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# AERODYNAMIC CHARACTERISTICS OF A PROPOSED PERSONNEL LAUNCH SYSTEM (PLS) LIFTING-BODY CONFIGURATION AT MACH NUMBERS FROM 0.05 TO 20.3

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## SUMMARY

A wind-tunnel investigation has been performed to determine the aerodynamic characteristics of a proposed lifting-body personnel launch system (PLS) configuration over a Mach range of 0.05 to 20.3. The test configuration had a low-aspect-ratio body with a flat undersurface and three fins on the upper aft body. Data are presented with a minimum of analysis.

## INTRODUCTION

The purpose of this report is to present in one document the published results of two experimental investigations (refs. 1 and 2) and the previously unpublished results from two additional investigations of a lifting-body configuration which is being studied by the NASA Langley Research Center as a candidate for the NASA Assured Crew Return Capability (ACRC, ref. 3) vehicle. References 1 and 2 presented the transonic and supersonic wind-tunnel results. This report includes results of the low-speed and initial hypersonic (Mach 20.3 in helium) experimental investigations. References 1 and 2 discuss the lifting-body configuration as an ACRC candidate, whereas this report proposes the configuration for a larger role in the nation's space transportation system as a personnel launch system (PLS) configuration. The PLS has been proposed as a priority cargo vehicle to be used to supplement the Space Shuttle system. The PLS will be vertically launched on an expendable booster and will be used primarily to carry supplies or crew to and from the Space Station Freedom. The lifting body configuration for the ACRC study was sized to (1) carry an eight-man crew, (2) fit inside the Shuttle payload bay,

and (3) meet space station docking requirements. The same size vehicle is being retained as the initial lifting-body configuration considered for the PLS role. The design is 24.6 feet long and features a low-aspect-ratio body with a flat undersurface and three fins on the aft upper body. The outboard (tip) fins are rolled outboard 40° from the vertical. The concept has two sets of longitudinal control surfaces: (1) elevons on the aft portion of the outboard fins and (2) four body flaps on the aft fuselage. Lateral control can be maintained by deflection of the center fin or differential deflection of the elevons or body flaps.

A wind-tunnel investigation has been initiated at Langley to define the aerodynamic characteristics of the lifting body over a Mach number range from 0.05 to 20.3. The complete aerodynamic data base for the proposed lifting-body PLS configuration is still being defined. The study is now entering the "CFD code calibration" phase whereby high-fidelity models are being designed and fabricated to obtain highly accurate measurements of forces, moments, pressure distributions, and heat transfer distributions.

The use of high-fidelity models is necessary to determine the influence of Mach number, Reynolds number, ratio of specific heats, density ratio across the bow shock, and wall temperature on the lifting-body configuration throughout its flight regime. At hypersonic flight conditions, a blunt-nosed shape such as the proposed PLS will generally experience mostly supersonic flow over the windward surface at low angles of attack; thus, the configuration would exhibit "slender body" behavior (strong dependence on Mach number, Reynolds number, ratio of specific heats, and wall temperature). At high angles of attack (at hypersonic conditions), however, the configuration would experience mostly subsonic flow over the windward surface, thereby invoking the Mach number independence principle and lessening the effects of Reynolds number and wall temperature, but having a possibly strong dependence on shock density

ratio. At this time, three different scale models of moderate fidelity have
been tested: (1) a 0.02-scale model in the Langley Hypersonic Helium Tunnel
Facility, (2) a 0.07-scale model in the Unitary Plan Wind Tunnel and Calspan
8-Foot Transonic Tunnel, and (3) a 0.20-scale model in the Langley 30 x 60 Ft
Tunnel. The tests encompassed a wide range of angles of attack and sideslip.
Control effectiveness was studied for all Mach numbers except 20.3. The
system of axes used for the determination of forces, moments, velocities, and
angles is shown in figure 1. Data are presented in the form of plots and data
files on an enclosed floppy disk. Instructions for reading the disk and
accessing the data are given in the appendix.

## SYMBOLS

| | |
|---|---|
| $b$ | body span, ft |
| $C_D$ | drag coefficient, drag/$qS_{ref}$ |
| $C_L$ | lift coefficient, lift/$qS_{ref}$ |
| $C_l$ | rolling-moment coefficient, rolling moment/$qS_{ref}b$ |
| $C_{l_\beta}$ | $\Delta C_l/\Delta\beta$, per deg |
| $C_{l_{\delta_a}}$ | $\Delta C_l/\Delta\delta_a$, per deg |
| $C_{l_{\delta_r}}$ | $\Delta C_l/\Delta\delta_r$, per deg |
| $C_m$ | pitching-moment coefficient, pitching moment/$qS_{ref}\ell$ |
| $C_n$ | yawing-moment coefficient, yawing moment/$qS_{ref}b$ |
| $C_{n_\beta}$ | $\Delta C_n/\Delta\beta$, per deg |
| $C_{n_{\delta_a}}$ | $\Delta C_n/\Delta\delta_a$, per deg |
| $C_{n_{\delta_r}}$ | $\Delta C_n/\Delta\delta_r$, per deg |
| $C_p$ | pressure coefficient, $(p_{local} - p_{free\ stream})/q$ |
| $C_Y$ | side-force coefficient, side force/$qS_{ref}$ |
| $C_{Y_\beta}$ | $\Delta C_Y/\Delta\beta$, per deg |
| $C_{n_{\delta_a}}$ | $\Delta C_n/\Delta\delta_a$, per deg |
| $C_{Y_{\delta_r}}$ | $\Delta C_Y/\Delta\delta_r$, per deg |

L/D        lift/drag ratio

$\ell$        length of root chord (body length), ft

M        Mach number

p        pressure, $lb/ft^2$

q        free-stream dynamic pressure, $lb/ft^2$

$S_{ref}$        basic body planform area (excluding tip fins), $ft^2$

X        longitudinal model body axis

Y        lateral model body axis

Z        vertical model body axis

$\alpha$        angle of attack, deg

$\beta$        angle of sideslip, deg

$\delta a$        differential control deflection angle $\dfrac{\delta_{e,L} - \delta_{e,R}}{2}$

        or $\dfrac{\delta_{BF,L} - \delta_{BF,R}}{2}$, deg

$\delta_{BF}$        body flap deflection angle (positive when deflected downward), deg

$\delta_e$        elevon deflection angle (positive when deflected downward), deg

$\delta_r$        rudder deflection angle (positive when deflected with the trailing edge to the left), deg

## Subscripts

L        left

max        maximum value

R        right

trim        trimmed condition (zero moment)

## DESCRIPTION OF MODELS

The three test models were scaled from the design flight-scale PLS vehicle shown in figure 2. The models were of moderate fidelity and were

constructed to obtain preliminary force and moment characteristics of the lifting-body configuration. A photograph of each of the models is shown in figure 3. The proposed PLS vehicle consists of a low-aspect-ratio body with a flat undersurface and a blunt base. Three fins are mounted on the upper aft portion of the model. The baseline center fin is relatively small, and the large outboard (tip) fins are rolled outward 40° from the vertical. A larger center fin was tested at low speeds on the 0.20-scale model. A comparison between the baseline center fin and the large center fin is shown in figure 2(c). All fins are characterized by a thick flat plate cross section with a cylindrical leading edge and a blunt trailing edge. The location of the control surfaces on the configuration is shown in figures 1-3, and the geometric characteristics of the baseline flight-scale PLS vehicle are shown in table 1. Additionally, a list of body coordinates is enclosed on a floppy disk, and information on accessing the coordinates is given in the appendix.

## DESCRIPTION OF TESTS

The low-speed tests were conducted in the Langley 30 x 60-Foot Wind Tunnel (ref. 4) at a Mach number of approximately 0.05. The tunnel is a closed-circuit, double-return, continuous flow design with an open throat.

The transonic tests were conducted in the Calspan 8-Foot Transonic Wind Tunnel (ref. 4) at Mach numbers of 0.6, 0.8, 0.9, 0.95, 1.1, and 1.2. The tunnel is a closed-circuit, single-return, variable-density facility. The Reynolds number for the transonic tests was held constant at $3.5 \times 10^6$ per foot.

The supersonic tests were conducted in the Langley Unitary Plan Wind Tunnel (ref. 4) at Mach numbers of 1.6, 2.0, 2.5, 3.0, 3.5, 4.0, and 4.5. The tunnel is a supersonic, closed-circuit design with two test legs. The Reynolds number for the supersonic tests was held constant at $2 \times 10^6$ per foot.

The hypersonic tests were conducted in the Langley Hypersonic Helium Tunnel Facility (HHTF, ref. 4) at a Mach number of 20.3. The tunnel is an intermittent, blowdown design which utilizes purified helium. The Reynolds number for the hypersonic tests was held constant at $6.8 \times 10^6$ per foot.

Further details on all of the test facilities can be found in reference 4. All drag data presented are uncorrected for base pressure. Where applicable, customary corrections for sting deflection, balance deflection, and tunnel interference were applied to the data. A wind-tunnel test schedule detailing model configuration and test conditions is given in table 2.

## RESULTS AND DISCUSSION

Low-Speed Aerodynamics - The low-speed aerodynamic characteristics of the proposed PLS vehicle are shown in figures 4-10. The basic configuration is longitudinally stable with nearly linear lift and pitching-moment coefficients up to an angle of attack of 23° (fig. 4(a)). The configuration is also seen to be directionally and laterally stable up to an angle of attack in excess of 25° (fig. 4(b)). As shown in figure 5, the body flaps provide trim for the vehicle over a wide angle-of-attack range. Effects of rudder, center fin size, and all-movable center fin are also presented.

Transonic Aerodynamics - The transonic aerodynamic characteristics of the proposed PLS vehicle are shown in figures 11-19. The complete model was found to be longitudinally and laterally stable throughout the transonic speed range. Elevon, body flap, and center fin effectiveness data are presented. The model trimmed near the maximum lift-to-drag value (3.1) at a Mach number of 0.6 and at low angles of attack (between 2° and 3°) through the transonic speed range.

Supersonic Aerodynamics - The supersonic aerodynamic characteristics of the proposed PLS vehicle are shown in figures 20-27. The PLS model was longitudinally stable about the design center-of-gravity location. With pitch controls undeflected, the model trimmed at negative angles of attack at Mach

numbers from 1.6 to 3.0. Above Mach 3.0, the basic longitudinal trim angle increased, and the configuration trimmed near maximum L/D. The directional stability level at longitudinal trim conditions decreased with increasing speed and became zero at Mach numbers from 2.5 to 3.0 before regaining stability at higher speeds.

Hypersonic Aerodynamics - The hypersonic aerodynamic characteristics of the proposed PLS vehicle are shown in figures 28 and 29. Experimental data at Mach 20.3 in helium are given along with estimates made using the Aerodynamic Preliminary Analysis System (APAS) (ref. 5). The calculations used Newtonian impact theory to approximate the pressures on the surface of the vehicle. The viscous shear stresses were calculated using the reference temperature and reference enthalpy methods. These techniques are discussed in detail in reference 5.

The maximum hypersonic L/D of the PLS model in helium was found to be 1.43. The vehicle was trimmed at an angle of attack of 26.5°, very near maximum L/D. Theoretical calculations predict a maximum L/D value of 1.41 and a trim angle of attack of 27.8° in helium at Mach 20.3. As another reference, APAS calculations are shown for the PLS vehicle at Mach 10 in air. The maximum predicted L/D in air was 1.36, and the trim angle of attack was identical to the APAS helium calculation. The experimental data showed the proposed PLS vehicle to be directionally stable in the angle-of-attack range for longitudinal trimmed conditions at hypersonic speeds. No control deflections were tested.

Experimental Data Base - All experimental data obtained on the proposed PLS vehicle have been placed on two floppy disks enclosed in the back of this report. The data base can be accessed using the R:BASE (ref. 6) system. Information on accessing the data using R:BASE can be found in the appendix.

## CONCLUDING REMARKS

A wind-tunnel investigation has been made to determine the aerodynamics of a proposed PLS lifting-body vehicle throughout the speed range from Mach 0.05 to Mach 20.3. The configuration was found to be longitudinally and laterally stable about the design center-of-gravity of 54 percent of the body length. The configuration was controlled in the pitch plane with either elevons on the trailing edge of the rolled-out tip fins or body flaps mounted on the aft fuselage. A small all-movable center fin or rudder provided yaw control. A larger version of the center fin was tested at low subsonic speeds. No control deflection data were available at hypersonic speeds. The hypersonic helium data agreed well with theoretical calculations. Based on these calculations and past hypersonic tests for this class of vehicle, no major differences are expected between the hypersonic helium data and the hypersonic air data when they become available. All of the experimental data have been placed in a structured data base using the R:BASE system and are included on two floppy disks enclosed in the back of this report.

## REFERENCES

1. Ware, G. M.: Transonic Aerodynamic Characteristics of a Proposed Assured Crew Return Capability (ACRC) Lifting-Body Configuration. NASA TM 4117, July 1989.

2. Ware, G. M.: Supersonic Aerodynamic Characteristics of a Proposed Assured Crew Return Capability (ACRC) Lifting-Body Configuration. NASA TM 4136, December 1989.

3. Ware, G. M.; Spencer, B.; and Micol, J.: Aerodynamic Characteristics of Proposed Assured Crew Return Capability (ACRC) Configurations. AIAA Paper No. 89-2172, July 1989.

4. Penaranda, Frank E. and Freda, M. Shannon, eds.: Aeronautical Facilities Catelogue. Volume 1 - Wund Tunnels. NASA RP-1132, 1985.

5.  Cruz, C. I. and Wilhite, A. W.:  Prediction of High-Speed Aerodynamic
    Characteristics Using the Aerodynamic Preliminary Analysis System (APAS).
    AIAA Paper No. 89-2173, July 1989.

6.  R:BASE Series 4000 User's Manual Tutorial.  MICRORIM.  1985.

APPENDIX

Aerodynamic Data. The data presented in plotted form within this report are available on the enclosed magnetic personal computer disk. The floppy disk will allow access to both body axis and stability axis data in ASCII test file format. Identification of the available data is presented in the Wind Tunnel Schedule (table 2).

To be able to use the disk, the following equipment is required:

(1) An IBM Personal Computer (or equivalent) with a minimum of 640K or RAM.

(2) A 5-1/4 inch 1.2M disk drive.

(3) A hard disk drive.

The files included on the disk are:

(1) READ_NOW.BAT - test file providing information not included herein.

(2) LB0001F1.RBF -     MICRORIM R:Base data base files. These binary
    LB0001F2.RBF       files require R:Base software to access. Data
    LB0001F3.RBF       base name is LB0001F.

(3) LB0001.EXE -     Compiled application files which will allow the
    LB0001.OVL       R:Base data base files to be manipulated as
    LB0001.MSG       outlined in the following paragraph.

(4) INSTALLH.BAT - Installation program.

The LB0001 application program will allow:

(1) Creating ASCII text files of the data in either stability or body axis system format for use in a variety of mainframe and PC software.

(2) Printing the data in tabular form.

(3) Printing a detailed run log for all the tests.

To access the data base, insert the disk in the 1.2M drive, enter <INSTALLH>, and follow the instructions displayed on the screen.

<u>Test Facility Identification</u>. The following identification codes will facilitate the retrieval of the data on the floppy disk.

|  | <u>Site</u> | <u>Facility</u> | <u>Test</u> |
|---|---|---|---|
| 30 x 60 FST | 1 | C | 9999 |
| CALSPAN | 3 | D | 100 |
| UPWT TS #1 | 1 | I | 1636 |
| UPWT TS #2 | 1 | L | 1497 |
| HHTF | 1 | Q | 497 |

<u>Surface Geometry</u>. A file containing the surface coordinates for the surface of the proposed lifting-body PLS vehicle is stored on the enclosed floppy disk. The geometry is based on a subset of the coordinates used by the numerical milling machine used to construct the 0.20-scale and 0.07-scale models. There are a total of 1429 surface grid points tabulated. The fuselage is defined at 21 stations and the number of points per station varies from 1 (at the nose) to 130 (at the base). The name of the geometry file on the disk is PLS.FUS.

Table 1.  Geometric Characteristics of Flight-Scale PLS Vehicle

Body alone:
Aspect ratio . . . . . . . . . . . . . . . . . . . . . . . . . . . .   0.6
Length (reference length), ft. . . . . . . . . . . . . . . . . . .  24.6
Span (reference span), ft. . . . . . . . . . . . . . . . . . . . .  11.6
Planform area (reference area), ft$^2$. . . . . . . . . . . . . . . 216.8
Baseline area, ft$^2$ . . . . . . . . . . . . . . . . . . . . . . .  40.0
Height (maximum), ft . . . . . . . . . . . . . . . . . . . . . . .   5.6

Body with fins:
Aspect ratio . . . . . . . . . . . . . . . . . . . . . . . . . . .   1.5
Length, ft . . . . . . . . . . . . . . . . . . . . . . . . . . . .  24.6
Span, ft . . . . . . . . . . . . . . . . . . . . . . . . . . . . .  19.5
Planform area, ft$^2$ . . . . . . . . . . . . . . . . . . . . . . . 254.3
Base area, ft$^2$ . . . . . . . . . . . . . . . . . . . . . . . . .  40.0
Height (to tip of fin), ft . . . . . . . . . . . . . . . . . . . .   7.0

Elevons:
Chord, ft. . . . . . . . . . . . . . . . . . . . . . . . . . . . .   1.3
Span, ft . . . . . . . . . . . . . . . . . . . . . . . . . . . . .   4.9
Area (each), ft$^2$ . . . . . . . . . . . . . . . . . . . . . . . .   5.0

Body flaps:
Chord, ft. . . . . . . . . . . . . . . . . . . . . . . . . . . . .   1.8
Span, ft . . . . . . . . . . . . . . . . . . . . . . . . . . . . .   3.3
Area (each), ft$^2$ . . . . . . . . . . . . . . . . . . . . . . . .   6.0

# Table 2. Run schedule for data on floppy disk.

| TEST PARAMETERS | | | | | FST | CALSPAN | | | | | | | UPWT TS #1 | | | UPWT TS #2 | | | | He |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $\alpha$, deg | $\beta$, deg | $\delta_e$, deg L/R | CNTR FIN | $\delta_{BF}$, deg L/R | MACH 0.05 | MACH 0.6 | MACH 0.8 | MACH 0.9 | MACH 0.95 | MACH 1.1 | MACH 1.2 | MACH 1.6 | MACH 2.0 | MACH 2.5 | MACH 3.0 | MACH 3.5 | MACH 4.0 | MACH 4.5 | MACH 20 |
| A | 0 | 0 | 0 | 0 | 5 | 54 | 40 | 39 | 20 | 64 | 166 | 48 | 41 | 28 | 1 | 9 | 17 | 25 | 4 |
| A | -2 | 0 | 0 | 0 | 4 | 55 | 42 | 38 | 21 | 66 | 167 | 47 | 40 | 30 | 3 | 11 | 19 | 27 | X |
| A | 2 | 0 | 0 | 0 | 6 | 53 | 41 | 34 | 23 | 65 | 168 | X | X | X | 4 | 12 | 20 | 28 | X |
| 0 | B | 0 | 0 | 0 | X | 48 | 43 | 33 | 24 | 67 | 169 | 42 | 35 | 33 | X | X | X | X | X |
| 5 | B | 0 | 0 | 0 | X | 49 | 44 | 32 | 25 | 68 | 170 | 43 | 36 | 32 | 5 | 13 | X | X | X |
| 10 | B | 0 | 0 | 0 | X | 50 | 45 | 31 | 26 | 69 | 171 | 44 | 37 | 34 | 6 | 14 | 21 | 29 | X |
| 15 | B | 0 | 0 | 0 | X | 51 | 46 | 30 | 27 | 70 | 172 | 45 | 38 | 31 | 7 | 15 | 22 | 30 | X |
| 20 | B | 0 | 0 | 0 | 33 | 52 | 47 | 29 | 28 | 71 | 173 | X | X | X | 8 | 16 | 23 | 31 | X |
| 25 | B | 0 | 0 | 0 | X | X | X | X | X | X | X | X | X | X | X | X | 24 | 32 | X |
| A | 0 | 5 | 0 | 0 | X | 198 | 197 | 196 | 195 | 194 | 193 | X | X | X | X | X | X | X | X |
| A | 0 | 10 | 0 | 0 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | 0 | -5 | 0 | 0 | X | 210 | 209 | 208 | 207 | 206 | 205 | 49 | 50 | 51 | X | X | X | X | X |
| A | 0 | -10 | 0 | 0 | X | 216 | 215 | 214 | 213 | 212 | 211 | 53 | 54 | 52 | 33 | 34 | 35 | 36 | X |
| A | 0 | 0 | 0 | -10 | 13 | 180 | 179 | 178 | 177 | 176 | 175 | 58 | 59 | 60 | 41 | 43 | 44 | 45 | X |
| A | 0 | 0 | 0 | 10 | 15 | 192 | 191 | 190 | 189 | 188 | 187 | X | X | X | X | X | X | X | X |

NUMBERS UNDER MACH HEADING ARE RUNS IN DESIGNATED FACILITY
A = ANGLE-OF-ATTACK SWEEP
B = ANGLE-OF-SIDESLIP SWEEP
X = DATA NOT AVAILABLE

13

# Table 2. Continued.

| α, deg | β, deg | δ$_e$, deg L/R | CNTR FIN | δ$_{BF}$, deg L/R | FST MACH 0.05 | CALSPAN MACH 0.6 | MACH 0.8 | MACH 0.9 | MACH 0.95 | MACH 1.1 | MACH 1.2 | UPWT TS #1 MACH 1.6 | MACH 2.0 | MACH 2.5 | UPWT TS #2 MACH 3.0 | MACH 3.5 | MACH 4.0 | MACH 4.5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 0 | 0 | OFF | 0 | 43 | 101 | 97 | 83 | 75 | 132 | 111 | 70 | 74 | 67 | 83 | 86 | 89 | 92 |
| A | -2 | 0 | OFF | 0 | X | 102 | 99 | 85 | 77 | 133 | 112 | 72 | 73 | 69 | 84 | 87 | 90 | 93 |
| A | 2 | 0 | OFF | 0 | X | 100 | 96 | 86 | 76 | 131 | 110 | 71 | 75 | 68 | 85 | 88 | 91 | 94 |
| 0 | B | 0 | OFF | 0 | X | 103 | 95 | 87 | 78 | 126 | 118 | X | X | X | X | X | X | X |
| 5 | B | 0 | OFF | 0 | X | 104 | 94 | 88 | 79 | 127 | 123 | X | X | X | X | X | X | X |
| 10 | B | 0 | OFF | 0 | X | 105 | 93 | 89 | 80 | 128 | 122 | X | X | X | X | X | X | X |
| 15 | B | 0 | OFF | 0 | X | 106 | 92 | 90 | 81 | 129 | 124 | X | X | X | X | X | X | X |
| 20 | B | 0 | OFF | 0 | X | 108 | 155 | 148 | 82 | 130 | 125 | X | X | X | X | 98 | 101 | 104 |
| A | 0 | OFF | OFF | 0 | 53 | 159 | 155 | 148 | 145 | 139 | 154 | 76 | 79 | 82 | 95 | 98 | 101 | 104 |
| A | -2 | OFF | OFF | 0 | X | 158 | 157 | 149 | 146 | 140 | 152 | 78 | 81 | 84 | 96 | 99 | 102 | 105 |
| A | 0 | 5 | OFF | 0 | X | 160 | 156 | 147 | 144 | 138 | 153 | 77 | 80 | 83 | 97 | 100 | 103 | 106 |
| A | 0 | 0 | 5 | 0 | X | 223 | 222 | 220 | 219 | 218 | 217 | 64 | 65 | 66 | X | X | X | X |
| A | 0 | 0 | 0 | -10/10 | X | 186 | 185 | 184 | 183 | 182 | 181 | X | X | X | X | X | X | X |
| A | 0 | -5/5 | 0 | 0 | X | 204 | 203 | 202 | 201 | 200 | 199 | X | X | X | X | X | X | X |
| A | 0 | -10/10 | 0 | 0 | X | X | X | X | X | X | X | 55 | 56 | 57 | 37 | 38 | 39 | 40 |
| A | 0 | -10/10 | 5 | 0 | X | X | X | X | X | X | X | X | X | X | 50 | 51 | 52 | 53 |

NUMBERS UNDER MACH HEADING ARE RUNS IN DESIGNATED FACILITY
A = ANGLE-OF-ATTACK SWEEP
B = ANGLE-OF-SIDESLIP SWEEP
X = DATA NOT AVAILABLE

14

# Table 2. Continued.

| | TEST PARAMETERS | | | | FST | CALSPAN | | | | | | | UPWT TS #1 | | | UPWT TS #2 | | | | He |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $\alpha$, deg | $\beta$, deg | $\delta_e$, deg L/R | CNTR FIN | $\delta$BF deg L/R | MACH 0.05 | MACH 0.6 | MACH 0.8 | MACH 0.9 | MACH 0.95 | MACH 1.1 | MACH 1.2 | MACH 1.6 | MACH 2.0 | MACH 2.5 | MACH 3.0 | MACH 3.5 | MACH 4.0 | MACH 4.5 | MACH 20 |
| A | -3 | 0 | 0 | 0 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | 12 |
| A | -10 | 0 | 0 | 0 | 2 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | -5 | 0 | 0 | 0 | 3 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | 5 | 0 | 0 | 0 | 7 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | 10 | 0 | 0 | 0 | 8 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 12 | B | 0 | 0 | 0 | 9 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 14 | B | 0 | 0 | 0 | 10 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 16 | B | 0 | 0 | 0 | 11 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | 0 | 0 | 0 | -5 | 12 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | 0 | 0 | 0 | 5 | 14 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | 0 | 15/-15 | 0 | 0 | 16 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | 0 | 30/-30 | 0 | 0 | 17 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | 0 | -15/15 | 0 | 0 | 18 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | 0 | -30/30 | 0 | 0 | 19 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | 0 | 0 | 0 | -30/30 | 21 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |

NUMBERS UNDER MACH HEADING ARE RUNS IN DESIGNATED FACILITY
A = ANGLE-OF-ATTACK SWEEP
B = ANGLE-OF-SIDESLIP SWEEP
X = DATA NOT AVAILABLE

# Table 2. Continued.

| TEST PARAMETERS | | | | | FST | CALSPAN | | | | | | | UPWT TS #1 | | | UPWT TS #2 | | | | He |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $\alpha$, deg | $\beta$, deg | $\delta_e$, deg L/R | CNTR FIN | $\delta_{BF}$, deg L/R | MACH 0.05 | MACH 0.6 | MACH 0.8 | MACH 0.9 | MACH 0.95 | MACH 1.1 | MACH 1.2 | MACH 1.6 | MACH 2.0 | MACH 2.5 | MACH 3.0 | MACH 3.5 | MACH 4.0 | MACH 4.5 | MACH 20 |
| A | -10 | 0 | 0 | -30/30 | 22 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | -5 | 0 | 0 | -30/30 | 23 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | 0 | 0 | 0 | -30/30 | 24 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | 5 | 0 | 0 | -30/30 | 25 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | 10 | 0 | 0 | -30/30 | 26 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | 0 | 0 | 0 | 0/30 | 27 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | 0 | 0 | $15^2$ | 0 | 28 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | 0 | 0 | $30^2$ | 0 | 29 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | 0 | 0 | 30 | 0 | 30 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | 0 | 0 | 15 | 0 | 31 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 18 | B | 0 | 0 | 0 | 32 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | 0 | 0 | 0 | 30 | 34 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | 0 | 0 | OFF | -30 | 35 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | -5 | 0 | OFF | 0 | 42 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | 5 | 0 | 0 | 0 | 44 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |

NUMBERS UNDER MACH HEADING ARE RUNS IN DESIGNATED FACILITY
A = ANGLE-OF-ATTACK SWEEP
B = ANGLE-OF-SIDESLIP SWEEP
X = DATA NOT AVAILABLE

SUPERSCRIPTS
1 = LARGE CENTER FIN
2 = ALL-MOVABLE FIN

# Table 2. Concluded.

| α, deg | β, deg | $\delta_e$, deg L/R | CNTR FIN | $\delta_{BF}$, deg L/R | FST MACH 0.05 | CALSPAN MACH 0.6 | MACH 0.8 | MACH 0.9 | MACH 0.95 | MACH 1.1 | MACH 1.2 | UPWT TS #1 MACH 1.6 | MACH 2.0 | MACH 2.5 | UPWT TS #2 MACH 3.0 | MACH 3.5 | MACH 4.0 | MACH 4.5 | He MACH 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | -5 | 0 | 0[1] | 0 | 45 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | 0 | 0 | 0[1] | 0 | 46 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | 5 | 0 | 0[1] | 0 | 47 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | 0 | 0 | 30[1] | 0 | 48 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | 0 | 0 | 15[1] | 0 | 49 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | 0 | 0 | 15[1,2] | 0 | 50 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | 0 | 0 | 30[1,2] | 0 | 51 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | -5 | OFF | OFF | 0 | 52 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | 5 | OFF | OFF | 0 | 54 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | -10 | 30/-30 | 0[1] | 0 | 58 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | -5 | 30/-30 | 0[1] | 0 | 59 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | 5 | 30/-30 | 0[1] | 0 | 60 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | 10 | 30/-30 | 0[1] | 0 | 61 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| A | -10 | 0 | 30 | 0 | 62 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |

NUMBERS UNDER MACH HEADING ARE RUNS IN DESIGNATED FACILITY
A = ANGLE-OF-ATTACK SWEEP
B = ANGLE-OF-SIDESLIP SWEEP
X = DATA NOT AVAILABLE

SUPERSCRIPTS
1 = LARGE CENTER FIN
2 = ALL-MOVABLE FIN

Figure 1. Sketch of system of axes used in the investigation, showing positive direction of forces, moments, velocities, and angles.

Body Flap

19.5

11.5

7.1

Body flap

Elevon

13.3

24.6
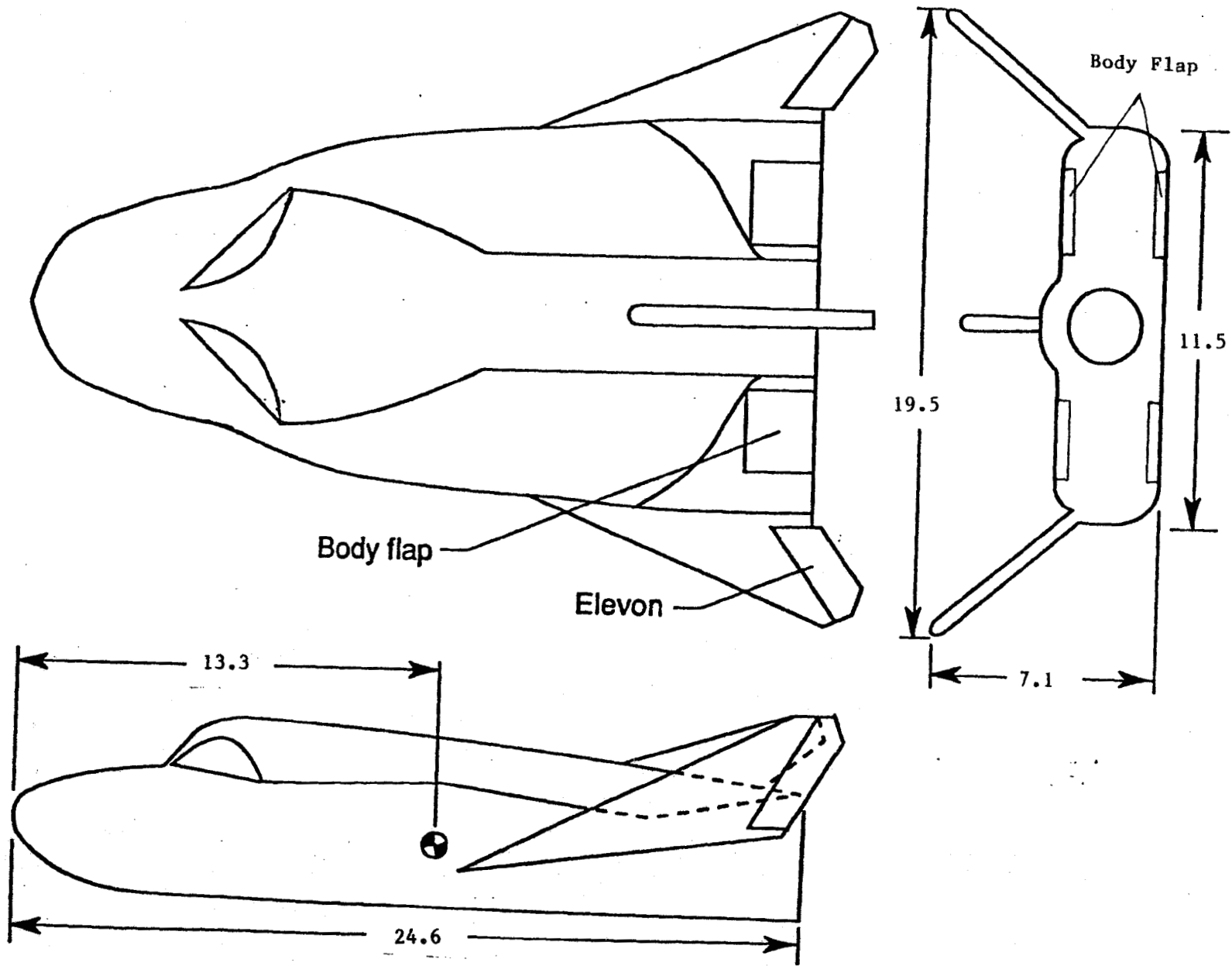
(a) Three-view

Figure 2. Sketch of flight-scale PLS vehicle. Dimensions are in feet.
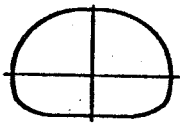
STA 1.19
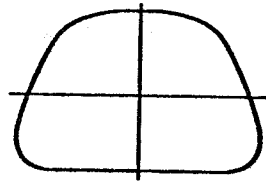
STA 3.57
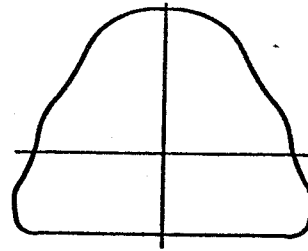
STA 6.07
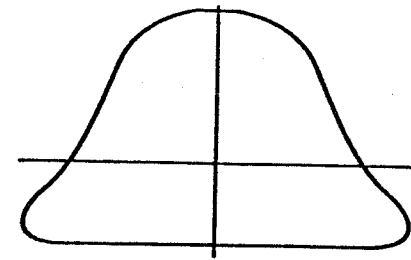
STA 8.45
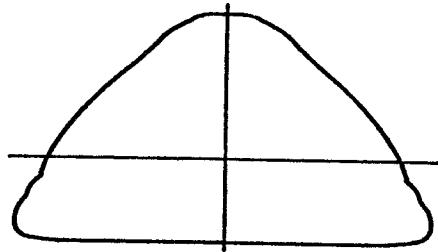
STA 10.95
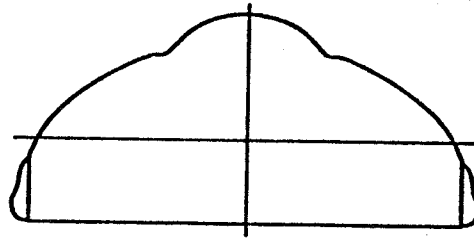
STA 14.76
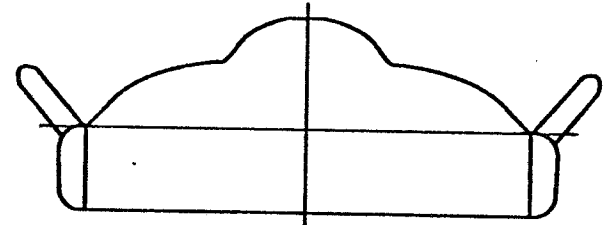
STA 18.45
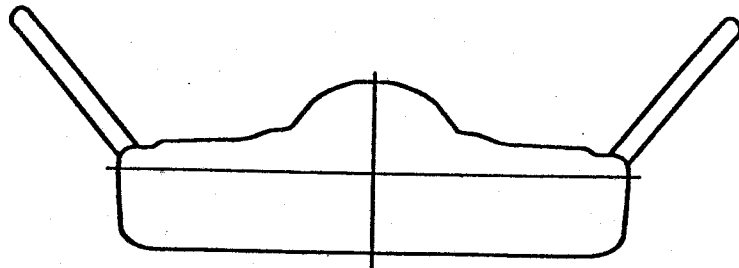
STA 22.14
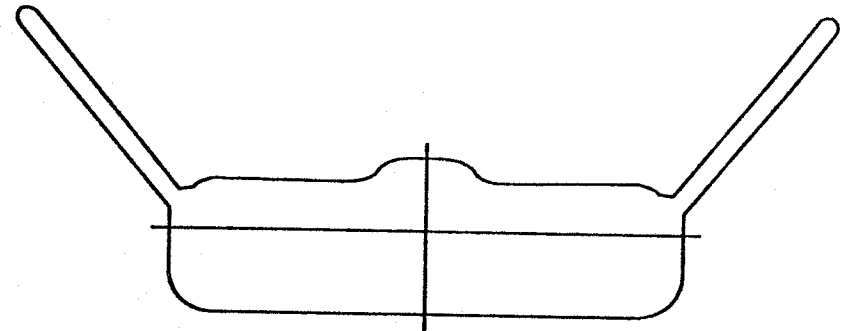
STA 24.56

(b) Vehicle section cuts

Figure 2. Continued.

― Baseline center fin (total area = 8.70 ft$^2$, rudder area = 4.29 ft$^2$)

― ― ― Large center fin (total area = 15.00 ft$^2$, rudder area = 6.33 ft$^2$)

Rudder hinge line

Axis of rotation
for all-movable
tail motion

1.78

2.36

5.41
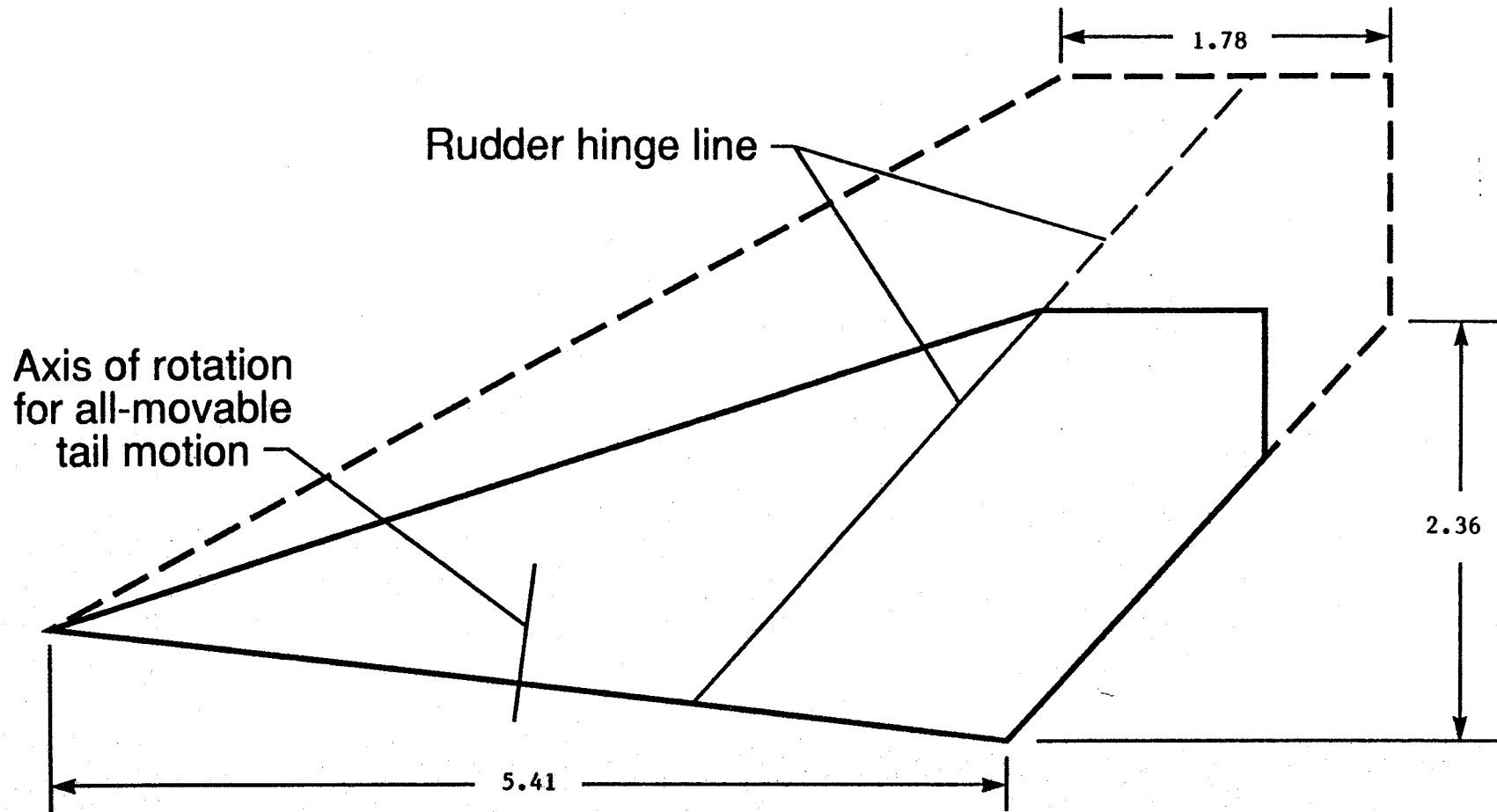
(c) Center fin geometry

Figure 2. Concluded.
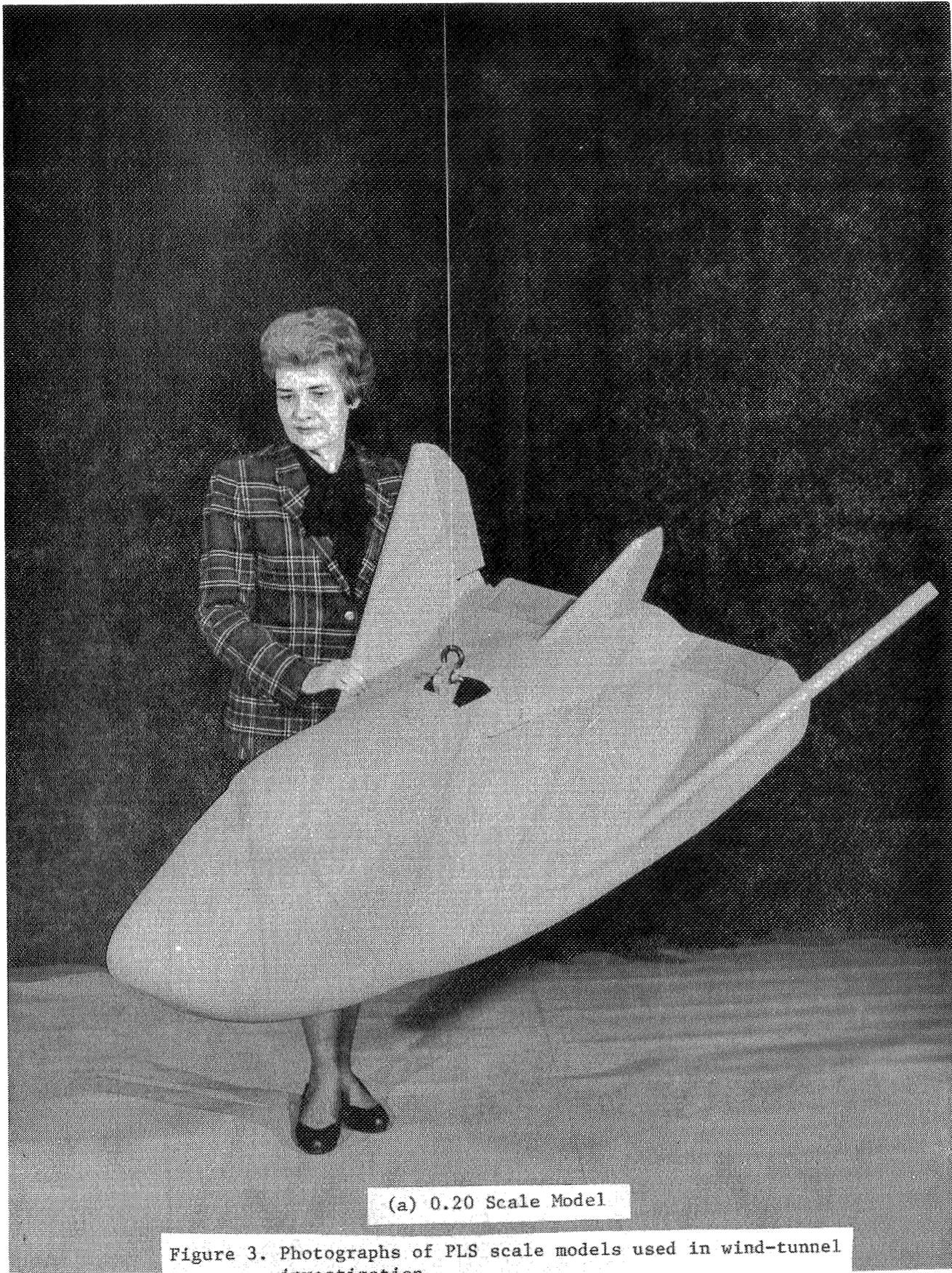
(a) 0.20 Scale Model

Figure 3. Photographs of PLS scale models used in wind-tunnel
investigation.
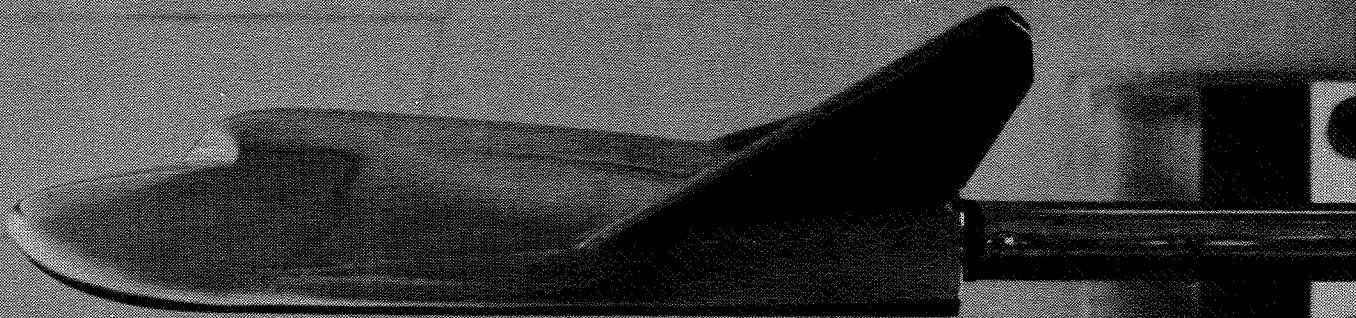
(c) 0.02 Scale Model

Figure 3. Concluded.
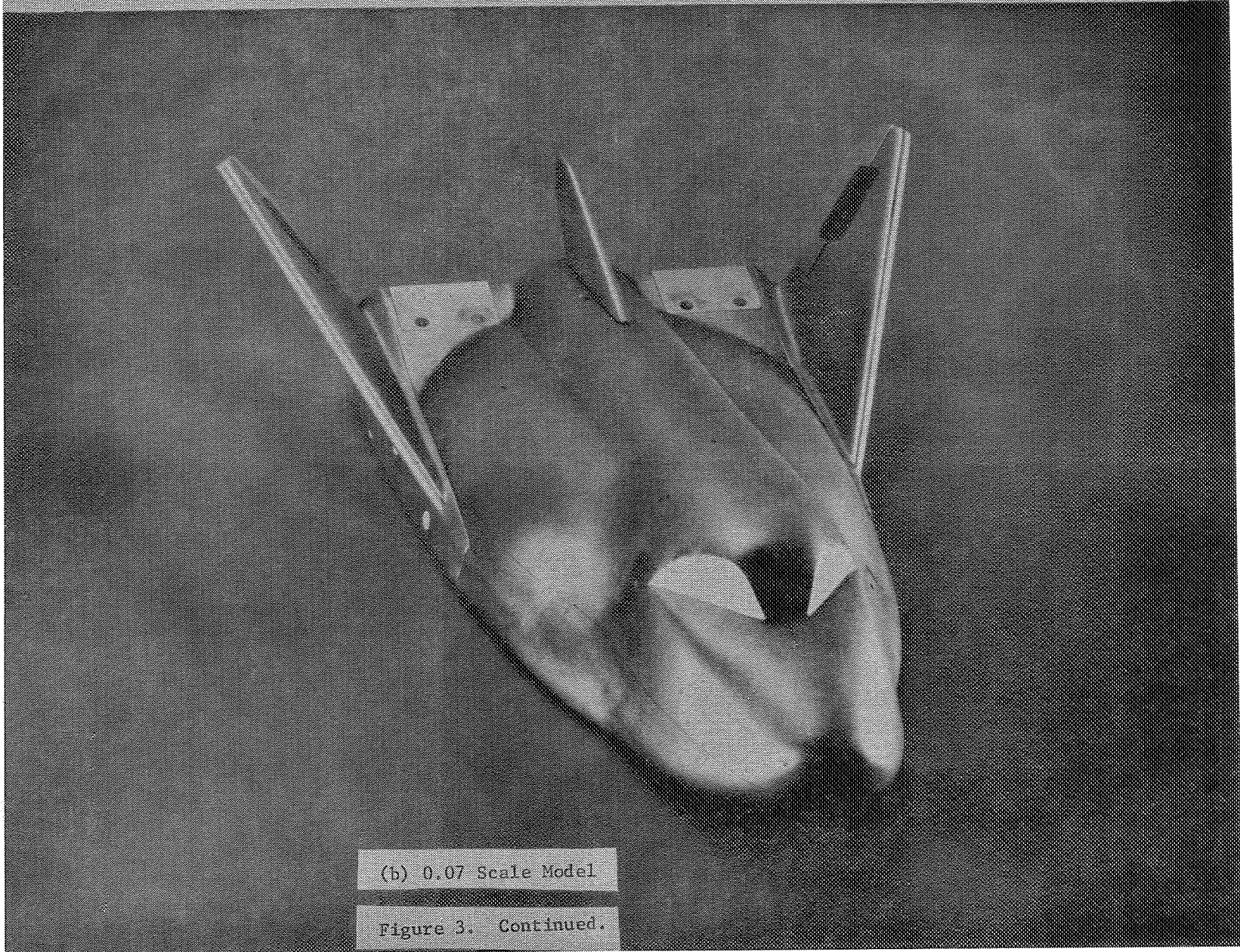
(b) 0.07 Scale Model

Figure 3. Continued.
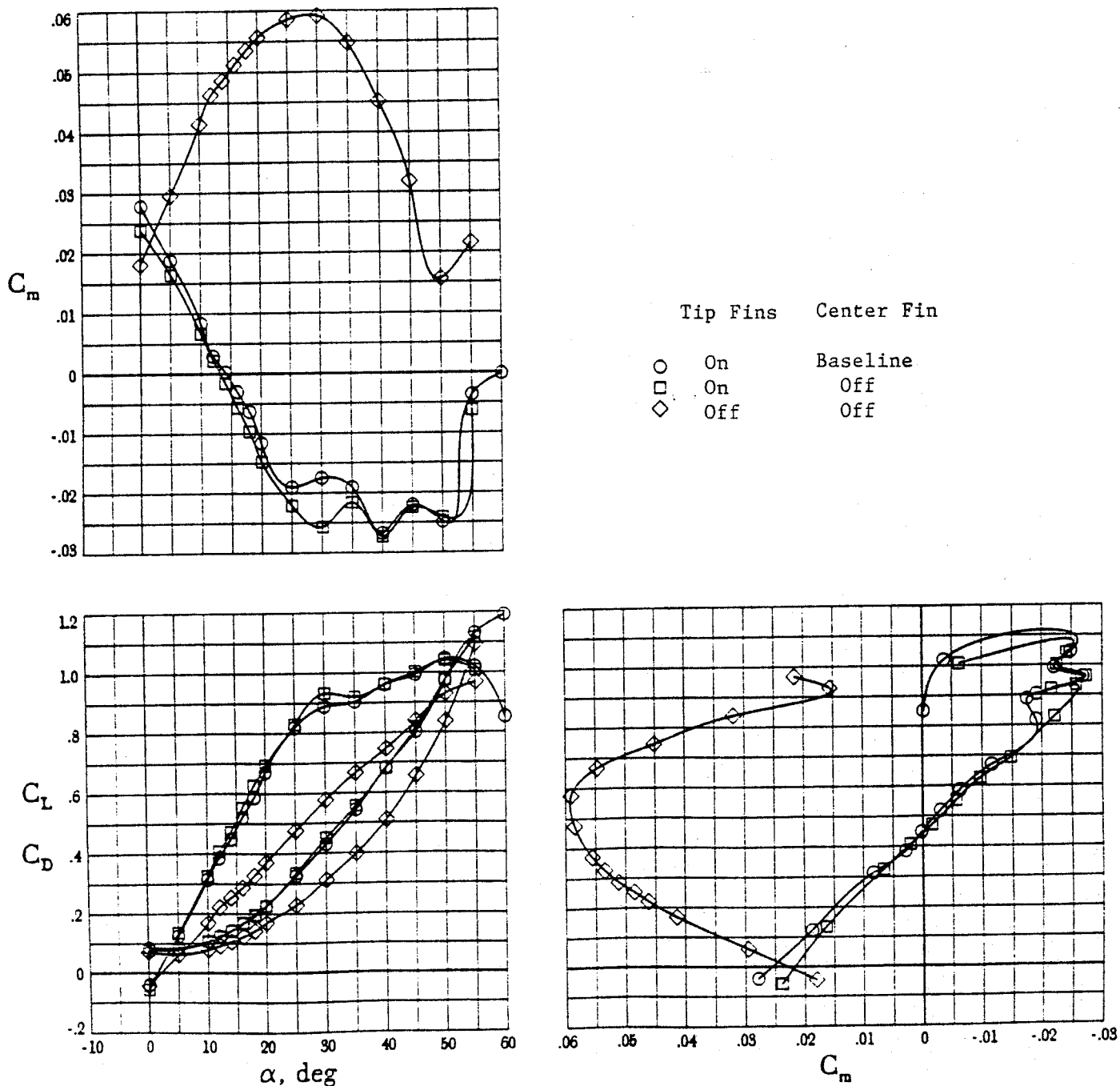
(a) Longitudinal characteristics.

Figure 4. Effect of center fin and tip fins on low-speed aerodynamics.
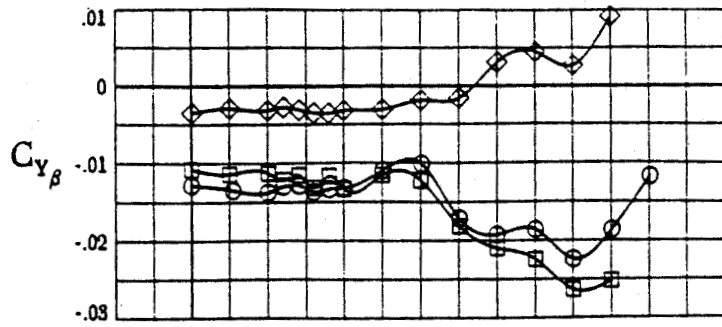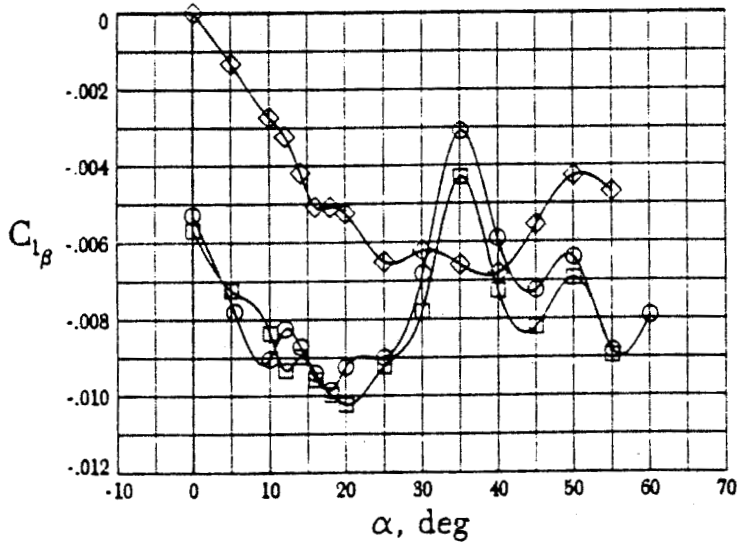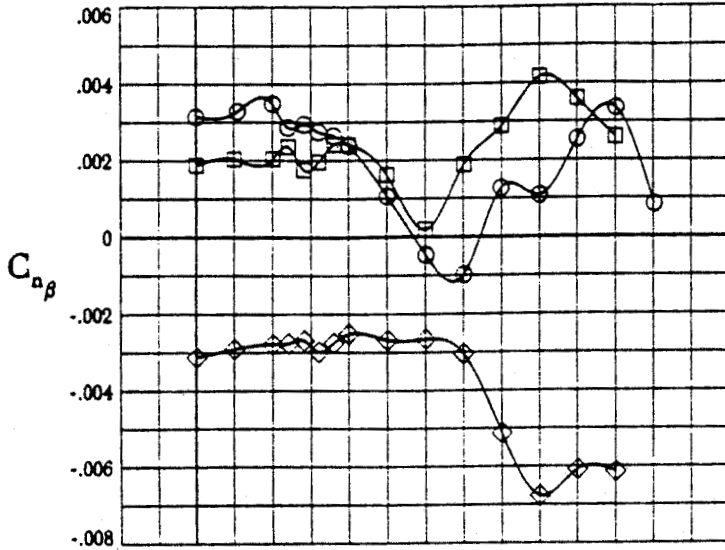
(b) Lateral-directional characteristics.

Figure 4. Concluded.
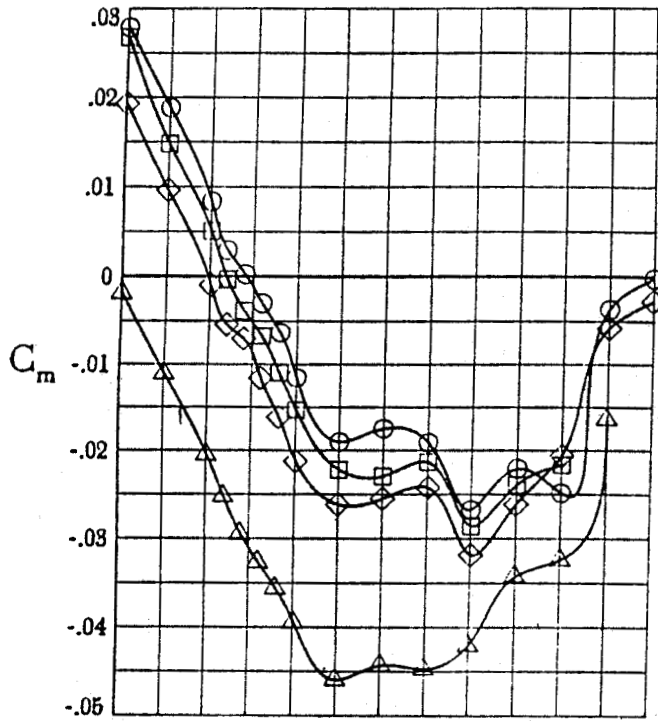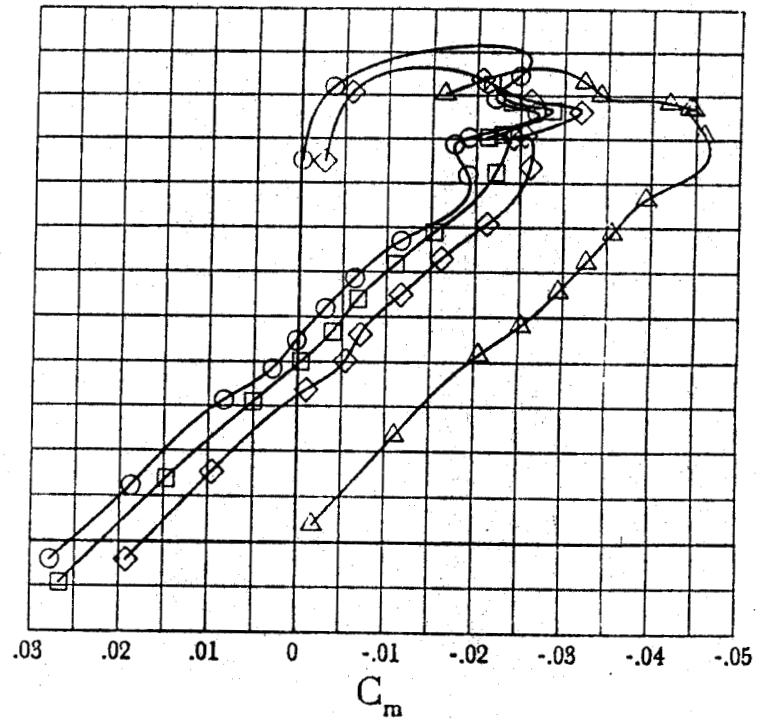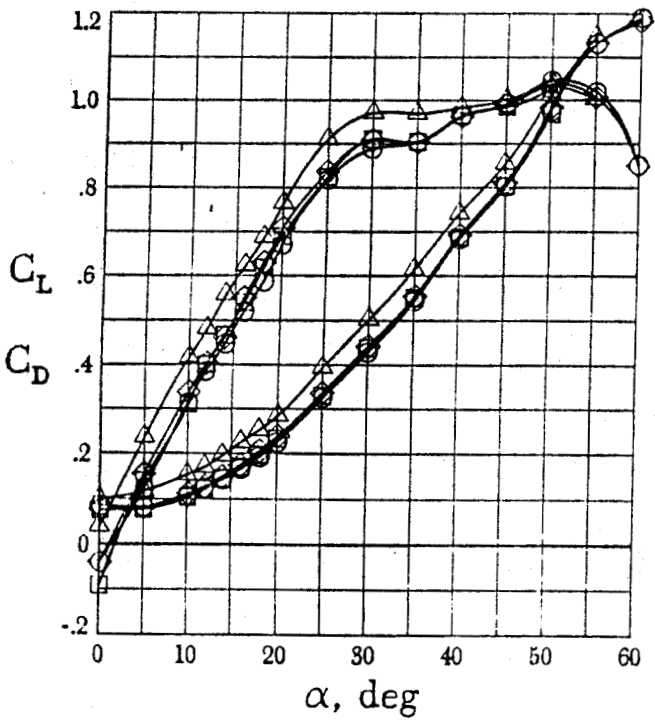
(a) Positive body flap deflections.

Figure 5. Effect of body flaps on low-speed aerodynamics.
Baseline Configuration.
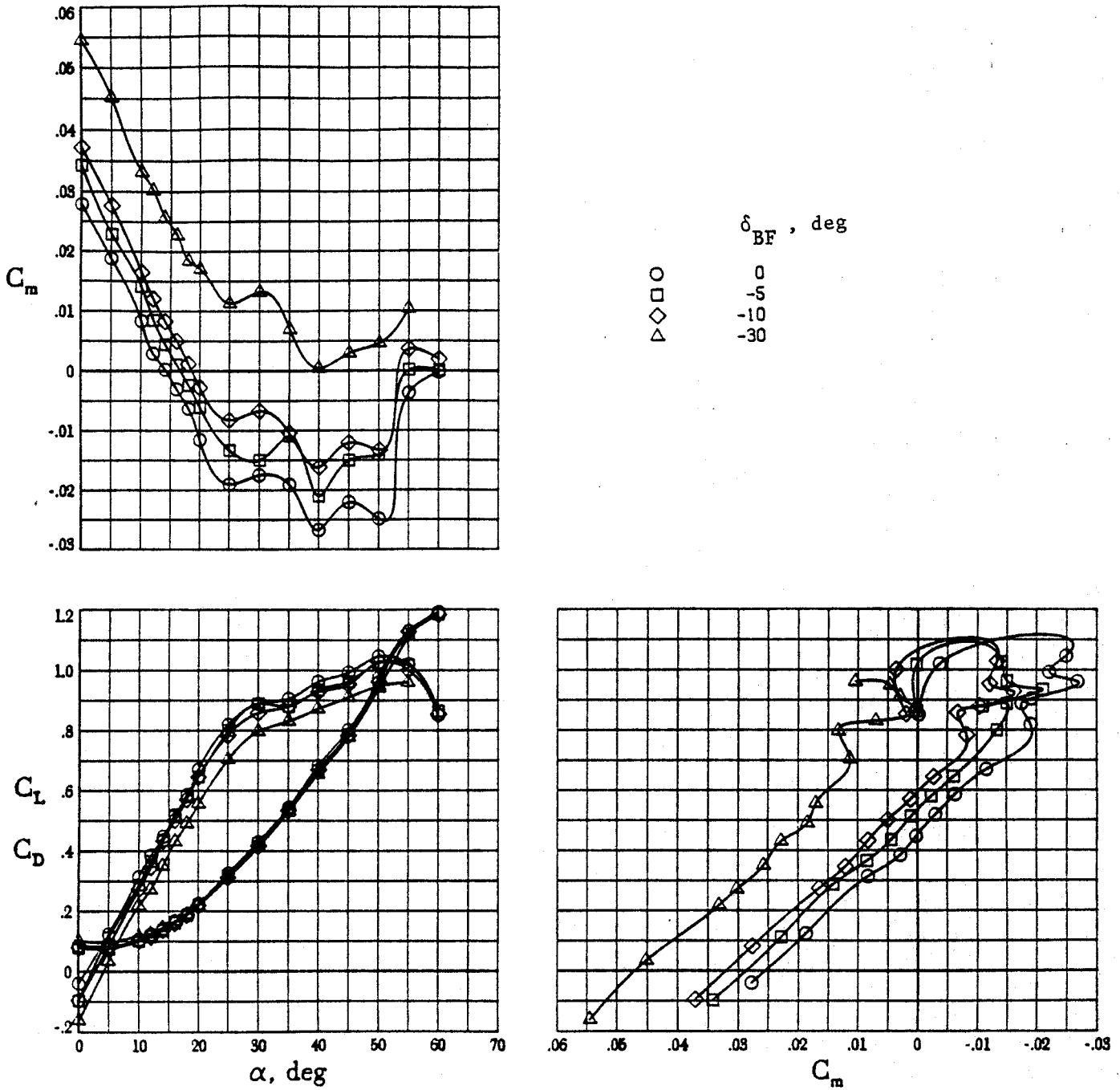
(b) Negative body flap delections.

Figure 5. Concluded.
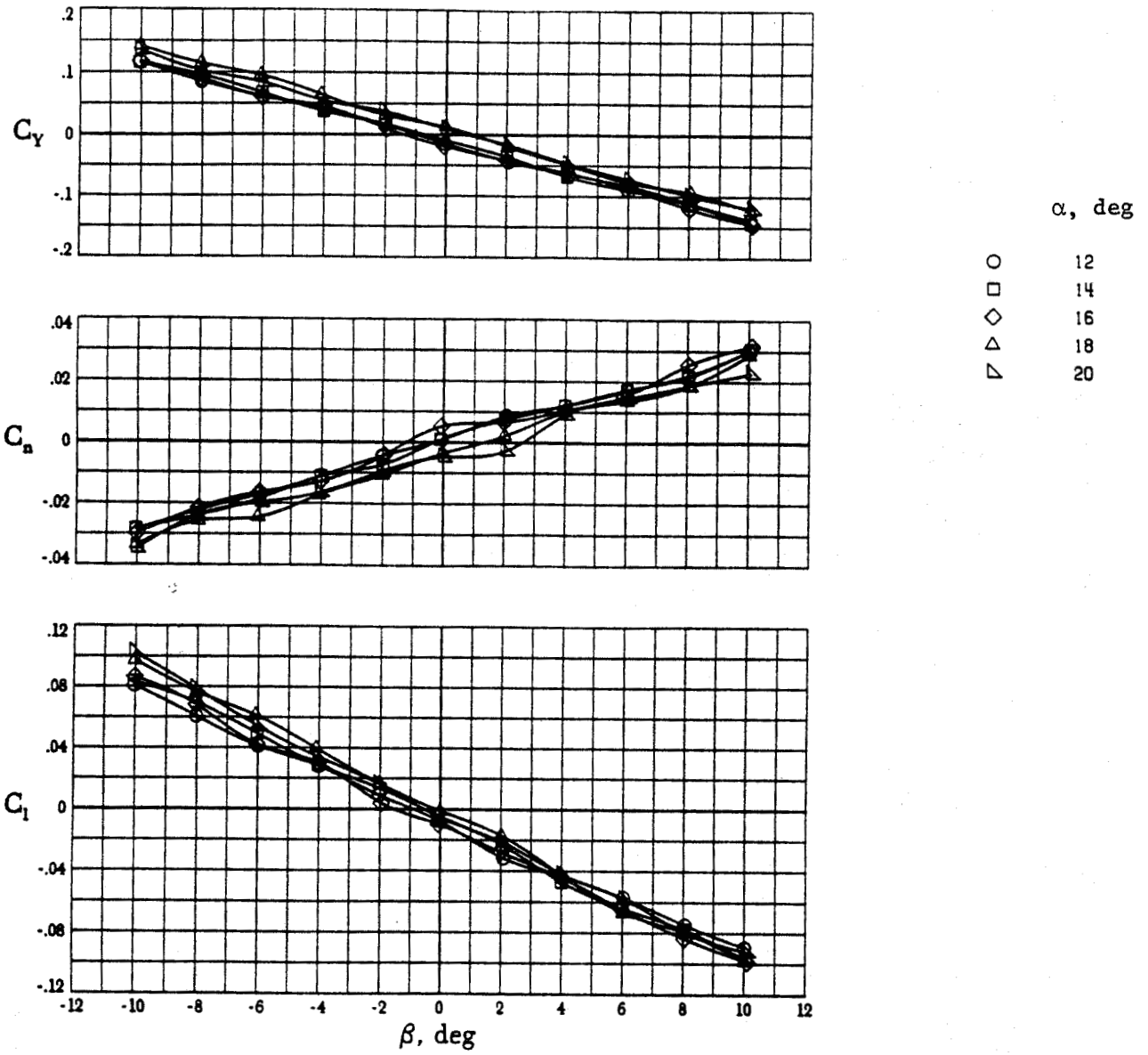
Figure 6. Effect of sideslip on low-speed lateral-directional
aerodynamics. Baseline Configuration.
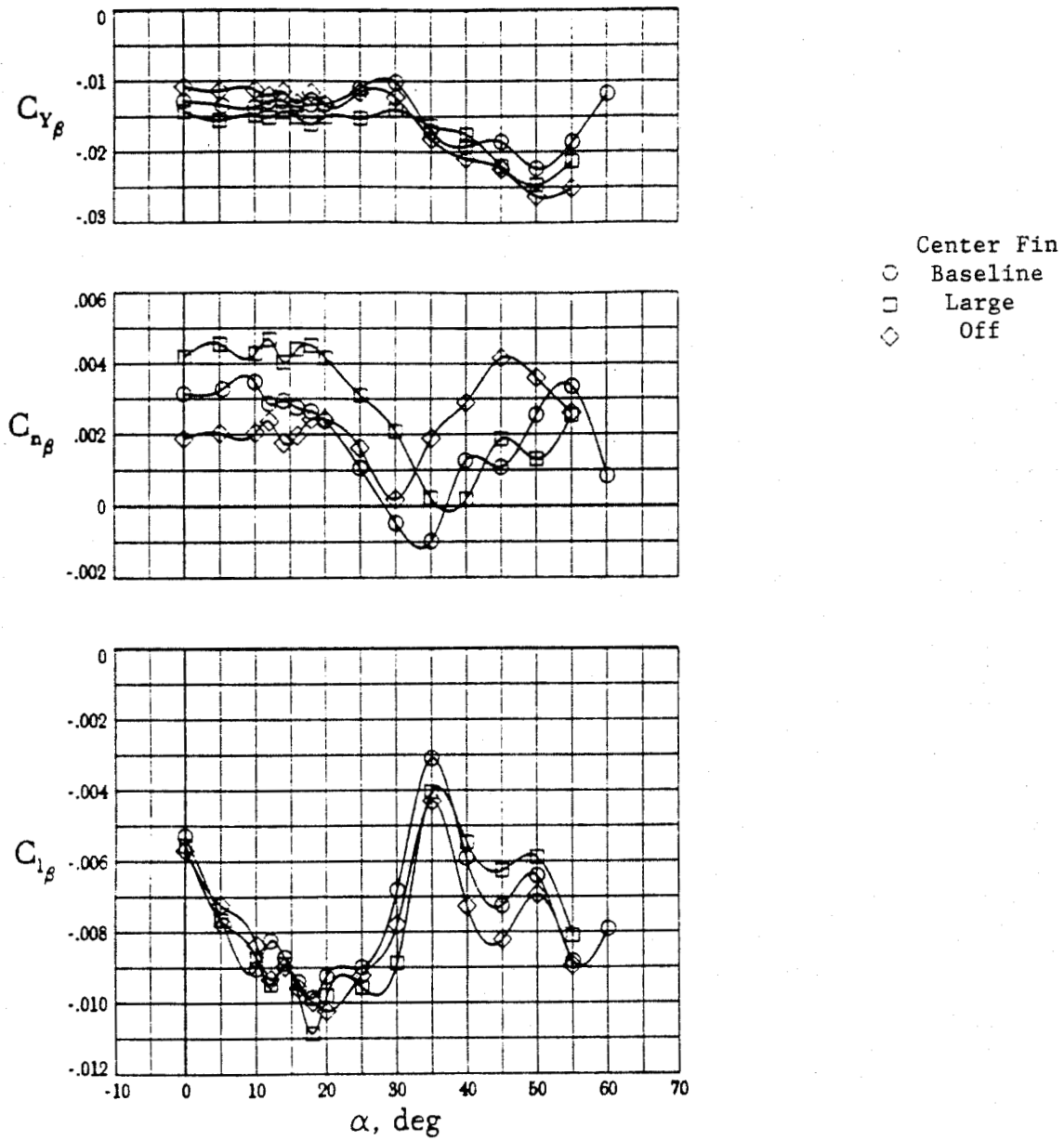
Figure 7. Effect of size of center fin on low-speed lateral-
directional aerodynamics.
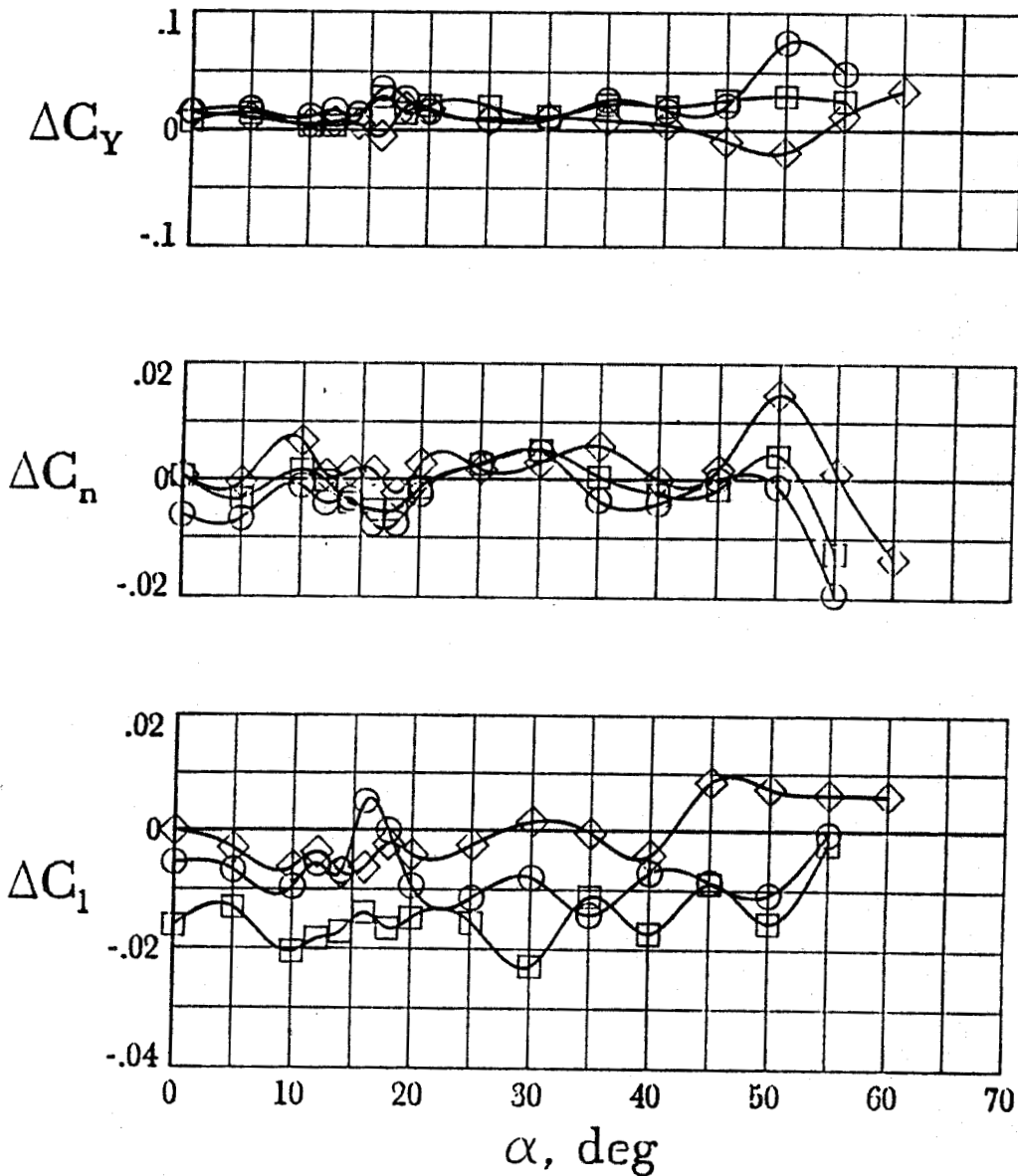
Figure 8. Effect of differentially deflected body flaps on low—speed
lateral—directional aerodynamics. Baseline configuration.
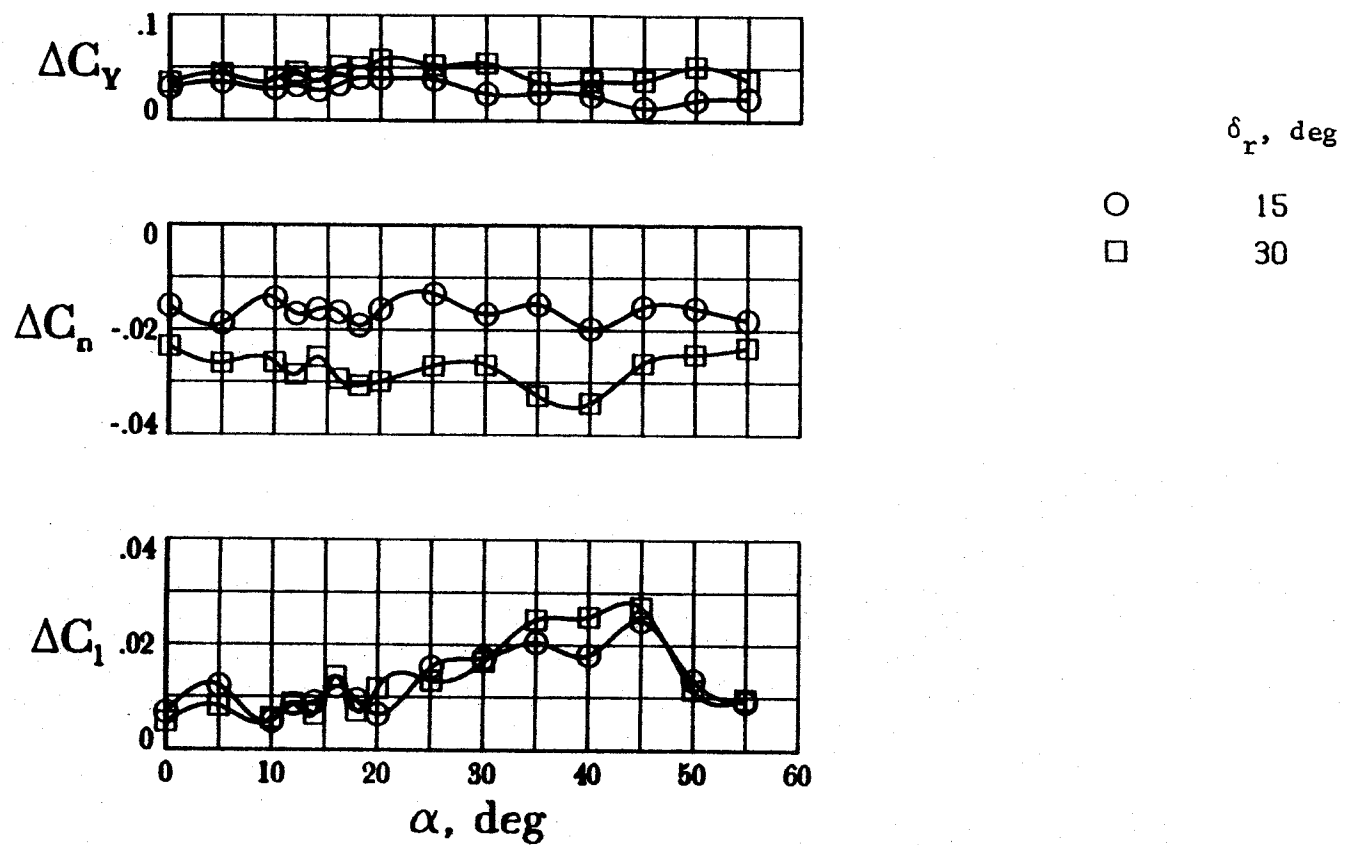
Figure 9. Low-speed baseline rudder control effectiveness.
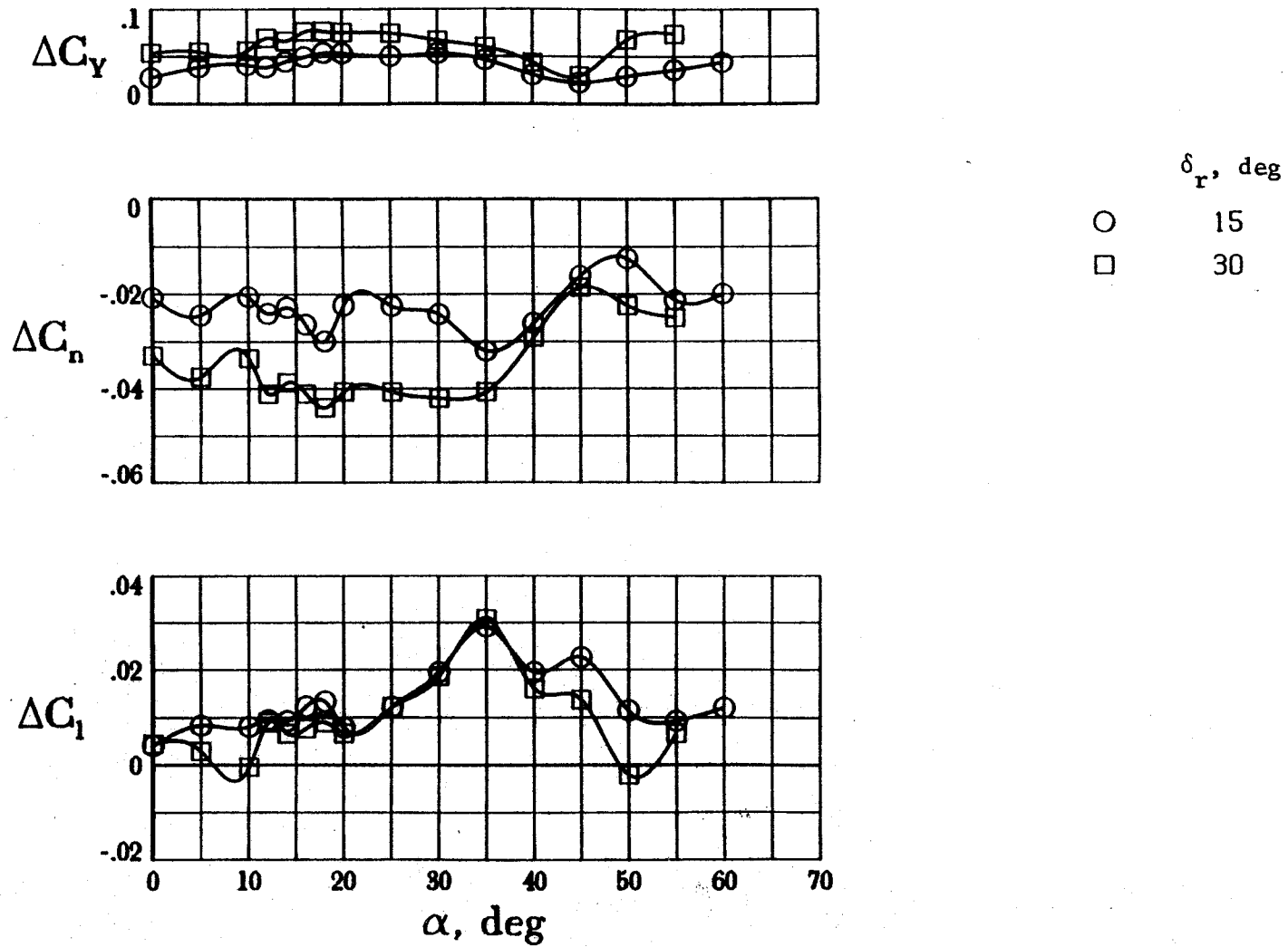
Figure 10. Low-speed control effectiveness with all-movable baseline center
fin.
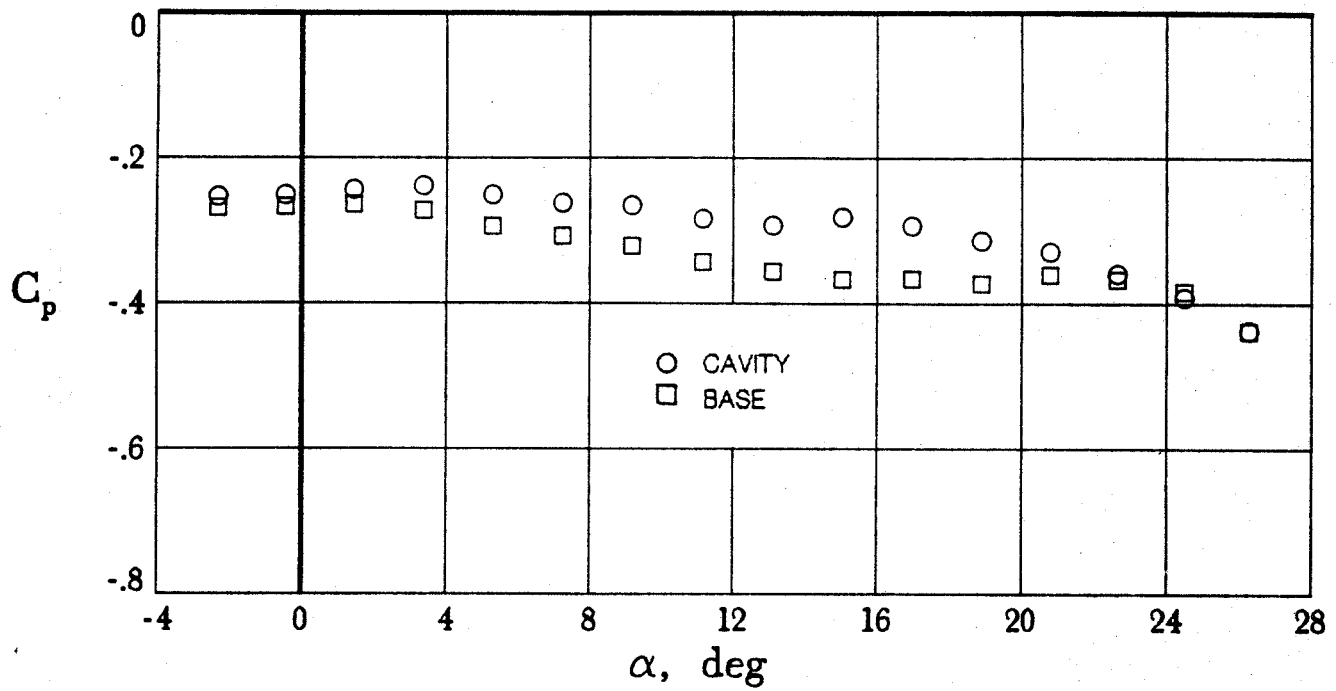
(a) $M = 0.6$.
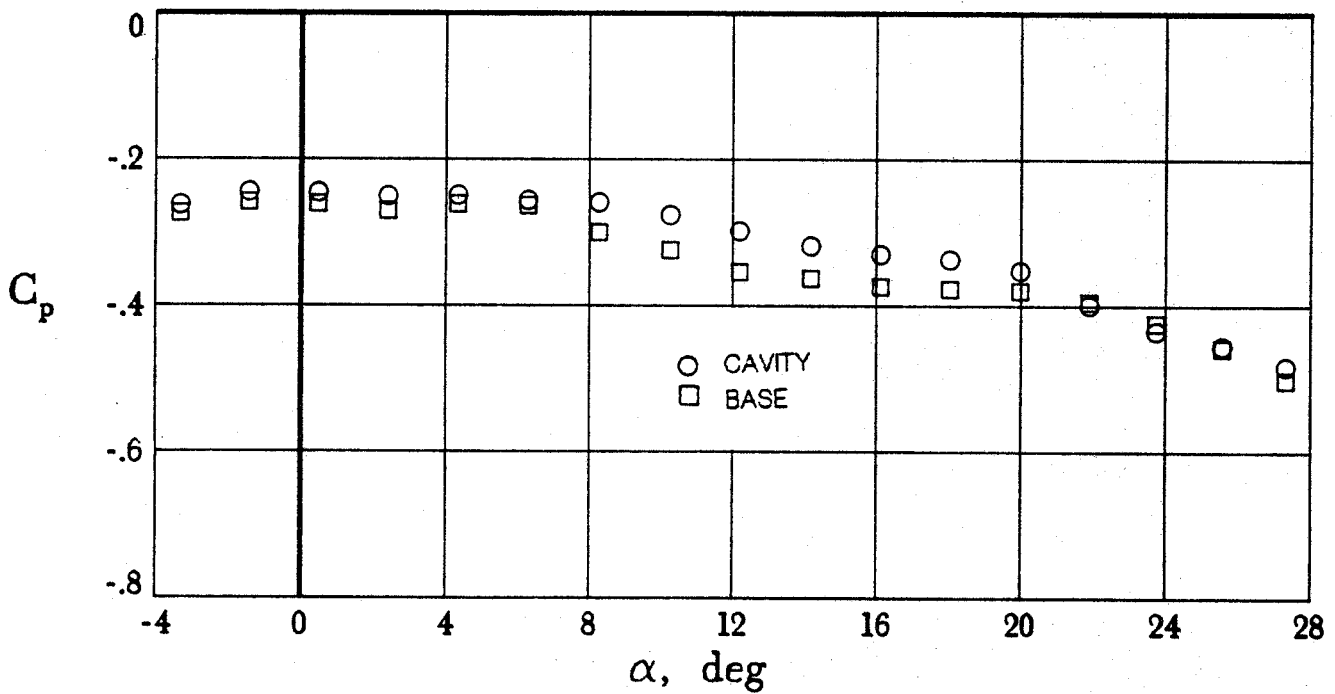


(b) $M = 0.8$.

Figure 11. Model base and sting-cavity pressures measured in transonic tests.
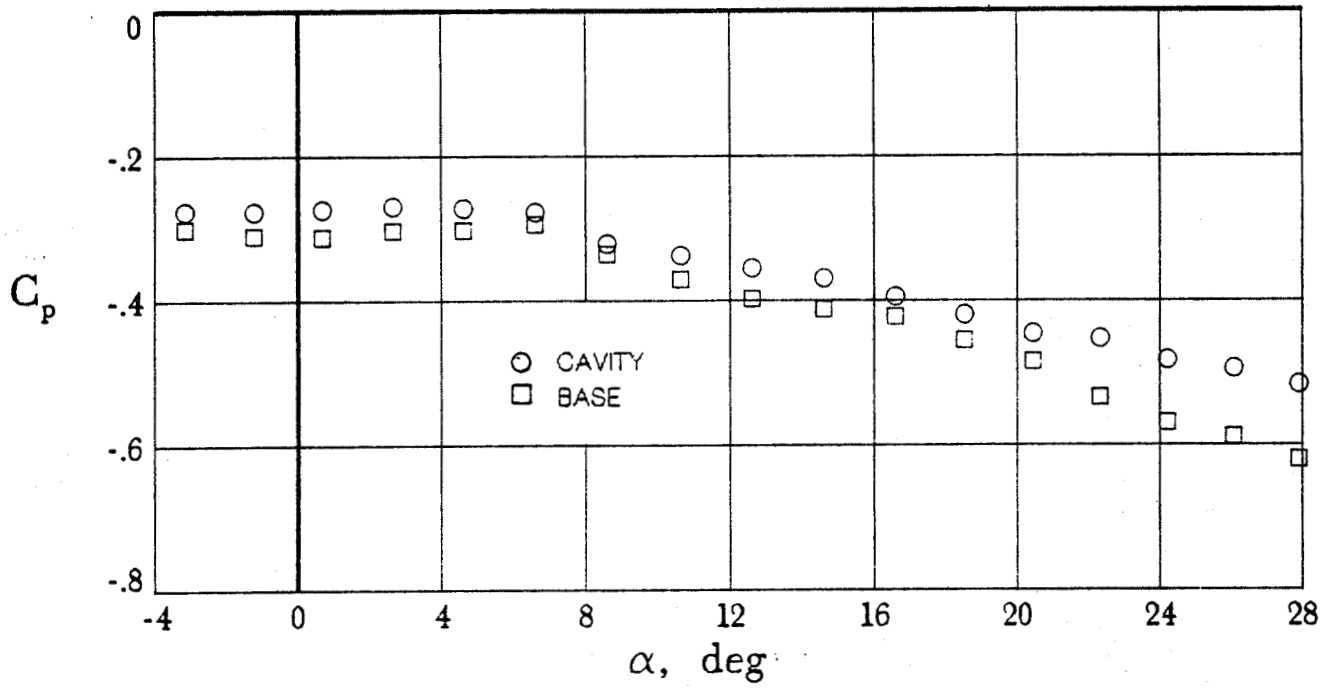
(c) $M = 0.9$.
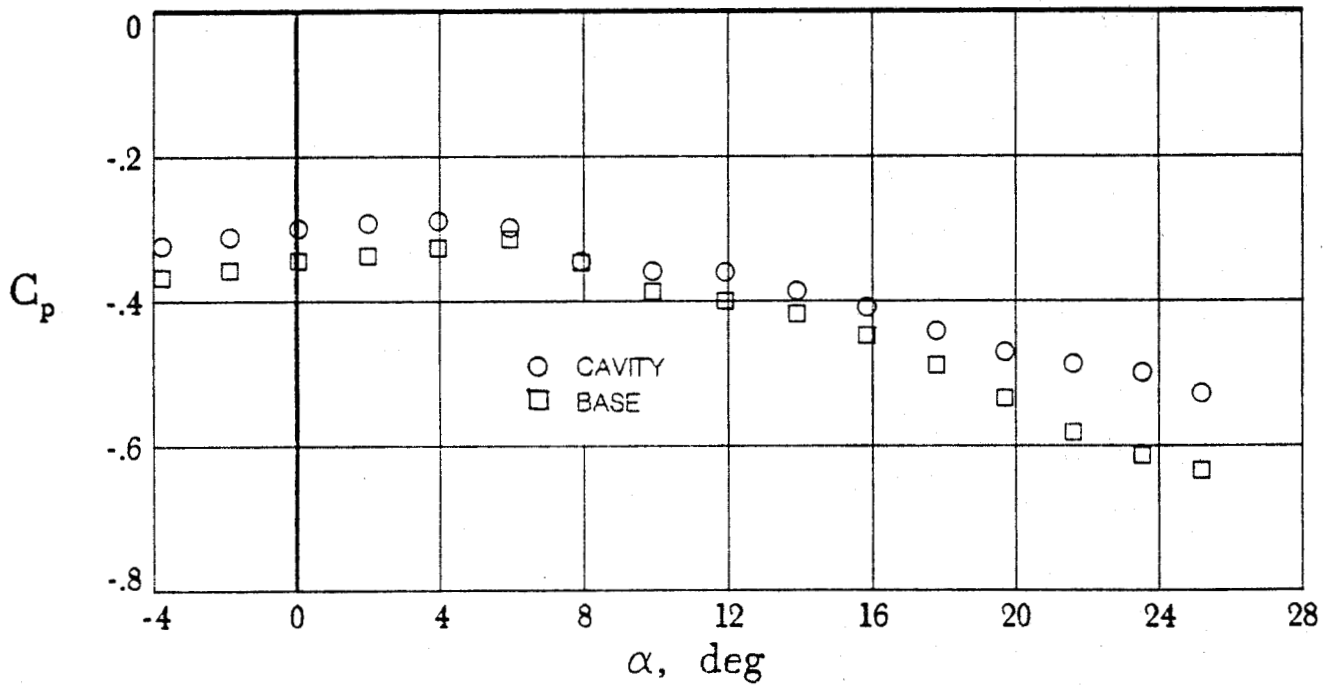


(d) $M = 0.95$.

Figure 11. Continued.
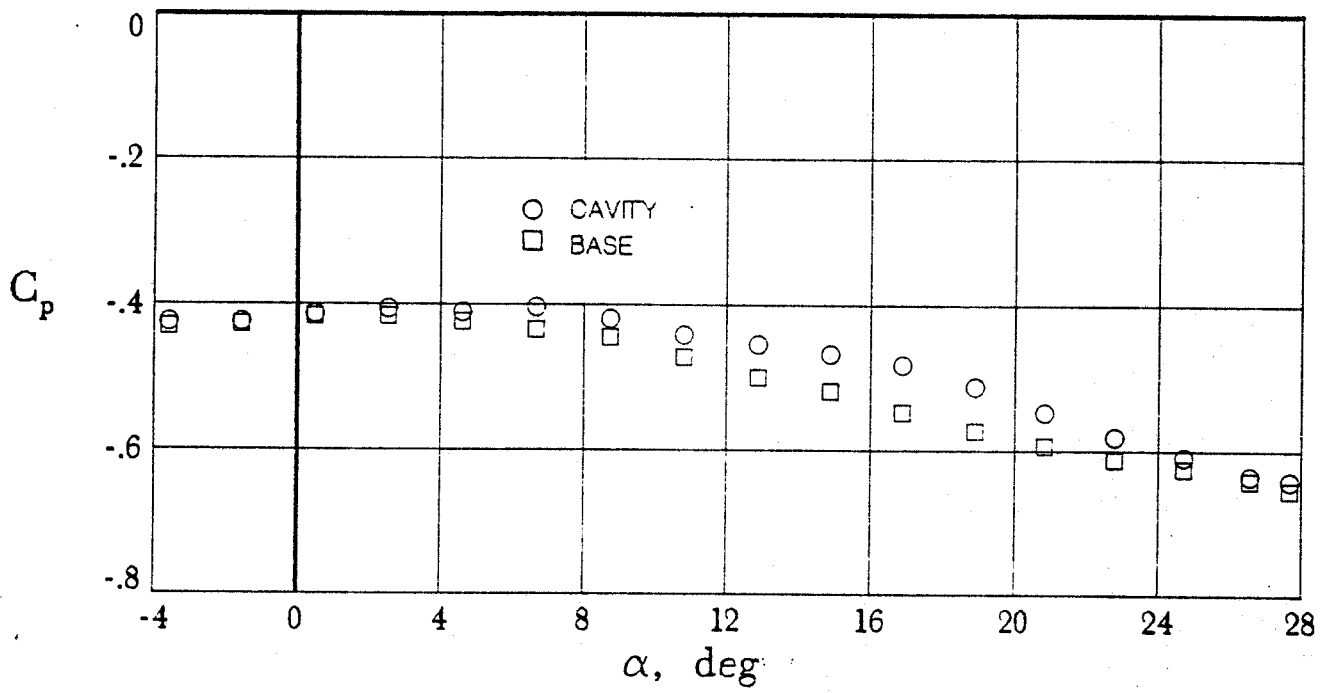
(e) $M = 1.1$.
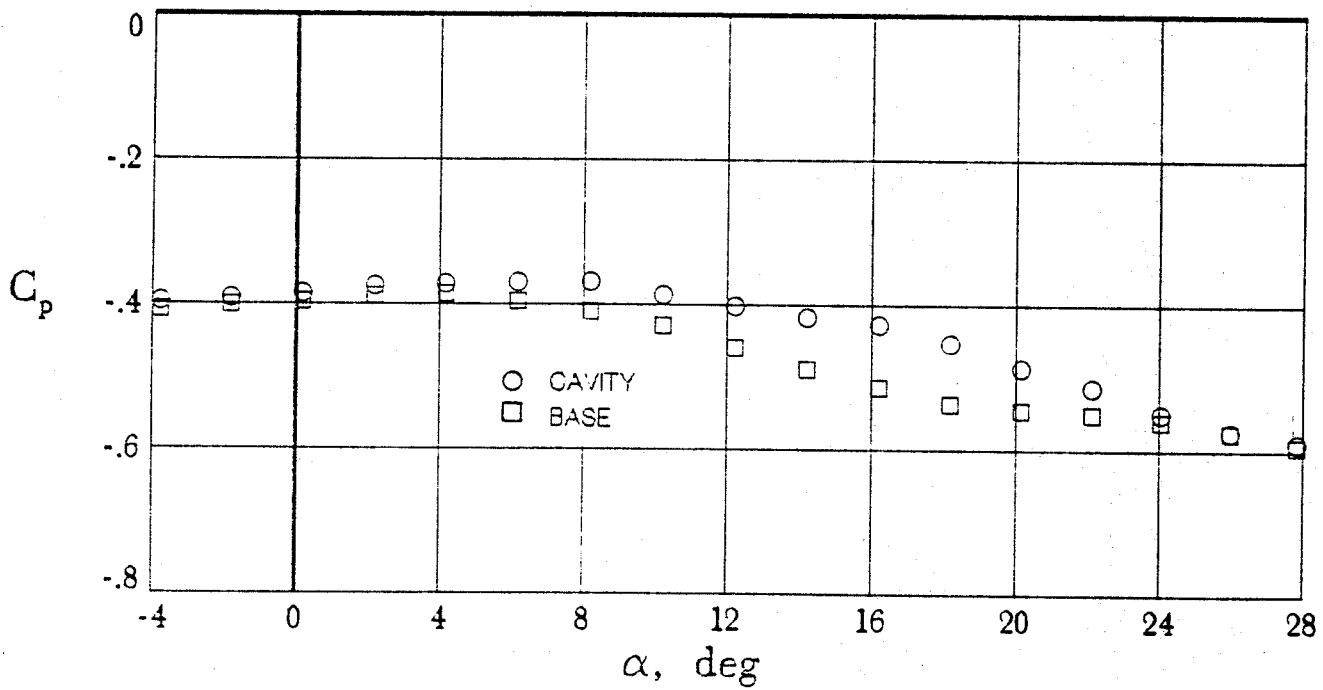


(f) $M = 1.2$.

Figure 11. Concluded.

(a) $C_L$ versus $\alpha$.

(b) $C_D$ versus $\alpha$.
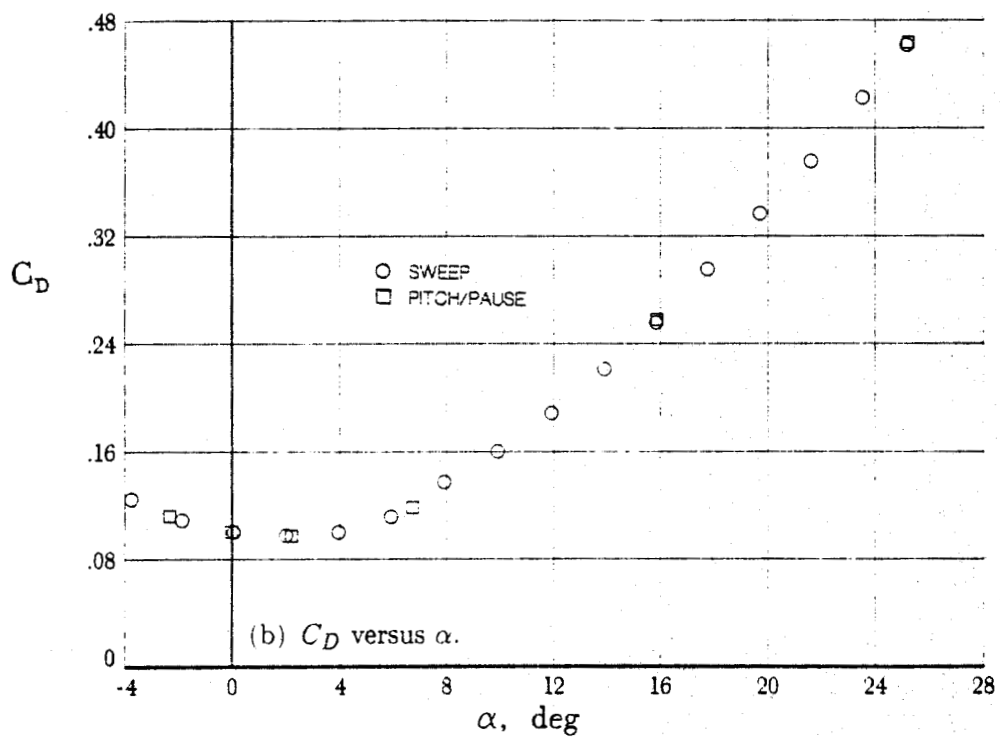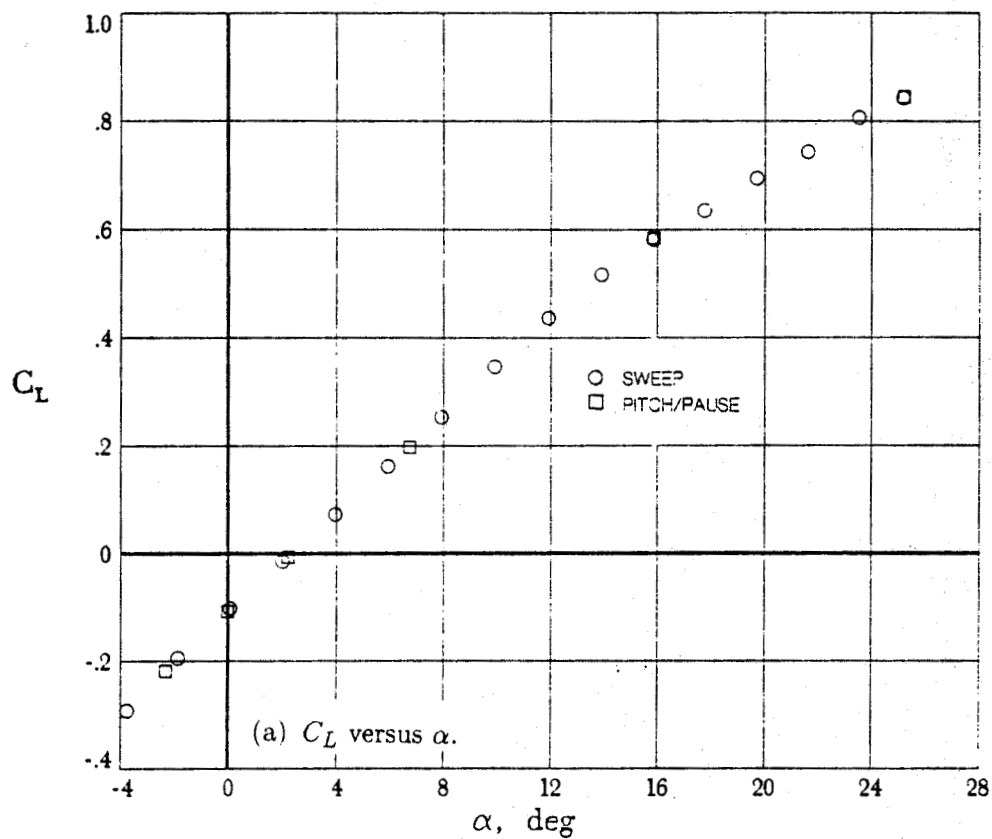
Figure 12. Comparison of data taken using sweep and pitch/pause methods. $M = 0.6$.

(c) $C_m$ versus $\alpha$.

(d) $C_m$ versus $C_L$.

Figure 12. Continued.

(e) $L/D$ versus $\alpha$.

Figure 12. Concluded.

(a) $C_L$ versus $\alpha$ at $M = 0.6$.
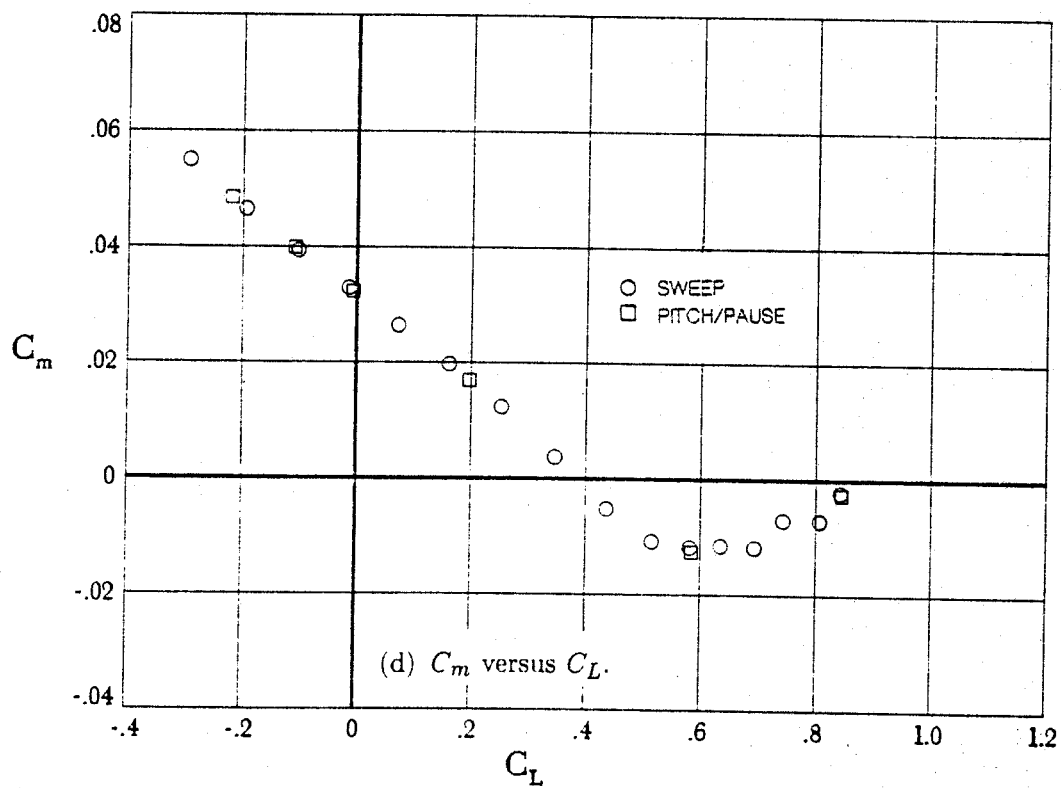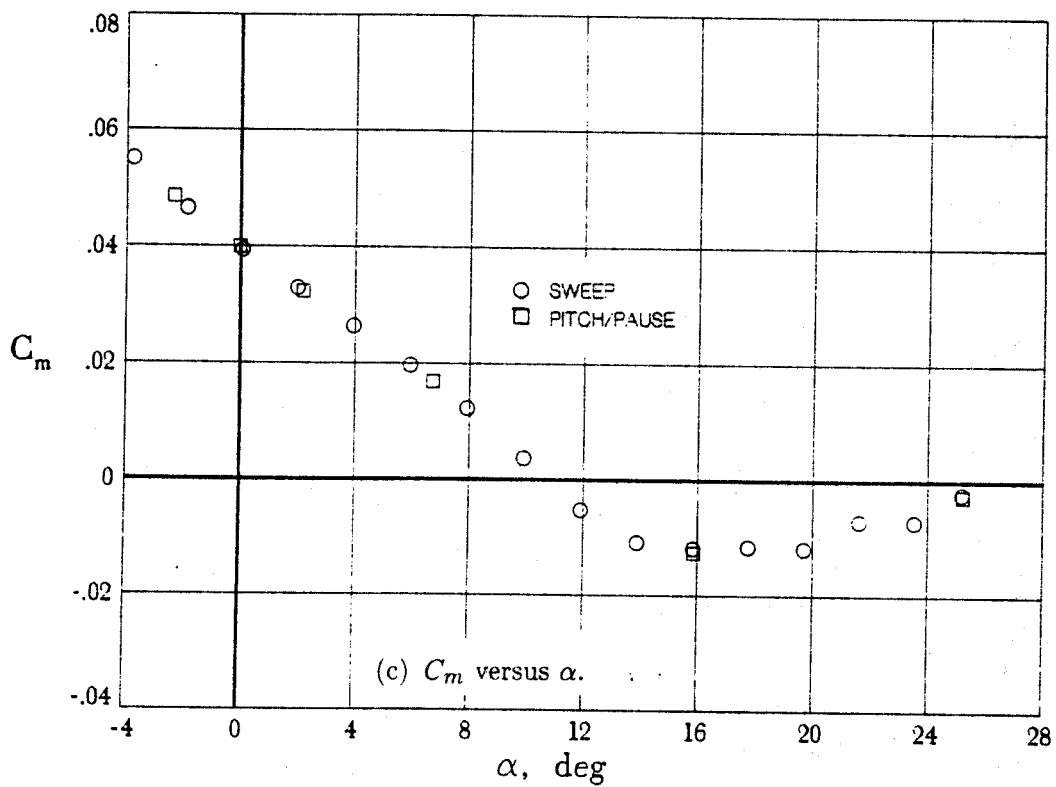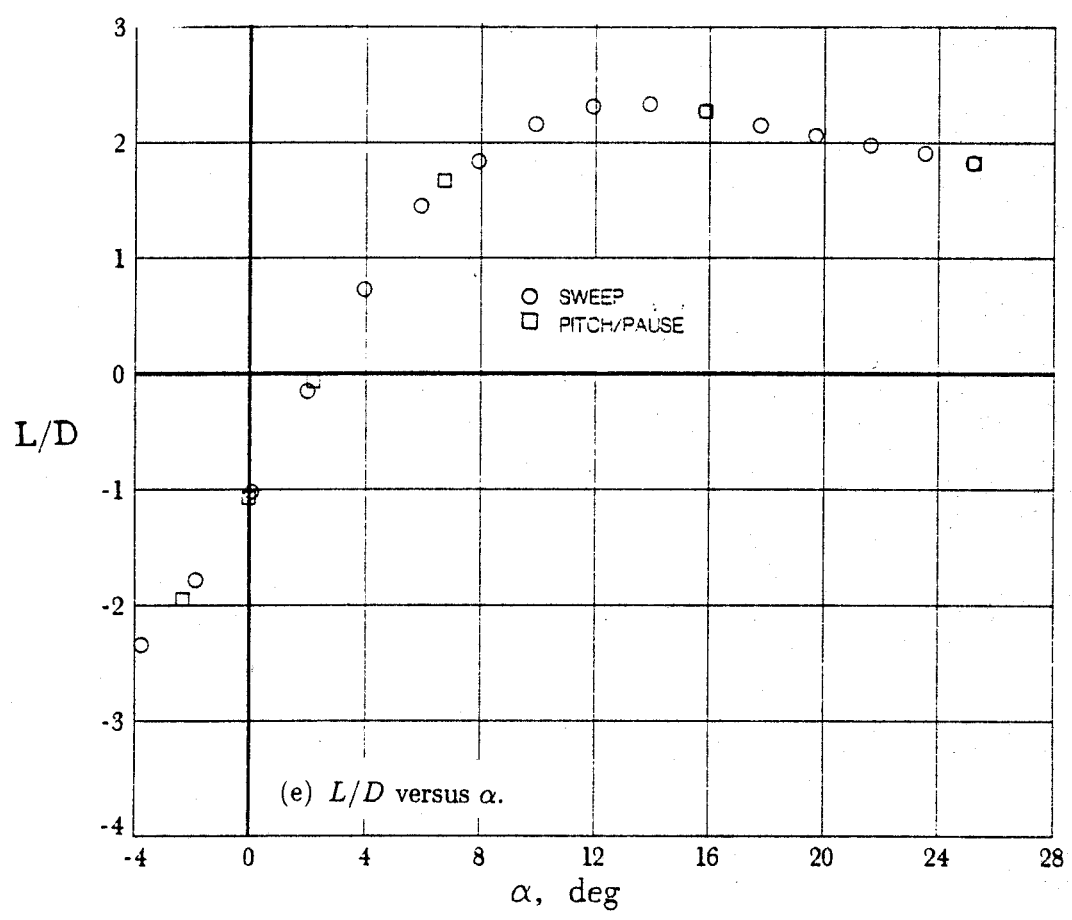


(a) $C_L$ versus $\alpha$ at $M = 0.8$. Continued.
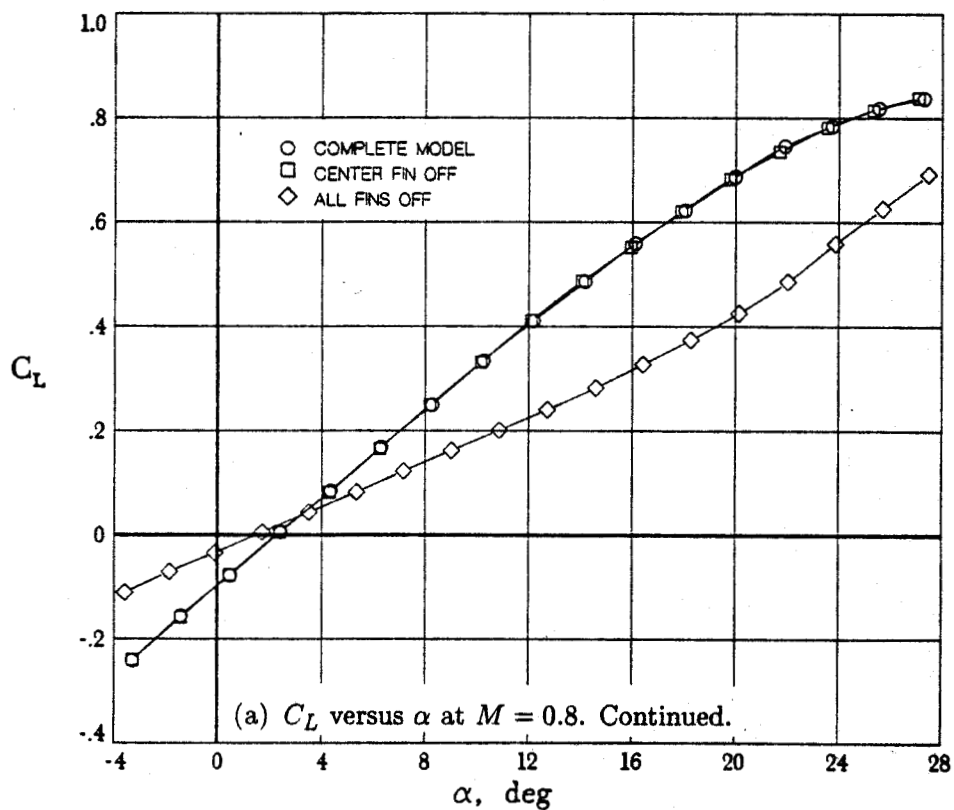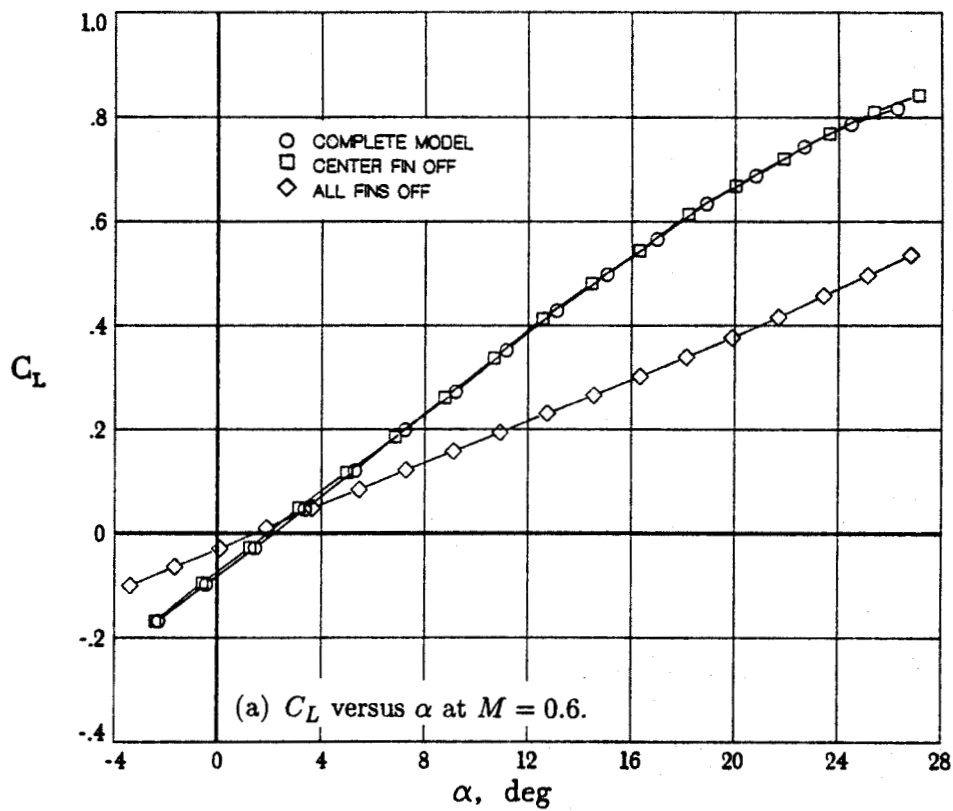
Figure 13. Effect of fins on longitudinal aerodynamic characteristics of model at transonic speeds.

(a) $C_L$ versus $\alpha$ at $M = 0.9$. Continued.



(a) $C_L$ versus $\alpha$ at $M = 0.95$. Continued.

Figure 13. Continued.

(a) $C_L$ versus $\alpha$ at $M = 1.1$. Continued.



(a) $C_L$ versus $\alpha$ at $M = 1.2$. Concluded.

Figure 13. Continued.

(b) $C_D$ versus $\alpha$ at $M = 0.6$.



(b) $C_D$ versus $\alpha$ at $M = 0.8$. Continued.

Figure 13. Continued.

(b) $C_D$ versus $\alpha$ at $M = 0.9$. Continued.



(b) $C_D$ versus $\alpha$ at $M = 0.95$. Continued.

Figure 13. Continued.

(b) $C_D$ versus $\alpha$ at $M = 1.1$. Continued.



(b) $C_D$ versus $\alpha$ at $M = 1.2$. Concluded.

Figure 13. Continued.

(c) $C_m$ versus $\alpha$ at $M = 0.6$.



(c) $C_m$ versus $\alpha$ at $M = 0.8$. Continued.

Figure 13. Continued.

(c) $C_m$ versus $\alpha$ at $M = 0.9$. Continued.



(c) $C_m$ versus $\alpha$ at $M = 0.95$. Continued.

Figure 13. Continued.

(c) $C_m$ versus $\alpha$ at $M = 1.1$. Continued.

○ COMPLETE MODEL
□ CENTER FIN OFF
◇ ALL FINS OFF

$\alpha$, deg

(c) $C_m$ versus $\alpha$ at $M = 1.2$. Concluded.

○ COMPLETE MODEL
□ CENTER FIN OFF
◇ ALL FINS OFF

$\alpha$, deg

Figure 13. Continued.

(d) $C_m$ versus $C_L$ at $M = 0.6$.



(d) $C_m$ versus $C_L$ at $M = 0.8$. Continued.

Figure 13. Continued.

(d) $C_m$ versus $C_L$ at $M = 0.9$. Continued.



(d) $C_m$ versus $C_L$ at $M = 0.95$. Continued.

Figure 13. Continued.

(d) $C_m$ versus $C_L$ at $M = 1.1$. Continued.

(d) $C_m$ versus $C_L$ at $M = 1.2$. Concluded.

Figure 13. Continued.

(e) $L/D$ versus $\alpha$ at $M = 0.6$.

(e) $L/D$ versus $\alpha$ at $M = 0.8$. Continued.

Figure 13. Continued.

(e) $L/D$ versus $\alpha$ at $M = 0.9$. Continued.



(e) $L/D$ versus $\alpha$ at $M = 0.95$. Continued.

Figure 13. Continued.

(e) $L/D$ versus $\alpha$ at $M = 1.1$. Continued.



(e) $L/D$ versus $\alpha$ at $M = 1.2$. Concluded.

Figure 13. Concluded.

(a) $C_L$ versus $\alpha$ at $M = 0.6$.

(a) $C_L$ versus $\alpha$ at $M = 0.8$. Continued.

Figure 14. Effect of elevon and body flap on longitudinal aerodynamic characteristics of model at transonic speeds.

(a) $C_L$ versus $\alpha$ at $M = 0.9$. Continued.

| ELEVON | BODY FLAP |
|--------|-----------|
| ○ −10° | 0° |
| □ −5° | 0° |
| ◇ 0° | 0° |
| △ 5° | 0° |
| ◁ 0° | −10° |
| ◷ 0° | 10° |



(a) $C_L$ versus $\alpha$ at $M = 0.95$. Continued.

| ELEVON | BODY FLAP |
|--------|-----------|
| ○ −10° | 0° |
| □ −5° | 0° |
| ◇ 0° | 0° |
| △ 5° | 0° |
| ◁ 0° | −10° |
| ◷ 0° | 10° |

Figure 14. Continued.

(a) $C_L$ versus $\alpha$ at $M = 1.1$. Continued.

(a) $C_L$ versus $\alpha$ at $M = 1.2$. Concluded.

Figure 14. Continued.

(b) $C_D$ versus $\alpha$ at $M = 0.6$.



(b) $C_D$ versus $\alpha$ at $M = 0.8$. Continued.

Figure 14. Continued.

(b) $C_D$ versus $\alpha$ at $M = 0.9$. Continued.



(b) $C_D$ versus $\alpha$ at $M = 0.95$. Continued.

Figure 14. Continued.

ELEVON | BODY FLAP
○ -10° | 0°
□ -5° | 0°
◇ 0° | 0°
△ 5° | 0°
◁ 0° | -10°
◻ 0° | 10°

(b) $C_D$ versus $\alpha$ at $M = 1.1$. Continued.



ELEVON | BODY FLAP
○ -10° | 0°
□ -5° | 0°
◇ 0° | 0°
△ 5° | 0°
◁ 0° | -10°
◻ 0° | 10°

(b) $C_D$ versus $\alpha$ at $M = 1.2$. Concluded.

Figure 14. Continued.

(c) $C_m$ versus $\alpha$ at $M = 0.6$.



(c) $C_m$ versus $\alpha$ at $M = 0.8$. Continued.

Figure 14. Continued.

(c) $C_m$ versus $\alpha$ at $M = 0.9$. Continued.



(c) $C_m$ versus $\alpha$ at $M = 0.95$. Continued.

Figure 14. Continued.

(c) $C_m$ versus $\alpha$ at $M = 1.1$. Continued.

| ELEVON | BODY FLAP |
|--------|-----------|
| ○ -10 | 0° |
| □ -5 | 0° |
| ◇ 0° | 0° |
| △ 5° | 0° |
| ◁ 0° | -10° |
| ▷ 0° | 10° |

(c) $C_m$ versus $\alpha$ at $M = 1.2$. Concluded.

| ELEVON | BODY FLAP |
|--------|-----------|
| ○ -10° | 0° |
| □ -5° | 0° |
| ◇ 0° | 0° |
| △ 5° | 0° |
| ◁ 0° | -10° |
| ▷ 0° | 10° |

Figure 14. Continued.

(d) $C_m$ versus $C_L$ at $M = 0.6$.

| ELEVON | BODY FLAP |
|--------|-----------|
| ○ -10° | 0° |
| □ -5° | 0° |
| ◇ 0° | 0° |
| △ 5° | 0° |
| ◁ 0° | -10° |
| ▷ 0° | 10° |



(d) $C_m$ versus $C_L$ at $M = 0.8$. Continued.

| ELEVON | BODY FLAP |
|--------|-----------|
| ○ -10° | 0° |
| □ -5° | 0° |
| ◇ 0° | 0° |
| △ 5° | 0° |
| ◁ 0° | -10° |
| ▷ 0° | 10° |

Figure 14. Continued.

(d) $C_m$ versus $C_L$ at $M = 0.9$. Continued.



(d) $C_m$ versus $C_L$ at $M = 0.95$. Continued.

Figure 14. Continued.

(d) $C_m$ versus $C_L$ at $M = 1.1$. Continued.



(d) $C_m$ versus $C_L$ at $M = 1.2$. Concluded.

Figure 14. Continued.

(e) $L/D$ versus $\alpha$ at $M = 0.6$.



(e) $L/D$ versus $\alpha$ at $M = 0.8$. Continued.

Figure 14. Continued.

(e) $L/D$ versus $\alpha$ at $M = 0.9$. Continued.

| | ELEVON | BODY FLAP |
|---|---|---|
| ○ | -10° | 0° |
| □ | -5° | 0° |
| ◇ | 0° | 0° |
| △ | 5° | 0° |
| ▷ | 0° | -10° |
| ◁ | 0° | 10° |

(e) $L/D$ versus $\alpha$ at $M = 0.95$. Continued.

| | ELEVON | BODY FLAP |
|---|---|---|
| ○ | -10° | 0° |
| □ | -5° | 0° |
| ◇ | 0° | 0° |
| △ | 5° | 0° |
| ▷ | 0° | -10° |
| ◁ | 0° | 10° |

Figure 14. Continued.

(e) $L/D$ versus $\alpha$ at $M = 1.1$. Continued.



(e) $L/D$ versus $\alpha$ at $M = 1.2$. Concluded.

Figure 14. Concluded.

Figure 15. Variation of transonic longitudinal trim characteristics of baseline configuration with Mach number. No controls deflected.
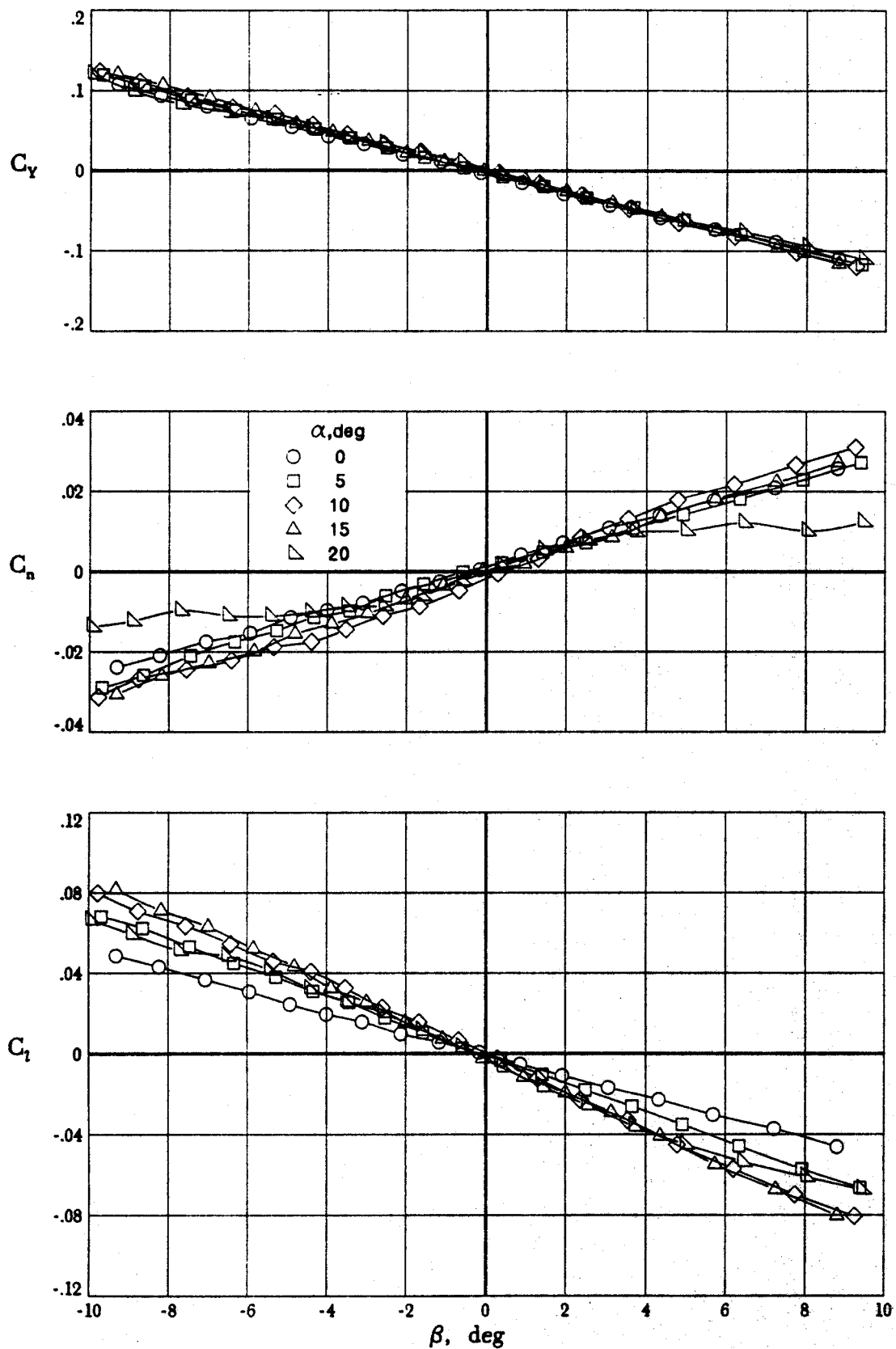
(a) $M = 0.6$.

Figure 16. Variation of transonic lateral aerodynamic characteristics with sideslip.
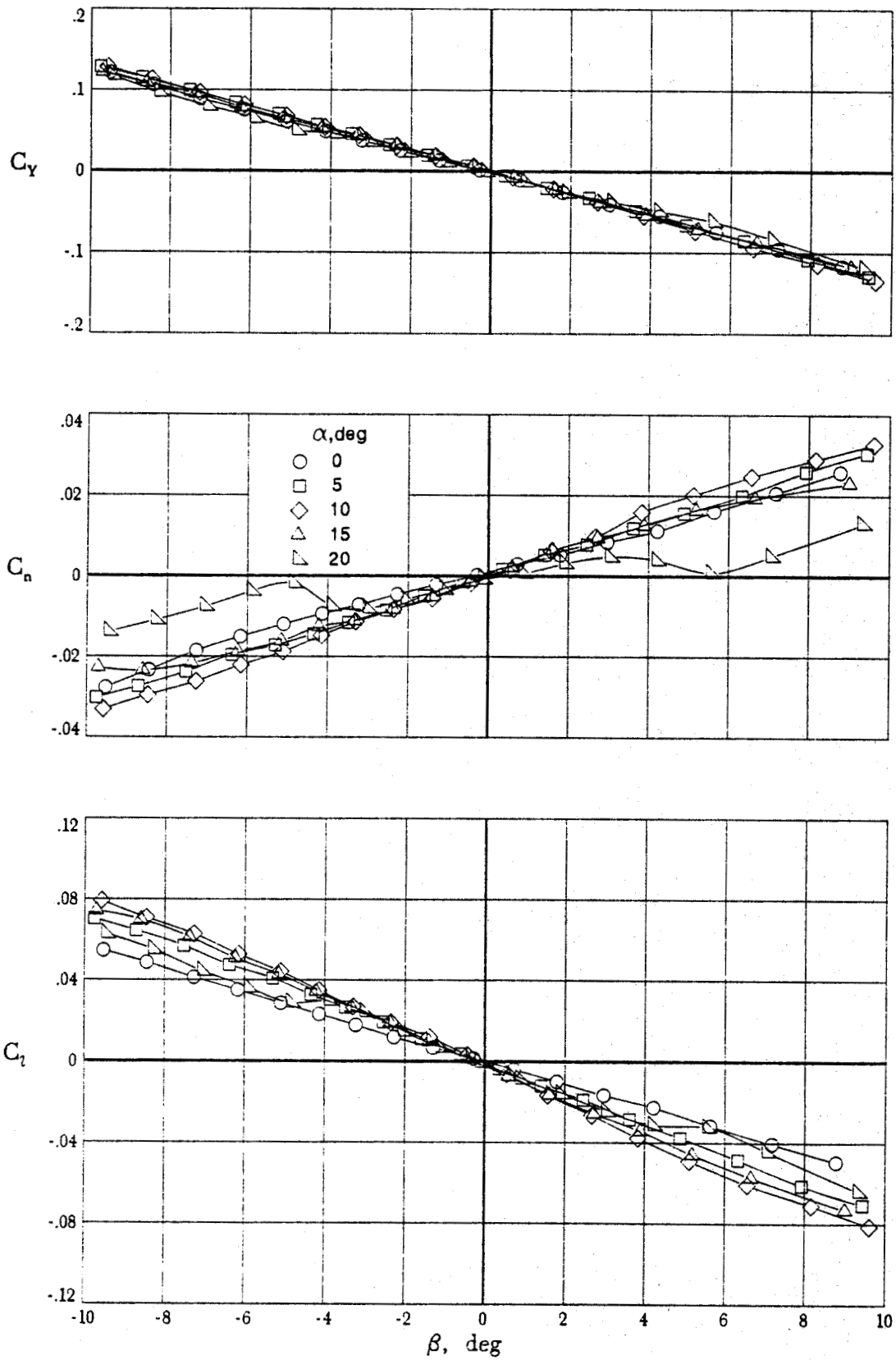
(b) $M = 0.8$.

Figure 16. Continued.
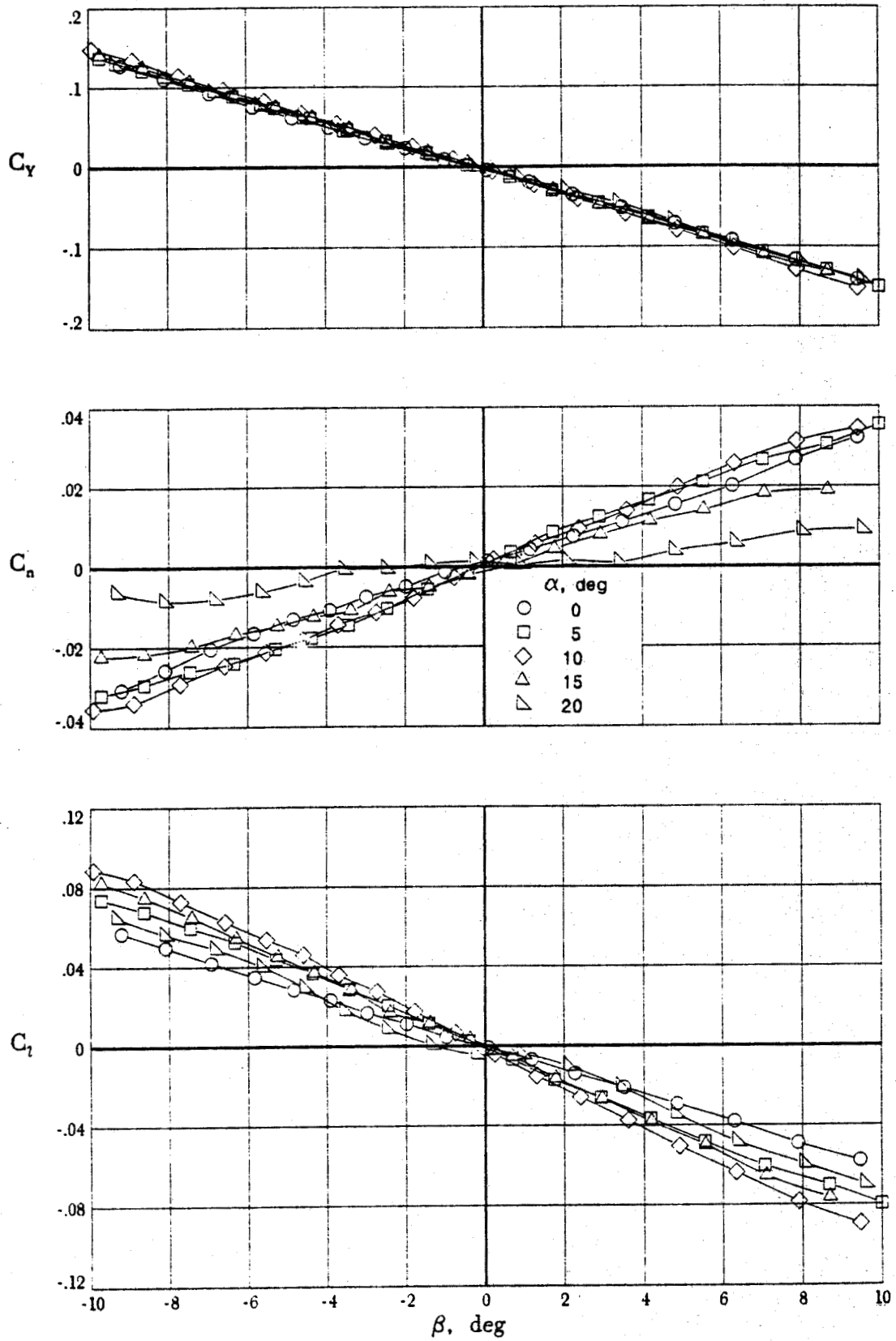
(c) $M = 0.9$.

Figure 16. Continued.
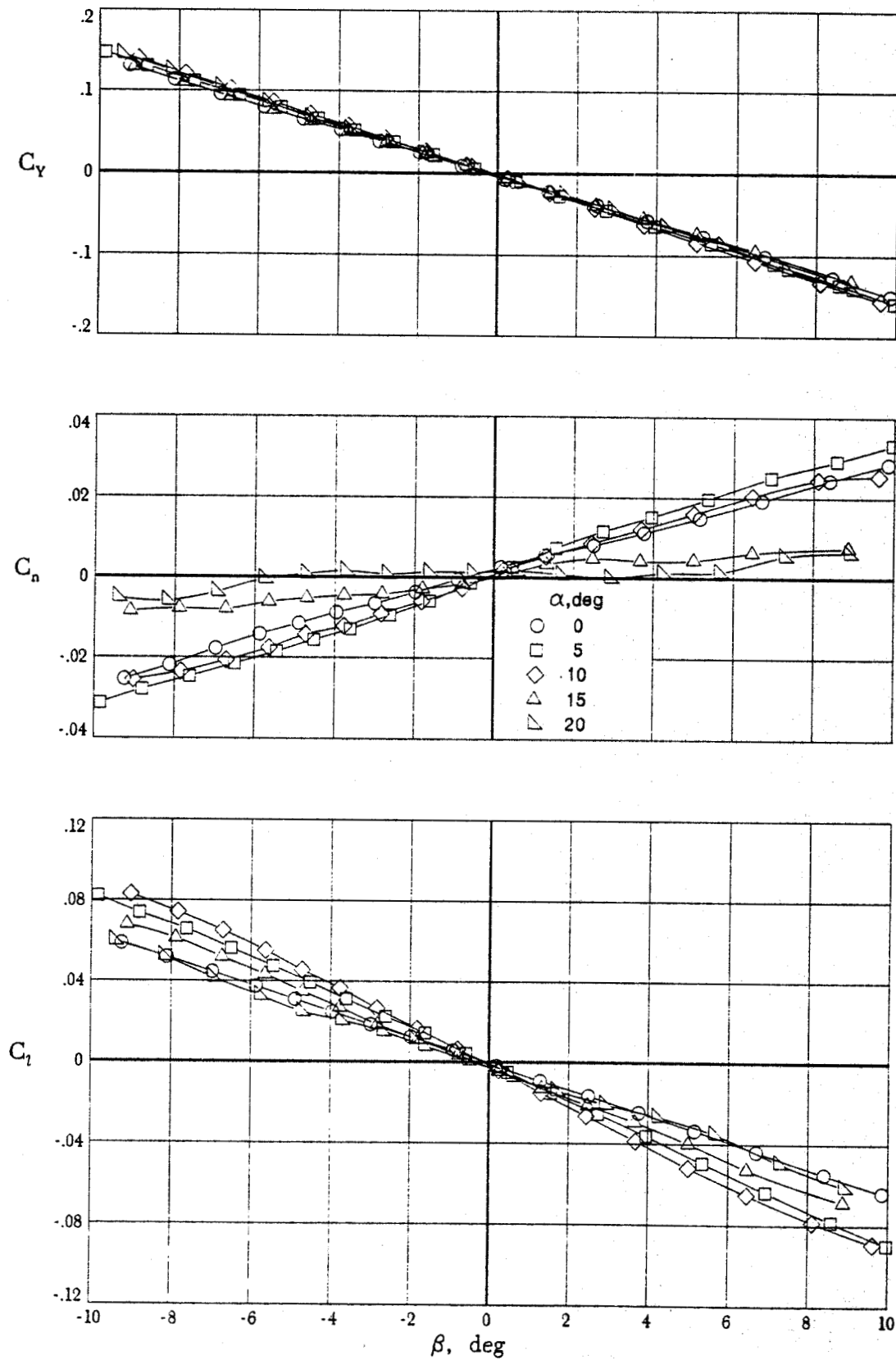
(d) $M = 0.95$.

Figure 16. Continued.
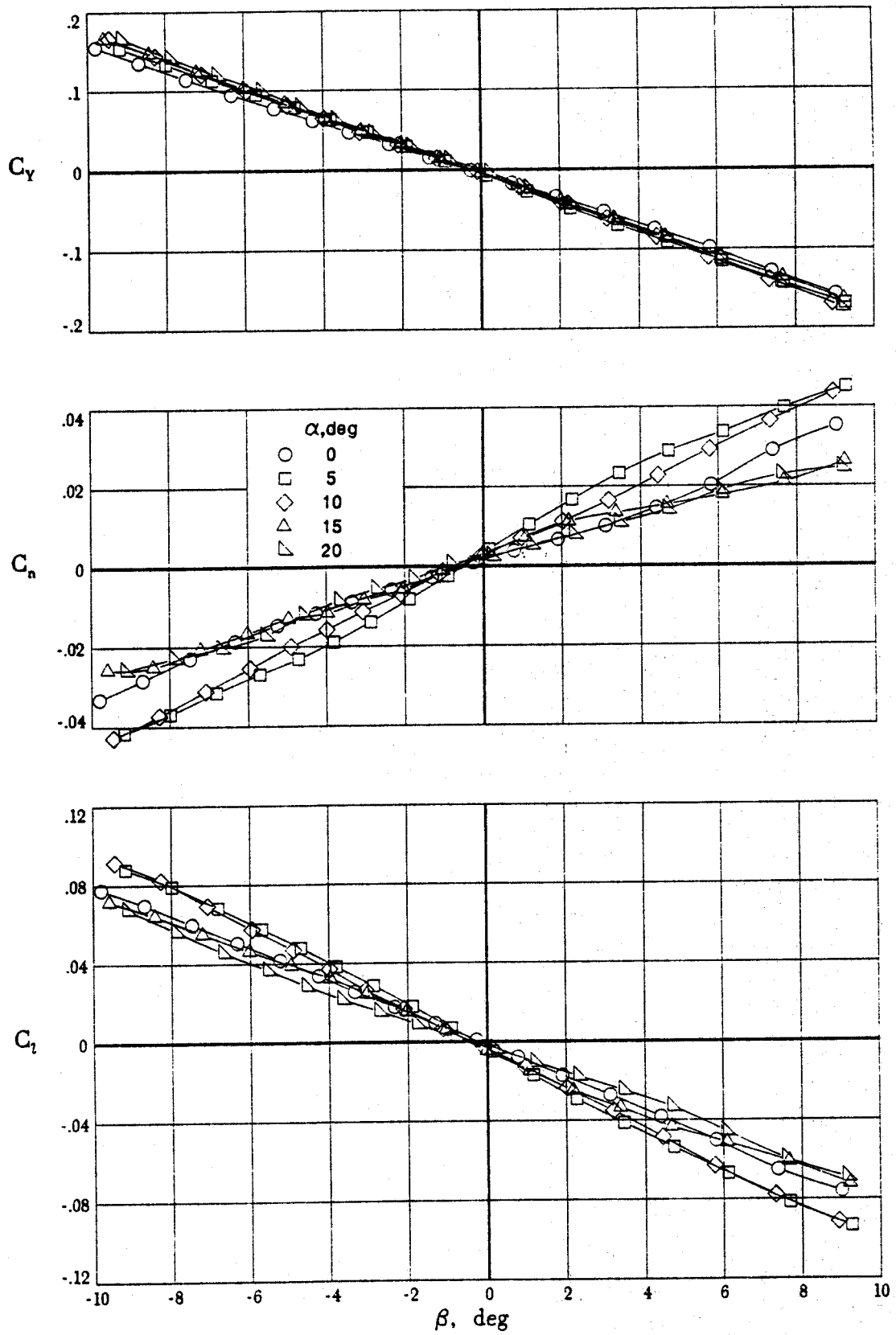
(e) $M = 1.1$.

Figure 16. Continued.
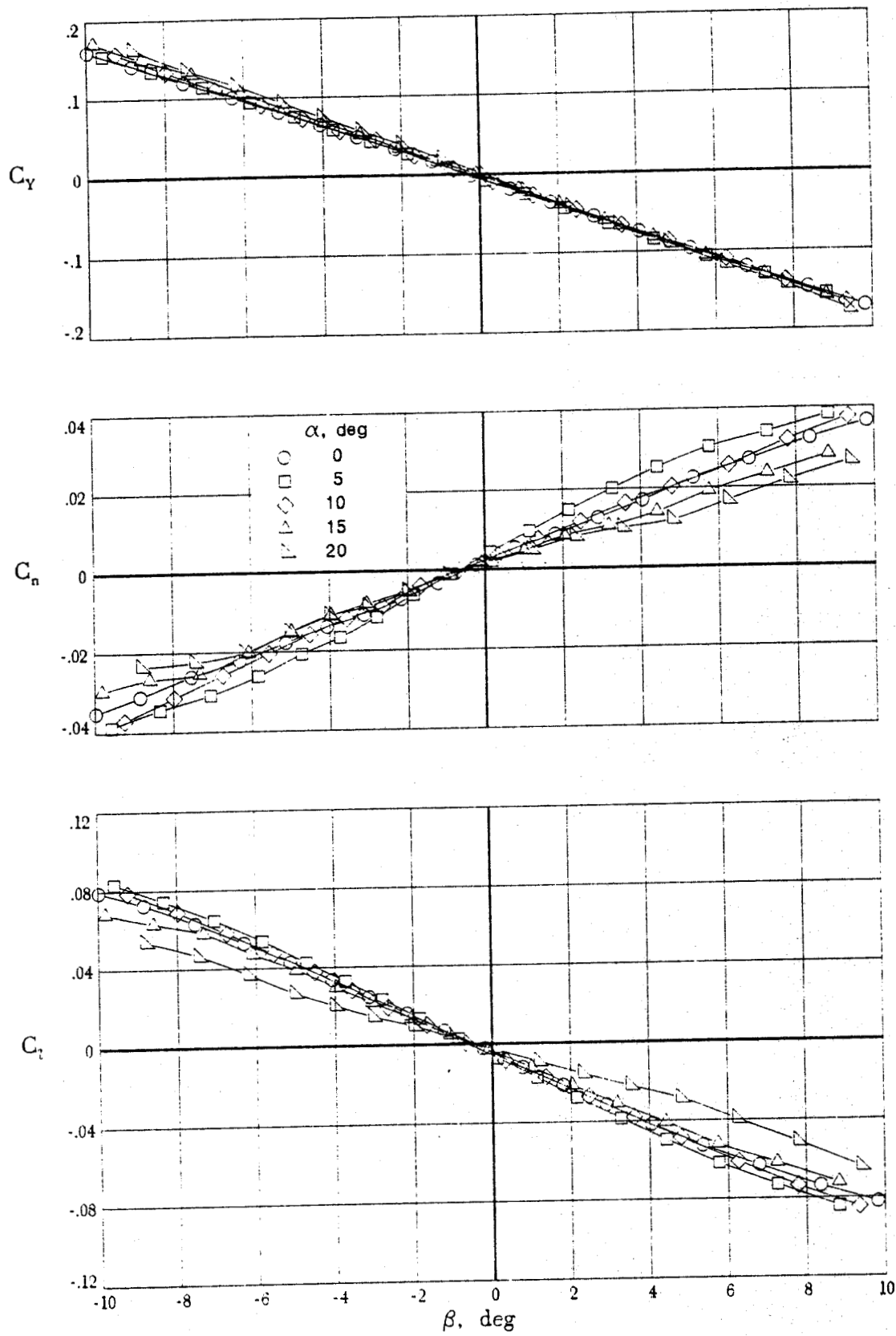
(f) $M = 1.2$.

Figure 16. Concluded.
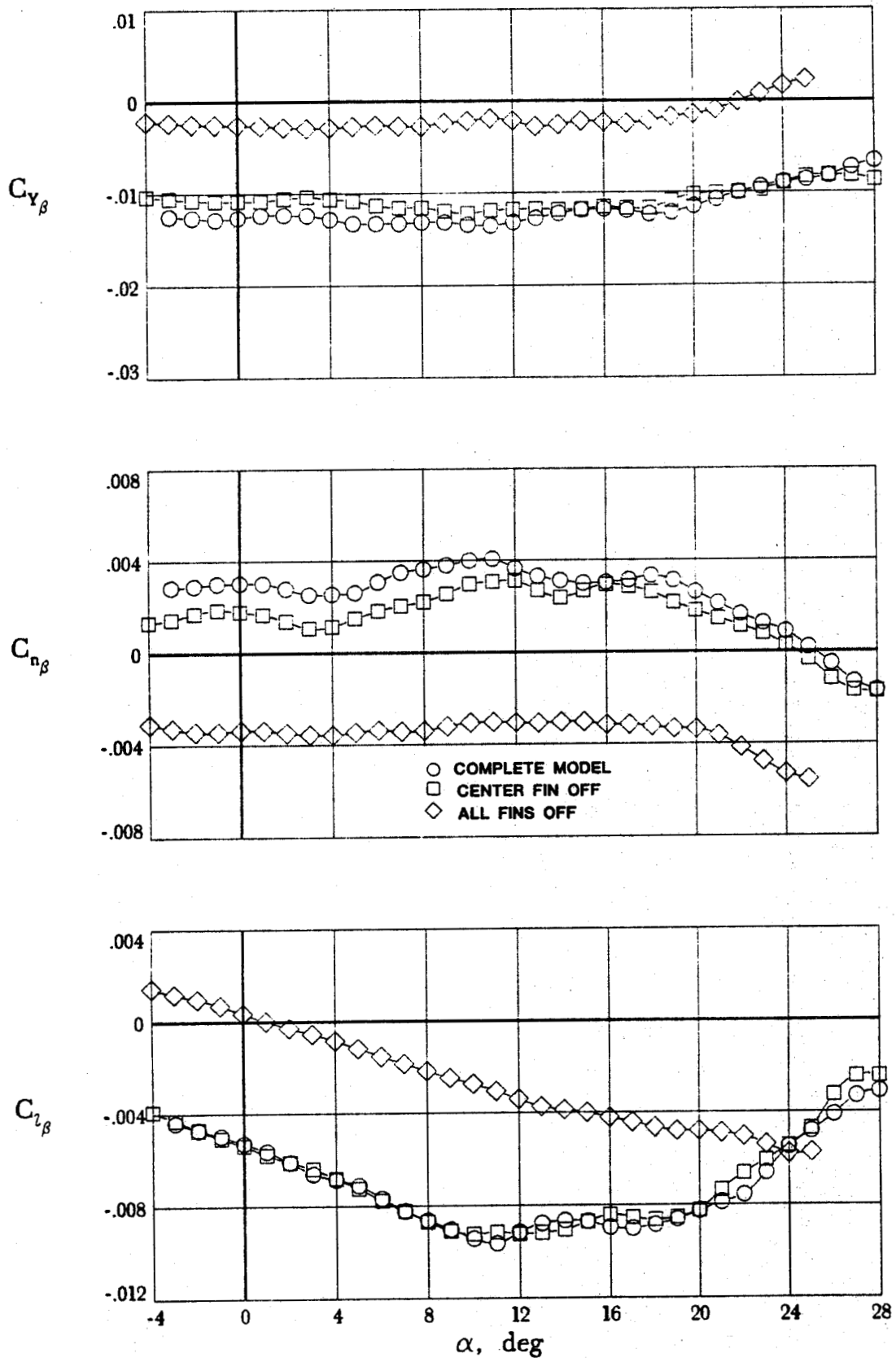
(a) $M = 0.6$.

Figure 17. Effect of fins on transonic lateral-directional stability
characteristics.
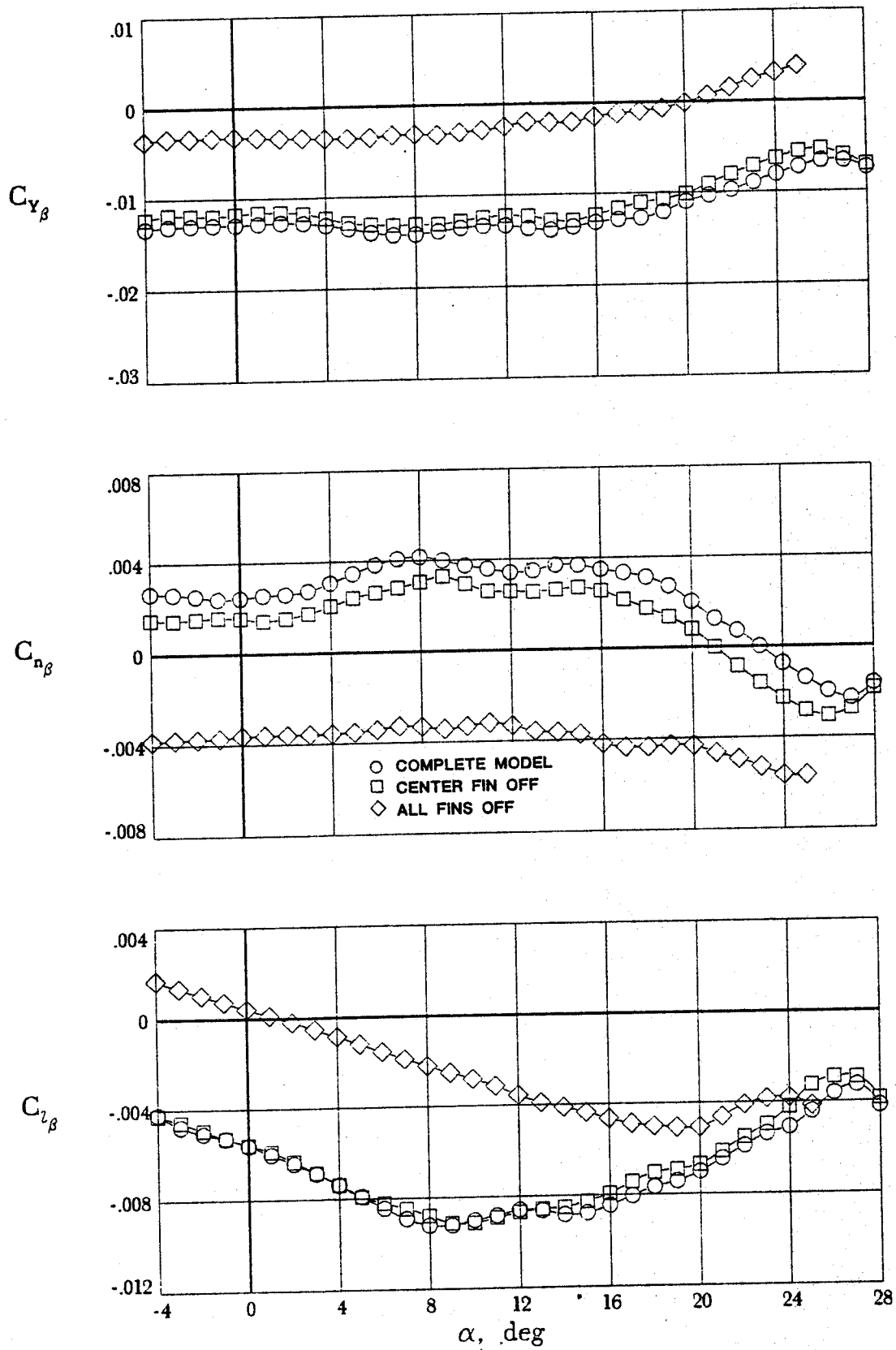
(b) $M = 0.8$.

Figure 17. Continued.
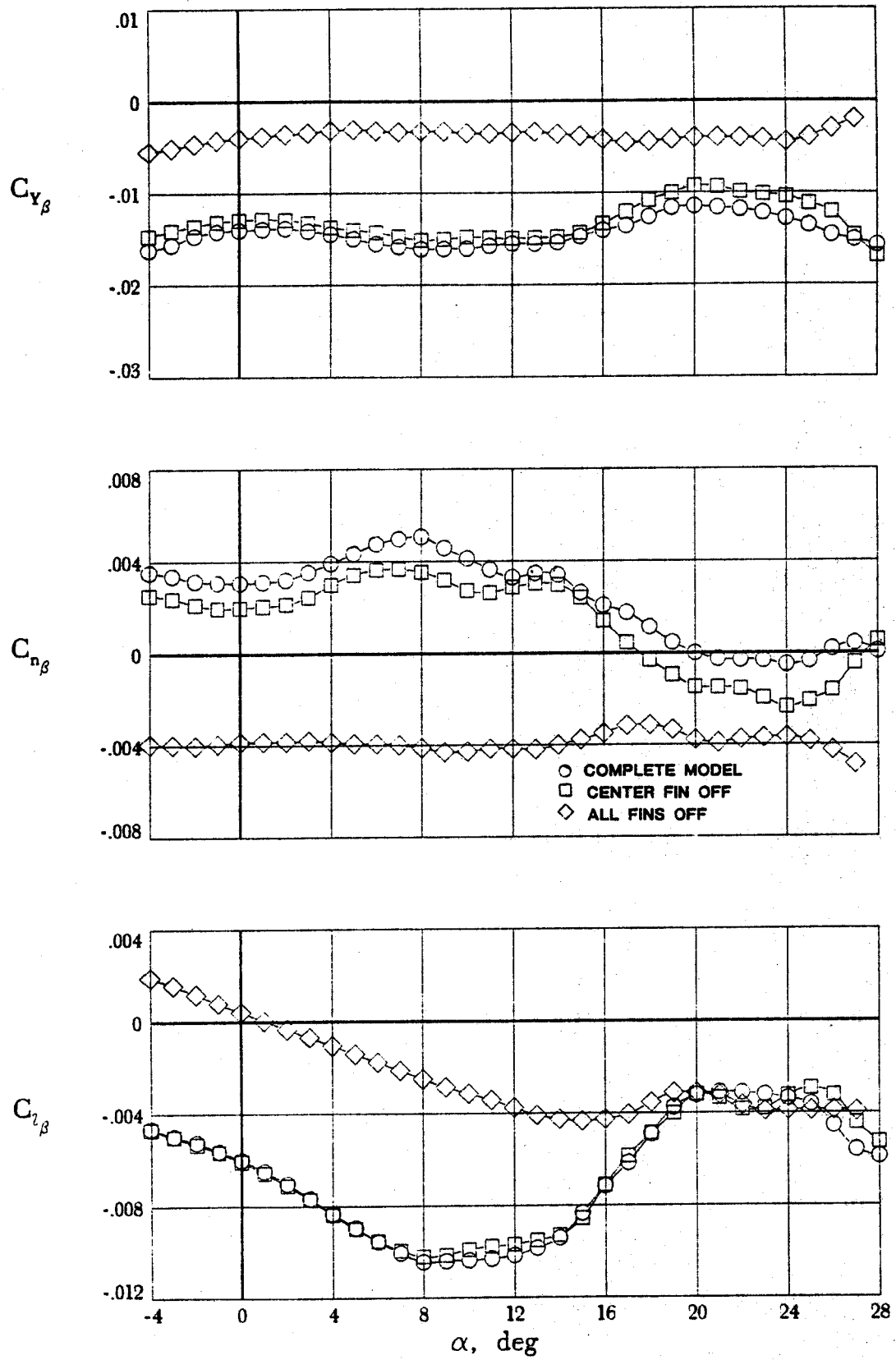
(c) $M = 0.9$.

Figure 17. Continued.
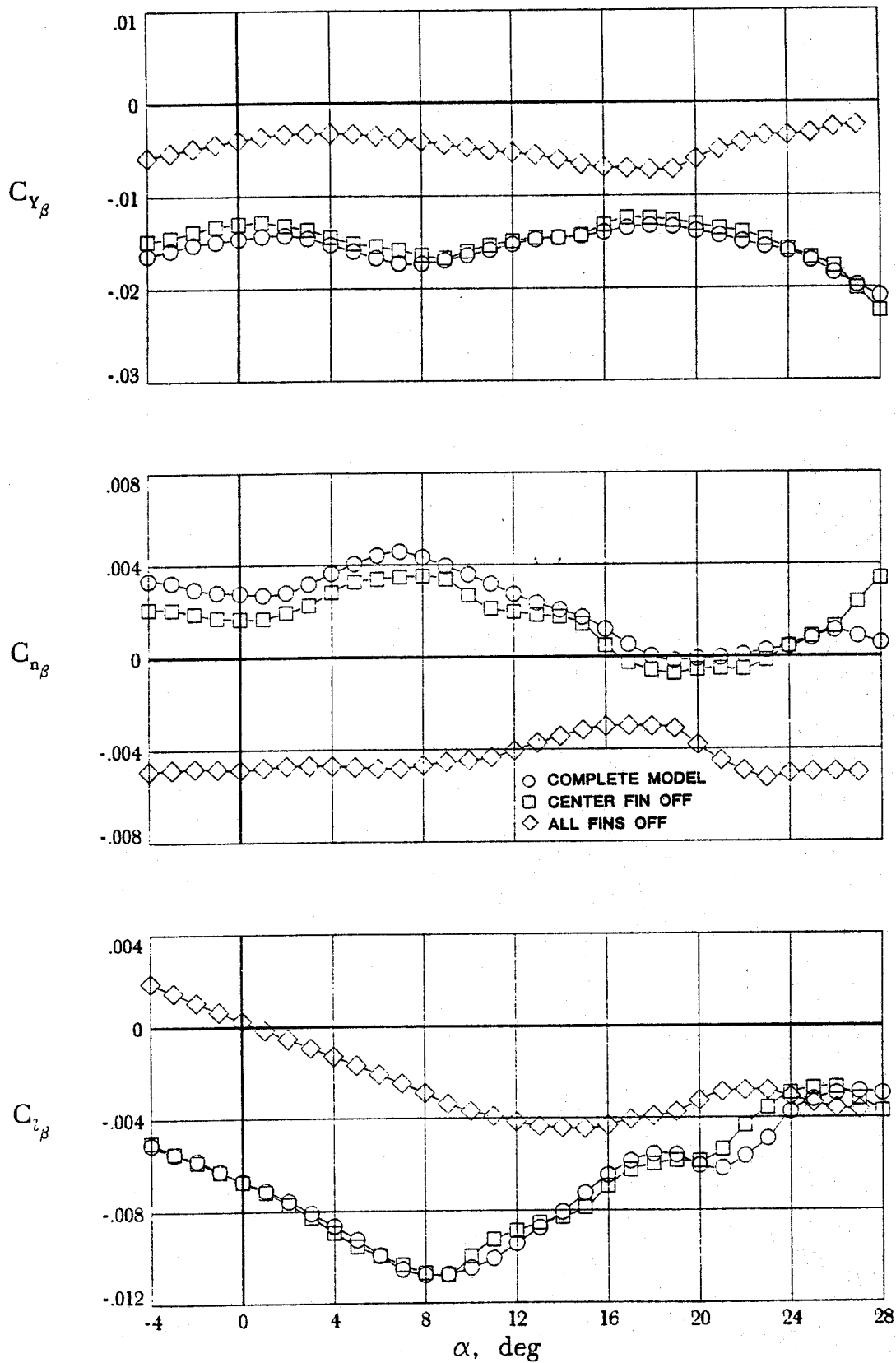
(d) $M = 0.95$.

Figure 17. Continued.
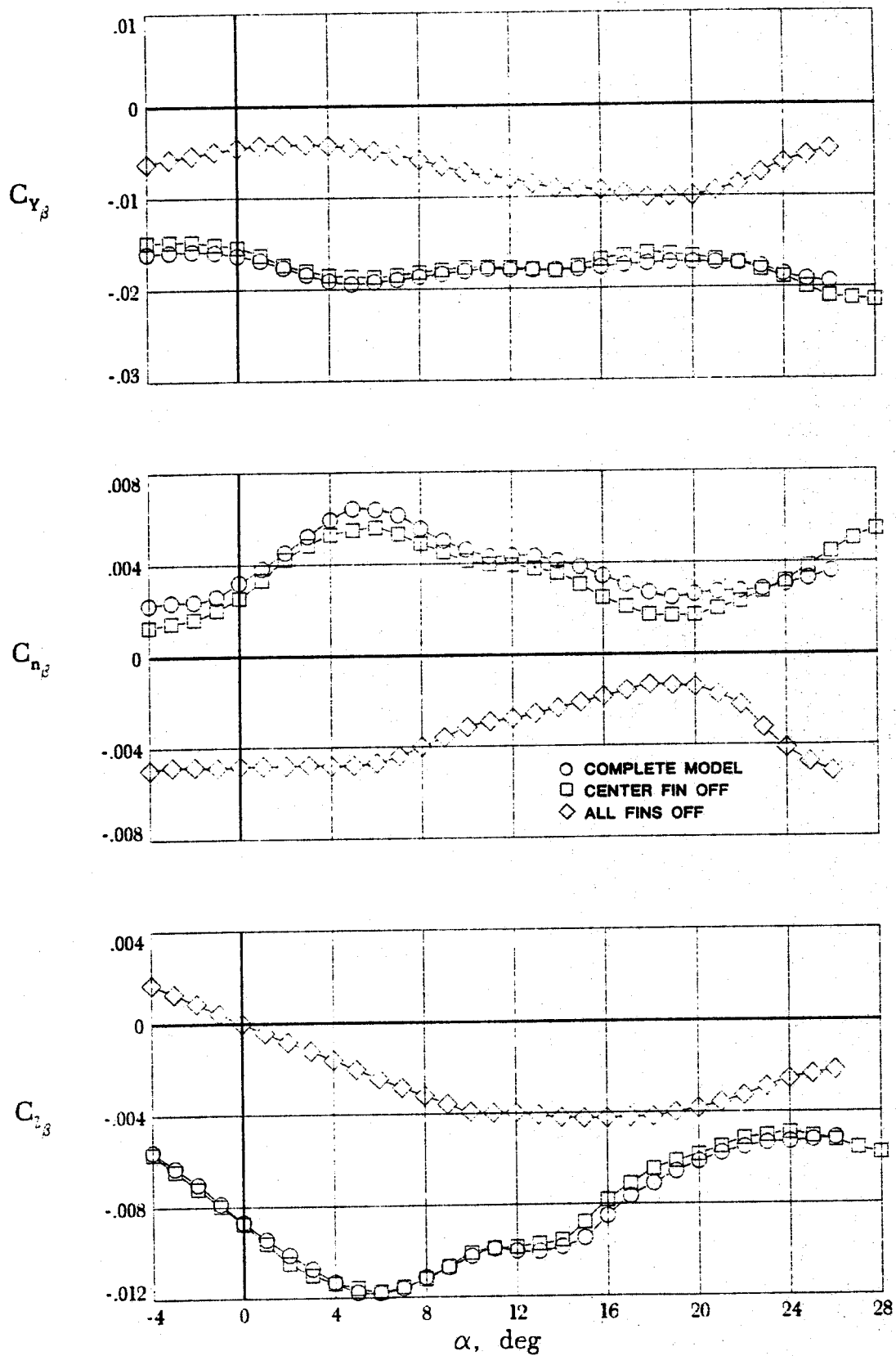
(e) $M = 1.1$.

**Figure 17.** Continued.
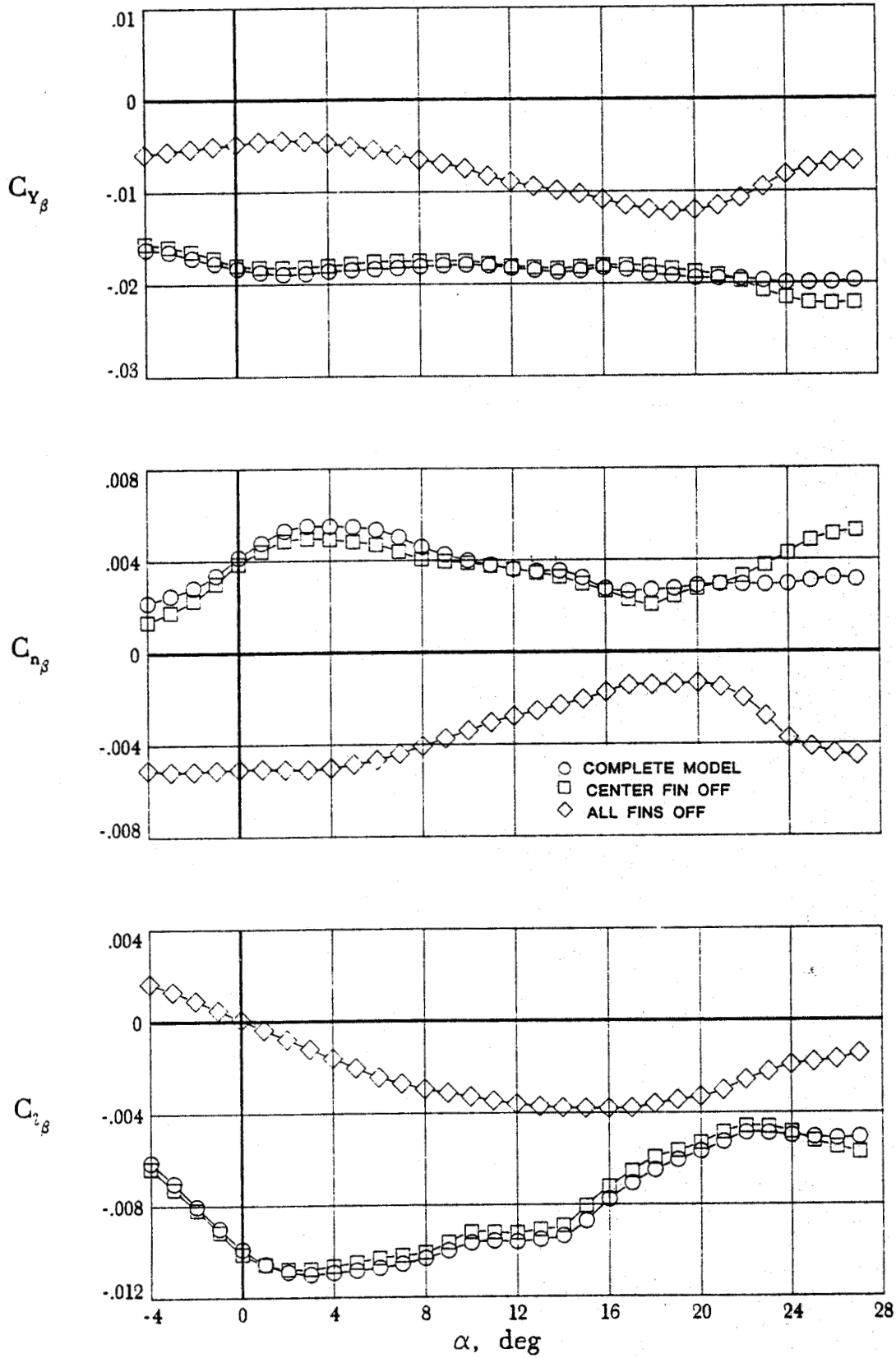
(f) $M = 1.2$.

Figure 17. Concluded.
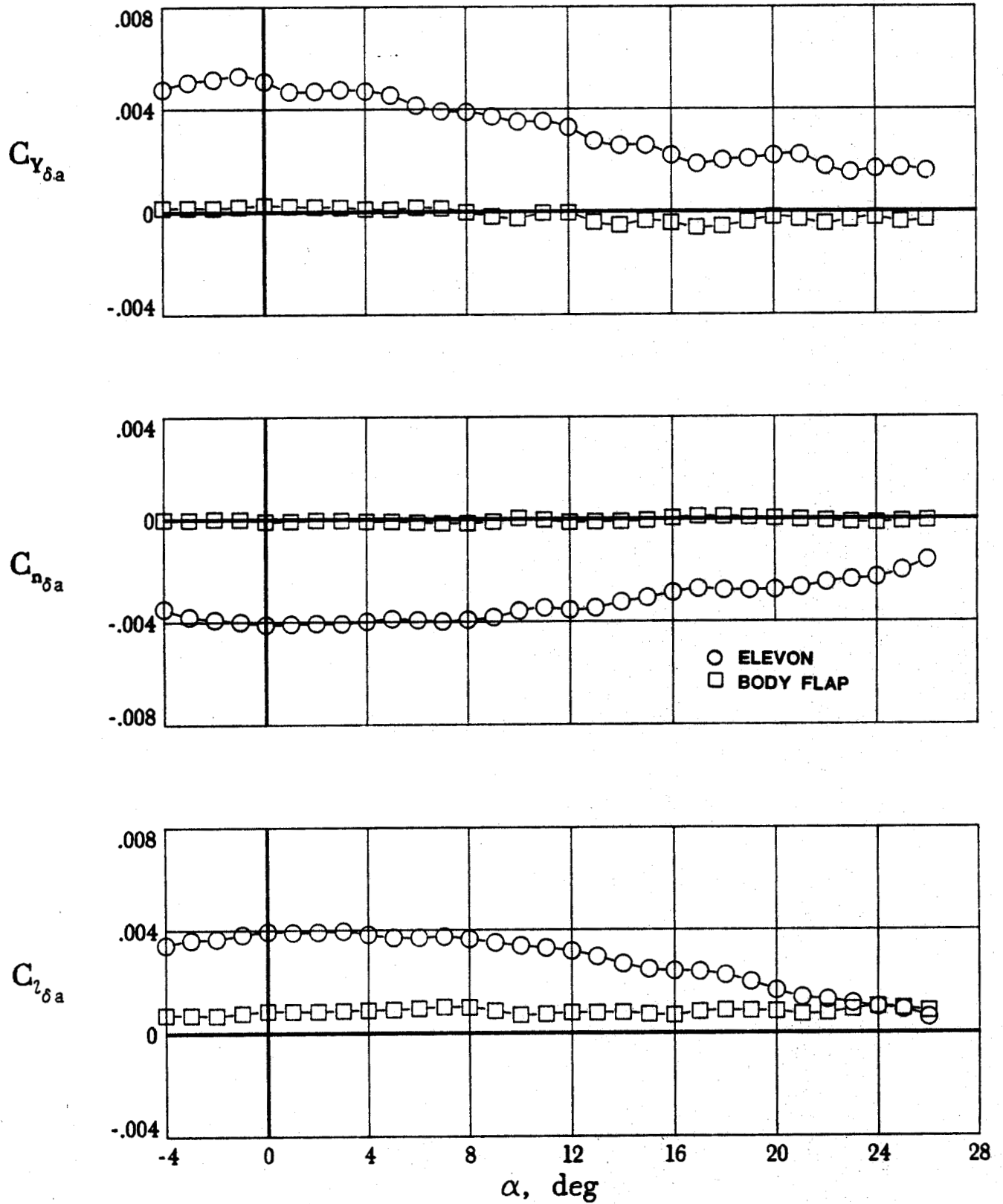
(a) $M = 0.6$.

Figure 18. Transonic roll control effectiveness.
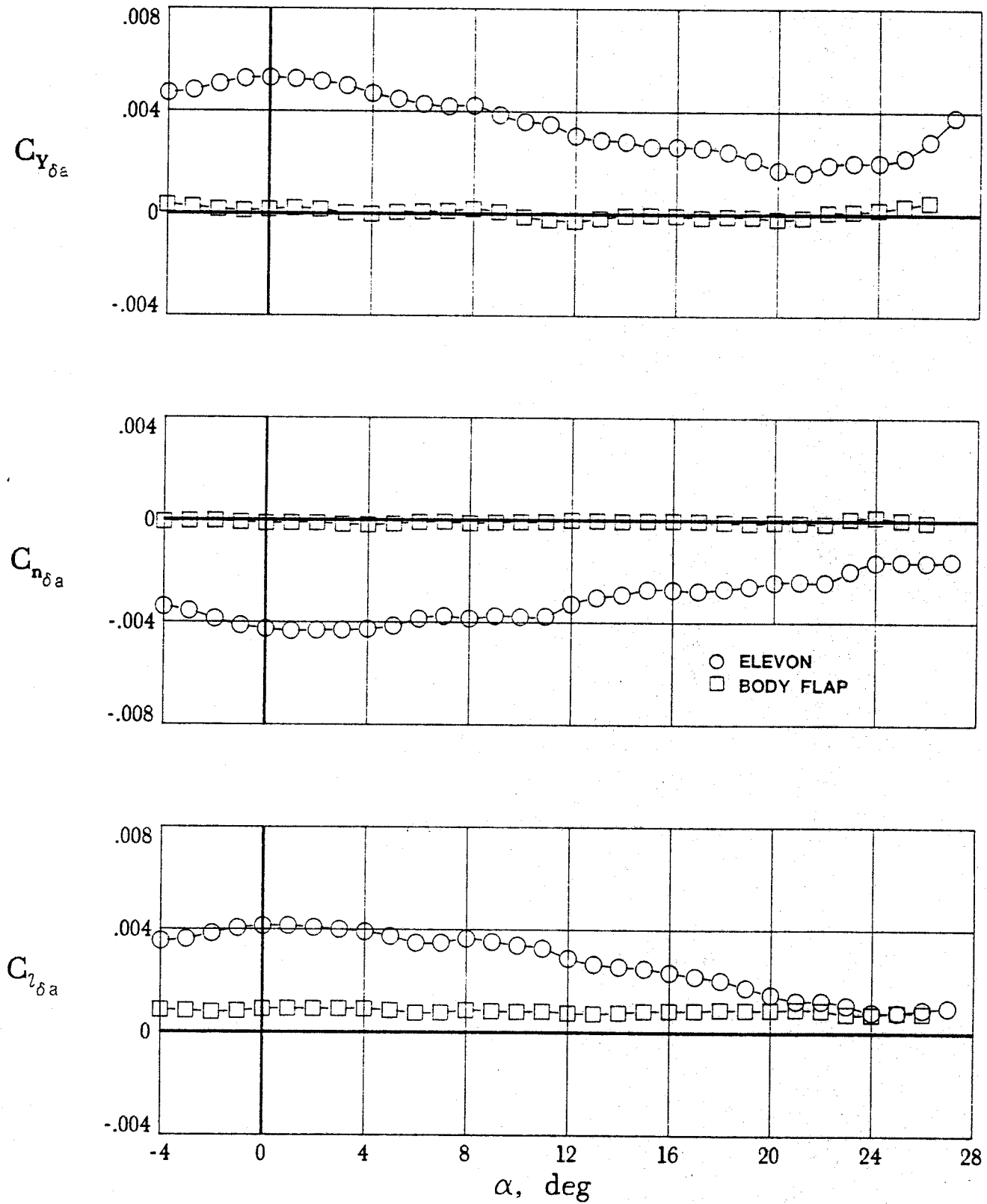
(b) $M = 0.8$.

Figure 18. Continued.
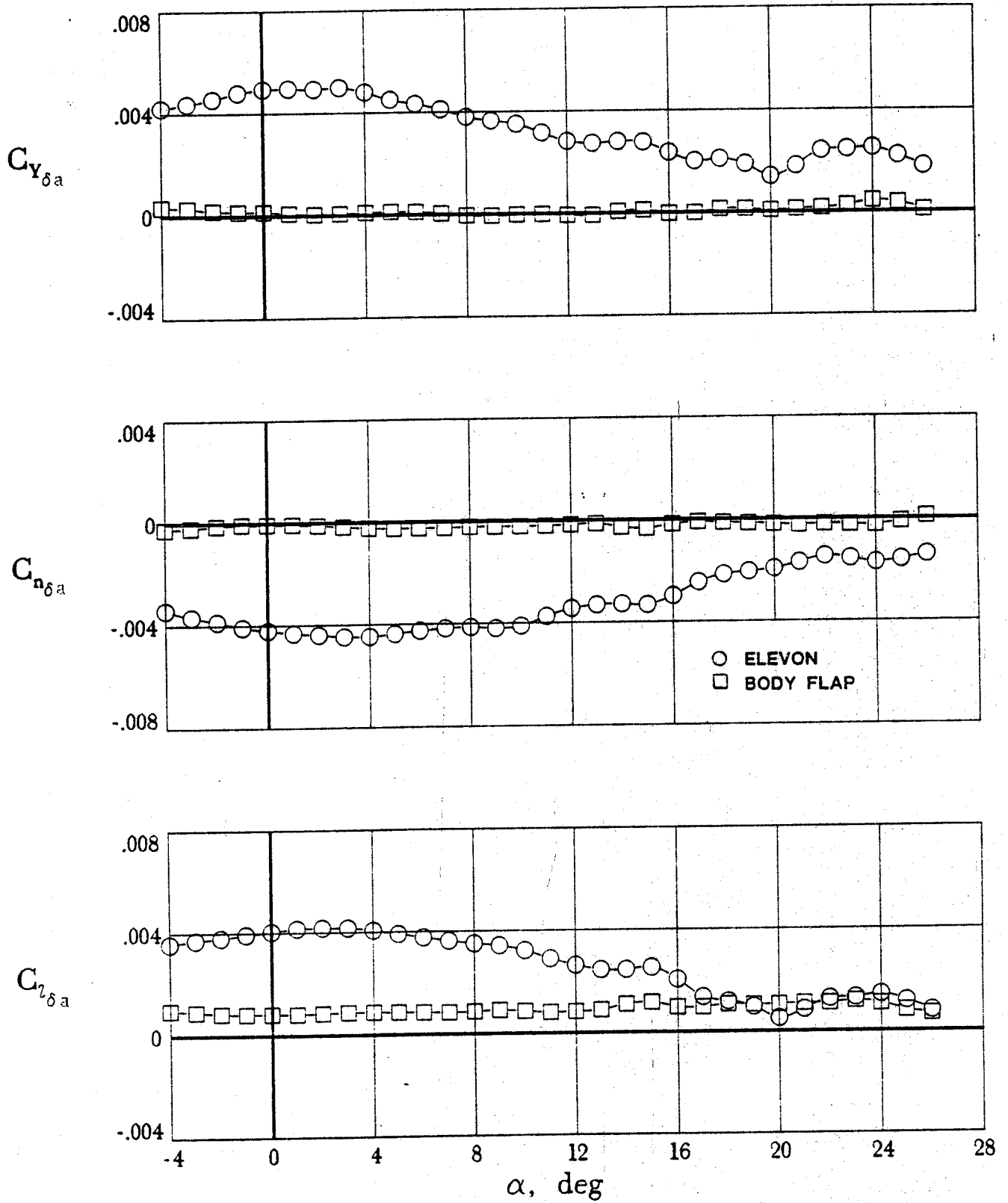
(c) $M = 0.9$.

Figure 18. Continued.
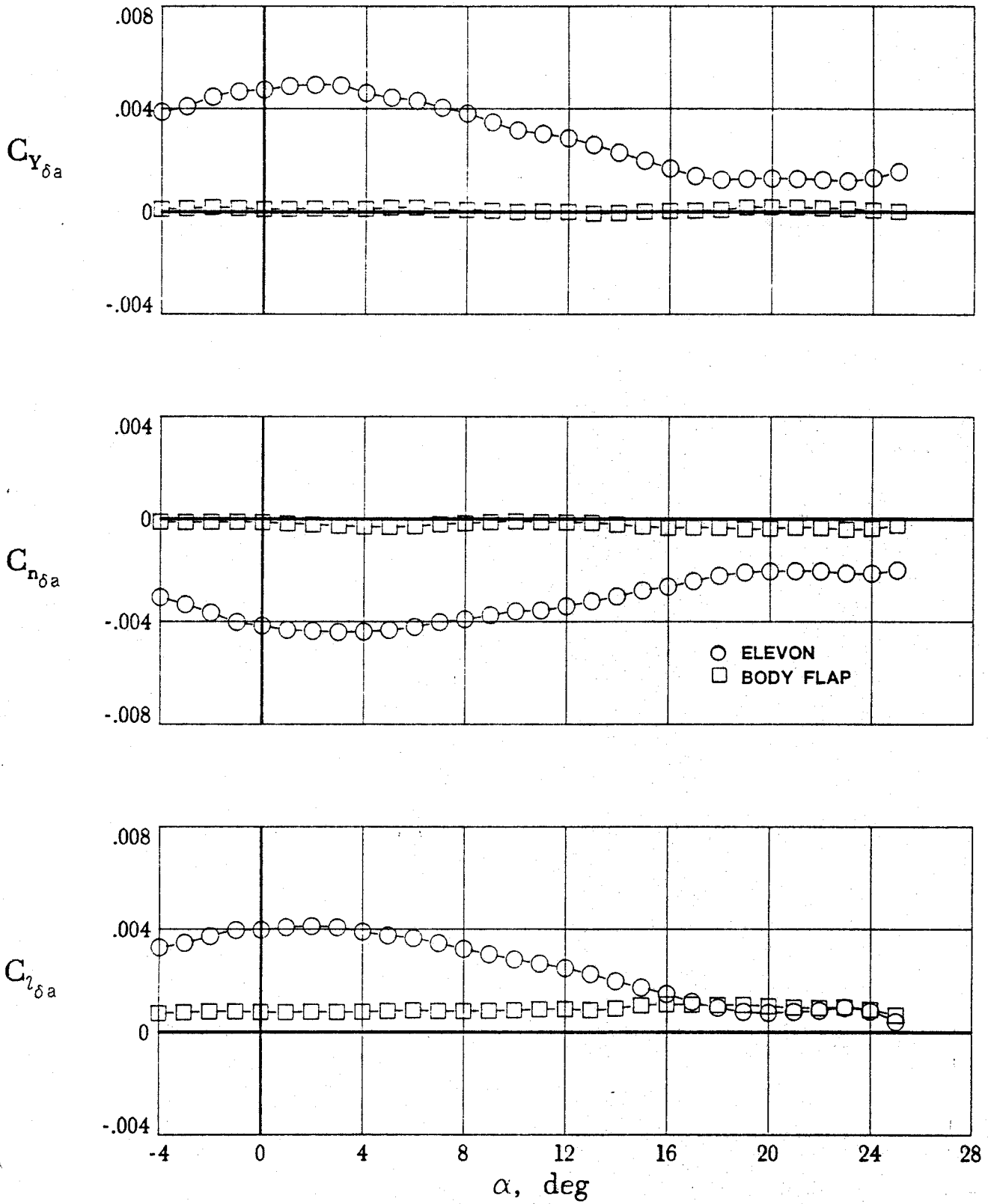
(d) $M = 0.95$.

Figure 18. Continued.
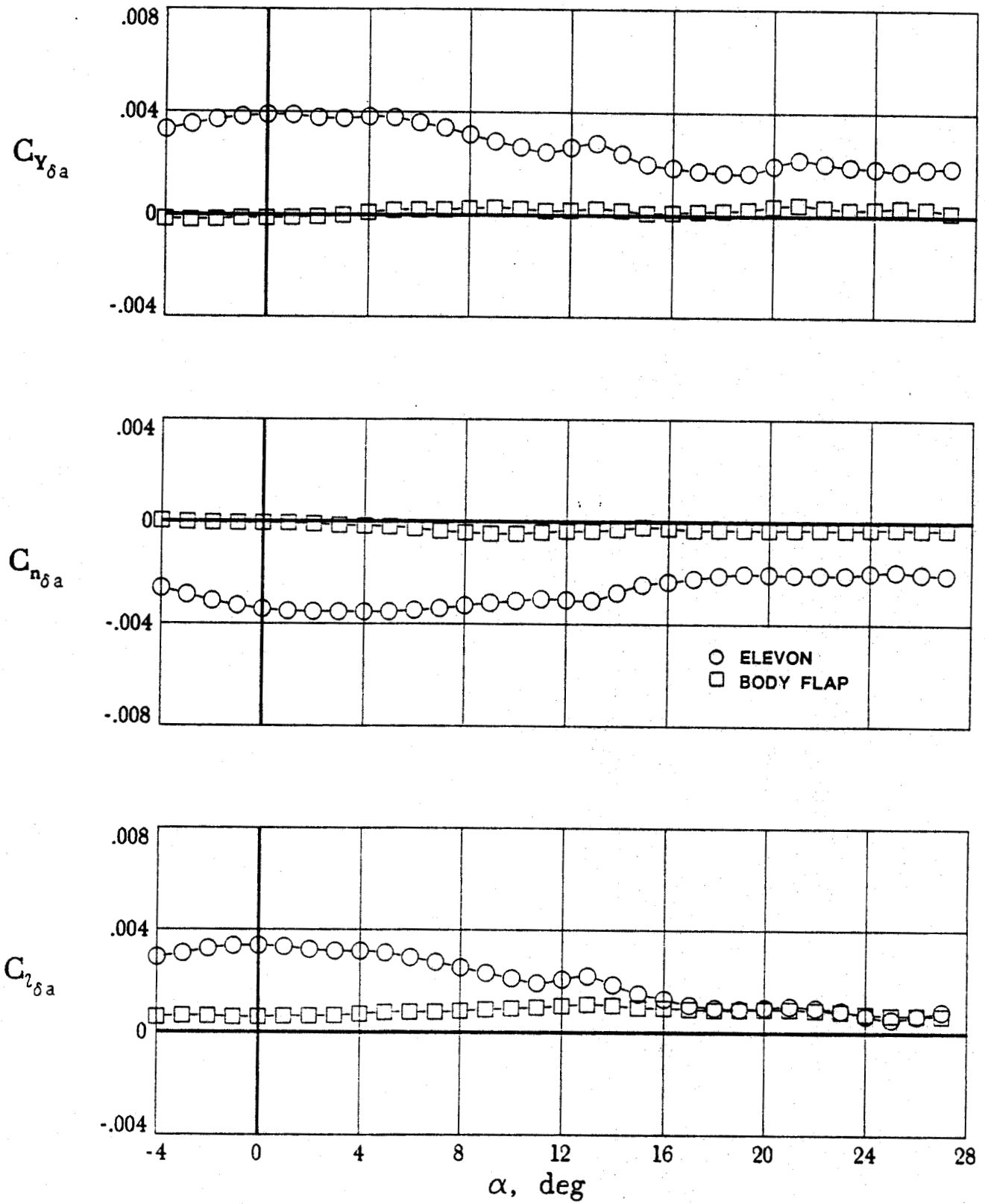
(e) $M = 1.1$.

Figure 18. Continued.
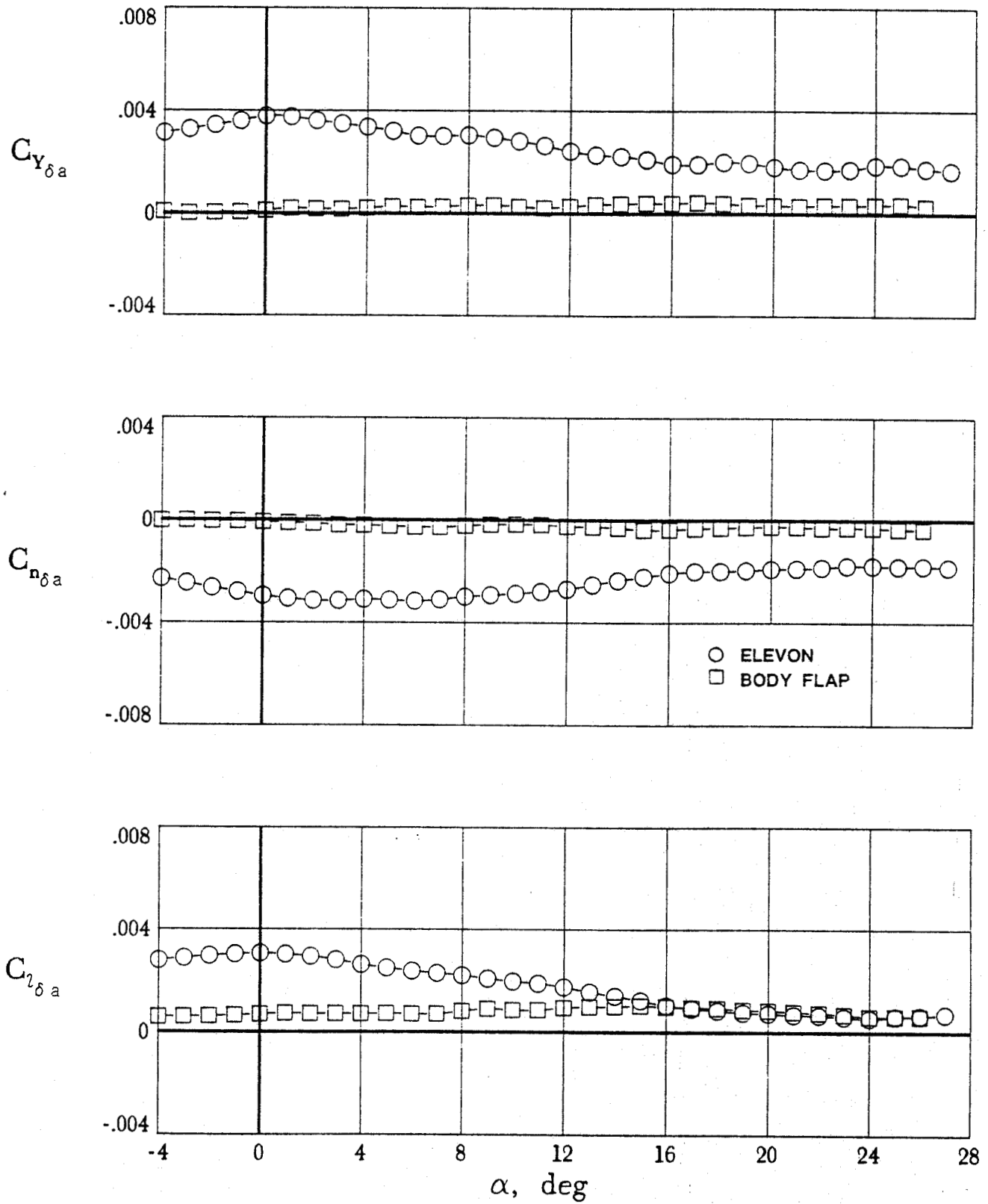
(f) $M = 1.2$.

Figure 18. Concluded.
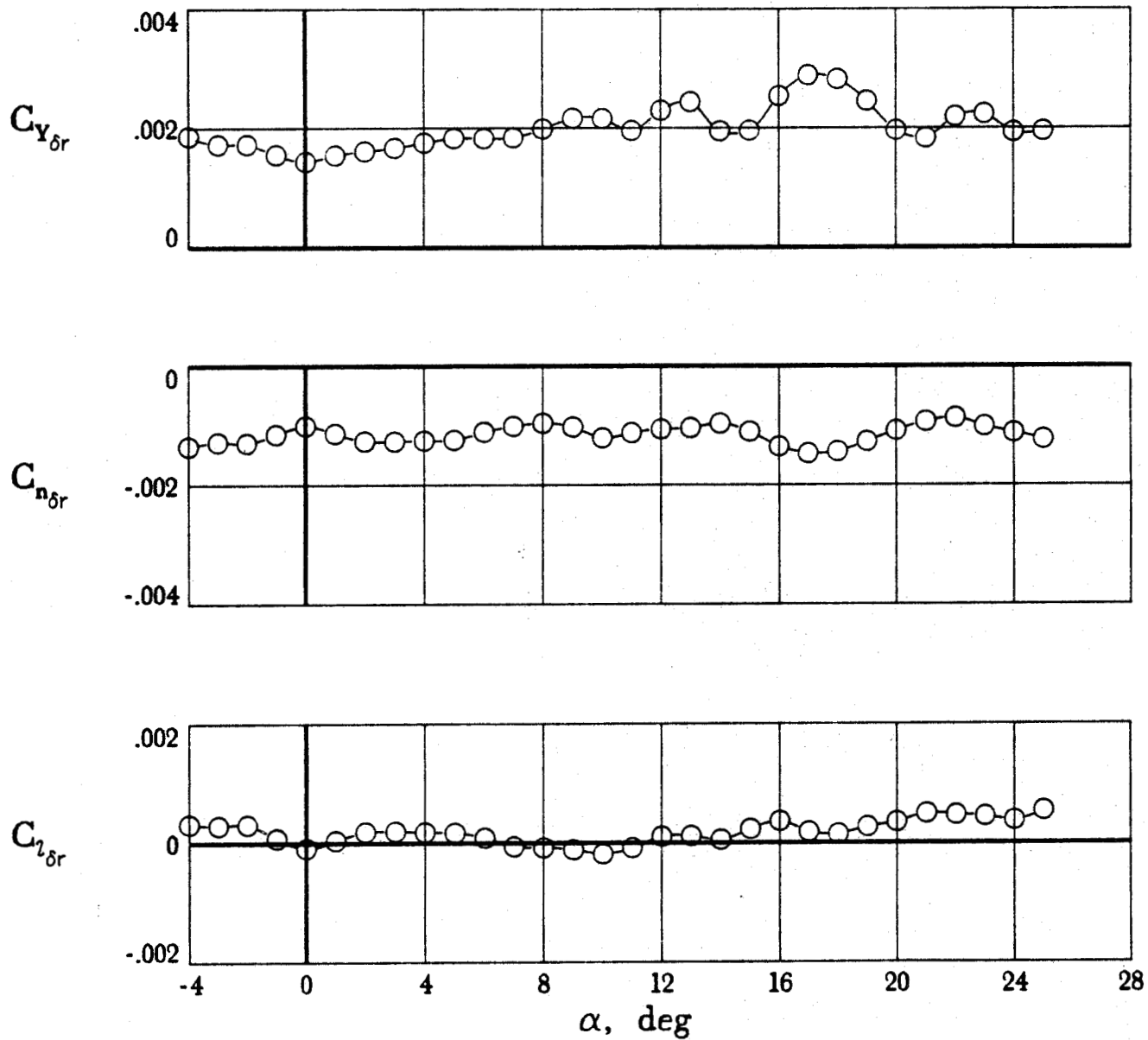
(a) $M = 0.6$.

Figure 19. Transonic yaw control effectiveness.
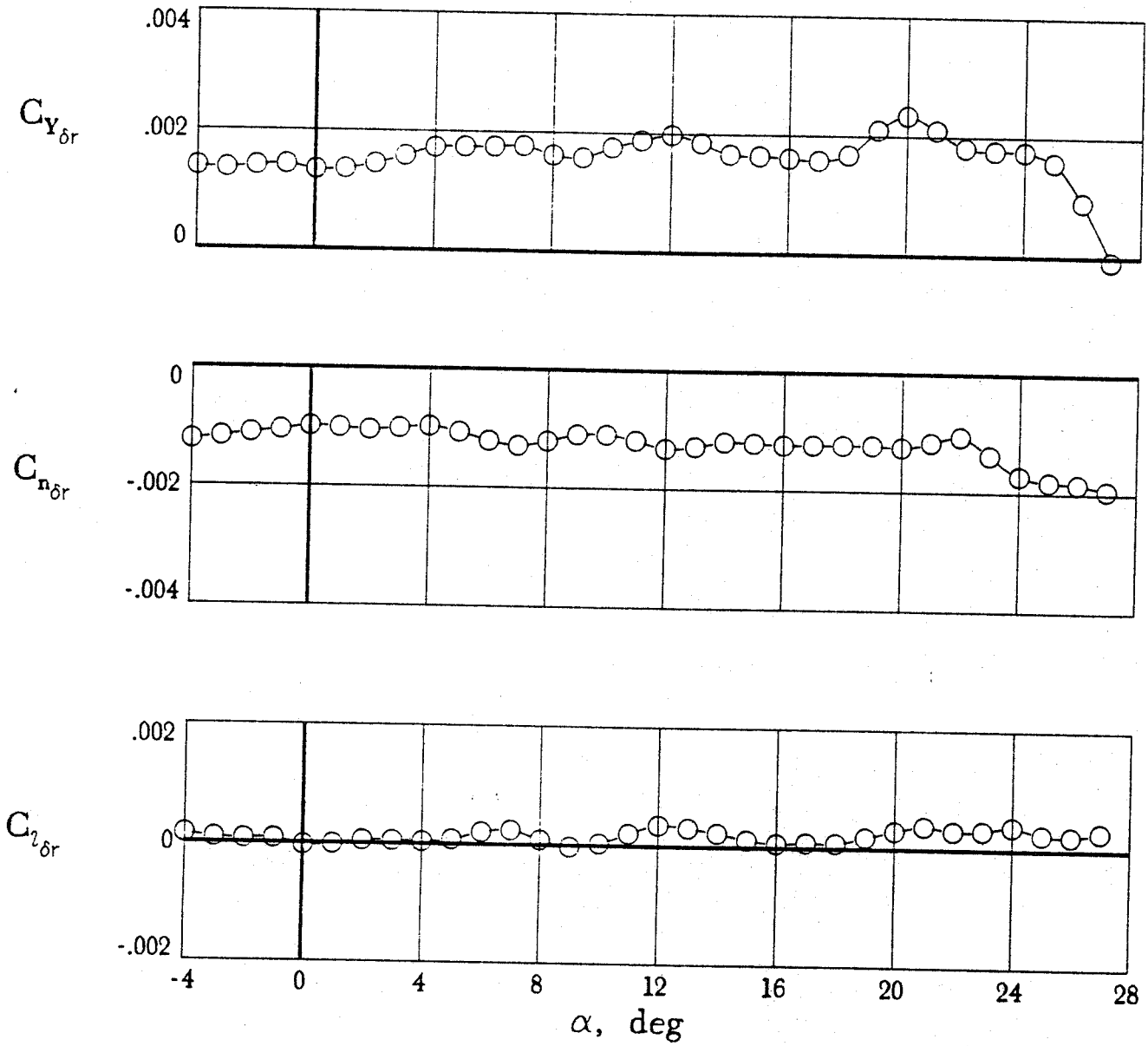
(b) $M = 0.8$.

Figure 19. Continued.
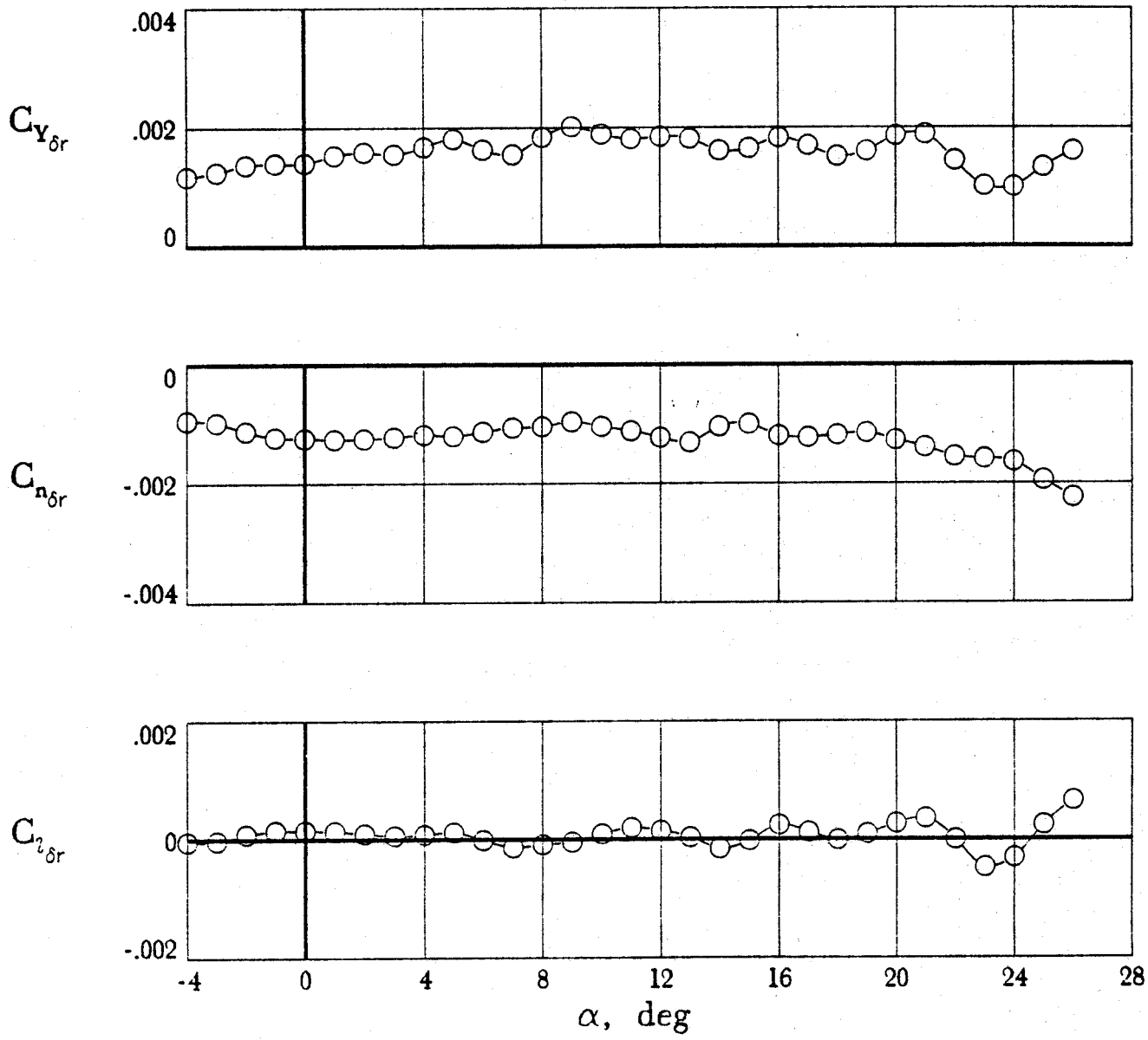
(c) $M = 0.9$.

Figure 19. Continued.
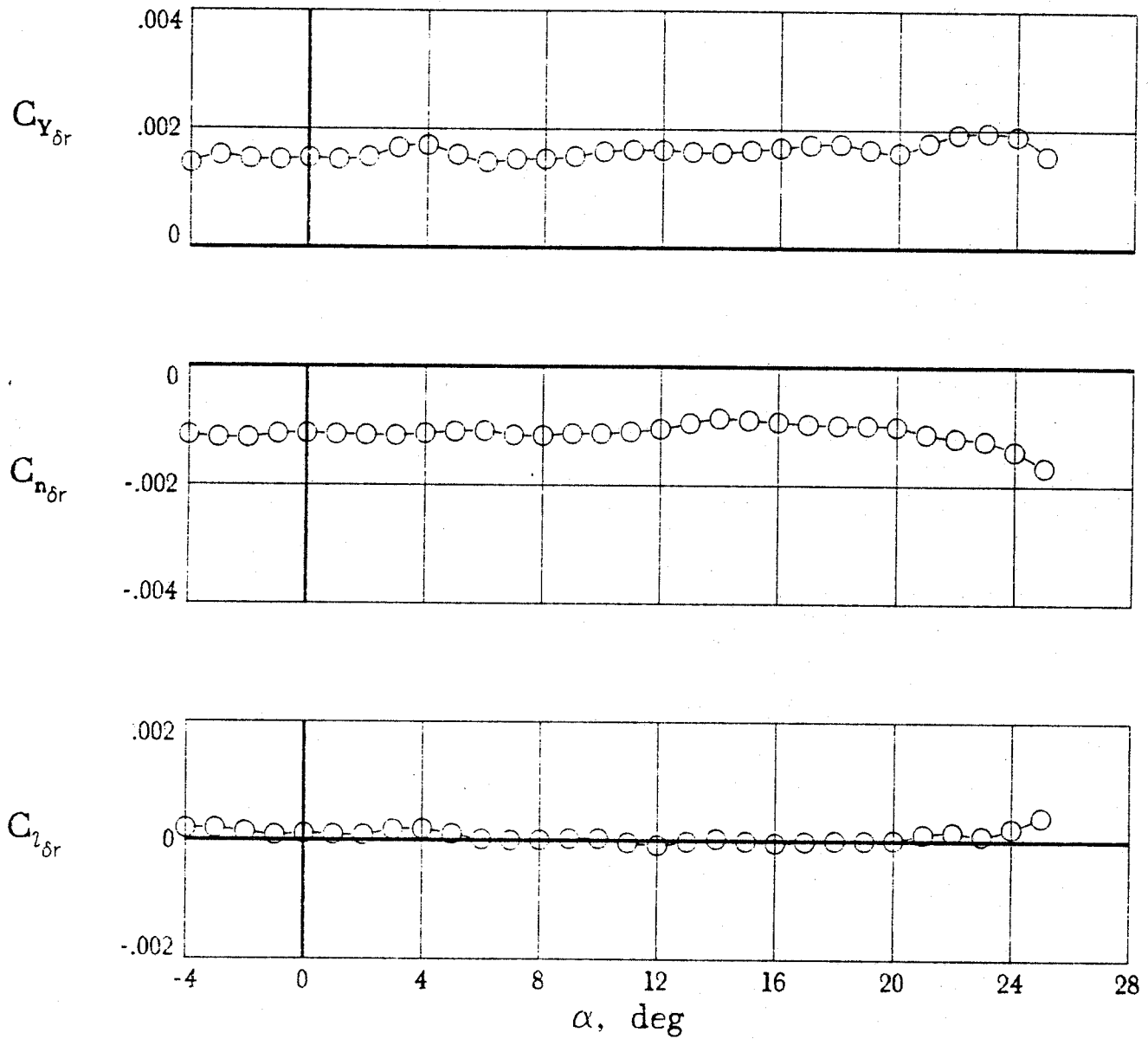
(d) $M = 0.95$.

Figure 19. Continued.
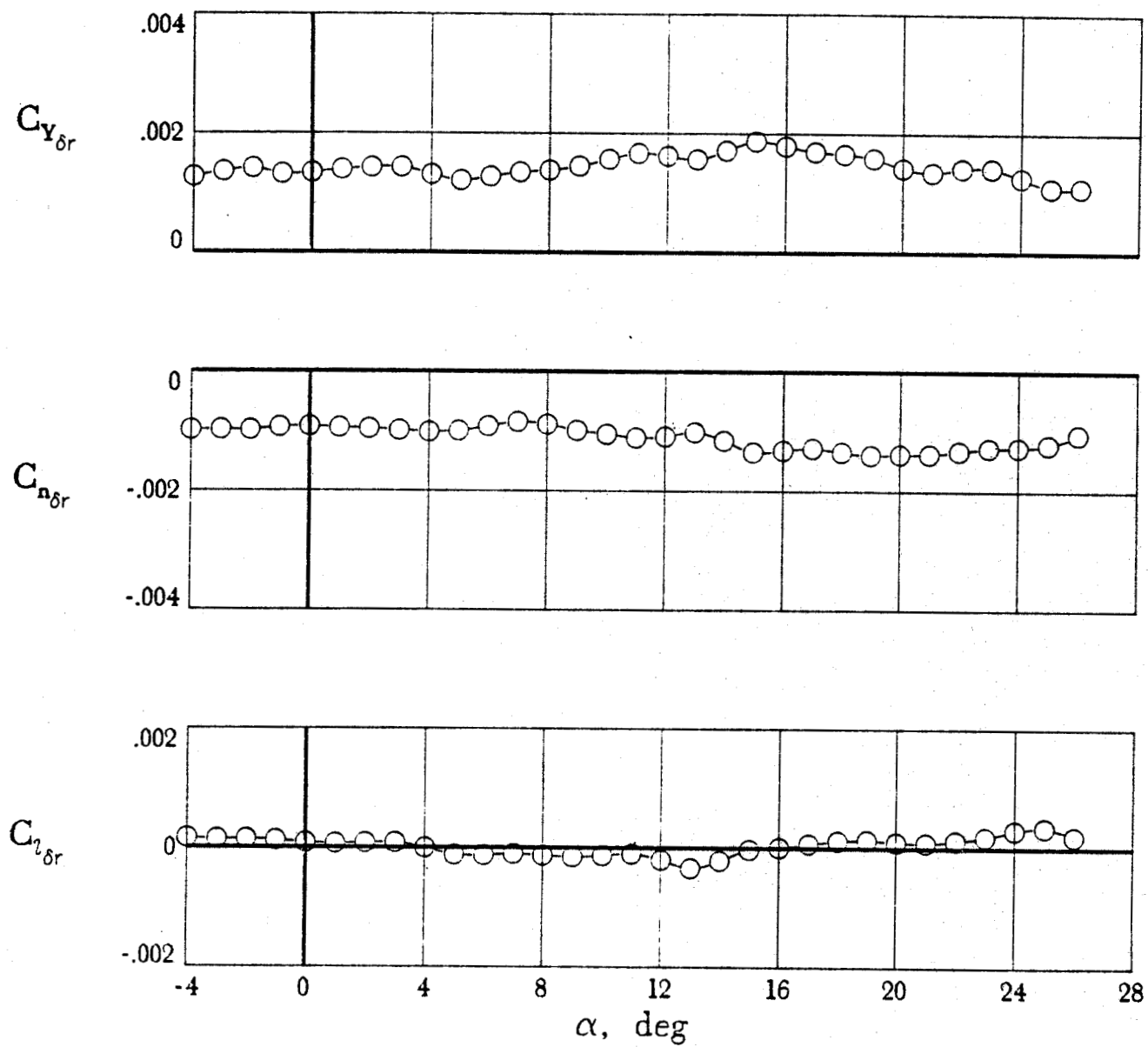
(e) $M = 1.1$.

Figure 19. Continued.
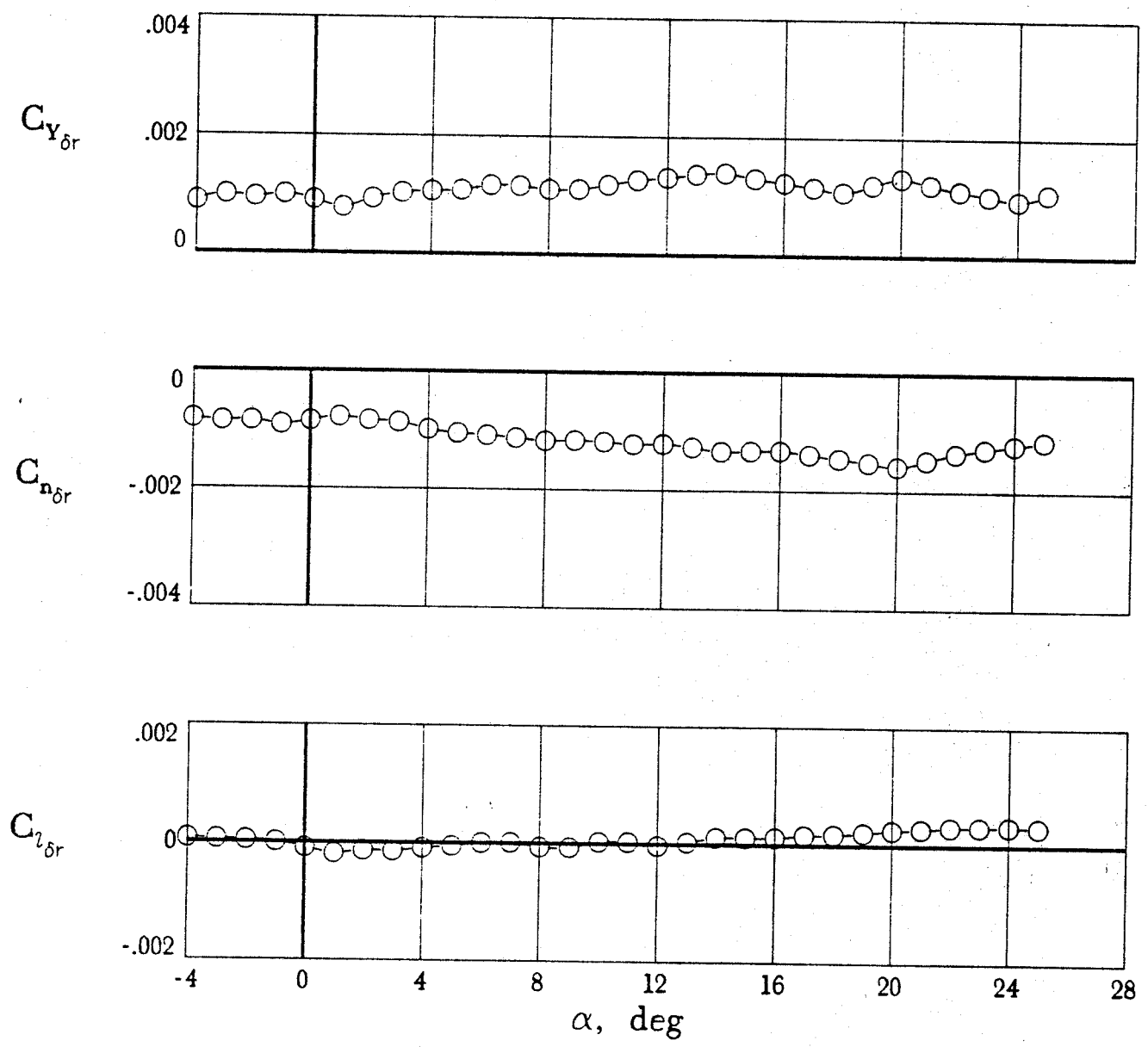
(f) $M = 1.2$.

Figure 19. Concluded.
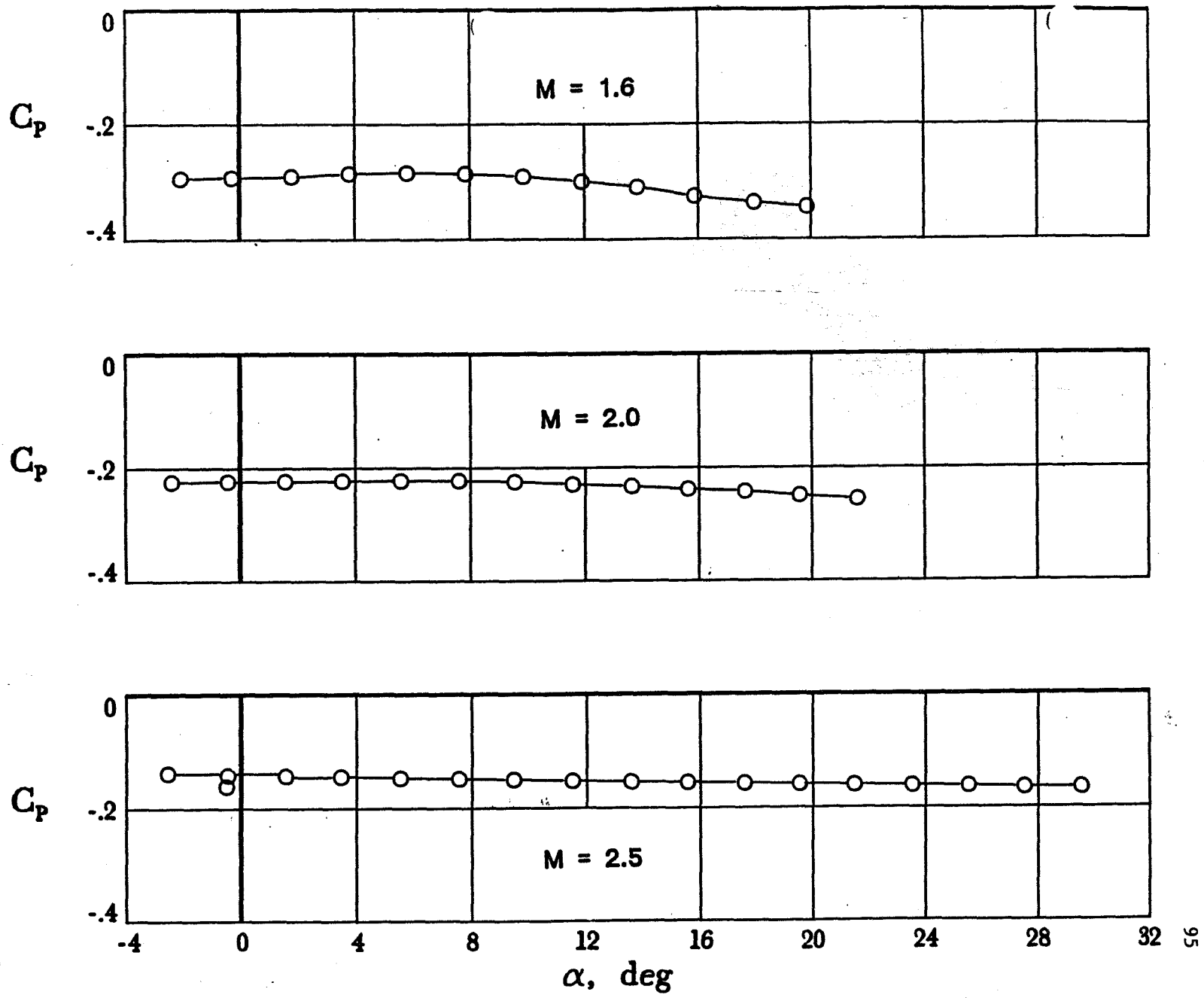
Figure 20. Model base pressures measured in supersonic investigation.
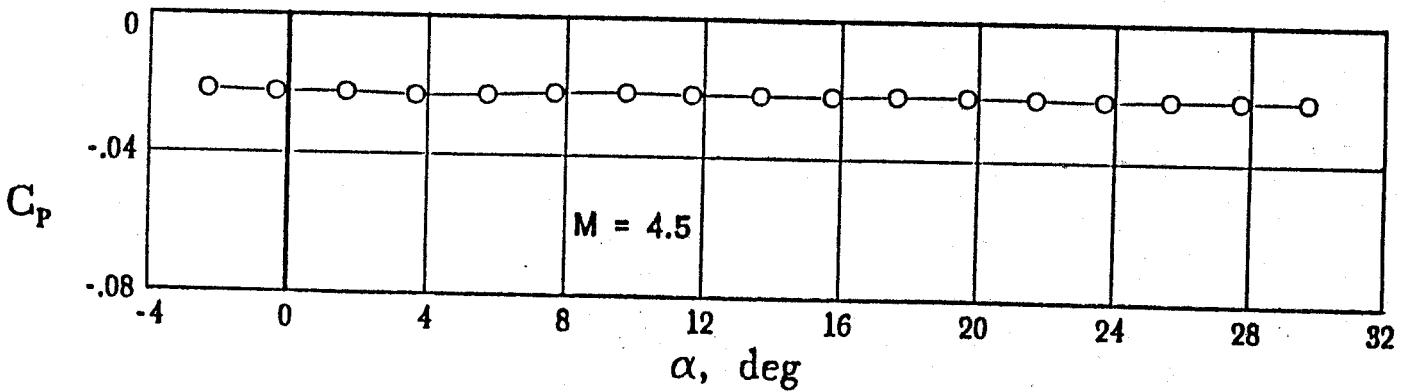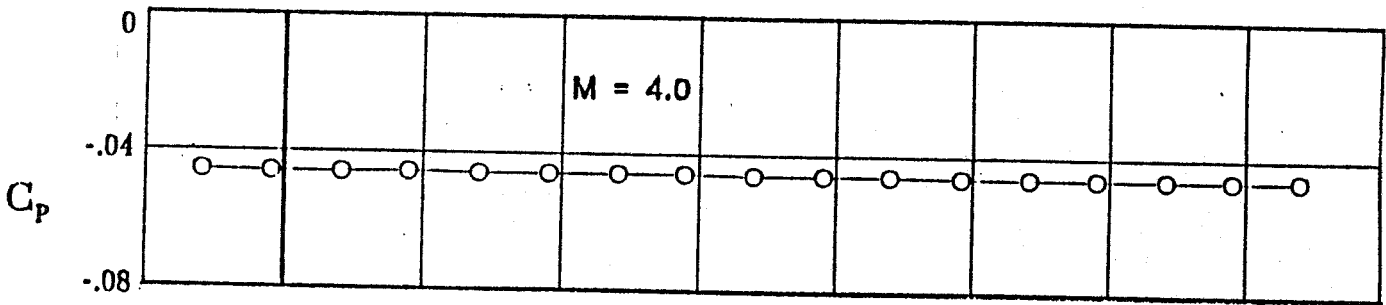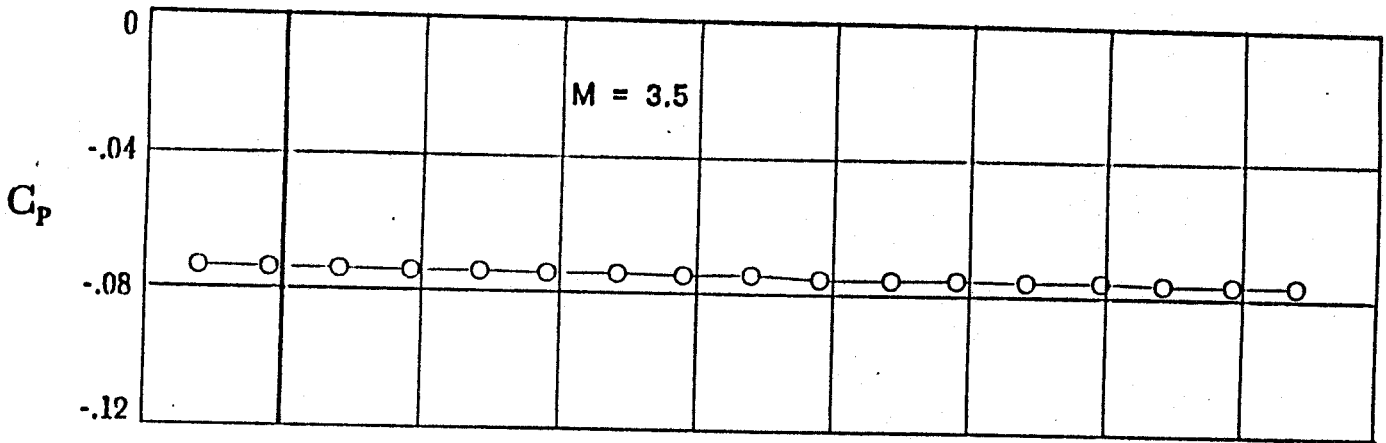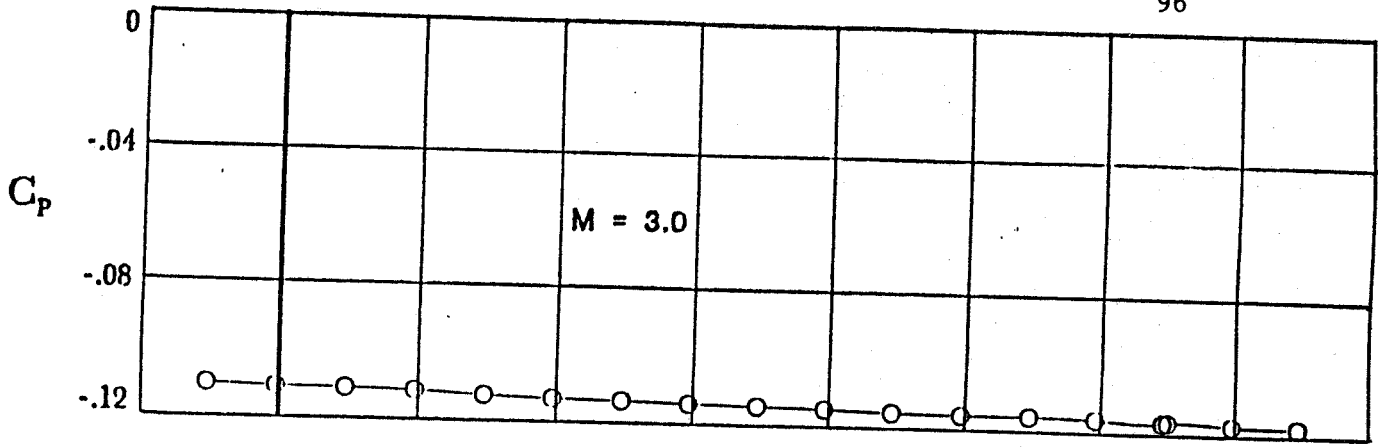
Figure 20. Concluded.
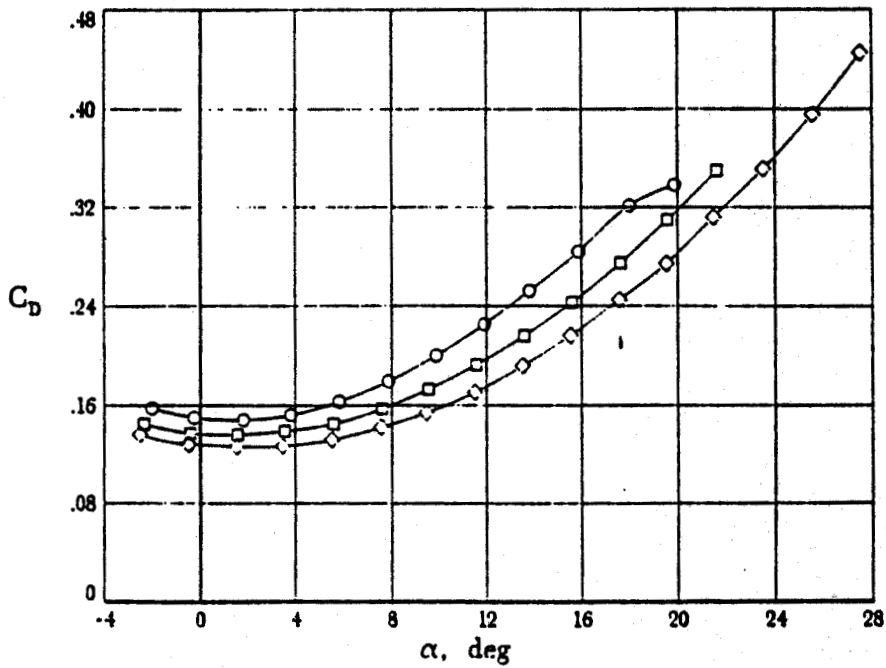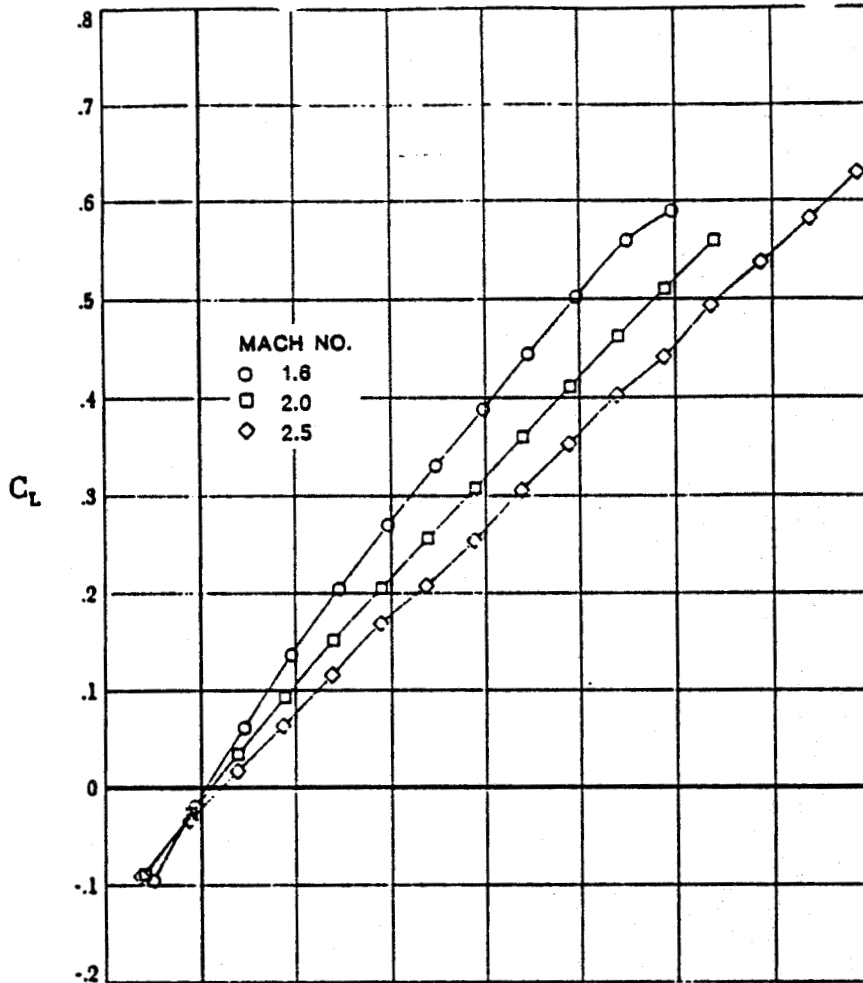
(a) $C_L$ VS $\alpha$ and $C_D$ VS $\alpha$

Figure 21. Effect of Mach number variation on the supersonic longitudinal
aerodynamic characteristics of the model.
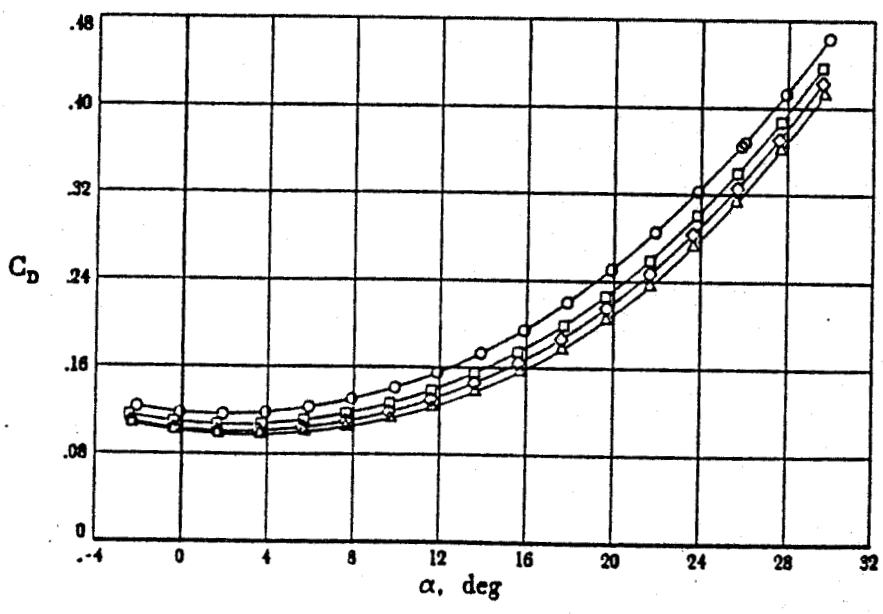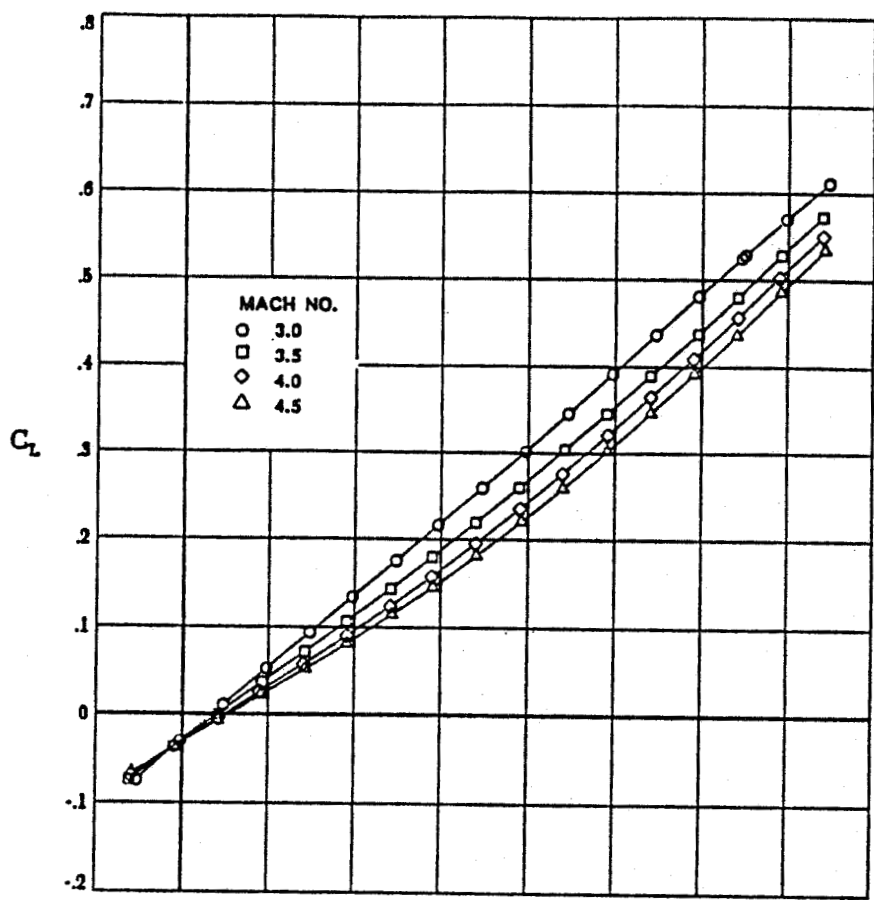
(a) $C_L$ VS $\alpha$ and $C_D$ VS $\alpha$

Figure 21. Continued.
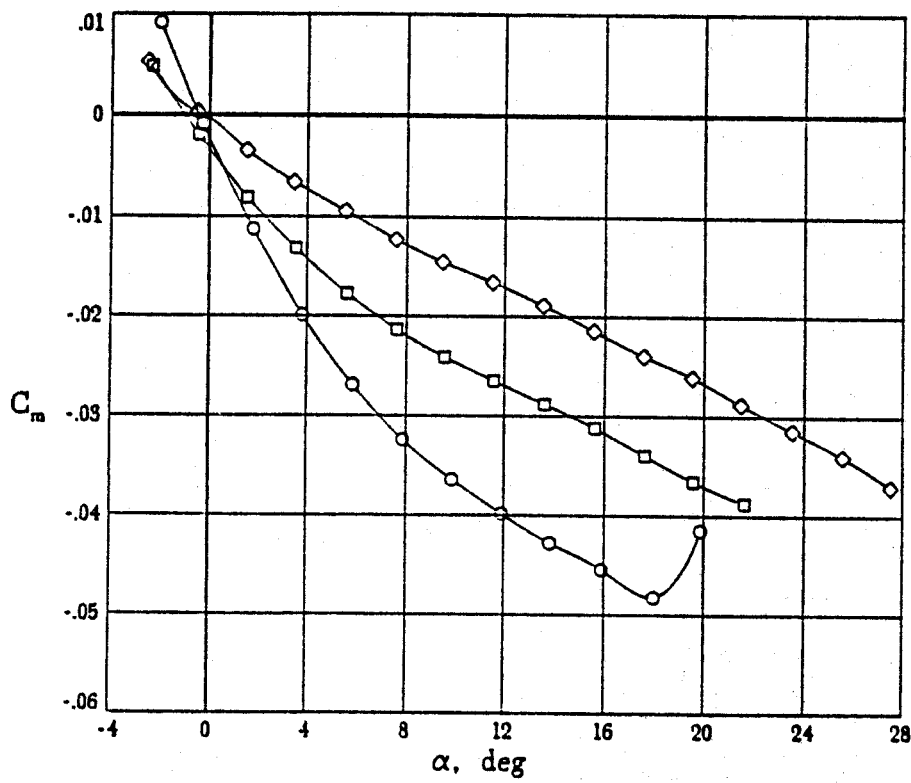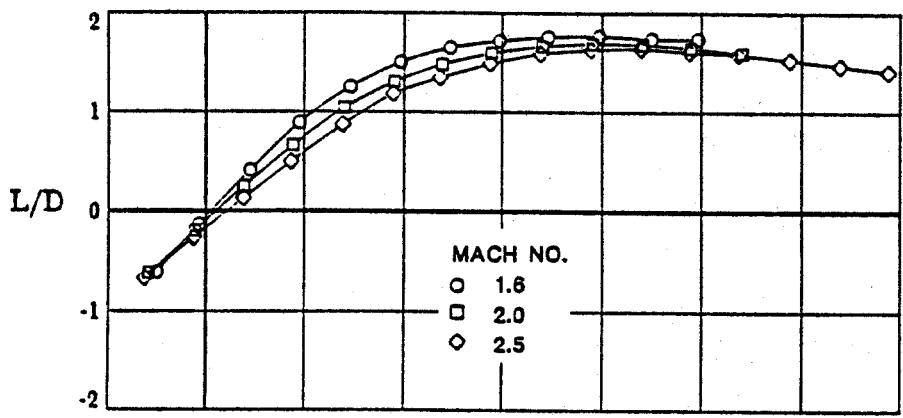
(b) L/D VS $\alpha$ and $C_m$ VS $\alpha$

Figure 21. Continued.
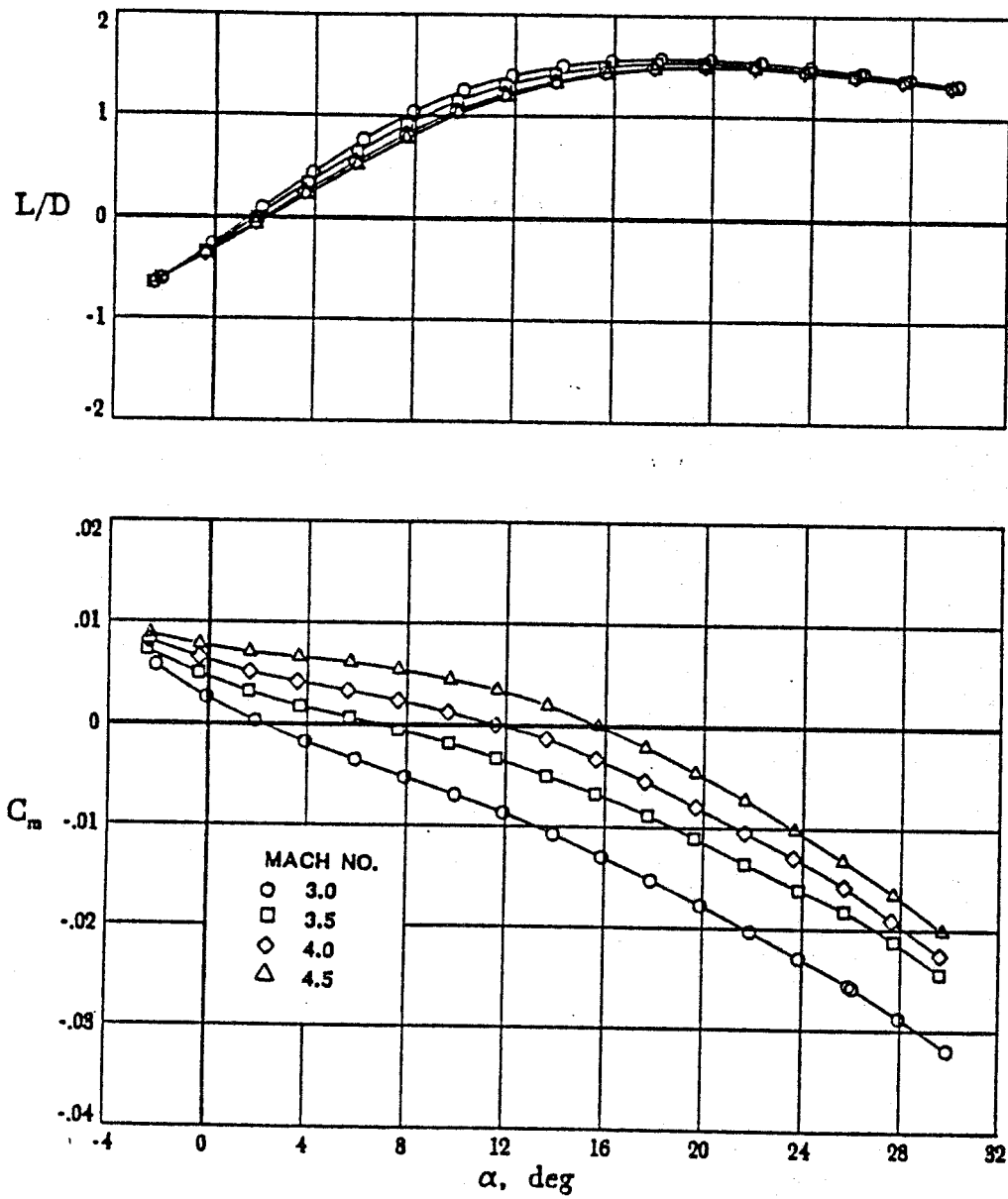
(b) L/D VS $\alpha$ and $C_m$ VS $\alpha$

Figure 21. Concluded.
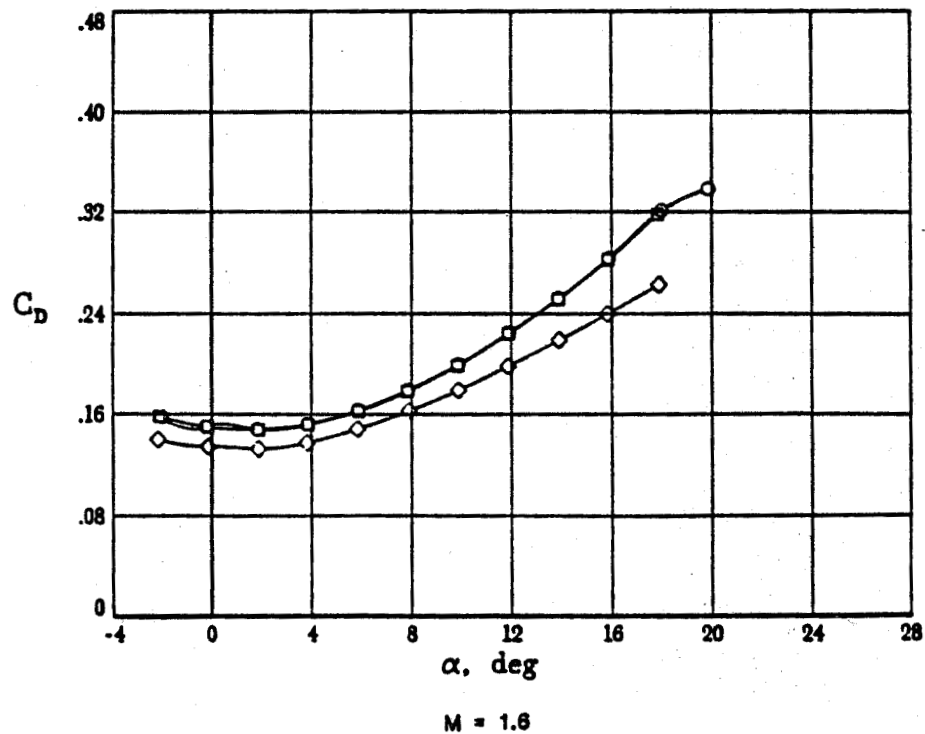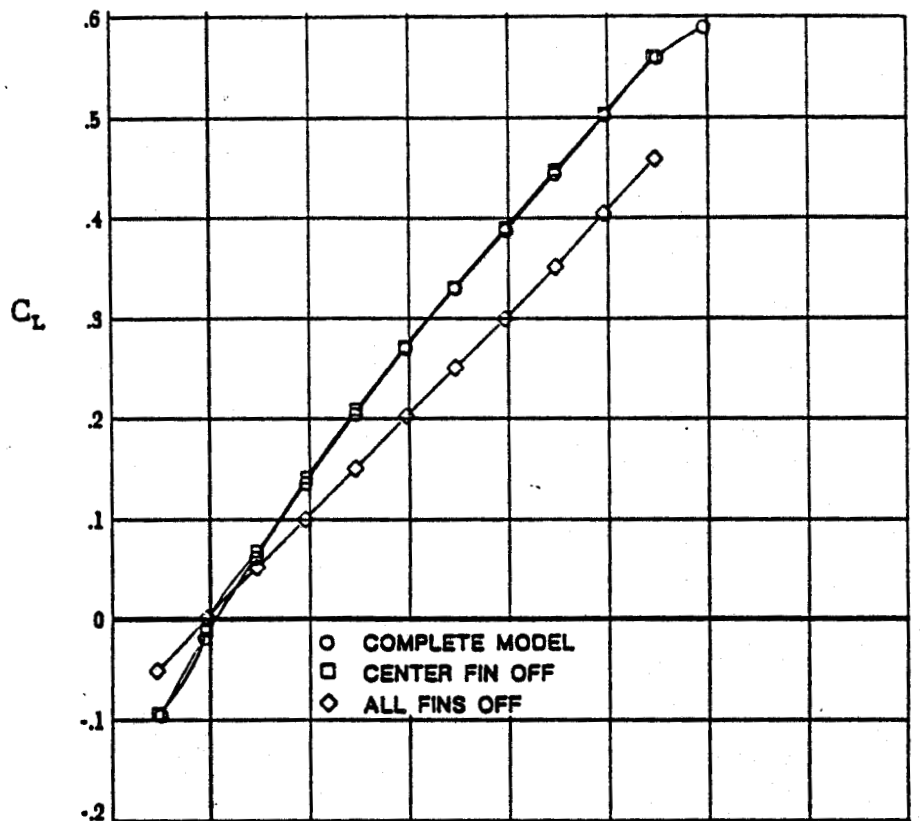
(a) $C_L$ VS $\alpha$ and $C_D$ VS $\alpha$

Figure 22. Effect of fins on the supersonic longitudinal aerodynamic characteristics of the model.

L/D

O   COMPLETE MODEL
□   CENTER FIN OFF
◇   ALL FINS OFF

$C_m$

$\alpha$, deg

M = 1.6

(b) L/D VS $\alpha$ and $C_m$ VS $\alpha$

Figure 22. Continued.

(a) $C_L$ VS $\alpha$ and $C_D$ VS $\alpha$

Figure 22. Continued.

(b) L/D VS $\alpha$ and $C_m$ VS $\alpha$

Figure 22. Continued.

(a) $C_L$ VS $\alpha$ and $C_D$ VS $\alpha$

Figure 22. Continued.

(b) L/D VS α and $C_m$ VS α

Figure 22. Continued.

(a) $C_L$ VS $\alpha$ and $C_D$ VS $\alpha$

Figure 22. Continued.

(b) L/D VS $\alpha$ and $C_m$ VS $\alpha$

Figure 22. Continued.

(a) $C_L$ VS $\alpha$ and $C_D$ VS $\alpha$

Figure 22. Continued.

(b) L/D VS $\alpha$ and $C_m$ VS $\alpha$

Figure 22. Continued.

(a) $C_L$ VS $\alpha$ and $C_D$ VS $\alpha$

Figure 22. Continued.

M = 4.0

(b) L/D VS α and $C_m$ VS α
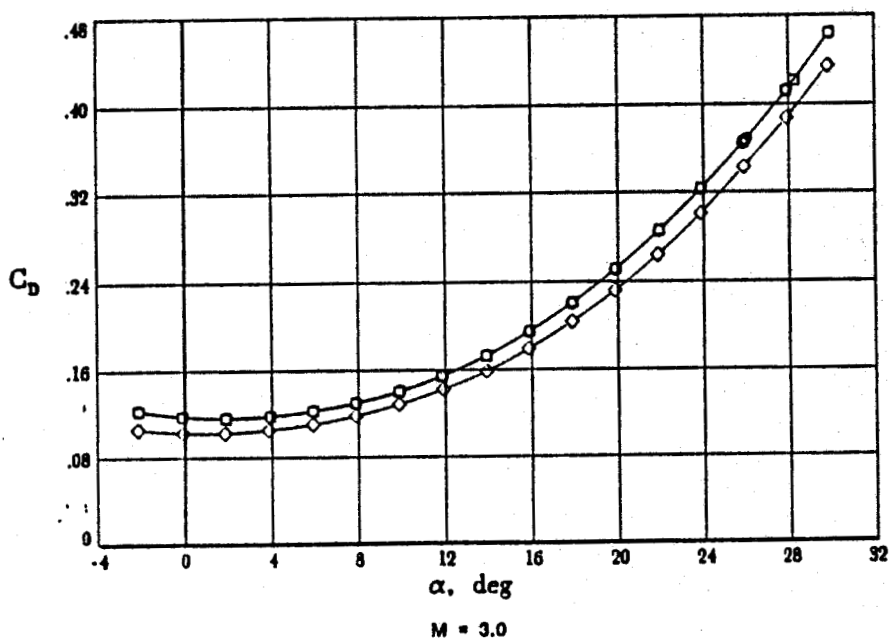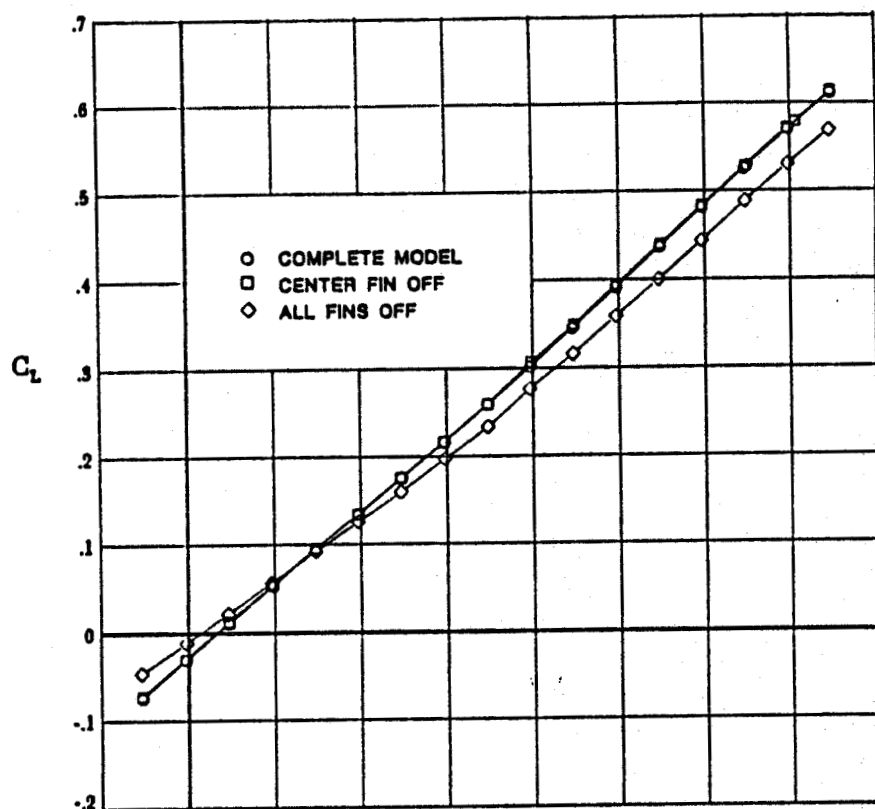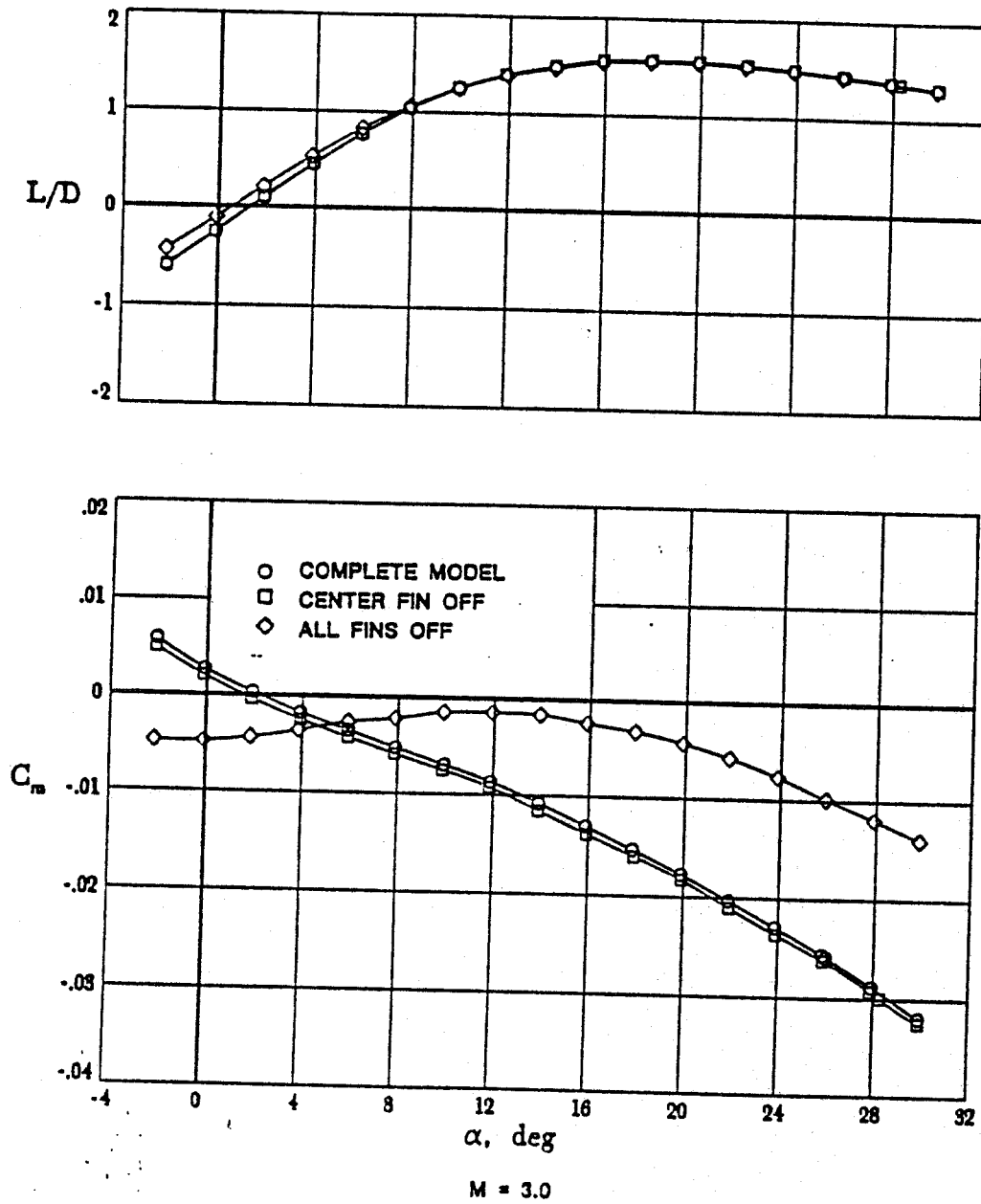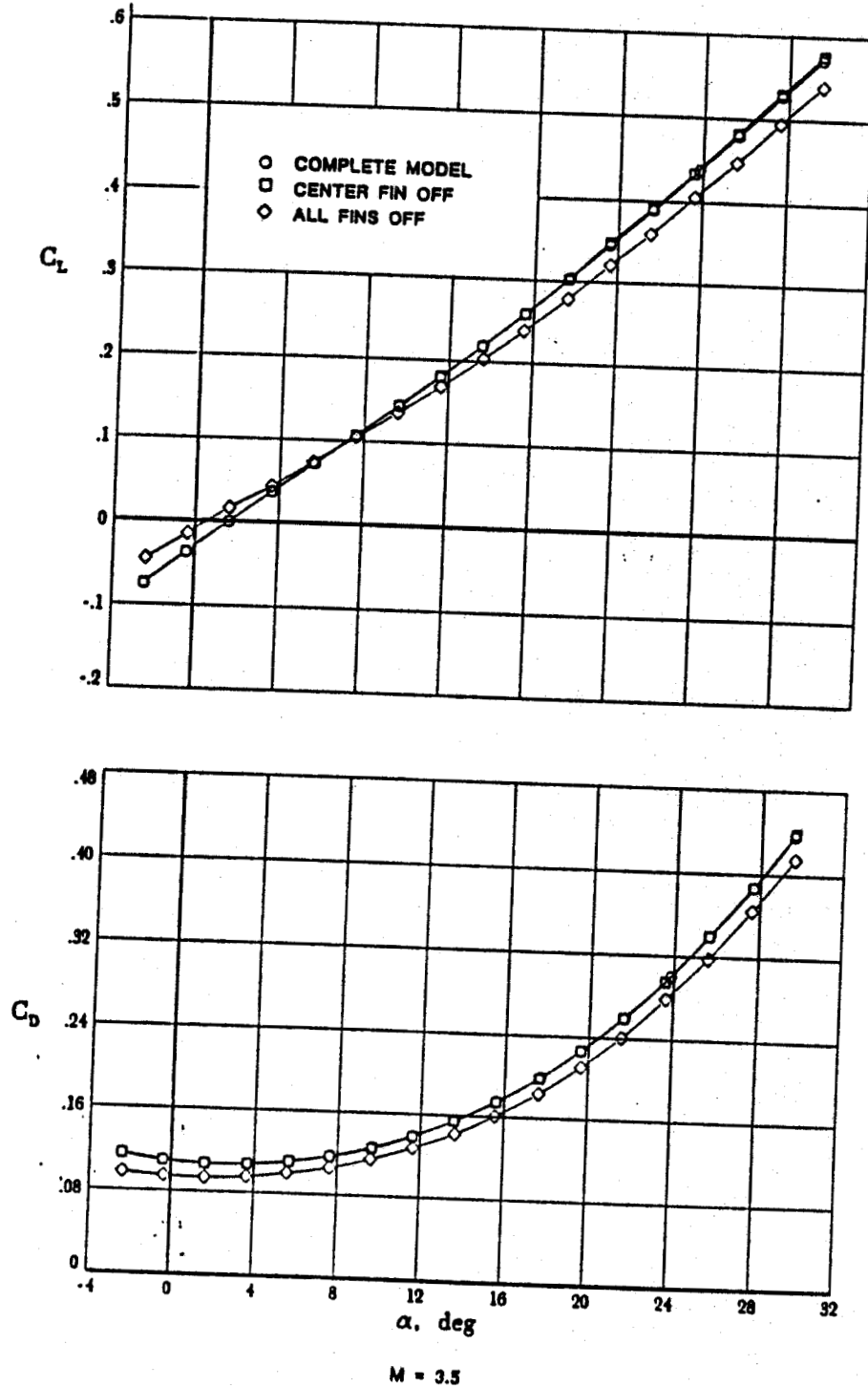
Figure 22. Continued.

M = 4.5

(a) $C_L$ VS $\alpha$ and $C_D$ VS $\alpha$

Figure 22. Continued.

M = 4.5

(b) L/D VS $\alpha$ and $C_m$ VS $\alpha$

Figure 22. Concluded.
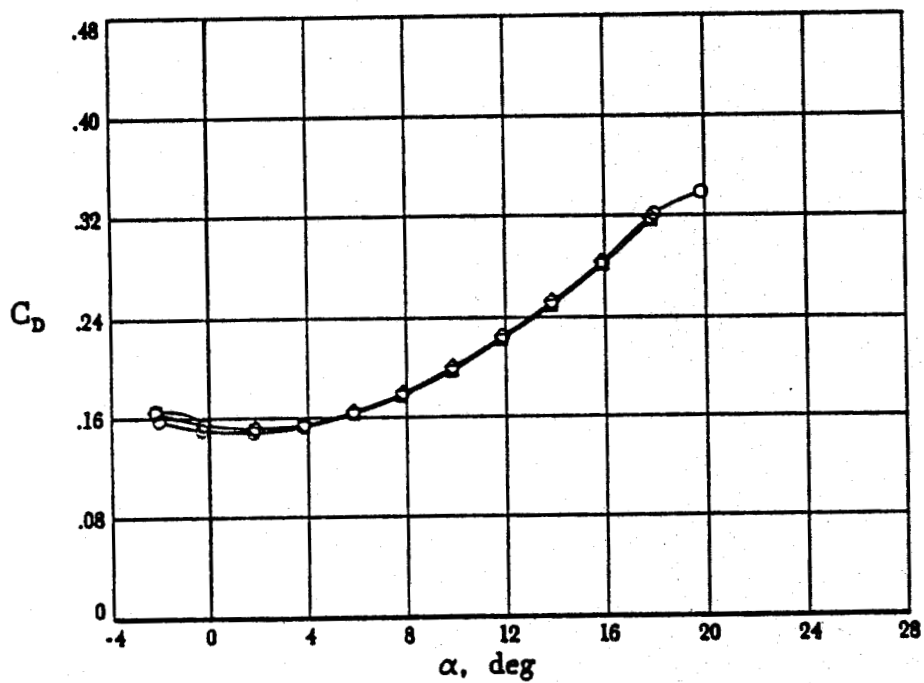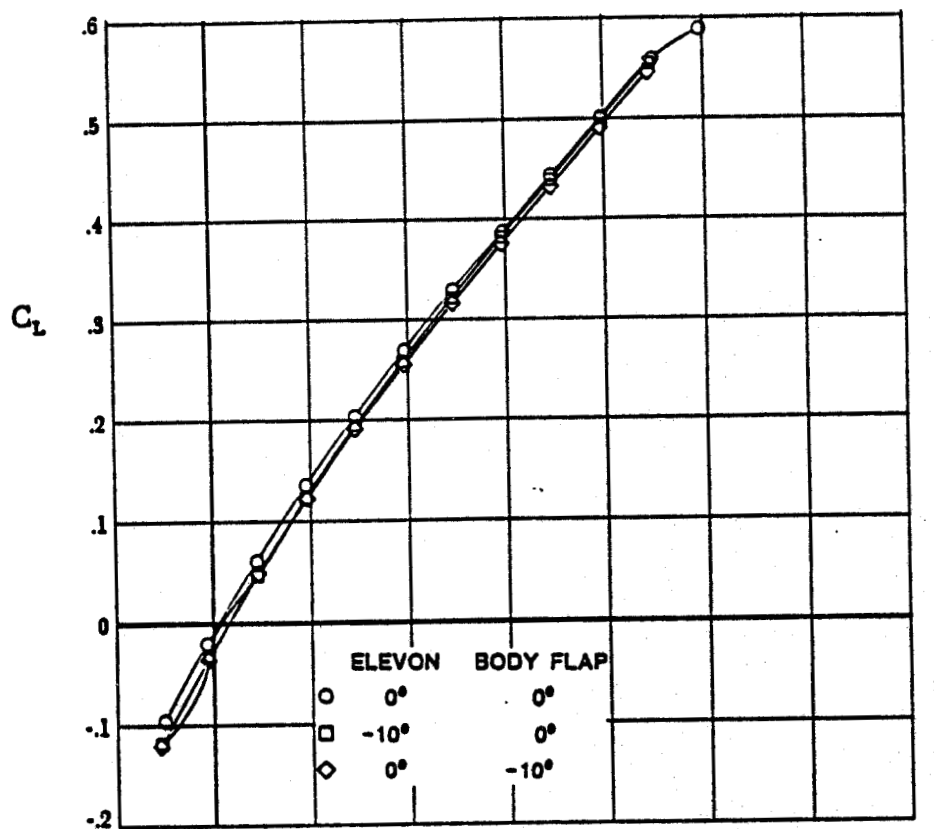
(a) $C_L$ VS $\alpha$ and $C_D$ VS $\alpha$

Figure 23. Effect of elevon and body flap on the supersonic longitudinal characteristics of the model.

ELEVON    BODY FLAP
○      0°         0°
□    -10°         0°
◇      0°       -10°

M = 2.0

(a) $C_L$ VS $\alpha$ and $C_D$ VS $\alpha$

Figure 23. Continued.

ELEVON    BODY FLAP
○    0°         0°
□   -10°        0°
◇    0°        -10°

M = 2.5

(a) $C_L$ VS $\alpha$ and $C_D$ VS $\alpha$

Figure 23. Continued.

ELEVON | BODY FLAP
○ 0° | 0°
□ -10° | 0°
◇ 0° | -10°

M = 3.0

(a) $C_L$ VS $\alpha$ and $C_D$ VS $\alpha$

Figure 23. Continued.

(a) $C_L$ vs $\alpha$ and $C_D$ vs $\alpha$

Figure 23. Continued.

(a) $C_L$ VS $\alpha$ and $C_D$ VS $\alpha$

Figure 23. Continued.

M = 4.5

(a) $C_L$ VS $\alpha$ and $C_D$ VS $\alpha$

Figure 23. Continued.

(b) L/D VS $\alpha$ and $C_m$ VS $\alpha$

Figure 23. Continued.

ELEVON | BODY FLAP
○ | 0° | 0°
□ | -10° | 0°
◇ | 0° | -10°

$M = 2.0$

(b) L/D VS $\alpha$ and $C_m$ VS $\alpha$

Figure 23. Continued.

(b) L/D VS $\alpha$ and $C_m$ VS $\alpha$

Figure 23. Continued.

(b) L/D vs $\alpha$ and $C_m$ vs $\alpha$

Figure 23. Continued.

(b) L/D VS $\alpha$ and $C_m$ VS $\alpha$

Figure 23. Continued.

(b) L/D VS $\alpha$ and $C_m$ VS $\alpha$

Figure 23. Continued.

(b) L/D vs $\alpha$ and $C_m$ vs $\alpha$

Figure 23. Concluded.
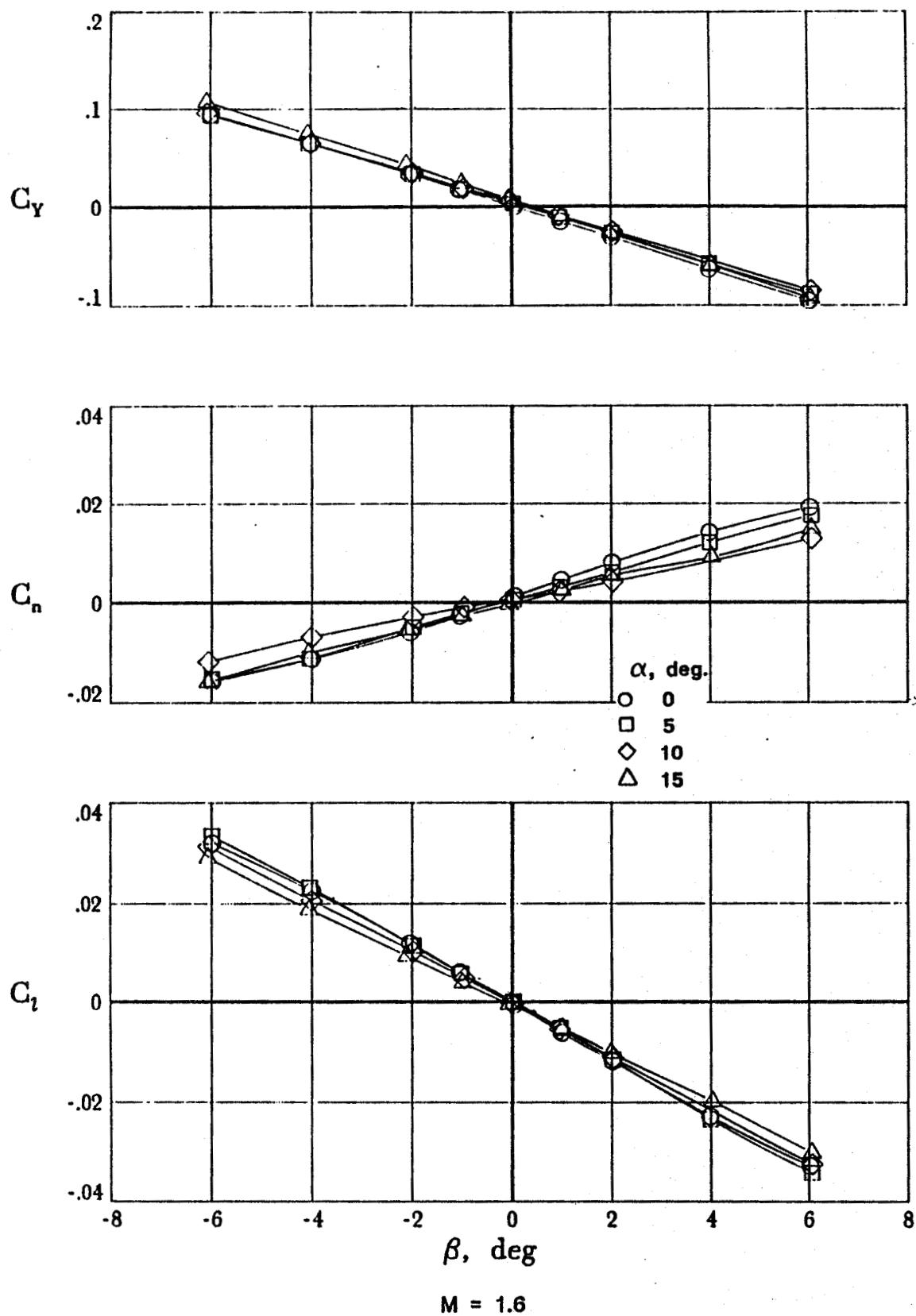
Figure 24. Variation of supersonic lateral aerodynamic characteristics with angle of sideslip.
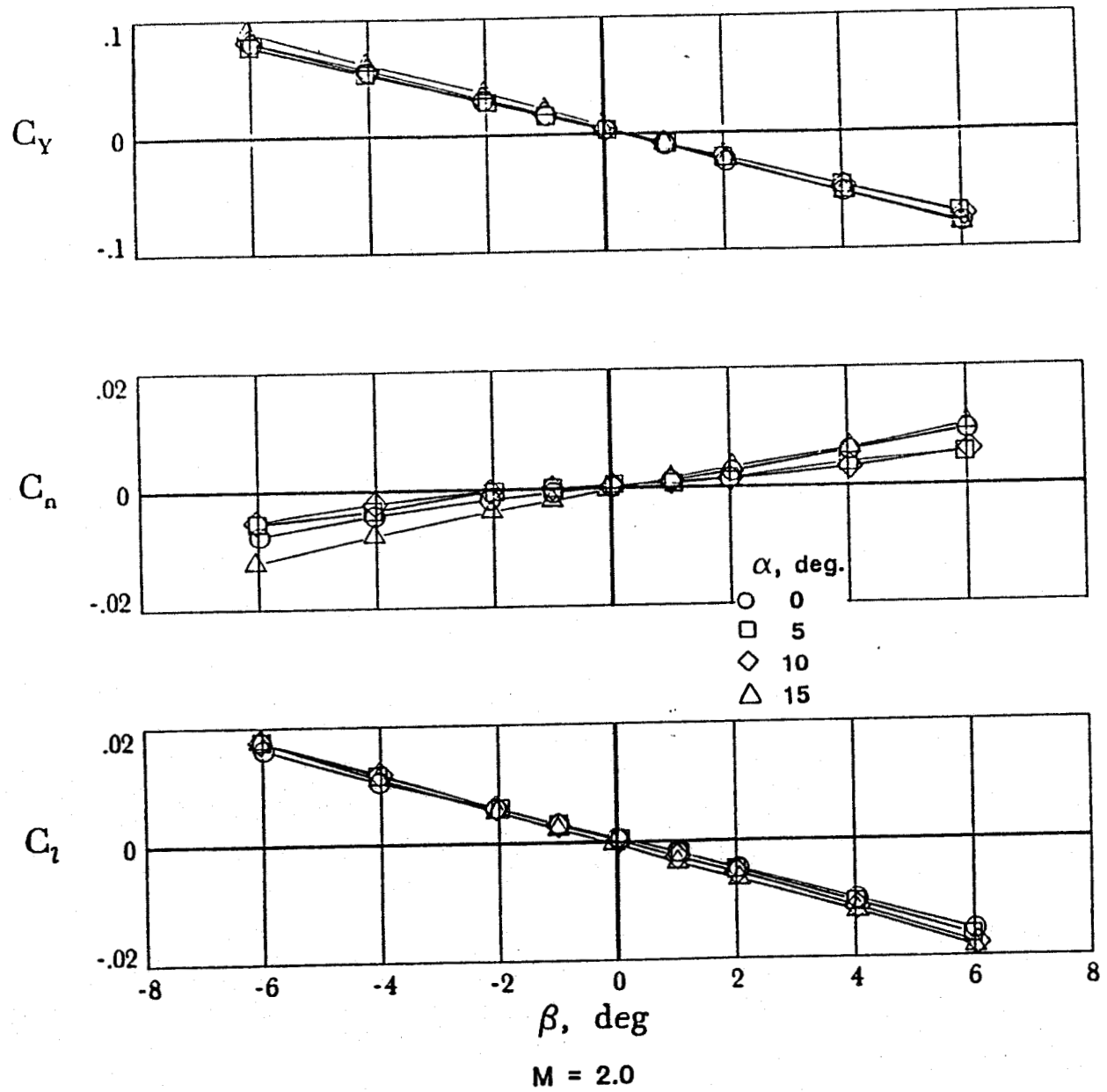
Figure 24. Continued.
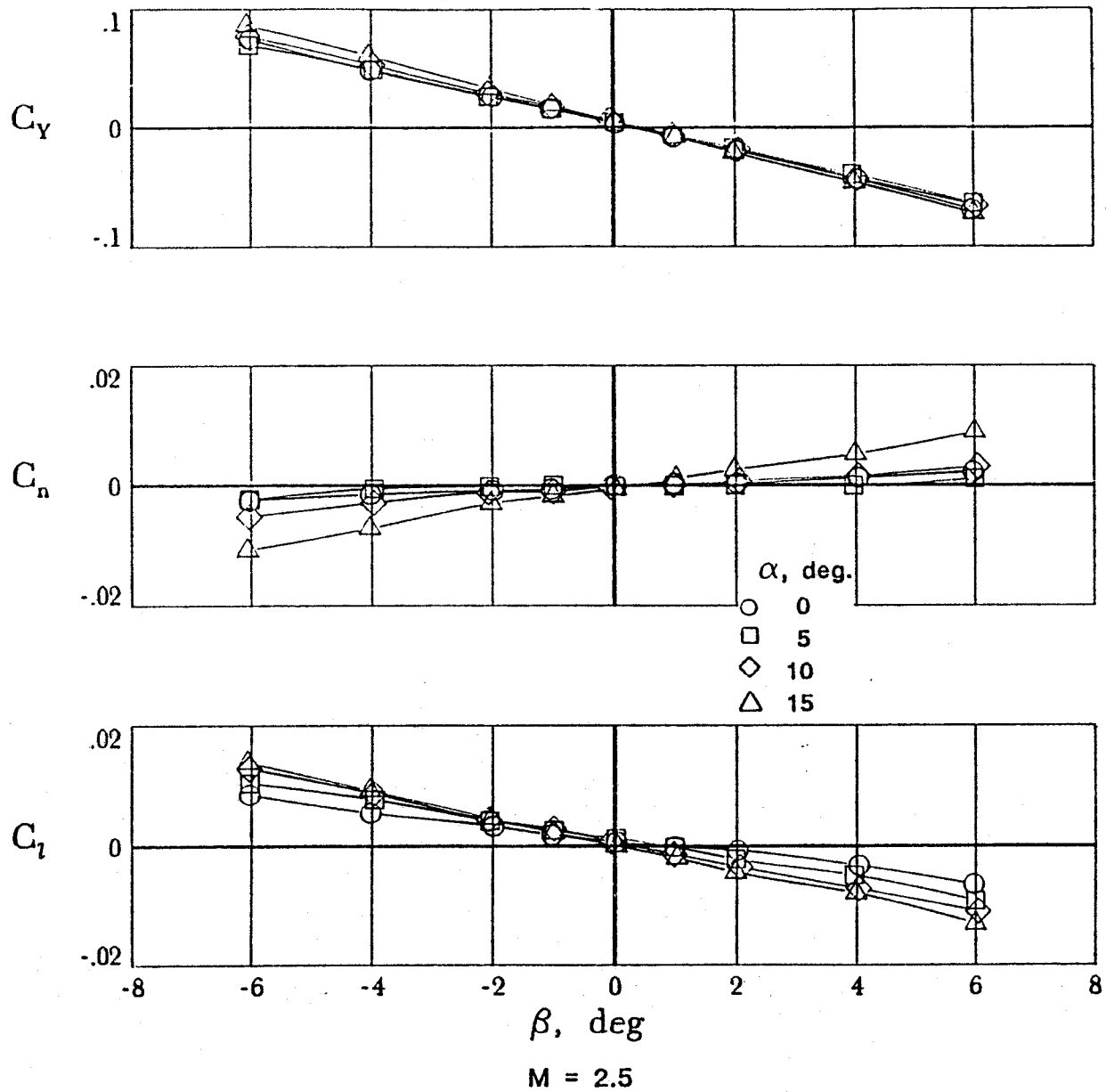
$\beta, \ deg$

M = 2.5

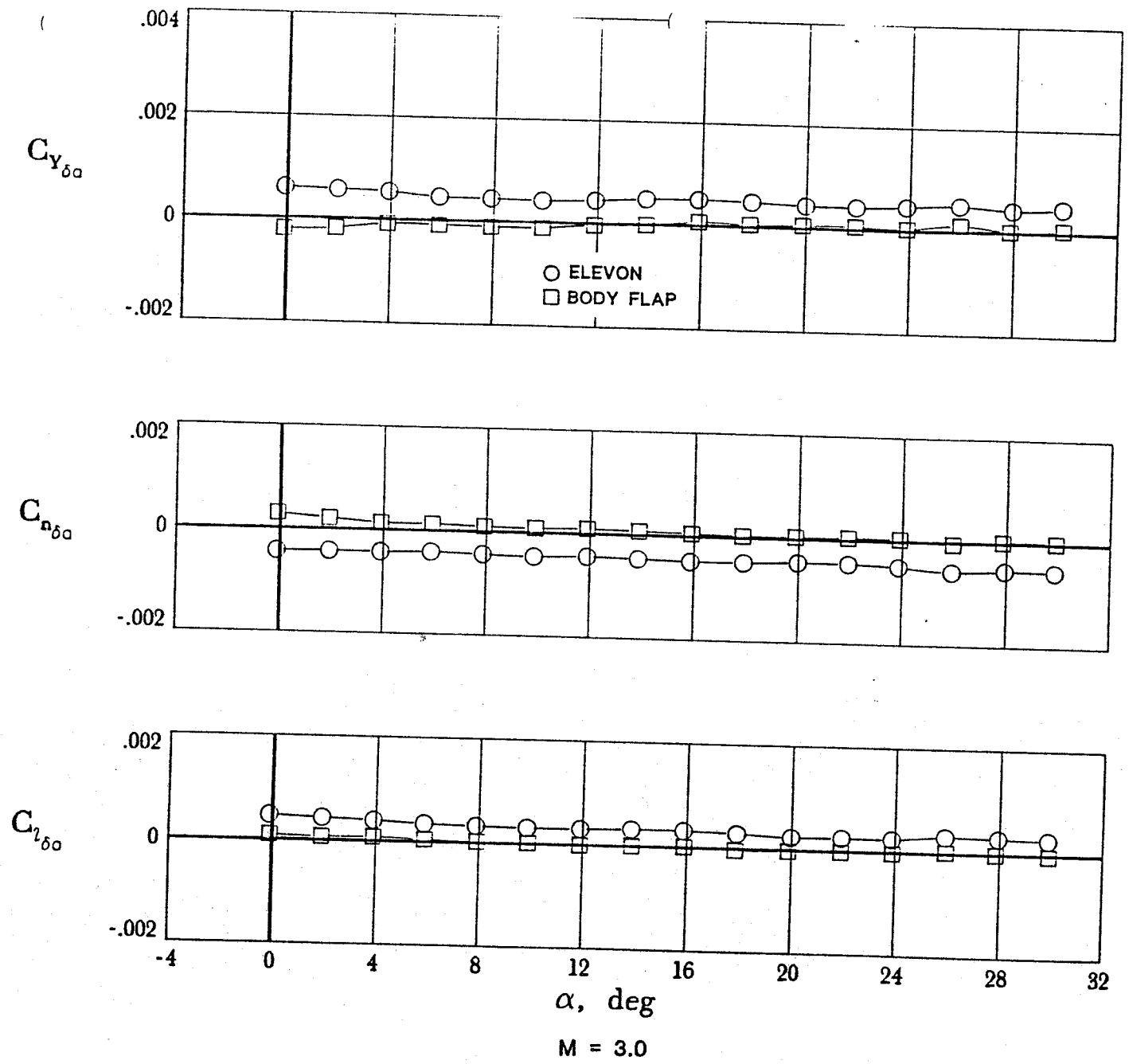Figure 24. Continued.

Figure 24. Continued.

Figure 24. Continued.

$\alpha$, deg.
○ 10
□ 15
◇ 20
△ 25

M = 4.0
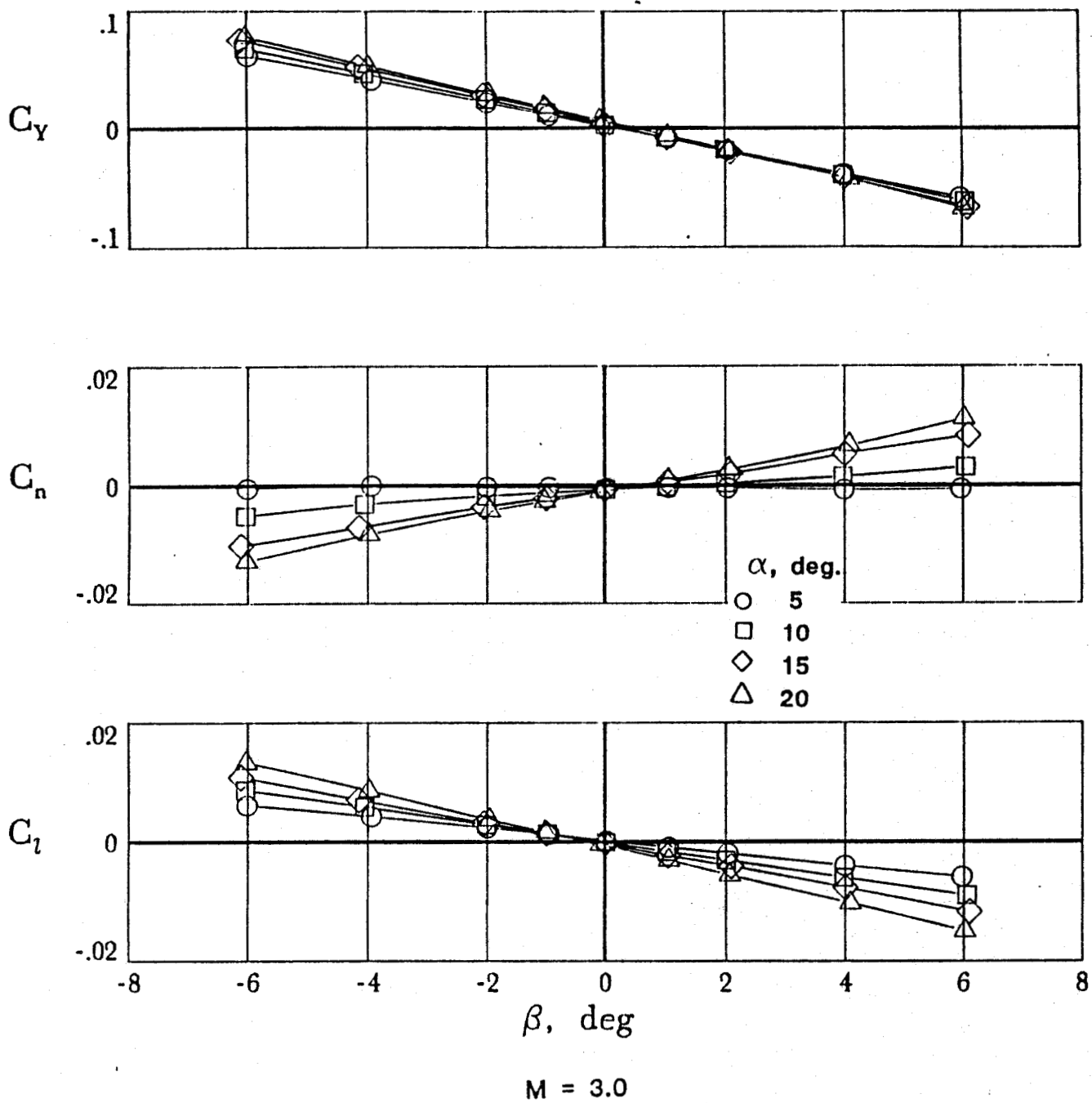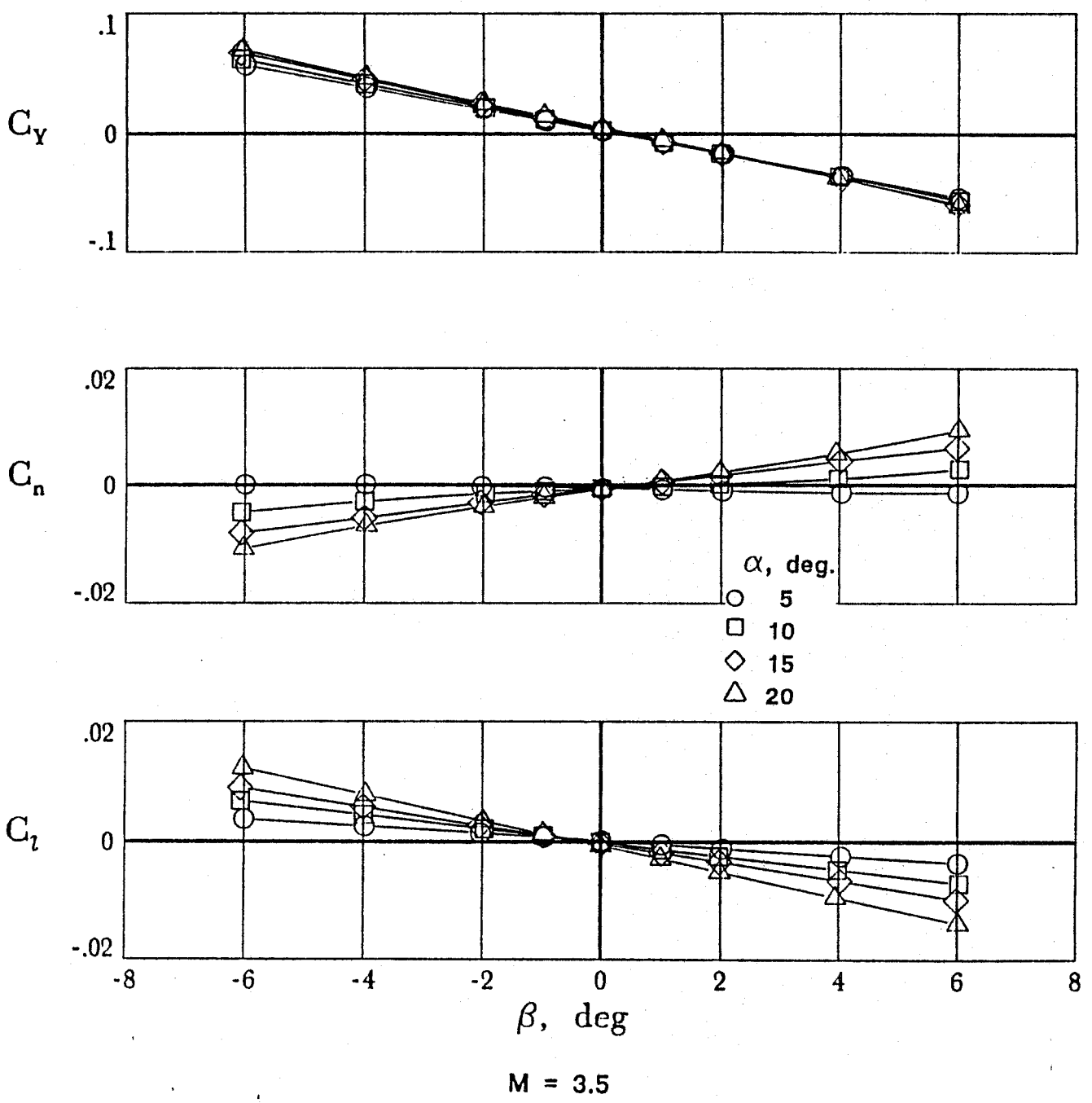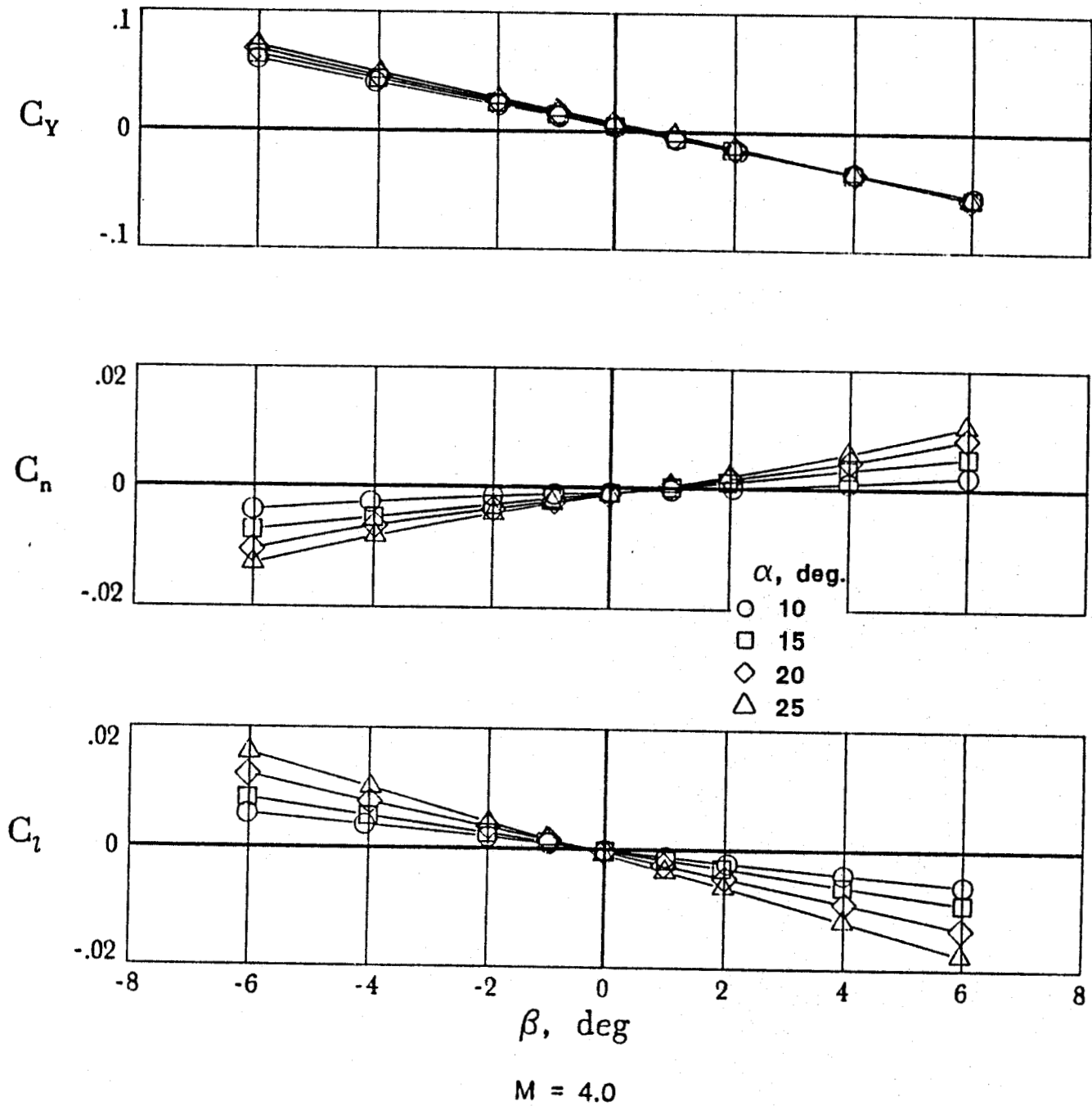
Figure 24. Continued.
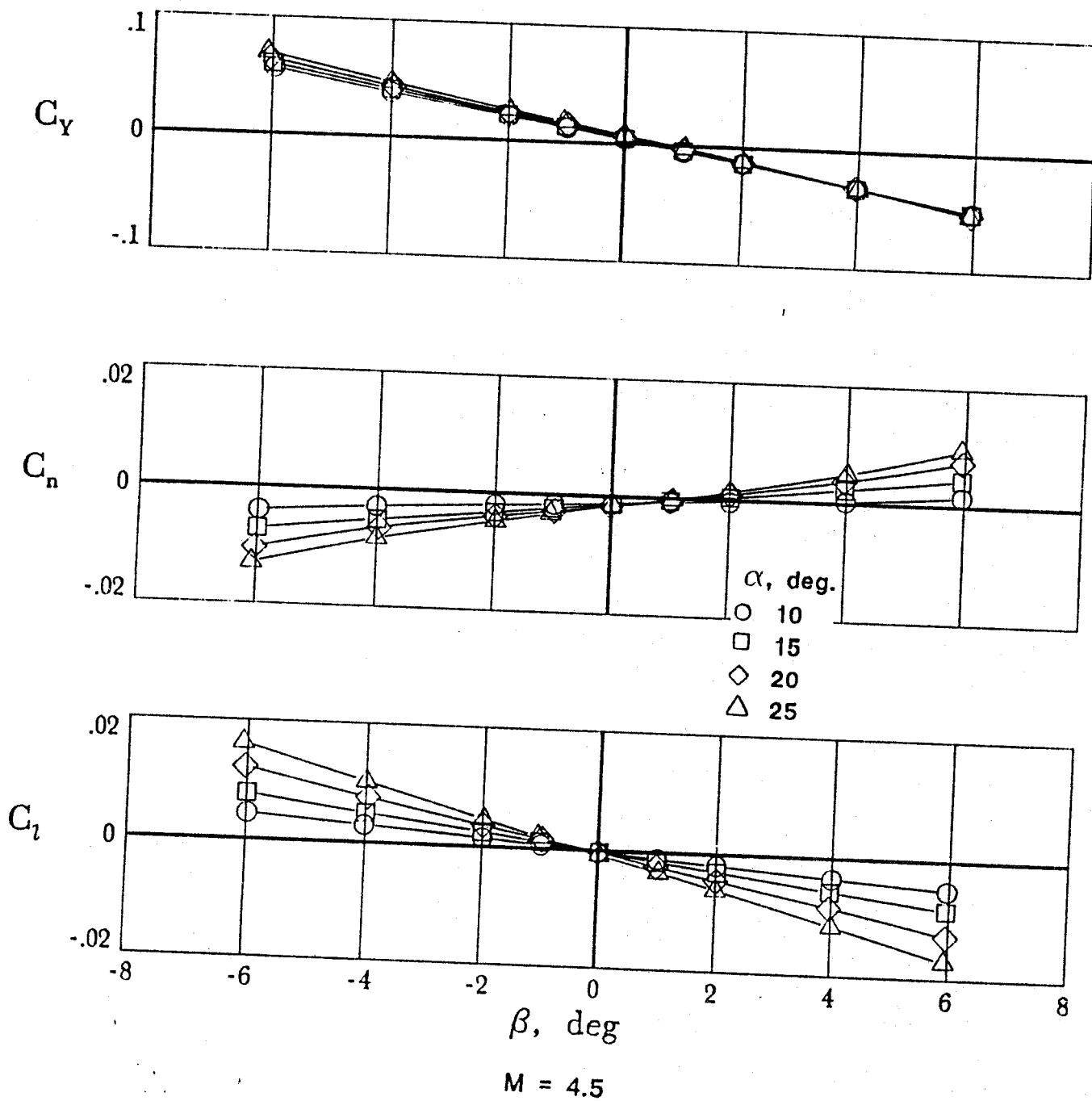
Figure 24. Concluded.
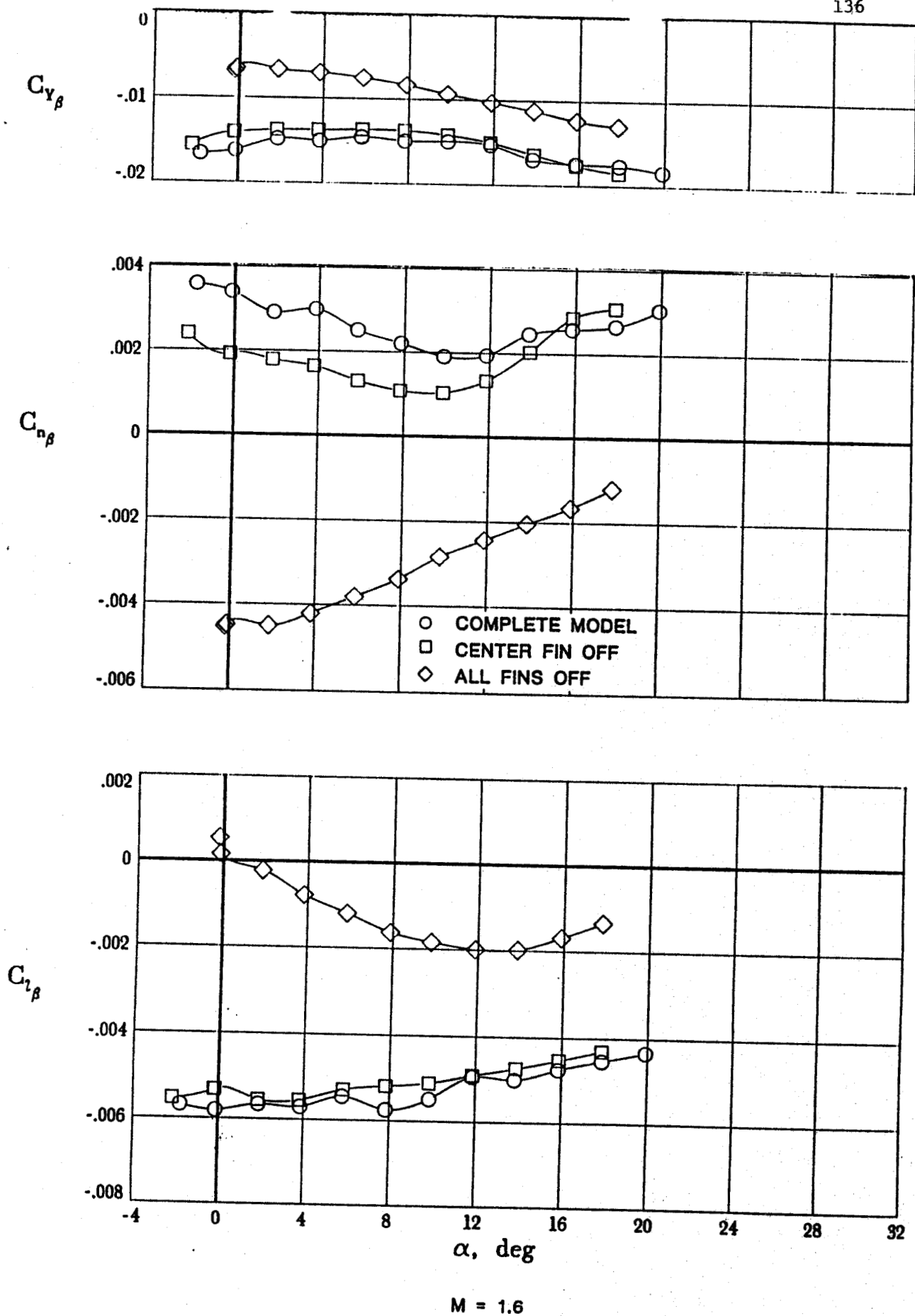
Figure 25. Effect of fins on the supersonic lateral-directional stability
characteristics of the model.
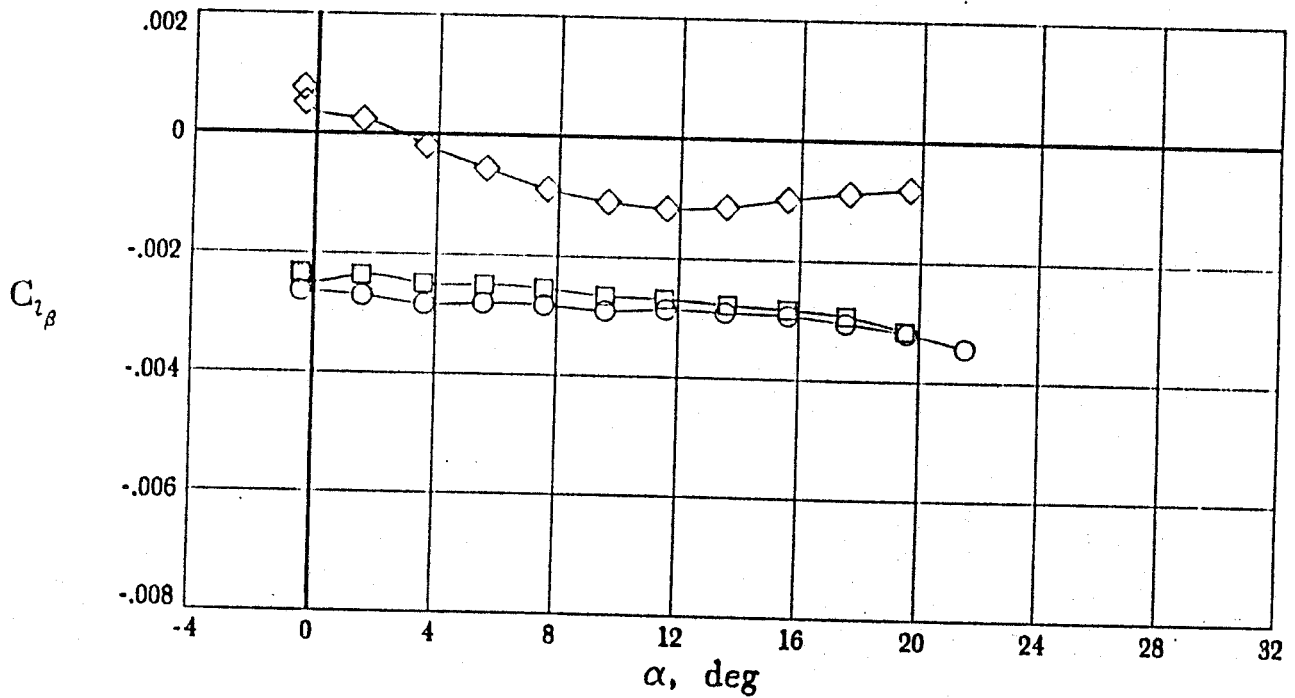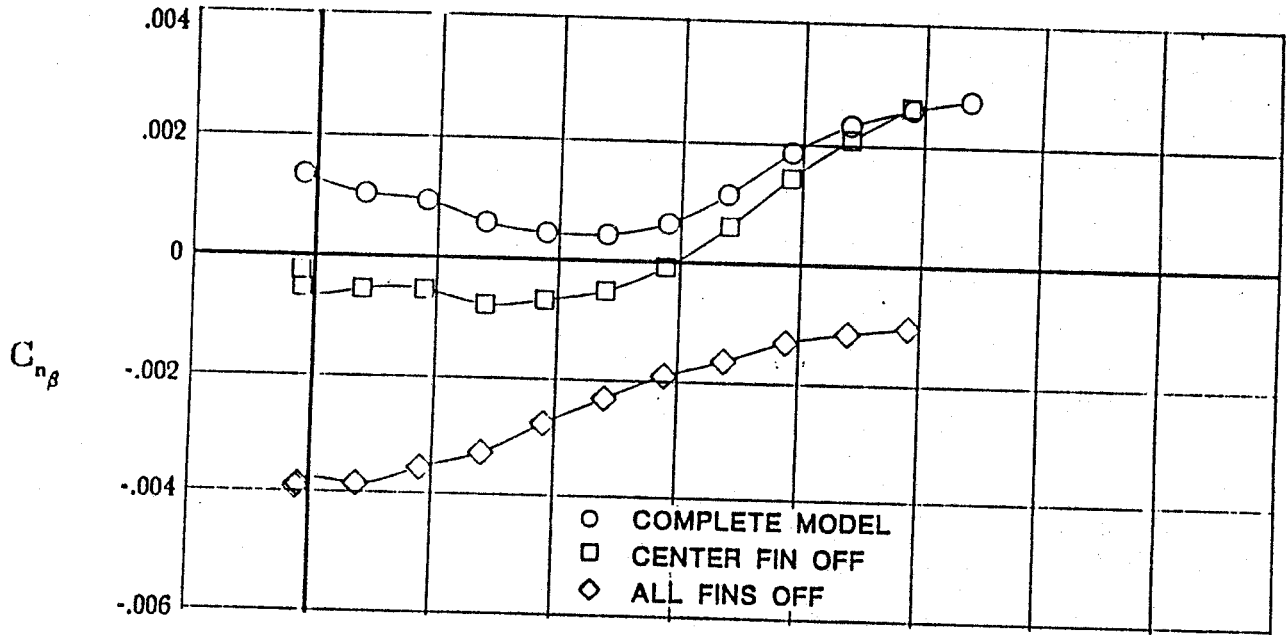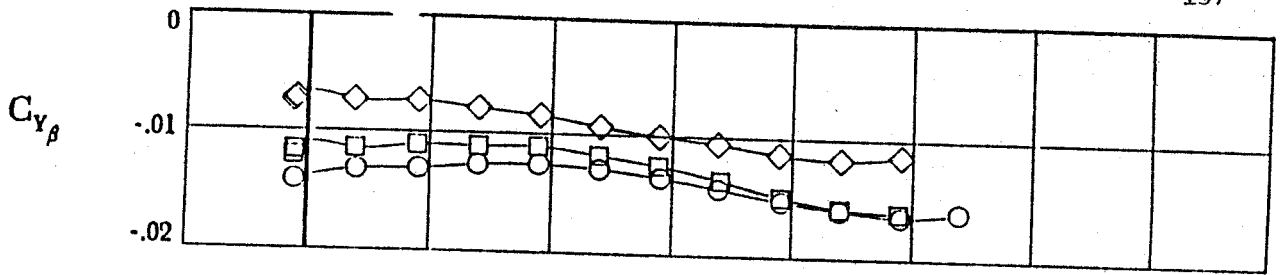
Figure 25. Continued.

$C_{Y_\beta}$

$C_{n_\beta}$

○ COMPLETE MODEL
□ CENTER FIN OFF
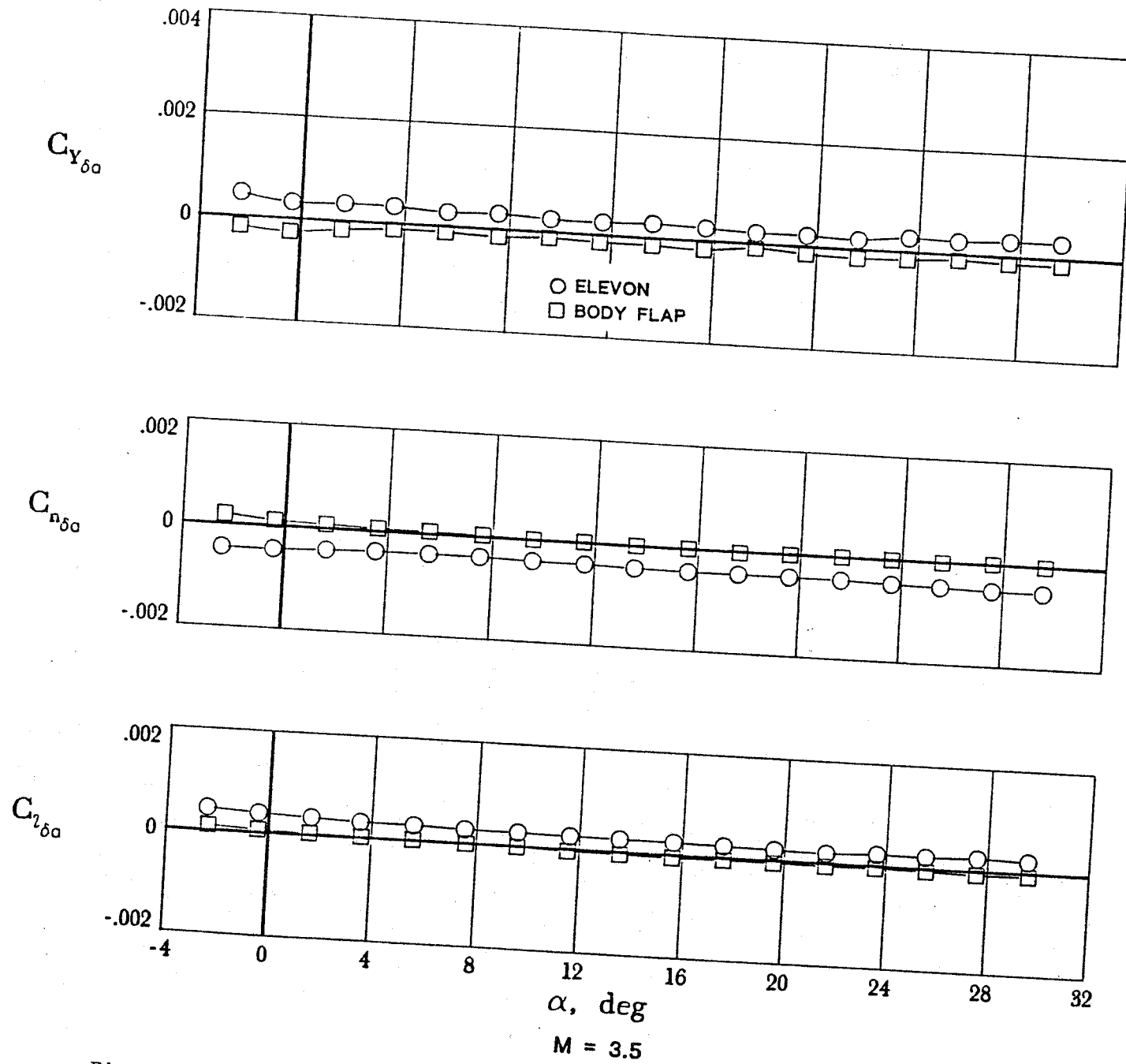◇ ALL FINS OFF

$C_{l_\beta}$

$\alpha$, deg

M = 2.5

Figure 25. Continued.

Figure 25. Continued.
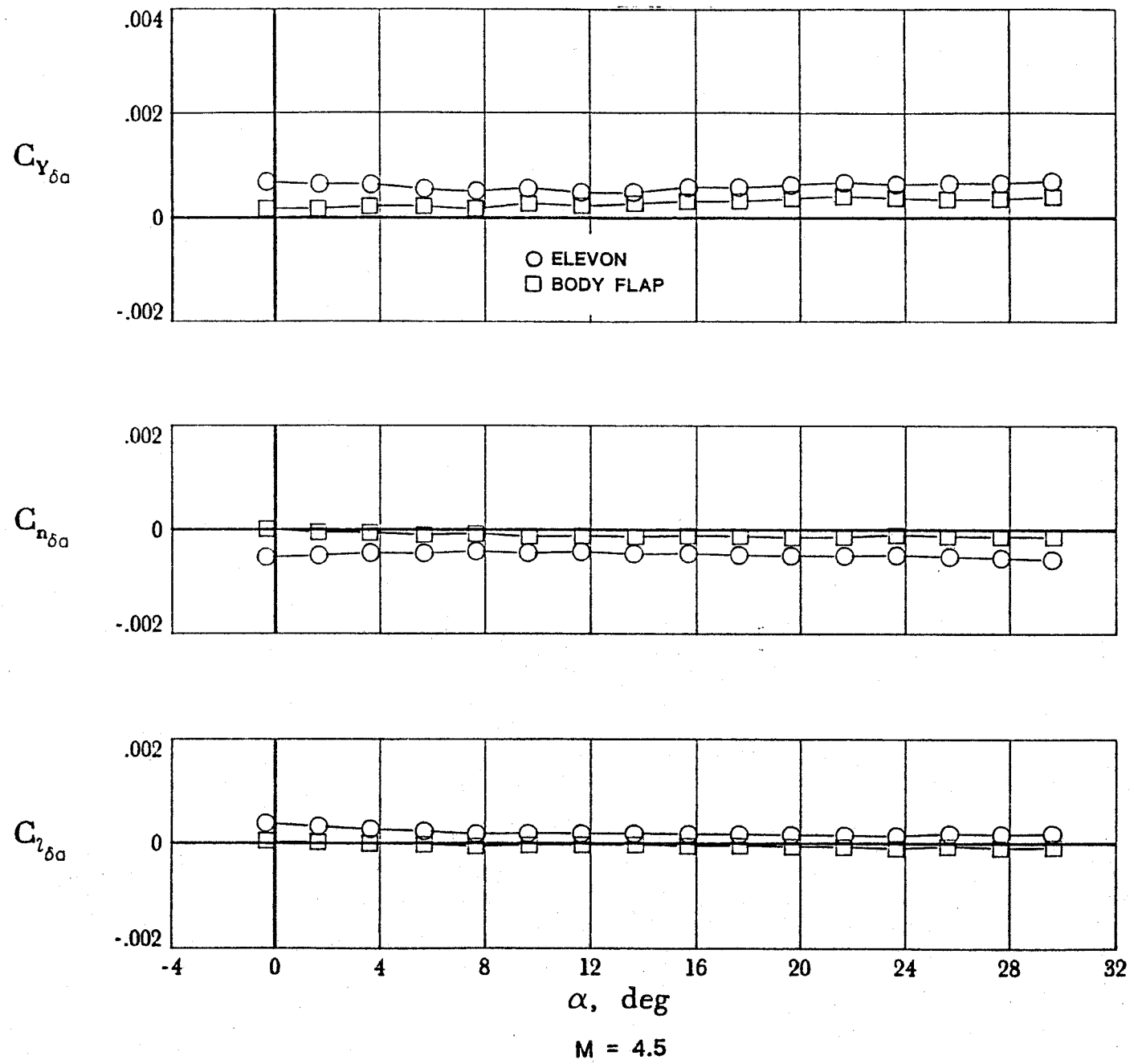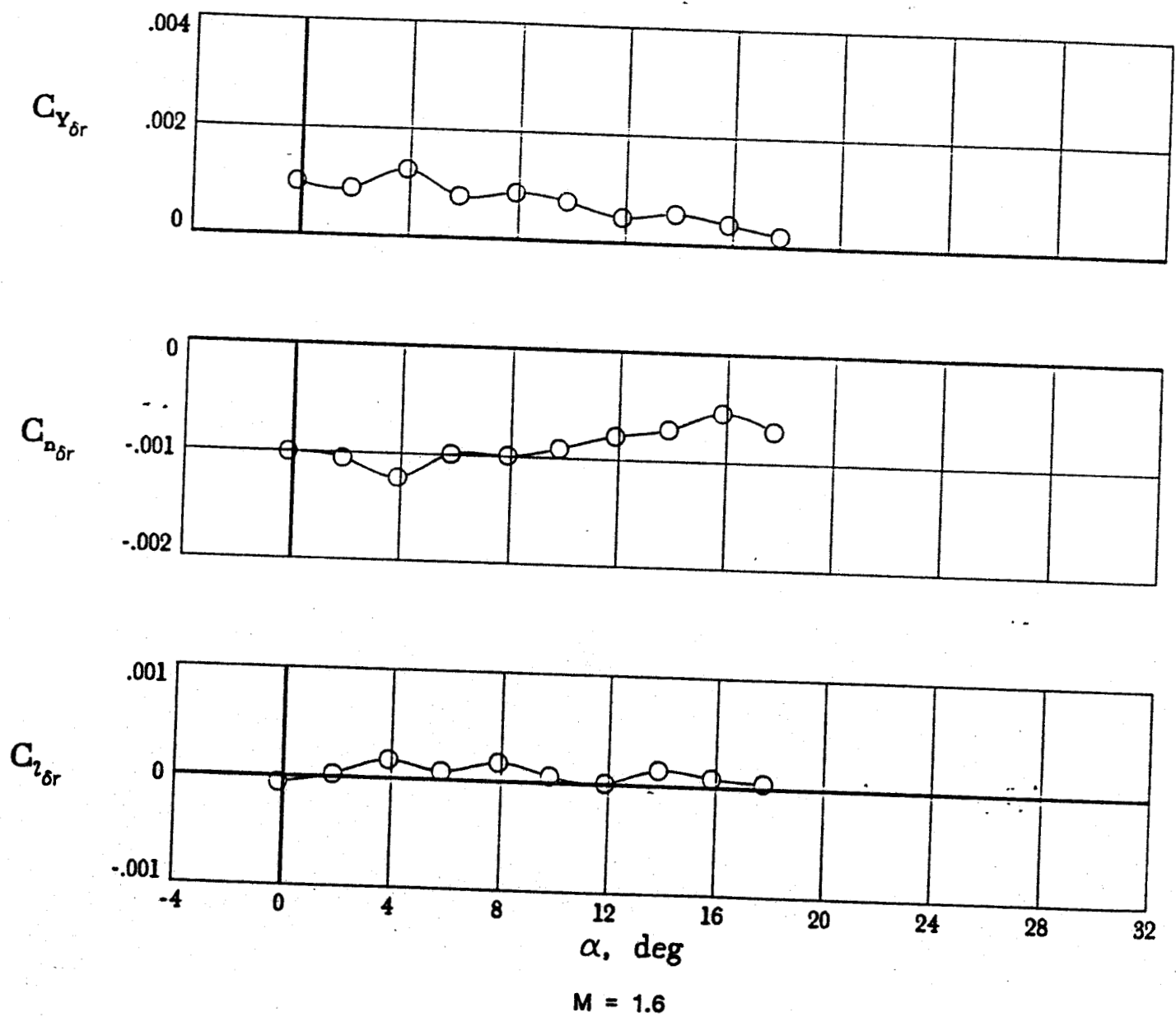
Figure 25. Continued.

Figure 25. Continued.

$C_{Y_\beta}$

$C_{n_\beta}$

O  COMPLETE MODEL
□  CENTER FIN OFF
◇  ALL FINS OFF

$C_{l_\beta}$

$\alpha$, deg

M = 4.5
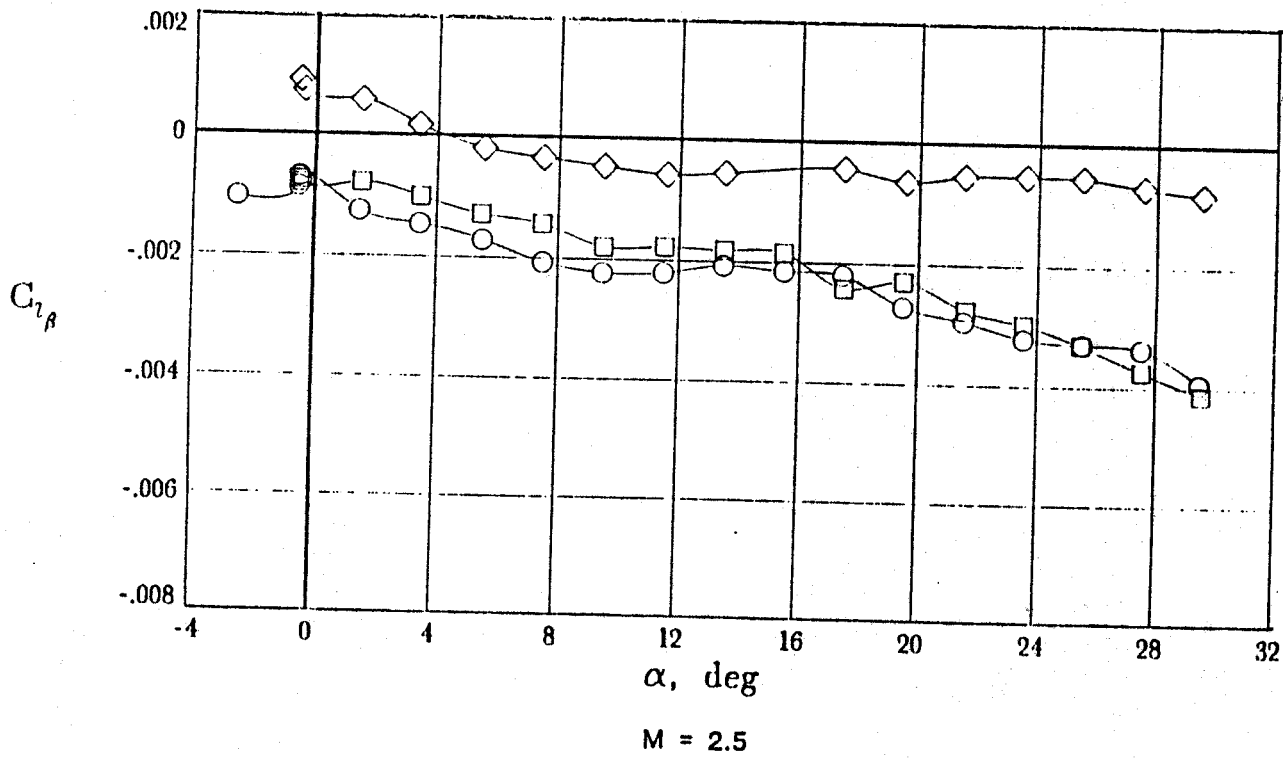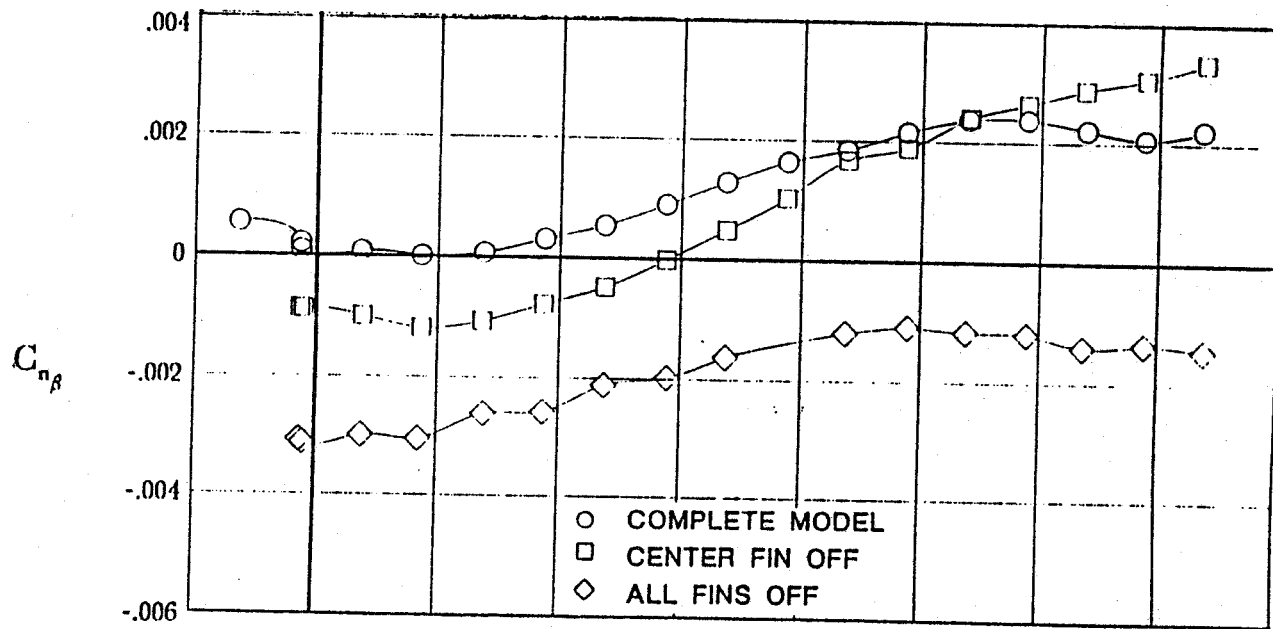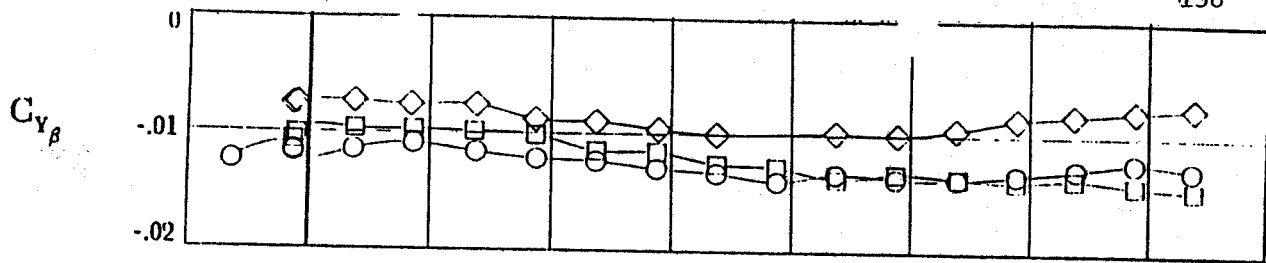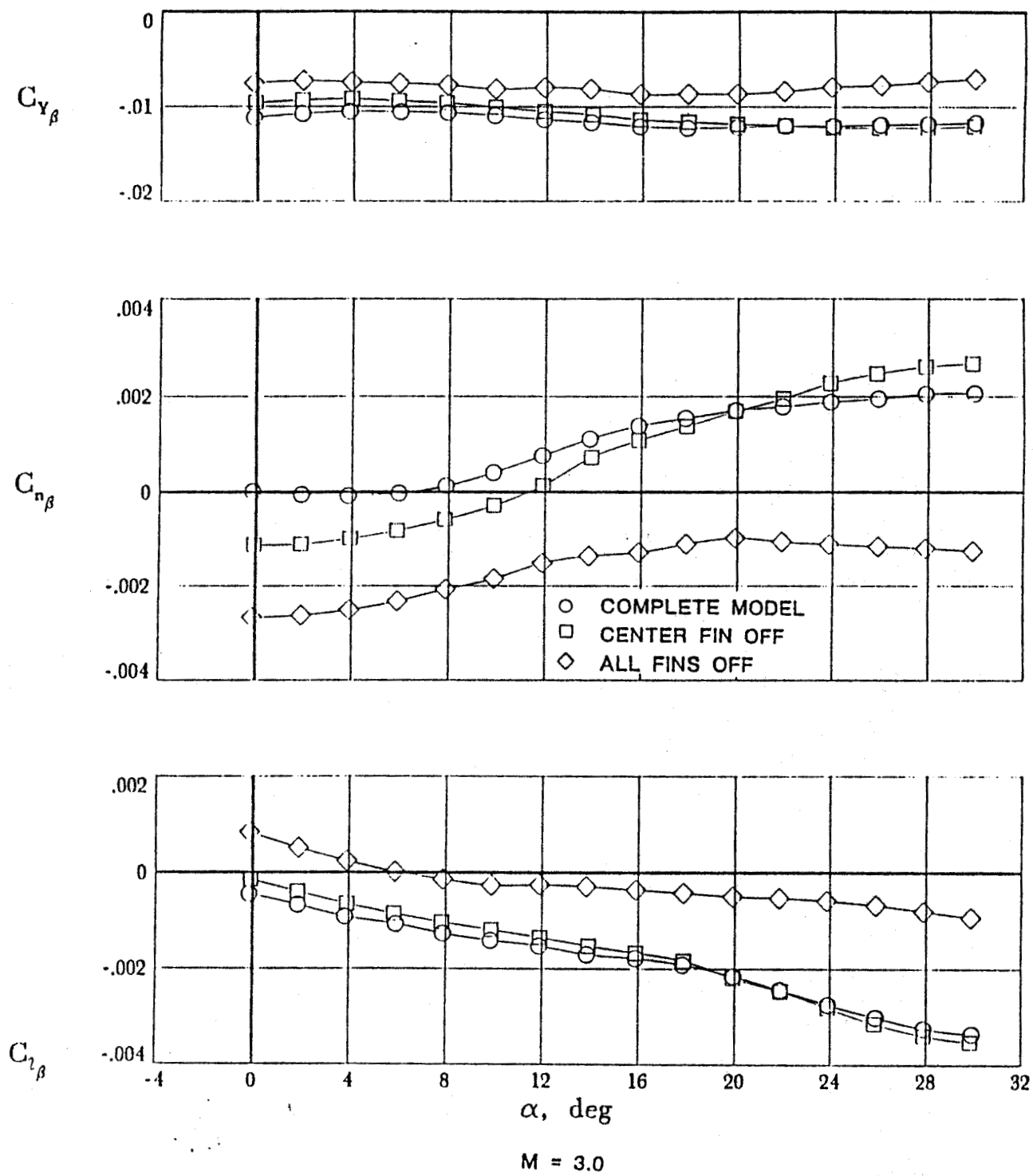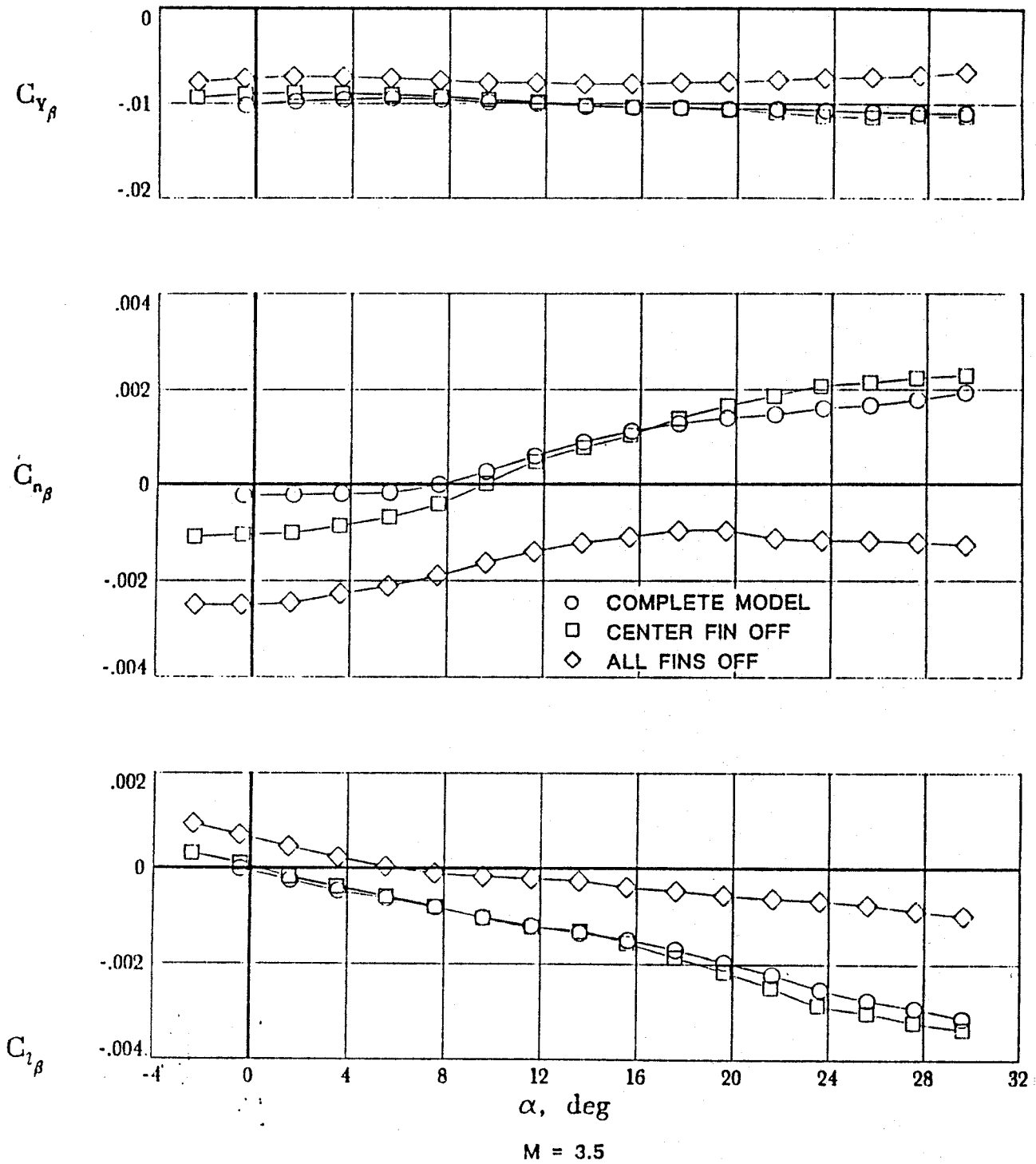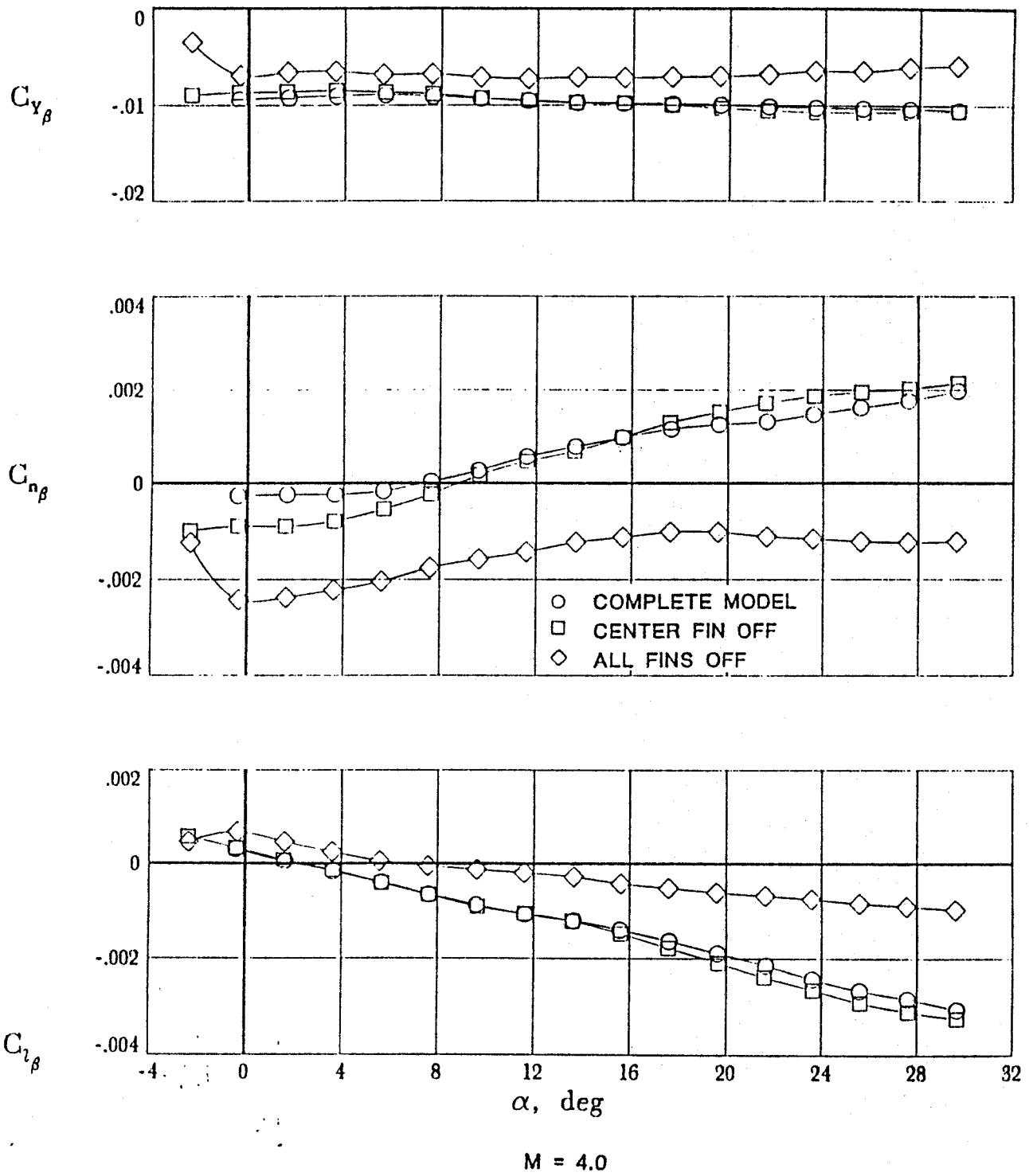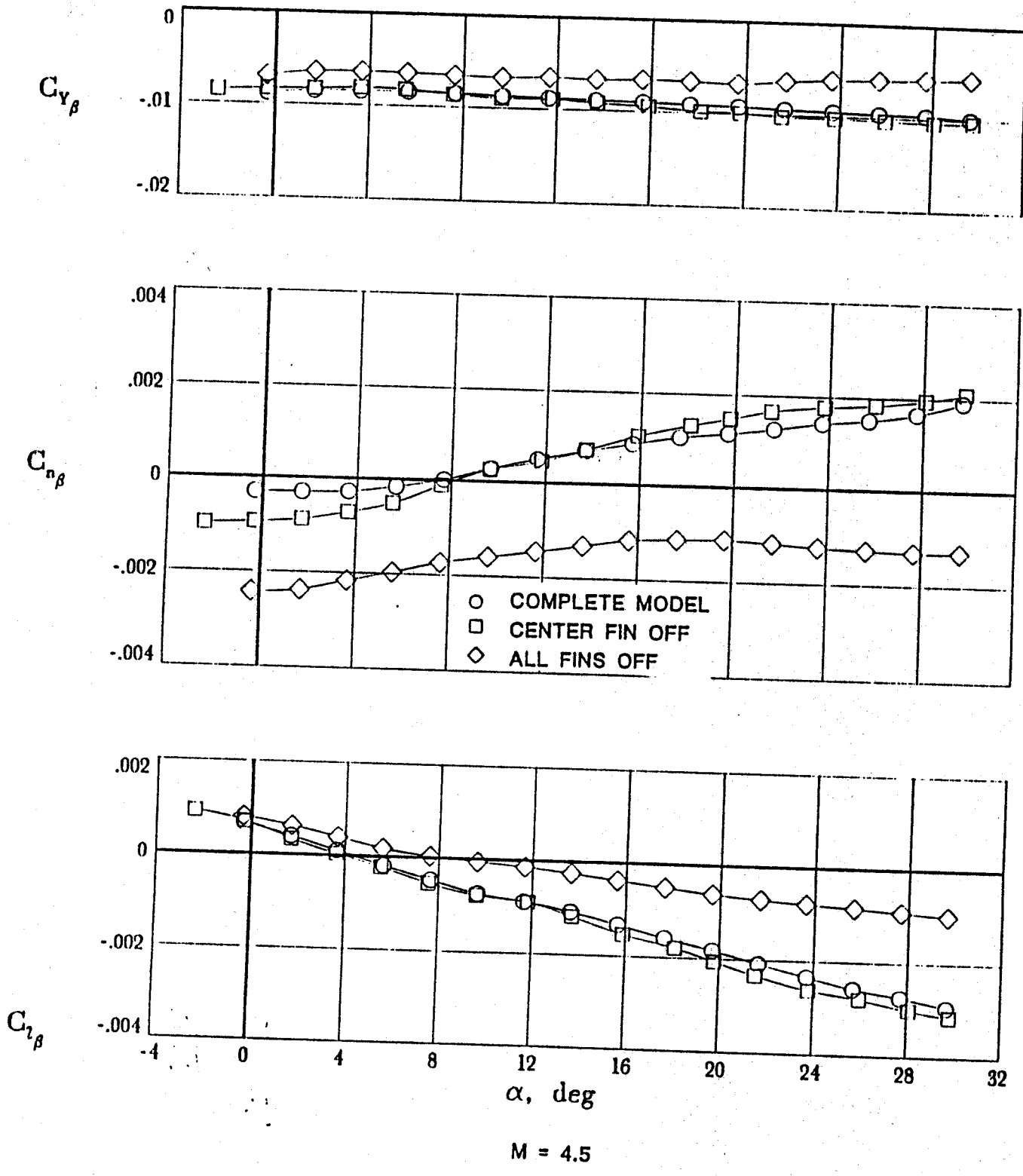
Figure 25. Concluded.
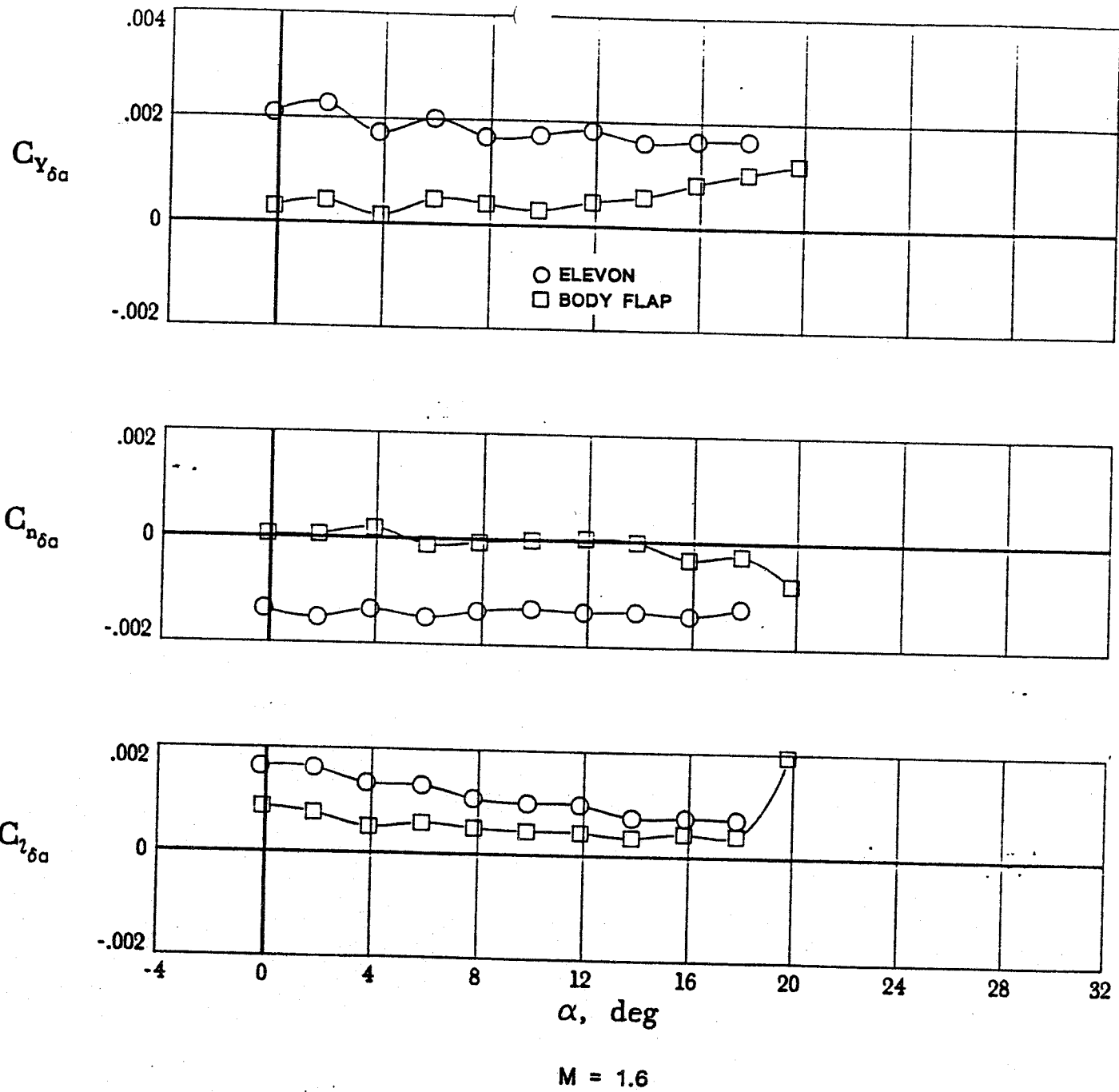
Figure 26. Supersonic roll control effectiveness.
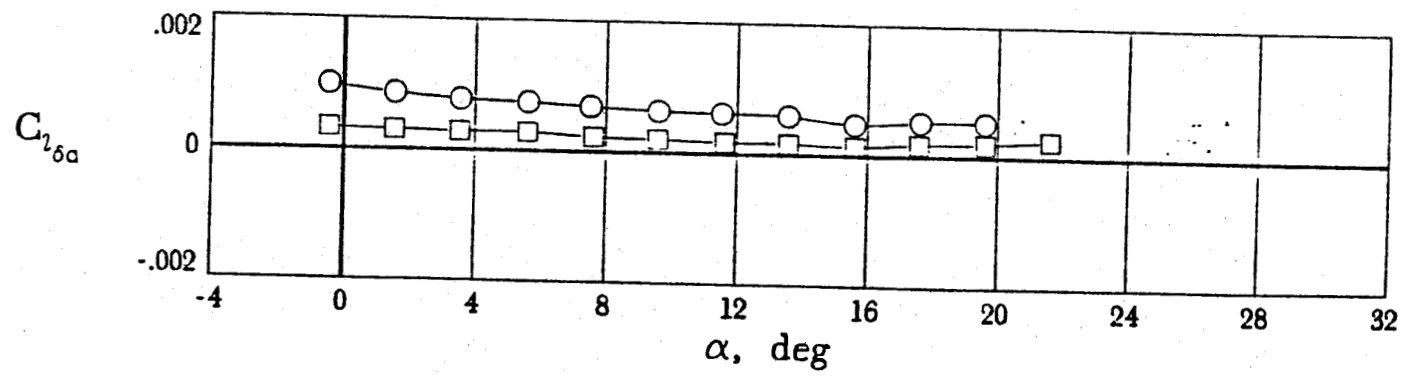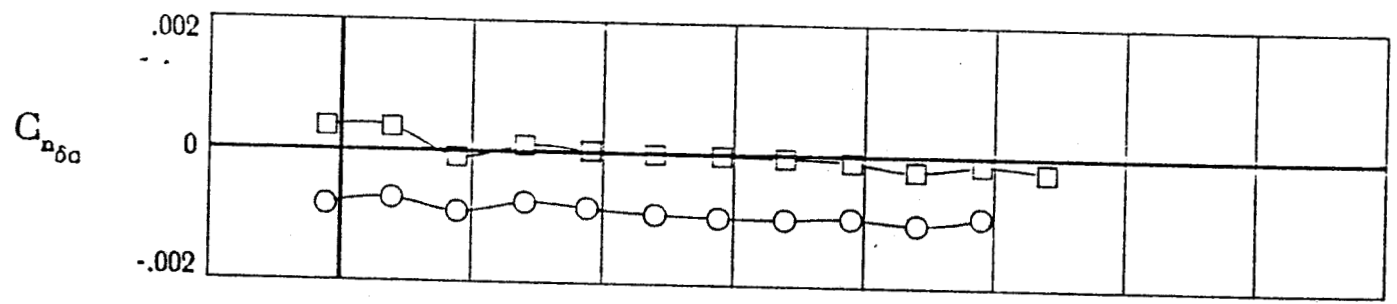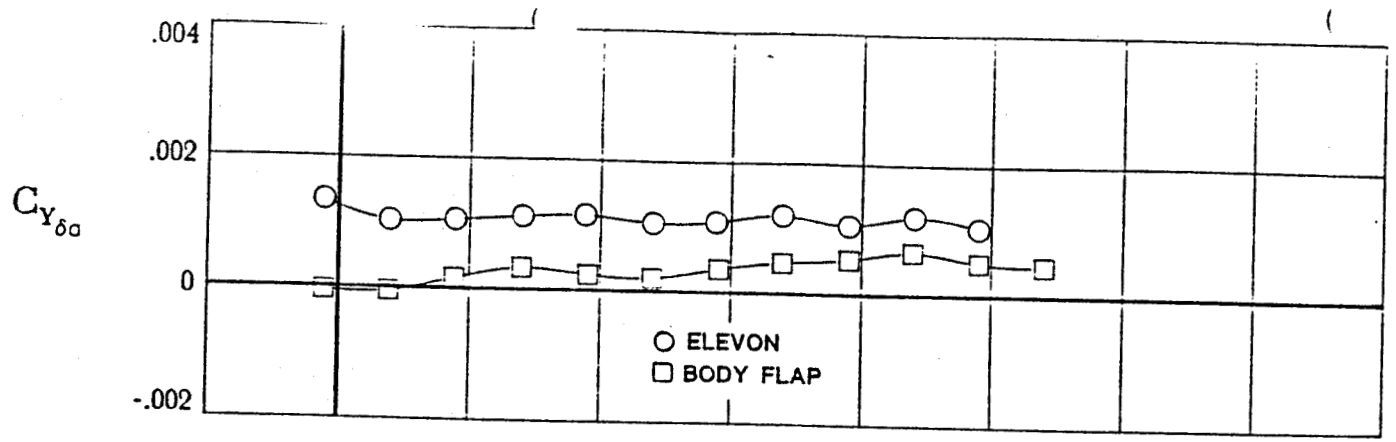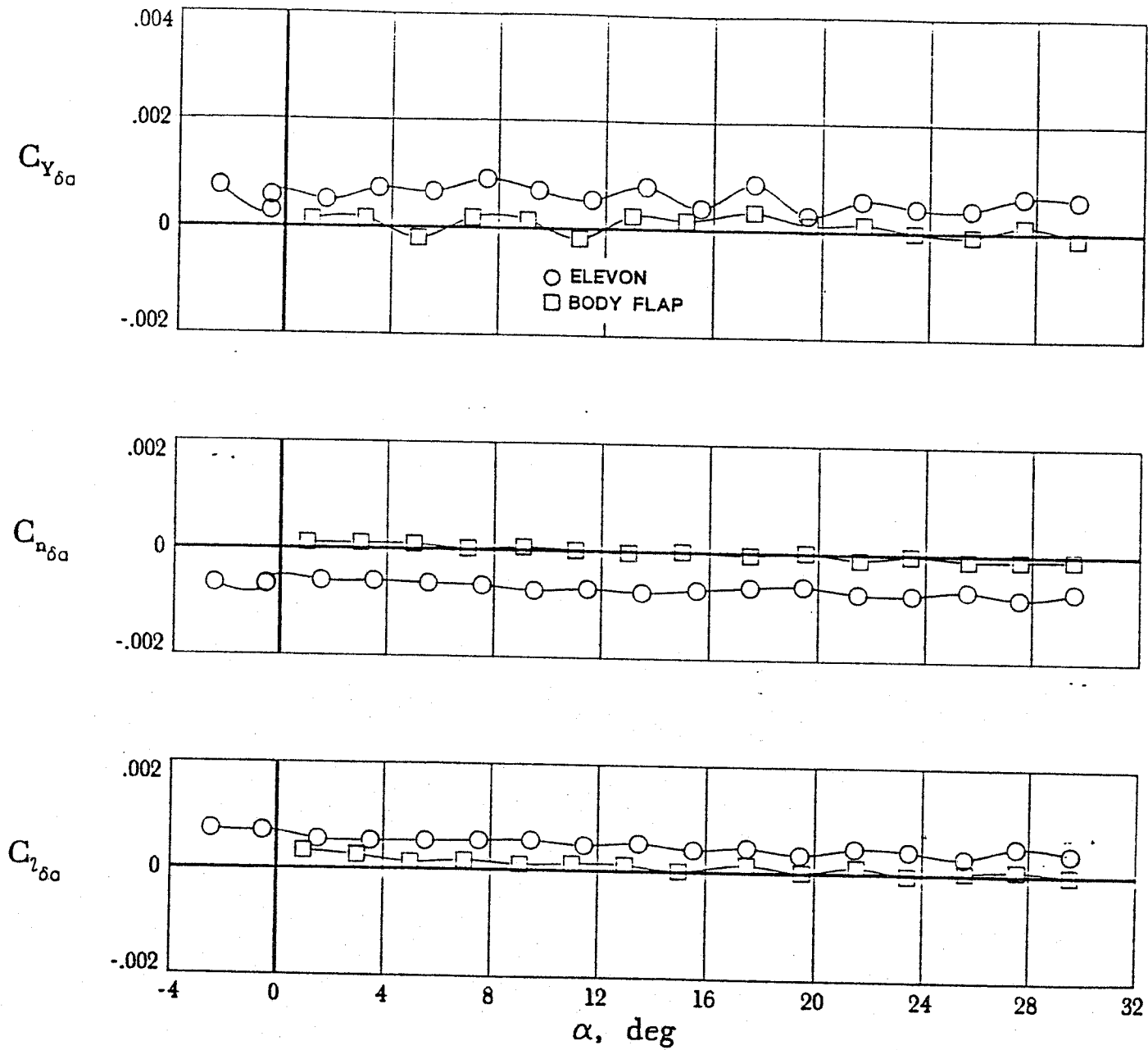
Figure 26. Continued.

Figure 26. Continued.

Figure 26. Continued.

M = 3.0

Figure 26. Continued.
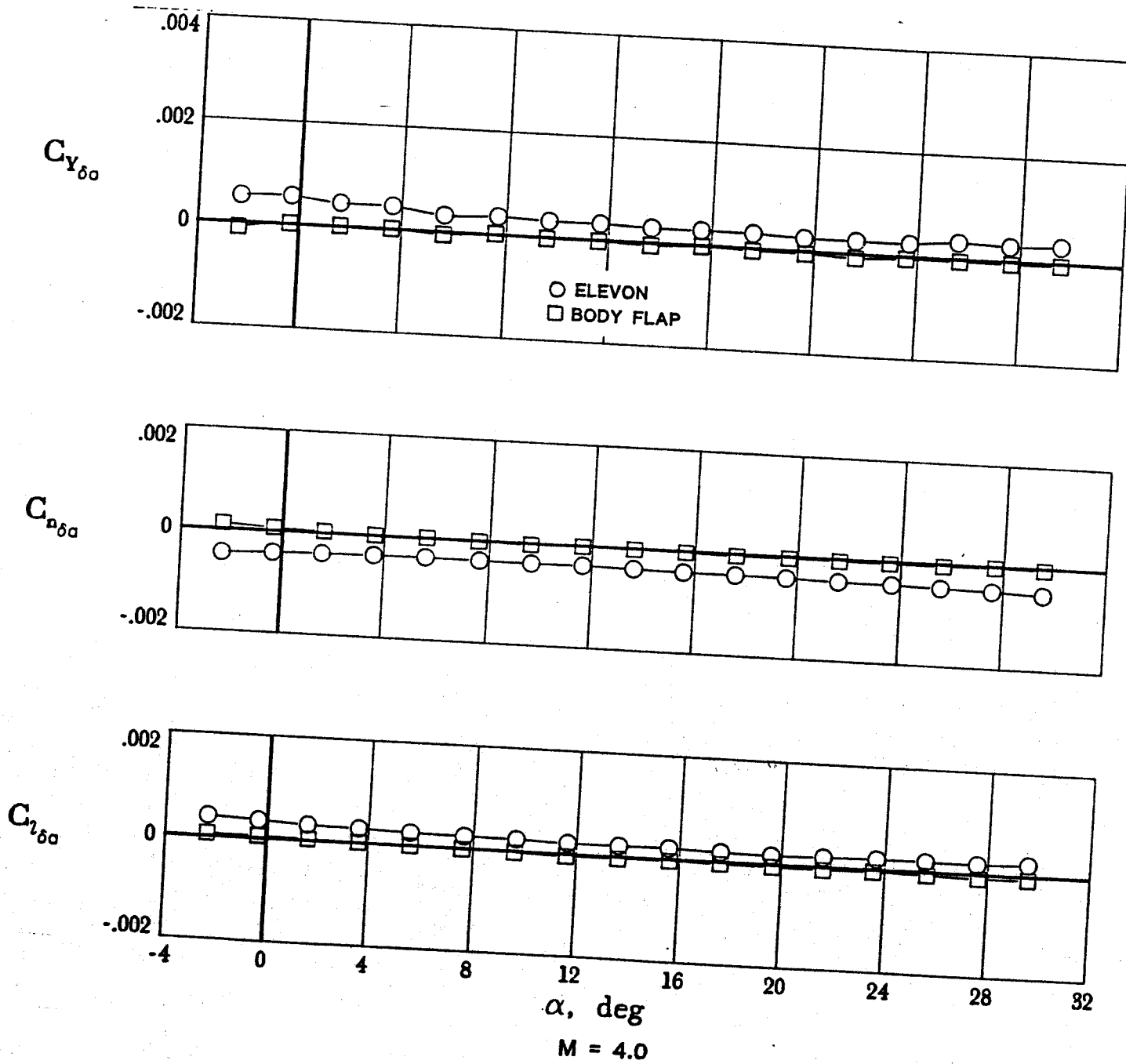
Figure 26. Continued.

Figure 26.    Concluded.
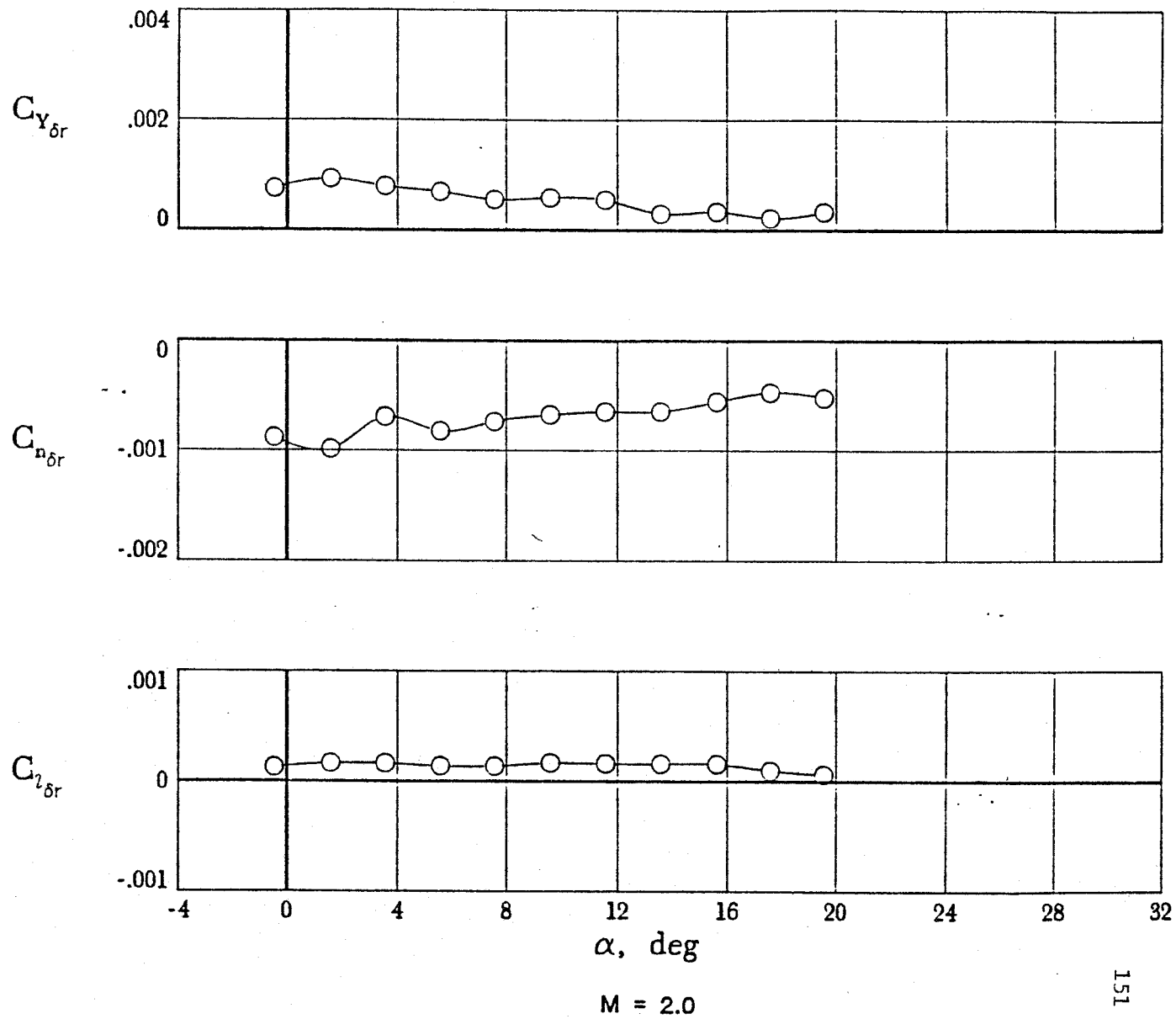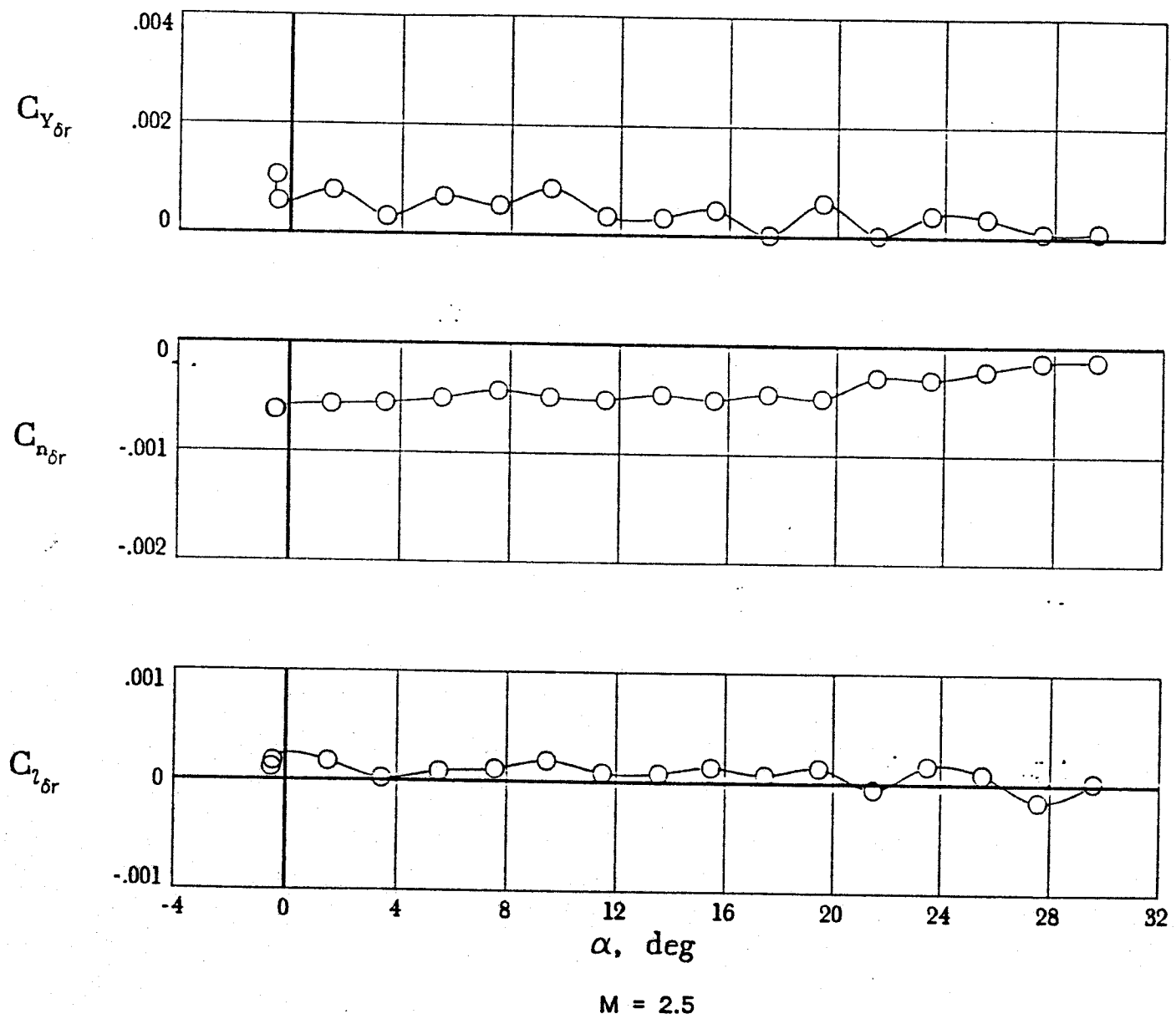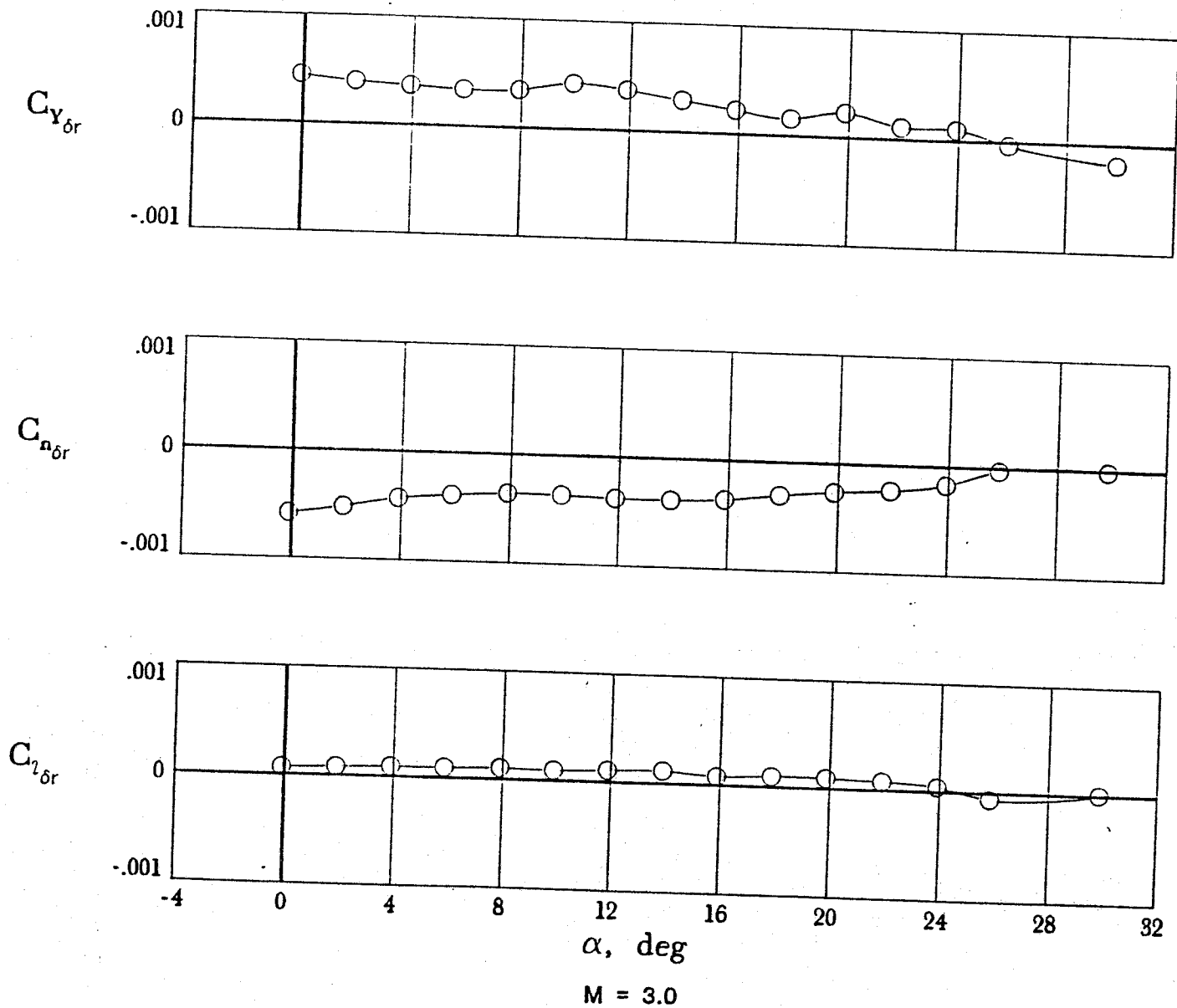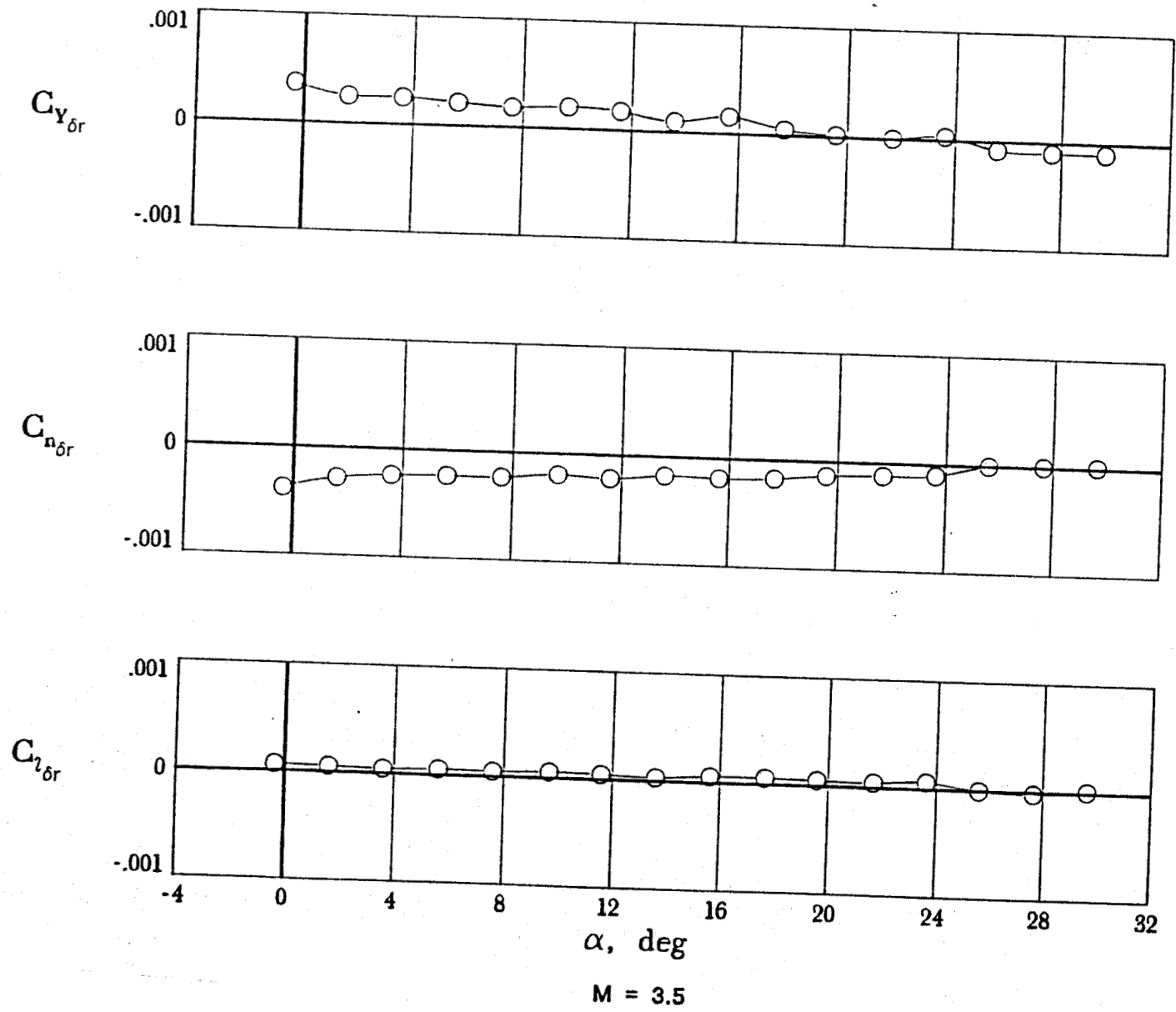
Figure 27. Supersonic yaw control effectiveness.

$M = 1.6$

Figure 27.    Continued.

Figure 27. Continued.

M = 2.5

$\alpha$, deg

M = 3.0

Figure 27.    Continued.

Figure 27.    Continued.
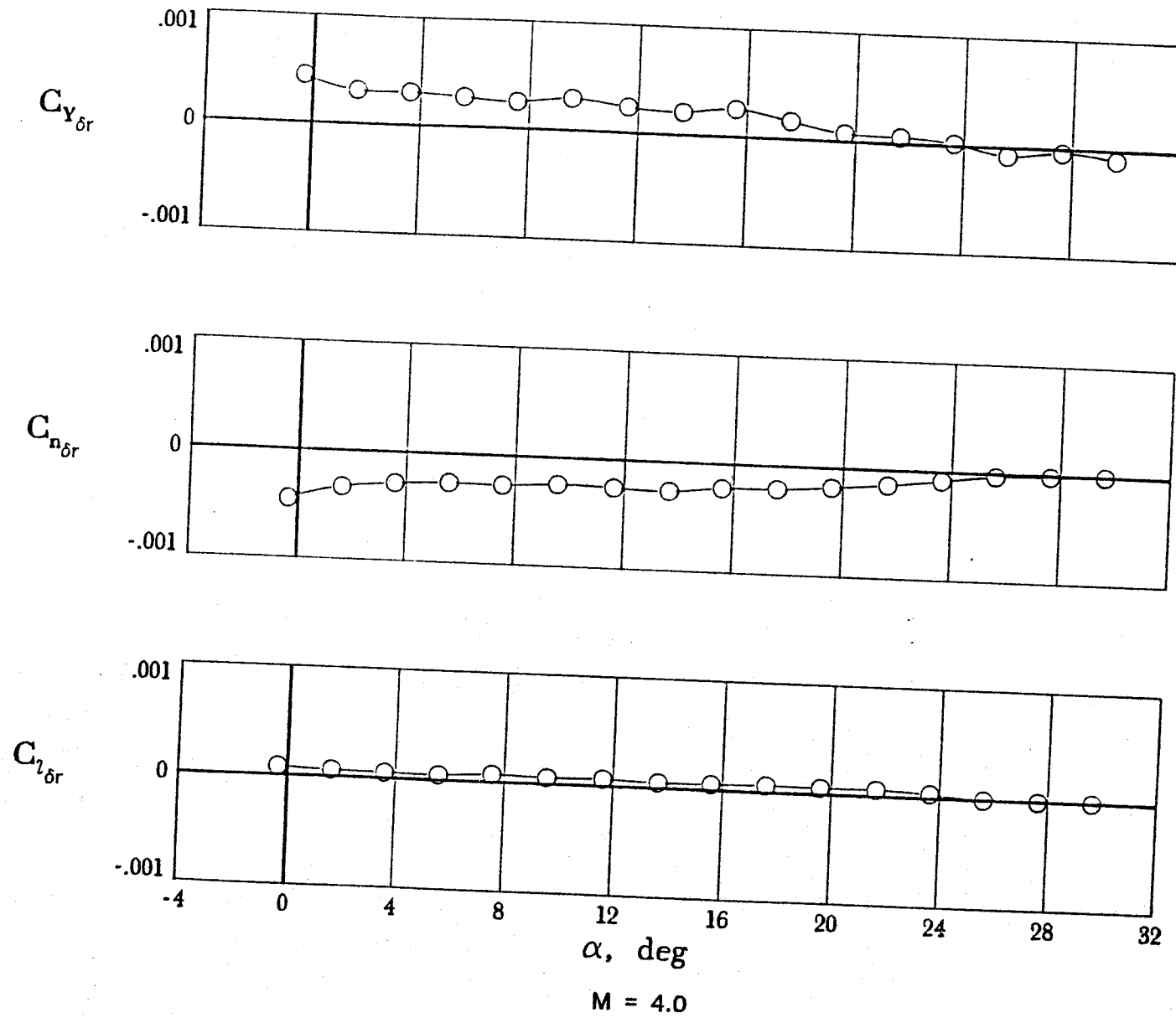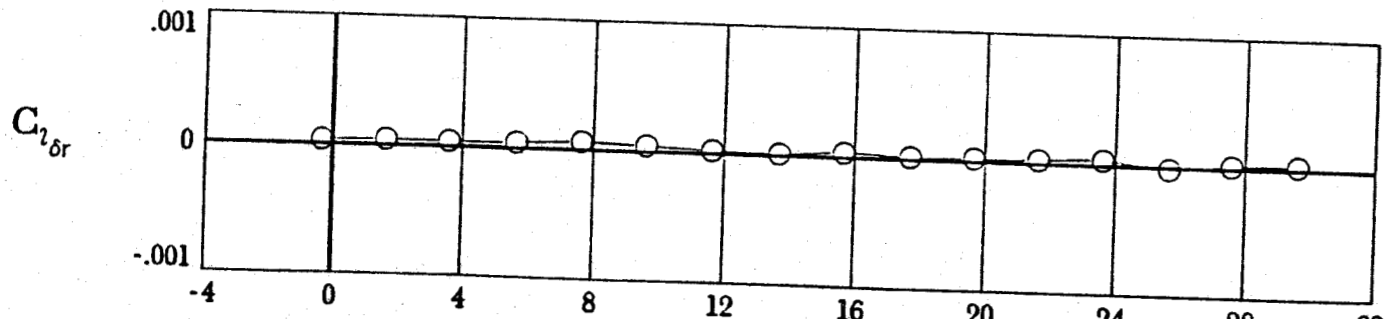
M = 3.5

Figure 27. Continued.
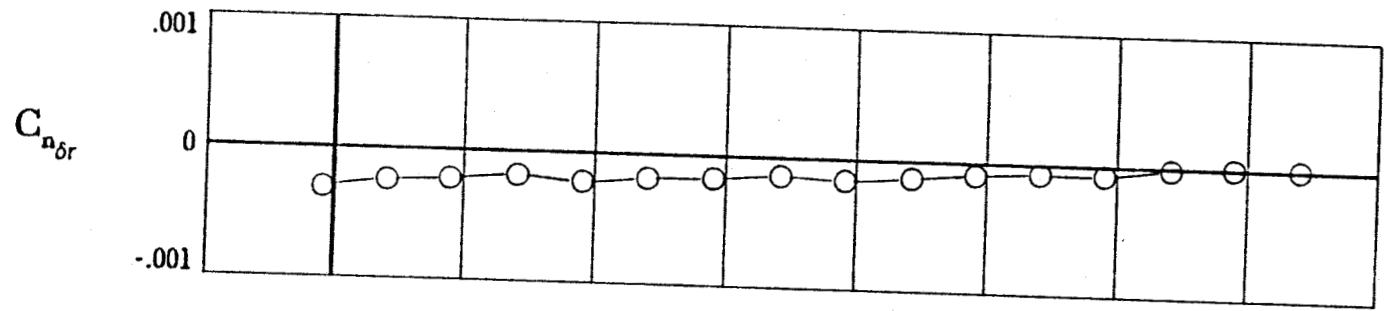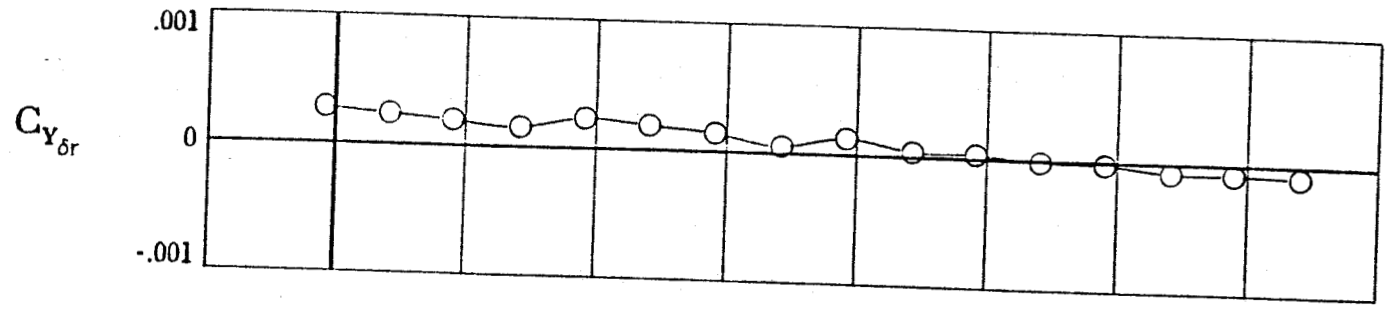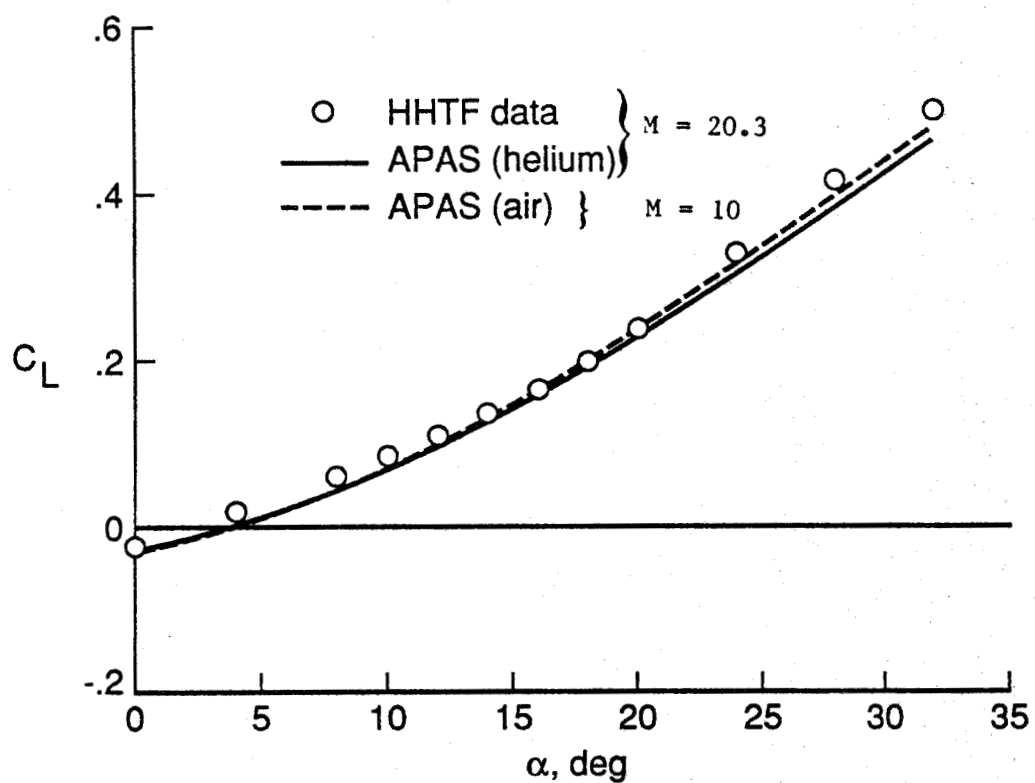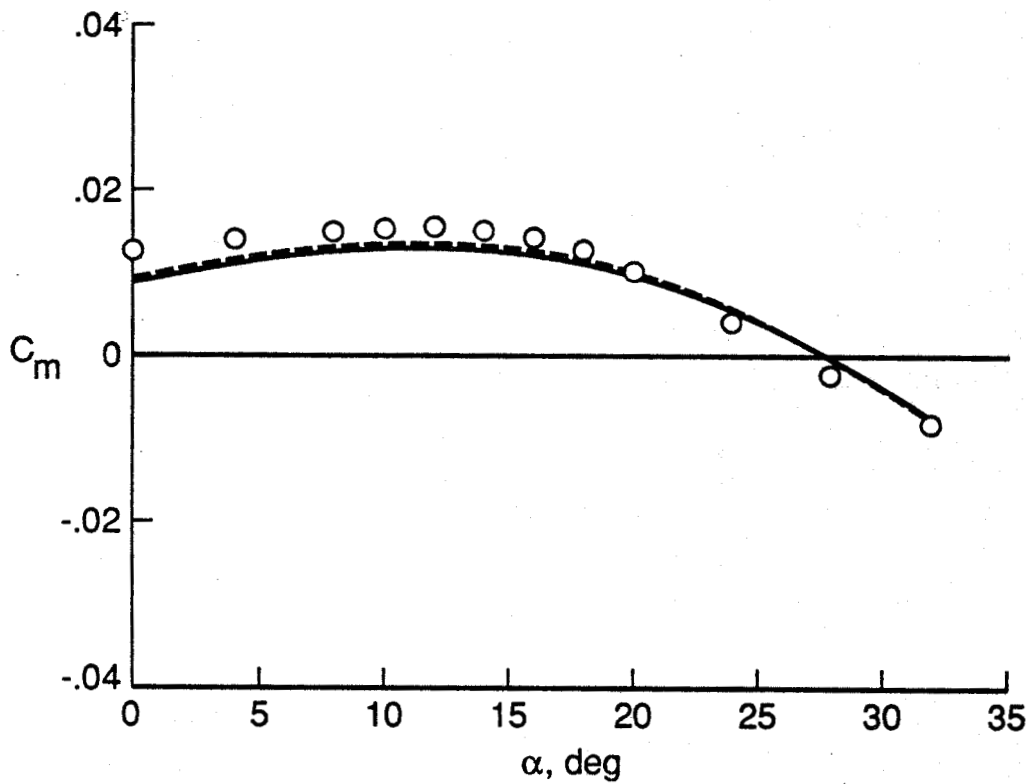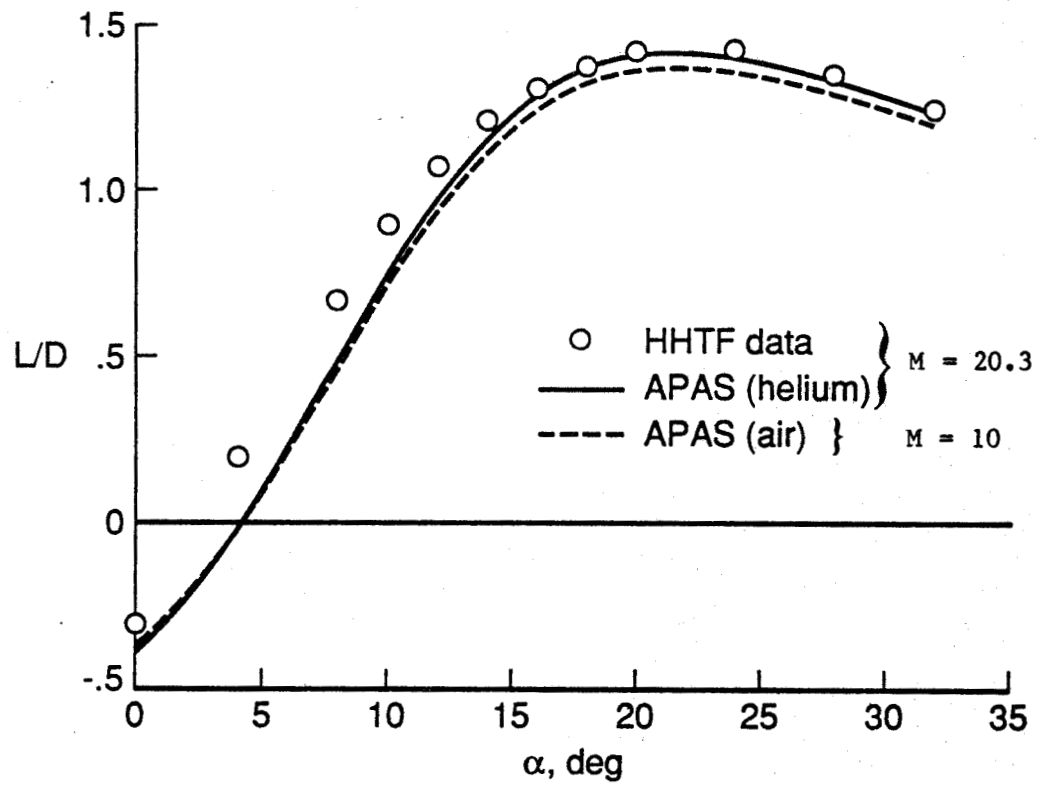
Figure 27. Concluded.
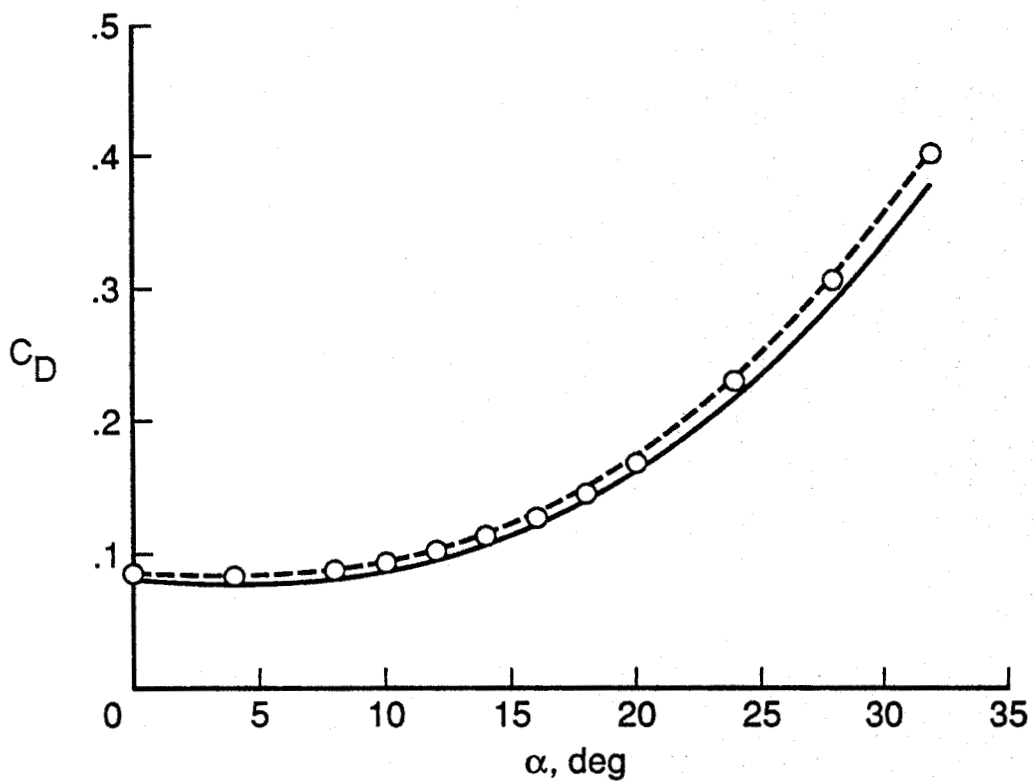
(a) $C_L$ versus $\alpha$ and $C_D$ versus $\alpha$.

Figure 28. Longitudinal aerodynamics of the proposed PLS vehicle at hypersonic speeds.

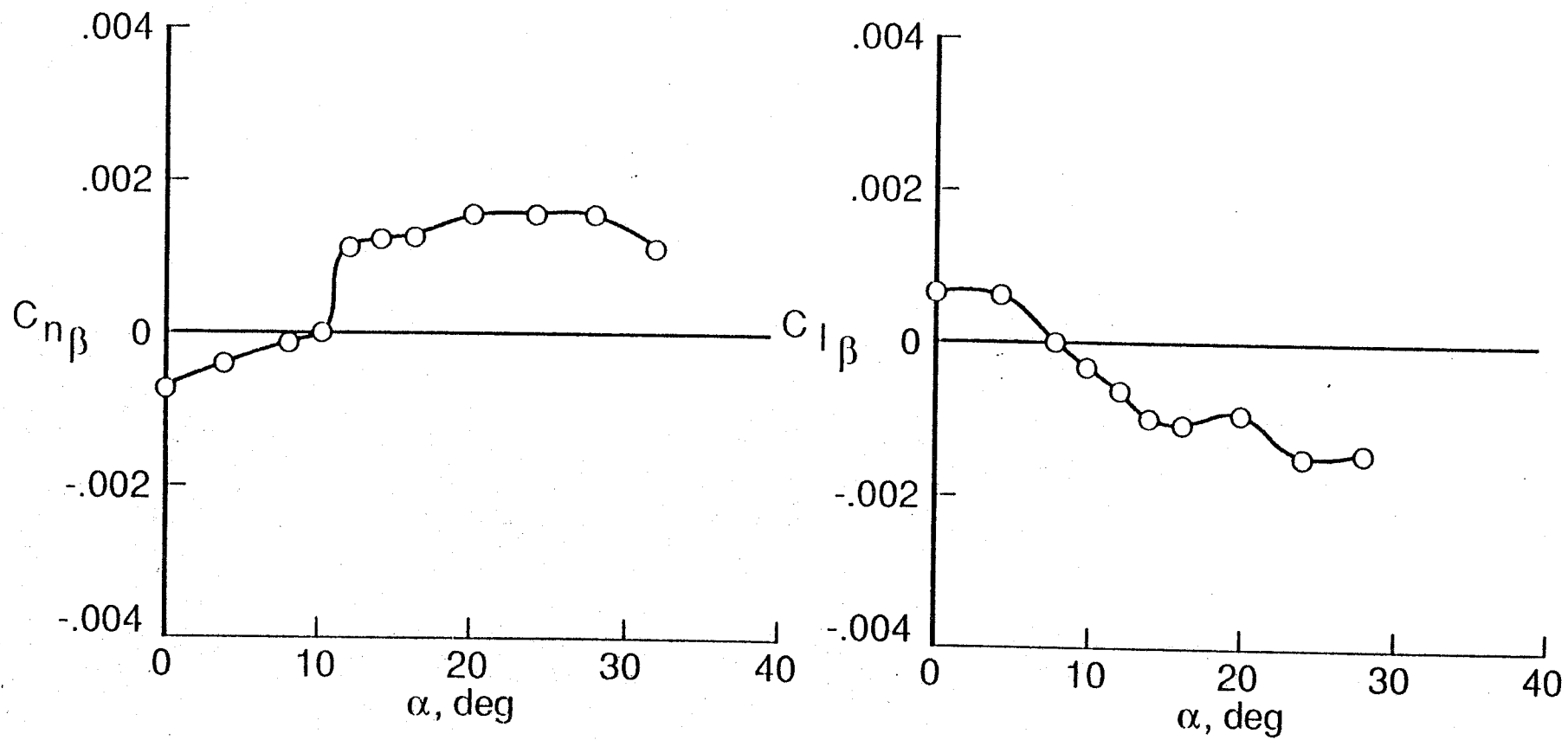(b) L/D versus $\alpha$ and $C_m$ versus $\alpha$.

Figure 28. Concluded.

Figure 29. Lateral-directional aerodynamics of the proposed PLS vehicle at Mach 20.3 in helium.

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**15. Supplementary Notes**

**16. Abstract**

A wind-tunnel investigation has been performed to determine the aerodynamic characteristics of a proposed lifting-body personnel launch system (PLS) configuration over a Mach range of 0.05 to 20.3. The test configuration had a low-aspect-ratio body with a flat undersurface and three fins on the upper aft body. Data are presented with a minimum of analysis.

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