TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 236

PROPELLER DESIGN

EXTENSION OF TEST DATA ON A FAMILY OF MODEL PROPELLERS BY MEANS OF THE MODIFIED BLADE ELEMENT THEORY - II

By Fred E. Weick
Langley Memorial Aeronautical Laboratory

Washington
May, 1926

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL NOTE NO. 236.

EXTENSION OF TEST DATA ON A FAMILY OF MODEL PROPELLERS BY MEANS OF THE MODIFIED BLADE ELEMENT THEORY - II.

By Fred E. Weick.

Summary

This report is the second of a series of four on propeller design, and describes the method used to extend the data obtained from tests on a family of thirteen model propellers to include all propellers of the same form likely to be met in practice. This necessitates the development of a method of propeller analysis which when used to calculate the powers and efficiencies gives results which check the tests throughout their range. Airfoil characteristics are derived from the model propeller tests themselves and used in the single section method of analysis (given in the first of this series, N.A.C.A. Technical Note No. 235) to calculate the powers and efficiencies for propellers outside of the test range.

Introduction

N.A.C.A. Technical Report No. 237, entitled "Tests on Thirteen Navy Type Model Propellers," by W. F. Durand, gives the test data on a family of thirteen Navy model wood propellers. These tests are the basis of the Navy design system.

The terms used in describing propellers of Navy form are given in Table I.

In the family of models tested the basic series consisted of seven propellers, each having an aspect ratio of 6 and a camber ratio of 1, but with pitch-diameter ratios varying from .5 to 1.1. Variations of aspect ratio and camber ratio were made at a pitch-diameter ratio of .7 only. The aspect ratios tested were 5, 6, 6.5, and 7.5, each with a camber ratio of 1. The camber ratios were 1, 1.1, 1.2, and 1.3, each with an aspect ratio of 6.

The results of the tests are recorded in terms of power absorbed and efficiency, for various values of $\frac{V}{nD}$. The power is given as a dimensionless power coefficient,

$$C_P = \frac{P}{\rho \; n^3 \; D^5}$$

where P = power in ft. lb. per sec. The efficiency is also in dimensionless units and the results may be applied to any size propeller working under the same conditions as the model. Corrections for tip speed and fuselage interference are given in N.A.C.A. Technical Note No. 225 (Reference 1).

The family of Navy propellers tested was relatively small. This report describes the method used in extending the data to include all pitch-diameter ratios, aspect ratios, and camber ratios likely to be needed. The use of the extended data in propeller design is shown in Technical Note No. 237.

Method of Extending Model Propeller Test Data

The first step in this method of extending the test results of the family of propellers was to develop a system of propeller analysis which gives computed performance agreeing with the test results throughout the range of the family. For this purpose, special airfoil characteristics have been calculated from the model propeller tests themselves, and used in connection with the single section blade element analysis described in the first of this series, N.A.C.A. Technical Note No. 235.

Using the single section method with airfoil characteristics obtained in the McCook Field high speed wind tunnel, calculations of the power coefficient and efficiency were made for the model propellers covering the range of the family tested. Since these terms are in dimensionless units, the size of the propeller does not affect them, and 10 ft. propellers revolving at 1800 R.P.M. were taken for convenience. The computation for the propeller of pitch-diameter ratio .9, aspect ratio 6, and camber ratio 1, operating at a $\frac{V}{nD}$ of .70 was made as follows:

Speed of advance = 210 ft. per sec.

r/R = .75

b = .66 ft.

h_U/b = .107

$r = 3.75$ ft.

$S = \frac{2\pi r}{bB} = 17.8$

$\Phi_\beta = \text{arc tan}\,\frac{\text{pitch}}{2\pi r} = 20.9^\circ$

$\Phi = \text{arc tan}\,\frac{V}{2\pi rn} = 16.6^\circ$

$\alpha = \Phi_\beta - \Phi = 4.3^\circ$

$C_L = .746$ (from U.S. Air Service Propeller Manual)

$\delta C_L = .042$

$C'_L = C_L - C_L = .704$

$\epsilon = .7^\circ$

$\alpha' = \alpha - \epsilon = 3.6^\circ$

L/D (α') = 19.6 (from U.S. Air Service Propeller Manual)

$\gamma = \text{arc tan}\,(\frac{D}{L}(\alpha') + \tan\epsilon) = 3.6^\circ$

$K_p = \frac{b\,C'_L}{2\,D\,\sin^2\Phi} = .285$

$Q'_c = K_p \times \frac{r}{D} \times \sin(\Phi+\gamma) = .0368$

$Q = .272\,\rho\,V^2\,D^3\,B\,Q'_c$

$P = 2\pi n Q$ ft. lb. per sec.

and $C_P = \frac{P}{\rho\,n^3\,D^5} = 1.71\,B\,Q'_c\left(\frac{V}{nD}\right)^2$

$= 1.71 \times 2 \times .0368 \times .7^2 = .0617$

$\eta = \frac{.416 \times \frac{V}{nD}}{\tan(\Phi+\gamma)} = .792$

From the model tests, $C_p = .0631$ and $\eta = .782$. In order to find the airfoil characteristics which would have made the calculations agree with the test results, the last few steps can be reversed using the test results as a basis. Thus from the efficiency equation above

$$\tan(\Phi+\gamma) = \frac{.416 \times \frac{V}{nD}}{.782} = .372$$

$$\Phi + \gamma = 20.4^\circ$$

and $$\gamma = 20.4^\circ - \Phi = 5.8^\circ$$

Then $\tan\gamma = \frac{D}{L}(\alpha') + \tan\epsilon$, and since ϵ remains practically constant for slight changes in efficiency or power in the same propeller

$$\frac{D}{L}(\alpha') = \tan\gamma - \tan\epsilon$$

$$= .0664 - .0122$$

$$= .0542$$

and $$\frac{L}{D}(\alpha') = 18.4 \quad \text{for} \quad \alpha' = 3.6^\circ$$

The power coefficient depends on b, D, r, Φ, C'_L and γ, all but the last two remaining constant. Therefore, the C'_L which would have given the test value of C_P can be obtained as follows:

$$C'_L = C'_L\text{ (original)} \times \frac{C_P\text{ (test)}}{C_P\text{ (calculated)}} \times \frac{\sin(\Phi+\gamma)\text{ (calc.)}}{\sin(\Phi+\gamma)\text{ (test)}}$$

$$= .704 \times \frac{.651}{.617} \times \frac{\sin 20.2^\circ}{\sin 20.4^\circ} = .713$$

Then $C_L = C'_L + \partial C_L = .713 + .042 = .755$ for $\alpha = 4.3^\circ$.

The values of C_L and L/D obtained from the model propeller tests in the above manner are plotted in Fig. 5 for propellers of camber ratio 1. The values of C_L all lie very close to a smooth curve indicating the essential correctness of this method of analysis. The values of L/D are more scattered but the accuracy is within the experimental error of the model tests, since a small change in propeller efficiency results from a comparatively large change in L/D.

In Fig. 6 the faired curves are shown for all the camber ratios tested. Using these values of C_L and L/D calculations of C_P and η check the propeller tests throughout their range to within 2 or 3 per cent.

The propeller section characteristics in Fig. 6 have been used in the single section method of analysis to calculate values of C_P and η for propellers of all aspect ratios, camber ratios, and pitch-diameter ratios likely to be needed in practice. The use of these data in designing and analyzing propellers is shown in the third of this series, N.A.C.A. Technical Note No. 237.

TABLE I.

Explanation of Terms

D - Diameter of propeller in feet.

P - Geometrical pitch in feet.

R - Tip radius in feet = D/2

r - Radius of any section of propeller in feet.

c - Maximum blade width in feet.

b - Blade width at any section in feet.

B - Number of blades in propeller.

V - Velocity of advance in ft./sec.

n - Revolutions of propeller per second.

AR - Aspect ratio. $AR = \frac{D}{cB}$

CR - Camber standard of propeller blade as a whole. This is the ratio of the thickness of the entire propeller blade to that of a standard blade, the variation in thickness along the radius being the same for all blades. (The standard variation of section thickness ratio along the radius is shown in Fig. 1. If the curve is increased by 10 per cent at every point the camber ratio is 1.1.)

Standard Navy Form - A wood propeller having a variation in thickness ratio in accordance with Fig. 1, distribution of blade width as shown in Fig. 2, blade sections in accordance with Fig. 3, and the centers of gravity of its sections located as shown in Fig. 4, is said to be of standard Navy form.

C_P – Power coefficient of propeller.

P – Power in ft. lb. per sec.

Reference

1. Weick, Fred E. : Propeller scale effect and body interference.

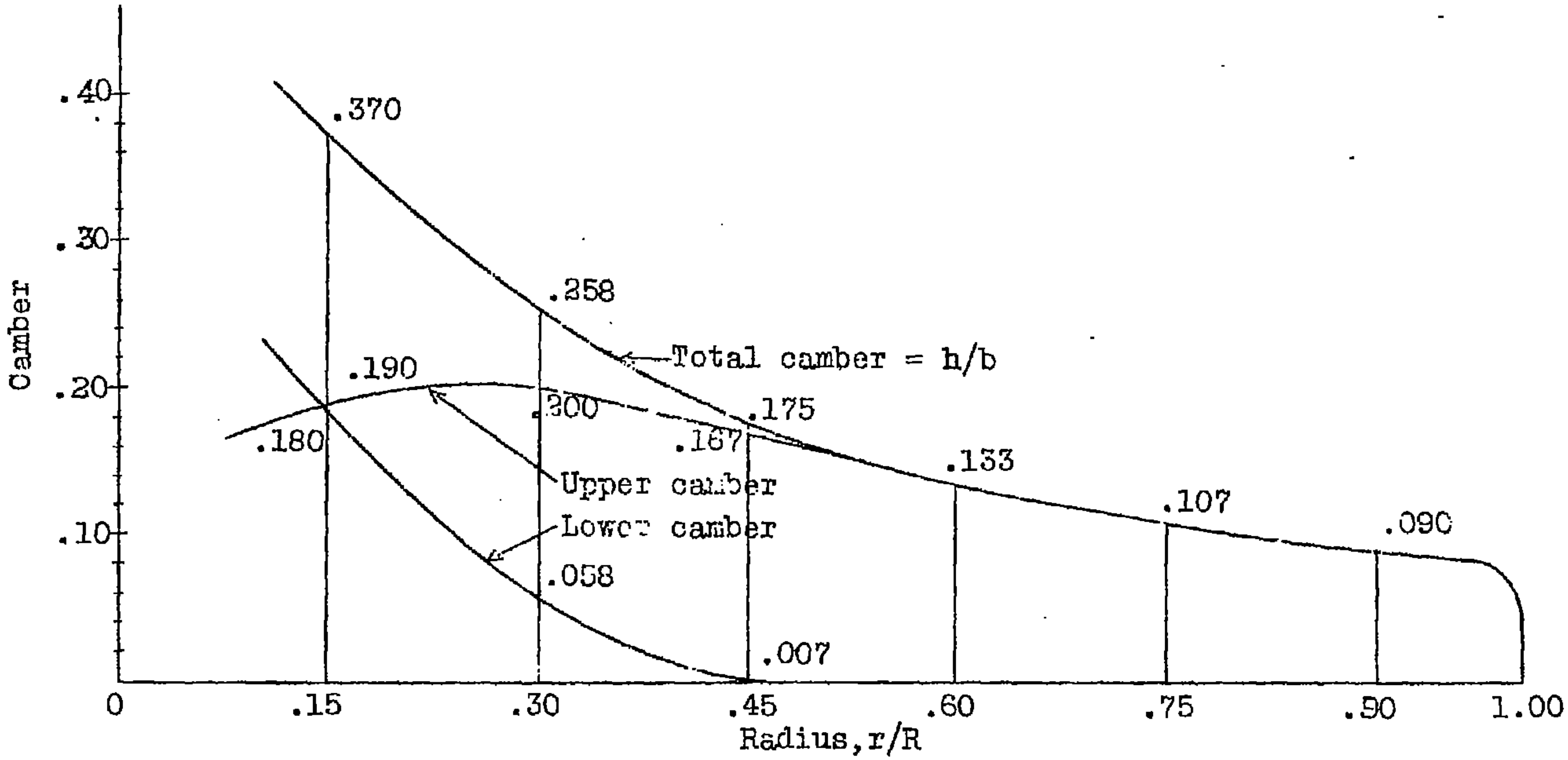


Fig.1 Curve of cambers for CR = 1.

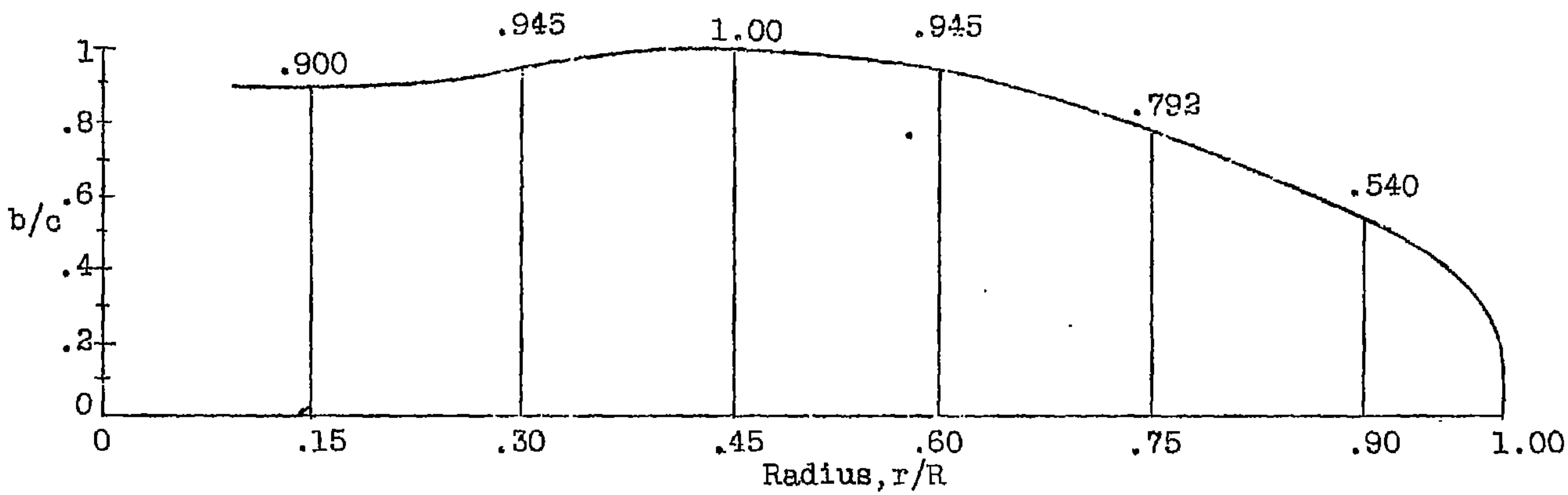
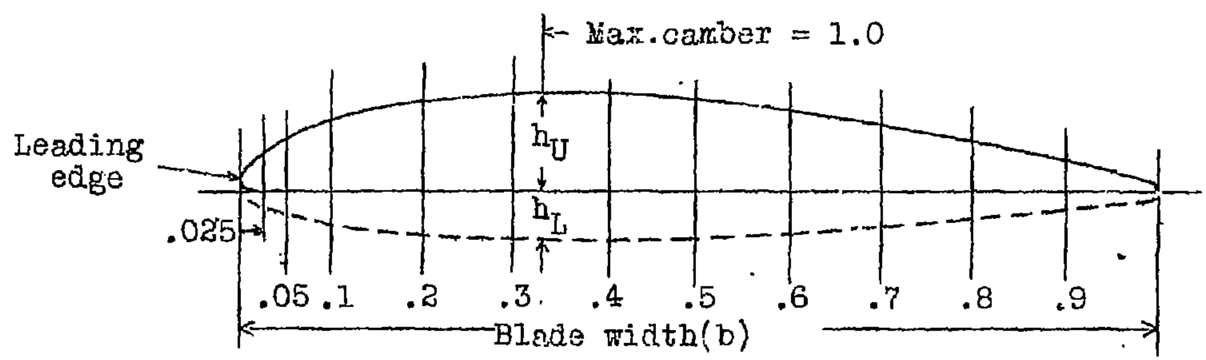


Fig.2 Blade width based on maximum width.



Station	LER	.025	.05	.1	.2	.3	.4	.5	.6	.7	.8	.9	TER
Ordinate	.10	.41	.59	.79	.95	.998	.99	.95	.87	.74	.56	.35	.077

Fig.3 Navy standard blade section. R.A.F.No.6 modified, flat face.

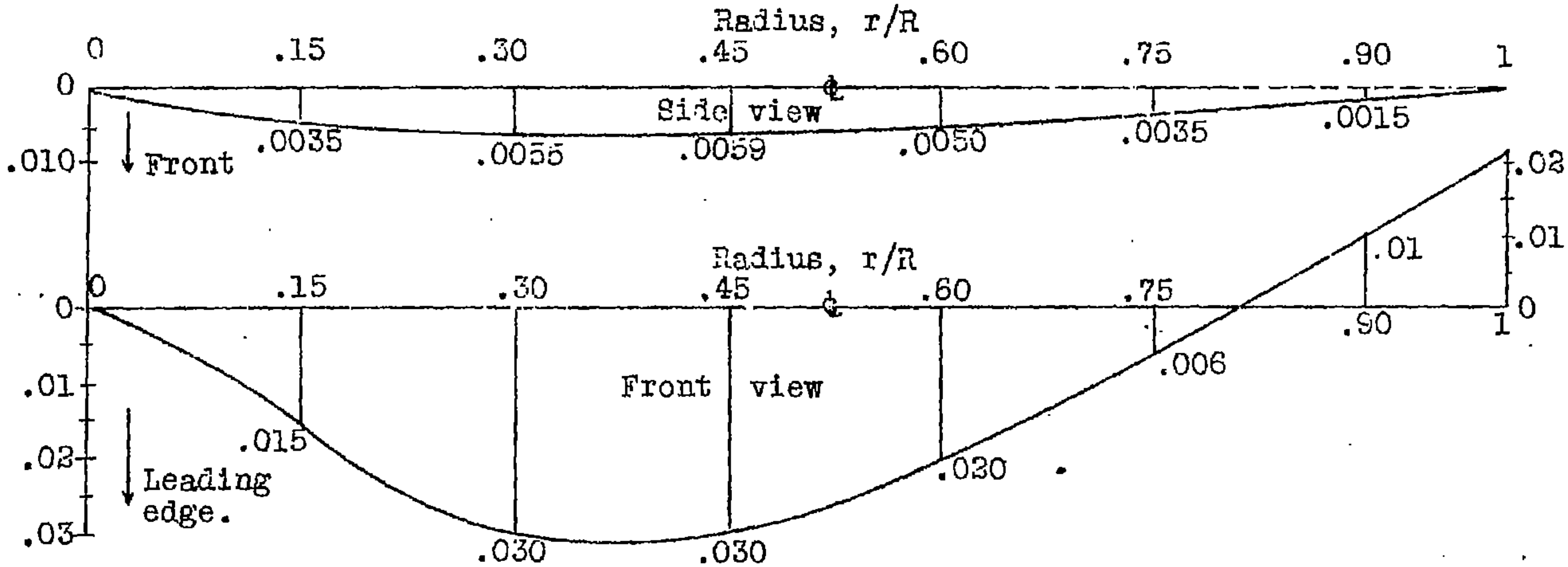


Fig. 4 Path of centers of gravity of sections. Offsets in terms of tip radius.

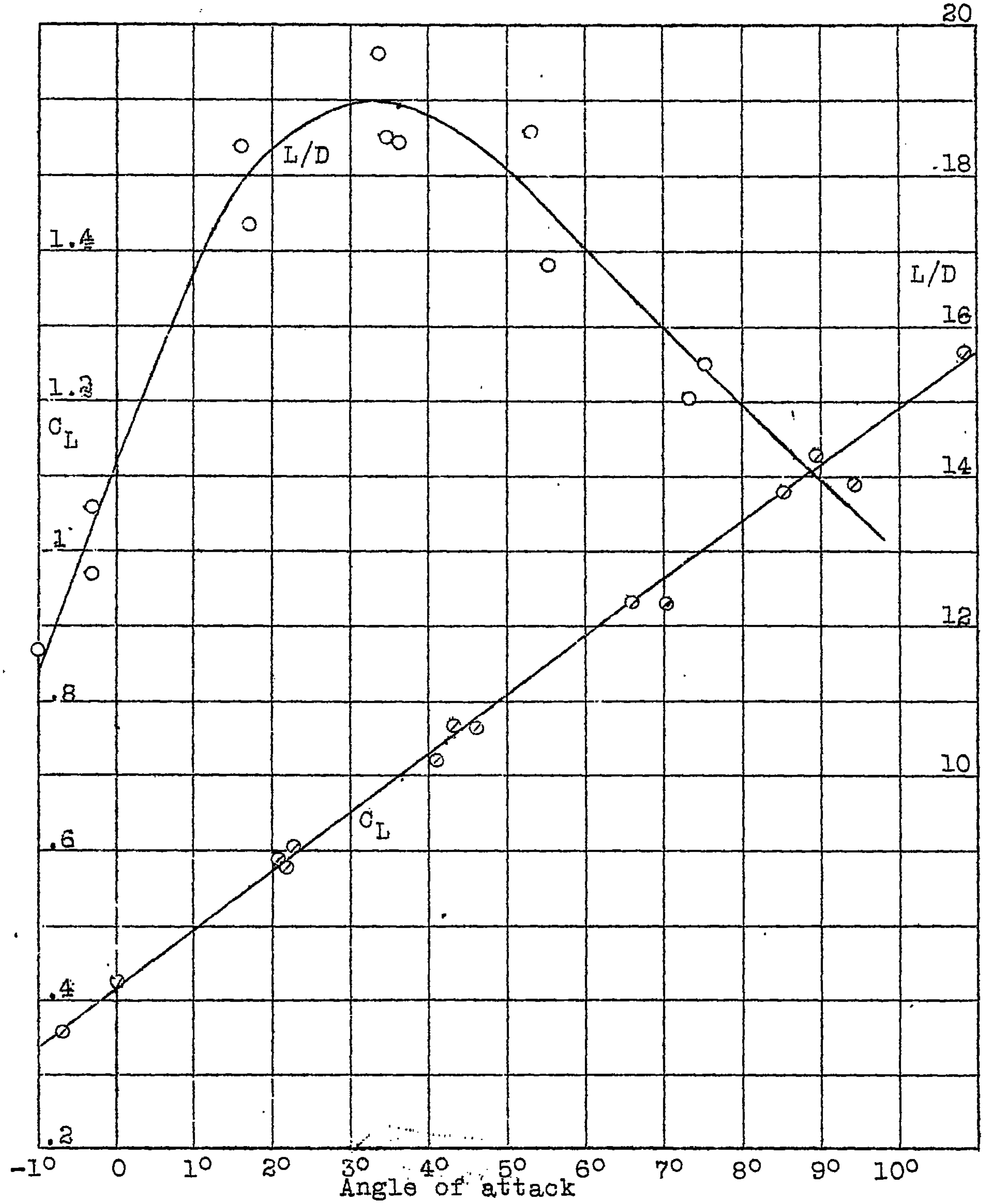


Fig.5 Propeller section characteristics. Obtained from propellers of CR = 1.

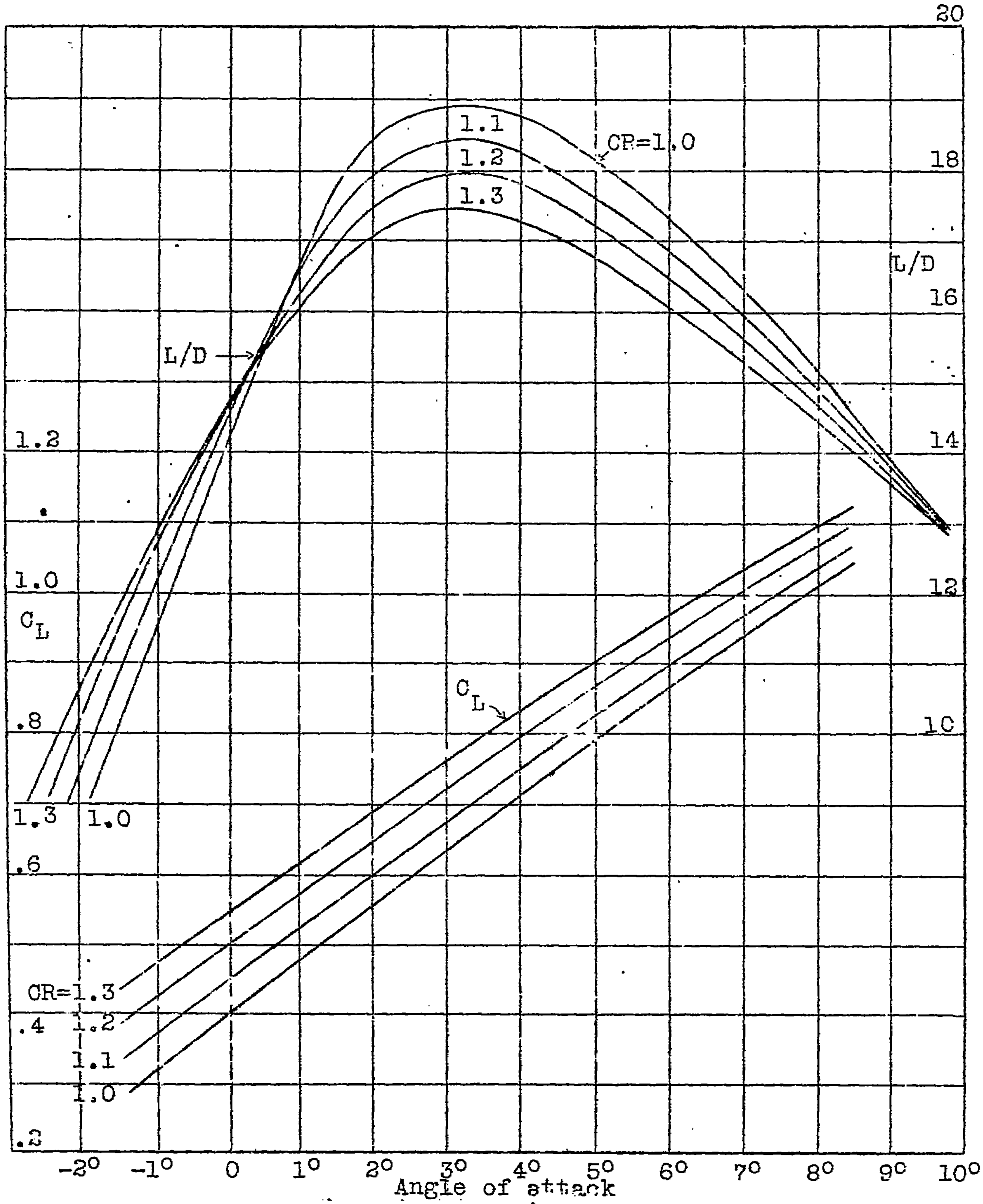


Fig.3 Propeller section characteristics. Curves faired and adjusted.