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REPORT No. 75

THE AERODYNAMIC PROPERTIES OF THICK AEROFOILS SUITABLE FOR INTERNAL BRACING

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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THE AERODYNAMIC PROPERTIES OF THICK AEROFOILS SUITABLE FOR INTERNAL BRACING

BY

F. H. NORTON

Aerodynamical Laboratory, National Advisory Committee for Aeronautics,
Langley Field, Va.

REPORT No. 75.

THE AERODYNAMIC PROPERTIES OF THICK AEROFOILS SUITABLE FOR INTERNAL BRACING.

By F. H. NORTON.

INTRODUCTION.

The object of this investigation is the determination of the characteristics of various types of wings having sufficient depth to entirely inclose the wing bracing, and also to provide data for the further design of such sections. This type of wing is of interest—first, because it eliminates the resistance of the interplane bracing, a portion of the airplane that sometimes absorbs one-quarter of the total power required to fly; second, because it simplifies the construction and assembly of the wing structure, and, third, because these wings may be made to give a very high maximum lift. At the present time, thick internally braced sections are used with considerable success on several German machines, notably the Fokker and Junker biplanes. This type of wing was not original with the Germans, however, for an Antoinette monoplane was built and flown in France about 1910, which was entirely braced from inside the wing section. This wing was flat bottomed and had a maximum h/c ratio of one-sixth.

It was intended to investigate the following subjects:

1. Effect of changing the upper and lower camber of thick aerofoils of uniform section.
2. Effect of thickening the center and thinning the tips of a thin aerofoil.
3. Effect of adding a convex lower surface to a tapered section.
4. Effect of changing the mean thickness with constant center and tip sections.
5. Effect of varying the chord along the span.
6. Effect of varying the thickness and chord in a more complex manner.

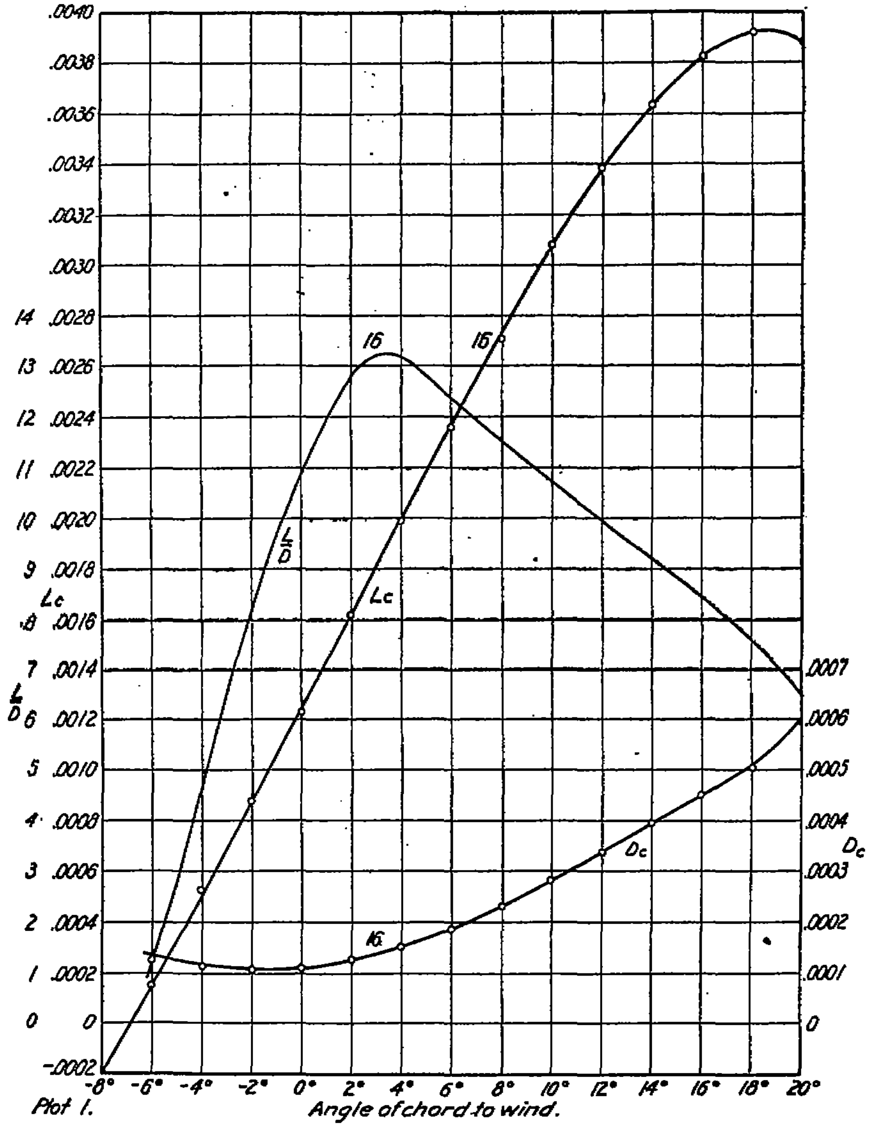
The last subject is not yet completed and will be treated later.

All the sections in this test unless otherwise stated are square ended 3 by 18 inch models, tested with an end spindle at 30 M. P. H. and are comparable with the tests of the U. S. A. sections. Lc and Dc are in pounds per square foot and M. P. H. units, and the center of pressure is given in fractions of the chord from the leading edge. The results have a precision of about 1 per cent.

THICK CONSTANT SECTION WINGS.

The Durand 13 section gave such an unusually high maximum lift that some slight changes were made in the upper camber to determine its best form and height. The surfaces were made of wax, scraped to size as described in report No. 74. As some of these sections were tested by students and the ordinates were not as accurately produced as in the later sections, the results of the runs are not plotted here. (See the bulletin of the Experimental Department Airplane Engineering Division, December, 1918.) They are sufficiently precise, however, to warrant general conclusions. Except for the higher and more stable maximum lift, these sections gave results that are in agreement with the N. P. L tests on varying the upper and lower camber.

On thick sections the maximum ordinate must be kept closely to one-third of the chord from the leading edge. Moving it farther back gives a flatter, but lower burble point, while moving it forward gives a lower and very unstable lift curve. With the maximum ordinate one-third of the chord from the leading edge and a section similar to the Durand 13, the highest maximum lift is reached when the greatest thickness is about 0.477 inch on a 3-inch chord. Beyond this height, the lift curve is unstable and decreases with increase in camber. A section was tried with a thin trailing edge, but there was no improvement and the lift curve had a very bad break in it. The Durand 13 section was also tested with a Constantin type of leading edge. The lift increased rapidly to about 10°, then slowly to about 30°. The maximum Lc and the maximum L/D were not improved, however, with this change. It seems evident that the best upper camber has a maximum height of about 0.477 inch on a 3-inch chord, one-third of the way from the leading edge, giving a maximum Lc of about 0.00400 and a maximum L/D of 13.

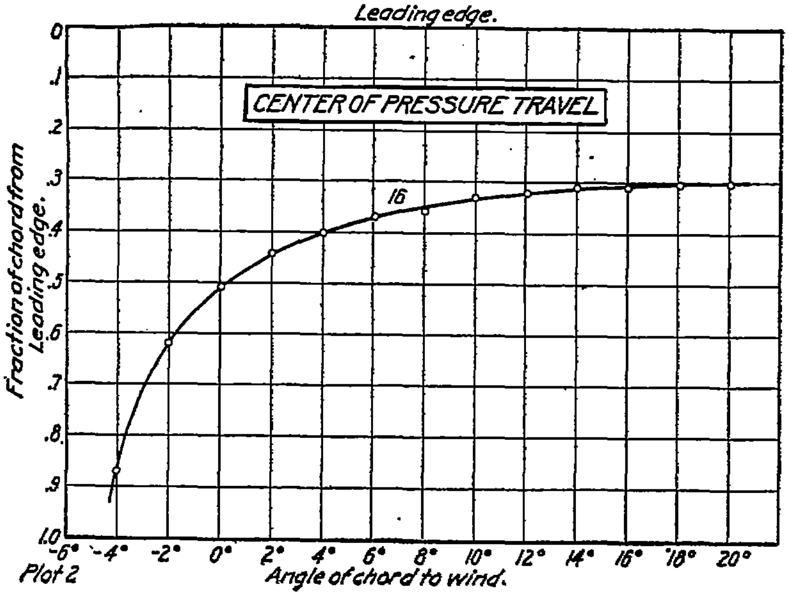


Plot I.

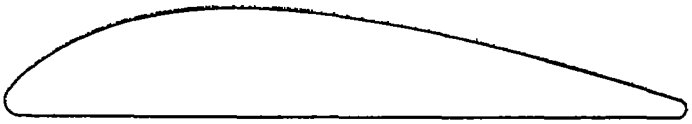
The lower surface has less effect on the aerofoil than the upper. As this surface is made more convex the lift and the drag decrease until a minimum drag is reached when the section is symmetrical. The minimum drag also moves to lower angles as the lower surface is made more convex. The maximum L/D is not affected by small changes in the lower surface, but the L/D at low angles is improved by a small convex camber. One section with a concave lower surface was interesting, in that it showed a positive, but unstable, lift at −40° incidence. Its maximum value for L^c was 0.00422. Several other irregular lower surfaces were tried, but showed no great improvement over the flat lower surface.

The best flat bottomed section (used as the master section, Fig. 3) seems to be No. 16, which has an h/c ratio of 0.158, a maximum Lc of (0.00392), and a maximum L/D of (13.1). The lift, drag, and L/D for this section are plotted on Plot 1 and the C. P. movement on Plot 2. To illustrate the decrease in wing area allowed by using this wing section, we may take as an example a high-powered machine weighing 4,000 pounds and having a wing area (R. A. F. 15 section) of 450 square feet, a loading of about 9 pounds per square foot. To have the same landing speed an area of 300 square feet would be sufficient with the No. 16 section.

These wings of deep constant section are satisfactory in respect to spar room and maximum lift, but the L/D is about 20 per cent lower than for the wings used at present.



Plot 2



MASTER SECTION

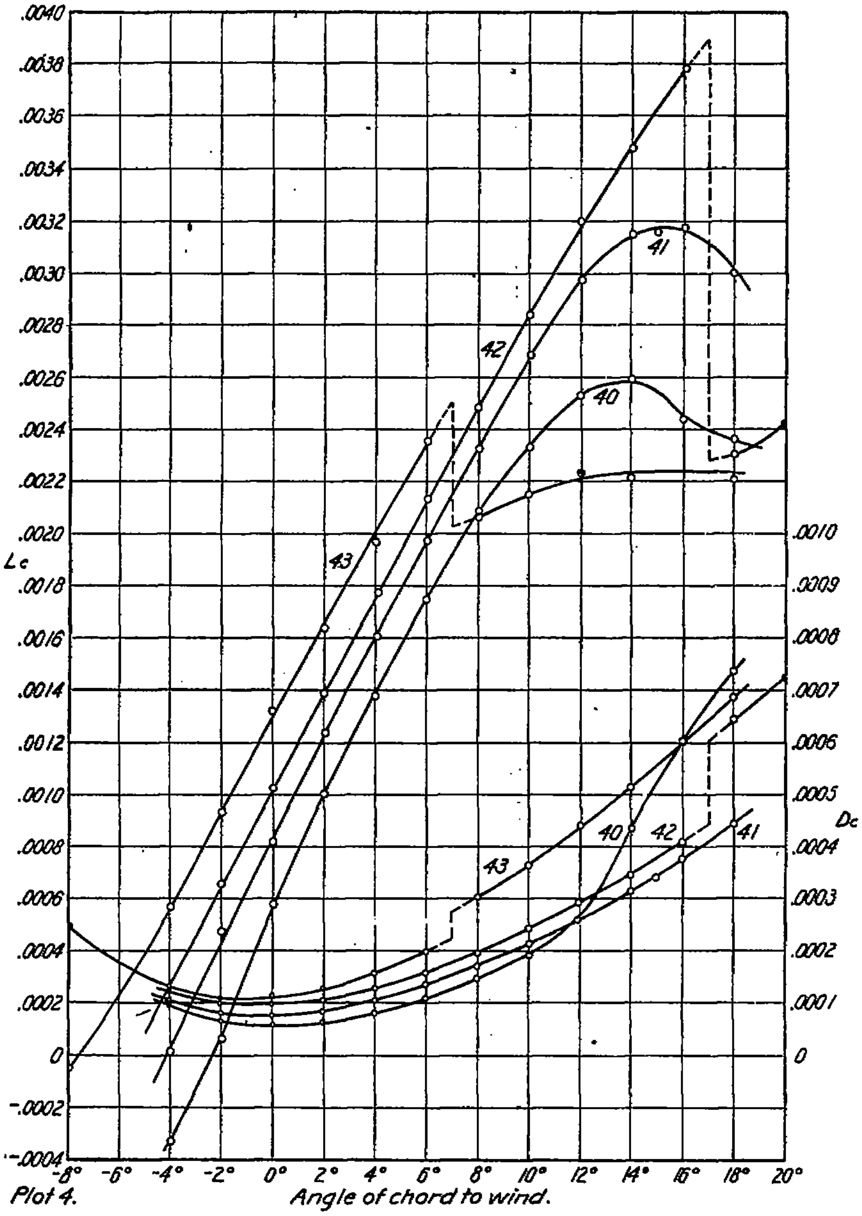
3X Model Size Center Section for #42 and #46

FIGURE 3.

THE EFFECT OF THICKENING THE CENTER OF A THIN WING.

The object of this test is to determine the effects of thickening the center of the span, and thinning the tips, of a standard type of section. All sections through these wings, perpendicular to the leading edge, are similar to a master section, a modified Durand 13 (Fig. 3). All ordinates were obtained by reducing from the corresponding ordinate of the master section in the same proportion as the maximum ordinate is reduced by a smooth curve from the center to the tip of the wing. This curve is nearly parabolic with its vertex at the center of the span. All sections were made flat bottomed for ease in cutting. There are two series, No. 40–No. 43, where the section at the tip has a chord to depth ratio 13, and the center of the span is thickened successively, and No.44–No. 46 where the tip has a chord to depth ratio of 25 and the center is successively thickened in the same way except that the deepest section is omitted because of its obvious unsuitability as shown by No. 43. The center of the pressure travel was not plotted for sections No. 44–No. 46 because it was thought that nothing of interest would be shown. The models were constructed of maple, 3 by 18 inches and were within 0.005 inch of the ordinates given in the following tables. Lc and Dc (Plots 4 and 5) and L/D (Plots 6 and

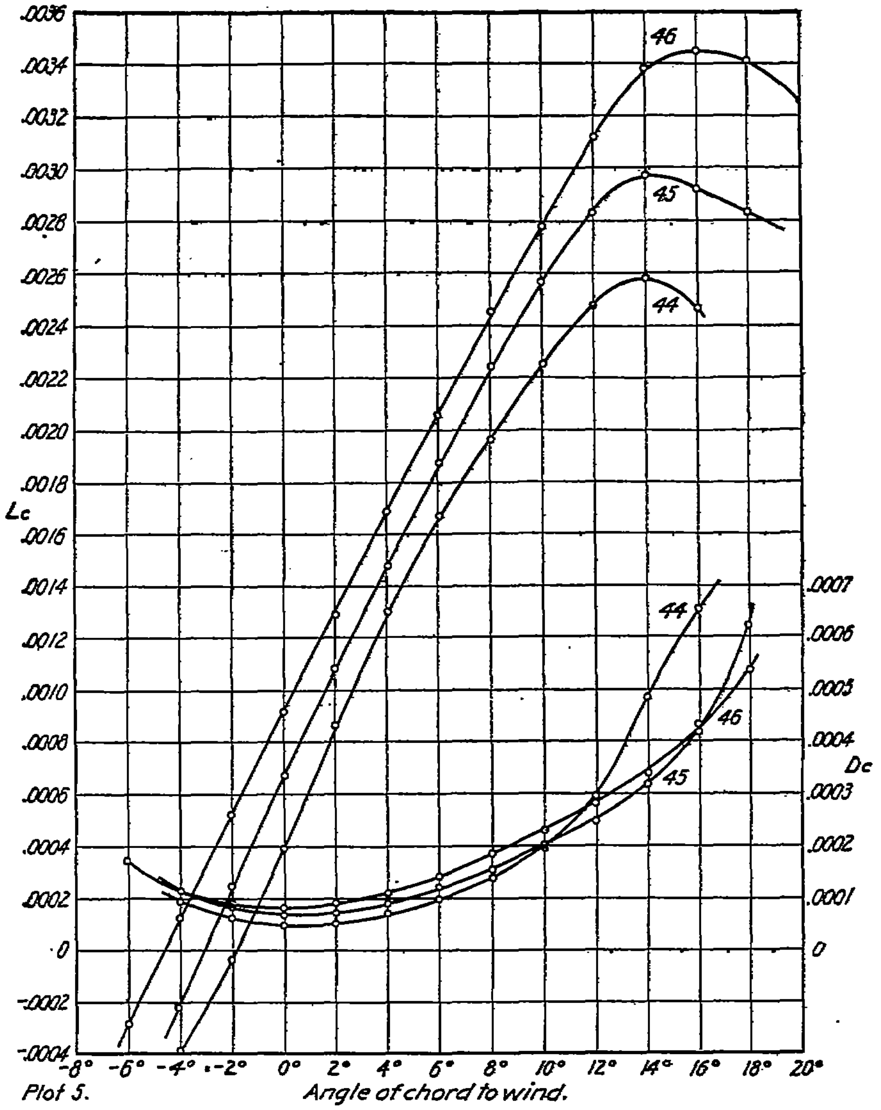
7) are plotted against angle of incidence for each case. Where the curve was discontinued, a sharp break was made, as a fairer representation than a smooth curve. On Plot 8 the L/D is also plotted against $\frac{\text{Lc}}{\text{Lc max.}}$ as giving most readily the comparative merits of the various sections. A fast machine must fly at 2 to 3 times its minimum speed so that a high speed wing must have a high L/D at one-fourth to one-ninth of the maximum Lc. The center of pressure travel for sections No. 40–No. 43 is plotted in the usual manner (Plot 9). Figure 3 shows the master section and Figure 10 shows the front profile of the wings. Although drawn to scale, they are not intended as accurate representations of the wings, but simply to show the relative shape of the sections.



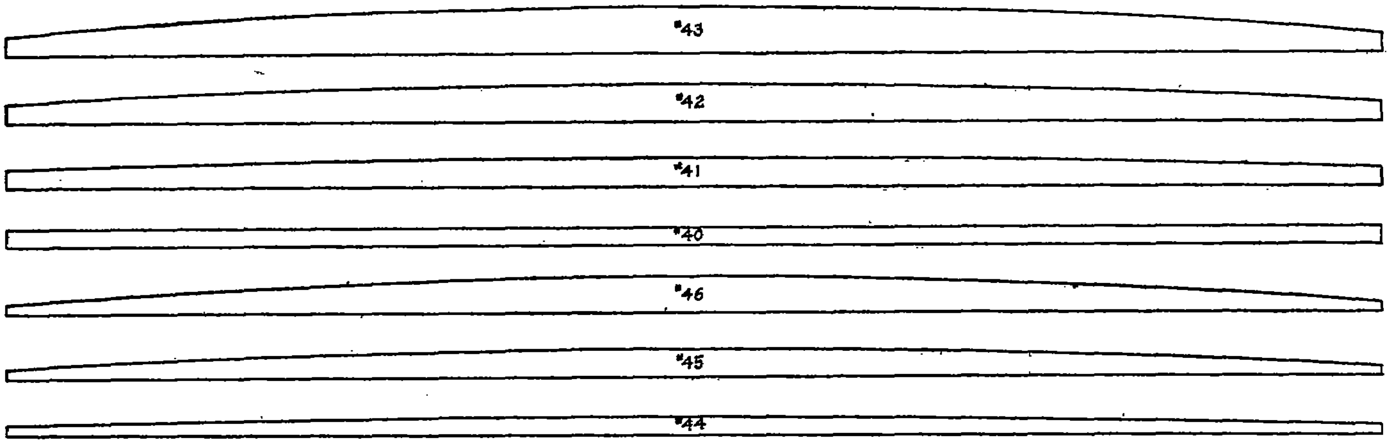
Plot 4.

The following facts are evident from the curves:

Lift.—As the wing is thickened in the center, the lift curve shifts to the left and the maximum lift increases until *h/c* in the center of about 0.158 is reached, after which the flow is unstable and the maximum rapidly decreases. Thinning the tips shifts the lift curve toward the right,



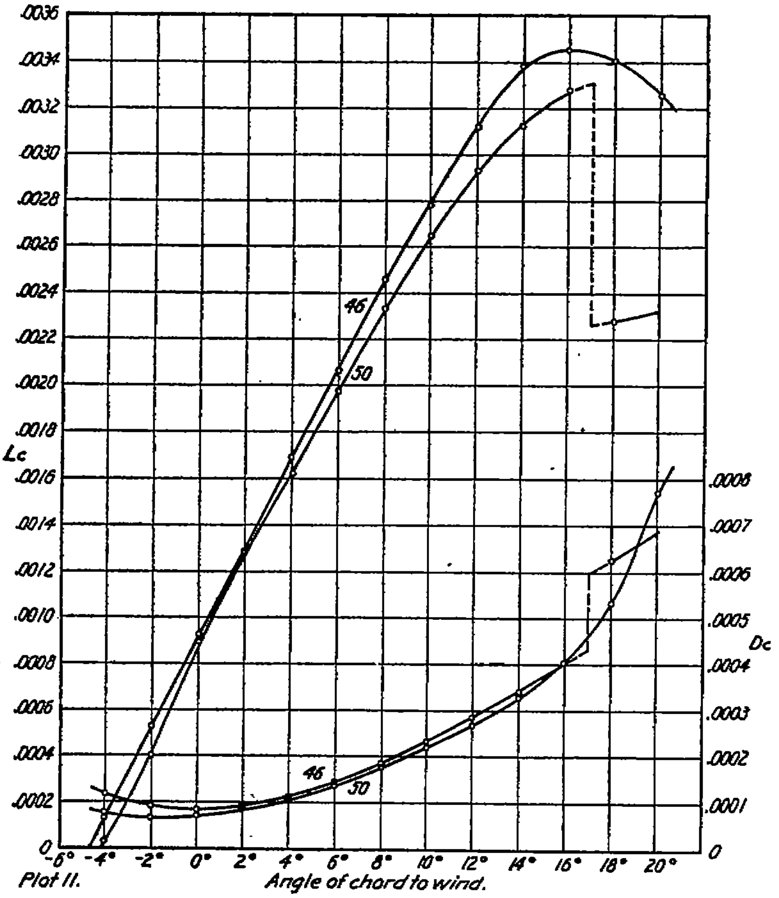
Plot 5.



MAXIMUM SECTION NORMAL TO CHORD
Full Size Chord = 3"

FIGURE 10

lowers and flattens the maximum, except where the wing is already thin, in which case the maximum is unchanged. Sections No. 42 and No. 45 show quite a high maximum, 0.00378 and 0.00345 as compared with 0.00258 for the constant section wing (No. 40). Sections No. 42 and No. 43 show a break in the air flow that is common in many thick sections. At certain angles of incidence there may be two or even more types of flow. This condition is somewhat analogous to a supersaturated solution, as a given type of flow can be carried beyond its normal point of breaking if the angle of incidence is changed slowly and carefully, but if jarred or left for a considerable time will revert to its stable value. This instability is lessened and in some cases disappears with an increase in velocity to 40 M. P. H. This instability of flow is also associated with aspect ratio, for even the R. A. F. 6 shows a break in the lift curve at very low aspect ratios.



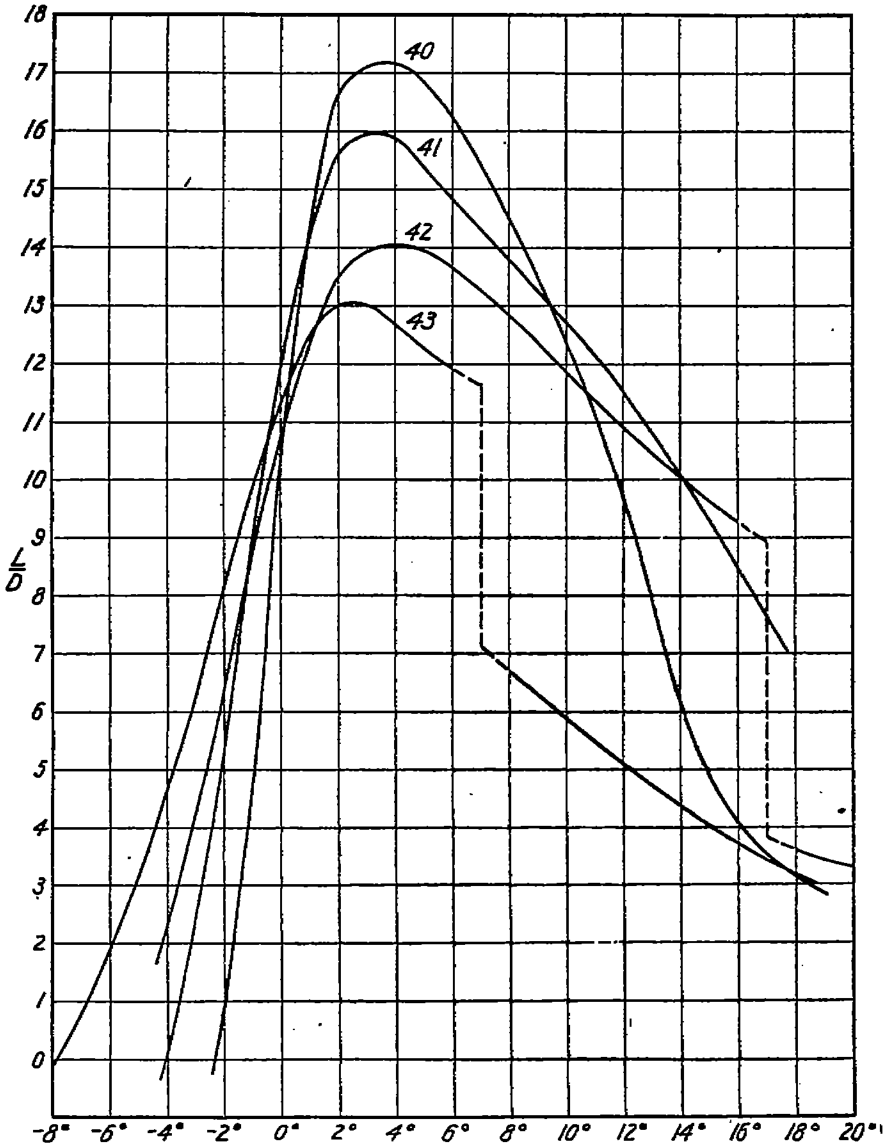
Plot 11.

Drag.—The minimum drag decreases with the thickness of the center section, reaching the rather low value of 0.0048 for No. 44. The thinner sections, however, show a pronounced increase in drag at high angles, 14° to 20°, in fact, exceeding the drag of the thicker wings. Thinning the tips decreases the drag at all angles.

L/D.—The L/D increases at all angles as the wing is thinned down. With reference to Plot— the thickest wing, No. 43, gives a comparatively poor performance, while the thinnest, No. 44, is shown to be most excellent in this respect; the other sections falling between them. The max. L/D ranges from 13 to 18.2, increasing progressively as the wing is thinned.

Center of pressure.—The center of pressure travel becomes less, and the C. P. is slightly farther to the rear as the thickness is increased. The travel on No. 40 lies 28 per cent from the leading edge at 12° and 51 per cent at 0° while on No. 43 it moves, between the same angles, from 35 to 47 per cent.

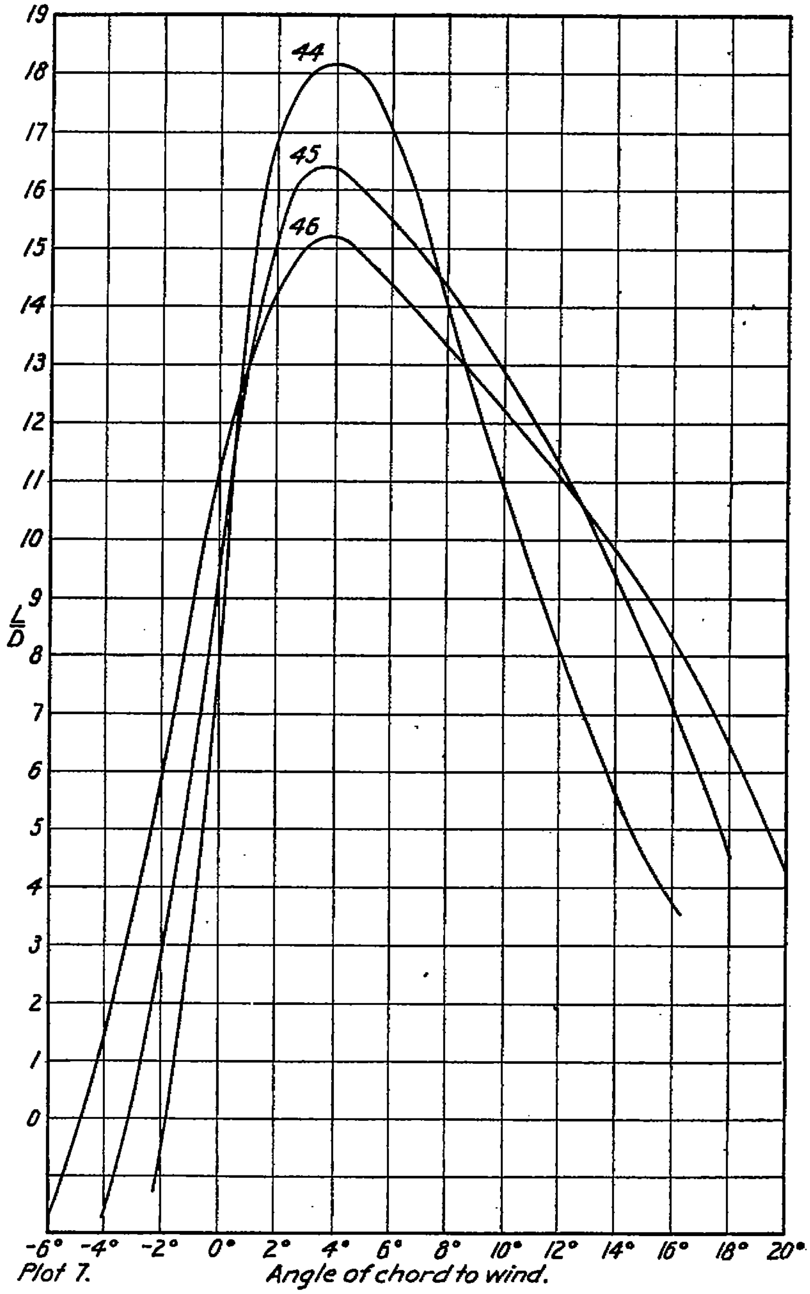
This test shows that a thin flat-bottomed wing (No. 40) may be thickened in the center until an h/c ratio of 0.158 is reached (No. 42), with an increase in maximum lift of 50 per cent and a decrease in the maximum L/D of 18 per cent and in the L/D at one-ninth maximum Lc of 30 per cent. If at the same time the tip is thinned to an h/c ratio of $\frac{1}{25}$ (No. 46) the maximum lift is increased 32 per cent the maximum L/D is reduced 12 per cent and the L/D at one-ninth maximum Lc is reduced 18 per cent as compared with No. 40. The thickness can not be increased beyond this, for the maximum Lc and L/D fall off rapidly. If a flat-bottom section (No. 40) be thinned at the tips to an h/c ratio of one-twenty-fifth (No. 44) the maximum lift is unchanged but the maximum L/D is increased 6 per cent and the L/D and one-ninth maximum Lc is increased 20 per cent. The wing is, of course, of no use for internal bracing, but is included in this report to complete the series.



Plot 6.

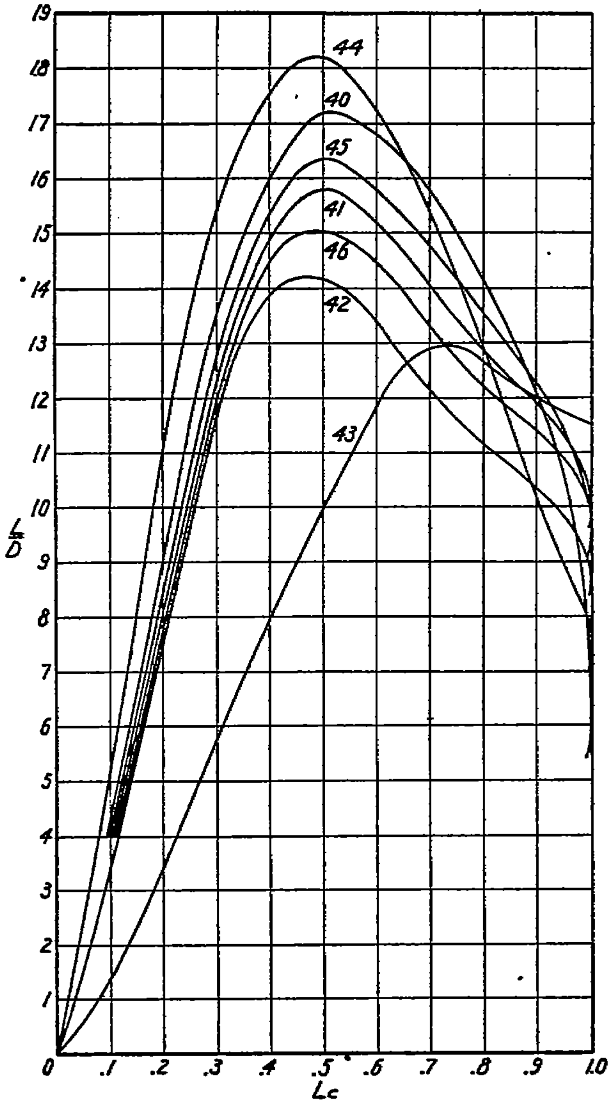
There is no particular reason why these sections should be compared to No. 44, as this was simply a reduction of the matter section to the thickness of an average wing. It happens to have a fairly good L/D and a rather low maximum lift. For a more general comparison, section

No. 46, the most practical section for internal bracing, can be compared with a high lift section, U. S. A. 2. Section No. 46 has a 7 per cent increase in maximum lift and a 3 per cent decrease in maximum L/D over the U. S. A. 2, and the L/D at one-ninth maximum Lc is 30 per cent higher on section No. 45.

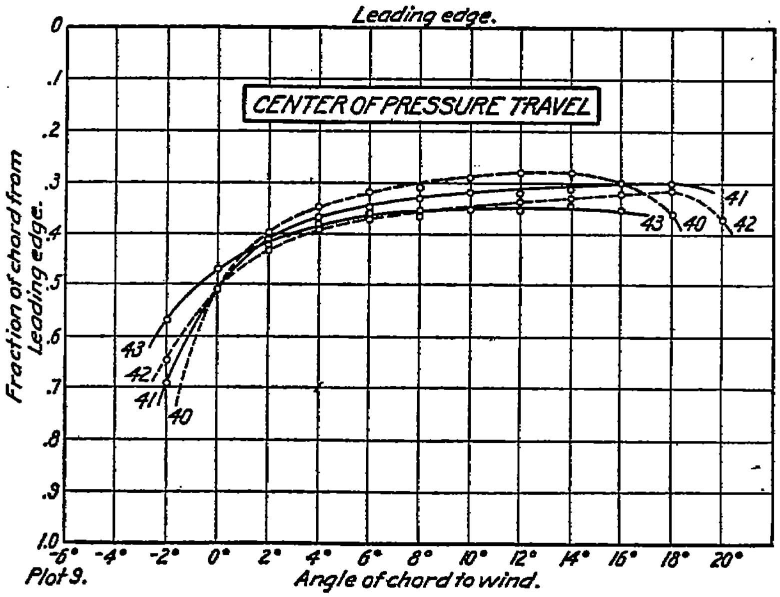


THE EFFECT OF ADDING A CONVEX LOWER SURFACE TO A THICK TAPERED WING.

As the limit of thickness is reached with a flat-bottomed section when *h/c* equals 0.158, it is intended to determine the effect of adding a convex lower surface to wings No. 46 and No. 51, so that the *h/c* ratio will be increased to one-fifth at the center (Fig. 16). These sections, No. 50 and No. 53, have the lower surface reduced in the same manner as the upper surface is reduced in going from the center to the tips. The spar room is increased 25 per cent and the


19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
L/D
44
40
45
41
46
42
43
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
Lc/Lc Max.

Plot 8.

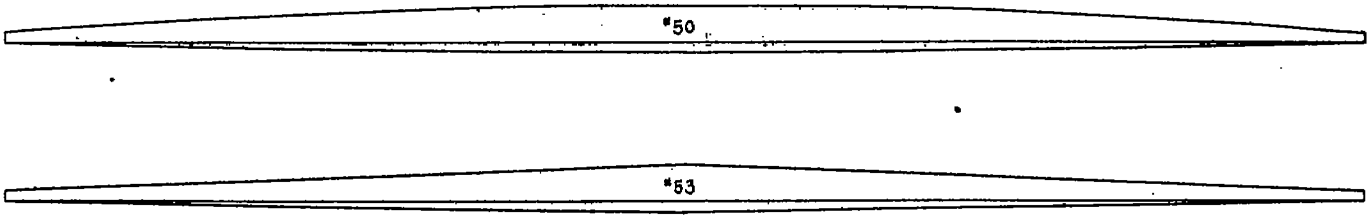

Leading edge.
CENTER OF PRESSURE TRAVEL
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
Fraction of chord from Leading edge.
41
43
40
42
43
42
41
40
-6°
-4°
-2°
0°
2°
4°
6°
8°
10°
12°
14°
16°
18°
20°
Angle of chord to wind.

Plot 9.

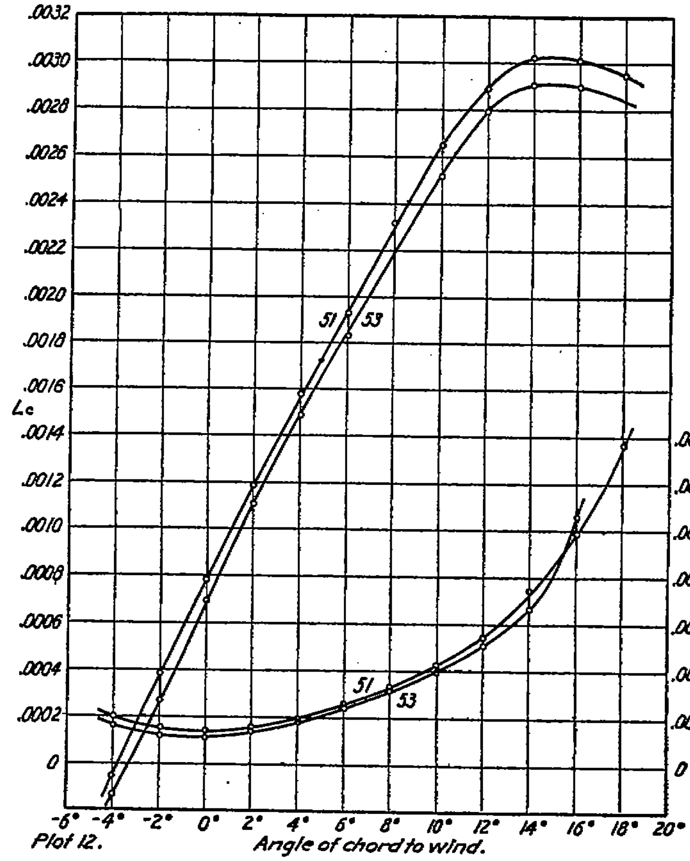
general performance of the section is improved by this addition, making this one of the few changes that are both structurally and aerodynamically beneficial.

Adding a convex lower surface of this type gives the following results:

Lift.—The maximum Lc is reduced 3 to 6 per cent. The lift is reduced at all angles, but at 0° to 4° is quite high, giving a decided hump to the curve at this point. This characteristic was noticed when a convex lower surface was added to the Durand 13. Section No. 50 gave an unstable burble point at 30 M. P. H., but at 40 M. P. H. gave a very flat maximum with the same value of Lc. (Plots 11 and 12.)



MAXIMUM SECTION NORMAL TO CHORD
FULL SIZE CHORD=3"
FIGURE 16.

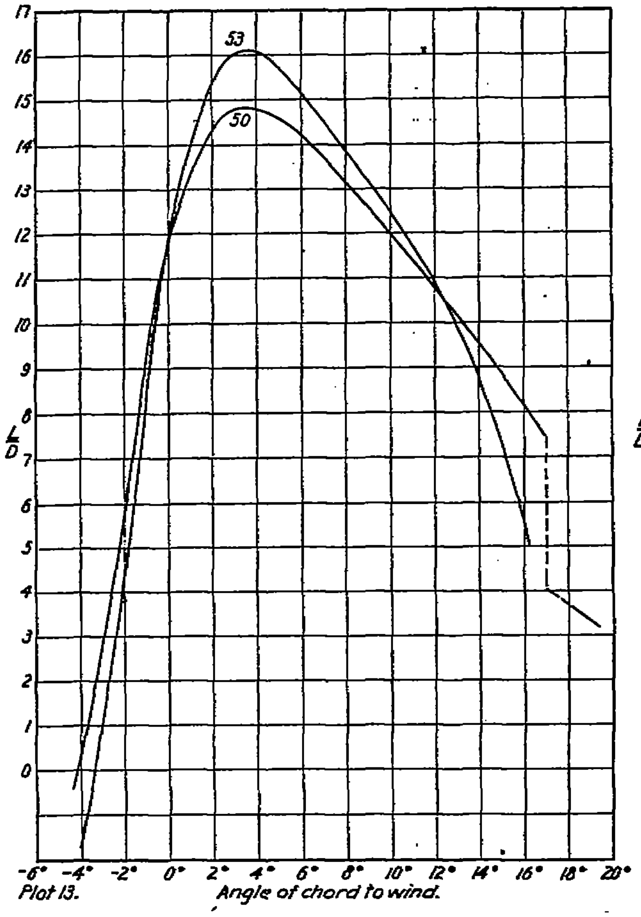


Plot 12.

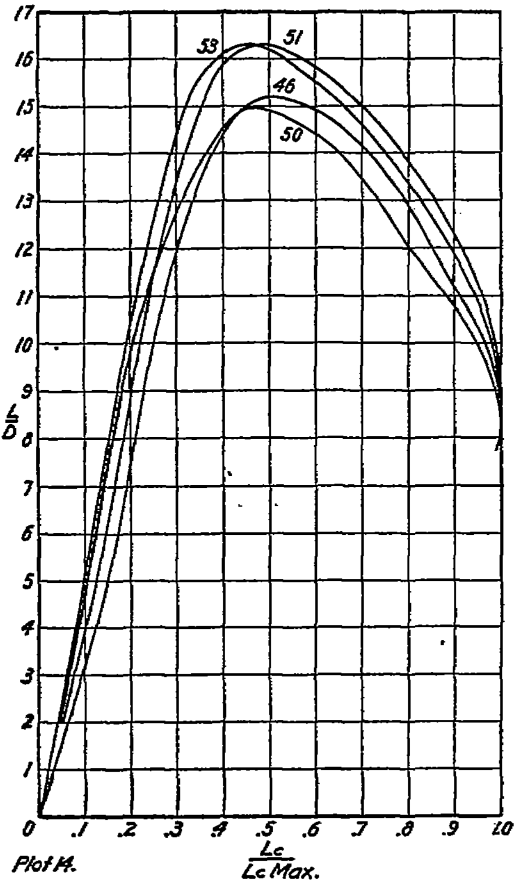
Drag.—The drag is lowered at all angles except near the burble point, and the position of the minimum is moved to more negative angles. The minimum is lowered about 20 per cent, and has a flatter curvature (Plots 11 and 12).

L/D.—The maximum L/D is reduced 1 or 2 per cent, but the L/D at one-quarter maximum L^c is increased 10 per cent, and that at one-ninth maximum L^c 35 per cent (Plots 13 and 14).

Center of pressure travel.—The center of pressure travel for No. 50 is plotted in Plot 15, and shows no difference from the travel on thin sections.

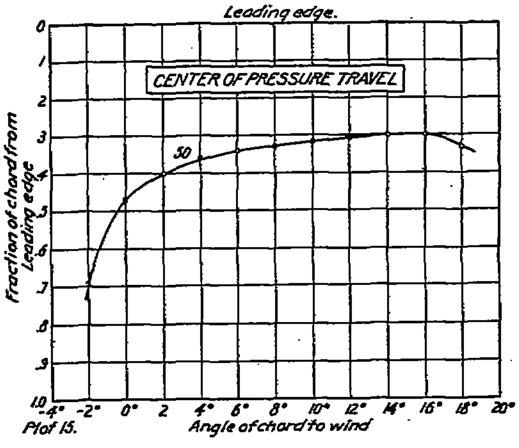


Plot 13.



Plot 14.

Both of these sections are excellent from every point of view. They allow room for ample spars (10-inch depth on a 5-foot chord), have a high maximum Lc, a maximum L/D only slightly lower than the average for thin wings, yet have an L/D at low values of Lc that is only exceeded by a few thin sections. Section No. 50 gives the higher maximum lift and the greater room for spars, but No. 53 gives the higher efficiency.



Plot 15.

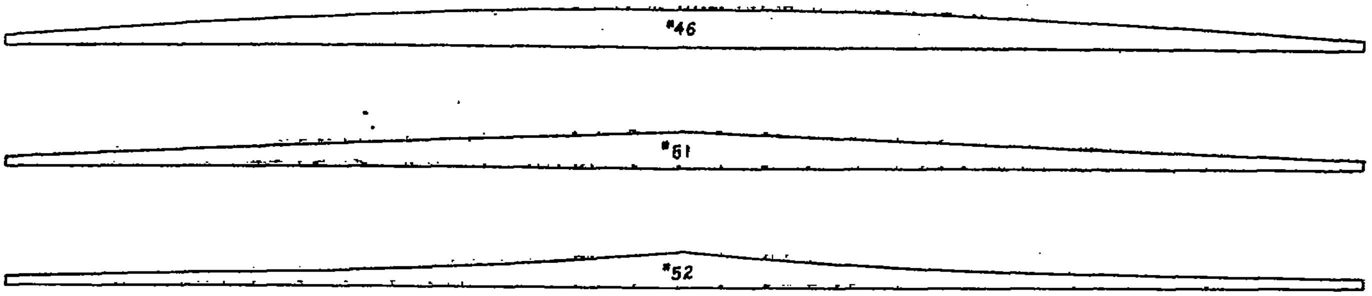
THE EFFECT OF VARYING THE MEAN THICKNESS IN A SERIES OF WINGS WITH CONSTANT TIP AND CENTER SECTIONS.

The object of this series was the determination of the effects due to thinning the wing more or less rapidly from the center to the tips. Front profiles of these sections (Nos. 46, 51, 52) are shown on figure 17.

The following facts are evident from this test:

Lift.—The lift is everywhere decreased as the section is thinned and all the sections show a flat burble point. The lift does not decrease as rapidly as the thickness, for the lift is approaching the limiting value of a flat plate. (Plot 18.)

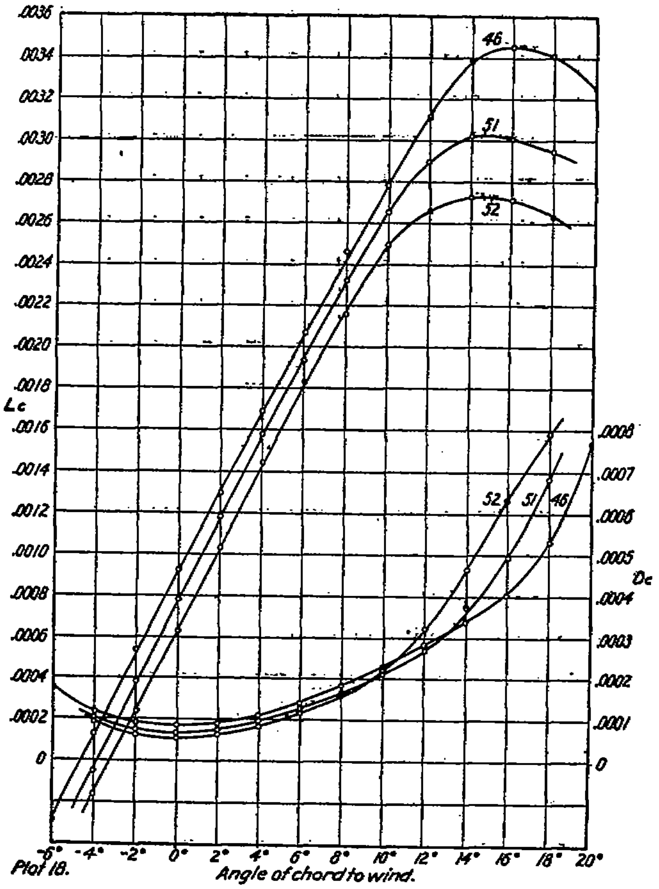
Drag.—The drag at low angles decreases with the thickness, but less rapidly as the wing becomes thinner. It is interesting to notice that above 12° the thicker wing has the least drag. (Plot 18.)



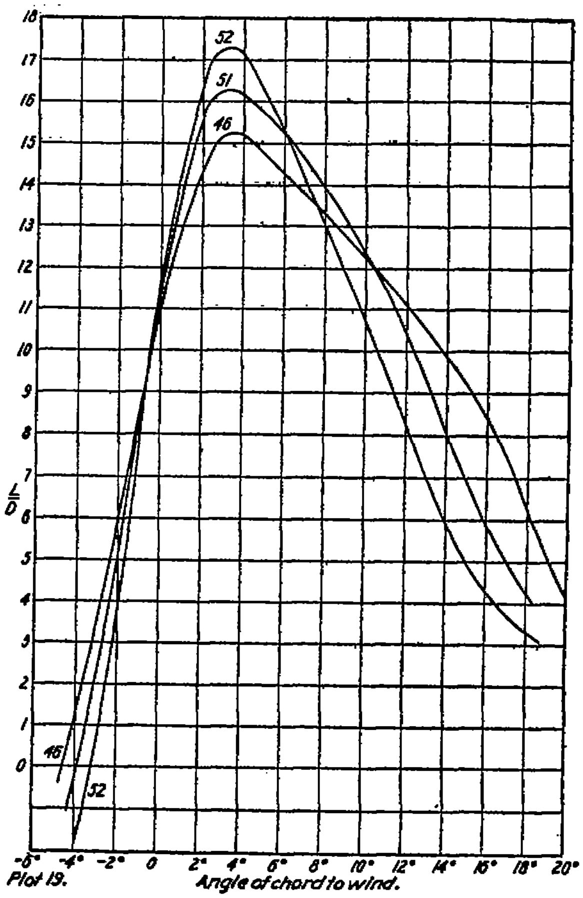
MAXIMUM SECTION, NORMAL TO CHORD
Full Size. Chord = 3"

FIGURE 17

L/D.—The maximum L/D increases as the wing is thinned, reaching 17.4 for No. 52. At low angles the efficiency is increased in the same way. At high angles, however, the thicker wings are the more efficient. (Plots 19 and 20.)



Plot 18.

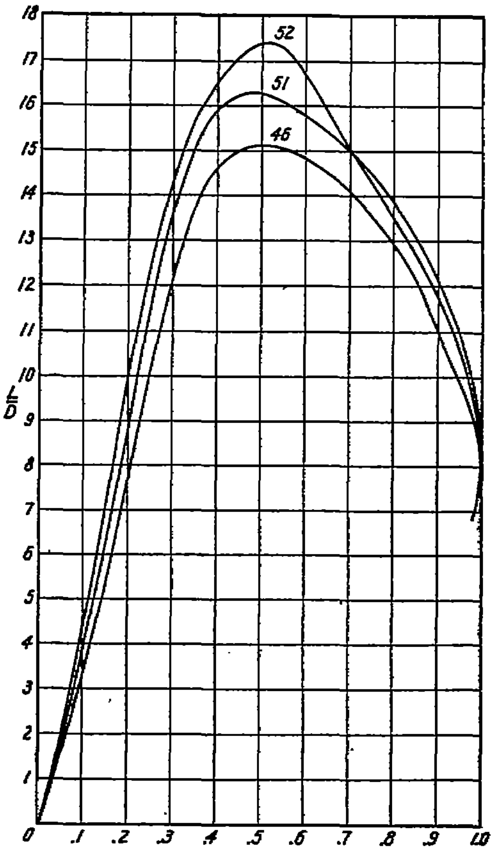


Plot 19.

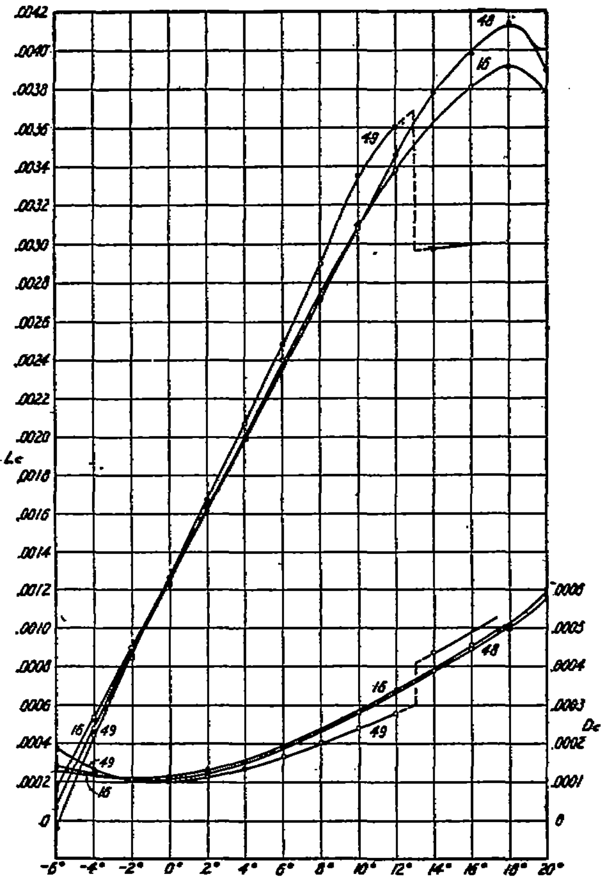
Conclusions.—The results obtained from this series show that these wings have properties in general in close agreement with those of a uniform mean section. The more strongly tapered ones show, however, an evidently greater efficiency at low angles than the mean uniform section would indicate.

WINGS WITH VARYING CHORD.

The wind tunnel investigations of wings that have a chord which varies along the span is a rather difficult problem, because of the great alteration in the properties of similar aerofoils, when the chord is changed. It seems evident, at least with thick sections, that the chord can not be reduced to less than 2 inches at 30 M. P. H. without introducing a break in the air flow that materially reduces the value of the maximum lift. For instance, a wing with a 2-inch chord at the tip and a 3-inch mean chord, gives a uniformly better performance than a similar constant section wing, but if the tip is reduced to 1¾ inches, with the same mean chord, the performance is markedly inferior to the constant section wing. Again, section No. 49 (Plots 21, 22, 23), having a 24-inch span and a 1½-inch chord at the tip, gave a maximum Lc 0.00360, but when 3 inches were cut off of each tip, leaving an 18-inch span and a 2-inch chord at the tip (Fig. 24), the maximum Lc was increased to 0.00413. This does not prove, however, that on a full-sized machine, where the LV is large, a small chord at the tip is a disadvantage.



Plot 20.



Plot 21.

For this same reason it seems probable that wind-tunnel tests on wings with raked and rounded tips, although showing a considerable advantage over a square tip, do not show as comparatively great an improvement as actually occurs on the full-sized machine. In order to investigate this matter fully, a series of similar sections should be tested with the greatest possible range in LV.

This subject of varying the chord was taken up not so much with the hope of improving the aerodynamic properties of the wing, but because of the structural advantages possessed by this type of wing. When the chord is diminished at the tip and increased at the center, not only is the spar depth increased at the center, but the center of lift of the wing is brought closer to the body, thus decreasing the bending moment in the spars. If the wing is tapered sufficiently, the spars can be brought together at the tips as in the German Ago, simplifying and increasing the rigidity of the drag truss.

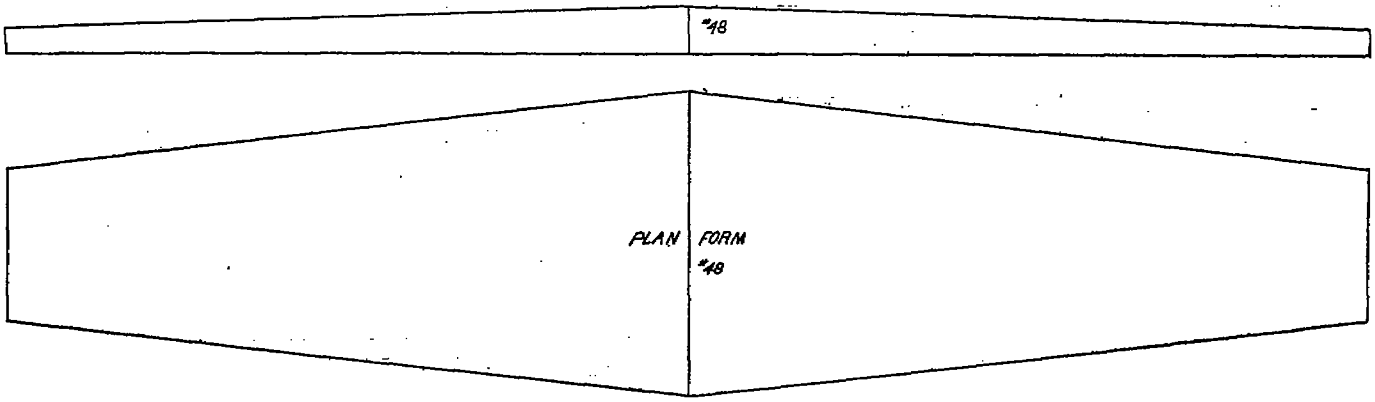
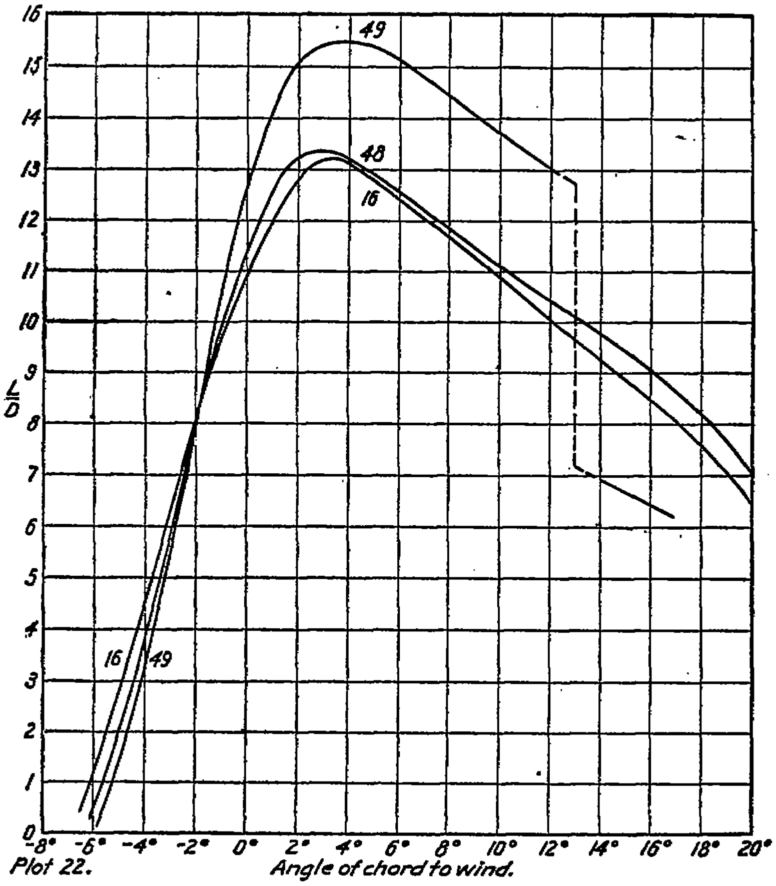
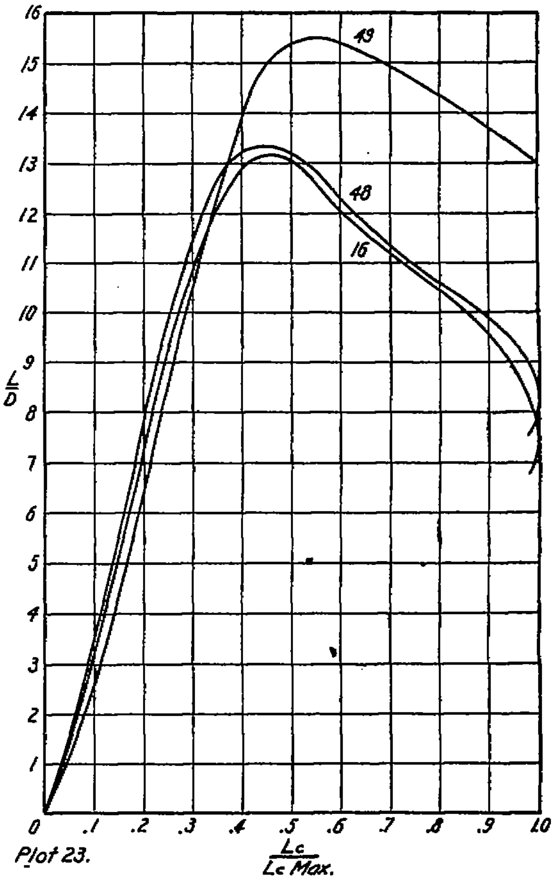


FIGURE 24.

In comparing sections 16 and 48 (Plots 21, 22, 23) it is seen that the section with a varying chord has 5 per cent higher maximum lift and substantially the same L/D at all points. When



Plot 22.



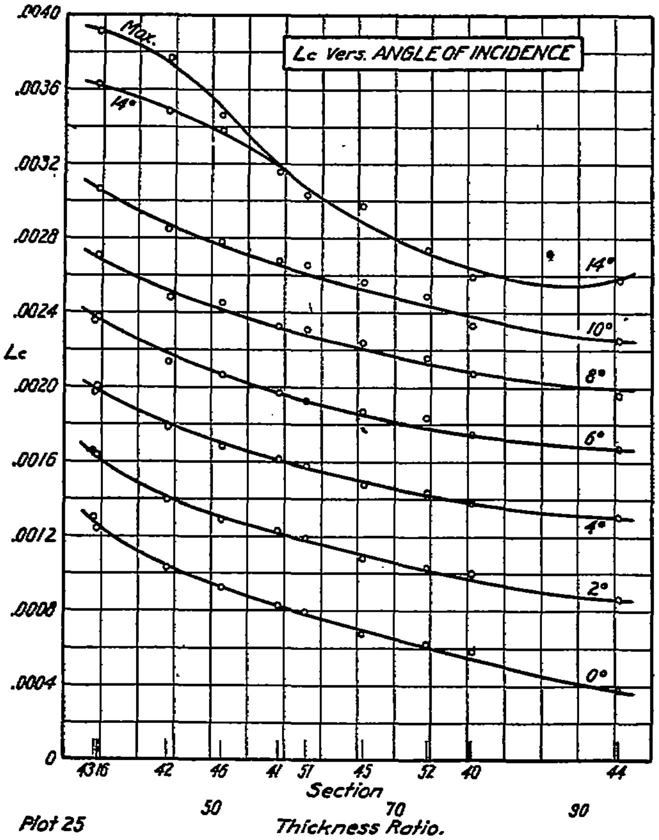
Plot 23.

the L/D is plotted against $\frac{\text{Lc}}{\text{Lc Max.}}$ it is evident that the constant section wing is inferior in efficiency at every point. There was time for only a very limited study of this subject, but the results show enough promise to deserve further investigation.

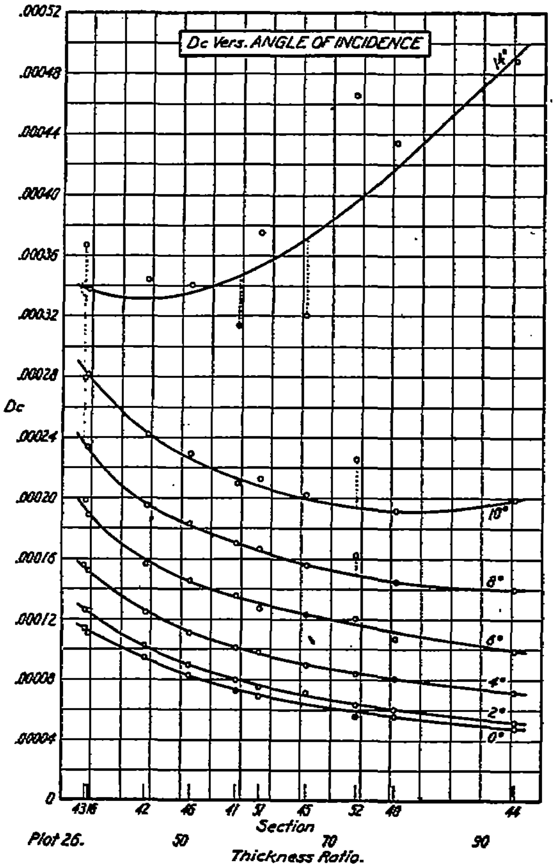
SUMMARY.

It is a rather difficult matter to compare the properties of the different sections tested because of the number of variables present. It was thought that a comparison could be best made by plotting the mean thickness of the wing against the Lc, Dc, and L/D for various angles of incidence, and against L/D for various values of Lc. Instead of using the actual thickness of the wing the ratio of the span to the mean thickness is used, and will be termed thickness ratio. In this report the term will be applied only when the aspect ratio is six. Another characteristic of the wing is the ratio of the mean thickness of the wing to the maximum thickness, or amount of taper. These characteristics for a number of the wings are tabulated below:

Wing No.	Mean thickness.	Thickness ratio.	Mean ord. / Max. ord.
40	0.230	78.3	1.000
41	.314	57.3	.930
42	.399	45.1	.837
43	.483	37.3	.805
44	.191	94.3	.830
45	.271	66.5	.768
46	.351	51.3	.737
51	.298	60.4	.625
52	.245	73.4	.535
16	.477	37.6	1.000



Plot 25

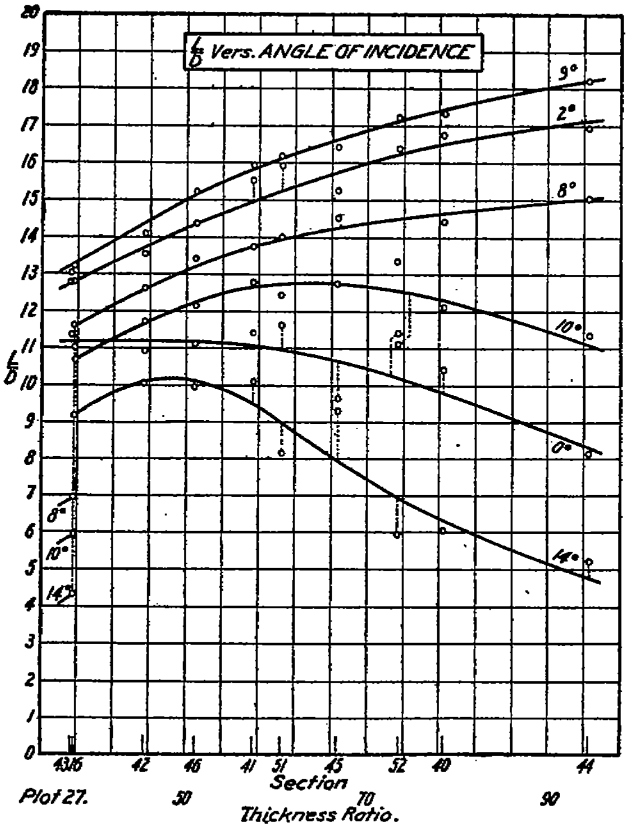


Plot 26.

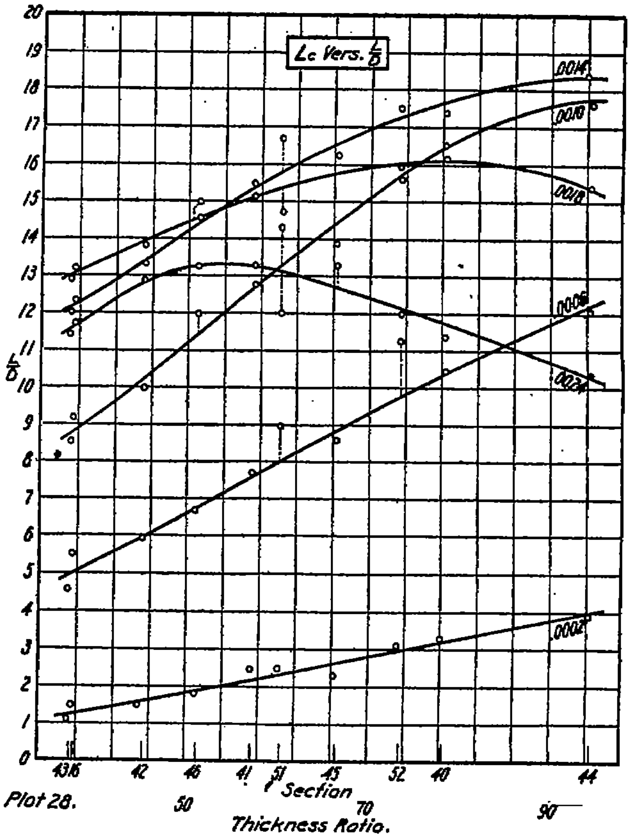
On plots 25 to 28 the properties of these wings are plotted against thickness ratio. It was not expected that the points would lie on a smooth curve, but it was hoped that there would be enough regularity to determine a mean line, from which the deviation of the points could be studied.

It is seen from plot 25 that the lift coefficient decreases with an increase of thickness ratio, and of course will approach the values for a flat plate. As the thickness ratio is decreased below 50 the Lc at low angles begins to increase rapidly, but at high angles increases less rapidly and at the highest lift has reached a maximum at about 37. It is interesting to notice that wings Nos. 43 and 16, having practically the same mean thickness, lie closely together up to 6°, after which the flow breaks on the former and its lift values at high angles are very low. All the other points lie closely to the mean curves and show nothing of interest.

On plot 26 it is seen that the drag at low angles increases as the thickness ratio decreases, but at 10° the drag is a minimum when the thickness ratio is 80, and at 14° when it is 50. At low angles the drag is quite regular, but at high angles the points do not lie on a smooth curve. As would be expected, wing No. 43 has abnormally high values of drag above 6°, but below this agrees well with No. 16. Wing No. 52, and to a lesser extent No. 51, show an unusually low drag at small angles and a large drag at high angles. From the table above it will be noticed that these two wings have the greatest taper of any.



Plot 27.



Plot 28.

The points on plot 27 are naturally less regular than on the others, but it is evident that the efficiency increases with the thickness ratio between 2° and 8°, but at lower and higher angles it occurs at a lower thickness ratio. The efficiency is higher with the thicker wings at 0° only because this angle is farther from the angle of zero lift on the thick wings and not because these wings are more efficient at high speeds. At high angles, however, wings with athickness ratio of about 50 are the most efficient.

This is shown more clearly on plot 28 where the efficiency is plotted against thickness ratio for various values of Lc. For low values of Lc the efficiency increases steadily with the thickness ratio, but at Lc of 0.0014 the efficiency reaches a maximum, which moves to lower values of thickness ratio as the Lc increases. Again Nos. 52 and 51 show an abnormally high efficiency at low and medium values of Lc. No. 16 shows a slightly higher L/D at all angles than No. 43.

It may be concluded from these curves that the areodynamic properties of a series of similar wings depend in a regular way on the mean thickness, no matter what the taper. It seems possible then to predict the properties of any varying section wing with fair accuracy from a study of similar constant section wings. It is impossible, however, to exceed at any point of the wing an h/c ratio of 0.159 without exceeding the critical value. Therefore, in order to obtain the highest maximum lift, the wing should be of constant section. Wings that have a considerable degree of taper appear to have better high-speed properties than uniform section wings. This improvement is not very large but is well outside the experimental error.

In order to show clearly the relative properties of the various sections tested and their relation to the usual types of wings, their more important characteristics are tabulated below, together with a few repersentative thin sections:

Section No.	Maximum Lc.	Maximum L/D.	L/D at ½ maximum Lc.	L/D at ¼ maximum Lc.	L^c at maximum L/D.	L/D at maximum Lc.	Minimum Dc.	Maximum h/c.
40	0.00259	17.2	11.5	4.8	0.00134	6.0	0.000056	0.077
41	.00318	15.9	10.2	4.2	.00150	9.6	.000072	.118
42	.00378	14.1	9.6	3.8	.00176	9.3	.000095	.159
43	.00236	13.0	4.6	1.5	.00197	12.0	.000109	.200
44	.00258	18.2	13.6	5.8	.00125	5.5	.000048	.077
45	.00297	16.4	10.6	4.4	.00141	9.0	.000070	.118
46	.00345	15.2	9.8	4.0	.00166	8.3	.000083	.159
50	.00328	14.9	11.5	5.2	.00155	7.9	.000066	.200
51	.00302	16.2	11.5	4.5	.00158	5.7	.000067	.159
52	.00272	17.3	12.5	5.0	.00144	8.7	.000054	.159
53	.00292	16.2	12.6	5.7	.00145	7.6	.000057	.200
48	.00413	13.3	10.0	3.9	.00200	8.2	.000108	.212
16	.00392	13.2	9.0	3.6	.00188	6.9	.000108	.159
R. A. F. 6	.00304	16.6	11.0	4.2	.00129	6.9	.000068	.068
R. A. F. 15	.00269	15.8	13.0	6.3	.00103	9.5	.000048	.057
U. S. A. 2	.00322	15.7	8.8	3.1	.00162	9.3	.000088	.063
U. S. A. 1	.00278	16.7	12.3	5.4	.00130	9.6	.000056	.057

In comparison with the usual types of thin sections a thick uniform section like No. 16 shows the following differences:

1. Thick sections may give 50 per cent higher maximum lift.
2. Thick sections are more likely to give an unstable flow at large angles of incidence.
3. On thick sections the angle of no lift occurs at lower angles of incidence and the burble point at higher angles, thus extending the angular flying range.
4. Thick sections have a flatter drag curve; that is, the minimum drag is higher, but Dc rises less rapidly on either side of the minimum.
5. The L/D curve for thick sections is flatter than for thin sections, rising to a lower maximum, but holding a value close to its maximum at high and low angles of incidence.
6. The center of pressure travel of thick sections is further to the rear and of less extent than on thin sections.
7. Thick sections are more efficient at high angles of incidence.

The best tapered sections give lower maximum L/D than the thin sections, but the efficiency at all other points is as good.

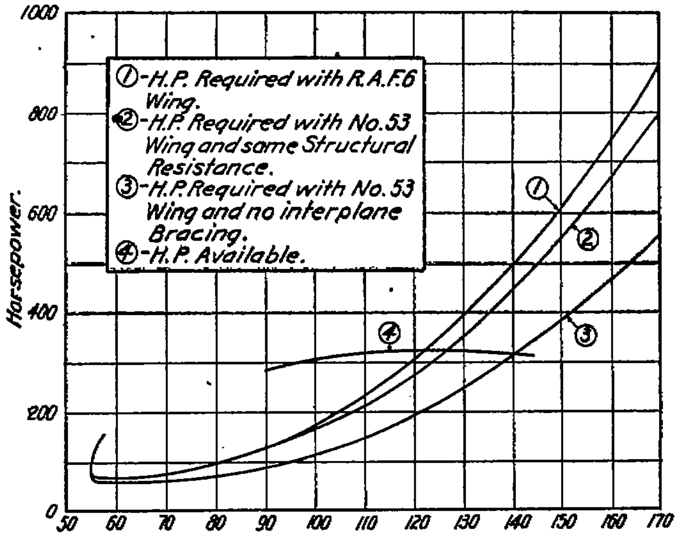
By tapering the wing both in plan form and thickness it should be possible to construct a wing which has an h/c ratio in the center (mean chord) of 0.270 and aerodynamic properties comparing quite favorably with the thin sections used now. This thickness would make possible the use of 14-inch spars on a 5-foot mean chord. A tapered wing has the advantage of having the greater part of the lift on the portion of the wing close to the body, due both to the greater area and to higher lift sections at this part of the wing, thus decreasing the bending moment in the spars.

To illustrate the value of thick wings on a machine, the performance is plotted for a 400 H. P. 3,600-pound biplane, using first a R. A. F. 6 section with the usual wing bracing, second, section 53 with the same bracing, and third, 53 without external bracing. No corrections were added to the data from wind tunnel tests, as only comparative results were required.

Section loading (coefficient of parasite resistance).	R. A. F. 6, 9.1 pounds, square feet 0.036.		No. 53, 8.8 pounds, square feet 0.036.		No. 53, 8.8 pounds, square feet 0.017.	
	(*Velocity in M. P. H.*)	(*H. P. required.*)	(*Velocity in M. P. H.*)	(*H. P. required.*)	(*Velocity in M. P. H.*)	(*H. P. required.*)
2	230	3,590	180	950	180	650
0	128	370	113	228	113	155
2	92	131	90	125	90	89
4	79	93	77	89	77	66
8	63	68	64	69	64	56
12	56	65	56	66	56	57
16	55	92	55	81	55	72

From the H. P. curves plotted below (Plot 29), assuming a curve of available H. P., the following summary is obtained:

Section.	Maximum speed.	Minimum power.	Climb.
R. A. F. 6	122 M. P. H	65 H. P	1,470 feet per min.
No. 53	126 M. P. H	66 H. P	1,470 feet per min.
No. 53	140 M. P. H	56 H. P	1,750 feet per min.



Plot 29.

Compared with the R. A. F. 6, No. 53 section under the same conditions of structural resistance gives the same power to climb and increases the maximum speed 4 M. P. H. Without interplane bracing this section increases the climb about 20 per cent and the maximum speed from 122 to 140 M. P. H.

It seems evident from these tests on models that wings may be designed with ample room for cantilever spars and have at the same time aerodynamic properties comparing favorably with the thin sections used now.

This subject of varying section wings is so large that only a beginning has been made in this report, for there is an almost infinite number of variables to study. The results, however, show enough promise to warrant further research with wings in which the chord and thickness are varied in a more complex manner. The thick tapered wings should also be tested on full-sized machines.

Ordinates for No. 40.

Chord station.		Chord station.	
00	0.044	120	0.228
10	.094	140	.221
20	.132	160	.207
30	.160	180	.190
40	.181	200	.170
50	.186	220	.147
60	.207	240	.122
70	.216	260	.094
80	.223	280	.065
90	.228	300	.032
100	.230		

The lower surface is plane and ordinates given are the distances of the upper surface above this in inches.

Ordinates for No. 41.

Chord station.	Distance from center of span in inches.				
	0	3	5	7	9
00	0.070	0.067	0.064	0.057	0.044
10	.145	.140	.132	.118	.094
20	.202	.196	.185	.165	.132
30	.246	.238	.225	.200	.160
40	.278	.270	.254	.227	.181
50	.301	.292	.275	.245	.196
60	.318	.309	.291	.260	.207
70	.333	.323	.304	.271	.216
80	.343	.333	.313	.280	.223
90	.350	.339	.319	.285	.228
100	.353	.343	.323	.283	.230
120	.350	.339	.319	.285	.228
140	.340	.329	.310	.277	.221
160	.318	.309	.291	.260	.207
180	.292	.283	.267	.238	.190
200	.263	.255	.239	.213	.170
220	.226	.219	.207	.184	.147
240	.187	.181	.171	.152	.121
260	.144	.140	.132	.118	.094
280	.100	.097	.091	.081	.065
300	.050	.049	.045	.041	.032

This lower surface is plane and ordinates given are the distances of the upper surface above this in inches.

Ordinates for No. 42.

Chord station.	Distance from center of span in inches.				
	0	3	5	7	9
0	0.095	0.091	0.088	0.069	0.044
10	.195	.187	.170	.142	.094
20	.273	.261	.240	.199	.132
30	.332	.319	.290	.242	.160
40	.375	.359	.328	.273	.181
50	.406	.389	.355	.296	.196
60	.430	.412	.376	.313	.207
70	.449	.430	.393	.327	.216
80	.463	.442	.405	.337	.223
90	.472	.452	.414	.344	.228
100	.477	.457	.417	.348	.230
120	.472	.452	.412	.344	.228
140	.458	.439	.402	.334	.221
160	.430	.412	.376	.318	.207
180	.394	.377	.345	.287	.190
200	.353	.338	.309	.257	.170
220	.305	.292	.267	.222	.147
240	.252	.242	.221	.183	.122
260	.195	.187	.171	.142	.094
280	.134	.128	.117	.098	.065
300	.068	.064	.060	.049	.032

The lower surface is plane and ordinates given are the distances of the upper surface above this in inches.

Ordinates for No. 43.

Chord station.	Distance from center of span in inches.				
	0	3	5	7	9
00	0.119	0.113	0.107	0.081	0.014
10	.245	.233	.208	.165	.094
20	.344	.327	.293	.232	.132
30	.417	.397	.354	.281	.161
40	.472	.448	.401	.318	.181
50	.511	.485	.434	.345	.196
60	.541	.514	.460	.364	.207
70	.565	.536	.480	.381	.216
80	.582	.553	.495	.393	.223
90	.591	.564	.505	.402	.228
100	.600	.570	.510	.405	.230
120	.594	.564	.505	.402	.228
140	.577	.547	.490	.389	.222
160	.541	.514	.460	.366	.207
180	.495	.472	.421	.334	.190
200	.444	.422	.377	.300	.170
220	.384	.365	.326	.259	.147
240	.317	.301	.269	.214	.122
260	.245	.233	.208	.165	.091
280	.169	.160	.144	.113	.065
300	.084	.080	.072	.057	.032

The lower surface is plane and ordinates given are the distances of the upper surface above this in inches.

Ordinates for No. 44.

Chord station.	Distance from center of span in inches.				
	0	3	5	7	9
00	0.044	0.042	0.037	0.031	0.024
10	.094	.089	.080	.067	.049
20	.132	.125	.112	.094	.069
30	.160	.152	.136	.113	.084
40	.181	.172	.154	.128	.094
50	.196	.186	.167	.139	.102
60	.207	.196	.176	.147	.108
70	.216	.204	.184	.153	.113
80	.223	.211	.190	.158	.117
90	.228	.216	.194	.162	.119
100	.230	.218	.196	.163	.120
120	.228	.216	.194	.162	.119
140	.221	.209	.188	.157	.116
160	.207	.196	.176	.147	.108
180	.190	.180	.162	.135	.099
200	.170	.161	.145	.120	.089
220	.147	.139	.126	.104	.077
240	.122	.115	.104	.086	.063
260	.094	.089	.080	.067	.049
280	.065	.062	.055	.046	.034
300	.032	.031	.027	.023	.017

Ordinates for No. 45.

Chord station.	Distance from center of span in inches.				
	0	3	5	7	9
00	0.070	0.065	0.056	0.042	0.024
10	.145	.134	.115	.087	.049
20	.202	.189	.161	.121	.069
30	.246	.228	.196	.148	.084
40	.278	.258	.221	.167	.094
50	.301	.279	.240	.180	.102
60	.318	.296	.253	.191	.108
70	.333	.309	.263	.200	.113
80	.344	.318	.273	.206	.117
90	.350	.324	.279	.210	.119
100	.353	.327	.281	.212	.120
120	.350	.324	.278	.210	.119
140	.340	.313	.271	.204	.116
160	.318	.295	.253	.191	.108
180	.292	.270	.232	.175	.099
200	.261	.242	.207	.158	.089
220	.226	.210	.180	.136	.077
240	.187	.174	.149	.112	.063
260	.144	.133	.115	.087	.049
280	.100	.093	.079	.060	.034
300	.050	.046	.040	.030	.017

The lower surface is plane and ordinates given are the distances of the upper surface above this in inches.

Ordinates for No. 46.

Chord station.	Distance from center of span in inches.				
	0	3	5	7	9
0	0.095	0.087	0.073	0.052	0.024
10	.195	.179	.150	.108	.049
20	.273	.250	.211	.150	.069
30	.332	.305	.256	.183	.084
40	.375	.344	.289	.206	.094
50	.406	.373	.312	.223	.102
60	.430	.395	.331	.236	.108
70	.449	.413	.346	.247	.113
80	.463	.425	.356	.254	.117
90	.472	.433	.363	.259	.119
100	.477	.437	.367	.262	.120
120	.472	.433	.363	.259	.119
140	.458	.420	.353	.252	.116
160	.430	.395	.331	.236	.108
180	.394	.361	.303	.217	.099
200	.353	.324	.271	.194	.089
220	.305	.280	.235	.168	.077
240	.252	.231	.194	.139	.063
260	.195	.179	.150	.107	.049
280	.134	.123	.103	.074	.034
300	.068	.062	.052	.037	.017

The lower surface is plane and ordinates given are the distances of the upper surface above this in inches.

Ordinates of undersurface No. 50.

Chord station.	Distance from center of span in inches.				
	0	3	5	7	9
0	0.000	0.000	0.000	0.000	0.000
10	.023	.020	.016	.009	.000
20	.042	.035	.029	.016	.000
30	.060	.052	.041	.023	.000
40	.074	.064	.051	.029	.000
50	.090	.079	.062	.035	.000
60	.100	.087	.069	.039	.000
70	.109	.096	.075	.043	.000
80	.116	.101	.080	.045	.000
90	.121	.106	.084	.047	.000
100	.123	.109	.085	.048	.000
120	.121	.106	.084	.047	.000
140	.118	.103	.062	.046	.000
160	.110	.097	.076	.430	.000
180	.100	.087	.069	.039	.000
200	.087	.076	.060	.034	.000
220	.073	.064	.050	.029	.000
240	.058	.050	.040	.022	.000
260	.040	.035	.028	.016	.000
280	.020	.017	.014	.008	.000
300	.000	.000	.000	.000	.000

Ordinates below chord line upper surface same as No. 46.

Ordinates for No. 51.

Chord station.	Distance from center of span in inches.		Chord station.	Distance from center of span in inches.	
	0	9		0	9
0	0.095	0.024	120	0.472	0.119
10	.195	.049	140	.458	.116
20	.273	.069	160	.430	.108
30	.332	.084	180	.394	.099
40	.375	.094	200	.353	.089
50	.406	.102	220	.305	.077
60	.430	.108	240	.252	.063
70	.449	.113	260	.195	.049
80	.463	.117	280	.134	.034
90	.472	.119	300	.068	.017
100	.477	.120			

Straight line between center section and tip. Undersurface flat.

Ordinates for No. 52.

Chord station.	Distance from center of span in inches.				
	0	3	5	7	9
0	0.095	0.055	0.038	0.027	0.024
10	.195	.113	.077	.056	.049
20	.273	.159	.108	.078	.069
30	.332	.193	.132	.095	.084
40	.375	.218	.149	.107	.094
50	.406	.236	.161	.116	.102
60	.430	.250	.170	.123	.108
70	.449	.261	.178	.128	.113
80	.463	.269	.184	.132	.117
90	.472	.274	.187	.134	.119
100	.477	.277	.189	.136	.120
120	.472	.274	.187	.134	.119
140	.458	.267	.182	.131	.116
160	.430	.250	.170	.123	.108
180	.394	.229	.156	.113	.099
200	.353	.206	.140	.102	.089
220	.305	.177	.121	.088	.077
240	.252	.147	.100	.072	.063
260	.195	.113	.078	.056	.049
280	.134	.078	.053	.038	.034
300	.068	.040	.027	.019	.017

The lower surface is plane and the ordinates given are the distances above this in inches.

Ordinates for undersurface for No. 53.

Chord station.	Distance from center of span in inches.		Chord station.	Distance from center of span in inches.	
	0	9		0	9
0	0.000	0.000	120	0.121	0.000
10	.023	.000	140	.118	.000
20	.042	.000	160	.110	.000
30	.060	.000	180	.100	.000
40	.074	.000	200	.087	.000
50	.090	.000	220	.073	.000
60	.100	.000	240	.058	.000
70	.109	.000	260	.040	.000
80	.116	.000	280	.020	.000
90	.121	.000	300	.000	.000
100	.123	.000			

Upper surface the same as No. 51.

○