TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 361

THE EFFECT OF SMALL VARIATIONS IN PROFILE OF AIRFOILS

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Summary

This report deals with the effect of small variations in ordinates specified by different laboratories for the same airfoil section. This study was made in connection with a more general investigation of the effect of small irregularities of the airfoil surface on the aerodynamic characteristics of an airfoil. The tests were conducted in the Variable Density Wind Tunnel of the National Advisory Committee for Aeronautics upon two models of the Göttingen 387 airfoil section and two symmetrical airfoil models having comparable shapes, the N.A.C.A. 0021 and the N.A.C.A. 100.

These tests show that small changes in airfoil contours, resulting from variations in the specified ordinates, have a sufficiently large effect upon the airfoil characteristics to justify the taking of great care in the specification of ordinates for the construction of models.

Introduction

It is well known that the ordinates specified by one laboratory for a given wing section may vary somewhat from those specified by another laboratory. Little direct information is available to show just what effect a modification of the profile has upon the aerodynamic characteristics of an airfoil. A variation in specified ordinates may be attributed to several causes. Unless excessive care is used, an airfoil cannot be constructed exactly as specified. The measured ordinates are usually published and will not, therefore, correspond to those from which the airfoil was made. Often deliberate small changes are introduced by refairing the original surface curves or by slight modifications of the profile. Also, it may be impossible to obtain exactly the original ordinates.

The most common method used to detect the differences between airfoil profiles is to compare the fairness of the curves drawn through the ordinates plotted to enlarged scales. A superior method of judging fairness is to examine the curves of the first and second derivatives of the profile. An approximate method of obtaining this is to take first and second differences between the ordinates of equally spaced stations. Since the radius of curvature of any curve depends upon the first and second derivatives, the fairness of the first and second difference curves will indicate the fairness of the surface.

This report covers an investigation of the effect of small changes in airfoil contours resulting from variations in the specified ordinates, and is published in connection with a more general investigation on the aerodynamic effects of small irregularities of airfoil surfaces. Later reports will give the effects of fabric sag, abrupt breaks near the leading edge caused by the presence of a plywood nose, and general surface roughness.

The present investigation was made in the Variable Density Wind Tunnel at the Langley Memorial Aeronautical Laboratory on two airfoils of the Göttingen 387 section, and on two symmetrical airfoils having comparable shapes, namely, the N.A.C.A. 0021 and the N.A.C.A. 100. The Göttingen airfoils were constructed from different sets of specified ordinates and are designated in this report as the Göttingen 387-G and the Göttingen 387. The two symmetrical models were included because the differences in ordinates specifying the two sections approximate the differences often encountered in specified ordinates for the same section.

Apparatus and Tests

A description of the Variable Density Wind Tunnel, in which these tests were performed, and a discussion of the principles upon which its operation is based, are given in Reference 1. This description, however, applies to the tunnel in its original form. Although fundamentally the same, the present tunnel differs from the original in the type of entrance cone and return

passage, and in some minor respects.

The airfoil models were all 5 by 30 inches; the two Göttingen 387 models were made of duralumin and the other two of mahogany. Usual force tests were made at an approximate Reynolds Number of 3.4×10^6.

Results and Discussion

The geometric characteristics of the airfoils are illustrated by the profile plots. Figure 1 gives the profile of the Göttingen 387-G, constructed from the Göttingen laboratory ordinates (Reference 2), compared with the Göttingen 387 profile, as constructed from the ordinates given in the N.A.C.A. Technical Report No. 124 (Reference 3). The full profiles are plotted to an enlarged vertical scale, whereas the nose and tail are plotted to a large natural scale. The specified and measured ordinates are given in Table I. Measurements were made to an accuracy of ±0.0005 inch.

First and second differences were taken between the measured ordinates at each 5 per cent station for the two Göttingen models. The results are plotted in Figure 2, and illustrate the fairness of the surfaces. The dotted curves represent the derivatives of a fair surface from which, by working back, the ordinates may be obtained. This has been done and the results given in Table I under the heading "Göttingen 387 - Faired." Figure 3 is a plot similar to Figure 2, showing the difference curves for four sets of specified ordinates for the Göttingen 387 (Refer-

ences 2 to 5, inclusive). In this case, the differences were taken for each 10 per cent station.

A comparison between the aerodynamic characteristics of the two airfoils is given in Figures 4 and 5. Figure 4 gives the lift and drag coefficients, L/D ratio, and center of pressure, plotted against the angle of attack, for a wing of aspect ratio 6 in free air. Figure 5 gives plots of the profile drag coefficient, angle of attack, and moment coefficient about the quarter chord, against the lift coefficient, for a wing of infinite aspect ratio. These curves show the Göttingen 387-G to have 4.5 per cent lower maximum lift, 8.0 per cent lower minimum profile drag, and 3.5 per cent higher maximum L/D, than the Göttingen 387. There is little difference in the moment or center of pressure characteristics for the two sections. The accuracy of the results is indicated by the check points shown on the curve sheets.

Similar plots of the geometric and aerodynamic characteristics of the N.A.C.A. 0021 and the N.A.C.A. 100 are given in Figures 6 to 9, inclusive. These curves show the N.A.C.A. 0021 to have 9.4 per cent higher maximum lift, the same minimum profile drag, and 2.3 per cent higher maximum L/D, then the N.A.C.A. 100.

Conclusions

Small changes in airfoil contours resulting from variations in the specified ordinates have a sufficiently large effect upon the airfoil characteristics to justify the taking of great care in the specification of ordinates for the construction of models.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., December 18, 1930.

References

1. Munk, Max M. and Miller, Elton W. : The Variable Density Wind Tunnel of the National Advisory Committee for Aeronautics. N.A.C.A. Technical Report No. 227, 1926.

2. : Ergebnisse der Aerodynamischen Versuchsanstalt zu Göttingen. III, Lieferung, 1927. Edited by L. Prandtl and A. Betz.

3. National Advisory Committee for Aeronautics : Aerodynamic Characteristics of Aerofoils - II. N.A.C.A. Technical Report No. 124, 1921.

4. National Advisory Committee for Aeronautics : Aerodynamic Characteristics of Aerofoils - IV. N.A.C.A. Technical Report No. 244, 1926.

5. Louden, F. A. : Collections of Wind Tunnel Data on Commonly Used Wing Sections. N.A.C.A. Technical Report No. 331, 1929.

TABLE I. Ordinates of Airfoil Sections

(All dimensions given in per cent of chord)

Distance from leading edge	Göttingen 387			
	measured		specified	
	upper	lower	upper	lower
0			3.61	3.61
1-1/4	6.74	1.42	6.74	1.35
2-1/2	7.98	.84	7.98	.81
5	9.88	.38	9.87	.36
7-1/2	11.30	.18	11.32	.18
10	12.38	.10	12.40	.13
15	13.82	.00	13.83	.00
20	14.78	.06	14.77	.08
25	15.24	.14		
30	15.38	.20	15.36	.22
35	15.26	.26		
40	14.88	.34	14.88	.38
45	14.28	.40		
50	13.52	.49	13.48	.54
55	12.62	.49		
60	11.62	.49	11.59	.54
65	10.46	.48		
70	9.22	.48	9.16	.54
75	7.94	.48		
80	6.60	.44	6.58	.50
85	5.16	.36		
90	3.62	.24	3.61	.27
95	2.04	.14	1.99	.16
100			.37	.00

TABLE I. Ordinates of Airfoil Sections (Cont.)
(All dimensions given in per cent of chord)

Distance from leading edge	Göttingen 387-G				Göttingen 387	
	measured		specified		faired	
	upper	lower	upper	lower	upper	lower
0			3.20	3.20	3.36	3.36
1-1/4	6.38	1.54	6.25	1.50		
2-1/2	7.68	1.08	7.65	1.05		
5	9.54	.56	9.50	.55	9.63	.56
7-1/2	10.90	.28	10.85	.25		
10	11.98	.12	11.95	.10	12.15	.12
15	13.46	.00	13.40	.00	13.64	.00
20	14.44	.02	14.40	.00	14.61	.02
25	14.96	.10			15.16	.10
30	15.10	.20	15.05	.20	15.36	.19
35	15.00	.30			15.26	.28
40	14.66	.38	14.60	.40	14.90	.36
45	14.14	.42			14.32	.42
50	13.42	.46	13.35	.45	13.55	.46
55	12.50	.48			12.62	.48
60	11.44	.48	11.35	.50	11.56	.48
65	10.26	.48			10.39	.46
70	8.98	.46	8.90	.45	9.13	.42
75	7.62	.40			7.80	.37
80	6.20	.34	6.15	.30	6.41	.31
85	4.74	.26			4.97	.24
90	3.28	.18	3.25	.15	3.49	.16
95	1.78	.08	1.75	.05	1.98	.08
100			.15	.15	.45	.00

TABLE I. Ordinates of Airfoil Sections (Cont.)
(All dimensions given in per cent of chord)

Distance from leading edge	N.A.C.A. 0021				N.A.C.A. 100			
	measured		specified		measured		specified	
	upper	lower	upper	lower	upper	lower	upper	lower
0			0	0			0	0
1-1/4	3.30	3.04	3.32	3.32	2.94	3.20	3.16	3.16
2-1/2	4.60	4.34	4.57	4.57	4.26	4.40	4.52	4.52
5	6.24	6.08	6.22	6.32	6.02	6.12	6.25	6.25
7-1/2	7.36	7.28	7.35	7.35	7.22	7.32	7.38	7.38
10	8.14	8.16	8.20	8.20	8.14	8.20	8.24	8.24
15	9.30	9.28	9.35	9.35	9.30	9.40	9.45	9.45
20	9.94	9.90	10.04	10.04	10.04	10.02	10.17	10.17
25	10.26	10.26	10.40	10.40	10.40	10.38		
30	10.36	10.36	10.50	10.50	10.48	10.46	10.50	10.50
35	10.28	10.30	10.41	10.41	10.40	10.34		
40	10.00	10.08	10.16	10.16	10.16	10.08	10.23	10.23
45	9.60	9.74	9.77	9.77	9.80	9.72		
50	9.10	9.26	9.27	9.27	9.30	9.14	9.44	9.44
55	8.50	8.68	8.68	8.68	8.78	8.66		
60	7.84	7.98	7.99	7.99	8.10	7.98	8.21	8.21
65	7.12	7.20	7.23	7.23	7.32	7.20		
70	6.28	6.38	6.41	6.41	6.44	6.38	6.59	6.59
75	5.44	5.50	5.53	5.53	5.52	5.48		
80	4.50	4.54	4.59	4.59	4.52	4.50	4.68	4.68
85	3.52	3.54	3.59	3.59	3.48	3.48		
90	2.46	2.52	2.53	2.53	2.40	2.38	2.52	2.52
95	1.34	1.46	1.41	1.41	1.22	1.28	1.34	1.34
100			.22	.22			.11	.11

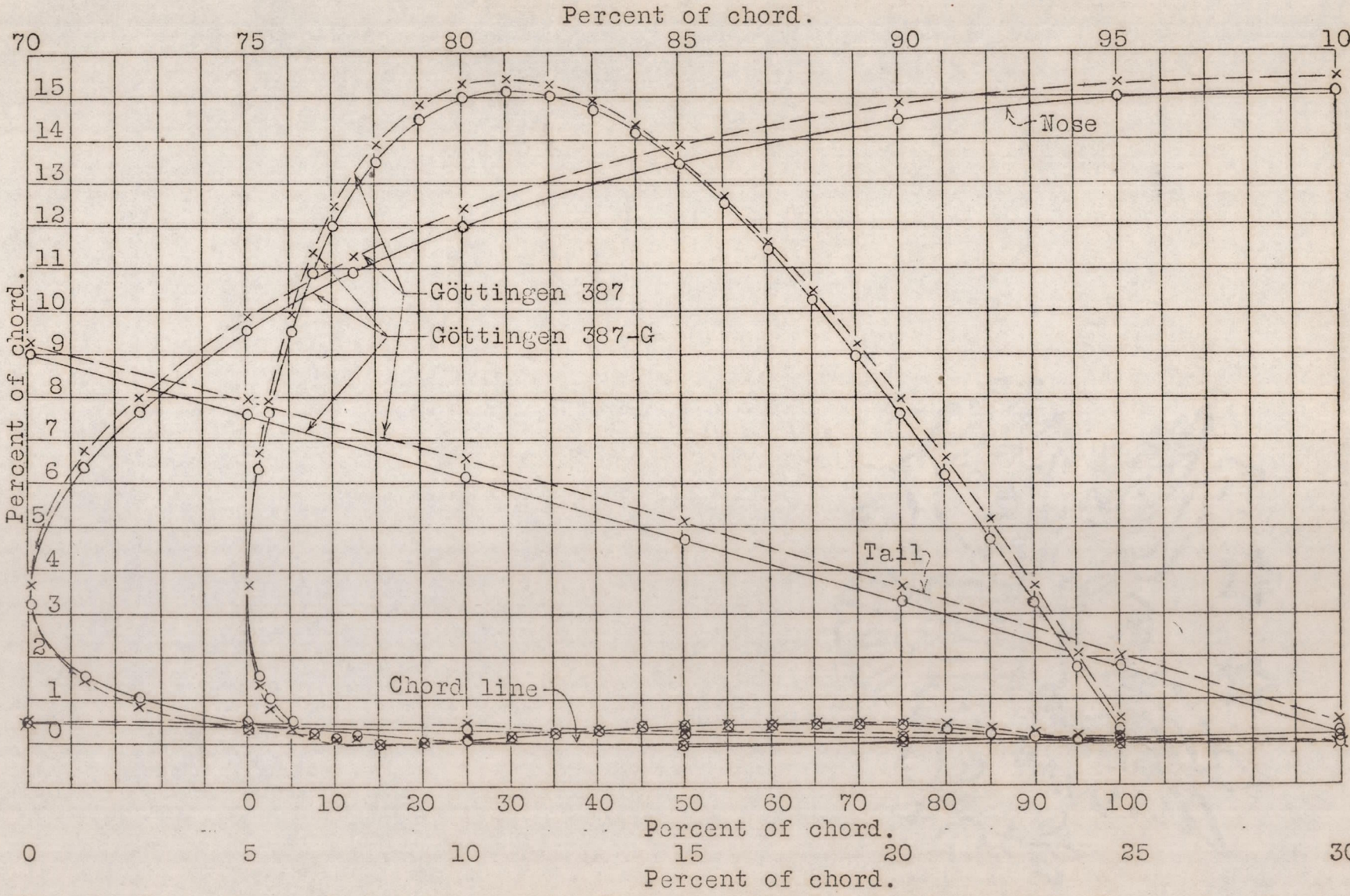

Fig. 1

Fig. 1 Comparison of airfoil profiles Göttingen 387-G & Göttingen 387. Measured ordinates.

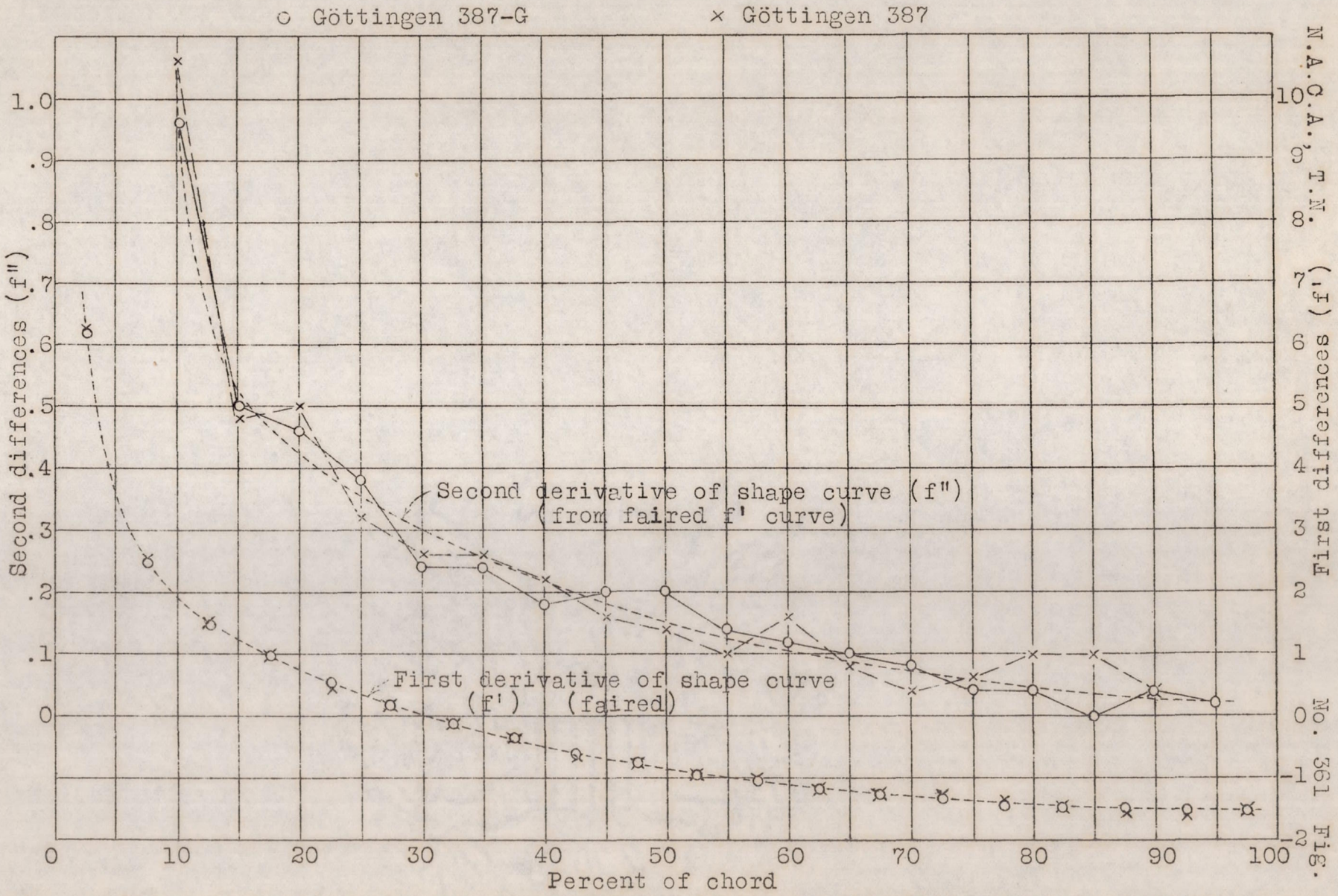

Fig. 2 Shape derivatives for Göttingen 387-G & Göttingen 387. From measured ordinates for upper surface.

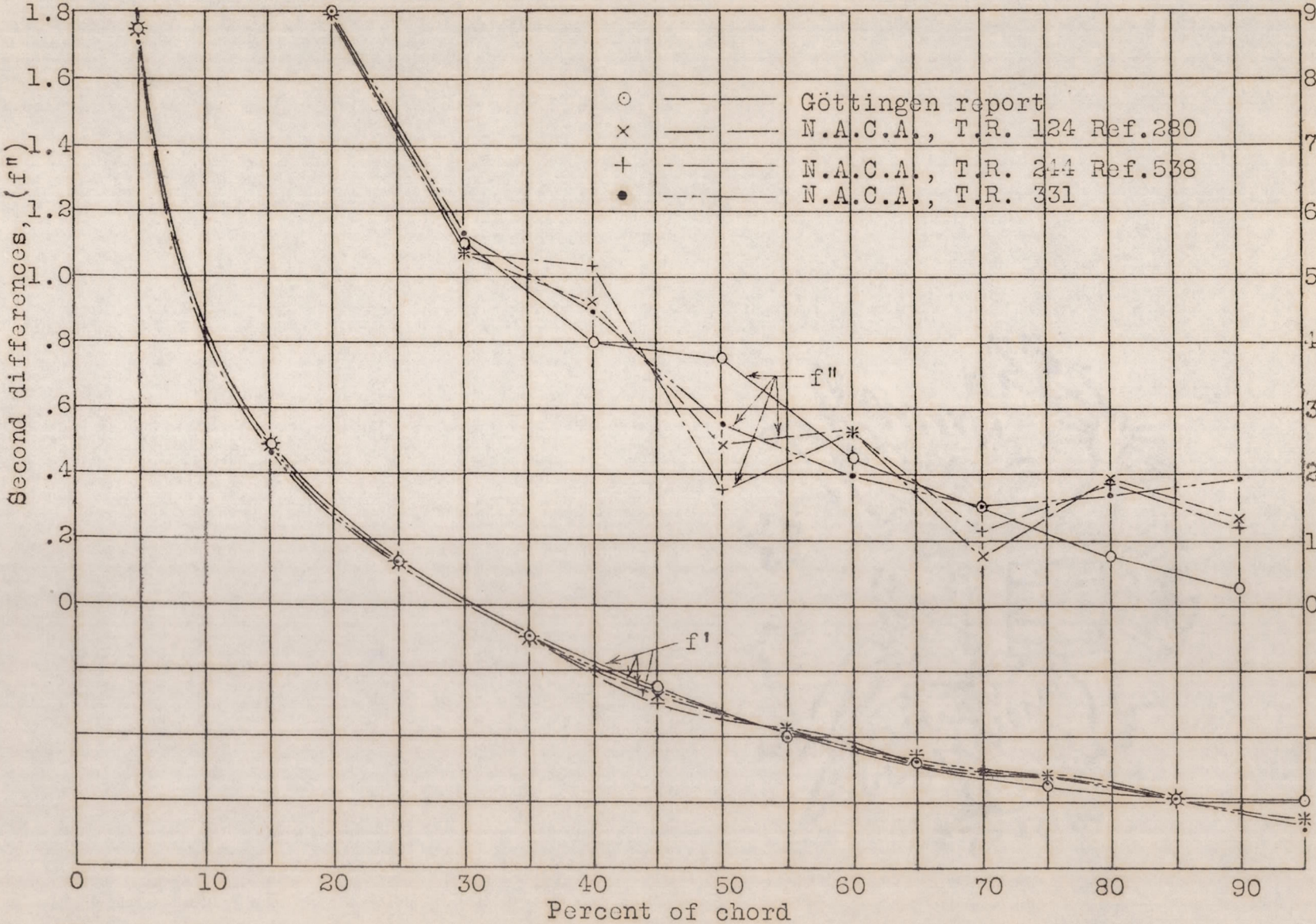

Fig. 3 Shape derivatives for Göttingen 387. From specified ordinates for upper surface.

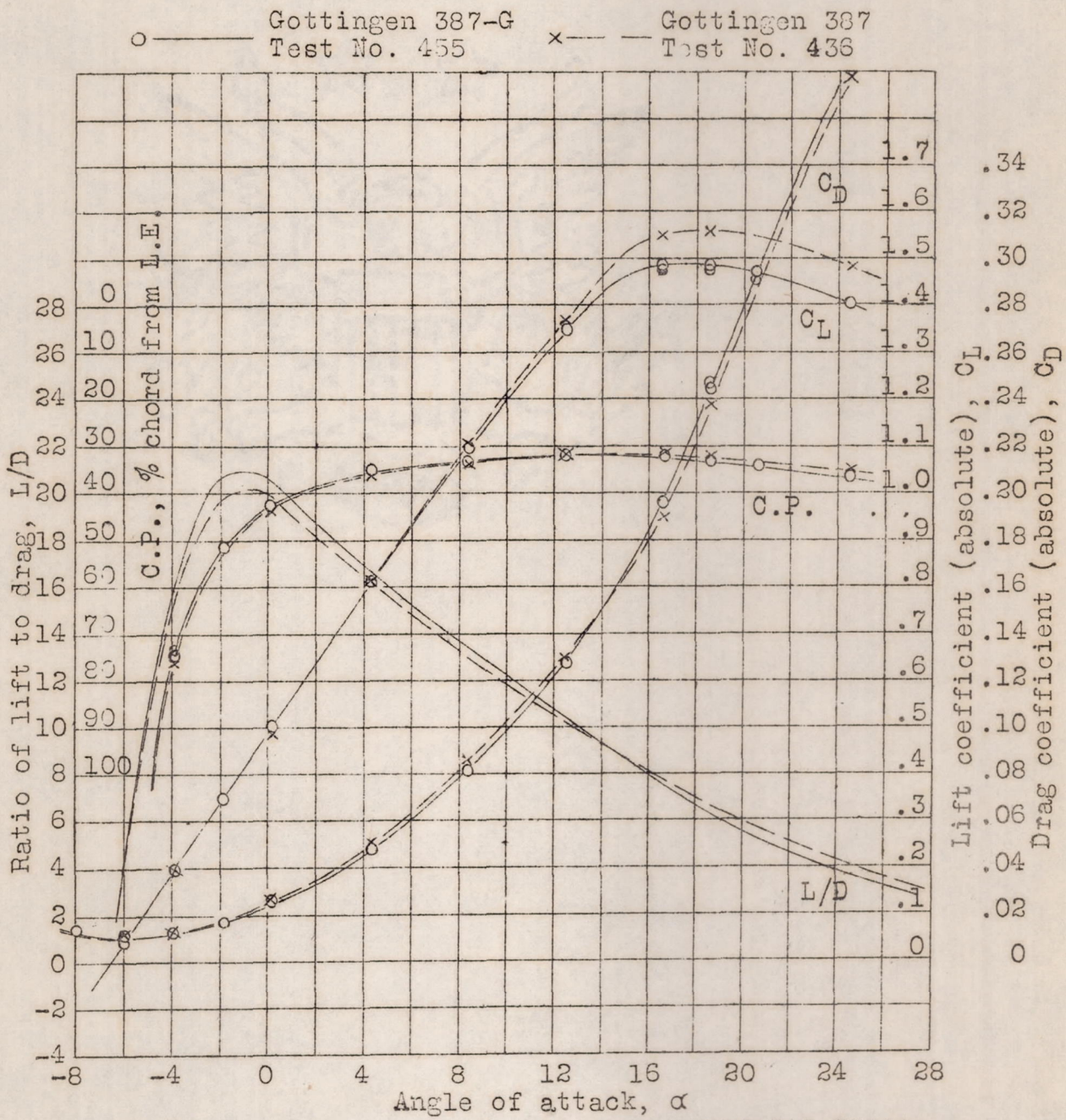

Fig. 4 Comparative curves for Göttingen 387-G & Göttingen 387. R.N. = 3.4×10^6. Corrected to aspect ratio 6 in free air.

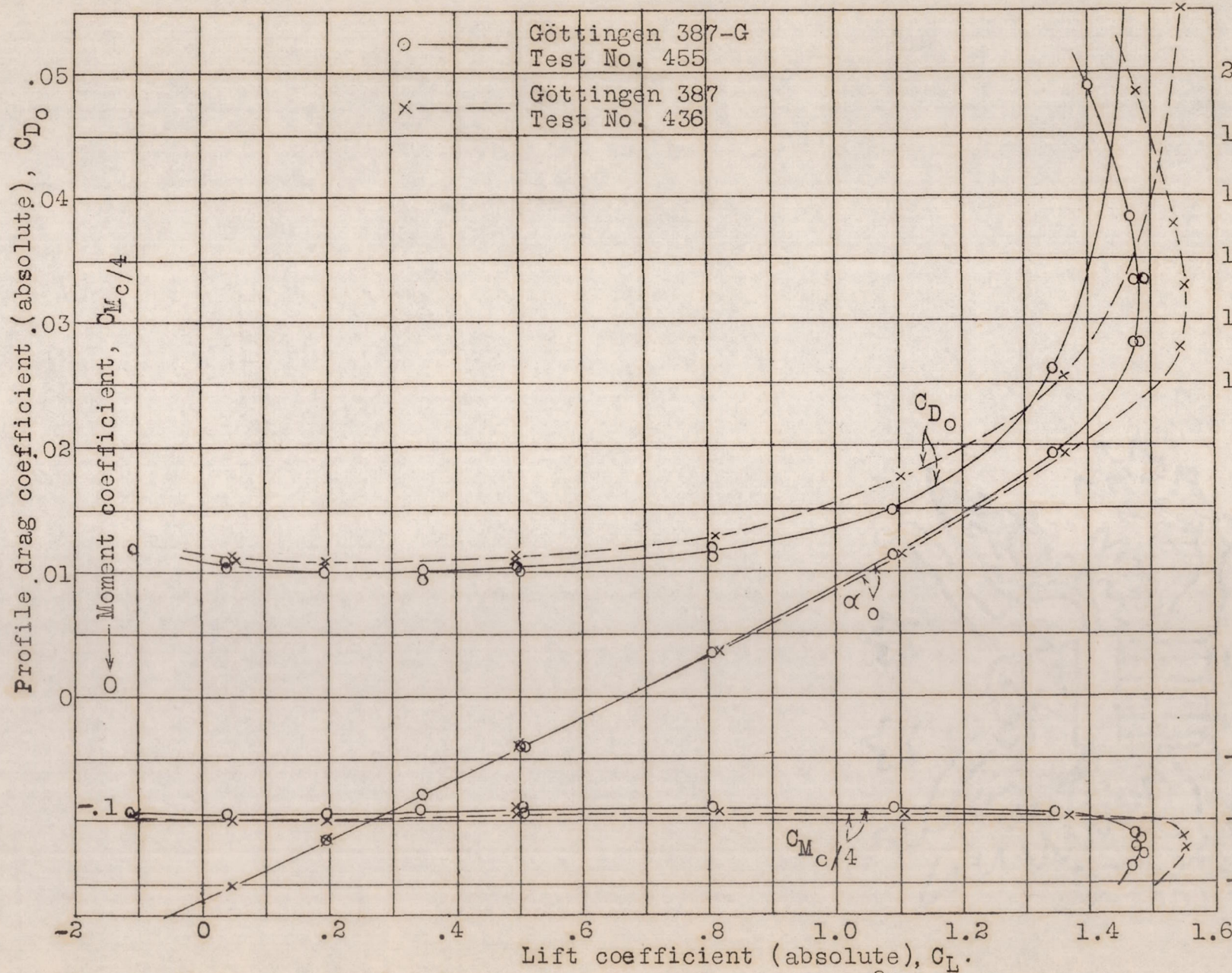

Fig. 5 Göttingen 387-G & Göttingen 387. R.N. = 3.4×10^6. Comparative curves.

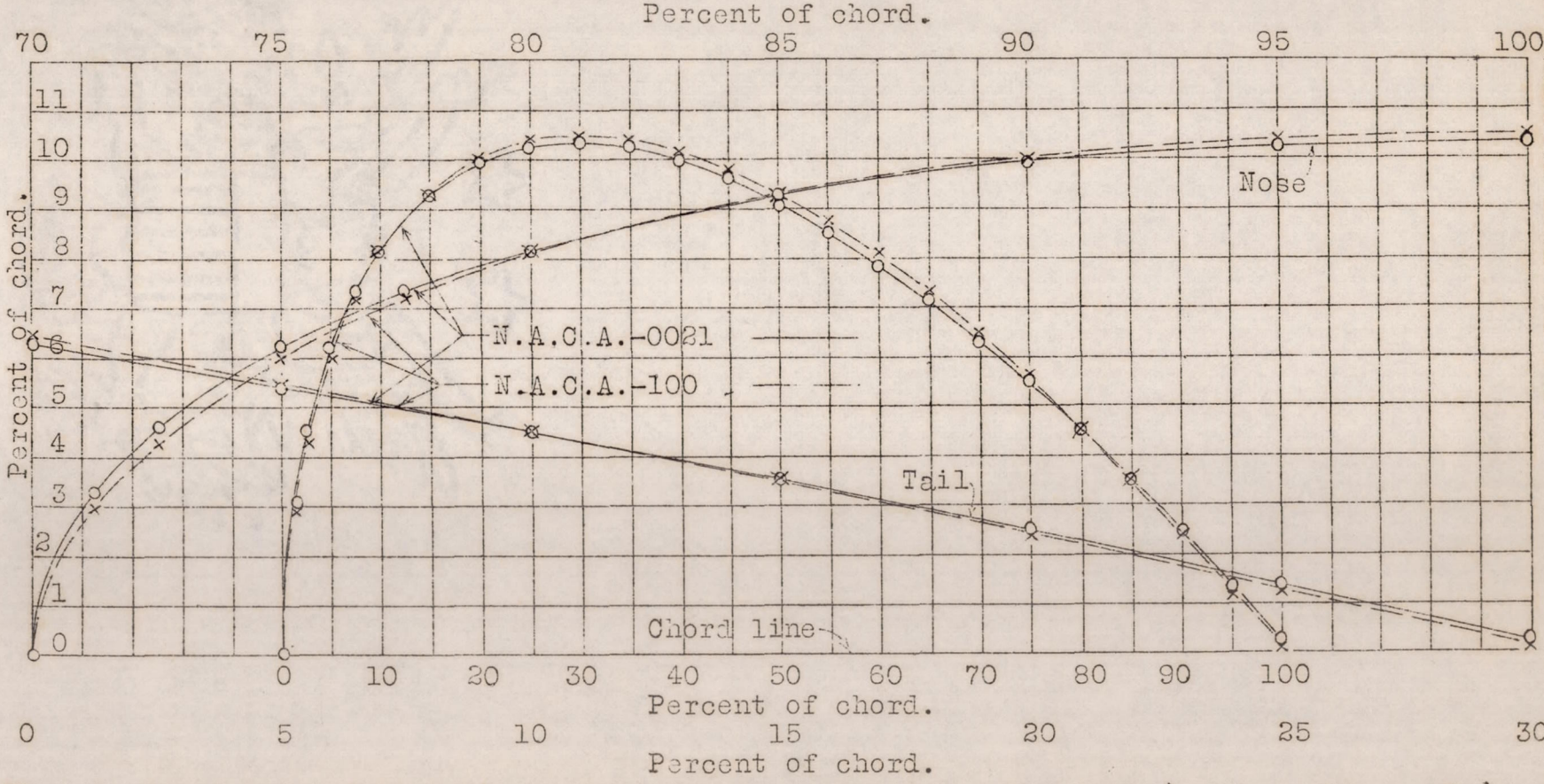

Fig. 6 Comparison of airfoil profiles N.A.C.A.-0021 & N.A.C.A.-100 (half profiles only). Measured ordinates.

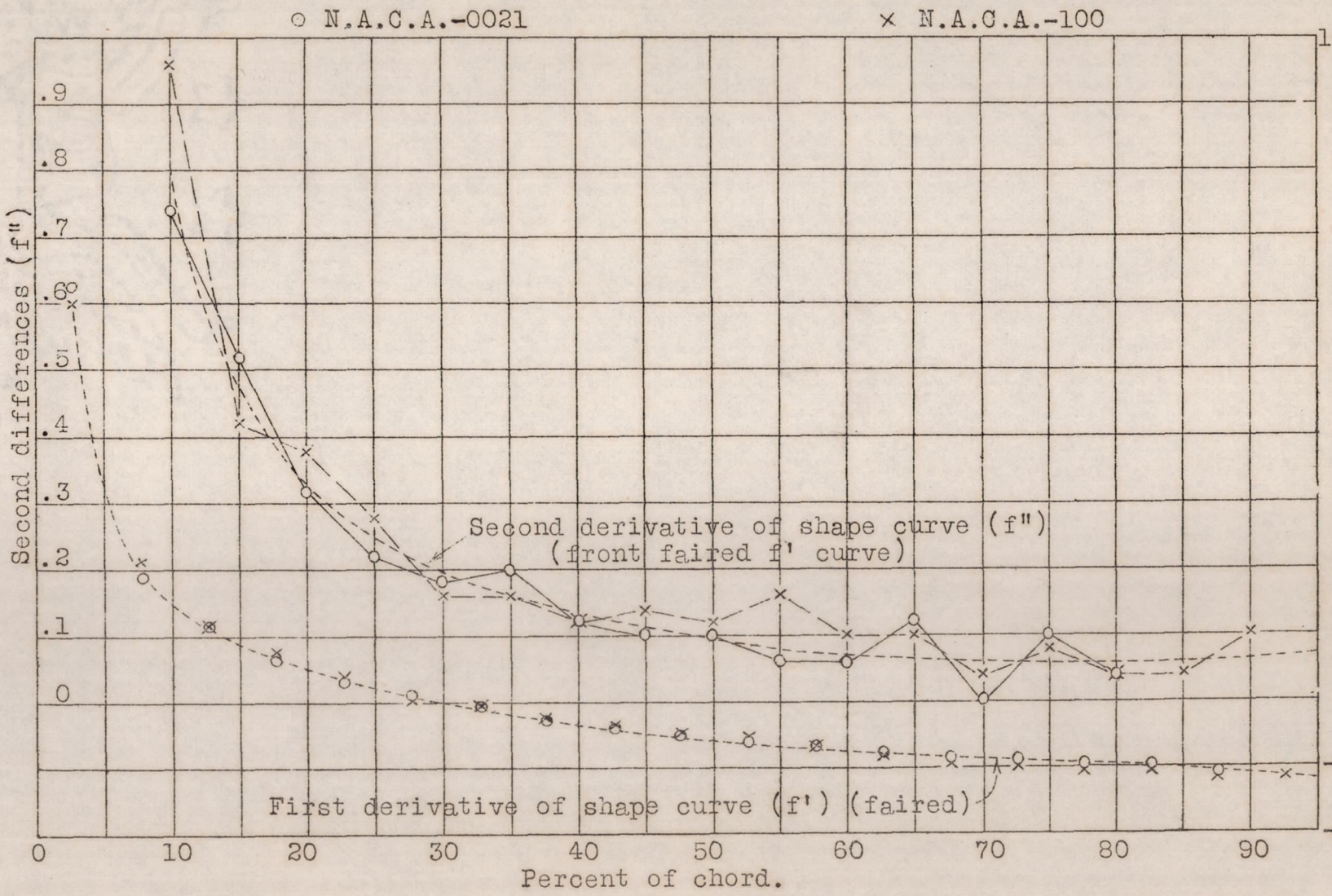

Fig. 7 Shape derivatives for N.A.C.A.-0021 & N.A.C.A.-100. From measured ordinates.

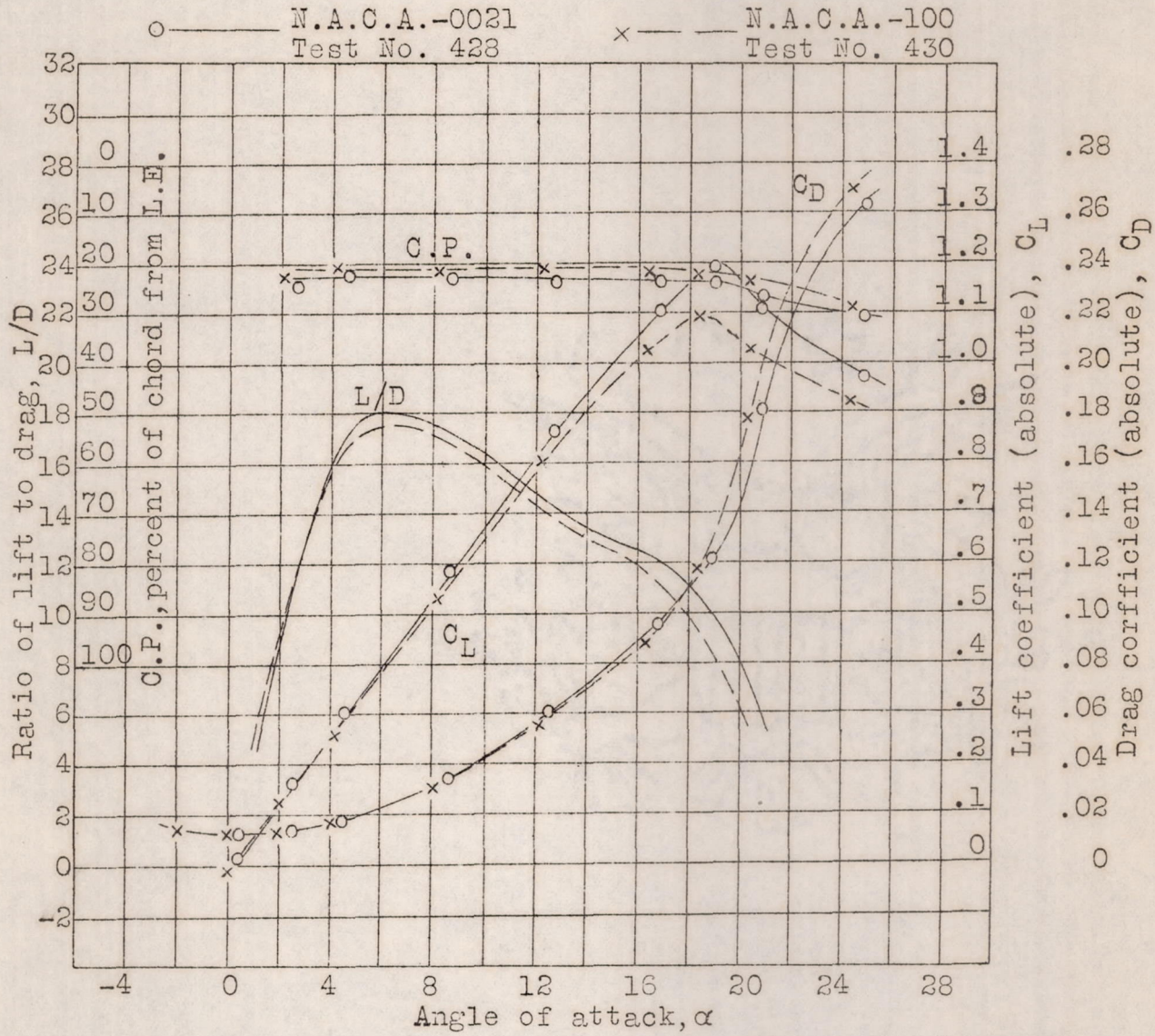

Fig. 8 Comparative curves for N.A.C.A.-0021 & N.A.C.A.-100. R.N. = 3.4×10^6. Corrected to aspect ratio 6 in free air.

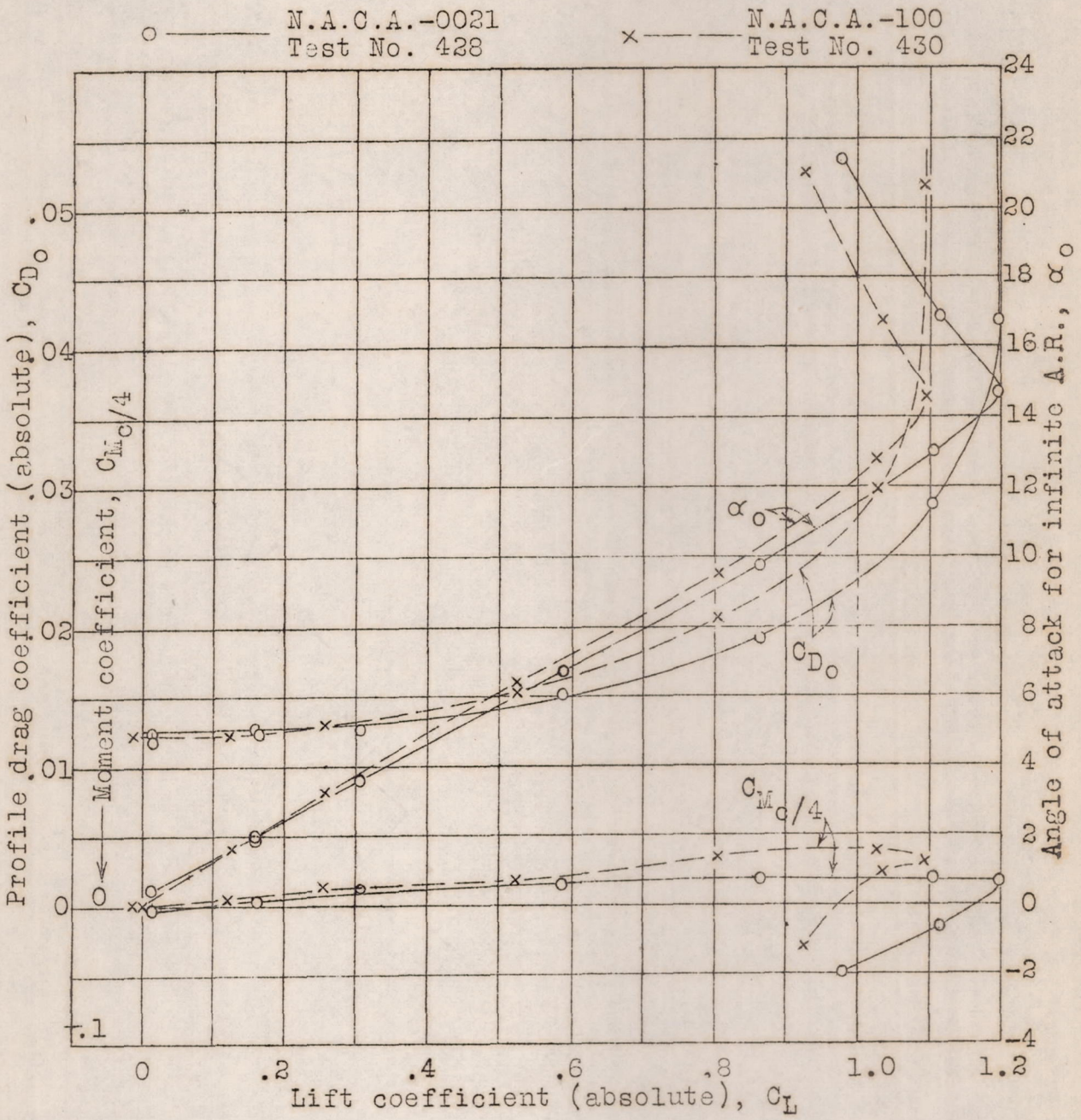

Fig. 9 Comparative curves for N.A.C.A.-0021 & N.A.C.A.-100
R.N. = 3.4×10^6