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TECHNICAL MEMORANDUM

X-549

EFFECTS OF HORIZONTAL-CONTROL PLANFORM AND WING-LEADING-EDGE MODIFICATION ON LOW-SPEED LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF A CANARD AIRPLANE CONFIGURATION

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ABSTRACT

An investigation at low subsonic speeds has been conducted in the Langley 300-MPH 7- by 10-foot tunnel. The basic wing had a trapezoidal planform, an aspect ratio of 3.0, a taper ratio of 0.143, and an unswept 80-percent-chord line. Modifications to the basic wing included deflectable full-span and partial-span leading-edge chord-extensions. A trapezoidal horizontal control similar in planform to the basic wing and a 60° sweptback delta horizontal control were tested in conjunction with the wing. The total planform area of each horizontal control was 16 percent of the total basic-wing area. Modifications to these horizontal controls included addition of a full-span chord-extension to the trapezoidal planform and a fence to the delta planform.

*Title, Unclassified.

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SUMMARY

An investigation has been conducted at low subsonic speeds to study the effects of horizontal-control planform and wing-leading-edge modification on the longitudinal aerodynamic characteristics of a general research canard airplane configuration. The basic wing of the model had a trapezoidal planform, an aspect ratio of 3.0, a taper ratio of 0.143, and an unswept 80-percent-chord line. Modifications to the wing included addition of full-span and partial-span leading-edge chord-extensions. Two horizontal-control planforms were employed in the study; one was a 60° sweptback delta planform and the other was a trapezoidal planform similar to that of the basic wing. Modifications to these horizontal controls included addition of a full-span leading-edge chord-extension to the trapezoidal planform and a fence to the delta planform.

For the basic-wing—trapezoidal-canard configuration, rather abrupt increases in stability occurred at about 12° angle of attack. A slight pitch-up tendency occurred for the delta-canard configuration at approximately 8° angle of attack.

A comparison of the longitudinal control effectiveness for the basic-wing—trapezoidal-canard combination and for the basic-wing—delta-canard combination indicates higher values of control effectiveness at low angles of attack for the trapezoidal canard. The control effectiveness for the delta-canard configuration, however, is seen to hold up for higher canard deflections and to higher angles of attack. Use of a full-span chord-extension deflected approximately 30° on the trapezoidal canard greatly improved the control characteristics of this configuration and enabled a sizeable increase in trim lift to be realized.

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The addition and deflection of a partial-span wing chord-extension tended to alleviate wing-leading-edge separation at low angles of attack and to reduce canard interference effects. Improvement in the high lift characteristics of the basic wing were also noted for high chord-extension deflections. The addition of the wing chord-extension provided rather large increases in maximum lift-drag ratios for both canard configurations, as compared with those for the chord-extension-off configurations, and also improved the pitching-moment characteristics of the delta-canard configurations at high lift coefficients.

INTRODUCTION

Because of the desirability of efficient supersonic cruise capability for both military and commercial transport aircraft, a considerable amount of aerodynamic research has been directed towards the development of supersonic configurations having high lift-drag ratios. Because of the increase in longitudinal stability encountered at supersonic speeds the drag due to trimming the aircraft becomes a primary factor in the supersonic efficiency. One method of reducing this trim-drag problem is the use of a canard trimming surface, and considerable research has been carried out on various canard configurations at supersonic speeds. (See, for example, refs. 1, 2, and 3.) Investigations at subsonic speeds on some of the more promising designs (for example, refs. 4 and 5) have indicated some rather serious subsonic problem areas. Such factors as loss of control effectiveness and low lift efficiency due to canard-wing interference create landing and take-off problems which tend to offset the supersonic performance advantages. Methods of improving canard control effectiveness by use of high-lift canard devices (refs. 6 and 7) have also been investigated and indicated promising results with regard to increasing trim-lift range and allowable center-of-gravity travel. However, the presence of a canard-induced flow field at the wing results in low values of overall-configuration lifting efficiency and further decreases in efficiency accompanying the canard deflection required for trim at moderate values of lift coefficient.

The present investigation has been initiated to investigate methods of improving the trim-lift capability at low subsonic speeds by wing-planform modifications that may reduce or take advantage of canard-induced flow-field effects and to investigate the effect of canard planform and modification on overall efficiency and control effectiveness at moderate and high lifts. (The term "canard" is used in this report to refer to the horizontal control of the canard configuration.) The use of a wing-leading-edge chord-extension as a means of increasing lift-drag ratio at subsonic speeds (as indicated in ref. 8) has also been investigated. The wing employed in the investigation had a trapezoidal planform. A trapezoidal planform gave higher values of lift-drag ratio at supersonic speeds than did a delta planform in the investigation of reference 9 and also indicated higher values of lift-drag ratio at high subsonic speeds in the results presented in reference 4.

A trapezoidal-planform canard similar to the basic wing and a delta-planform canard having an aspect ratio of 2.62 were investigated. The total planform area of each canard surface was 16 percent of the basic-wing planform area, and the distance from the moment reference to the quarter-chord point of the mean aerodynamic chord for both planforms was held constant.

SYMBOLS

Data in this paper are presented about the wind-axis system which is shown in figure 1, with the coefficients nondimensionalized by the area and mean aerodynamic chord of the basic wing. The moment reference point was located 4.06 inches or $0.225\bar{c}_w$ ahead of $\bar{c}_w/4$ for all tests unless otherwise specified.

b_w wing span, ft

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

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

$C_{L,max}$ maximum lift coefficient

C_{L_α} lift-curve slope per degree

$\Delta C_{L,c}$ incremental lift due to presence of canard surface

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

$C_{m_{\delta_c}}$ canard-control-effectiveness parameter, $\Delta C_m/\delta_c$

$\bar{c}_c$ canard mean aerodynamic chord

$\bar{c}_c/4$ quarter-chord point of canard mean aerodynamic chord

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

$\bar{c}_w/4$	quarter-chord point of wing mean aerodynamic chord
L/D	lift-drag ratio
$(L/D)_{max}$	maximum lift-drag ratio
q	dynamic pressure, lb/sq ft
S_w	wing area, sq ft
α	angle of attack, deg
δ_c	deflection of canard surface, deg
$\delta_{n,c1}$	deflection of trapezoidal-canard-surface chord-extension, deg
$\delta_{n,w}$	deflection of wing chord-extension, deg
$(\delta_{n,w})_i$	wing-chord-extension deflection inboard of $0.332b_w/2$ station
$(\delta_{n,w})_o$	wing-chord-extension deflection outboard of $0.332b_w/2$ station
η_L	lift-efficiency factor, $\dfrac{(C_{L,WBC} - C_{L,WB})}{(C_{L,BC} - C_{L,B})}$, or $\dfrac{(\Delta C_{L,c})_{wing\ on}}{(\Delta C_{L,c})_{wing\ off}}$

Subscripts and abbreviations:

B	body
W	wing
C_1	trapezoidal canard surface
C_2	delta canard surface
$C_{2,f}$	delta canard surface, with fence on

MODEL

The model configurations and component parts are shown in figure 2. The body was a circular ogive, symmetrical in all planes, with a maximum diameter of 4.5 inches and a fineness ratio of 13.33.

The basic wing had a trapezoidal planform similar to that of the basic trapezoidal wing of references 4, 5, and 9, an NACA 65A004 airfoil section parallel to the plane of symmetry, an aspect ratio of 3.0, a taper ratio of 0.143, and an unswept 80-percent-chord line. Full-span and partial-span leading-edge chord-extensions, each of which had a tip extension 20 percent of the basic-wing tip chord and a root extension 10 percent of the basic-wing root chord and was of flat-plate section with a leading-edge radius of 1/16 inch, could be deflected down to a maximum of approximately 30°. The partial-span chord-extension had the root chord 7.50 inches from the fuselage center line, corresponding to approximately 0.93b/2 of the delta canard, and the inboard and outboard sections could be differentially deflected.

The trapezoidal canard surface was of flat-plate section similar in planform to the basic wing and had a total planform area equal to 16 percent of the total basic-wing area. The construction of the chord-extension located on this canard was similar to that of the full-span wing chord-extension. (See fig. 2.) The delta canard was also of flat-plate section with a leading-edge sweep of 60°, an unswept trailing edge, and a total planform area equal to 16 percent of the basic-wing area. A fence was located at a 0.66 spanwise station on this canard surface. (See fig. 3.) The hinge line for both canard surfaces corresponded to the quarter-chord point of the mean aerodynamic chord of each canard planform (fig. 2).

TESTS AND CORRECTIONS

The present investigation was conducted in the Langley 300-MPH 7- by 10-foot tunnel at a dynamic pressure of approximately 57 pounds per square foot. The average test Reynolds number, based on the wing mean aerodynamic chord, was approximately 2.10×10^6. The model was mounted on a single support strut (fig. 3) and tested through an angle-of-attack range from -2° to 24° and at 0° sideslip. All forces and moments were measured by means of a mechanical balance system.

Blockage corrections determined by the method of reference 10 have been applied to the dynamic pressure and drag, and jet-boundary corrections determined by the method of reference 11 have been applied to the angle of attack, pitching-moment, and drag coefficients. Drag coefficients have also been corrected for tunnel buoyancy effects. Tare corrections for strut interference have also been applied to the lift and pitching moment.

PRESENTATION OF RESULTS

The figures that present the basic data for the configurations investigated are presented in the following table:

DISCUSSION

Longitudinal Stability

A comparison of the longitudinal stability characteristics of the two basic configurations is presented in figure 4. The data indicate a rather abrupt increase in stability occurring at about 12° angle of attack for the configuration having the trapezoidal canard while a slight pitch-up tendency exists at about 8° for the configuration having the delta canard.

In an effort to explain the nonlinear variation of pitching moment with lift coefficient noted for the trapezoidal-canard configuration the effect of various component parts for the trapezoidal-canard arrangement has been investigated (fig. 5). The rather large increase in longitudinal stability for the wing—body—trapezoidal-canard configuration between 12° and 20° angle of attack results from the combination of increasing stability of the wing-body arrangement (associated with wing-leading-edge separation) noted in this region and the decrease of the canard-body instability. The abrupt pitch-up above 20° angle of attack noted for the complete configuration may be attributed to the pitch-up tendency of the basic wing due to tip stall, being aggravated by the canard-induced flow-field effects, and to the direct canard effect associated with its decreasing lift characteristics at high angles of attack.

The slight pitch-up tendency for the configuration having the delta canard can be seen from figure 13 to be associated with the canard itself as indicated by increasing instability with increasing angle of attack. This canard instability, when combined with the basic wing, which indicates increasing stability at moderate angles of attack, as mentioned in connection with the trapezoidal canard, results in a fairly linear variation of pitching moment in the moderate angle-of-attack range (fig. 4). The pitch-up tendency at high lift of the delta-canard configuration is also directly related to the continued increasing canard instability coupled with tip stall associated with the wing. In this connection it is noted that addition and deflection of a partial-span wing chord-extension reduced the pitch-up tendency of the delta-canard configuration occurring at high lifts, by delaying the wing tip stall to higher angles of attack (fig. 16). This improvement in wing lifting capabilities is detrimental to the longitudinal stability associated with the trapezoidal-canard configuration since the abrupt increase in stability, noted for the basic configuration, is further increased in the moderate lift range. (See, for examples, figs. 8 and 9.)

Thus, a comparison of the longitudinal stability characteristics of the wing—trapezoidal-canard configuration with those of the wing—delta-canard configuration indicates the importance of canard-planform selection for a given wing planform in determining the overall pitching-moment characteristics.

Longitudinal Control

Figure 18 presents the control effectiveness for the trapezoidal and delta canards and the effects of the addition of the basic wing. The trapezoidal canard indicates higher values of control effectiveness than did the delta control at low angles of attack for the wing-off condition. The control effectiveness for the delta canard, however, is seen to hold up for higher canard deflection and to higher angles of attack due to the angle for $C_{L,max}$ being greater for this planform. The addition of the wing had little effect on the overall variation of control effectiveness with angle of attack for these planforms, although the magnitude is somewhat reduced because of canard-wing interference.

The use of a full-span chord-extension deflected approximately 30° on the trapezoidal canard surface greatly improved the control characteristics of this configuration (fig. 19(a)) and enabled a sizeable increase in the trim-lift coefficient to be realized. The moment reference has been adjusted for both arrangements to render approximately 5 percent low-lift stability. It should be pointed out that the improvement in the control power is believed to be due mainly to the deflection of the chord-extension rather than to the chord-extension itself. The effect on the canard-body configuration can be seen in figure 10.

The addition of a fence to the delta-canard arrangement (fig. 19(b)) did not increase maximum trim lift although it reduced to some extent the nonlinearities at the moderate lift coefficients associated with the fence-off configuration. Again the moment reference has been adjusted to provide 5 percent low-lift stability for both arrangements.

Figure 20 presents the longitudinal control characteristics of the trapezoidal canard with a full-span chord-extension deflected approximately 30° and the delta canard with a fence. These canards are used in combination with the wing having a partial-span chord-extension. The addition of the partial-span wing chord-extension on the trapezoidal canard configuration indicated little or no improvement in the control characteristics noted for this configuration without the partial-span wing chord-extension. The addition of the partial-span wing chord-extension to the delta canard configuration also had little effect on the control effectiveness of this configuration. However, reduction in the large variation in pitching moment at high lifts is noted, due to the delay in wing tip stall by use of the partial-span wing chord-extension.

Canard-Wing Interference

One problem area of prime interest in canard considerations at subsonic speeds is the effect of the canard-induced flow on the overall longitudinal aerodynamic characteristics of this type of configuration. The canard efficiency factor η_L, which is a measure of the amount of available canard lift that is obtained, is directly related to the average downwash at the wing induced by the canard surface. (See refs. 2, 3, and 5.) If there were no interference between canard surface and the wing, the lifting efficiency would be 1.0, and, if the total amount of lift produced by the canard surface is lost at the wing due to interference, the lifting efficiency is 0.

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A comparison of the lifting capabilities of the delta and trapezoidal canard controls without high-lift devices may be seen in figure 4, which presents the effects of canard planform on the aerodynamic characteristics of the basic-wing—body configuration. An interesting point to note is the fact that, even though the addition of the delta canard to the basic-wing—body configuration was less destabilizing than the trapezoidal canard, due to lower values of C_{L_α} for the delta canard, slight increases in overall configuration lift over those realized for the trapezoidal-canard arrangement are present, which suggests that the delta planform has higher lifting efficiency because of less interference effects on the wing, as noted in reference 7. This effect could also result in higher $(L/D)_{max}$ for the delta-canard arrangement. Also, more wing area is located in the upwash field for the delta canard surface than for the trapezoidal canard surface, possibly resulting in the higher lifting efficiency as suggested in reference 5.

Figure 21 presents trends of (L/D) for some of the configurations tested and indicates that the $(L/D)_{max}$ for the delta-canard configuration approaches the $(L/D)_{max}$ realized for the basic-wing—body combination closer than the trapezoidal-canard arrangement.

A partial-span wing-leading-edge chord-extension was added to the wing at the estimated delta-canard tip vortex location for $\alpha = 4^\circ$, in an effort to take advantage of the canard upwash field and also to reduce the canard-induced wing-tip stall characteristics of the basic wing as noted in figure 4. Gains in $(L/D)_{max}$ are noted for both canard-planform arrangements by use of the wing chord-extension. It should be noted, however, that the partial-span wing chord-extension, being located at the approximate delta-canard tip vortex location, had its root section located in the downwash field of the trapezoidal canard and, thereby, the effect of favorable upwash was reduced somewhat.

The effects of the addition of the wing chord-extension in reducing canard-induced flow effects for the trapezoidal-canard arrangement may be seen in figure 22, which presents visual flow studies at various angles of attack. For $\alpha = 4^\circ$, which is approximately the angle for $(L/D)_{max}$, the wing with chord-extension off has considerable outflow along the leading edge due apparently to the canard-induced flow effect, whereas the addition and slight deflection of the wing chord-extension tends to straighten out the flow across the total wing span, which helps explain the reason for the realized increases in $(L/D)_{max}$ with the wing chord-extension.

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SUMMARY OF RESULTS

An investigation has been conducted at low subsonic speeds to study the effects of canard planform and wing modification on the longitudinal aerodynamic characteristics of general research canard-airplane configuration. Trapezoidal and delta canard planforms were employed in the investigation. Modifications to the canard surfaces included addition of a full-span leading-edge chord-extension to the trapezoidal planform and a fence to the delta planform. Modifications to the wing included addition of full- and partial-span leading-edge chord-extensions. The results of the investigation may be summarized in the following observations:

1. For the basic-wing—trapezoidal-canard configuration, rather abrupt increases in stability occurred at about 12° angle of attack. A slight pitch-up tendency occurred for the delta-canard configuration at approximately 8° angle of attack.

2. A comparison of the longitudinal control effectiveness for the basic-wing—trapezoidal-canard combination and for the basic-wing—delta-canard combination indicates higher values of control effectiveness at low angles of attack for the trapezoidal canard. The control effectiveness for the delta-canard configuration, however, is seen to hold up for higher canard deflections and to higher angles of attack. Use of a full-span chord-extension deflected approximately 30° on the trapezoidal canard greatly improved the control characteristics of this configuration and enabled a sizeable increase in trim lift to be realized.

3. The addition and deflection of a partial-span wing chord-extension tended to alleviate wing-leading-edge separation at low angles of attack and to reduce canard interference effects. Improvement in the high lift characteristics of the basic wing were also noted for high chord-extension deflections. The addition of the wing chord-extension provided rather large increases in maximum lift-drag ratios for both canard configurations, as compared with those for the chord-extension-off configurations, and also improved the pitching-moment characteristics of the delta-canard configurations at high lift coefficients.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., May 9, 1961.

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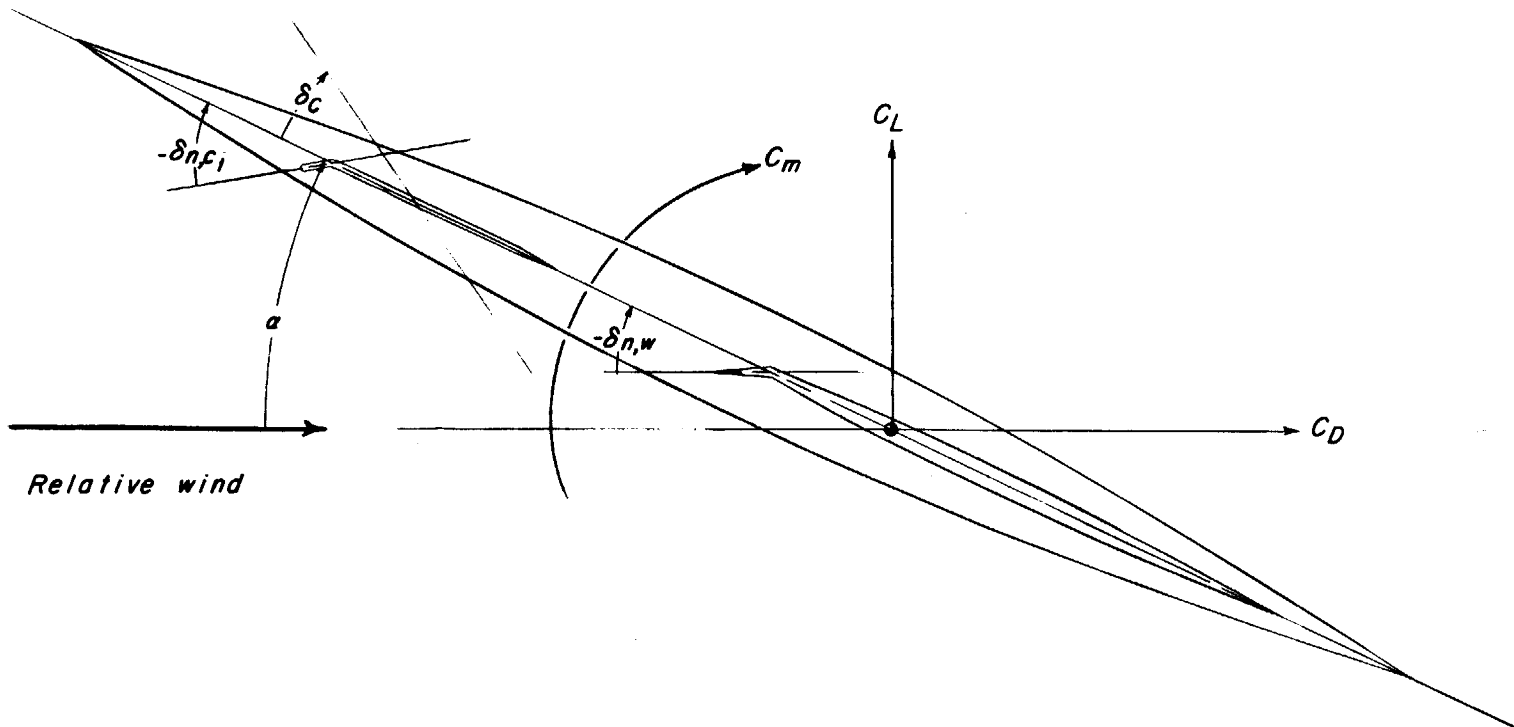

Figure 1.- Wind-axis system, with positive directions of forces, moments, and angular deflections indicated by the arrows.

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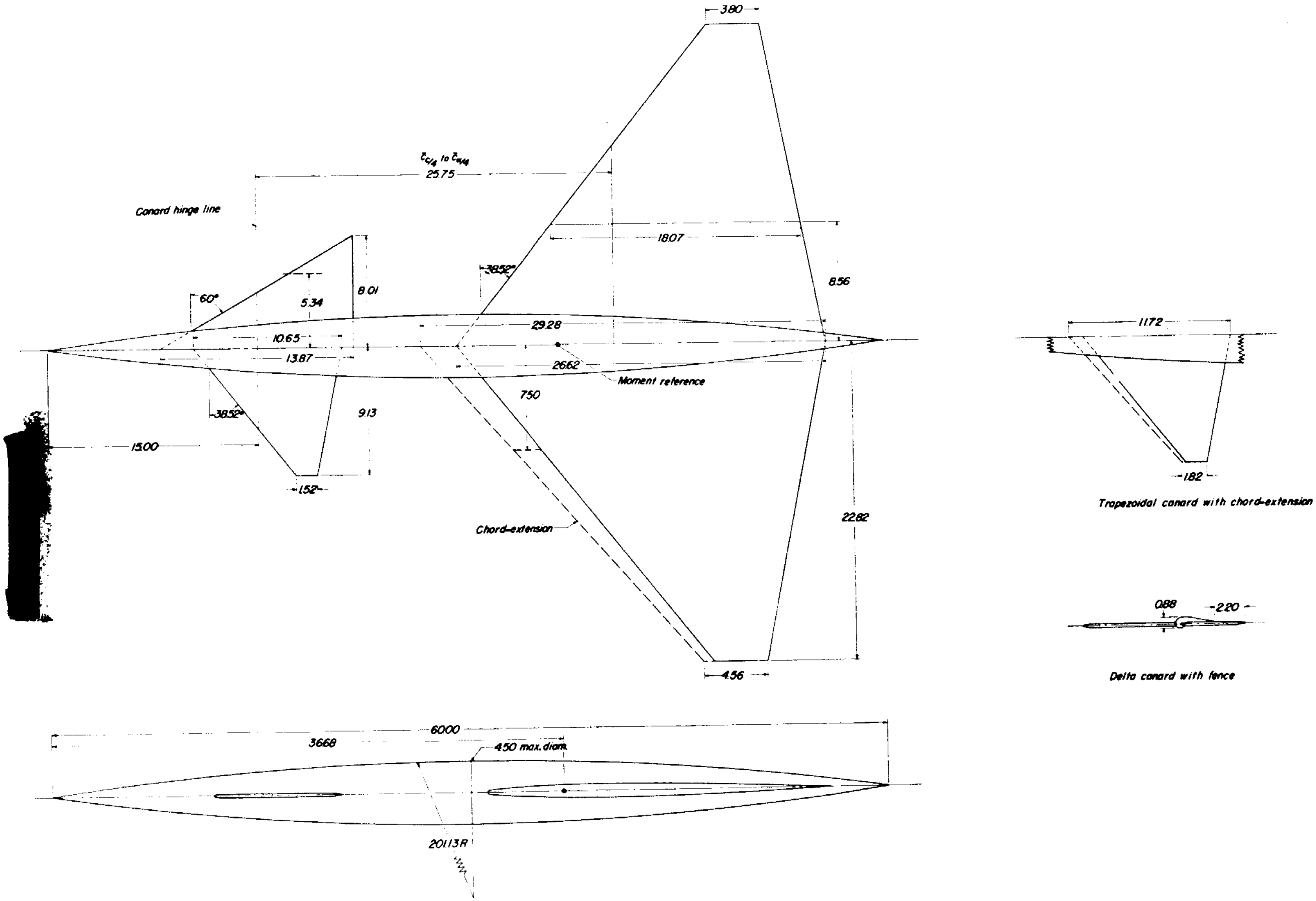

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Figure 2.- Geometric characteristics of the configurations used in the present investigation. All dimensions are in inches unless otherwise noted.

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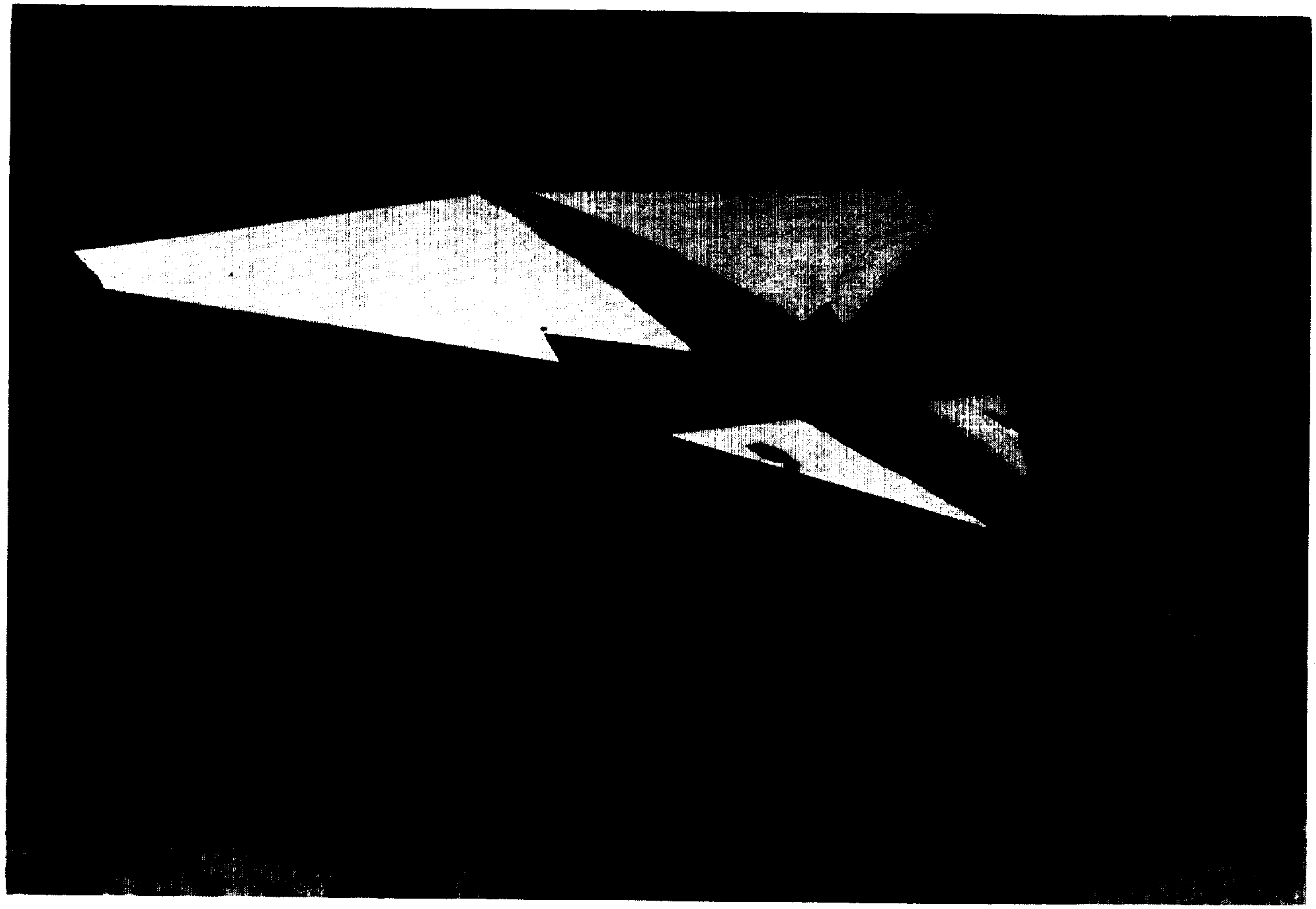

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Figure 3.- Configuration having a delta canard with fence and wing with partial-span chord-extension, mounted in the Langley 300-MPH 7- by 10-foot tunnel.

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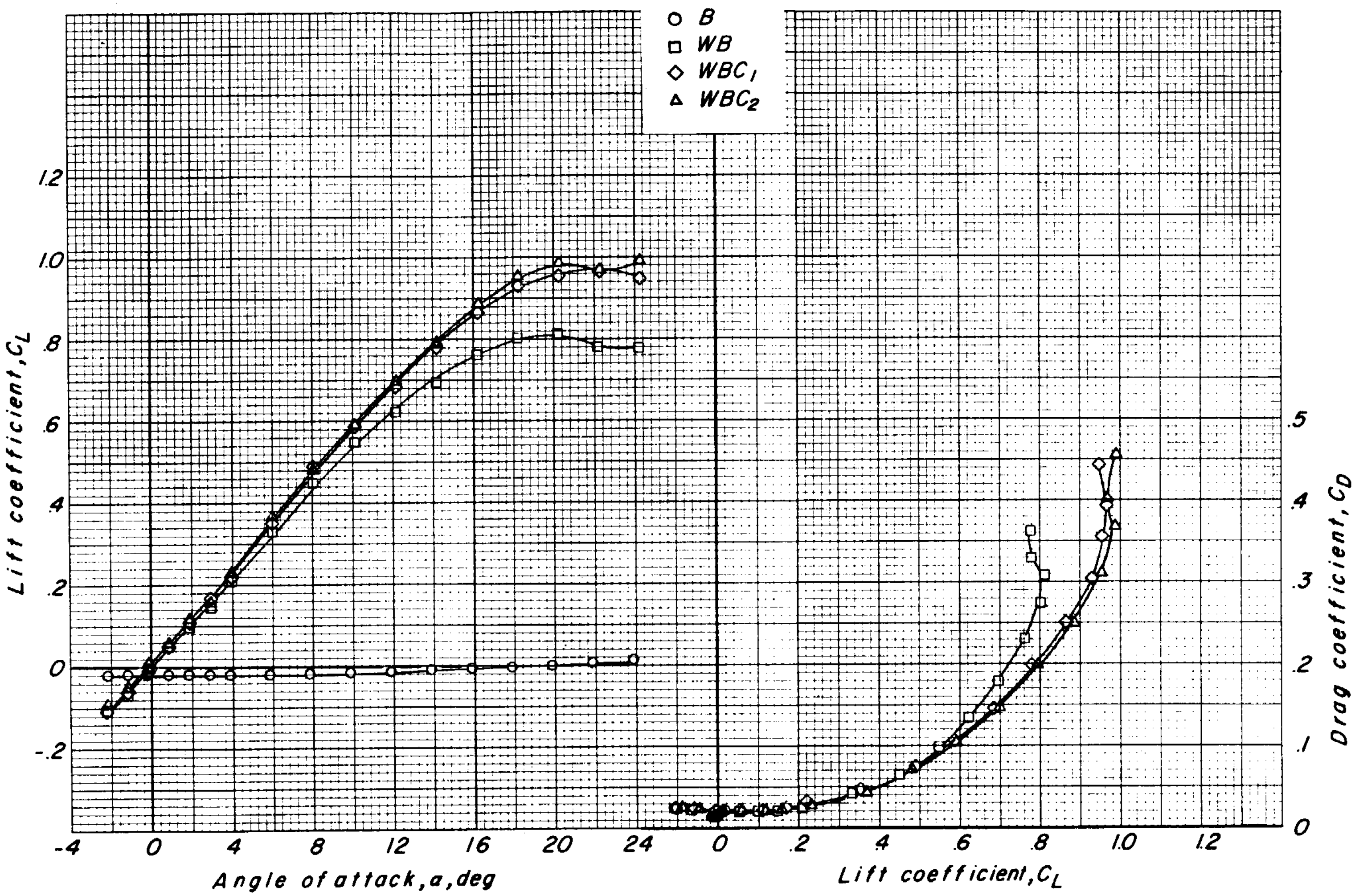

Figure 4.- Effect of the addition of delta and trapezoidal canard surfaces on the longitudinal aerodynamic characteristics of various configuration component parts. All control surfaces at zero deflection.

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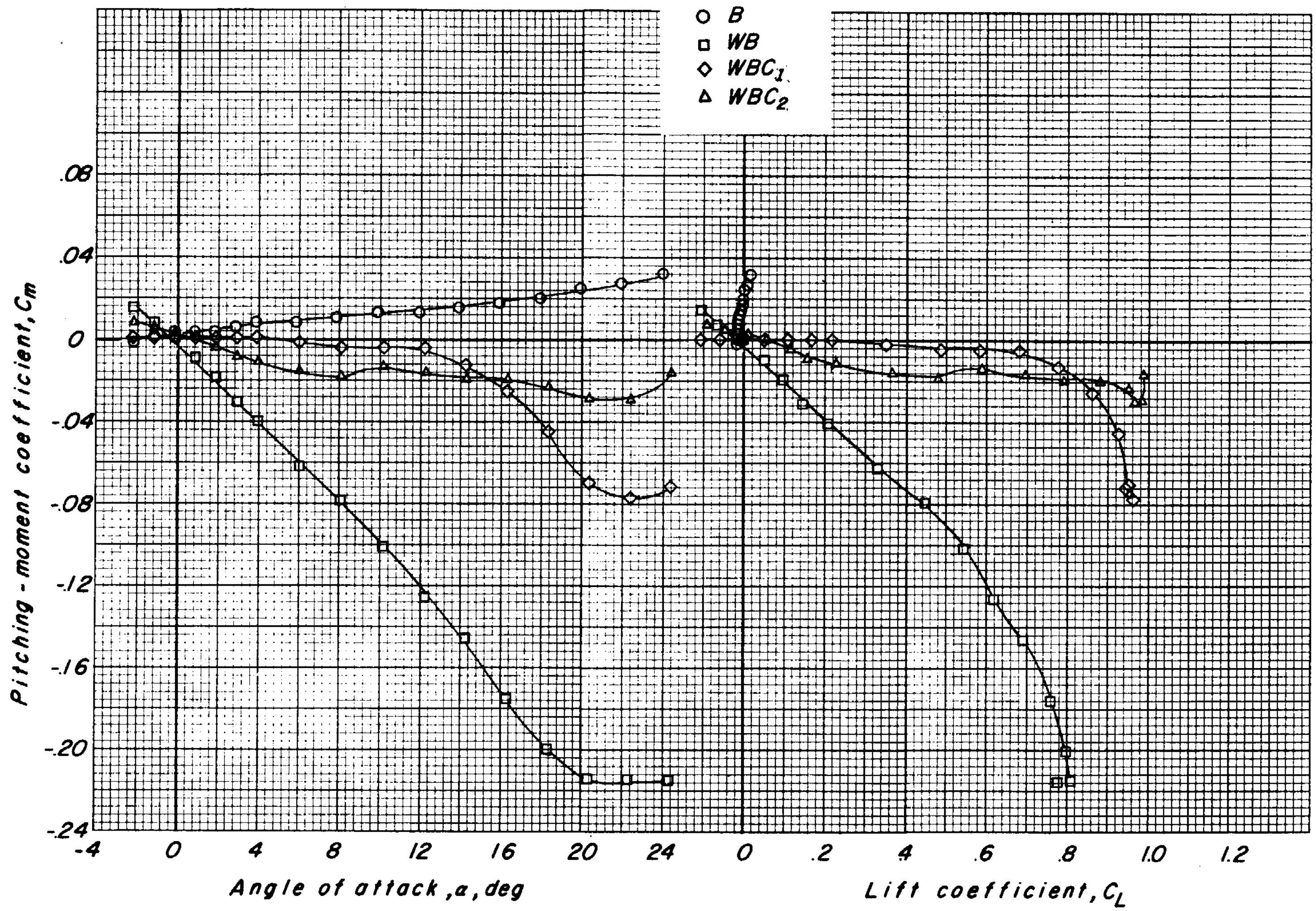

Figure 4.- Concluded.

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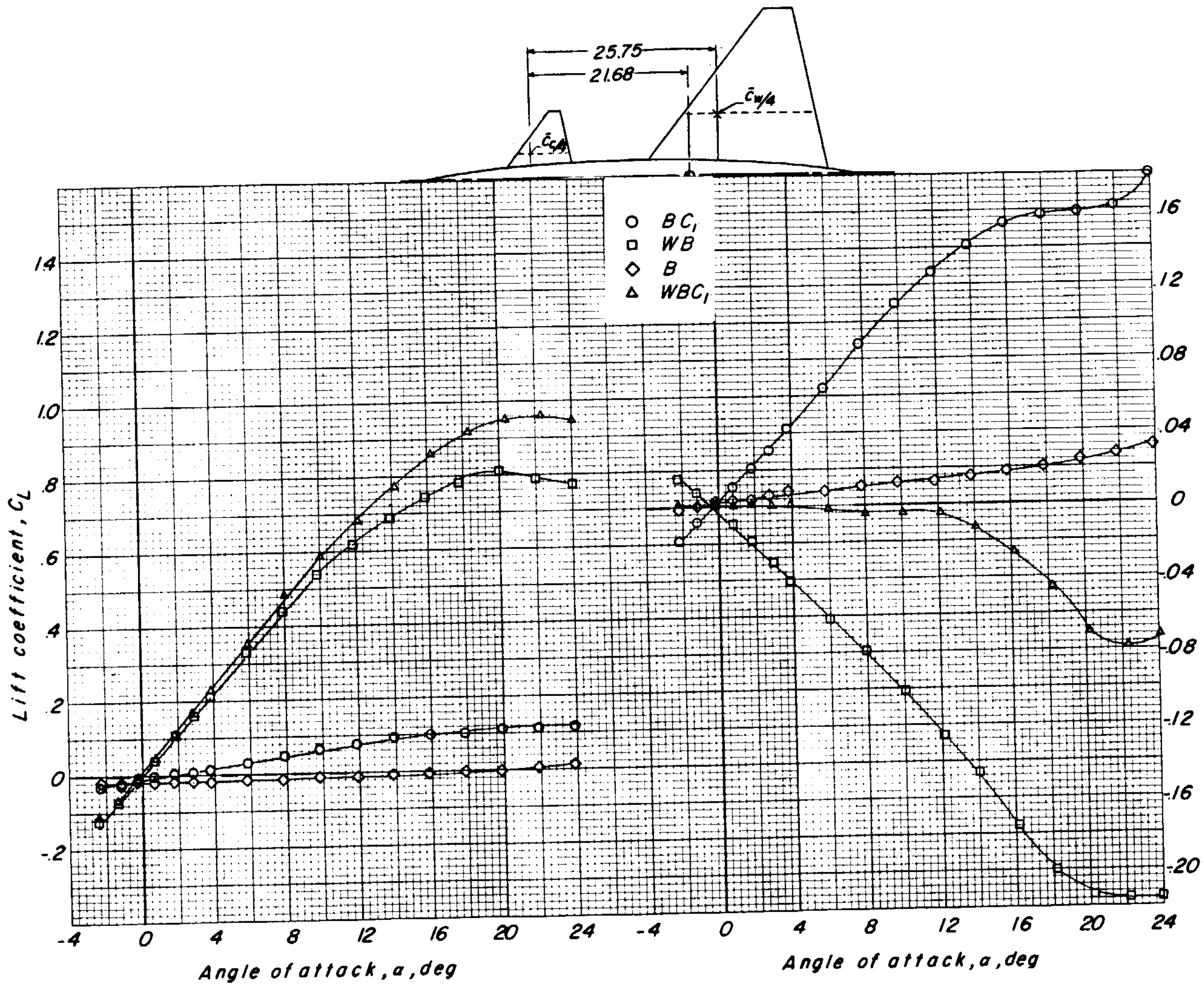

Figure 5.- Effect of various component parts on the longitudinal aerodynamic characteristics of the basic-wing—trapezoidal-canard configuration. All controls at zero deflection.

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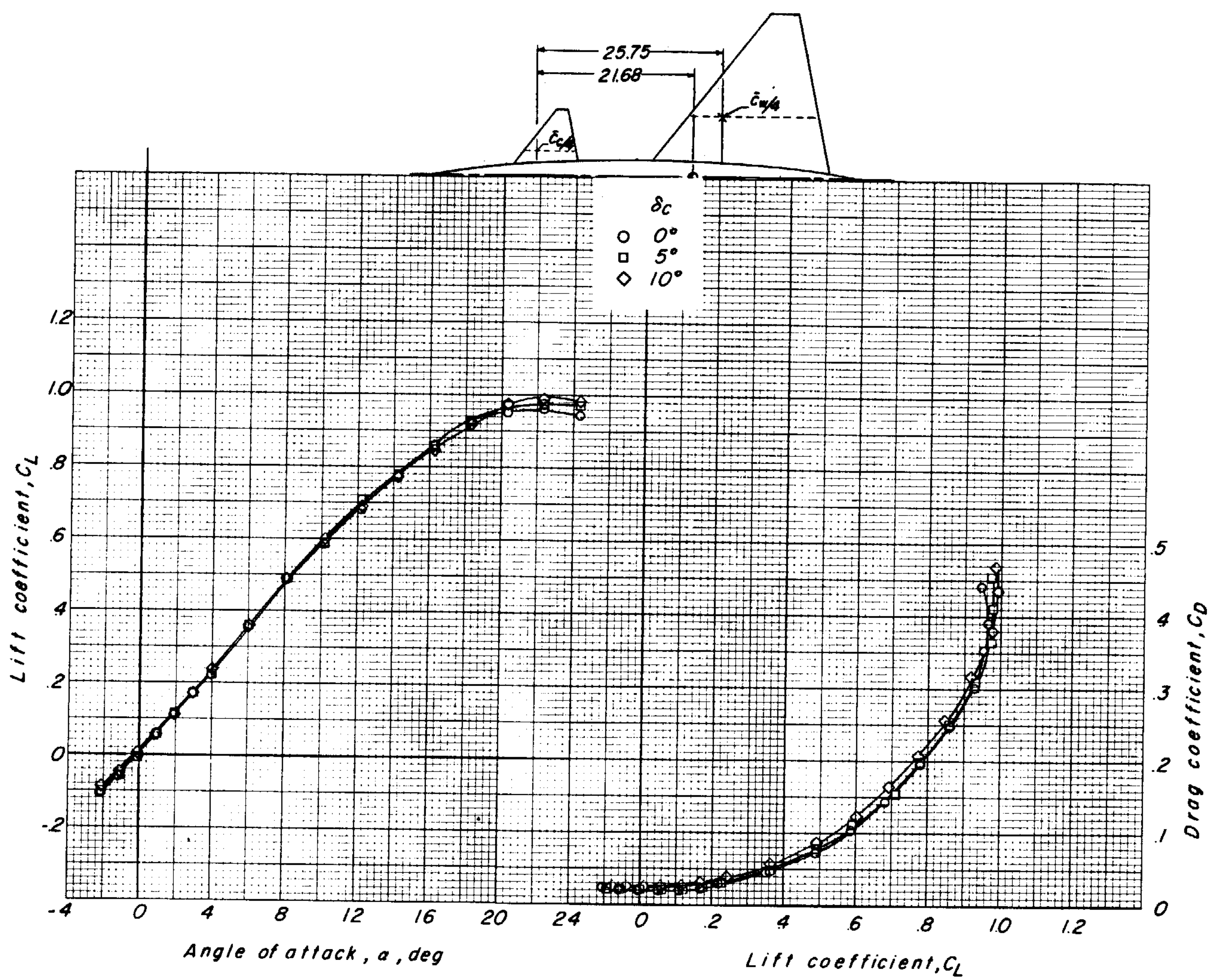

Figure 6.- Longitudinal control characteristics of the basic-wing—trapezoidal-canard configuration, WBC_1.

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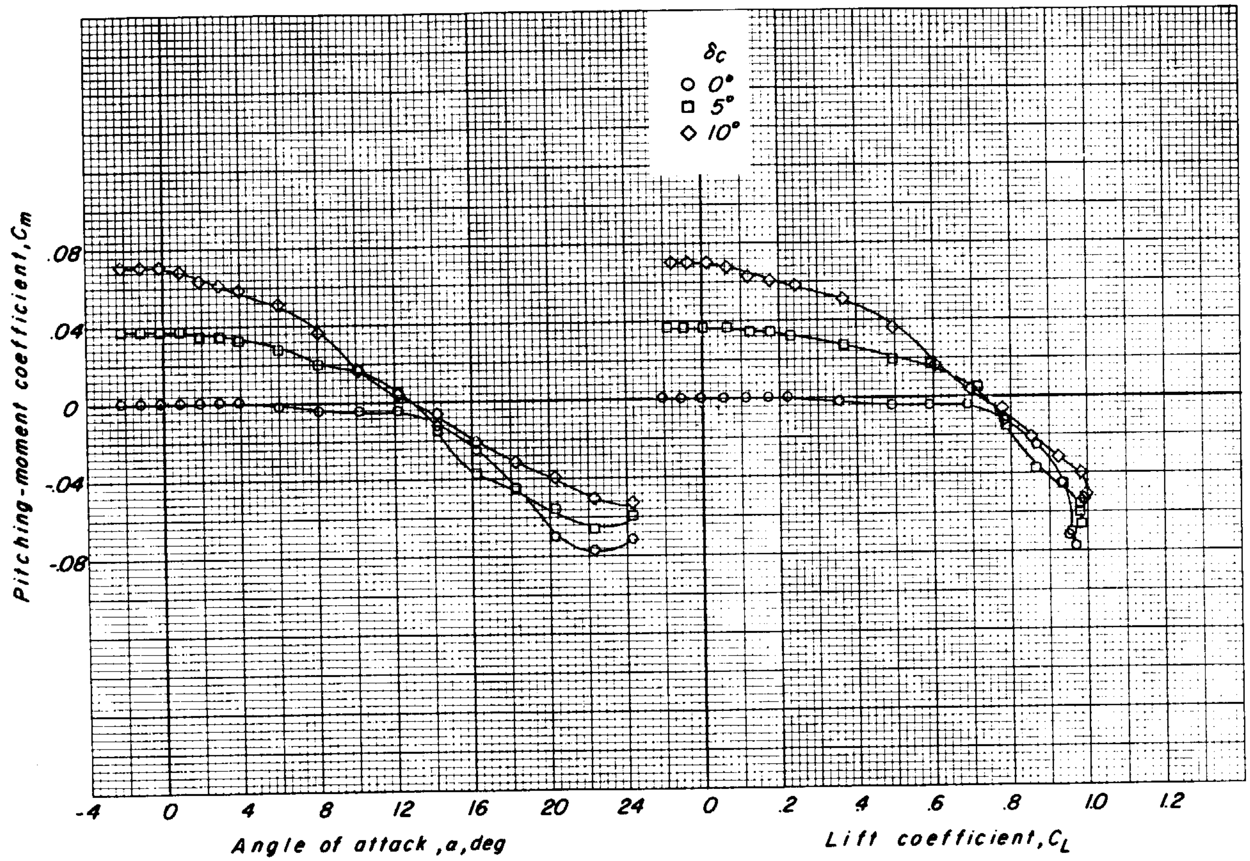

Figure 6.- Concluded.

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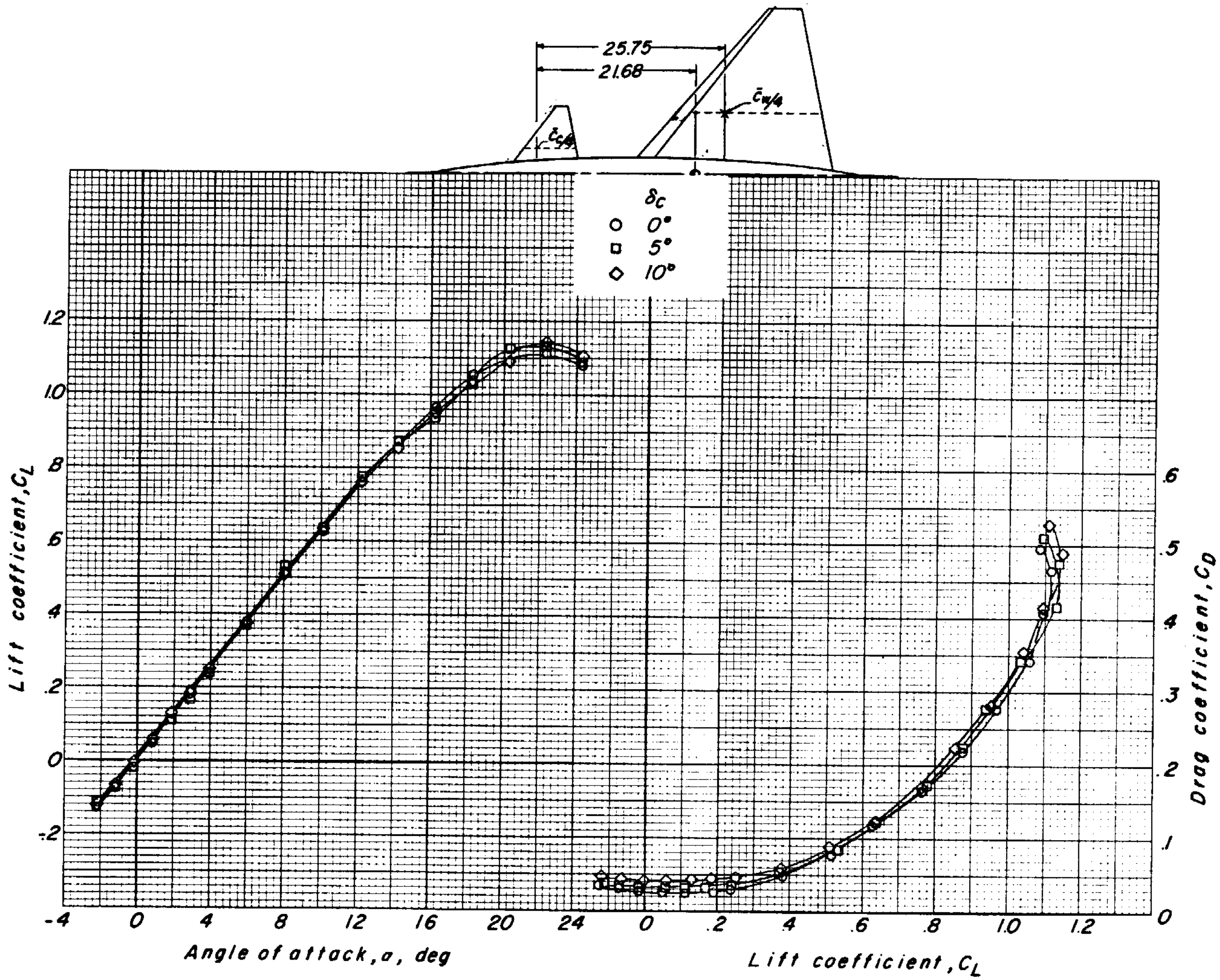

Figure 7.- Longitudinal aerodynamic characteristics of the configuration having a trapezoidal canard and the wing with full-span leading-edge chord-extension, WBC_1. $\delta_{n,w} = 0^{\circ}$.

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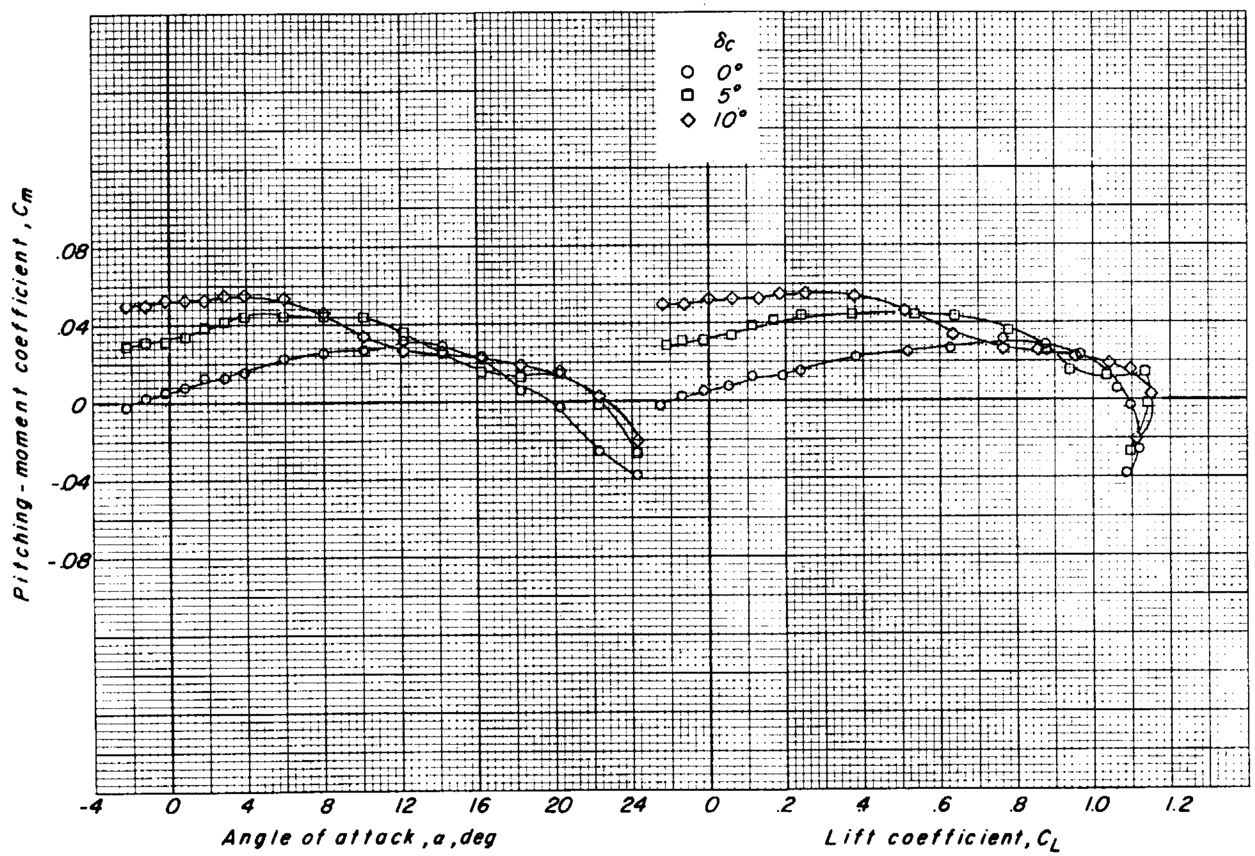

Figure 7.- Concluded.

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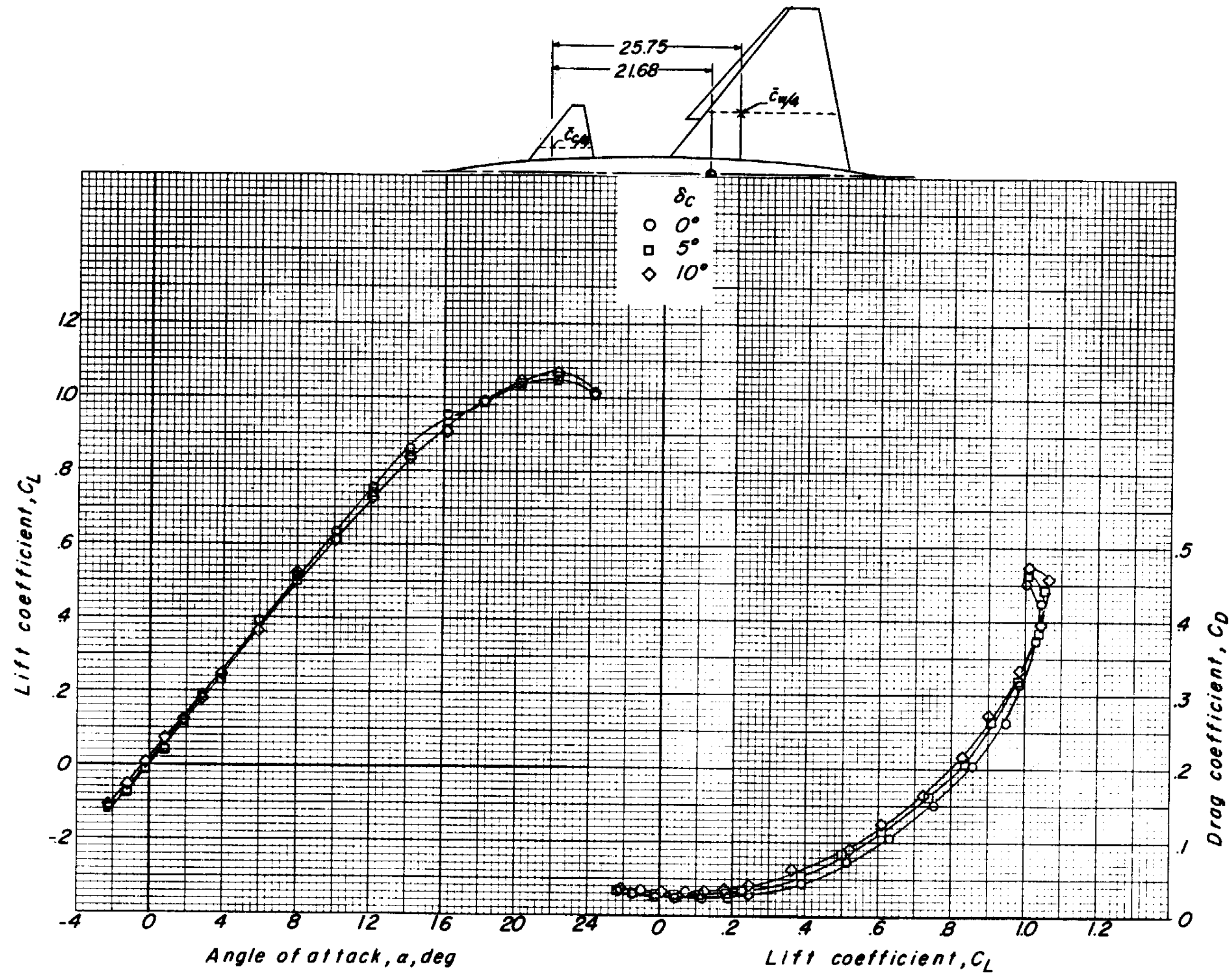

Figure 8.- Longitudinal aerodynamic characteristics of the configuration having a trapezoidal canard and the wing with partial-span leading-edge chord-extension, WBC_1. $\delta_{n,w} = 0^{\circ}$.

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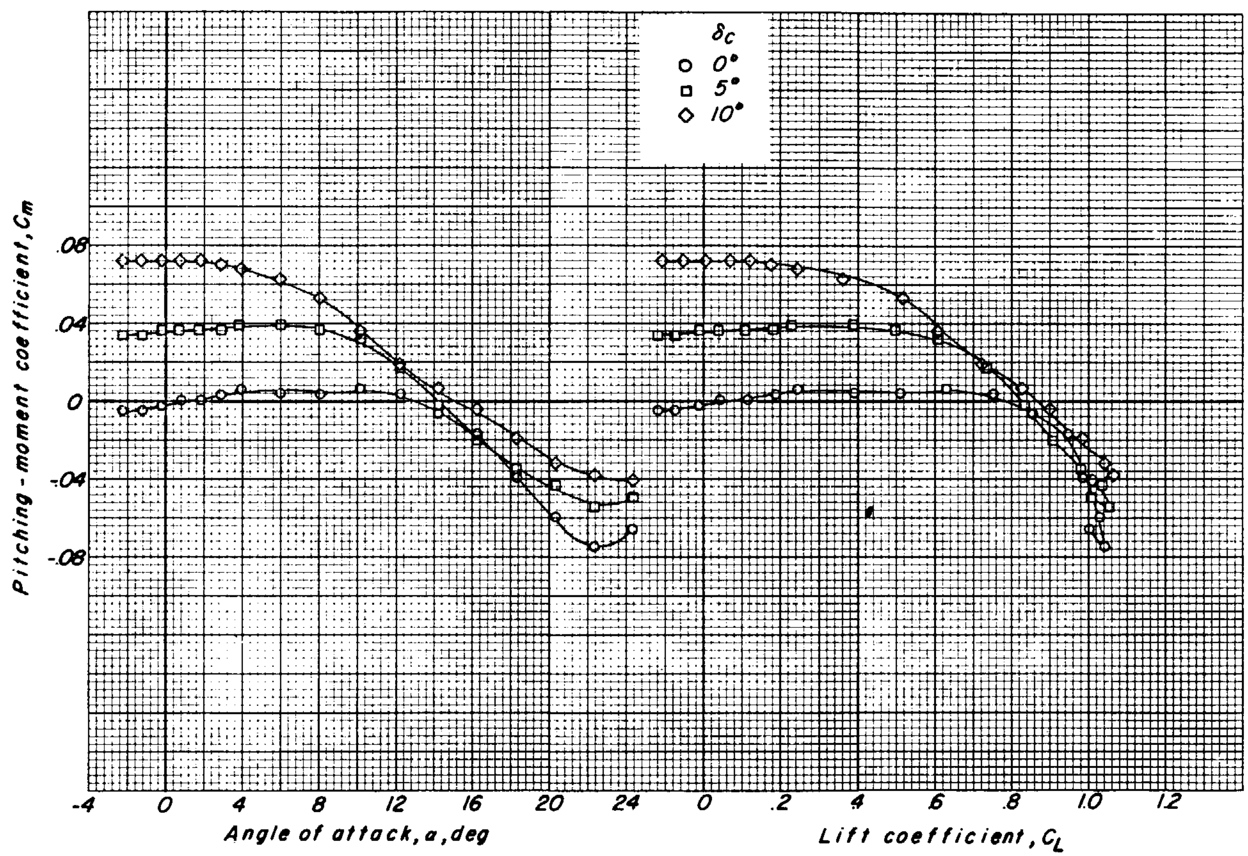

Figure 8.- Concluded.

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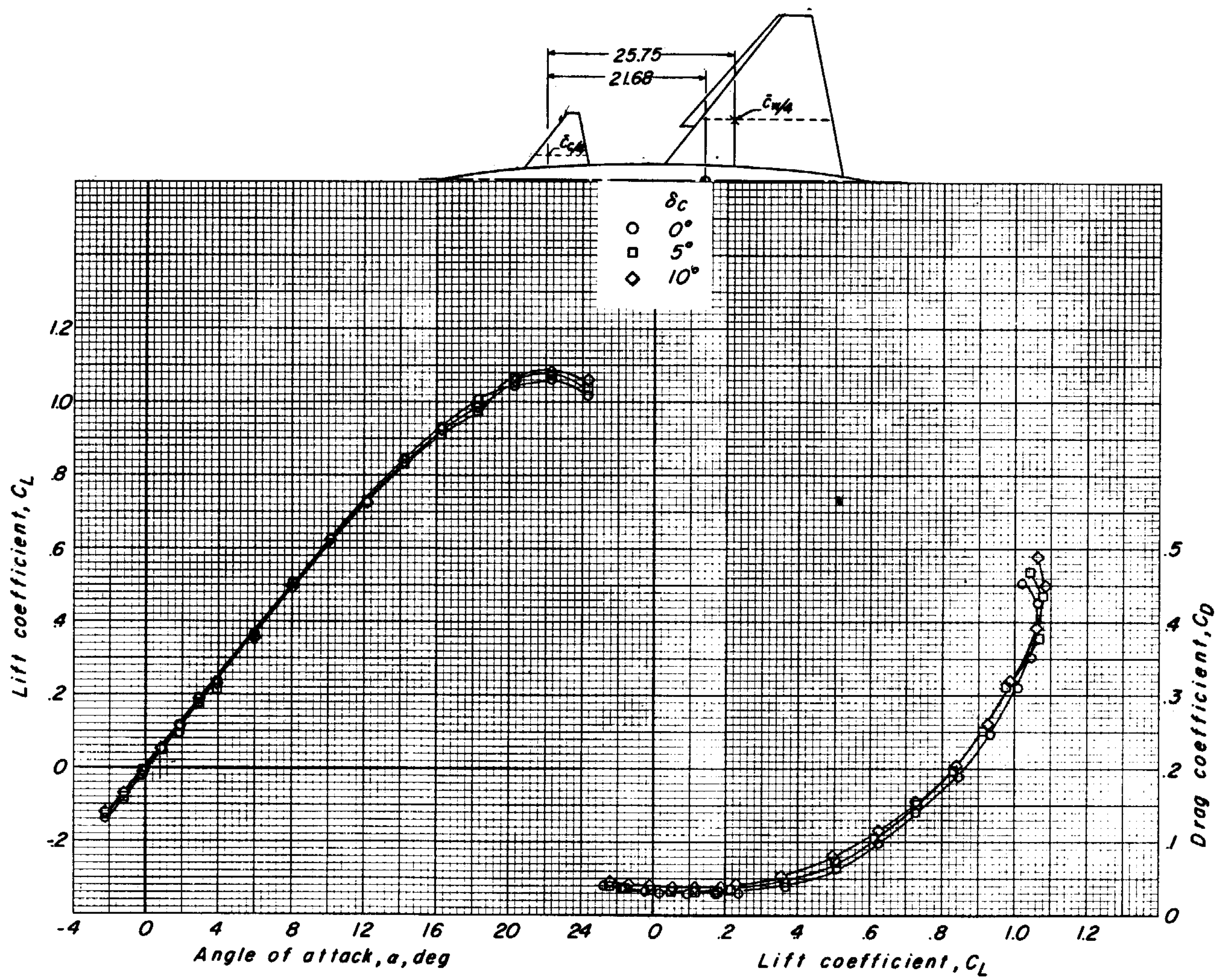

Figure 9.- Longitudinal aerodynamic characteristics of the configuration having a trapezoidal canard and the wing with partial-span leading-edge chord-extension, WBC_1. $\delta_{n,w} = -15^{\circ}$.

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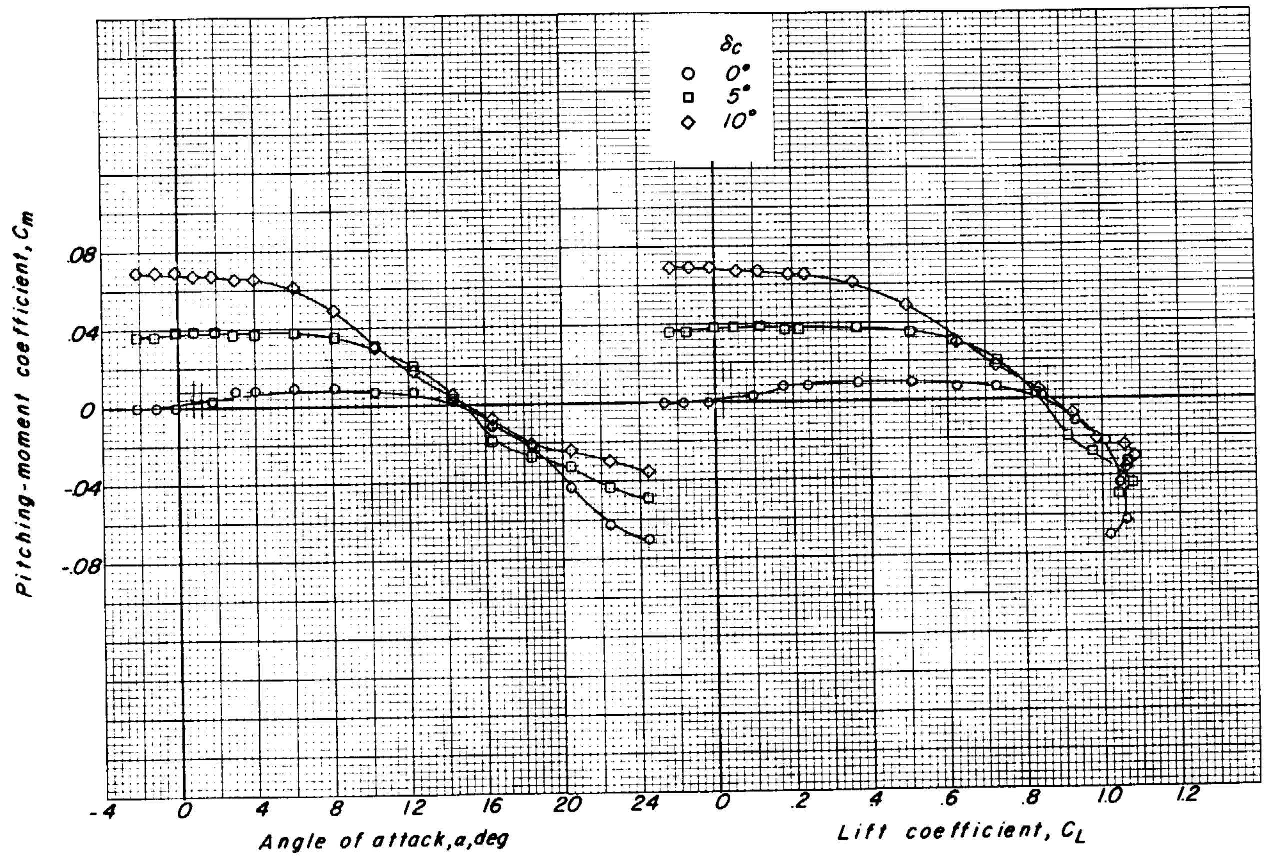

Figure 9.- Concluded.

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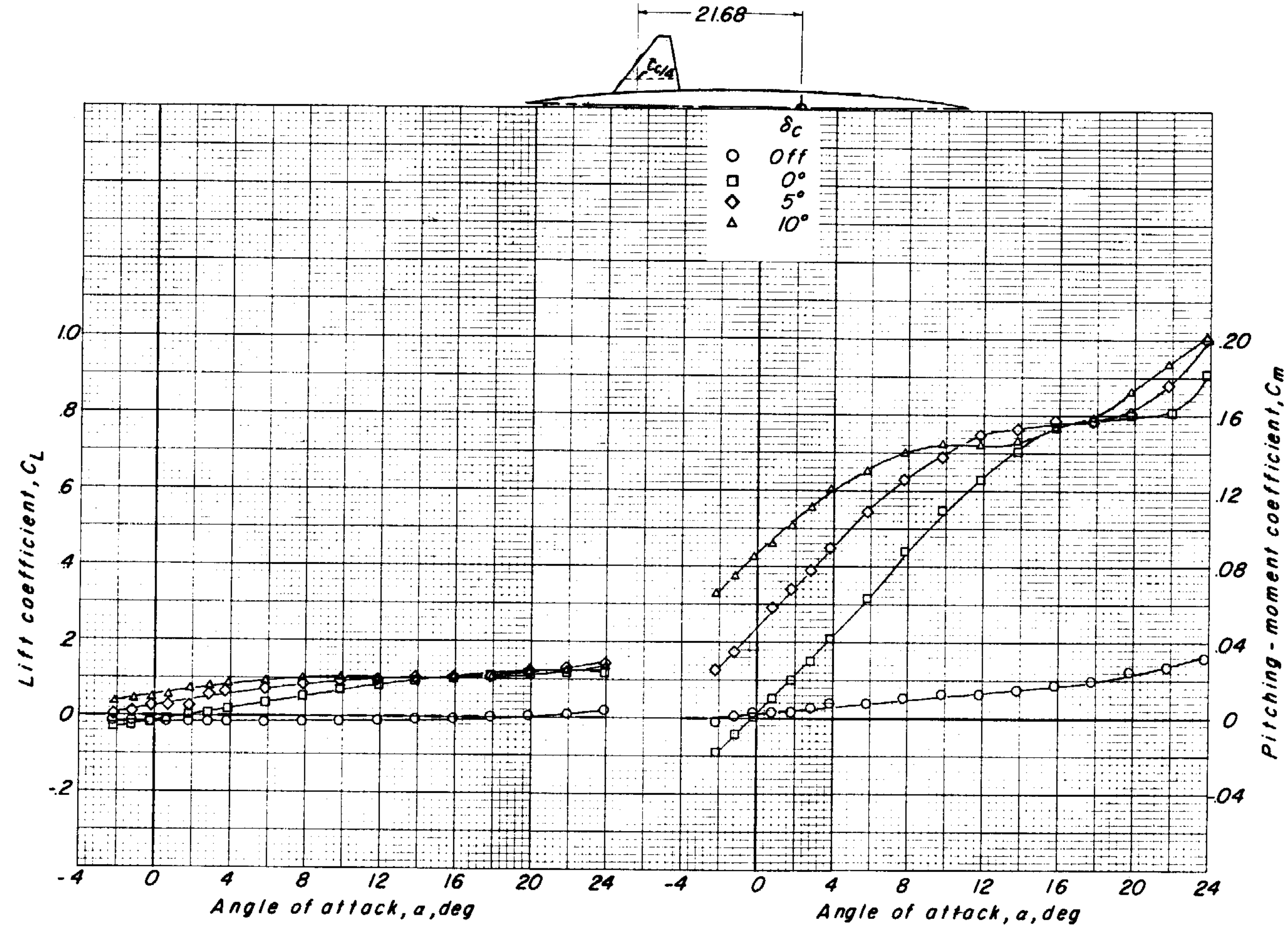

(a) Basic trapezoidal canard.

Figure 10.- Longitudinal control characteristics of the configuration having a trapezoidal canard surface and with the wing off, BC_1.

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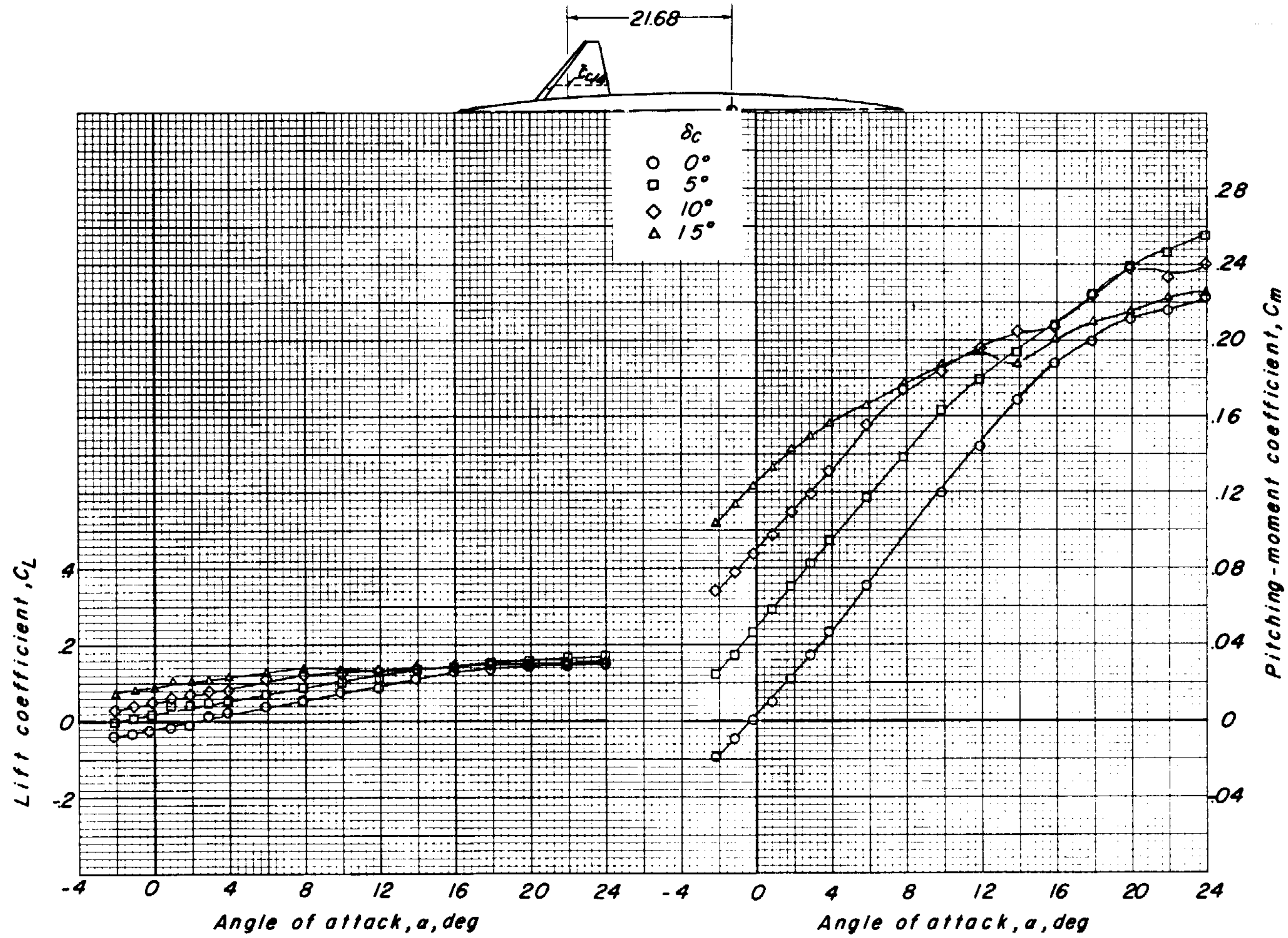

(b) Trapezoidal canard with full-span leading-edge chord-extension. $\delta_{n,cl} = -30°$.

Figure 10.- Concluded.

[redacted]

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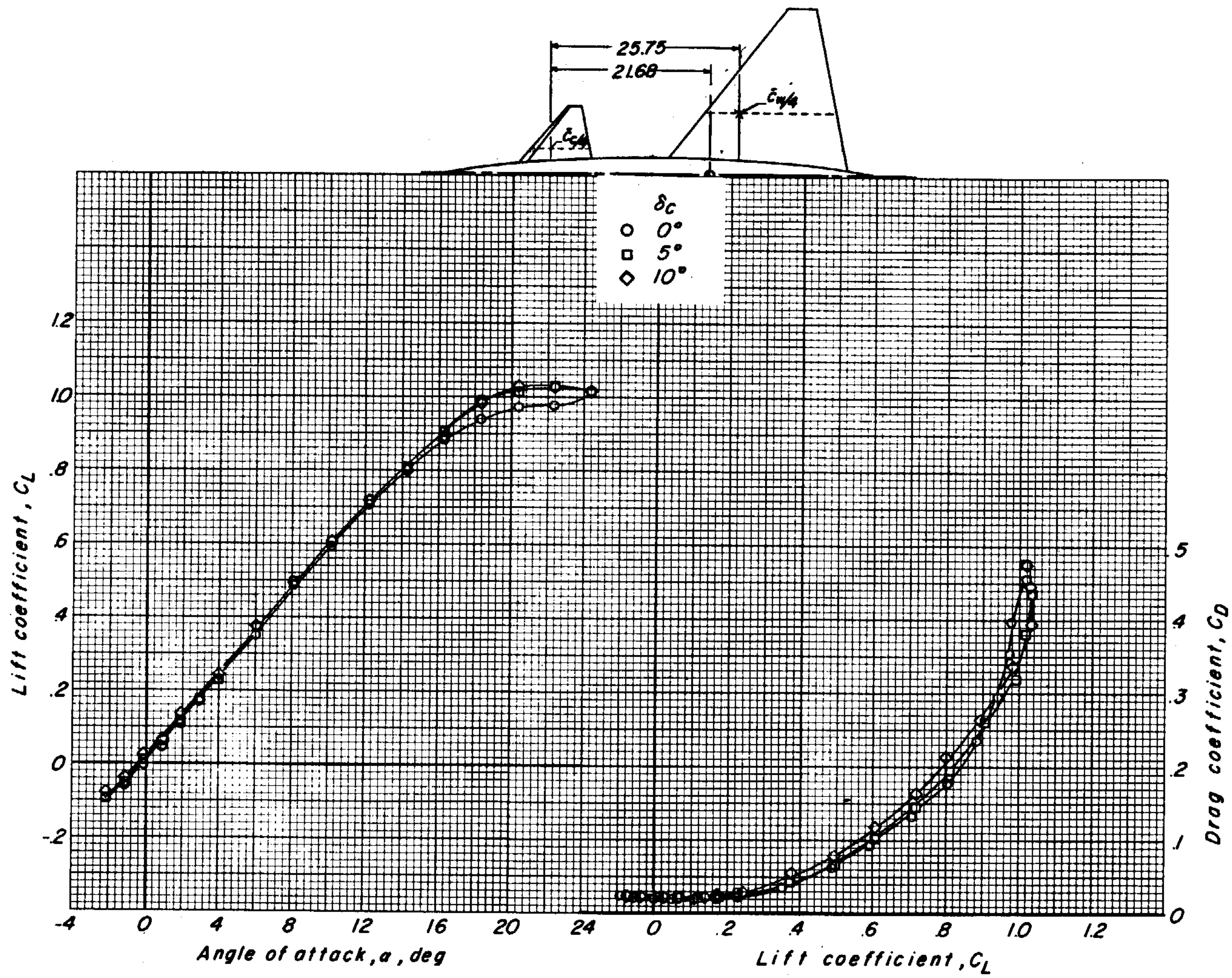

Figure 11.- Longitudinal aerodynamic characteristics of the configuration having the basic wing and a trapezoidal canard with full-span chord-extension, WBC_1. $\delta_{n,cl} = -30^{\circ}$.

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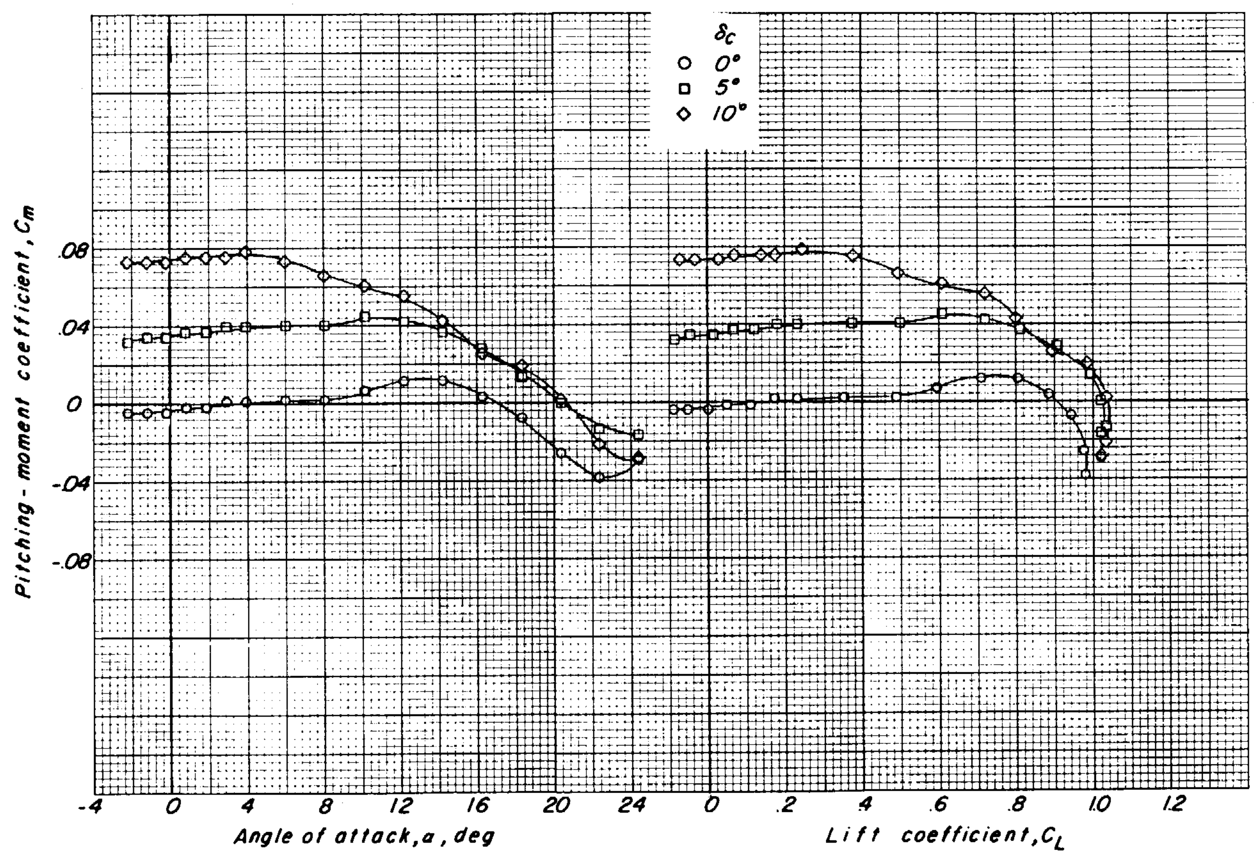

Figure 11.- Concluded.

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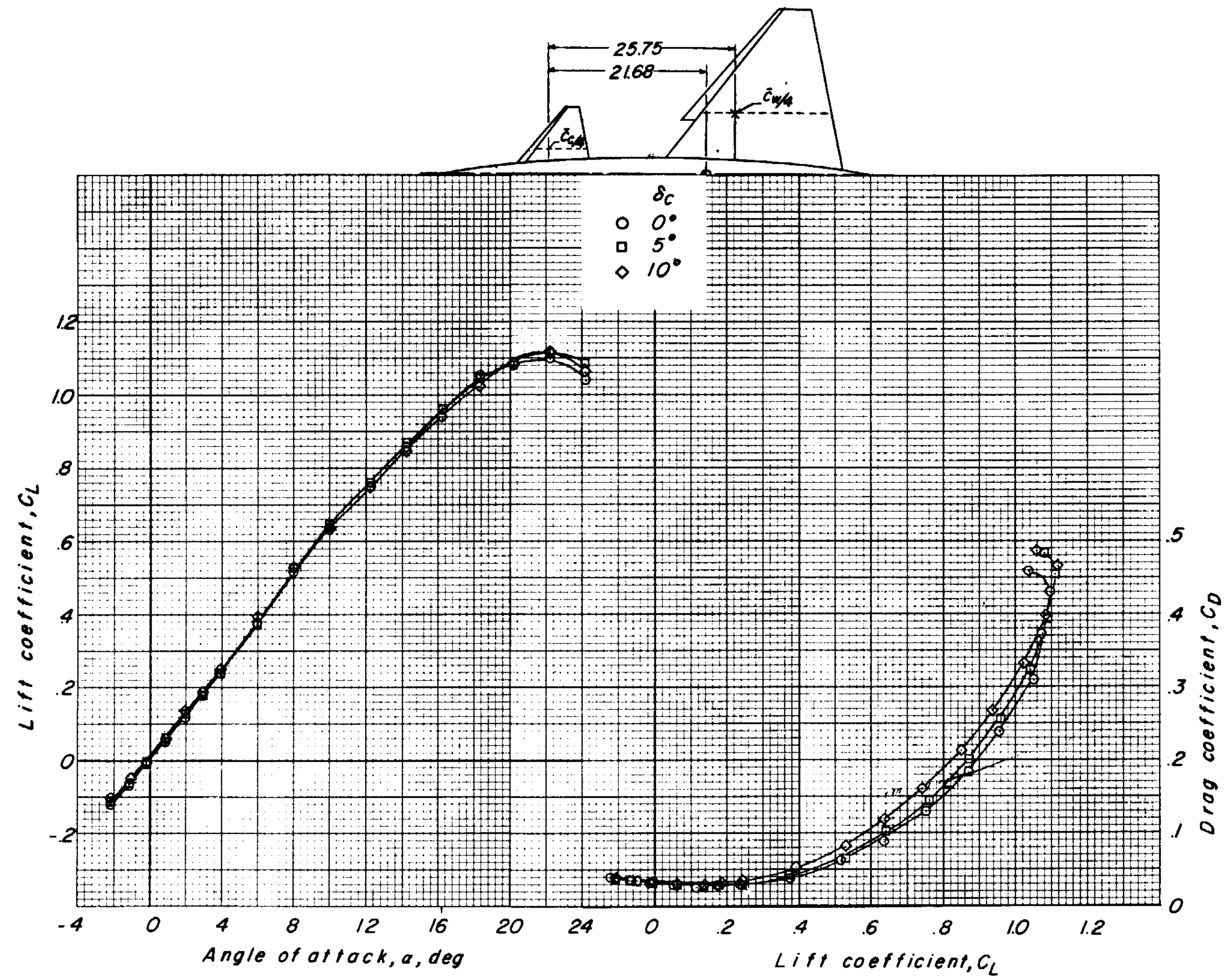

Figure 12.- Longitudinal aerodynamic characteristics of the configuration having a trapezoidal canard with full-span chord-extension and the wing having partial-span chord-extension. $\delta_{n,cl} = -30^{\circ}$; $\delta_{n,w} = -10^{\circ}$.

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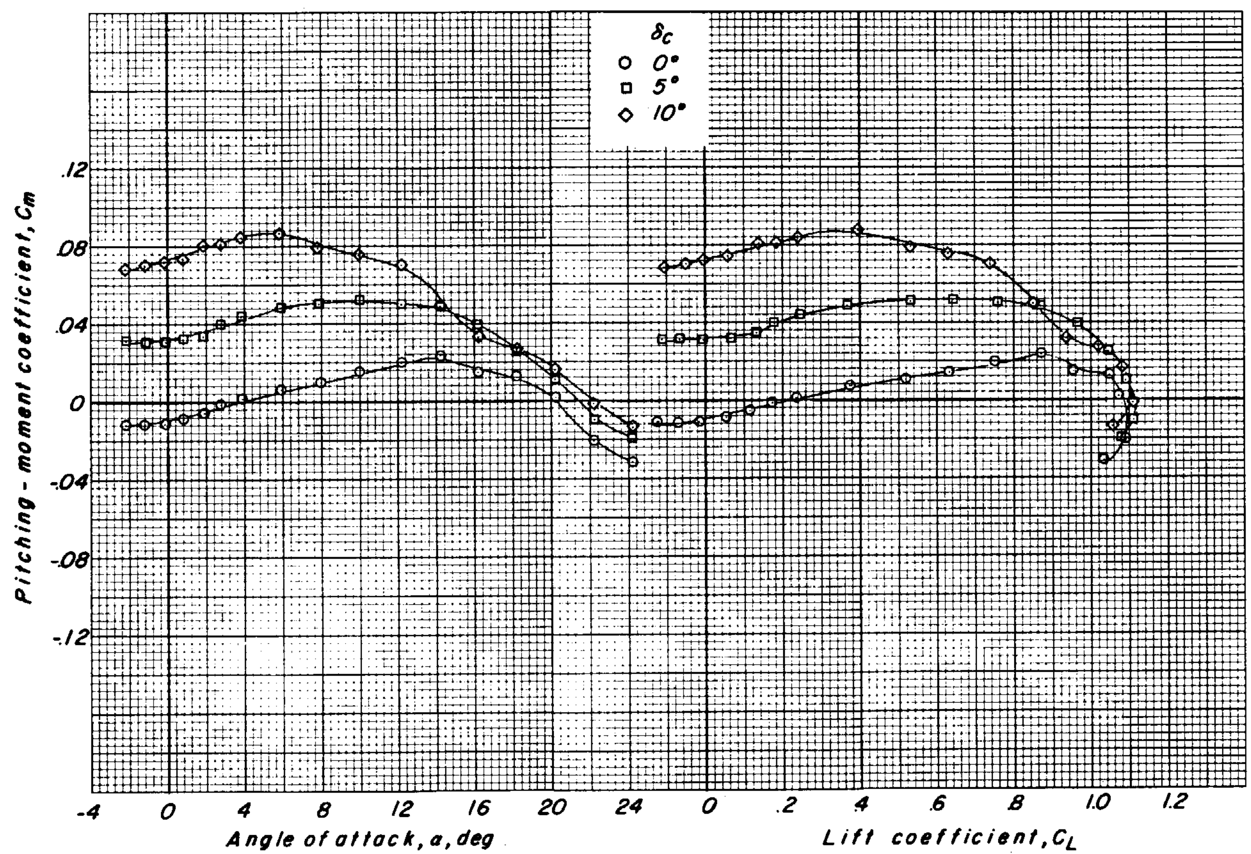

Figure 12.- Concluded.

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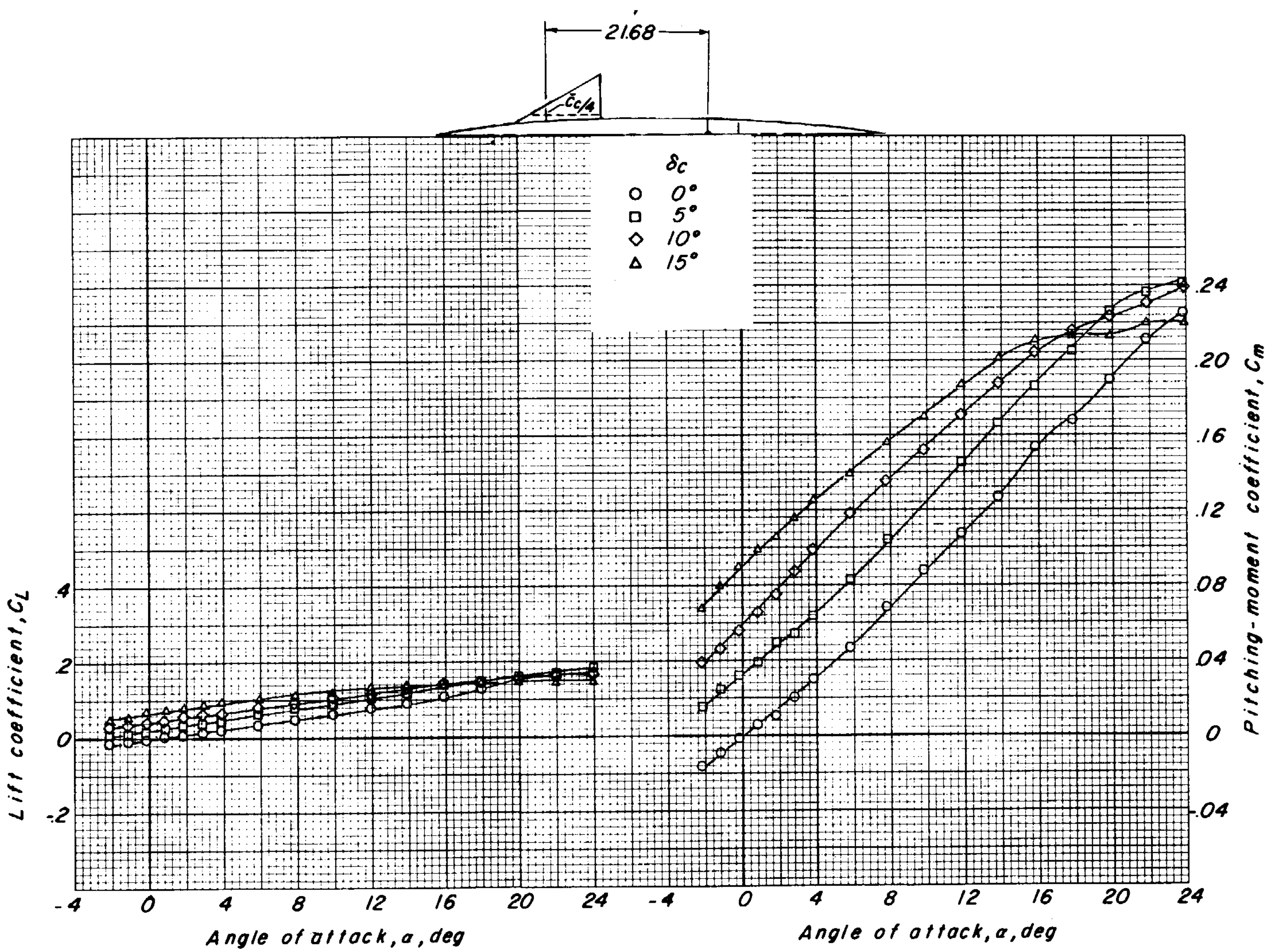

Figure 13.- Longitudinal control characteristics of the configuration having a delta canard with wing off, BC_2.

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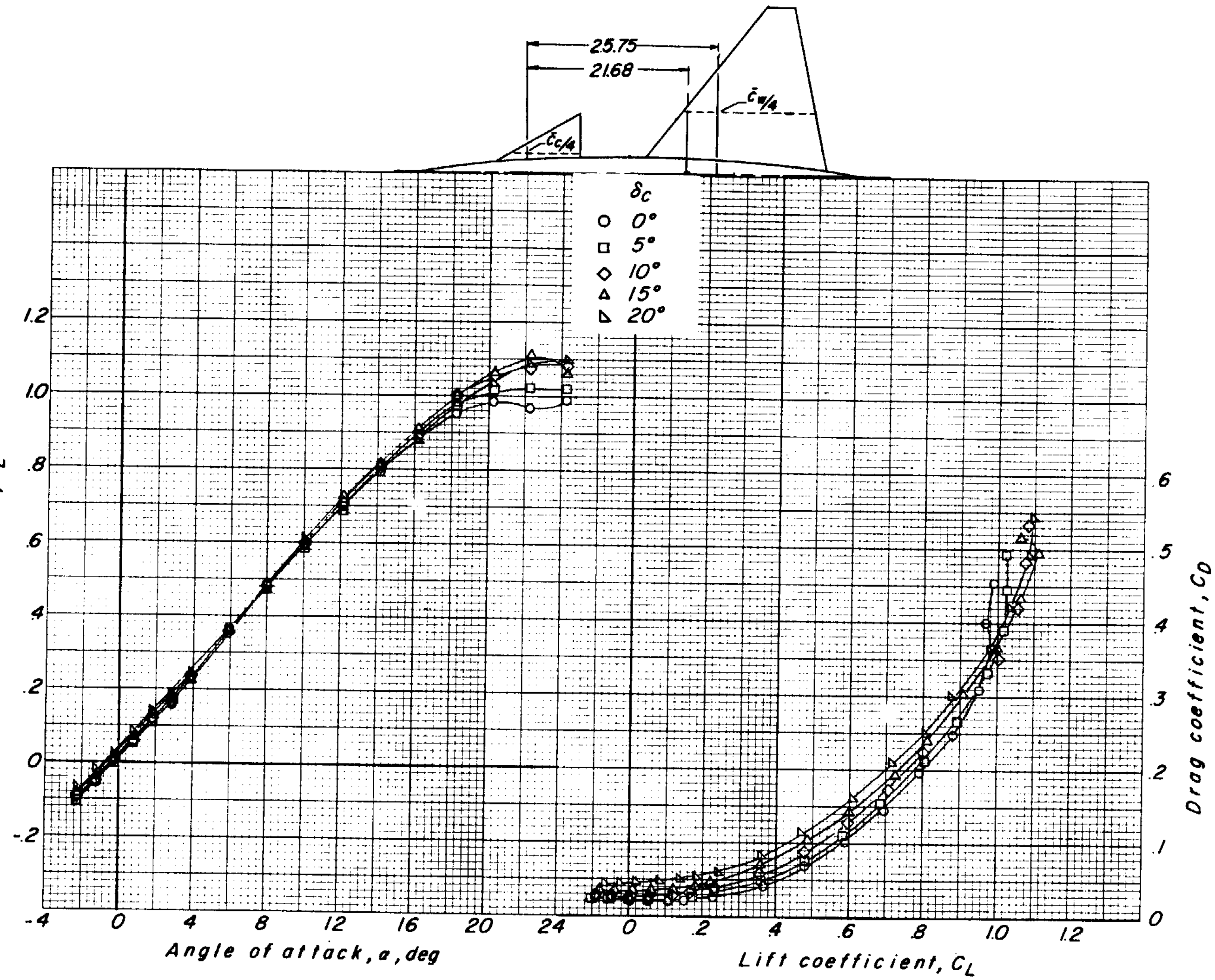

Figure 14.- Longitudinal control characteristics of the configuration having a delta canard and the basic wing, WBC_2.

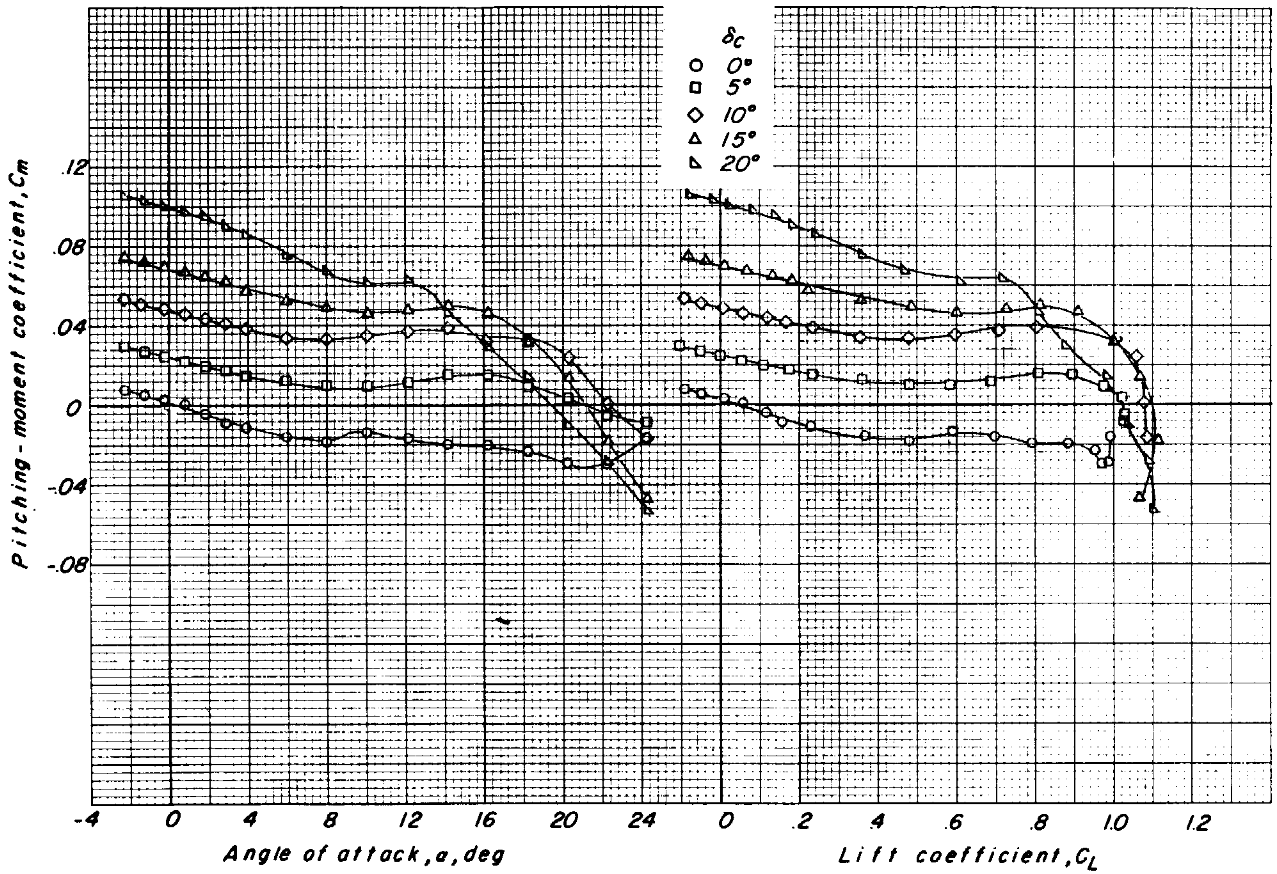

Figure 14.- Concluded.

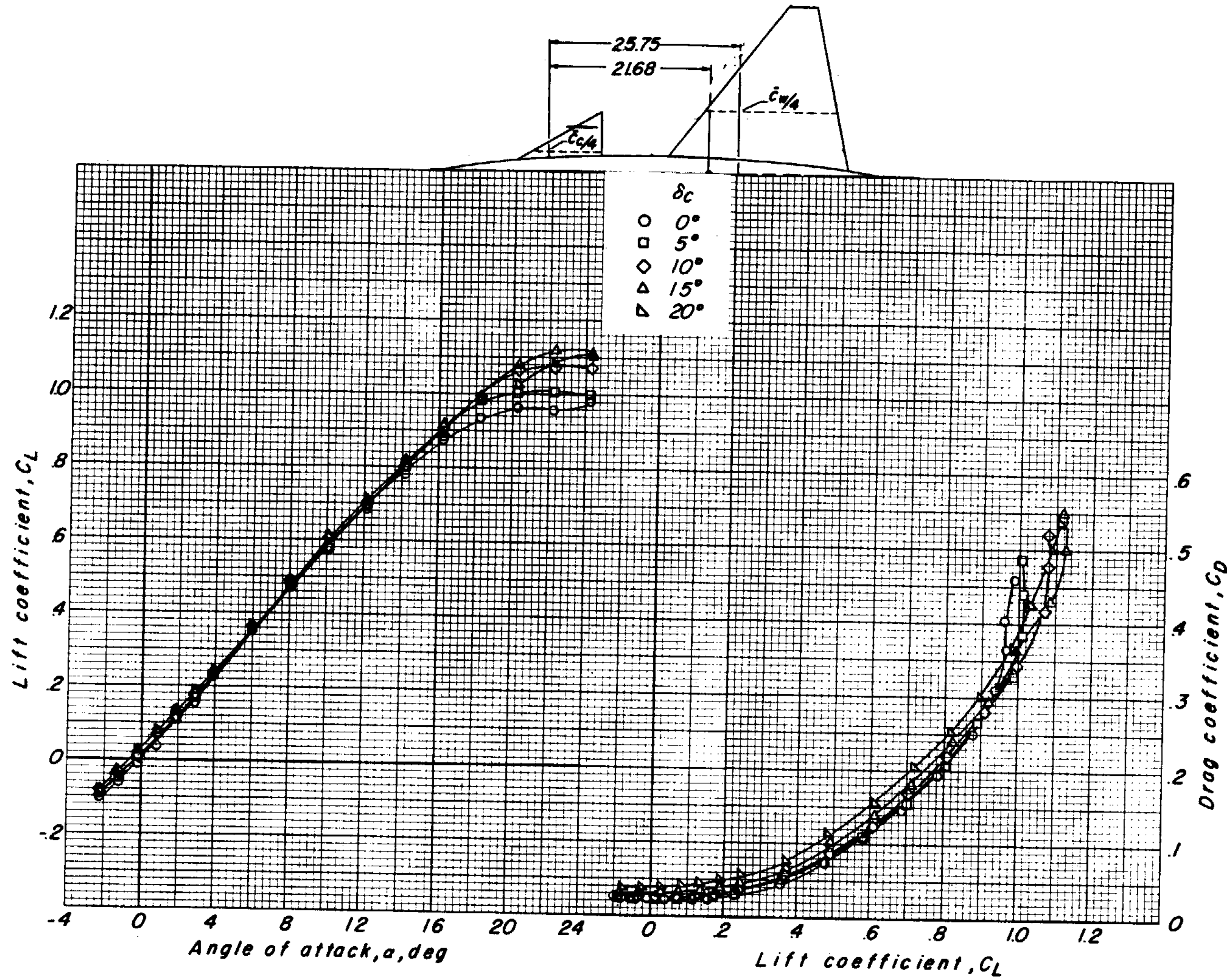

Figure 15.- Longitudinal control characteristics of the configuration having the basic wing and a delta canard with a fence, $WBC_{2,f}$.

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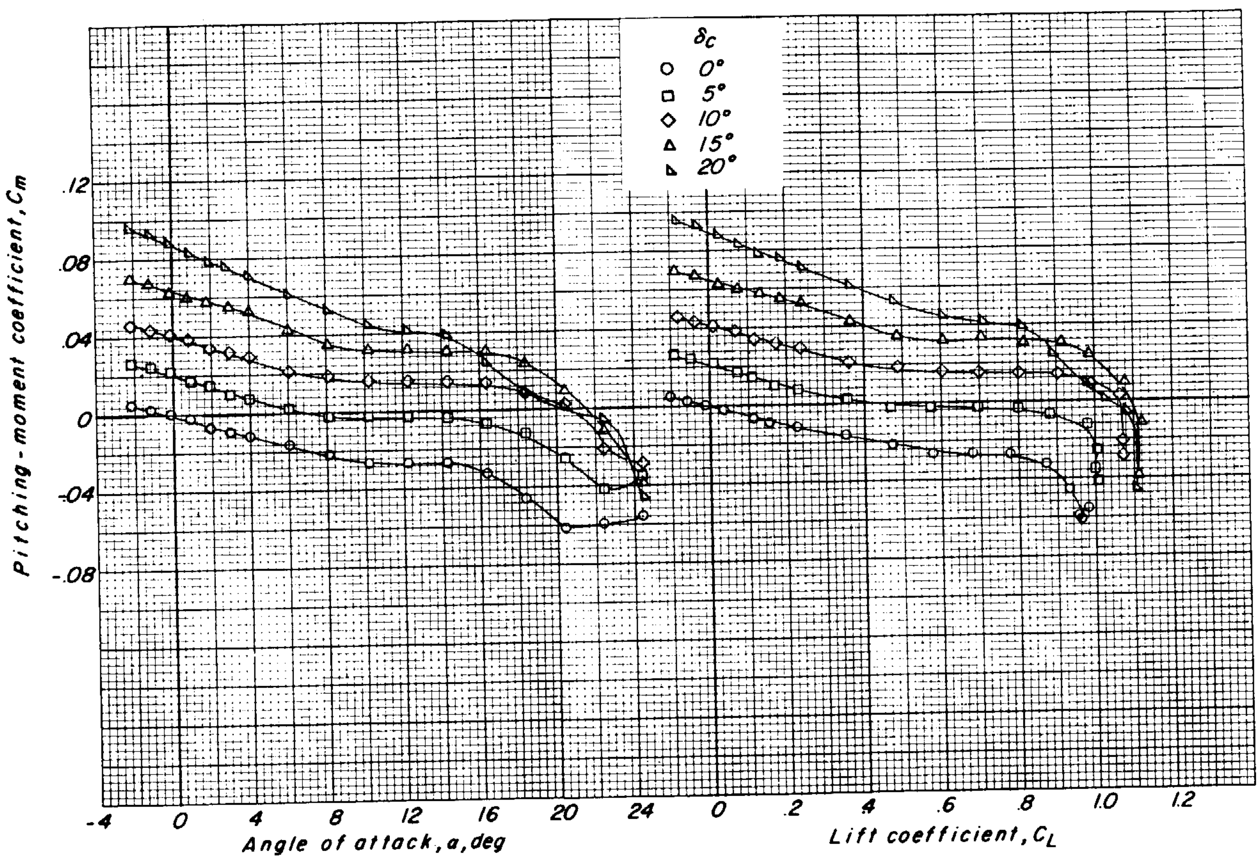

Figure 15.- Concluded.

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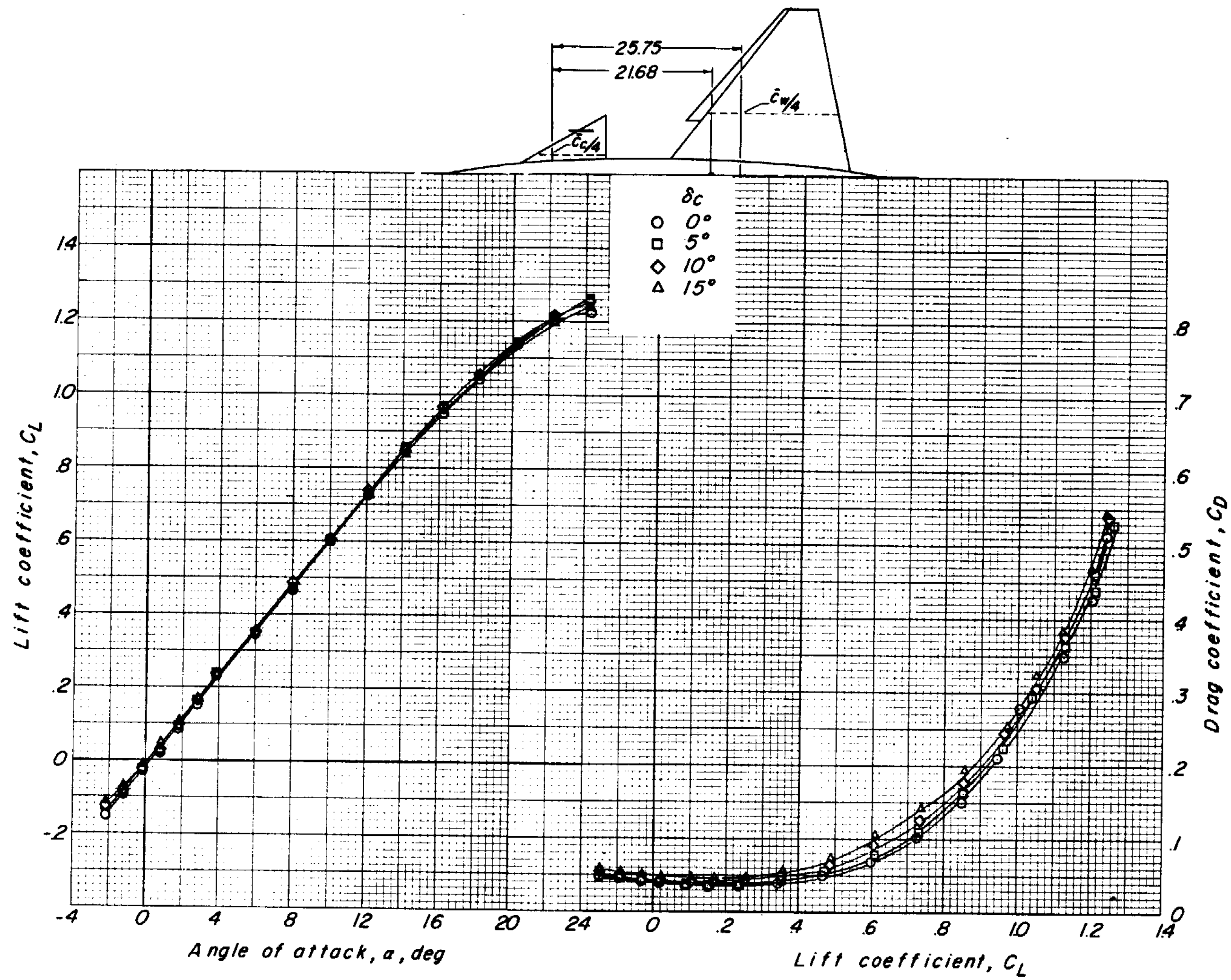

Figure 16.- Longitudinal control characteristics of the configuration having a delta canard with a fence and the wing having a partial-span chord-extension, $WBC_{2,f}$. $\delta_{n,w} = -30°$.

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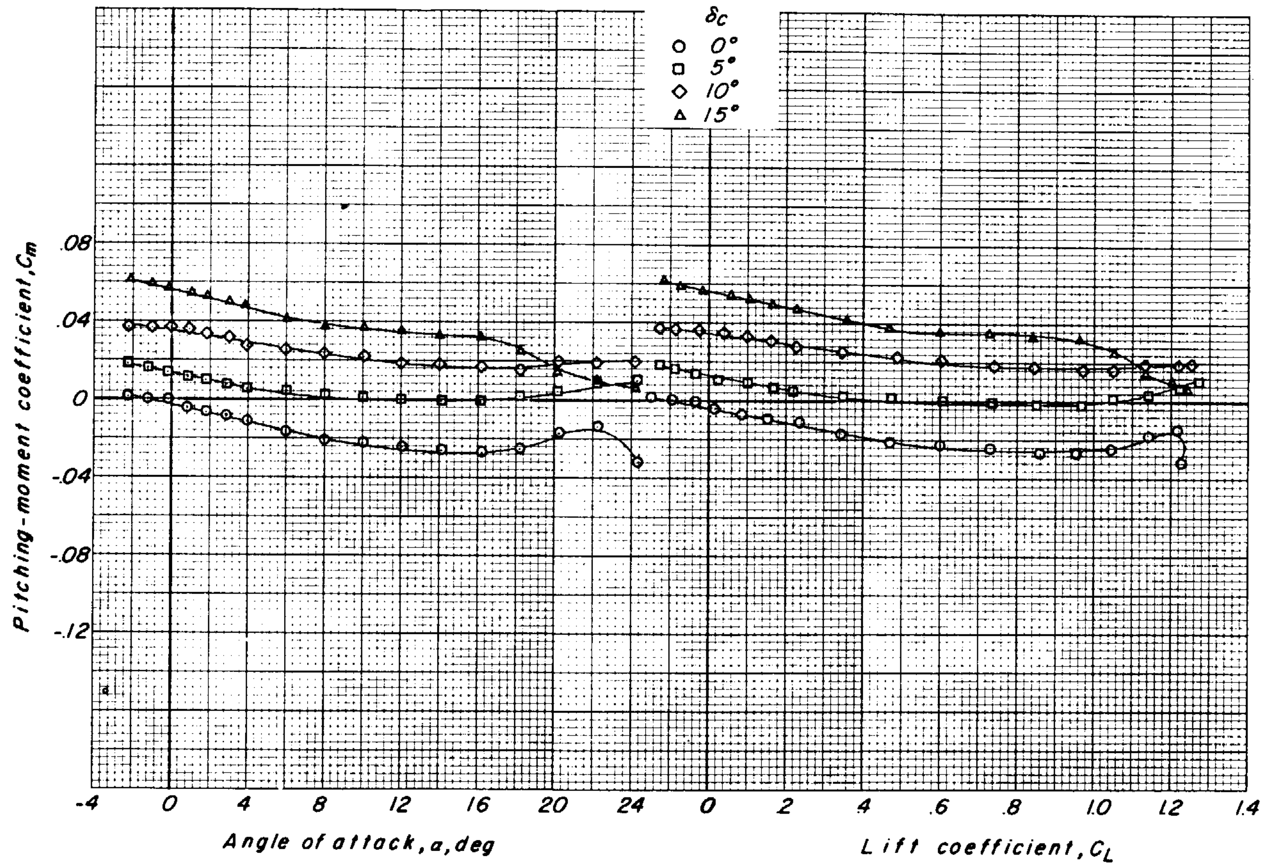

Figure 16.- Concluded.

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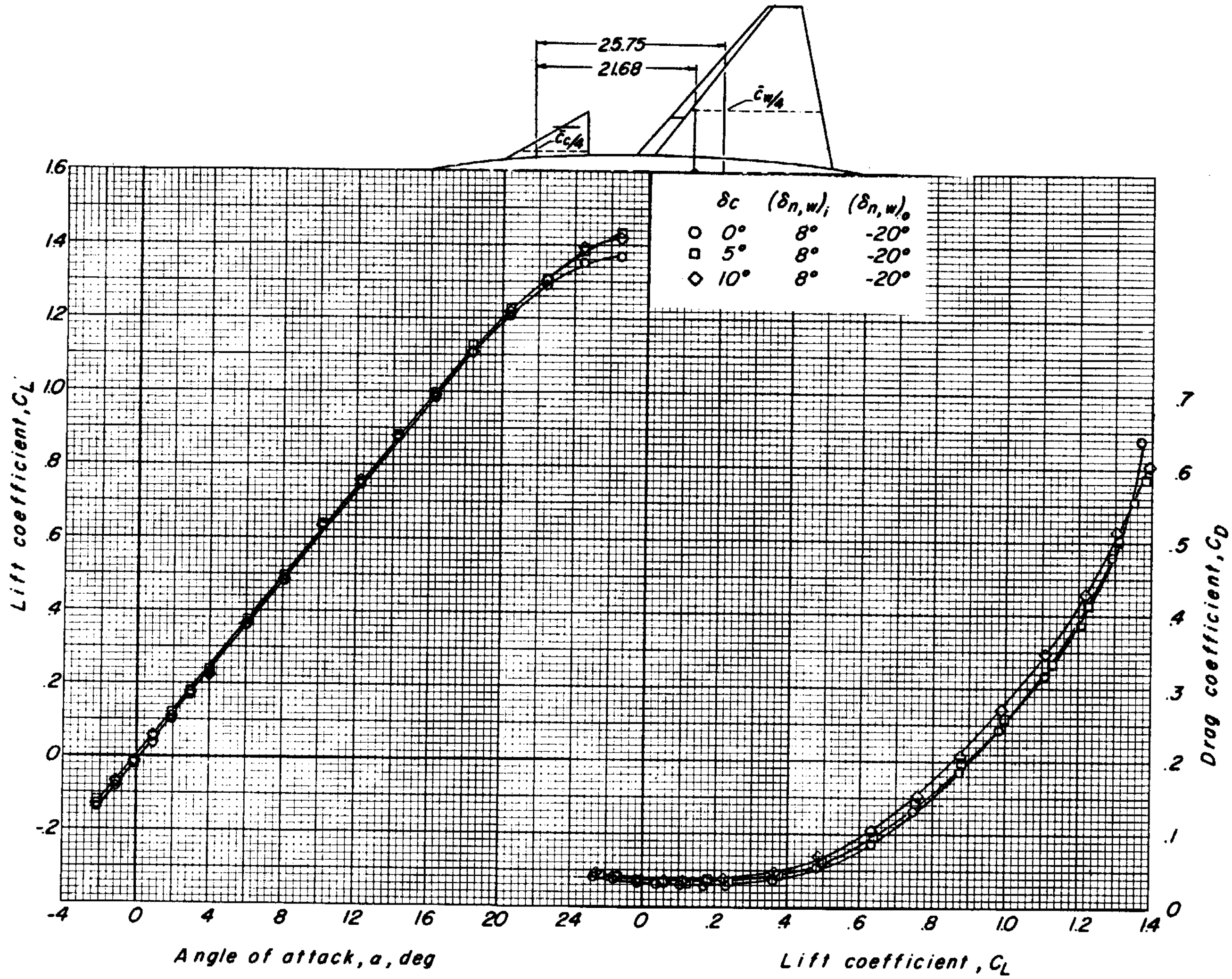

Figure 17.- Longitudinal control characteristics of the configuration having a delta canard with a fence and the wing having differentially deflected full-span leading-edge chord-extension, $WBC_{2,f}$.

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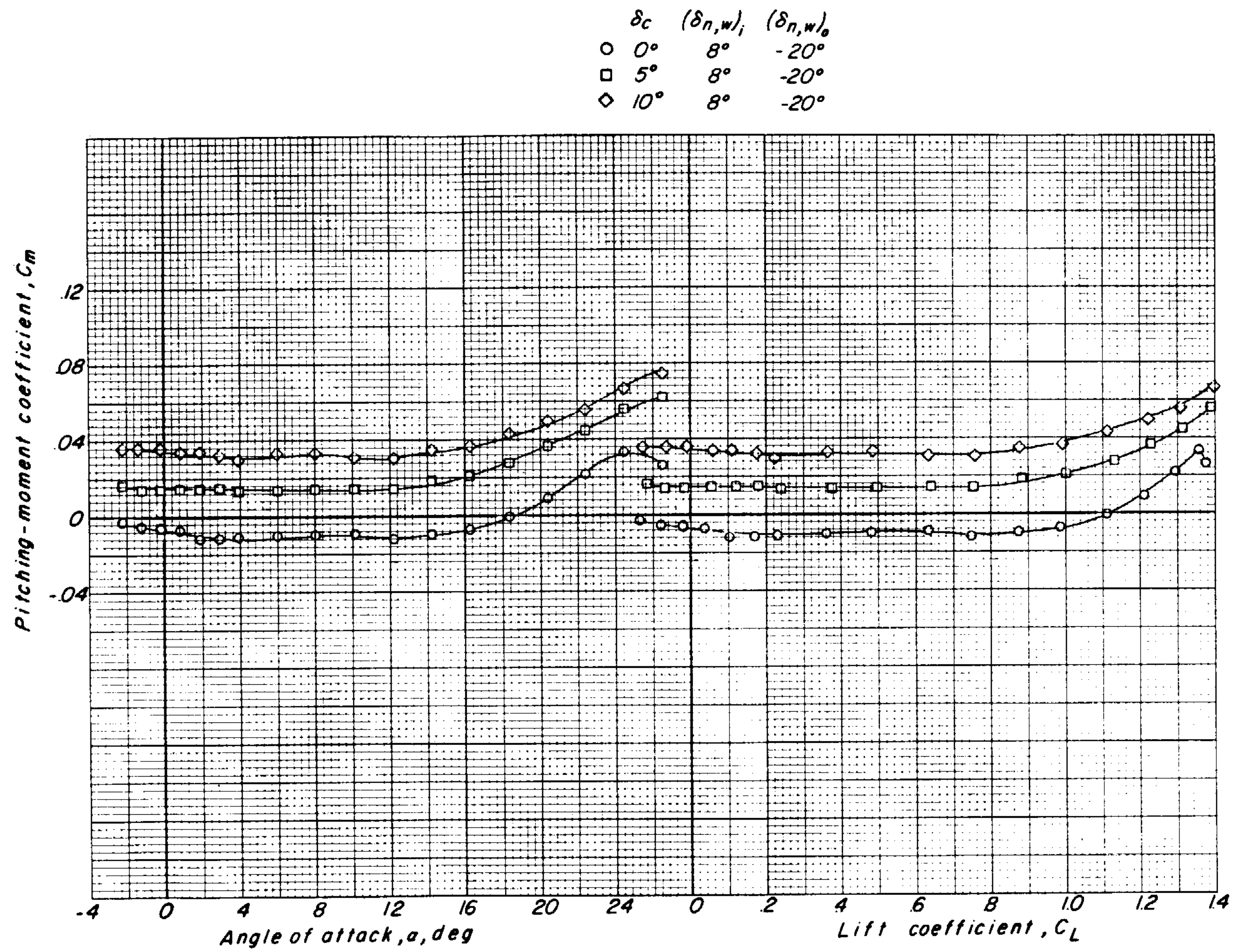

Figure 17.- Concluded.

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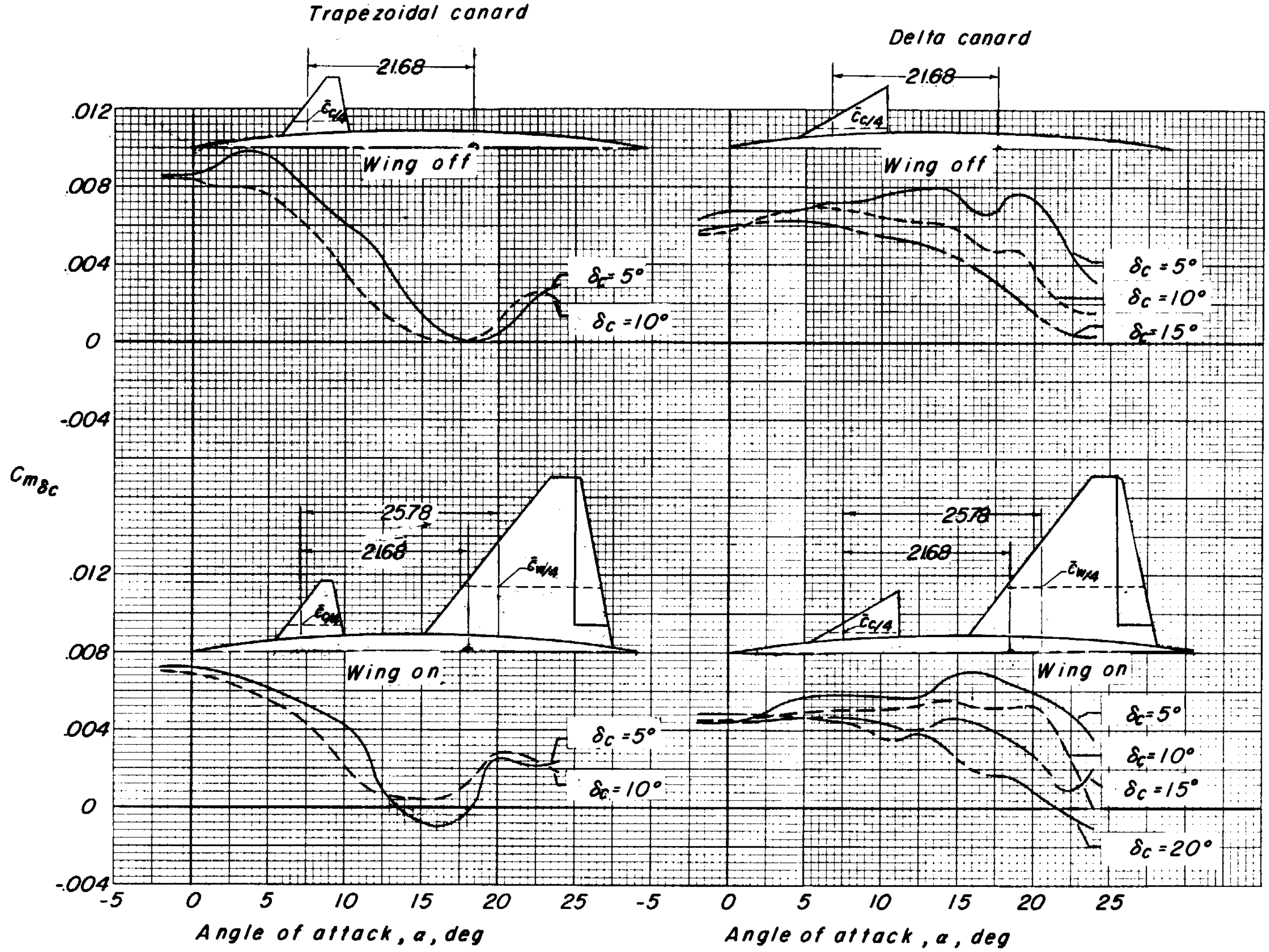

Figure 18.- Longitudinal control effectiveness of the basic trapezoidal canard and the delta canard with and without the basic wing.

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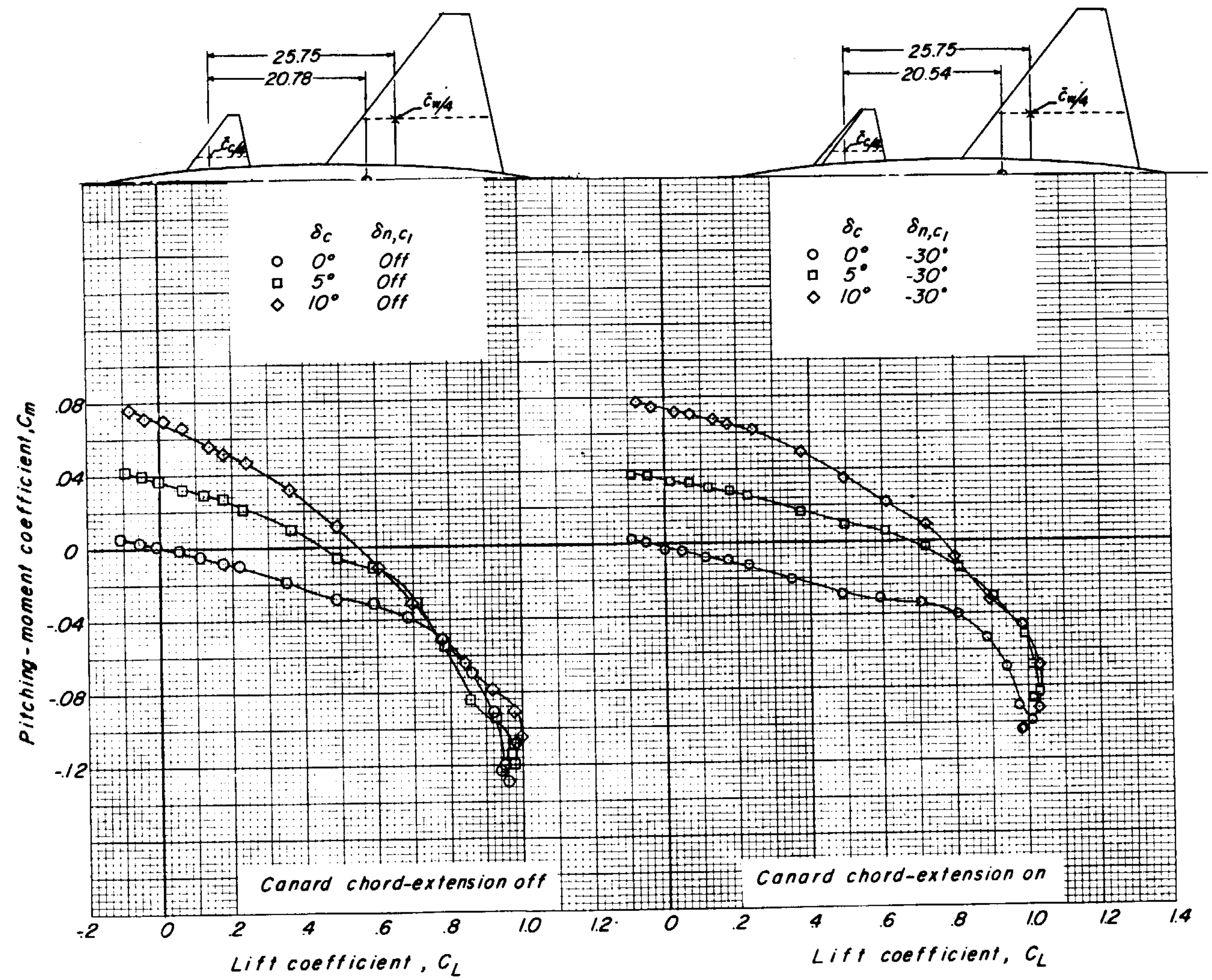

(a) Trapezoidal canard. Moment reference locations have been adjusted to render approximately 5 percent low-lift stability.

Figure 19.- The effects of canard modifications on the control effectiveness associated with the basic-wing—canard configuration.

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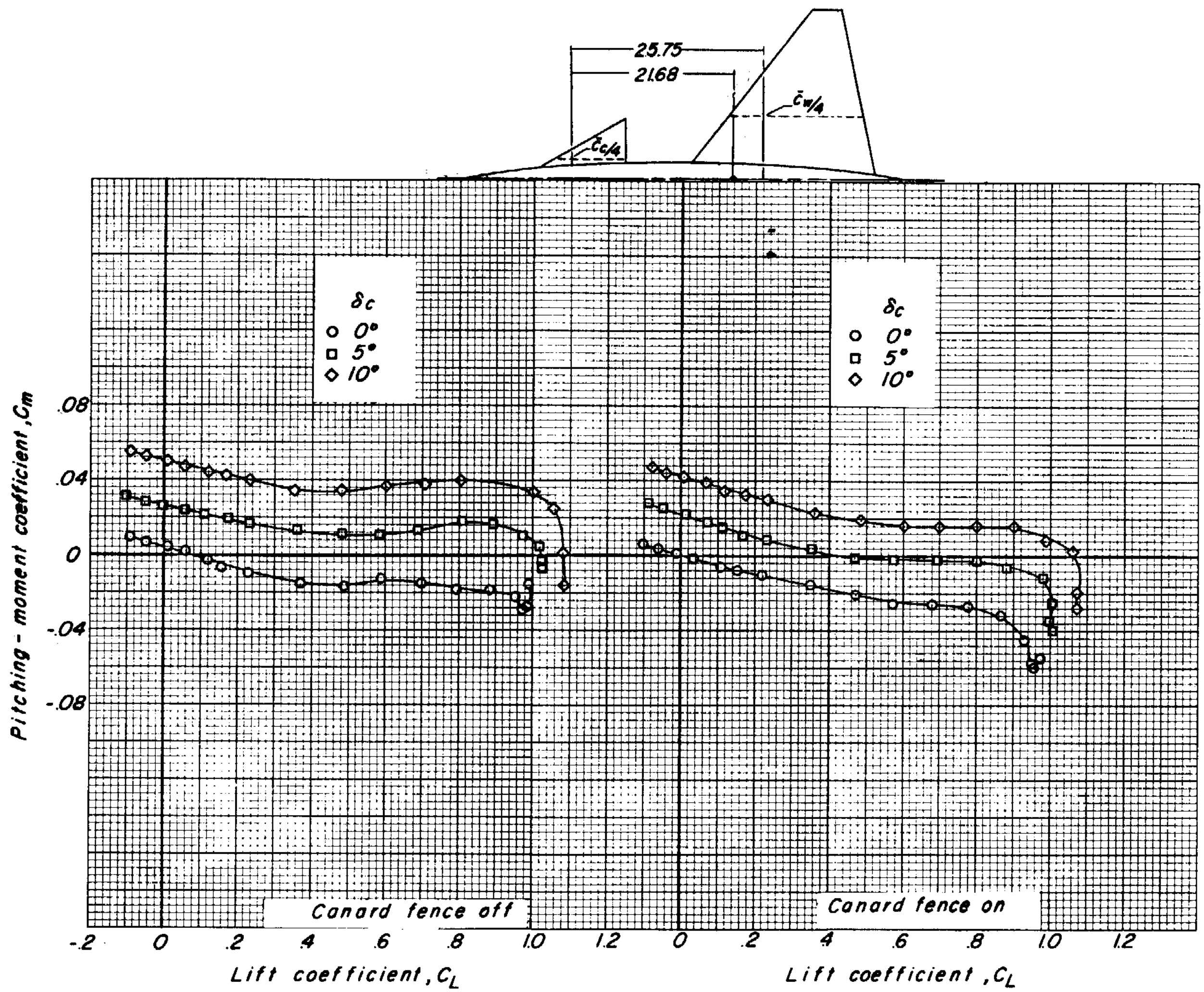

(b) Delta canard with and without fence.

Figure 19.- Concluded.

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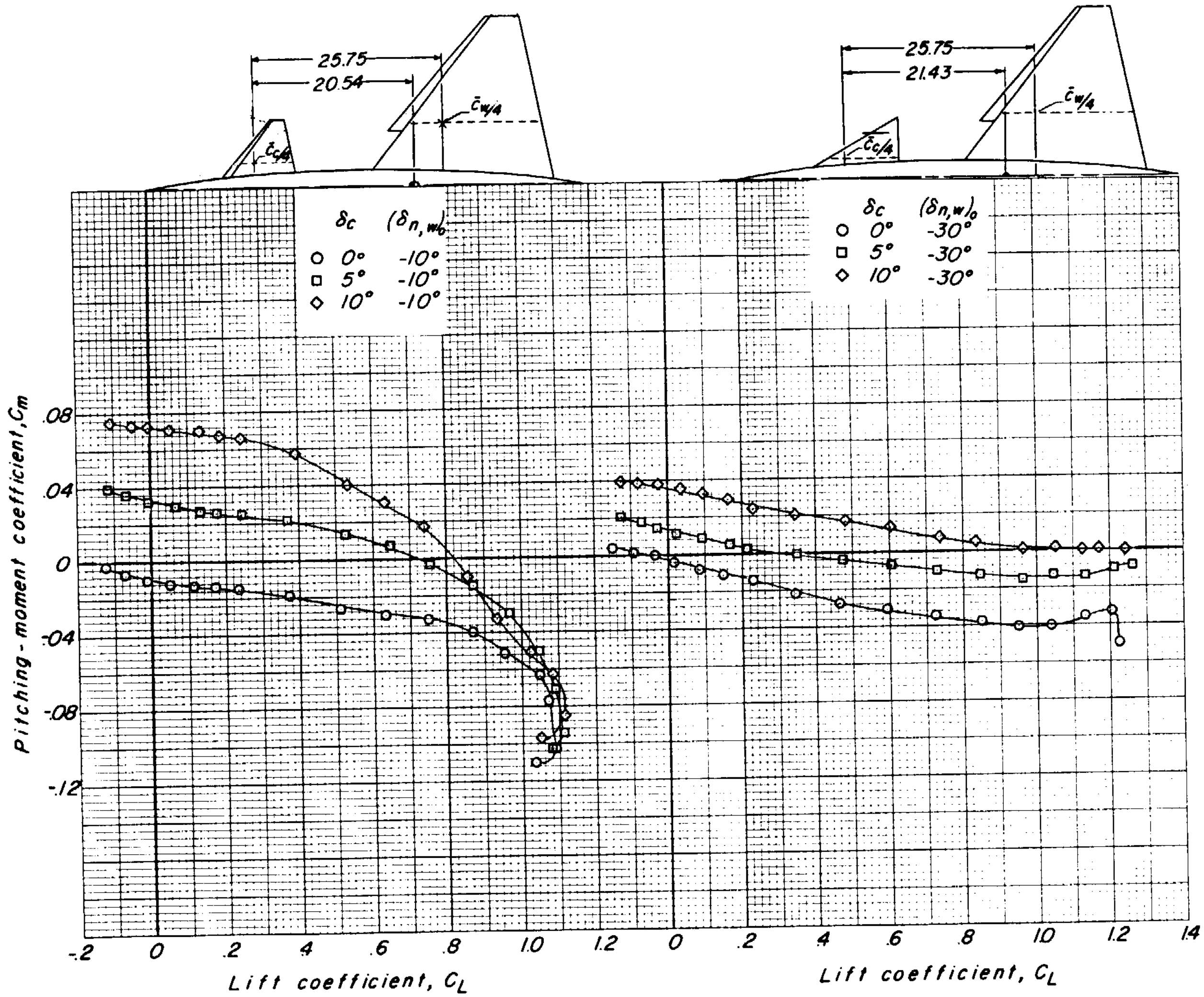

Figure 20.- Comparison of the longitudinal stability and control characteristics associated with the trapezoidal canard having a full-span chord-extension, $\delta_{n,cl} = -30^{\circ}$, and with the delta canard having a fence. The moment reference has been adjusted to render approximately 5 percent low-lift stability for both configurations.

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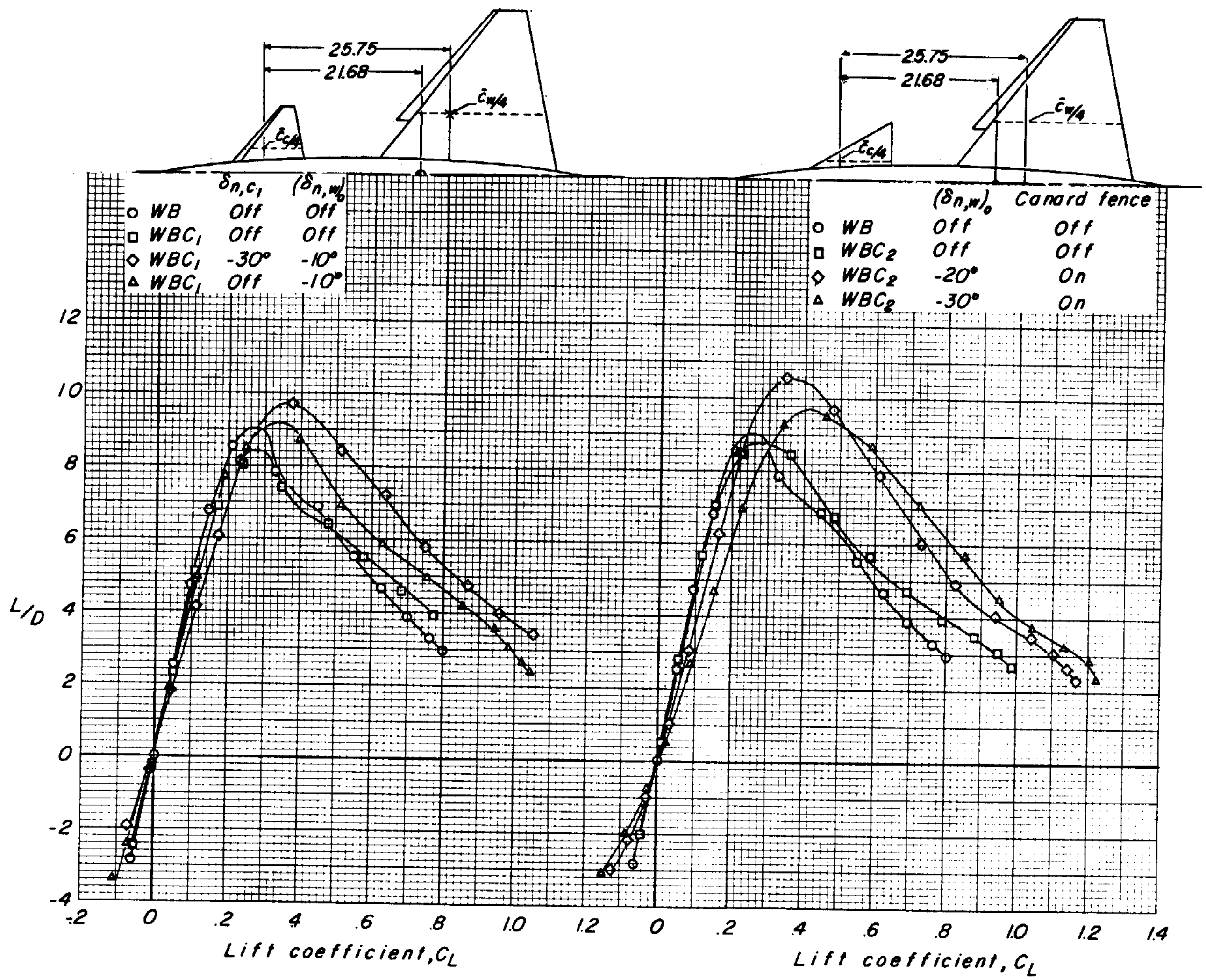

Figure 21.- Comparison of the trends in L/D for various configurations with the trapezoidal canard and delta canard. $\delta_c = 0^o$.

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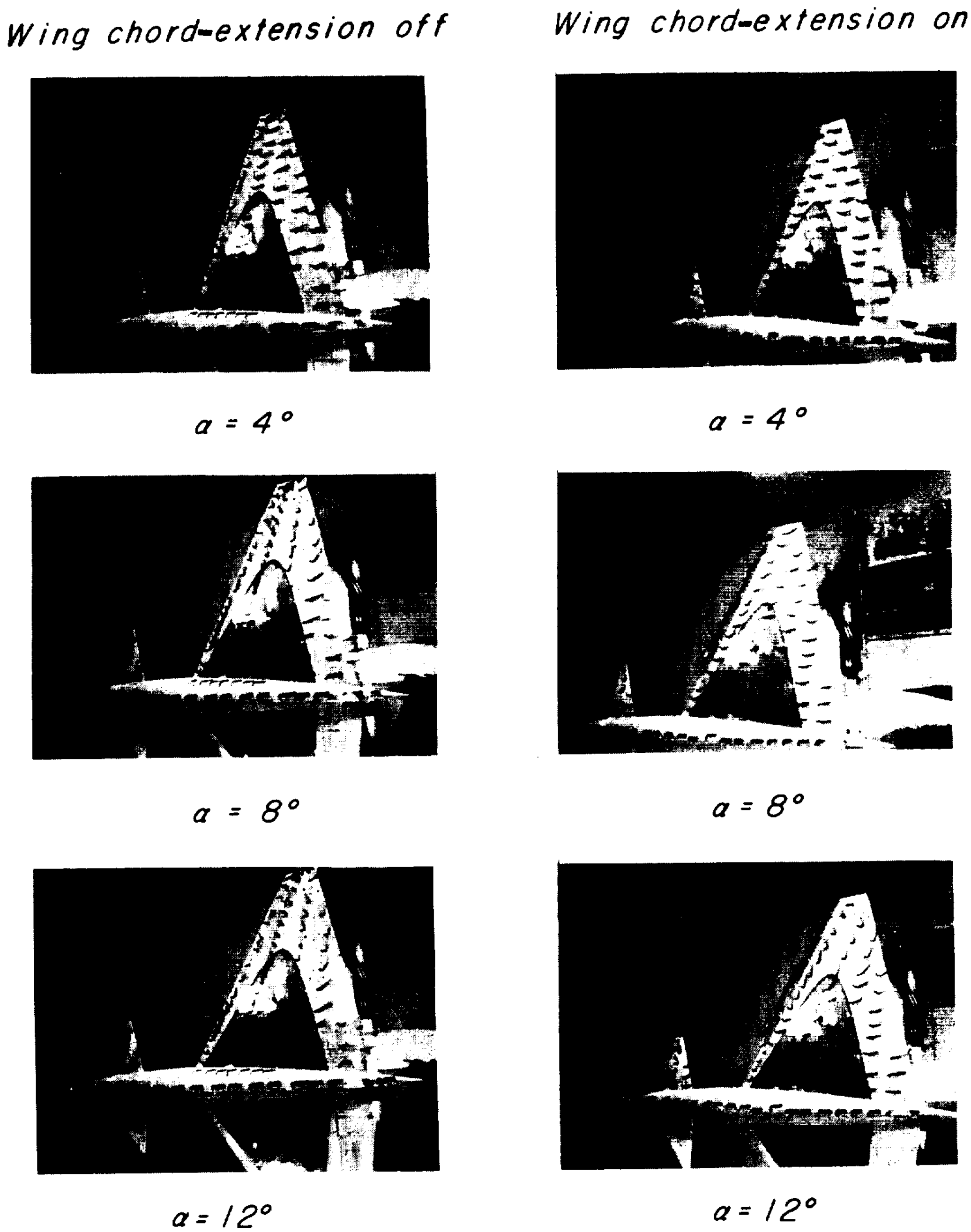

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Figure 22.- Comparison of the canard-induced flow effects on the wing at various angles of attack for the configurations having a trapezoidal canard and the basic wing, and the wing with a partial-span chord-extension deflected -10°.

[redacted]