye with respect to the scale will be necessary. Another instrument, also using the natural horizon, is shown in figure 8. The position of the pilot's eye does not affect the reading in this case. The instrument may be mounted on the windshield in such a position that the image of the horizon is thrown on the scale, even in a seaplane arranged so that the bow obstructs the pilot's view of the horizon at high angles.

CONCLUSIONS

The examples of this note are based upon model tests that are subject to an unknown scale effect. Although it is believed that the scale effect is small because of the large size of the models used in the N.A.C.A. tank, it is possible that some of the effects noted do not apply strictly to full-scale conditions. The design conditions assumed in these examples approximate those of a rather heavily loaded flying boat. The importance of the whole subject of best trim angles is considerably reduced when a seaplane of low power loading is being considered.

Subject to these qualifications, and to such others as may arise from peculiarities in the water performance of a given hull form, the following conclusions may be drawn from the examples presented:

1. The angle of wing setting selected to give the least total resistance at 85 percent of the stalling speed will be satisfactory throughout the take-off run.

2. The trim angles giving the minimum water resistance will also give the least total resistance at any speed during the take-off. Deviations of more than about 1° in the regions of low excess thrust and more than 2° or 3° during the remainder of the take-off, will result in a serious increase in the time and distance required.

3. When a take-off is made with a head wind of less than 15 knots, the best trim angle for a given water speed does not differ by more than about 1° from that calculated for a take-off with no wind.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., December 7, 1933.

APPENDIX

Sample Calculations

General Data

The following design data used in the examples in this note are the same as those used in references 1 and 2:

Gross load, Δ_o - - - - - - - - - - 15,000 lb.

Wing area, S_w - - - - - - - - - - - 1,000 sq.ft.

Power - - - - - - - - - - - - - - - - - 1,000 hp.

Effective aspect ratio, considering ground effect - - - - - - - - - 7.0

Parasite drag coefficient, excluding hull - - - - - - - - - - - 0.05

Airfoil - - Clark Y (data taken from N.A.C.A. T.R. No. 352, p. 26)

The water characteristics of Model 11-A given in reference 2 are used in these examples. The beam chosen for the example in that reference was 96.9 inches (8.07 feet). The constants used in the calculations are thus:

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

$$C_\Delta = \frac{\Delta}{w\ b^3} = \frac{\Delta}{64 \times 526} = \frac{\Delta}{33700}$$

$$C_R = \frac{R}{33700}$$

Where

C_V is the speed coefficient

C_Δ, the load coefficient

C_R, the resistance coefficient

V, the speed, ft. per sec.

g, the acceleration of gravity, ft. per sec.^{2}

w, density of water, lb. per cu.ft.

b, beam, ft.

The thrust curve used in the present examples differs slightly from that used in references 1 and 2 in that it was obtained from actual test data recently published in reference 5. The thrust curve used in the previous notes was calculated by Diehl's empirical method as explained in reference 1.

EFFECT OF WING SETTING

The calculation of the effect of wing setting at a given speed is shown in the following table. The speed chosen is 56.3 feet per second, corresponding to a speed coefficient, $C_V = 3.5$.

α, deg.	4	6	8	10	12	14
C_L	0.70	0.85	1.01	1.16	1.28	1.37
L, lb.	2,620	3,190	3,790	4,350	4,800	5,130
Δ, lb.	12,380	11,810	11,210	10,650	10,200	9,870
C_Δ	.368	.352	.333	.317	.304	.294
C_R	.0623	.0592	.0560	.0332	.0510	.0491
R, lb.	2,100	1,990	1,890	1,790	1,720	1,660
C_D	.084	.0975	.113	.130	.1485	.170
D, lb.	310	360	420	480	550	630
R+D, lb.	2,410	2,350	2,310	2,270	2,270	2,290
τ_o, deg.	5.7	5.6	5.5	5.4	5.4	5.3
i, deg.	-1.7	.4	2.5	4.6	6.6	8.7

In this table,

α, the angle of attack, is selected as the independent variable.

C_L is read for each value of α from figure 11 of reference 1.

L is the wing lift calculated from the relation

$$L = C_L\ S_W\ \frac{\rho\ V^2}{2} = 3{,}750\ C_L$$

Δ is the gross load less the wing lift, 15,000 - L.

$$C_\Delta = \frac{\Delta}{33700}\ .$$

C_R is read for the appropriate value of C_Δ from the curve for $C_V = 3.5$ in figure 10 of reference 2.

R, the water resistance $= C_R \times 33{,}700$.

C_D is read for the corresponding value of α from figure 11 of reference 1.

$$D = C_D\ S_W\ \frac{\rho\ V^2}{2} = 3{,}750\ C_D.$$

$R + D$ is the total resistance.

τ_o is the best trim angle for the corresponding values of C_Δ and C_V read from figure 11 of reference 2.

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

EFFECT OF DEVIATION FROM THE BEST TRIM ANGLE

The following table shows the calculation of the total air-plus-water resistance for a series of speeds, with the trim held 1-1/2° above the best angle throughout the run.

C_V	1.8	2.2	2.6	3.0	4.0	5.0	5.5	6.0
V, f.p.s.	28.9	35.3	41.7	48.1	64.2	80.2	88.3	96.3
τ_o, deg.	7.4	7.5	7.0	6.4	4.8	4.3	4.1	3.7
τ, deg.	8.9	9.0	8.5	7.9	6.3	5.8	5.6	5.2
α, deg.	15.6	15.7	15.2	14.6	13.0	12.5	12.3	11.9
C_L	1.405	1.40	1.415	1.40	1.33	1.305	1.29	1.27
L, lb.	1390	2070	2920	3830	6470	9940	11900	13950
Δ_f, lb.	13610	12930	12080	11170	8530	5060	3100	1050
Δ_m, lb.	73.2	69.5	64.9	60.0	45.9	27.2	16.7	5.6
R_m, lb.	11.35	13.1	12.35	10.5	8.4	7.0	6.25	4.6
R_f, lb.	2110	2440	2300	1950	1560	1300	1160	860
C_D	.187	.188	.1825	.1755	.159	.154	.152	.148
D, lb.	183	277	375	481	775	1170	1400	1630
R+D, lb.	2290	2720	2680	2430	2340	2470	2560	2490

In this table,

C_V, the speed coefficient, is the independent variable.

$V = C_V \times \sqrt{gb} = 16.1\ C_V$.

τ_o is the best trim angle for the speed and load in question, determined in the manner described in the example of reference 1. A curve of τ_o against speed for the present example is given in figure 7.

τ, the trim angle used $= \tau_0 + 1.5^\circ$.

α, the angle of attack $= \tau + i = \tau + 6.7$.

C_L is read for the appropriate value of α from figure 11 of reference 1.

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

Δ_f is the full-scale load = 15,000 - L.

Δ_m is the load reduced to the scale of

$$\text{model 11-A} = \Delta_f \times \left(\frac{17}{96.9}\right)^3 = \frac{\Delta f}{185.5}\ .$$

R_m is the model resistance at the appropriate values of C_V, Δ_m, and τ.

In order to get R_m the original model data given in figures 2 to 6 of reference 2 must be used. Cross curves of model resistance against angle, similar to those of figure 1 of the present note, are drawn from these data. These are again cross-faired by drawing curves of R_m against Δ_m for the appropriate value of τ for each value of C_V. R_m is then read for the corresponding value of Δ_m.

R_f is the full-scale water resistance = 185.2 R_m.

C_D is the air drag coefficient of the seaplane read from figure 11 of reference 1.

$$D = C_D\ S_W\ \frac{\rho\ V^2}{2} = 1.185\ C_D\ V^2.$$

R + D is the total resistance.

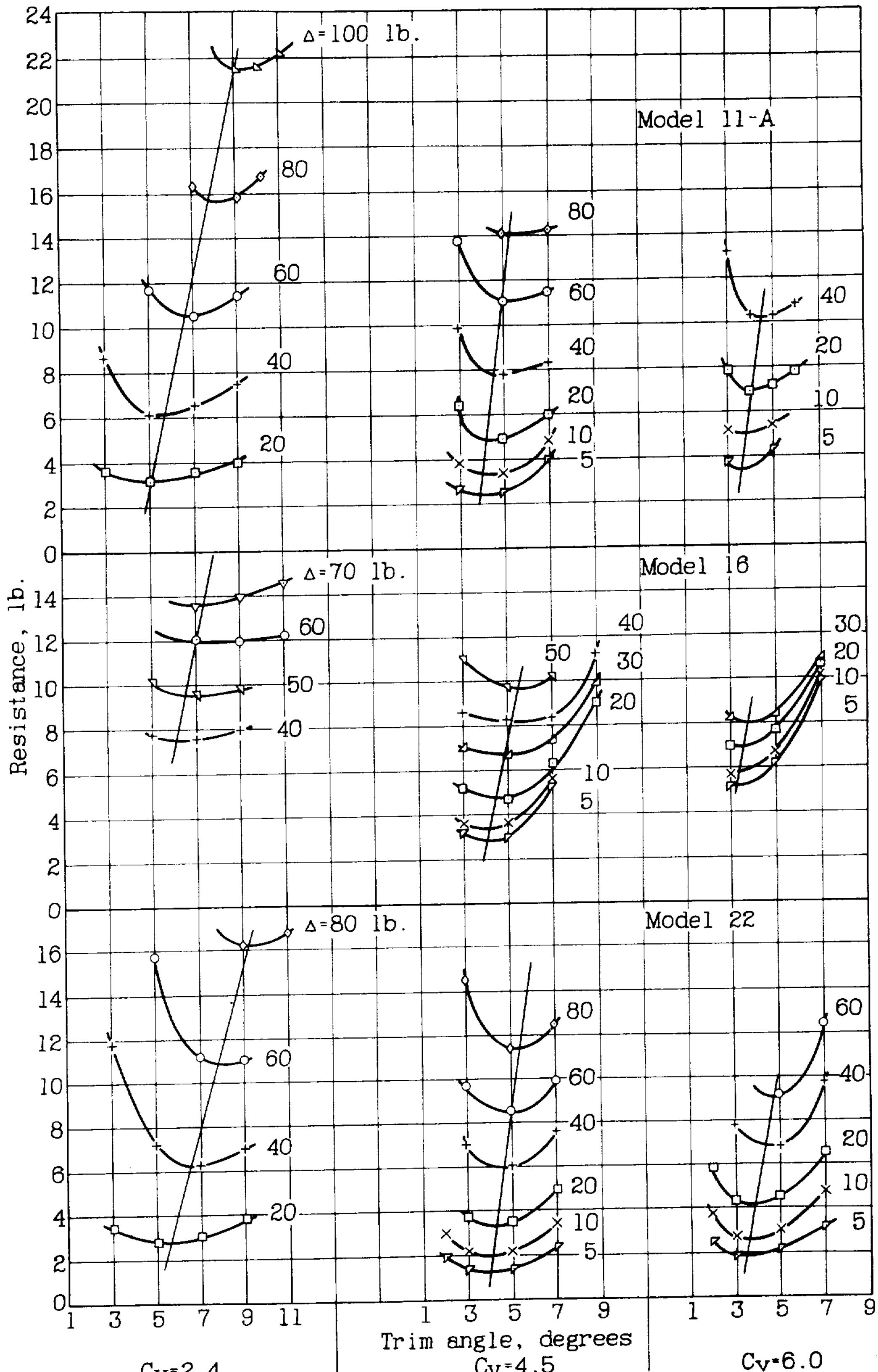


Figure 1.- Variation of model resistance with trim angle.

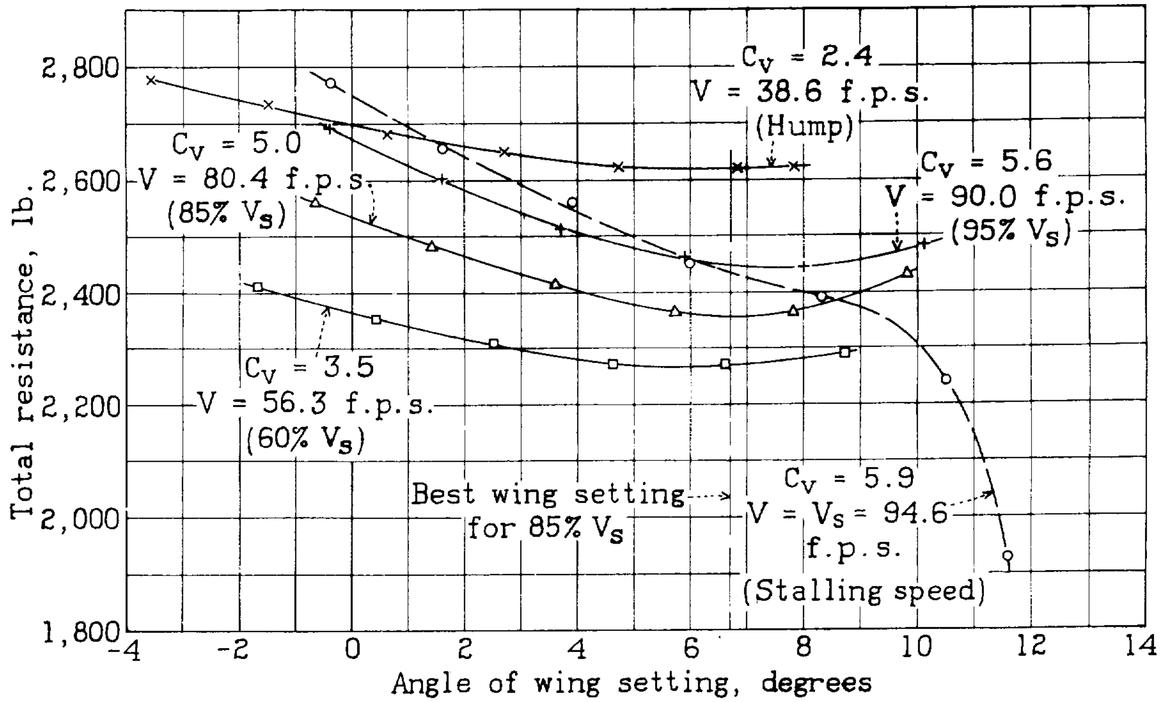


Figure 2.- Variation of total resistance with wing setting.

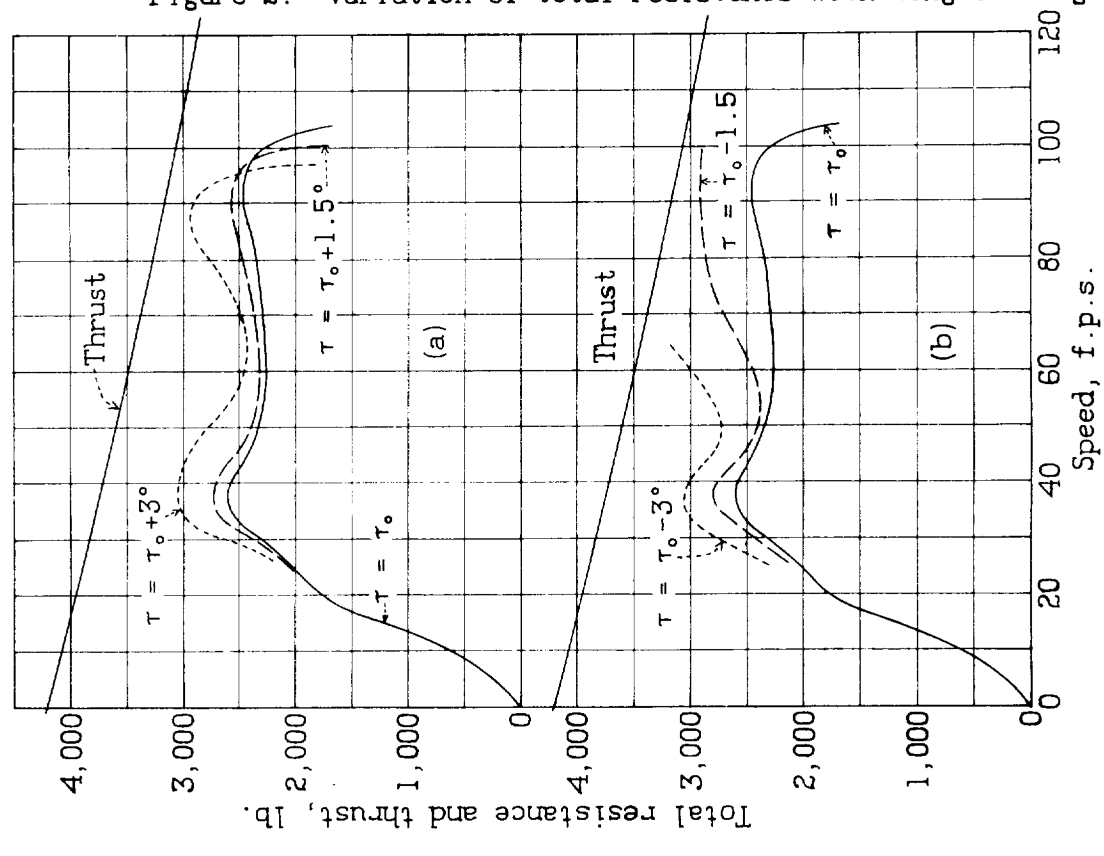
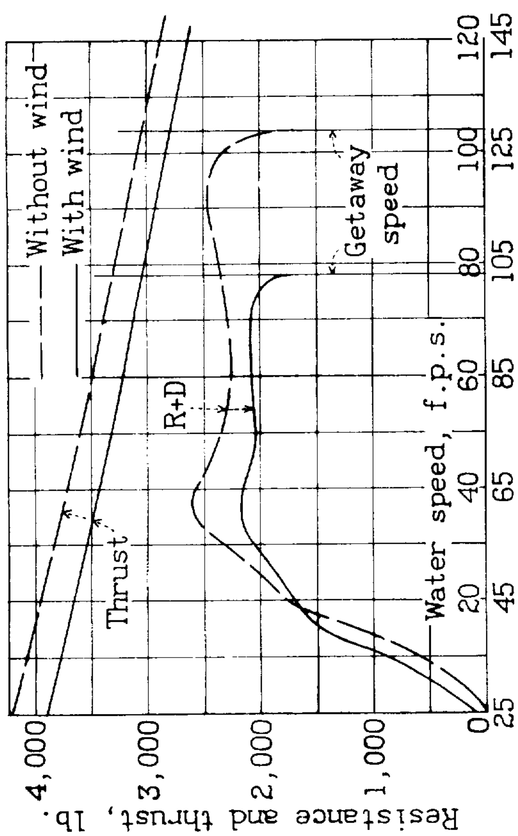


Figure 3.- Effect of deviation from best trim angle.



Air speed with 25 f.p.s. wind, f.p.s.

Figure 4.- Effect of wind on total resistance and thrust.

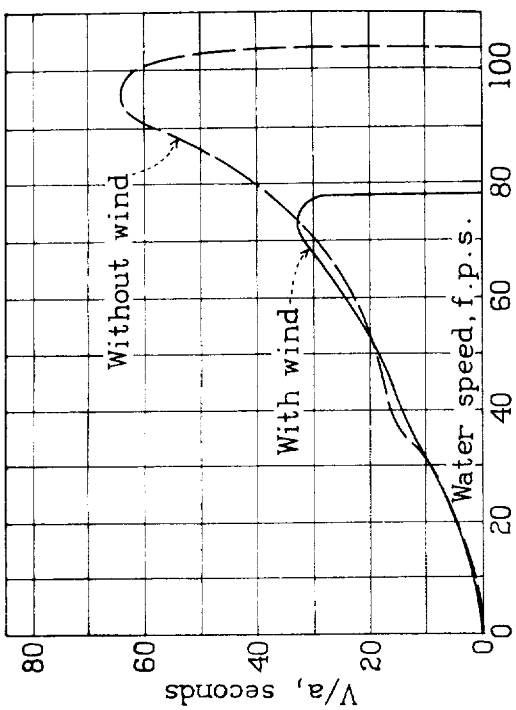


Figure 6.- Effect of wind on take-off run. Distance = $\int_o^V \frac{V}{a}\, dV$ = area under curve.

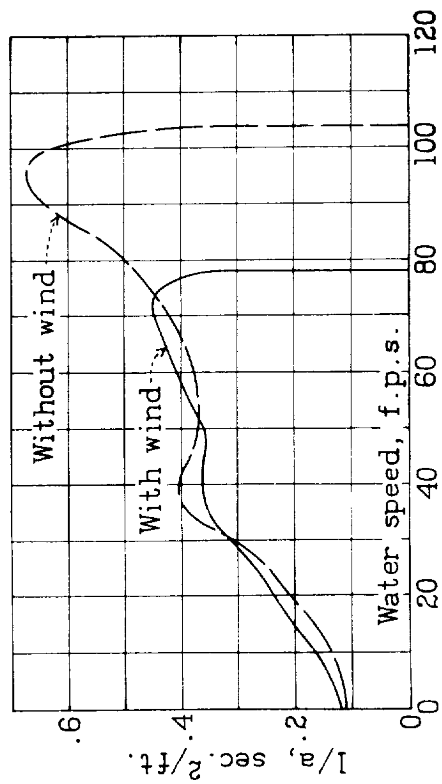


Figure 5.- Effect of wind on take-off time. Time = $\int_o^V \frac{1}{a}\, dV$ = area under curve.

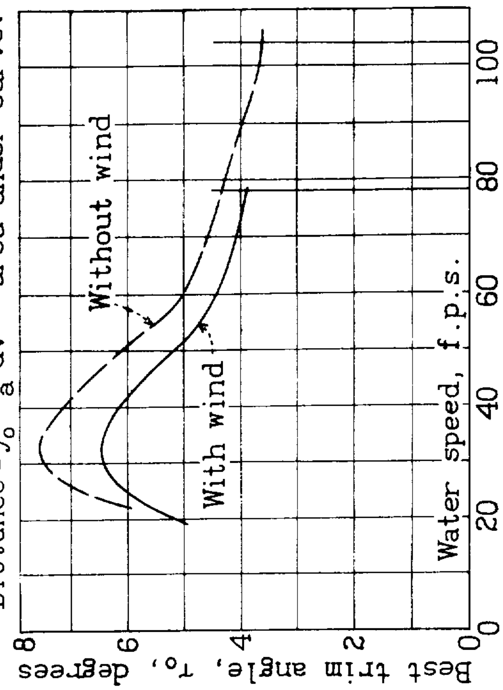


Figure 7.- Effect of wind on best trim angle.

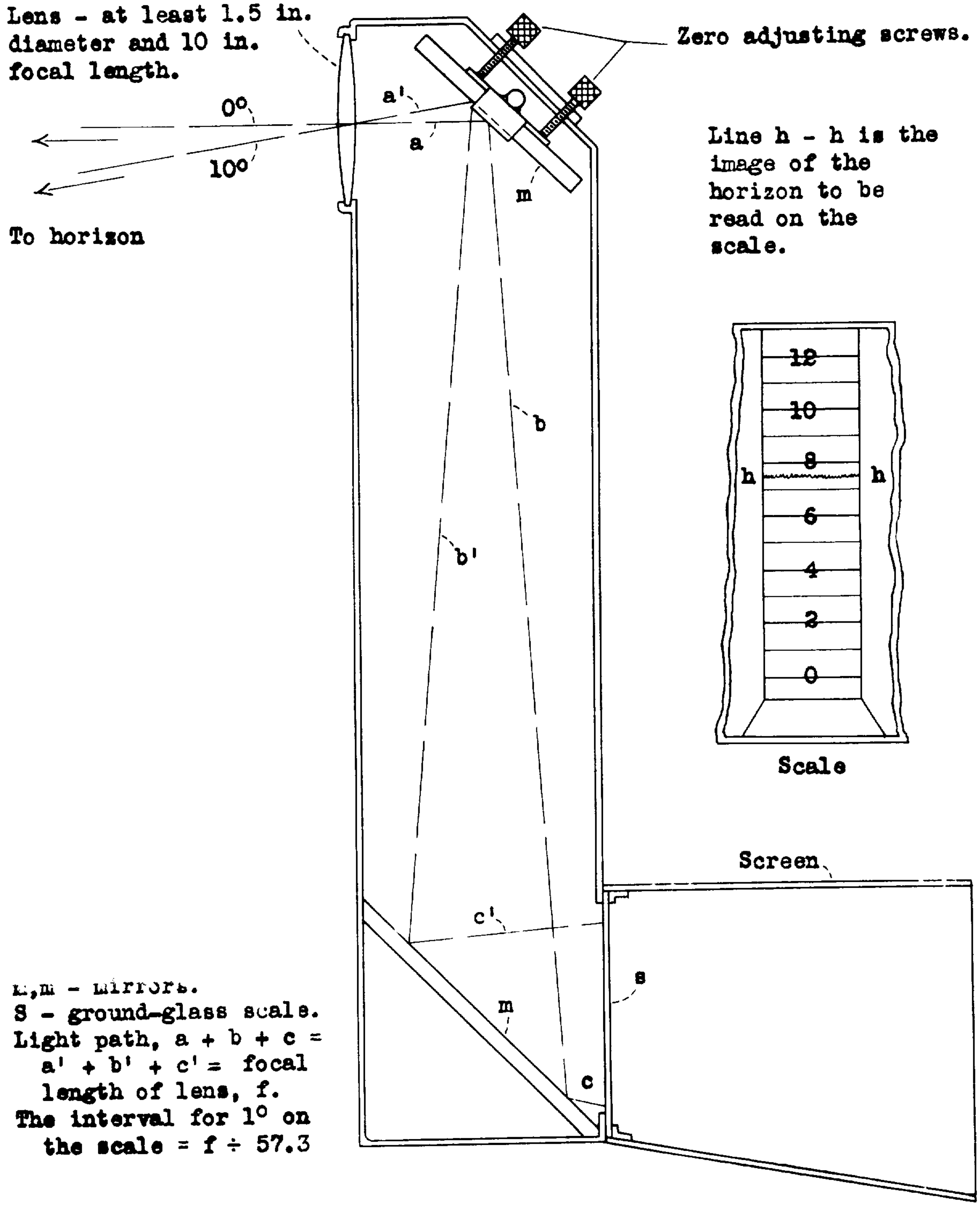


Figure 8.-Diagram of trim-angle indicator.