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TECHNICAL MEMORANDUM
X-178

EXPLORATORY INVESTIGATION AT MACH NUMBER OF 2.01 OF THE LONGITUDINAL STABILITY AND CONTROL CHARACTERISTICS OF A WINGED REENTRY CONFIGURATION

By Gerald V. Foster

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Page 2: The sentence beginning on line 17 should be changed to read as follows:

The moment reference point is located at a longitudinal station corresponding to the 63.64-percent root-chord station (1.61 percent mean geometric chord forward of wing center of area).

Page 8, Figure 1(a): The dimension from the wing apex to moment reference center should be changed from 11.78 to 11.07.

NASA - Langley Field, Va.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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EXPLORATORY INVESTIGATION AT MACH NUMBER OF 2.01 OF THE LONGITUDINAL STABILITY AND CONTROL CHARACTERISTICS OF A WINGED REENTRY CONFIGURATION

By Gerald V. Foster

SUMMARY

An investigation has been conducted to determine the longitudinal stability and control characteristics of a reentry configuration at a Mach number of 2.01. The configuration consisted of clipped delta wing with hinged wing-tip panels.

The results indicate that deflecting the wing-tip panels from a position normal to the wing chord plane to a position coincident with the wing chord plane resulted in a stabilizing change in the pitching-moment characteristics but did not significantly affect the nonlinearity of the pitching-moment variation with angle of attack.

The trailing-edge controls were effective in producing pitching moment throughout the angle-of-attack range for control deflections up to at least 60°. The control deflection required for trim, however, varied nonlinearly with angle of attack. It would appear that this nonlinearity as well as the maximum deflection required for trim could be greatly decreased by utilizing a leading-edge control in conjunction with a trailing-edge control.

INTRODUCTION

A general investigation is being conducted by the National Aeronautics and Space Administration to determine aerodynamic information through a wide range of Mach numbers upon which preliminary design studies of the stability and control characteristics of reentry vehicles can be based. The initial effort has been directed toward a study of the effects of wing plan form on the aerodynamic characteristics of reentry configurations at angles of attack up to 90° at high subsonic speeds (ref. 1). The present investigation has been conducted at a Mach number of 2.01 in the Langley 4- by 4-foot supersonic pressure tunnel to determine the longitudinal stability and control characteristics of a reentry configuration having a clipped delta wing with wing-tip panels which could be deflected upward from 0° to 90° with respect to the wing chord plane. The model with the wing-tip panels deflected 90° simulates a reentry configuration, whereas the model with the wing-tip panels at 0° simulates a glide-landing configuration. The effects of some flap-type controls were investigated on the configuration with wing-tip panels deflected 90°. The results obtained during this investigation of the various configurations through an angle-of-attack range from 0° to 90° are presented herein.

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5

SYMBOLS

All coefficients presented herein are referred to the body-axis system except the lift and drag coefficients which are referred to the stability-axis system. The moment reference point is located at a longitudinal station corresponding to the 65.7-percent root-chord station.

The coefficients and symbols are defined as follows:

C_L lift coefficient, Lift/qS

C_N normal-force coefficient, Normal force/qS

C_D drag coefficient, Drag/qS

C_A axial-force coefficient, Axial force/qS

C_m pitching-moment coefficient, Pitching moment/$qS\bar{c}$

q free-stream dynamic pressure, lb/sq ft

S wing area excluding hinged wing tips and controls, sq ft

$\bar{c}$ wing mean geometric chord (based on plan form with tips deflected 90°), ft

M free-stream Mach number

α angle of attack, deg

δ_{LE} leading-edge control deflection, positive for control leading edge deflected up, deg

δ_t wing-tip deflection, positive for wing tips deflected up, deg

δ_f trailing-edge control deflection, positive for control trailing edge deflected up, deg

δ_{trim} control deflection required for trim, deg

L/D lift-drag ratio, C_L/C_D

MODEL AND APPARATUS

The model used during these tests consisted of a clipped delta wing with a body having a fineness ratio of 5.12. The arrangement and details of the model components are shown in figure 1. The wing, constructed of 0.25-inch-thick sheet metal, had rounded leading edges and leading-edge sweepback of 73°. The wing was tested with two sets of hinged wing-tip panels, one having a trapezoidal plan form, the other a rectangular plan form. The trapezoidal wing-tip panel, referred to herein as the "large wing tip," had approximately twice the projected area of the rectangular panel, which is referred to as the "small wing tip." These wing tips could be deflected from a position coincident with the wing chord plane to a position normal to the chord plane (fig. 1). The pitch-control devices consisted of a trailing-edge flap-type control and two leading-edge controls located near the wing apex. The two leading-edge controls differed in projected area by a factor of 2.

The model was mounted in the tunnel by a support system which permitted variation of the angle of attack from 0° to 90° (fig. 2). The force and moment characteristics were obtained through the use of an internal six-component strain-gage balance. In varying the model angle of attack, the model was rotated about a point which coincides with the balance center.

TESTS, CORRECTIONS, AND ACCURACY

The tests were made in the Langley 4- by 4-foot supersonic pressure tunnel which is briefly described in reference 2. The tests were made at a Mach number of 2.01, a stagnation temperature of 100° F, and a stagnation pressure of 4 pounds per square inch absolute. The Reynolds number, based on the mean geometric chord, was 1.03×10^{6}. The stagnation dewpoint was maintained sufficiently low (-25° F or below) to prevent condensation effects from being encountered in the test section. Tests were made through an angle-of-attack range from 0° to 90° at a sideslip angle of 0°.

The angles of attack were corrected for the deflections of the balance and sting under load. The axial-force data presented herein included pressure drag acting on the model base. The model-support method used in these tests may introduce sting-interference effects at large angles of attack; however, tests to determine these effects were not made. Some unpublished results obtained with an 8.56-inch circular disk mounted on the support systems used in the present tests indicate that the center of pressure of $\alpha = 90^{\circ}$ is approximately 0.02 diameter rearward of the center of area.

Estimated probable errors in the force and moment data based on the repeatability of the results, zero shifts, calibration, and random errors of instruments are as follows:

C_N	±0.015
C_A	±0.003
C_m	±0.002
α, deg	±0.1
M	±0.01

PRESENTATION OF RESULTS

Schlieren photographs of the model with and without tips deflected are presented as figure 3. Other results are presented in the following figures:

	Figure
Effect of large wing tips at various deflection angles on the aerodynamic characteristics	4
Effect of small wing tip at various deflection angles on the aerodynamic characteristics	5
Effect of leading-edge controls on the aerodynamic characteristics of model with large wing tips at $\delta_t = 90^{\circ}$	6
Effect of trailing-edge control on the aerodynamic characteristics of model with large wing tips at $\delta_t = 90^{\circ}$	7
Variation of control deflection required for trim with α . . .	8

DISCUSSION

Effects of Wing-Tip Deflection

The results presented in figures 4 and 5 indicate that deflecting the wing tips from a position normal to the wing chord plane $\left(\delta_t = 90^\circ\right)$ to a position coincident with the wing chord plane $\left(\delta_t = 0^\circ\right)$ resulted in an increase in negative C_m throughout the angle-of-attack range since the wing tips were located aft of the moment reference point. The pitching moment varied nonlinearly with α regardless of wing-tip deflection. The pitching moments indicate a pitch-up tendency at angles of attack of approximately 30° with wing tip deflected to either 60° or 90°, and at angles of attack of approximately 40° with the wing tips deflected either 0° or 20°. Above an angle of attack of approximately 60°, the pitching-moment variation again becomes stable for the assumed center-of-gravity location. Comparison of the results presented in figures 4 and 5 indicates that decrease in wing-tip size had no appreciable effect on the aerodynamic characteristics of the configuration with the wing tips normal to the chord plane. With the wing tips deflected $\left(\delta_t = 0^\circ\right.$ and $\left.20^\circ\right)$, however, the change in pitching moment is less at a given value of α for the smaller wing-tip control.

Effect of Control Devices

The effects of leading-edge and trailing-edge controls on the longitudinal aerodynamic characteristics of the model with the large wing tips at $\delta_t = 90^\circ$ are shown in figures 6 and 7, respectively. In general, the addition of leading-edge controls (fig. 6) resulted in a gradually increasing increment in pitching-moment coefficient with increasing angle of attack up to about $\alpha = 45^\circ$. At angles of attack greater than about 45°, the effects of large leading-edge control $\left(\delta_{LE} = 0^\circ\right)$ are approximately constant whereas the effects of the small leading-edge control decreased. A comparison of the pitching-moment-coefficient increment due to the small and large leading-edge controls at angles of attack greater than 45° (fig. 6) would appear to indicate that the effectiveness of this type of control is approximately proportional to the projected area of the control. Estimates were made of the pitching-moment contribution of these leading-edge controls for an angle of attack of 90°. Based on a flat-plate drag coefficient of 1.9, estimated pitching moment due to the small controls agrees with the pitching-moment increment obtained experimentally; whereas, a similar estimate for the large leading-edge control was approximately 50 percent of the experimental increment.

The results presented in figure 7 indicate that the trailing-edge control is effective in producing pitching moment throughout the angle-of-attack range for control deflection angles up to at least 60°. Because of the nonlinear pitching-moment characteristics of the model, the variation of trailing-edge control deflection required for trim with angle of attack is decidedly nonlinear (fig. 8). Figure 8 also indicates that the use of the large leading-edge controls in conjunction with the trailing-edge controls would reduce the nonlinearity as well as decrease the range of trailing-edge control angles required for trim provided the leading-edge control introduced no interference effects.

CONCLUDING REMARKS

The results of an investigation at a Mach number of 2.01 of the longitudinal aerodynamic characteristics of a reentry configuration having a clipped delta wing with deflectable tips indicate that deflecting the wing tips from a position normal to a position coincident with the wing chord plane resulted in a stabilizing change in the pitching-moment characteristics but did not significantly affect the nonlinearity of the pitching-moment variation with angle of attack.

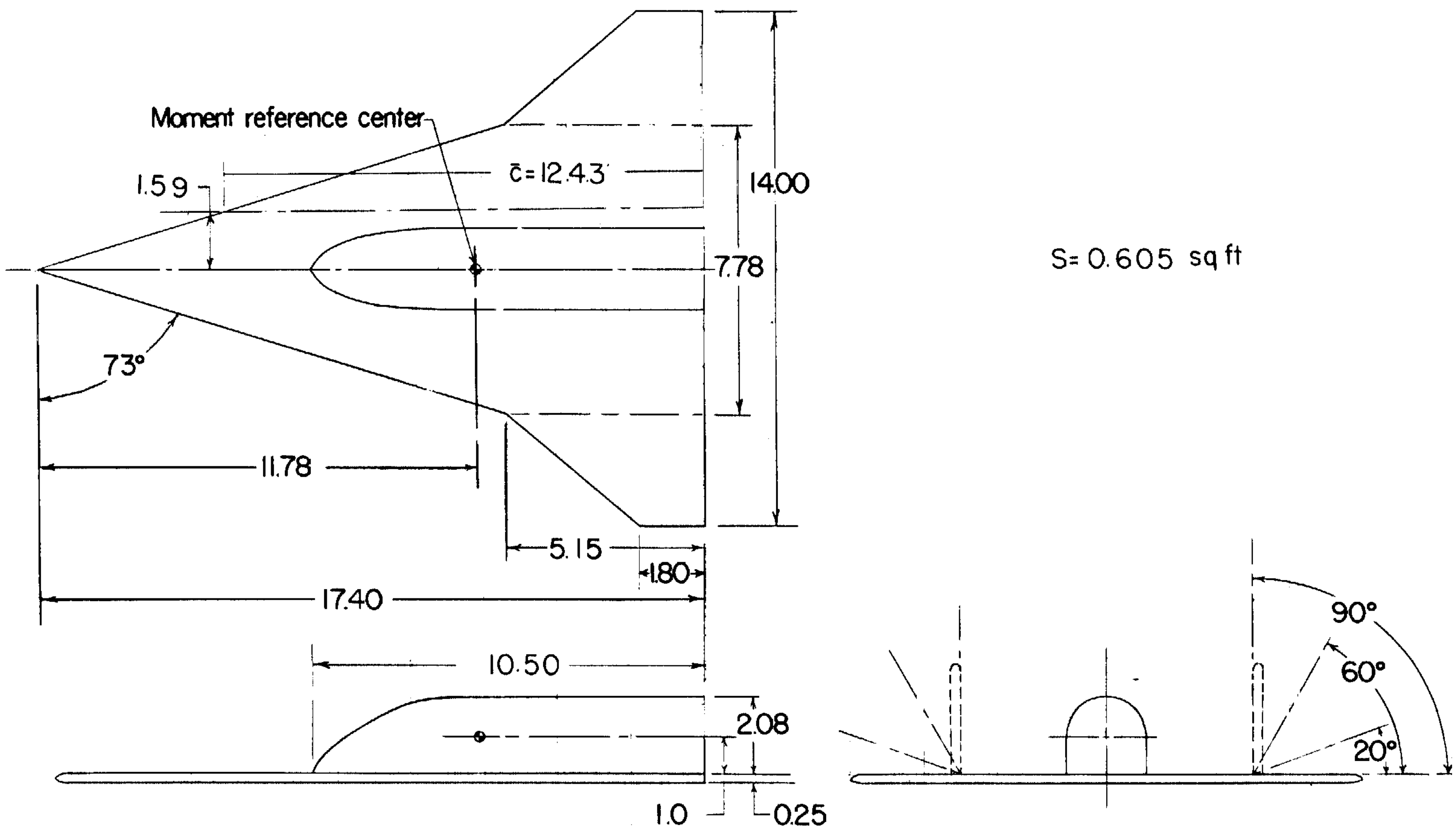
The trailing-edge controls were effective in producing pitching moment throughout the angle-of-attack range for control deflections up to at least 60°. The control deflection required for trim, however, varied nonlinearly with angle of attack. It would appear that this nonlinearity as well as the maximum deflection required for trim could be greatly decreased by utilizing a leading-edge control in conjunction with trailing-edge controls.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., August 17, 1959.

REFERENCES

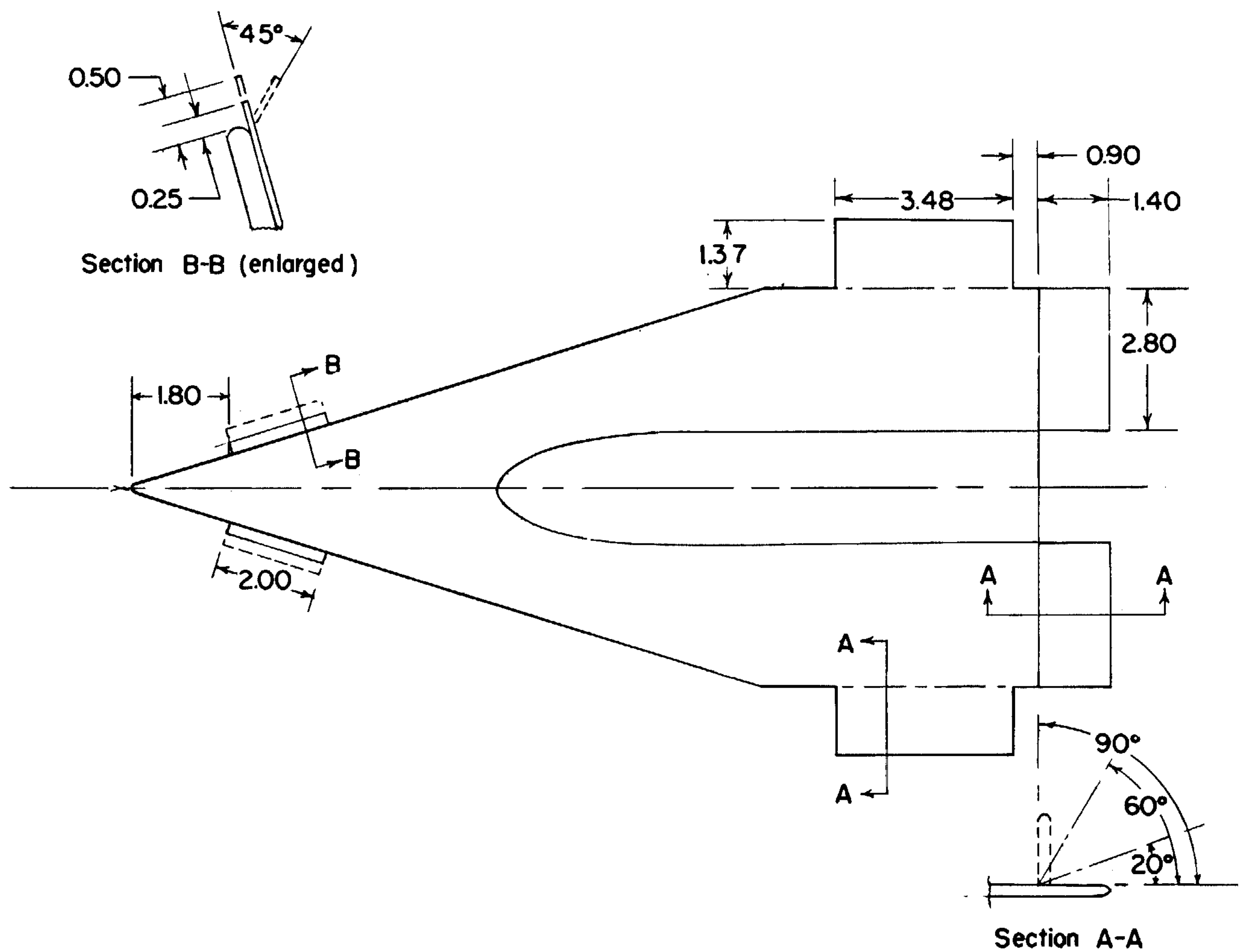
1. Spencer, Bernard, Jr.: High-Subsonic-Speed Investigation of the Static Longitudinal Aerodynamic Characteristics of Several Delta-Wing Configurations for Angles of Attack From 0° to 90°. NASA TM X-168, 1959.

2. Robinson, Ross B., and Driver, Cornelius: Aerodynamic Characteristics at Supersonic Speeds of a Series of Wing-Body Combinations Having Cambered Wings With an Aspect Ratio of 3.5 and a Taper Ratio of 0.2 - Effects of Sweep Angle and Thickness Ratio on the Aerodynamic Characteristics in Pitch at $M = 1.60$. NACA RM L51K16a, 1952.



(a) Model with large wing tip.

Figure 1.- Details of model. All dimensions are in inches unless otherwise noted.



(b) Model with small wing tip and leading- and trailing-edge controls.

Figure 1.- Concluded.

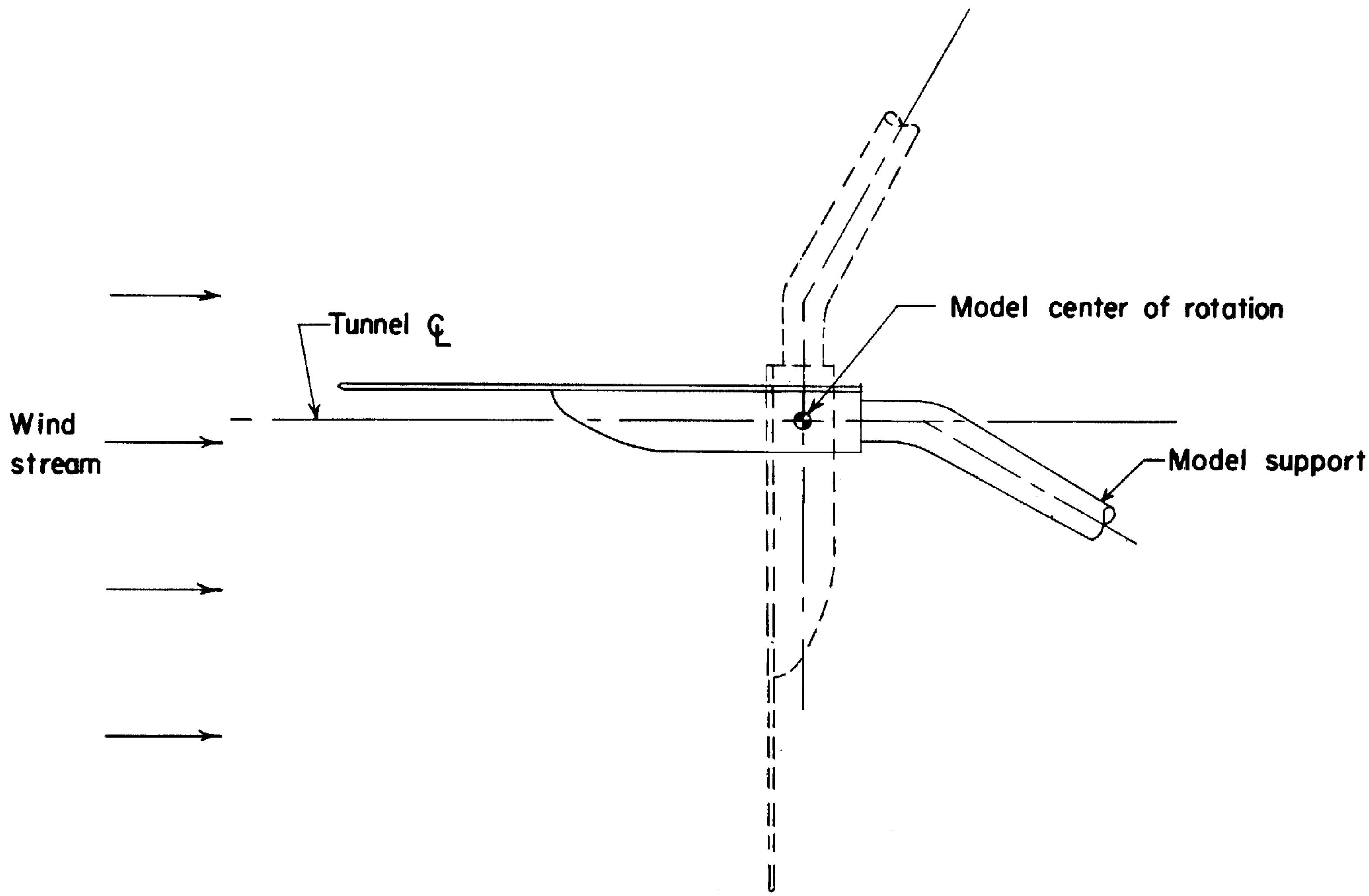


Figure 2.- Schematic diagram illustrating model test position at angles of attack of 0° and 90°.

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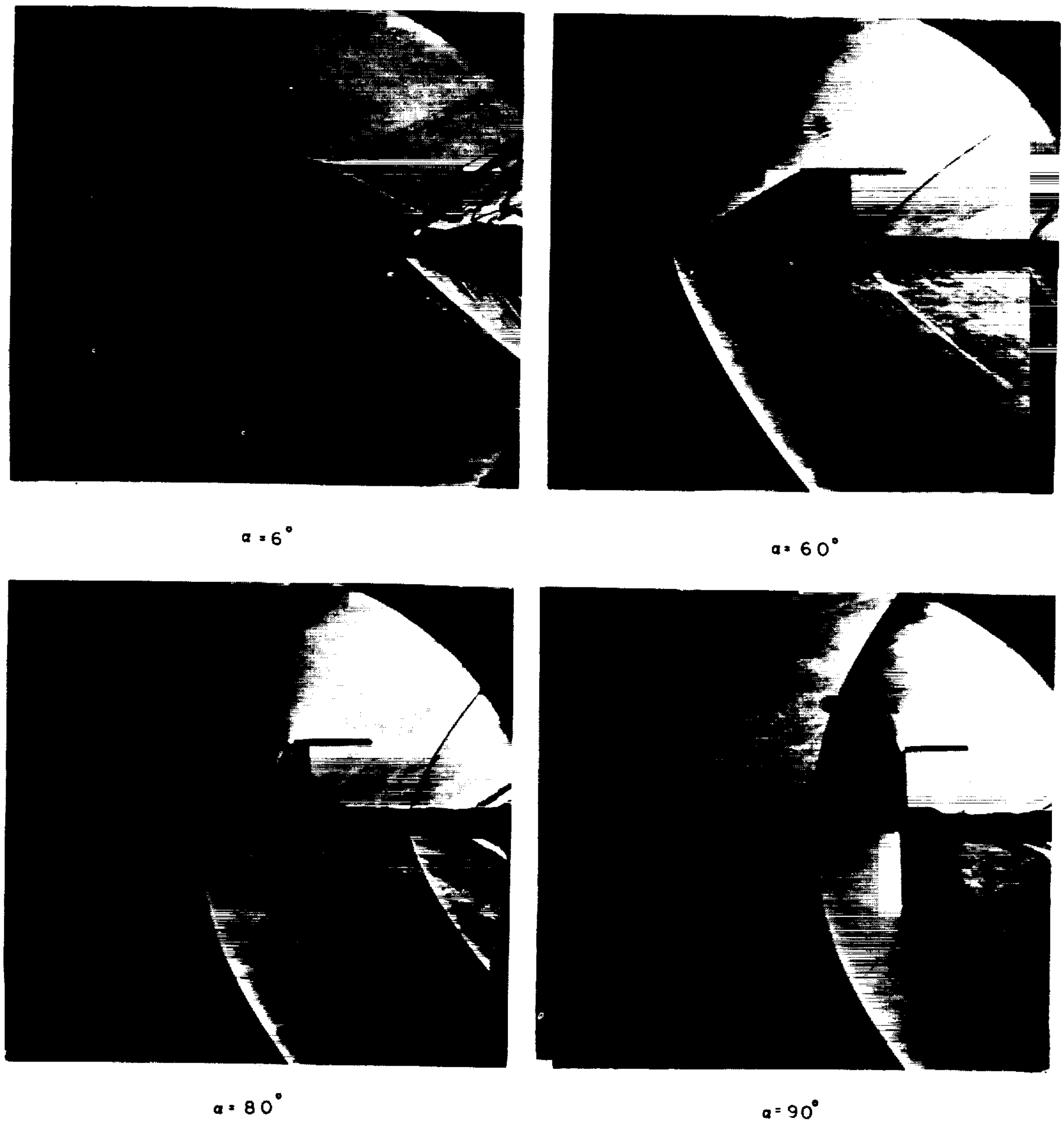
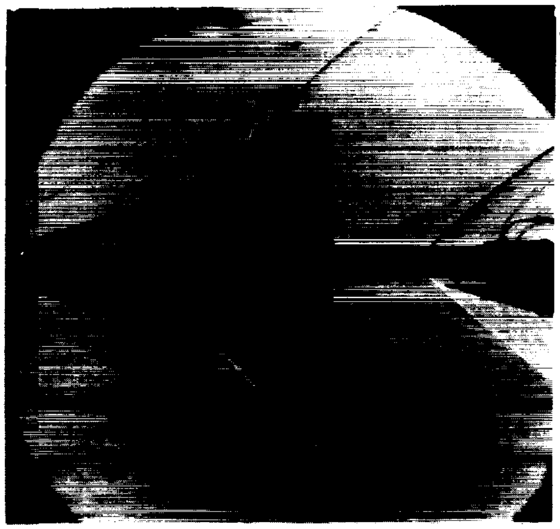
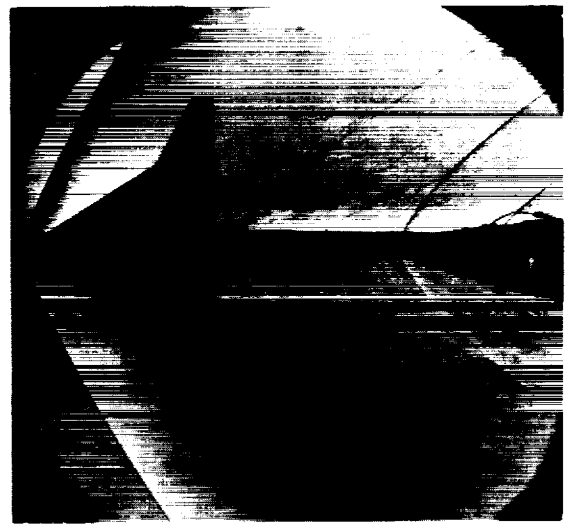


(a) Wing tips deflected 90°. L-59-5052

Figure 3.- Schlieren photographs of model.

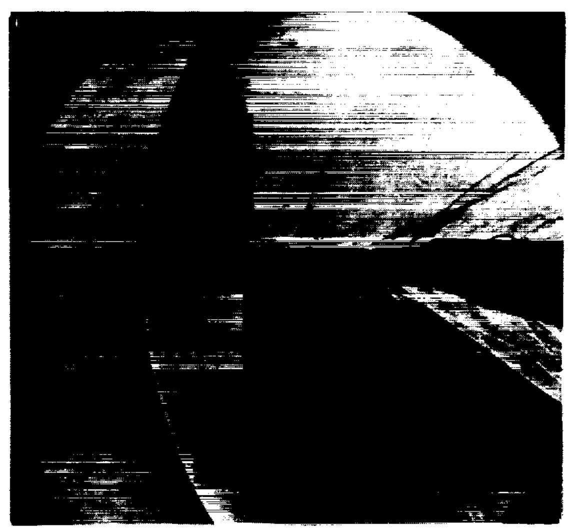


$\alpha = 6^\circ$



$\alpha = 60^\circ$

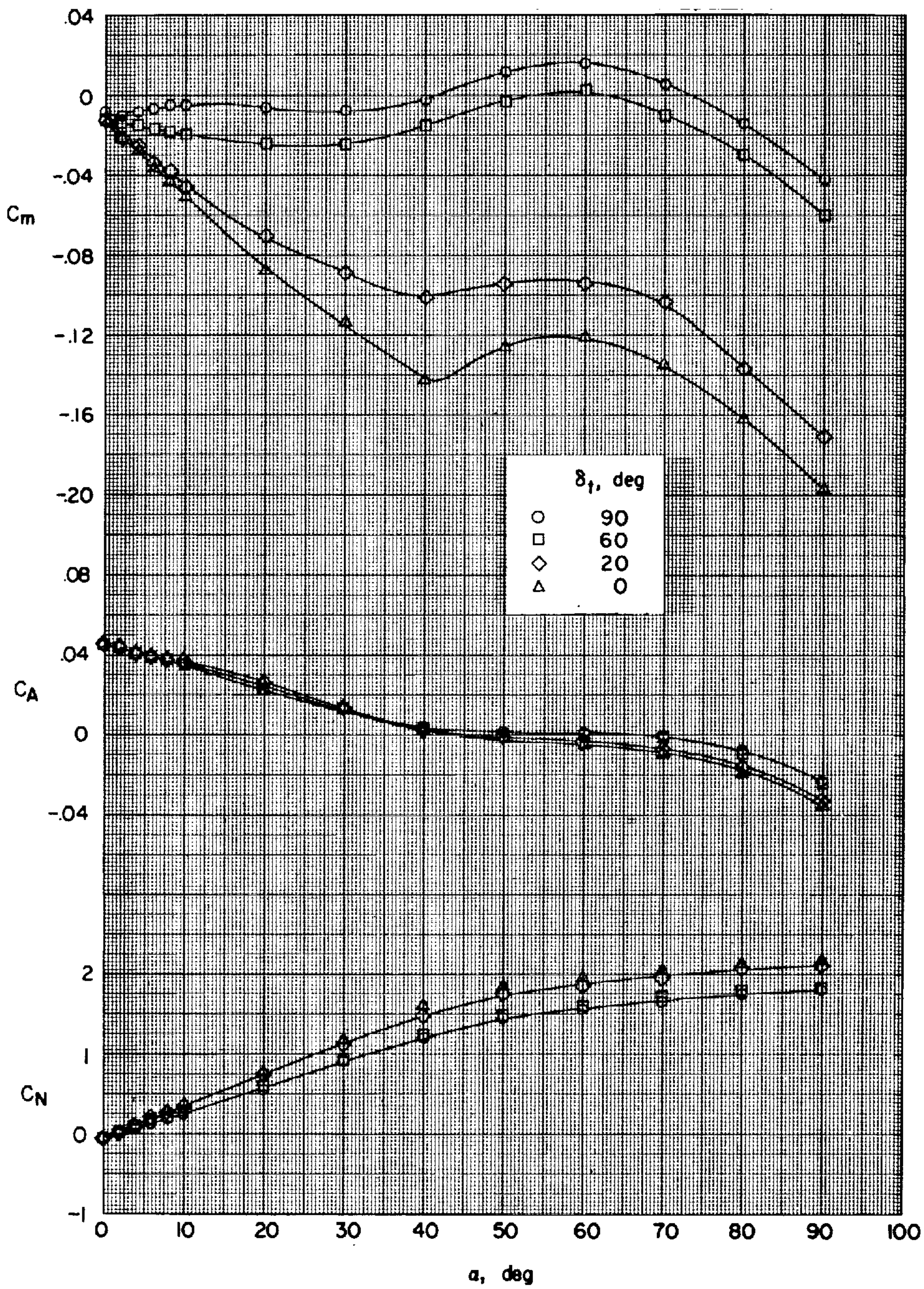
$\alpha = 80^\circ$



$\alpha = 90^\circ$

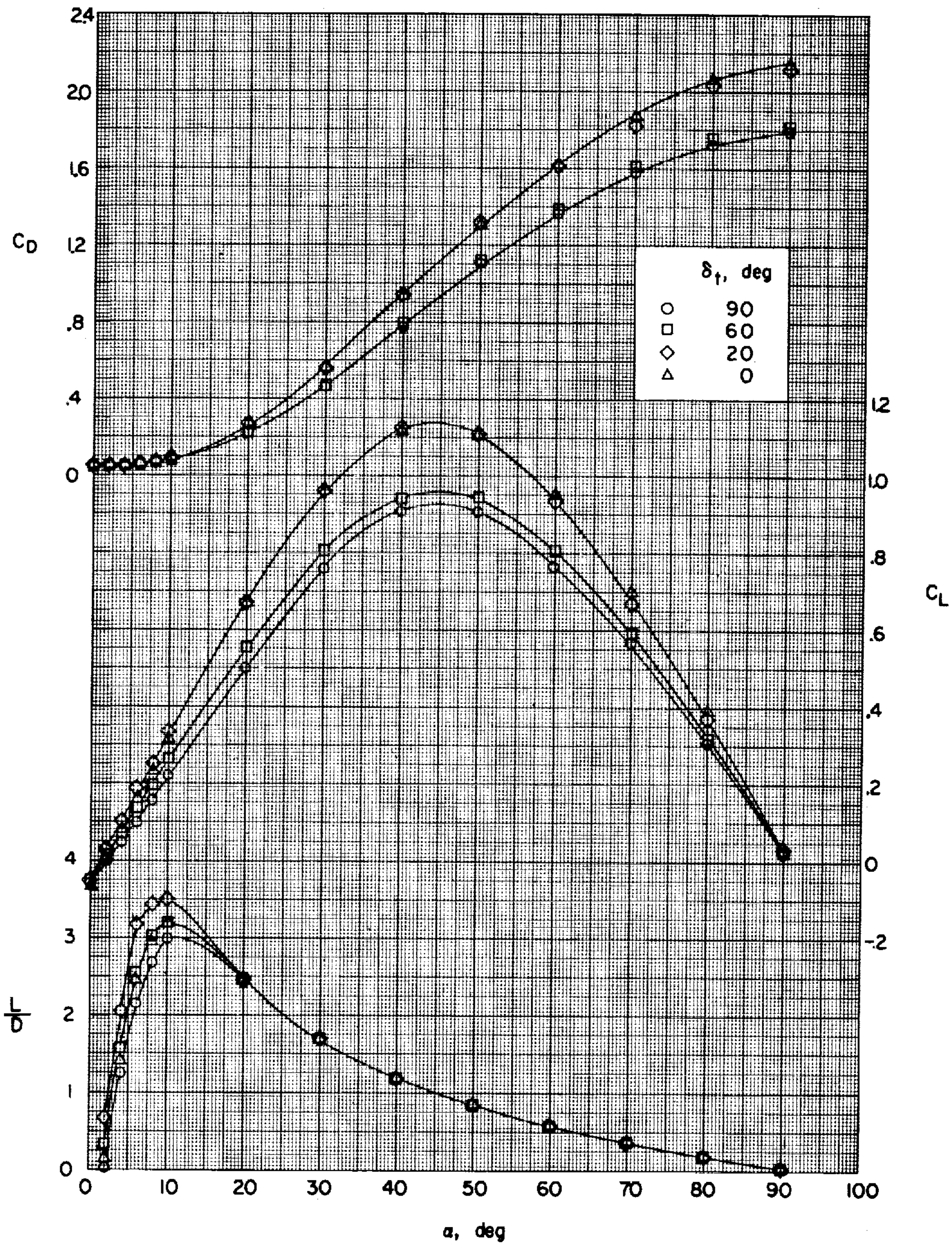
(b) Wing tips deflected 0°. L-59-5053

Figure 3.- Concluded.



(a) Variation of C_m, C_A, and C_N with α.

Figure 4.- Aerodynamic characteristics of model with large wing tips at various deflections.



(b) Variation of C_D, C_L, and L/D with α.

Figure 4.- Concluded.

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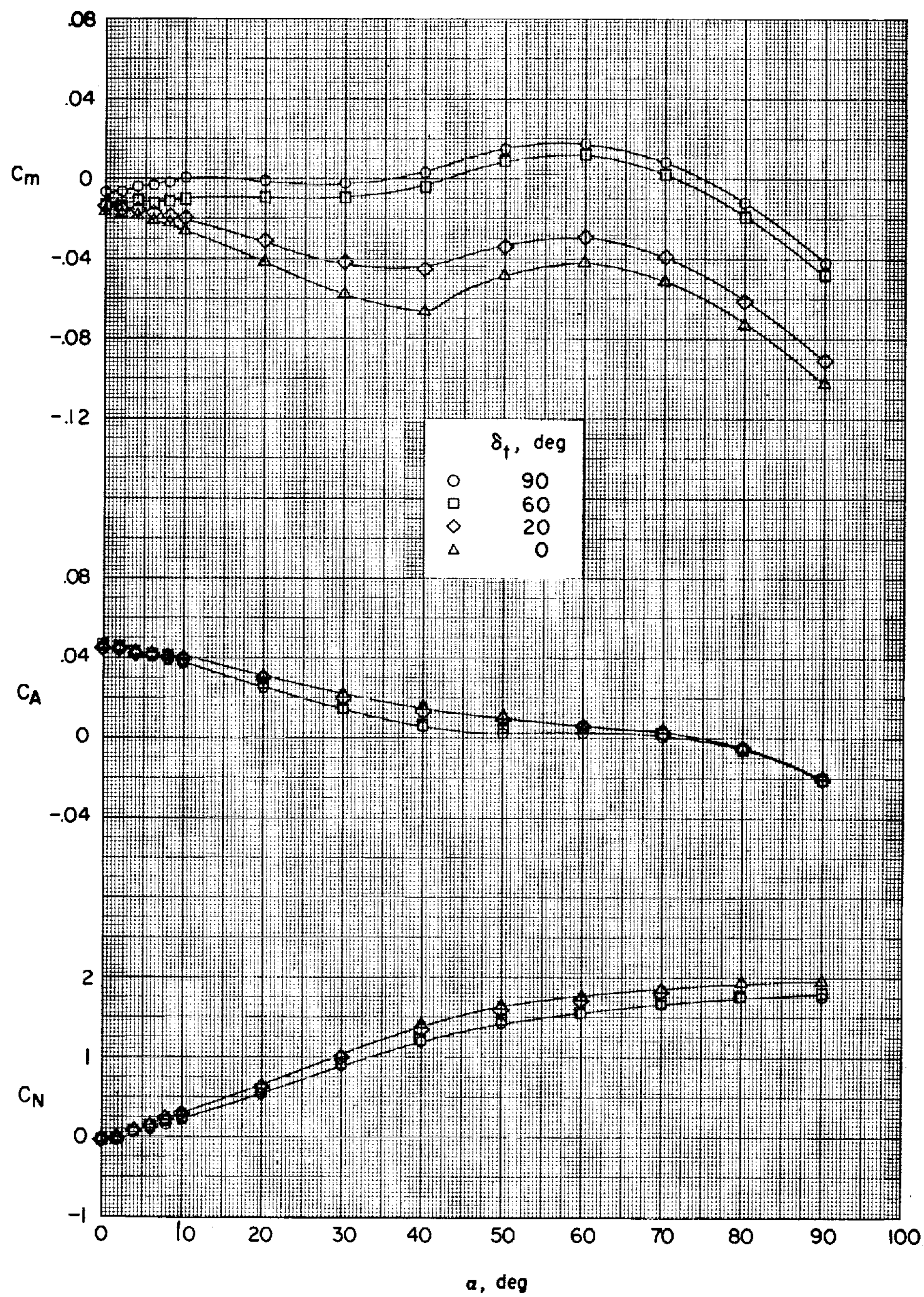
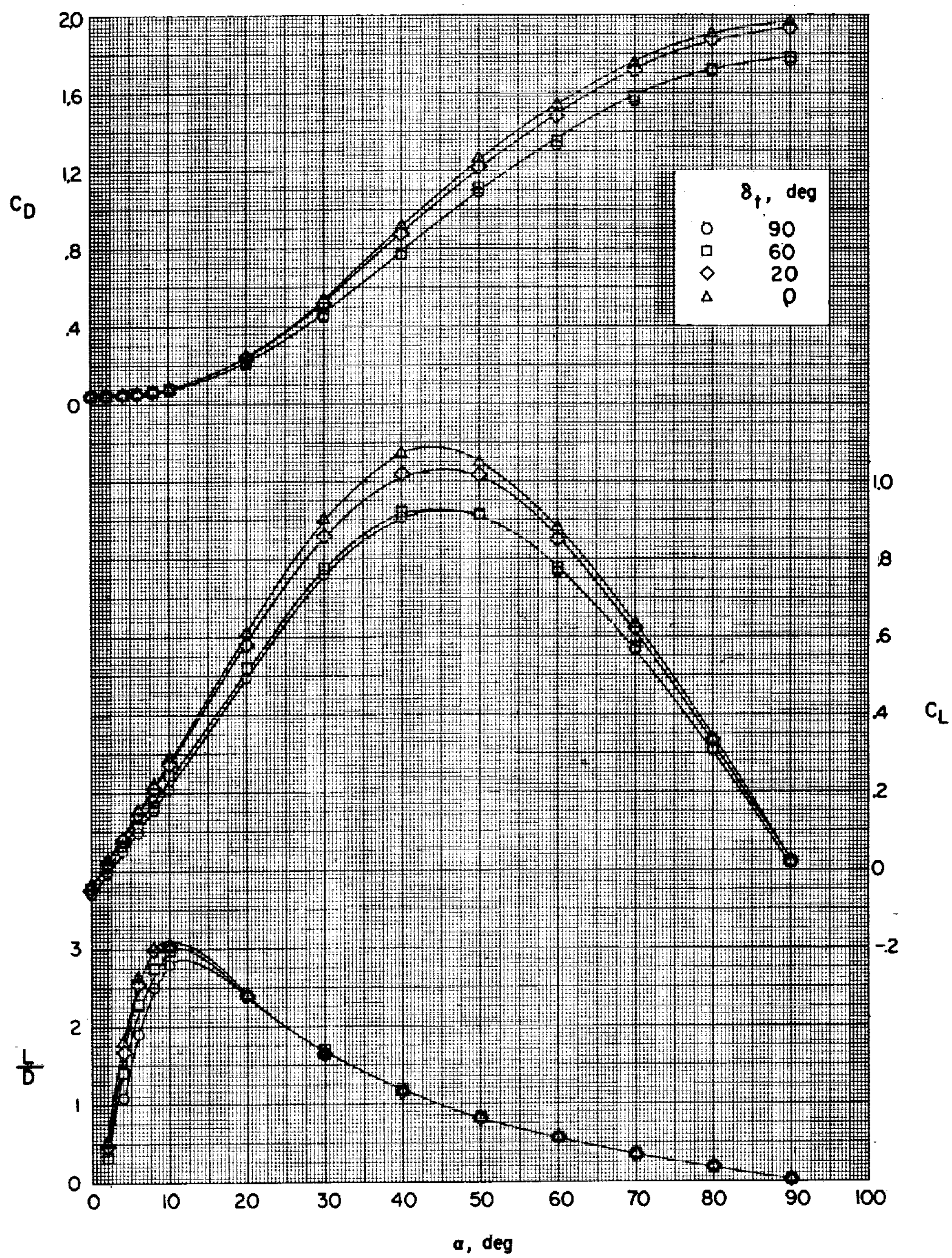


(a) Variation of C_m, C_A, and C_N with α.

Figure 5.- Aerodynamic characteristics of model with small wing tips at various deflections.



(b) Variation of C_D, C_L, and L/D with α.

Figure 5.- Concluded.

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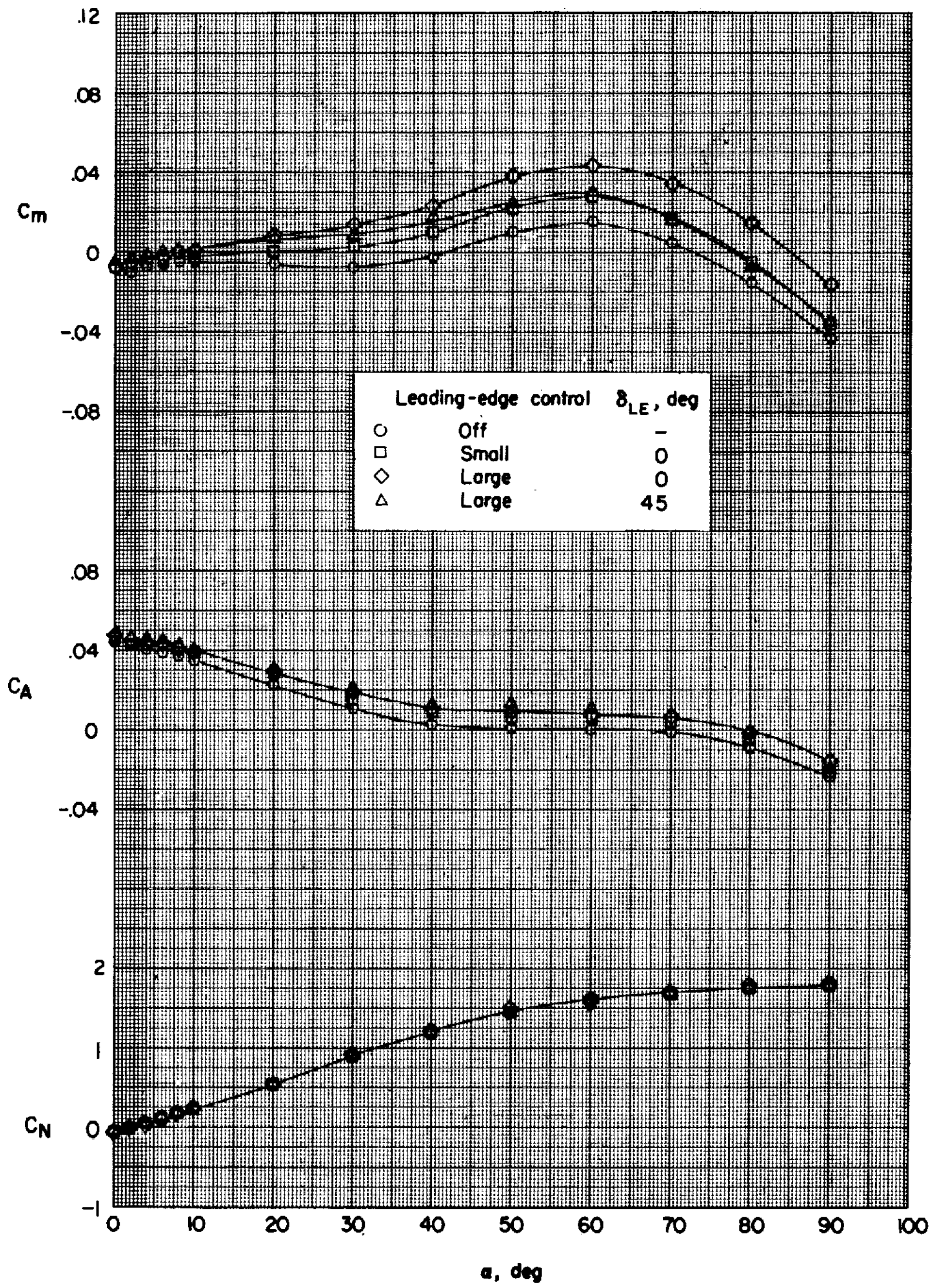
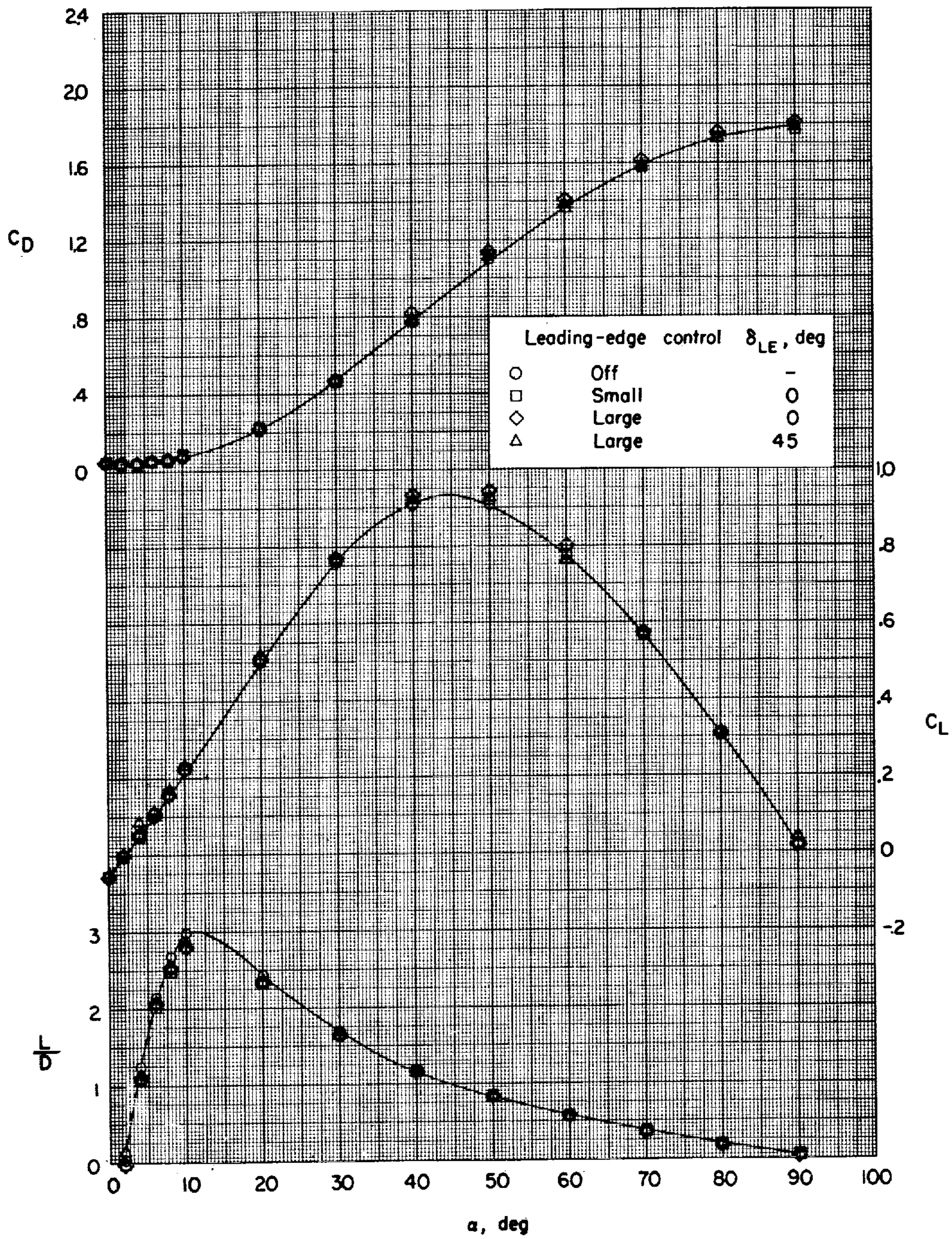


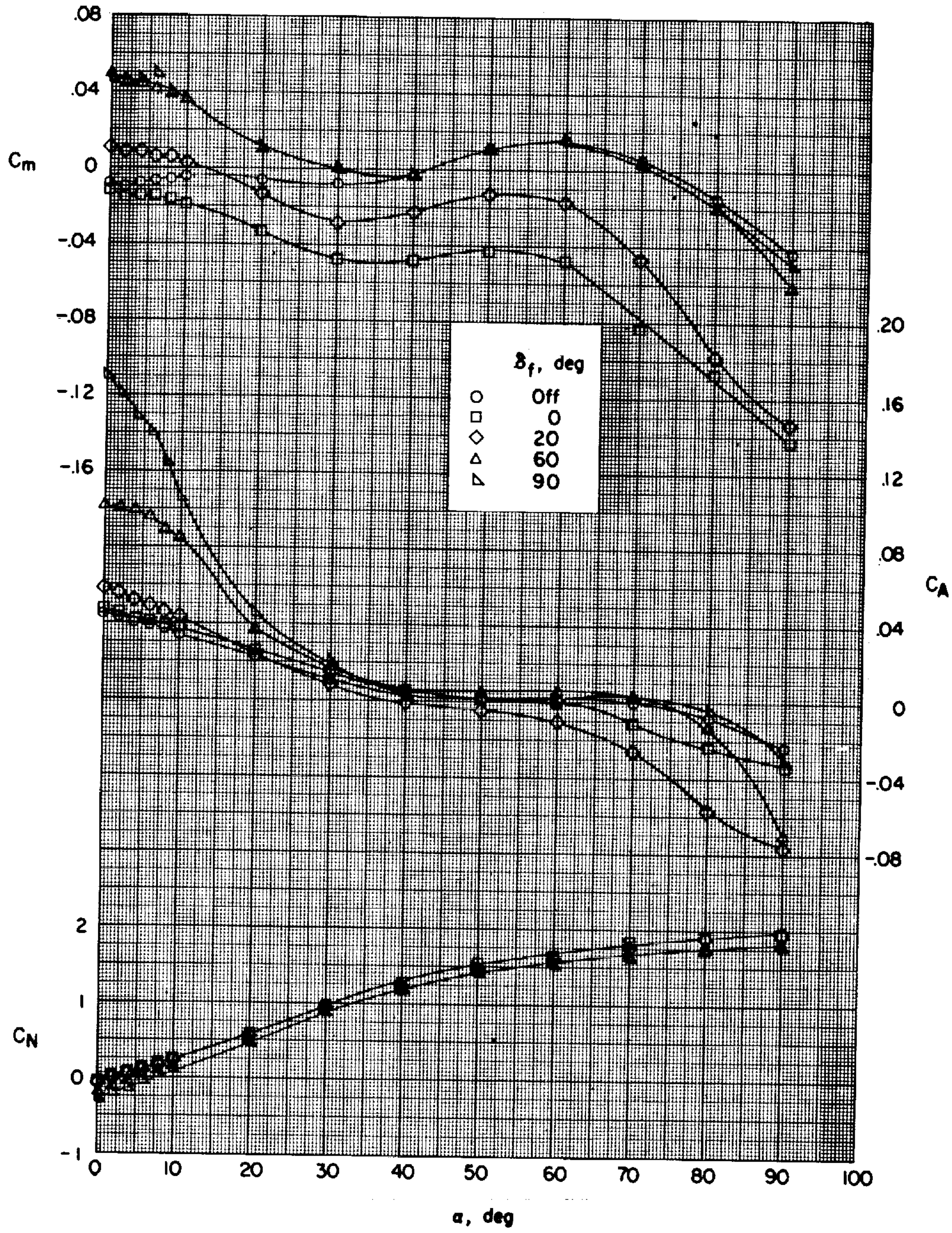
(a) Variation of C_m, C_A, and C_N with α.

Figure 6.- Effect of leading-edge controls on aerodynamic characteristics of model with large wing tips at $\delta_t = 90^{\circ}$.



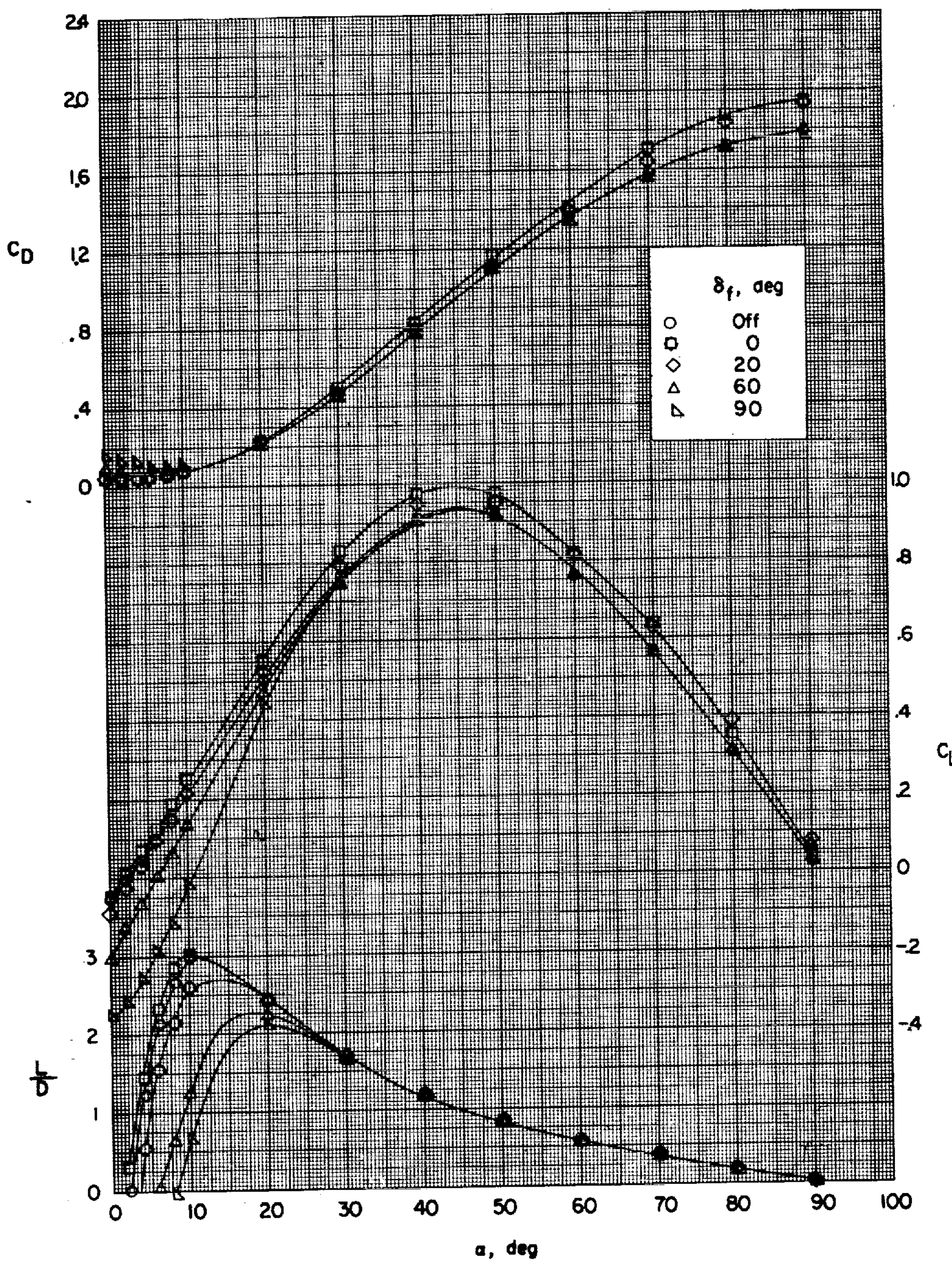
(b) Variation of C_D, C_L, and L/D with α.

Figure 6.- Concluded.



(a) Variation of C_m, C_A, and C_N with α.

Figure 7.- Effect of trailing-edge control on aerodynamic characteristics of model with large wing tips at $\delta_t = 90^{\circ}$.



(b) Variation of C_D, C_L, and L/D with α.

Figure 7.- Concluded.

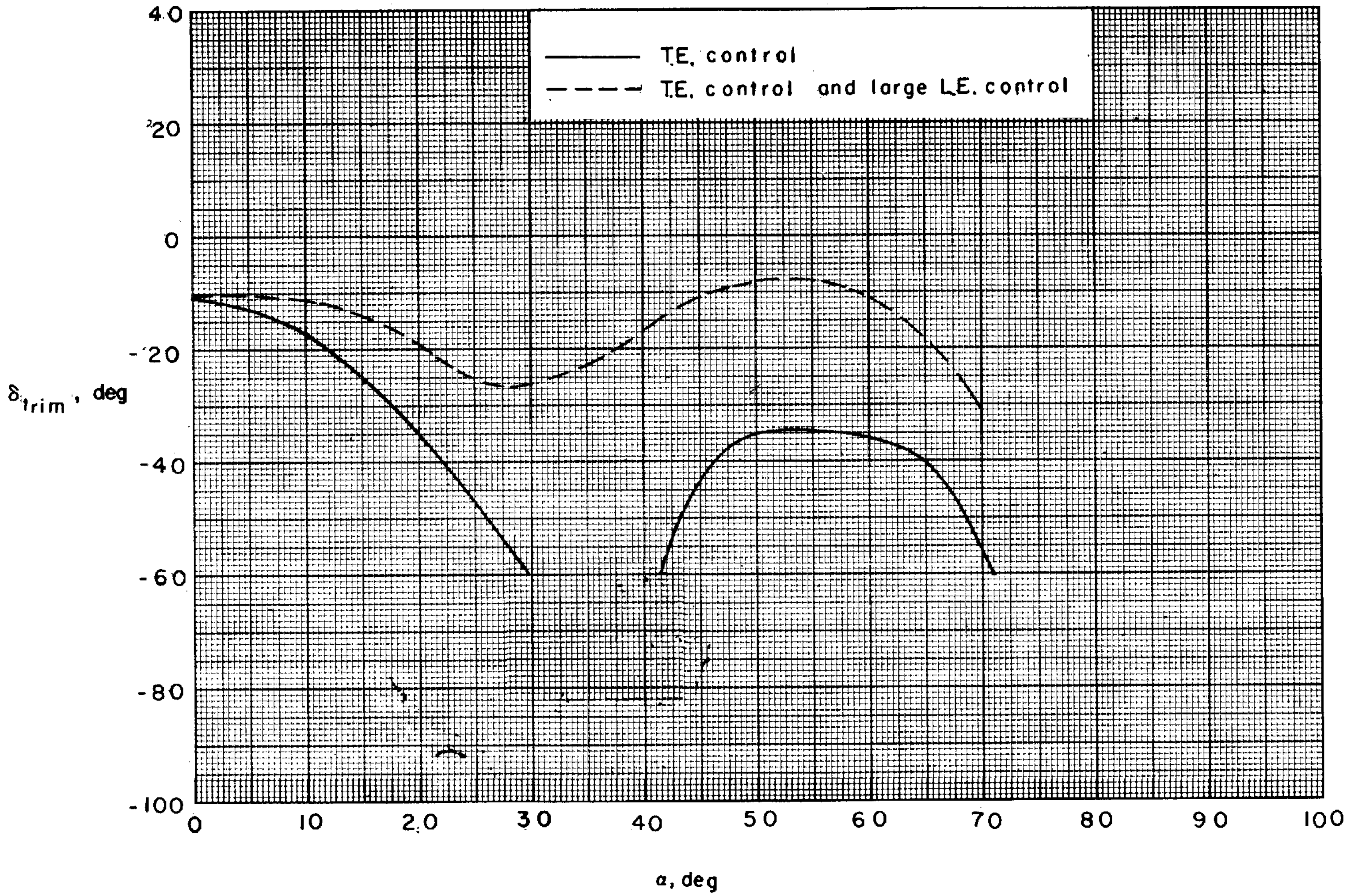


Figure 8.- Variation of trailing-edge control deflection required for trim with angle of attack.