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RESEARCH MEMORANDUM

AERODYNAMIC LOADS ON AN EXTERNAL STORE ADJACENT TO A 60° DELTA WING AT MACH NUMBERS FROM 0.75 TO 1.96

By William M. Hadaway

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Langley Field, Va.

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SUMMARY

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An investigation has been made in the Langley 9- by 12-inch blowdown tunnel to determine separately the aerodynamic characteristics of both a Douglas Aircraft Company (DAC) store and a semispan delta-wing—fuselage configuration in the presence of each other. The store was located at the 50-percent-semispan station with the store nose both ahead of and behind the wing leading edge for two longitudinal and three vertical positions. Data were obtained through a Mach number range from 0.75 to 1.96 and at angles of attack from -3° to 12°. The test Reynolds numbers were between 2.3×10^6 to 3.1×10^6. Limited effects of pylon modification were also obtained at Mach number 1.62.

With the store nose behind the wing leading edge and the store adjacent to the wing, there was a forward shift in wing-fuselage aerodynamic center at Mach numbers above 0.75; however, changes in wing normal-force and bending-moment coefficients were small or negligible.

The variation of store normal-force coefficient with angle of attack was generally negative or approximately zero with the store beneath the wing. Variation of store pitching-moment coefficient with angle of attack was positive with the store nose ahead of the wing leading edge but approximately zero with the nose behind the leading edge.

For the present tests, the most critical loading condition throughout the Mach number range appeared to be due to the large outwardly directed side forces on the store at moderate and high angles of attack when the store was adjacent to the wing and the store nose ahead of the wing leading edge. With the store nose moved behind the wing leading edge, however, the variations of store side-force coefficient with angle of attack C_{Y_α} were about one-third the magnitudes obtained with the nose ahead of the wing leading edge throughout the Mach number range.

Author

INTRODUCTION

Continued use of external stores on high-speed aircraft has necessitated extensive investigation of their effects on aircraft performance characteristics and also of the effects of the aircraft wing and fuselage interference on the external store loads. Area-rule concepts have been shown to apply to the determination of the drag of aircraft-store configurations at transonic speeds and, to some extent, supersonic speeds (ref. 1). Additional information on the effects of store size, shape, and position on aircraft performance at supersonic speeds are reported in references 2 and 3. Information on external store loads at transonic and supersonic speeds, however, is relatively meager, although considerable work has been done at high subsonic speeds (refs. 4 and 5, for example) and the effects of store position on the store loads at low angles of attack have been extensively investigated at Mach number 1.6 (ref. 6). There is considerable need for information on external store loads at transonic and supersonic speeds both from the standpoint of structural-support design as well as an aid to the estimation of jettison characteristics. In order to provide this information, the investigation conducted in the Langley 9- by 12-inch blowdown tunnel of the effects of stores on the aerodynamic characteristics of a 45° swept wing, an unswept wing, and a 60° delta wing (refs. 2, 7, 8, and 9) has been extended to include the measurements of store loads. These data for the 45° swept wing and the unswept wing are presented in references 10 and 11, respectively, and the present paper presents store loads information for the 60° delta-wing—body combination.

The 60° delta semispan wing had an aspect ratio of 2.31 and NACA 65A003 airfoil sections. The store, which had a Douglas Aircraft Company (DAC) shape, was sting-mounted independently of the semispan wing-body combination and at no time was attached to or in contact with the wing. Forces (except drag) and moments on the store and on the wing-body combination were measured simultaneously as both wing-body combination and store were rotated through an angle-of-attack range of -3° to 12° for a limited number of store positions. Tests were made in a transonic slotted nozzle at Mach numbers from 0.75 to 1.20 and in three supersonic nozzles at Mach numbers of 1.41, 1.62, and 1.96. The test Reynolds numbers based on wing mean aerodynamic chord ranged from 2.3×10^6 to 3.1×10^6.

SYMBOLS AND COEFFICIENTS

C_N normal-force coefficient, $\frac{\text{Normal force}}{qS_w}$

[redacted]

C_m pitching-moment coefficient, $\frac{\text{Pitching moment about } 0.25\bar{c}}{qS_w\bar{c}}$

C_B bending-moment coefficient, $\frac{\text{Bending moment}}{qS_w\frac{b}{2}}$

C_{N_s} store normal-force coefficient, $\frac{\text{Store normal force}}{qS_s}$

C_{m_s} store pitching-moment coefficient, $\frac{\text{Store pitching moment about } 0.4l}{qS_s l}$

C_{Y_s} store lateral-force coefficient, $\frac{\text{Store lateral force}}{qS_s}$

C_{n_s} store yawing-moment coefficient, $\frac{\text{Store yawing moment about } 0.4l}{qS_s l}$

q free-stream dynamic pressure

S_w semispan wing area

$\bar{c}$ wing mean aerodynamic chord, $\frac{1}{S_w}\int_0^{b/2} c^2 dy$

c local wing chord

b wing span (twice distance from root chord to wing tip)

S_s store maximum cross-sectional area

l closed length of store

α angle of attack of wing, deg

α_s angle of attack of store, deg

z minimum distance from wing lower surface to store longitudinal axis (positive down)

d maximum store diameter

x chordwise distance from line perpendicular to $\bar{c}$ at quarter-chord station to store $0.4l$ point

y spanwise distance from wing root chord to store longitudinal axis

[redacted]

$\left(\frac{z}{d}\right)_p$ denotes pylon required to reach store when store longitudinal axis is at z distance below wing

V_o free-stream velocity

R Reynolds number based on $\bar{c}$

M Mach number

$\frac{d}{d\alpha}$ rate of change of coefficient with angle of attack

Subscripts:

w wing and fuselage

s store

p pylon

f fuselage

MODELS

The principal dimensions of the semispan wing-body combination are shown in figure 1. The 60° delta wing was fabricated from heat-treated steel and had NACA 65A003 airfoil sections parallel to the airstream and an aspect ratio of 2.31.

The external store had a DAC shape and a fineness ratio of 8.58 based on the closed length. The store was made of steel and cut off at 80 percent of its closed length to permit entry of an internal electrical strain-gage balance. Store ordinates and sting-mounting arrangements are given in figure 2 and a photograph of a typical test condition is shown in figure 3. All tests were made with the store at spanwise station $2y/b = 0.50$ and at longitudinal station $x/\bar{c} = 0.151$ or 0.453. For the store positions adjacent to the wing ($z/d = 0.5$) the pylon consisted of little more than a fairing between the wing and store, being attached to the wing by pinning and sweating to the wing but not connected to the store. The fairing for the rearward located store consisted only of a thin brass sheet, but for the forward store location the fairing (or pylon) had NACA 65A010 airfoil sections. A limited investigation of

the pylon configuration was made at 1.62 with the store at $x/\bar{c} = 0.151$ and $z/d = 1.0$. Data were obtained with a connecting pylon of 1.67 inches chord length ($0.417l$), the leading edge of which coincided with the wing leading edge; with the pylon moved rearward $0.20l$ from the wing leading edge and the aft 14 percent of the pylon removed to insure noninterference with the support sting; and with 50 percent of the remaining pylon removed (25 percent to 50 percent and 75 percent to 100 percent). The configurations tested and the relative store positions and pylon plan forms are presented in figure 4.

TUNNEL

The tests were made in the Langley 9- by 12-inch blowdown tunnel, which was supplied with compressed air at $2\frac{1}{3}$ atmospheres by the Langley 19-foot pressure tunnel. The air was passed through a drying agent of silica gel and then through finned electrical heaters in the region between the 19-foot tunnel and the blowdown tunnel test section to insure condensation-free flow at supersonic speeds in the test region. The criteria used for the drying and heating necessary to reduce the air dewpoint below critical values are given in reference 12.

Three turbulence damping screens were installed in the settling chamber between the heaters and the test region. Four interchangeable nozzle blocks provided test-section Mach numbers of 0.75 to 1.20, 1.41, 1.62, and 1.96.

Supersonic Nozzles

Extensive calibrations of the test-section flow characteristics of the three supersonic fixed nozzles are reported in reference 13. Calibration results indicated the following test-section flow conditions:

Average Mach number	1.41	1.62	1.96
Maximum deviation in Mach number	±0.02	±0.01	±0.02
Maximum deviation in stream angle, deg	±0.25	±0.20	±0.20
Average Reynolds number	2.9×10^6	2.5×10^6	2.3×10^6

[redacted]

Transonic Nozzle

A description of the transonic nozzle, which had a 7- by 10-inch rectangular test section, together with a discussion of the flow characteristics obtained from limited calibration tests, is presented in reference 14. Satisfactory flow conditions in the test section are indicated from the minimum Mach number (0.75) to $M = 1.20$. Maximum deviations from the average test-section Mach number are given in figure 5(a). Stream-angle deviation probably did not exceed $\pm 0.1^\circ$ at any Mach number. The average transonic Reynolds numbers of the investigation are presented in figure 5(b) as a function of Mach number.

TEST TECHNIQUE

The semispan wing-fuselage model was cantilevered from a five-component strain-gage balance set flush with the tunnel floor. The balance and model rotated together as the angle of attack was changed. The aerodynamic forces and moments on the model were measured with respect to the balance axes. The fuselage was separated from the tunnel floor by a 0.25-inch aluminum shim which has been shown in references 15 and 16 to minimize the effects of the boundary layer on the flow over the fuselage surface for $M = 1.9$. A clearance gap of about 0.010 inch was maintained between the fuselage shim and the tunnel floor with no wind load.

The external store was attached to the forward end of an internal four-component strain-gage balance. The downstream end of the balance sting was supported by a strut from the tunnel floor, and the store and sting pivoted about a point 12.25 inches ($2.70\bar{c}$) downstream of the wing $\bar{c}/4$. The store angle of attack and position in a direction normal to its own axis were controllable during tests within limits and permitted an angle-of-attack range of about 6° per test run. The sting support was repositioned between runs and three runs were required to obtain data throughout the angle-of-attack range from -3° to 12°.

Two small electrical contacts on the side of the store nearest the wing permitted alinement of the store with the pylon and also gave an indication of fouling between the two. A minimum gap of about 0.02 inch was maintained at all times unless otherwise stated.

Jet-boundary interference and reflection-plane effects at high subsonic speeds cannot be theoretically evaluated at present for the transonic nozzle. The experimental evidence available (refs. 10 and 14), however, indicate that the wing-plus-interference (wing-fuselage minus fuselage) characteristics are reasonably reliable except in the Mach number range between 0.94 and 1.04. In this range, significant quantitative differences are found between pitching moments for a sweptback wing

[redacted]

measured in the transonic nozzle and those measured in other facilities where the ratio of tunnel cross-sectional area to model wing area was considerably larger. The store forces and moments in this speed range are believed to be relatively free from interference effects and the incremental wing forces and moments due to the presence of the store are considered reliable. (See ref. 10.) Reflection of shock or expansion waves emanating from the model back onto the wing fuselage or store by the tunnel walls is known to occur at supersonic Mach numbers less than 1.2, although at Mach numbers of 1.05 or less the effects of reflected disturbances are believed to be small. Data are not presented for the Mach number range between 1.05 and 1.2. At $M = 1.2$, the reflected fuselage bow wave is believed to pass downstream of the wing and store.

Chord forces on the semispan wing-fuselage combination in the presence of the external store were measured but not presented because they were in error by an unknown amount due to interference of the store balance supporting strut on fuselage base pressures. (See ref. 10.) For this reason, measured normal forces for this condition could not be rotated to the wind axis and presented as lift. Parts of other wing data have also been omitted because wing strain-gage wires became disconnected during the tests.

ACCURACY OF MEASUREMENTS

An estimate of the probable errors introduced in the present data by instrument-reading errors and measuring-equipment errors are presented in the following table:

C_{N_w}	± 0.01
C_{m_w}	± 0.002
C_{B_w}	± 0.002
α, deg	± 0.05
C_{N_s}, C_{Y_s}	± 0.01
C_{m_s}, C_{n_s}	± 0.001
α_s, deg	± 0.20
x	$\pm 0.008\bar{c}$
y	$\pm 0.01b/2$
z	$\pm 0.03d_s$

The preceding measurement accuracy for the store angle of attack α_s refers to the angle between the store and the wing and does not include inaccuracies in measurement of the wing-fuselage angle of attack. The minimum gap and the alinement between store and wing in the pitch

[redacted]

plane were fixed by setting the heights of the electrical contacts on the store with wind off. Alinement during tests was determined by simultaneously making or breaking of the two electrical contacts on the store. The vertical position was then determined by means of a calibrated lead screw which moved the store normal to its longitudinal axis. Therefore, the store angle of attack and vertical position relative to the wing were essentially independent of the deflection of the store supporting system or of the wing due to air loads. In the lateral plane the store position measurement accuracy was determined from static load calibrations. The longitudinal location of the store was fixed before each run. The accuracy given above was essentially the variation in x relative to the wing during each run due to the different points of rotation of the wing and the store.

Tests of the store alone were made both with the electrical contacts raised and with the contacts faired smooth with the store surface. Differences in the measured loads were well within the stated experimental accuracies.

RESULTS AND DISCUSSION

It should be noted that for all store positions tested, a pylon was attached to the wing. In the case of the store located one-half store diameter (plus a very small gap) below the wing lower surface, the pylon was little more than a fairing between wing and store. Therefore, when the store was moved away from the wing without changing the pylon, a condition existed that will be referred to as the "pylon off" condition.

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Effect of chordwise store location	8
Effect of vertical store location (pylon off)	9

[redacted]

Figure

Force and moment characteristics of store alone and in presence of wing-fuselage:
C_{N_s}, C_{m_s}, C_{Y_s}, and C_{n_s} plotted against α -
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Force and moment characteristics of the store adjacent to the wing-fuselage at two spanwise stations:
C_{N_s} and C_{m_s} ($\alpha = 0^\circ$, 6°) plotted against M 15
C_{Y_s} and C_{n_s} ($\alpha = 0^\circ$, 6°); and $\frac{dC_{Y_s}}{d\alpha}$ and $\frac{dC_{n_s}}{d\alpha}$ ($\alpha = 6^\circ$) plotted against M 16

Wing Loads

The absolute values of the wing-fuselage force and moment coefficients have little if any application to conventional wing-fuselage configurations because of the arbitrary shape of the test body which includes the boundary-layer shim. However, the changes in the wing-fuselage characteristics due to the presence of the store are believed to be reliable, and the increments are of primary interest herein.

Figure 14 indicates that, in general, the presence of the store caused small changes in $\frac{dC_{N_w}}{d\alpha}$ and $\frac{dC_{B_w}}{d\alpha}$ at $\alpha = 0^\circ$. The presence of the store caused a forward shift in wing aerodynamic center at all Mach numbers tested above 0.75 when the store nose was behind the wing leading edge. When the store nose was shifted ahead of the wing leading edge at supersonic Mach numbers, the wing aerodynamic center was shifted to a more rearward location. The forward located store pitching-moment-coefficient data were not obtained at low angles of attack in the transonic range.

[redacted]

Store Loads

With the store in the presence of the wing fuselage, the variations of store normal-force coefficient with angle of attack $C_{N_{s_\alpha}}$ were generally either negative or approximately zero at moderate and high angles of attack throughout the Mach number range (figs. 10 and 11). As a consequence, the store normal-force coefficients at angle of attack were not only smaller than the store alone values but were also negative in some instances. Furthermore, with the store adjacent to the wing, the store normal-force coefficient at moderate and high angles of attack was generally of less magnitude for the store nose ahead of the wing leading edge ($x/\bar{c} = 0.151$) than for the store nose behind the wing leading edge ($x/\bar{c} = 0.453$) — particularly at supersonic Mach numbers (figs. 10 and 15). The variations of store pitching moment with angle of attack $C_{m_{s_\alpha}}$ were positive throughout the angle-of-attack range with the store nose ahead of the wing leading edge; however, with the store nose behind the leading edge, the values of $C_{m_{s_\alpha}}$ were approximately zero (fig. 10).

Probably the most significant result of the investigation is indicated by the store side forces and the effect of a supporting pylon. As shown in figure 10, the store side-force coefficients were of very large negative magnitude (outward) at moderate and high angles of attack with the store adjacent to the wing ($(z/d)_s = 0.5$) and the store nose ahead of the wing leading edge ($x/\bar{c} = 0.151$). Figure 16 indicates that the magnitudes of $C_{Y_{s_\alpha}}$ for this condition remained fairly constant through the Mach number range. There was pronounced nonlinear variation of side-force coefficient with angle of attack at angles near zero for some Mach numbers tested; therefore these $C_{Y_{s_\alpha}}$ values were obtained at $\alpha = 6^\circ$ where the slopes were more representative of moderate and high angle-of-attack data. The large store side forces, particularly at high angles of attack and supersonic Mach numbers, are of importance because the force was in the direction of least structural strength of the store support. With the store still tangent to the wing but moved rearward so that the store nose was behind the wing leading edge ($x/\bar{c} = 0.453$), store $C_{Y_{s_\alpha}}$ values were reduced by approximately two-thirds throughout the Mach number range (figs. 10 and 16). At this rearward location, movement of the store away from the wing in increments of half-store diameters, indicated negligible change in store side-force coefficient in the supersonic speed range at which the tests were made (fig. 11).

Tests were made at $M = 1.62$ to determine the effect of a pylon on the store side forces with the store nose ahead of the wing leading edge ($x/\bar{c} = 0.151$). Figure 12 indicates that lowering the store one-half store diameter from the wing (without adding pylon) reduced the magnitudes

[redacted]

of $C_{Y_{s_\alpha}}$ and side-force coefficients at moderate angles of attack by more than half. A connecting pylon was attached to the wing and $C_{Y_{s_\alpha}}$ was increased to a value slightly larger negatively than that for the store adjacent to the wing. This same effect of store pylon on large store side-force coefficient and $C_{Y_{s_\alpha}}$ values of the store in the presence of both a 45° sweptback wing-body and an unswept wing-body combination (store nose ahead of wing leading edge) was observed in references 10 and 11. A summary of the effects of pylon on C_{Y_s} as a function of z/d_s is presented in figure 13. These data indicate that for tests where wing-fuselage combination and store are separated for purposes of measuring interference loads and moments, as in this investigation, a very small gap between store and wing, or pylon, can cause appreciable change in the measured store side-force coefficient and be misleading for some store positions — particularly with the store nose ahead of the wing leading edge. Although this pylon effect was obtained only at $M = 1.62$ in the present investigation, results of other store locations throughout the Mach number range as well as results of references 10 and 11 tend to indicate strongly that with the store nose ahead of the wing leading edge, the powerful influence of the pylon on the store side force would exist throughout the Mach number range.

The pylon was moved rearward 0.20l behind the wing leading edge and the aft 14 percent removed to insure noninterference with the support sting (see fig. 4). Results indicated that this pylon modification reduced the magnitude of the store side-force coefficients slightly and approached those values for the store adjacent to the wing (fig. 12). Further removal of 50 percent of the pylon indicated a shift in the $C_{Y_{s_\alpha}}$ slope and the C_{Y_s} increment at $\alpha = 0°$ which decreased the side-force values at moderate and high angles of attack but increased them in the low angle-of-attack range (fig. 12). Results indicate that even a small supporting pylon could tend to load up both the store and pylon.

CONCLUSIONS

Results of tests of a Douglas Aircraft Company store beneath a 60° delta wing-fuselage combination at the 50-percent-semispan station from Mach numbers of 0.75 to 1.96 indicate the following:

1. The presence of the store adjacent to the wing caused a forward shift in wing aerodynamic center through the Mach number range when the store nose was behind the wing leading edge; however, variations of wing normal-force and bending-moment coefficients for all store locations tested were small and, in some cases, negligible.

[redacted]

2. The variation of store normal-force coefficient with angle of attack was generally negative or approximately zero in slope with the store beneath the wing; consequently, the values at high angles of attack were smaller than those for the store alone. Variation of store pitching-moment coefficient with angle of attack was positive when the store nose was ahead of the leading edge of the wing, but the slope was approximately zero with the store nose behind the wing leading edge.

3. Large outward store side forces at moderate and high angles of attack were obtained throughout the Mach number range with the store adjacent to the wing or to a pylon, and the store nose ahead of the wing leading edge. Limited data at a Mach number of 1.62 and reference data indicate that the same large side-force condition would exist through the Mach number range with the store lowered from the wing and connected by a pylon.

4. For a store location where large side forces are present, separation of the store from the wing or pylon by a very small air gap (as can be done in wind-tunnel testing) can appreciably reduce the measured store side forces.

5. Location of the store adjacent to the wing with the store nose behind the wing leading edge resulted in store side forces of about one-third the values obtained with the store nose ahead of the wing.

6. A reduction in pylon lateral area reduced the store side force at moderate and high angles of attack.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., January 24, 1956.

[redacted]

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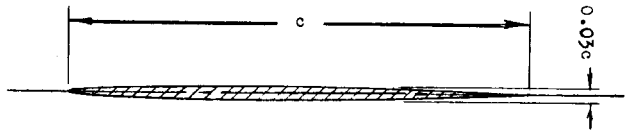
Fuselage Coordinates	
Station	Radius
0	0
0.500	0.087
1.000	.166
1.500	.240
2.000	.305
2.500	.361
3.000	.410
3.500	.453
4.000	.480
4.500	.497
5.000	.500
10.000	.500



Section AA (enlarged)

NACA 65A003 airfoil section (typical)

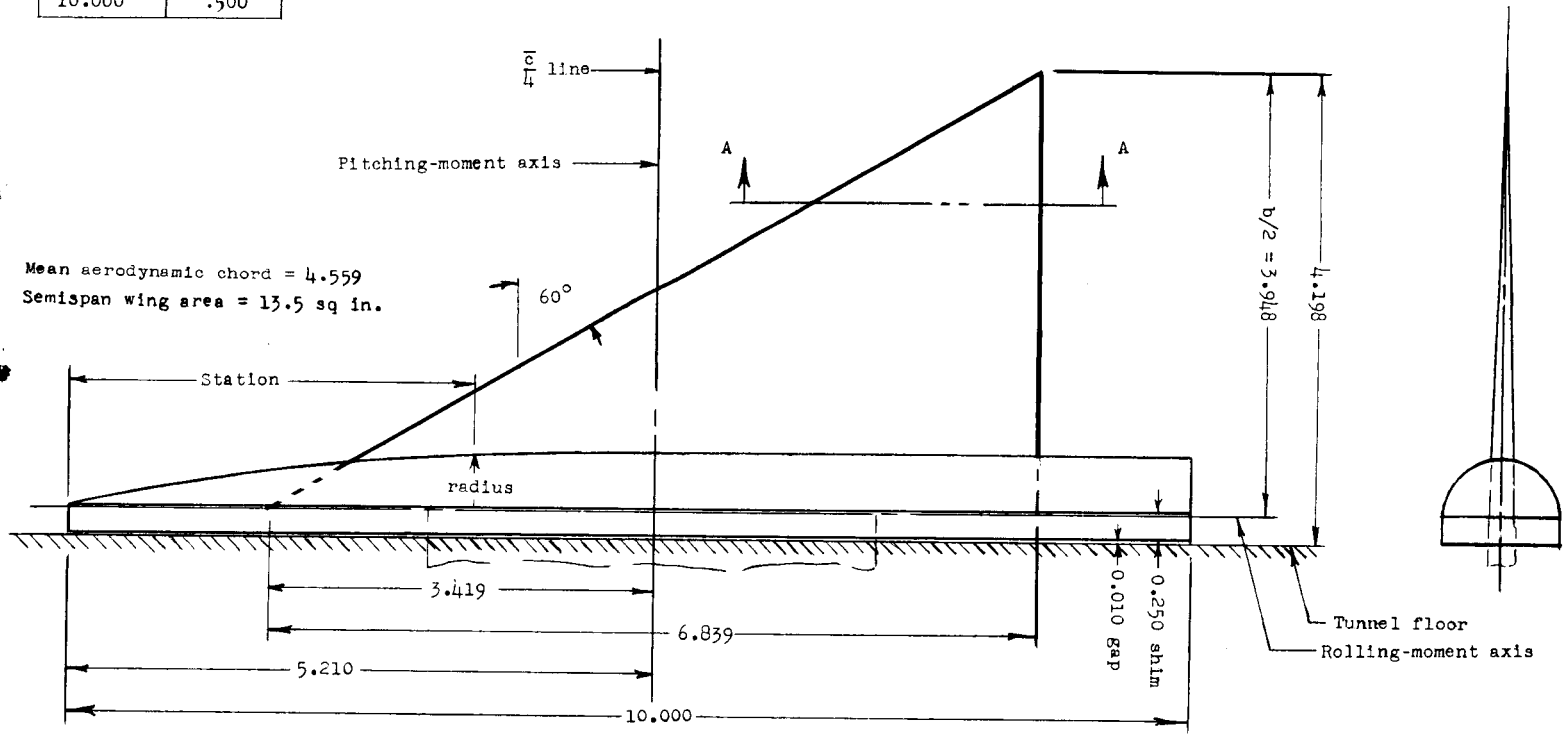


Figure 1.- Details of unswept semispan delta wing. All dimensions are in inches.

Douglas Store Ordinates	
Station	Radius
0	0
0.076	0.036
.188	.080
.299	.116
.411	.140
.519	.160
.630	.176
.742	.188
.966	.211
1.185	.227
1.408	.233
1.983	.233
2.206	.229
2.426	.219
2.645	.203
2.873	.184
3.200	.148
3.990	0

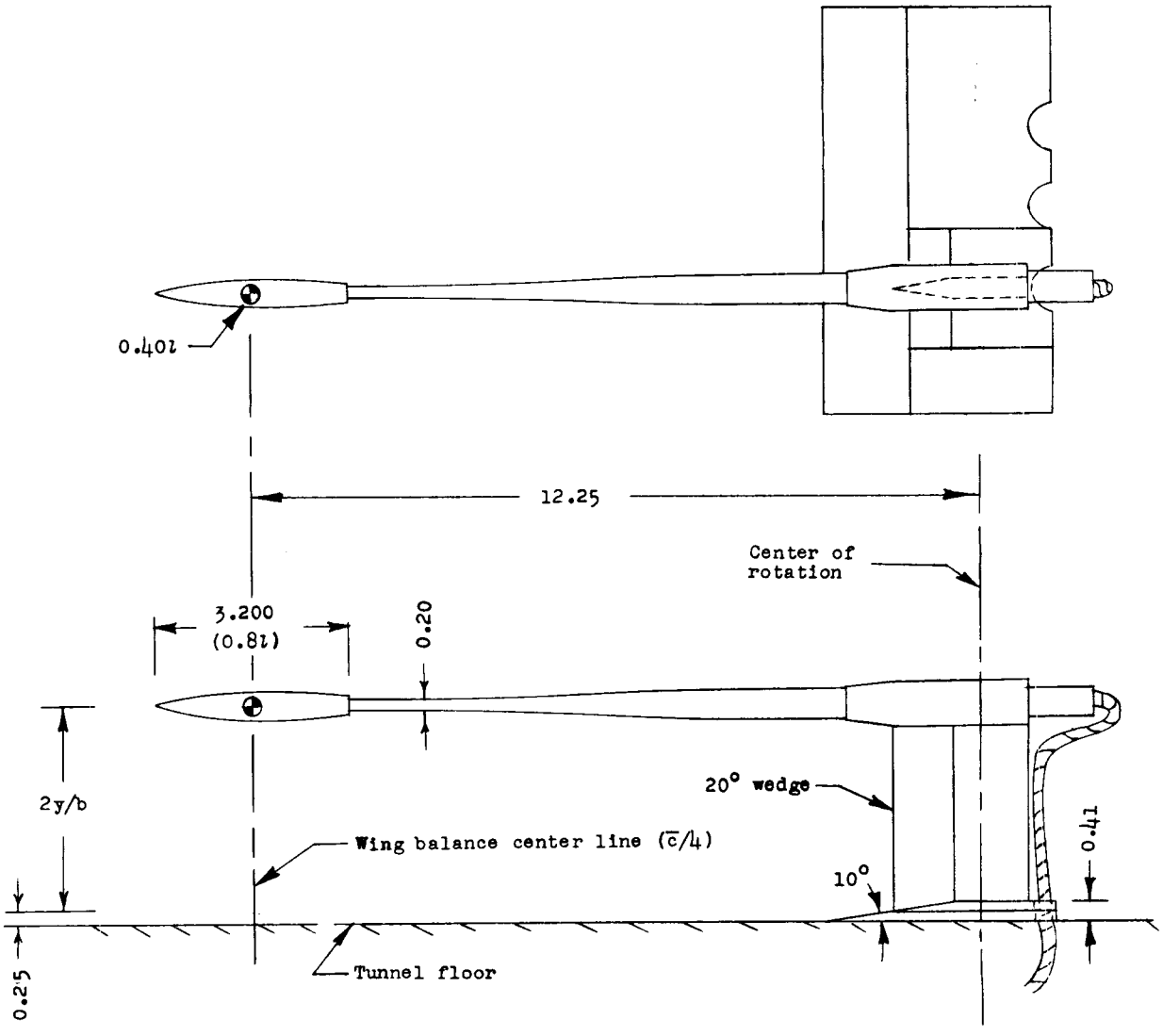


Figure 2.- Details of the sting-mounted DAC store. All dimensions are in inches.

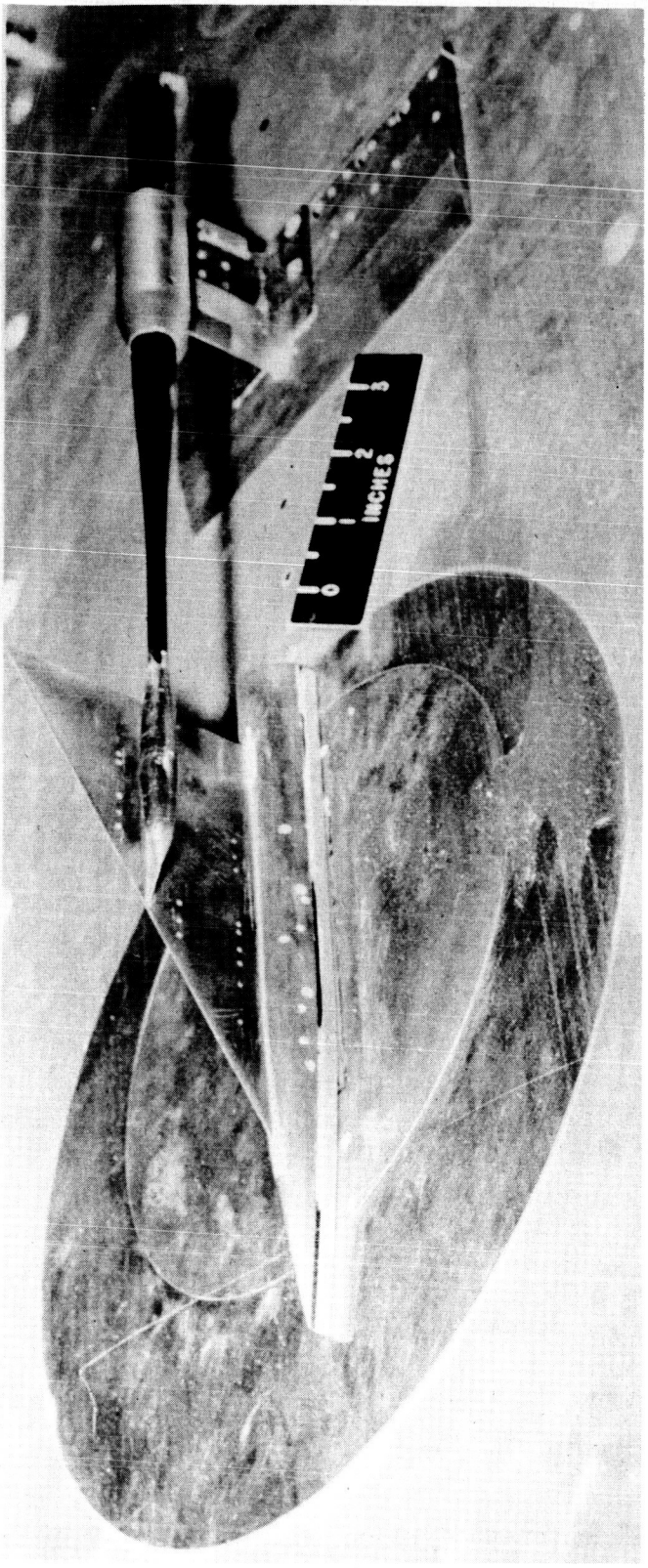


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Figure 3.- A typical test setup (store position: $2y/b = 0.50$, $x/\bar{c} = 0.453$, $z/d = 0.5$).

[redacted]

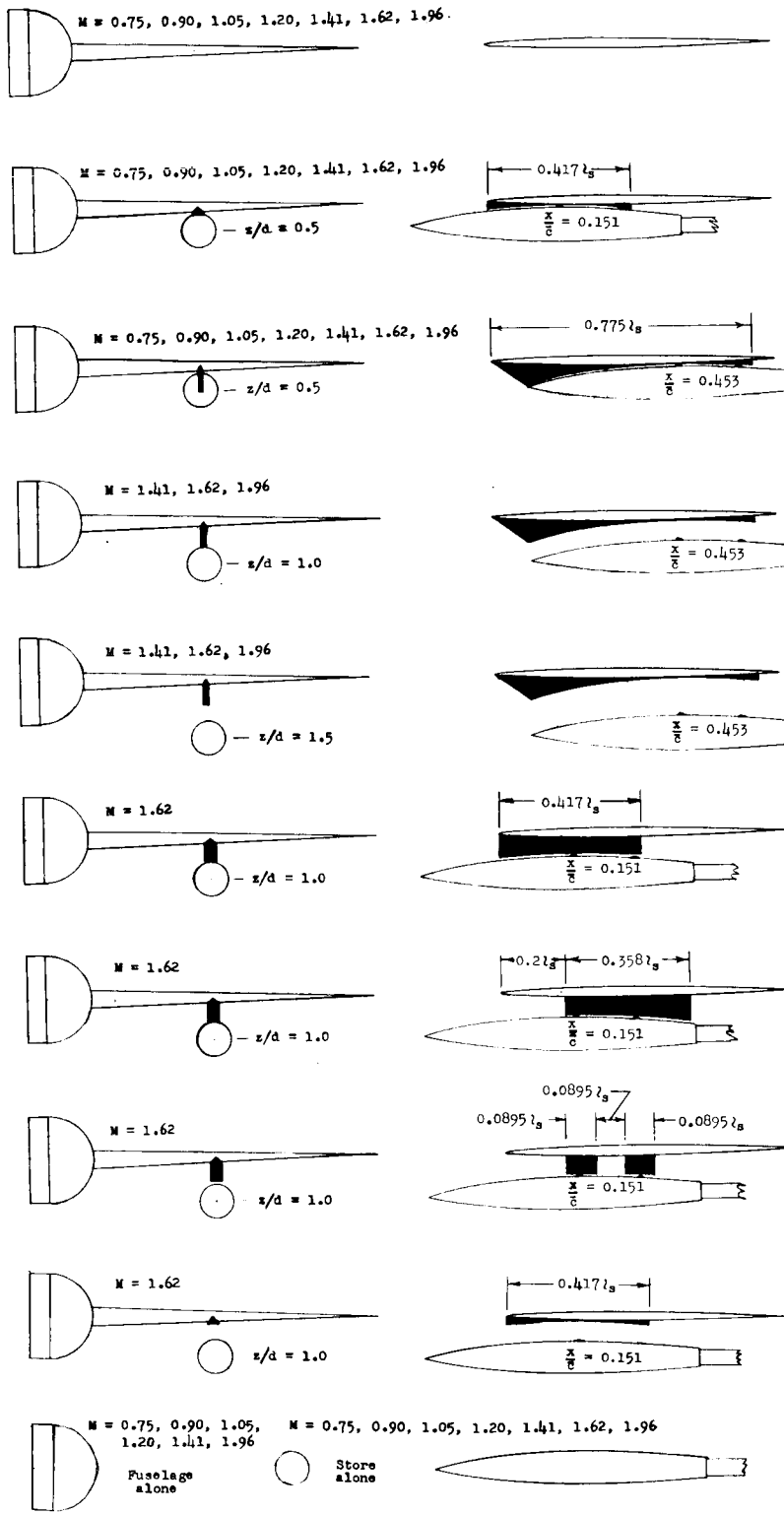
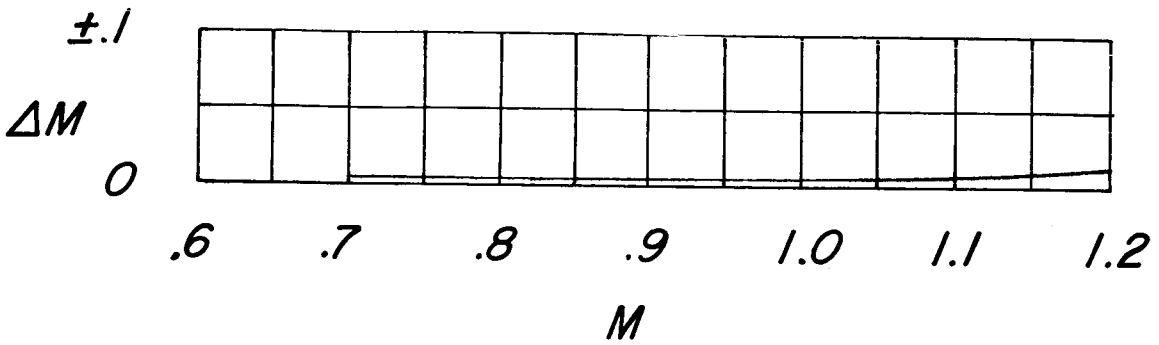
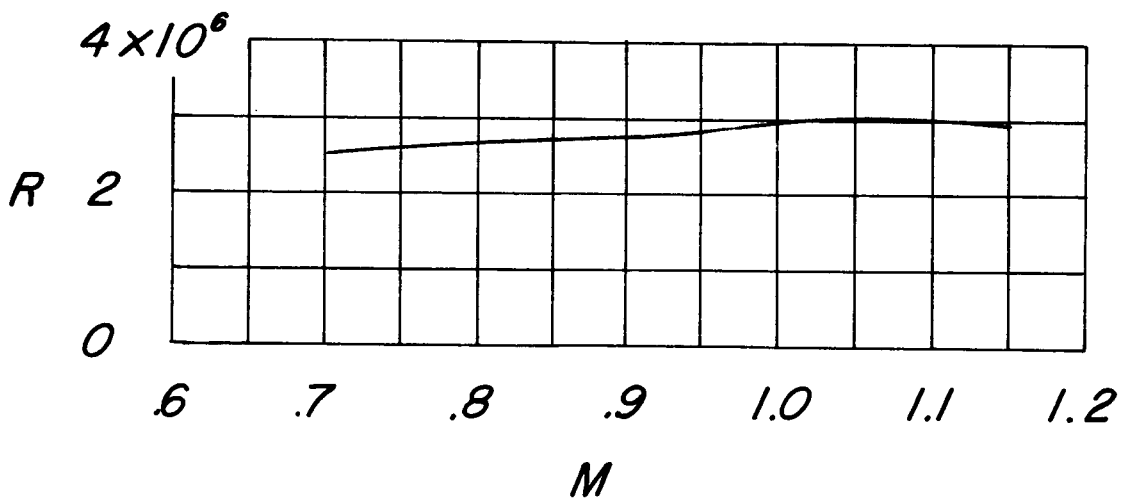


Figure 4.- Configuration of the present investigation and Mach numbers at which they were tested (2y/b = 0.50).



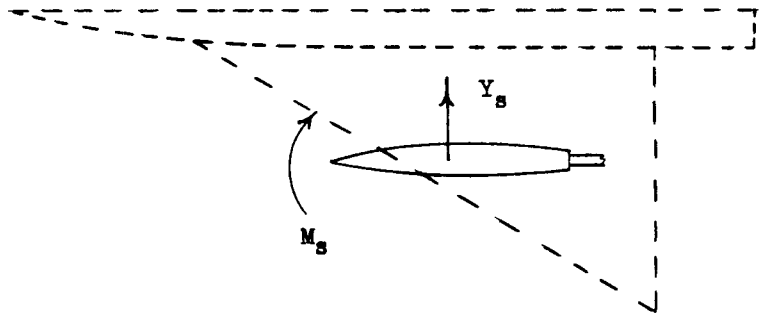
(a) Maximum deviation from test-section Mach number (tunnel clear).



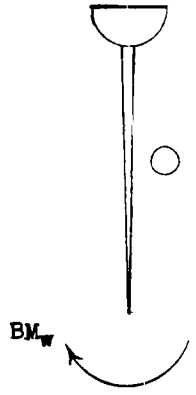
(b) Variation of test Reynolds number, based on $\bar{c}$, with Mach number.

Figure 5.- Variation of Reynolds number and deviation of test-region Mach number with Mach number.

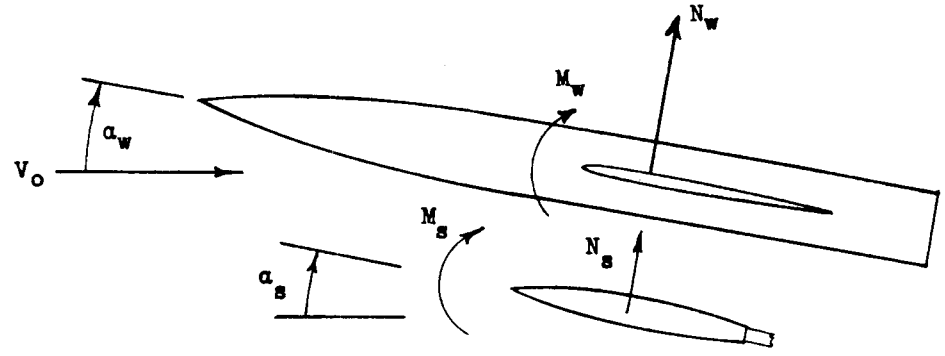
[redacted]



Lateral plane



Rear view



Longitudinal plane

Figure 6.- Positive direction of forces and moments measured on cantilevered wing-fuselage model and on sting-mounted store model.

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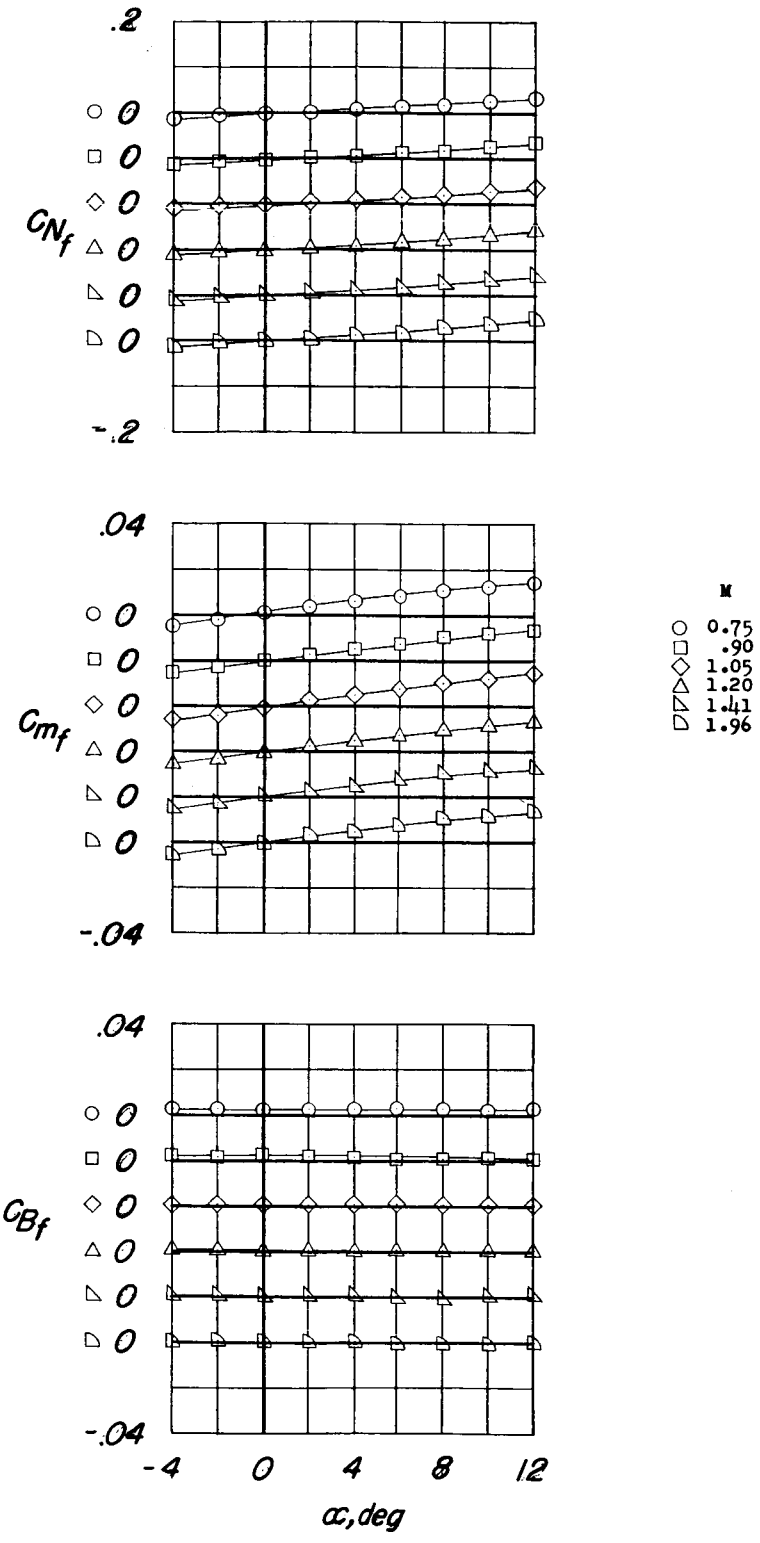
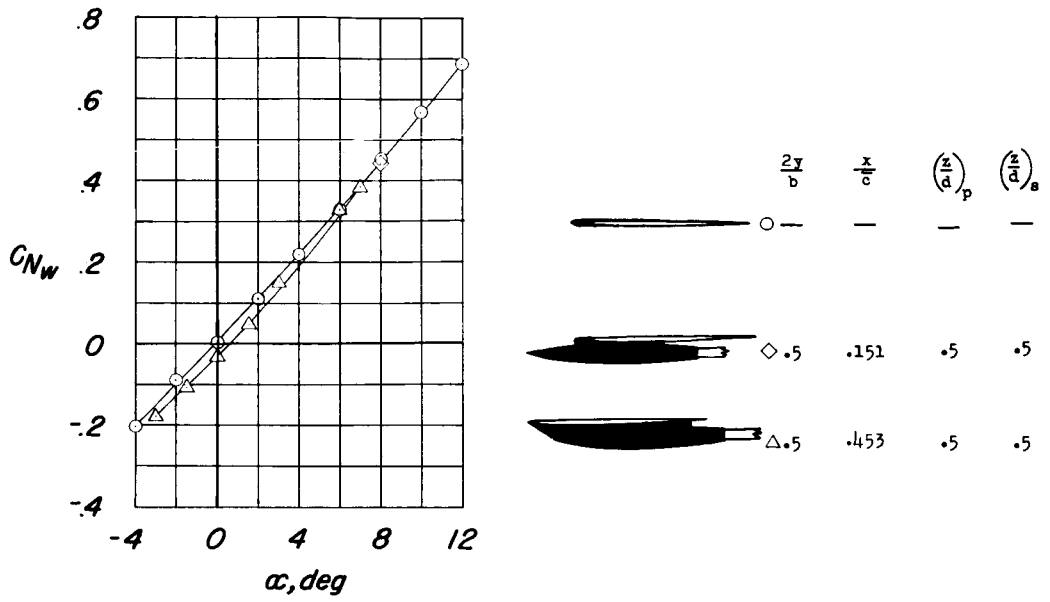
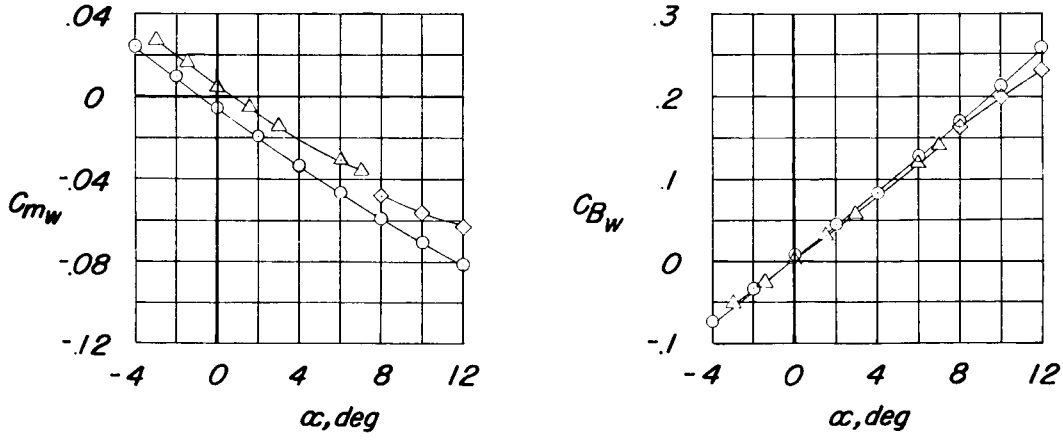


Figure 7.- Aerodynamic characteristics of the fuselage alone.

[redacted]





(a) M = 0.75.

Figure 8.- Influence of the DAC store chordwise location on the aerodynamic characteristics of the wing-fuselage combination.

[redacted]

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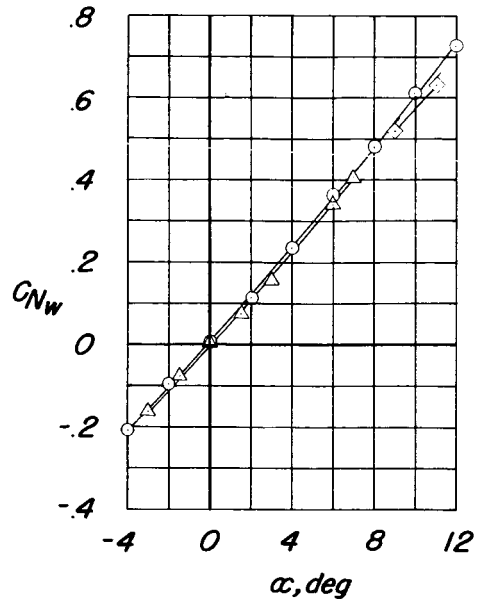
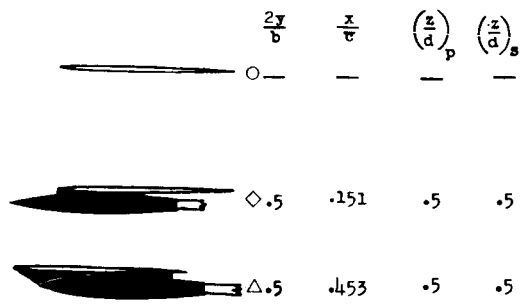
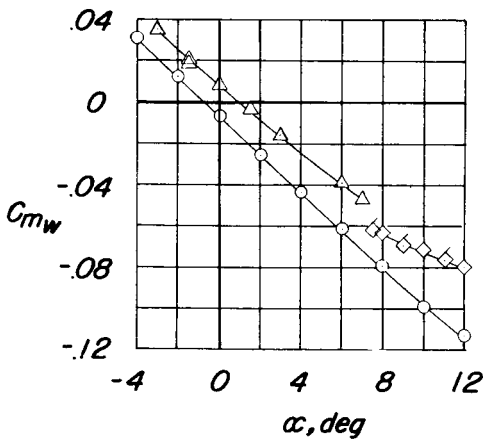
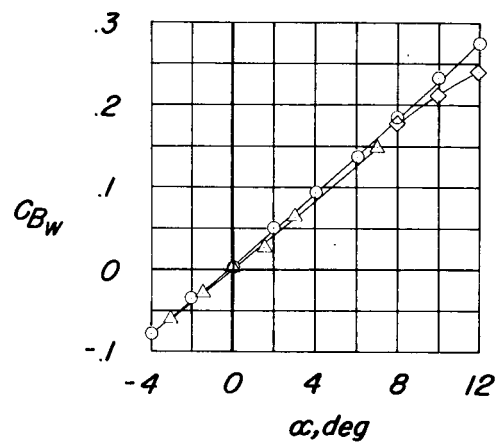




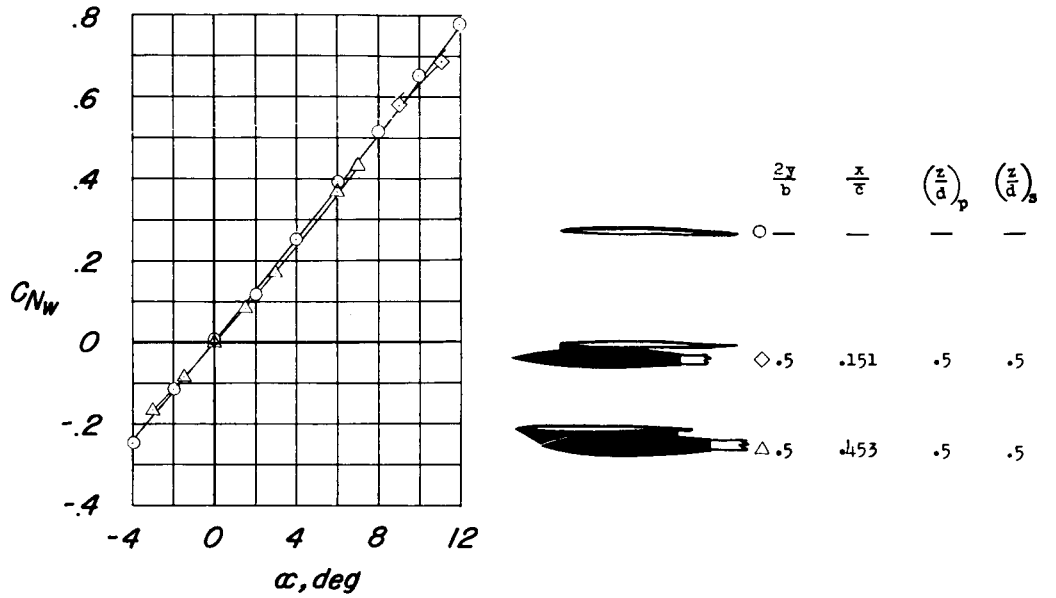


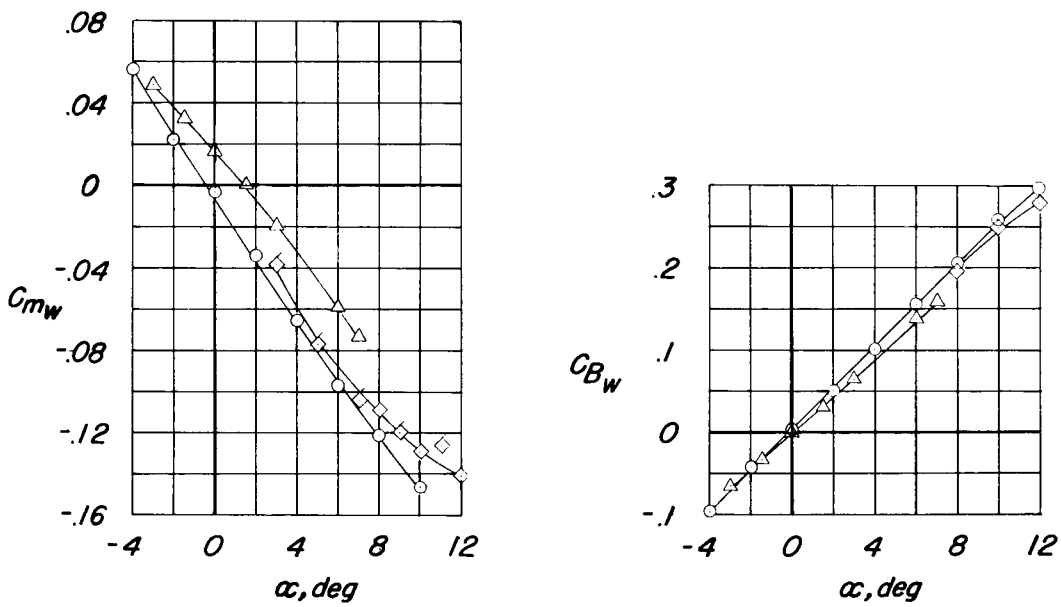


(b) M = 0.90.

Figure 8.- Continued.

[redacted]

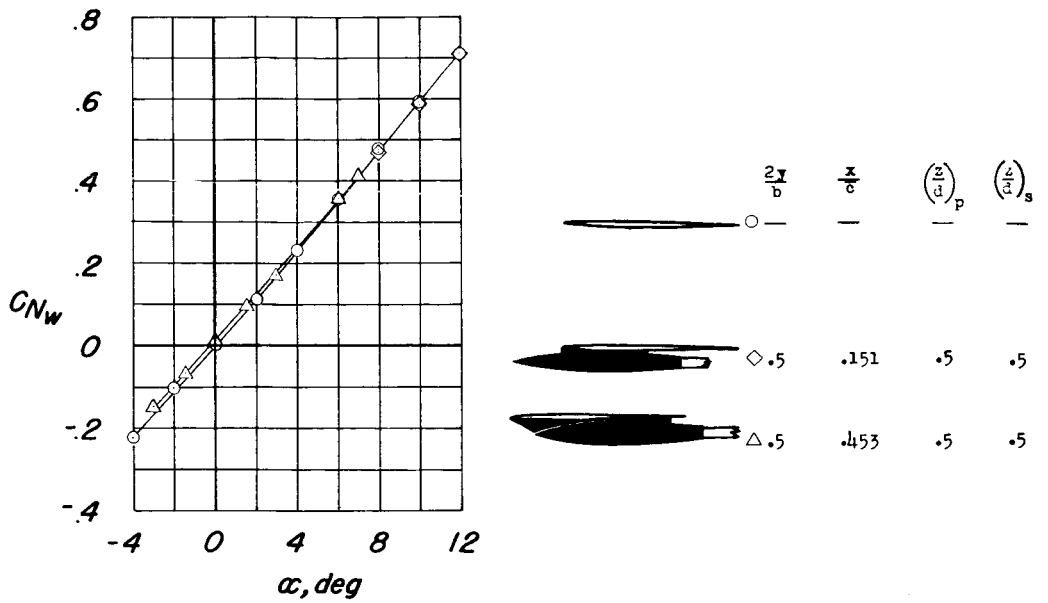


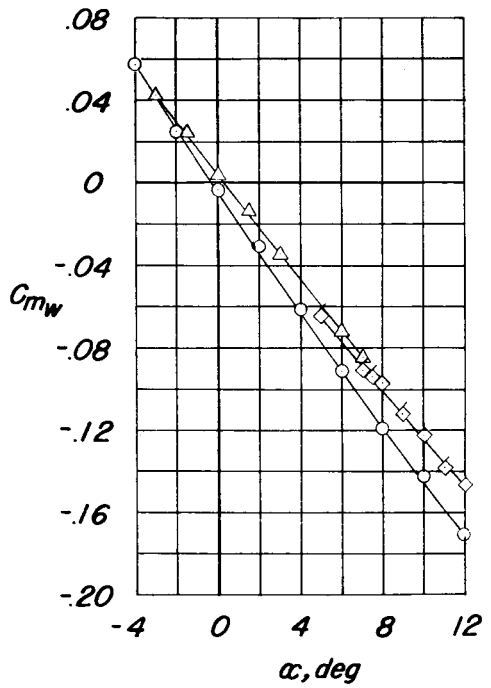


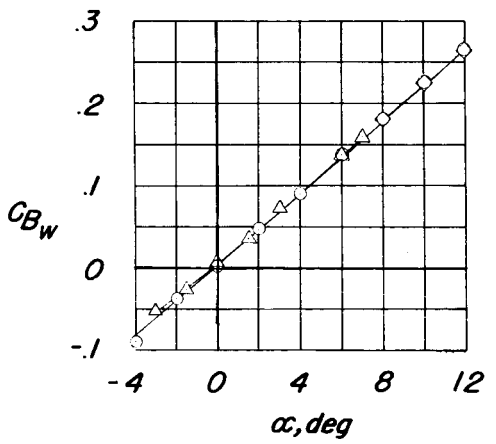
(c) M = 1.05.

Figure 8.- Continued.

[redacted]



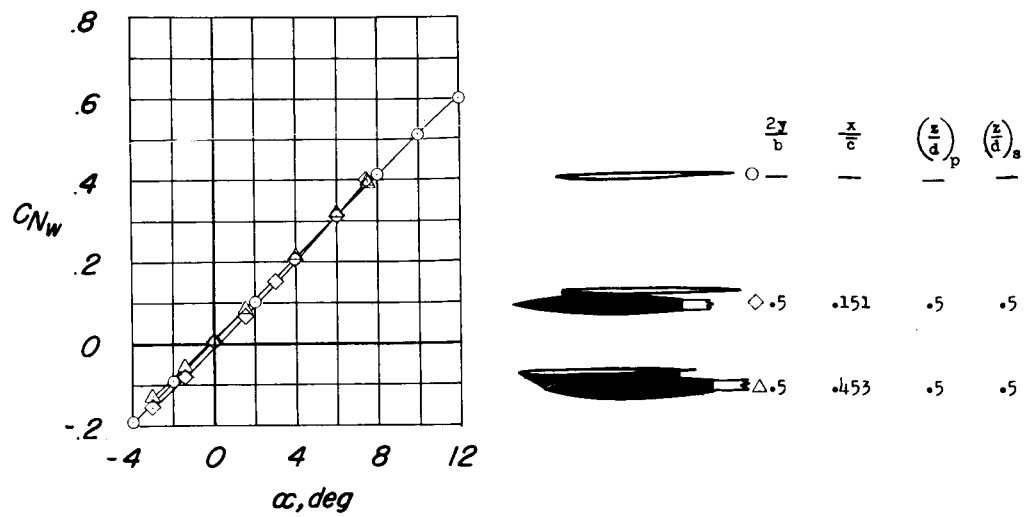


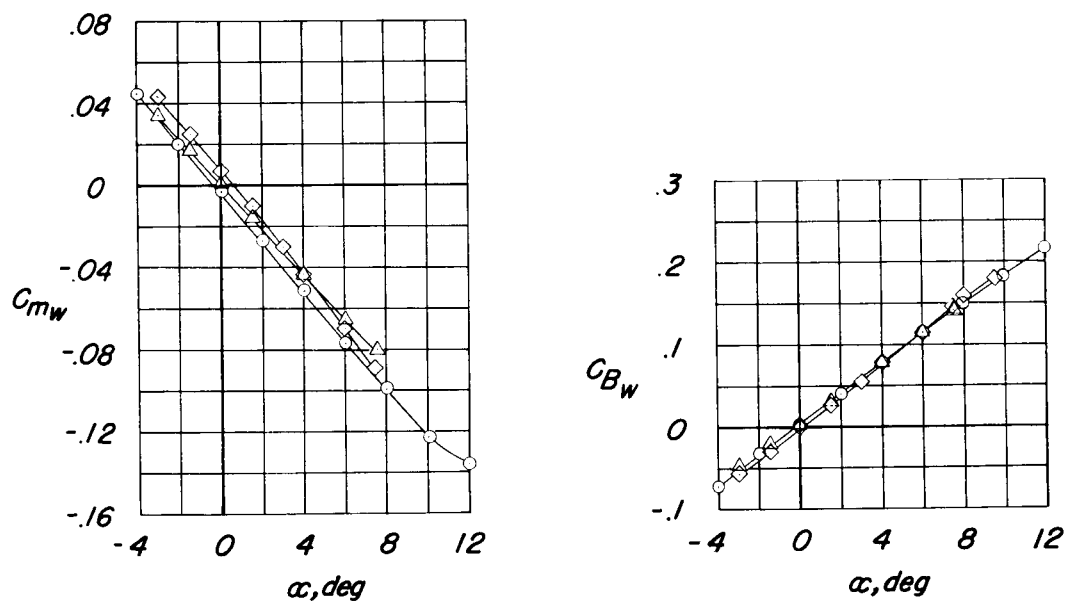


(d) M = 1.20.

Figure 8.- Continued.

[redacted]





(e) M = 1.41.

Figure 8.- Continued.

[redacted]

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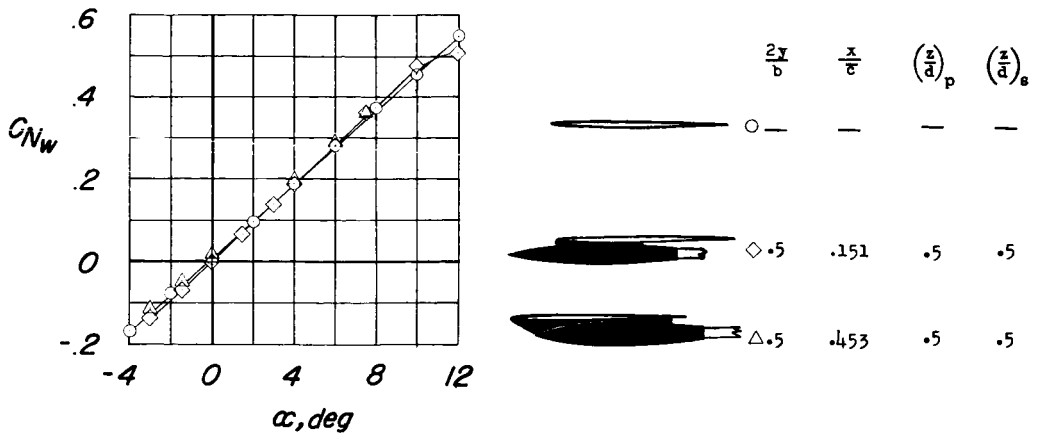

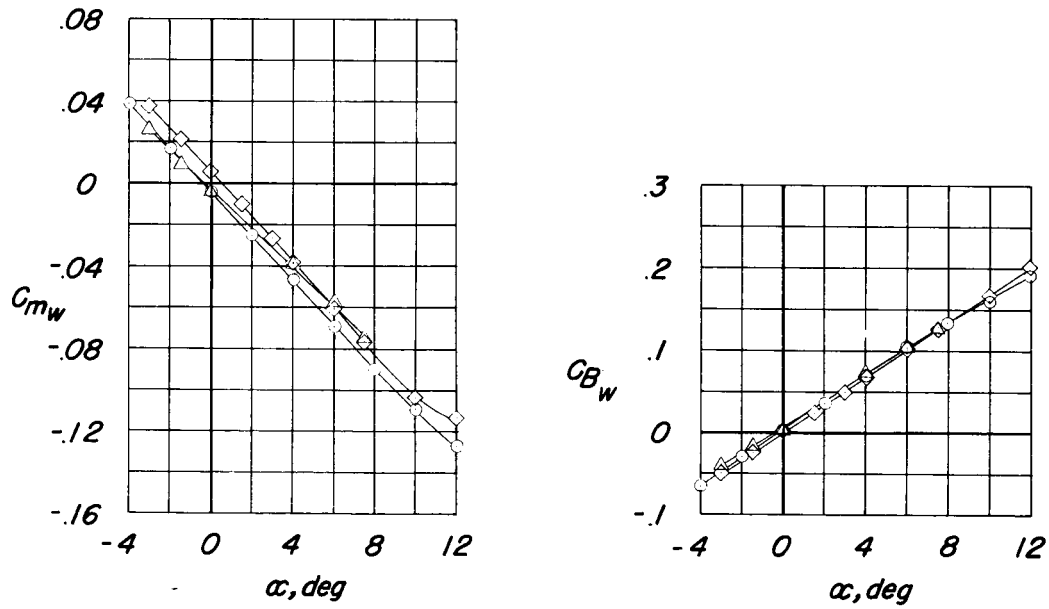

(f) M = 1.62.

Figure 8.- Continued.

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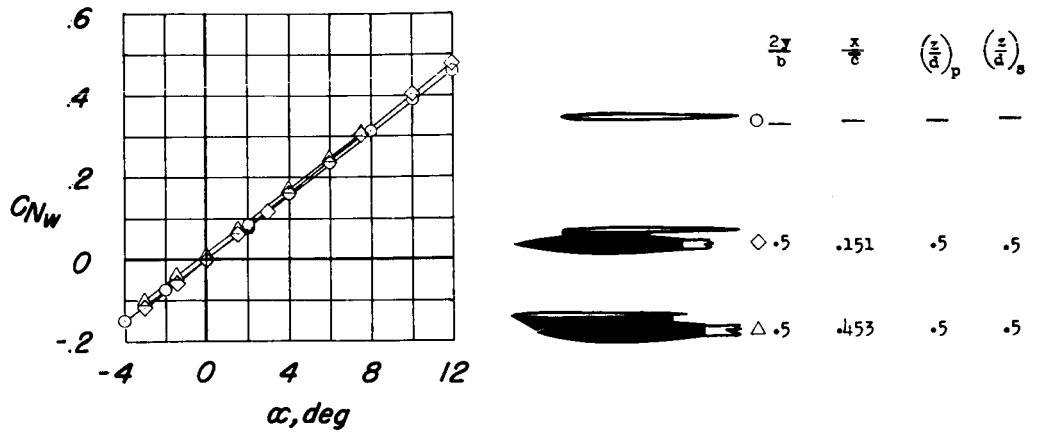
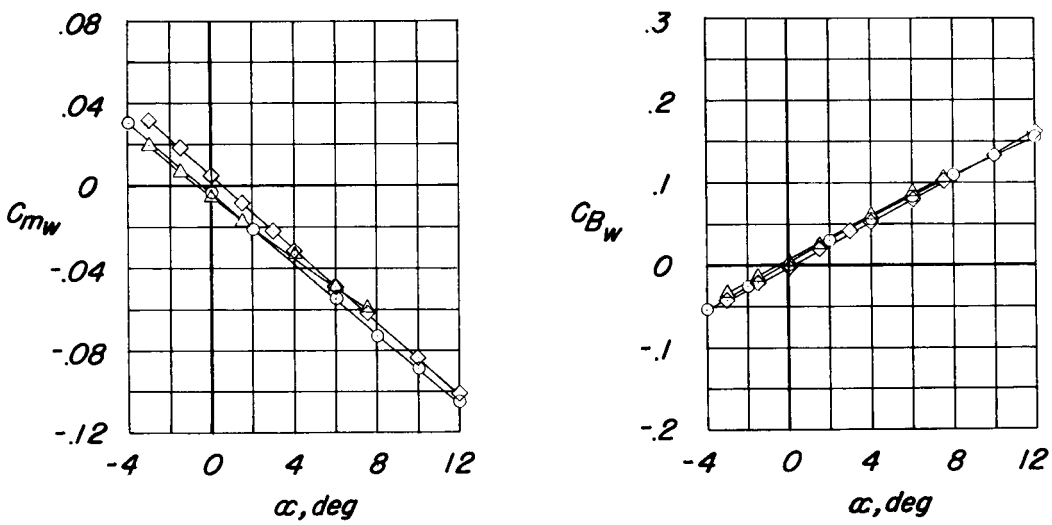
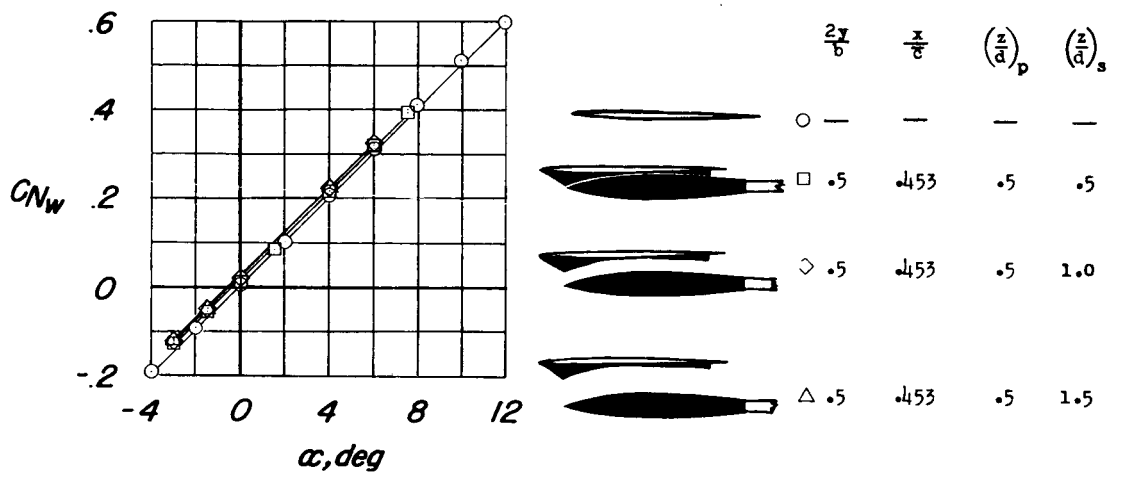
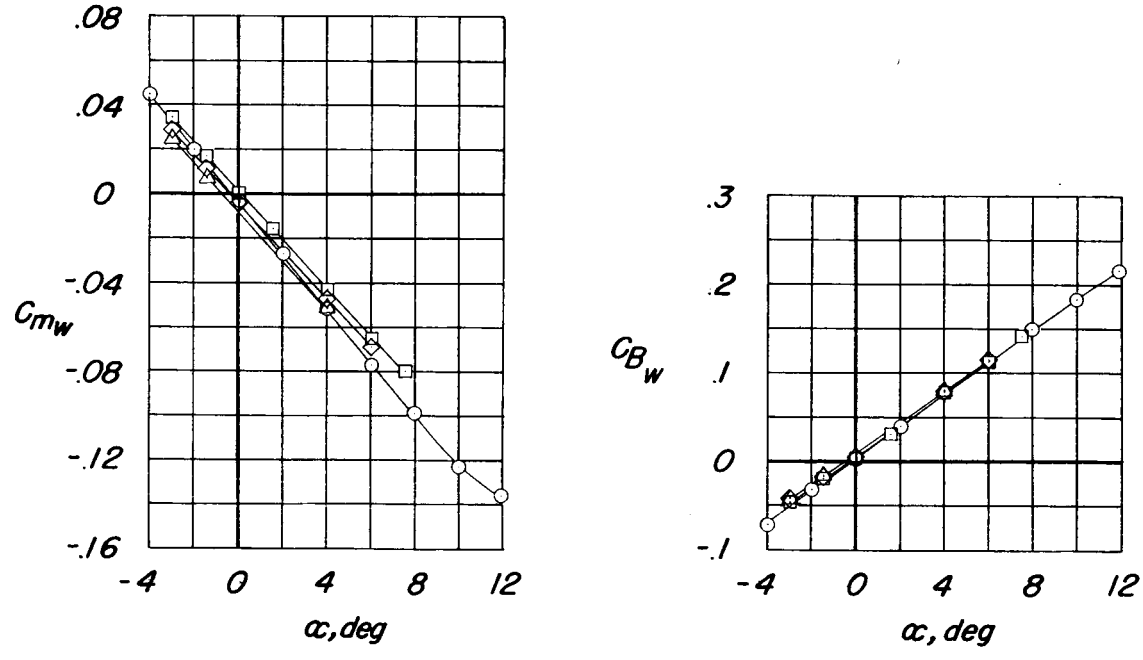




(g) M = 1.96.

Figure 8.- Concluded.

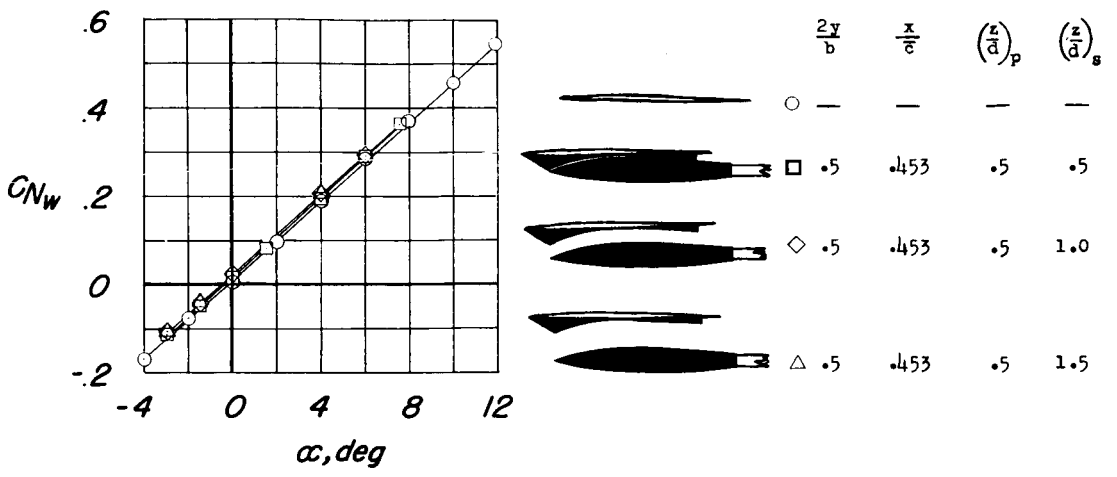


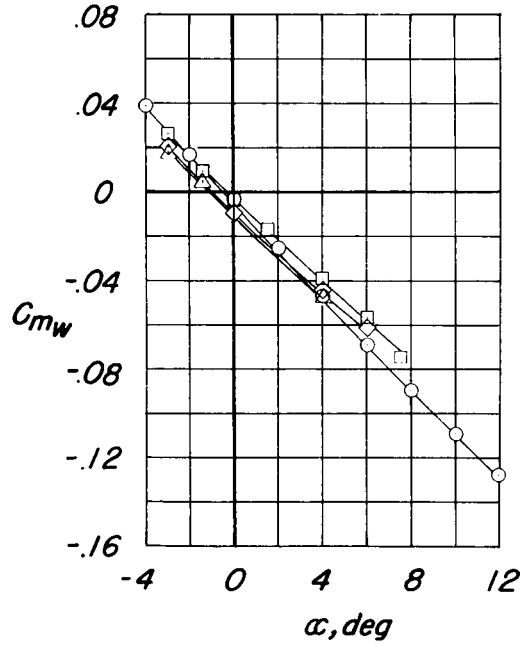


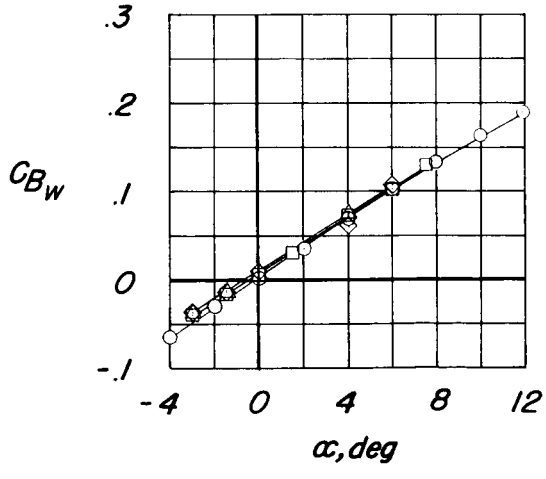
(a) M = 1.41.

Figure 9.- Influence of the DAC store vertical location on the aerodynamic characteristics of the wing-fuselage combination.

[redacted]



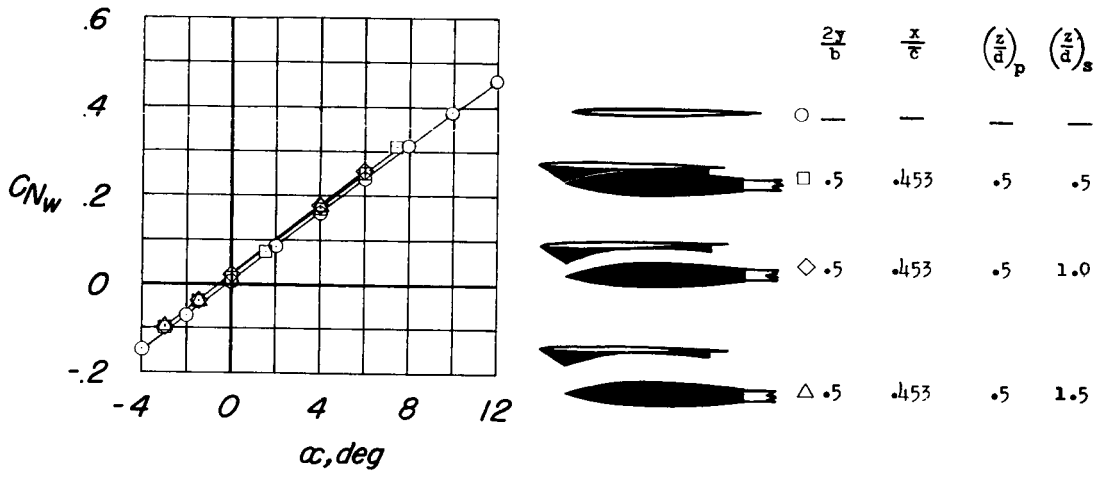


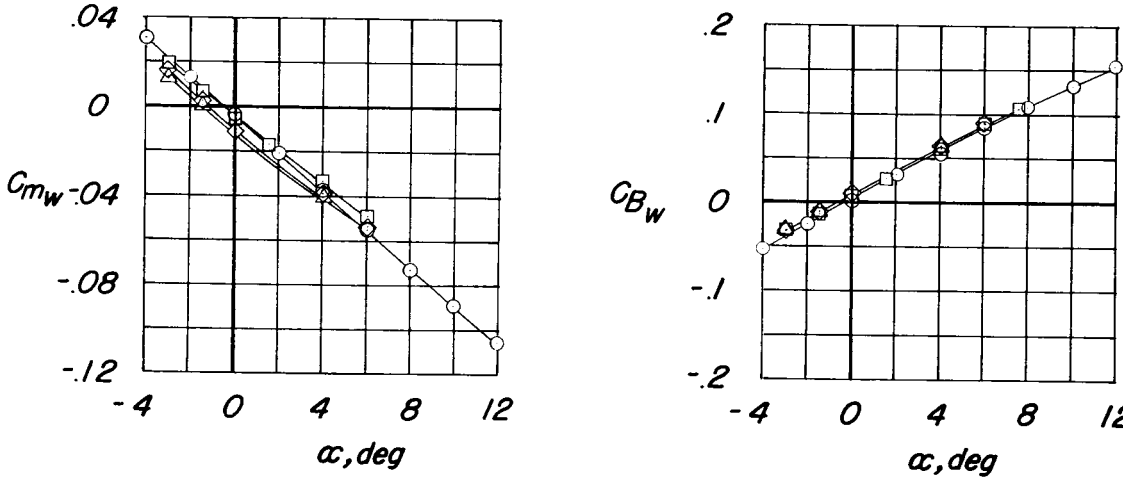


(b) M = 1.62.

Figure 9.- Continued.

[redacted]

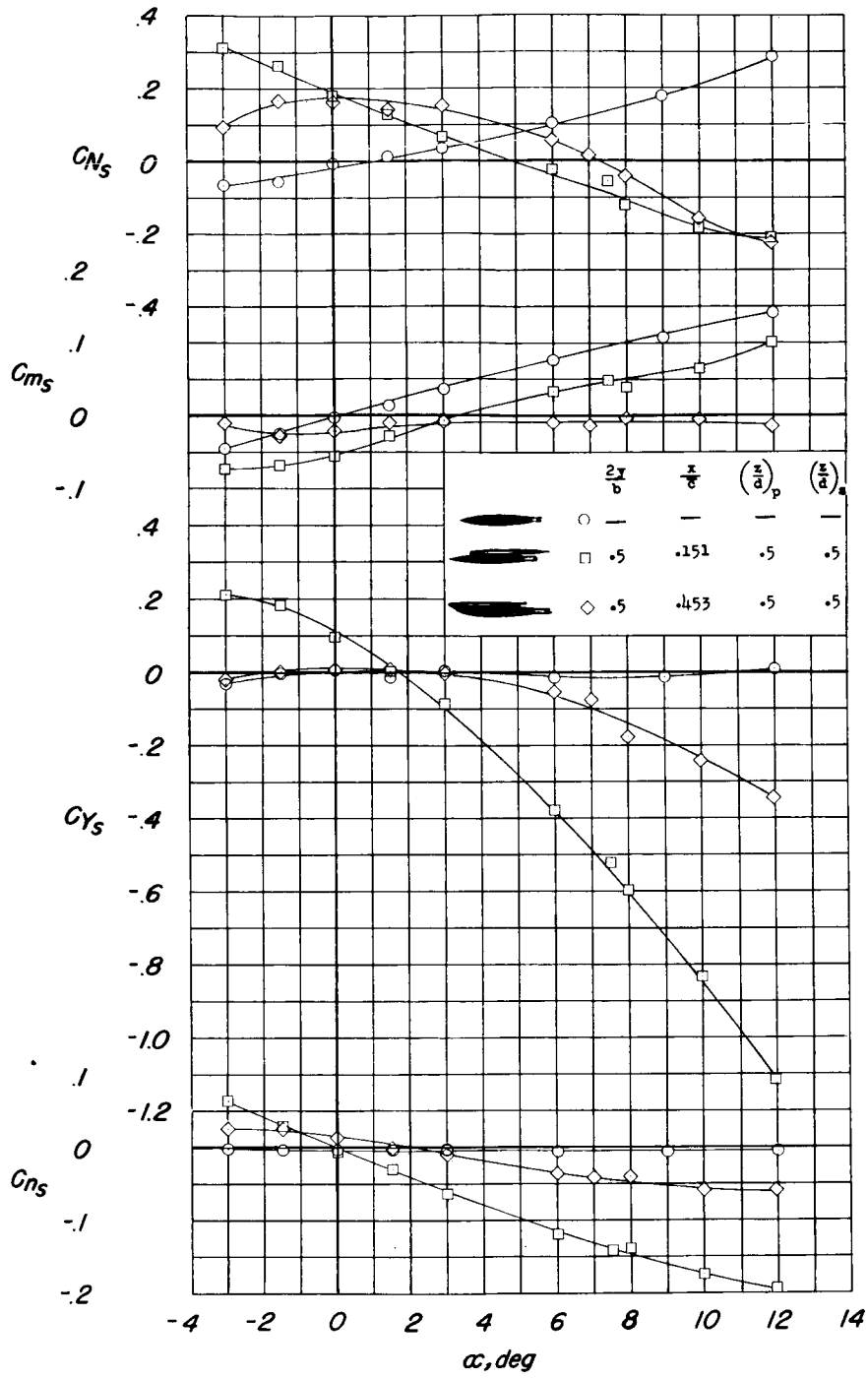




(c) M = 1.96.

Figure 9.- Concluded.

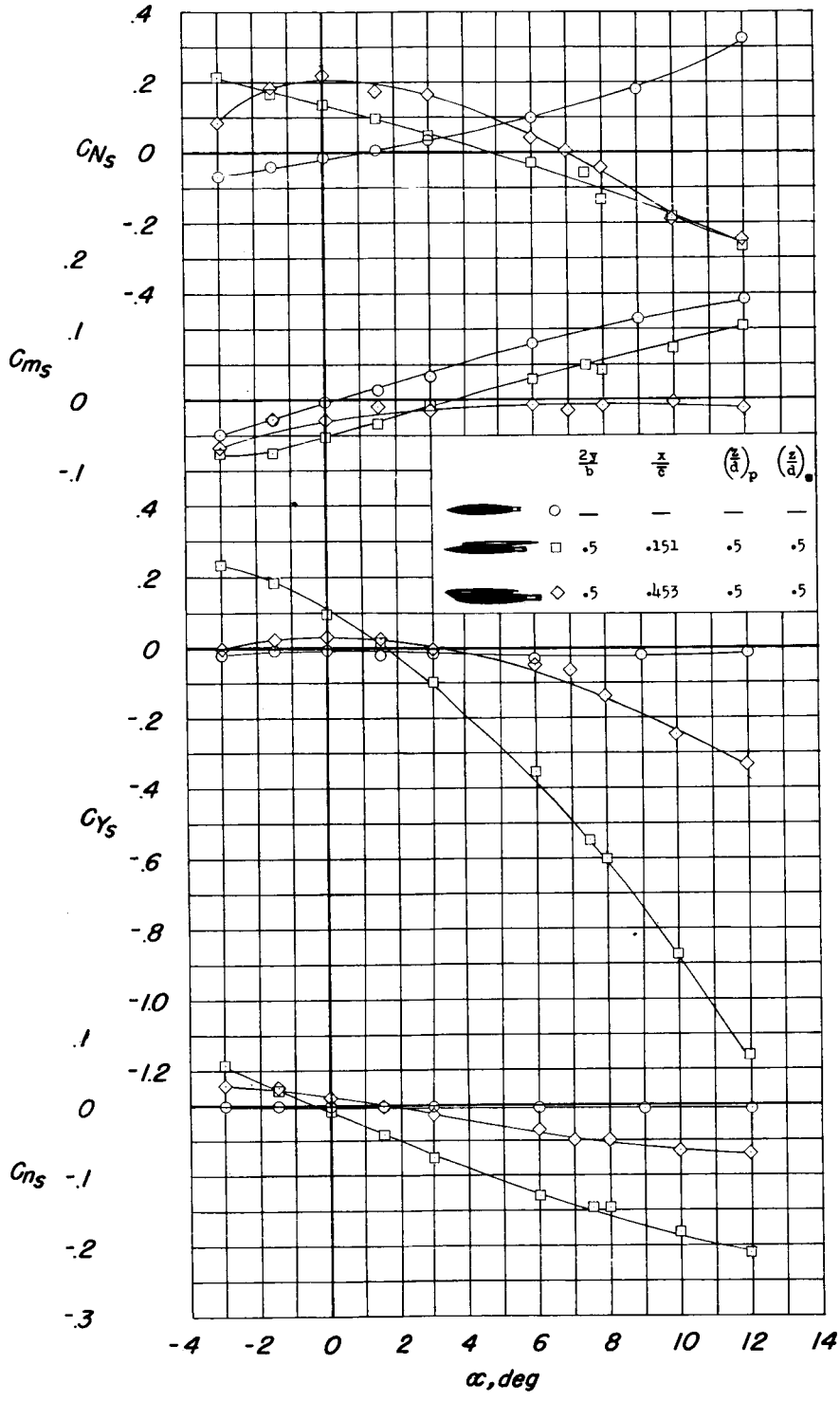
[redacted]



(a) M = 0.75.

Figure 10.- Aerodynamic characteristics of the DAC store at two chordwise locations relative to the wing.

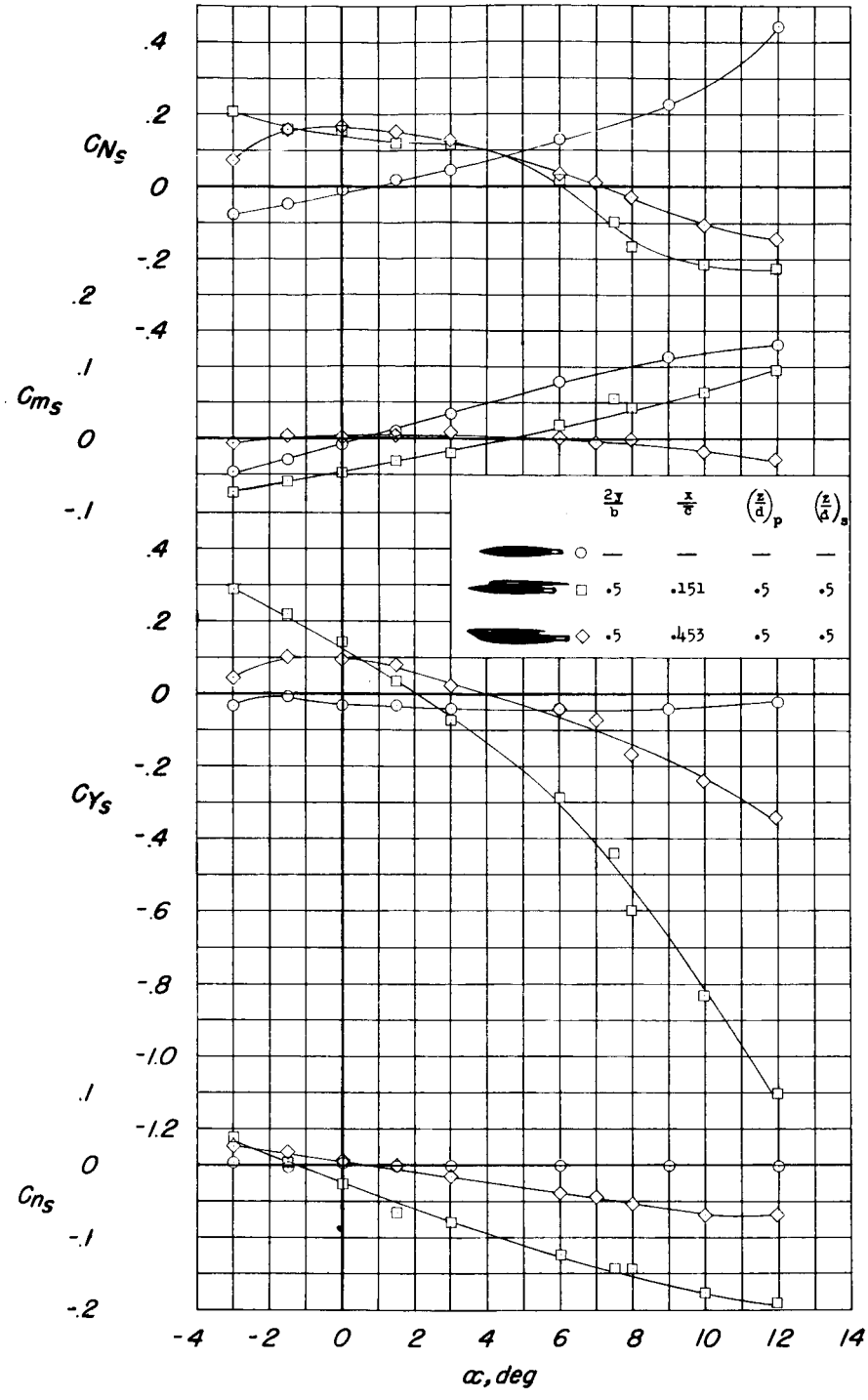
C[redacted]



(b) M = 0.90.

Figure 10.- Continued.

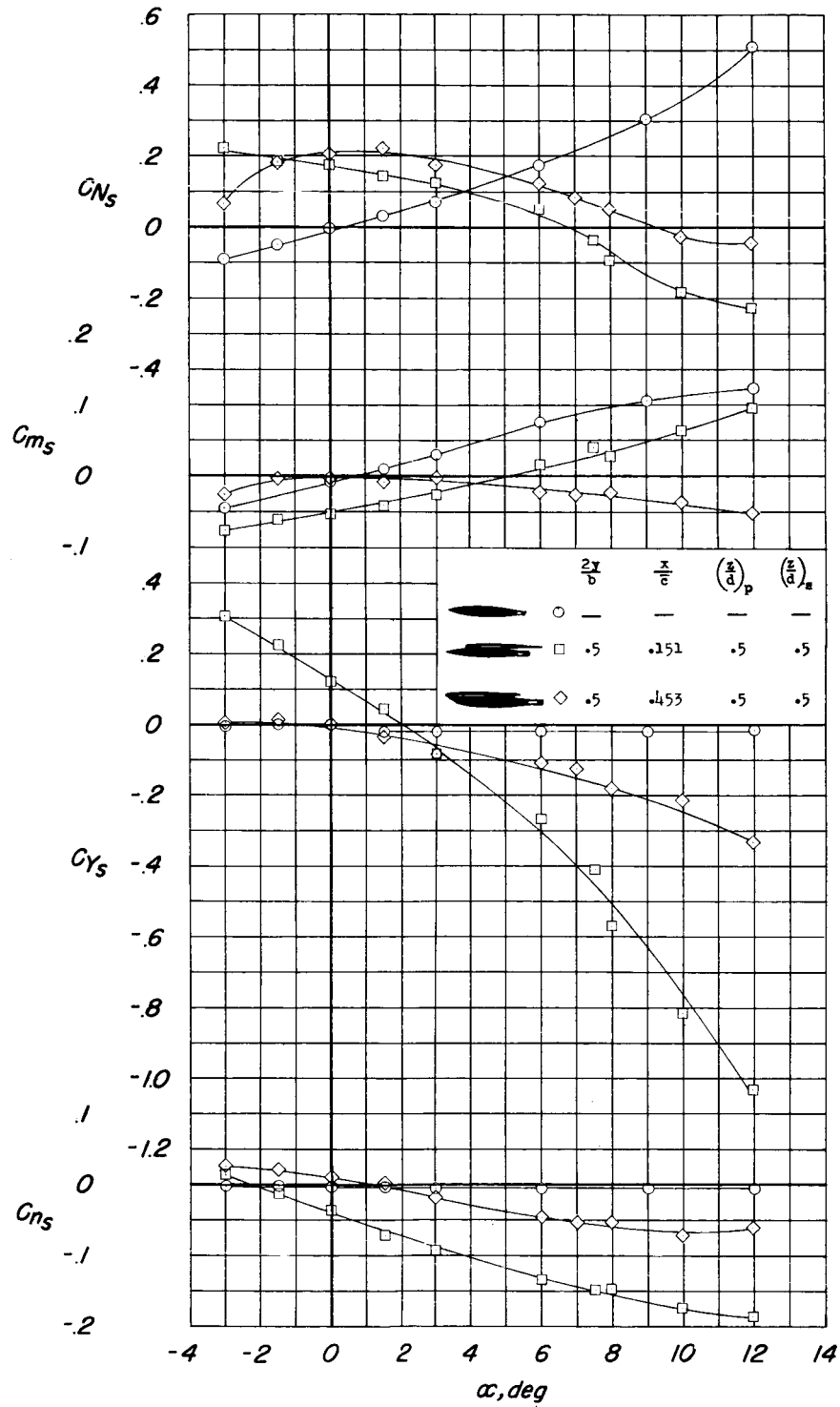
[redacted]



(c) M = 1.05.

Figure 10.- Continued.

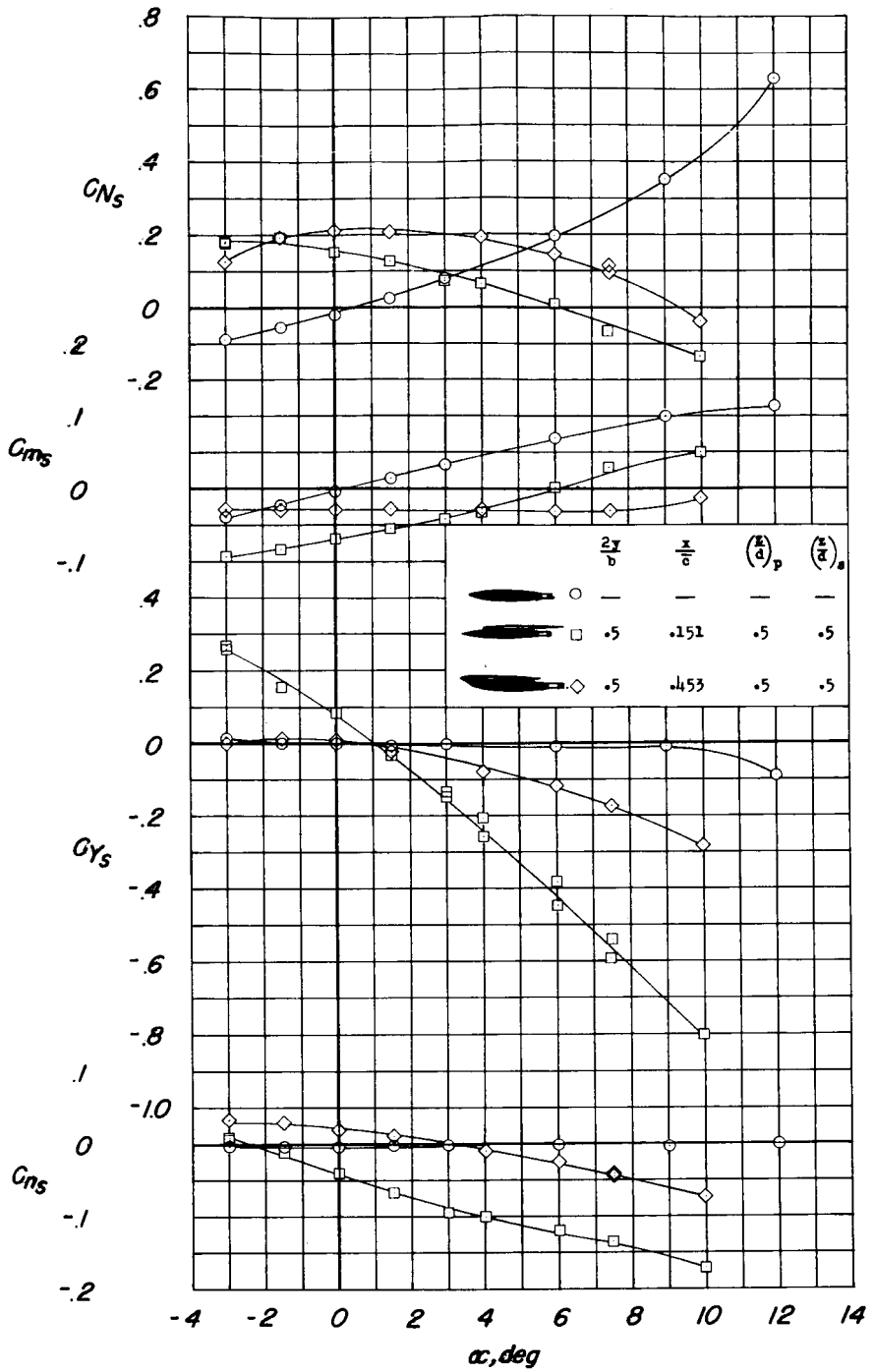
[redacted]



(d) M = 1.20.

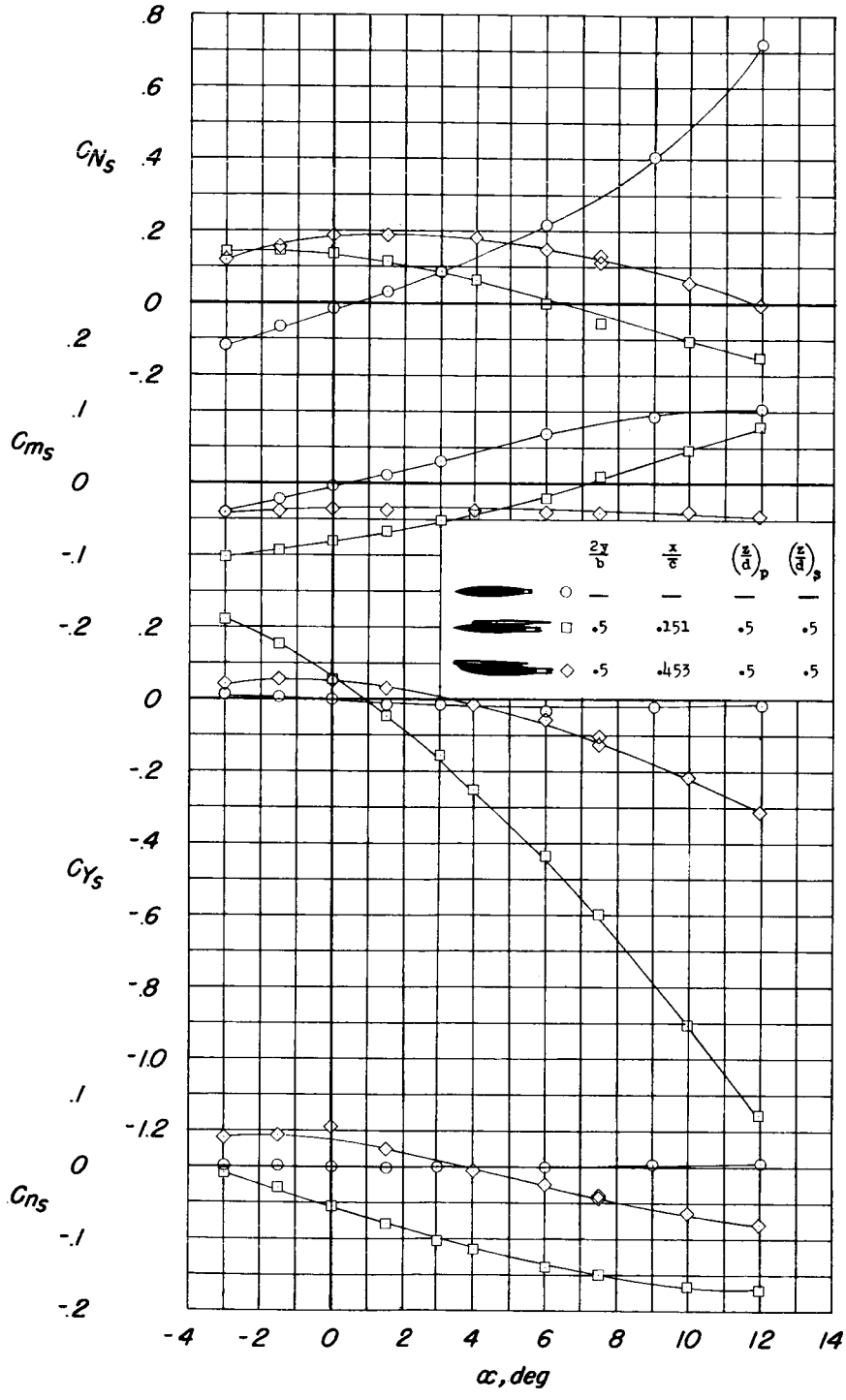
Figure 10.- Continued.

[redacted]



(e) M = 1.41.

Figure 10.- Continued.



(f) M = 1.62.

Figure 10.- Continued.

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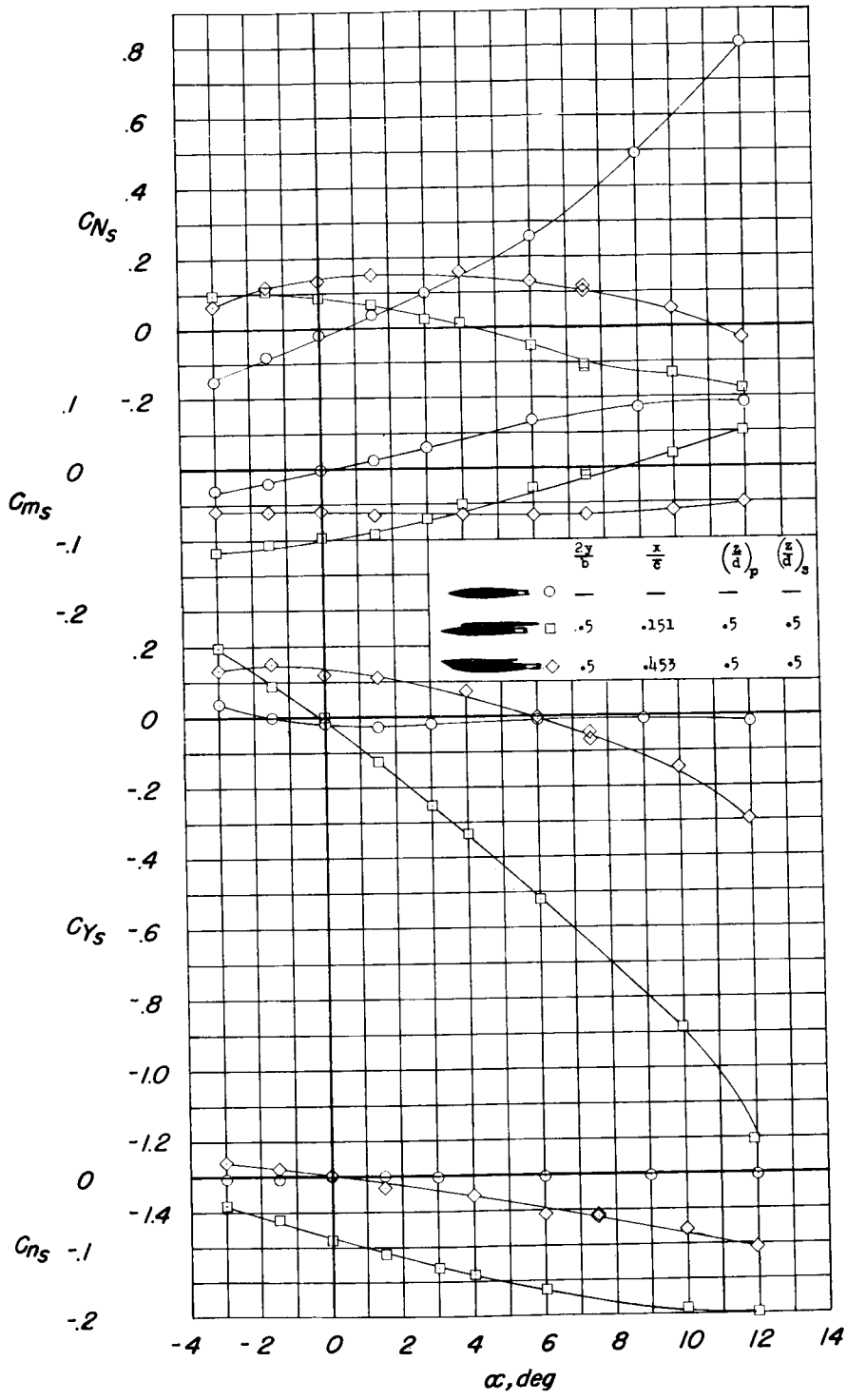

(g) M = 1.96.

Figure 10.- Concluded.

[redacted]

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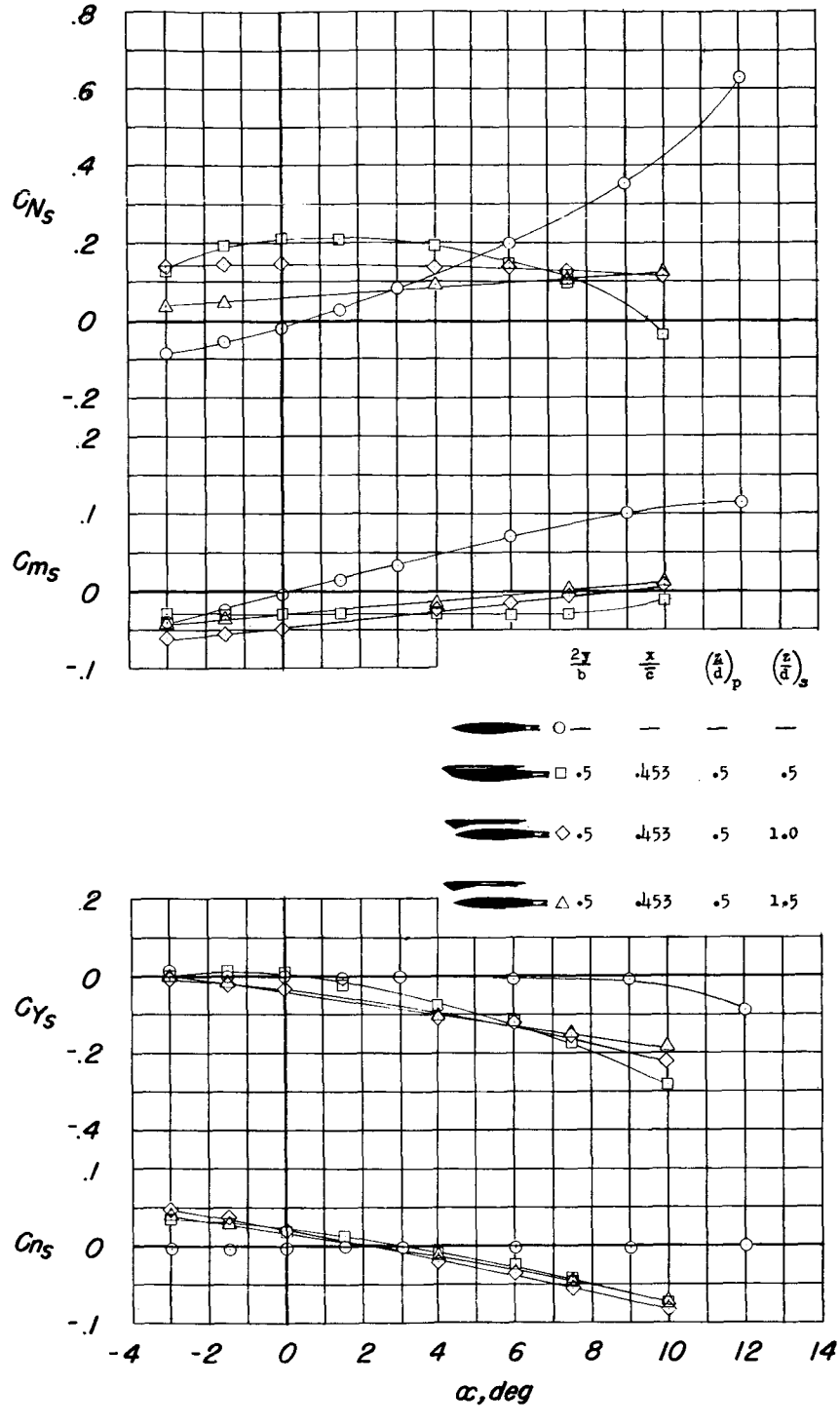
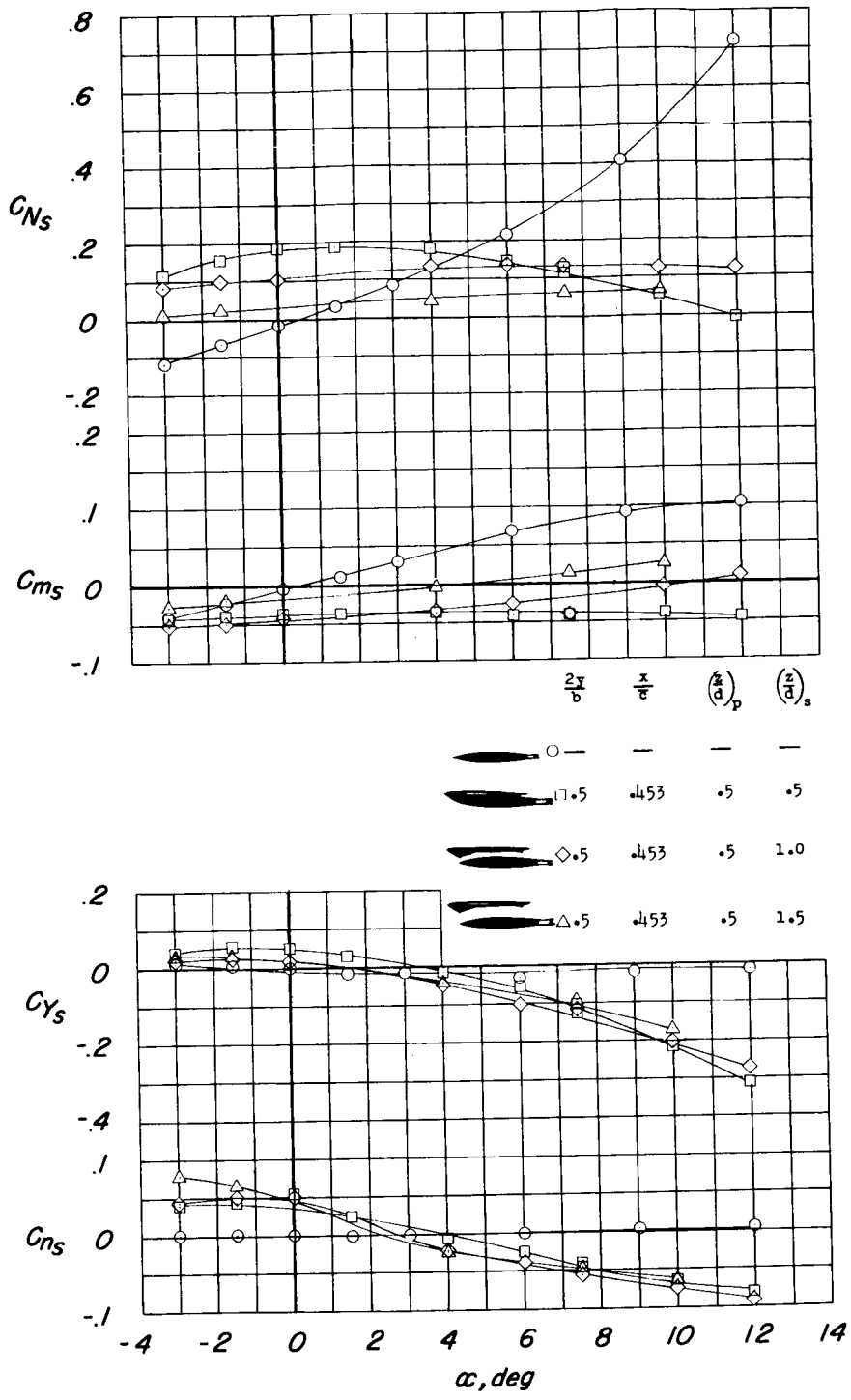


(a) M = 1.41.

Figure 11.- Aerodynamic characteristics of the DAC store at various vertical locations relative to the wing ($x/\bar{c}$ = 0.453).

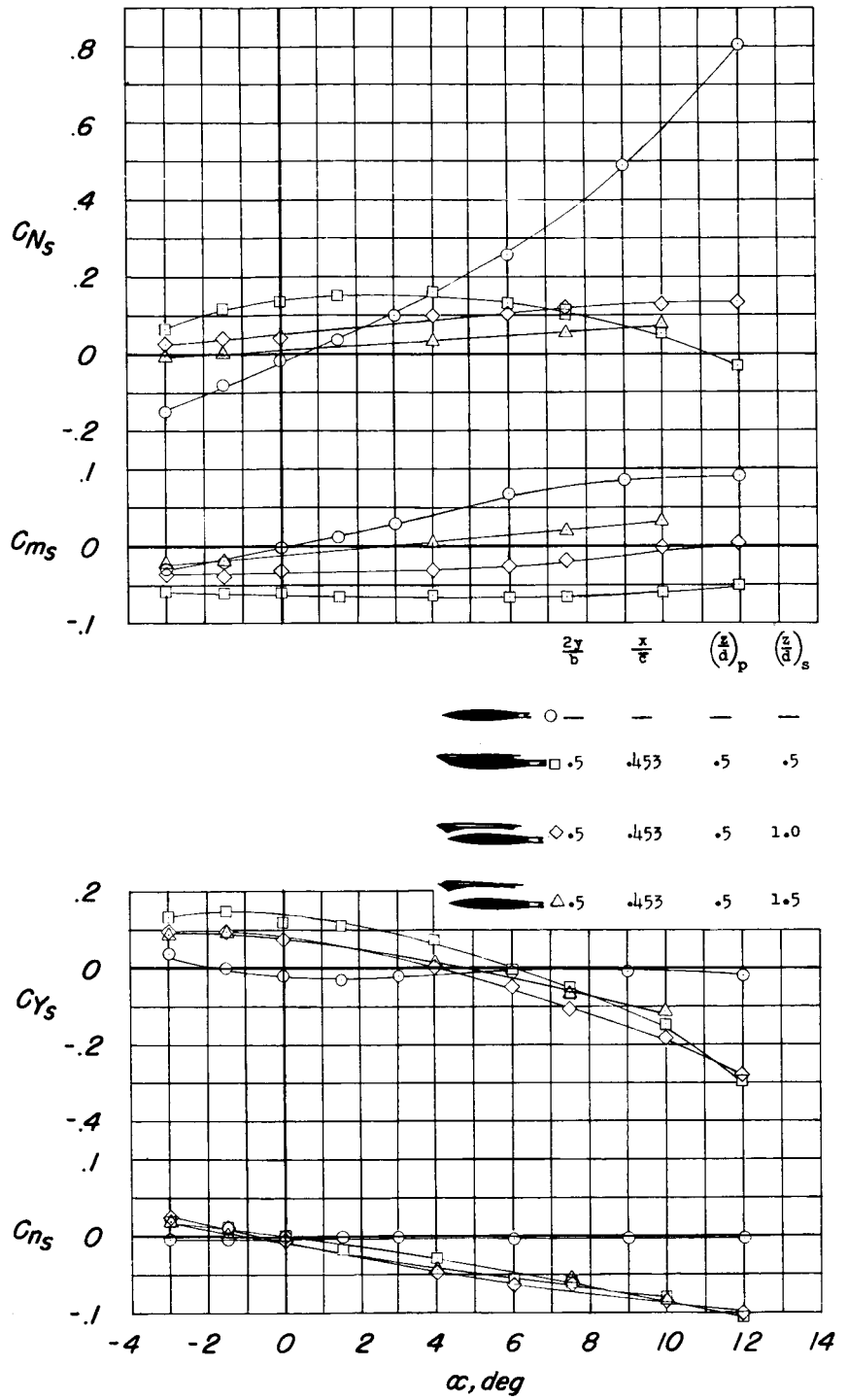
[redacted]



(b) M = 1.62.

Figure 11.- Continued.

[redacted]



(c) M = 1.96.

Figure 11.- Concluded.

[redacted]

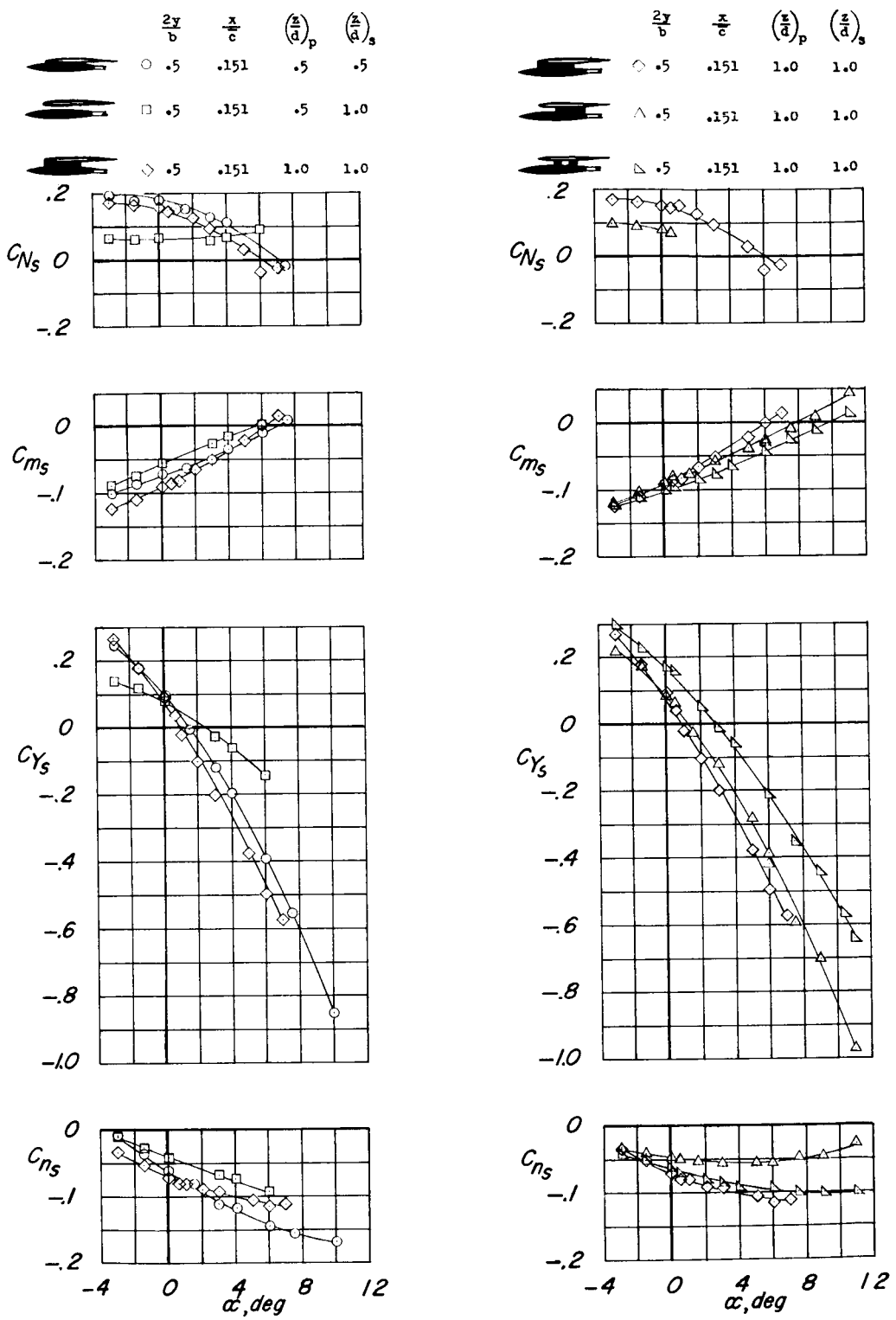


Figure 12.- Effect of various pylon configurations on the aerodynamic characteristics of the DAC store at M = 1.62.

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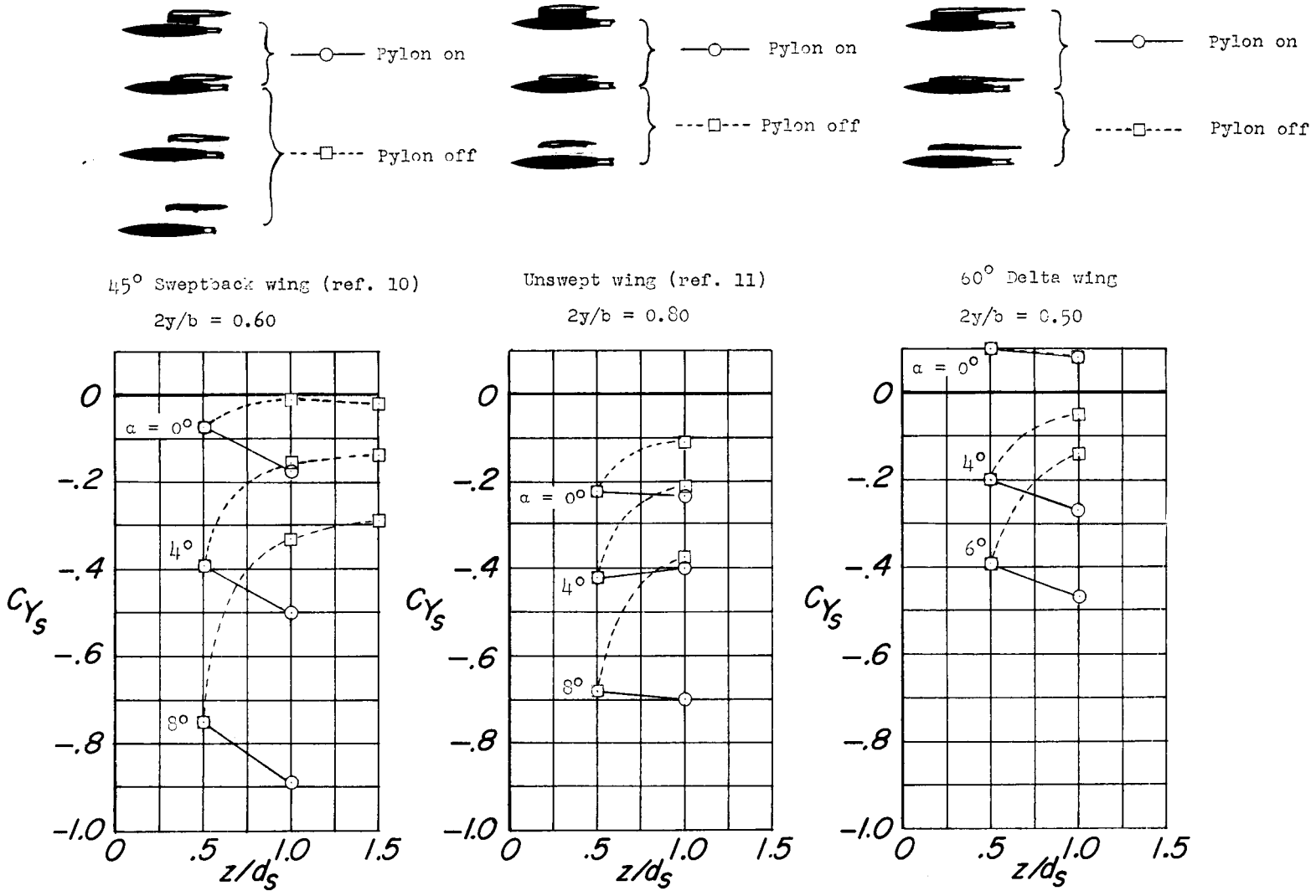

Figure 13.- Effect of pylon on store side-force coefficient with store beneath a sweptback wing, an unswept wing, and the 60° delta wing of the present investigation. M = 1.62.

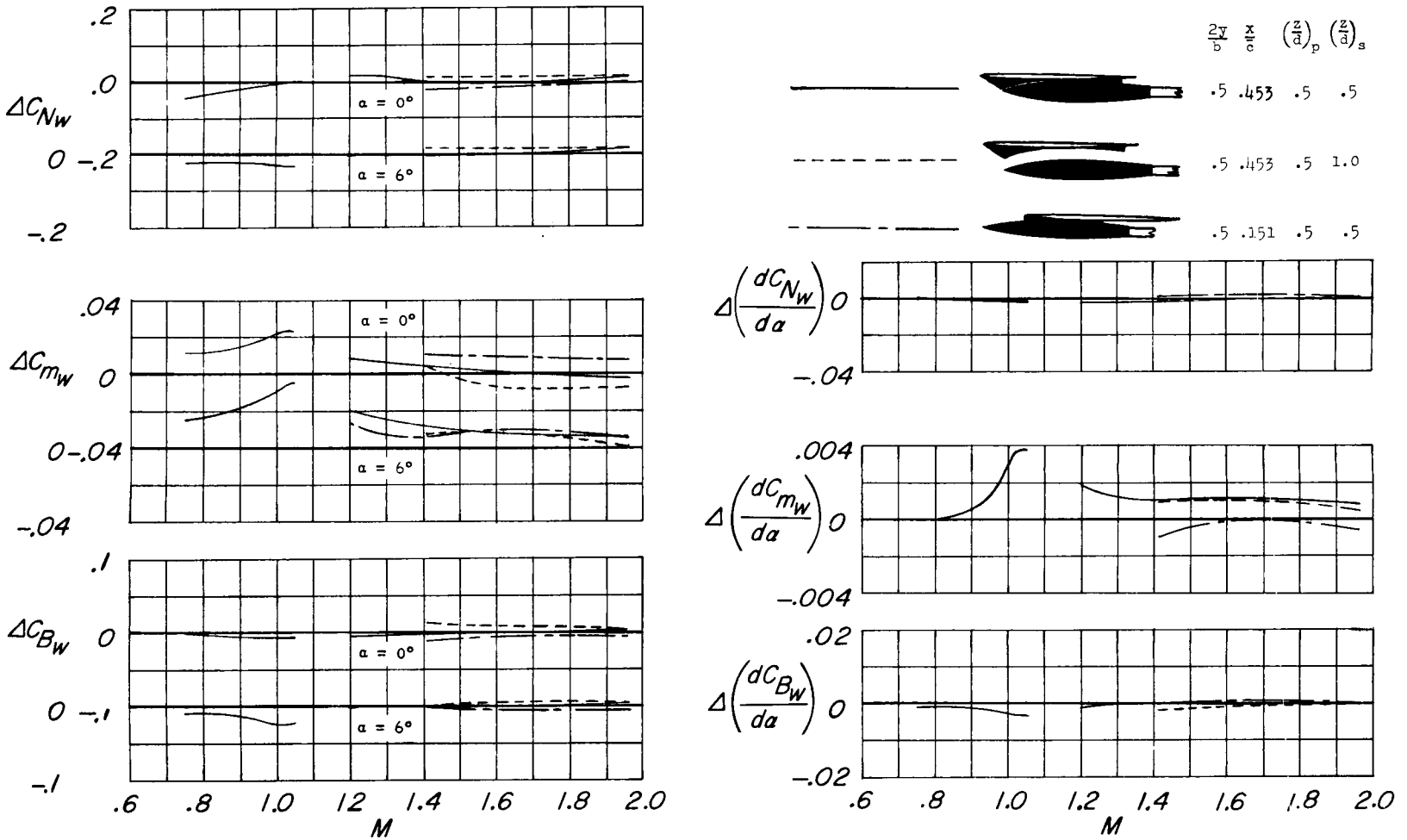

Figure 14.- Variation with Mach number of the incremental wing force, moment, and slope changes due to the presence of the store at various positions relative to the wing.

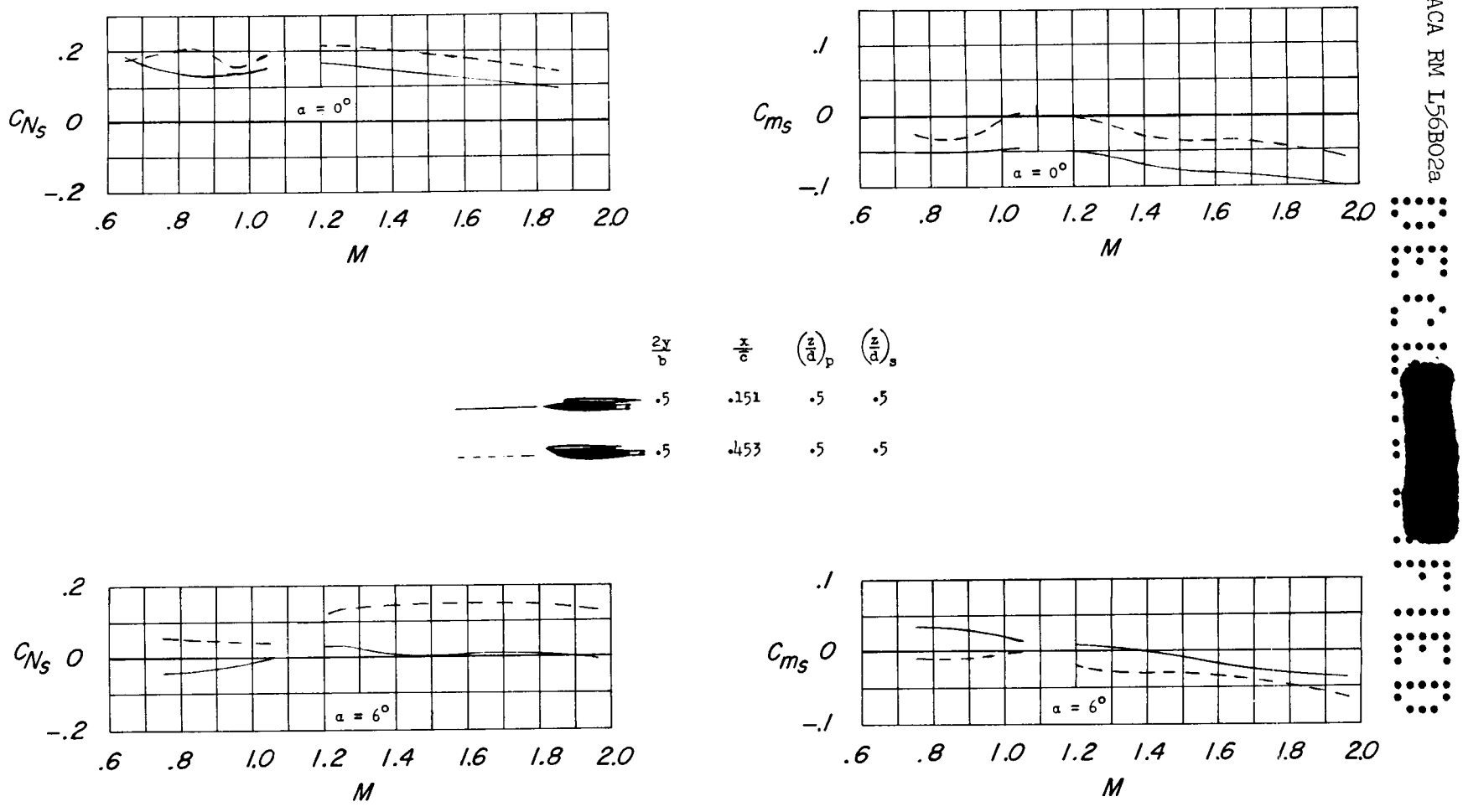

Figure 15.- Influence of chordwise store position on the variation of DAC store normal-force coefficient and pitching-moment coefficient with Mach number.

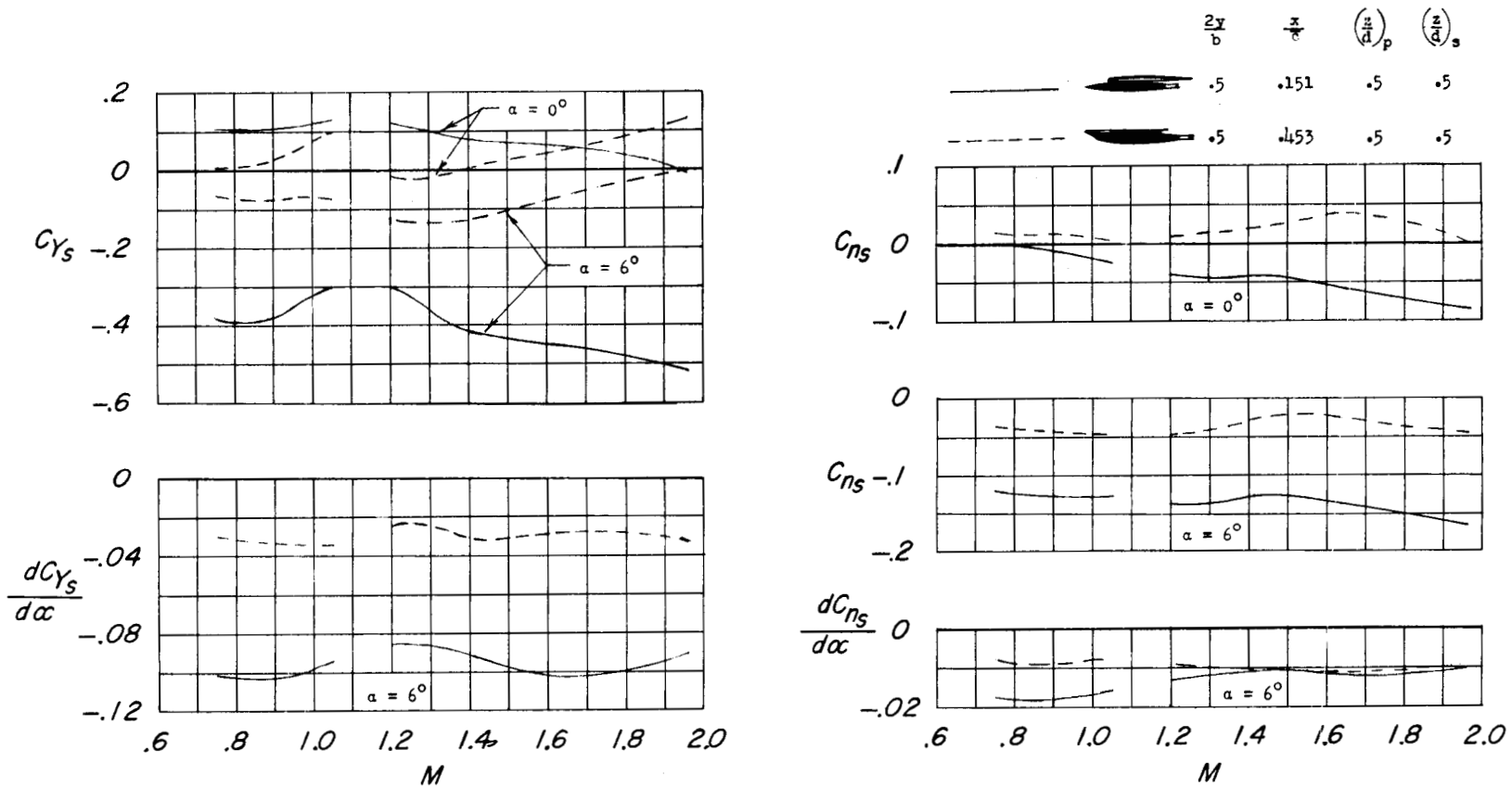

Figure 16.- Influence of chordwise position on the variation of DAC store side-force coefficient, yawing-moment coefficient, and slopes of $\frac{dC_{Y_s}}{d\alpha}$ and $\frac{dC_{n_s}}{d\alpha}$ with Mach number.

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