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INVESTIGATION OVER MOVING GROUND PLANE OF A TRANSPORT AIRPLANE MODEL USING BLOWING OVER FLAPS FOR BOUNDARY-LAYER CONTROL

by Raymond D. Vogler

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INVESTIGATION OVER MOVING GROUND PLANE OF A TRANSPORT AIRPLANE MODEL USING BLOWING OVER FLAPS FOR BOUNDARY-LAYER CONTROL

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SUMMARY

An investigation at low speeds over a still and a moving ground plane was made to determine the effects of ground proximity on the longitudinal aerodynamic characteristics of a model of a transport airplane. The four-engine model was equipped for blowing over the flaps for boundary-layer control. Compressed air was used to furnish flap blowing as well as to furnish the thrust for the two inboard engines. The model was investigated in and out of ground effect through an angle-of-attack range, a flap blowing momentum range, and a thrust range.

Results show that flap blowing substantially increases (100 percent at $\alpha = 0^{\circ}$) the lift coefficient through the angle-of-attack range in or out of ground effect. The presence of the ground reduces the lift and drag coefficients and reduces the down load on the tail; thereby, more negative tail incidence is required for trim. The lift reduction increases with increase in flap blowing and height reduction to a maximum of about 20 percent of the out-of-ground-effect lift. The still and the moving ground planes show negligible difference in effect on model forces and moments except for the model very close to the ground and with a large amount of blowing momentum where the more realistic moving ground plane shows small increments of increased lift, decreased drag, and positive pitch when compared with the still ground plane.

INTRODUCTION

The effect of ground proximity on the aerodynamic characteristics of aircraft is of increasing importance for airplanes with high-lift devices such as jet flaps and vertical-lift jet engines. The ground in a wind tunnel is usually simulated by a false floor or board under the model. The simulation is not quite true in that the moving air in the tunnel produces a boundary-layer velocity gradient adjacent to the ground board which does not exist in actual flight in still air. The effect of the boundary layer on tunnel data has in the past been neglected, but with jet flaps and jet-lift engines, impingement of the jet on the tunnel ground board would cause boundary-layer separation. Whether the separation has a significant effect on the model data depends upon the particular model configuration (ref. 1).

A number of methods have been used in getting model data in which the problem of boundary-layer separation has been avoided or alleviated. References 2 and 3 report the results of a moving model over a stationary ground plane. Reference 4 reports the use of an image model to simulate a ground midway between the model and the image model. In the present investigation, the ground plane was a belt that moved with approximately the same speed as the free-stream tunnel air. This setup prevented the buildup of any boundary layer on the ground plane.

The purposes of this investigation were (1) to determine the aerodynamic characteristics of the model at low speed in the presence of a moving ground plane with the model operating under various combinations of thrust and blowing over deflected flaps and (2) to determine any differences between the data obtained with the model over a moving and over a stationary ground plane.

SYMBOLS

The force and moment data are presented about the stability axes. The units of measure used in this report are given in the International System of Units (SI). (See ref. 5.)

b wing span, centimeters

$\bar{c}$ mean aerodynamic chord of wing, centimeters

C_L lift coefficient, $\frac{\text{Lift}}{qS}$

C_D drag coefficient, $\frac{\text{Drag}}{qS}$

C_m pitching-moment coefficient about $0.30\bar{c}$, $\frac{\text{Pitching moment}}{qS\bar{c}}$

$\Delta C_L, \Delta C_D, \Delta C_m$ incremental lift, drag, and pitching-moment coefficients

C_j jet engine thrust coefficient, $\frac{\text{Engine thrust}}{qS}$

C_μ flap blowing momentum coefficient, $\frac{\dot{m}V}{qS}$

h height of model above ground plane, measured to quarter-chord point of $\bar{c}$ (model with power off, $\alpha = 0^{\circ}$, and $q = 0$), centimeters

i_t incidence of horizontal tail with respect to wing chord plane, degrees

$\dot{m}$ mass rate flow from nozzles in wing, kilograms per second

q free-stream dynamic pressure, 412 newtons per square meter

S wing area, square meters

V jet velocity from nozzles in wing, based on isentropic expansion from wing-plenum-chamber total pressure to tunnel static pressure, meters per second

α fuselage angle of attack, degrees (Wing incidence = 2°)

$\alpha_{t,o}$ tail angle of attack for zero lift on the tail, degrees

δ_f flap deflection, degrees

ϵ downwash angle, degrees

MODEL AND APPARATUS

The model with the vertical tail removed was a 0.068-scale model of a commercial transport airplane. A three-view drawing of the model is shown in figure 1 and photographs of the model over the moving ground plane are shown in figures 2 and 3. The vertical cable shown in the photographs was attached to the model near the moment center and to a counterweight outside the test section. (See fig. 4.) Without the counterweight, the model weight would have exceeded the load capacity of the balance. The cable passed over pulleys, allowing vertical movement of the counterweight as the model height changed.

The four-engine model had leading-edge slats and plain flaps on the wing and leading-edge slats on the horizontal tail. Boundary-layer control was obtained by blowing over the flaps from nozzles in the wing. High pressure air was brought to the model through two tubes having a diameter of 1.90 centimeters. One tube furnished air for blowing over the flaps and the other tube supplied thrust power to the two inboard engines. The two outboard engines were not powered since they were outboard of the deflected flaps.

Desired thrust and blowing momentum were maintained by monitoring total pressures in the engine exits and wing plenum chambers.

A sketch showing the model, sting support system, and the moving ground plane (belt) in the 17-foot (5.18-meter) test section of the Langley 300-MPH 7- by 10-foot tunnel is shown in figure 4. The air lines were securely anchored to the top of the vertical section of the sting. The lines from the model to the anchor point were shielded from the free stream as shown in the photographs (figs. 2 and 3). The telescoping vertical arm of the sting system provided model vertical movement, and angle of attack was varied by pitching the sting system by moving it along a sector of a vertical circular track.

The moving ground plane was obtained by means of a fabric belt between two rollers driven by an electric motor. The boundary layer on the tunnel floor upstream of the belt was removed with a suction slot just upstream of the belt. Boundary-layer buildup on the moving ground plane could be prevented by making the belt velocity approximately equal to the free-stream velocity.

TESTS AND CORRECTIONS

Tests were made with the model at heights from the ground plane of 10 to 69 percent of the model span. Landing-wheel touchdown is at a height of 9.4 percent span. The angle of attack ranged from -4° to 16° with the model out of ground effect and from 0° to 8° at the position nearest to the ground plane. Most of the data were obtained with the flaps deflected 60° though some were obtained at deflections of 30° and 70°. Various combinations of engine thrust and blowing over the flaps were used throughout the range of heights over the ground plane. The jet flap blowing coefficient C_{μ} was varied from 0 to 0.15, and the engine thrust coefficient C_j was varied from 0 to 0.32. All tests were run at a free-stream dynamic pressure of 412 newtons per square meter.

Data at all model heights above the ground plane (except at $h/b = 0.69$, which is considered out of ground effect) were obtained with the ground plane moving with approximately free-stream velocity. A few tests with the model at various heights and several tests with the model close to the ground plane ($h/b = 0.10$) were made with the ground plane stationary to determine the effect of the moving ground plane. The height of the model was measured with the model at rest at $\alpha = 0^{\circ}$, and this height h is the height of the model above the ground plane measured to the quarter-chord point of the wing mean aerodynamic chord. This height increases with model lift because of the bending of the sting system. The measured height also increases as the angle of attack increases since the pivot center of the circular track supporting the sting system is above and downstream of the mounting point of the model. The corrected ratio of the height of the quarter-chord point of the mean aerodynamic chord to the model span may be obtained from the following equation:

$$\left(\frac{h}{b}\right)_{corrected} = 0.3582(1 - \cos\alpha) + 0.1695 \sin\alpha + \cos\alpha\left[\frac{h}{b} + 0.00426\left(C_L \cos\alpha + C_D \sin\alpha\right)\right]$$

The correction to the measured height ratio is generally small but can reach a maximum of 0.03 or 0.04 at high angles of attack near the ground plane.

No blockage or jet-boundary corrections to the data have been made. Blockage corrections to the free-stream velocity are negligible in this tunnel for conventional models. Reference 6 indicates that jet-boundary corrections for model heights and wake deflection angles encountered in this investigation would be small or negligible for all model heights except the greatest.

RESULTS AND DISCUSSION

Presentation of Results

Basic wind-tunnel data showing the longitudinal aerodynamic characteristics of the model for various distances (heights) from the ground plane and for various power and flap blowing conditions are presented in figures 5 to 14. Some summarizing plots giving more detailed effects of the ground plane are presented in figures 15 to 18. A description of the contents of these data figures is presented in the following table:

Figure	Description	h/b	δ_f, deg	C_μ	C_j	i_t, deg
5	Effect of ground, power off, no flap blowing	0.10 to 0.69	30	0	0	-6
6	Effect of ground, power off, flap blowing	0.10 to 0.69	70	0 to 0.15	0	-6
7	Effect of ground, power on, flap blowing	0.10 to 0.69	60	0 to 0.15	0 to 0.32	Tail off
8	Effect of ground, power on, flap blowing	0.10 to 0.69	60	0 to 0.10	0 to 0.32	-6
9	Effect of moving ground plane	0.10 to 0.41	60	0.10	0.32	-6
10	Effect of thrust, flap blowing	0.69	60	0 to 0.15	0 to 0.32	Tail off
11	Effect of thrust, flap blowing	0.69	60	0 to 0.10	0 to 0.32	-6
12	Effect of thrust, flap blowing	0.69	60	0 to 0.10	0 to 0.32	-10
13	Effect of horizontal tail, away from ground plane	0.69	60	0 to 0.10	0 to 0.32	Range
14	Effect of horizontal tail, near the ground plane	0.12	60	0 to 0.10	0 to 0.32	Range
15	Incremental coefficients due to ground effect	0.10 to 0.25	60	0 to 0.10	0 and 0.32	-6
16	Comparison of ground-plane effects	0.10 and 0.69	60	0 to 0.10	0 and 0.32	-6
17	Incremental coefficients produced by moving ground plane	0.10	60	0 to 0.10	0 to 0.32	-6
18	Downwash angles over the horizontal tail	0.12 and 0.69	60	0 to 0.10	0 to 0.32	-------

The method of coping with the excessive weight of the model and the air-line attachments to the model resulted in restraints on the model which are not ordinarily present in wind-tunnel testing. These restraints were determined for model configurations through the angle-of-attack range for each model height from the ground plane for wind-off conditions and subtracted from the force and moment readings for the wind-on tests. However, these restraints or other factors have produced some scatter in the basic data.

Longitudinal Aerodynamic Characteristics
Over Moving Ground Plane

The effect of the ground plane on the model longitudinal aerodynamic characteristics is shown in figures 5 to 8. Only a few runs at various heights were made without thrust or flap blowing at a flap deflection of 30° (fig. 5). At a flap deflection of 70° (fig. 6), data were obtained at all model heights through the flap momentum range and at zero thrust. The remainder of the basic data at a flap deflection of 60° included the effects of height, thrust, and blowing momentum. Comparison of figures 6(a) and 8(a) indicates little difference between the out-of-ground effect data for the model with a flap deflection of 60° and those for the model with a flap deflection of 70°. The 70° flaps are a little more effective in ground effect. In either case, the model usually shows a larger lift coefficient in ground effect than out of ground effect at zero angle of attack. However, the fact that this condition is reversed when the tail is removed (fig. 7(a)) indicates that the increased lift in ground effect at $\alpha = 0^{\circ}$ is largely a result of the reduction in down load on the tail as it encounters ground effect. Thus, the change in lift-curve slope at various model heights (figs. 6(a) and 8(a)) results primarily from the ground effect on the tail. An analysis of the incremental pitching moments resulting from the tail without flap blowing (figs. 7 and 8) indicates that at high angles of attack the down load on the tail out of ground effect becomes an up load as the model moves close to the ground.

The preceding discussion was with reference to the model without flap blowing. With flap blowing, the lift coefficients are substantially increased (about doubled at $\alpha = 0^{\circ}$) in or out of ground effect, and the major effect of the ground on the model is a result of the effects of the ground on the wing rather than on the tail. With the tail off or on (figs. 7 and 8), there is a severe loss in lift as the model approaches the ground plane. The loss increases with increase in angle of attack and flap blowing momentum as well as with reduction in model height. Maximum lift in ground effect usually occurs at about $\alpha = 8^{\circ}$ and at this angle of attack the lift-coefficient loss is about 20 percent of the out-of-ground-effect lift coefficient. This percentage loss remains about the same for all flap blowing momentum values though the incremental values increase with increased blowing. These incremental values at zero and at maximum thrust conditions are shown in figure 15 as a function of model height for various angles of attack and flap blowing momentums. These increments were obtained from the basic data of figure 8 by subtracting from the tabulated in-ground-effect values the out-of-ground-effect values.

The data also show that large reductions in drag occur as the model approaches the ground plane with or without flap blowing momentum (figs. 5 to 8 and 15). One would normally expect drag reductions to accompany reductions in lift, but at the same lift coefficient (though at higher angles of attack) the drag in ground effect is much less than the drag out of ground effect. As in the lift case, the drag continued to decrease as the model got nearer the ground plane up to the minimum distance investigated. The increments of drag reduction (fig. 15) also increase with increase in angle of attack. The increments of drag in figure 15 were not determined at equivalent lift coefficients but at a common angle of attack for both in and out of ground effect.

The tail-off model is about neutrally stable at small angles of attack out of ground effect with or without blowing over the flap (fig. 7). The pitching moments become less negative as the ground is approached and the model becomes highly unstable especially with flap blowing and at increased angles of attack. The presence of the ground plane and the spanwise flow toward the wing tips result in a lift loss outboard on the swept wing. The addition of the horizontal tail at -6° of incidence (fig. 8) stabilizes the model and provides trim at small to moderate angles of attack in or out of ground effect with no flap blowing. With flap blowing and in ground effect, a tail incidence of -6° is insufficient to trim the model because of the reduced downwash at the tail in the presence of the ground plane. The model usually shows an increase in stability with reduction in height above the ground with tail on (fig. 8) as contrasted with increased instability with tail off (fig. 7). The incremental values of pitching-moment coefficient through the height range ($h/b = 0.10$ to 0.25) at various angles of attack are given in figure 15.

The effect of engine thrust as found by examining figures 7 and 8 are about as expected. As the thrust is increased the maximum lift is increased and the drag reduced since the lift and drag include components of the thrust. At zero angle of attack where the lift component of the thrust is zero or negligible, there is an appreciable increase in lift with an increase in thrust with no flap blowing. This would indicate that the jet efflux impinging on the lower surface of the flap is improving the flow over the flap. The improvement is present with the small values of flap blowing but has disappeared with maximum flap blowing momentum. These effects may be seen more directly in figures 10 and 11 in which the out-of-ground-effect data of figures 7 and 8 have been replotted, and also in figure 13. Since the thrust line of the engine is below the moment center of the model, thrust increases the nose-up moment of the model (fig. 10) except when there is no blowing over the flap (fig. 10(a)). In this case, the increment of negative pitching moment resulting from improved flow over the flap cancels the positive moment produced by the engine thrust. Thrust has negligible effect on the stability of the model.

Comparison of Still- and Moving-Ground-Plane Effects

Early in the investigation some runs were made to determine any differences in measured forces and moments on the model over a still and a moving ground plane.

Experience with other models has shown that any differences would most likely occur with the model close to the ground plane and with high momentum jets impinging on the ground plane. Results obtained for the present model at several heights above the ground plane are shown in figure 9 and support the results from previous experience. Data with and without the ground plane (belt) moving were obtained only at the closest positions ($h/b = 0.10$) for the range of thrusts and flap blowing momentums (fig. 8). Figure 16 gives a comparison of the coefficients for the model in and out of ground effect with and without the ground plane moving for the flap blowing momentum range $\left(C_\mu = 0 \text{ to } 0.10\right)$. The comparison shows that the differences between the data for the still and the moving ground plane are roughly 5 to 15 percent of the ground effect at $h/b = 0.10$ and maximum flap blowing. The curves of figure 16 were plotted from tabulated data and are presented mainly to show the relative effects between ground-plane conditions and ground effect for two angles of attack. The incremental effects of the moving ground plane through a range of angle of attack, flap blowing momentum, and thrust are presented in figure 17. These curves were determined by plotting the data of figure 8 against angle of attack and obtaining the increments from faired curves. The data show that when the model is close to the ground plane, the more realistic moving ground plane generally shows small increments of increased lift, decreased drag, and positive pitch when compared with the still ground plane. There is little variation in incremental coefficients with angle of attack or thrust.

Tail Effectiveness and Downwash Angles

The effect of the horizontal tail with various amounts of negative incidence is shown in figures 13 and 14 for the out-of-ground and in-ground conditions, respectively. The large diving moments of the basic wing-flap-fuselage combination are greatly increased by flap blowing momentum in or out of ground effect as shown by the tail-off pitching-moment data. Under these conditions the tail must produce a large down force to trim the model. This force is obtained by using a large airfoil with inverted leading-edge slats and negative incidence. Large downwash angles are favorable if the tail does not stall. Figure 13 shows that a tail incidence of -10° is sufficient to trim the model out of ground effect up to a lift coefficient of about 2.3; whereas, in ground effect (fig. 14) this tail incidence is able to trim up to a lift coefficient of only about 1.6. When the model is out of ground effect, the load on the tail is downward and is reduced some by model angle of attack; but, in ground effect, the down load is reduced more rapidly as the angle of attack is increased and even becomes an up load for some conditions, as can be seen from the lift curves of figures 14(g), 14(h), and 14(i). Larger negative incidences than -10° were not investigated in ground effect; however, an incidence of -15° (fig. 13(i)) was investigated out of ground effect and gave a pitching-moment curve that indicated more than adequate trimming power and good stability through the angle-of-attack range.

The pitching moments of figures 13 and 14 were plotted against tail incidence for various angles of attack, and the average downwash angles at the tail were determined from the relation $\alpha_{tail} = i_t + \alpha_{wing} - \left(\epsilon + \alpha_{t,o}\right)$. The expression $\alpha_{t,o}$ of this equation takes into account the fact that the tail angle of attack for zero lift on the tail is not zero since the tail has a leading-edge slat. The value of this term is unknown but is constant. A linear variation of pitching moment with tail incidence was assumed and the lines were extrapolated to zero tail incidence. The fact that only two points were usually available for determining each line may account for some of the irregular variation in $\epsilon + \alpha_{t,o}$ shown plotted in figure 18. With the model out of ground effect (fig. 18(a)), the downwash angles increase with model angle of attack and with flap blowing momentum; such trends are desirable. With the model in ground effect (fig. 18(b)), the downwash angles are greatly reduced. The fact that there is little increase in downwash angle with model angle of attack accounts for some of the loss in down load on the tail mentioned previously. Thrust has little effect on the downwash angles in or out of ground effect with flap blowing, but thrust tends to reduce the downwash angle in ground effect without flap blowing.

SUMMARY OF RESULTS

An investigation was made of the low-speed longitudinal aerodynamic characteristics of a model of a transport airplane over a moving ground plane. The swept-wing four-engine model had leading-edge slats on the wing and tail and partial-span wing flaps, usually deflected 60°. Compressed air from nozzles in the wing was blown over the flaps for boundary-layer control. The two inboard engines were also powered with compressed air.

Results are as follows:

1. With flap blowing, the lift coefficients are substantially increased (about doubled at $\alpha = 0^{\circ}$) in or out of ground effect.

2. With flap blowing, the presence of the ground produces a reduction in lift coefficient which increases with angle of attack, flap blowing momentum, and reduction in model height. The maximum reduction for the conditions investigated is about 20 percent of the out-of-ground-effect lift coefficient. The presence of the ground also gives large reductions in drag coefficient, increases model stability, and requires more negative tail incidence for trim as a result of decreased downwash angles.

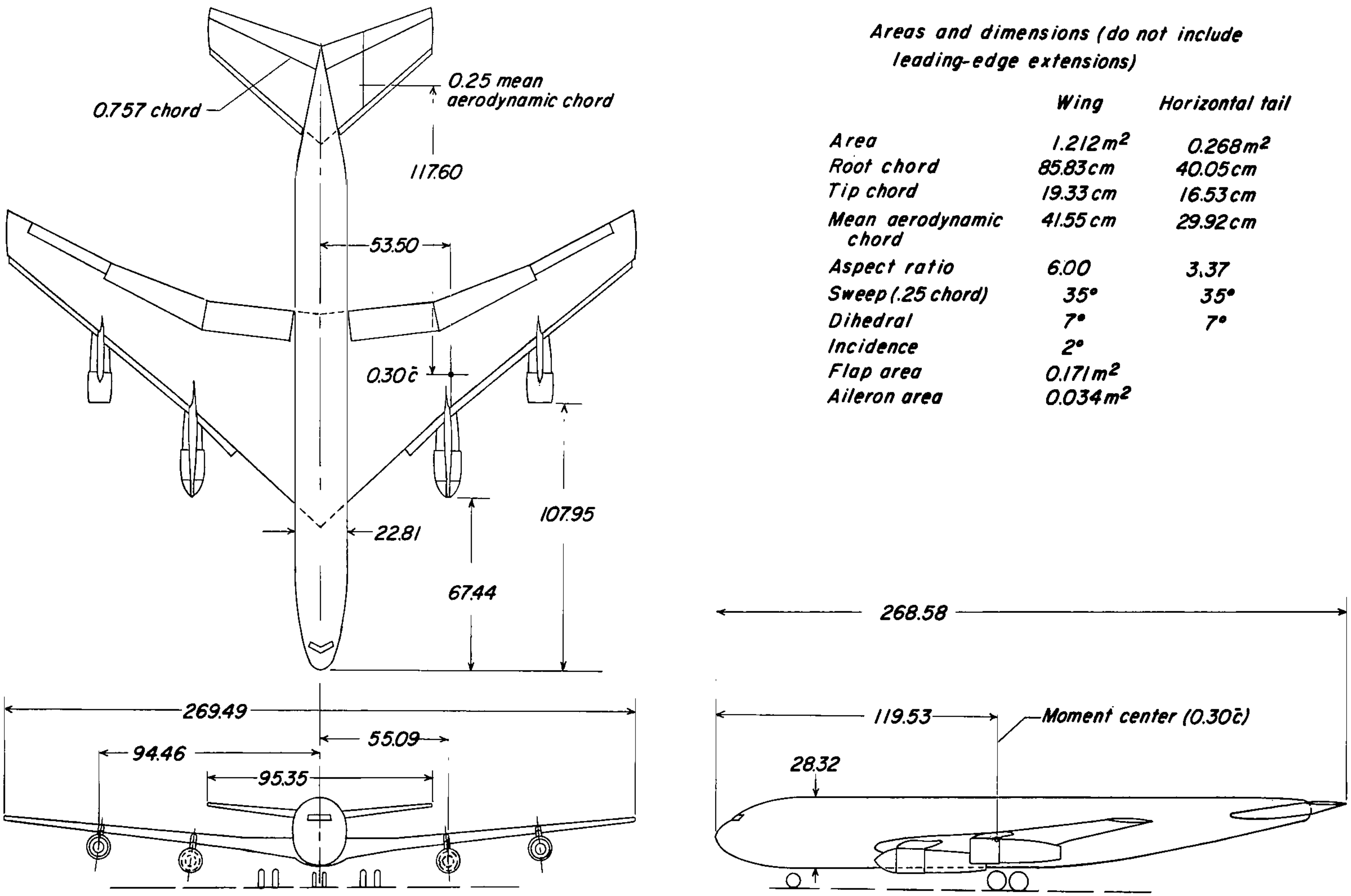
3. The difference between the still- and the moving-ground-plane effects on model forces and moments is negligible except for the model very close to the ground with a large amount of flap blowing momentum. With the model at a height above the ground plane of 10 percent of the span, measured from the quarter-chord point of the mean

aerodynamic chord, the more realistic moving ground plane generally shows small increments of increased lift, decreased drag, and positive pitch when compared with the still ground plane.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., January 24, 1967,
721-01-00-16-23.

REFERENCES

1. Turner, Thomas R.: Endless-Belt Technique for Ground Simulation. Conference on V/STOL and STOL Aircraft, NASA SP-116, 1966, pp. 435-446.
2. Turner, Thomas R.: Ground Influence on a Model Airfoil With a Jet-Augmented Flap as Determined by Two Techniques. NASA TN D-658, 1961.
3. Curtiss, H. C., Jr.; Putman, W. F.; and Traybar, J. J.: The Princeton Dynamic Model Track. AIAA Aerodynamic Testing Conference, Mar. 1964, pp. 33-41.
4. Fink, Marvin P.; and Lastinger, James L.: Aerodynamic Characteristics of Low-Aspect-Ratio Wings in Close Proximity to the Ground. NASA TN D-926, 1961.
5. Mechtly, E. A.: The International System of Units – Physical Constants and Conversion Factors. NASA SP-7012, 1964.
6. Heyson, Harry H.: Linearized Theory of Wind-Tunnel Jet-Boundary Corrections and Ground Effect for VTOL-STOL Aircraft. NASA TR R-124, 1962.



Areas and dimensions (do not include leading-edge extensions)

	Wing	Horizontal tail
Area	1.212 m^2	0.268 m^2
Root chord	85.83 cm	40.05 cm
Tip chord	19.33 cm	16.53 cm
Mean aerodynamic chord	41.55 cm	29.92 cm
Aspect ratio	6.00	3.37
Sweep (.25 chord)	35°	35°
Dihedral	7°	7°
Incidence	2°	
Flap area	0.171 m^2	
Aileron area	0.034 m^2	

Figure 1.- **Three-view drawing of the model. All dimensions are in centimeters.**

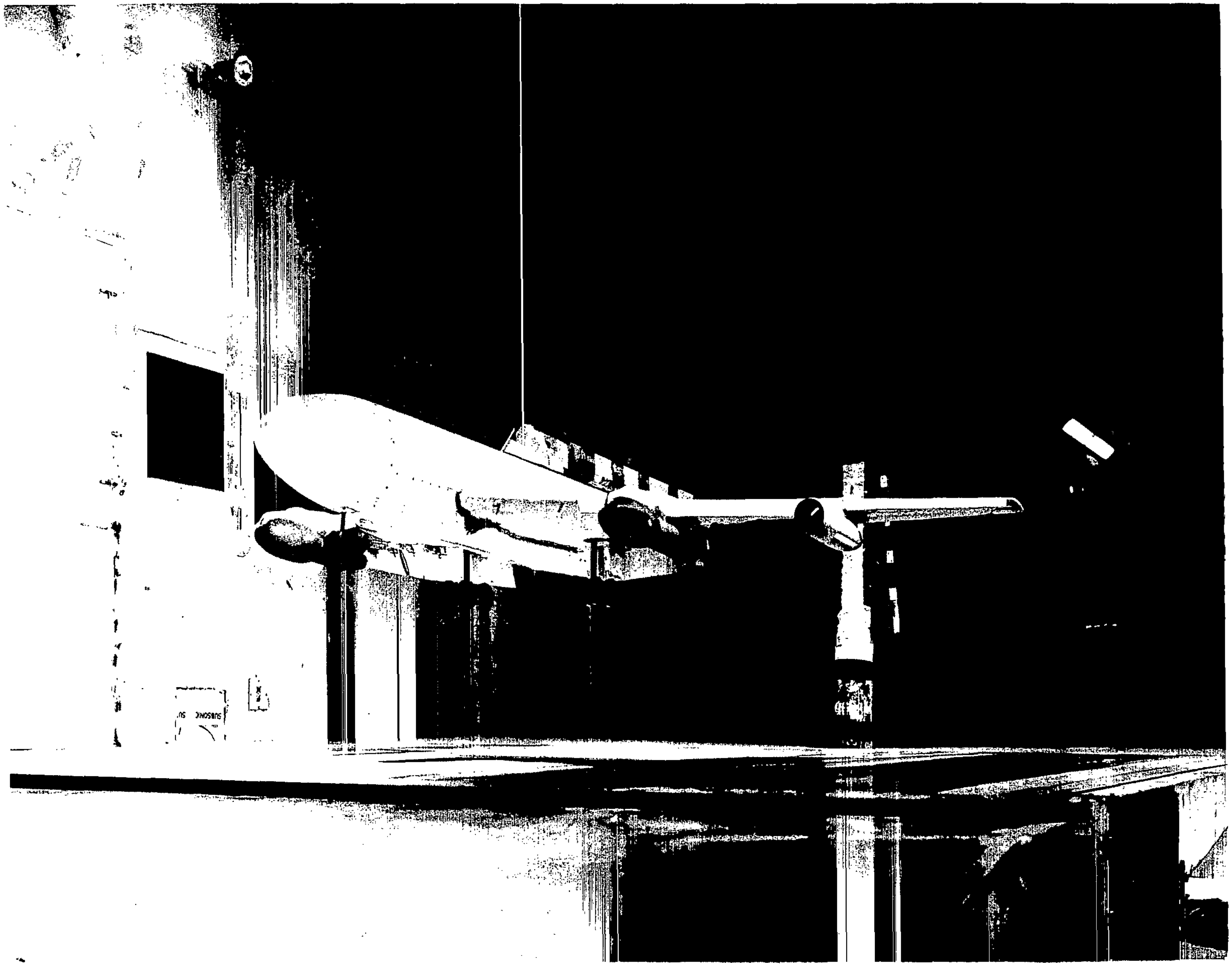


Figure 2.- Bottom view of the model. L-65-233

Figure 3.- Top view of the model near the moving ground plane. L-65-234

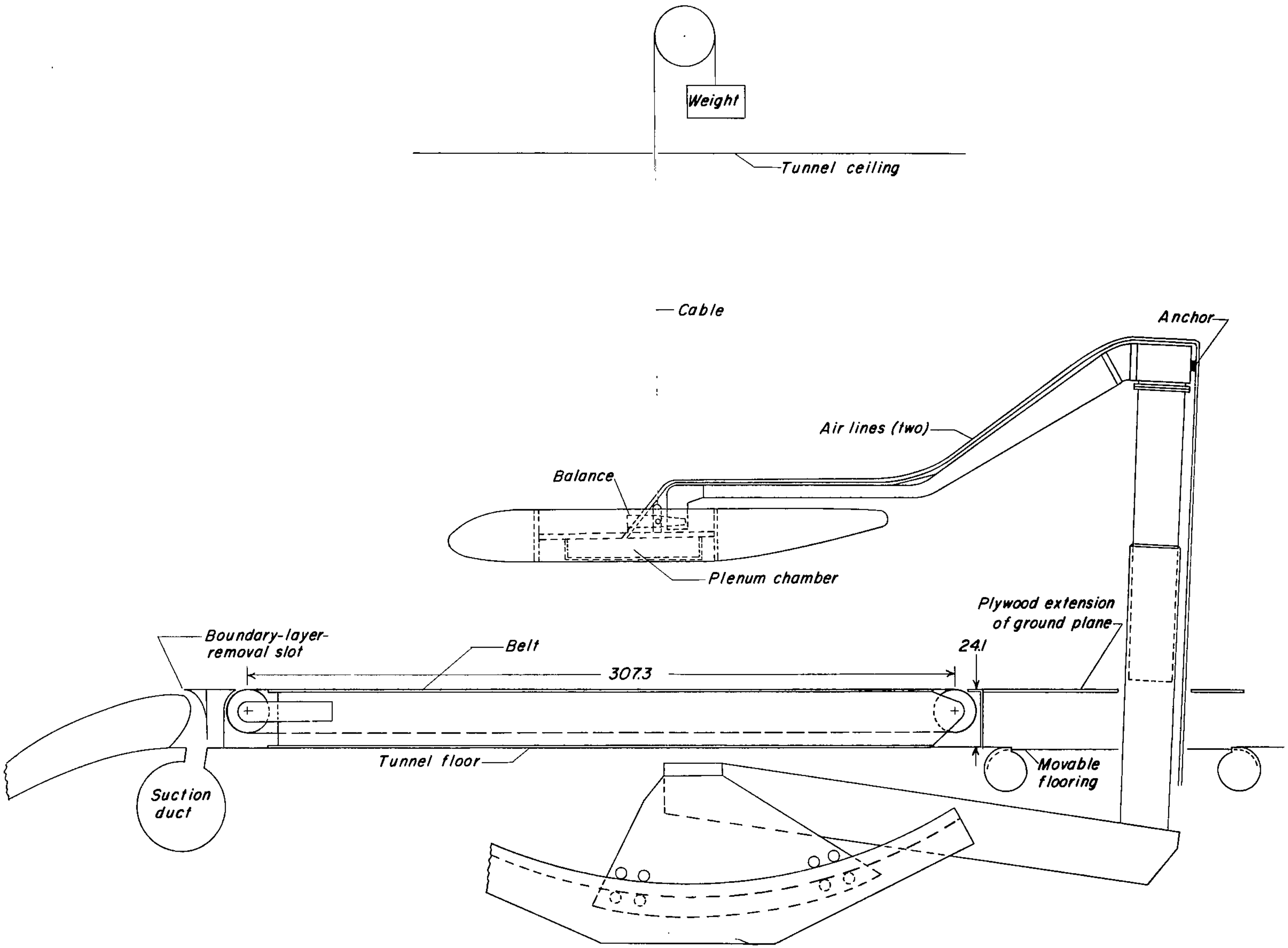


Figure 4.- Sketch showing model, sting support system, ground belt, and air lines, with shield over air lines removed. Dimensions are in centimeters.

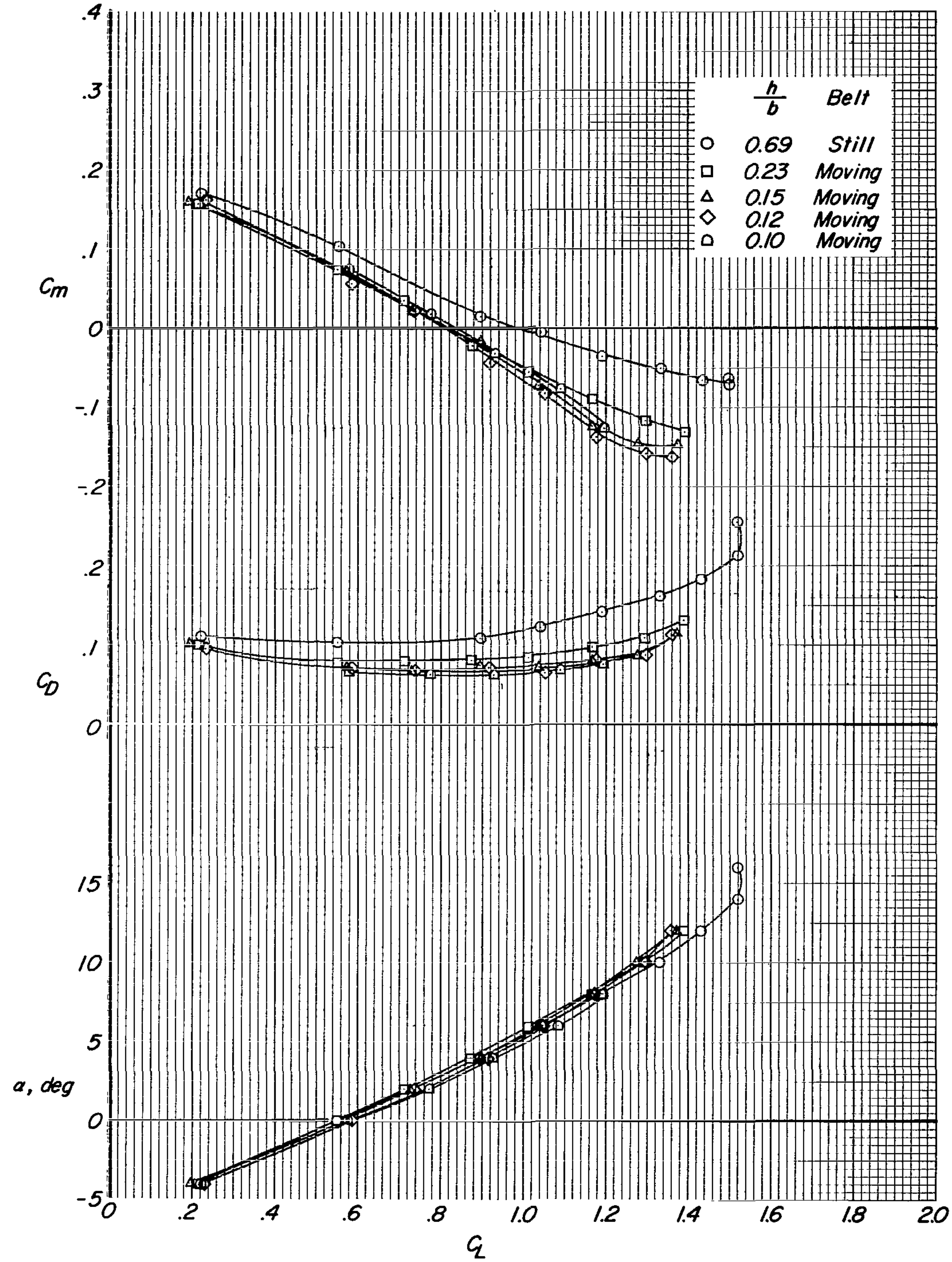
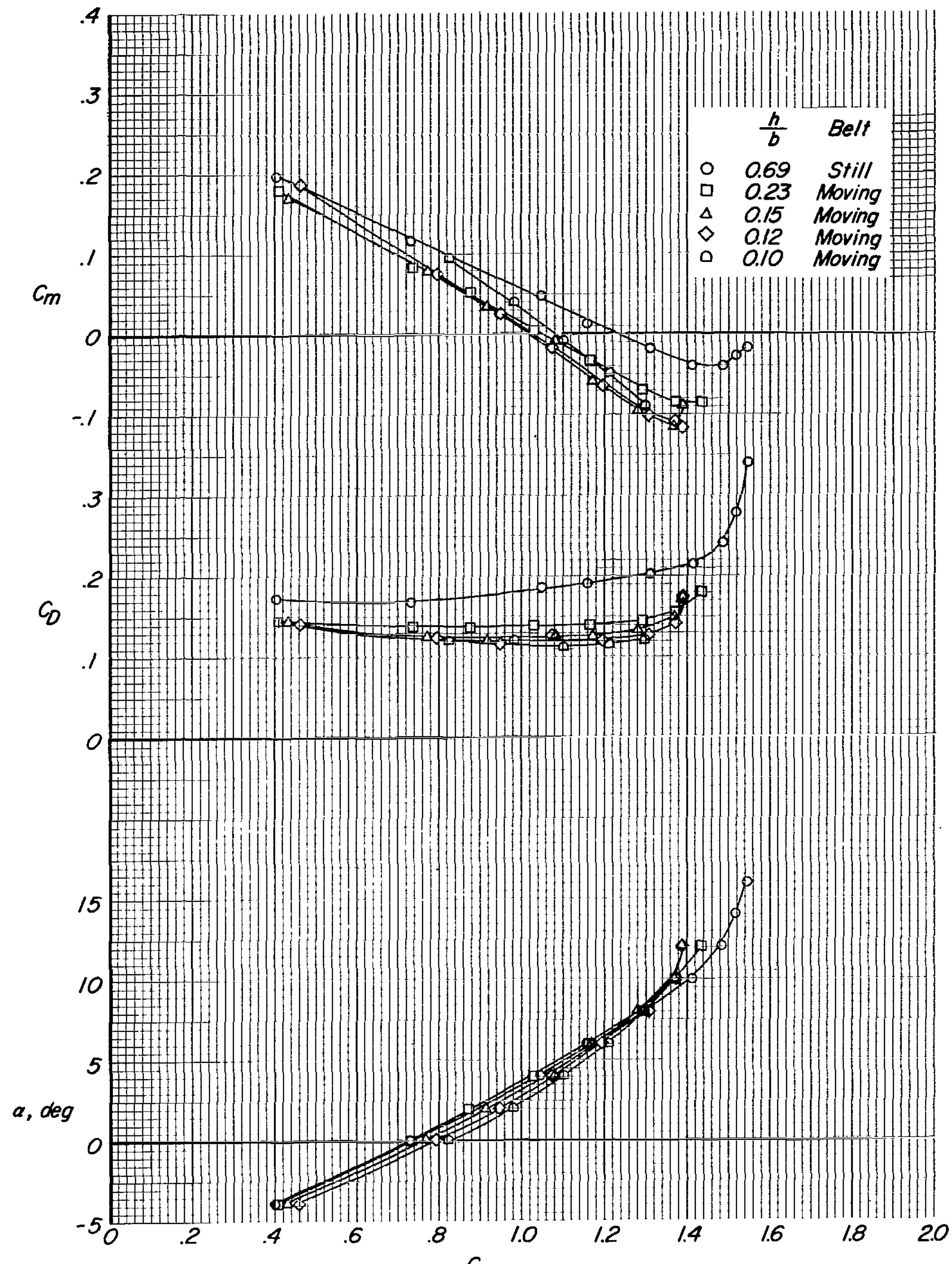
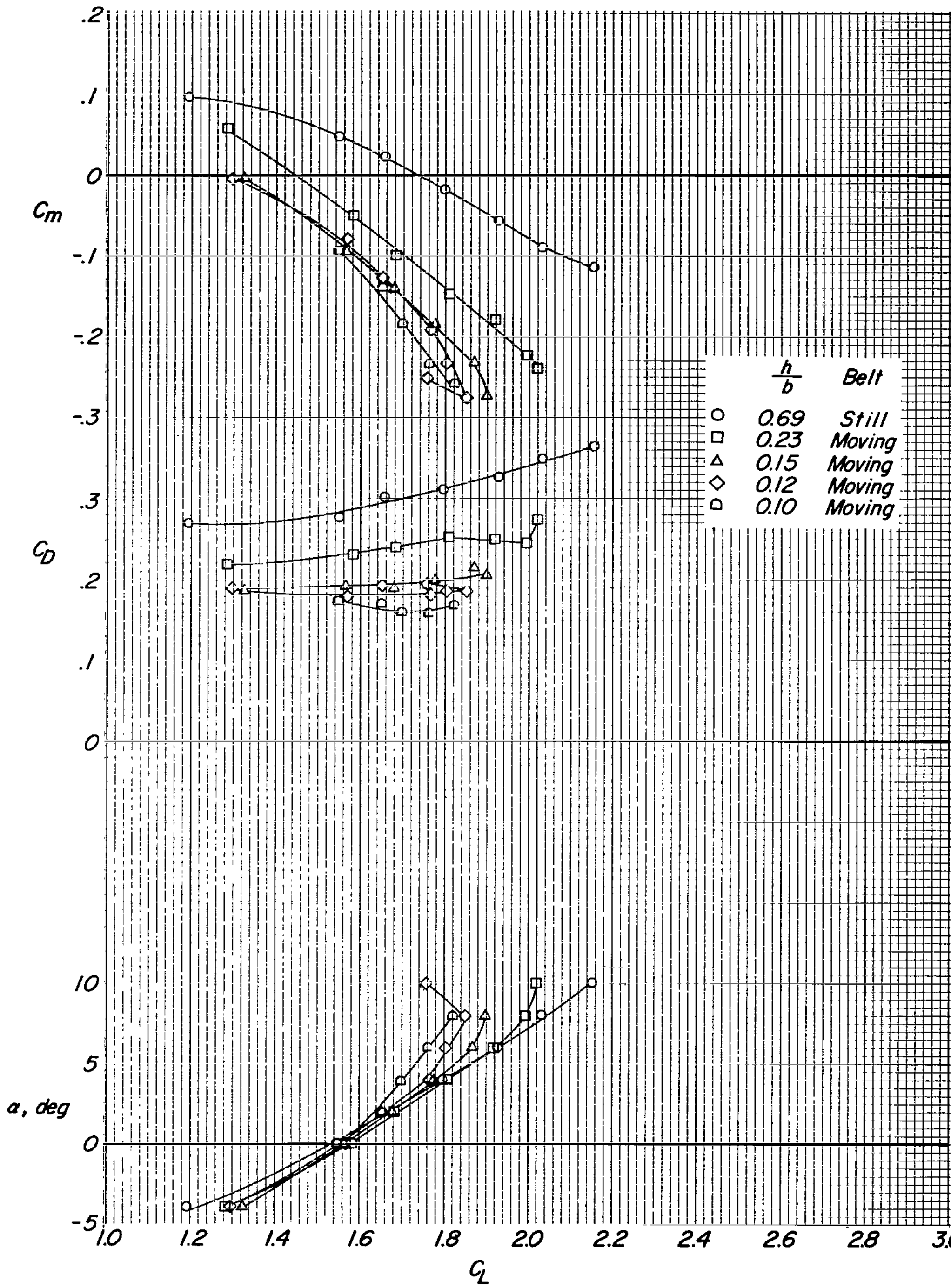


Figure 5.- Effect of the ground plane on the characteristics of the model at various heights with no thrust and no flap blowing. $\delta_f = 30^\circ$; $C_\mu = 0$; $C_j = 0$; $i_t = -6^\circ$.



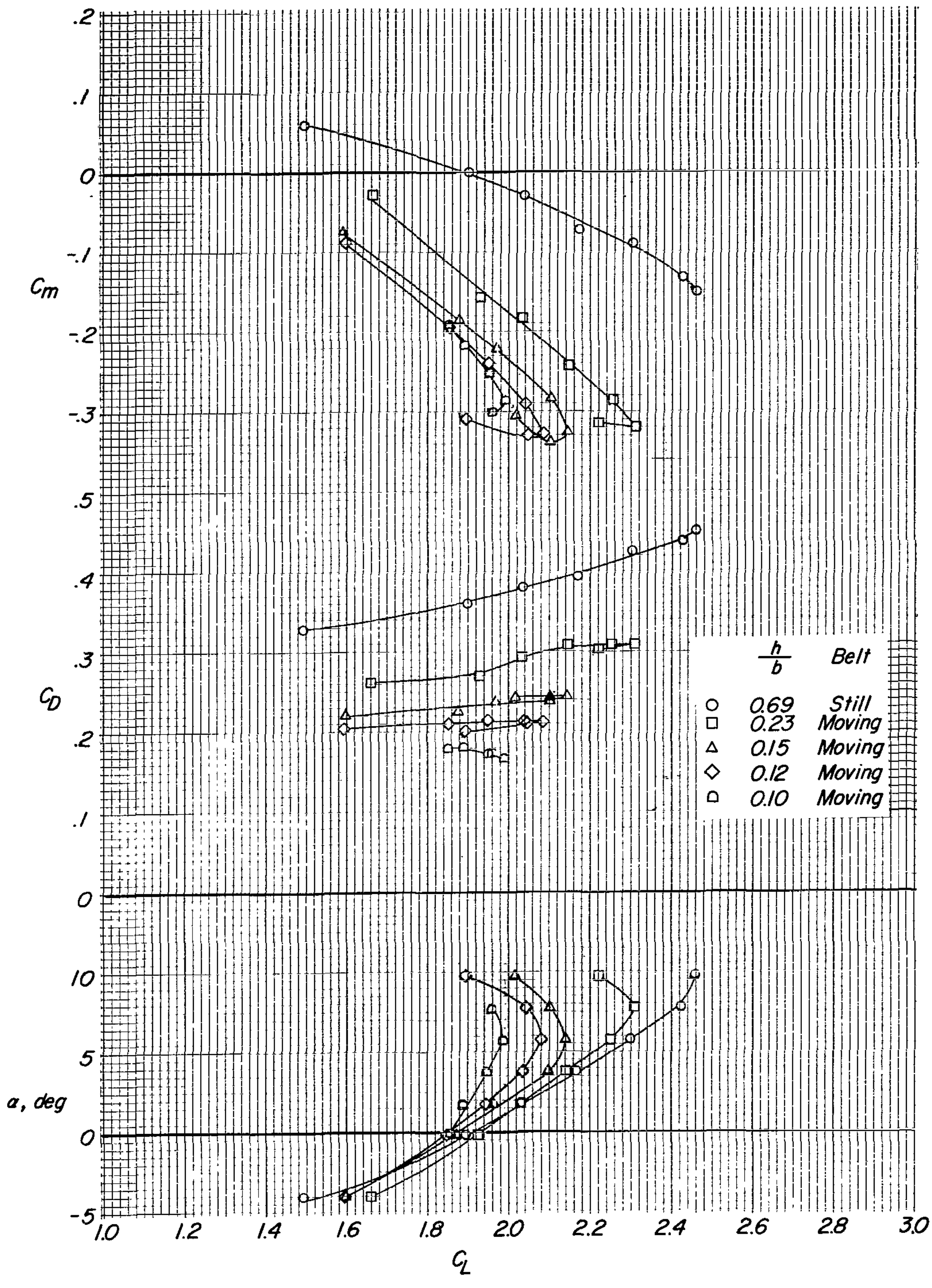
(a) $C_\mu = 0$.

Figure 6.- Effect of the ground plane on the characteristics of the model at various heights for different flap blowing momentums. $\delta_f = 70^0$; $C_j = 0$; $i_t = -6^0$.



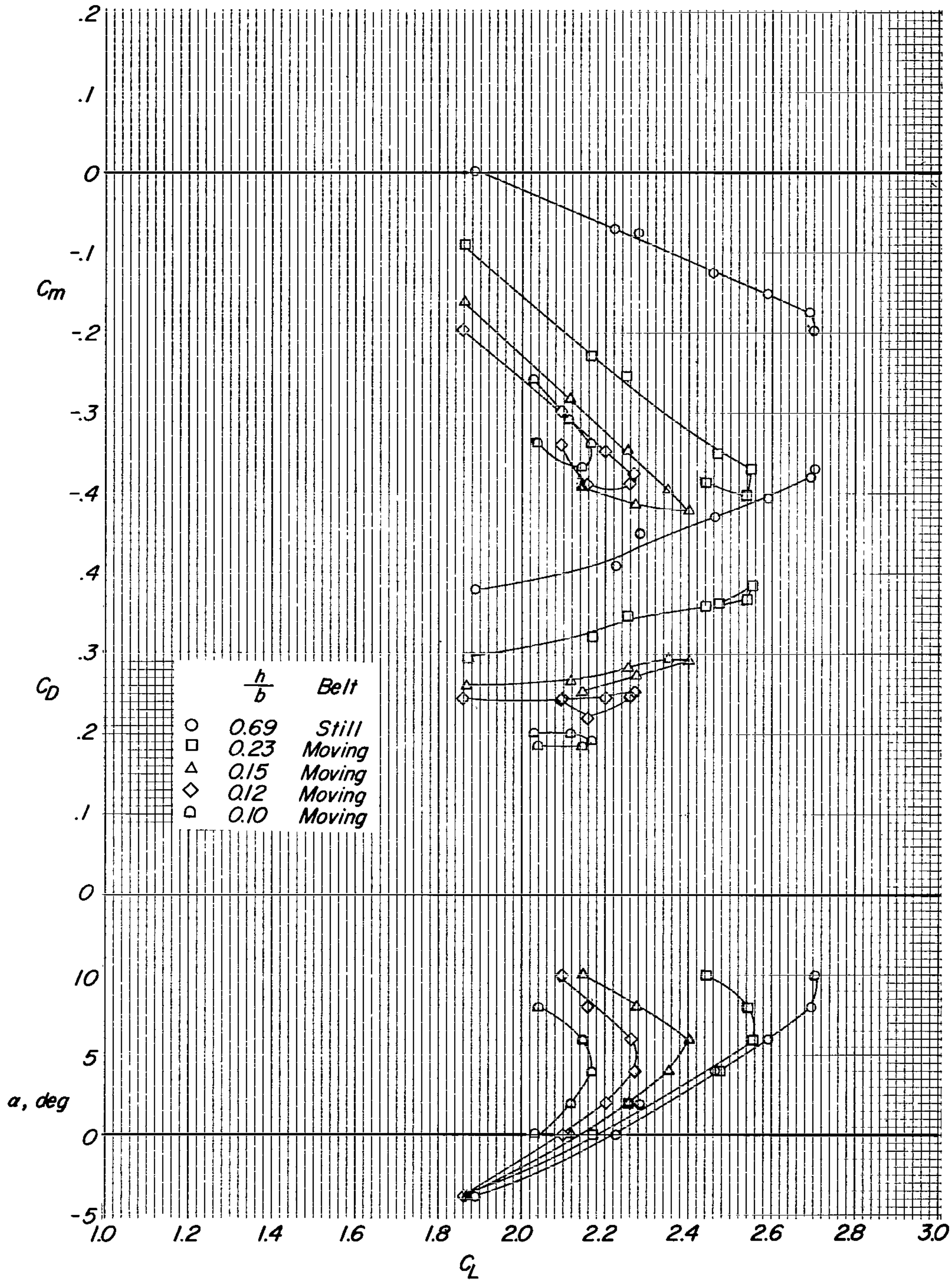
(b) $C_\mu = 0.05$.

Figure 6.- Continued.



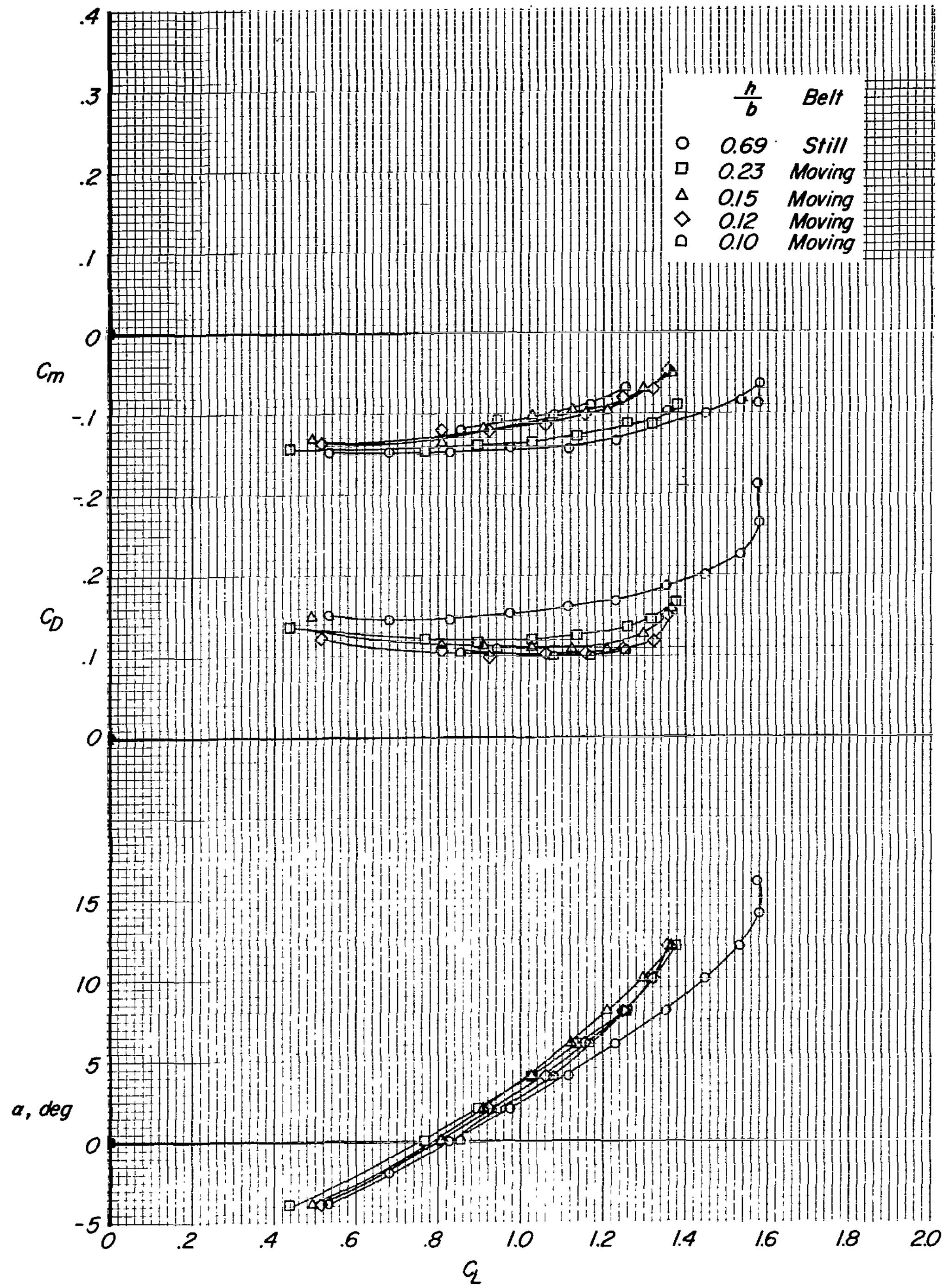
(c) $C_\mu = 0.10$.

Figure 6.- Continued.



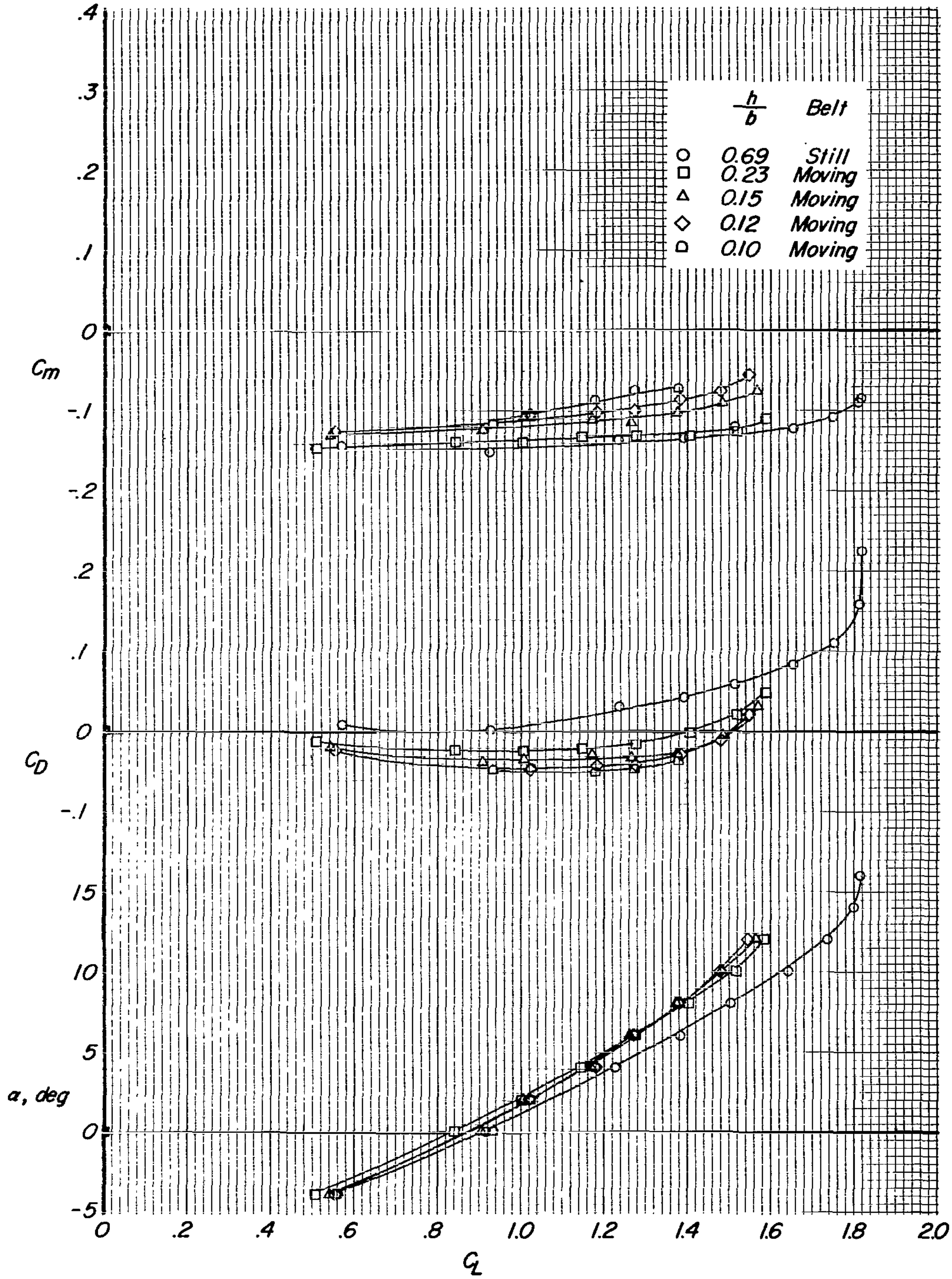
(d) C_μ = 0.15.

Figure 6.- Concluded.



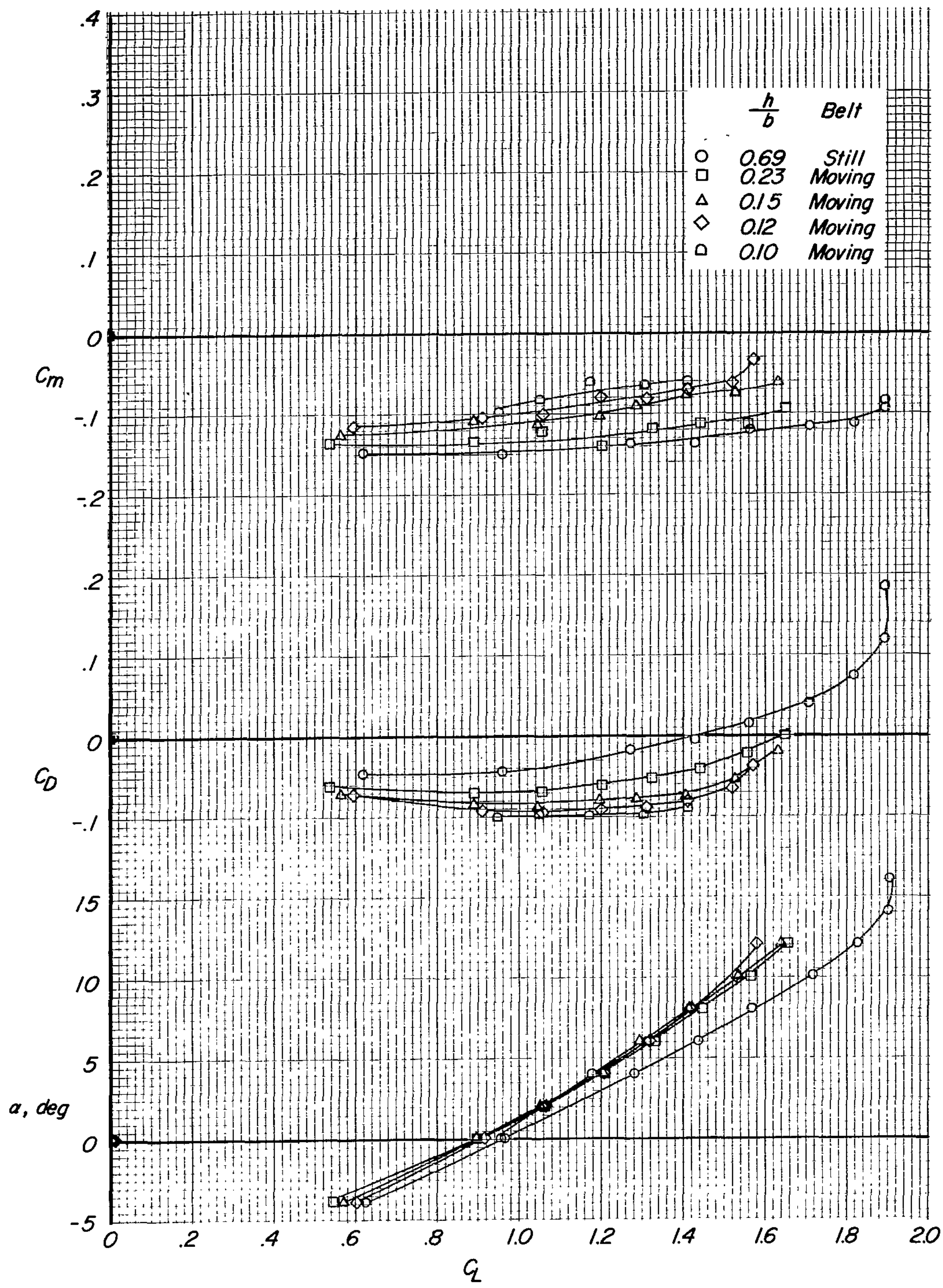
(a) $C_\mu = 0$; $C_j = 0$.

Figure 7.- Effect of the ground plane on the characteristics of the model at various heights for different combinations of thrust and flap blowing momentum. $\delta_f = 60^{\circ}$; tail off.



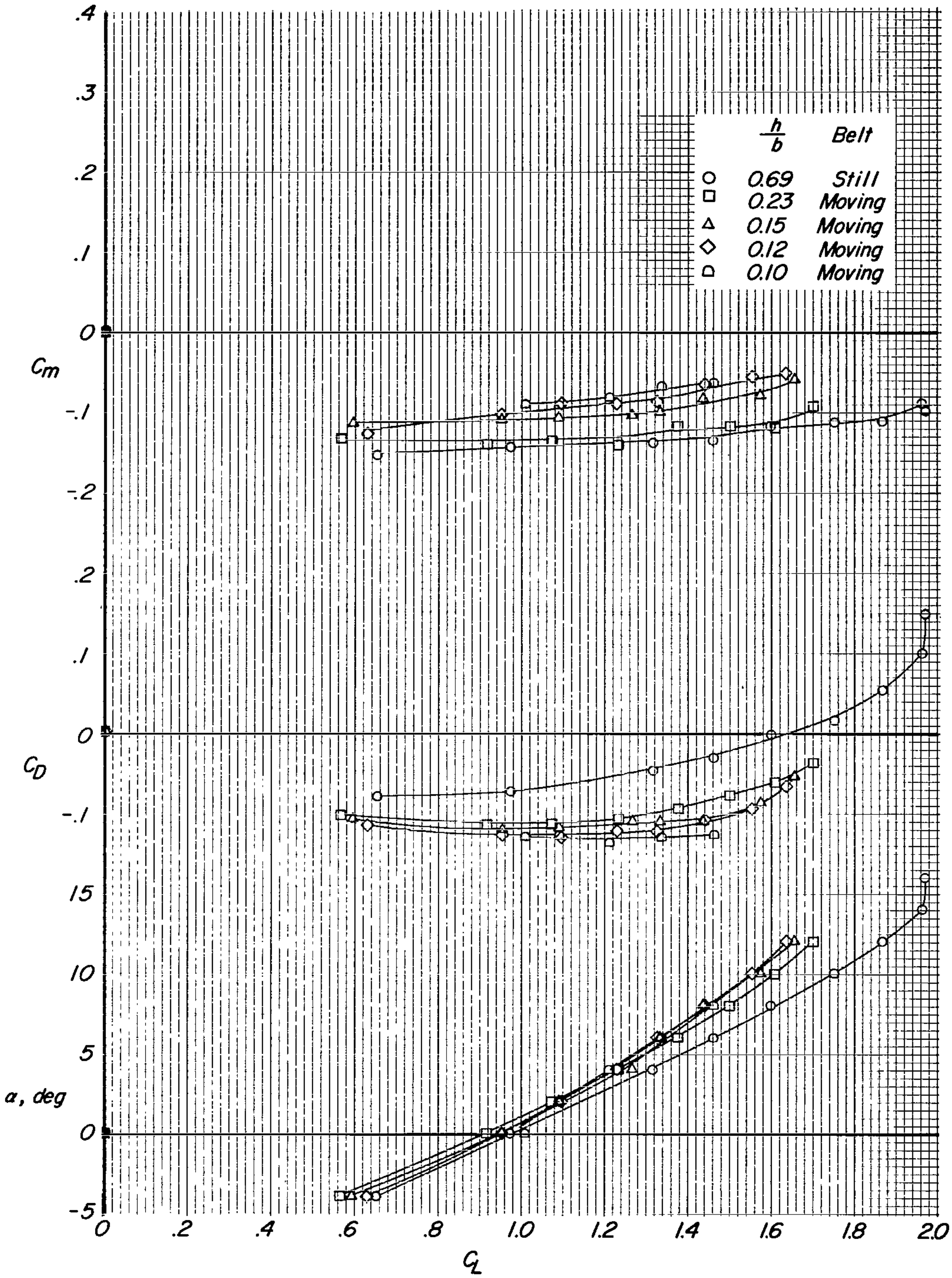
(b) $C_\mu = 0$; $C_j = 0.17$.

Figure 7.- Continued.



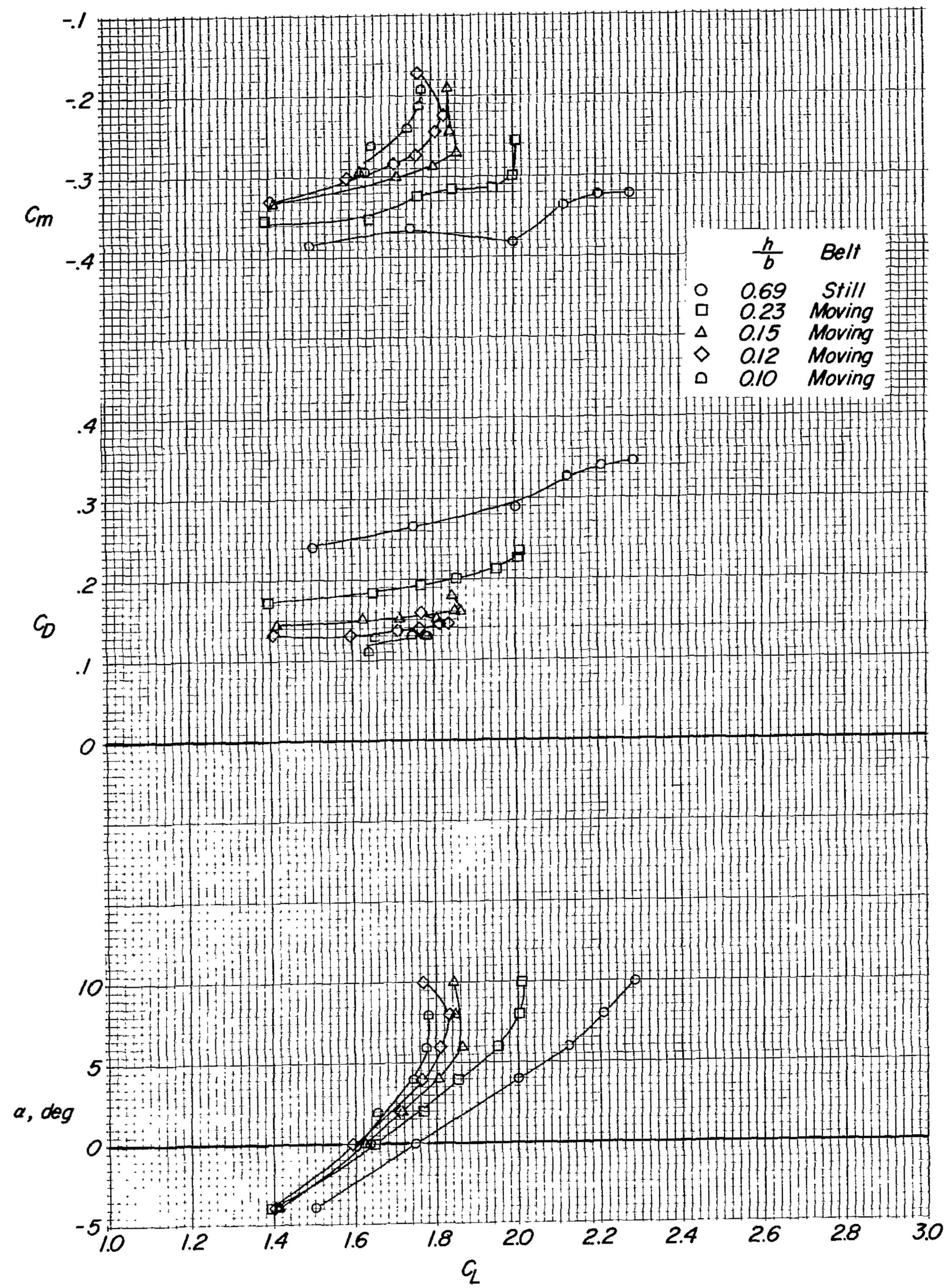
(c) $C_{\mu} = 0$; $C_j = 0.25$.

Figure 7.- Continued.



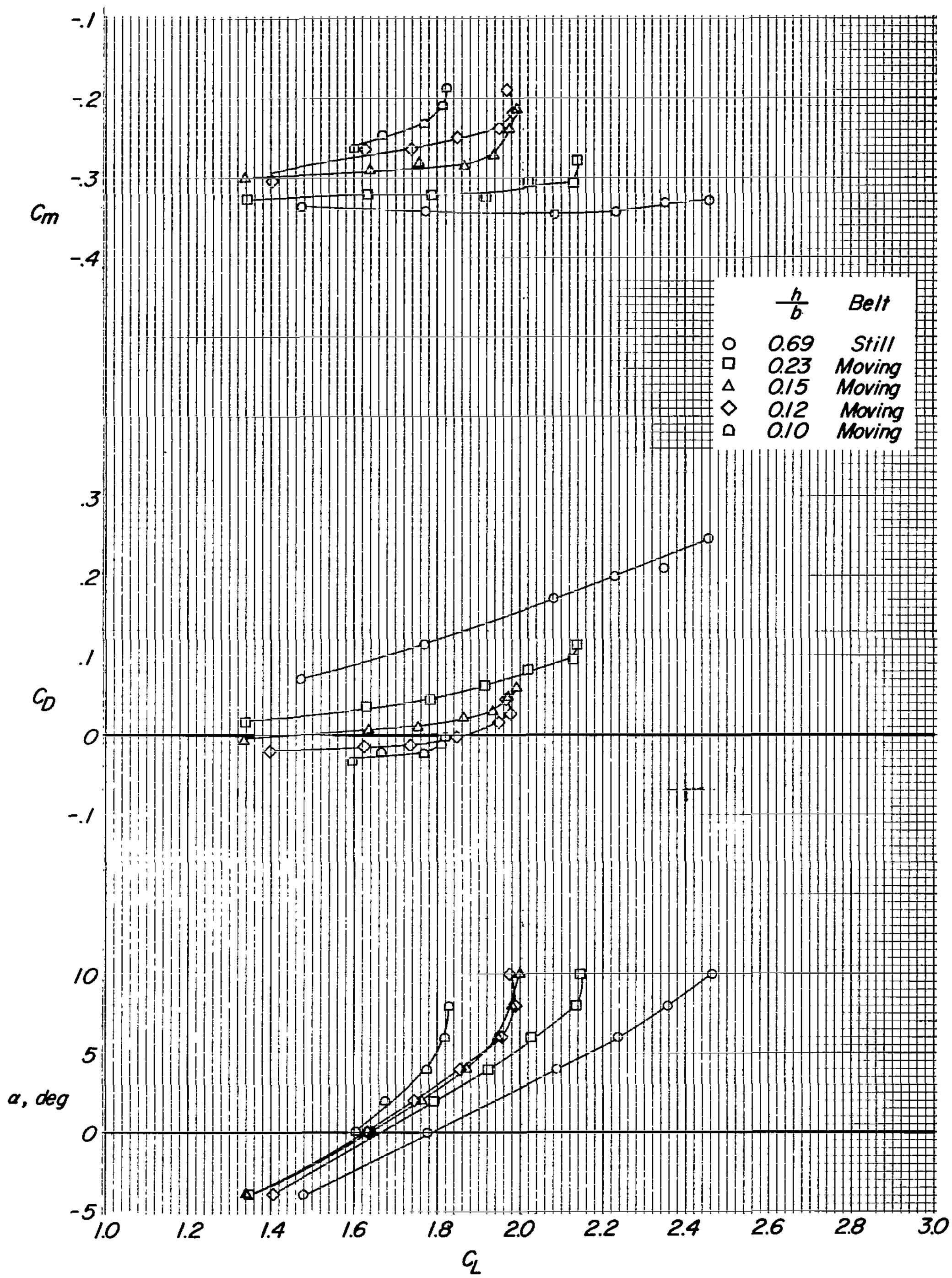
(d) $C_\mu = 0$; $C_j = 0.32$.

Figure 7.- Continued.



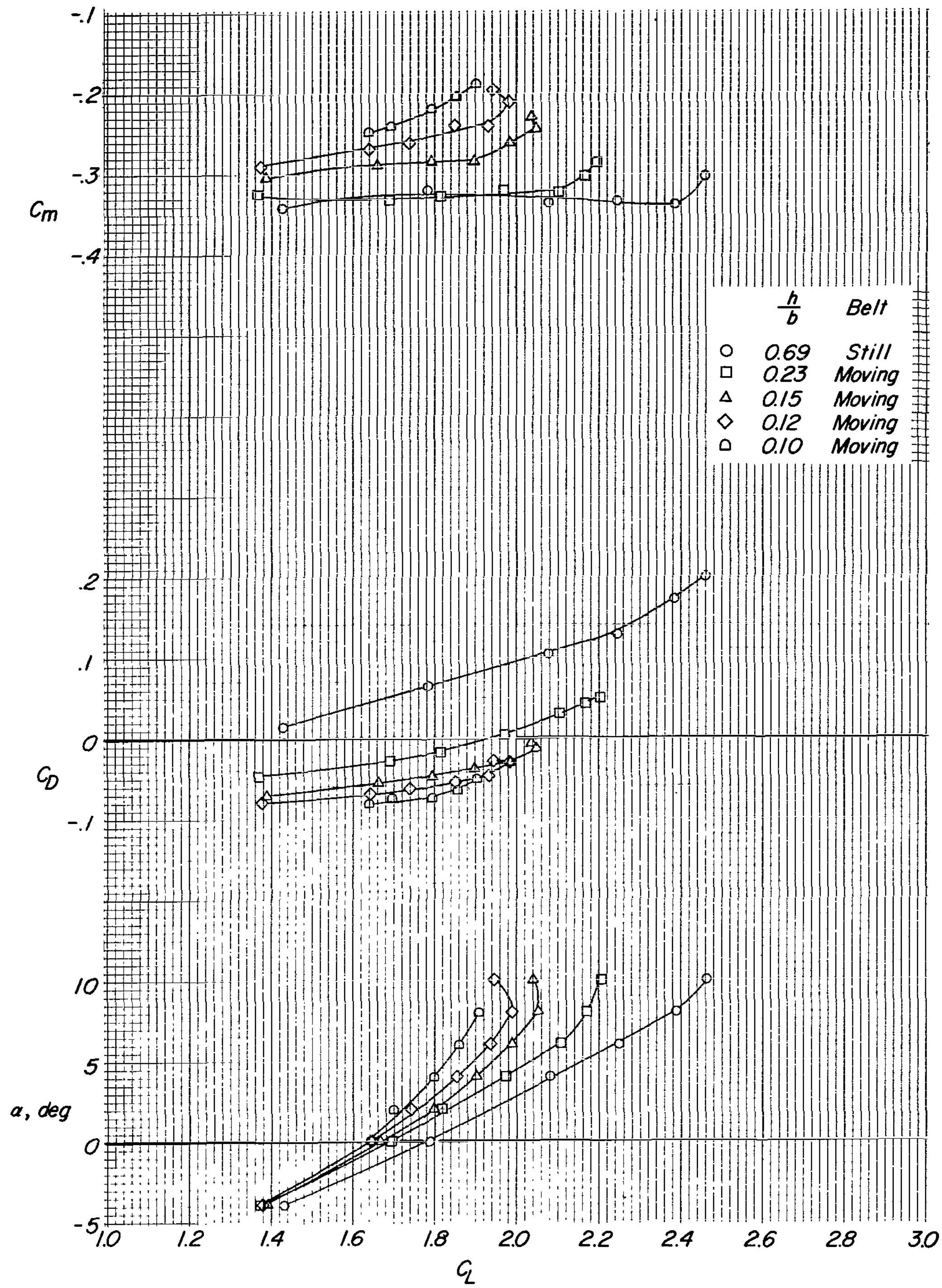
(e) $C_\mu = 0.05$; $C_j = 0$.

Figure 7.- Continued.



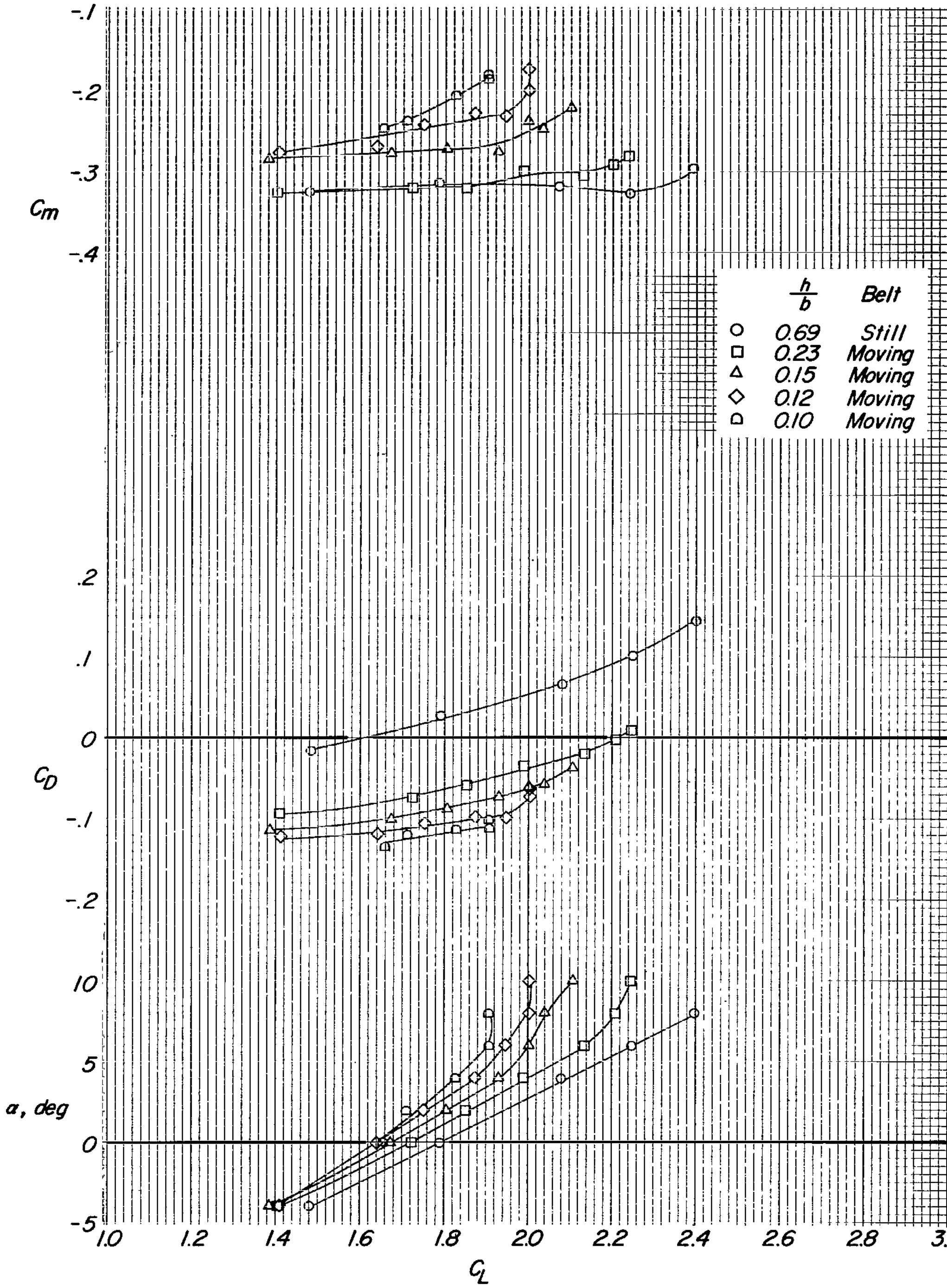
(f) $C_\mu = 0.05$; $C_j = 0.17$.

Figure 7.- Continued.



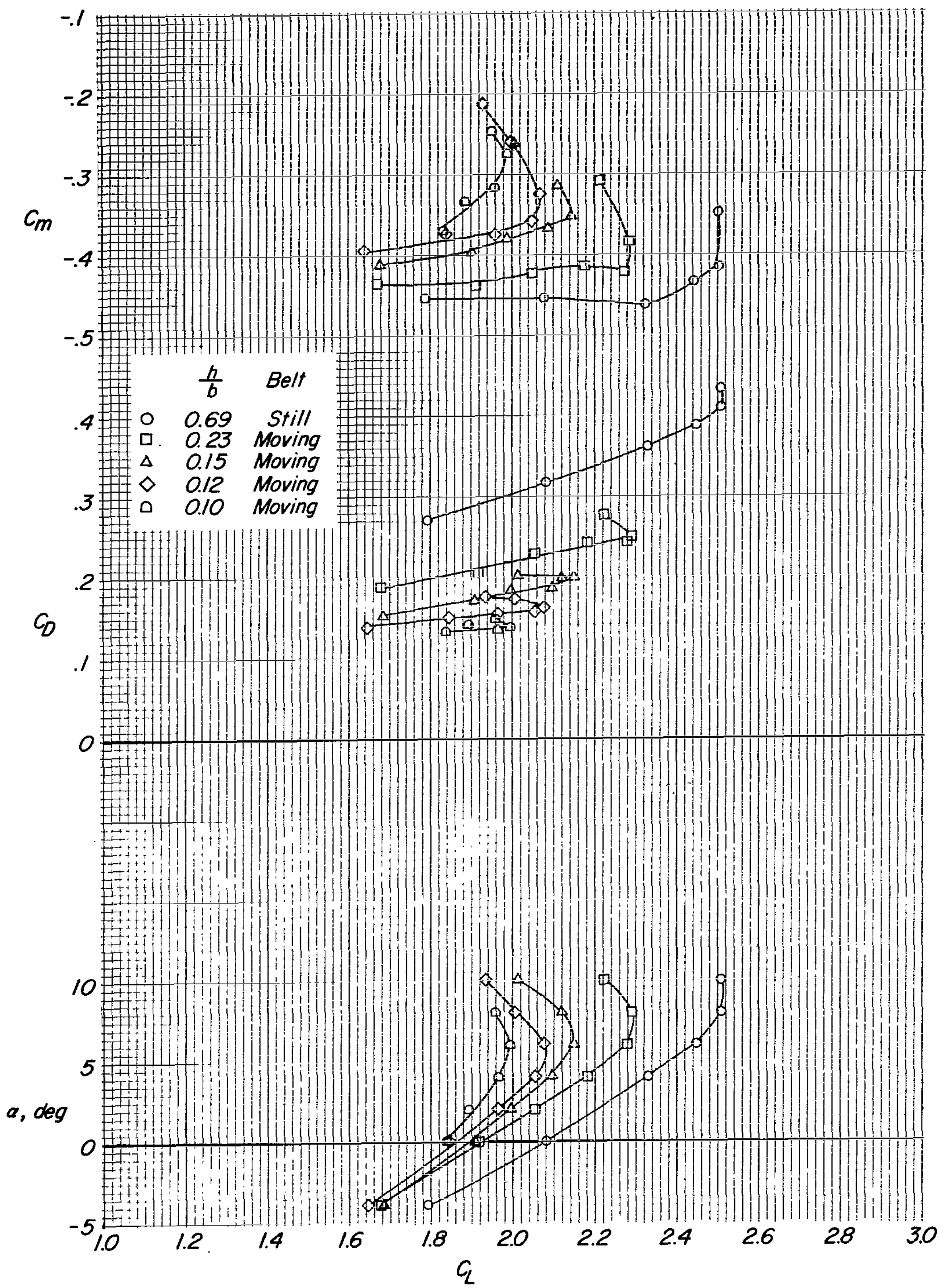
(g) $C_{\mu} = 0.05$; $C_j = 0.25$.

Figure 7.- Continued.



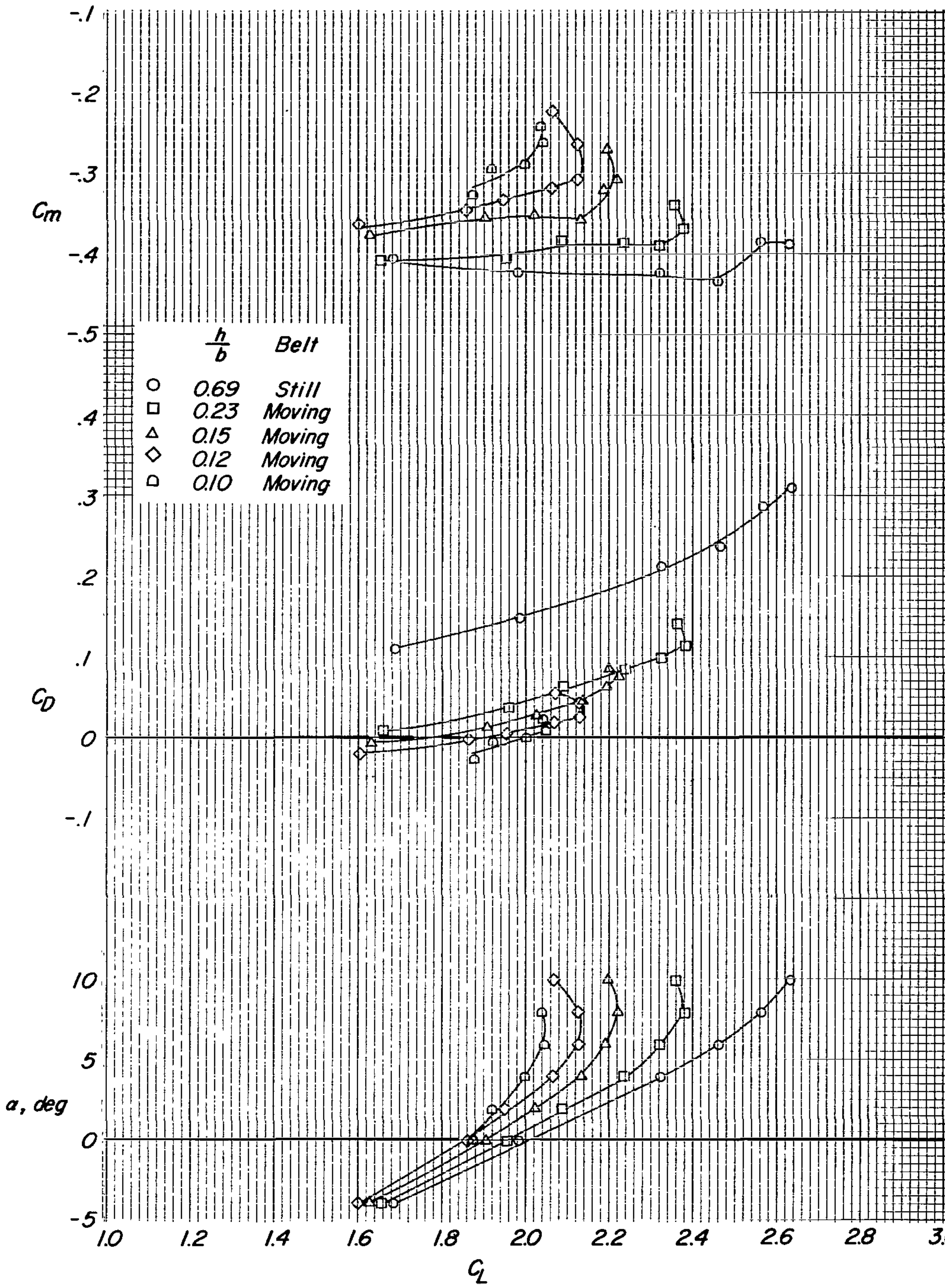
(h) $C_\mu = 0.05$; $C_j = 0.32$.

Figure 7.- Continued.



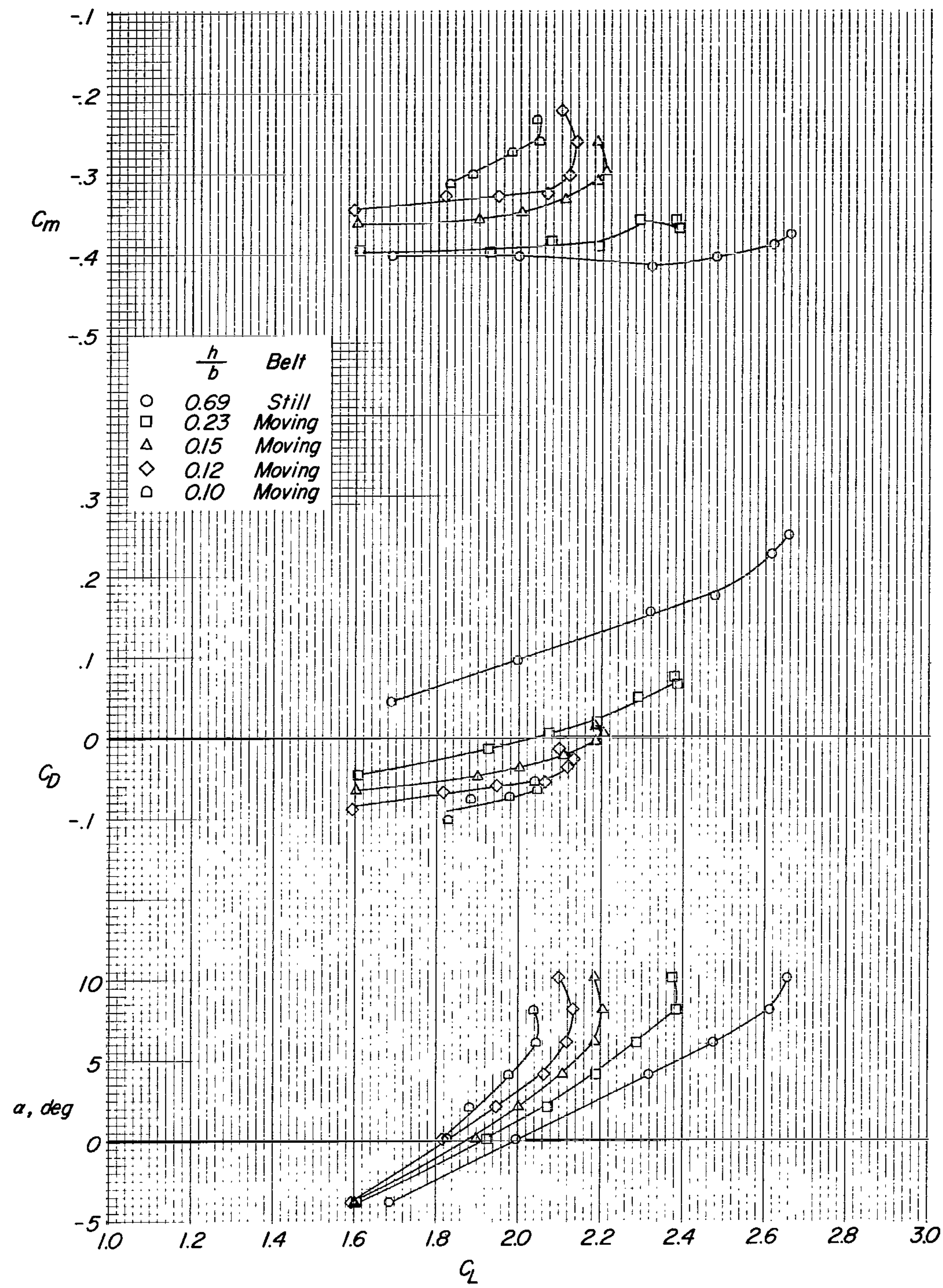
(i) $C_{\mu} = 0.10$; $C_j = 0$.

Figure 7.- Continued.



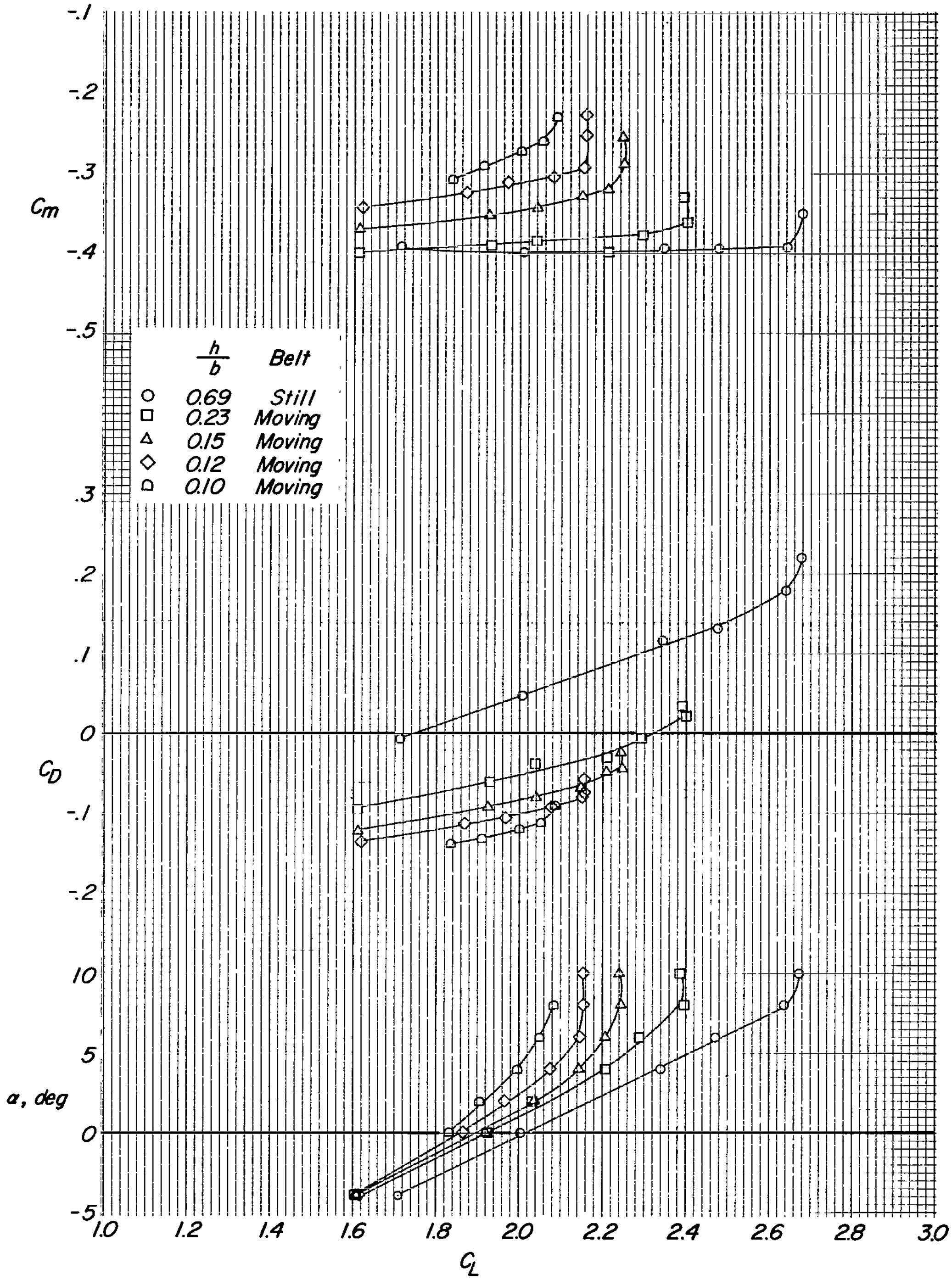
(j) $C_\mu = 0.10$; $C_j = 0.17$.

Figure 7.- Continued.



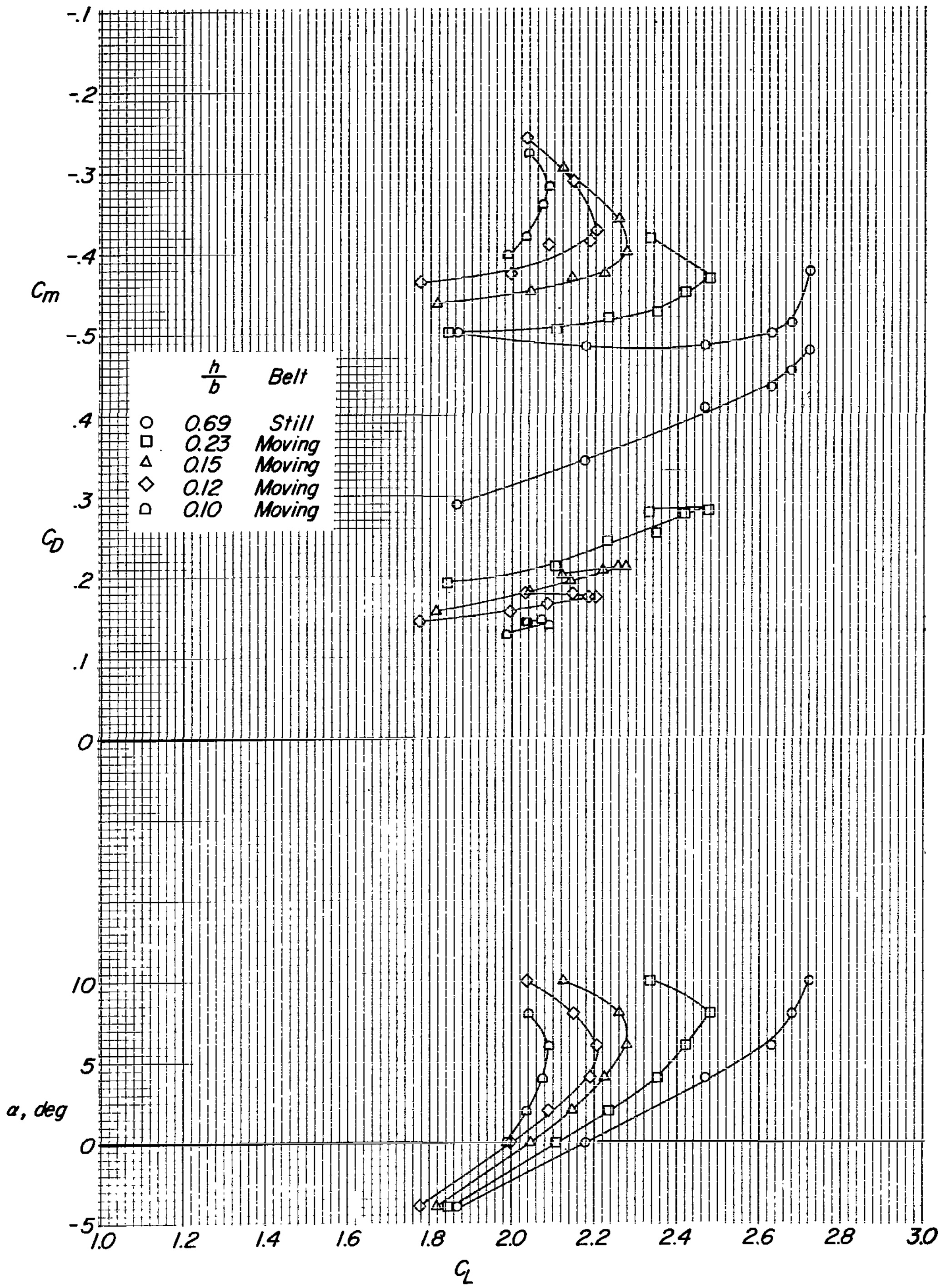
(k) $C_\mu = 0.10$; $C_j = 0.25$.

Figure 7.- Continued.



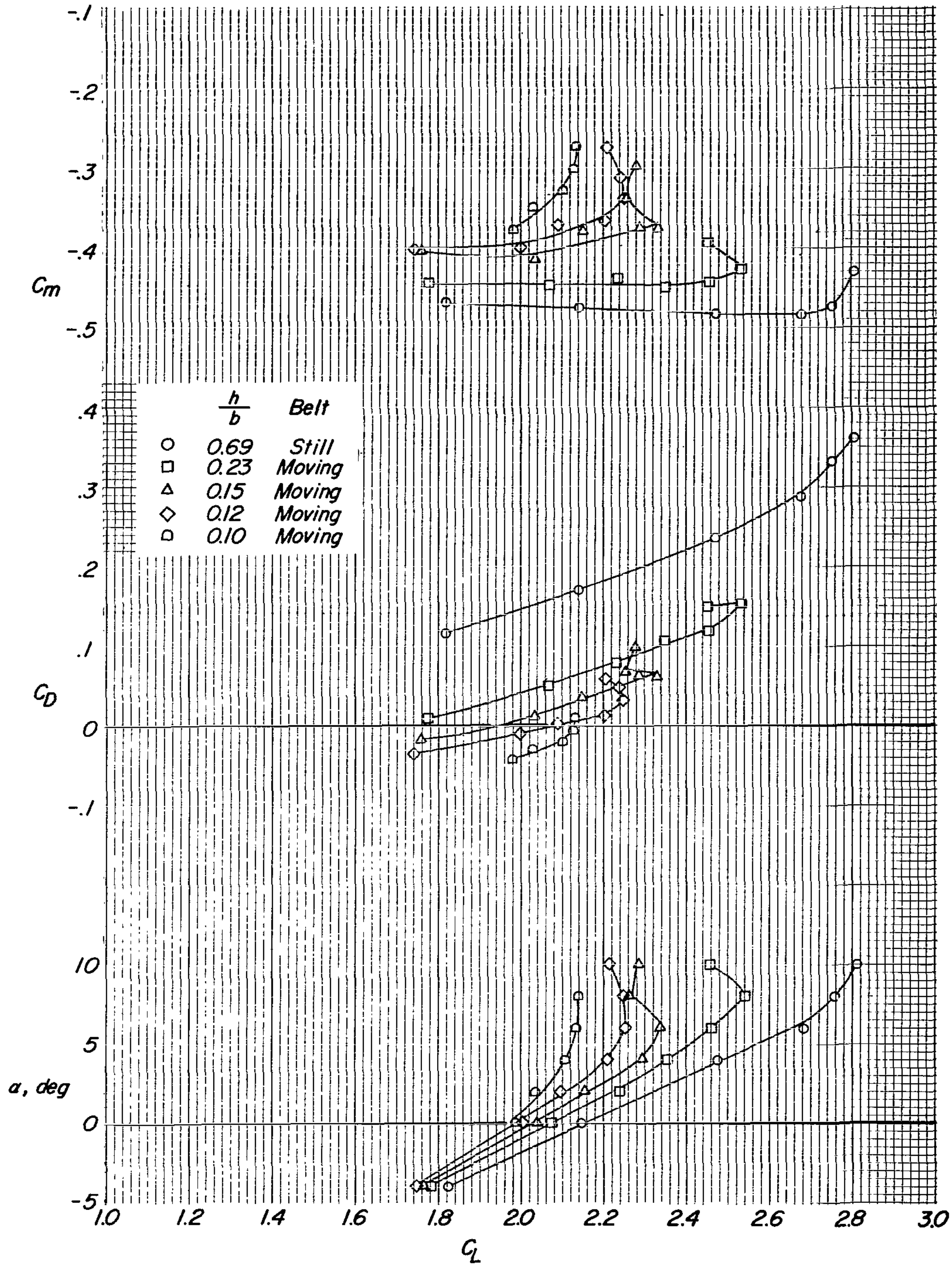
(l) $C_\mu = 0.10$; $C_j = 0.32$.

Figure 7.- Continued.



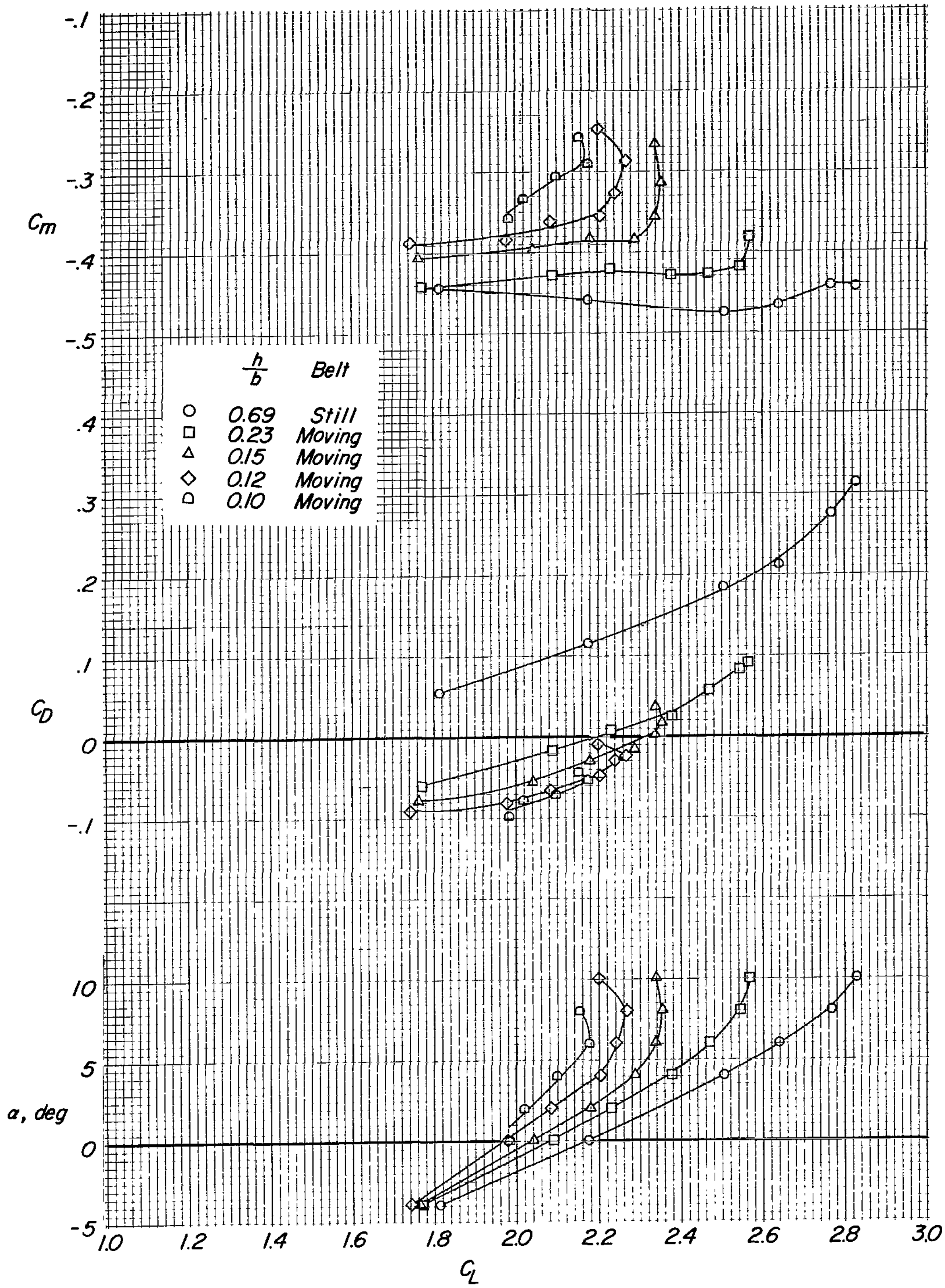
(m) $C_\mu = 0.15$; $C_j = 0$.

Figure 7.- Continued.



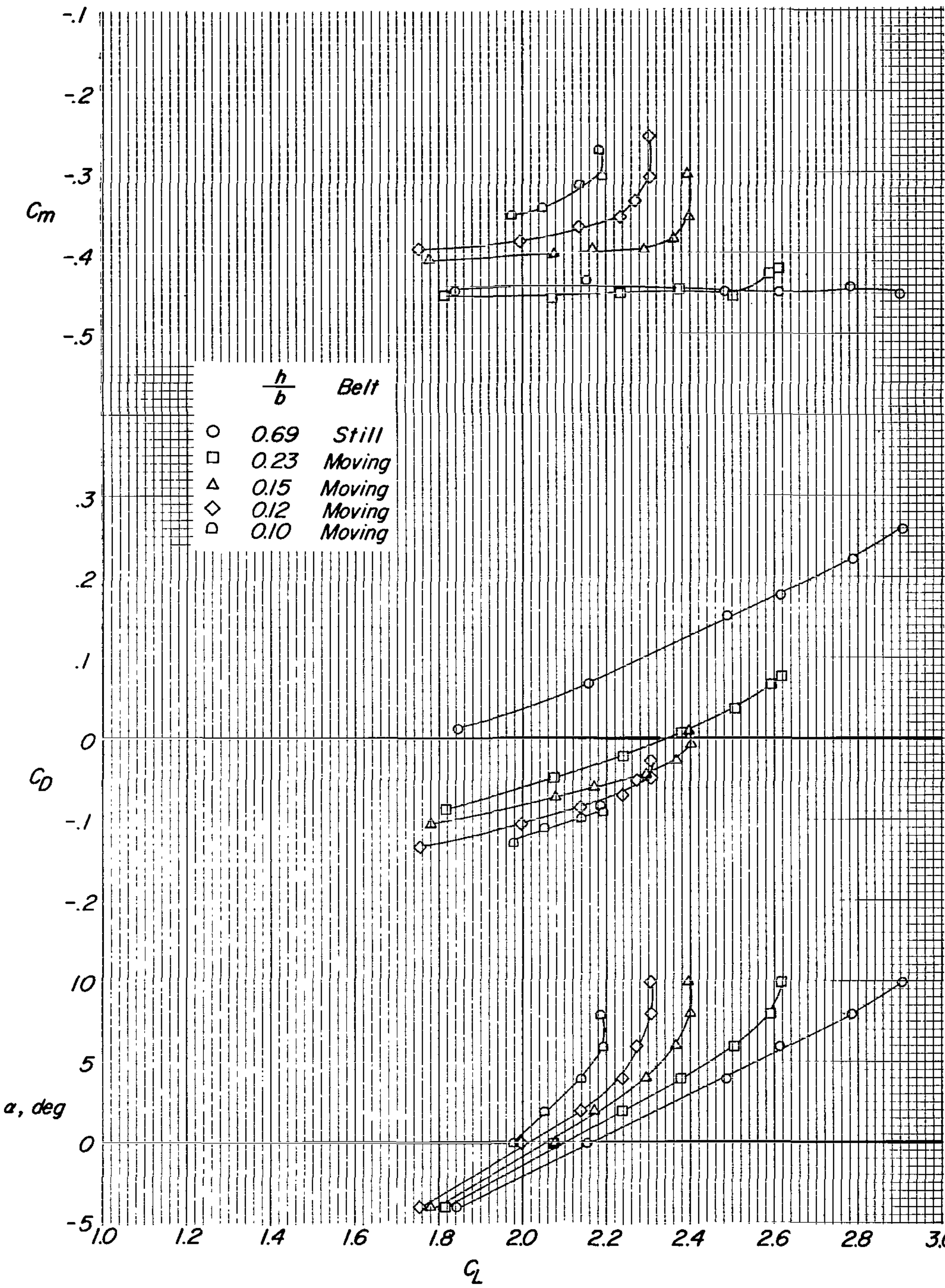
(n) $C_\mu = 0.15$; $C_j = 0.17$.

Figure 7.- Continued.



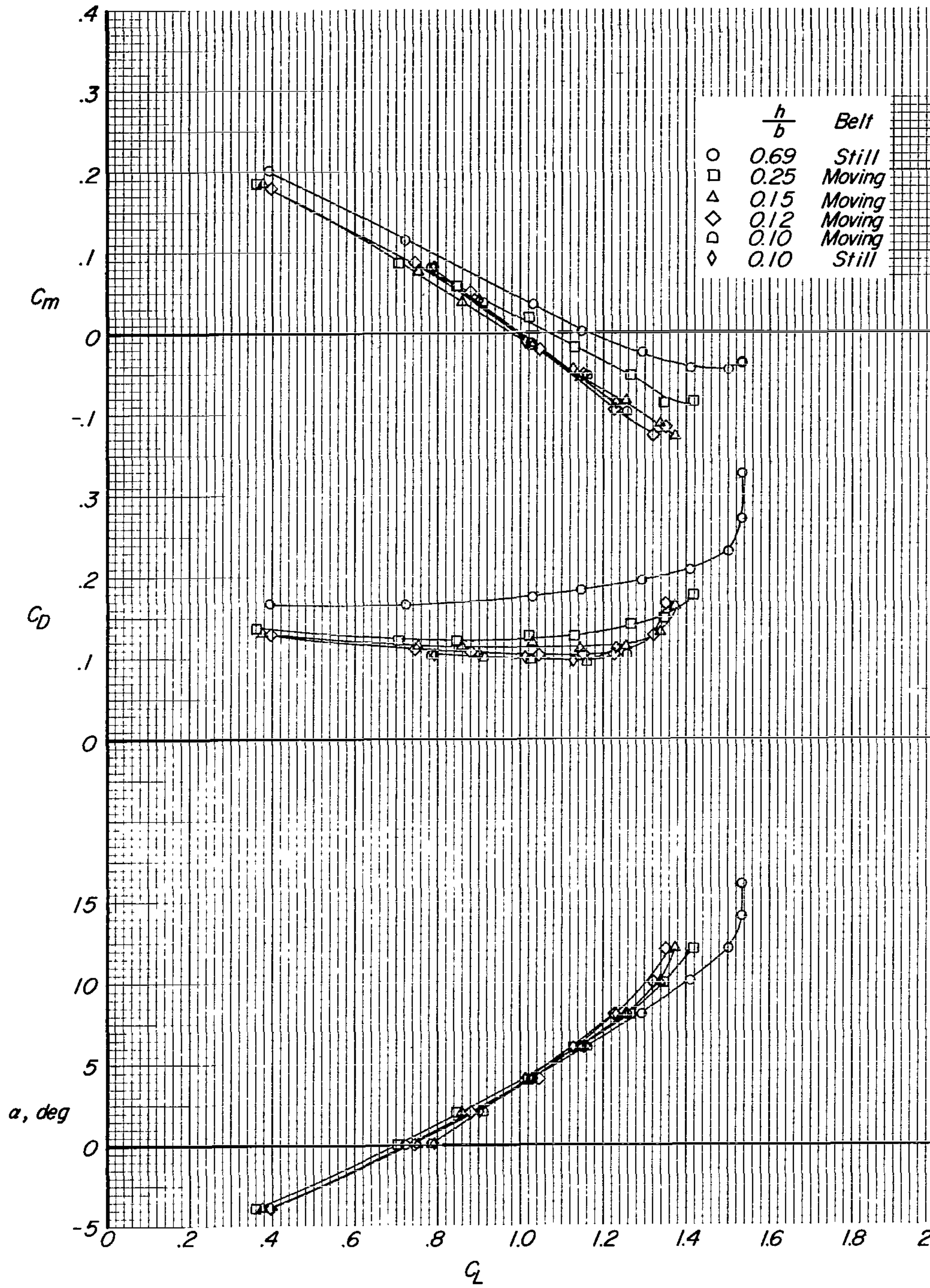
(o) $C_\mu = 0.15$; $C_j = 0.25$.

Figure 7.- Continued.



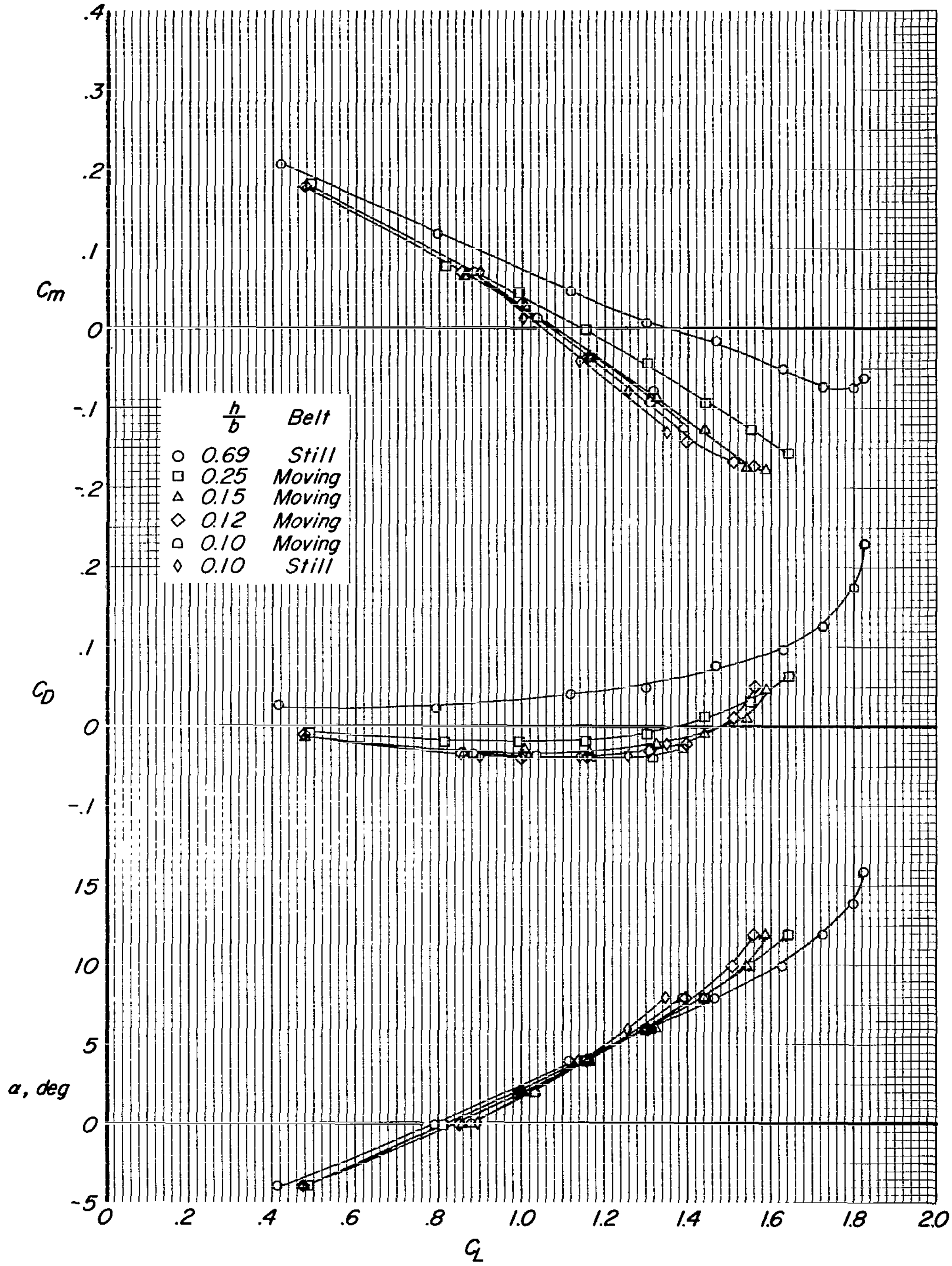
(p) $C_{\mu} = 0.15$; $C_j = 0.32$.

Figure 7.- Concluded.



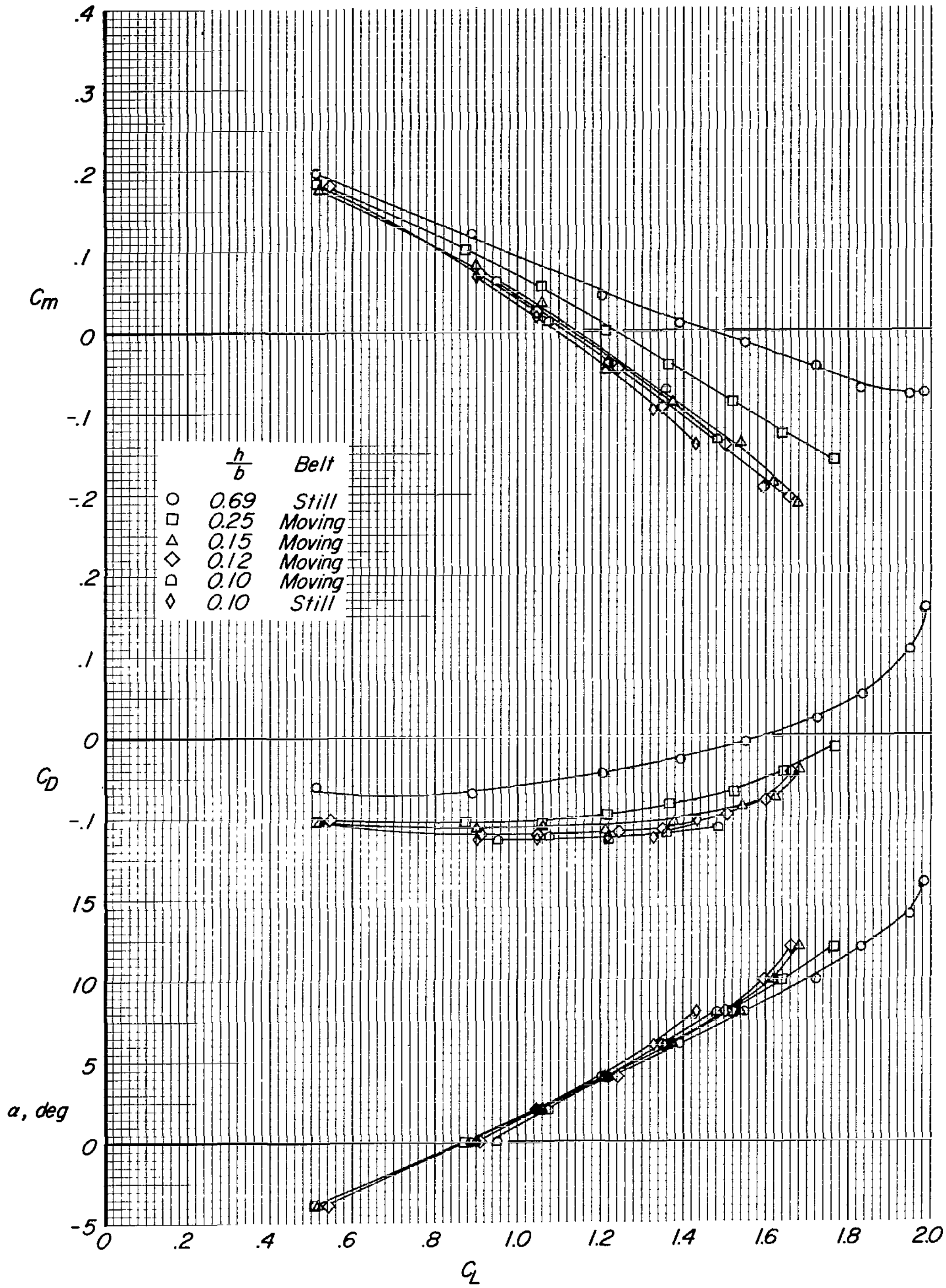
(a) $C_\mu = 0$; $C_j = 0$.

Figure 8.- Effect of the ground plane on the characteristics of the model at various heights for different combinations of thrust and flap blowing momentum. $\delta_f = 60^o$; $i_t = -6^o$.



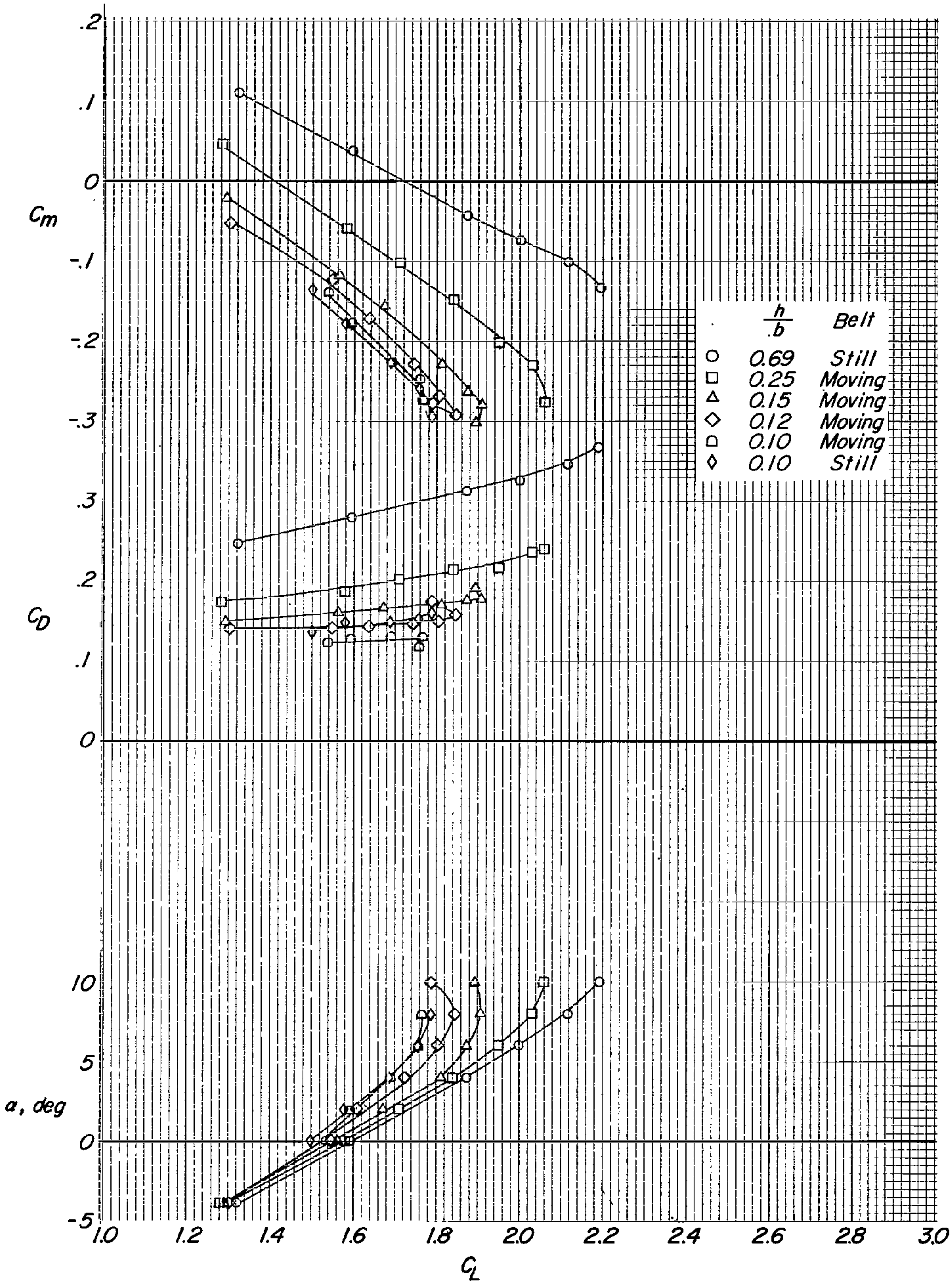
(b) $C_\mu = 0$; $C_j = 0.17$.

Figure 8.- Continued.



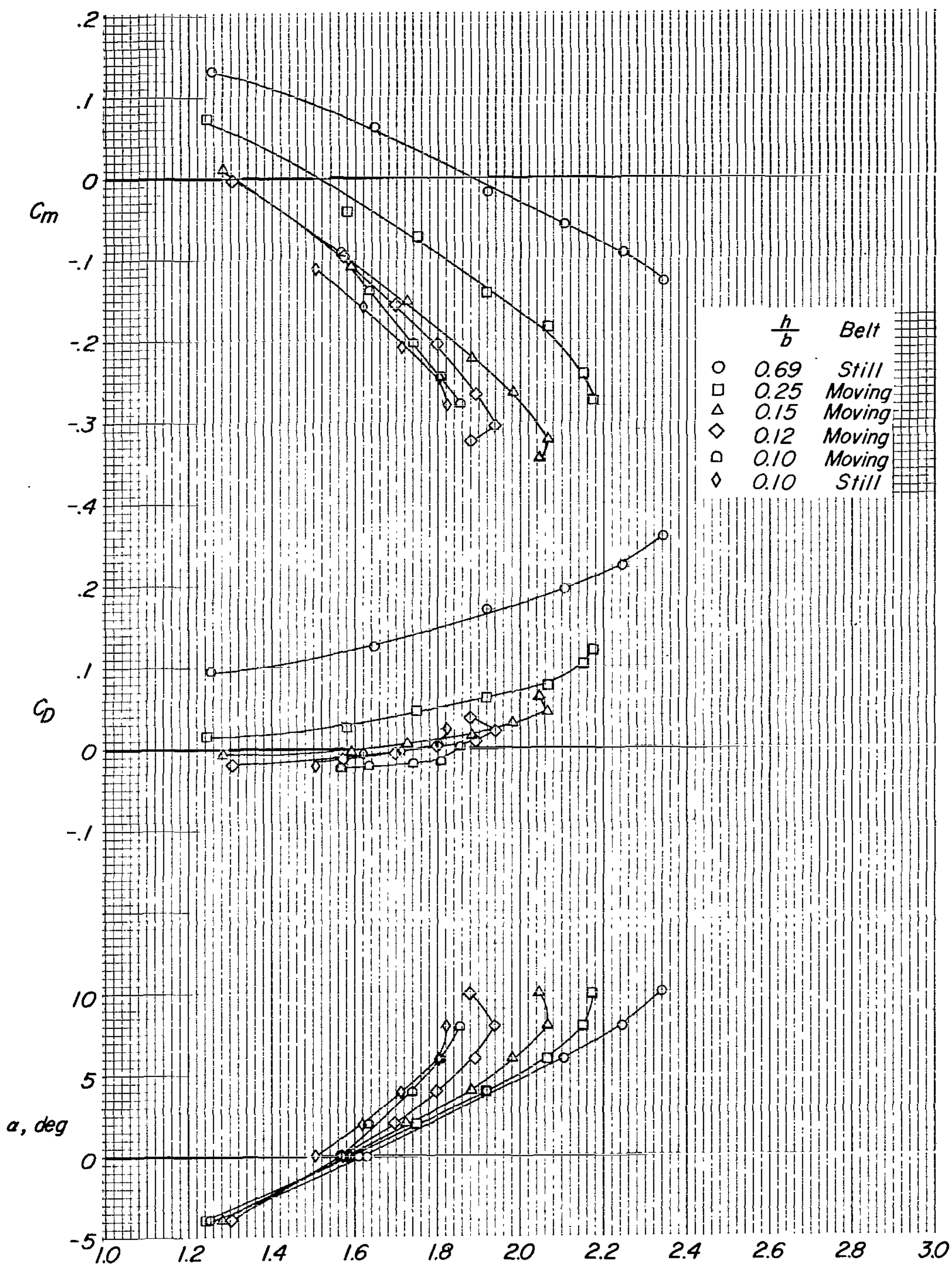
(c) $C_\mu = 0$; $C_j = 0.32$.

Figure 8.- Continued.



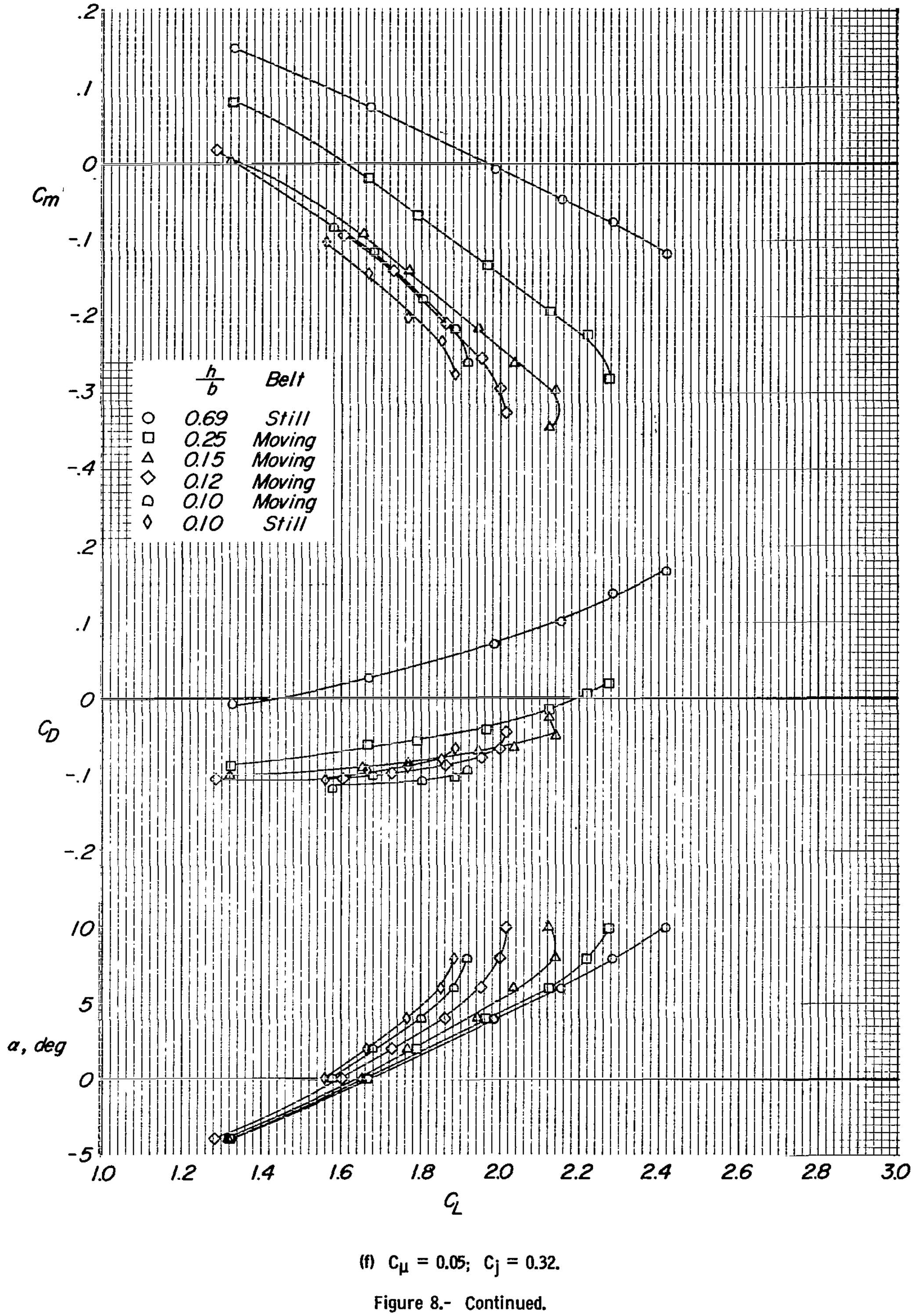
(d) $C_\mu = 0.05$; $C_j = 0$.

Figure 8.- Continued.



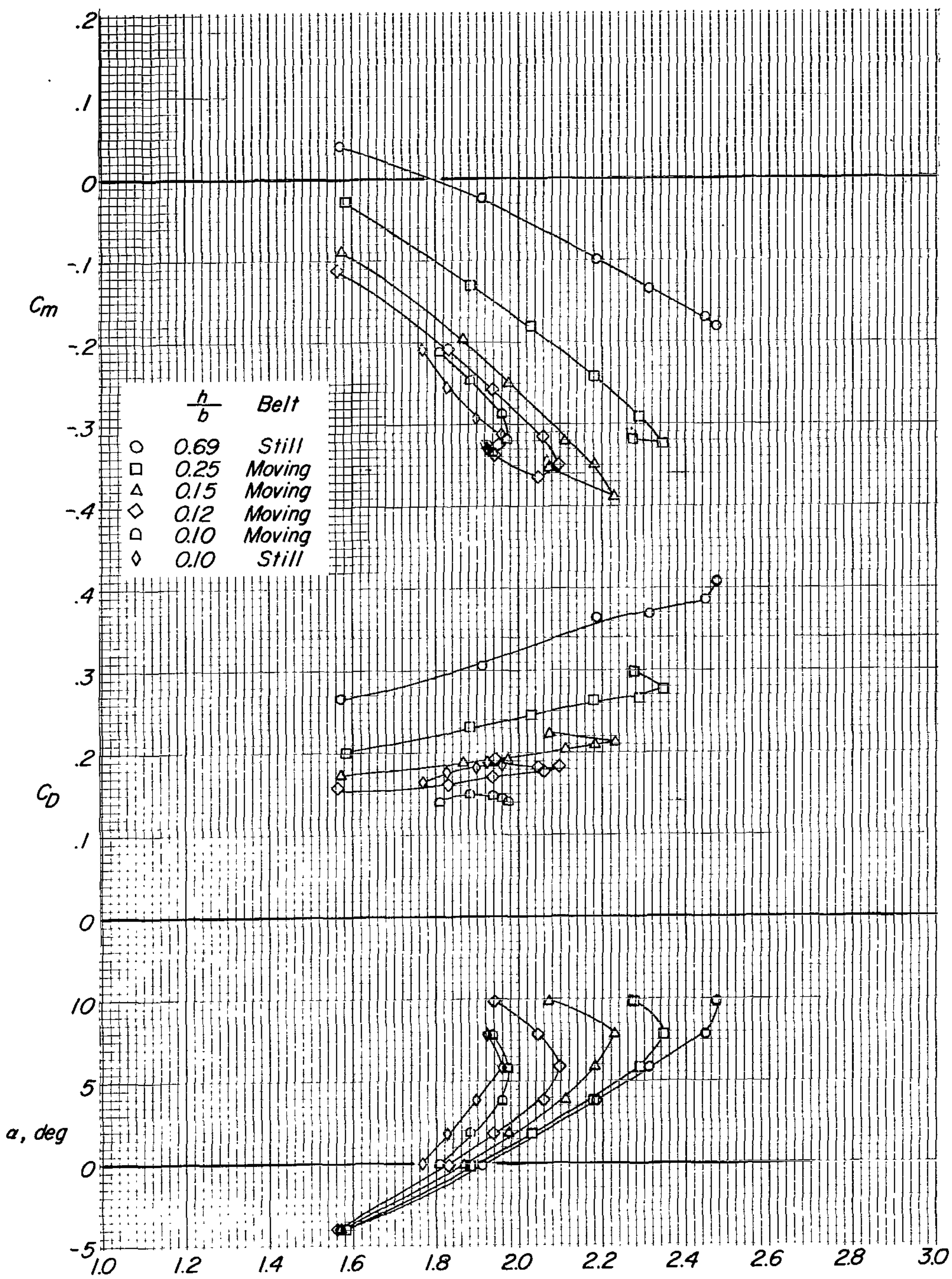
(e) $C_\mu = 0.05$; $C_j = 0.17$.

Figure 8.- Continued.



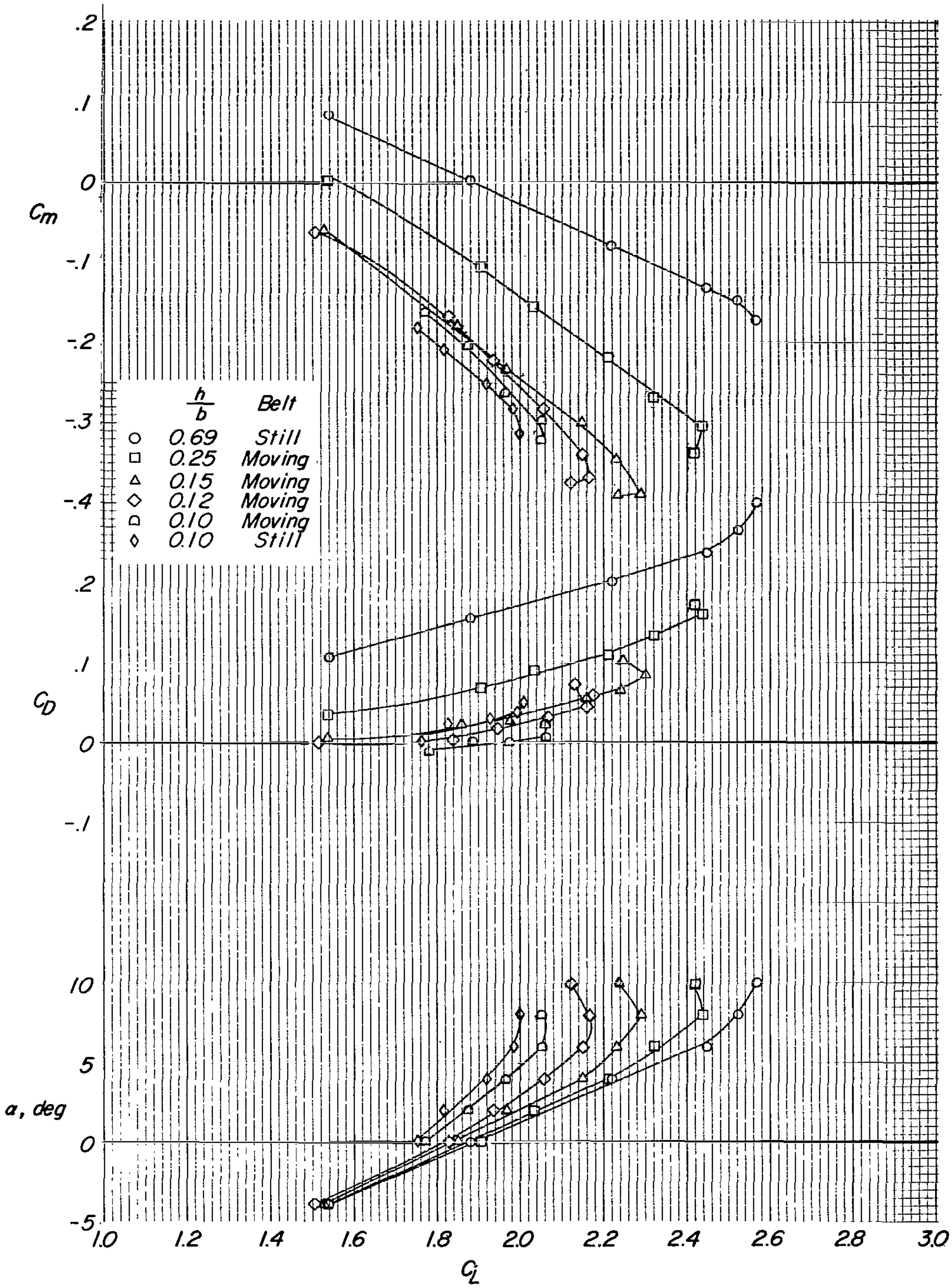
(f) $C_\mu = 0.05$; $C_j = 0.32$.

Figure 8.- Continued.



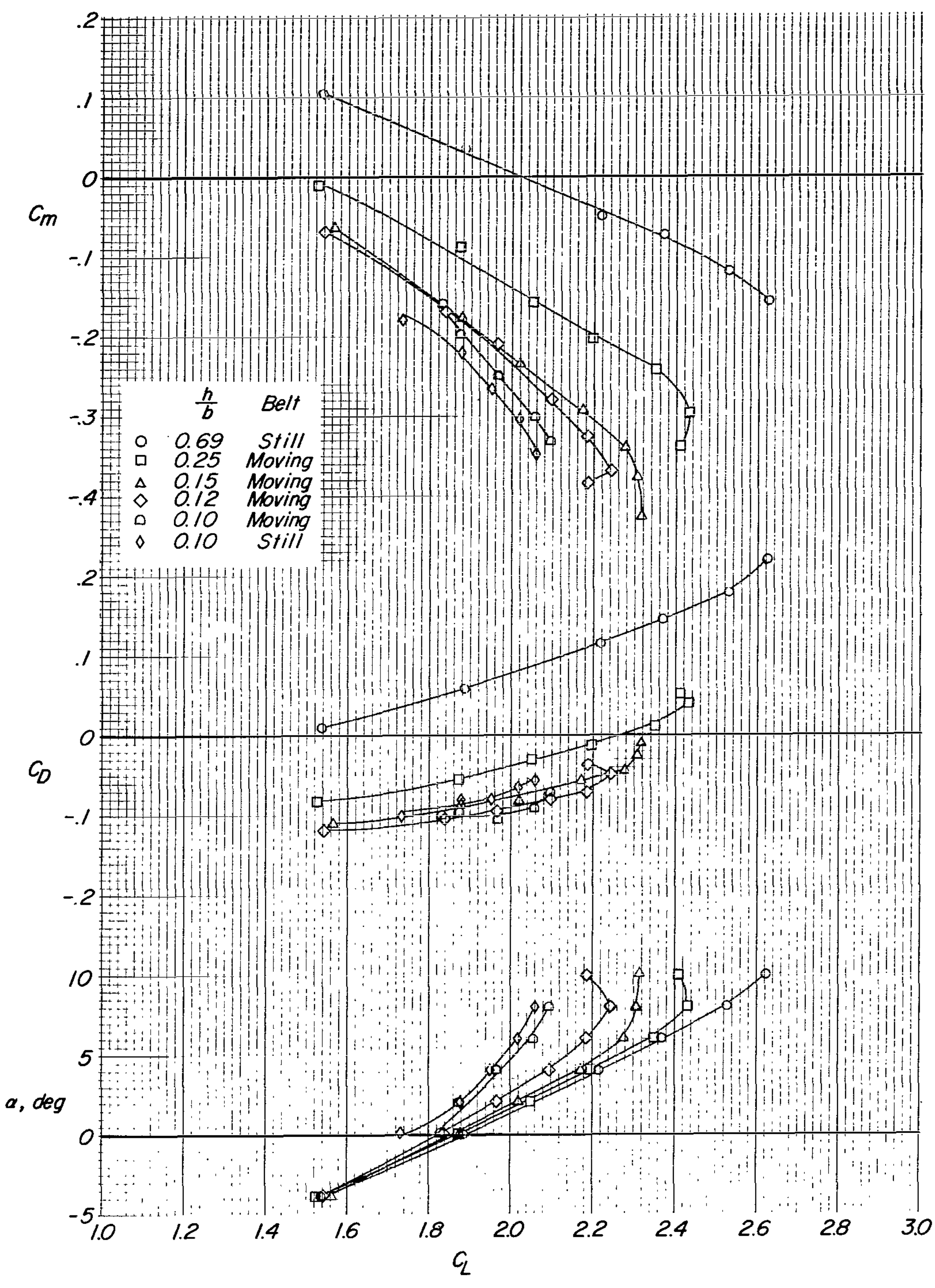
(g) $C_\mu = 0.10$; $C_j = 0$.

Figure 8.- Continued.



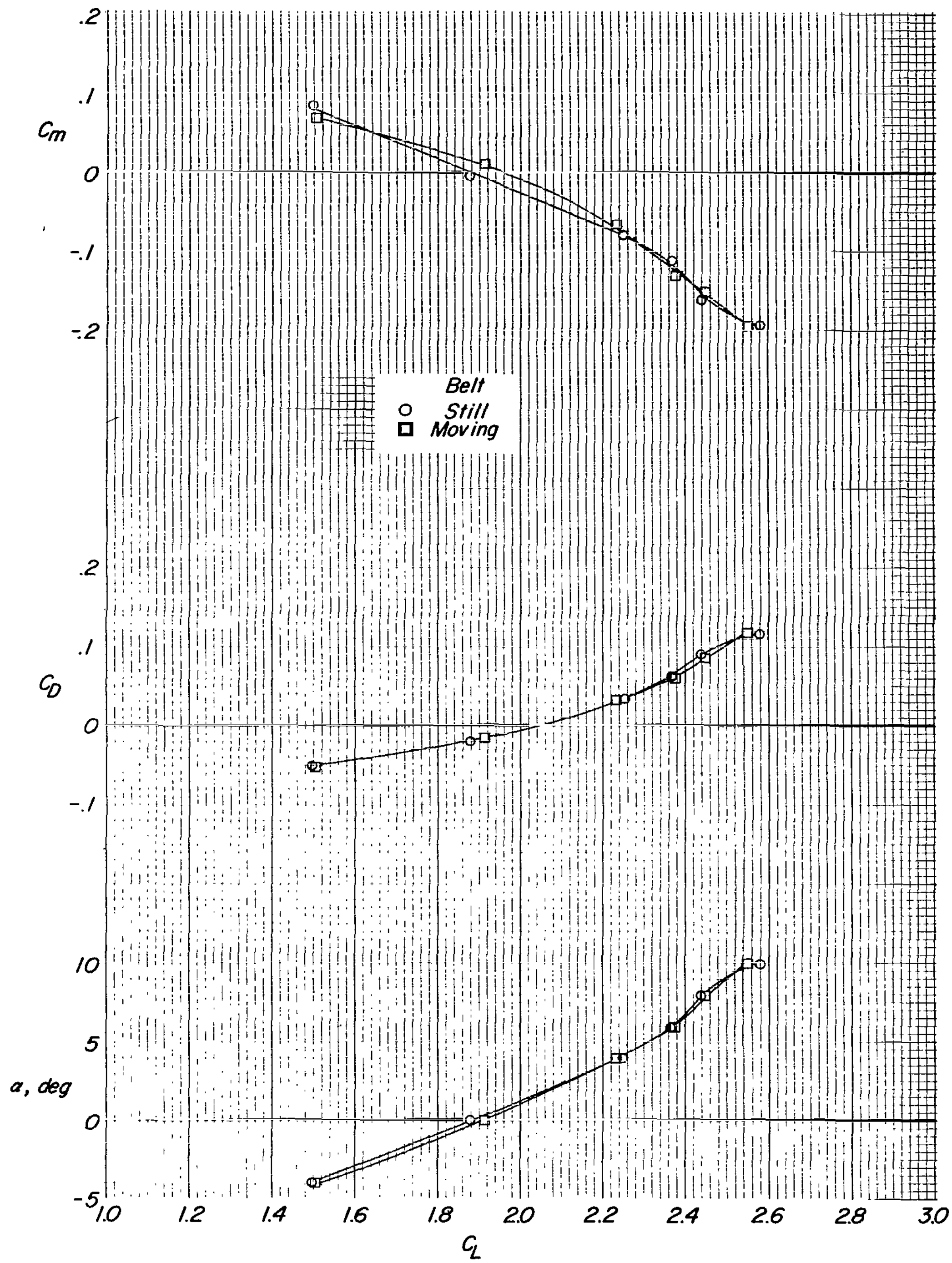
(h) $C_\mu = 0.10$; $C_j = 0.17$.

Figure 8.- Continued.



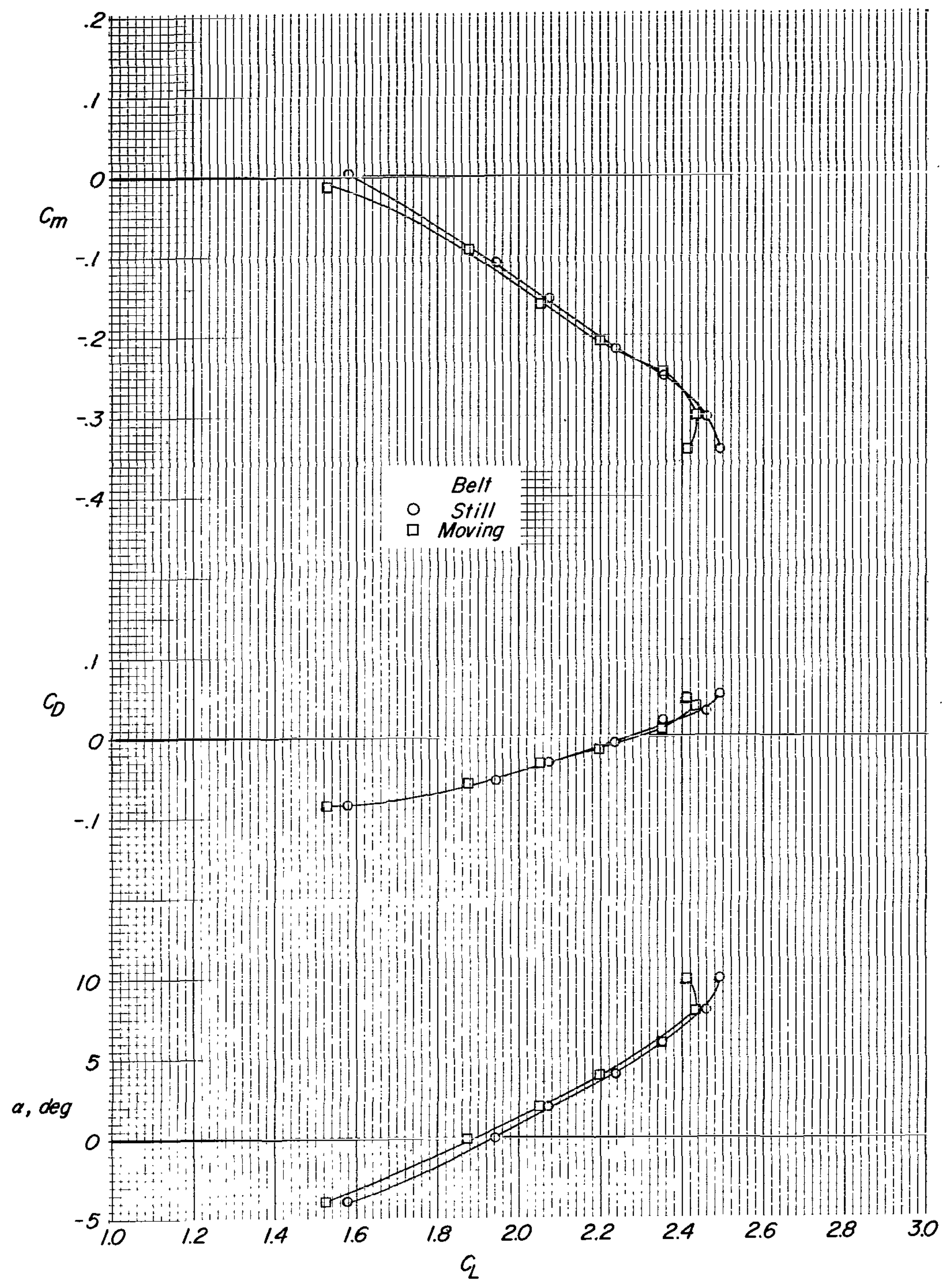
(i) $C_\mu = 0.10$; $C_j = 0.32$.

Figure 8.- Concluded.



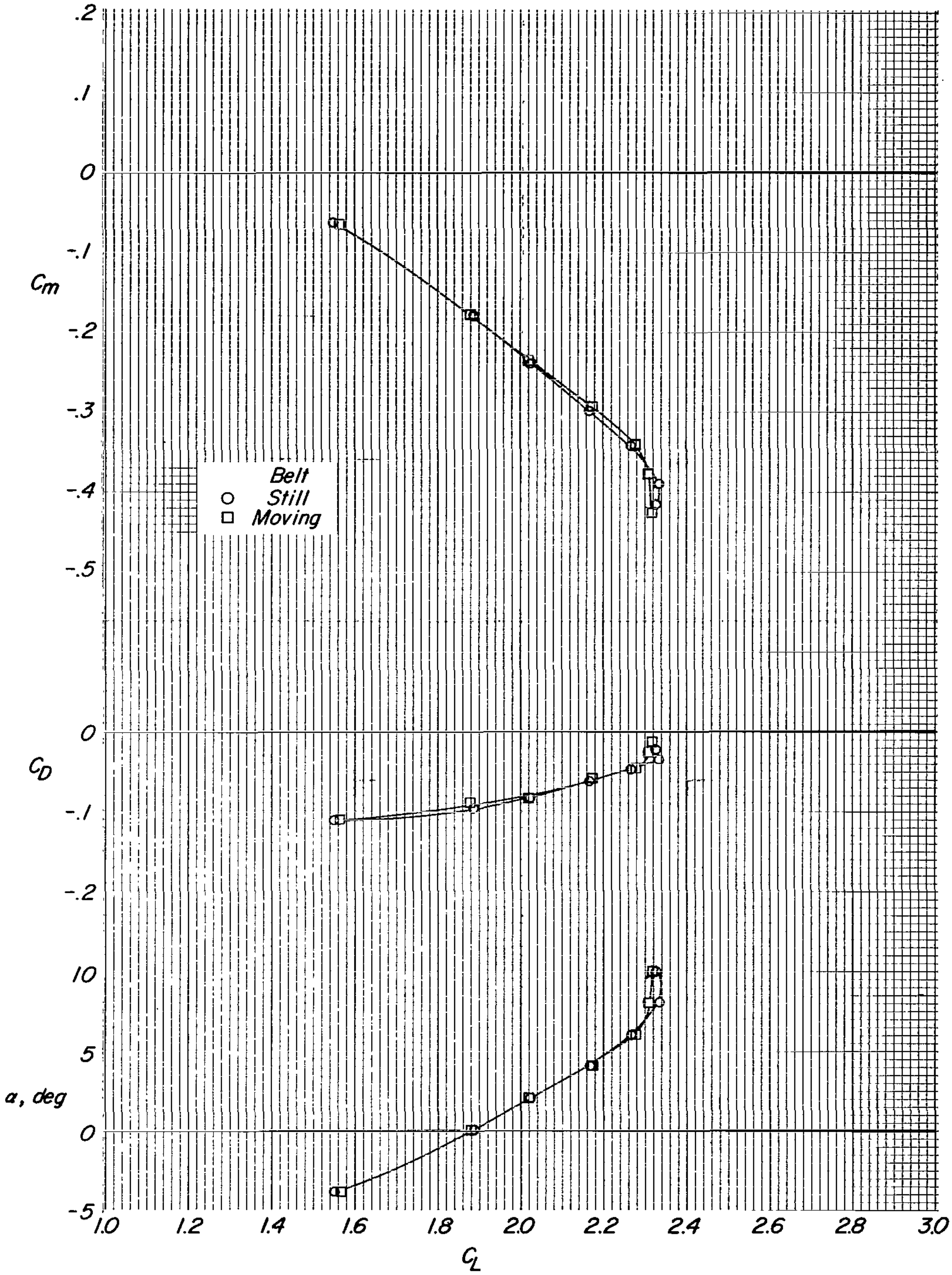
(a) h/b = 0.41.

Figure 9.- Effect of the moving ground plane (belt) on the characteristics of the model at various heights for a constant high thrust and flap blowing momentum. $\delta_f = 60^o$; $C_\mu = 0.10$; $C_j = 0.32$; $i_t = -6^o$.



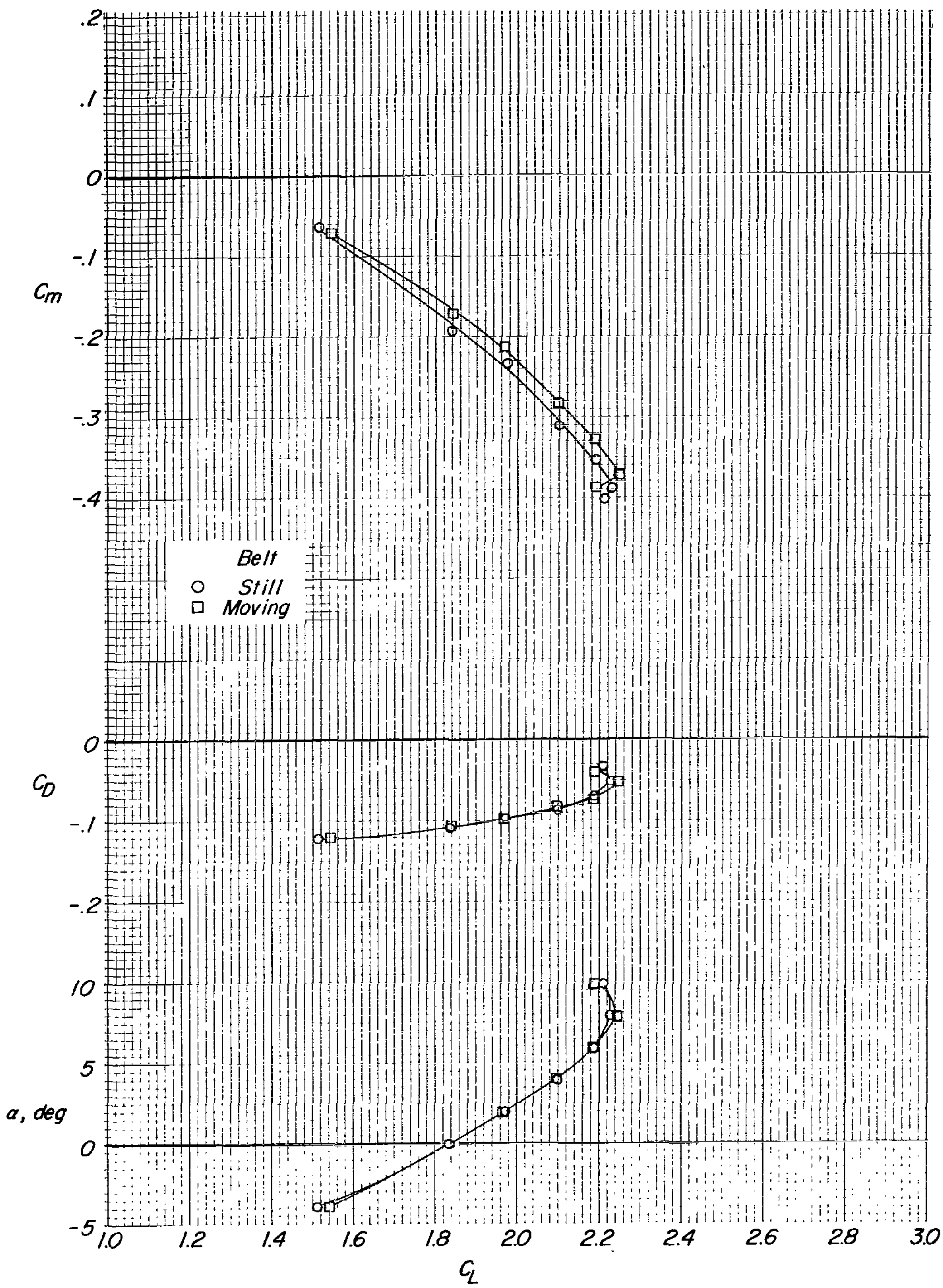
(b) h/b = 0.25.

Figure 9.- Continued.



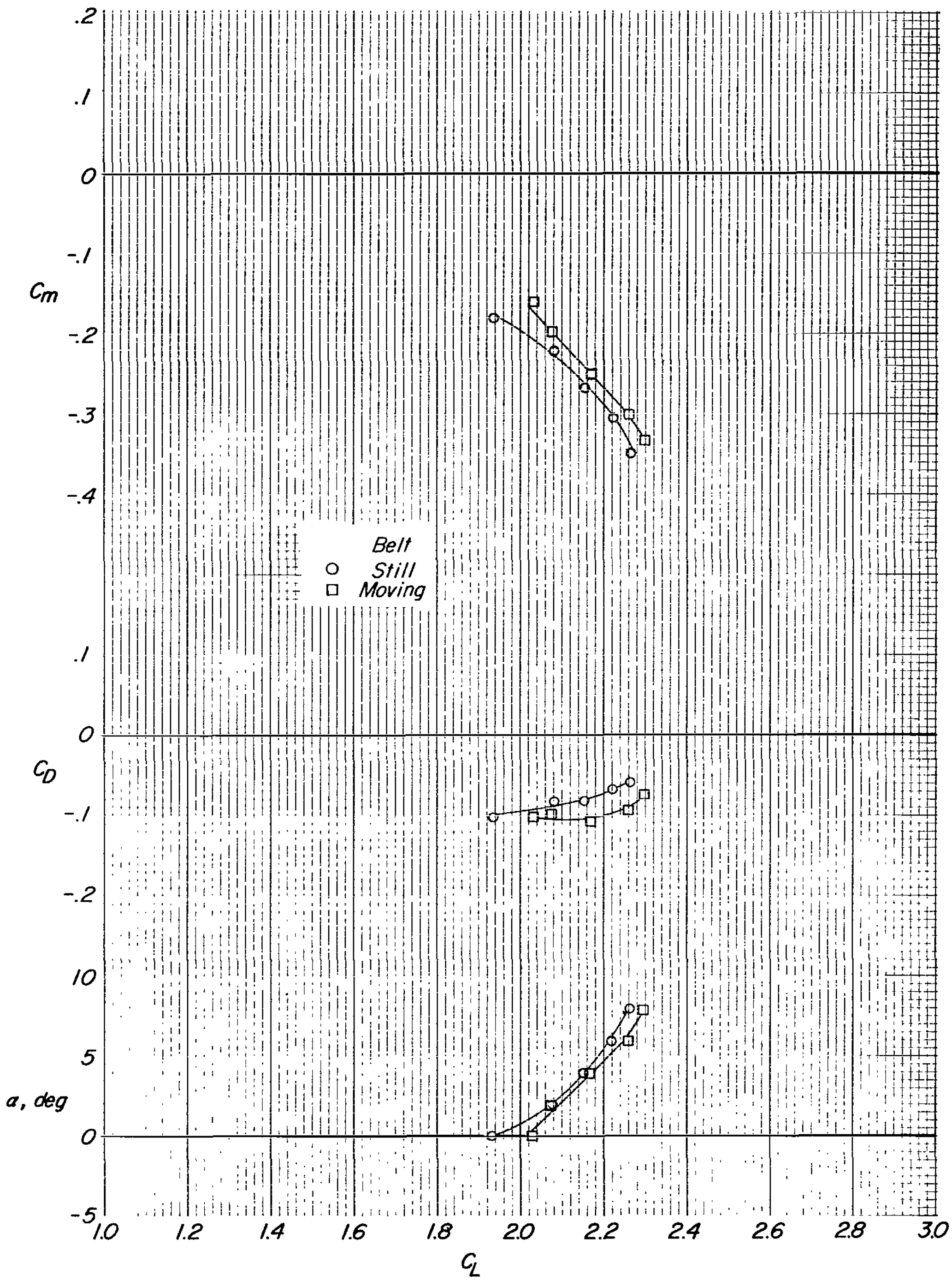
(c) h/b = 0.15.

Figure 9.- Continued.



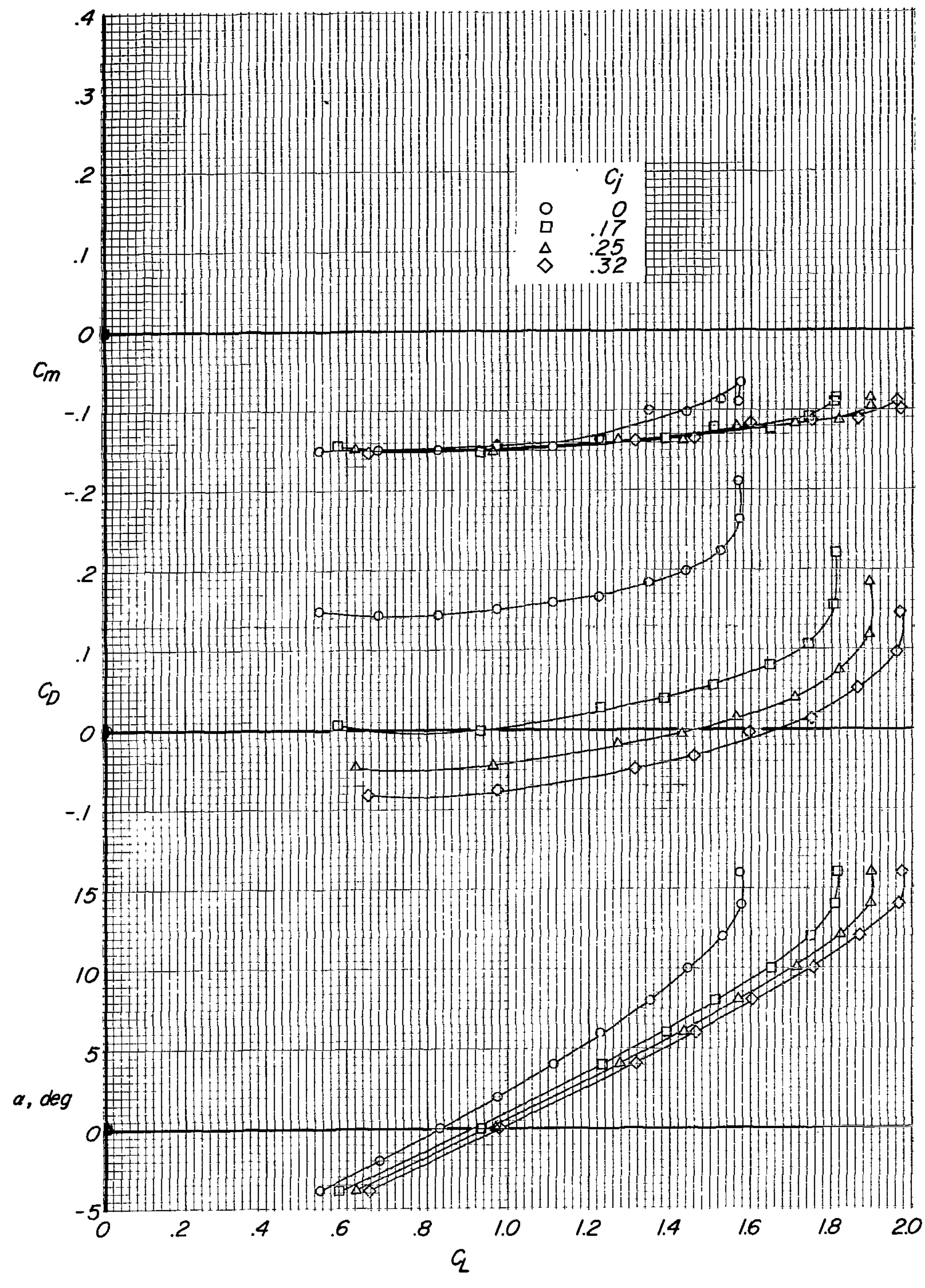
(d) h/b = 0.12.

Figure 9.- Continued.



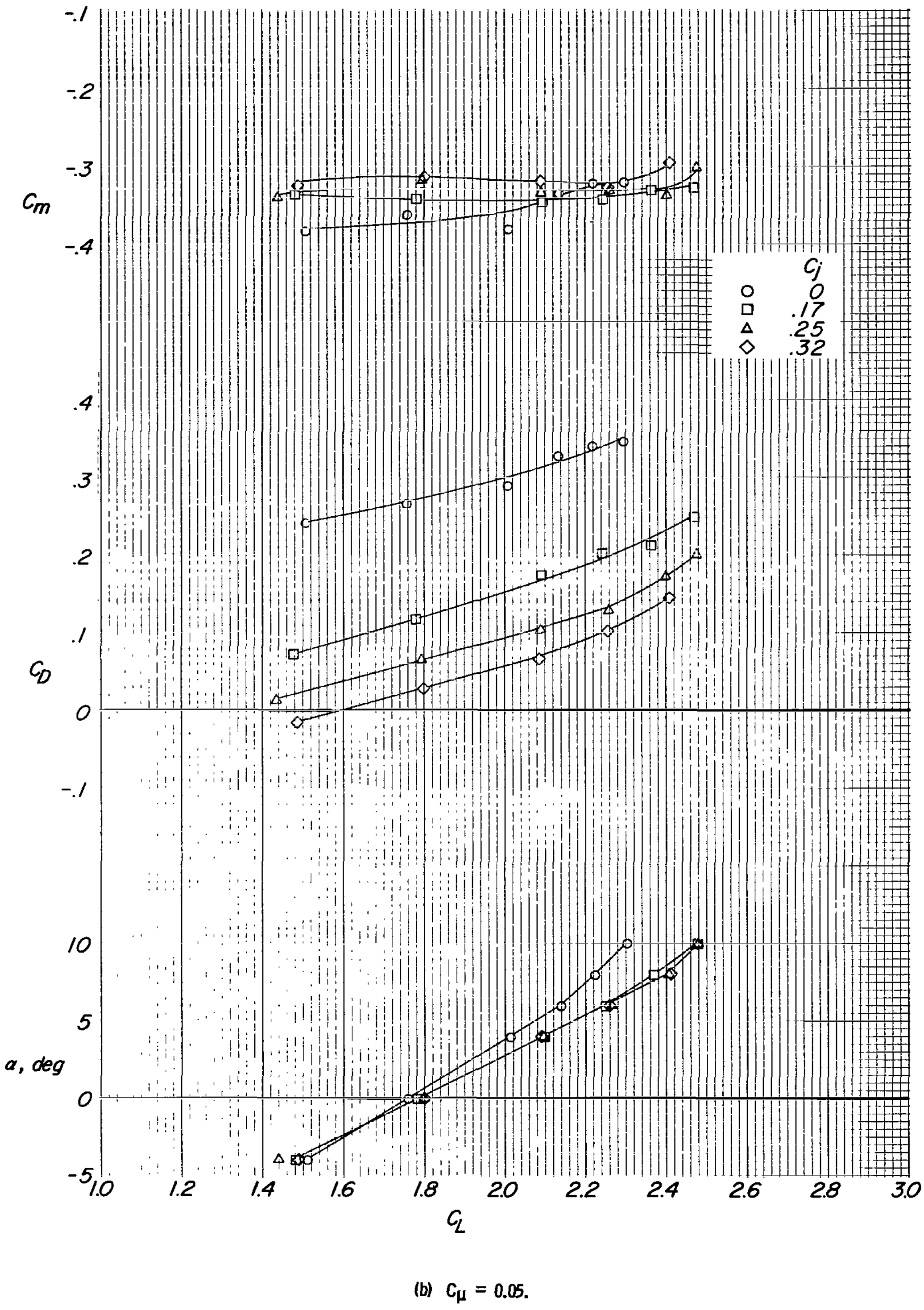
(e) h/b = 0.10.

Figure 9.- Concluded.



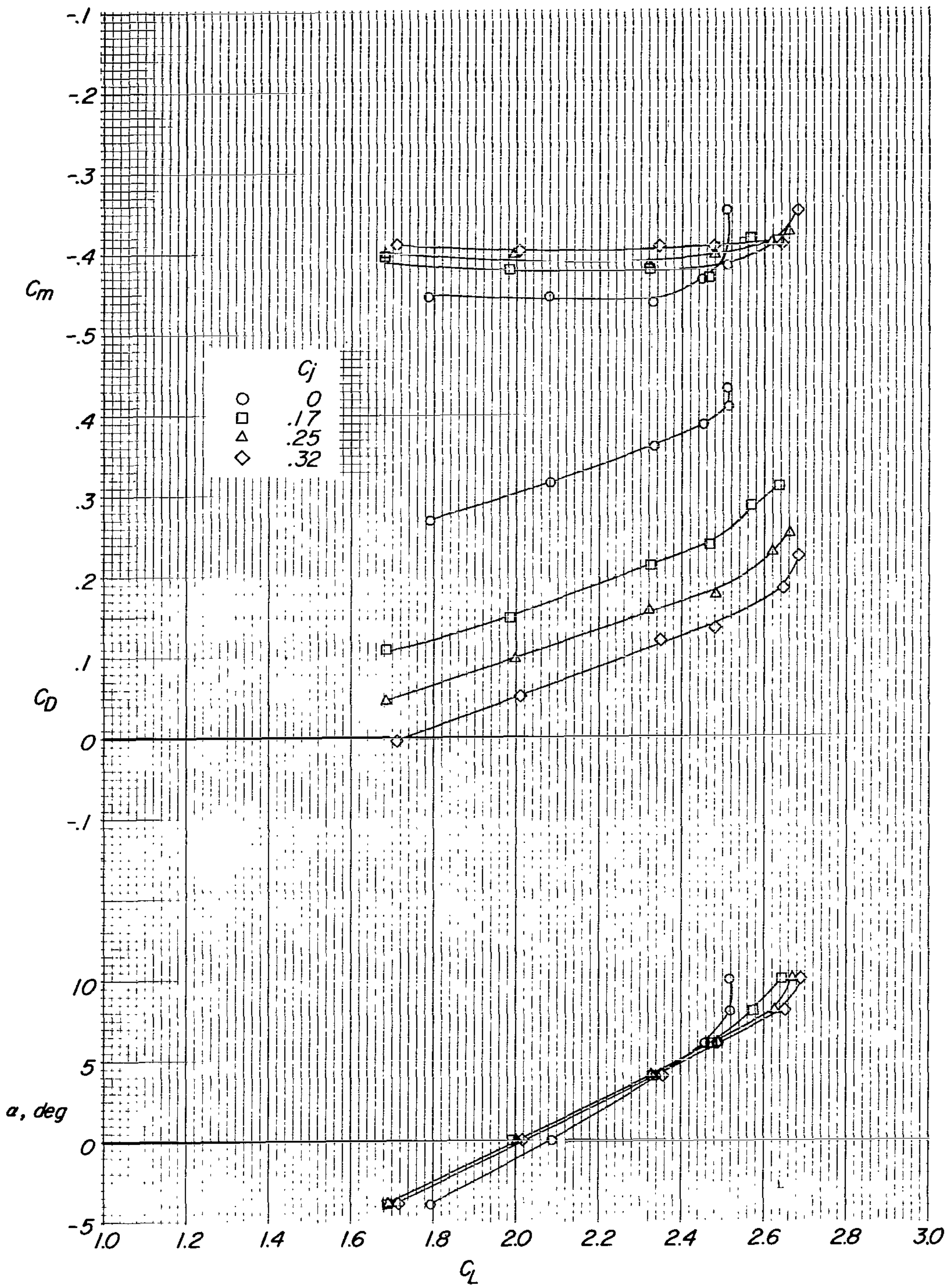
(a) $C_\mu = 0$.

Figure 10.- Effect of thrust on the characteristics of the model away from the ground plane with various flap blowing momentums. $h/b = 0.69$; $\delta_f = 60^0$; tail off.



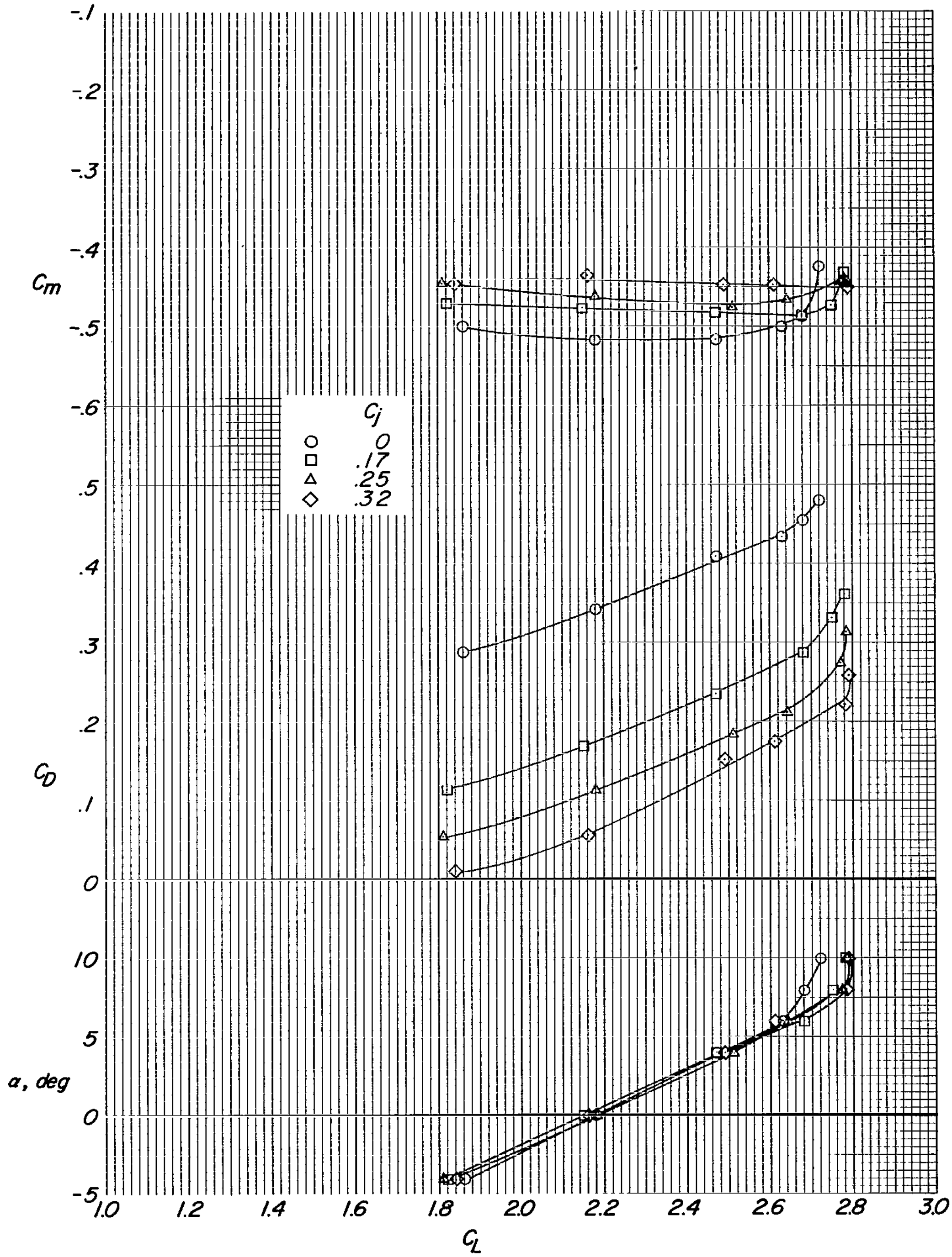
(b) $C_\mu = 0.05$.

Figure 10.- Continued.



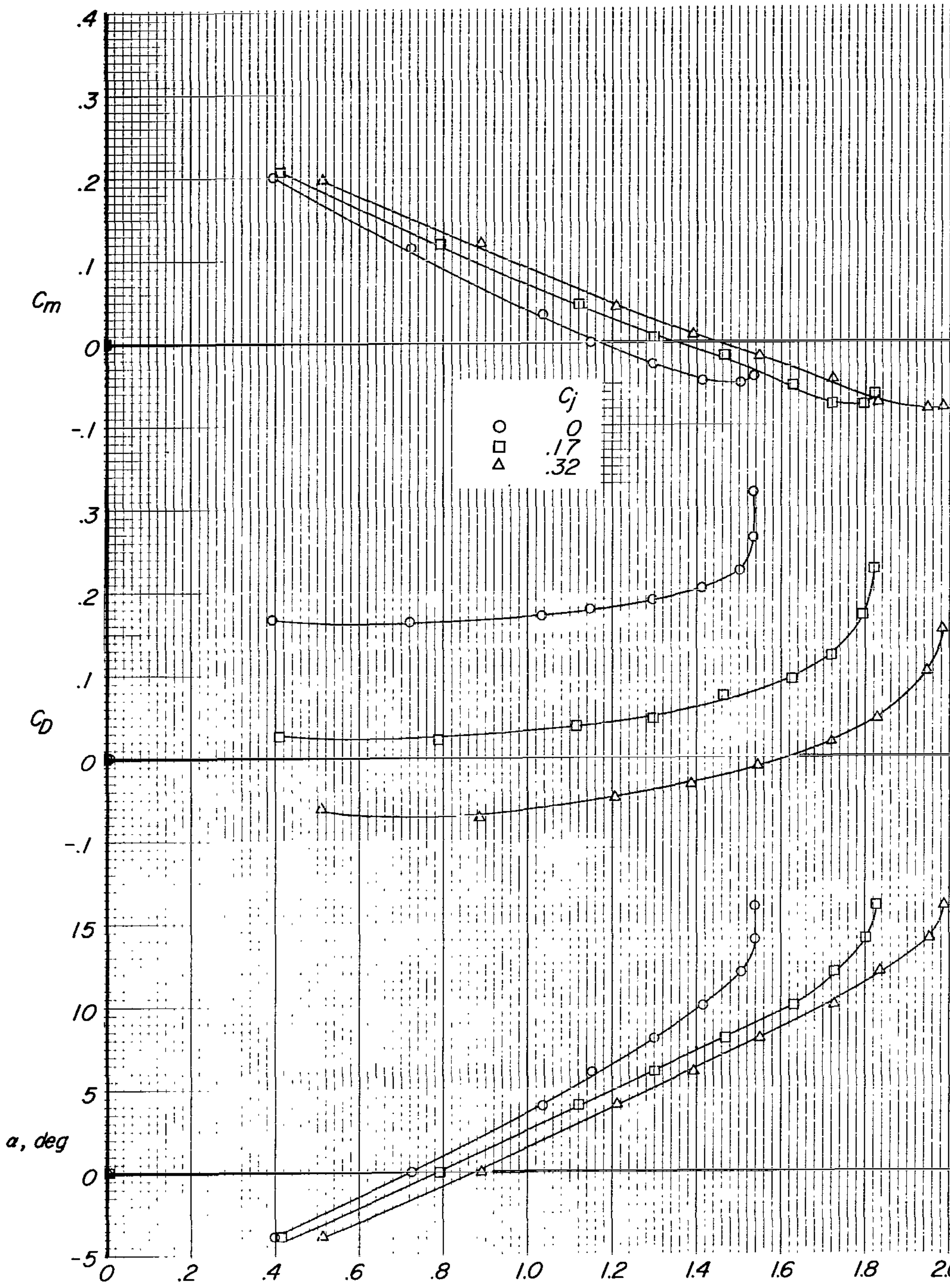
(c) $C_\mu = 0.10$.

Figure 10.- Continued.



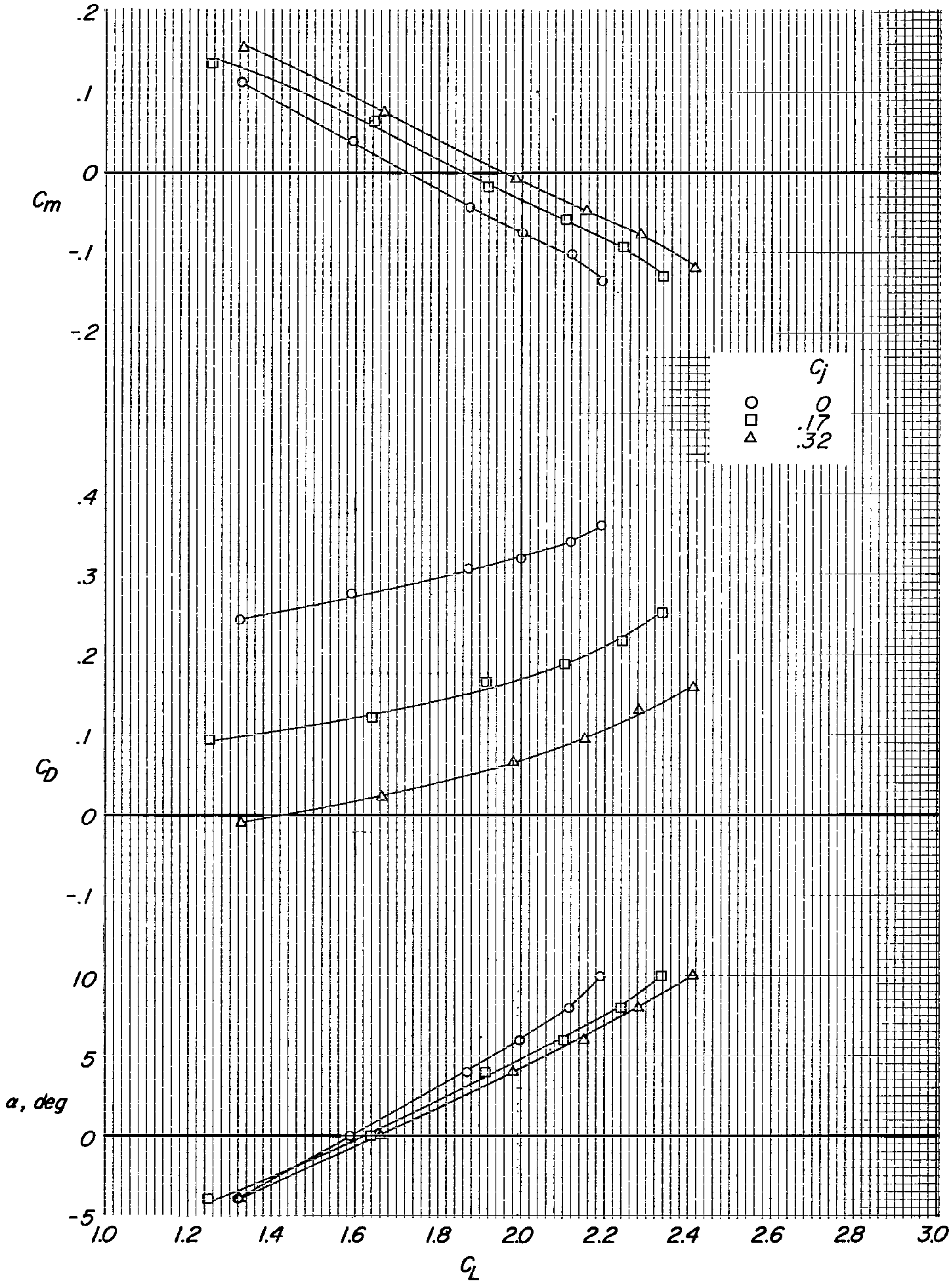
(d) $C_\mu = 0.15$.

Figure 10.- Concluded.



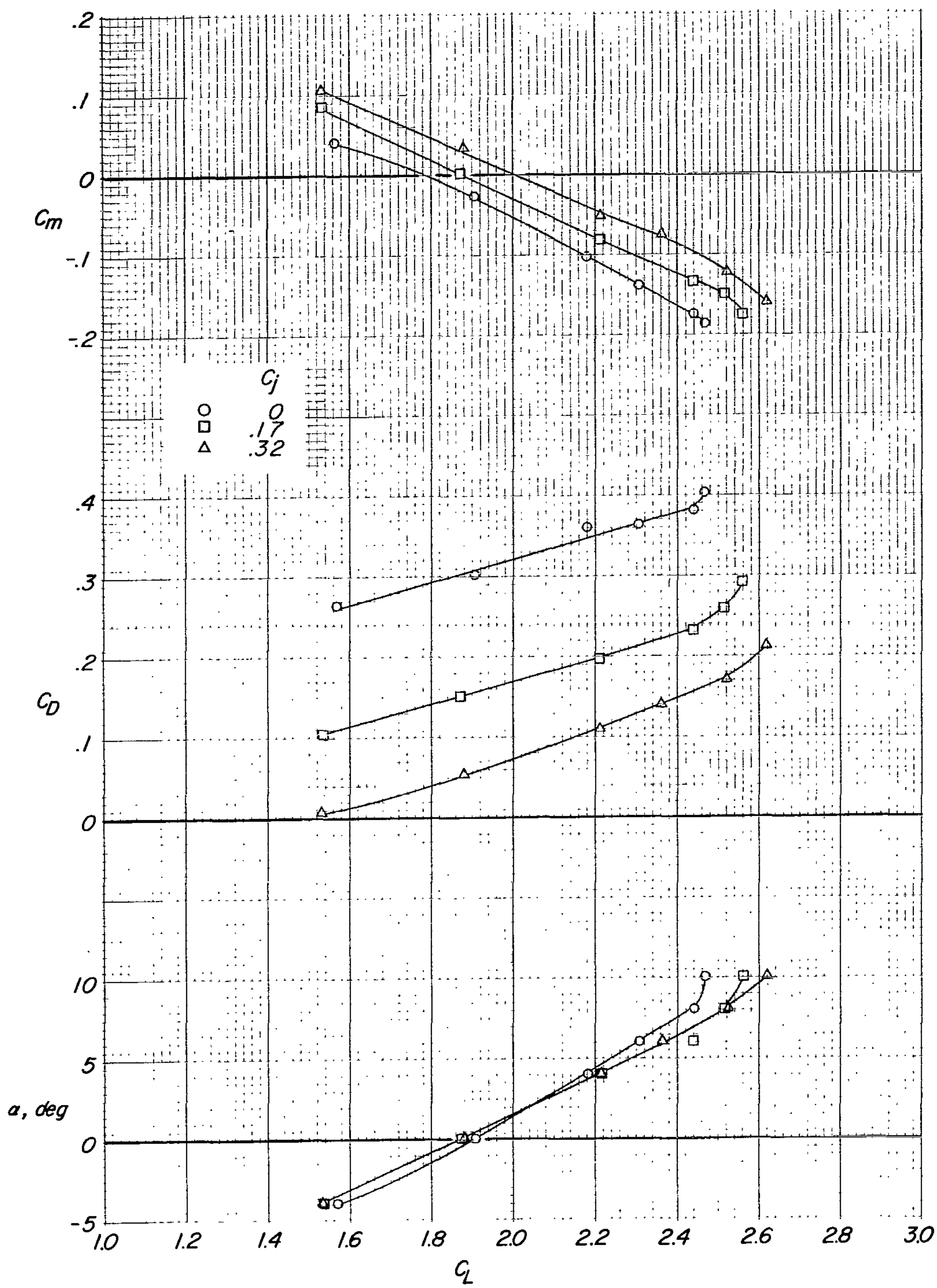
(a) $C_\mu = 0$.

Figure 11.- Effect of thrust on the characteristics of the model away from the ground plane with various flap blowing momentums. $h/b = 0.69$; $\delta_f = 60^0$; $i_t = -6^0$.



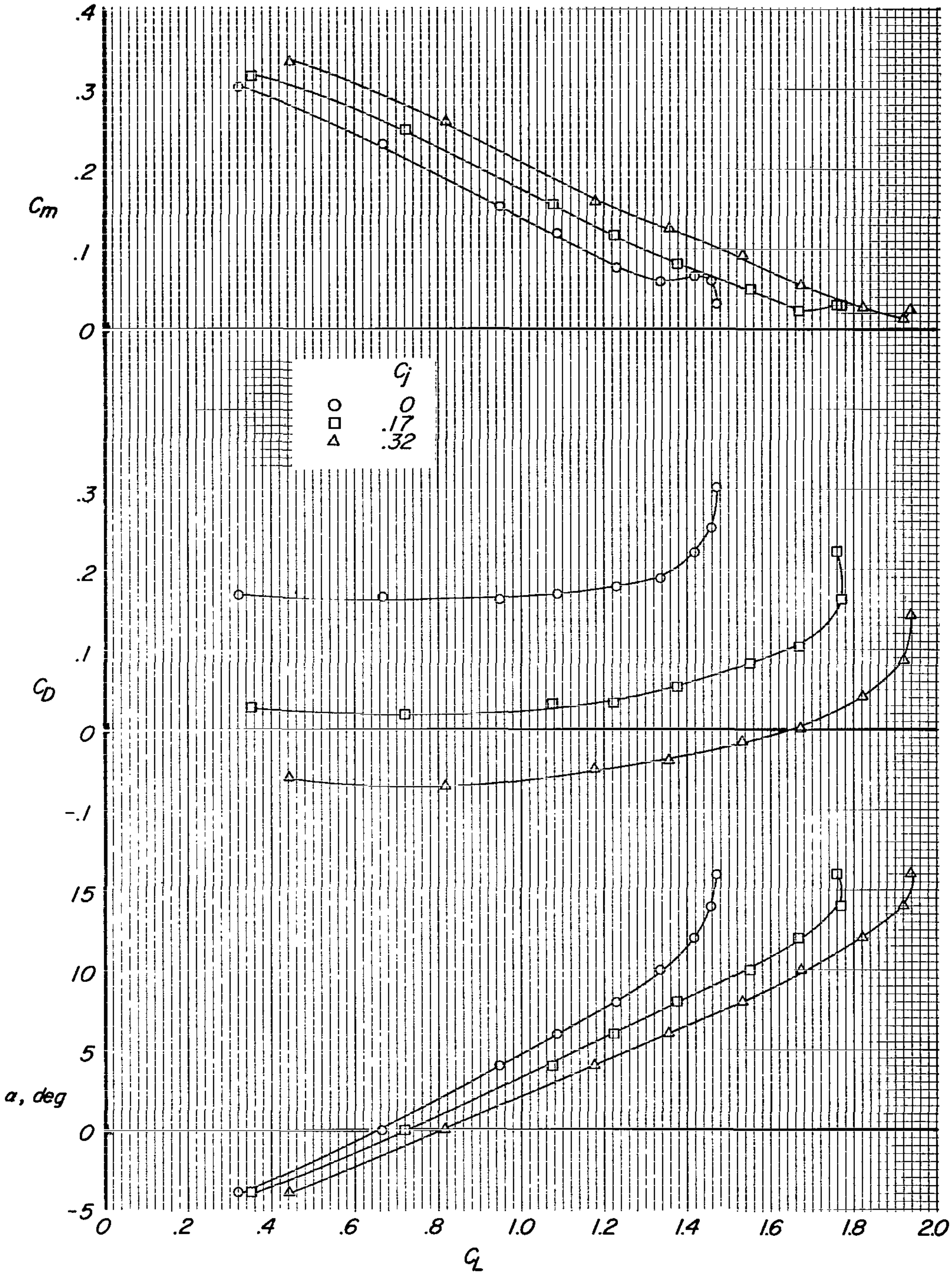
(b) $C_\mu = 0.05$.

Figure 11.- Continued.



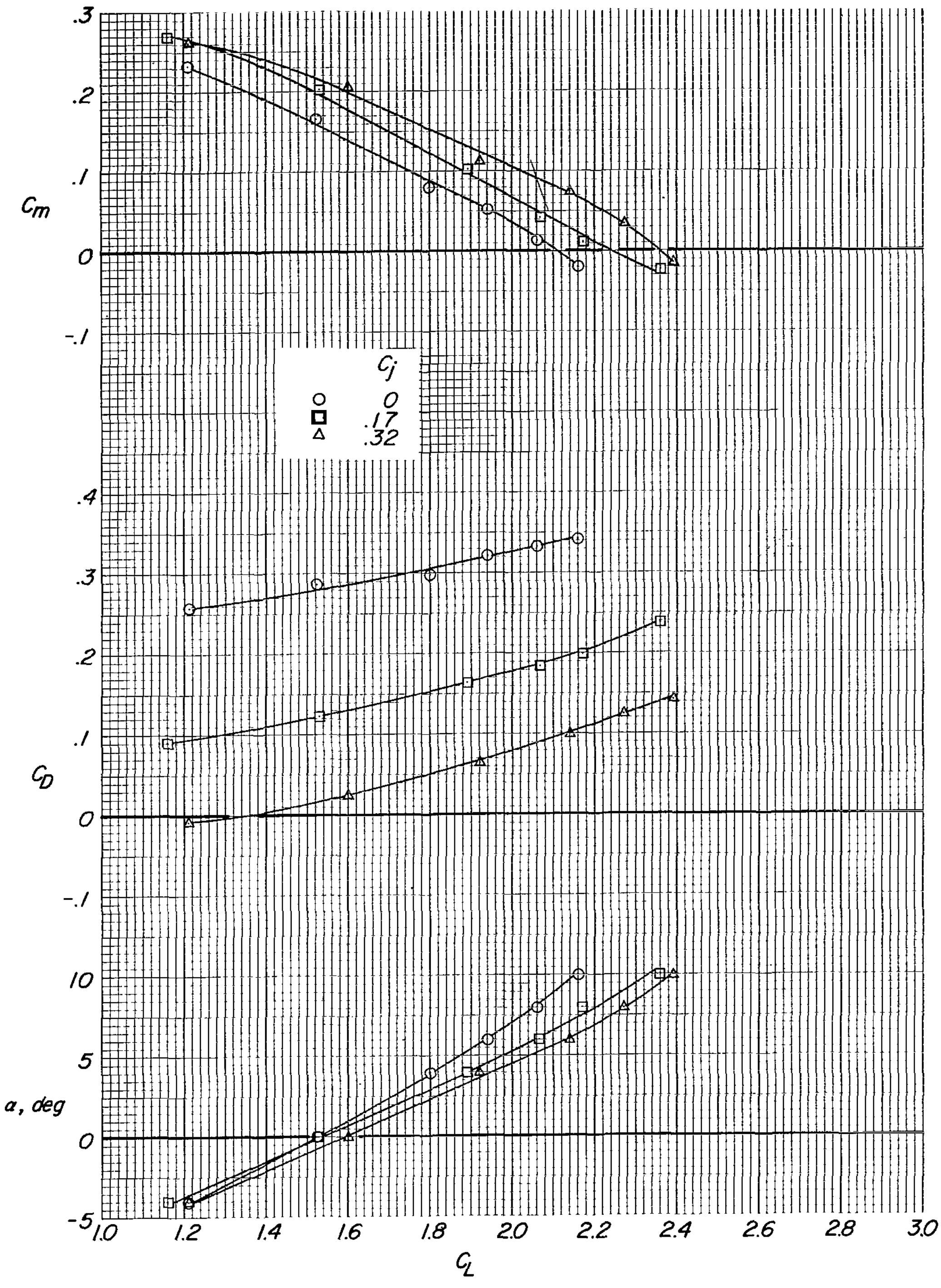
(c) $C_\mu = 0.10$.

Figure 11.- Concluded.



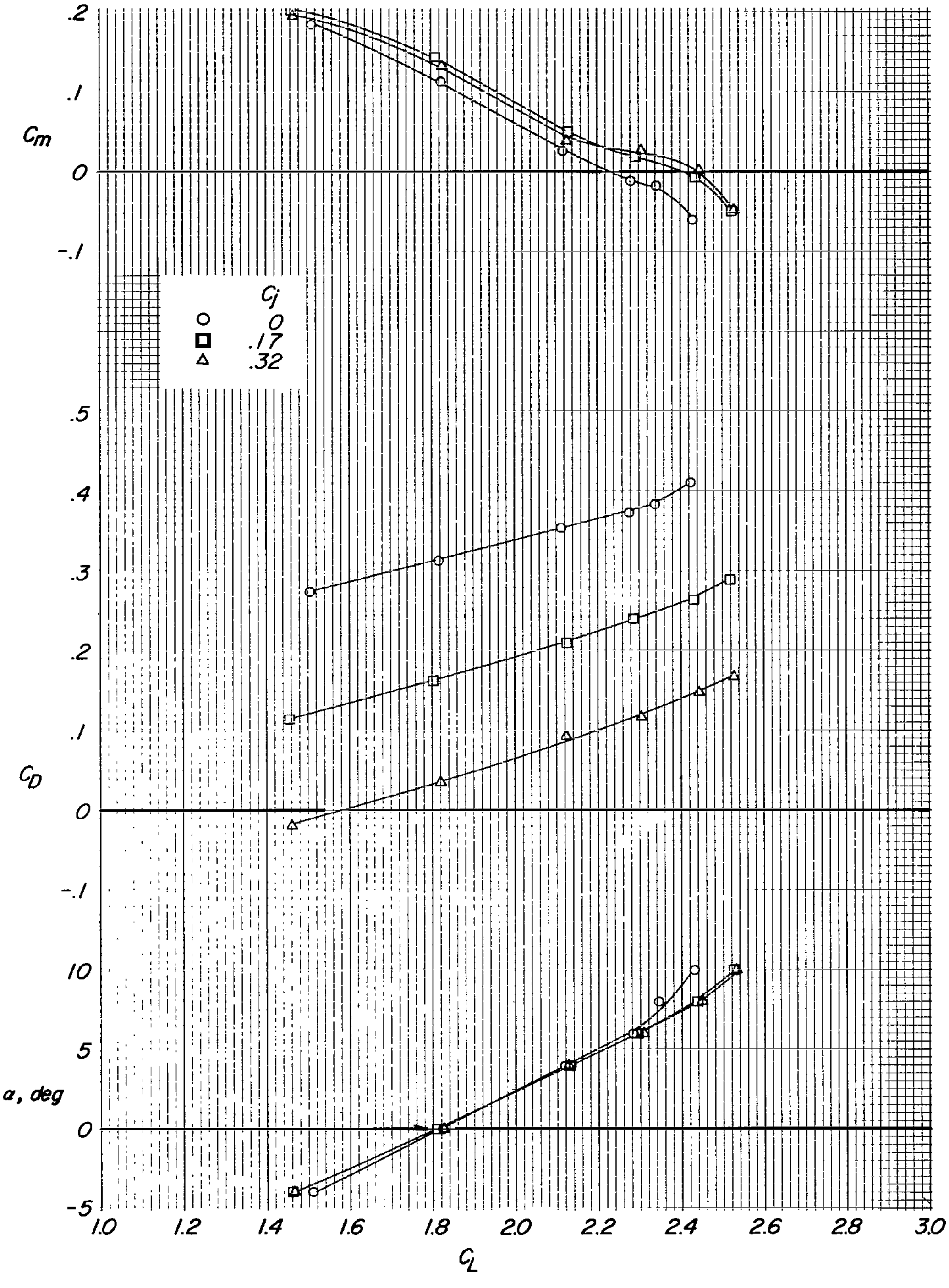
(a) $C_\mu = 0$.

Figure 12.- Effect of thrust on the characteristics of the model away from the ground plane with various flap blowing momentums. $h/b = 0.69$; $\delta_f = 60^{\circ}$; $i_t = -10^{\circ}$.



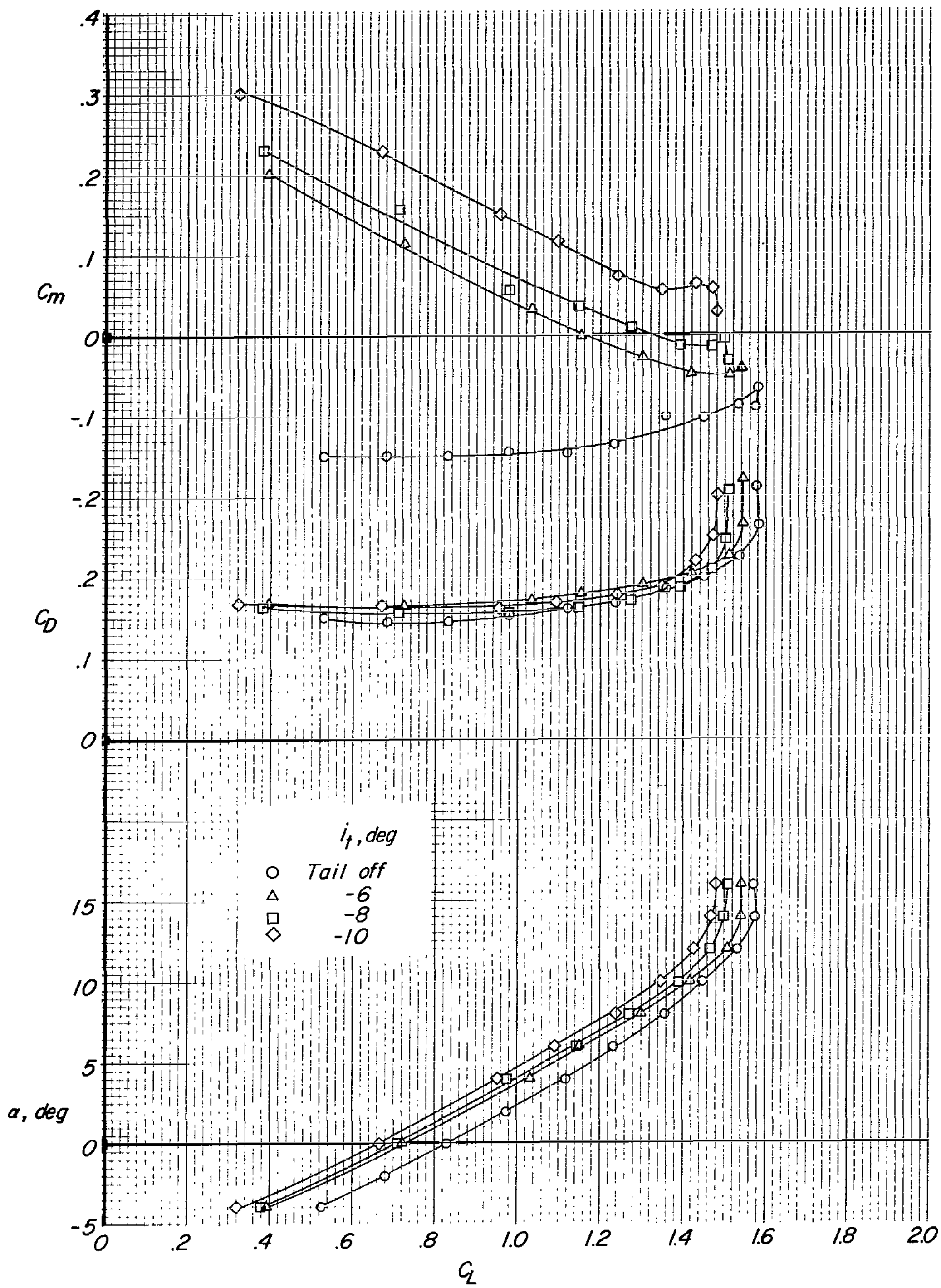
(b) $C_\mu = 0.05$.

Figure 12.- Continued.



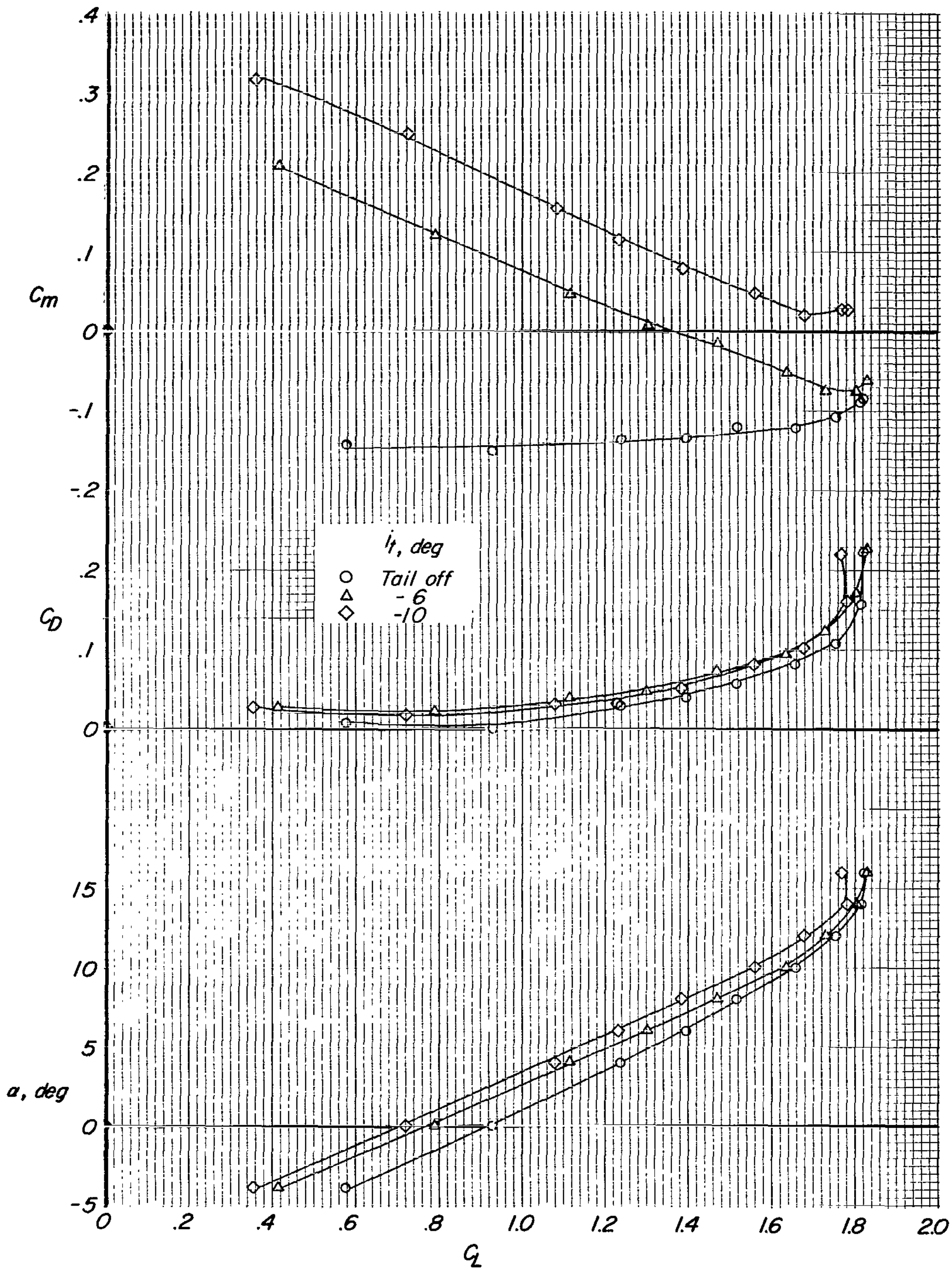
(c) $C_\mu = 0.10$.

Figure 12.- Concluded.



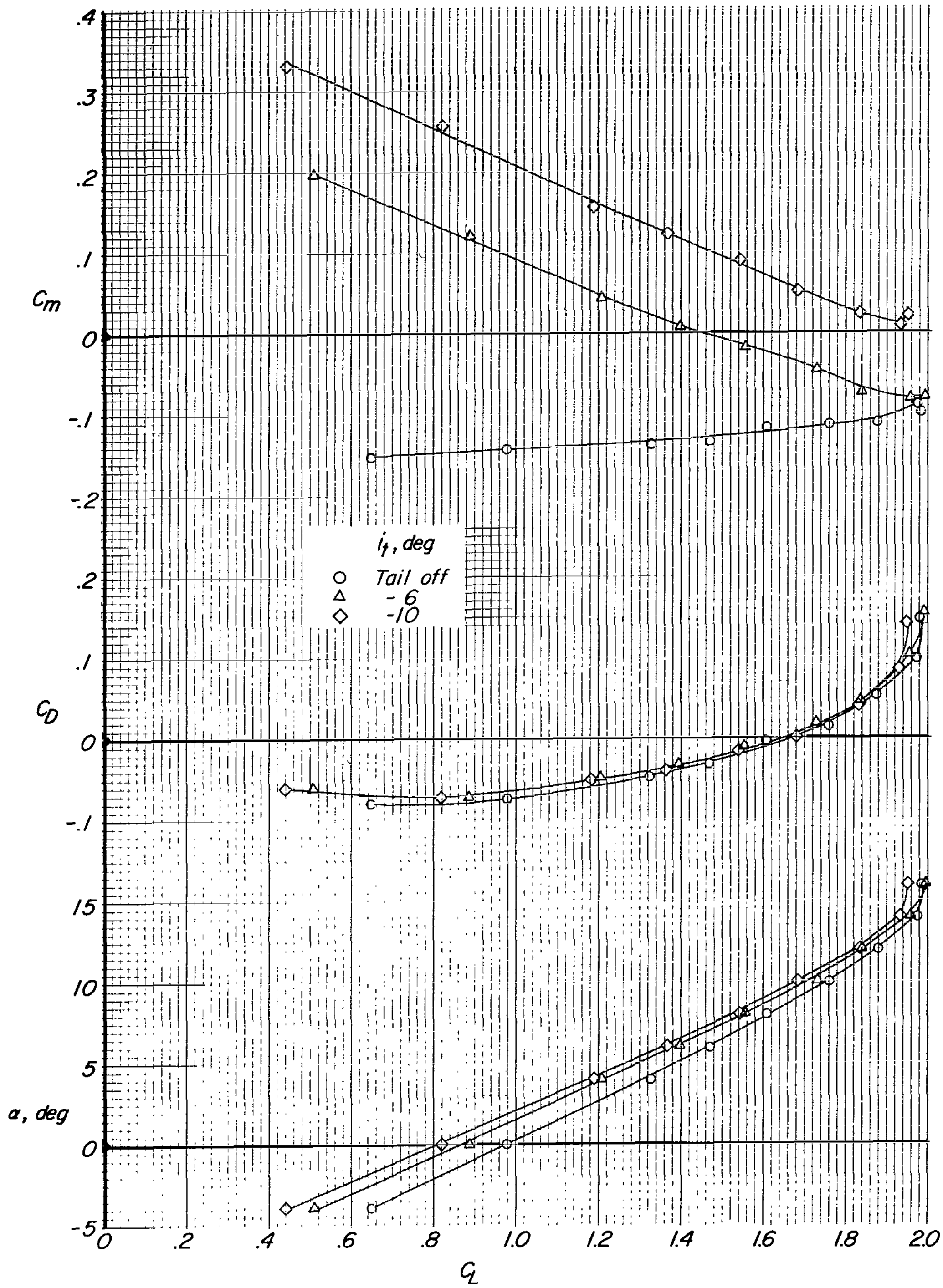
(a) $C_{\mu} = 0$; $C_j = 0$.

Figure 13.- Effect of the horizontal tail on the characteristics of the model away from the ground plane for various combinations of thrust and flap blowing momentums. $h/b = 0.69$; $\delta_f = 60^{\circ}$.



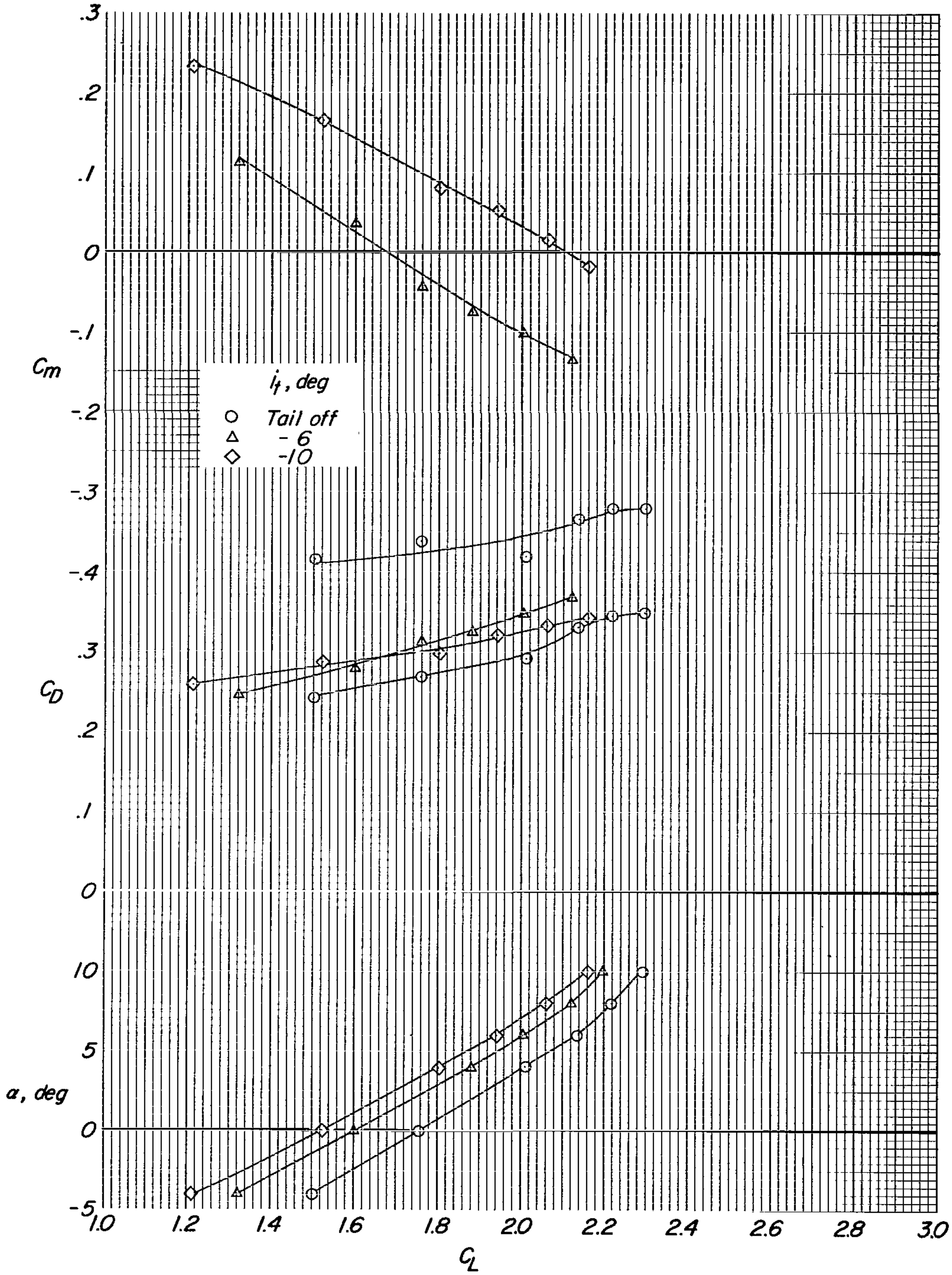
(b) $C_\mu = 0$; $C_j = 0.17$.

Figure 13.- Continued.



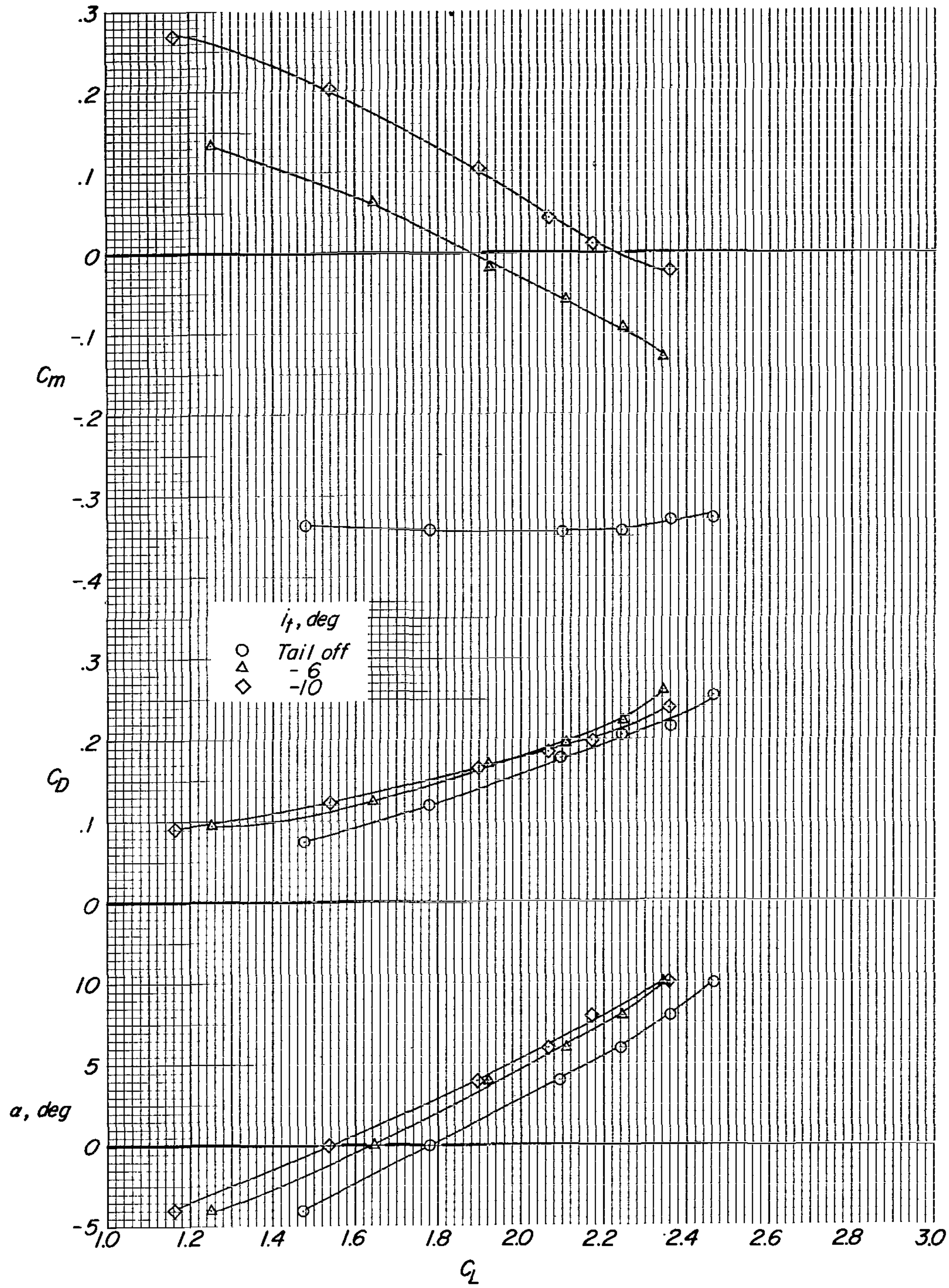
(c) $C_\mu = 0$; $C_j = 0.32$.

Figure 13.- Continued.



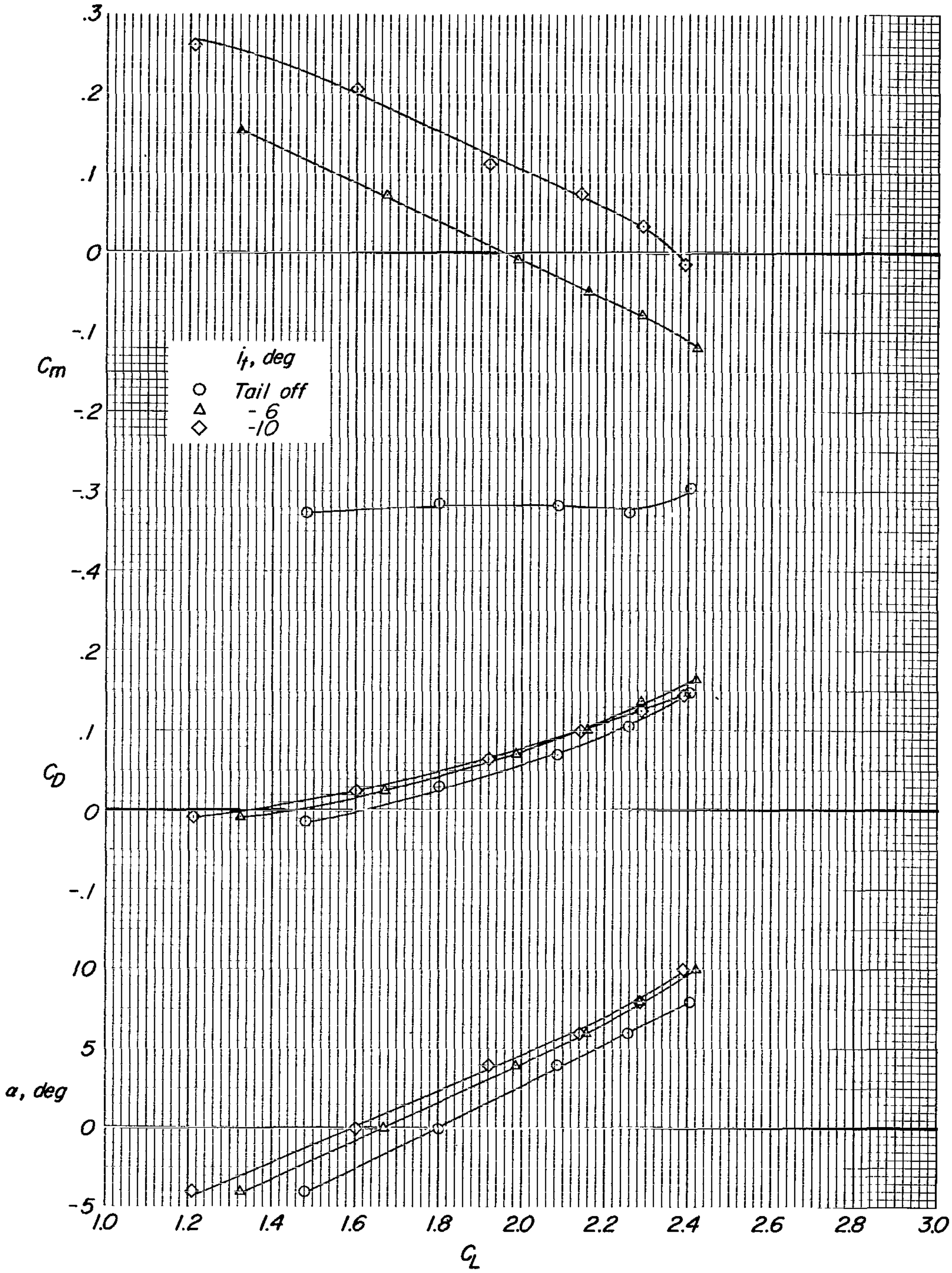
(d) $C_\mu = 0.05$; $C_j = 0$.

Figure 13.- Continued.



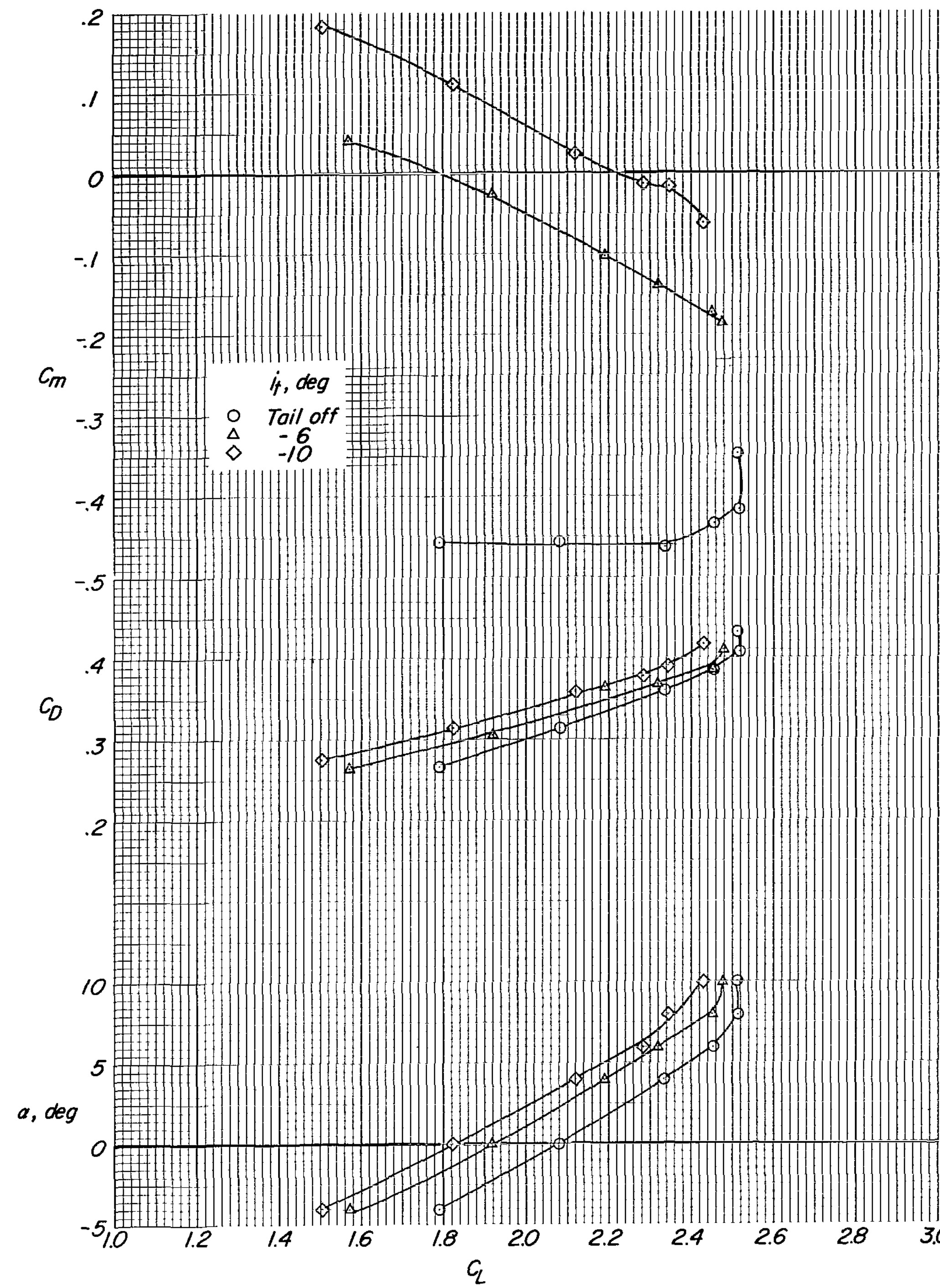
(e) $C_\mu = 0.05$; $C_j = 0.17$.

Figure 13.- Continued.



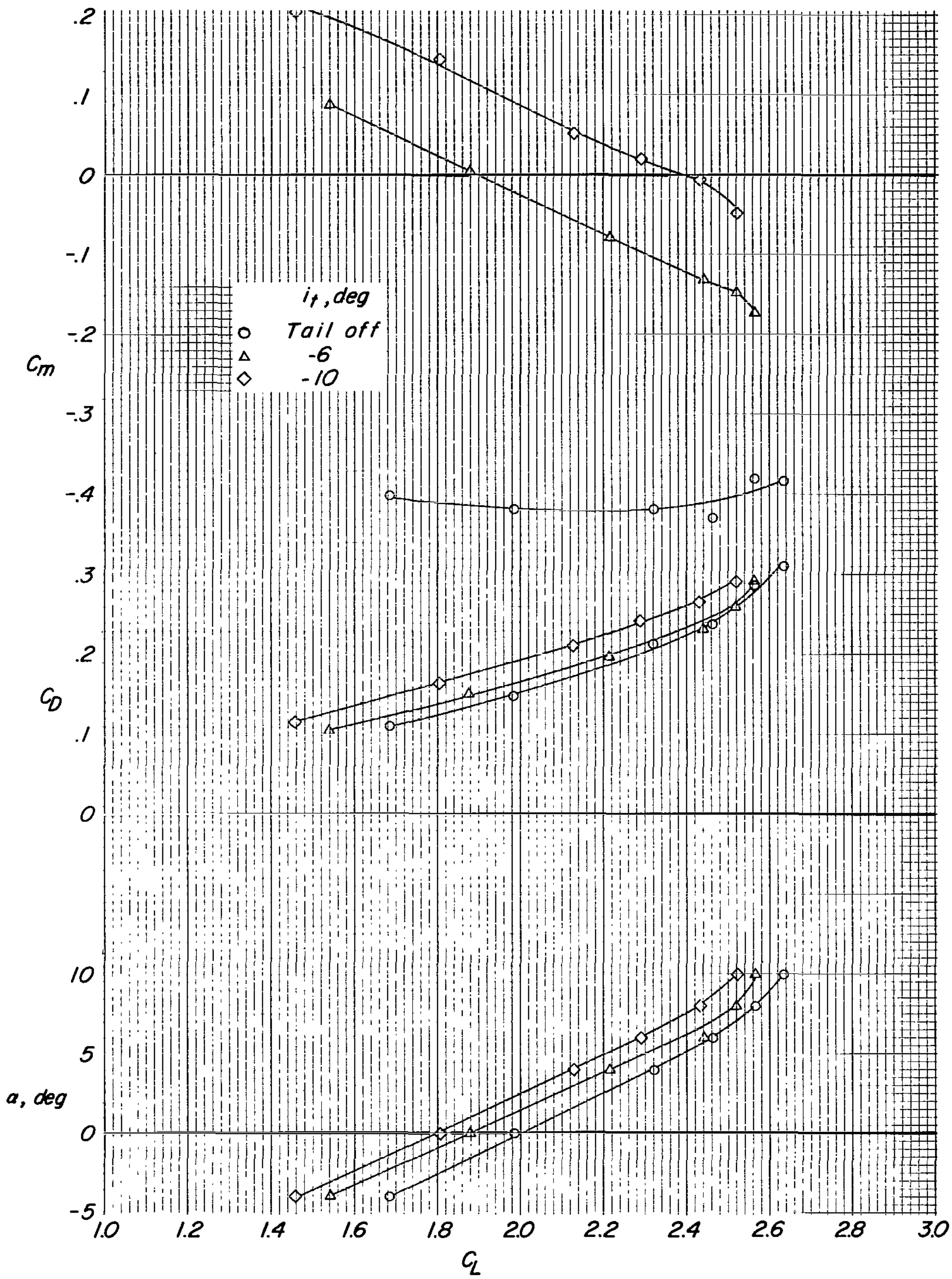
(f) $C_\mu = 0.05$; $C_j = 0.32$.

Figure 13.- Continued.



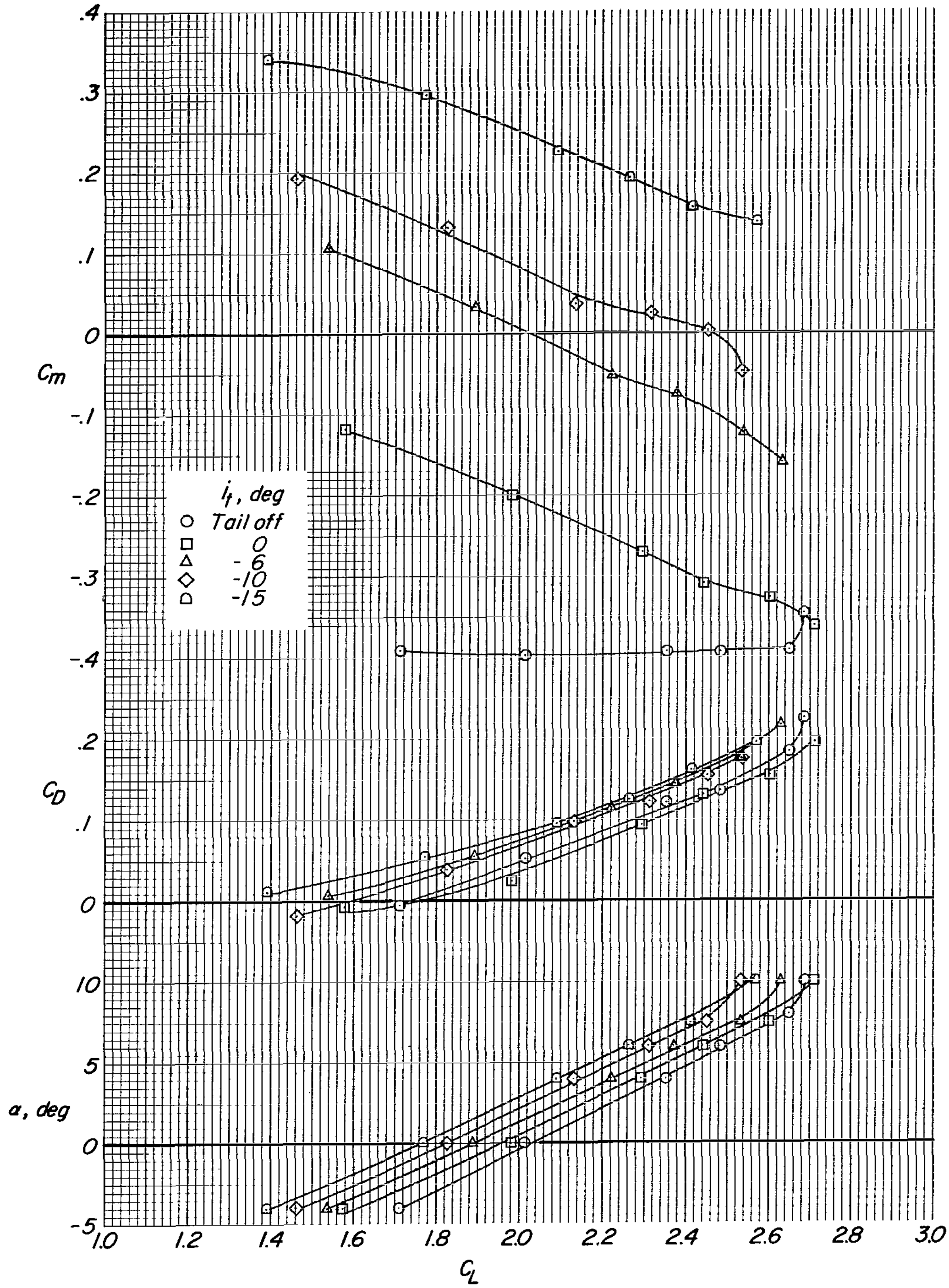
(g) $C_\mu = 0.10$; $C_j = 0$.

Figure 13.- Continued.



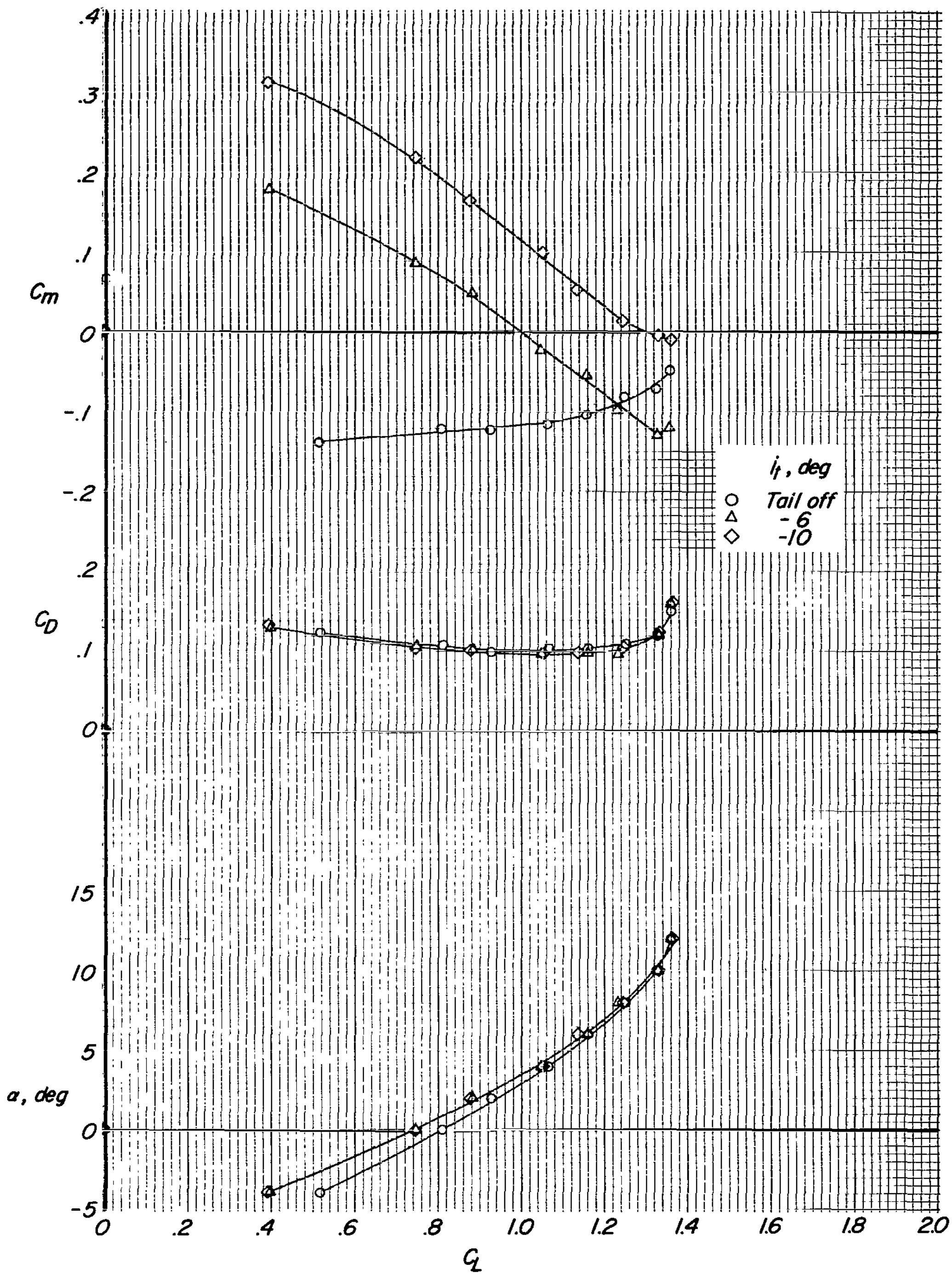
(h) $C_\mu = 0.10$; $C_j = 0.17$.

Figure 13.- Continued.



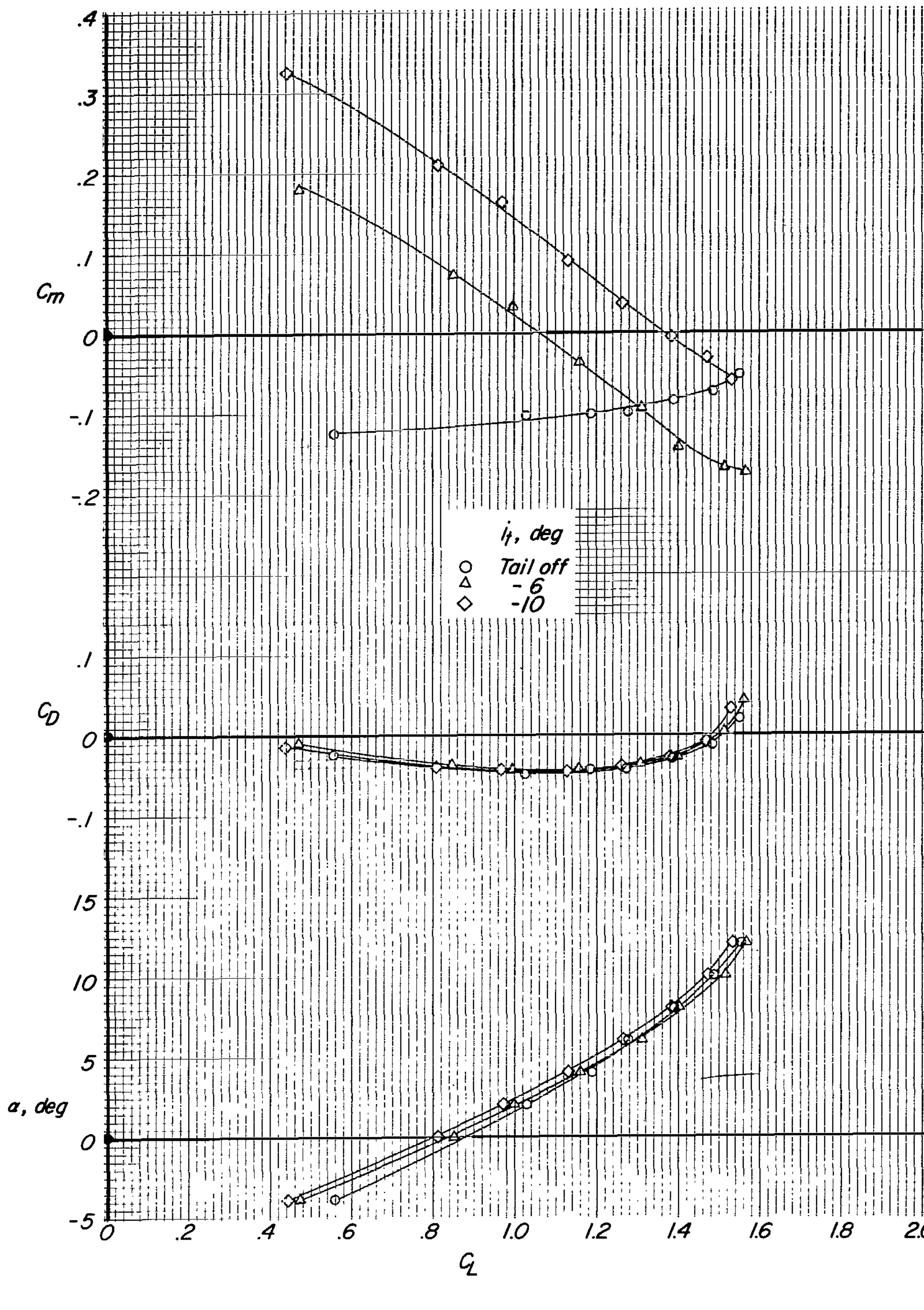
(i) $C_\mu = 0.10$; $C_j = 0.32$.

Figure 13.- Concluded.



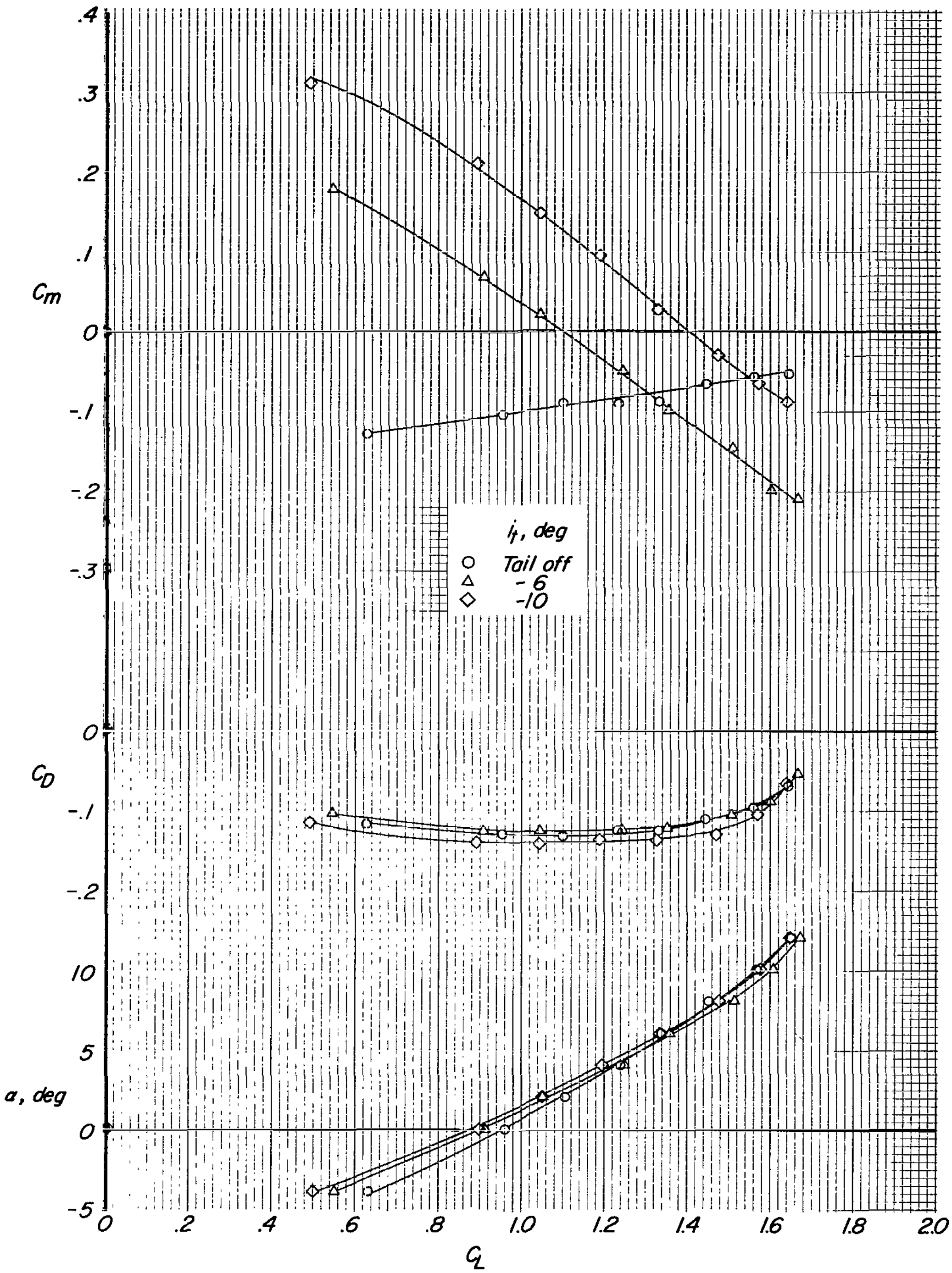
(a) $C_\mu = 0$; $C_j = 0$.

Figure 14.- Effect of the horizontal tail on the characteristics of the model near a moving ground plane for various combinations of thrust and flap blowing momentum. $h/b = 0.12$; $\delta_f = 60^o$.



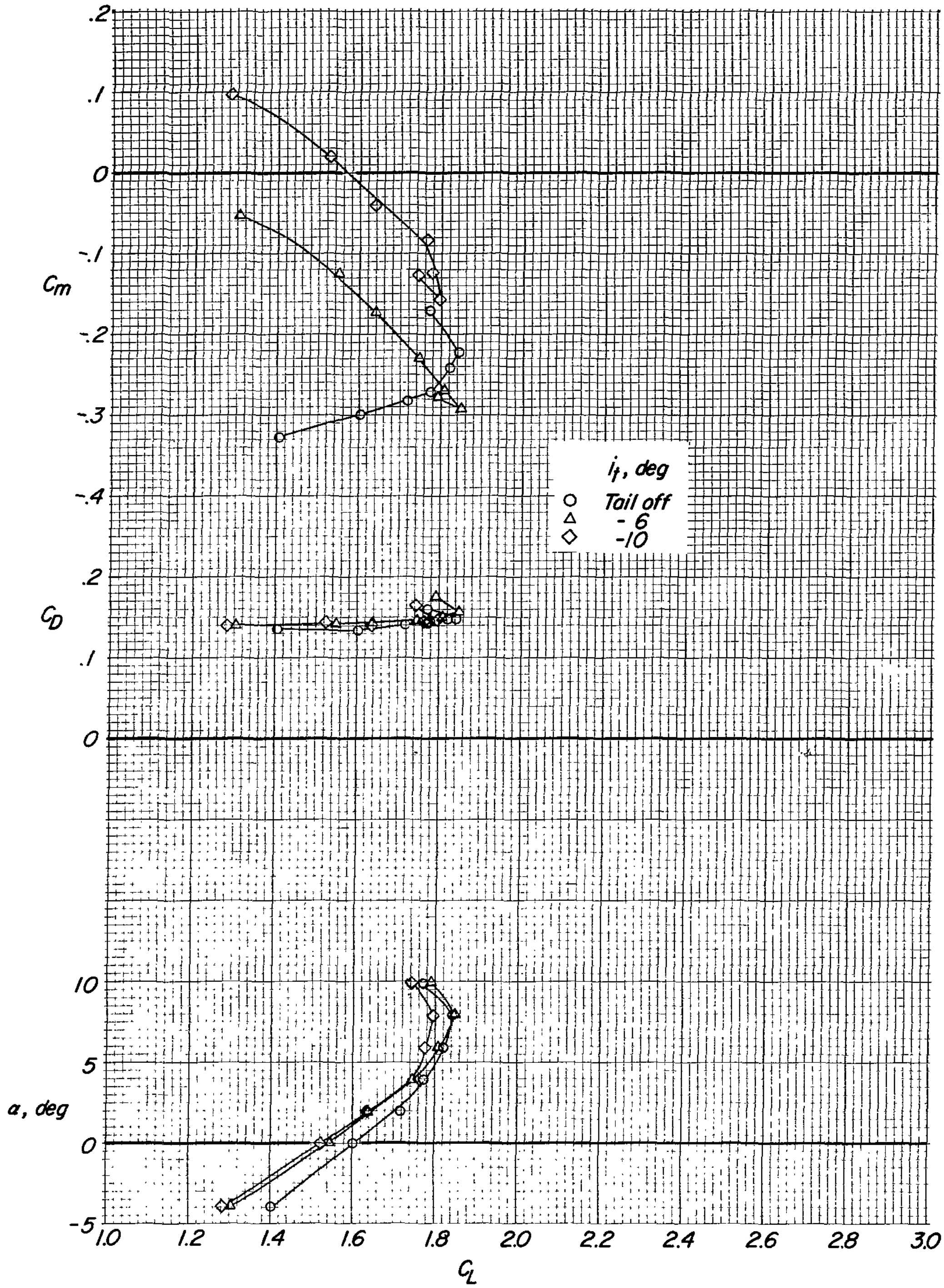
(b) $C_\mu = 0$; $C_j = 0.17$.

Figure 14.- Continued.



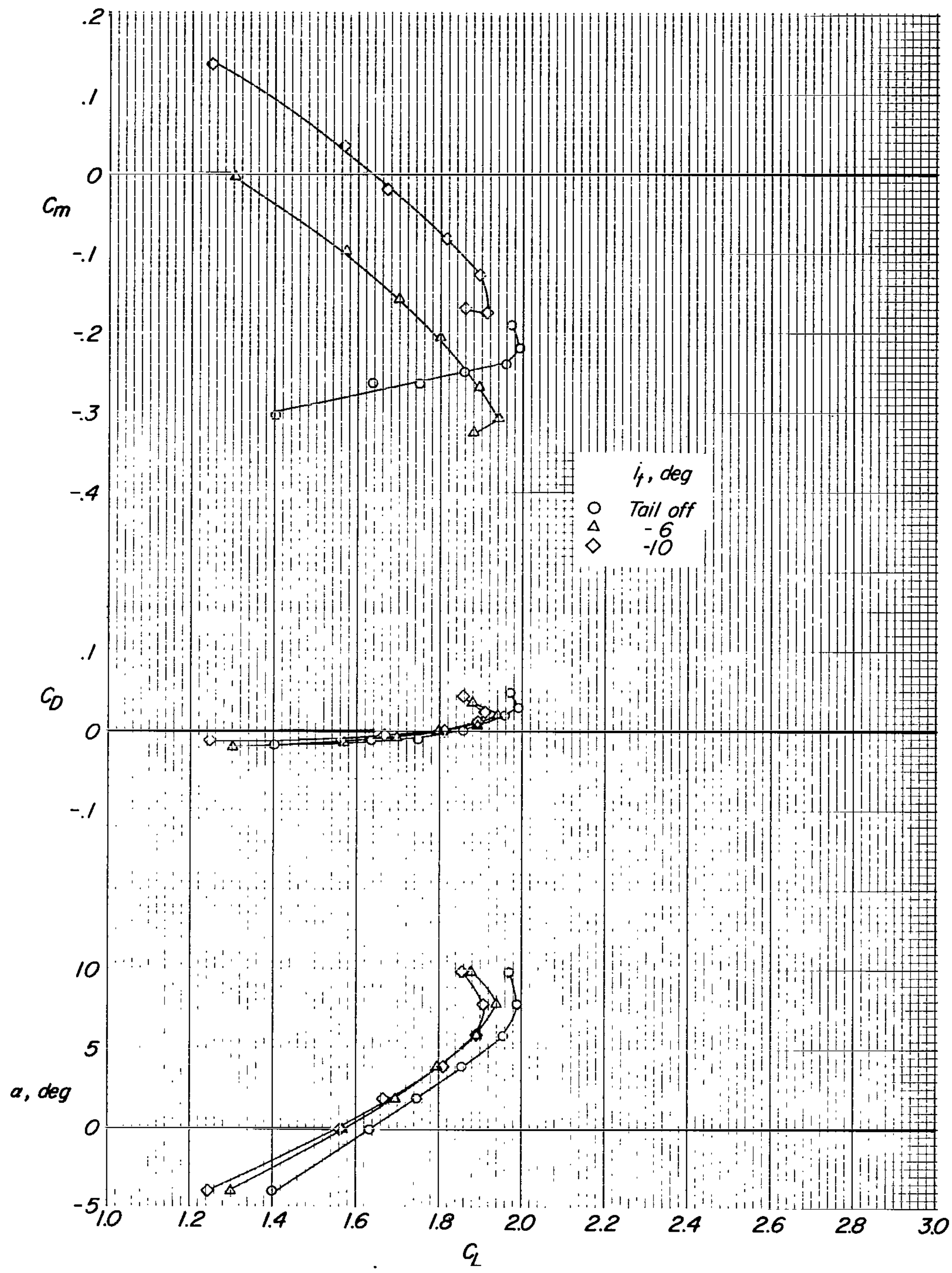
(c) $C_\mu = 0$; $C_j = 0.32$.

Figure 14.- Continued.



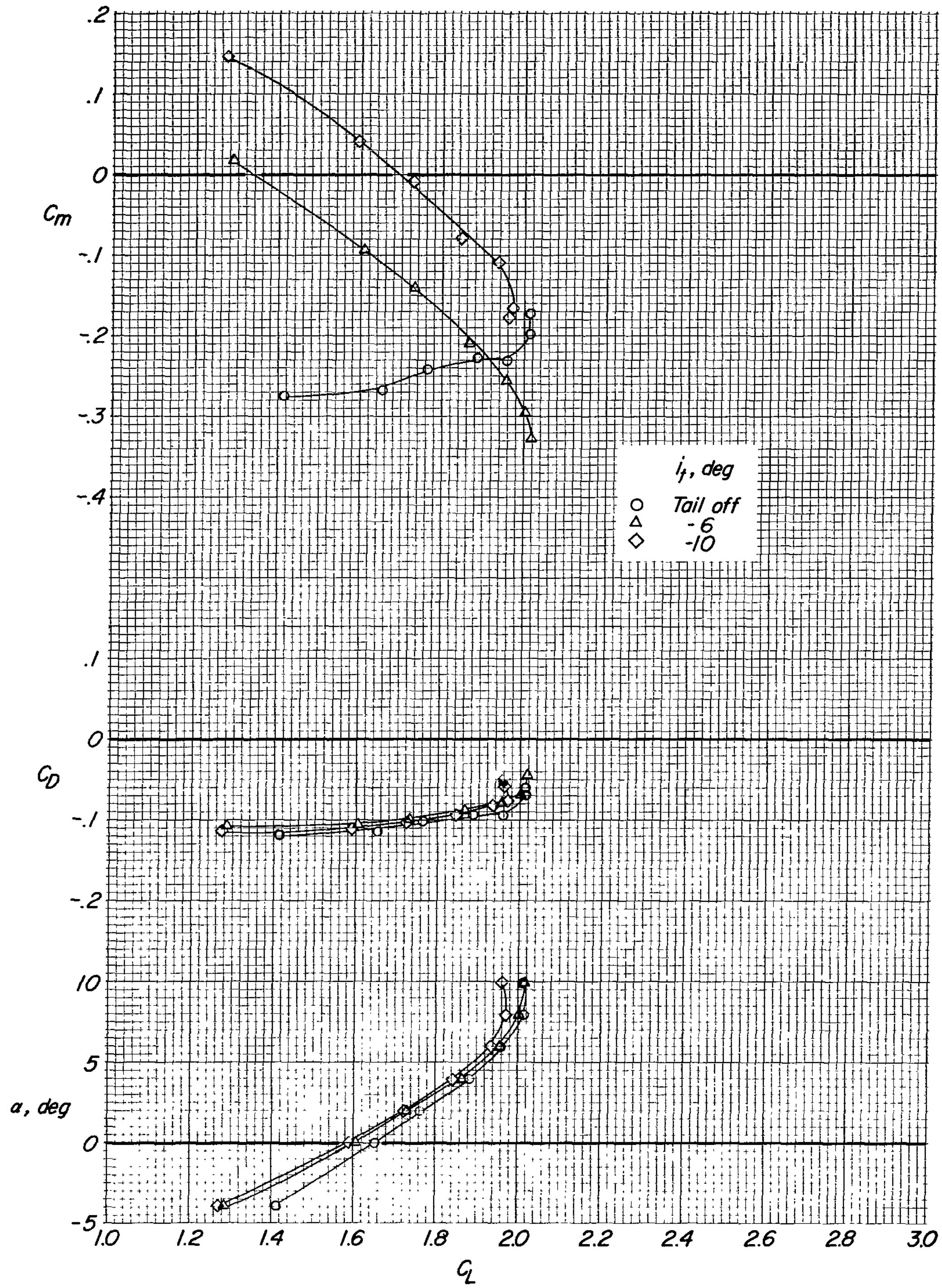
(d) $C_{\mu} = 0.05$; $C_j = 0$.

Figure 14.- Continued.



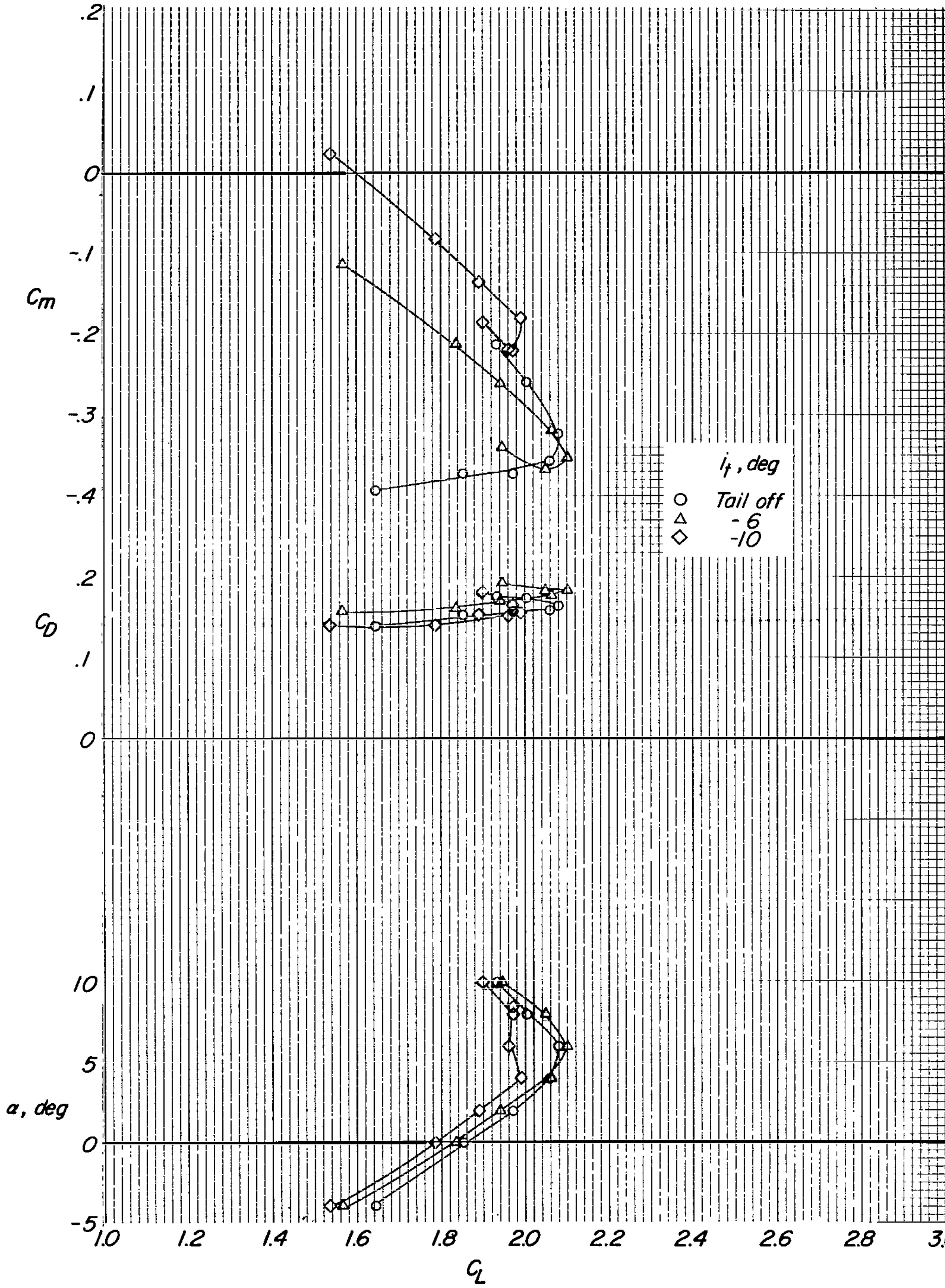
(e) $C_\mu = 0.05$; $C_j = 0.17$.

Figure 14.- Continued.



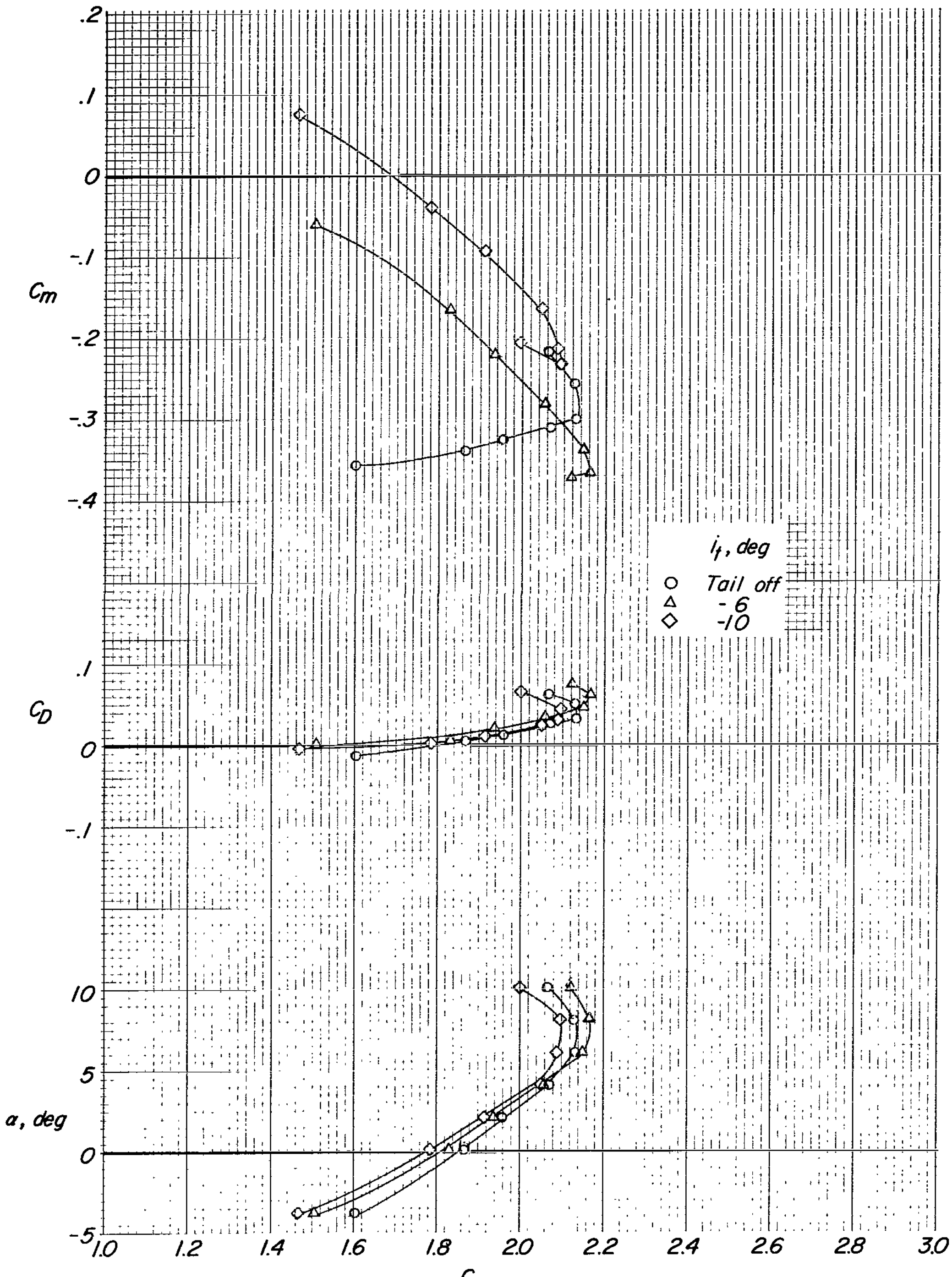
(f) $C_\mu = 0.05$; $C_j = 0.32$.

Figure 14.- Continued.



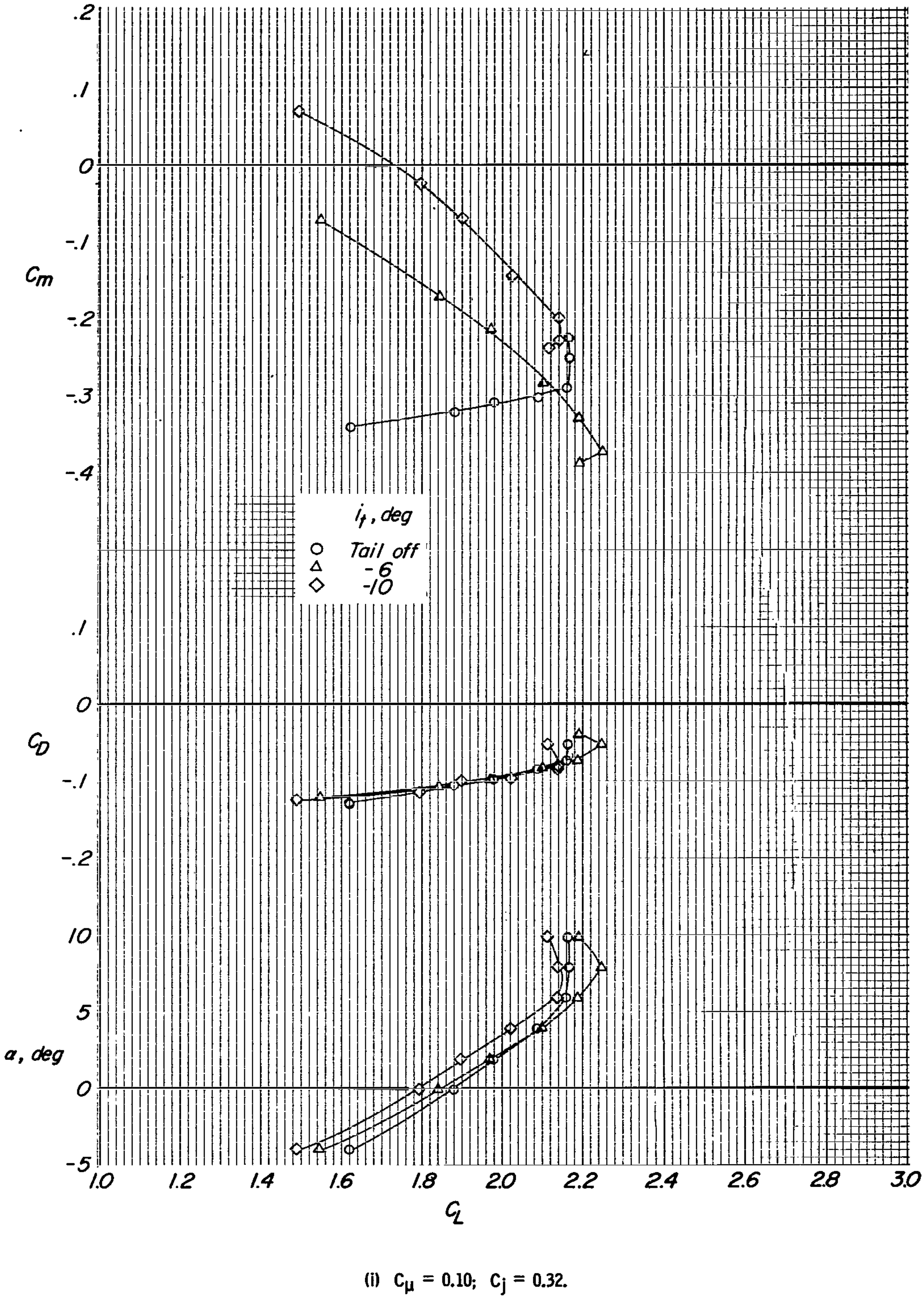
(g) $C_\mu = 0.10$; $C_j = 0$.

Figure 14.- Continued.



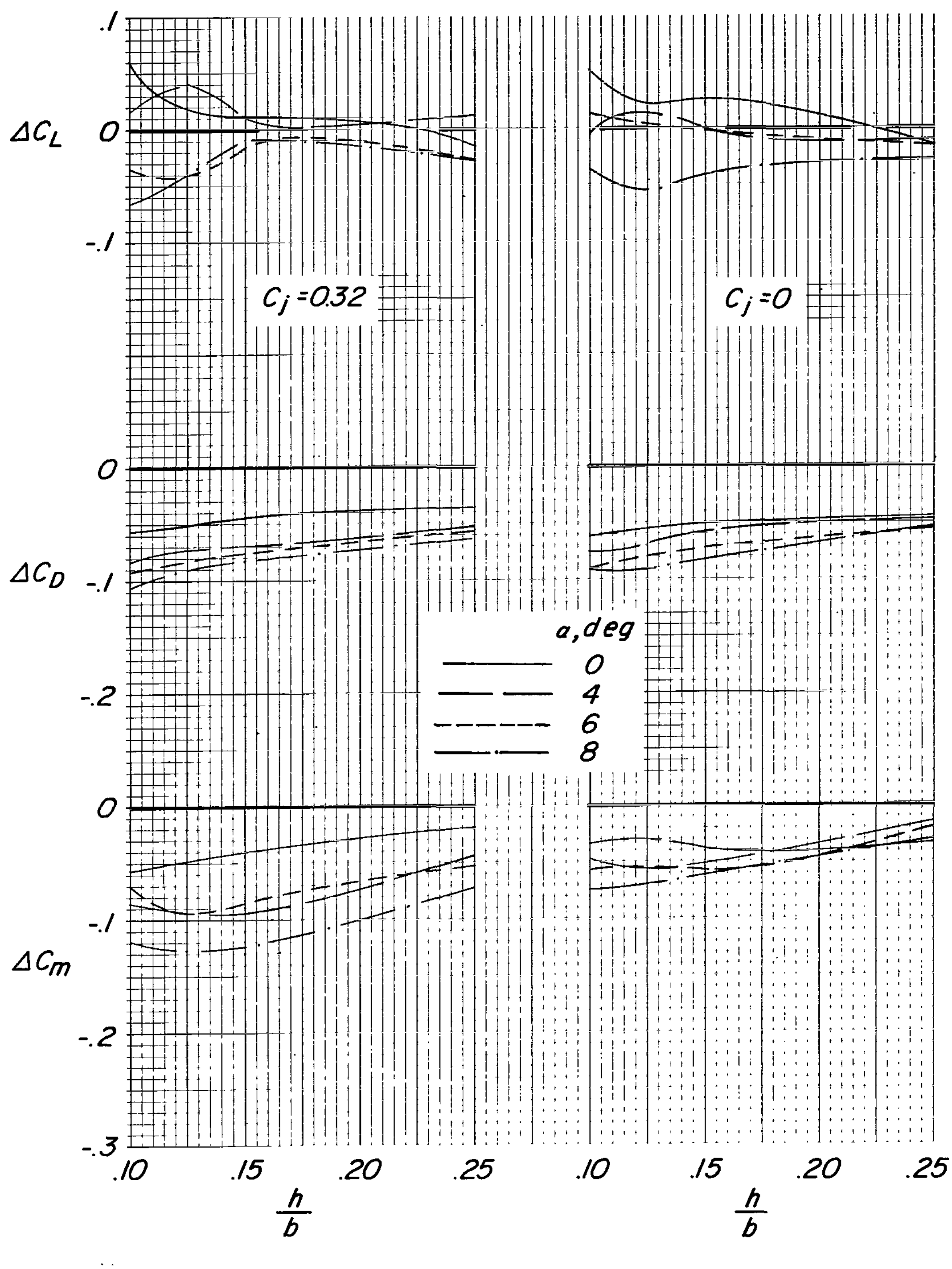
(h) $C_\mu = 0.10$; $C_j = 0.17$.

Figure 14.- Continued.



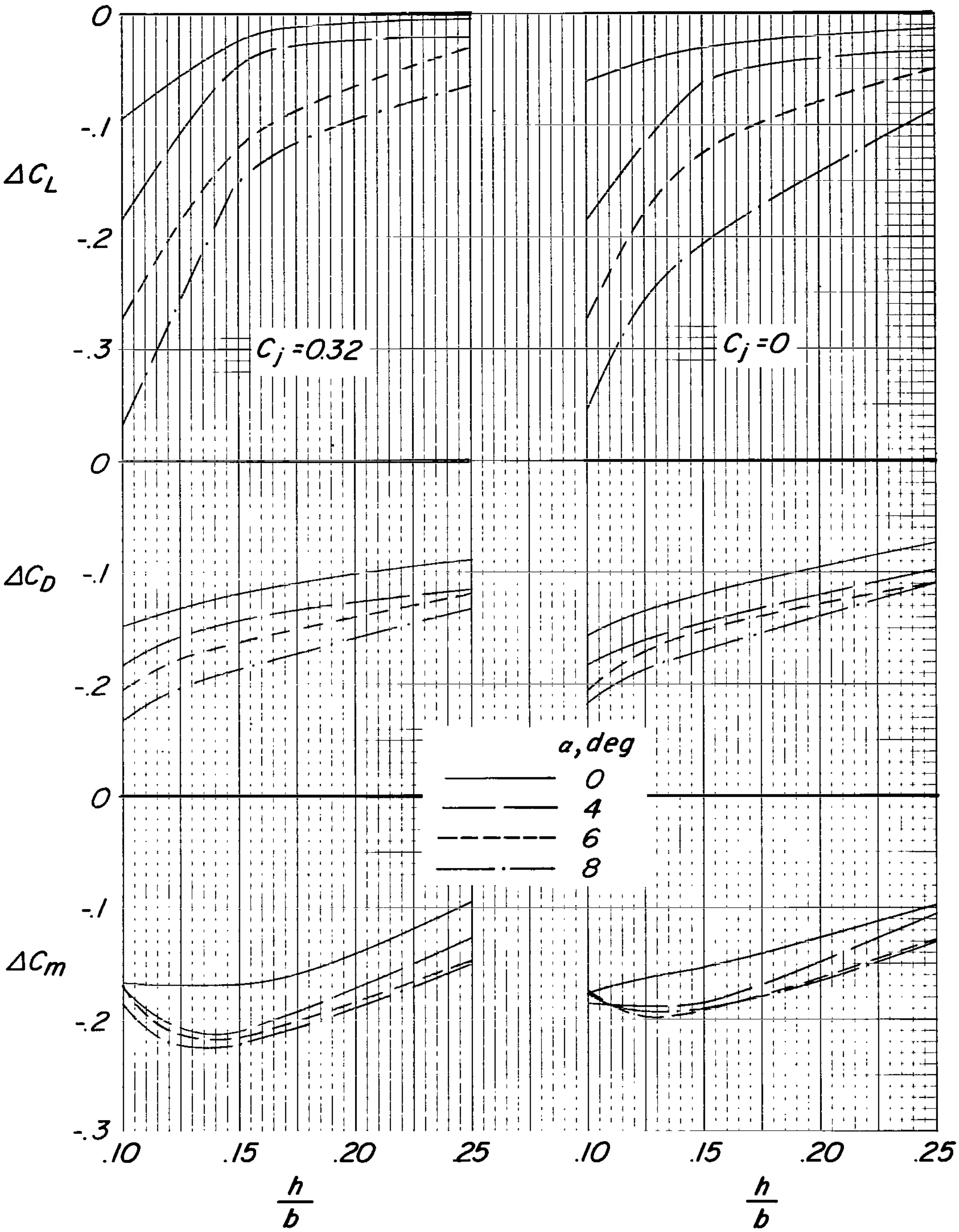
(i) $C_\mu = 0.10$; $C_j = 0.32$.

Figure 14.- Concluded.



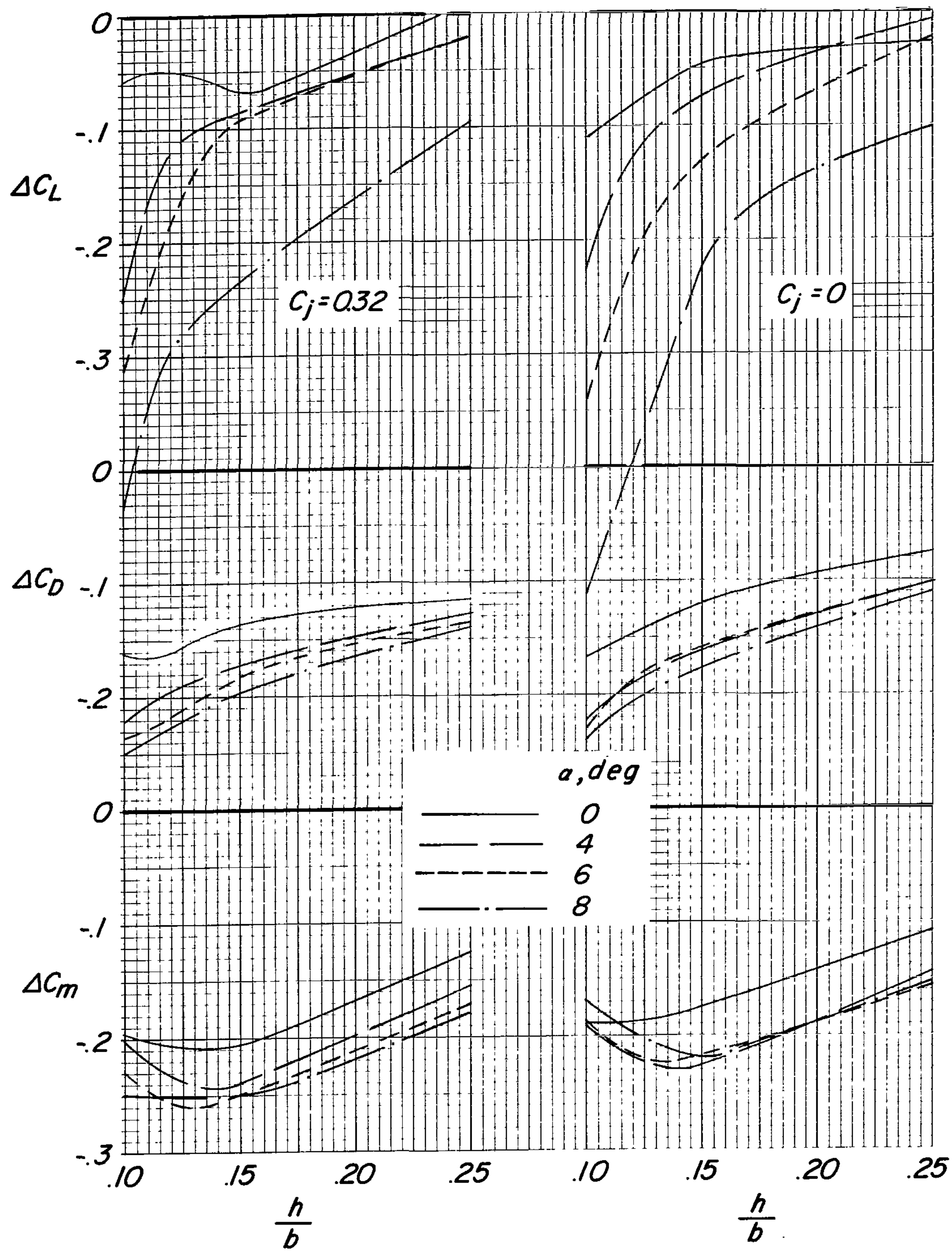
(a) $C_\mu = 0$.

Figure 15.- Ground-effect incremental lift, drag, and pitching-moment coefficients of the model for a range of heights above the moving ground plane. $\delta_f = 60^\circ$; $i_t = -6^\circ$.



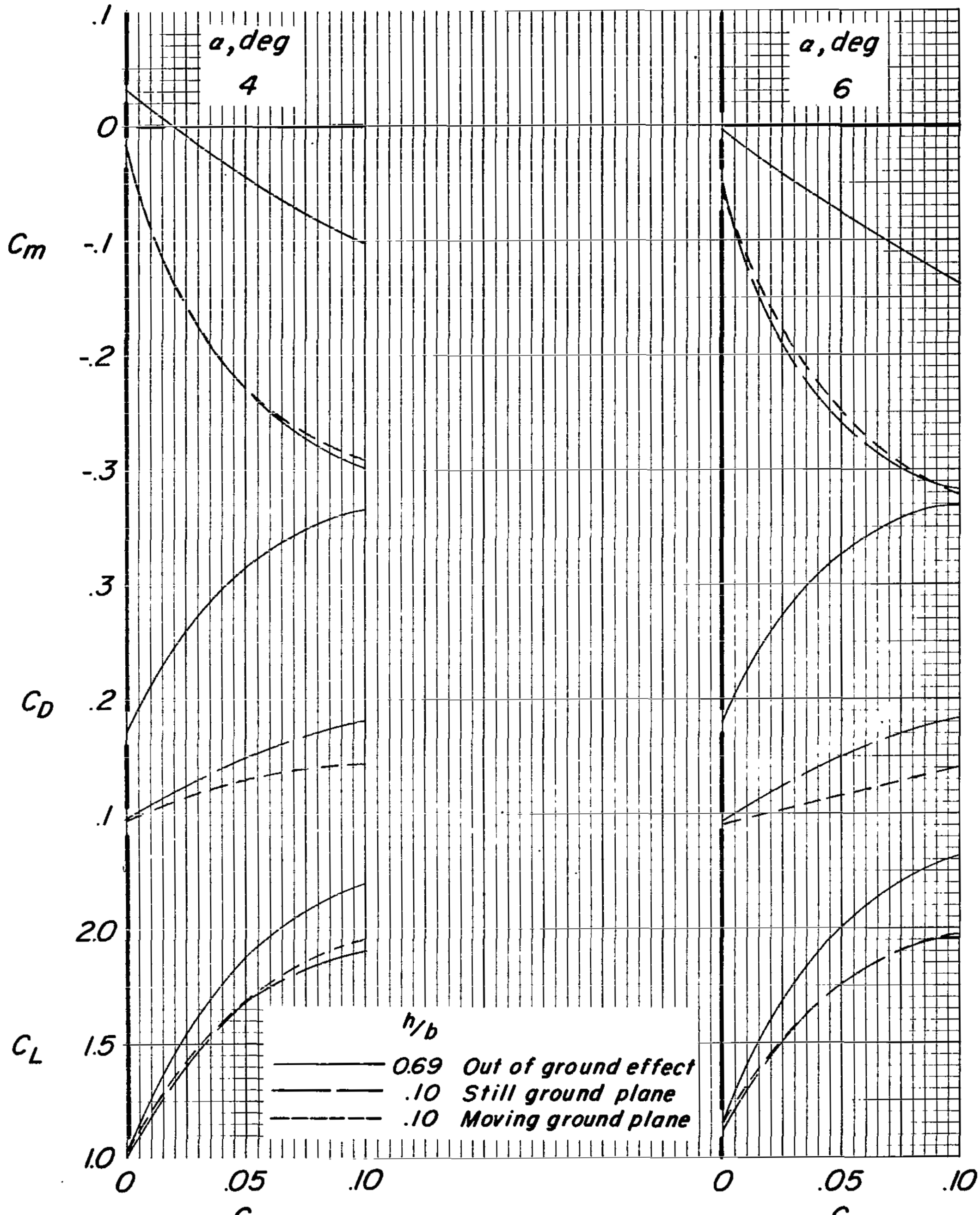
(b) $C_\mu = 0.05$.

Figure 15.- Continued.



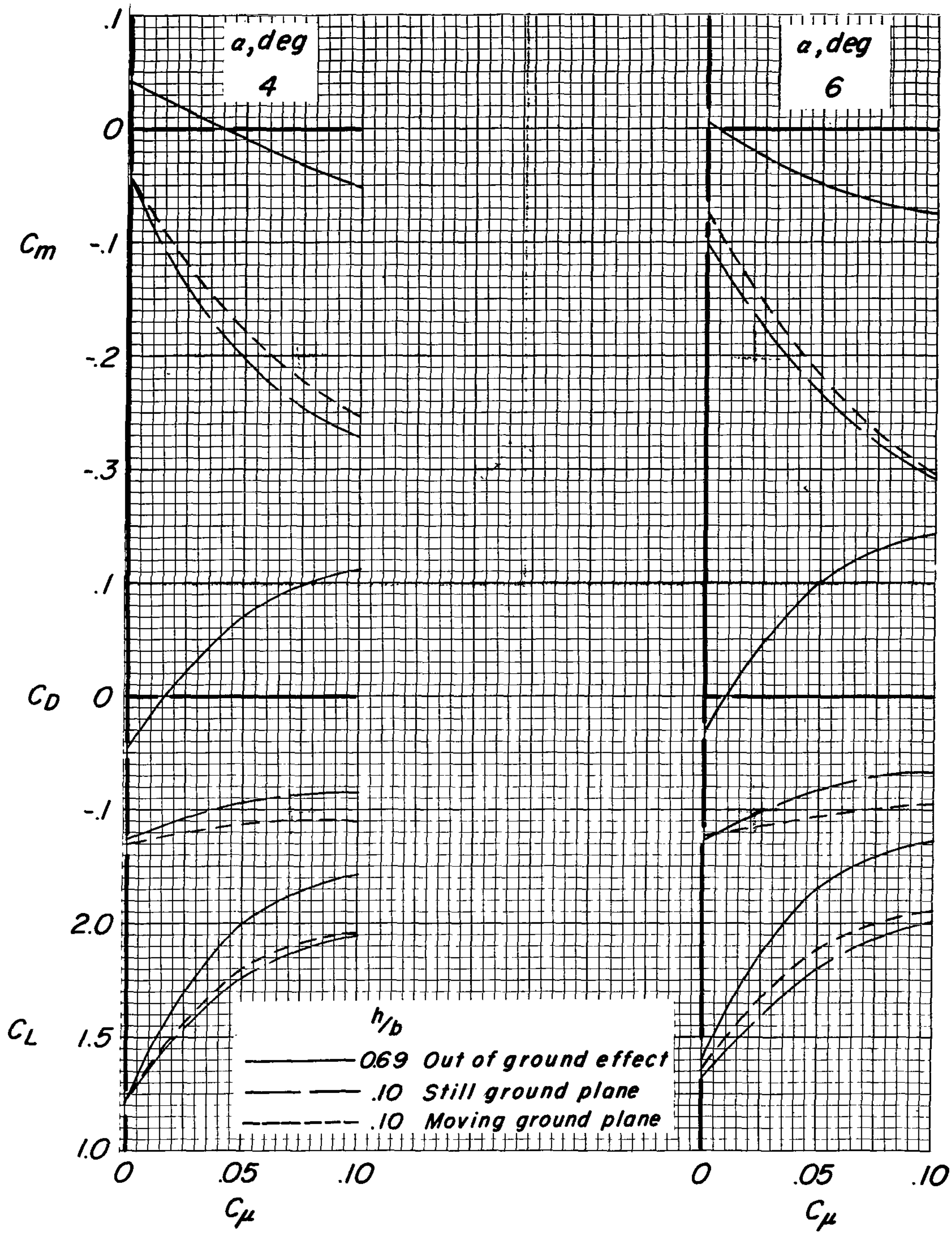
(c) C_μ = 0.10.

Figure 15.- Concluded.



(a) $C_j = 0$.

Figure 16.- Effect of a still and a moving ground plane on the aerodynamic coefficients of the model for a flap blowing momentum range. $\delta_f = 60^0$; $i_t = -6^0$.



(b) $C_j = 0.32$.

Figure 16.- Concluded.

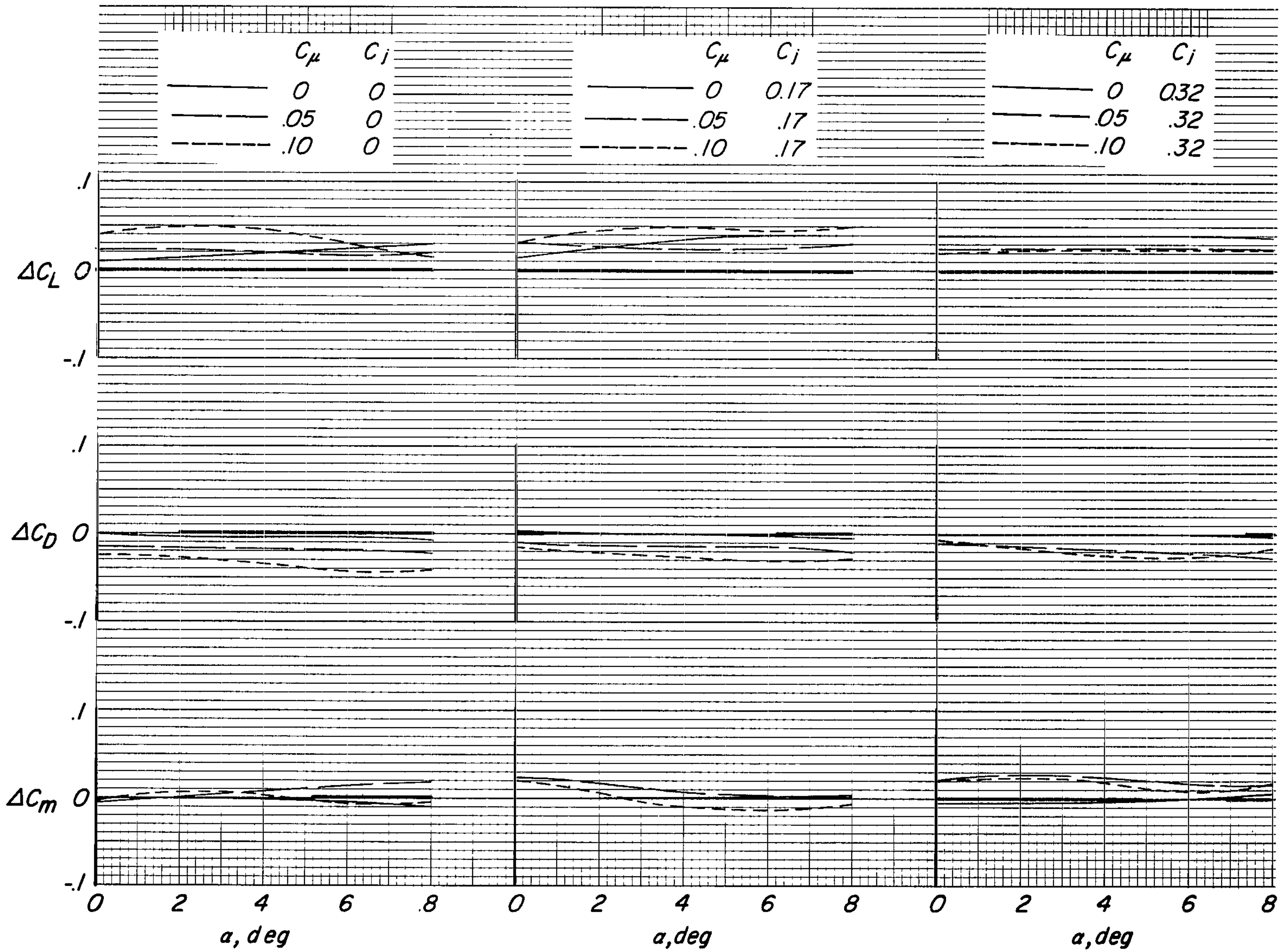
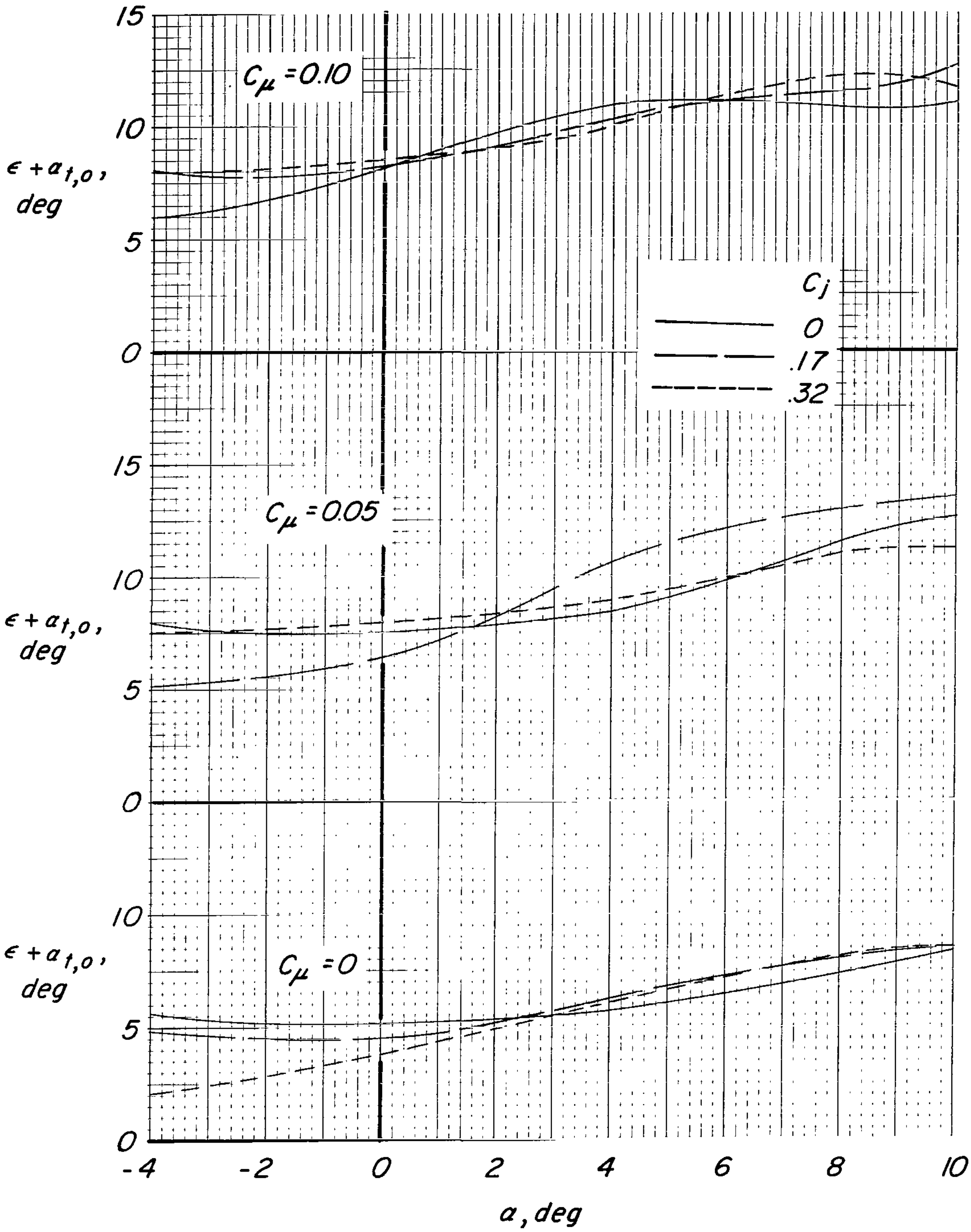
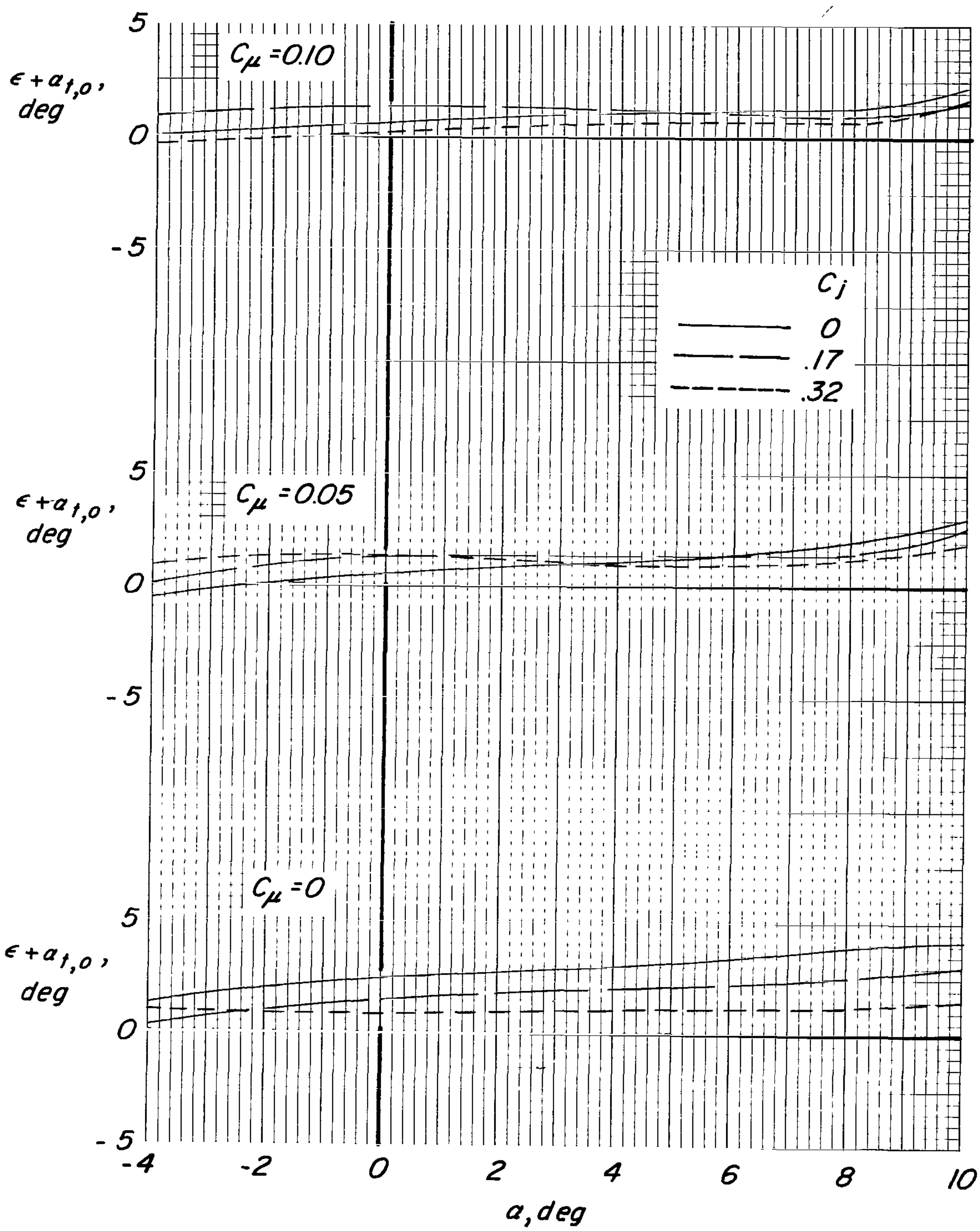


Figure 17.- Incremental lift, drag, and pitching-moment coefficients produced by the moving ground plane as compared with the still ground plane for various combinations of flap blowing and thrust. $h/b = 0.10$; $\delta_f = 60^o$; $i_t = -6^o$.



(a) h/b = 0.69.

Figure 18.- Relative effects of thrust, flap blowing momentum, and the ground plane on the estimated downwash angles over the horizontal tail. $\delta_f = 60^{\circ}$.



(b) h/b = 0.12.

Figure 18.- Concluded.

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