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WIND-TUNNEL INVESTIGATION OF A BEVELED AILERON SHAPE

DESIGNED TO INCREASE THE USEFUL DEFLECTION RANGE

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MEMORANDUM REPORT

for the

Army Air Forces, Materiel Command

WIND-TUNNEL INVESTIGATION OF A BEVELED AILERON SHAPE

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INTRODUCTION

The useful range of deflection of a control surface is ordinarily limited by the occurrence of flow separation on the convex side of the surface behind the hinge. After this separation occurs the hinge moment increases rapidly, making it extremely difficult to deflect the aileron beyond this point at high speed. An aileron following the shape of the original airfoil forms an outside corner on one side of the flap hinge when it is deflected through a small angle. The increased local velocity around this corner, which is followed by an adverse pressure gradient, is responsible for the flow separation.

When beveled ailerons were constructed for the XP-51 airplane, the bevel was built up by spreading the upper and lower surfaces apart behind the hinge (see fig. 1, configuration B, and fig. 2 of reference 1), making a slight inside corner on each surface. During the flight tests, it was noted that these ailerons showed a somewhat greater useful range of deflections and gave slightly better control at low speed than did the original ailerons.

In an attempt to further increase the useful range of angular deflections, the aileron shown in figure 1, configuration C, was designed. The more pronounced inside corner at the aileron hinge point causes an initial positive pressure peak, so that a certain amount of deflection is possible before the pressure curve becomes flat. The purpose of the present investigation made in the Langley Memorial Aeronautical Laboratory two-dimensional low-turbulence tunnel was to determine the general

aerodynamic characteristics of this aileron and, in particular, to determine its useful angular range.

APPARATUS AND METHODS

A scale model having a 36-inch wing chord and 35.75-inch span was made to correspond to the measured ordinates of an intermediate section of the aileron portion of the wing (16 inches outboard from the inboard end of the right aileron) of the XP-51 airplane. The wing section was modified aft of the 70-percent chord point in order to fair in the 0.150-chord aileron. (See fig. 1, configuration C.) The ordinates of the modified wing section forward of the aileron hinge line and the original measured ordinates of the plain wing are given in table I.

The aileron shapes tested are shown in figure 2. The three ailerons were hinged at the 85-percent chord point. Therefore, with the 0.145-chord aileron the wing chord was reduced approximately 0.2 inch. In the sealed condition, the aileron nose gap was sealed with thin rubber dam.

For the low-drag condition, the model was finished with number 400 waterpaper to produce aerodynamically smooth surfaces. For the high-drag condition, the model surfaces were the same as in the low-drag condition; but roughness strips, made of carborundum grains embedded in glue on a 1-inch strip of Scotch tape, were placed on the upper and lower surfaces near the leading edge of the model.

Lift and drag measurements of the model were made by the methods described in reference 2. The profile-drag and lift coefficients were based on a nominal wing chord of 36 inches. The aileron hinge moments were measured by means of a calibrated torque rod and the coefficient is based on the actual chord and span of the aileron.

All tests were made at a dynamic pressure of 59.7 pounds per square foot, which corresponds to a velocity of about 150 miles per hour and a test Reynolds number of approximately 4,000,000. The test program is given in the following table.

Aileron deflection, $\pm 30^\circ$, for all runs

Run no.	Aileron	α_0 (deg)	Gap condition	Surface condition
1	1	0	Seal	Smooth
2	1	0	No seal	Smooth
3	1	0	Seal	Roughness strips
4	2	0	Seal	Smooth
5	2	0	Seal	Roughness strips
6	3	0	Seal	Smooth
7	3	0	Seal	Roughness strips
8	3	0, ± 4.1 8.3	Seal	Roughness strips

RESULTS AND DISCUSSION

Effect of hinge-gap seal.- The effects of sealing the hinge gap on the aileron characteristics can be seen from the results presented in figure 3. With the gap open there is a tendency for aileron 1 to overbalance for small deflections. A similar tendency has been found in other tests on beveled-trailing-edge ailerons. As shown in figure 3, this tendency to overbalance was eliminated by sealing the gap to stop the flow of air. Apparently the pressure difference resulting from a small deflection of the aileron is sufficient to cause a large portion of the boundary layer to flow from one side of the airfoil to the other through the hinge gap, accentuating the effect of the bevel. In addition to eliminating the overbalance, sealing the gap also reduced the increment in lift for the larger aileron deflections. This is not in agreement with the usually favorable effect of sealing the gap of contour ailerons or less severely shaped ailerons. In a practical installation the effect of the hinge gap may, of course, be influenced by the internal pressure in the wing.

Effect of surface condition and Reynolds number.-

Because the balancing action of the bevel depends on the boundary-layer thickness and profile, it is to be expected that the amount of balance obtained may vary considerably with surface roughness and Reynolds number. Because the boundary-layer thickness near the trailing edge of the airfoil is intimately related to the drag coefficient and because the form of the boundary-layer profile near the trailing edge varies little for thin airfoils at small angles of attack, it is to be expected that the balancing action of the bevel can be related to the drag coefficient of the section. The effects of Reynolds number, position of transition, and surface condition on aileron characteristics may therefore be correlated with their known effects on profile drag.

The effect of changes in profile drag on the aileron characteristics is indicated by the results presented in figure 4. The presence of the roughness strips approximately doubles the drag of the airfoil section in each case. A comparison between the high- and low-drag conditions for the three configurations shows that the slope of the hinge-moment curve is reduced for small deflections and the increment of lift is reduced for almost all aileron deflections by the addition of the roughness strips near the leading edge of the model.

For a conservative design, the control surface should be proportioned so as to avoid overbalance with the highest profile-drag coefficient the wing would be expected to have in service.

Although these results (fig. 4) may be taken as an indication of the effect of drag on a moderately thin airfoil, it is not thought that the results can be safely applied to airfoils of greater thickness. On thicker airfoils the boundary layer at the trailing edge is often considerably nearer the separation point, and the behavior of the aileron under these circumstances may be quite different.

Effect of aileron profile.- The effects of aileron profile on the aileron characteristics are presented in figures 4 and 5.

In figure 4(a) the hinge moment and lift characteristics are given for aileron 1, which had a trailing-edge bevel angle of 27° . In the smooth condition, the

results show that for this moderate bevel angle the hinge-moment and lift characteristics are approximately linear until a down deflection of 25° is reached. For upward deflections near -10° , an abrupt change occurs in the slope of the hinge-moment curve. Although aileron 1 would give the required lateral control at low speeds, the large negative value (-0.0053) of $(\partial c_h / \partial \delta_a)_a$ combined with the characteristic positive value of $(\partial c_h / \partial \alpha)_{\delta_a}$ for beveled-trailing-edge ailerons would result in too large stick forces at high speeds to suit present-day control requirements. The results in figure 4(b), wing smooth, show that aileron 2 with a bevel angle of 30° , an increase of 3° in the bevel angle of aileron 1, would also fail to give the required lateral control at high speed because of the too large negative value (-0.0044) of $(\partial c_h / \partial \delta_a)_a$. The results in figure 4(c), wing smooth, show that aileron 3 with a bevel angle of 33° , an increase of 3° in the bevel angle of aileron 2, combined with a reduction in aileron chord of $0.005c$ had a value of -0.0020 for $(\partial c_h / \partial \delta_a)_a$ which should be low enough to give the required lateral control at high speeds on a pursuit plane of conventional size.

A comparison of figures 4(a), 4(b), and 4(c) shows that by increasing the bevel angle from 27° to 33° the slope of the hinge-moment curve is progressively reduced at small deflections, resulting in considerable curvature of the hinge-moment curve, while the lift-characteristic curves remain about the same for the three ailerons.

No contour aileron was tested for comparison with the modified aileron; hence, it is not possible to state definitely that the results of these tests show an increase in the range of useful deflection over the usual contour aileron, although low values of the hinge moment appear to be extended to greater deflections than is ordinarily found for conventional shapes.

Figure 5 gives a comparison of drag polars for the modified aileron section and the plain wing section with and without a $0.187c$ contour aileron. This comparison shows that in the range of test Reynolds number an increase in minimum profile drag $c_{d_{min}}$ of about

0.0002 resulted from deforming the plain section with a contour aileron to form the modified section and aileron.

Because the results given in figure 6, wing leading edge rough, showed that a 35° bevel angle would just balance out the aileron hinge moments with the model at 0° angle of attack, tests were made to determine the characteristics of aileron 3 with the model, leading edge rough, at other angles of attack. These results (fig. 6) show that, as the angle of attack was increased from 0° to 4.1° and to 8.3° , aileron 3 showed positive hinge-moment slopes in the negative deflection range. It will be noted, however, that the combination of right and left ailerons is not overbalanced.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 8, 1944.

REFERENCES

1. White, M. D., and Hoover, Herbert H.: Flight Tests of Modifications to Improve the Aileron Control Characteristics of a North American XP-51 Airplane (A.C. No. 41-38). NACA MR, June 20, 1942.
2. Abbott, Ira H., von Doenhoff, Albert E., and Stivers, Louis S., Jr.: Summary of Airfoil Data. NACA ACN No. L5C05, 1945.
3. Abbott, Frank T., Jr., and Underwood, William J.: Wind-Tunnel Investigation of Profile Drag and Lift of an Intermediate Wing Section of the XP-51 Airplane with Beveled Trailing-Edge and Contour Ailerons. NACA MR, Jan. 27, 1943.

TABLE I

AIRFOIL ORDINATES OF INTERMEDIATE WING SECTION OF XP-51 AIRPLANE

Plain wing section			Modified wing section		
x/c	y _U /c	y _L /c	x/c	y _U /c	y _L /c
0	0	0	0	0	0
.0125	.0184	-.0134	.0125	.0184	-.0134
.025	.0267	-.0181	.025	.0267	-.0181
.05	.0368	-.0249	.05	.0368	-.0249
.075	.0438	-.0304	.075	.0438	-.0304
.10	.0500	-.0349	.10	.0500	-.0349
.15	.0598	-.0412	.15	.0598	-.0412
.20	.0664	-.0464	.20	.0664	-.0464
.25	.0717	-.0506	.25	.0717	-.0506
.30	.0763	-.0546	.30	.0763	-.0546
.35	.0787	-.0550	.35	.0787	-.0550
.40	.0793	-.0552	.40	.0793	-.0552
.45	.0790	-.0545	.45	.0790	-.0545
.50	.0769	-.0530	.50	.0769	-.0530
.60	.0675	-.0447	.60	.0675	-.0447
.70	.0520	-.0319	.70	.0520	-.0319
.80	.0338	-.0168	.80	.0328	-.0173
.805	.0326	-.0163	.85	.0220	-.0080
.8125		-.0156			
.815		-.0154			
.8175		-.0151			
.82		-.0143			
.85	.0228	-.0113			
.90	.0133	-.0066			
.95	.0056	-.0024			
.998	.0011	-.0011			
1.000	0	0			

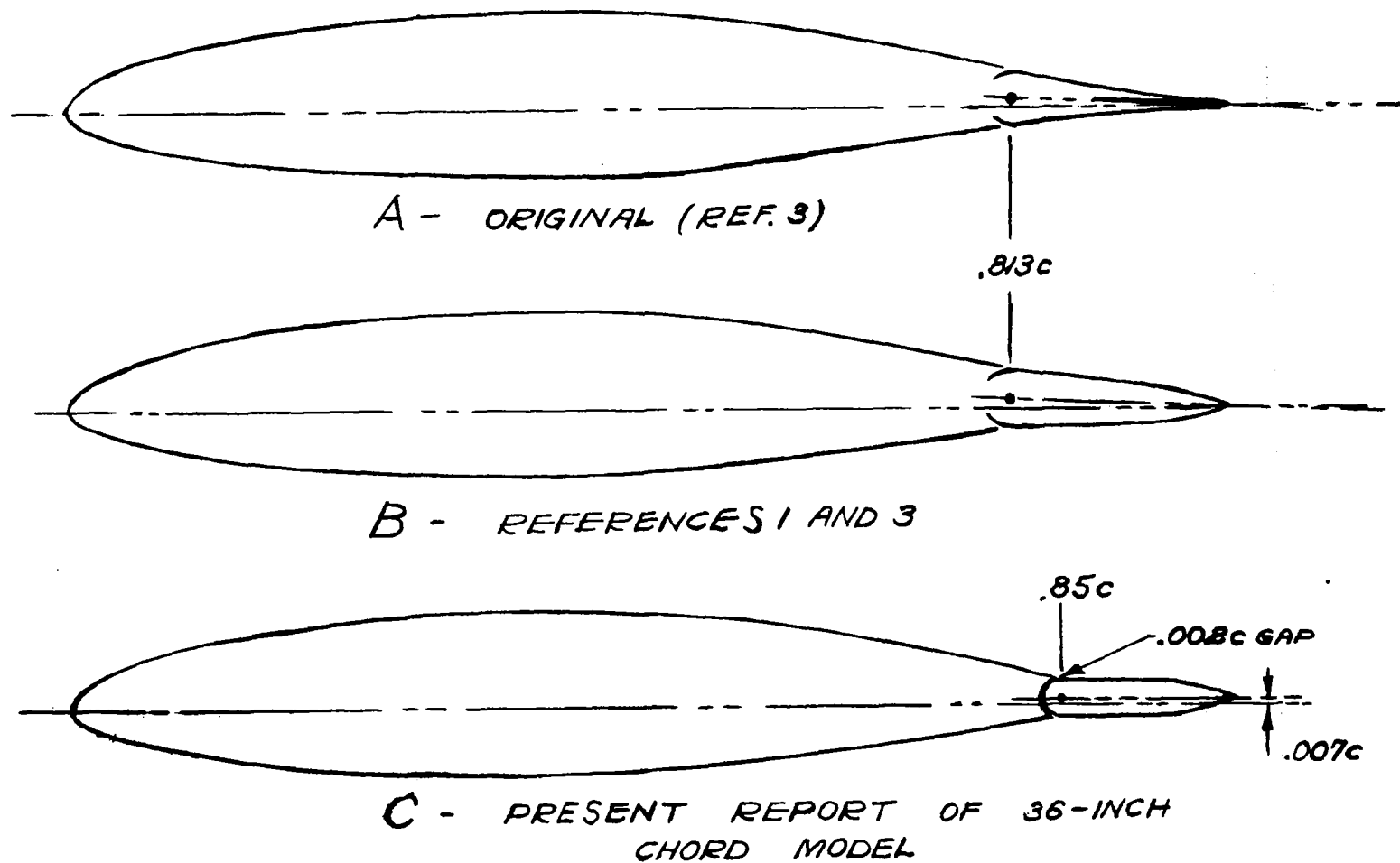


Figure 1.- Comparison of aileron shapes tested for XP-51 airplane. Configuration C is model configuration reported herein.

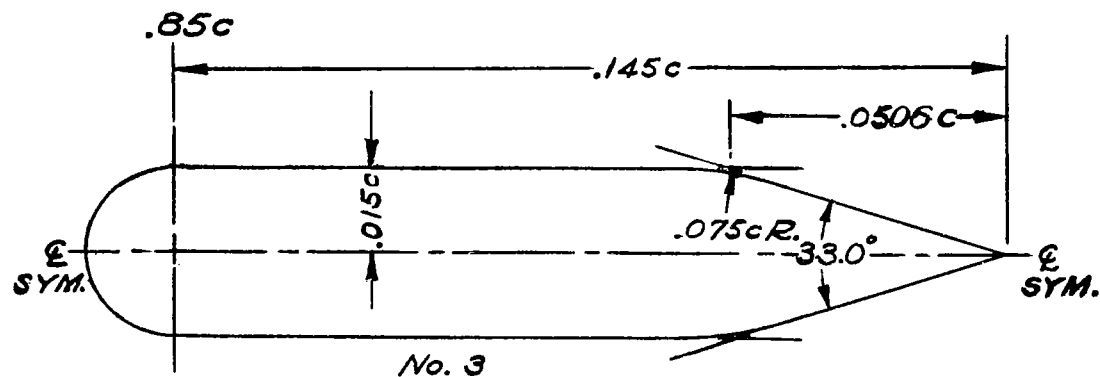
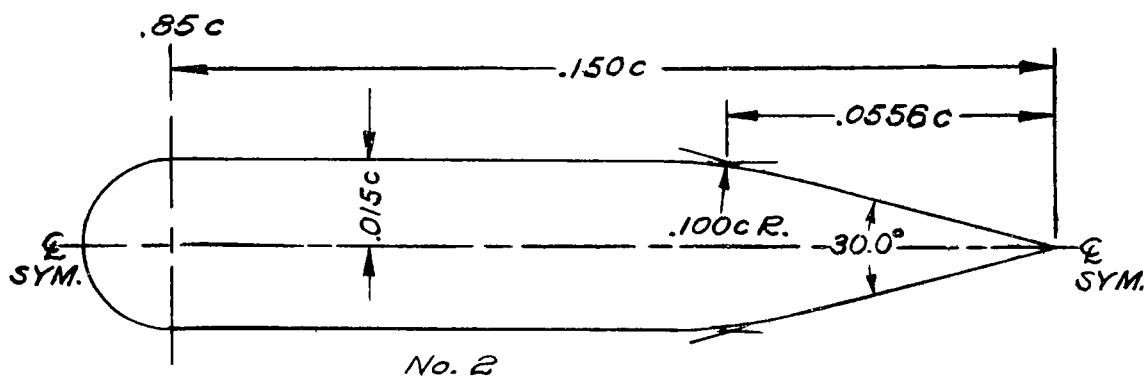
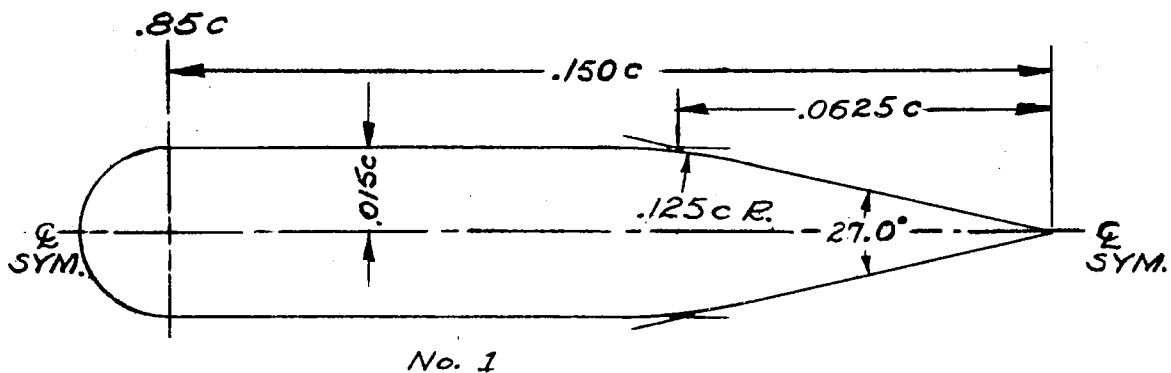


Figure 2.— Aileron shapes tested on 36-inch chord model of XP-51 wing section.

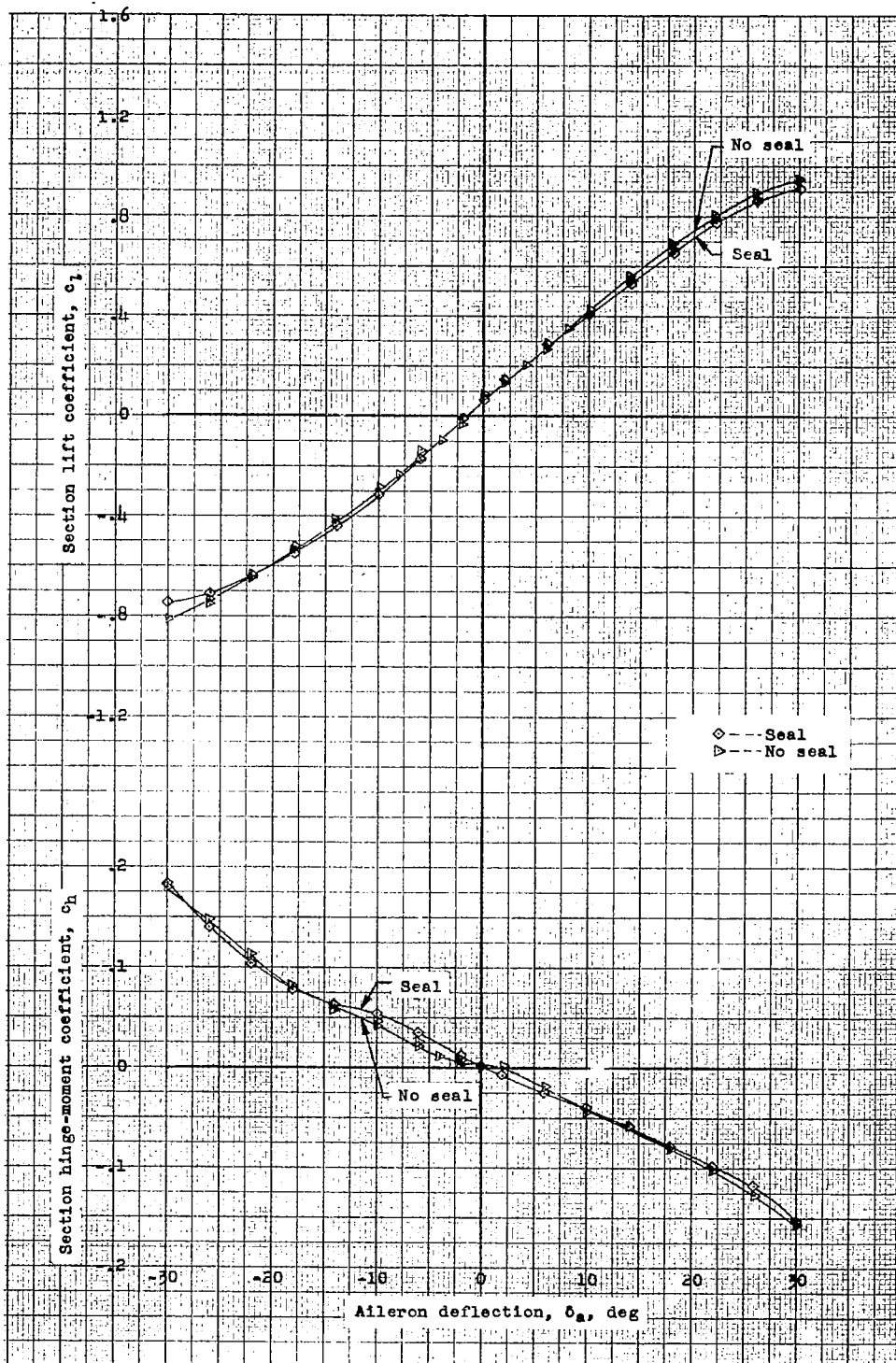
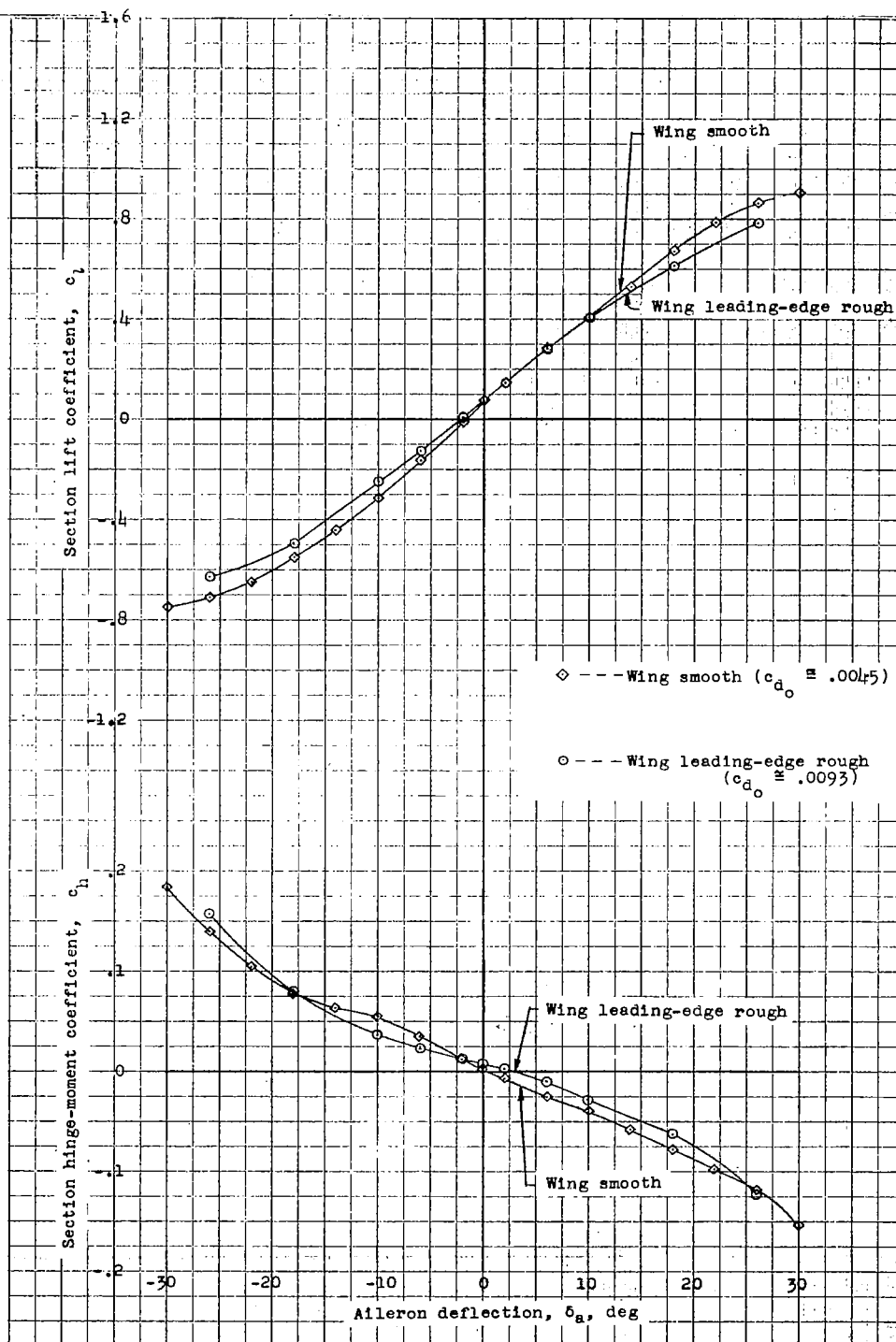
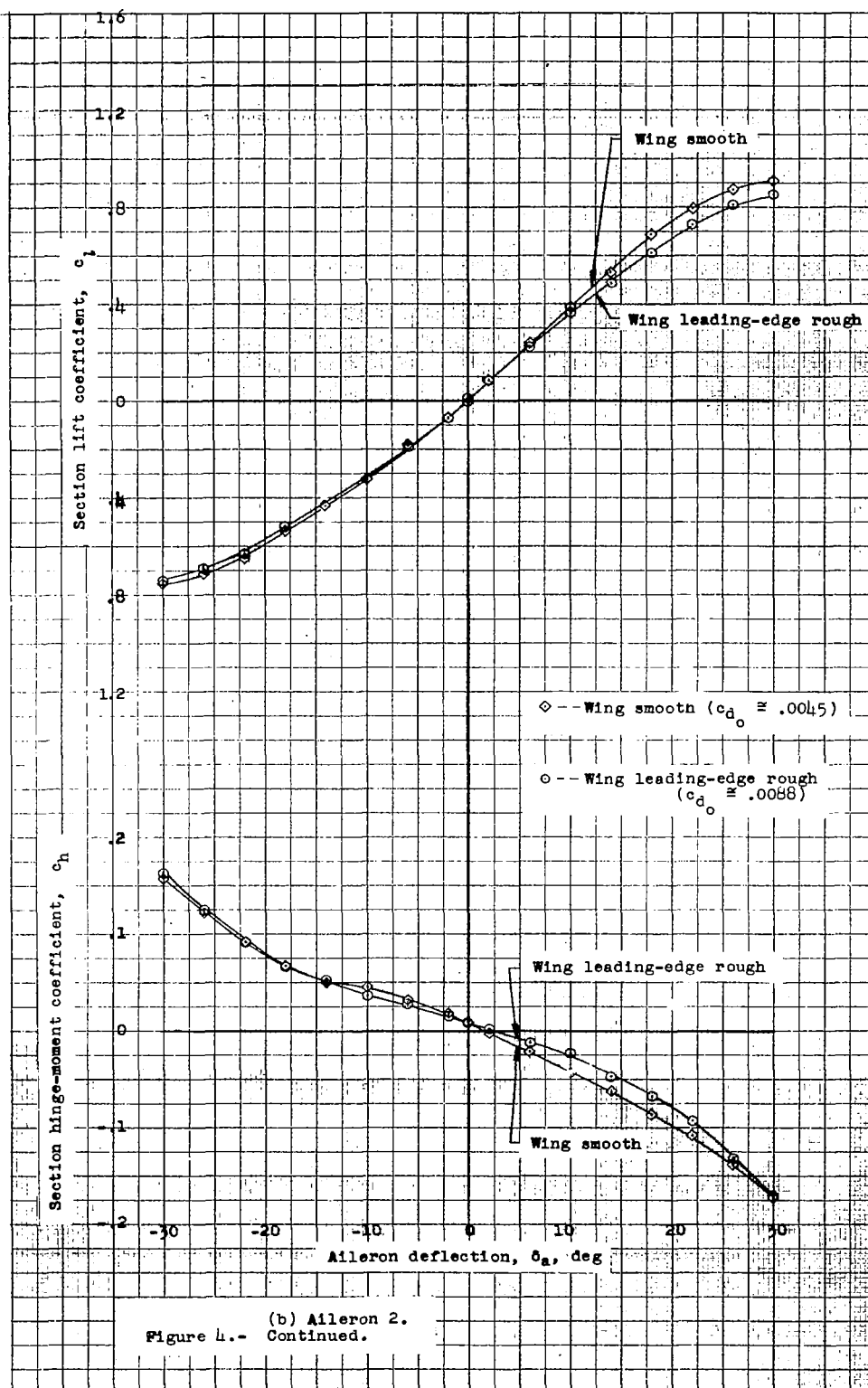
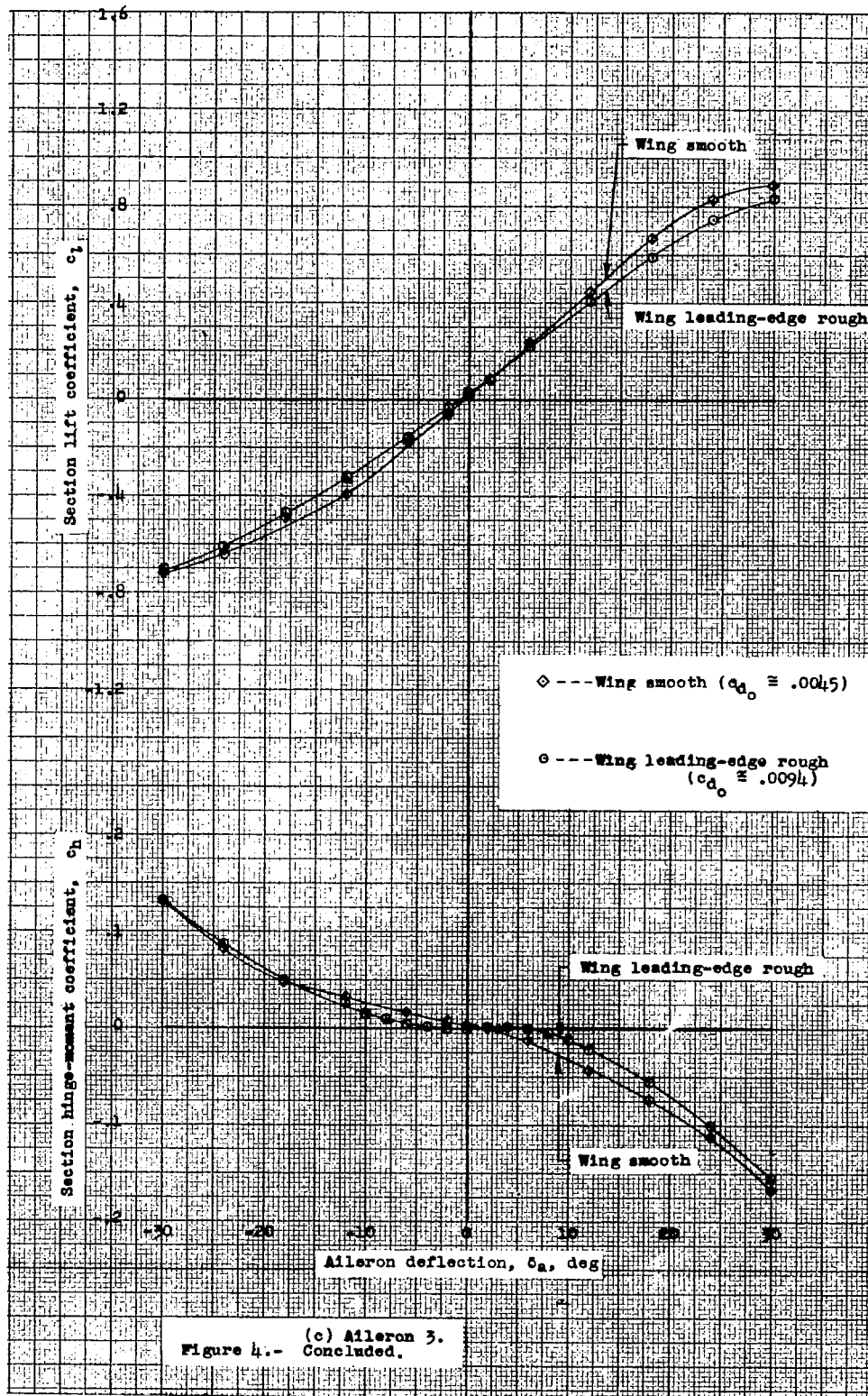


Figure 3.- Effect of hinge gap on section aileron characteristics of aileron 1 on a scale model of the intermediate wing section of the XP-51 airplane. $\alpha_0, 0^\circ$; wing smooth ($c_{d0} \approx .0045$); R, 4×10^6 .



(a) (Aileron 1.
 Figure 4.- Effect of wing leading-edge roughness on section
 aileron characteristics of a modified aileron on a scale
 model of the intermediate wing section of the XP-51 airplane.
 $\alpha_0, 0^\circ$; sealed; $R, 4 \times 10^6$.





Modified aileron section - aileron 1

○ -- Seal $\delta_a, 0^\circ$; $R, 4 \times 10^6$
 + -- No seal $\delta_a, 0^\circ$; $R, 4 \times 10^6$

———— Plain wing section; $R, 6 \times 10^6$ (fig. 5 - ref. 3)
 ----- Plain wing section with 0.187c contour aileron;
 $R, 6 \times 10^6$; no seal. (fig. 10 - ref. 3)

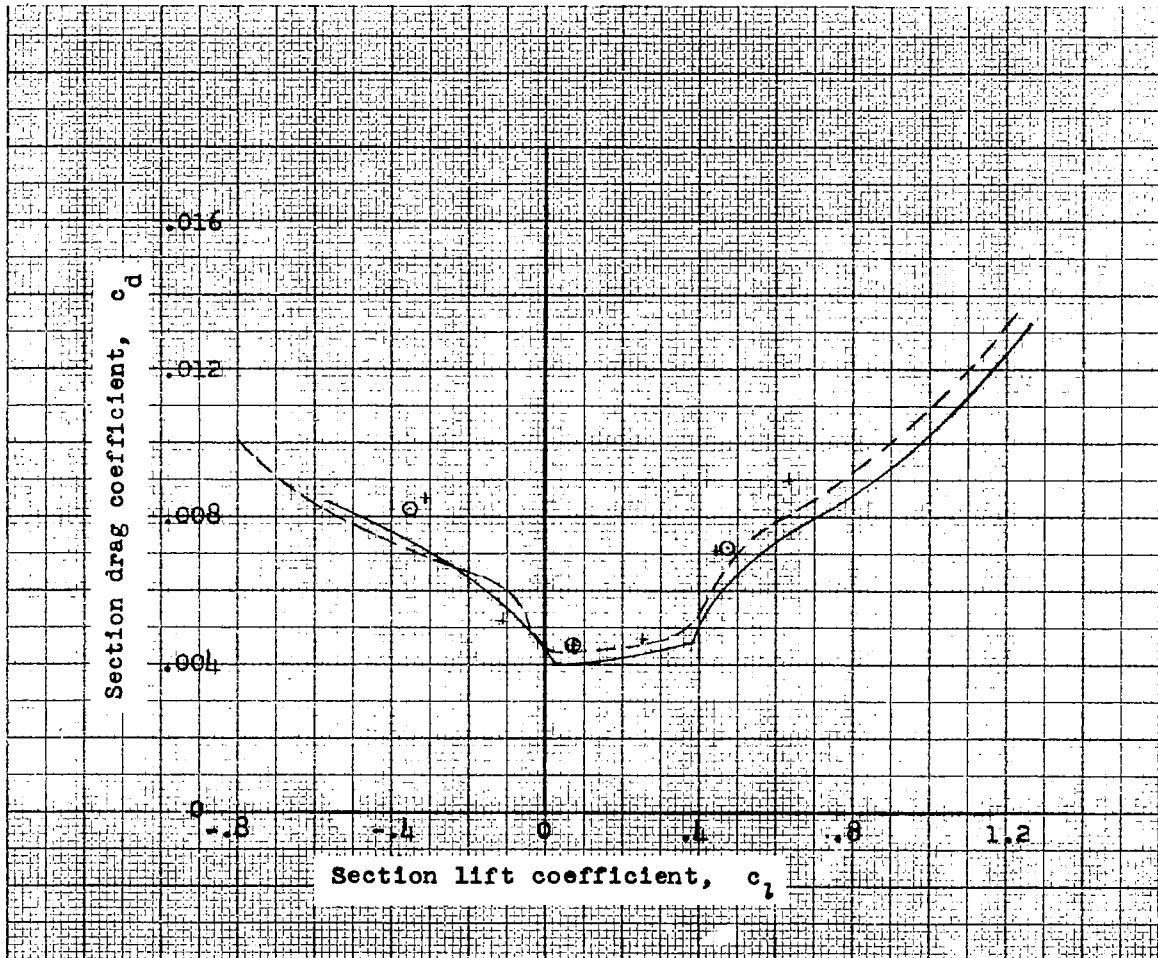


Figure 5.- Comparison of the drag polars of the modified wing section with aileron 1 and the plain wing with and without a contour aileron.

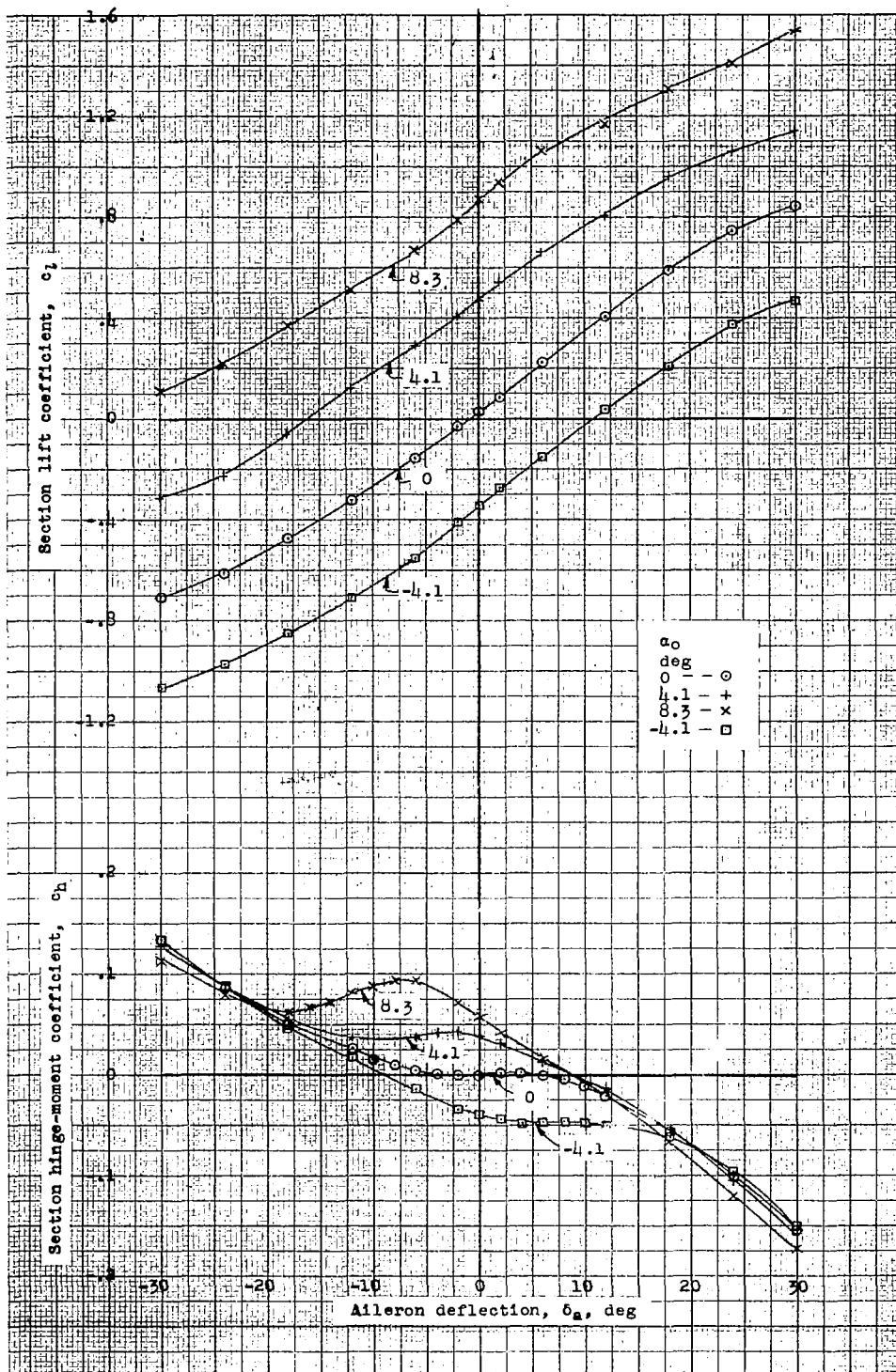


Figure 6.- Section aileron characteristics of aileron 3 on a scale model of the intermediate wing section of the XP-51 airplane. Wing leading-edge rough, sealed; $R, 4 \times 10^6$.

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Lift, drag, section and profile lift and drag, and hinge moments of the aileron were tested in a low turbulence tunnel to determine its useful angular range. Tests were made at various gap and surface conditions. Results show that the useful deflection range may be increased by a more pronounced inside corner at the aileron hinge point thus causing an initial positive peak pressure, so that a certain amount of deflection is possible before the pressure curve becomes flat.

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