REPORT No. 152

THE AERODYNAMIC PROPERTIES OF THICK AIRFOILS, II

CONTINUATION OF REPORT No. 75

By F. H. NORTON and D. L. BACON
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SUMMARY.

This investigation was undertaken by the National Advisory Committee for Aeronautics as an extension of N. A. C. A. Report No. 75 for the purpose of studying the effect of various modifications in a given wing section, including changes in thickness, height of lower camber, taper in thickness, and taper in plan form with special reference to the development of thick, efficient airfoils. The method consisted in testing the wings in the N. A. C. A. 5-foot wind tunnel at speeds up to 50 meters (164 feet) per second while they were being supported on a new type of wire balance. Some of the airfoils developed showed results of great promise. For example, one wing (No. 81) with a thickness in the center of 4.5 times that of the U. S. A. 16 showed both a uniformly higher efficiency and a higher maximum lift than this excellent section. These thick sections will be especially useful on airplanes with cantilever construction.

INTRODUCTION.

In the past there have been a considerable number of tests made upon thick, constant section airfoils;[1] but the only systematic tests that have been published on thinned or tapered airfoils are given in N. A. C. A. Report No. 75. As the airfoils tested there were necessarily run at the low speed of 14.3 meters (46.9 feet) per second, some of that work has been repeated in the present report at speeds of from 30 to 50 meters (98.4 to 164 feet) per second in order to reduce the scale correction. The work has also been extended to many new types of section, but as there are so many variables to investigate this report is only the beginning of the subject. Further tests are now being carried out along lines indicated by the results obtained here, and there is reason to believe that both the structural and the aerodynamic efficiency can yet be considerably increased.

APPARATUS AND METHODS.

All the tests were run in the N. A. C. A. 5-foot wind tunnel which has been fully described elsewhere.[2] As the usual N. P. L. balance used in this tunnel was not adapted to holding wings at high speed or wings with thin tips at any speed, it was found necessary to design and construct a new type of balance for this work. After careful consideration of the various types of wind-tunnel balances it was decided that the most satisfactory for these conditions was the wire type of balance similar to that used in Germany. This balance will support the wing near its center and can be used at high-air speeds. A full description of this balance is given in Technical Note No. 65.

[1] Technische Berichte; R. & M. 322, British Advisory Committee; S. A. E. Journal, March, 1921.
[2] S. A. E. Journal, May, 1921.

All of the airfoils for this investigation were cut from laminated maple on the special machine described in N. A. C. A. Report No. 74. The models could be made very quickly in this way and with an accuracy better than 0.125 mm. (0.005 inch), although, if great care was taken, the surface could be worked to within 0.050 mm. (0.002 inch) of the given dimensions. At times some difficulty was experienced with the tips of the thin airfoils curling, owing to the impossibility of taking an equal amount of wood off from both sides of the blank; so that they had to be held in clamps till immediately before the tests. Excepting the cases where the plan form was tapered, all of the models were 76.2 by 457 mm. (3 by 18 inches).

The models were tested for lift, drag, and center of pressure from slightly above the angle of zero lift to beyond the burble point, at a standard speed of 30 meters (98.4 feet) per second, excepting in a few cases where additional tests were made at a higher speed. It should be noted that this tunnel is particularly free from turbulence due to the position of the honeycombs and that therefore the maximum lift given for each section is approximately 8 per cent lower than for the same sections tested in the M. I. T. wind tunnel. Comparison is made however with the U. S. A. 16 section tested under identical conditions.

The results were first plotted in polar diagrams using absolute lift and drag coefficients. This method of plotting was used as it combined the usual lift and drag in one curve, and it also has the advantage of simplicity when the theory of the wings is studied mathematically. The lift drag ratio of each wing is plotted against lift coefficient, as this method is considered the most satisfactory for showing the relative efficiency of the various aerofoils. The center of pressure is plotted, as is usual, against the lift coefficient.

SCOPE OF TESTS.

It should be noted that the section of the upper surface of every airfoil in this investigation is proportional to the master section, and that the lower surface is either flat or proportional to one master lower camber; that is, no attempt was made to perform experiments on the section itself, but only to determine the effect of thickening or thinning in various ways a master section having an initially good performance.

The first series investigated was a number of wings of varied thickness all proportional to the master section, as shown in figure 1. (Group A, Nos. 69, 66, 64, 68, and 71.) It was not expected that anything new would be learned fron this test, as experiments had been carried out before on a similar series of sections, but it was desired to obtain the coefficients of these particular sections for the purpose of comparison. The second series shown in figure 2 (Group B, Nos. 62, 64, 65, 61, and 77) was evolved by adding to the lower surface of the master section various degrees of lower camber, both positive and negative. The wings of the third series as shown in figure 3 (Group C, Nos. 54, 55, 56, 57, 58, and 73) were all of rectangular plan form but tapered in thickness from specified sections at the center of the span to an imaginary knife edge one chord length beyond the wing tip. The upper surfaces of these airfoils were all alike, while the lower surface was varied in camber. The wings of the fourth series as shown in figure 4 (Group D, Nos. 64, 59, 60, and 72) are tapered in plan form and all sections are geometrically similar to the master section, the bottom surfaces being in all cases flat. The span, the mean chord, and consequently the aspect ratio, are held the same for all of these sections.

After testing these four groups of airfoils it was apparent that something might be gained by combining in a new group the most desirable features of the wings already tested. In this way by superimposing the taper of Group B on the thinned airfoils of Group C the new Group CD was formed (Nos. 56, 79, and 82), figure 3a, and then by adding to this the convex lower surface of No. 73 there were obtained the more complex wings of the C′D′ Group (Nos. 73, 81, and 80) figure 3b. It will be noted that No. 64 is common to Groups A, B, and D, 56 to C and CD, and No. 73 to C and C′D′. To show the alterations in the various wing sections more clearly their characteristics are grouped together in Table I below:

TABLE I.—*Showing the characteristics and groupings of the sections.*

Maximum upper ordinates on 3-inch chord.	Maximum lower ordinates on 3-inch chord.	Constant section, Group B.	Thinned, Group C.	Tapered, Group D.			Tapered, Group CD.		
				4 by 2 inches.	5 by 1 inch.	6 by 0 inch.	4 by 2 inches.	5 by 1 inch.	6 by 0 inch.
	Inches.								
0.477	+0.154	No. 62	No. 54						
.477	+ .138		No. 55						
.477	0.00	No. 64	No. 56	No. 59	No. 60	No. 72	No. 79		No. 82
.477	− .123	No. 65							
.477	− .138		No. 57						
.477	− .154	No. 61	No. 58						
.477	− .184		No. 73				No. 81	Group C'D'.	No. 80

GROUP A.

0.230	0	No. 69							
.358	0	No. 66							
.477	0	No. 64							
.600	0	No. 68							
.800	0	No. 71							

PRECISION.

The models were originally constructed in all cases to within 0.125 mm. (0.005 inch) of the given dimensions. However, those airfoils, which were made very thin at the tips, had a tendency to curl slightly, so that the change in camber from this cause at the tip of the wing was at times as much as 0.25 to 0.37 mm. (0.01 to 0.015 inch), which accounts for the slight irregularity of the results on wings of this type. It also appears that some error is due to the difficulty of obtaining on the models the exact shape of the entering edge desired. The measurement of the forces can be considered accurate to 3 per cent, as a number of wings were checked to within this amount by retesting after readjusting the balance. The center of pressure measurements are good to better than 2 per cent of the chord.

The data has been plotted with as great a precision as the original values possessed, so that no error is introduced by this process. It should be noticed that there was tested on the same balance and under exactly the same conditions a standard wing, the U. S. A. 16, and that the corresponding coefficients have been plotted for comparison.

THE EFFECT OF VARYING THE HEIGHT OF THE UPPER CAMBER ON A FLAT-BOTTOMED SECTION.

GROUP A.

The effect of increasing the upper camber on both lift and drag is clearly shown in figure 5. Up to a thickness ratio of 0.28 the maximum lift increases as a linear function of the thickness ratio, and may be expressed by the formula: $C_L \text{ max.} = 0.87 + 2.5 \dfrac{\text{thickness}}{\text{chord}}$. It was found that the thickest section, No. 71, gave a decided break in the lift curve for the standard speed of test and that an air speed of 47.7 meters per second (106.7 m. p. h.) was necessary to eliminate this break. The data for this wing was therefore taken at this speed, and the coefficients are therefore slightly more favorable than would have been the case under the standard test conditions.

In figure 6 are shown the L/D curves for this series of wings and indicate nothing unusual except that the values are much higher at a speed of 30 meters (98.4 feet) per second than at 14.3 meters (46.9 feet) per second, at which speed most of the previous researches were performed.

In figure 7 are plotted the center of pressure curves for this series of sections. It is observed that the center of pressure moves further back on the wing as the section is thickened, or as the curvature of the median line increases.

THE EFFECT OF VARYING THE LOWER CAMBER ON THE MASTER SECTION.

GROUP B.

The lift and drag coefficients of Group B, as shown in figure 8, indicate that as the lower camber is made more convex the drag and the lift both decrease quite rapidly.

The L/D curves plotted in figure 9 show clearly that the maximum L/D as well as the L/D at low values of the lift coefficient increases with the convexity of the lower camber at least until a thickness ratio of 0.20 is reached. This very valuable property was not shown when tests were run on similar sections at 14.3 meters (46.9 feet) per second, and it is evident that the scale of the test increases the value of the thicker sections, and that even the order of merit of a series of airfoils may be altered by the change in scale.

The center of pressure curves given in figure 10 show a very similar form, excepting that they become more nearly horizontal and further forward with a more convex section.

It should be noted how valuable a moderate degree of convex camber is. It first increases the efficiency of the wing, especially at the high speeds; second, it allows more room for spars; and, third, it reduces the center of pressure travel. As the value of the convex camber is much more evident at high speeds of test in the wind tunnel it is very probable that in free flight the convex lower camber will be of even greater benefit.

THE EFFECT OF VARYING THE LOWER CAMBER OF AN AEROFOIL THINNED AT THE TIPS.

GROUP C.

The convex lower camber proved so advantageous on the uniform section wings that it was thought advisable to try the same alterations on wings thinned at the tips. The lift and drag coefficients for Group C are plotted in figure 11 and show the same characteristics noted under Group B, excepting that both the lift and drag are slightly lower as would be expected.

The L/D is plotted in figure 12 as before, and due to the thinner tips, the efficiency is much higher than for Group B, and it increases steadily as the lower camber is made more convex. The remarkably high efficiency of some of the thicker wings should be noticed; for example, the maximum L/D of 20.4 reached with section No. 73, which is a value considerably higher than that of the R. A. F. 15 or the U. S. A. 16 wings tested under the same conditions. The efficiency at low lift coefficients is correspondingly high, so that this type of wing would probably give an excellent high speed performance when applied to an airplane, and at the same time would allow the use of generous spars for cantilever construction.

The center of pressure curves are shown for this group in figure 13 and show less travel and a more forward position of the center of pressure for these airfoils than for the corresponding flat bottom wings, but otherwise exhibit no unusual features.

THE EFFECT OF TAPERING A WING IN PLAN FORM.

GROUP D.

The wings in Group D have everywhere a section proportional to the master section but taper in plan form in various degrees. The lift and drag of these sections are plotted in figure 14, and show little effect due to the tapering. It was found, however, that wing No. 72, for which the tips had a very small Reynolds number, had a much greater scale correction than the rectangular wings, which leads us to believe that the slight inferiority of the tapered wings does not hold for full scale construction, and it is quite possible that a highly tapered wing in full flight might have considerable aerodynamic advantages over a rectangular one.

The center of pressure travel is nearly independent of the taper as shown in figure 16, in spite of the fact that the moment of area about the Y axis is greater for the more tapered models. A further investigation by the method of pressure distribution explains this phenomena by showing that the center of pressure motion is proportionately smaller near the center of a tapered wing than near the tips.

It would appear from this that designers need have no fear in using wings of great chord near the body as the slope of the moment curve is the same as for rectangular wings of the same mean chord.

THE EFFECT OF BOTH THINNING AND TAPERING A FLAT-BOTTOMED AEROFOIL.

GROUP CD.

The airfoils of Group CD were formed by combining the plan form of Group D with the flat-bottomed tapered section of Group C as it was hoped that some valuable section might be developed in this way. The lift and drag curves for these sections are shown in figure 20 and indicate practically no difference between the rectangular and the medium tapered section. The wing which is tapered to a point at the tip however shows a considerable inferiority in lift which may be due to the scale effect.

The same thing is indicated in figure 18 for the L/D curve—that is, the section with the greatest taper is considerably inferior to the other two.

Center of pressure curves for this series are plotted in figure 19 and indicate that the center of pressure is slightly further forward at high angles of attack for the section having the greatest taper.

THE EFFECT OF BOTH THINNING AND TAPERING AN AEROFOIL HAVING A CONVEX LOWER SURFACE.

GROUP C'D'.

This series was studied as it was hoped that it would combine the good qualities of several of the other types of wing, and the excellent results obtained showed that our expectations were realized, and indicate that the rectangular and medium taper are nearly alike, but that the extreme taper has a lower lift coefficient as in the preceding series.

The L/D, which is plotted in figure 21, shows a slight decrease in the maximum with increase in taper, due probably to the reduction in scale at the wing tip. All of the wings however show good maximum values, in all cases above 18. The high speed efficiency of the wing seems to vary little with the taper.

The center of pressure curves plotted in figure 22 show, as before, a slightly further forward position for large tapers but the travel in that case is no greater.

It should be noted that all of the wings of this series are excellently adapted to an airplane with cantilever construction, as they are deep enough for internal bracing, have a fair value of the maximum lift coefficient, and have high efficiency at all speeds.

CONCLUSIONS.

As the aim of this investigation was to produce a wing with the most favorable aerodynamic properties combined with sufficient thickness to permit generous cantilever spars, it was thought that the best method of showing clearly the relative values of the various wings was to plot their important characteristics against the maximum thickness divided by the mean chord. This has been done in the charts shown in figures 23, 24, and 25.

Referring particularly to figure 23, where the maximum lift coefficient is plotted against the maximum thickness divided by the mean chord for each section, it will be seen that from the master section No. 64 there are a series of curves branching out in various directions representing the alterations made in this section. For example, taking Group A of flat-bottomed constant sections which are represented by circles, we obtain a curve starting with the flat plate and gradually rising to a maximum lift coefficient of 1.51 at a thickness ratio of 0.266. Intersecting this curve at the master section is the curve for Group B representing the sections with varying lower camber. Lower down another parallel curve represents the flattened airfoils of Group C with various lower cambers. The airfoil of Group D tapered in plan form is represented by a nearly horizontal line which reaches a high thickness ratio. Again the curves for the special series CD and C'D' closely resemble those for Group D but start from the points representing sections 56 and 73 of Group C rather than from the master section 64.

This chart is of value, as it will show us very closely the maximum lift coefficient for any new type of wings corresponding to a modification of the master section by its position on the chart without the necessity of making actual tests. It also shows us in what direction we should extend our research in order to produce the most marked improvement.

The minimum drag for the various sections is plotted in the same way in figure 24, and the effect on the minimum drag of increasing the lower camber is very clearly brought out. It is interesting to note that the minimum drag can be cut down nearly to the values obtained by the best thin sections now in use, even when the thickness is increased to as much as 0.441 of the chord, and it is expected that even greater thicknesses than these could be reached if it was found desirable without any marked increase in the minimum drag. As in the preceding chart, it is indicated here in what direction further research should be carried in order to produce the most valuable wing.

In the third chart, figure 25, the maximum L/D is plotted against the maximum thickness divided by the mean chord. This chart shows strikingly how greatly the thickness of the wings has been increased over that of the U. S. A. 16 and yet the same maximum efficiency has been retained.

For the sake of convenient comparison the various characteristics of all of the wings tested in this report are assembled in Table 2, together with those of the U. S. A. 16 wing tested under the same conditions.

TABLE II.

Group.	Airfoil.	Maximum thickness. / Mean chord.	Maximum C_L.	Minimum C_D.	Maximum L/D.
A	69	0.076	0.99	0.019	18.2
	66	.119	1.14	.022	19.2
	64	.159	1.32	.034	15.0
	68	.200	1.30	.044	14.1
	71	.267	1.51	.059	12.3
B	62	.108	1.55	.057	12.3
	64	.159	1.32	.034	15.0
	65	.200	1.19	.023	14.6
	61	.210	1.22	.020	14.9
	77	.231	1.18	.018	15.6
C	54	.108	1.22	.028	18.5
	55	.113	1.17	.029	19.1
	56	.159	1.12	.022	19.7
	57	.205	1.07	.017	19.9
	58	.210	1.04	.014	20.3
	73	.220	.95	.013	20.4
D	64	.159	1.32	.034	15.0
	59	.212	1.43	.036	15.6
	60	.265	1.34	.034	15.6
	72	.318	1.36	.037	13.6
CD	56	.159	1.12	.022	19.7
	79	.212	1.15	.023	18.6
	82	.318	.97	.023	15.0
C′D′	73	.220	.95	.013	20.4
	81	.295	1.03	.015	19.2
	80	.441	.83	.015	18.2
U. S. A.	16	.062	.94	.013	19.1

It may be stated in conclusion that wings of this size must be tested at least as fast as 30 meters (98.4 feet) per second to get results which may be used consistently on full-sized machines and that with heavily tapered wings this speed is probably not high enough to show their true value. It also seems quite probable that wings with a high convex lower camber will show up to considerably greater advantage in full scale conditions than they do in the tunnel, so that it is of the utmost importance to obtain tests on wings of this kind in free flight. It was also shown by these tests that the center of pressure travel on thick wings is not necessarily greater than on thin wings.

While some of the sections developed in this report probably combine more advantages in one airfoil than any sections so far developed, it is very probable that by using a different master section and by using other types of plan form that even better results can be obtained, and research is now being carried out in these directions.

STATIONS AND ORDINATES AT CENTER AND TIP OF SPAN FOR N. A. C. A. AEROFOILS—Group A.

Stations in per cent of chord.	No. 69.		No. 66.		No. 68.		No. 71.	
	Upper.	Lower.	Upper.	Lower.	Upper.	Lower.	Upper.	Lower.
0.00	0.96	0.96	1.50	1.50	2.52	2.52	3.35	3.35
1.25	2.17	0.10	3.38	0.15	5.66	0.25	7.55	0.34
2.50	2.77	0	4.31	0	7.23	0	9.64	0
5	3.76	0	5.85	0	9.81	0	13.08	0
7.50	4.62	0	7.20	0	12.08	0	16.10	0
10	5.33	0	8.31	0	13.92	0	18.56	0
15	6.30	0	9.81	0	16.45	0	21.93	0
20	6.90	0	10.75	0	18.03	0	24.03	0
30	7.58	0	11.80	0	19.79	0	26.37	0
*40	7.58	0	11.80	0	19.79	0	26.37	0
50	7.15	0	11.14	0	18.68	0	24.90	0
60	6.34	0	9.87	0	16.54	0	22.05	0
70	5.28	0	8.22	0	13.77	0	18.36	0
80	4.05	0	6.30	0	10.57	0	14.08	0
90	2.65	0	4.13	0	6.92	0	9.22	0
95	1.90	0	2.96	0	4.97	0	6.62	0
100	0.55	0.55	0.86	0.86	1.45	1.45	1.92	1.92
*33.3	7.66	0.00	11.93	0.00	20.00	0.00	26.66	0.00

No. 64 is the master section of this group and its ordinates are given with fig. 2, Group B.

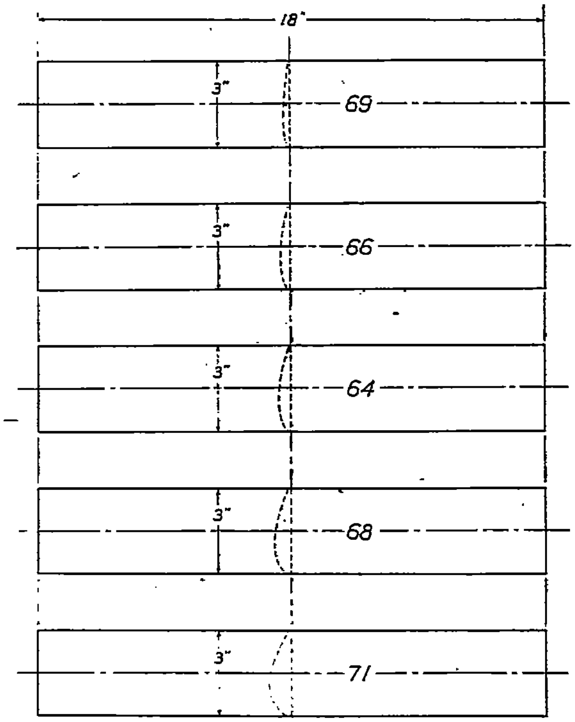

Fig. 1 GROUP-A

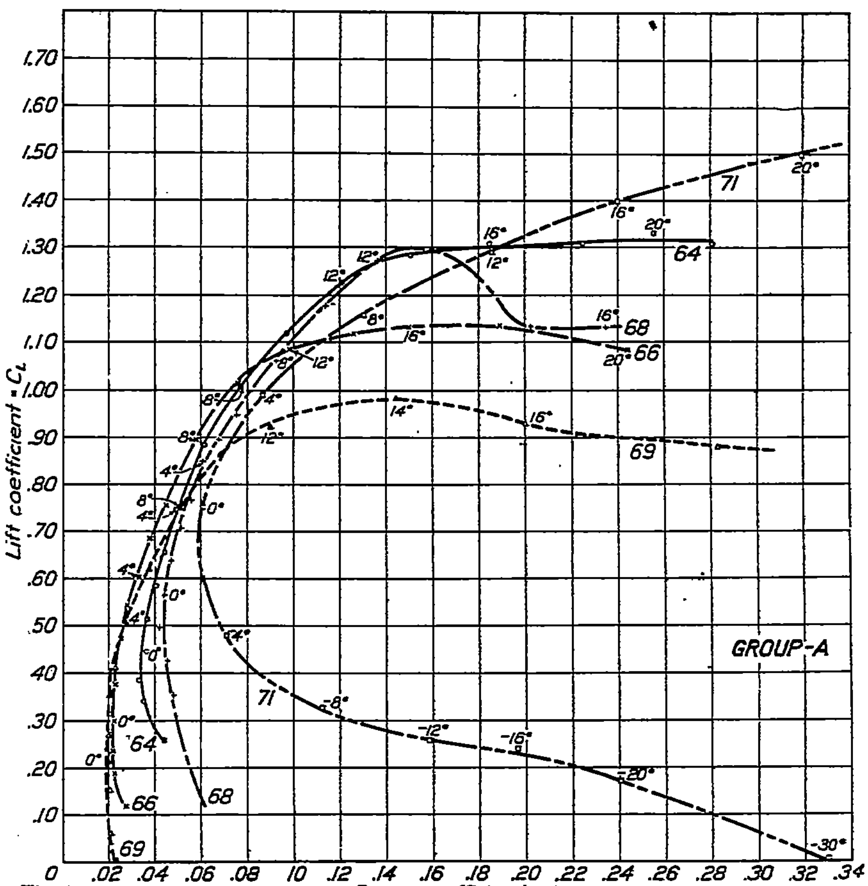

Fig. 5

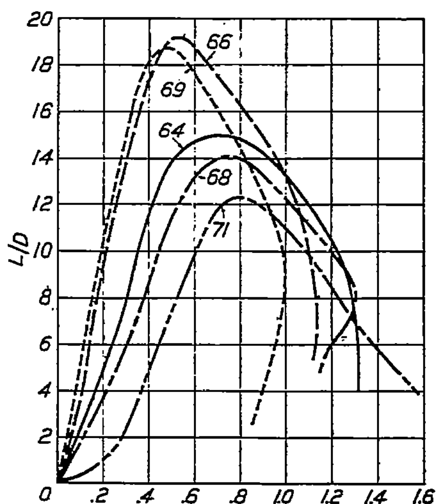

Fig. 6.

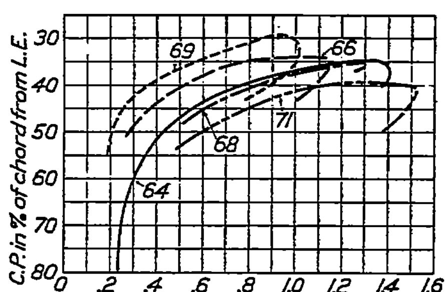

Fig. 7.

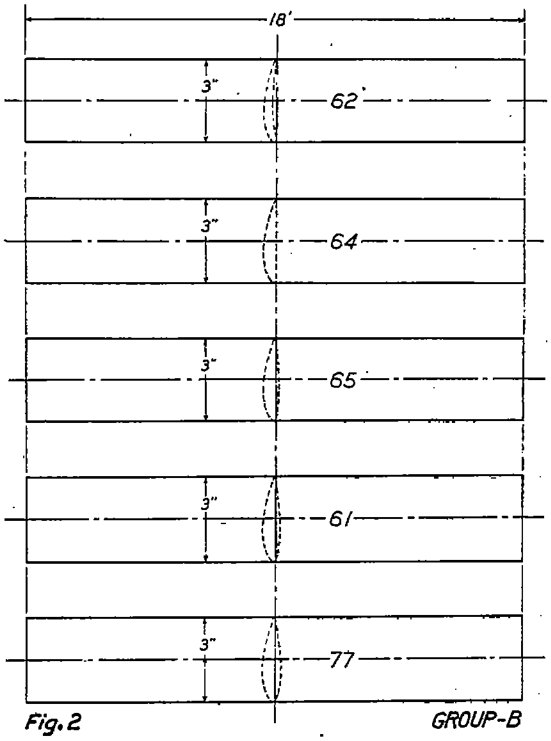

Fig. 2 GROUP-B

STATIONS AND ORDINATES AT CENTER AND TIP OF SPAN FOR N. A. C. A. AEROFOILS.—GROUP B.						
Stations, in per cent of chord.	Nos. 64–62, 65–61, 77–64,	No. 64.	No. 62.	No. 65.	No. 61.	No. 77.
	Upper.	Lower.	Lower.	Lower.	Lower.	Lower.
0	2.00	2.00	2.00	2.00	2.00	2.00
1.25	4.50	0.20	0.46	−0.37	−0.46	−0.64
2.50	5.75	0	0.75	−0.60	−0.75	−1.05
5	7.80	0	1.39	−1.11	−1.39	−1.94
7.50	9.60	0	1.94	−1.55	−1.94	−2.71
10	11.07	0	2.50	−2.00	−2.50	−3.50
15	13.08	0	3.44	−2.75	−3.44	−4.81
20	14.33	0	4.19	−3.35	−4.19	−5.86
30	15.73	0	5.04	−4.03	−5.04	−7.05
*40	15.73	0	5.04	−4.03	−5.04	−7.05
50	14.85	0	4.75	−3.80	−4.75	−6.65
60	13.15	0	4.17	−3.33	−4.17	−5.82
70	10.95	0	3.38	−2.70	−3.38	−4.72
80	8.40	0	2.41	−1.93	−2.41	−3.38
90	5.50	0	1.25	−1.00	−1.25	−1.75
95	3.95	0	0.63	−0.50	−0.63	−0.87
100	1.15	1.15	1.15	+1.15	+1.15	+1.15
*33.3	15.90	0.00	5.13	−4.10	−5.13	−7.17

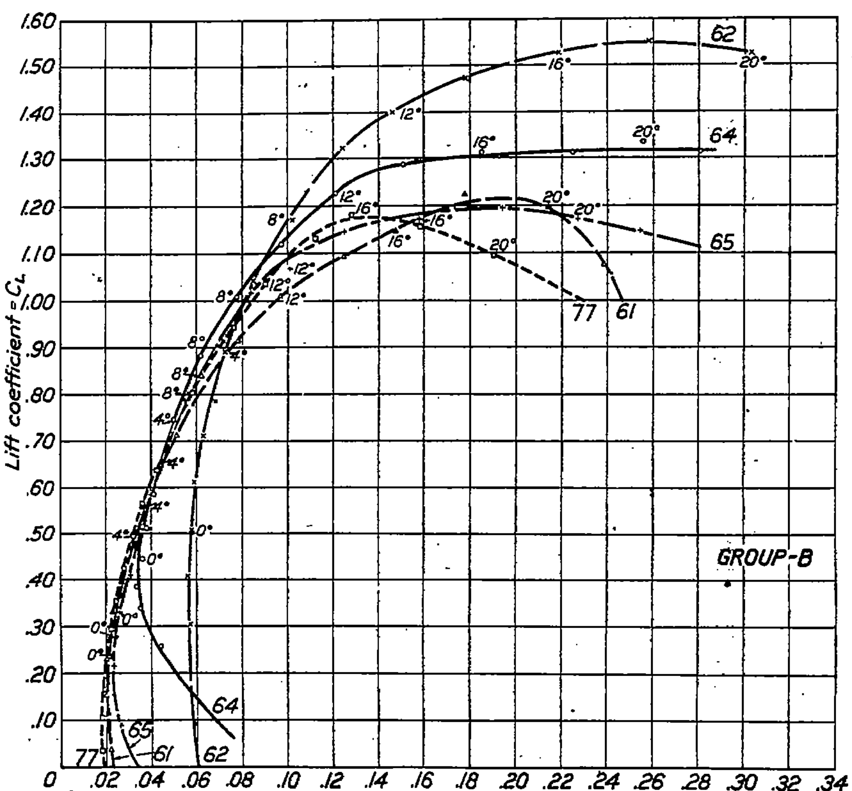

Fig. 8.

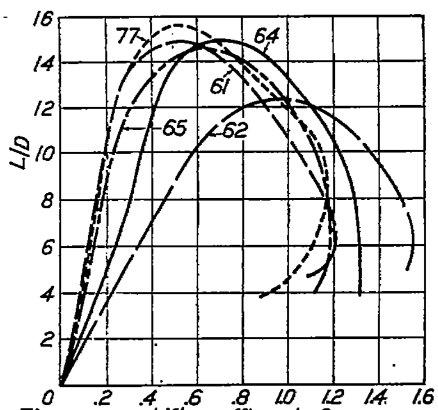

Fig. 9.

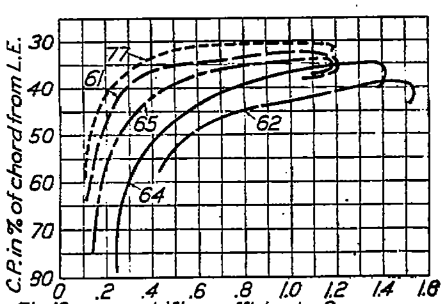

Fig. 10

Stations, in per cent of chord.	Nos. 54-55, 56-57, 58-73, Upper.	No. 54. Lower.	No. 55. Lower.	No. 56. Lower.	No. 57. Lower.	No. 58. Lower.	No. 73. Lower
Group C.—At Center of Span.							
0	2 00	2.00	2 00	2 00	2.00	2.00	2.00
1.25	4.50	0.46	0.42	0.20	0.42	−0.46	−0.56
2.50	5 75	0.75	0.67	0	−0.67	−0.75	−0.90
5	7.80	1.39	1.25	0	−1.25	−1.39	−1.67
7.50	9.60	1.94	1.74	0	−1.74	−1.94	−2.33
10	11.07	2.50	2 24	0	−2.24	−2.50	−3.00
15	13.08	3.44	3 09	0	−3.09	−3.44	−4.13
20	14.33	4.19	3 76	0	−3.76	−4.19	−5.03
30	15.73	5.04	4 52	0	−4.52	−5.04	−6.05
*40	15.73	5.04	4 52	0	−4.52	−5 04	−6.05
50	14.85	4.75	4 26	0	−4.26	−4.75	−5.70
60	13.15	4.17	3 74	0	−3.74	−4.17	−5.00
70	10.95	3.38	3.03	0	−3.03	−3.38	−4.05
80	8.40	2.41	2.17	0	−2.17	−2.41	−2.90
90	5.50	1.25	1.12	0	−1.12	−1.25	−1.50
95	3.95	0.63	0.56	0	−0.56	−0.63	−0.75
100	1.15	1.15	1.15	1.15	+1.15	+1.15	+1.15
*33.3	15.90	5.13	4.60	0.00	−4.60	−5.18	−6.15
At Tip of Span.							
0	0.50	0.50	0.50	0.50	0.50	0 50	0.50
1.25	1.12	0.12	0.10	0 05	−0.10	−0.12	−0.14
2.50	1.44	0 19	0.17	0	−0.17	−0.19	−0.22
5	1.95	0.35	0 31	0	−0.31	−0.35	−0.42
7.50	2 40	0.48	0.43	0	−0.43	−0.48	−0 58
10	2.76	0.62	0.56	0	−0.56	−0 62	−0.75
15	3 27	0.86	0.77	0	−0.77	−0.86	−1.03
20	3.58	1.05	0.94	0	−0.94	−1.05	−1.26
30	3.93	1.26	1.13	0	−1.13	−1.26	−1.51
*40	3 93	1.26	1.13	0	−1.13	−1.26	−1.51
50	3.71	1.19	1 07	0	−1.07	−1.19	−1.43
60	3.28	1.04	0.93	0	−0.93	−1.04	−1.25
70	2 73	0.84	0.76	0	−0.76	−0.84	−1.01
80	2.10	0.60	0.54	0	−0.54	−0.60	−0.72
90	1.37	0.31	0.28	0	−0.28	−0.31	−0 38
95	0.99	0.16	0.14	0	−0.14	−0.16	−0.19
100	0.29	7.29	0.29	0.29	+0.29	+0.29	+0 29
*33.3	3.97	1.28	1.15	0.00	−1.15	−1.28	−1.54

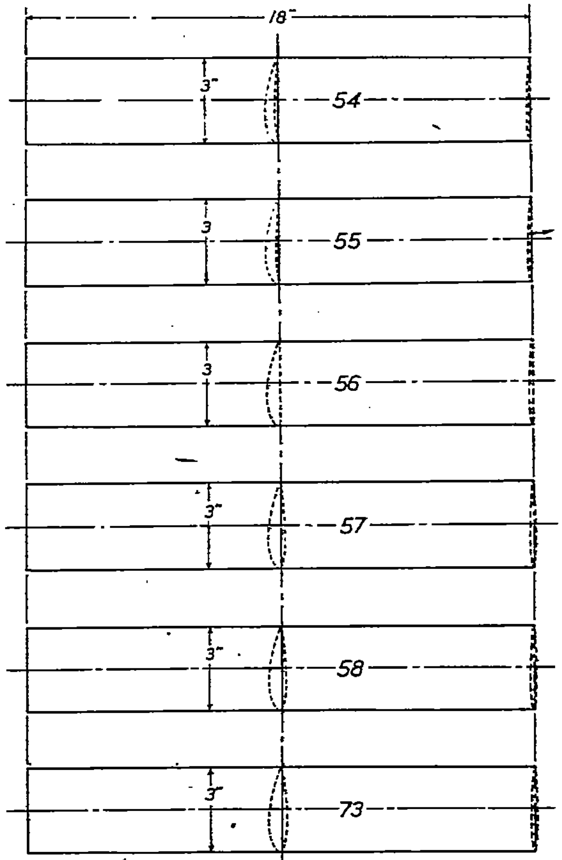

Fig.3

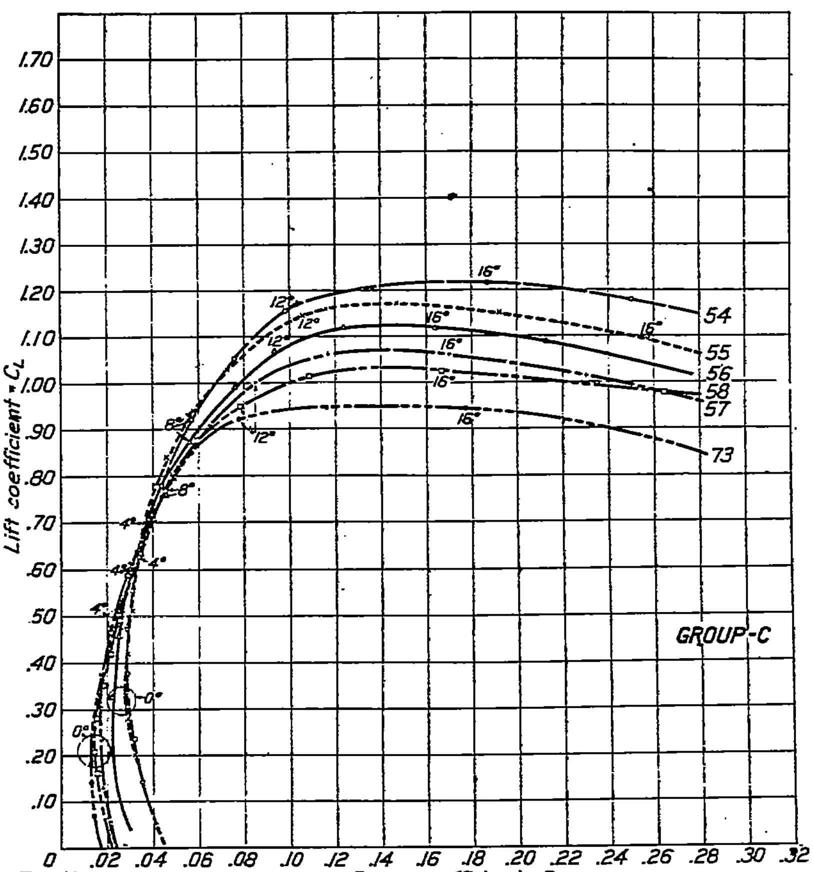

Fig. 11

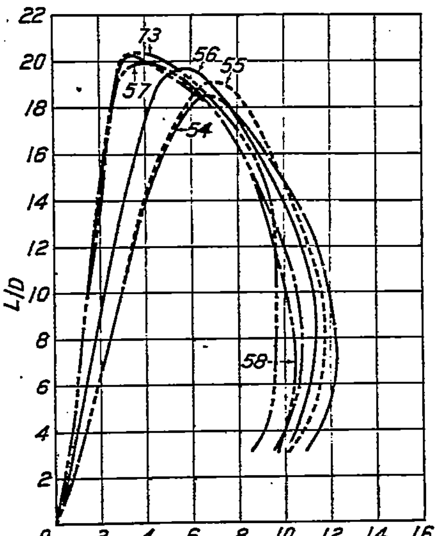

Fig. 12

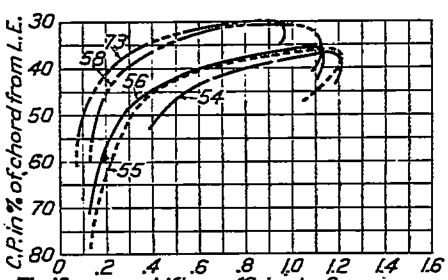

Fig. 13

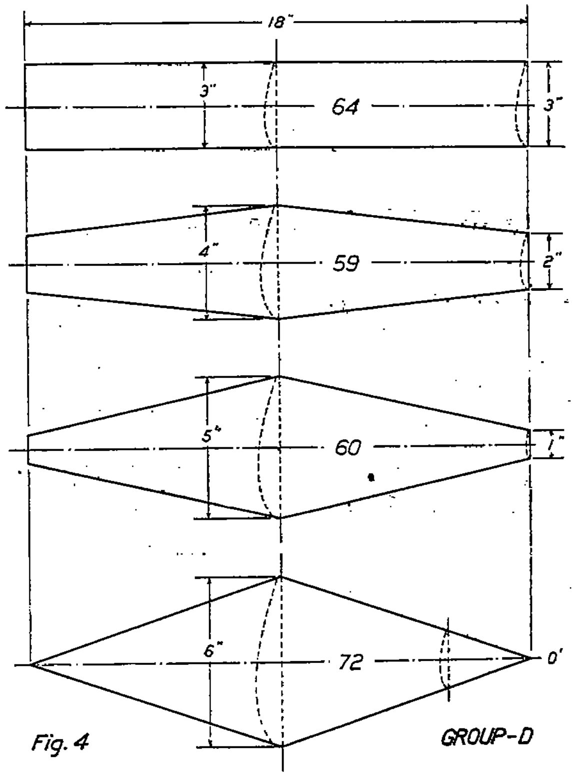

Fig. 4

STATIONS AND ORDINATES FOR N. A. C. A. AIRFOILS—GROUP D.						
Stations in per cent of chord.	Nos. 64, 59, 60, center and tip.		No. 72, center of span.		No. 72, tip of span.	
	Upper.	Lower.	Upper.	Lower.	Upper.	Lower.
0	2.00	2.00	2.00	2.00	Chord and ordinate tapered to a point.	
1.25	4.50	0.20	4.50	0.20		
2.50	5.75	0	5.75	0		
5	7.80	0	7.80	0		
7.50	9.60	0	9.60	0		
10	11.07	0	11.07	0		
15	13.08	0	13.08	0		
20	14.33	0	14.33	0		
30	15.73	0	15.73	0		
*40	15.73	0	15.73	0		
50	14.85	0	14.85	0		
60	13.15	0	13.15	0		
70	10.95	0	10.95	0		
80	8.40	0	8.40	0		
90	5.50	0	5.50	0		
95	3.95	0	3.95	0		
100	1.15	1.15	1.15	1.15		
*33.3	15.90	0.00	15.90	0.00		

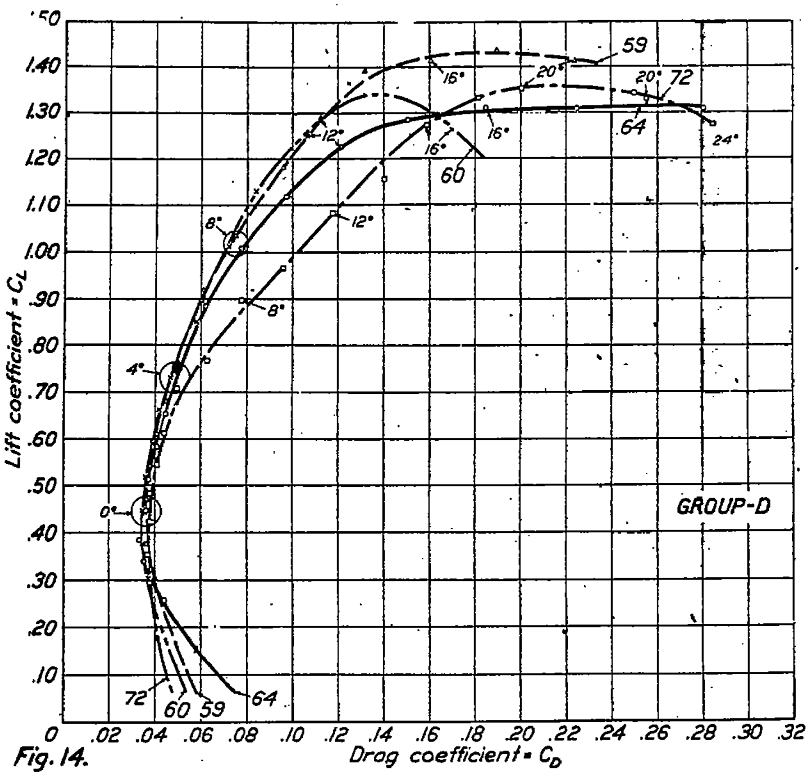

Fig. 14.

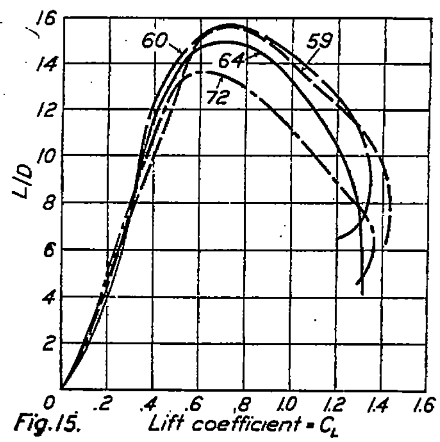

Fig. 15.

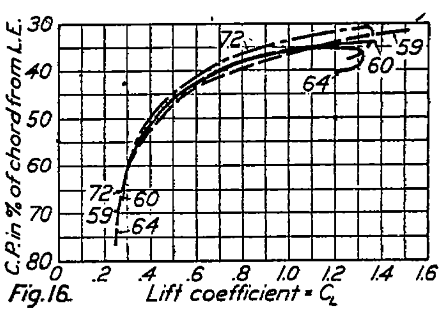

Fig. 16.

STATIONS AND ORDINATES FOR N. A. C. A. AIRFOILS—GROUP CD.

Stations in per cent of chord.	Nos. 56, 79, 82, center of span.		Nos. 56, 79, tip of span.		No. 82, tip of span.	
	Upper.	Lower.	Upper.	Lower.	Upper.	Lower.
0	2.00	2.00	0.50	0.50	Chord and ordinate tapered to a point.	
1.25	4.50	0.20	1.12	0.05		
2.5	5.75	0	1.44	0		
5	7.80	0	1.95	0		
7.5	9.00	0	2.40	0		
10	11.07	0	2.70	0		
15	13.08	0	3.27	0		
20	14.33	0	3.58	0		
30	15.73	0	3.93	0		
*40	15.73	0	3.93	0		
50	14.85	0	3.71	0		
60	13.15	0	3.28	0		
70	10.95	0	2.73	0		
80	8.40	0	2.10	0		
90	5.50	0	1.37	0		
95	3.95	0	0.99	0		
100	1.15	1.15	0.29	0.29		
*33.3	15.90	0.00	3.97	0.00		

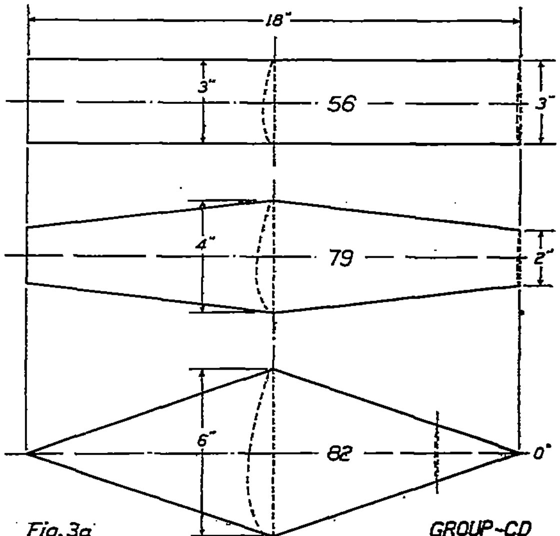

Fig. 3a

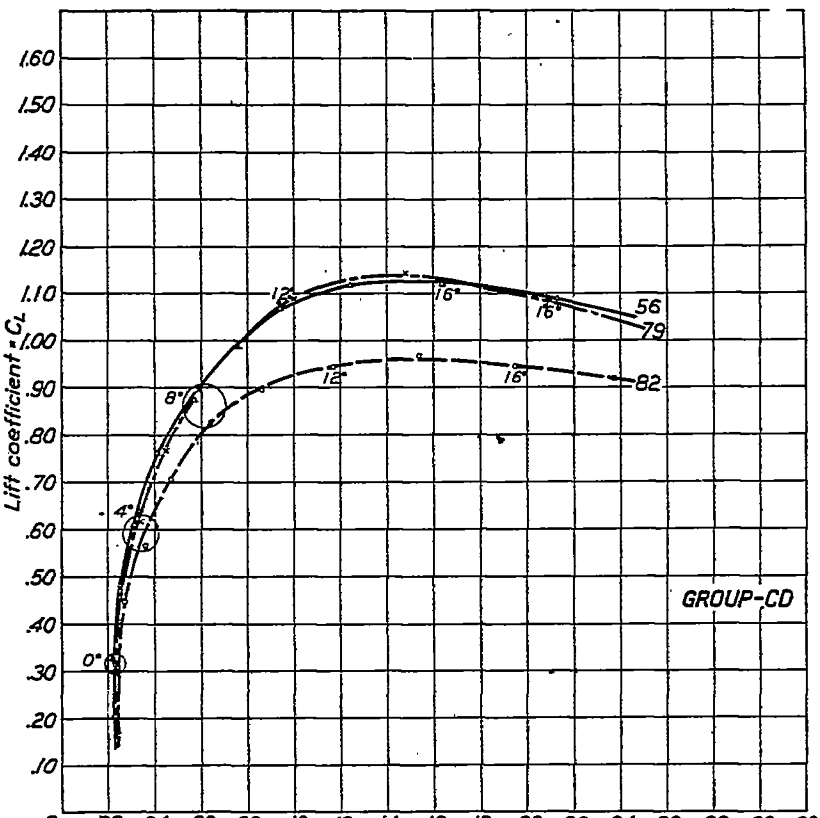

Fig. 17.

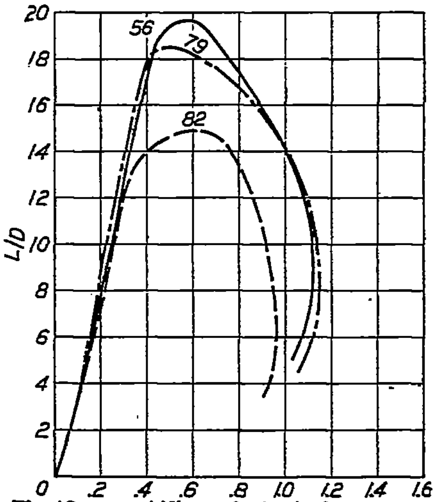

Fig. 18

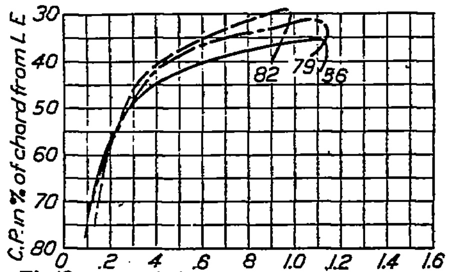

Fig. 19

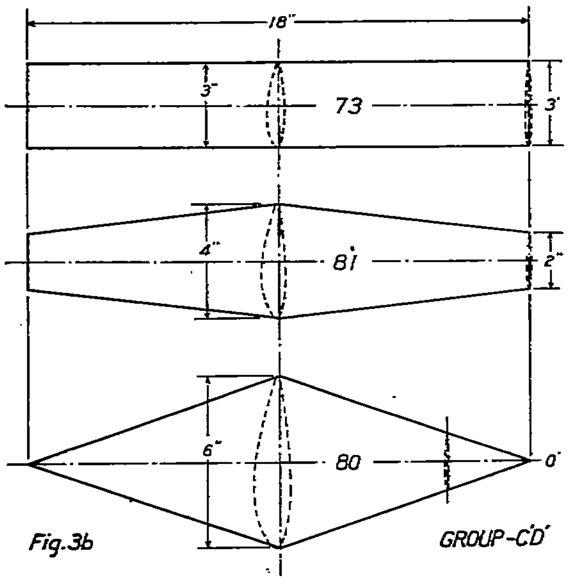

Fig. 3b

STATIONS AND ORDINATES FOR N. A. C. A. AIRFOILS—GROUP C'D'.

Stations in per cent of chord.	Nos. 73, 80, 81, center of span		Nos. 73, 81, tip of span.		No. 80, tip of span.	
	Upper.	Lower.	Upper.	Lower.	Upper.	Lower.
0	2.00	2.00	0.50	0.50	Chord and ordinate tapered to a point.	
1.25	4.50	−0.53	1.12	−0.14		
2.5	5.75	−0.90	1.44	−0.22		
5	7.80	−1.67	1.95	−0.42		
7.5	9.60	−2.33	2.40	−0.58		
10	11.07	−3.00	2.76	−0.75		
15	13.08	−4.13	3.27	−1.03		
20	14.33	−5.03	3.58	−1.23		
30	15.73	−6.05	3.93	−1.51		
*40	15.73	−6.05	3.93	−1.51		
50	14.85	−5.70	3.71	−1.43		
60	13.15	−5.00	3.28	−1.25		
70	10.95	−4.05	2.73	−1.01		
80	8.40	−2.90	2.10	−0.72		
90	5.50	−1.80	1.37	−0.38		
95	3.95	−0.75	0.99	−0.19		
100	1.15	+1.15	0.29	+0.29		
*33.3	15.90	−6.15	3.97	−1.54		

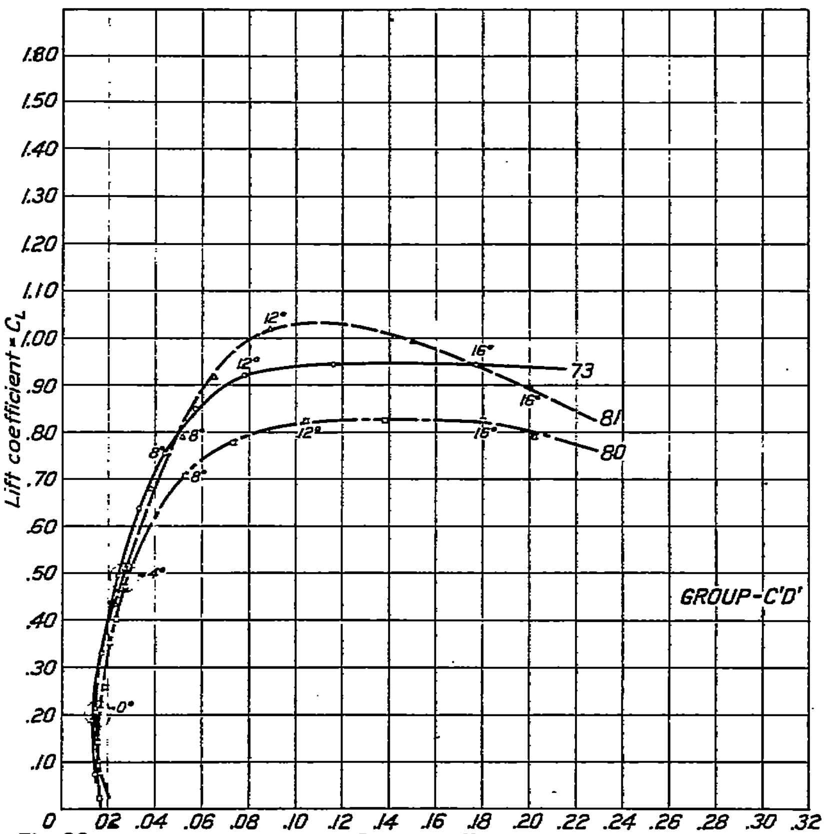

Fig 20

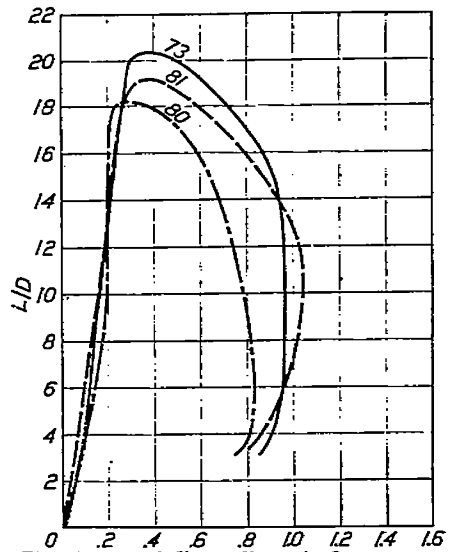

Fig. 21

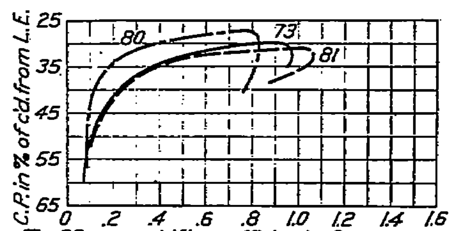

Fig. 22

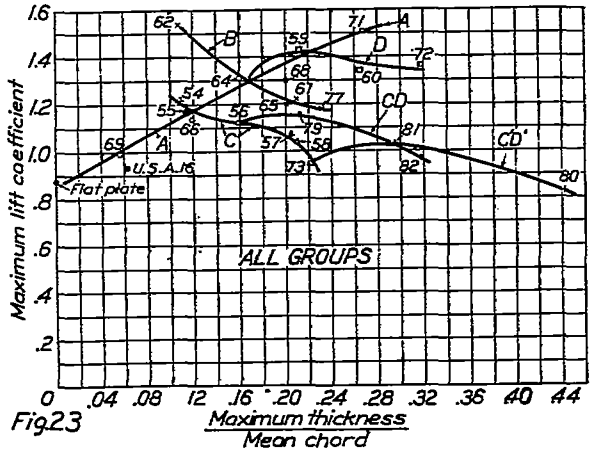

Fig.23

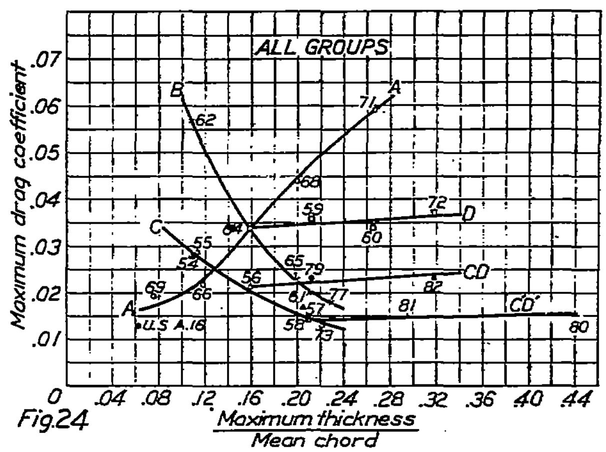

Fig.24

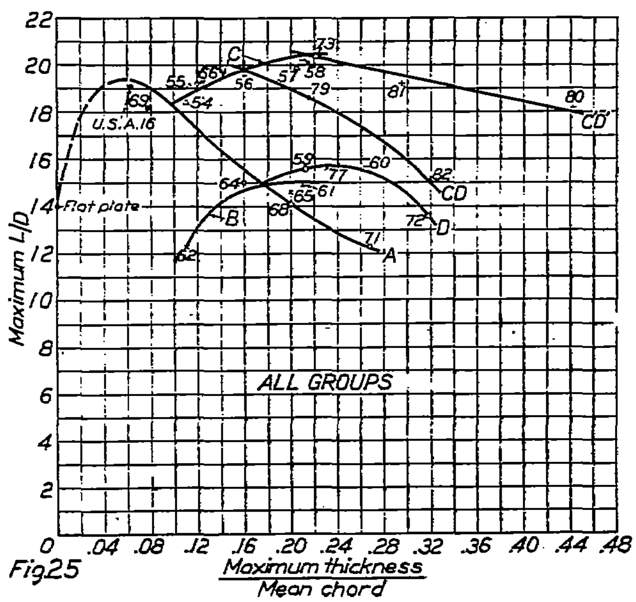

Fig.25