(1)

NASA-TM-74074

NASA Technical Memorandum 74074

Supersonic Longitudinal Aerodynamic Characteristics of Two Space Shuttle Orbiter Configurations

James C. Ellison

NOVEMBER 1977

NASA

NASA Technical Memorandum 74074

Supersonic Longitudinal Aerodynamic Characteristics of Two Space Shuttle Orbiter Configurations

James C. Ellison
Langley Research Center
Hampton, Virginia

National Aeronautics
and Space Administration

Scientific and Technical
Information Office

1977

SUMMARY

An investigation was conducted in the Langley Unitary Plan wind tunnel to determine the supersonic longitudinal aerodynamic characteristics of 0.015-scale models of the Rockwell International 089B and 139B space shuttle orbiter configurations and the 139B orbiter with a modified forebody. The models each had a 45° swept delta wing that was blended into the body with an 81° swept fillet to form a double-delta planform. The vertical tail had a split rudder deflected 27.5° on each side to form a speed brake. Tests were conducted at Mach numbers of 2.5, 3.9, and 4.6 at a Reynolds number, based on the body length of the 089B model, of 4.15×10^6. The angle-of-attack range was -4° to 44° for 0° sideslip.

The large negative values of zero-lift pitching-moment coefficient generated by the 089B were decreased by decreasing the wing incidence (139B) and by modifying the forebody of the 139B.

For angles of attack corresponding to those of a nominal shuttle mission, the models could be trimmed and were statically stable at a Mach number of 2.5. Each model could be trimmed at Mach numbers of 3.9 and 4.6 with neutral stability or slight instability. The 089B could not be trimmed at angles of attack between 10.4° and 18° for a Mach number of 3.9 or at angles of attack between 7° and 19° for a Mach number of 4.6. The trimmed lift-drag ratio decreased slightly over the increasing Mach number range and was about 0.3 lower for the 089B.

INTRODUCTION

Since 1969 the National Aeronautics and Space Administration has been engaged in the space shuttle program, and thousands of hours have been expended in wind-tunnel testing of space shuttle concepts. Much of this wind-tunnel testing has been focused on evaluating the aerodynamic characteristics of space shuttle orbiter configurations in the Mach number range from 0 to 20. (See refs. 1 to 3.)

Following its orbital mission, the shuttle orbiter returns to Earth at a high angle of attack (about 35°) at hypersonic speeds until it slows to supersonic speeds, at which time the angle of attack is decreased to that required to maintain a maximum lift-drag ratio and thus maximize cross range. The orbiter lands in a conventional, but unpowered, horizontal mode.

The purpose of this investigation was to evaluate the effects of two modifications to the shuttle orbiter configuration which were directed toward improving the longitudinal stability and trim characteristics at supersonic speeds. These modifications (suggested by Langley Research Center personnel in conjunction with the prime contractor) reduced the wing incidence from 3.0° to 0.5° and moved the forebody upward in an attempt to alleviate the large negative pitch at zero lift.

This wind-tunnel investigation is an evaluation and comparison of the supersonic aerodynamic characteristics of 0.015-scale models of the Rockwell International 089B (ref. 2), 139B (ref. 3), and the 139B with a modified forebody (MOD 139B). Data were obtained in the Langley Unitary Plan wind tunnel at Mach numbers of 2.5, 3.9, and 4.6 at a Reynolds number, based on the body length of the 089B model, of 4.15×10^{6}. The angle-of-attack range was -4° to 44° for 0° sideslip.

SYMBOLS

The data are referred to the stability-axis system. All longitudinal aerodynamic coefficients are normalized with respect to the area and the mean aerodynamic chord of the basic 45° delta wing excluding the wing-body fairing (i.e., 81° fillet). The moments are referenced to the center-of-gravity locations shown in figures 1 and 2.

$\bar{c}$ mean aerodynamic chord (basic 45° wing), 18.090 cm

C_D drag coefficient, $\frac{\text{Drag}}{q_{\infty}S}$

C_L lift coefficient, $\frac{\text{Lift}}{q_{\infty}S}$

$C_{L_{\alpha}}$ lift-curve slope, $\frac{\partial C_L}{\partial \alpha}$, per degree

C_m pitching-moment coefficient, $\frac{\text{Pitching moment}}{q_{\infty}S\bar{c}}$

$C_{m,o}$ pitching-moment coefficient at zero lift

$C_{m_{\alpha}}$ longitudinal stability parameter, $\frac{\partial C_m}{\partial \alpha}$, per degree

C_p pressure coefficient, $\frac{\text{Measured pressure - Free-stream pressure}}{q_{\infty}}$

L/D lift-drag ratio

M	Mach number
OMS	orbital maneuvering system
q_∞	free-stream dynamic pressure, Pa
S	area of 45° delta wing, 0.056 m^2
α	angle of attack, deg
α_{nom}	nominal operational angle of attack (see fig. 5), deg
δ_{BF}	body flap deflection angle, deg
δ_e	elevon deflection angle, deg

Subscripts:

max	maximum
min	minimum

DESCRIPTION OF MODELS

Sketches of the 0.015-scale models of the Rockwell International 089B and 139B orbiter configurations are presented in figures 1 and 2. Each model had a 45° swept delta wing that was blended into the body with an 81° swept fillet to form a double-delta planform. Pertinent details of the body, wing, and vertical tail are given in table I. The vertical tail had a split rudder that was deflected 27.5° on each side to form a speed brake with 55° flare. In addition, the forebody of the 139B model could be removed and replaced with the modified forebody, designated MOD 139B. (See fig. 2(b).)

Large fairings on each side at the base of the models represent the orbital maneuvering system (OMS) housing, and the fairing extending from the canopy aft to the vertical tail along the top of the 089B body simulates the cargo-handling arms housing. The elevons and body base flap were attached with mounting brackets set at various deflection angles. Figure 3 is a photograph of the 089B model.

APPARATUS, TESTS, AND DATA REDUCTION

Tests were conducted in the high-Mach-number test section of the Langley Unitary Plan wind tunnel, a variable-pressure, continuous-flow facility. (See ref. 4.) The test section is 1.22 m square and 2.13 m long. The Mach number in this test section can be varied from approximately 2.3 to 4.7 by changing the position of the asymmetric sliding-block nozzles ahead of the test section.

The models were sting supported and forces and moments were measured on a six-component, internally mounted strain-gage balance. Measurements were obtained at Mach numbers of 2.5, 3.9, and 4.6 at a Reynolds number, based on the 089B model length, of 4.15×10^6 and for an angle-of-attack range of -4° to 44° at 0° sideslip. The drag values presented are the gross drag values, which include base drag. However, the pressures in the balance chamber, on the model base, and on the base of the OMS were measured and are presented in figure 4 in pressure-coefficient form for the 089B model with undeflected controls.

A strip of No. 60 grit, 0.16 cm wide, was affixed 3.05 cm aft of the apex of the model nose and 1.02 cm aft of the leading edges (measured in the streamwise direction) of the wing and vertical tail to insure turbulent flow over the models.

RESULTS AND DISCUSSION

Flight Regimes

For a high-cross-range mission, the shuttle orbiter was designed to maintain an initial angle of attack near 35° throughout the hypersonic regime. In the supersonic regime, there would be a transition to lower angles of attack, and the split rudder would be flared 27.5° on each side to provide a speed brake with 55° flare. A nominal angle-of-attack schedule is given in figure 5, and for the Mach number range of this investigation (2.5 to 4.6), the flight angle of attack varies from approximately 14° to 23°.

Longitudinal Aerodynamic Characteristics

The longitudinal aerodynamic characteristics of the three configurations at Mach numbers of 2.5, 3.9, and 4.6 with $\delta_e = 0^\circ$ and $\delta_{BF} = -14.25^\circ$, are presented in figure 6. The variation of C_L with angle of attack was typical for this speed regime. Because of the wing incidence the 089B had values of C_L and C_D greater than the 139B and MOD 139B, which were essentially equal. At $M = 2.5$ all the configurations were longitudinally stable over the angle-of-attack range, and the increased value of $C_{m,o}$ for the MOD 139B resulted in a stable trim point at $\alpha = 4^\circ$ $(\delta_e = 0^\circ)$. However, at the higher Mach numbers the 089B was neutrally stable at $-2^\circ \leqq \alpha \leqq 6^\circ$, whereas the 139B and MOD 139B were slightly unstable or neutrally stable for $\alpha < 8^\circ$ and $\alpha < 12^\circ$, respectively.

A summary of the low-angle-of-attack characteristics (through $\alpha = 0^\circ$) and the untrimmed maximum lift-drag ratios is presented in figure 7.

The large negative values of $C_{m,o}$ generated by the 089B were decreased by decreasing the wing incidence (forming the 139B) and by moving the forebody upward (MOD 139B). In fact, the increment related to the modified forebody was equivalent to the increment related to reducing incidence; furthermore, these increments in C_m were nearly constant over the angle-of-attack range. These modifications achieved the desired effects: producing a positive increment in $C_{m,o}$ and improving trim characteristics. These modifications also improved the maximum lift-drag ratio by about 0.1.

Effects of elevon and base-flap deflections on the longitudinal aerodynamic characteristics are presented in figures 8 to 10 and summarized for trimmed conditions in figure 11. Main interest is focused on the nominal operational angle of attack (indicated by bars in fig. 11). At $M = 2.5$ and $\alpha = 13.5^{\circ}$ all the configurations could be trimmed and were stable, but the 089B had a trim penalty in L/D of about 0.3. The 089B could not be trimmed with the available elevon deflection angles for $10.4^{\circ} \leqq \alpha \leqq 18^{\circ}$ at $M = 3.9$ or for $7^{\circ} \leqq \alpha \leqq 19^{\circ}$ at $M = 4.6$; however, for α_{nom} at $M = 3.9$ and 4.6 the 089B was trimmed, although unstable. At all Mach numbers the value of trimmed L/D at α_{nom} for the 089B was about 0.3 below the values for the 139B and MOD 139B. The trim penalty at $M = 2.5$ and the inability to trim at the higher Mach numbers for the 089B are attributed to the large negative values of $C_{m,o}$ for $\delta_e = 0^{\circ}$. The 139B and MOD 139B were trimmable over the angle-of-attack range and had essentially no trim penalty at α_{nom}; however, because of interpolation of the data fairings between values of elevon deflection angles, the stability of the configurations is uncertain at some angles of attack.

SUMMARY OF RESULTS

The aerodynamic characteristics of 0.015-scale models of the Rockwell International 089B and 139B space shuttle orbiter configurations have been obtained at supersonic Mach numbers of 2.5, 3.9, and 4.6. In addition, the 139B was tested with a modified forebody. Results of this wind-tunnel investigation are summarized as follows:

1. The large negative values of zero-lift pitching-moment coefficient generated by the 089B were decreased by decreasing the wing incidence (139B) and by moving the forebody upward (MOD 139B).

2. For angles of attack corresponding to those of a nominal shuttle mission:

   a. The models were trimmable and stable at a Mach number of 2.5.

   b. The models could be trimmed but were unstable at Mach numbers of 3.9 and 4.6.

   c. The trimmed lift-drag ratio decreased slightly over the Mach number range and was about 0.3 less for the 089B.

3. The 089B could not be trimmed for angles of attack between 10.4° and 18° at a Mach number of 3.9 or between 7° and 19° at a Mach number of 4.6.

Langley Research Center
National Aeronautics and Space Administration
Hampton, VA 23665
October 31, 1977

REFERENCES

1. Ware, George M.; Spencer, Bernard, Jr.; and Fournier, Roger H.: Supersonic Aerodynamic Characteristics of the North American Rockwell ATP Shuttle Orbiter. NASA TM X-2804, 1973.

2. Freeman, Delma C., Jr.; Boyden, Richmond P.; and Davenport, E. E.: Supersonic Dynamic Stability Derivatives of a Modified 089B Shuttle Orbiter. NASA TM X-72630, 1974.

3. Stone, David R.; and Mulfinger, Robert: Hypersonic Stability and Control Characteristics of the Rockwell International 139-B Space Shuttle Orbiter. NASA TM X-71968, 1974.

4. Schaefer, William T., Jr.: Characteristics of Major Active Wind Tunnels at the Langley Research Center. NASA TM X-1130, 1965.

TABLE I.- GEOMETRIC CHARACTERISTICS OF 0.015-SCALE MODELS

	089B	139B
Body:		
Length (excludes base flap), cm	50.607	49.160
Maximum height, cm	9.449	9.315
Maximum width, cm	10.096	10.196
Fineness ratio	5.012	4.822
Base area, m^2	0.00418	0.00418
Cavity area, m^2	0.00316	0.00316
OMS pod base area (total), m^2	0.00177	0.00177
Wing:		
Area,[a] m^2	0.056	0.056
Span, cm	35.687	35.687
Aspect ratio	2.265	2.265
Dihedral angle, deg	3.500	3.500
Leading-edge sweep angle, deg	45.00	45.00
Trailing-edge sweep angle, deg	-10.24	-10.24
Root chord at center line, cm	26.260	26.260
Tip chord, cm	5.253	5.253
Mean aerodynamic chord,[a] cm	18.090	18.090
Airfoil section at body	Modified NACA 0010-64	
Airfoil section at tip	Modified NACA 0012-64	
Incidence, deg	3.00	0.50
Twist, deg	3.00	3.00
Vertical tail:		
Area including voids, m^2	0.00863	0.00890
Span, cm	12.029	12.029
Aspect ratio	1.675	1.675
Leading-edge sweep angle, deg	45.00	45.00
Trailing-edge sweep angle, deg	26.249	26.249
Root chord, cm	10.230	10.230
Tip chord, cm	4.133	4.133
Leading wedge angle, deg	10.00	10.00
Trailing wedge angle, deg	14.92	14.92
Leading-edge radius, cm	0.076	0.076

[a]Model reference dimension.

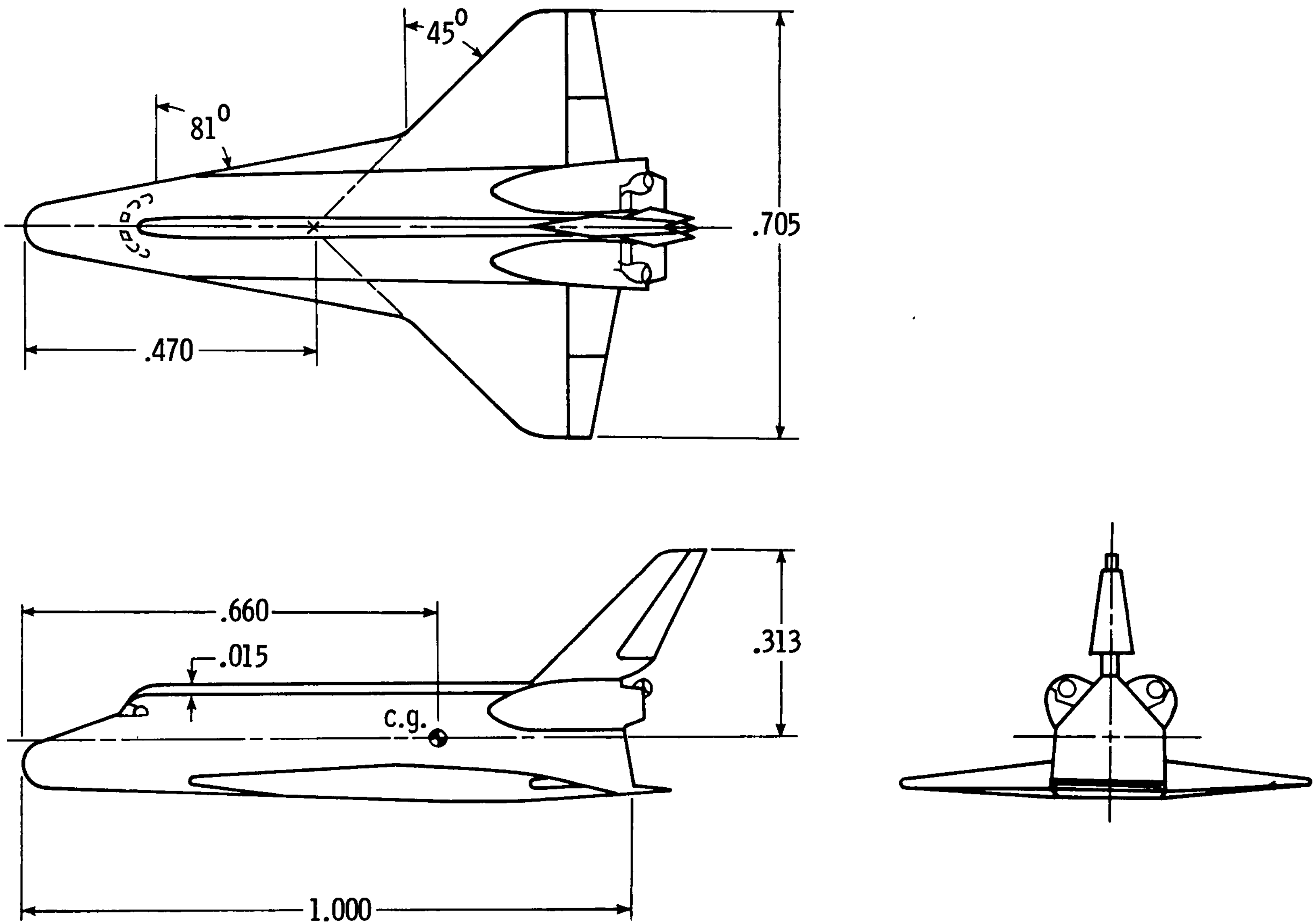
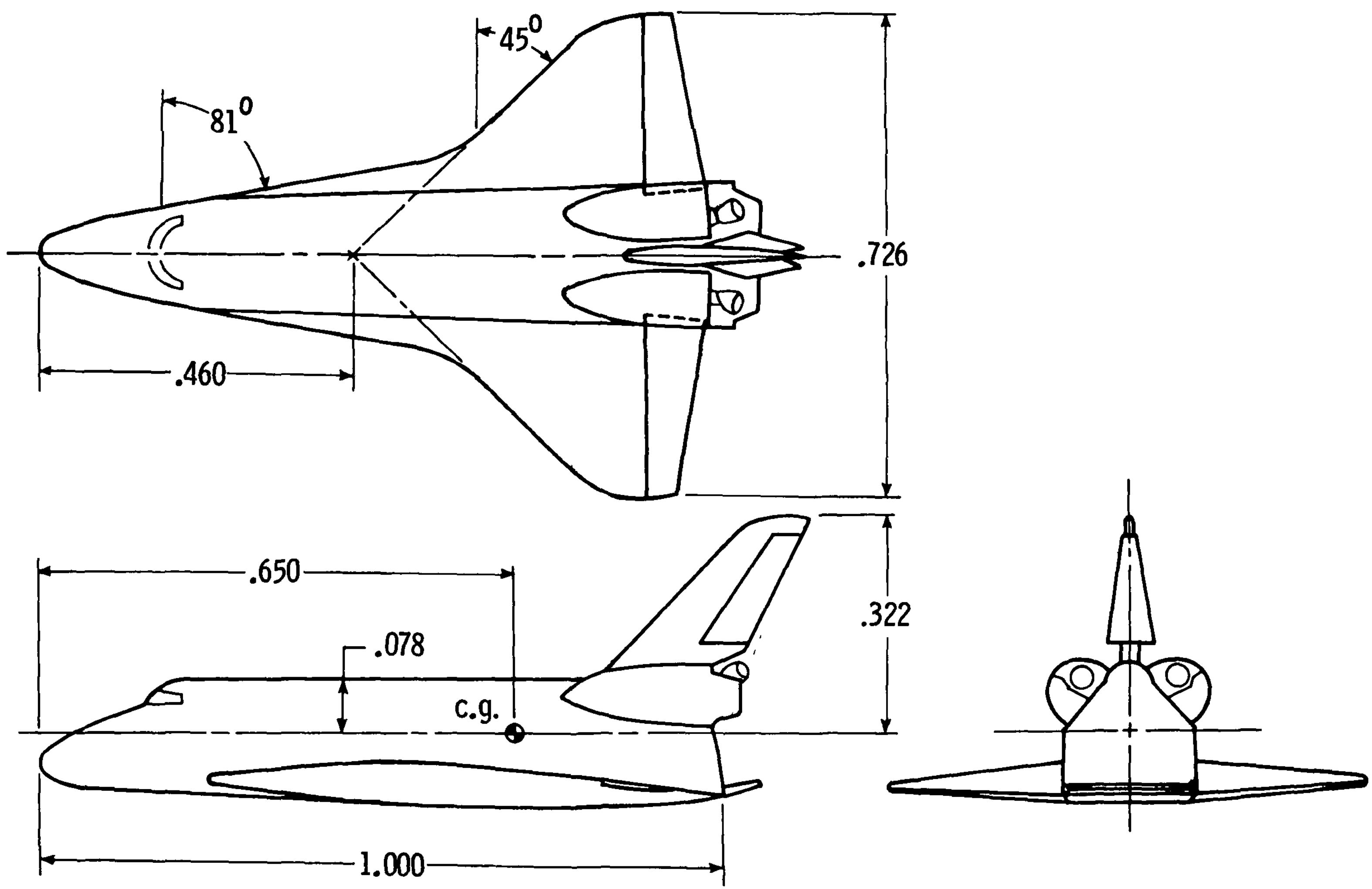
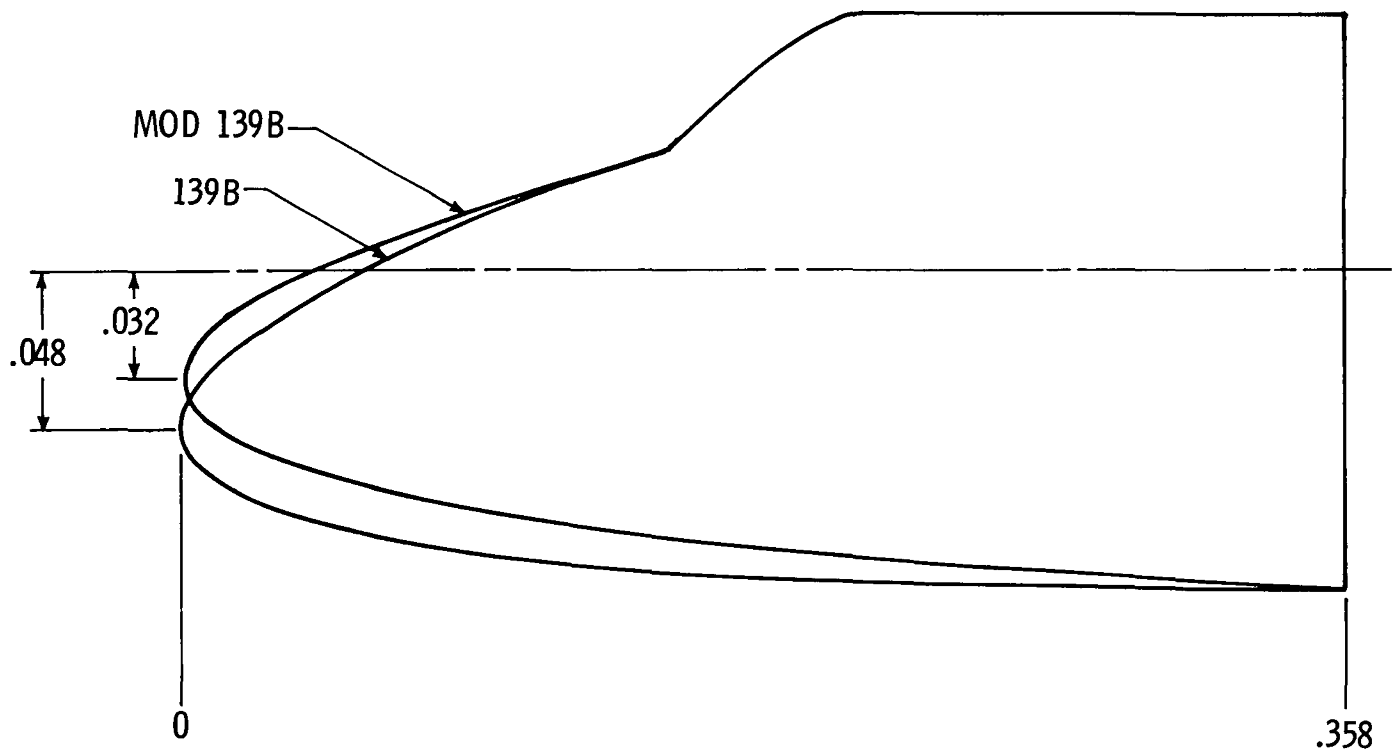


Figure 1.- Sketch of 089B model. All linear dimensions are in terms of body length (50.607 cm).



(a) Model detail.

Figure 2.- Sketch of 139B model. All linear dimensions are in terms of body length (49.161 cm).



(b) Forebody detail.

Figure 2.- Concluded.

L-73-4344

Figure 3.- Photograph of 089B model.

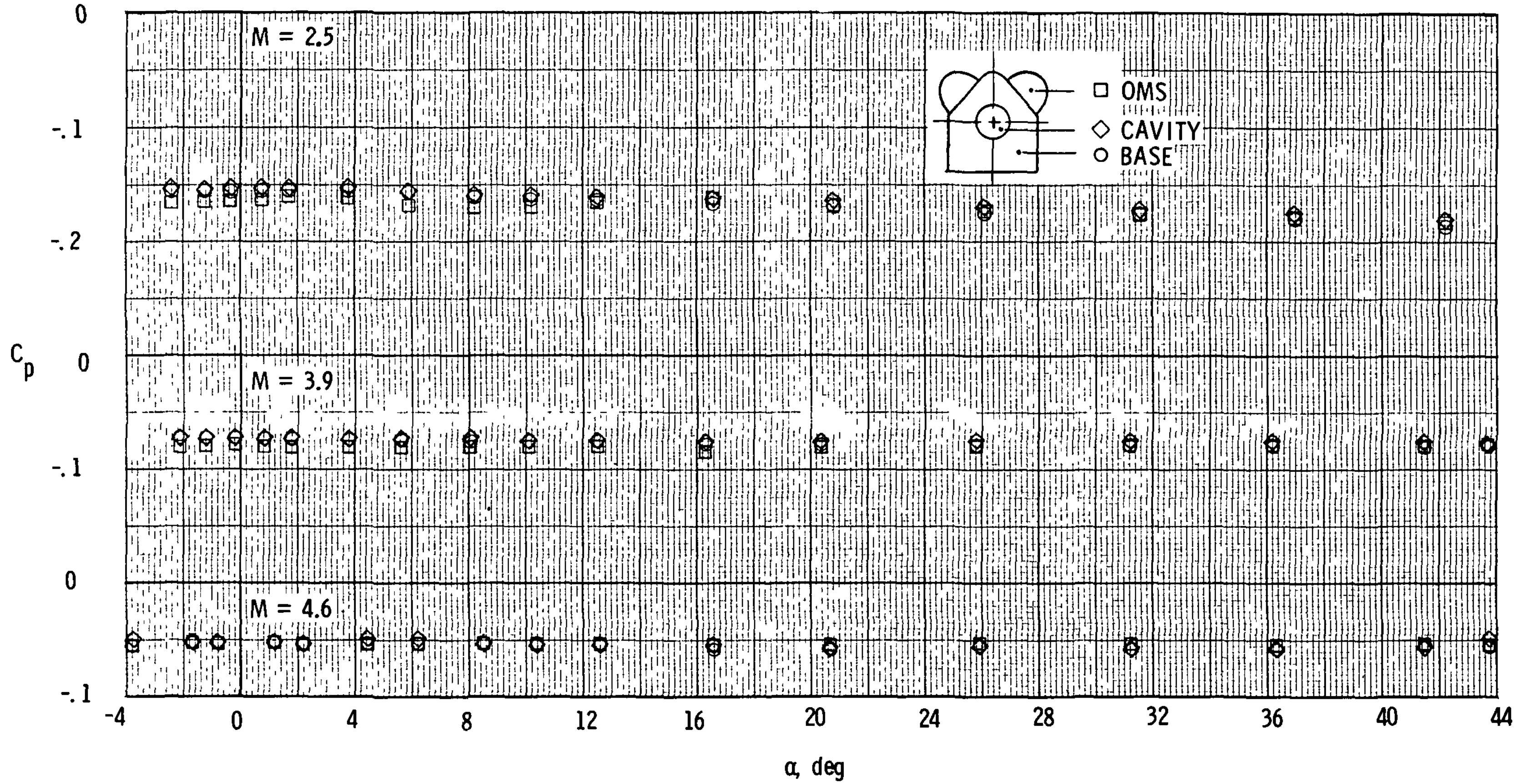


Figure 4.- Base and chamber pressure coefficients for the 089B model. $\delta_e = 0^o$; $\delta_{BF} = 0^o$.

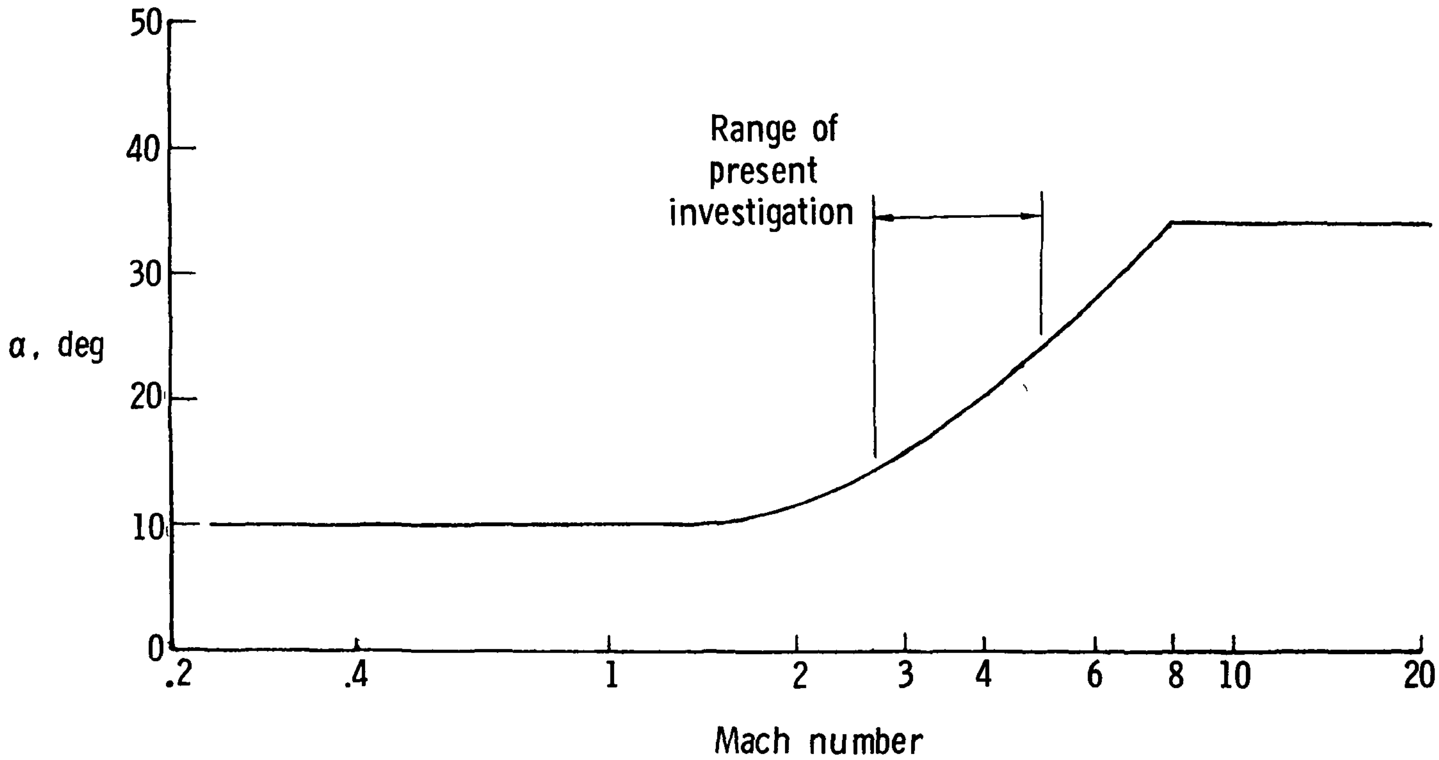
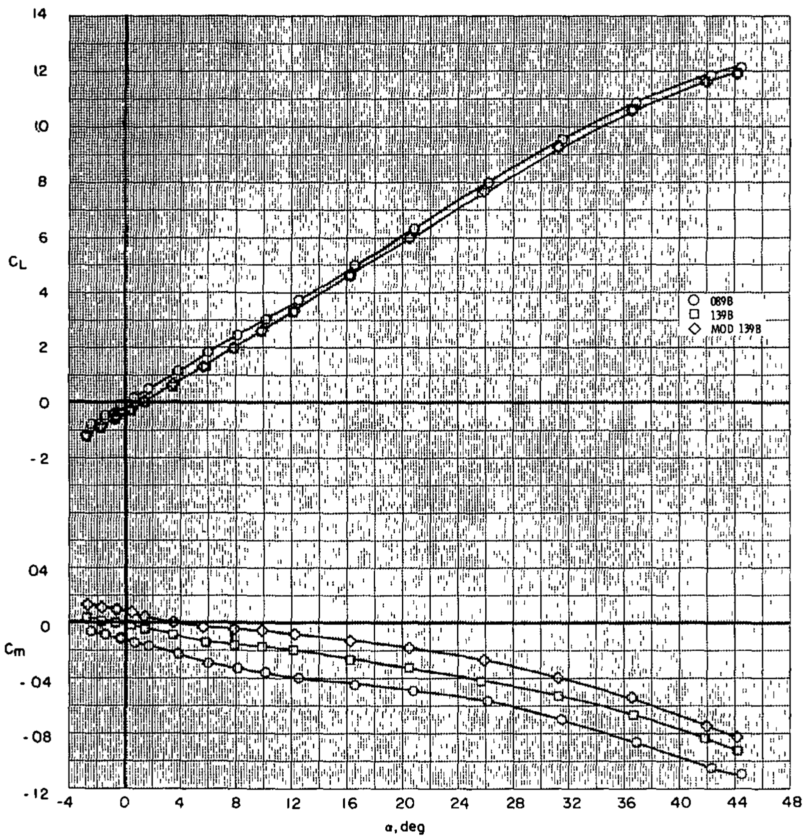
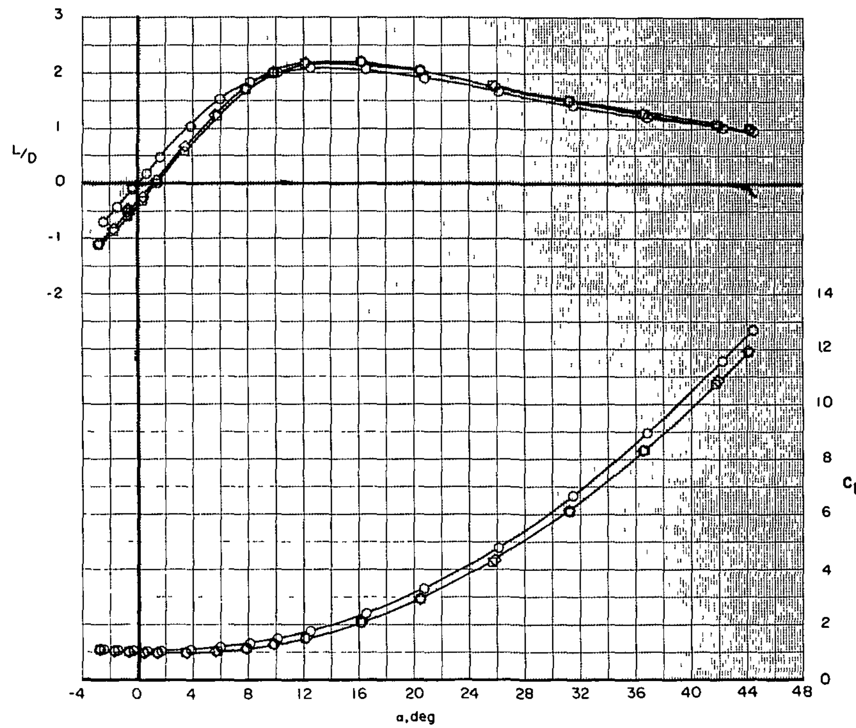


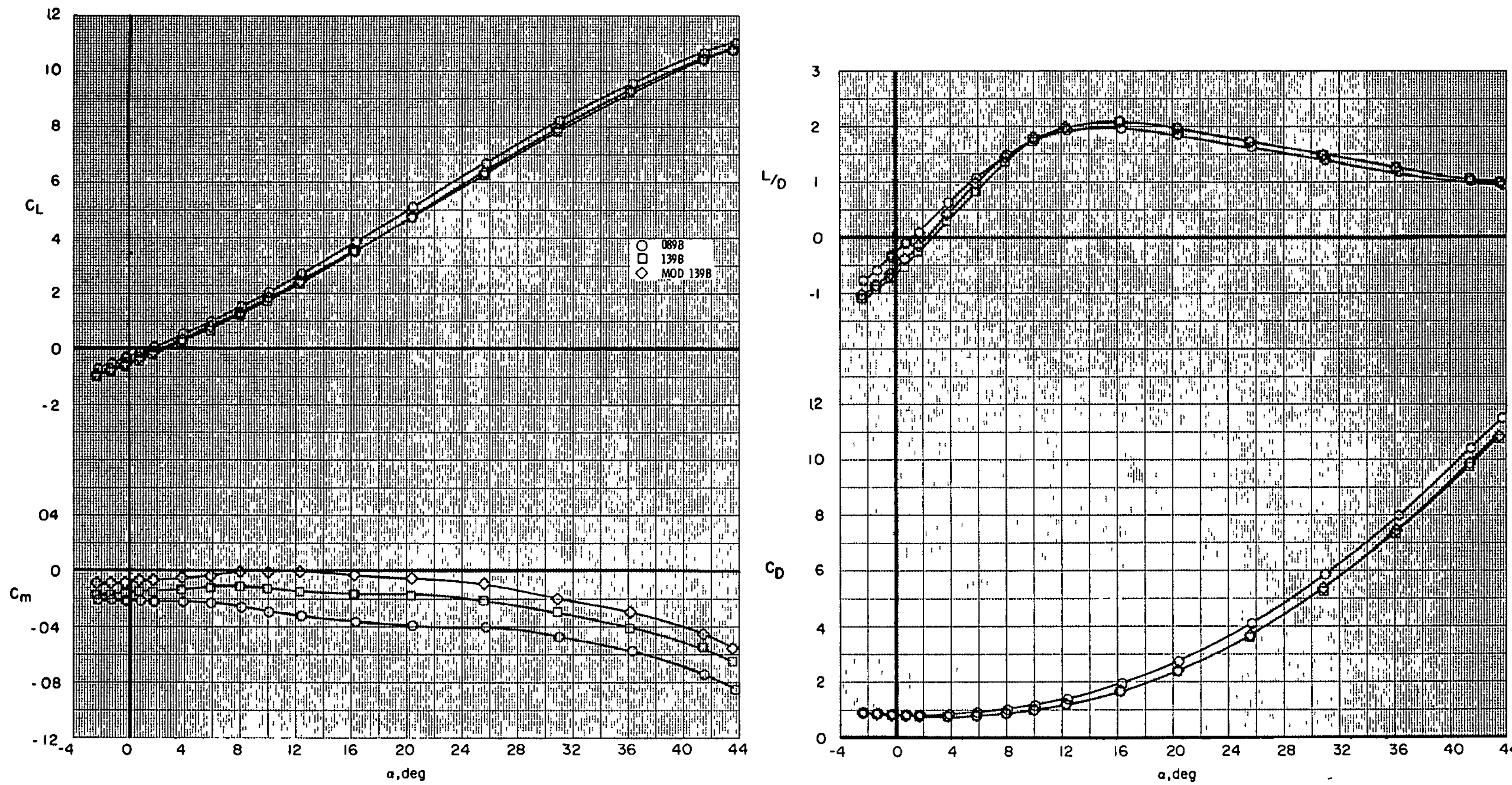
Figure 5.- Nominal operational angle-of-attack schedule.





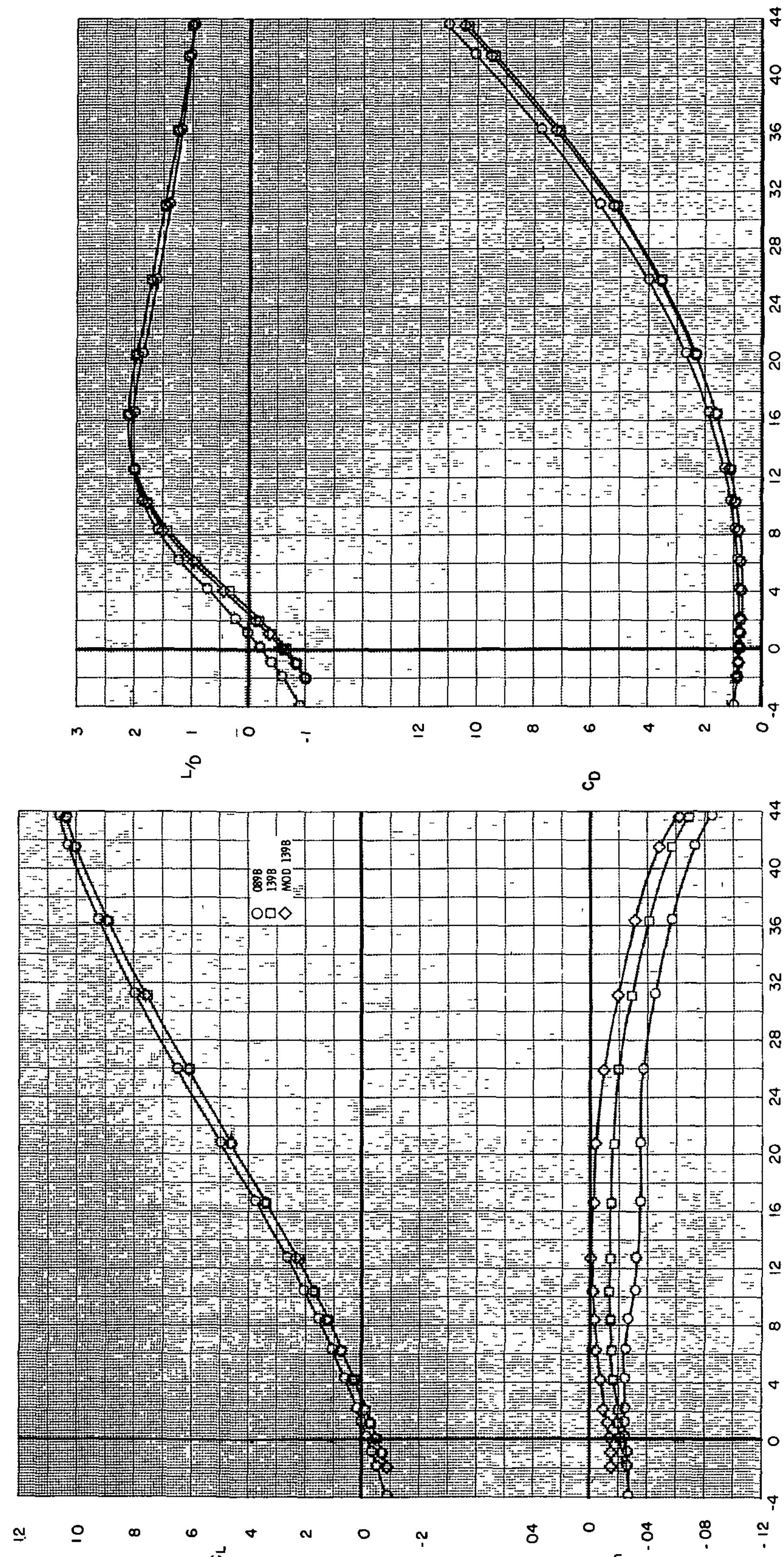
(a) M = 2.5.

Figure 6.- Comparison of longitudinal aerodynamic characteristics. $\delta_e = 0^o$; $\delta_{BF} = -14.25^o$.



(b) M = 3.9.

Figure 6.- Continued.



(c) M = 4.6.

Figure 6.- Concluded.

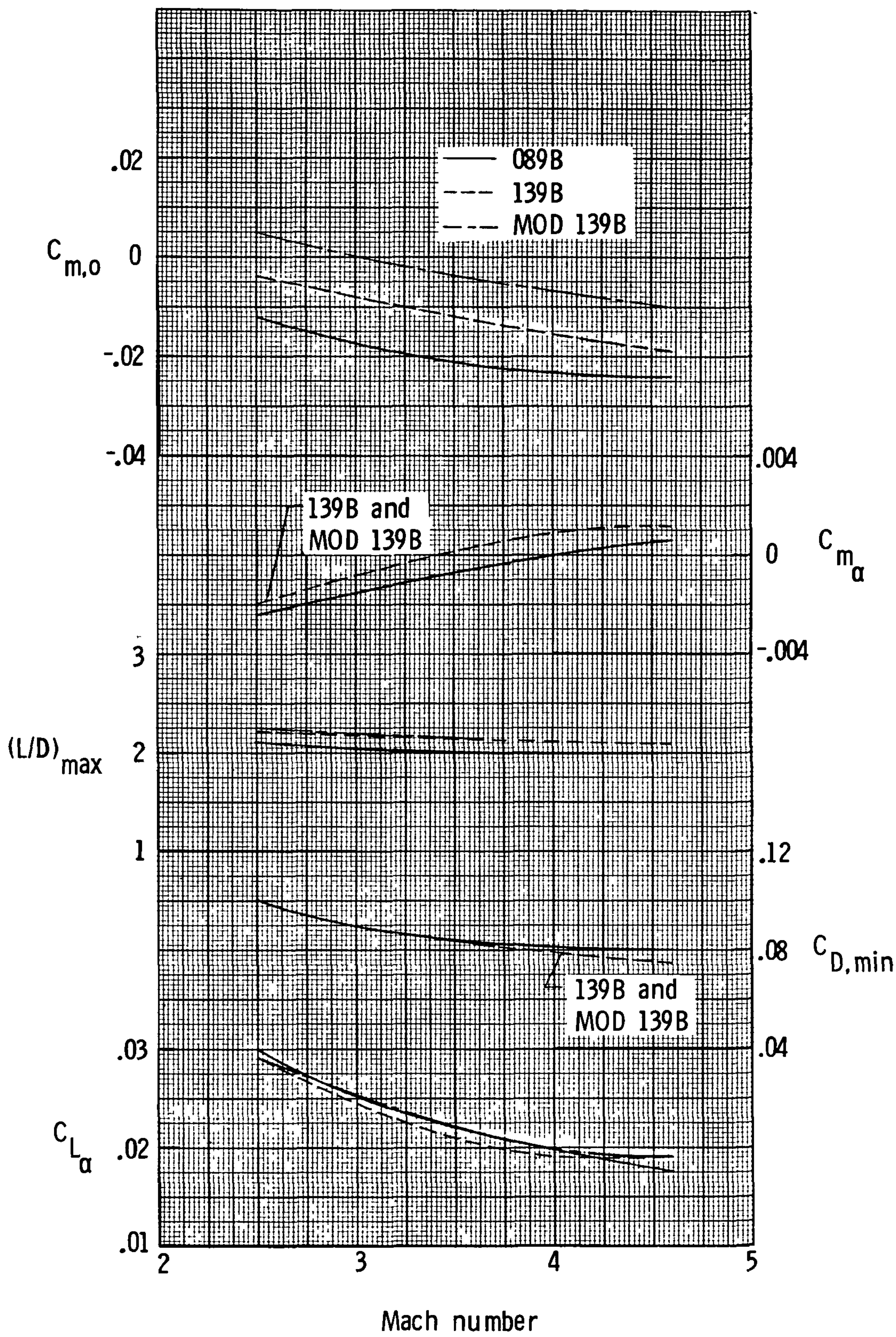
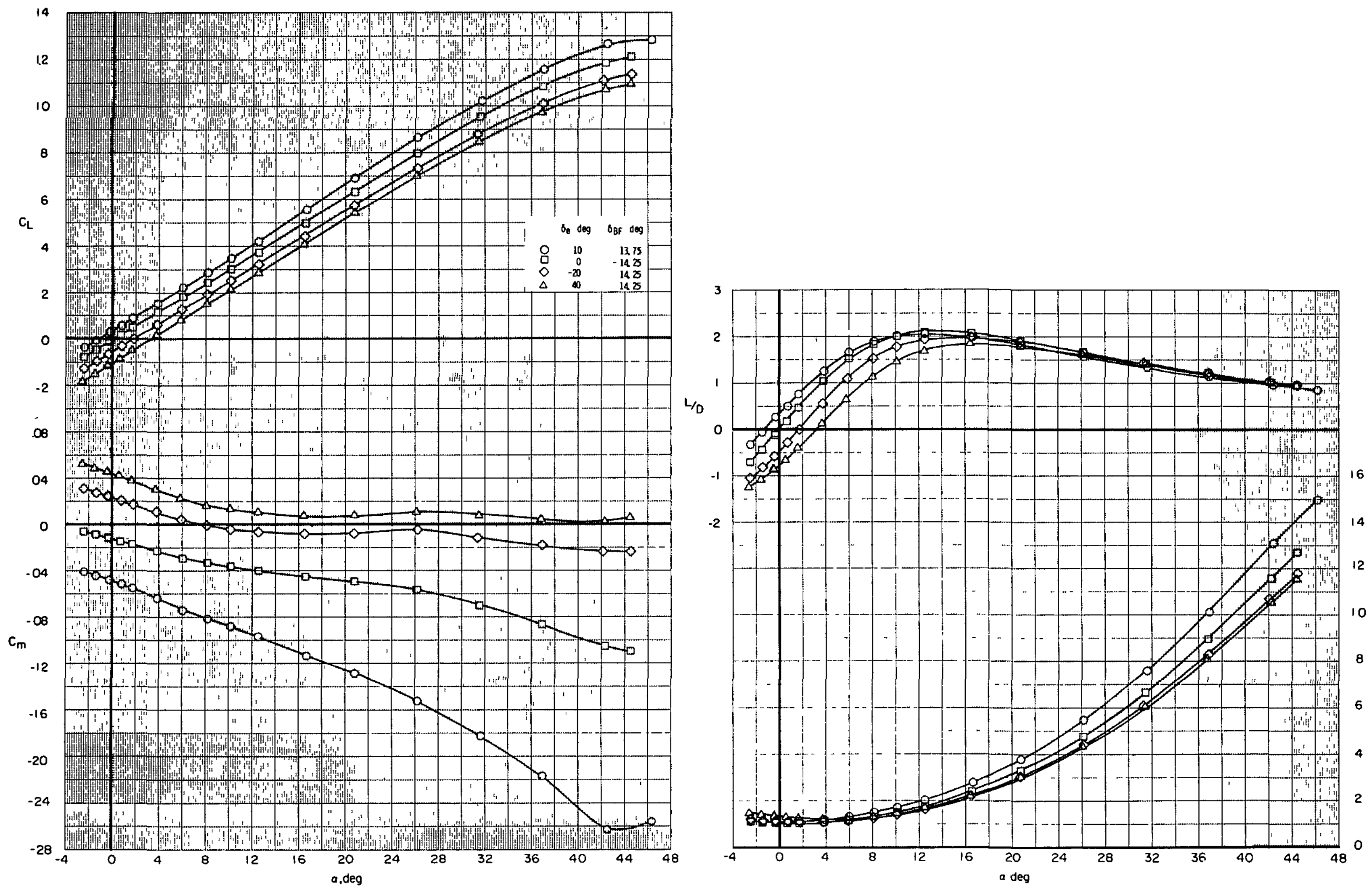
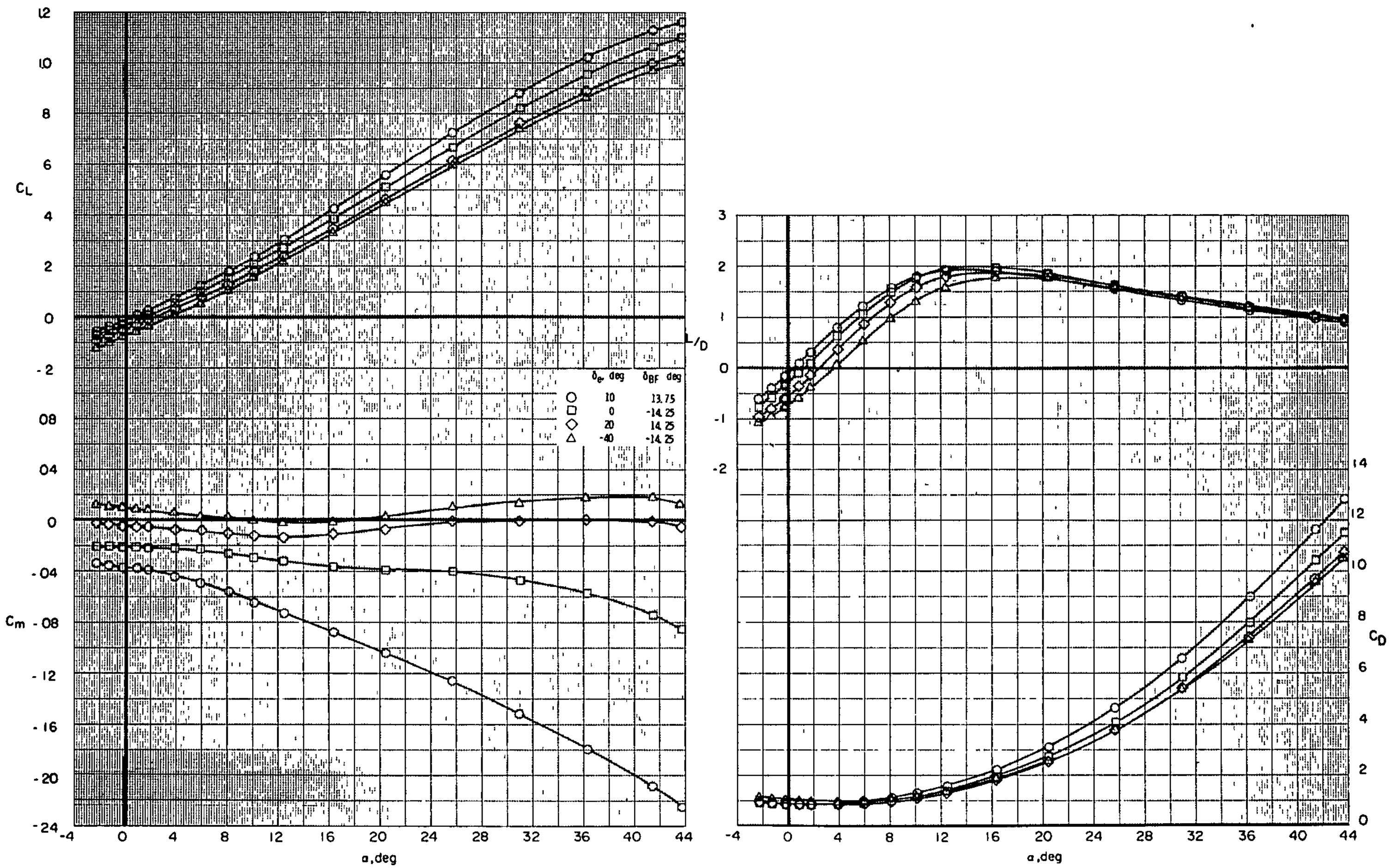


Figure 7.- Summary of untrimmed longitudinal aerodynamic characteristics.



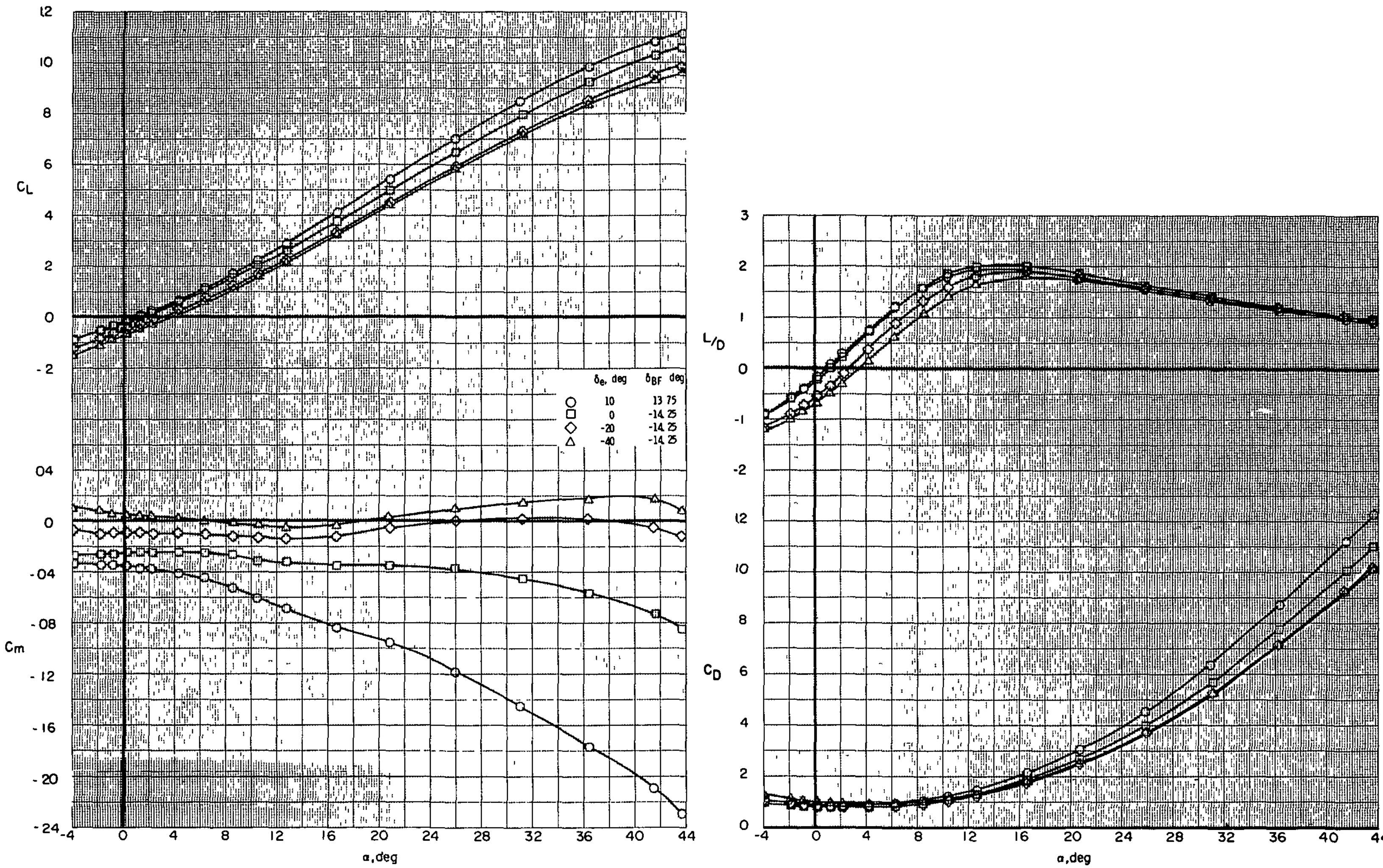
(a) M = 2.5.

Figure 8.- Effect of control deflections on longitudinal aerodynamic characteristics of the 089B model.



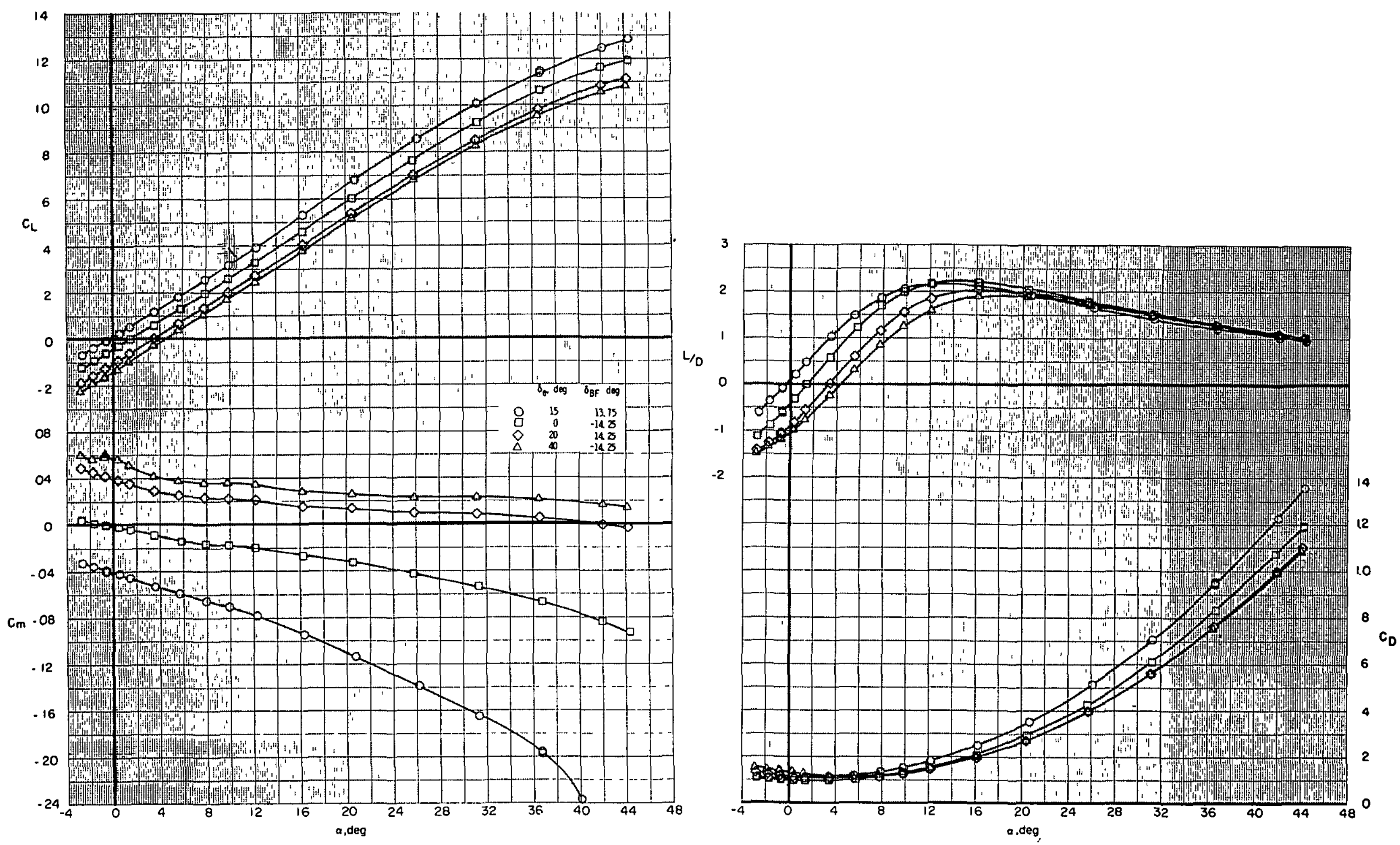
(b) M = 3.9.

Figure 8.- Continued.



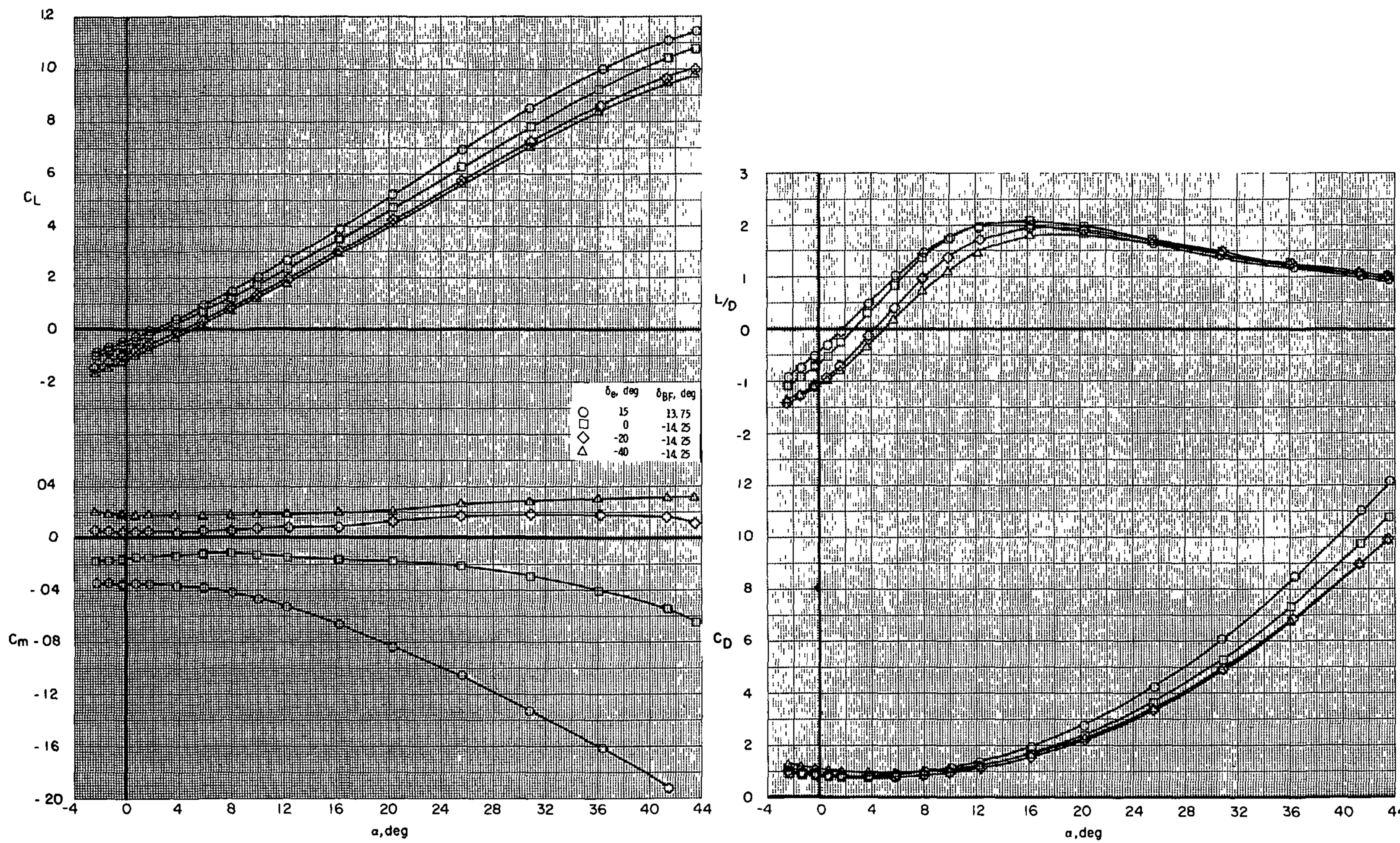
(c) M = 4.6.

Figure 8.- Concluded.



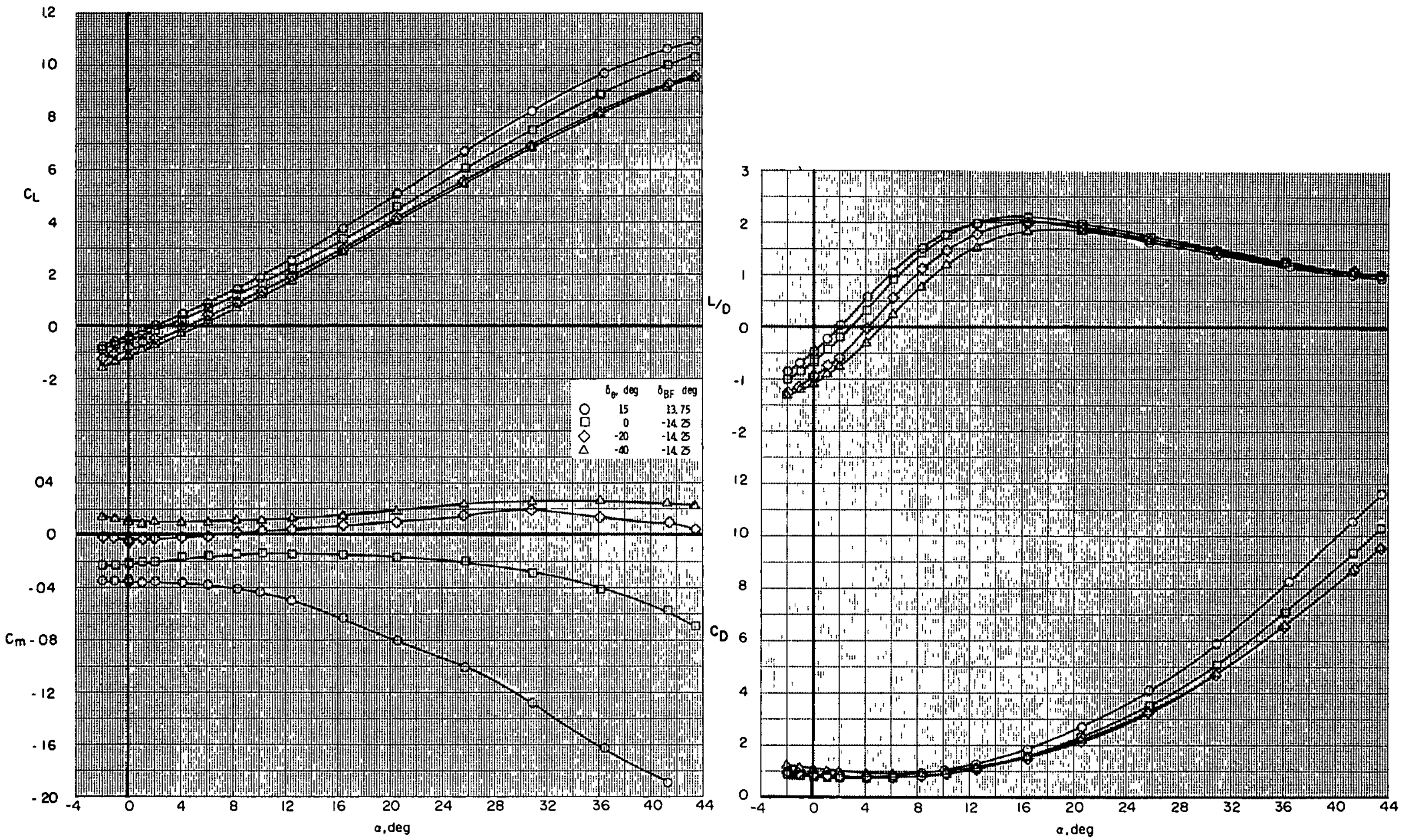
(a) M = 2.5.

Figure 9.- Effect of control deflections on longitudinal aerodynamic characteristics of the 139B model.



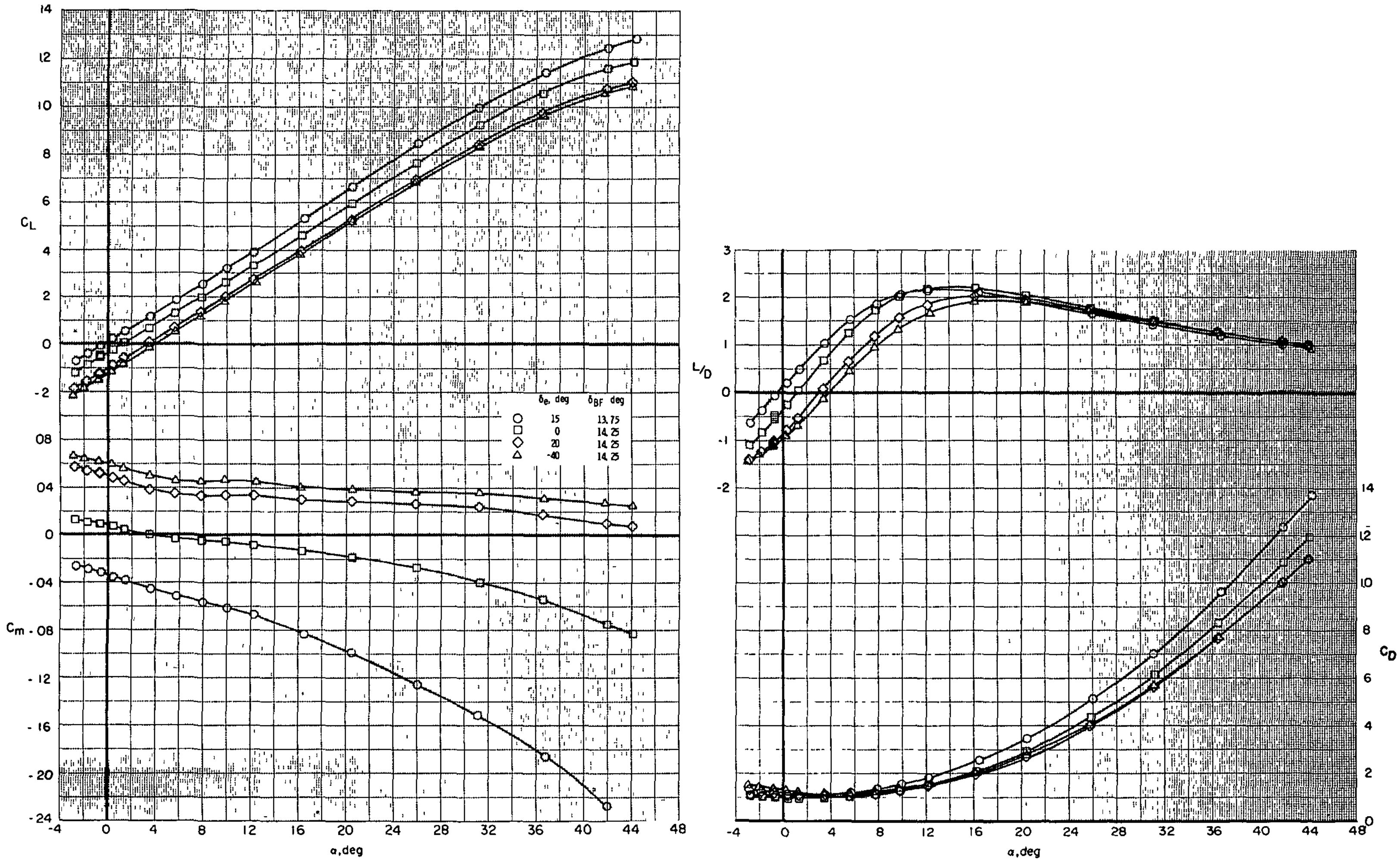
(b) M = 3.9.

Figure 9.- Continued.



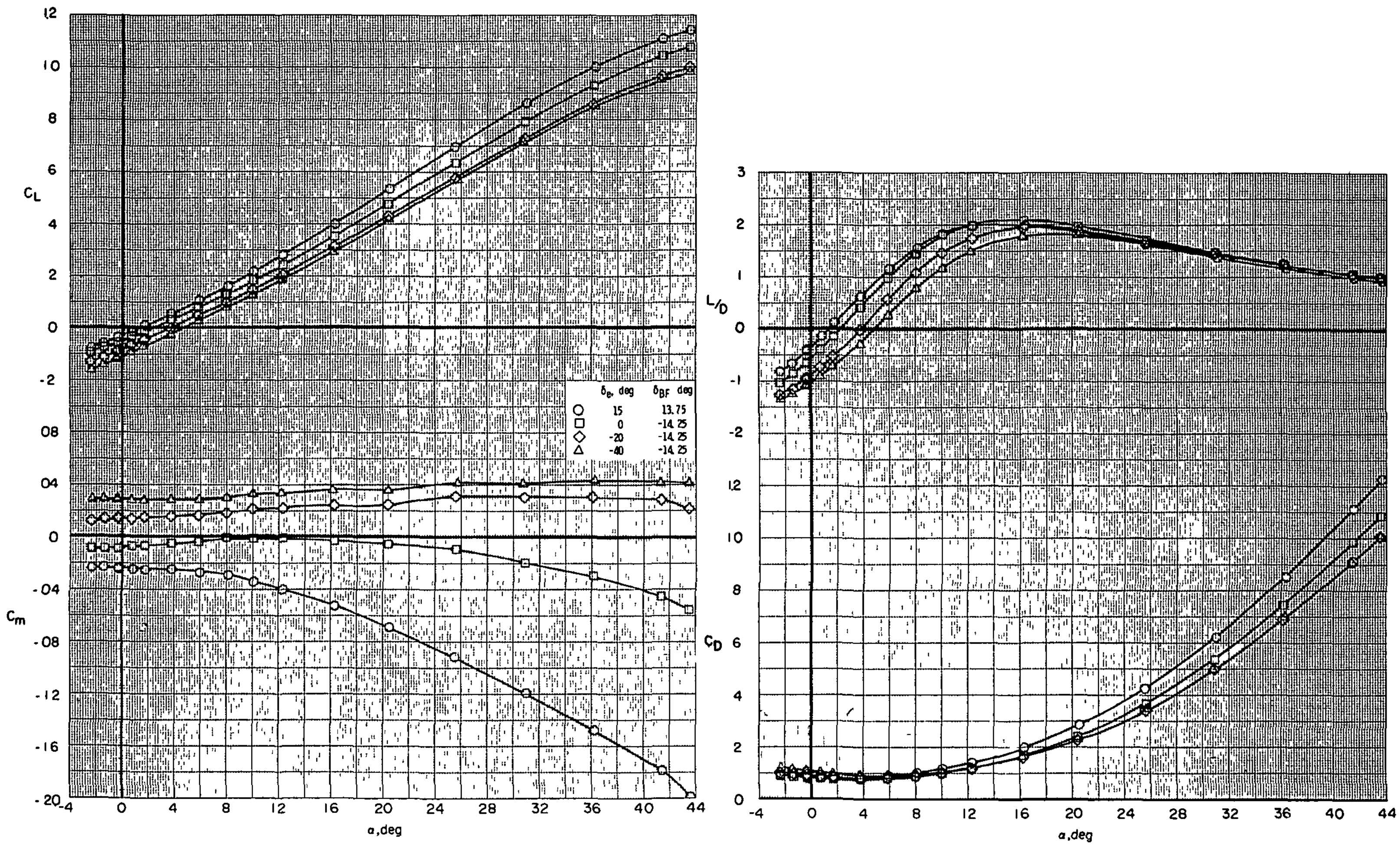
(c) M = 4.6.

Figure 9.- Concluded.



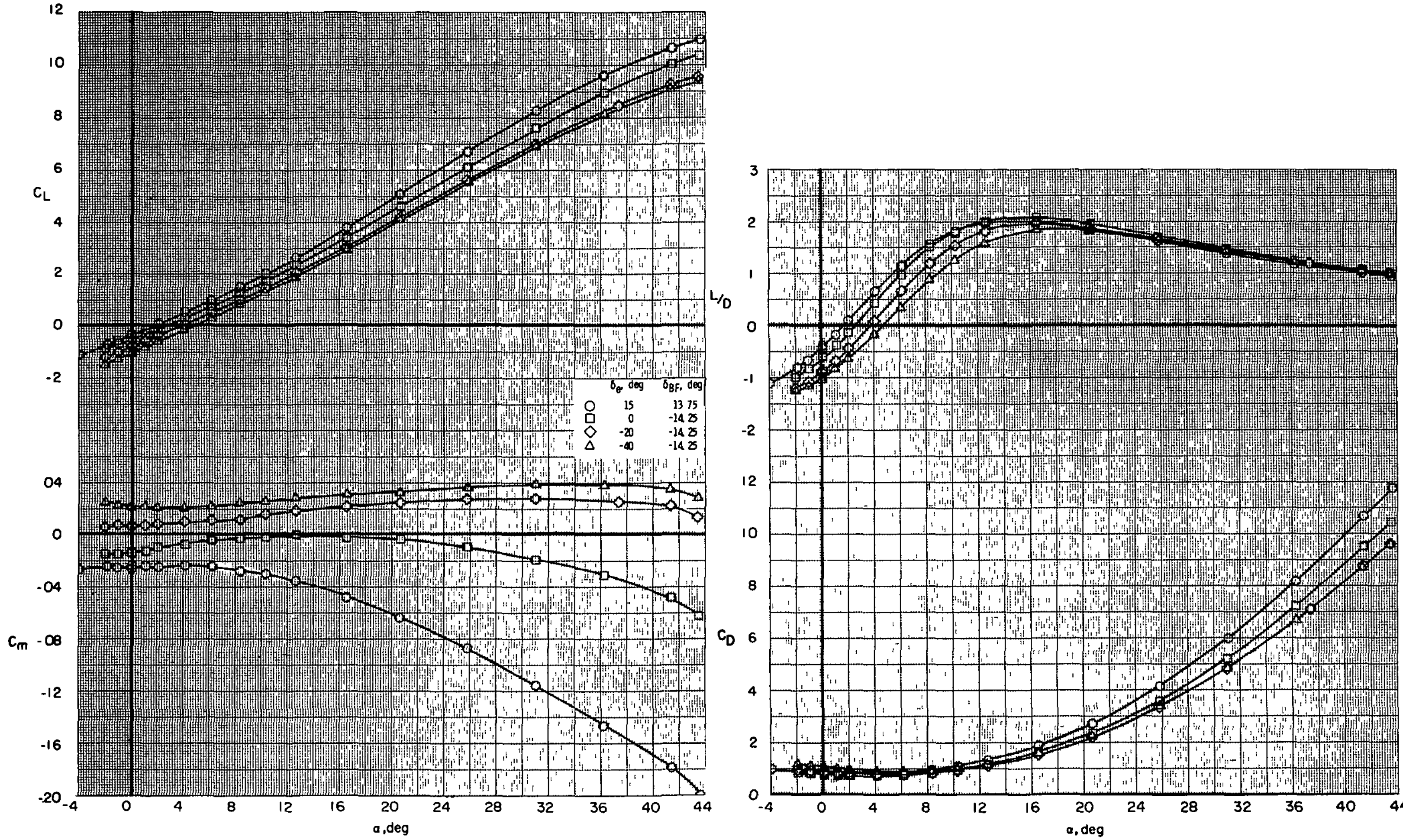
(a) M = 2.5.

Figure 10.- Effect of control deflections on longitudinal aerodynamic characteristics of the modified 139B model.



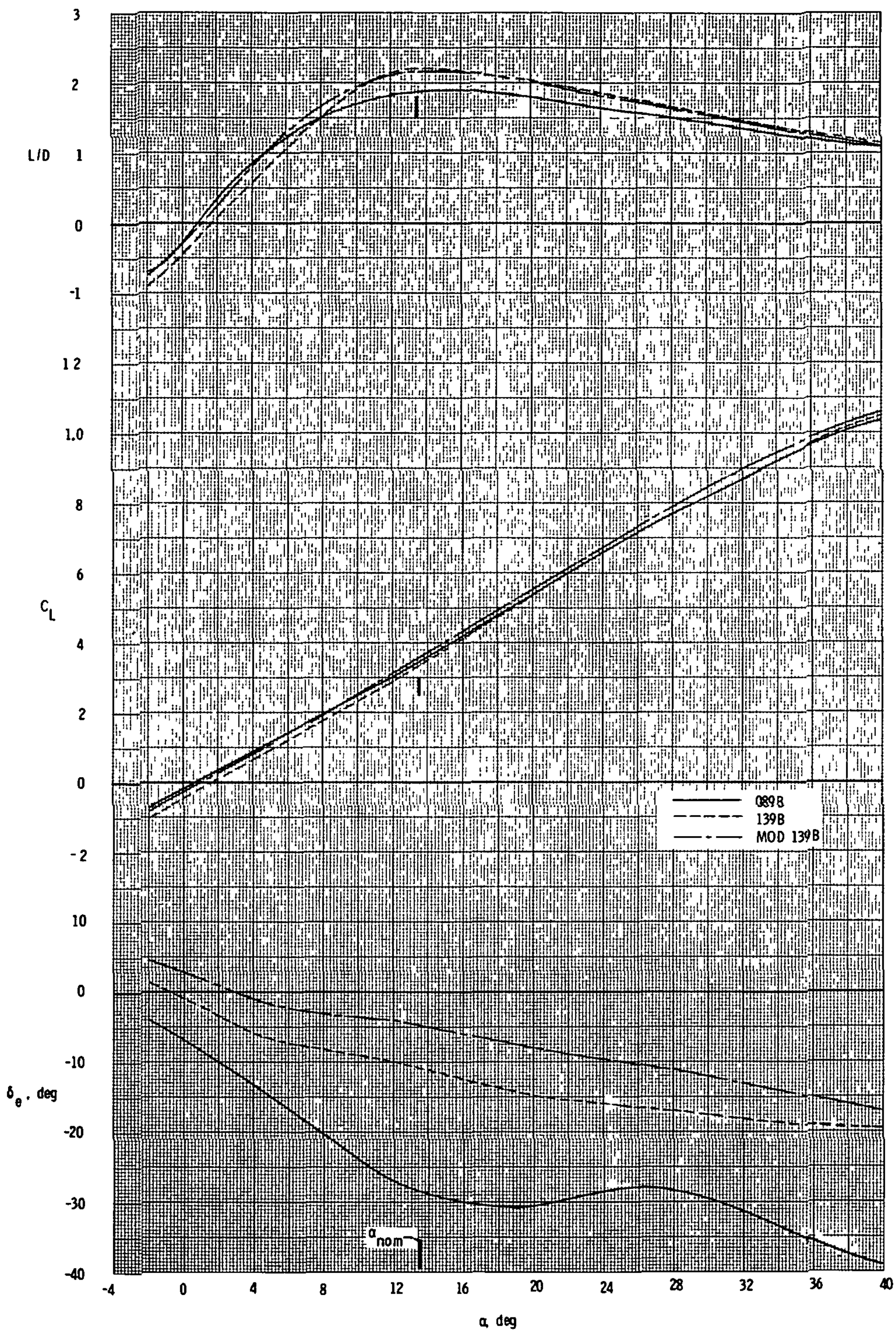
(b) M = 3.9.

Figure 10.- Continued.



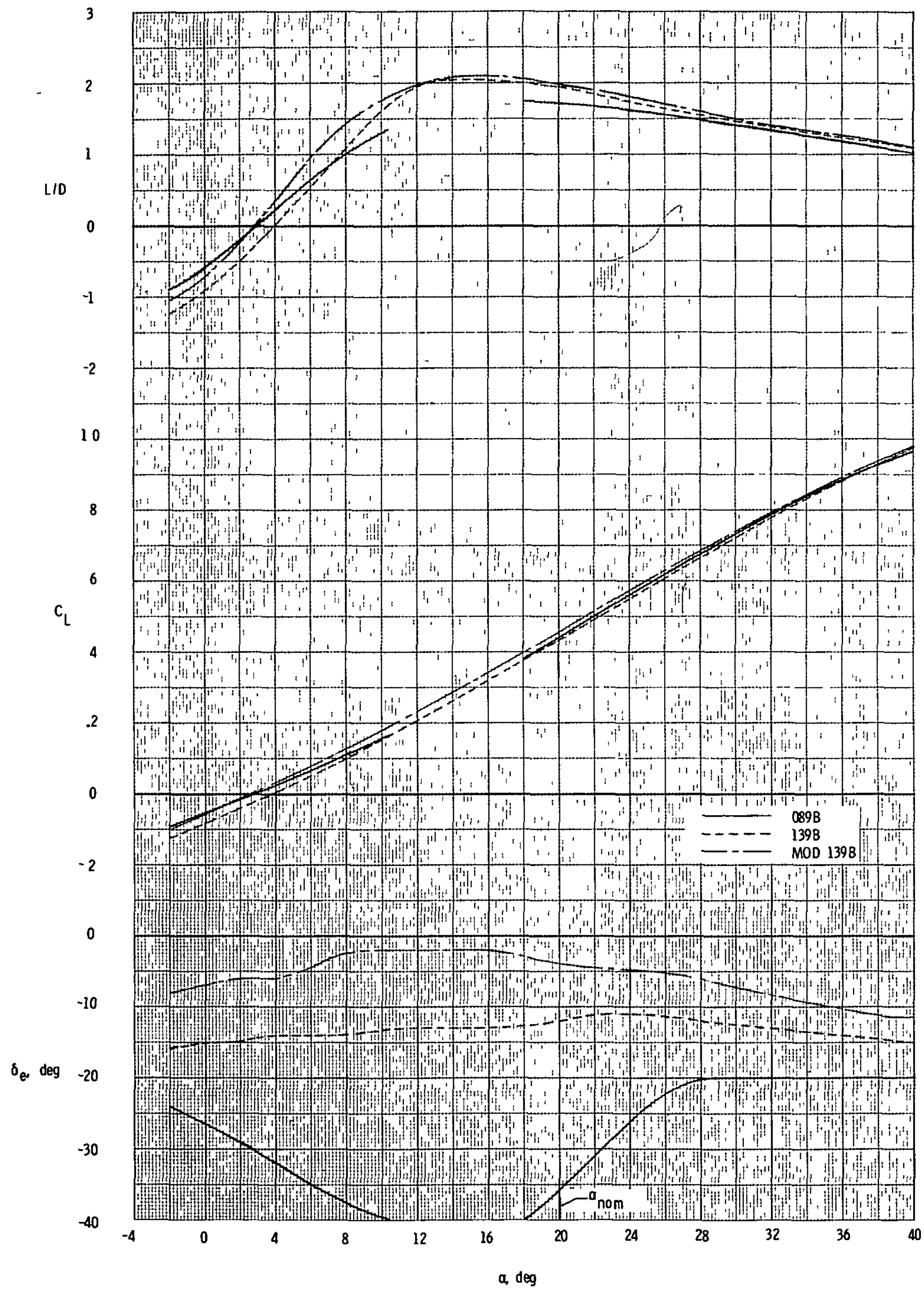
(c) M = 4.6.

Figure 10.- Concluded.



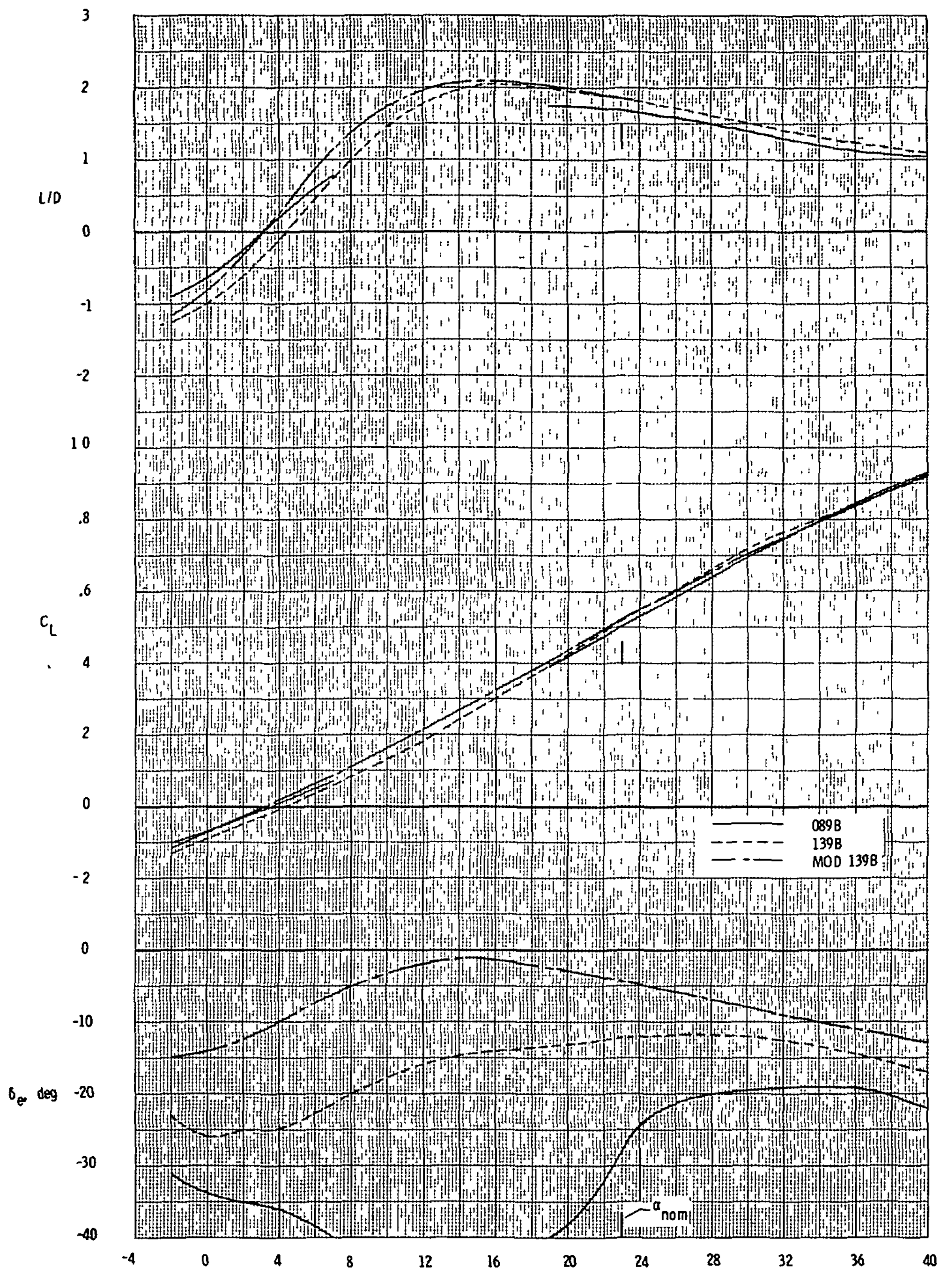
(a) M = 2.5.

Figure 11.- Trimmed longitudinal aerodynamic characteristics.



(b) M = 3.9.

Figure 11.- Continued.



(c) M = 4.6.

Figure 11.- Concluded.

1 Report No NASA TM-74074	2 Government Accession No	3 Recipient's Catalog No
4 Title and Subtitle SUPERSONIC LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF TWO SPACE SHUTTLE ORBITER CONFIGURATIONS		5 Report Date November 1977 6 Performing Organization Code
7 Author(s) James C. Ellison		8 Performing Organization Report No L-11787
9 Performing Organization Name and Address NASA Langley Research Center Hampton, VA 23665		10 Work Unit No 506-26-30-04 11 Contract or Grant No
12 Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546		13 Type of Report and Period Covered Technical Memorandum 14 Sponsoring Agency Code

15 Supplementary Notes

16 Abstract

An investigation was conducted in the Langley Unitary Plan wind tunnel to determine the supersonic longitudinal aerodynamic characteristics of 0.015-scale models of the Rockwell International 089B and 139B space shuttle orbiter configurations and the 139B orbiter with a modified forebody. The models each had a 45° swept delta wing that was blended into the body with an 81° swept fillet to form a double-delta planform. The vertical tail had a split rudder deflected 27.5° on each side to form a speed brake. Tests were conducted at Mach numbers of 2.5, 3.9, and 4.6 at a Reynolds number, based on the body length of the 089B model, of 4.15×10^{6}. Angles of attack varied from -4° to 44° at 0° sideslip.

17 Key Words (Suggested by Author(s)) Shuttle orbiter Aerodynamics	18 Distribution Statement Unclassified – Unlimited Subject Category 02		
19 Security Classif (of this report) Unclassified	20 Security Classif (of this page) Unclassified	21 No of Pages 29	22 Price* $4.00

*For sale by the National Technical Information Service, Springfield, Virginia 22161

NASA-Langley, 1977

G. Fuchs 246/1/246/

National Aeronautics and
Space Administration

Washington, D.C.
20546

Official Business
Penalty for Private Use, $300

THIRD-CLASS BULK RATE

Postage and Fees Paid
National Aeronautics and
Space Administration
NASA-451

U.S.MAIL

5 2 1U,A, 100777 S90844HU
MCDONNELL DOUGLAS CORP
ATTN: PUBLICATIONS GROUP, PR 15246
P O BOX 516
ST LOUIS MO ~~63166~~

NASA

POSTMASTER: If Undeliverable (Section 158 Postal Manual) Do Not Return