

DEC 23 1946

ARR No. 3J28

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

# WARTIME REPORT

ORIGINALLY ISSUED

October 1943 as  
Advance Restricted Report 3J28

WIND-TUNNEL TESTS OF TWO TAPERED WINGS WITH  
STRAIGHT LEADING EDGES AND WITH CONSTANT-  
CHORD CENTER SECTIONS OF DIFFERENT SPANS

By Richard W. Fairbanks and Sidney R. Alexander

Langley Memorial Aeronautical Laboratory  
Langley Field, Va.

# NACA

WASHINGTON

NACA  
LANGLEY MEMORIAL AERONAUTICAL  
LABORATORY  
Langley Field, Va.

NACA WARTIME REPORTS are reprints of papers originally issued to provide rapid distribution of advance research results to an authorized group requiring them for the war effort. They were previously held under a security status but are now unclassified. Some of these reports were not technically edited. All have been reproduced without change in order to expedite general distribution.

## NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

## ADVANCE RESTRICTED REPORT

WIND-TUNNEL TESTS OF TWO-TAPERED WINGS WITH  
STRAIGHT LEADING EDGES AND WITH CONSTANT-  
CHORD CENTER SECTIONS OF DIFFERENT SPANS

By Richard W. Fairbanks and Sidney R. Alexander

## SUMMARY

An investigation was conducted in the NACA 19-foot pressure tunnel of two-tapered wings with NACA 230-series airfoil sections, straight leading edges, and constant-chord center sections. The spans, areas, and root chords of both wings were equal. The center-section span of one wing was equal to the root chord; whereas the center-section span of the other was equal to twice the root chord. Both wings were equipped with partial- and full-span simple split flaps.

Lift, drag, and pitching-moment coefficients were determined for the plain wing and for each flap arrangement through a test Reynolds number range of 2,600,000 to 4,700,000. Stalling characteristics were determined for the plain wings and with flaps deflected  $60^\circ$ .

The results of this investigation indicate that the wing with the square center section has greater maximum lift coefficients and greater increments of maximum lift due to flap deflections than the wing with the rectangular center section. The difference in drag coefficient for the plain wings is not appreciable. The aerodynamic-center locations were determined as 0.239 of the mean chord back of the leading edge for the wing with square center sections and 0.244 of the mean chord for the wing with rectangular center section. Stall progressions starting at the center section and working outboard were indicated for both wings. Deflecting the flaps on both wings resulted in a sudden stall.

## INTRODUCTION

A series of tests is being conducted in the 19-foot pressure tunnel of LMAL at the request of the Bureau of

Aeronautics, Navy Department, to determine the aerodynamic and stalling characteristics of conventional wings with a nonlinear distribution of both area and section aerodynamic centers. The models for these tests were constructed by the Navy Department from specifications furnished by the NACA. Tests of two tapered wings with constant-chord center sections and straight trailing edges designated wings III and VI are reported in reference 1. The present report covers tests of two tapered wings with constant-chord center sections and straight leading edges, which are designated wings I and IV.

The location of wing aerodynamic center is dependent upon the distribution of area and section aerodynamic centers along the span. Research reported in reference 2 provides data for determining the approximate location of the aerodynamic center for wings with a nonlinear distribution either of area or of section aerodynamic centers. Calculated values for the wing aerodynamic centers were obtained by the method of reference 2 for comparison with the experimental values obtained in the tests. Values of section aerodynamic centers for these particular wing sections were taken from reference 3.

For the tests reported herein, lift, drag, and pitching-moment characteristics were determined for each wing without flaps and with partial- and full-span simple split flaps at various deflections through a Reynolds number range from 2,600,000 to 4,700,000. A study of the stalling characteristics of the wings was also made.

### MODELS

The plain wings or basic models were furnished by the Bureau of Aeronautics, Navy Department, and were built to NACA specifications. These wings have been designated wing I and wing IV. The general dimensions of the two wings are given in figure 1. They were constructed of laminated mahogany to NACA 230-series airfoil sections, and were sprayed with lacquer and sanded smooth. The airfoil sections are NACA 23015 at the root and NACA 23009 at the construction tip. The maximum ordinate points of the upper surface lie in the same horizontal plane and the leading edges are straight. Neither wing has geometric twist. The span, area, root chord, and aspect ratio of both wings are equal. The center-section span of wing I is equal to the root chord, and the center-section span of wing IV is equal to twice the root chord. The taper ratios for the

outer panels are 2.00 and 2.86 and the forward sweep of the quarter-chord points of the outer panels is  $3.17^\circ$  and  $5.25^\circ$  for wings I and IV, respectively.

The flaps used were 20-percent-chord simple split flaps constructed of thin metal. The desired flap deflections were obtained by inserting triangular wooden blocks between the wing lower surface and the flap. The flap spans were 53 percent of the wing span for the partial-span condition and 90 percent of the wing span for the full-span condition.

### TESTS

The tests were conducted in the NACA 19-foot pressure tunnel with the air in the tunnel compressed to an absolute pressure of 35 pounds per square inch, and with the model mounted on the standard wing supports (fig. 2). The purpose of the tests was to determine the aerodynamic and stalling characteristics of conventional wings with nonlinear distribution of both area and section aerodynamic centers.

The method of testing was similar to that used in reference 1 and values are believed to be accurate within the following limits:

$\alpha$ , degrees . . . . .	$\pm 0.1$
$C_{L_{max}}$ . . . . .	$\pm 0.03$
$C_m$ . . . . .	$\pm 0.005$
$C_D (C_L = 0)$ . . . . .	$\pm 0.0003$

Lift, drag, and pitching-moment data were obtained from force tests for the plain wings ( $\delta f = 0^\circ$ ) and for the wings with partial-span and full-span flaps deflected  $15^\circ$ ,  $30^\circ$ ,  $45^\circ$ , and  $60^\circ$ . The tests covered an angle-of-attack range from  $-6^\circ$  to the angle of stall at test Reynolds numbers of approximately 2,600,000, 3,700,000, and 4,700,000. A study of the stalling characteristics was made by observing the action of wool tufts attached to the upper surface of the wing. Sketches, still pictures, and moving pictures were made of the stall progression at various angles of attack for the plain wing and for the wing with partial-span and full-span flaps deflected  $60^\circ$  at a Reynolds number of approximately 4,700,000.

## RESULTS AND DISCUSSION

## Symbols

The data are presented in terms of standard nondimensional coefficients and are corrected for model support tare and interference. The coefficients and symbols used herein are defined as follows:

$C_L$  lift coefficient ( $L/qS$ )

$C_D$  drag coefficient ( $D/qS$ )

$C_m$  pitching-moment coefficient about quarter-chord point of root section ( $M/qS\bar{c}$ )

where

$L$  lift, pounds

$D$  drag, pounds

$M$  pitching moment, foot-pounds

$q$  dynamic pressure of undisturbed air stream, pounds per square foot ( $\frac{1}{2}\rho V^2$ )

$S$  wing area (32.14 sq ft)

$\bar{c}$  mean chord,  $S/b$  (2.14 ft)

$b$  wing span (15 ft)

$\rho$  mass density of air, slugs per cubic foot

$V$  free-stream velocity, feet per second

and

$\delta_f$  flap deflection measured between lower surface of wing and flap, degrees

$\alpha$  angle of attack of root chord corrected for jet-boundary effect and air-flow misalignment, degrees

- R Reynolds number based on mean wing chord ( $\rho V \bar{c} / \mu$ )
- $\mu$  coefficient of viscosity
- M Mach number (ratio of free-stream velocity to speed of sound)

### Lift and Stalling Characteristics

Force-test data for the range of Reynolds numbers are presented in figures 3 to 8. Comparison of the lift values at  $\delta_f = 0$  reveals that wing I has a maximum lift coefficient of 1.64 (fig. 5) as compared with 1.62 (fig. 8) for wing IV. The variation of maximum lift coefficient with Reynolds number is shown in figures 9 and 10. No consistent variation is indicated. Figure 11 shows variation of increment of maximum lift with flap deflection. The increment of maximum lift coefficient due to partial- and full-span split flaps deflected  $60^\circ$  is 0.74 and 1.10, respectively, for wing I and 0.65 and 0.98, respectively, for wing IV.

A comparison of the data presented in figures 5, 8, and 11 with similar data of reference 1 reveals that the wing with a straight leading edge has a higher maximum lift and a greater increment of maximum lift due to split flaps than the corresponding wing with a straight trailing edge.

The stall diagrams are shown in figures 12 to 17. The stall progression of both wings without flaps is rapid, the stall starting at the center section and moving outward. The tips did not stall throughout the range of angles of attack investigated. A decided cross flow was noted along the trailing edge inward as far as the constant-chord section. The addition of partial-span and full-span flaps has little effect on the angle of stall. With flaps deflected, both wings have a sudden stall, the most critical condition being when the full-span flaps are deflected  $60^\circ$ .

A comparison of the stalling characteristics of the wings reported herein with those of reference 1 reveals that wings I and IV have higher angles of stall and a more rapid stall progression than wings III and VI of reference 1. For wings I and IV the stall starts at the center section; whereas for the wings of reference 1 the stall starts outboard and progresses toward the center.

### Drag Characteristics

A comparison of the drag curves of plain wings I and IV reveals no appreciable difference in the drag coefficients up to a lift coefficient of 1.0.

### Pitching-Moment Characteristics

The pitching-moment curves for wings I and IV are shown together in figure 18 for comparison. Both curves have a positive slope, indicating that the wing aerodynamic center is forward of the quarter-chord point of the root section. The slope of the pitching-moment curve for wing I indicates that its aerodynamic center is farther forward. Because wing IV has greater sweepforward than wing I, the effect of increasing the center-section span is to decrease the tendency of the sweepforward to shift the aerodynamic center forward.

The positions of the wing aerodynamic centers measured from the leading edge were determined both from the experimental data of reference 3 and by calculation according to the method outlined in reference 2. A comparison of these results is given in the following table:

Wing	Horizontal location of aerodynamic center back of leading edge in terms of $S/b$	
	Experimental	Calculated
I	0.239	0.256
IV	.244	.262

### CONCLUSIONS

The tests reported herein were of two tapered wings having straight leading edges and constant-chord center sections but with different center-section spans. The center-section span of wing I was equal to the chord and that of wing IV was twice the chord. The results indicate the following conclusions:

1. Wing I has greater maximum lift coefficients and greater increments of maximum lift coefficient due to split flaps than Wing IV for all comparable conditions tested.

2. The increment of maximum lift coefficient due to split flaps is greater for the wings with straight leading edges than for similar wings with straight trailing edges.

3. The difference in drag coefficients of wing I and wing IV at low and moderate lift coefficients is not appreciable.

4. The effect of increase in center-section span is to decrease the shift of the aerodynamic center of the wing in the direction of the wing-sweep.

Langley Memorial Aeronautical Laboratory,  
National Advisory Committee for Aeronautics,  
Langley Field, Va.

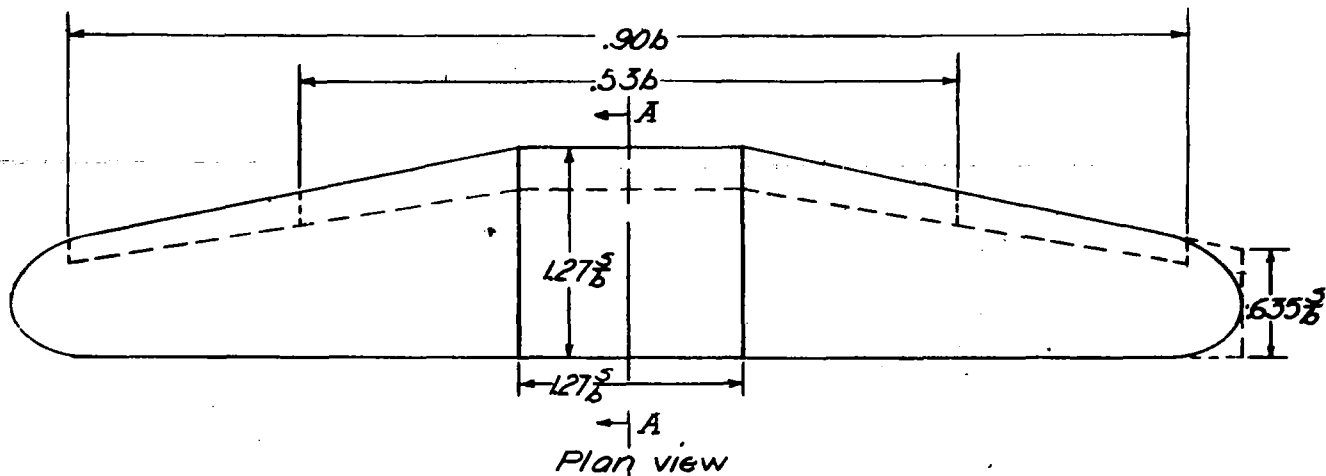
#### REFERENCES

1. Neely, Robert H.: Wind-Tunnel Tests of Two Tapered Wings with Straight Trailing Edges and with Constant-Chord Center Sections of Different Spans. NACA A.R.R., March 1943.
2. Anderson, Raymond F.: Determination of the Characteristics of Tapered Wings. Rep. No. 572, NACA, 1936.
3. Jacobs, Eastman N., and Rhode, R. V.: Airfoil Section Characteristics as Applied to the Prediction of Air Forces and Their Distribution on Wings. Rep. No. 631, NACA, 1938.



NACA

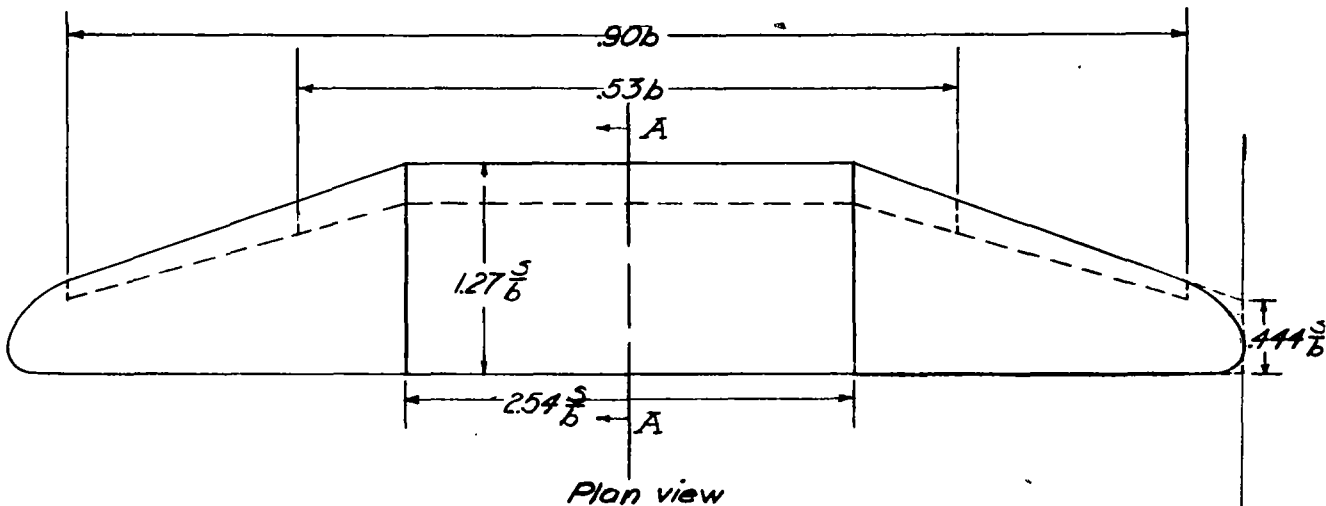
Fig. 1



Plan view

Front view

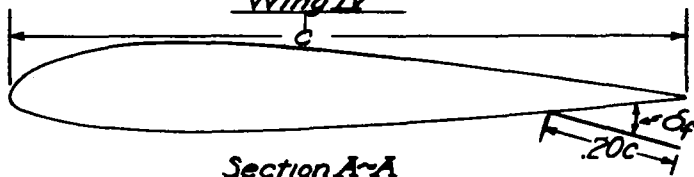
Wing I



Plan view

Front view

Wing IV



Section A-A

Figure 1.—General dimensions of wings I and IV

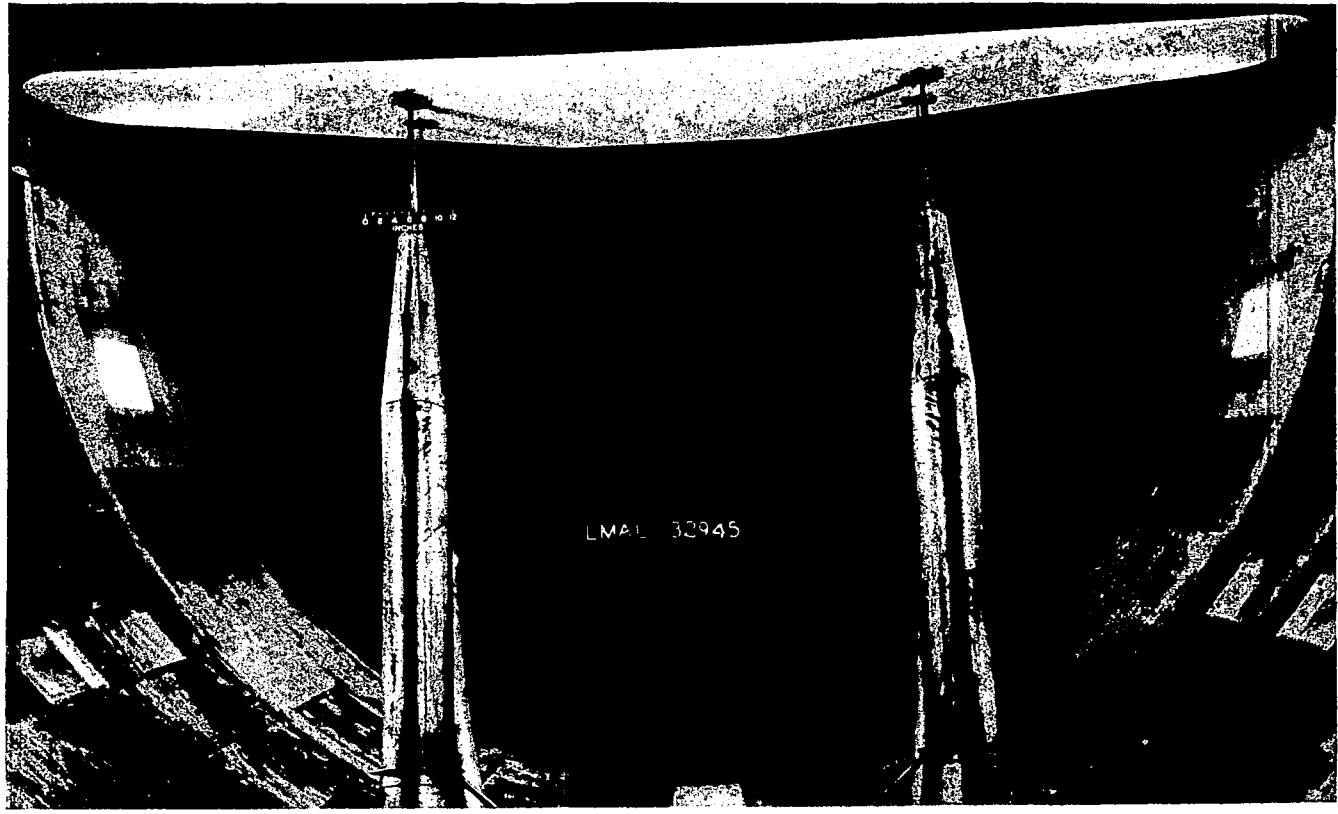


Figure 2.- Wing 1 on standard supports in NACA 19-foot pressure tunnel.

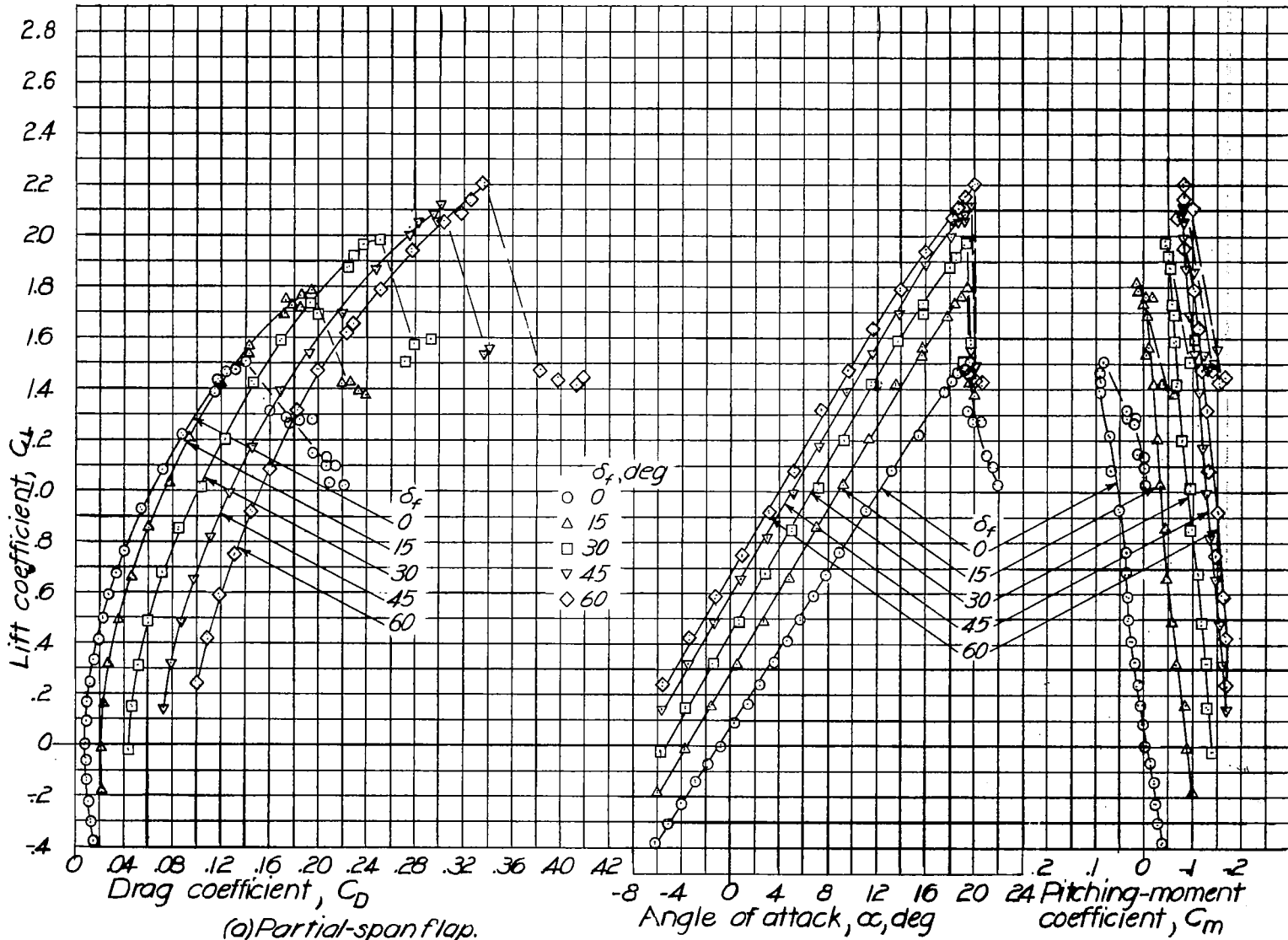


Figure 3.—Aerodynamic characteristics of wing I with 0.20c split flap.  $R \approx 2,620,000$ ;  $M = 0.08$ .

(1 block = 10 divisions on 1/64 Arch. scale)

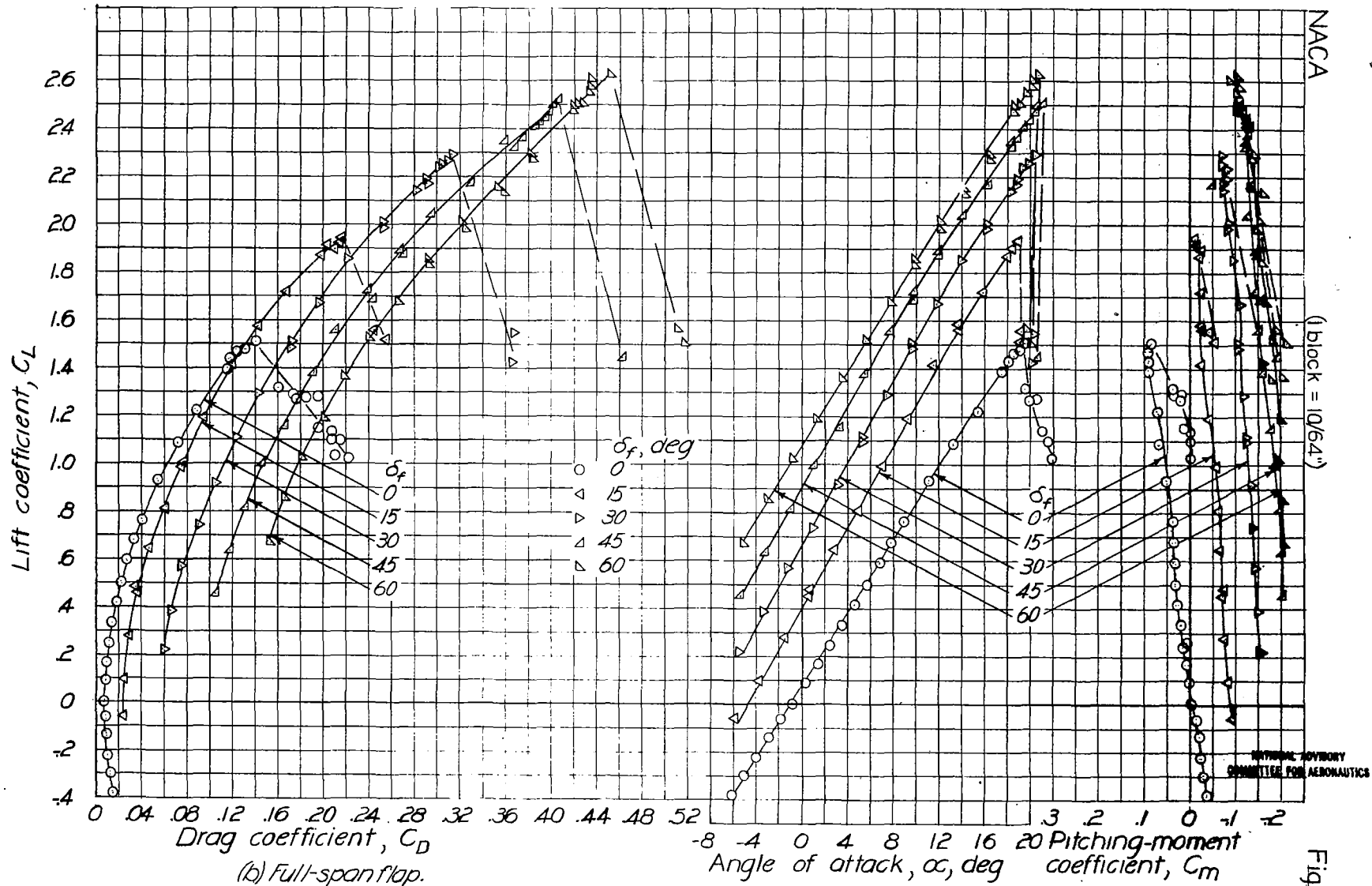
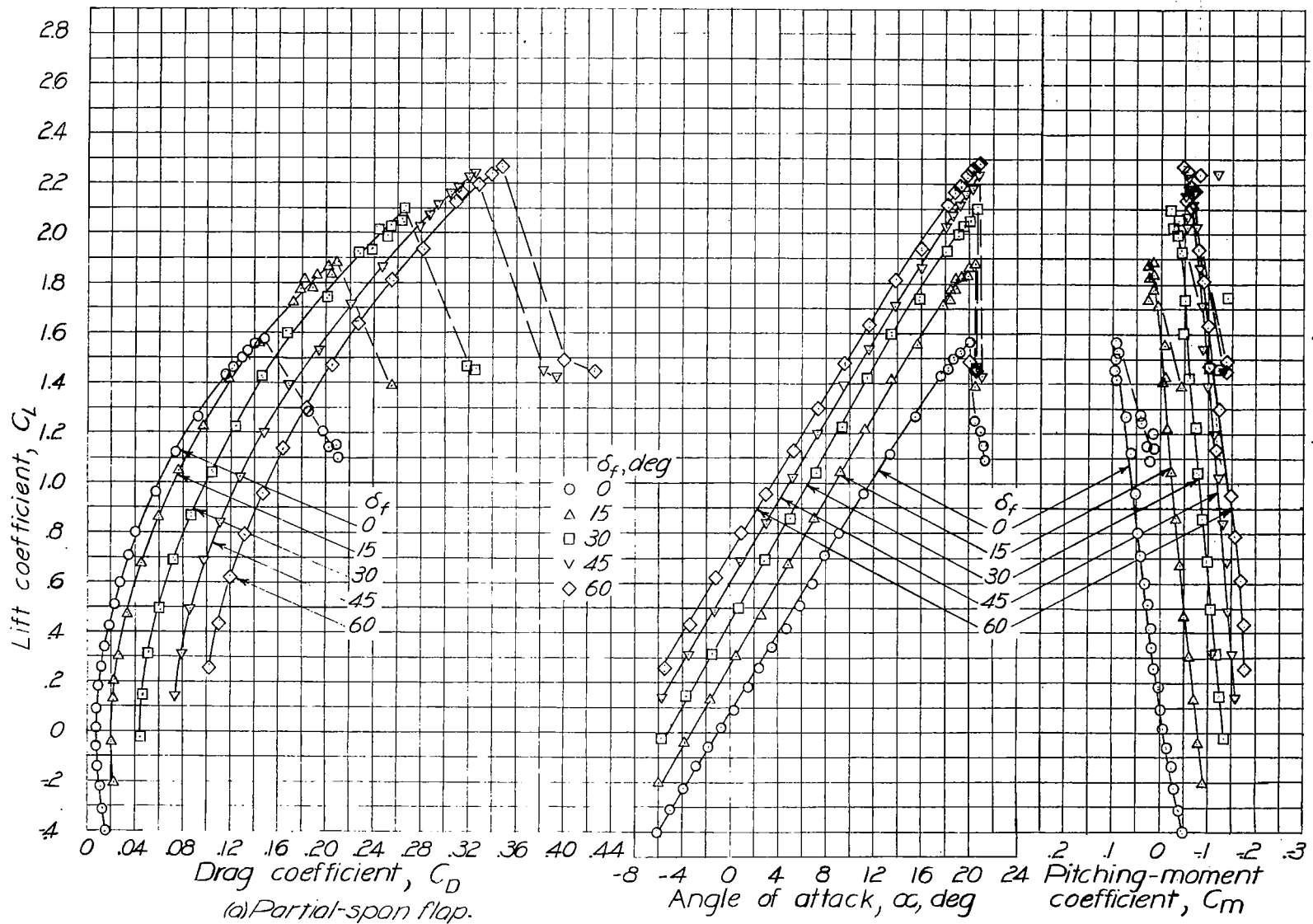


Figure 3 — Concluded.

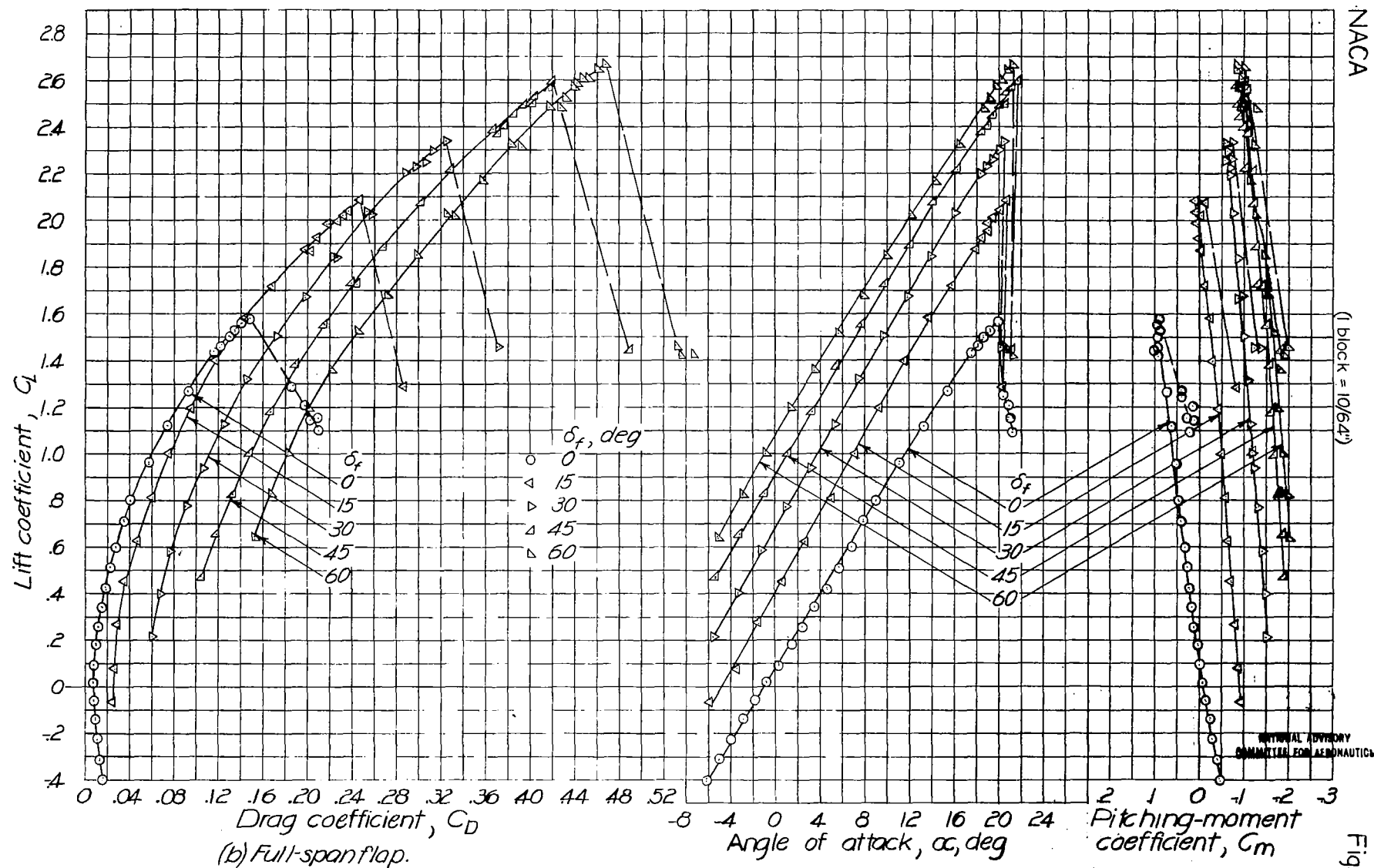
Fig. 3b



(Block = 10/64)

Figure 4.—Aerodynamic characteristics of wing I with 0.20c split flap.  $R \approx 3,660,000$ ;  $M = 0.11$ .

NACA



(b) Full-span flap.

Figure 4.—Concluded.

Fig. 4b

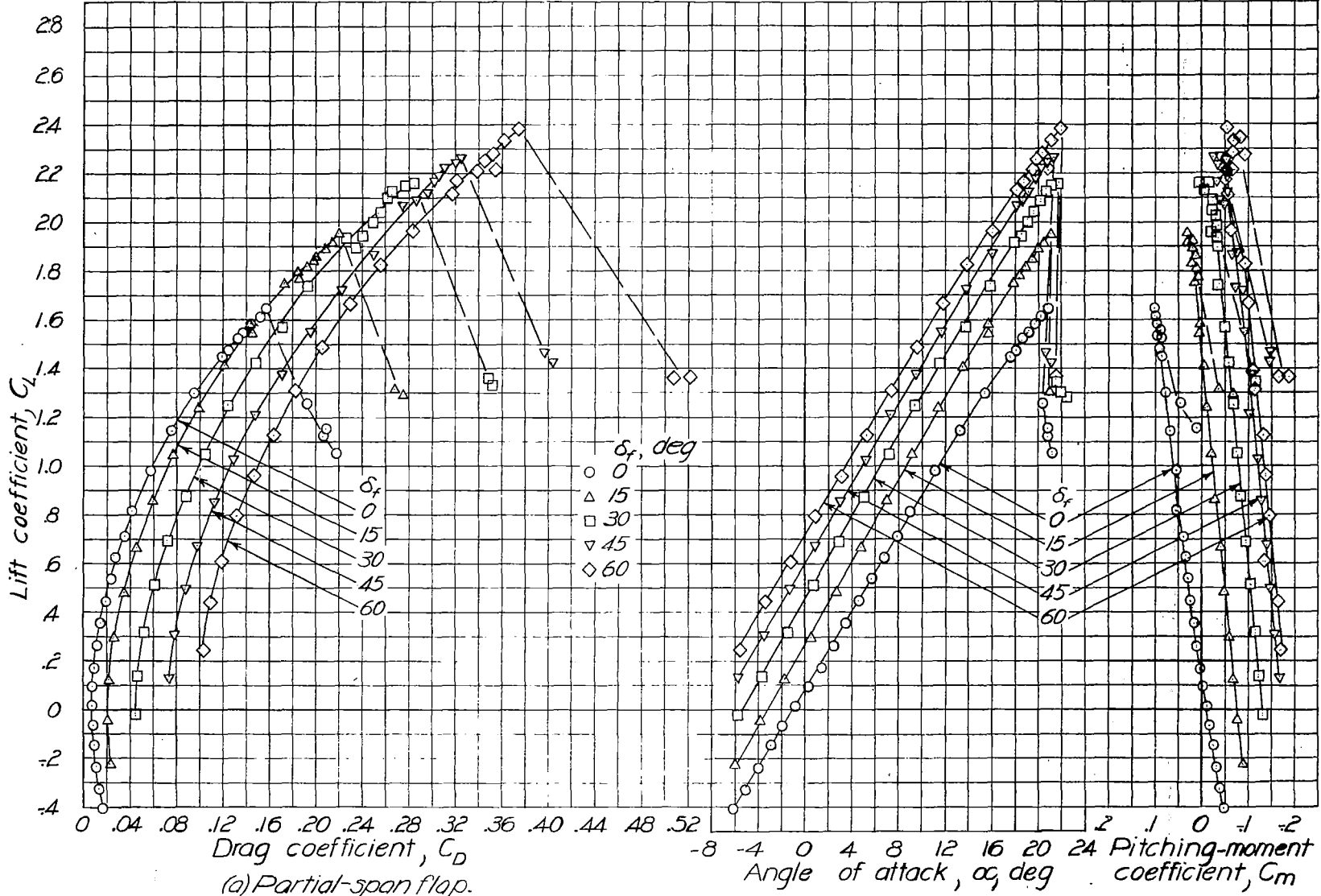
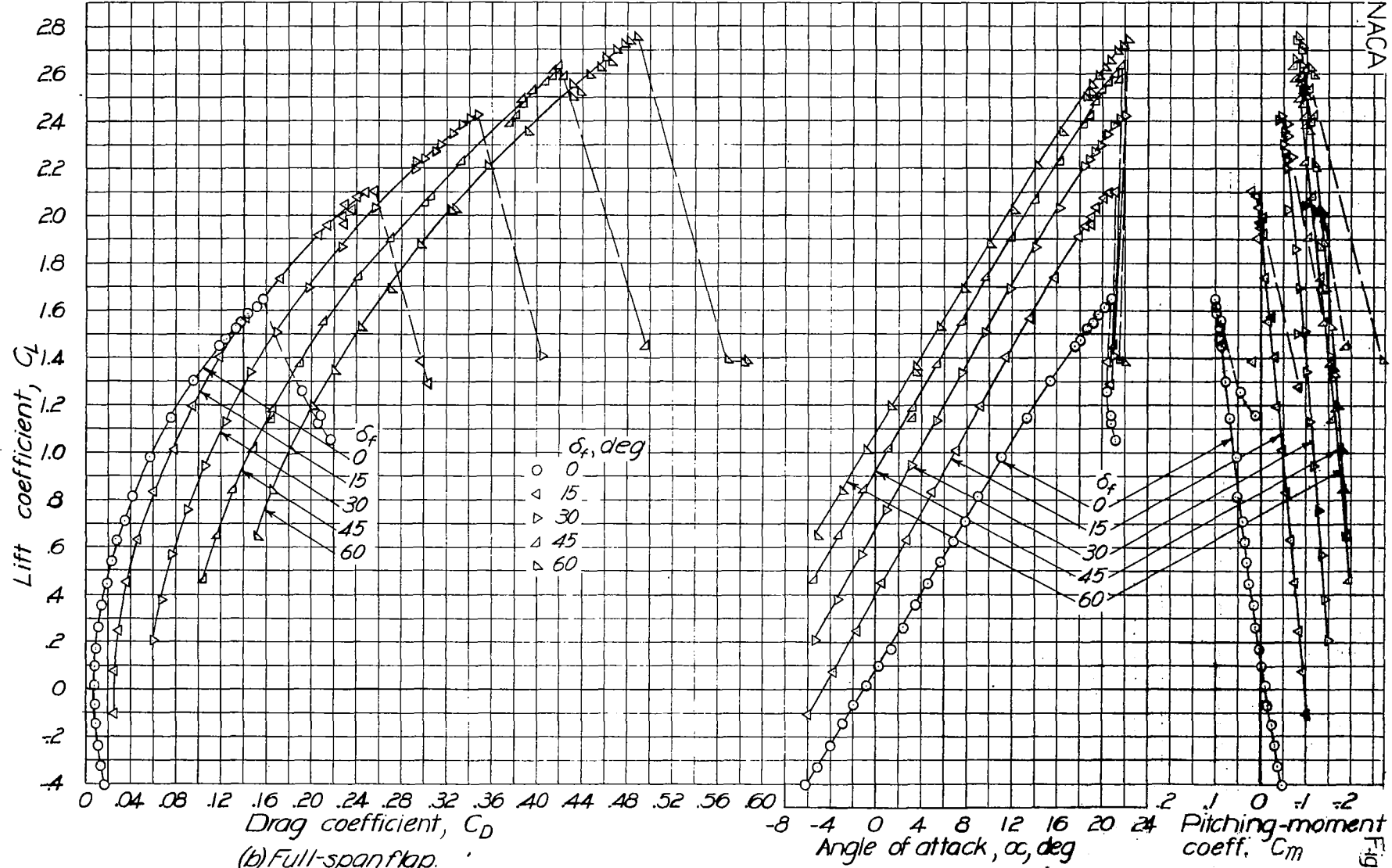


Figure 5.—Aerodynamic characteristics of wing I with 0.20c split flap.  $R \approx 4,690,000$ ;  $M = 0.14$ .



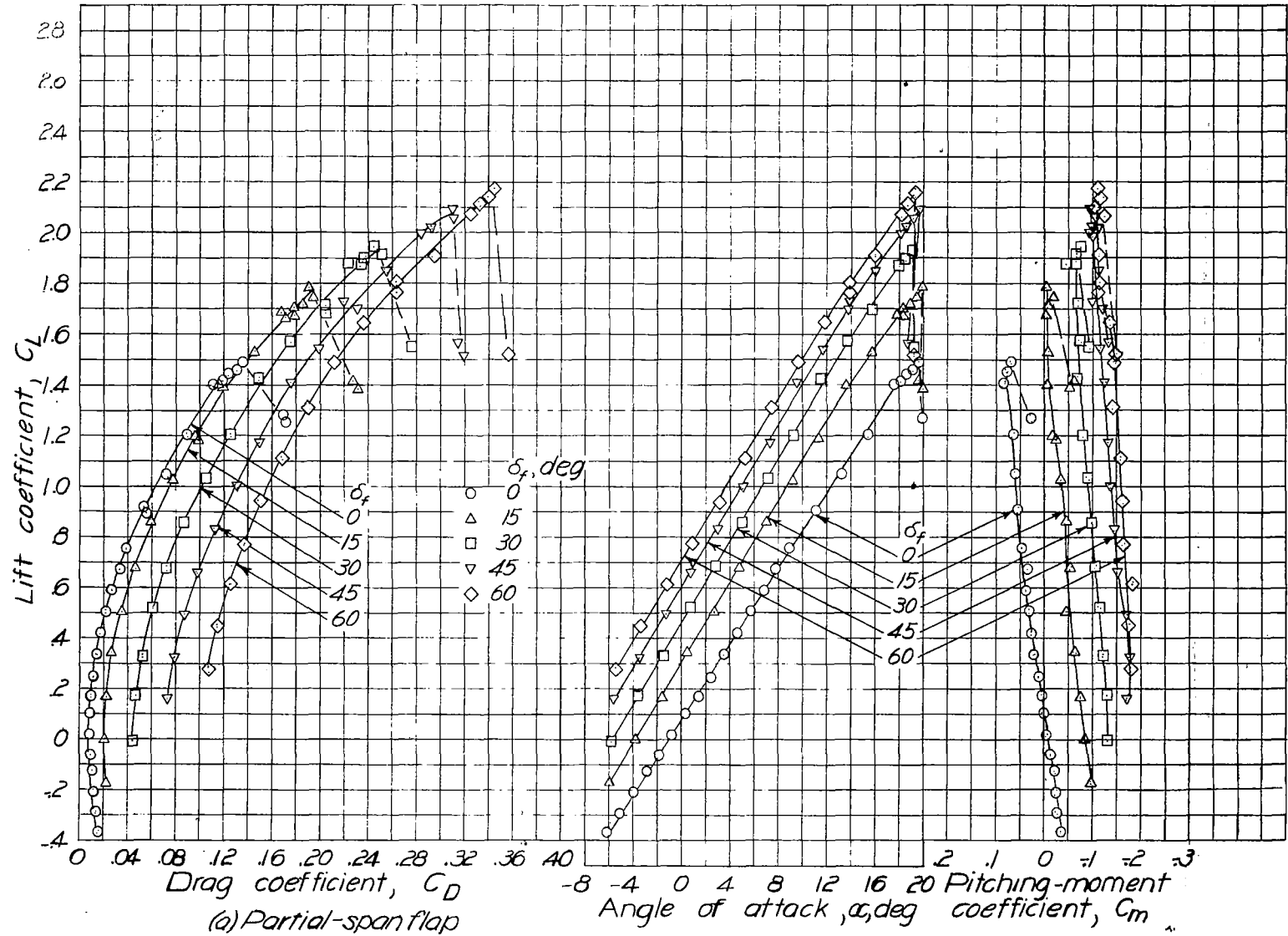
(b) Full-span flap.

Figure 5.—Concluded.

(1 block = 10/64")

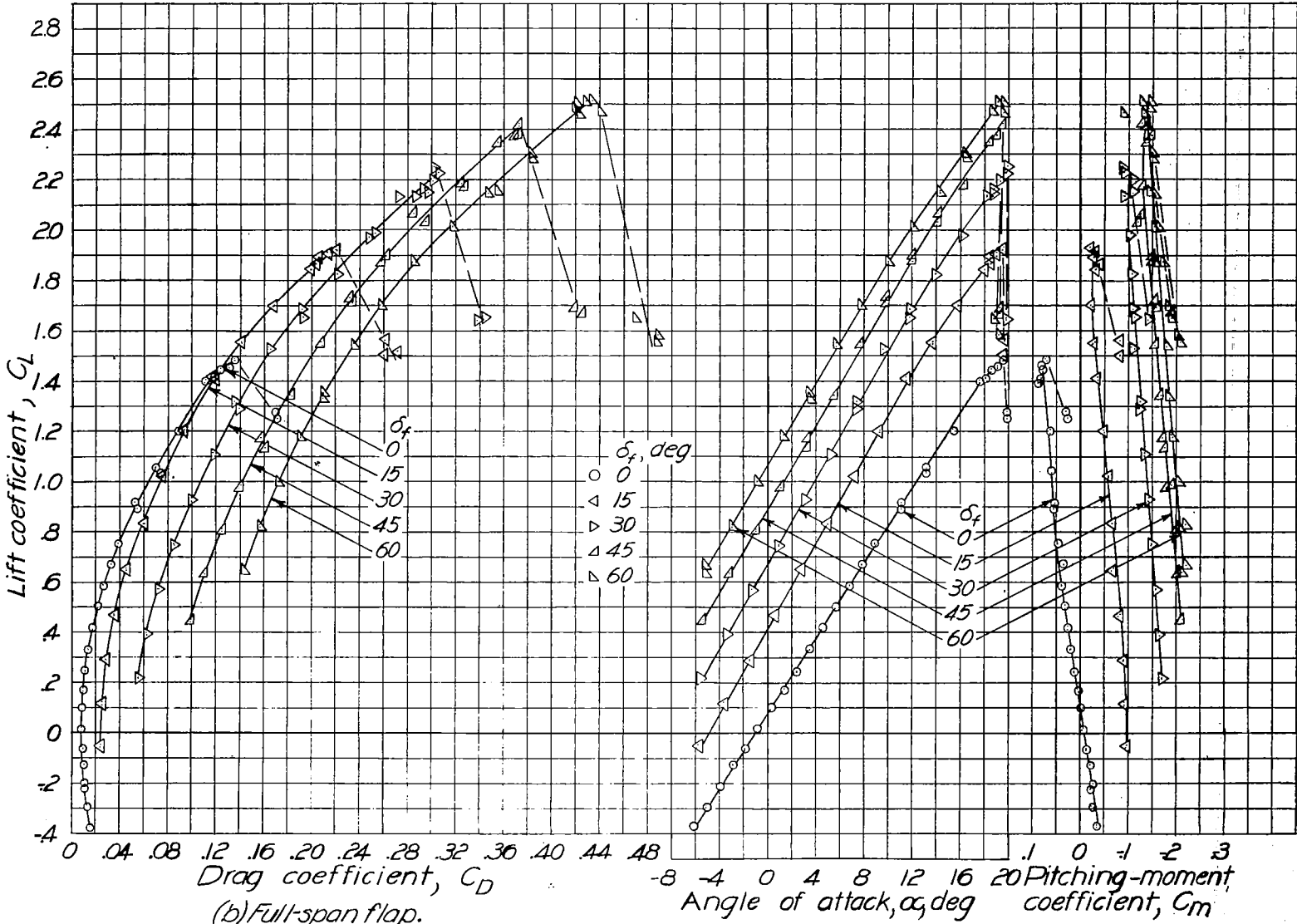
Fig. 5b





(Block = 10/64)

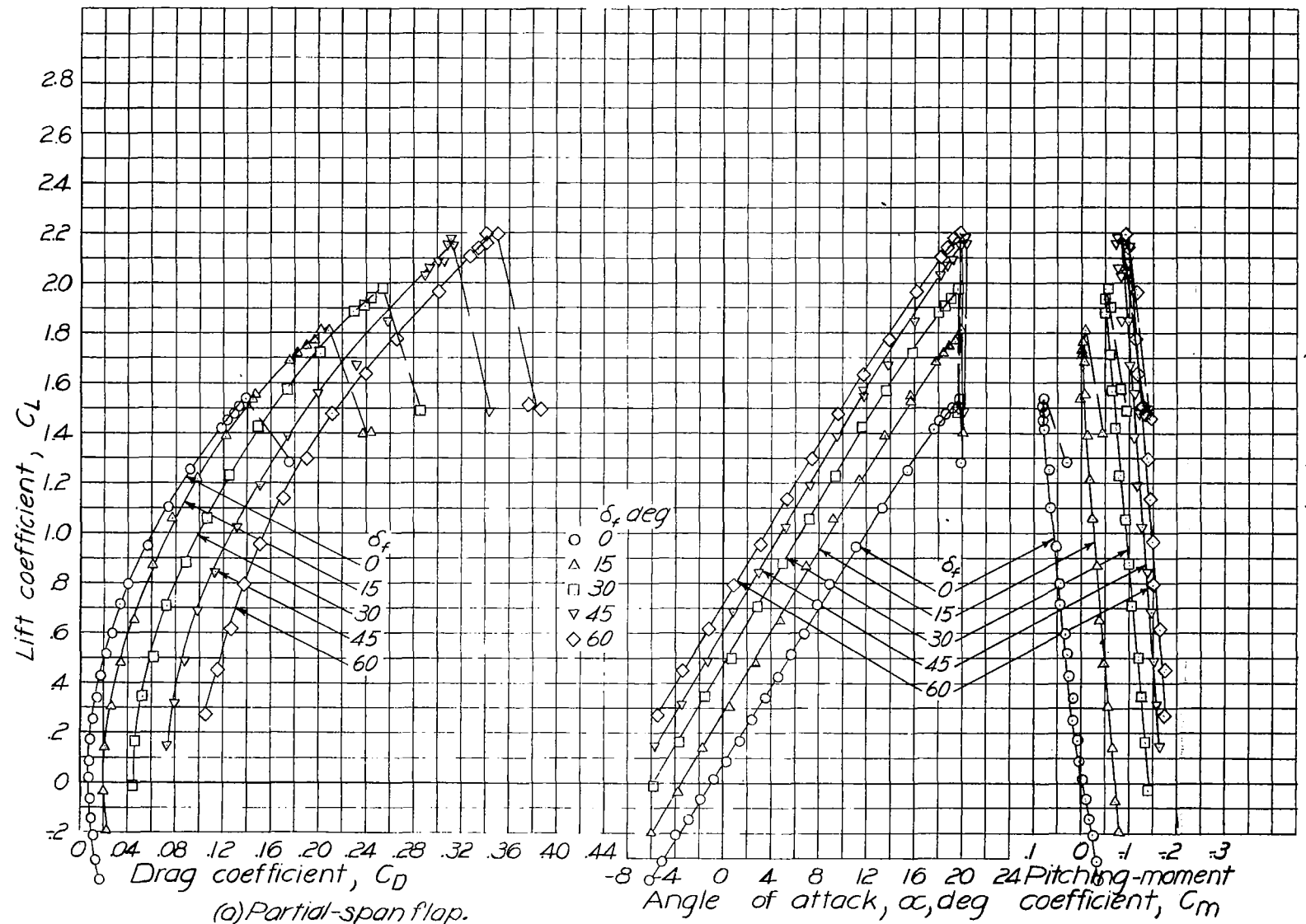
Figure 6.—Aerodynamic characteristics of wing IV with 0.20c split flap.  $R \approx 2,630,000$ ;  $M = 0.08$ .



(1 block = 10/64")

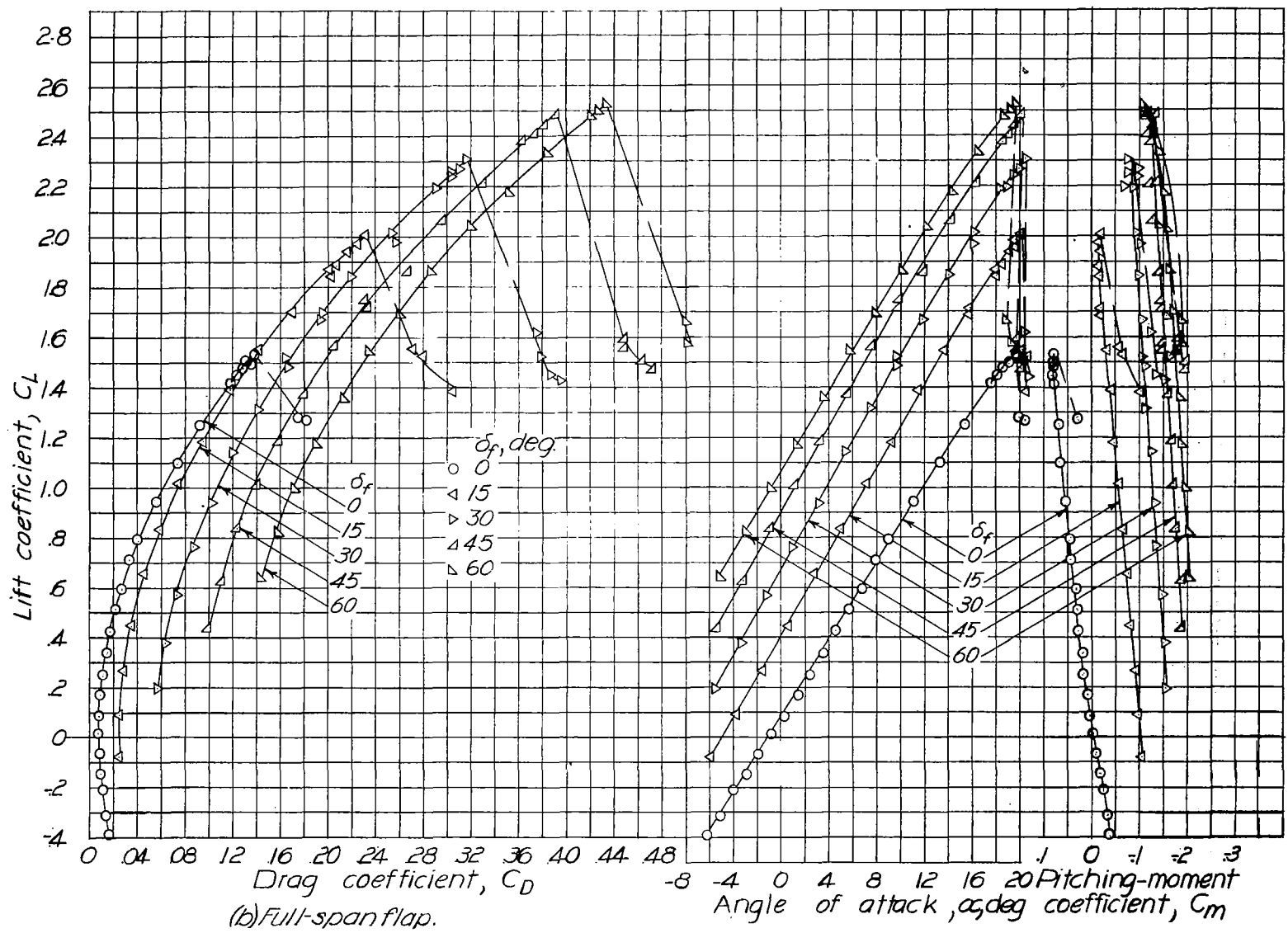
Figure 6.— Concluded.

Fig. 6b



(block = 10/64")

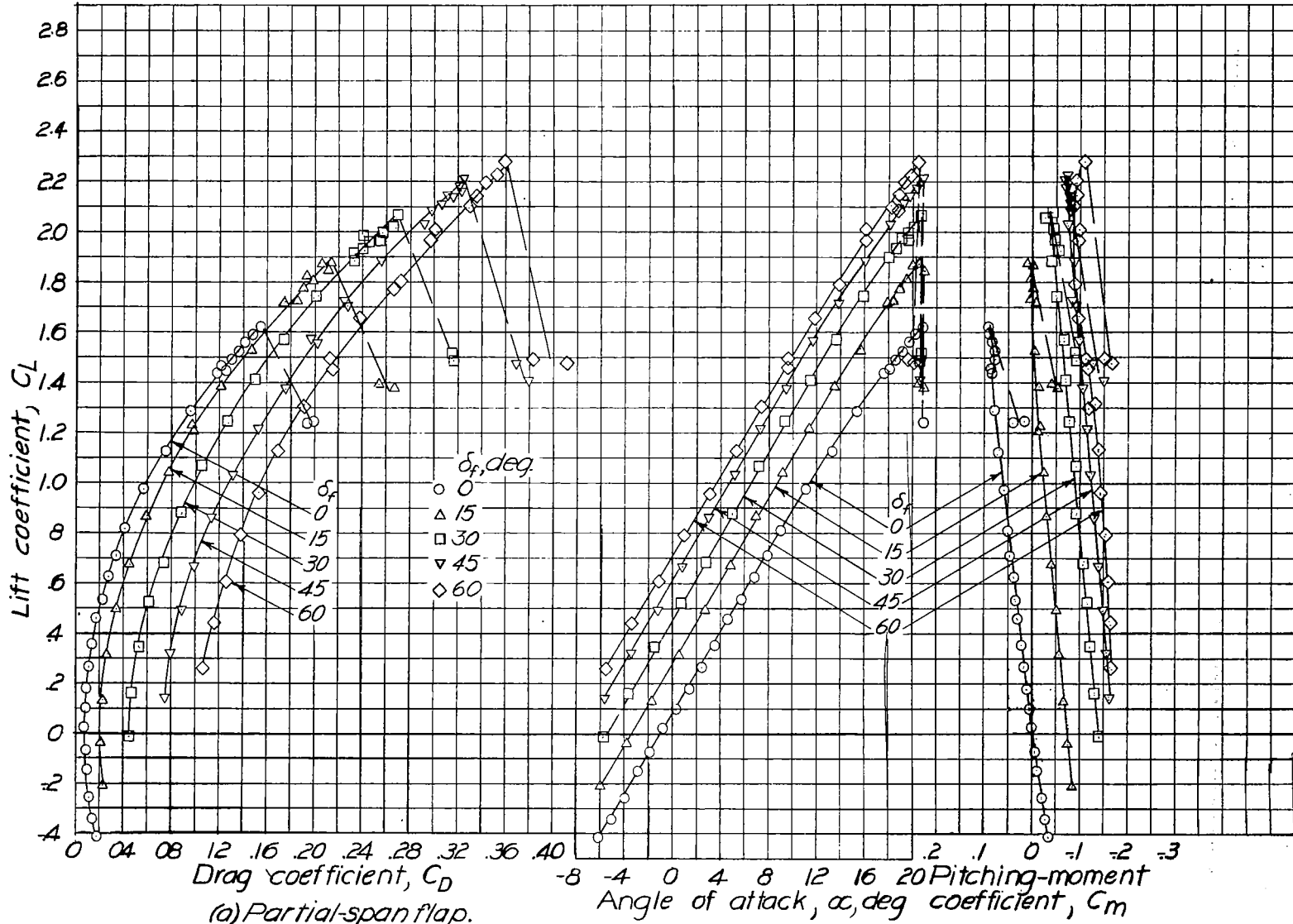
Figure 7.—Aerodynamic characteristics of wing IV with 0.20c split flap.  $R \approx 3,690,000$ ;  $M = 0.11$ .



(1 block = 10/64")

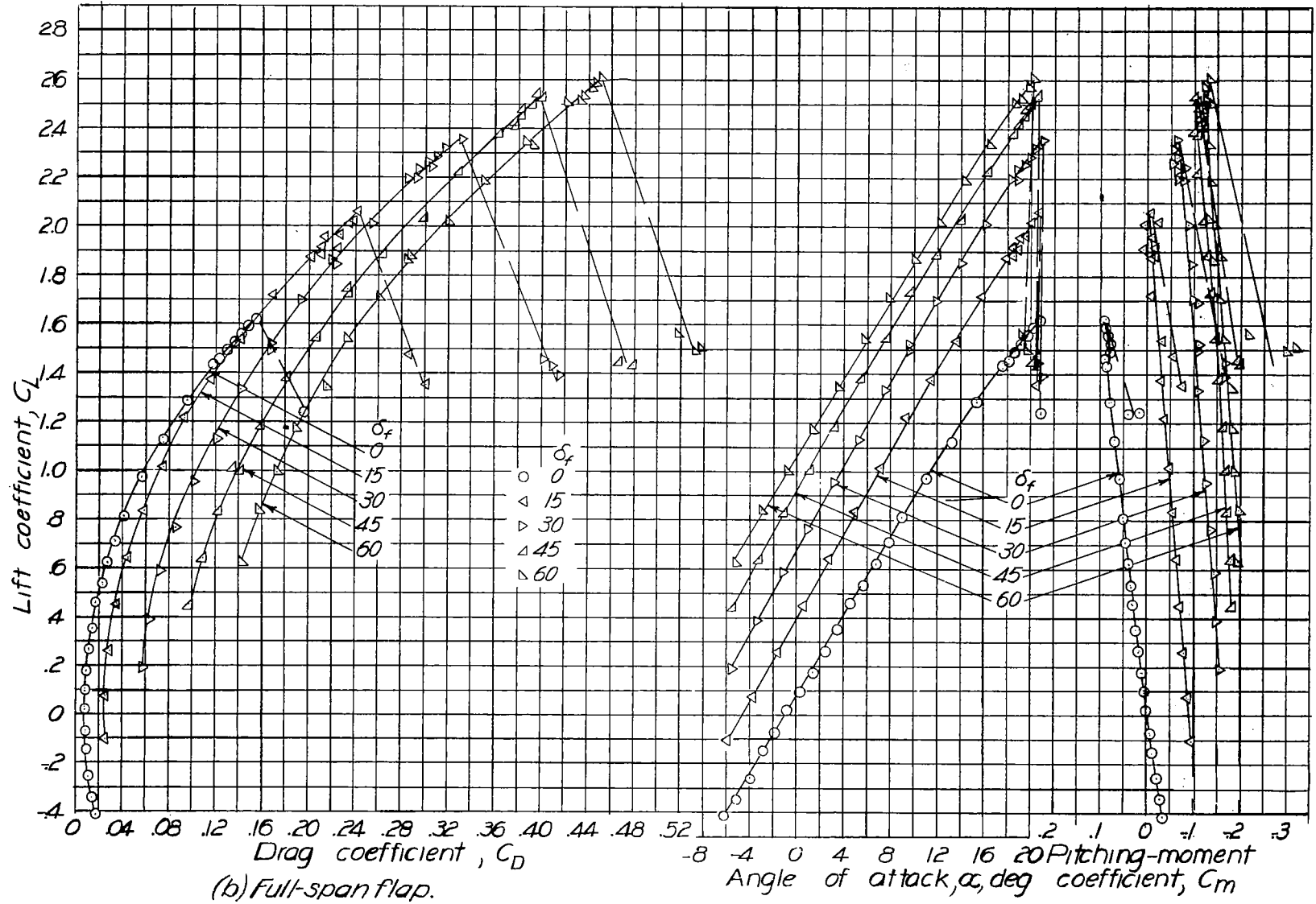
(b) Full-span flap.  
Figure 7. - Concluded.

Fig. 7b



(l block = 10/64")

Figure 8.—Aerodynamic characteristics of wing IV with 0.20c split flap.  $R \approx 4,720,000$ ;  $M = 0.14$ .



(1 block = 10/64")

(b) Full-span flap.

Figure 8.—Concluded.

Fig 8b

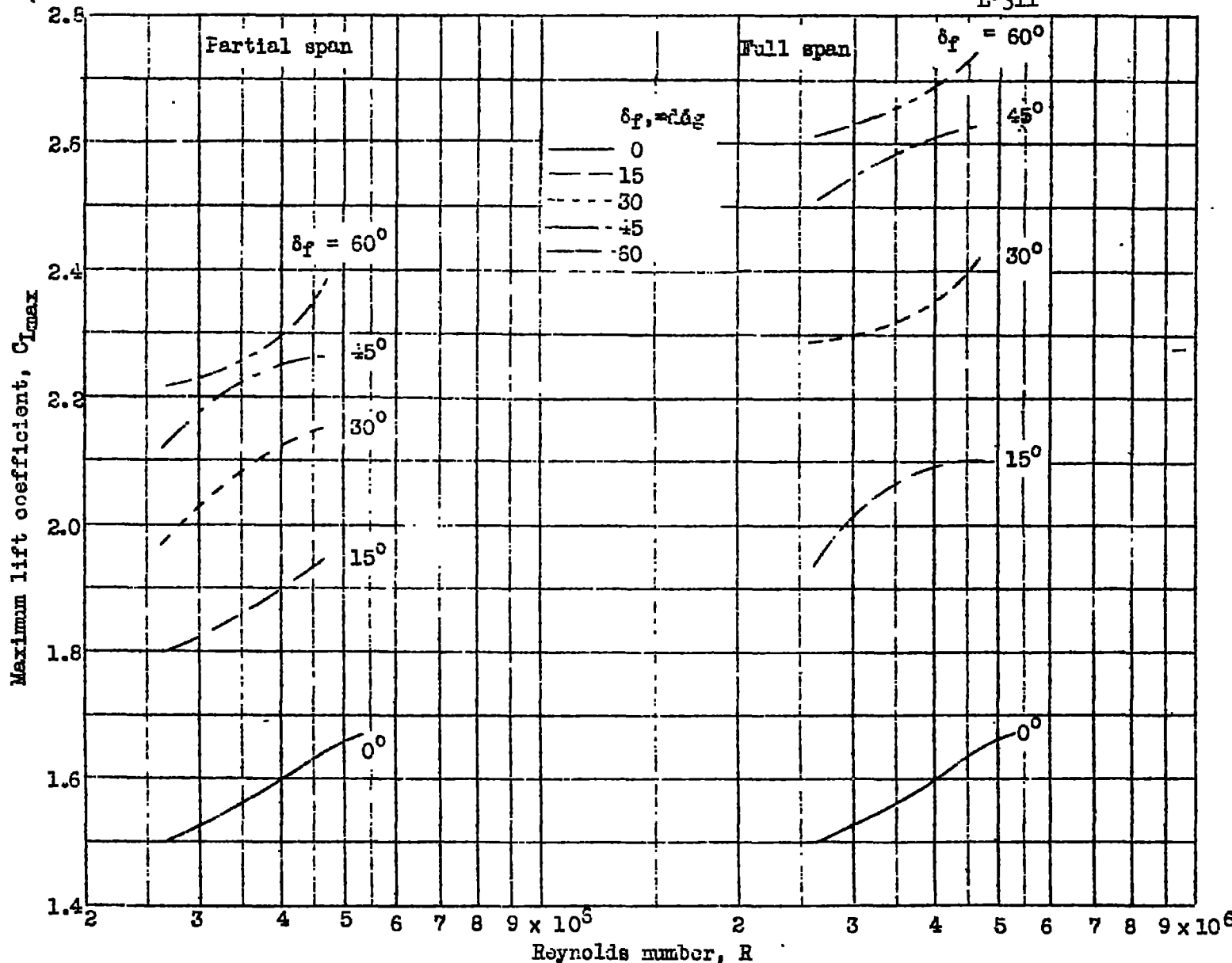


Figure 9.- Variation of maximum lift coefficient with Reynolds number, wing I.

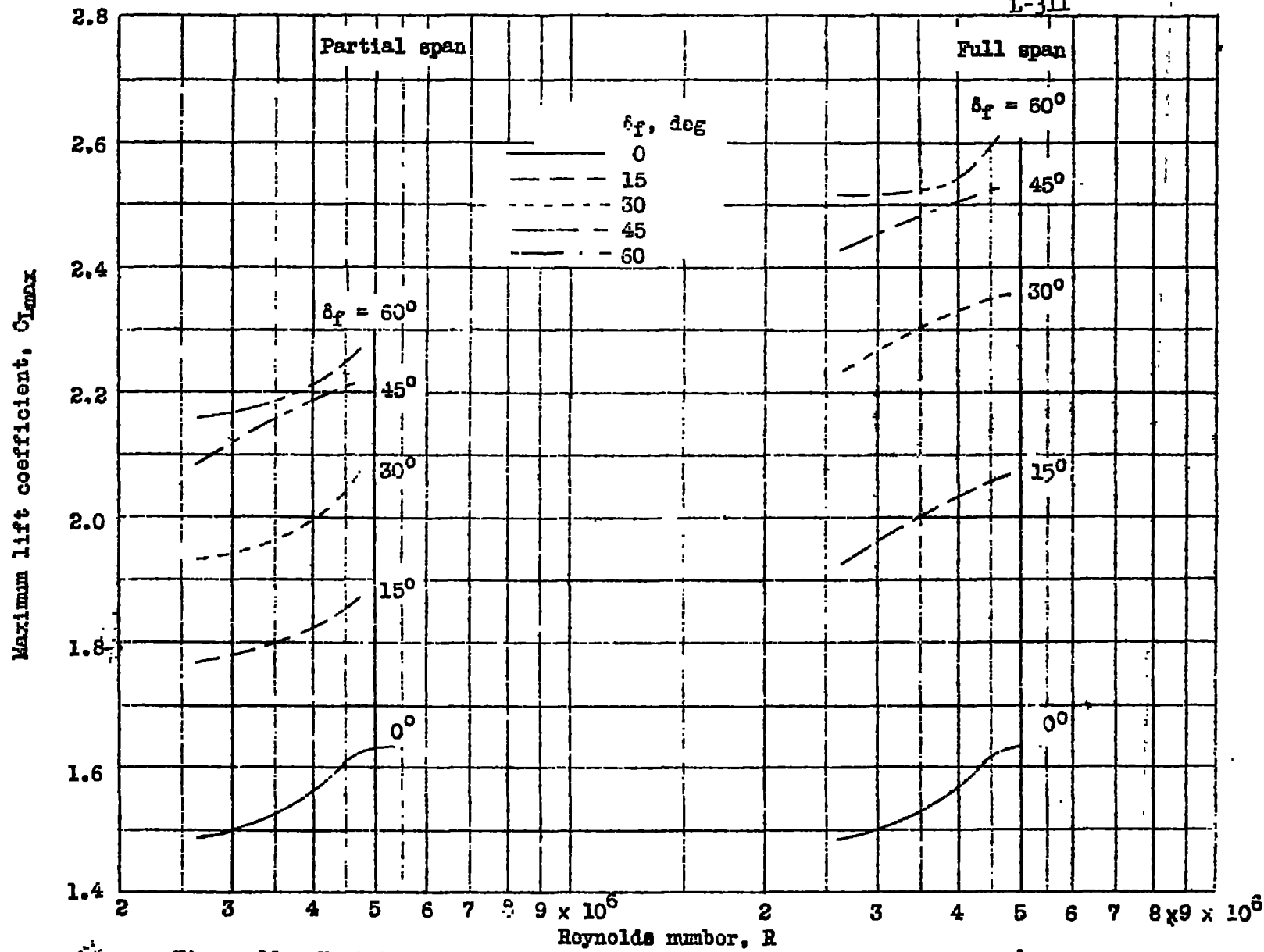


Figure 10.- Variation of maximum lift coefficient with Reynolds number; wing IV.



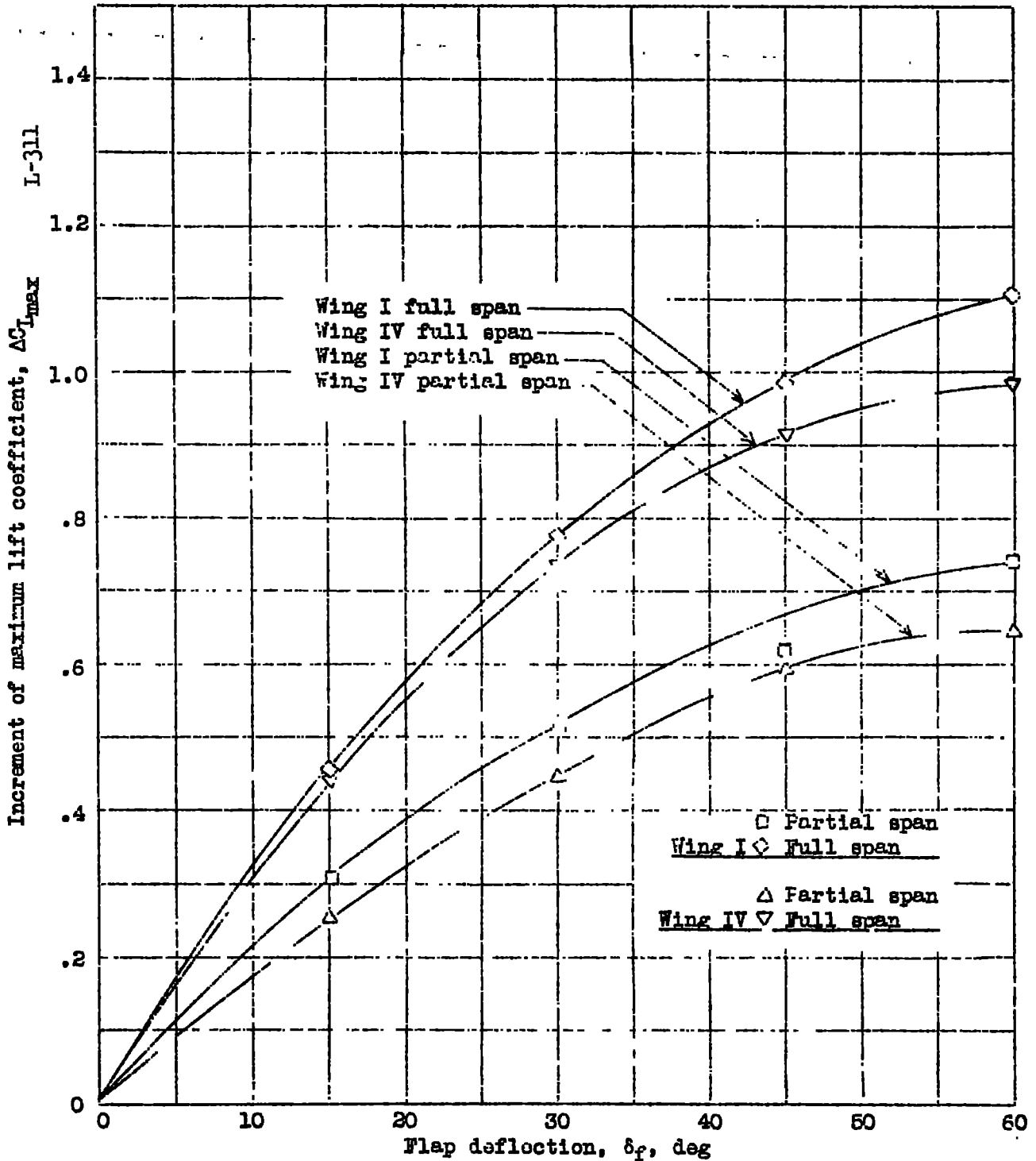


Figure 11.- Variation in maximum lift with flap deflection.  $R \approx 4,700,000$ ;  $M = 0.14$ .

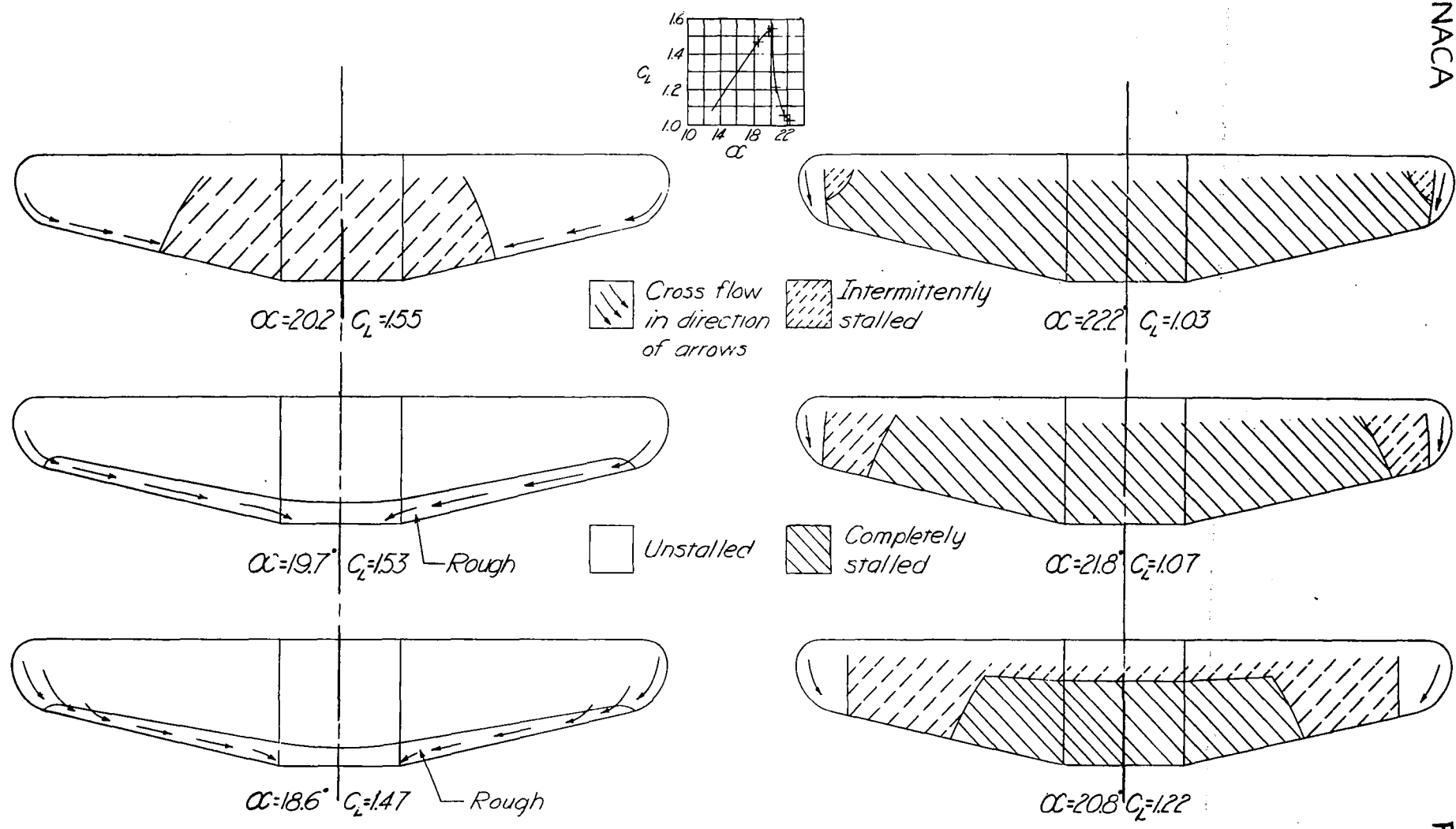


Figure 12.— Stall diagrams of wing I. Plain wing;  $R \approx 4,690,000$ ;  $M = 0.14$ .

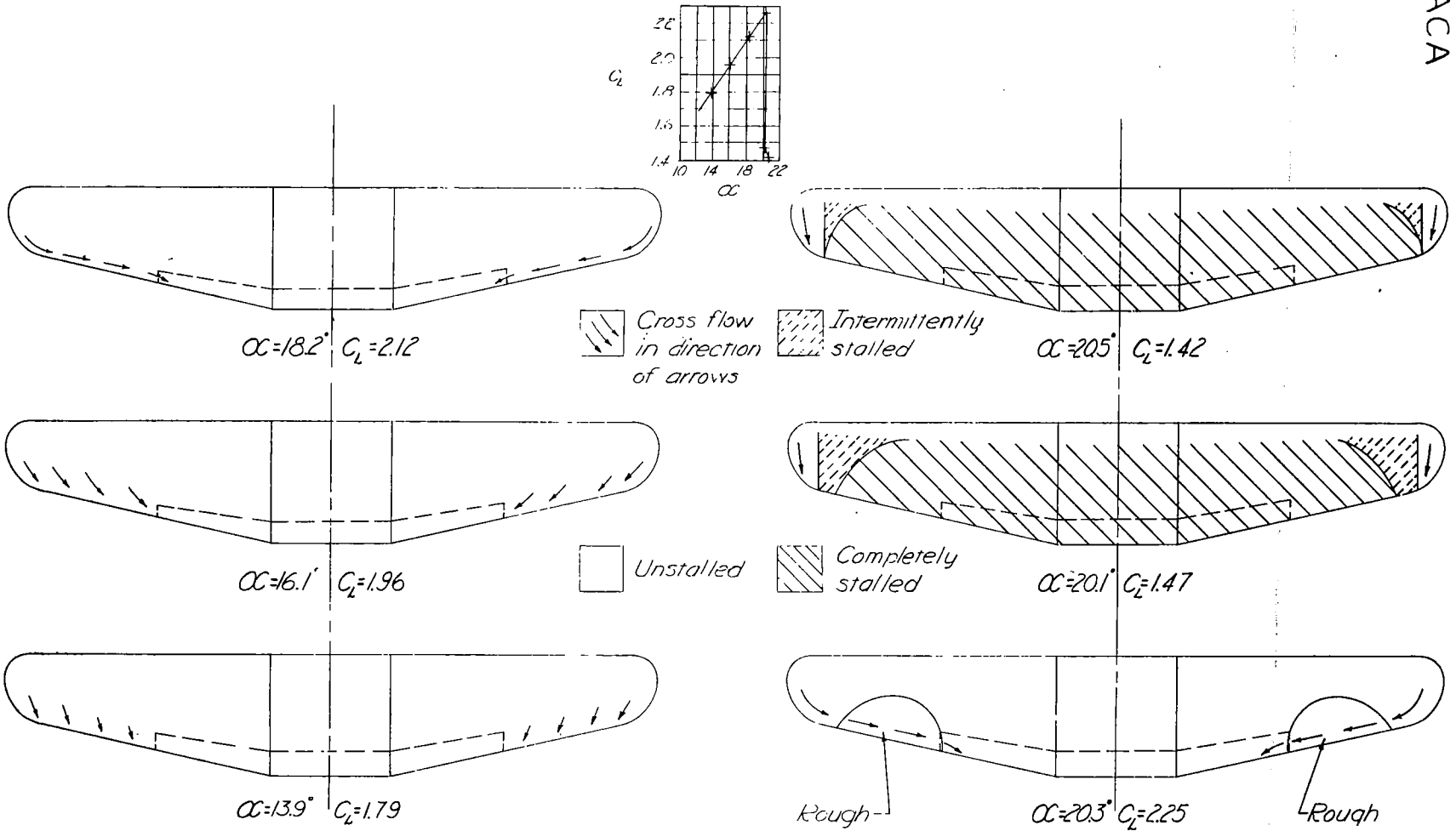


Figure 3.— Stall diagrams of wing I with 0.20c partial-span split flap.  $\delta_f = 60^\circ$ ;  $R \approx 4,690,000$ ;  $M = 0.14$ .

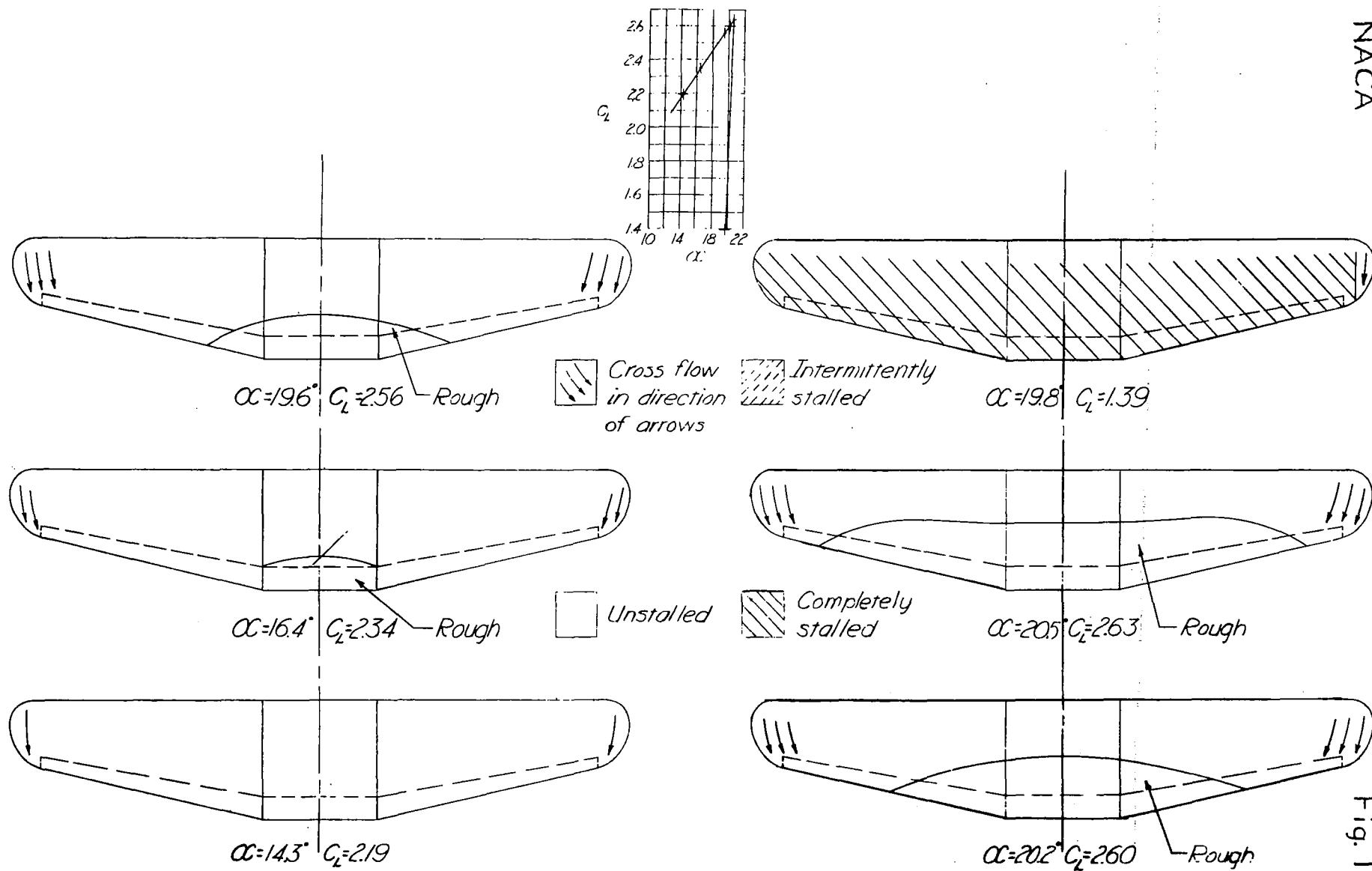


Figure 14.— Stall diagrams of wing I with 0.20c full-span split flap.  $\delta_f = 60^\circ$ ;  $R \approx 4,690,000$ ;  $M = 0.14$ .

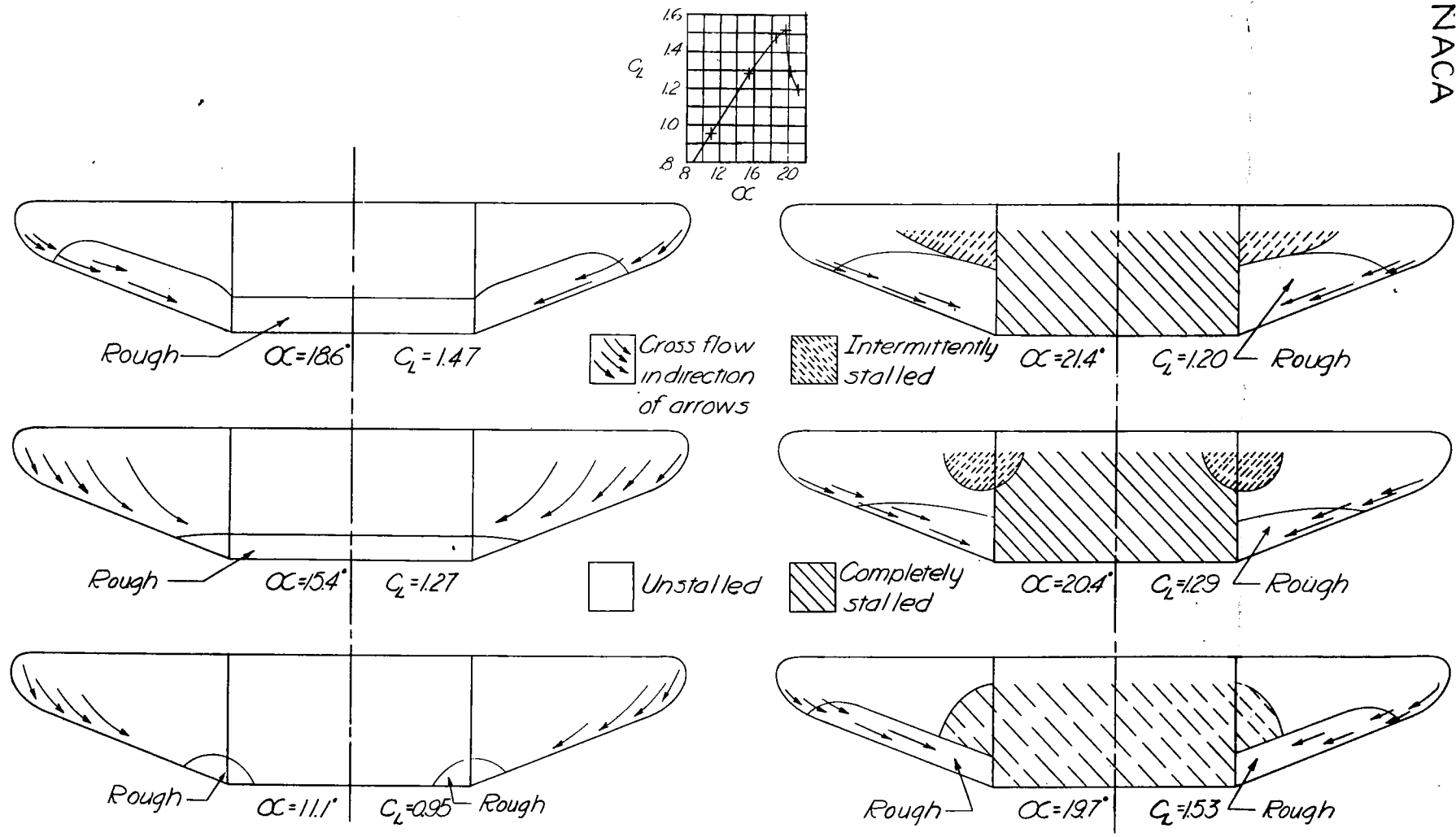


Figure 15.- Stall diagrams of wing IV. Plain wing;  $R \approx 4,720,000$ ;  $M = 0.14$ .

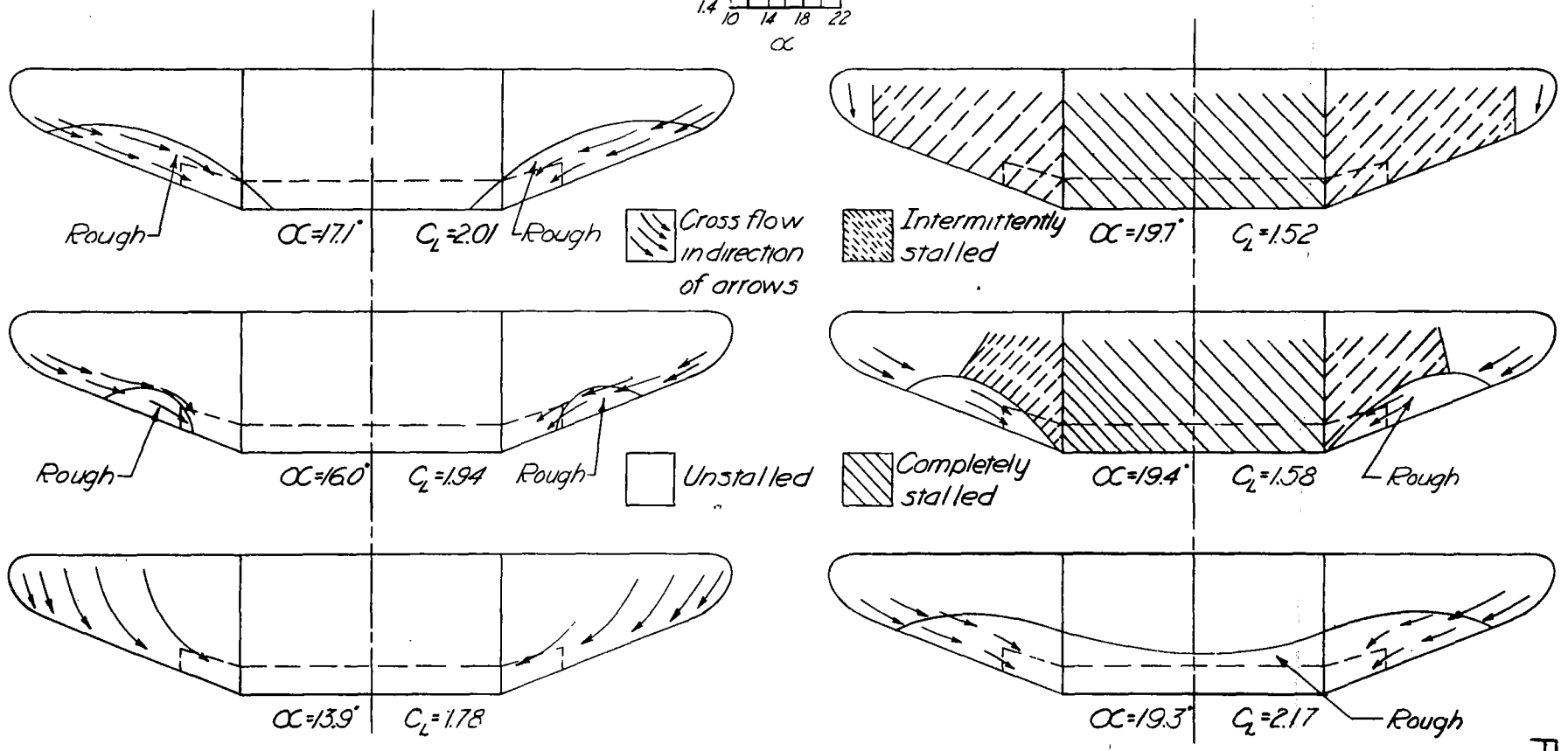
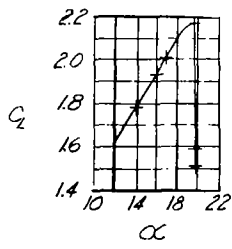


Figure 16.— Stall diagrams of wing IV with Q20c partial-span split flap.  $\delta_f = 60^\circ$ ;  $R \approx 4,720,000$ ;  $M = 0.14$ .

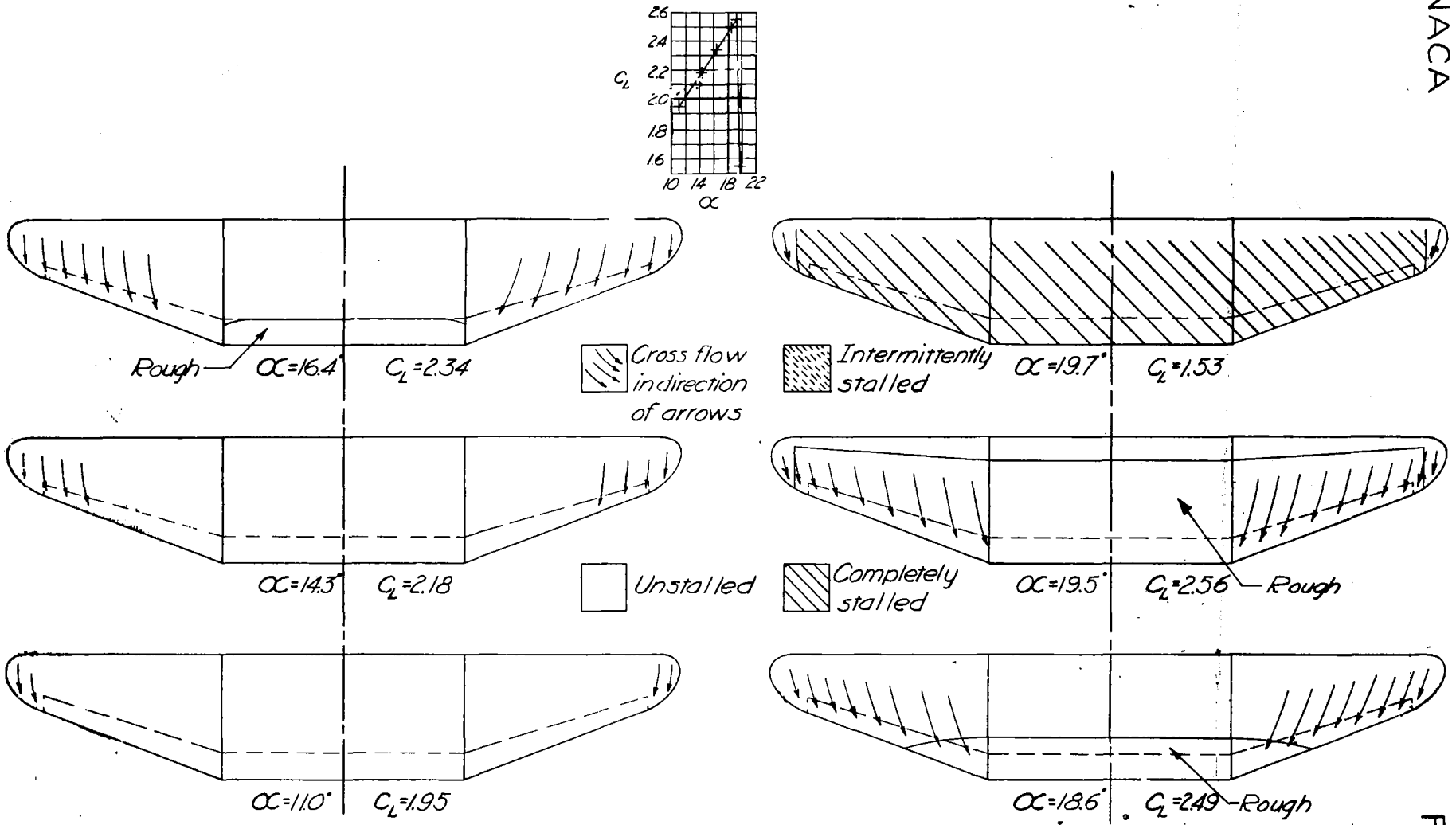


Figure 17.— Stall diagrams of wing IV with 0.20c full-span split flap.  $\delta_x = 60^\circ$ ;  $R \approx 4,720,000$ ;  $M = 0.14$ .

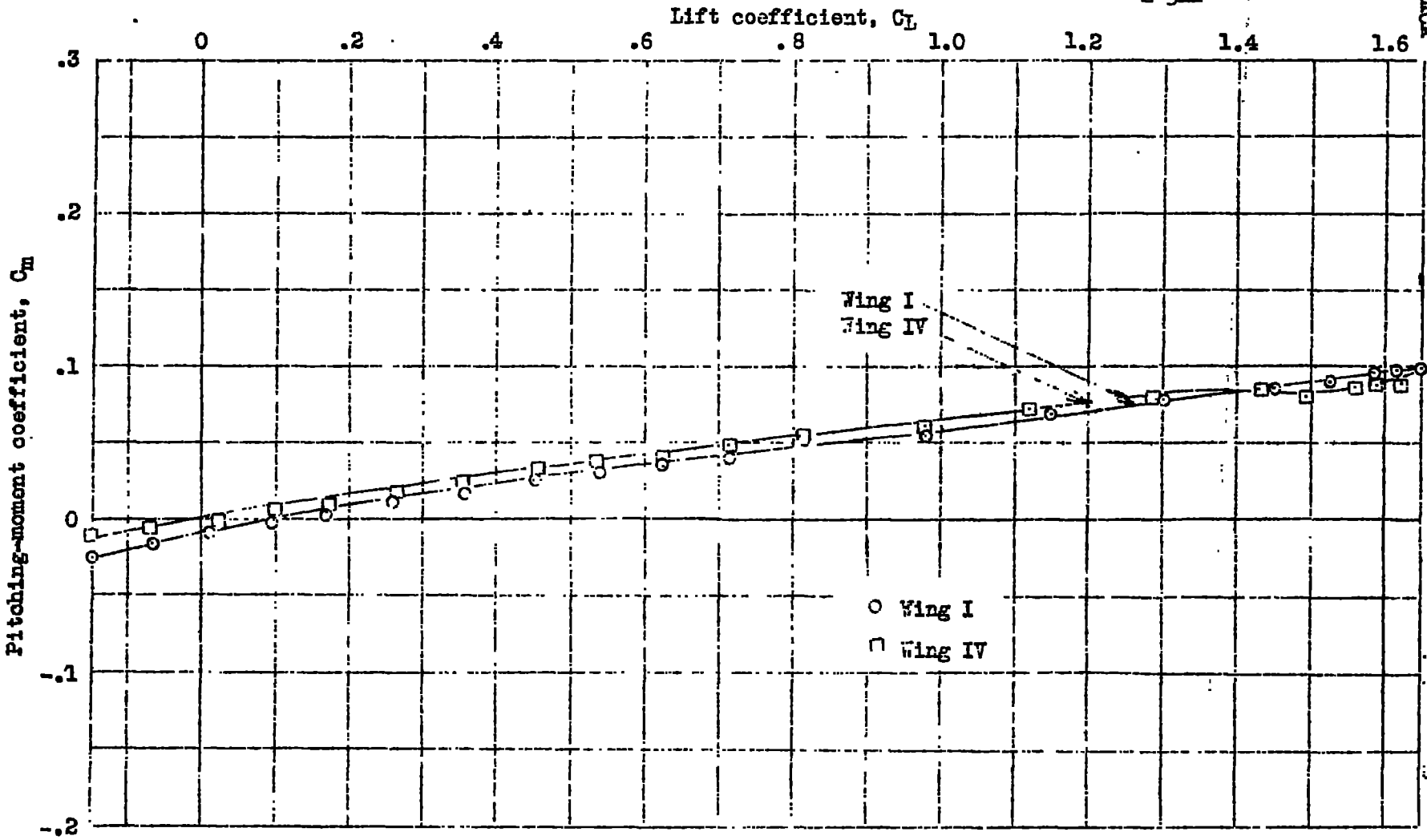


Figure 18.- Variation of pitching-moment coefficient with lift coefficient. Plain wings;  $R \approx 4,700,000$ ;  $M = 0.14$ .



REPORT (OR) (OR)

Fairbanks, R. W.  
Alexander, S. R.

DIVISION: Aerodynamics (2)

SECTION: Wings and Airfoils (6)

CROSS REFERENCES: Wings - Aerodynamics (99150); Airfoils  
- Drag (08200) Wings - Lift (99169)

ATI- 7688

ORIG. AGENCY NUMBER

ARR-3 J28

REVISION

AUTHOR(S)

AMER. TITLE: Wind-tunnel tests of two tapered wings with straight leading edges and with constant-chord center sections of different spans

FORGN. TITLE:

ORIGINATING AGENCY: National Advisory Committee for Aeronautics, Washington, D. C.

TRANSLATION:

COUNTRY	LANGUAGE	FORGN. CLASS.	U. S. CLASS.	DATE	PAGES	ILLUS.	FEATURES
U.S.	Eng.		Unclass.	Oct '43	31	26	photos, tables, disgs, graph

ABSTRACT

Wind-tunnel tests were conducted to determine differences in lift and drag coefficients and the differences in the stall and pitching moment characteristics of two wings. A wing with a square center section showed better maximum lift coefficients than a wing with a rectangular center. Drag coefficients were approximately the same for both wings. Increasing the center section span moves the aerodynamic center away from direction of wing sweep.

NOTE: Requests for copies of this report must be addressed to: N.A.C.A., Washington, D. C.