NASA TECHNICAL NOTE

NASA TN D-6627

c.1

NASA TN D-6627

WIND-TUNNEL STUDY OF SLOT SPOILERS FOR DIRECT LIFT CONTROL

by Dominick Andrisani II, Garl L. Gentry, Jr., and Joseph W. Stickle

Langley Research Center
Hampton, Va. 23365

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JANUARY 1972

1. Report No. NASA TN D-6627	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle WIND-TUNNEL STUDY OF SLOT SPOILERS FOR DIRECT LIFT CONTROL		5. Report Date January 1972
		6. Performing Organization Code
7. Author(s) Dominick Andrisani II, Garl L. Gentry, Jr., and Joseph W. Stickle		8. Performing Organization Report No. L-8014
9. Performing Organization Name and Address NASA Langley Research Center Hampton, Va. 23365		10. Work Unit No. 760-71-03-01
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		13. Type of Report and Period Covered Technical Note
		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

An investigation has been conducted in the Langley 300-MPH 7- by 10-foot tunnel to obtain data for a slot-spoiler direct lift control system. Slot spoilers are believed to have advantages over flap-type direct lift control (DLC) systems because of the small amount of power required for actuation.

These tests, run at a Reynolds number of 1.4×10^6, showed that up to 78 percent of the lift due to flap deflection could be spoiled by opening several spanwise slots within the flaps. For a given lift change the drag change was significantly less than that which would be obtained by a variable-flap DLC system. A nozzle-shaped slot was the most effective of the slot shapes tested.

17. Key Words (Suggested by Author(s)) Direct lift control devices; Spoilers; Slot spoilers		18. Distribution Statement Unclassified – Unlimited	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 41	22. Price* $3.00

*For sale by the National Technical Information Service, Springfield, Virginia 22151

WIND-TUNNEL STUDY OF SLOT SPOILERS FOR DIRECT LIFT CONTROL

By Dominick Andrisani II, Garl L. Gentry, Jr.,
and Joseph W. Stickle
Langley Research Center

SUMMARY

An investigation has been conducted in the Langley 300-MPH 7- by 10-foot tunnel to obtain data for a slot-spoiler direct lift control system. Slot spoilers are believed to have advantages over flap-type direct lift control (DLC) systems because of the small amount of power required for actuation.

These tests, run at a Reynolds number of 1.4×10^6, showed that up to 78 percent of the lift due to flap deflection could be spoiled by opening several spanwise slots within the flaps. For a given lift change the drag change was significantly less than that which would be obtained by a variable-flap DLC system. A nozzle-shaped slot was the most effective of the slot shapes tested.

INTRODUCTION

The need for improved flight-path control during approach and landing has spurred interest in direct lift control (DLC). Direct lift control allows the pilot to control lift and therefore flight-path angle without rotating the aircraft to a new angle of attack. This eliminates the time delay normally associated with rotation and greatly increases the pilot's ability to make quick flight-path changes.

Many methods have been proposed for achieving DLC, such as symmetrically variable flaps, ailerons (refs. 1 and 2) or spoilers, boundary-layer control, and thrust vectoring. Most of these require costly and complex actuator systems to achieve control-surface deflection rates adequate for DLC. A need therefore exists for a simple inexpensive DLC system. The slot spoiler has been suggested as a means of meeting this requirement.

The slot spoiler consists of a spanwise slot or passageway cut through a trailing-edge wing flap near its leading edge. The slot provides a vent for air to pass from the high-pressure area on the lower flap surface to the low-pressure area on the upper flap surface. The jet of air emerges from the slot traveling nearly perpendicular to the air-flow over the flap and causes the flow to separate over the flap. In this way the slot spoiler can be used to reduce some portion of the lift generated by the flap. The slot can be designed to experience little or no aerodynamic hinge moments, whereas flaps or ailerons have large hinge moments. As a result, the power required to actuate the slot spoiler is much less than that required to actuate flaps or ailerons.

To provide two-way direct lift control, slot spoilers would initially be partially opened to spoil some flap lift and the aircraft would be stabilized on a flight path. Lift control would then be possible by symmetrically increasing or decreasing the slot opening. In addition, lateral control could be achieved by differential actuation of the slot openings.

The data from reference 3 indicated that slot spoilers do, in fact, reduce flap-induced lift. The data, however, were not considered suitable for design of a control system because of the relatively low test Reynolds number, 0.41×10^6. In order to expand the data of reference 1, the present tests were conducted in the Langley 300-MPH 7- by 10-foot tunnel at a Reynolds number of 1.46×10^6.

This report presents longitudinal data for both plain flaps and single-slotted flaps. These flaps were tested at various deflection angles and a range of angle of attack from -4° to 16°. Parameters which were varied in the investigation include slot-spoiler width, shape, and chordwise and spanwise locations.

SYMBOLS

Figure 1 shows the positive directions of forces, moments, and angles used in the presentation of the data. Pitching moment was referred to the quarter chord of the model wing.

Measurements and calculations were made in the U.S. Customary Units. They are presented herein in the International System of Units (SI) followed by the U.S. Customary Units in parentheses.

c — wing chord, 38.1 cm (15.0 in.)

C_D — drag coefficient, $\frac{\text{Drag force}}{qS}$

C_L — lift coefficient, $\frac{\text{Lift force}}{qS}$

C_m — pitching-moment coefficient, $\frac{\text{Pitching moment}}{qSc}$

l — distance from flap trailing edge to center line of slot-spoiler opening, cm (in.)

q free-stream dynamic pressure, 1915 N/m^2 (40 lb/ft^2)

S wing area, 0.813 m^2 (8.75 ft^2)

V_∞ relative wind velocity

α angle of attack of fuselage center line, degrees

δ_f flap deflection angle, positive when trailing edge is down, degrees

$\Delta C_{L,f}$ lift increment due to flap deflection

ΔC_D change in drag coefficient $\left((C_D)_{\text{slot open}} - (C_D)_{\text{slot closed}}\right)$

ΔC_L change in lift coefficient $\left((C_L)_{\text{slot open}} - (C_L)_{\text{slot closed}}\right)$

ΔC_m change in pitching-moment coefficient $\left((C_m)_{\text{slot open}} - (C_m)_{\text{slot closed}}\right)$

Δx width of slot-spoiler opening at upper surface, cm (ft)

WIND-TUNNEL MODEL

The model, which is shown in figures 2 and 3, was constructed of aluminum alloy and was sting mounted. The wing was of NACA 23012 airfoil section with a 213.4-cm (84.0 in.) span, a 38.1-cm (15.0 in.) constant chord, and an aspect ratio of 5.6. A body fairing extended 27.5 cm (10.8 in.) ahead and 10.9 cm (4.3 in.) aft of the wing.

Two types of flaps having a span equal to 83.3 percent of the wing span were tested (fig. 4): a plain flap with chord equal to 28.9 percent of the wing chord and a single-slotted flap with chord equal to 25.6 percent of the wing chord.

Located in both left and right wing flaps were three rectangular slots 27.2 cm (10.7 in.) long and 3.0 cm (1.2 in.) wide. The total slot length was 76.25 percent of the wing span. Maximum slot width available was 8.0 percent of the wing chord and could be decreased in increments of 1 percent chord.

Slot width and shape were varied by placing inserts into the slots. The slot shapes were tested only on the single-slotted flap and are shown in figure 5. For discussion purposes, the slot shapes are referred to as rectangular, tapered, and nozzle. The three tapered shapes are referred to as taper 4, taper 3, and taper 2. Taper 4 had the largest lower surface opening and taper 2 had the smallest lower surface opening. These are illustrated in figure 5, where the upper surface opening of 0.01c is shown.

TEST CONDITIONS

The investigation was made in the 7- by 10-foot test section of the Langley 300-MPH 7- by 10-foot tunnel at a free-stream dynamic pressure of approximately 1915 N/m^2 (40 lb/ft^2). The Reynolds number, based on wing chord and free-stream velocity, was approximately 1.46×10^6.

The plain flap was tested at deflection angles of 0°, 15°, 25°, 30°, and 35°. The single-slotted flap was tested at deflection angles of 0°, 15°, 30°, 35°, and 40°. Angle of attack varied from -4° to 16° in increments of 2°.

Slot width for the rectangular slot was varied from 0.01c to 0.06c. For the tapered and nozzle-shaped slots, width varied from 0.01c to 0.05c. Slot width for all shapes was made greater by removing inserts on the trailing-edge side of the slot opening. The slot center line therefore shifted toward the flap trailing edge as the slot width was increased, unless otherwise specified.

For a constant slot width of 0.04c, the slot center line (measured from the flap trailing edge) was varied from 0.24c to 0.20c for the plain flap and from 0.21c to 0.17c for the single-slotted flap. In addition, tufts on the upper surface of the wing and flap were observed on both flap configurations at 30° flap deflection and at an angle of attack ranging from -4° to 14° with slots closed and open to a width of 0.02c.

Force and moment measurements and angle of attack were recorded for the various test conditions. No corrections have been applied to these data for blockage or tunnel-wall effects, since these have been found in reference 4 to be small.

PRESENTATION OF RESULTS

The data obtained in the investigation are presented in the following figures:

DISCUSSION OF RESULTS

The discussion of data shows the effects of varying slot width, position, and shape on lift, drag, and pitching moment. The applicability of slot spoilers to direct lift control (DLC) is also discussed.

Effects of Flap Deflection

Figure 6 shows that the single-slotted flap was almost twice as effective at increasing lift as the plain flap. Most of the lift increase occurred for flap deflections between 0^{o} and 30^{o}. Model vibration limited the maximum angle of attack to values below those necessary to fully define stall.

Effects of Rectangular-Shaped Slot Spoilers

Effects of slot-spoiler opening on plain flap.- On the wing with plain flaps the lift coefficient was substantially reduced when rectangular-shaped slot spoilers were opened. This result is shown in figure 7 for various flap deflections. The lift-curve slope is generally slightly reduced as the slot is opened.

As the slot spoiler was opened, the lift coefficient decreased for all slot openings except one. This exception $\left(\frac{\Delta x}{c} = 0.01, \quad \delta_f = 35^{o}, \text{ fig. } 7(c)\right)$ is believed to have resulted because the flow through the slot spoiler was inadvertently restricted. The reduced slot flow was believed to have been insufficient to induce separation of the flow over the flap, and instead, the boundary layer was energized. The result was an increase in lift. The restriction of flow through the slot was caused by the lower wing partially blocking the slot spoiler, as shown in figure 8.

Effects of varying slot opening at constant angle of attack are shown in figure 9. The lift coefficient was reduced as much as 0.37. The greatest lift spoiling throughout the range of slot openings was at a flap deflection of 25^{o}. Ideally, a DLC device should affect only lift, but in practice, this is difficult to obtain. As lift is spoiled with slot spoilers, drag is decreased and pitching moment is increased (nose up).

The irregularity of the curves in figure 9 at $\frac{\Delta x}{c} = 0.01$ is a result of the lower wing interference mentioned earlier.

Because the effects of slot spoilers were not investigated in the unique region between $\frac{\Delta x}{c} = 0.01$ and $\frac{\Delta x}{c} = 0$, where flow through the slot spoiler is small, this region is shown dashed in figures 9, 11, and 12 to indicate greater uncertainty in line fairing.

Effects of slot-spoiler opening on single-slotted flap.- Opening the rectangular slot spoilers on the wing with the single-slotted flap reduced the lift coefficient about 0.8 for all flap deflections tested (figs. 10 and 11). This lift spoiling was more than twice that for the same slot spoiler on the plain flap. As with the plain flap, the lift-curve slope was slightly reduced as the slot spoiler was opened.

As the slot spoilers were opened at a constant angle of attack, lift and drag were reduced while pitching moment increased (nose up), as shown in figure 11. As with the plain flap, the greatest lift spoiling occurred at the smallest flap deflection tested.

A comparison of slot-spoiler effectiveness on both plain and single-slotted flaps is provided in figure 12. Slot spoilers on plain flaps spoiled up to 60 percent of the flap-induced lift; and on single-slotted flaps, up to 74 percent.

When the slot spoilers on single-slotted flaps were opened 1 percent chord, 50 percent of the lift was spoiled. This large change due to initial slot opening was not as noticeable on plain flaps.

Effects of chordwise location for the plain flap.- Slot spoilers on plain flaps were most effective when located 0.23c from the flap trailing edge, and moving the slot center line either forward or rearward reduced the amount of lift spoiled. Lift spoiling at the most forward location tested was reduced by the lower wing interference. These results are shown in figure 13 for a constant slot width of 0.04c.

Effects of chordwise location for the single-slotted flap.- The most forward slot center-line location which was tested on single-slotted flaps spoiled the largest amount of lift. Moving the slot center-line location rearward reduced the amount of lift spoiled. These results are shown in figure 14.

Effects of spanwise location.- Each semispan of the wind-tunnel model had three identical slot-spoiler sections at different spanwise locations in the flap, as shown in figure 1. Each of the three sections was opened separately and it was found that the center and inboard slots spoiled the same amount of lift and that the outboard slot was only 70 percent as effective as either of the other two. This is shown in figure 15 for the wing with the single-slotted flap.

Tuft observations.- With slot spoilers either closed or open to a slot width of 0.02c, the flow over the plain flap was separated for the entire range of angle of attack. No appreciable difference between slot closed and open was observed upstream of the slot, especially near stall.

The flow over the single-slotted flap with slot spoilers closed was not fully separated up to an angle of attack of 10°. With the slot spoiler open to a slot width of 0.02c, flow over the flap was separated at all angles of attack. As with the plain flap, no appreciable upstream effects were noted.

Effect of Slot Shape

The effects of the various slot shapes, which are illustrated in figure 5, are shown in figures 16 and 17 for the single-slotted flap.

The nozzle-shaped slot was the most effective of the slot shapes. The nozzle-shaped slot spoiled a lift coefficient of 0.85, or 78 percent of the flap lift, as shown in figure 16(d). This represents the largest lift spoiling found in the investigation and was obtained at the relatively small slot width of 0.03c.

The rectangular slot shape is less effective than the other shapes at a slot width of 0.01c, as shown in figure 17(a).

Figure 16 shows that the maximum lift spoiling for taper 2 and the nozzle shape occurred at $\frac{\Delta x}{c} = 0.03$. Tapers 3 and 4 spoiled maximum lift at $\frac{\Delta x}{c} = 0.05$. All of the shape data showed that for a given change in lift, all shapes produced the same drag and pitching-moment changes.

To determine the effects of closing the nozzle-shaped slot with a small barrier, a plug was inserted in the nozzle-shaped slot (fig. 5). The results, shown in figure 16(d), indicate that the nozzle with the plug slightly decreased lift and slightly increased drag and pitching moment compared with the single-slotted flap with no slot spoiler.

Comparison of Slot Spoilers With Flaps for DLC Application

Since much previous research has been done with variable-deflection trailing-edge flaps as a means of modulating lift, it is meaningful to compare the slot spoiler with a rapidly movable flap DLC system.

When a DLC system is operated, changes in lift, drag, and pitching moment result. These changes were found for a slot spoiler and for a rapidly movable flap DLC system and are shown in figure 18 as a function of angle of attack. The slot spoiler was opened to a width of 0.06c at $\delta_f = 30^{\circ}$. The data for the movable-flap DLC system were calculated from figure 6 by determining the number of degrees the flap would have to be moved from its initial 30° deflection to spoil the same amount of lift as was spoiled by the slot spoiler.

Figure 18 shows that the changes in drag coefficient were significantly smaller with a slot spoiler than with the variable-deflection flap. The pitching moments with the two systems were about the same.

The main advantage of slot spoilers is that the slot-spoiler actuator could be designed to have no aerodynamic hinge moments and, therefore, would require little power. The flaps, on the other hand, experience large aerodynamic hinge moments and must be moved rapidly more than 20° to achieve the same amount of lift spoiling as with the slot spoiler. This would require a far larger amount of power.

CONCLUSIONS

A wind-tunnel study has been conducted to gain further information on the use of slot spoilers for direct lift control. The following conclusions are based on tests run at a Reynolds number of 1.46×10^{6}.

1. Slot spoilers used on a deflected flap provide a very effective means of controlling lift. Up to 78 percent of the flap-induced lift can be spoiled.

2. The drag changes are significantly smaller with a slot spoiler than with a variable-deflection flap producing the same lift decrement.

3. A nozzle-shaped slot spoiler is the most effective at lift spoiling.

4. In general, moving the slot-spoiler center line rearward on the flap makes the spoiler less effective.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., December 15, 1971.

REFERENCES

1. Etheridge, J. D.; and Mattlage, C. E.: Direct Lift Control as a Landing Approach Aid in the F-8C Airplane. Simulator and Flight Tests. Rep. No. 2-53310/4R-175 (Contract N62269-2403), LTV Vought Aeronaut. Div., Dec. 13, 1964.

2. Stickle, Joseph W.; Patton, James M.; and Henry, Robert C.: Flight Tests of a Direct Lift Control System During Approach and Landing. NASA TN D-4854, 1968.

3. Stickle, Joseph W.; and Henry, Robert C.: Wind-Tunnel Study To Explore the Use of Slot Spoilers To Modulate the Flap-Induced Lift of a Wing. NASA TN D-4664, 1968.

4. Staff of Powered-Lift Aerodynamics Section, NASA Langley Res. Center: Wall Effects and Scale Effects in V/STOL Model Testing. AIAA Aerodynamic Testing Conference, Mar. 1964, pp. 8-16.

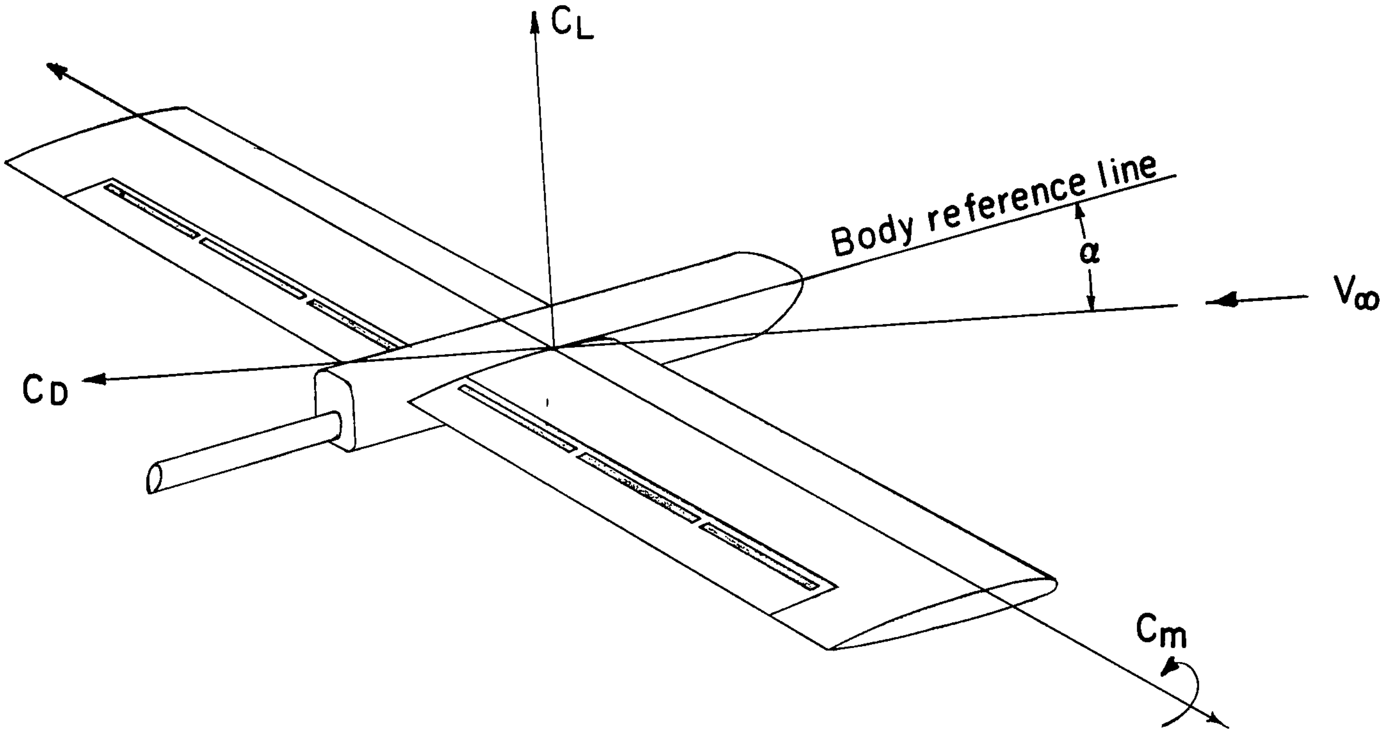


Figure 1.- Positive directions of coefficients.

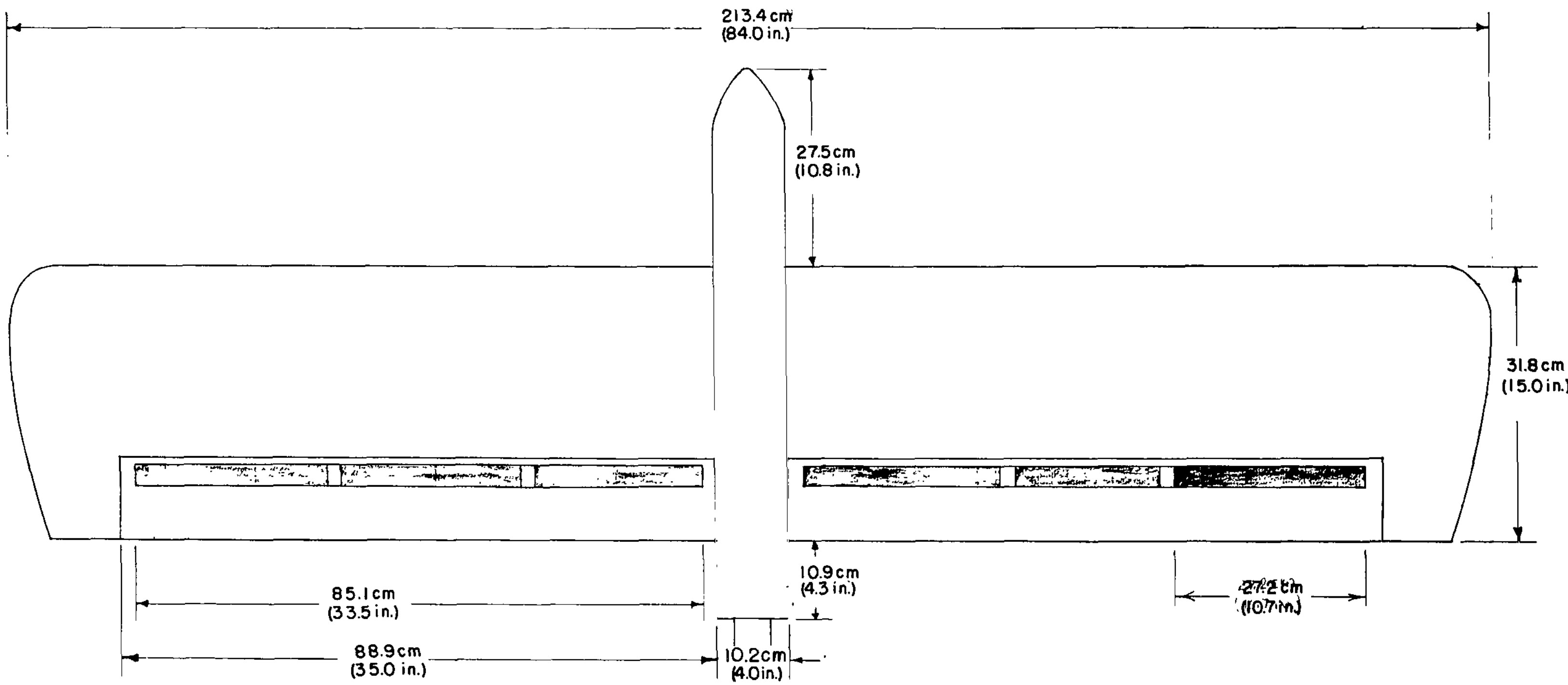
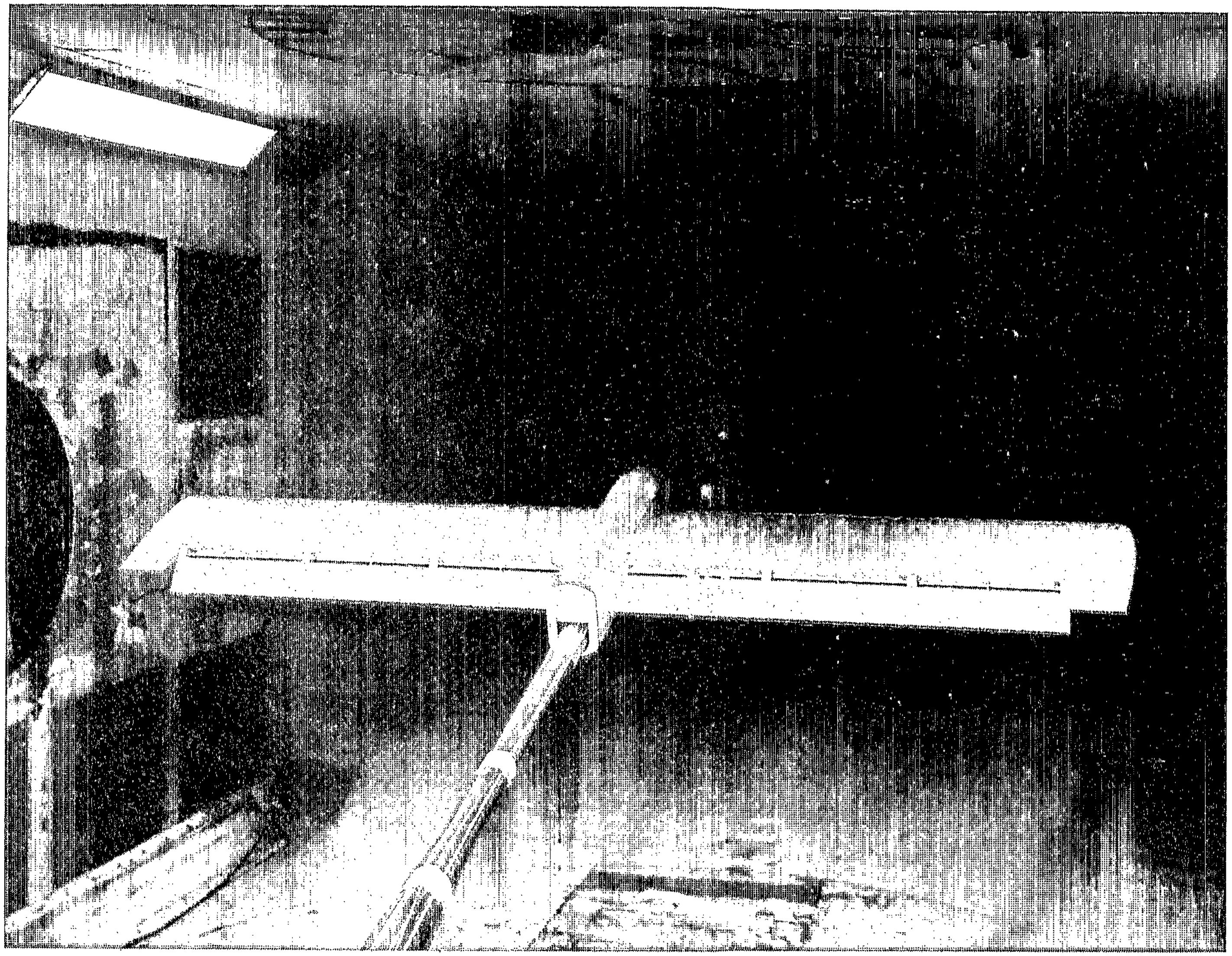


Figure 2.- Model planform.



L-69-3576

Figure 3.- Photograph of model in tunnel.

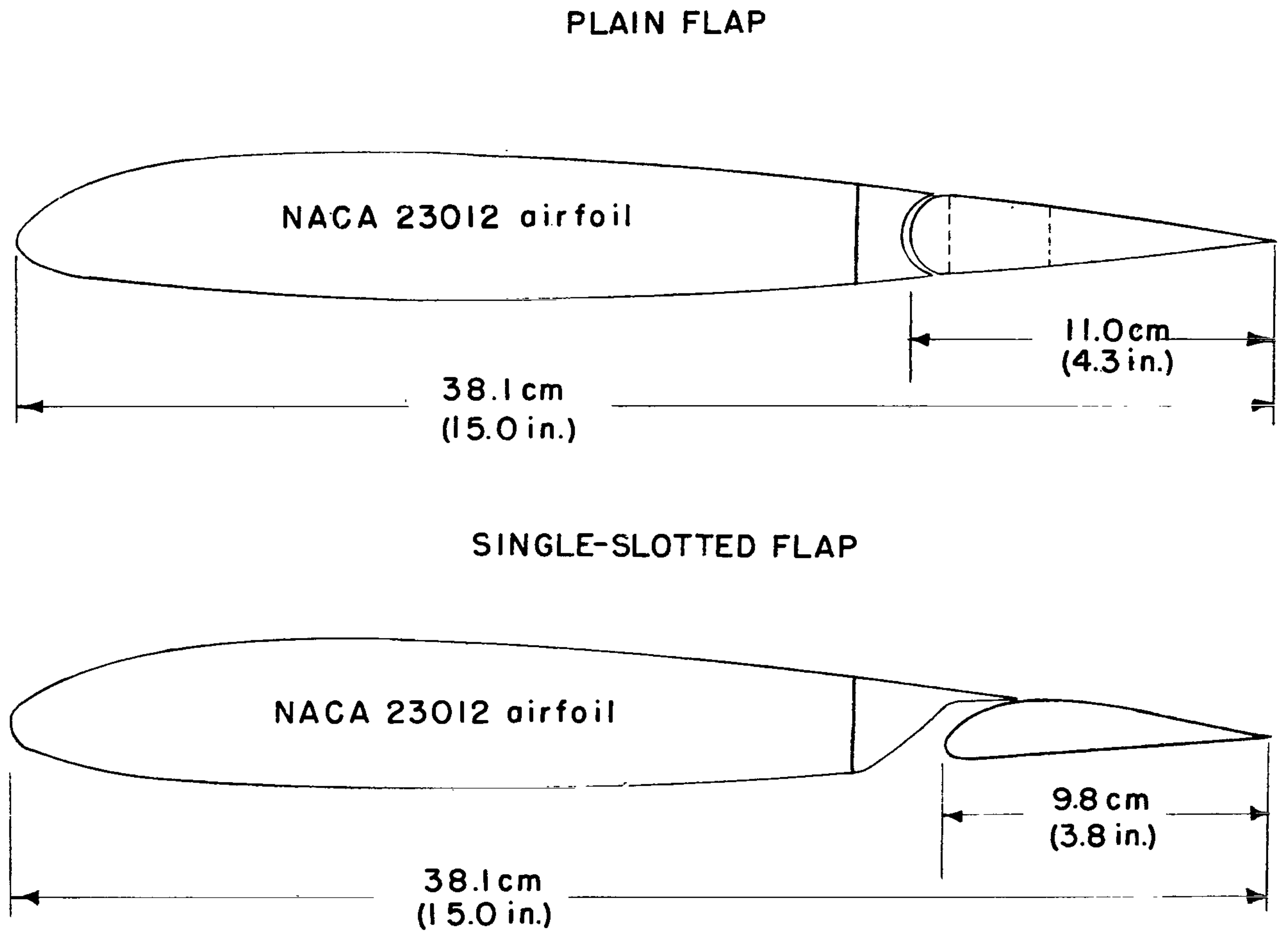


Figure 4.- Flap types.

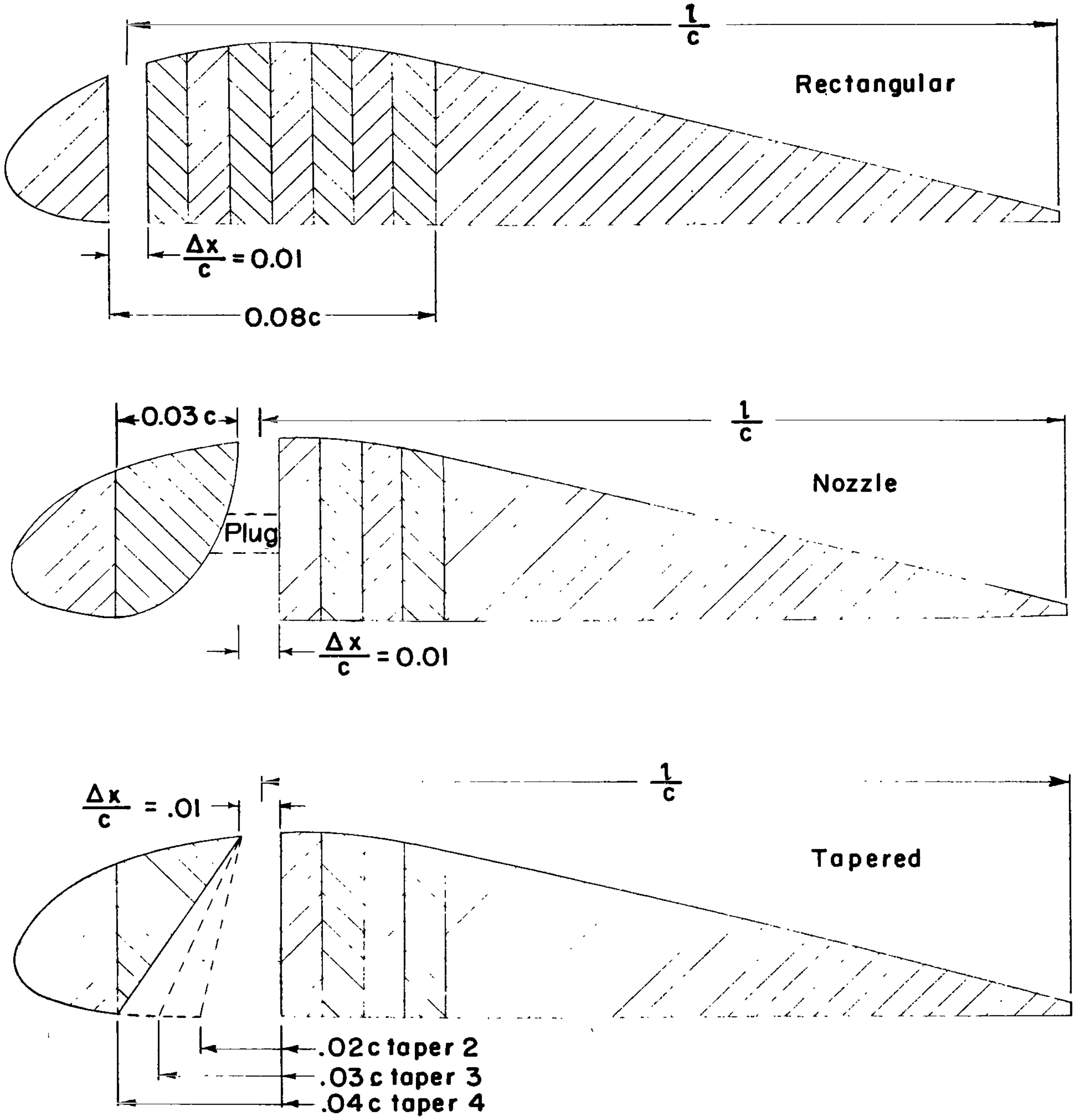
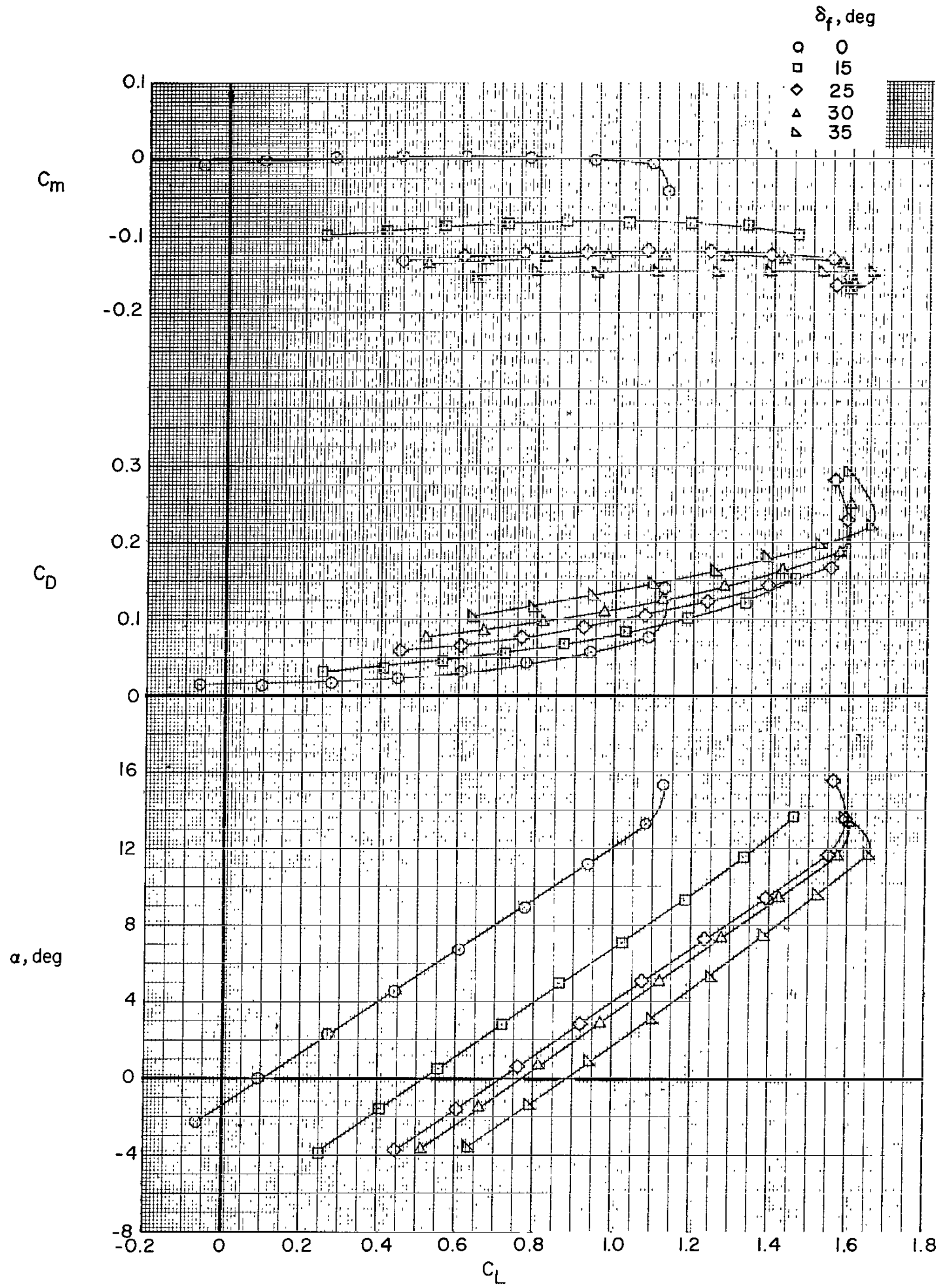
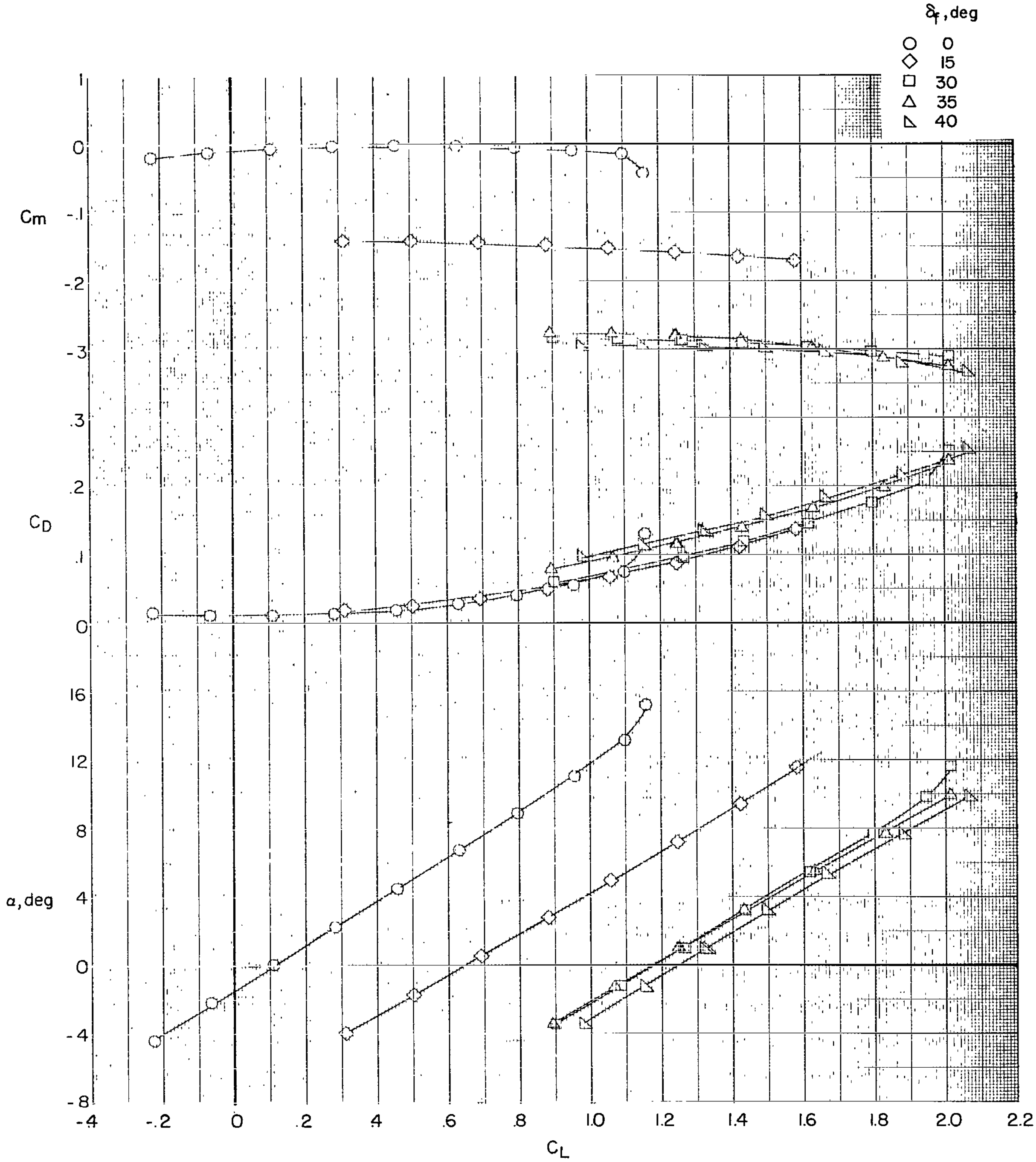


Figure 5.- Slot shapes.



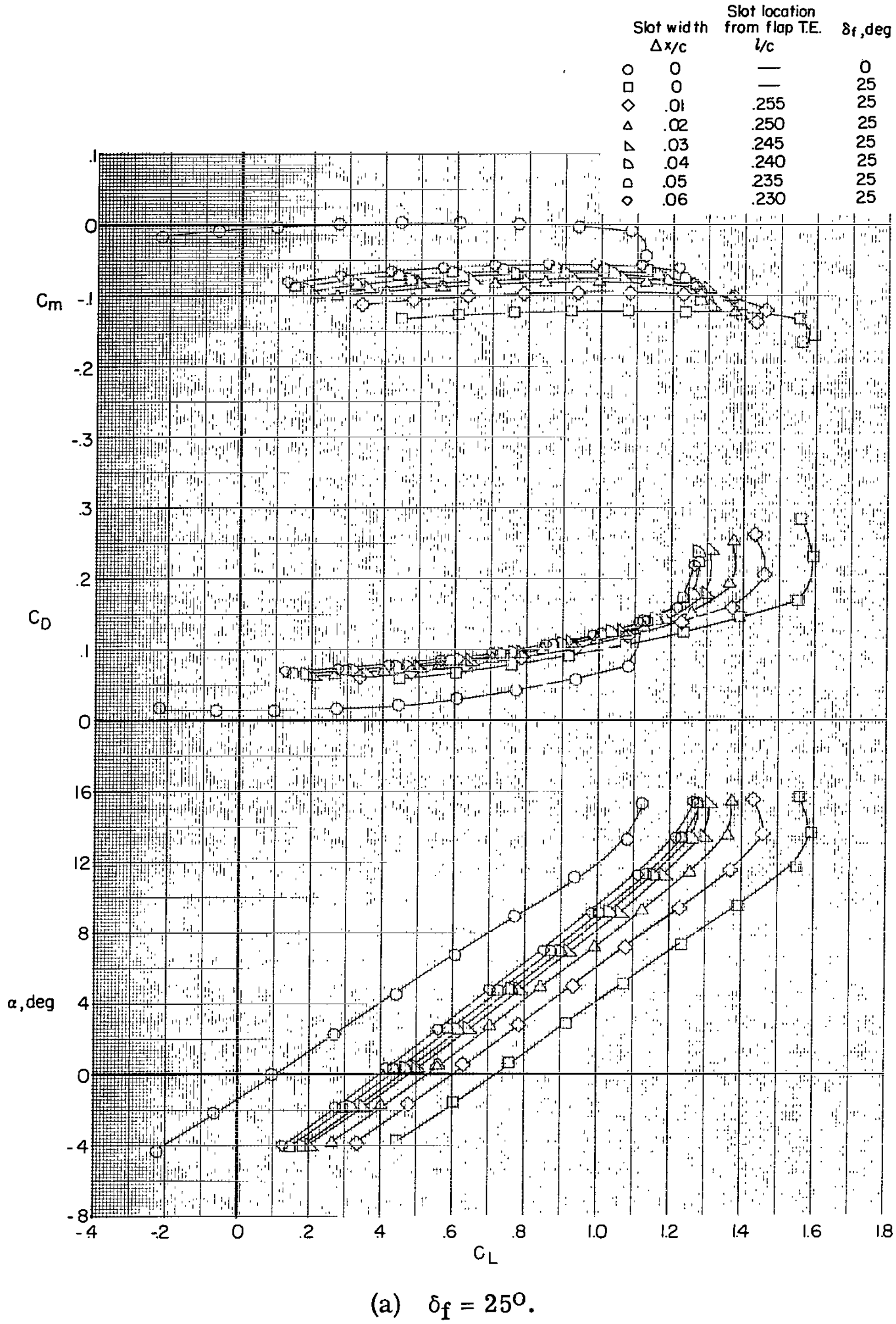
(a) Plain flap.

Figure 6.- Effects of flap deflection on longitudinal aerodynamic characteristics.



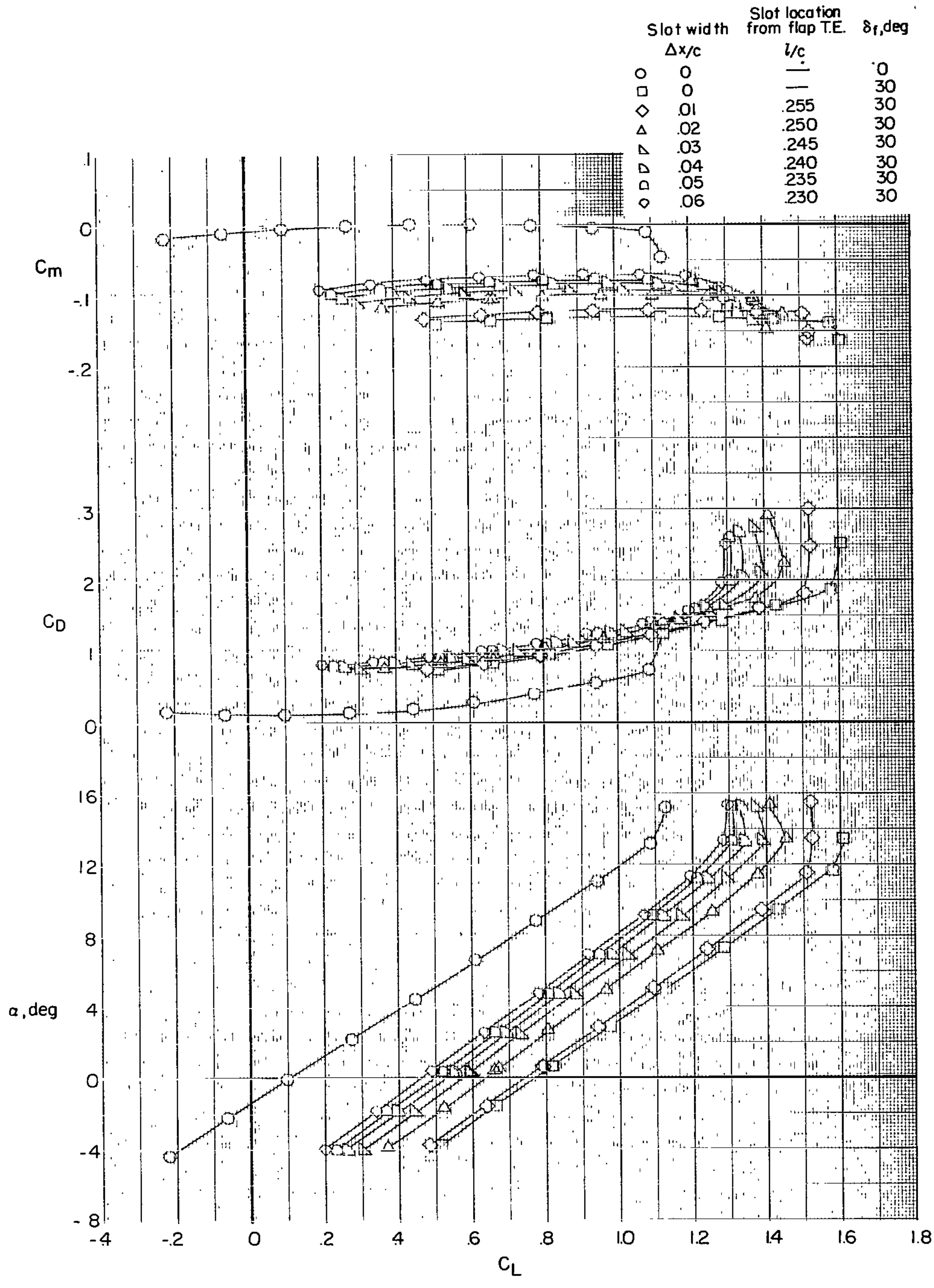
(b) Single-slotted flap.

Figure 6.- Concluded.



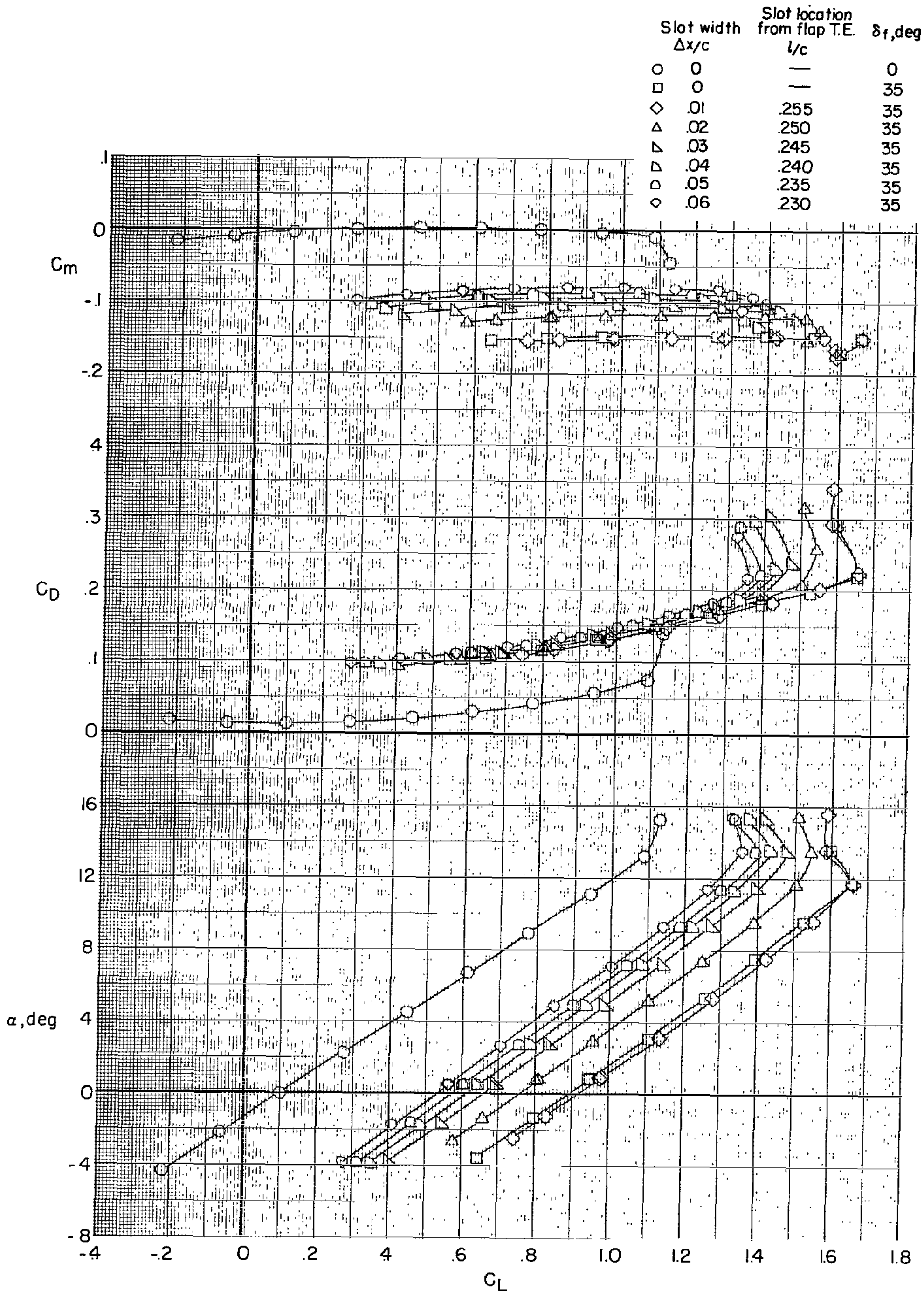
(a) $\delta_f = 25^{\circ}$.

Figure 7.- Effect of rectangular slot spoiler on longitudinal aerodynamic characteristics of wing with plain flaps.



(b) $\delta_f = 30^o$.

Figure 7.- Continued.



(c) $\delta_f = 35^{\circ}$.

Figure 7.- Concluded.

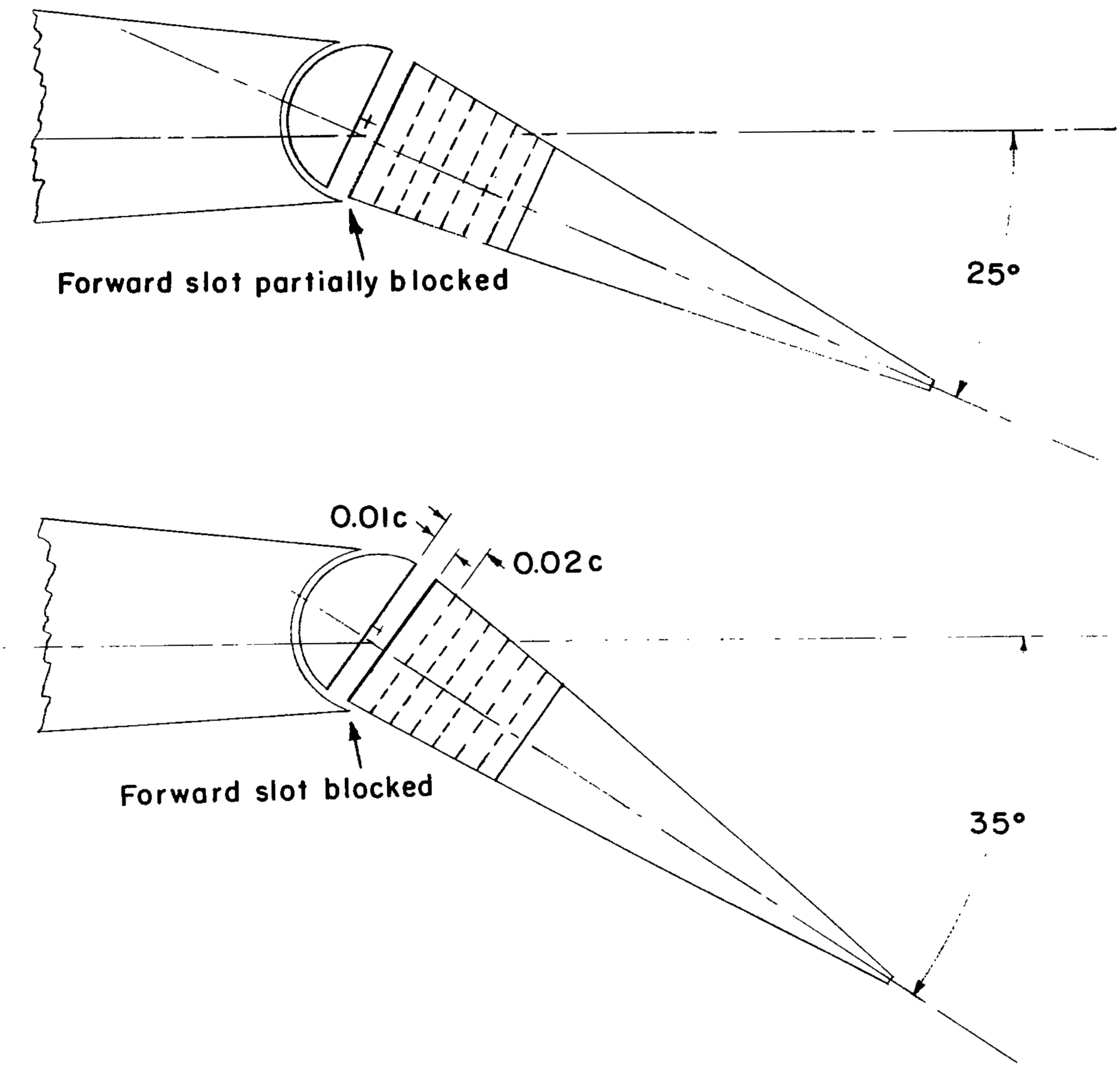


Figure 8.- Interference between lower wing surface and slot spoiler on plain flaps.

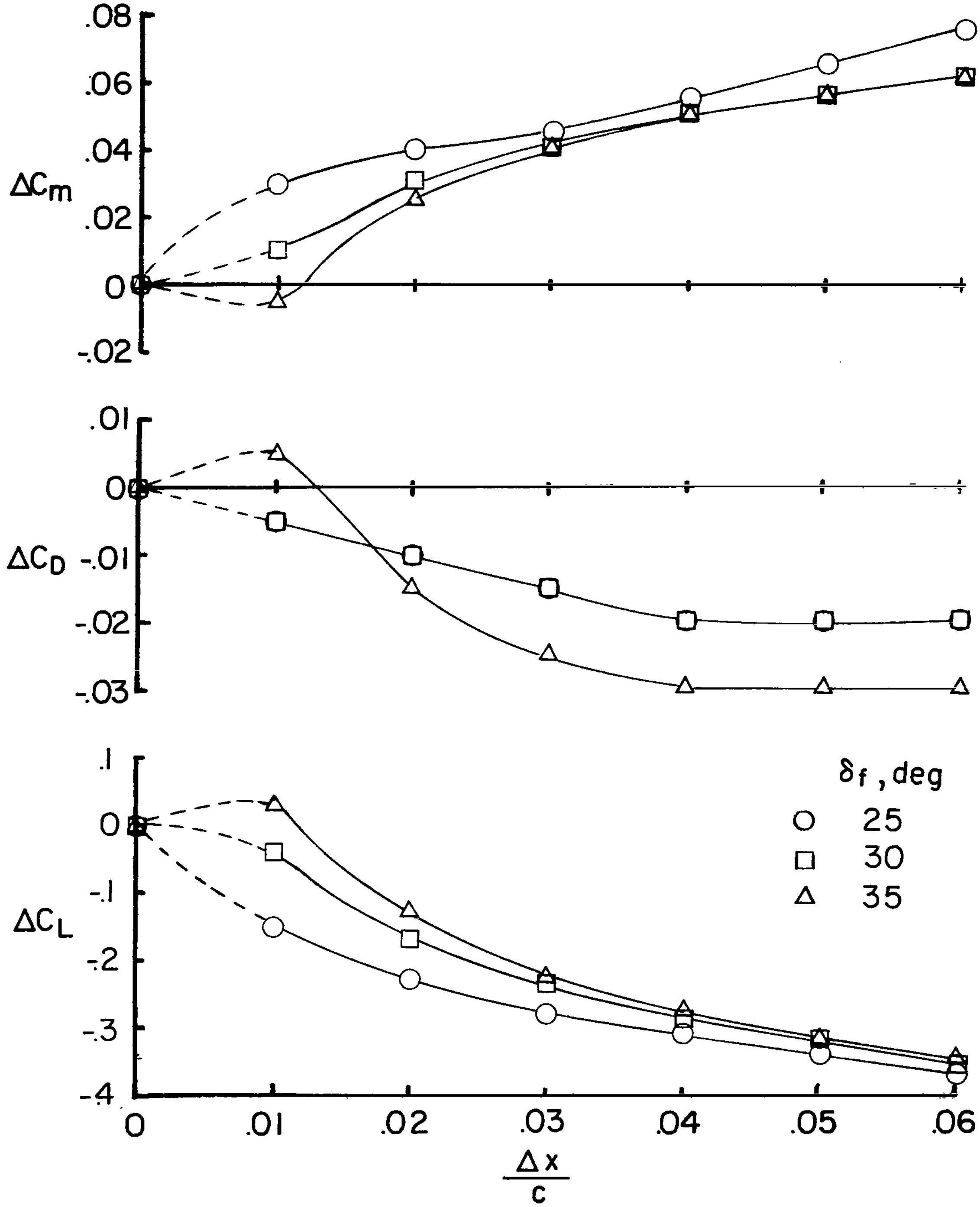
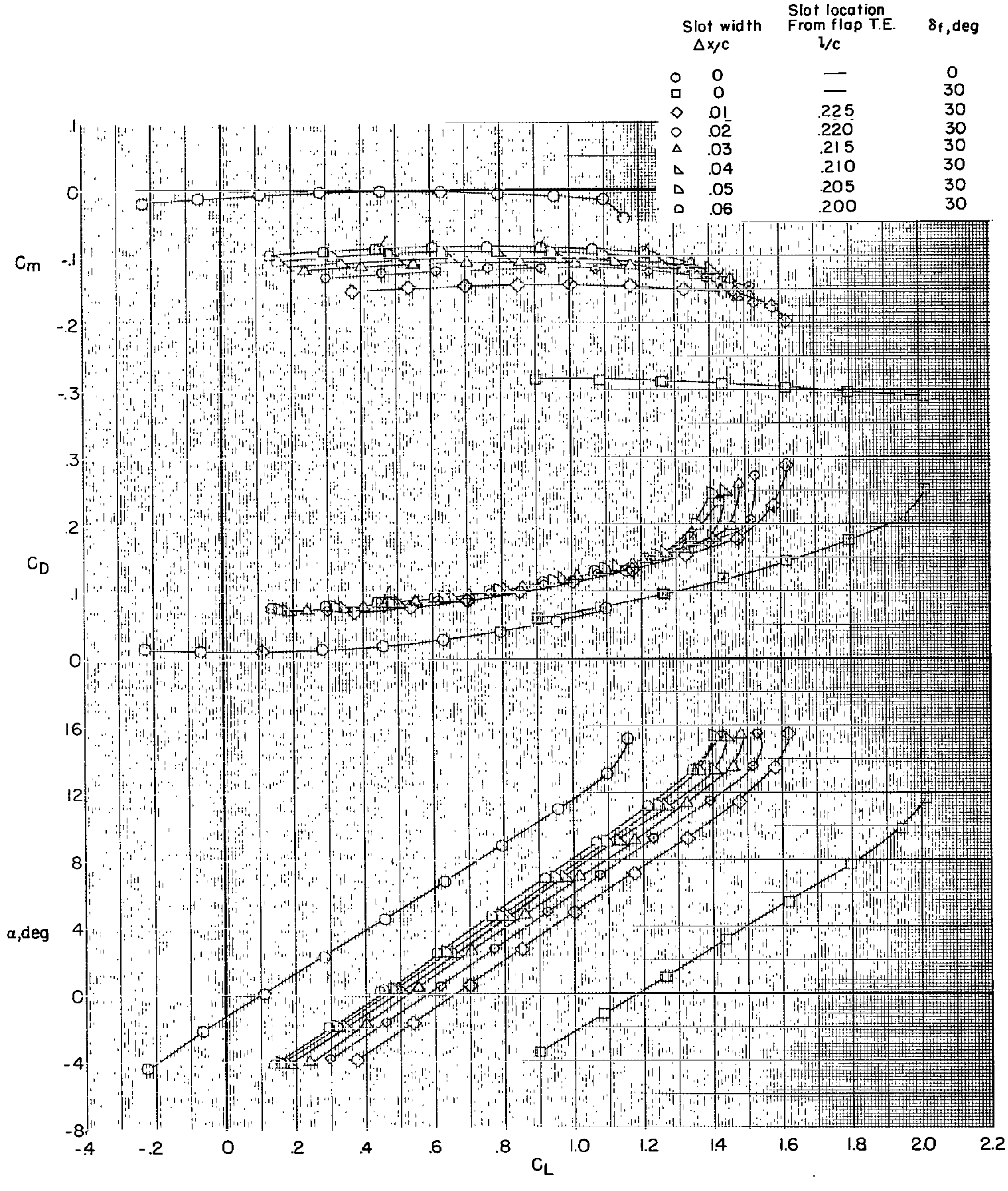
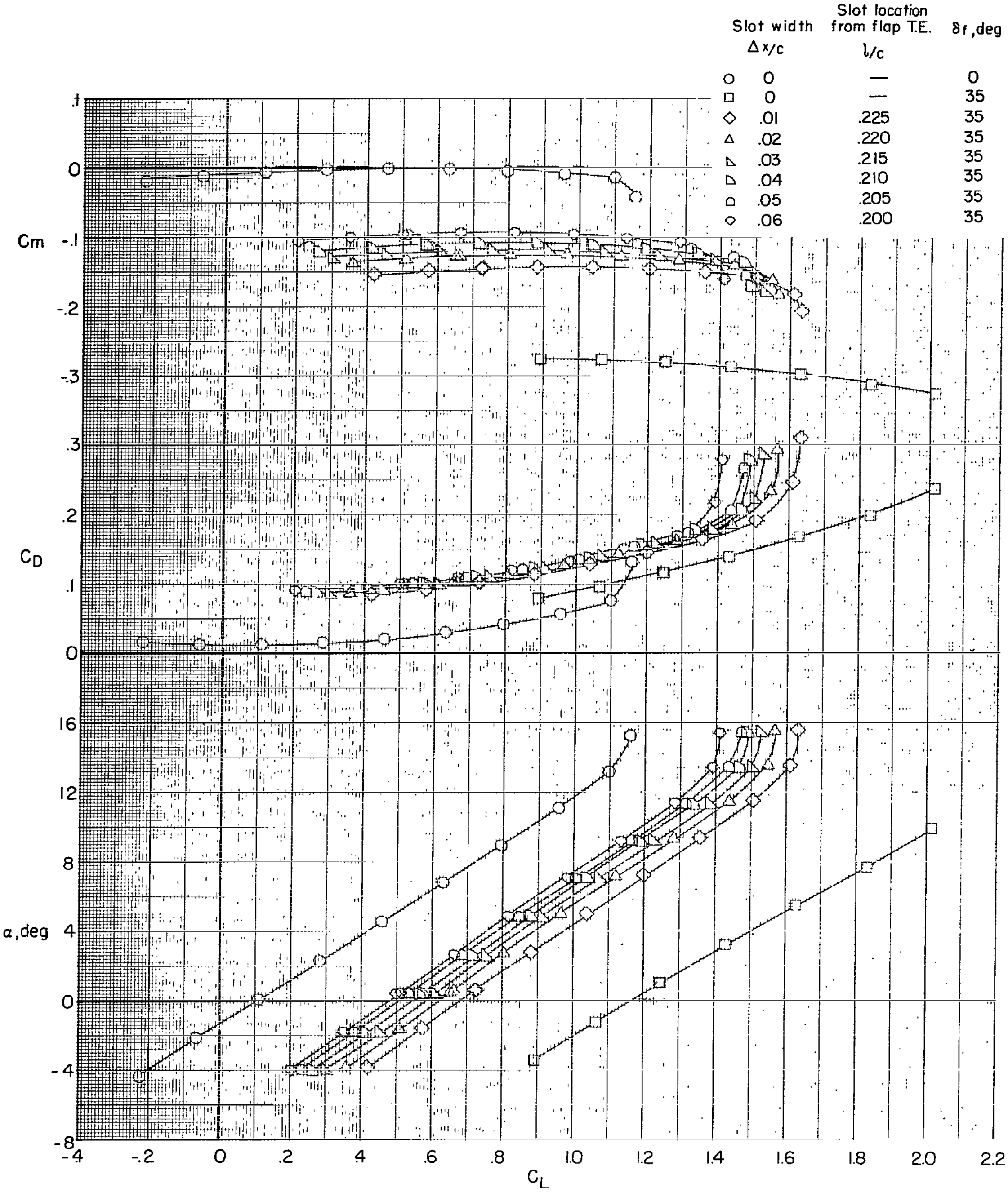


Figure 9.- Variation of changes in lift, drag, and pitching-moment coefficients with slot opening on wing with plain flaps. Rectangular slot; $\alpha = 8^{\circ}$.



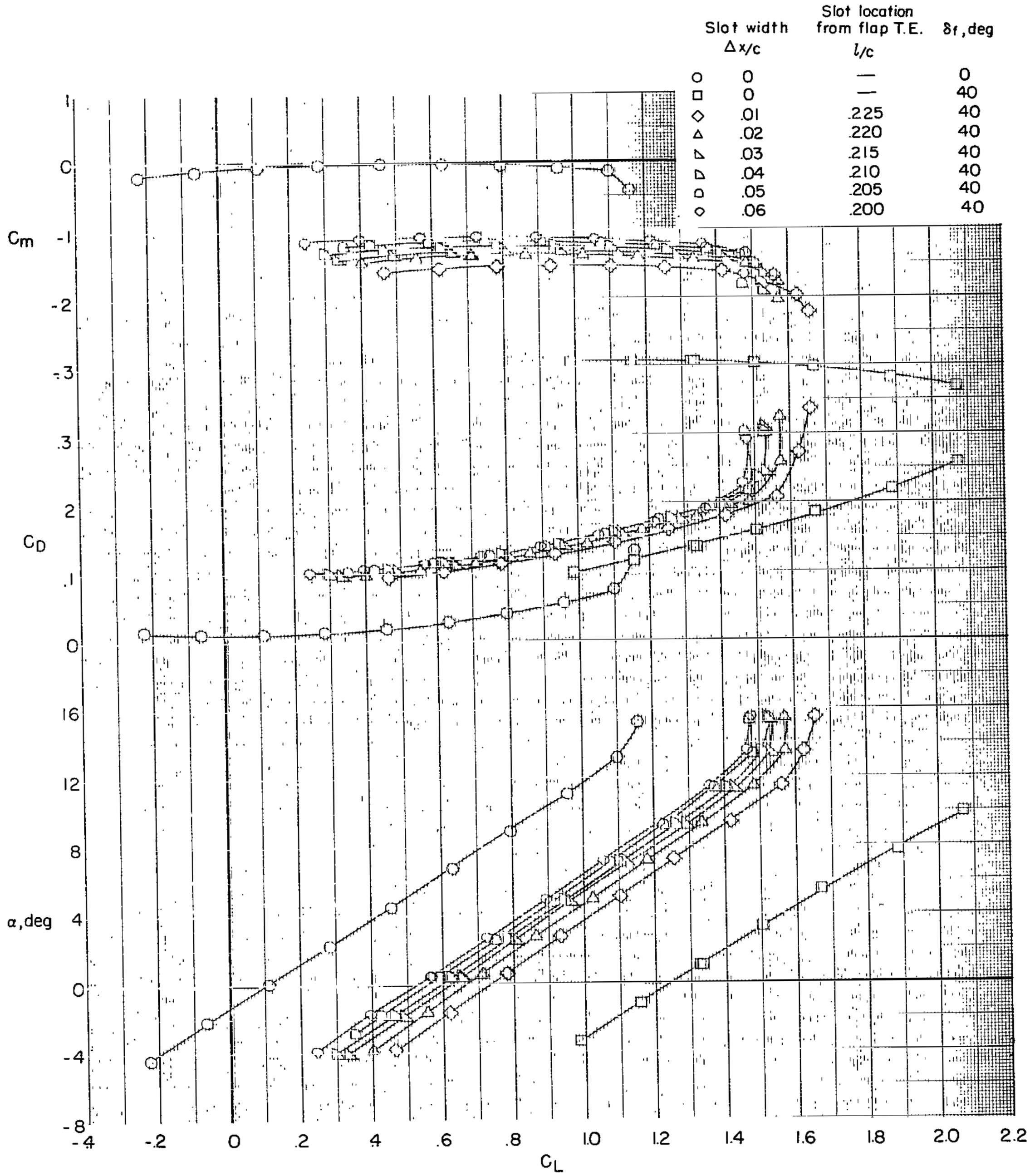
(a) $\delta_f = 30^\circ$.

Figure 10.- Effects of rectangular slot spoiler on longitudinal aerodynamic characteristics of wing with single-slotted flaps.



(b) $\delta_f = 35^o$.

Figure 10.- Continued.



(c) $\delta_f = 40^o$.

Figure 10.- Concluded.

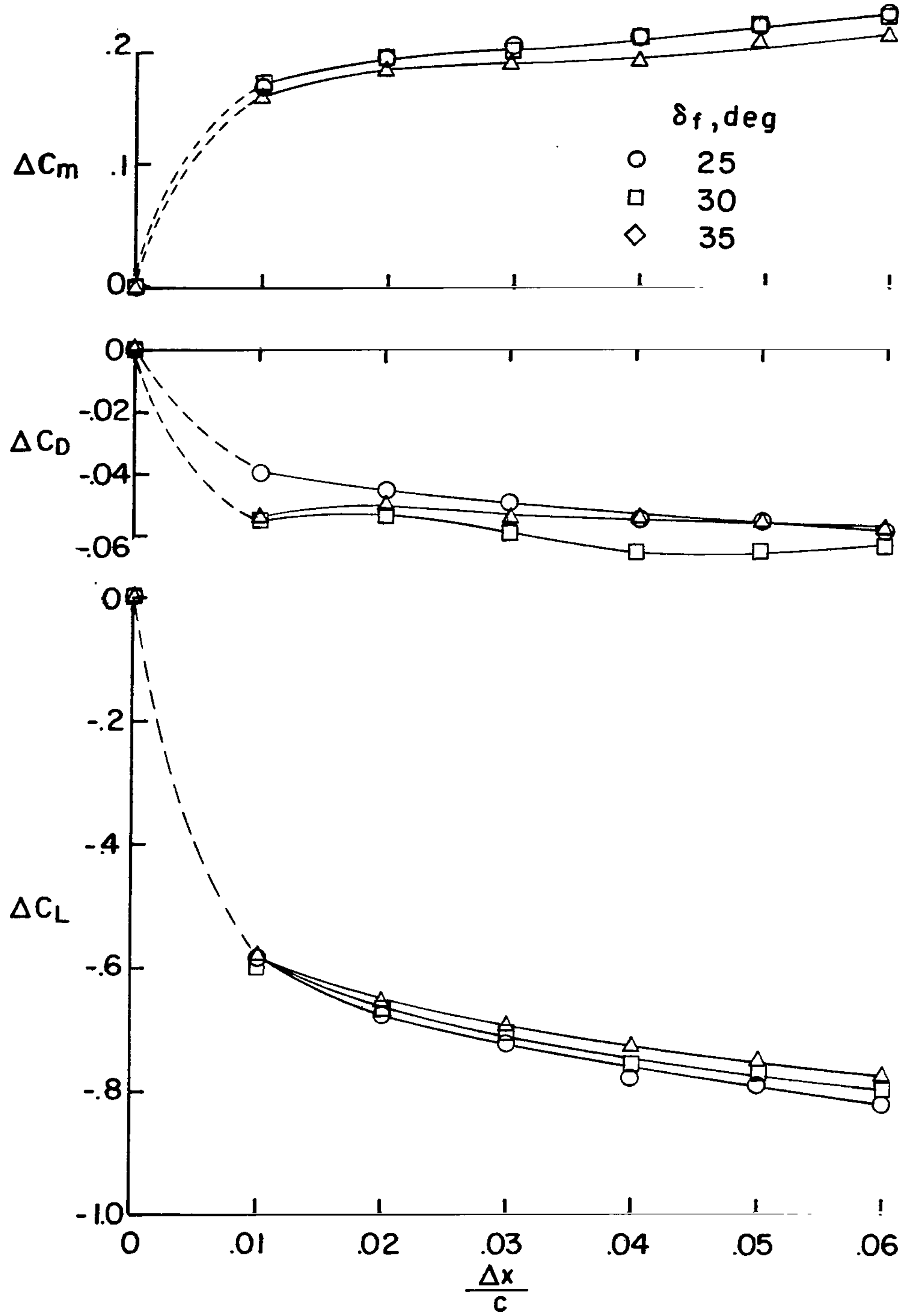


Figure 11.- Variation of changes in lift, drag, and pitching-moment coefficients with slot opening on wing with single-slotted flaps. Rectangular slot; $\alpha = 8^{\circ}$.

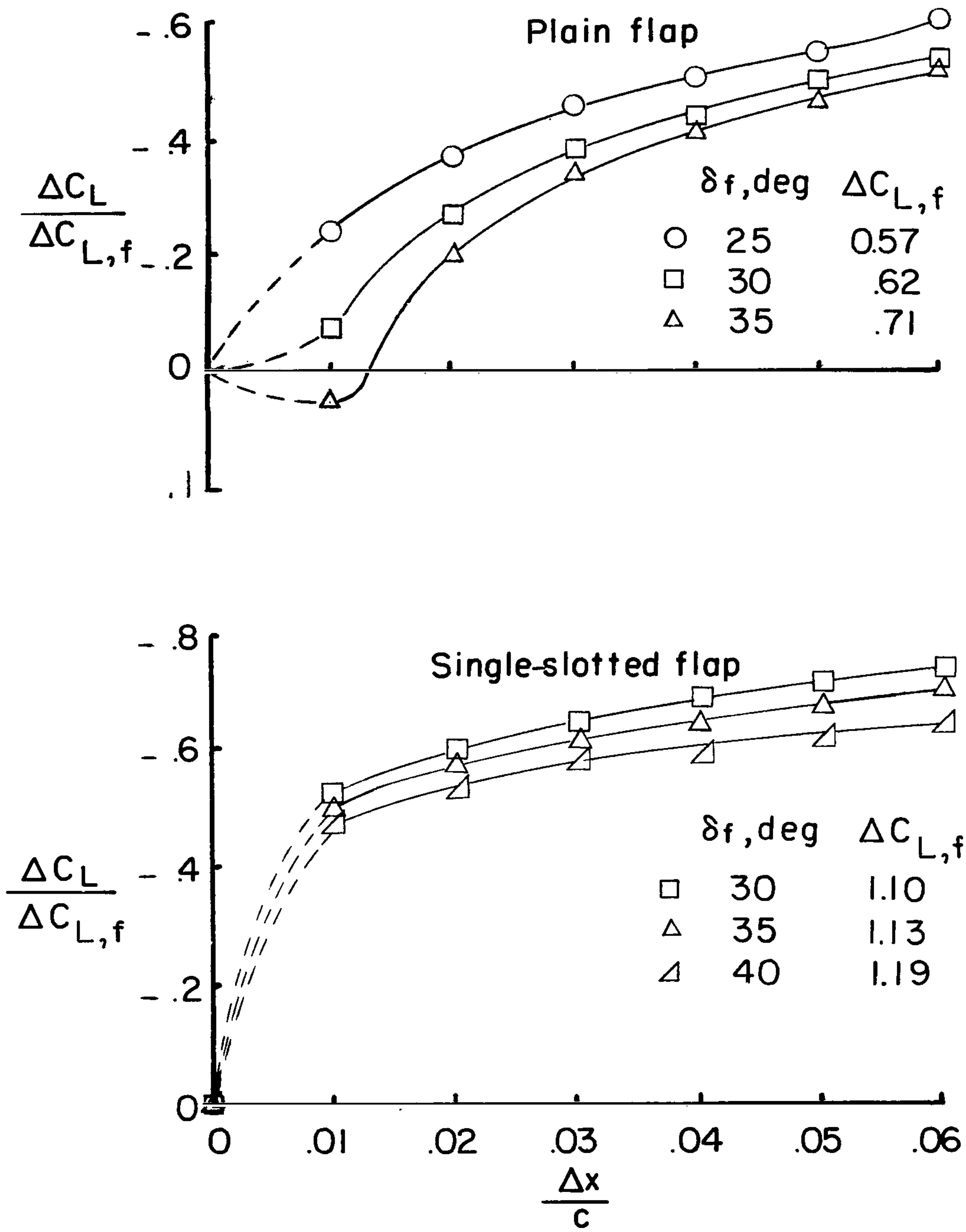
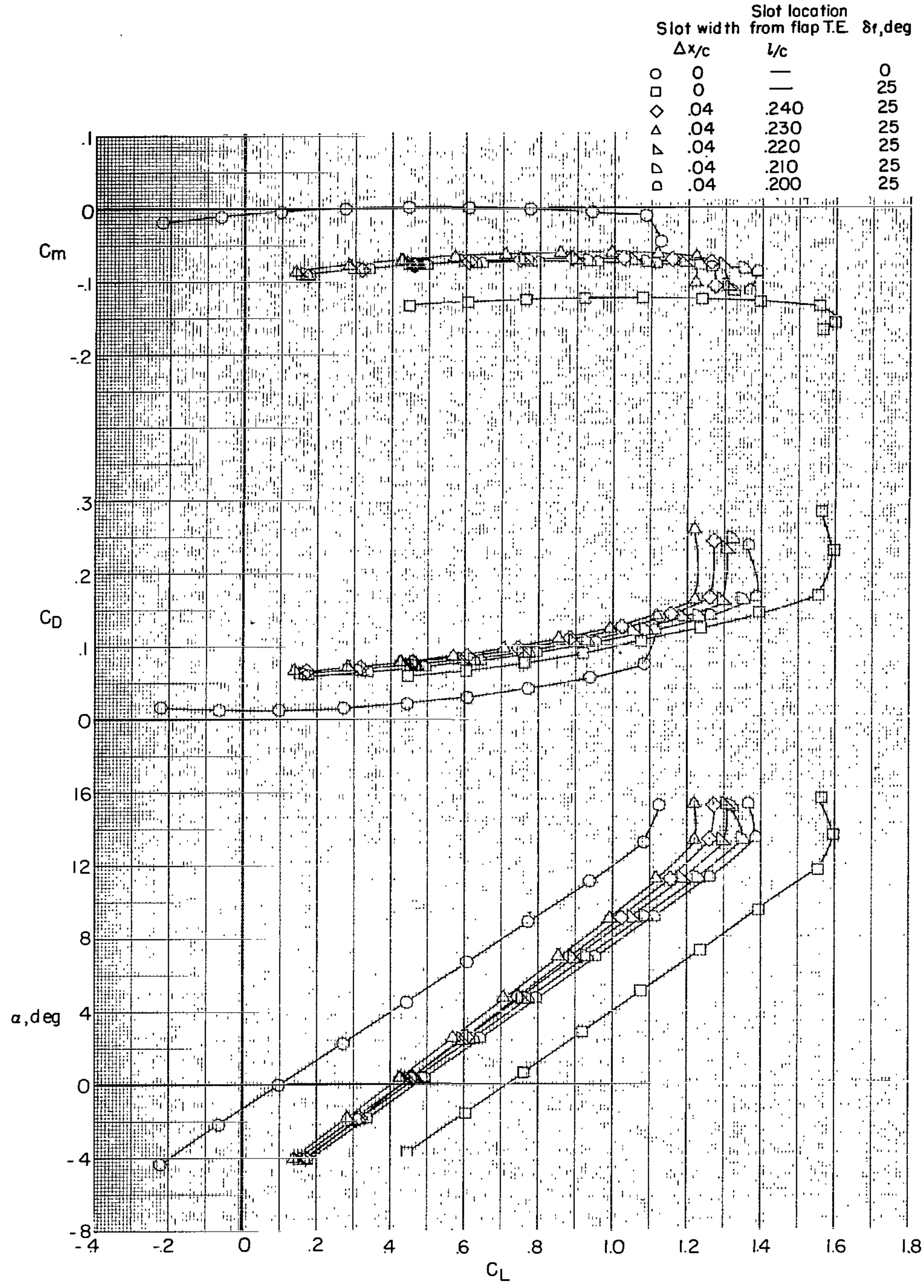
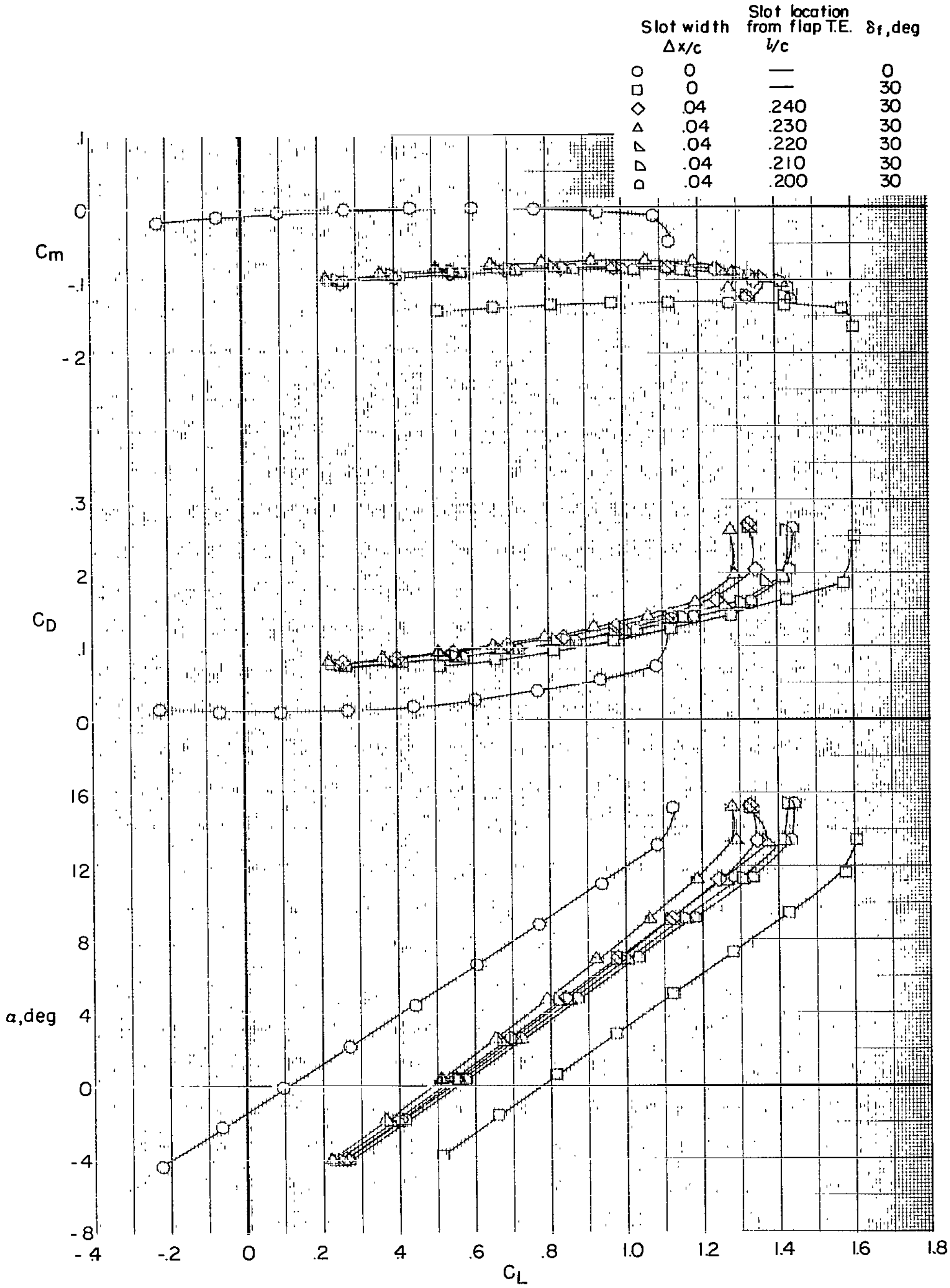


Figure 12.- Comparison of slot-spoiler effectiveness on wings with plain and single-slotted flaps. Rectangular slot; $\alpha = 8^{\circ}$.



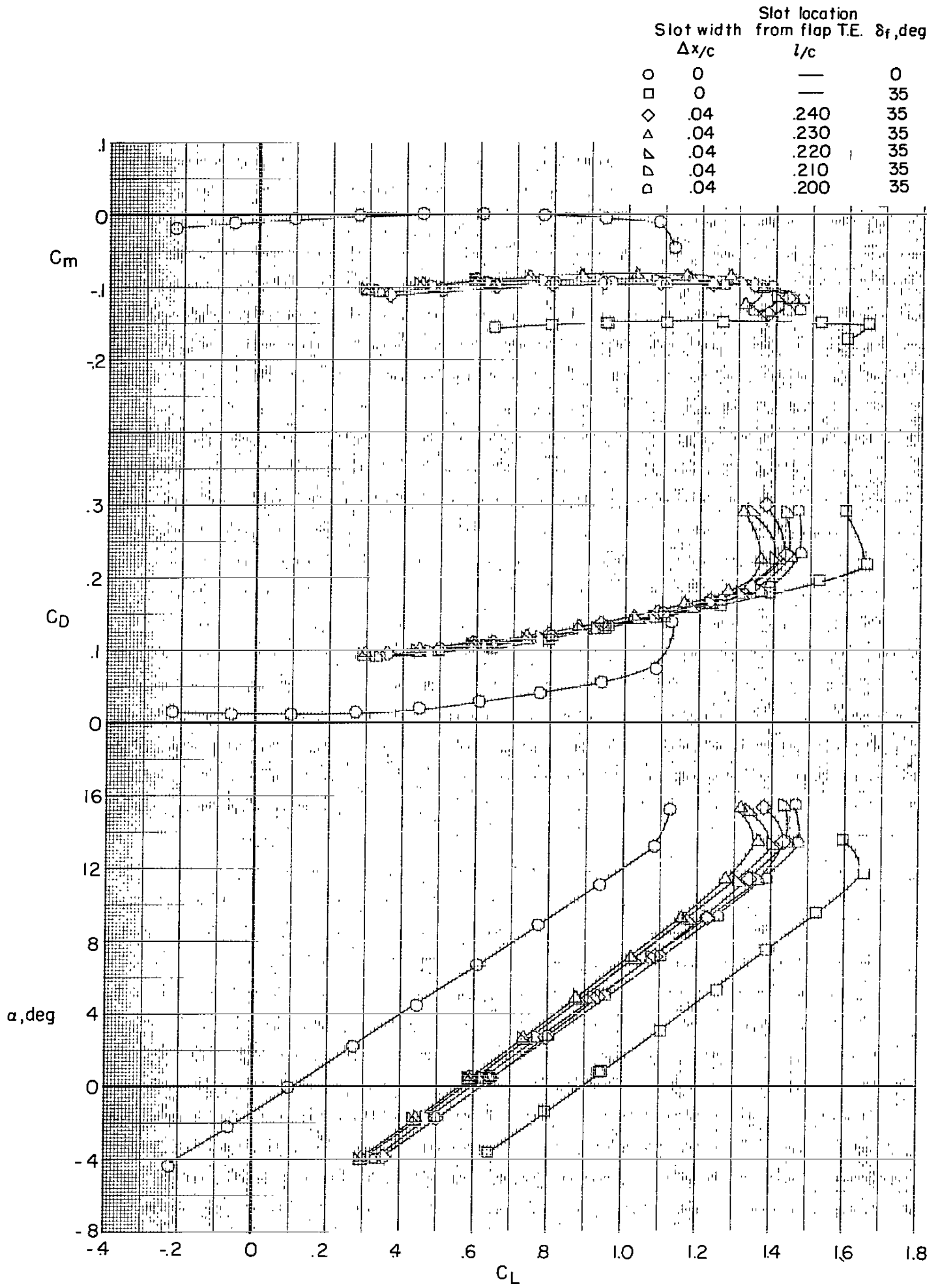
(a) $\delta_f = 25^{\circ}$.

Figure 13.- Effects of chordwise location of rectangular slot spoiler on longitudinal aerodynamic characteristics of wing with plain flaps.



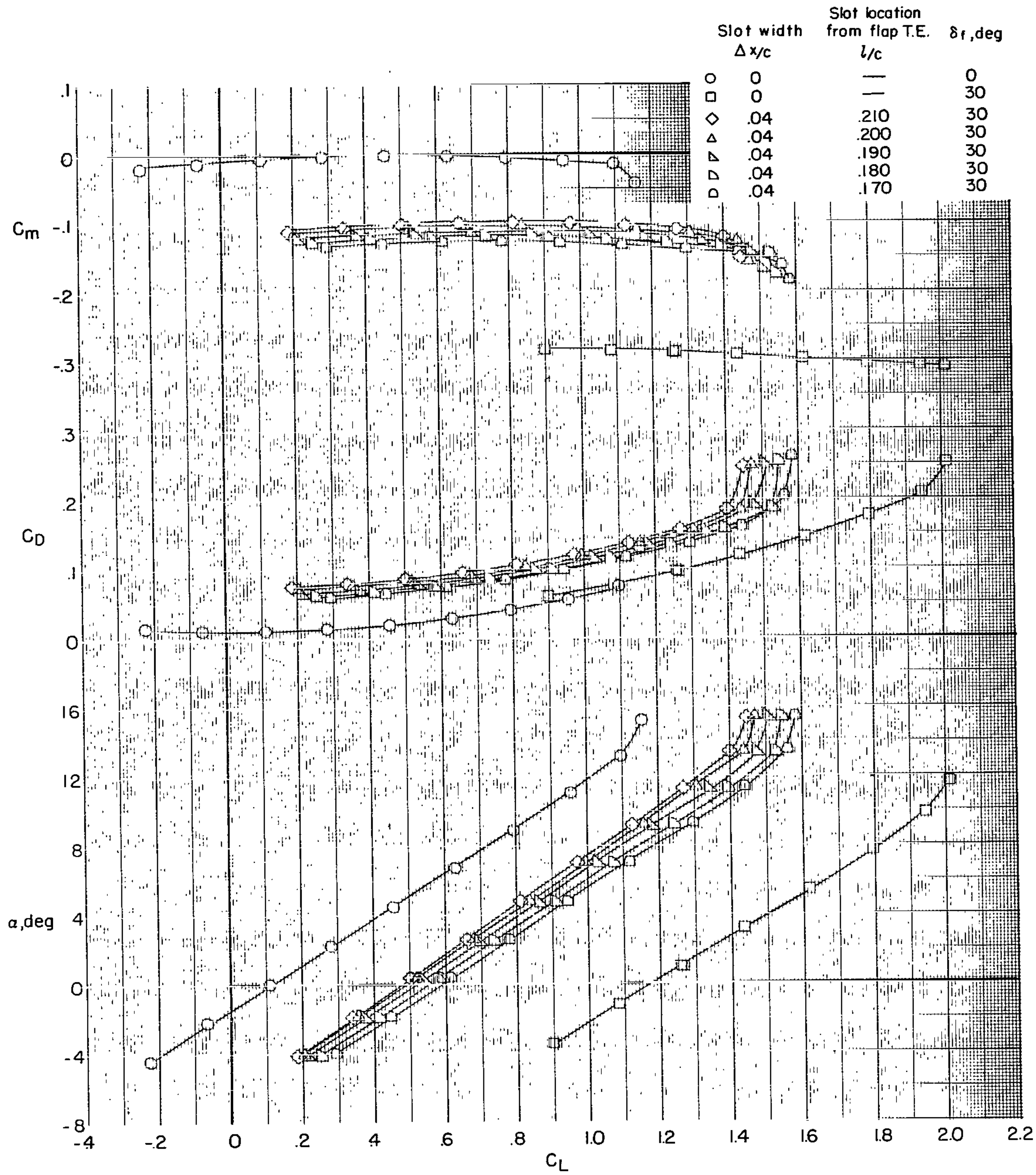
(b) $\delta_f = 30^{\circ}$.

Figure 13.- Continued.



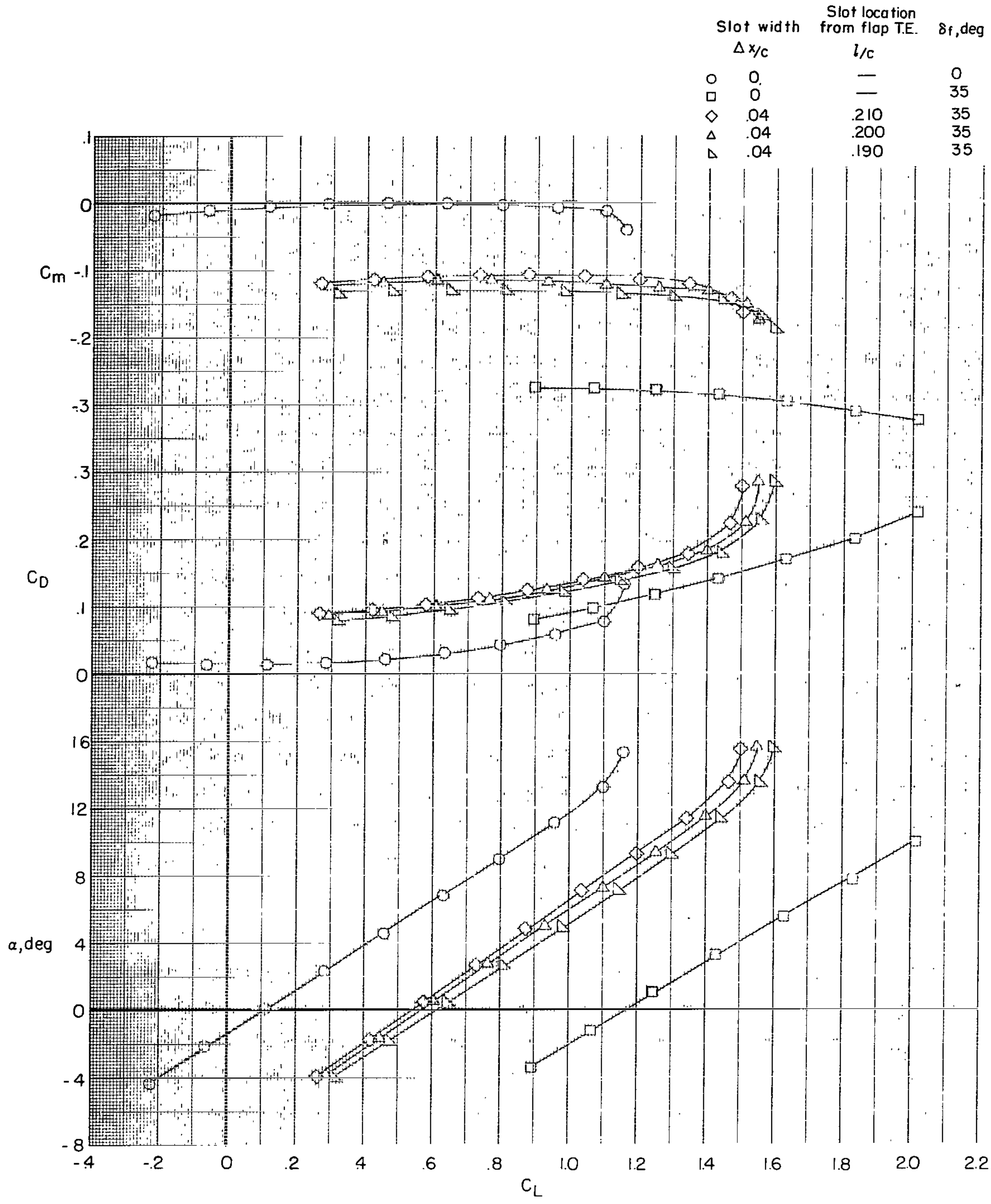
(c) $\delta_f = 35^o$.

Figure 13.- Concluded.



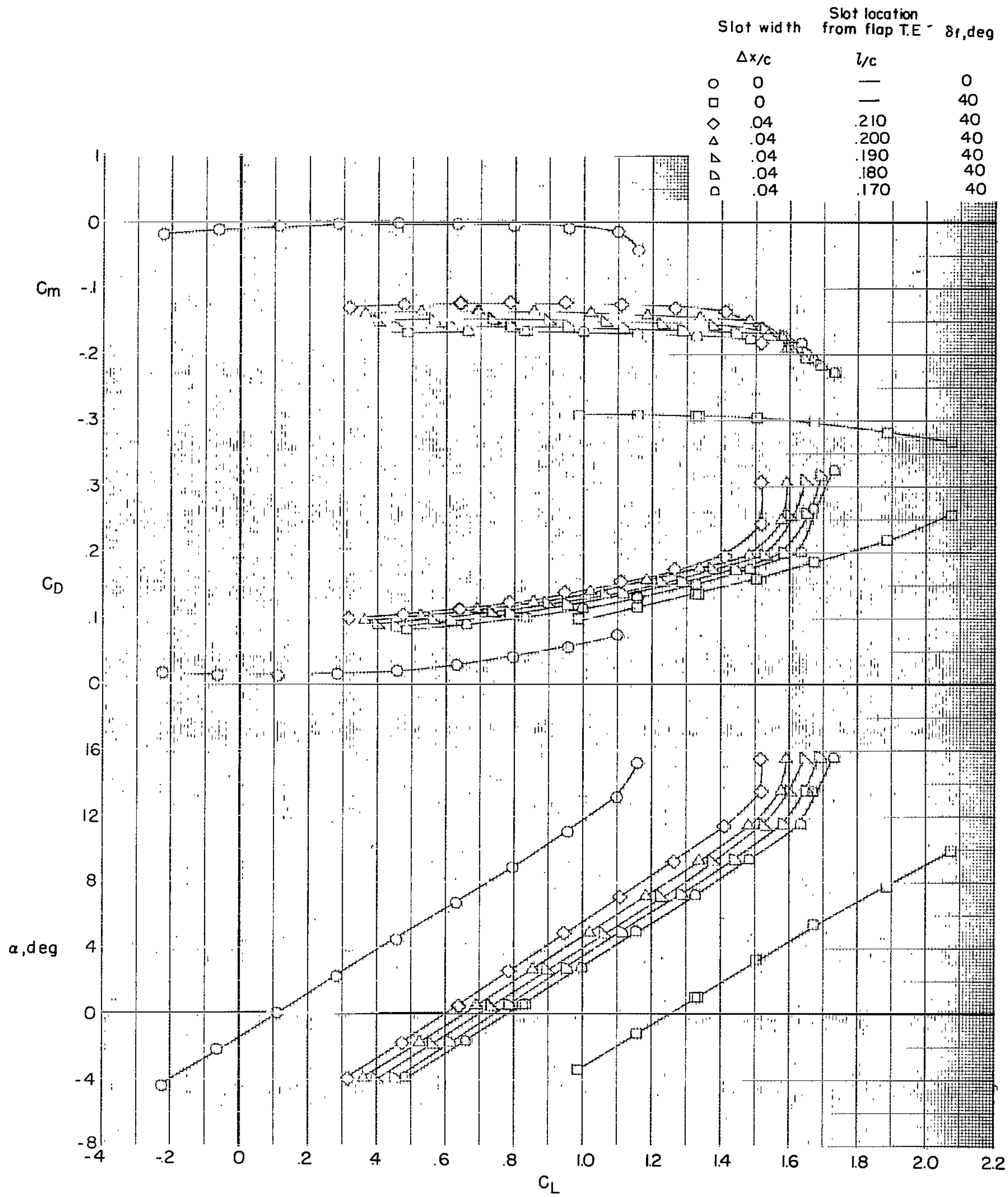
(a) $\delta_f = 30^{\circ}$.

Figure 14.- Effects of chordwise location of rectangular slot spoiler on longitudinal aerodynamic characteristics of wing with single-slotted flaps.



(b) $\delta_f = 35^{\circ}$.

Figure 14.- Continued.



(c) $\delta_f = 40^o$.

Figure 14.- Concluded.

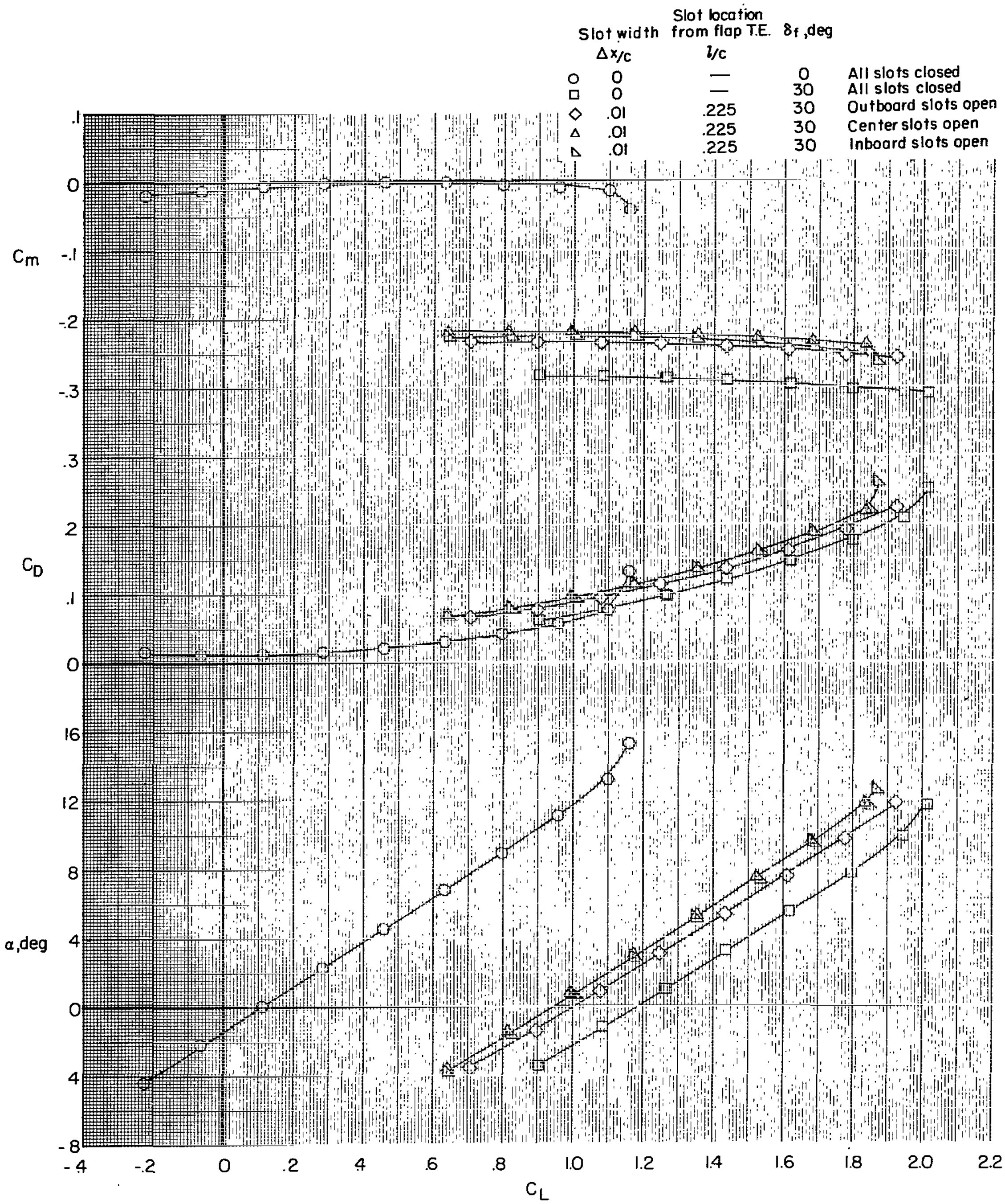
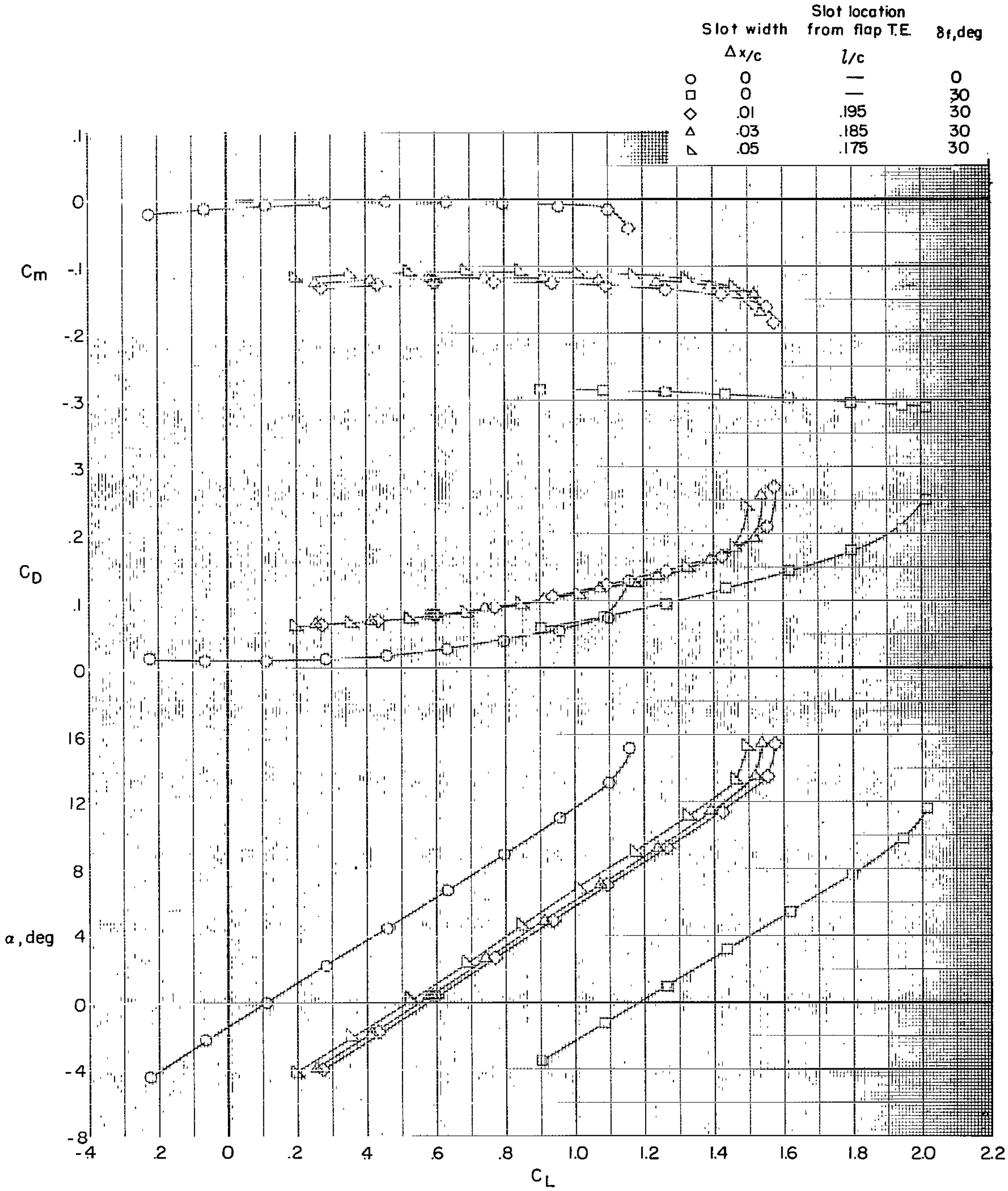
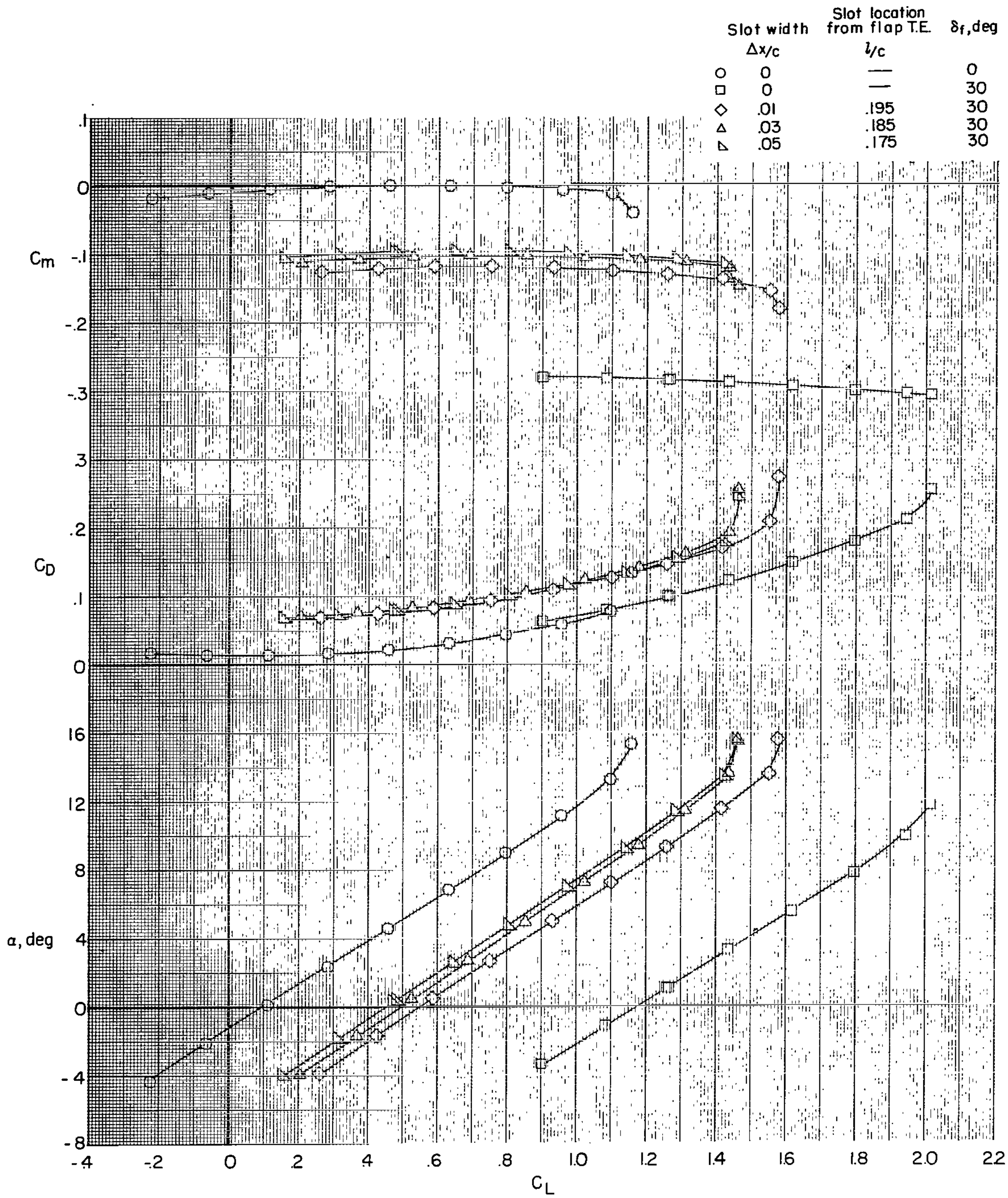


Figure 15.- Effects of spanwise location of slot spoiler on wing with single-slotted flaps.



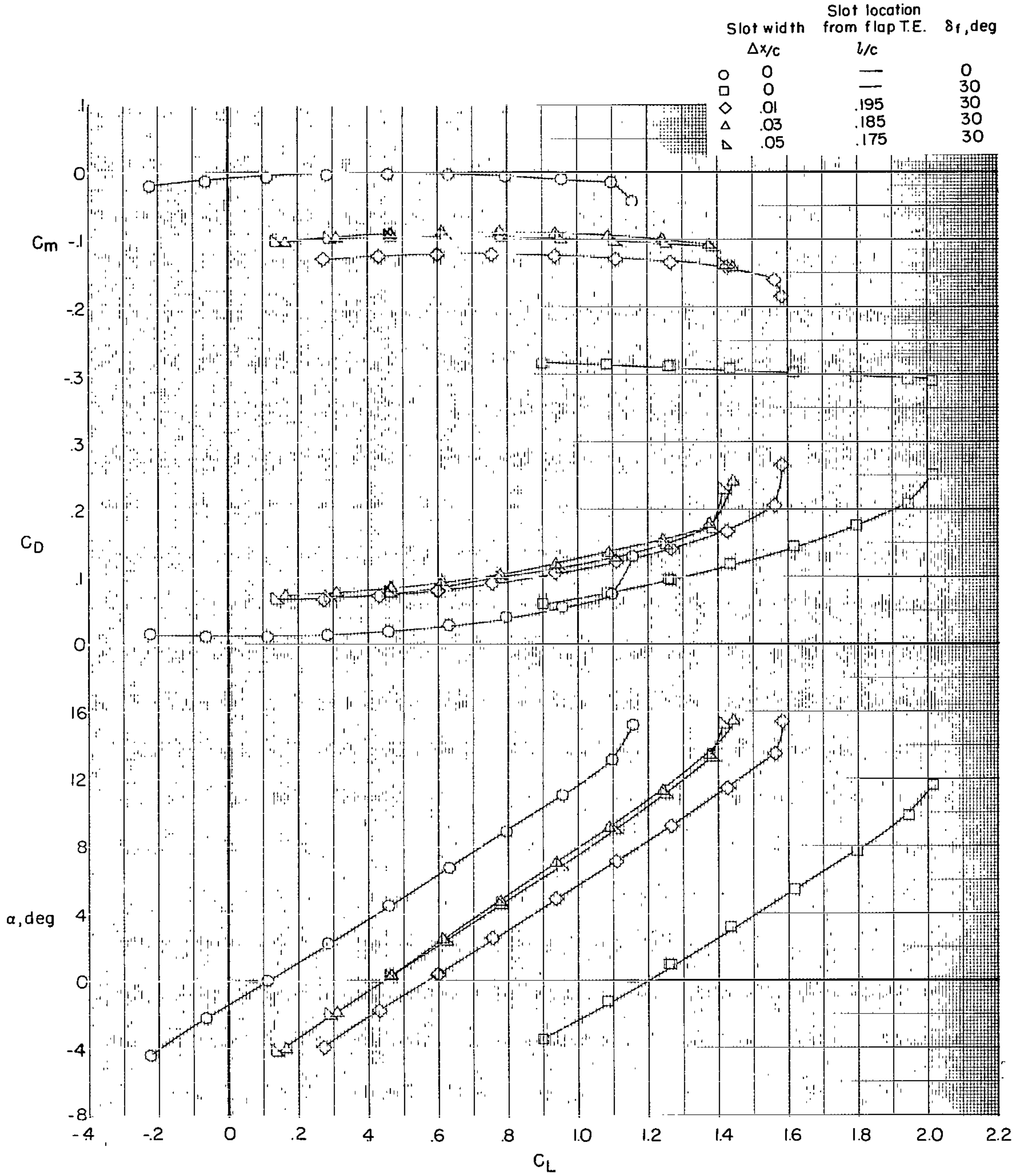
(a) Taper 4.

Figure 16.- Effects of slot-spoiler opening on longitudinal aerodynamic characteristics of wing with single-slotted flap for various slot shapes.



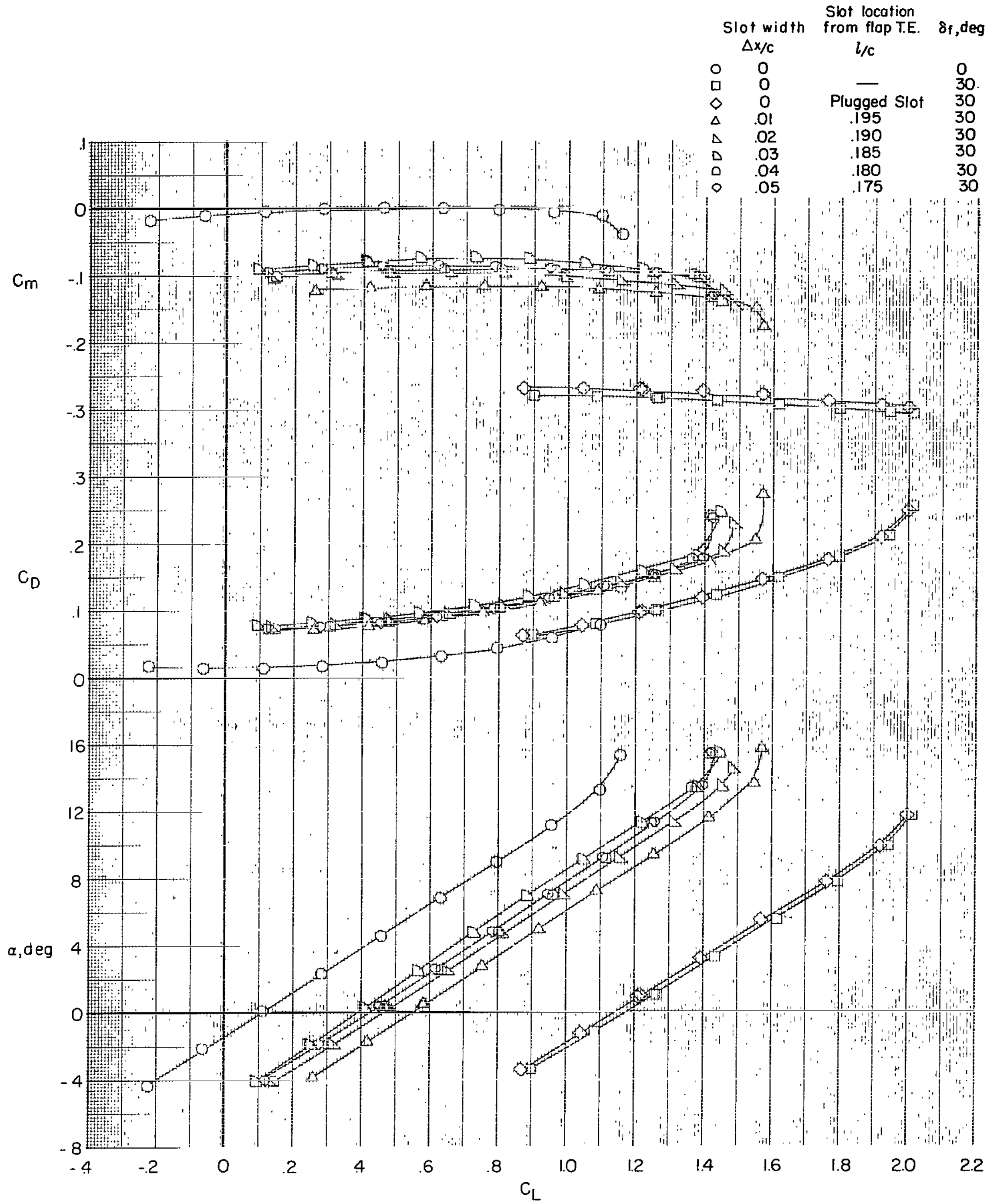
(b) Taper 3.

Figure 16.- Continued.



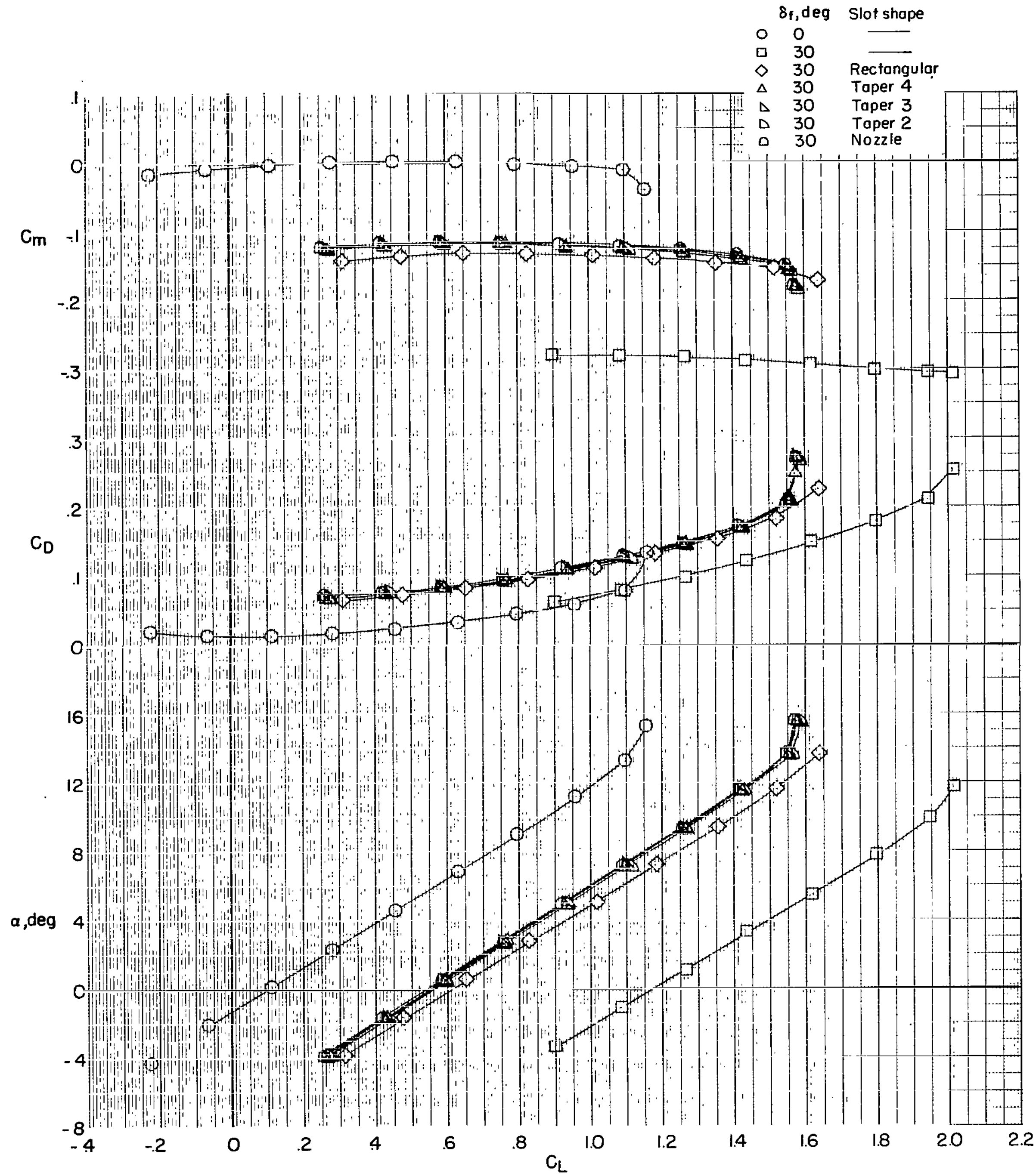
(c) Taper 2.

Figure 16.- Continued.



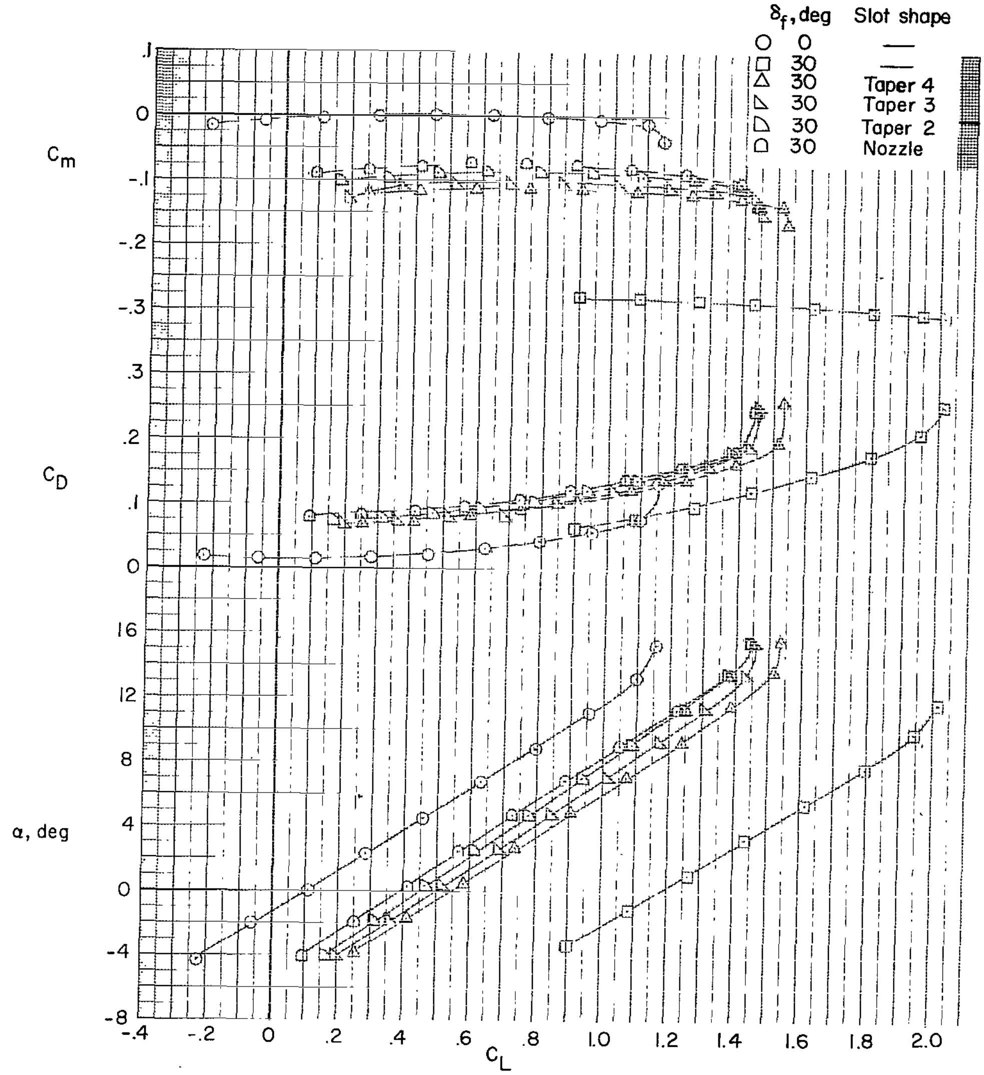
(d) Nozzle.

Figure 16.- Concluded.



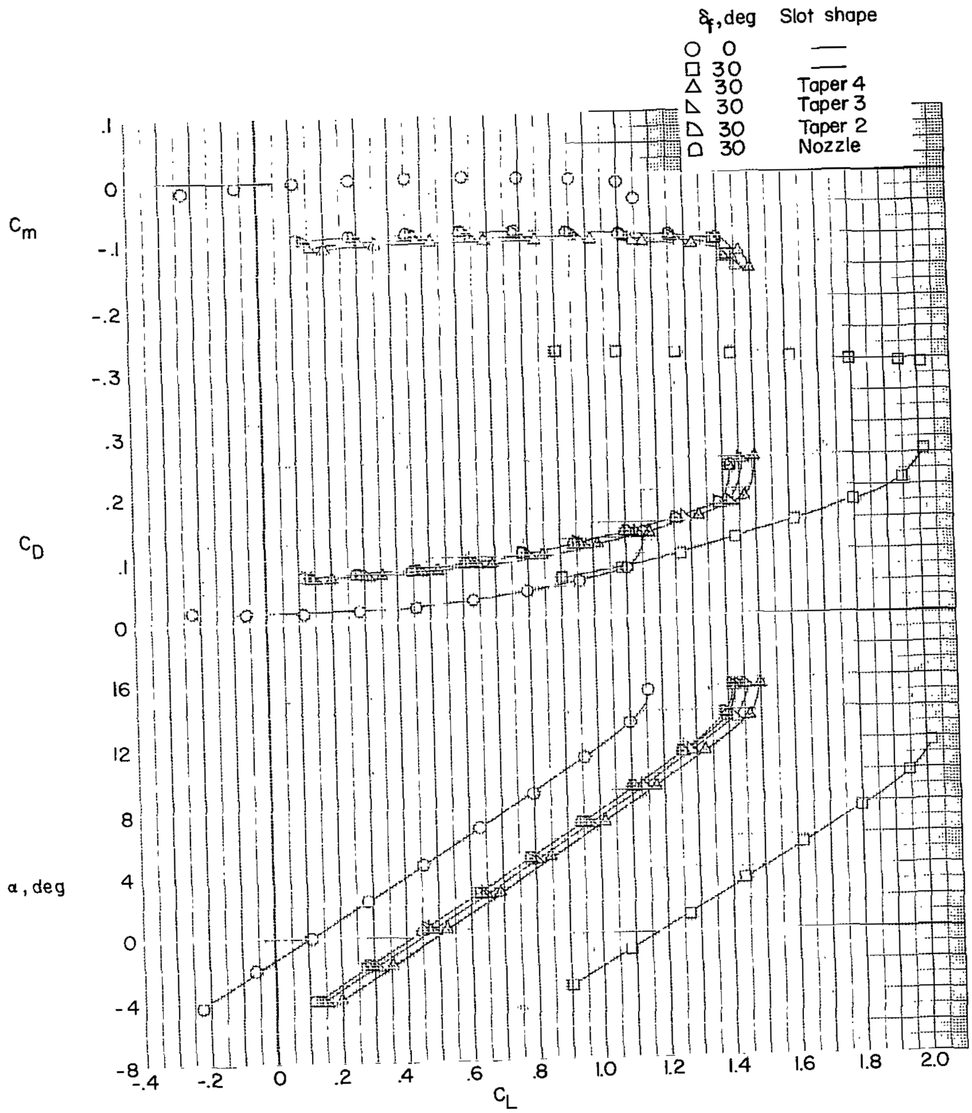
(a) $\frac{\Delta x}{c} = 0.01$; $\frac{l}{c} = 0.195$.

Figure 17.- Comparison of effects of slot-spoiler shapes on longitudinal aerodynamic characteristics of wing with single-slotted flaps for various slot openings.



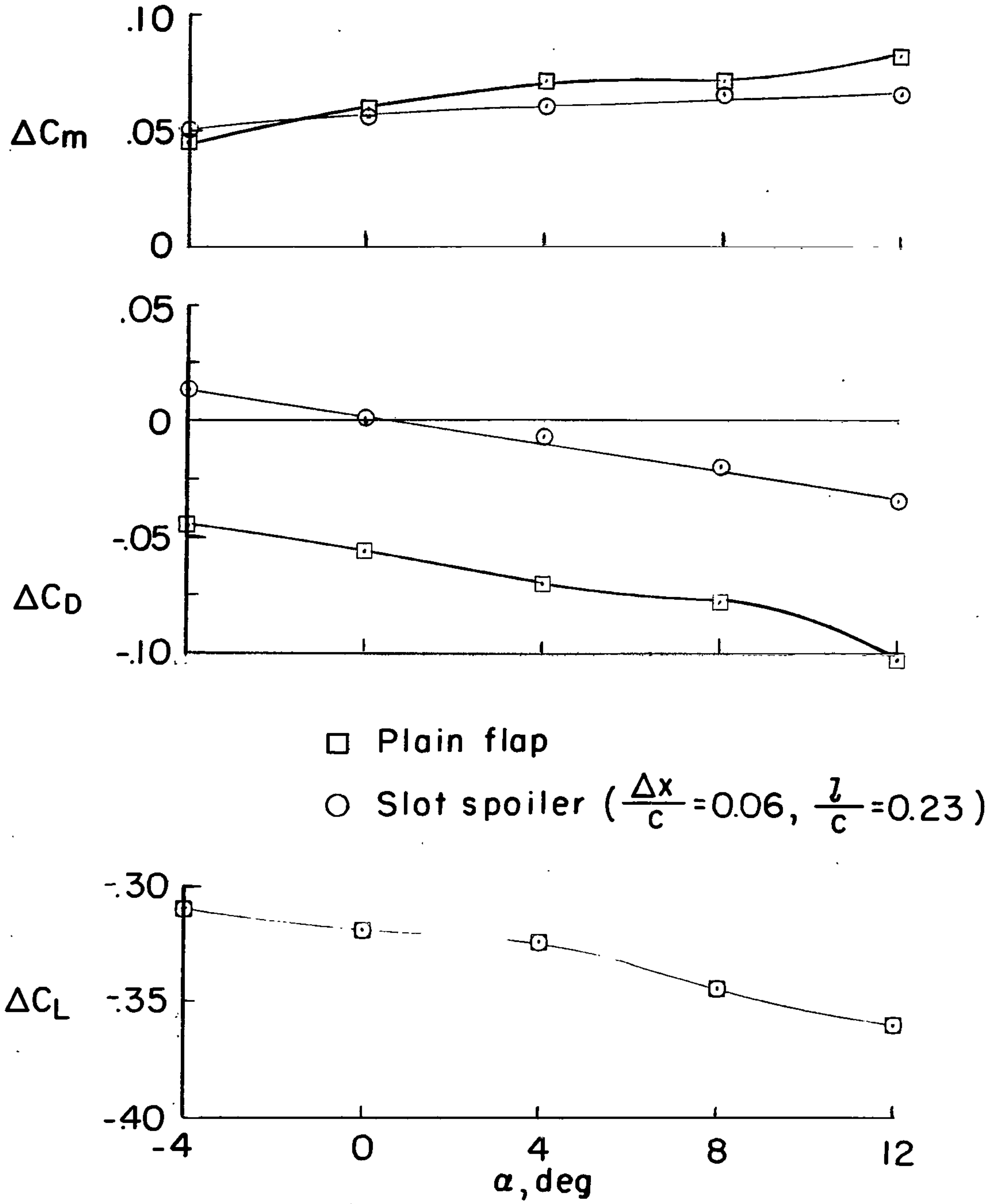
(b) $\frac{\Delta x}{c} = 0.03$; $\frac{l}{c} = 0.185$.

Figure 17.- Continued.



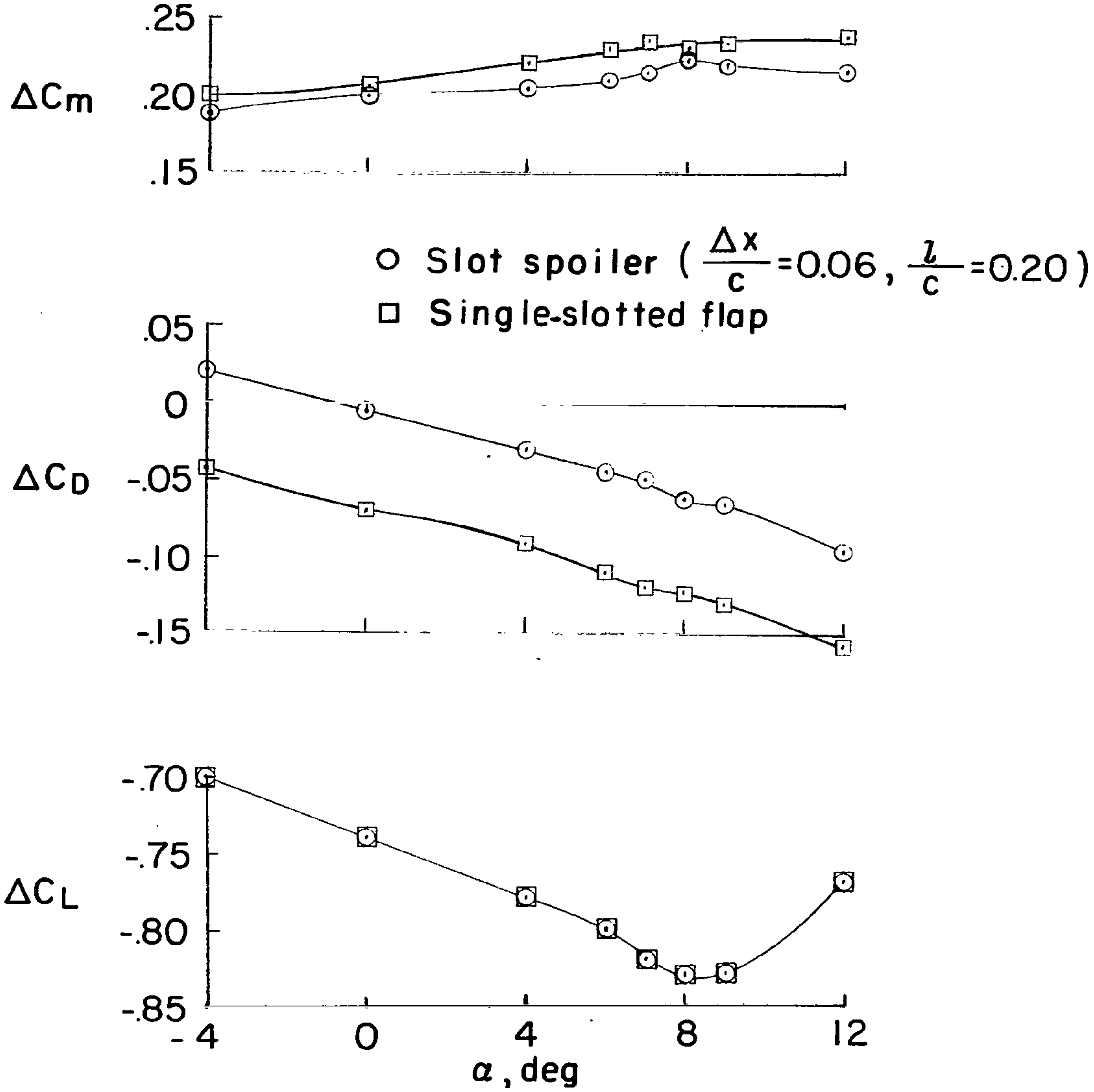
(c) $\frac{\Delta x}{c} = 0.05$; $\frac{l}{c} = 0.175$.

Figure 17.- Concluded.



(a) Plain flap.

Figure 18.- Comparison of effects of opening a slot spoiler at $\delta_f = 30^o$ with a DLC system varying only flap deflection to produce the same lift change.



(b) Single-slotted flap.

Figure 18.- Concluded.

NATIONAL AERONAUTICS AND SPACE ADMISTRATION
WASHINGTON, D.C. 20546

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300

FIRST CLASS MAIL

POSTAGE AND FEES PAID
NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION

U.S.MAIL

001 001 C1 U 01 720114 S00903DS
DEPT OF THE AIR FORCE
AF WEAPONS LAB (AFSC)
TECH LIBRARY/WLOL/
ATTN: E LOU BOWMAN, CHIEF
KIRTLAND AFB NM 87117

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

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION OFFICE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546