NACA

RESEARCH MEMORANDUM

LOW-SPEED ROLL EFFECTIVENESS OF A DIFFERENTIALLY

DEFLECTED HORIZONTAL-TAIL SURFACE

ON A 42° SWEPT-WING MODEL

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SUMMARY

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An investigation has been made in the Langley free-flight tunnel to
determine the roll effectiveness of a differentially deflected horizontal
tail on a 42° swept-wing model. The model was tested through an angle-
of-attack range of 0° through the stall in the clean and landing config-
urations with the horizontal tail in a low position. The model was also
tested in the clean configuration with the horizontal tail in the middle
or high positions.

In general, differential deflection of the horizontal tail had little
effect on the longitudinal characteristics of the model. At low angles
of attack the rolling moments produced by the tail (at a mean tail inci-
dence of 0°) were less than half those produced by the ailerons, but near
the stall the moments produced by the two controls were almost equal.
The rolling moments for the three tail positions were generally less for
-15° incidence than those for a tail incidence of 0° over the angle-of-
attack range. Evaluated on the basis of longitudinal trim conditions,
differential deflection of the horizontal tail produced large favorable
yawing moments when the tail was in the low position and large adverse
yawing moments when the tail was in a high position but produced only
small yawing moments for the middle-tail position.

Author

INTRODUCTION

Interest has recently been shown in the use of all-movable horizontal
tails deflected differentially for roll control. The results of previous
investigations (refs. 1 to 7) show that the roll effectiveness of the
horizontal tail is less than that for ailerons at low angles of attack
but that the roll effectiveness of the horizontal tail is maintained up
to high angles of attack and at transonic speeds where ailerons tend to

lose some of their effectiveness. These results, therefore, appear to indicate some promise for controls of this type.

In order to provide additional information on tail roll controls, force tests have been conducted in the Langley free-flight tunnel on a 42° swept-wing model with the all-movable horizontal tail deflected differentially. Tests were made of the model in the clean configuration with the horizontal tail in three vertical positions: low, middle (midway of the exposed height of the vertical tail) and high (on top of the vertical tail). Tests were made in the landing configuration with the low tail position.

SYMBOLS

The data are presented in the form of standard NACA coefficients of forces and moments. The longitudinal data are referred to the stability system of axes and the lateral data are referred to the body system of axes. (See fig. 1.) The coefficients are based on the dimensions of the wing plan form, the chord extension being neglected. The origin of the axes was located to correspond to a center-of-gravity position of 28.7 percent and 35.0 percent of the mean aerodynamic chord for the model in the clean configuration and the landing configuration, respectively.

S   wing area, sq ft

$\bar{c}$ wing mean aerodynamic chord, ft

V   airspeed, ft/sec

b   wing span, ft

q   dynamic pressure, $\dfrac{\rho V^2}{2}$, lb/sq ft

ρ air density, slugs/cu ft

β angle of sideslip, deg

ψ angle of yaw, deg

ϕ angle of bank, deg

α angle of attack of fuselage reference line, deg

i_w angle of incidence of wing with respect to fuselage reference line, deg

i_t angle of incidence of horizontal tail with respect to fuselage reference line, deg

δ difference in deflection between a pair of control surfaces used as lateral controls, positive when left-hand control has more positive deflection, deg

δ_f symmetrical deflection of wing trailing-edge control, measured perpendicular to hinge line, deg

δ_{ILE} deflection of inboard wing leading-edge, deg

δ_{OLE} deflection of outboard wing leading-edge, deg

X_S longitudinal force, lb

Y lateral force, lb

Z_S normal force, lb

F_Y side force, lb

F_L lift, lb

F_D drag, lb

M_Y pitching moment, ft-lb

M_X rolling moment, ft-lb

M_Z yawing moment, ft-lb

C_L lift coefficient, Lift/qS

C_D drag coefficient, Drag/qS

C_m pitching-moment coefficient, $M_Y/qS\bar{c}$

C_n yawing-moment coefficient, M_Z/qSb
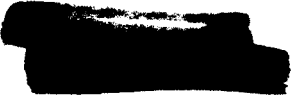
C_l rolling-moment coefficient, M_X/qSb

C_Y lateral-force coefficient, F_Y/qS

Subscripts:

w   wing

t   horizontal tail

L   left

R   right

S   stability axis

APPARATUS AND MODEL

The tests were conducted in the Langley free-flight tunnel with a sting-type support system and an internally mounted strain-gage balance. A three-view drawing of the model is shown in figure 2 and the dimensional characteristics are given in table I. With the model in the clean configuration the wing incidence was -1^O and the leading- and trailing-edge flaps were at 0°. For the landing configuration the wing incidence was 9°, the inboard and outboard leading-edge flaps were down 25° and 30°, respectively, and the trailing-edge flaps were down 20°. When the horizontal tail was in the middle or high position, the center section, which represented the unexposed section of the horizontal tail in the low position, was used for longitudinal trim but not for roll control. That is, only the original exposed area was deflected differentially.

TESTS

Force tests were made to determine the rolling effectiveness of the horizontal tail with the vertical tail off and on. The horizontal tail in the low position was deflected differentially $\pm10^O$ and $\pm15^O$ from tail incidences of 0° and -15° for the clean and landing configurations. The tail in the middle and high positions was deflected $\pm15^O$ from tail incidences of 0° and -15° for the clean configuration only. Tests were made to determine the effect of differential deflection of the low horizontal tail on the longitudinal characteristics of the model for both the clean and landing conditions. The longitudinal characteristics of the model with the tail in the middle and high position were determined in the clean condition only.

All tests were run at a dynamic pressure of 4.37 pounds per square foot, which corresponds to an airspeed of about 61 feet per second at standard sea-level conditions and to a test Reynolds number of 0.51×10^6 based on the mean aerodynamic chord of 1.309 feet.

RESULTS AND DISCUSSION

Longitudinal Characteristics

Static longitudinal characteristics of the model with the horizontal tail in the low position are presented in figure 3 for the model in the clean and landing configurations. The effects of tail incidence and differential deflection of the horizontal tail for the low, middle, and high positions are shown in figure 4 for the model in the clean condition. The greater effectiveness of the middle and high horizontal tails is attributed principally to the fact that in these cases the entire tail (not just the exposed area) was deflected for control. The effectiveness of the tail in the high position is slightly greater than that of the tail in the middle position apparently because of the greater tail length for the tail in the high position. (See table I and fig. 2.) In general, differential deflection of the horizontal tail had little effect upon the longitudinal characteristics of the model.

Lateral Characteristics

Presented in figures 5 and 6 are the incremental values of C_l, C_n, and C_Y produced by deflecting the low horizontal tail differentially $\pm 10°$ and $\pm 15°$ for mean tail incidences of $0°$ and $-15°$ for the model in the clean and landing configurations with the vertical tail off and on. For the model in the clean configuration (fig. 5), the roll effectiveness is much less at low angles of attack for an incidence of $-15°$ than it is for $0°$ because one of the surfaces is stalled. At high angles of attack, however, the roll effectiveness is greater with the $-15°$ incidence, because this incidence then tends to keep the tail unstalled. For the model in the landing configuration (fig. 6), the overall variation of roll effectiveness with angle of attack was generally similar but the values of ΔC_l were somewhat smaller than that for the model in the clean configuration. This decreased effectiveness in the landing configuration is probably caused by stalling on one of the surfaces resulting from the increased downwash at a given angle of attack produced by flap deflection and wing incidence. In general, the data of figures 5 and 6 show smaller rolling moments with vertical tail on than with vertical tail off apparently because the loads induced on the vertical tail by the differentially deflected low horizontal tail produce adverse rolling moments.

The data show that differential deflection of the horizontal tail had little effect on the yawing moments with the vertical tail off but the deflection produced very large yawing moments with the tail on. The large yawing moments, which occurred for both tail incidences, were produced by the asymmetrical loads induced on the vertical tail by the horizontal tail. These large yawing moments resulted in large values of

the parameter $\frac{\Delta C_n}{\Delta C_l}$ which would probably be considered undesirable from a flying-qualities standpoint.

The data for the horizontal tail in the middle and high positions for the model in the clean configuration are shown in figures 7 and 8, respectively. In order to show the effect of tail position, the vertical-tail-on data from figures 7 and 8 and similar data from figure 5 for the low-tail position are compared in figure 9. The data of figure 9(a) are directly comparable at zero angle of attack where the model was approximately in trim for all three tail positions. The data of figure 9(b) for -15° tail incidence are not directly comparable at any given angle of attack because the trim angle of attack is different for each tail position. (See fig. 4.) Although not directly comparable, the data of figure 9(b) should give some indication of the effect of tail position in the high angle-of-attack range.

The data of figure 9(a) show that at 0° tail incidence the incremental rolling moments for the tail in the low and middle positions were generally similar and somewhat less than the incremental rolling moments for the tail in the high position. The rolling moments were greater for the tail in the high position than for the middle and low tail positions apparently because of the difference in the loads induced on the vertical tail, and additionally, at the higher angles of attack from the difference in downwash on the horizontal tail. The yawing moments were favorable for the low tail position, almost zero for the middle tail position, and adverse for the high tail position. The changes in yawing moment with variation in height of the horizontal tail were caused by changes in both the magnitude and direction of the induced loads on the vertical tail.

A comparison of the data of figures 9(a) and 9(b) shows that the rolling moments for the three tail positions were generally less for -15° incidence than those for a tail incidence of 0° over the angle-of-attack range, except for the low tail position at high angles of attack. In the high angle-of-attack range, the rolling moments with the -15° incidence were greater for the low tail position than for the middle and high tail positions probably because of the differences in downwash at the tail.

The reasons for the large positive increase in yawing moment for the middle and high tail positions, at low angles of attack, when the incidence is changed from 0° to -15° are not fully understood. Only a portion of these changes in yawing moment can be explained by a consideration of the differential tail drag. On the basis of the present data, no explanation can be given for the changes in the yawing moment from a large negative value to a large positive value when the incidence of the high horizontal tail is changed from 0° to -15°. Actually, the yawing-moment data of figure 9(b) are of practical significance only in the high

angle-of-attack range where the model is in trim longitudinally with the tail incidence of -15°. For these trim conditions, changes in tail position cause changes in yawing moment that are in the same direction as, but smaller than, those shown by the data of figure 9(a) for 0° incidence. Interpolations based on the data of figures 4 and 9 indicate, for trimmed conditions at intermediate angles of attack, the same general variation of yawing moment with tail position would be obtained.

In figure 10 is shown a comparison of the incremental rolling and yawing moments produced by the ailerons and the low horizontal tail ($i_t = 0$) up to an angle of attack of 50°. At low angles of attack the ailerons are more than twice as effective as the horizontal tail as a roll control. As the angle of attack increases, the rolling moments of the aileron drop off rapidly until at an angle of attack of about 18° they become approximately equal to the moments produced by the horizontal tail. Above an angle of attack of 32° the rolling moments produced by the horizontal tail drop off to zero whereas the ailerons maintain some effectiveness through an angle of attack of 50°. The yawing moments produced by the ailerons were favorable up to an angle of attack of 18° and then become rather small and erratic over the remaining angle-of-attack range. The yawing moments produced by the horizontal tail were favorable up to an angle of attack of about 28° and became highly adverse at very high angles of attack. It should be pointed out that, although the horizontal tail and the ailerons produced about the same yawing moments at an angle of attack of 0°, the important control parameter $\frac{\Delta C_n}{\Delta C_l}$ is much greater for the tail control. As pointed out previously, this large value of $\frac{\Delta C_n}{\Delta C_l}$ for the low horizontal tail would probably lead to undesirable flying qualities.

<div align="center">CONCLUSIONS</div>

Results of an investigation made to determine the rolling effectiveness of an all-movable horizontal tail when deflected differentially indicate the following conclusions:

1. Differential deflection of the horizontal tail had little effect on the longitudinal characteristics of the model.

2. At low angles of attack the rolling moments produced by the low tail (at a mean tail incidence of 0°) were less than half those produced by the ailerons but near the stall the moments produced by the two controls were almost equal.

3. The incremental rolling moments for the three tail positions were generally less for -15° incidence than those for a tail incidence of 0° over the angle-of-attack range.

4. Evaluated on the basis of longitudinal trim conditions, differential deflection of the horizontal tail produced large favorable yawing moments when the tail was in the low position and large adverse yawing moments when the tail was in the high position but produced only small yawing moments for the middle tail position.

Langley Aeronautical Laboratory,
    National Advisory Committee for Aeronautics,
        Langley Field, Va., April 12, 1956.

REFERENCES

1. Koenig, David G.: Tests in the Ames 40- by 80-Foot Wind Tunnel of an Airplane Configuration With an Aspect Ratio 3 Triangular Wing and an All-Movable Horizontal Tail - Longitudinal and Lateral Characteristics. NACA RM A52L15, 1953.

2. Tinling, Bruce E., and Karpen, A. V.: The Effects of Trailing-Edge Flaps on the Subsonic Aerodynamic Characteristics of an Airplane Model Having a Triangular Wing of Aspect Ratio 3. NACA RM A54I07, 1955.

3. English, Roland D.: Free-Flight Investigation, Including Some Effects of Wing Aeroelasticity, of the Rolling Effectiveness of an All-Movable Horizontal Tail With Differential Incidence at Mach Numbers From 0.6 to 1.5. NACA RM L54K30, 1955.

4. Critzos, Chris C.: Lateral-Control Investigation at Transonic Speeds of Differentially Deflected Horizontal-Tail Surfaces for a Configuration Having a 6-Percent-Thick, 45° Sweptback Wing. NACA RM L55I26, 1955.

5. Savage, Howard F., and Tinling, Bruce E.: The Static Lateral and Directional Subsonic Aerodynamic Characteristics of an Airplane Model Having a Triangular Wing of Aspect Ratio 3. NACA RM A55B11, 1955.

6. Campbell, John P.: The Use of the Horizontal Tail for Roll Control. NACA RM L55L16a, 1956.

7. Mitchell, Jesse L., and Vitale, A. James: Free-Flight Investigation of the Control Effectiveness of a Differentially Deflected Horizontal Tail at Mach Numbers From 0.8 to 1.6. NACA RM L56B20, 1956.

TABLE I

DIMENSIONAL CHARACTERISTICS OF MODEL TESTED

IN THE LANGLEY FREE-FLIGHT TUNNEL

Wing:
  Airfoil section at root . . . . NACA 65A006
  Airfoil section at tip . . . . NACA 65A005
  Area (without chord-extension), sq ft 4.63
  Span, ft 3.96
  Aspect ratio 3.39
  Root chord (on fuselage reference line), ft 1.87
  Tip chord (without chord-extension), ft 0.462
  Tip chord (with chord-extension), ft 0.518
  Mean aerodynamic chord, $\bar{c}$, ft 1.309
  Sweep of quarter chord, deg 42
  Dihedral, deg . . . . -5
  Taper ratio (without chord-extension) 0.247
  Incidence:
    Clean configuration, deg . . . . -1
    Landing configuration, deg 9

Horizontal tail:
  Airfoil section at root . . . . NACA 65A006
  Airfoil section at tip . . . . NACA 65A004
  Area:
    Total, sq ft 1.154
    Exposed (low tail only), sq ft 0.711
  Span:
    Total, ft 2.01
    Movable panel, ft 0.76
  Root chord (on fuselage reference line), ft 1.00
  Tip chord, ft 0.148
  Sweep of quarter chord, deg 45
  Dihedral, deg 5.42
  Aspect ratio (based on total tail area) 3.50
  Taper ratio 0.148
  Longitudinal distance from 0.287 $\bar{c}$ to quarter chord of tail:
    Low, ft 1.473
    Middle, ft 1.830
    High, ft 2.24
  Vertical distance from center of gravity:
    Low, ft . . . . -0.067
    Middle, ft 0.79
    High, ft 1.32

Vertical tail:
  Airfoil section at root . . . . NACA 65A006
  Airfoil section at tip . . . . NACA 65A004
  Area (dorsal fin exposed and including 0.0926 ft² of), ft² 1.0
  Span, ft 1.063
  Root chord (on fuselage reference line), ft 1.455
  Tip chord, ft 0.380
  Sweep of quarter chord, deg 45
  Aspect ratio 1.24
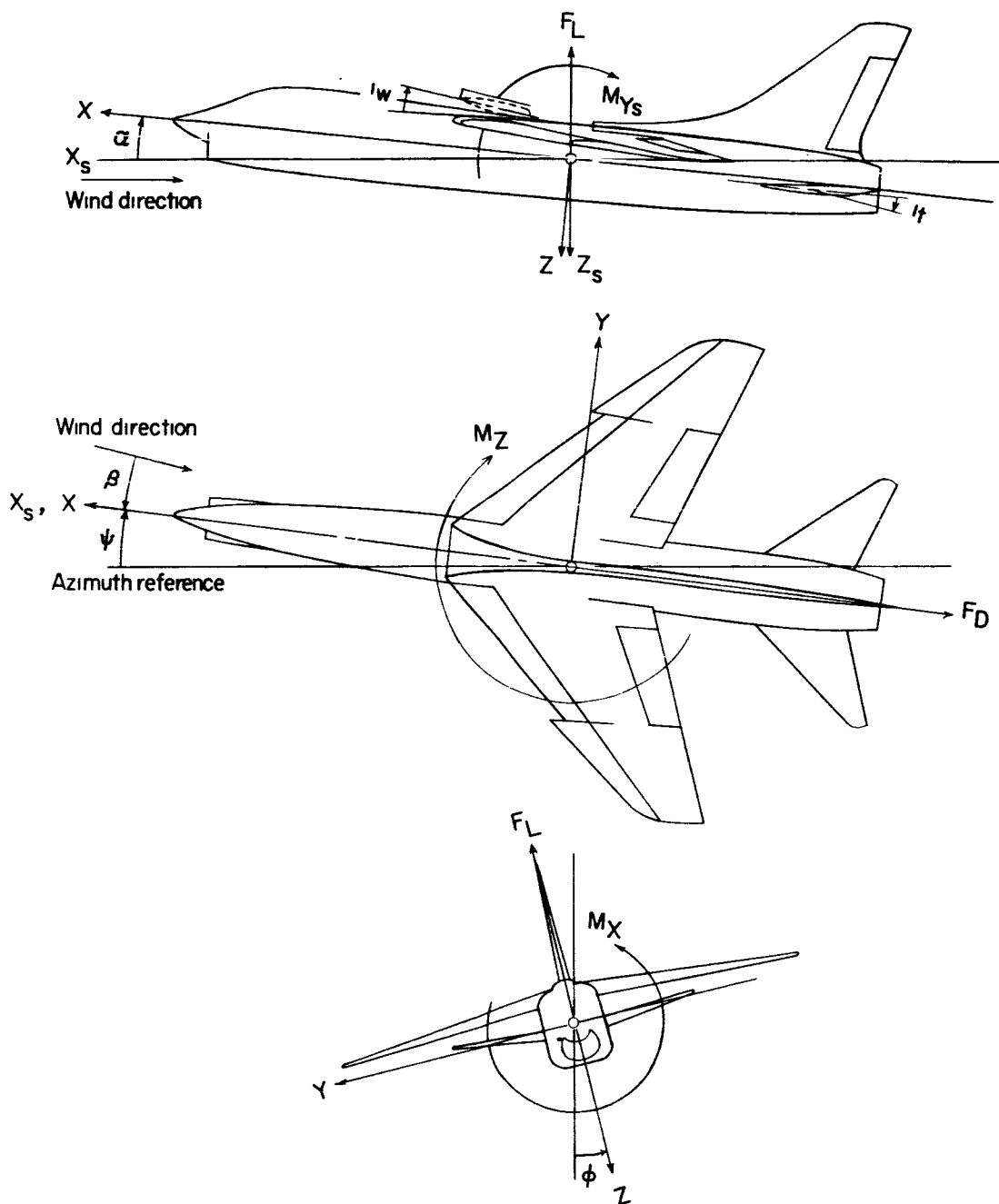 Taper ratio 0.26

Figure 1.- System of axes used in the investigation. The longitudinal
   data are referred to the stability system of axes and the lateral
   data are referred to the body system of axes. Arrows indicate posi-
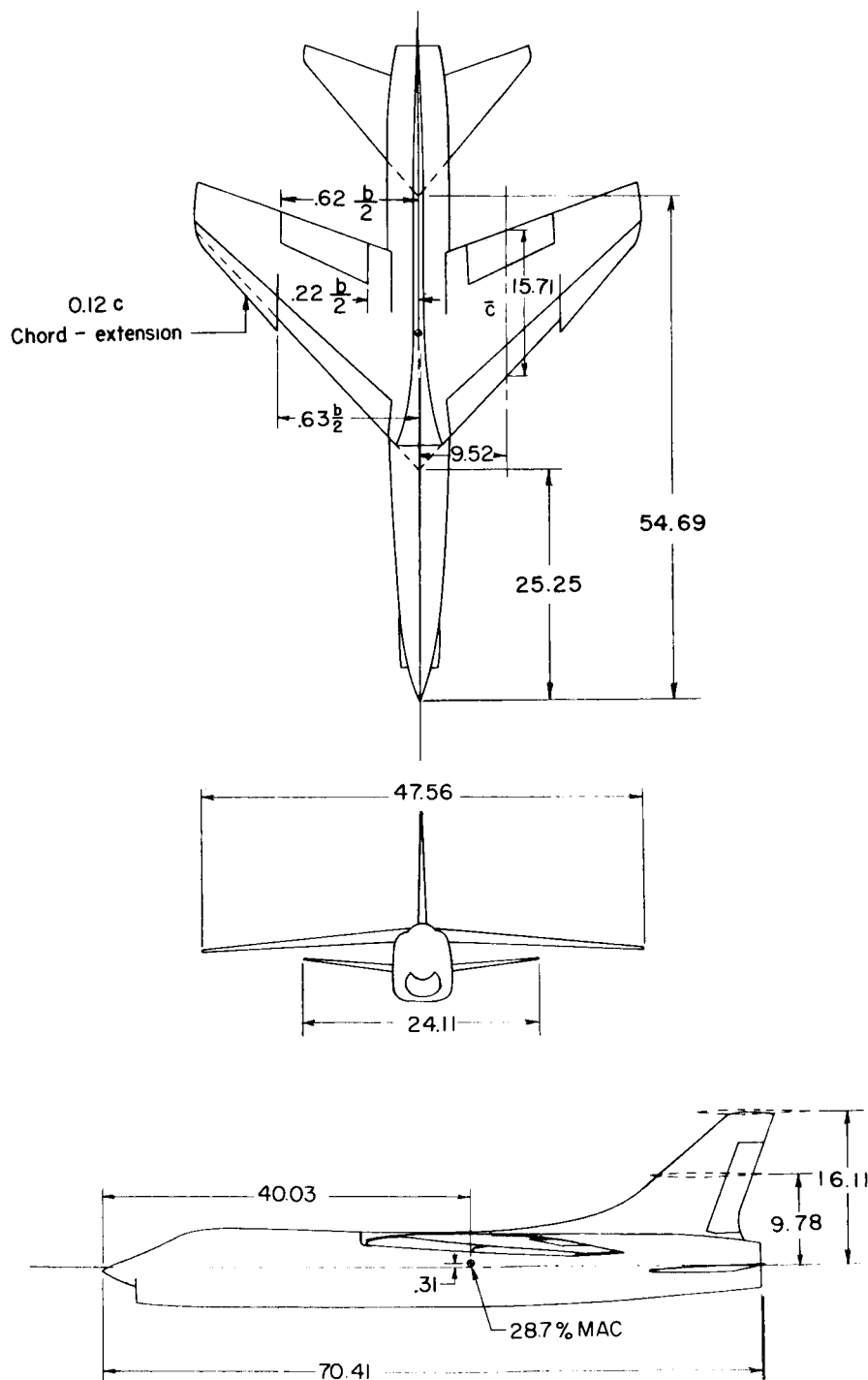   tive directions of moments, forces, and angles.

Figure 2.- Three-view drawing of the model used in the investigation.
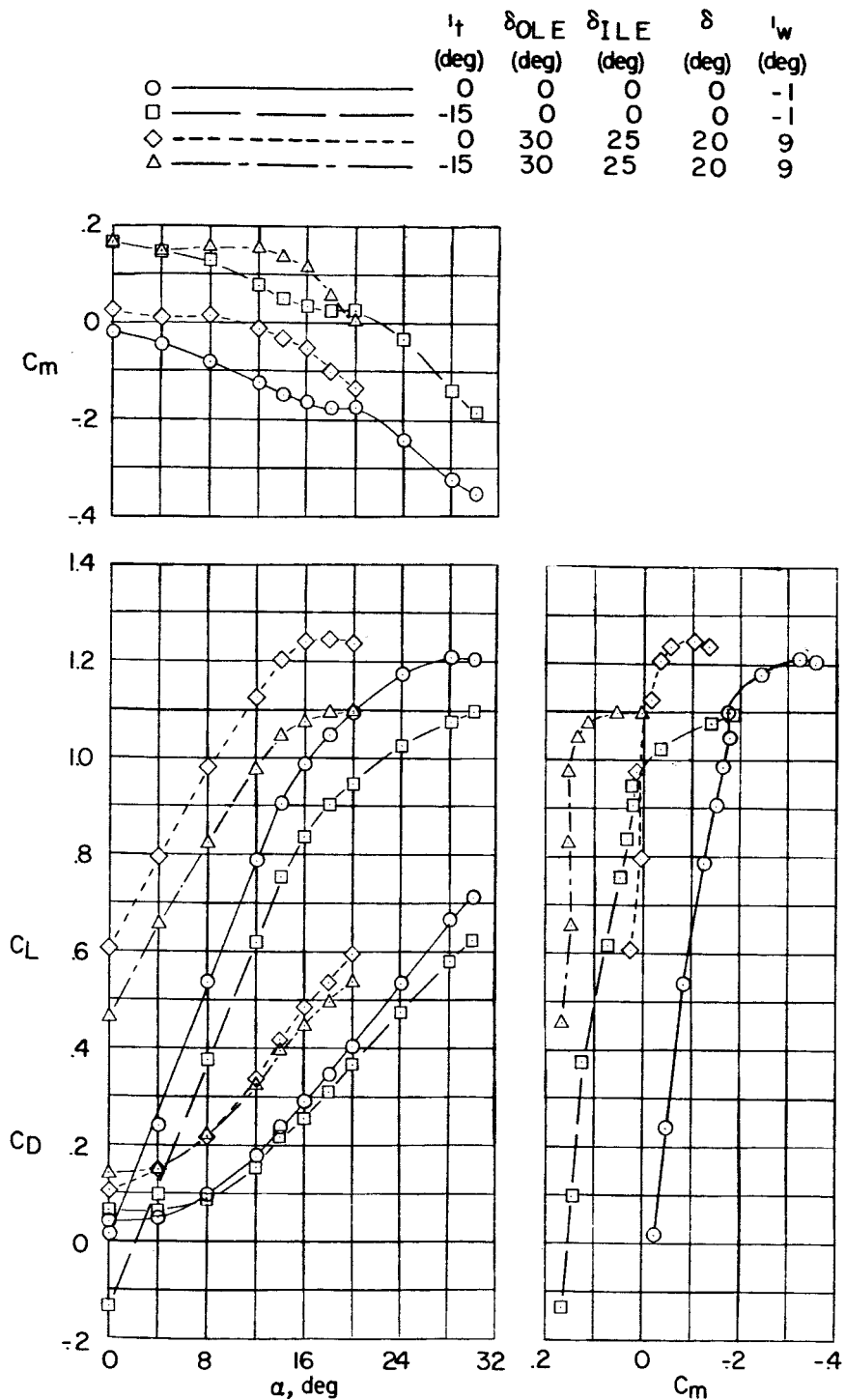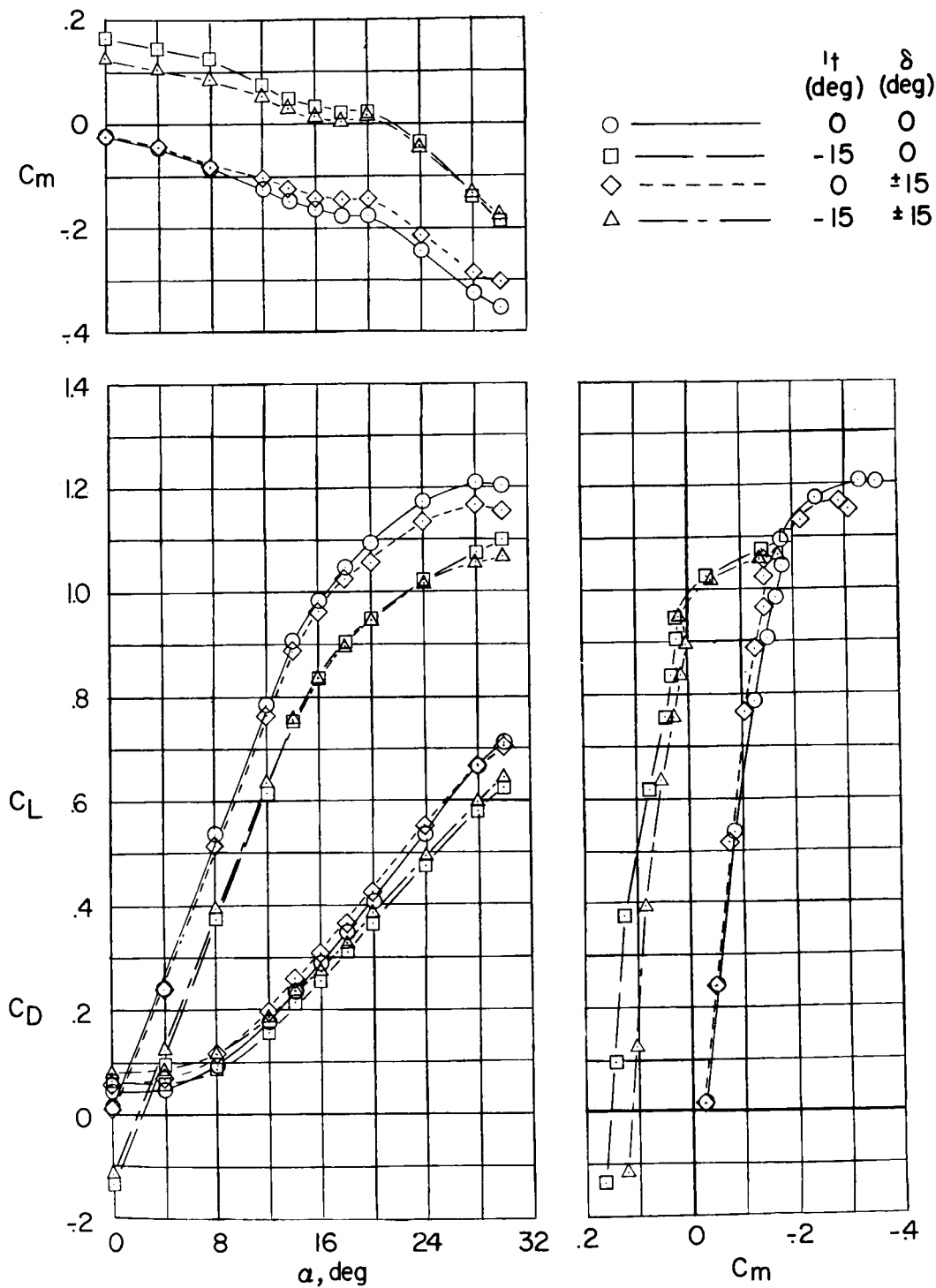All dimensions are in inches.

Figure 3.- Longitudinal characteristics of the model in the clean and landing conditions with the horizontal tail in the low position.

(a) Horizontal tail in low position.

Figure 4.- Effect of vertical position and differential deflection of
the horizontal tail on the longitudinal characteristics of the model
in the clean condition. All flap deflections zero. $i_w = -1°$.
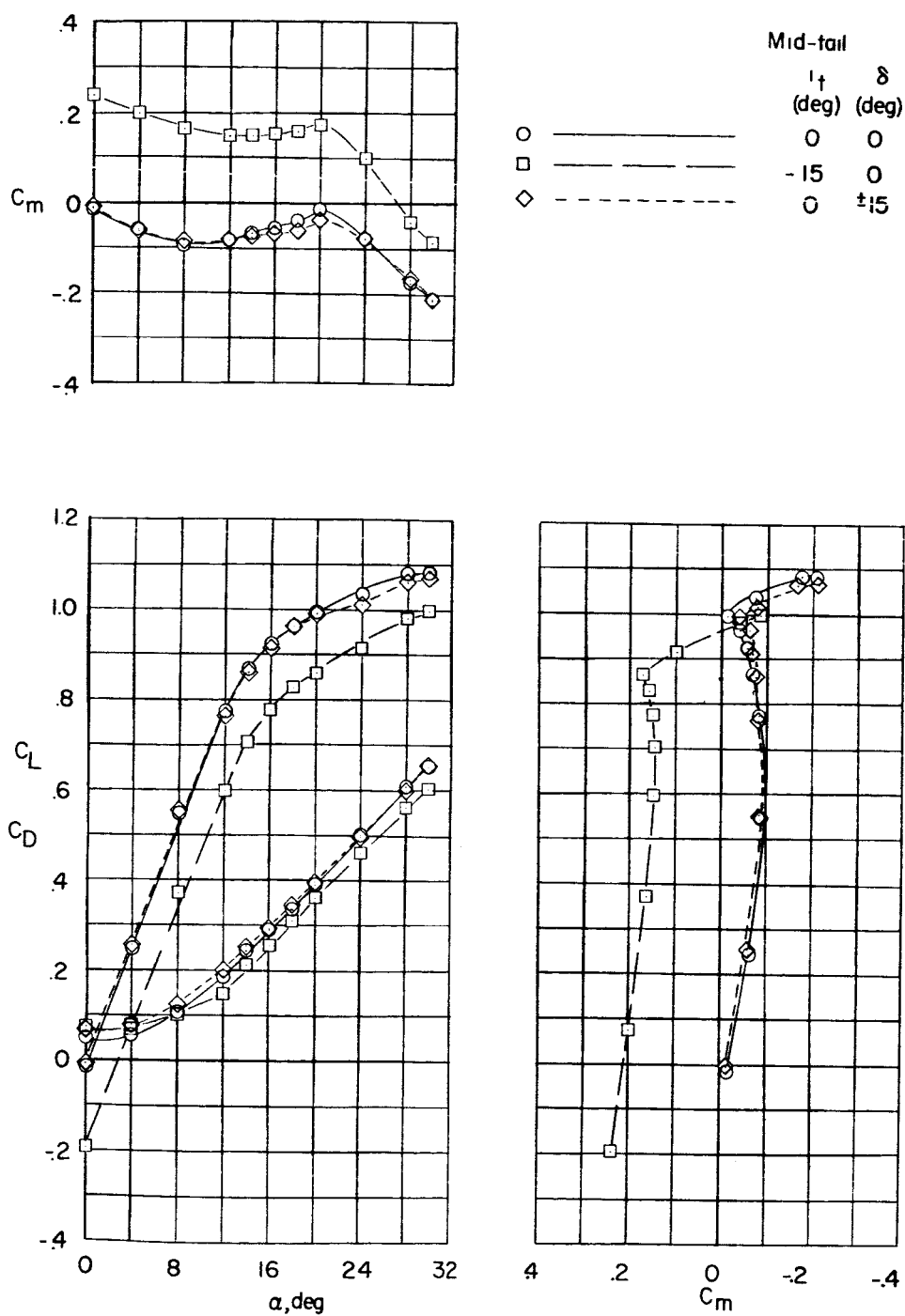
(b) Horizontal tail in middle position.
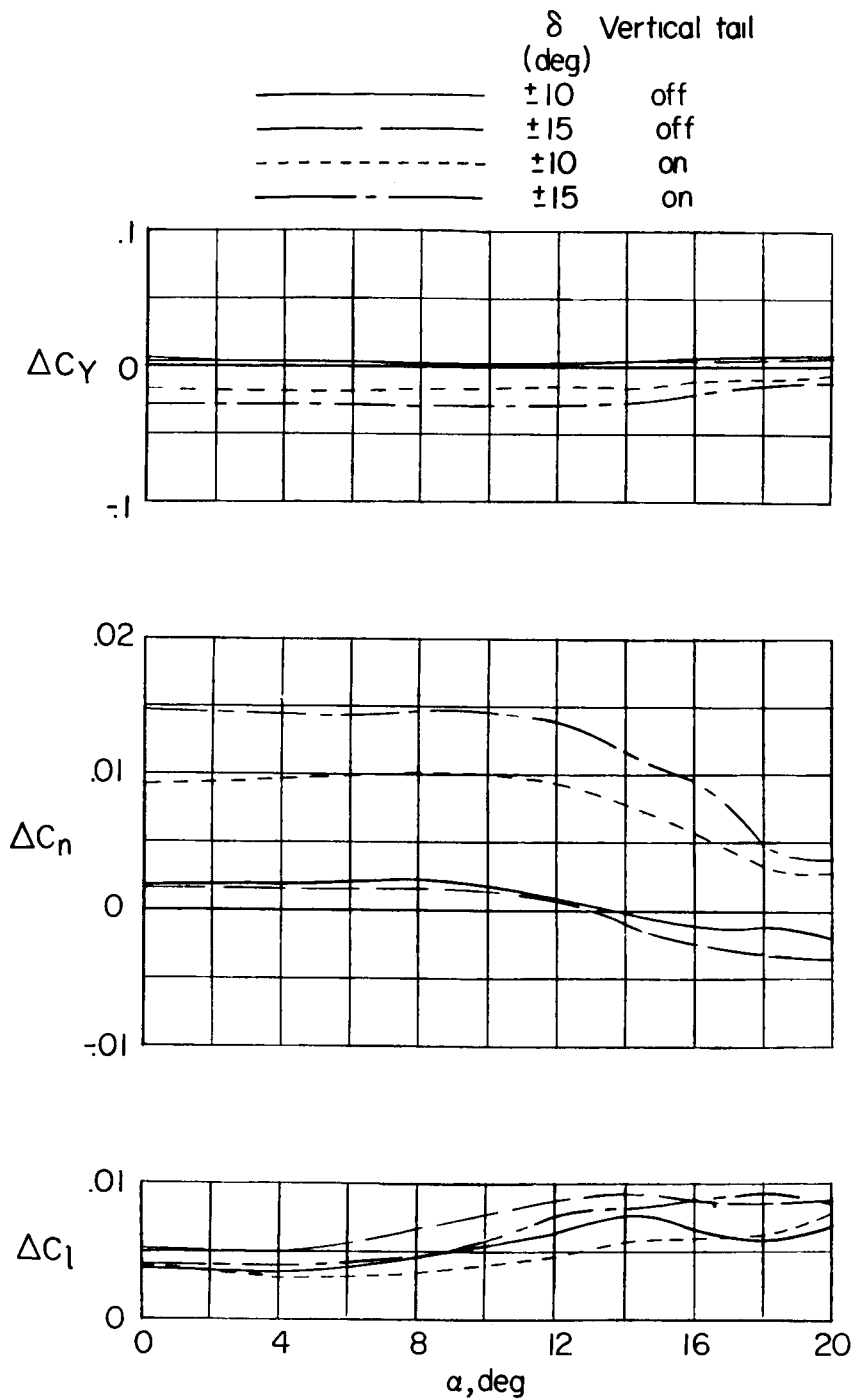
Figure 4.- Continued.
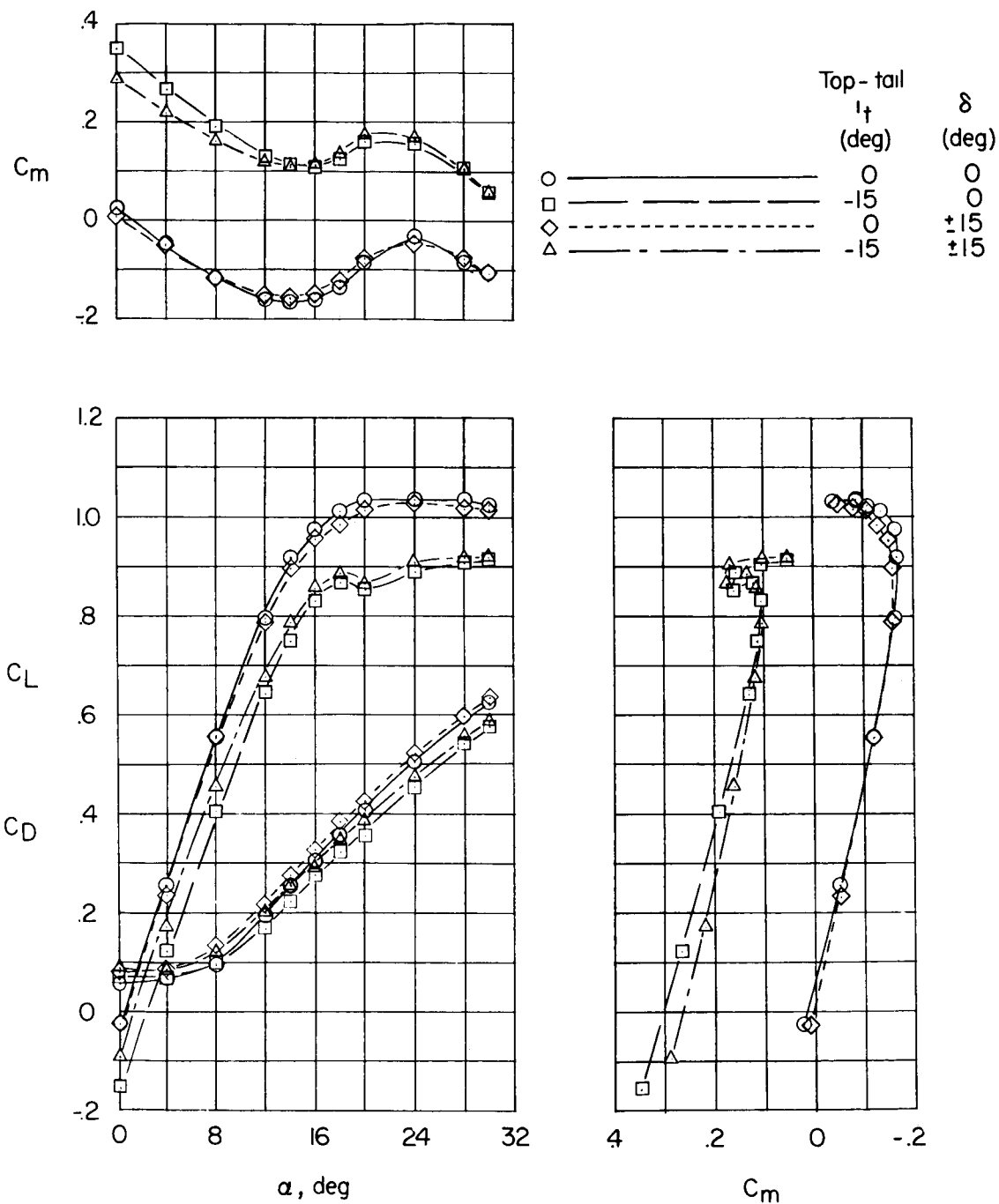
(c) Horizontal tail in high position.

Figure 4.- Concluded.
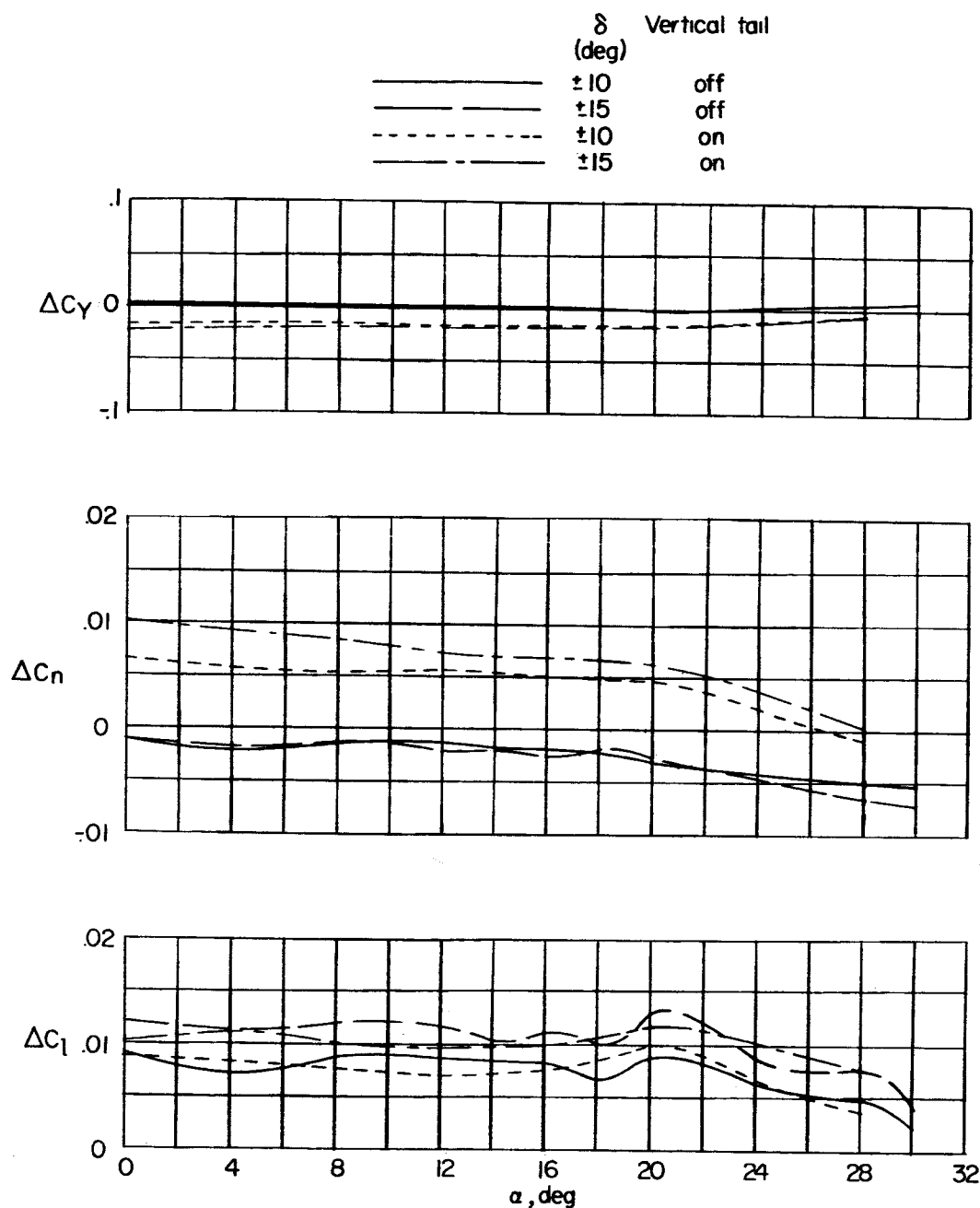
(a) $i_t = 0°$.

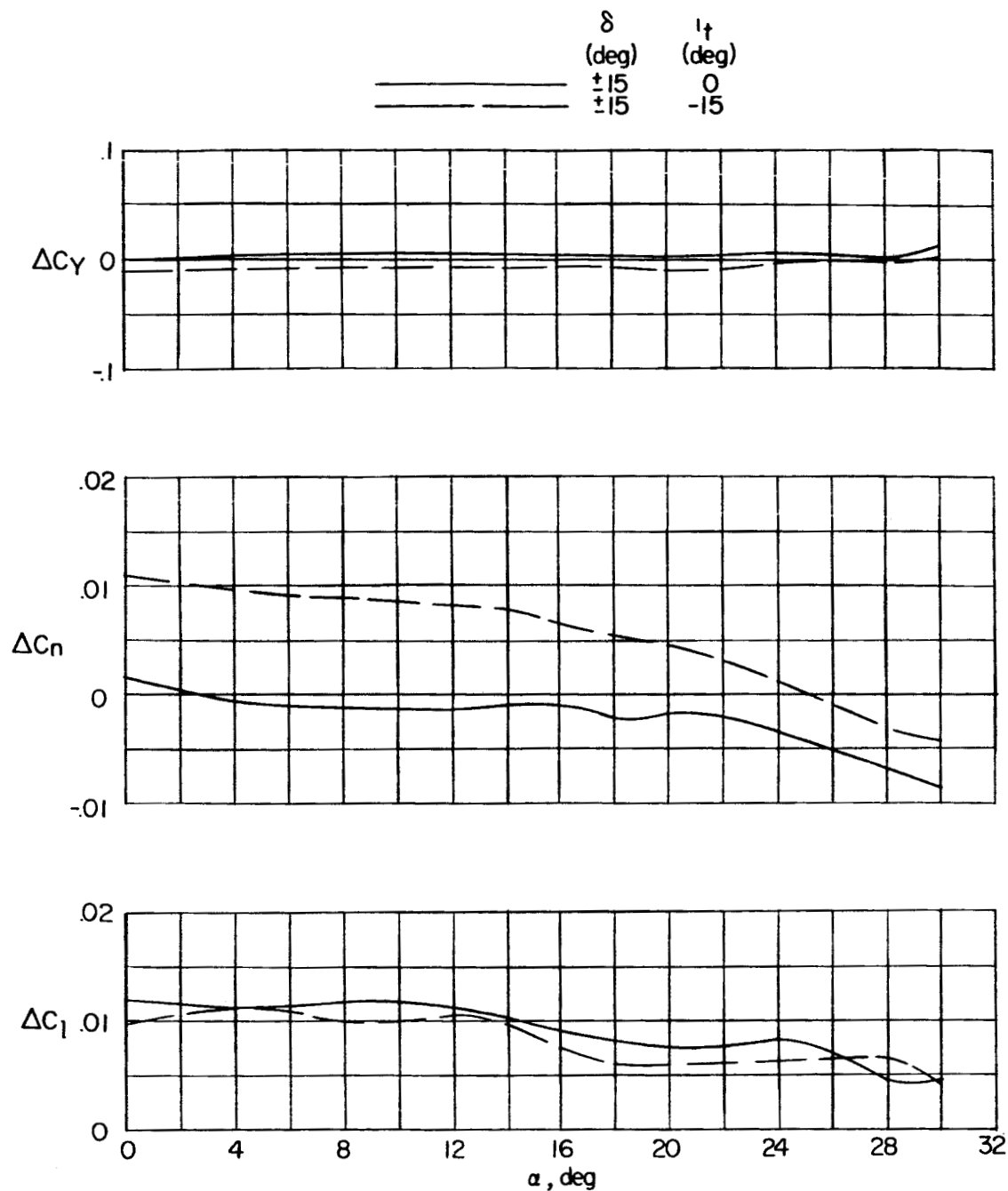Figure 5.- Increments in the lateral-force and moment coefficients produced by differential deflection of the horizontal tail in the low position for the model in the clean condition.
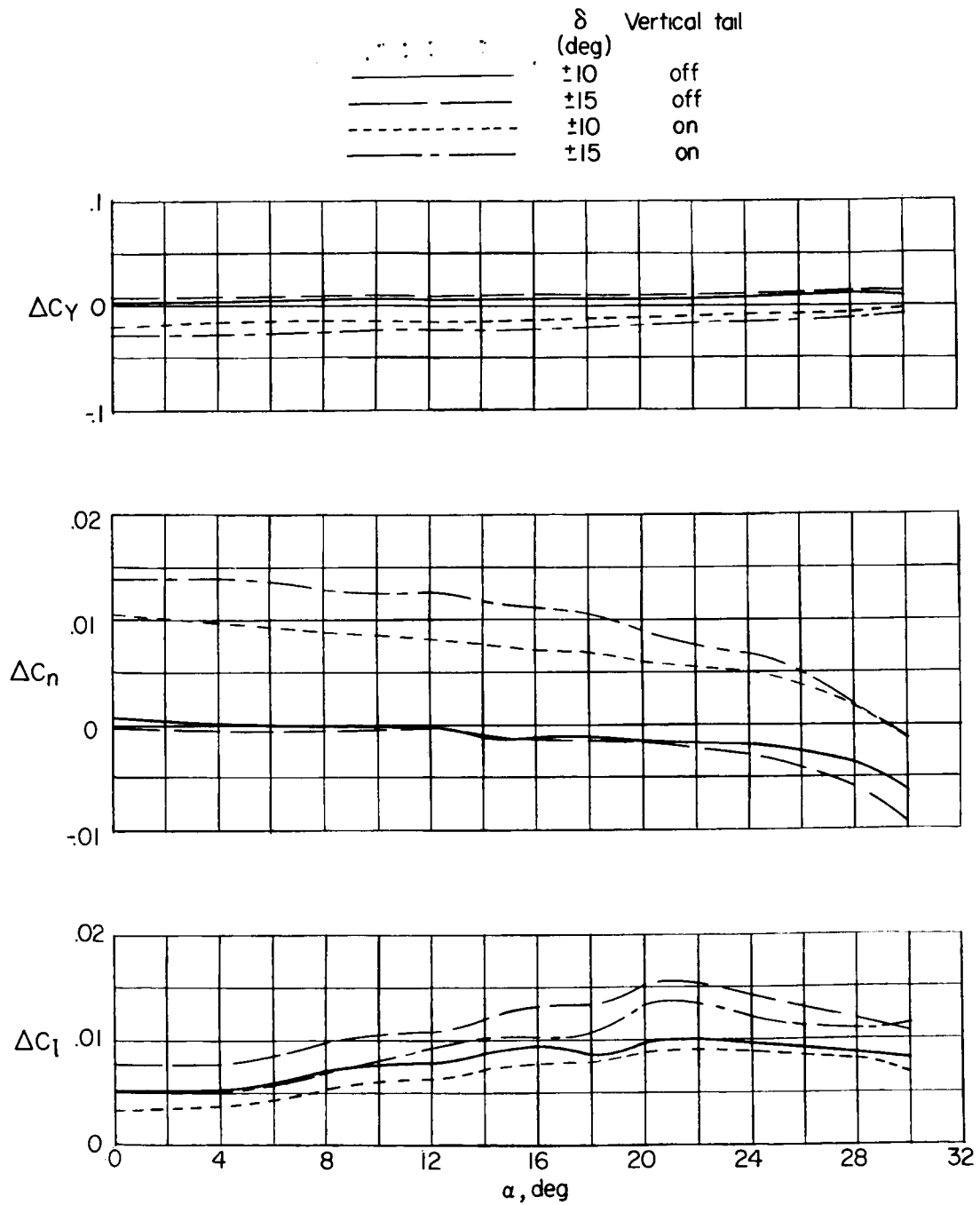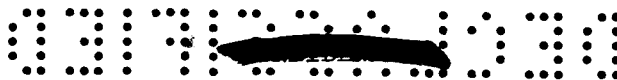
(b) $i_t = -15^o$.

Figure 5.- Concluded.
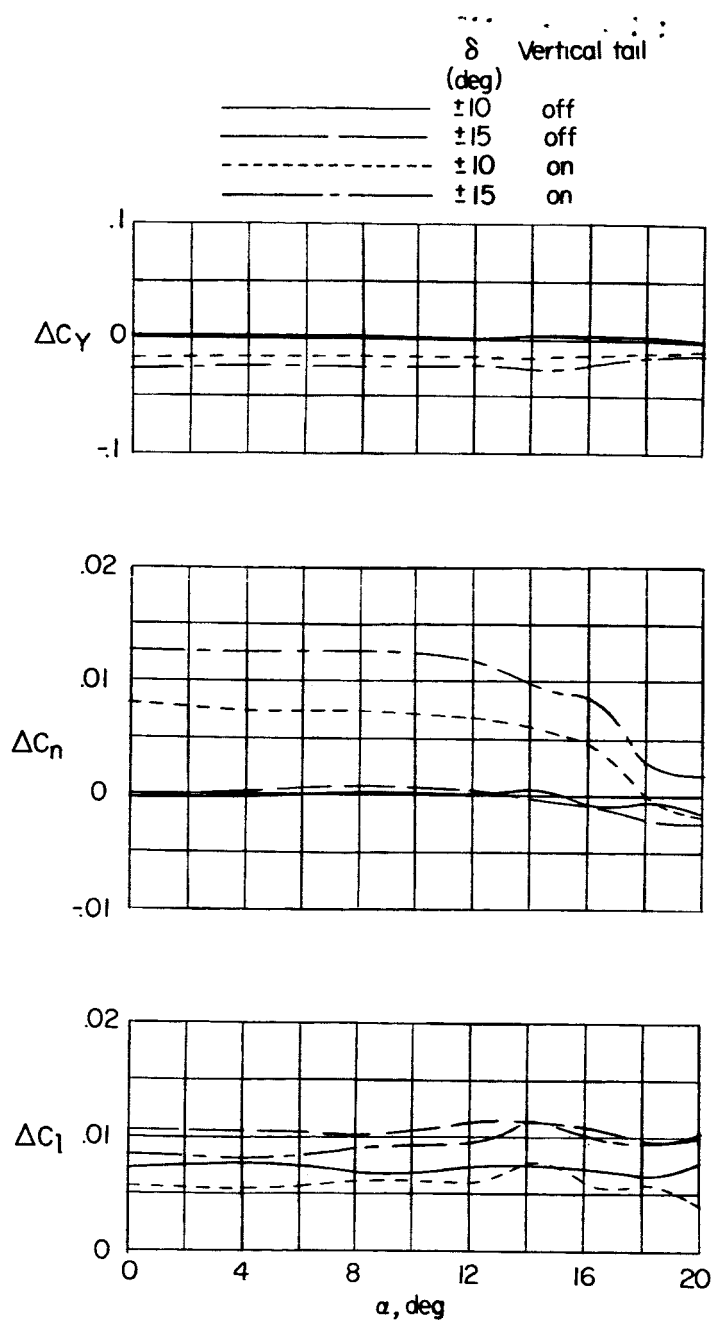
(a) $i_t = 0°$.

Figure 6.- Increments in the lateral-force and moment coefficients pro-
duced by differential deflection of the horizontal tail in the low
position for the model in the landing condition.

(b) $i_t = -15°$.

Figure 6.- Concluded.

Figure 7.- Increments in the lateral-force and moment coefficients produced by differential deflection of the horizontal tail in the middle position for the model in the clean configuration with vertical tail on.
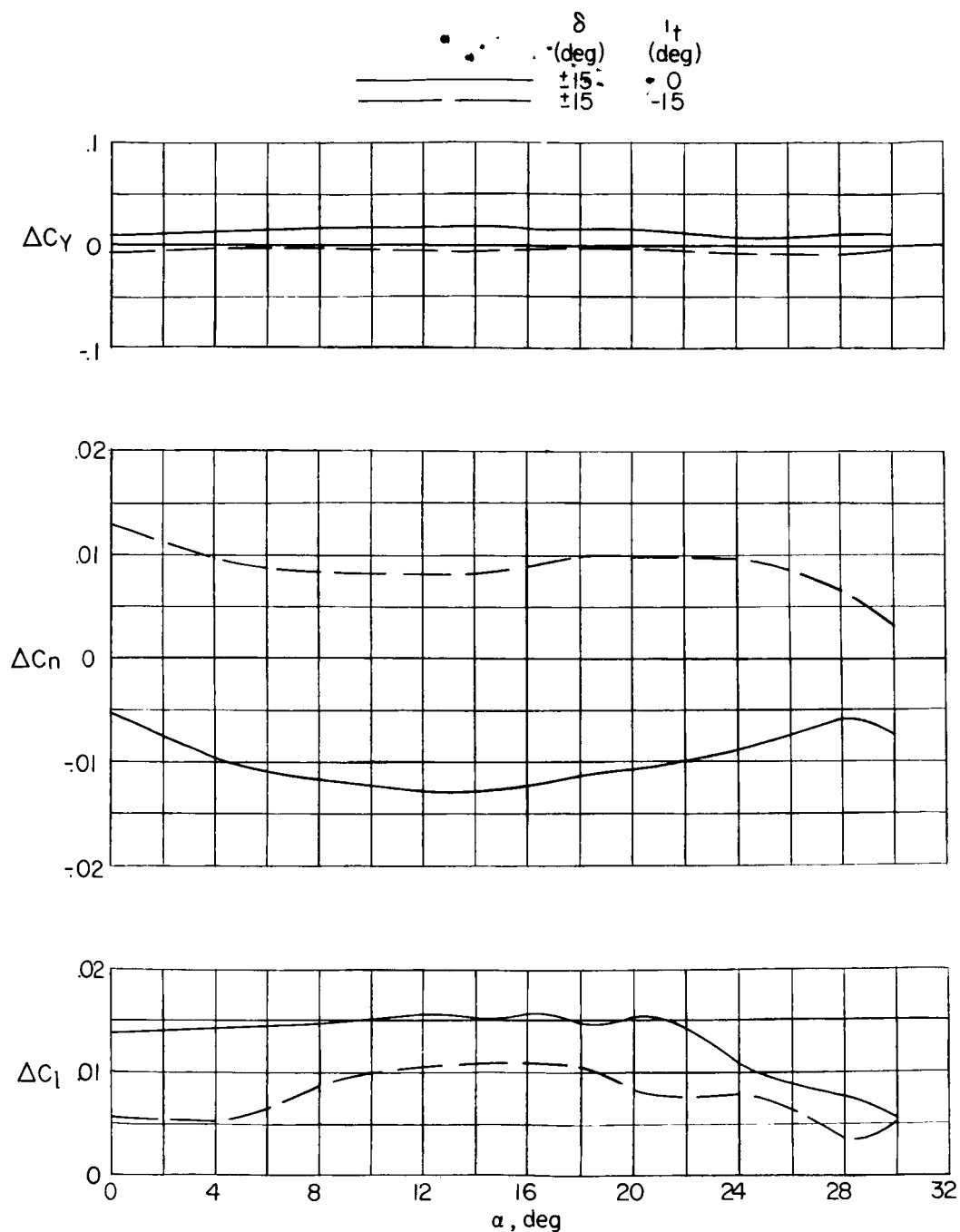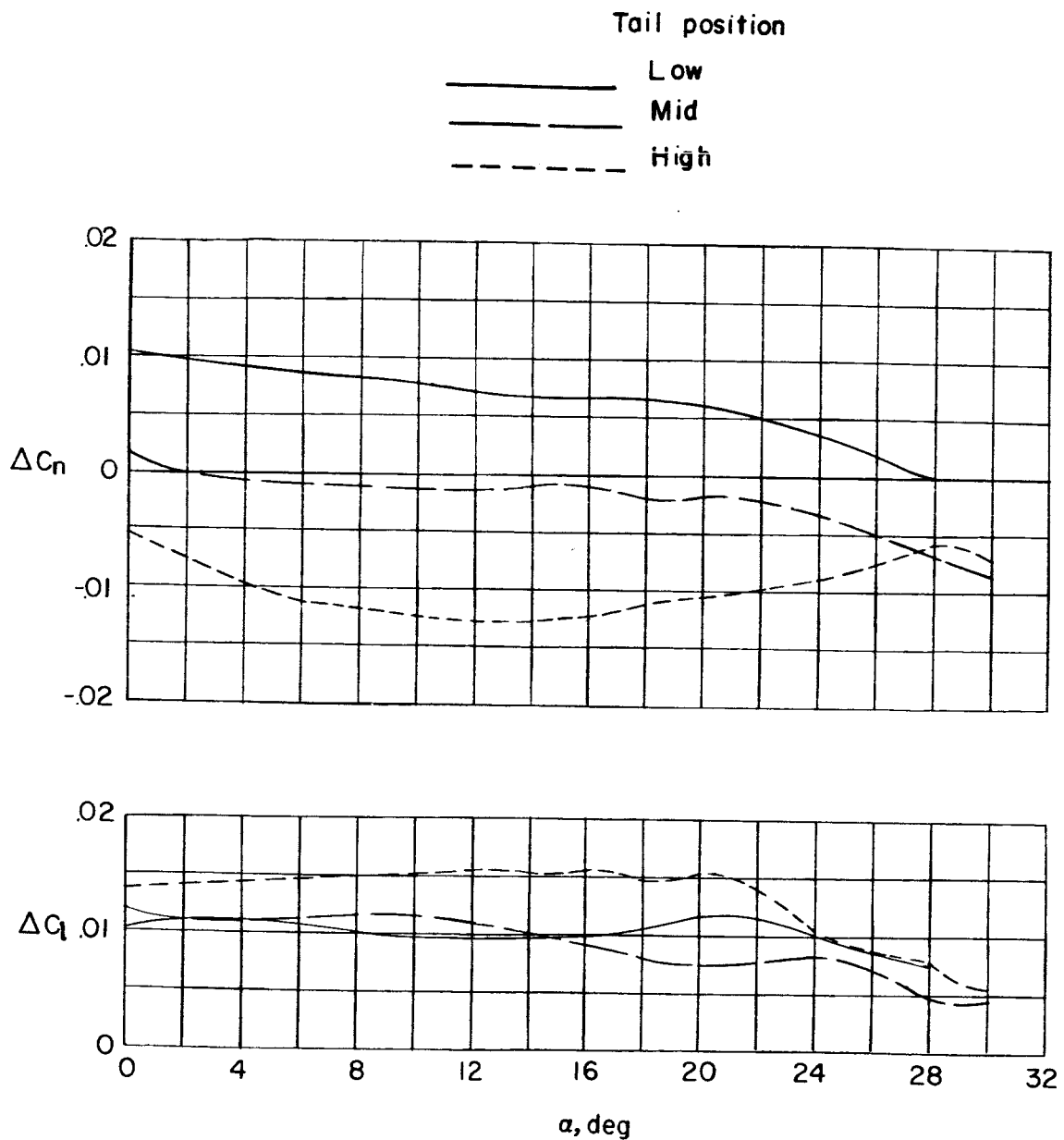
Figure 8.- Increments in the lateral-force and moment coefficients produced by differential deflection of the horizontal tail in the high position for the model in the clean configuration with vertical tail on.

Tail position

_____ Low

_____ _____ Mid

_ _ _ _ _ _ High

(a) $i_t = 0°$.

Figure 9.- Comparison of the yawing- and rolling-moment coefficients pro-
duced by differential deflection of the horizontal tail at various
vertical positions. $\delta = \pm 15°$.

Tail position

Low

Mid

High

ΔC_n

ΔC_l
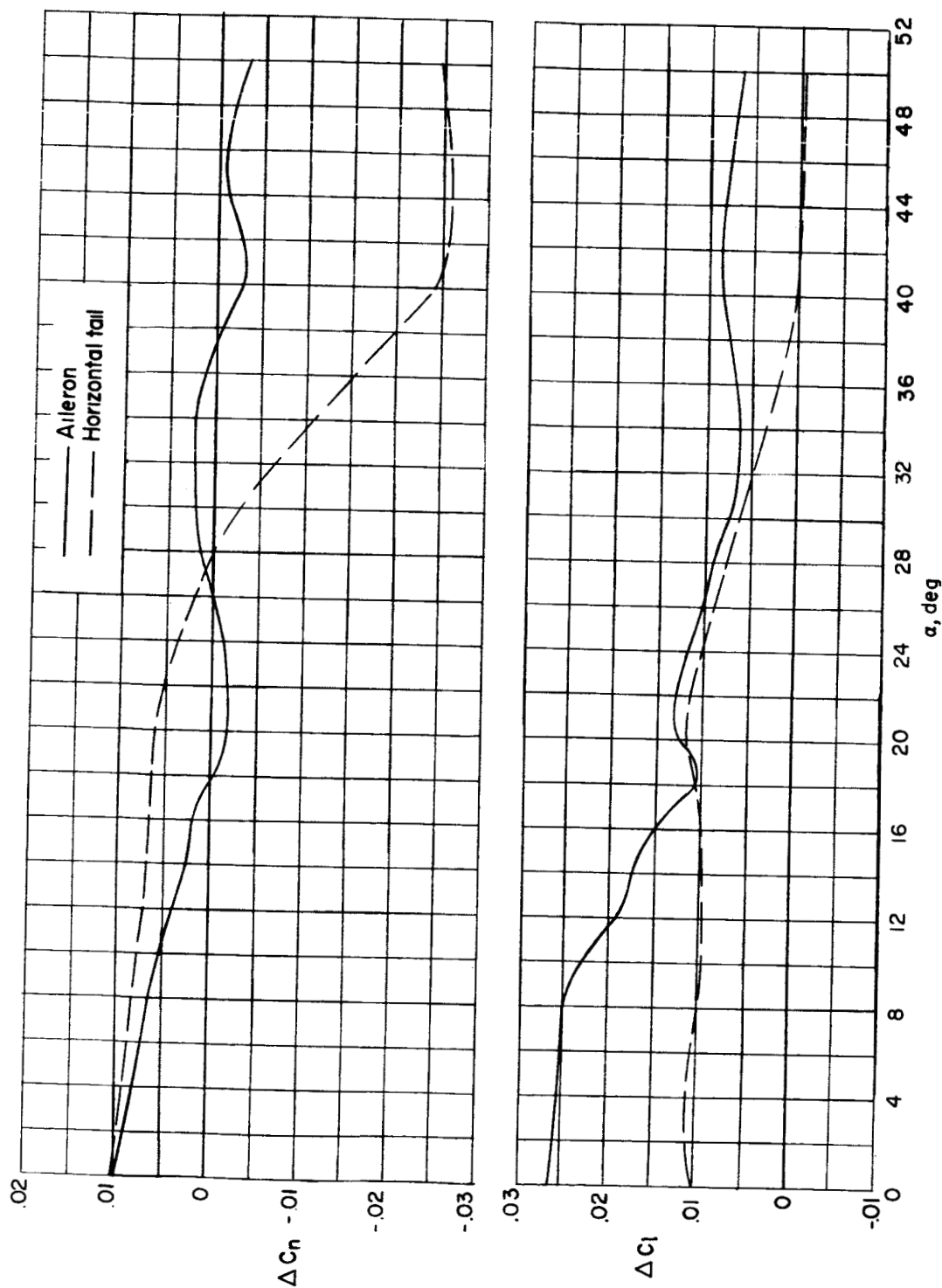
α, deg
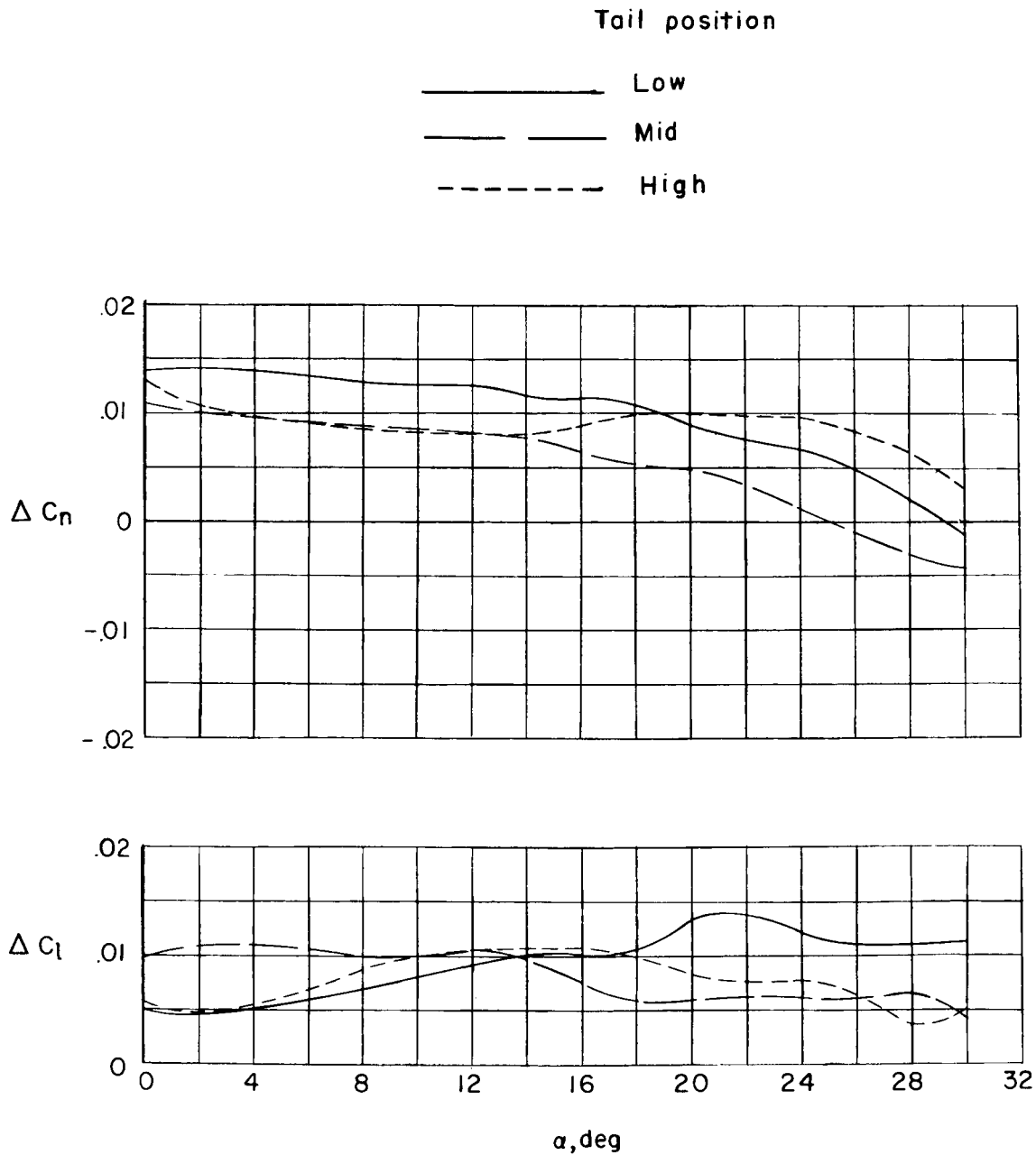
(b) $i_t = -15^o$.

Figure 9.- Concluded.

Figure 10.- Comparison of the lateral-control effectiveness produced by the ailerons and horizontal tail (low position). $\delta = \pm 15°$; $i_t = 0°$.