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EFFECTS OF A TYPICAL NACELLE ON THE CHARACTERISTICS OF A THICK LOW-DRAG AIRFOIL CRITICALLY AFFECTED BY LEADING-EDGE ROUGHNESS

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EFFECTS OF A TYPICAL NACELLE ON THE CHARACTERISTICS OF A THICK LOW-DRAG AIRFOIL CRITICALLY AFFECTED BY LEADING-EDGE ROUGHNESS

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SUMMARY

Tests were made to study the effects of a typical nacelle on the characteristics of a thick low-drag airfoil which had been shown from previous tests to be subject to separation difficulties resulting from leading edge roughness; that is, the airfoil with roughness had been shown to have sharp drag increases at moderate angles of attack. The present results tend to substantiate the results of previous tests which indicated that the airfoil was unconservative with respect to separation difficulties. On the other hand, unconservative sections of this type appear to show less serious drag increases with nacelle interference than with leading-edge roughness. The leading-edge roughness adopted as a standard may therefore be considered to remain the most satisfactory means of judging such airfoils.

INTRODUCTION

The NACA low-drag airfoils first investigated, and most of those for which data are presented in reference 1, were intended to be of conservative design to avoid serious separation difficulties even with rough leading edges. The thickness, camber, and position of minimum pressure of these airfoils were chosen to produce conservative pressure recoveries over the rearward part of the upper surface. In connection with early applications of these airfoils, questions arose concerning possible adverse effects of conventional nacelles on these sections; a program of tests of several representative nacelles on low-drag wings was consequently started. The first two series of tests showed that the drag and interference of the nacelles on a moderately thick low-drag wing were small (references 2 and 3).

Later applications of low-drag airfoils to long-range bombers with high wing loadings resulted in an increase in the airfoil thickness ratios and cambers to the point where it was feared that excessive drag coefficients resulting from turbulent separation might be experienced in the useful flight range of lift coefficients if the leading edges became roughened. An investigation of the effect of extreme leading-edge roughness on airfoils in the doubtful range (reference 4) indicated that the conservative range of airfoil design was probably being exceeded.

As a preliminary study of interference effects on low-drag airfoils, a later investigation was made in which several airfoils were tested with an intersecting flat plate normal to the span. The results indicated small interference effects for two conservative airfoils and large, although not severe, effects on an airfoil which had previously been shown to be unconservative with respect to leading-edge roughness (reference 5).

The present investigation was made to study the effects of a typical nacelle on one of the airfoils that had been shown to be unconservative with respect to leading-edge roughness. Tests of the smooth wing and of the wing with leading-edge roughness were made both with and without the nacelle and the results are presented herein for comparison.

MODEL AND TEST METHODS[1]

The nacelle of reference 2 was chosen for the investigation because results of tests of this nacelle on a moderately thick low-drag wing have been reported in reference 2. For the present tests,

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[1]At the time this report was originally published, some of the corrections required for reducing the test data to free-air conditions had not been determined. The values of section lift coefficient c_l for the NACA 65,2-422, a = 1.0 airfoil section (figs. 2,3, and 4) should be corrected by the equation

$$c_{l_{(corrected)}} = 0.965c_l + 0.014$$

The values of section lift coefficient c_l for the NACA 66,2-216, a = 0.6 airfoil section (fig. 3) should be corrected by the following equation

$$c_{l_{(corrected)}} = 0.965c_l + 0.006$$

the nacelle was mounted on an NACA 65,2-422, a = 1.0, (approx.), airfoil which had previously been shown to have marked drag increases at moderate angles of attack after the application of extreme leading-edge roughness. The wing model had a chord of 2 feet and a span of 3 feet (tunnel test-section width). The wing was set at an angle of incidence of 1° to the thrust line of the nacelle and, for practical reasons, the nacelle was mounted about 1 nacelle width off the tunnel center line. Two views of the wing-nacelle combination and details of the internal-air flow arrangement are shown in figure 1.

The tests were conducted in the NACA two-dimensional low-turbulence pressure tunnel. The drag coefficients for the combination were obtained by the methods outlined in references 2 and 3. The roughness applied to the leading edge of the wing for some of the tests was the standard roughness described in reference 4 and extended from the tunnel wall to the nacelle-wing juncture on each side of the nacelle.

SYMBOLS

The data are presented with the use of the following symbols:

c_d section drag coefficient

Δc_{d_c} additional external-drag coefficient based on area equal to airfoil chord squared

c_l section lift coefficient

A_e model exit area, square inches

V_e/V_o ratio of exit velocity to free-stream velocity

$\Delta H_e/q_o$ ratio of total pressure loss at exit to free-stream dynamic pressure

ΔC_{D_F} coefficient of drag due to internal losses

ΣC_{D_F} coefficient of total drag and interference

C_{D_F} coefficient of external drag and interference $\left(\Sigma C_{D_F} - \Delta C_{D_F}\right)$

Values of the drag coefficient C_{D_F} are based on the model frontal area, 29.08 square inches.

RESULTS AND DISCUSSION

Test results of internal-flow measurements and corresponding drag increments are given in table I. The drag increments Δc_{d_c} due to the external drag of the nacelle are plotted in figure 2 to the same scale as the section drag coefficients, and the shaded area represents the additional drag increments of the nacelle. This method of plotting provides a convenient comparison with section characteristics by reducing the drag of the nacelle to the additional section drag coefficient spread over 1 chord of span.

It can be seen in figure 2 that, over a span equal to 1 chord, the additional drag of the nacelle is not so large as the drag due to leading-edge roughness. In figure 3, however, the external drag of the nacelle on the smooth wing appears appreciably higher at the lower lift coefficients than the drag of the same nacelle on a conservative low-drag wing (reference 2). This higher drag for the nacelle on the unconservative wing is indicated in spite of the fact that the nacelle wetted area is reduced when mounted on the thicker wing. Unfortunately, no comparison can be made at higher lifts because the lift range of the drag tests in reference 2 was limited.

Results of tests of the nacelle on the wing with leading-edge roughness indicate sharp increases in the nacelle external-drag coefficients at comparatively low lift coefficients. This sharp increase in drag can be seen, in figure 3, to occur at lower lift coefficients for the nacelle on the wing with leading-edge roughness than for the nacelle on the smooth wing.

The section lift comparisons of figure 4 show practically no change in lift coefficient with the addition of the nacelle at the lower angles of attack. However, the measurements indicate increases in lift coefficient at the higher angles of attack for the wing in both conditions with the addition of the nacelle.

CONCLUDING REMARKS

Unconservative airfoil sections of the type tested appear to show less serious drag increases with nacelle interference than with leading-edge roughness; the standard leading-edge roughness may consequently be considered the more satisfactory means of judging such airfoils.

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REFERENCES

1. Jacobs, Eastman N., Abbott, Ira H., and Davidson, Milton: Preliminary Low-Drag-Airfoil and Flap Data from Tests at Large Reynolds Numbers and Low Turbulence, and Supplement. NACA A.C.R., March 1942.

2. Ellis, Macon C., Jr.: Some Lift and Drag Measurements of a Representative Bomber Nacelle on a Low-Drag Wing. NACA C.B., May 1942.

3. Ellis, Macon C., Jr.: Some Lift and Drag Measurements of a Representative Bomber Nacelle on a Low-Drag Wing - II. NACA C.B., Sept. 1942.

4. Jacobs, Eastman N., Abbott, Ira H., and Davidson, Milton: Investigation of Extreme Leading-Edge Roughness on Thick Low-Drag Airfoils to Indicate Those Critical to Separation. NACA C.B., June 1942.

5. Abbott, Ira H.: Interference Effects of Longitudinal Flat Plates on Low-Drag Airfoils. NACA C.B., Nov. 1942.

TABLE I

INTERNAL FLOW MEASUREMENTS AND DRAG INCREMENTS
[Maximum cross-sectional area of model = 29.08 sq in.]

Wing condition	c_l	A_e			V_e/V_o			$\Delta H_e/q_o$			ΔC_{D_F}			ΣC_{D_F}	C_{D_F}
		(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)		
Smooth	0.39	3.72	0.27	0.78	0.86	0.73	0.66	0.29	0.51	0.39	0.035	0.004	0.008	0.104	0.057
Do------	.73	3.72	.27	.78	.87	.60	.58	.31	.49	.37	.038	.003	.006	.114	.067
Do------	1.00	3.72	.27	.78	.88	.45	.51	.41	.51	.40	.052	.003	.006	.308	.247
Leading-edge roughness	.32	3.72	.27	.78	.86	.73	.66	.29	.51	.39	.035	.004	.008	.090	.043
Leading-edge roughness	.42	3.72	.27	.78	.87	.69	.63	.29	.50	.38	.035	.004	.007	.108	.062
Leading-edge roughness	.50	3.72	.27	.78	.87	.65	.60	.30	.49	.37	.037	.003	.007	.136	.089
Leading-edge roughness	.59	3.72	.27	.78	.87	.60	.53	.31	.49	.37	.038	.003	.006	.194	.147

[a]Engine-cooling-air exit.
[b]Auxiliary-cooling-air exit.
[c]Carburetor-air exit.

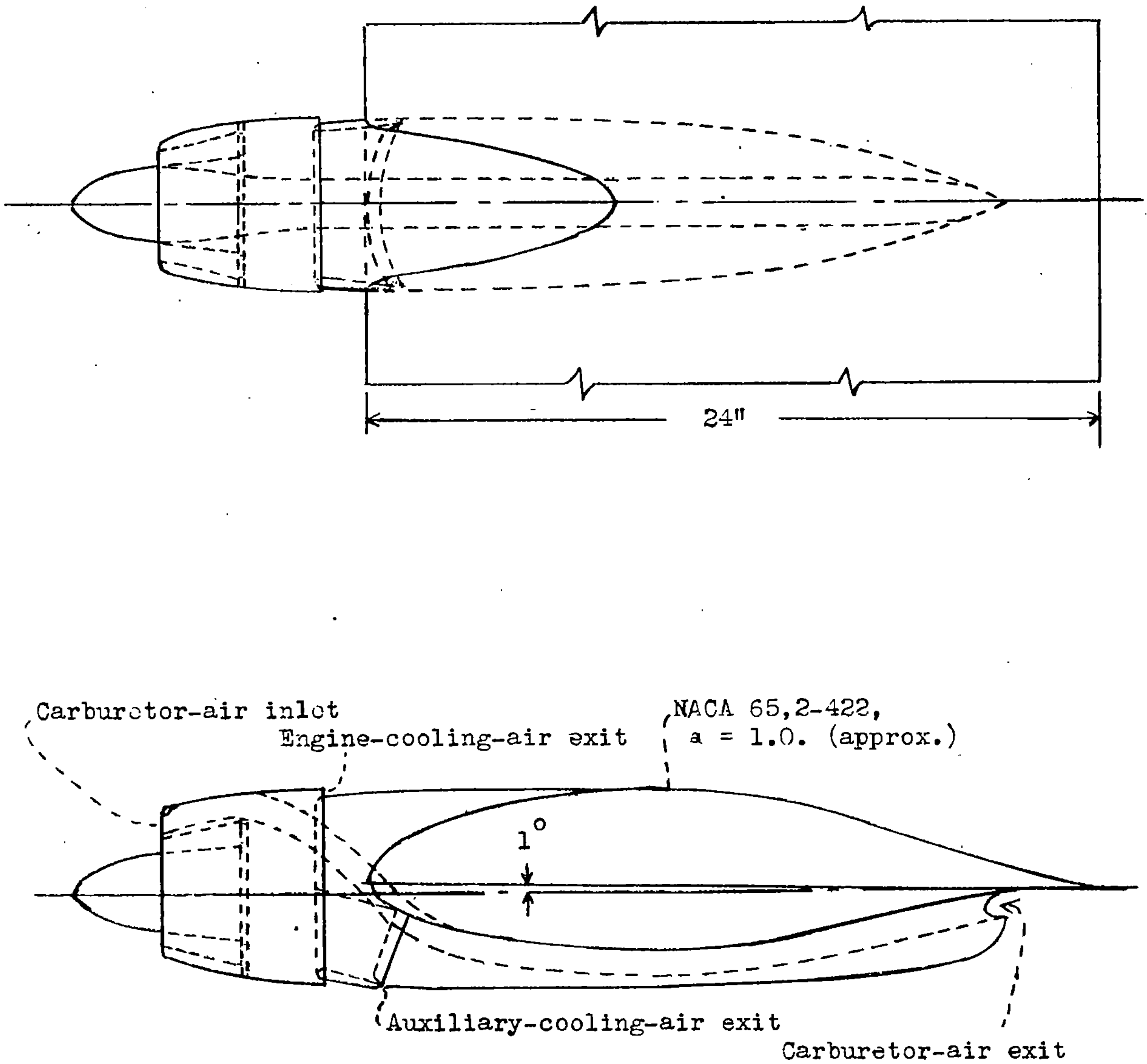

Figure 1.- Nacelle-wing combination showing details of internal air flow.

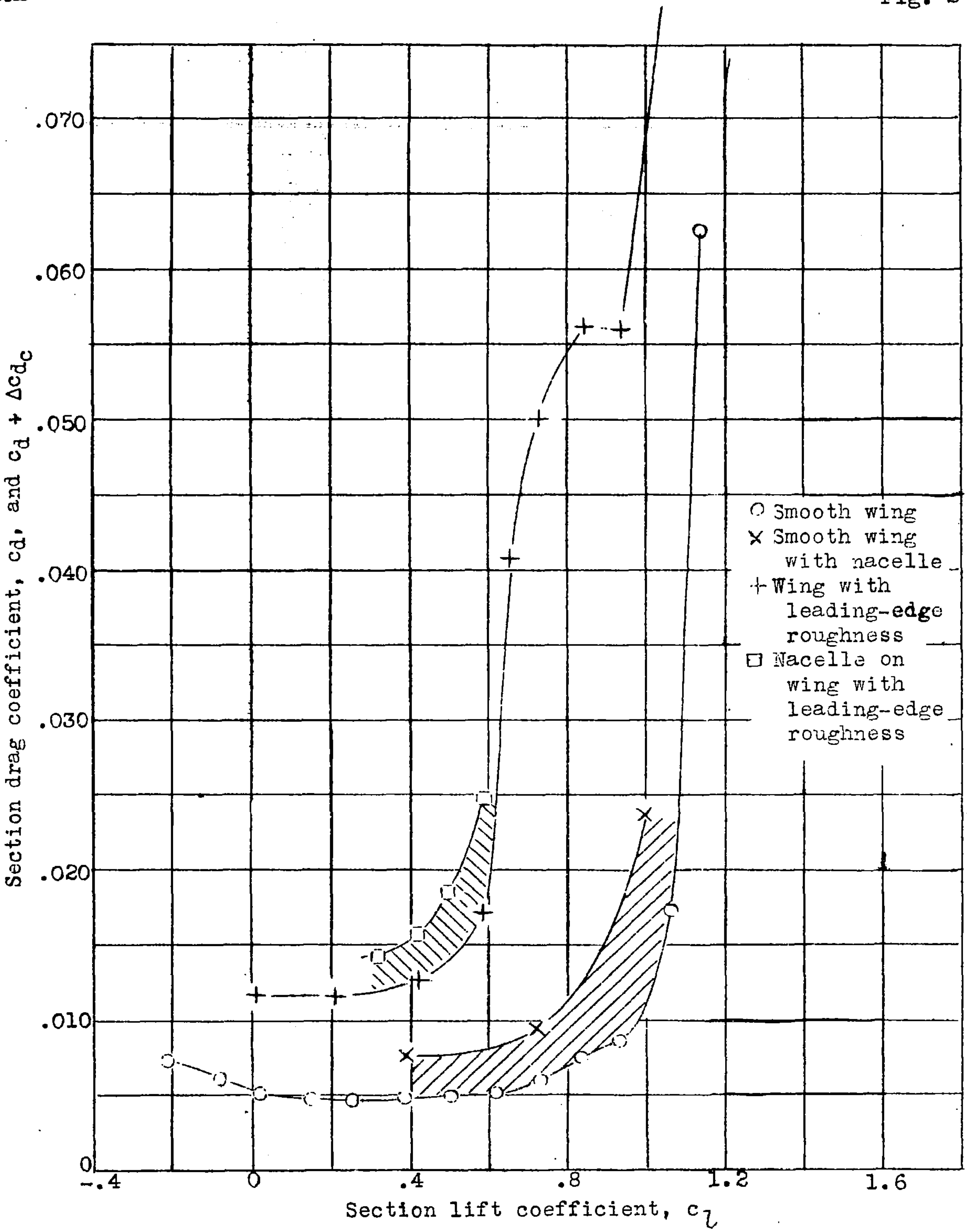

Figure 2.- Comparison of drag-coefficient increments of nacelle. R_{wing}, 6×10^6.

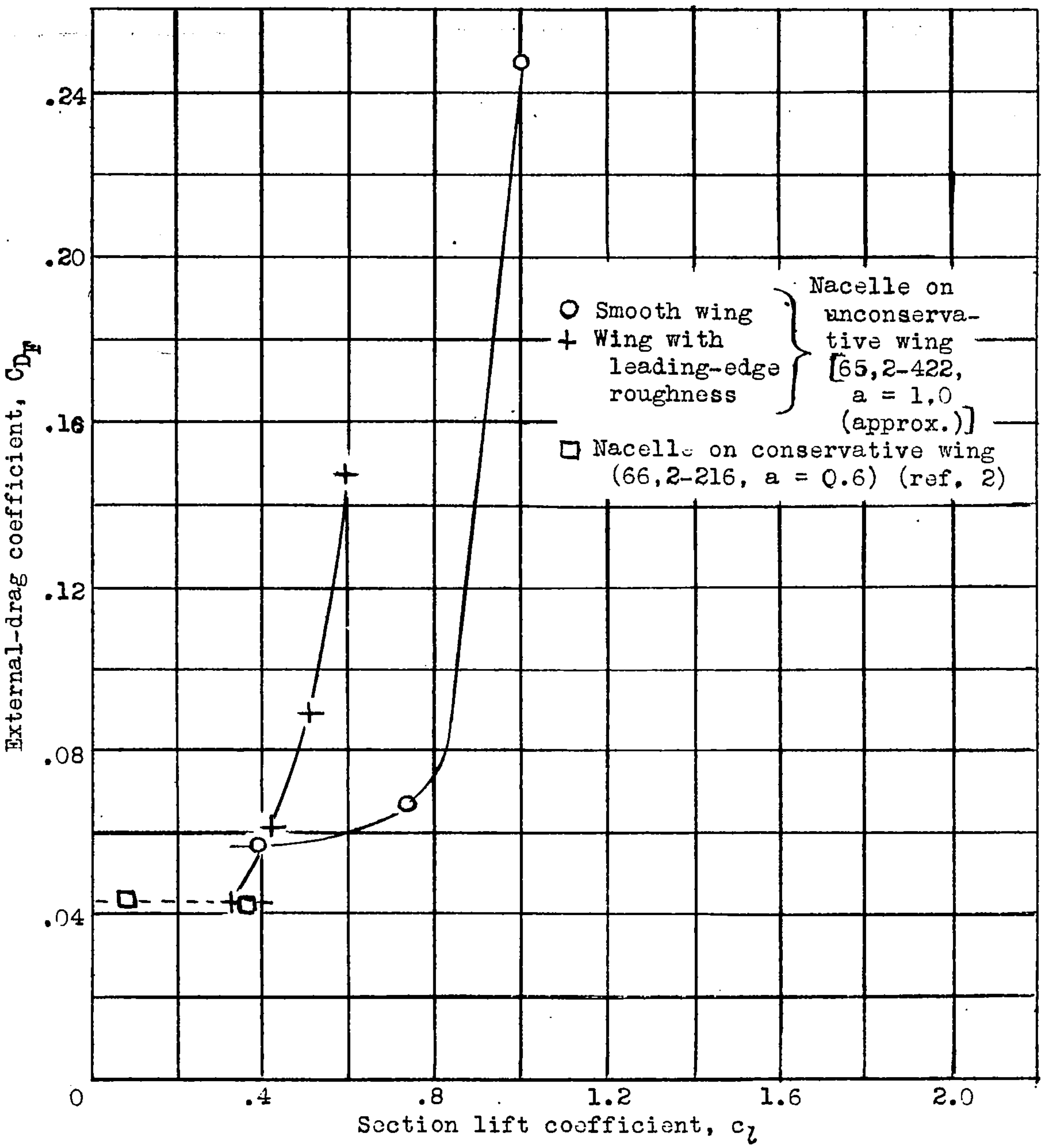

Figure 3.- Comparison of nacelle external-drag coefficients. R_{wing}, 6×10^6.

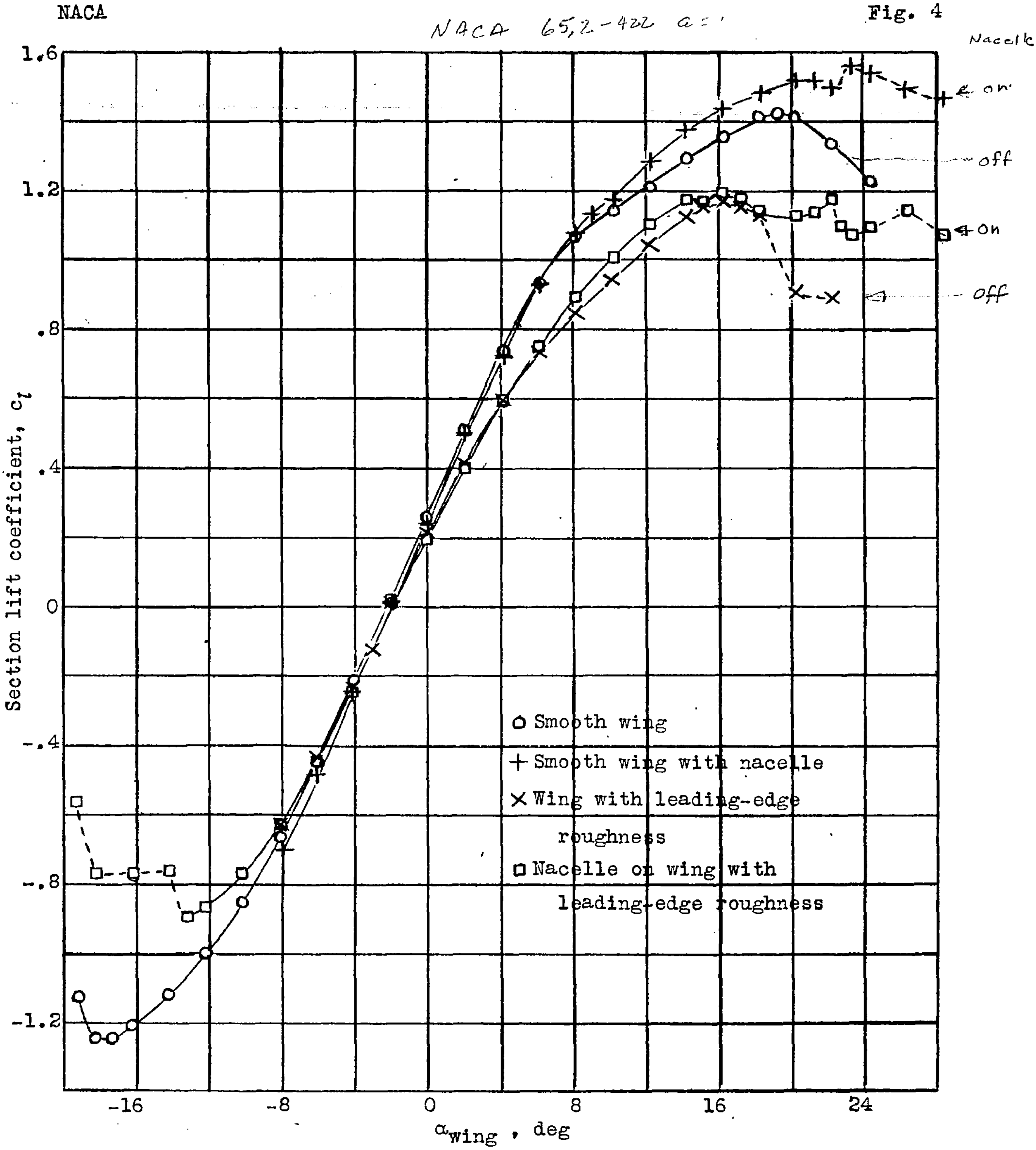

Figure 4.- Comparison of section lift coefficients of wing with and without nacelle. R_{wing}, 6×10^6.