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TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 567

TESTS OF N.A.C.A. AIRFOILS IN THE VARIABLE-DENSITY WIND TUNNEL. SERIES 230

By Eastman N. Jacobs and Robert M. Pinkerton
Langley Memorial Aeronautical Laboratory

Washington
May 1936

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TESTS OF N.A.C.A. AIRFOILS IN THE VARIABLE-DENSITY WIND TUNNEL. SERIES 230

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SUMMARY

The results of tests of six airfoils having the N.A.C.A. 230 mean line and varying in thickness from 0.06c to 0.21c are presented. These results agree with previous findings in showing that aerodynamically the best section is one of moderate thickness. The data are of value mainly in connection with the design of tapered wings having sections based on the N.A.C.A. 230 mean line.

INTRODUCTION

An extensive investigation of a large number of related airfoil sections made in the N.A.C.A. variable-density wind tunnel (reference 1) indicated that the increase in maximum lift with increasing camber was more rapid as the maximum camber was moved forward from a point near the 0.3c position. Later, in order further to investigate airfoils of this type, another series of related airfoils was developed (reference 2) having mean-line shapes derived to permit a forward extension of the maximum-camber position. All these sections were of the same thickness (12 percent c) but the maximum-camber position varied from 0.25c to 0.05c behind the leading edge. These tests, and also some additional tests (unpublished) indicated that airfoils with a range of camber positions forward of the normal positions possessed improved characteristics. One of the best of these, the N.A.C.A. 23012 having the maximum camber at 0.15c behind the leading edge, was chosen as representative of this group of improved airfoils.

This new airfoil section was first announced at the ninth annual Aircraft Engineering Research Conference in May 1934. Because of the marked interest in the new section, tests of a 6- by 36-foot model of the N.A.C.A. 23012 airfoil were made in the N.A.C.A. full-scale tunnel to verify the characteristics found for the airfoil in the variable-density tunnel. (See reference 3.) The full-scale tests verified the excellent characteristics of the new section.

The present paper has been prepared to satisfy a demand for data on the N.A.C.A. 230 series of airfoils of varying thickness. Several requests for such data have been received, particularly for use in the design of tapered wings based on the N.A.C.A. 230 mean line. Results of tests of the following six airfoils based on the 230 mean line and varying in thickness from 0.06c to 0.21c are presented herein:

N.A.C.A. 23006

N.A.C.A. 23009

N.A.C.A. 23012

N.A.C.A. 23015

N.A.C.A. 23018

N.A.C.A. 23021

APPARATUS AND TESTS

The test consisted of routine measurements of lift, drag, and pitching moment for standard 5- by 30-inch metal airfoil models at a test Reynolds Number of 3,000,000 in the N.A.C.A. variable-density wind tunnel. The test procedure and accuracy are the same as those discussed in references 2 and 3.

RESULTS AND DISCUSSION

The data are presented in a manner that is a slight modification of the standard graphic form. (See figs. 1 to 6.) The data in the left-hand portion of the plot give the airfoil profile, the table of ordinates, and the aerodynamic characteristics in the usual standard form for rectangular airfoils of aspect ratio 6. Included also is a portion of the lift curve in the neighborhood of maximum lift obtained at a reduced Reynolds Number. These additional data are made available as an indication of the scale effect on maximum lift and are more nearly applicable than the data obtained at the high Reynolds Number to the prediction of landing speeds for airplanes of moderate size.

The right-hand portion of the plot presents the air-foil-section data in a form slightly different from that heretofore employed (reference 1). The effects of turbulence are included by presenting these data corrected to the effective Reynolds Number (reference 3). The value of the effective Reynolds Number at which the data are applicable to flight is indicated on each figure. There has been applied a correction for tip effects, which has previously been used in tabulating important section data but not in graphic presentations of the section characteristics.

The values employed in this report in making corrections for the effect of turbulence are tentative and may be slightly revised as the result of further tests.

In order to distinguish these more accurate section data from those previously presented, new symbols have been adopted, thus:

$$c_{l_o},\quad c_{d_o},\quad c_{m_{a.c.}}$$

instead of the old symbols,

$$C_L,\ C_{D_o},\ C_{m_{c/4}}$$

The lower-case letters represent <u>section</u> characteristics as contrasted with the <u>wing</u> characteristics for which the capital letters are used; the pitching-moment coefficient represents pitching moments about the aerodynamic center of the section rather than about the quarter-chord point. The corresponding aerodynamic-center position is also indicated in each figure.

The above-mentioned tip corrections as applied in deriving these section characteristics result from the fact that section characteristics derived from tests of airfoils having square tips are subject to small corrections necessitated by tip losses. On the assumption that more accurate section characteristics can be obtained from tests of rounded-tip airfoils, the following empirical corrections have been derived from comparative tests of airfoil models with and without rounded tips:

$$C_{L_{max}} = 1.03 \quad C_{L_{max}}'$$

$$a_o = 0.96 \ a_o'$$

$$\alpha_o = \alpha_o' + 0.39 \ C_L$$

$$c_{d_o} = C_{D_o} + 0.0016 \ C_L^2 - 1/3 \ (t - 6) \ 0.0002 \ (t \geqq 6)$$

where the prime symbols refer to the uncorrected values heretofore given and t is the airfoil thickness in percentage of the chord.

In addition to the graphic presentation, the most important characteristics of each section are presented in table I. These tabulated characteristics are corrected for turbulence and tip effects.

The variation of the aerodynamic characteristics with thickness as shown by these data is in agreement with previous findings (reference 1). The angle of zero lift remains practically the same throughout the range of thicknesses tested, while the slope of the lift curve decreases considerably with increasing thickness (table I). The pitching moment about the aerodynamic center is small and decreases in magnitude with increasing thickness; the position of the aerodynamic center is somewhat farther forward for the 18 amd 21 percent thick airfoils than it is for the thinner airfoils. Plots of the lift and drag characteristics are shown in figure 7, which includes, for comparison, the minimum profile drag curve for the N.A.C.A. symmetrical airfoils. The results presented in figure 7, agreeing with reference 1, show that, aerodynamically, the best section is one of moderate thickness.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., November 8, 1935.

REFERENCES

1. Jacobs, Eastman N., Ward, Kenneth E., and Pinkerton, Robert M.: The Characteristics of 78 Related Airfoil Sections from Tests in the Variable-Density Wind Tunnel. T.R. No. 460, N.A.C.A., 1933.

2. Jacobs, Eastman N., and Pinkerton, Robert M.: Tests in the Variable-Density Wind Tunnel of Related Airfoils Having the Maximum Camber Unusually Far Forward. T.R. No. 537, N.A.C.A., 1935.

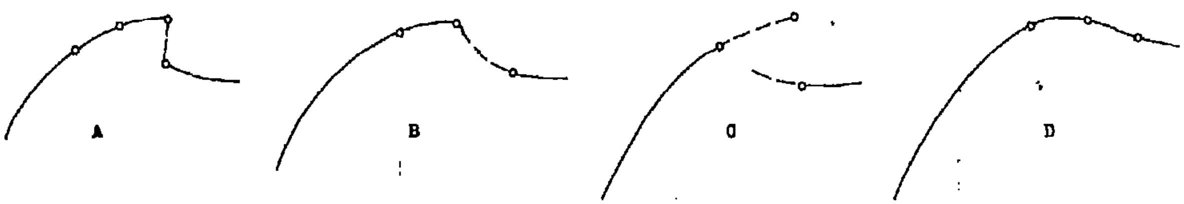
3. Jacobs, Eastman N., and Clay, William C.: Characteristics of the N.A.C.A. 23012 Airfoil from Tests in the Full-Scale and Variable-Density Tunnels. T.R. No. 530, N.A.C.A., 1935.

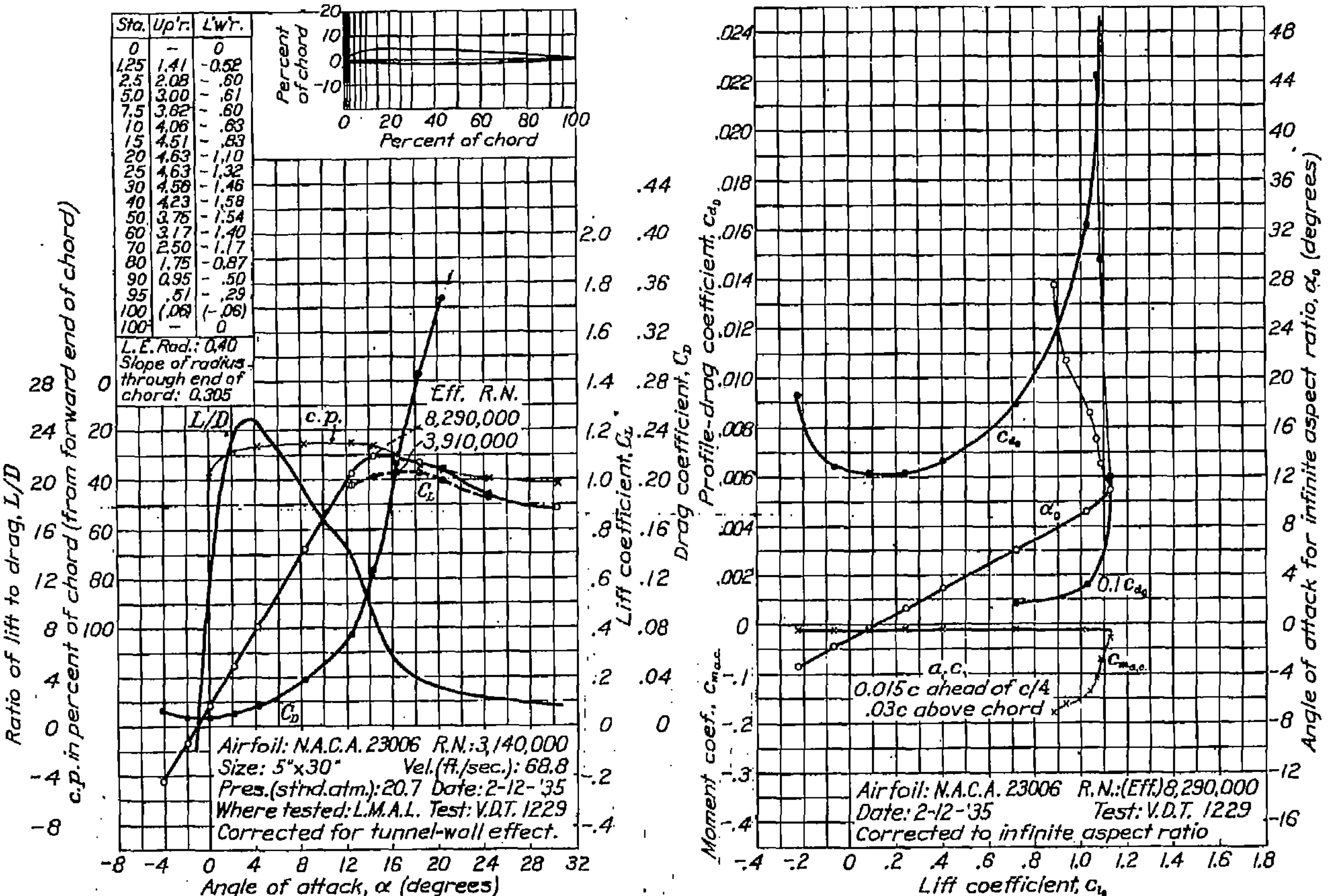
TABLE I

Airfoil Data

Airfoil section	Type[1] of $C_{L_{max}}$	Effective R.N. millions	$C_{L_{max}}$	α_0 at $C_{L_{max}}$ (deg.)	*Fundamental section characteristics*: α_{l_0} (deg.)	a_0 (per deg.)	$c_{l_{opt}}$	$c_{d_{0_{min}}}$	$c_{m_{a.c.}}$	a.c. percent c from c/4: ahead	a.c. percent c from c/4: above	Derived and additional characteristics that may be used for structural design: $C_{L_{max}}/c_{d_{0_{min}}}$	c.p. at $C_{L_{max}}$	Wing characteristics (A.R. 6, round tips): a_6 (per rad.)	Wing characteristics (A.R. 6, round tips): $C_{D_{min}}$	Thickness percent c at – 0.15c	Thickness percent c at – 0.65c	Thickness percent c at – max.	Camber (percent c)
N.A.C.A. 23006	D	8.29	1.13	11	-1.2	0.100	0.15	0.0061	-0.012	1.5	3	185	28	4.38	0.0062	5.34	4.13	6	1.8
N.A.C.A. 23009	A	8.26	1.60	16	-1.1	.099	.08	.0065	-.009	1.4	3	246	25	4.33	.0066	8.02	6.21	9	1.8
N.A.C.A. 23012	A	8.37	1.68	17	-1.1	.099	.10	.0071	-.009	1.6	3	237	25	4.33	.0072	10.69	8.26	12	1.8
N.A.C.A. 23015	A	8.37	1.66	17	-1.1	.098	.10	.0081	-.008	1.6	3	205	24	4.30	.0082	13.38	10.36	15	1.8
N.A.C.A. 23018	B	8.16	1.53	16	-1.2	.097	.08	.0091	-.006	2.3	3	168	24	4.26	.0091	16.04	12.39	18	1.8
N.A.C.A. 23021	B	8.13	1.40	15	-1.2	.092	.07	.0101	-.005	2.8	3	139	24	4.09	.0102	18.70	14.44	21	1.8

[1] Type of lift-curve peak as shown in the sketches:





Sta.	Up'r.	L'w'r.
0	—	0
1.25	1.41	-0.52
2.5	2.08	- .60
5.0	3.00	- .61
7.5	3.62	- .60
10	4.06	- .63
15	4.51	- .83
20	4.63	-1.10
25	4.63	-1.32
30	4.56	-1.46
40	4.23	-1.58
50	3.75	-1.54
60	3.17	-1.40
70	2.50	-1.17
80	1.75	-0.87
90	0.95	- .50
95	.51	- .29
100	(.06)	(-.06)
100	—	0

Figure 1.- N.A.C.A. 23006 airfoil

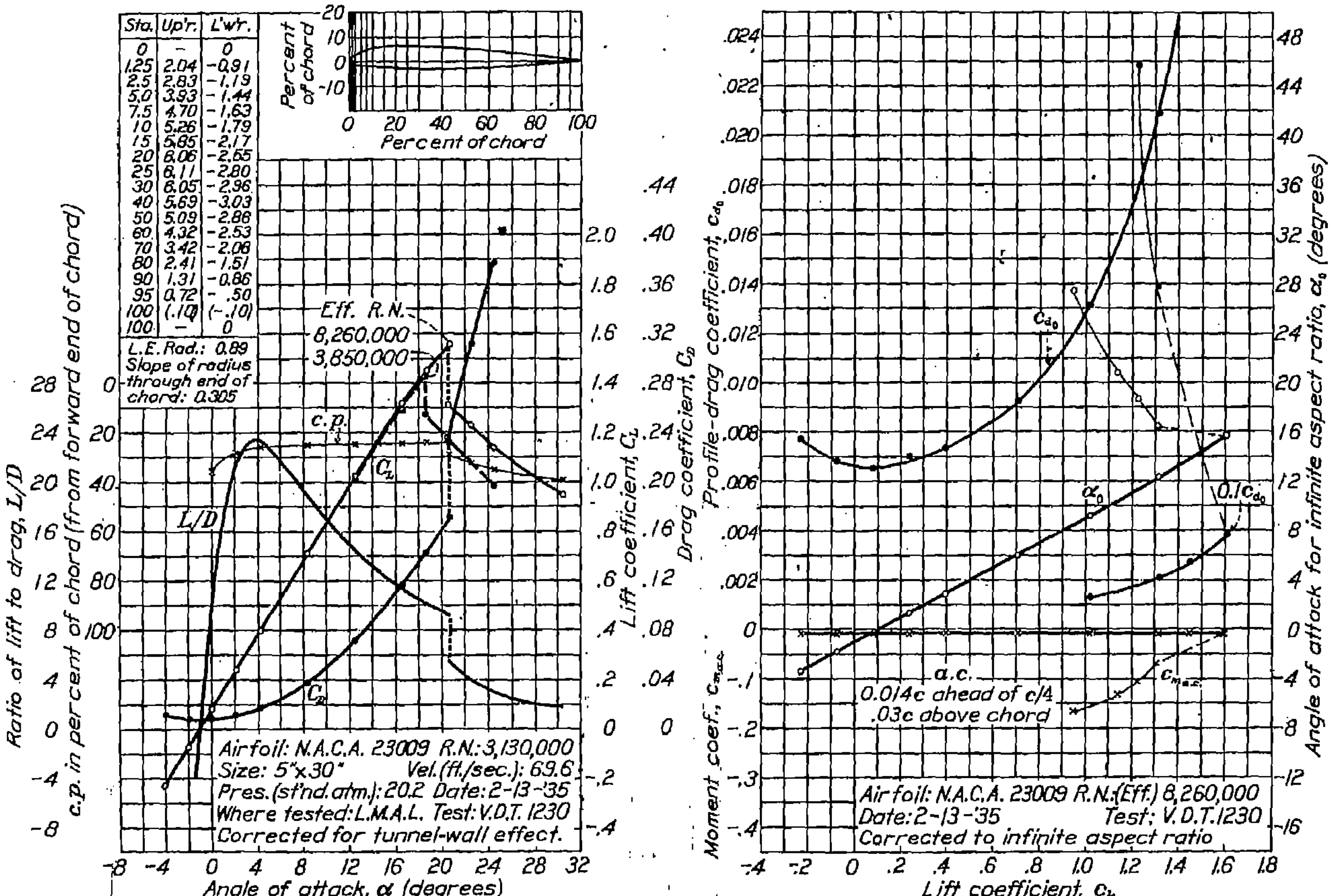


Figure 2.- N.A.C.A. 23009 airfoil

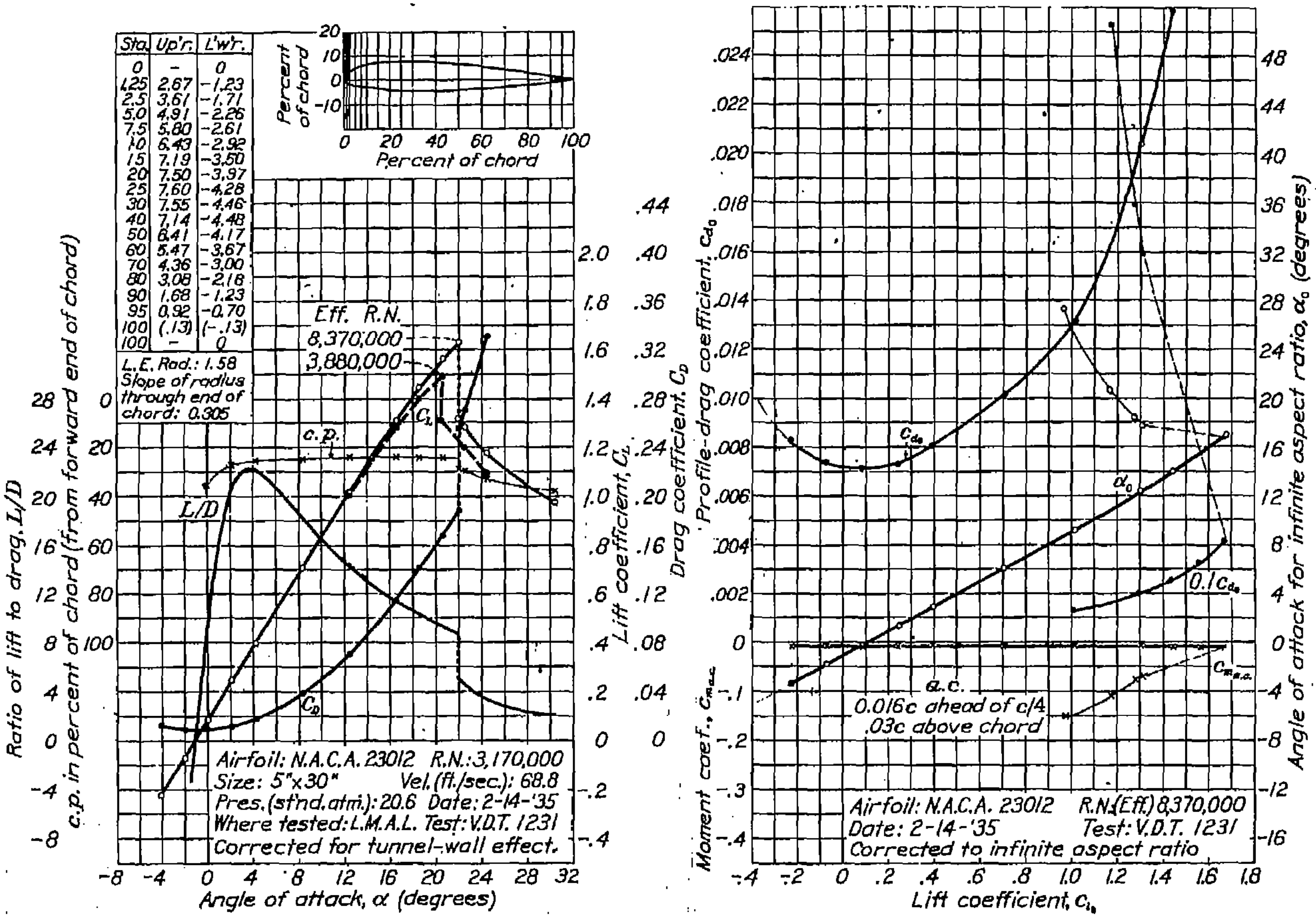


Figure 3.- N.A.C.A. 23012 airfoil

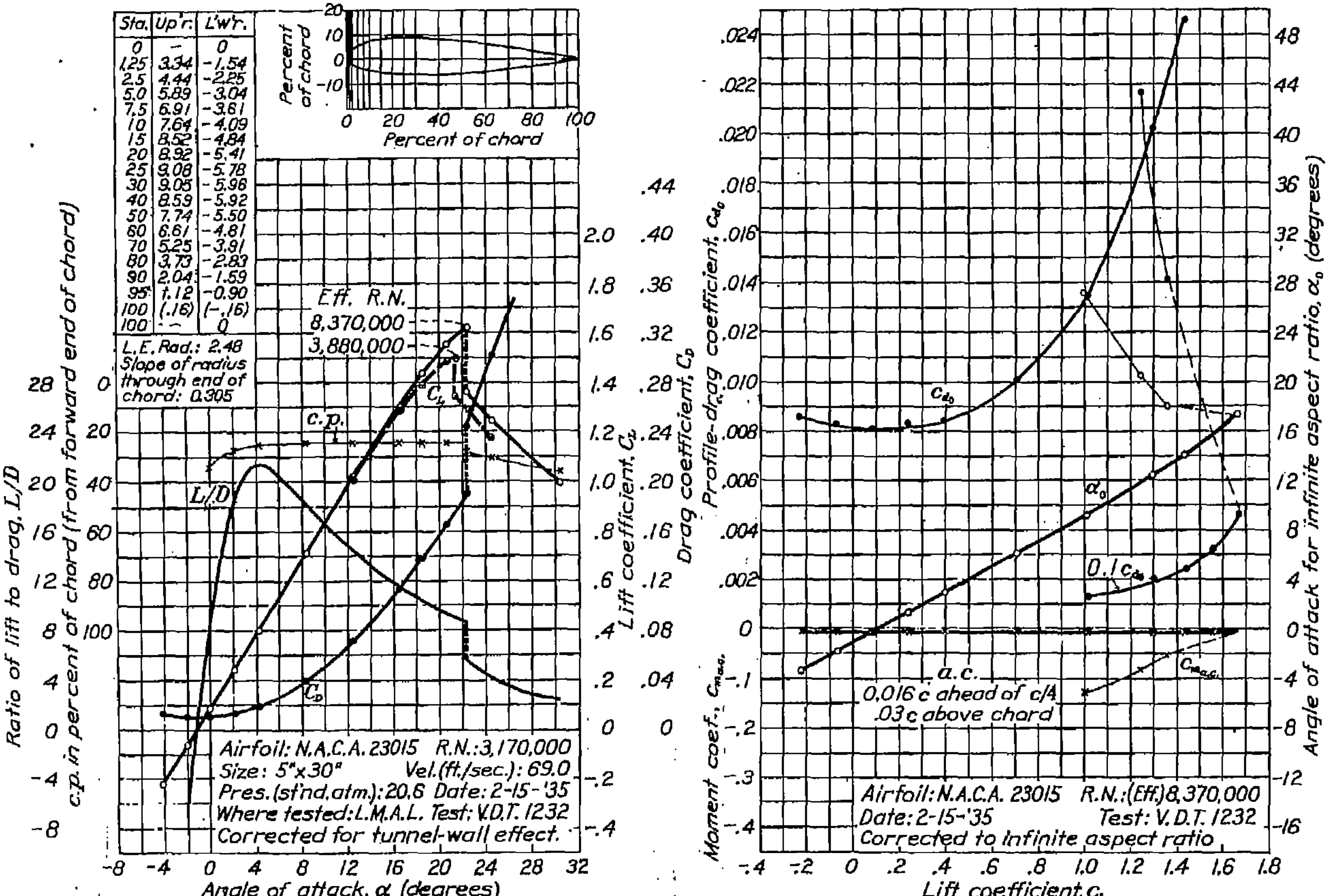


Figure 4.- N.A.C.A. 23015 airfoil

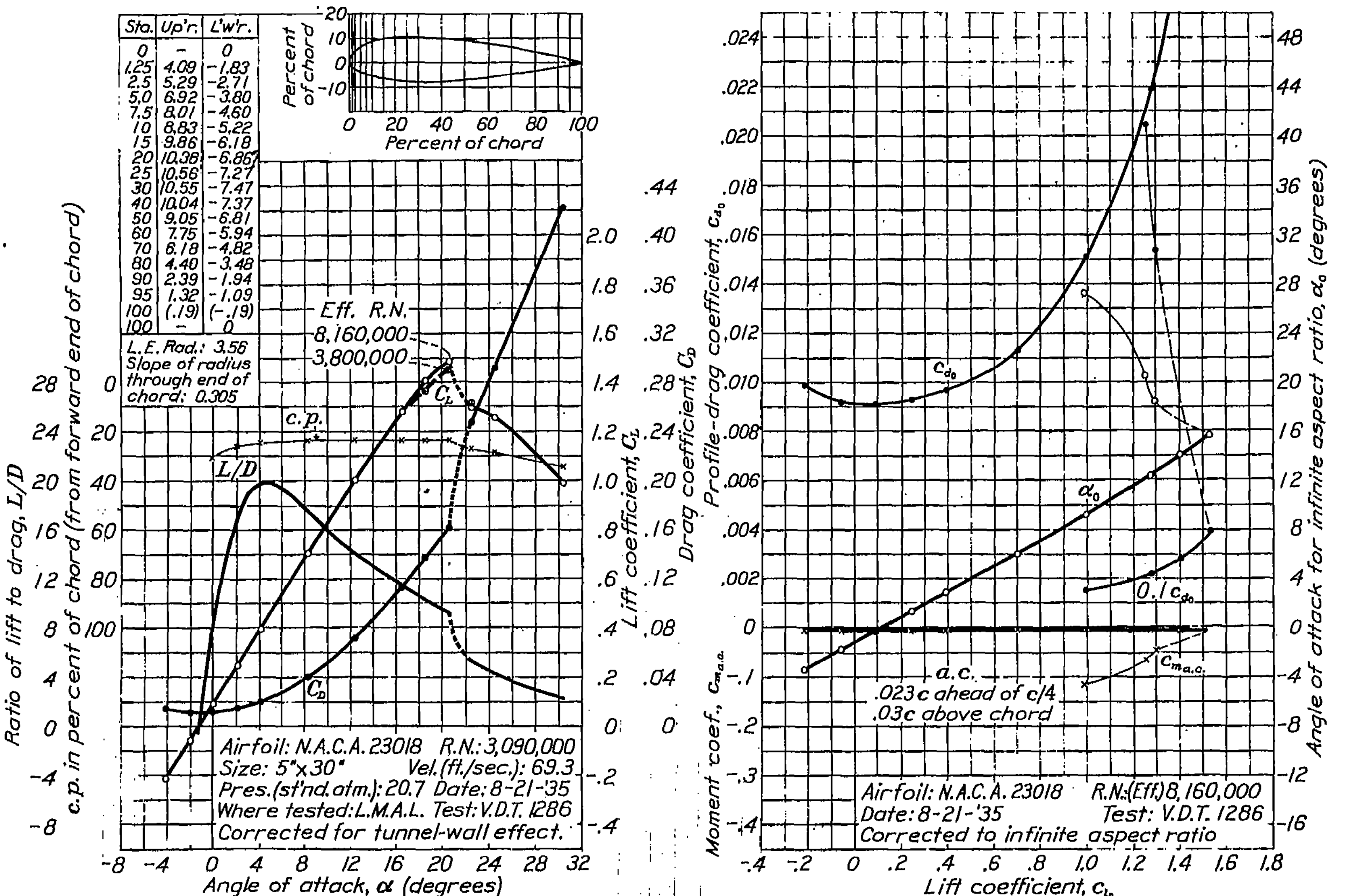
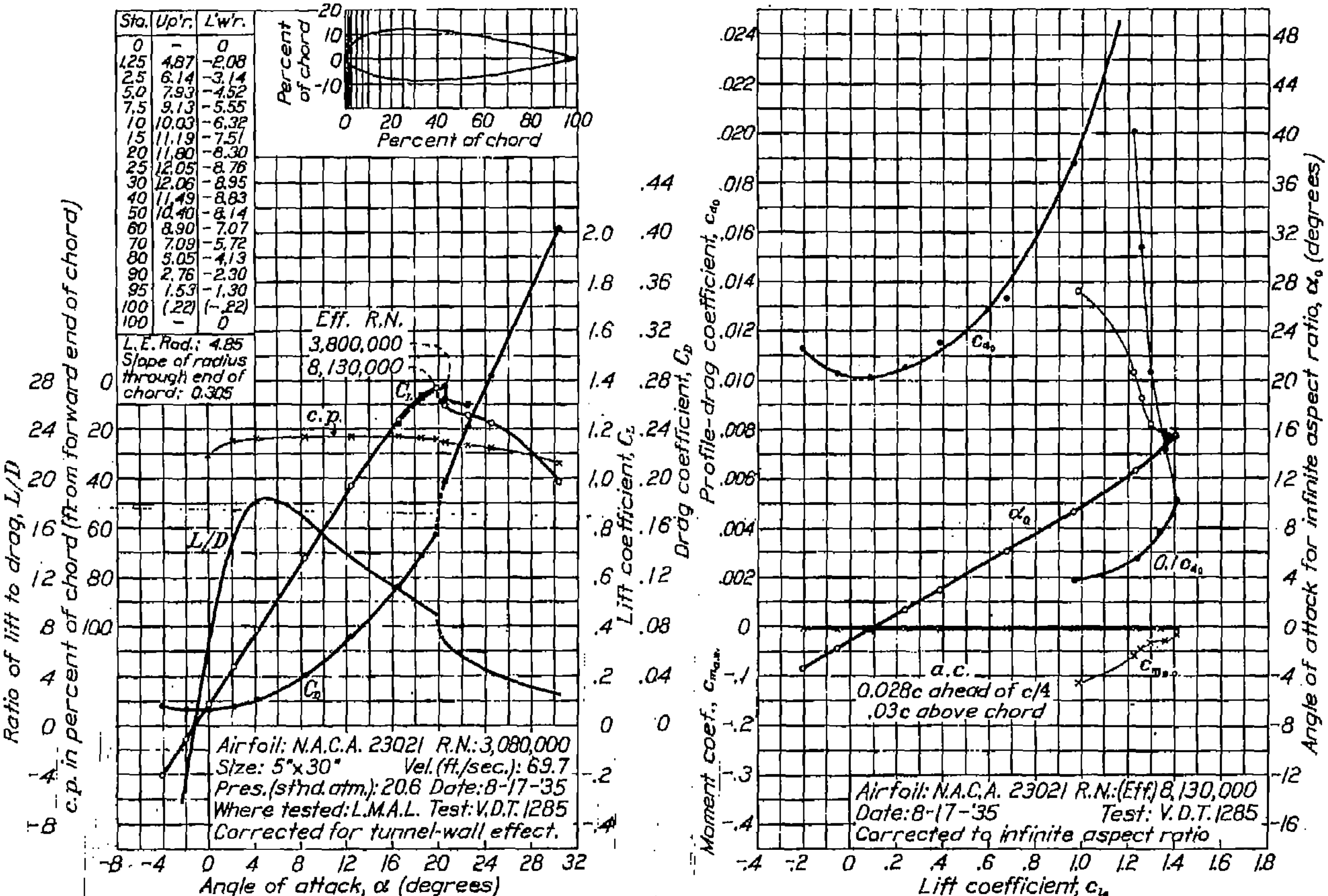


Figure 5.- N.A.C.A. 23018 airfoil.



Sta.	Up'r.	L'w'r.
0	–	0
1.25	4.87	-2.08
2.5	6.14	-3.14
5.0	7.93	-4.52
7.5	9.13	-5.55
10	10.03	-6.32
15	11.19	-7.51
20	11.80	-8.30
25	12.05	-8.76
30	12.06	-8.95
40	11.49	-8.83
50	10.40	-8.14
60	8.90	-7.07
70	7.09	-5.72
80	5.05	-4.13
90	2.76	-2.30
95	1.53	-1.30
100	(.22)	(-.22)
100	–	0

Figure 6.- N.A.C.A. 23021 airfoil

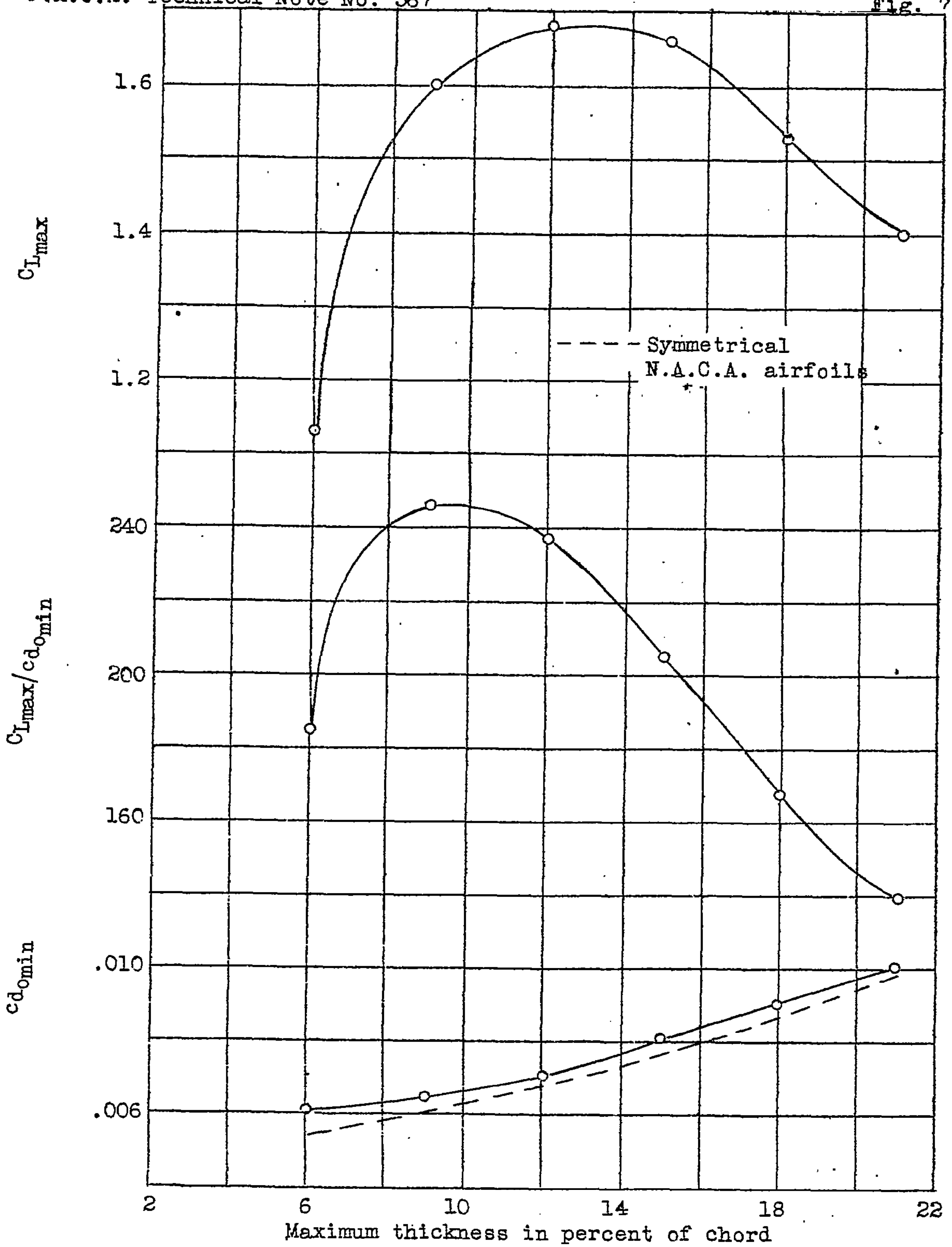


Figure 7.- Variation of lift and drag characteristics with thickness ratio.