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MEMORANDUM

EFFECTS OF FOREBODY DEFLECTION ON THE STABILITY AND CONTROL CHARACTERISTICS OF A CANARD AIRPLANE CONFIGURATION WITH A HIGH TRAPEZOIDAL WING AT A MACH NUMBER OF 2.01

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MEMORANDUM 4-4-59L

EFFECTS OF FOREBODY DEFLECTION ON THE STABILITY AND CONTROL CHARACTERISTICS OF A CANARD AIRPLANE CONFIGURATION WITH A HIGH TRAPEZOIDAL WING AT A MACH NUMBER OF 2.01*

By M. Leroy Spearman and Cornelius Driver

SUMMARY

An investigation has been conducted in the Langley 4- by 4-foot supersonic pressure tunnel at a Mach number of 2.01 to determine the effects of forebody deflection on the stability and control characteristics of a canard airplane configuration. The configuration had a high trapezoidal aspect-ratio-3 wing, a trapezoidal canard surface, and a single swept vertical tail. Forebody deflection angles of 0°, 2°, and 4° were investigated.

The results indicated that nose-up deflections of the forebody provided positive increments of pitching moment with little increase in drag and hence would be useful in reducing the pitch-control requirements and the attendant losses in lift-drag ratio due to trimming. Deflection of the forebody, however, aggravated the decrease in directional stability with increasing angle of attack by causing a loss in tail contribution and by increasing the instability of the wing-body combination.

INTRODUCTION

A research program is underway at the Langley 4- by 4-foot supersonic pressure tunnel to determine the aerodynamic characteristics of several canard airplane configurations. Various phases of the program are presented in references 1 to 7. As an extension to this program, an investigation has been made at a Mach number of 2.01 to determine

*Title, Unclassified.

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the effects of forebody deflection on the aerodynamic characteristics of a canard configuration.

As pointed out in references 5 and 8, the use of a deflectable forebody offers a means of providing positive increments of pitching moment with little increase in drag. This approach should be useful in reducing the pitch-control trimming requirements and the attendant losses in lift-drag ratio due to trimming. However, some changes in the interference effects of the forebody and canard-surface flow fields on the wing and vertical tail might be expected as the forebody is deflected. It was the purpose of the present investigation to determine the extent to which the longitudinal and lateral stability and control characteristics of a generalized canard configuration might be affected by changes in forebody deflection. The configuration investigated had a high trapezoidal wing, a trapezoidal canard surface, and a single swept vertical tail. Three different forebody deflections were investigated.

SYMBOLS

The results are presented as force and moment coefficients with lift, drag, and pitching-moment coefficients referred to the stability-axis system and rolling-moment, yawing-moment, and side-force coefficients referred to the body-axis system. The reference center of moments for the basic data was on the body center line at a point 12 inches forward of the base for all bodies.

C_N normal-force coefficient, Normal force/qS

C_L lift coefficient, Lift/qS

C_A axial-force coefficient, Axial force/qS

C_D drag coefficient, Drag/qS

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

C_l rolling-moment coefficient, Rolling moment/qSb

C_n yawing-moment coefficient, Yawing moment/qSb

C_Y side-force coefficient, Side force/qS

q free-stream dynamic pressure

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S	wing area including body intercept
b	wing span
$\bar{c}$	wing mean geometric chord
α	angle of attack, deg
β	angle of sideslip, deg
δ_c	angle of canard-surface deflection (measured from forebody center line), deg
δ_n	forebody deflection angle, deg
L/D	lift-drag ratio
C_{n_β}	directional-stability parameter (measured between $\beta \approx 0^\circ$ and 4°), $\Delta C_n/\Delta\beta$
C_{l_β}	effective-dihedral parameter (measured between $\beta \approx 0^\circ$ and 4°), $\Delta C_l/\Delta\beta$
C_{Y_β}	side-force parameter (measured between $\beta \approx 0^\circ$ and 4°), $\Delta C_Y/\Delta\beta$
$\partial C_m/\partial C_L$	longitudinal stability parameter (measure of static margin)
$C_{m_{\delta_c}}$	pitching effectiveness, $\partial C_m/\partial\delta_c$

Components and subscripts:

V	vertical tail
max	maximum value
trim	value at $C_m = 0$
0	value of zero lift

MODELS AND APPARATUS

Details of the model are shown in figure 1 and the geometric characteristics are presented in table I. A photograph of the model is

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shown in figure 2. Coordinates of the body are given in table II. The various forebody deflections were obtained by using the same forebody with the addition of center-body adapters of different angles. The canard-surface hinge-line location was fixed with respect to the forebody and hence the canard surface moved with the forebody as the forebody deflection was varied. The canard surface was motor driven and the deflections were set by remote control. Canard-surface deflections are referenced to the forebody center line for each forebody deflection.

Force and moment measurements were made through the use of a six-component internal strain-gage balance. The model was mounted in the tunnel on a remote-controlled rotary sting.

TESTS AND CORRECTIONS

The tests were made in the Langley 4- by 4-foot supersonic pressure tunnel at a Mach number of 2.01, a stagnation pressure of 10 pounds per square inch, and a stagnation temperature of 100° F. The stagnation dewpoint was maintained sufficiently low (-25° F or less) so that no significant condensation effects were encountered in the test section.

The angles of attack and sideslip were corrected for deflection of the balance and sting under load. The base pressure was measured and the axial force was adjusted to a base pressure equal to free-stream static pressure.

The estimated variations in the individual measured quantities based on zero shifts and repeatability alone are as follows:

C_N	±0.0003
C_A	±0.0010
C_m	±0.0004
C_l	±0.0004
C_n	±0.0001
C_Y	±0.0015

The maximum probable error in angle of attack and sideslip is ±0.2°. The canard-surface deflection angle is set within ±0.1° and the Mach number variation is within ±0.01.

DISCUSSION

Longitudinal Stability and Control

The effects of forebody deflection on the aerodynamic characteristics in pitch for various combinations of component parts are presented in figure 3. For a constant lift coefficient, the effect of nose-up forebody deflection is to provide substantial positive increments of pitching moment with a small decrease in angle of attack and only a small increase in drag (figs. 3(a) and 3(b)). The addition of the canard surface at $\delta_c = 0^\circ$ provides a further positive increment in pitching moment and an additional increase in drag (fig. 3(c)).

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The effects of canard-surface deflection on the aerodynamic characteristics in pitch for forebody deflections of 0°, 2°, and 4° are presented in figure 4. Deflection of the forebody has little effect on the stability level $\partial C_m / \partial C_L$ or on the pitching-moment effectiveness of the canard control $C_{m_{\delta_c}}$. However, because of the positive increment of $C_{m,0}$ provided by forebody deflection, progressive increases in trim lift are obtainable for a given canard-surface deflection as the forebody is deflected. For some stability levels, deflection of the forebody might provide sufficient pitching moment so that it would be possible to trim with negative canard-surface deflections; thus, the drag generally associated with canard-surface deflection might be reduced. This characteristic is indicated for the configuration with the 4° forebody deflection (fig. 4(c)) wherein the maximum value of L/D increases with negative canard-surface deflection. Neglecting any upwash flow around the forebody, the angle of attack of the canard surface for $(L/D)_{max}$ with $\delta_c = 0^\circ$ is about 8.5° $\left(\delta_n = 4^\circ \text{ and } \alpha = 4.5^\circ\right)$. With $\delta_c = -5^\circ$, the angle of attack of the canard surface at $(L/D)_{max}$ is about 3.5°; with $\delta_c = -10^\circ$, the angle of attack of the canard surface is about -1.5°. Thus, the increase in $(L/D)_{max}$ with negative control deflections is a result of the reduction in local angle of attack of the canard surface. Presumably a control deflection that exactly alined the canard surface with the local stream direction $\left(\delta_c = -8.5^\circ \text{ for } \delta_n = 4^\circ\right)$ would provide a still higher $(L/D)_{max}$ since the canard surface would be adding only its minimum drag.

Inasmuch as the present investigation was limited to a maximum forebody deflection angle of 4°, it may be possible that additional trim-drag benefits could be obtained with greater forebody deflections. This would be particularly true if sufficient upwash is developed around the deflected forebody to provide a local positive angle of attack at the canard surface while the canard surface is set for trim at a negative deflection with respect to the free-stream direction. Under these conditions, the canard surface would not only provide a positive lift increment but the lift vector would be inclined forward so as to provide a negative drag increment.

The basic data of figure 4 have been used to determine the effects of forebody deflection on the trim longitudinal characteristics for a constant stability level. (See fig. 5.) The primary effect of nose-up forebody deflection is to decrease the control deflections required to trim for a given lift and hence decrease the drag due to trimming. As a result, with increasing nose-up forebody deflection, there is an increase in maximum values of L/D and in L/D at the higher lift coefficients.

The variation of $(L/D)_{max,trim}$ with stability level has been determined for forebody deflections of 0° and 4°. These values were obtained from the data presented in figure 4 by using various moment centers to provide various arbitrary stability levels. (See fig. 6.) Higher values of $(L/D)_{max,trim}$ were obtained for the 4° deflected nose than for the undeflected nose.

Lateral and Directional Stability

The effects of forebody deflection on the sideslip derivatives are presented in figure 7. Results for the complete configuration (fig. 7(a)) indicate a decrease in C_{n_β} with increasing angle of attack that becomes progressively worse as the forebody is deflected. This decrease in C_{n_β} due to forebody deflection is probably associated in part with an interference effect of the forebody and canard wake on the vertical tail since a progressive decrease in $-C_{Y_\beta}$ with increasing forebody deflection is also indicated.

A comparison of figures 7(a) and 7(b) indicates that the presence of the canard surface has a slight destabilizing effect on the variation of C_{n_β} with angle of attack. The results presented in figure 7(b) indicate that deflection of the forebody not only causes a loss in tail contribution throughout the angle-of-attack range but also causes a destabilizing increment of C_{n_β} with increasing angle of attack for the wing-body combination. This decrease in C_{n_β} with the vertical tail removed is accompanied by an increase in $-C_{Y_\beta}$ which indicates that deflection of the forebody causes a destabilizing force over the forebody region. However, both the level of C_{n_β} and the variation of C_{n_β} with angle of attack could be improved through the use of ventral fins or twin vertical tails and possibly through the use of forebody strakes (ref. 5).

CONCLUSIONS

An investigation has been made in the Langley 4- by 4-foot supersonic pressure tunnel at a Mach number of 2.01 to determine the effects of forebody deflection on the stability and control characteristics of a canard airplane configuration with a trapezoidal wing.

The results indicated that nose-up deflections of the forebody provided positive increments of pitching moment with little increase in drag and hence would be useful in reducing the pitch-control requirements and the attendant losses in lift-drag ratio due to trimming. Deflection of the forebody, however, aggravated the decrease in directional stability with increasing angle of attack by causing a loss in tail contribution and by increasing the instability of the wing-body combination.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., January 9, 1959.

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1. Driver, Cornelius: Longitudinal and Lateral Stability and Control Characteristics of Two Canard Airplane Configurations at Mach Numbers of 1.41 and 2.01. NACA RM L56L19, 1957.

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5. Spearman, M. Leroy, and Driver, Cornelius: Some Factors Affecting the Stability and Performance Characteristics of Canard Aircraft Configurations. NACA RM L58D16, 1958.

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TABLE I

GEOMETRIC CHARACTERISTICS OF MODEL

Body:	
Maximum diameter, in.	3.33
Length, in.	37.0
Base area, sq in.	8.71
Fineness ratio	11.1
Wing:	
Span, in.	24
Root chord at body center line, in.	12.8
Tip chord, in.	3.2
Area, sq in.	192
Aspect ratio	3
Taper ratio	0.25
Mean geometric chord, in.	8.96
Sweep angle of leading edge	30° 58'
Sweep angle of 75-percent-chord line, deg	0
Thickness ratio, percent chord	4
Section	Circular arc
Canard:	
Total exposed area, sq in.	13.59
Ratio of exposed area to wing area	0.0707
Section	Hexagonal
Constant thickness, in.	0.1875
Leading-edge angle normal to leading edge, deg	10
Trailing-edge angle normal to trailing edge, deg	10
Sweep angle of leading edge, deg	38.6
Vertical tail:	
Total exposed area, sq in.	23.42
Sweep angle of leading edge, deg	60
Panel aspect ratio	1.11
Taper ratio	0.314
Section	Wedge slab
Leading-edge angle normal to leading edge, deg	10.6
Constant thickness, in.	0.1875

TABLE II

BODY COORDINATES

Body station (measured along center line), in.	Radius (normal to center line), in.
0	0
.297	.076
.627	.156
.956	.233
1.285	.307
1.615	.378
1.945	.445
2.275	.509
2.605	.573
2.936	.627
3.267	.682
3.598	.732
3.929	.780
4.260	.824
4.592	.865
4.923	.903
5.255	.940
5.587	.968
5.920	.996
6.252	1.020
6.583	1.042
17.75	1.667
37.00	1.667

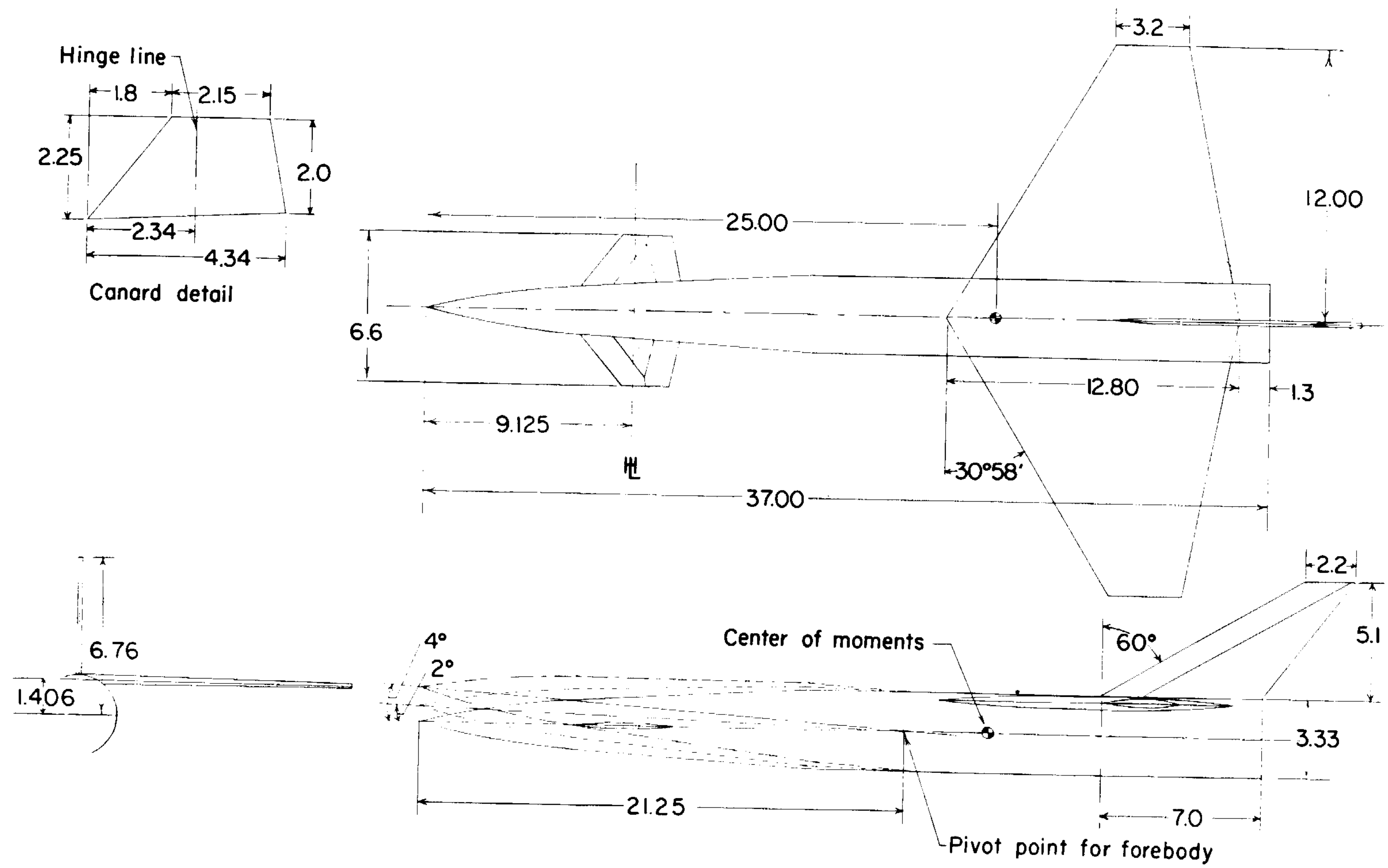

Figure 1.- Details of model. All linear dimensions are in inches.

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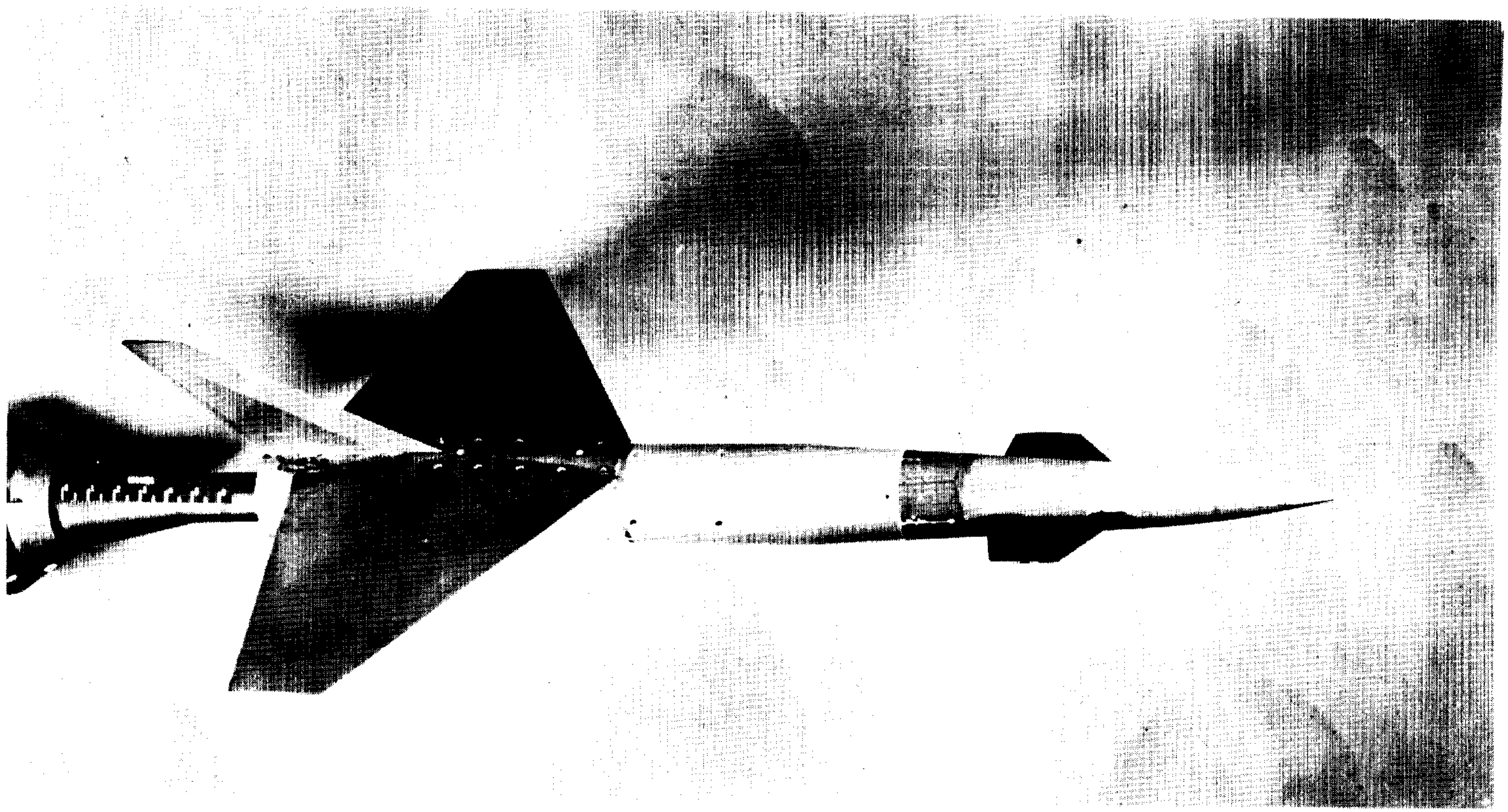

Figure 2.- Photograph of model. L-57-2681

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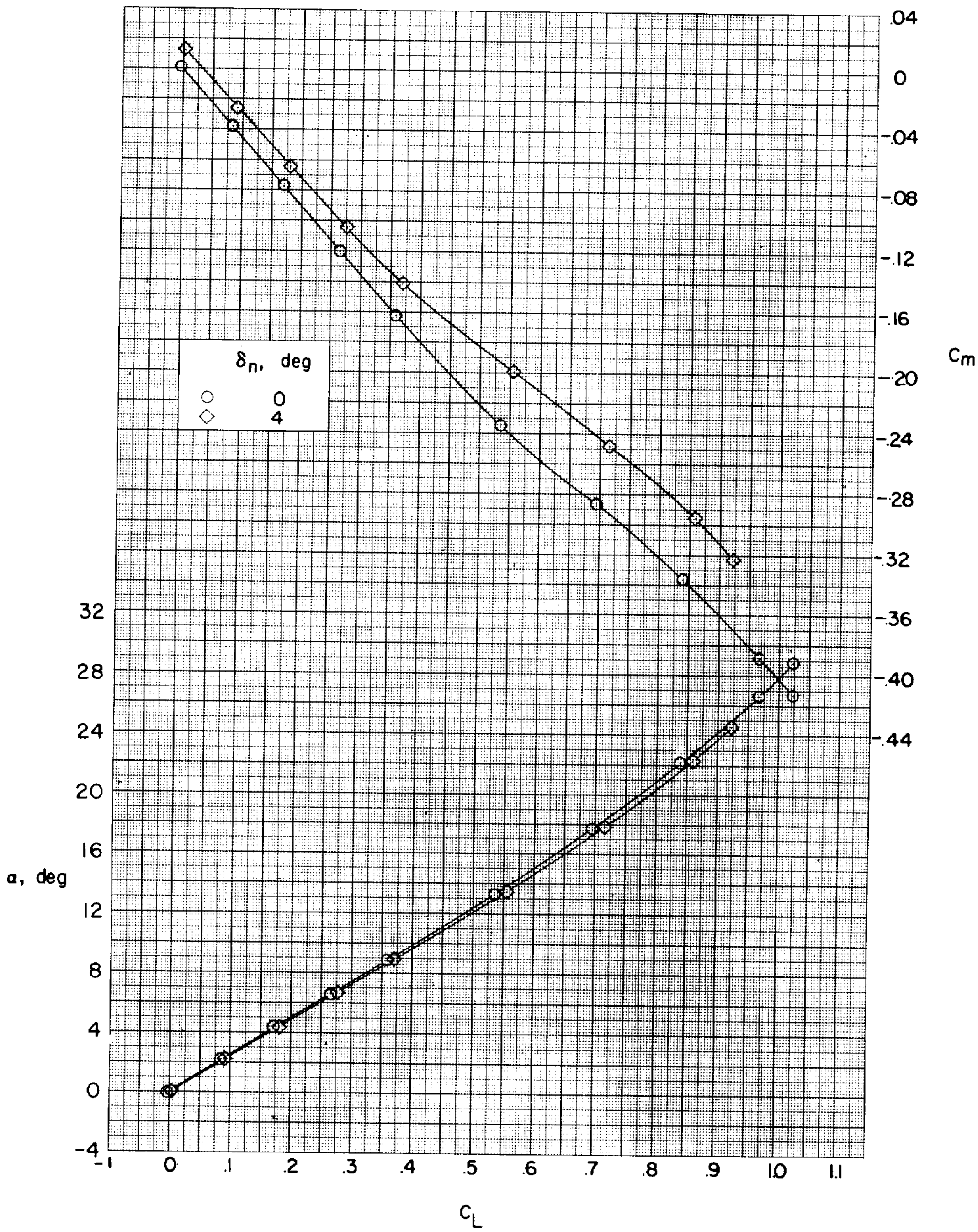

(a) Wing-body configuration.

Figure 3.- Effect of forebody deflection on the aerodynamic characteristics in pitch for various combinations of component parts.

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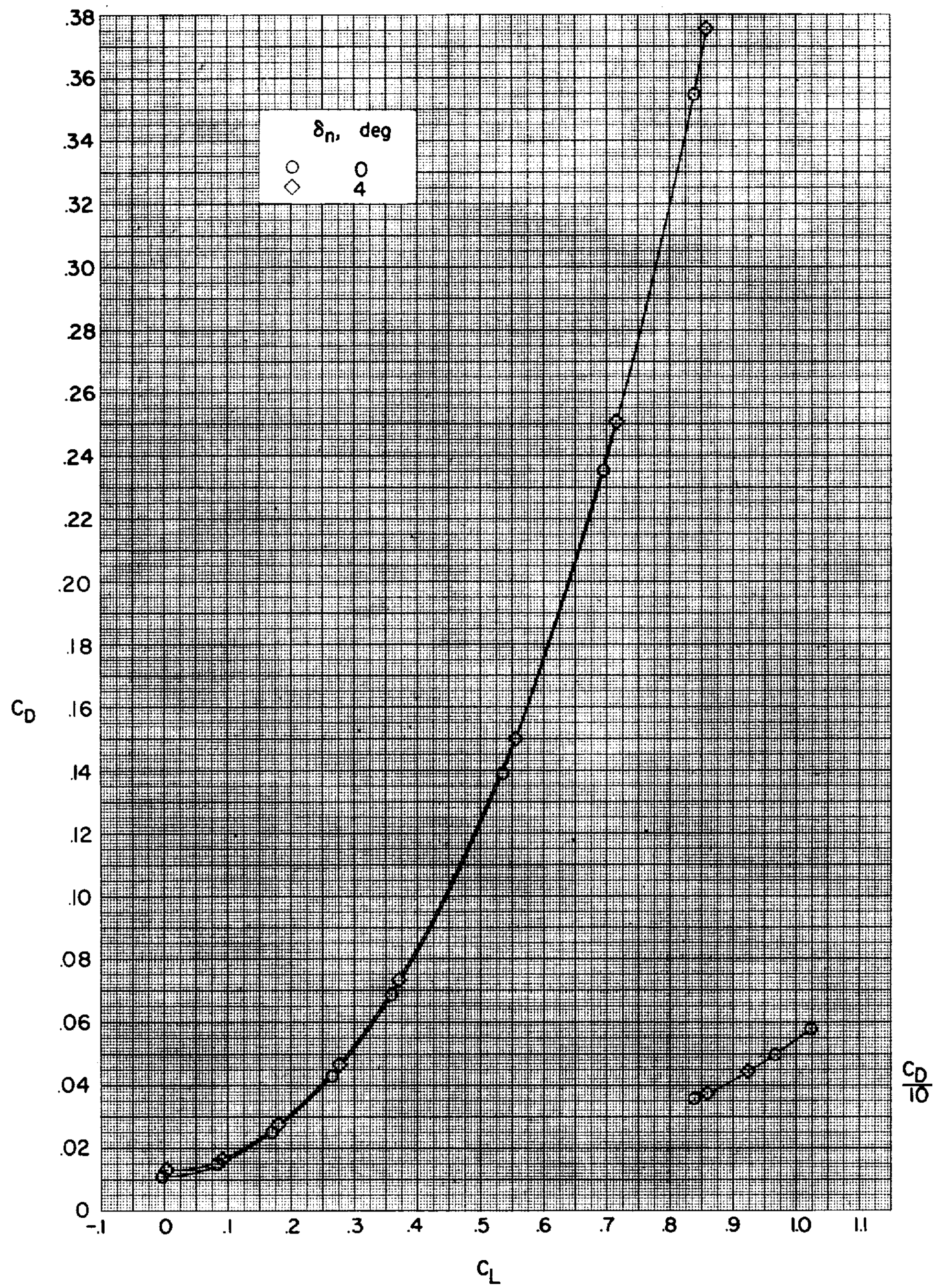

(a) Concluded.

Figure 3.- Continued.

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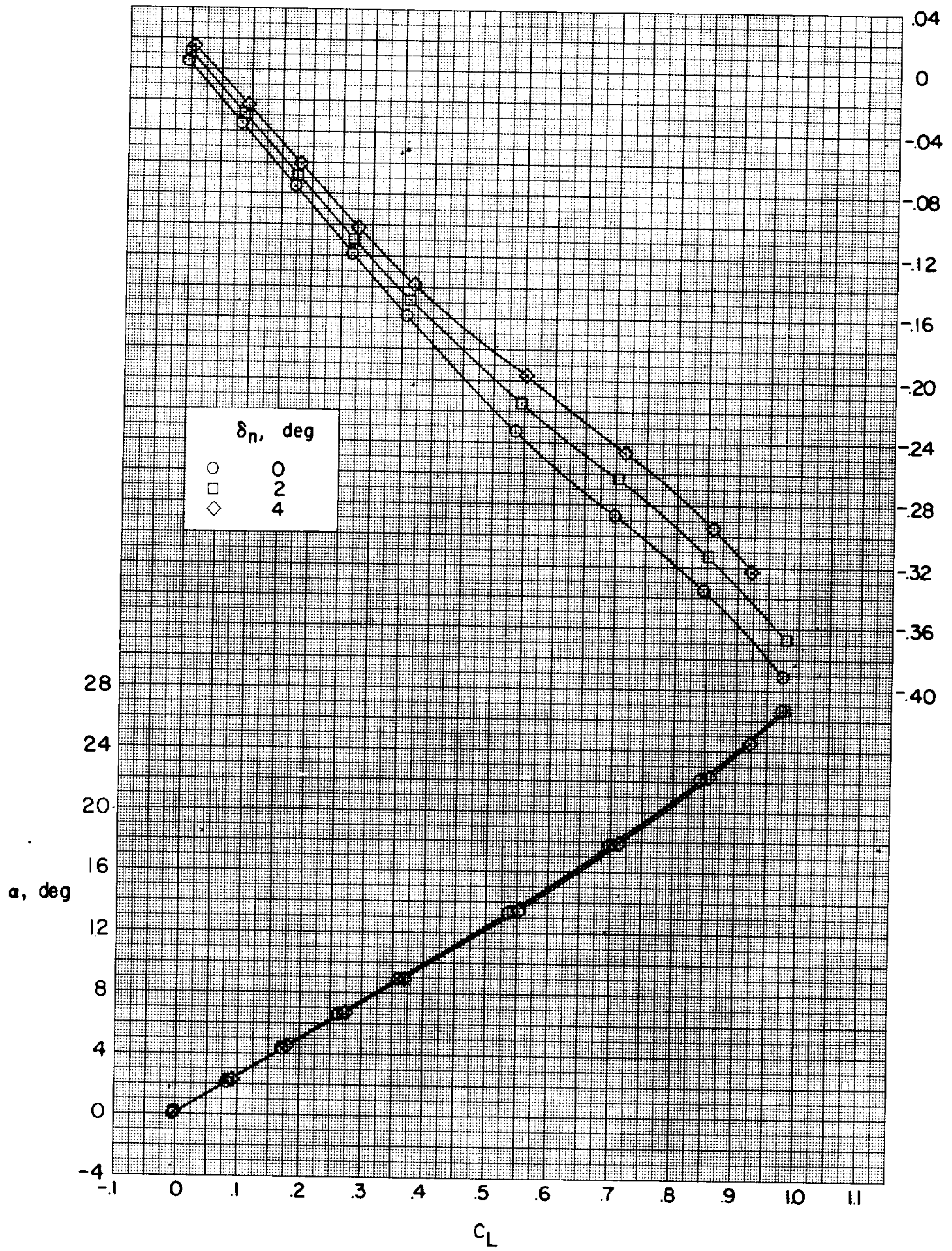

(b) Wing—body—vertical-tail configuration.

Figure 3.- Continued.

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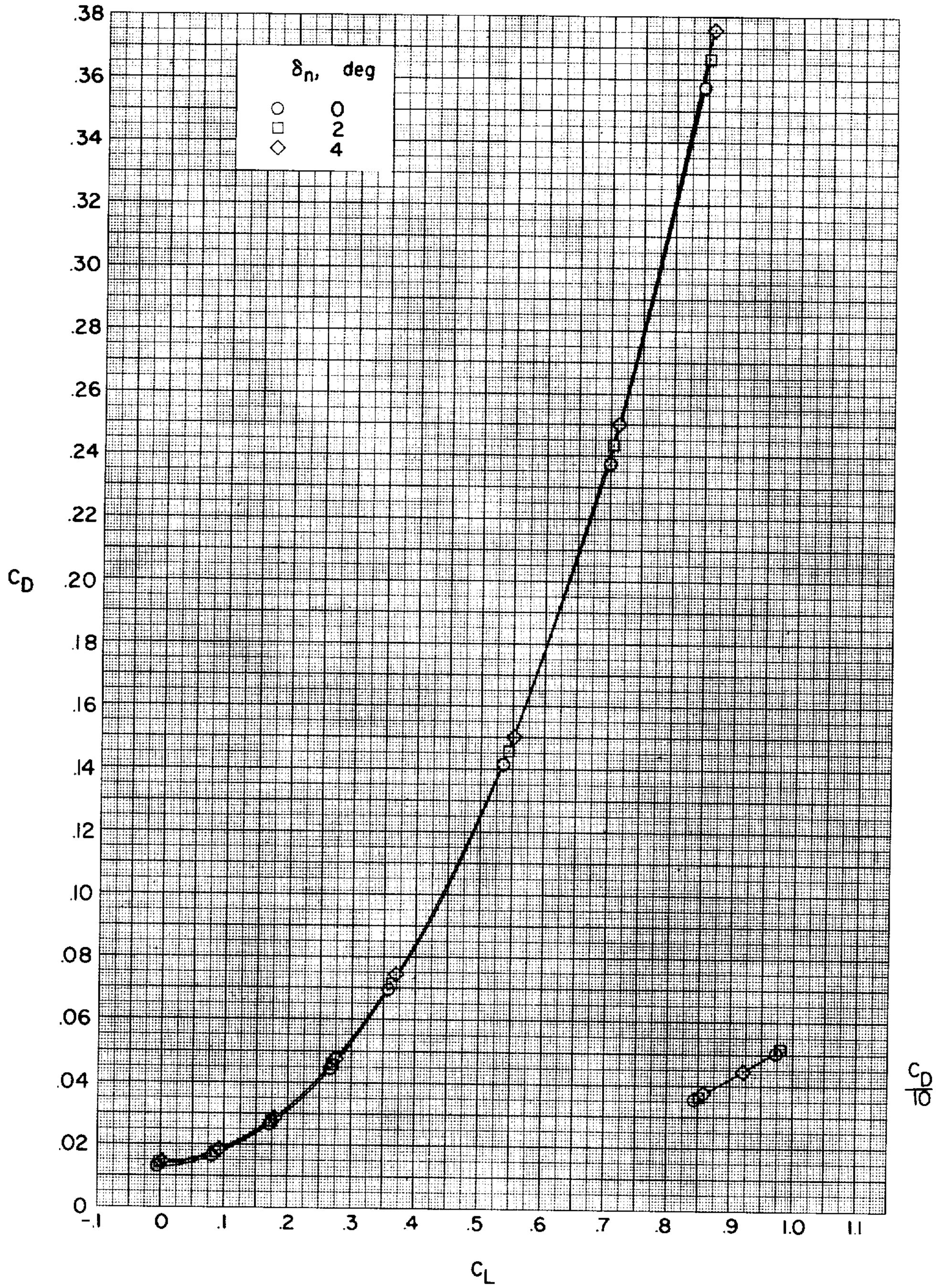

(b) Concluded.

Figure 3.- Continued.

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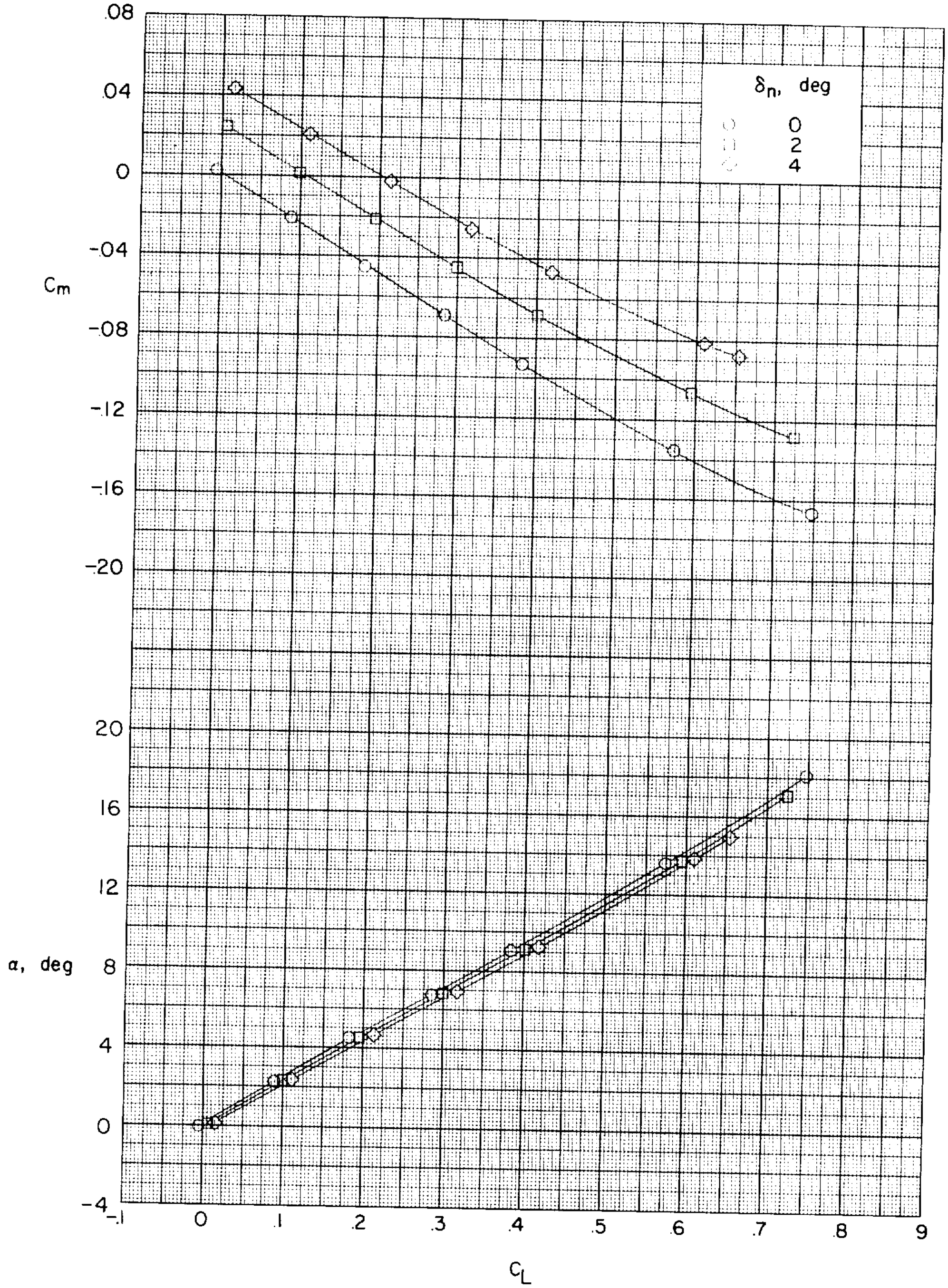

(c) Complete model.

Figure 3.- Continued.

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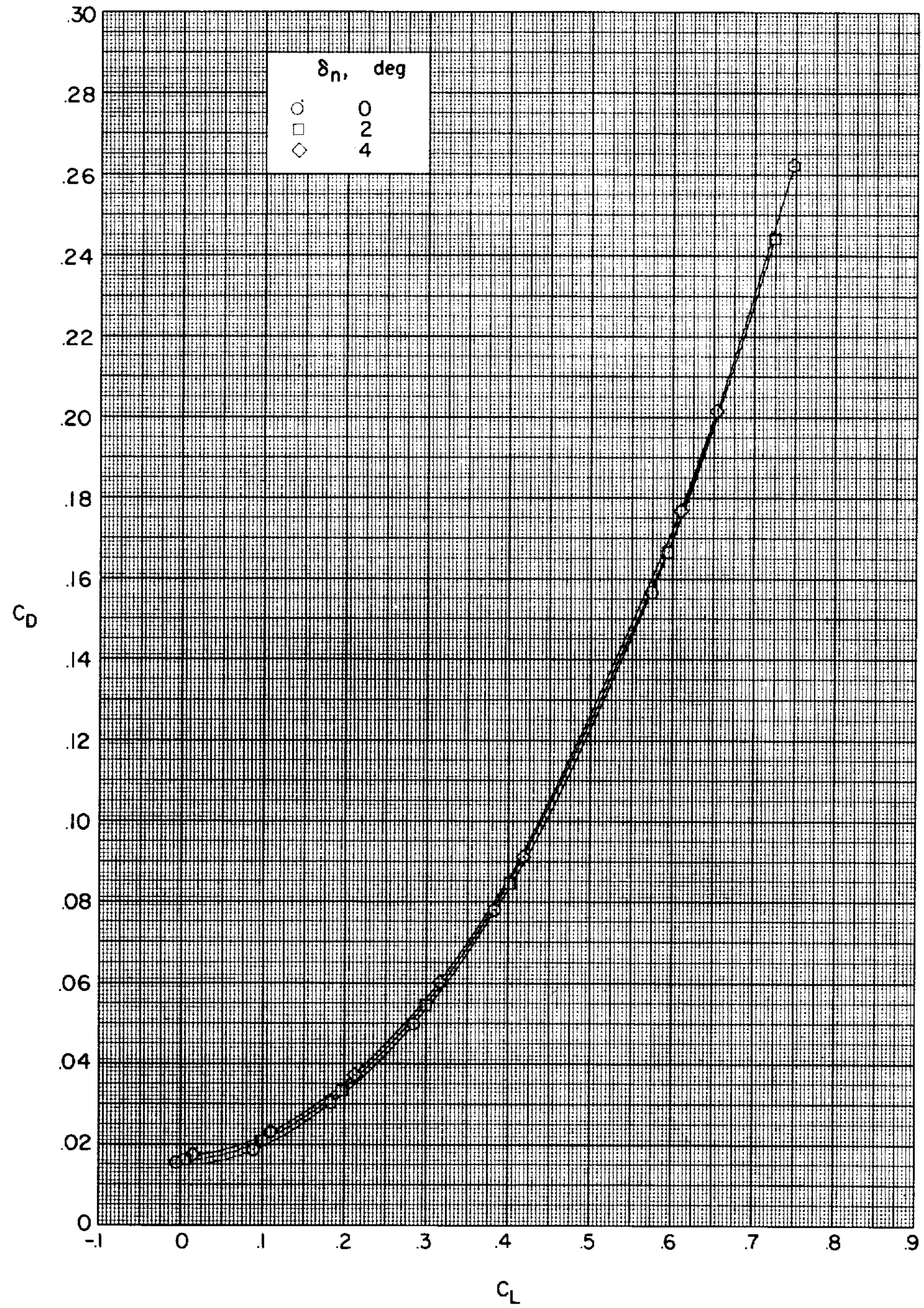

(c) Concluded.

Figure 3.- Concluded.

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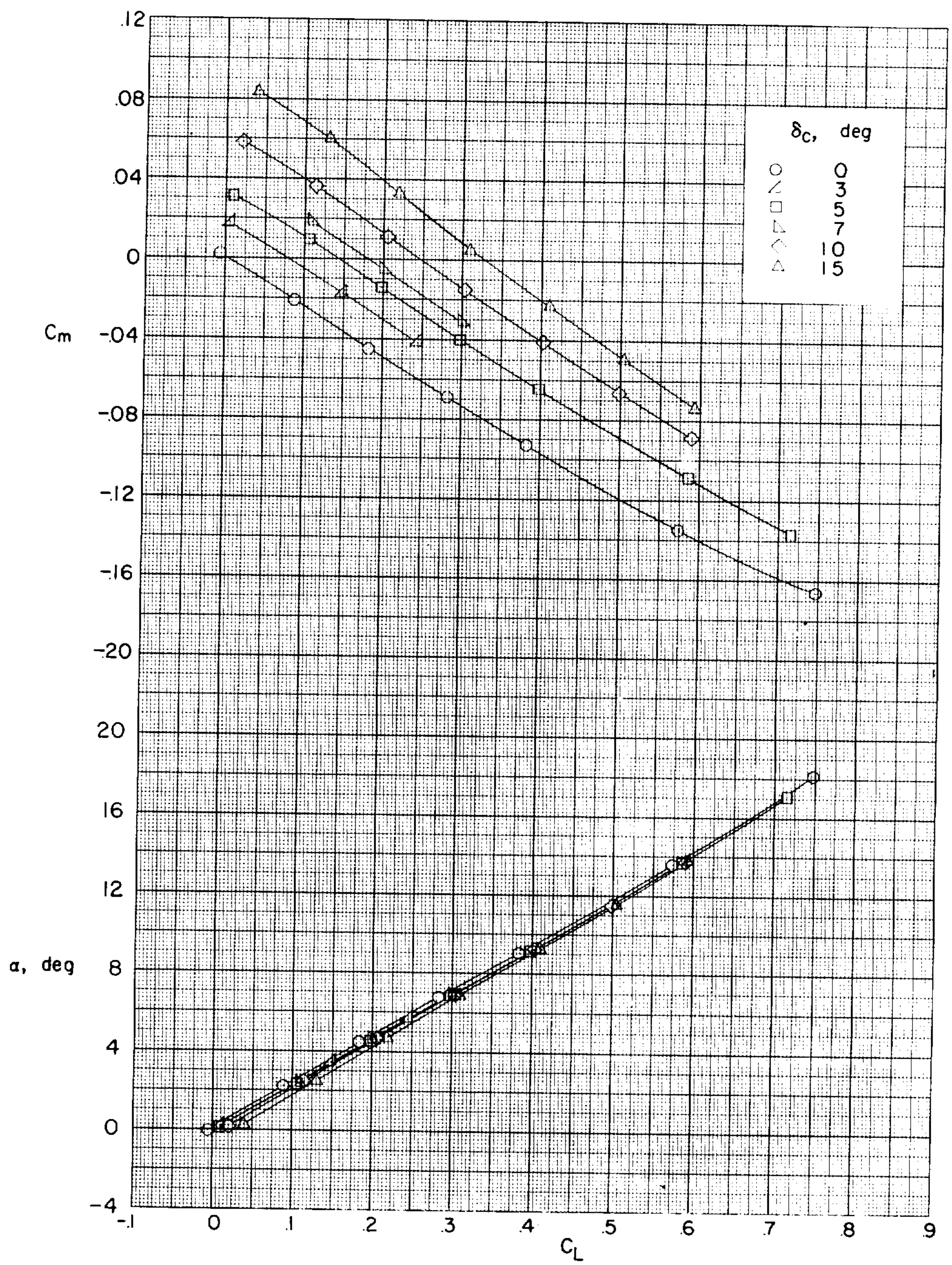

(a) $\delta_n = 0^\circ$.

Figure 4.- Effect of canard-surface deflection on the aerodynamic charteristics in pitch for various forebody deflections. Complete model.

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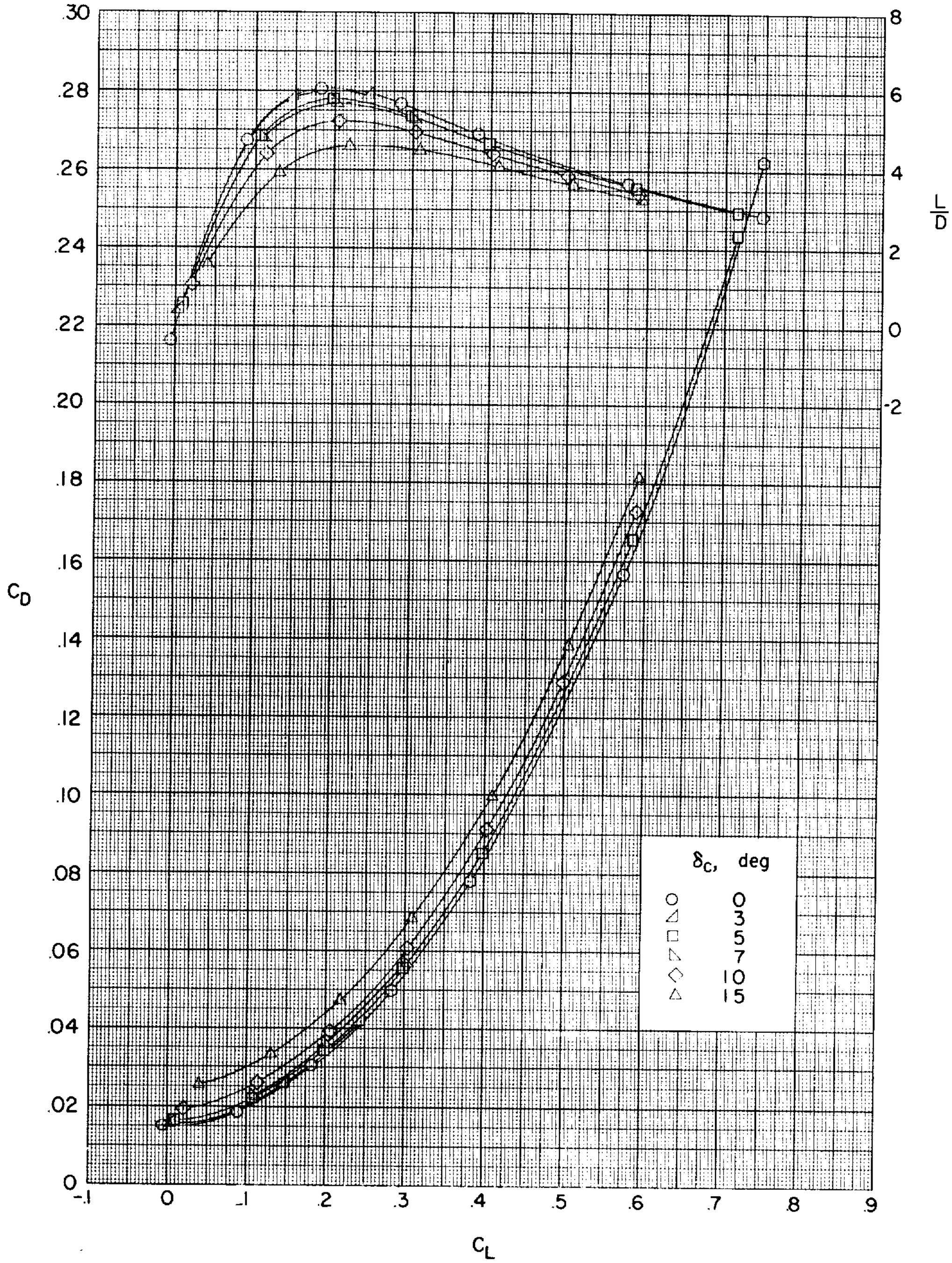

(a) Concluded.

Figure 4.- Continued.

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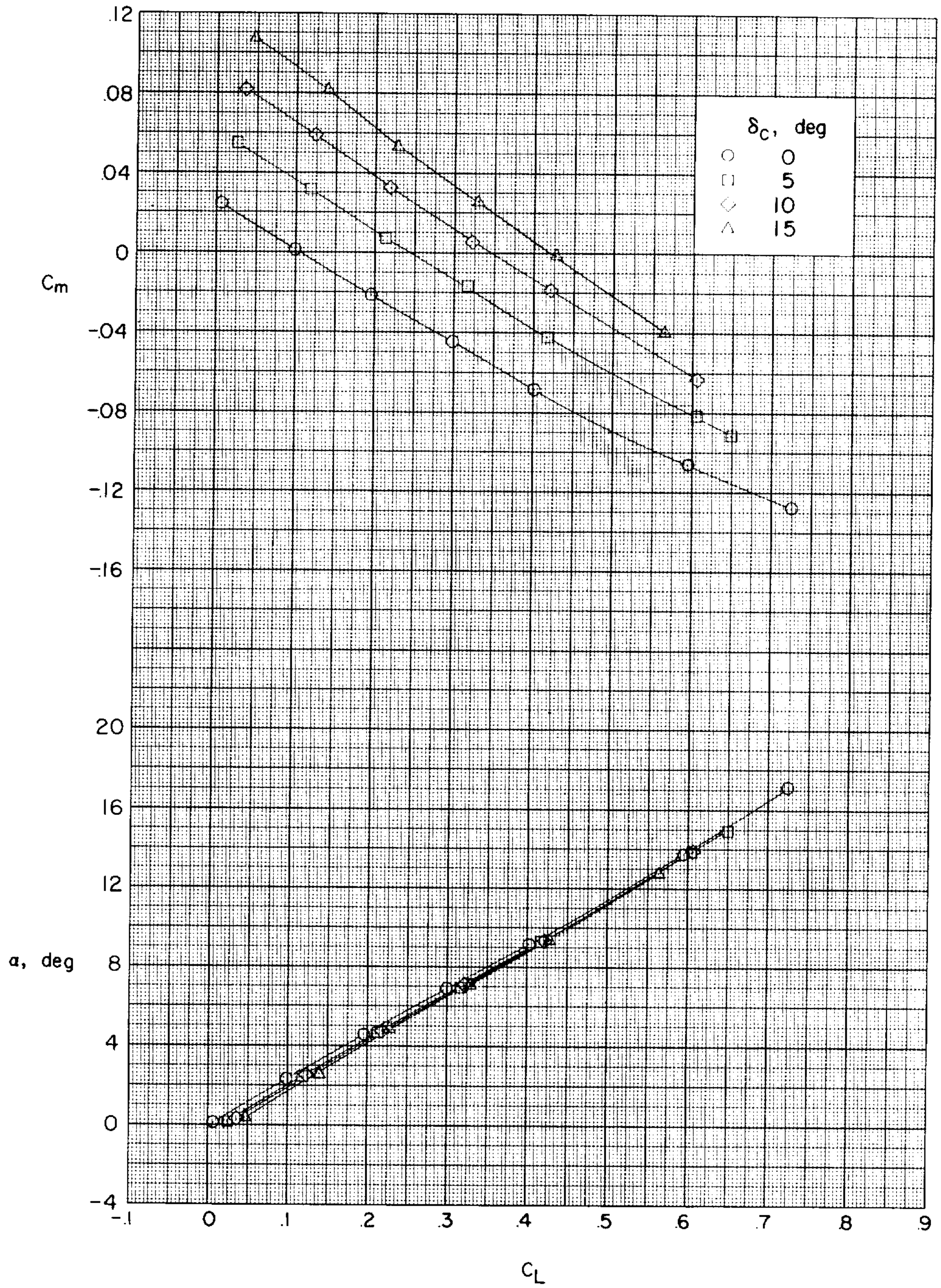

(b) $\delta_n = 2^o$.

Figure 4.- Continued.

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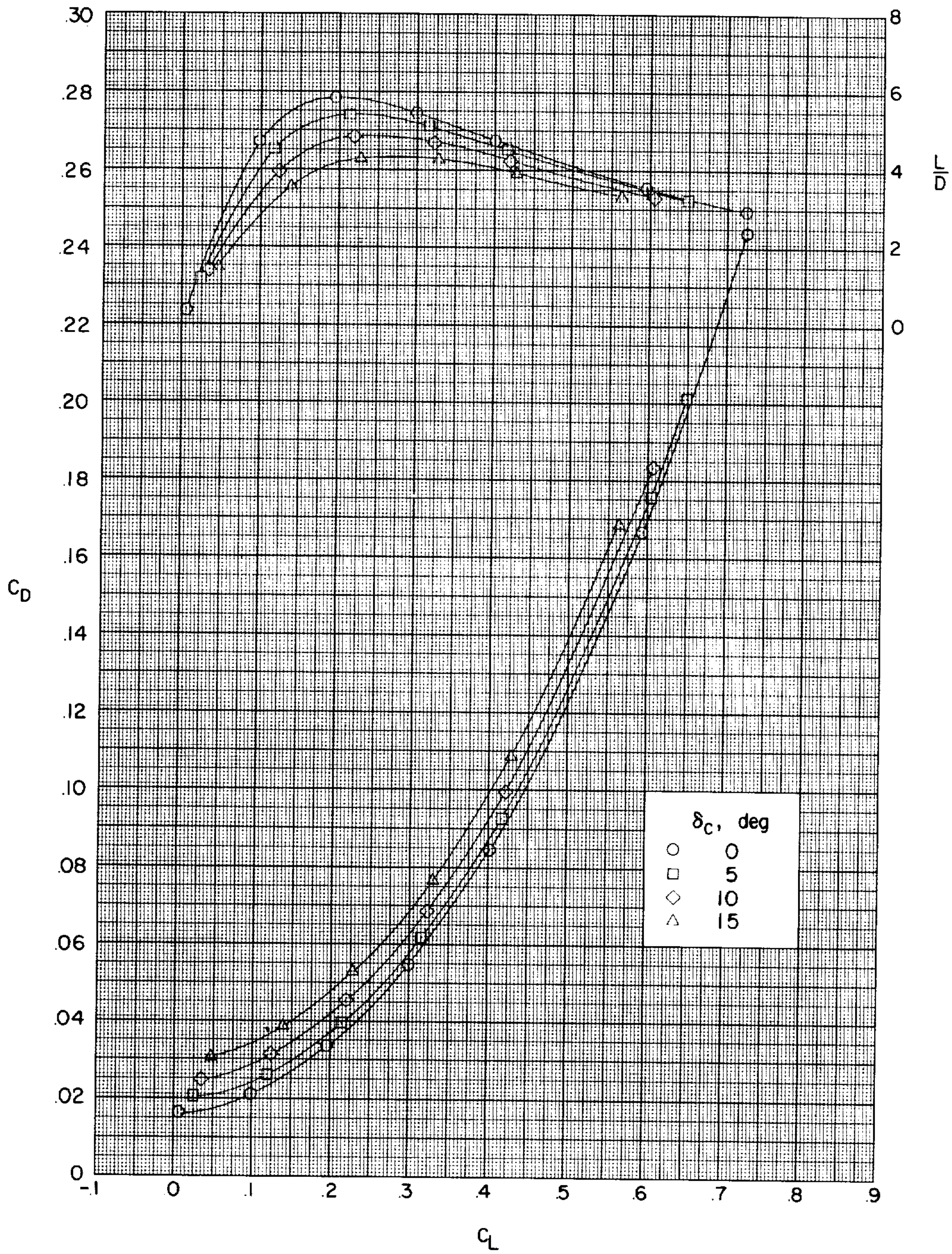

(b) Concluded.

Figure 4.- Continued.

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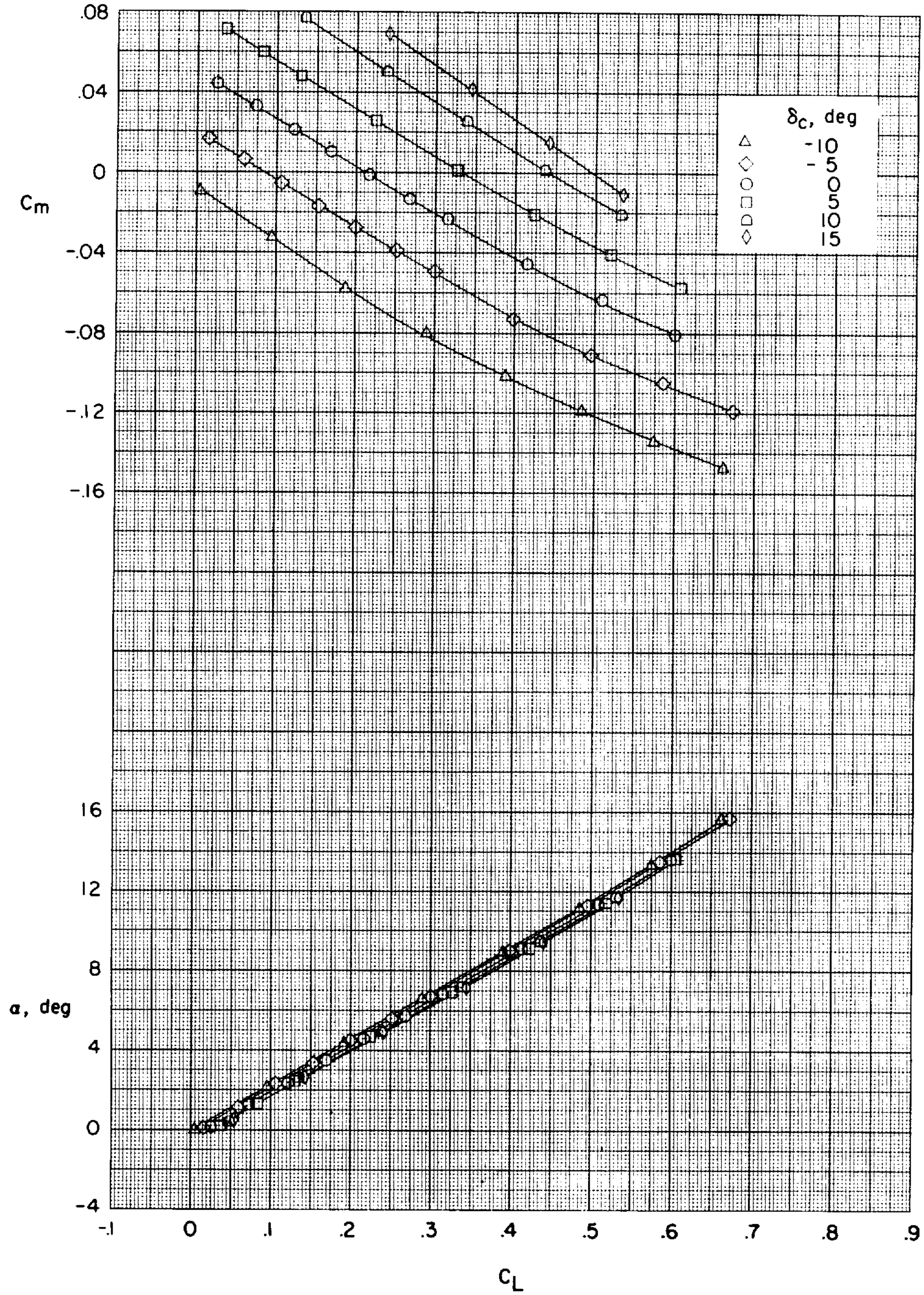
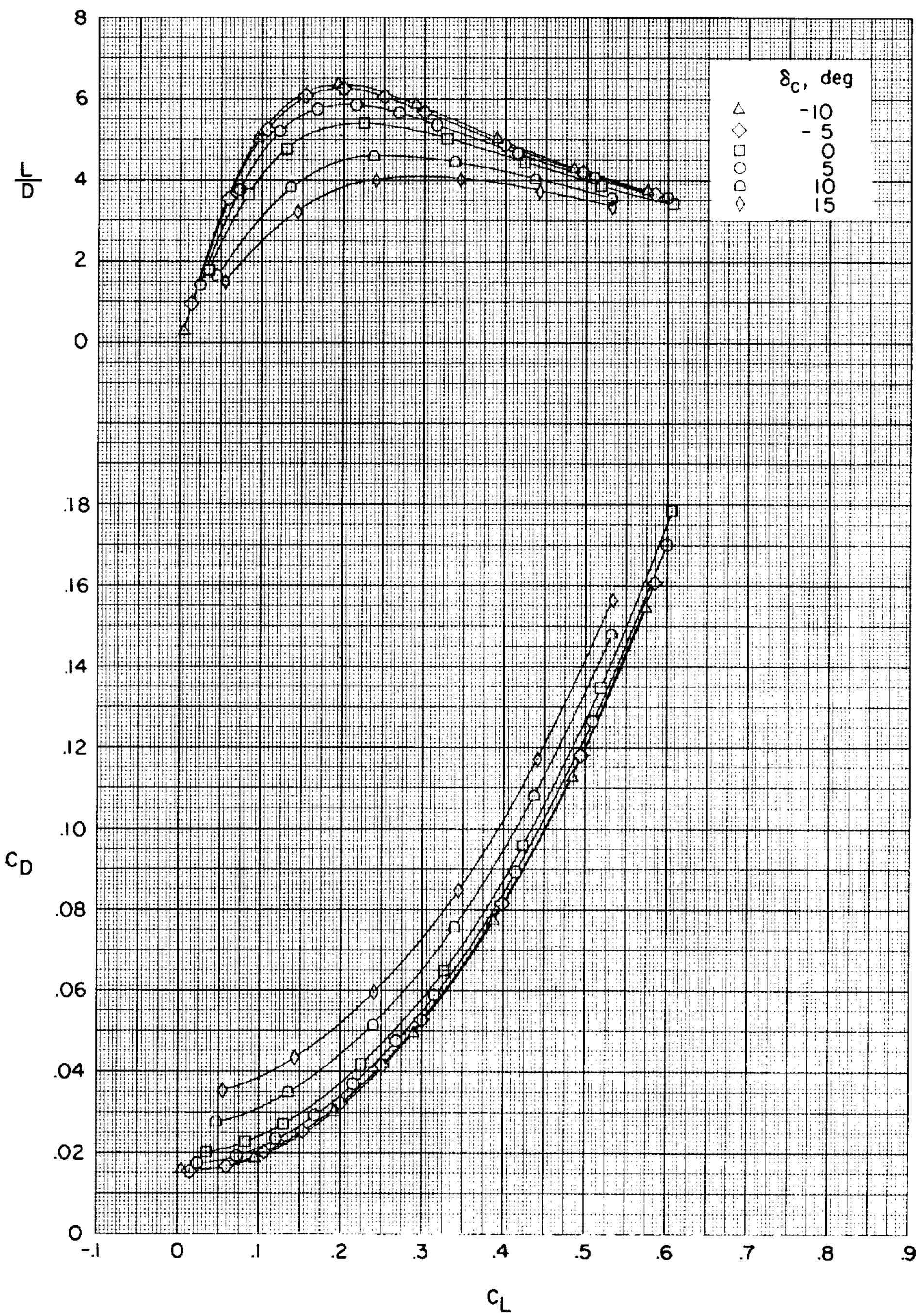


(c) $\delta_n = 4^{\circ}$.

Figure 4.- Continued.



(c) Concluded.

Figure 4.- Concluded.

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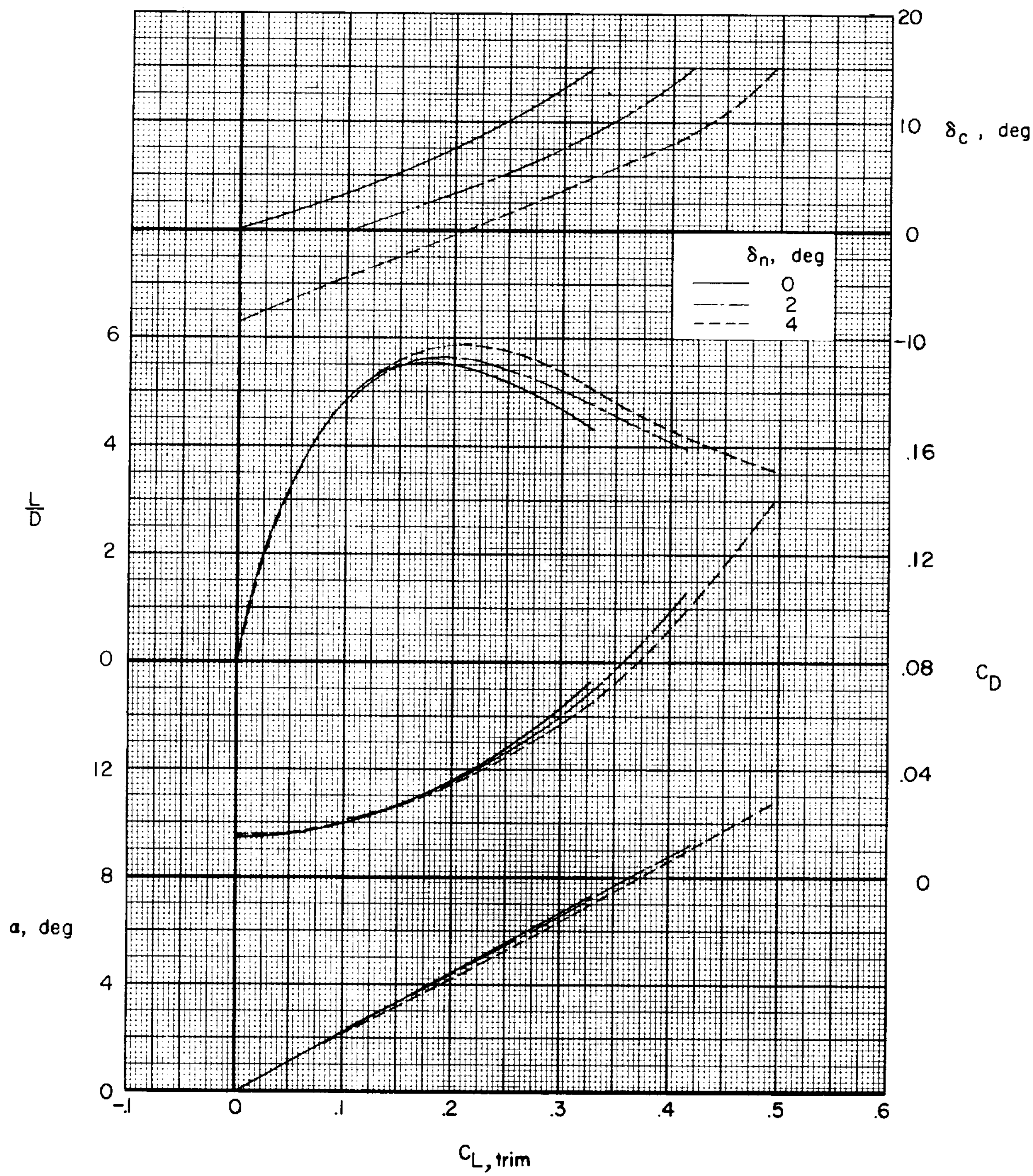

Figure 5.- Effect of forebody deflection on trim longitudinal characteristics for complete model. $\partial C_m/\partial C_L = -0.24$.

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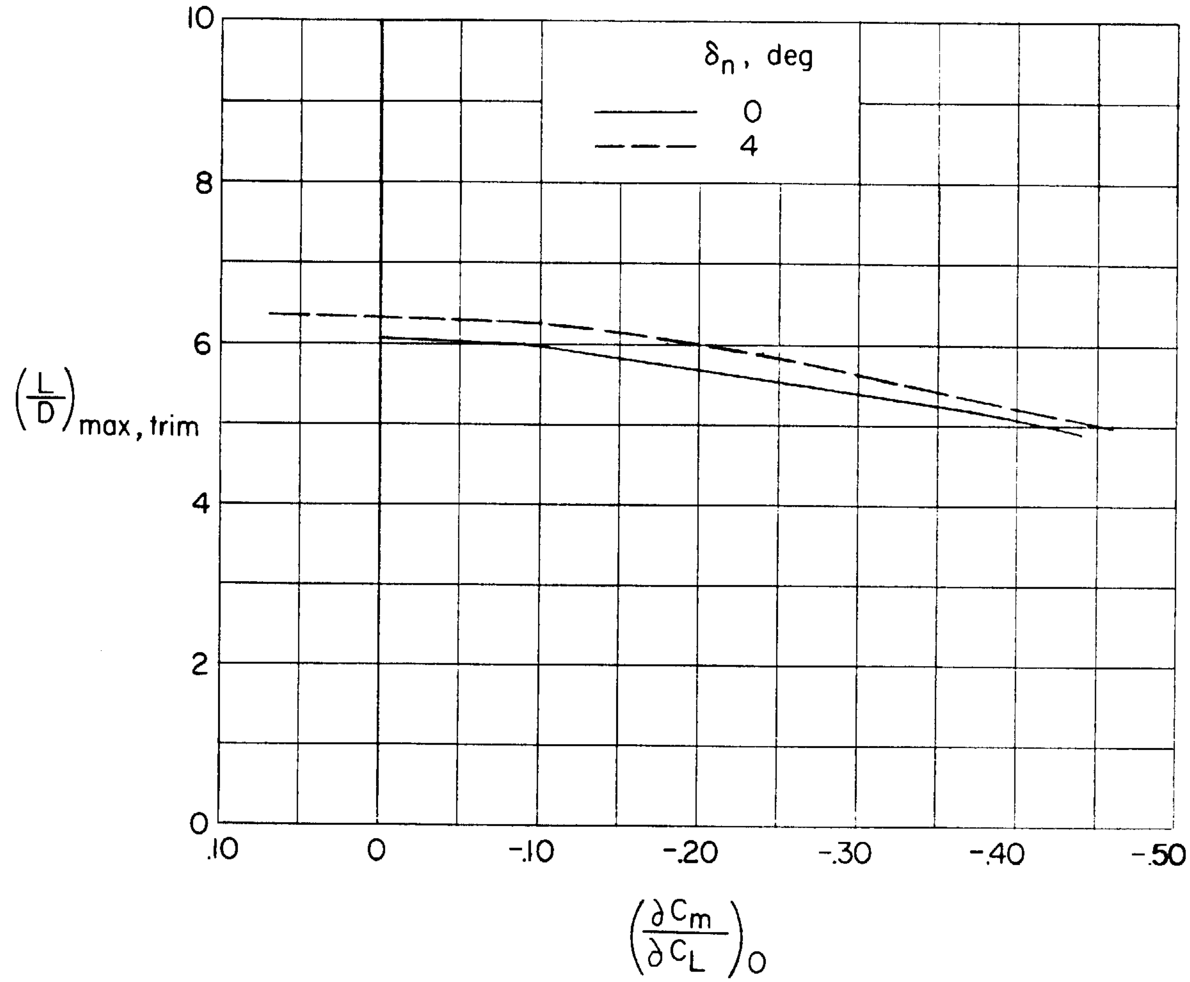

Figure 6.- Variation of $\left(\frac{L}{D}\right)_{max,trim}$ with static longitudinal stability for forebody deflections of 0° and 4°. Complete model.

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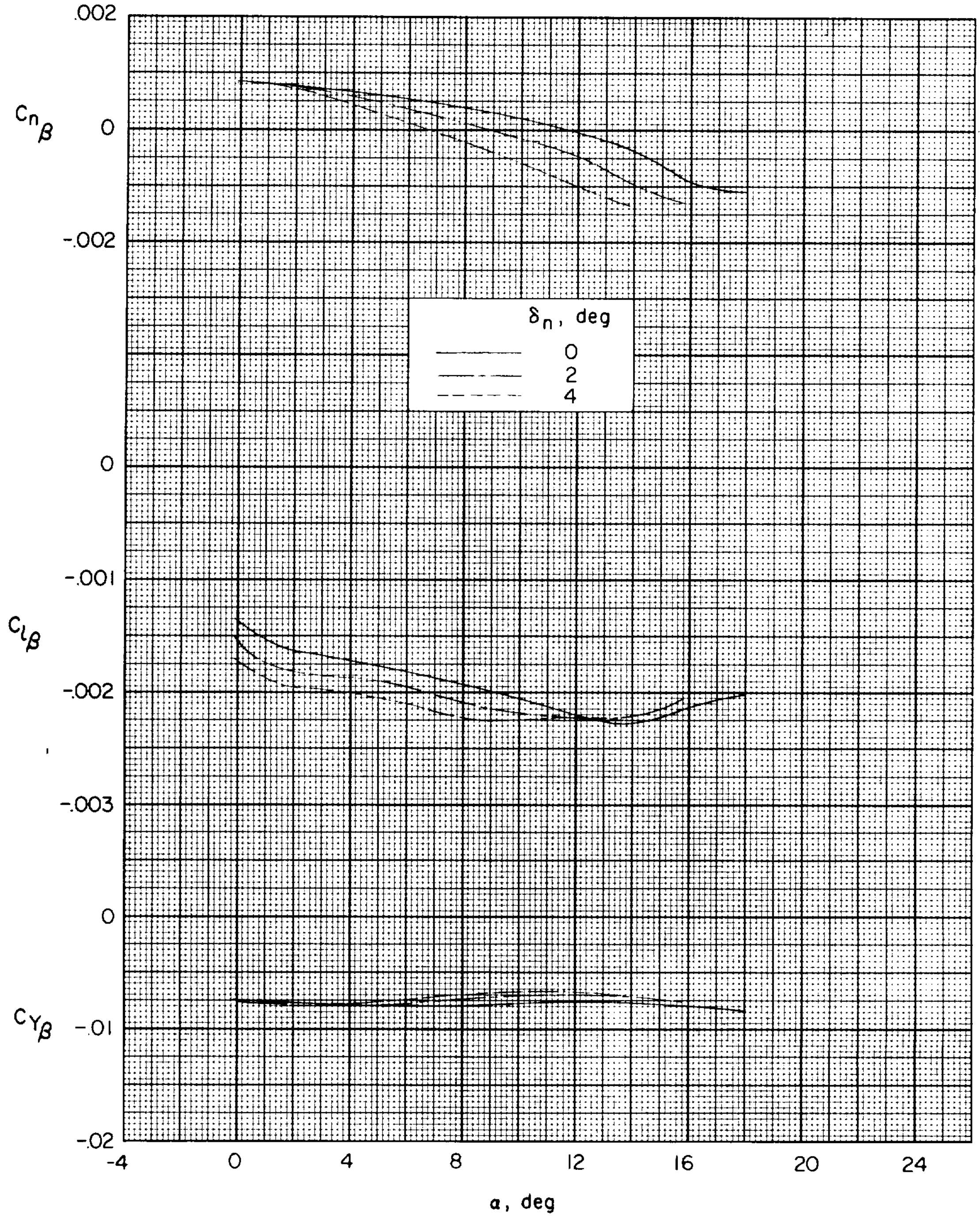
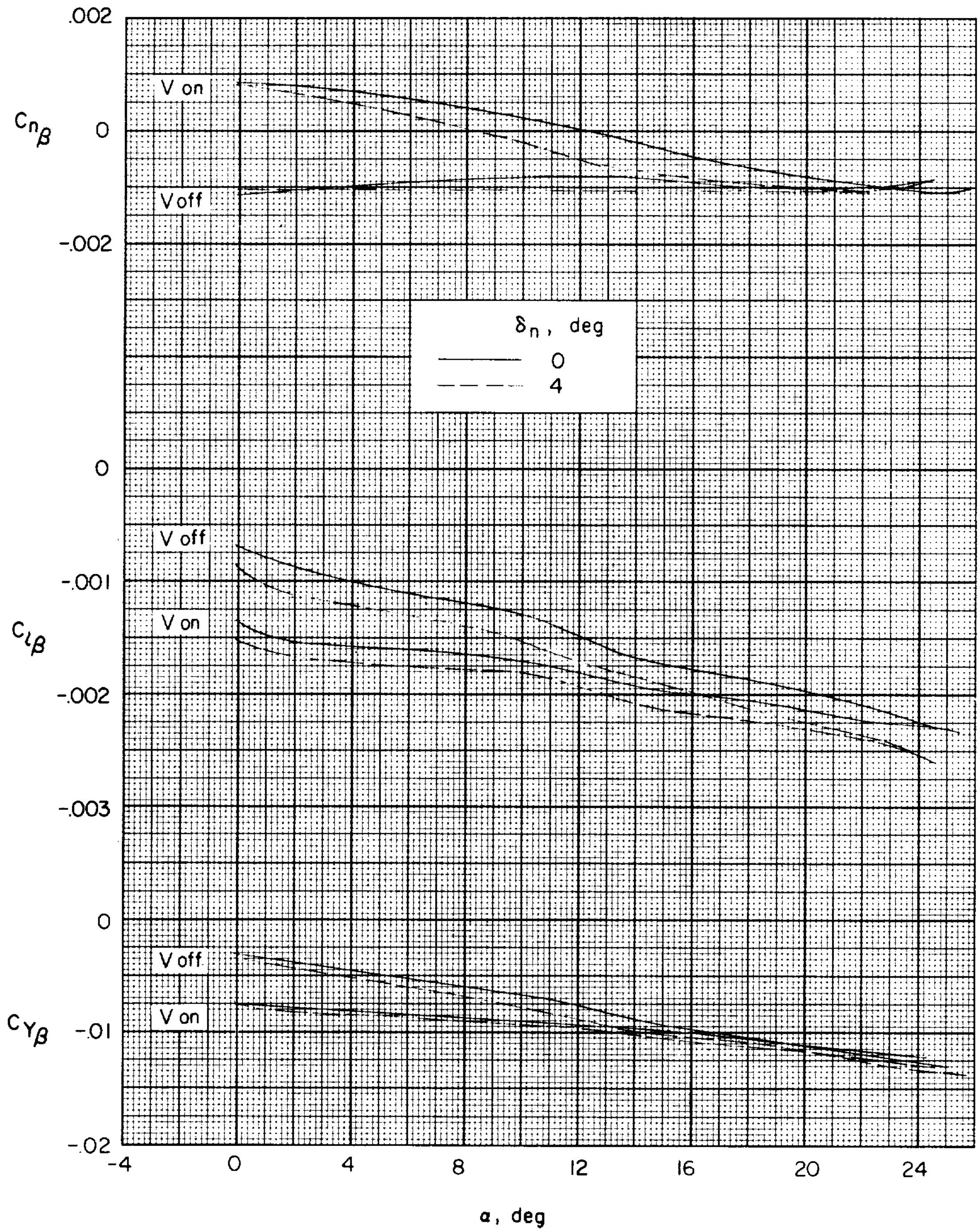


(a) Complete model.

Figure 7.- Effect of forebody deflection on sideslip derivatives.



(b) Canard surface off.

Figure 7.- Concluded.

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(Title, Unclassified)

The configuration investigated included forebody deflection angles of 0°, 2°, and 4°. A single swept vertical tail was employed. The tests were made through a combined angle-of-attack and sideslip range from 0° to about 20° with control deflections ranging from 0° to 15°. In addition to the complete model, tests were made of various combinations of component parts.

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1. Airplanes - Components in Combination (1.7.1.1)
2. Stability, Longitudinal - Static (1.8.1.1.1)
3. Stability, Lateral - Static (1.8.1.1.2)
4. Stability, Directional - Static (1.8.1.1.3)
5. Control, Longitudinal (1.8.2.1)

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I. Spearman, M. Leroy
II. Driver, Cornelius
III. NASA MEMO 4-4-59L

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[redacted]