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MEMORANDUM REPORT

for the

Air Technical Service Command, Army Air Forces

AERODYNAMIC CHARACTERISTICS OF FOUR REPUBLIC AIRFOIL SECTIONS FROM TESTS IN LANGLEY TWO-DIMENSIONAL LOW-TURBULENCE TUNNELS

By Milton M. Klein

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Suitable for deposit

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SUMMARY

Four airfoils sections, designed by the Republic Aviation Corporation for the root and tip sections of the XF-12 airplane, were tested in the Langley two-dimensional low-turbulence tunnels to obtain their aerodynamic characteristics. Lift characteristics were obtained at Reynolds numbers of 3,000,000, 6,000,000, 9,000,000, and 14,000,000, whereas drag characteristics were obtained at Reynolds numbers of 3,000,000, 6,000,000, and 9,000,000. Pressure distributions were obtained for one of the root sections for several angles of attack at a Reynolds number of 2,600,000.

Comparison of the root section that appeared best from the tests with the corresponding NACA 65-series section shows the Republic section has a higher maximum lift and higher calculated critical speeds, but a higher minimum drag. In addition, with standard roughness applied to the leading edge, the maximum lift of the Republic airfoil is lower than that of the NACA airfoil.

Comparison of the Republic tip section with the corresponding NACA 65-series section shows the Republic airfoil has a lower maximum lift and a higher minimum drag than the NACA airfoil. The calculated critical speeds of the Republic section are slightly higher than those of the NACA section.

INTRODUCTION

At the request of the Army Air Service Technical Command, tests were made to obtain the aerodynamic characteristics of four airfoil sections designed by the Republic Aviation Corporation for the XF-12 airplane. The airfoils, which had thickness ratios of 13 and 18 percent, corresponding to the tip and root sections of the wing, were designed to have moderate extents of laminar flow. The lift and drag characteristics were obtained by tests conducted in the Langley two-dimensional low-turbulence pressure tunnel (TDT). One of the 18-percent thick airfoils was tested in the Langley two-dimensional low-turbulence tunnel (LTT) to obtain pressure distributions at several angles of attack.

SYMBOLS

a	fraction of chord for which mean line loading is constant
c_l	section lift coefficient (l/qc)
$c_{l_{max}}$	maximum section lift coefficient
c_d	section drag coefficient (d/qc)
$c_{d_{min}}$	minimum section drag coefficient
S	low-speed pressure coefficient $\left(\frac{H - p}{q}\right)$
l	lift per unit span
d	drag per unit span
c	airfoil chord
H	free-stream total pressure
p	local static pressure
q	free-stream dynamic pressure
M_{cr}	critical Mach number

R Reynolds number

α_o section angle of attack, degrees

MODELS AND TESTS

The models, submitted by the Republic Aviation Corporation, were of laminated wood construction and had a chord length of 24 inches. The models were designated as follows: R-4,40-413-.6; R-4,40-218-1; R-4,40-318-1; R-4,50-418-1. In this designation the symbols have the following meaning:

R	Republic Aviation Corporation
first digit	family of airfoil
next two digits	location of maximum thickness of airfoil in percent chord
next digit	design c_l
next two digits	maximum thickness of airfoil
last digit	value of a for mean line of airfoil

Ordinates for these airfoils, supplied by the manufacturer, are presented in tables I through IV. The method of testing was the same as that described in reference 1 for 2-foot chord models in the TDT.

Lift data were obtained at Reynolds numbers of 3,000,000, 6,000,000, 9,000,000 and 14,000,000 and drag data at 3,000,000, 6,000,000, and 9,000,000. Lift and drag with standard roughness applied to the leading edge (reference 1) were obtained at a Reynolds number of 6×10^6. In addition, pressure distributions were obtained for the R-4,40-318-1 at a Reynolds number of 2.6×10^6, for angles of attack of -1.02°, 0°, and 2.03°. The highest Mach number encountered during the tests was less than 0.16; therefore, the results may be considered free of compressibility effects.

Corrections for wind-tunnel wall interference were made by the following equations where the primed quantities represent the angles of attack and aerodynamic coefficients uncorrected for tunnel wall effects:

$$\alpha_o = 1.015\,\alpha_o' \tag{1}$$

$$c_d = (1 - 0.034\Lambda)\,c_d' \tag{2}$$

$$c_l = (0.985 - 0.034\Lambda)\,c_l' \tag{3}$$

$$S = (1 - 0.034\Lambda)\,S' \tag{4}$$

The value of the correction factor Λ to be used in the above equations is given in the following table:

Model	Λ
R-4,40-413-.6	0.241
R-4,40-218-1	.343
R-4,40-318-1	.343
R-4,50-418-1	.395

Examination of equations (1) through (4) shows that the corrections are of the order of only a few percent. An explanation of the tunnel wall corrections applied to data obtained from the Langley two-dimensional tunnels is given in the appendix of reference 1.

RESULTS AND DISCUSSION

The lift and drag characteristics of the four airfoils are presented in figures 1 through 4. Pressure distributions for the R-4,40-318-1 are presented in figures 5 through 7 for several angles of attack. The 13 percent section (R-4,40-413-.6), designed for the tip section, has a high maximum lift and a low minimum drag relative to airfoils of comparable shape and thickness, and a range of c_l of 0.2 for low-drag at a Reynolds number of 9×10^6 (fig. 1); it may therefore be considered satisfactory. Although the R-4,50-418-1 airfoil section, which was one of the 3 airfoils designed for the root section, has a moderate maximum lift and a low minimum drag, it also has a very narrow low-drag range and shows an extremely rapid increase in drag for positive lifts outside the low-drag range (fig. 4). This airfoil is therefore considered unsatisfactory for the root section. The two alternate 18 percent sections, R-4,40-218-1 (fig. 2) and R-4,40-318-1 (fig. 3) have minimum drags somewhat greater than the minimum drag of the R-4,50-418-1. However, they have a greater range of c_l for low drag and show only a moderate increase in drag for positive lifts outside the low-drag range. While the two alternate sections have approximately the same drag characteristics, the maximum lift of the R-4,40-318-1 was greater than that of the R-4,40-218-1. On this basis the R-4,40-318-1 appears to be the best choice for the root section.

The Republic sections have pressure distributions somewhat similar to the NACA 65 series. A comparison has therefore been made of the aerodynamic characteristics of the R-4,40-413-.6 and R-4,40-318-1 with those of the corresponding NACA 65-series airfoil sections in the following table:

Airfoil section	$c_{l_{max}}$ $R = 9 \times 10^6$	$c_{d_{min}}$ $R = 9 \times 10^6$	$c_{l_{max}}$ for standard roughness $R = 6 \times 10^6$
R-4,40-413-.6	1.59	0.0047	1.18
NACA 65_1-413	1.63	.0039	1.30
R-4,40-318-1	1.59	.0049	1.13
NACA 65_3-318	1.53	.0042	1.17

The values for the NACA sections have been obtained by interpolation of the values given in reference 1 to the proper camber and thickness.

In addition, a comparison of the theoretical critical speed curves of the R-4,40-413-.6 and R-4,40-318-1 and the corresponding NACA 65-series sections has been made in figures 8 and 9, where critical Mach number is plotted against low-speed lift coefficient. The critical speeds for the Republic sections were obtained by calculating their theoretical pressure distributions for various lift coefficients; the critical Mach number corresponding to the maximum value of S in each pressure distribution was then obtained from the plot of critical Mach number against low-speed pressure coefficient as given in reference 1. The critical-speed curves for the NACA sections were obtained by interpolation of the critical-speed data for the NACA 65 series as given in reference 1. Critical-speed values for the R-4,40-318-1 obtained from the experimental pressure distributions (figs. 5, 6, and 7) have been spotted on figure 9. Good agreement with the theoretical values may be observed.

Comparison of the characteristics of the Republic and NACA sections shows that, for a thickness ratio of 13 percent, the NACA airfoil has a higher maximum lift with and without standard roughness and a lower minimum drag than the Republic section. The critical speed values are approximately the same except at higher lifts where the critical speeds of the NACA airfoil are lower than those of the Republic airfoil. For a thickness ratio of 18 percent, the Republic section has higher critical speeds and maximum lift but a somewhat lower maximum lift with standard roughness and a higher minimum drag. These results indicate that the Republic R-4,40-318-1 and NACA 65_3-318 airfoil sections are equally suitable for use as the root section of the XF-12 airplane; however, the NACA 65_1-413 appears to be more suitable than the Republic R-4,40-413-.6 for the tip section.

CONCLUDING REMARKS

1. The Republic 13-percent airfoil R-4,40-413-.6 has a lower maximum lift and a higher minimum drag than the NACA 65 section 65_1-413; the calculated critical speeds of the Republic section are approximately the same as those of the NACA section except at the higher lifts where the Republic section has slightly higher critical speeds than the NACA section.

2. The Republic 18-percent airfoil R-4,40-318-1 has a higher maximum lift and higher calculated critical speeds than the NACA section 65_3-318, but a somewhat higher minimum drag. With standard roughness applied to

the leading edge the maximum lift of the Republic section is lower than that of the NACA section.

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Approved:

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EMJ

REFERENCES

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

TABLE I.- ORDINATES FOR THE REPUBLIC R-4,40-413-.6 AIRFOIL SECTION

Stations and ordinates given in percent of airfoil chord

Upper Surface		Lower Surface	
Station	Ordinate	Station	Ordinate
0.50	1.408	0.50	0.709
.75	1.667	.75	.888
1.25	2.095	1.25	1.175
2.50	2.924	2.50	1.646
5.00	4.120	5.00	2.231
7.50	5.019	7.50	2.609
10.00	5.771	10.00	2.869
15.00	6.930	15.00	3.238
20.00	7.818	20.00	3.459
25.00	8.467	25.00	3.606
30.00	8.938	30.00	3.654
35.00	9.247	35.00	3.654
40.00	9.399	40.00	3.606
45.00	9.399	45.00	3.503
50.00	9.242	50.00	3.346
55.00	8.922	55.00	3.140
60.00	8.429	60.00	2.896
65.00	7.736	65.00	2.653
70.00	6.886	70.00	2.398
75.00	5.879	75.00	2.101
80.00	4.791	80.00	1.765
85.00	3.638	85.00	1.402
90.00	2.436	90.00	1.002
95.00	1.245	95.00	.563
100.00	.039	100.00	.039

L. E. radius: 1.143
Slope: 0.21297

TABLE II.- ORDINATES FOR THE REPUBLIC R-4,40-218-1 AIRFOIL SECTION

Stations and ordinates given in percent of airfoil chord

Upper Surface		Lower Surface	
Station	Ordinate	Station	Ordinate
0.50	1.600	0.50	1.220
.75	1.954	.75	1.510
1.25	2.495	1.25	1.970
2.50	3.460	2.50	2.810
5.00	4.770	5.00	3.935
7.50	5.740	7.50	4.765
10.00	6.520	10.00	5.390
15.00	7.725	15.00	6.325
20.00	8.610	20.00	6.980
25.00	9.242	25.00	7.430
30.00	9.692	30.00	7.710
35.00	9.965	35.00	7.885
40.00	10.070	40.00	7.925
45.00	10.010	45.00	7.830
50.00	9.805	50.00	7.600
55.00	9.445	55.00	7.245
60.00	8.910	60.00	6.750
65.00	8.230	65.00	6.130
70.00	7.395	70.00	5.395
75.00	6.420	75.00	4.580
80.00	5.325	80.00	3.685
85.00	4.145	85.00	2.742
90.00	2.880	90.00	1.770
95.00	1.500	95.00	.875
100.00	0	100.00	0

L. E. radius: 2.250
Slope: 0.07807

TABLE III.- ORDINATES FOR THE REPUBLIC R-4,40-318-1 AIRFOIL SECTION

Stations and ordinates given in percent of airfoil chord

Upper Surface		Lower Surface	
Station	Ordinate	Station	Ordinate
0.50	1.759	0.50	1.119
.75	2.084	.75	1.412
1.25	2.609	1.25	1.885
2.50	3.595	2.50	2.700
5.00	4.967	5.00	3.768
7.50	5.993	7.50	4.520
10.00	6.813	10.00	5.103
15.00	8.089	15.00	5.972
20.00	9.023	20.00	6.569
25.00	9.707	25.00	6.986
30.00	10.183	30.00	7.248
35.00	10.482	35.00	7.379
40.00	10.609	40.00	7.396
45.00	10.569	45.00	7.281
50.00	10.365	50.00	7.052
55.00	9.991	55.00	6.698
60.00	9.447	60.00	6.220
65.00	8.742	65.00	5.625
70.00	7.883	70.00	4.920
75.00	6.869	75.00	4.129
80.00	5.733	80.00	3.286
85.00	4.494	85.00	2.419
90.00	3.141	90.00	1.534
95.00	1.663	95.00	.677
100.00	.017	100.00	.017

L. E. radius: 0.948
Slope: 0.25484

TABLE IV.- ORDINATES FOR THE REPUBLIC R-4,50-418-1 AIRFOIL SECTION

Stations and ordinates given in percent of airfoil chord

Upper Surface		Lower Surface	
Station	Ordinate	Station	Ordinate
0.50	1.542	0.50	0.928
.75	1.855	.75	1.171
1.25	2.398	1.25	1.555
2.50	3.354	2.50	2.267
5.00	4.713	5.00	3.170
7.50	5.772	7.50	3.805
10.00	6.576	10.00	4.318
15.00	7.850	15.00	5.059
20.00	8.834	20.00	5.574
25.00	9.630	25.00	5.958
30.00	10.239	30.00	6.267
35.00	10.679	35.00	6.482
40.00	10.960	40.00	6.633
45.00	11.159	45.00	6.763
50.00	11.223	50.00	6.801
55.00	11.139	55.00	6.765
60.00	10.886	60.00	6.539
65.00	10.370	65.00	6.184
70.00	9.583	70.00	5.614
75.00	8.495	75.00	4.836
80.00	7.138	80.00	3.822
85.00	5.514	85.00	2.653
90.00	3.756	90.00	1.504
95.00	1.906	95.00	.656
100.00	0	100.00	0

L. E. radius: 1.620
Slope: 0.1689

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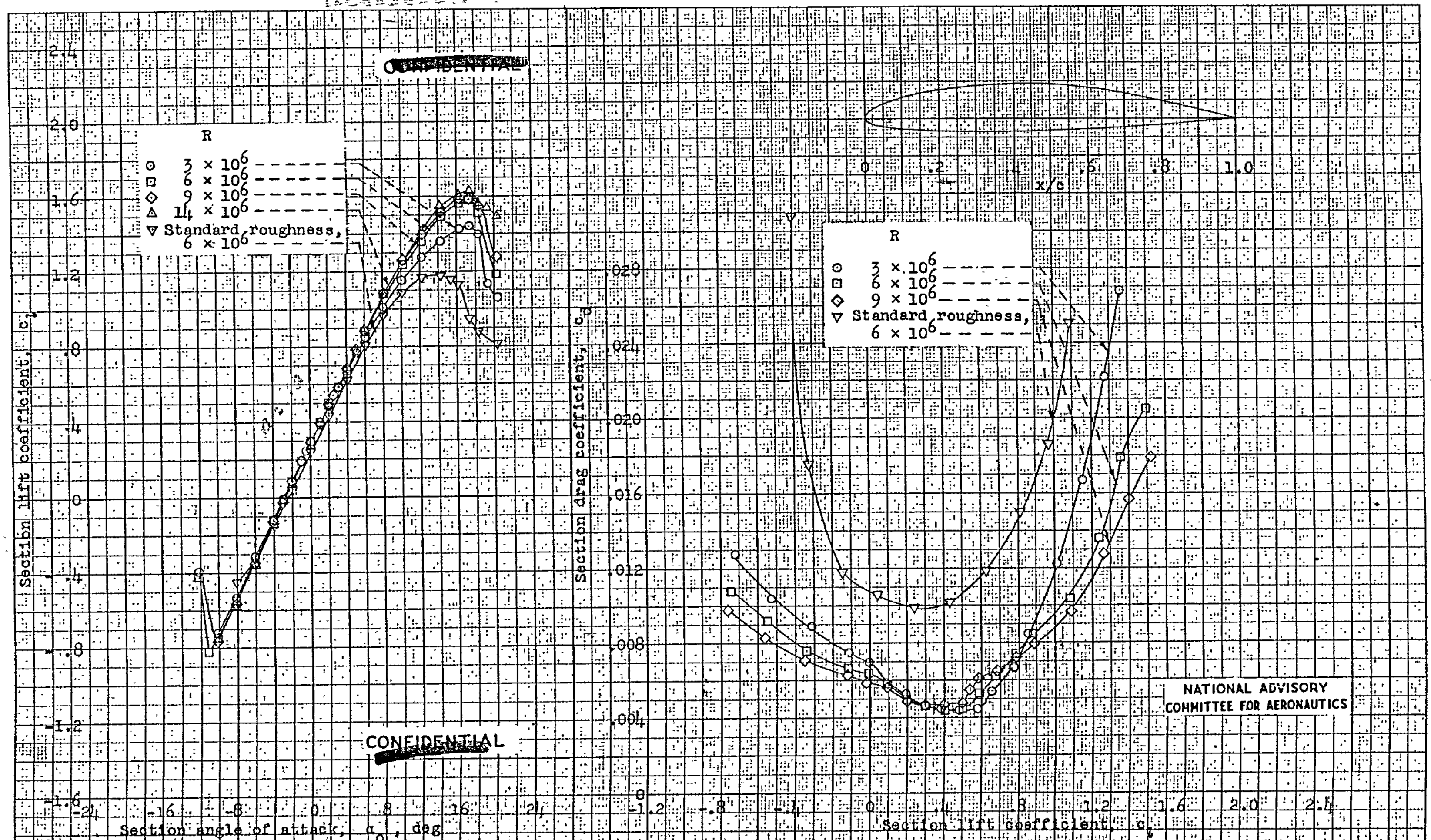

Figure 1.- Section aerodynamic characteristics for the Republic R-4,40-413-.6 airfoil section; TDT test 649.

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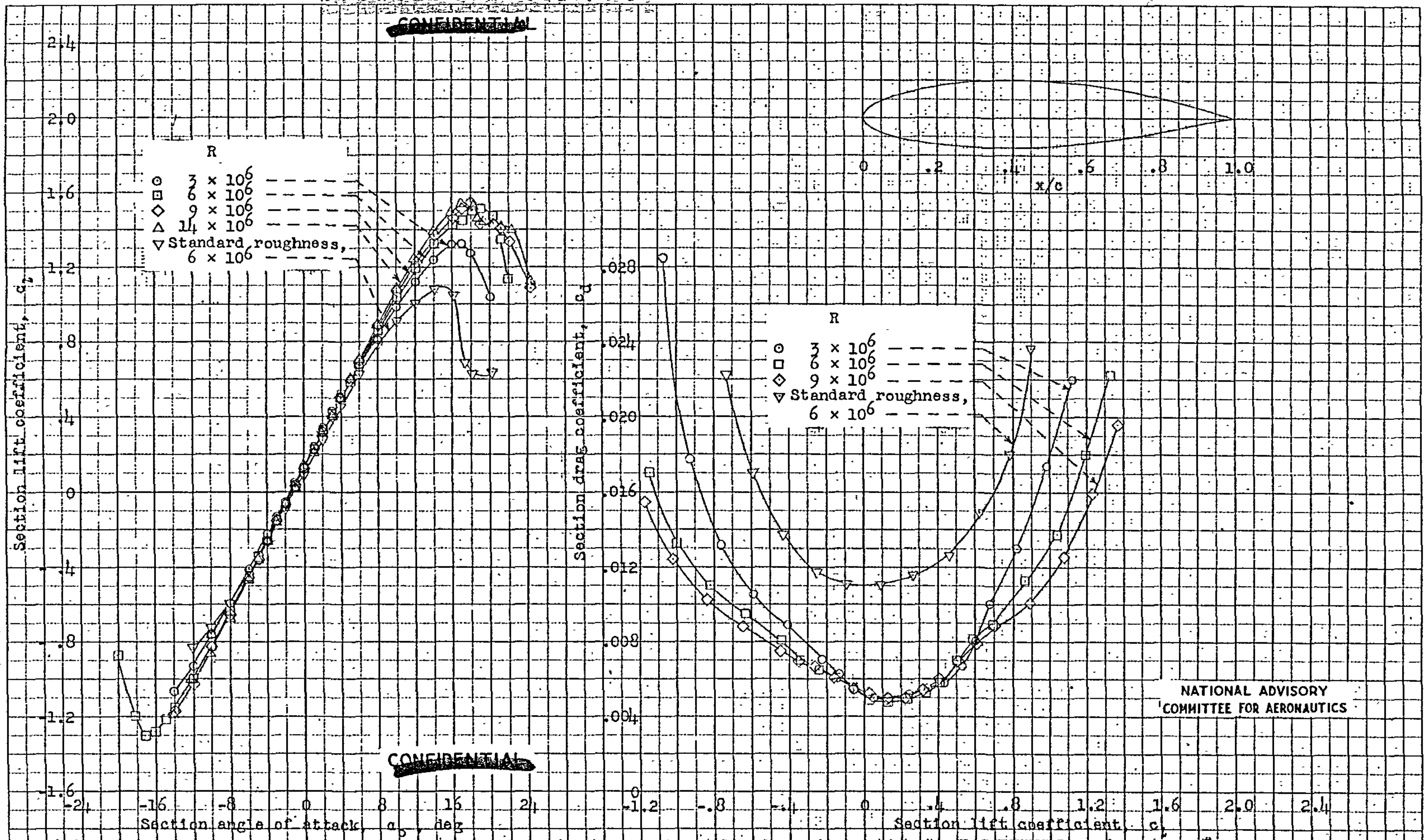

Figure 2.- Section aerodynamic characteristics for the Republic R-4,40-218-1 airfoil section; TDT test 678.

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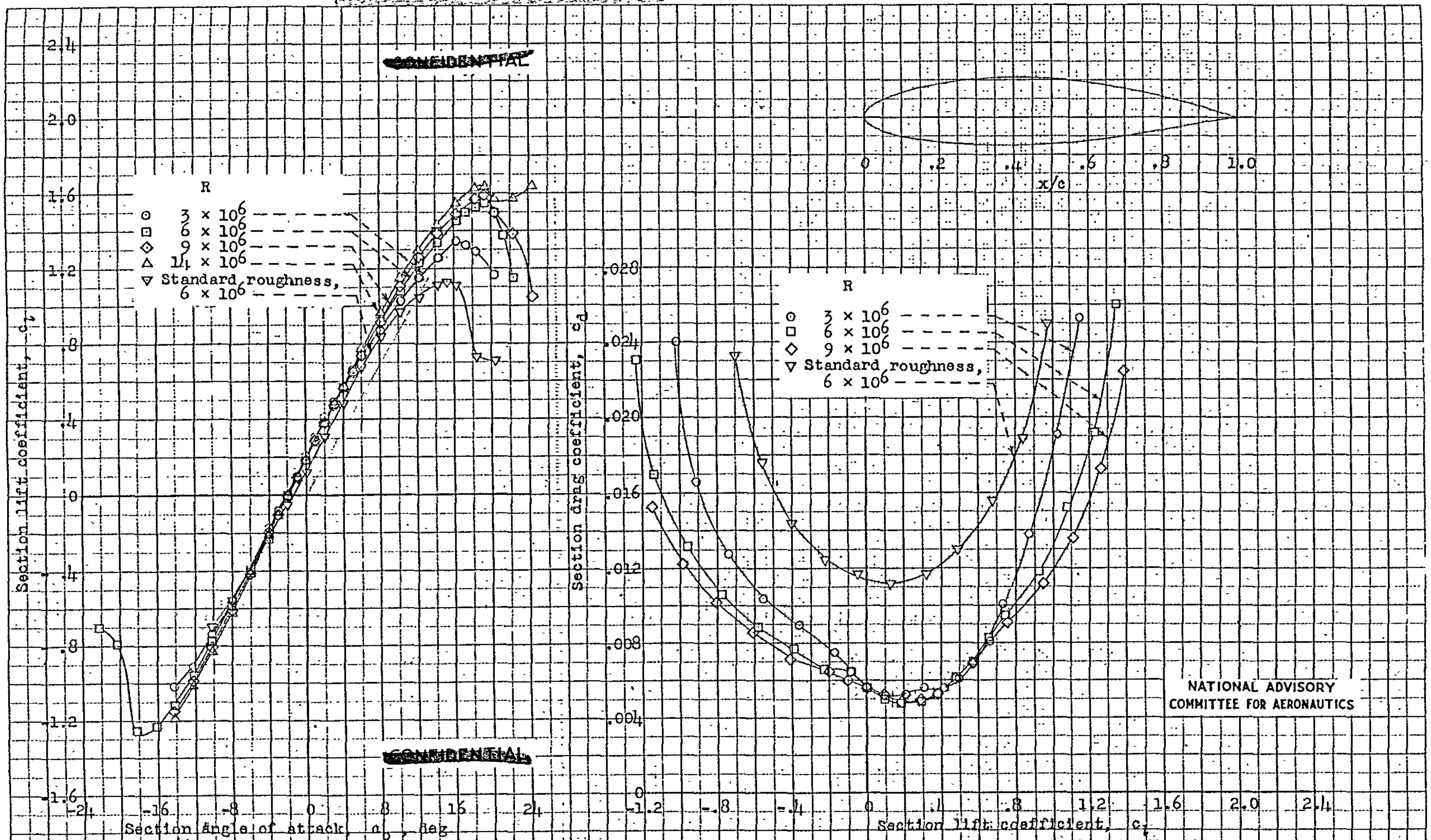

Figure 3.- Section aerodynamic characteristics for the Republic R-4,40-318-1 airfoil section; TDT test 677.

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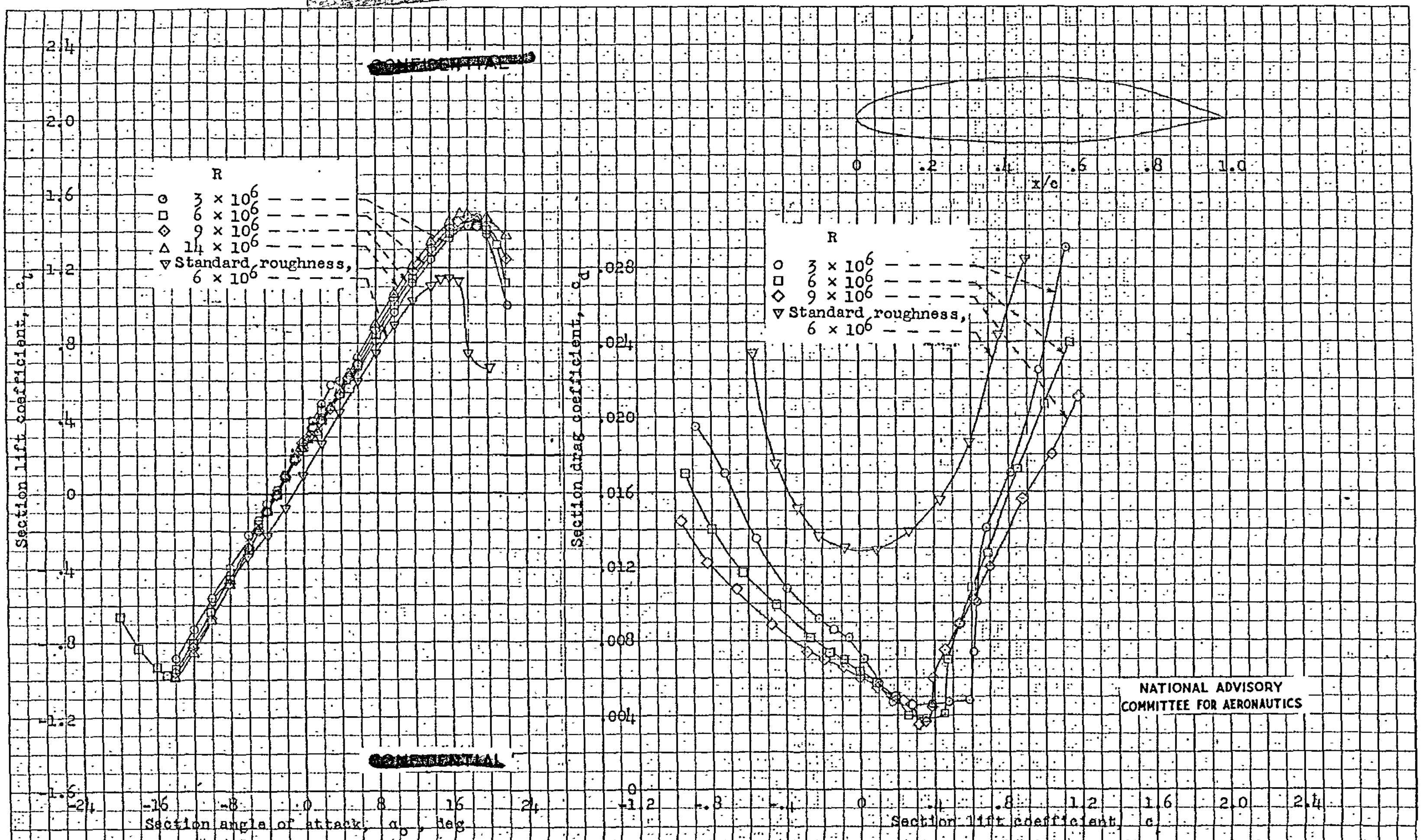


Figure 4.- Section aerodynamic characteristics for the Republic R-4,50-418-1 airfoil section; TDT test 652.

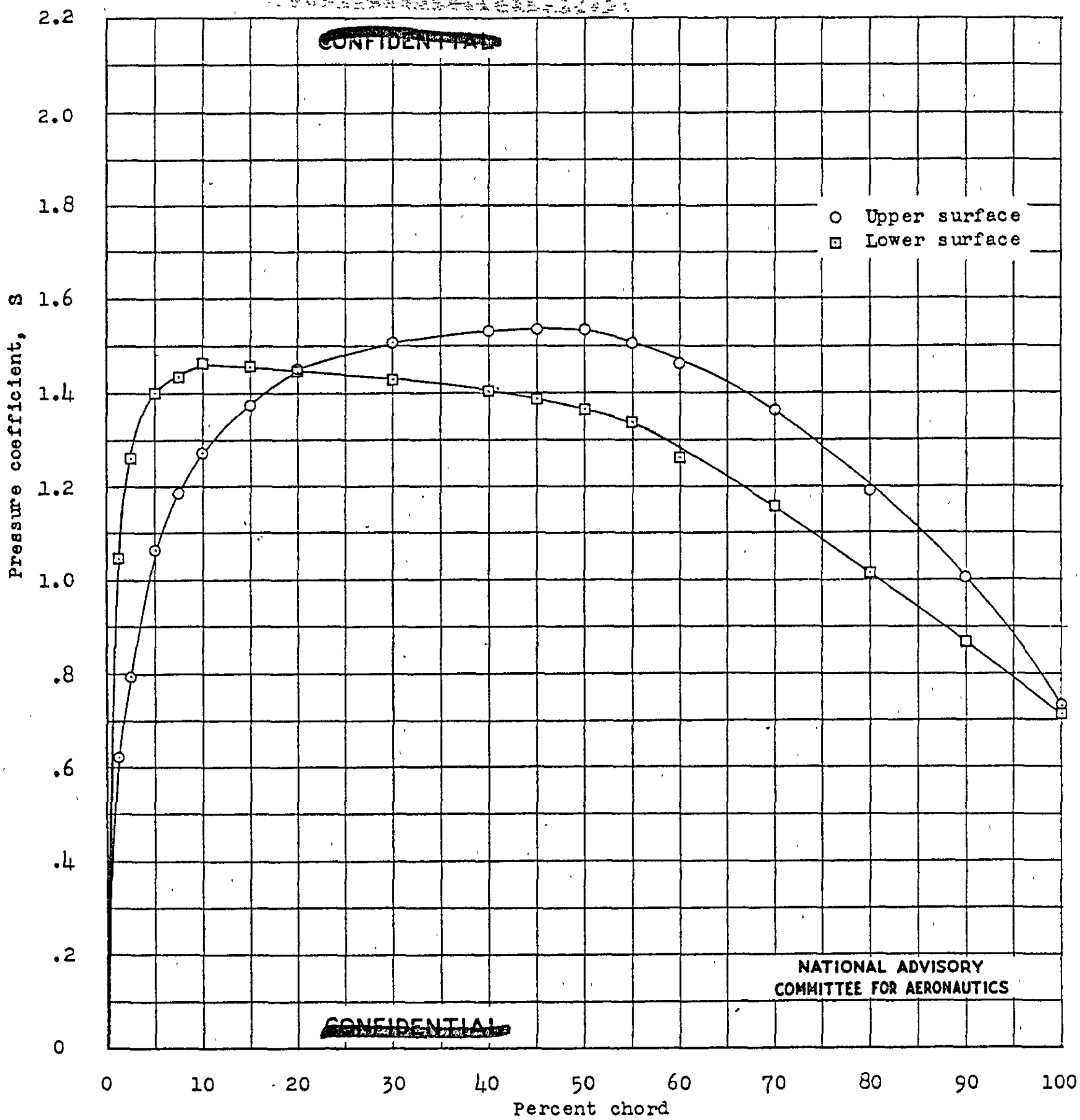


Figure 5.- Pressure distribution for the Republic R-4,40-318-1 airfoil section; LTT test 379; α_0 , -1.02°; R, 2.6×10^6.

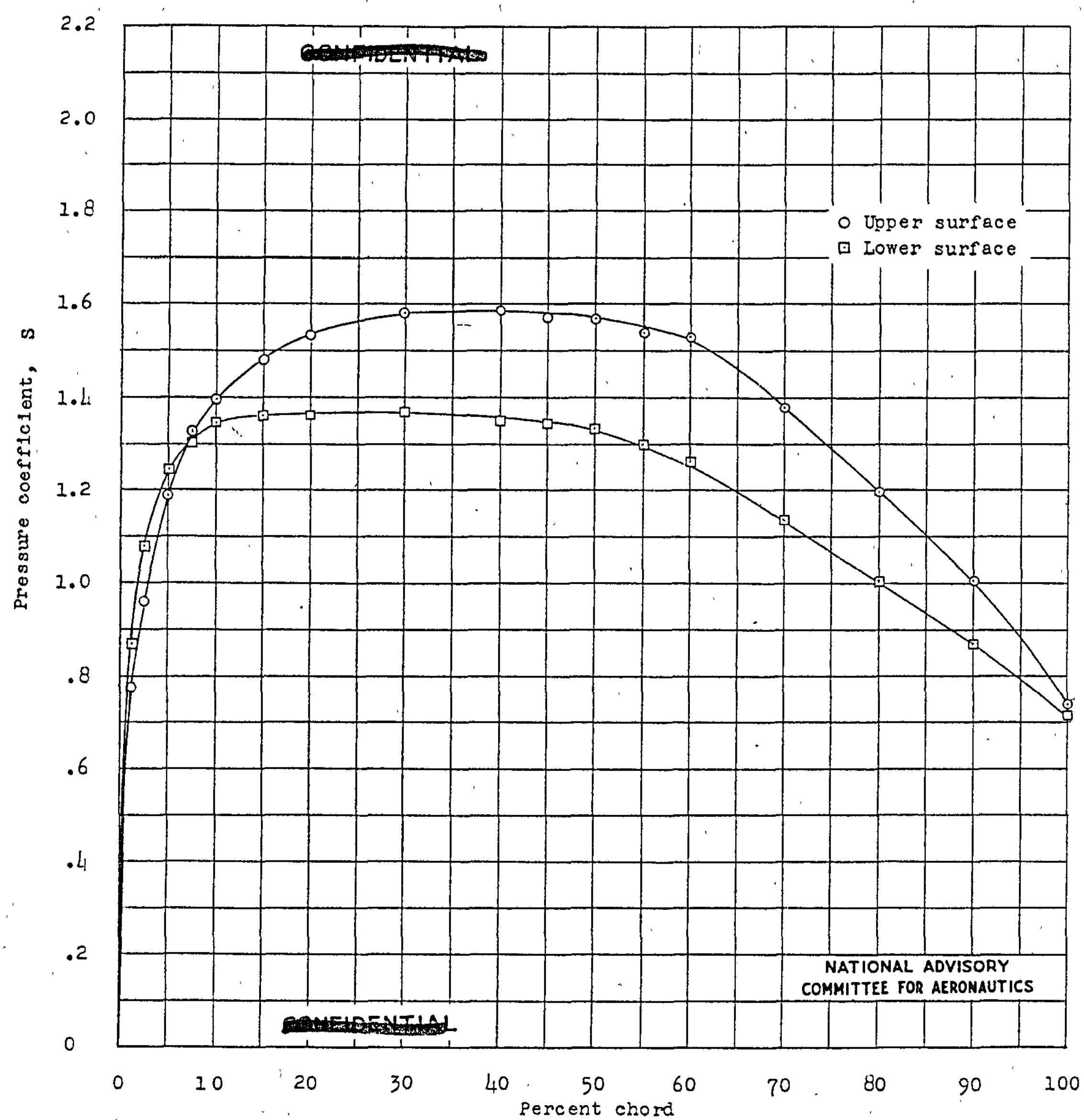


Figure 6.- Pressure distribution for the Republic R-4,40-318-1 airfoil section; LTT test 379; α_o, 0°; R, 2.6×10^6.

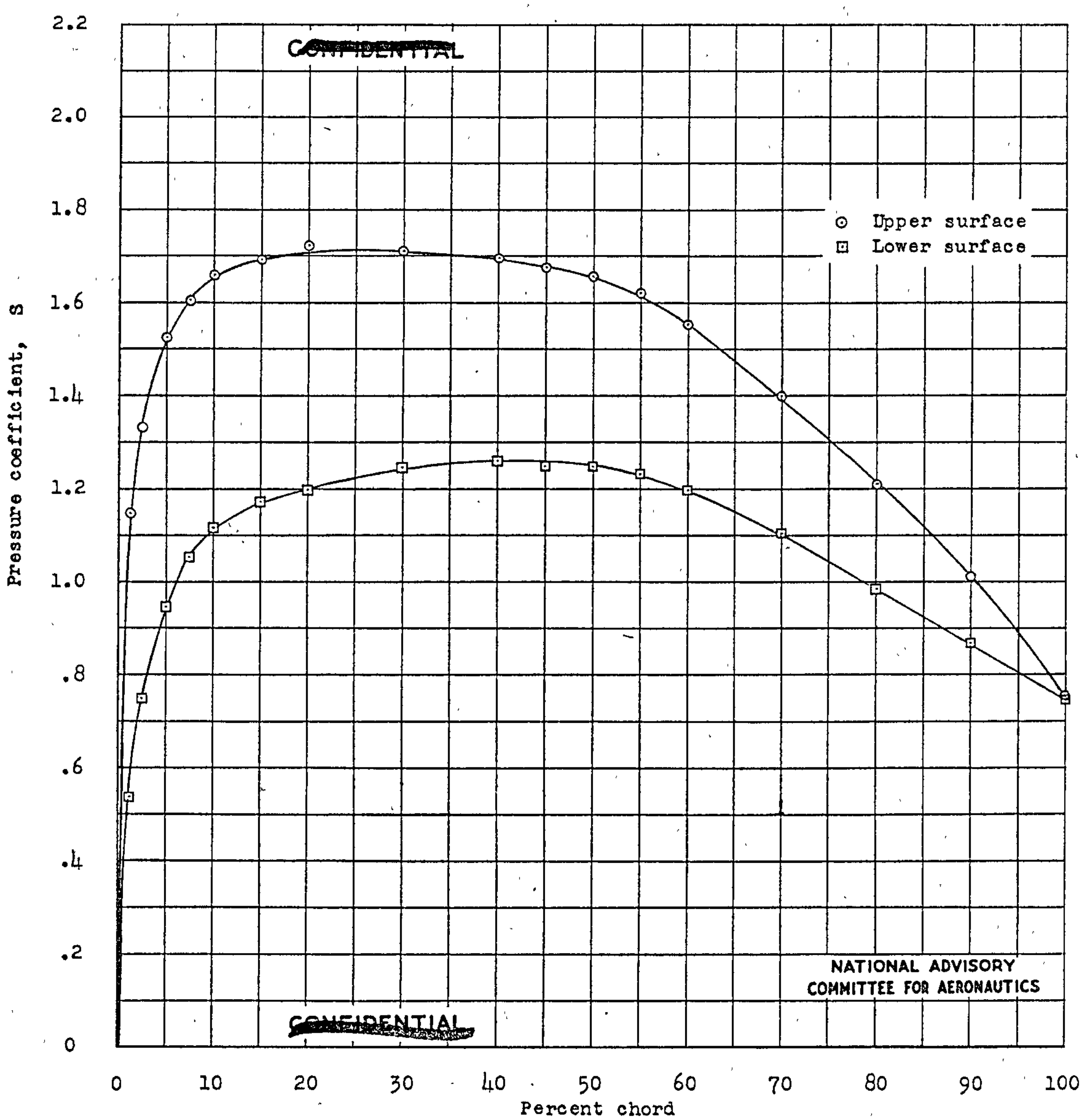
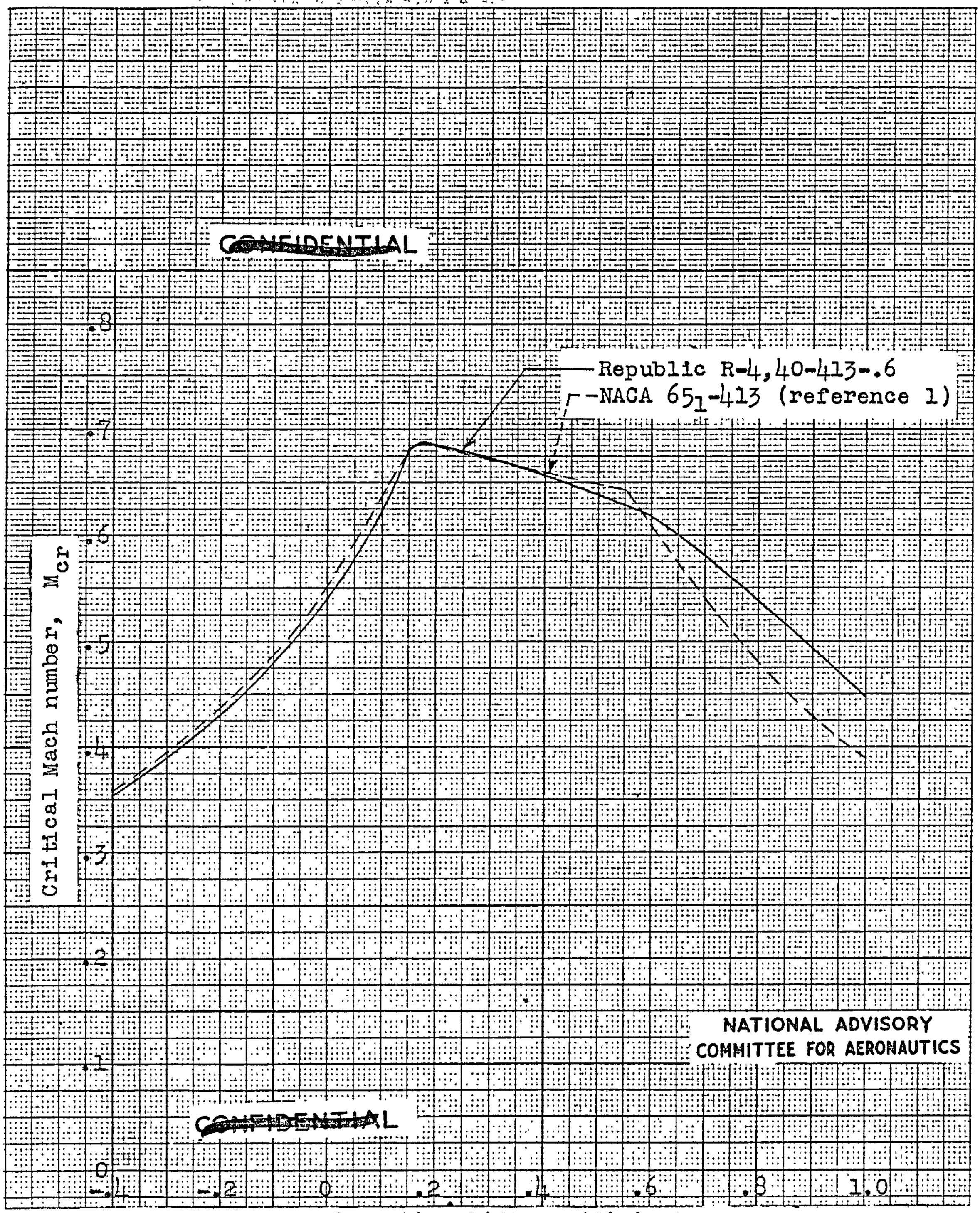
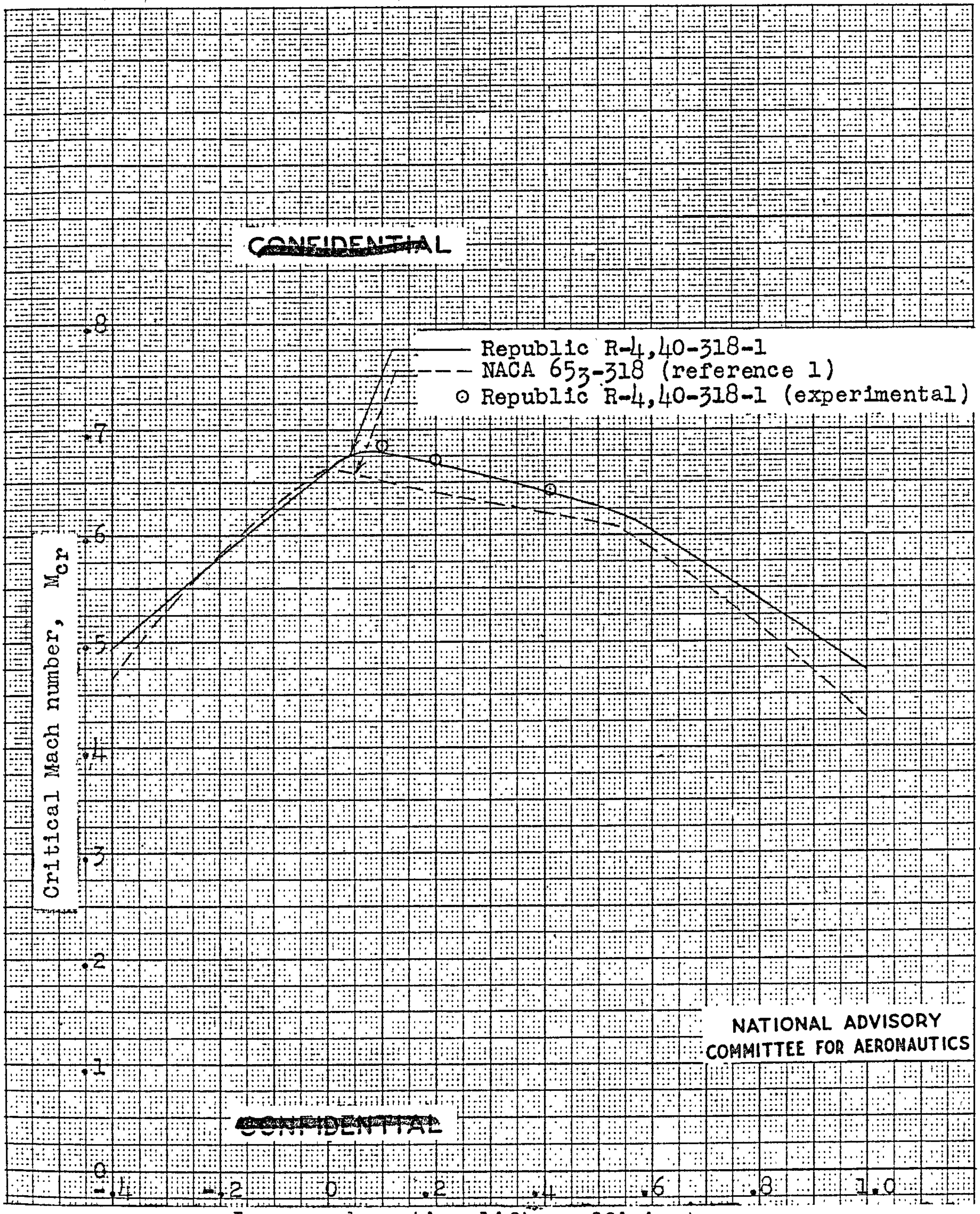


Figure 7.- Pressure distribution for the Republic R-4,40-318-1 airfoil section; LTT test 379; a_o , 2.03°; R, 2.6 × 10^6.



Low-speed section lift coefficient, c_l

Figure 8.- Variation of critical Mach number with low speed section lift coefficient for the Republic R-4,40-413-.6 and the NACA 65_1-413 airfoil sections.



Low-speed section lift coefficient, c_l

Figure 9.- Variation of critical Mach number with low speed section lift coefficient for the Republic R-4,40-318-1 and the NACA 65_3-318 airfoil sections.