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 distribu-
tion tests on the right upper wing panel of a Douglas M-3 air-
plane 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 with-
in 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 Aero-
nautics at Langley Field, Va. This investigation has been out-
lined 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 informa-
tion of value could be obtained with little additional work.

The results of tests on three tips have already been re-
ported: 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 investi-
gation; 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 bi-
plane 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 lo-
cated 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 sim-
ultaneously the pressures at ribs X and C, sufficient in-
formation 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 at-
tack measurement does not detract from the usefulness of the
results, the measurement of this quantity was considered ad-
visable 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.   : The Pressure Distribution over
        and   a Douglas Wing Tip on a Biplane
   Lundquist, Eugene E.   in Flight. N.A.C.A. Technical
                                 Note No. 347, Aug., 1930.

2. Rhode, Richard V.   : The Pressure Distribution over
        and   a Square Wing Tip on a Biplane
   Lundquist, Eugene E.   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.

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*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	A	B	C	D	E	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

Orifice	Wing $C_N = -.159$					
	Rib					
	A	B	C	D	E	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

Orifice	Wing C_N = -.047					
	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

Orifice	Wing C_N = .020					
	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

| Orifice | Rib | | | | | |
	X	A	B	D	E	F
	Wing C_N = .108					
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

| Orifice | Rib | | | | | |
	A	B	C	D	E	F
	Wing C_N = .373					
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

Orifice	Wing C_N = .542					
	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

Orifice	Wing C_N = .758					
	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

Orifice	Wing C_N = 1.574					
	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	1.55
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						
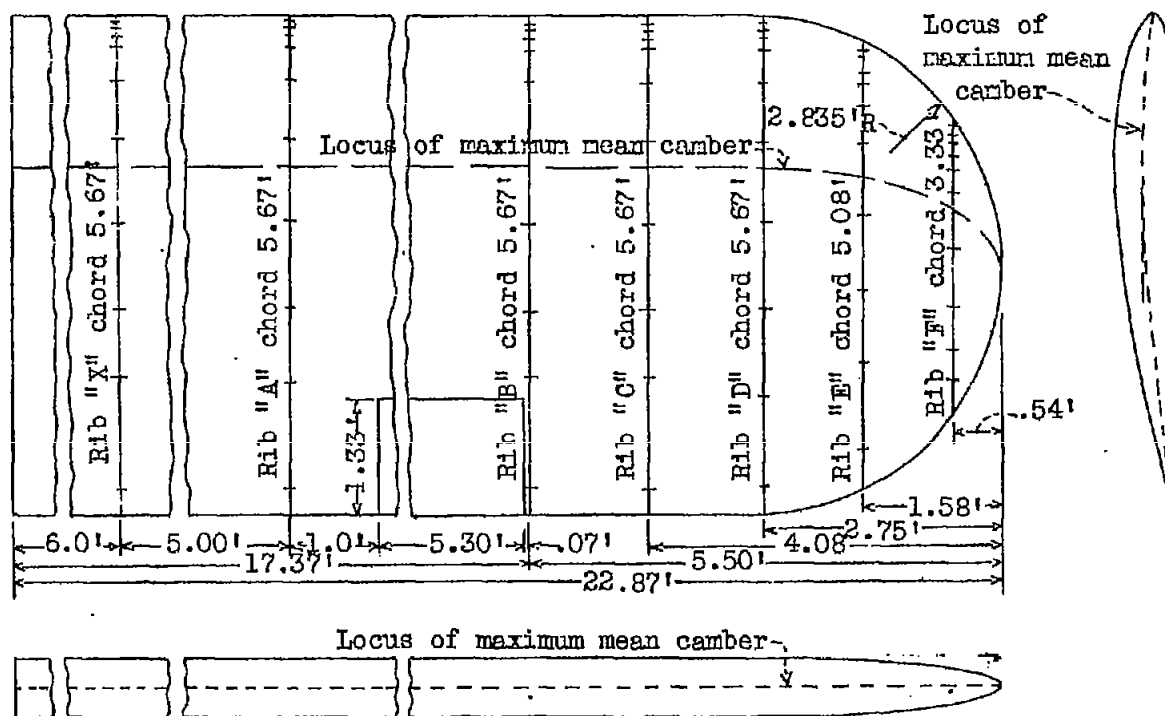
Fig.1

Fig.1 M-3 wing with pressure ribs and orifice locations (semicircular tip).
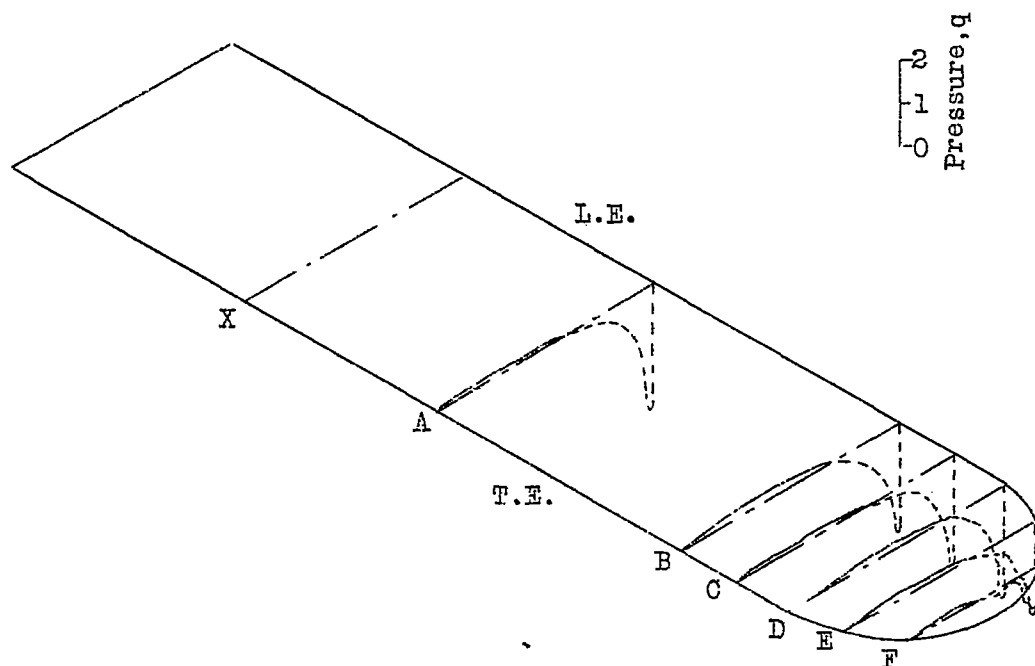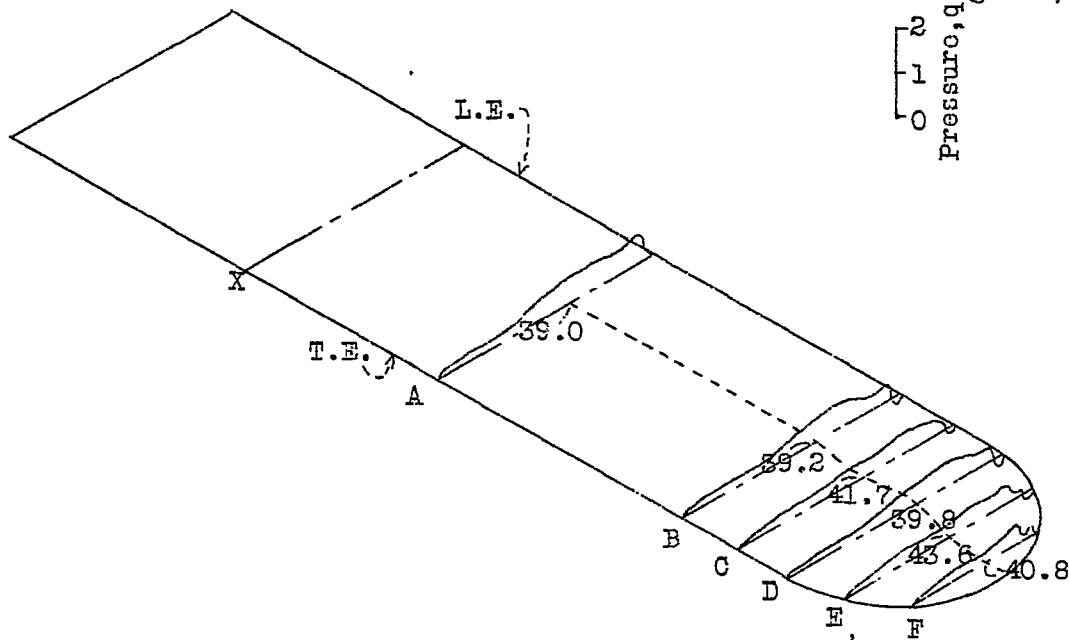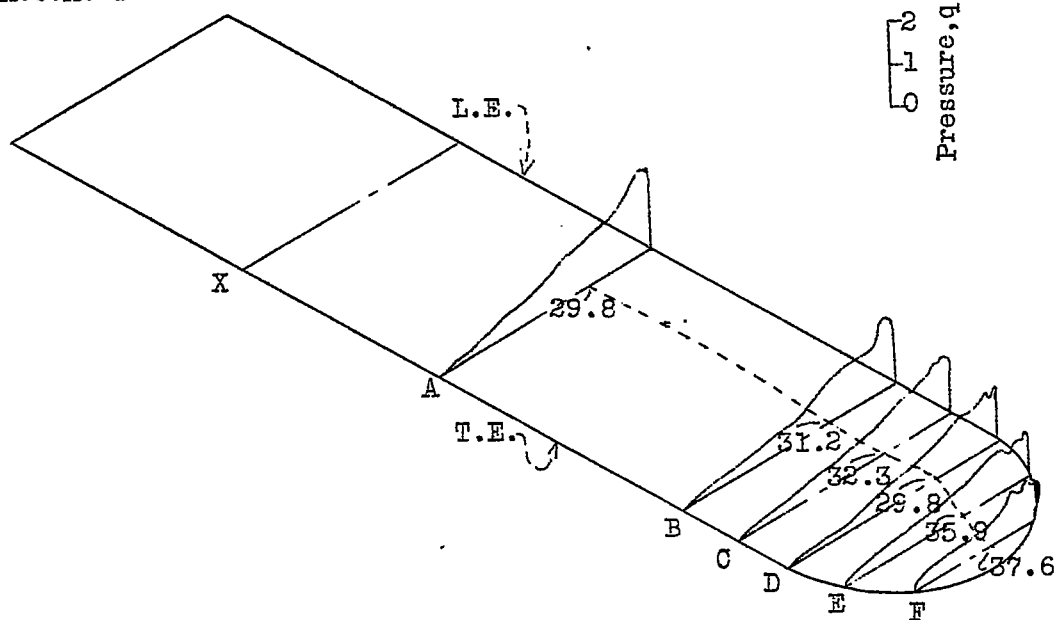
Fig.2a Pressure distribution. Wing $C_N = -.159$
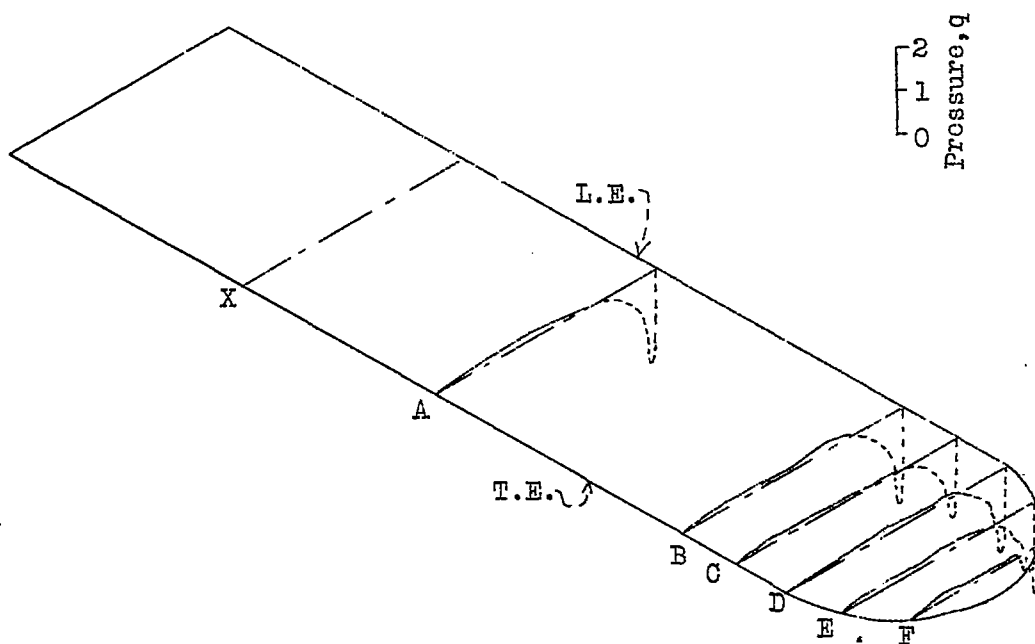
Fig.2b Pressure distribution. Wing $C_N = -.047$
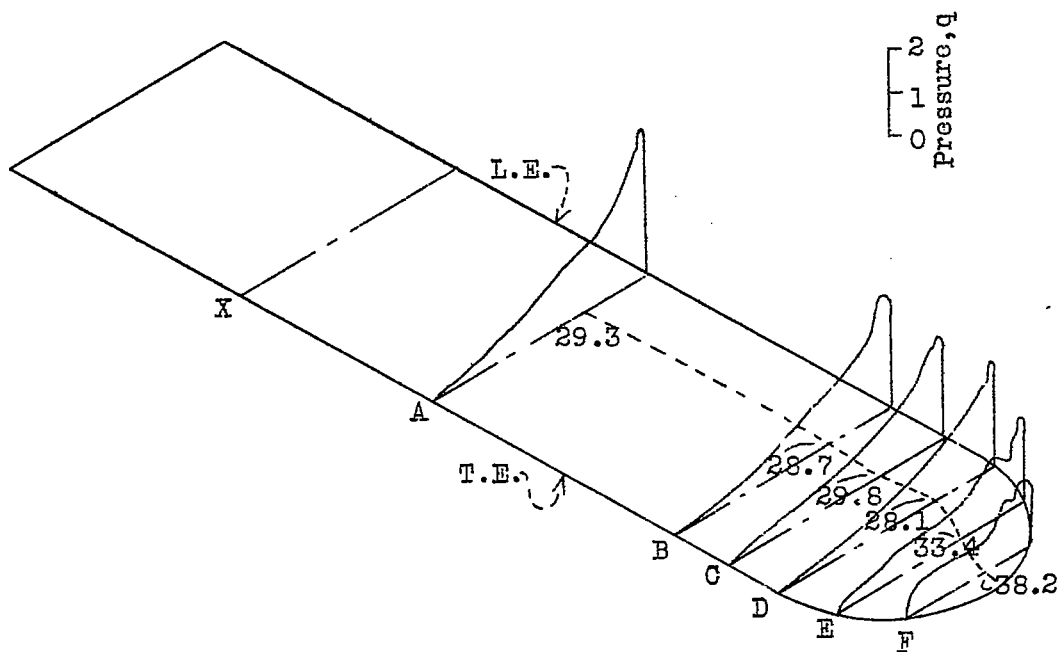
Fig.2c Pressure distribution. Wing C_N=.020
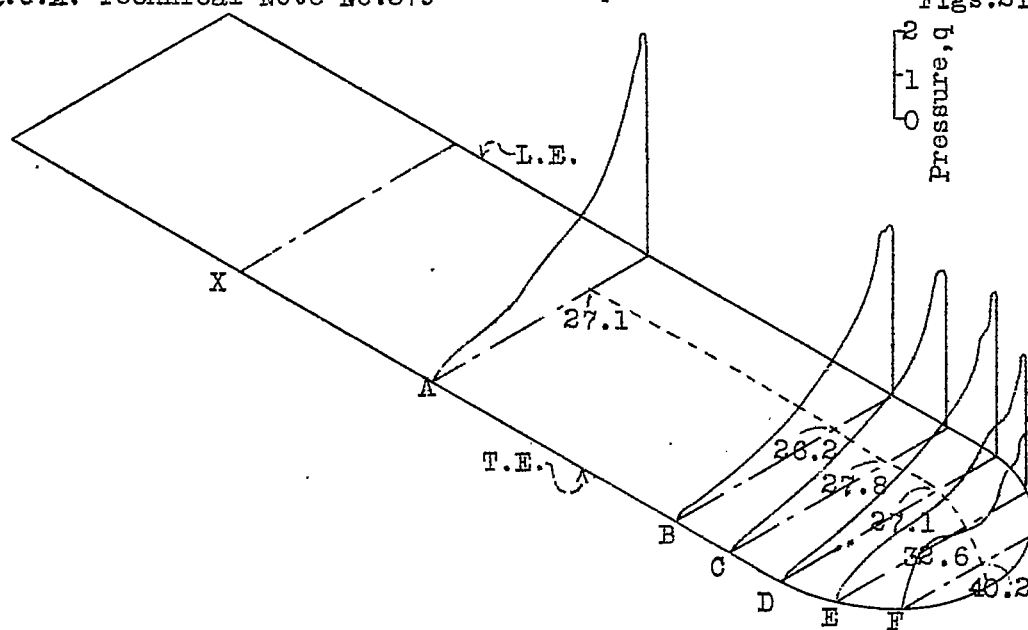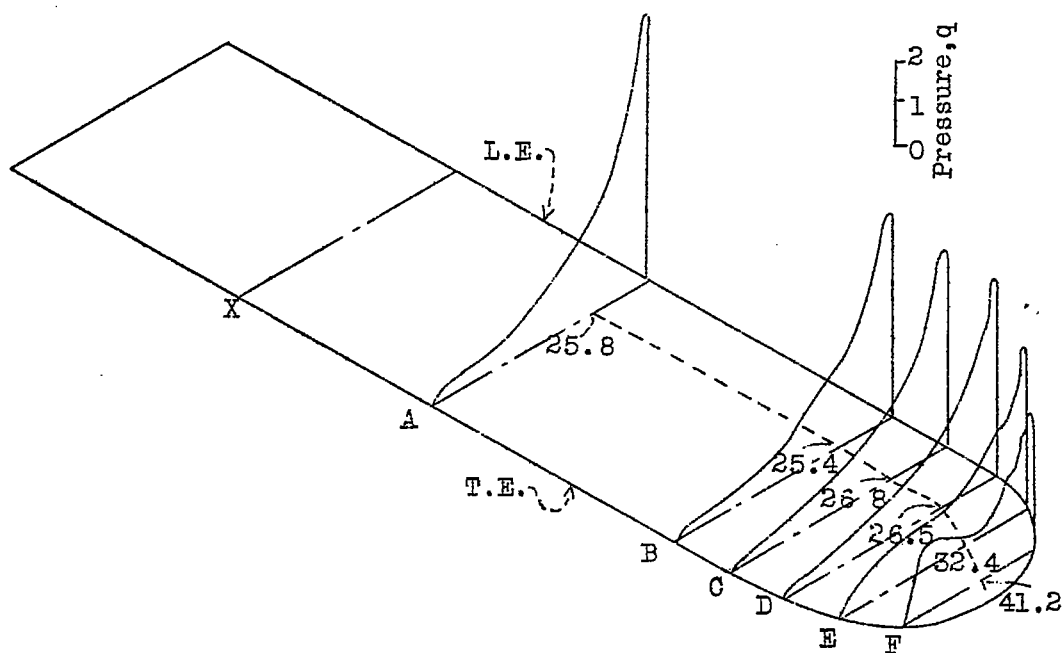

Fig.2d Pressure distribution. Wing C_N=.108

Fig.2e Pressure distribution. Wing C_N=.373
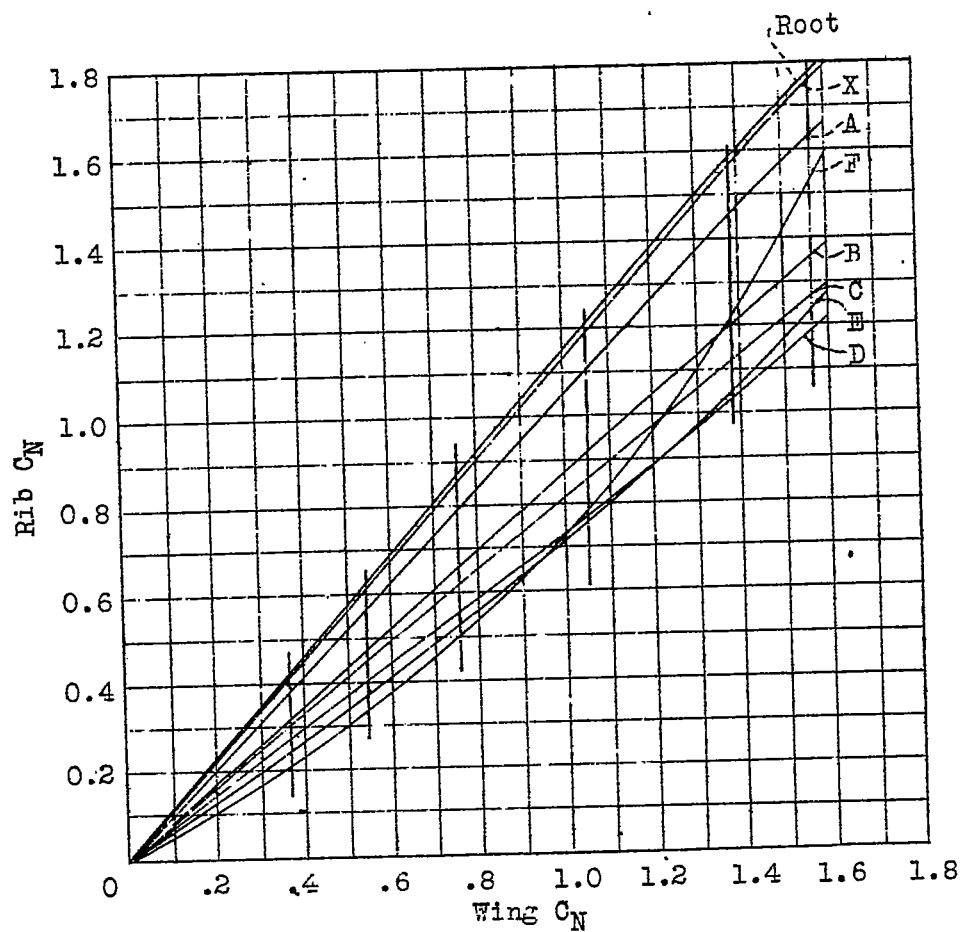
Fig.2f Pressure distribution. Wing C_N=.542
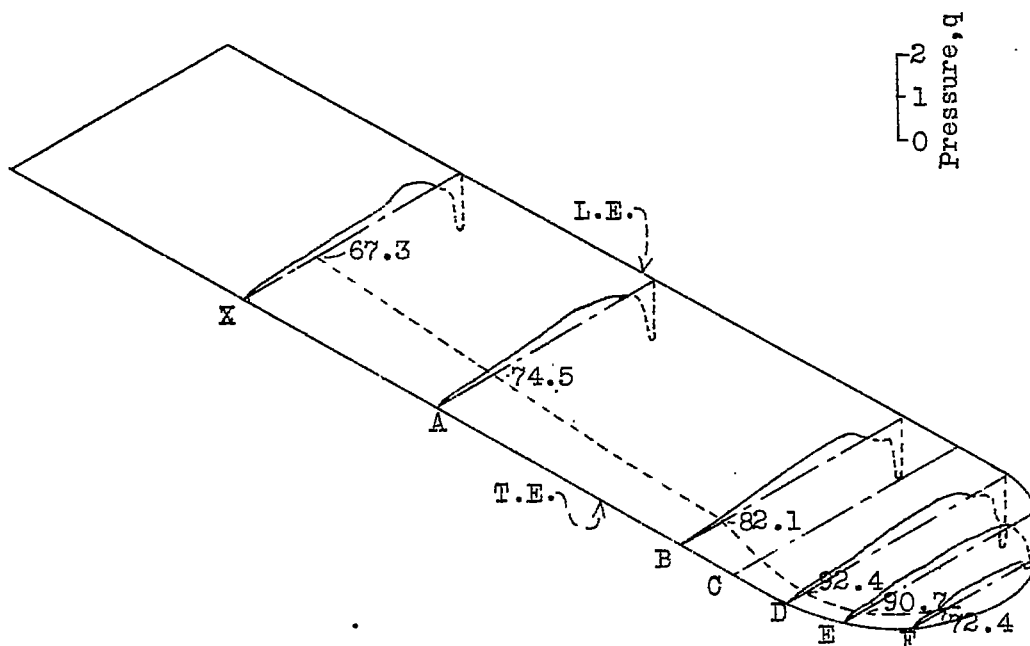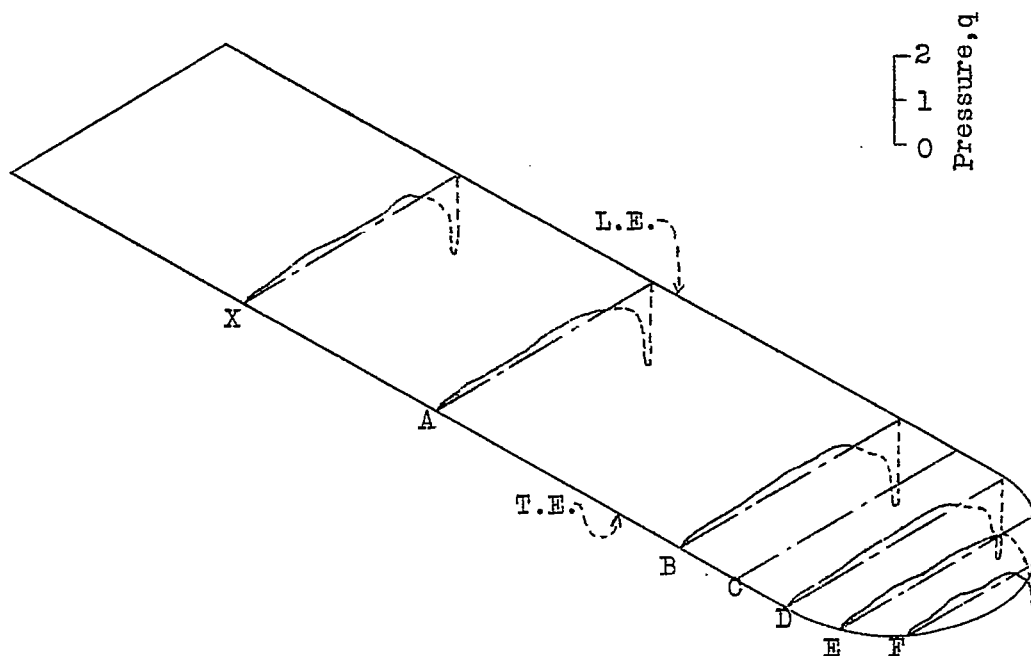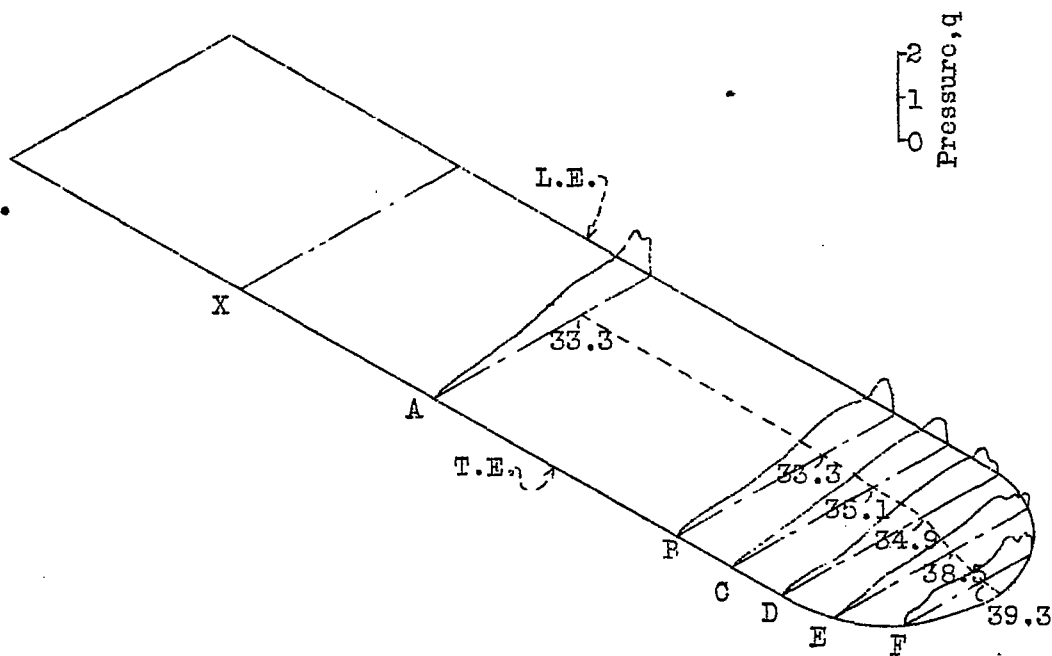
Fig.2g Pressure distribution. Wing C_N=.758

Fig.2h Pressure distribution. Wing C_N=1.048

Fig.2i Pressure distribution. Wing C_N=1.387
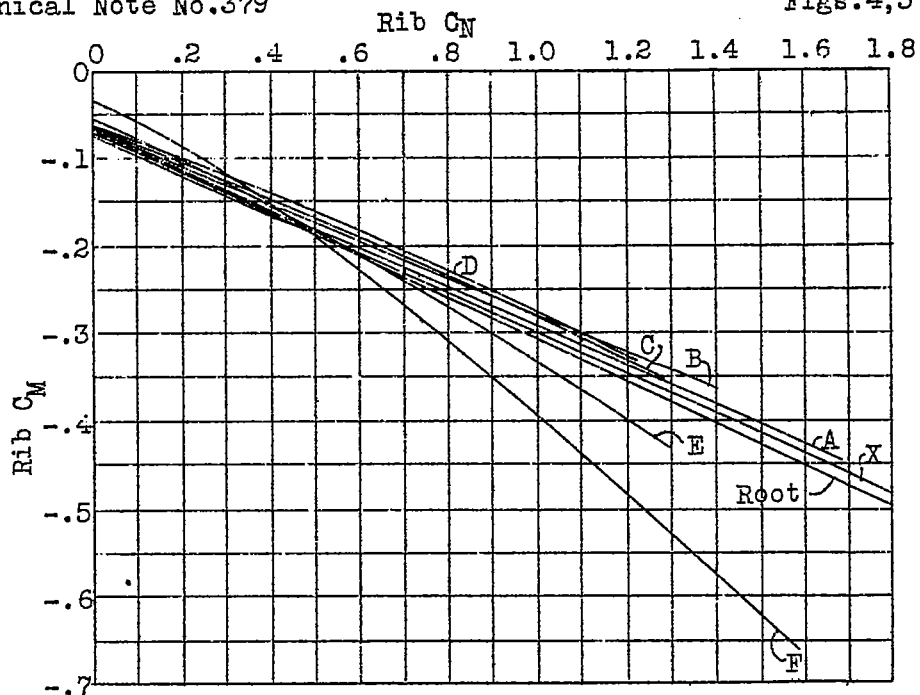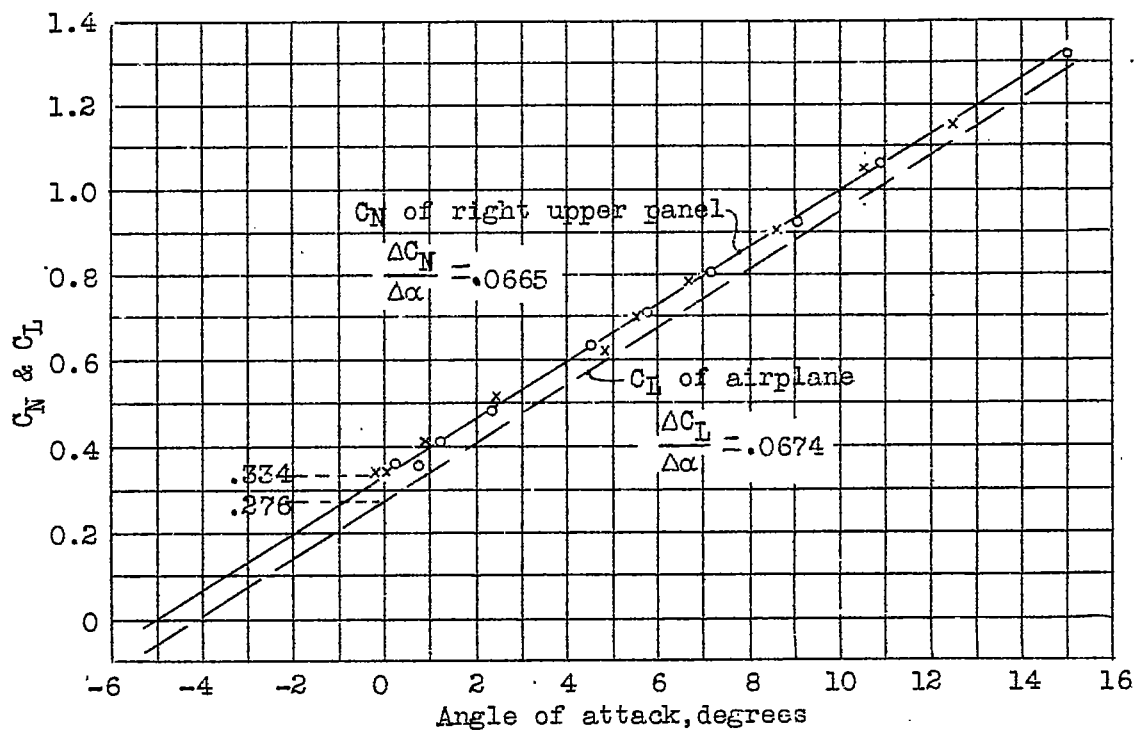

Fig.2j Pressure distribution. Wing C_N=1.574

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.