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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 500

THE INFLUENCE OF TIP SHAPE ON THE WING LOAD DISTRIBUTION AS DETERMINED BY FLIGHT TESTS

By RICHARD V. RHODE

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AERONAUTIC SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Abbreviation	Unit	Abbreviation
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	s	second (or hour)	sec. (or hr.)
Force	F	weight of 1 kilogram	kg	weight of 1 pound	lb.
Power	P	horsepower (metric)		horsepower	hp.
Speed	V	kilometers per hour	k.p.h.	miles per hour	m.p.h.
		meters per second	m.p.s.	feet per second	f.p.s.

2. GENERAL SYMBOLS

W, Weight $= mg$

g, Standard acceleration of gravity $= 9.80665$ m/s^2 or 32.1740 ft./sec.^{2}

m, Mass $= \frac{W}{g}$

I, Moment of inertia $= mk^2$. (Indicate axis of radius of gyration k by proper subscript.)

μ, Coefficient of viscosity

ν, Kinematic viscosity

ρ, Density (mass per unit volume)

Standard density of dry air, 0.12497 kg-m^{-4}-s^2 at 15° C. and 760 mm; or 0.002378 lb.-ft.$^{-4}$-sec.^{2}

Specific weight of "standard" air, 1.2255 kg/m^3 or 0.07651 lb./cu.ft.

3. AERODYNAMIC SYMBOLS

S, Area

S_w, Area of wing

G, Gap

b, Span

c, Chord

$\frac{b^2}{S}$, Aspect ratio

V, True air speed

q, Dynamic pressure $= \frac{1}{2}\rho V^2$

L, Lift, absolute coefficient $C_L = \frac{L}{qS}$

D, Drag, absolute coefficient $C_D = \frac{D}{qS}$

D_o, Profile drag, absolute coefficient $C_{D_o} = \frac{D_o}{qS}$

D_i, Induced drag, absolute coefficient $C_{D_i} = \frac{D_i}{qS}$

D_p, Parasite drag, absolute coefficient $C_{D_p} = \frac{D_p}{qS}$

C, Cross-wind force, absolute coefficient $C_C = \frac{C}{qS}$

R, Resultant force

i_w, Angle of setting of wings (relative to thrust line)

i_t, Angle of stabilizer setting (relative to thrust line)

Q, Resultant moment

Ω, Resultant angular velocity

$\rho\frac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension (e.g., for a model airfoil 3 in. chord, 100 m.p.h. normal pressure at 15° C., the corresponding number is 234,000; or for a model of 10 cm chord, 40 m.p.s. the corresponding number is 274,000)

C_p, Center-of-pressure coefficient (ratio of distance of $c.p.$ from leading edge to chord length)

α, Angle of attack

ϵ, Angle of downwash

α_o, Angle of attack, infinite aspect ratio

α_i, Angle of attack, induced

α_a, Angle of attack, absolute (measured from zero-lift position)

γ, Flight-path angle

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By RICHARD V. RHODE
Langley Memorial Aeronautical Laboratory

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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REPORT No. 500

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By Richard V. Rhode

SUMMARY

Pressure measurements were made in flight on the right upper wing of an M–3 airplane. The effects of tip plan form, washout, and transverse camber were investigated with eight tip forms in unyawed conditions throughout the range of positive lift coefficients from zero lift to the stall.

The principal conclusion is that the tip plan form does not influence the span distribution of the coefficients of normal force and moment. It is shown inferentially that temperature, humidity, and the aging of the wood and fabric wing structure used on the M–3 airplane have an appreciable influence on the load distribution.

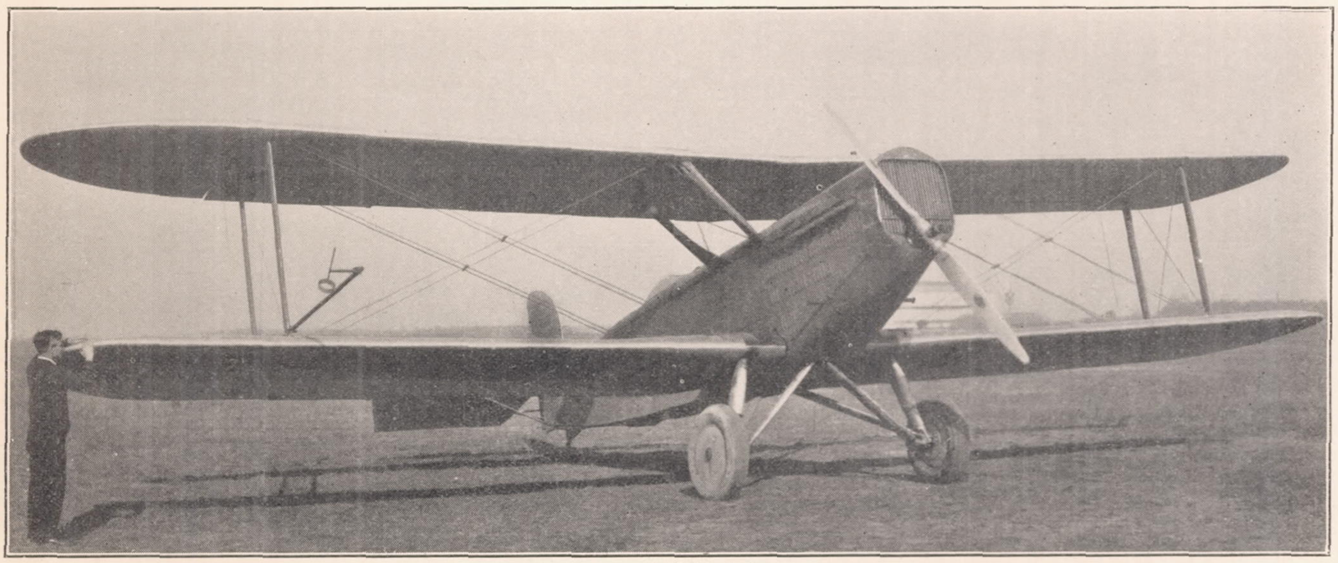

Figure 1.—The M–3 airplane.

INTRODUCTION

This investigation was conducted for the purpose of providing systematic data that could be used as a partial basis for the formulation of more satisfactory design rules to govern the assumed distribution of load over wing tips. Although the data have previously been published as technical notes (references 1 to 6), they are here collected and discussed as a unit in order to record the principal general conclusions of the investigation.

The investigation was made in flight on a biplane and was confined, in the main, to a study of the influence of tip plan form on the load distribution in unyawed conditions over the right upper wing, although some data were also obtained on the effect of washout and lateral camber.

Although necessarily limited in scope, the results should be of considerable value in the estimation of the load distribution, both for use in induced-drag calculations and in structural-design requirements.

The investigation was conducted by the National Advisory Committee for Aeronautics at Langley Field, Va.

APPARATUS AND METHOD

Airplane.—The airplane used in these tests was a Douglas M–3 (fig. 1). This airplane is a conventional biplane with a moderately high aspect ratio. Its principal characteristics are given in table I.

Instruments.—The instruments used in the pressure tests were a diaphragm type recording multiple manometer (N.A.C.A. type 60) and an N.A.C.A. air-speed recorder. A recording accelerometer was also used as a guide to prevent overloading the airplane structure in the pull-up maneuvers required to attain high lift coefficients in the pressure tests, and as a means of measuring the total normal force so that the air-speed calibration could be related to the normal-force coefficient (C_N)[1] in accelerated flight.

Ten pairs of orifices were installed in the right upper wing panel at each of the rib stations defined in table II. Each pair consisted of an orifice in the upper surface of the wing and one directly below it in the lower surface. The orifices were connected to the manometers in such a manner that the difference in pressure between upper and lower surfaces at each orifice location was measured. No measurements were actually made at the wing root, and the data given later for this section were obtained by extrapolation. The influence of interference factors near the root, such as fuselage and slipstream, were therefore largely avoided.

The swiveling pitot-static head used in the air-speed measurements was mounted on a boom about 0.9 chord length forward of the right lower wing at the outer strut location (fig. 1). In this manner the interference of the wing was reduced to a small value.

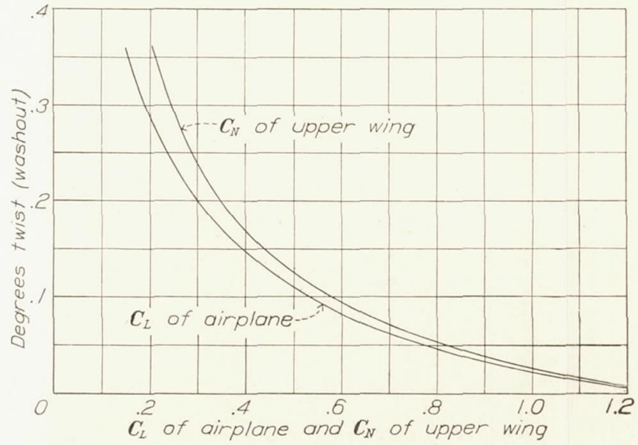

FIGURE 2.—Torsion at N-strut with unit load factors.

The instruments were mounted in an insulated compartment which was kept at a constant temperature by means of an electrical heater controlled by a thermostat and deriving its energy from a generator driven by the airplane engine. Before each flight the heater was connected to an external source of energy for about an hour and a half in order to allow the instruments to reach equilibrium at a constant temperature. By this means the accuracy of the measurements was considerably increased.

Preliminary tests.—Prior to the main tests, the air-speed installation was calibrated over a speed course in the usual manner. It was found that the wind interference at the location of the pitot-static head was small at most angles of attack, the maximum effect being to reduce the measured air speed about 3.3 percent at minimum speed.

Measurements of torsional deflection of the cellule were made in steady glides by means of a surveyor's level, which was used to sight on scales attached to a boom secured to the outer struts. The results of these measurements are shown on figure 2.

Precautions observed.—In addition to maintaining the instruments at constant temperature, the following precautions were observed. Except in the case of wing tip 6, the wings were rigged to have a slight amount of washin sufficient approximately to compensate for the torsional deflection of the cellule under the conditions in which the low angle-of-attack measurements were made. The rigged twist was frequently checked during the tests. Thus the results were obtained for zero twist. At the high angles of attack, conditions were such that the torsional deflection would not offset the rigged twist; but at the high angles the rigged twist was such a small fraction of the angle of attack that its effect was negligible.

All test maneuvers were made in the vertical plane to avoid yaw and roll. In addition to level-flight runs, push-downs were performed to obtain measurements at zero lift, and pull-ups were made to obtain results at high-lift coefficients. The calibration of the air-speed installation was applied to the measurements made in these maneuvers on the basis of lift coefficient.

The ailerons in the upper wing were shortened so that they did not extend through the pressure ribs. Thus the influence of slight aileron displacements and of the gap between wing and aileron was reduced to a minimum. Furthermore, the necessity for aileron displacement in the test runs was eliminated by careful rigging of the cellule and by counterbalancing the weight of the installation in the right upper wing with a weight placed in the left wing.

In order to verify an assumption that the tip shape of the lower wing does not affect the load distribution over the upper wing, certain of the tests were made with two widely different tip shapes on the lower wing.

PRECISION

The temperature of the instruments in the insulated box was maintained constant within $\pm 0.5°$ F. Temperature effects were therefore negligible. Frequent calibrations of the manometers and air-speed recorder showed changes between calibrations not exceeding 2 percent. The calibration made nearest to each test run was always used; hence, errors in pressure measurements were less than 2 percent.

The calibration of the air-speed installation was used directly for the test runs in level flight. Interference errors were therefore eliminated in these runs and the accidental error did not exceed 1 percent. In the accelerated-flight conditions, the installation calibra-

[1] The normal-force coefficient of the airplane is defined by the following expression:

$$C_N = \frac{N}{\frac{1}{2}\rho V^2 S_w}$$

where N is the component of total air force normal to the wing chord and S_w is the wing area. C_N is thus analogous to the lift coefficient and may be used not only for the airplane as a whole but also for individual wings and for localized sections of a wing. In the last case, called "rib C_N", the reference area is zero and C_N becomes the ratio of the average pressure over the wing section to the dynamic pressure.

tion was used on the basis of airplane normal-force coefficient as determined from the accelerometer measurements. It is estimated that the air speed in these cases is correct to within 2 percent. Thus, for these cases, wing and rib C_N as integrated from pressure measurements may be in error by 4 percent as a result of erroneous air-speed measurements, or by 6 percent considering the pressure errors. These errors, however, do not greatly affect the relations between the coefficients given in the final results, as indicated by figures 3 and 4, and hence have no appreciable influence on the span C_N curves nor on the curves of C_m about the leading edge. Moment coefficients about the aerodynamic center may, however, be considerably in

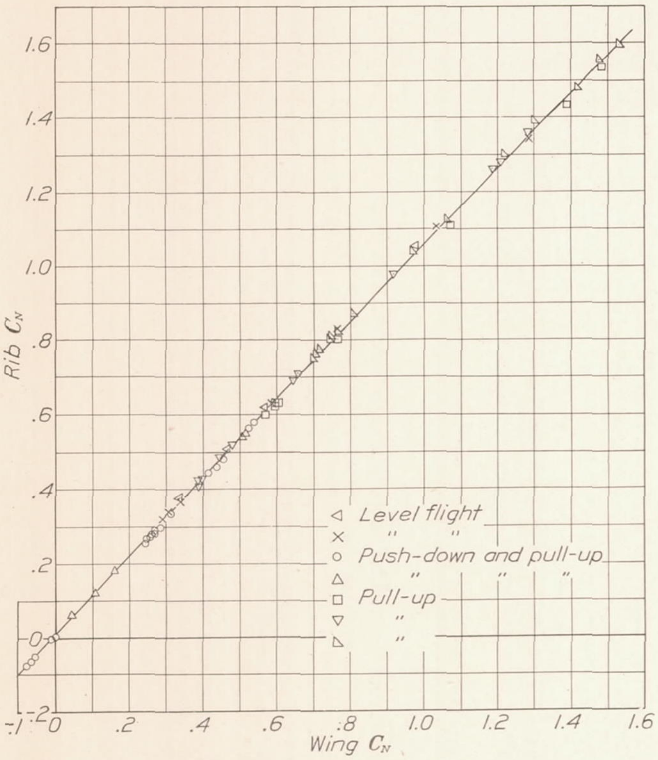

FIGURE 3.—Experimental points for rib A, Douglas tip (rib C_N against wing C_N)

error and they are useful only for indicating general trends, as will be discussed later.

WING-TIP SHAPES

Variations in plan form only.—Tips 1 to 5, which vary in plan form only, are shown in figures 5 to 13. The ordinates are given in tables III to VI. In all these tips, care was taken to maintain the basic airfoil section (Clark Y) to the extreme tip and to avoid twist. The front elevations of the tips were kept symmetrical by designing them so that the forward projections of the loci of the maximum mean camber were straight lines, as shown in the figures.

While tip 2 does not come strictly within this category, it is viewed for the purpose of this investigation as a square tip with a faired end to be compared with the truly square tip. The fairing is defined by similar approximately equilateral triangular sections in the plane normal to the chord and plane of symmetry.

Miscellaneous shapes.—Tip 6 is defined in figures 14 and 15 and table VII. This tip was on the airplane as received and was tested as a representative example of conventional design practice. In this tip the Clark Y section was not maintained, the sections approaching the symmetrical toward the end. The effect of this degeneration of section is to introduce aerodynamic washout defined by the directions of the zero-lift lines of the sections for two-dimensional flow. Figure 16 shows the rigged twist as tested and also the aerodynamic washout for this tip determined on the basis of Munk's method for finding the direction of zero lift.

Tip 7, defined by figures 17 and 18 and table VIII, was designed with the object of attaining straight center-of-pressure loci in both high and low angle-of-attack conditions. The leading-edge arc of the tip plan form is a quadrant of an ellipse with semimajor

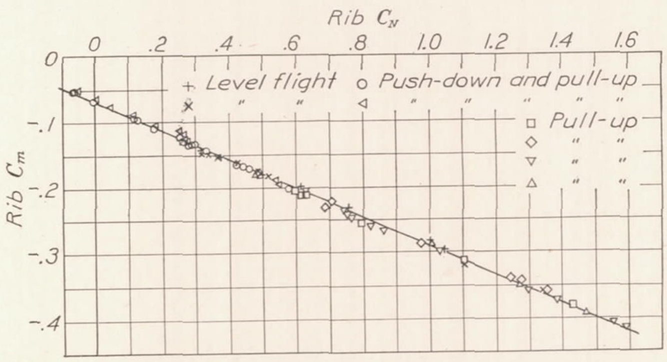

FIGURE 4.—Experimental points for rib A, Douglas tip (rib C_m against rib C_N)

axis 0.71*c* and semiminor axis 0.29*c*. The trailing-edge arc is circular with radius 0.71*c*. The front elevation is symmetrical and the tip is slightly washed out.

Tip 8, which is the same as tip 4 except in front elevation, is defined by figure 19 and table IX. This tip was, at the time the test program was devised, the standard tip for airplanes of the United States Navy, and it was tested at the request of the Bureau of Aeronautics, Navy Department.

RESULTS

Effects of variations in plan form.—Charts showing the relations between rib C_N and wing C_N, and between rib C_m and rib C_N, for tips 1 to 5 are given in figures 5 to 13. In all cases the dispersion of experimental points, which were omitted in the charts for the sake of clarity, was of the same order as indicated in figures 3 and 4.

In the case of the square tip, tests were conducted with both square and Douglas tips on the lower wing. No consistent differences in the measurements were observed, and the curves of figures 5 and 7 therefore represent both cases. In all other cases the results were obtained with the Douglas tip on the lower wing.

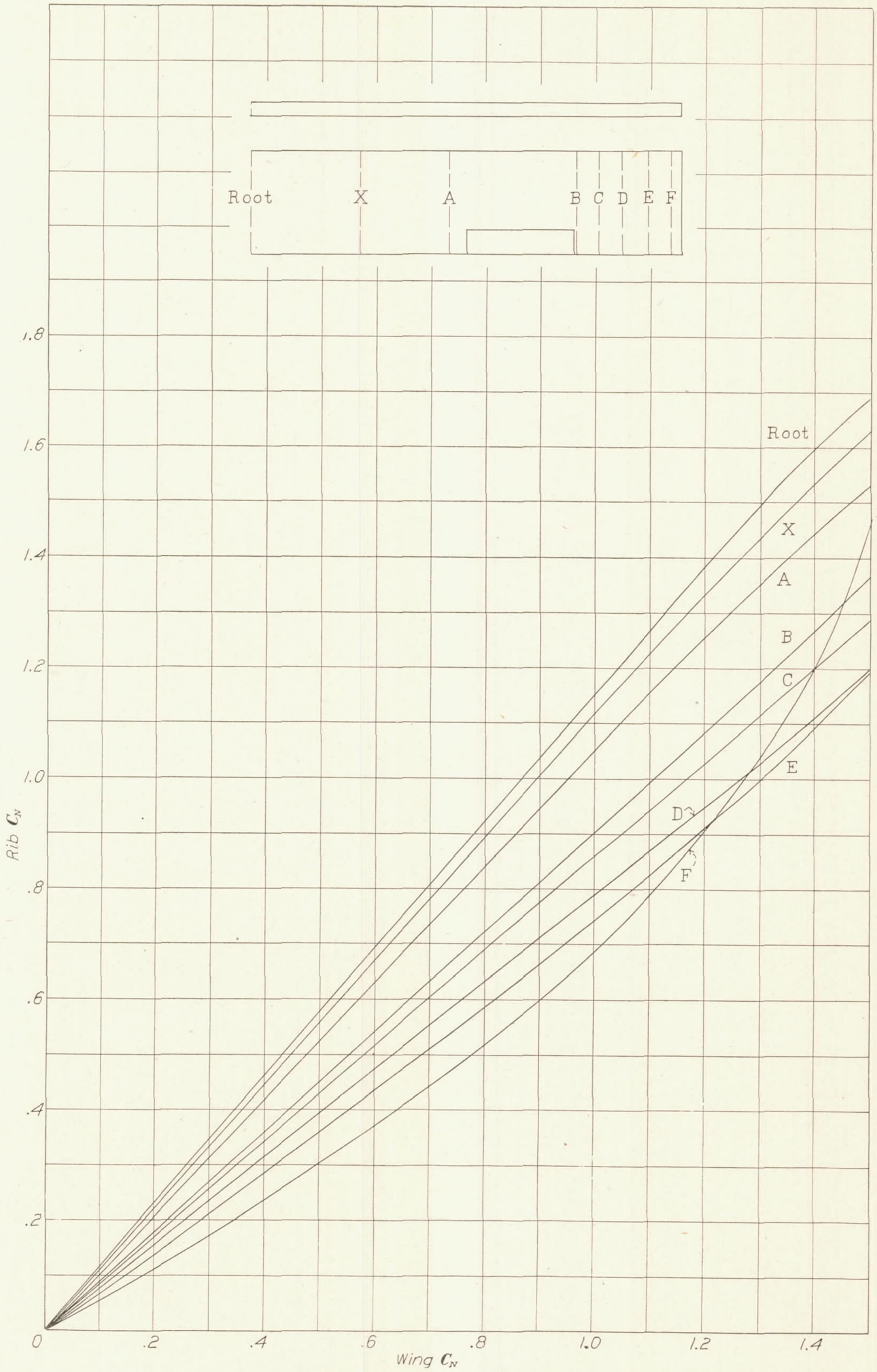

FIGURE 5.—Relation between rib C_N and wing C_N; square tip (tip 1).

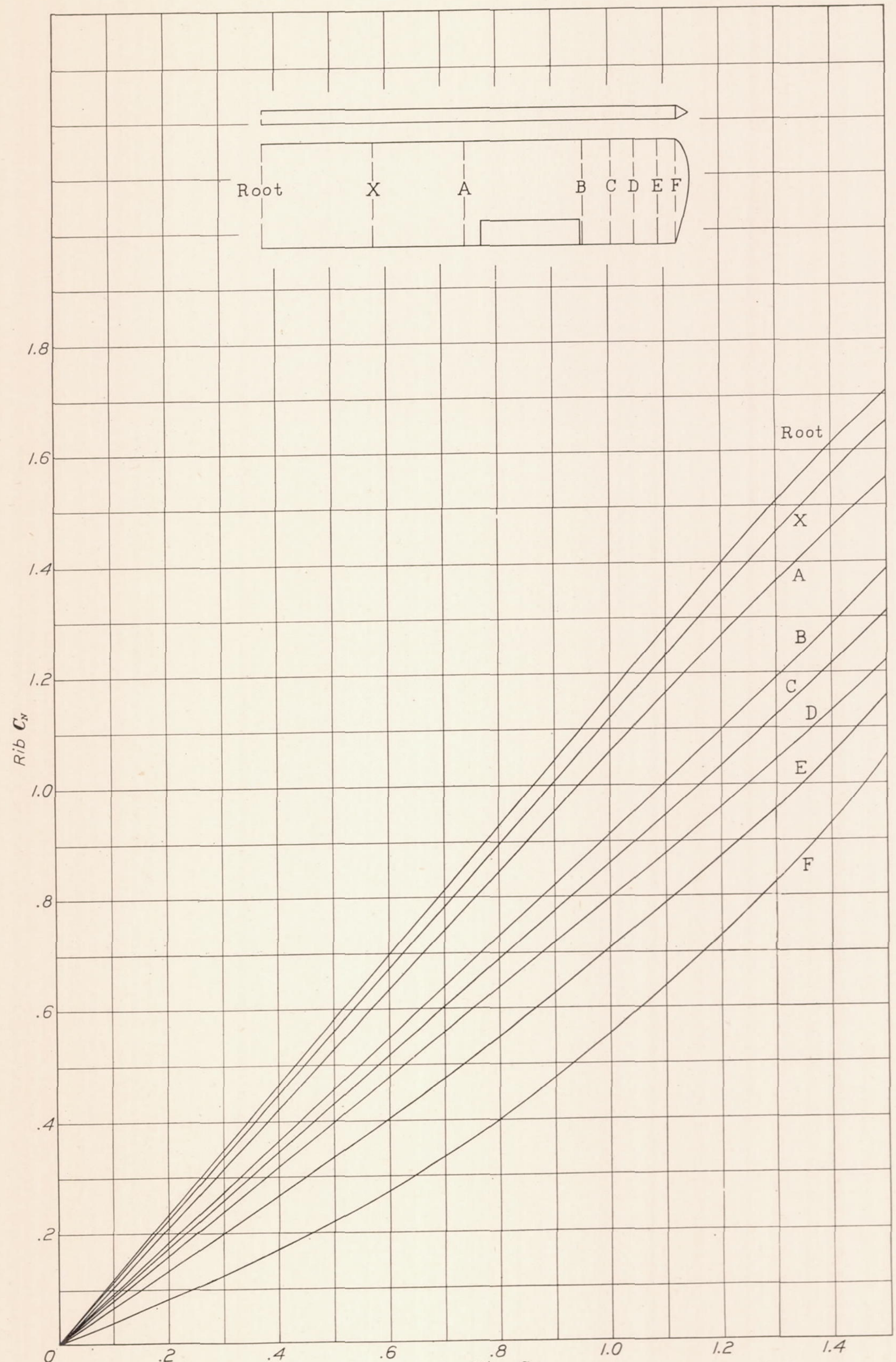

FIGURE 6.—Relation between rib C_N and wing C_N; faired square tip (tip 2).

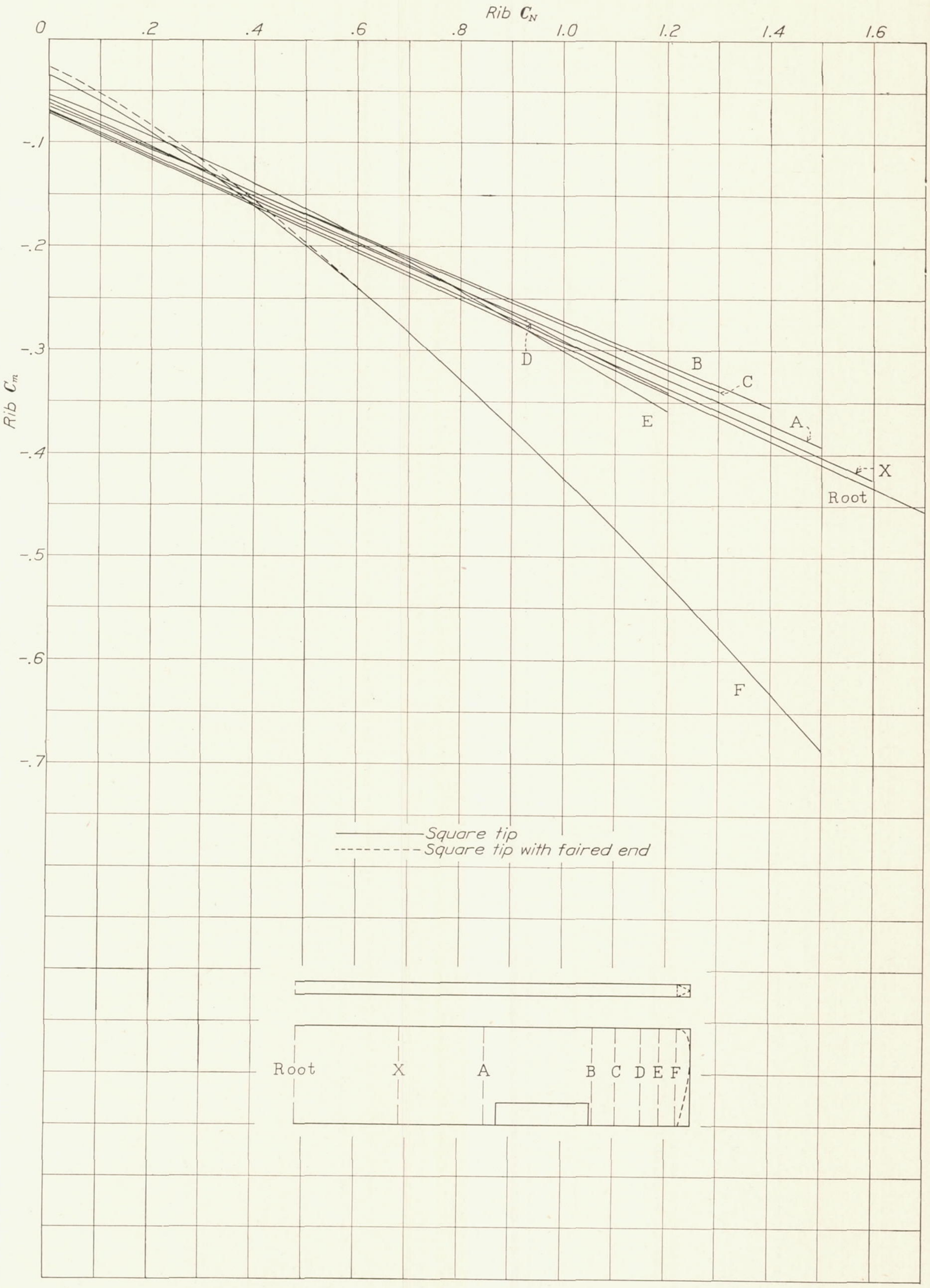

FIGURE 7.—Relation between rib C_m and rib C_N; square and faired square tips (tips 1 and 2).

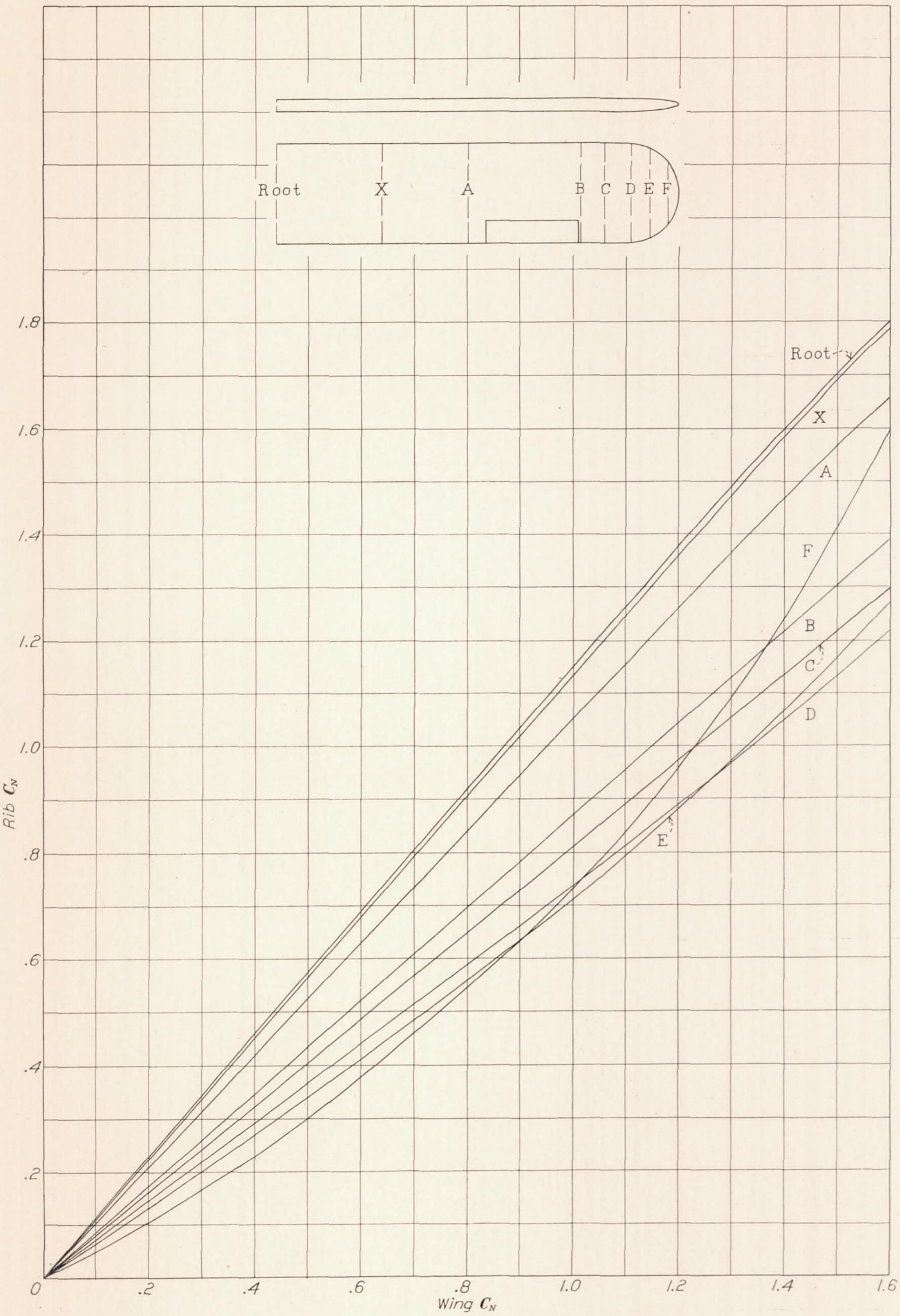

FIGURE 8.—Relation between rib C_N and wing C_N; circular tip (tip 3).

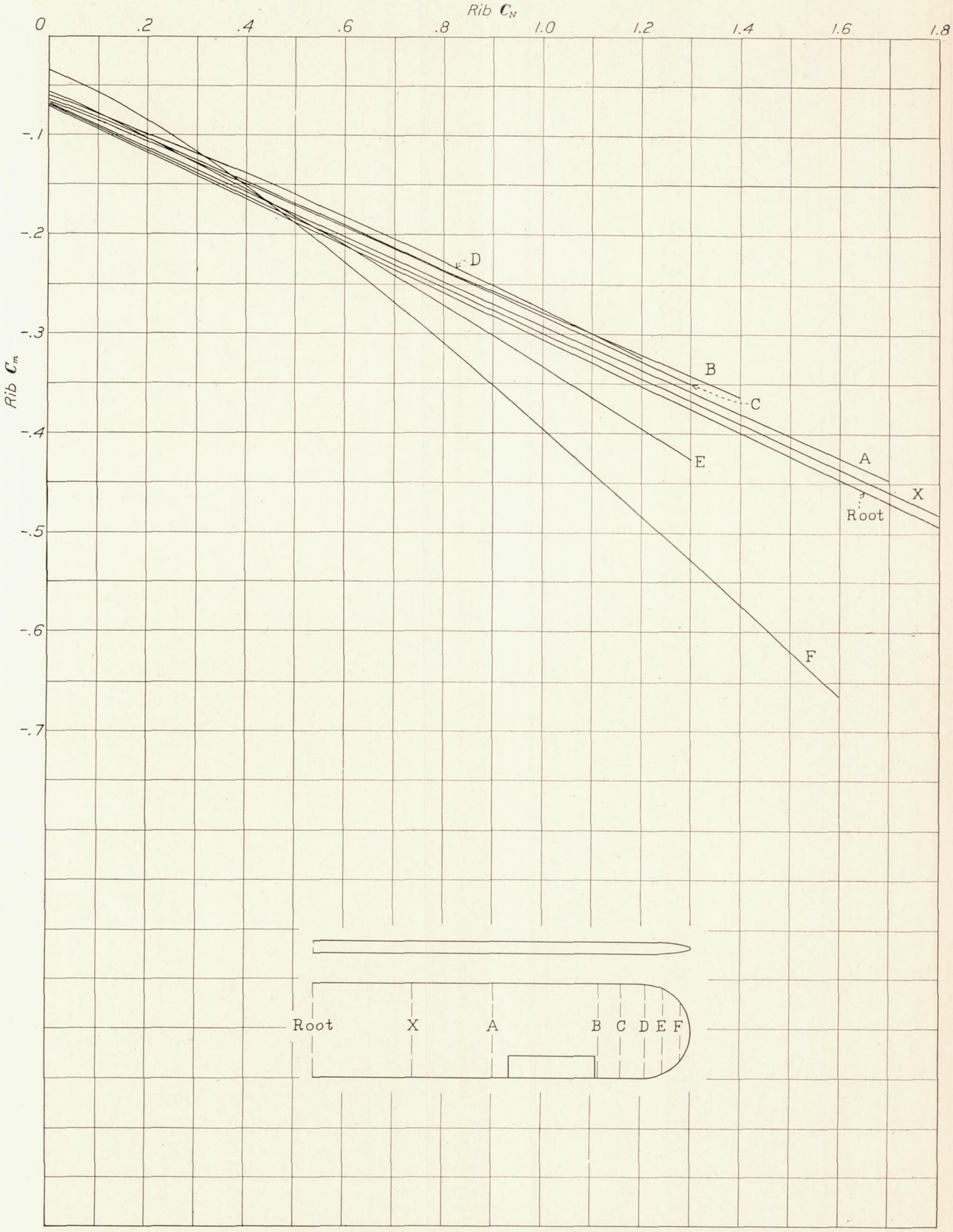

FIGURE 9.—Relation between rib C_m and rib C_N; circular tip (tip 3).

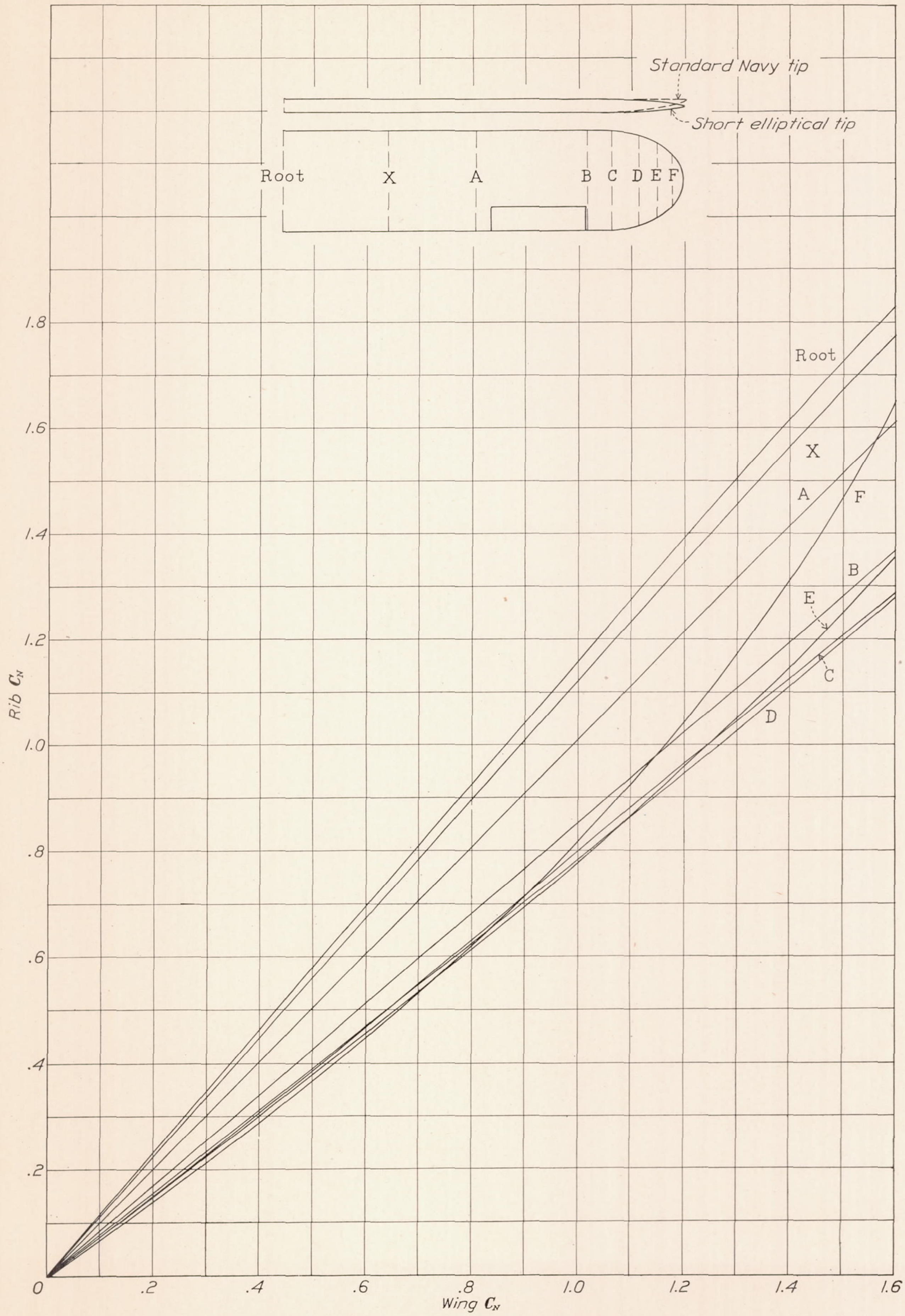

FIGURE 10.—Relation between rib C_N and wing C_N; short elliptical tip (tip 4).

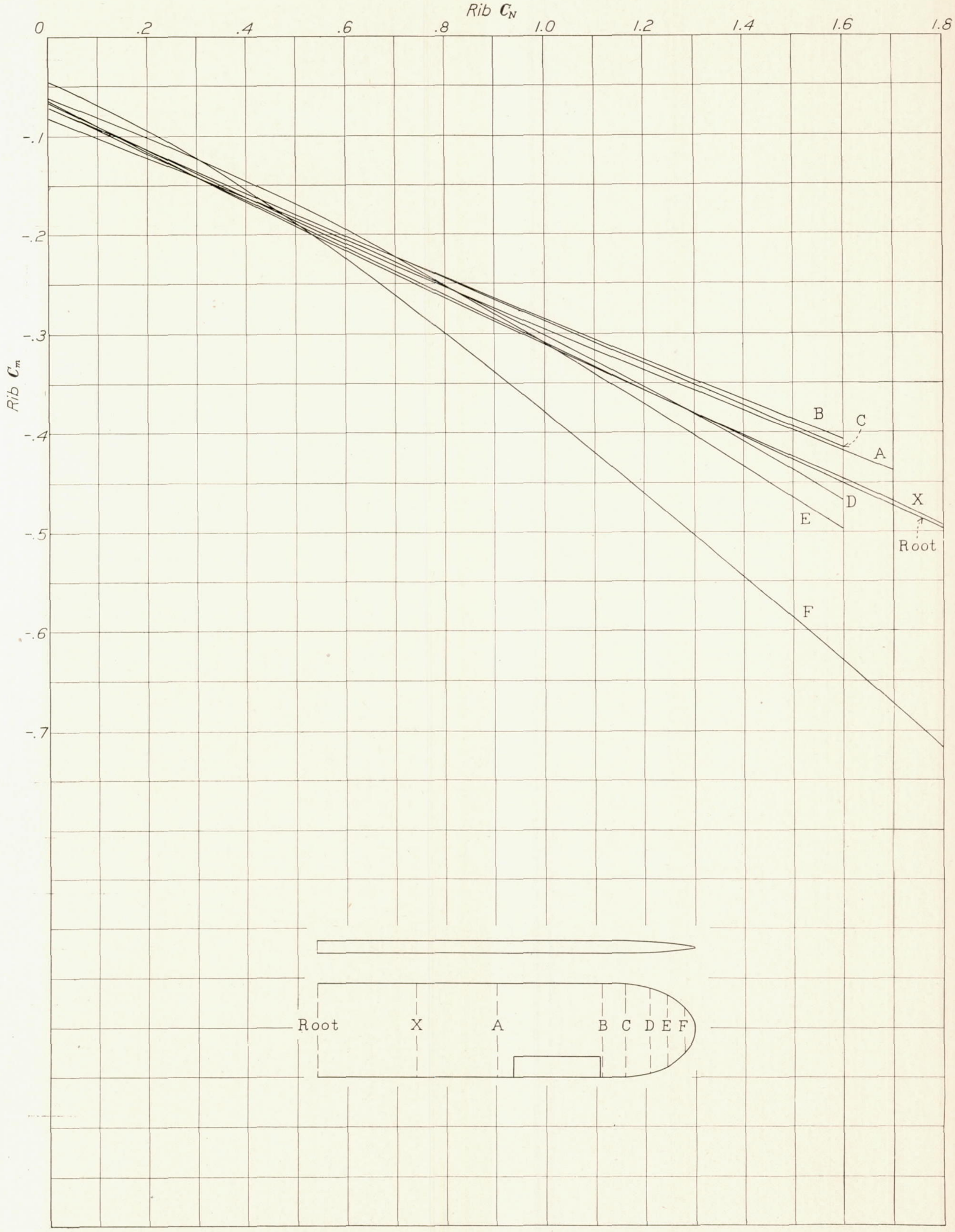

FIGURE 11.—Relation between rib C_m and rib C_N; short elliptical tip (tip 4).

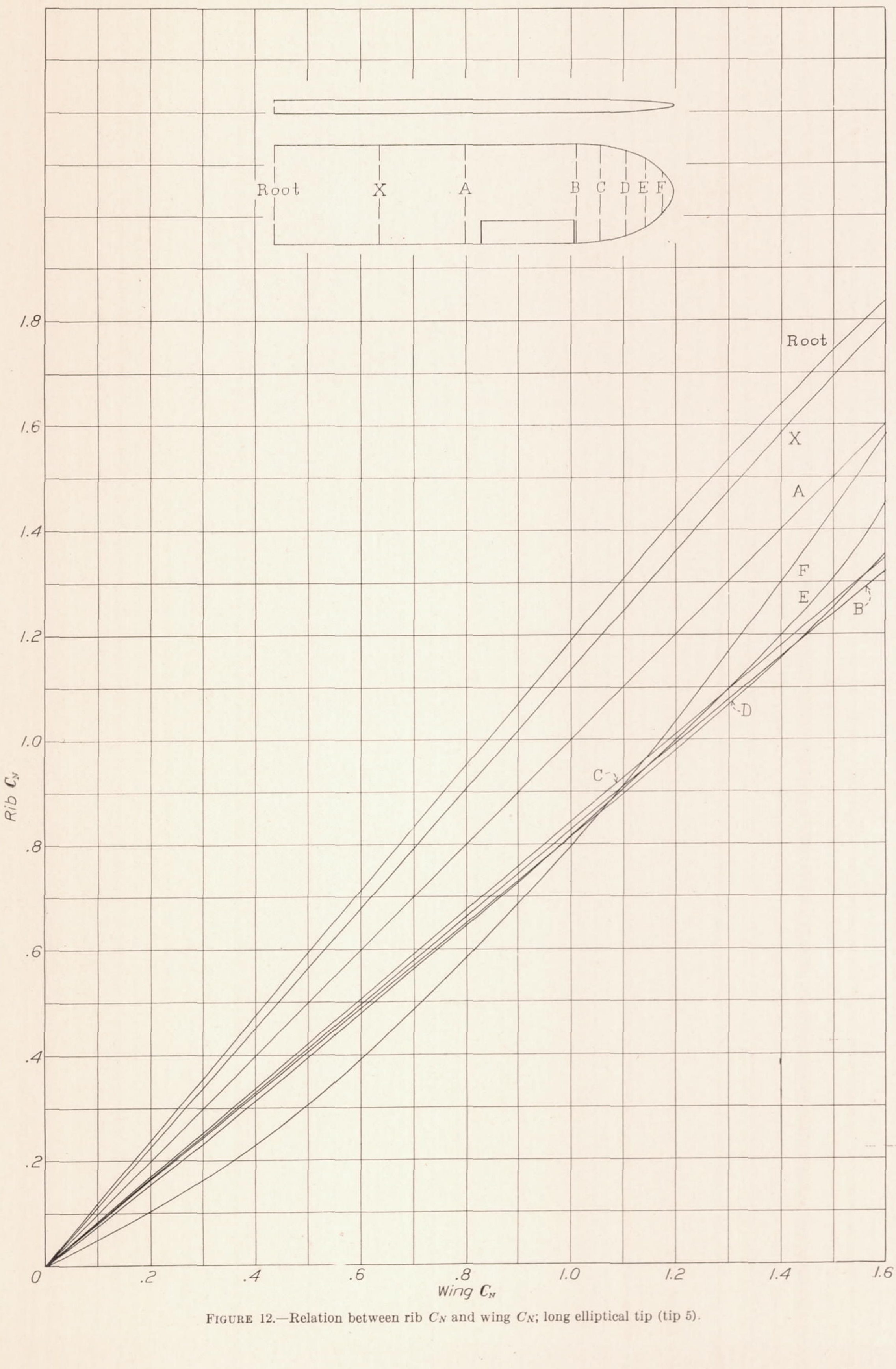

FIGURE 12.—Relation between rib C_N and wing C_N; long elliptical tip (tip 5).

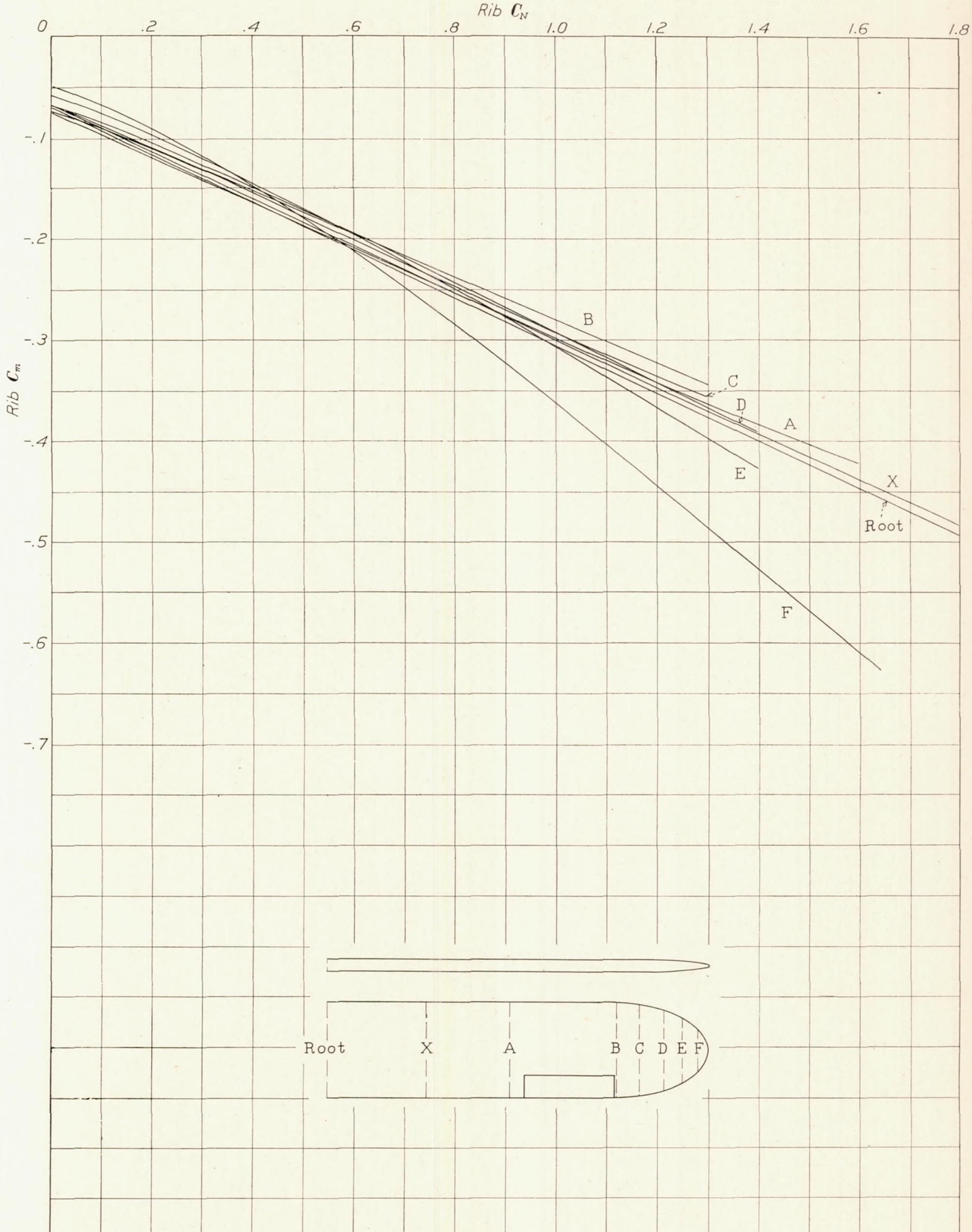

FIGURE 13.—Relation between rib C_m and rib C_N; long elliptical tip (tip 5).

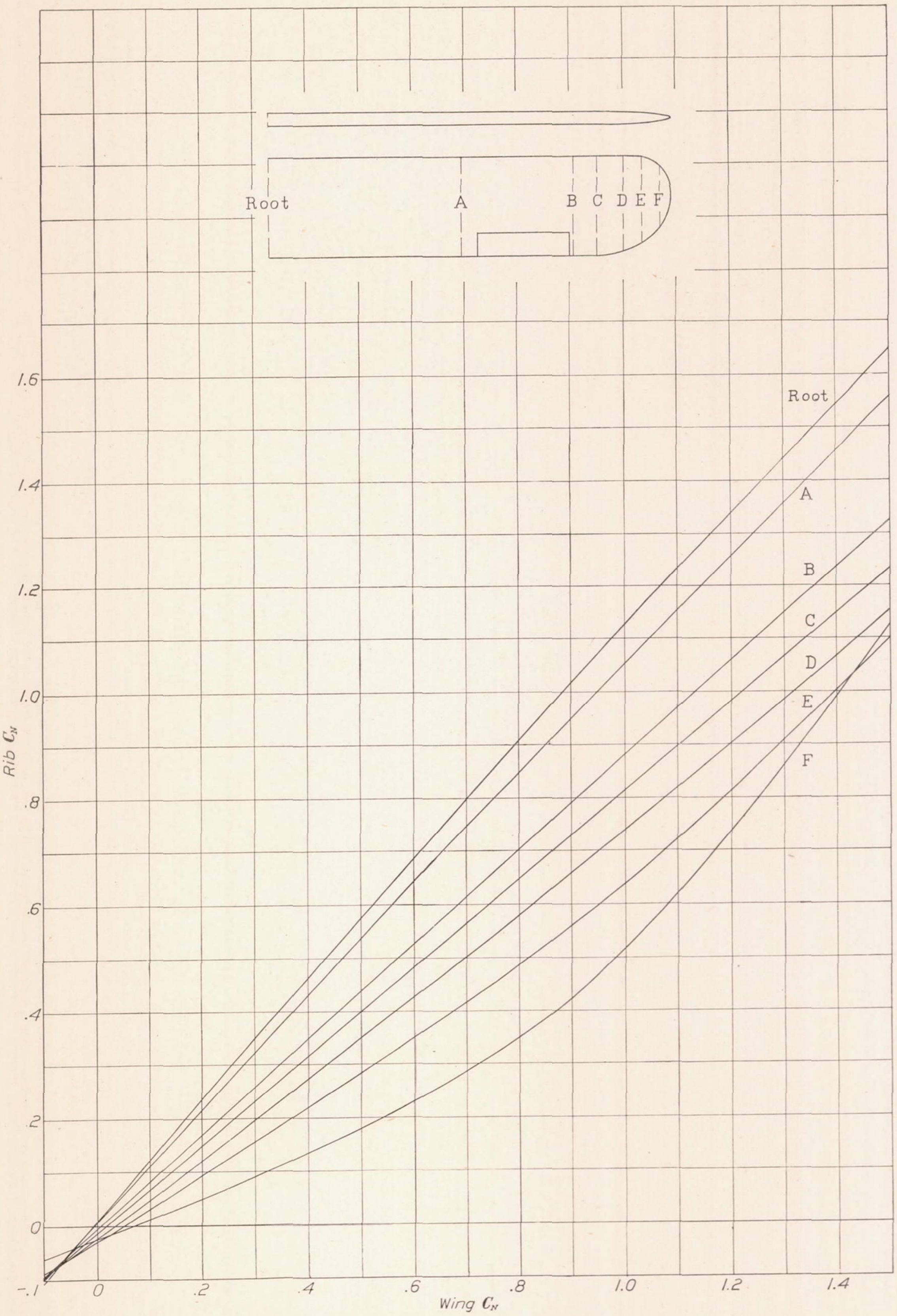

FIGURE 14.—Relation between rib C_N and wing C_N; Douglas tip (tip 6).

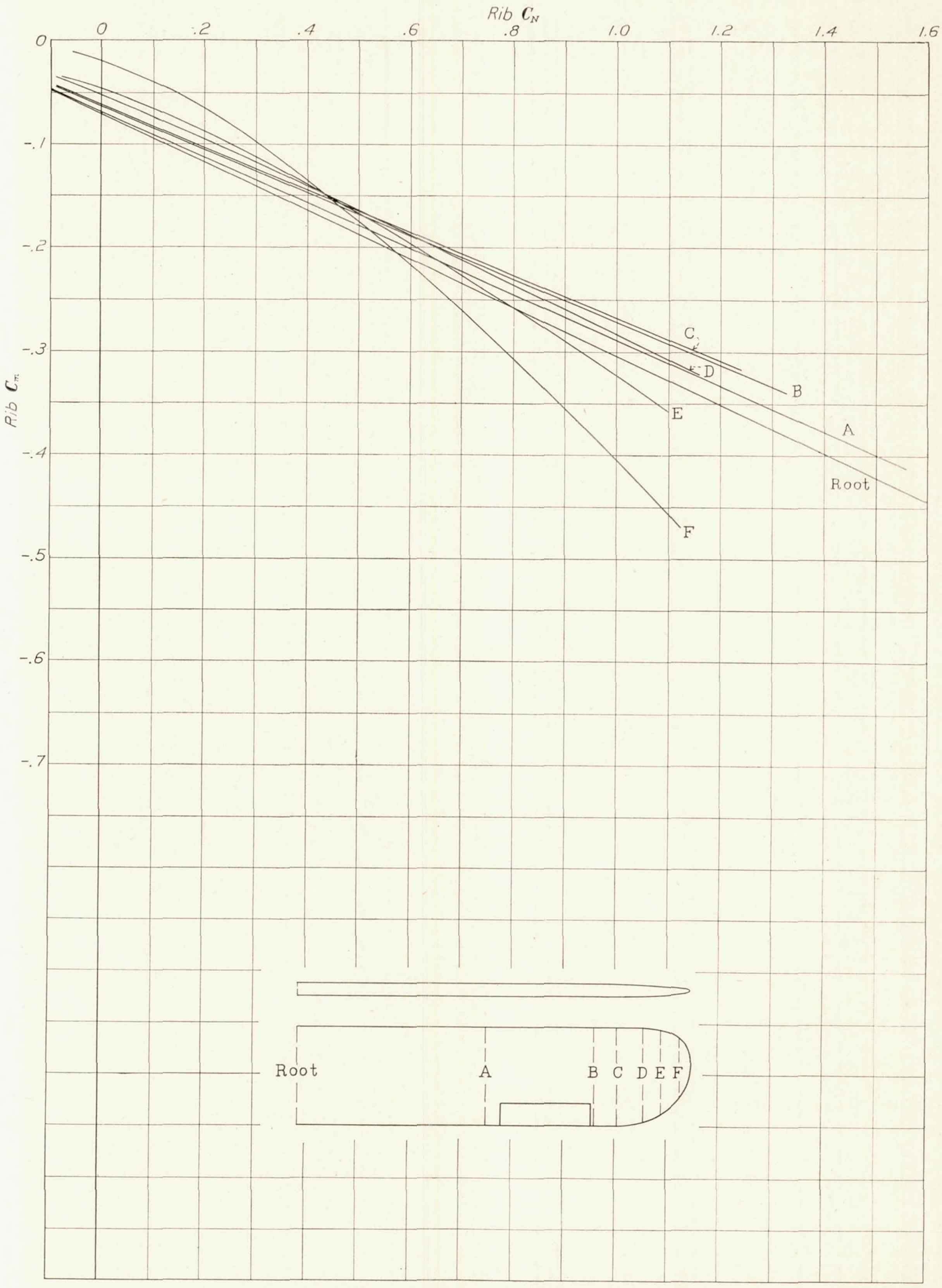

FIGURE 15.—Relation between rib C_m and rib C_N; Douglas tip (tip 6).

A comparison between figures 5 and 6 indicates that the principal effect of the faired end on the square tip was to reduce greatly the load near the extreme tip at high values of wing C_N. With this exception, which is probably due to the effect of the sharp edges of the fairing, a comparison of the results in this group indicates that the influence of plan form is quite small, if it exists at all. Figures 20 and 21 illustrate this point well. While a small part of the band widths in these figures may be accounted for by errors in measurement, a detailed analysis of the data has indicated that most of the dispersion is the result of variations of section profiles and incidences that were caused both by imperfect construction of the several tips and by deformations of the wood and fabric due to changes of temperature, humidity, and age. It is therefore believed that the width of the bands is substantially a measure of the probable variations of load distribution that occur in service as a result of such causes. In view of these minor variations with tip plan form, average results from tips 1, 3, 4, and 5 are tabulated in tables X and XI, from which the load distribution can be determined with small error for any practical tip plan form.

Effect of washout and lateral camber.—Charts showing the relations between rib C_N and wing C_N, and between rib C_m and wing C_N, for tips 6, 7, and 8 are given in figures 14 and 15 and in 17, 18, and 19.

The effect of washout on the span C_N distribution in the cases of the Douglas and N.A.C.A. tips is indicated in figures 14 and 17 and also in figure 20. Such effects can be predicted with satisfactory precision for practical purposes by a modified strip method, using the C_N relations given for the "unwashed" tips at each section. When doing this, it is of course necessary to relate C_N to angle of attack so that the influence of local variations of incidence can be interpreted in terms of C_N.

The effect of the lateral camber of the standard Navy tip on the span C_N distribution was found to be within the experimental error. The C_N relations for this tip are therefore the same as for the short elliptical tip given in figure 10. The moment coefficients measured differed slightly from those for the short elliptical tip, however, and are therefore shown separately in figure 19.

The extent to which the objective of the N.A.C.A. tip design was attained is indicated in figure 22, which shows the center-of-pressure loci for representative cases at high and low angles of attack. The center-of-pressure loci at high angles of attack are not straight lines but curve aft as a result of the relatively large pressures that occur near the trailing edge at the tip. At low angles of attack, however, the center-of-pressure loci are reasonably straight. It should be possible, with the present data at hand, to design a tip to have any predetermined load characteristics within reasonable limits. For example, the center-of-pressure loci at high angles of attack can be straightened by shearing the tip sections farther forward by an amount consistent with the relations between C_N and C_m given in figures 17 and 18.

Effect of temperature, humidity, and age of wing structure.—While the effects of temperature, humidity, and age have been briefly mentioned above, figure 23 is presented to portray these effects more vividly. In order to obtain the results shown in this figure, the average values of $C_{m_{3/4}}$ at $C_N=1.0$ for each set of data on rib A, which remained unaltered during the course of the tests, are plotted against the time of year at which each set of data was obtained. It may be inferred from this curve that in the damp winter weather the fabric and rib structure "soften" and permit greater deflections, which increase the camber and hence the value of the moment coefficient. The same tendency is indicated with respect to the age of the airplane. The magnitudes of both effects are fairly large, and it is evident that as a result of the variations in structural stiffness the span-load and span-moment distributions will differ from time to time on the same wing under the same flight conditions.

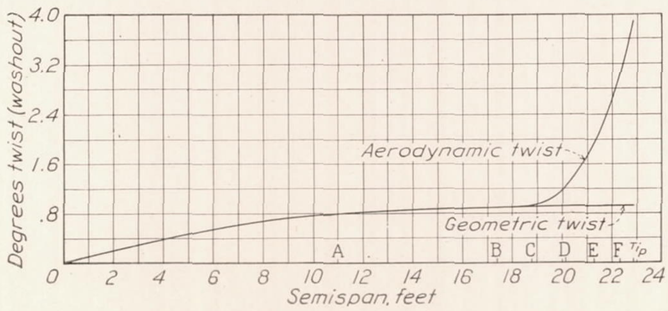

FIGURE 16.—Aerodynamic twist on Douglas tip.

CONCLUSIONS

It may be concluded from this investigation that:

1. The distributions of C_N and C_m along the span are practically independent of tip plan form in unyawed conditions.
2. A sharp-edged tip fairing on a rectangular wing drastically reduces the load near the extreme tip at high angles of attack.
3. Lateral camber of the tip has no appreciable effect on the load distribution in unyawed conditions.
4. The shape of the lower wing tip of a biplane of normal relative dimensions has no appreciable influence on the distribution over the upper wing tip.
5. Temperature, humidity, and aging, on wings of wood and fabric construction, under given loading conditions, apparently result in changes of wing shape sufficiently great to cause appreciable variations of load distribution.

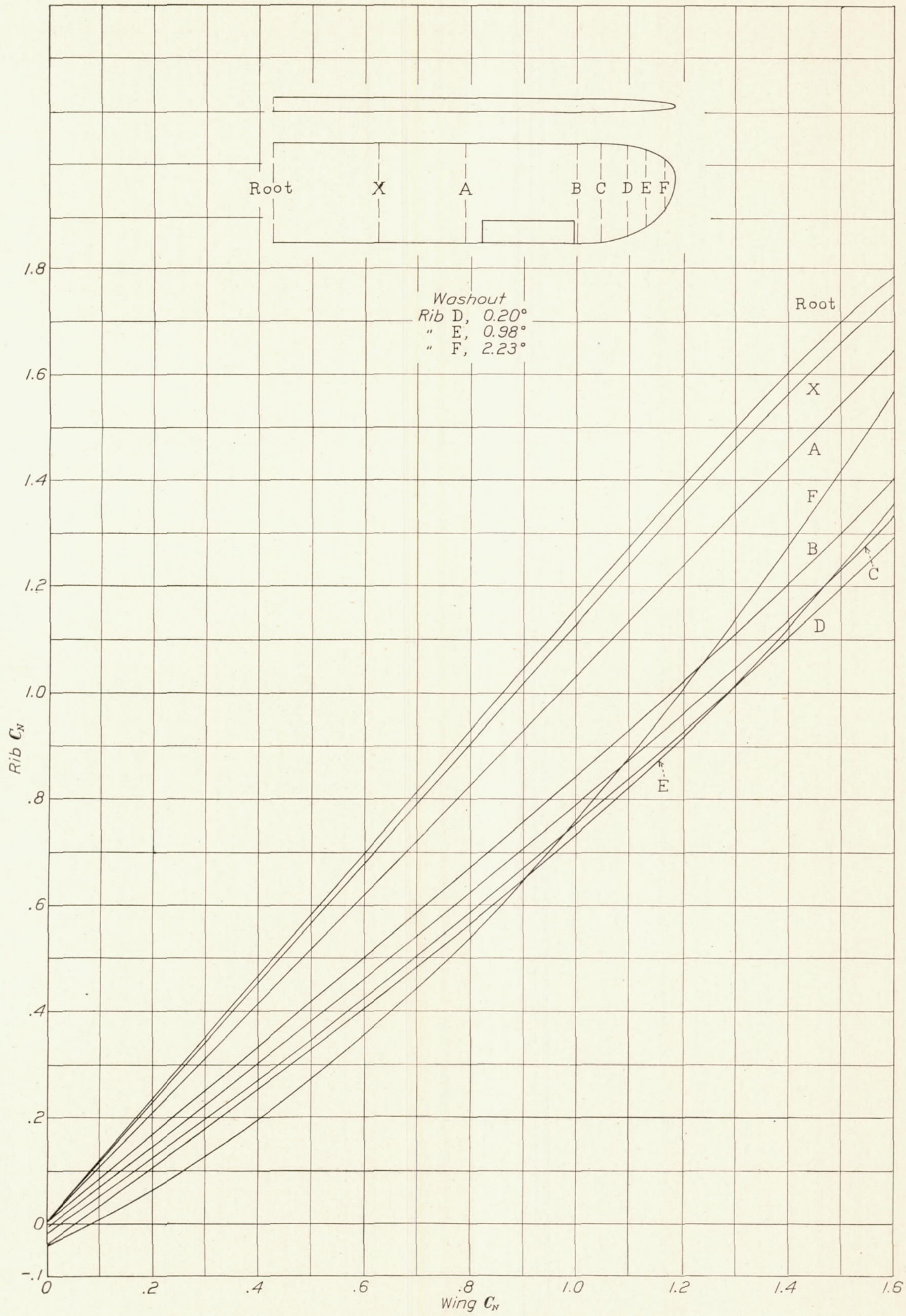

FIGURE 17.—Relation between rib C_N and wing C_N; N.A.C.A. tip (tip 7).

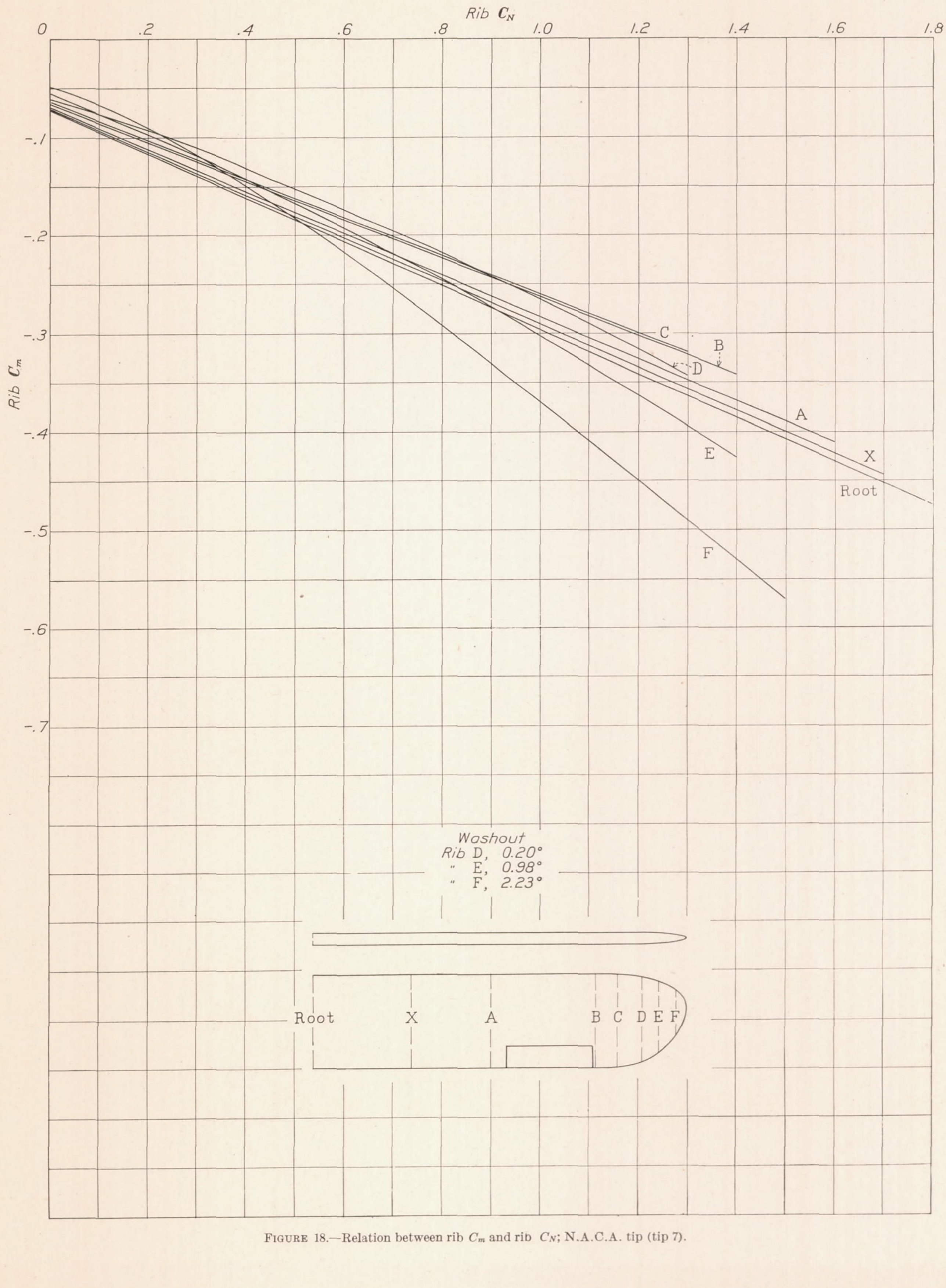

FIGURE 18.—Relation between rib C_m and rib C_N; N.A.C.A. tip (tip 7).

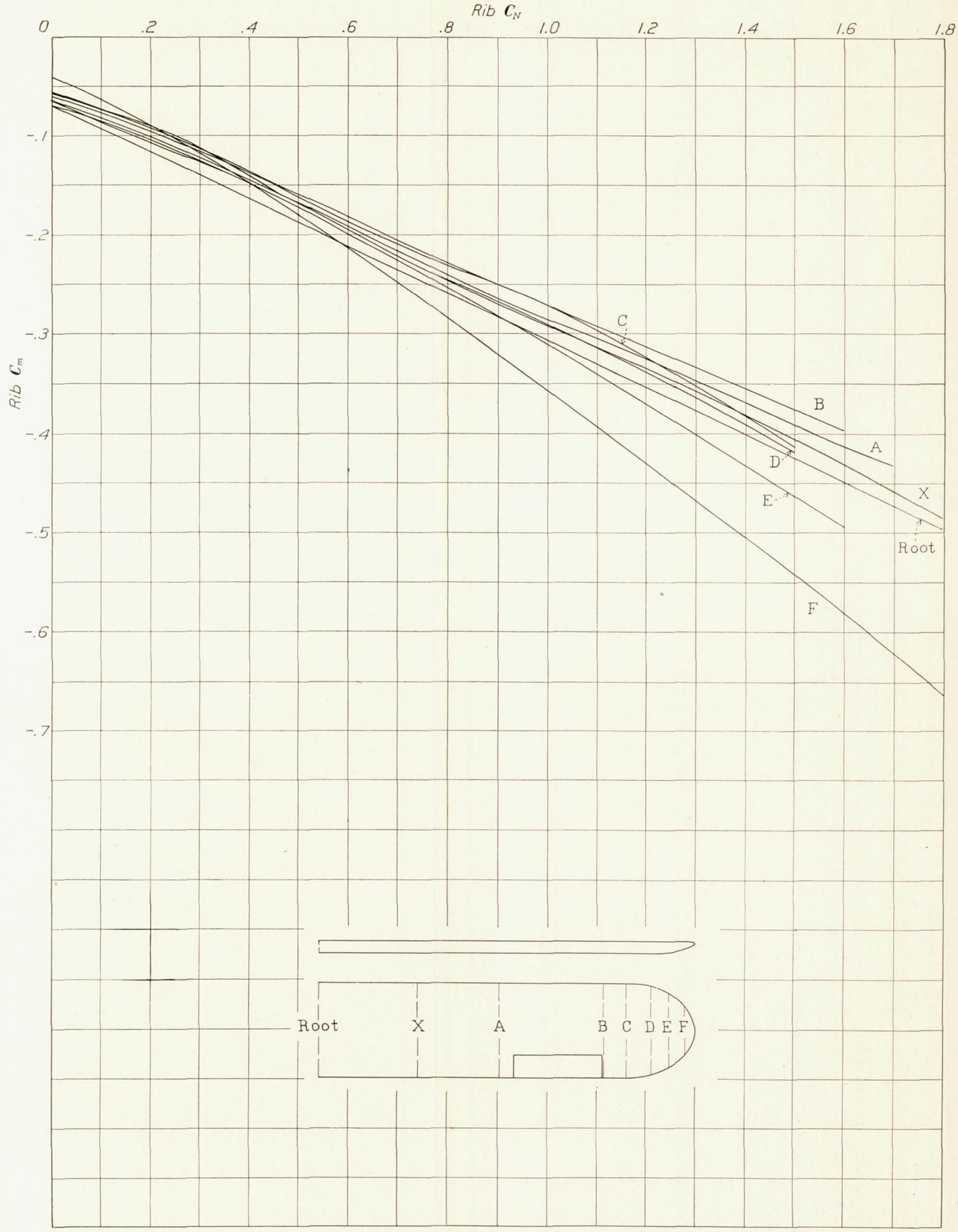

FIGURE 19.—Relation between rib C_m and rib C_N; standard Navy tip (tip 8).

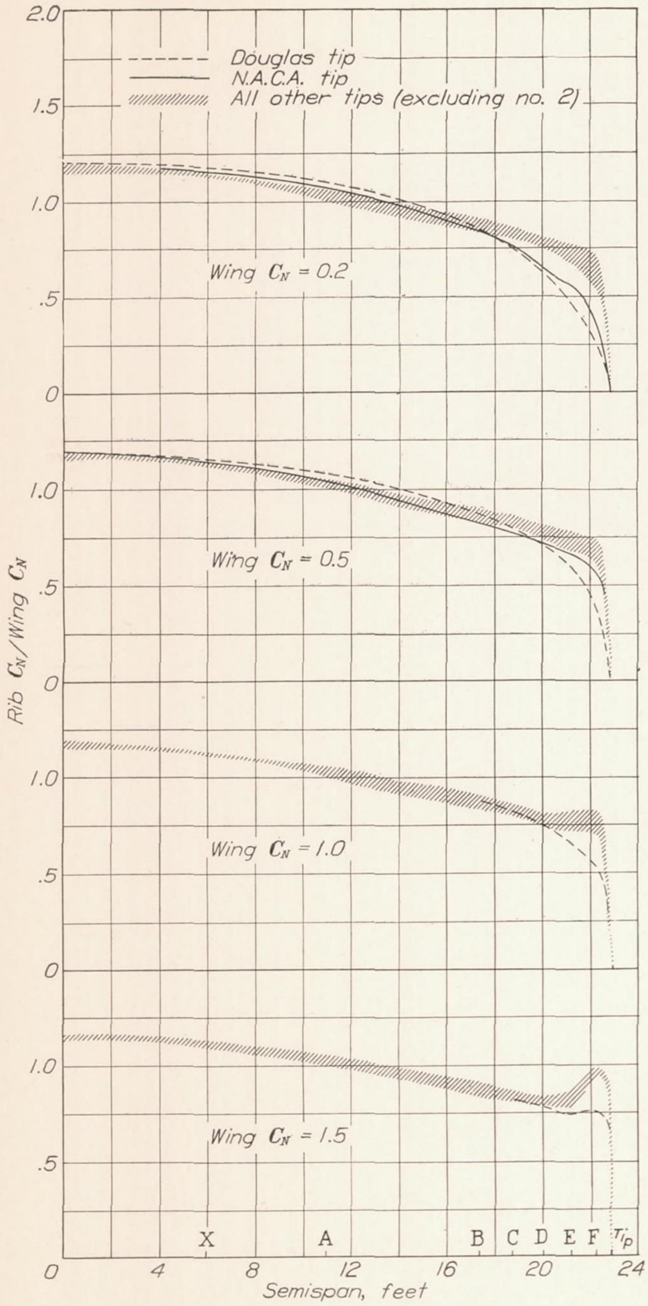

FIGURE 20.—Composite span C_N distribution for wing with variations only in tip plan form compared with span C_N distribution for wings with washed-out tips.

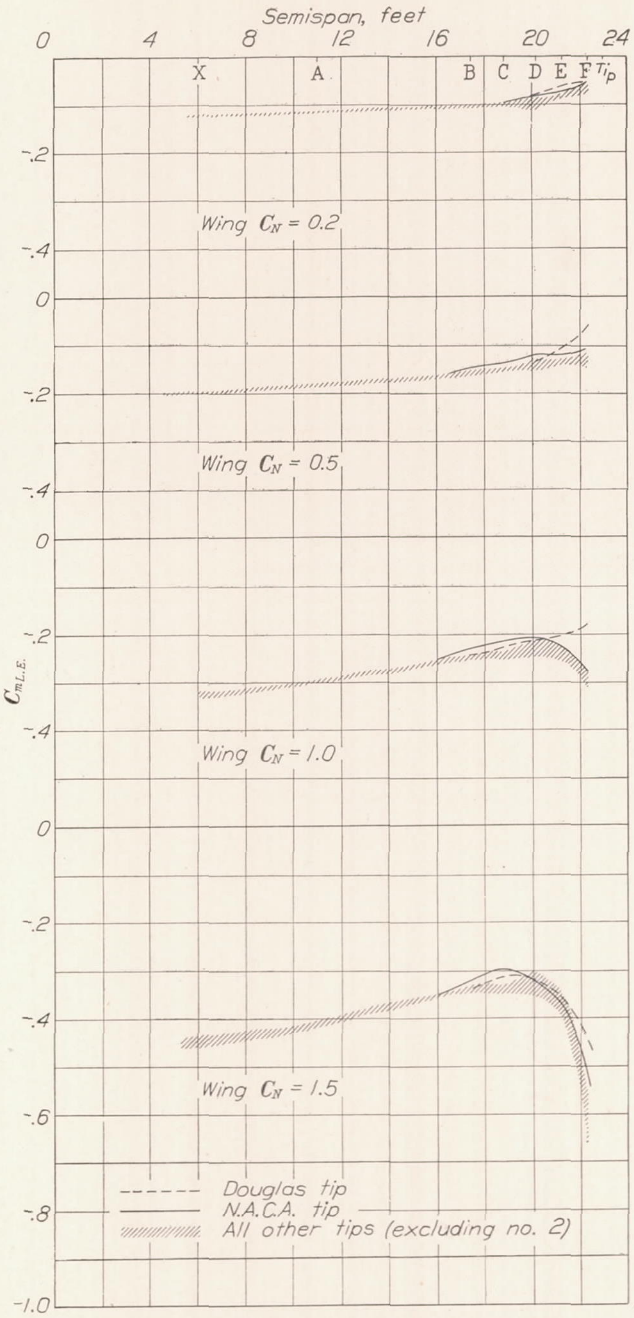

FIGURE 21.—Composite span C_m distribution for wing with variations only in tip plan form compared with span C_m distribution for wings with washed-out tips.

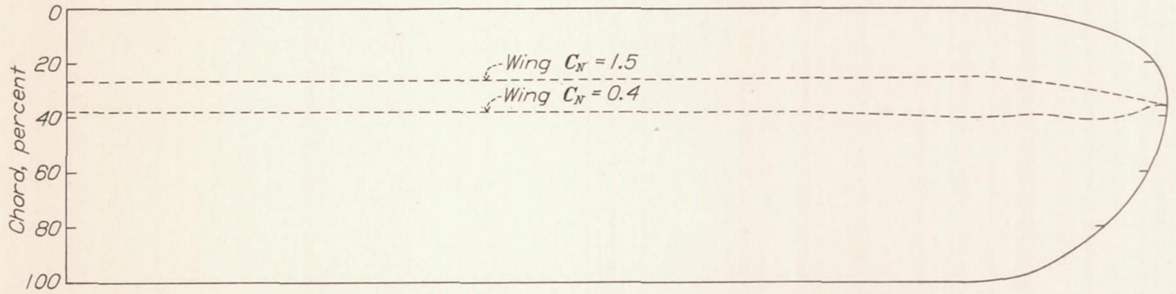

FIGURE 22.—The loci of center of pressure for N.A.C.A. tip at high and low lift coefficients.

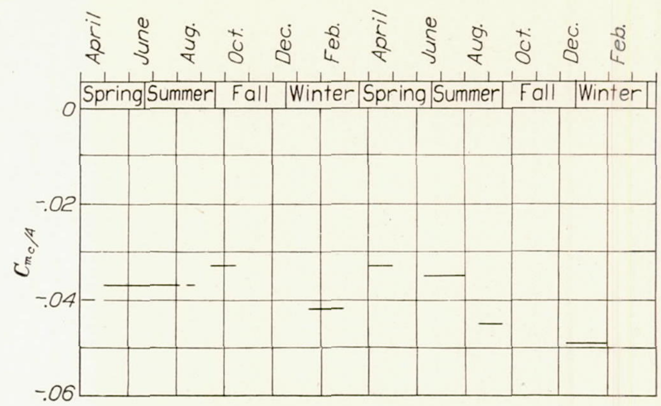

FIGURE 23.—Variation, with season of $C_{mc/4}$ at $C_L=1.0$ for rib A.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY,
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
LANGLEY FIELD, VA., *June 9, 1934.*

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TABLE I

CHARACTERISTICS OF DOUGLAS M-3 AIRPLANE

Type	Biplane.
Airfoil	Clark Y.
Span (upper and lower)	45 ft. 10 in.
Chord (upper and lower)	5 ft. 8 in.
Gap	6 ft. 0 in.
Stagger	None.
Position of *c.g.* in percent of chord	29.
Areas (sq. ft.):	
Right upper wing, including aileron	126.4.
Right lower wing, including aileron	126.4.
Total wing area	505.6.
Horizontal tail surfaces	58.0.
Vertical tail surfaces	17.7.
Weight during tests	4,840 lb.
Engine	Liberty.
Rated hp. at 1,750 r.p.m.	420.
Power loading	11.52 lb. per hp.
Wing loading	9.57 lb. per sq. ft.

TABLE II

RELATIVE DIMENSIONS AND LOCATIONS OF PRESSURE RIBS

Tip	Ratio of chord to root chord							
	Root	X	A	B	C	D	E	F
1	1.000	--------	1.000	1.000	1.000	1.000	1.000	1.000
2	1.000	--------	1.000	1.000	1.000	1.000	1.000	1.000
3	1.000	1.000	1.000	1.000	1.000	1.000	.896	.588
4	1.000	1.000	1.000	1.000	1.000	.940	.782	.489
5	1.000	1.000	1.000	1.000	.962	.857	.693	.427
6	1.000	--------	1.000	1.000	1.000	.979	.882	.600
7	1.000	1.000	1.000	1.000	1.000	.948	.794	.501
8	1.000	1.000	1.000	1.000	1.000	.940	.782	.489
	Distance from tip (root-chord length)							
1	4.035	--------	2.095	0.970	0.724	0.490	0.282	0.097
2	4.035	--------	2.095	.970	.724	.490	.282	.097
3	4.035	2.978	2.095	.970	.720	.485	.279	.095
4	4.035	2.978	2.095	.970	.720	.485	.279	.095
5	4.035	2.978	2.095	.970	.720	.485	.279	.095
6	4.035	--------	2.095	.970	.720	.485	.279	.095
7	4.035	2.978	2.095	.970	.720	.485	.279	.095
8	4.035	2.978	2.095	.970	.720	.485	.279	.095

TABLE III

ORDINATES OF PRESSURE RIBS

SQUARE TIP

TIPS 1 AND 2

Station in percent chord	Clark Y		Rib A		Rib B		Rib C		Rib D		Rib E		Rib F	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
0	3.50	3.50	3.49	3.49	3.36	3.36	3.49	3.49	3.35	3.35	3.54	3.54	3.17	3.17
1.25	5.45	1.93	5.56	1.93	5.34	1.79	5.42	1.84	5.38	1.88	5.56	1.93	5.51	1.75
2.5	6.50	1.47	6.52	1.47	6.38	1.33	6.43	1.38	6.39	1.43	6.43	1.43	6.39	1.29
5	7.90	.93	8.00	.97	7.90	.83	8.00	.87	7.90	.87	7.90	.83	7.86	.78
7.5	8.85	.63	9.05	.65	8.91	.28	8.96	.46	8.92	.51	9.01	.46	8.82	.51
10	9.60	.42	9.74	.46	9.65	.32	9.65	.32	9.65	.37	9.74	.37	9.60	.32
15	10.68	.15	10.76	.28	10.67	.14	10.62	.18	10.71	.18	10.75	.18	10.66	.09
20	11.36	.03	11.26	.09	11.26	.05	11.26	.05	11.27	.09	11.35	.09	11.30	.00
30	11.70	.00	11.73	.00	11.81	.00	11.81	.00	11.72	.00	11.67	.00	11.67	.00
40	11.40	.00	11.36	.00	11.40	.05	11.45	.00	11.44	.00	11.40	.00	11.30	.00
50	10.52	.00	10.48	.00	10.58	.03	10.58	.05	10.52	.09	10.66	.09	10.48	.05
60	9.15	.00	9.19	−.05	9.42	.09	9.25	.14	9.24	.09	9.24	.14	9.24	.09
65	8.30	.00	8.27	.00	8.54	.09	8.45	.14	8.36	.09	8.36	.18	8.32	.09
70	7.35	.00	7.36	.00	7.68	.09	7.67	.14	7.49	.14	7.40	.14	7.40	.14
80	5.22	.00	5.33	.00	5.65	.18	5.70	.23	5.51	.09	5.51	.18	5.51	.14
90	2.80	.00	2.80	−.05	3.31	.23	3.31	.18	3.12	.05	3.08	.14	3.12	.14
95	1.49	.00	1.52	−.09	2.02	.14	2.02	.09	1.84	−.05	1.88	.05	1.84	.14
100	.12	.00	.23	−.23	.74	.00	.65	.00	.46	−.23	.55	−.05	.60	.00

NOTE.—All ordinates given are in percent of chord.

TABLE IV

ORDINATES OF PRESSURE RIBS

CIRCULAR TIP

TIP 3

Station in percent chord	Clark Y		Rib X		Rib A		Rib B		Rib C		Rib D		Rib E		Rib F	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
0	3.50	3.50	3.40	3.40	3.49	3.49	3.36	3.36	3.49	3.49	3.35	3.35	3.58	3.58	3.45	3.45
1.25	5.45	1.93	5.47	1.84	5.56	1.93	5.34	1.79	5.42	1.84	5.41	1.88	5.73	2.00	5.99	1.80
2.5	6.50	1.47	6.53	1.29	6.52	1.47	6.38	1.33	6.43	1.38	6.34	1.43	6.71	1.57	6.87	1.57
5	7.90	.93	7.90	.87	8.00	.97	7.90	.83	8.00	.87	7.75	.87	7.92	1.03	8.11	1.17
7.5	8.85	.63	8.82	.51	9.05	.65	8.91	.28	8.96	.46	8.88	.57	8.82	.72	8.96	.77
10	9.60	.42	9.65	.41	9.74	.46	9.65	.32	9.65	.32	9.59	.32	9.40	.47	9.79	.48
15	10.68	.15	10.61	.18	10.76	.28	10.67	.14	10.62	.18	10.59	.04	10.56	.26	10.84	.18
20	11.36	.03	11.21	.05	11.26	.09	11.26	.05	11.26	.05	11.17	.00	11.21	.11	11.50	.08
30	11.70	.00	11.67	.00	11.73	.00	11.81	.00	11.81	.00	11.66	.00	11.81	.05	11.86	.03
40	11.40	.00	11.30	.00	11.36	.00	11.40	.05	11.45	.00	11.47	−.04	11.39	.00	11.46	.00
50	10.52	.00	10.48	.00	10.48	.00	10.58	.03	10.58	.05	10.57	.00	10.51	.00	10.63	.00
60	9.15	.00	9.19	.00	9.19	−.05	9.42	.09	9.25	.14	9.10	.04	9.19	.00	9.46	.03
65	8.30	.00	8.27	.05	8.27	.00	8.54	.09	8.45	.14	8.22	.00	8.30	.00	8.74	.05
70	7.35	.00	7.35	.09	7.36	.00	7.68	.09	7.67	.14	7.35	.00	7.37	.05	7.76	.05
80	5.22	.00	5.38	.00	5.33	.00	5.65	.18	5.70	.23	5.22	.04	5.30	.05	5.49	.05
90	2.80	.00	2.90	.00	2.80	−.05	3.31	.23	3.31	.18	2.81	.00	2.83	.00	3.07	.00
95	1.49	.00	1.65	.00	1.52	−.09	2.02	.14	2.02	.09	1.51	−.04	1.19	−.05	1.87	.00
100	.12	.00	.37	.00	.23	−.23	.74	.00	.65	.00	.26	.00	.05	−.10	.30	.00

NOTE.—All ordinates given are in percent of chord.

TABLE V

ORDINATES OF PRESSURE RIBS

SHORT ELLIPTICAL TIP

TIP 4

Station in percent chord	Clark Y		Rib X		Rib A		Rib B		Rib C		Rib D		Rib E		Rib F	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
0	3.50	3.50	3.40	3.40	3.49	3.49	3.36	3.36	3.49	3.49	3.28	3.28	3.42	3.42	3.58	3.58
1.25	5.45	1.93	5.47	1.84	5.56	1.93	5.34	1.79	5.42	1.84	5.34	1.81	5.44	--------	--------	1.72
2.5	6.50	1.47	6.53	1.29	6.52	1.47	6.38	1.33	6.43	1.38	6.31	1.41	6.44	1.47	6.59	1.32
5	7.90	.93	7.90	.87	8.00	.97	7.90	.83	8.00	.87	7.84	.93	7.86	.94	7.92	.93
7.5	8.85	.63	8.82	.51	9.05	.65	8.91	.28	8.96	.46	8.78	.58	8.84	.66	8.79	.57
10	9.60	.42	9.65	.41	9.74	.46	9.65	.32	9.65	.32	9.51	.38	9.54	.11	9.54	.39
15	10.68	.15	10.61	.18	10.76	.28	10.67	.14	10.62	.18	10.56	.11	10.60	.00	10.65	.18
20	11.36	.03	11.21	.05	11.26	.09	11.26	.05	11.26	.05	11.19	.00	11.25	.00	11.22	.00
30	11.70	.00	11.67	.00	11.73	.00	11.81	.00	11.81	.00	11.63	.00	11.65	.00	11.35	.00
40	11.40	.00	11.30	.00	11.36	.00	11.40	.05	11.45	.00	11.29	.00	11.35	.00	10.99	.00
50	10.52	.00	10.48	.00	10.48	.00	10.58	.03	10.58	.05	10.45	−.05	10.46	−.06	10.23	.00
60	9.15	.00	9.19	.00	9.19	−.05	9.42	.09	9.25	.14	9.16	−.05	9.22	.00	8.91	.00
65	8.30	.00	8.27	.05	8.27	.00	8.54	.09	8.45	.14	8.26	−.05	8.27	.00	8.00	.00
70	7.35	.00	7.35	.09	7.36	.00	7.68	.09	7.67	.14	7.31	.00	7.35	.00	7.07	−.09
80	5.22	.00	5.38	.00	5.33	.00	5.65	.18	5.70	.23	5.30	.00	5.27	−.06	5.00	.00
90	2.80	.00	2.90	.00	2.80	−.05	3.31	.23	3.31	.18	2.83	.00	2.82	.00	2.65	.00
95	1.49	.00	1.65	.00	1.52	−.09	2.02	.14	2.02	.09	1.43	−.05	1.59	.00	1.42	.00
100	.12	.00	.37	.00	.23	−.23	.74	.00	.65	.00	.19	.00	.25	.00	.18	.00

NOTE.—All ordinates given are in percent of chord.

TABLE VI

ORDINATES OF PRESSURE RIBS

LONG ELLIPTICAL TIP

TIP 5

Station in percent chord	Clark Y		Rib X		Rib A		Rib B		Rib C		Rib D		Rib E		Rib F	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
0	3.50	3.50	3.40	3.40	3.49	3.49	3.36	3.36	3.44	3.44	3.58	3.58	3.65	3.65	3.52	3.52
1.25	5.45	1.93	5.47	1.84	5.56	1.93	5.34	1.79	5.47	1.85	5.67	1.87	5.30	2.01	5.69	1.83
2.5	6.50	1.47	6.53	1.29	6.52	1.47	6.38	1.33	6.43	1.42	6.49	1.41	6.28	1.51	6.48	1.31
5	7.90	.93	7.90	.87	8.00	.97	7.90	.83	7.80	.92	7.78	.93	7.72	.95	7.79	1.00
7.5	8.85	.63	8.82	.51	9.05	.65	8.91	.28	8.74	.64	8.77	.65	8.70	.53	8.76	.69
10	9.60	.42	9.65	.41	9.74	.46	9.65	.32	9.54	.44	9.51	.43	9.46	.32	9.48	.48
15	10.68	.15	10.61	.18	10.76	.28	10.67	.14	10.60	.15	10.50	.17	10.48	.15	10.62	.21
20	11.36	.03	11.21	.05	11.26	.09	11.26	.05	11.29	.02	11.17	.00	11.16	.06	11.24	.10
30	11.70	.00	11.67	.00	11.73	.00	11.81	.00	11.58	.00	11.53	.00	11.73	.00	11.58	.00
40	11.40	.00	11.30	.00	11.36	.00	11.40	.05	11.23	.02	11.27	.00	11.28	.00	11.27	.00
50	10.52	.00	10.48	.00	10.48	.00	10.58	.03	10.35	.05	10.45	.05	10.37	.00	10.34	.00
60	9.15	.00	9.19	.00	9.19	−.05	9.42	.09	9.07	.05	9.06	.05	9.01	.02	9.00	.00
70	7.35	.00	7.35	.09	7.36	.00	7.68	.09	7.31	.06	7.26	.05	7.06	.00	7.28	.00
80	5.22	.00	5.38	.00	5.33	.00	5.65	.18	5.12	.06	5.19	.09	4.92	.00	5.17	.03
90	2.80	.00	2.90	.00	2.80	−.05	3.31	.23	2.72	.00	2.79	.12	2.50	.00	2.55	.00
95	1.49	.00	1.65	.00	1.52	−.09	2.02	.14	1.45	.00	1.54	.12	1.23	.00	1.38	.00
100	.12	.00	.37	.00	.23	−.23	.74	.00	.15	.00	.26	.07	.15	−.04	.14	.00

NOTE.—*All ordinates given are in percent of chord.*

TABLE VII

ORDINATES OF PRESSURE RIBS

DOUGLAS TIP

TIP 6

Station in percent chord	Clark Y		Rib A		Rib B		Rib C		Rib D		Rib E		Rib F	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
0	3.50	3.50	3.49	3.49	3.36	3.36	3.49	3.49	3.56	3.56	4.37	4.37	4.52	4.52
1.25	5.45	1.93	5.56	1.93	5.34	1.79	5.42	1.84	5.53	2.02	6.14	2.40	6.80	3.14
2.5	6.50	1.47	6.52	1.47	6.38	1.33	6.43	1.38	6.56	1.50	6.76	1.93	7.51	2.52
5	7.90	.93	8.00	.97	7.90	.83	8.00	.87	8.11	.94	8.02	1.30	8.19	2.14
7.5	8.85	.63	9.05	.65	8.91	.28	8.96	.46	9.14	.56	8.80	.94	8.50	2.07
10	9.60	.42	9.74	.46	9.65	.32	9.65	.32	9.84	.38	9.58	.63	8.88	1.92
15	10.68	.15	10.76	.28	10.67	.14	10.62	.18	10.74	.23	10.42	.31	9.65	1.46
20	11.36	.03	11.26	.09	11.26	.05	11.26	.05	11.15	.09	11.05	.10	9.80	1.15
30	11.70	.00	11.73	.00	11.81	.00	11.81	.00	11.62	.00	11.31	.00	10.19	.54
40	11.40	.00	11.36	.00	11.40	.05	11.45	.00	11.30	.00	11.15	.00	10.03	.15
50	10.52	.00	10.48	.00	10.58	.03	10.58	.05	10.40	.05	10.48	.05	9.57	.00
60	9.15	.00	9.19	−.05	9.42	.09	9.25	.14	9.09	.05	9.32	.05	8.73	.00
65	8.30	.00	8.27	.00	8.54	.09	8.45	.14	8.38	.09	8.75	.10	8.19	.08
70	7.35	.00	7.36	.00	7.68	.09	7.67	.14	7.45	.09	7.92	.10	7.76	.15
80	5.22	.00	5.33	.00	5.65	.18	5.70	.23	5.25	.23	5.89	.21	6.50	.23
90	2.80	.00	2.80	−.05	3.31	.23	3.31	.18	3.04	.23	3.85	.42	4.82	.23
95	1.49	.00	1.52	−.09	2.02	.14	2.02	.09	1.87	.09	2.71	.62	3.90	.38
100	.12	.00	.23	−.23	.74	.00	.65	.00	.75	.00	1.67	.52	2.99	.69

NOTE.—All ordinates given are in percent of chord.

TABLE VIII

ORDINATES OF PRESSURE RIBS

N.A.C.A. TIP

TIP 7

Station in percent chord	Clark Y		Rib X		Rib A		Rib B		Rib C		Rib D		Rib E		Rib F	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
0	3.50	3.50	3.40	3.40	3.49	3.49	3.36	3.36	3.49	3.49	3.11	3.11	3.19	3.19	3.85	3.85
1.25	5.45	1.93	5.47	1.84	5.56	1.93	5.34	1.79	5.42	1.84	5.53	1.80	5.62	1.91	5.78	2.47
2.5	6.50	1.47	6.53	1.29	6.52	1.47	6.38	1.33	6.43	1.38	6.46	1.26	6.54	1.28	6.78	1.94
5	7.90	.93	7.90	.87	8.00	.97	7.90	.83	8.00	.87	7.86	.78	7.99	.82	8.07	1.20
7.5	8.85	.63	8.82	.51	9.05	.65	8.91	.28	8.96	.46	8.79	.48	9.04	.46	8.99	.91
10	9.60	.42	9.65	.41	9.74	.46	9.65	.32	9.65	.32	9.52	.25	9.73	.24	9.63	.73
15	10.68	.15	10.61	.18	10.76	.28	10.67	.14	10.62	.18	10.48	.05	10.54	.00	10.66	.47
20	11.36	.03	11.21	.05	11.26	.09	11.26	.05	11.26	.05	11.12	.00	11.12	−.17	11.27	.26
30	11.70	.00	11.67	.00	11.73	.00	11.81	.00	11.81	.00	11.55	.00	11.58	−.17	11.92	.09
40	11.40	.00	11.30	.00	11.36	.00	11.40	.05	11.45	.00	11.16	.05	11.23	−.11	11.56	.00
50	10.52	.00	10.48	.00	10.48	.00	10.58	.03	10.58	.05	10.29	.05	10.54	−.11	10.74	.00
60	9.15	.00	9.19	.00	9.19	−.05	9.42	.09	9.25	.14	8.84	.00	9.15	−.17	9.37	.00
65	8.30	.00	8.27	.05	8.27	.00	8.54	.09	8.45	.14	8.06	.05	8.34	−.17	8.63	.00
70	7.35	.00	7.35	.09	7.36	.00	7.68	.09	7.67	.14	7.08	.20	7.41	−.17	7.90	.00
80	5.22	.00	5.38	.00	5.33	.00	5.65	.18	5.70	.23	5.48	.43	5.34	−.17	5.70	.00
90	2.80	.00	2.90	.00	2.80	−.05	3.31	.23	3.31	.18	3.68	.73	3.02	−.17	3.76	−.09
95	1.49	.00	1.65	.00	1.52	−.09	2.02	.14	2.02	.09	2.58	.73	1.80	−.17	2.76	−.09
100	.12	.00	.37	.00	.23	−.23	.74	.00	.65	.00	1.16	.68	.41	−.24	1.12	−.26

NOTE.—All ordinates given are in percent of chord.

TABLE IX

ORDINATES OF PRESSURE RIBS

STANDARD NAVY TIP

TIP 8

Station in percent chord	Clark Y		Rib X		Rib A		Rib B		Rib C		Rib D		Rib E		Rib F	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
0	3.50	3.50	3.40	3.40	3.49	3.49	3.36	3.36	3.49	3.49	3.17	3.17	3.65	3.65	2.83	2.83
1.25	5.45	1.93	5.47	1.84	5.56	1.93	5.34	1.79	5.42	1.84	5.17	1.56	5.53	2.24	5.18	1.11
2.5	6.50	1.47	6.53	1.29	6.52	1.47	6.38	1.33	6.43	1.38	6.25	1.08	5.75	1.54	5.93	.75
5	7.90	.93	7.90	.87	8.00	.97	7.90	.83	8.00	.87	7.65	.69	7.99	1.19	7.05	.36
7.5	8.85	.63	8.82	.51	9.05	.65	8.91	.28	8.96	.46	8.69	.44	8.93	.88	8.40	.09
10	9.60	.42	9.65	.41	9.74	.46	9.65	.32	9.65	.32	9.53	.30	9.52	--------	8.94	−.09
15	10.68	.15	10.61	.18	10.76	.28	10.67	.14	10.62	.18	10.60	.11	10.76	.28	10.27	−.30
20	11.36	.03	11.21	.05	11.26	.09	11.26	.05	11.26	.05	11.28	−.05	11.40	.00	10.93	−.48
30	11.70	.00	11.67	.00	11.73	.00	11.81	.00	11.81	.00	11.62	−.05	11.70	−.11	11.41	−.48
40	11.40	.00	11.30	.00	11.36	.00	11.40	.05	11.45	.00	11.41	.00	11.40	−.11	11.41	−.39
50	10.52	.00	10.48	.00	10.48	.00	10.58	.03	10.58	.05	10.45	−.05	10.65	−.06	10.84	−.30
60	9.15	.00	9.19	.00	9.19	−.05	9.42	.09	9.25	.14	9.06	.00	9.18	.00	9.51	.00
70	7.35	.00	7.35	.09	7.36	.00	7.68	.09	7.67	.14	7.23	.00	7.41	.00	7.74	.00
80	5.22	.00	5.38	.00	5.33	.00	5.65	.18	5.70	.23	5.00	−.05	5.17	.00	5.96	.09
90	2.80	.00	2.90	.00	2.80	−.05	3.31	.23	3.31	.18	2.52	−.09	2.75	.00	3.85	.09
95	1.49	.00	1.65	.00	1.52	−.09	2.02	.14	2.02	.09	1.22	−.14	1.43	.00	2.62	.18
100	.12	.00	.37	.00	.23	−.23	.74	.00	.65	.00	−.06	−.14	.13	.00	.66	.18

NOTE.—All ordinates given are in percent of chord.

TABLE X

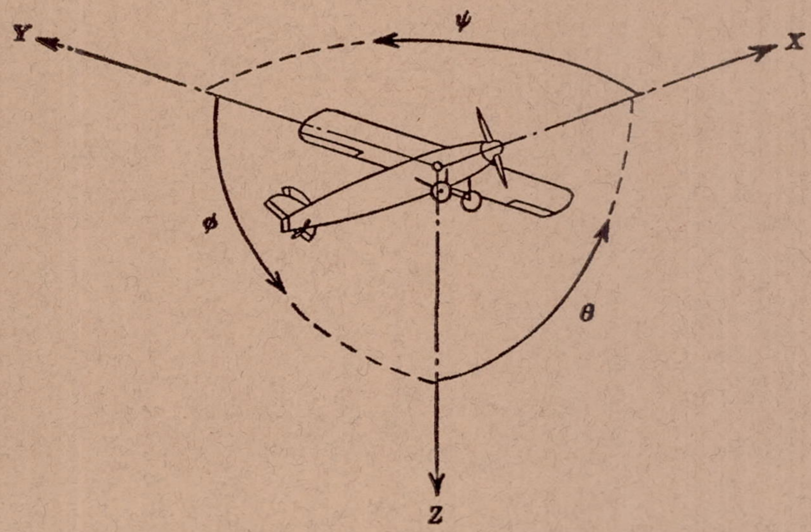
LOAD DISTRIBUTION AVERAGE RESULTS FROM TIPS 1, 3, 4, AND 5

Wing C_N	Rib C_N							
	Root	X	A	B	C	D	E	F
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
.1	.117	.113	.103	.087	.082	.077	.071	.056
.2	.233	.226	.206	.173	.165	.155	.144	.115
.3	.349	.338	.308	.259	.247	.233	.218	.179
.4	.465	.450	.411	.345	.330	.311	.292	.246
.5	.581	.563	.514	.432	.413	.389	.368	.318
.6	.697	.676	.617	.518	.495	.467	.445	.397
.7	.814	.789	.719	.604	.578	.545	.521	.479
.8	.930	.902	.822	.691	.662	.624	.601	.566
.9	1.047	1.014	.925	.777	.744	.702	.681	.657
1.0	1.162	1.127	1.028	.864	.828	.781	.763	.757
1.1	1.278	1.239	1.129	.950	.911	.861	.848	.867
1.2	1.393	1.350	1.231	1.037	.994	.942	.937	.987
1.3	1.506	1.460	1.333	1.123	1.077	1.023	1.028	1.118
1.4	1.614	1.568	1.433	1.209	1.160	1.107	1.125	1.266
1.5	1.715	1.670	1.528	1.299	1.244	1.195	1.229	1.446

TABLE XI

LOAD DISTRIBUTION AVERAGE RESULTS FROM TIPS 1, 3, 4, AND 5

Rib C_N	Rib C_m							
	Root	X	A	B	C	D	E	F
0	−0.071	−0.068	−0.069	−0.069	−0.066	−0.067	−0.060	−0.040
.1	−.094	−.091	−.092	−.090	−.088	−.087	−.078	−.064
.2	−.117	−.115	−.115	−.110	−.109	−.108	−.100	−.091
.3	−.141	−.139	−.137	−.131	−.130	−.128	−.122	−.121
.4	−.164	−.162	−.160	−.152	−.152	−.150	−.146	−.154
.5	−.187	−.185	−.182	−.174	−.173	−.172	−.171	−.189
.6	−.210	−.208	−.205	−.195	−.195	−.195	−.198	−.226
.7	−.234	−.232	−.227	−.216	−.217	−.218	−.225	−.265
.8	−.256	−.255	−.249	−.237	−.240	−.242	−.254	−.305
.9	−.280	−.278	−.271	−.258	−.262	−.266	−.283	−.347
1.0	−.303	−.301	−.293	−.279	−.284	−.290	−.312	−.390
1.1	−.326	−.324	−.314	−.300	−.306	−.315	−.342	−.433
1.2	−.349	−.346	−.336	−.320	−.328	−.340	−.373	−.478
1.3	−.372	−.369	−.357	−.341	−.349	--------	−.409	−.523
1.4	−.395	−.392	−.378	--------	--------	--------	--------	−.568
1.5	−.419	−.415	−.399	--------	--------	--------	--------	−.614
1.6	−.442	−.438	−.423	--------	--------	--------	--------	--------
1.7	−.465	−.465	--------	--------	--------	--------	--------	--------
1.8	−.494	--------	--------	--------	--------	--------	--------	--------



Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	Rolling	L	$Y \longrightarrow Z$	Roll	ϕ	u	p
Lateral	Y	Y	Pitching	M	$Z \longrightarrow X$	Pitch	θ	v	q
Normal	Z	Z	Yawing	N	$X \longrightarrow Y$	Yaw	ψ	w	r

Absolute coefficients of moment

$C_l = \frac{L}{qbS}$ (rolling) $C_m = \frac{M}{qcS}$ (pitching) $C_n = \frac{N}{qbS}$ (yawing)

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

D, Diameter
p, Geometric pitch
p/D, Pitch ratio
V', Inflow velocity
V_s, Slipstream velocity
T, Thrust, absolute coefficient $C_T = \frac{T}{\rho n^2 D^4}$
Q, Torque, absolute coefficient $C_Q = \frac{Q}{\rho n^2 D^5}$
P, Power, absolute coefficient $C_P = \frac{P}{\rho n^3 D^5}$
C_s, Speed-power coefficient $= \sqrt[5]{\frac{\rho V^5}{P n^2}}$
η, Efficiency
n, Revolutions per second, r.p.s.
Φ, Effective helix angle $= \tan^{-1}\left(\frac{V}{2\pi r n}\right)$

5. NUMERICAL RELATIONS

1 hp. = 76.04 kg-m/s = 550 ft-lb./sec.
1 metric horsepower = 1.0132 hp.
1 m.p.h. = 0.4470 m.p.s.
1 m.p.s. = 2.2369 m.p.h.
1 lb. = 0.4536 kg
1 kg = 2.2046 lb.
1 mi. = 1,609.35 m = 5,280 ft.
1 m = 3.2808 ft.