REPORT No. 196

COMPARISON OF MODEL PROPELLER TESTS WITH AIRFOIL THEORY

By WILLIAM F. DURAND AND E. P. LESLEY
National Advisory Committee for Aeronautics

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PURPOSE

The purpose of the investigation covered by the present report, which was prepared for publication by the National Advisory Committee for Aeronautics, was the examination of the degree of approach which may be anticipated between laboratory tests on model airplane propellers and results computed by the airfoil theory, based on tests of airfoils representative of successive blade sections.

The general basis of such a comparison implies the following:

(1) The selection of a series of blade sections from hub to tip as sufficiently representing the form and character of the blade viewed as a complex airfoil.

(2) The determination, for these sections, of a series of angles of attack based on the geometry of the propeller and the assumed value of the ratio v/nD.

(3) The correction of the angles of attack as developed in (2) in order to allow for some inflow velocity, i. e., some acceleration of the air before it reaches the plane of rotation of the blade.

(4) The construction of model airfoils and their test over a range of angles of attack sufficiently wide to cover the desired range in values of v/nD for the propeller, and at such air speeds as may be available.

(5) The correction of the results of such airfoil tests for (*a*) aspect ratio, (*b*) wind speed, and (*c*) possible blade interference.

(6) The values of the lift and drag coefficients with their ratio, thus corrected, are then to be used in the equations representing the well-known airfoil theory of the action of a propeller blade. These equations give directly values of thrust and torque and from which coefficients for thrust and power and values of efficiency are readily found. These values corrected for hub effect are then ready for comparison with the results of direct propeller model test.

In considering such a program in its more general aspect it is known that the corrections for angles of attack and for aspect ratio, speed and interference rest either on experimental data or on somewhat uncertain theoretical assumptions. The general situation as regards these four sets of corrections is far from satisfactory, and while it is recognized that occasion exists for the consideration of such corrections, their determination in any given case is a matter of considerable uncertainty. There exists at the present time no theory generally accepted and sufficiently comprehensive to indicate the amount of such corrections, and the experimental data available is, at best, uncertain in its application to individual cases.

It is furthermore obvious that, in practice, the application of the airfoil theory as based on airfoil tests will gain in simplicity and in readiness of use, directly in proportion to the degree to which such uncertain corrections may be omitted from consideration.

For these reasons, in the first and present phase of this investigation, consideration of all corrections has been omitted and the application of the theory has thus been reduced to its simplest possible form. This first phase of a more extended possible program was undertaken in the hope that by the application of the theory in this simplified form to a considerable number of propellers distributed regularly over the more normal field of design, some generally consistent tendency of the divergence between test and computation might appear. Naturally where no corrections are made, divergencies of considerable amounts might be expected, but this would not necessarily be an objection provided such departures from experimental results were found reasonably consistent and subject to empirical expression in terms of the characteristics of the case.

If such were found to be the case, the application of the theory in its simplest possible form followed by a readily applied empirical correction might well be found shorter and simpler than an attempt to introduce into the data the various individual corrections as outlined above.

Should the assumption, on which this simpler phase of the investigation is based, prove ill-founded, there still remains open the possibility of further search for some system of corrections which will not unduly complicate the procedure and which might, at the same time, serve to bring into a satisfactory agreement direct laboratory tests on the propellers and computations based on airfoil tests.

The results as given later seem to indicate that the hope on which this phase of the investigation was based was not well founded. The divergencies between the two sets of results, while showing certain elements of consistency, are on the whole too large and too capriciously distributed to justify the use of the theory in this simplest form for other than approximate estimates or for comparative purposes.

The further investigation of the matter with a view to the development of suitable systems of corrections, therefore, remains open as a remaining and uncompleted part of the more general investigation.

While, therefore, the results of this first phase of the investigation are less positive than had been hoped might be the case, nevertheless the establishment of the general degree of approach between the two sets of results which might be anticipated on the basis of this simpler mode of application, seems in any event to have been desirable and to have abundantly justified the time and effort required.

SCOPE OF THE INVESTIGATIONS

An examination of geometrical characteristics showed that representative blade sections, 5 per blade and spaced as in Figure 1, for 80 model propellers as previously tested, could be provided by 48 section forms. A résumé of the results of tests on these 80 model propellers together with detailed specifications regarding geometrical form and proportions will be found in Report No. 141.

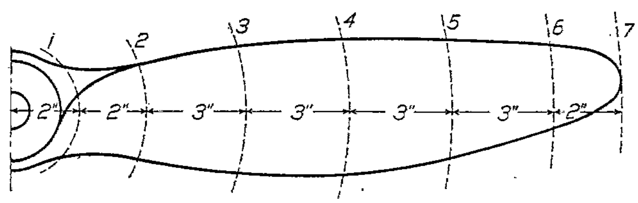

Fig. 1

Based on these 48 section forms, airfoils were made up with a uniform chord of 3 inches and span of 18 inches. These airfoils were then tested at the aerodynamic laboratory of the California Institute of Technology. The results of the tests are given in Figures 14 to 61.[1] With respect to these tests, A. A. Merrill, of the California Institute of Technology, remarks as follows:

"The airfoils were tested at a uniform velocity of 44 feet per second, standard air. Absolute coefficients L_c and D_c are obtained from the equations

$$\text{Lift} = L_c \rho A V^2$$
$$\text{Drag} = D_c \rho A V^2$$

[1] In order to make these airfoils directly comparable with other airfoils published by N. A. C. A., the new absolute coefficients C_L and C_D are used in these figures. They are convertible to the L_c and D_c, used in this report, by dividing by 2.

"The balance used has three axes—two horizontal and one vertical. It is supported on knife edges set in the ends of the horizontal axes. This necessitates the measurement of L and D components at different times and may be the cause of an error, inasmuch as these components are only mathematical resolutions of a resultant pressure and variable flow may cause a change in the line of action of this resultant for tests made at different times but with the same angle of incidence.

"It has been found, and is shown in Figures 14 and 61, that with thick sections variable flow is a very common occurrence when the Vl is as low as it is in these tests, namely 11, where V is in feet per second and l is the length of the chord in feet. There is evidence to show that this variable flow tends to disappear with an increase of Vl, so that in interpreting these graphs at actual propeller speeds it is presumably more accurate to ignore the region which these tests show as variable and smooth out the graph. When variable flow occurs it means that the change in the stream lines rotates the resultant away from or toward the vertical and this of course causes the L and D components to vary inversely in magnitude. Most of the graphs show this: That is they show that in regions where the L drops suddenly the D rises suddenly but there are some cases, namely, airfoils 24, 28, 30, and 47, where one component changes radically with no corresponding change in the other. This is probably due to a flow at the time one component was measured, different from the flow at the time the other was measured. In every test where there was variable flow, repeat tests were made and the results as shown were checked.

"There are other errors inherent in the balance and method. Thus the balance weighs 65 pounds and this weight has to be carried by knife edges which are required to respond to forces as low as 0.001 pound. This means that the percentage error in small D measurements is bound to be high. This balance is so designed that it is impossible to set the knife edges so accurately as to reduce the friction to as low a figure as can be obtained with the point support in the N. P. L. type. There is another error caused by variable flow which alters the velocity calibration constant, and this error is probably inherent in all wind tunnel work. The combined effect of these errors has been found, from scores of repeat tests, to be of such magnitude that it makes the third decimal place in absolute coefficients uncertain by as much as two units. This possible error must be taken into consideration in interpreting and using these graphs.

"Attention is called to airfoils 11, 16, 21, and 26. These show an increase in positive L as the angle of incidence decreases in the region of $-1°$. Airfoil 21 was tested through angles down to $-23°$ and two maxima for positive L were found, namely, at $-5°$ and $-13°$. A similar phenomenon has been found for thick screw airfoils at the Aerodynamic Laboratory of the Massachusetts Institute of Technology."

The serial numbers of the 80 model propellers with the radii of the various sections and the numbers of the corresponding airfoils are shown in Table I. The models are arranged in groups or families; in each of which a single plan form, area, and set of sections is represented. The difference between any two members of a single group is thus in pitch or in distribution of pitch only. For further detailed description the reader is referred to National Advisory Committee for Aeronautics Report No. 141.

TABLE I

Group No.	Serial number of propeller and description	Radius of section, inches	Number of airfoil
1	1, 5, 9, 13, 17, 21, 80, 111, 145. Straight or club form, noncambered driving face, mean blade width .15 r.	4	1
		7	2
		10	3
		13	4
		16	5
2	25, 29, 33, 37, 41, 45. Straight or club form, concave driving face, mean blade width .15 r	4	6
		7	7
		10	8
		13	9
		16	10
3	2, 6, 10, 14, 18, 22, 81, 112, 146. Straight or club form, noncambered driving face, mean blade width .20 r.	4	11
		7	12
		10	13
		13	14
		16	15
4	26, 30, 34, 38, 42, 46. Straight or club form, concave driving face, mean blade width .20 r	4	16
		7	17
		10	18
		13	19
		16	20
5	3, 7, 11, 15, 19, 23, 82, 113, 127, 128, 129, 130, 131, 132, 133, 134, 135, 136, 137, 138, 139. Curved or saber form, noncambered driving face, mean blade width .15 r.	4	21
		7	22
		10	23
		13	24
		16	25
6	27, 31, 35, 39, 43, 47. Curved or saber form, concave driving face, mean blade width .15 r	4	26
		7	27
		10	28
		13	29
		16	30
7	4, 8, 12, 16, 20, 24, 83, 114, 144. Curved or saber form, noncambered driving face, mean blade width .20 r.	4	31
		7	32
		10	33
		13	34
		16	35
8	28, 32, 36, 40, 44, 48. Curved or saber form, concave driving face, mean blade width .20 r	4	36
		7	37
		10	38
		13	39
		16	40
9	90, 92, 94. Curved or saber form, slightly concave driving face, mean blade width .15 r	4	26
		7	41
		10	42
		13	43
		16	44
10	115, 116, 117, 118, 119. Curved or saber form, slightly convex driving face, mean blade width .15 r	4	21
		7	45
		10	46
		13	47
		16	48

AIRFOIL THEORY OF THE PROPELLER

The form in which the airfoil theory has been developed for use in this particular investigation may be outlined as follows:

In Figure 2 let the hatched area denote an element of the propeller with notation as follows:

dA = area.
L = lift.
D = drag.
dT = element of thrust.
dR = element of transverse resistance.
r = radius.
k_1 = lift coefficient.
k_2 = drag coefficient.
p = geometrical pitch.
q = advance per revolution.
v = speed of advance along an axial line (OF, fig. 2).
u = velocity through air along line OC.
n = revolutions per second.
Δ = density of air (kg. per cu. m. or lb. per cu. ft.).
θ = angle of attack BOC.
β = pitch angle BOA.
α = angle of motion of element with transverse.
$\gamma = \cot^{-1} L/D$.
Q = torque.
U = useful power in foot pounds per sec.
E = effective power in foot pounds per sec.

We have then:

$$dT = L\cos\alpha - D\sin\alpha \quad (1)$$

$$dR = L\sin\alpha + D\cos\alpha \quad (2)$$

We have from the theory of the airfoil:

$$g\ L = k_1\ \Delta\ dA\ u^2 \quad (3)$$

$$d\ D = k_2\ \Delta\ dA\ u^2 \quad (4)$$

where L and D are measured in gravity units and k_1, k_2 are nondimensional coefficients. Substituting these values of L and D in equations (1), (2) we have

$$g\ dT = \Delta\ dA\ u^2\ (k_1\cos\alpha - k_2\sin\alpha) \quad (5)$$

$$g\ dR = \Delta\ dA\ u^2\ (k_1\sin\alpha + k_2\cos\alpha) \quad (6)$$

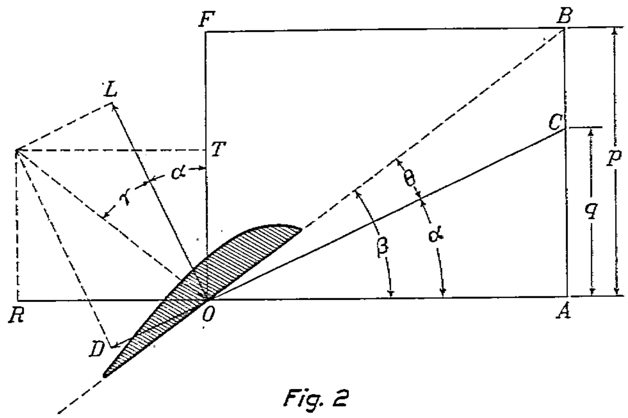

Fig. 2

We now define an auxiliary angle γ by $\cot\gamma = L/D = k_1/k_2$ and substitute for k_2 in terms of k_1 and $\tan\gamma$, placing for u^2 its value, $n^2\ (4\ \pi^2\ r^2 + q^2)$.

This gives the values in the form:

$$g\ dT = k_1\ \Delta\ dA\ n^2 \sec\gamma\cos\ (\alpha+\gamma)\ (4\ \pi^2\ r^2 + q^2) \quad (7)$$

$$g\ dR = k_1\ \Delta\ dA\ n^2 \sec\gamma\sin\ (\alpha+\gamma)\ (4\ \pi^2\ r^2 + q^2) \quad (8)$$

Whence, summing for the entire blade, we have

$$g\,T = \Delta\ n^2\ \Sigma\ [k_1\ dA\ \sec\gamma\ \cos\ (\alpha+\gamma)\ (4\ \pi^2\ r^2 + q^2)] \quad (9)$$

$$g\ rR = gQ = \Delta\ n^2\ \Sigma\ [k_1\ dA\ \sec\gamma\ \sin\ (\alpha+\gamma)\ r\ (4\ \pi^2\ r^2 + q^2)] \quad (10)$$

We may then employ additional notation as follows:

D = diam. of propeller.
$x = v/nD$.
η = efficiency = $U \div E$.
I_1 = integration of quantities in bracket of (9).
I_2 = integration of quantities in bracket of (10).

We note also $q = v/n = Dx$.

We have then:

$$g\,U = \Delta\ n^2\ v\ I_1$$
$$gE = 2\ \pi\ \Delta\ n^3\ I_2$$

Then

$$\eta = \frac{v}{2\pi n}\left(\frac{I_1}{I_2}\right) = \frac{Dx}{2\pi}\left(\frac{I_1}{I_2}\right) \quad (11)$$

For E we define the coefficient

$$C_1=\frac{gE}{\Delta n^3 D^5}=\frac{2\pi I_2}{D^5} \quad (12)$$

Comparison with the results of the wind tunnel model tests have been made throughout by means of these two quantities, η (efficiency) and C_1 (effective power coefficient).

For the purposes of the investigation, sections of the model blade were taken at five radial distances as indicated at 2, 3, 4, 5, 6, Figure 1. Model airfoils were then made up representing these sections and tested as elsewhere noted. These tests plotted graphically give values of k_1, k_2 and hence cot γ and γ for any stated or assumed value of θ, the angle of attack.

The next step is to compute the bracket expressions in (9) and (10) for each of the five sets of values as given by the sections 2 to 6. Thus:

$$\theta=\beta-\alpha=\tan^{-1}\frac{p}{2\pi r}-\tan^{-1}\frac{Dx}{2\pi r}$$

k_1 = lift coefficient as found by experiment on the model airfoils.

dA = elements of area. For purposes of integration, however, we must consider this as $dA \div dr$ with a dr outside the bracket. With this understanding and the foot as the unit, the measure of dA/dr becomes the width of the blade at the given point, measured in feet.

$\gamma=\cot^{-1} L/D=\cot^{-1} k_1/k_2$ and found therefore directly from the model airfoil research.

$\alpha=\tan^{-1}\frac{Dx}{2\pi r}$ as above.

$q=Dx$ as above.

In this connection it is useful to note that the ratio of the two bracket expressions of (9) and (10) is $r \tan(\alpha+\gamma)$. We have, therefore, simply to multiply the value as found for (9) by this factor in order to derive the value for (10).

The next step is then to effect an integration of the bracket expression over the effective length of the blade, using for this purpose the five sample values as found.

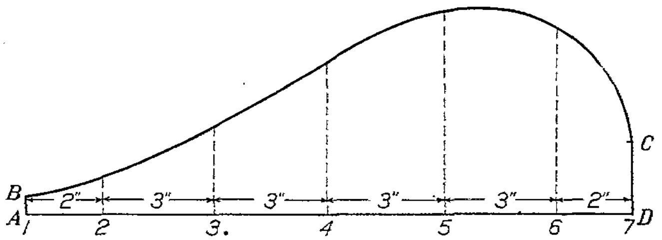

Fig. 3

To this end the effective length of blade has been considered as extending from location 1, Figure 1, at 2 inches from the center, out to the tip of the blade. The problem is therefore to effect an integration of an area $ABCD$, Figure 3, extending between ordinates 1 and 7, but using only ordinates 2 to 6, inclusive.

To this end it was assumed that the second degree parabolic law which might be taken as holding for ordinates 4, 3, 2, might be extended to include ordinate 1, and similarly for ordinates 4, 5, 6, and 7. On this assumption a rule was developed as follows:

$$A=\frac{4}{81}[7(y_2+y_6)+4(y_3+y_5)+5y_4] \quad (13)$$

where A denotes the area in question and y_2, y_3, etc., the successive ordinates y_2 to y_6.

Denote the summation of the functions within the bracket of equation (13) as carried out for (9) and (10) respectively, by Σ_1 and Σ_2.

We shall then have, for a single blade of the propeller:

$$I_1=\frac{4}{81}\Sigma_1$$

$$I_2=\frac{4}{81}\Sigma_2$$

and from (13) for the propeller as a whole

$$\eta=\frac{Dx}{2\pi}\frac{I_1}{I_2}=\frac{Dx}{2\pi}\left(\frac{\Sigma_1}{\Sigma_2}\right) \qquad (14)$$

Likewise from (12) for a single blade with $D=3$ ft.

$$C_1=\frac{8\pi\Sigma^2}{81D_5}=.001277\ \Sigma_2$$

or for two blades:

$$C_1=.002554\ \Sigma_2 \qquad (1)$$

A sample computation follows:

x	.5				
q	1.5				
r	.333	.583	.833	1.083	1.333
p	2.7	2.7	2.7	2.7	2.7
tan β	1.2892	.7368	.5158	.3969	.3223
tan α	.7177	.4098	.2867	.2205	.1796
β	52°–12′	36°–23′	27°–17′	21°–39′	17°–52′
α	35°–40′	22°–17′	16°–00′	12°–26′	10°–11′
θ	16°–32′	14°–08′	11°–17′	9°–13′	7°–35′
Airfoil No.	21	22	23	24	25
k_1	.188	.377	.625	.550	.496
cot γ	1.46	3.30	10.64	11.14	11.46
γ	34°–25′	16°–51′	5°–22′	5°–08′	4°–59′
sec γ	1.212	1.045	1.005	1.004	1.004
$\alpha+\gamma$	70°–05′	39°–08′	21°–22′	17°–34′	15°–10′
cos $(\alpha+\gamma)$	.3407	.7753	.9313	.9534	.9652
$4\ \pi^2\ r^2+q^2$	6.64	15.68	29.66	48.58	72.44
dA	.250	.268	.262	.223	.1585
[ ] (9)	.129	1.283	4.550	5.725	5.505
tan $(\alpha+\gamma)$	2.7600	.8136	.3912	.3166	.2711
[ ] (10)	.119	.609	1.481	1.968	1.990

y_2	.129	y_2	.119
y_6	5.505	y_6	1.990
Sum	5.634×7=39.438	Sum	2.109×7=14.763
y_3	1.283	y_3	.609
y_5	5.725	y_5	1.968
Sum	7.008×4=28.032	Sum	2.577×4=10.308
y_4	4.550×5=22.750	y_4	1.481×5= 7.405
	$\Sigma_1=90.220$		$\Sigma_2=32.476$

$$C_1=32.476\times\ .002554=.0830$$

(13) $$\eta=\frac{90.22\times1.5}{32.476\times2\pi}=.663$$

DISCUSSION OF RESULTS

The results of computations similar to that illustrated in the preceding section, and for values of v/nD represented by the range of angle of attack used in the airfoil tests, together with values of C_1 and η as determined by tests of the model propellers, are shown in Figures 4 to 11 and Table II.

From the diagram and table it may be seen that there is a general similarity in form for the power coefficient (C_1) and the efficiency (η) curves, as derived by the two methods. There appears to be, however, no relation generally consistent for all propellers. In some cases the computed C_1 is more than that determined by propeller test and in others it is less. The same is true for the efficiency η.

It may be seen that the computations for C_1 and η for a single set of airfoils, representing a single group or family of propellers, are generally consistent. The following points of variation, or of similarity between computed and propeller test results, are noted for the various groups.

Group 1.—Computed C_1 is generally less than propeller test value. Computed η is slightly smaller than propeller test value for moderate and large pitch ratio propellers, but greater for small pitch ratio propellers. Computed η is often high for small v/nD and low for large v/nD, the curves thus crossing.

Group 2.—Computed C_1 is generally less than propeller test value. Computed η is generally close to propeller test value, but is high for small v/nD and low for large v/nD, the two curves thus crossing near the peak.

Group 3.—Computed C_1 is generally more than propeller test value, but sometimes decreases at small v/nD until less than propeller test value. Computed η is generaly more than that derived from propeller test, the difference being greater for propellers of small pitch ratio.

Group 4.—Same as for Group 3.

Group 5.—Computed C_1 is generally lower but sometimes in close agreement with propeller test results. Computed η is generally low except for small pitch ratio propellers, where it is high.

Group 6.—Computed C_1 is generally close to propeller test value, with a tendency to be high at small v/nD and low at large v/nD, the curves thus crossing. Computed η generally close to propeller test results but with tendency to be high at small v/nD and low at large v/nD.

Group 7.—The same as for Groups 3 and 4.

Group 8.—The same as for Groups 3, 4 and 7.

Group 9.—Computed C_1 generally low. Computed η generally close to propeller test value, but high for small v/nD and low for large v/nD, being thus like Group 2.

Group 10.—Computed C_1 generally close to propeller test value except at small v/nD. Computed η generally close to propeller test value.

From the above the following tendencies may be noted: Groups 1, 2, 5, 6, 9, and 10, narrow blade propellers having a mean aspect ratio of about 6, which is the aspect ratio of the airfoils, give computed values of C_1 usually less than those derived from propeller tests. Computed η for these groups is generally lower than the propeller test value but often close to it.

Groups 3, 4, 7, and 8, wide blade propellers having a mean aspect ratio ofabout 4.5, give computed C_1 and η generally more than propeller test values.

About 450 values of C_1 and η were computed. Of the 300 computed values of C_1 that are within the usual working ranges of the 80 model propellers, 153 are less than those shown by model test, and 147 are more. Forty-four are within 2 per cent. The mean divergence from model test results is 7.6 per cent. For the corresponding computed efficiencies, 140 are less than those shown by model test, 3 are the same, and 157 are more. Forty-eight are within one point. The mean divergence is 3.2 points.

In order to check previous work and to determine if variation in the section of airfoil might in some measure be the cause of the above differences, two further tests beside those shown in Figures 14 to 61 were made at the California Institute of Technology. The first was upon airfoil 9, which, before testing, was examined with reference to warping or change of form. No sensible change in form was found. The second was upon airfoil 4A, presumably the same as No. 4.

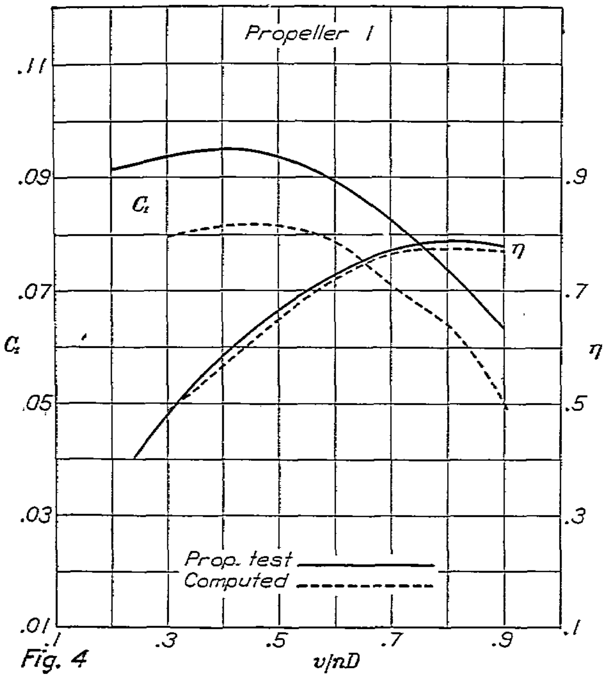

Fig. 4

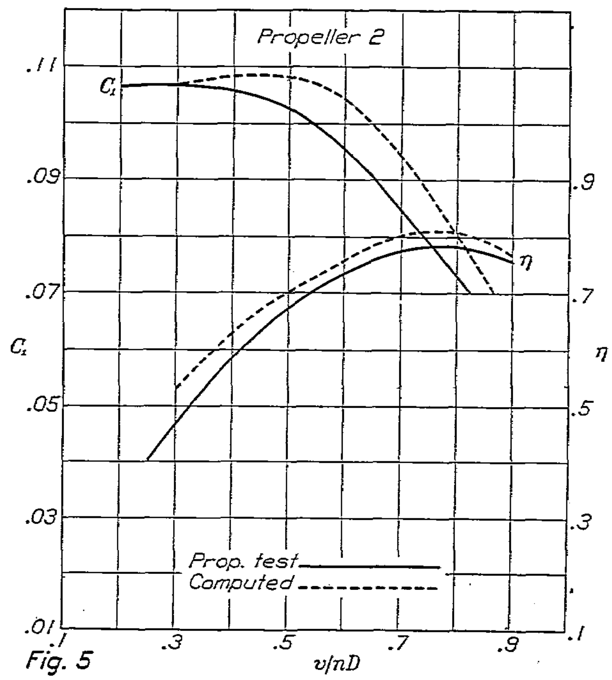

Fig. 5

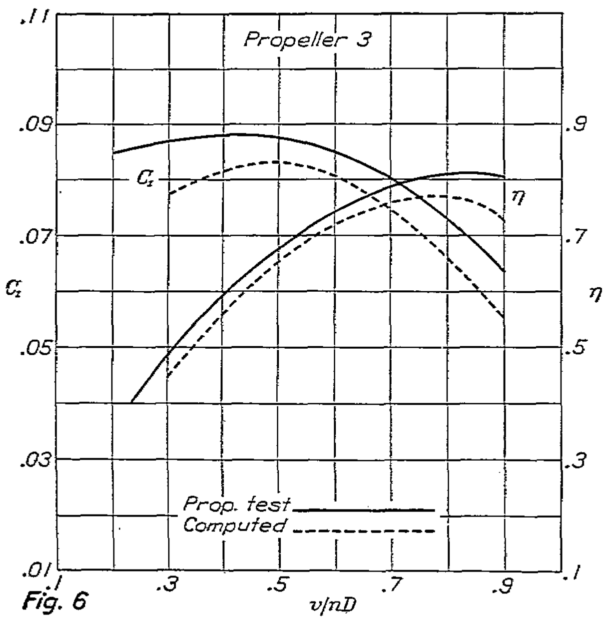

Fig. 6

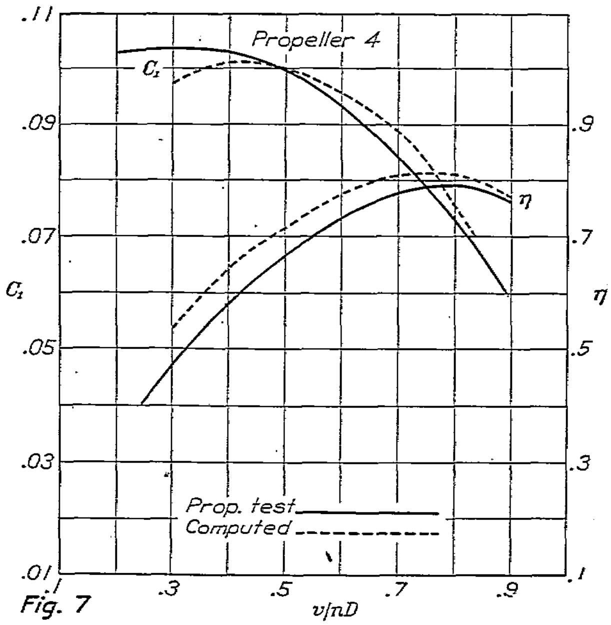

Fig. 7

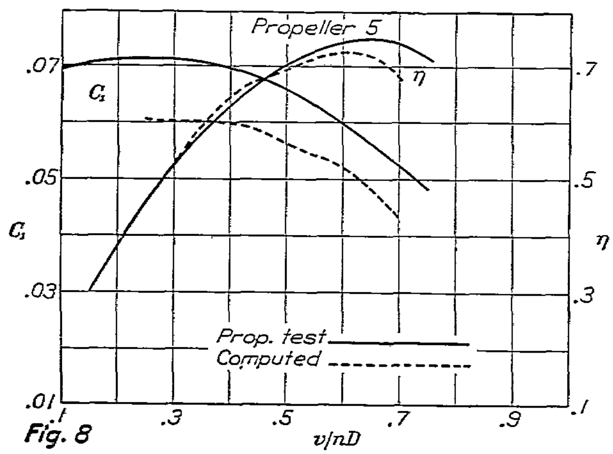

Fig. 8

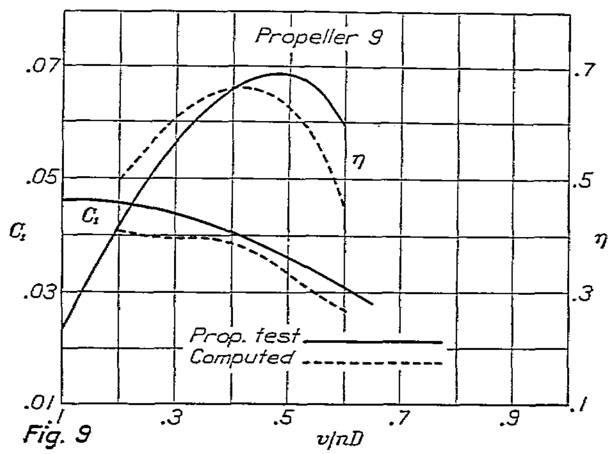

Fig. 9

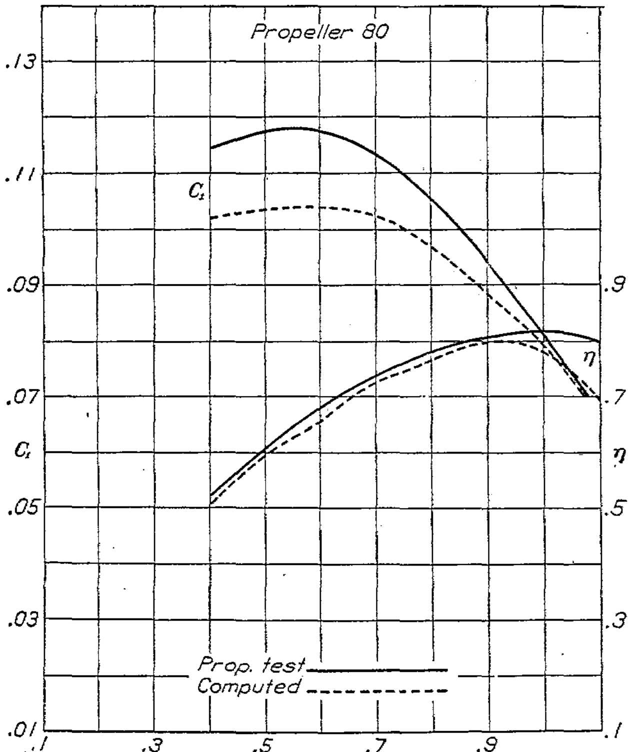

Fig. 10

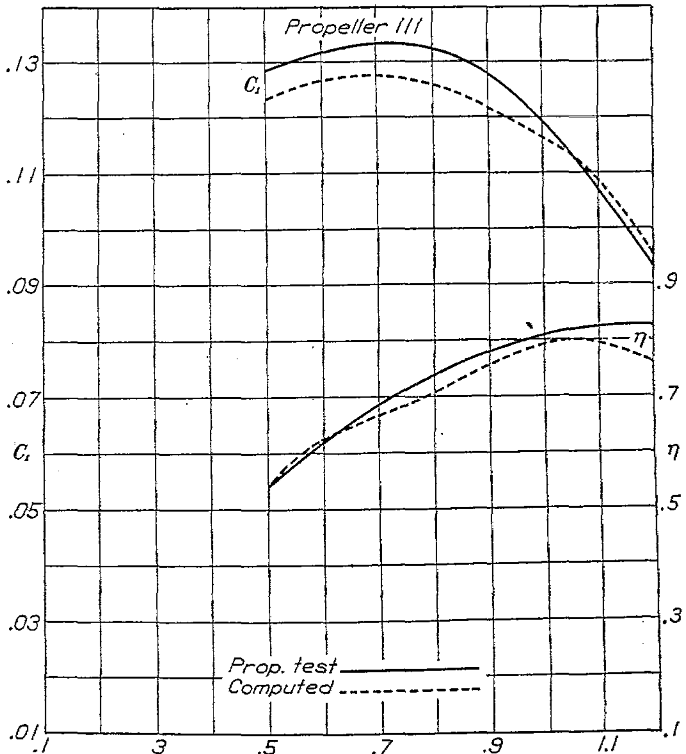

Fig. 11

This airfoil was laid out by a draftsman without reference to the template used in making No. 4. A new template and airfoil, 4A, were made. After the airfoil was finished it was compared with No. 4. The two were found to be very slightly different. They had the same chord and same maximum thickness but 4A was found to be about 0.01″ thinner than No. 4 midway between the maximum thickness ordinate and the trailing edge. Either No. 4 or 4A was believed to be as nearly representative of the 13″ radius section of propellers 1, 5, 9, etc., as it was practicable to make them with ordinary drafting methods and woodworking tools.

The tests of airfoil 4A gave a lift coefficient, k_1, and a lift-drag ratio somewhat greater than for No. 4, the difference for k_1 being about 8 per cent of the value for No. 4. In the case of L/D there was the same order of difference but it was less uniform. The two tests of airfoil 9 showed, however, differences in the same direction and of about the same moment.

Some further tests of airfoils 21 to 25 were also made in order to determine: First, if the breaks or irregularities in the curves of the coefficients, k_1, k_2, and L/D, as shown in Figures 14 to 61, would disappear if the airfoils were tested at high speeds; and second, if substantially the same values would result from tests made in two different laboratories but using speeds substantially the same. These further tests were conducted at Langley Memorial Aeronautical Laboratory. The first were run with a velocity of 30 meters per second or about 67 miles per hour, and the second with a velocity of 30 miles per hour, the same as that used at the California Institute of Technology.

The 67 miles per hour tests gave results considerably different from those at the lower speed. In all but airfoil 21 the variable flow that occurred at the lower speed entirely disappeared. With No. 21, however, a variable flow that did not occur at the lower speed appeared at the higher one. The values of L/D as determined by the high-speed tests were generally much higher than those for low speed.

The 30 miles per hour tests of Langley Memorial Aeronautical Laboratory gave results generally similar to those of the California Institute of Technology, about the same variable flow occurring at the same angles of attack. There was, however, a sufficient difference between the coefficients as determined by the two labaratories, to make an appreciable difference in computed propeller performance. Figures 12 and 13 show the results of computations for propellers 3 and 7 from the three sets of airfoil tests. By a comparison of Figure 12 with Figure 6 and of Figure 13 with propeller No. 7 of Table II, it may be seen that the C_t as determined by model propeller test is, except for low values of v/nD, generally close to the mean of the computed values as derived from the two airfoil tests of Langley Memorial Aeronautical Laboratory, and considerably more than the computed value as derived from the airfoil tests of the California Institute of Technology. For η the propeller model tests indicate an efficiency near the mean of all airfoil tests. The 30 miles per hour tests of both laboratories show efficiencies lower than those derived from propeller model tests and the 67 mile per hour airfoil tests give efficiencies higher.

It may be noted that the difference in the values of C_t as computed from the 30 miles per hour airfoil tests of the two laboratories is about 7.5 per cent, while the difference in the values of η is about two points. The results of computations from tests of airfoils by different laboratories, but at the same air speeds, thus differ by about the same amount as the mean divergence of computed results from propeller test results.

From the foregoing it appears that if propeller power and efficiency are computed from airfoil tests at moderate speed, an error of sensible amount may be anticipated in both. It also

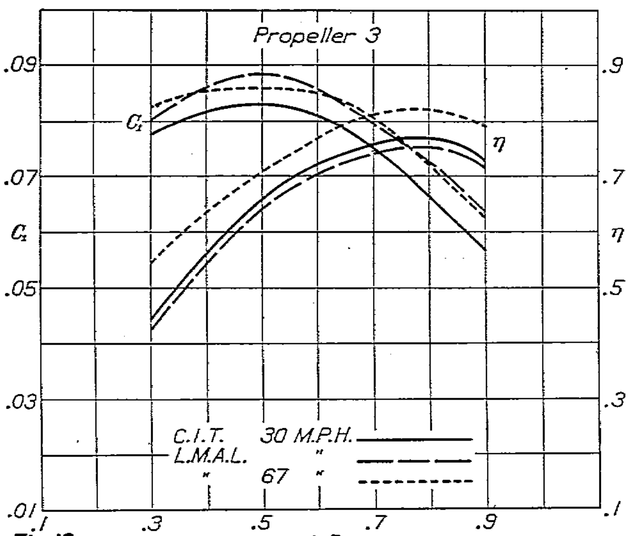

Fig. 12

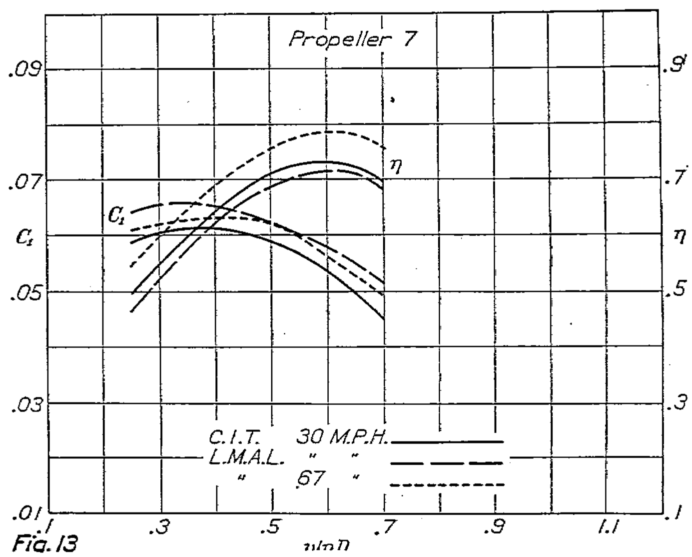

Fig. 13

appears that while corrections for inflow velocity, for Vl ratio and aspect ratio might in some instances bring computed coefficients closer to those derived by propeller model tests, in other instances the differences would apparently be increased.

It seems probable that the unknown elastic properties of the model propellers, causing various forms to yield when under heavy load in different amounts and in various ways, may be a considerable factor contributing to the difference between computed performance and model test, under high and extreme values of the slip. At moderate slips, however, the forces acting upon the model propellers are not of such magnitude as to cause sensible distortion and an explanation of differences in the propeller coefficients as derived from airfoil tests and propeller tests must be looked for elsewhere, presumably in the relative delicacy of the former, and in the difficulty of determining within a probable error of some per cent the values of lift and drag coefficients applicable over some considerable range of air speeds, and especially as derived from airfoils of small size and at a single speed no greater than 30 miles per hour.

An examination of the aerodynamic characteristics of the various airfoils as shown in Figures 14 to 61 shows the very considerable frequency of variable flow, with consequent uncertainty in the values to be employed. This condition is presumably due to the relatively low wind speed employed as previously noted. To the extent to which such conditions of

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instability are likely to present themselves in airfoil tests to a corresponding degree will the data be of uncertain significance in connection with computations such as those dealt with in the present report.

It is, of course, equally true that should conditions of instability of air flow develop in the operation of the model propeller, then the same uncertainties will be reflected in tests on the model. However, considering the actual speed of the blade as the resultant of the wind speed and of the rotative speed, the likelihood of multiple modes of flow in the propeller seems relatively small and it seems reasonable to hope that with a consistent and single value set of coefficients for the airfoils as representing the propeller sections, some considerably nearer approach might be made toward a consistent empirical relation between the two sets of results than is evidenced by the results of the present investigation.

Whatever may be the likelihood of developing a relatively simple systematic and consistent relation between model propeller tests and the results of airfoil computations, it is clear that no such end can be realized as long as we are confronted with the phenomenon of mutiple modes of flow and with resulting uncertainty in the values to be employed. Further progress in this direction will therefore depend in very large measure upon the practicability of establishing a set of aerodynamic characteristics for airfoil, free from uncertainties due to instability of flow, and at the same time consistently applicable to the range of speed conditions to be met with in the model test.

TABLE II

PROPELLER NO. 1

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.3	0.0940	0.0795	0.479	0.482
.4	.0952	.0814	.585	.566
.5	.0938	.0815	.667	.650
.6	.0895	.0787	.729	.723
.7	.0825	.0708	.770	.764
.8	.0737	.0636	.788	.771
.9	.0630	.0502	.780	.768

PROPELLER NO. 2

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.3	0.1068	0.1068	0.472	0.531
.4	.1057	.1082	.585	.636
.5	.1024	.1080	.674	.700
.6	.0950	.1040	.736	.758
.7	.0847	.0944	.774	.803
.8	.0725	.0800	.781	.806
.9	.0593	.0645	.757	.762

PROPELLER NO. 3

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.3	0.0870	0.0774	0.487	0.447
.4	.0880	.0818	.594	.560
.5	.0872	.0852	.679	.659
.6	.0845	.0809	.744	.718
.7	.0802	.0749	.788	.758
.8	.0733	.0660	.809	.770
.9	.0629	.0558	.805	.722

PROPELLER NO. 4

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.3	0.1035	0.0970	0.476	0.537
.4	.1030	.1011	.583	.646
.5	.0994	.1000	.668	.712
.6	.0927	.0956	.734	.780
.7	.0841	.0899	.778	.803
.8	.0732	.0750	.797	.810
.9	.0590	.0606	.761	.764

PROPELLER NO. 5

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.25	0.0713	0.0603	0.461	0.464
.4	.0695	.0600	.630	.653
.5	.0661	.0561	.702	.696
.6	.0601	.0523	.745	.728
.7	.0526	.0429	.743	680

PROPELLER NO. 6

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.25	0.0762	0.0792	0.461	0.534
.4	.0717	.0788	.635	.666
.5	.0655	.0731	.710	.745
.6	.0569	.0646	.733	.760
.7	.0466	.0505	.705	.744

PROPELLER NO. 7

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.25	0.0686	0.0589	0.473	0.493
.4	.0667	.0611	.650	.642
.5	.0626	.0589	.730	.710
.6	.0568	.0532	.772	730
.7	.0494	.0447	.767	.694

PROPELLER NO. 8

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.25	0.0726	0.0732	0.463	0.573
.4	.0677	.0718	.634	.687
.5	.0605	.0676	.708	.760
.6	.0517	.0591	.755	.775
.7	.0421	.0460	.734	.735

PROPELLER NO. 9

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.2	0.0455	0.0402	0.419	0.492
.3	.0439	.0393	.561	.608
.4	.0405	.0386	.659	.655
.5	.0359	.0330	.684	.623

PROPELLER NO. 10

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.2	0.0487	0.0512	0.421	0.518
.3	.0458	.0505	.572	.656
.4	.0409	.0450	.657	.729
.5	.0337	.0379	.659	.692

PROPELLER NO. 11

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.2	0.0451	0.0412	0.434	0.484
.3	.0440	.0410	.590	.601
.4	.0417	.0380	.682	.689
.5	.0378	.0350	.707	.640

TABLE II—Continued

PROPELLER NO. 12

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.2	0.0471	0.0468	0.426	0.533
.3	.0453	.0461	.571	.649
.4	.0412	.0432	.655	.710
.5	.0340	.0353	.665	.671

PROPELLER NO. 13

0.3	0.0928	0.0800	0.469	0.484
.4	.0934	.0824	.580	.568
.5	.0916	.0823	.669	.658
.6	.0867	.0804	.736	.722
.7	.0795	.0762	.779	.755
.8	.0708	.0656	.796	.758
.9	.0610	.0495	.779	.704

PROPELLER NO. 14

0.3	0.1100	0.1044	0.466	0.537
.4	.1085	.1095	.575	.630
.5	.1041	.1088	.660	.701
.6	.0966	.1048	.730	.764
.7	.0860	.0948	.775	.798
.8	.0731	.0806	.786	.811
.9	.0586	.0642	.750	.774

PROPELLER NO. 15

0.3	0.0888	0.0761	0.475	0.490
.4	.0908	.0829	.586	.590
.5	.0902	.0828	.684	.667
.6	.0865	.0802	.749	.720
.7	.0800	.0733	.787	.765
.8	.0719	.0661	.804	.767
.9	.0622	.0537	.790	.649

PROPELLER NO. 16

0.3	0.1030	0.0987	0.478	0.545
.4	.1016	.1024	.587	.644
.5	.0979	.1010	.673	.711
.6	.0915	.0967	.745	.773
.7	.0829	.0875	.791	.805
.8	.0717	.0735	.803	.808
.9	.0570	.0517	.774	.761

PROPELLER NO. 17

0.25	0.0687	0.0616	0.453	0.467
.4	.0664	.0607	.628	.648
.5	.0613	.0577	.710	.724
.6	.0545	.0514	.761	.731
.7	.0465	.0422	.759	.669

PROPELLER NO. 18

0.25	0.0738	0.0789	0.448	0.533
.4	.0680	.0780	.630	.690
.5	.0607	.0726	.717	.763
.6	.0517	.0624	.762	.778
.7	.0418	.0506	.728	.751

PROPELLER NO. 19

0.25	0.0611	0.0605	0.462	0.500
.4	.0589	.0607	.647	.644
.5	.0555	.0573	.730	.713
.6	.0504	.0526	.777	.757
.7	.0437	.0452	.738	.706

PROPELLER NO. 20

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.25	0.0754	0.0715	0.455	0.499
.4	.0701	.0715	.629	.681
.5	.0639	.0666	.714	.751
.6	.0556	.0567	.765	.771
.7	.0454	.0440	.757	.727

PROPELLER NO. 21

0.25	0.0455	0.0401	0.495	0.554
.4	.0402	.0378	.664	.692
.5	.0346	.0340	.704	.665

PROPELLER NO. 22

0.2	0.0479	0.0517	0.412	0.515
.3	.0455	.0504	.556	.658
.4	.0403	.0445	.643	.742
.5	.0331	.0386	.641	.678

PROPELLER NO. 23

0.2	0.0413	0.0412	0.425	0.484
.3	.0403	.0402	.577	.614
.4	.0373	.0384	.673	.664
.5	.0335	.0349	.696	.648

PROPELLER NO. 24

0.2	0.0454	0.0459	0.429	0.539
.3	.0427	.0457	.576	.666
.4	.0378	.0420	.663	.705
.5	.0310	.0329	.671	.654

PROPELLER NO. 25

0.3	0.1140	0.0905	0.433	0.496
.4	.1168	.0963	.546	.572
.5	.1162	.1004	.636	.668
.6	.1126	.0971	.701	.717
.7	.1066	.0922	.744	.744
.8	.0981	.0852	.755	.729
.9	.0872	.0692	.735	.694

PROPELLER NO. 26

0.4	0.1176	0.1193	0.564	0.624
.5	.1137	.1208	.651	.686
.6	.1065	.1210	.716	.756
.7	.0973	.1144	.758	.785
.8	.0859	.1008	.759	.790
.9	.0731	.0810	.705	.721

PROPELLER NO. 27

0.4	0.1027	0.0989	0.578	0.582
.5	.1033	.1020	.659	.652
.6	.1003	.1006	.719	.714
.7	.0940	.0961	.759	.736
.8	.0854	.0882	.772	.764
.9	.0751	.0741	.746	.694

PROPELLER NO. 28

0.4	0.1140	0.1082	0.565	0.639
.5	.1124	.1129	.646	.702
.6	.1075	.1121	.713	.759
.7	.0988	.1060	.763	.794
.8	.0863	.0935	.783	.789
.9	.0724	.0774	.741	.735

TABLE II—Continued

PROPELLER NO. 29

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.25	0.0890	0.0692	0.424	0.500
.4	.0904	.0733	.600	.640
.5	.0861	.0711	.676	.686
.6	.0783	.0655	.714	.719
.7	.0695	.0578	.709	.669

PROPELLER NO. 30

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.25	0.0864	0.892	0.433	0.508
.4	.0826	.0884	.602	.663
.5	.0759	.0873	.680	.735
.6	.0665	.0787	.721	.751
.7	0560	.0645	.691	.686

PROPELLER NO. 31

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.25	0.0792	0.0726	0.448	0.482
.4	.0791	.0757	.607	.634
.5	.0754	0743	.684	.684
.6	.0689	.0699	.734	.696
.7	.0604	.0580	.727	.668

PROPELLER NO. 32

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.25	0.0838	.0759	0.440	0.540
.4	.0825	.0787	.610	.684
.5	.0760	.0797	.694	.744
.6	.0670	.0733	.739	.751
.7	.0571	.0623	.701	.696

PROPELLER NO. 33

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.2	0.0579	0.0499	0.397	0.481
.3	.0588	.0508	.585	.578
.4	.0560	.0483	.620	.638
.5	.0503	.0427	.631	.620

PROPELLER NO. 34

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.2	0.0540	0.0591	0.410	0.501
.3	.0524	.0617	.537	.637
.4	.0478	.0581	.606	.684
.5	.0401	.0499	.590	.621

PROPELLER NO. 35

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.2	0.0557	0.0509	0.404	0.463
.3	.0560	.0538	.541	.579
.4	.0531	.0522	.627	.623
.5	.0477	.0454	.643	.605

PROPELLER NO. 36

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.2	0.0580	0.0535	0.400	0.526
.3	.0571	.0533	.531	.653
.4	.0524	.0512	.612	.675
.5	.0446	.0477	.622	.634

PROPELLER NO. 37

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.4	0.1186	0.0972	0.544	0.602
.5	.1157	.1005	.635	.672
.6	.1092	.0980	.702	.718
.7	.1007	.0921	.745	.739
.8	.0898	.0835	.761	.751
.9	.0777	.0699	.741	.650

PROPELLER NO. 38

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.4	0.1212	0.1244	0.560	0.620
.5	.1155	.1240	.652	.685
.6	.1064	.1230	.721	.757
.7	.0949	.1140	.760	.789
.8	.0818	.0904	.747	.780
.9	.0674	.0802	.669	.730

PROPELLER NO. 39

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.4	0.1039	0.1000	0.582	0.580
.5	.1039	.1004	.661	.651
.6	.1013	.1010	.720	.712
.7	.0960	.0956	.757	.735
.8	.0874	.0862	.770	.735
.9	.0760	.0737	.740	.714

PROPELLER NO. 40

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.4	0.1161	0.1111	0.561	0.652
.5	.1125	.1115	.650	.715
.6	.1050	.1103	.718	.766
.7	.0945	.1030	.759	.795
.8	.0821	.0924	.765	.785
.9	.0688	.0715	.722	.716

PROPELLER NO. 41

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.25	0.0880	0.0717	0.419	0.508
.4	.0875	.0738	.589	.643
.5	.0807	.0712	.674	.688
.6	.0716	.0656	.723	.714
.7	.0713	.0541	.709	.664

PROPELLER NO. 42

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.25	0.0875	0.0899	0.418	0.519
.4	.0846	.0911	.603	.683
.5	.0768	.0875	.685	.735
.6	.0668	.0772	.725	.743
.7	.0553	.0640	.690	.698

PROPELLER NO. 43

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.25	0.0780	0.0725	0.448	0.482
.4	.0787	.0761	.614	.635
.5	.0751	.0736	.690	.685
.6	.0690	.0683	.731	.722
.7	.0612	.0564	.711	.667

PROPELLER NO. 44

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.25	0.0833	0.0787	0.434	0.555
.4	.0807	.0815	.604	.692
.5	.0736	.0777	.681	.748
.6	.0647	.0715	.707	.750
.7	.0548	.0597	.666	.684

PROPELLER NO. 45

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.2	0.0563	0.0499	0.400	0.484
.3	.0561	.0509	.535	.587
.4	.0535	.0491	.602	.644
.5	.0492	.0424	.591	.609

PROPELLER NO. 46

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.2	0.0607	0.0594	0.399	0.509
.3	.0589	.0614	.534	.642
.4	.0539	.0567	.609	.674
.5	.0461	.0492	.590	.622

PROPELLER NO. 47

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.2	0.0518	0.0513	0.415	0.479
.3	.0515	.0529	.545	.481
.4	.0489	.0513	.608	.618
.5	.0442	.0445	.602	.595

PROPELLER NO. 48

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.2	0.0560	0.0526	0.402	0.530
.3	.0544	.0543	.541	.650
.4	.0496	.0522	.605	.677
.5	.0434	.0456	.579	.612

TABLE II—Continued

PROPELLER NO. 80

v/nD	C_t Propeller test	C_t Computed	η Propeller test	η Computed
0.5	0.1171	0.1031	0.610	0.594
.6	.1170	.1040	.680	.658
.7	.1130	.1025	.737	.729
.8	.1053	.0969	.779	.765
.9	.0943	.0887	.806	.800
1.0	.0811	.0795	.816	.778
1.1	.0665	.0646	.796	.683

PROPELLER NO. 81

0.5	0.1359	0.1396	0.610	0.657
.6	.1315	.1417	.684	.715
.7	.1229	.1376	.740	.762
.8	.1105	.1320	.781	.806
.9	.0960	.1164	.803	.824
1.0	.0797	.1003	.796	.829
1.1	.0624	.0780	.748	.840

PROPELLER NO. 82

0.5	0.1094	0.1010	0.628	0.571
.6	.1106	.1068	.704	.653
.7	.1080	.1045	.757	.728
.8	.1016	.0998	.796	.762
.9	.0924	.0912	.823	.806
1.0	.0811	.0806	.834	.785
1.1	.0678	.0677	.817	.732

PROPELLER NO. 83

0.5	0.1273	0.1330	0.620	0.668
.6	.1255	.1330	.693	.727
.7	.1198	.1262	.750	.780
.8	.1107	.1224	.791	.827
.9	.0975	.1090	.815	.833
1.0	.0814	.0937	.816	.818
1.1	.0629	.0717	.784	.784

PROPELLER NO. 90

0.2	0.0500	0.0466	0.426	0.477
.3	.0489	.0475	.570	.593
.4	.0453	.0474	.653	.645
.5	.0398	.0438	.665	.633

PROPELLER NO. 92

0.25	0.0734	0.0695	0.451	0.495
.4	.0732	.0684	.637	.636
.5	.0705	.0677	.710	.698
.6	.0650	.0631	.749	.716
.7	.0574	.0549	.750	.681

PROPELLER NO. 94

0.4	0.0987	0.0907	0.588	0.591
.5	.0987	.0935	.667	.647
.6	.0964	.0906	.728	.715
.7	.0905	.0863	.771	.753
.8	.0816	.0818	.790	.785
.9	.0704	.0686	.776	.738

PROPELLER NO. 111

0.5	0.1284	0.1233	0.541	0.538
.6	.1318	.1265	.623	.624
.7	.1336	.1270	.689	.667
.8	.1322	.1258	.742	.708
.9	.1276	.1215	.782	.756
1.0	.1189	.1161	.810	.795
1.1	.1070	.1082	.827	.794
1.2	.0927	.0950	.829	.762
1.3	.0766	.0755	.814	.716

PROPELLER NO. 112

v/nD	C_t Propeller test	C_t Computed	η Propeller test	η Computed
.05	0.1703	0.1586	0.536	0.558
.6	.1691	.1733	.617	.664
.7	.1646	.1769	.682	.721
.8	.1570	.1728	.735	.774
.9	.1462	.1665	.775	.803
1.0	.1319	.1560	.802	.828
1.1	.1141	.1390	.815	.832
1.2	.0951	.1208	.813	.830
1.3	.0753	.0950	.777	.800

PROPELLER NO. 113

0.5	0.1320	0.1072	0.577	0.447
.6	.1380	.1195	.655	.525
.7	.1400	.1262	.711	.654
.8	.1380	.1300	.756	.731
.9	.1327	.1260	.791	.762
1.0	.1240	.1175	.819	.792
1.1	.1124	.1073	.838	.797
1.2	.0990	.0985	.837	.774

PROPELLER NO. 114

0.5	0.1557	0.1500	0.561	0.596
.6	.1588	.1600	.634	.680
.7	.1596	.1660	.694	.734
.8	.1556	.1625	.742	.772
.9	.1458	.1582	.780	.811
1.0	.1308	.1430	.807	.838
1.1	.1137	.1292	.823	.840
1.2	.0957	.1065	.822	.836

PROPELLER NO. 115

0.2	0.0404	0.0389	0.422	0.477
.3	.0394	.0392	.579	.579
.4	.0358	.0369	.674	.665
.5	.0304	.0288	.705	.680

PROPELLER NO. 116

0.25	0.0552	0.0565	0.459	0.503
.4	.0527	.0566	.632	.649
.5	.0496	.0534	.718	.723
.6	.0441	.0488	.769	.750
.7	.0364	.0395	.760	.715

PROPELLER NO. 117

0.3	0.0760	0.0720	0.492	0.474
.4	.0771	.0776	.594	.602
.5	.0777	.0774	.673	.672
.6	.0757	.0744	.737	.721
.7	.0688	.0711	.782	.760
.8	.0578	.0620	.798	.765
.9	.0443	.0491	.770	.726

PROPELLER NO. 118

0.4	0.0972	0.0869	0.540	0.495
.5	.0999	.0929	.631	.612
.6	.1011	.0976	.699	.684
.7	.1000	.0987	.753	.732
.8	.0946	.0920	.789	.758
.9	.0852	.0866	.810	.792
1.0	.0729	.0759	.819	.790
1.1	.0586	.0598	.804	.736

PROPELLER NO. 119

0.5	0.1153	0.0880	0.561	0.417
.6	.1177	.1136	.646	.605
.7	.1210	.1236	.710	.698
.8	.1221	.1216	.760	.736
.9	.1196	.1178	.790	.765
1.0	.1125	.1119	.813	.805
1.1	.1011	.1021	.818	.824
1.2	.0851	.0889	.802	.785

TABLE II—Continued

PROPELLER NO. 127

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.2	0.0401	0.0410	0.430	0.482
.3	.0385	.0379	.548	.630
.4	.0346	.0384	.627	.672

PROPELLER NO. 128

0.2	0.0369	0.0410	0.440	0.482
.3	.0346	.0408	.562	.610
.4	.0308	.0379	.615	.663

PROPELLER NO. 129

0.25	0.0630	0.0610	0.473	0.501
.4	.0611	.0602	.632	.648
.5	.0573	.0574	.706	.710
.6	.0511	.0517	.746	.718

PROPELLER NO. 130

0.25	0.0596	0.0609	0.474	0.504
.4	.0573	.0597	.629	.656
.5	.0539	.0570	.696	.709
.6	.0481	.0521	.724	.733

PROPELLER NO. 131

0.3	0.0855	0.0761	0.480	0.449
.4	.0880	.0851	.581	.584
.5	.0866	.0835	.668	.669
.6	.0817	.0801	.740	.729
.7	.0714	.0745	.789	.764
.8	.0639	.0652	.800	.766
.9	.0523	.0575	.772	.737

PROPELLER NO. 132

0.3	0.0859	0.0781	0.493	0.395
.4	.0881	.0835	.595	.603
.5	.0870	.0838	.672	.670
.6	.0818	.0800	.734	.735
.7	.0737	.0742	.776	.757
.8	.0633	.0666	.788	.773
.9	.0513	.0577	.756	.737

PROPELLER NO. 133

0.4	0.1075	0.0985	0.521	0.421
.5	.1107	.0990	.619	.580
.6	.1119	.1078	.695	.683
.7	.1093	.1045	.750	.728
.8	.1037	.0998	.789	.778
.9	.0955	.0925	.810	.781
1.0	.0841	.0813	.808	.782
1.1	.0702	.0706	.782	.695

PROPELLER NO. 134

0.4	0.1085	0.0944	0.539	0.421
.5	.1121	.0984	.625	.553
.6	.1132	.1091	.695	.683
.7	.1114	.1048	.746	.730
.8	.1060	.1003	.784	.771
.9	.0974	.0920	.805	.802
1.0	.0865	.0802	.810	.782
1.1	.0745	.0697	.796	.703

PROPELLER NO. 135

v/nD	C_1 Propeller test	C_1 Computed	η Propeller test	η Computed
0.4	0.1074	0.0993	0.543	0.413
.5	.1122	.1000	.624	.530
.6	.1129	.1087	.691	.690
.7	.1098	.1053	.744	.730
.8	.1031	.0981	.784	.782
.9	.0936	.0913	.810	.787
1.0	.0811	.0788	.815	.774
1.1	.0669	.0701	.785	.758

PROPELLER NO. 136

0.5	0.1299	0.1175	0.553	0.442
.6	.1341	.1180	.640	.520
.7	.1394	.1265	.710	.666
.8	.1416	.1317	.759	.731
.9	.1380	.1263	.794	.761
1.0	.1303	.1199	.815	.772
1.1	.1191	.1099	.824	.800
1.2	.1046	.0972	.821	.784

PROPELLER NO. 137

0.5	0.1274	0.1180	0.575	0.440
.6	.1334	.1210	.654	.498
.7	.1378	.1260	.715	.678
.8	.1390	.1319	.760	.733
.9	.1360	.1265	.795	.768
1.0	.1284	.1205	.815	.794
1.1	.1168	.1095	.824	.803
1.2	.1029	.0961	.814	.795

PROPELLER NO. 138

0.5	0.1375	0.1170	0.569	0.439
.6	.1430	.1180	.645	.514
.7	.1453	.1302	.707	.648
.8	.1431	.1330	.757	.736
.9	.1373	.1270	.791	.768
1.0	.1282	.1215	.813	.790
1.1	.1170	.1097	.826	.800
1.2	.1037	.0958	.824	.755

PROPELLER NO. 139

0.15	0.0249	.0245	0.385	0.458
.2	.0247	.0254	.469	.524
.25	.0241	.0258	.517	.540
.3	.0234	.0250	.522	.530

PROPELLER NO. 144

0.15	0.0234	0.0274	0.395	0.500
.2	.0226	.0274	.461	.562
.25	.0216	.0265	.488	.585
.3	.0201	.0247	.470	.563

PROPELLER NO. 145

0.15	0.0262	0.0253	0.370	0.422
.2	.0261	.0253	.448	.504
.25	.0258	.0247	.491	.534
.3	.0255	.0230	.504	.521

PROPELLER NO. 146

0.15	0.0258	0.0290	0.382	0.503
.2	.0245	.0288	.451	.571
.25	.0230	.0278	.493	.597
.3	.0211	.0271	.491	.582

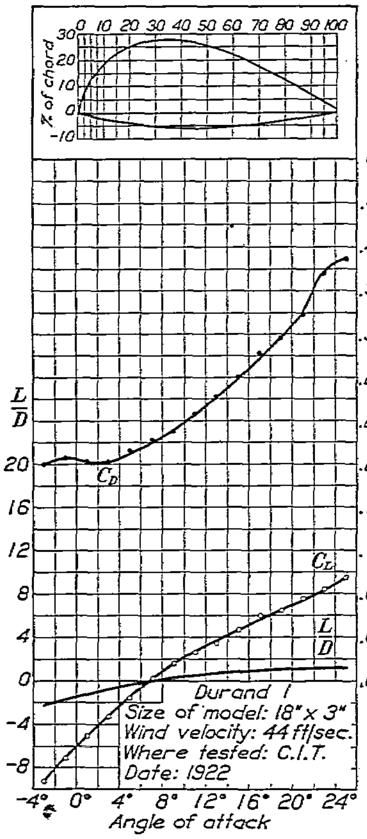

Fig. 14

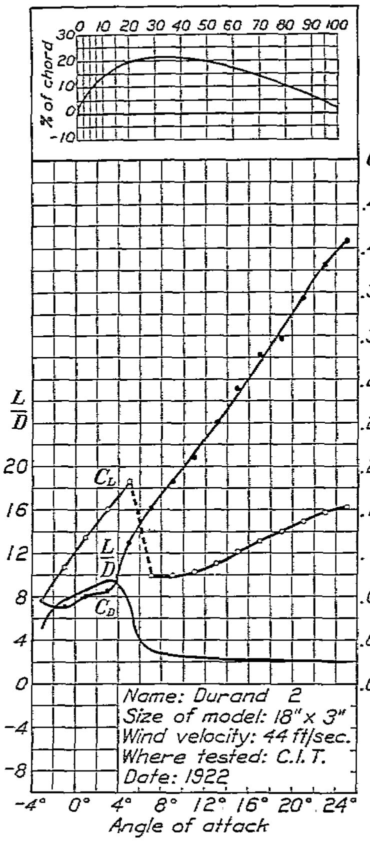

Fig. 15

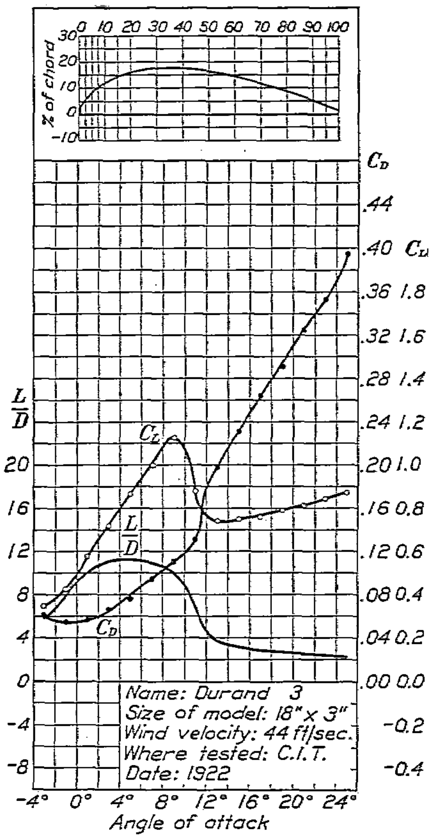

Fig. 16

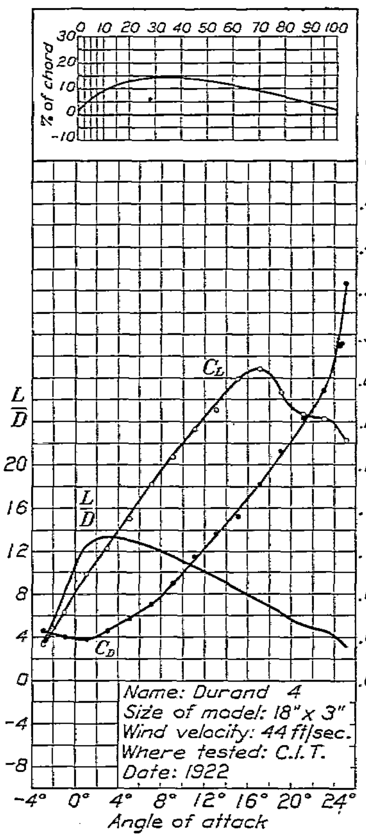

Fig. 17

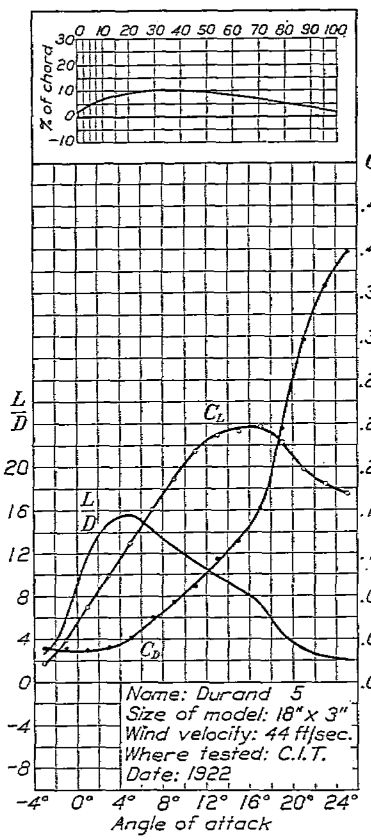

Fig. 18

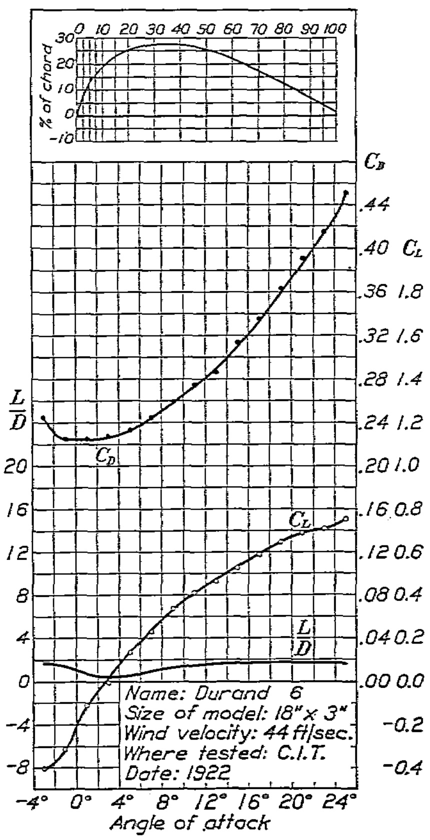

Fig 19

The new absolute coefficients C_L and C_D, which are twice as large as the old absolute L_C and D_C, are used on these figures.

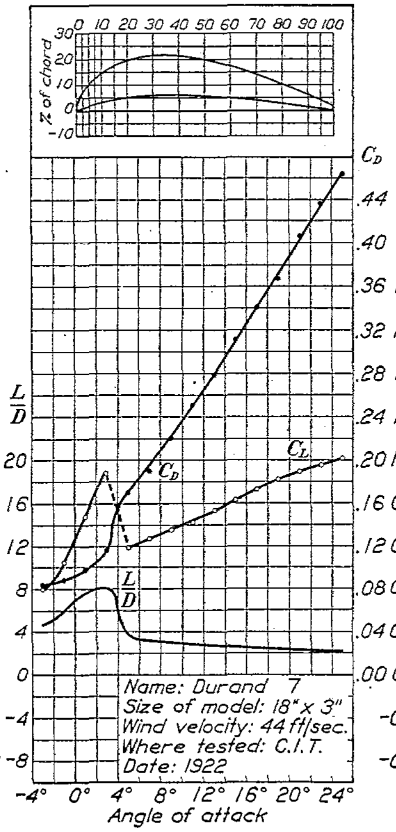

FIG. 20

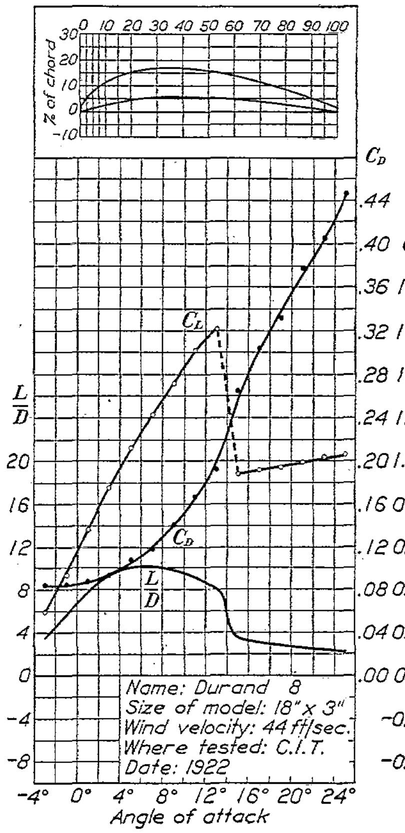

FIG. 21

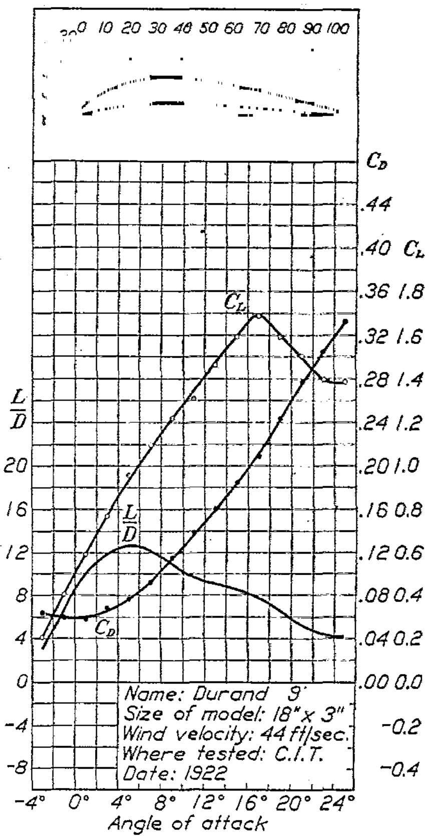

FIG. 22

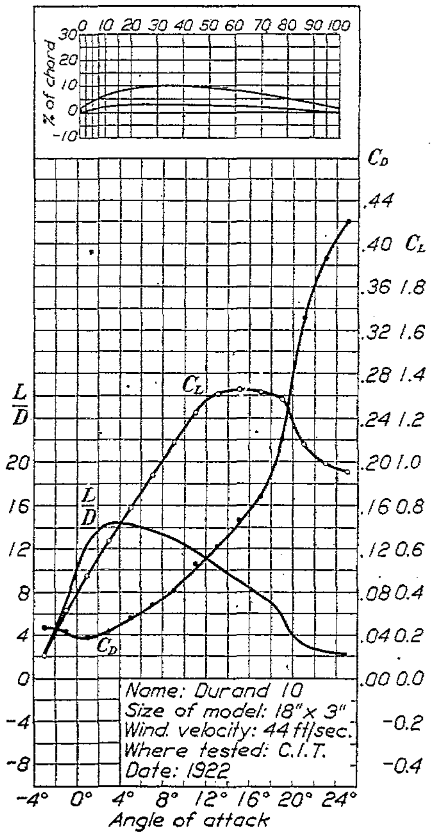

FIG. 23

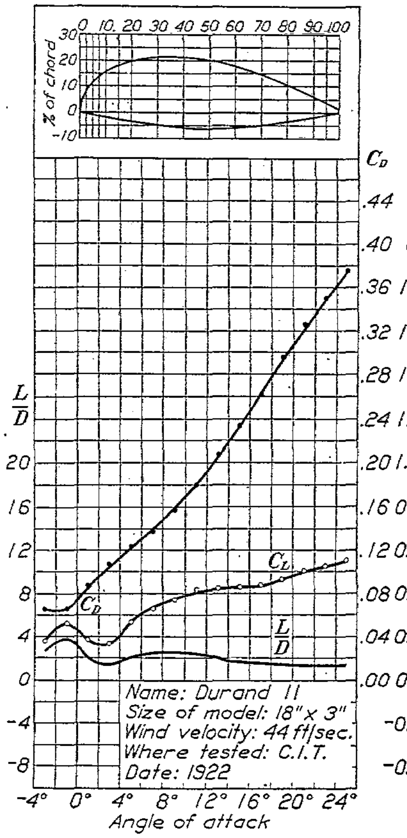

FIG. 24

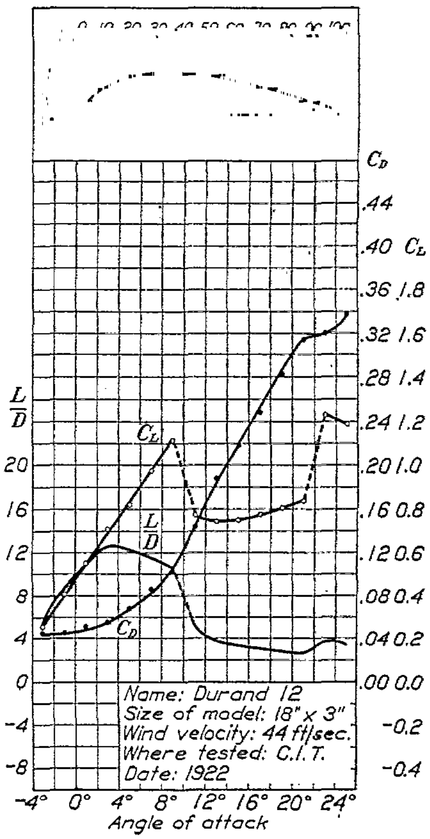

FIG. 25

The new absolute coefficients C_L and C_D, which are twice as large as the old absolute L_C and D_C, are used on these figures.

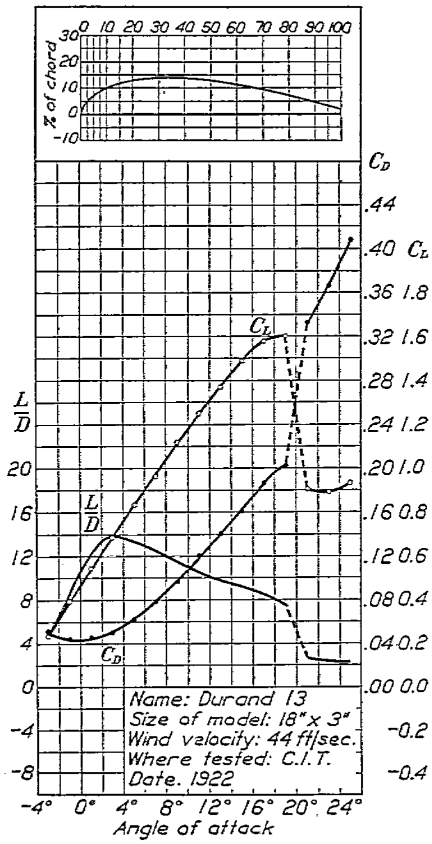

FIG. 26

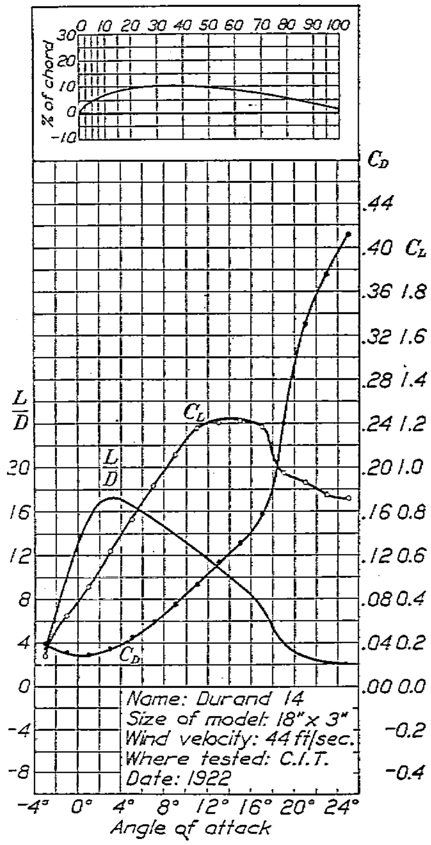

FIG. 27

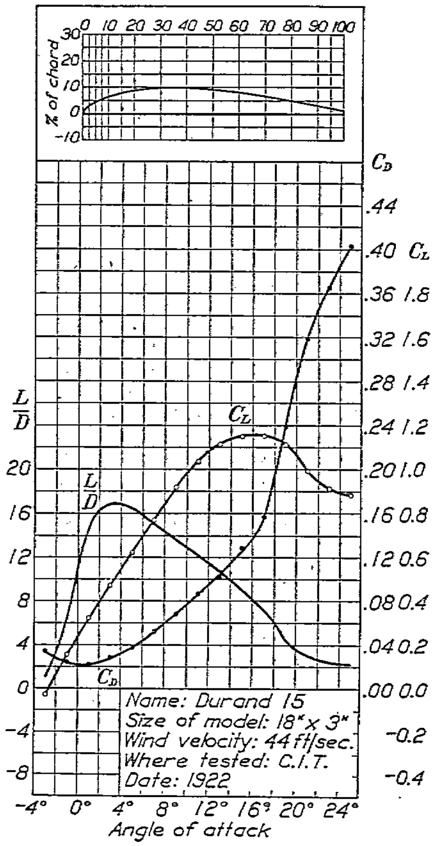

FIG. 28

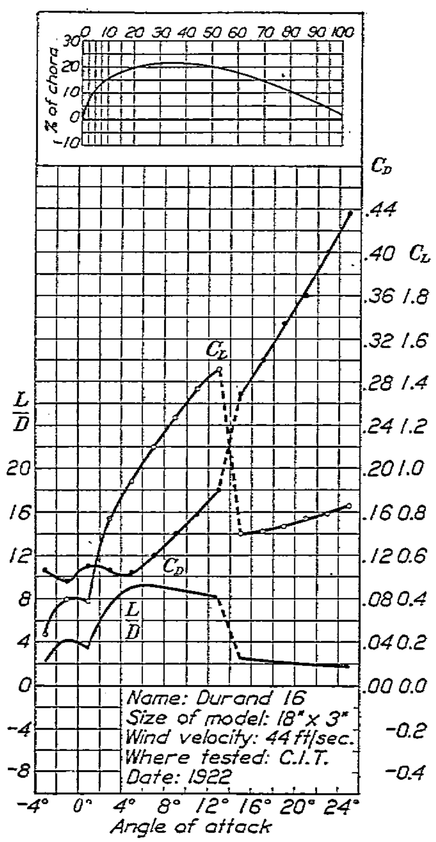

FIG. 29

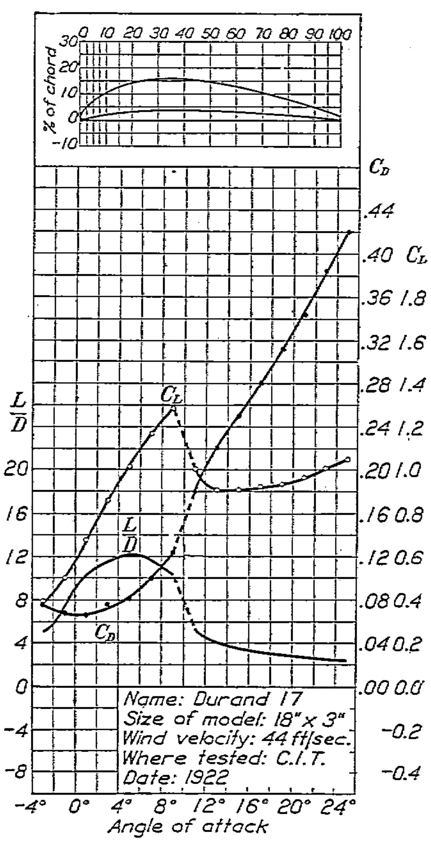

FIG. 30

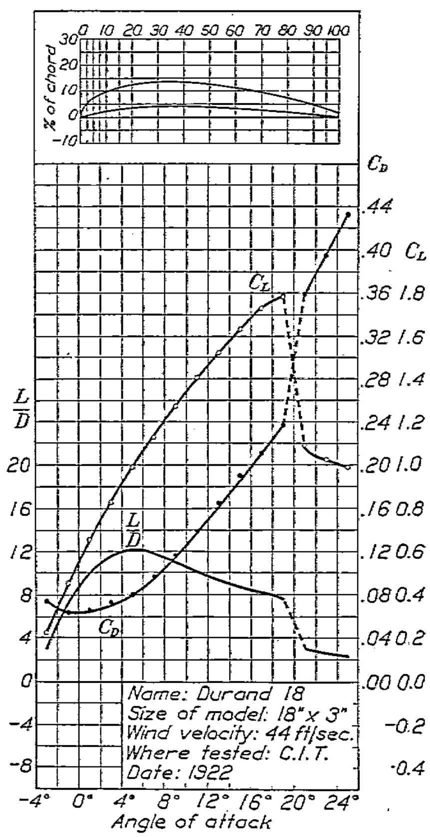

FIG. 31

The new absolute coefficients C_L and C_D, which are twice as large as the old absolute L_C and D_C, are used on these figures.

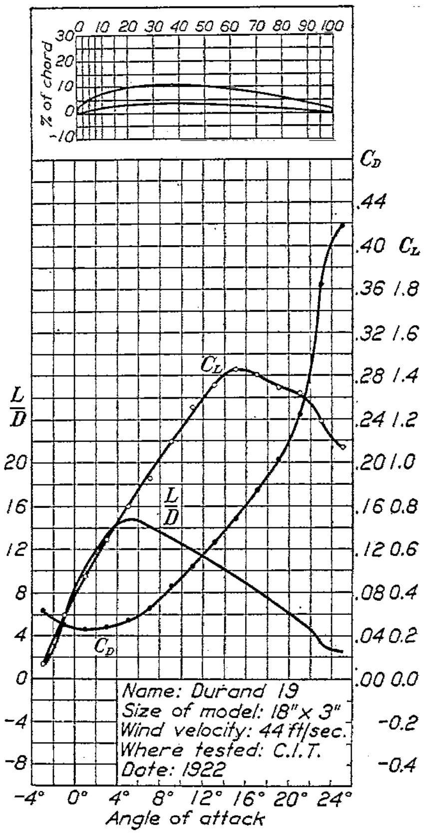

FIG. 32

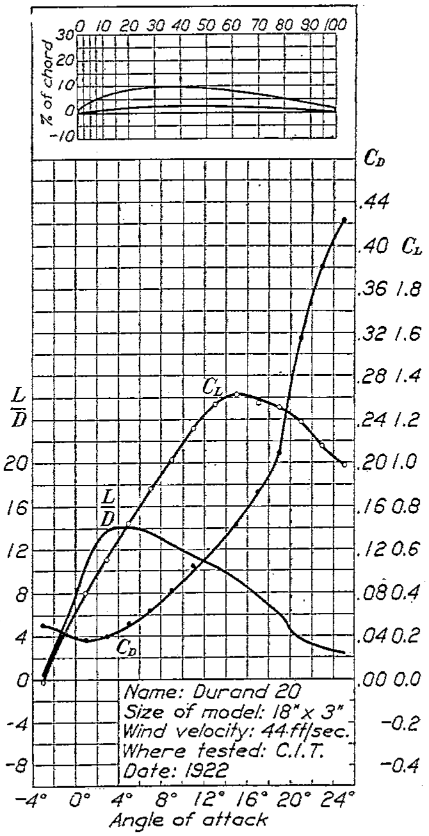

FIG. 33

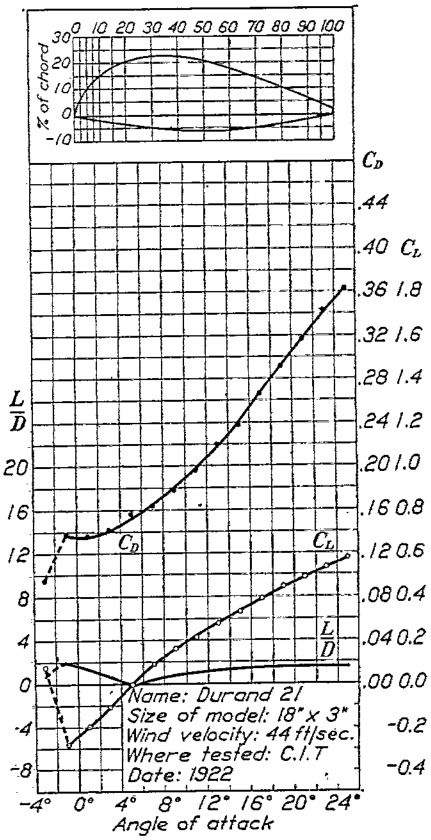

FIG. 34

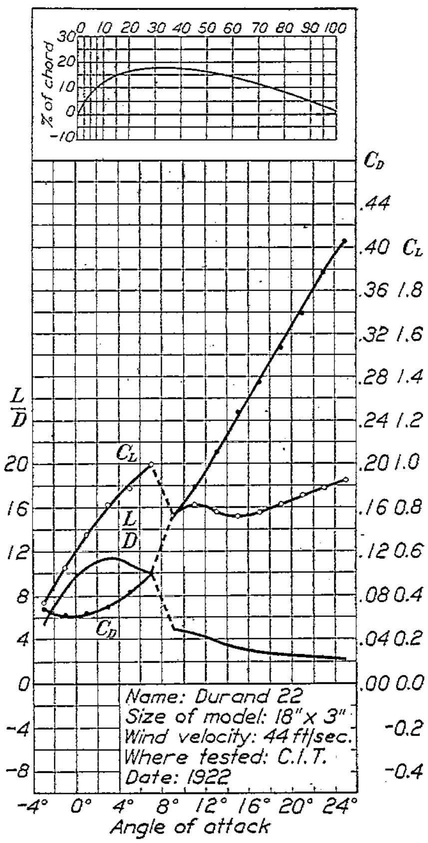

FIG. 35

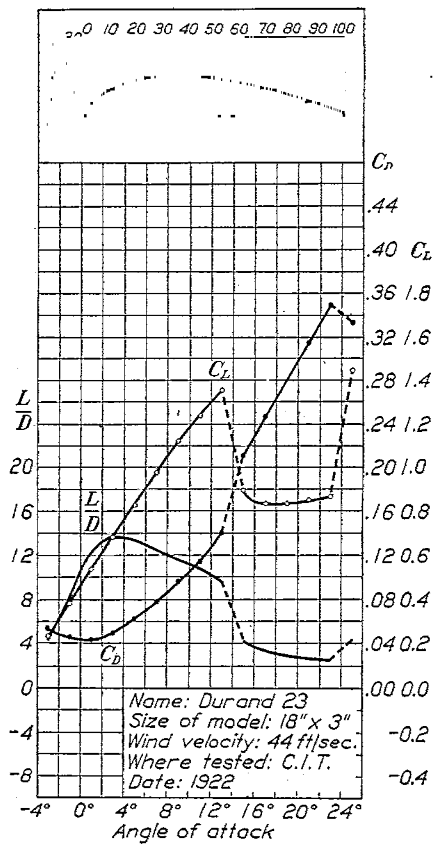

FIG. 36

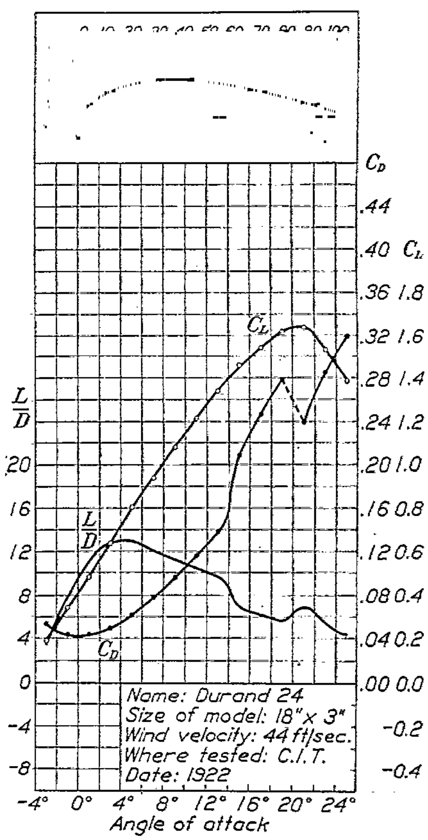

FIG. 37

The new absolute coefficients C_L and C_D, which are twice as large as the old absolute L_C and D_C, are used on these figures.

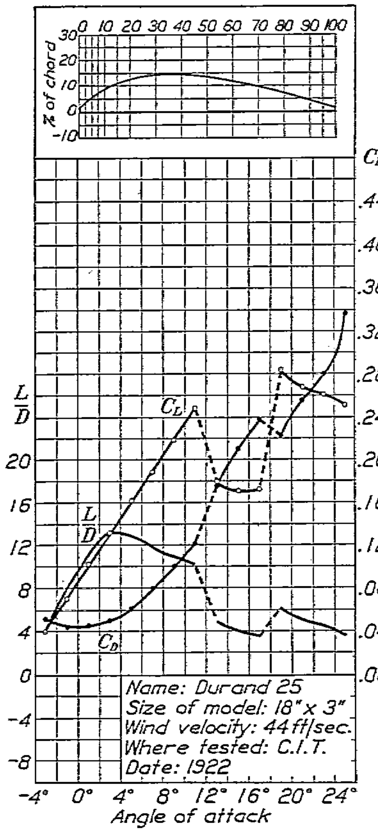

FIG. 38

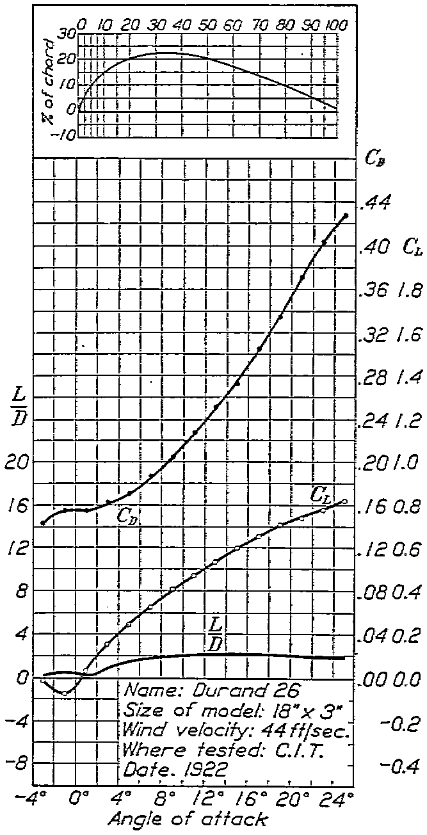

FIG. 39

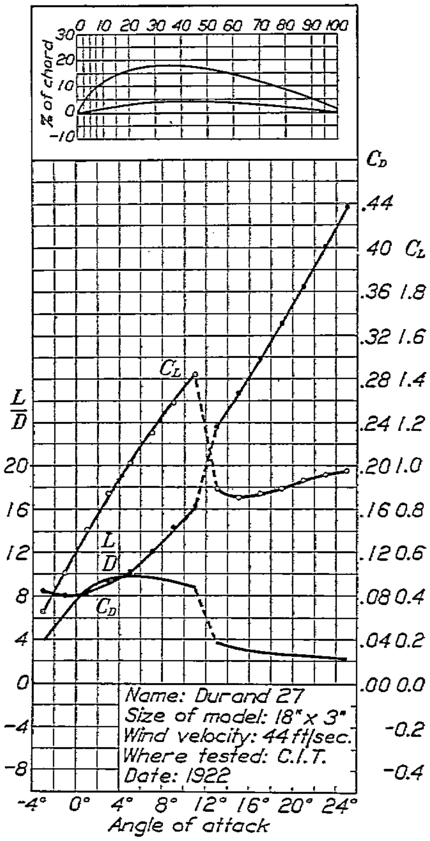

FIG. 40

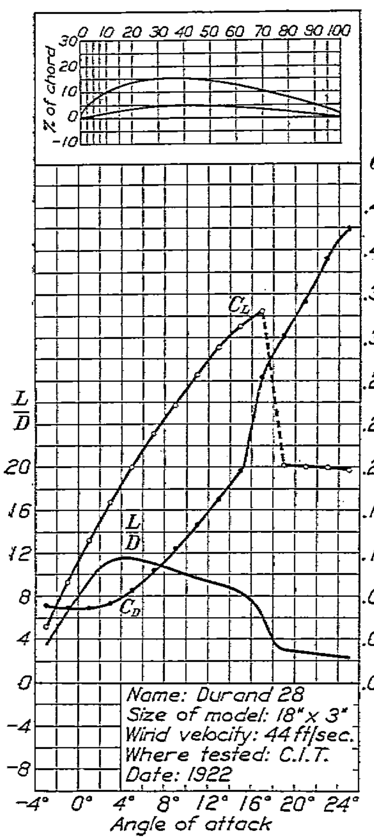

FIG. 41

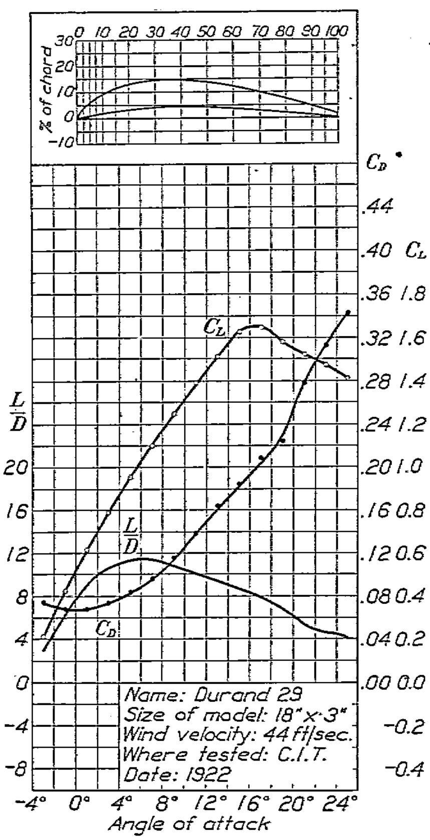

FIG. 42

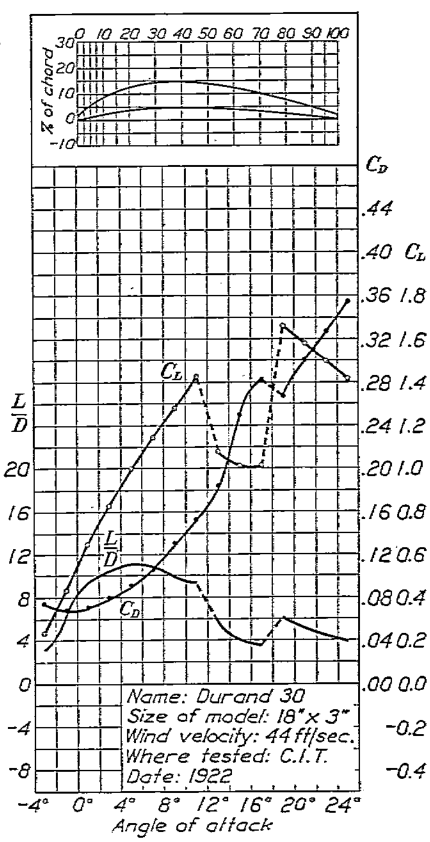

FIG. 43

The new absolute coefficients C_L and C_D, which are twice as large as the old absolute L_C and D_C, are used on these figures.

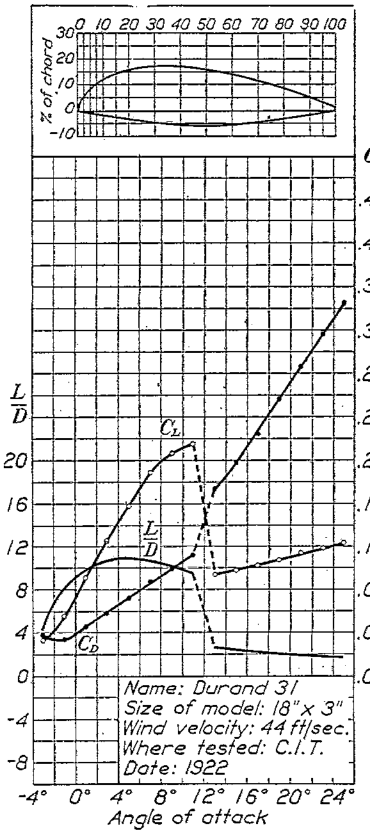

FIG. 44

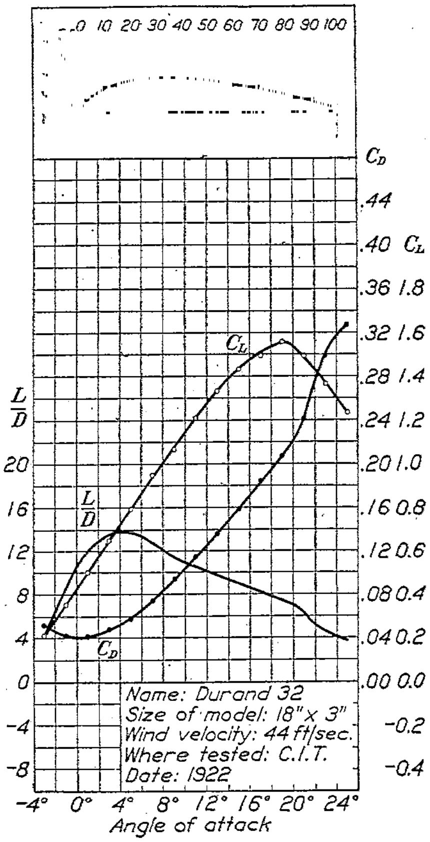

FIG. 45

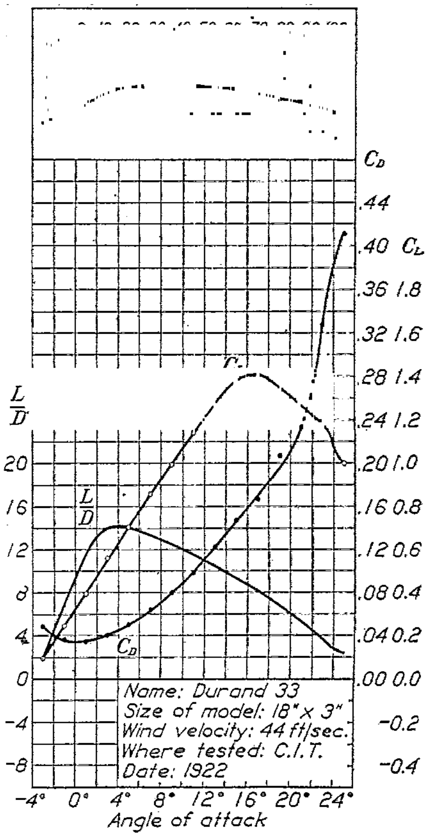

FIG. 46

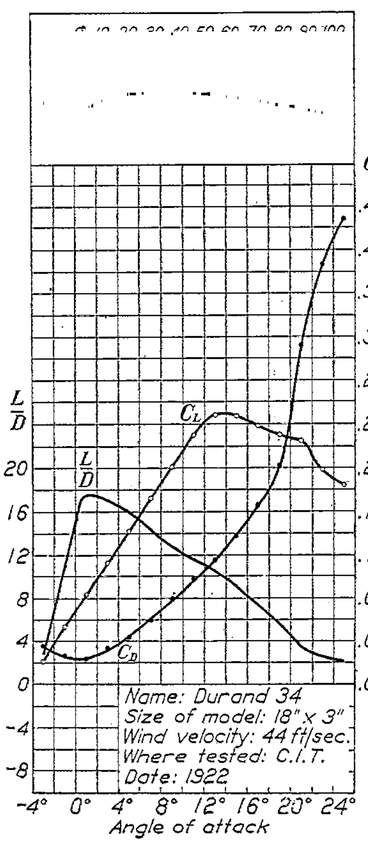

FIG. 47

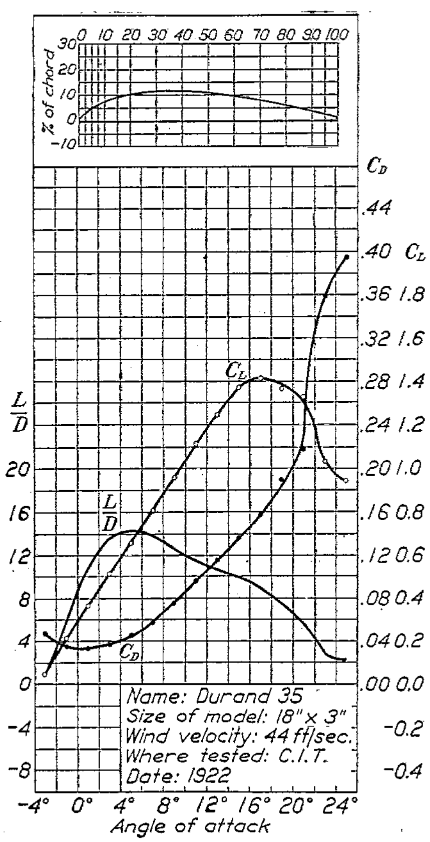

FIG. 48

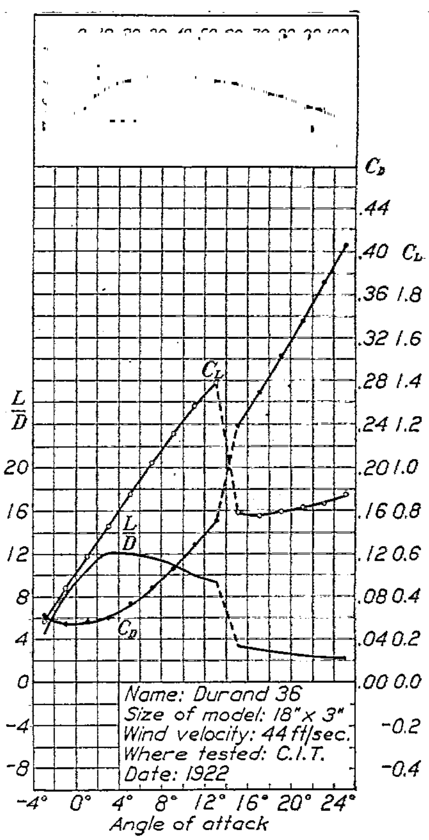

FIG. 49

The new absolute coefficients C_L and C_D, which are twice as large as the old absolute L_C and D_C, are used on these figures.

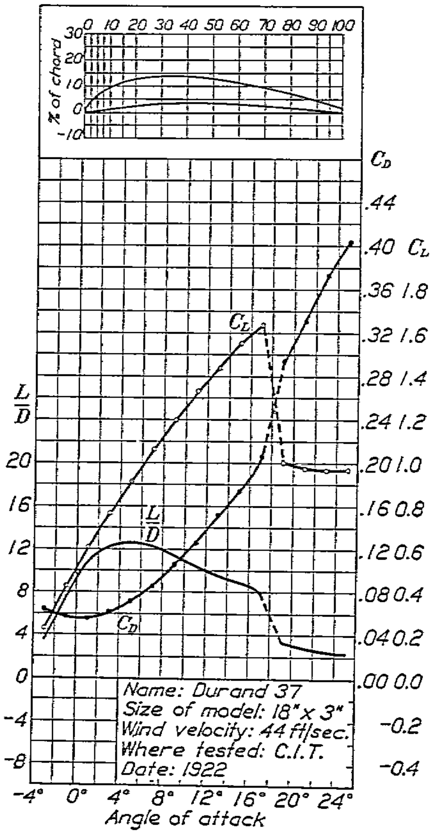

FIG. 50

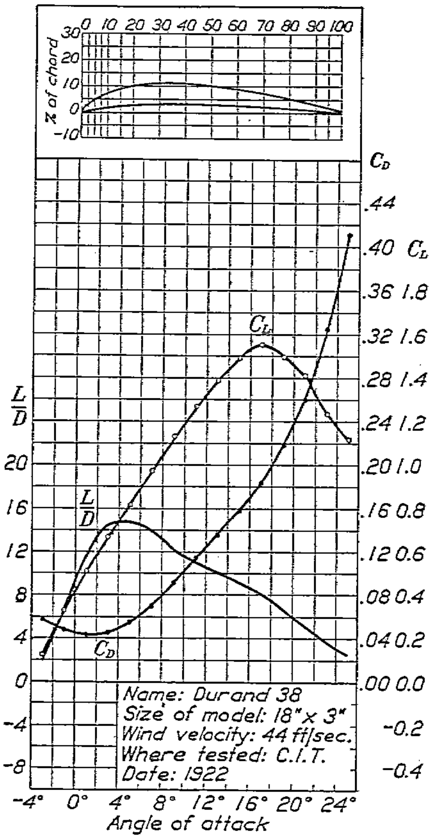

FIG. 51

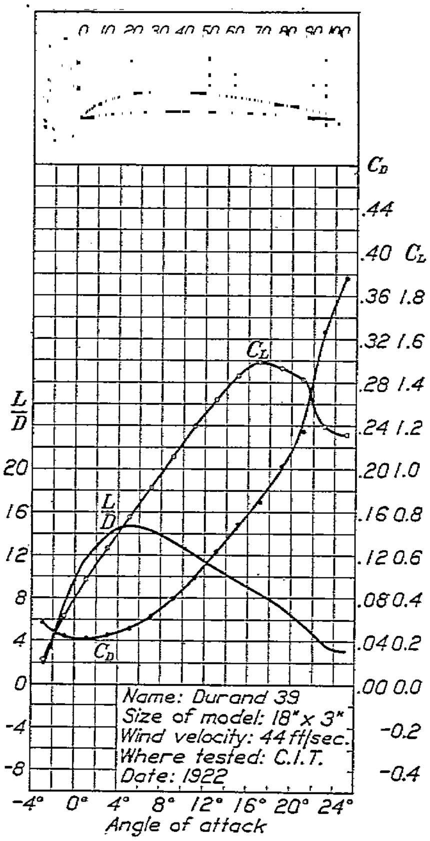

FIG. 52

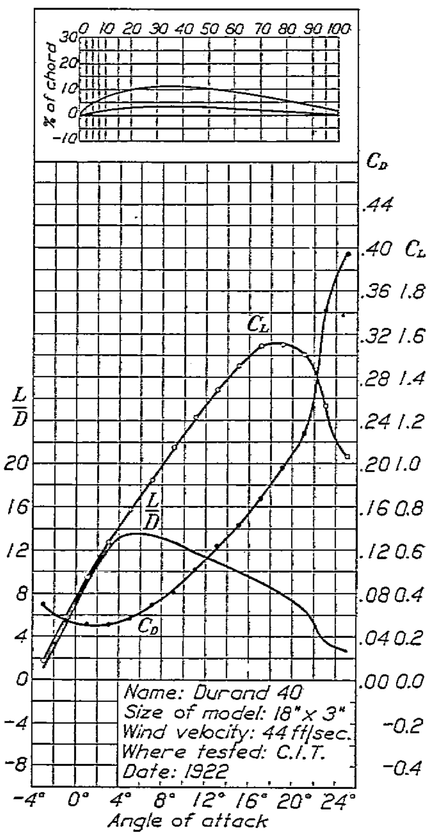

FIG. 53

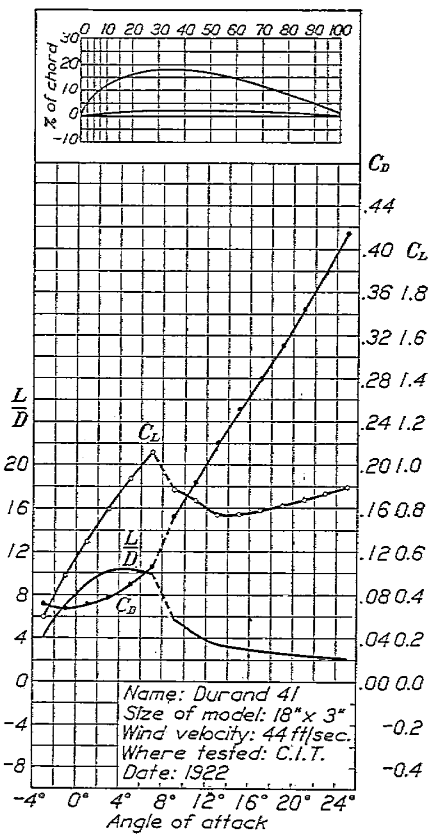

FIG. 54

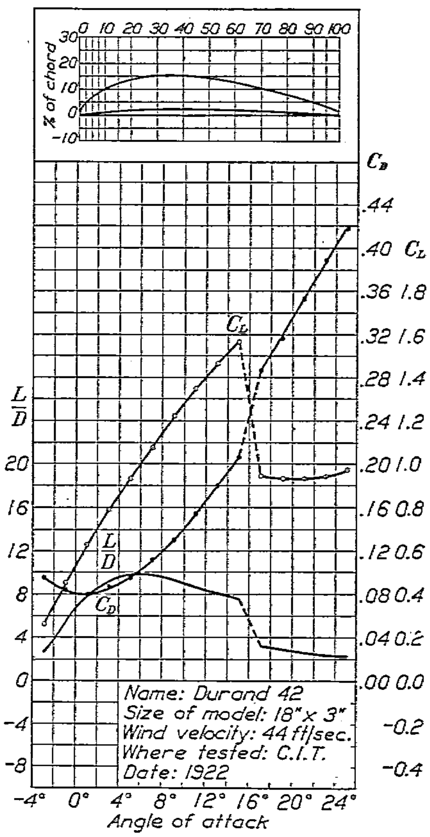

FIG. 55

The new absolute coefficients C_L and C_D, which are twice as large as the old absolute L_C and D_C, are used on these figures.

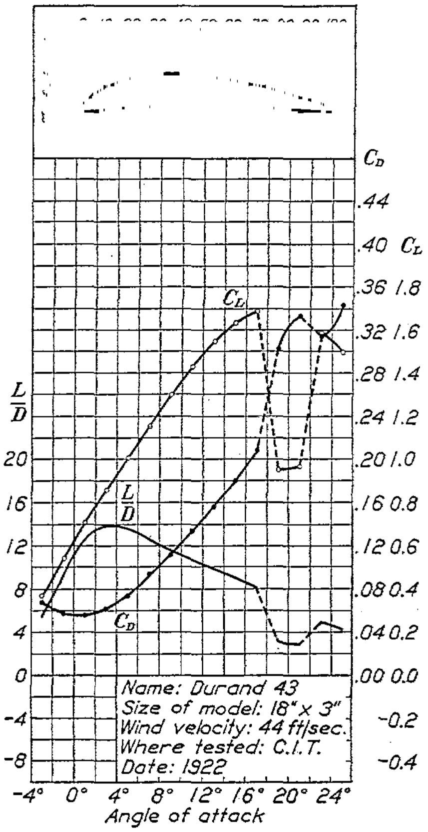

FIG. 56

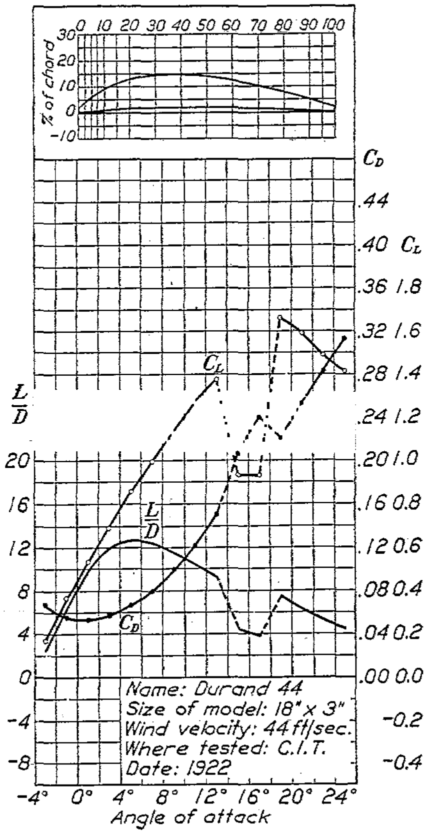

FIG. 57

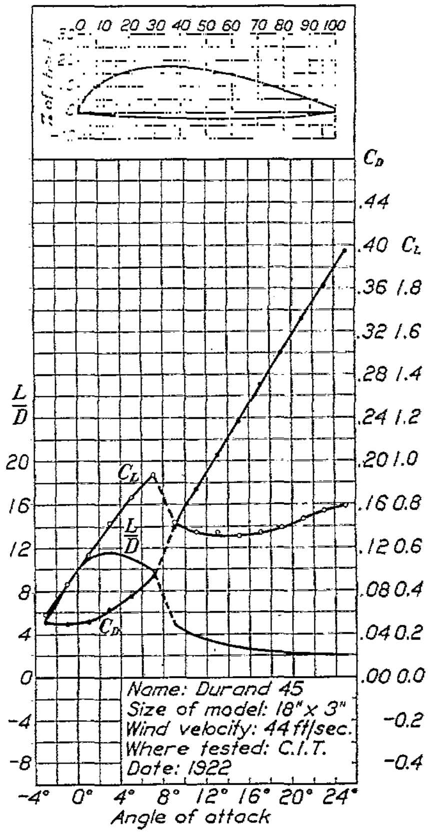

FIG. 58

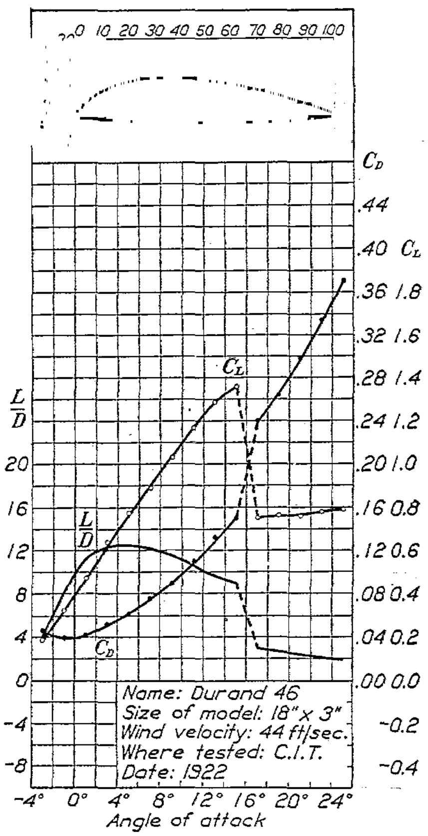

FIG. 59

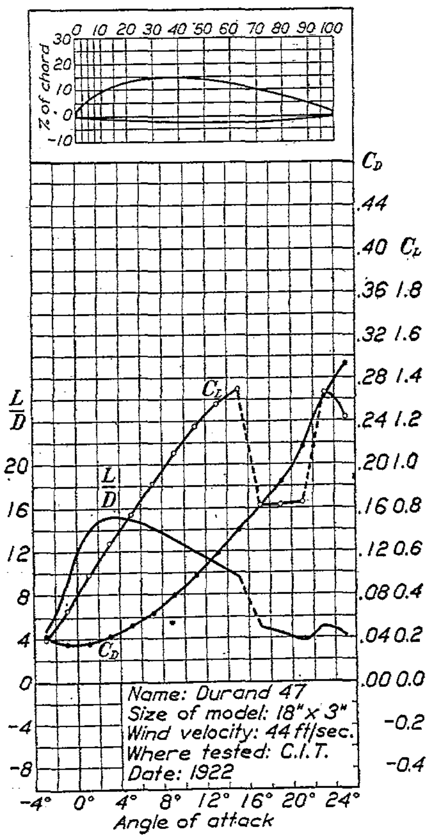

FIG. 60

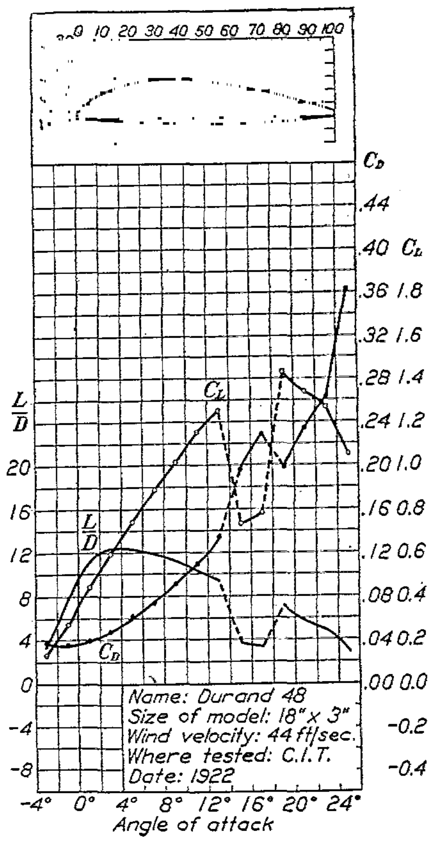

FIG. 61

The new absolute coefficients C_L and C_D, which are twice as large as the old absolute L_C and D_C, are used on these figures.