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RESEARCH MEMORANDUM

for the

Air Materiel Command, Army Air Forces

EFFECT OF SLOT-ENTRY SKIRT EXTENSIONS ON AERODYNAMIC CHARACTERISTICS OF A WING SECTION OF THE XB-36 AIRPLANE EQUIPPED WITH A DOUBLE SLOTTED FLAP

By Jones F. Cahill

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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EFFECT OF SLOT-ENTRY SKIRT EXTENSIONS ON AERODYNAMIC CHARACTERISTICS OF A WING SECTION OF THE XB-36 AIRPLANE EQUIPPED WITH A DOUBLE SLOTTED FLAP

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SUMMARY

An investigation was made in the Langley two-dimensional low-turbulence tunnel on a wing section for the XB-36 airplane equipped with a double slotted flap to determine the effect on lift and drag of various slot-entry skirt extensions. Aerodynamic loads were also determined for the flap and fore flap.

A skirt extension of 0.787c was found to provide the best combination of high maximum lift with flap deflected and low drag with flap retracted. The data showed that the maximum lift at intermediate (20° to 45°) flap deflections was lowered considerably by the slot-entry extension; but at high flap deflections the effect was small. An increase in Reynolds number from 2.4 million to 6.0 million increased the maximum lift coefficient at a flap deflection of 55° from 3.12 to 3.30 and from 1.18 to 1.40 for the flap retracted condition, but did not greatly affect the maximum lift coefficient for intermediate flap deflections. The flap and fore flap load data indicated that the maximum lift coefficients at high flap deflections are limited by a breakdown in the flow over the flaps.

INTRODUCTION

At the request of the Army Air Technical Service Command, tests were made in the Langley two-dimensional low-turbulence tunnels on an airfoil model with a double slotted flap submitted by the Consolidated Aircraft Corporation. The model, which represented an intermediate inboard wing section of the XB-36 airplane was first tested to determine the effects on lift and drag characteristics of various skirt extensions at the slot entry at a Reynolds number of 2.4×10^6. Lift and pitching-moment characteristics for flap deflections from 0° to 55° and the effect of a slot seal on the drag characteristics with flap retracted were determined at a Reynolds number of 6.0×10^6 with the slot extension which was found to provide the best combination of high maximum lift coefficient with flap deflected and low drag with flap retracted. Aerodynamic loads for both the flap and the fore flap were determined from pressure-distribution measurements.

SYMBOLS

c_l	section lift coefficient
c_{l_o}	section lift coefficient at 0° angle of attack
$c_{l_{max}}$	section maximum lift coefficient
$c_{m_{c/4}}$	section pitching-moment coefficient about the airfoil quarter chord point
α_o	section angle of attack
c_d	section drag coefficient
c_{n_f}	flap section normal force coefficient based on flap chord
$c_{n_{ff}}$	fore flap section normal force coefficient based on fore flap chord
c_{c_f}	flap section chord force coefficient based on flap chord
$c_{c_{ff}}$	fore flap section chord force coefficient based on fore flap chord
c_{m_f}	flap section moment coefficient about flap leading edge based on flap chord
$c_{m_{ff}}$	fore flap section moment coefficient about fore flap leading edge based on fore flap chord
c	airfoil chord

δ_f flap deflection, degrees

x, y horizontal and vertical positions, respectively, of flap reference point measured from trailing edge of slot lip

ΔP pressure-difference coefficient, $\frac{H_o - p_u}{q_o} - \frac{H_o - p_l}{q_o}$

where

H_o free-stream total pressure

p_u, p_l local static pressure at a point along the chord, on upper and lower surfaces, respectively

q_o free-stream dynamic pressure

MODEL AND TESTS

The body of the airfoil was constructed of laminated mahogany and the flap and fore flap were made of steel. A sketch of the airfoil and flaps is shown in figure 1 and ordinates are given in table 1. The airfoil section was formed by a fairing between the NACA 63,4-422 root section and NACA 63(420)-517 tip section of the XB-36 wing and was approximately 21.4 percent thick.

For the purpose of presenting the flap and fore flap loads, a chord line was defined for the fore flap as the maximum length line through the leading and trailing edges. This chord line made an angle of 41.2° with the flap chord line and defines the fore flap chord length as 8.33 percent of the wing chord. The flap and fore flap were fixed together and were designed to operate as a single unit. The chord of the double slotted flap was then 24.5 percent of the wing chord. When plotted, the ordinates as given in table I show the flap and fore flap in their correct relative position.

Exploratory tests were made at a Reynolds number of 2.4 million to determine the effect on lift and drag characteristics of various skirt extensions at the slot entry as shown in figure 1. All of the succeeding tests were made with the slot-entry skirt extension which was found to provide the best combination of high maximum lift coefficients with flap deflected and low drag coefficients with flap retracted. The lift and moment characteristics of the model were determined for various flap deflections at a Reynolds number of 6 million. The effect on the drag characteristics of a seal that prevented the leakage of air through the slot when the flap is retracted was also investigated at a Reynolds number of 6.0 million. Pressure-distribution measurements were made at a Reynolds number of 2.4×10^6 for the purpose of evaluating the flap and fore flap loads. The effect on the lift characteristics of small deviations of the double slotted flap from its normal position was investigated at Reynolds number of 2.4 million.

Lift, drag, and pitching-moment tests were made by the methods presented in reference 1 and the data were corrected to free air values according to the methods given in the appendix of reference 1.

RESULTS AND DISCUSSION

Data are shown in figure 2 for the airfoil with the flap retracted with various slot-entry skirt extensions. The gap between the flap and the slot lip was kept sealed during these tests. The skirt extension is shown to have very little effect on the lift characteristics. The drag coefficients of the model with no skirt extension are considerably higher than those with either of the skirt extensions in the range of lift coefficients probably used for both high-speed and cruising flight. It may be noted that over a fairly large range of lift coefficients the drag for the intermediate skirt extension is lower than that with the longest skirt. It is thought that this phenomenon is due to spanwise flow of low energy air through the slot and away from the plane of measurement of the drags when the model was equipped with the intermediate extension. Because the longest skirt completely fairs over the gap at the slot entry the measurements with the longest skirt are probably more reliable and it would be advisable to use the higher drag for either of these conditions. The effect of unsealing the flap gap on the drag characteristics at a Reynolds number of 6.0 million is shown in figure 3. The seal is shown to provide a consistent decrease in the drag coefficients for all lift coefficients below about 1.0 at this Reynolds number.

Figure 4 shows the effect on lift characteristics of various skirt extensions at a flap deflection of 30° and a Reynolds number of 2.4×10^6. The shorter skirt extensions are shown to cause a decrease in the lift curve slope and in the maximum lift coefficient. The longest skirt extension also causes, in addition to these, a change in the zero lift angle.

Lift characteristics for flap deflections from 0° to 55° are shown in figure 5 for three skirt extensions. The maximum lift coefficient and the lift coefficient of 0° angle of attack are plotted against flap deflection in figure 6. This figure shows that, although the lifts at the highest and lowest deflections are not greatly affected by the skirt extension, at intermediate deflections between 20° and 45° approximately, a large loss in maximum lift is caused by the skirt extension of 0.825c. The 0.787c skirt extension has little effect on the lift at 0° angle of attack but the 0.825c extension decreases the lift considerably for flap deflections of 30° and 40°. A sketch of the rear part of the airfoil with the flap deflected 40° is shown on each sheet of figure 5. A comparison of these sketches shows that the longest skirt extension blocks off the fore flap almost completely at the 40° deflection. This blocking of the flow through the slot between the flap and the slot lip is probably the cause of the decrease in lift with this skirt extension. At the higher deflections (50° and 55°) the slot is no longer completely blocked (fig. 1).

From the results of the preceding tests, the 0.787c skirt extension was chosen for the remainder of the investigation, because the loss in maximum lift coefficient resulting from the use of this extension is not great and some decrease in drag can be expected below that of the wing with no skirt extension.

Lift characteristics for the model with the 0.787c skirt extension at a Reynolds number of 6 million are shown in figure 7. The maximum lift coefficients are approximately the same as those obtained at the lower Reynolds number for the intermediate flap deflections (see fig. 5(b)), but there is a noticeable increase in the maximum lift coefficients for both the highest deflections (50° and 55°) and for the flap retracted condition. The highest maximum lift coefficient measured at this Reynolds number was 3.30 at a flap deflection of 55° compared to a value of 3.12 at a Reynolds number of 2.4×10^6. Pitching-moment coefficients of the model for the 0.787c skirt extension at a Reynolds number of 6.0 million are shown in figure 8. It may be seen that large changes in trim and stability may be expected through the angle of attack range with the flap deflected. The trim changes are not serious since they occur at lift coefficients well below that at which the flap would normally be deflected. The stability changes are important, however, since they are destabilizing at high lift coefficients and may tend to promote adverse stalling characteristics.

Flap and fore flap load data are shown in figure 9. The data include normal and chord force coefficients and moment coefficients about the flap and fore flap leading edges. The force and moment coefficients are defined with respect to the flap and fore flap chord lines. The flap and fore flap loads show a uniform variation with flap deflection up to a deflection of 40°. Above a deflection of 40° the loads not only cease to show a unifrom variation with flap deflection, but also show irregular variations with lift coefficient at a given flap deflection. Reference to figure 5(b) shows that, at this Reynolds number, the lifts also cease to increase with flap deflection above a deflection of 40°. Load distribution diagrams for an angle of attack of 6.1° at flap deflections of 40° and 55° are shown in figure 10. These load distribution diagrams show that the flap is stalled at the 55° deflection although the flow over the fore flap remains good. The flap stall, of course, causes a decrease in the load over the entire airfoil and, as shown in figure 9(b), causes the load on the fore flap to stop increasing with flap deflection. These considerations show that the loss in flap effectiveness above a flap deflection of 40° is caused by a breakdown in the flow over the flap.

Fore flap normal force coefficients have previously been reported (reference 2) which were as high as 5.0. This normal-force coefficient was measured, however, at a flap deflection of 65° while the fore flap normal-force coefficients in reference 2 for lower deflections (40° and below) were about of the same magnitude as those for the combination reported in this paper. Because the loss in lift effectiveness for this airfoil-flap combination is a result of the breakdown in the flow over the flap and because a similar double slotted flap arrangement tested on another airfoil (reference 2) showed that it was possible to maintain good flow characteristics to higher deflections by a proper arrangement of flap and fore flap positions, it is possible that the flap and fore flap positions for this combination could be changed to provide higher lifts and higher flap loads at higher flap deflections.

In order to determine the effect on maximum lift of small changes in flap position, lift data were obtained at flap deflections of 20° and 30° for flap positions slightly displaced from the positions corresponding to the predetermined flap path (fig. 1). These data are shown in figure 9. The maximum lift coefficient for the 20° deflection was decreased by the change in position while the maximum lift coefficient for the 30° deflection was increased.

CONCLUSIONS

A model of a wing section of the XB-36 airplane was tested in the Langley two-dimensional low-turbulence tunnels to show the effects of various slot entry-skirt extensions on the aerodynamic characteristics. The results of these tests provided the following conclusions:

1. A skirt extension of 0.787c was found to provide the best combination of high maximum lift with flap deflected and low drag with flap retracted.

2. The maximum lift coefficients of the model with the flap at intermediate deflections (20° to 45°) were largely decreased by the slot-entry skirt extension, but at higher deflections the effect of the entry skirt on maximum lift was negligible.

3. An increase in Reynolds number from 2.4 million to 6.0 million increased the maximum lift coefficient from 3.12 to 3.30 at a flap deflection of 55°, and from 1.18 to 1.40 for the flap retracted condition but did not greatly affect the maximum lift coefficient for intermediate flap deflections.

4. Flap and fore flap load data indicate that the maximum lift coefficients at high flap deflections are limited by a breakdown in the flow over the flaps.

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

Jones F. Cahill

Jones F. Cahill
Aeronautical Engineer

Approved:

Clinton H. Dearborn

Clinton H. Dearborn
Chief of Full-Scale Research Division

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1. Abbott, Ira H., von Doenhoff, Albert E., and Stivers, Louis S., Jr.: Summary of Airfoil Data. NACA ACR No. L5C05, 1945.

2. Cahill, Jones F.: Aerodynamic Data for a Wing Section of the Republic XF-12 Airplane Equipped with a Double Slotted Flap. NACA MR No. L6A08a, Army Air Forces, 1946.

TABLE I.- ORDINATES FOR MODEL OF INTERMEDIATE
INBOARD WING SECTION OF XB-36 AIRPLANE

[All stations and ordinates in percent of airfoil chord with respect to airfoil chord line]

[redacted]

Airfoil Section

Station	Ordinate	
	Upper Surface	Lower Surface
0	0.971	-----
.3125	1.86	-1.13
.625	2.39	-1.78
1.25	3.15	-2.56
2.5	4.28	-3.53
5	5.92	-4.76
10	8.26	-6.40
20	11.13	-8.26
30	12.48	-8.94
40	12.48	-8.54
50	11.56	-7.40
60	9.98	-5.81
70	7.82	-3.99
80	5.25	-2.07
90	2.50	-.42
95	1.21	.03
100	0	-.06

Slot

Station	Ordinate
75.4	-0.48
75.9	1.07
76.4	1.73
77	2.36
77.6	2.81
79	3.40
80.3	3.72
81	3.80
81.6	3.84
82.4	3.85
83.2	3.83
84.6	3.70
85.8	3.49
87	3.20

Flap

Station	Ordinate	
	Upper Surface	Lower Surface
81	1.35	-1.14
81.6	2.12	-1.54
82.6	----	-1.66
83	2.97	-----
84.3	3.33	-----
85.6	3.40	-----
86	----	-1.07
86.8	3.27	-----
88.2	3.02	-----
90	2.50	-.42
92.5	1.87	-.12
95	1.21	.03
97.5	.60	-----
100	----	-.06

Fore Flap

Station	Ordinate	
	Upper Surface	Lower Surface
75.5	----	-0.70
75.9	0.85	-1.92
76.4	1.50	-2.09
77	2.14	-1.88
77.6	2.58	-1.05
79	3.18	1.77
80.3	3.51	3.05
81	3.60	3.40
82	3.71	3.64

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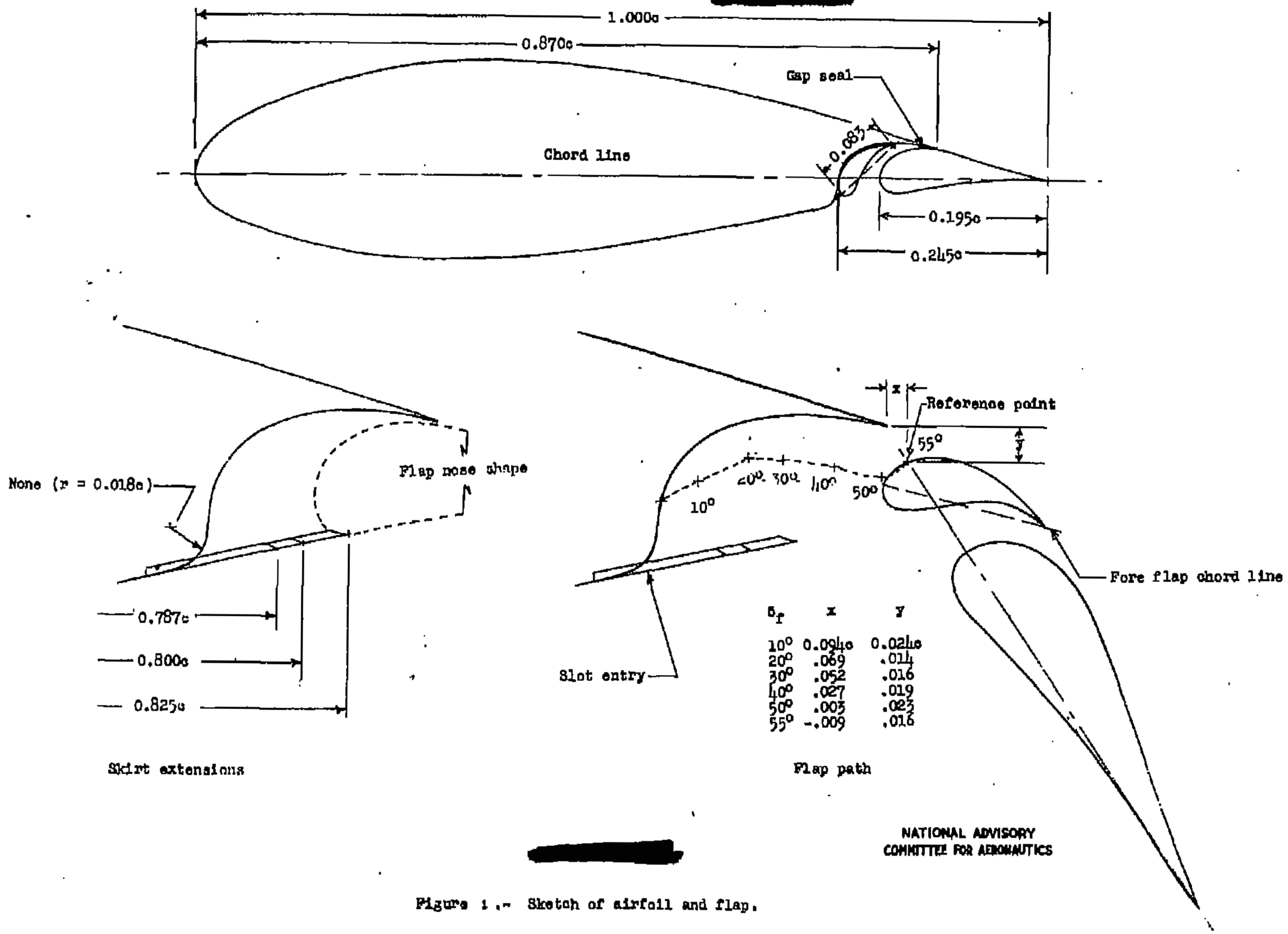

δ_f	x	y
10°	0.094c	0.024c
20°	.069	.014
30°	.052	.016
40°	.027	.019
50°	.003	.023
55°	-.009	.016

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Figure 1.- Sketch of airfoil and flap.

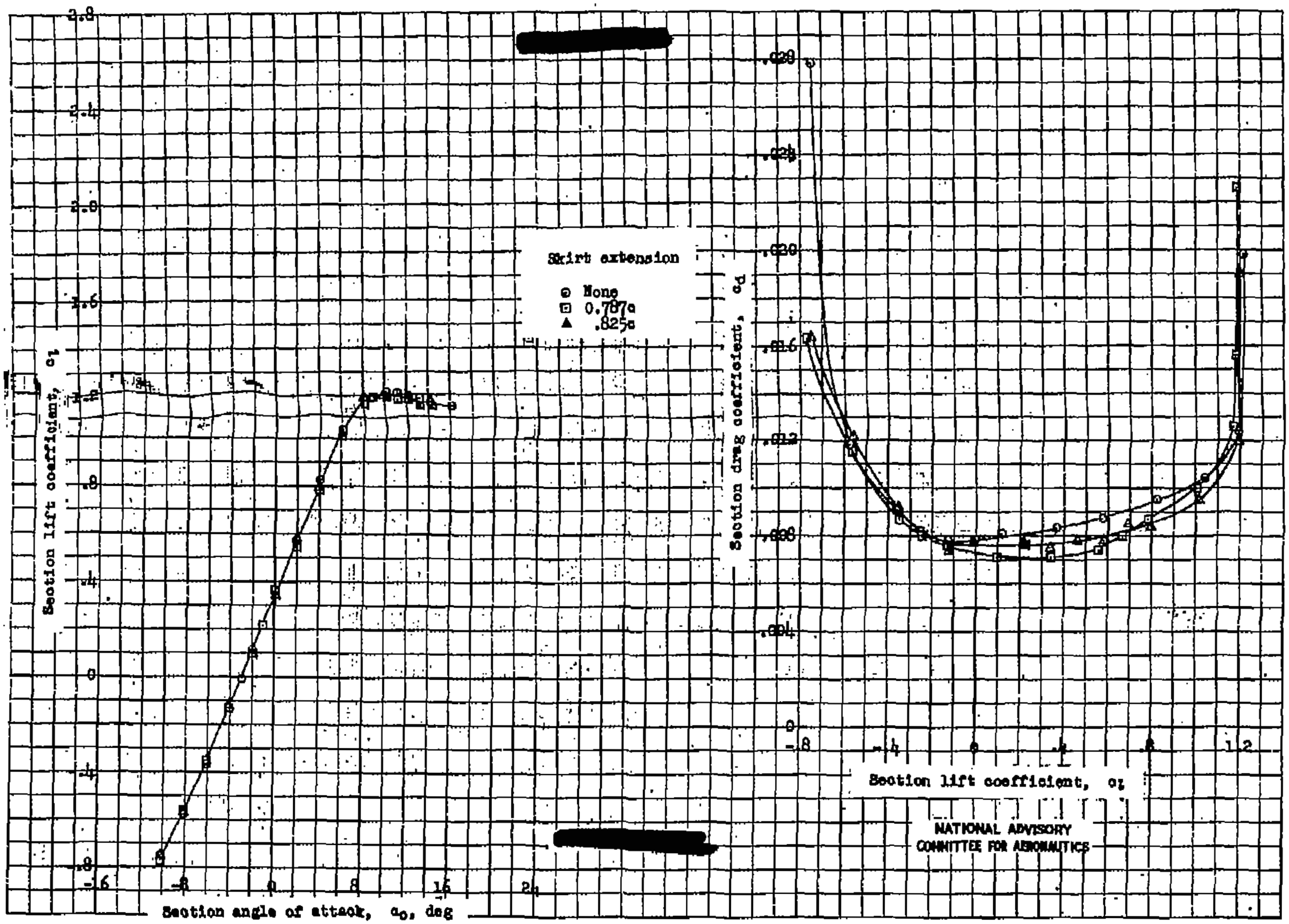

Figure 2 .- Section lift and drag characteristics of a wing section of the XB-36 airplane equipped with a double slotted flap with various skirt extensions. Flap retracted; $R = 2.4 \times 10^6$; flap gap sealed.

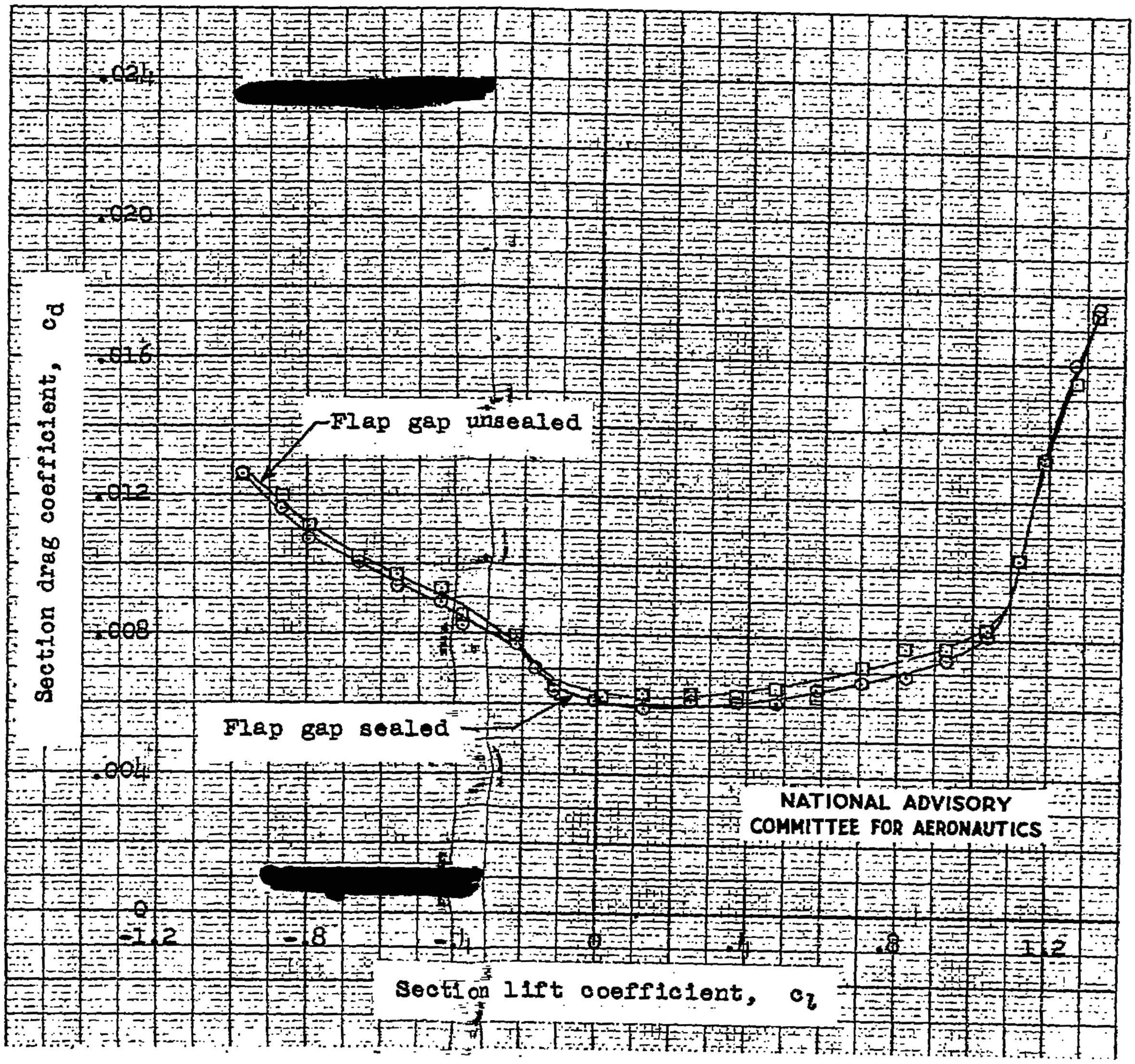

Figure 3 .- Effect of flap gap seal on section drag characteristics of a wing section of the XB-36 airplane equipped with a double slotted flap. 0.787c skirt extension; $R = 6.0 \times 10^6$.

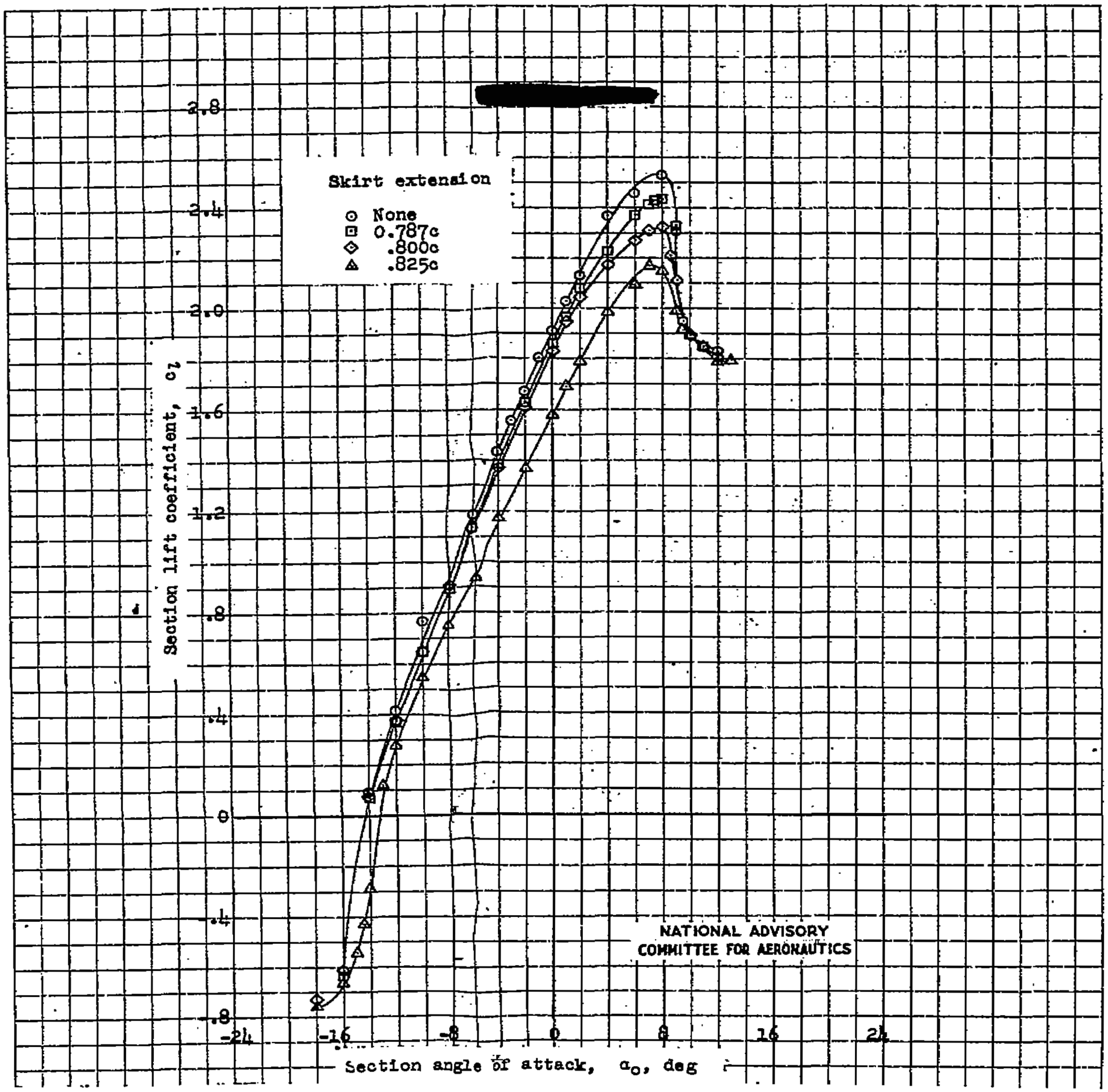

Figure 4 .- Lift characteristics of a wing section of the XB-36 airplane equipped with a double slotted flap with various skirt extensions. $\delta_f = 30^{\circ}$; $R = 2.4 \times 10^6$.

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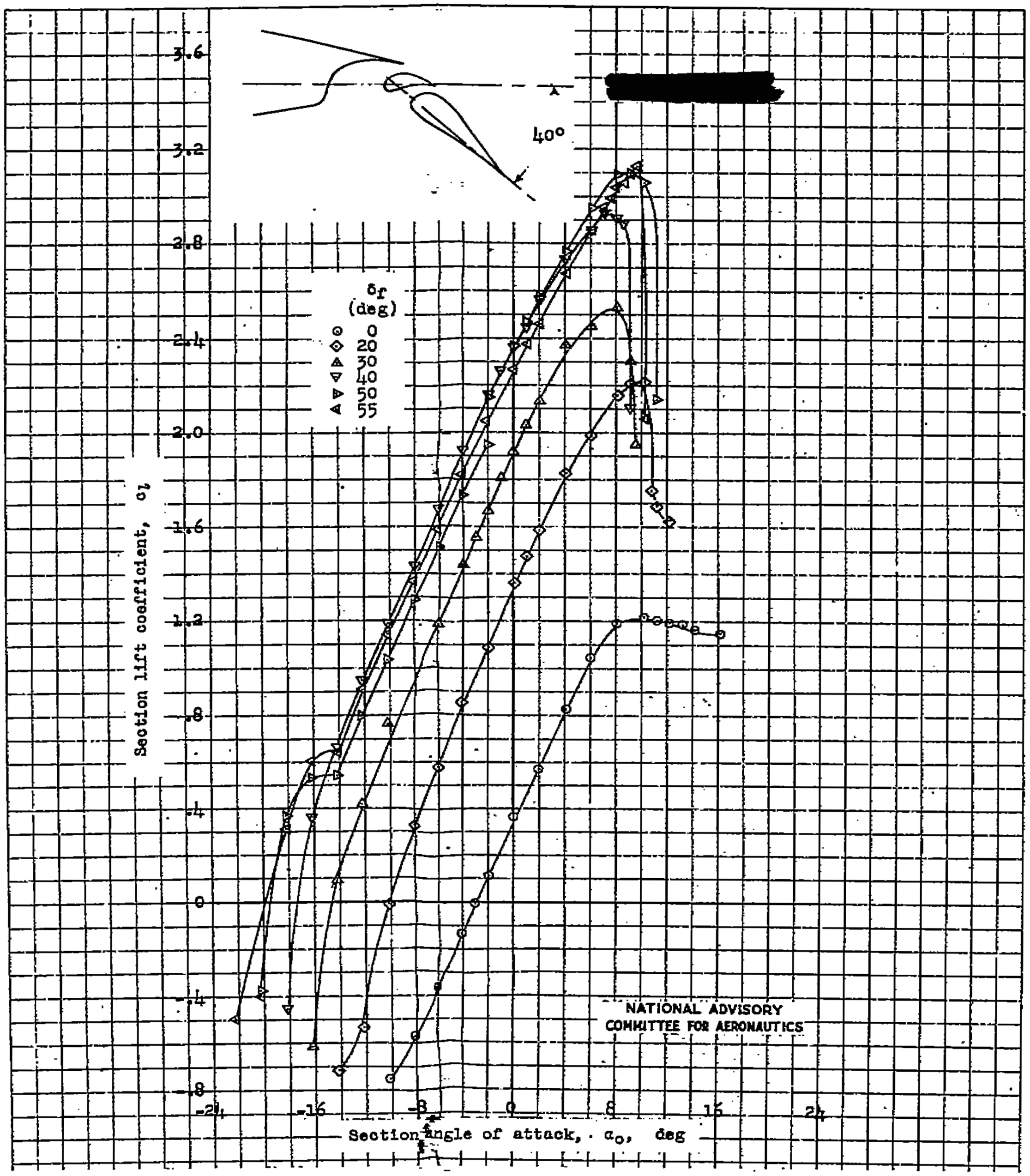

(a) No skirt extension.

Figure 5 .- Section lift characteristics of a wing section of the XB-36 airplane equipped with a double slotted flap with various skirt extensions. $R = 2.4 \times 10^6$.

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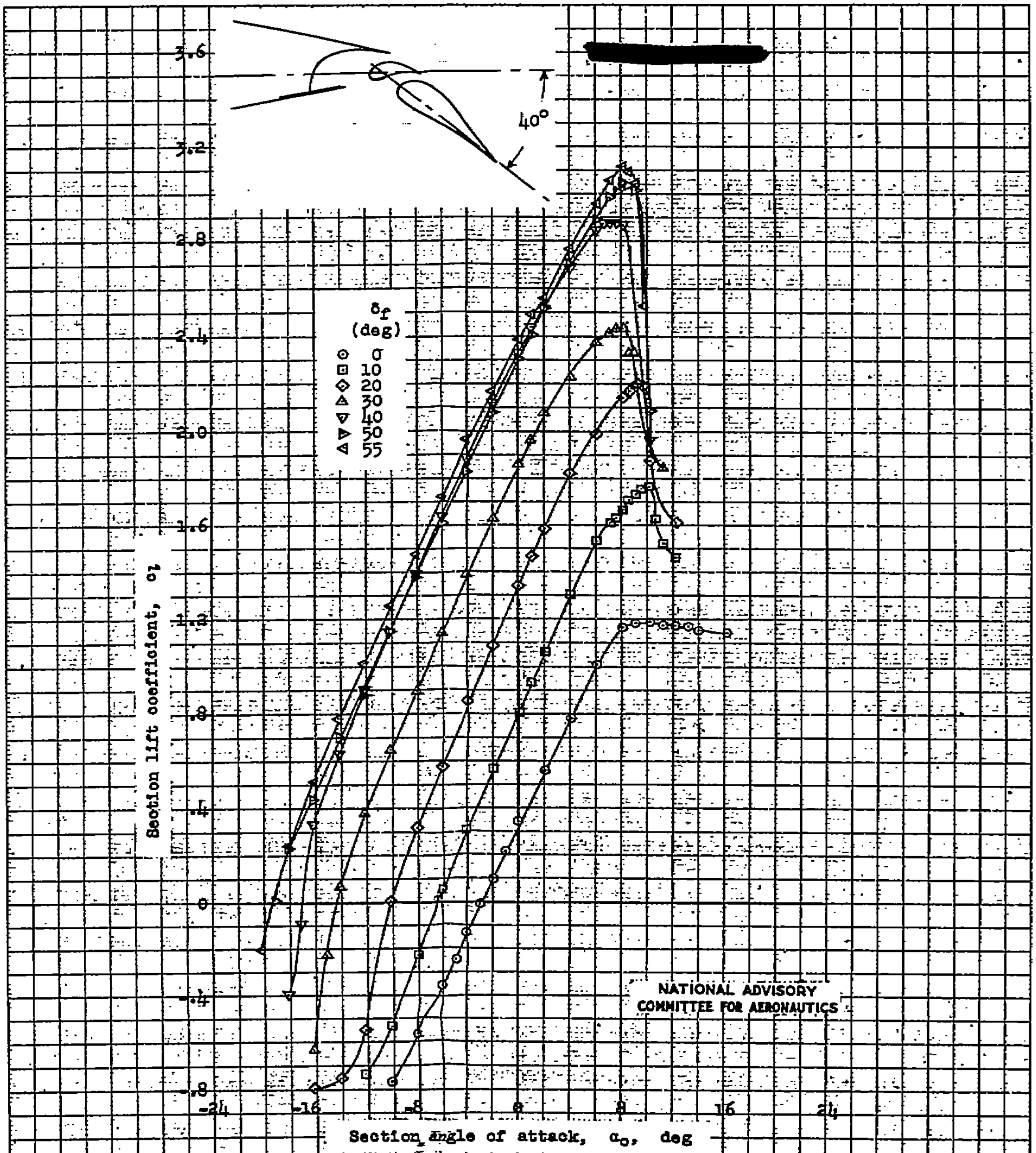
[redacted]



(b) 0.787c skirt extension.

Figure 5 .- Continued.

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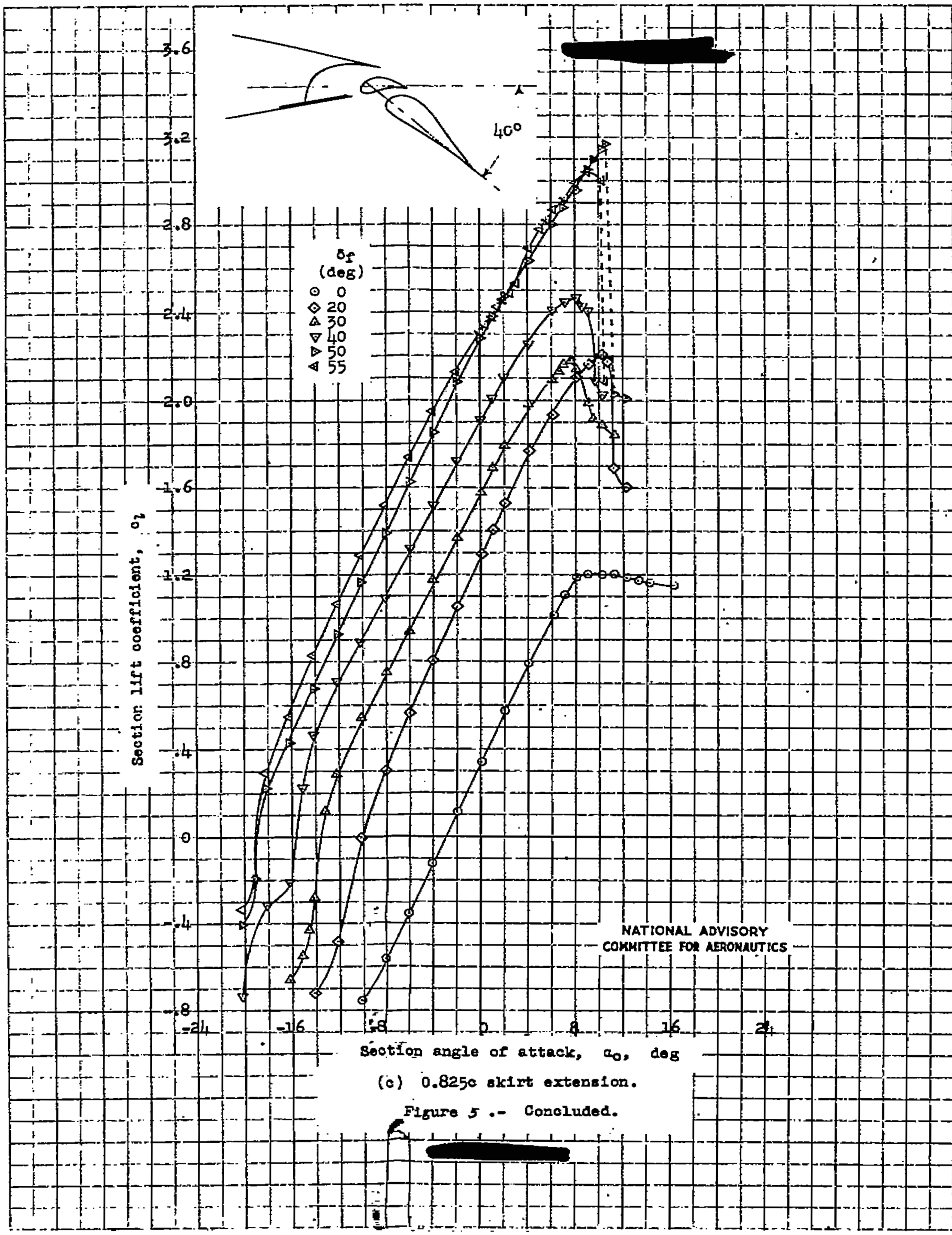

(c) 0.825c skirt extension.

Figure 5 .- Concluded.

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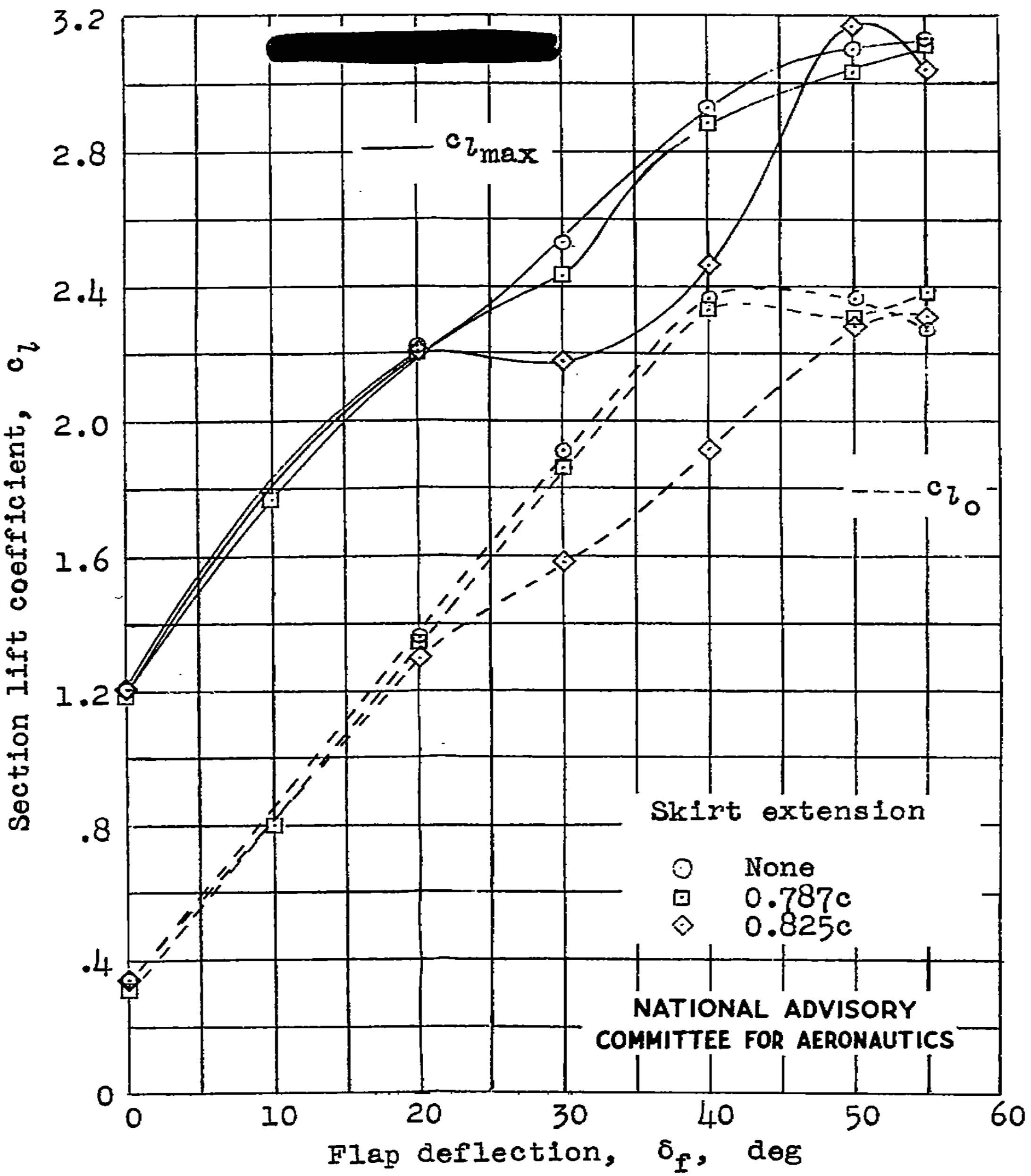

Figure 6 .- Variation of maximum section lift coefficient and section lift coefficient at 0° angle of attack with flap deflection for several different slot entry skirt extensions. $R = 2.4 \times 10^6$.

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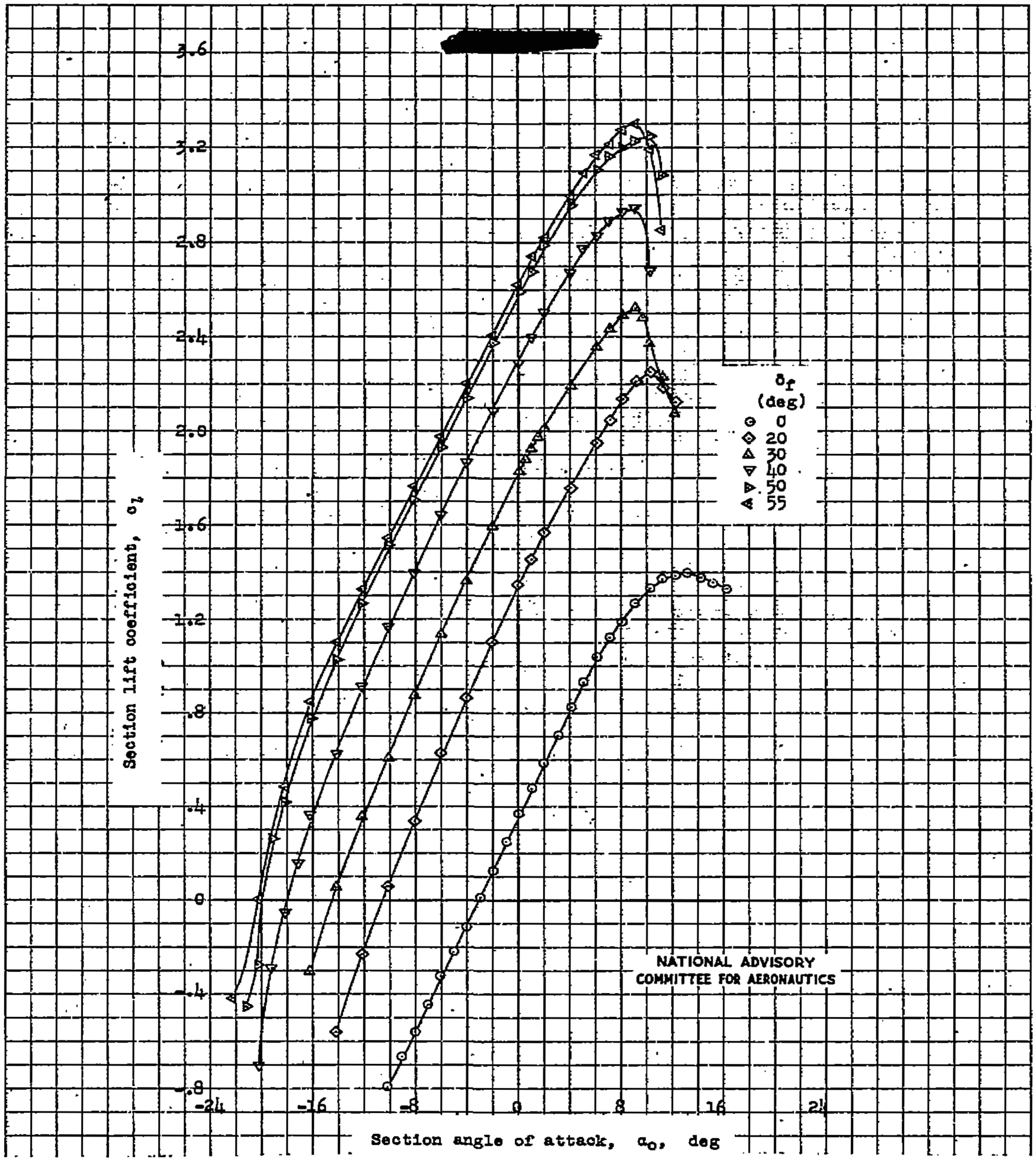

Figure 7 .- Section lift characteristics of a wing section of the XB-36 airplane equipped with a double slotted flap. 0.787c skirt extension; $R = 6 \times 10^6$.

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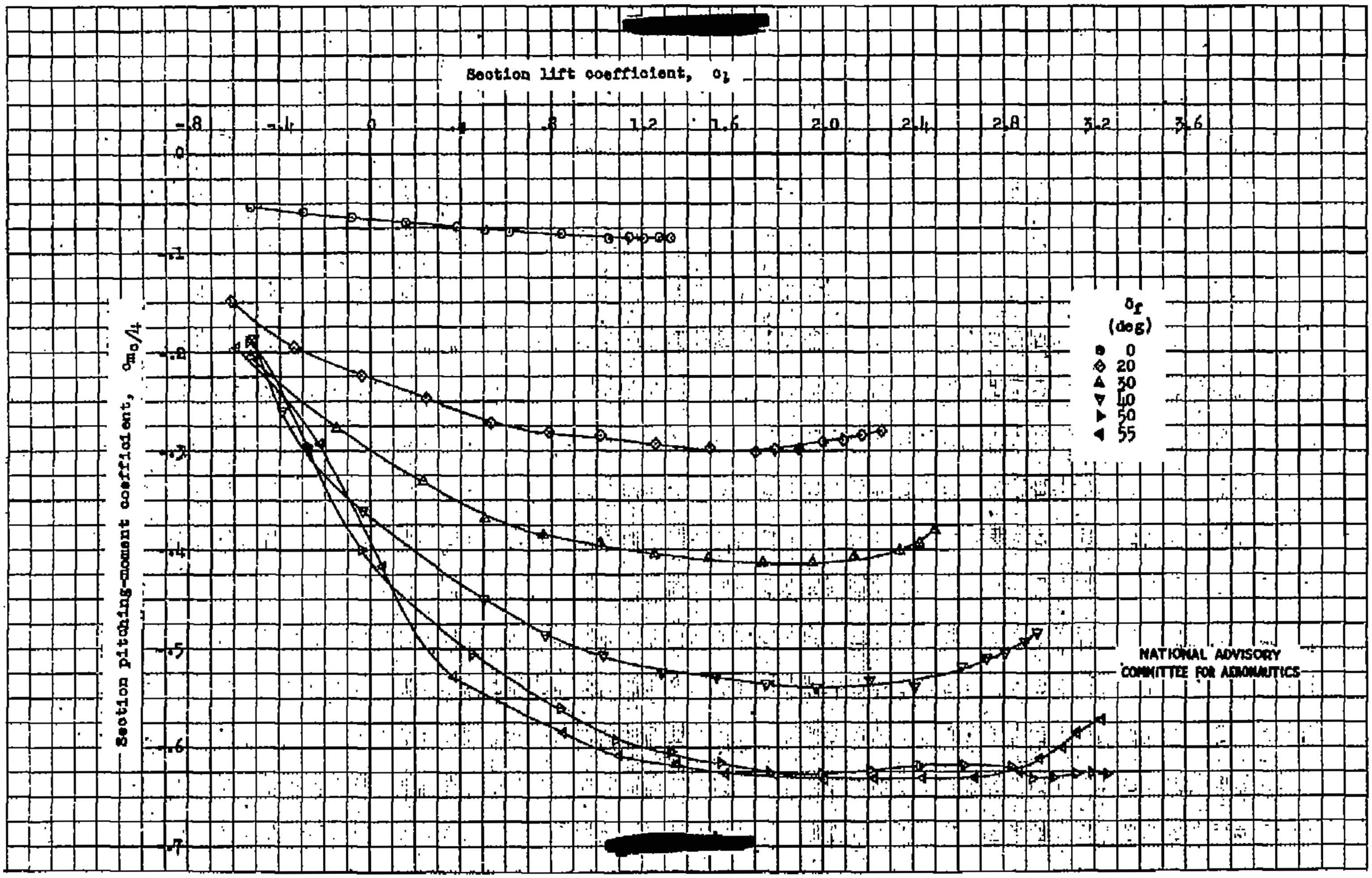
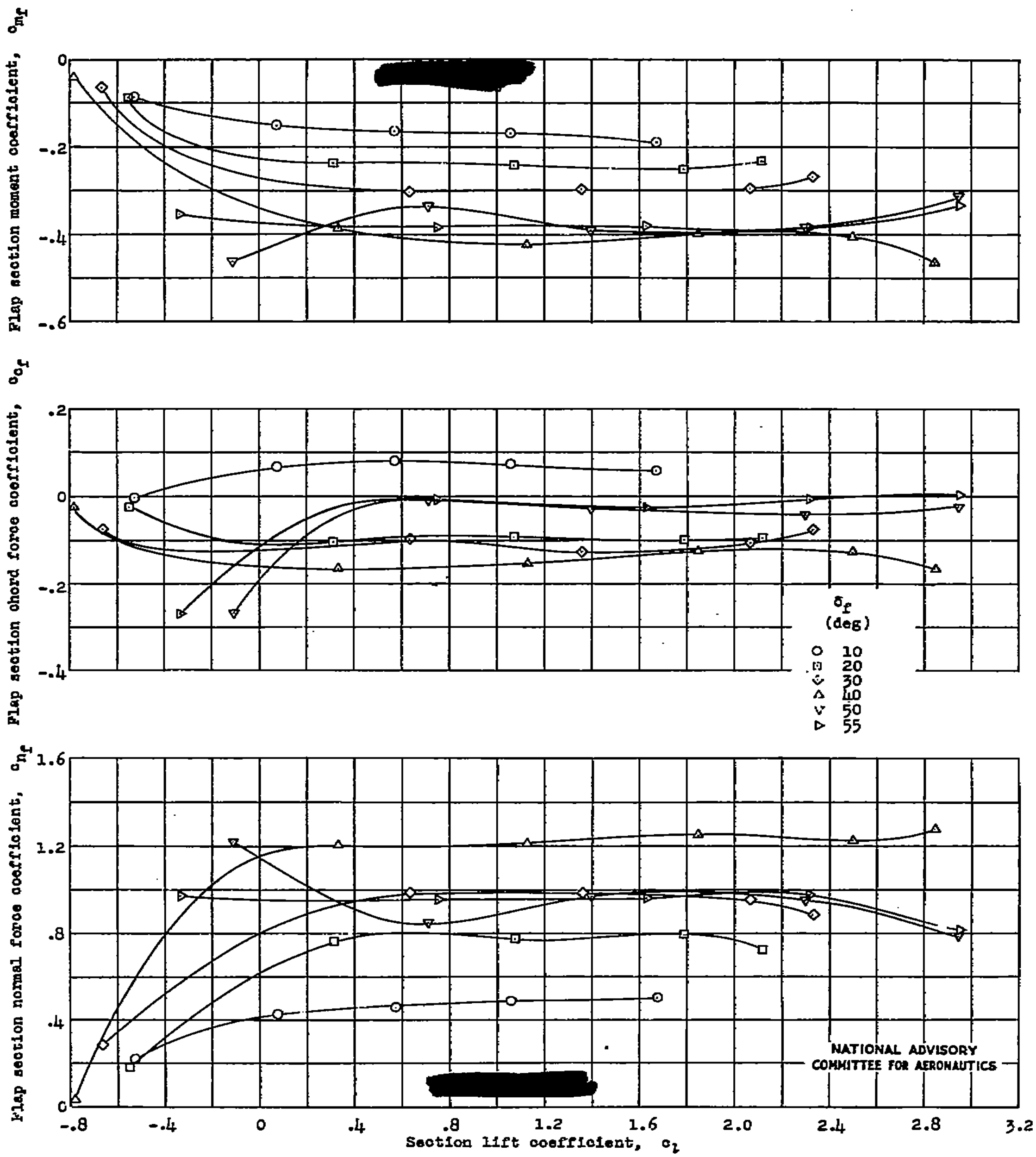


Figure 8 .- Section pitching moment characteristics of a wing section of the XB-36 airplane equipped with a double slotted flap. 0.787c skirt extension; $R = 6.0 \times 10^6$.



(a) Flap.

Figure 9 .- Section force and moment characteristics for a double slotted flap on a wing section of the XB-36 airplane. 0.787c skirt extension; $R = 2.4 \times 10^6$.

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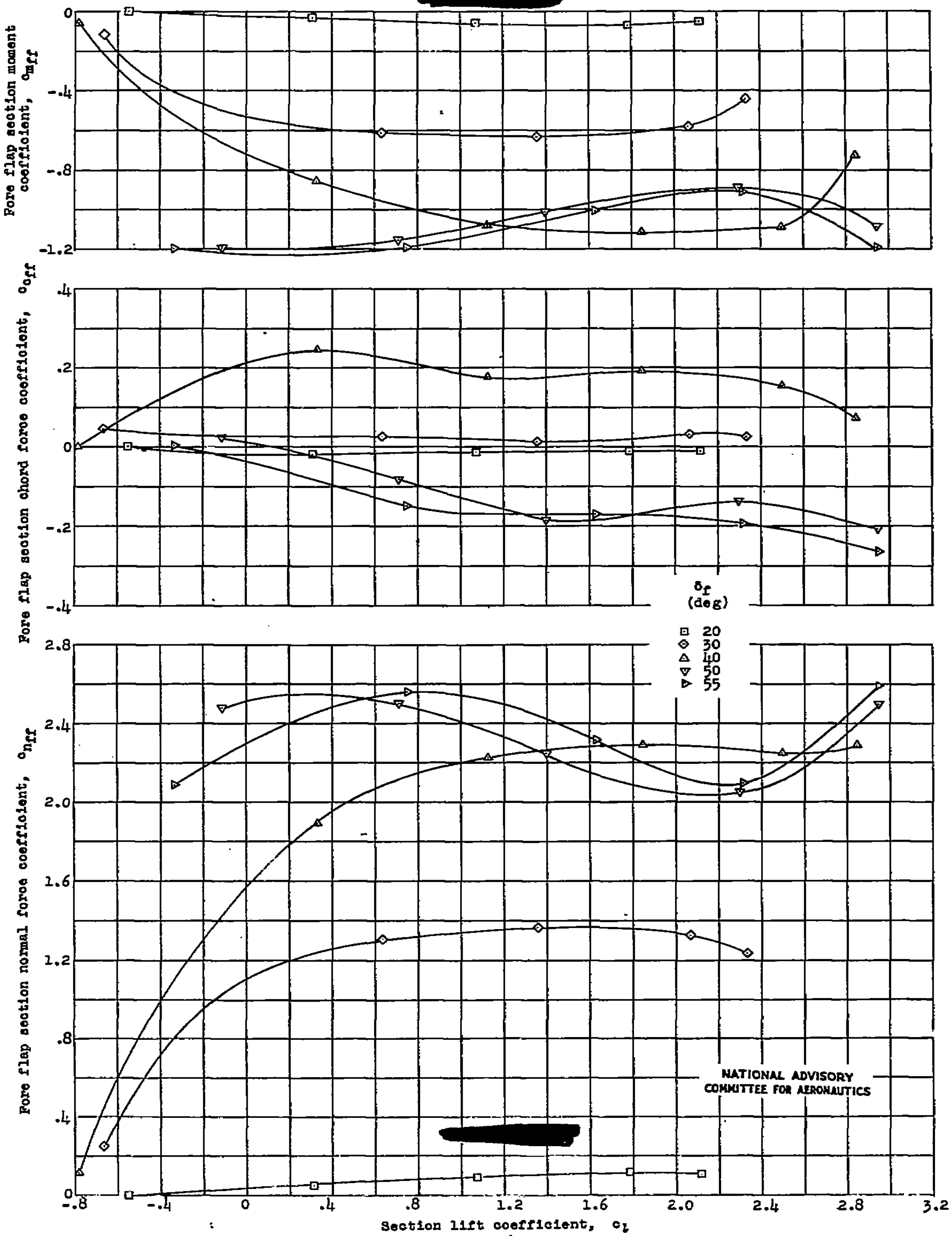

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(b) Fore flap.

Figure 9.- Concluded.

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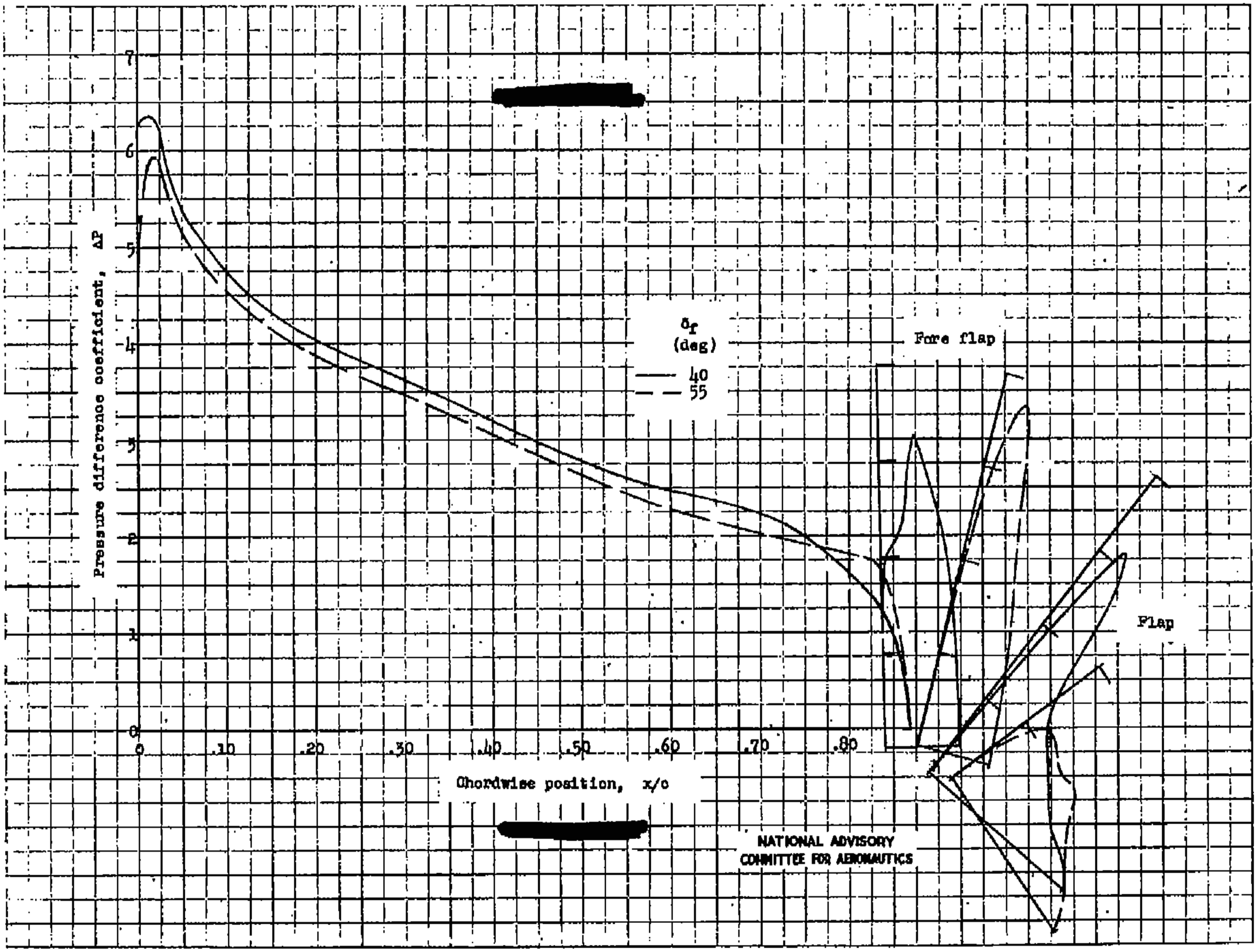

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Figure 10.- Load distributions for an airfoil section of the XB-36 airplane equipped with a double slotted flap. $\alpha_0 = 6.1°$; $R = 2.4 \times 10^6$; 0.787c skirt extension.

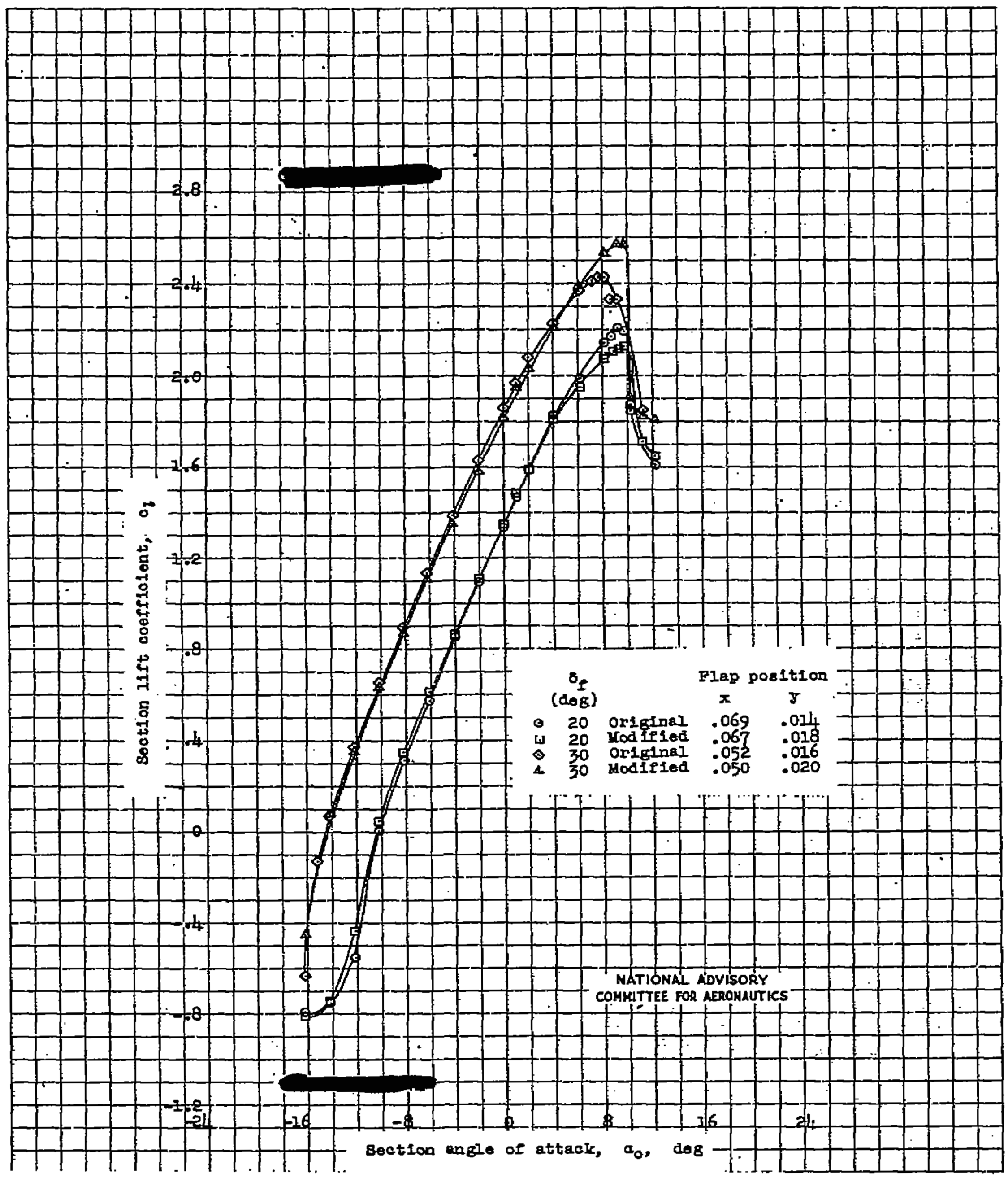

Figure 11 .- Effect on lift characteristics of small changes in flap position. $R = 2.4 \times 10^6$; 0.737c skirt extension.