TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

No. 263

WIND TUNNEL TESTS OF CORRECTION FORMULA FOR WINGS OF LARGE SPAN.

By C. Wieselsberger.

From Report II of the Göttingen Aerodynamic Institute, 1923.

May, 1924.

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WIND TUNNEL TESTS OF CORRECTION FORMULA FOR WINGS OF LARGE SPAN.*

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In the section entitled "Versuchstechnik" of Report I, it was stated that wing experiments in an artificial air stream are subject to error, due to the fact that the wing is not situated in an unlimited body of air but in an air stream of finite diameter. This error increases in proportion to the ratio between the wing span and the diameter of the air stream. It has been found that the wing drag obtained in a free air stream is too large. Moreover, the angle of attack of the wing must also be corrected. According to Prandtl ("Tragflugeltheorie II. Mitteilung, No. 11), the additional drag D', for a cylindrical stream of cross-section S_0 and diameter d, has, under the assumption of an elliptical distribution of the lift L over the wing span b, the following value

$$D' = \frac{L^2}{8qS_0} \quad 1 + \frac{3}{16}\left(\frac{b}{d}\right)^4 + \frac{5}{64}\left(\frac{b}{d}\right)^8 + \frac{175}{4096}\left(\frac{b}{d}\right)^{12} + \dots \; .$$

The spans of the models used in wind tunnel experiments are usually 0.8 - 1.2 m (2.62 - 3.94 ft.). For these dimensions the bracketed portion of the above equation, which is represented by θ in Fig. 1, is but slightly affected by the length of the span,

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* From Report II of the Göttingen Aerodynamic Institute, 1923, pp. 17-20.
" " " , 1927, p. 166.

Correction on p. 4 see Report III

so that the mean value of 1.009 m (3.31 ft.) is sufficiently accurate. If we further introduce the cross-section $S_o = 4\ m^2$ (43 sq.ft.) into the equation, we then obtain the additional drag, due to the finite diameter of the air stream, as approximately

$$D' = 0.0315\ m^{-2} \frac{L^2}{q} .$$

All wing drags are corrected with the aid of this formula, and indeed by subtracting the drag D' from the measured drag. If models of greater span than 1.2 m (3.9 ft.) are employed, the additional drag, with reference to the existing relation b/d, must be calculated according to the exact equation given first.

The theory, by means of which the given drag correction was obtained, was based on various assumptions (e.g., elliptical distribution of the lift) which do not always hold true. For this reason, it was desirable to test the equation for the additional drag in regard to its reliability and range of application. With this end in view, five rectangular, geometrically similar wing models were made with spans b, of 60 (23.62), 90 (35.43), 120 (47.24), 150(59.05) and 180 cm (70.87 in.) and their polar curves determined. They all had the same aspect ratio of 1 : 5, their chords being respectively 12 (4.72), 18 (7.08), 24 (9.45) 30 (11.81) and 36 cm (14.17 in.). The Göttingen wing section No. 389 with a flat pressure side was used (See report I, pp. 76 and 90). In order to eliminate the effect of the Reynolds number on the wing drag for the different chords, all the experiments were executed with the same Reynolds number with reference to the chord l, namely, with $R = \frac{Vl}{\nu} \sim 240000$ (index value $E = Vl = 3600$ mm × m/s). The wing with the shortest chord was tested at a wind velocity of about 30 m (98.4 ft.)/s. The velocities for the other wings were respectively about 20 (65.6), 15 (49.2), 12 (39.4) and 10 m (32.8 ft.)/s. The results are given in Tables I-V and are also represented graphically, Figure 2 giving the polar curves without the correction and Figure 3 with the correction. It is seen that the original polar curves for the differently sized wings differ considerably from one another. Even with a span of one meter (3.28 feet), which is most frequently employed in wing-section experiments, the error in the drag amounted to several per cent. If, however, the measured drags are corrected by using the given approximation formula, we find that the measuring points of all except the largest wing fall on the same curve. For the largest wing (of 180 cm (70.87 in.) span), the application of the approximation formula gives points which fall to the right of the actual polar curve. This wing model is therefore too large for the 2.24 m (7.35 ft.) wind tunnel and would give erroneous results. On the other hand, the experiments show that the models, up to a span of 150 cm (59.05 in.) admit of the satisfactory application of the correction formula for the additional drag, so that their polar curves can be accurately determined. Of course, the employment of the largest possible models is very desirable, both on account of the larger Reynolds number and the greater accuracy obtainable, in the construction of the models.

The additional drag is due to the production of a vertical disturbing velocity which changes the original direction of the air flow against the wing. Hence the angle of attack must also be corrected. The additional angle of attack α' in degrees is given by

$$\alpha' = \frac{57.3\ L}{8\ q\ S_0} \quad 1 + \frac{3}{16}\left(\frac{b}{d}\right)^4 + \dots \quad .$$

For spans of 0.8 to 1.2 m (2.62 to 3.94 ft.) and an air stream of S_0 = 4 sq.m (43 sq.ft.), this expression may be replaced by the approximation $\alpha' = 0.0315\ m^{-2}\ \frac{L}{q}$.

Tables I-V give the corrected angles of attack. The original angles of attack of all the wing models went by intervals of 3 degrees (-9, -6, -3, 0, 3, etc.). On plotting C_L, both against the original and also against the corrected angles of attack (Figs. 4 and 5), we find that here also the previous discrepancies mostly disappear. The agreement is less complete, however, than in the correction of the drag. There remains a systematic deviation, which may be construed as the effect of the deflection of the air flow. This effect is being theoretically investigated. We may therefore expect a refinement in the corrections of the experimental results - which, however, can be of importance only for very large wings.

Table I.

Wing 60 × 12 cm (23.6 × 4.72 in.)

V = 29.8 m/s (97.8 ft./sec.)

Angle of attack	C_L	C_D	
		Without corrections	With corrections
-9°	-.255	.0732	.0730
-6	-.044	.0158	.0158
-3	.158	.0159	.0159
0	.340	.0206	.0204
2.9	.560	.0330	.0321
5.9	.770	.0520	.0510
8.9	.961	.0794	.0772
11.9	1.083	.1103	.1073
14.9	1.120	.148	.145
17.9	1.058	.239	.236

Table II.

Wing 90 × 18 cm (35.43 × 7.09 in.)

V = 20.0 m/s (65.6 ft./sec.)

Angle of attack	C_L	C_D	
		Without corrections	With corrections
-8.9°	-.213	.0595	.0593
-6	-.028	.0173	.0173
-3	.165	.0154	.0151
-0.1	.358	.0203	.0196
2.8	.560	.0335	.0318
5.8	.764	.0530	.0501
8.7	.932	.0785	.0740
11.7	1.070	.110	.104
14.7	1.115	.148	.141
17.7	1.065	.215	.209

Table III

Wing 120 × 24 cm (47.24 × 9.45 in.)

V = 14.8 m/s (48.6 ft./sec.)

Angle of attack	C_L	C_D	
		Without corrections	With corrections
-8.9°	-.205	.0630	.0625
-6	-.006	.0180	.0180
-3.1	.175	.0168	.0168
-0.2	.366	.0221	.0208
2.7	.572	.0358	.0328
5.6	.765	.0572	.0519
8.5	.931	.0827	.0752
11.4	1.090	.113	.103
14.4	1.133	.155	.142
17.4	1.118	.207	.196

Table IV

Wing 150 × 30 cm (59.05 × 11.8 in.)

V = 11.8 m/s (38.7 ft./sec.)

Angle of attack	C_L	C_D	
		Without corrections	With corrections
-8.9°	-.198	.0654	.0650
-6	-.002	.0158	.0158
-3.1	.178	.0161	.0156
-0.3	.368	.0217	.0197
2.6	.555	.0342	.0299
5.5	.734	.0551	.0475
8.4	.907	.0825	.0707
11.2	1.063	.114	.0982
14.2	1.134	.153	.135
17.2	1.124	.202	.185

Table V.

Wing 180 × 36 cm (70.87 × 14.17 in.)

V = 10.1 m/s (33.1 ft./sec.)

Angle of attack	C_L	C_D	
		Without corrections	With corrections
-8.8°	-.180	.0591	.0584
-6	.009	.0156	.0156
-3.2	.177	.0145	.0135
-0.4	.346	.0229	.0203
2.4	.532	.0386	.0324
5.2	.699	.0579	.0470
8.0	.875	.0864	.0695
10.8	1.030	.122	.0990
13.6	1.140	.158	.126
16.7	1.118	.197	.168

Translated by Dwight M. Miner,
National Advisory Committee
for Aeronautics.

$$D = \frac{1}{8q} \frac{L^2}{S_o} \theta$$

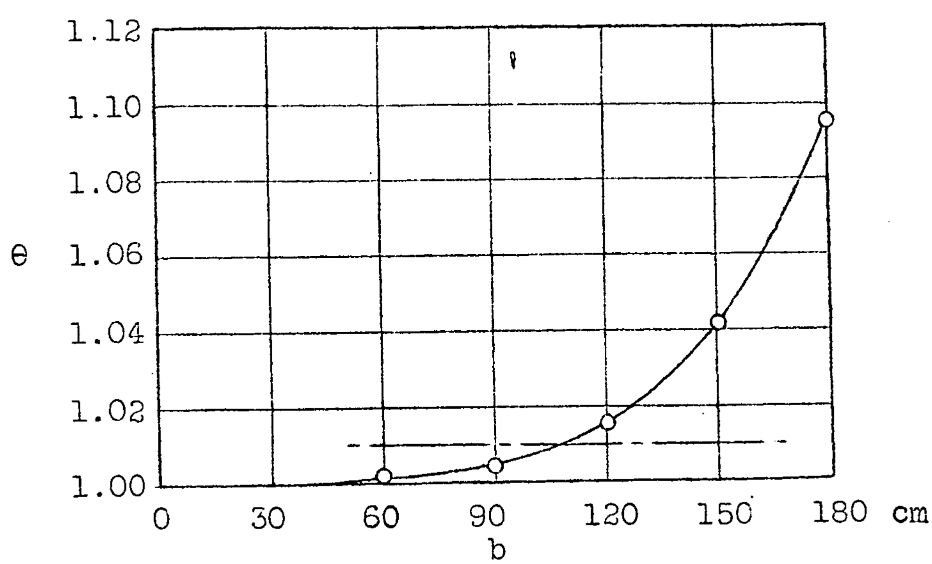


Fig. 1 Airstream correction. Elliptical distribution.

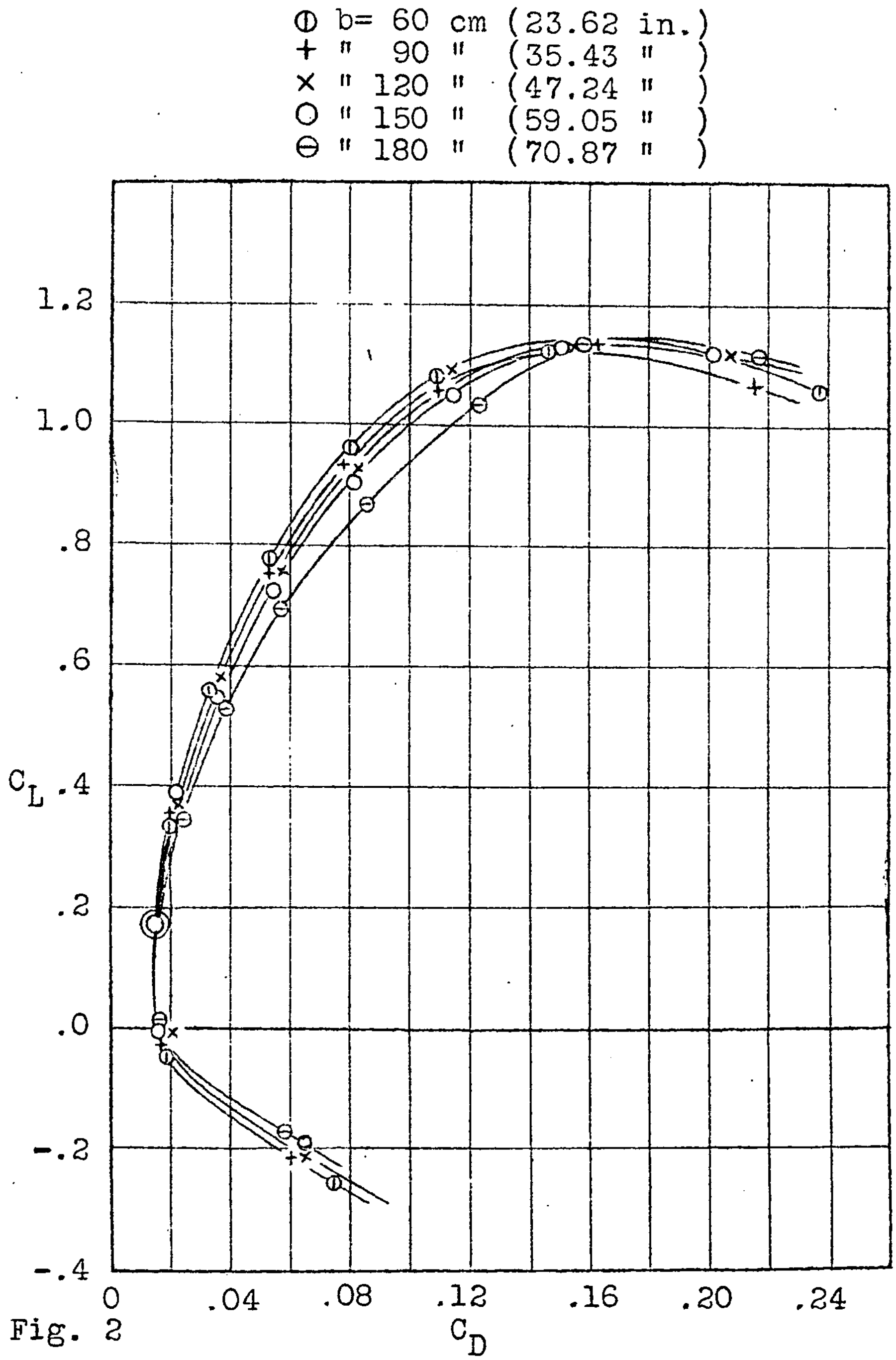
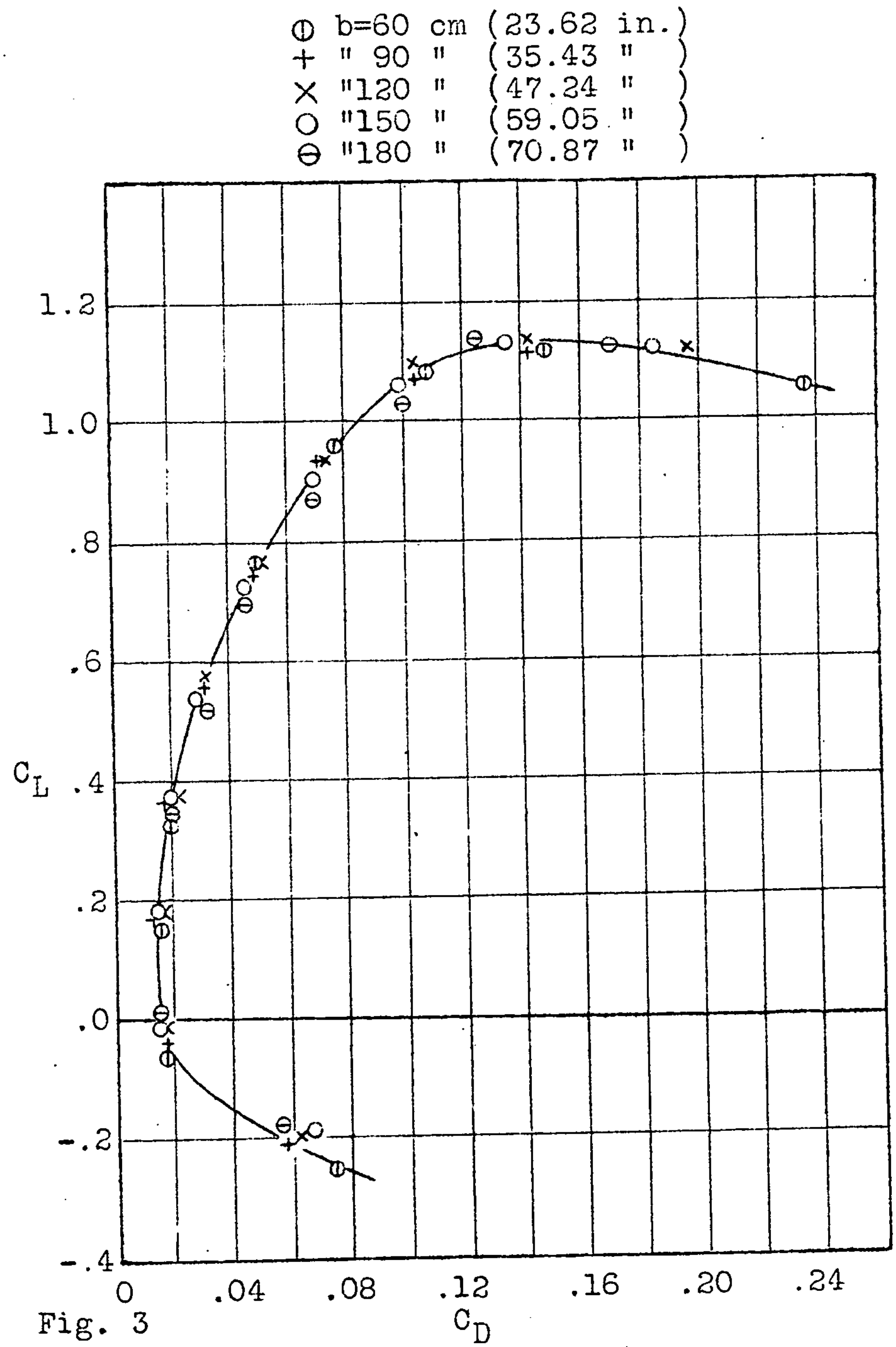

ɸ b= 60 cm (23.62 in.)
+ " 90 " (35.43 ")
× " 120 " (47.24 ")
○ " 150 " (59.05 ")
⊖ " 180 " (70.87 ")
1.2
1.0
.8
.6
C_L .4
.2
.0
-.2
-.4
0
.04
.08
.12
.16
.20
.24
C_D

Fig. 2


b=60 cm (23.62 in.)
" 90 " (35.43 ")
"120 " (47.24 ")
"150 " (59.05 ")
"180 " (70.87 ")
1.2
1.0
.8
.6
C_L .4
.2
.0
-.2
-.4
0
.04
.08
.12
.16
.20
.24
C_D
Fig. 3

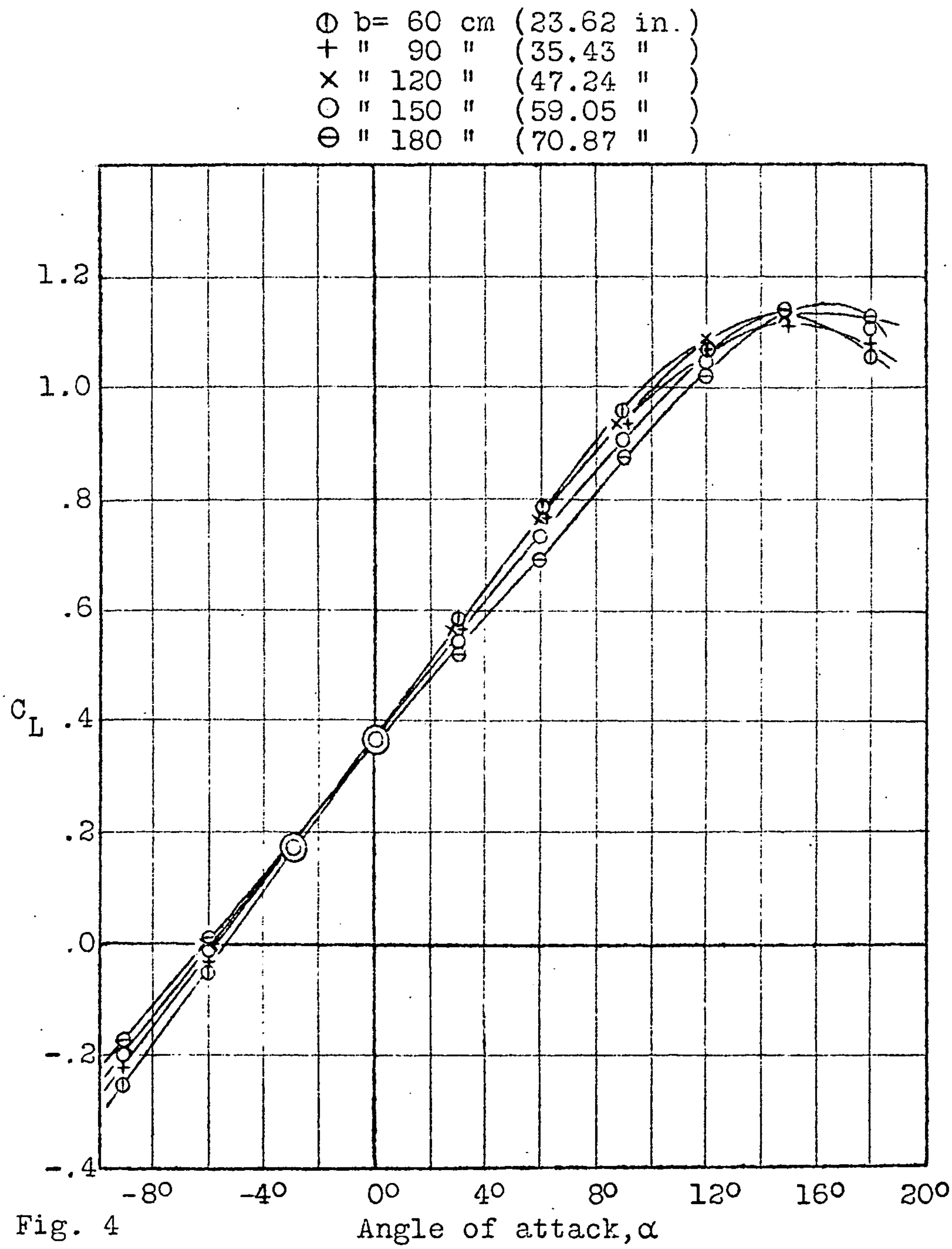

⦶ b= 60 cm (23.62 in.)
+ " 90 " (35.43 ")
× " 120 " (47.24 ")
○ " 150 " (59.05 ")
⊖ " 180 " (70.87 ")
C_L
1.2
1.0
.8
.6
.4
.2
.0
-.2
-.4
-8°
-4°
0°
4°
8°
12°
16°
20°
Angle of attack, α

Fig. 4

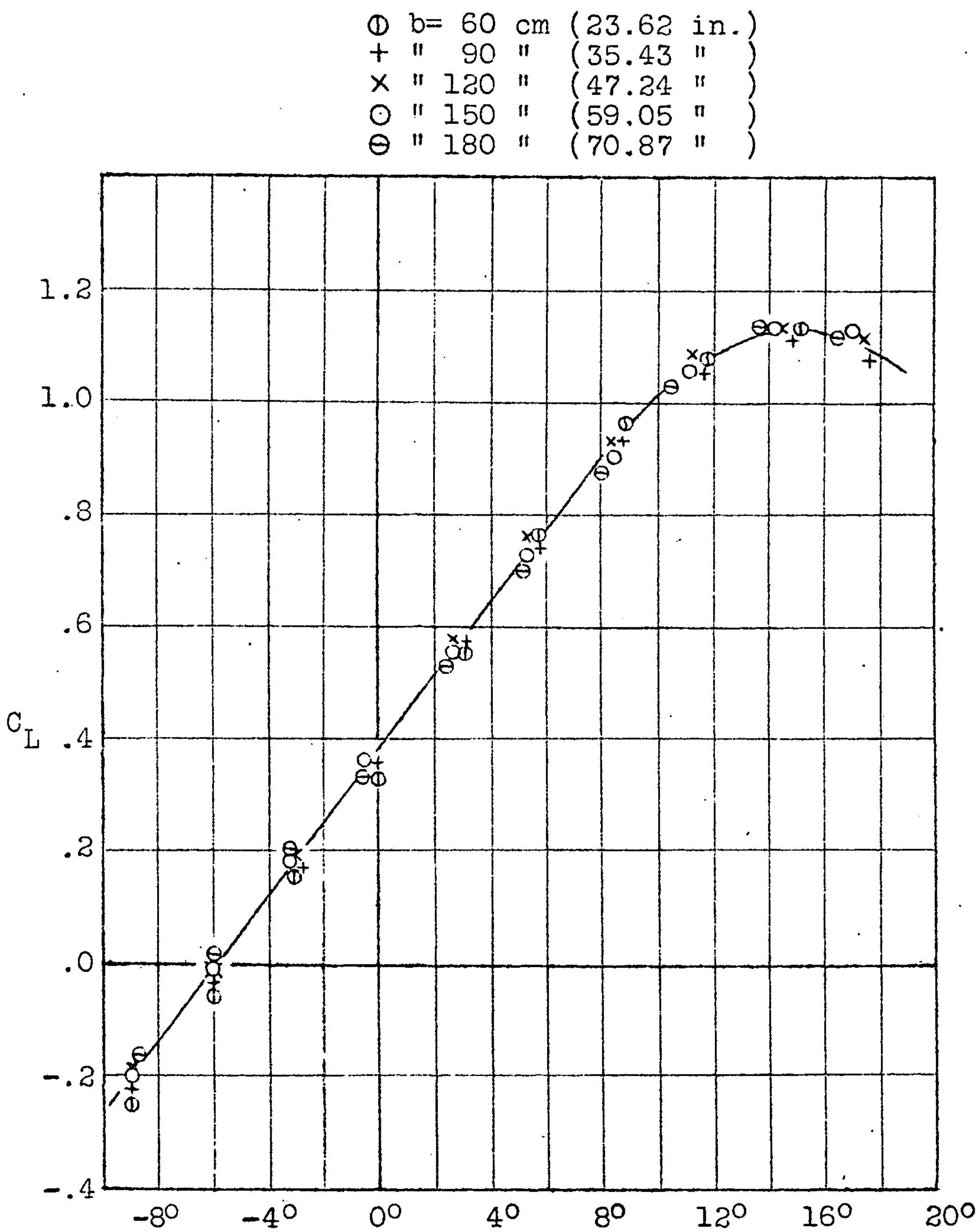


Fig. 5 Angle of attack, α