NASA TECHNICAL NOTE

NASA TN D-3728

NASA TN D-3728

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ff 653 July 65

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • DECEMBER 1966

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SUMMARY

An experimental investigation has been made in the Langley 15-inch hypersonic flow apparatus to determine the effects of wing vertical position, canard planform, canard size, and fuselage length on the effectiveness of canard controls on high-fineness-ratio configurations having a 45^{o} swept-leading-edge trapezoidal wing. In addition, the effects of the canards on the lateral and directional characteristics of the configurations were determined. Some comparisons have been made with data from a previous investigation of configurations having a 70^{o} swept delta wing to show the effects of wing planform on canard effectiveness. The tests were made at a Mach number of 10.03, at a Reynolds number, based on wing mean aerodynamic chord, of approximately 0.5×10^{6}, and at angles of attack from about -4^{o} to 20^{o} for sideslip angles of 0^{o} and -5^{o}.

The results indicate that the high-wing configurations had lower lift coefficients and greater canard effectiveness than the low-wing configurations as a result of the interference of the canard wake and/or shock field with the flow over the high wing. Canard effectiveness increased with both canard size and increasing body length (canard moment arm). However, canard planform had very little effect on canard control effectiveness. The lift-curve slope and the canard effectiveness were greater for the configurations with the trapezoidal wing than for the configurations with the 70^{o} swept delta wing.

The canard controls caused a small reduction in directional stability of both the high- and low-trapezoidal-wing configurations. The canards also caused an increase in positive effective dihedral on the high-wing configurations, but had essentially no effect on the effective dihedral of the low-wing configurations. The vertical tails increased the directional stability and the positive effective dihedral of both the high- and low-trapezoidal-wing configurations.

INTRODUCTION

There has been considerable interest in the past in the use of canard controls at supersonic speeds because of the greater control effectiveness and higher maximum lift-drag ratios obtainable with this type of control as compared with conventional aft controls. (See refs. 1 to 4.) In experimental investigations of various hypersonic configurations (for example, ref. 5), it has been found that conventional aft pitch controls lose effectiveness when they come within the hypersonic "shadow region." Since canard controls would not be subject to this blanketing effect, owing to their forward location, and since canards have been found advantageous at supersonic speeds, it is of interest to determine their effectiveness at the higher Mach numbers for use in various hypersonic cruise-vehicle concepts requiring high aerodynamic efficiency. The National Aeronautics and Space Administration has therefore initiated an experimental program to investigate the effectiveness of canard controls on airplane type configurations at hypersonic speeds.

The purpose of the present experimental investigation was to determine the hypersonic characteristics of a generalized airplane configuration having a trapezoidal planform wing and canard controls. The tests were undertaken primarily to determine the effects of canard size and planform, fuselage length, wing vertical location, and wing-tip-mounted vertical tails on the aerodynamic characteristics of the configuration. The effects of wing planform on canard control effectiveness were also determined by comparing the results of an investigation of airplane configurations with a 70° swept delta wing (ref. 6) with the results of the present investigation.

The present investigation was made in the Langley 15-inch hypersonic flow apparatus at a Mach number of 10.03 and at a Reynolds number, based on wing mean aerodynamic chord, of 0.5×10^{6}. The tests were made over an angle-of-attack range from approximately -4° to 20° at sideslip angles of 0° and -5°. Canard deflection angle was varied from 0° to 20°.

SYMBOLS

All force and moment coefficients are referenced to the body axes system except the lift and drag coefficients, which are referenced to the stability axes system. The origin of these axes systems is located on the fuselage center line at 60 percent of the total model length.

Measurements for this investigation were taken in the U.S. Customary System of Units. Equivalent values are indicated herein parenthetically in the International System of Units (SI). Details concerning the use of SI, together with physical constants and conversion factors, are given in reference 7.

b	wing span
$\bar{c}$	mean aerodynamic chord
C_D	drag coefficient, $\frac{\text{Drag}}{qS}$
C_L	lift coefficient, $\frac{\text{Lift}}{qS}$
C_l	rolling-moment coefficient, $\frac{\text{Rolling moment}}{qSb}$
C_m	pitching-moment coefficient, $\frac{\text{Pitching moment}}{qS\bar{c}}$
C_n	yawing-moment coefficient, $\frac{\text{Yawing moment}}{qSb}$
C_Y	side-force coefficient, $\frac{\text{Side force}}{qS}$
ΔC_m	incremental pitching-moment coefficient, $C_{m,\delta} - C_{m,\delta=0^{o}}$
C_{l_β}	effective-dihedral parameter (determined between $\beta = 0^{o}$ and $\beta = -5^{o}$)
C_{n_β}	directional-stability parameter (determined between $\beta = 0^{o}$ and $\beta = -5^{o}$)
C_{Y_β}	side-force derivative (determined between $\beta = 0^{o}$ and $\beta = -5^{o}$)
d	model body diameter
L/D	lift-drag ratio
q	free-stream dynamic pressure
r	radial coordinate
S	wing planform area
S_c	canard planform area (including that portion inside fuselage)

S_T area of vertical tail

x longitudinal coordinate, measured rearward from nose of model

x_{cg} longitudinal distance of moment reference center from model nose

α angle of attack (referenced to fuselage center line), deg

β angle of sideslip, deg

δ canard deflection angle relative to fuselage center line, positive when leading edge is up, deg

Model component designations:

B_1 short body

B_2 long body

C_1 small delta canard

C_2 large delta canard

C_3 small trapezoidal canard

W_1 high wing

W_2 low wing

MODELS

Drawings of the models and components are shown in figure 1 and photographs of the models are presented as figure 2. The model consisted basically of a cylindrical fuselage with a 2/3-power-law nose, a wing, canard controls, and wing-tip-mounted vertical tails. The trapezoidal planform wing had a taper ratio of 0.361 (based on the theoretical root chord), a 45° swept leading edge, and an aspect ratio of 1.30. The wing also had a diamond airfoil section with a maximum thickness of 5 percent chord in the stream direction. Provisions were made for the wing to be tested either on the top or the bottom of the fuselage. (See fig. 1.)

Three interchangeable canard controls were provided for the model. Two of the canard controls had 45° swept-leading-edge delta planforms which differed in area and the third had a 22.5° swept-leading-edge trapezoidal planform with essentially the same area as the smaller delta canard. (See fig. 1(c).) The ratio of the canard total planform area S_c to the wing reference area S was 0.189 for the larger delta canard and approximately 0.14 for the smaller delta canard and the trapezoidal canard. The hinge line of each canard control was located 2.454 inches (6.253 cm) from the fuselage nose. These canards could be deflected through a range of angles from 0° to 20°. In order to change the effective moment arm of the canard controls, the length of the fuselage could be varied by inserting a cylindrical spacer just behind the 2/3-power-law nose. (Compare figs. 1(a) and 1(b) and see fig. 2(c).) This change in fuselage length resulted in a change in fuselage fineness ratio from 10.8 to 12.

The vertical tails had a trapezoidal planform with 45° of leading-edge sweep, a taper ratio of 0.524, and 5-percent-thick diamond airfoil sections. The vertical tails were mounted on the wing upper surface at the wing tips.

APPARATUS AND TESTS

The tests were made in the Langley 15-inch hypersonic flow apparatus, which operates at a Mach number of 10.03. A brief description of this facility and typical Mach number distributions are given in reference 8. Forces and moments were measured with a sting-supported, internally mounted, six-component strain-gage balance.

The tests were made at a tunnel stagnation pressure of about 800 psia (5510 kN/m^2) and at a stagnation temperature of approximately 1100° F (866° K). The stagnation temperature used in these tests is below the theoretical temperature required to prevent liquefaction of the air during the expansion in the tunnel; however, an investigation reported in reference 9 showed that no effective condensation would exist at the present test conditions. The stagnation pressure and temperature used in the present tests correspond to a free-stream Reynolds number, based on the wing mean aerodynamic chord, of approximately 0.5×10^6. The tests were made through an angle-of-attack range from -4° to 20° at sideslip angles of approximately 0° and -5°. For each of the two wing locations, high and low, and each of the fuselage lengths, the model was tested both without the canard and with each of the three canard surfaces at deflection angles of 0°, 5°, 10°, and 20°. Some of the tests were made with the vertical tails off; however, most of the tests were made with the vertical tails on. Thus, unless otherwise stated, a model designated configuration $W_1B_1C_1$, for example, would have the vertical tails on.

ACCURACY AND CORRECTIONS

The estimated accuracy of the force and moment coefficients (based on balance accuracy), angle of attack, and angle of sideslip are as follows:

C_L	± 0.009
C_D at $\alpha = 0^o$	± 0.002
C_D at $\alpha = 20^o$	± 0.005
C_m	± 0.007
C_n	± 0.002
C_Y	± 0.002
C_l	± 0.0004
α, deg	± 0.1
β, deg	± 0.1

The angle of attack and angle of sideslip have been corrected for sting and balance deflections due to aerodynamic loads. The data have not been corrected for the effects of base pressure. However, if the base pressure were zero, the decrement in drag coefficient at $\alpha = 0^o$ due to base pressure would be only 0.0007.

PRESENTATION OF RESULTS

The results of the investigation are presented as follows:

	Figure
Longitudinal aerodynamic characteristics:	
Configuration $W_1B_1C_1$	3
Configuration $W_1B_1C_2$	4
Configuration $W_1B_2C_1$	5
Configuration $W_1B_2C_2$	6
Configuration $W_1B_2C_3$	7
Configuration $W_2B_1C_1$	8
Configuration $W_2B_2C_1$	9
Configuration $W_2B_2C_2$	10
Configuration $W_2B_2C_3$	11

DISCUSSION

Longitudinal Aerodynamic Characteristics

General trends.- The C_L and C_m curves for the trapezoidal-wing configurations (figs. 3 to 11) with the canard on as well as off are nonlinear and basically similar in shape for all configurations tested. The results indicate a noticeable increase in lift-curve slope with increasing angle of attack accompanied by stabilizing changes in pitching-moment coefficient for both the canard-off and canard-on configurations. For the canard-on configurations, control deflection results in a decrease in longitudinal stability at low values of lift coefficient. At the higher test lift coefficients, however, the effects of control deflection on stability are configuration dependent. The pitching-moment curves are also typically nonlinear in such a way that canard control effectiveness increases with increasing C_L. From Newtonian impact theory considerations, it has been shown in reference 6 that these nonlinear lift and pitching-moment curves are typical of canard configurations at hypersonic speeds.

In general, wing vertical position, canard size and planform, and fuselage length have only small effects on drag coefficient. However, as a result of the increase in drag coefficient with increases in canard deflection, the maximum lift-drag ratio decreases from approximately 3 to 2 for a canard deflection from 0° to 20° for all configurations tested.

Effects of wing vertical position.- The low-wing configurations (W_2) with canards off have a slightly greater lift-curve slope and are slightly less stable than the corresponding high-wing configurations (W_1). (See figs. 12(a) and 12(b).) The addition of the canards at $\delta = 0^{o}$ causes an increase in C_L at all test angles of attack and a reduction in longitudinal stability for both the high- and low-wing configurations.

For the low-wing configurations (figs. 8 to 11), the lift coefficient at all test angles of attack shows a consistent increase with increasing canard deflection from $\delta = 0^{o}$ to $\delta = 20^{o}$. For the high-wing configurations (figs. 3 to 7), however, this is not always the case. At $\alpha = 0^{o}$, the increment in C_L due to a given canard deflection is approximately the same for both the high- and low-wing configurations. But as angle of attack increases, the increment in C_L due to a given canard deflection decreases for the high-wing configurations until, near an angle of attack of 20^{o}, lift coefficient decreases with increasing canard deflection angle in some cases. This loss in lift with increasing canard deflection is probably associated with the interference of the canard wake and/or shock field on the flow over the wing and on the flow in the wing-body juncture region of the high-wing configurations.

Increasing canard deflection produces a considerably greater increment in pitching-moment coefficient on the high-wing configurations than on the corresponding low-wing configurations. (See fig. 12.) This greater effectiveness of the canards on the high-wing configurations results from the loss in C_L due to canard-wing interference on the high-wing configurations effectively increasing the pitching-moment coefficient since the center of pressure of the wing is behind the assumed moment reference center.

It should be pointed out here and in the discussions which follow that the various comparisons of canard effectiveness (e.g., fig. 12(c)) are made for configurations that have different levels of stability. However, because of the variations of stability with C_L for these configurations, the effects of the different stability levels cannot be readily separated from the canard effectiveness. Therefore, for the present tests, the canard control effectiveness comparisons are made with the moment reference center for all configurations located at 60 percent of the fuselage length.

Effects of canard size.- Increasing the total planform area of the delta canard controls by 34 percent generally produces small increases in lift coefficient at a given angle of attack and positive increments in pitching-moment coefficient at a given C_L. (See fig. 13.) As a result, the stability of the large-canard configurations (C_2) is less than that of the corresponding small-canard configurations (C_1). The variation of incremental pitching-moment coefficient ΔC_m at constant values of C_L with canard deflection shown in figure 13(c) indicates that canard effectiveness increases with canard size.

Effects of canard planform.- The small delta canard controls (C_1) and the trapezoidal canard controls (C_3) have essentially the same total planform area; however, the trapezoidal canard surfaces have approximately 18 percent less exposed planform area. The results presented in figure 14 indicate that even with this difference in exposed area there is essentially no effect of canard planform on lift coefficient at all canard deflections and there are only small effects on pitching-moment coefficient at $\delta = 0^{\circ}$. Generally, the trapezoidal canard controls produce a smaller increment in pitching-moment coefficient for a given control deflection than the delta canard controls (fig. 14(c)); however, these differences in control effectiveness are small.

Effects of fuselage length.- With the moment reference center located at 60 percent of the fuselage length, the long-body (B_2) and short-body (B_1) configurations do not have their moment reference centers in the same position relative to the wing. The moment reference center for the long-body configurations is 0.48 inch (1.219 cm) ahead of the moment reference center for the short-body configurations. As a result the basic (canard-off) long-body configurations are more stable than the short-body configurations. (See fig. 15.) At lift coefficients near zero and with the canard controls at $\delta = 0^{\circ}$, the increased canard moment arm counteracts the more forward moment-reference-center location of the long-body configurations so that fuselage length has essentially no effect on the stability of either the high- or low-wing configurations. (See fig. 15.) However, at the higher test lift coefficients, the long-body configurations with $\delta = 0^{\circ}$ are more stable than the short-body configurations. As canard deflection angle is increased, the canard controls on the long-body configurations produce greater increments in pitching-moment coefficient than on the short-body configurations with wings in either a high or low position. Increasing the length of the fuselage for both canard-off and canard-on configurations causes small increases in the slope of the lift curve. (See figs. 15(a) and 15(b).)

Effects of wing planform.- The effects of wing planform on lift coefficient, pitching-moment coefficient, and canard control effectiveness are shown in figure 16 where selected data from reference 6 for both high- and low-delta-wing configurations are compared with data for corresponding trapezoidal-wing configurations from the present investigation. The fuselage and canard controls for the delta-wing configurations of reference 6 are identical to the present trapezoidal-wing configurations except for some minor variations in the wing-fuselage attachment region. The delta wing has a planform area approximately 2.5 percent smaller than the present trapezoidal wing; however, this small difference in wing reference area should not significantly affect the data comparisons. It should be noted that there appears to be some effect of wing planform on lift coefficient at $\alpha = 0^{\circ}$. (See fig. 16.) However, inasmuch as reference 6 indicated that there is a small spurious zero shift in the delta-wing data, the effects of wing planform on C_L at $\alpha = 0^{\circ}$ should not be considered in comparing the data. There does appear to be a considerable effect of wing planform on lift-curve slope. The trapezoidal-wing configurations with a leading-edge sweep of 45° have a greater lift-curve slope than the 70° swept-delta-wing configurations, as expected. For the high-wing configurations (figs. 16(a) and 16(b)), there is no significant effect of wing planform on the variation of pitching-moment coefficient with lift coefficient for the configurations without the canards or with the canards at $\delta = 0^{o}$. For the low-wing configurations (figs. 16(c) and 16(d)), however, the trapezoidal-wing configurations without the canards as well as those with the canards are more stable than the corresponding delta-wing configurations. Increasing the canard deflection angle produces greater increments in pitching-moment coefficient on the trapezoidal-wing configurations than on the delta-wing configurations regardless of wing vertical position. (See fig. 16(e).)

Lateral and Directional Aerodynamic Characteristics

The lateral and directional stability parameters C_{n_β}, C_{l_β}, and C_{Y_β} have been determined from data obtained at sideslip angles of 0^{o} and -5^{o}. Data obtained through a range of sideslip angles from approximately -9^{o} to 3^{o} indicate that the variation of C_n, C_l, and C_Y with sideslip angle is essentially linear between $\beta = 0^{o}$ and -5^{o} at an angle of attack of 0^{o}. It has been assumed that changing the canard size and planform, the wing vertical position, and the fuselage length will not affect this linearity of the lateral and directional characteristics at angles of attack greater than 0^{o}.

Effects of canards.- The addition of either the small delta canard (C_1) or the trapezoidal canard (C_3) at $\delta = 0^{o}$ to either the high- or low-wing—long-body configurations has no significant effects on the lateral and directional stability characteristics of the configurations at angles of attack near 0^{o}. (See figs. 17 and 18.) At angles of attack greater than zero, however, the addition of the canards causes reductions in the directional stability of the high- as well as the low-wing configurations. Above an angle of attack of about 6^{o}, canard addition also causes an increase in the positive effective dihedral of the high-wing configurations but has essentially no effect on the effective dihedral of the low-wing configurations. Deflecting the canards from 0^{o} to 10^{o} causes a further increase in the positive effective dihedral of the high-wing configurations but does not significantly affect the effective dihedral of the low-wing configurations or the directional stability of the high- and low-wing configurations.

Effects of wing vertical position.- A comparison of the effects of wing vertical position on the lateral and directional characteristics of the long-body—trapezoidal-wing configuration (fig. 17) indicates that the high-wing configuration generally has slightly more directional stability, a much greater positive effective dihedral, and a greater slope of the side-force curve than the low-wing configuration. These effects generally increase with angle of attack as a result of the sides of the body being increasingly shielded from the airflow by the low wing and thereby greatly reducing the available restoring moment necessary for stability of the low-wing configuration.

Effects of canard planform.- As can be seen in figure 18, canard planform has very little effect on the lateral and directional aerodynamic characteristics of the long-body high-trapezoidal-wing configuration.

Effects of wing planform.- The outboard vertical tails on the trapezoidal-wing configurations are each approximately 38 percent larger than the vertical tails on the delta-wing configurations of reference 6. (The value of S_T/S for the trapezoidal-wing configurations is 0.081 and that for the delta-wing configurations is 0.061.) Therefore, any comparisons of the lateral and directional aerodynamic characteristics of the delta- and trapezoidal-wing configurations with the vertical tails on will include the effects of vertical-tail size. The effects of wing planform alone can then best be seen by comparing the lateral and directional aerodynamic characteristics of the delta- and trapezoidal-wing configurations with the vertical tails off. (See fig. 19.) Wing planform shape has essentially no effect on directional stability. The high-trapezoidal-wing configurations have less positive dihedral than the high-delta-wing configurations when the canards are off. However, when the canards are added at $\delta = 0^{\circ}$ there are only small effects of wing planform on C_{l_β} for the high-wing configurations. When the canards are deflected 10°, the high-trapezoidal-wing configurations have greater positive effective dihedral at angles of attack above about 10°; below this angle of attack, the high-delta-wing configurations have the greater positive effective dihedral. The low-delta-wing configuration has a greater positive effective dihedral than the low-trapezoidal-wing configurations at angles of attack above approximately 4° when the canards are off as well as when the canards are at $\delta = 0^{\circ}$ and 10°.

Effects of vertical tails.- Adding the vertical tails to both the low- and high-trapezoidal-wing configurations (fig. 20) causes an increase in the directional stability, as would be expected. The vertical tails also increase the positive effective dihedral of the high- and low-wing configurations; however, the increases in C_{l_β} of the low-wing (W_2) configurations are small.

Similar trends are noted in reference 6 for the effects of vertical tails on the lateral and directional aerodynamic characteristics of the delta-wing configurations. Since the vertical tails on the delta-wing configurations, however, are smaller than the vertical tails on the trapezoidal-wing configurations, the magnitude of the effect of vertical tails on C_{n_β}, C_{l_β}, and C_{Y_β} for the delta-wing configurations differs somewhat from that for the trapezoidal-wing configurations.

SUMMARY OF RESULTS

An experimental investigation has been made in the Langley 15-inch hypersonic flow apparatus at a Mach number of 10.03 to determine the effects of wing vertical position, canard planform, canard size, and fuselage length on the longitudinal, lateral, and directional aerodynamic characteristics of a canard configuration with a trapezoidal planform wing having a 45° swept leading edge. In addition some comparisons with data from a previous investigation of a configuration with a 70° swept delta wing have been made to show the effects of wing planform on the aerodynamic characteristics.

The investigation indicates the following results:

1. The high-trapezoidal-wing configurations had lower lift coefficients and greater canard control effectiveness than the corresponding low-wing configurations, probably because of interference of the canard wake and/or shock field with the flow over the high wing.

2. The effectiveness of the canards increased with canard size but was not significantly affected by change in canard planform (i.e., delta and trapezoidal).

3. The canard controls were more effective on the long-body than on the short-body configurations with the trapezoidal wing in either a high or low vertical position.

4. The lift-curve slope and the effectiveness of the canard controls were greater for the trapezoidal-wing configurations than for corresponding delta-wing configurations.

5. Addition of the canards caused a small reduction in the directional stability of both the high- and low-trapezoidal-wing configurations and also caused an increase in the positive effective dihedral of the high-wing configurations, but did not significantly affect the effective dihedral of the low-wing configurations.

6. The high-trapezoidal-wing configurations have slightly greater directional stability and greater positive effective dihedral than the corresponding low-wing configurations.

7. There were only small effects of wing planform on the lateral and directional characteristics of the configurations.

8. The vertical tails increased the directional stability and the positive effective dihedral of both the high- and low-trapezoidal-wing configurations; however, the increases in the positive effective dihedral of the low-wing configurations were small.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., July 18, 1966,
126-13-03-09-23.

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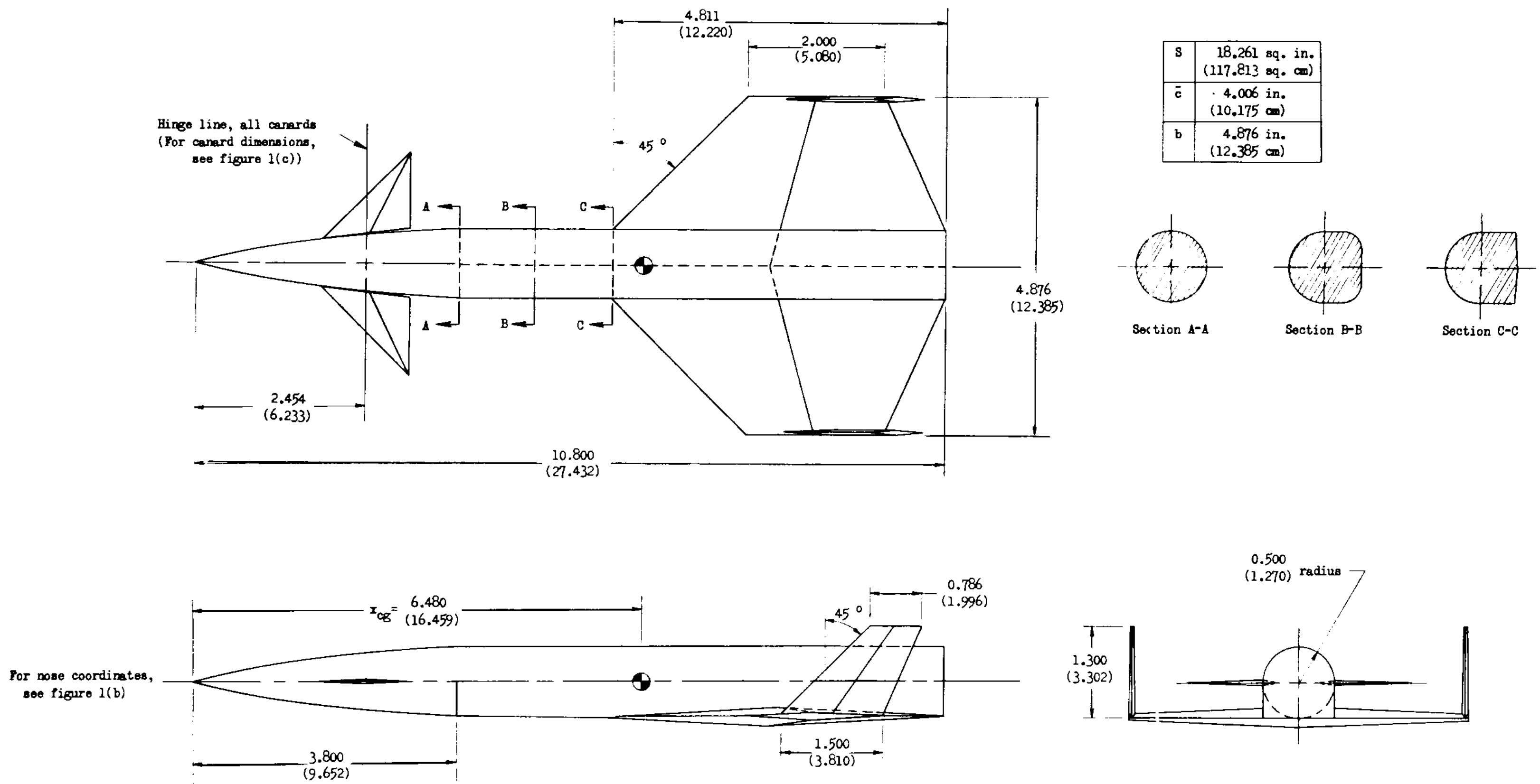
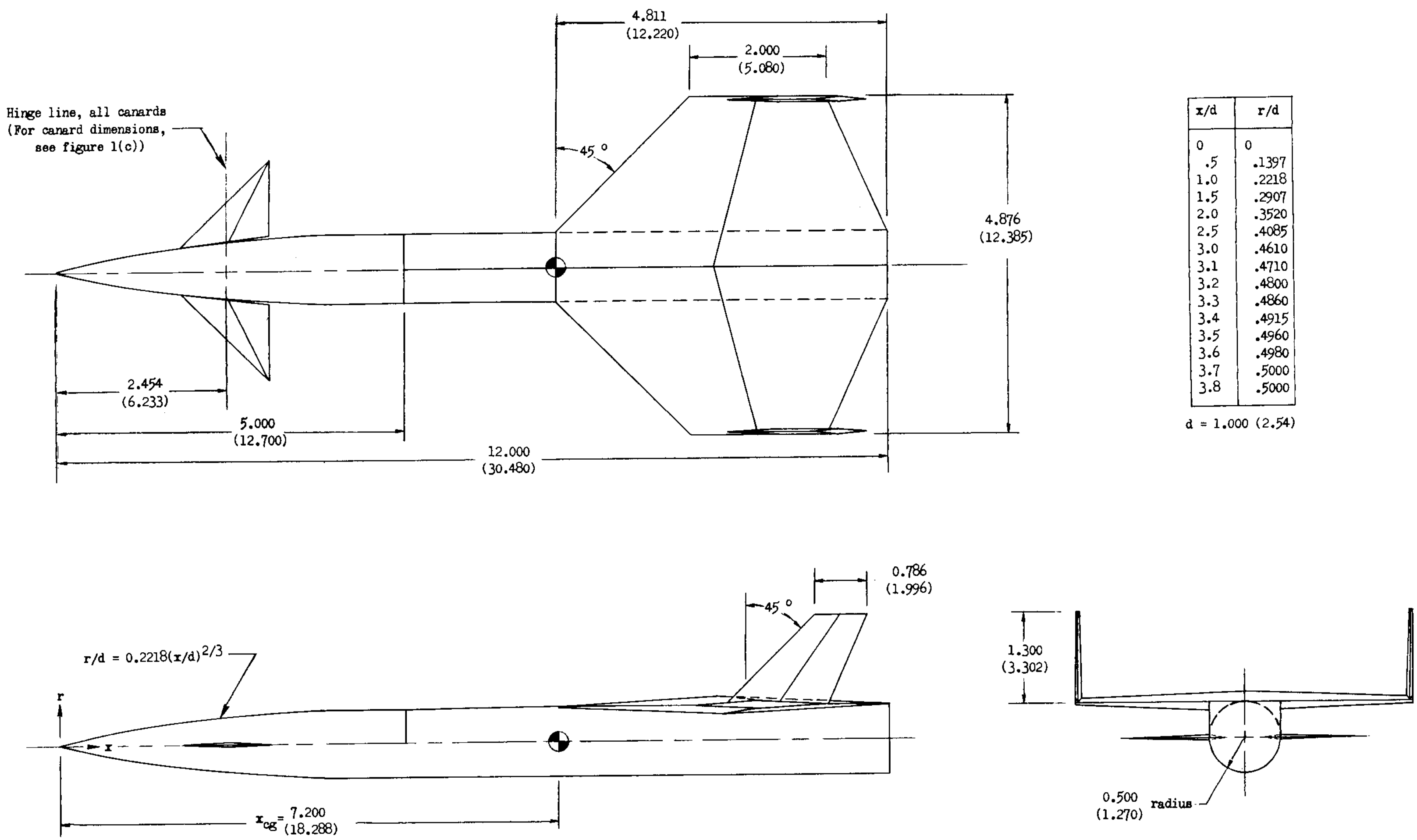


S	18.261 sq. in. (117.813 sq. cm)
$\bar{c}$	4.006 in. (10.175 cm)
b	4.876 in. (12.385 cm)

(a) Low-wing—short-body configuration ($W_2B_1C_2$).

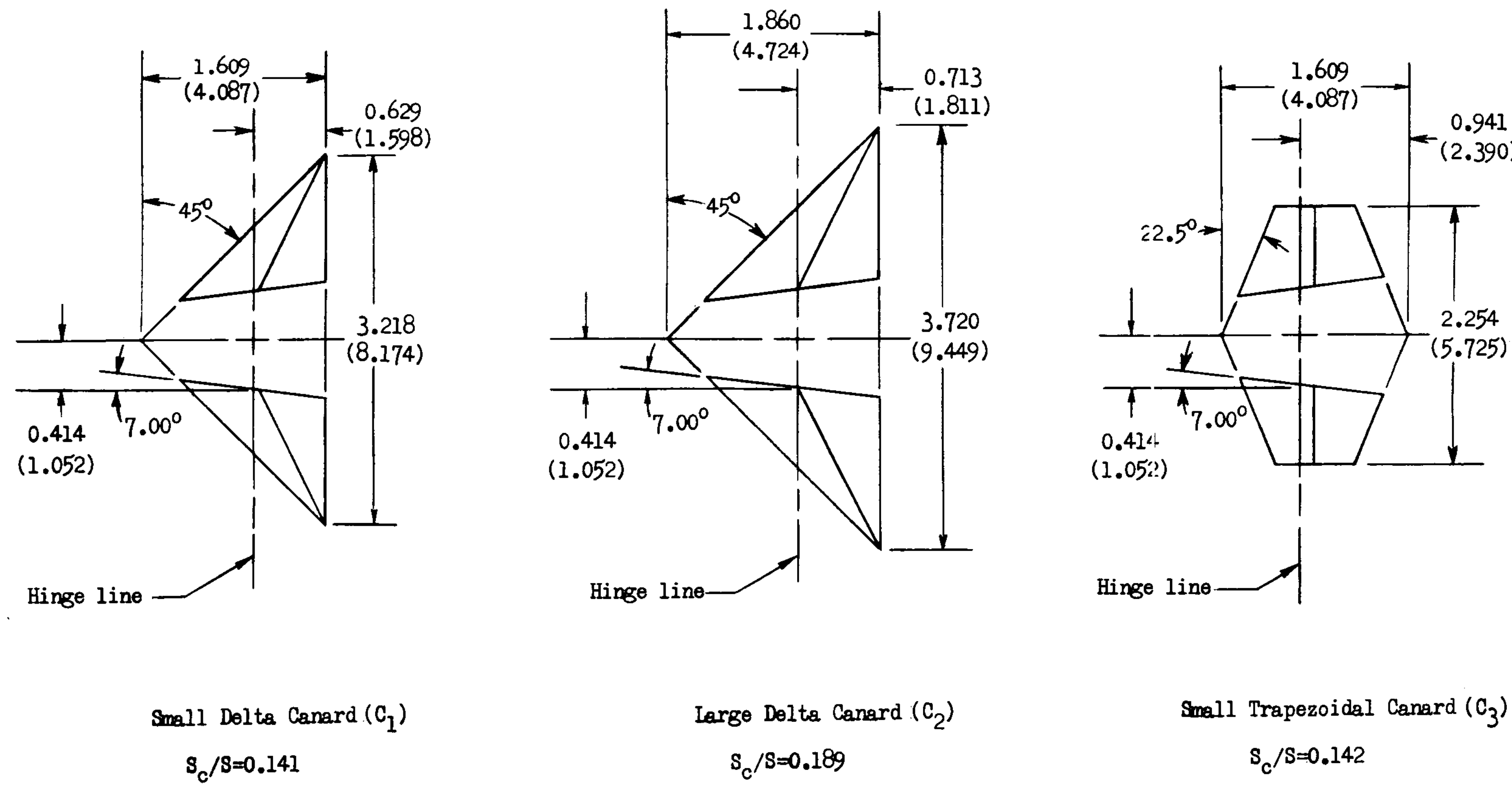
Figure 1.- Model drawings. All dimensions are in inches (centimeters). All airfoil sections have 5-percent-thick diamond sections.



x/d	r/d
0	0
.5	.1397
1.0	.2218
1.5	.2907
2.0	.3520
2.5	.4085
3.0	.4610
3.1	.4710
3.2	.4800
3.3	.4860
3.4	.4915
3.5	.4960
3.6	.4980
3.7	.5000
3.8	.5000

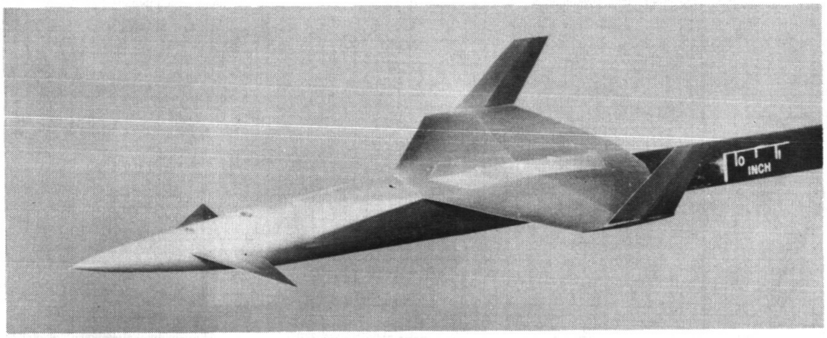
(b) High-wing—long-body configuration ($W_1B_2C_2$).

Figure 1.- Continued.

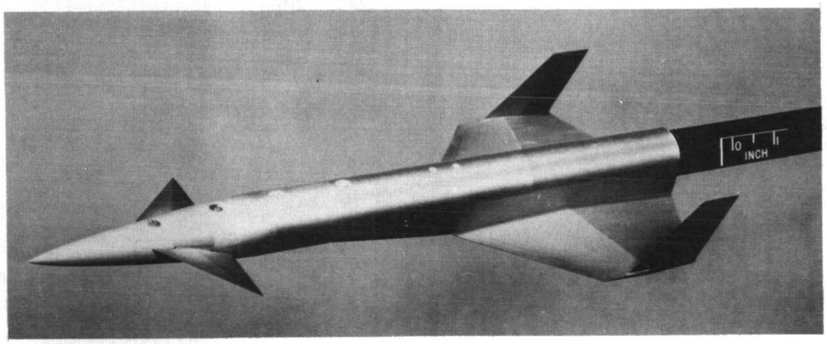


(c) Planform details of canard control surfaces.

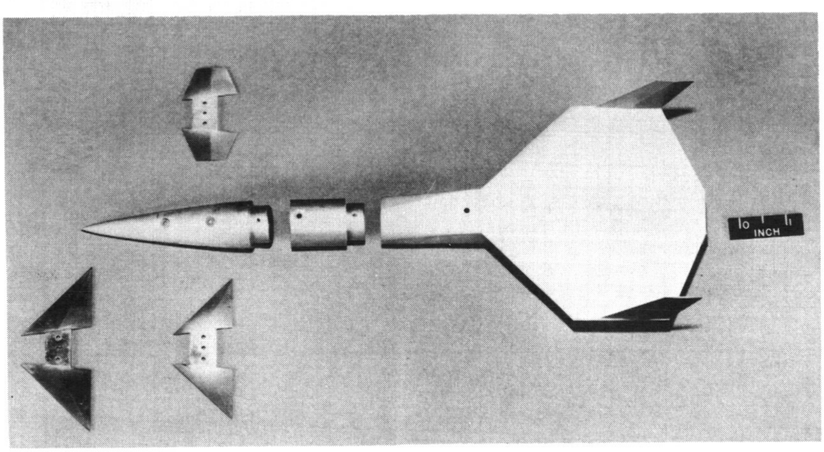
Figure 1.- Concluded.



(a) Configuration $W_1B_1C_2$; $\delta = 10^0$. L-64-6877



(b) Configuration $W_2B_2C_2$; $\delta = 10^0$. L-64-6880



(c) Planform view of all model components. L-64-6879

Figure 2.- Selected model photographs.

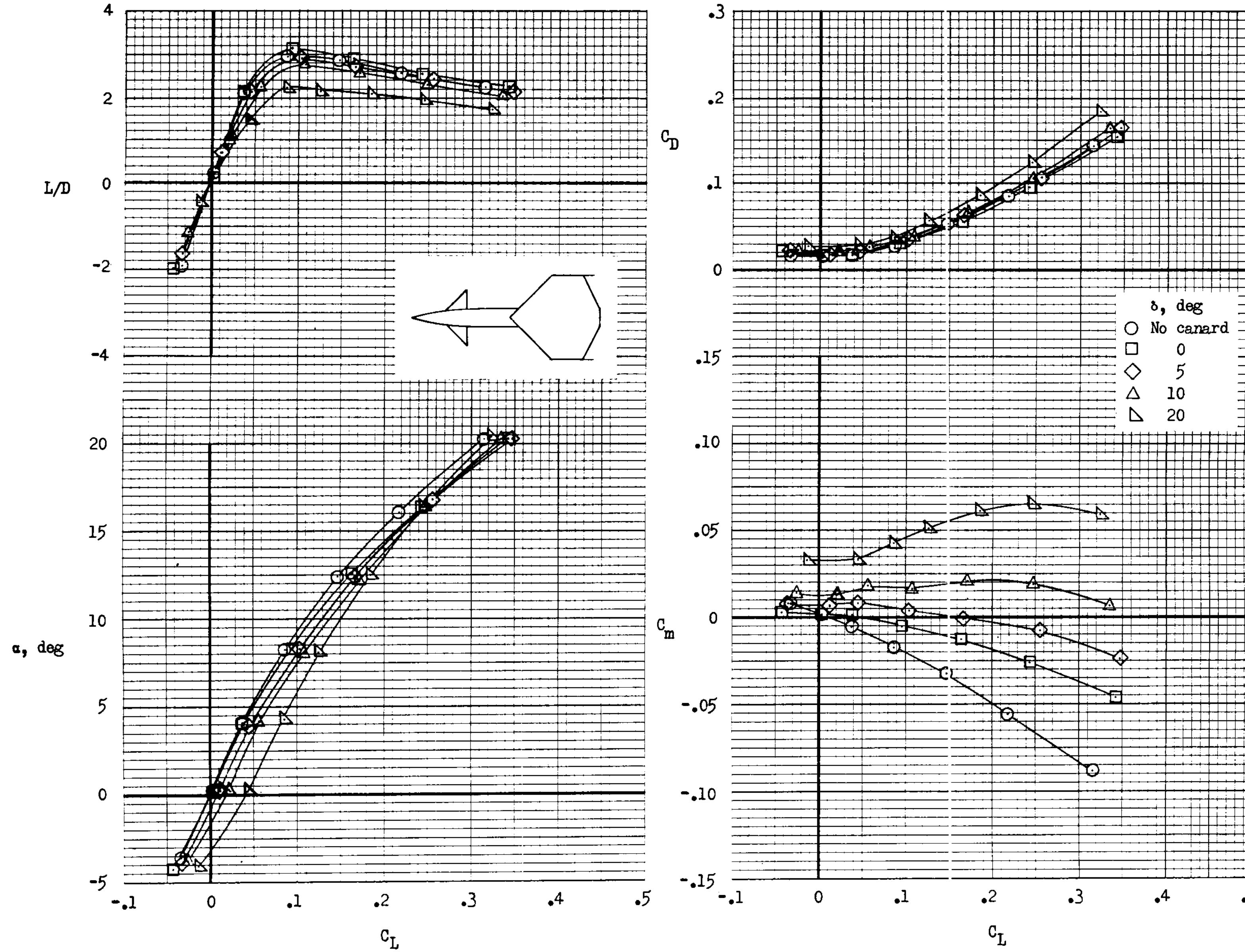


Figure 3.- Longitudinal aerodynamic characteristics of configuration W_1BC_1.

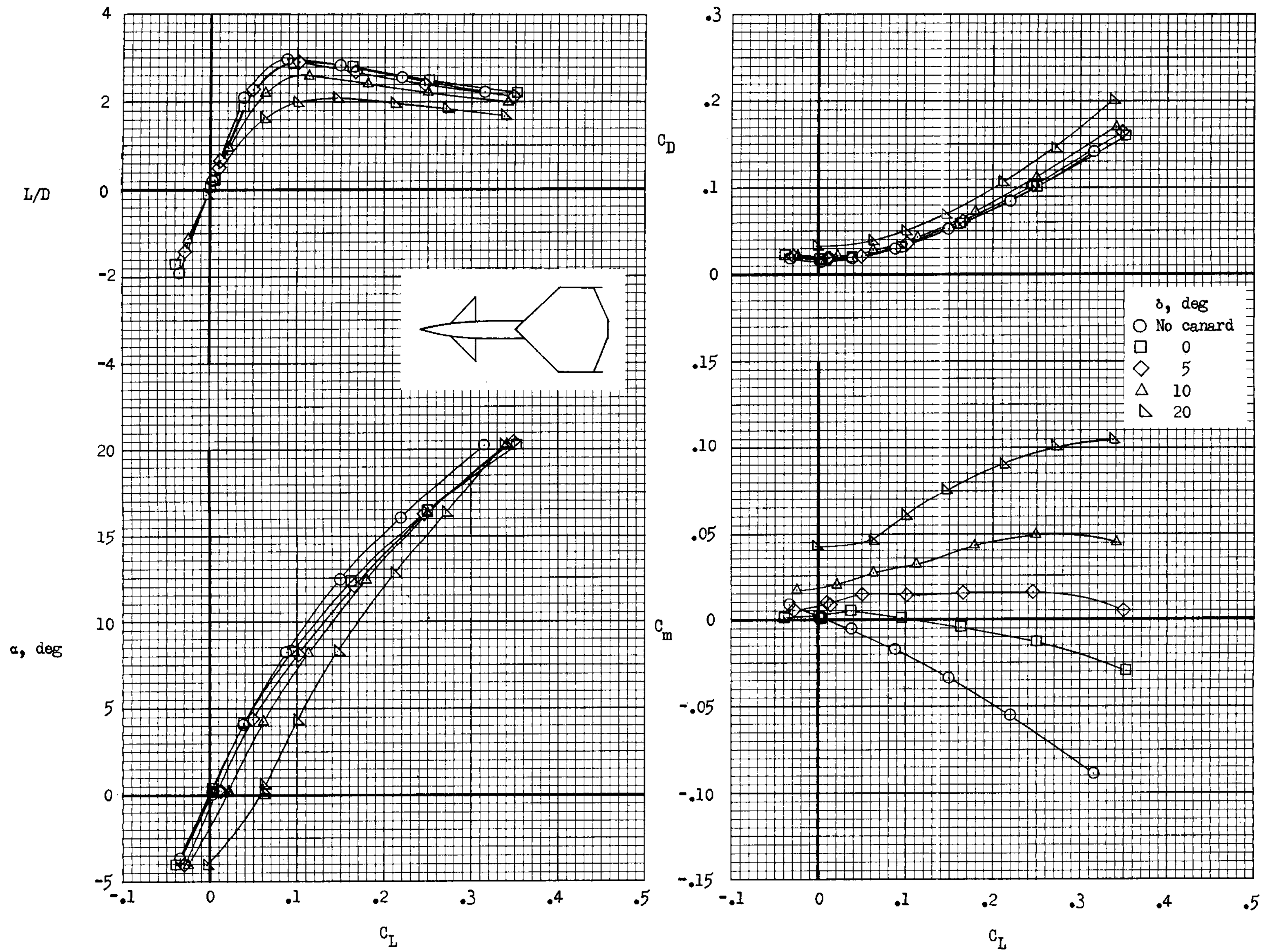


Figure 4.- Longitudinal aerodynamic characteristics of configuration $W_1B_1C_2$.

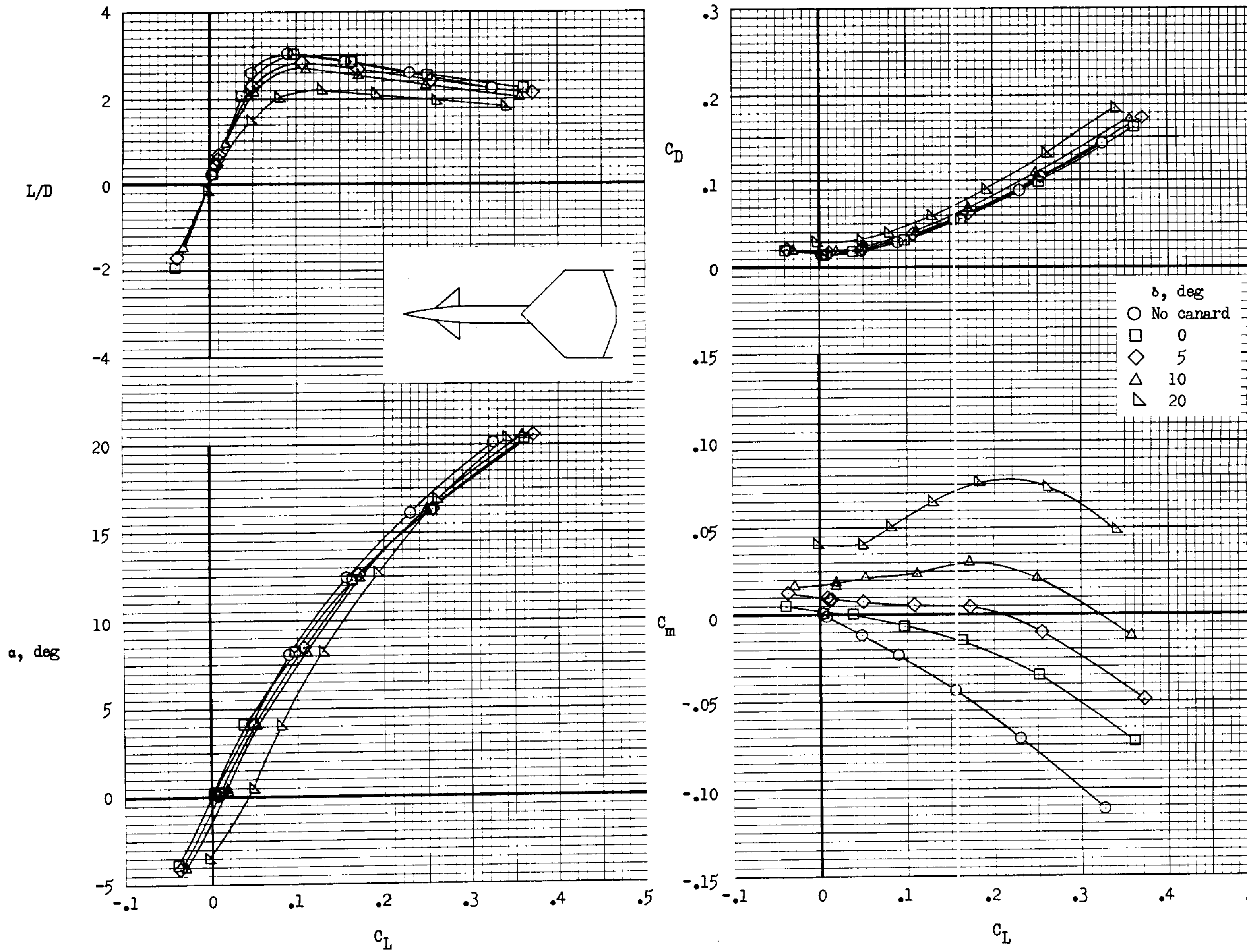


Figure 5.- Longitudinal aerodynamic characteristics of configuration $W_1B_2C_1$.

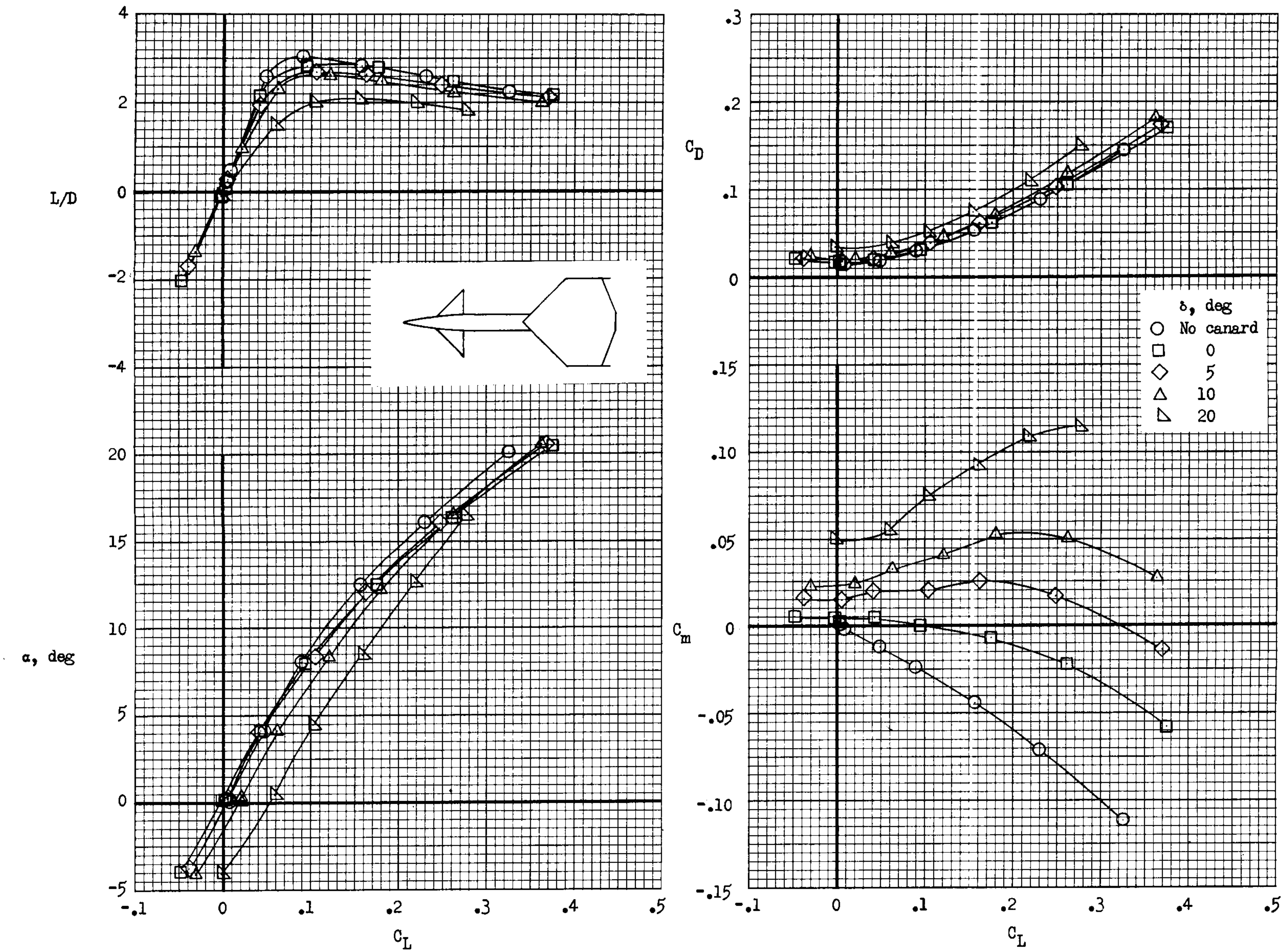


Figure 6.- Longitudinal aerodynamic characteristics of configuration $W_1B_2C_2$.

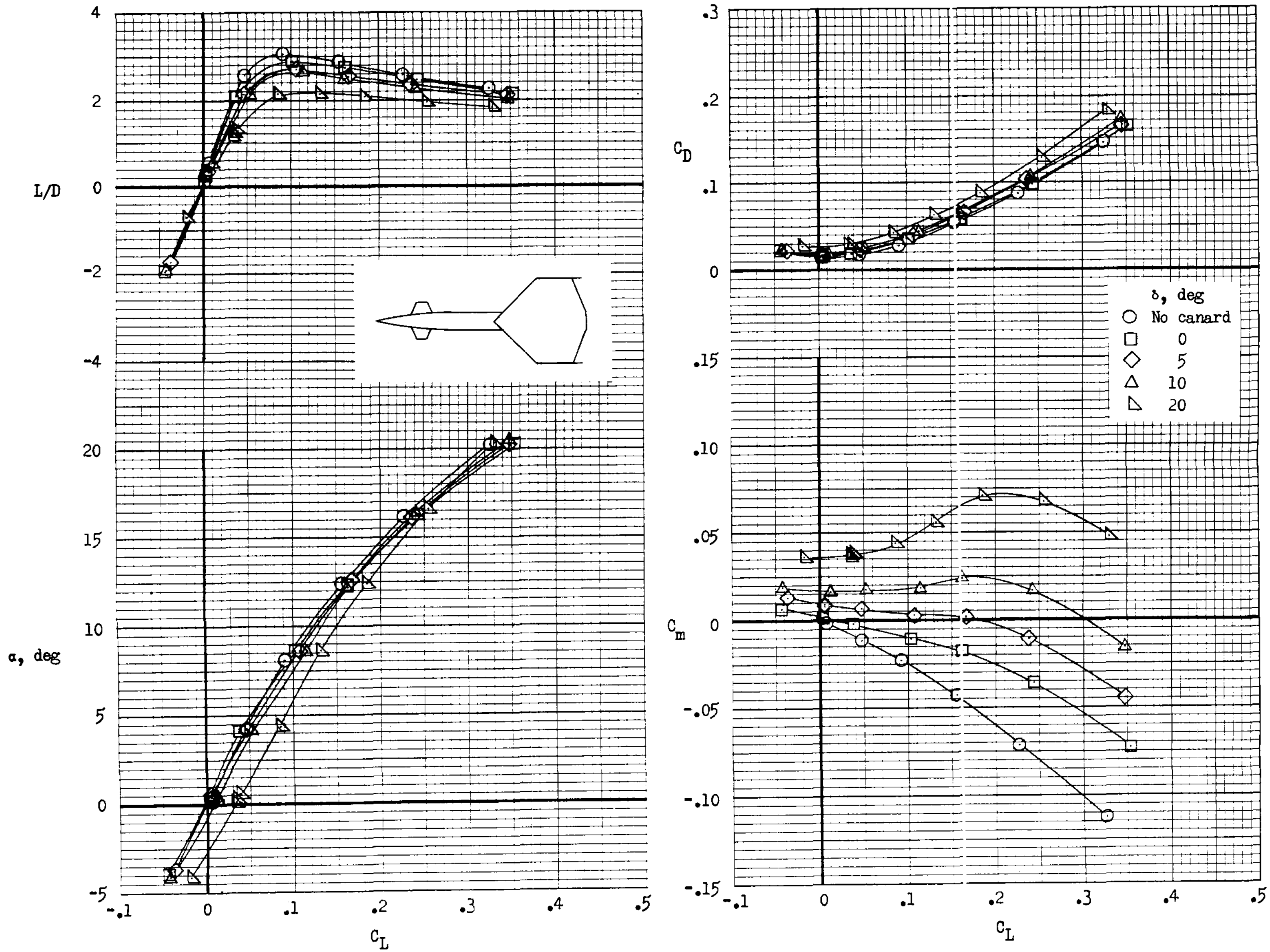


Figure 7.- Longitudinal aerodynamic characteristics of configuration $W_1B_2C_3$.

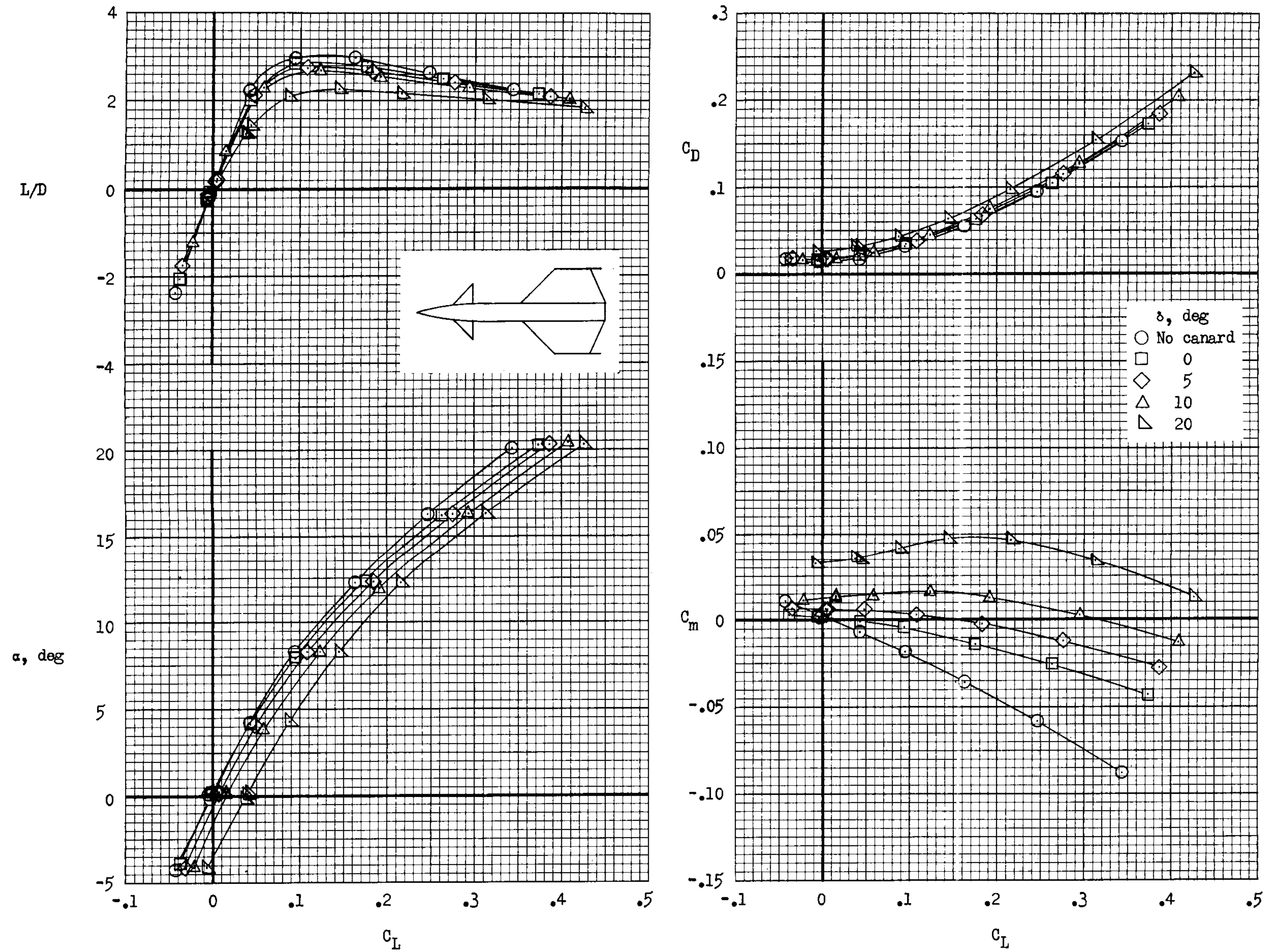


Figure 8.- Longitudinal aerodynamic characteristics of configuration $W_2B_1C_1$.

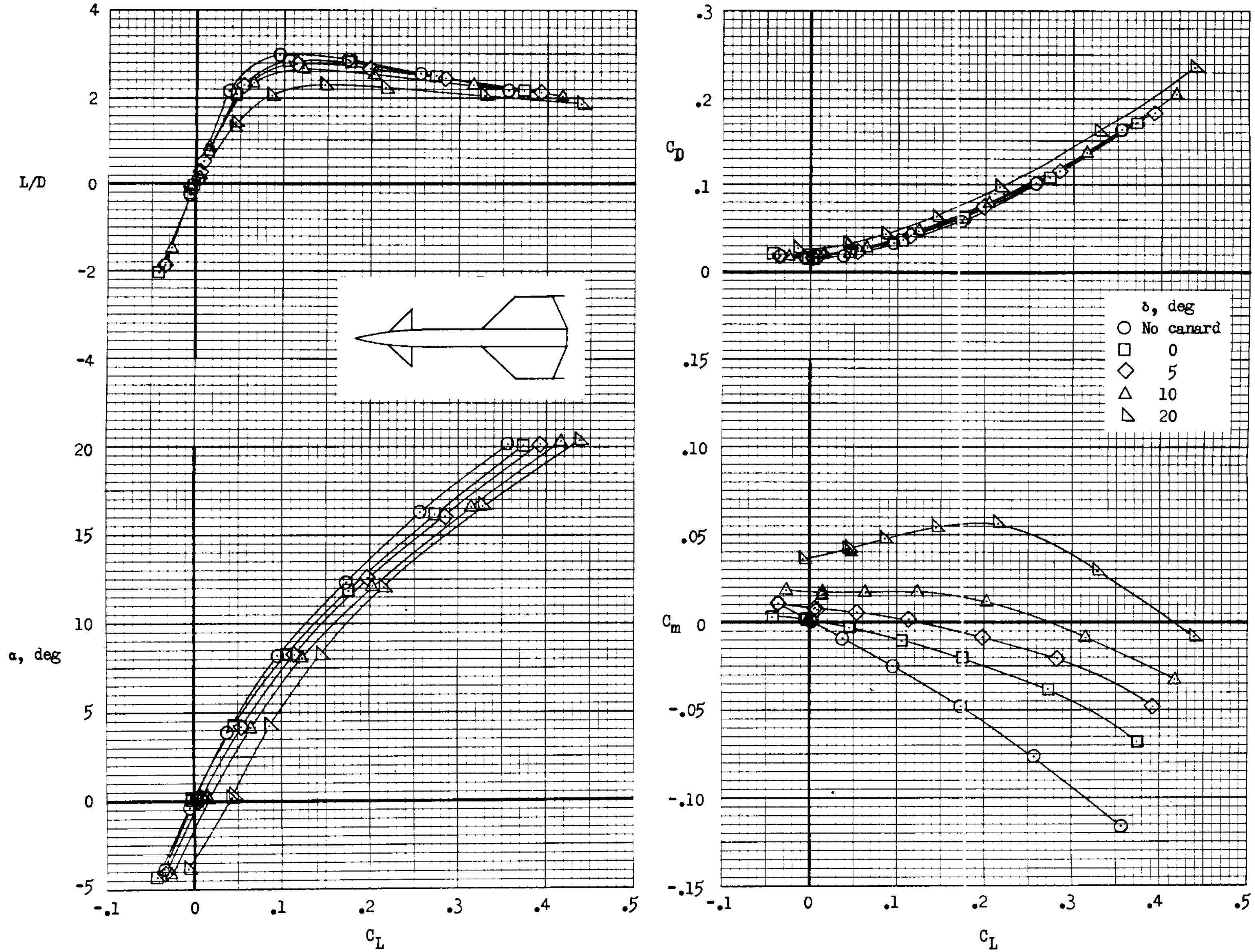


Figure 9.- Longitudinal aerodynamic characteristics of configuration $W_2B_2C_1$.

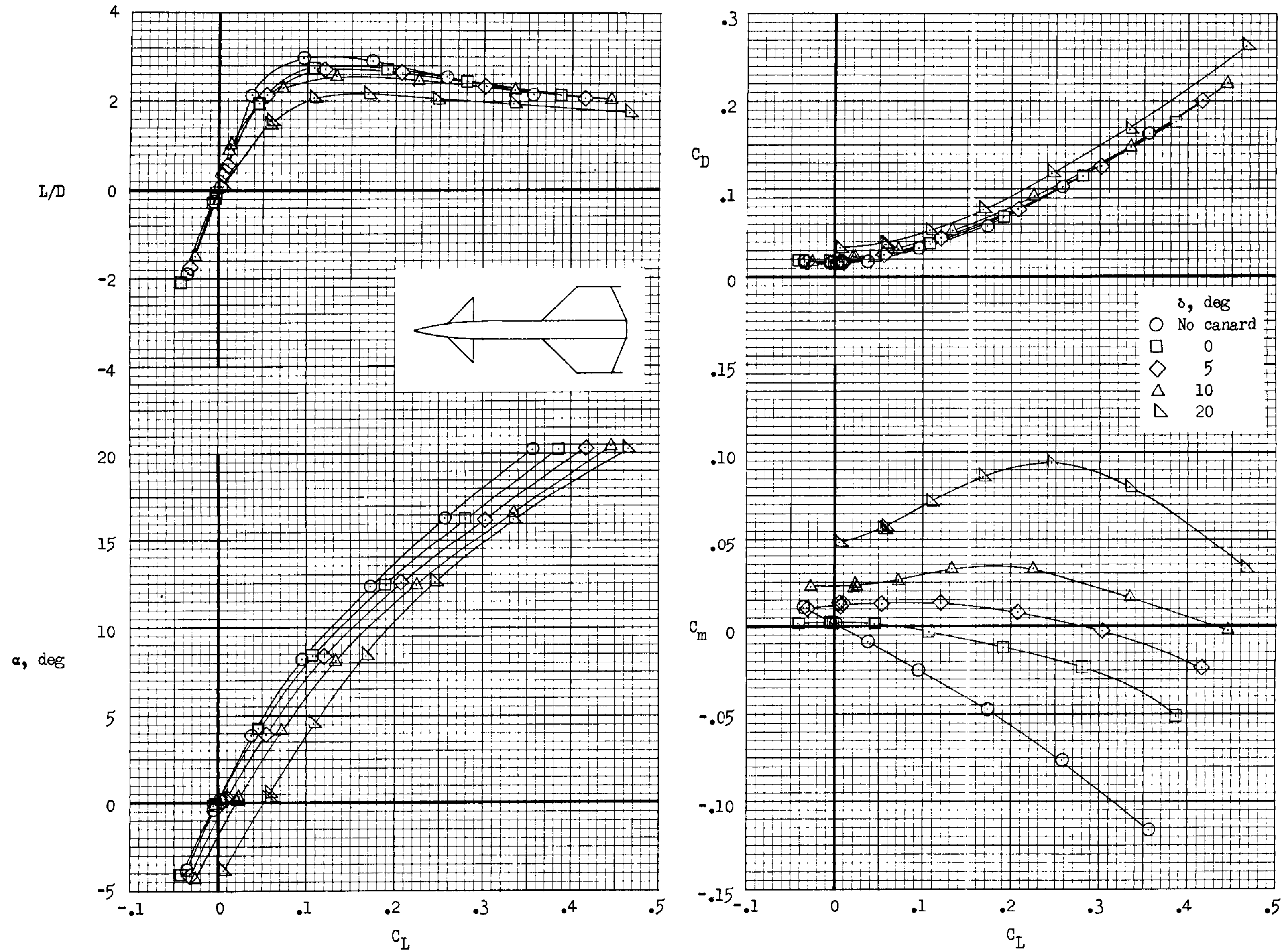


Figure 10.- Longitudinal aerodynamic characteristics of configuration $W_2B_2C_2$.

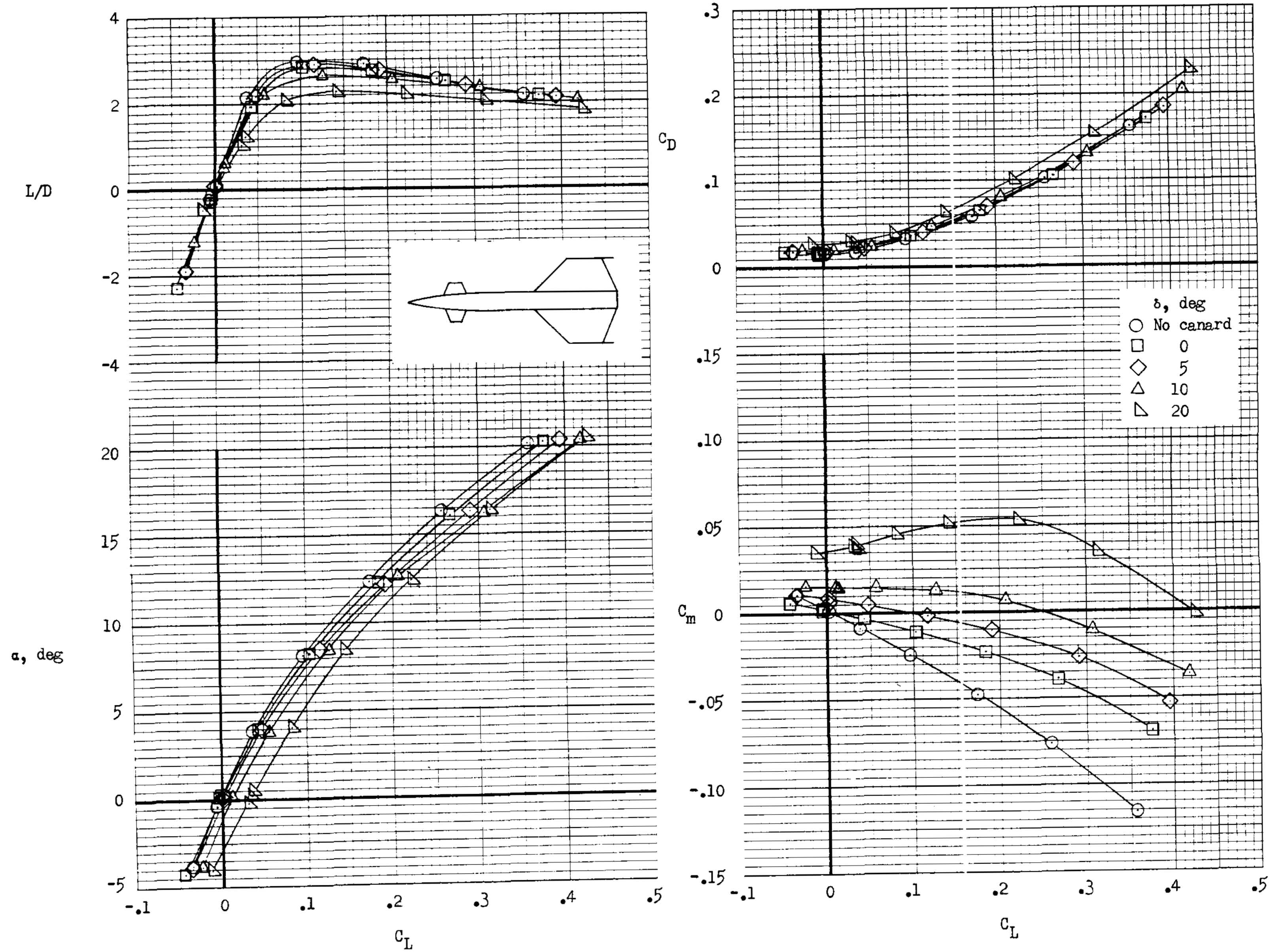
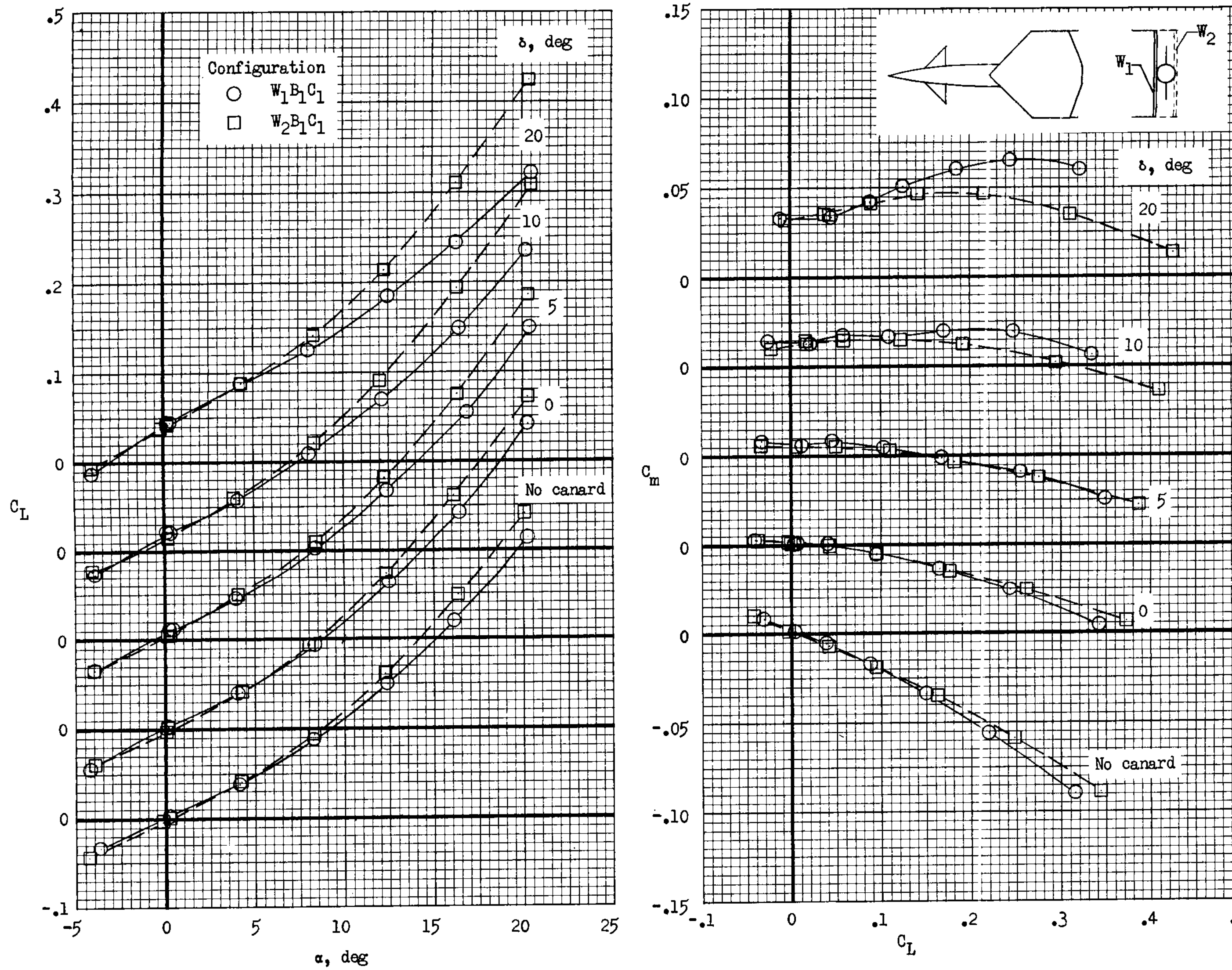
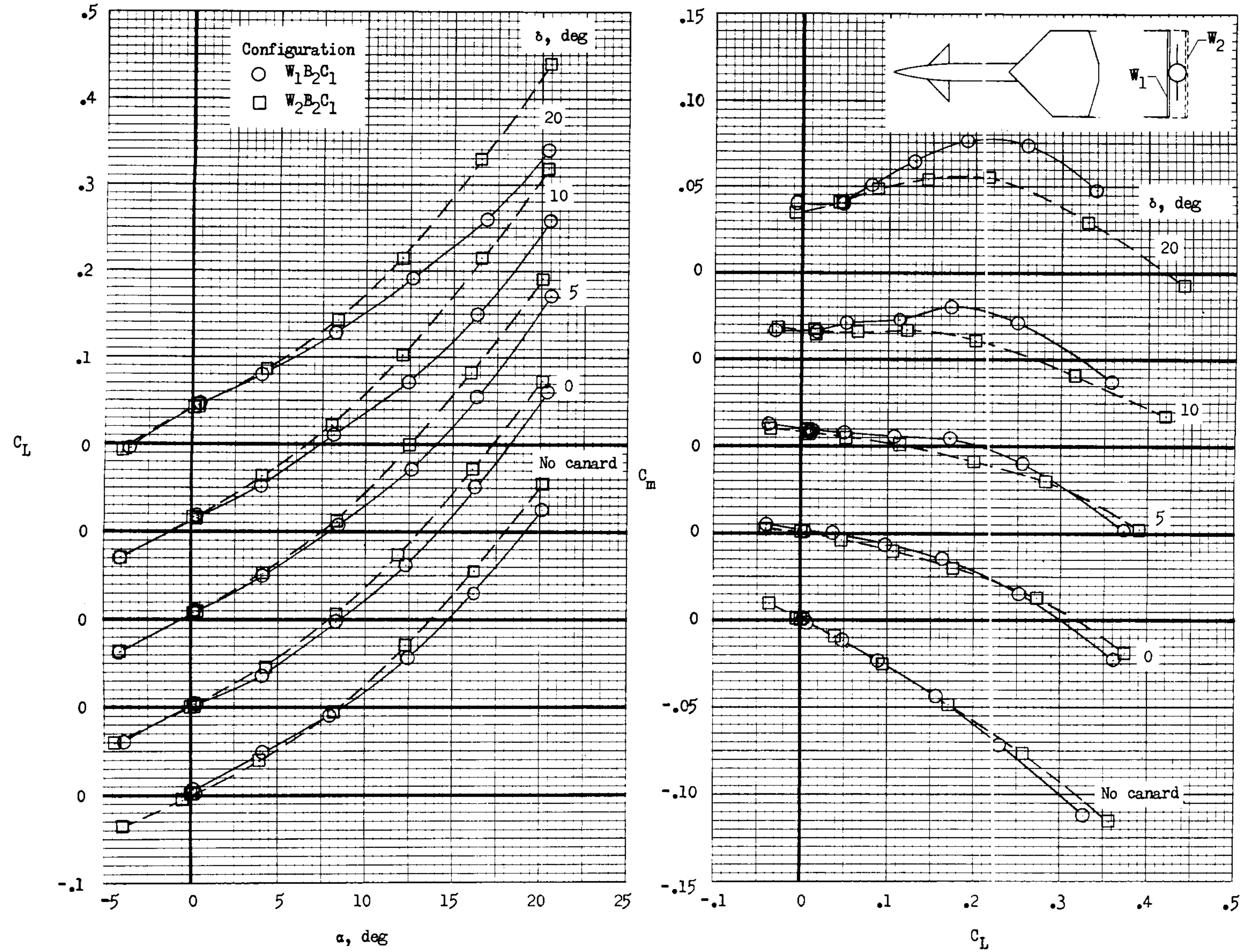


Figure 11.- Longitudinal aerodynamic characteristics of configuration $W_2B_2C_3$.



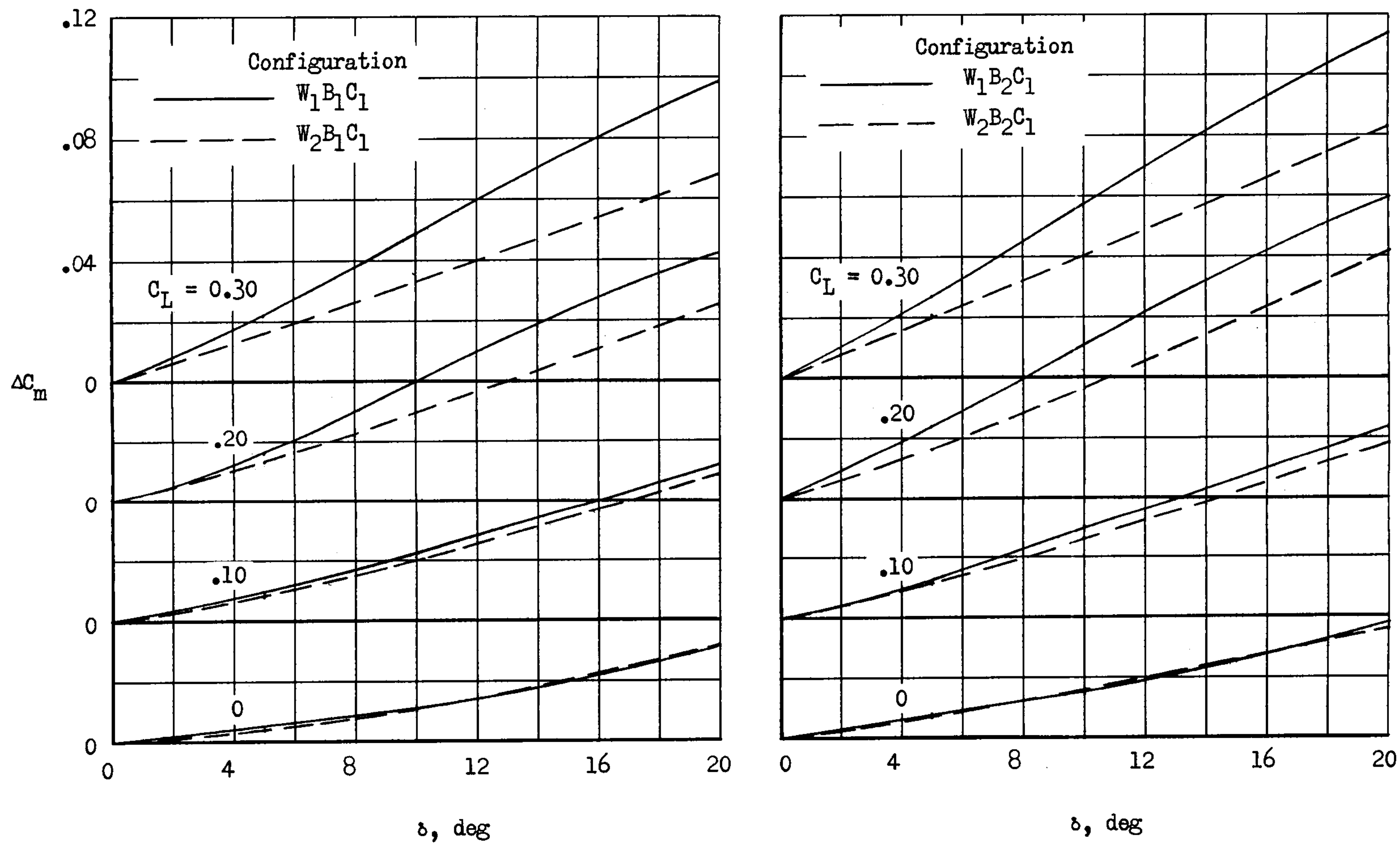
(a) Short-body—small-delta-canard configurations.

Figure 12.- Effects of wing vertical position.



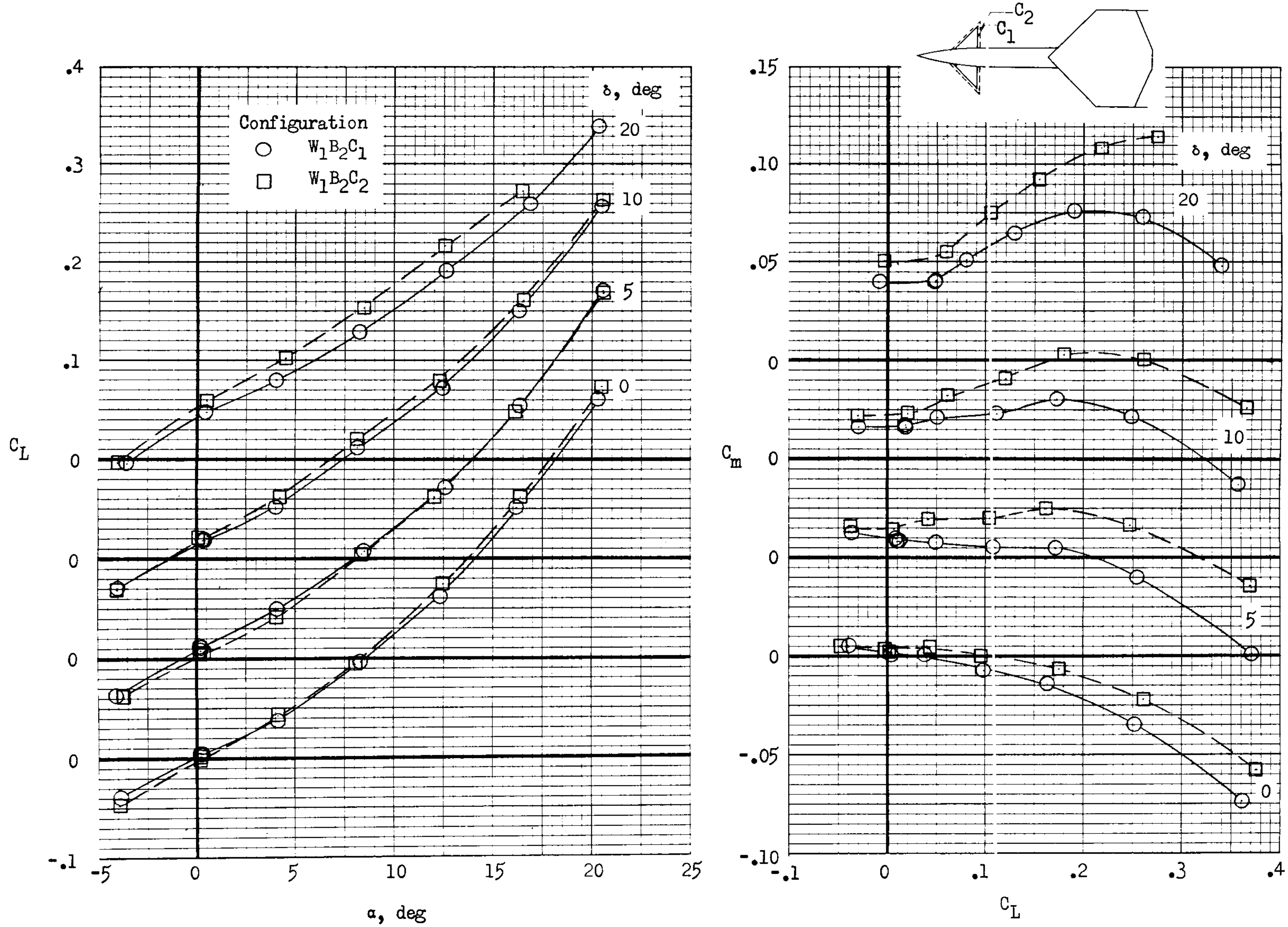
(b) Long-body—small-delta-canard configurations.

Figure 12.- Continued.



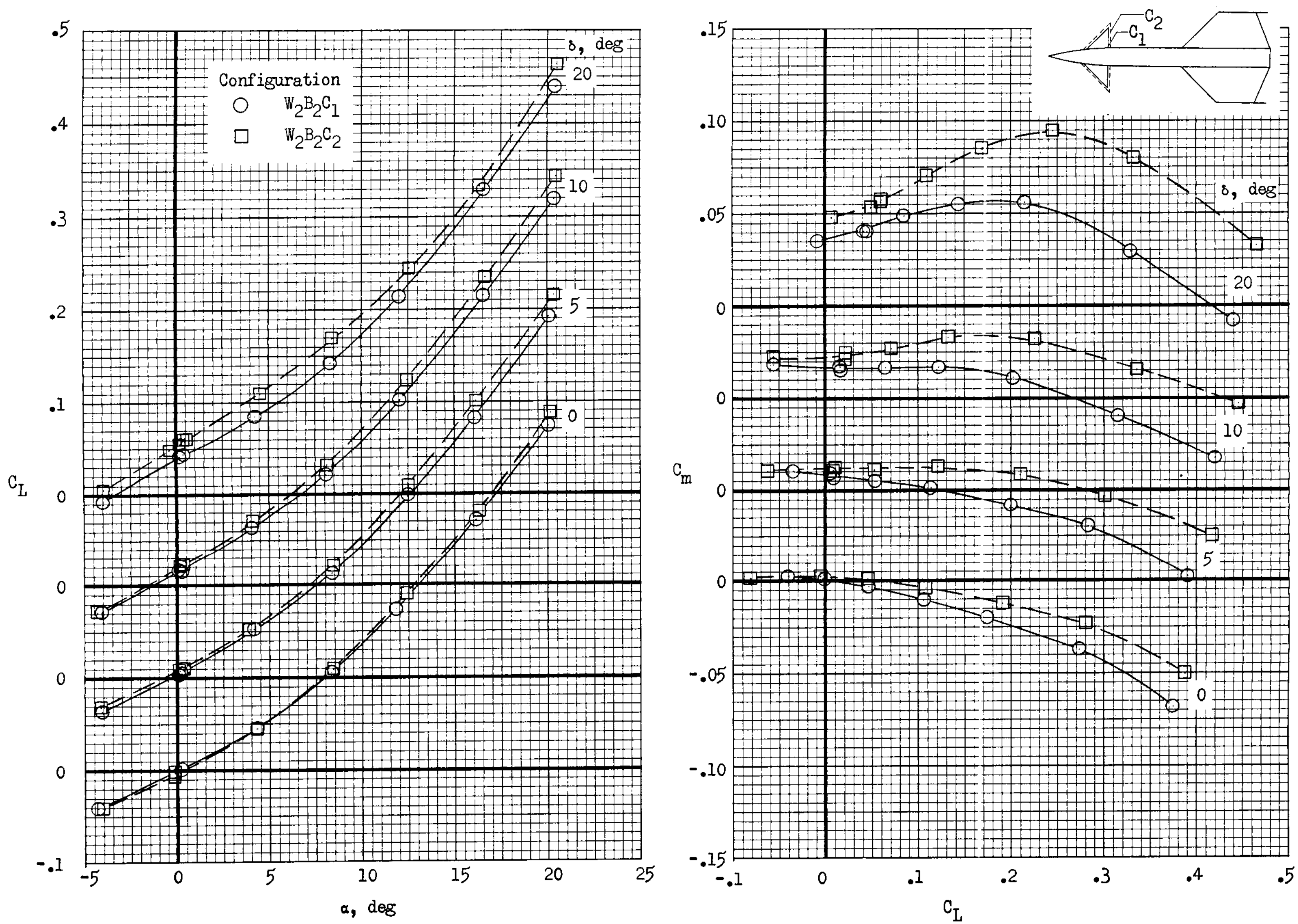
(c) Variation of ΔC_m with δ for long- and short-body—small-delta-canard configurations.

Figure 12.- Concluded.



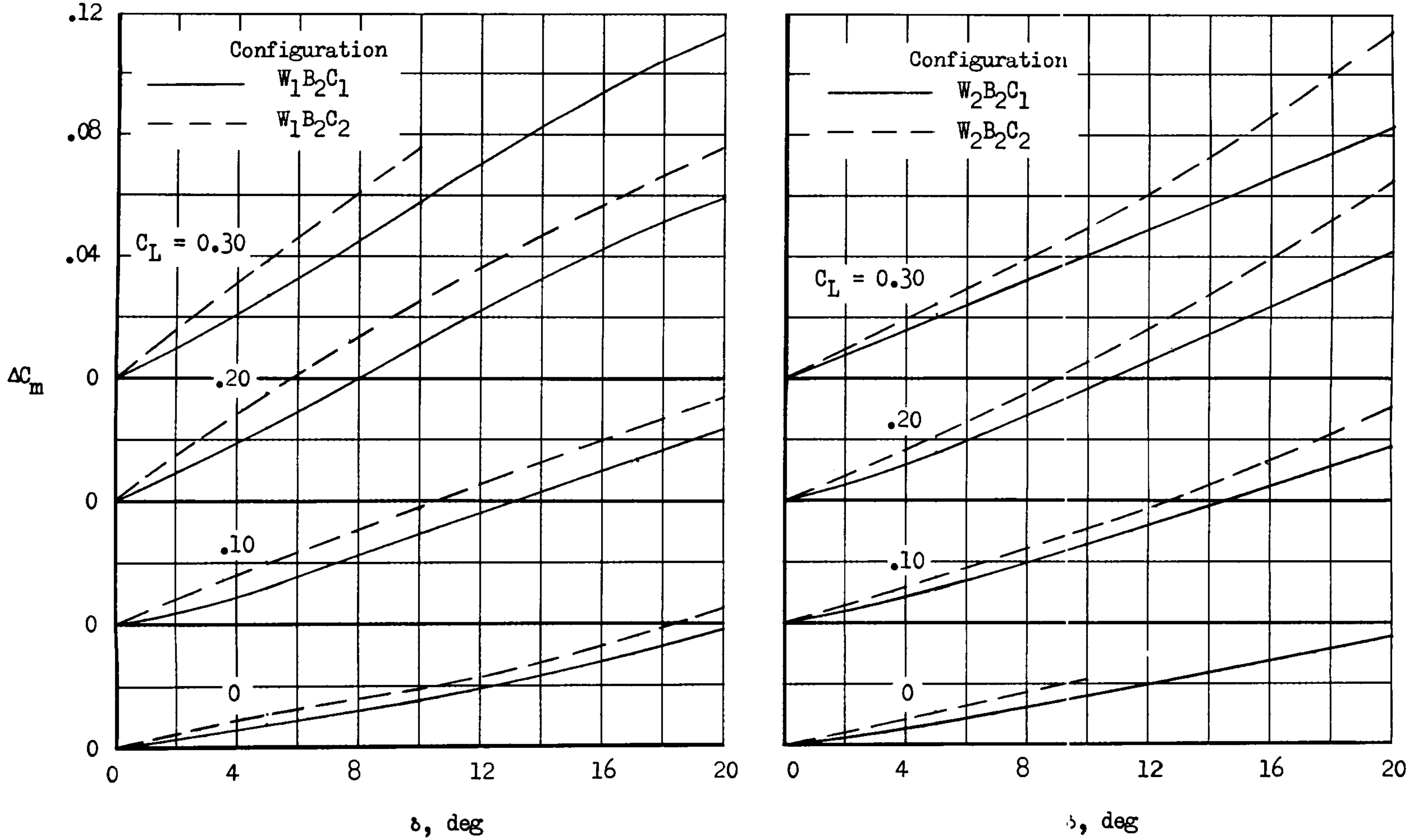
(a) High-wing—long-body configurations.

Figure 13.- Effects of canard size.



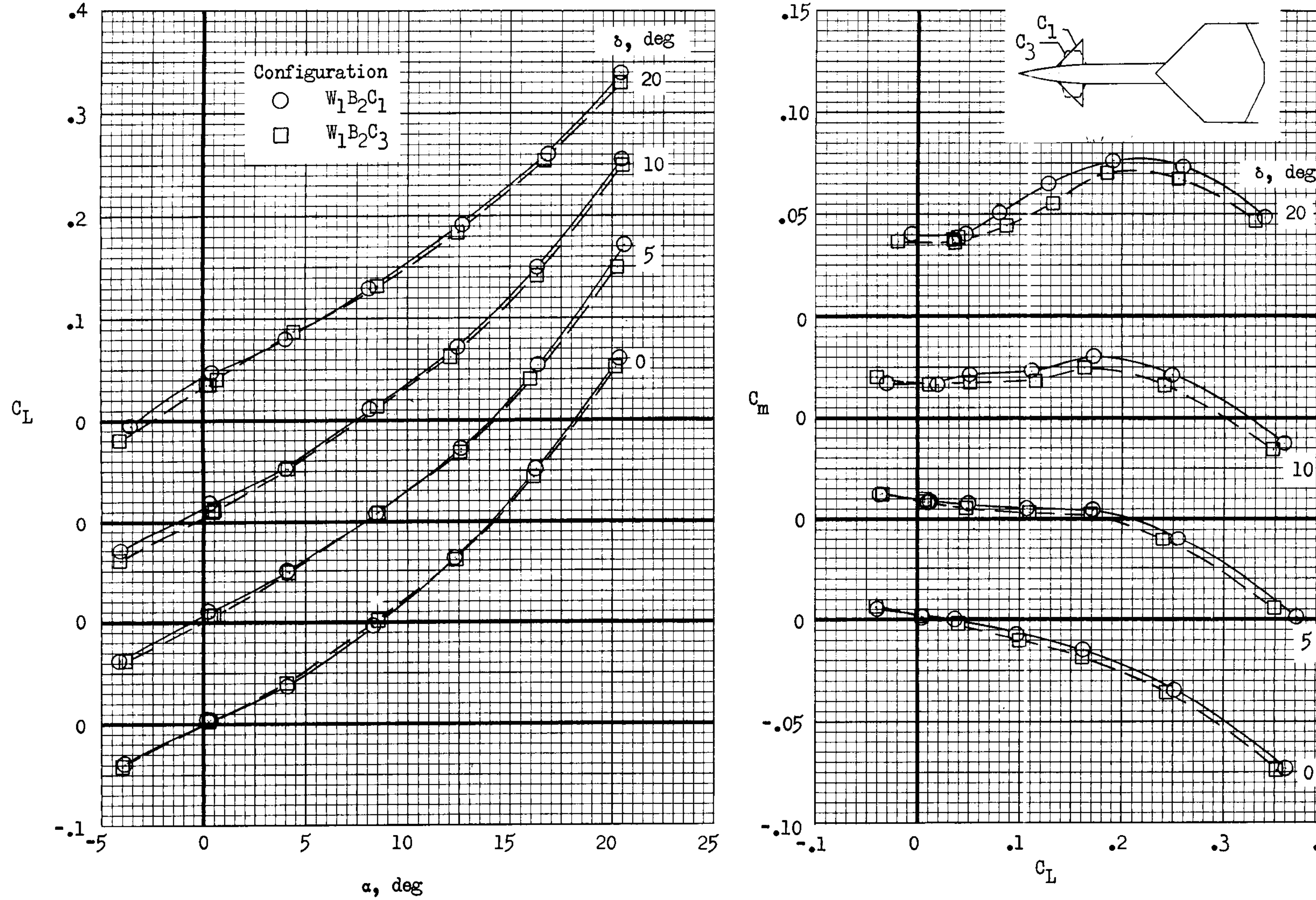
(b) Low-wing—long-body configurations.

Figure 13.- Continued.



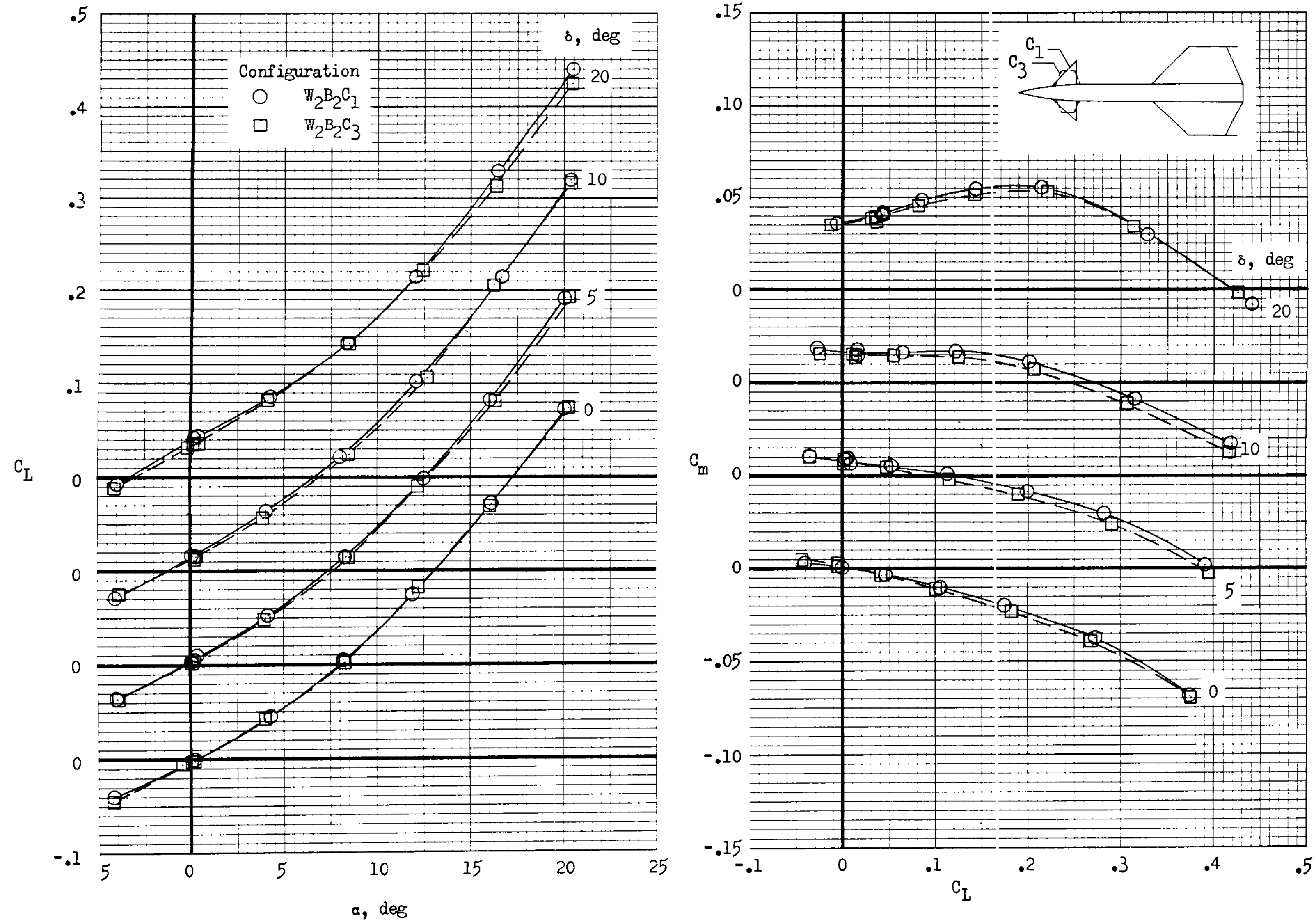
(c) Variation of ΔC_m with δ for high- and low-wing—long-body configurations.

Figure 13.- Concluded.



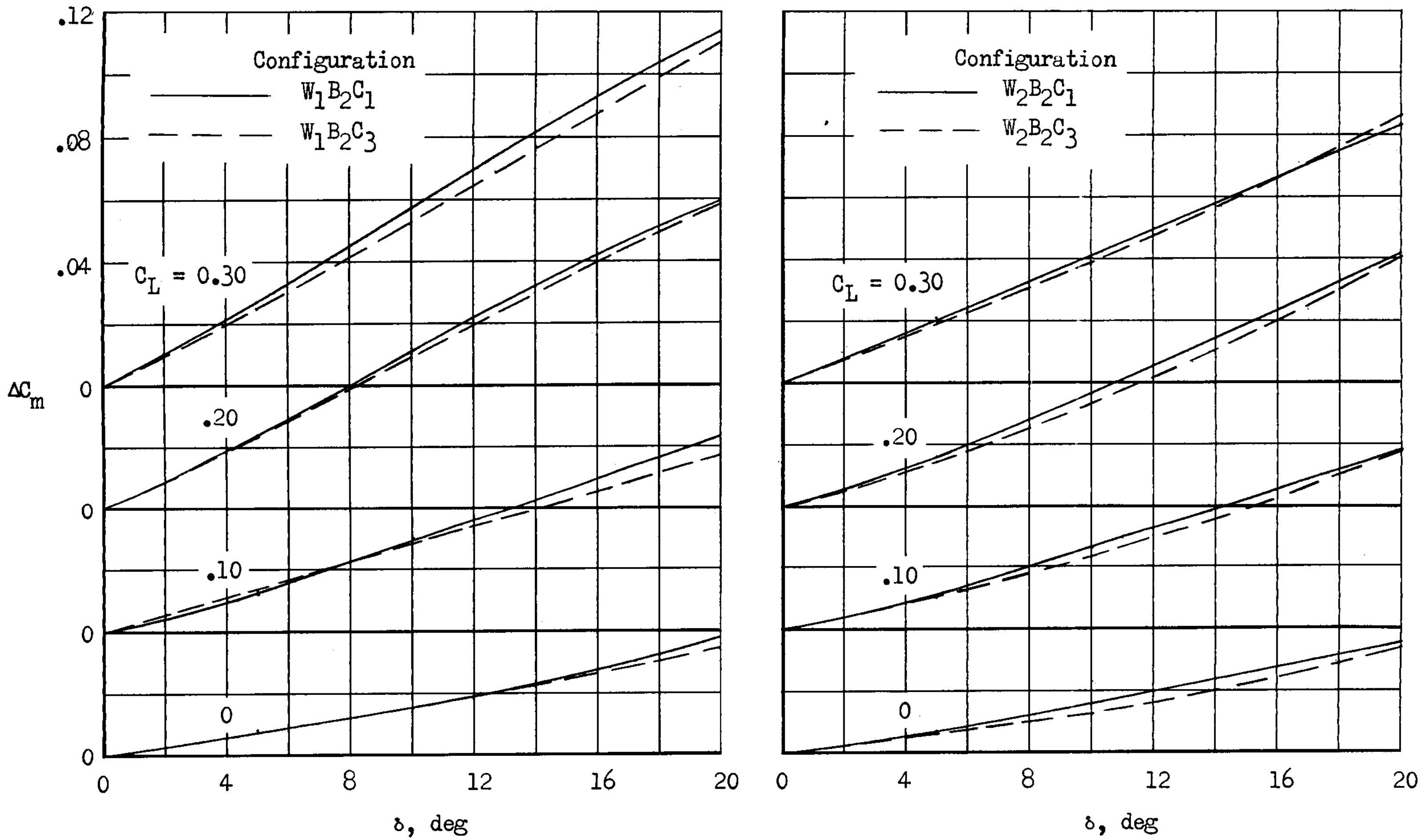
(a) High-wing—long-body configurations.

Figure 14.- Effects of canard planform.



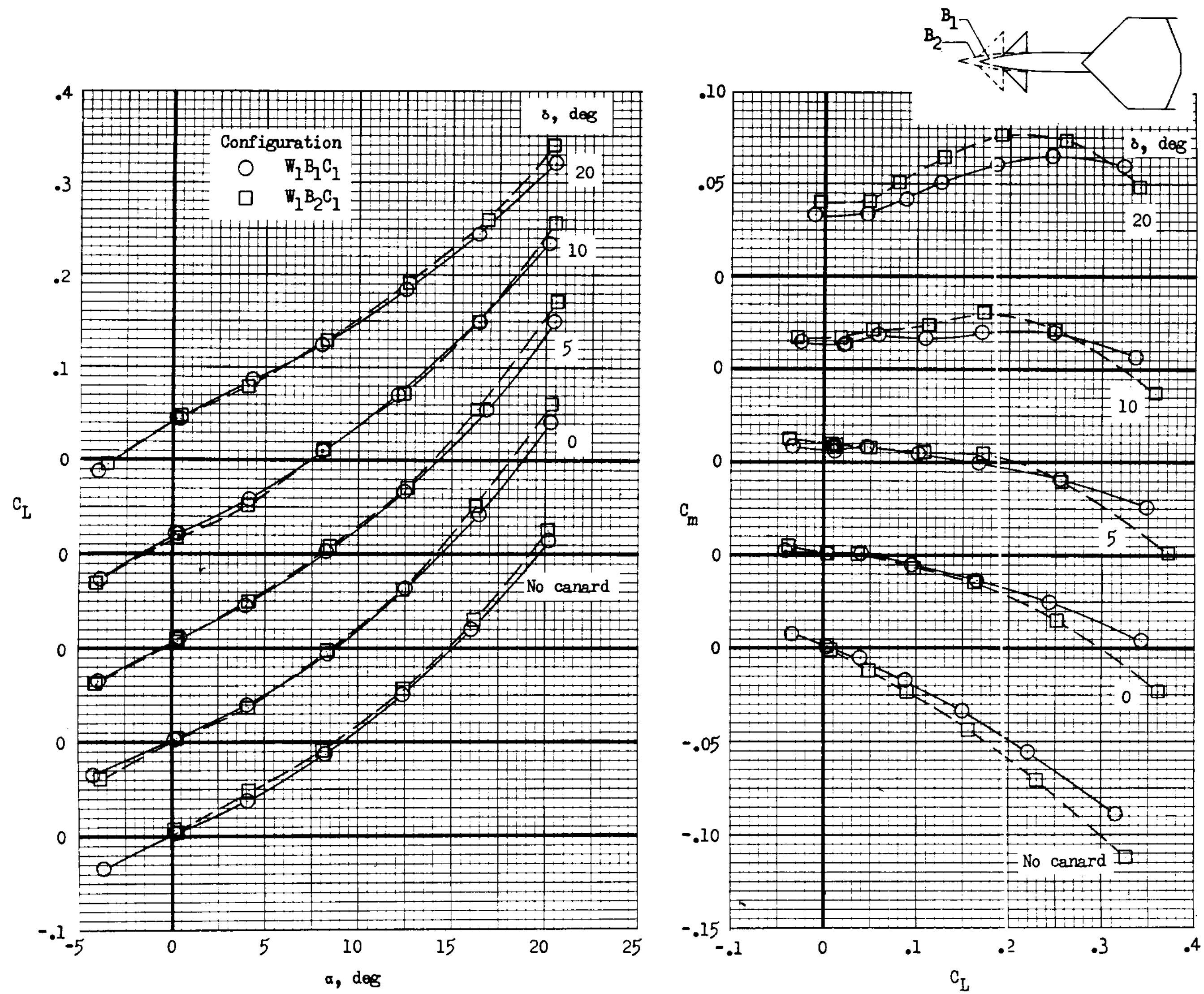
(b) Low-wing—long-body configurations.

Figure 14.- Continued.



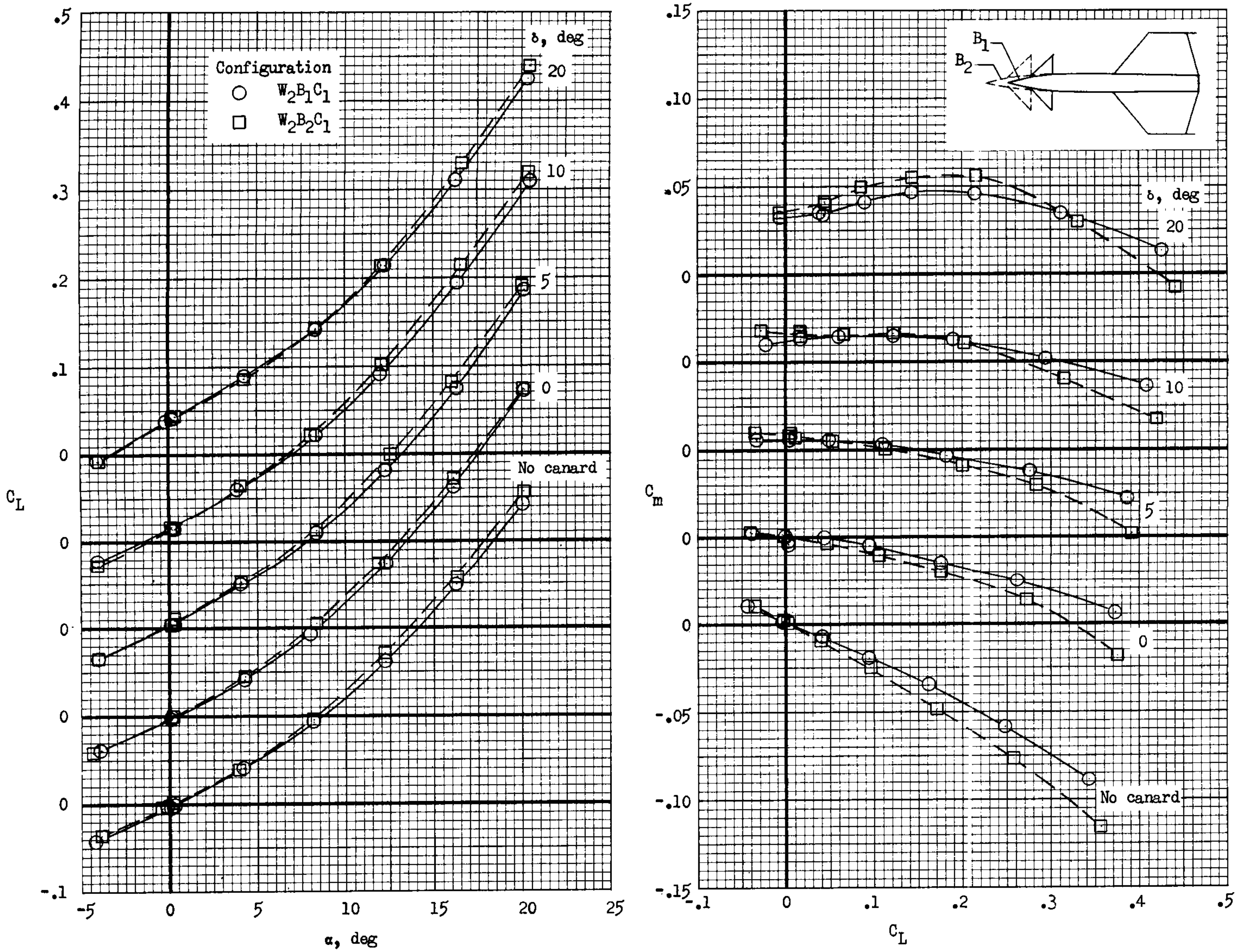
(c) Variation of ΔC_m with δ for high- and low-wing—long-body configurations.

Figure 14.- Concluded.



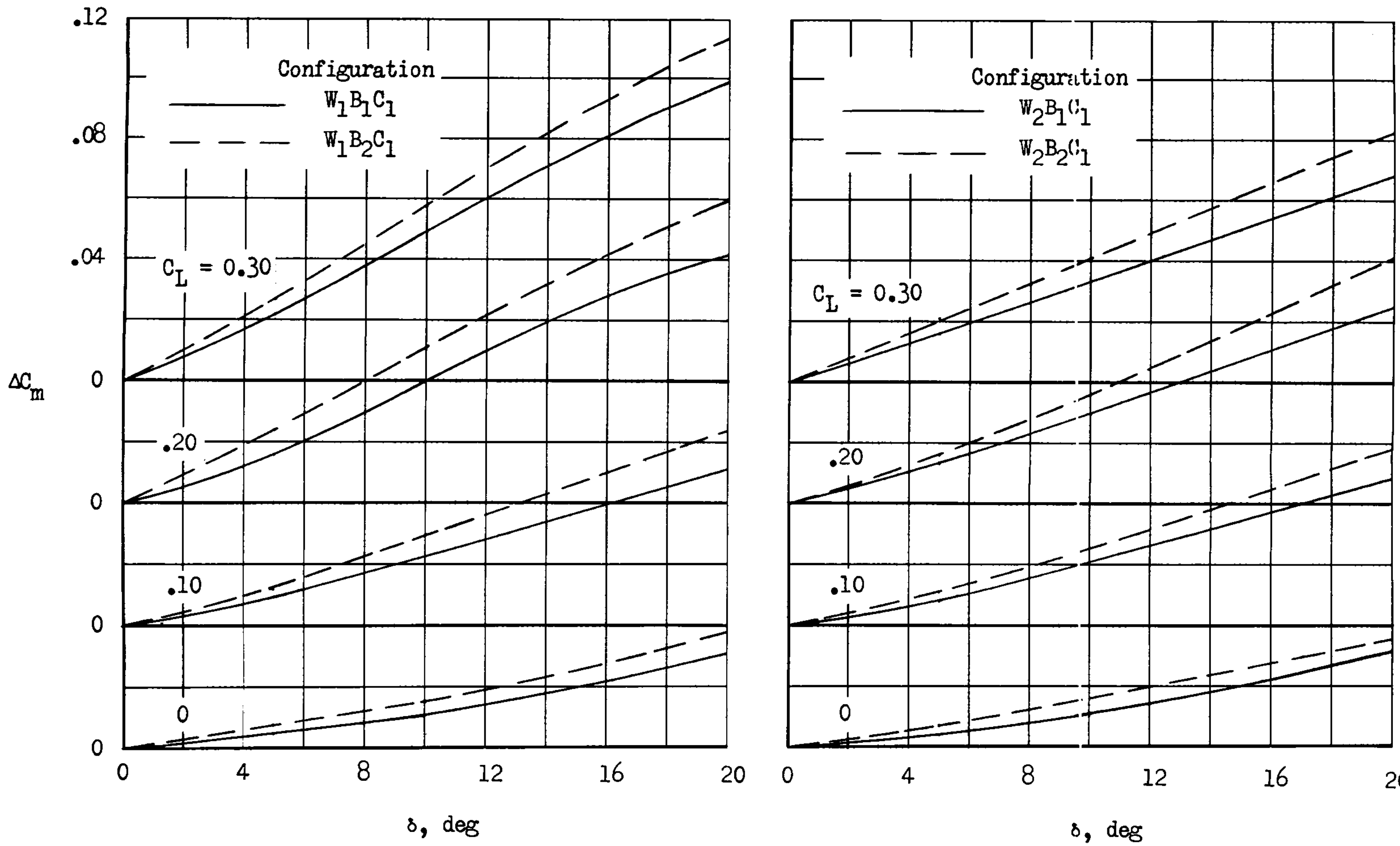
(a) High-wing—small-delta-canard configurations.

Figure 15.- Effects of fuselage length.



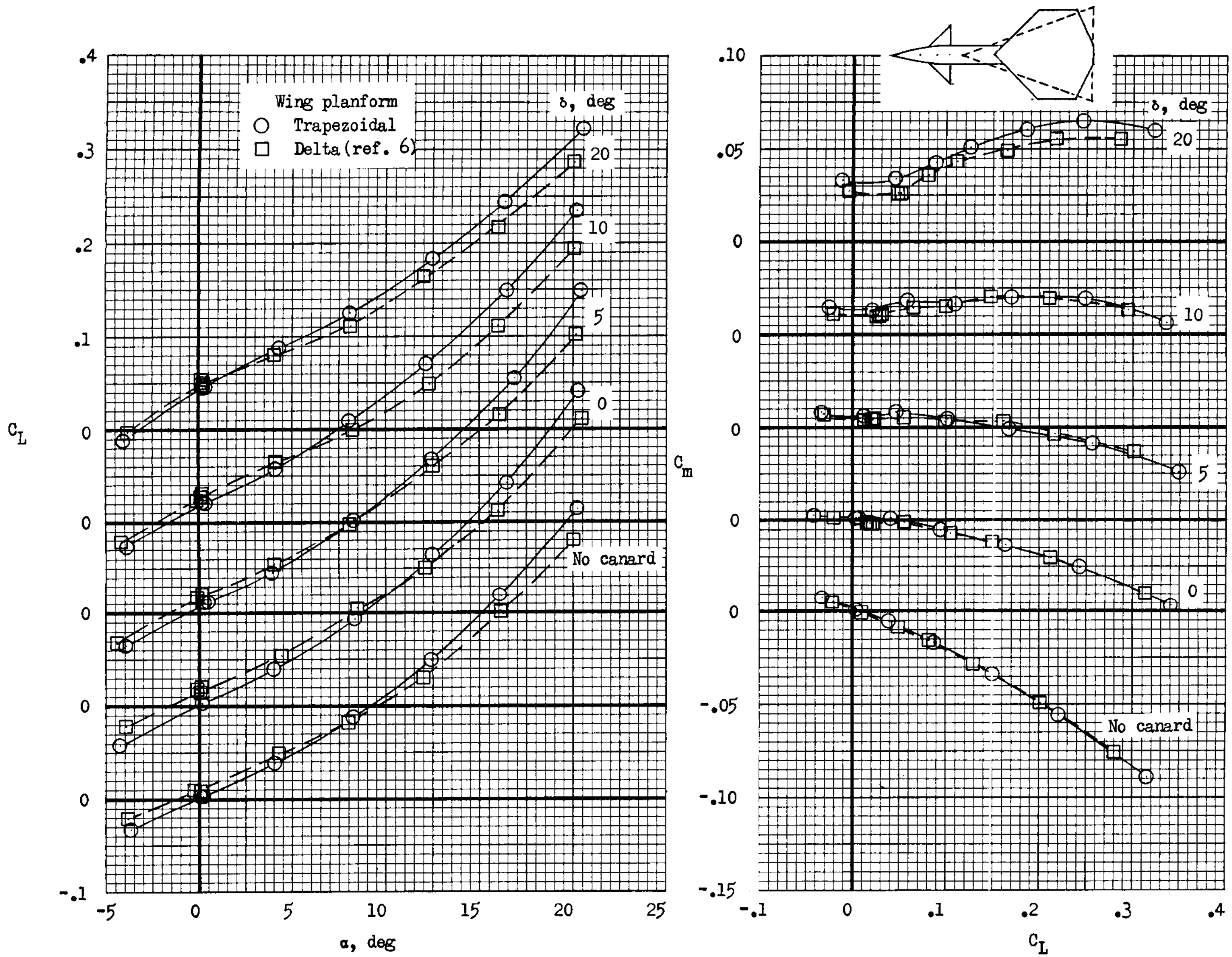
(b) Low-wing—small-delta-canard configurations.

Figure 15.- Continued.



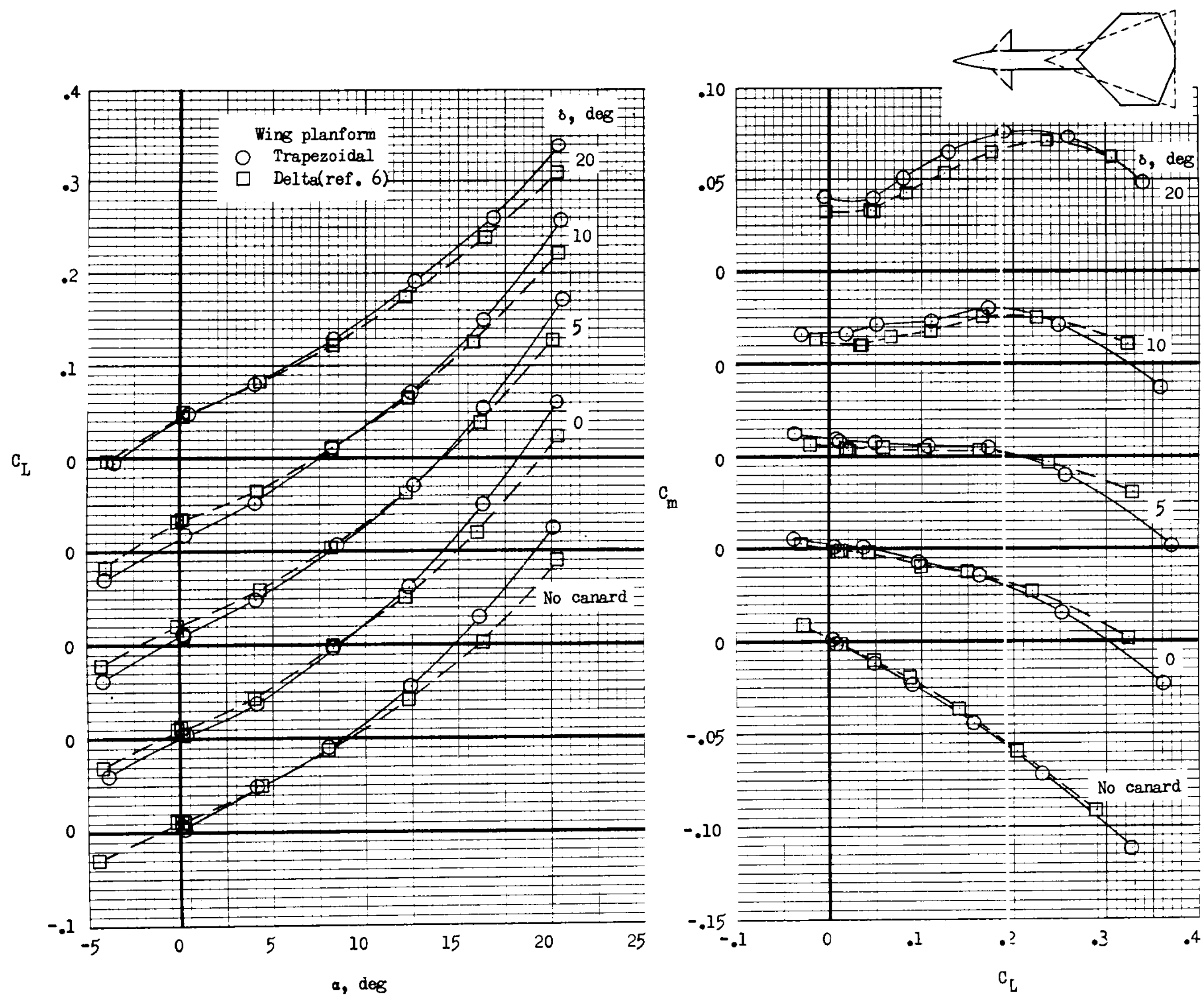
(c) Variation of ΔC_m with δ for high- and low-wing—small-delta-canard configurations.

Figure 15.- Concluded.



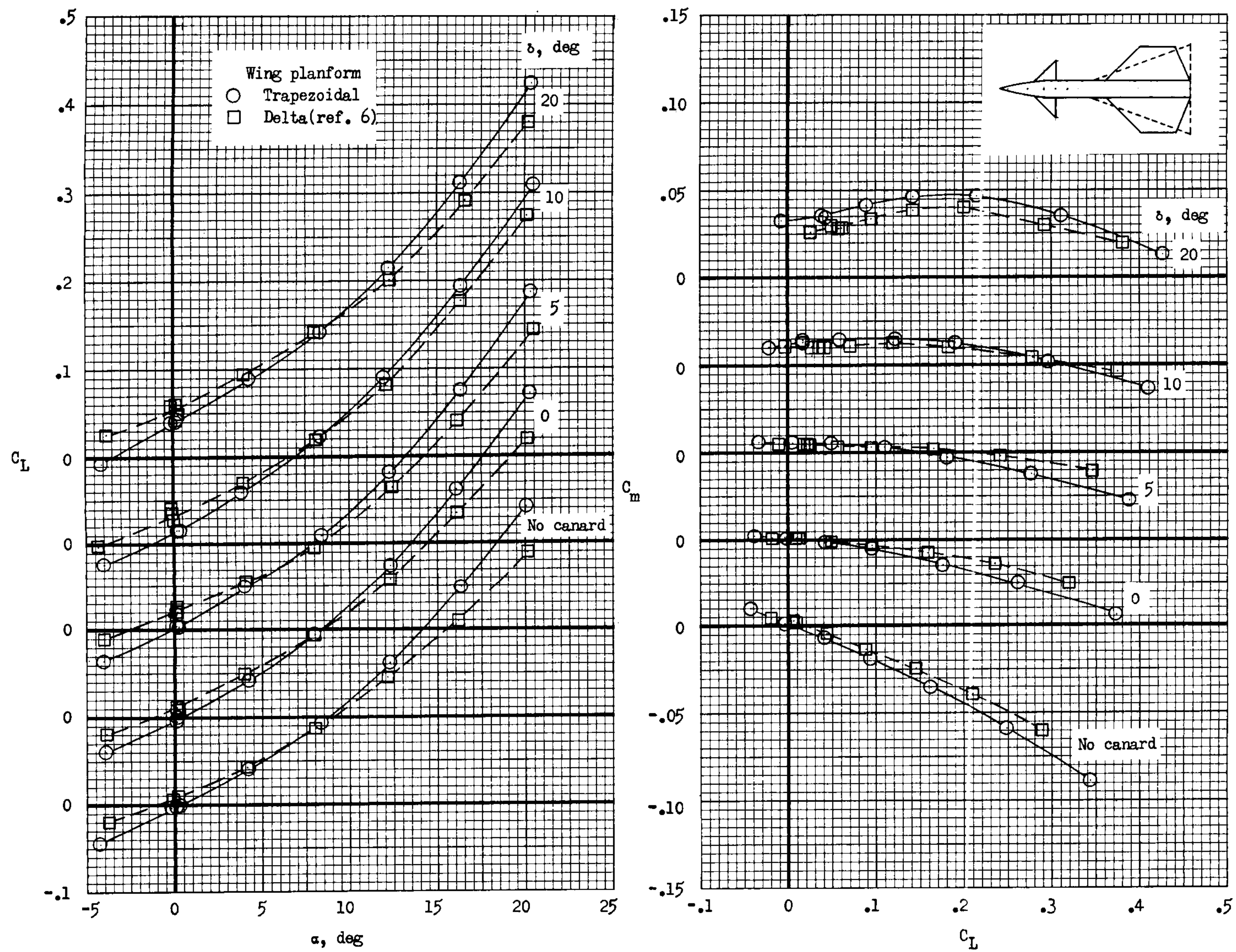
(a) High-wing—short-body—small-delta-canard configuration ($W_1B_1C_1$).

Figure 16.- Effects of wing planform.



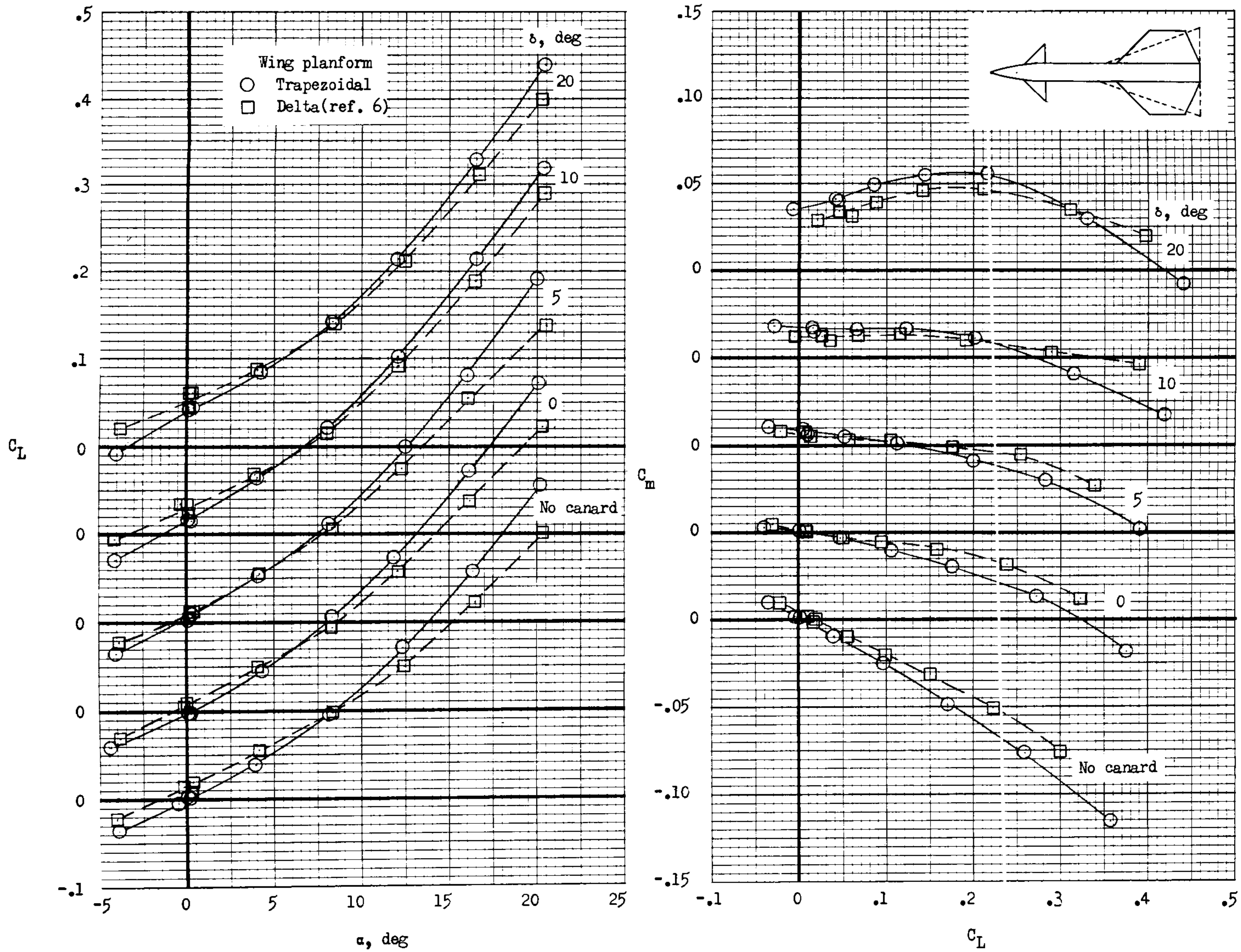
(b) High-wing—long-body—small-delta-canard configuration ($W_1B_2C_1$).

Figure 16.- Continued.



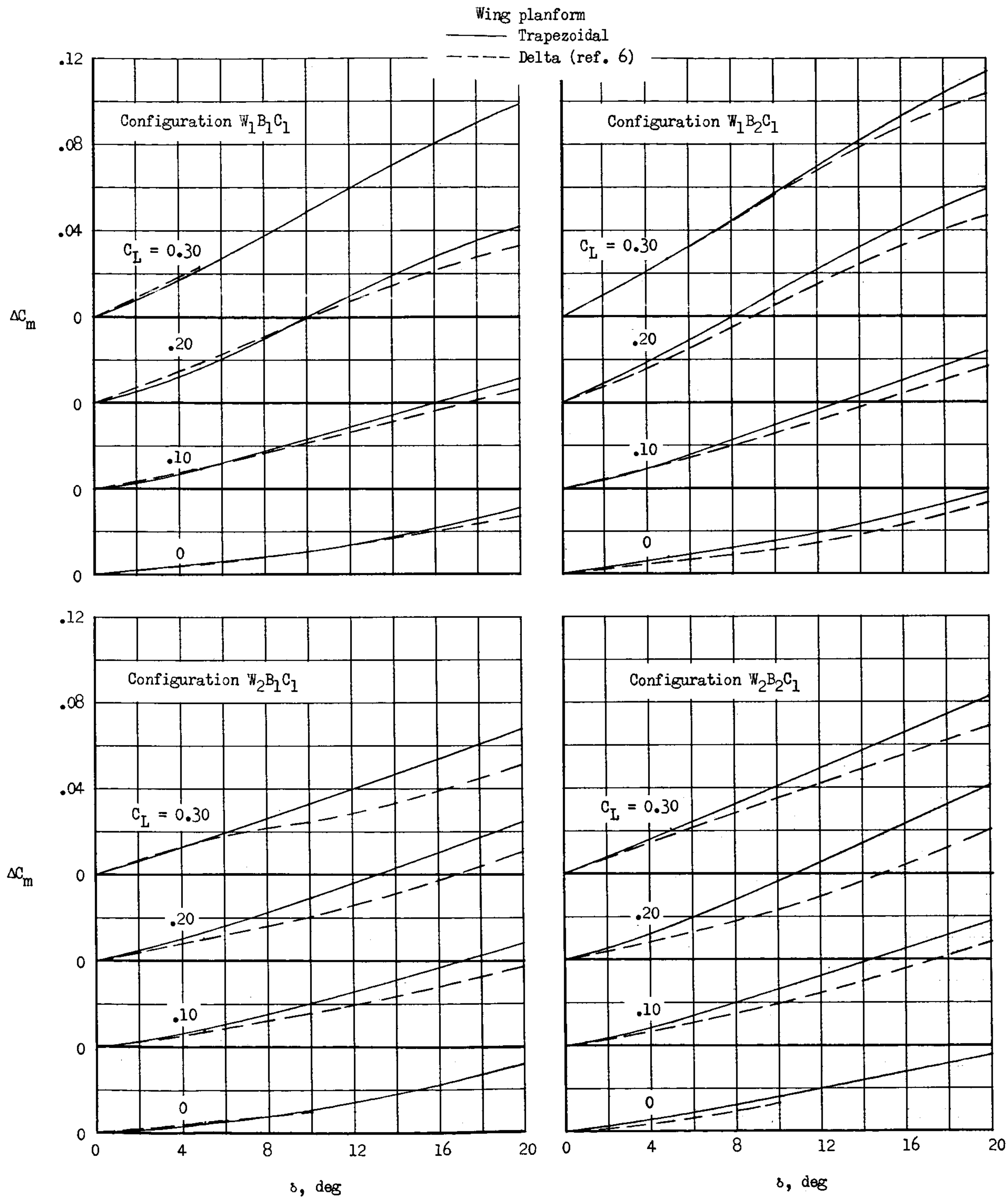
(c) Low-wing—short-body—small-delta-canard configuration ($W_2B_1C_1$).

Figure 16.- Continued.



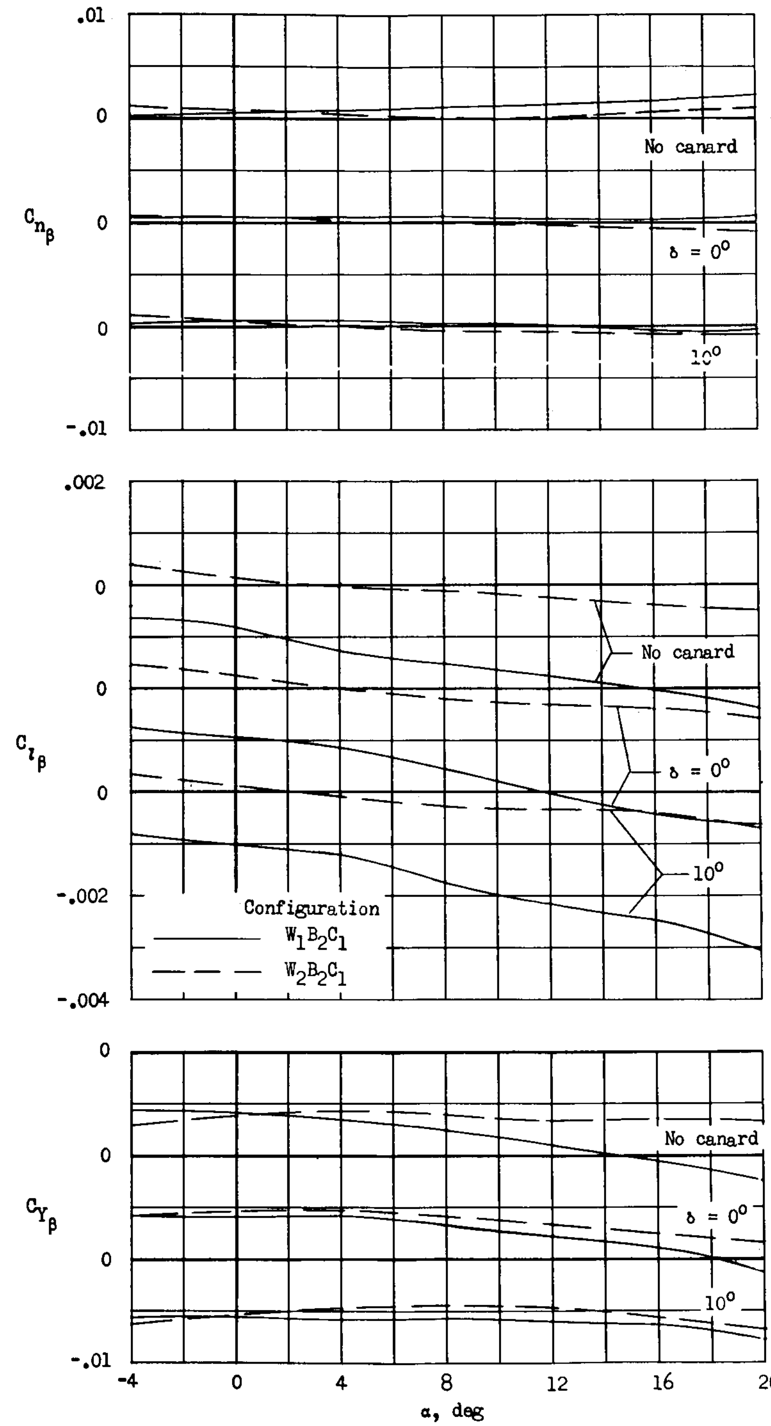
(d) Low-wing—long-body—small-delta-canard configuration ($W_2B_2C_1$).

Figure 16.- Continued.



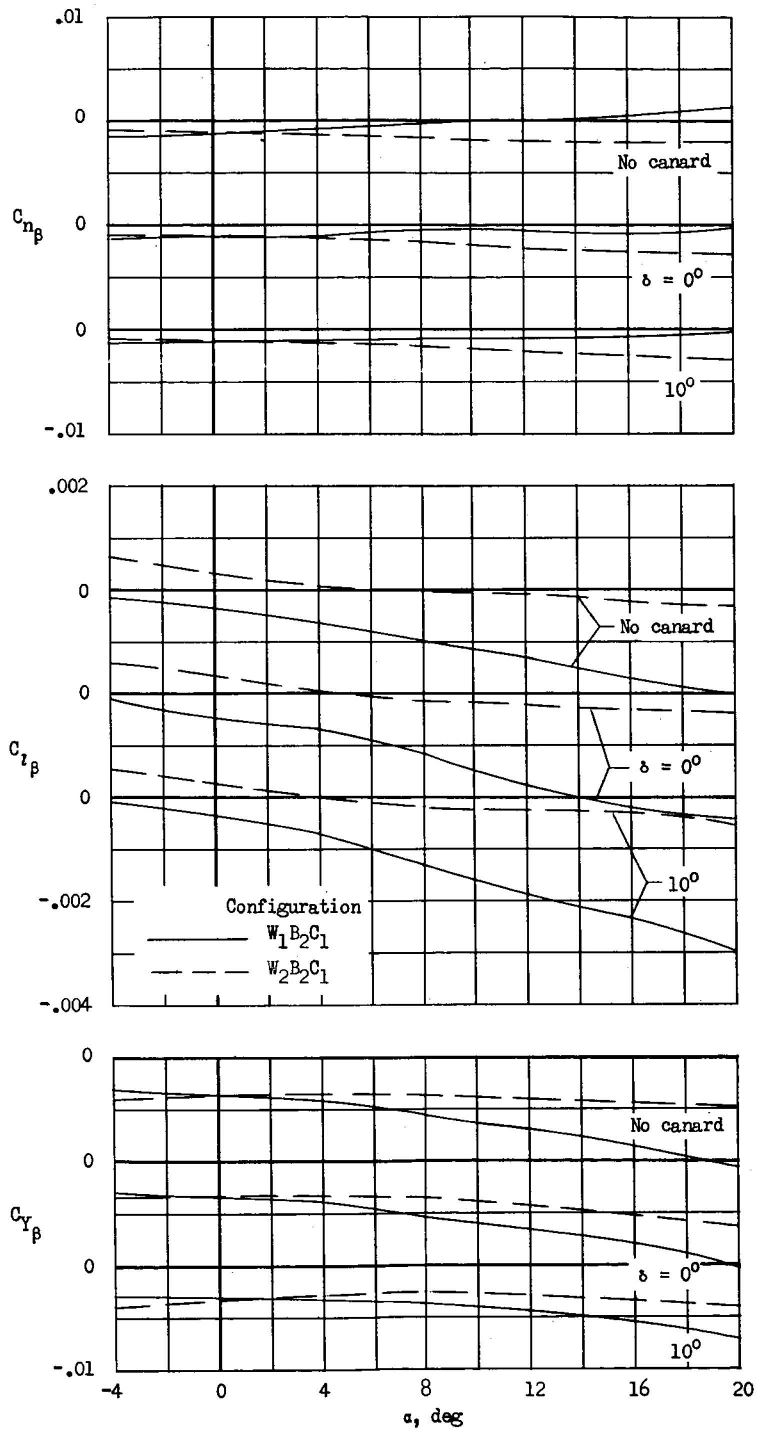
(e) Variation of ΔC_m with δ for the various configurations.

Figure 16.- Concluded.



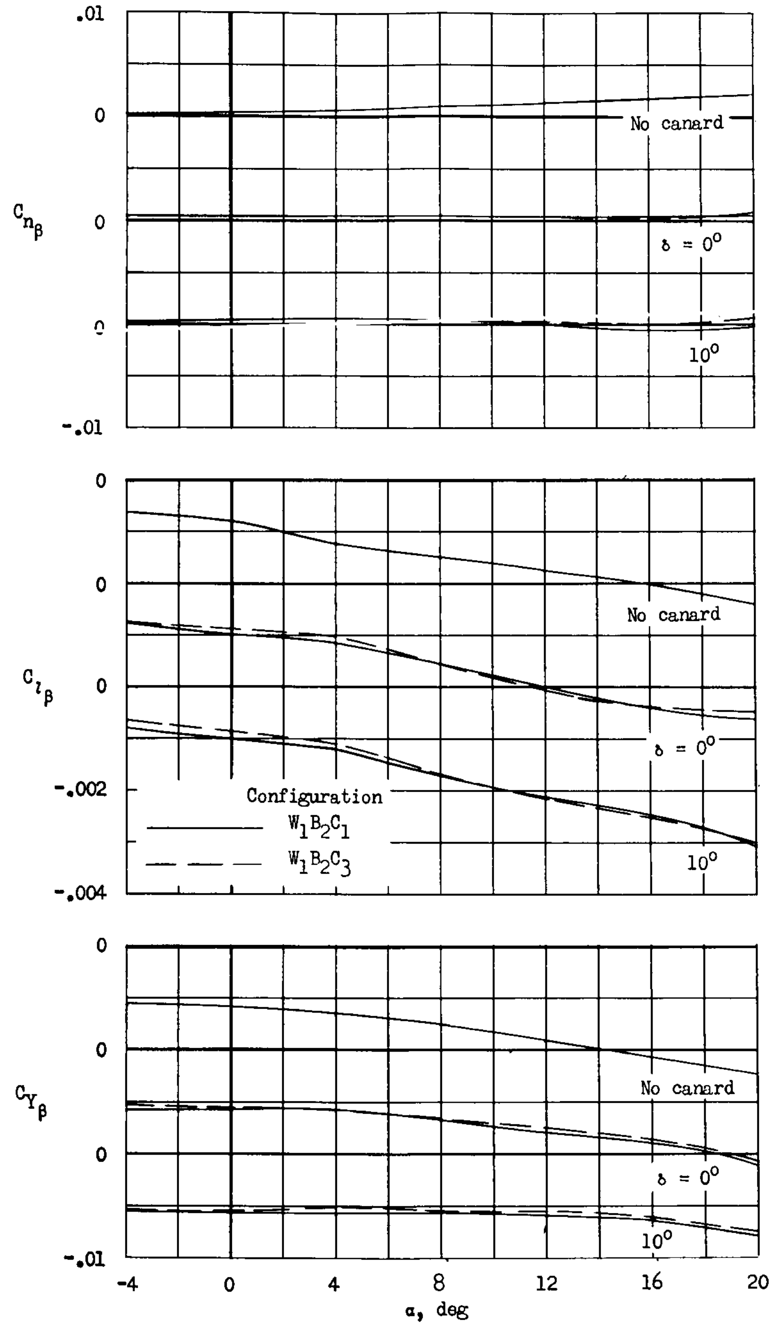
(a) Vertical tails on.

Figure 17.- Effect of wing vertical position on lateral and directional aerodynamic characteristics of trapezoidal-wing—long-body configuration with and without small delta canard.



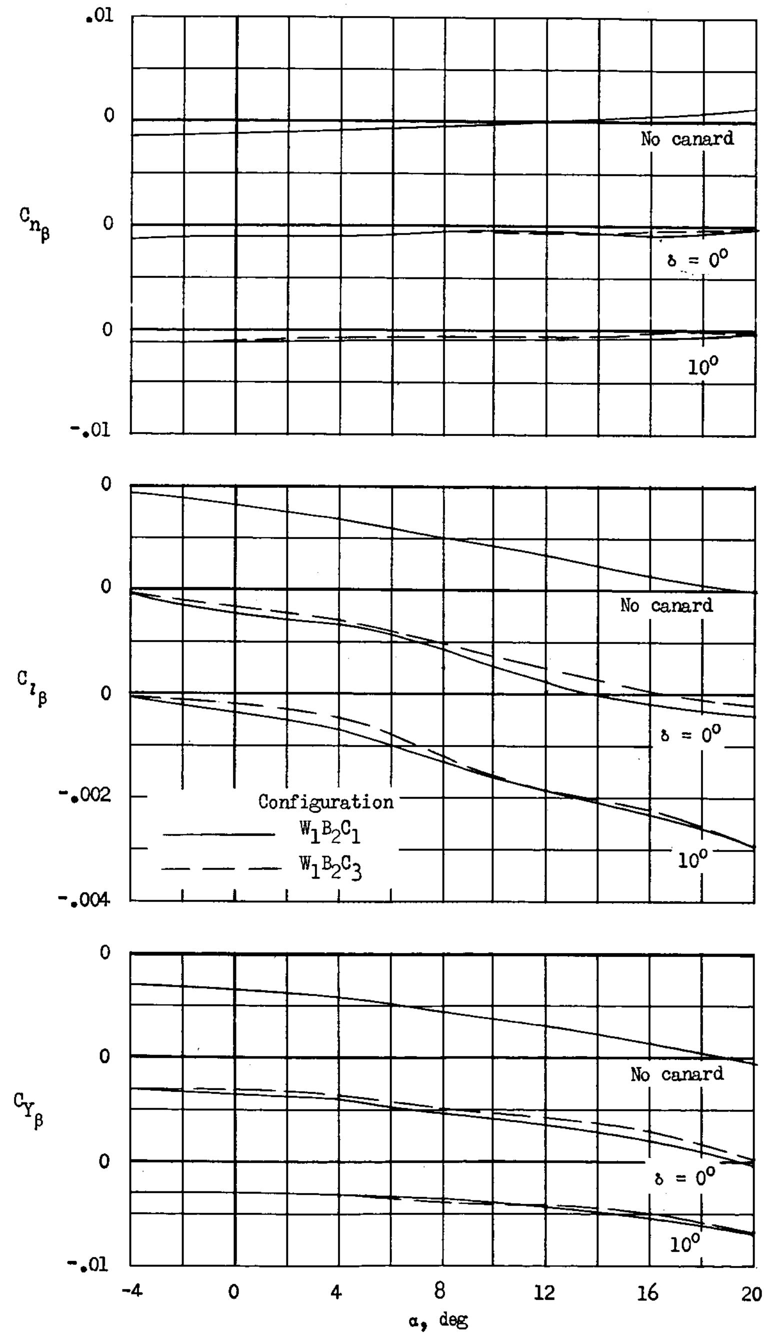
(b) Vertical tails off.

Figure 17.- Concluded.



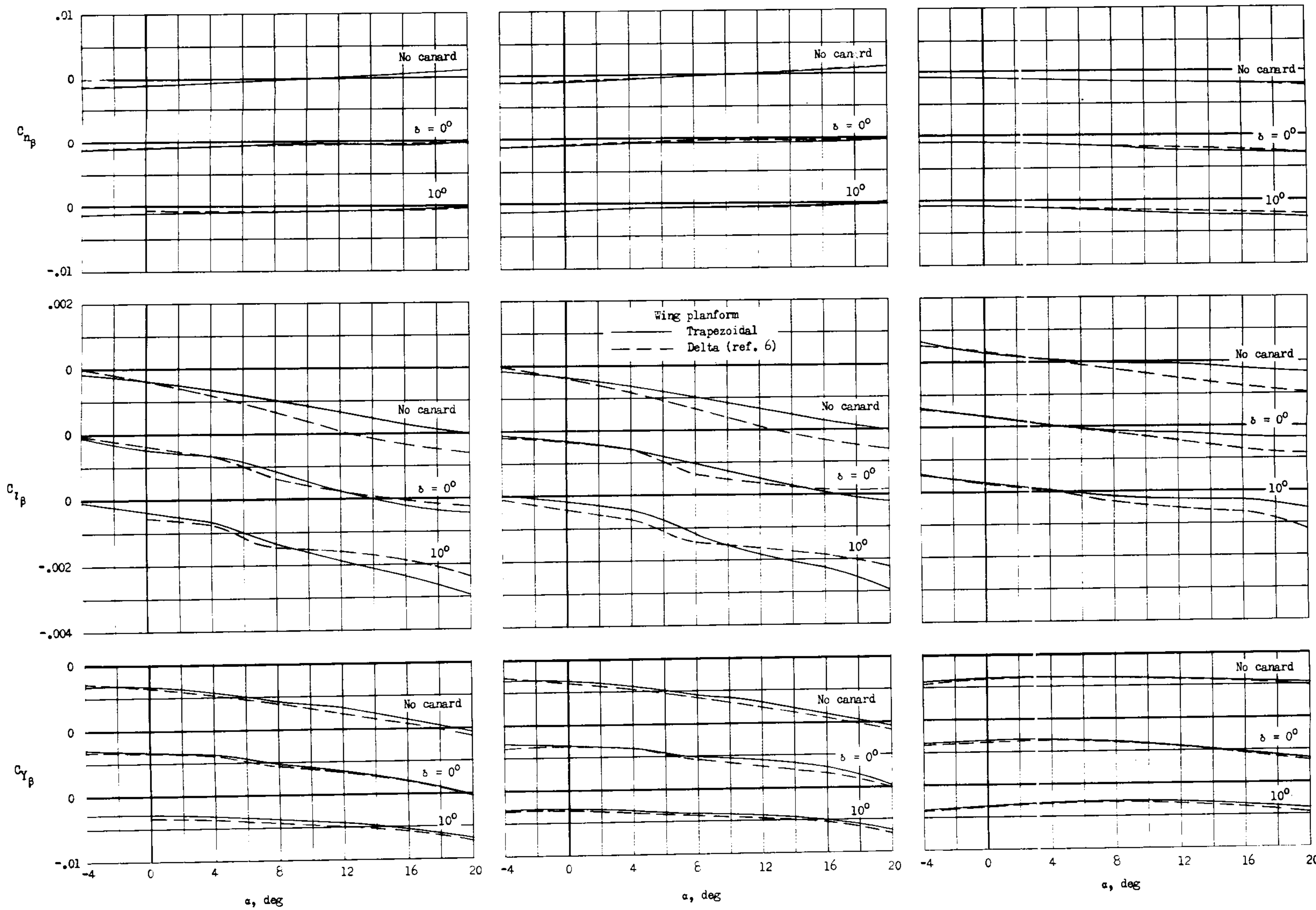
(a) Vertical tails on.

Figure 18.- Effect of canard planform on lateral and directional aerodynamic characteristics of high-trapezoidal-wing—long-body configuration with small canard controls. (Configuration without canard shown for comparison.)



(b) Vertical tails off.

Figure 18.- Concluded.

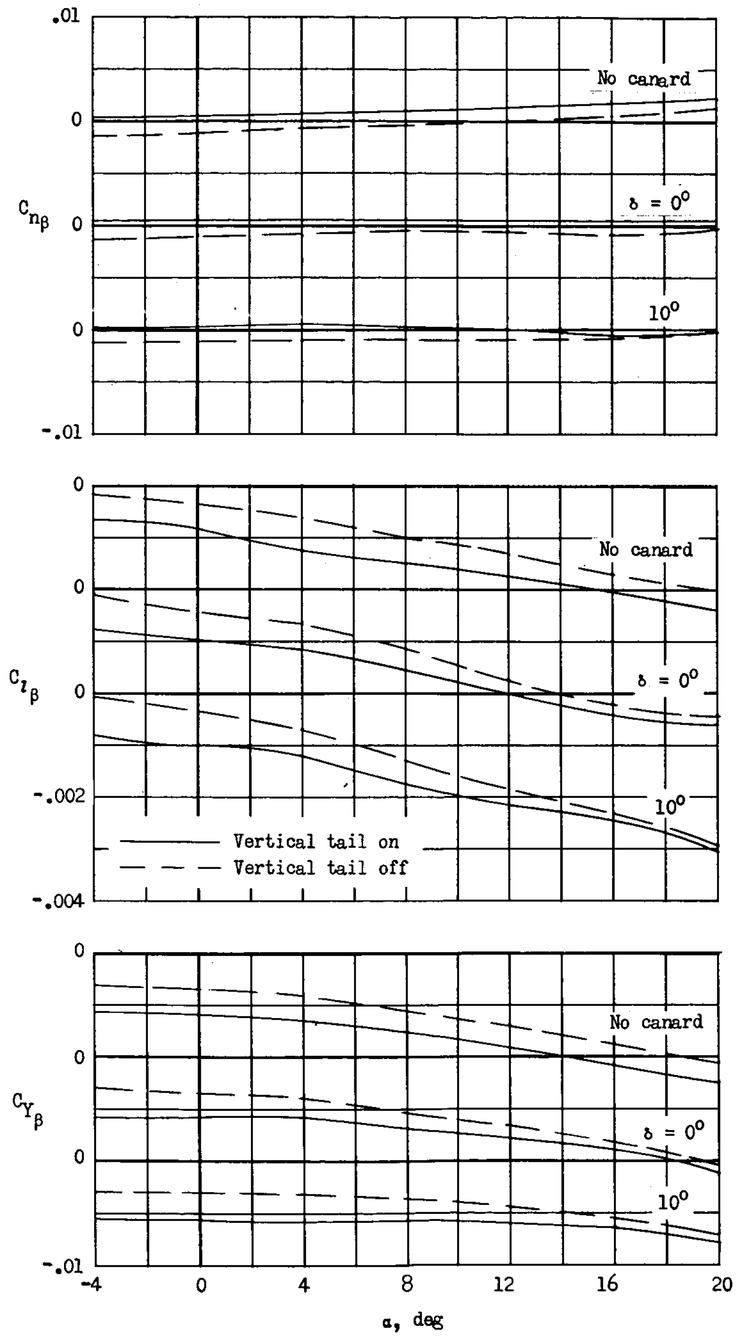


(a) Configuration $W_1B_2C_1$.

(b) Configuration $W_1B_2C_3$.

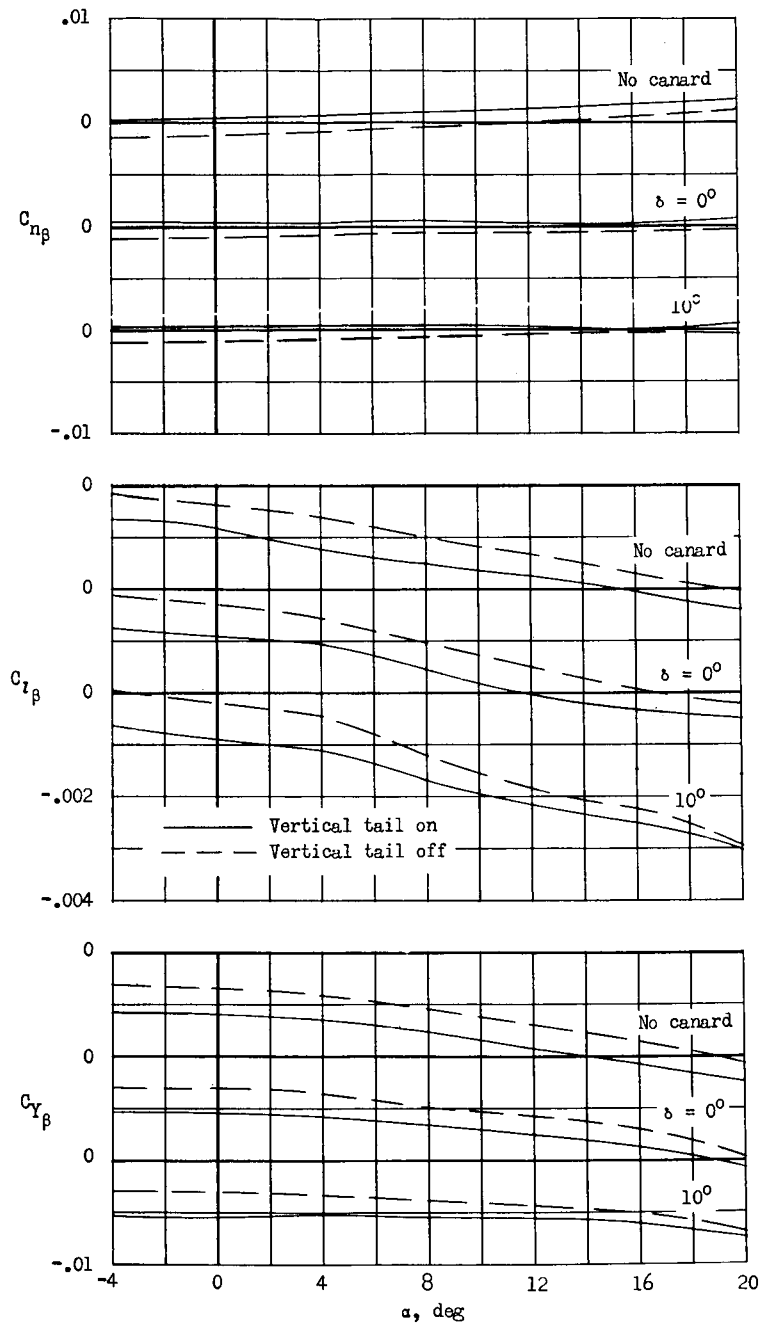
(c) Configuration $W_2B_2C_1$.

Figure 19.- Effects of wing planform on lateral and directional aerodynamic characteristics of various configurations. Vertical tails off.



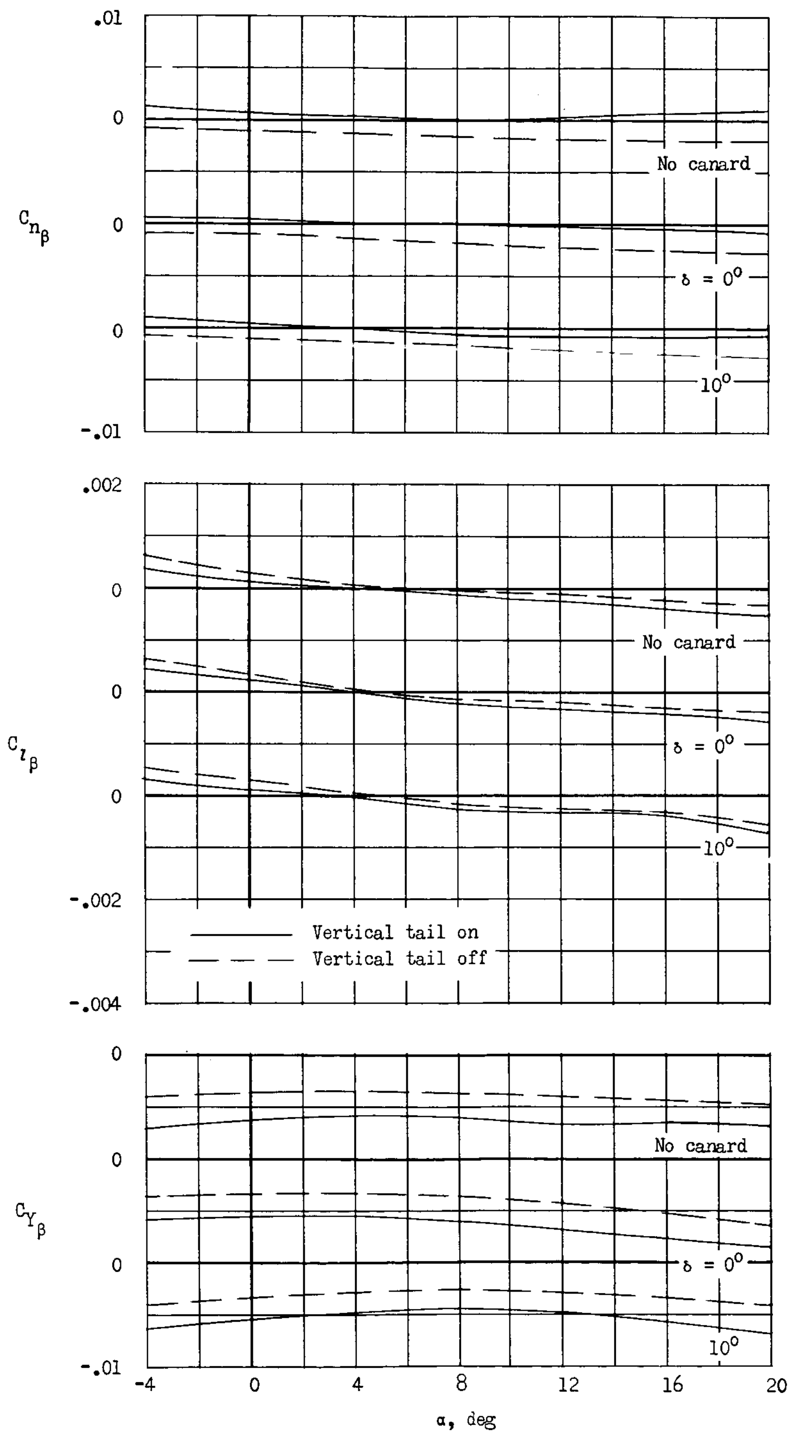
(a) Configuration $W_1B_2C_1$.

Figure 20.- Effect of vertical tails on lateral and directional aerodynamic characteristics of various trapezoidal-wing configurations with and without canard controls.



(b) Configuration $W_1B_2C_3$.

Figure 20.- Continued.



(c) Configuration $W_2B_2C_1$.

Figure 20.- Concluded.

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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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