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EFFECT OF GROUND ON CHARACTERISTICS OF MODEL OF A  
LOW-WING AIRPLANE WITH FULL-SPAN SLOTTED FLAP  
WITH AND WITHOUT POWER

By I. G. Recant and A. R. Wallace

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## NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ADVANCE RESTRICTED REPORT

EFFECT OF GROUND ON CHARACTERISTICS OF MODEL OF A  
LOW-WING AIRPLANE WITH FULL-SPAN SLOTTED FLAP  
WITH AND WITHOUT POWER

By I. G. Recant and A. R. Wallace

## SUMMARY

Ground-effect tests were made in the LMAL 7- by 10-foot tunnel of a model of a low-wing, pursuit-type airplane equipped with a full-span 25-percent-chord slotted flap. The model was mounted at two heights above a flat plate that represented the ground and was tested with and without power. At each height and power condition, tests were made with two stabilizer and several elevator settings. Tests were also made with the tail removed. Sufficient data were obtained to determine the elevator deflection required for trim and the downwash angles in the region of the tail at each lift coefficient. The downwash angles derived from the power-off test data for one height above the ground plate were compared with computed angles.

It was found that the elevator deflection required for landing in a three-point attitude with the full-span slotted flap was considerably greater than that required with a partial-span split flap. The application of power reduced the required deflection. The presence of the ground reduced the downwash angle and the rate of change of downwash angle with angle of attack, either with or without power. Computed values of the downwash angle (if the effect of the windmilling propeller is neglected) were about  $1\frac{3}{4}^{\circ}$  lower than those values derived from the test data. Computed values of elevator deflection required for trim would therefore be about  $3^{\circ}$  higher than the values obtained in the tests with the propeller windmilling.

## INTRODUCTION

The problem of getting the tail down for landing has always been of importance because the elevator deflection

required to trim the airplane near maximum lift coefficient is markedly increased by the presence of the ground (reference 1). In fact, the ability of the tail to trim the airplane near the ground at the angle of attack for maximum lift coefficient has been a major criterion in the design of the tail. The present trend toward the use of full-span flaps has made this criterion critical, and computations have shown that it may be difficult, if not impossible to meet this requirement with the tail arrangements now in use. Considerable uncertainty also exists about the effect of the ground plus the slipstream (when the airplane is landing with power or taking off) on the characteristics of the airplane. The present report describes the tests made to provide information on these subjects.

A model, equipped with a full-span 25-percent-chord slotted flap, was tested in the presence of a ground board. The use of a ground board or plate to represent the ground is justified, at least for determination of elevator deflections required for trim when the airplane is landing, because previous tests using a plate have given results that agree satisfactorily with flight data (reference 2).

#### MODEL AND APPARATUS

The model used, which is shown in figure 1, is very similar to the 1/5-scale model of the Curtiss P-36A airplane. The wing has the same area, plan form, section, aspect ratio, and so forth, as the P-36A model. In addition, it is fitted with a 25-percent-chord slotted flap that covers about 93 percent of the span. The flap is deflected  $30^\circ$  and extends under the fuselage with the gap between the two halves sealed. The fuselage in side elevation is the same as the fuselage of the P-36A model. It was modified in plan form to eliminate the concavity at the cowl that is present on the fuselage of the P-36A model. The tail surfaces and the landing gear are the same as those used on the P-36A model.

Power was obtained from a 56-horsepower water-cooled induction motor fitted with an electrically indicating tachometer and mounted in the nose of the model. A metal, 2-foot-diameter propeller with three adjustable blades was used. The blades were set at  $25^\circ$  at three-quarters of the propeller radius for all the tests.

The ground was simulated by a flat wooden plate extending completely across the tunnel and several feet in front of and behind the model. This plate could slide on vertical rods, which were placed one at each corner, in such a way that the distance from the model to the plate could be set at any desired value. The plate is fully described in references 2 and 3.

### TESTS AND RESULTS

Test conditions.— The tests were made in the LMAL 7- by 10-foot wind tunnel. A dynamic pressure of 16.37 pounds per square foot was maintained for all tests, corresponding to a velocity of about 80 miles per hour under standard sea-level conditions and to a test Reynolds number of about 1,000,000 based on the wing mean aerodynamic chord of 16.32 inches.

Coefficients and symbols.— The results of the tests are given in the form of standard NACA coefficients of force and moment based on model wing area and mean aerodynamic chord. All moments are taken about the center-of-gravity location (26.7 percent of the mean aerodynamic chord) shown in figure 1. The coefficients are defined as follows:

- $C_D$  drag coefficient (propeller off) ( $D/q_0S$ )
- $C_{DR}$  resultant drag coefficient (propeller on) ( $D_R/q_0S$ )
- $C_L$  lift coefficient ( $L/q_0S$ )
- $C_m$  pitching-moment coefficient about center of gravity  
( $M/q_0S\bar{c}$ )
- $C_{m_t}$  pitching-moment coefficient about center of gravity  
due to tail ( $M_t/q_0S\bar{c}$ )
- $T_c'$  effective model thrust coefficient ( $T_e/qS$ )
- $T_c$  effective propeller thrust coefficient
- $$\left( T_c = \frac{T_e}{\rho V^2 D^2} = 1.18 T_c' \right)$$

where

- D drag with propeller off
- $D_R$  resultant drag with propeller on
- L lift
- M pitching moment
- $M_t$  pitching moment due to tail
- $q_0$  free-stream dynamic pressure (16.37 lb/sq ft)  $\left(\frac{1}{2} \rho V^2\right)$
- S wing area (9.44 sq ft)
- $\bar{c}$  wing mean aerodynamic chord (1.36 ft)
- $V/nD$  advance-diameter ratio
- $T_e$  effective thrust, pounds
- $\rho$  mass density of air, slugs per cubic foot
- V airspeed, feet per second
- n propeller speed, revolutions per second
- D propeller diameter (2 ft)

Additional symbols used are defined as follows:

- $\alpha$  angle of attack of thrust line, degrees
- $i_t$  angle of stabilizer setting with respect to thrust line, positive when trailing edge is down, degrees
- $\delta_e$  elevator deflection with respect to stabilizer chord, positive when trailing edge is down, degrees
- $\alpha_t$  angle of attack of tail, degrees
- $\epsilon$  downwash angle, positive when vertical velocity at tail is downward (tends to reduce angle of attack of tail), degrees
- $\delta_f$  flap deflection, degrees

- $\beta$  propeller-blade setting at three-quarters of propeller radius ( $25^\circ$ )
- $h/\bar{c}$  distance of ground plate below pivot point in terms of mean aerodynamic chord (fig. 1)
- $c$  wing chord at any section

Corrections.— Data obtained with the propeller wind-milling were not corrected for tares caused by the support strut, but those from tests with power were corrected. The tare corrections for the cases with power were obtained from tests with a dummy support without a ground plate.

Tunnel-wall corrections to the data when the value of  $h/\bar{c}$  was 0.658 ( $h = 10.75$  in.) were not made because they were found to be negligible (reference 3). When the ground plate was 27 inches below the pivot point, the following corrections were made:

$$\Delta C_D = \delta_w \frac{S}{C} C_L^2 \quad (1)$$

$$\Delta \alpha = \delta_w \frac{S}{C} C_L (57.3) \quad (2)$$

$$\Delta C_m = C_L \frac{S}{C} (57.3) \frac{\partial C_m}{\partial i_t} \left[ \frac{1}{\sqrt{q/q_0}} \delta_{\text{total}} - \delta_w \right] \quad (3)$$

where

$\delta_w$  jet-boundary correction factor for wing (0.037)

$\delta_{\text{total}}$  total jet-boundary correction factor at tail location (0.065)

$C$  tunnel cross-section area (57.5 sq ft)

$\frac{\partial C_m}{\partial i_t}$  change in pitching moment per degree change in tail setting

$q/q_0$  ratio of dynamic pressure at tail to free-stream dynamic pressure

Equations (1) and (2) are standard wind-tunnel correction formulas. Equation (3) is equivalent to equation

(16) of reference 4. The standard jet-boundary correction factor  $\delta_w$  was so corrected that it applied only to the top and the sides of the tunnel, leaving the effect of the ground board in the results. In order to make this correction to  $\delta_w$ , the value of  $\delta_w$  was reduced in the same ratio as in reference 3 for correction to ground-board test results. The value of  $\delta_{total}$  was reduced in the same manner as the value of  $\delta_w$  after it was obtained from figure 5 of reference 4. All corrections are added to the tunnel data. When the tail was removed, no correction was applied to the pitching moment.

Test Procedure.— The ground plate was set at two distances below the model. At one position ( $h = 10.75$  in.) it just cleared the wheels of the landing gear at zero angle of attack. In this position the wheels were about  $1\frac{1}{4}$  inches above the plate at an angle of attack of  $10^\circ$ . At the second position  $h$  was 27 inches. In each position tests were made with the propeller windmilling and with power through an angle-of-attack range from about  $-6^\circ$  to the stall. For each power condition tests were made at two stabilizer settings with elevator neutral and with the tail removed. At one of the stabilizer settings ( $2^\circ$ ) several elevator settings were tested. Lift, drag, and pitching moment were measured for each test.

The power-on tests were run in such manner that, with elevator neutral and stabilizer set at about  $2^\circ$ , the thrust coefficient at a given lift coefficient was as indicated in figure 2. The curve in this figure represents about 256 horsepower at sea level with a wing loading of 23.7 pounds per square foot. For other elevator or stabilizer settings the propeller speed at a given angle of attack was kept the same as for the test with the stabilizer angle of  $2^\circ$  and elevator neutral. The propeller speed required for a given thrust was obtained from a propeller calibration of thrust coefficient against propeller speed. This calibration had been made with flap neutral at zero angle of attack with no ground plate present. The thrust coefficient was determined as the difference between the drag coefficients with the propeller removed and the propeller operating:

$$T_c' = 0.847 T_c = C_D - C_{D_R}$$

DISCUSSION

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Effect of stabilizer setting.— The effects of stabilizer setting with the ground plate at two heights with power on and with propeller windmilling are shown in figure 3. With the ground at the closest position with respect to the model ( $h/\bar{c} = 0.658$ ) and with propeller windmilling (fig. 3(a)) the slope of the pitching-moment curve  $\frac{dC_m}{d\alpha}$  is about  $-0.014$ . This value is the same as

that obtained for the model of the P-36A airplane with partial-span split flaps near the ground (reference 2). The pitching-moment curves for the two stabilizer settings are parallel, as would be expected, and they indicate a value for  $\frac{\partial C_m}{\partial i_t}$  of about  $-0.0234$ . This value is slightly

higher than that obtained for the P-36A model with partial-span split flap away from the ground in which case  $\frac{\partial C_m}{\partial i_t}$  was  $-0.0227$ . The increase is readily explained by the increase in effective aspect ratio of the tail near the ground.

At the same ground height ( $h/\bar{c} = 0.658$ ) but with power on (fig. 3(b)), the slope of the pitching-moment curve varies with angle of attack and with stabilizer setting, as is usually the case with power on. These curves are so far from trim that the value of  $\frac{dC_m}{d\alpha}$  has little significance, but it may be pointed out that the minimum value of slope shown is about  $-0.012$ . In comparison, the P-36A model with power on and the same elevator and stabilizer setting but away from the ground had almost neutral stability. Thus, the stabilizing influence of the ground even when power is applied, is quite marked. The value of  $\frac{\partial C_m}{\partial i_t}$  increases from  $-0.0257$  at  $\alpha = -5^\circ$  to  $-0.0343$  at  $\alpha = 9^\circ$ , giving an indication of the increase in slipstream velocity over the tail as the lift coefficient increases.

When the ground height is increased to  $h/\bar{c} = 1.65$ ,  $\frac{\partial C_m}{\partial i_t}$  with the propeller windmilling (fig. 3(c)) is  $-0.0235$ . When power is applied (fig. 3(d)),  $\frac{\partial C_m}{\partial i_t}$  has a smaller variation with  $\alpha$  than when the ground is at  $h/\bar{c} = 0.658$ . Thus, it appears that in free air most of the slipstream is below the tail and that the presence of the ground tends to push the slipstream up closer to the tail.

Effect of elevator deflection.— The effect of elevator deflection with the ground at two heights and with power on and propeller windmilling is shown in figure 4. For either height above the ground and with the propeller windmilling (figs. 4(a) and 4(c)), the effect of elevator deflection is normal. The elevator, however, loses its effectiveness beyond a deflection of  $-25^\circ$  and no further increment in pitching moment is obtained by a  $-30^\circ$  deflection. It does not necessarily follow that this loss in effectiveness beyond  $25^\circ$  would occur with a full-scale model because of a favorable scale effect that has been observed in some tests.

When power is applied (figs. 4(b) and 4(d)), the slopes of the pitching-moment curves decrease with negative elevator deflection (increase in download), as is to be expected. It is interesting to note that the elevator effectiveness when  $h/\bar{c} = 0.658$  does not decrease very much even at a deflection of  $-30^\circ$ . It is also interesting to compare the slope of the pitching-moment curves with power on and with propeller windmilling for trim conditions. At the ground height  $h/\bar{c} = 0.658$ , an elevator deflection of  $-20^\circ$  trims the model at  $C_L = 1.79$  when the propeller is windmilling (fig. 4(a)). With power on (fig. 4(b)), the model is trimmed at  $C_L = 1.93$  by an elevator deflection of  $-15^\circ$ . At these lift coefficients,  $\frac{dC_m}{d\alpha} = -0.015$  for the case of the windmilling propeller and  $-0.012$  for the power-on case.

Elevator deflection required for trim.— The elevator deflections required for trim at any lift coefficient with propeller windmilling and with power on with the ground plate at two distances from the model are shown in figure 5. It may be seen that power considerably decreases the elevator deflection required for trim. Although the power

used in the present tests was greater than would be required for level flight (see figs. 4(b) and 4(d)), the data of figure 5 indicate that it should be much easier to get the tail down for landing with power on than with propeller windmilling.

Effect of flap span on elevator deflection for trim.

In order to determine the effect of flap span on the elevator deflection required for trim when the airplane is landing, it would be desirable to compare these elevator deflections at the maximum lift coefficients with the deflections that would be obtained in full-scale tests. The present tests were made at a low Reynolds number and therefore the maximum lift coefficients and the angles of attack at which these coefficients occur are considerably lower than the full-scale values. As normal landings are made with the airplane in a three-point attitude, the elevator deflection required for trim in this attitude should be a satisfactory basis for comparison. Curves were therefore plotted of elevator deflection required for trim at various angles of attack with the full-span slotted flap and with a partial-span split flap. The curves are shown in figure 6. The data for the partial-span split flaps were taken from reference 2. Since the angle of attack of the airplane in the three-point attitude is  $14.3^\circ$ , the curves of figure 6 were extrapolated to this angle of attack. This extrapolation, which assumes practically no change in elevator effectiveness, indicates that a deflection of about  $-20^\circ$  is required with the partial-span split flap and a deflection of about  $-33^\circ$  is required with the full-span slotted flap.

Pitching moment due to the tail.— Figure 7 presents the characteristics of the model with and without the tail and with power on and with propeller windmilling for the two heights of the ground plate. The pitching moment contributed by the tail for each of the various conditions was determined from the data of these figures by the equation

$$C_{m_t} = C_{m_t}(\text{tail on}) - C_{m_t}(\text{tail off}) \quad (4)$$

The results are shown in figure 8. The fact that there is so little difference between the slope of the curves of pitching moment due to tail with power on or off when  $h/\bar{c} = 0.658$  may result from the tendency of the increase

in  $q/q_0$  due to power to counteract the increase in  $d\epsilon/d\alpha$  due to power.

Incidentally, figure 7 indicates that there must be either some interference between fuselage and tail or else the tail drag contributes an appreciable pitching moment, because the angle of attack at which the tail-off pitching moment equals the tail-on pitching moment (tail moment is zero) does not correspond to the angle of attack at which the tail-off lift equals the tail-on lift (tail lift is zero). This discrepancy, however, may also be caused by inaccuracy in the measurement of the relatively small changes in lift due to the removal of the tail. If the discrepancy is due to interference, the tail angles of attack and the downwash angles derived from these curves must be considered effective angles rather than actual angles.

Angles at tail.— The average angles of attack of the tail for each power condition and ground-plate height were obtained from the equation

$$\alpha_t = C_{m_t} \frac{1}{\partial C_m / \partial i_t} \quad (5)$$

The value of  $C_{m_t}$  for each case was obtained from figure 8 and the value of  $\frac{\partial C_m}{\partial i_t}$  for each case was obtained from figure 3. The tail angles of attack are shown in figure 9(a).

If the tail angles of attack are known, the average downwash angles at the tail may be computed from the formula

$$\epsilon = \alpha + i_t - \alpha_t \quad (6)$$

These downwash angles are shown in figure 9(b). In figure 9(c) the downwash angles are plotted against the lift coefficient of the model without the tail. It may be seen that the partial-span split flap gives higher values of downwash than the full-span slotted flap for the same conditions of lift, propeller operation, and ground distance. Also, as the model approaches the ground plate, not only the downwash angle but also the slope  $d\epsilon/dC_L$  decreases. This condition is true whether power is on or off.

Comparison between computed and experimental values of downwash angles.— The downwash angles at the elevator hinge were computed for the case when the ground was 10.75 inches below the pivot ( $h/\bar{c} = 0.658$ ) by the method given in reference 5. These computed angles are compared with the experimental values in figure 10. The comparison is not strictly justified because the computed downwash values do not take into account the effect of the windmilling propeller. The figure indicates that the presence of the windmilling propeller in the present case increases the downwash angle by about  $1\frac{3}{4}^{\circ}$  throughout the lift range. Thus, computations of elevator deflection required for trim, if the effect of the windmilling propeller is neglected, will give values greater than actually required. Since the elevator on the model is about 60 percent as effective as the stabilizer, however, the difference between the computed elevator deflections and those obtained in the tests will be only about  $3^{\circ}$ .

Maximum lift coefficient.— The maximum lift coefficient of the model with the full-span slotted flap, tail removed, power off, and near the ground was 2.0 (fig. 7(a)). Because a larger value was anticipated, calculations were made using the method of reference 6 to determine the maximum lift coefficient that might be expected. The results of the computations indicated that the wing of this model with the full-span slotted flap would give a maximum lift coefficient of 2.25 in the tunnel with the ground plate removed. When a correction was made for the effect of the ground (reference 3), this maximum lift coefficient was reduced to about 2.1.

## CONCLUSIONS

For a model of a low-wing pursuit-type airplane equipped with a 25-percent-chord full-span slotted flap deflected  $30^{\circ}$ :

1. The elevator deflection required for landing in a three-point attitude was considerably greater than that required when a 25-percent-chord, 55-percent-span split flap deflected  $45^{\circ}$  was used.
2. The elevator deflection required for landing was reduced by the application of power.

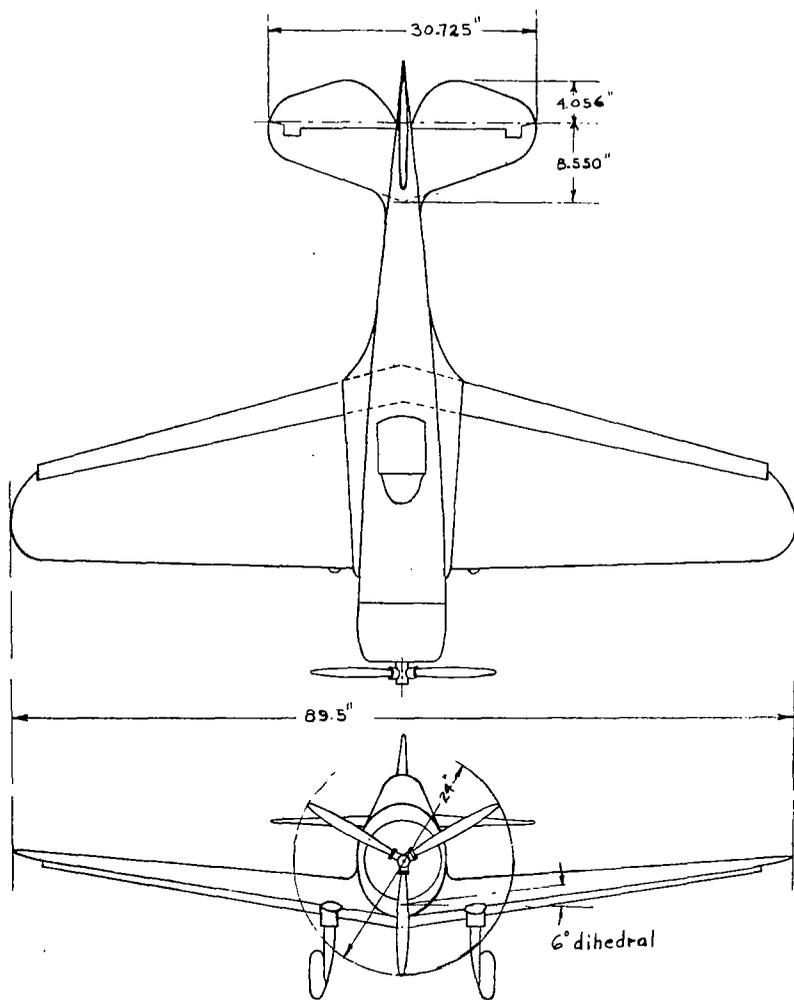
3. The presence of the ground reduced the downwash angles and the rate of change of downwash with angle of attack, whether or not power was applied.

4. Theoretically determined downwash angles, if the effects of the windmilling propeller were neglected, were smaller than those derived from test data with power on. The use of the theoretical values in estimating elevator deflection required for landing gave conservative results.

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(sq in.)

Wing area 1359.3

Horizontal-tail area 276.5

Elevator area back of hinge 88.7

Vertical-tail area 119.5

$h$ (in.)	$h/E$	$d$ (in.)
10.75	0.658	16.29
27.0	1.65	32.54

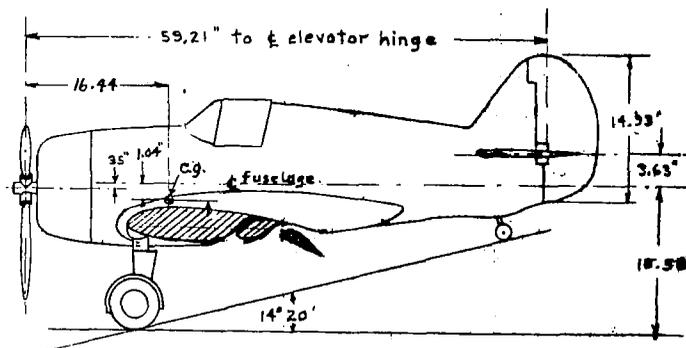
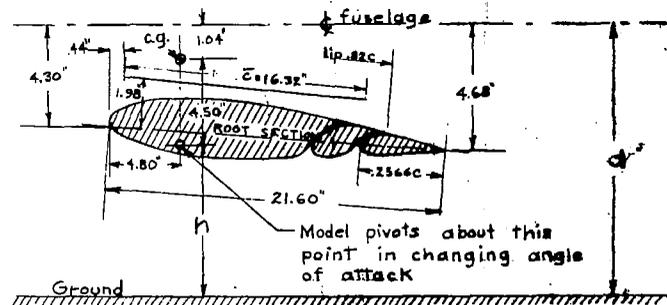


FIGURE 1.- MODIFIED  $\frac{1}{5}$ -SCALE MODEL OF THE P-36A AIRPLANE SHOWING THE FULL-SPAN 25-PERCENT-CHORD SLOTTED FLAP USED.

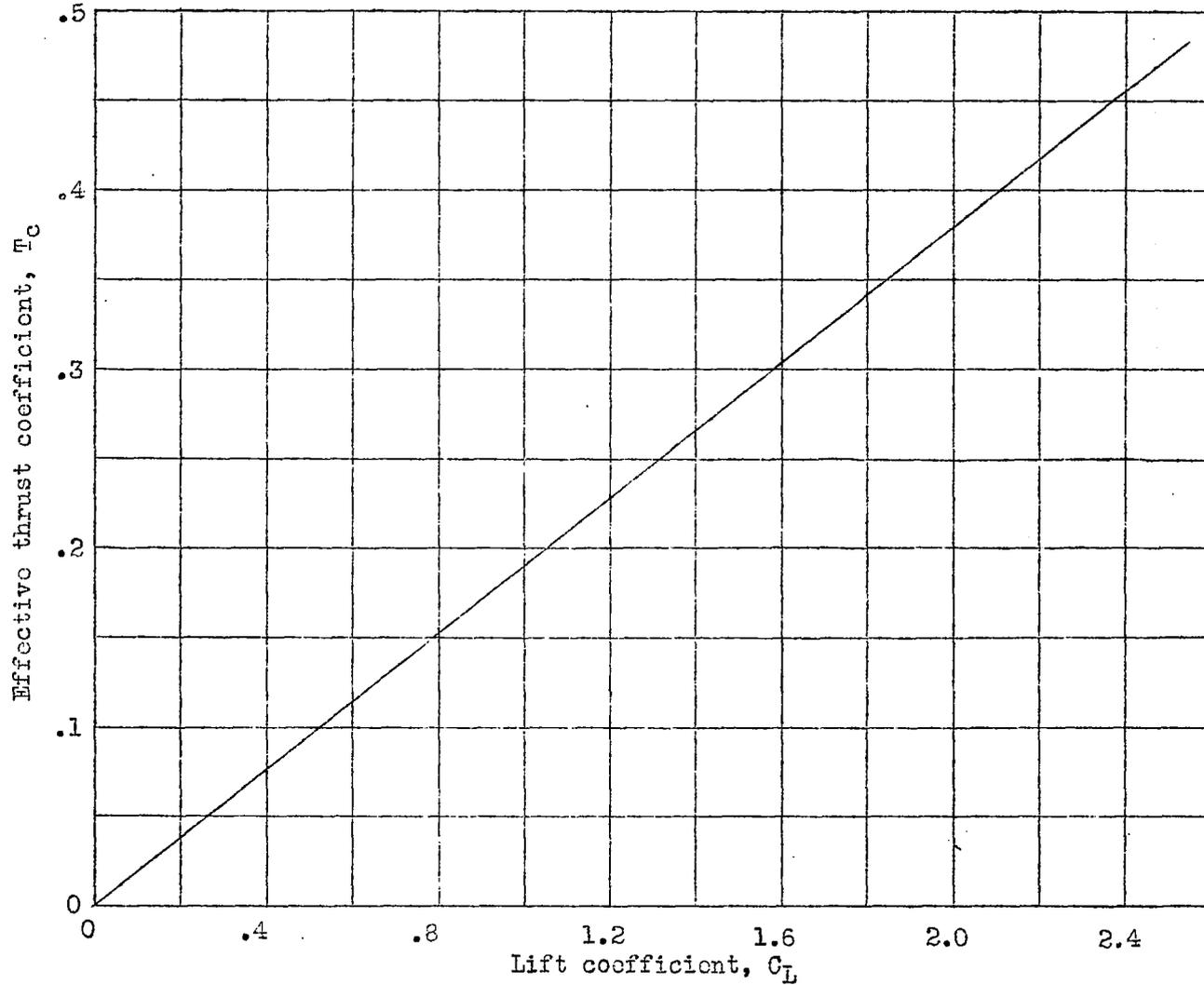
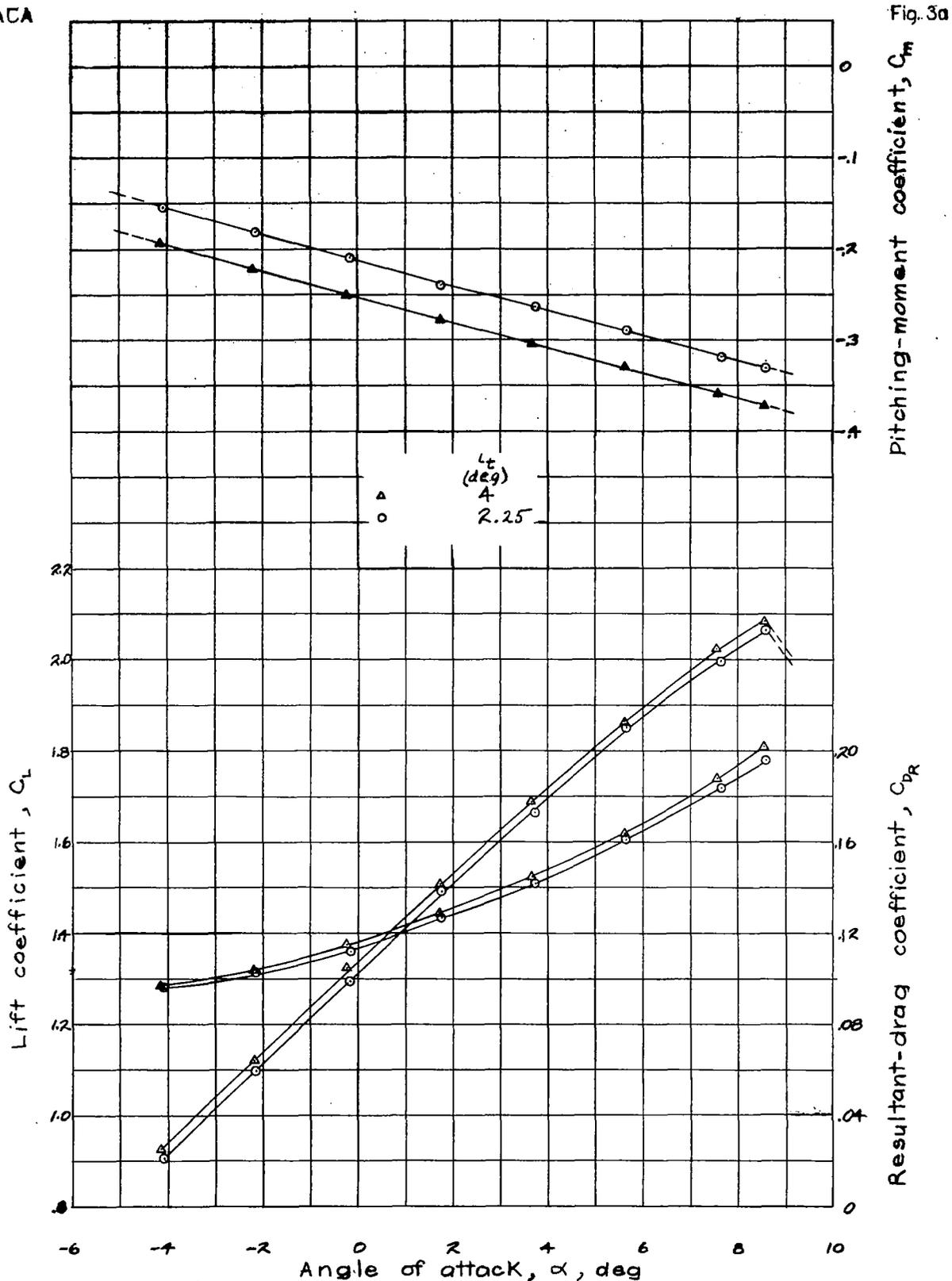
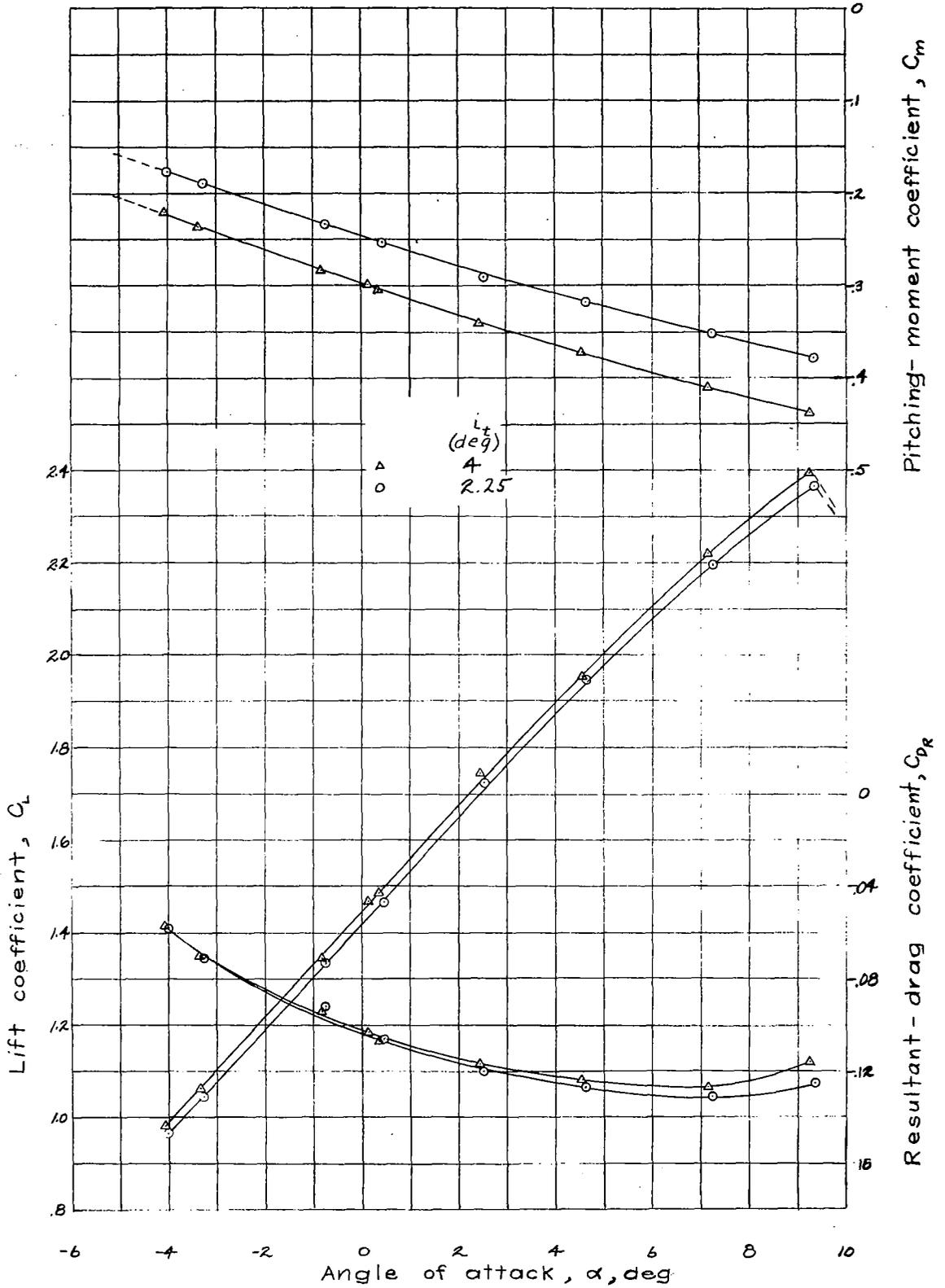


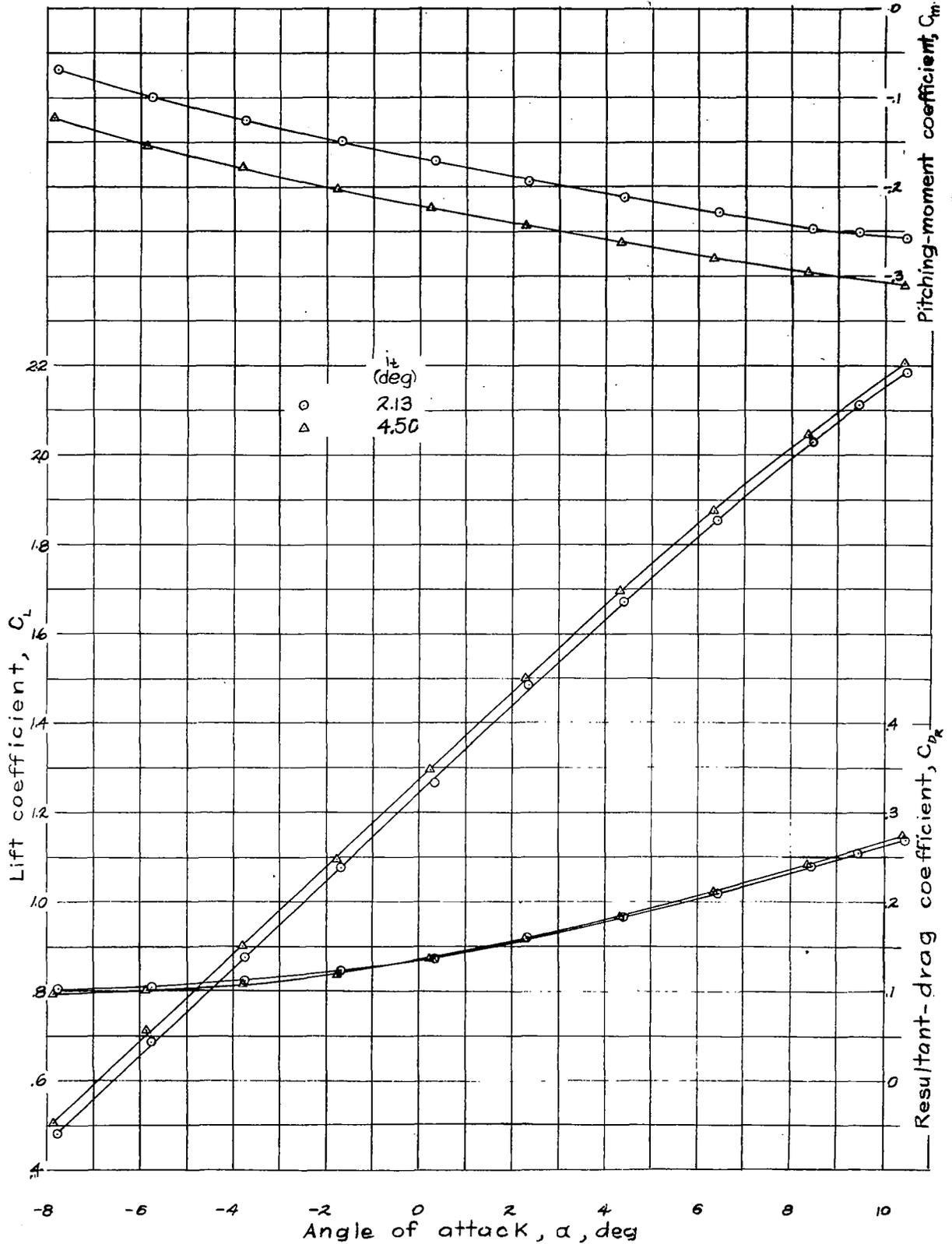
Figure 2.- Effective thrust coefficient at any lift coefficient used in tests of modified P-36A model near ground.  $T_c = T/\rho V^2 D^2 = 1.18T_c'$ .



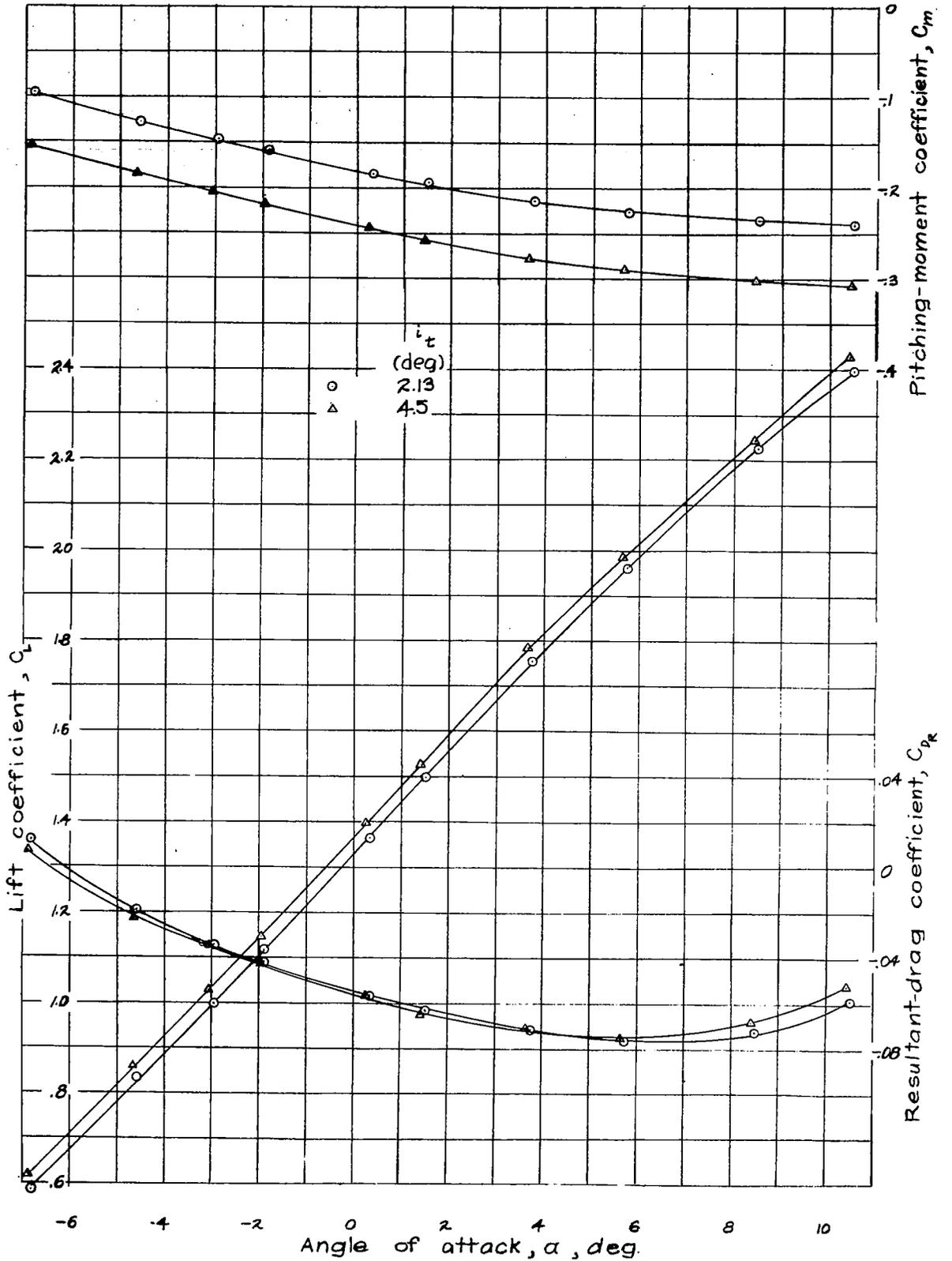
(a) Propeller windmilling;  $h/\bar{c}$ , 0.658.  
 FIGURE 3.- Effect of stabilizer setting on characteristics of modified P-36A low-wing model with full-span 2.25c slotted flap near ground.  $\delta_f$ ,  $30^\circ$ ;  $\delta_e$ ,  $0^\circ$ ;  $\beta$ ,  $25^\circ$ ;  $q$ , 16.37 pounds per square foot.



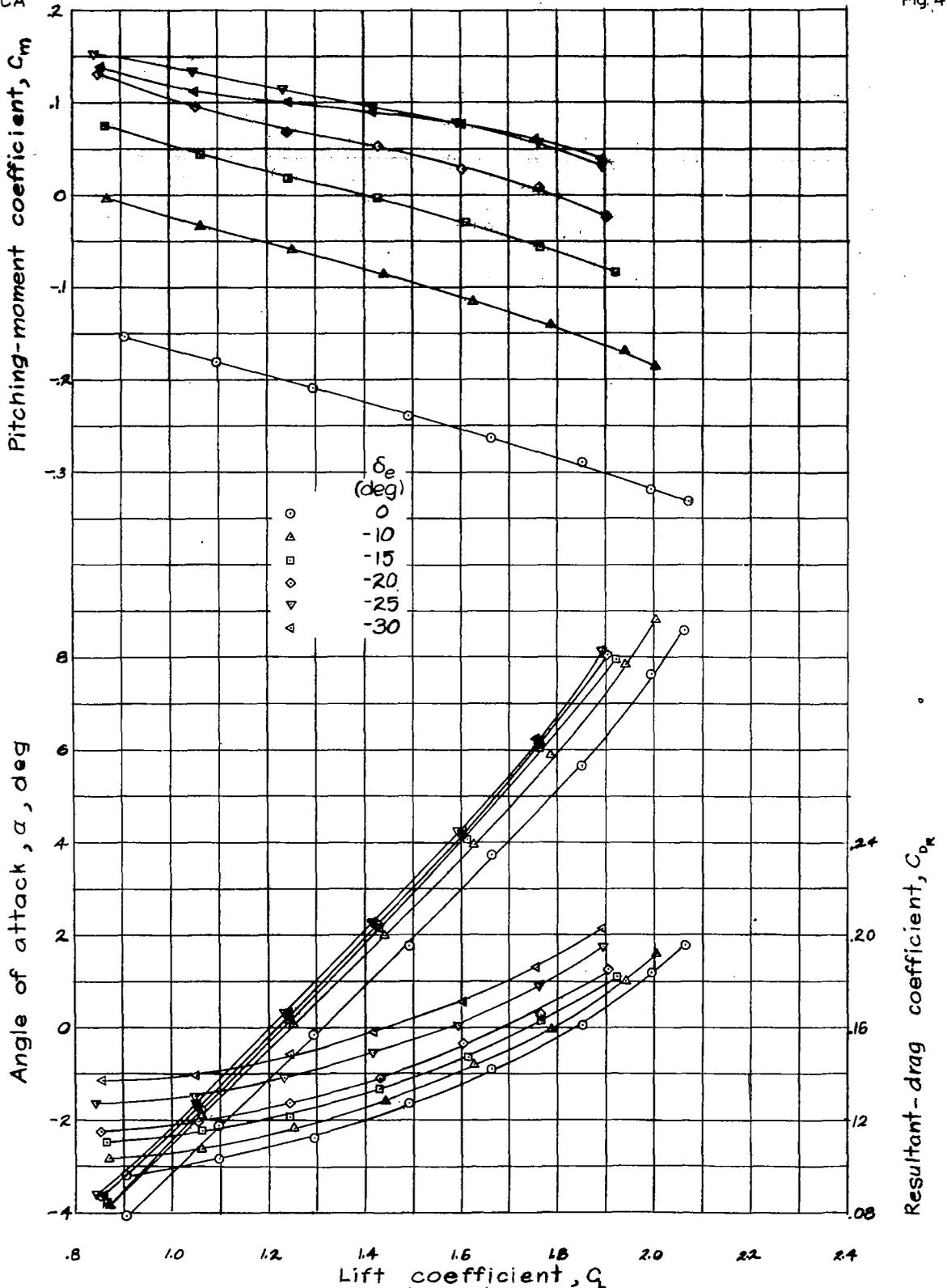
(b) Power on;  $h/\bar{c}$ , 0.658.  
Figure 3.- Continued.



(c) Propeller windmilling;  $h/\bar{c}$ , 1.65.  
Figure 3.-Continued.

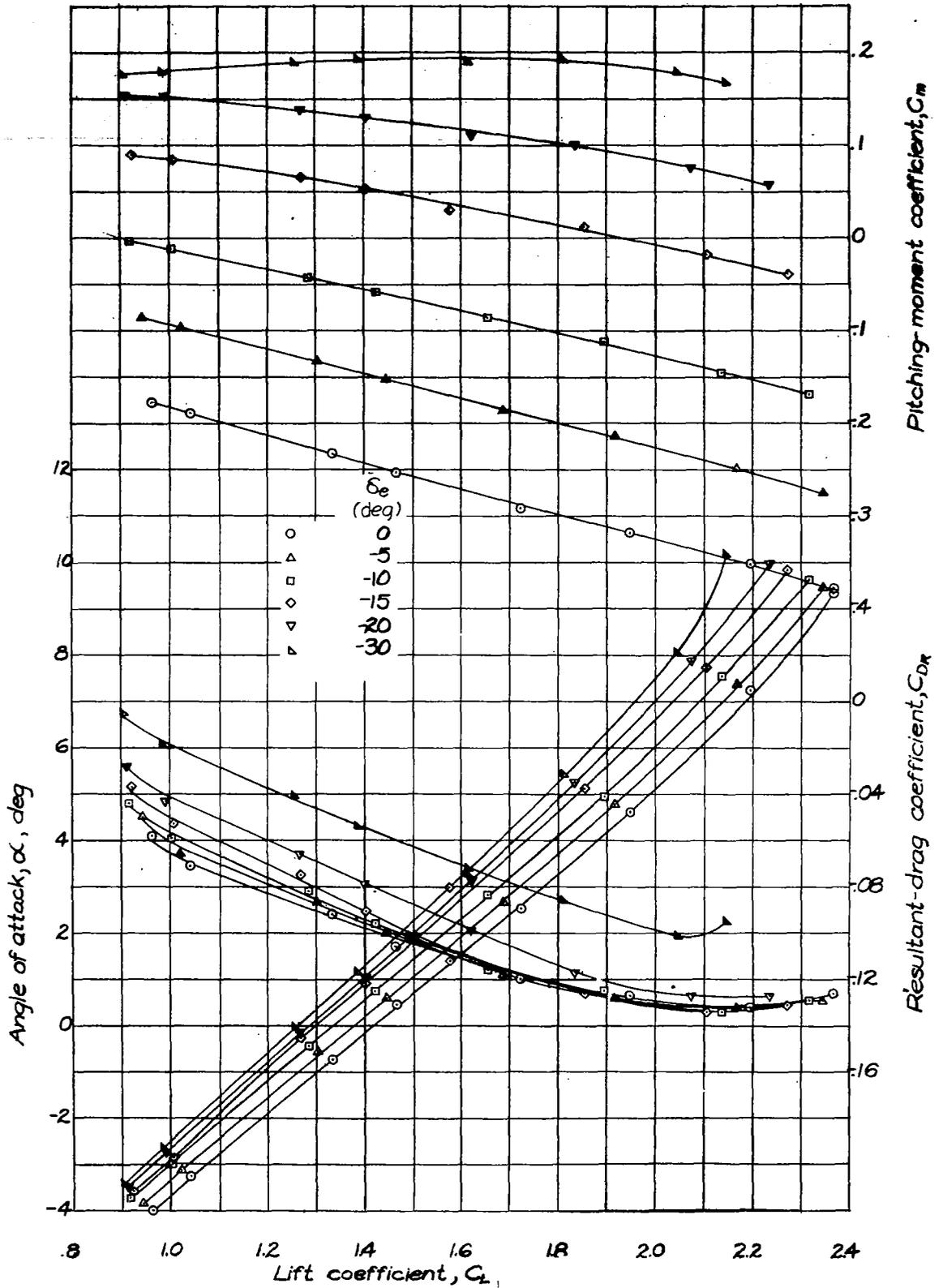


(d) Power on;  $h/\bar{c}$ , 1.65.  
 Figure 3.- Concluded.

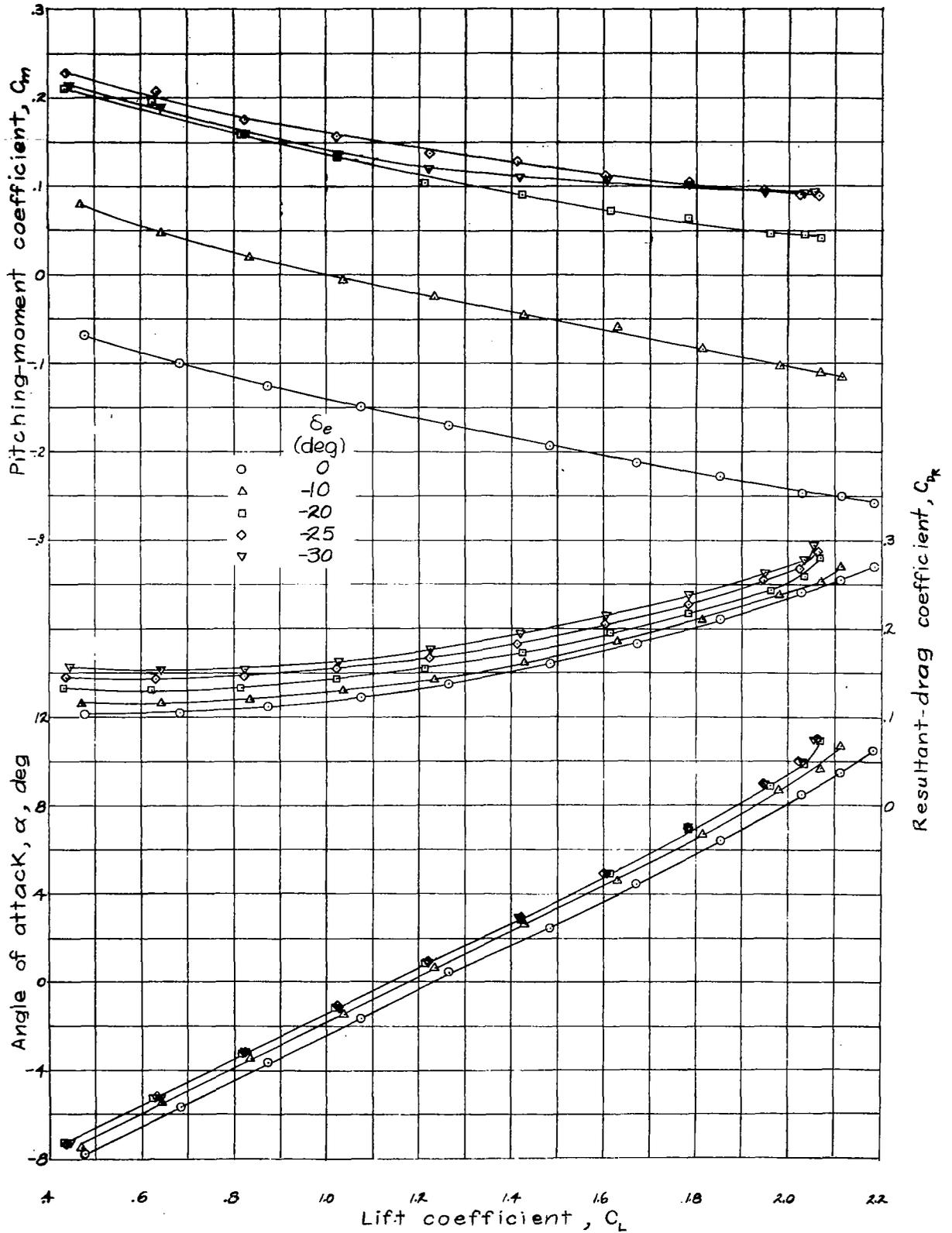


(a) Propeller windmilling;  $\eta/\bar{c}$ , 0.658;  $i_t$ , 2.25°.

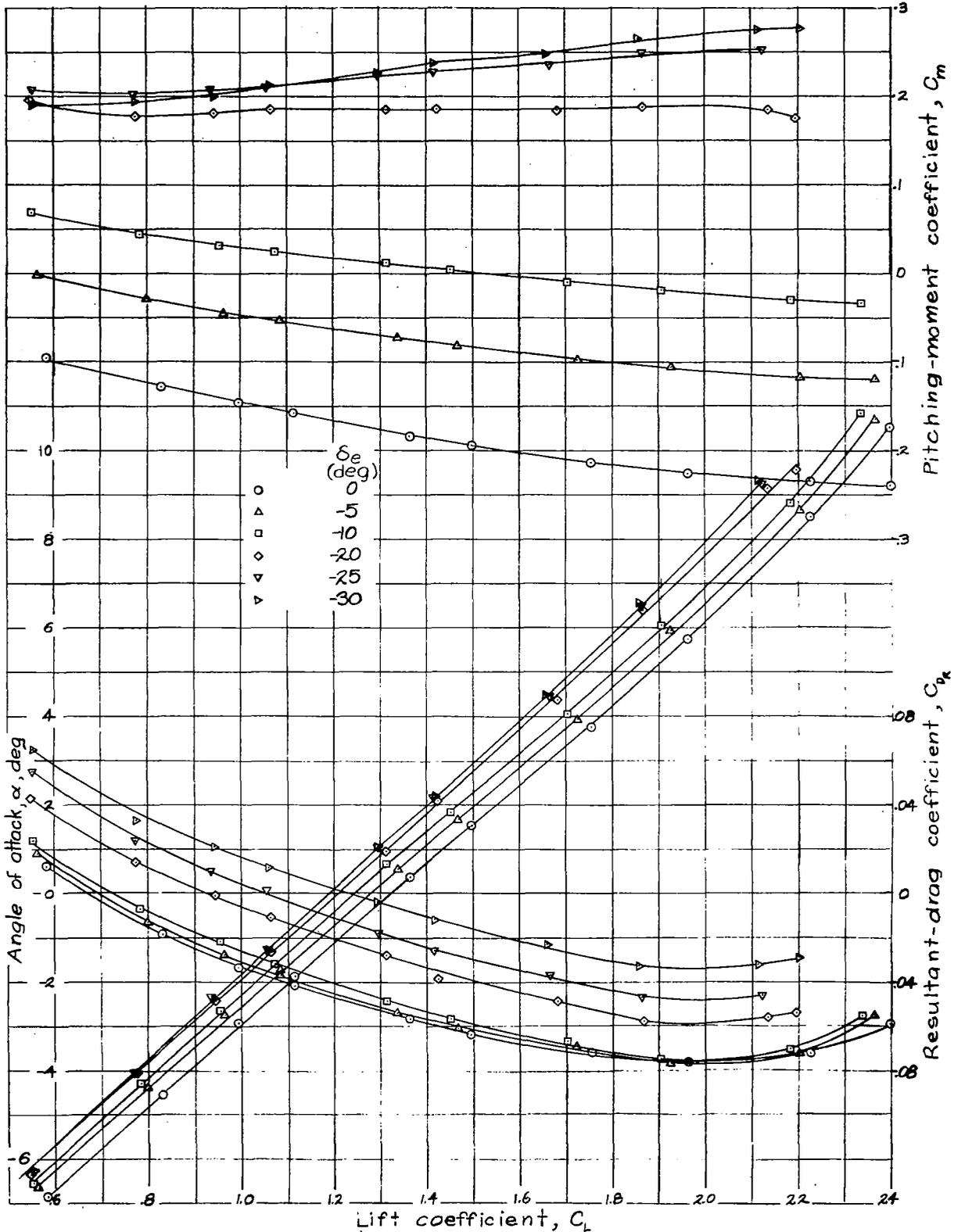
Figure 4.- Effect of elevator deflection on characteristics of modified P-36 A low-wing model with full-span 0.25c slotted flap near ground  $\delta_f$ , 30°;  $\beta$ , 25°;  $q$ , 16.37 pounds per square foot.



(b) Power on;  $h/\bar{c}$ , 0.658;  $l_t$ , 2.25°  
 Figure 4.- Continued.



(c) Propeller windmilling;  $\eta/\bar{c}$ , 1.65;  $l_t$ , 2.13°  
 Figure 4.- Continued.



(d) Power on;  $h/\bar{c}$ , 1.65;  $i_t$ , 2.13°  
 Figure 4.- Concluded.

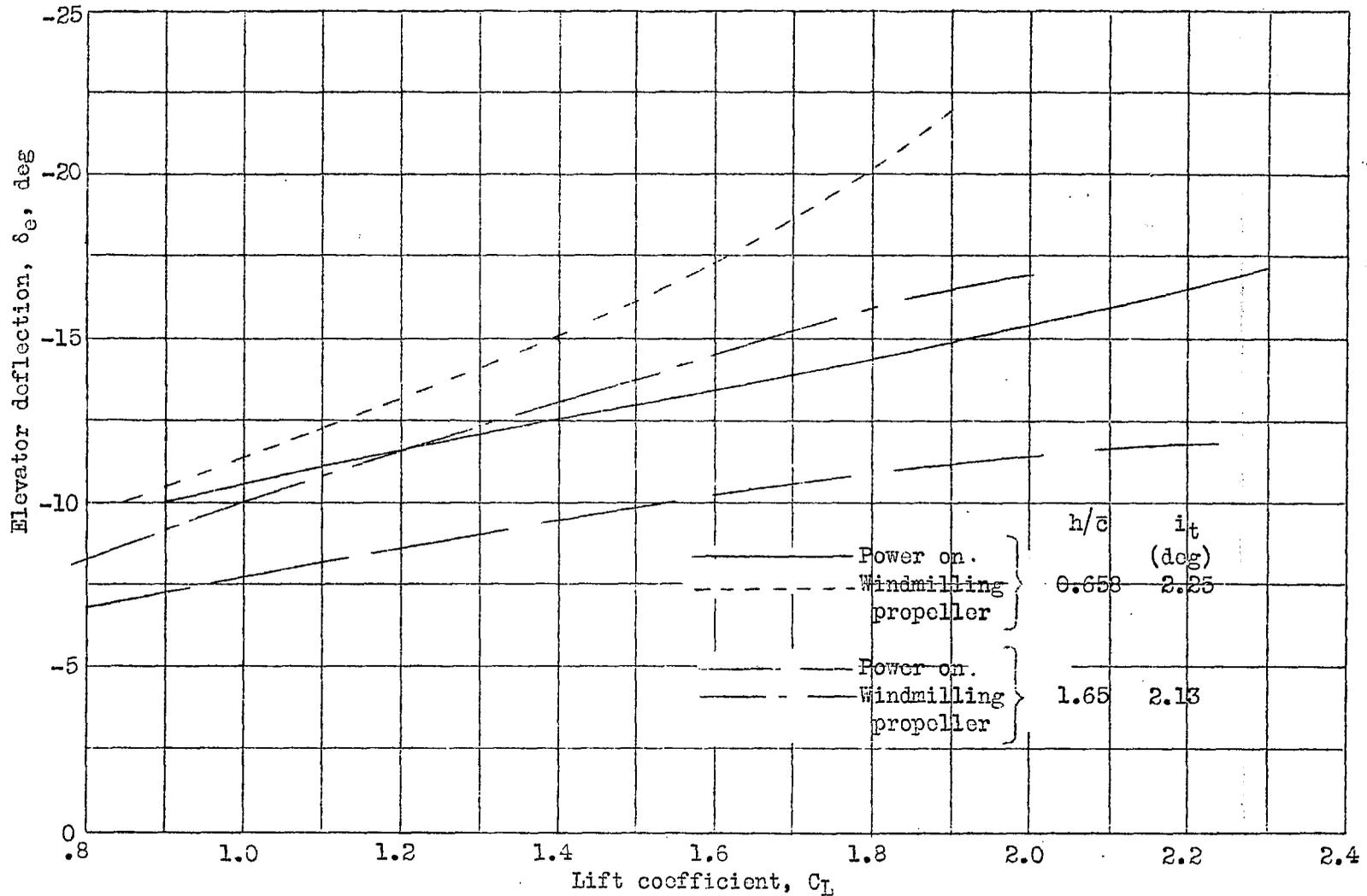


Figure 5.- Effect of power on elevator deflection required for trim at any lift coefficient. Modified P-36A low-wing model with full-span 0.25c slotted flap near ground.  $\delta_f, 30^\circ$ ;  $\beta, 25^\circ$ ;  $q, 16.37$  pounds per square foot.

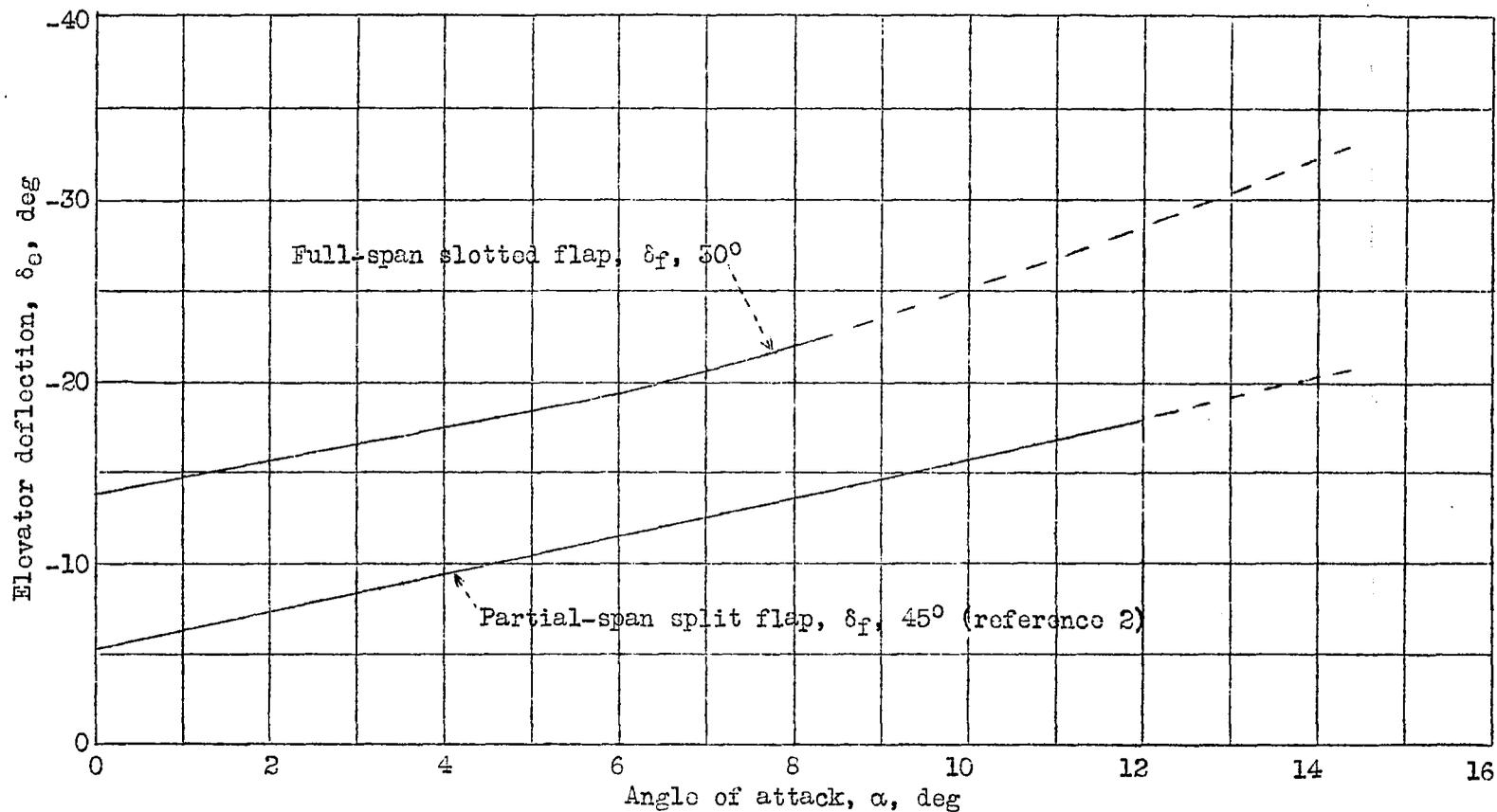
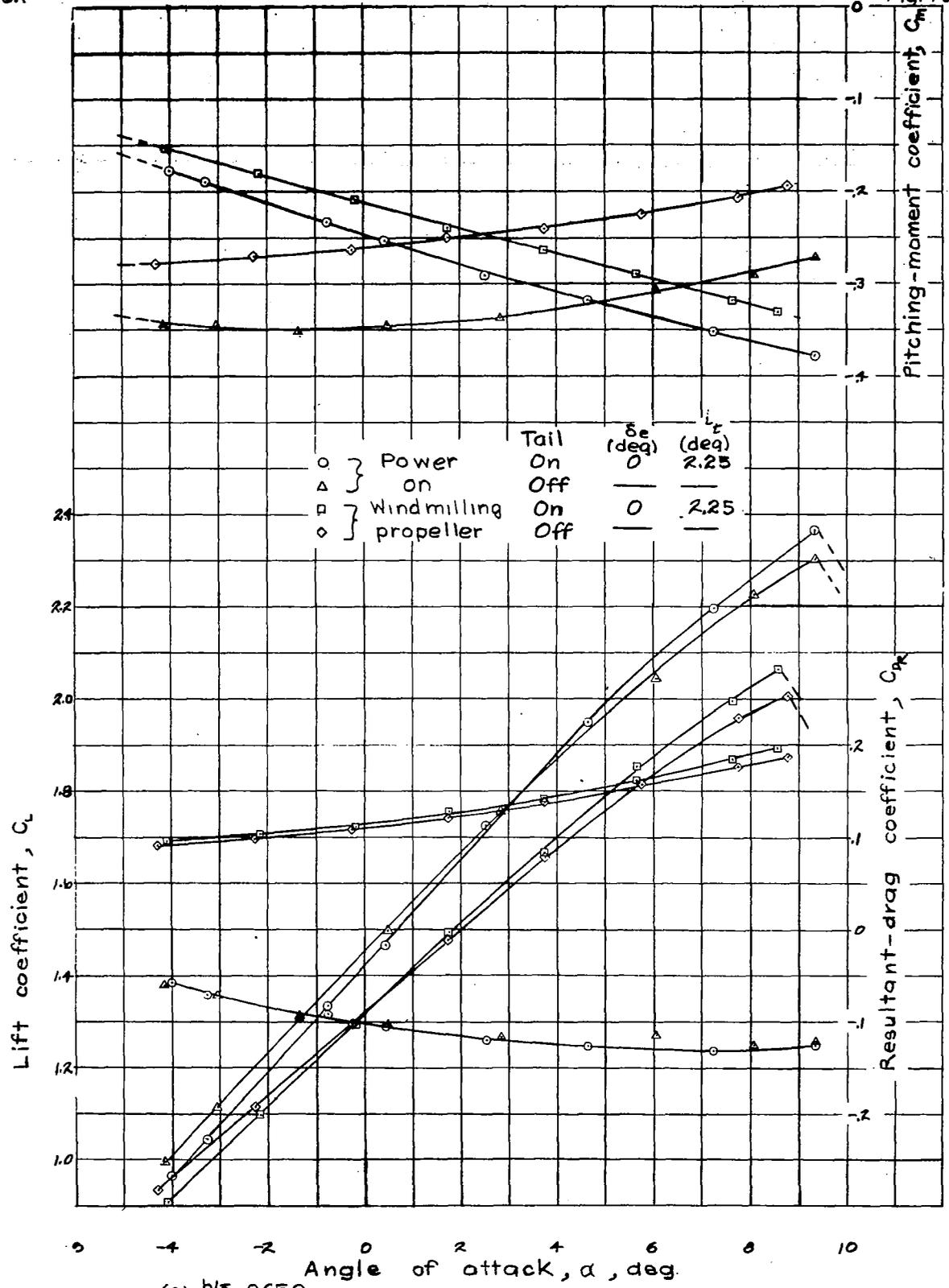
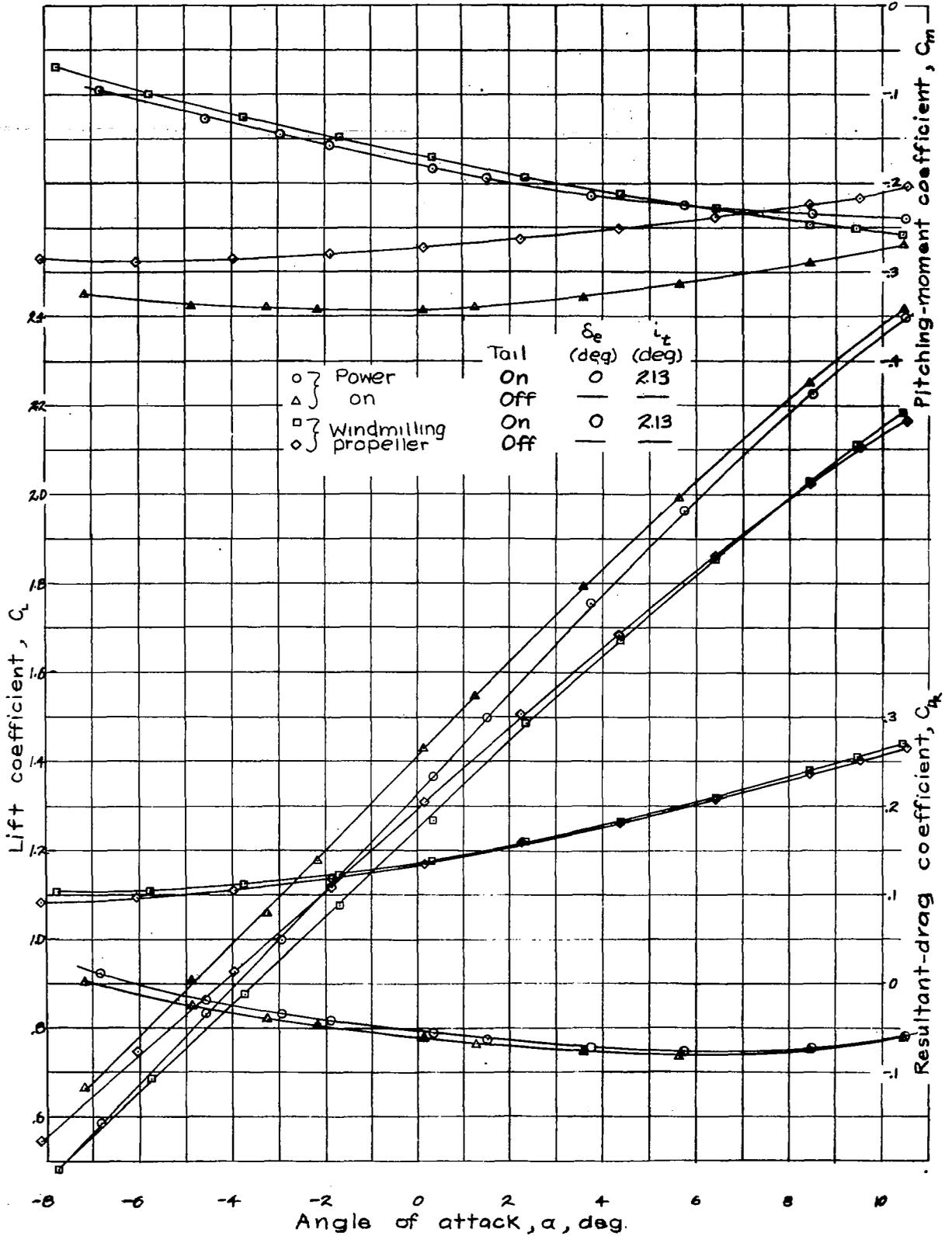


Figure 6.- Comparison of elevator deflection required for trim at any angle of attack with full-span and with partial-span flaps. P-36A low-wing model near ground. Windmilling propeller;  $h/\bar{c}$ , 0.658;  $q$ , 16.37 pounds per square foot.



(a)  $h/\bar{c}, 0.658$ .

Figure 7.- Effect of power on aerodynamic characteristics of modified P-36A low-wing model with full-span 0.25c slotted flap near ground.  $\delta_f, 30^\circ$ ;  $\beta, 25^\circ$ ;  $q, 16.37$  pounds per square foot.



(b)  $h/\bar{c}$ , 1.65.  
Figure 7.- Concluded.

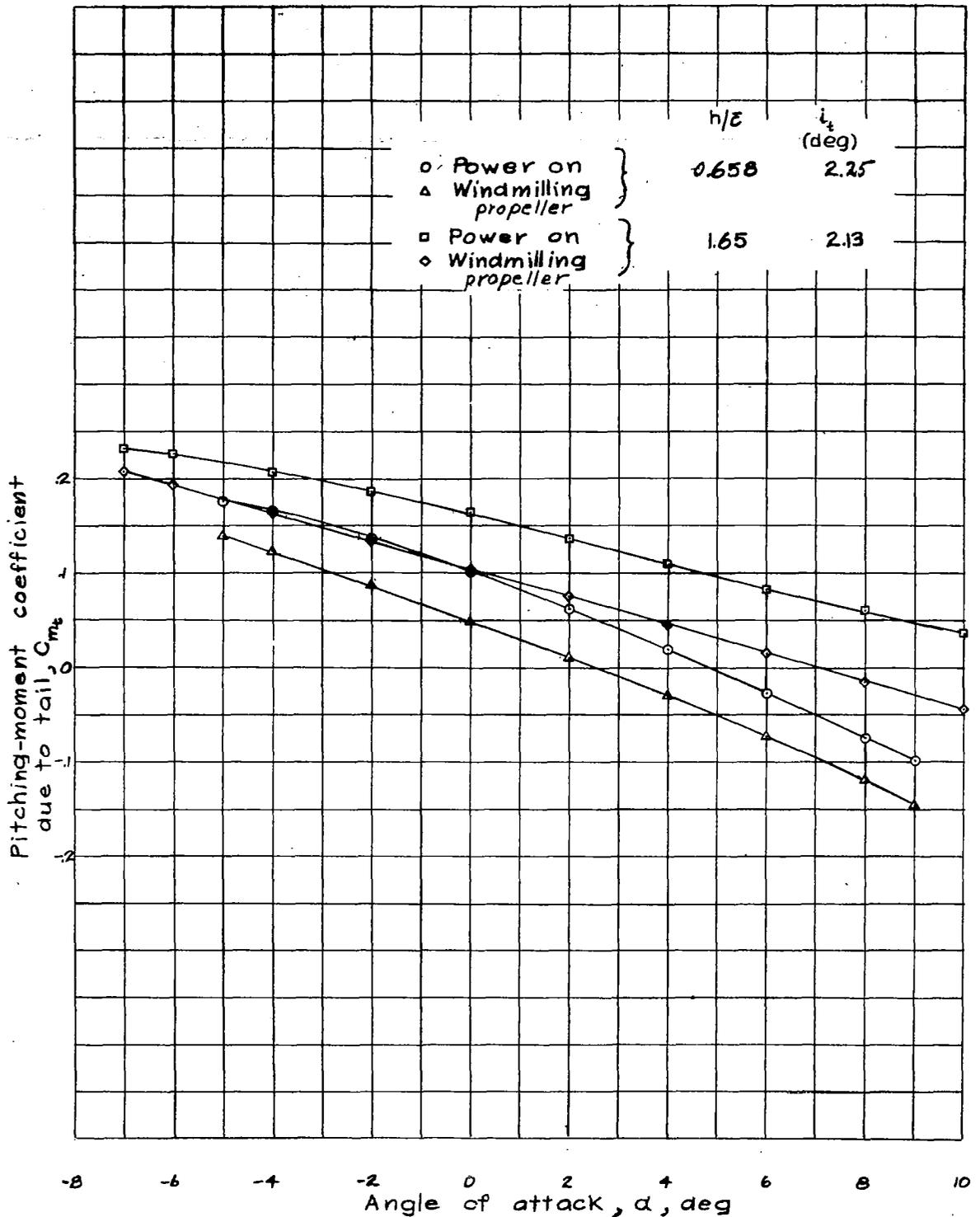
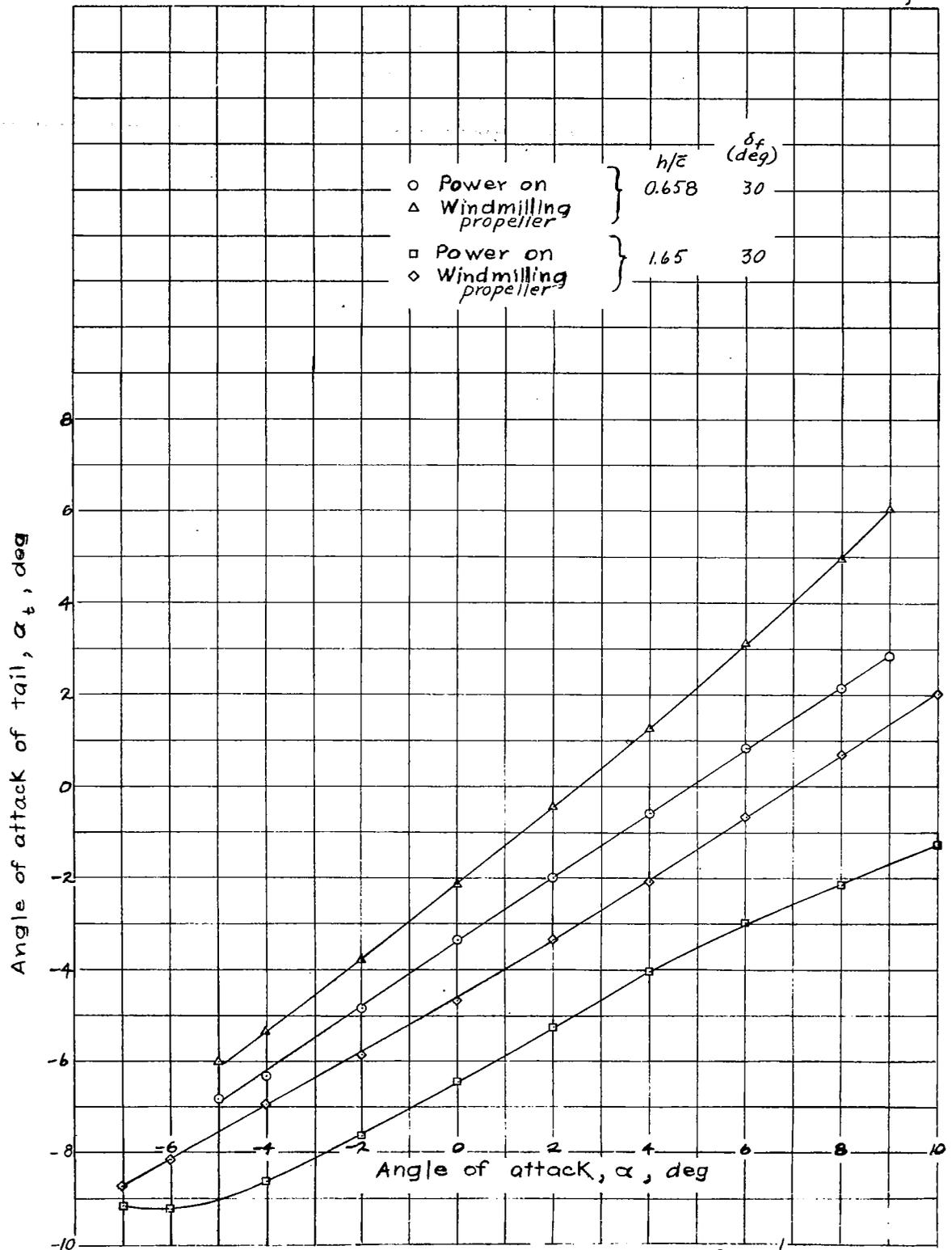
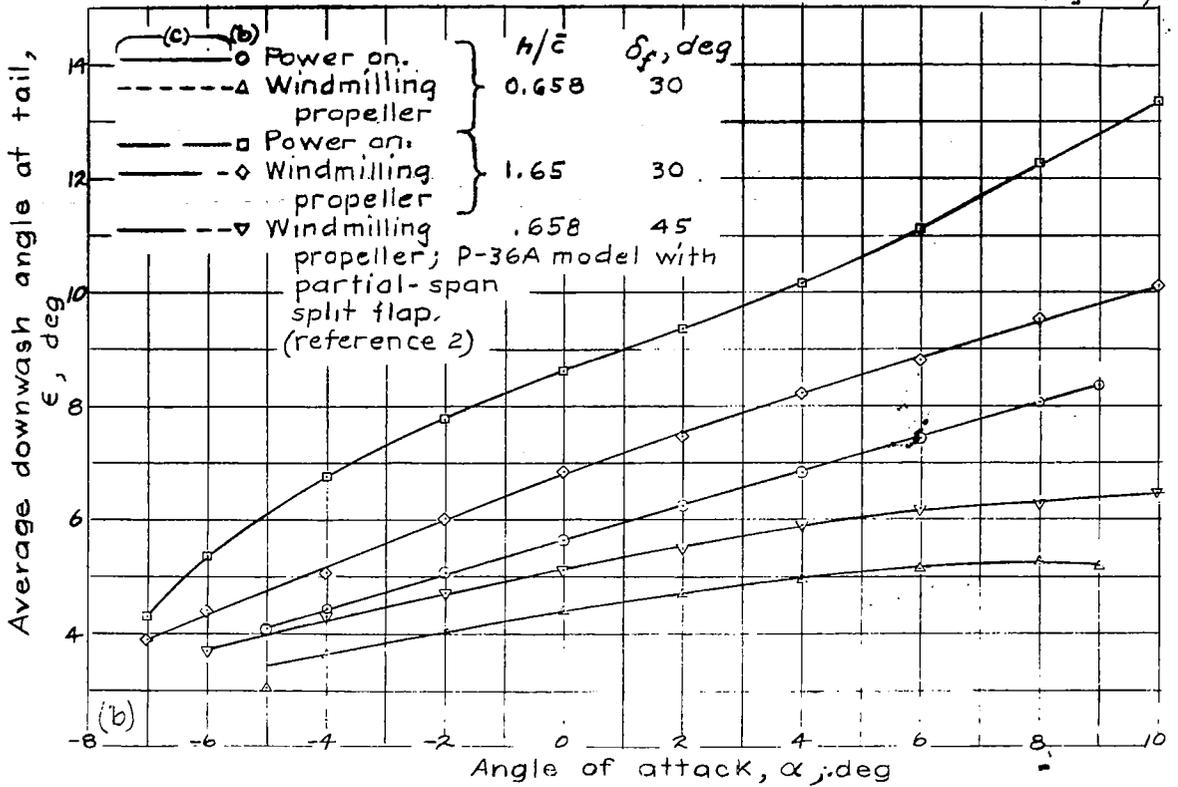


Figure 8.- Effect of power on pitching-moment coefficient due to tail of modified P-36 A low-wing model with full-span 0.25c slotted flap near ground.  $\delta_t, 30^\circ$ ;  $\delta_e, 0^\circ$ ;  $\beta, 25^\circ$ ;  $q, 16.37$  pounds per square foot.  $C_{m_t} = C_{m_{tail\ on}} - C_{m_{tail\ off}}$

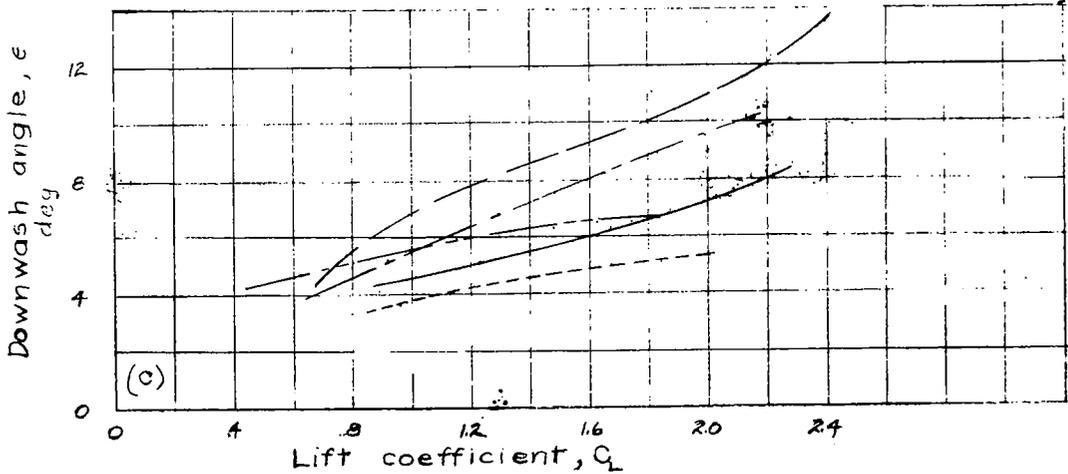


(a) Effect of power on angle of attack of the tail.  $\alpha_t = C_{m_t} \frac{1}{\delta C_m}$

Figure 9.-Effect of power on angles at the tail of the modified P-36A low-wing model with full span 0.25c slotted flap near ground.  $\delta_e, 0^\circ; \beta, 25^\circ; q, 16.37$  pounds per square foot.



(b) Effect of power on the downwash angle. Variation with model angle of attack.  $\epsilon = \alpha + \alpha_t - \alpha_{t'}$ .  
Figure 9.- Continued.



(c) Effect of power on the downwash angle. Variation with model lift coefficient.  
Figure 9.- Concluded.

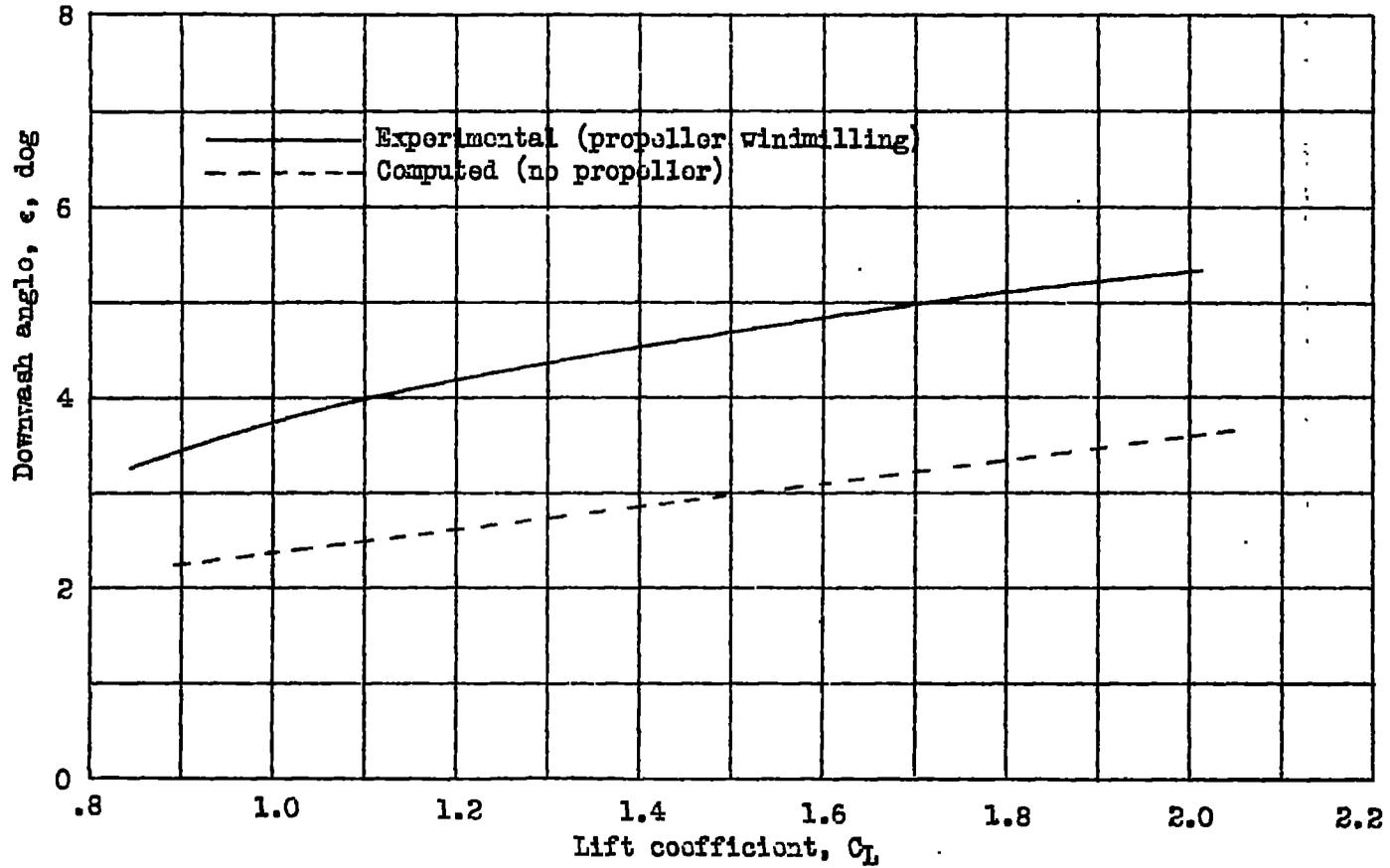


Figure 10.- Comparison between experimental and computed values of downwash angles for modified P-36A low-wing model with full-span 0.25c slotted flap near ground.  $\delta_t = 30^\circ$ ,  $h/c = .658$ .

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