TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 379

THE PRESSURE DISTRIBUTION OVER A SEMICIRCULAR WING TIP ON A BIPLANE IN FLIGHT

By Richard V. Rhode and Eugene E. Lundquist
Langley Memorial Aeronautical Laboratory

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Summary

This note presents the results of flight pressure distribution tests on the right upper wing panel of a Douglas M-3 airplane equipped with a semicircular wing tip.

The results are given in tables and curves in such form that the load distribution for any normal force coefficient within the usual range encountered in flight may easily be determined.

The tests were made at Langley Field, Va., by the National Advisory Committee for Aeronautics in January and February, 1931.

Introduction

To supply reliable and systematic information on the effect of changes in wing-tip plan form on the load distribution, a flight investigation of the pressure distribution over wing tips has been undertaken by the National Advisory Committee for Aeronautics at Langley Field, Va. This investigation has been outlined to include pressure measurements on the right upper panel of a Douglas M-3 airplane with several variations in tip form, systematic in the main, but also including a few odd shapes, either because such forms are commonly used or because information of value could be obtained with little additional work.

The results of tests on three tips have already been reported: the "Douglas" tip in Reference 1, and the square tip, both with and without a faired end, in Reference 2. This paper is the third of a series presenting the results of this investigation; it comprises the data obtained when a semicircular tip was used on the right upper panel. During these tests a rounded tip of the "Douglas" form (see Reference 1) was used on the right lower panel. However, as was shown in previous tests (Reference 2), the results obtained on the upper wing may be considered to be unaffected by the shape of the lower tip.

Methods and Apparatus

The M-3 airplane being used in these tests is a normal biplane having, however, an aspect ratio somewhat higher than usual. The characteristics of this airplane are given in Table I. The shape of the wing-tip plan form is given in Figure 1 and the ordinates of the profiles in Table II. The Clark Y section was maintained throughout the span. The sections were so located vertically that the points of maximum mean camber lay in a plane parallel to the main chord of the wing.

The wings were rigged with a washin of about 0.2 degree. Deflection measurements previously made (Reference 1) indicated that this amount would be sufficient to approximately cancel the torsional deflection at the low angles of attack. However, at high angles of attack the torsional deflection is practically zero (Reference 1), and the rigged washin therefore resulted in an "effective twist." This twist was such a small percentage of the angle of attack in this condition that it had a negligible effect on the results, and consequently they can be considered to closely represent conditions for zero wing twist throughout the range of angle of attack investigated.

The same procedure was followed in these tests as was used in the tests on the "Douglas" and on the square tips (References 1 and 2). As in the case of the square tip, the extra pressure rib X was connected in place of rib C in approximately one-half of the runs. Although it was not possible to measure simultaneously the pressures at ribs X and C, sufficient information was obtained on both ribs to establish the span load and the moment curves at stations X and C.

In addition to the quantities measured in previous tests, the angle of attack was also measured. This measurement was omitted in the previous tests because no instruments for the purpose were available. Although the lack of the angle of attack measurement does not detract from the usefulness of the results, the measurement of this quantity was considered advisable in order to establish the pressure data on a basis suitable for comparison with corresponding wind tunnel results. This consideration was particularly applicable in this series of tests as the order of accuracy of the data was sufficiently high to justify such a comparison. The practice followed in measuring angle of attack was to record the attitude of the airplane with respect to the ground by means of a pendulum inclinometer, while the pilot maintained level flight by means of an indicating statoscope.

Precision

As mentioned in References 1 and 2, the accuracy of these tests was maintained at a higher level than had been possible in previous investigations, largely because of the installation of all instruments in an insulated compartment which was kept at a constant temperature. The angle of attack values are considered accurate to ±0.5 degree. The discussion of precision given in Reference 1 applies to all other measurements given, as no changes have been made in apparatus, methods, or procedure. The flight records were taken over a period of three weeks; the instrument calibrations made at the beginning and end of this period agreed with each other.

Results

The results are given in Figures 2a to 5, inclusive, and in Tables IV, V, and VI. The coefficients there referred to are defined as follows:

$$\text{Wing } C_N = \frac{\text{Wing Normal Force}}{q \times \text{Wing Area}}$$

$$\text{Rib } C_N = \frac{\text{Rib Normal Force}}{q \times \text{Rib Chord}}$$

$$\text{Rib } C_M = \frac{\text{Moment of Rib Normal Force About L.E.}}{q \times (\text{Rib Chord})^2}$$

Figures 2a to 2j, inclusive, show representative pressure plots throughout the range of C_N investigated, the pressures for these cases being tabulated in Table IV. The final usable results are given in Figures 3 and 4, which show the variation of rib C_N with wing C_N and rib C_M with rib C_N, respectively. These curves were established by a large number of points, as in Figures 6 and 7 of Reference 1, but the points were omitted to avoid confusion. The curves for the root section were obtained by extrapolating span-C_N curves and span-C_M curves from considerable data. Owing to the extrapolation, the curves do not represent the true conditions near the fuselage and in the slipstream, but they represent more nearly the ideal conditions in which there is no effect from fuselage and propeller.

Tables V and VI give coordinates of the curves of Figures 3 and 4 to allow their construction on a larger and more accurate scale, if so desired. To use Figures 3 and 4: for any wing C_N (or, practically speaking, for any wing lift coefficient), the span-C_N distribution may be obtained from Figure 3 by plotting the corresponding values of rib C_N at their proper locations on the span base line as determined from Figure 1. The values of rib C_M corresponding to these values of rib C_N may be determined from Figure 4, and the center of pressure locus can be drawn from the relation $C_p = C_M/C_N$. To obtain the span-load distribution, the ordinates of the span-C_N curve must be reduced at the tip in the same ratio as the reduction in chord length.

By means of the curve of wing C_N versus angle of attack in Figure 5, the results given in Figures 2, 3, and 4 may be correlated with angle of attack. The lift curve of the airplane has been included in Figure 5 as a matter of interest only and has not been corrected for the component of propeller thrust normal to the relative wind.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 15, 1931.

References

1. Rhode, Richard V. and Lundquist, Eugene E.: The Pressure Distribution over a Douglas Wing Tip on a Biplane in Flight. N.A.C.A. Technical Note No. 347, Aug., 1930.

2. Rhode, Richard V. and Lundquist, Eugene E.: The Pressure Distribution over a Square Wing Tip on a Biplane in Flight. N.A.C.A. Technical Note No. 360, Jan., 1931.

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	
C.G. in per cent of chord	29	
Areas (sq.ft.):	Original	*Semicircular Right Upper
Right upper wing, including aileron	126.4	126.6
Right lower wing, including aileron	126.4	126.4
Total wing area	505.6	505.8
Horizontal tail surfaces	58	
Vertical tail surfaces	17.7	
Weight during tests	4840 lb.	
Engine	Liberty	
Rated hp at 1750 r.p.m.	420	
Power loading	11.52 lb./hp	
Wing loading	9.57 lb./sq.ft.	

*Left wing panels remained unchanged.

TABLE II

Ordinates of Pressure Ribs

Station in per cent 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
.00	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
2.50	6.50	1.466	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
5.00	7.90	.933	7.90	.87	8.00	.97	7.90	.83	8.00	.87	7.75	.87	7.92	1.03	8.11	1.17
7.50	8.85	.629	8.82	.51	9.05	.65	8.91	.28	8.96	.46	8.88	.57	8.82	.72	8.96	.77
10.00	9.60	.42	9.65	.41	9.74	.46	9.65	.32	9.65	.32	9.59	.32	9.40	.47	9.79	.48
15.00	10.685	.15	10.61	.18	10.76	.28	10.67	.14	10.62	.18	10.59	.04	10.56	.26	10.84	.18
20.00	11.36	.033	11.21	.05	11.26	.09	11.26	.05	11.26	.05	11.17	.00	11.21	.11	11.50	.08
30.00	11.70	.00	11.67	.00	11.73	.00	11.81	.00	11.81	.00	11.66	.00	11.81	.05	11.86	.03
40.00	11.40	.00	11.30	.00	11.36	.00	11.40	.05	11.45	.00	11.47	-.04	11.39	.00	11.46	.00
50.00	10.515	.00	10.48	.00	10.48	.00	10.58	.03	10.58	.05	10.57	.00	10.51	.00	10.63	.00
60.00	9.148	.00	9.19	.00	9.19	-.05	9.42	.09	9.25	.14	9.10	.04	9.19	.00	9.46	.03
65.00	8.30	.00	8.27	.05	8.27	.00	8.54	.09	8.45	.14	8.22	.00	8.30	.00	8.74	.05
70.00	7.35	.00	7.35	.09	7.36	.00	7.68	.09	7.67	.14	7.35	.00	7.37	.05	7.76	.05
80.00	5.216	.00	5.38	.00	5.33	.00	5.65	.18	5.70	.23	5.22	.04	5.30	.05	5.49	.05
90.00	2.802	.00	2.90	.00	2.80	-.05	3.31	.23	3.31	.18	2.81	.00	2.83	.00	3.07	.00
95.00	1.494	.00	1.65	.00	1.52	-.09	2.02	.14	2.02	.09	1.51	-.04	1.19	-.05	1.87	.00
100.00	.12	.00	.37	.00	.23	-.23	.74	.00	.65	.00	.26	.00	.05	.10	.30	.00

Note: All ordinates given are in per cent of chord.

TABLE III

Orifice Locations in Per Cent Chord

Orifice No.	Rib X	Rib A	Rib B	Rib C	Rib D	Rib E	Rib F
1	1.47	1.54	1.47	1.47	1.26	1.70	2.77
2	2.94	3.06	2.94	3.02	2.65	3.36	5.44
3	4.41	4.45	4.41	4.49	4.37	6.79	7.99
4	6.62	6.69	6.70	6.69	6.47	9.35	12.13
5	13.24	13.31	13.30	13.30	13.09	14.03	17.35
6	25.00	25.00	25.00	25.00	24.85	22.40	25.27
7	41.18	41.30	41.40	41.30	41.00	38.35	43.40
8	58.95	59.50	59.10	58.80	58.40	54.75	63.40
9	72.30	73.70	72.00	72.30	76.00	71.10	78.30
10	94.20	94.40	94.50	94.40	93.70	91.00	88.30

TABLE IV

Recorded Pressures in Multiples of q

Wing C_N = -.159

Orifice	Rib A	Rib B	Rib C	Rib D	Rib E	Rib F
1	-2.77	-2.38	-2.37	-2.45	-2.05	-1.38
2	-1.97	-1.84	-1.80	-1.60	-1.65	- .90
3	-1.45	-1.32	-1.39	-1.48	-1.04	- .67
4	-1.13	-1.04	-1.09	- .99	- .85	- .52
5	- .52	- .56	- .49	- .43	- .38	- .08
6	- .09	- .07	- .09	.02	- .12	- .07
7	.06	.12	.04	.15	.09	0
8	.12	.12	.12	.20	.14	.13
9	.07	.14	.15	.07	.18	.07
10	.05	.04	.05	--	.07	.07

TABLE IV (cont.)

Recorded Pressures in Multiples of q

Wing C_N = -.047						
Orifice	Rib					
	A	B	C	D	E	F
1	-2.09	-2.14	-1.76	-1.88	-1.52	-1.05
2	-1.49	-1.26	-1.33	-1.19	-1.25	- .55
3	-1.03	- .95	-1.00	-1.07	- .72	- .39
4	- .71	- .66	- .72	- .61	- .60	- .32
5	- .33	- .32	- .25	- .24	- .17	.09
6	.07	.11	.04	.13	.01	.04
7	.15	.17	.09	.20	.15	.04
8	.15	.12	.15	.22	.15	.14
9	.11	.15	.16	.08	.18	.11
10	.04	.04	.05	--	.08	.04

TABLE IV (cont.)

Recorded Pressures in Multiples of q

Wing C_N = .020						
Orifice	Rib					
	X	A	B	D	E	F
1	-1.75	-1.81	-1.88	-1.78	-1.39	-1.08
2	-1.50	-1.30	-1.38	-1.22	-1.09	- .59
3	- .81	- .96	- .78	-1.07	- .57	- .32
4	- .52	- .51	- .60	- .53	- .36	- .23
5	- .12	- .15	- .33	- .23	- .07	.02
6	.25	.13	.19	.18	.07	.10
7	.18	.28	.27	.25	.20	.11
8	.20	.19	.22	.21	.18	.21
9	.14	.14	.14	.12	.22	.08
10	.04	.09	.05	--	.06	.04

TABLE IV (cont.)

Recorded Pressures in Multiples of q

Wing C_N = .108

Orifice	Rib					
	X	A	B	D	E	F
1	-1.29	-1.33	-1.40	-1.61	-1.15	-.61
2	-1.09	- .95	-1.07	- .98	- .85	-.33
3	- .46	- .62	- .39	- .75	- .37	-.17
4	- .22	- .25	- .32	- .31	- .18	-.08
5	.09	.08	- .10	- .06	.08	.13
6	.42	.25	.31	.29	.18	.14
7	.25	.38	.32	.31	.24	.20
8	.24	.23	.23	.25	.23	.22
9	.15	.15	.15	.12	.22	.08
10	.05	.08	.04	--	.06	0

TABLE IV (cont.)

Recorded Pressures in Multiples of q

Wing C_N = .373

Orifice	Rib					
	A	B	C	D	E	F
1	.06	-.11	-.11	-.23	-.14	0
2	.18	.10	.10	-.07	-.14	.18
3	.38	.42	.22	.02	.15	.29
4	.64	.44	.32	.35	.19	.15
5	.61	.40	.45	.43	.43	.48
6	.60	.61	.50	.57	.43	.40
7	.62	.51	.41	.50	.40	.27
8	.36	.31	.32	.29	.31	.25
9	.23	.19	.26	.14	.27	.19
10	.10	.07	.05	--	.06	.07

TABLE IV (cont.)

Recorded Pressures in Multiples of q

Wing C_N = .542						
Orifice	Rib					
	A	B	C	D	E	F
1	.92	.61	.64	.33	.41	.43
2	.93	.82	.73	.48	.37	.53
3	1.07	1.01	.78	.55	.49	.60
4	1.25	.95	.83	.81	.47	.48
5	1.01	.75	.75	.72	.66	.71
6	.85	.81	.71	.75	.63	.55
7	.76	.62	.52	.59	.47	.33
8	.44	.37	.38	.36	.38	.32
9	.28	.21	.30	.18	.32	.33
10	.08	.06	.06	--	.09	.15

TABLE IV (cont.)

Recorded Pressures in Multiples of q

Wing C_N = .758						
Orifice	Rib					
	A	B	C	D	E	F
1	1.92	1.46	1.34	1.30	1.02	.92
2	1.92	1.63	1.41	1.13	.92	.98
3	1.97	1.70	1.41	1.12	.93	1.10
4	1.92	1.55	1.46	1.29	.76	.81
5	1.53	1.13	1.10	1.07	.98	.94
6	1.15	1.10	.93	.93	.87	.64
7	.93	.81	.64	.64	.59	.41
8	.53	.42	.46	.38	.49	.45
9	.33	.30	.35	.18	.38	.37
10	.10	.11	.09	--	.17	.30

TABLE IV (cont.)

Recorded Pressures in Multiples of q

Wing C_N = 1.048

Orifice	Rib					
	A	B	C	D	E	F
1	3.44	2.62	2.40	2.49	1.98	1.58
2	3.05	2.70	2.50	2.02	1.82	1.60
3	3.06	2.72	2.32	2.02	1.52	1.53
4	2.72	2.32	2.25	1.98	1.20	1.23
5	2.16	1.77	1.60	1.57	1.35	1.32
6	1.55	1.42	1.23	1.22	1.20	.94
7	1.18	.99	.82	.80	.75	.63
8	.69	.54	.56	.48	.61	.65
9	.44	.36	.42	.26	.50	.64
10	.13	.11	.12	--	.22	.56

TABLE IV (cont.)

Recorded Pressures in Multiples of q

Wing C_N = 1.387

Orifice	Rib					
	A	B	C	D	E	F
1	5.08	3.97	3.71	3.82	3.23	2.73
2	4.74	3.96	3.76	3.18	2.81	2.45
3	4.52	3.93	3.58	3.03	2.35	2.39
4	4.15	3.51	3.24	2.88	2.03	1.90
5	2.98	2.57	2.21	2.12	1.92	1.81
6	2.01	1.81	1.60	1.55	1.57	1.37
7	1.41	1.18	1.05	1.00	1.03	.96
8	.78	.60	.66	.63	.85	1.11
9	.48	.40	.47	.35	.71	1.23
10	.20	.17	.15	--	.32	1.01

TABLE IV (cont.)

Recorded Pressures in Multiples of q

Wing C_N = 1.574						
Orifice	Rib					
	A	B	C	D	E	F
1	6.29	4.83	4.67	4.63	3.91	3.33
2	5.78	4.87	4.67	3.91	3.45	2.92
3	5.43	4.65	4.28	3.71	2.82	2.82
4	4.92	4.20	3.88	3.41	2.44	2.27
5	3.51	3.01	2.61	2.51	2.26	2.13
6	2.30	2.01	1.82	1.75	1.80	1.67
7	1.47	1.23	1.14	1.10	1.14	1.14
8	.76	.59	.69	.67	.95	1.45
9	.45	.44	.48	.38	.83	1.65
10	.30	.20	.18	--	.39	1.28

TABLE V

Coordinates of Curves of Figure 3

Wing C_N	Rib C_N							
	Root	X	A	B	C	D	E	F
.0	.000	.000	.000	.000	.000	.000	.000	.000
.1	.115	.113	.105	.087	.081	.073	.067	.050
.2	.230	.227	.210	.174	.162	.147	.134	.105
.3	.344	.340	.315	.261	.244	.220	.201	.167
.4	.459	.453	.420	.348	.325	.294	.269	.232
.5	.574	.567	.526	.436	.406	.367	.337	.302
.6	.689	.680	.631	.523	.487	.440	.409	.378
.7	.804	.793	.736	.610	.568	.514	.483	.459
.8	.918	.906	.841	.697	.650	.587	.560	.544
.9	1.033	1.020	.946	.784	.731	.662	.636	.631
1.0	1.148	1.133	1.051	.871	.812	.737	.715	.730
1.1	1.263	1.246	1.156	.958	.893	.814	.797	.841
1.2	1.378	1.360	1.261	1.045	.974	.891	.882	.960
1.3	1.491	1.476	1.366	1.132	1.056	.970	.972	1.092
1.4	1.600	1.587	1.470	1.219	1.136	1.052	1.067	1.245
1.5	1.705	1.690	1.569	1.307	1.218	1.135	1.168	1.410
1.6	1.802	1.79	1.661	1.394	1.299	1.217	1.274	1.596

TABLE VI

Coordinates of Curves of Figure 4

Rib C_N	Rib C_M							
	Root	X	A	B	C	D	E	F
.0	-.071	-.070	-.069	-.065	-.063	-.060	-.056	-.034
.1	-.095	-.093	-.092	-.087	-.085	-.080	-.080	-.058
.2	-.118	-.116	-.114	-.108	-.106	-.099	-.104	-.086
.3	-.142	-.139	-.136	-.129	-.127	-.120	-.129	-.118
.4	-.165	-.162	-.158	-.150	-.149	-.140	-.155	-.152
.5	-.189	-.185	-.181	-.172	-.170	-.161	-.182	-.189
.6	-.212	-.208	-.203	-.193	-.192	-.183	-.211	-.228
.7	-.236	-.231	-.225	-.214	-.214	-.205	-.240	-.269
.8	-.259	-.254	-.247	-.235	-.236	-.227	-.270	-.310
.9	-.283	-.277	-.270	-.257	-.259	-.251	-.301	-.352
1.0	-.306	-.300	-.292	-.278	-.281	-.275	-.332	-.395
1.1	-.330	-.322	-.314	-.299	-.304	-.300	-.363	-.438
1.2	-.353	-.345	-.337	-.320	-.328	-.324	-.395	-.483
1.3	-.377	-.368	-.359	-.341	-.351		-.428	-.528
1.4	-.400	-.391	-.381	-.363				-.573
1.5	-.424	-.414	-.403					-.618
1.6	-.447	-.437	-.426					-.663
1.7	-.471	-.460	-.448					
1.8	-.494	-.483						

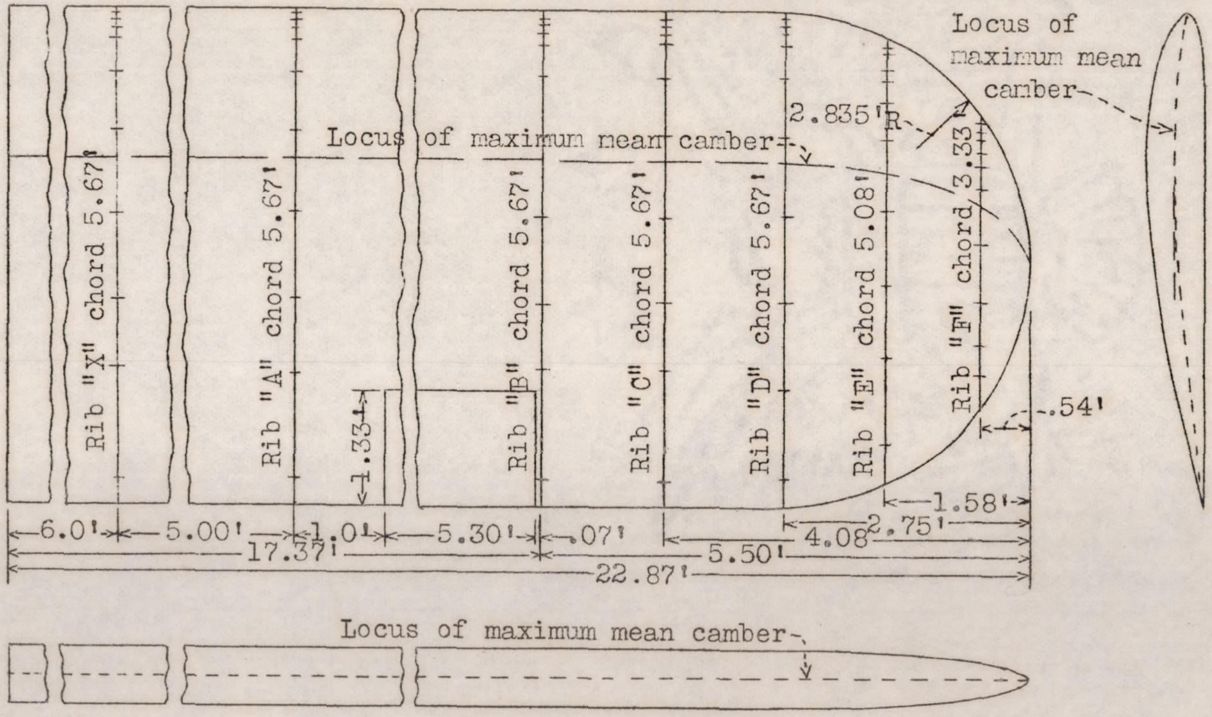

Fig.1 M-3 wing with pressure ribs and orifice locations (semicircular tip).

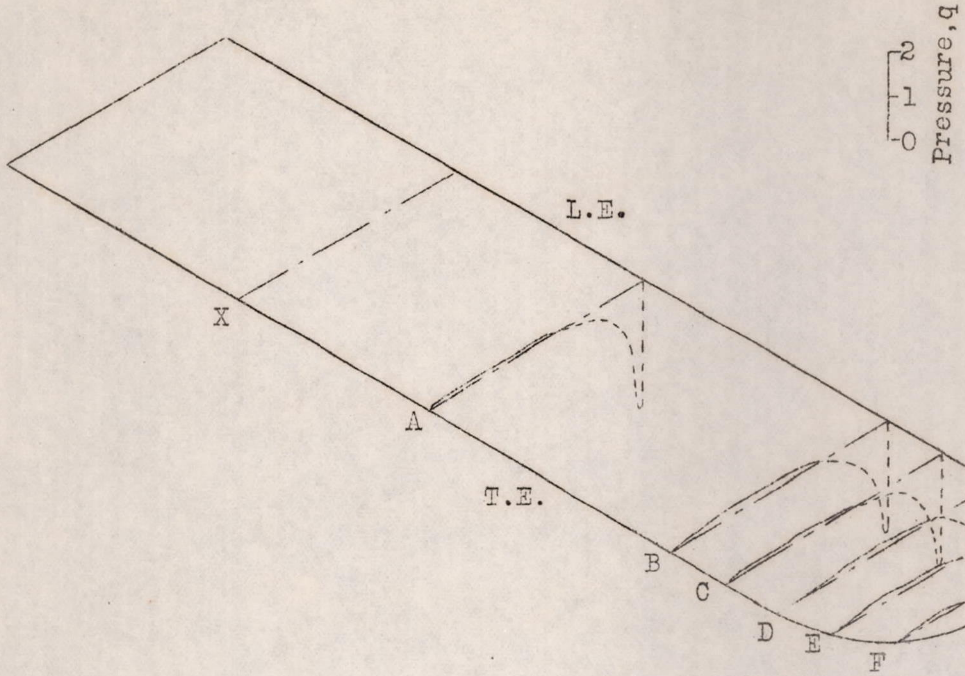

Fig.2a Pressure distribution. Wing $C_N = -.159$

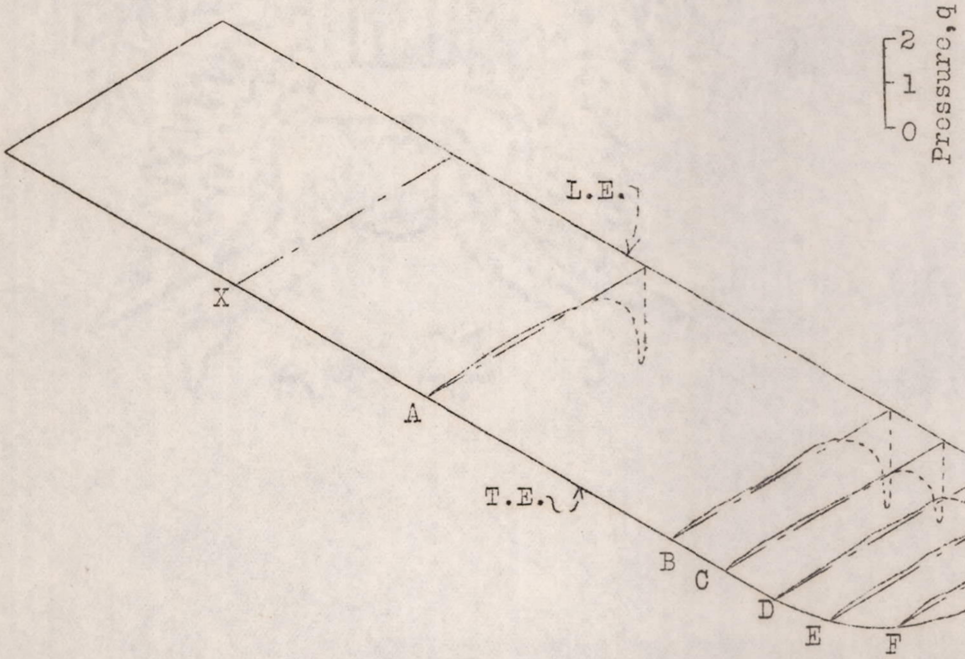

Fig.2b Pressure distribution. Wing $C_N = -.047$

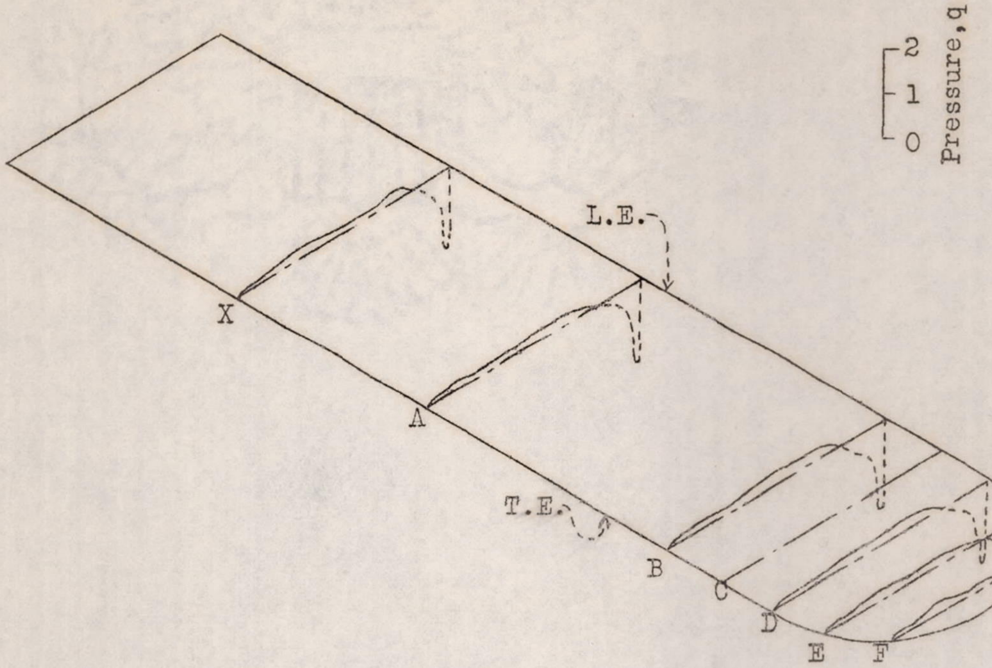

Fig.2c Pressure distribution. Wing C_N=.020

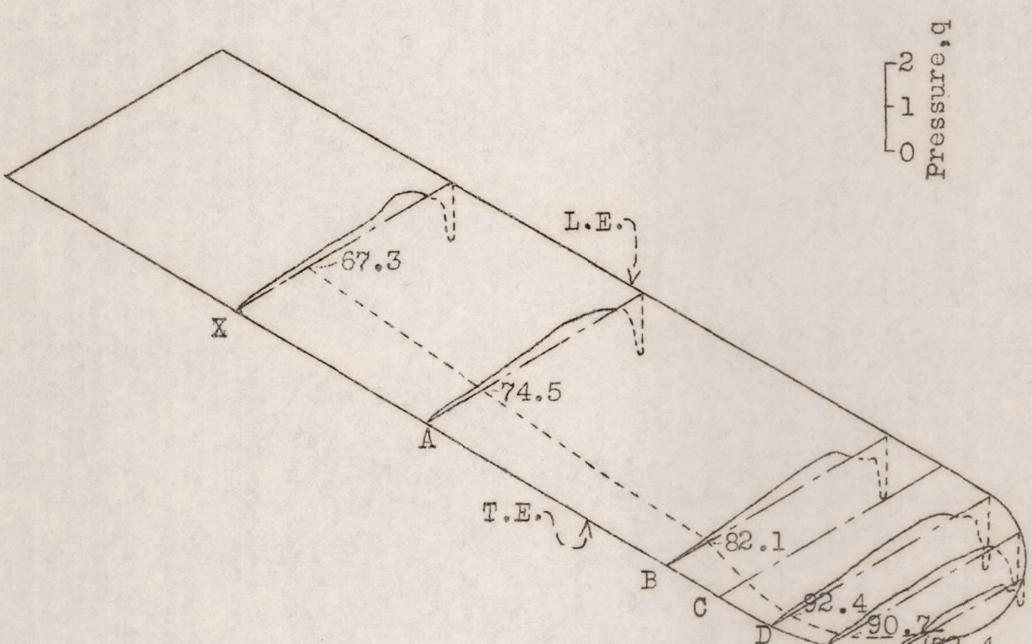

Fig.2d Pressure distribution. Wing C_N=.108

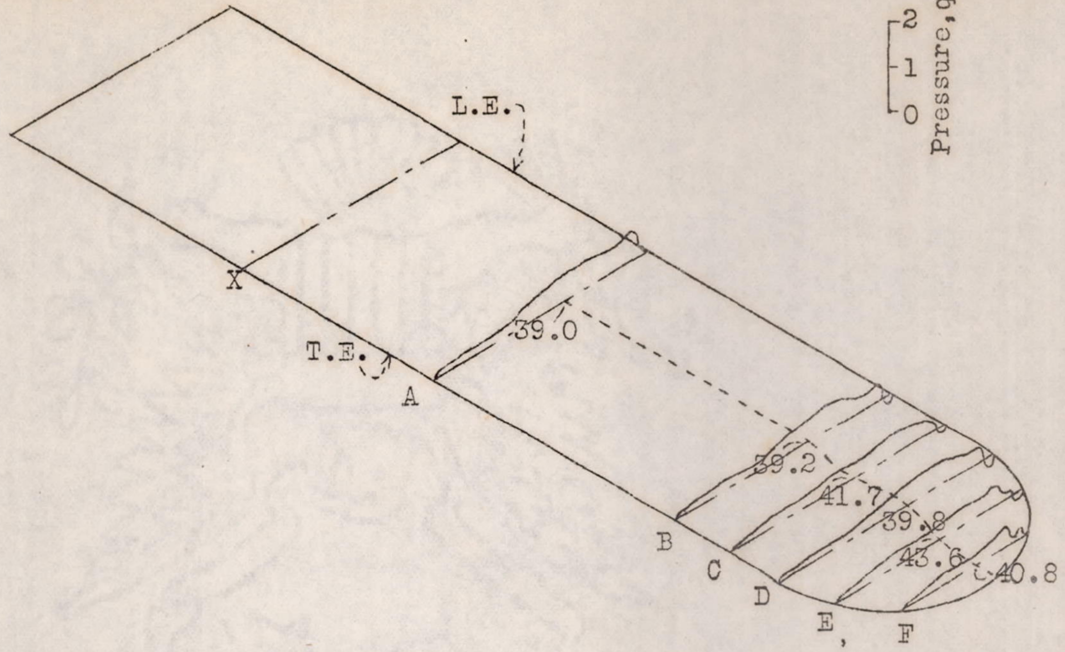

Fig.2e Pressure distribution. Wing C_N=.373

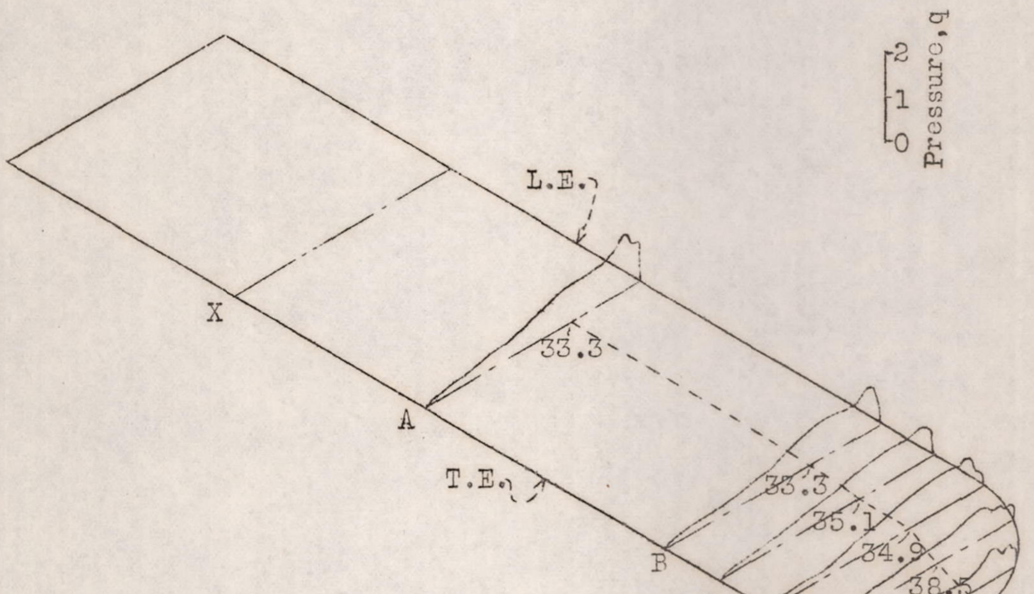

Fig.2f Pressure distribution. Wing C_N=.542

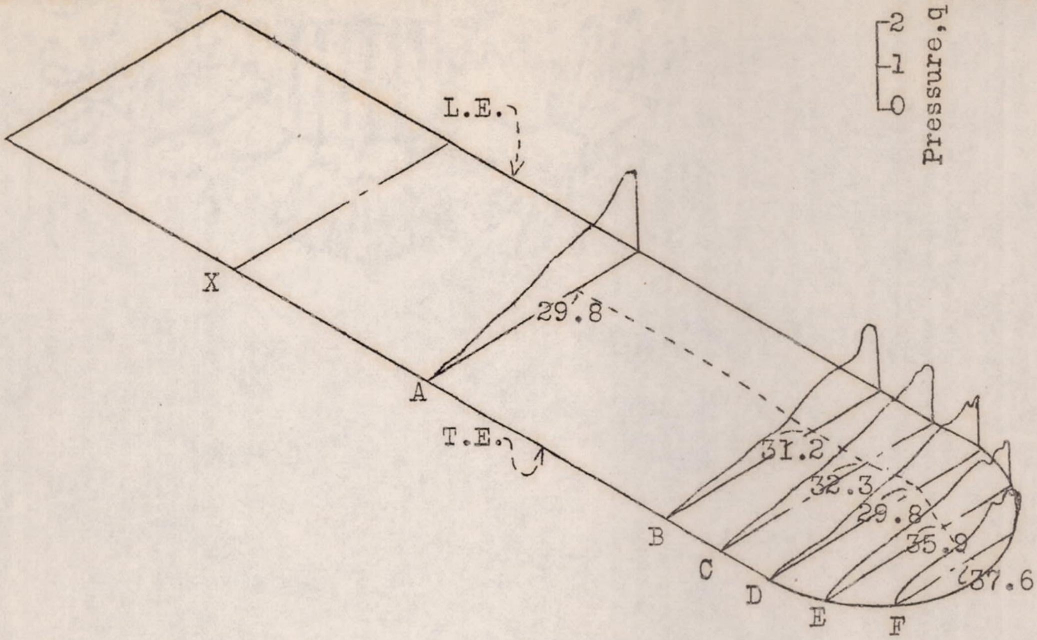

Fig. 2g Pressure distribution. Wing C_N=.758

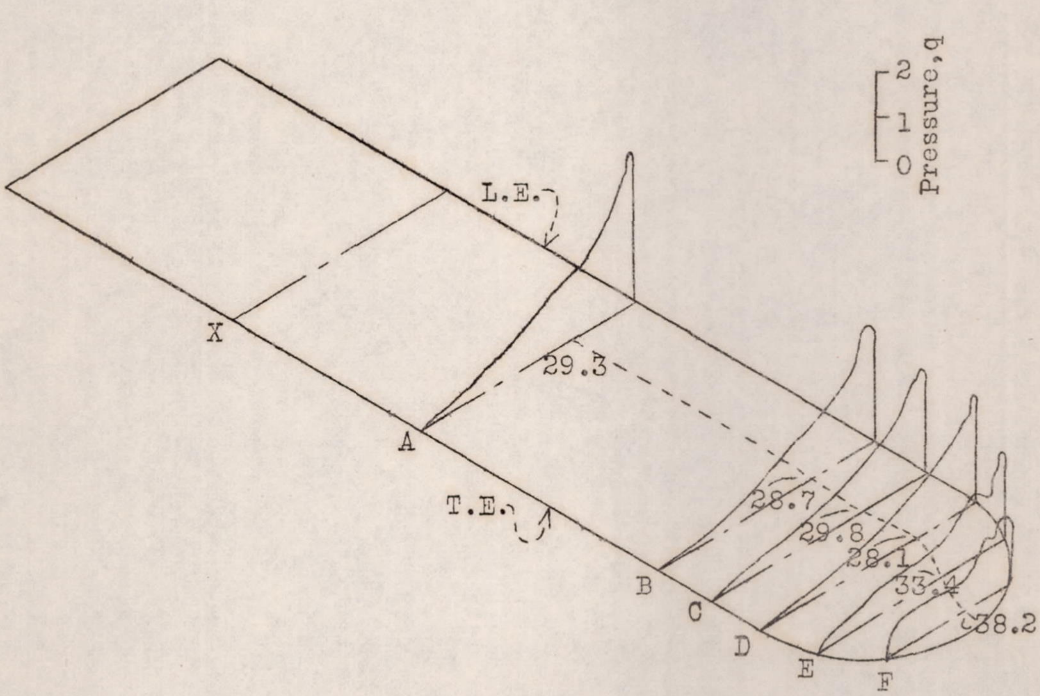

Fig. 2h Pressure distribution. Wing C_N=1.048

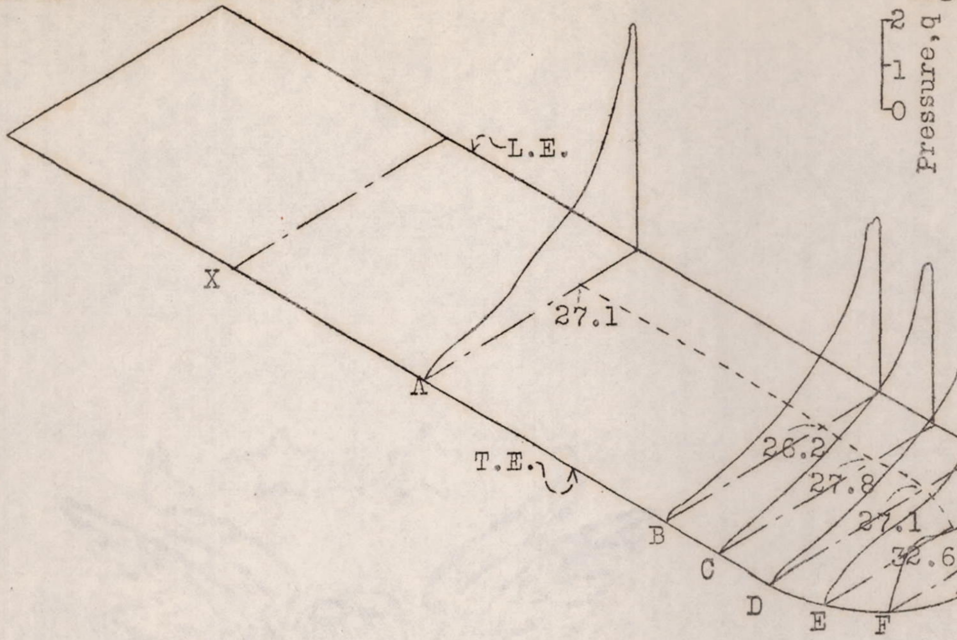

Fig.2i Pressure distribution. Wing C_N=1.387

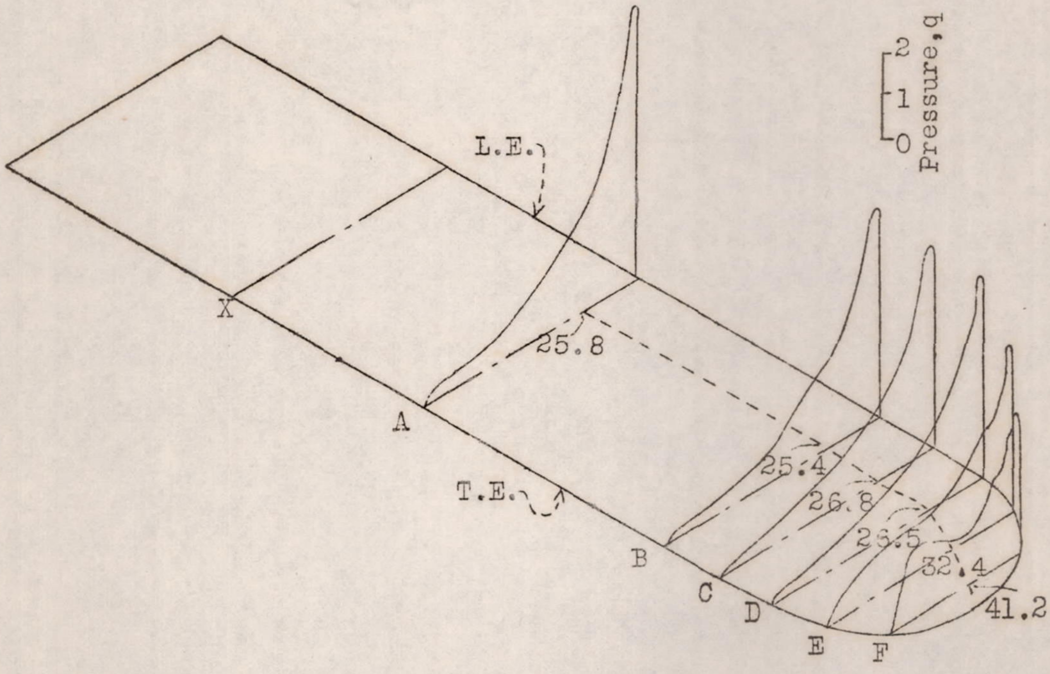

Fig.2j Pressure distribution. Wing C_N=1.574

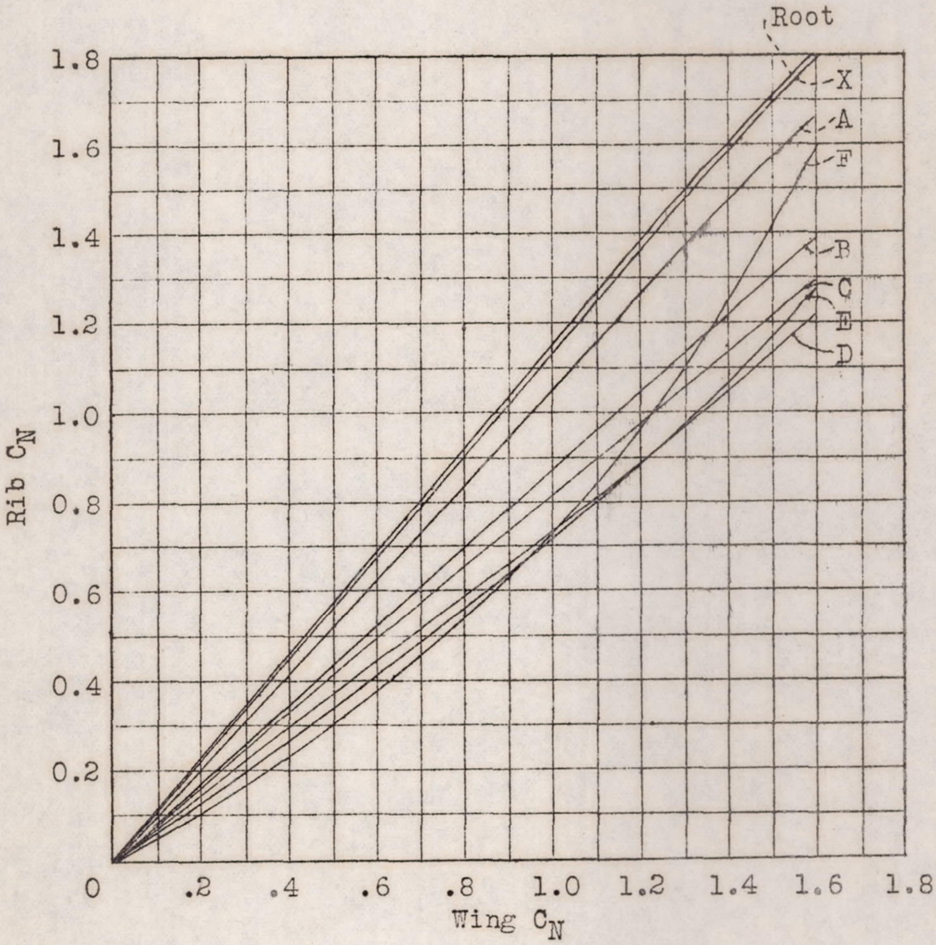

Fig.3 Rib C_N vs. wing C_N.

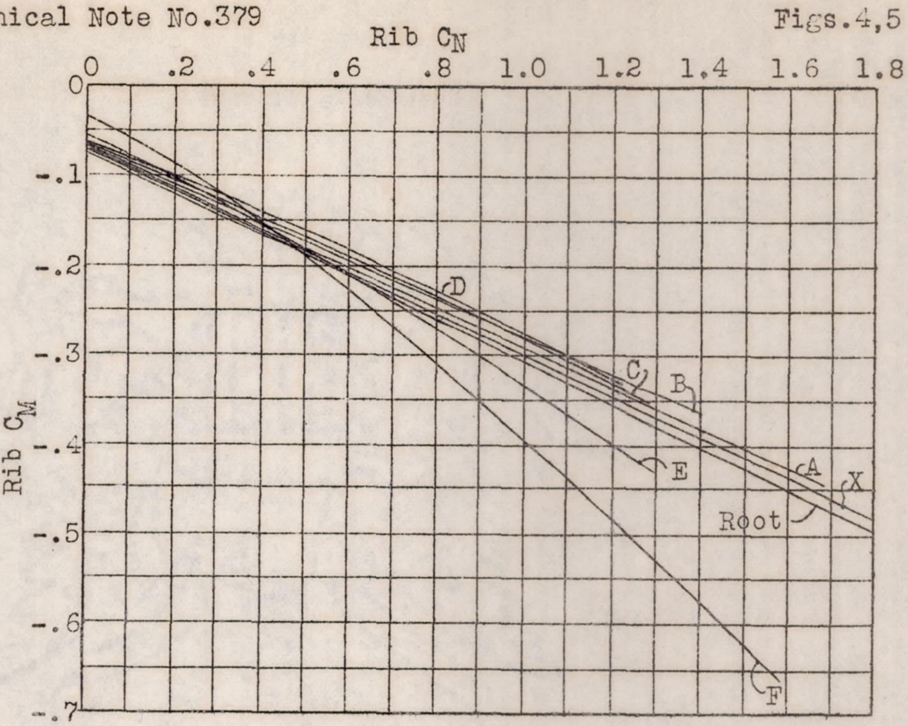

Fig.4 Rib C_M vs. rib C_N.

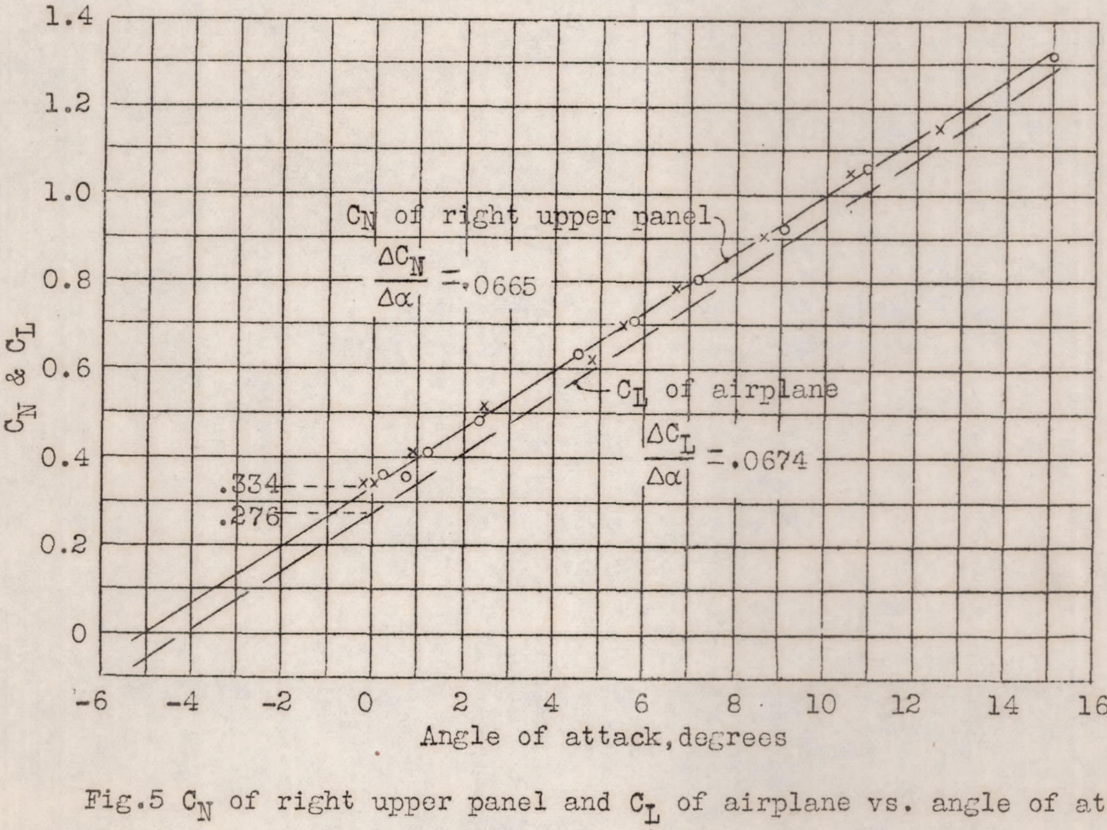

Fig.5 C_N of right upper panel and C_L of airplane vs. angle of attack.