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WIND-TUNNEL INVESTIGATION OF AN UNSWEPT AIRFOIL WITH A 0.098-CHORD BLOWING FLAP

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WIND-TUNNEL INVESTIGATION OF AN UNSWEPT AIRFOIL WITH A 0.098-CHORD BLOWING FLAP

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SUMMARY

An investigation of the longitudinal aerodynamic characteristics of an aspect-ratio-4.735 airfoil having a 9.8-percent-chord blowing flap has been made in and out of ground influence over the endless-moving-belt ground plane in the 5.18-meter (17-ft) test section of the former Langley 300-MPH 7- by 10-foot wind tunnel. For flap deflections of 30° or less, at a height of 0.25 span, ground effect was negligible; but at this ground height, at a flap deflection δ_f of 60° and a lift coefficient C_L of 8.0, the lift loss was 27 percent. The lift loss for this same condition $\left(\text{that is, } \delta_f = 60^{\circ};\ C_L = 8.0\right)$ becomes negligible at a height of one span.

INTRODUCTION

The continued and increasing interest in STOL aircraft has dictated the investigation of methods of obtaining lift coefficients well above normal operating lift coefficients of present airplanes. Various methods have been and are being investigated for using power to develop lift for low-speed flight; some of these methods are externally blown flaps, augmentor wings, upper surface blowing or circulation control by applying blowing or suction to the boundary layer. This investigation used high-pressure blowing over a trailing-edge flap to increase the lift coefficient. The highest quantity of blowing air used was well above that required to keep the flow from separating from the flap.

The data reported in this paper were obtained over a moving-belt ground plane with the model at various heights above the ground plane.

SYMBOLS

Measurements and calculations were made in the U.S. Customary Units. They are presented herein in the International System of Units (SI) with the equivalent values in the U.S. Customary Units given parenthetically. Factors relating the two systems are given in reference 1.

b	span, 1.22 meters (4.01 ft)
C_D	drag coefficient, $\frac{\text{Drag}}{q_\infty S}$
C_L	lift coefficient, $\frac{\text{Lift}}{q_\infty S}$
C_m	pitching-moment coefficient (moment reference center at 0.48c), $\frac{\text{Pitching moment}}{q_\infty Sc}$
C_μ	momentum coefficient, $\frac{\text{Static thrust (flaps off)}}{q_\infty S}$
c	chord, 0.258 meter (0.847 ft)
h	wing chord line (0.5c station) height, meters (ft)
q_∞	free-stream dynamic pressure, N/m^2 (lb/ft^2)
S	area (wing), 0.315 $meter^2$ (3.396 ft^2)
V_B	belt velocity, m/sec (ft/sec)
V_∞	free-stream velocity, m/sec (ft/sec)
α	angle of attack, deg
δ_f	flap deflection, deg

Subscripts:

max	maximum
m	measured mass flow
s	measured static thrust

APPARATUS AND TESTS

The blowing flap investigation in and out of ground influence was made over the moving-belt ground plane in the 5.18-meter (17-ft) test section of the former Langley

300-MPH 7- by 10-foot tunnel (refs. 2 and 3). The blowing flap of the aspect-ratio-4.735 wing (fig. 1) could be deflected from 0° to 75° in 15° increments. The forces and moments were measured with a six-component strain-gage balance mounted in a pod attached to the upper surface of the airfoil. (See fig. 2.) An electric angle indicator was mounted in the front end of the balance pod to measure the true geometric angle of attack of the model. High-pressure air (12 411 kN/m^2 (1800 lb/in^2)) for the blowing flap was brought through the sting to the back end of the balance. A 1.27-cm (0.5-in.) stainless-steel tube fastened rigidly to the sting passed through a clearance hole in the upper surface of the airfoil into a full-span chamber within the airfoil. This tube passed from the center line of the model to one wing tip, across to the other tip, then back to the center line where it was anchored rigidly to a high-pressure plenum ahead of the flap. The tube did not touch anything from the rigid mount on the sting to the rigid mount on the pressure plenum. This arrangement provided high-pressure air across the strain-gage balance to the model without any measurable tares.

The height of the airfoil chord plane at the 0.50 chord station was kept at a predetermined value from the ground plane for any given test by means of a transit and the telescoping vertical part of the model mounting strut.

The mass flow of the air blown over the flap was measured by a calibrated venturi flowmeter. A thermocouple and two pressure taps were installed just ahead of the exit slot for determining exit pressure and temperature. The static thrust of the model with the flap removed was calibrated against a wing plenum reference pressure. (See fig. 3.) The spanwise pressure variation of the exit slot is shown in figure 4.

Most of the tests were made at a dynamic pressure of 478.8 N/m^2 (10 lb/ft^2) and through an angle-of-attack range from -10° to stall. The remaining tests were made at a dynamic pressure of 287.3 N/m^2 (6 lb/ft^2). The momentum coefficient was varied from 0 to 3.28. The height of the chord plane ($\alpha = 0^{\circ}$) varied from 0.062 span to 2.0 spans, and the flap deflection varied from 0° to 75°.

RESULTS AND DISCUSSION

The momentum coefficient C_{μ} used in these data is based on the measured static thrust with the flap removed. It is realized that there may be minor errors in this method, such as the possibility of a small reduced base pressure on the downstream part of the airfoil and also a small drag from an induced flow past the airfoil. Both of these effects would tend to reduce the measured thrust. For comparison, the momentum coefficient based on measured mass flow and exit velocity has been computed. These results are presented in figure 5 and show that the momentum coefficient based on mass flow and exit velocity is 1.151 times the momentum coefficient based on static thrust. These results indicate an 87-percent exit nozzle efficiency.

The effect of belt velocity on lift coefficient C_L, drag coefficient C_D, and pitching-moment coefficient C_m for a typical condition for this investigation $\left(\delta_f = 60^\circ;\ h/b = 0.125;\ \alpha = 0^\circ\right)$ is shown in figure 6. Lift coefficient is the only coefficient appreciably affected by belt velocity. Ground-belt velocity would be the same as tunnel stream velocity for normal wind-tunnel testing.

The variation of lift, drag, and pitching-moment coefficients with angle of attack for various flap deflections, through a height and blowing momentum coefficient range, is shown in figure 7. In general, the lift-curve slope and maximum lift coefficient increased with momentum coefficient. All configurations were unstable in pitch for the moment center used (0.48c).

The variation of lift coefficient with momentum coefficient for the various flap deflections at $\alpha = 0^\circ$ at a height that was effectively out of the ground influence is summarized in figure 8. The variation of $C_{L,max}$ with C_μ for $\delta_f = 60^\circ$ is shown in figure 9.

For flap deflections of 30° or less, the ground effect was negligible for heights of 0.25 span or larger. (See figs. 7(c) and 7(d).) The effects of ground height for flap deflections of 60° and 75° are summarized in figure 10. At a height of 0.25 span, the in-ground influence loss of lift may be as much as 27 percent for $C_L = 8.0$ and $\delta_f = 60^\circ$.

CONCLUDING REMARKS

An investigation of the longitudinal characteristics of an aspect-ratio-4.735 airfoil having a 9.8-percent-chord blowing flap has been made in and out of ground influence over the endless-moving-belt ground plane. In general, lift coefficient C_L and maximum lift coefficient $C_{L,max}$ increased with momentum coefficient C_μ. For flap deflections of 30° or less, at a height of 0.25 span, the ground effect was negligible; but at this ground height, at a flap deflection of 60° and a lift coefficient of 8.0, the loss in lift was 27 percent of the lift obtained out of ground effect.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., November 9, 1972.

REFERENCES

1. Mechtly, E. A.: The International System of Units – Physical Constants and Conversion Factors (Revised). NASA SP-7012, 1969.

2. Turner, Thomas R.: A Moving-Belt Ground Plane for Wind-Tunnel Ground Simulation and Results for Two Jet-Flap Configurations. NASA TN D-4228, 1967.

3. Turner, Thomas R.: Endless-Belt Technique for Ground Simulation. Conference on V/STOL and STOL Aircraft, NASA SP-116, 1966, pp. 435-446.

AIRFOIL ORDINATES	
x, percent chord	y, percent chord
1.2297	2.3315
2.4594	3.2109
4.9188	4.3679
7.3782	5.1648
9.8377	5.7550
14.7565	6.5716
19.6754	7.0536
24.5942	7.3084
29.5130	7.3782
39.3507	7.1323
49.1884	6.6699
59.0261	6.0994
68.8637	5.3910
78.7014	4.3286
88.5391	2.7054
93.4579	1.7216
98.3768	.5607
100.0000	.1180

L.E.R. = 2.439 (percent chord)

Wing span, 1.222 m (4.01 ft)
Wing chord, .258 m (.847 ft)
Wing area, .315 sqm (3.396 sq ft)

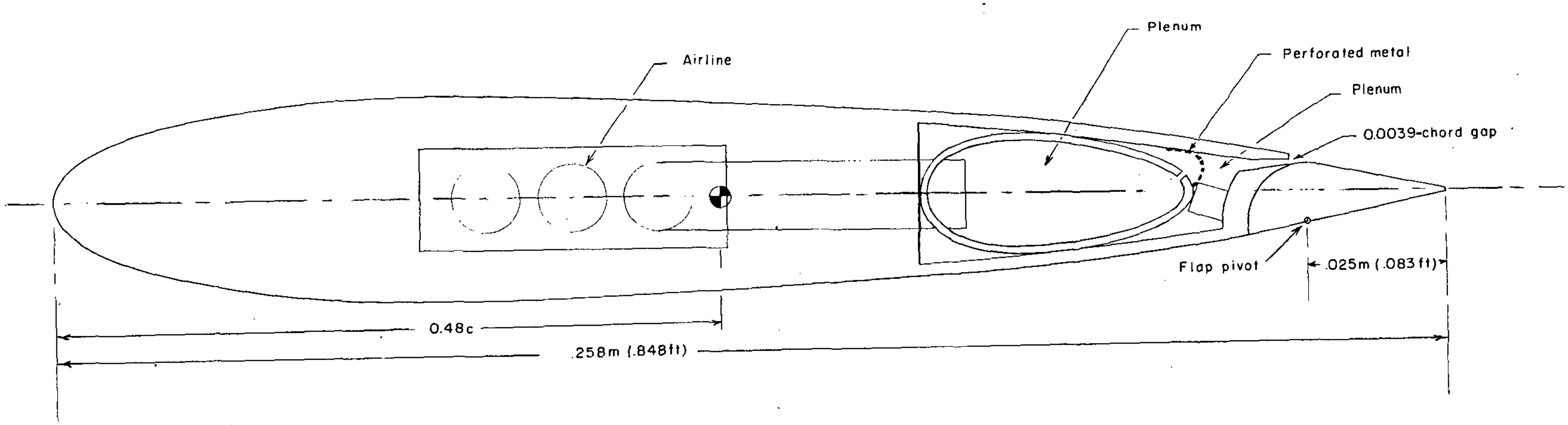


Figure 1.- Details of rectangular planform airfoil with blowing flap.

L-68-3493

Figure 2.- Photograph of model.

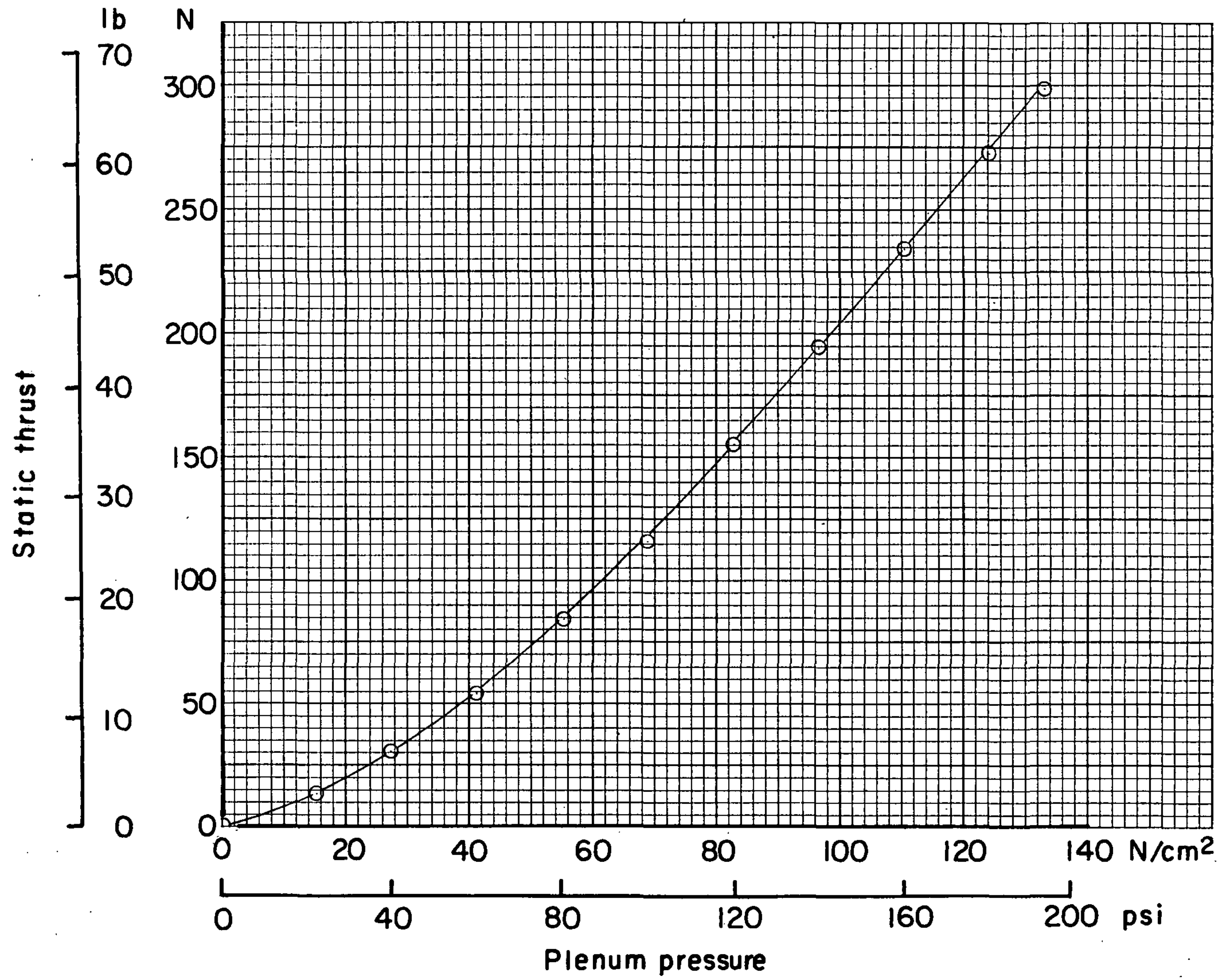


Figure 3.- Variation of static thrust with plenum pressure.

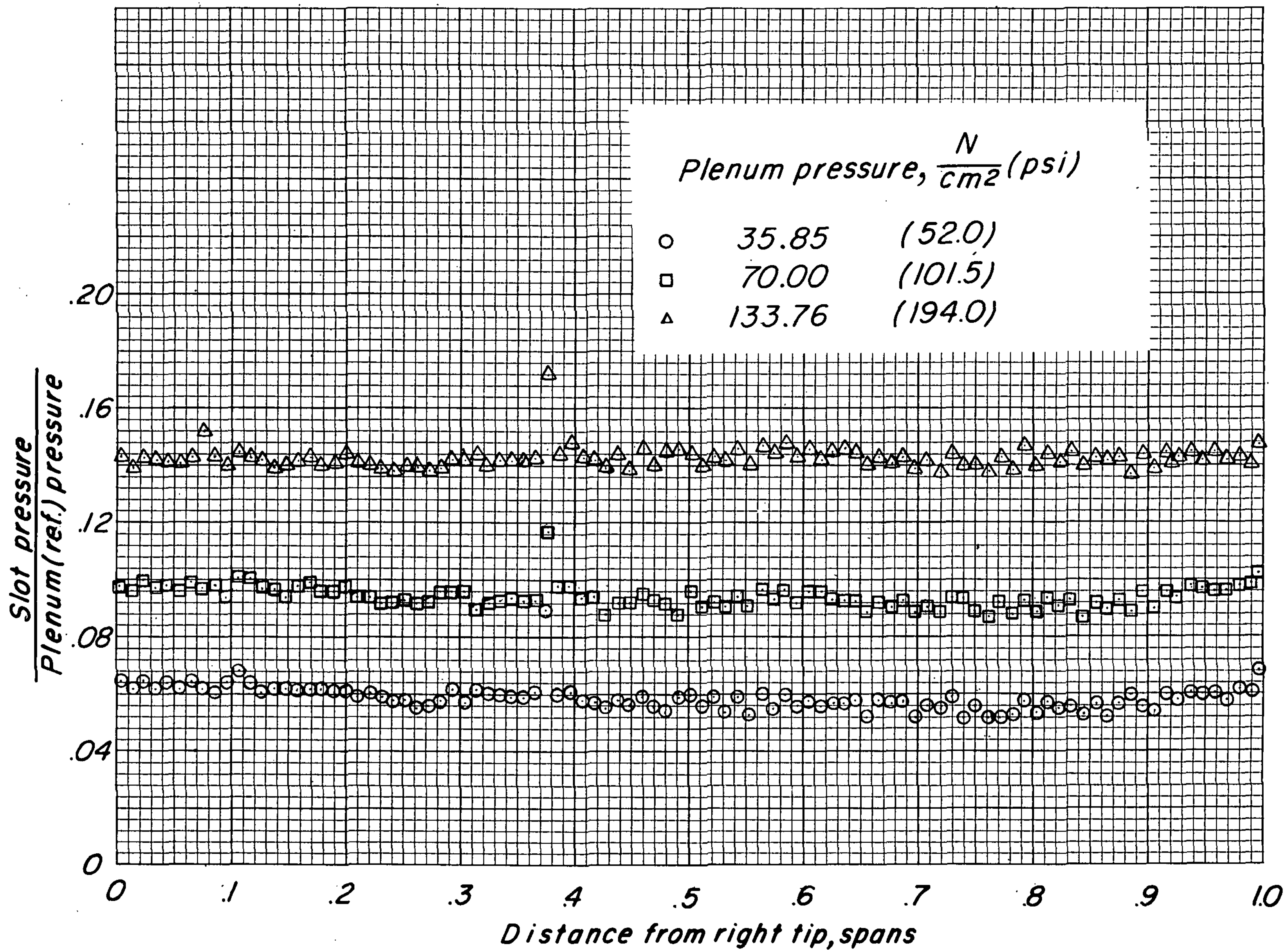


Figure 4.- Spanwise distribution of blowing slot exit pressure.

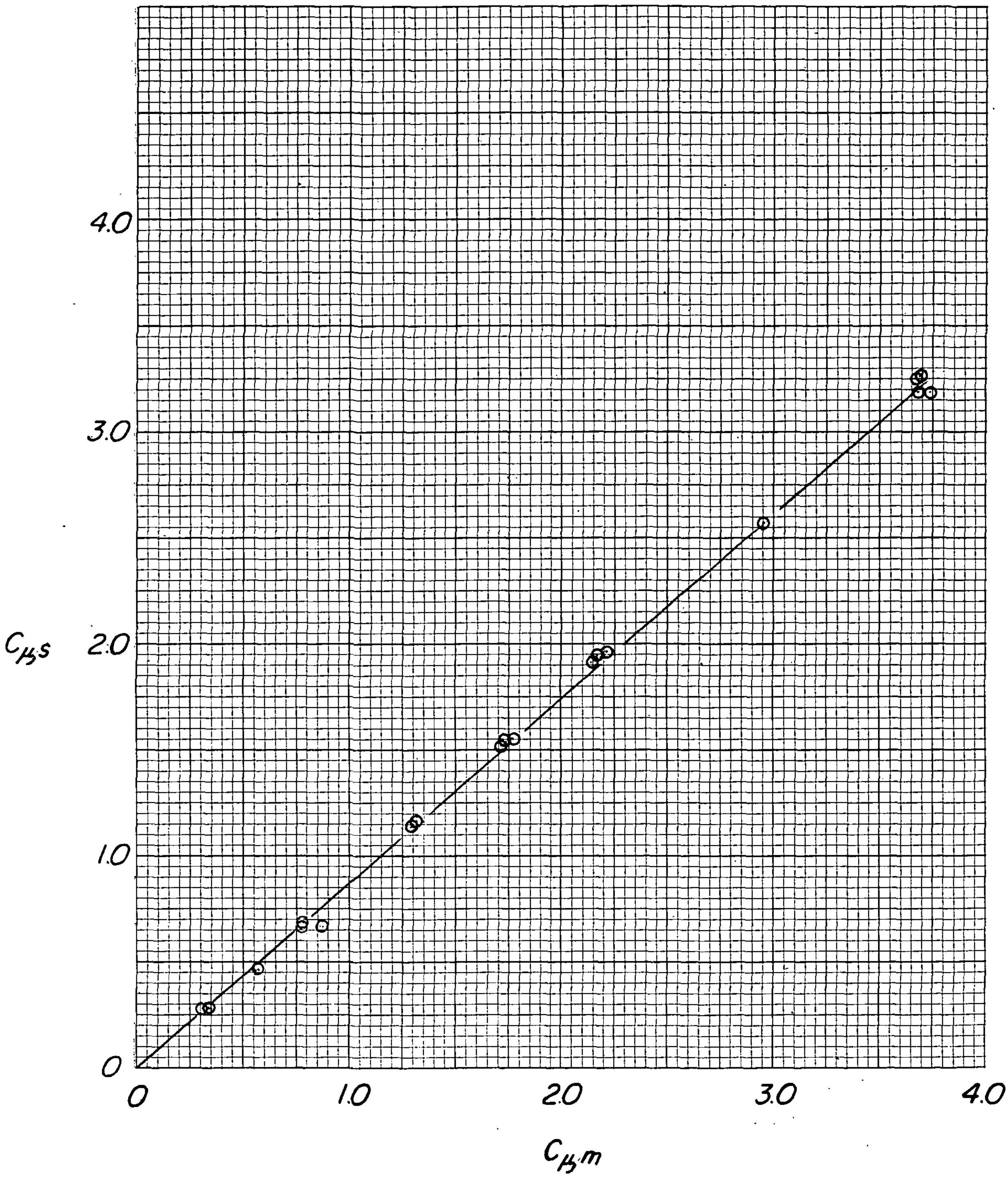


Figure 5.- Variation of C_μ based on measured static thrust with C_μ based on measured mass flow.

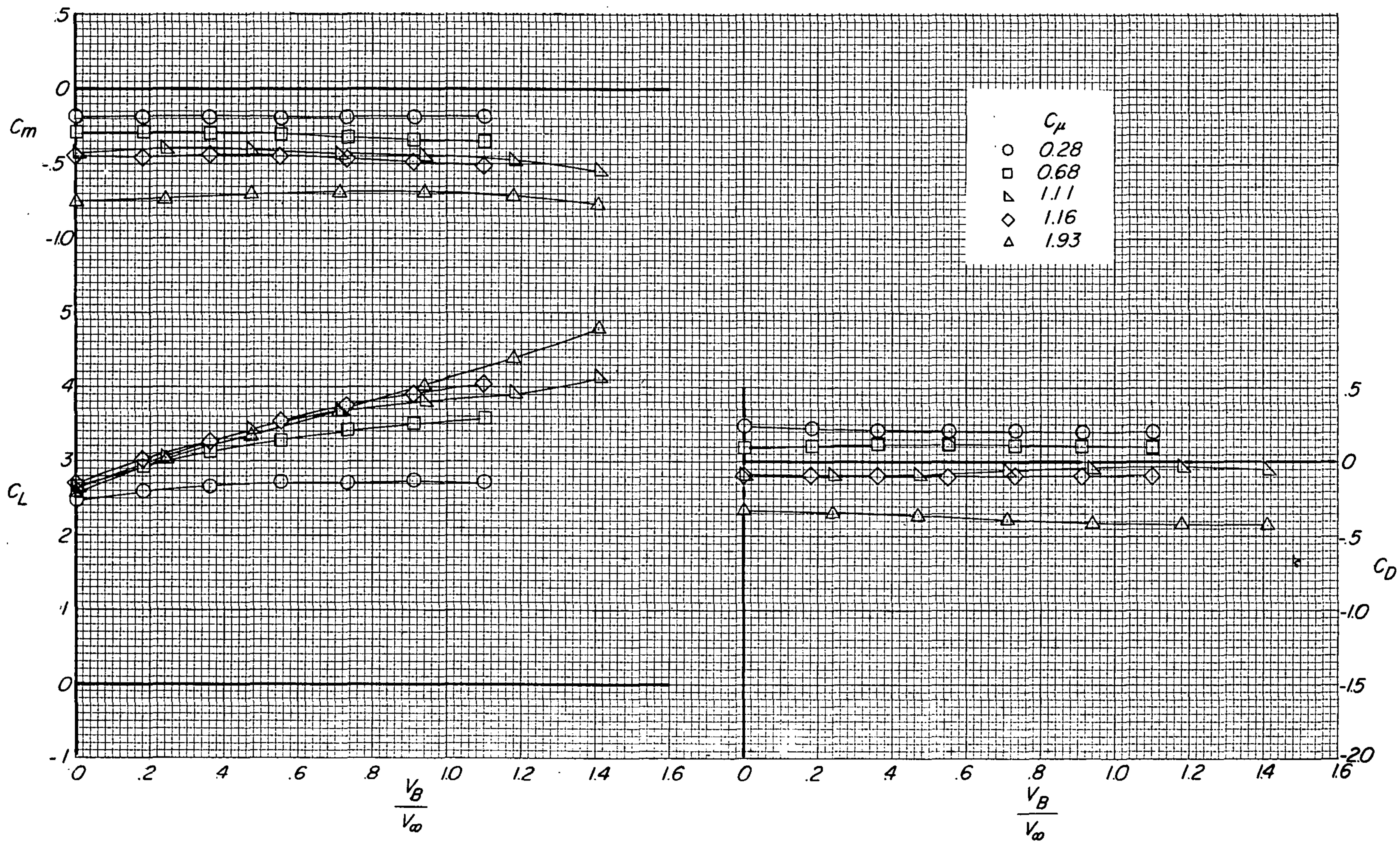
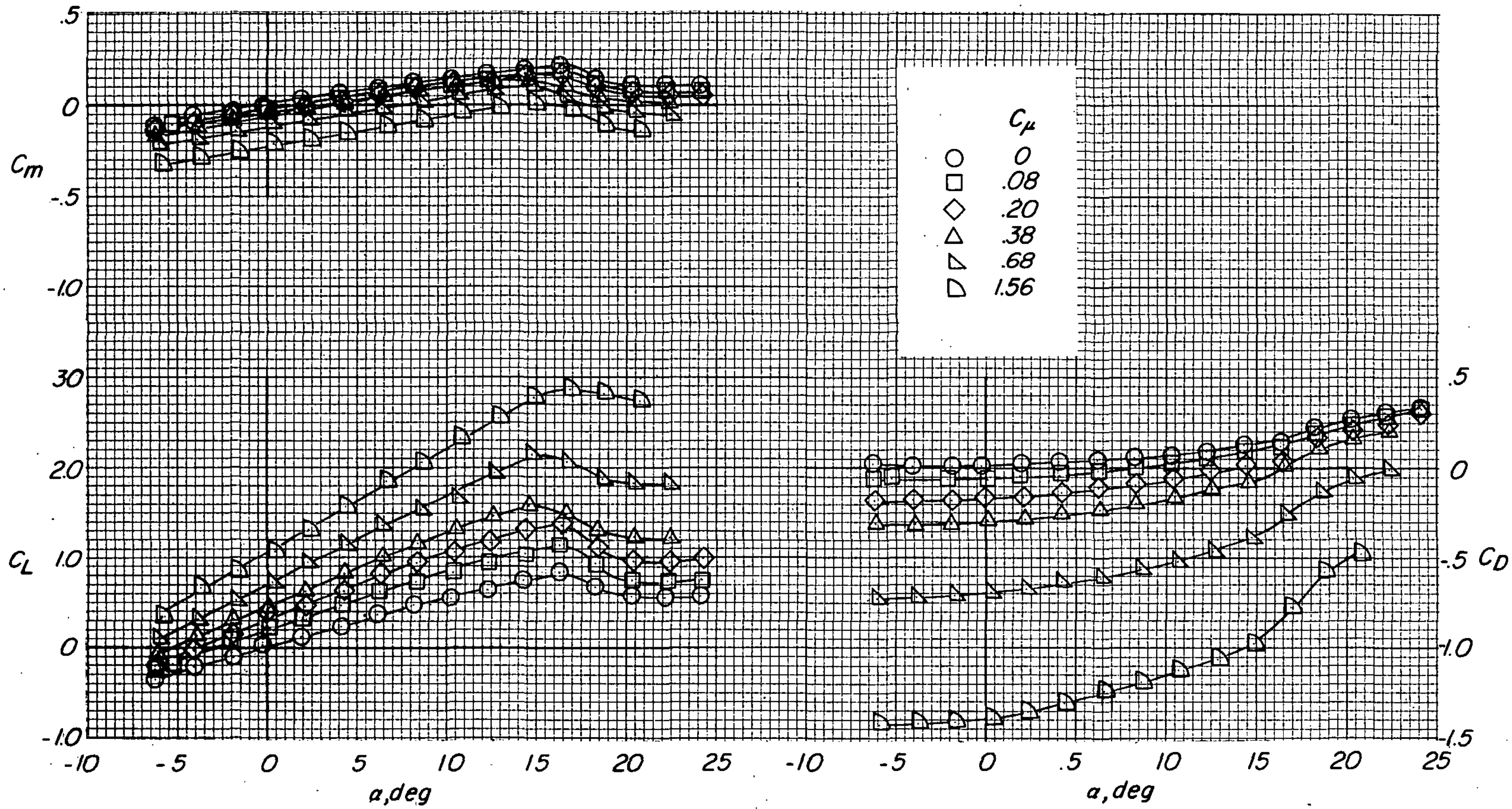
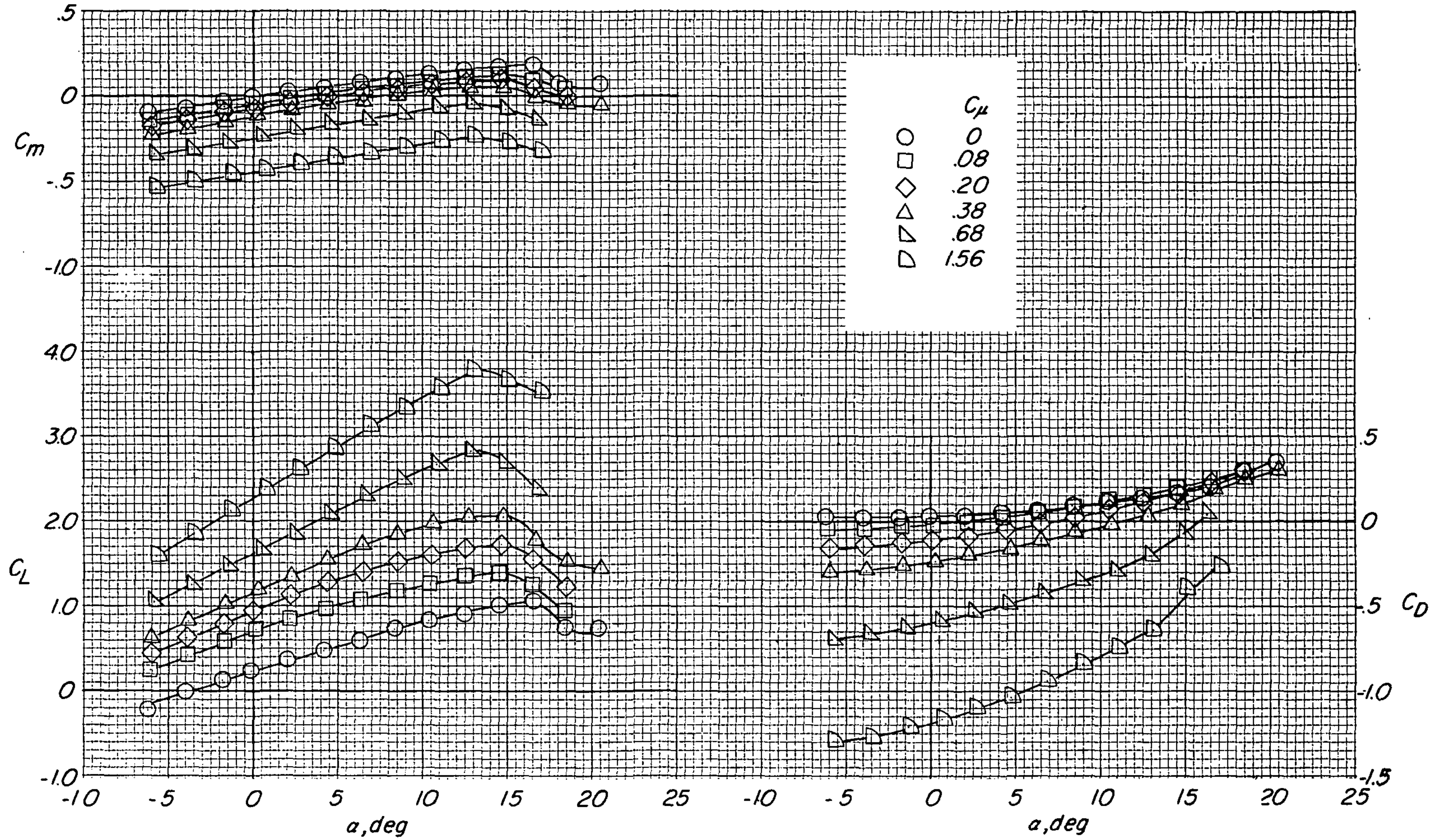


Figure 6.- Effect of belt velocity. $\delta_f = 60^\circ$; $h/b = 0.125$; $\alpha = 0^\circ$.



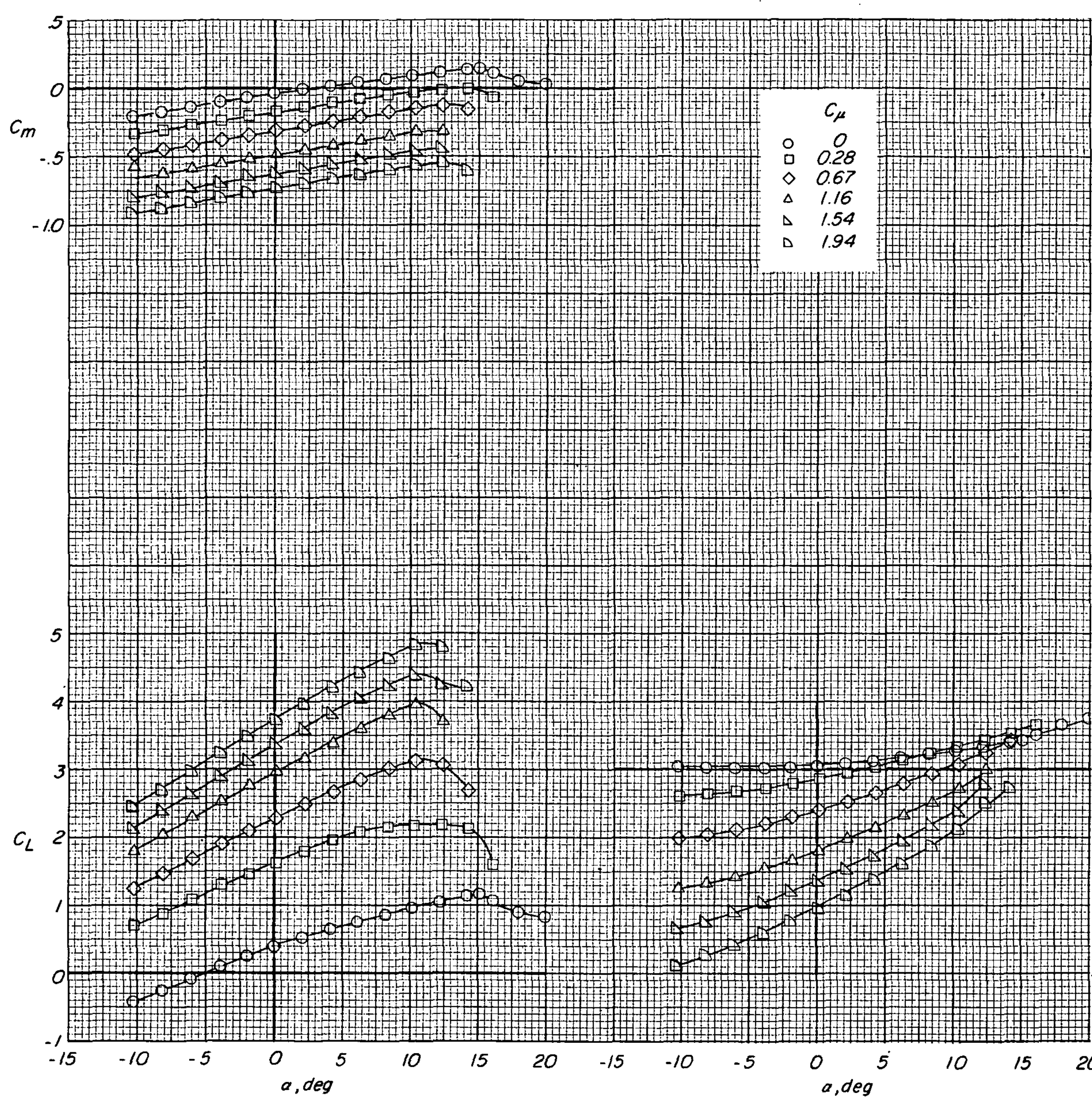
(a) $\delta_f = 0^{\circ}$; $h/b = 0.625$; $V_B/V_\infty = 1.00$.

Figure 7.- Aerodynamic characteristics.



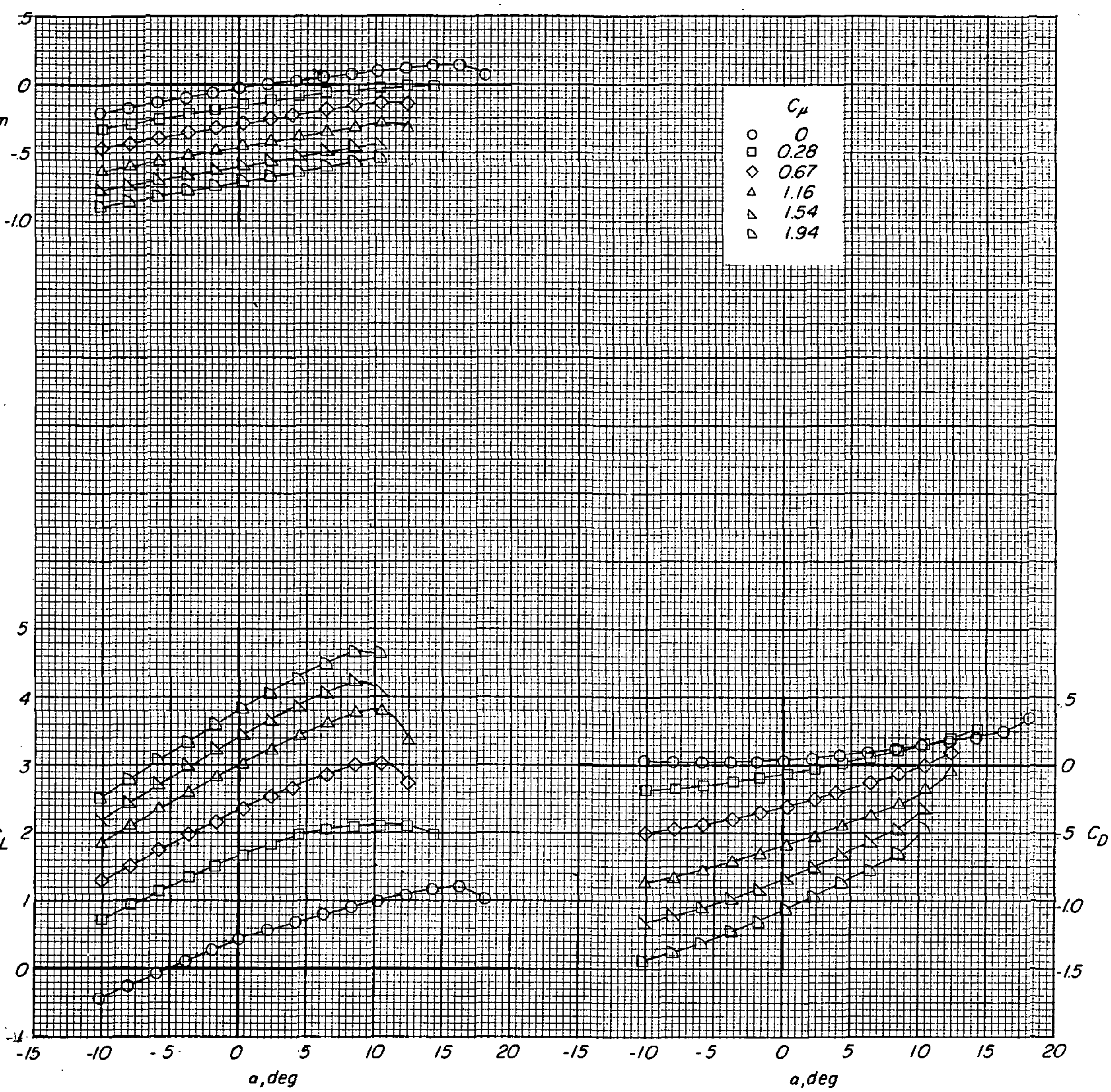
(b) $\delta_f = 15^{o}$; $h/b = 0.625$; $V_B/V_\infty = 1.00$.

Figure 7.- Continued.



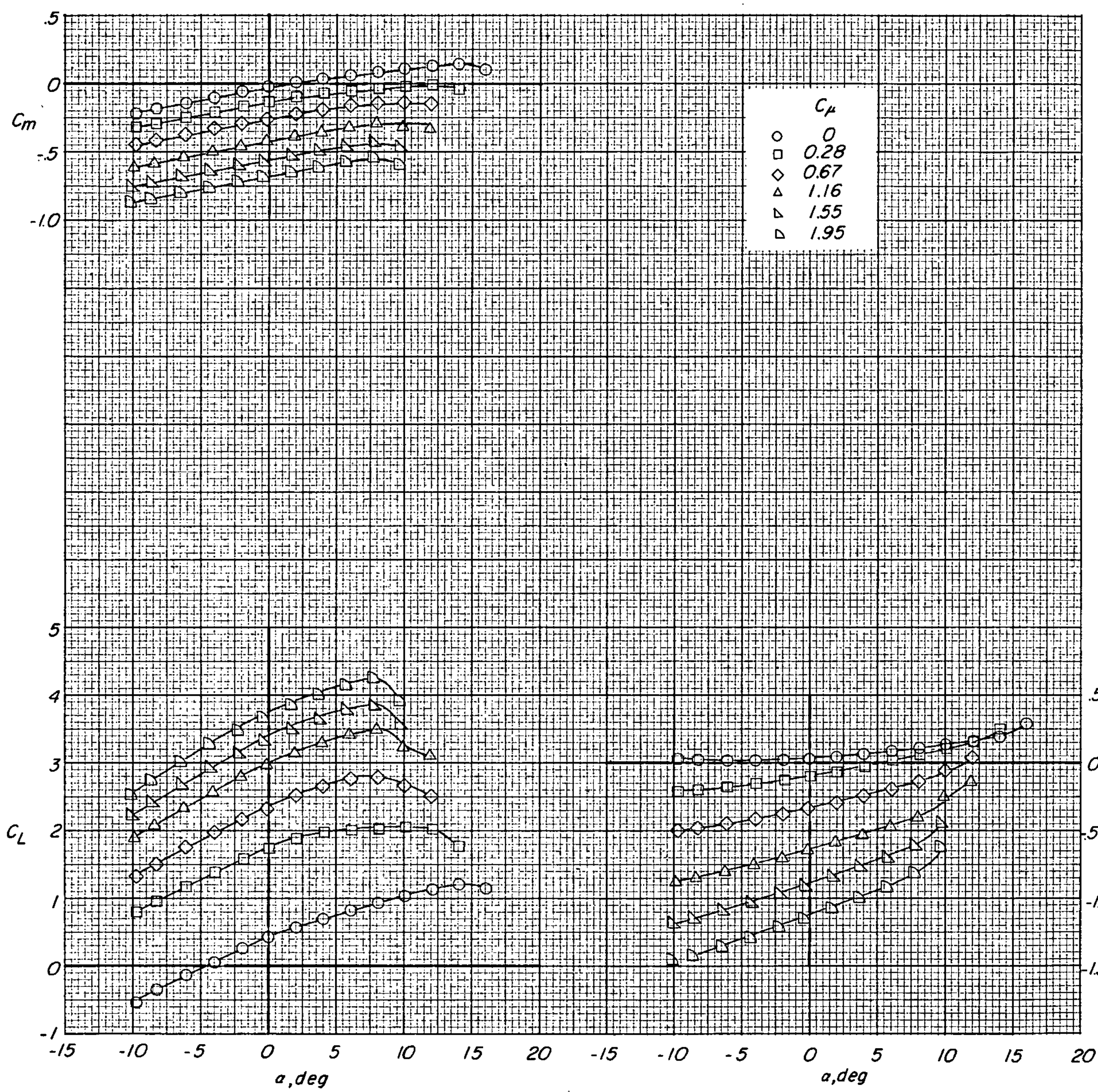
(c) $\delta_f = 30^{\circ}$; $h/b = 0.50$; $V_B/V_\infty = 1.00$.

Figure 7.- Continued.



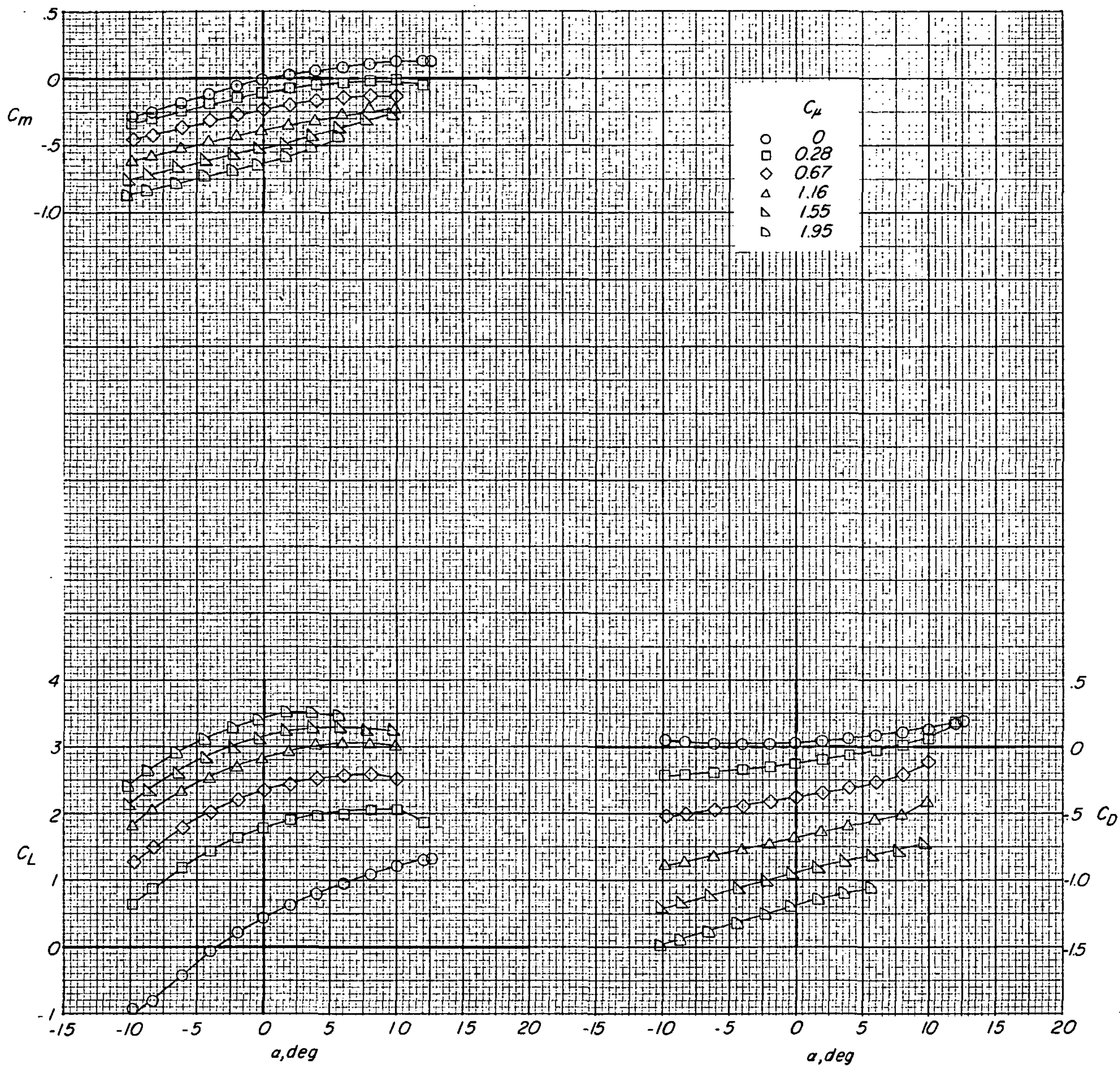
(d) $\delta_f = 30^\circ$; $h/b = 0.25$; $V_B/V_\infty = 1.00$.

Figure 7.- Continued.



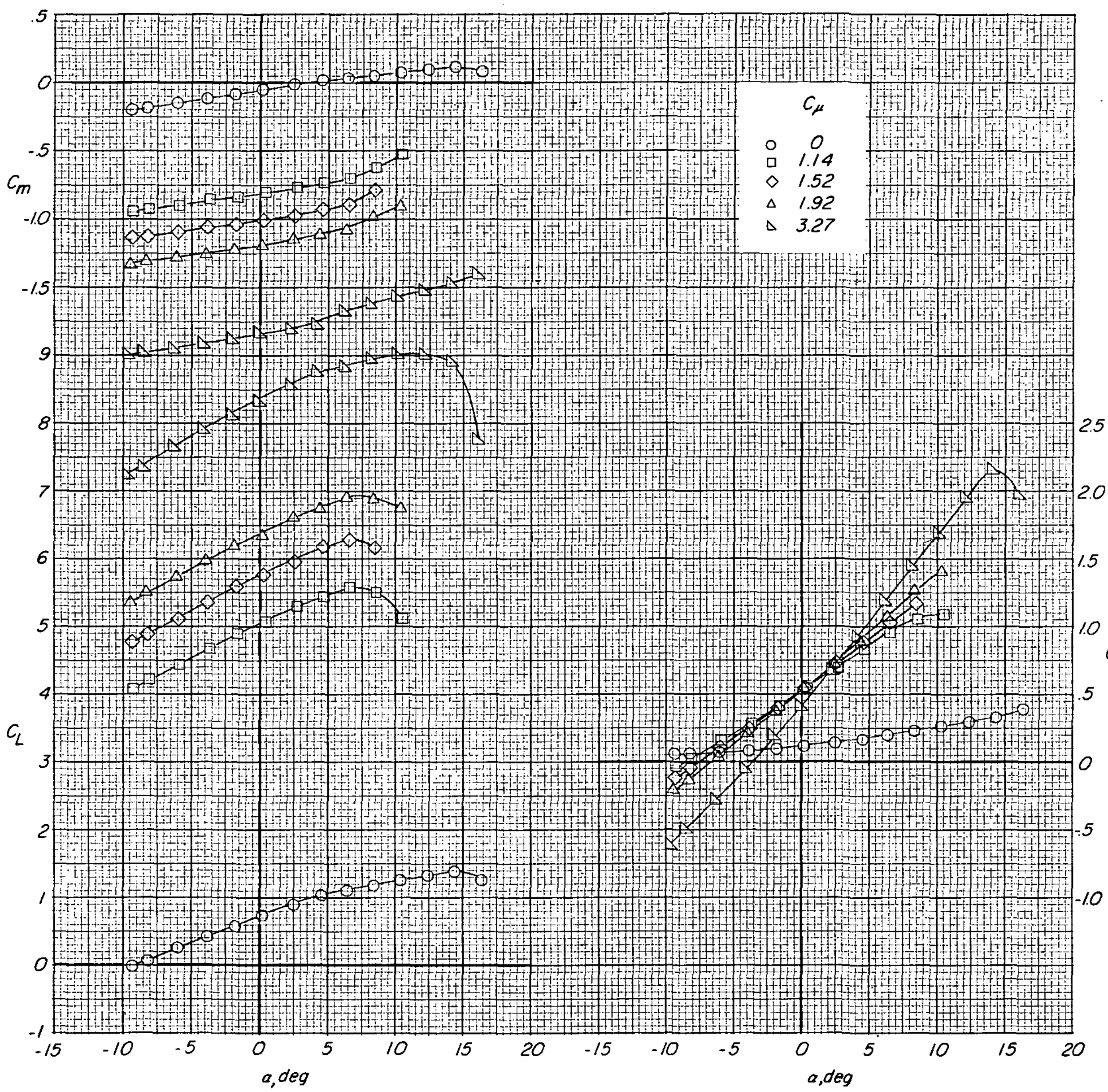
(e) $\delta_f = 30^{\circ}$; $h/b = 0.125$; $V_B/V_\infty = 1.00$.

Figure 7.- Continued.



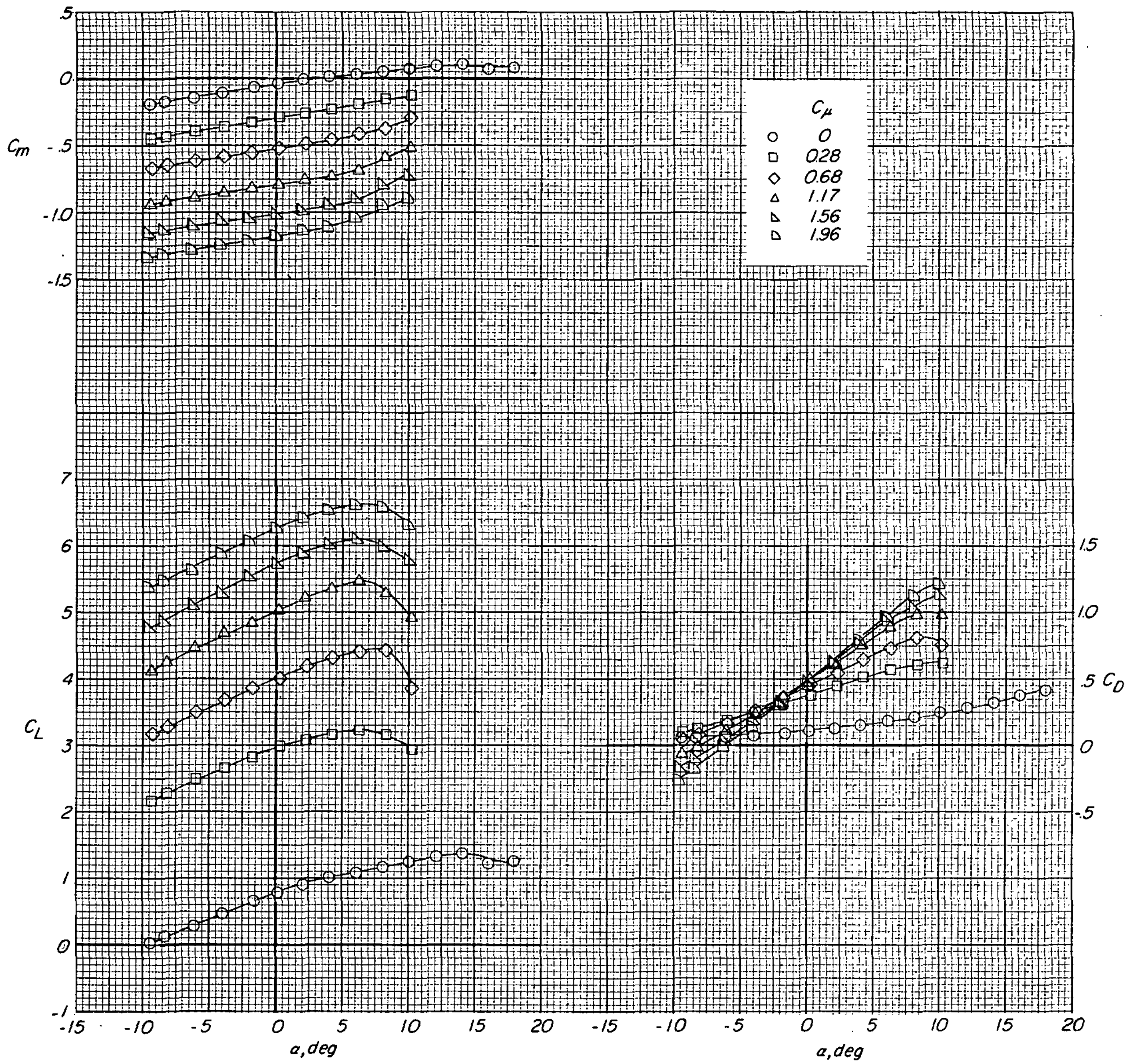
(f) $\delta_f = 30^{\circ}$; $h/b = 0.062$; $V_B/V_\infty = 1.00$.

Figure 7.- Continued.



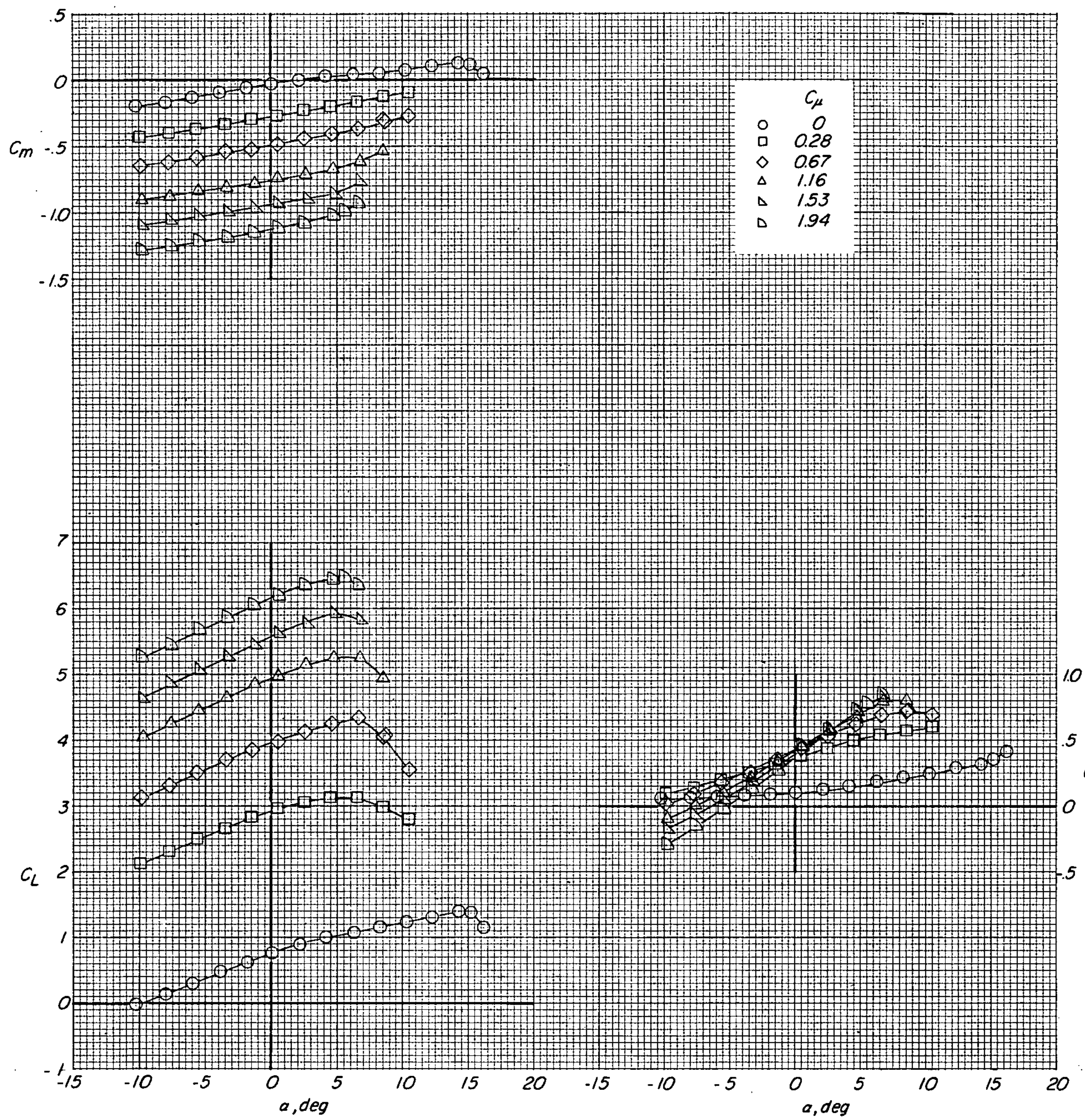
(g) $\delta_f = 60^{\circ}$; $h/b = 2.00$; $V_B/V_\infty = 1.00$.

Figure 7.- Continued.



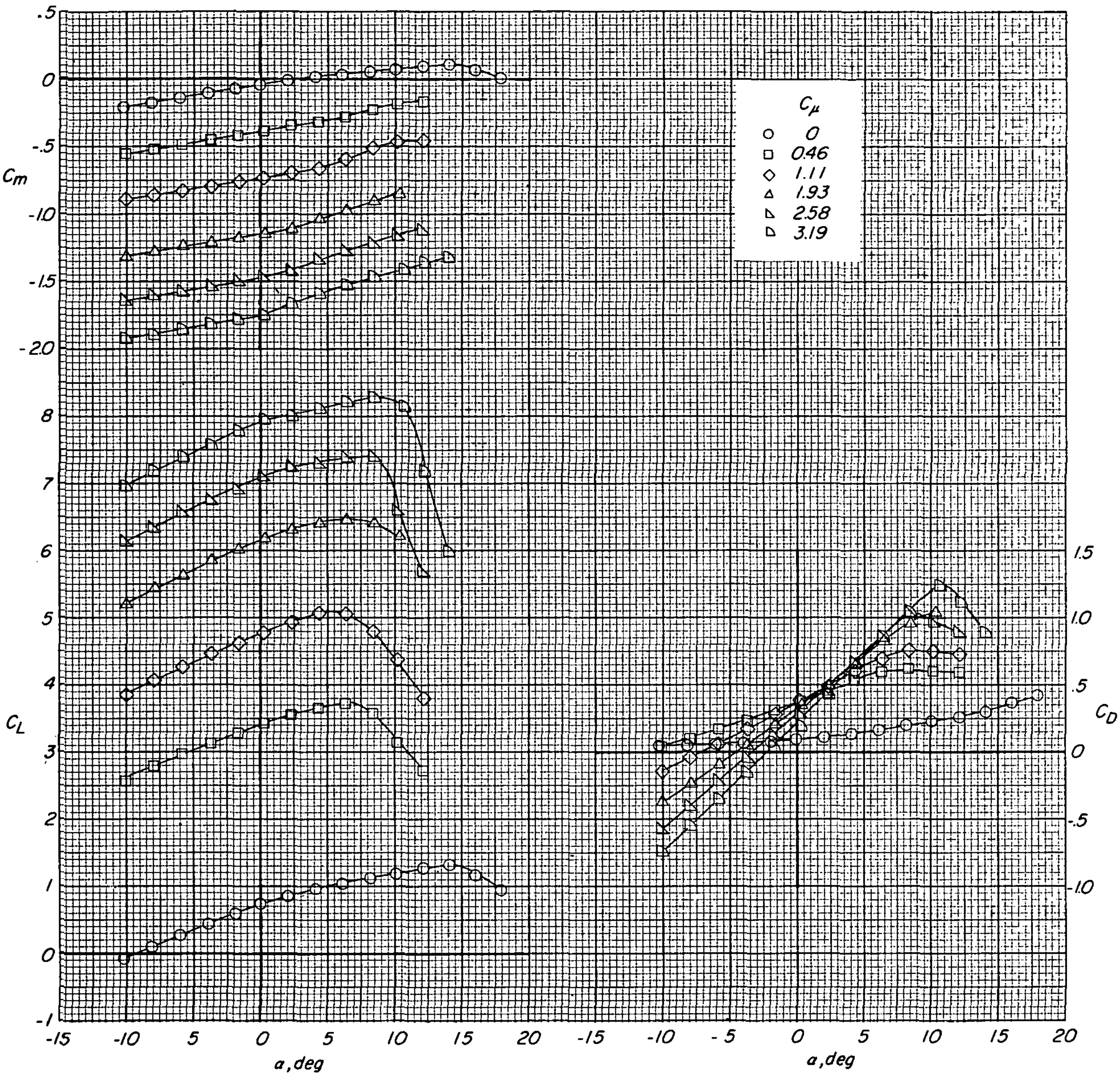
(h) $\delta_f = 60^\circ$; $h/b = 1.00$; $V_B/V_\infty = 1.00$.

Figure 7.- Continued.



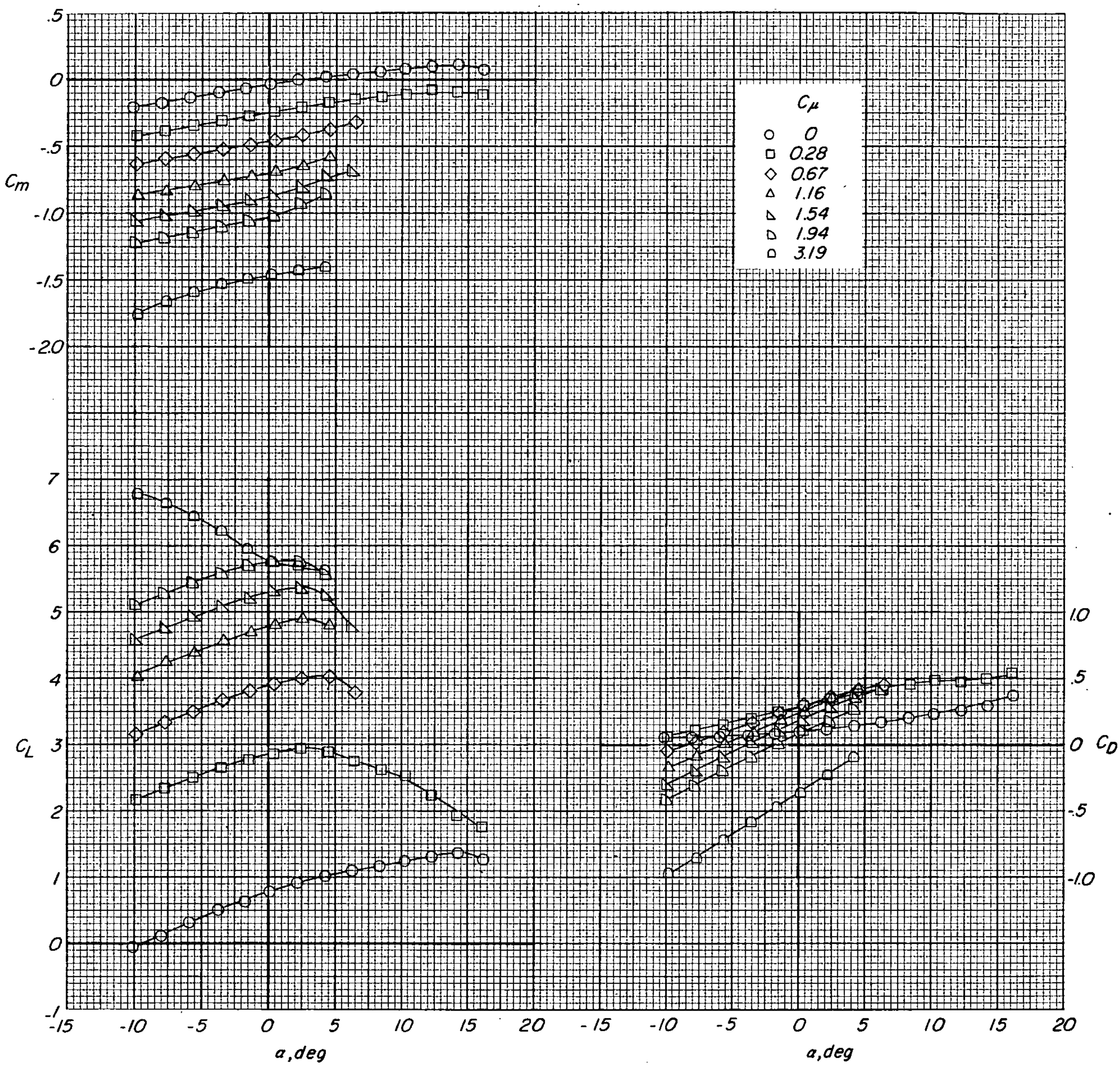
(i) $q_\infty = 9.95$; $\delta_f = 60^o$; $h/b = 0.50$; $V_B/V_\infty = 1.00$.

Figure 7.- Continued.



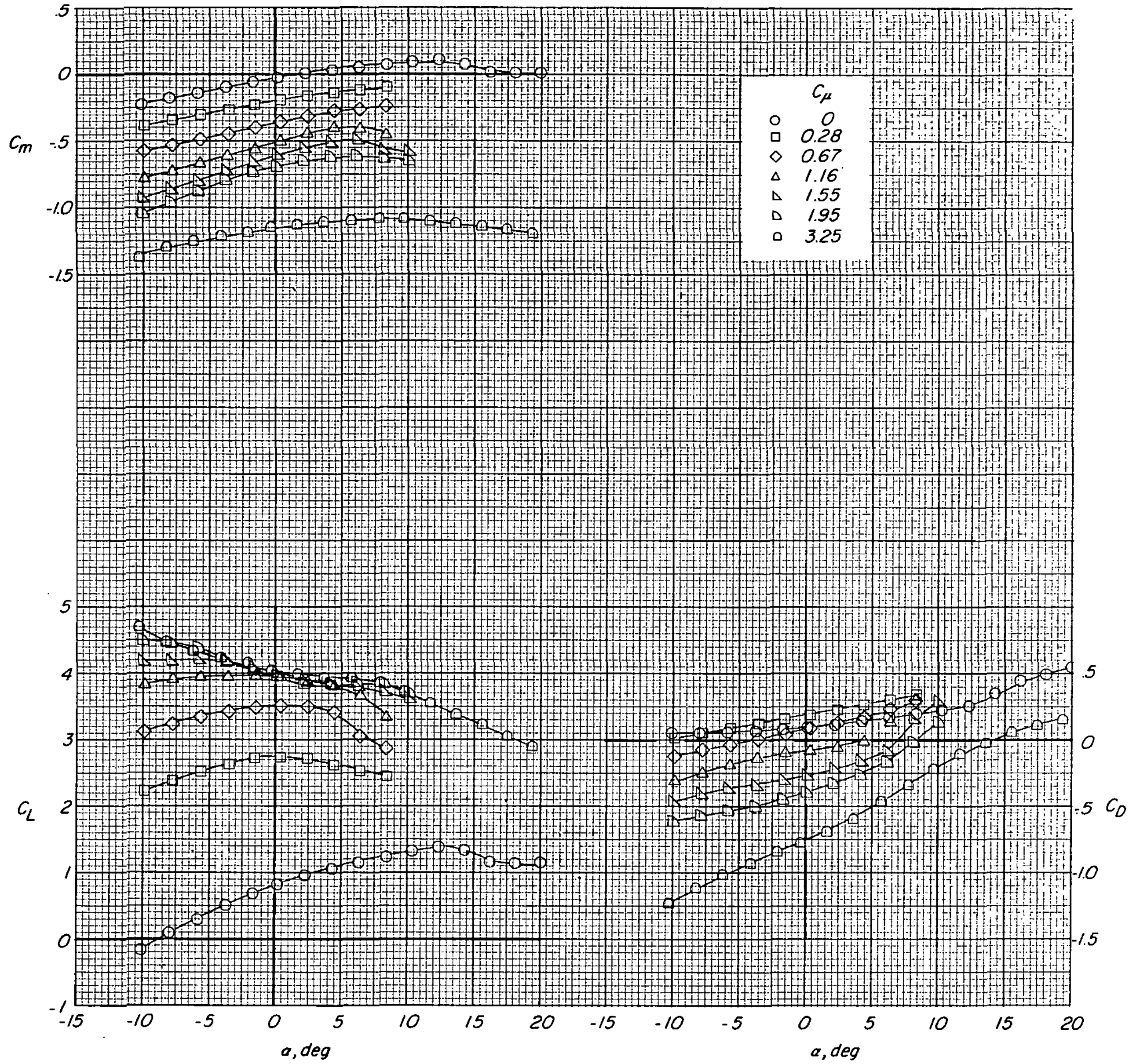
(j) $q_\infty = 5.96$; $\delta_f = 60^0$; $h/b = 0.50$; $V_B/V_\infty = 1.00$.

Figure 7.- Continued.



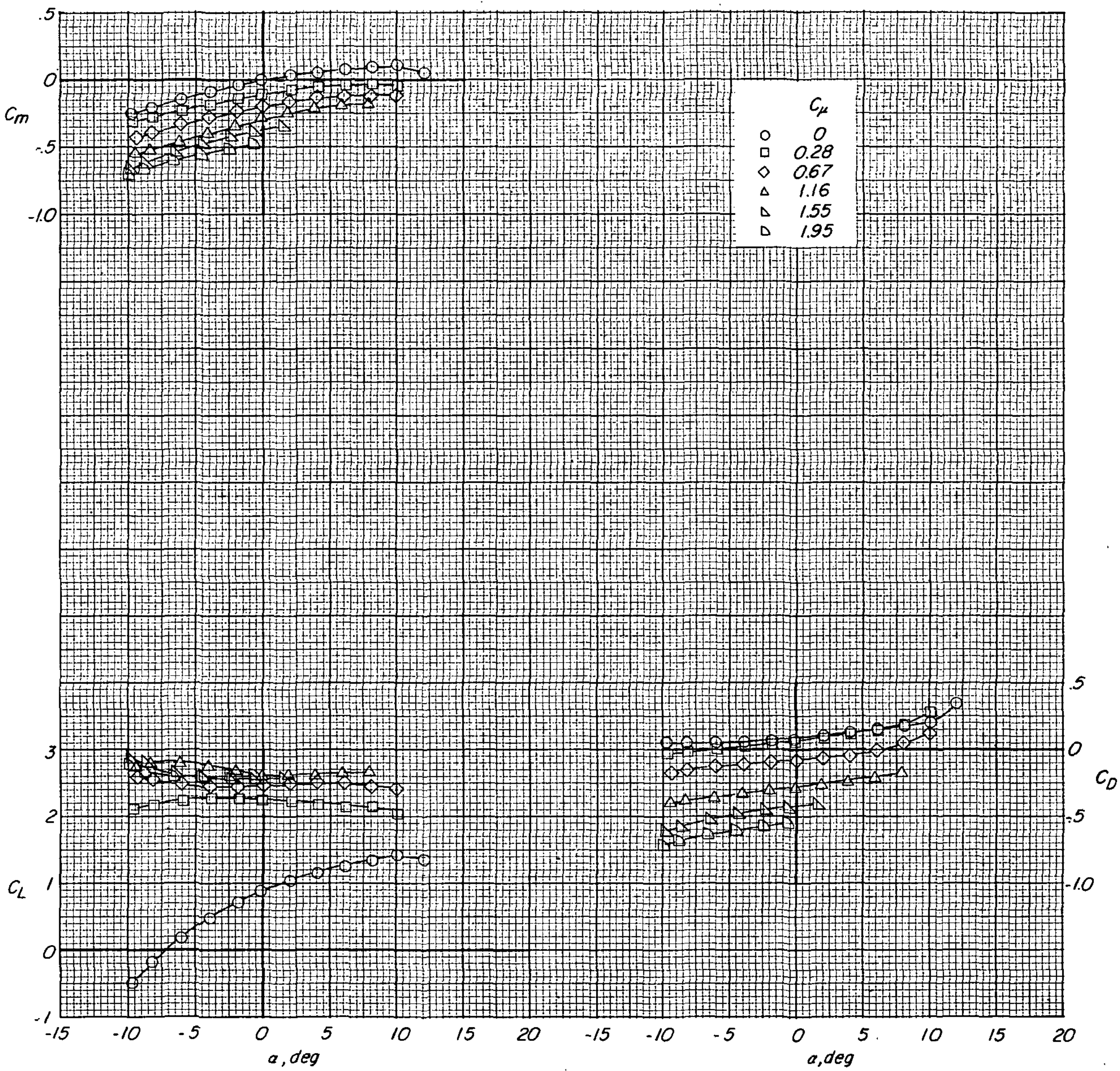
(k) $\delta_f = 60^{\circ}$; $h/b = 0.25$; $V_B/V_\infty = 1.00$.

Figure 7.- Continued.



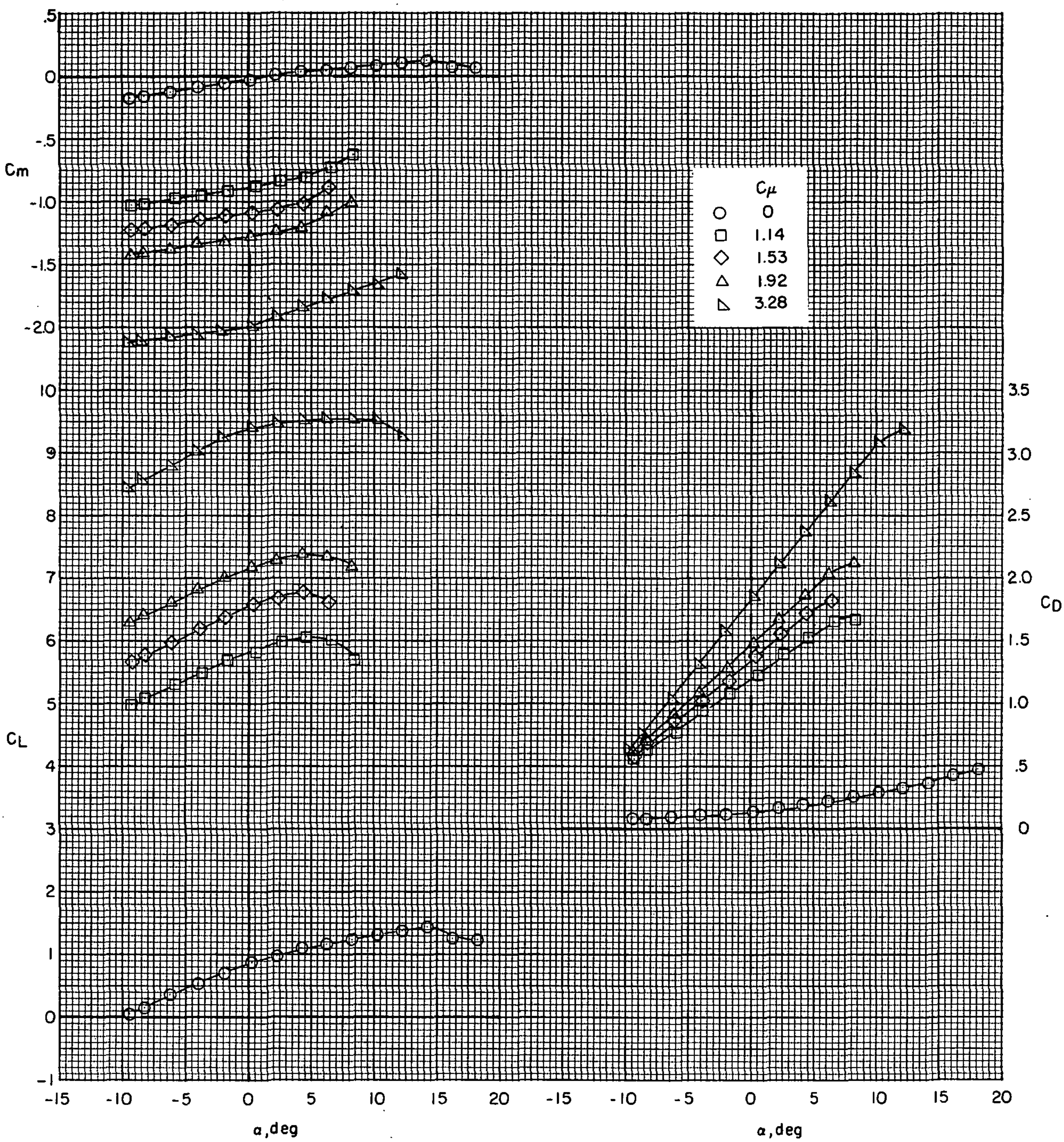
(l) $\delta_f = 60^o$; $h/b = 0.125$; $V_B/V_\infty = 1.00$.

Figure 7.- Continued.



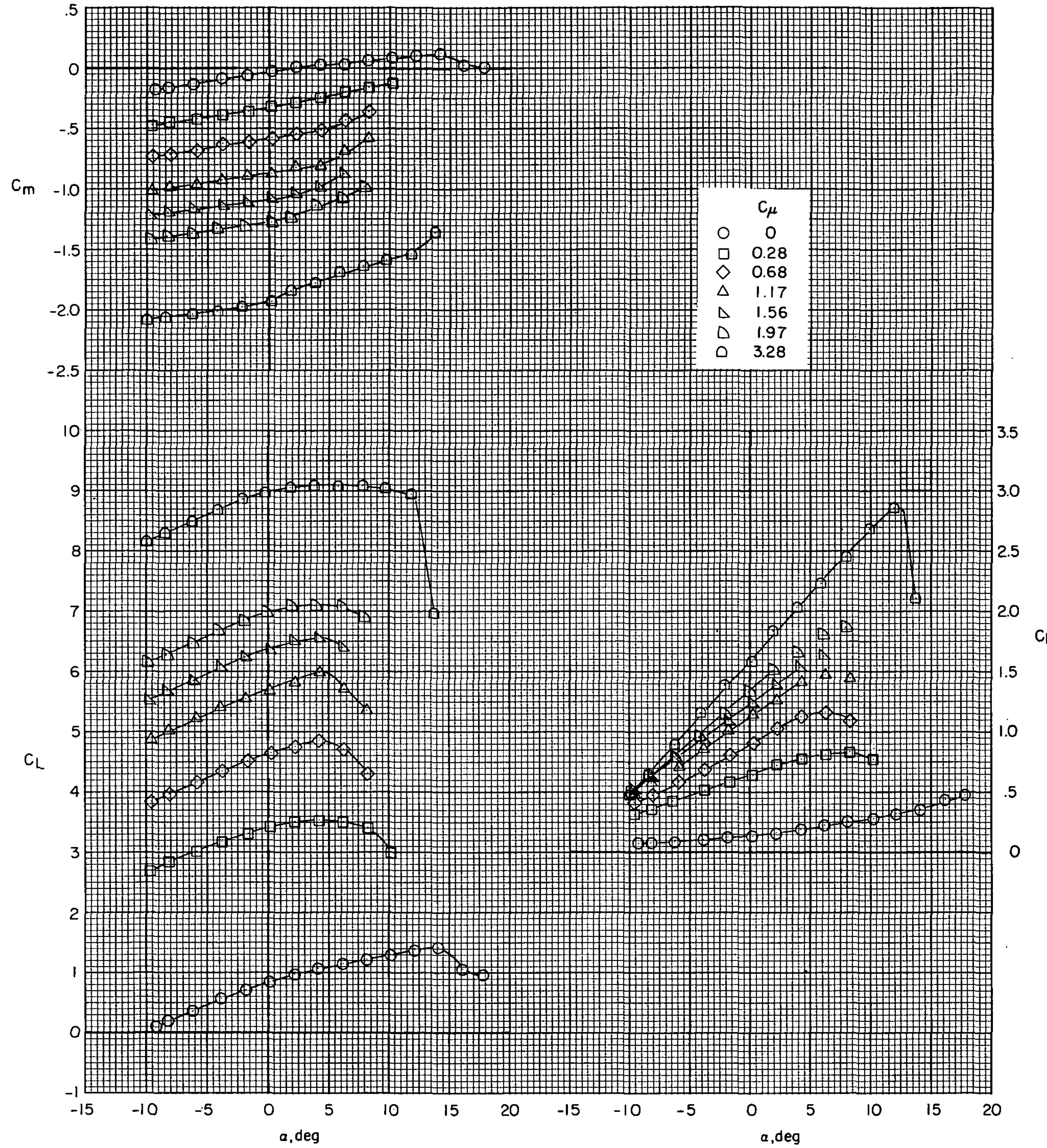
(m) $\delta_f = 60^{\circ}$; $h/b = 0.062$; $V_B/V_\infty = 1.00$.

Figure 7.- Continued.



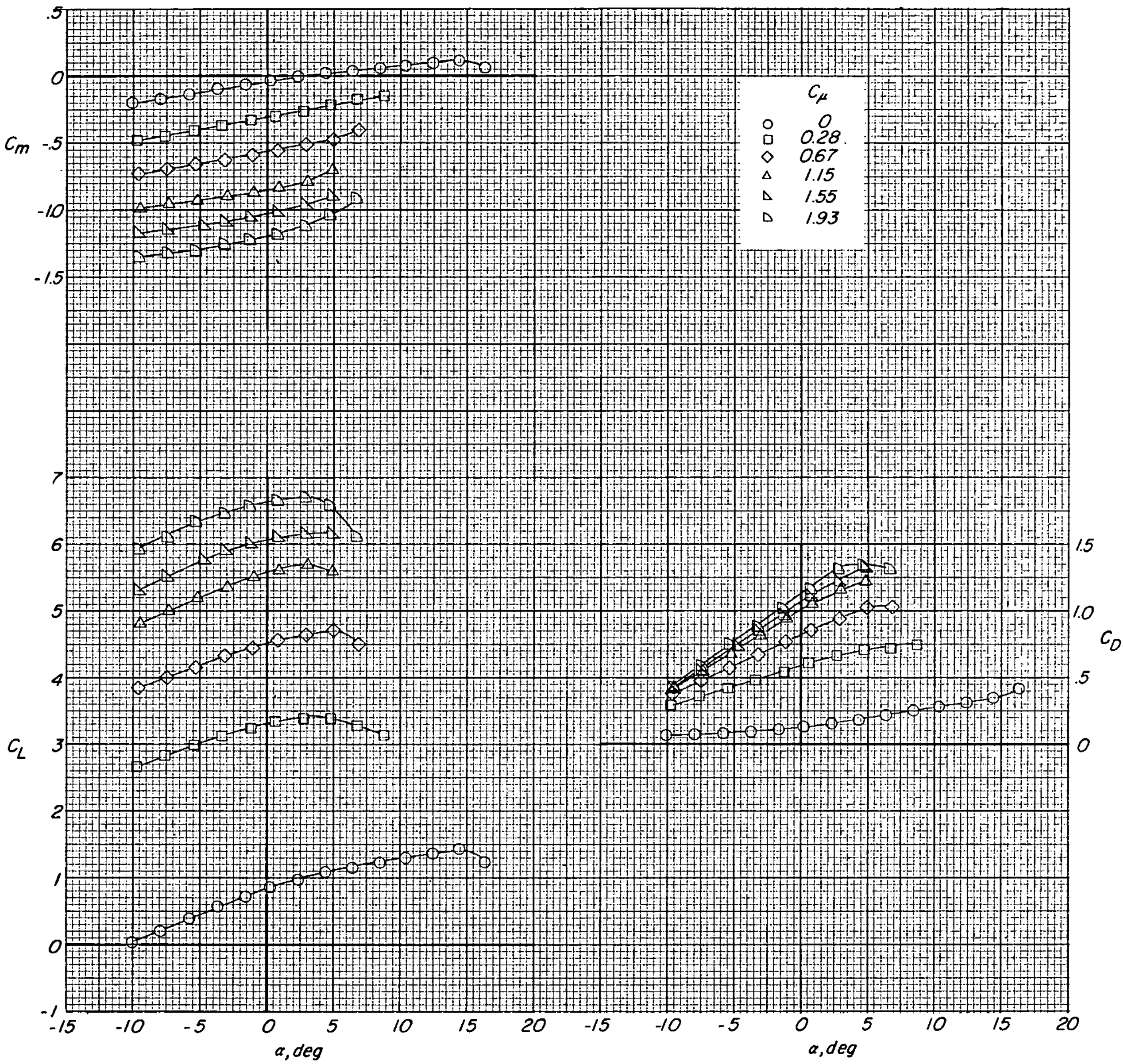
(n) $\delta_f = 75^{\circ}$; $h/b = 2.00$; $V_B/V_\infty = 1.00$.

Figure 7.- Continued.



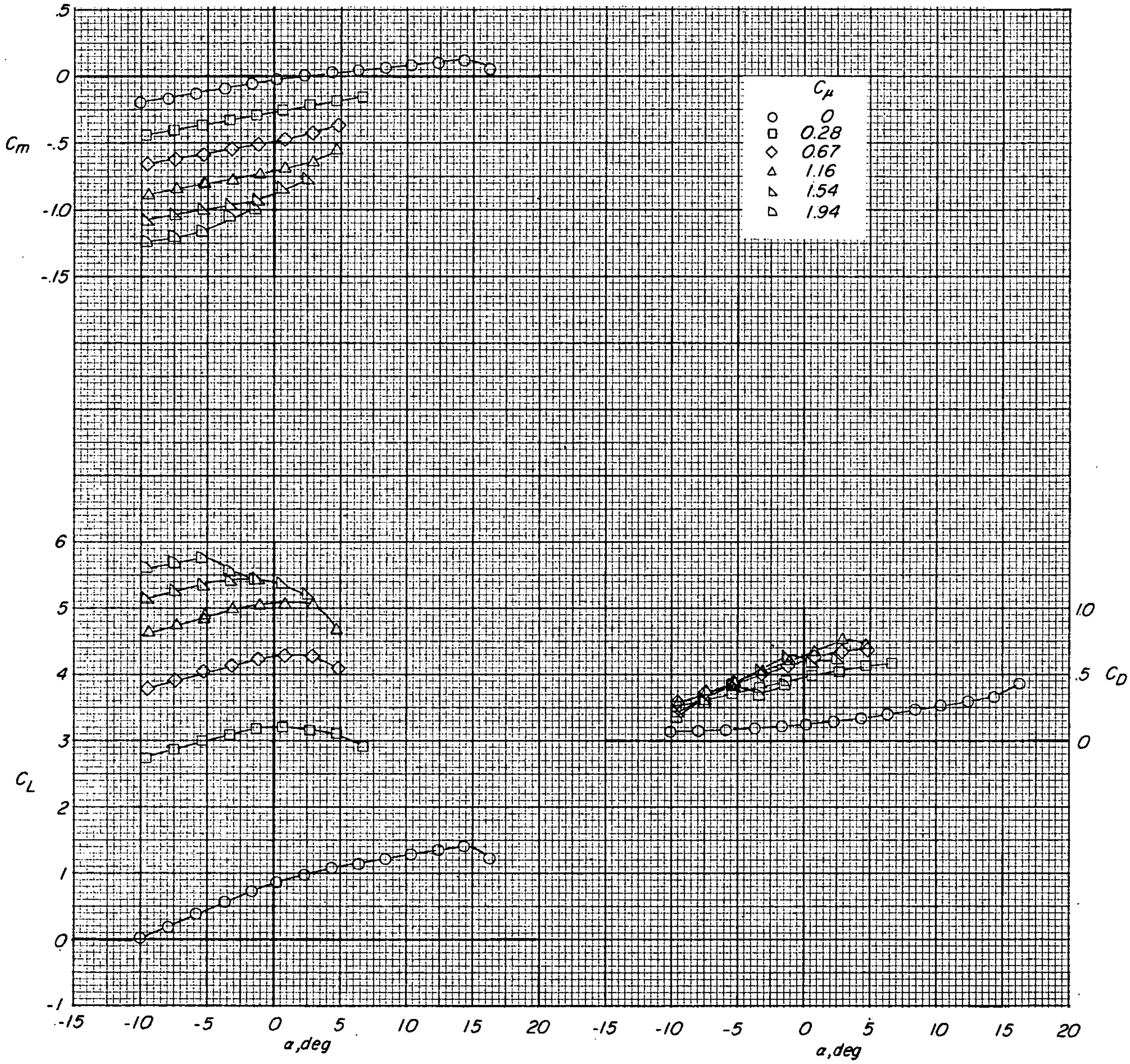
(o) $\delta_f = 75^0$; $h/b = 1.00$; $V_B/V_\infty = 1.00$.

Figure 7.- Continued.



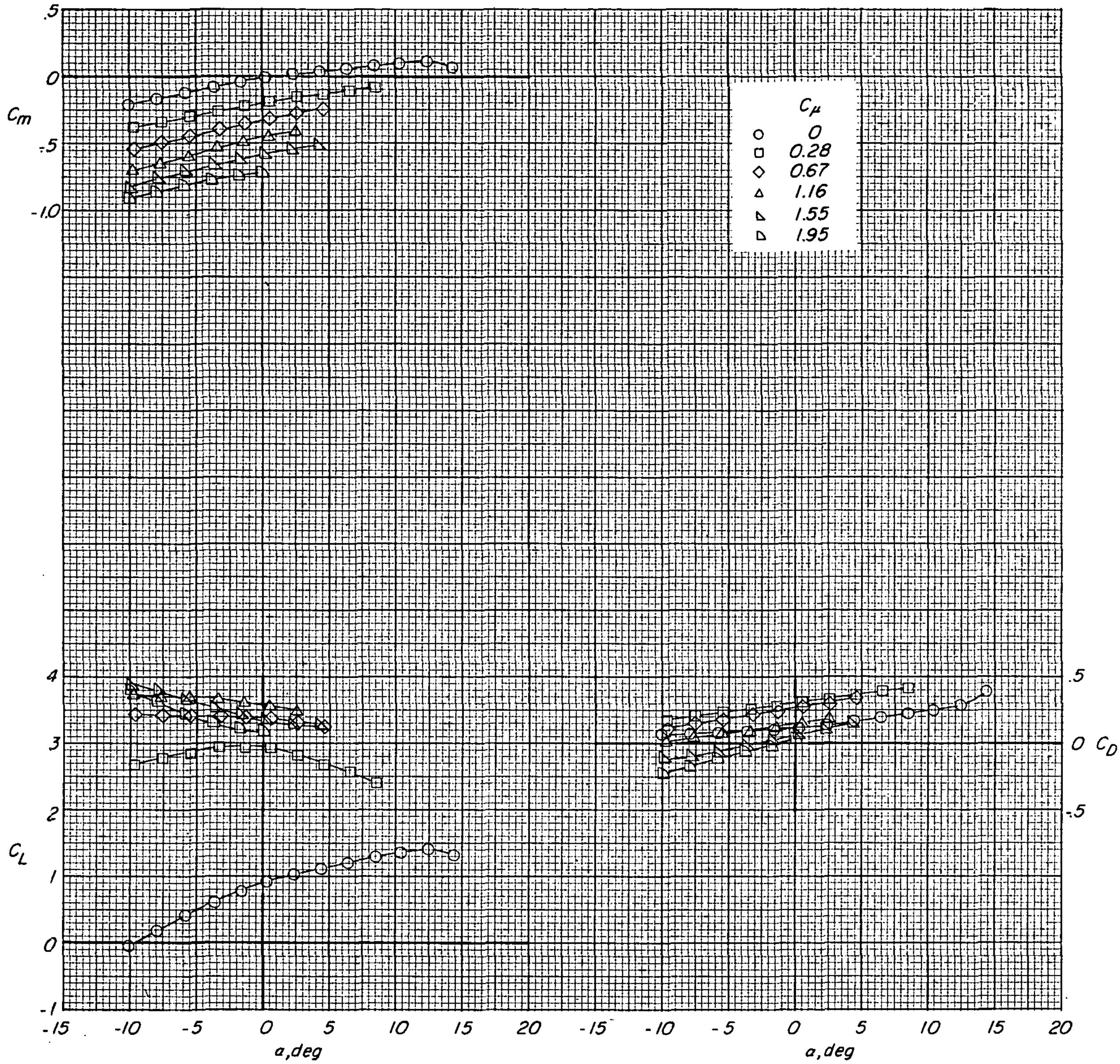
(p) $\delta_f = 75^o$; $h/b = 0.50$; $V_B/V_\infty = 1.00$.

Figure 7.- Continued.



(q) $\delta_f = 75^o$; $h/b = 0.25$; $V_B/V_\infty = 1.00$.

Figure 7.- Continued.



(r) $\delta_f = 75^{\circ}$; $h/b = 0.125$; $V_B/V_\infty = 1.00$.

Figure 7.- Concluded.

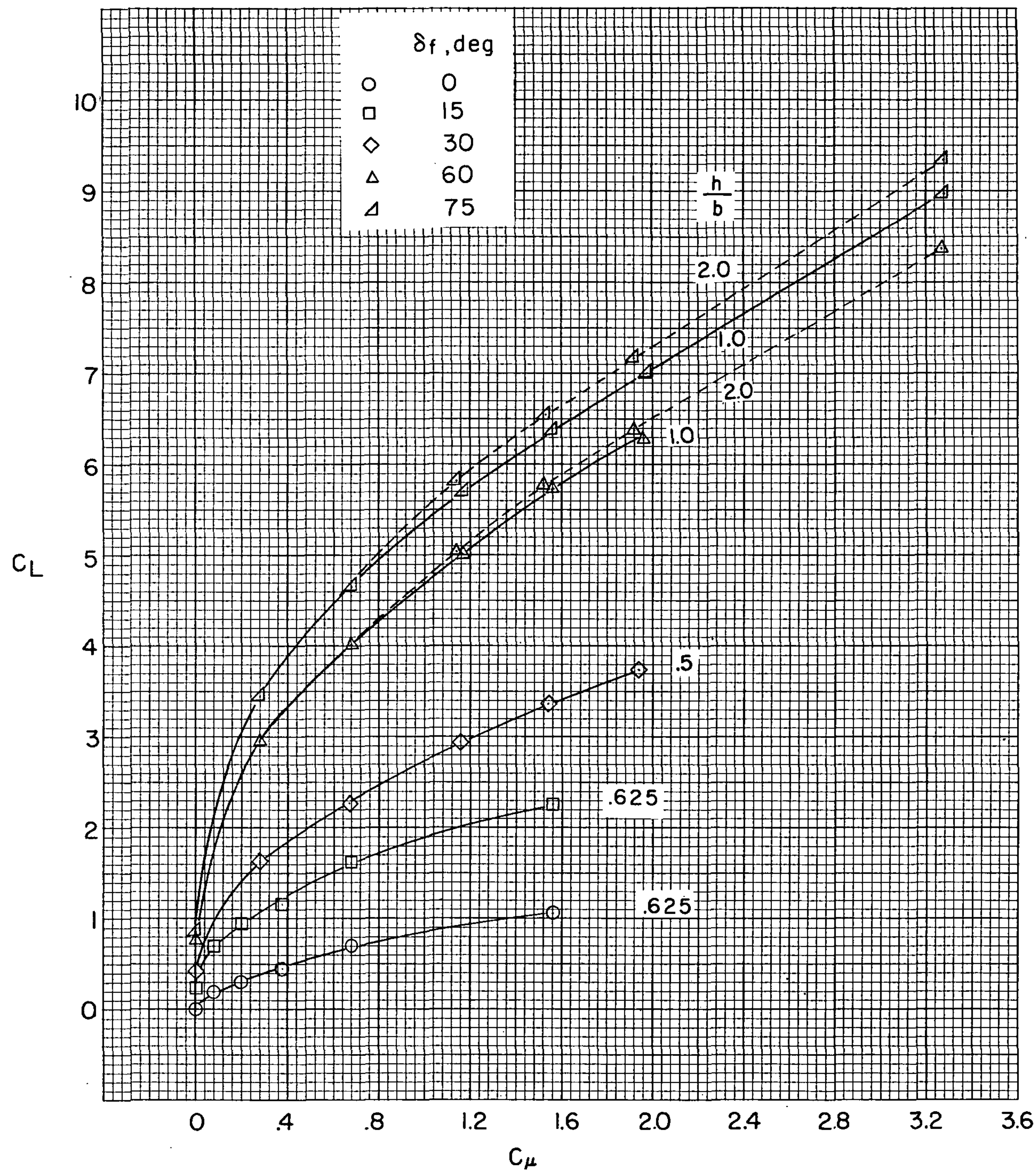


Figure 8.- Variation of C_L with C_μ. $\alpha = 0^{\circ}$; $V_B/V_\infty = 1.00$.

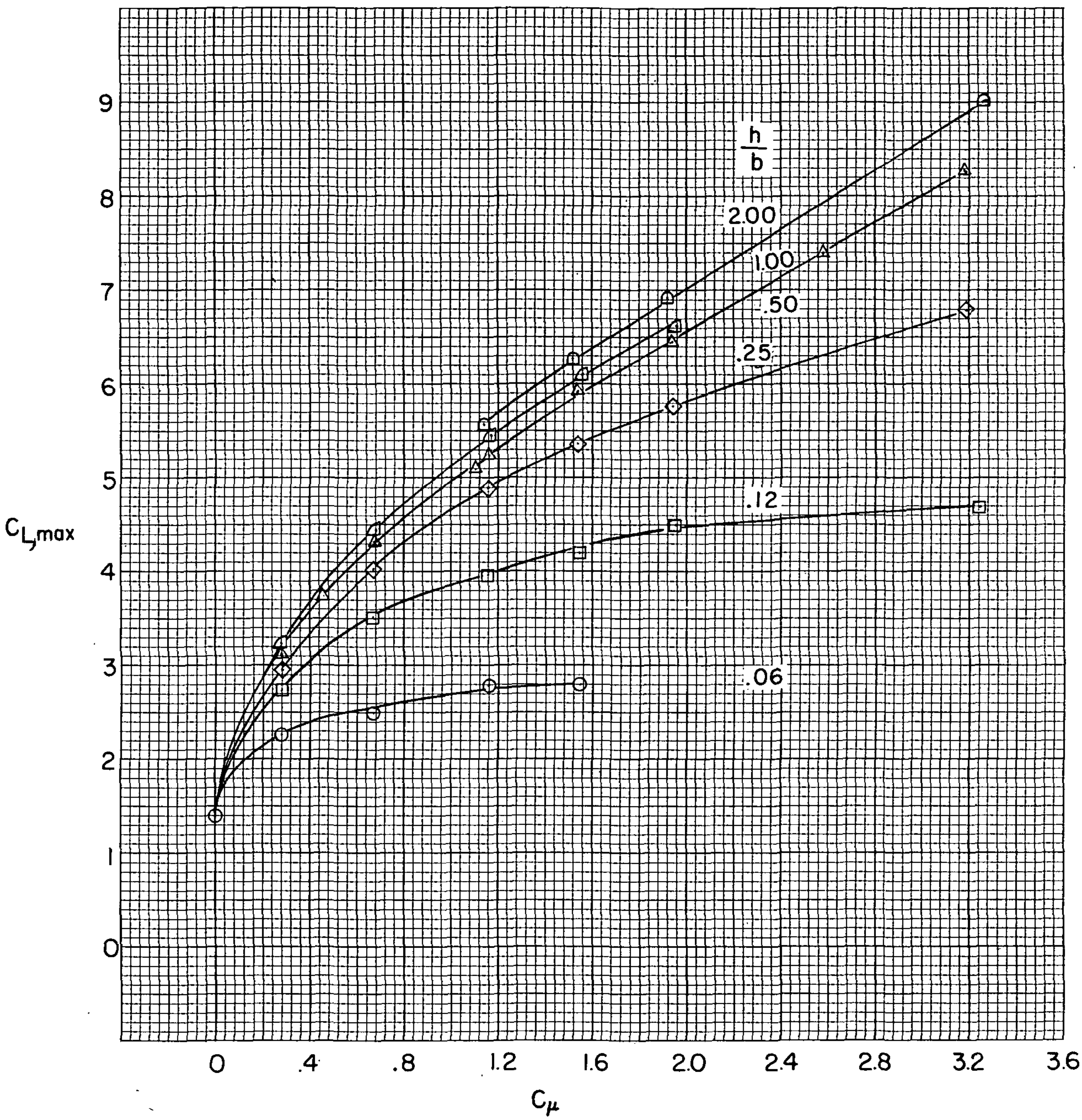


Figure 9.- Variation of $C_{L,max}$ with C_μ. $\delta_f = 60^o$; $V_B/V_\infty = 1.00$.

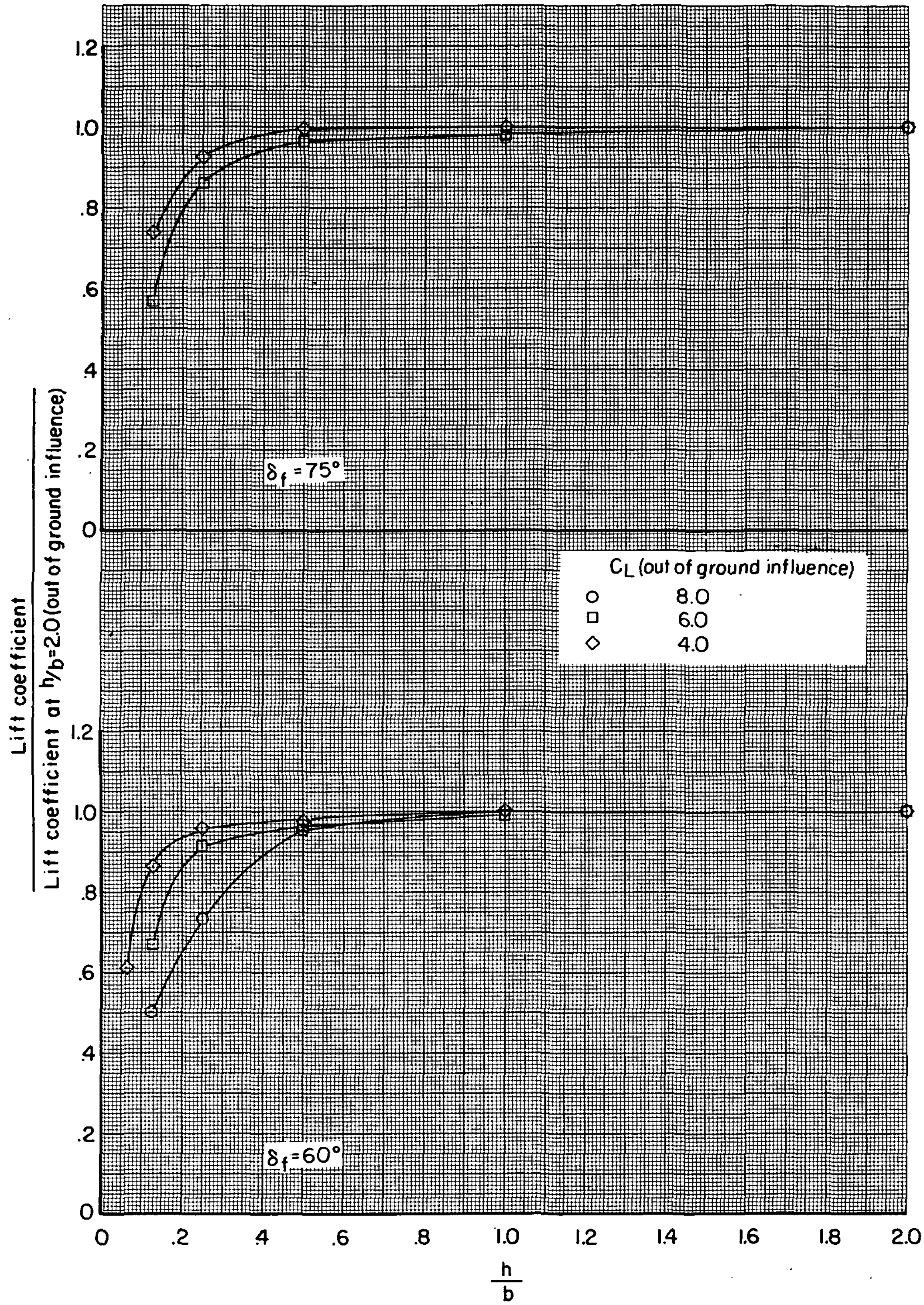


Figure 10.- Variation of lift ratio with h/b. $\alpha = 0^{\circ}$.

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