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TECHNICAL NOTES

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PRECISION OF WING SECTIONS AND CONSEQUENT AERODYNAMIC EFFECTS

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Summary

This investigation was carried out by the National Advisory Committee for Aeronautics at the Langley Memorial Aeronautical Laboratory to determine the precision of wing sections of wood fabric construction used on a number of airplanes. It was found that all wing sections deviated more or less from their respective prototypes. The mean thickness of the section was computed for those wings with a noticeable sag. The aerodynamic effects resulting from consideration of thickness variation are then estimated from existing empirical information. The rib, sag and specified measurements of fourteen sections investigated are given in Fig. 2.

Introduction

In the present airplane wings constructed of wood and fabric a certain imperfection is inevitable, which gives an airfoil section differing more or less from that intended. It was decided, therefore, to measure all the airplane wings available at the Langley Memorial Aeronautical Laboratory (Table I) in order to determine how much this variation might be, and furthermore, to determine what may be considered as being the mean airfoil section of such wings involving sag.

If any considerable physical variation is found in these sections, not only will it indicate that it would be unnecessary to use extreme care in making a model for wind tunnel tests of a wing used unless the variation is also incorporated, but it may be considered of sufficient importance to justify wind tunnel tests of such wing models incorporating the variations. An example of this nature is found in the determination of the comparative value of veneer and linen wing covering.

Besides those irregularities brought about by poor workmanship in the assembling of a rib, or by distortion due to aging, by far the largest apparent imperfection on existing wings is that introduced by sagging of the fabric covering between consecutive ribs as a result of the flexibility of the trailing edge and by the desirability of a certain amount of tautness of the covering.

The undoped fabric when properly stretched along the wing span gives a continuous surface over the ribs, but as soon as each coat of dope is applied contraction takes place along both dimensions. The result is, with the exception of the veneer covered leading edge, a contour which is far from being uniform. The sag obviously depends on the rib spacing, on the flexibility of the trailing edge, and on the tautness of the fabric; the deepest sag occurs invariably at the section of greatest curvature, namely at the top forward third, and ends at the edges of the veneer reinforcements.

Undoubtedly the form and extent of this sag are considerably altered in flight under various stress conditions. This being, however, the subject for a future investigation, it will be taken up in another publication.

Apparatus Used and Method of Measuring Wing Sections

Fig. 1 illustrates the apparatus used in this investigation; a parallelogram frame, standing on adjustable legs and carrying a number of extension pointers. The upper beam of this frame can be detached so that the apparatus can be assembled around any wing section along the span of a rigged airplane.

The measurements consisted in setting a sufficient number of the slotted pointers normally to the section. From these an exact duplicate of the contour can be traced by transferring the points on a piece of drawing paper. In spite of its simple form the above apparatus gave satisfactory results with but little effort.

In all wings investigated, two sections were measured, one at the rib and another at the sag. The worst cases of each wing, together with the relative specified section, arranged in the most plausible order, are given in Fig. 2, while the respective specified and actual thicknesses are given in Table I. In each case the full line represents the original intended section as plotted from data of technical reports (Reference 1). The dotted line represents the contour taken at the rib and the dot and dash line that taken at the sag, midway between two consecutive ribs. Several wings with stiff trailing edges offered very little sag, at times hardly measurable and at others entirely negligible; in the latter two cases the dotted line stands for both rib and sag contours.

The results given in Table II need a few words of explanation. The mean ordinate of the various wing sections is obtained as follows, from the combination of rib and sag contours. Let the transverse section included between two consecutive ribs and the upper and lower surfaces be given by Fig. 3; A-B and A'-B' being very nearly parabolas, the ordinate at any point on the curve is:

$$y = kx^2 + c \tag{1}$$

The mean ordinate between the x axis and either line of the fabric is therefore,

$$y_m = \int_{-a}^{a} \frac{y dx}{2a} \tag{2}$$

$$= \frac{1}{2a} \int_{-a}^{a} (kx^2 + c) \, dx \tag{3}$$

$$y_m = \frac{ka^2 + 3c}{3} \tag{4}$$

At $x = a$, $b = ka^2 + c$, and $k = (b - c)/a^2$

Substituting these values in equation (4) we obtain the mean ordinate for the top and bottom sags. The sum of the two gives the distance between the two curves, or the mean thickness of the airfoil section, namely,

$$t_m = y_m + y_m' = \frac{2}{3}\left\{b + b' + 2\,(c + c')\right\}$$

Strictly speaking, the curves A-B and A'-B' can be anything between arcs of circles and catenaries, depending on the load distribution or stresses in the fabric. The choice of the parabola in this case is justified partly by the uniform load distribution along x - x, but to a greater extent by the fact that these curves are very flat and no appreciable error is introduced by such assumption.

Discussion

As mentioned before, the most important question of this investigation is the aerodynamic effect of sag entering in varying degrees into all airfoils of wood-fabric construction. The writer proposes to consider the sag as producing a reduction in section thickness.

From this point of view, and the help of wind tunnel data (Fig. 4) it can be safely concluded that only in the worst case, of the U.S.A.-35B section (Fig. 2), is this reduction of any consequence. It amounts to 0.3 per cent of thickness, corresponding to a drop of nearly 0.07 in the maximum value of its absolute lift coefficient.

The above reduction in section thickness produces no appreciable difference in the drag, as can be verified by Fig. 4, representing the effect of changing thickness ratio with a constant camber of the median line.

The same general conclusion was arrived at with reference to sag, by the R.A.F. staff after an investigation on their section No. 14, modified to represent the sag in the fabric (Reference 2).

From a series of tests on veneer and fabric-covered airfoils for the purpose of determining the effect of sag, Kumbruch (Reference 3) gave similar results, as given in Fig. 5. It will be seen from these polar diagrams that the greatest aerodynamic effect experimentally determined for Reynolds Number of 12000, is in accord with the value found in this note by consideration of the mean thickness, although at double the value of Reynolds Number Kumbruck's results show a still smaller effect.

No other section measured exhibits enough reduction due to sag to be considered of serious consequence to the aerodynamic characteristics of the wing. There are, however, a number of variations to which the attention of the reader is called, by reference to Fig. 2

Investigations on the relative merits of various airfoil coverings, systematic inquiries on the effects of variation in thickness, in lower, upper and mean camber, position of maximum ordinate, modifications of leading edge, reversal of tail angle, etc., have been successfully carried out on models by British (Reference 4) and German (Reference 5) aerodynamic institutions and very valuable information can be derived therefrom by the careful engineer.

Conclusions

As far as sag is concerned, the aerodynamic effect, considered as being caused by a reduction in thickness, is negligible. In the worst case measured, that of a U.S.A.-35B, the effect due to a reduction of 0.3 per cent of the maximum thickness produces a drop of only .07 in the maximum value of its lift coefficient, but no appreciable difference in the drag.

It should be noted also that this aerodynamic discrepancy takes place only at the highest angles of attack, and that for ordinary flying attitude the sag effect, even for the above case, is of no appreciable consequence.

These considerations lead to the conclusion that the aerodynamic effect due to sag in airfoils of wood-fabric construction does not warrant the incorporation of sag in a model wing, such error being in most cases within the limits of experimental accuracy.

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Table I.

List of Wing Sections Measured.

Section	Chord ft.	Rib Dist. in.	d/c %	t/c %	Remarks	
Göttingen 298	4.00	11.5	24.2	12.7	Sagged	Used on Fokker
Göttingen 387	4.00	12.5	26.1	15.1	"	" " Sperry
Clark Y	4.00	11.5	23.9	5.10	"	" " "
U.S.A.-27	4.00	11.75	24.0	11.0	"	" " "
U.S.A.-27	4.72	12.0	21.3	11.0	"	" " T.S.
U.S.A.-27	7.52	11.5	12.7	11.0	Little	" " DT
U.S.A.35B	4.00	11.5	23.9	11.6	Sagged	" " Sperry
Fage & Coll.2	7.12	12.75	14.9	8.2	None	" " Amphibian
Eiffel - 36	5.00	13.0	21.9	6.9	Little	" " JN
U.S.D.-9A	5.50	12.5	19.1	6.3	None	" " DH
U.S.A.-5	4.00	12.0	25.0	6.3	Sagged	" " Sperry
R.A.F.-15	4.00	12.0	25.0	5.7	"	" " "
R.A.F.-15	5.00	13.5	22.4	5.7	None	" " SE-5
R.A.F.-15	4.64	12.0	21.8	5.7	"	" " VE-7
Spad	4.18	4.9	9.8	5.4	Sagged	" " Spad

Table II.

Specified and Computed Thickness Due to Sag in Fabric.

Section	Sta.-% of c	0	10	20	30	40
Göttingen 298 (c = 1220 cm)	Spec. t_m Comp. t_m	0 0	12.55 12.30	13.60 14.00	13.28 14.05	12.34 13.11
Göttingen 387 (c = 1220 cm)	Spec. t_m Comp. t_m	0 0	12.41 12.28	14.69 14.38	15.12 14.90	14.47 14.25
Clark Y (c = 1220 cm)	Spec. t_m Comp. t_m	0 0	9.10 9.30	11.26 11.10	11.73 11.54	11.44 11.25
U.S.A.-27 (c = 1220 cm)	Spec. t_m Comp. t_m	0 0	9.34 9.34	11.30 10.70	10.95 10.75	10.36 10.37
U.S.A.-27 (c = 1440 cm)	Spec. t_m Comp. t_m	0 0	8.99 8.85	10.90 10.63	10.90 10.74	10.34 10.22
U.S.A.-35B (c = 1220 cm)	Spec. t_m Comp. t_m	0 0	9.34 9.36	11.30 10.94	11.56 11.26	11.06 10.84
Eiffel 36 (c = 1523 cm)	Spec. t_m Comp. t_m	0 0	5.52 5.71	6.56 6.83	6.87 7.00	6.70 6.77
U.S.A.-5 (c = 1220 cm)	Spec. t_m Comp. t_m	0 0	5.45 5.64	6.35 6.46	6.27 6.50	5.86 6.27
R.A.F.-15 (c = 1220 cm)	Spec. t_m Comp. t_m	0 0	6.19 6.08	6.19 6.04	5.82 5.76	5.57 5.51
Spad (c = 1275 cm)	Spec. t_m Comp. t_m	0 0	4.15 3.91	5.10 4.94	5.33 5.24	5.37 5.24

Specified and Computed Thickness Due to Sag in Fabric.

Section	Sta.-% of c	50	60	70	80	90	100
Göttingen 298 (c = 1220 cm)	Spec. t_m	11.11	9.42	7.45	5.00	2.58	0
	Comp. t_m	11.84	10.25	8.03	5.53	2.87	0
Göttingen 387 (c = 1220 cm)	Spec. t_m	12.90	11.00	8.68	6.03	3.32	0
	Comp. t_m	12.74	10.83	8.50	5.90	3.16	0
Clark Y (c = 1220 cm)	Spec. t_m	10.66	9.26	7.42	5.45	3.03	0
	Comp. t_m	10.23	9.05	7.27	5.25	4.12	0
U.S.A.-27 (c = 1220 cm)	Spec. t_m	9.94	9.29	7.86	5.90	3.40	0
	Comp. t_m	9.82	9.13	7.75	5.75	3.25	0
U.S.A.-27 (c = 1440 cm)	Spec. t_m	9.85	9.13	7.80	5.93	3.19	0
	Comp. t_m	9.77	9.08	7.75	5.82	3.04	0
U.S.A.-35B (c = 1220 cm)	Spec. t_m	9.91	8.48	6.72	4.83	2.54	0
	Comp. t_m	9.78	8.46	6.70	4.86	2.56	0
Eiffel 36 (c = 1523 cm)	Spec. t_m	6.10	5.25	4.07	2.85	1.64	0
	Comp. t_m	6.28	5.46	4.55	3.41	2.09	0
U.S.A.-5 (c = 1220 cm)	Spec. t_m	5.57	5.13	4.55	3.61	2.38	0
	Comp. t_m	5.85	5.28	4.55	3.61	2.24	0
R.A.F.-15 (c = 1220 cm)	Spec. t_m	5.41	5.12	4.63	3.89	2.38	0
	Comp. t_m	5.26	4.94	4.41	3.61	2.25	0
Spad (c = 1275 cm)	Spec. t_m	5.22	4.70	4.00	2.94	1.61	0
	Comp. t_m	5.08	4.56	3.92	2.86	1.54	0

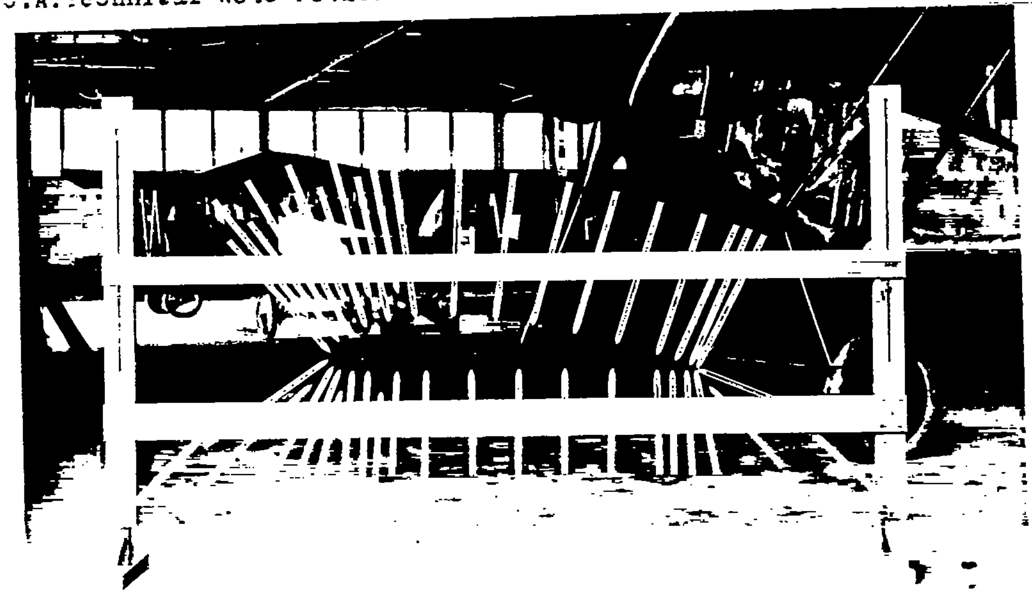


Fig.1 Wing contour measuring device.

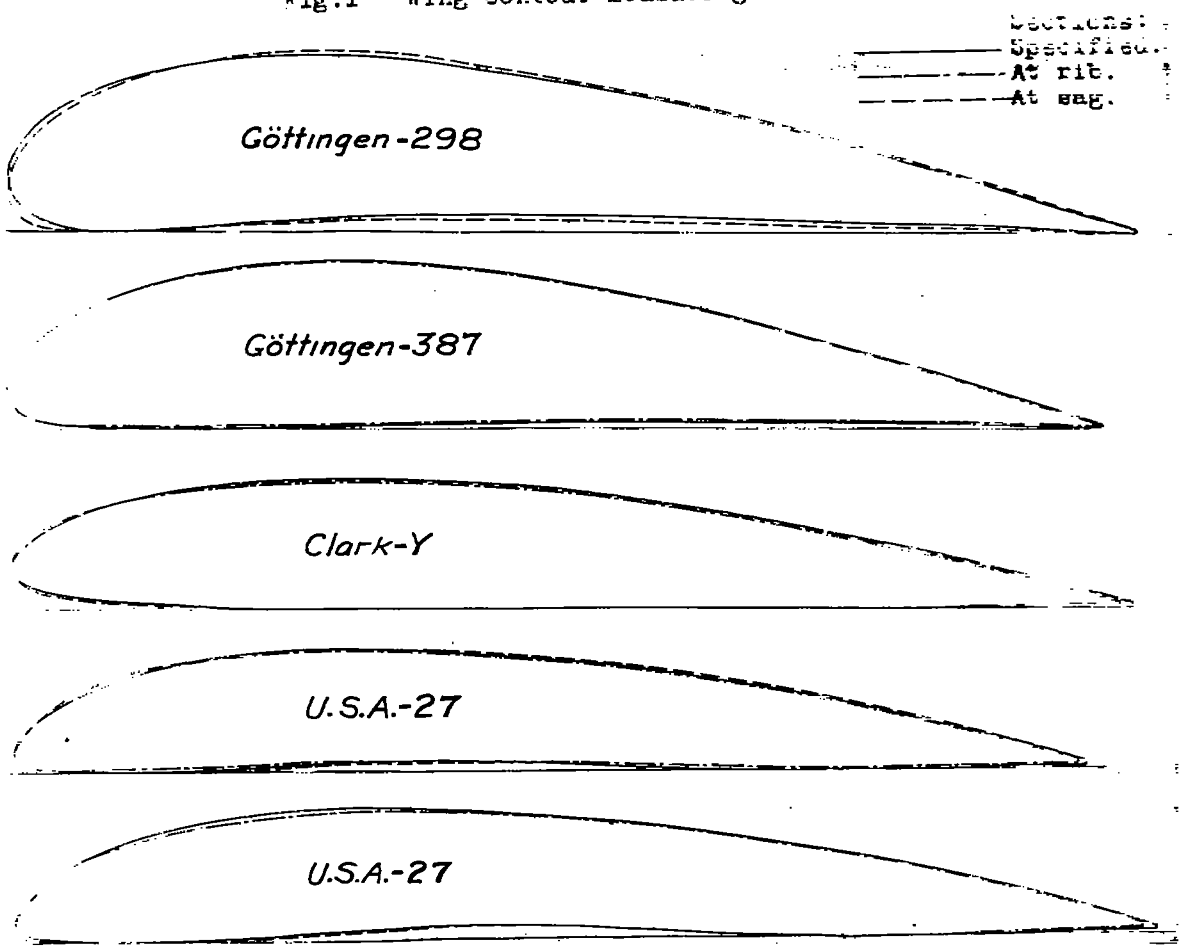
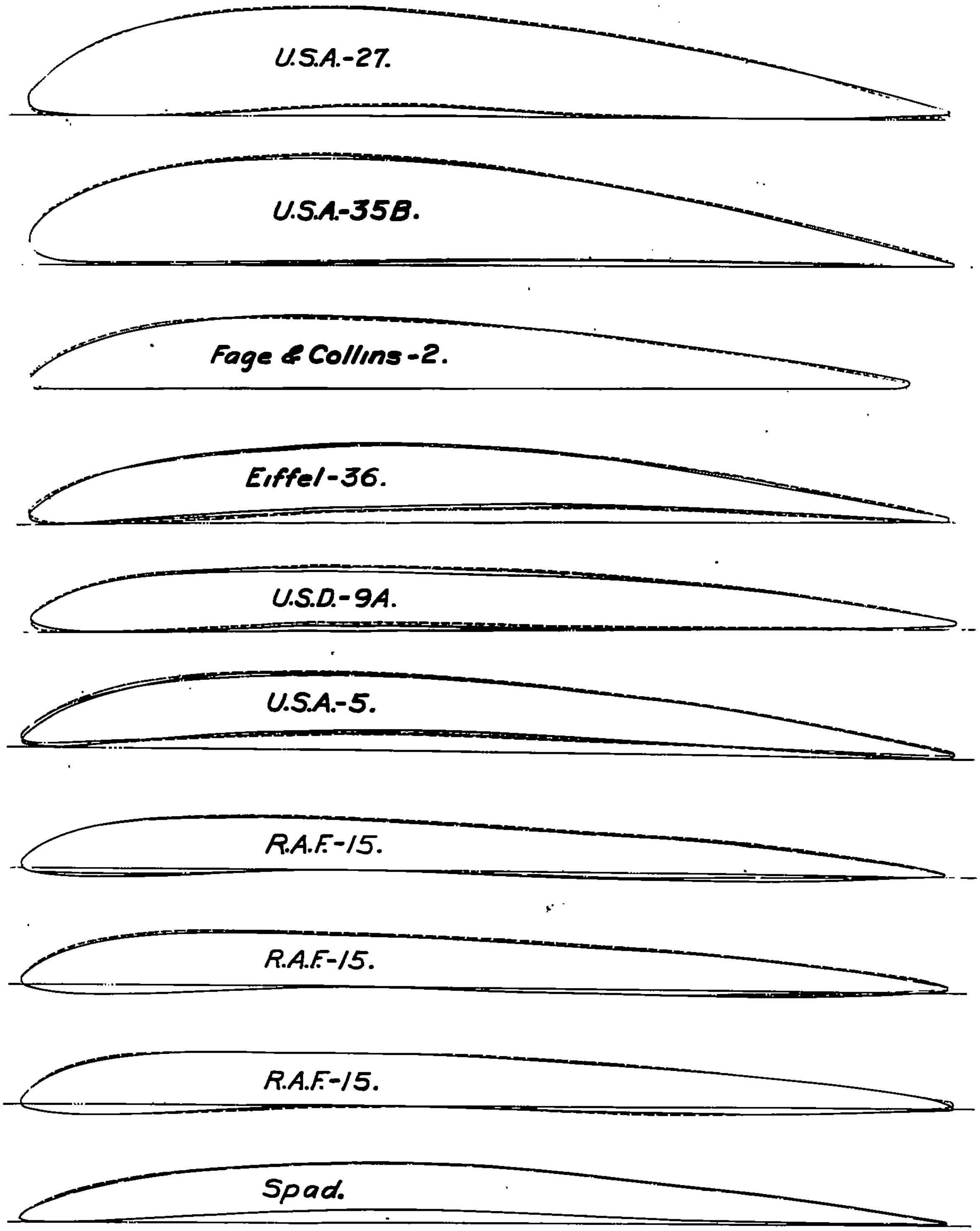


Fig.2 Wing sections measured (Continued on next page)



Specified section — Section at rib — Section at sag

Fig.3 continued

311 A.S.

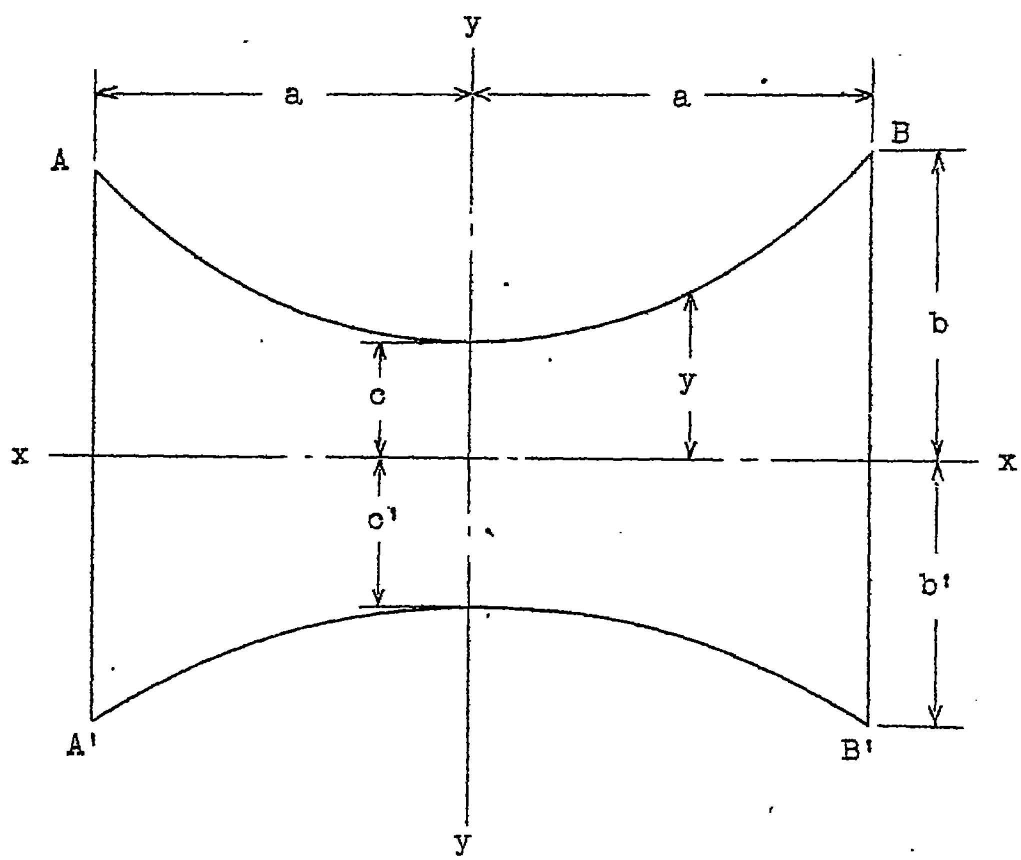


Fig.3 Section showing sag of fabric between two ribs.

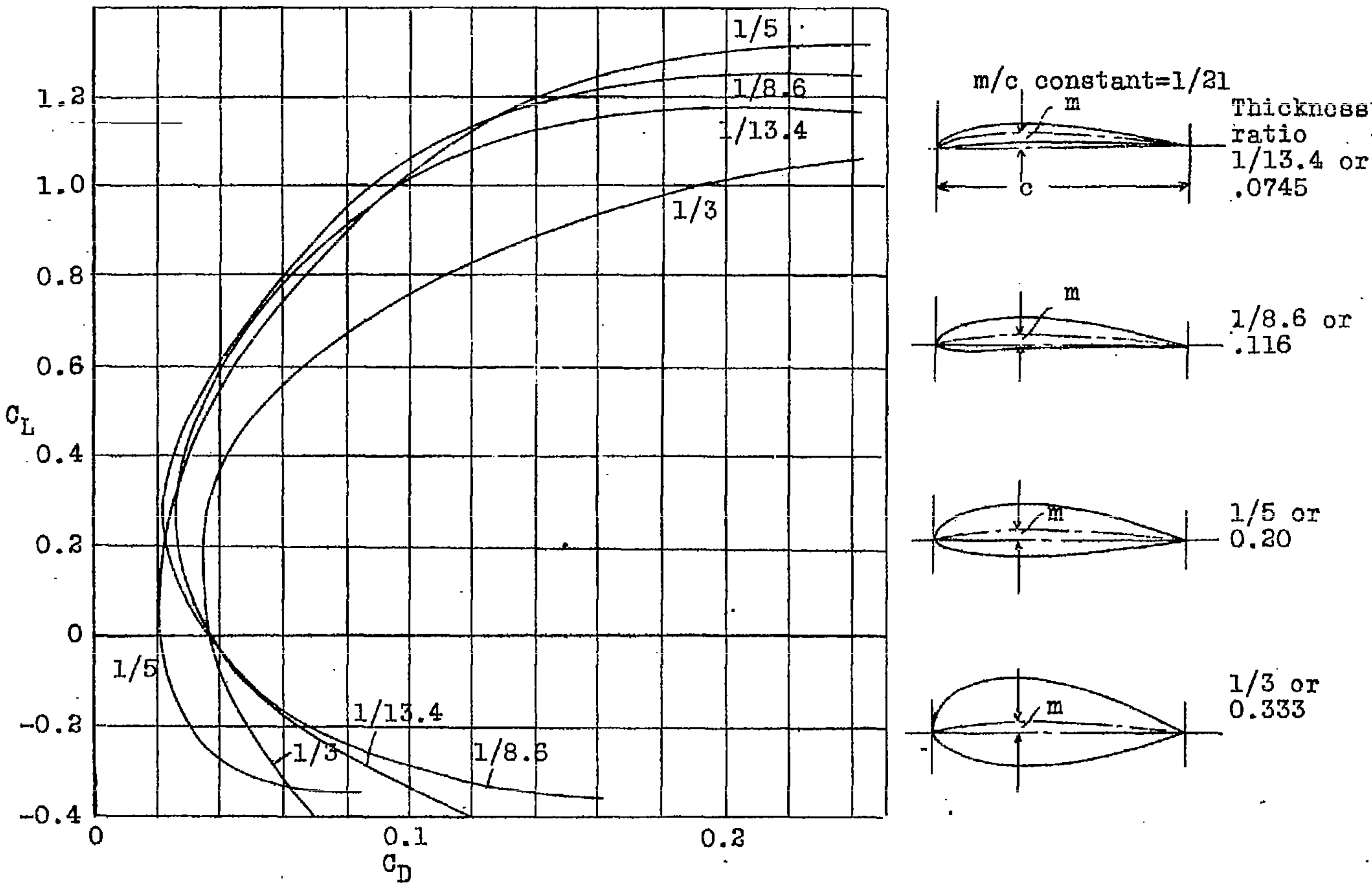


Fig.4 Data showing the effect of changing the thickness ratio with a constant camber of the median line.

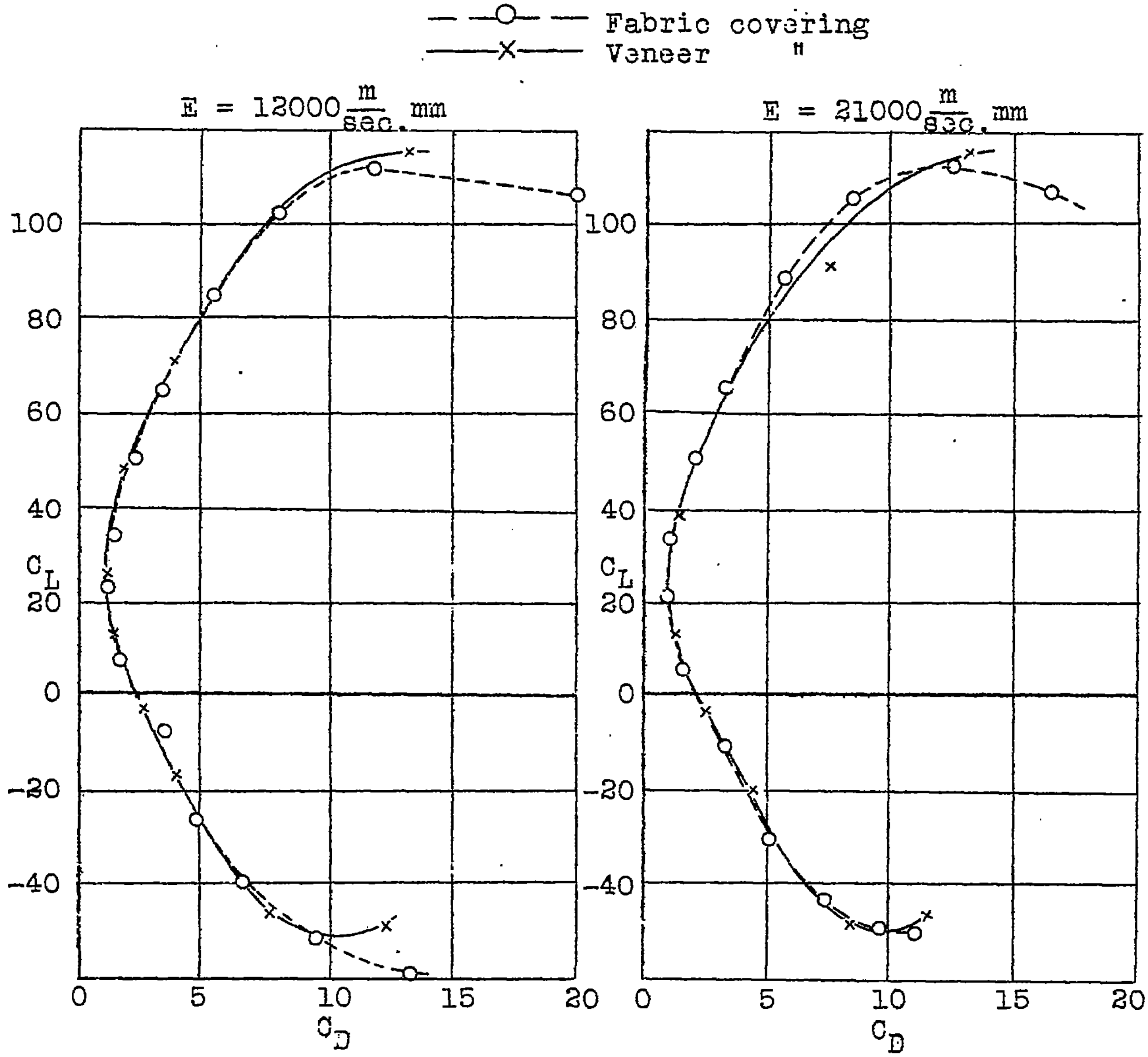


Fig.5 Polar diagram for veneer and fabric covered wings.