

THE EFFECT OF LARGE EXTERNAL STORES
ON THE LOW SPEED LONGITUDINAL
AERODYNAMIC CHARACTERISTICS OF A 60°
DELTA WING-FUSELAGE COMBINATION

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In Partial Fulfillment
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Master of Science in Aeronautical Engineering

By
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LIST OF SYMBOLS

A	aspect ratio, $(\frac{b^2}{S})$
C_L	lift coefficient, (lift/qS)
$C_{L_{\max}}$	maximum lift coefficient
ΔC_{L_1}	boundary induced lift coefficient acting on the quarter-chord-line
C_D	drag coefficient, (drag/qS)
ΔC_{D_j}	jet boundary correction to drag coefficient
C_M	pitching moment coefficient, $(\text{pitching moment}/qSc)$
C_{M_0}	zero lift pitching moment coefficient
ΔC_{M_1}	correction to pitching moment coefficient due to boundary induced distortion of spanwise lift distribution
ΔC_{M_2}	correction to pitching moment coefficient due to boundary induced streamline curvature
ΔC_{M_j}	jet boundary correction to pitching moment coefficient
C_{L_α}	lift curve slope, $(dC_L/d\alpha)$, /degree
$C_{M_{C_L}}$	longitudinal static stability derivative, (dC_{M_c}/dC_L)
D	store diameter
L	store length

L/D	store fineness ratio
S	wing area
V	free stream velocity
X/D	store nose position with respect to the wing leading edge divided by store diameter
b	wing span
c	local wing chord
c'	mean geometric chord
\bar{c}	mean aerodynamic chord
c_l	section lift coefficient
q	incompressible dynamic pressure, $(\rho V^2/2)$
q_0	dynamic pressure at the centerline of the tunnel without blocking correction
q_{0c}	dynamic pressure at the centerline of the tunnel corrected for solid blocking
q_{eff}	effective dynamic pressure over the model
w	jet boundary induced upwash velocity
x	longitudinal coordinate
x_1	longitudinal distance from the root end of the one-quarter- chord line to the centroid of boundary induced lift on the one-quarter-chord line

x_o	longitudinal distance from the root end of the one-quarter-chord line to the pitching moment axis
y	lateral coordinate measured from the model centerline
y_1	lateral distance to centroid of induced lift on the one-quarter-chord line
Λ	sweep angle, degrees
Δ	incremental variation of characteristics from clean model values
α	angle of attack, degrees
$\Delta\alpha_j$	jet boundary correction to angle of attack, degrees
ϵ	tunnel blocking correction factor
η	nondimensional wing semi-span station, $(2y/b)$
ρ	mass density of air

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SUMMARY

This paper is the result of a low speed experimental investigation performed in the Georgia Institute of Technology nine-foot diameter wind tunnel in order to determine the low speed effects of large externally mounted stores on the longitudinal aerodynamic characteristics of a 60° delta-wing and fuselage combination. The tests were conducted at an effective Reynold's number of 3.37 million. The parameters studied are: store fineness ratio ($L/D = 8$ and 12); store positions along the center-line of the fuselage (forward - $X/D = 3.03$, mid - $X/D = -3.60$, and aft - $X/D = -8.67$); wing store positions consisting of two chordwise locations (forward - $X/D = 3.5$, and aft - $X/D = 0.0$) at each of three spanwise stations ($\eta = 0.22, 0.40$, and 0.60) symmetrically located on each wing; and upper and lower surface store location. The store positions used in this investigation were chosen to provide a partial coverage of the locations which might be chosen for minimum drag at high speeds in accordance with the area progression rule.

The results of this investigation are presented as the effects of the above parameters on lift, minimum drag, and pitching moment. The results on lift consist of the effects of stores on maximum lift and lift curve slope. The results on pitching moment include the effects of stores on longitudinal static stability derivative at $C_L = 0$ and $C_L = 0.6$, on zero lift pitching moment, and the effects of certain selected store positions and fineness ratios on longitudinal stability derivative at

$$C_L > 0.6.$$

The effects of fuselage store positions on minimum lift and lift curve slope are small, but wing store positions cause appreciable decrements in maximum lift and appreciable increments in lift curve slope. Lift curve slope is not affected by store fineness ratio (for $L/D = 8$ and $L/D = 12$). There is a trend which shows that stability is increased by aft movement of the store tail fins, either by the increase of store fineness ratio, by change in chordwise store location on the wing or fuselage, or by outboard movement of store position along the wing.

The effects of the parameters studied on C_{M_0} are small with the exception of forward wing positions which cause appreciable positive increments.

CHAPTER I

INTRODUCTION

Since the development of nuclear and thermonuclear bombs, it has become imperative that this country's air defense be made as impenetrable as possible. Ground to air weapons are necessary to the air defense system, but an inherent limitation to such weapons is the fact that they may be most effectively utilized as a last defense for destroying an enemy bomber after it has reached the proximity of its target. Therefore, the interceptor fighter, which would be capable of destroying hostile bombers before they could approach their targets, is a very necessary part of the air defense system. However, the extremely high speeds and altitudes at which present and future bombers will operate make it difficult for an interceptor to achieve close or prolonged contact or to renew contact once a firing run has been made.

The next logical step in the evolution of air to air weapons for use by interceptors seems to be the development of large rockets and missiles equipped with nuclear war heads. Such weapons could be made effective when fired from large distances since the nuclear war head with its large radius of destruction would increase the probability of kill without requiring a high degree of accuracy in firing or guidance. In the event that such weapons should be made available in the near future, they could be utilized by interceptors which are in production or near production, without appreciable modification, provided that they could be

mounted externally without seriously reducing the airplanes performance characteristics. Also, it might conceivably prove more desirable to mount such weapons or stores externally rather than to design an airplane of sufficient size and complexity to provide for internal carriage.

It is the object of this experimental investigation to determine the effects of large external stores on the low speed longitudinal characteristics of a delta-wing type aircraft. Undoubtedly, there are many parameters related to the size, shape, and location of large external stores which would affect the aerodynamic characteristics of the aircraft upon which they were mounted. This investigation is limited to the effects of five such parameters. They are: the effect of store fineness ratio, the effect of store mounting positions along the centerline of the fuselage, the effect of spanwise and chordwise location of store mounting positions on the wing, and the effect of upper and lower surface store mounting positions. The data for upper surface store positions were obtained from tests conducted by the author, and the data for lower surface positions were obtained from a master's thesis by Henry C. Howard (1). The store positions used in this investigation were chosen to provide a partial coverage of the locations which might be chosen for minimum drag at high speeds in accordance with the area progression rule, without particular regard for structural or other considerations.

CHAPTER II

APPARATUS AND TESTS

The tests were conducted in the Georgia Institute of Technology nine-foot diameter wind tunnel (2). This tunnel is of the single return type with a closed circular test section vented to the atmosphere. The model was mounted on a conventional three support balance system with two supports forward and one support aft. The two forward supports were completely enclosed in windshields below the mounting bayonets, but the aft support was only partially enclosed. The balance system is capable of measuring six components of force and moment by means of six remotely operated electromechanical beam balances.

The model consisted of a delta-wing and fuselage combination and two variable length finned stores simulating large rockets or missiles. The two forward mounting points, about which pitching moment was measured, were located at the quarter-chord-point of the wing mean aerodynamic chord. A drawing of the model with stores attached is shown in Fig. 1.

The delta planform used 60° sweep at the quarter-chord-line and had a span of 48 inches which gave an aspect ratio of 1.73. The airfoil consisted of NACA 0009 sections parallel to the wing root. The wing was constructed of laminated mahogany with the exception of the wing tips which were made of solid aluminum. Detailed dimensions of the wing are shown in Fig. 2.

The fuselage was a body of revolution utilizing the ordinates of an NACA 64012 airfoil with an 80 inch chord. The basic shape was cut at the point of maximum diameter (40 per cent chord), and a straight cylindrical section of this maximum diameter and 20 inches in length was inserted. The basic airfoil shape was further modified by the substitution of a straight taper from the 60 per cent chord point aft to the trailing edge in order to eliminate the cusp of the 64 series airfoils. The last 27.5 per cent of the basic shape was cut off to give a blunt base five inches in diameter. A drawing of the fuselage and table of ordinates are given in Fig. 3.

The nose of the three inch diameter stores was a 37.5 inch radius ogive, 10.5 inches or 3.5 store diameters in length. The center sections were formed from lengths of three inch outside diameter aluminum tubing. Two sets of tubing were used to give two different overall store lengths corresponding to store fineness ratios, or ratios of length to diameter, of eight and twelve. The cylindrical tail sections were slotted to admit tail fins which were constructed of 1/8 inch aluminum alloy sheet. The leading edges of the tail fins were rounded to a radius of 1/16 inch.

The store mounting pylons were constructed without sweep or taper using an NACA 0009 airfoil section. The pylon length was 4.5 inches, or 1.5 store diameters, and the chord was 7.6 inches. Details of store and pylon construction are shown in Fig. 4.

The pylon-store assembly was mounted on the model so that there was a minimum clearance of 1.5 store diameters between the body of the store and the surface of the model. The variable pylon length necessary to provide this minimum clearance at all store mounting positions was

provided through the use of aluminum bushings between the base of the pylon and the model, and the space between the model and the pylon base was faired with plaster of paris.

Three store mounting positions (forward, mid, and aft) were provided along the centerline of the fuselage. Fuselage store positions are referenced in terms of X/D ratio; where X is the distance between the nose of the store and the leading edge of the wing-root-chord, and D is the store diameter. The forward fuselage position corresponds to $X/D = 3.03$, and mid fuselage position corresponds to $X/D = -3.60$, and the aft position corresponds to $X/D = -8.67$. At the forward position, the nose of the store was aligned with the nose of the fuselage; at the mid position, the nose of the store was aligned with the intersection of the wing leading edge and the fuselage; and at the aft position, the tail of the $L/D = 12$ store was aligned with the aft end of the fuselage.

Six symmetrically located mounting positions were provided on each wing. Two chordwise positions were provided at each of three semi-span stations, located at 22, 40, and 60 per cent semi-span. Wing store positions are referenced by spanwise location in terms of $\eta = \frac{2y}{b}$ and by chordwise location in terms of X/D ratio where X is measured from the nose of the store to the local leading edge of the wing. The forward chordwise positions ($X/D = 3.5$) were located such that the leading edge of the mounting pylon was aligned with the local leading edge of the wing, and the aft chordwise positions ($X/D = 0.0$) were located such that the nose of the store was aligned with the local leading edge of the wing. Details of wing store locations are shown in Fig. 2. Figure 5 shows the assembled model mounted in the tunnel with the $L/D = 12$ stores mounted on the 40 per cent semi-span station of the wing at the forward chordwise position.

CHAPTER III

PROCEDURE

In the basic tests used in this investigation, force data for lift, drag, and pitching moment were taken at angles of attack from minus six to plus forty degrees. The configurations tested consisted of the clean model, the model with one store of each fineness ratio mounted at each of the three fuselage positions, and the model with two stores of each fineness ratio mounted symmetrically at each of six wing positions.

The mean velocity over the model was held at 100 miles per hour, indicated, corresponding to an effective Reynold's number of 3.37 million based on the wing mean aerodynamic chord. Previous tests of wing and store combinations without the fuselage showed no measurable effect of Reynold's number over the range from 2.45 to 3.97 million (3).

In addition to the above tests, tuft studies were made for the clean model and for one store-on configuration. In order to provide a more extensive flow study with only one store-on configuration, two $L/D = 12$ stores were mounted assymmetrically on the wing. One store was mounted on the aft position at the 22 per cent semi-span station, and the other store was mounted on the aft position at the 40 per cent semi-span station.

The mean dynamic pressure over the model was calculated by integrating the product of the local dynamic pressure, as found by a previous

survey of the jet, and the local wing chord over the span of the model (4). Corrections for solid blocking were made as outlined in the Appendix on page 20. Model support tare and interference were evaluated by the image support method (5).

The model was initially constructed without camber; however, subsequent warping caused a slight amount of camber to appear. For this reason, the flow angularity corrections were made so as to include a correction for the slight camber, giving lift and moment curves which appear symmetrical.

The pitching moment was corrected for gravity tare at each angle of attack. The wind-off lift and drag readings were not affected by changes in angle of attack. Tunnel boundary corrections to drag, pitching moment, and angle of attack were computed in accordance with the method set forth in NACA Technical Note 2454 as outlined on pages 21 - 23 of the Appendix (6).

CHAPTER IV

RESULTS

The results of this investigation are shown in Figs. 6 through 17. The lift curve, drag polar, and pitching moment polar for the clean model and one representative store-on configuration are presented in Figs. 6, 11, and 13. In order to simplify the discussion, the results have been divided into three main sections concerned with the effects of store fineness ratio and store location on lift, drag, and pitching moment respectively. Figs. 6 through 10 present the incremental effects on lift, Figs. 11 through 12 the incremental effects on drag, and Figs. 14 through 17 present the effects on pitching moment.

Lift

Maximum Lift

Clean Model.--(Fig. 6) The clean model exhibits the very gradual stall and high stalling angle of attack normally expected from a delta wing configuration. Tuft photographs for the clean model, shown in Fig. 7, indicate that the flow over the upper surface at $C_{L_{max}}$ is unsteady with large spanwise velocity components, but no complete separation is evident.

Fuselage Store Positions.--(Fig. 8) The variation in maximum lift caused by stores on the fuselage is small for all positions and fineness ratios with very little difference noted between the upper and lower surface positions. There is an almost linear decrease in maximum lift with store

movement aft along the fuselage for both upper and lower surface positions. The effect of fineness ratio is reversed between the upper and lower surface positions with the $L/D = 12$ stores causing less maximum lift on the upper surface while the $L/D = 8$ stores cause less maximum lift on the lower surface. It might be expected that the fuselage store positions should cause only small changes in maximum lift since they are located on the centerline of the model where there is no spanwise flow, and therefore any detrimental interference effects should be small and partially offset by the additional lift on the stores themselves.

Wing Store Positions.---(Fig. 9) The variation in maximum lift caused by stores at the forward wing positions on the upper and lower surfaces and by stores at the aft wing positions on the upper and lower surfaces are plotted on separate sets of coordinate axes with spanwise position as the abscissa. At the forward chordwise positions ($X/D = 3.5$), stores on the lower surface cause considerably larger decrements in maximum lift than stores at corresponding positions on the upper surface. At the aft positions ($X/D = 0.0$), the reverse is true, and the upper surface positions cause the larger decrements. The effect of store fineness ratio is also reversed between upper and lower surface positions as it was for fuselage positions. No general trends as to the effect of spanwise store location are evident.

At the lower surface positions, it is believed that the most harmful interference effects are caused by the interference of the nose of the store with the flow over the upper surface of the wing at high posi-

tive angles of attack in addition to the possibility that the mounting pylons restrict the formation of the leading edge vortex. This explanation is supported by the fact that the forward positions on the lower surface cause the larger decrements in maximum lift, and at the forward positions, the nose of the store is 10.5 inches ahead of the wing leading edge; while the leading edge of the mounting pylon coincides with the leading edge of the wing. It is believed that the most detrimental effect of upper surface store positions on maximum lift is caused by the fact that the mounting pylons stall and cause complete flow separation over portions of the upper surface of the wing as seen from tuft studies in Fig. 7.

The reversal of the effect of fineness ratio between the upper and lower surface positions may arise from the additional lift of the long afterbody of the $L/D = 12$ store which partially offsets the detrimental interference effects when stores are on the lower surface. On the upper surface, however, it is believed that the stores themselves do not contribute appreciable lift, and thus any additional interference effects of the longer store are not offset.

Lift Curve Slope

Clean Model.---(Fig. 6) The lift curve of the clean model is linear to a lift coefficient of approximately 0.4, but the slope increases over the range from $C_L = 0.4$ to $C_L = 1.0$ at which point the model begins to stall. The nonlinear portion is due to the formation of a leading edge vortex caused by flow separation at the leading edge (7). The incremental store effects are computed for the linear range. The clean model value of the

Lift curve slope is 0.034 / degree.

Fuselage Store Positions.---(Fig. 10) Lift curve slope is insensitive to store fineness ratio, and the effects of fuselage store positions are small, approximately 1.5 per cent of the clean model value. The lower surface positions cause slight decrements in slope, and the upper surface positions cause slight increments. This result seems reasonable since fuselage store positions should have little or no effect on the magnitude or distribution of the downwash.

Wing Store Positions.---(Fig. 10) Lift curve slope is insensitive to store fineness ratio at all wing positions but is increased by spanwise movement of the stores toward the tip for both forward and aft positions on the upper and lower surfaces. The upper surface positions cause the greater increases in slope. It is seen that the forward positions ($X/D = 3.5$) cause the greater increases in slope for both the upper and lower surface locations. This indicates that the forward positions nearest the wing tip provide the greatest end plating effect. The fact that store fineness ratio has no effect indicates that mounting pylon position is the important parameter affecting lift curve slope.

Drag

Minimum Drag

Clean Model.---(Fig. 11) The minimum drag coefficient of the clean model ($C_{D_{min}} = 0.01$) is seen to occur at $C_L = 0.025$ instead of at zero lift. This is the result of the inadvertent camber in the model as mentioned previously.

Fuselage Store Positions.--The drag data for fuselage store positions are of doubtful accuracy, and there was not sufficient time to check the data by rerunning the tests. Therefore, the minimum drag data for fuselage store positions are omitted.

Wing Store Positions.--(Fig. 12) The incremental increases in minimum drag coefficient for forward and aft wing positions are plotted on separate sets of coordinate axes with spanwise position as the abscissa. Minimum drag is sensitive to store fineness ratio, spanwise position, and chordwise position; though no general trends are evident. At the forward positions, the $L/D = 8$ stores cause the least drag except at the outboard position. At the aft positions, the effects of fineness ratio are small, and the $L/D = 8$ stores cause the least drag at the inboard positions while the $L/D = 12$ stores cause the least drag at the outboard position. The drag caused by the $L/D = 12$ stores decreases with outboard spanwise movement, but the effect of spanwise movement on the drag caused by the $L/D = 8$ stores indicates no general trend.

Pitching Moment

Longitudinal Stability Derivative

Clean Model.--(Fig. 13) The slope of the pitching moment polar, $C_{M_{C_L}}$, increases with lift coefficient from $C_L = 0$ to $C_L = 0.6$ and then remains constant from $C_L = 0.6$ to $C_L = 1.1$ where the effects of stall begin to cause irregularities. The model is stable at all lift coefficients below $C_{L_{max}}$. At $C_L = 0$, $C_{M_{C_L}} = -0.124$, and at $C_L = 0.6$, $C_{M_{C_L}} = -0.210$.

Fuselage Store Positions, $C_L = 0$.---Figure 14 shows the incremental variation of $C_{M_{CL}}$ for fuselage store positions at zero lift. Since the model is symmetrical, there is no difference between upper and lower surface positions, and only the upper surface data are presented. The $L/D = 12$ store has negligible effect at all positions; while the $L/D = 8$ store is destabilizing forward of the mid position and slightly stabilizing aft of the mid position.

Fuselage Store Positions, $C_L = 0.6$.---The incremental variation of $C_{M_{CL}}$ for stores on the upper and lower surface fuselage positions is presented in Fig. 15. All upper surface store positions are slightly destabilizing. The effect of fore and aft movement of stores on the upper surface is negligible for the $L/D = 12$ store and small for the $L/D = 8$ store. For lower surface positions, the $L/D = 8$ store is slightly destabilizing with movement aft causing a slight increase in stability. The $L/D = 12$ store on the lower surface is destabilizing at the forward position but stabilizing at the aft and mid positions with movement aft from the forward to the mid position causing an appreciable increase in stability. In general, stability is more sensitive to fore and aft position for stores on the lower surface.

Wing Store Positions, $C_L = 0$.---(Fig. 14) At the forward positions, the $L/D = 8$ stores are destabilizing at all spanwise stations, and the $L/D = 12$ stores are destabilizing at the two inboard positions but stabilizing at the outboard position. There is a trend which shows that aft movement of the store tail fins, either by change in chordwise position or by outboard movement along the span, increases stability. It is noted that out-

board movement along the span at the same chordwise position also corresponds to aft movement along the MAC because of the wing sweep. The $L/D = 12$ stores are more stabilizing at all positions as would be expected since increasing the fineness ratio moves the finned portions of the stores aft.

Wing Store Positions, $C_L = 0.6$.--(Fig. 16) The incremental variation of $C_{M_{C_L}}$ for forward and aft wing store positions is plotted on separate sets of coordinate axes with spanwise position as the abscissa. There is a very general trend which shows that stability is increased by store movement aft, either by change in chordwise position or by outboard movement along the span. The most prominent exceptions to this trend are the $L/D = 8$ stores at the forward positions on the lower surface which become more destabilizing with outboard movement, and the $L/D = 8$ stores at the aft positions on the upper surface which cause maximum stability at the 40 per cent semi-span station. In general, the $L/D = 12$ stores are more stabilizing than the $L/D = 8$ stores.

Wing Store Positions, $C_L > 0.6$.--At high positive angles of attack, three of the upper surface positions cause more or less abrupt changes in the stability derivative. Stability is decreased over a certain range of lift coefficient and then increased again over a higher range. This effect is evident for stores of both fineness ratios at the forward and aft 60 per cent semi-span positions and at the aft 40 per cent semi-span positions. In all cases the $L/D = 12$ stores cause the greater effects. The lift coefficient at which the stability is decreased is dependent on store position and fineness ratio. The most critical effects are caused

by stores at the aft 60 per cent semi-span station, as shown in Fig. 17. In this instance, the model is unstable over a range of lift coefficient from $C_L = 0.78$ to $C_L = 0.83$, and the change in stability is very abrupt. Figure 13 shows that the $L/D = 12$ stores at the aft 40 per cent semi-span positions cause an unstable range from $C_L = 1.01$ to $C_L = 1.055$. It is believed that these effects are due to the fact that the store tail fins become immersed in the wake behind the wing at some high positive angle of attack. This explanation is supported by the fact that the change in stability derivative in every case is accompanied by a decrease in lift curve slope over the same range of lift coefficient.

Zero Lift Pitching Moment

Fuselage Store Positions.--(Fig. 18) C_{M_0} is not appreciably affected by fuselage store positions. Both fineness ratios at the forward position cause slight positive values of C_{M_0} which decrease almost linearly to small negative values at the aft position.

Wing Store Positions.--(Fig. 18) C_{M_0} for forward and aft wing positions is plotted against spanwise station. Both fineness ratios at the forward inboard positions cause positive values of C_{M_0} which decrease with outboard movement along the span until C_{M_0} is negligible at the outboard positions. At the forward positions, the $L/D = 8$ stores cause the more positive values except at the outboard position where the effect of fineness ratio is reversed slightly. Stores at the aft wing positions cause only small C_{M_0} changes which show no significant trend with spanwise movement.

CHAPTER V

CONCLUSIONS

The following conclusions have been reached on the basis of the data obtained in this investigation.

1. Store fineness ratio has no measurable effect on lift in the low angle of attack range.
2. Maximum lift coefficient is not appreciably affected by fuselage store positions.
3. There are no wing store positions which cause increments in maximum lift. The largest decrements in maximum lift are caused by forward chordwise positions on the lower surface. At the aft wing positions, stores on the upper surface cause the larger decrements in maximum lift.
4. Lift curve slope is not appreciably affected by fuselage store positions.
5. Wing store positions cause positive increments in lift curve slope which increase with outboard spanwise movement of store location. Aft wing positions and upper surface positions cause the greater increases in slope.
6. Minimum drag data for wing store positions indicate that the drag caused by the $L/D = 12$ stores decreases with spanwise movement toward the tip, but the drag increments caused by the $L/D = 8$ stores are smallest at the inboard positions for for-

ward chordwise location and at the inboard and outboard position for aft chordwise location. The effects of store fineness ratio on minimum drag are larger for forward positions than for aft positions.

7. Static stability is increased by increased store fineness ratio or by store movement aft, either by change in chordwise position or by store movement toward the wing tip at the same chordwise position.

CHAPTER VI

RECOMMENDATIONS

It is recommended that this study be extended to cover some of the many effects of external stores which have been omitted, such as:

1. A more exhaustive study of store location including: The effects of antisymmetric store location, the effects of more than two stores on the wing, the effects of two or more stores located off the fuselage center line, and the effect of semi-submerged stores.
2. The effects of pylon design including airfoil section, pylon length, pylon taper, and pylon sweep.
3. The effects of pylons only.
4. An evaluation of the interference effects.
5. The effects of wing camber, thickness, twist, aspect ratio, taper ratio, and sweep angle.
6. The effects on control effectiveness at low speeds.
7. The effects of stores on the dynamics of the airplane.
8. The problem of the proper separation of the stores from the airplane upon firing or free release.

A P P E N D I X

TUNNEL BLOCKING CORRECTIONS

The tunnel blocking corrections were made in accordance with Ref. 5 as follows:

$$q_{o_c} = q_o (1 + 2 \epsilon)$$

Where

$$\epsilon = 1/4 \frac{\text{Model frontal area}}{\text{Test Section area}}$$

q_o = centerline value of q as determined by the tunnel piezometer setting

q_{o_c} = centerline value of q corrected for solid blocking

$$q_{\text{mean}} = \frac{\int_{-b/2}^{b/2} q \, c \, d \, y}{S}$$

Where q_{mean} was determined by integrating the tunnel q distribution found in Ref. 5.

$$\frac{q_{\text{mean}}}{q_o} = 1.012$$

From the above data, the effective q over the model was calculated by:

$$q_{\text{eff.}} = q_o (1 + 2 \epsilon) \frac{q_{\text{mean}}}{q_o}$$

The model frontal area includes the following:

Frontal area of support windshields	3.34 sq. ft.
Frontal area of the model	1.02 sq. ft.
Frontal area of the stores (for store-on tests only)	<u>0.147</u> sq. ft.
Total	4.507 sq. ft.

TUNNEL BOUNDARY CORRECTIONS

The boundary corrections were made in accordance with NACA Technical Note 2454 (6). The boundary induced upwash in the vicinity of the wing is assumed to vary linearly in the chordwise direction so that circular-arc camber is introduced by the jet boundary. Since, according to thin airfoil theory, the effective angle of attack for an airfoil with circular-arc camber is the angle at the three-quarter-chord point, the angle of attack correction is obtained from the induced upwash at the three-quarter-chord line weighted according to the additional spanwise loading and integrated across the span.

$$\Delta\alpha_j = 57.3 C_L \int_0^1 \left(\frac{w}{V C_L} \right) 0.75 \frac{c_1 c}{C_L c} d \left(\frac{2 y}{b} \right)$$

The boundary correction to the drag coefficient is due to the inclination of the lift vector by the induced upwash at the one-quarter-chord point. The correction to the drag coefficient is the product of the lift coefficient and the average angle along the one-quarter-chord line.

$$\Delta C_{D_j} = C_L^2 \int_0^1 \left(\frac{w}{V C_L} \right)_{0.25} \frac{C_L c}{C_L c} d \left(\frac{2y}{b} \right)$$

The boundary correction to the pitching moment coefficient is given in two parts (a) the moment resulting from the outward shift in the spanwise center of lift caused by the induced washin along the three-quarter-chord line due to wing sweep and (b) the couple due to the induced circular-arc camber caused by the alteration of streamline curvature. The pitching moment correction was determined as follows:

ΔC_{L_1} is the incremental lift coefficient due to the induced angle along the $\frac{3c}{4}$ line.

$$\Delta C_{L_1} = 57.3 a C_L \int_0^1 \left(\frac{w}{V C_L} \right)_{0.75} \frac{C_L c}{C_L c} d \left(\frac{2y}{b} \right)$$

The lateral center of pressure for ΔC_{L_1} is given by:

$$\begin{aligned} \frac{2y_1}{b} &\approx \frac{\frac{36.48}{A}}{1 + \frac{36.48}{A}} \int_0^1 \frac{C_L c}{C_L c} \frac{2y}{b} d \left(\frac{2y}{b} \right) \\ &+ \frac{\frac{57.3 a C_L}{\Delta C_{L_1}}}{1 + \frac{36.48}{A}} \int_0^1 \left(\frac{w}{V C_L} \right)_{0.75} \frac{C_L c}{C_L c} \frac{2y}{b} d \left(\frac{2y}{b} \right) \end{aligned}$$

The longitudinal distance, x_1 , of the center of pressure from the root end of the one-quarter-chord line is given by:

$$\frac{x_1}{c'} = \frac{2 y_1}{b} - \frac{b}{2 c'} \tan \Lambda \quad 0.25$$

The correction due to the outward shift of the center of pressure, ΔC_{M_1} is given by:

$$\Delta C_{M_1} = a C_L \frac{\Delta C_{L_1}}{a C_L} \frac{x_1 - x_0}{c'}$$

The correction due to the couple, ΔC_{M_2} is given by:

$$\Delta C_{M_2} = \frac{\pi \cos \Lambda \quad 0.50 C_L}{4} \int_0^1 \left[\frac{w}{V C_L \quad 0.75} - \frac{w}{V C_L \quad 0.25} \right] \frac{c^2}{c'} d \left(\frac{2y}{b} \right)$$

$$\Delta C_{M_j} = \Delta C_{M_1} + \Delta C_{M_2}$$

All corrections are additive. The corrections calculated by numerical integration of the above equations are as follows:

$$\begin{array}{ll} \Delta \alpha_j & \dots \dots \dots 1.32 C_L \\ \Delta C_{D_j} & \dots \dots \dots 0.0185 C_L^2 \\ \Delta C_{M_j} & \dots \dots \dots 0.00772 C_L \end{array}$$

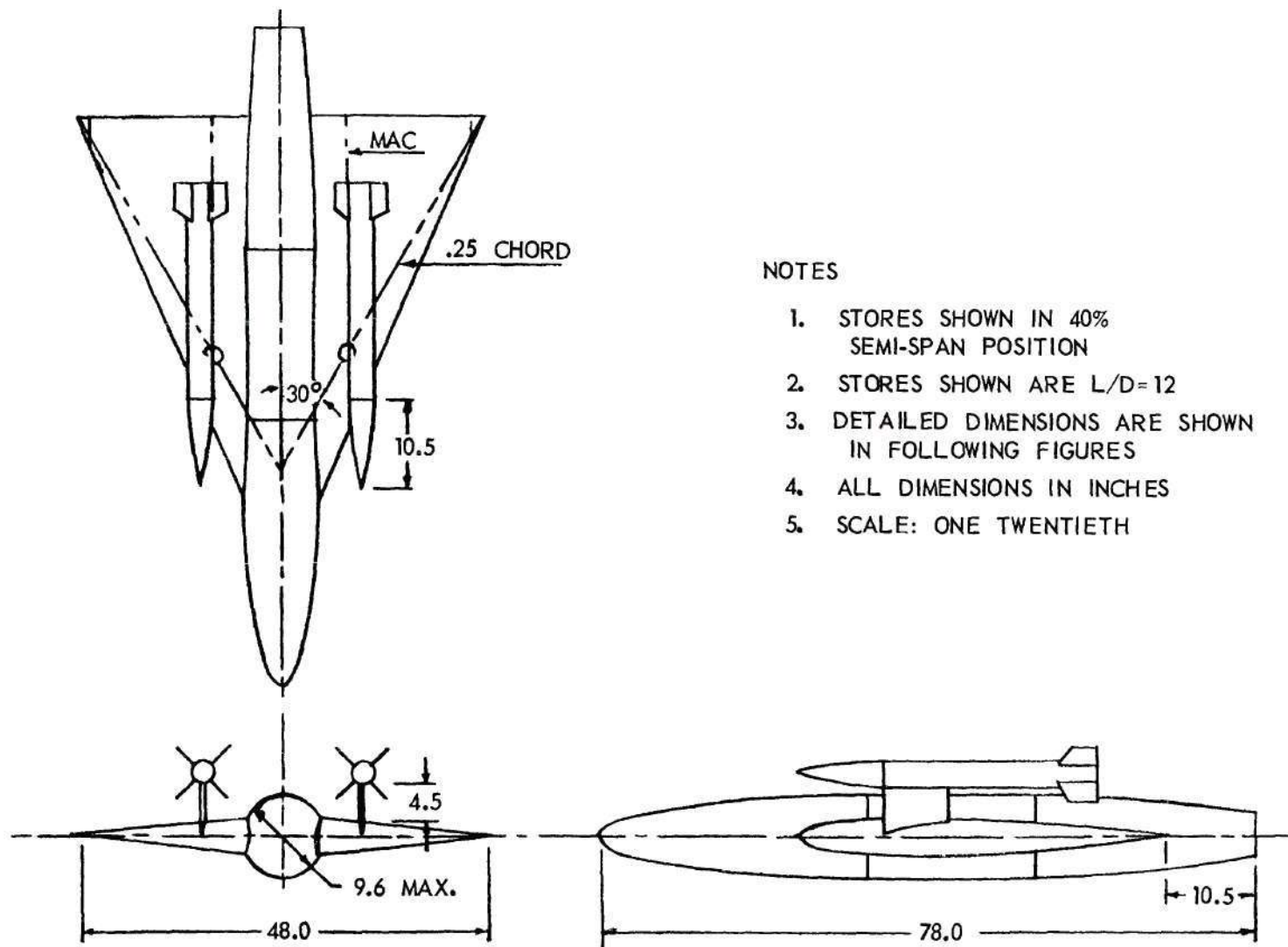
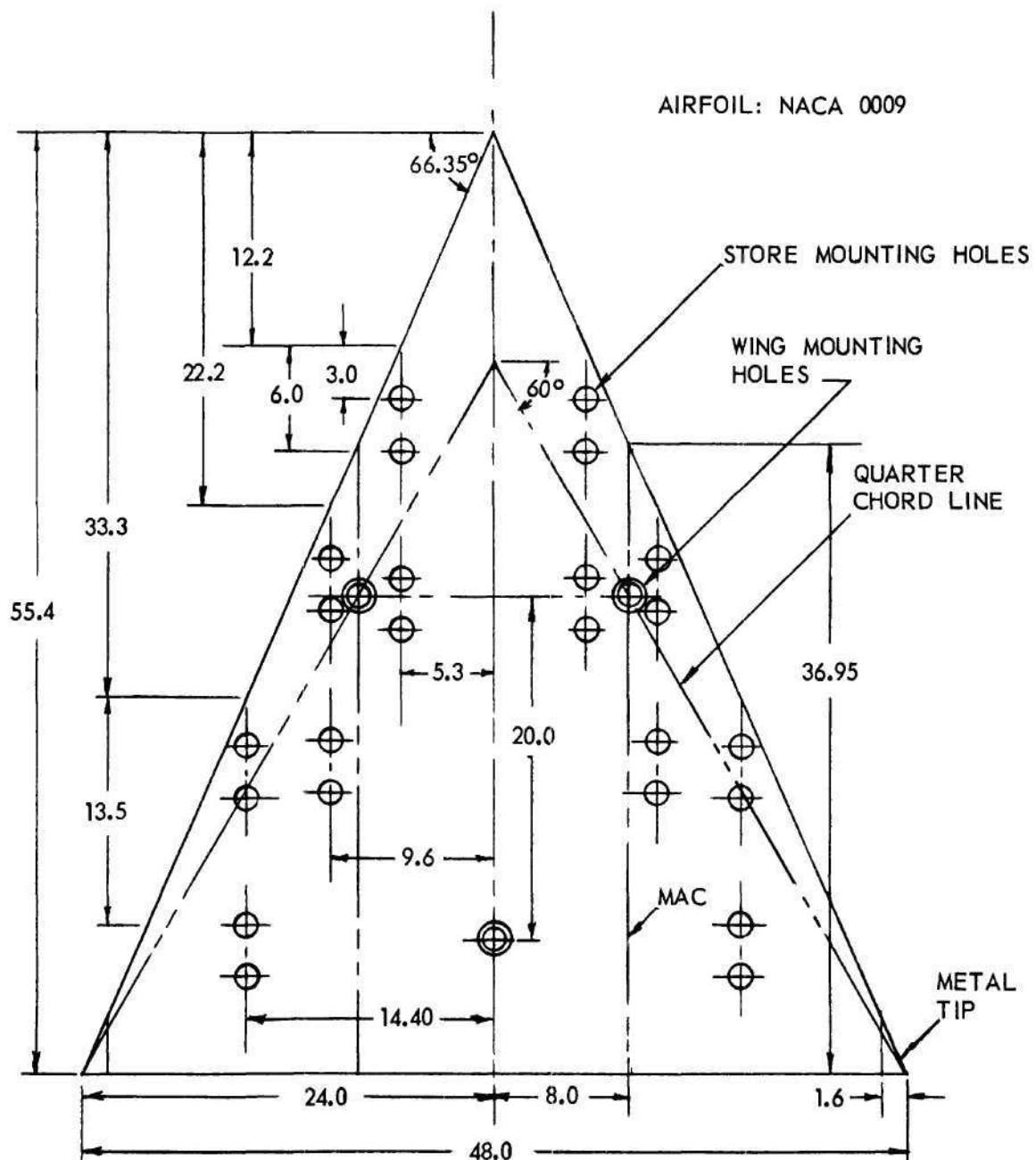
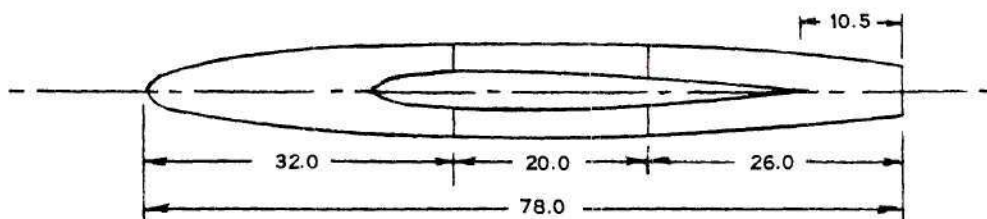


Figure 1. Assembled Delta-Wing Model.



ALL DIMENSIONS IN INCHES EXCEPT AS NOTED SCALE: ONE TENTH

Figure 2. Dimensions of Delta.



FUSELAGE - SIDE VIEW

ORDINATES IN INCHES

STATION	RADIUS
0.	0.
0.4	0.78
0.6	0.94
1.0	1.19
2.0	1.63
4.0	2.25
6.0	2.72
8.0	3.10
12.0	3.70
16.0	4.14
24.0	4.68
32.0	4.79
52.0	4.79
60.0	4.38
68.0	3.64
76.0	2.68
78.0	2.30
L.E. RAD.	0.83

Figure 3. Fuselage Dimensions.

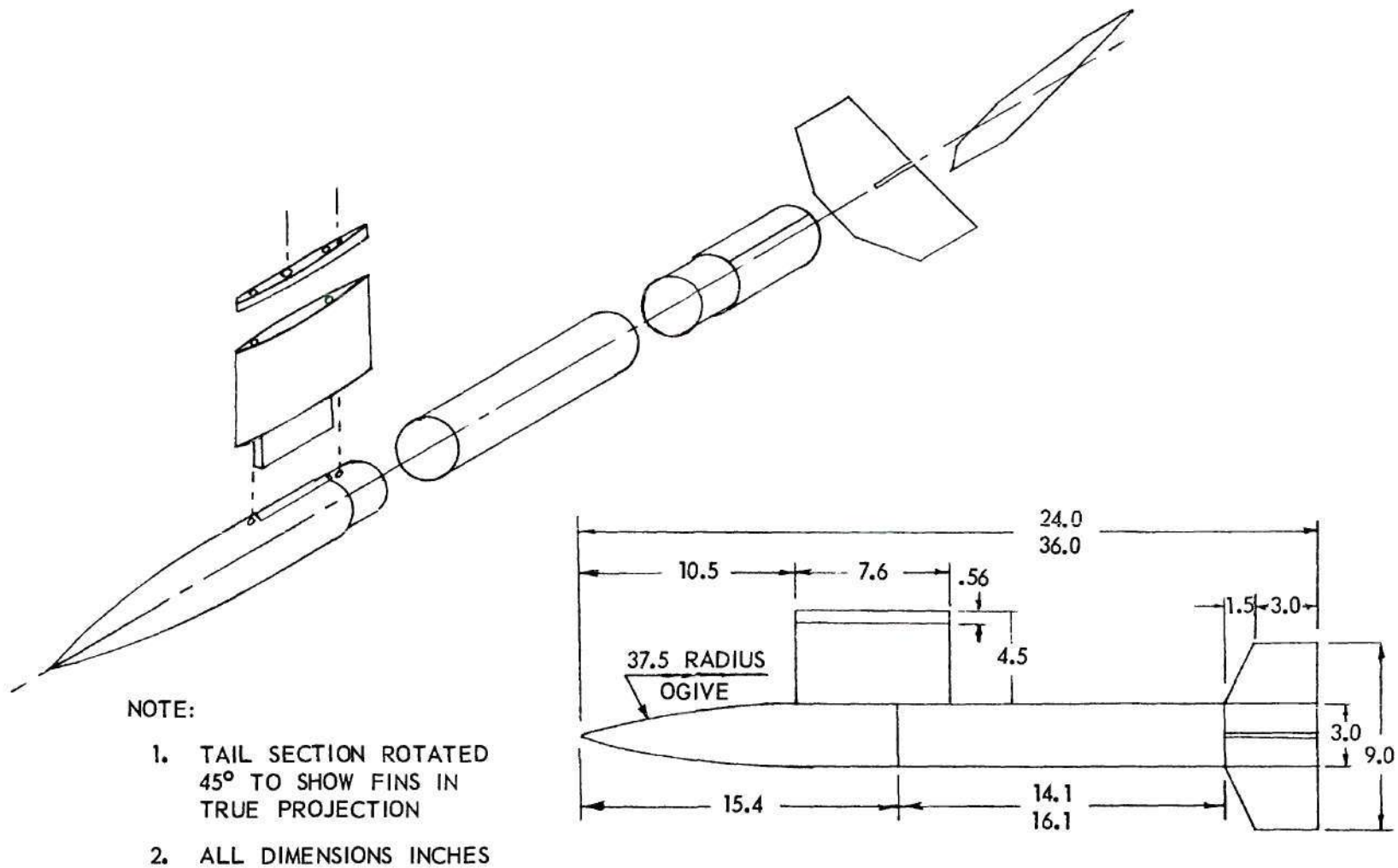


Figure 4. External Store.

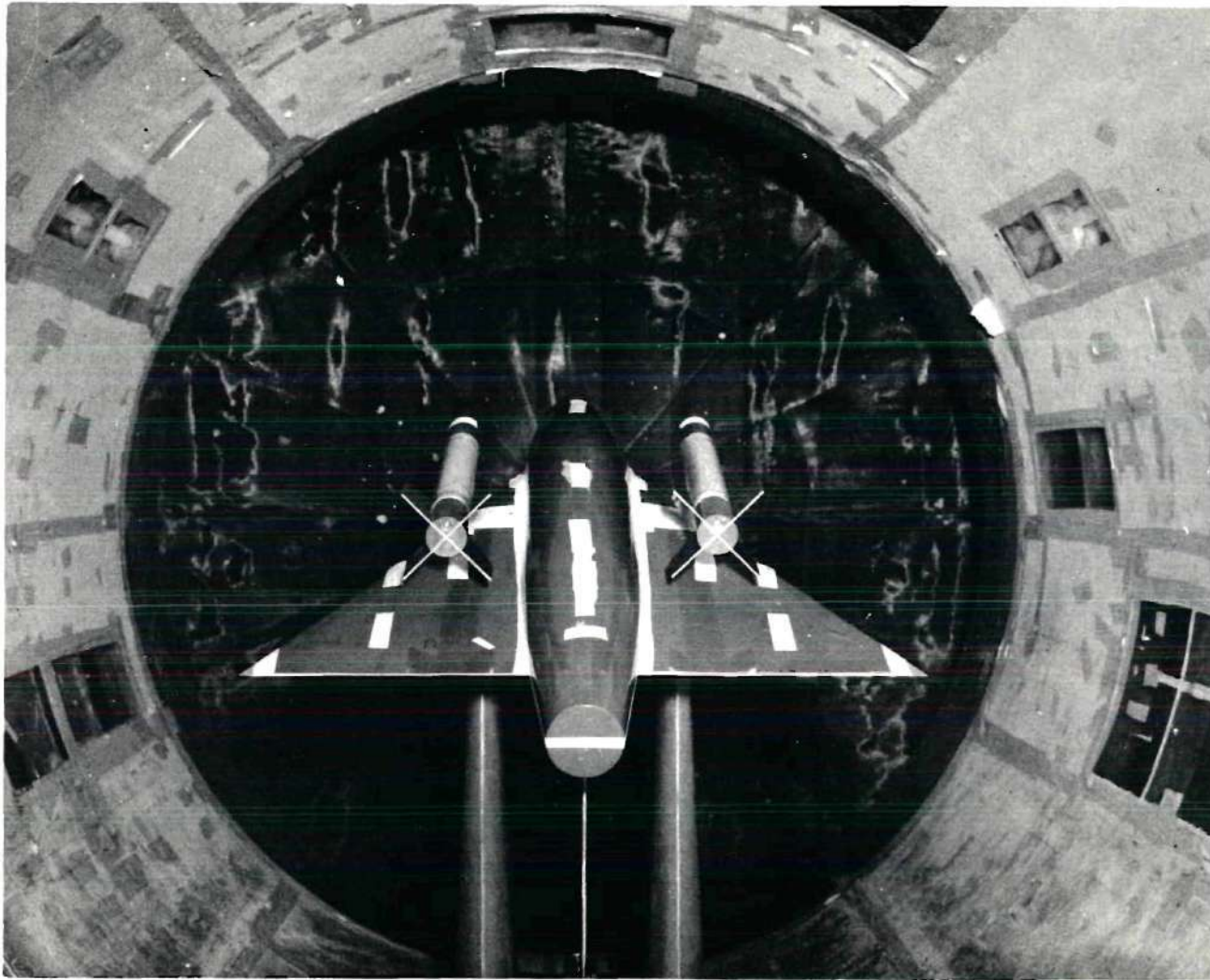


Figure 5. Complete Model Mounted in the Tunnel.

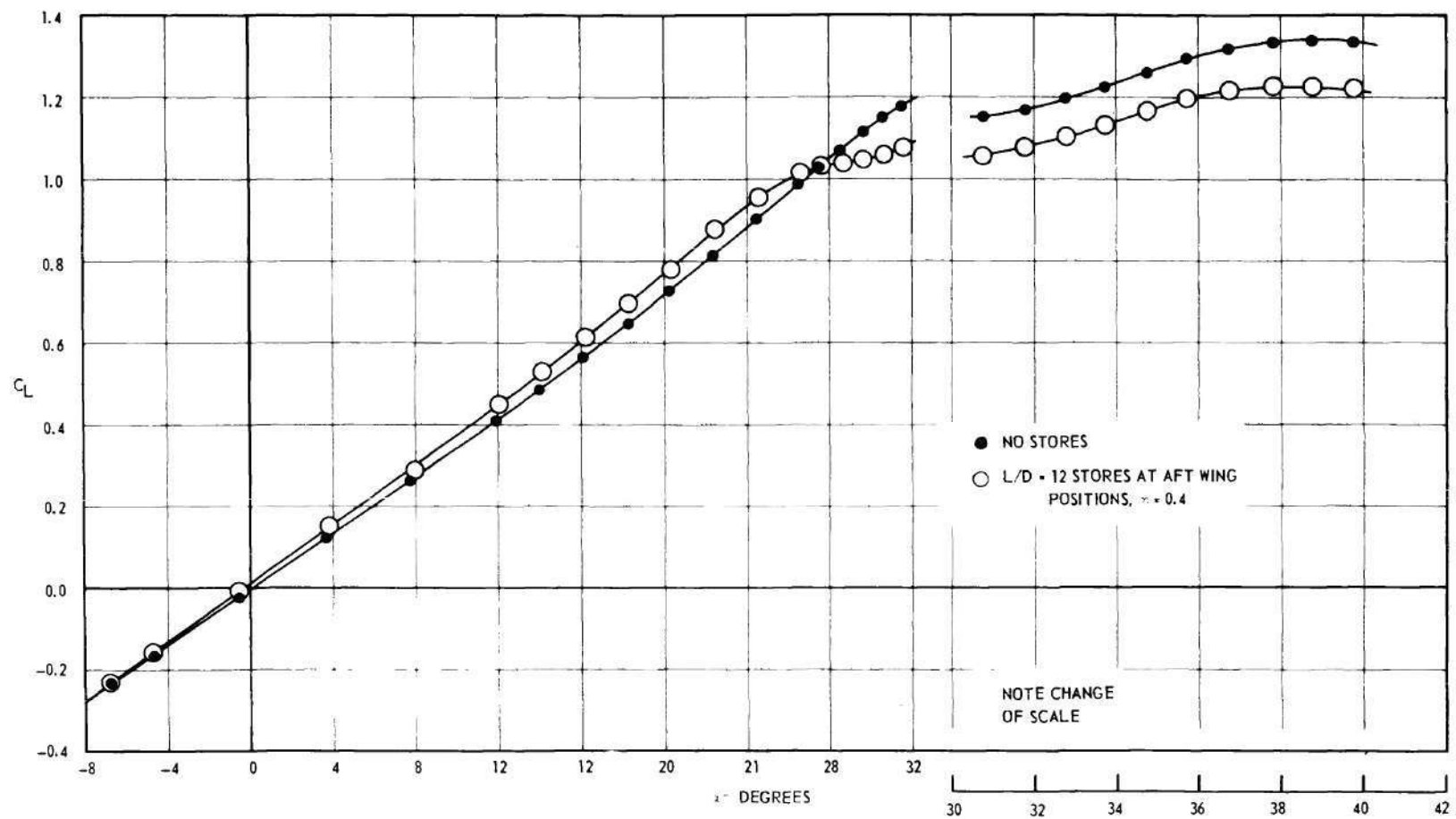
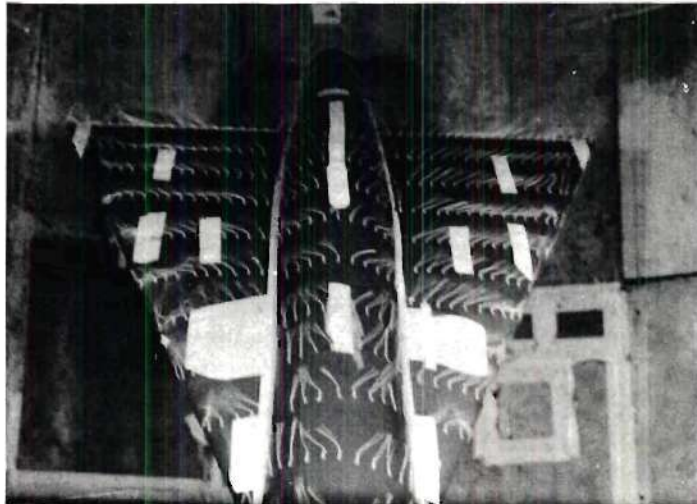
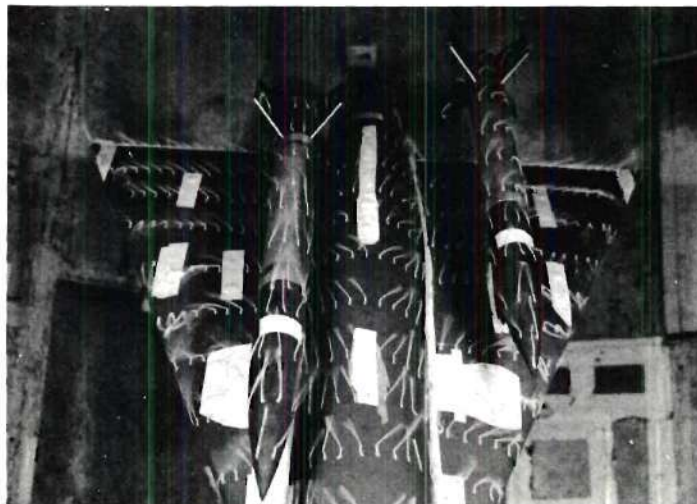


Figure 6. Typical Lift Curves.



CLEAN MODEL $\alpha = 40.8^\circ$



MODEL PLUS STORES $\alpha = 37.7^\circ$

Figure 7. Upper Surface Tuft Photographs..

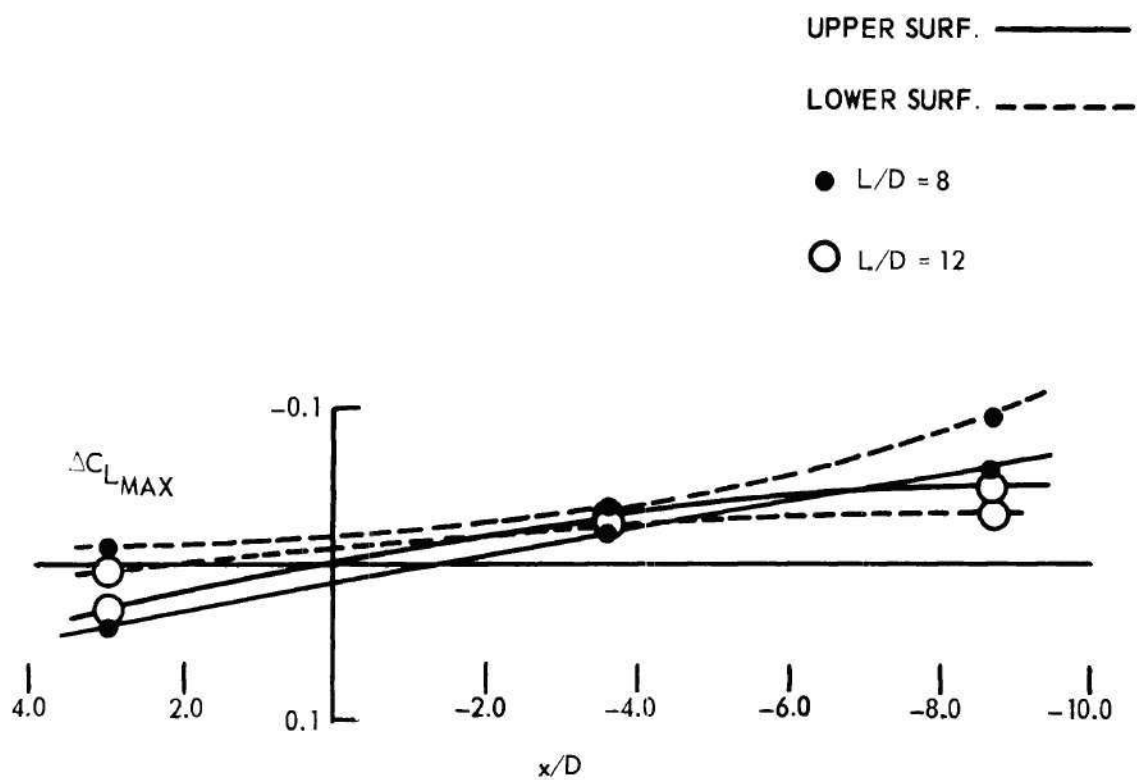


Figure 8. Incremental Variation of Maximum Lift, Fuselage Positions.

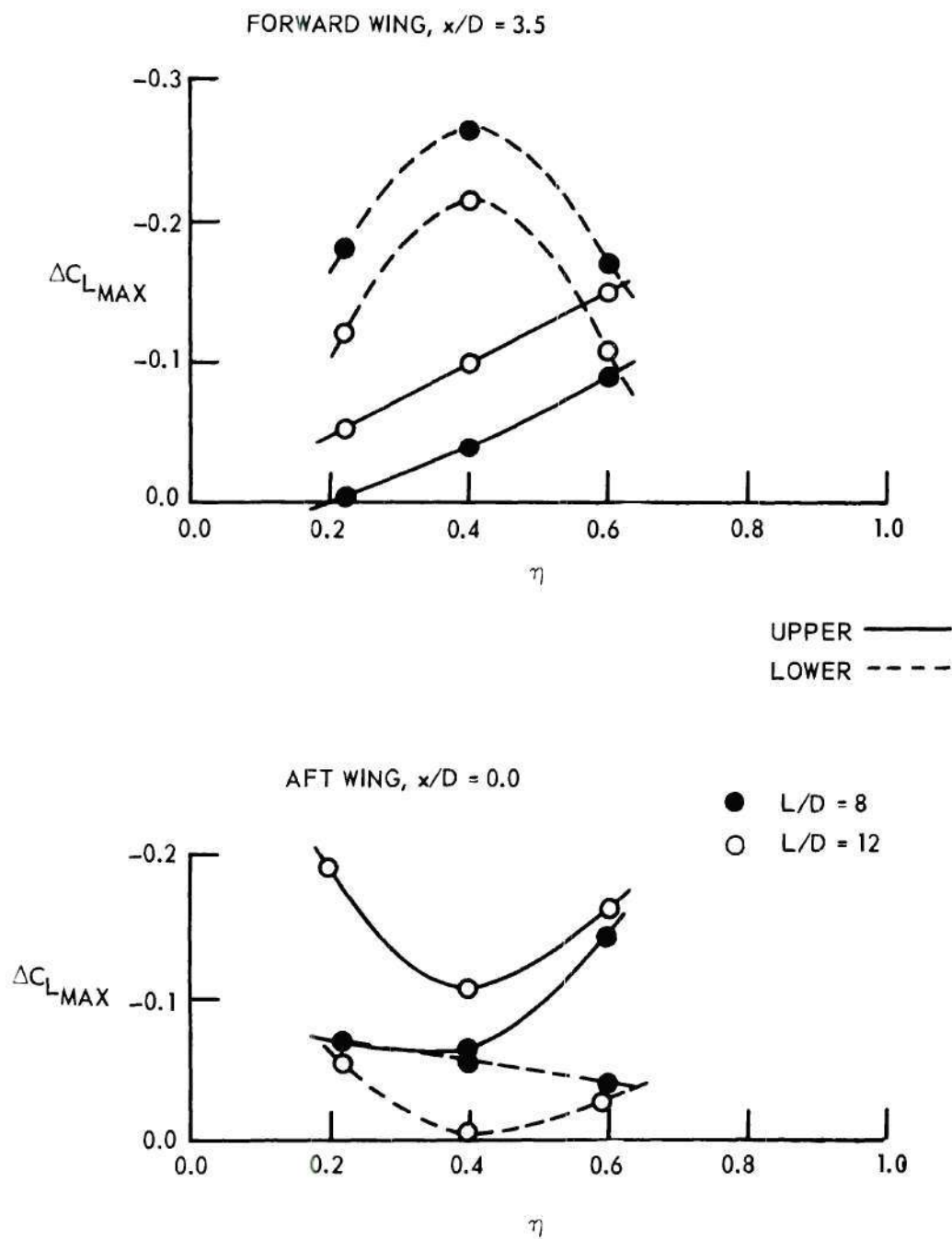


Figure 9. Incremental Variation of Maximum Lift, Wing Positions.

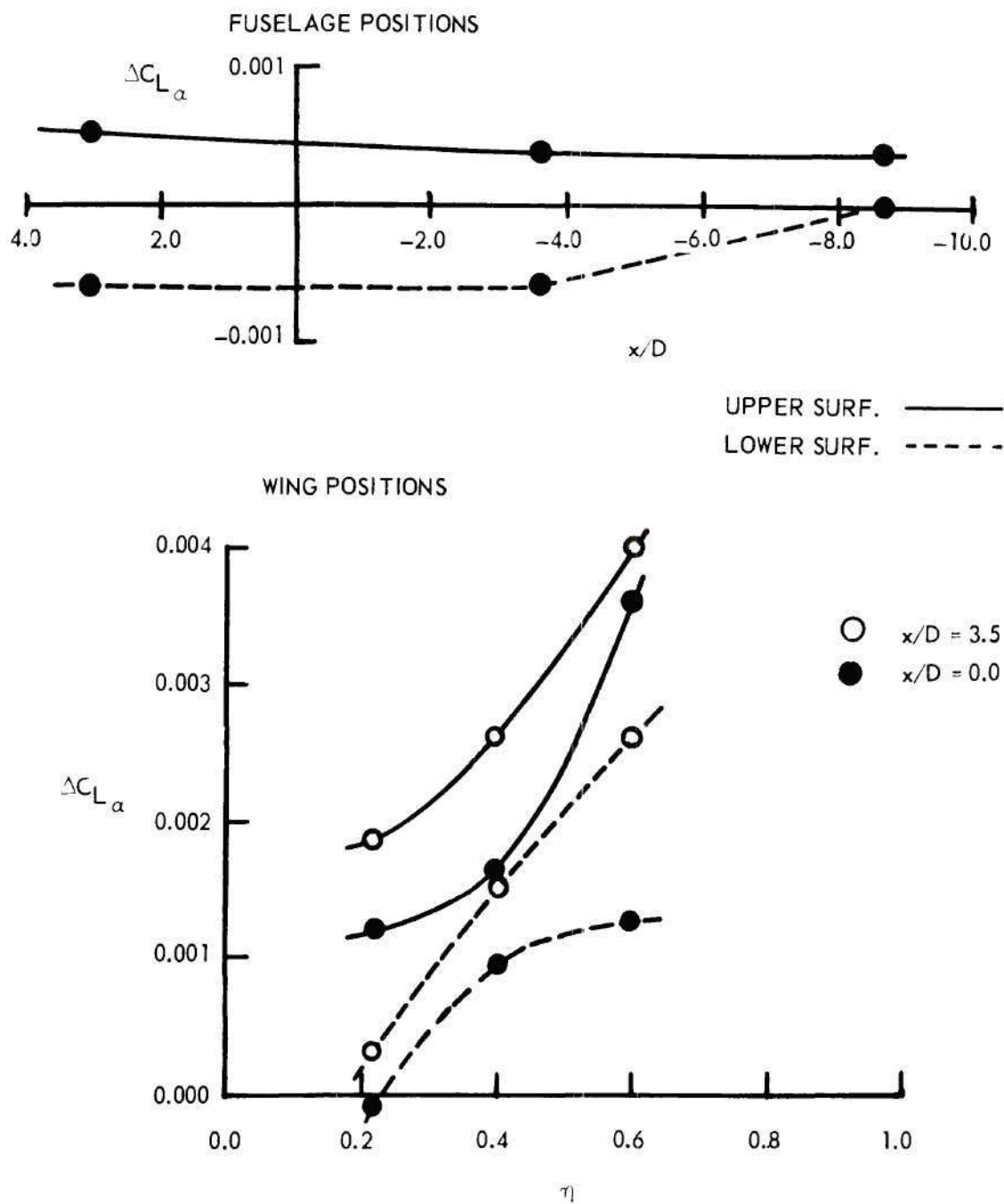


Figure 10. Incremental Variation of Lift Curve Slope.

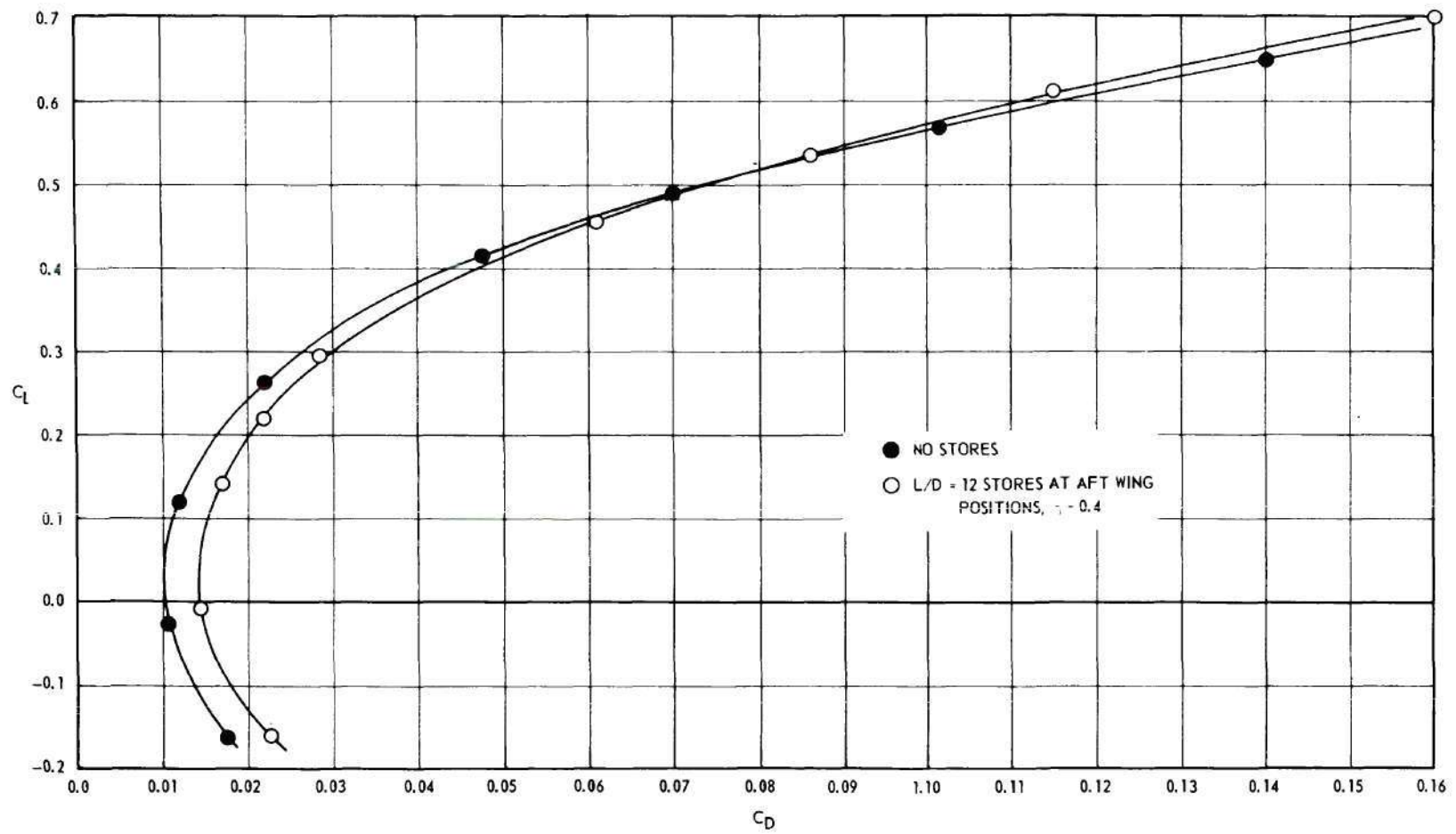


Figure 11. Typical Drag Polars.

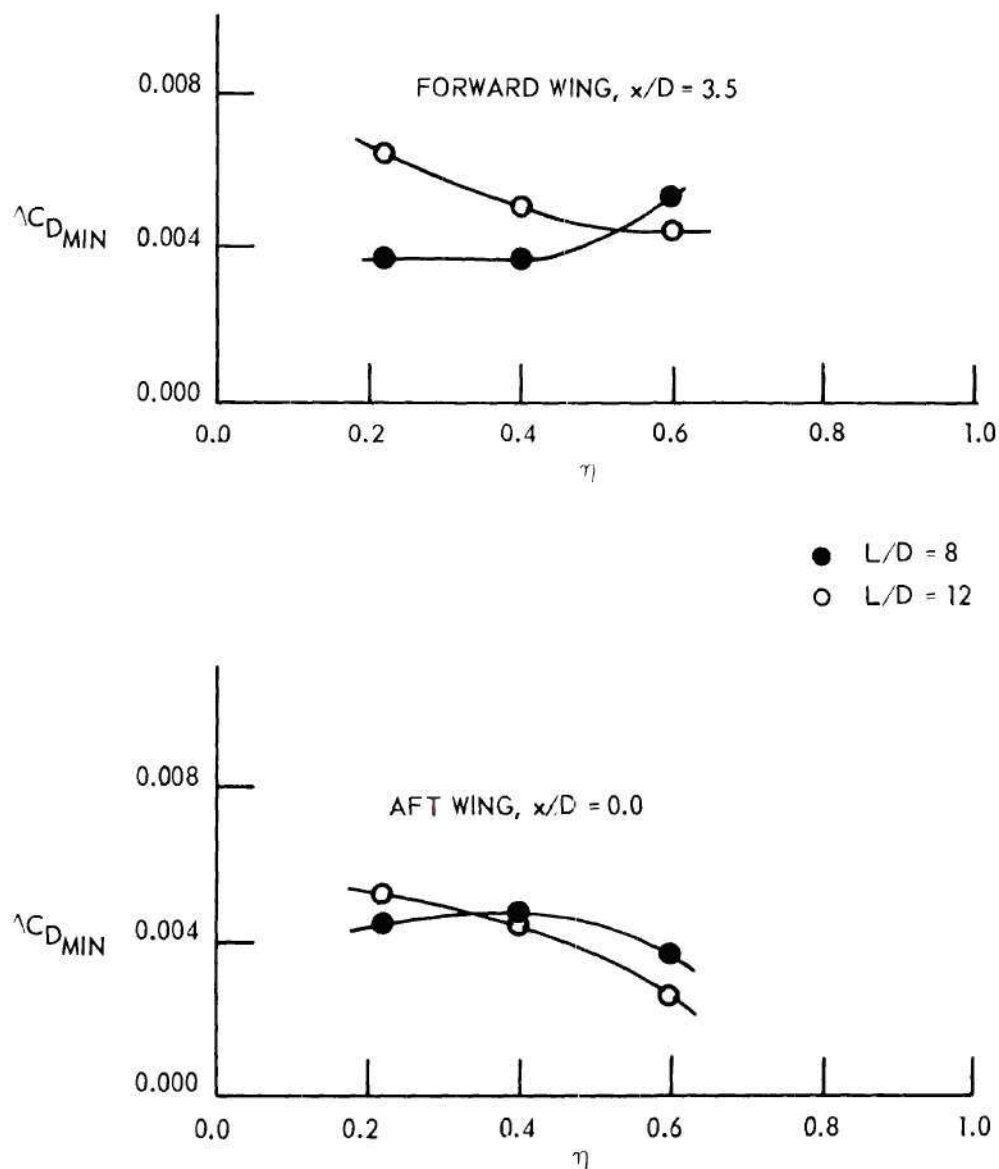


Figure 12. Incremental Variation of Minimum Drag.

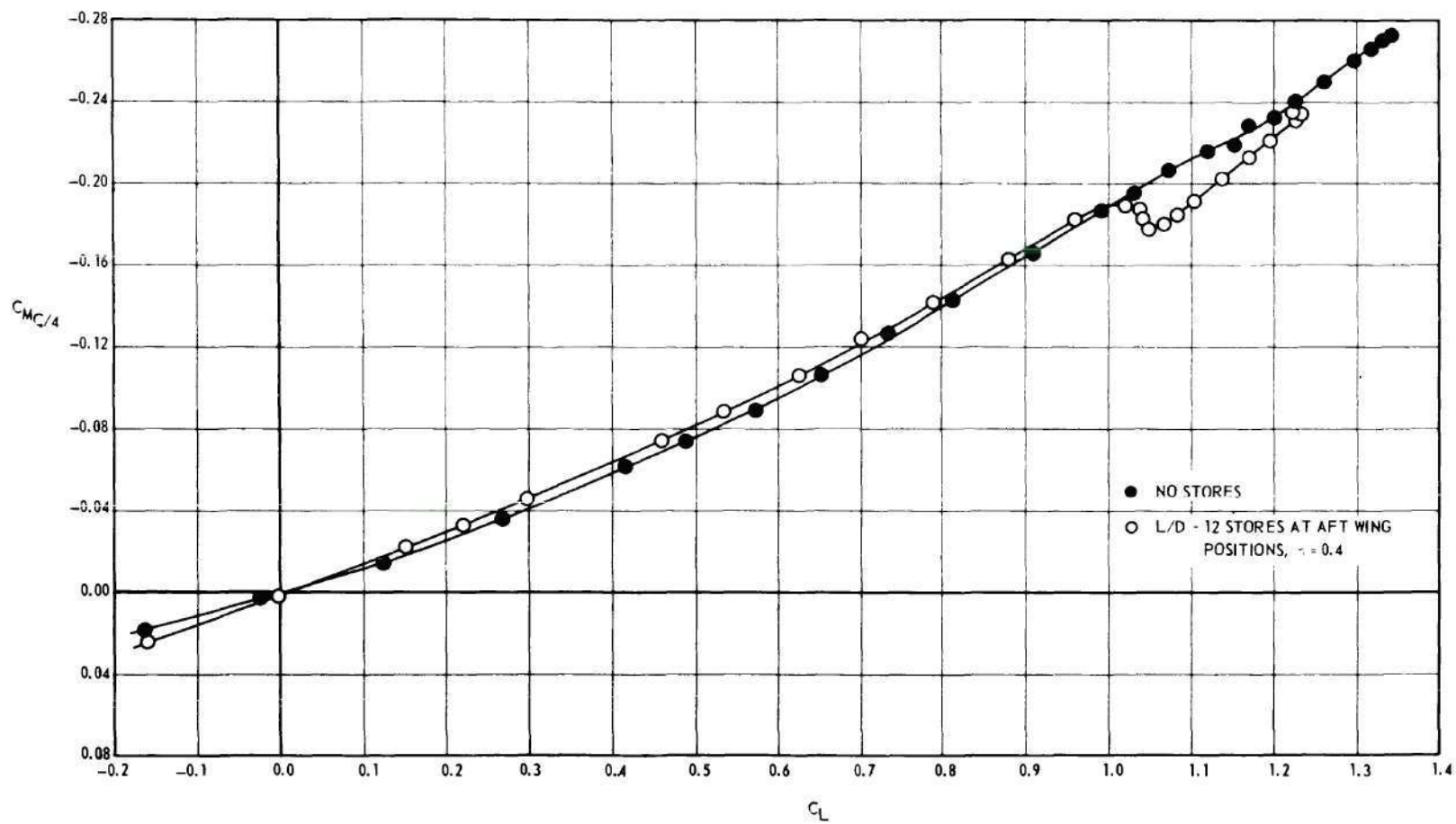


Figure 13. Typical Pitching Moment Polars.

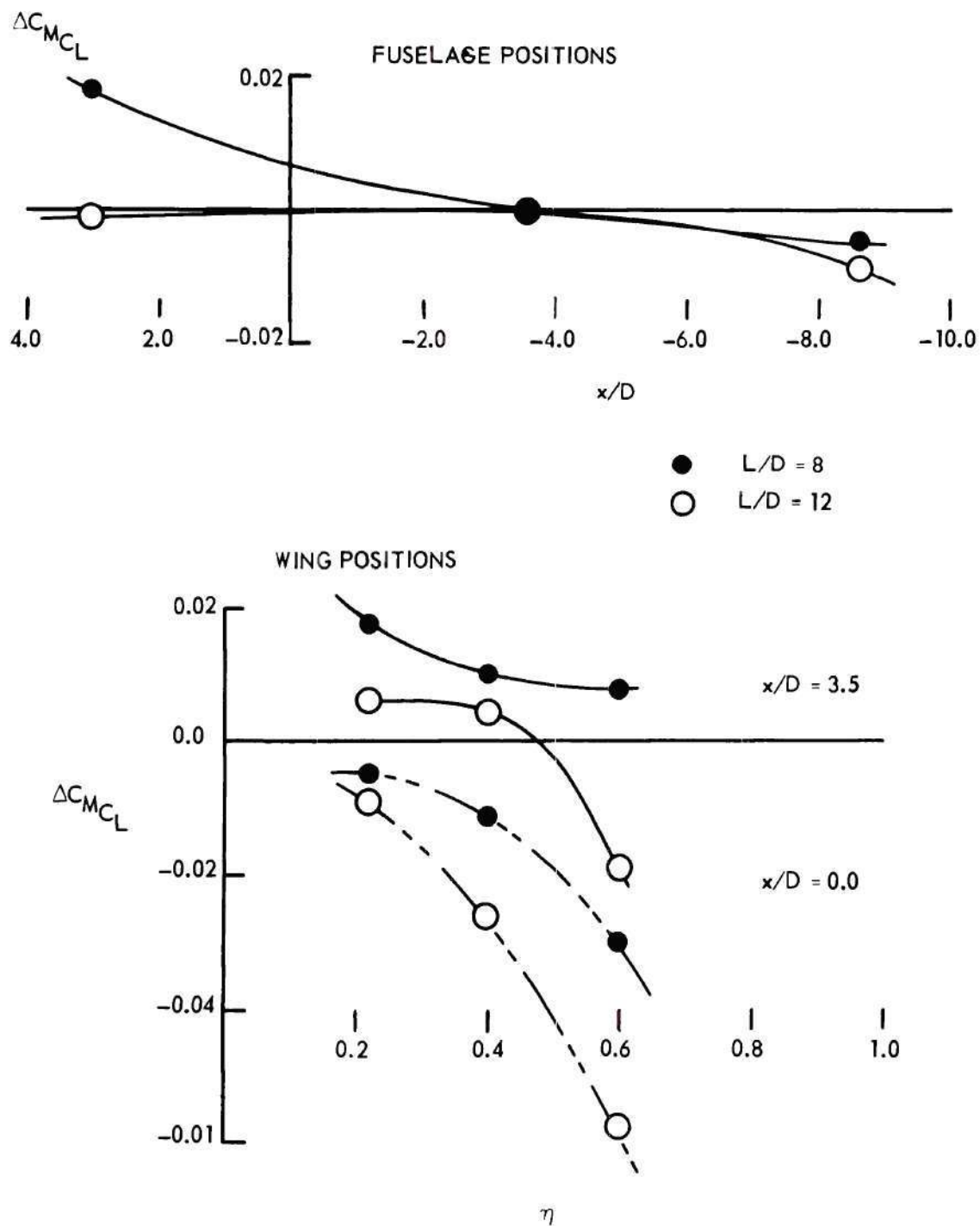


Figure 14. Incremental Variation of Stability Derivative $C_L = 0.0$.

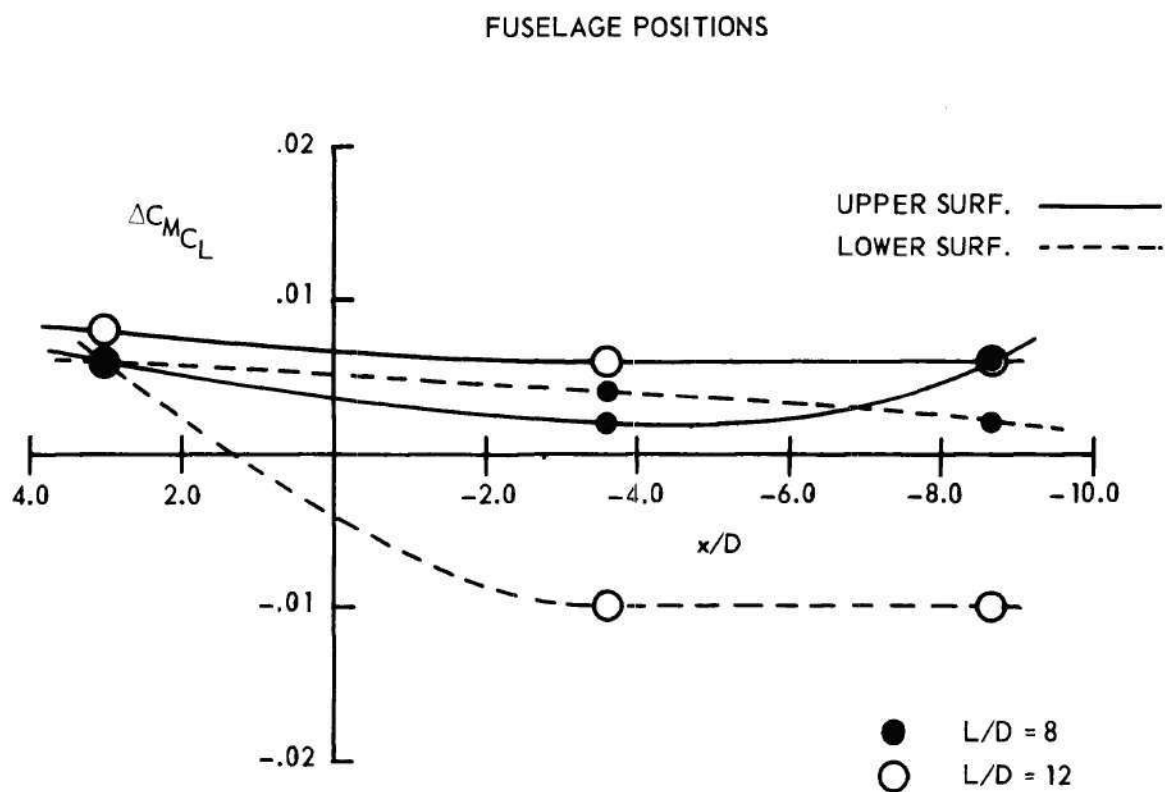


Figure 15. Incremental Variation of Stability Derivative $C_L = 0.6$.

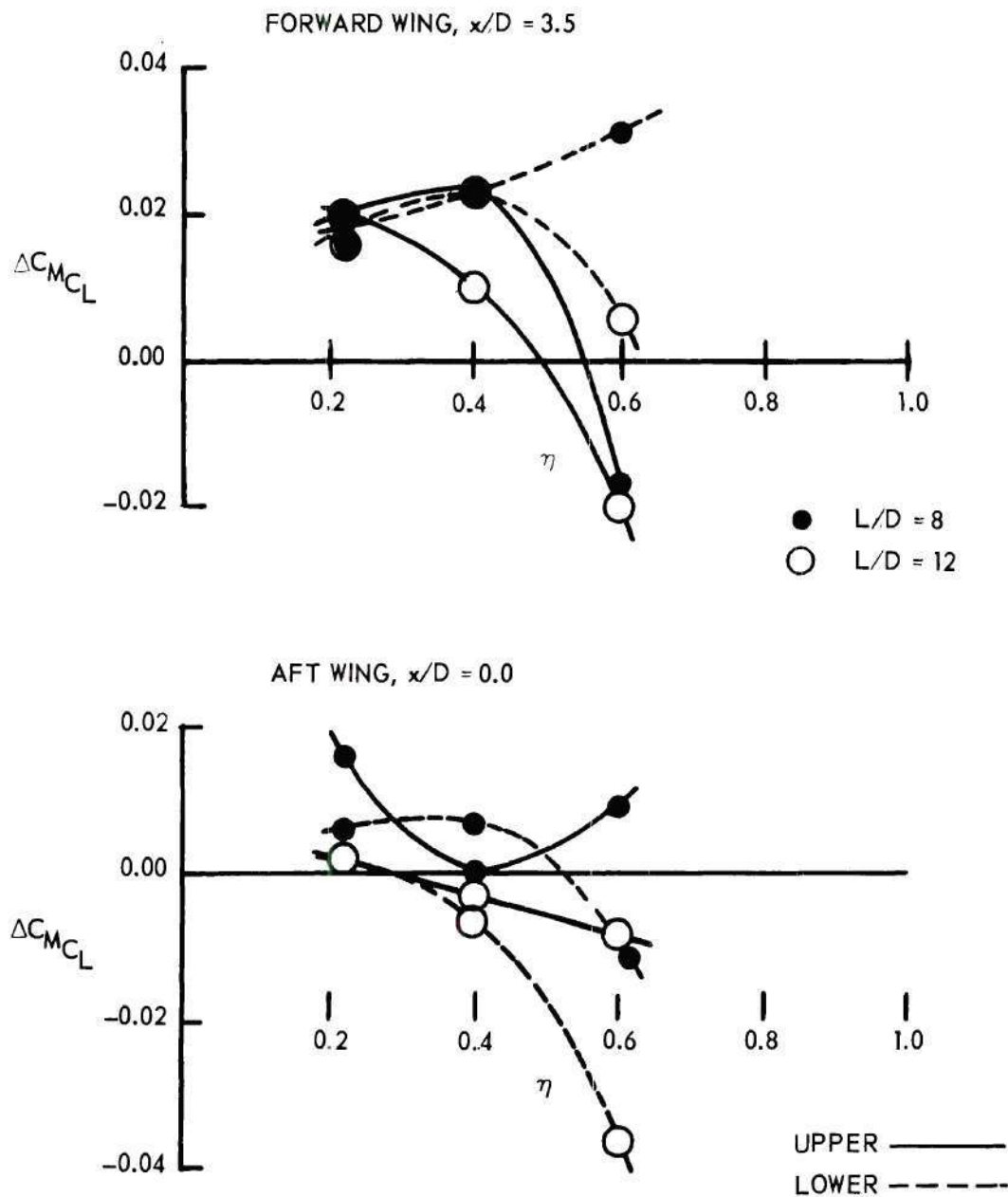


Figure 16. Incremental Variation of Stability Derivative $C_L = 0.6$.

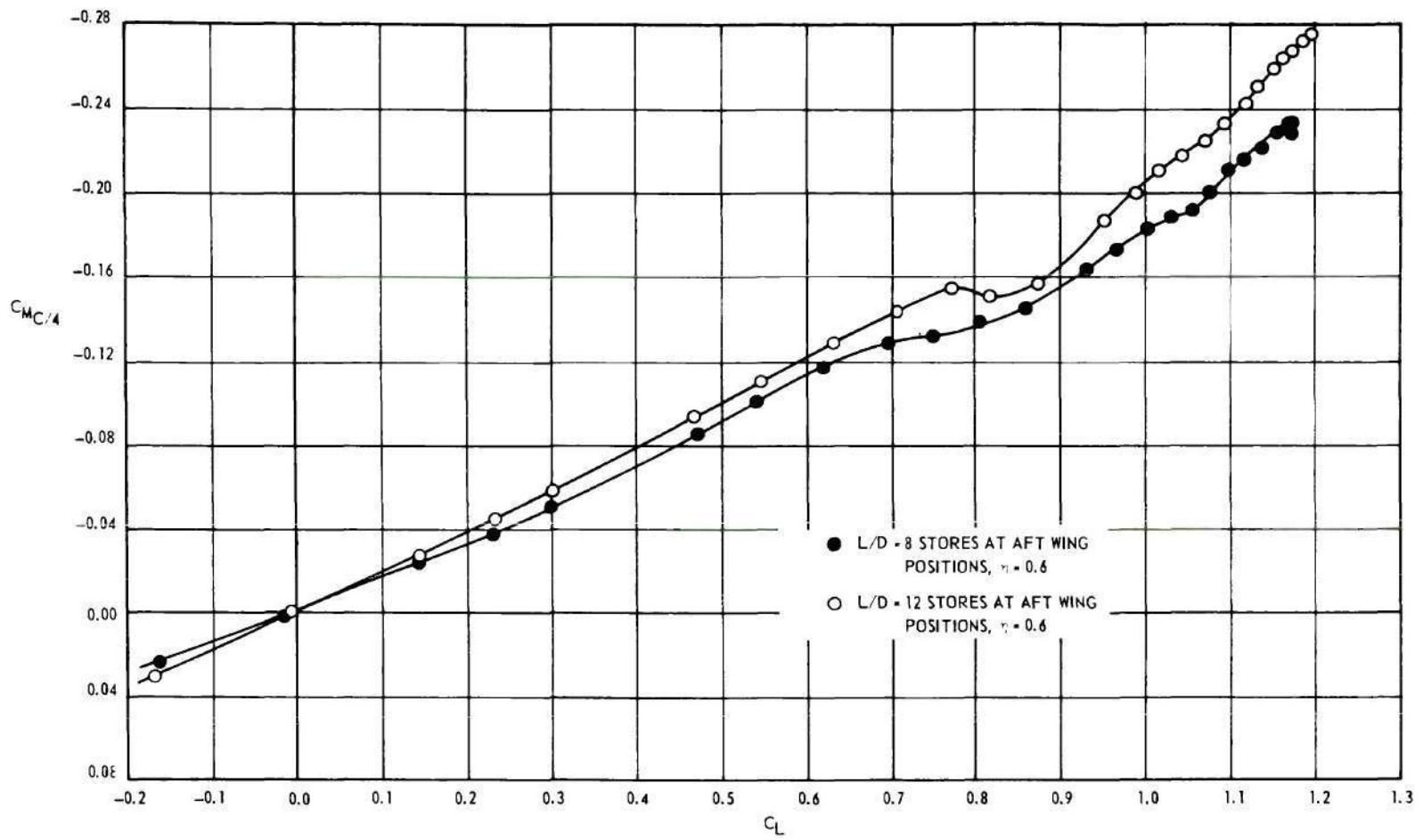


Figure 17. Pitching Moment Polars.

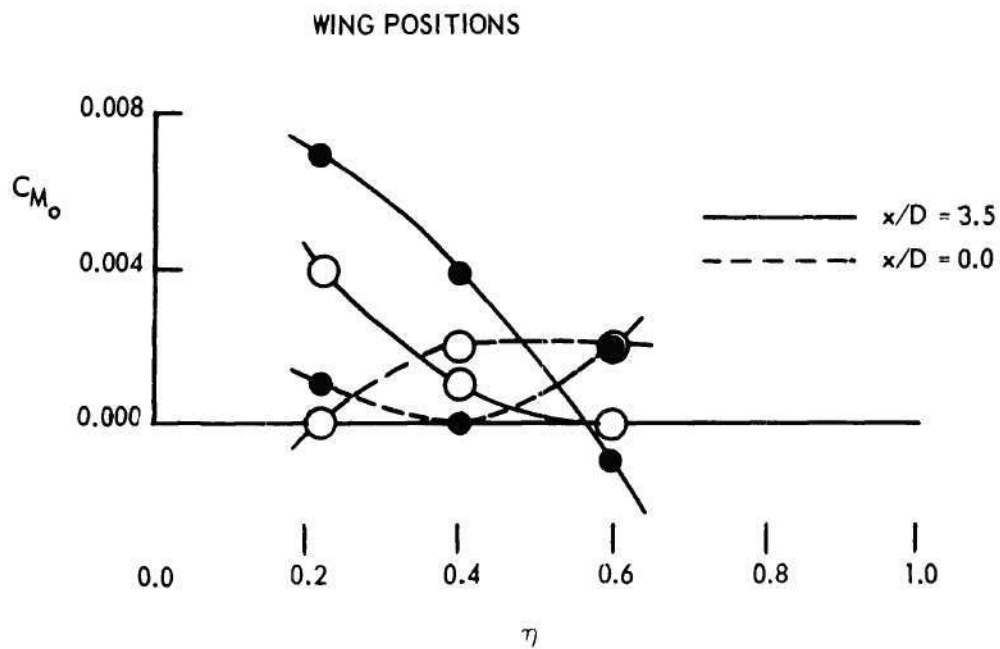
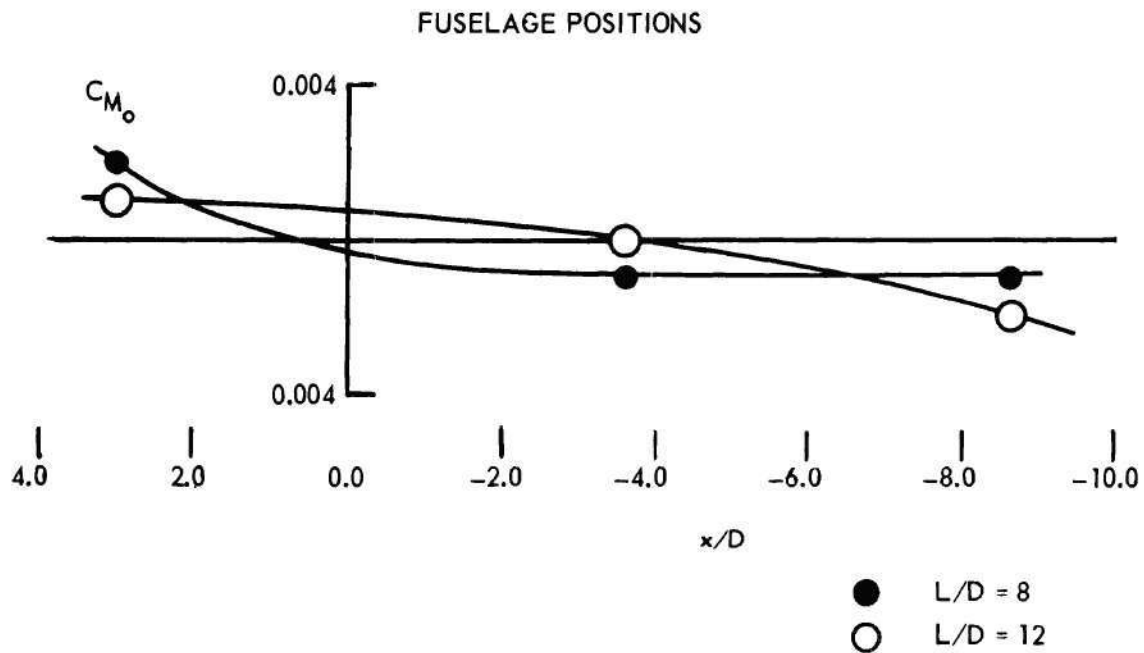


Figure 18. Variation of Zero Lift Pitching Moment Coefficient.

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