TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 487

TESTS OF THREE TAPERED AIRFOILS BASED ON THE N.A.C.A. 2200, THE N.A.C.A.-M6, AND THE CLARK Y SECTIONS

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SUMMARY

Three tapered airfoils based on the N.A.C.A. 2200, the N.A.C.A.-M6, and the Clark Y sections were tested in the variable-density wind tunnel at a Reynolds Number of approximately 3,100,000. The models, which were of aspect ratio 6, had constant chord center sections and rounded tips, and tapered in thickness from 18 percent at the roots to 9 percent at the tips. The aerodynamic characteristics are given by the usual dimensionless coefficients plotted for both positive and negative angles of attack and by effective profile-drag coefficients plotted against lift coefficients.

INTRODUCTION

For the purpose of providing standard airfoil characteristics for use in airplane design, the Matériel Division of the Army Air Corps requested that six airfoils having commonly used sections be tested in the variable-density wind tunnel. In accordance with this request, the six airfoils were tested and the results are given in reference 1. In order to extend the standard characteristics to tapered wings, the Matériel Division later requested that two of the sections, the N.A.C.A.-M6 and the Clark Y, be used as basic sections for two tapered airfoils. The N.A.C.A. therefore had two tapered airfoils constructed in accordance with the following specifications: plan taper 2:1, constant chord center section of length equal to the root chord, rounded tips, aspect ratio 6, and thickness taper 18 percent to 9 percent. After the tests of these airfoils were completed, tests of an additional tapered airfoil based on the N.A.C.A. 2200 sections were requested. This airfoil was supplied by the Consolidated Aircraft Corporation. The airfoils are referred to in this report, according to the basic sections, as the N.A.C.A. 2218-09, the N.A.C.A.-M6, and the Clark Y tapered airfoils.

AIRFOILS AND TESTS

The airfoils were constructed of aluminum alloy. For the N.A.C.A.-M6 and Clark Y airfoils, the tolerance on the ordinates was ±0.003 inch and the airfoils were measured to insure conformance with the tolerance. For the N.A.C.A. 2218-09 airfoil, the tolerance was ±0.004 inch, but this airfoil was not constructed or measured at the N.A.C.A. laboratory.

The airfoils are shown in figure 1. The plan forms and front elevations of the tapered portions of the airfoils were determined by basic trapezoids. In plan form the basic trapezoid was tapered 2:1 as shown by the dotted lines in figure 1. The tips of the tapered airfoils were formed within the trapezoidal tips. The trailing edge of each tip was determined by a radius from a center on the line of 25 percent stations, and the leading edge was determined by the condition that the line of 25 percent stations continue as a straight line to the extreme tip. The models had a mean chord of 5 inches and a span of 30 inches. The aspect ratio was 6.

The thickness taper (in percent of the chord) is from 18 percent at the root to 9 percent at the tip of the basic trapezoid. The thickness ratios of the tip sections 2, 3, and 4 are the same as the thickness ratios of the corresponding sections of the basic trapezoid.

The ordinates of the Clark Y and N.A.C.A.-M6 airfoils, which are given in tables I and II, were obtained by increasing the upper and lower ordinates of the basic sections by equal amounts, thereby leaving the mean line approximately unchanged. Ordinates of the 2218-09 tapered airfoil were given in inches on a working drawing of the model. However, as the ordinates of the tip sections were not given at all of the standard stations, a set of ordinates of the sections at standard stations was derived and is given in table III. The method of deriving these ordinates may be found in reference 2. The sections given in table III have the same thickness ratios as the Clark Y and N.A.C.A.-M6 airfoils. The sections given on the working drawing had slightly different thickness ratios at the tips.

For the three airfoils the chords of all sections along the span are parallel. For each half of the airfoils, sections between the root section and section 1 were formed by using straight-line elements between corresponding points of the root section and section 1.

In front elevation, for the Clark Y and N.A.C.A.-M6 airfoils, the upper surface at the 30 percent stations is formed by a straight line across the span between tip sections 1, as shown in figure 1. Then from section 1 to the tip the thickness at the 30 percent stations departs equally on the top and bottom from the thickness of the basic trapezoid. For the N.A.C.A. 2218-09 airfoil, however, the 30 percent ordinates were in line nearly to section 4, thereby producing an increased dihedral at the tips.

The variable-density wind tunnel and the methods of making airfoil tests are fully described in reference 3. The airfoils were tested under the usual large dynamic scale test conditions corresponding to a Reynolds Number of approximately 3,100,000 based on the mean chord. Lift, drag, and pitching moment were measured at both positive and negative angles of attack.

RESULTS AND DISCUSSION

The results of the tests are presented in figures 2, 3, and 4 in the form of dimensionless coefficients plotted against angle of attack. Corrections for the influence of the tunnel walls have been applied by the method of reference 2. The pitching-moment coefficients are referred to an axis about which they are practically constant for a considerable range of angle of attack. The intersection of this axis with the plane of symmetry is the aerodynamic center and the pitching-moment coefficients are accordingly designated $C_{m_{a.c.}}$. The location of the $C_{m_{a.c.}}$ axis is given from the quarter-chord point of the root chord as shown on the figures.

In order to facilitate comparison of the drag of the airfoils, a plot of effective profile-drag coefficient against lift coefficient is given in figure 5. The effective profile-drag coefficient C_{D_e} is given by

$$C_{D_e} = C_D - \frac{C_L^2}{6\,\pi}$$

where C_D is the total drag coefficient of the wings for aspect ratio 6, and $C_L{}^2/6\pi$ is the induced-drag coefficient of a wing of aspect ratio 6 with elliptical span loading.

Important characteristics of the three airfoils are given in the following table.

Airfoil	$C_{L_{max}}$	$C_{D_{e\ min}}$	$\dfrac{C_{L_{max}}}{C_{D_{e\ min}}}$	C_{m_0}
N.A.C.A. 2218-09	1.60	0.0100	160	-0.029
N.A.C.A.-M6	1.49	.0095	157	-.006
Clark Y	1.67	.0102	164	-.071

The values of $C_{L_{max}}/C_{D_{e\ min}}$ given in the table may be considered a measure of the relative efficiency of the airfoils. On this basis the order of merit is Clark Y, N.A.C.A. 2218-09, and N.A.C.A.-M6. The N.A.C.A. 2218-09 airfoil, however, has a more favorable value of C_{m_0} than the Clark Y.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., November 17, 1933.

REFERENCES

1. U.S. Army: Handbook of Instructions for Airplane Designers. U.S. Army Air Corps, Matériel Division; vol. I, Seventh Edition, November 1932.

2. 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.

3. Jacobs, Eastman N., and Abbott, Ira H.: The N.A.C.A. Variable-Density Wind Tunnel. T.R. No. 416, N.A.C.A., 1932.

Table I

ORDINATES OF CLARK Y TAPERED AIRFOIL

(Values in percent of chord)

Stations	Root section		Section 1		Section 2		Section 3		Section 4	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
0	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50
1-1/4	6.40	.98	5.49	1.89	5.38	2.00	5.27	2.11	5.14	2.24
2-1/2	7.85	.11	6.56	1.42	6.40	1.56	6.24	1.74	6.06	1.92
5	9.78	-.94	7.98	.84	7.76	1.06	7.54	1.30	7.28	1.54
7-1/2	11.06	-1.58	8.94	.54	8.70	.78	8.42	1.06	8.12	1.36
10	12.07	-2.05	9.71	.31	9.43	.59	9.13	.89	8.79	1.23
15	13.53	-2.69	10.81	.03	10.49	.35	10.15	.69	9.76	1.03
20	14.42	-3.02	11.50	-.10	11.15	.25	10.78	.62	10.36	1.04
25	14.75	-3.13	11.75	-.13	11.40	.22	11.02	.60	10.59	1.03
30	14.85	-3.15	11.83	-.14	11.48	.22	11.10	.60	10.66	1.03
40	14.47	-3.07	11.53	-.13	11.18	.22	10.81	.59	10.39	1.01
50	13.35	-2.83	10.64	-.12	10.32	.20	9.98	.54	9.59	.93
60	11.62	-2.46	9.26	-.10	8.98	.18	8.68	.48	8.34	.80
70	9.33	-1.98	7.44	-.08	7.22	.14	6.97	.37	6.69	.65
80	6.63	-1.41	5.28	-.06	5.12	.10	4.95	.27	4.76	.46
90	3.56	-.76	2.83	-.03	2.75	.05	2.66	.14	2.55	.25
95	1.89	-.40	1.50	-.02	1.46	.02	1.42	.08	1.36	.14
100	.15	-.03	.12	00	.12	00	.11	.01	.11	.01

Table II

ORDINATES OF N.A.C.A.-M6 TAPERED AIRFOIL

(Values in percent of chord)

Stations	Root section		Section 1		Section 2		Section 3		Section 4	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
0	0	0	0	0	0	0	0	0	0	0
1-1/4	2.90	-2.70	1.96	-1.76	1.85	-1.65	1.73	-1.53	1.60	-1.40
2-1/2	4.06	-3.46	2.80	-2.20	2.65	-2.05	2.49	-1.89	2.31	-1.71
5	5.71	-4.41	4.02	-2.72	3.82	-2.52	3.60	-2.30	3.36	-2.06
7-1/2	6.92	-5.00	4.92	-3.00	4.69	-2.77	4.44	-2.52	4.15	-2.23
10	7.94	-5.46	5.70	-3.22	5.43	-2.95	5.14	-2.66	4.82	-2.34
15	9.38	-6.02	6.80	-3.44	6.50	-3.14	6.17	-2.81	5.80	-2.44
20	10.34	-6.42	7.53	-3.61	7.20	-3.28	6.84	-2.92	6.44	-2.52
25	10.93	-6.63	7.99	-3.69	7.64	-3.34	7.27	-2.97	6.85	-2.55
30	11.21	-6.79	8.20	-3.77	7.85	-3.41	7.46	-3.03	7.03	-2.60
40	11.02	-6.86	8.03	-3.87	7.68	-3.52	7.29	-3.13	6.87	-2.71
50	10.05	-6.73	7.24	-3.92	6.91	-3.59	6.55	-3.23	6.15	-2.83
60	8.49	-6.29	6.01	-3.81	5.72	-3.52	5.41	-3.21	5.05	-2.85
70	6.59	-5.49	4.57	-3.47	4.33	-3.23	4.07	-2.97	3.78	-2.68
80	4.53	-4.29	3.05	-2.81	2.83	-2.64	2.69	-2.45	2.48	-2.24
90	2.38	-2.60	1.54	-1.76	1.45	-1.67	1.34	-1.56	1.22	-1.44
95	1.37	-1.57	.88	-1.08	.82	-1.02	.76	-.96	.69	-.89
100	.39	-.39	.26	-.26	.24	-.24	.23	-.23	.21	-.21

Table III

ORDINATES OF THE N.A.C.A. 2218-09 TAPERED AIRFOIL

(Values in percent of chord)

Stations	Root section		Section 1		Section 2		Section 3		Section 4	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
0	—	0	—	0	—	0	—	0	—	0
1-1/4	3.72	-2.14	2.41	-1.45	2.27	-1.37	2.14	-1.25	0.97	-1.16
2-1/2	4.93	-3.02	3.33	-1.97	3.15	-1.82	2.96	-1.69	2.73	-1.52
5	6.60	-4.15	4.61	-2.56	4.38	-2.35	4.13	-2.15	3.87	-1.90
7-1/2	7.80	-4.88	5.54	-2.89	5.29	-2.65	5.00	-2.39	4.69	-2.10
10	8.73	-5.38	6.27	-3.10	5.97	-2.83	5.67	-2.55	5.32	-2.22
15	9.95	-6.09	7.22	-3.44	6.90	-3.12	6.58	-2.78	6.18	-2.40
20	10.61	-6.61	7.72	-3.72	7.38	-3.38	7.02	-3.02	6.60	-2.60
25	10.89	-6.92	7.92	-3.92	7.56	-3.55	7.19	-3.20	6.75	-2.78
30	10.97	-7.03	7.95	-4.02	7.60	-3.66	7.22	-3.27	6.78	-2.85
40	10.59	-6.82	7.67	-3.91	7.32	-3.57	6.96	-3.20	6.53	-2.78
50	9.68	-6.20	7.01	-3.55	6.70	-3.25	6.36	-2.91	5.97	-2.53
60	8.38	-5.32	6.06	-3.04	5.79	-2.78	5.50	-2.49	5.15	-2.15
70	6.75	-4.25	4.88	-2.42	4.67	-2.21	4.44	-1.98	4.15	-1.72
80	4.84	-3.05	3.50	-1.74	3.35	-1.58	3.19	-1.42	2.98	-1.22
90	2.67	-1.69	1.91	-.96	1.85	-.89	1.74	-.79	1.62	-.68
95	1.47	-.96	1.05	-.56	1.00	-.50	.96	-.45	.89	-.40
100	.19	-.19	.13	-.13	.12	-.12	.11	-.11	.10	-.10
L.E. Rad.	3.56		1.58		1.40		1.21		1.02	
	The radius centers lie on a line of 2/10 slope through the end of the chord									

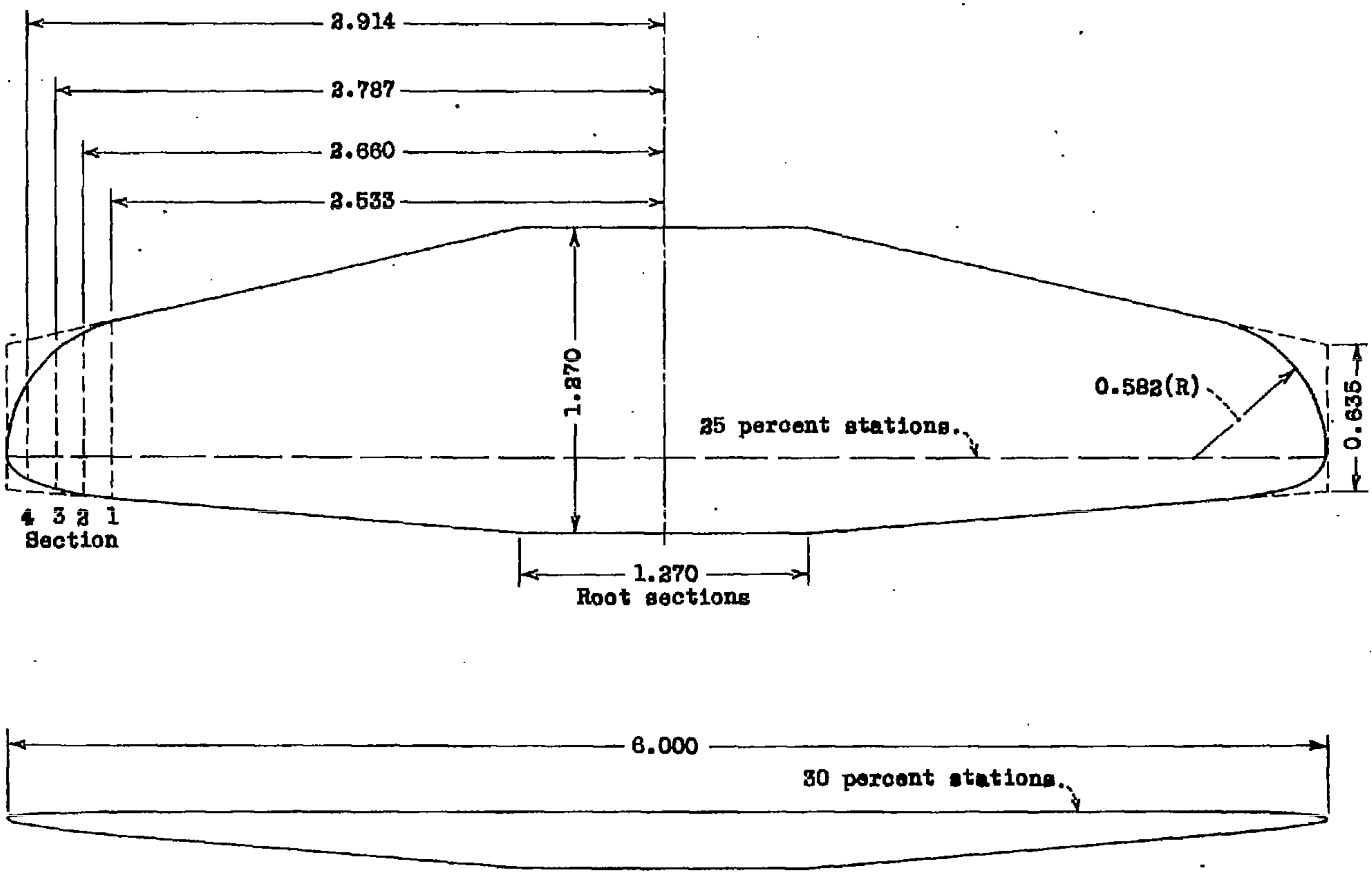

Figure 1. Dimensions of the airfoils expressed as ratios to the mean chord.

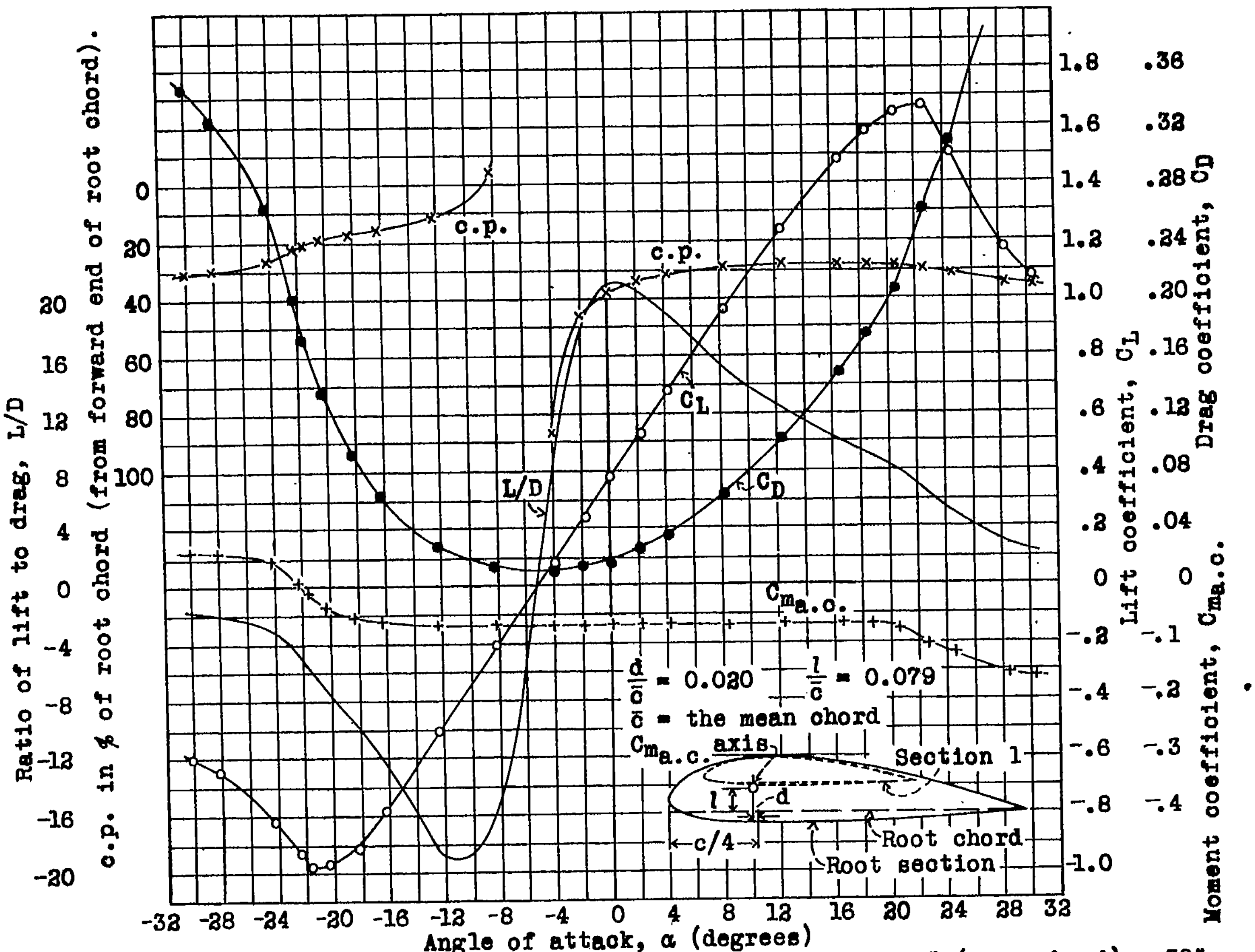

Figure 2.- Airfoil: Tapered Clark Y. R.N.: 3,170,000 Size: 5" (mean chord) x 30"
Vel. (ft./sec.): 68.9 Press. (st'n'd. atm.): 20.8 Dates: 1-6-33, 4-5-33
Where tested: L.M.A.L. Tests: V.D.T. 943, 1017 Results corrected for tunnel-wall effect.

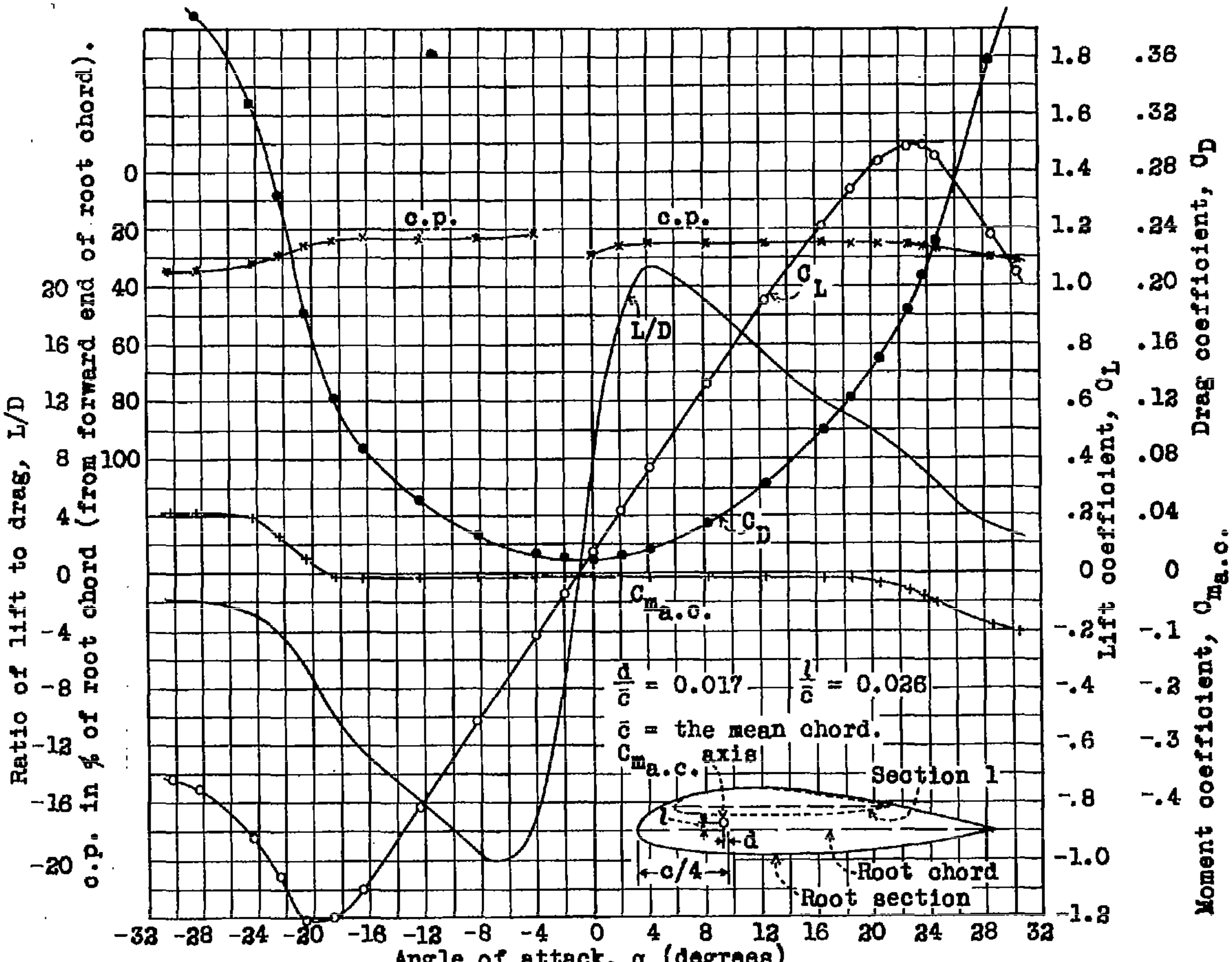

Figure 3.- Airfoil: Tapered N.A.C.A. -M6 R.N., 3,170,000 Size: 5" (mean chord) x 30" Vel. (ft./sec.): 69.0 Press. (st'n'd. atm.): 20.6. Dates: 1-7-33, 4-5-33. Where tested: L.M.A.L. Tests: V.D.T. 944, 1016. Results corrected for tunnel-wall effect.

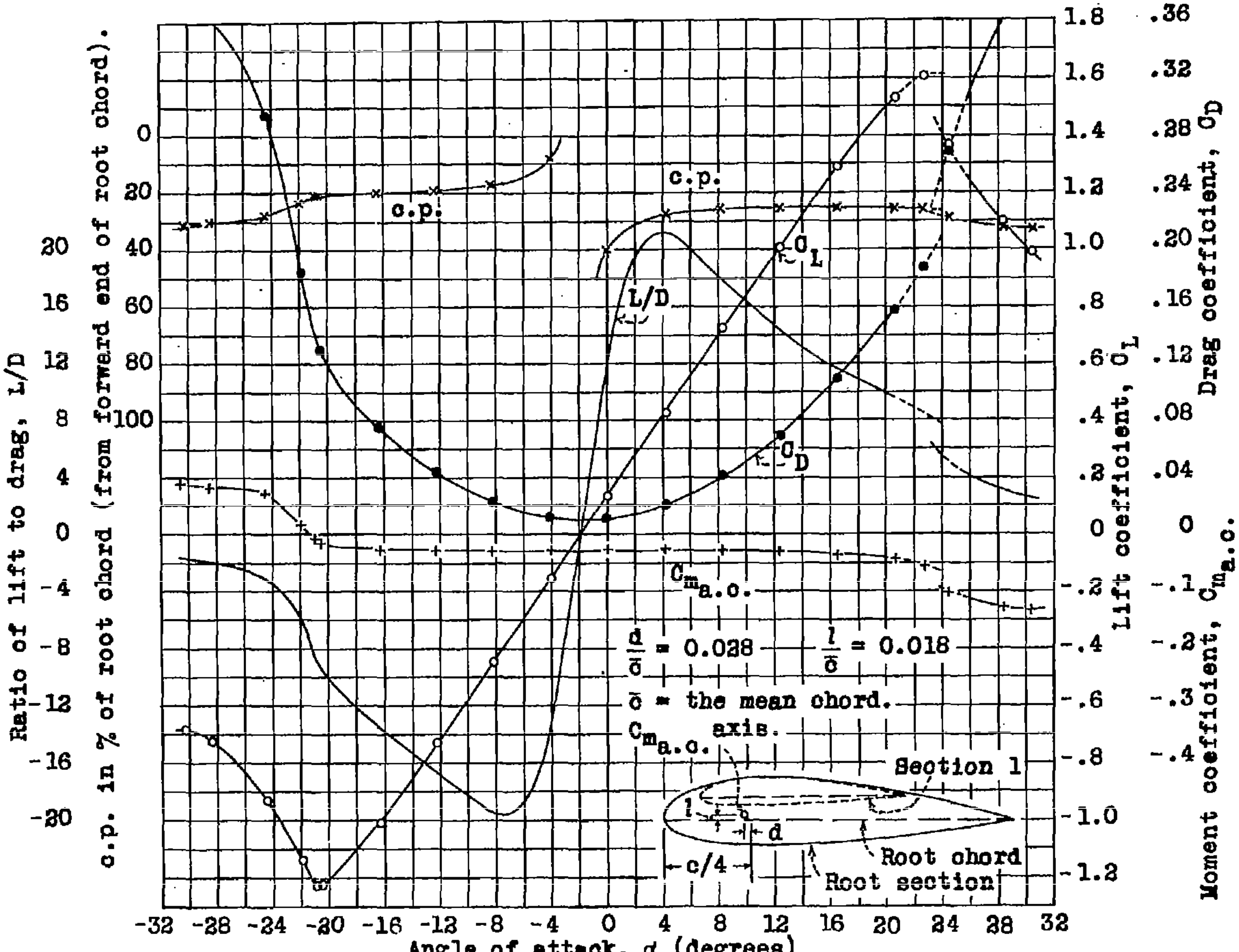

Figure 4. Airfoil: Tapered N.A.C.A. 2218-09 R.N.:3,160,000 Size: 5" (mean chord) x 30"
Vel. (ft./sec.): 69.4 Press. (st'n'd. atm.): 21.0 Date: 5-6-33.
Where tested: L.M.A.L. Test: V.D.T. 1038 Results corrected for tunnel-wall effect.

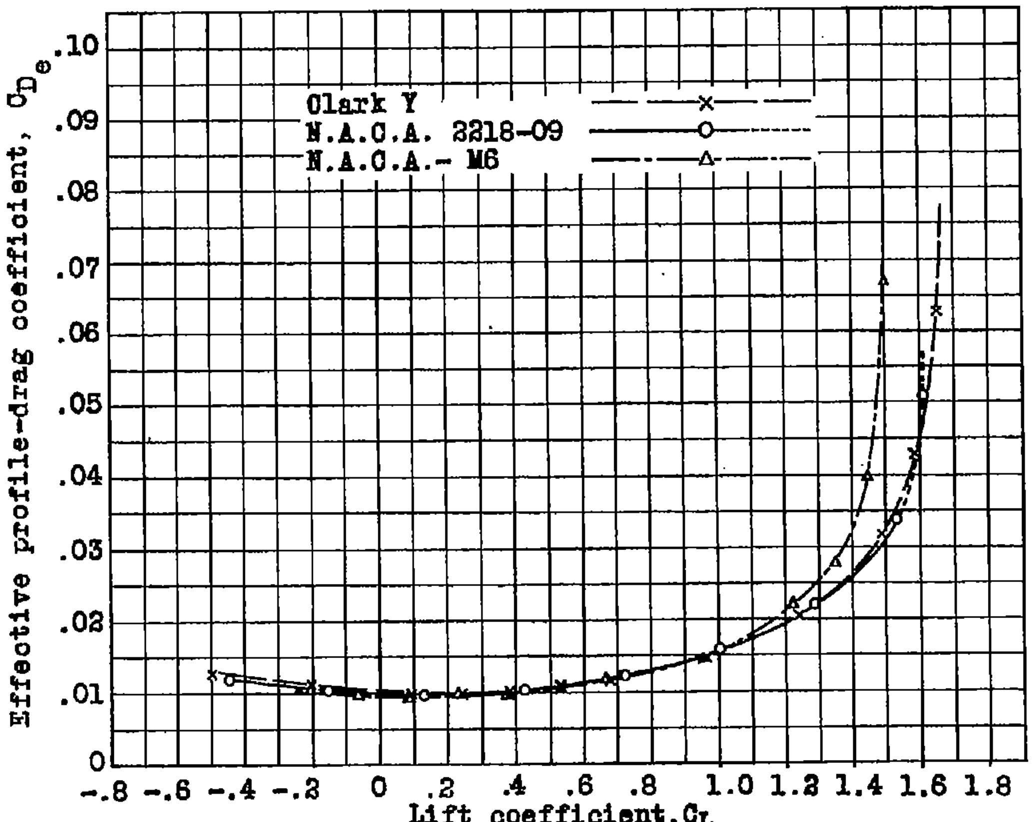

Figure 5.-Variation of effective profile-drag coefficient with lift coefficient