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TECHNICAL NOTE 3863

WIND-TUNNEL INVESTIGATION AT LOW SPEEDS TO DETERMINE THE
EFFECT OF ASPECT RATIO AND END PLATES ON A RECTANGULAR
WING WITH JET FLAPS DEFLECTED 85°

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SUMMARY

A wind-tunnel investigation was made at low speeds to determine the effect of aspect ratio and end plates on the aerodynamic characteristics of an unswept and untapered wing equipped with jet flaps deflected 85° and operating with momentum coefficients as high as 17.5.

The results indicated that the lift coefficient induced by the jet sheet (lift coefficient minus jet reaction in the lift direction) increased rapidly with increased aspect ratio and had maximum values of 2.9, 6.4, and 10.5 for aspect ratios of 2.8, 5.6, and 8.4, respectively. Various end plates increased the effective aspect ratio. The combination of the jet reaction at the trailing edge and the induced lift acting at the 0.4-chord station resulted in very large nose-down pitching-moment coefficients about the quarter chord of the wing.

INTRODUCTION

As the design speed and load capacity of airplanes continue to increase, the problem of take-off and landing becomes more serious. The necessary length of runways and the landing speeds may be reduced if the lifting power of the wing can be sufficiently increased at low speeds. At the present time, jet flaps are being considered with their twofold action in producing lift by increasing the circulation around the wing and by generating a reaction thrust in the lift direction. A discussion and theoretical analysis of the jet flap along with a correlation of theory with some experimental data are given in reference 1. Jet flaps of various types at different deflection angles and high momentum coefficients have been investigated and are reported in reference 2.

The purpose of this investigation was to determine the effect of wing aspect ratio and end plates on the aerodynamic characteristics of a wing equipped with a jet flap deflected 85° .

SYMBOLS

C_L	lift coefficient, $\frac{\text{Lift}}{qS}$
$(C_L)_\Gamma$	jet-circulation lift coefficient, $\left[C_L - (C_L)_{C_\mu=0} - C_\mu \sin(\delta + \alpha) \right]$
$(C_L)_{C_\mu=0}$	lift coefficient for $C_\mu = 0$ or jet off
C_D	drag coefficient, $\frac{\text{Drag}}{qS}$
$C_{D,i}$	induced drag coefficient
C_m	pitching-moment coefficient about wing quarter chord, $\frac{\text{Pitching moment}}{qS\bar{c}}$
$(C_m)_\Gamma$	jet-circulation pitching-moment coefficient
C_μ	momentum coefficient, $\frac{w_j V_j}{gqS}$
q	free-stream dynamic pressure, $\frac{\rho V^2}{2}$, lb/sq ft
S	wing area, sq ft
\bar{c}	wing mean aerodynamic chord, 0.60 ft
g	acceleration of gravity, 32.2 ft/sec ²
ρ	mass density of air, slugs/cu ft
V	free-stream velocity, ft/sec
w_j	weight rate of air flow through jet, lb/sec
V_j	jet-exit velocity assuming isentropic expansion to free-stream static pressure, $\sqrt{\frac{2\gamma}{\gamma-1} RTg \left[1 - \left(\frac{p}{p_p} \right)^{\frac{\gamma-1}{\gamma}} \right]}$, ft/sec

γ	ratio of specific heats for air, 1.4
R	universal gas constant, $\frac{\text{ft-lb}}{\text{lb}}/\text{OR}$
T	plenum chamber temperature, $^{\circ}\text{R}$
p	free-stream static pressure, lb/sq ft
p_p	total pressure in plenum chamber, lb/sq ft
α	angle of attack of wing-chord plane, deg
δ	jet-deflection angle, measured with respect to the wing-chord plane extended, deg
A	aspect ratio
x_{cp}	center of pressure, percent chord
$(x_{cp})_{\Gamma}$	center of pressure of jet-circulation lift, percent chord
η	wing efficiency factor
k_1, k_2	constants
Subscript:	
max	maximum

APPARATUS AND MODEL

The geometric characteristics of the semispan wings and the end plates used in this investigation are shown in figure 1. The wings were rectangular and unswept with aspect ratios of 2.8, 5.6, and 8.4. They were constructed by removing the rear portion of a 10-inch-chord NACA 0012 wing and installing a 0.75-inch-diameter tube and a plenum chamber. Compressed air flowed from the tube into the plenum chamber through 1/16-inch-diameter holes spaced 1/2-inch apart spanwise along the tube. The bottom surface of the wing at the trailing edge was faired to the surface of the tube in order to make a blunt trailing edge below the chord plane. The jet sheet of air formed an angle of 85° with the chord plane extended. The method of getting high-pressure air into the wing was the same as that described in reference 2. The weight rate of air flow was determined by means of a calibrated sharp-edge-orifice flowmeter,

and the pressures and temperatures for determining jet-exit velocities were measured in the wing plenum chamber.

TESTS AND CORRECTIONS

The models were mounted on the ceiling of the Langley 300 MPH 7- by 10-foot tunnel. Tests were made at an angle of attack of 0° through a range of momentum coefficients and at a constant momentum coefficient through an angle-of-attack range as indicated in the following table:

Aspect ratio	α , deg	C_μ	P_p/P	q , lb/sq ft	Reynolds number
2.8	0	0 to 4.85	1 to 6.10	10	350,000
5.6	0	0 to 7.25	1 to 5.15	5	250,000
8.4	0	0 to 17.66	1 to 5.35	2	158,000
8.4	0	0 to 7.07	1 to 5.35	5	250,000
2.8	-4 to 20	0.47	1.44	10	350,000
5.6	-4 to 20	0.49	1.49	10	350,000
8.4	-4 to 12	0.96	3.05	16.9	460,000

Jet-boundary corrections to the angle-of-attack and drag data were applied by the methods of reference 3. The corrections are based only on the aerodynamic lift coefficient obtained by subtracting the jet reaction from the total measured lift as indicated by the equations

$$\alpha = \alpha_{\text{tunnel}} + k_1 [C_L - C_\mu \sin(\delta + \alpha)]$$

$$C_D = C_{D,\text{measured}} + k_2 [C_L - C_\mu \sin(\delta + \alpha)]^2$$

where k_1 has values of 0.142, 0.094, and 0.047 and k_2 has values of 0.0025, 0.0016, and 0.0008 for aspect ratios of 8.4, 5.6, and 2.8, respectively.

RESULTS AND DISCUSSION

Lift Characteristics

The lift of a wing equipped with a jet flap consists of the jet-off lift on the wing due to angle of attack or flap deflection, the

reaction lift (the component of the jet in the thrust-lift direction), and the jet-circulation lift (the lift induced by the jet stream). The magnitude of the various components of the lift are shown in figure 2(a) for the aspect-ratio-8.4 wing with a jet angle of 85° . It can be seen that the jet-circulation lift increases with momentum coefficient over the lower range of momentum coefficients presented in figure 2(a). The value of jet-circulation lift for the aspect-ratio-8.4 wing reaches a maximum value of 10.5 at a momentum coefficient of about 12; the low-aspect-ratio wings reach a maximum value of less than 10.5 (figs. 2(b) and 2(c)). The maximum values of jet-circulation lift coefficient from figure 2 plotted against wing aspect ratio are presented in figure 3; these plots indicate that the jet-circulation lift increases rapidly with an increase in aspect ratio.

The maximum values of jet-circulation lift coefficient from figure 3 are used as an upper limit for the plots of the jet-circulation lift coefficient as a function of aspect ratio presented in figure 4 for several values of momentum coefficients. Figure 4 may be considered a preliminary design chart for estimating the lift coefficient of wings equipped with jet flaps. The lift coefficient can be obtained from the following equation:

$$C_L = (C_L)_{C_\mu=0} + (C_L)_\Gamma \frac{\delta}{85} + C_\mu \sin(\alpha + \delta)$$

It was noted from the results of reference 2 that the jet-circulation lift coefficient $(C_L)_\Gamma$ can be modified by the ratio $\delta/85$ which approximately accounts for jet deflections other than 85° . If this equation is applied to wings with high momentum blowing over flaps, the $(C_L)_{C_\mu=0}$ is the lift resulting from flap deflection without blowing.

It should be pointed out that in this investigation the momentum coefficient is based upon the mass of air and the expanded jet velocity and will show similar variation of measured thrust to theoretical thrust as was shown in reference 2. The theoretical momentum coefficient has been used in analyzing these data because it is believed that the momentum of the jet at the nozzle exit is largely responsible for the change in circulation around the wing and because the losses in the jet due to overexpanding, turning, and base pressure could not be individually evaluated from the results of these data.

End plates on wings with jet flaps (fig. 2) give increased lift as has been the case on wings without blowing, the increase being an increase in circulation lift since the jet reaction is the same with or without the end plates. In order to determine the effect of end plates

on effective aspect ratio, figure 5 was prepared by cross-plotting data from figure 2. The solid lines of figure 5 show the variation of total lift without end plates with geometric aspect ratio and the near-vertical lines were obtained from cross-plotted values of lift with end plates. The data show that various end plates increased the aspect ratio of one wing from 2.8 to an effective aspect ratio of 3.1 to 4.2 and the other wing, from 5.6 to an effective aspect ratio of 6.5 to 9. Of the two end plates of approximately equal area the rectangular one was more effective on the aspect-ratio-5.6 wing whereas the circular one was slightly more effective on the aspect-ratio-2.8 wing. The effectiveness of the end plates is retained throughout the angle-of-attack range with and without blowing except for the largest end plate above an angle of attack of 16° as shown in figure 6.

Drag Characteristics

At an angle of attack of 0° the increase in induced drag with blowing results from the increased circulation lift. From tests with and without blowing the induced drag and circulation lift may be easily

determined at $\alpha = 0^\circ$. From the equation for induced drag $C_{D,i} = \frac{(C_L)_\Gamma^2}{\eta \pi A}$, the efficiency factor η of the wing may be determined. Figure 7 shows the values of η for the three wings through a range of momentum coefficients obtained from the data of figure 8. The average values of η range from 0.7 to 0.85 for wings of this plan form without blowing. The efficiency factor decreases with momentum coefficient for the aspect-ratio-2.8 wing, but η increases to about 1.2 with blowing for the two wings of larger aspect ratio. These high values of η for the two larger aspect ratios may be associated with the induced thrust.

Pitching-Moment Characteristics

The combination of large jet-circulation lift coefficients with their center of pressure at about the $0.4\bar{c}$ and the jet reaction at the trailing edge results in the jet flap having large nose-down pitching-moment coefficients that increase with lift coefficient (fig. 9). Since the jet reaction accounts for a large part of the pitching moments, it would be desirable to eliminate as much of this as possible. A method for doing this is discussed in reference 2 where the jet reaction is directed more nearly through the center of moments.

Data are presented only for the aspect-ratio-8.4 wing because balance limitations reduced the accuracy of the data for the low-aspect-ratio wings. It should be pointed out, however, that the data for the low-aspect-ratio wings indicated trends very similar to those of the aspect-ratio-8.4 wing presented in figure 9.

CONCLUSIONS

A wind-tunnel investigation at low speeds to determine the effect of aspect ratio and end plates on the aerodynamic characteristics of an unswept and untapered wing equipped with jet flaps deflected 85° resulted in the following conclusions:

1. The lift coefficient resulting from the increased wing circulation produced by the jet flap increases rapidly with an increase in wing aspect ratio.

2. The maximum lift coefficient resulting from increased wing circulation produced by the jet flap is approximately 2.9, 6.4, and 10.5 for aspect ratios of 2.8, 5.6, and 8.4, respectively.

3. End plates increased the effective aspect ratios of the wings with jet flaps from 2.8 to approximately 3 to 4 and from 5.6 to approximately 6.5 to 9, depending upon the particular end plate.

4. The combination of the jet reaction at the trailing edge and the induced lift acting at the 0.4-chord station resulted in very large nose-down pitching moments about the quarter chord of the wing.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., August 29, 1956.

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1. Dimmock, N. A.: An Experimental Introduction to the Jet Flap. National Gas Turbine Establishment Rep. No. R.175, British Ministry of Supply, Apr. 1955.
2. Lockwood, Vernard E., Turner, Thomas R., and Riebe, John M.: Wind-Tunnel Investigation of Jet-Augmented Flaps on a Rectangular Wing to High Momentum Coefficients. NACA TN 3865, 1956.
3. Gillis, Clarence L., Polhamus, Edward C., and Gray, Joseph L., Jr.: Charts for Determining Jet-Boundary Corrections for Complete Models in 7- by 10-Foot Closed Rectangular Wind Tunnels. NACA WR L-123, 1945. (Formerly NACA ARR L5G31.)

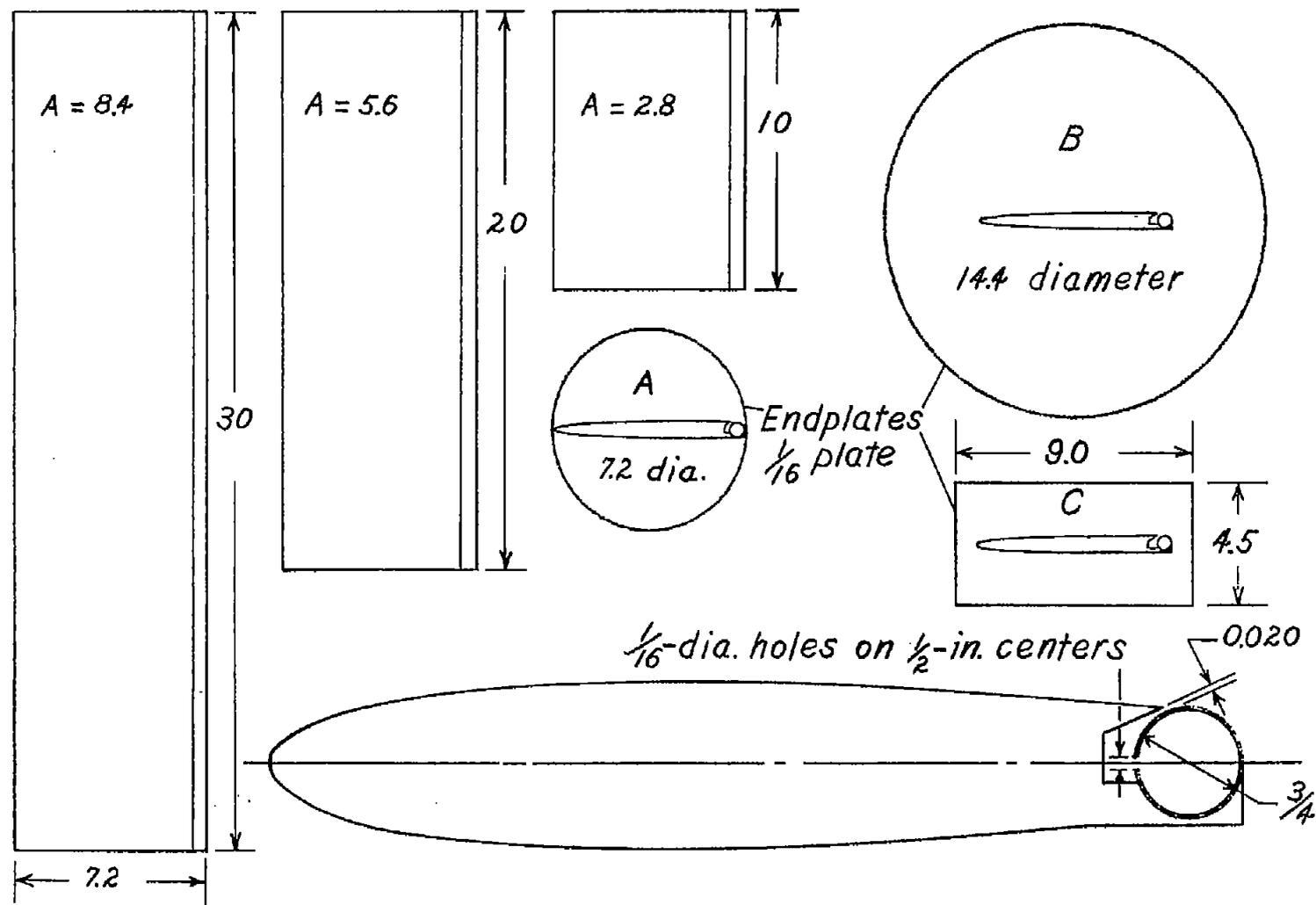
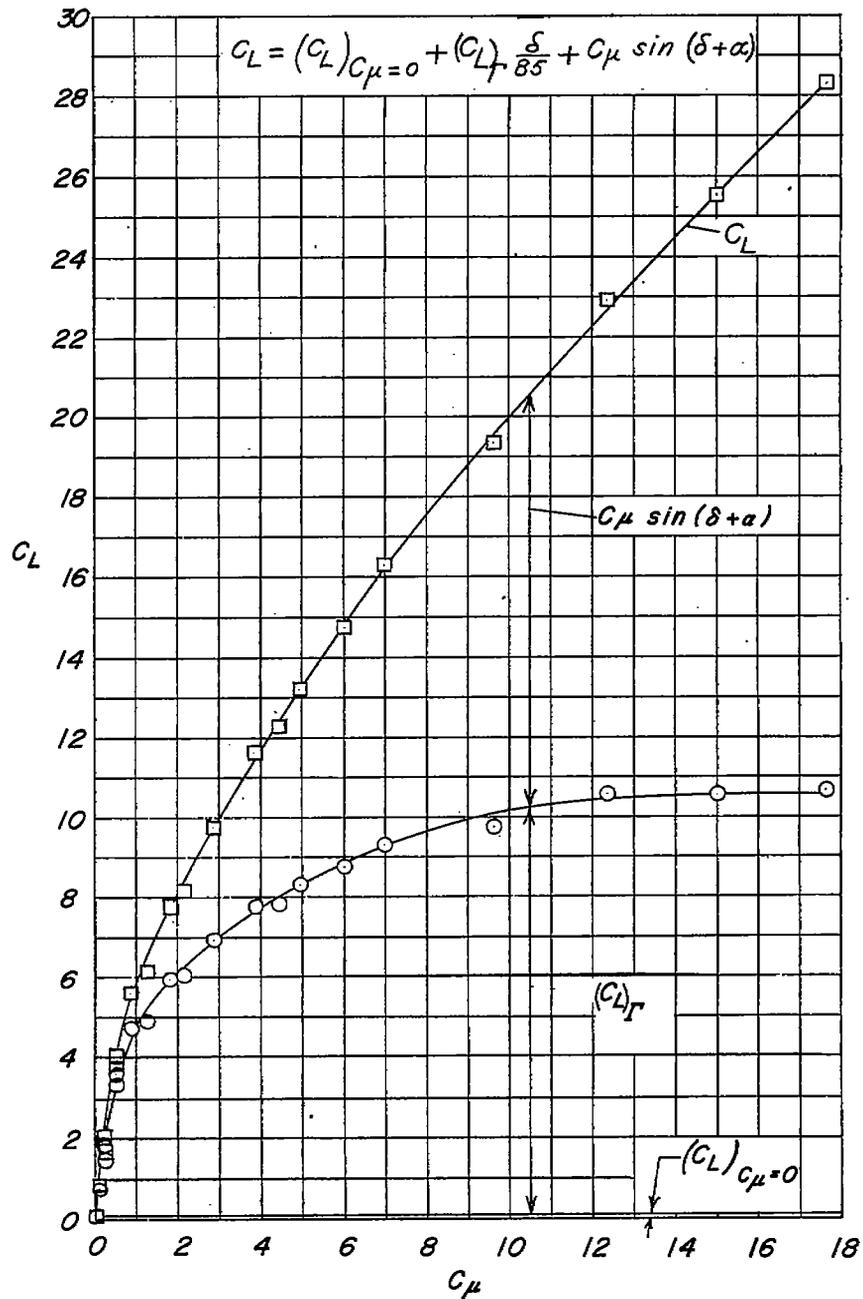
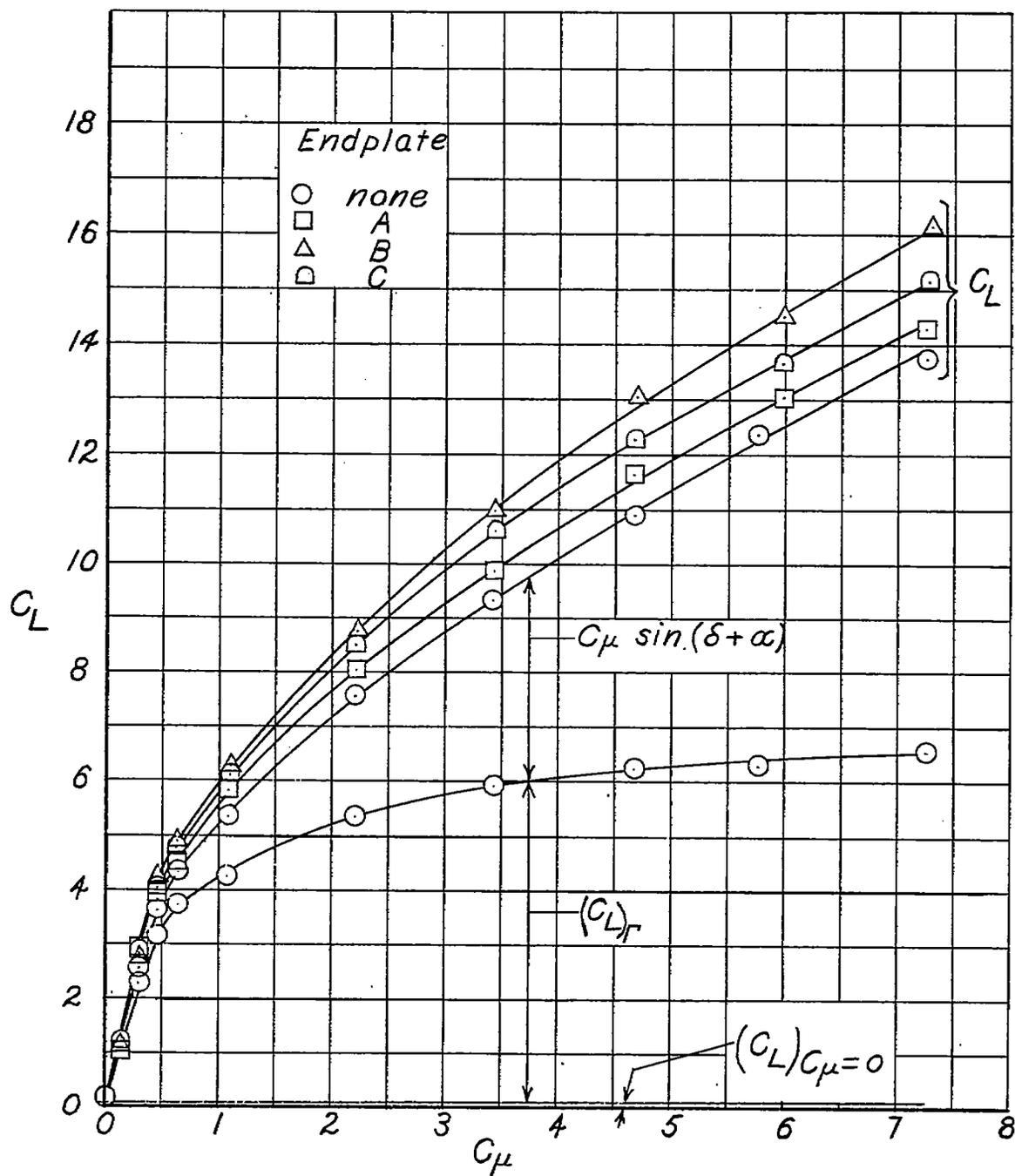


Figure 1.- Geometric characteristics of wings and end plates. All dimensions are in inches.



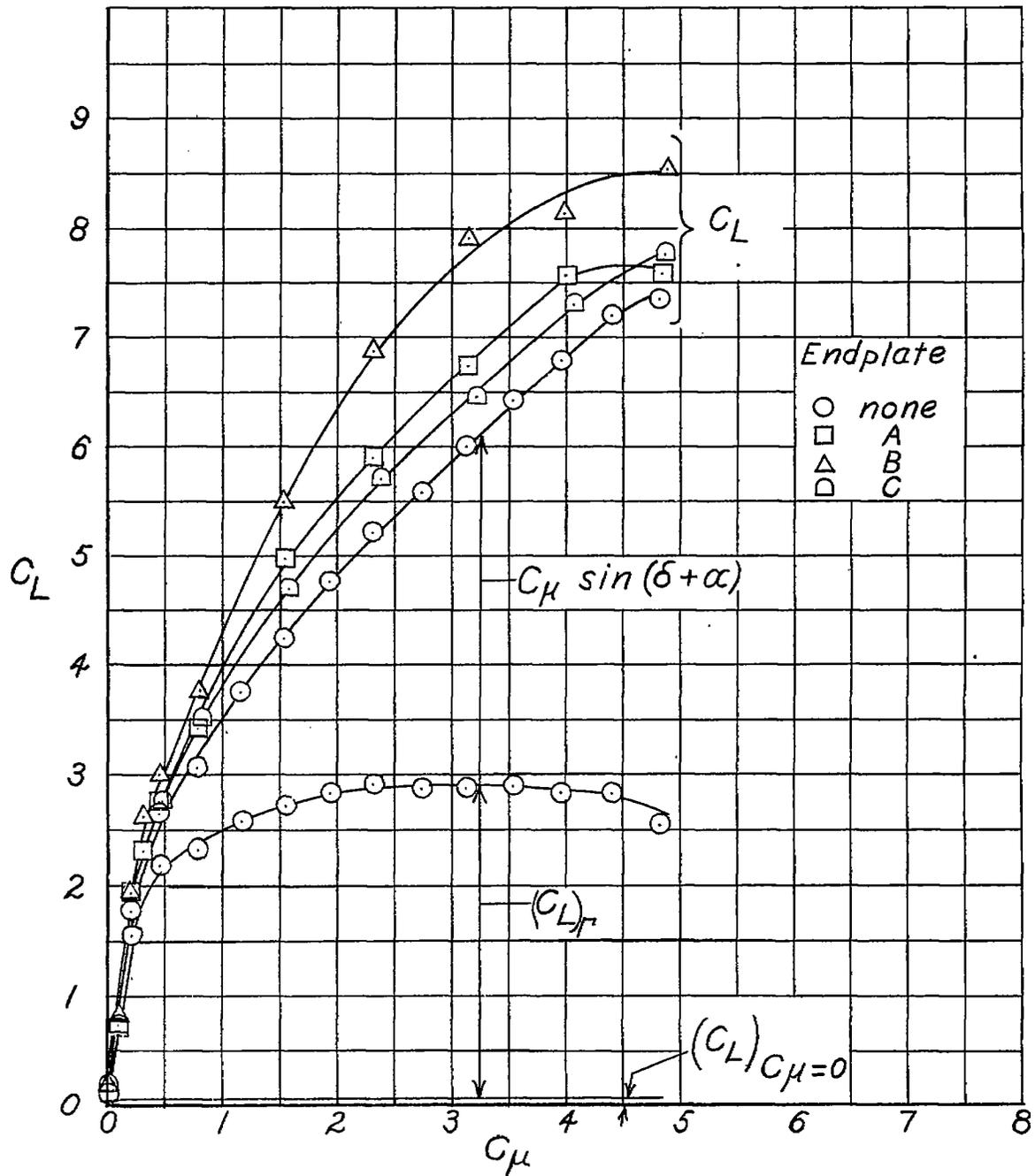
(a) Aspect ratio, 8.4; without end plates.

Figure 2.- Variation of lift coefficient with momentum coefficient for wings with jet flaps. $\alpha = 0^\circ$.



(b) Aspect ratio, 5.6; with and without end plates.

Figure 2.- Continued.



(c) Aspect ratio, 2.8; with and without end plates.

Figure 2.- Concluded.

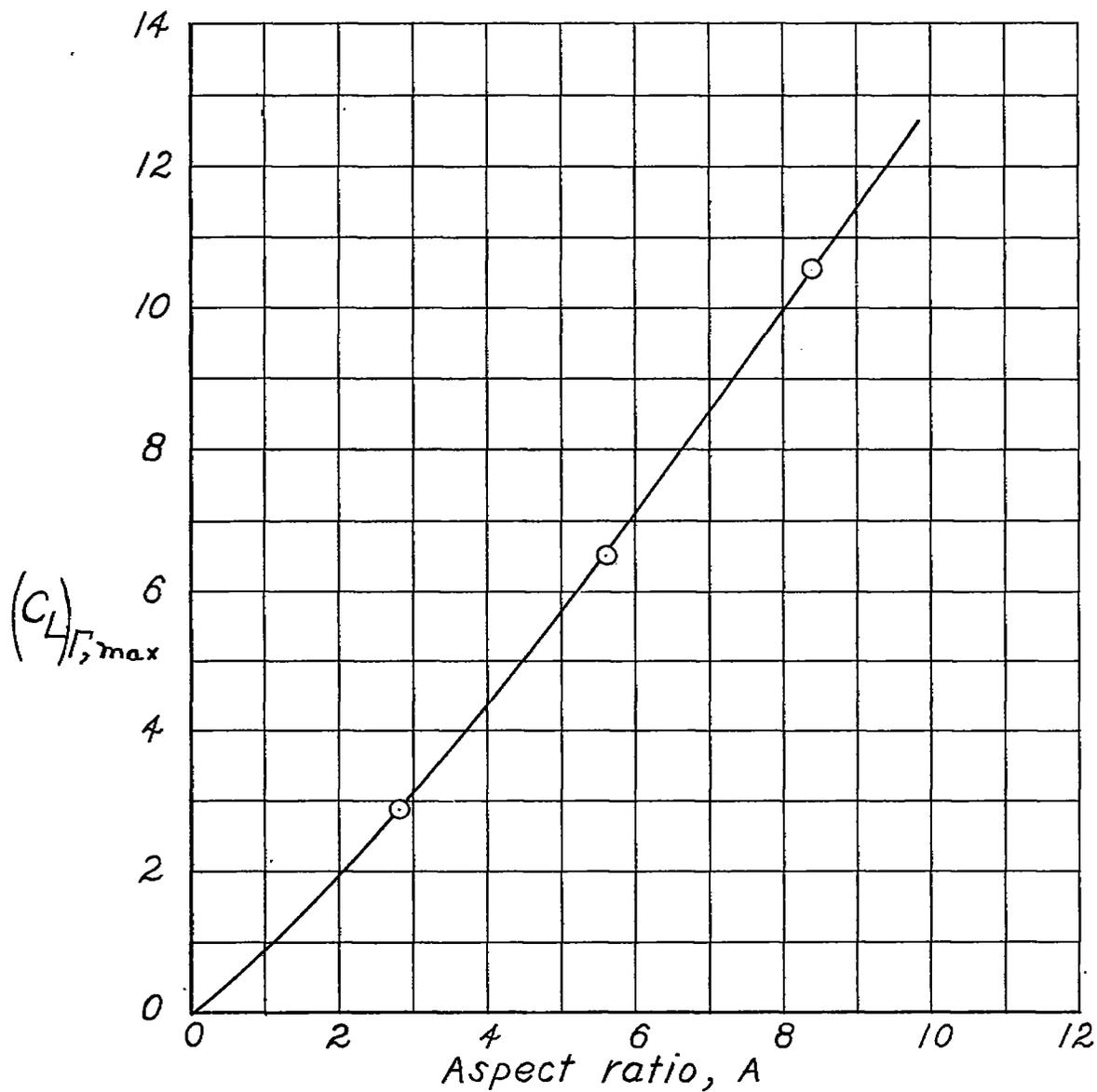


Figure 3.- Variation of maximum jet circulation lift coefficient with aspect ratio. Without end plates.

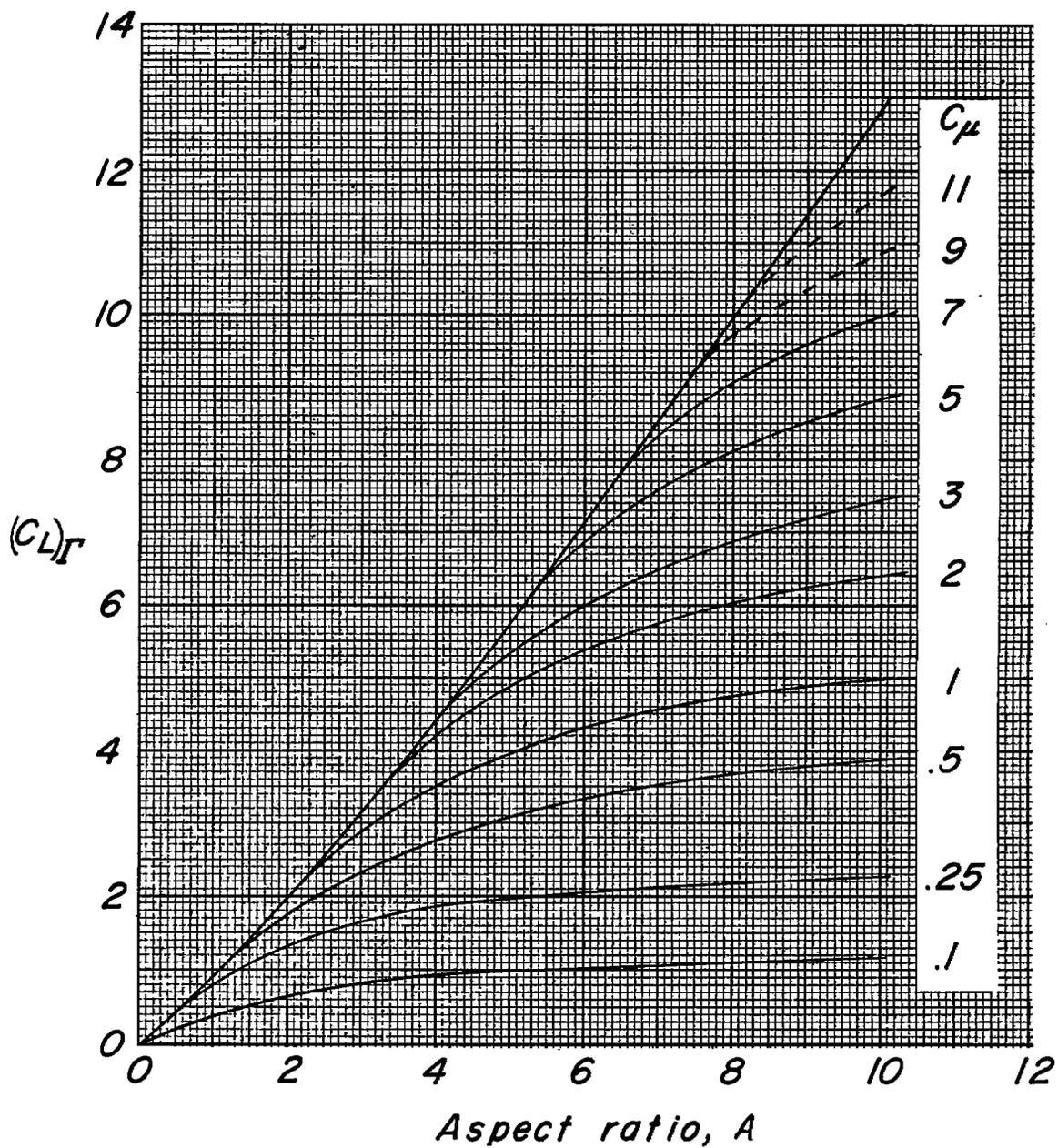


Figure 4.- Chart for estimating the jet circulation lift coefficient of wings with jet flaps.

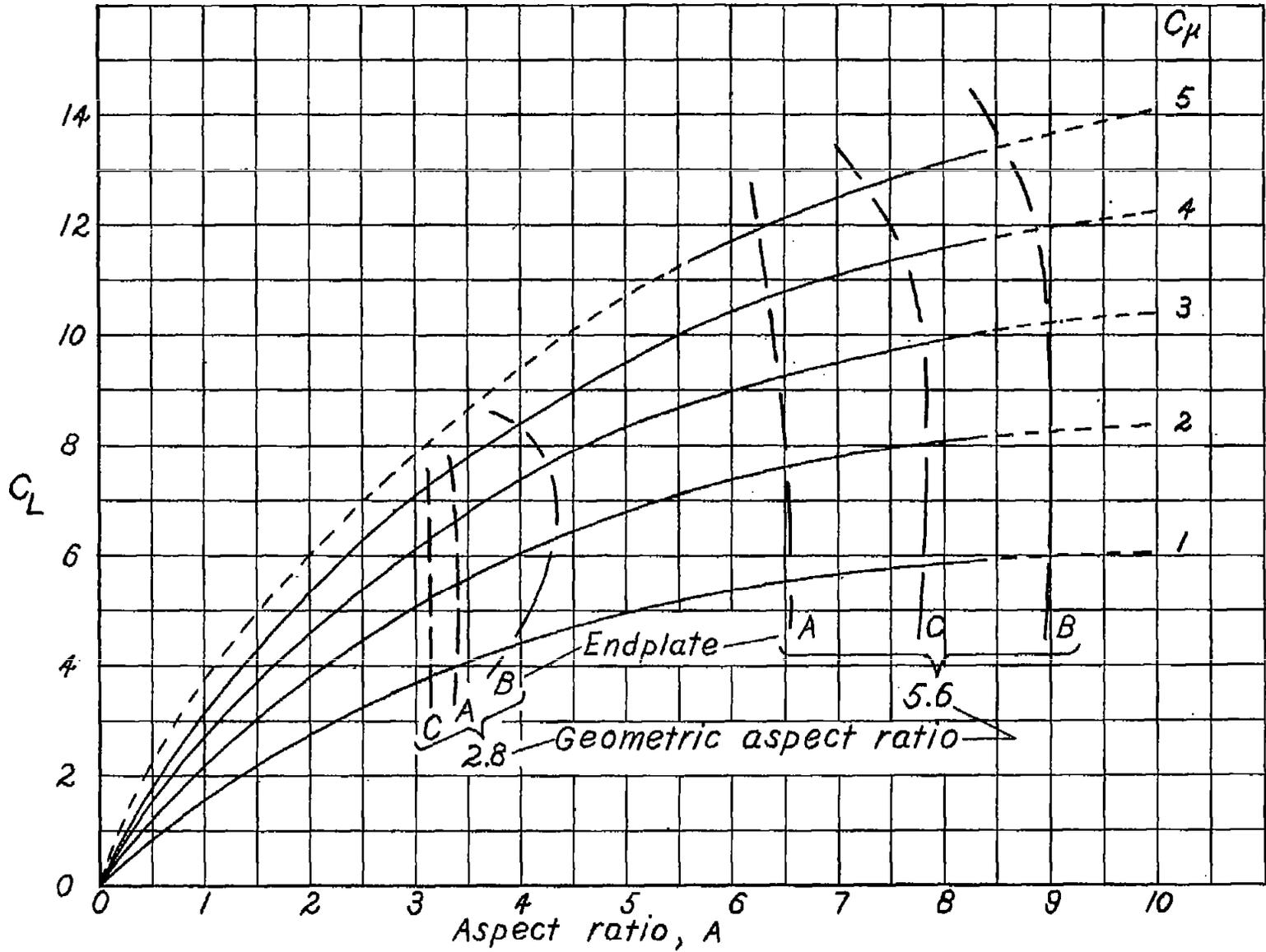
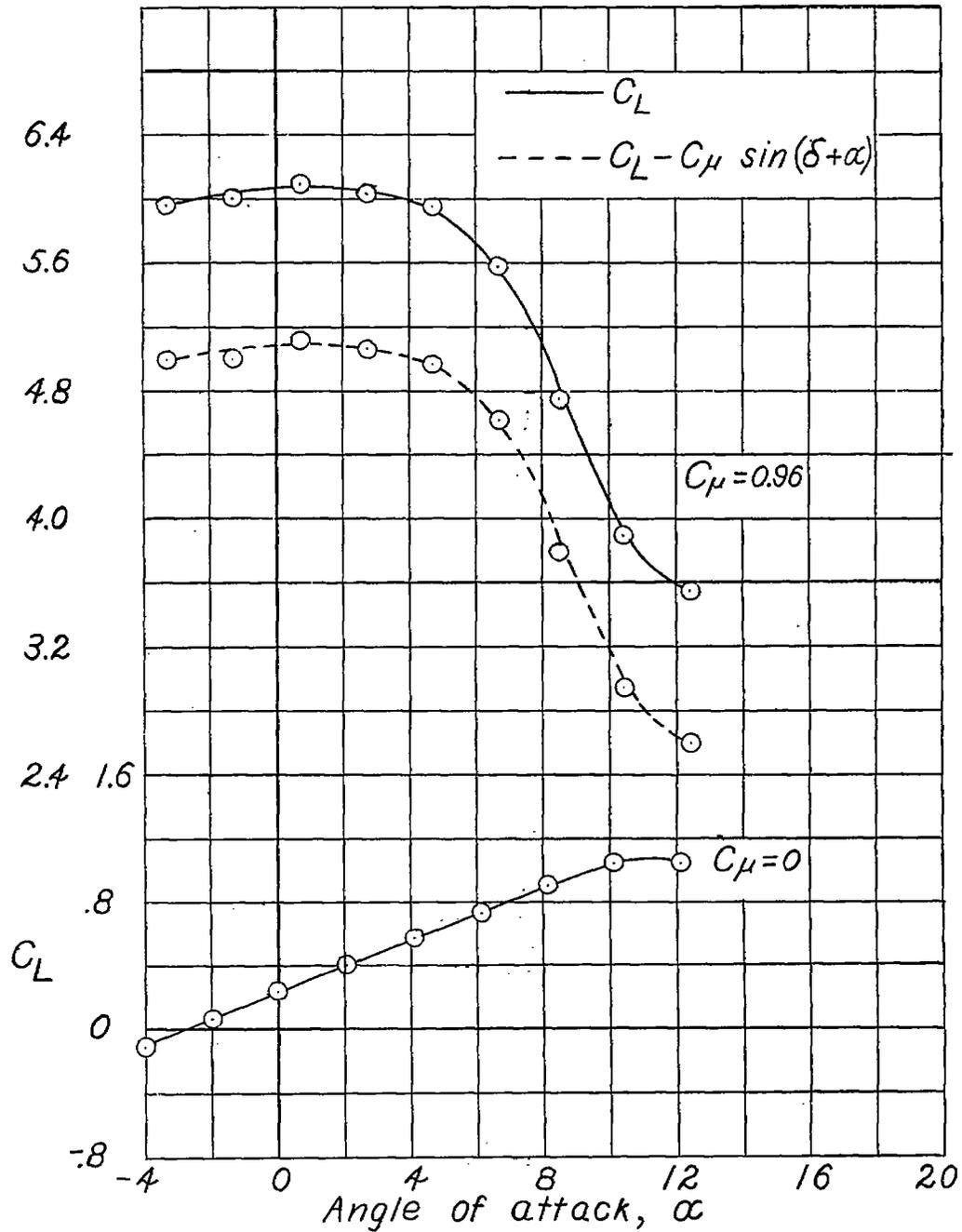
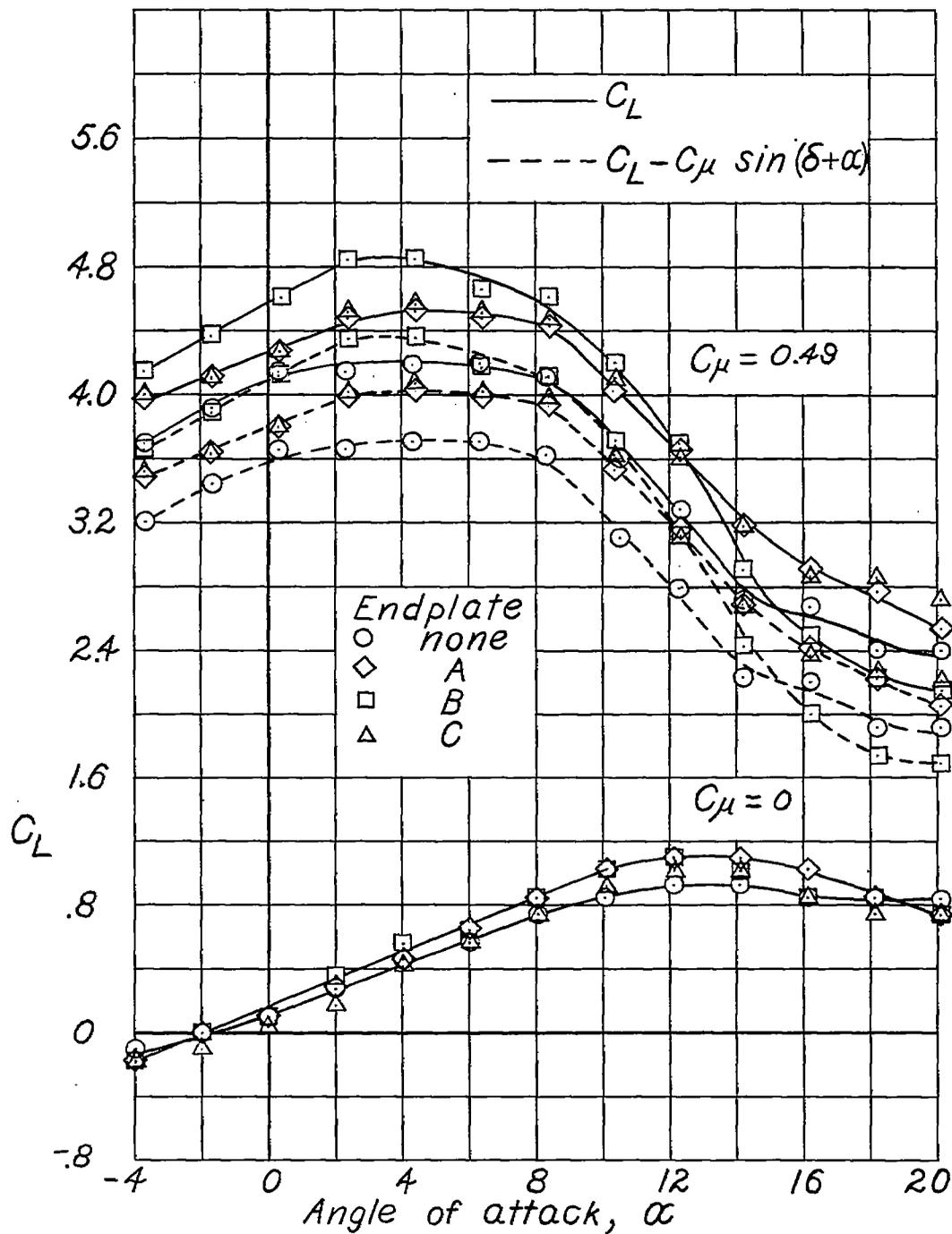


Figure 5.- Effect of end plates on aspect ratio of wings with jet flaps.
 $\alpha = 0^\circ$.



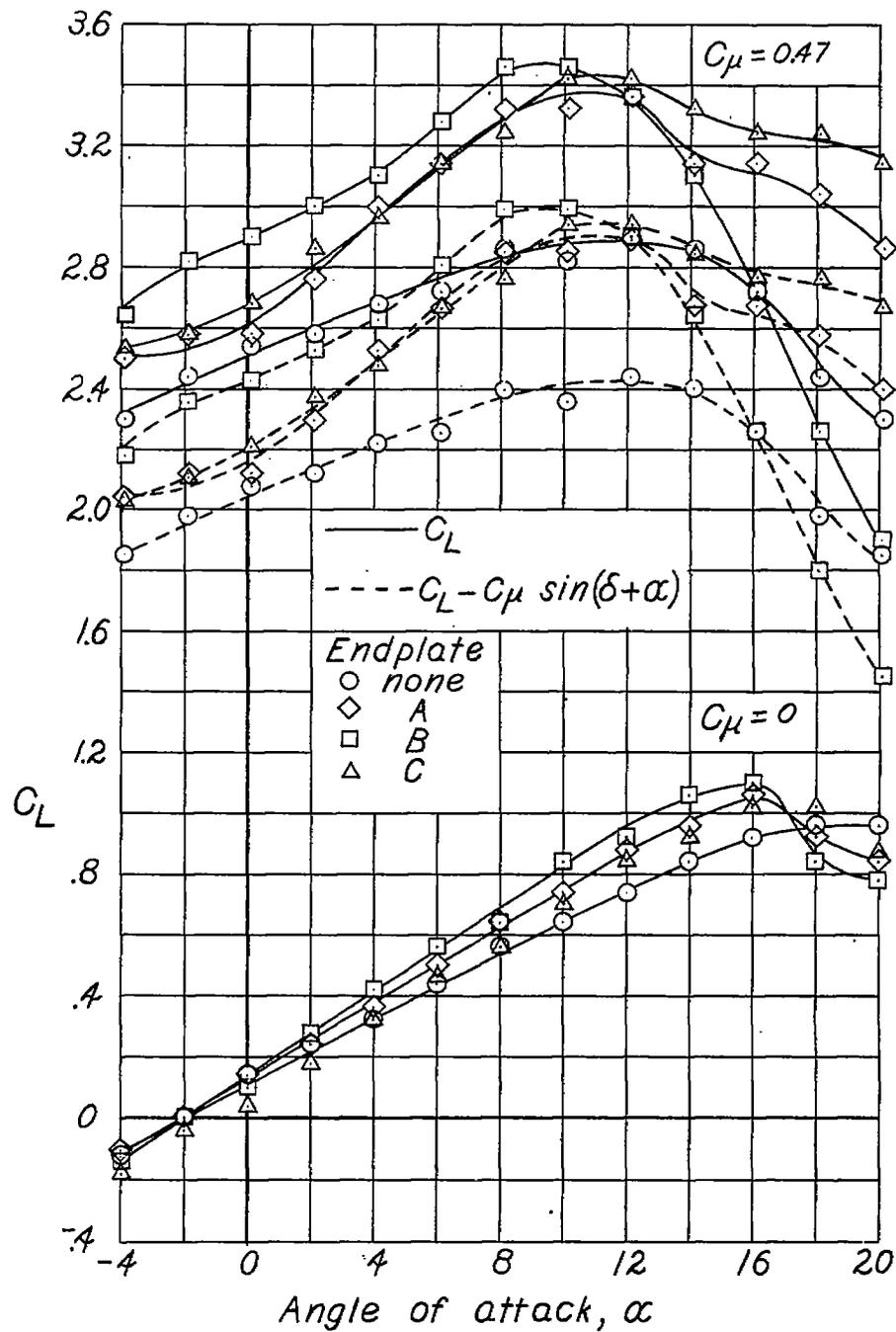
(a) Aspect ratio, 8.4; without end plates.

Figure 6.- Variation of lift coefficient with angle of attack with and without the jet flap.



(b) Aspect ratio, 5.6; with and without end plates.

Figure 6.- Continued.



(c) Aspect ratio, 2.8; with and without end plates.

Figure 6.- Concluded.

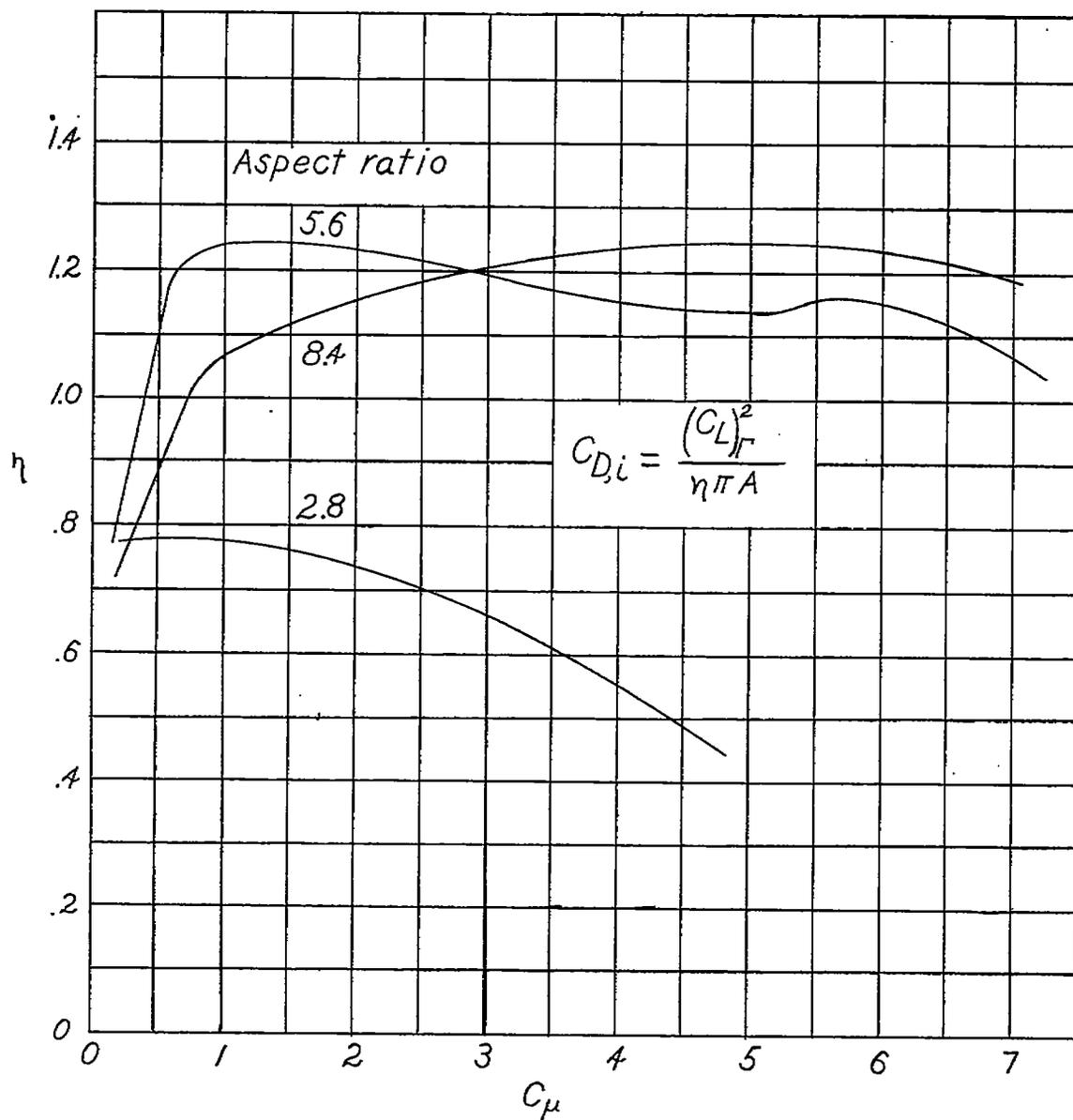


Figure 7.- Variation with momentum coefficient of the wing efficiency factor of the induced-drag equation. Without end plates.

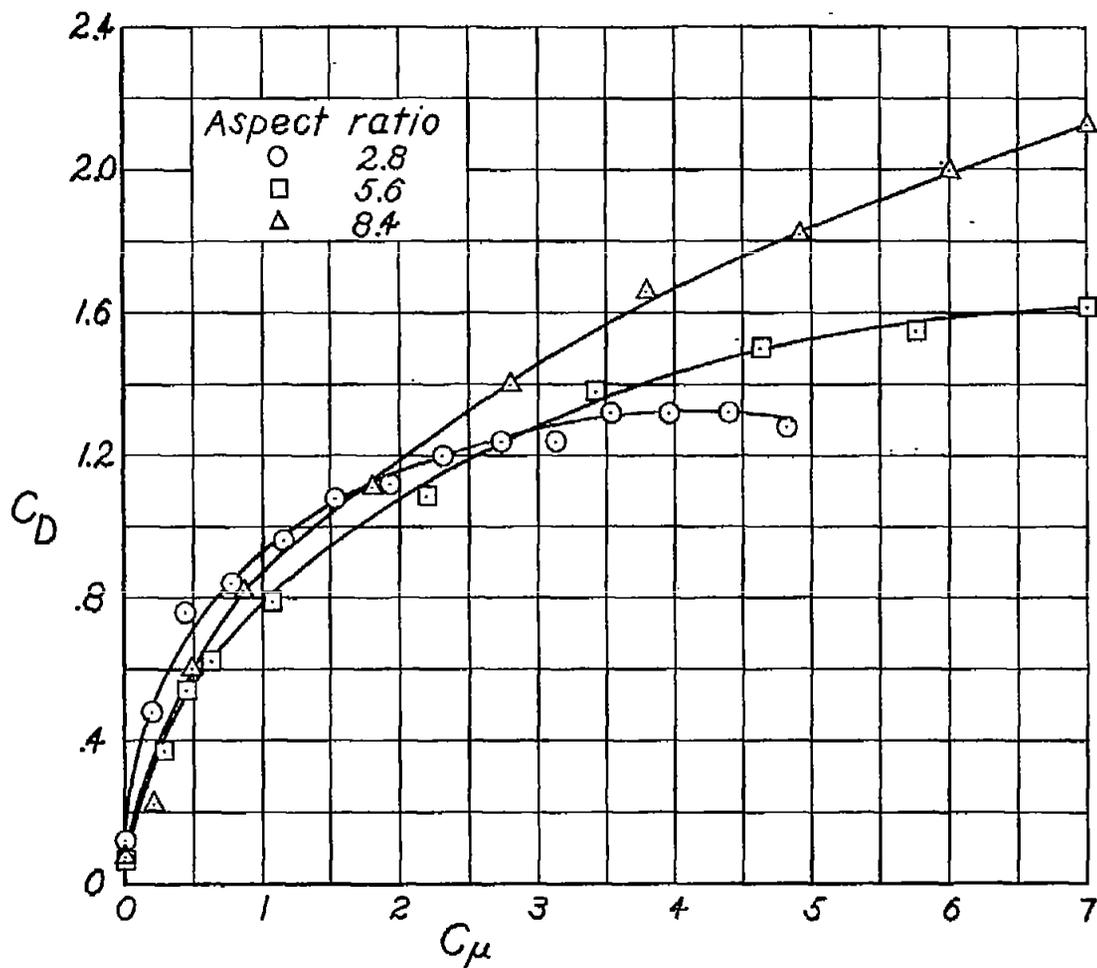


Figure 8.- Effect of aspect ratio on the variation of drag coefficient with momentum coefficient. $\alpha = 0^{\circ}$.

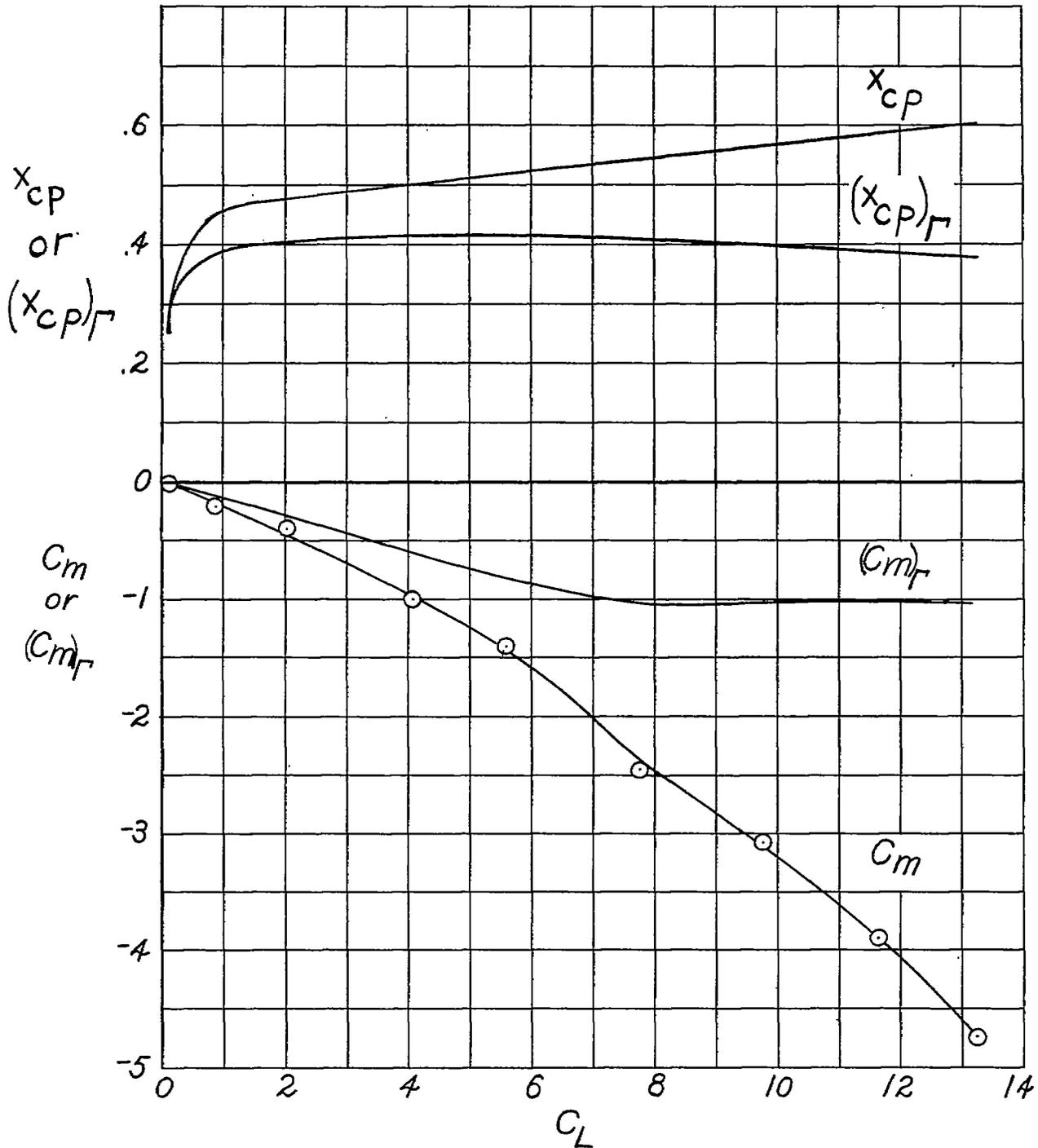


Figure 9.- Variation of pitching-moment coefficient and center of pressure with lift coefficient for a momentum coefficient range from 0 to 4.92. Aspect ratio, 8.4; $\alpha = 0^\circ$; without end plates.