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RESEARCH MEMORANDUM

WIND-TUNNEL INVESTIGATION AT HIGH SUBSONIC SPEEDS OF THE STATIC LONGITUDINAL STABILITY CHARACTERISTICS OF A COMPLETE MODEL HAVING CROPPED-DELTA, SWEPT, AND UNSWEPT WINGS AND SEVERAL HORIZONTAL-TAIL HEIGHTS

By Kenneth W. Goodson and Robert E. Becht

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Langley Field, Va.

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON
October 15, 1954

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

WIND-TUNNEL INVESTIGATION AT HIGH SUBSONIC SPEEDS OF THE STATIC LONGITUDINAL STABILITY CHARACTERISTICS OF A COMPLETE MODEL HAVING CROPPED-DELTA, SWEPT, AND UNSWEPT WINGS AND SEVERAL HORIZONTAL-TAIL HEIGHTS

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SUMMARY

An investigation was made at high subsonic speeds of a complete model equipped with various wings: a cropped-delta wing, a 30° swept wing, and an unswept wing. In general, the wings were unrelated geometrically, except that all wings were of aspect ratio 3.0. These wings were tested at a midheight position in conjunction with complete-model configurations having the horizontal tail in various locations, ranging in height from the wing-chord plane to the top of the vertical tail. The swept wing was also tested with the tail below the wing-chord plane. The tests were made in the Langley high-speed 7- by 10-foot tunnel at Mach numbers from 0.80 to 0.92.

The data show that the cropped-delta wing (horizontal tail off) has the most linear pitching-moment characteristics compared with the swept or unswept wings for the angle-of-attack and Mach number ranges tested. Addition of a tail in the chord plane extended generally provides increasing stability with increasing lift coefficient for any of these wings. Complete-model configurations having these wings and having the horizontal tail located at a medium-height position invariably result in either pitch-up or erratic pitching-moment curves in the moderately high lift range. With the high tail, the cropped-delta configuration shows the most nearly linear pitching-moment characteristics over a reasonably large lift-coefficient range of any of the tail-on configurations tested for the Mach number range covered. In the vicinity of maximum lift coefficient, however, all wings with the high tail showed an abrupt pitch-up, at least for a Mach number of 0.80.

The lift-curve slopes are about equal for the swept, unswept, and cropped-delta wings at Mach numbers of 0.80 and 0.90. The drag due to lift for these configurations is approximately the same at low lift coefficients at Mach numbers of 0.80 and 0.90. At higher lift coefficients at a Mach number of 0.90, the drag due to lift of the swept and unswept wings is lower than that of the cropped-delta wing probably because the cropped-delta wing (due to its greater thickness) reaches compressibility stall earlier than the other wings.

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INTRODUCTION

Many research and production-type airplanes experience abrupt reductions in longitudinal stability (pitch-up) at moderate and high lift coefficients, particularly when flying at high subsonic and transonic speeds. Investigations of thin-wing models having various sweep angles, aspect ratios, and taper ratios (refs. 1 to 6) have shown that these effects can be minimized by proper selection of wing plan form and horizontal-tail location. These data led to considerable interest in several low-aspect-ratio plan forms, three of which were tested in the present investigation. The three wings tested had cropped-delta, swept, and unswept plan forms.

In general, the wings of this investigation were unrelated geometrically, except that all wings were of aspect ratio 3.0. The cropped-delta wing used in this investigation was obtained from the delta wing of reference 3 by clipping the tips and thereby reducing the aspect ratio from 4.0 to 3.0. The section thickness of the cropped-delta wing was 6 percent of the streamwise chord; whereas, the thickness of the other wings was 4 percent of the chord. Longitudinal characteristics were determined for a model equipped with each of these wings and with the horizontal tail located at various heights.

COEFFICIENTS AND SYMBOLS

All data are presented with respect to the stability axes as shown in figure 1. The pitching-moment coefficients are referred to the quarter-chord point of the mean aerodynamic chord except where noted.

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

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

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

ΔC_D drag due to lift

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

ρ mass density of air, slugs/cu ft

V free-stream velocity, ft/sec

M Mach number

S wing area, sq ft

c local chord parallel to plane of symmetry, ft

c_r root chord, ft

c_t tip chord, ft

$\bar{c}$ wing mean aerodynamic chord, $\frac{2}{S}\int_0^{b/2} c^2 dy$, ft

$\bar{c}_V$ vertical-tail mean aerodynamic chord, ft

b wing span, ft

y spanwise distance from plane of symmetry, ft

z horizontal-tail height from fuselage center line, positive upward, ft

α angle of attack, deg

A aspect ratio

λ taper ratio

$\Lambda_{c/4}$ sweep of quarter-chord line, deg

MODEL AND APPARATUS

A three-view drawing of the midwing complete research model with the cropped-delta wing is shown in figure 2(a) and the swept and unswept wings are shown in figure 2(b). All wings were of aspect ratio 3 but had taper ratios of 0.143, 0.50, and 0.20, respectively. The tips of an existing aspect-ratio-4 delta wing of 0.06c thickness (ref. 3) were cut off to form the cropped-delta wing. The 30° swept wing and the unswept wing (50-percent-chord line unswept) were of new construction and were of 0.04c thickness. It is felt that the difference in thickness will not greatly affect the overall comparison of the stability characteristics of these complete-model configurations.

A sketch of the vertical locations of the horizontal tail is shown in figure 2(c). The construction of the tail assembly limited the incidence of the horizontal tail to 0° for all tail heights. The dimensions of the 10.93 fineness ratio fuselage are presented in figure 2(d).

TESTS

The sting-supported model was tested in the Langley high-speed 7- by 10-foot tunnel through a Mach number range of 0.80 to 0.92 and through an angle-of-attack range that varied with loading conditions (the maximum range being about -2° to 24°). The Reynolds number (based on the mean aerodynamic chord) varied with Mach number from about 2.5×10^{6} to 3.0×10^{6}. Only the horizontal tail (not the vertical tail) was removed for the tail-off pitch tests. Note that the low horizontal tail was tested only with the swept-wing configuration.

CORRECTIONS

Blockage corrections were applied to the results by the method of reference 7. Jet-boundary corrections to the angle of attack and drag were applied in accordance with reference 8. Corrections for effects of the longitudinal pressure gradient in the wind-tunnel test section have been applied to the data.

Model support tares have not been applied, except for a fuselage base-pressure correction to the drag. The corrected drag data represent a condition of free-stream static pressure at the fuselage base. From past experience, it is expected that the influence of the sting support on the model characteristics is negligible with regard to the lift and pitching moment.

The angle of attack has been corrected for deflection of the balance and sting support. No attempt has been made to correct the data for aeroelastic distortion of the model.

PRESENTATION OF RESULTS

The results of the investigation are presented in the following figures:

DISCUSSION

Pitching-moment characteristics.- The static longitudinal characteristics of complete-model configurations having cropped-delta, swept, or unswept wings and having several horizontal-tail locations are presented in figures 3, 4, and 5. In order to provide a more reasonable comparison of the stability characteristics of the present configurations, some of the data obtained at Mach numbers of 0.80 and 0.90 have been recomputed about centers of gravity such that a static margin of $0.05\bar{c}$ at a Mach number of 0.80 is obtained. (See fig. 6.) Note that the change in the slope $\left(\frac{\partial C_m}{\partial C_L}\right)_{C_L=0}$ caused by increasing the Mach number from 0.80 to 0.90 represents a change in stability caused by the change in Mach number.

In general, the departures from linearity for the tail-off pitching-moment curves are smaller for the cropped-delta wing than for either the 30° swept wing or for the unswept (50-percent-chord line unswept) wing at Mach numbers from 0.85 to 0.92 (figs. 3 to 6) for the lift-coefficient range tested. The cropped-delta wing does, however, have a slight tendency toward reduced stability at a lift coefficient of about 0.5 for Mach numbers of 0.80, 0.90, and 0.92. Addition of a horizontal tail to the model in the wing-chord plane extended alleviated any pitch-up tendency of these three wings at low Mach numbers (0.80 and 0.85), although at a Mach number of 0.90 a tendency toward pitch-up was indicated for the cropped-delta wing. Tails located in this region (center tail) resulted in increased stability near maximum lift coefficient for all wings. A low tail tested with only the swept wing for a limited angle-of-attack range showed characteristics similar to those obtained with the center tail. Location of the horizontal tail in the medium-height position invariably resulted in either pitch-up or erratic pitching-moment curves in the moderately high lift range for all configurations. With the horizontal tail located in the high position (T-tail), the cropped-delta configuration shows the most nearly linear pitching-moment characteristics over a reasonably large lift-coefficient range of any tail-on configuration tested for the Mach number range covered. In the vicinity of maximum lift coefficient, however, all high tail configurations show an abrupt pitch-up (at least, for a Mach number of 0.80), probably because the tail enters a region of increased downwash and reduced dynamic pressure in the wake of the wing. Above $M = 0.80$, the pitch-up tendency could not be explored so completely because balance limitations reduced the maximum angle of attack that could be obtained.

It should be pointed out that, in addition to the wing downwash effects on pitching-moment characteristics, the possible reduction of dynamic pressure at the tail at the higher angles of attack would affect (lower) the tail effectiveness. Because of the possible effect of dynamic pressure on the tail effectiveness, the magnitude of the pitch-up (abrupt unstable aerodynamic-center change) for the tail-on configurations might have been somewhat less pronounced if the incidence of the horizontal tail had been set to trim the model in the high angle-of-attack range rather than using the arbitrary value of 0° stabilizer incidence.

It is of interest to note that, over the test Mach number range, the change in aerodynamic center for the various tail-on configurations generally is about the same as the change with the horizontal tail off (fig. 7). A plot of the increment of pitching-moment-curve slope near $C_L = 0$ due to addition of the horizontal tail is shown against tail height in figure 8. These data show that the tail contribution to the stability at low lift invariably increases with increase in tail distance away from wing-chord plane and that the contribution is greatest with the 30° swept wing. Figure 8 also indicates that the horizontal-tail contribution to the stability for the low tail position (tested with the swept wing) is greater than for a tail located a similar distance above the wing-chord plane, probably because of the manner in which the tail tranverses the downwash field. This effect is also shown in reference 6.

Lift and drag characteristics.- At a Mach number of 0.80, the swept and unswept wings show a tendency to stall at a lift coefficient of about 0.75 (figs. 4(c) and 5(c)); whereas, no definite stall is noted for the cropped-delta wing (fig. 3(c)) at any of the test Mach numbers for the angle-of-attack range investigated. As the sonic speed is approached, however, stall of the swept and unswept wings is extended beyond the angle-of-attack range of the present tests. Although, the cropped-delta wing is superior in stall characteristics to the other wings, the lift-curve slopes are about the same for all wings at Mach numbers of 0.80 and 0.90 as illustrated in the following table:

Wing	$\left(\frac{\partial C_L}{\partial \alpha}\right)_{C_L=0}$	
	M = 0.80	M = 0.90
Cropped delta	0.065	0.074
Swept	.071	.074
Unswept	.065	.073

A comparison of the drag due to lift of the cropped-delta, swept, and unswept wings is shown in figure 9. In order to better compare the drag characteristics of these wings, drag due to lift (tail-off configuration) is presented to minimize the effect of airfoil thickness. At lift coefficients up to about 0.4, the drag due to lift is essentially the same for these wings for the Mach number range considered. At higher lift coefficients at $M = 0.90$, the cropped-delta wing seems to be definitely inferior to the others; however, this could result from greater compressibility stall effects caused by its greater thickness.

SUMMARY OF RESULTS

An investigation at high subsonic speeds of a complete model having either a cropped-delta, a swept, or an unswept wing indicates the following results:

Comparison of the cropped-delta, swept, and unswept wing-body configurations (horizontal tail off) shows that the cropped-delta configuration has the most linear pitching-moment curve for the angle-of-attack and Mach number ranges tested. Addition of a horizontal tail to the model in the wing-chord plane extended generally results in increasing stability with increasing lift coefficient. Complete-model configurations having these wings and having the horizontal tail located in a midheight position usually result in either pitch-up or erratic pitching-moment curves at moderately high lifts for all Mach numbers tested. For a tail located in the high position (T-tail), the cropped-delta configuration shows the most linear pitching-moment characteristics over a reasonably large lift-coefficient range of any of the tail-on configurations tested; however, at maximum lift an abrupt pitch-up occurs with any of the wings, at least at a Mach number of 0.80.

The lift-curve slopes of the swept, unswept, and cropped-delta wings are about equal at Mach numbers of 0.80 and 0.90. The drag due to lift of these wings is about the same at low lift coefficients for the Mach numbers considered. At high lift coefficients at a Mach number of 0.90, the drag due to lift for the swept and unswept wings is lower than that for the cropped-delta configurations probably because of the earlier compressibility stall with the thicker cropped-delta wing.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., July 29, 1954.

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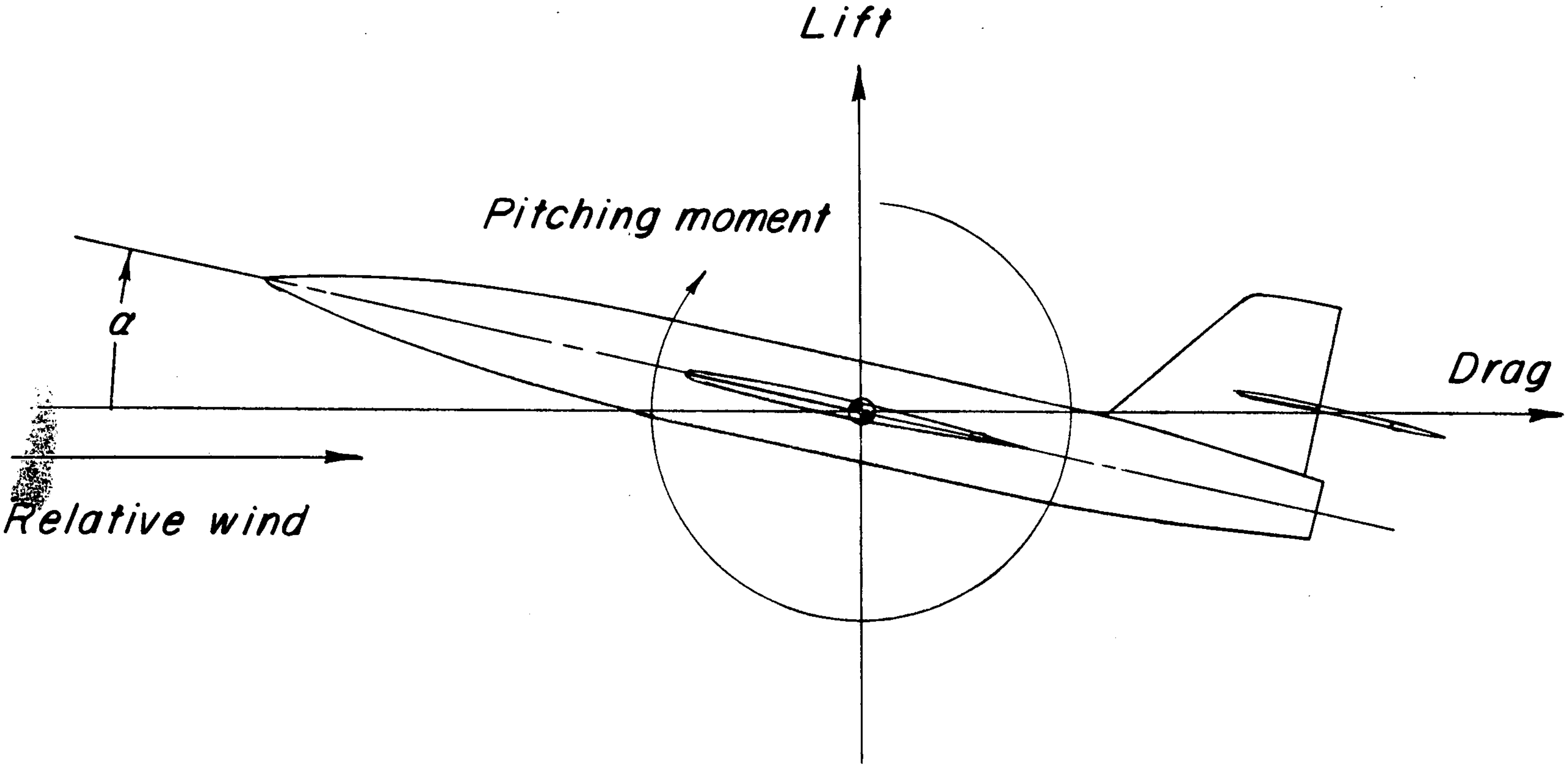
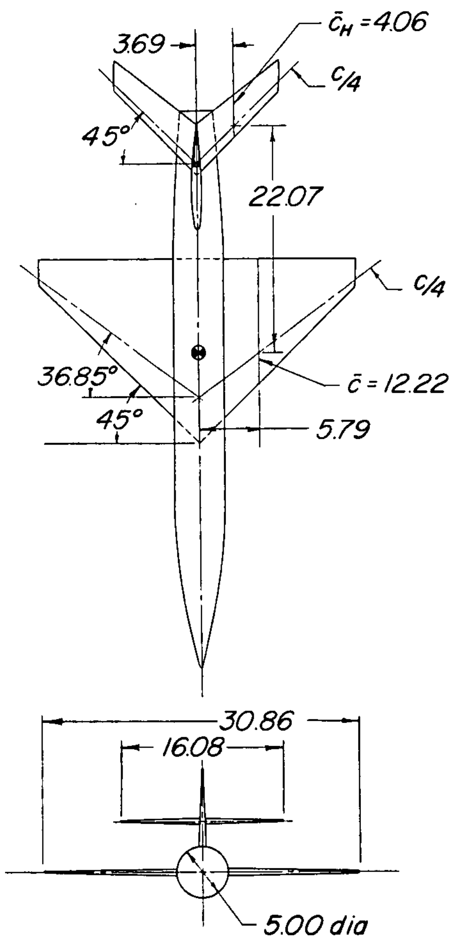
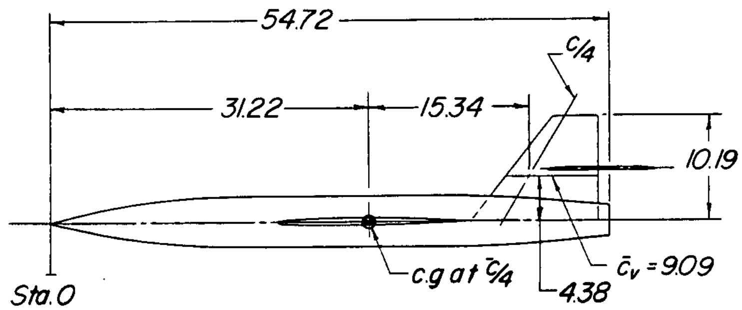


Figure 1.- System of axes. (Positive values of forces, moments, and angles are indicated by arrows.)

Geometric Characteristics of Test Model

	Cropped-delta wing	Horiz. tail	Vertical tail
Area, sq ft	2.20	.451	.612
A	3.00	3.98	1.18
λ	.143	.603	.411
c_t, in.	2.57	3.04	5.04
c_r, in.	18.00	5.04	12.27
$\Lambda_{c/4}$	36.85°	45°	28.01°
NACA airfoil section	65A006	65A006	63A009



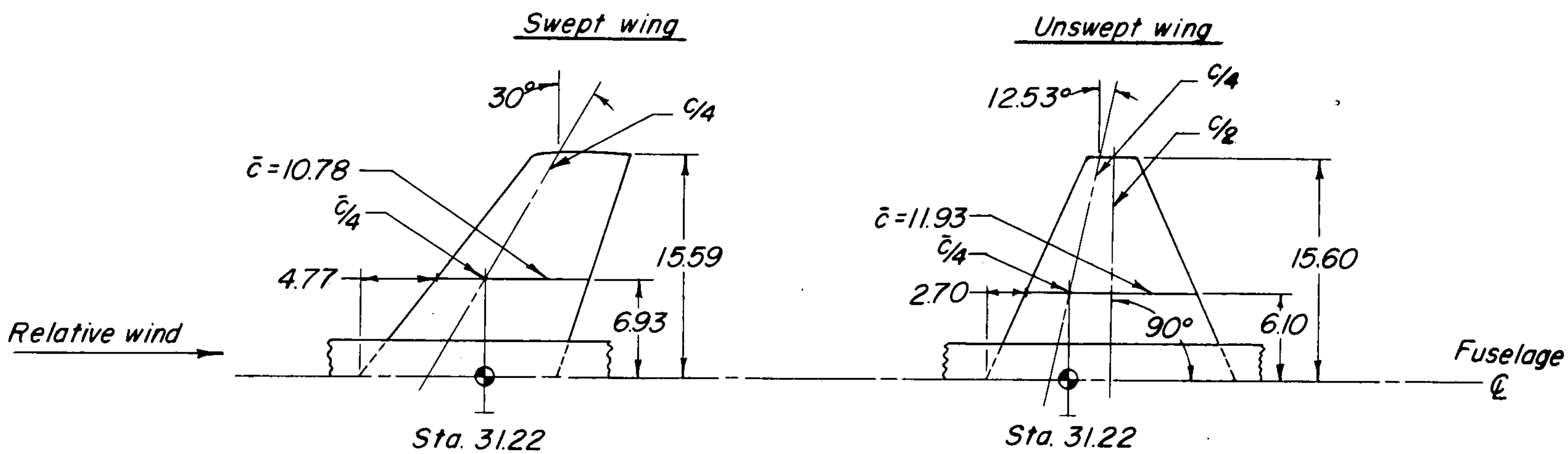


(a) Three-view drawing of model with a cropped-delta wing.

Figure 2.- Geometric characteristics of model. All dimensions in inches.

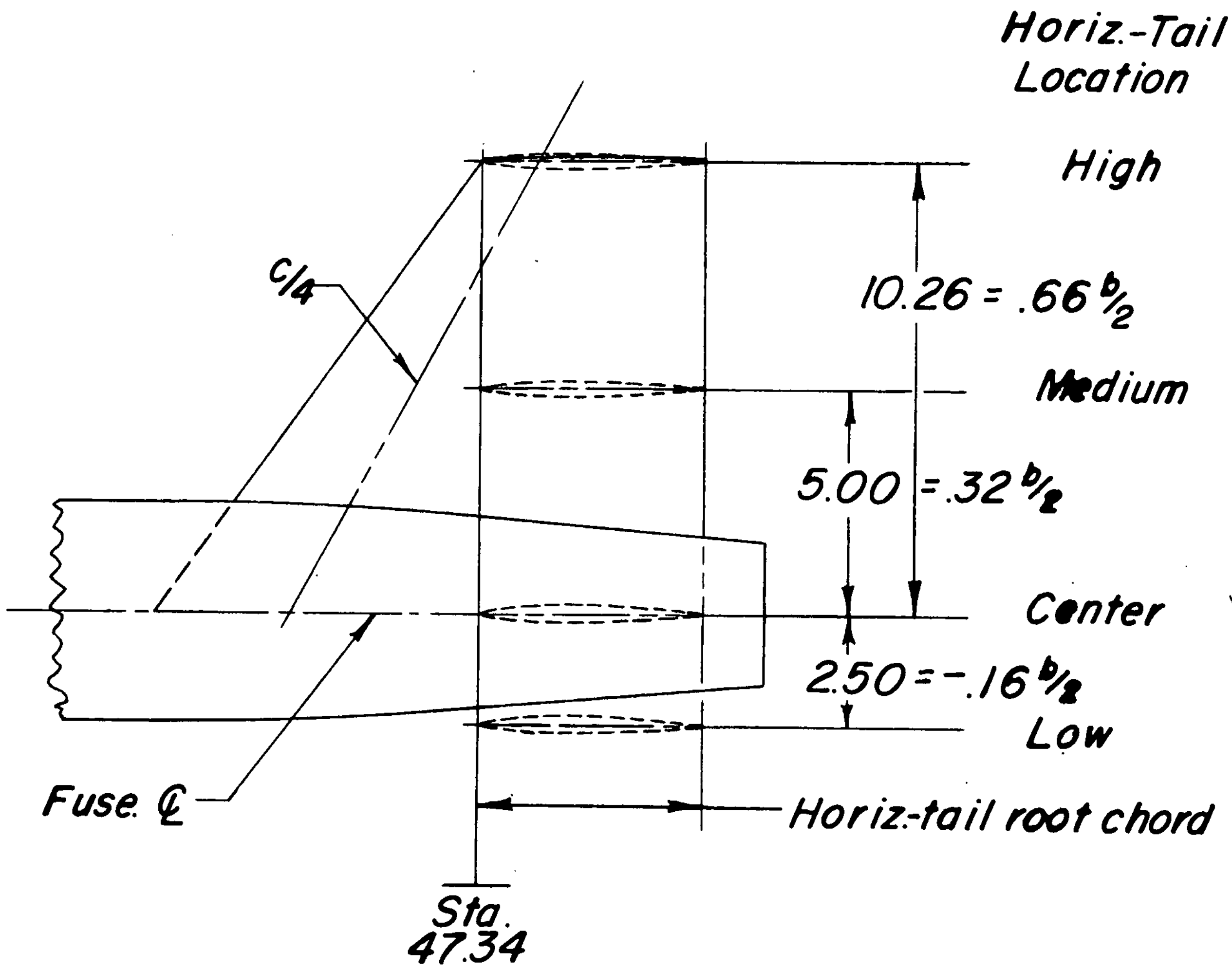
Geometric Characteristics

	Swept wing	Unswept wing
Area, sq ft	2.25	2.25
A	3.00	3.00
λ	.50	.20
c_t, in.	6.93	3.46
c_r, in.	13.86	17.32
$\Lambda_{c/4}$	30°	12.53°
NACA airfoil sections	65A004	65A004



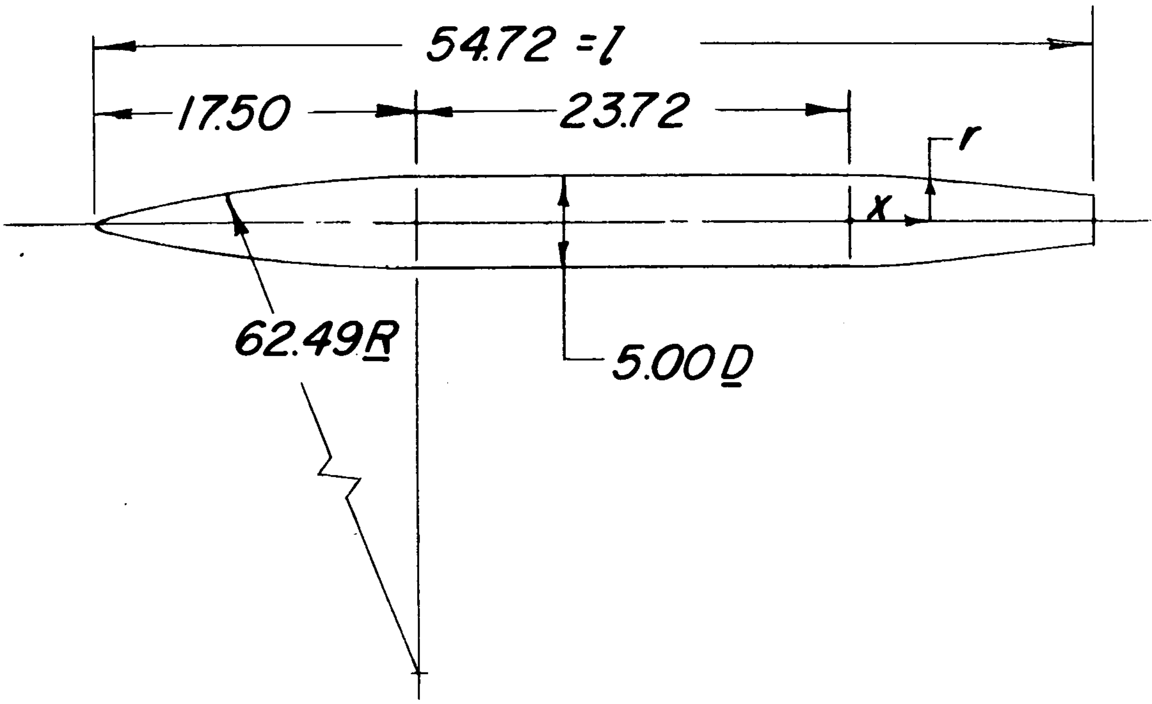
(b) Swept and unswept wings.

Figure 2.- Continued.



(c) Horizontal-tail locations.

Figure 2.- Continued.

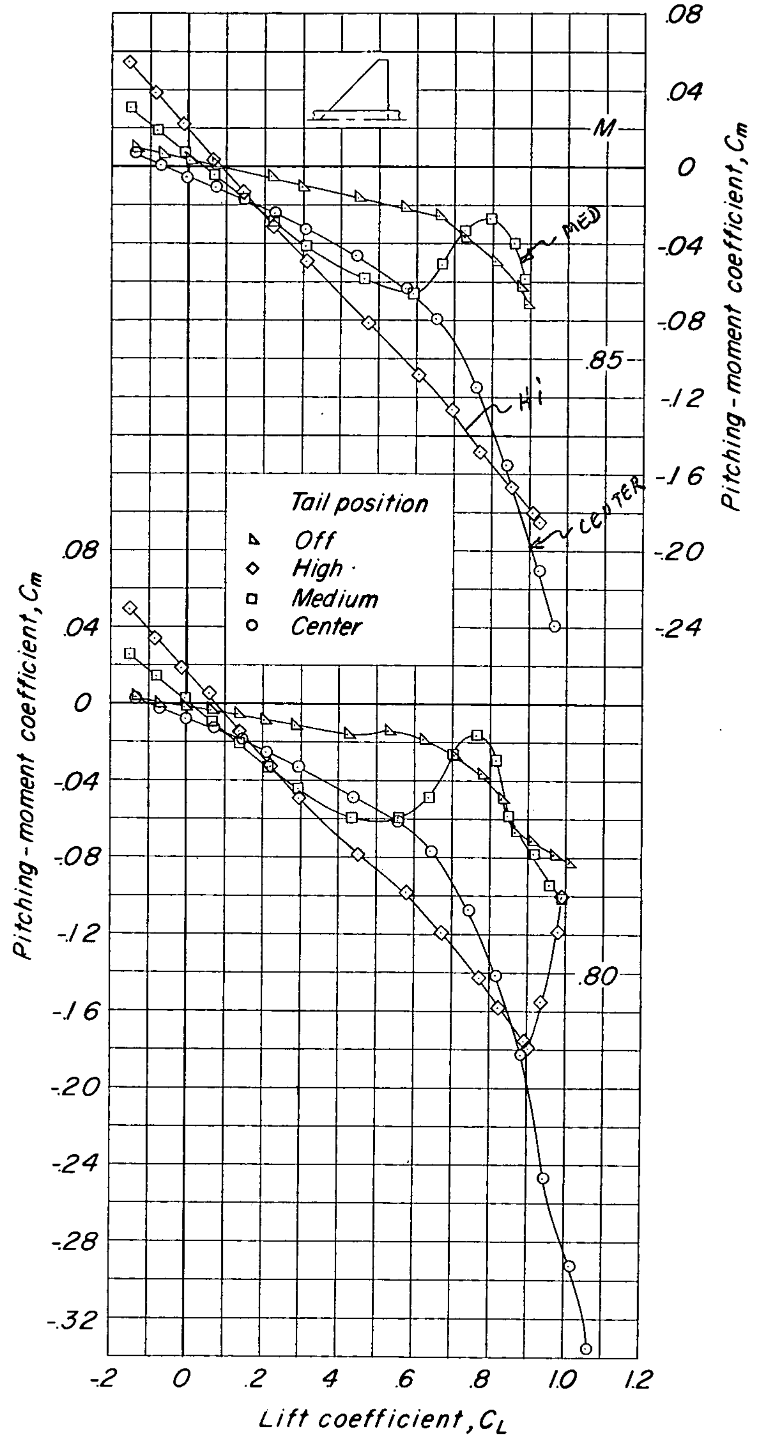


Afterbody Coordinates

x/l	r/l
0	.0456
.0320	.0445
.0639	.0427
.1187	.0390
Straight line taper	
.2460	.0301

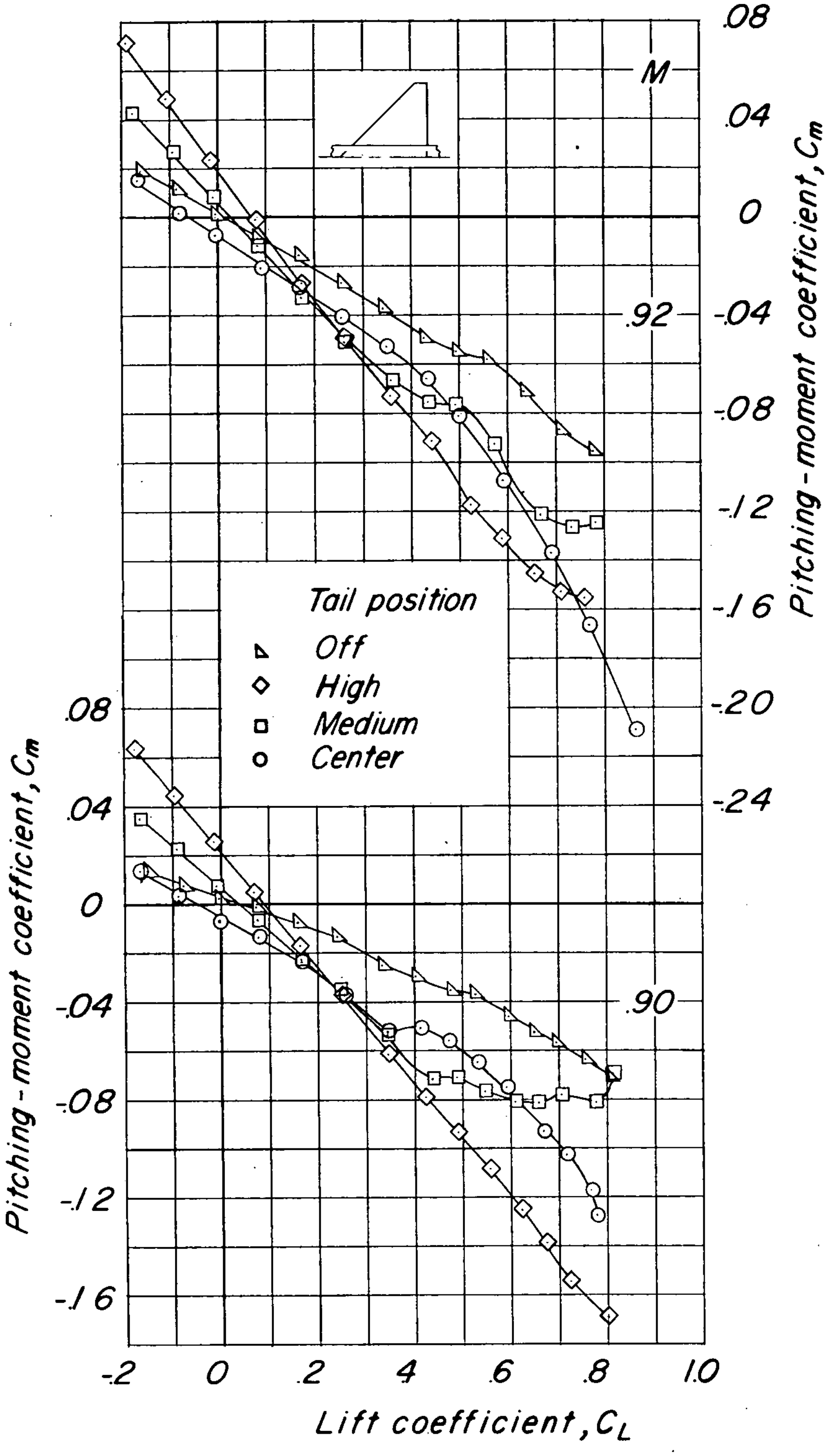
(d) Fuselage dimensions.

Figure 2.- Concluded.



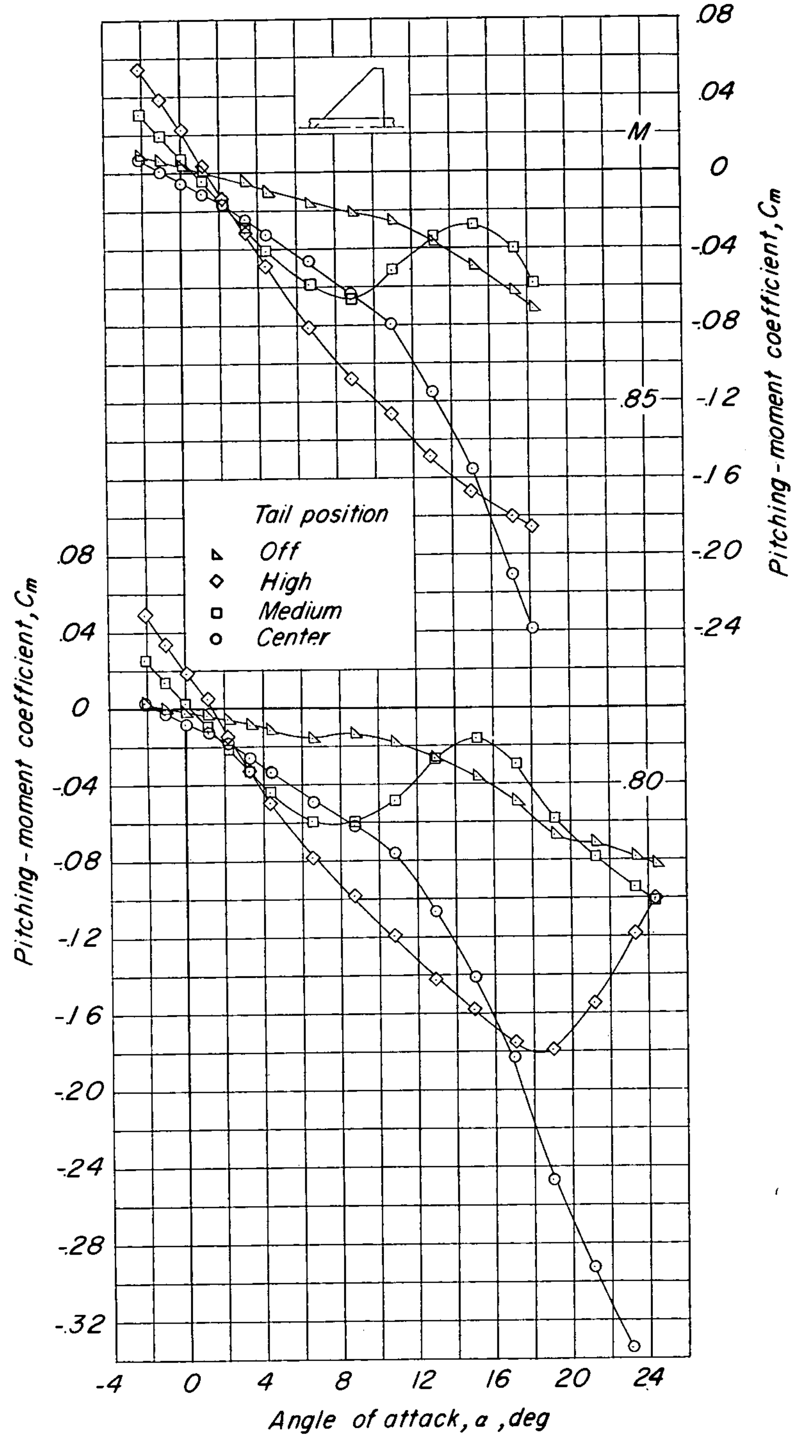
(a) C_m against C_L.

Figure 3.- Longitudinal characteristics of the model with a cropped-delta wing.



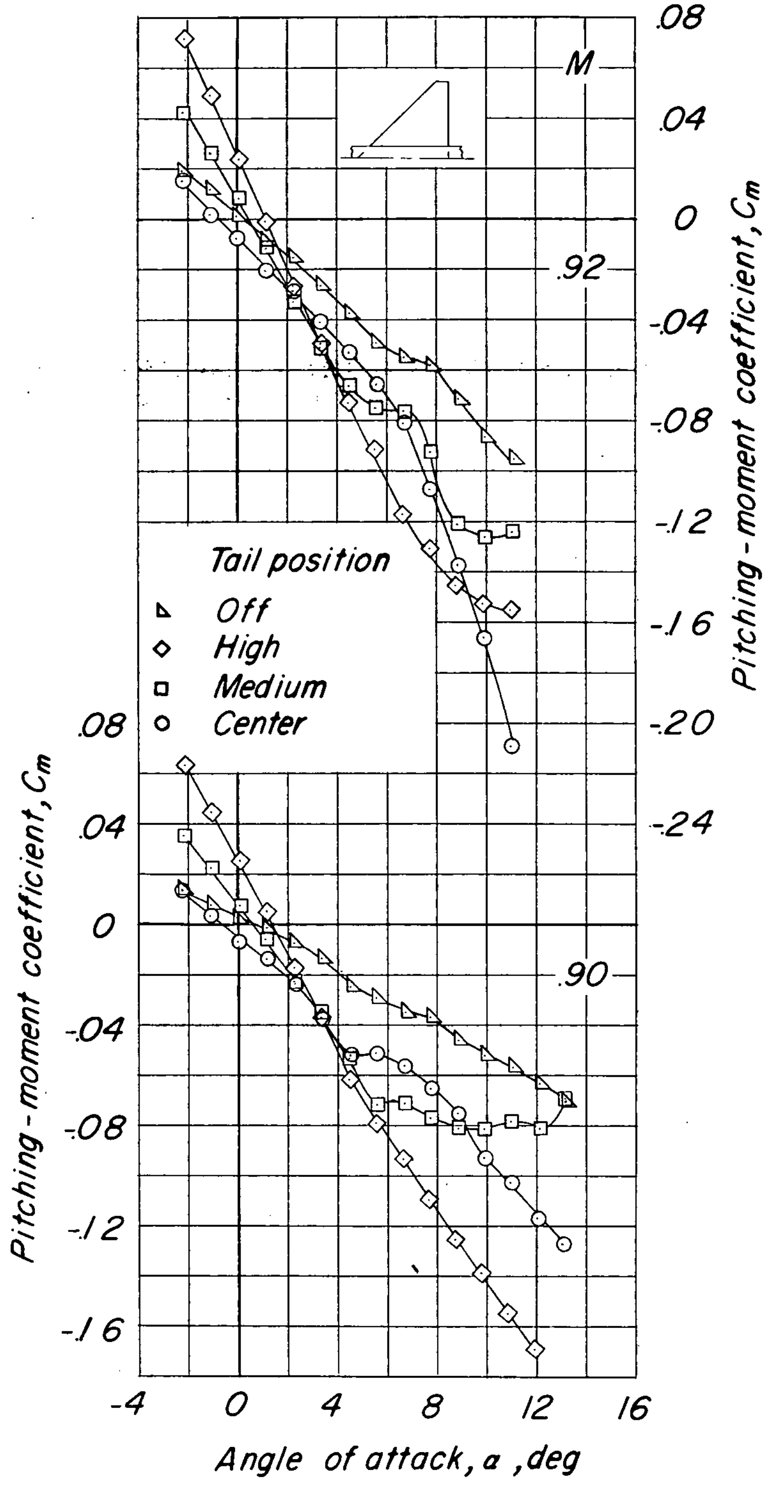
(a) Concluded.

Figure 3.- Continued.



(b) C_m against α.

Figure 3.- Continued.



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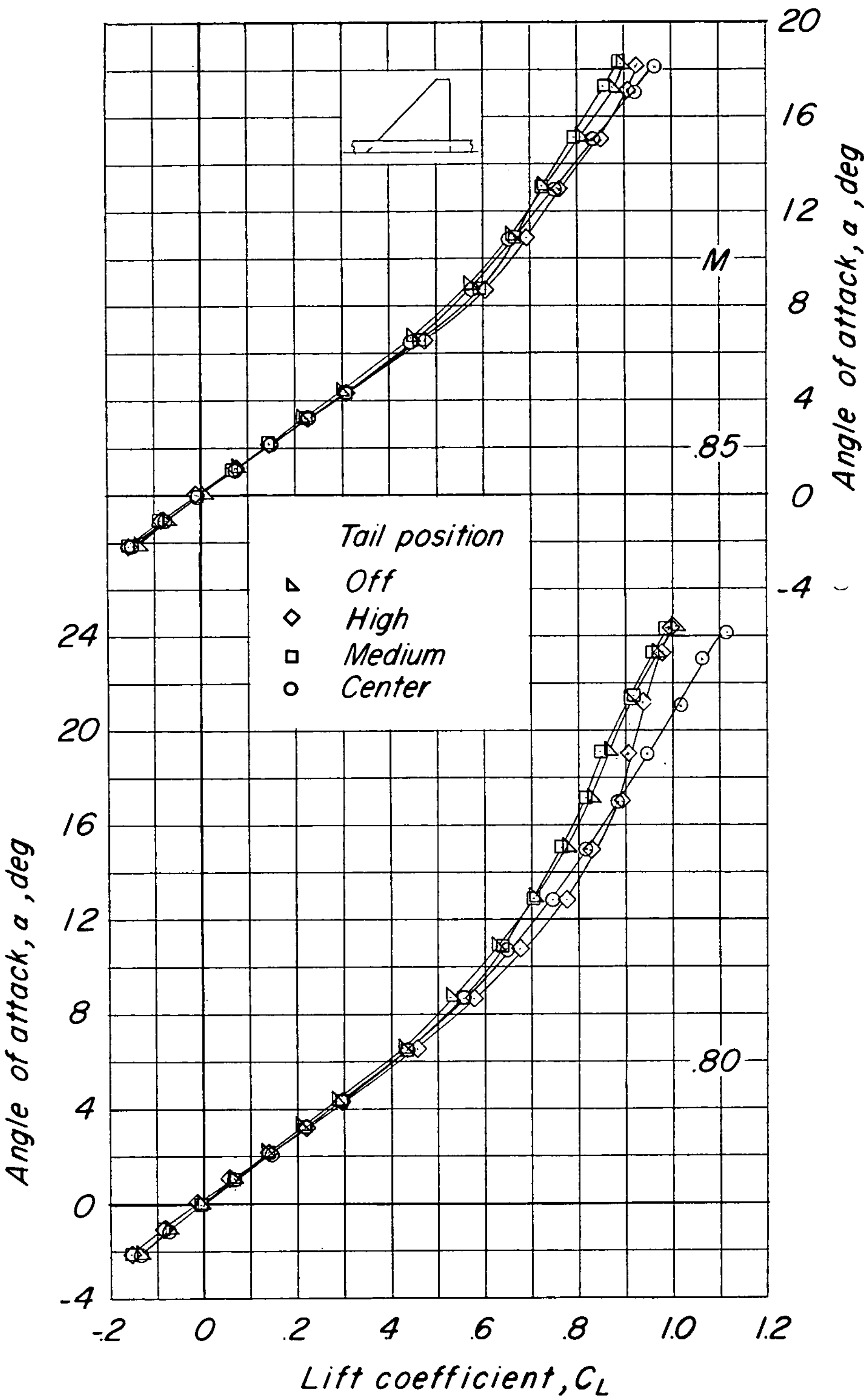

(c) α against C_L.

Figure 3.- Continued.

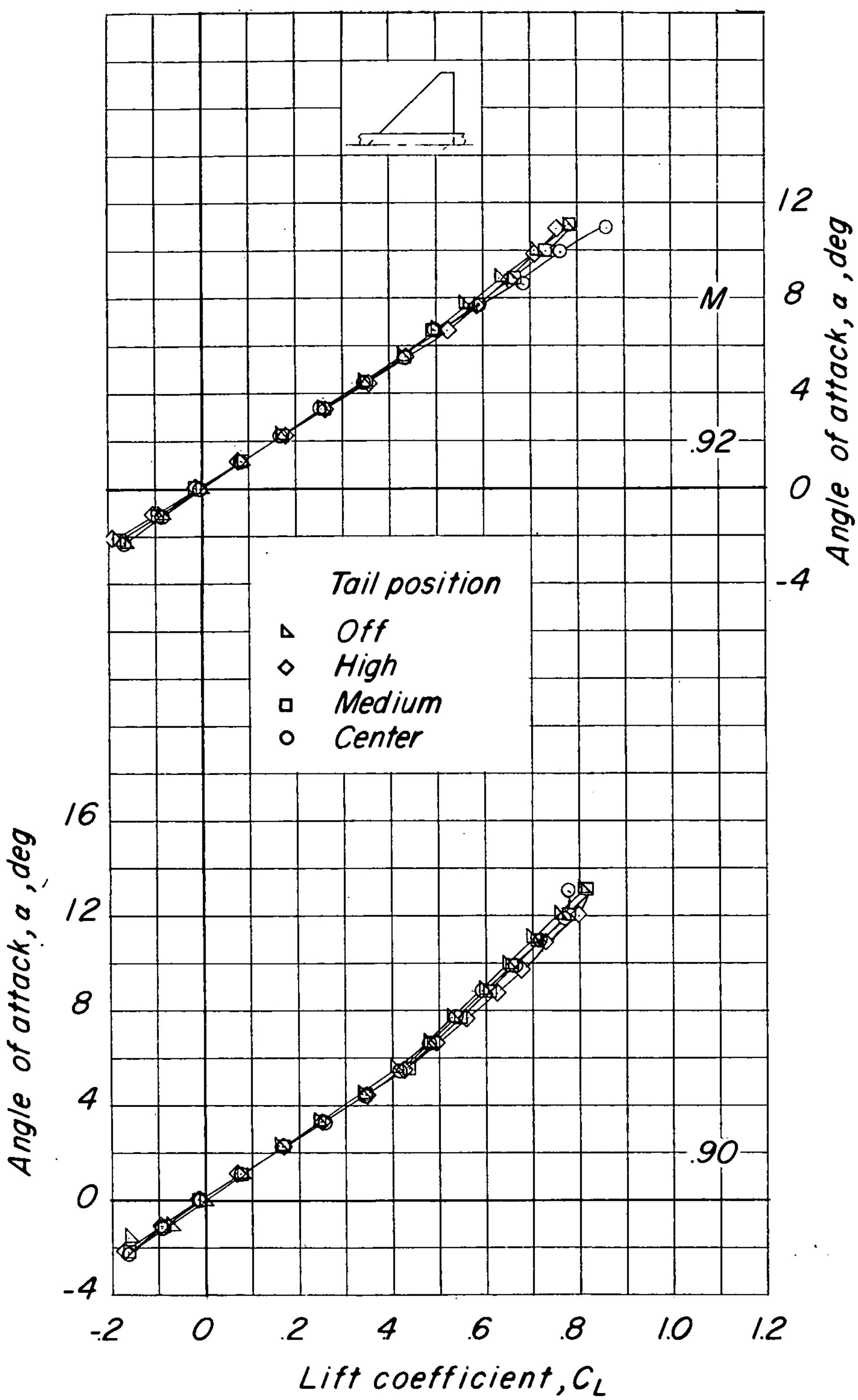

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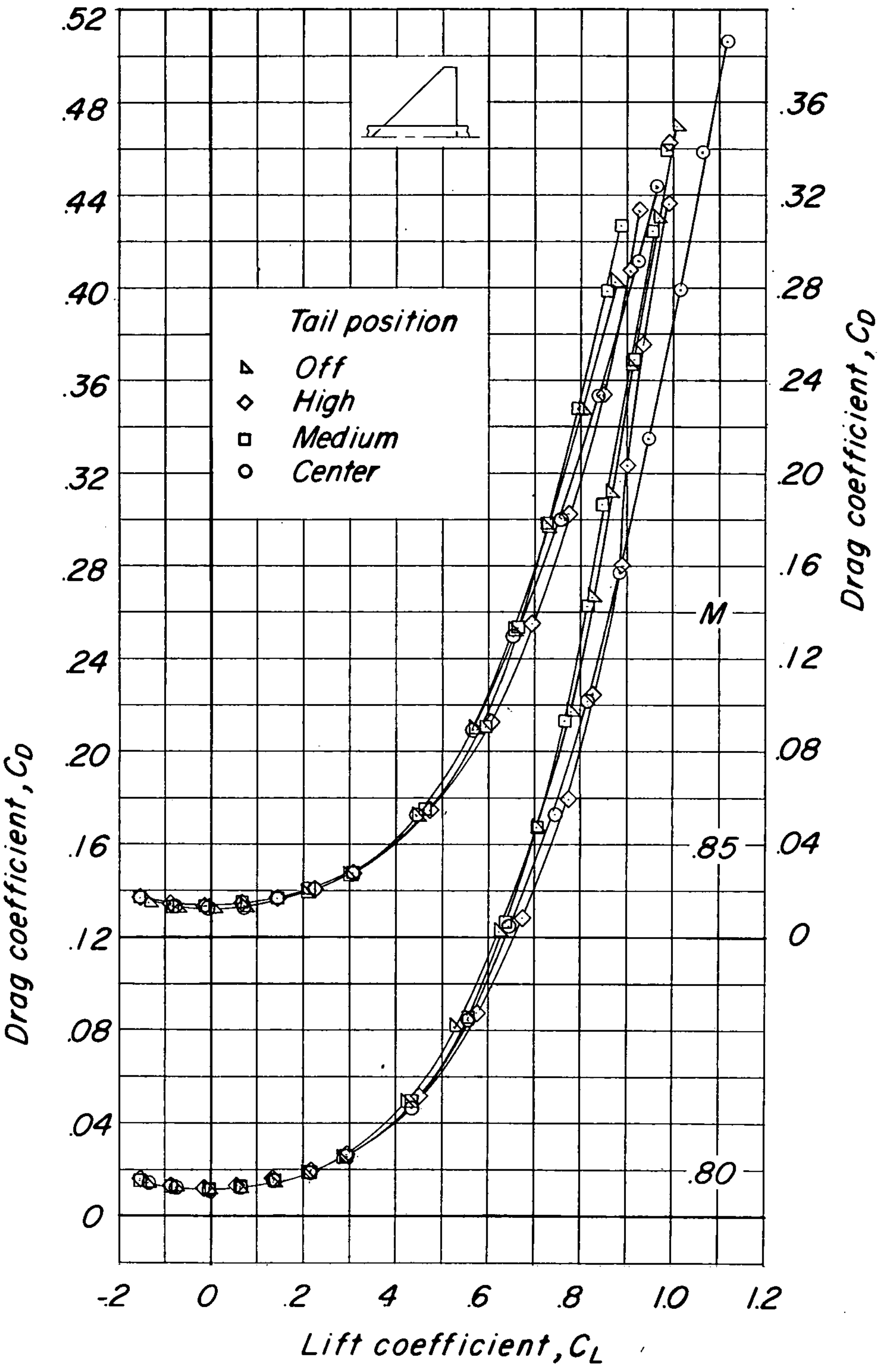
Figure 3.- Continued.



(d) C_D against C_L.

Figure 3.- Continued.

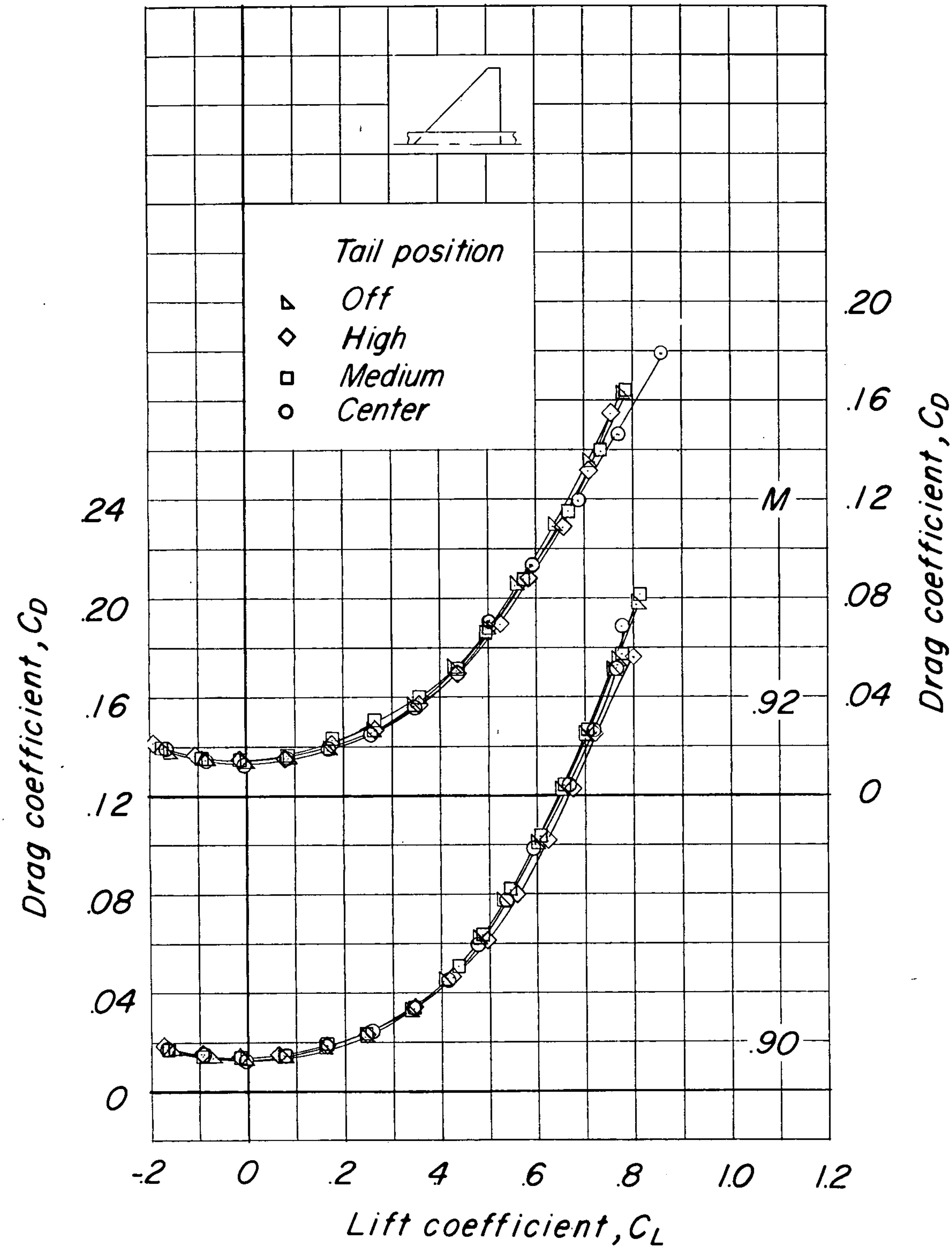


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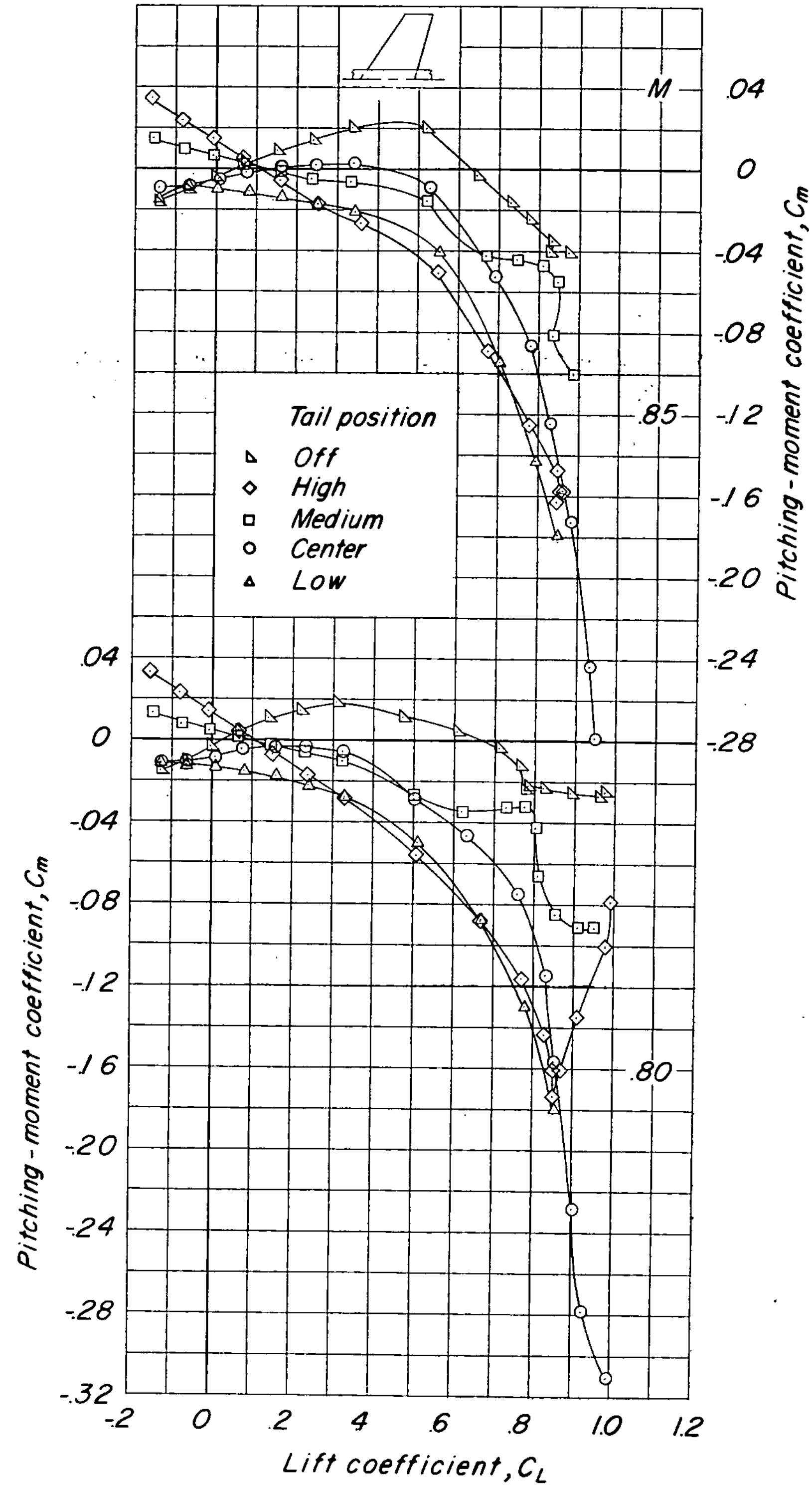
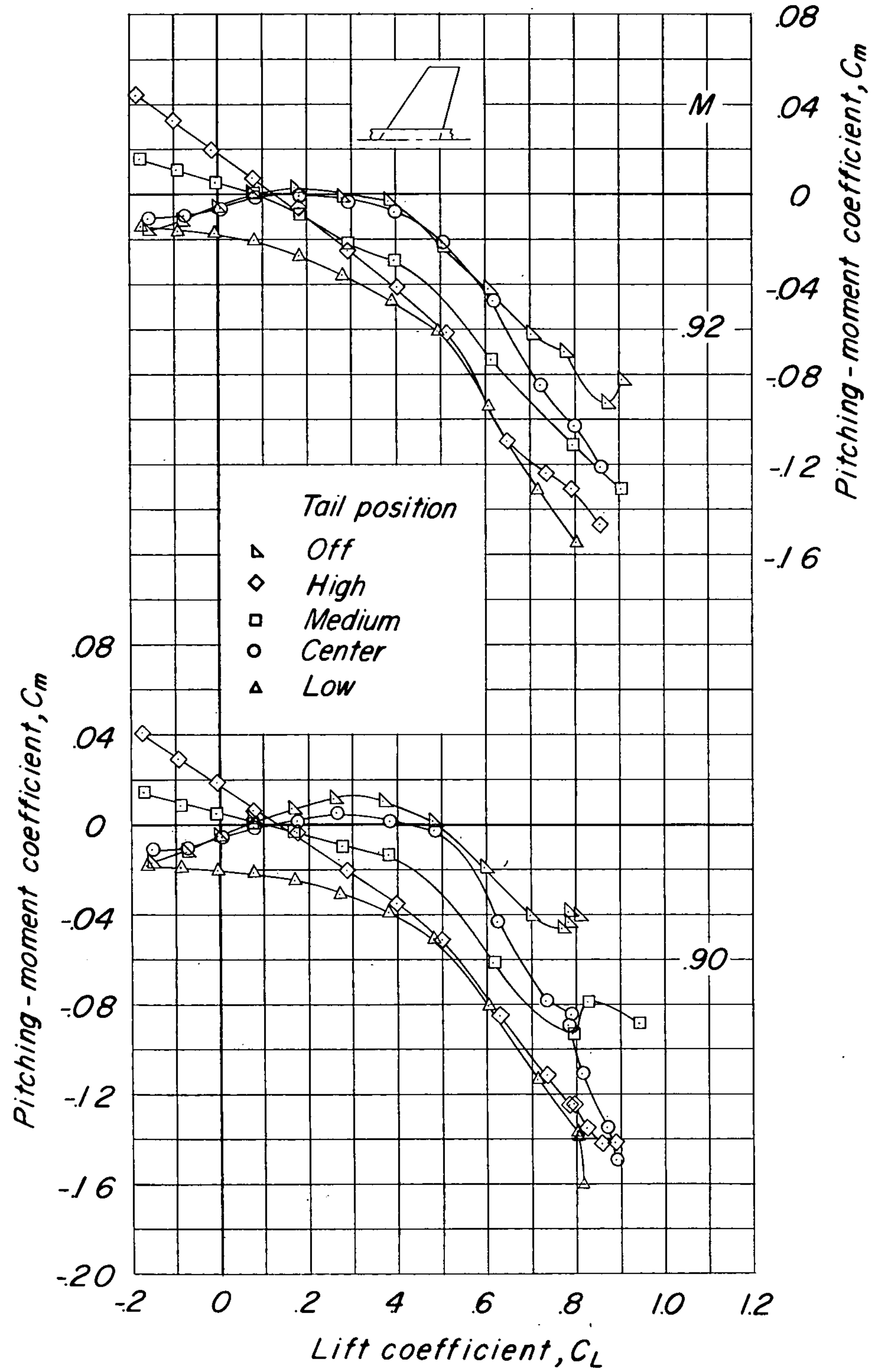
Figure 3.- Concluded.



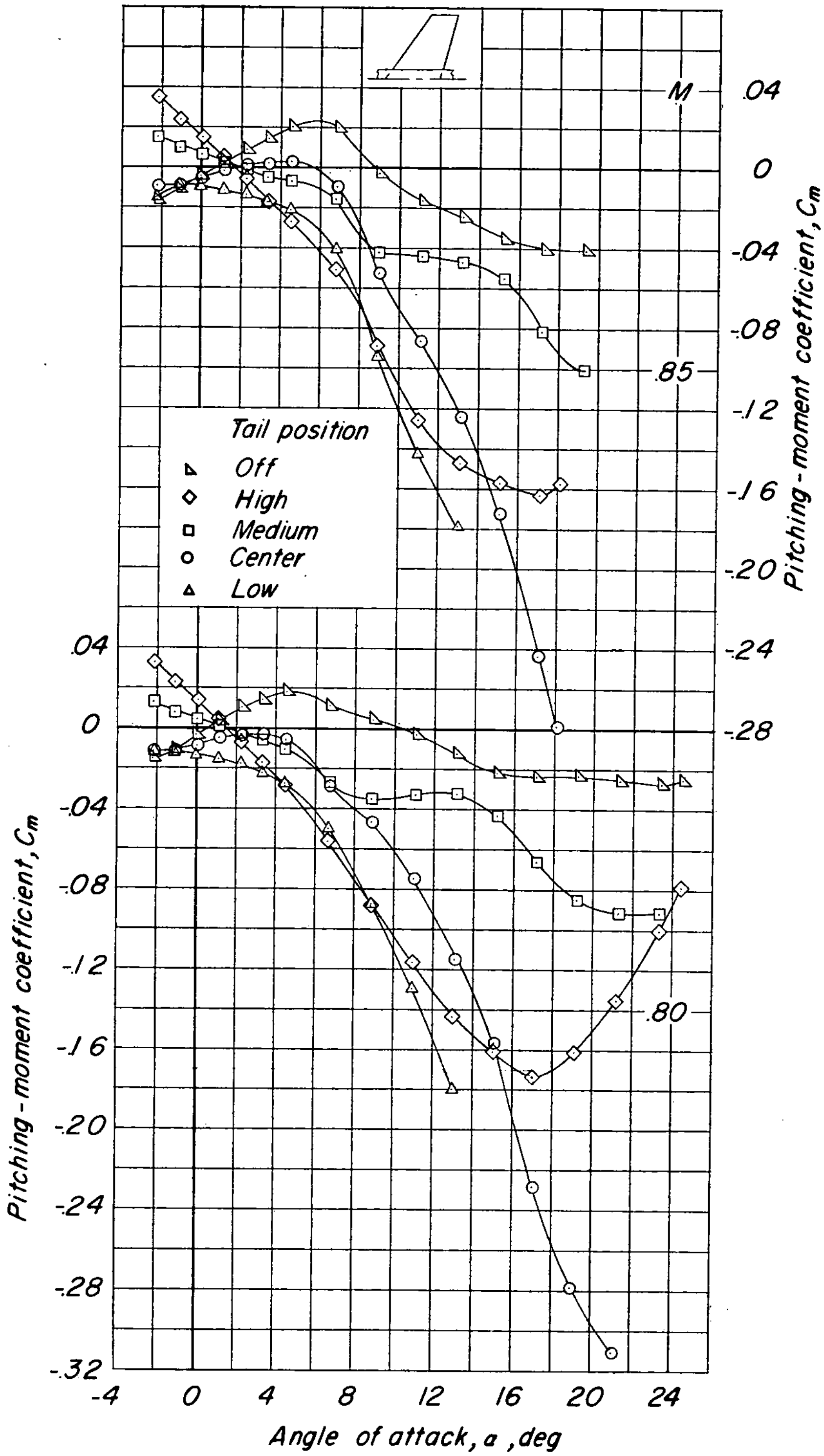
(a) C_m against C_L.

Figure 4.- Longitudinal characteristics of the model with a swept wing.



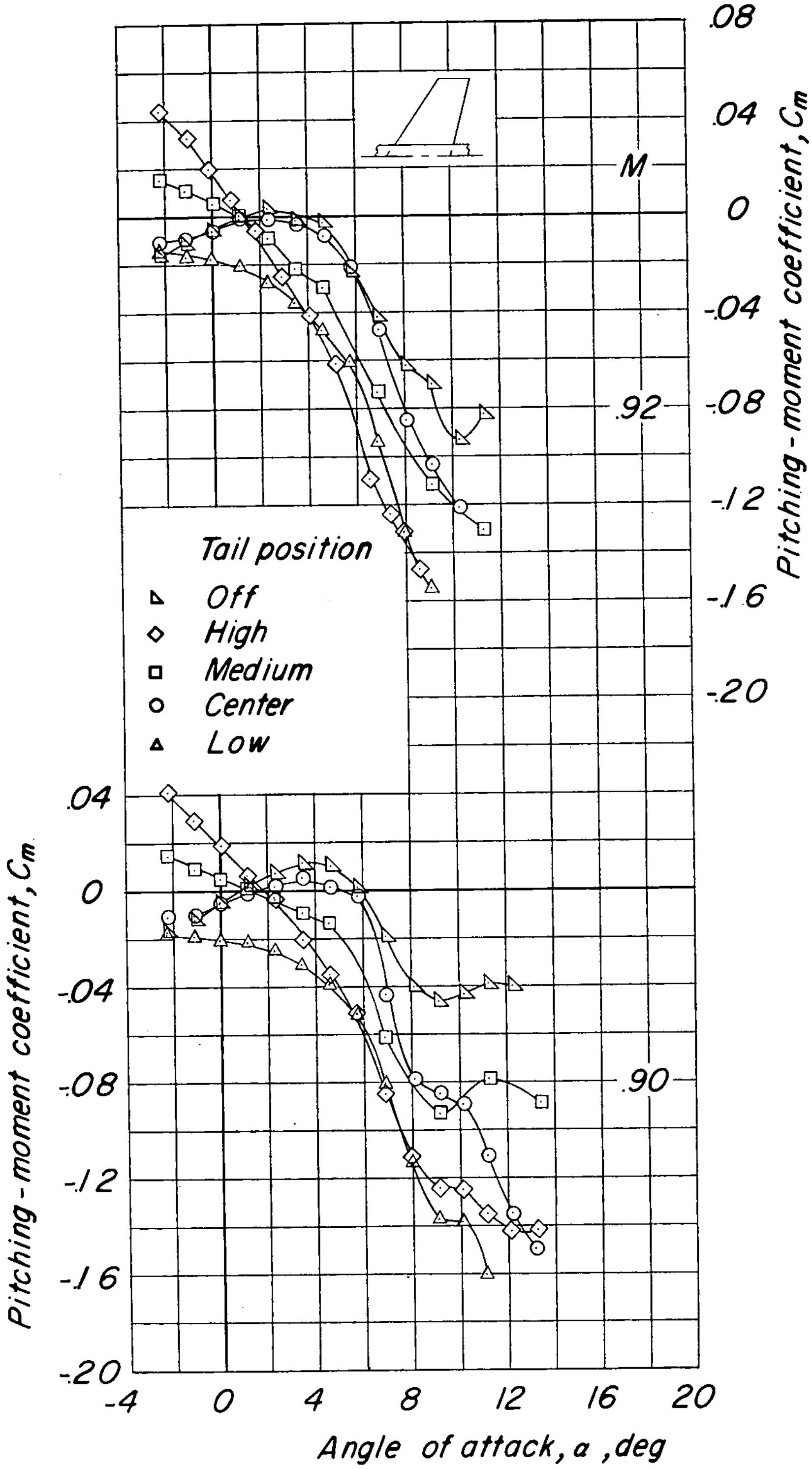
(a) Concluded.

Figure 4.- Continued.



(b) C_m against α.

Figure 4.- Continued.



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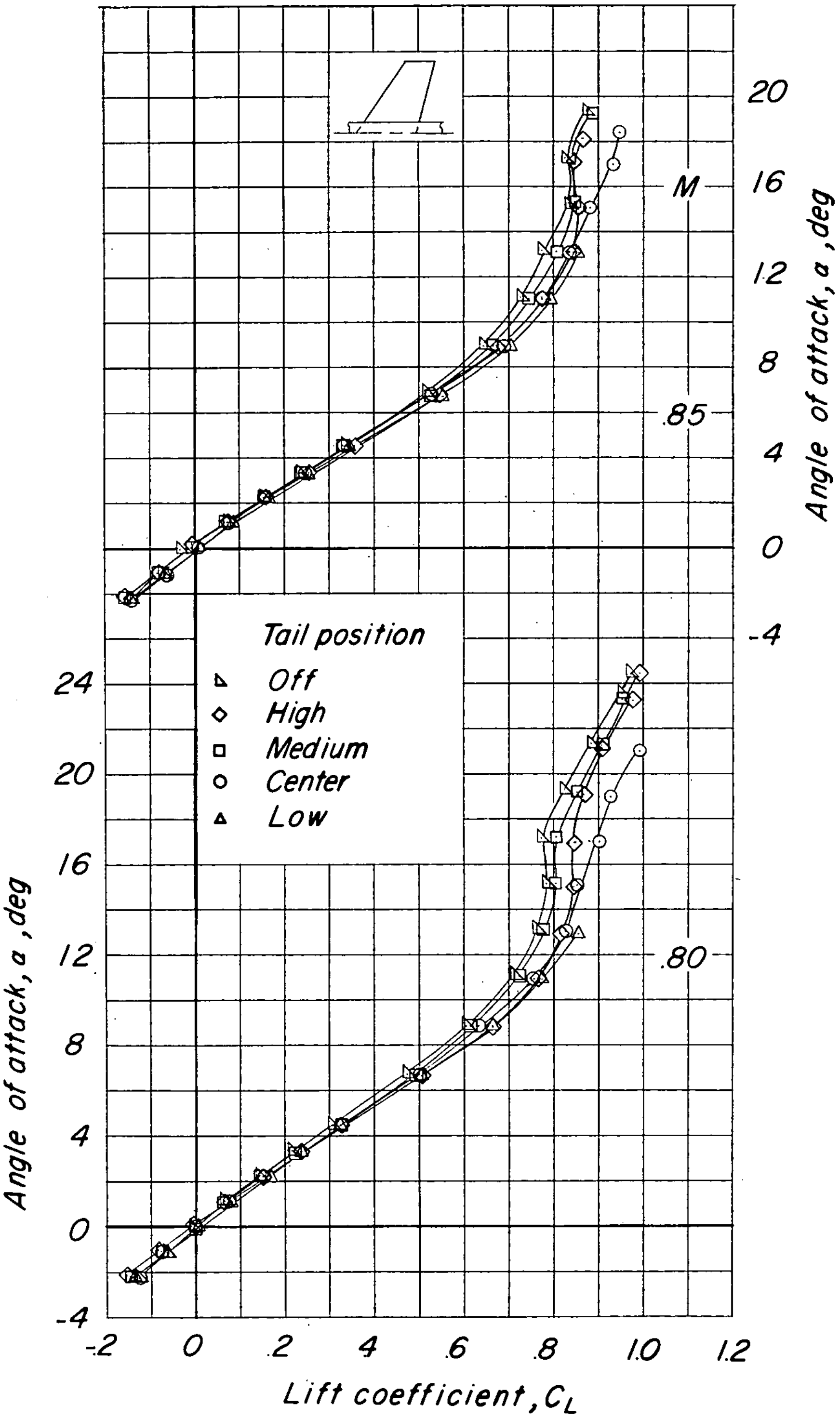

(c) α against C_L.

Figure 4.- Continued.

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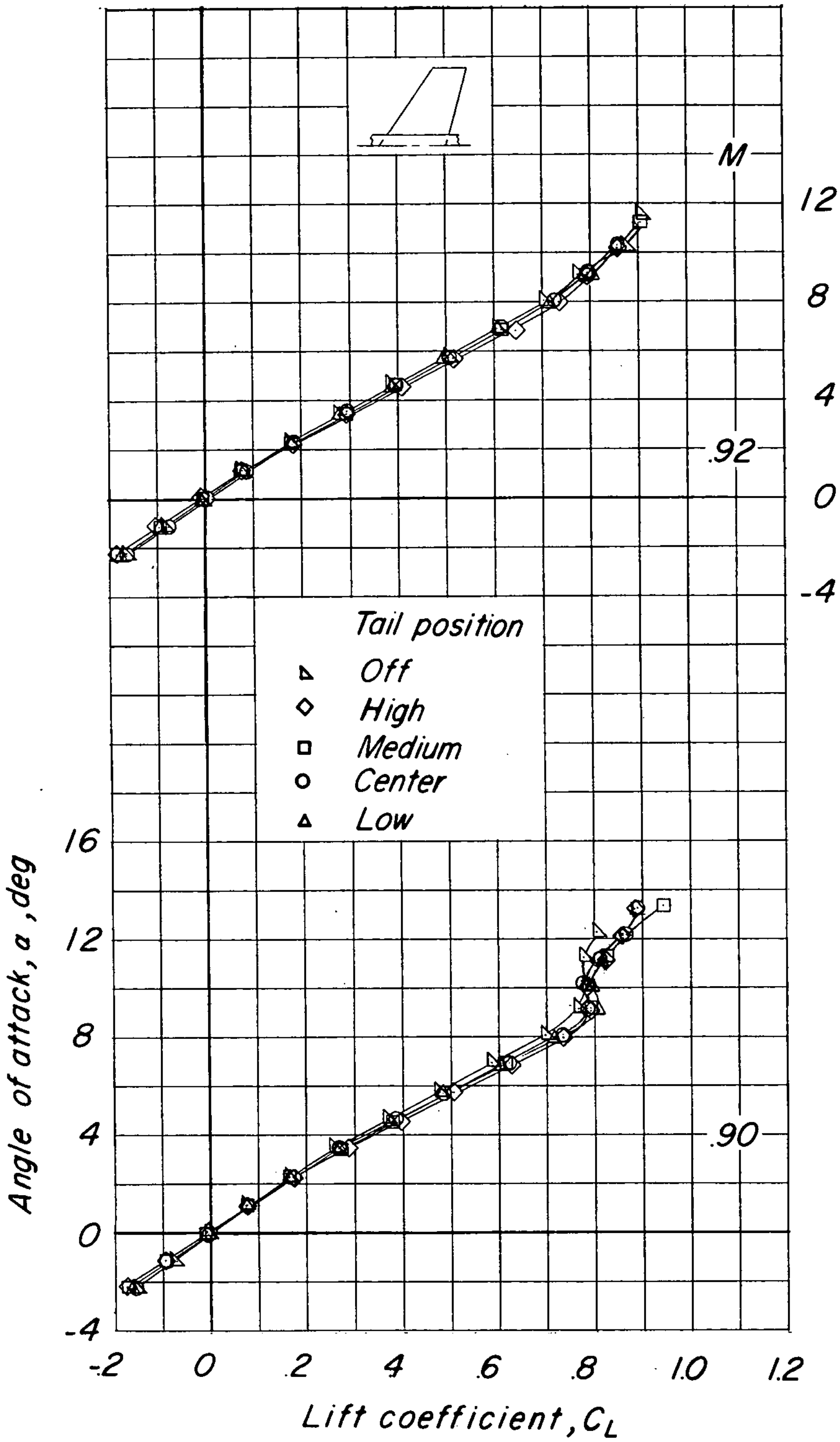

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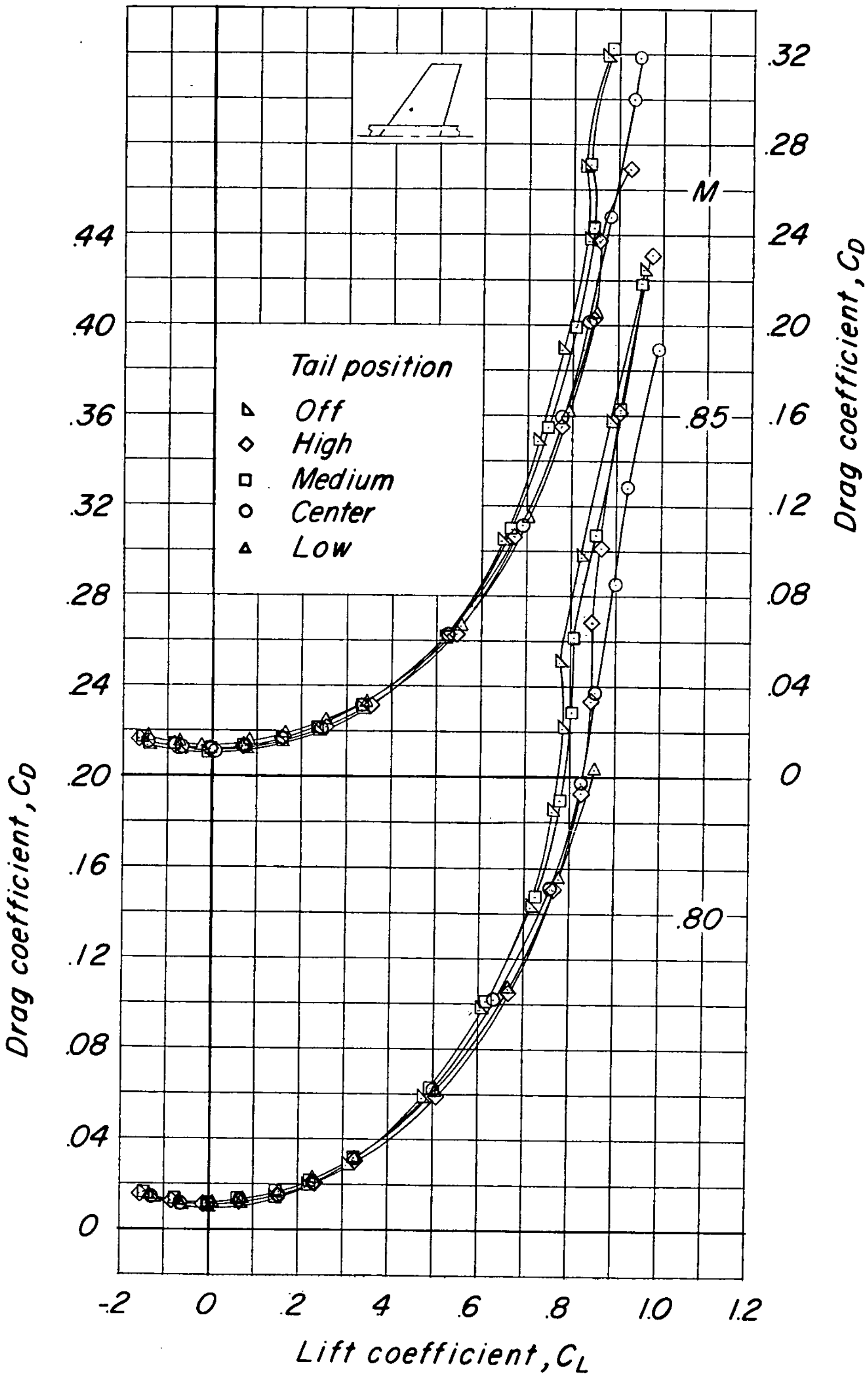

(d) C_D against C_L.

Figure 4.- Continued.

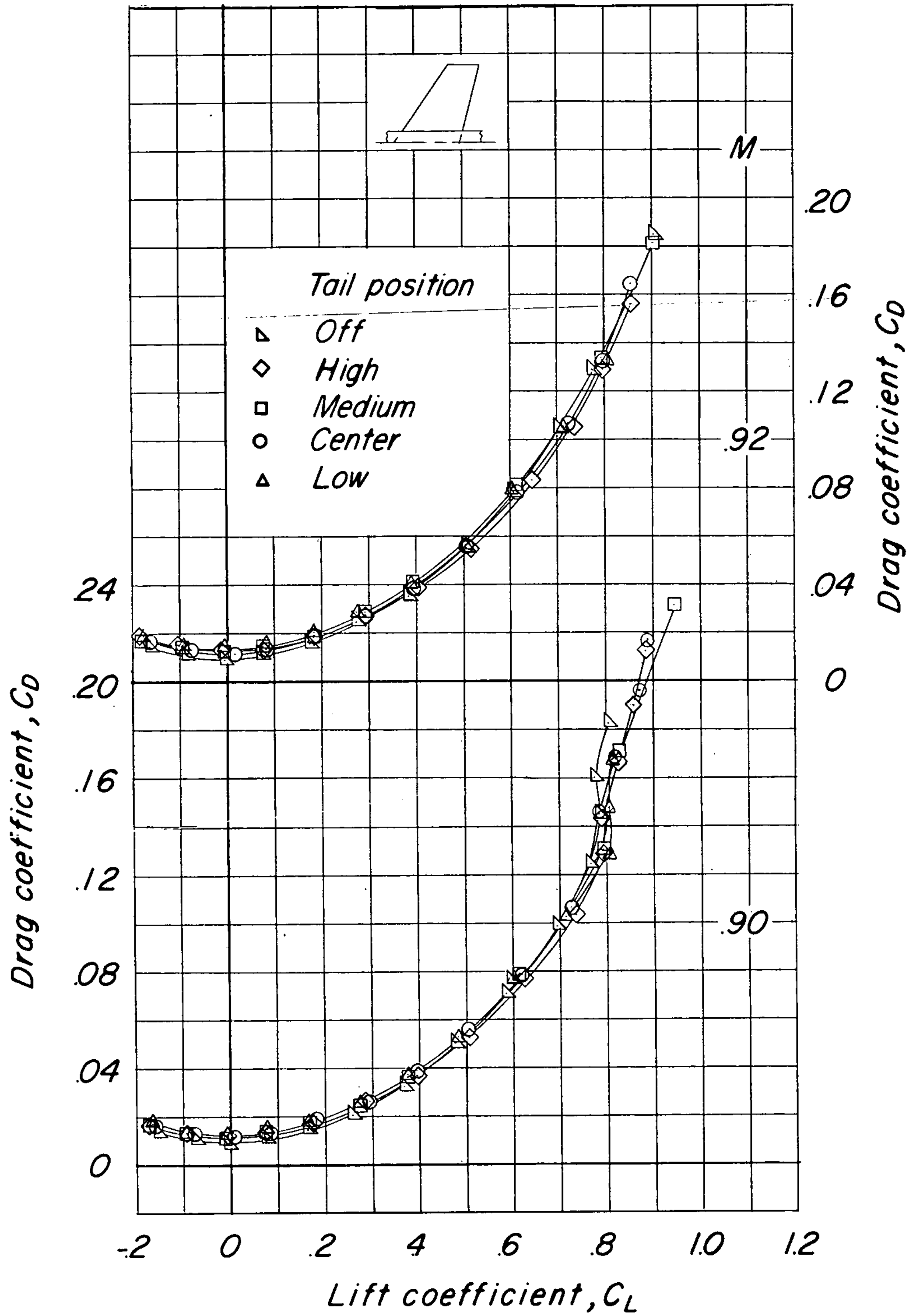

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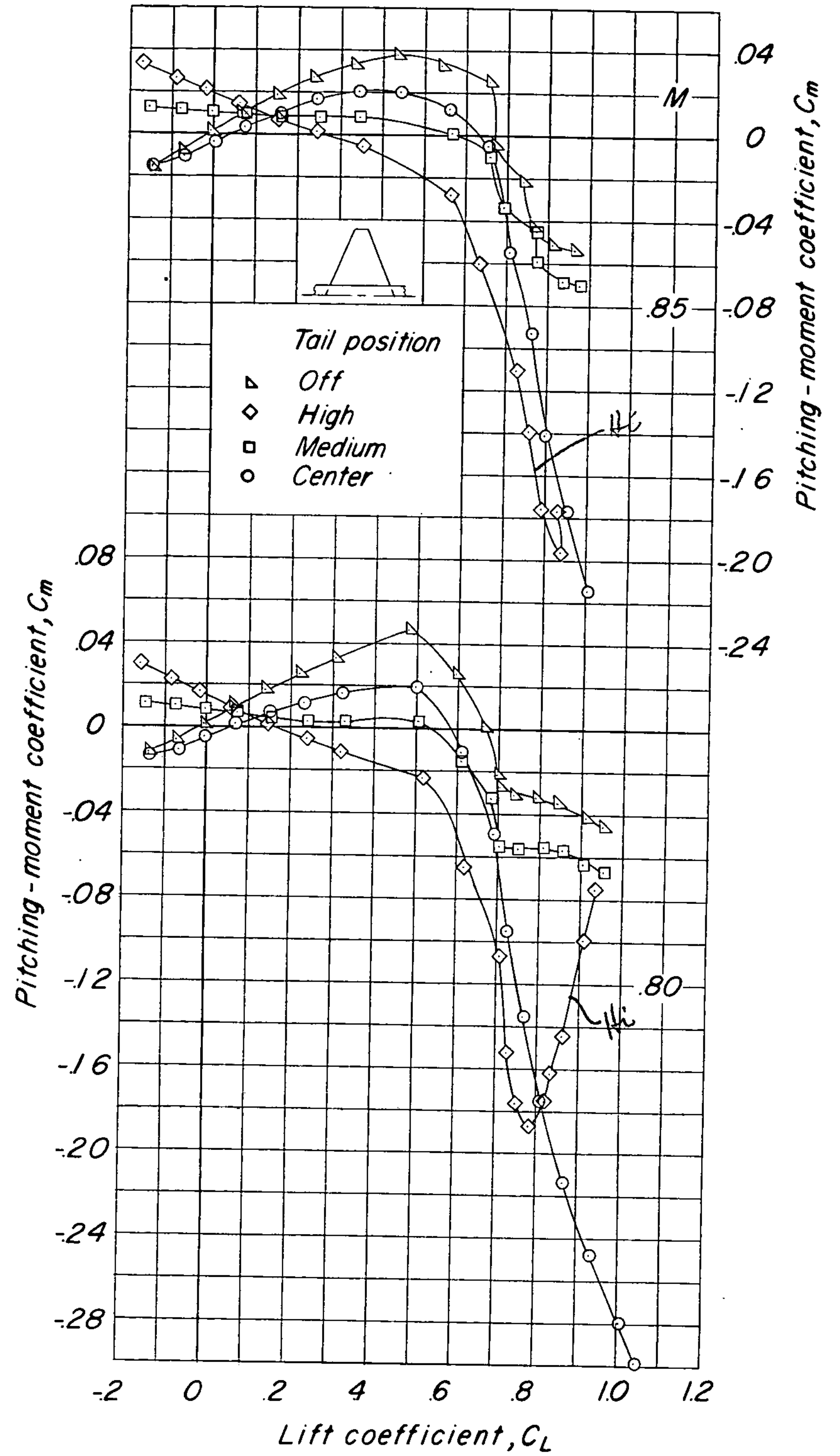
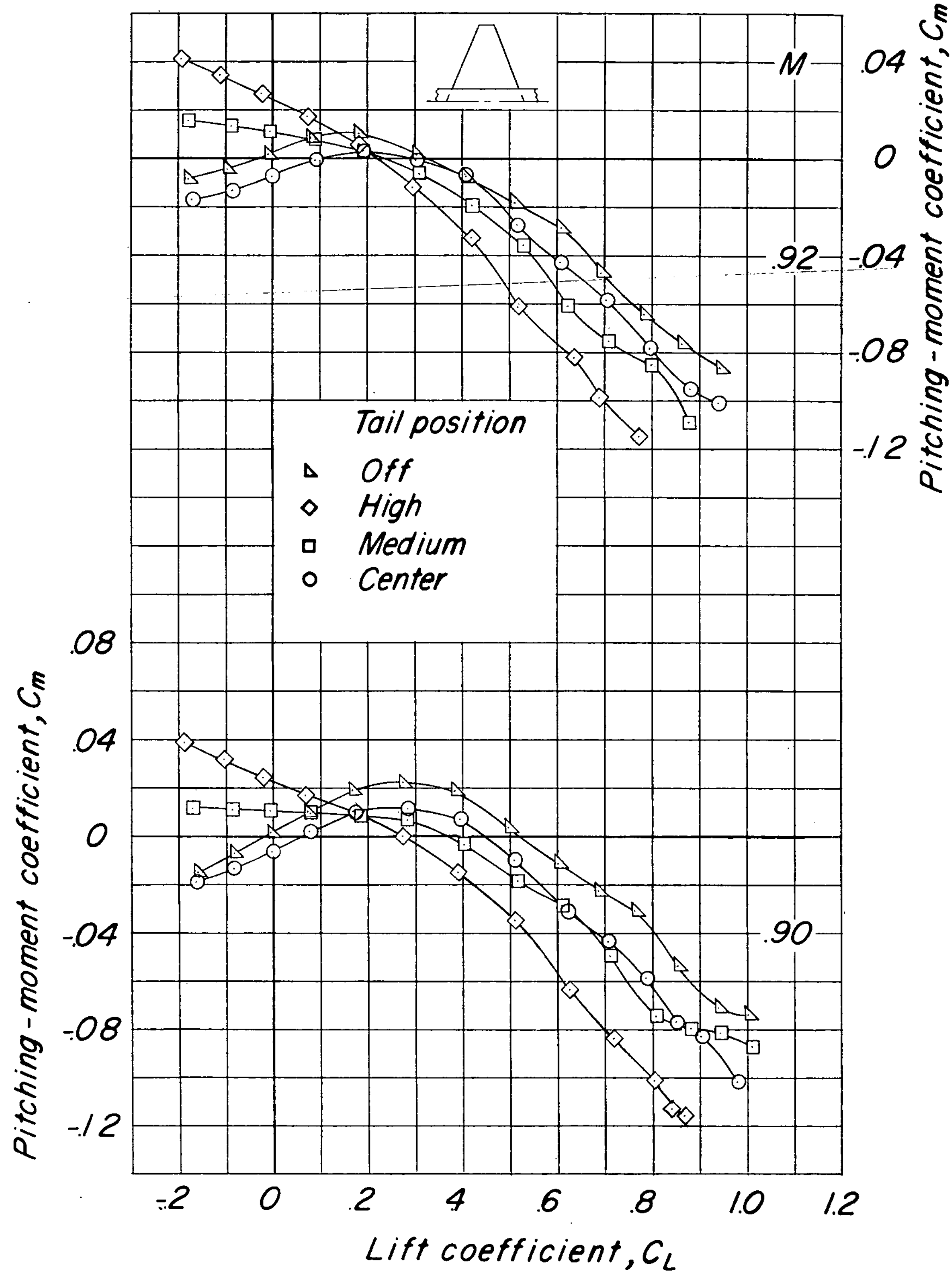
Figure 4.- Concluded.



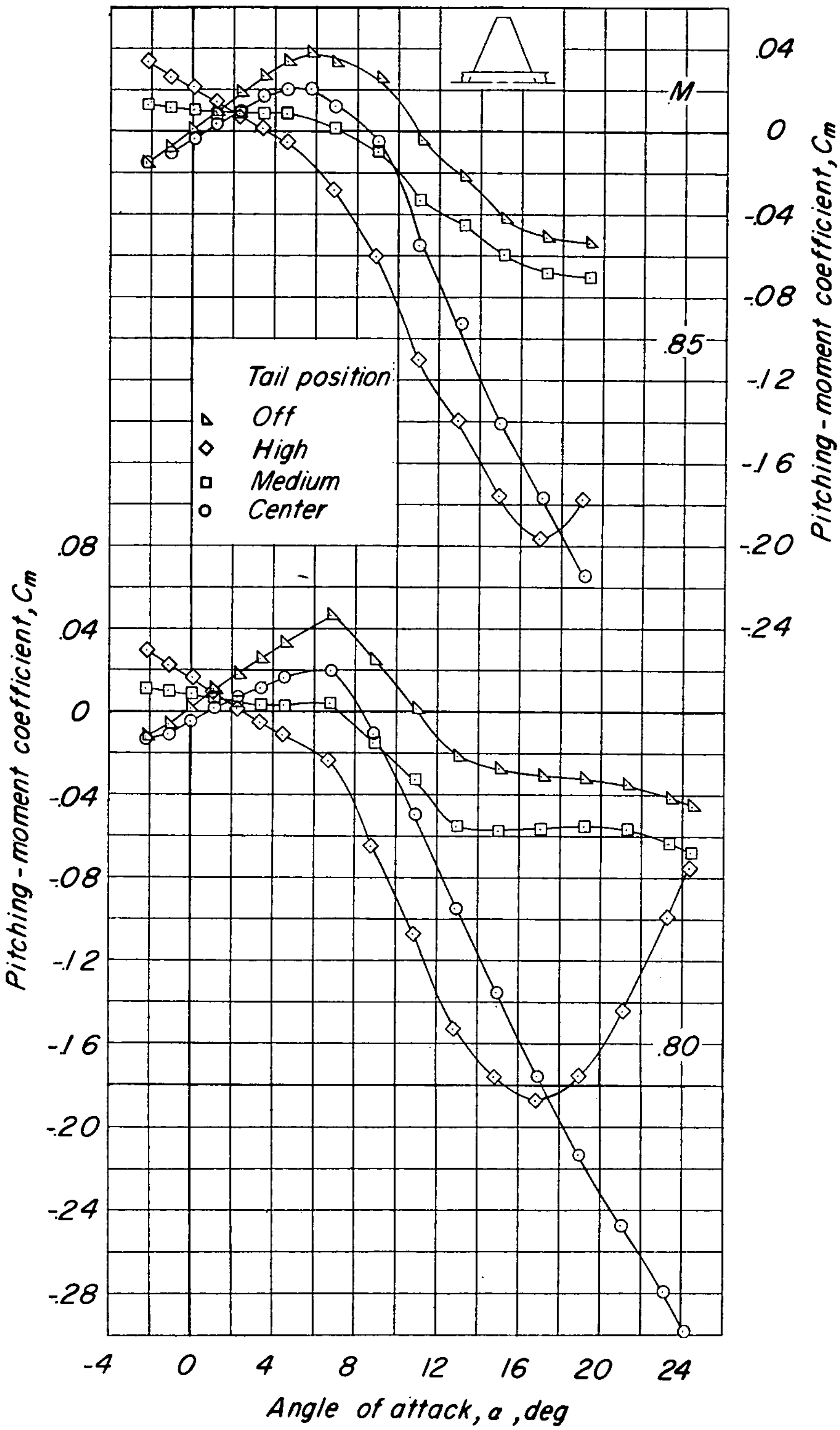
(a) C_m against C_L.

Figure 5.- Longitudinal characteristics of the model with an unswept wing.



(a) Concluded.

Figure 5.- Continued.



(b) C_m against α.

Figure 5.- Continued.

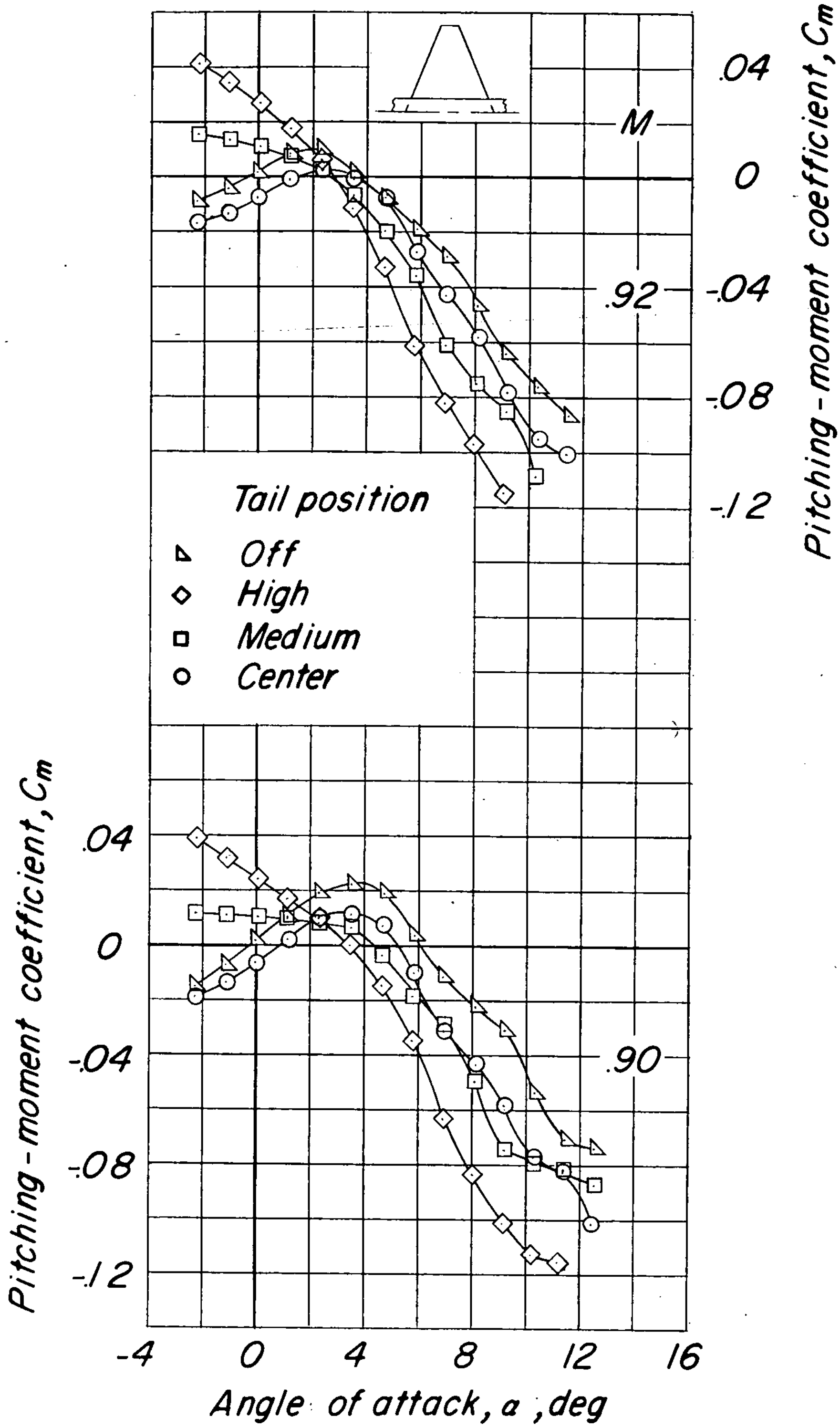


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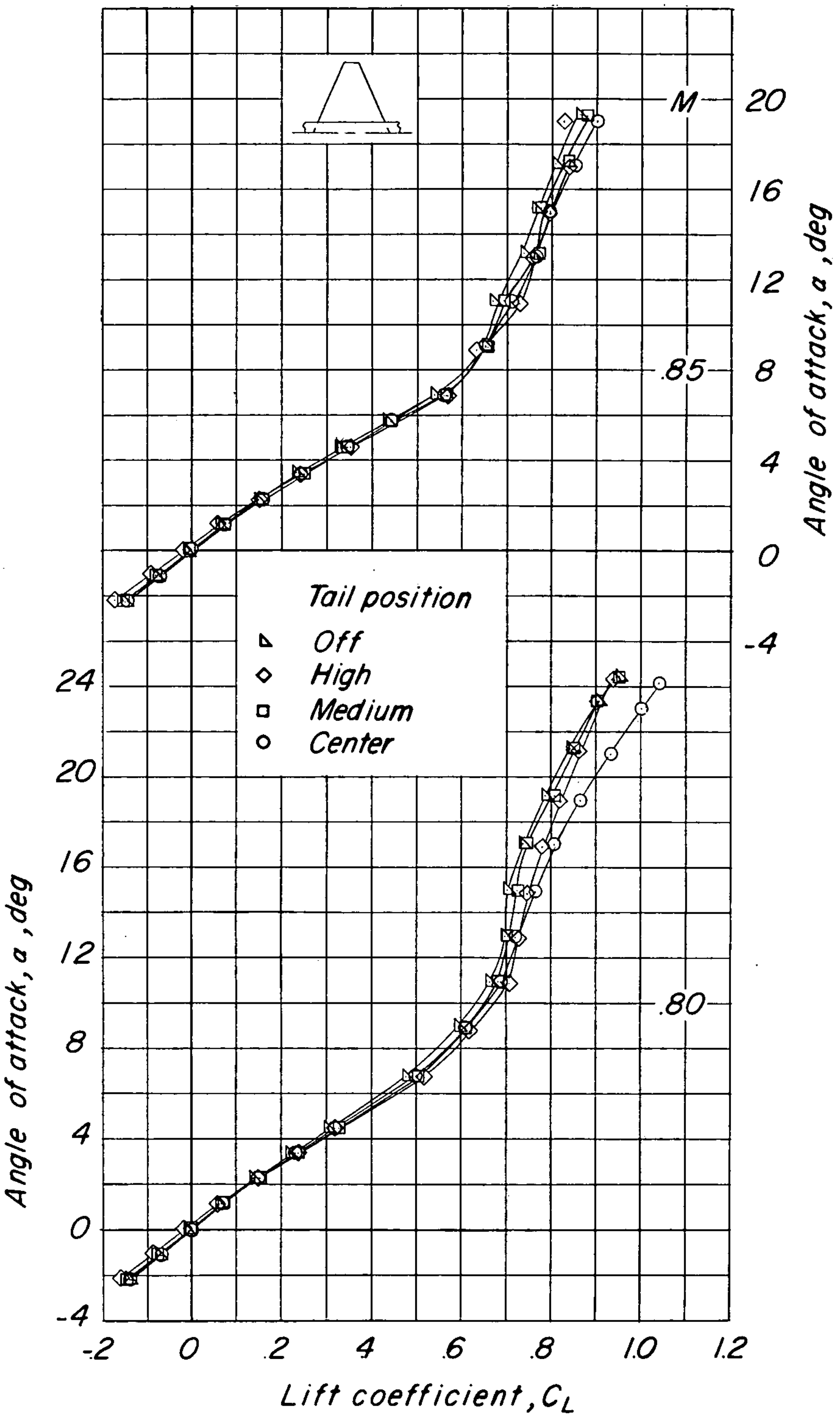
Figure 5.- Continued.



(c) α against C_L.

Figure 5.- Continued.

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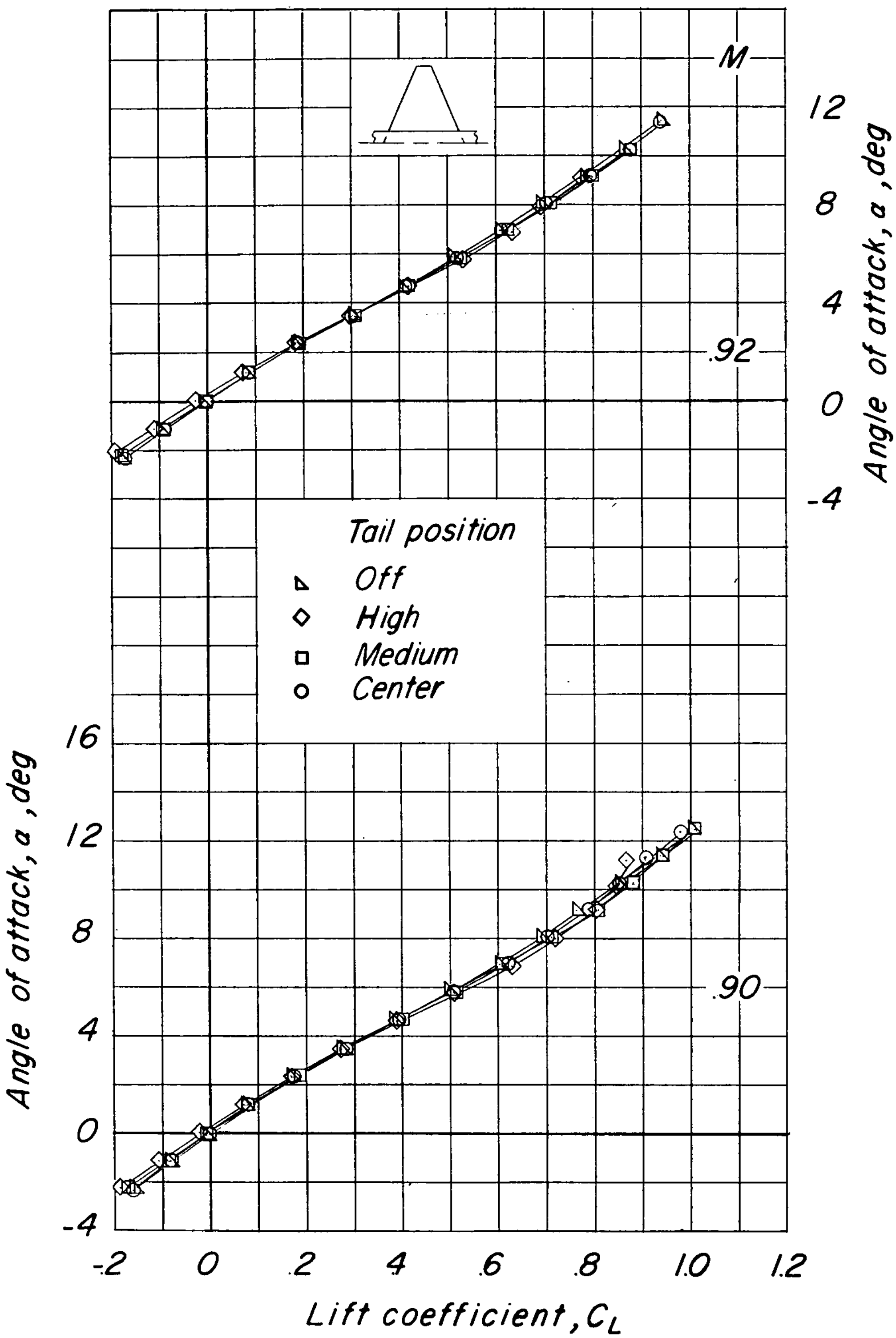
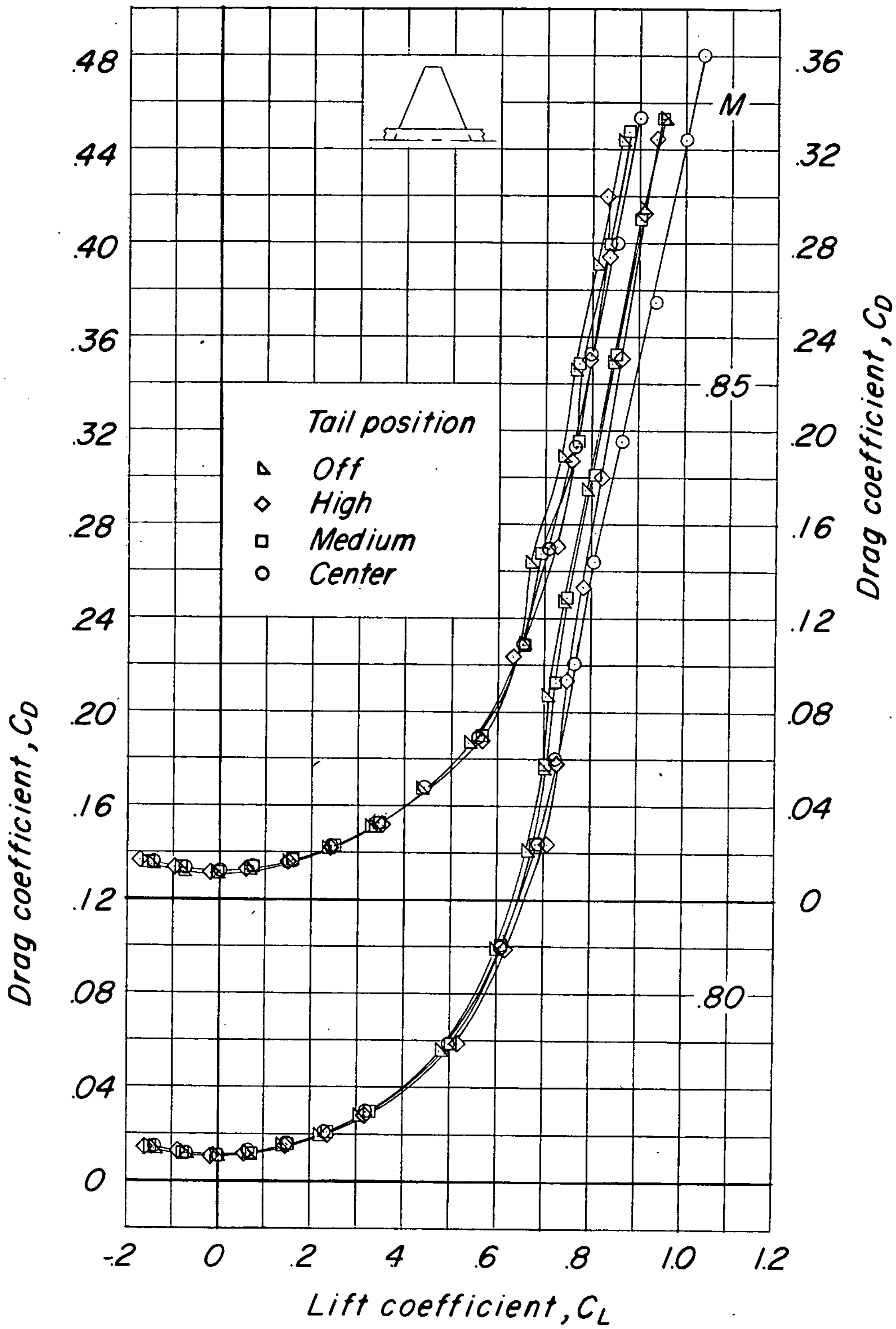


(c) Concluded.

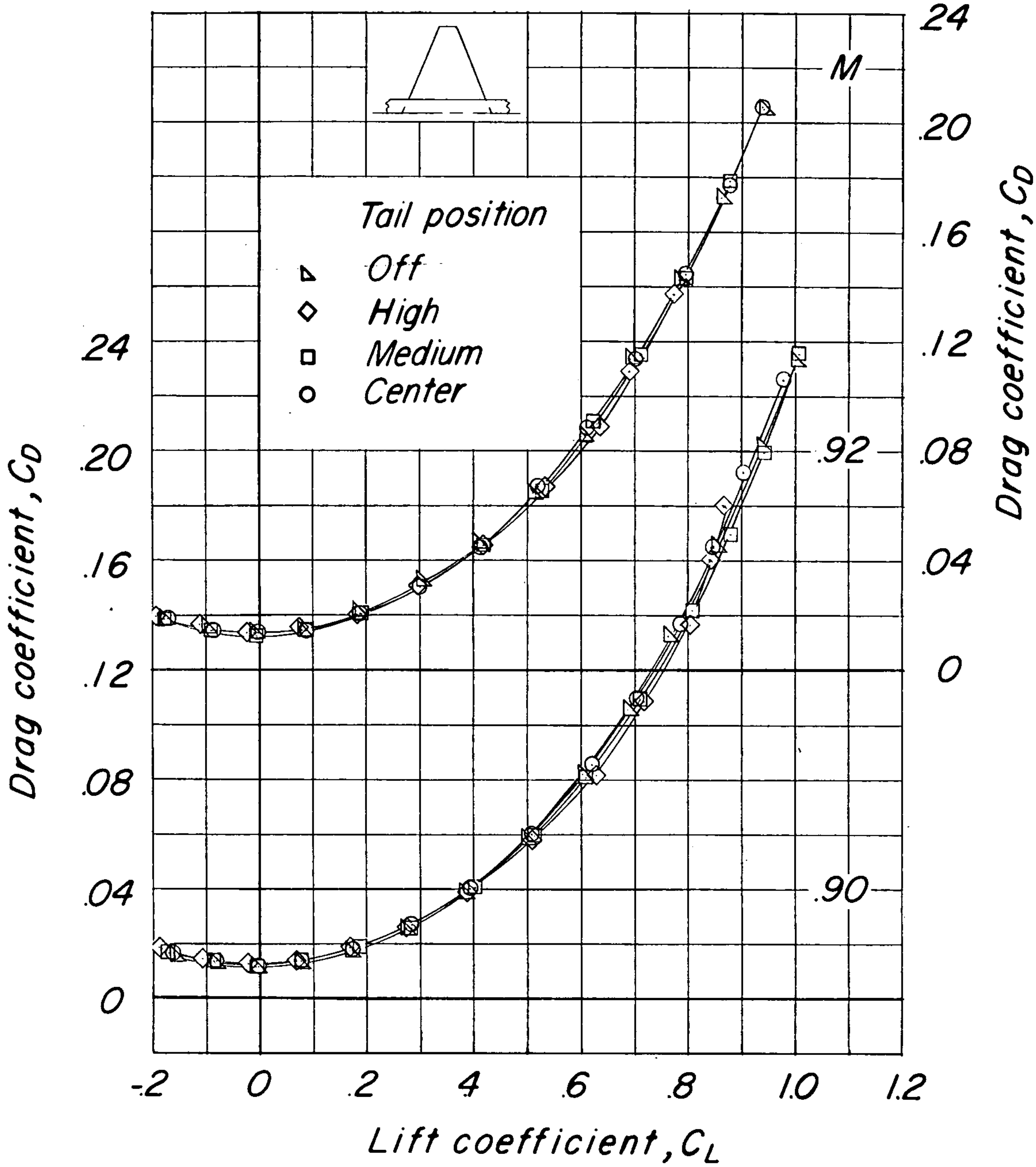
Figure 5.- Continued.



(d) C_D against C_L.

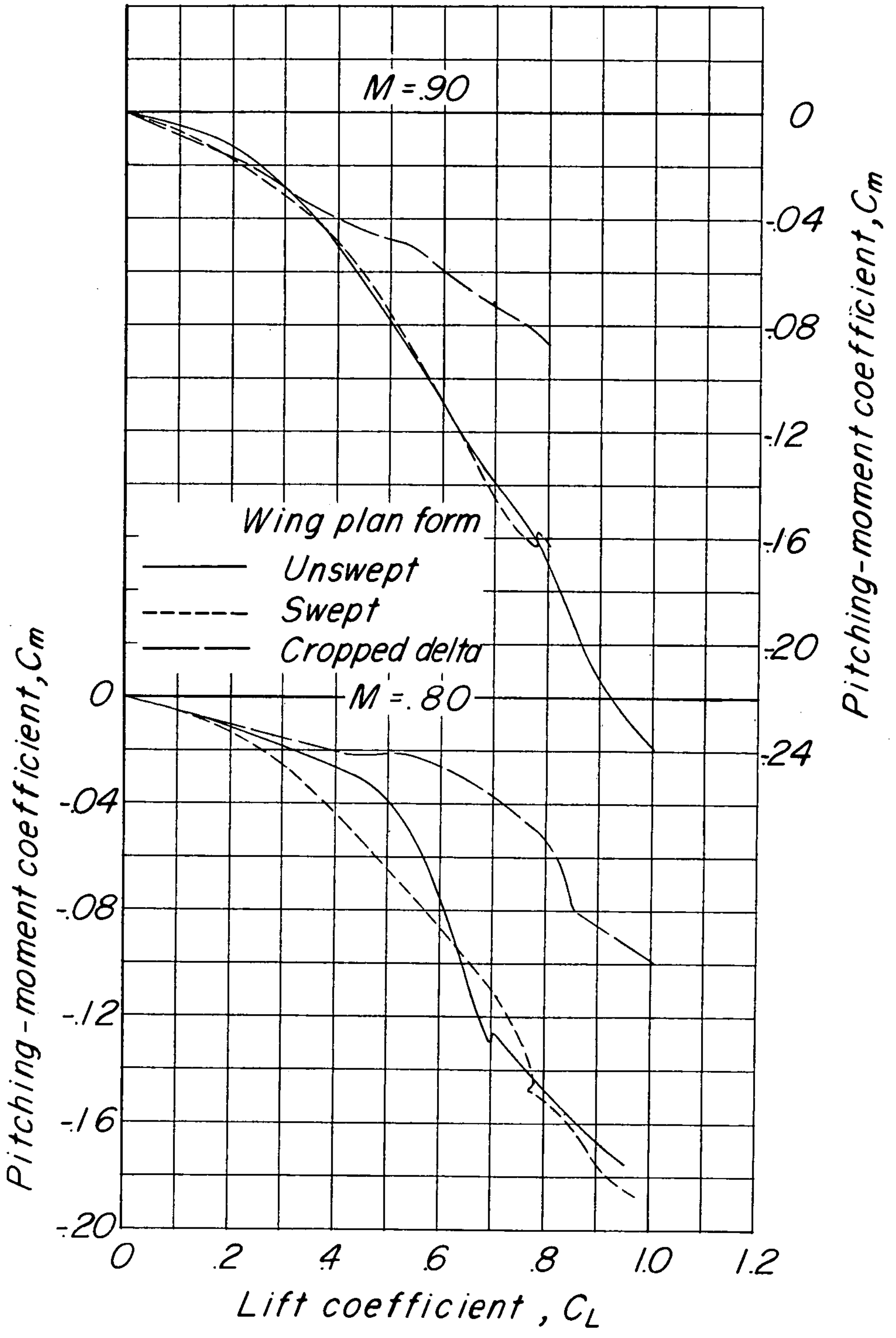
Figure 5.- Continued.

[redacted]



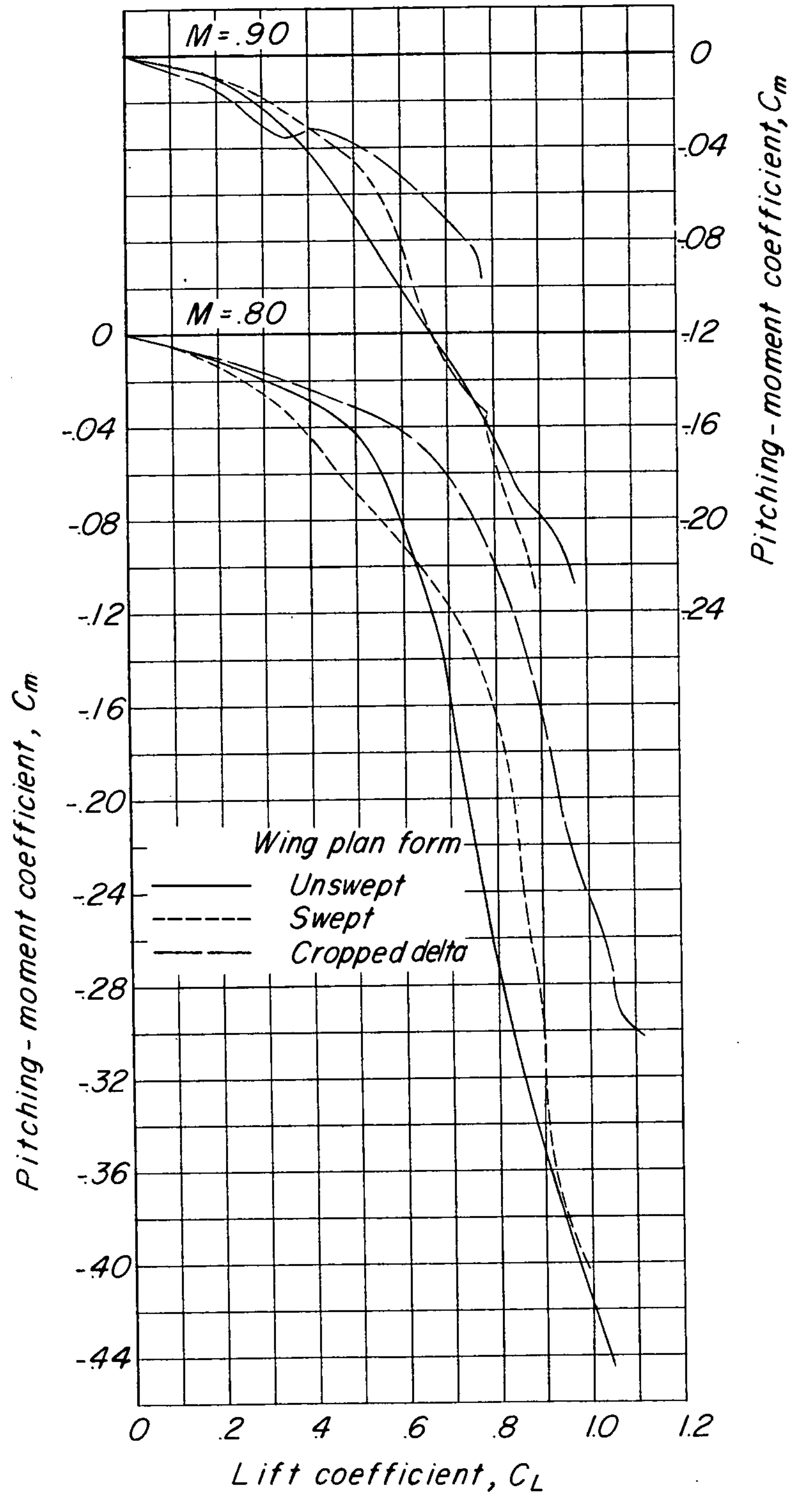
(d) Concluded.

Figure 5.- Concluded.



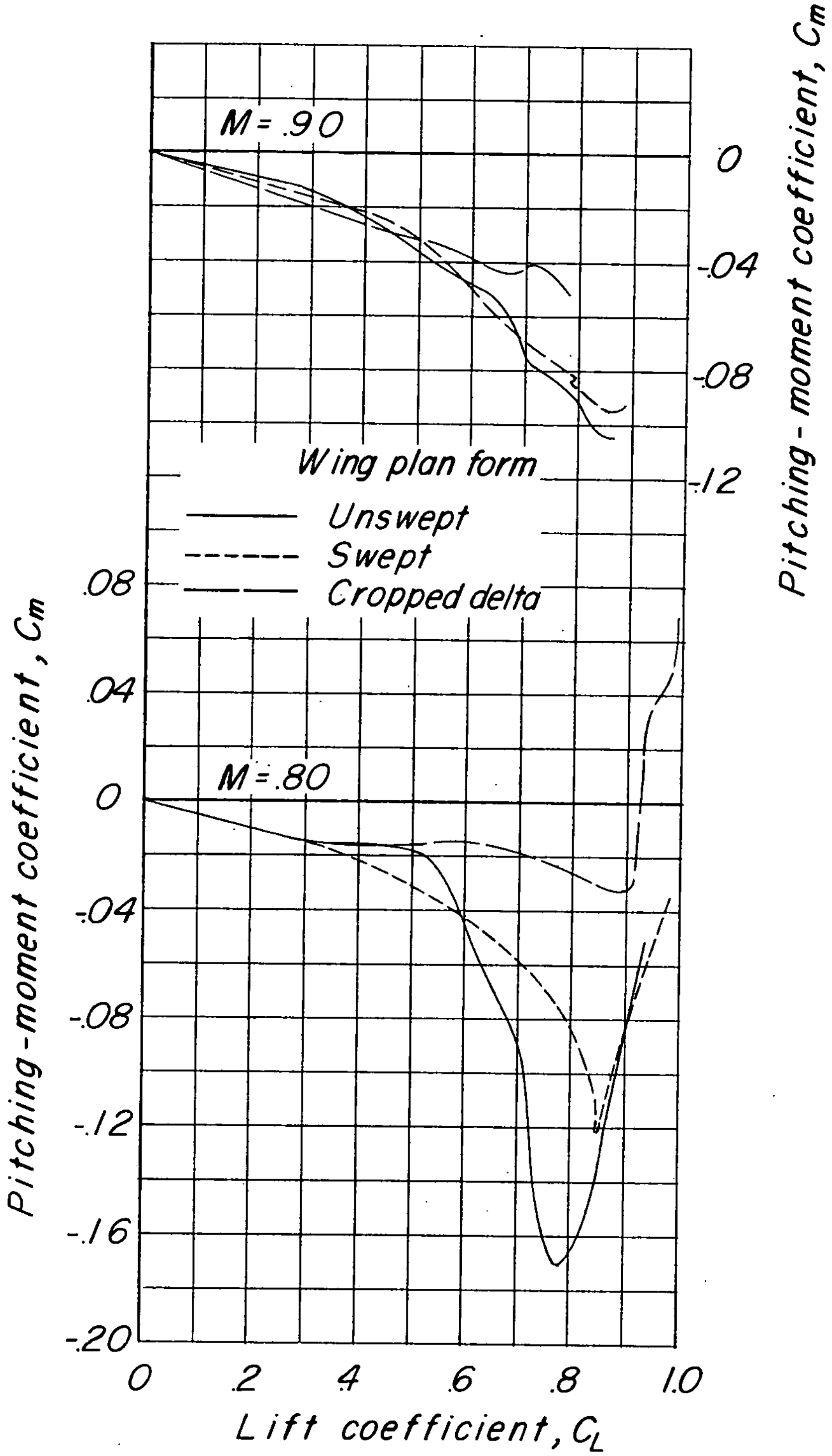
(a) Horizontal tail off.

Figure 6.- Longitudinal stability characteristics of the test model with various wings adjusted to a $0.05\bar{c}$ static margin at $M = 0.80$.



(b) Center tail.

Figure 6.- Continued.



(c) High tail.

Figure 6.- Concluded.

[redacted]

[redacted]

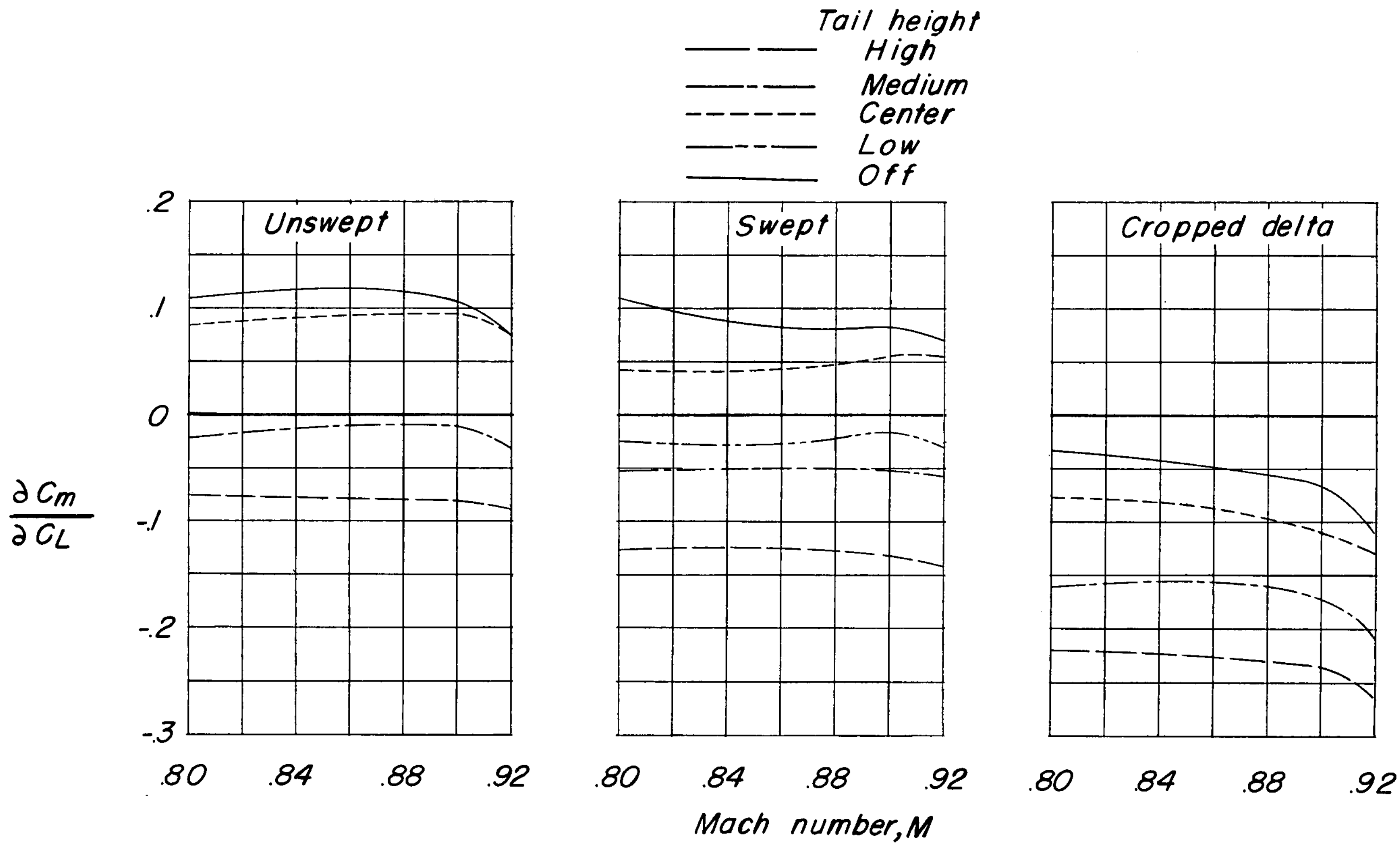


Figure 7.- Variation of $\partial C_m/\partial C_L$ with Mach number for the model with several wings and with various horizontal-tail heights. $C_L = 0$.

[redacted]

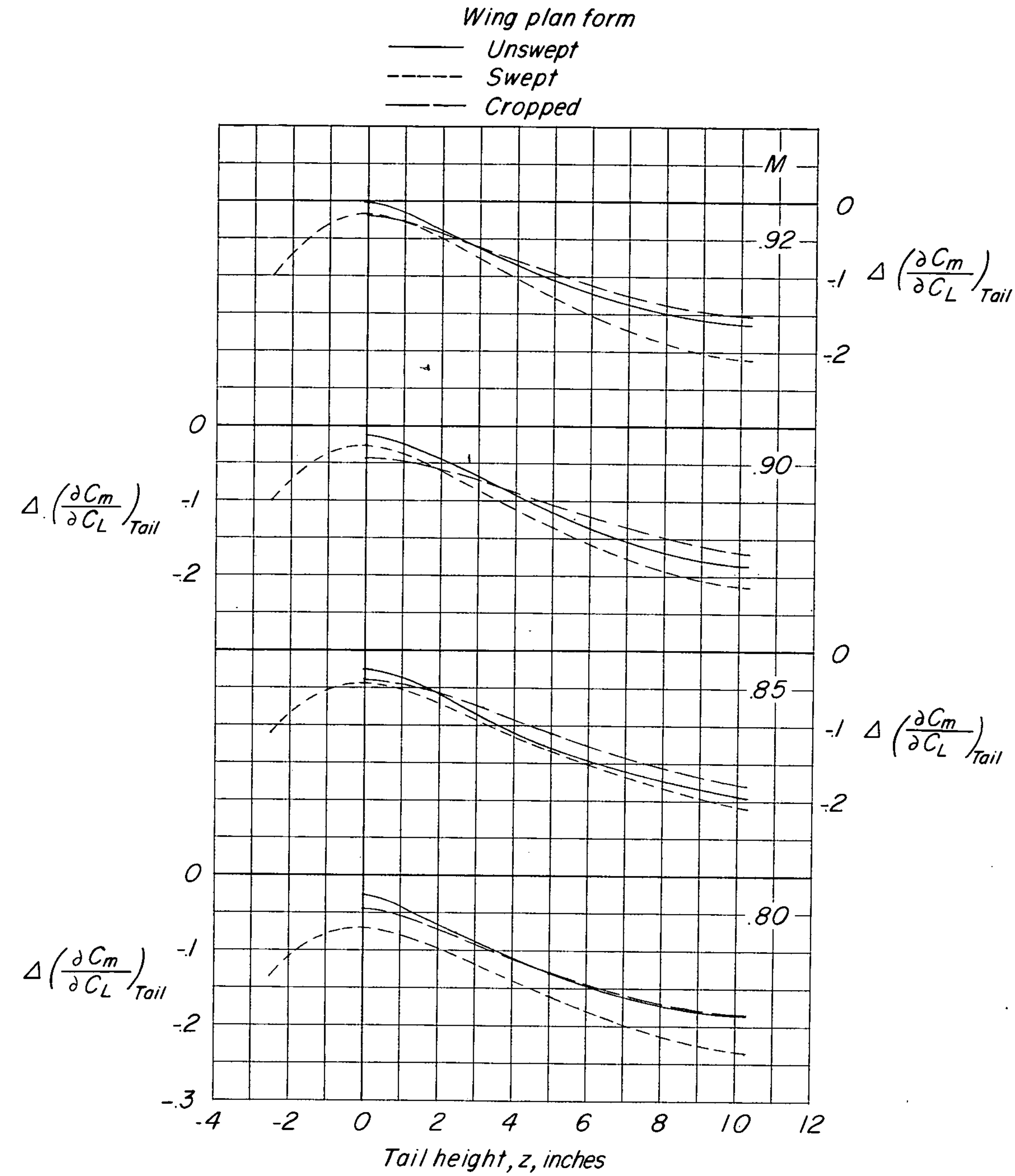


Figure 8.- Effect of tail height on the horizontal-tail contribution to the stability parameter of the model with various wings. $C_L = 0$.

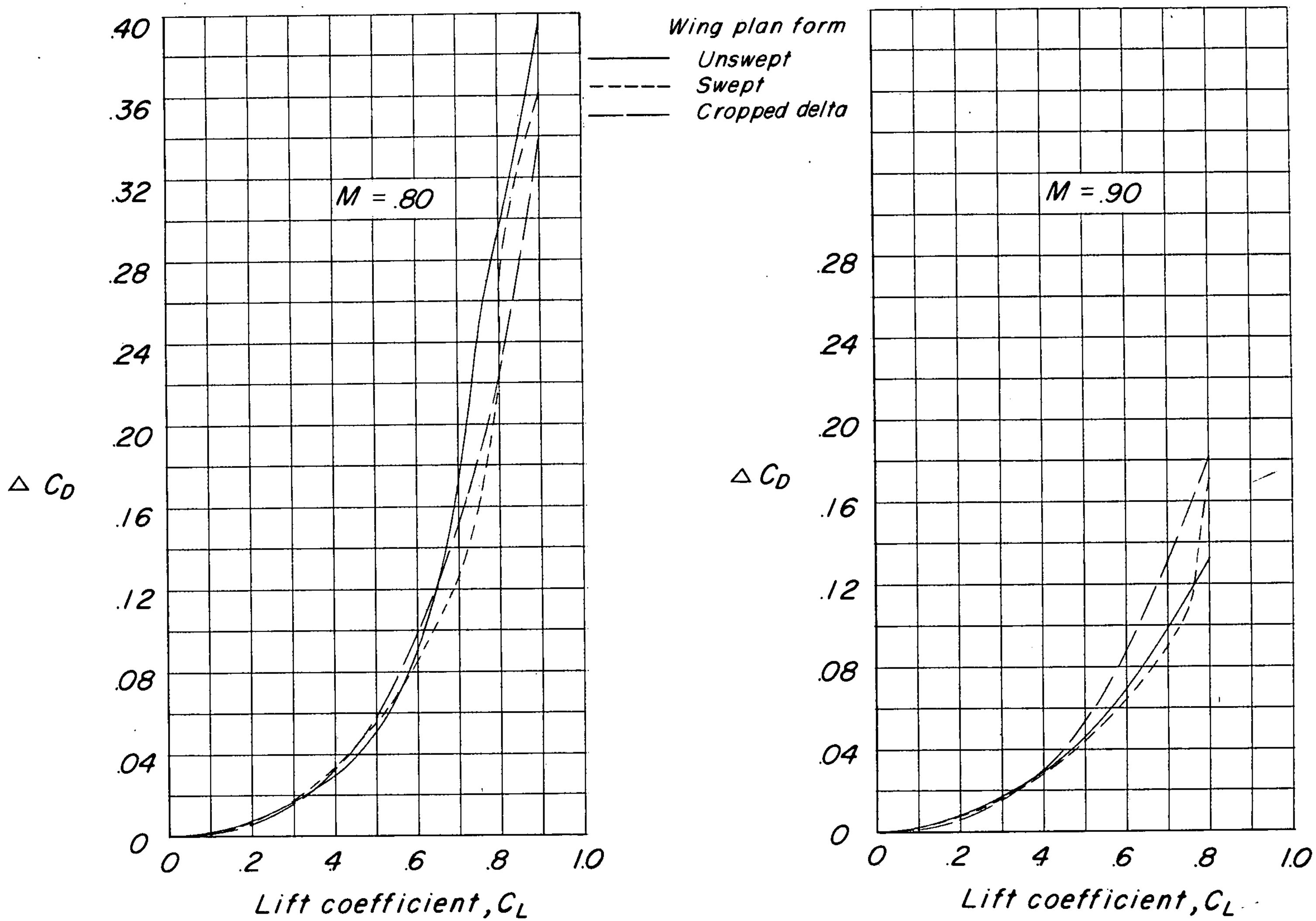


Figure 9.- Drag due to lift of the model with various wings. Horizontal tail off.