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THE SUBSONIC STATIC AERODYNAMIC CHARACTERISTICS OF AN AIRPLANE MODEL HAVING A TRIANGULAR WING OF ASPECT RATIO 3. III - EFFECTS OF TRAILING-EDGE FLAPS

By Bruce E. Tinling and A. V. Karpen

Ames Aeronautical Laboratory
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Washington
July 1957

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THE SUBSONIC STATIC AERODYNAMIC CHARACTERISTICS OF AN AIRPLANE MODEL HAVING A TRIANGULAR WING OF ASPECT RATIO 3. III - EFFECTS OF TRAILING-EDGE FLAPS[1]

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SUMMARY

A wind-tunnel investigation has been conducted to determine the low-speed aerodynamic characteristics of an airplane arrangement having an unswept horizontal tail and a triangular wing of aspect ratio 3 equipped with partial-span single-slotted flaps and plain ailerons. The effects of flap deflection on the longitudinal characteristics were investigated for tail positions either in or 10 percent of the wing semispan below the wing-chord plane. The rolling moment produced by the ailerons when the flaps were deflected was measured as well as the rolling moment produced by differential deflection of the horizontal-tail surfaces. The effects of small positive flap deflections on the longitudinal characteristics at Mach numbers up to 0.95 were also investigated. Most of the data were obtained at a Reynolds number of 2.5×10^6.

Satisfactory longitudinal stability up to a lift coefficient of 1.35 was attained only when the tail was below the wing-chord plane. The ailerons were ineffective for lift coefficients greater than about 1.0 when the flaps were deflected; however, adequate rolling effectiveness in this lift-coefficient range was attained by differential deflection of the horizontal tail. At Mach numbers up to 0.93, a flap deflection of 5° improved the lift-drag ratio for the balanced condition by roughly 10 percent at lift coefficients greater than 0.3.

INTRODUCTION

The aerodynamic characteristics of a model of an airplane having a triangular wing of aspect ratio 3 and an all-movable tail have been the subject of an investigation in the Ames 12-foot pressure wind tunnel. Results of parts of this investigation pertaining to the effects of horizontal-tail position and size and to the lateral and directional characteristics are reported in references 1 and 2. Ground effects on the longitudinal characteristics are reported in reference 3.

[1]Supersedes recently declassified NACA RM A54L07 by Bruce E. Tinling and A. V. Karpen, 1955.

The present part of the investigation was conducted to investigate the feasibility of using single-slotted flaps to improve the landing and take-off performance and of using small deflections of either partial or full-span flaps to improve the lift-drag ratio at Mach numbers up to 0.95. A limited number of data were also obtained to evaluate the effectiveness of trailing-edge ailerons and of differential deflection of the horizontal tail as lateral-control devices when the slotted flaps were deflected.

NOTATION

The positive direction of all forces, moments, and control surface deflections is indicated in figure 1.

A aspect ratio, $\frac{b^2}{S}$

b wing span

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

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

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

C_l rolling-moment coefficient, $\frac{\text{rolling moment}}{qSb}$

C_l' rolling-moment coefficient about the fuselage center line

C_n yawing-moment coefficient, $\frac{\text{yawing moment}}{qSb}$

C_Y side-force coefficient, $\frac{\text{side force}}{qS}$

c wing chord measured parallel to the plane of symmetry

c_r root chord measured parallel to the plane of symmetry

$\bar{c}$ wing mean aerodynamic chord

i_t incidence of the horizontal tail with respect to the wing-chord plane, deg

l_t tail length, longitudinal distance from the moment center to the horizontal-tail pivot line

M free-stream Mach number

p rolling velocity, radians per sec

q free-stream dynamic pressure

R Reynolds number, based on the wing mean aerodynamic chord

S area of the wing

t' wing thickness at the leading edge of the flap

x,y,z orthogonal system of coordinates with the x axis coinciding with the fuselage center line

$\frac{z'}{b/2}$ vertical distance from the wing-chord plane to the hinge axis of the horizontal tail, expressed as a fraction of the wing semispan

α angle of attack, deg

δ_a aileron angle, deg

δ_f flap deflection, deg

ϵ effective downwash angle, deg

$\Delta\delta_a$ difference between the deflection of the right and left ailerons, positive to induce a positive rolling moment

Δi_t difference between the incidence of the right and left panels of the horizontal tail, positive to induce a positive rolling moment

MODEL

The wing of the model tested during the investigation reported in reference 1 was modified to provide for single-slotted flaps and for ailerons. (See fig. 2,) The flap area was 11.1 percent of the wing area. As illustrated in figure 2(b), the flap slot remained closed for deflections up to 10°. The ailerons, which were plain flaps with unsealed radius noses, had an area equal to 6.7 percent of the total wing area. Both the ailerons and the flaps were supported by external brackets.

As illustrated in figure 2, the wing could be placed either on or 10 percent of the wing semispan above the fuselage center line. An unswept horizontal tail was located on the fuselage center line either 1.2 or 1.5 mean aerodynamic chord lengths behind the moment center. The area of the horizontal tail was 21.9 percent of the wing area. Further pertinent geometric details of the model can be found in figure 2 and in tables I and II.

Photographs showing the method of mounting the flaps and the method of supporting the model in the tunnel are presented in figure 3. A 4-inch-diameter, four-component strain-gage balance enclosed within the model body was used to measure the forces and moments. This balance was rotated 90° in order to measure side force and yawing moment.

CORRECTIONS TO DATA

The data have been corrected for the induced effects of the tunnel walls resulting from lift on the model by the method of reference 4. The magnitudes of the corrections which were added to the measured values are:

$$\Delta\alpha = 0.30\ C_L$$

$$\Delta C_D = 0.0045\ C_L^2$$

The induced effects of the tunnel walls on both the tail-on and tail-off pitching moments were calculated and found to be negligible.

Corrections to the data to account for the effects of constriction due to the tunnel walls were calculated by the method of reference 5. At a Mach number of 0.90, this correction amounted to an increase of about 1 percent in the dynamic pressure.

The effect of interference between the model and the sting support which could influence the measured forces and moments, particularly those due to the horizontal tail, is not known. It is believed that the main effect of the sting on the drag was to alter the pressure at the base of the model body. The pressure at the base of the model was measured and the drag data were adjusted to correspond to a base pressure equal to the free-stream static pressure.

RESULTS AND DISCUSSION

The moment center for each configuration was chosen to be identical to that selected for the analysis of the data in reference 1. (See table II.) The static margin with the flaps neutral, then, was 6 percent of the mean aerodynamic chord ($dC_m/dC_L = -0.06$) at a Mach number of 0.25 with zero lift and zero tail incidence for each combination of tail length and height.

Effects of Single-Slotted Flaps

Before discussing the results of the tests of the single-slotted flaps, it should be emphasized that the primary objective was to find the

effect of high-lift flaps on the longitudinal aerodynamic characteristics and not to find the flap location and angle for which the greatest lift increment could be attained. The flap setting for which the greatest increment in lift was attained, therefore, does not necessarily represent the optimum; however, the static longitudinal stability for a given flap deflection is believed to be representative of that which would exist despite minor changes in flap position to obtain the maximum lift increment.

Horizontal tail off.- The effect of the single-slotted flaps on the tail-off aerodynamic characteristics is shown in figure 4. With the ailerons neutral, and with the flaps deflected 40°, an increment of lift coefficient of about 0.55 was attained at angles of attack up to about 10°. A symmetrical deflection of the ailerons to 40° provided a further increment of lift coefficient of about 0.10. Further deflection of the flaps to 50° with the ailerons neutral (fig. 4) resulted in a reduced increment of lift. Moving the wing from the high to the mid position caused negligible changes in the lift increment due to flap deflection. (Compare data presented in figs. 4 and 5 for $\delta_f = 40^{\circ}$; $\delta_a = 0^{\circ}$, and $R = 2.5 \times 10^6$.)

Additional tests, for which no data are presented, were conducted with the flap nose in another position relative to the slot lip. This position was obtained by removing shims from between the flaps and the flap brackets. The thickness of the shims was 35 percent of the wing thickness at the leading edge of the flap. Thus, this position of the flap nose was farther forward than that illustrated in figure 2(b) and the gap was somewhat greater. This change in slot geometry did not alter the lift increment attained with 30° of deflection. A decrease in lift, however, accompanied further deflection of the flaps to 40°.

Deflection of the flaps, as would be anticipated, resulted in large reductions in drag at the higher lift coefficients and in a large nose-down increment in pitching moment. (See fig. 4.)

The effects of Reynolds number on the longitudinal characteristics with the flaps deflected 40° are illustrated in figure 5. An increase in the Reynolds number to 10 million resulted in small increases in the lift coefficient at the higher angles of attack, small reductions in the drag due to lift, and small increases in the nose-down pitching-moment coefficient.

Horizontal tail on.- The effect of deflection of the slotted flaps on the longitudinal stability when the horizontal tail was in the plane of symmetry is illustrated in figure 6. These data show deflection of the flaps to be destabilizing for lift coefficients between approximately 0.5 and 1.0. Subsequent data (fig. 7) illustrate that the horizontal tail was not stalled in this lift-coefficient range when the tail incidence was either 0.2° or 4.2°. The instability, therefore, must have been caused by the variation of downwash and dynamic pressure at the tail with angle of attack. The variation of pitching moment with lift for the flaps-down

case resembles closely the variation shown for the higher tail positions in reference 1 for the flaps-neutral case. It would seem likely, therefore, that the displacement of the downwash field by the flaps resulted in an unfavorable downwash variation with angle of attack similar to that encountered for the higher tail positions with the flaps neutral.

This instability was not encountered during the tests reported in reference 6 of an almost identical configuration which had nearly the same variation of lift coefficient with flap deflection. The models differed principally in that the model discussed in reference 6 had a wing thickness-chord ratio of 5 percent instead of 3-1/2 percent and had a greater flap span. The ratio of flap area to wing area was nearly the same for both models. It is believed that the change in flap plan form was the primary cause of the difference in test results. The procedure outlined in reference 6 was utilized to calculate the downwash from the results of the present investigation. In making the estimation of downwash for low angles of attack, it was necessary to predict the points of intersection of the tail-off pitching-moment curve with the tail-on pitching-moment curve for tail incidences greater than 4.2°. Stalling of the horizontal tail as the tail incidence was varied from 4.2° to -3.9° made the evaluation of dC_m/di_t needed in this prediction uncertain. It was assumed for the purpose of estimating the downwash, therefore, that the tail effectiveness was the same as when the flaps were neutral, $dC_m/di_t = -0.014$. The downwash variation with angle of attack calculated in this fashion is compared with the results of reference 6 in figure 8. It is obvious that the downwash at the tail of the model with the smaller flap span was considerably greater. This resulted in the tail height with respect to the wing wake being greater for the model of the present investigation. The destabilizing change in $d\epsilon/d\alpha$ at an angle of attack of about 4° for the model of the present investigation is evident, $z'/(b/2) = 0$.

When the wing was raised 0.10 wing semispan, a stabilizing change in $d\epsilon/d\alpha$ occurred as the angle of attack was increased beyond 4°. (See results for $z'/(b/2) = -0.10$ in fig. 8.) The longitudinal characteristics with the flaps down for this wing position are presented in figure 9. At low angles of attack, the nose-down pitching moment caused by a flap deflection of 40° was only slightly less than the maximum balancing pitching moment which could be developed by the horizontal tail at the longer tail length. (See fig. 9(a).) A similar situation existed for the shorter tail length (fig. 9(b)), except that the nose-down pitching moment caused by a flap deflection of only 30° was the maximum which could be balanced without stalling the horizontal tail. The data in figure 9 have been used to calculate the lift and drag for balance and are compared in figures 10 and 11 with similar calculations for the flaps neutral. For the longer tail length, a flap deflection of 40° increased the lift coefficient at balance by about 0.5 at moderate angles of attack, thereby reducing the angle of attack required to attain a given lift by about 8°. The maximum lift coefficient for this flap deflection was about 1.35 and was attained at an angle of attack of 23°. As previously noted, the flap deflection was limited to 30° for the shorter tail length. In this instance,

deflection of the flaps produced a lift increment of about 0.3 at moderate angles of attack, thereby allowing a reduction in angle of attack of about 6° to attain a given lift. The maximum lift coefficient for this flap deflection was only slightly less than that attained with a flap deflection of 40°.

Lateral Control Effectiveness With the Flaps Down

Trailing-edge ailerons.- The effectiveness of differential deflection of the trailing-edge ailerons in providing lateral control is shown in figure 12. It is immediately apparent from these data that the ailerons were ineffective in the lift-coefficient range which would probably be of interest with flaps down.

Horizontal tail as a lateral-control device.- The effectiveness of differential deflection of the two halves of the horizontal tail as a means of lateral control is illustrated in figure 13. At the balanced condition ($C_L \approx 1.2$ and 1.35), the horizontal tail was effective in producing a rolling-moment coefficient of about -0.015 for a differential deflection of -23.9°. The wing-tip helix angle $pb/2V$ resulting from this rolling-moment coefficient is estimated to be about 0.075 which is considered sufficient to provide adequate lateral control. (See ref. 7.) The damping in roll used in making this estimation was calculated by the method of reference 8. A large favorable yawing moment accompanied use of the horizontal tail as a lateral-control device, undoubtedly resulting from forces induced on the vertical fin. For the two average tail incidences for which lateral-control data were obtained, there was no change in the lift coefficient at which balance occurred due to differential deflection of the horizontal tail.

At lift coefficients greater than about 1.0, where adequate rolling effectiveness was attained, less than one-half of the pitching moment capacity of the horizontal tail was required to balance the model. At lower lift coefficients, the tail load required to balance the model approached the maximum which can be supplied by a horizontal tail of this size. (See fig. 9(a).) Use of the horizontal tail as a lateral control in this instance would surely result in stalling of the surface carrying the greater download. It is apparent, therefore, that the tail volume must be increased if adequate rolling moments are to be developed without impairing the longitudinal control at lift coefficients less than about 1.0 when the flaps are deflected 40°.

Effect of Small Flap Deflections at Mach Numbers Up to 0.95

As illustrated in figure 2(b), the flap was constructed so that the slot remained closed for deflections up to 10°. Tests were conducted at Mach numbers up to 0.95 to determine if deflection of the flap in this

manner would improve the lift-drag ratio. Tests were also conducted with both the ailerons and the flaps deflected 5° so as to simulate a full-span flap.

Tail-off characteristics.- The results of tests with the tail off (fig. 14) showed that deflecting the flap 5° afforded a greater improvement in the maximum lift-drag ratio than a deflection of 10° at Mach numbers greater than 0.60, and also caused a smaller nose-down increment in pitching moment. Symmetrical deflection of 5° of the ailerons as well as the flaps provided very little additional improvement in the lift-drag ratio at any Mach number and resulted in a greater nose-down increment of pitching moment.

Tail-on characteristics.- From the results of the tests with the tail off it was apparent that 5° of flap deflection offered the best possibility of improving the lift-drag ratio for the balanced condition since, in general, it provided the greatest improvement in lift-drag ratio and caused the smallest nose-down increment in pitching moment. The lift and pitching-moment data from tests with this flap deflection with the tail on are presented in figure 15. Comparison of these results with those presented in reference 1 for the flaps neutral indicates that deflection of the flaps 5° had no deleterious effects on the longitudinal stability of the model. The effect of this flap deflection on the lift-drag ratio for the balanced condition is shown in figure 16. The lift-drag ratios for the flaps-neutral case were calculated by applying the decrement in lift-drag ratio due to the tail at the incidence required for balance, as evaluated from the data in reference 1, to the lift-drag ratio obtained with the tail off and with the flaps neutral during the present investigation. In this fashion, account was taken of the drag of the flap and aileron brackets and the effect of any change in wing surface conditions. Comparison of these results with those for 5° of flap deflection indicates that deflection of the flap resulted in a significant improvement in the lift-drag ratio at lift coefficients greater than about 0.3 for Mach numbers up to about 0.93. Although the improvement in the lift-drag ratio was in no instance greater than about 1, the percentage improvement at lift coefficients from about 0.4 to 0.7 was as much as 10 percent.

CONCLUDING REMARKS

The present wind-tunnel investigation has evaluated the effects of single-slotted flaps on the aerodynamic characteristics of an airplane configuration having a thin triangular wing of aspect ratio 3. The results of low-speed tests indicate that 30° or 40° deflection of the flaps was destabilizing when the horizontal tail was in the wing-chord plane. Satisfactory longitudinal stability was obtained with these flap deflections when the tail was 0.10 wing semispan below the wing-chord plane. The increment of lift coefficient at the balanced condition

attainable with a flap deflection of 40° was about 0.50 at low angles of attack and about 0.24 at an angle of attack of 22°, resulting in a maximum lift coefficient of about 1.35.

Trailing-edge ailerons were found to be ineffective at lift coefficients greater than about 1.0 when the flaps were deflected 40°; however, differential deflection of the all-movable horizontal tail provided adequate lateral control in this lift-coefficient range.

A flap deflection of 5°, with the slot closed, improved the lift-drag ratio for the balanced condition at lift coefficients greater than about 0.3 at Mach numbers up to about 0.93.

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, Calif., Dec. 7, 1954

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2. Savage, Howard F., and Tinling, Bruce E.: The Subsonic Static Aerodynamic Characteristics of an Airplane Model Having a Triangular Wing of Aspect Ratio 3. II - Lateral and Directional Characteristics. NACA TN 4042, 1957. (Supersedes NACA RM A55B11)

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4. Sivells, James C., and Salmi, Rachel M.: Jet-Boundary Corrections for Complete and Semispan Swept Wings in Closed Circular Wind Tunnels. NACA TN 2454, 1951.

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7. Gilruth, R. R.: Requirements for Satisfactory Flying Qualities of Airplanes. NACA Rep. 755, 1943.

8. Campbell, John P., and McKinney, Marion O.: Summary of Methods for Calculating Dynamic Lateral Stability and Response and for Estimating Lateral Stability Derivatives. NACA TN 2409, 1951.

TABLE I.- GEOMETRIC PROPERTIES OF THE MODEL

Wing	
Aspect ratio	3.00
Taper ratio	0
Section	NACA 0003.5-63
Area, sq ft	4.000
Mean aerodynamic chord, ft	1.540
Span, ft	3.463
Leading-edge sweepback, deg	53.13
Slotted, trailing-edge flaps	
Chord, ft	0.292
Area, fraction of total wing area	0.111
Span, fraction of wing span	0.584
Ailerons	
Chord, ft	0.208
Area, fraction of total wing area	0.067
Horizontal tail	
Aspect ratio	4.00
Taper ratio	0.33
Section	NACA 0004-64
Area, sq ft	0.876
Span, ft	1.868
Pivot line	$0.45c_r$
Vertical tail (leading and trailing edges extended to fuselage center line)	
Aspect ratio (geometric)	1.5
Taper ratio	0.16
Section	NACA 0003.5-64
Area, sq ft	1.067
Span, ft	1.269
Leading-edge sweepback, deg	54.0
Fuselage	
Fineness ratio	
Short fuselage	10.9
Long fuselage	12.0

TABLE I.- GEOMETRIC PROPERTIES OF THE MODEL - Concluded

Fuselage (Continued)

Base Area, sq ft 0.1302

Coordinates[1] (long fuselage):

Distance from nose, in.	Radius, in.
0	0
5.00	.80
10.00	1.44
15.00	1.94
20.00	2.32
25.00	2.60
30.00	2.79
35.00	2.90
40.00	2.97
45.00	2.99
51.25	3.00
57.75	3.00
61.75	2.99
65.75	2.90
69.75	2.67
72.00	2.44

[1]Removable section from 51.25 to 57.75 inches from nose.

TABLE II.- MOMENT CENTERS AND TAIL LENGTHS

Tail height, $z'/(b/2)$	Moment center	Tail length, $l_t/\bar{c}$
-0.10	$0.415\bar{c}$	1.460
-.10	$.372\bar{c}$	1.153
0	$.375\bar{c}$	1.500

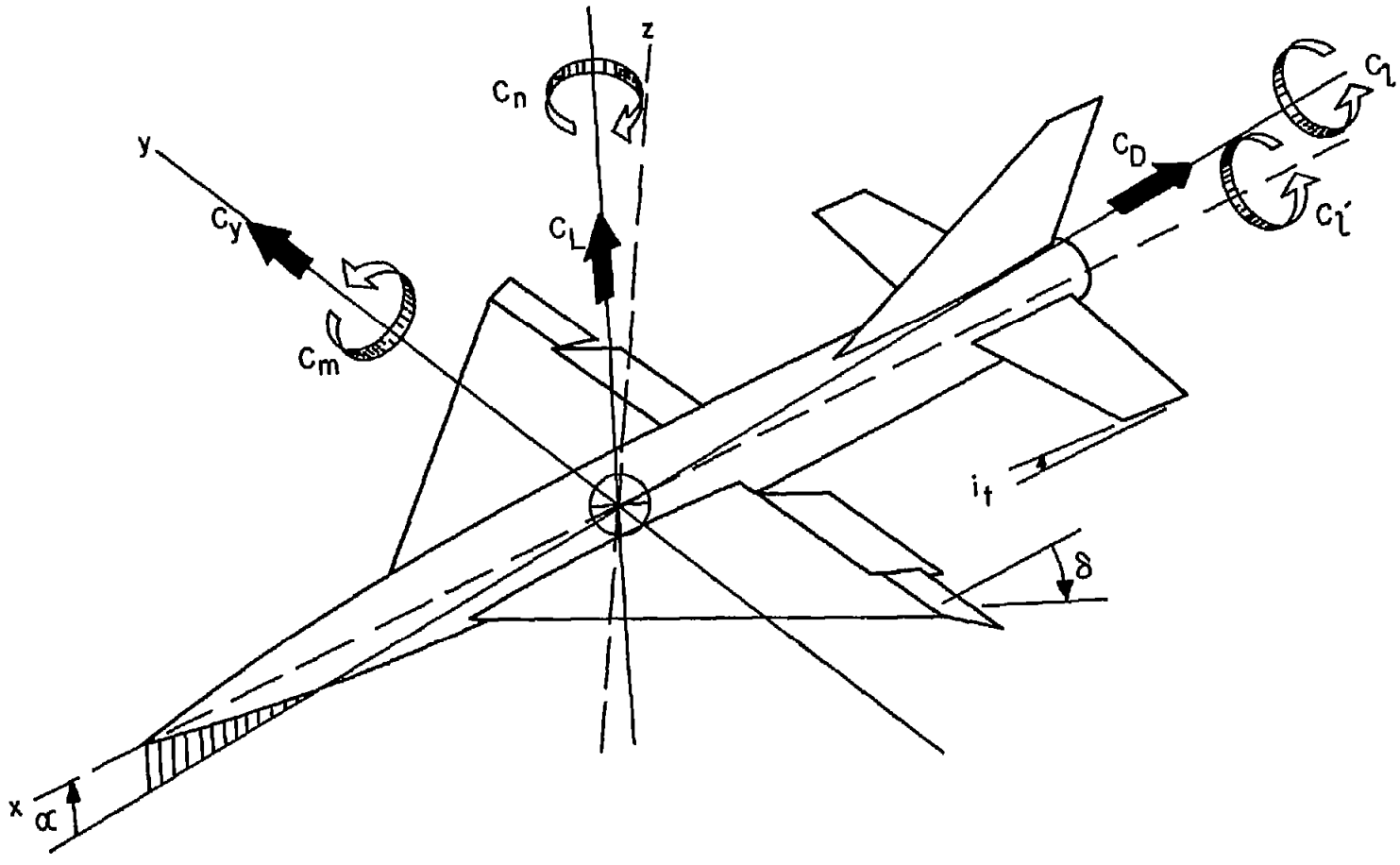
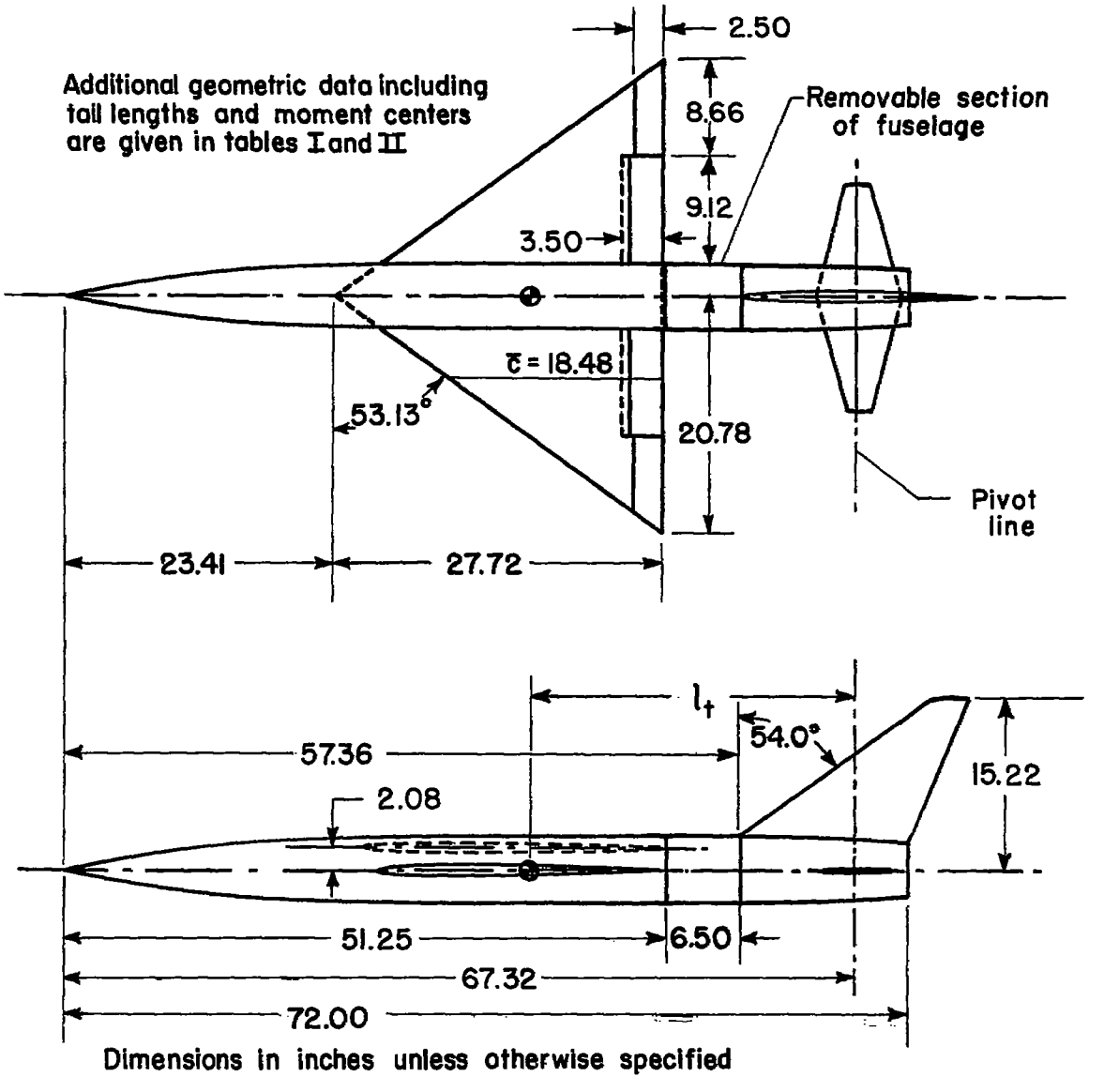
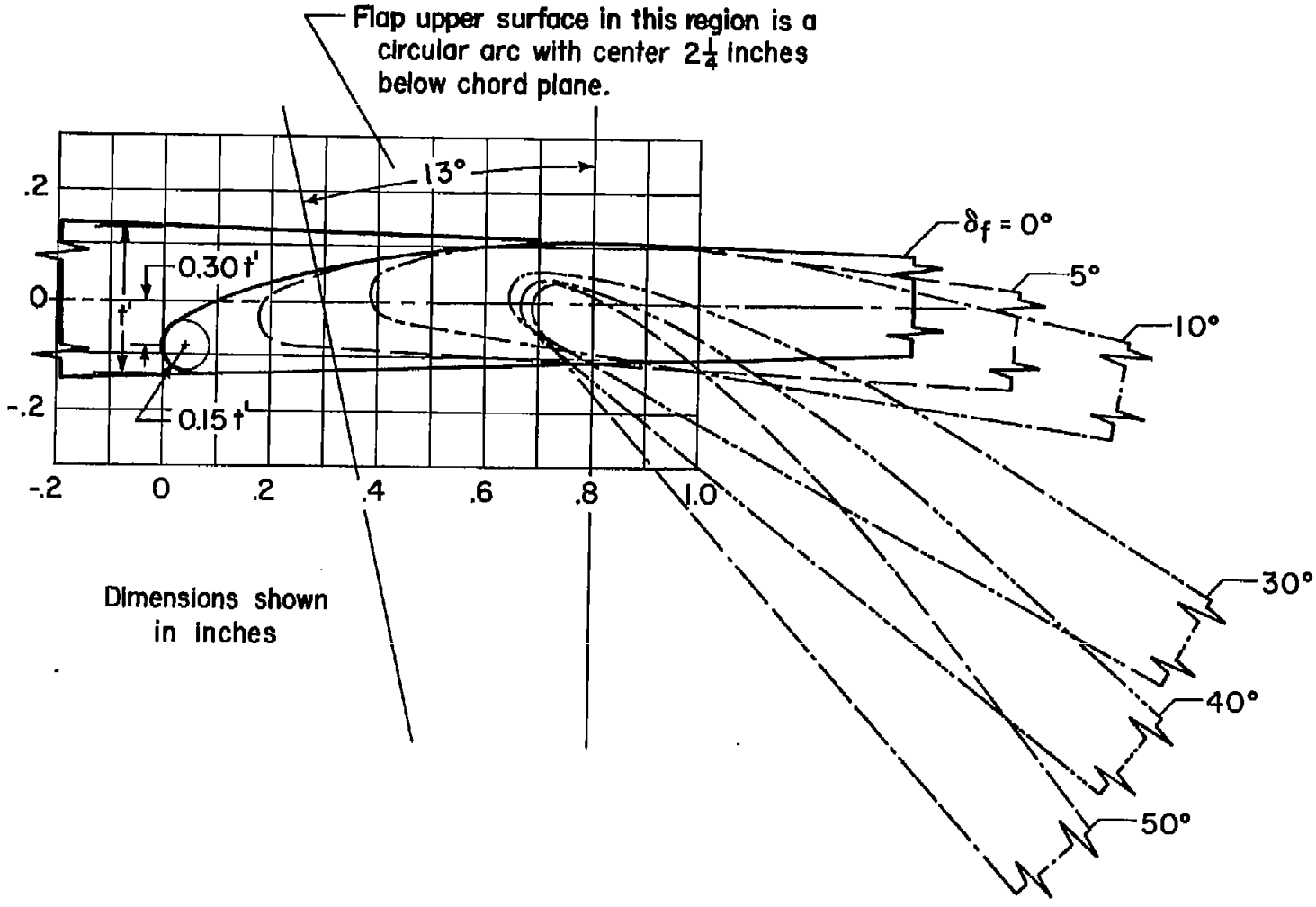


Figure 1.- The sign convention used in presentation of the data. All force and moment coefficients, and control-surface deflections shown are positive.



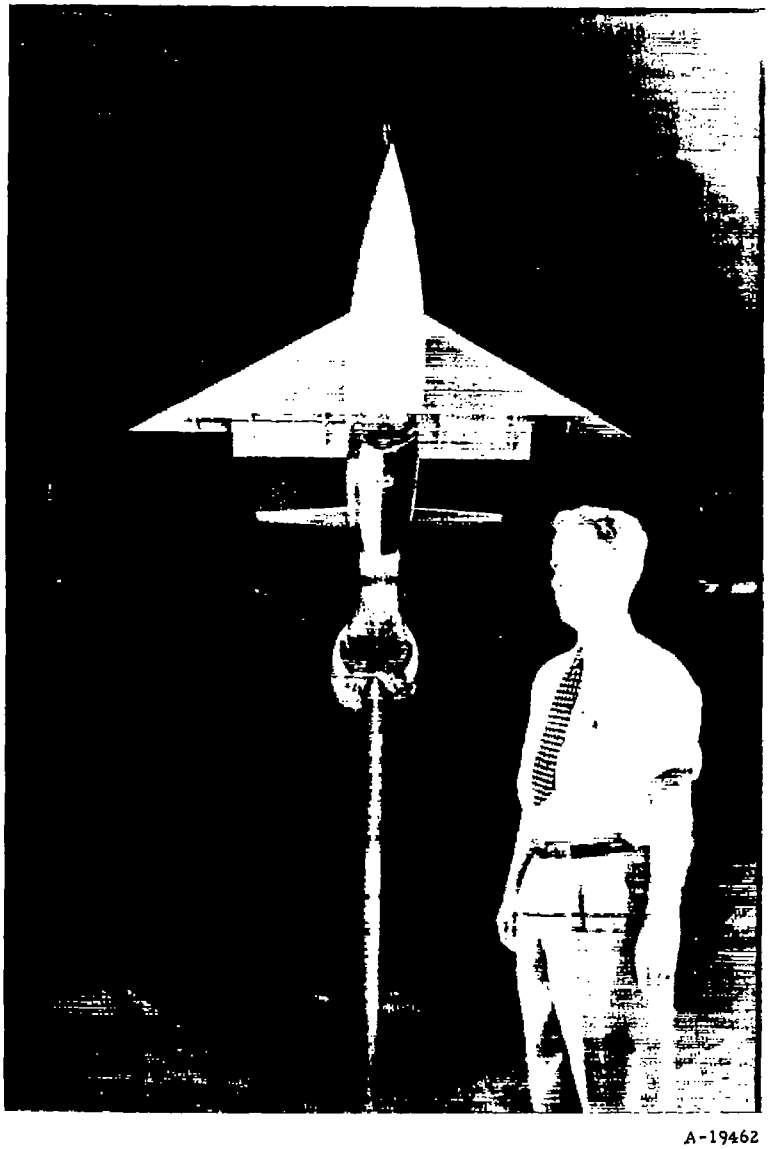
(a) Pertinent dimensions.

Figure 2.- Geometry of the model.



(b) Slot geometry.

Figure 2.- Concluded.



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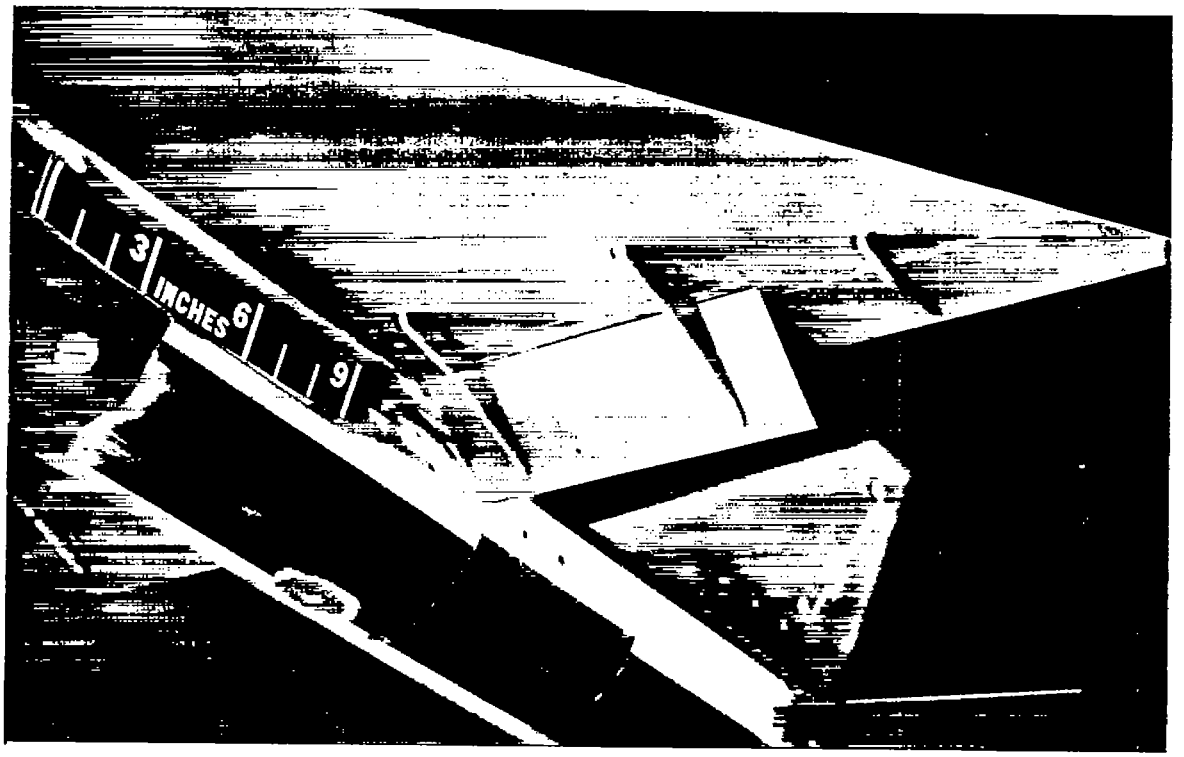
(a) Front view.

Figure 3.- The model, with the slotted flaps deflected 40°, mounted in the Ames 12-foot pressure wind tunnel.



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(b) Detail of the slotted flap and aileron.

Figure 3.- Concluded.

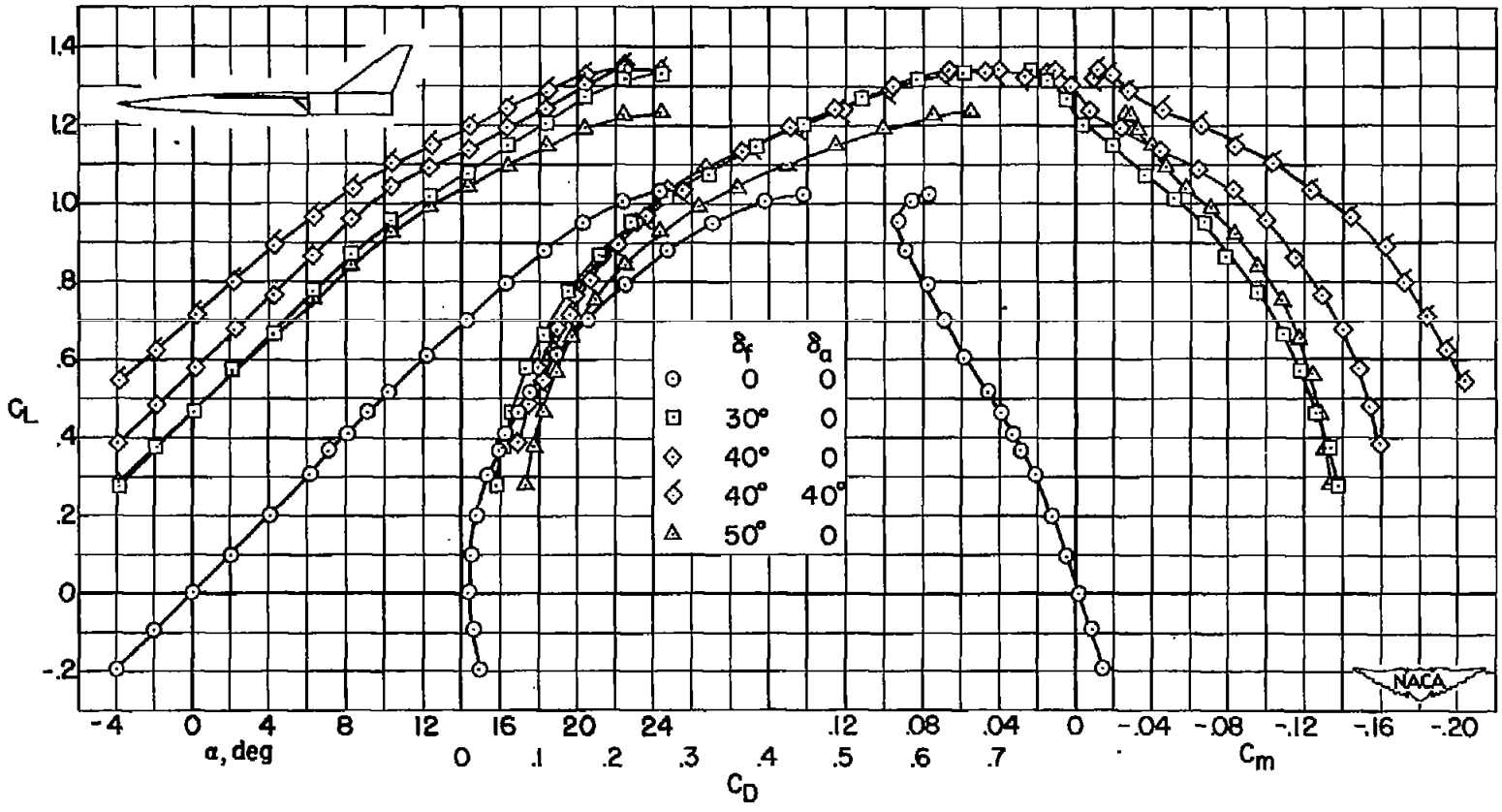


Figure 4.- The effect of flap deflection on the aerodynamic characteristics of the wing-fuselage combination; high wing; moment center at $0.415\bar{c}$; M = 0.25; R = 2.5×10^6.

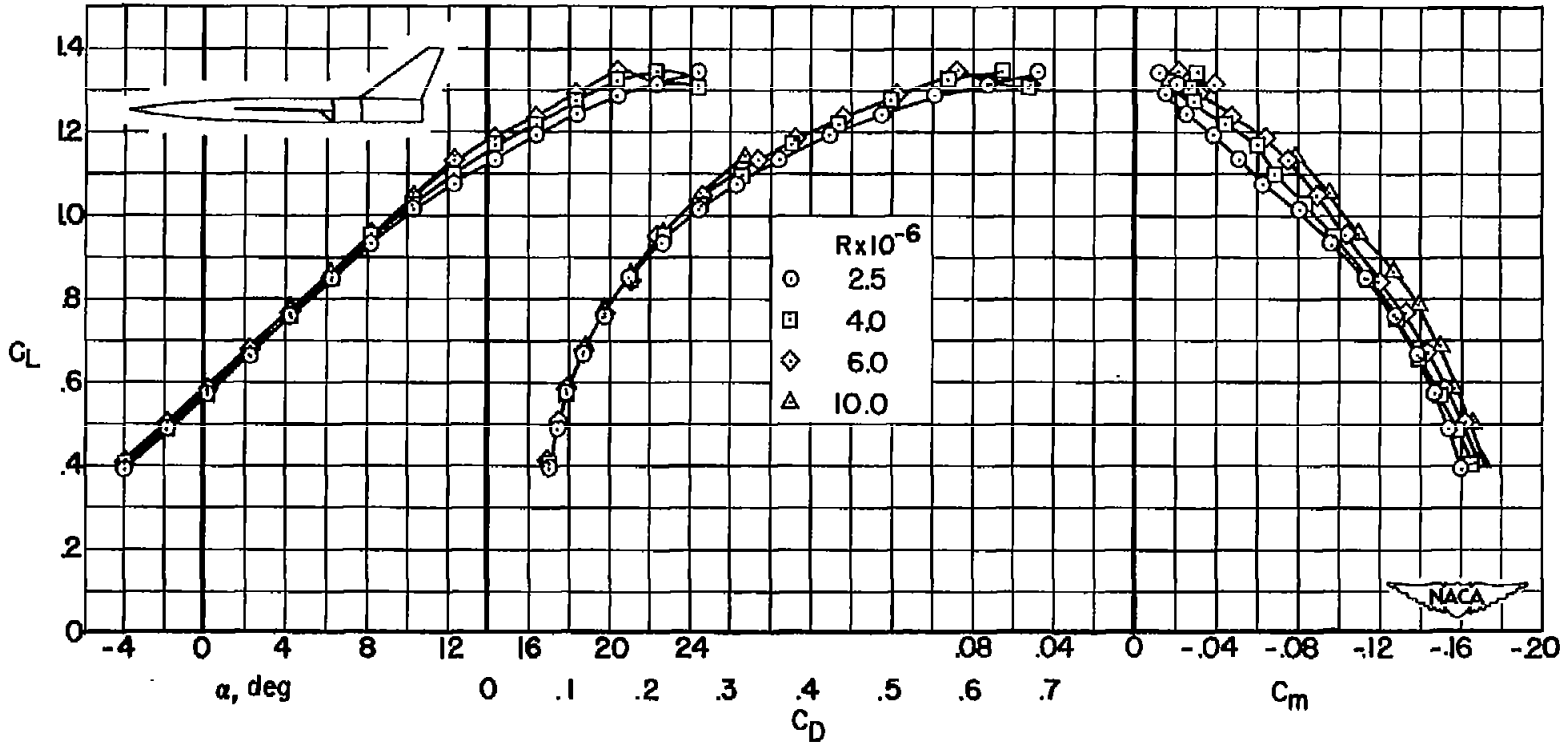


Figure 5.- The effect of Reynolds number on the aerodynamic characteristics of the wing-fuselage combination with the slotted flaps deflected 40°; mid wing; moment center at 0.415$\bar{c}$; M = 0.25.

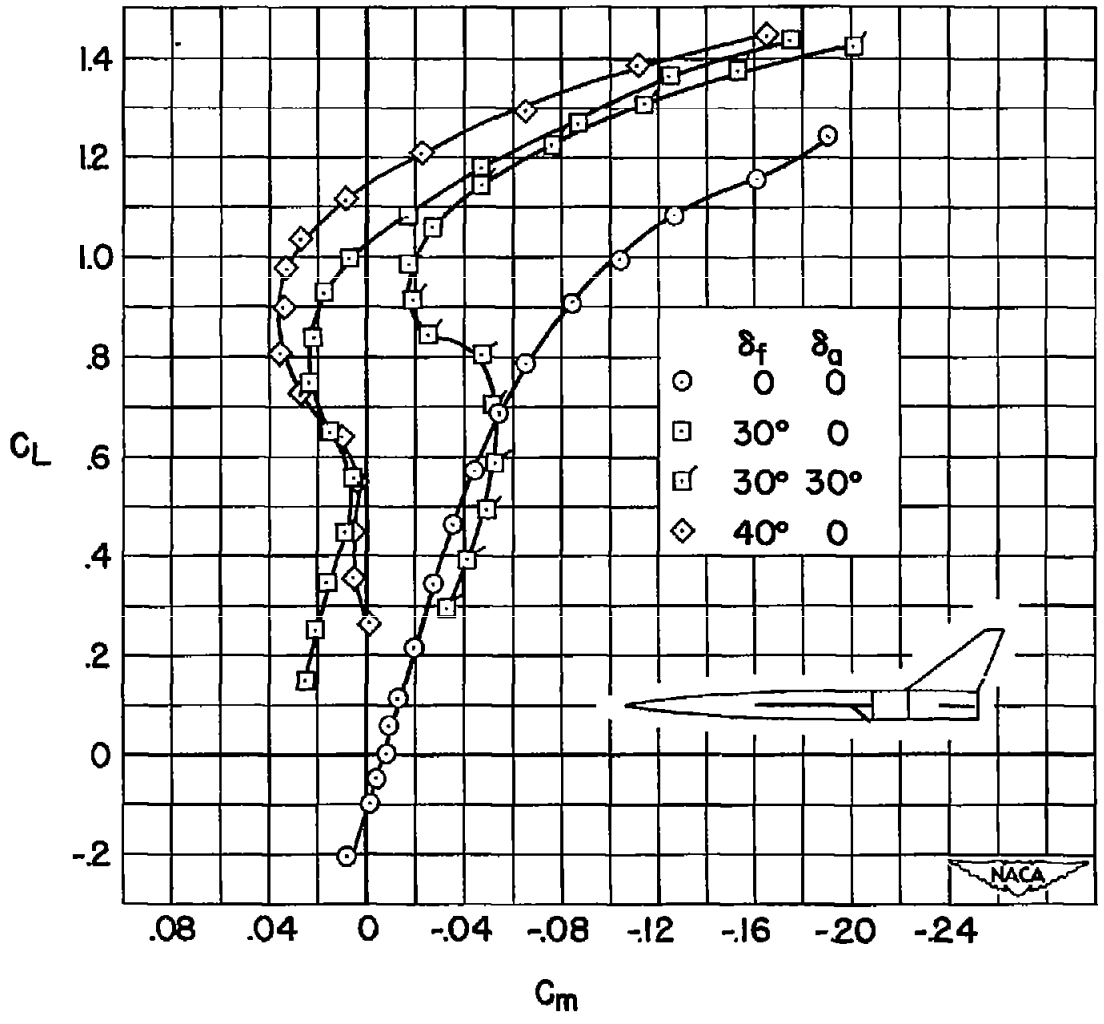
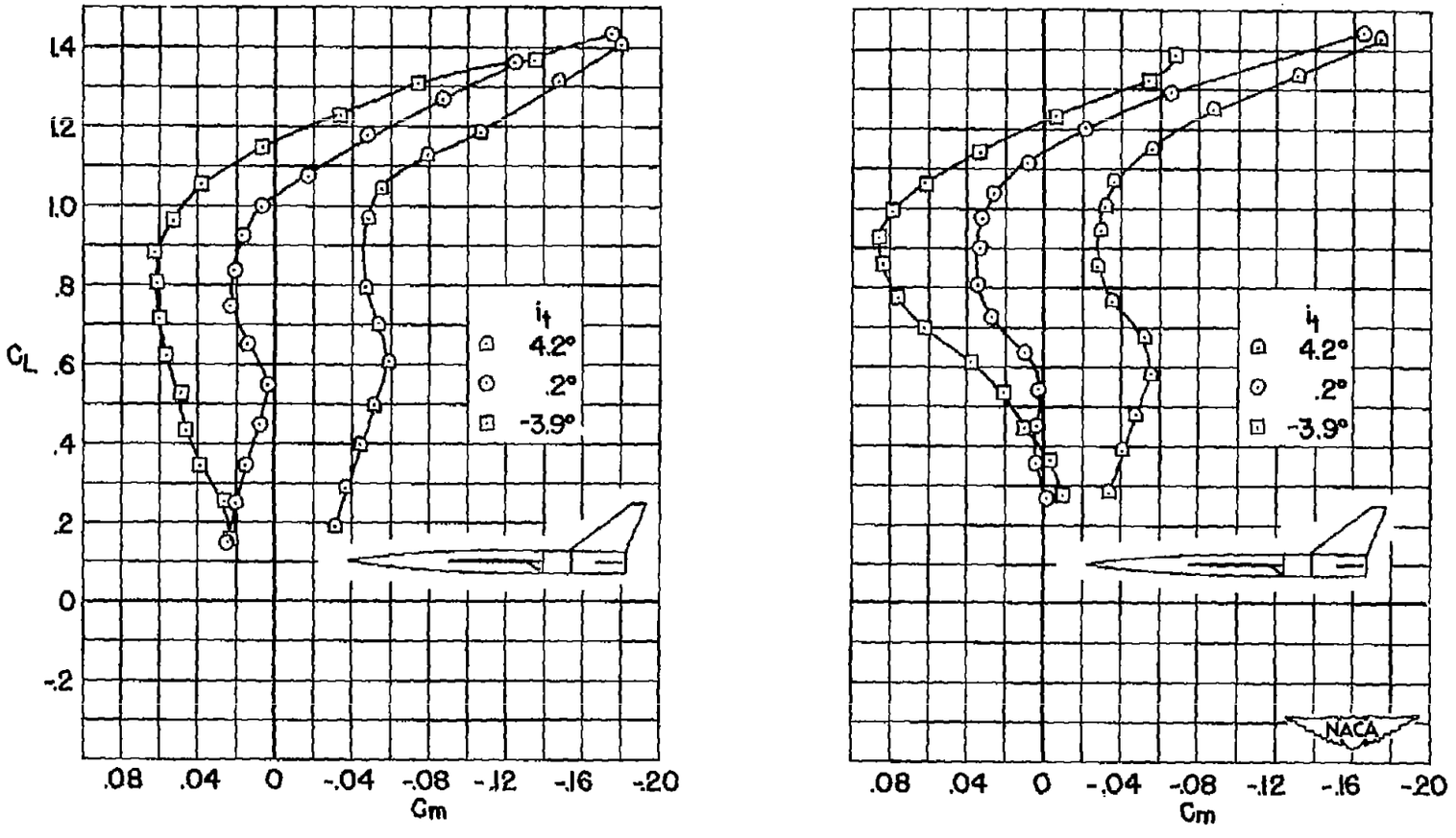


Figure 6.- The effect of flap deflection on the static longitudinal stability when the horizontal tail is in the wing-chord plane; $l_t/\bar{c} = 1.500$; $i_t = 0^{\circ}$; $M = 0.25$; $R = 2.5 \times 10^6$.



(a) $\delta_f = 30^\circ$

(b) $\delta_f = 40^\circ$

Figure 7.- The variation of pitching-moment coefficient with lift coefficient for several values of tail incidence when the horizontal tail is in the wing-chord plane; $l_t/\bar{c} = 1.500$; $M = 0.25$; $R = 2.5\times10^8$.

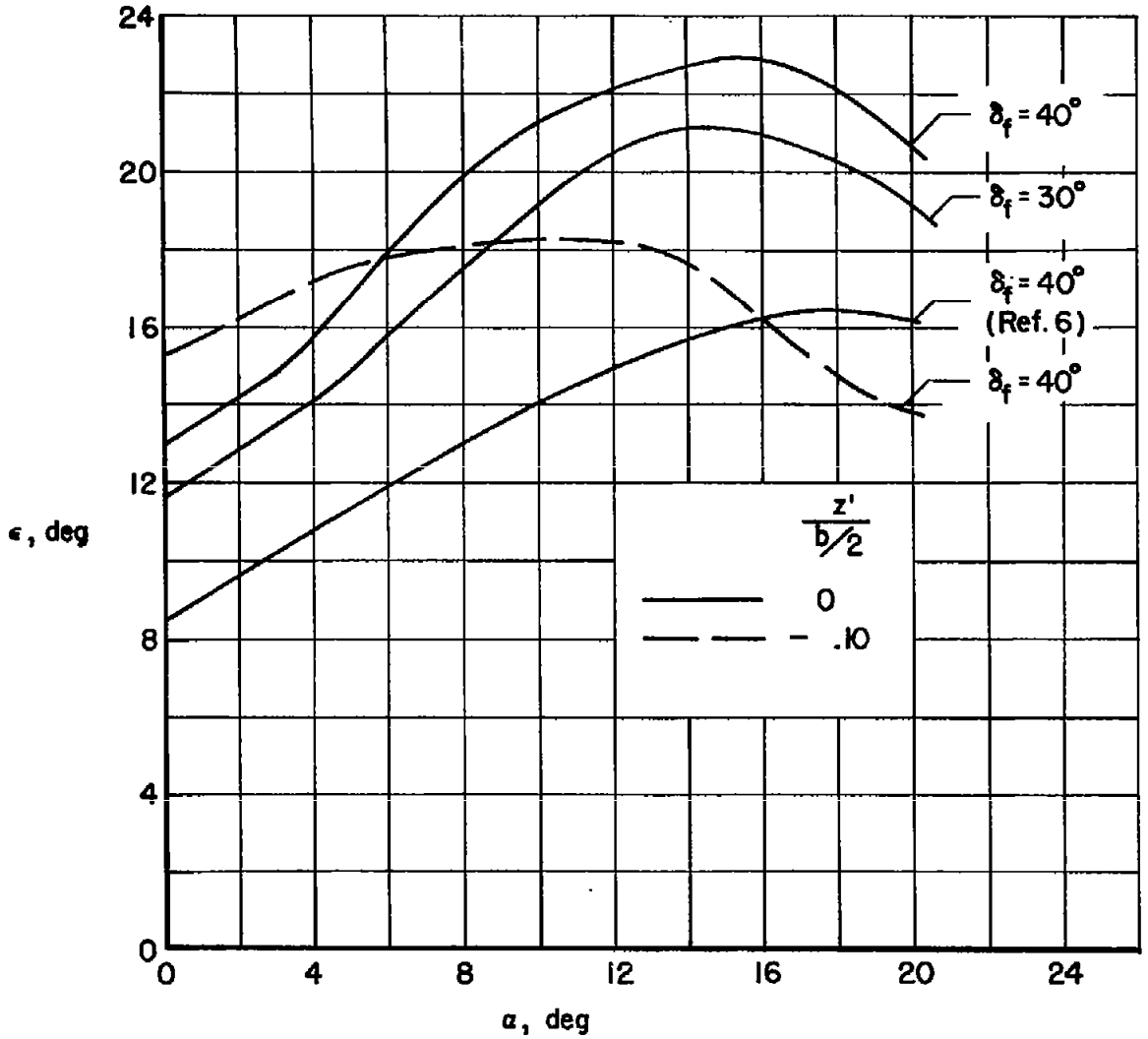
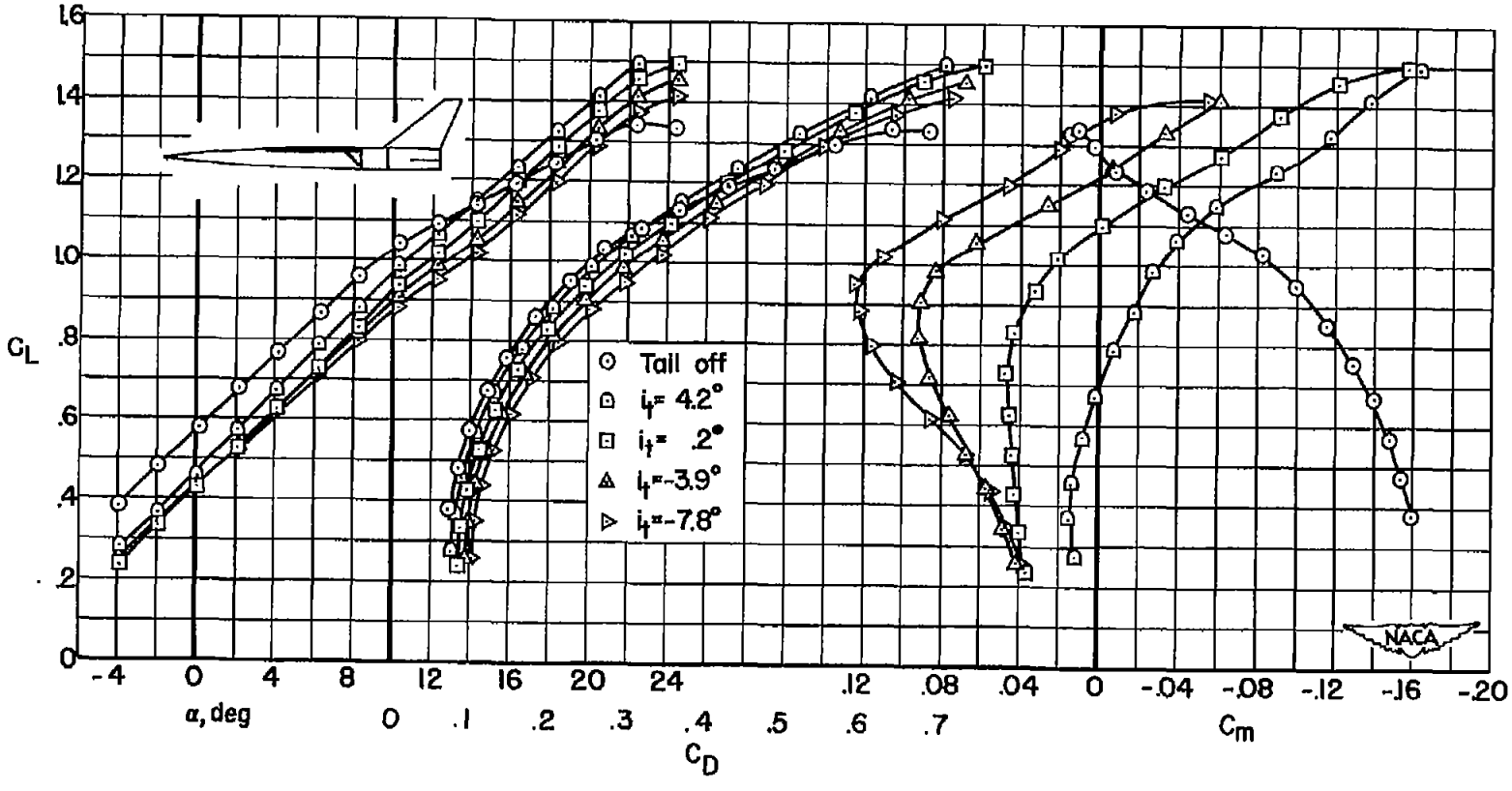
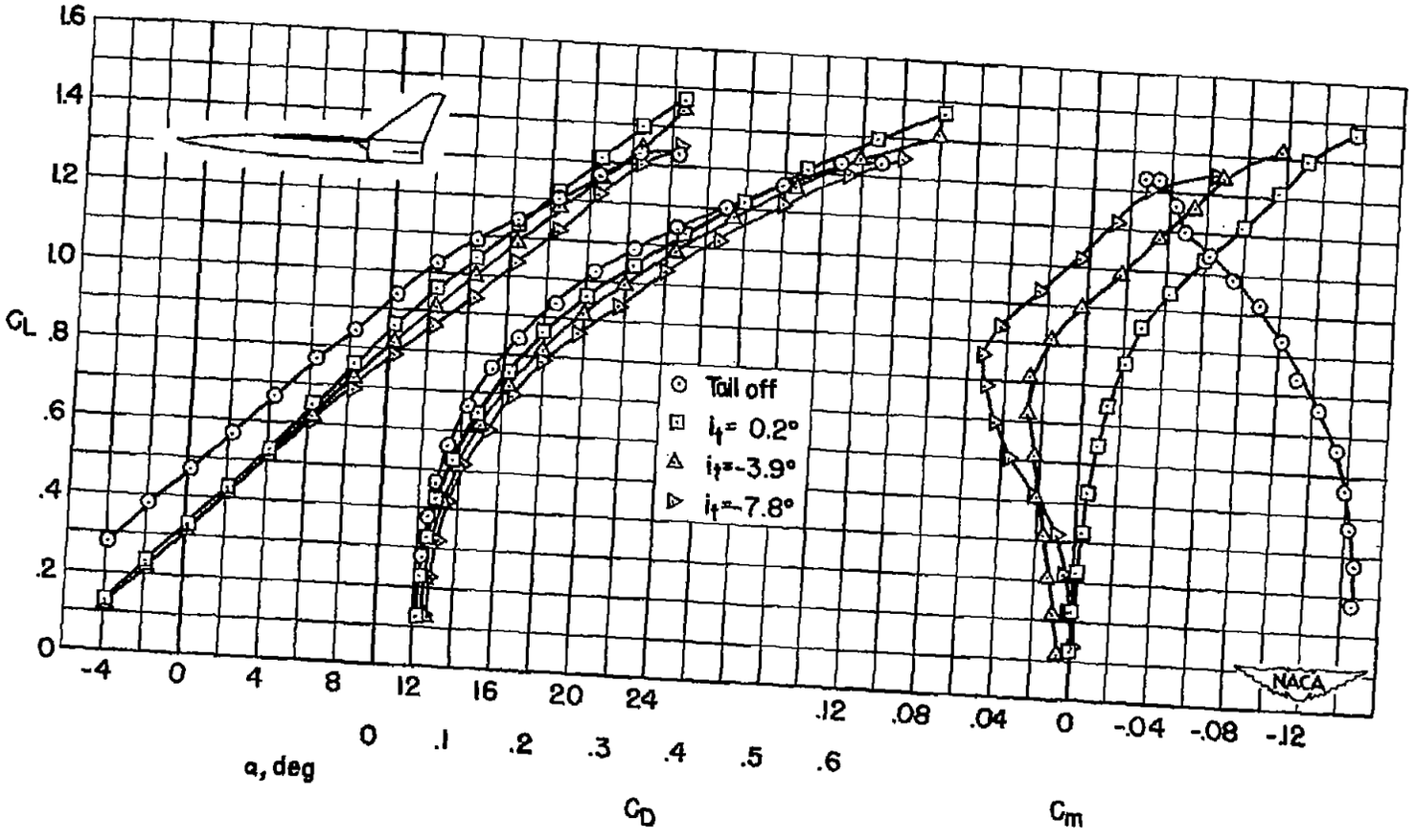


Figure 8.- The variation of effective downwash with angle of attack; $l_t/\bar{c} = 1.500$.



(a) $l_t/\bar{c}$ = 1.460; δ_f = 40°

Figure 9.- The lift, drag, and pitching-moment characteristics for several values of tail incidence when the horizontal tail is 0.10 b/2 below the wing-chord plane; M = 0.25; R = 2.5×10^6.



(b) $l_t/\bar{c}$ = 1.153; δ_f = 30°

Figure 9.- Concluded

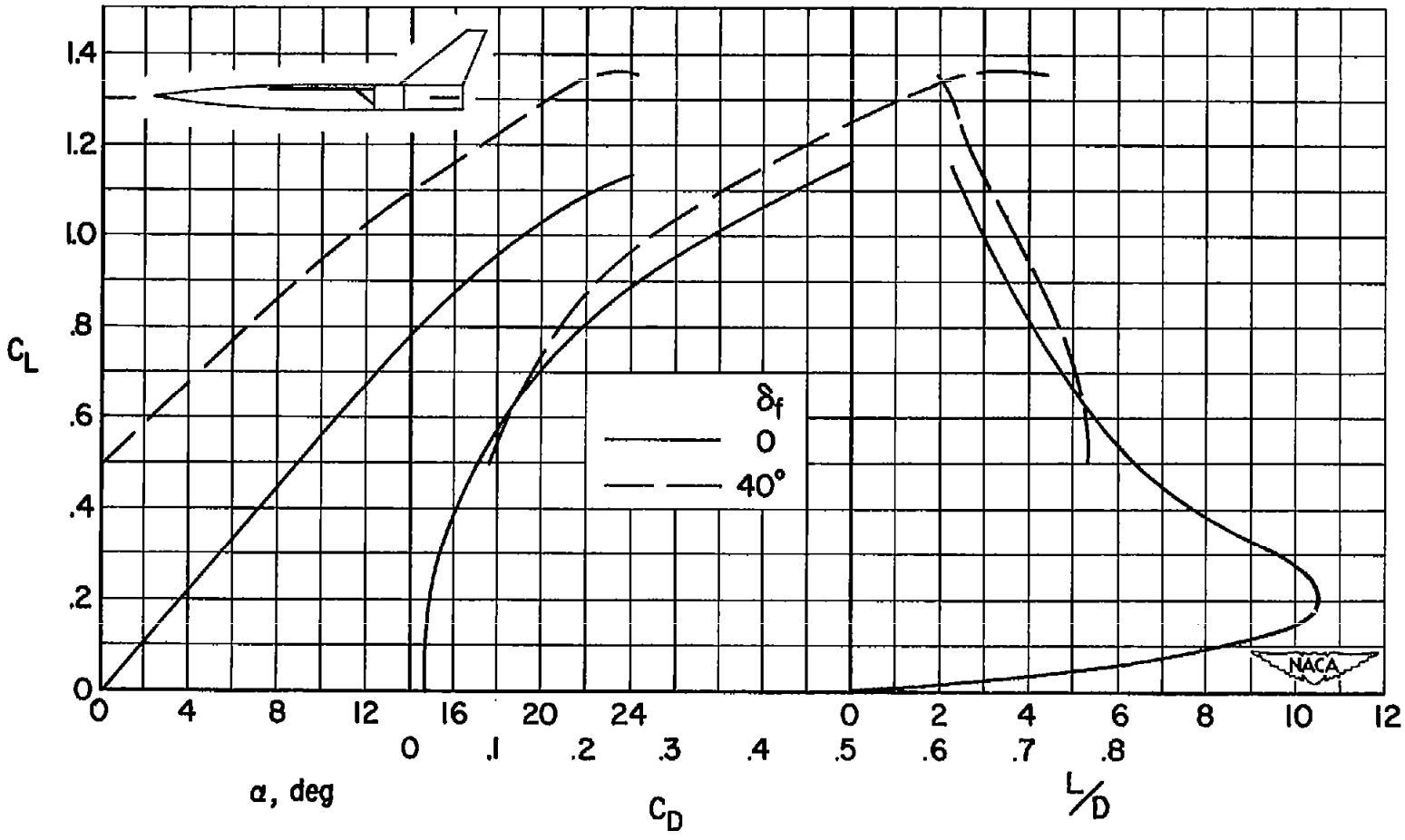


Figure 10.- The effect of 40° of flap deflection on the lift and drag characteristics for the balanced condition when the tail is 0.10 b/2 below the wing-chord plane and 1.460$\bar{c}$ behind the moment center; M = 0.25; R = 2.5×10⁶.

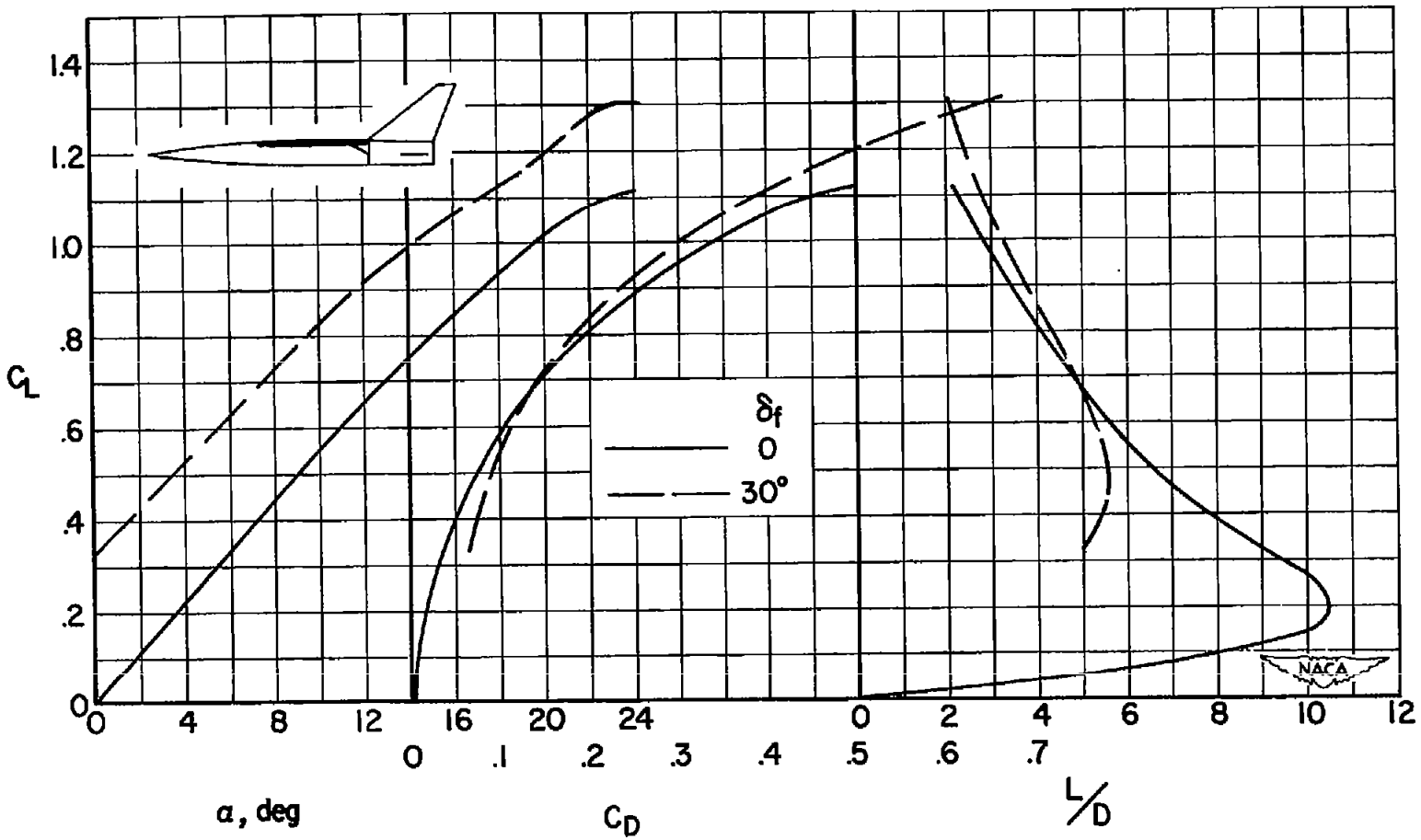


Figure 11.- The effect of 30° of flap deflection on the lift and drag characteristics for the balanced condition when the tail is 0.10 b/2 below the wing-chord plane and $1.153\bar{c}$ behind the moment center; M = 0.25; R = 2.5×10^6.

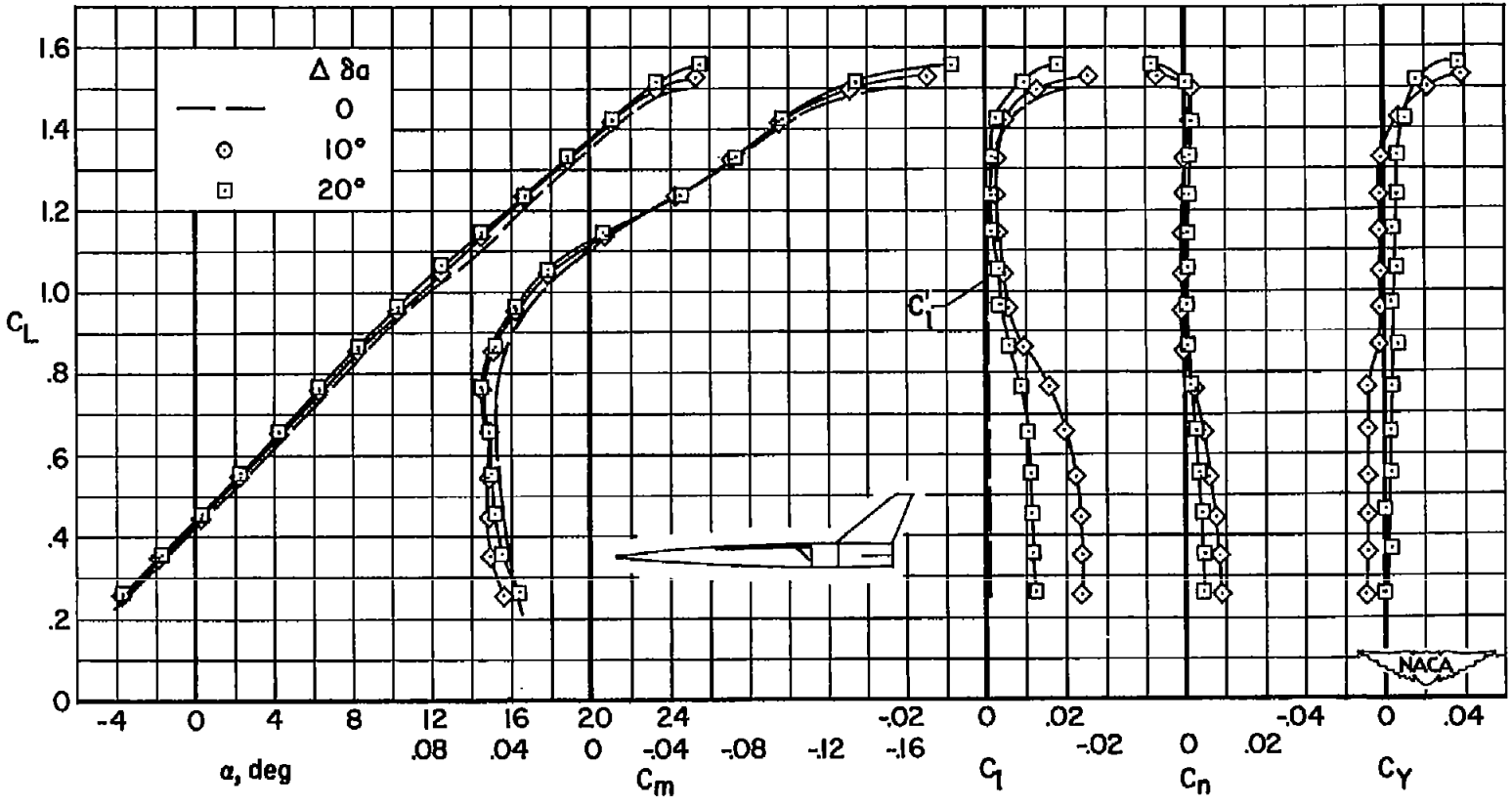


Figure 12.- The effect of asymmetric deflection of the ailerons on the aerodynamic characteristics when the flaps are deflected 40°; $i_t = 0.2^{\circ}$; $z'/(b/2) = -0.10$; $l_t/\bar{c} = 1.460$; $M = 0.25$; $R = 2.5\times10^6$.

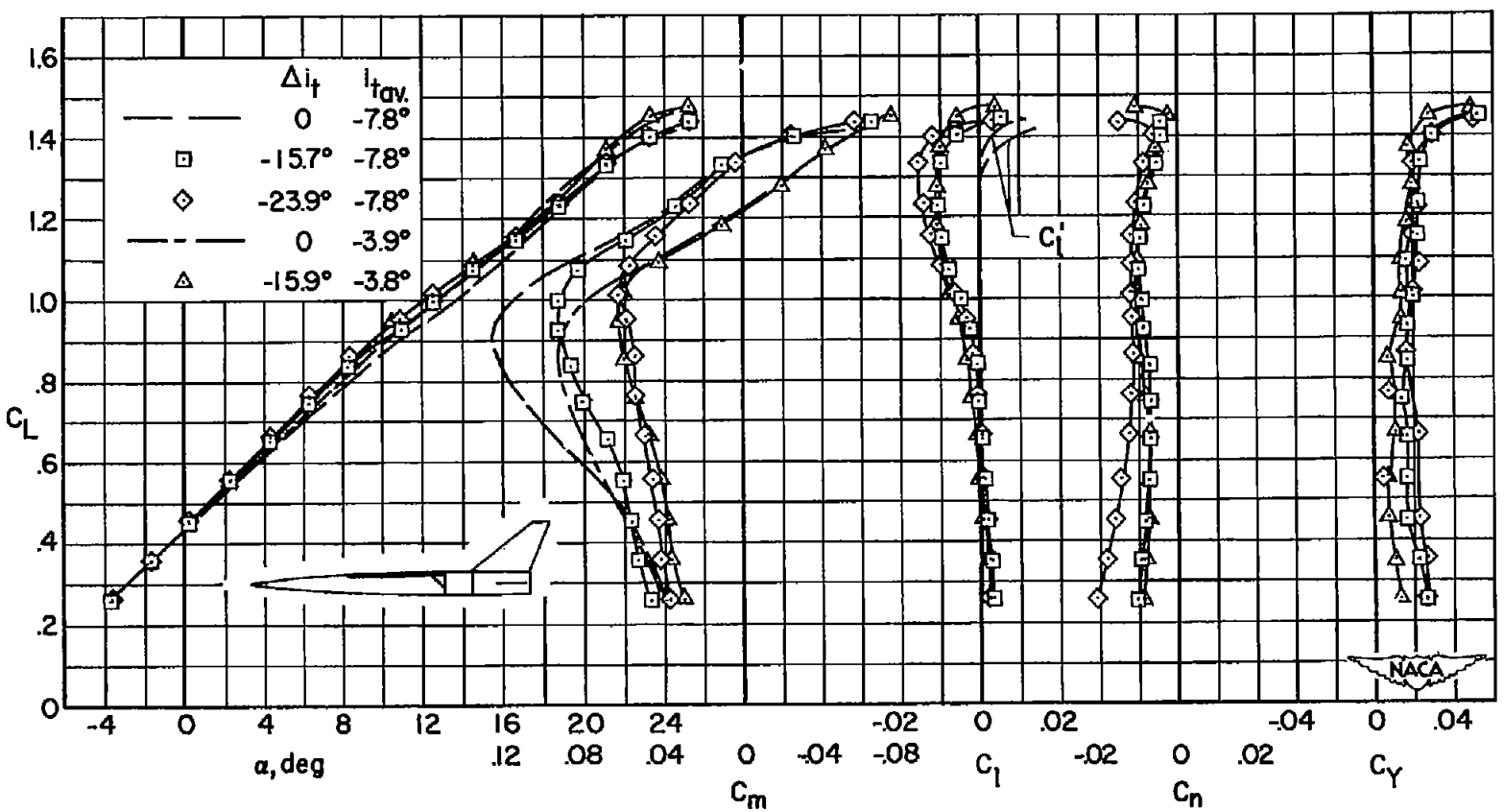
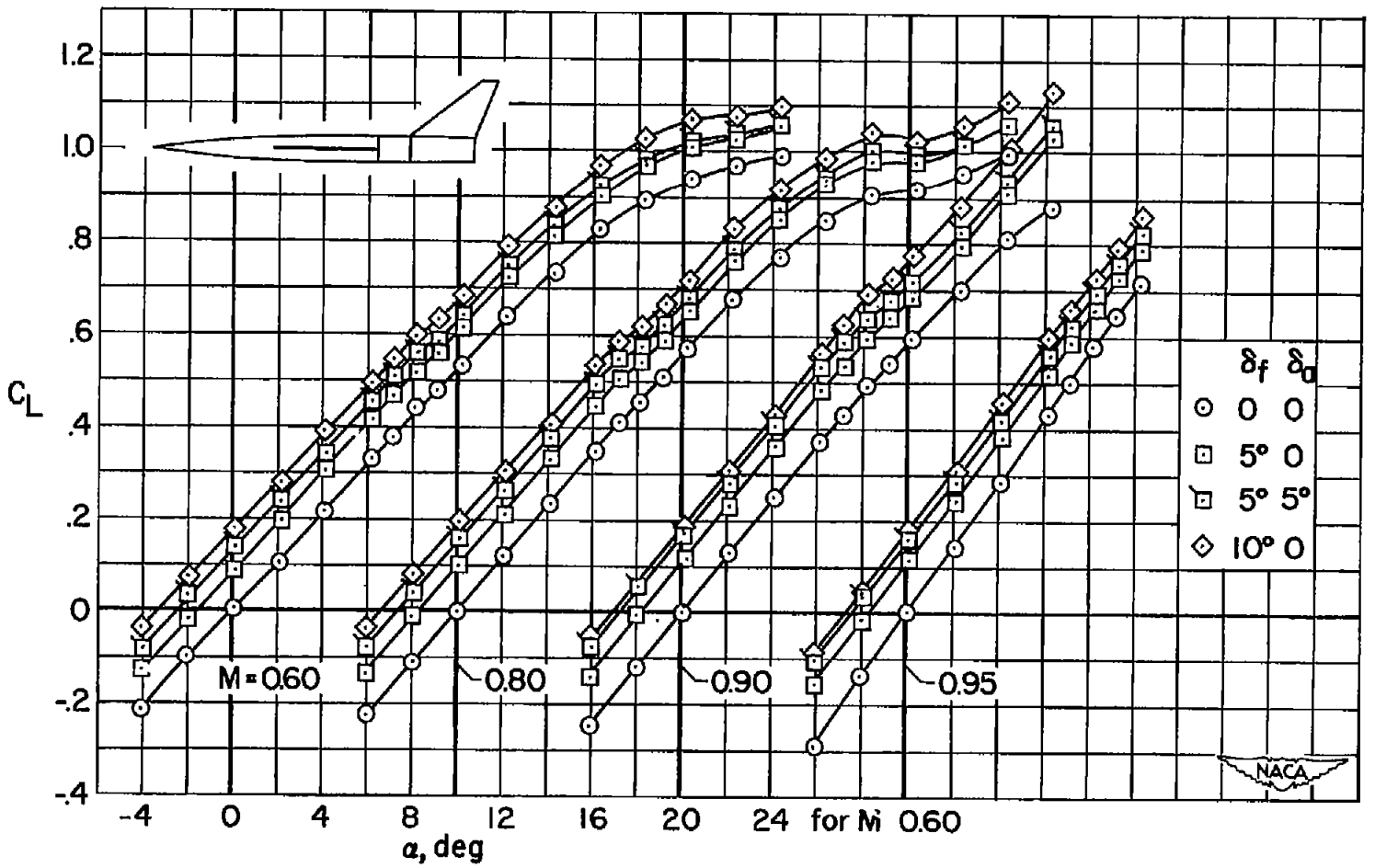
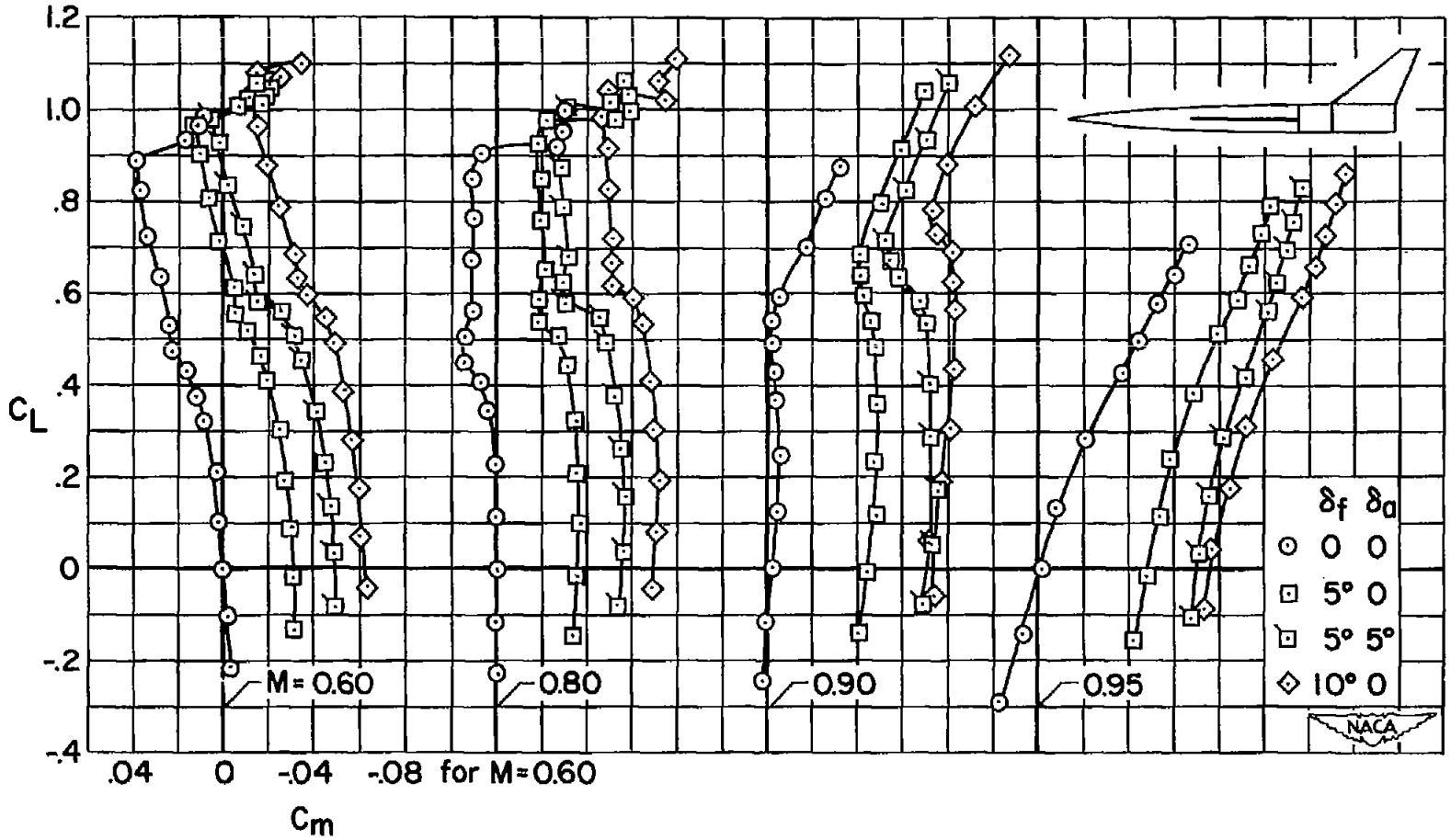


Figure 13.- The effect on the aerodynamic characteristics of deflection of the horizontal tail to provide lateral control when the flaps are deflected 40°; $z'/(b/2) = -0.10$; $l_t/\bar{c} = 1.460$; $M = 0.25$; $R = 2.5 \times 10^6$.



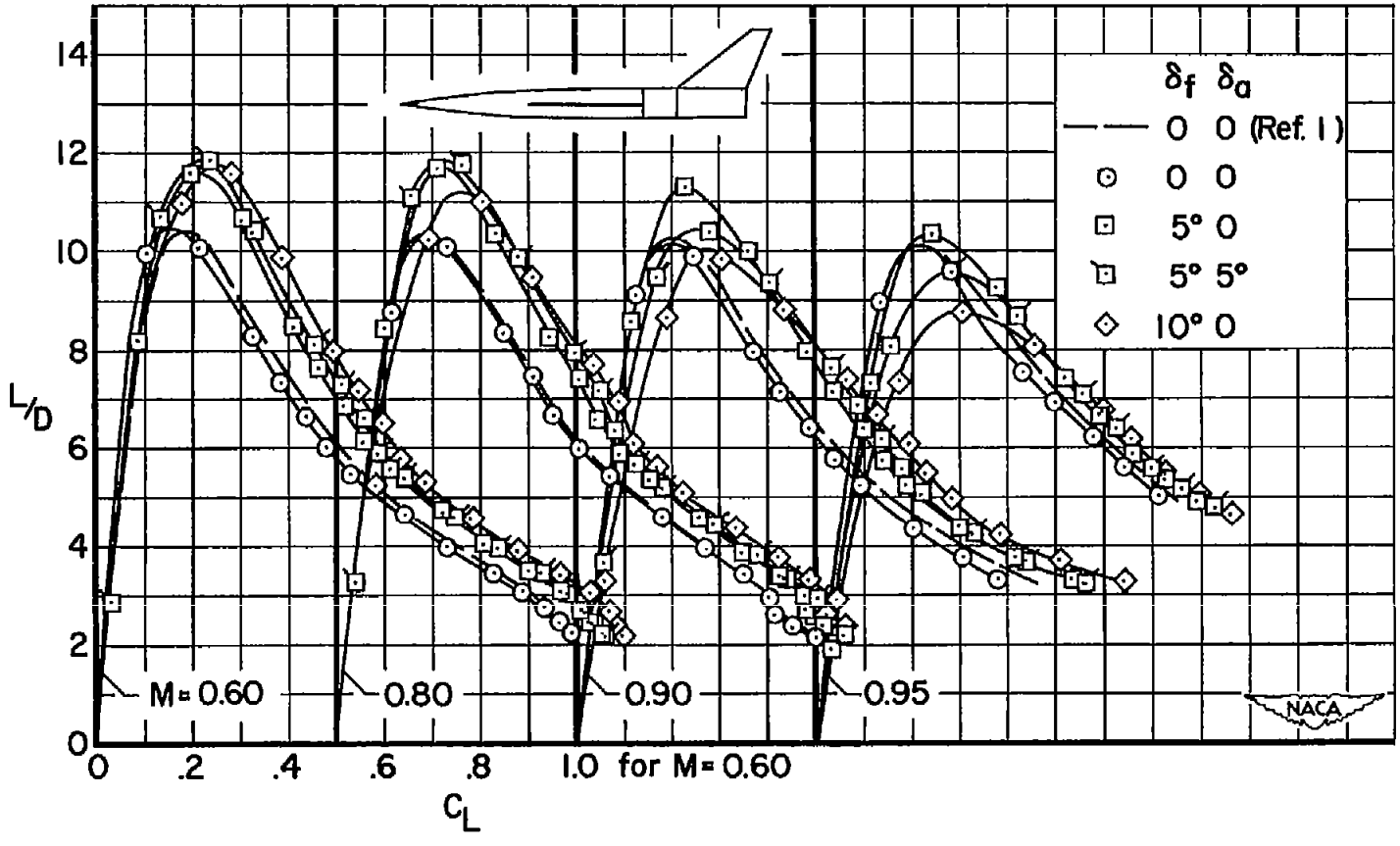
(a) C_L vs. α

Figure 14.- The effect of small symmetrical aileron and flap deflections on the lift, drag, and pitching moment of the wing-fuselage combination; mid wing; moment center at 0.375$\bar{c}$; R = 2.5×10^6.



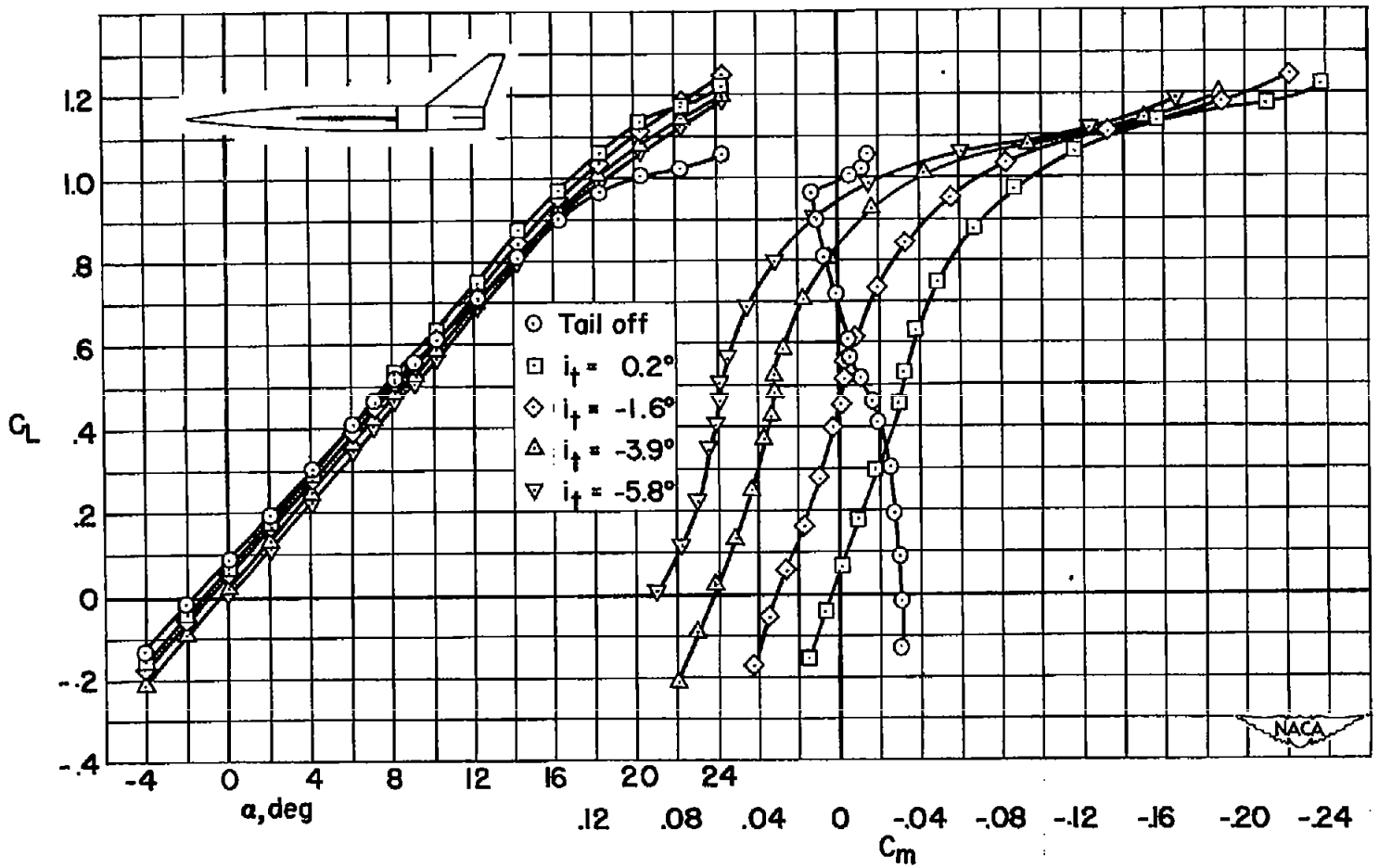
(b) C_L vs. C_m

Figure 14.- Continued.



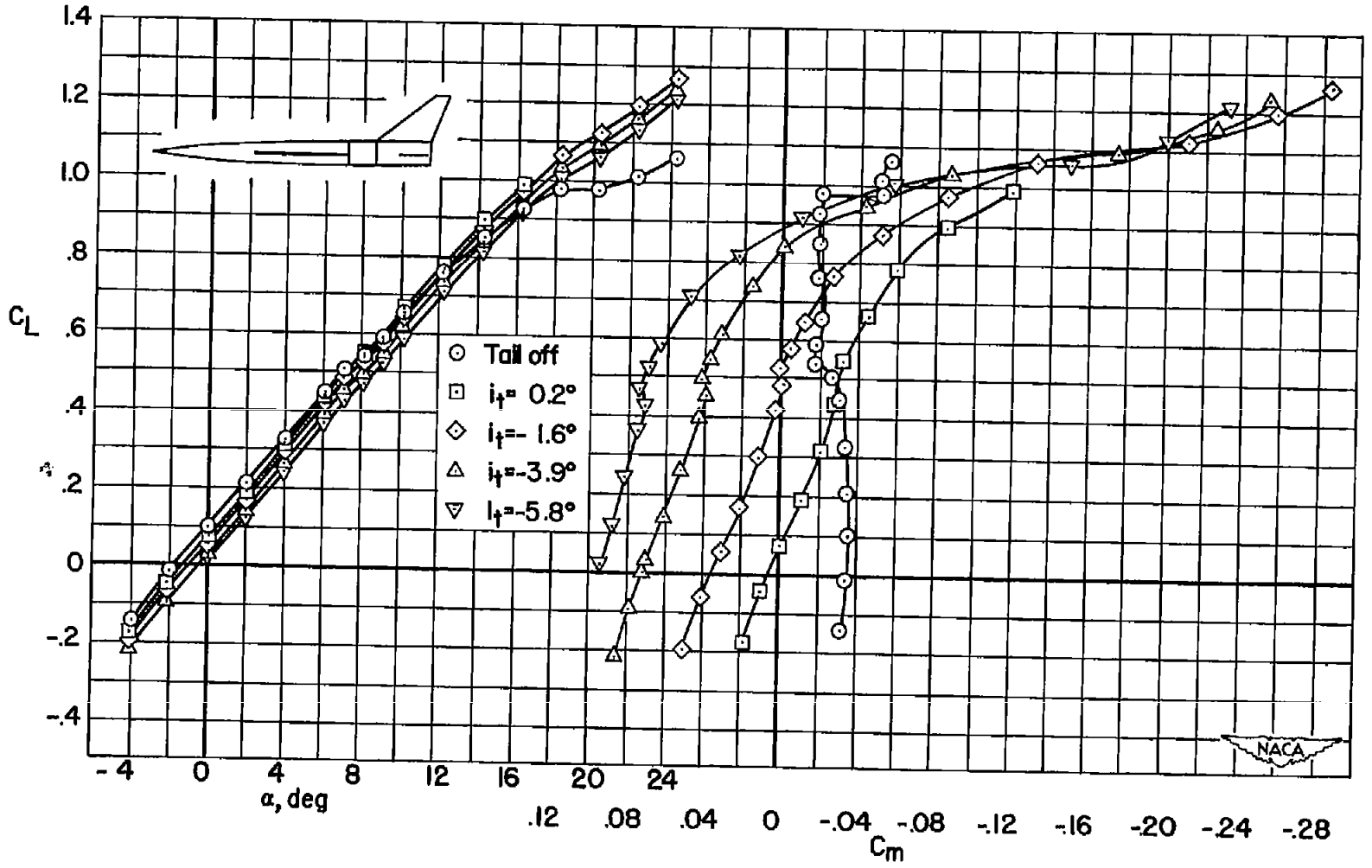
(c) L/D vs. C_L

Figure 14.- Concluded.



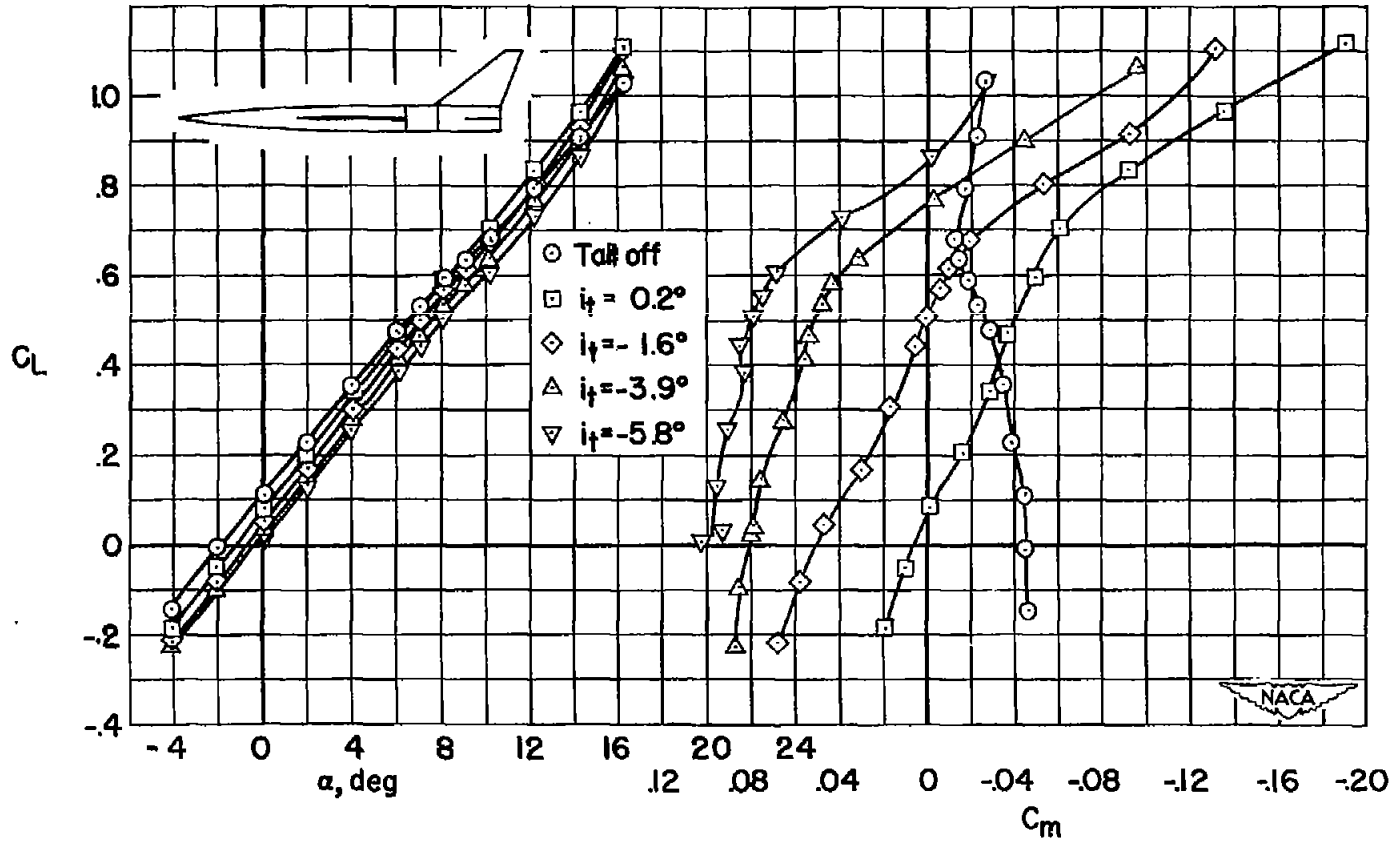
(a) M = 0.60

Figure 15.- The lift and pitching-moment characteristics with the flaps deflected 5° when the horizontal tail is in the wing-chord plane; $l_t/\bar{c}$ = 1.500; R = 2.5×10^6.



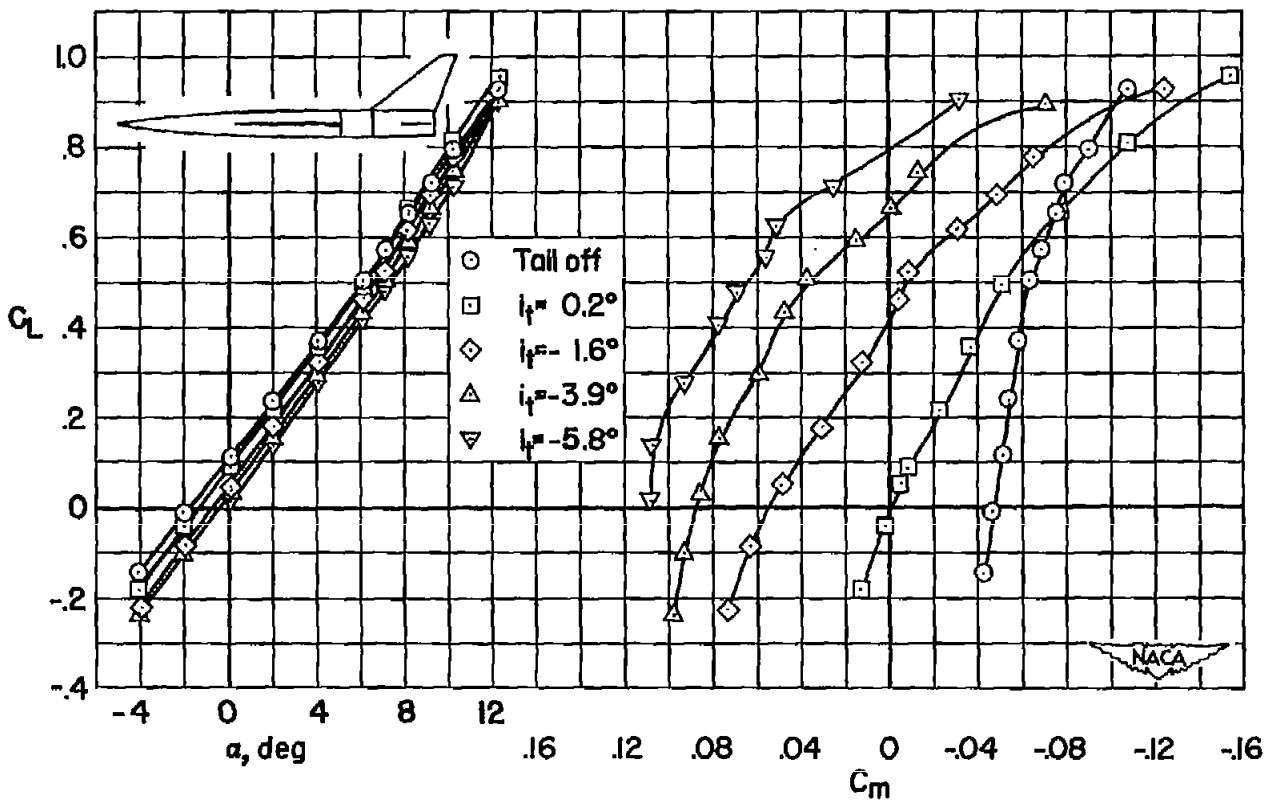
(b) M = 0.80

Figure 15.- Continued.



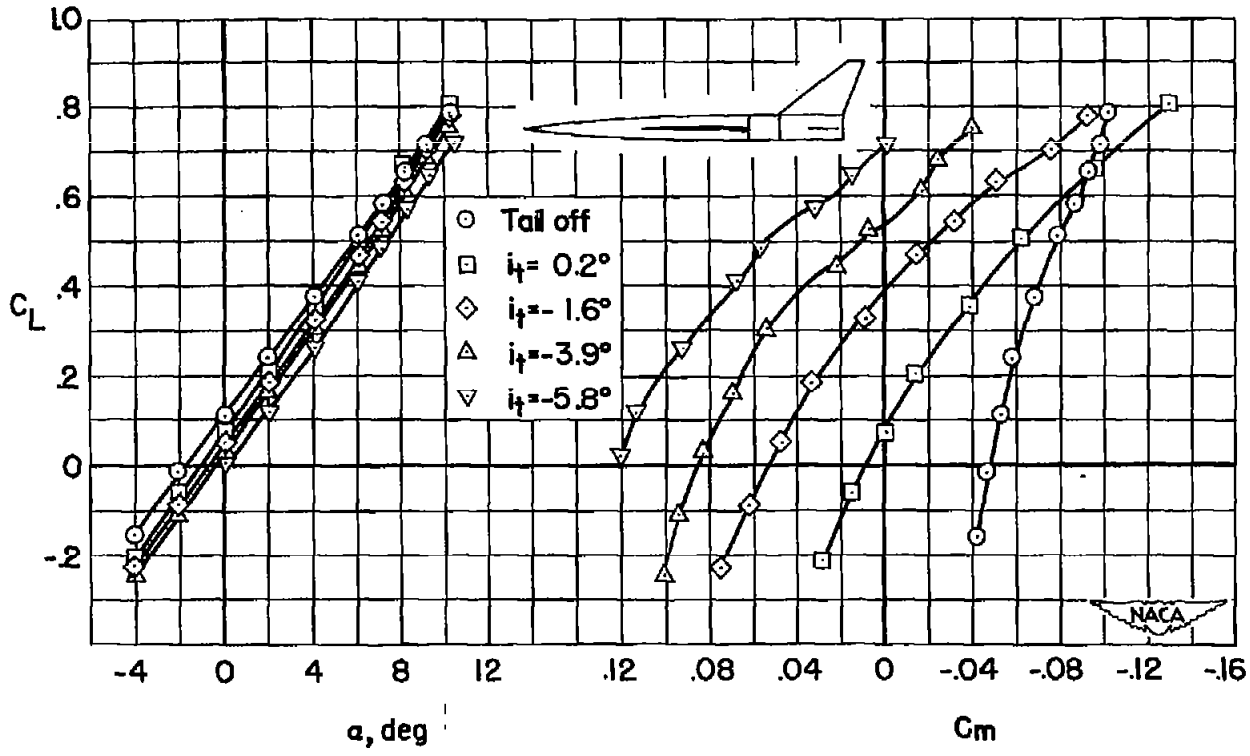
(c) M = 0.90

Figure 15.- Continued.



(d) M = 0.93

Figure 15.- Continued.



(e) M = 0.95

Figure 15.- Concluded.

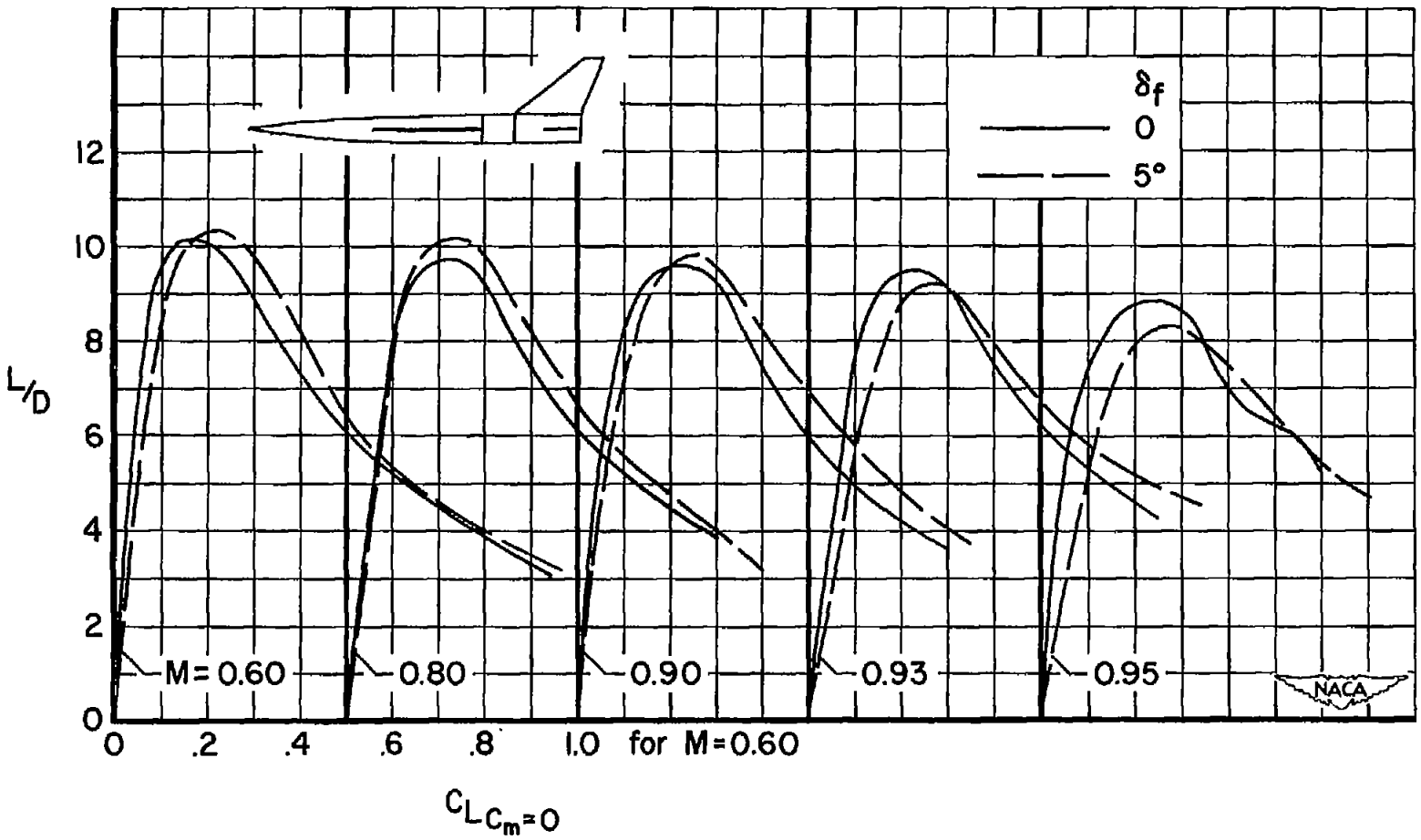


Figure 16.- The effect of deflecting the flaps 5° on the lift-drag ratio for the balanced condition with the horizontal tail in the wing-chord plane; $l_t/\bar{c} = 1.500$; $R = 2.5\times10^6$.

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