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A.R.C. Technical Report

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CURRENT PAPERS

Tests on a Swept-back Wing and Body with Endplates and Wing Tip Tanks in the Compressed Air Tunnel

By

C. Salter, M.A. and R. Jones, M.A., D.Sc.,

of the Aerodynamics Division, N.P.L.

With an Appendix

Comparison between the Measured Lift and Drag and Calculated Values for the Wing with Tip Tanks

By

Dr. J. Weber

of the R.A.E.

LONDON · HER MAJESTY'S STATIONERY OFFICE

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THREE SHILLINGS NET

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Tests on a Swept-back Wing and Body with Endplates and Wing Tip Tanks in the Compressed Air Tunnel

- By -
C. Salter, M.A., and R. Jones, M.A., D.Sc.,*
of the Aerodynamics Division, N.P.L.

3rd June, 1954

SUMMARY

In this report results are given of experiments carried out to determine the effect, in respect of lift, drag and pitching moment, of wing tip tanks and of two sizes of endplates on the tapered swept wing model already examined and described in Ref. 1.

The tests were undertaken primarily in order to extend the range of R for checks on the theoretical considerations of Ref. 2.

As regards lift and pitching moment the effects are found to be fairly well defined. The drag characteristics are however, less consistent but it appears that endplates have the effect of reducing the drag of the model over quite a large range of C_L. This does not apply in the case of wing tip tanks.

Introduction

The investigation follows the theoretical treatment of the effects of endplates on swept wings as described in Ref. 2 and the experimental results obtained at low Reynolds numbers at the R.A.E. It was undertaken in order to extend the range of R of the tests on endplates and to obtain evidence relating to typical wing tip tanks.

The tests were expected to involve the accurate measurement of quite small differences, e.g., about 2% theoretical increase in C_L for the small endplates, 3% for the large ones, with correspondingly accurate estimations (by differences) of ΔC_D for specified values of C_L^2.

The balance was known to be inherently capable of measuring such small differences with sufficient accuracy, except perhaps at the lower Reynolds numbers, but it was not known whether the readings would be steady enough for its full scope to be utilized. This would depend on the steadiness of the flow pattern on the model.

Model/

*The experimental work was carried out before Dr. Jones retired from official duties.

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Model

Most of the information relating to the model is given in Ref. 1 and is therefore not included in the present report. The modified outline is however reproduced in Fig. 1; the only differences from the previous model being in respect of the wing tips.

The four model conditions were as follows:-

(a) With square ended wing tips, i.e., parallel to the body centre line,

(b) with small endplates,

(c) with large endplates,

(d) with wing tip tanks.

The end plates were respectively 9.46 and 10.27 in. long, and 1.61 and 2.42 in. deep, the ends being semicircular (gross mean chord of model 13.59 in.). They were 14 S.W.G. thick and symmetrically placed about the wing tip chord line.

The tip tanks were 19.4 in. long with the maximum diameter of 2.42 in. extending from 35 to 55% of their length. They had the same angle of incidence as the wing tips and the mid points of their centre lines were situated in line with the mid points of the wing tip chords.

Range of Tests

The main tests covered angles of incidence from small negative values to high ones above the stall at Reynolds numbers ranging from 10^6 to 13×10^6. Measurements include those of lift, drag and pitching moment.

Some measurements were also made up to $R = 4 \times 10^6$ with two sizes of transition wires (0.01 and 0.016 in. diameter respectively) at 10% local chord from the leading edge on both surfaces.

Tables and Figures

Table I gives the observed results, for various angles of incidence up to 21°, without the use of transition wires (observations were actually continued up to 27.5°); Table II are those with transition wires as specified up to $\alpha = 16°$.

For a variety of reasons somewhat more scatter is present in the drag values than is desirable for the purpose of estimating ΔC_D. The procedure for reducing any uncertainties involved, if time had been available, would have been to carry out a fair amount of repetition of the observations after the first results had been fully evaluated and examined. As an alternative a further set of values of C_D is recorded in Table III. These are obtained from smoothed curves which, on the basis of past experience are judged to be probably the best smoothed curves.

For the same reason Table IV is included giving what are considered to be the best values of the slope and slope ratios of the C_D —— C_L^2 curves in the lower range of C_L. The points are also plotted in Fig. 6 but the table assists in the indication, by bracketed values, of where it is somewhat difficult to decide just what the value actually is.

Table IV gives the corresponding properties when transition wires are applied. The slope values are also plotted in Fig. 6.

The/

The figures in general are self explanatory. In particular, however, Fig. 7 shows typical curves at a high value of R for the variations of ΔC_D with C_L^2 in respect of the three tip forms.

In Fig. 3 the sequence of the curves is different from that in Figs. 2 and 4 and this difference is not to be taken as being due to a misprint.

Results

The same values of S and c have been taken as for the original model irrespective of the wing tip configuration.

Typical curves of C_L —— α, C_m —— C_L, C_D —— C_L and C_D —— C_L^2 at $R = 12 \times 10^6$ are shown in Figs. 2, 3 and 4. Generally speaking the major scale effects on the main characteristics appear in the range up to $R = 4 \times 10^6$. It will be noticed that the dip in the C_m —— C_L curve at $C_L = 0.8$ to 0.9 disappears with the fitting of endplates or tanks.

Scale effect on $d C_L/d\alpha$ is not large and on the ratios of the slopes is quite small (Fig. 5). The ratio is fairly constant at 1.025 for the small endplates and varies from 1.05 at low R to 1.035 at high R for the large plates. It is much higher for the tip tanks. The theoretical values mentioned earlier are 1.022 and 1.032 and refer to the ratio of values of C_L which, however, as this is not a strictly symmetrical model, is not the same as the ratio of slopes. C_{Lmax} generally occurs at angles of incidence greater than 21°.

Curves of C_{Dmin} —— R, taken from the smoothed curves, are also given in Fig. 5 and follow a normal pattern. Values of $d C_D/d C_L^2$ and their ratios are plotted in Fig. 6. Scale effect is considerable and the effect of endplates and tanks is not entirely consistent. The attachments result in an increased slope up to $R = 7$ or 8×10^6 and a decreased slope above this.

For the present purpose however the relations between ΔC_D and C_L^2 are of greater interest. It is known that in many cases the fitting of endplates can lead to a reduced drag at convenient values of C_L. The curves of ΔC_D —— C_L^2 show appreciable scale effect and the linear range is sometimes rather uncertain. Only the curves for $R = 12 \times 10^6$ are therefore reproduced in the present report (Fig. 7). On two of these the straight lines through the origins indicate the slopes anticipated from the considerations of Ref. 2. Further consideration is required from the theoretical aspect.

Generally speaking, except at the lower Reynolds numbers, ΔC_D with endplates has negative values for an appreciable range of C_L. With tip tanks ΔC_D is always positive and increases rapidly with C_L at low R but remains almost constant up to C_L of roughly 0.45 at high R.

The effect of transition wires on $d C_D/d C_L^2$ is shown in Fig.6. As would be expected the slope is much reduced but to a value even lower than at top R. It may be noted that at $R = 1.1 \times 10^6$ violent fluctuations showed that the thin wires were barely thick enough. Nevertheless, at $R = 1.5 \times 10^6$, the thick wires gave a higher value than the thin, both slopes being quite well defined.

Conclusion

The results presented in this report cover the effect of endplates and tip tanks on the three basic characteristics of an aircraft for a large range of R and of α.

They are given in some detail because of the desire to link them with the theoretical conclusions of Ref. 2. Although the inherent precision of the

C.A.T./

C.A.T. balance is very great, the extreme accuracy required for this particular investigation would have rendered further check measurements desirable if time had permitted and if the model had not introduced some uncertainty in not being symmetrical (see Fig. 1).

The results have, however, been fairly carefully checked for observation and calculation errors, and suggestions are made as to the best smoothing of the curves where some scatter of the points is present. Closer identification of the best smoothed curves can be obtained if desired by superposition of the observations for several adjacent values of R in ranges where scale effect can be seen to be negligible.

References

No.	Author(s)	Title, etc.
1	C. Salter, C. J. W. Miles and Miss H. M. Lee	Tests on a swept-back wing and body in the Compressed Air Tunnel. R. & M. 2738. May, 1950.
2	D. Küchemann and D. J. Kettle	The effect of endplates on swept wings. R.A.E. Report No. Aero. 2429. C.P. 104. June, 1951.

Table I/

Table I

Square Tips				Large Endplates				Small Endplates				Tip Tanks			
P = 2.06 Atmos ρV^2 = 24.65 lb/sq ft V = 70.6 f.p.s. R = 1.06×10^6				P = 2.17 Atmos ρV^2 = 24.65 lb/sq ft V = 69.6 f.p.s. R = 1.07×10^6				P = 2.09 Atmos ρV^2 = 24.65 lb/sq ft V = 71.2 f.p.s. R = 1.03×10^6				P = 2.19 Atmos ρV^2 = 24.65 lb/sq ft V = 70.1 f.p.s. R = 1.04×10^6			
α	C_L	C_D	C_m	α	C_L	C_D	C_m	α	C_L	C_D	C_m	α	C_L	C_D	C_m
-2.4	-0.149	0.0148	-0.0081	-2.4	-0.153	0.0172	-0.0051	-2.4	-0.151	0.0170$_5$	-0.0067	-2.35	-0.164	0.0181	-0.0013
-1.1	-0.083	0.0120	-0.0080	-1.1	-0.089	0.0138	-0.0058	-1.1	-0.082	0.0148	-0.0082	-1.1	-0.097	0.0129	-0.0030
+0.1	-0.021	0.0112	-0.0082	+0.1	-0.019	0.0124	-0.0081	+0.1	-0.016	0.0120	-0.0093	+0.1	-0.021	0.0119	-0.0088
1.3	+0.048	0.0114	-0.0099	1.3	+0.053	0.0121	-0.0115	1.3	+0.053	0.0113	-0.0115	1.3	+0.058	0.0123	-0.0146
2.55	0.115$_5$	0.0120$_5$	-0.0092	2.5	0.120	0.0140	-0.0130	2.55	0.122	0.0133	-0.0128	2.5	0.128	0.0134	-0.0177
3.75	0.179	0.0148	-0.0099	3.75	0.185	0.0163	-0.0144	3.8	0.184	0.0156	-0.0137	3.75	0.199	0.0166	-0.0218
5.0	0.247	0.0179	-0.0115	5.0	0.256	0.0197	-0.0174	5.0	0.252	0.0190	-0.0164	4.95	0.277	0.0213	-0.0273
6.15	0.314	0.0211$_5$	-0.0132	6.15	0.327	0.0241	-0.0220	6.15	0.324	0.0236	-0.0201	6.1	0.353	0.0272	-0.0342
7.4	0.383	0.0268	-0.0166	7.35	0.401	0.0304	-0.0263	7.4	0.396	0.0296	-0.0239	7.35	0.426	0.0354	-0.0413
8.6	0.451	0.0363	-0.0191	8.6	0.466	0.0396	-0.0291	8.6	0.463	0.0390	-0.0263	8.55	0.497	0.0473	-0.0466
9.8	0.524	0.0552	-0.0249	9.8	0.534	0.0591	-0.0310	9.8	0.532	0.0576	-0.0291	9.75	0.576	0.0671	-0.0526
11.0	0.597	0.0802	-0.0276	11.0	0.600	0.0815	-0.0290	11.0	0.596	0.0816	-0.0280	10.95	0.642	0.0917	-0.0529
12.25	0.667	0.106$_5$	-0.0253	12.25	0.661	0.107	-0.0238	12.25	0.654	0.107	-0.0233	12.2	0.705	0.118$_5$	-0.0478
13.5	0.714	0.130	-0.0192	13.5	0.708	0.132$_5$	-0.0175	13.5	0.708	0.133$_5$	-0.0175	13.45	0.753	0.143	-0.0406
14.7	0.759	0.161	-0.0181	14.7	0.742	0.160	-0.0135	14.7	0.740	0.159	-0.0139	14.65	0.787	0.170	-0.0363
15.95	0.807	0.192	-0.0159	15.95	0.783	0.186$_5$	-0.0113	15.95	0.778	0.189	-0.0121	15.9	0.833	0.202$_5$	-0.0355
17.2	0.848	0.221	-0.0162	17.25	0.819	0.217	-0.0110	17.25	0.816	0.218	-0.0122	17.15	0.868	0.235$_5$	-0.0349
18.5	0.891	0.252	-0.0164	18.55	0.851	0.247	-0.0109	18.45	0.855	0.248	-0.0129	18.45	0.919	0.271	-0.0376
19.75	0.921	0.289	-0.0174	19.8	0.885	0.285	-0.0114	19.7	0.879	0.287	-0.0136	19.75	0.935	0.301	-0.0336
21.05	0.943	0.326	-0.0179	21.1	0.892	0.316	-0.0128	21.1	0.900	0.317$_5$	-0.0139	21.05	0.960	0.338	-0.0346

Table I (Cont'd.)/

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Square Tips				Large Endplates				Small Endplates				Tip Tanks			
P = 3.88 Atmos ρV^2 = 49.2 lb/sq ft V = 72.9 f.p.s. R = 2.05×10^6				P = 4.53 Atmos ρV^2 = 49.2 lb/sq ft V = 67.8 f.p.s. R = 2.20×10^6				P = 4.68 Atmos ρV^2 = 49.25 lb/sq ft V = 67.3 f.p.s. R = 2.18×10^6				P = 4.09 Atmos ρV^2 = 49.2 lb/sq ft V = 72.4 f.p.s. R = 2.01×10^6			
α	C_L	C_D	C_m	α	C_L	C_D	C_m	α	C_L	C_D	C_m	α	C_L	C_D	C_m
-2.45	-0.155	0.0145	-0.0054	-2.45	-0.160	0.0146	-0.0024	-2.45	-0.160	0.0135	-0.0033	-2.4	-0.173	0.0148	+0.0026
-1.15	-0.084	0.0120	-0.0065	-1.15	-0.094	0.0119	-0.0041	-1.15	-0.093	0.0119	-0.0048	-1.15	-0.102	0.0121	-0.0013
+0.05	-0.021	0.0110	-0.0079	+0.1	-0.024	0.0110	-0.0069	+0.1	-0.024	0.0105	-0.0069	+0.05	-0.025	0.0106	-0.0065
1.25	+0.045	0.0104	-0.0089	1.25	+0.048	0.0109	-0.0101	1.25	+0.047	0.0108	-0.0098	1.25	+0.049	0.0108	-0.0124
2.5	0.111	0.0119	-0.0088	2.5	0.116	0.0124	-0.0115	2.5	0.112	0.0123	-0.0106	2.45	0.120	0.0126	-0.0157
3.7	0.179	0.0148	-0.0114	3.7	0.187	0.0157	-0.0156	3.75	0.184	0.0149	-0.0135	3.7	0.195	0.0161	-0.0220
4.95	0.249	0.0182	-0.0141	4.9	0.259	0.0190	-0.0201	4.95	0.253	0.0187	-0.0181	4.9	0.273	0.0201	-0.0283
6.1	0.315	0.0227	-0.0165	6.1	0.329	0.0234	-0.0239	6.1	0.324	0.0229	-0.0212	6.05	0.348	0.0266	-0.0346
7.35	0.387	0.0275	-0.0190	7.35	0.397	0.0293	-0.0271	7.35	0.391	0.0285	-0.0244	7.3	0.421	0.0339	-0.0408
8.55	0.449	0.0338	-0.0211	8.55	0.465	0.0352	-0.0300	8.55	0.458	0.0343	-0.0265	8.5	0.492	0.0423	-0.0479
9.75	0.516	0.0414	-0.0234	9.75	0.531	0.0435	-0.0329	9.75	0.526	0.0419	-0.0287	9.7	0.562	0.0542	-0.0553
11.0	0.581	0.0504	-0.0255	10.95	0.596	0.0528	-0.0353	10.95	0.590	0.0506	-0.0305	10.9	0.625	0.0677	-0.0596
12.2	0.643	0.0600	-0.0275	12.2	0.660	0.0639	-0.0376	12.2	0.654	0.0620	-0.0323	12.15	0.692	0.0853	-0.0628
13.45	0.712	0.0742	-0.0326	13.45	0.717	0.0855	-0.0392	13.45	0.719	0.0808	-0.0369	13.4	0.752	0.108_5	-0.0646
14.6	0.782	0.101	-0.0415	14.65	0.766	0.117	-0.0381	14.65	0.772	0.112_5	-0.0382	14.55	0.305	0.133_5	-0.0628
15.85	0.834	0.140	-0.0436	15.9	0.803	0.149_5	-0.0335	15.9	0.814	0.147_5	-0.0361	15.8	0.858	0.165_5	-0.0593
17.1	0.875	0.182	-0.0401	17.15	0.851	0.197	-0.0306	17.15	0.849	0.191	-0.0304	17.1	0.895	0.200	-0.0524
18.45	0.904	0.224	-0.0359	18.5	0.860	0.233	-0.0212	18.45	0.872	0.234	-0.0249	18.4	0.914	0.249	-0.0470
19.7	0.932	0.265	-0.0359	19.75	0.888	0.271	-0.0206	19.75	0.895	0.253	-0.0213	19.7	0.940	0.293	-0.0446
21.0	0.947	0.304	-0.0342	21.05	0.909	0.311	-0.0204	21.05	0.907	0.312	-0.0199	21.0	0.958	0.336	-0.0437

Table I (Cont'd.)/

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Square Tips				Large Endplates				Small Endplates				Tip Tanks			
P = 8.4 Atmos ρV^2 = 98.9 lb/sq ft V = 70.9 f.p.s. R = 4.19×10^6				P = 7.9 Atmos ρV^2 = 98.9 lb/sq ft V = 73.4 f.p.s. R = 4.04×10^6				P = 8.35 Atmos ρV^2 = 98.9 lb/sq ft V = 71.5 f.p.s. R = 4.13×10^6				P = 3.55 Atmos ρV^2 = 98.9 lb/sq ft V = 71.3 f.p.s. R = 4.08×10^6			
α	C_L	C_D	C_m	α	C_L	C_D	C_m	α	C_L	C_D	C_m	α	C_L	C_D	C_m
-2.45	-0.159	0.0142	-0.0023	-2.4	-0.164	0.0149	+0.0011	-2.45	-0.163	0.0144	+0.0001	-2.4	-0.178	0.0154	+0.0069
-1.15	-0.092	0.0117	-0.0052	-1.15	-0.092	0.0119	-0.0032	-1.15	-0.091	0.0117	-0.0040	-1.15	-0.102	0.0120	0
+0.05	-0.021	0.0103	-0.0077	+0.05	-0.022	0.0104	-0.0063	+0.05	-0.023	0.0104	-0.0068	+0.05	-0.025	0.0108	-0.0061
1.25	+0.048	0.0108	-0.0096	1.25	+0.050	0.0108	-0.0099	1.25	+0.047	0.0106	-0.0097	1.25	+0.051	0.0108	-0.0120
2.5	0.115	0.0121	-0.0109	2.45	0.119	0.0125	-0.0133	2.5	0.116	0.0121	-0.0125	2.45	0.125	0.0123	-0.0179
3.7	0.183	0.0145	-0.0139	3.7	0.189	0.0148	-0.0179	3.7	0.187	0.0147	-0.0168	3.65	0.202	0.0156	-0.0252
4.95	0.251	0.0175	-0.0163	4.9	0.262	0.0183	-0.0220	4.95	0.256	0.0182	-0.0204	4.9	0.278	0.0201	-0.0313
6.1	0.318	0.0218	-0.0190	6.1	0.332	0.0225	-0.0258	6.1	0.327	0.0224	-0.0237	6.05	0.351	0.0249	-0.0370
7.35	0.387	0.0271	-0.0217	7.3	0.406	0.0281	-0.0302	7.35	0.397	0.0273	-0.0271	7.25	0.429	0.0317	-0.0438
8.55	0.457	0.0335	-0.0250	8.55	0.475	0.0349	-0.0341	8.55	0.463	0.0335	-0.0302	8.5	0.500	0.0404	-0.0506
9.75	0.522	0.0407	-0.0278	9.7	0.542	0.0423	-0.0380	9.75	0.531	0.0411	-0.0337	9.65	0.570	0.0504	-0.0585
10.95	0.588	0.0486	-0.0307	10.95	0.610	0.0507	-0.0412	10.95	0.598	0.0497	-0.0365	10.85	0.640	0.0619	-0.0661
12.2	0.650	0.0586	-0.0334	12.2	0.678	0.0609	-0.0444	12.2	0.662	0.0593	-0.0393	12.1	0.697	0.0751	-0.0704
13.4	0.717	0.0687	-0.0363	13.4	0.737	0.0734	-0.0476	13.4	0.729	0.0698	-0.0421	13.35	0.766	0.0912	-0.0746
14.6	0.781	0.0805	-0.0398	14.6	0.800	0.0865	-0.0500	14.6	0.790	0.0825	-0.0446	14.55	0.819	0.111_5	-0.0771
15.85	0.837	0.0933	-0.0424	15.85	0.854	0.112	-0.0504	15.85	0.849	0.0975	-0.0475	15.75	0.872	0.134	-0.0768
17.1	0.908	0.108_5	-0.0476	17.1	0.886	0.148_5	-0.0436	17.1	0.886	0.132	-0.0455	17.0	0.924	0.164	-0.0738
18.4	0.948	0.171	-0.0531	18.4	0.918	0.193_5	-0.0390	18.45	0.912	0.190	-0.0410	18.35	0.964	0.207	-0.0727
19.7	0.959	0.232	-0.0428	19.7	0.924	0.242	-0.0335	19.7	0.928	0.238	-0.0356	19.6	0.982	0.255	-0.0663
20.95	0.970	0.280	-0.0359	21.0	0.944	0.285	-0.0355	21.0	0.946	0.284	-0.0370	20.9	1.001	0.298	-0.0638

Table I (Cont'd.)/

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Square Tips				Large Endplates				Small Endplates				Tip Tanks			
P = 16.3 Atmos ρV^2 = 198.6 lb/sq ft V = 72.2 f.p.s. R = 8.20×10^6				P = 16.9 Atmos ρV^2 = 198.6 lb/sq ft V = 71.8 f.p.s. R = 8.10×10^6				P = 17.2 Atmos ρV^2 = 198.5 lb/sq ft V = 71.8 f.p.s. R = 8.03×10^6				P = 16.6 Atmos ρV^2 = 198.6 lb/sq ft V = 72.8 f.p.s. R = 8.03×10^6			
α	C_L	C_D	C_m	α	C_L	C_D	C_m	α	C_L	C_D	C_m	α	C_L	C_D	C_m
-2.45	-0.164	0.0135	-0.0008	-2.45	-0.170	0.0144	+0.0026	-2.45	-0.166	0.0147	+0.0008	-2.4	-0.179	0.0156	+0.0077
-1.15	-0.091	0.0119	-0.0038	-1.15	-0.095	0.0122	-0.0017	-1.15	-0.096	0.0120	-0.0025	-1.15	-0.103	0.0126	+0.0016
+0.05	-0.022	0.0106	-0.0065	+0.05	-0.023	0.0114	-0.0062	+0.05	-0.019	0.0109	-0.0067	+0.05	-0.024	0.0114	-0.0060
1.25	+0.047	0.0105	-0.0089	1.25	+0.046	0.0110	-0.0102	1.25	+0.049	0.0109	-0.0103	1.2	+0.054	0.0113	-0.0133
2.45	0.115	0.0113	-0.0110	2.45	0.119	0.0122	-0.0141	2.45	0.118	0.0122	-0.0135	2.4	0.128	0.0128	-0.0193
3.7	0.185	0.0135	-0.0145	3.7	0.189	0.0141	-0.0188	3.7	0.187	0.0135	-0.0175	3.65	0.205	0.0150	-0.0263
4.9	0.252	0.0165	-0.0170	4.9	0.260	0.0178	-0.0233	4.9	0.260	0.0179	-0.0220	4.85	0.278	0.0190	-0.0321
6.1	0.322	0.0212	-0.0204	6.05	0.333	0.0218	-0.0278	6.05	0.328	0.0219	-0.0256	6.0	0.355	0.0240	-0.0387
7.3	0.389	0.0259	-0.0234	7.3	0.399	0.0272	-0.0320	7.3	0.399	0.0268	-0.0293	7.25	0.428	0.0309	-0.0452
8.55	0.459	0.0322	-0.0269	8.5	0.471	0.0337	-0.0366	8.5	0.467	0.0333	-0.0334	8.45	0.499	0.0384	-0.0520
9.75	0.522	0.0400	-0.0305	9.7	0.540	0.0411	-0.0410	9.7	0.532	0.0406	-0.0370	9.6	0.513	0.0481	-0.0601
10.95	0.591	0.0472	-0.0337	10.9	0.603	0.0498	-0.0447	10.95	0.603	0.0485	-0.0407	10.8	0.637	0.0592	-0.0681
12.2	0.656	0.0566	-0.0374	12.15	0.676	0.0595	-0.0491	12.15	0.668	0.0582	-0.0440	12.05	0.704	0.0733	-0.0741
13.4	0.723	0.0678	-0.0405	13.35	0.740	0.0708	-0.0527	13.35	0.737	0.0685	-0.0471	13.3	0.762	0.0872	-0.0763
14.6	0.782	0.0783	-0.0427	14.55	0.803	0.0837	-0.0553	14.55	0.797	0.0806	-0.0499	14.45	0.819	0.105	-0.0761
15.85	0.843	0.0918	-0.0452	15.8	0.853	0.102_5	-0.0537	15.8	0.854	0.0952	-0.0523	15.7	0.874	0.124	-0.0781
17.1	0.902	0.107	-0.0480	17.1	0.894	0.130	-0.0506	17.05	0.898	0.128	-0.0510	16.95	0.918	0.150_5	-0.0782
18.4	0.935	0.151_5	-0.0515	18.35	0.910	0.184	-0.0409	18.4	0.918	0.176	-0.0445	18.3	0.955	0.200	-0.0726
19.7	0.948	0.243	-0.0412	19.7	0.918	0.238	-0.0368	19.75	0.928	0.236	-0.0371	19.6	0.982	0.247	-0.0690
21.05	0.954	0.292	-0.0349	21.05	0.933	0.287	-0.0358	21.0	0.935	0.284	-0.0376	20.9	0.990	0.298	-0.0656

Table I (Cont'd.)/

Table I (Cont'd.)

Square Tips				Large Endplates				Small Endplates				Tip Tanks			
P = 20.4 Atmos ρV^2 = 252 lb/sq ft V = 73.8 f.p.s. R = 10.0×10^6				P = 20.4 Atmos ρV^2 = 252 lb/sq ft V = 73.3 f.p.s. R = 10.22×10^6				P = 21.3 Atmos ρV^2 = 252 lb/sq ft V = 72.3 f.p.s. R = 10.2×10^6				P = 21.9 Atmos ρV^2 = 252 lb/sq ft V = 73.1 f.p.s. R = 9.78×10^6			
α	C_L	C_D	C_m	α	C_L	C_D	C_m	α	C_L	C_D	C_m	α	C_L	C_D	C_m
-2.45	-0.162	0.0141	-0.0013	-2.45	-0.167	0.0143	+0.0024	-2.45	-0.166	0.0143	+0.0010	-2.4	-0.182	0.0150	+0.0087
-1.2	-0.091	0.0119	-0.0040	-1.15	-0.096	0.0119	-0.0016	-1.2	-0.094	0.0121	-0.0026	-1.15	-0.103	0.0131	+0.0015
+0.05	-0.0187	0.0103	-0.0064	+0.05	-0.024	0.0108	-0.0057	+0.05	-0.023	0.0105	-0.0063	+0.05	-0.024	0.0116	-0.0057
1.2	+0.048	0.0105	-0.0088	1.2	+0.046	0.0113	-0.0102	1.2	+0.048	0.0110	-0.0099	1.2	+0.052	0.0116	-0.0127
2.45	0.117	0.0114	-0.0113	2.45	0.119	0.0119	-0.0142	2.45	0.118	0.0119	-0.0134	2.4	0.128	0.0127	-0.0194
3.7	0.187	0.0135	-0.0147	3.65	0.190	0.0143	-0.0191	3.65	0.189	0.0138	-0.0178	3.6	0.205	0.0151	-0.0267
4.9	0.255	0.0168	-0.0174	4.9	0.261	0.0171	-0.0232	4.9	0.261	0.0172	-0.0218	4.85	0.277	0.0186	-0.0326
6.1	0.322	0.0212	-0.0207	6.05	0.332	0.0214	-0.0277	6.05	0.330	0.0214	-0.0259	6.0	0.350	0.0241	-0.0392
7.3	0.391	0.0260	-0.0239	7.3	0.402	0.0266	-0.0323	7.3	0.399	0.0266	-0.0275	7.2	0.427	0.0303	-0.0459
8.55	0.458	0.0326	-0.0272	8.5	0.473	0.0333	-0.0368	8.5	0.466	0.0329	-0.0336	8.4	0.502	0.0383	-0.0534
9.7	0.526	0.0397	-0.0307	9.65	0.544	0.0408	-0.0413	9.7	0.536	0.0407	-0.0376	9.55	0.572	0.0475	-0.0603
10.95	0.595	0.0475	-0.0339	10.9	0.608	0.0494	-0.0450	10.9	0.605	0.0467	-0.0410	10.75	0.644	0.0606	-0.0699
12.15	0.656	0.0579	-0.0372	12.15	0.679	0.0595	-0.0490	12.15	0.666	0.0581	-0.0441	12.0	0.706	0.0733	-0.0757
13.4	0.719	0.0679	-0.0400	13.35	0.741	0.0702	-0.0523	13.4	0.734	0.0683	-0.0467	13.25	0.761	0.0883	-0.0777
14.6	0.780	0.0803	-0.0423	14.55	0.798	0.0835	-0.0540	14.55	0.793	0.0797	-0.0485	14.45	0.817	0.1045	-0.0774
15.85	0.840	0.0923	-0.0436	15.85	0.846	0.1045	-0.0516	15.8	0.845	0.1025	-0.0491	15.7	0.869	0.1255	-0.0797
17.05	0.898	0.1265	-0.0529	17.1	0.885	0.1355	-0.0470	17.1	0.892	0.132	-0.0482	16.95	0.915	0.1455	-0.0762
18.45	0.911	0.216	-0.0386	18.45	0.896	0.196	-0.0386	18.45	0.904	0.194	-0.0417	18.3	0.948	0.203	-0.0726
19.75	0.920	0.264	-0.0317	19.8	0.909	0.251	-0.0327					19.6	0.972	0.254	-0.0671
21.05	0.933	0.304	-0.0341	21.05	0.916	0.293	-0.0303	21.05	0.918	0.291	-0.0322	20.9	0.988	0.304	-0.0637

Table I (Cont'd.)/

Table I (Cont'd.)

Square Tips				Large Endplates				Small Endplates				Tip Tanks			
P = 23.95 Atmos ρV^2 = 311.4 lb/sq ft V = 75.8 f.p.s. R = 12.04×10^6				P = 25.15 Atmos ρV^2 = 311.4 lb/sq ft V = 75.7 f.p.s. R = 11.68×10^6				P = 24.7 Atmos ρV^2 = 311.4 lb/sq ft V = 75.7 f.p.s. R = 11.84×10^6				P = 25.1 Atmos ρV^2 = 311.4 lb/sq ft V = 75.6 f.p.s. R = 11.7×10^6			
α	C_L	C_D	C_m	α	C_L	C_D	C_m	α	C_L	C_D	C_m	α	C_L	C_D	C_m
-2.5	-0.160	0.0137	-0.0013	-2.45	-0.170	0.0145	+0.0030	-2.45	-0.168	0.0144	+0.0004	-2.4	-0.180	0.0154	+0.0085
-1.2	-0.090	0.0116	-0.0040	-1.2	-0.097	0.0120	-0.0016	-1.2	-0.094	0.0123	-0.0028	-1.15	-0.103	0.0124	+0.0016
+0.05	-0.020	0.0107	-0.0067	+0.05	-0.026	0.0112	-0.0059	+0.05	-0.023	0.0109	-0.0063	+0.05	-0.027	0.0114	-0.0053
1.2	+0.048	0.0107	-0.0089	1.2	+0.046	0.0108	-0.0101	+1.2	+0.049	0.0107	-0.0098	1.2	+0.050	0.0110	-0.0123
2.45	0.119	0.0112	-0.0113	2.45	0.119	0.0117	-0.0143	2.45	0.117	0.0117	-0.0133	2.4	0.127	0.0121	-0.0187
3.7	0.187	0.0137	-0.0148	3.65	0.190	0.0137	-0.0190	3.65	0.191	0.0136	-0.0179	3.6	0.204	0.0147	-0.0265
4.9	0.255	0.0167	-0.0176	4.9	0.261	0.0169	-0.0236	4.9	0 260	0.0167	-0.0218	4.8	0.278	0.0186	-0.0328
6.1	0.324	0.0207	-0.0208	6.05	0.333	0.0207	-0.0280	6.05	0.331	0.0206	-0.0260	5.95	0.354	0.0233	-0.0391
7.3	0.394	0.0262	-0.0242	7.25	0.404	0.0263	-0.0325	7.25	0.402	0.0259	-0.0299	7.2	0.428	0.0297	-0.0458
8.55	0.463	0.0325	-0.0277	8.5	0.474	0.0327	-0.0370	8.5	0.470	0.0324	-0.0337	8.4	0.499	0.0375	-0.0526
9.7	0.530	0.0402	-0.0312	9.65	0.544	0.0406	-0.0416	9.7	0.539	0.0402	-0.0378	9.55	0.572	0.0473	-0.0605
10.95	0.593	0.0485	-0.0342	10.9	0.610	0.0494	-0.0457	10.9	0.608	0.0485	-0.0414	10.75	0.642	0.0592	-0.0684
12.15	0.661	0.0574	-0.0373	12.15	0.676	0.0592	-0.0495	12.15	0.673	0.0580	-0.0442	11.95	0.704	0.0736	-0.0741
13.4	0.722	0.0678	-0.0399	13.35	0.741	0.0706	-0.0527	13.35	0.734	0.0685	-0.0467	13.2	0.762	0.0883	-0.0758
14.6	0.781	0.0796	-0.0414	14.5	0.801	0.0847	-0.0542	14.55	0.799	0.0801	-0.0486	14.4	0.820	0.106	-0.0784
15.8	0.845	0.106	-0.0490	15.8	0.848	0.1062	-0.0511	15.8	0.847	0.1035	-0.0480	15.65	0.870	0.129	-0.0799
17.05	0.886	0.1675	-0.0483	17.1	0.880	0.1446	-0.0455	17.05	0.887	0.1405	-0.0475	16.95	0.912	0.1585	-0.0753
18.5	0.904	0.233	-0.0357	18.5	0.893	0.2110	-0.0341	18.45	0.897	0.207	-0.0362	18.3	0.949	0.213	-0.0687
19.8	0.916	0.277	-0.0322	19.8	0.898	0.2590	-0.0279	19.8	0.912	0.256	-0.0314	19.6	0.970	0.270	-0.0602
21.05	0.928	0.316	-0.0330	21.05	0.917	0.3010	-0.0293	21.1	0.926	0.300	-0.0312	20.95	0.973	0.312	-0.0558

Table I (Cont'd)/

Table I (Cont'd)

Square Tips				Large Endplates				Small Endplates				Tip Tanks			
P = 24.8 Atmos ρV^2 = 354.5 lb/sq ft V = 80.3 f.p.s. R = 12.7×10^6				P = 24.5 Atmos ρV^2 = 354.5 lb/sq ft V = 81.0 f.p.s. R = 12.6×10^6				P = 24.5 Atmos ρV^2 = 354.5 lb/sq ft V = 80.0 f.p.s. R = 12.98×10^6				P = 24.5 Atmos ρV^2 = 354.5 lb/sq ft V = 80.75 f.p.s. R = 12.72×10^6			
α	C_L	C_D	C_m	α	C_L	C_D	C_m	α	C_L	C_D	C_m	α	C_L	C_D	C_m
-2.45	-0.161	0.0139	-0.0010	-2.45	-0.165	0.0145	+0.0024	-2.45	-0.167	0.0144	+0.0011	-2.45	-0.178	0.0149	-0.0081
-1.2	-0.093	0.0113	-0.0035	-1.2	-0.095	0.0122	-0.0017	-1.2	-0.095	0.0123	-0.0027	-1.15	-0.103	0.0126	+0.0013
+0.05	-0.023	0.0104	-0.0061	+0.05	-0.023	0.0111	-0.0060	+0.05	-0.023	0.0107	-0.0065	+0.05	-0.026	0.0111	-0.0056
1.2	+0.047	0.0104	-0.0086	1.2	+0.048	0.0112	-0.0101	1.2	+0.049	0.0106	-0.0100	1.2	+0.051	0.0108	-0.0124
2.45	0.116	0.0110	-0.0110	2.45	0.119	0.0120	-0.0141	2.45	0.121	0.0118	-0.0136	2.4	0.126	0.0123	-0.0188
3.7	0.186	0.0131	-0.0144	3.65	0.194	0.0144	-0.0194	3.65	0.190	0.0138	-0.0179	3.6	0.202	0.0142	-0.0260
4.9	0.257	0.0163	-0.0175	4.85	0.260	0.0167	-0.0231	4.9	0.259	0.0164	-0.0216	4.8	0.275	0.0181	-0.0321
6.1	0.323	0.0204	-0.0205	6.05	0.331	0.0208	-0.0273	6.05	0.333	0.0206	-0.0259	5.95	0.351	0.0232	-0.0386
7.3	0.395	0.0260	-0.0240	7.25	0.404	0.0266	-0.0322	7.25	0.403	0.0263	-0.0300	7.15	0.426	0.0296	-0.0453
8.55	0.463	0.0319	-0.0275	8.45	0.474	0.0336	-0.0368	8.5	0.472	0.0328	-0.0342	8.35	0.504	0.0374	-0.0525
9.7	0.530	0.0396	-0.0311	9.65	0.539	0.0406	-0.0408	9.65	0.538	0.0405	-0.0378	9.5	0.568	0.0466	-0.0593
10.95	0.596	0.0481	-0.0344	10.85	0.611	0.0490	-0.0450	10.9	0.606	0.0485	-0.0414	10.75	0.637	0.0582	-0.0669
12.15	0.662	0.0574	-0.0373	12.1	0.674	0.0600	-0.0487	12.1	0.673	0.0584	-0.0444	11.95	0.699	0.0723	-0.0722
13.3	0.720	0.0677	-0.0395	13.3	0.738	0.0709	-0.0519	13.35	0.739	0.0685	-0.0465	13.2	0.757	0.0863	-0.0745
14.6	0.786	0.0793	-0.0415	14.5	0.797	0.0843	-0.0525	14.55	0.794	0.0811	-0.0479	14.35	0.820	0.1055	-0.0781
15.8	0.848	0.1065	-0.0495	15.8	0.839	0.108	-0.0491	15.8	0.851	0.1055	-0.0479	15.5	0.868	0.1275	-0.0775
17.1	0.883	0.1715	-0.0464	17.1	0.869	0.158	-0.0407	17.1	0.876	0.148	-0.0409	16.95	0.902	0.1555	-0.0709
18.5	0.900	0.235	-0.0354	18.5	0.881	0.218	-0.0326	18.5	0.891	0.216	-0.0326	18.3	0.938	0.223	-0.0630
19.8	0.908	0.279	-0.0319	19.8	0.897	0.266	-0.0289	19.8	0.913	0.264	-0.0299	19.6	0.962	0.266	-0.0588
21.05	0.927	0.316	-0.0329	21.1	0.901	0.304	-0.0295	21.1	0.917	0.306	-0.0304	20.9	0.976	0.322	-0.0596

Table II/

Table II

No Wires				With Thick Transition Wires											
P = 1 Atmos ρV^2 = 12.07 lb/sq ft V = 72.1 f.p.s. R = 0.51×10^6				P = 1 Atmos ρV^2 = 12.07 lb/sq ft V = 72.3 f.p.s. R = 0.51×10^6				P = 2.21 Atmos ρV^2 = 24.7 lb/sq ft V = 68.8 f.p.s. R = 1.08×10^6				P = 3.23 Atmos ρV^2 = 34.2 lb/sq ft V = 68.1 f.p.s. R = 1.52×10^6			
α	C_L	C_D	C_m	α	C_L	C_D	C_m	α	C_L	C_D	C_m	α	C_L	C_D	C_m
-2.4	-0.148	0.0162	-0.0059	-2.4	-0.150	0.0194	-0.0021	-2.45	-0.159	0.0183	-0.0033	-2.45	-0.161	0.0173	-0.0039
-1.1	-0.083	0.0145	-0.0062	-1.1	-0.083	0.0174	-0.0043	-1.15	-0.090	0.0155	-0.0054	-1.15	-0.091	0.0154	-0.0057
+0.1	-0.014	0.0128	-0.0069	+0.1	-0.016	0.0167	-0.0058	+0.05	-0.022	0.0145	-0.0074	+0.05	-0.022	0.0141	-0.0074
1.3	+0.052	0.0128	-0.0076	1.3	+0.052	0.0168	-0.0077	1.25	+0.047	0.0149	-0.0090	1.25	+0.046	0.0141	-0.0091
2.55	0.115	0.0137	-0.0061	2.5	0.120	0.0180	-0.0097	2.5	0.116	0.0155	-0.0108	2.5	+0.112	0.0155	-0.0108
3.75	0.178	0.0165	-0.0074	3.75	0.186	0.0201	-0.0122	3.7	0.183	0.0171	-0.0127	3.7	0.181	0.0171	-0.0124
5.0	0.247	0.0205	-0.0112	5.0	0.252	0.0227	-0.0128	4.95	0.250	0.0207	-0.0138	4.95	0.249	0.0202	-0.0140
6.15	0.317	0.0257	-0.0164	6.15	0.315	0.0227	-0.0132	6.1	0.318	0.0250	-0.0164	6.1	0.315	0.0247	-0.0157
7.4	0.386	0.0335	-0.0186	7.4	0.381	0.0340	-0.0138	7.35	0.383	-	-0.0161	7.35	0.380	0.0295	-0.0171
8.6	0.470	0.0487	-0.0252	8.6	0.459	0.0510	-0.0213	8.55	0.448	0.0389	-0.0180	8.6	0.447	0.0362	-0.0189
9.8	0.536	0.0678	-0.0261	9.8	0.528	0.0706	-0.0238	9.75	0.525	0.0572	-0.0250	9.75	0.508	0.0453	-0.0202
11.0	0.598	0.0897	-0.0244	11.0	0.604	0.0873	-0.0232	10.95	0.602	0.0814	-0.0279	11.0	0.585	0.0672	-0.0276
12.25	0.651	0.111	-0.0206	12.25	0.660	0.113	-0.0199	12.2	0.666	0.106_5	-0.0244	12.2	0.655	0.0925	-0.0296
13.5	0.702	0.135	-0.0159	13.5	0.701	0.137	-0.0159	13.45	0.725	0.131_5	-0.0202	13.45	0.712	0.121_5	-0.0276
14.7	0.749	0.162	-0.0151	14.7	0.756	0.162	-0.0151	14.65	0.763	0.159	-0.0172	14.65	0.766	0.155_5	-0.0220
15.95	0.788	0.192	-0.0140	15.95	0.795	0.217	-0.0142	15.9	0.808	0.189	-0.0162	15.85	0.805	0.235	-0.0193

All these runs with square tip configuration

Table II (Cont'd.)/

Table II (Cont'd.)

With Thin Transition Wires

P = 0.99 Atmos ρV^2 = 12.1 lb/sq ft V = 71.5 f.p.s. R = 0.51 × 10^6				P = 3.18 Atmos ρV^2 = 34.2 lb/sq ft V = 67.2 f.p.s. R = 1.55 × 10^6				P = 4.18 Atmos ρV^2 = 49.2 lb/sq ft V = 70.4 f.p.s. R = 2.12 × 10^6				P = 8.43 Atmos ρV^2 = 98.95 lb/sq ft V = 72.4 f.p.s. R = 4.36 × 10^6			
α	C_L	C_D	C_m	α	C_L	C_D	C_m	α	C_L	C_D	C_m	α	C_L	C_D	C_m
-2.4	-0.142	0.0174	-0.0069	-2.45	-0.159	0.0172	-0.0036	-2.45	-0.160	0.0161	-0.0034	-2.45	-0.159	0.0149	-0.0028
-1.1	-0.078	0.0156	-0.0072	-1.15	-0.089	0.0147	-0.0056	-1.15	-0.091	0.0137	-0.0053	-1.15	-0.091	0.0130	-0.0049
+0.1	-0.012	0.0143	-0.0078	+0.05	-0.023	0.0136	-0.0073	+0.05	-0.023	0.0125	-0.0071	+0.05	-0.021	0.0117	-0.0068
1.3	+0.053	0.0144	-0.0079	1.25	+0.048	0.0141	-0.0095	1.25	+0.046	0.0128	-0.0090	1.25	+0.047	0.0117	-0.0090
2.55	0.118	0.0158	-0.0082	2.5	0.115	0.0150	-0.0111	2.5	0.114	0.0133	-0.0109	2.45	0.115	0.0125	-0.0113
3.75	0.183	0.0175	-0.0100	3.7	0.184	0.0166	0.0133	3.7	0.182	0.0158	-0.0132	3.7	0.183	0.0147	-0.0141
5.0	0.251	0.0213	-0.0124	4.95	0.249	0.0199	0.0147	4.95	0.250	0.0191	-0.0149	4.9	0.253	0.0183	-0.0171
6.15	0.320	0.0263	-0.0153	6.1	0.317	0.0238	0.0162	6.1	0.316	0.0231	-0.0169	6.1	0.319	0.0225	-0.0201
7.35	0.386	0.0327	-0.0169	7.35	0.382	0.0286	0.0176	7.35	0.383	0.0283	-0.0188	7.35	0.389	0.0275	-0.0235
8.55	0.462	0.0488	-0.0227	8.6	0.443	0.0347	0.0186	8.55	0.452	0.0343	-0.0208	8.55	0.457	0.0340	-0.0270
9.8	0.531	0.0685	-0.0246	9.75	0.508	0.0438	0.0205	9.75	0.517	0.0417	-0.0231	9.75	0.524	0.0416	-0.0314
11.0	0.596	0.0878	-0.0229	11.0	0.580	0.0642	0.0272	11.0	0.581	0.0504	-0.0248	10.95	0.592	0.0502	-0.0357
12.25	0.653	0.110	-0.0196	12.2	0.658	0.0899	0.0303	12.2	0.643	0.0630	-0.0280	12.2	0.658	0.0594	-0.0401
13.5	0.694	0.135	-0.0152	13.45	0.712	0.119	-0.0292	13.45	0.716	0.0870	-0.0364	13.4	0.725	0.0702	-0.0447
14.7	0.742	0.161	-0.0145	14.65	0.768	0.152	-0.0250	14.6	0.782	0.116	-0.0414	14.6	0.789	0.0817	-0.0491
15.95	0.793	0.191	-0.0141	15.85	0.838	0.204	-0.0325	15.85	0.828	0.150	-0.0413	15.85	0.853	0.0954	-0.0542

All these runs with square tip configuration

Table III/

Table III

Values of C_D taken from Smoothed Curves

C_L^2	C_D	C_D	ΔC_D	C_D	ΔC_D	C_D	ΔC_D
	Square Tips	Large Endplates		Small Endplates		Wing Tip Tanks	
R = 1.05							
0.002	0.0112	0.0125_5	0.0013_5	0.0114	0.0002	0.0120	+0.0008
0.004	0.0114	0.0128	0.0014	0.0116_5	0.0002_5	0.0122	0.0008
0.006	0.0115_5	0.0130	0.0014_5	0.0118_5	0.0003	0.0123_5	0.0008
0.008	0.0117_5	0.0132_5	0.0015	0.0121_5	0.0004	0.0125_5	0.0008
0.01	0.0120	0.0135	0.0015	0.0124	0.0004	0.0127	0.0007
0.02	0.0131	0.0147	0.0016	0.0138	0.0007	0.0139	0.0008
0.03	0.0142_5	0.0159	0.0016_5	0.0151	0.0008_5	0.0152_5	0.0010
0.04	0.0153	0.0170	0.0017	0.0163	0.0010	0.0165	0.0012
0.06	0.0174_5	0.0191_5	0.0017	0.0186	0.0011_5	0.0190	0.0015_5
0.08	0.0195	0.0213	0.0018	0.0209	0.0014	0.0215	0.0020
0.10	0.0216	0.0233	0.0017	0.0231	0.0015	0.0239	0.0023
0.15	0.0275	0.0289	0.0014	0.0289	0.0014	0.0305	0.0025
0.20	0.0345	0.0363	0.0018	0.0361	0.0016	0.0385	0.0040
0.25	0.0478	0.0478	0.0	0.0479	0.0001	0.0430	0.0002
0.30	0.0625	0.0640	0.0015	0.0630	0.0004	0.0592	-0.0034
0.35	0.0778	0.0788	0.0012	0.0804	0.0022	0.0726	-0.0056
0.40	0.0922	0.0940	0.0018	0.0968	0.0046	0.0880	-0.0042
0.45	0.1083	0.1120	0.0037	0.1147	0.0064	0.1039	-0.0044
0.50	0.1265	0.1313	0.0048	0.1334	0.0069	0.1194	-0.0071
0.55	0.1482	0.1599	0.0117	0.1620	0.0138	0.1369	-0.0113
R = 2.0							
0.002	0.0105_5	0.0109_5	$+0.0004_5$	0.0107_5	+0.0002	0.0107_5	0.0002
0.004	0.0108	0.0112	0.0004	0.0111_5	0.0003_5	0.0110_5	0.0002_5
0.006	0.0110_5	0.0114_5	0.0004	0.0114_5	0.0004	0.0113	0.0002_5
0.008	0.0113_5	0.0117	0.0003_5	0.0117	0.0003_5	0.0116	0.0002_5
0.01	0.0117	0.0120	0.0003	0.0120	0.0003	0.0119	0.0002
0.02	0.0131	0.01325	0.0001_5	0.01325	0.0001_5	0.0134	0.0003
0.03	0.0145	0.0145_5	0.0000_5	0.0145	0.0	0.0148	0.0003
0.04	0.0157	0.0158_5	0.0001_5	0.0157	0.0	0.0161	0.0004
0.06	0.0181	0.0182_5	0.0001_5	0.0180	-0.0001	0.0187	0.0006
0.08	0.0204	0.0204_5	0.0000_5	0.0203	-0.0001	0.0213	0.0009
0.10	0.0226	0.0225	-0.0001	0.0225_5	-0.0000_5	0.0238	0.0012
0.15	0.0282	0.0280_5	-0.0001_5	0.0282	0.0	0.0303	0.0021
0.20	0.0335_5	0.0337	$+0.0001_5$	0.0335	-0.0000_5	0.0367	0.0031_5
0.25	0.0391	0.0395	0.0004	0.0390	-0.0001	0.0437	0.0046
0.30	0.0455	0.0458_5	0.00035	0.0448	-0.0007	0.0515	0.0060
0.35	0.0521	0.0522	0.0001	0.0508	-0.0013	0.0607	0.0086
0.40	0.0586	0.0588	0.0002	0.0577	-0.0009	0.0698	0.0112
0.45	0.0658	0.0661	0.0003	0.0664	+0.0006	0.0800	0.0142
0.50	0.0730	0.0780	0.0050	0.0770	0.0040	0.0900	0.0170

Table III (Cont'd)/

Table III (Cont'd)

C_L^2	C_D	C_D	ΔC_D	C_D	ΔC_D	C_D	ΔC_D
	Square Tips	Large Endplates		Small Endplates		Wing Tip Tanks	
R = 4.1							
0.002	0.0107	0.0107_5	$+0.0000_5$	0.0106_5	-0.0000_5	0.0108	+0.0001
0.004	0.0109_5	0.0110	0.0000_5	0.0109_5	0.0	0.0110_5	+0.0001
0.006	0.0112_5	0.0113	0.0000_5	0.0112	-0.0000_5	0.0112_5	0.0
0.008	0.0115	0.0117	0.0002	0.0114_5	-0.0000_5	0.0115	0.0
0.01	0.0117_5	0.0118	0.0000_5	0.0117	-0.0000_5	0.0117	-0.0000_5
0.02	0.0129	0.0129_5	0.0000_5	0.0129	0.0	0.0130	+0.0001
0.03	0.0140_5	0.0141_5	0.0001	0.0141	$+0.0000_5$	0.0143	0.0002_5
0.04	0.0151_5	0.0153	0.0001_5	0.0153	0.0001_5	0.0156_5	0.0005
0.06	0.0173_5	0.0174	0.0000_5	0.0175	0.00015	0.0181	0.0007_5
0.08	0.0195_5	0.0195	-0.0000_5	0.0197	0.0001_5	0.0204	0.0008_5
0.10	0.0216	0.0214	-0.0002	0.0216_5	0.0000_5	0.0227_5	0.0011_5
0.15	0.0271	0.0265	-0.0006	0.0264_5	-0.0006_5	0.0284_5	0.0013_5
0.20	0.0326_5	0.0320_5	-0.0006	0.0318	-0.0008_5	0.0340	0.0013_5
0.25	0.0383	0.0376	-0.0007	0.0375	-0.0008	0.0404	0.0021
0.30	0.0440	0.0429	-0.0011	0.0432	-0.0008	0.0471	0.0031
0.35	0.0496_5	0.0484	-0.0012_5	0.0489	-0.0007_5	0.0539	0.0042_5
0.40	0.0552	0.0540	-0.0012	0.0547	-0.0005	0.0607	0.0055
0.45	0.0613	0.0598	-0.0015	0.0607	-0.0006	0.0685	0.0072
0.50	0.0672	0.0670	-0.0002	0.0662	-0.0010	0.0763	0.0091
0.55	0.0732	0.0744	+0.0012	0.0724	-0.0008	0.0847	0.0115
0.60	0.0794	0.0814_5	0.0020_5	0.0792	-0.0002	0.0934	0.0140
0.65	0.0856	0.0879_5	0.0023_5	0.0861	+0.0005	0.1045	0.0189
0.70	0.0933	0.0990	0.0057	0.0942	+0.0009		
R = 8.1							
0.002	0.0105	0.0110_5	$+0.0005_5$	0.0109	0.0004	0.0113_5	0.0008_5
0.004	0.0106_5	0.0111_5	0.0005	0.0111	0.0004_5	0.0115	0.0008_5
0.006	0.0107	0.0113	0.0006	0.0112_5	0.0005_5	0.0116_5	0.0009_5
0.008	0.0109	0.0115	0.0006	0.0114_5	0.0005_5	0.0118	0.0009
0.01	0.0110_5	0.0117	0.0006_5	0.0116_5	0.0006	0.0120	0.0009_5
0.02	0.0119_5	0.0127	0.0007_5	0.0126_5	0.0007	0.0128_5	0.0009
0.03	0.0130	0.0137_5	0.0007_5	0.0137_5	0.0007_5	0.0138_5	0.0008_5
0.04	0.0140_5	0.0148	0.0007_5	0.0147_5	0.0007	0.0149	0.0008_5
0.06	0.0161_5	0.0168	0.0006_5	0.0169_5	0.0008	0.0170_5	0.0009
0.08	0.0182_5	0.0188_5	0.0006	0.0191	0.0008_5	0.0192	0.0008_5
0.10	0.0202_5	0.0208	0.0005_5	0.0210_5	0.0008	0.0211_5	0.0009
0.15	0.0256_5	0.0259_5	0.0003	0.0260	0.0003_5	0.0268_5	0.0012
0.20	0.0314	0.0313_5	-0.0000_5	0.0312	-0.0002	0.0326_5	0.0012_5
0.25	0.0370	0.0367_5	-0.0002_5	0.0369_5	-0.0000_5	0.0386	0.0016
0.30	0.0423	0.0423	0.0	0.0424_5	$+0.0001_5$	0.0448	0.0025
0.35	0.0476	0.0479_5	$+0.0003_5$	0.0476	0.0	0.0511	0.0035
0.40	0.0230	0.0534	+0.0004	0.0526	-0.0004	0.0583	0.0053
0.45	0.0588_5	0.0588_5	0.0	0.0582_5	-0.0006	0.0660_5	0.0072
0.50	0.0646_5	0.0644_5	-0.0002	0.0639	-0.0007_5	0.0742	0.0095_5
0.55	0.0706	0.0708	+0.0002	0.0698	-0.0008	0.0827	0.0121
0.60	0.0766_5	0.0777	0.0000_5	0.0756_5	-0.0010	0.0918	0.0151_5
0.65	0.0829	0.0844	0.0015	0.0825	-0.0004	0.1007	0.0178
0.70	0.0900	0.0939	0.0039	0.0906	+0.0006	0.1105	0.0205

Table III (Cont'd)/

Table III (Cont'd.)

C_L^2	C_D	C_D	ΔC_D	C_D	ΔC_D	C_D	ΔC_D
	Square Tips	Large End Plates		Small End Plates		Wing Tip Tanks	
R = 10.0							
0.002	0.0104$_5$	0.0109	0.0004$_5$	0.0108$_5$	0.0004	0.0115	0.0010$_5$
0.004	0.0106	0.0111$_5$	0.0005$_5$	0.0110	0.0004	0.0116	0.0010
0.006	0.0107$_5$	0.0113	0.0005$_5$	0.0111$_5$	0.0004	0.0117$_5$	0.0010
0.008	0.0109	0.0115$_5$	0.0006$_5$	0.0113	0.0004	0.0119$_5$	0.0010$_5$
0.01	0.0111	0.0117	0.0006	0.0115	0.0004	0.0121	0.0010
0.02	0.0120	0.0126$_5$	0.0006$_5$	0.0123$_5$	0.0003$_5$	0.0130	0.0010
0.03	0.0130	0.0136$_5$	0.0006$_5$	0.0133$_5$	0.0003$_5$	0.0139$_5$	0.0009$_5$
0.04	0.0140$_5$	0.0146	0.0005$_5$	0.0143	0.0002$_5$	0.0149	0.0008$_5$
0.06	0.0162$_5$	0.0164	0.0001$_5$	0.0163$_5$	+0.0001	0.0169$_5$	0.0007
0.08	0.0185$_5$	0.0183$_5$	-0.0002	0.0184	-0.0001$_5$	0.0191	0.0005$_5$
0.10	0.0208	0.0203	-0.0005	0.0204$_5$	-0.0003$_5$	0.0213	0.0005
0.15	0.0259$_5$	0.0253$_5$	-0.0006	0.0256$_5$	-0.0003	0.0268$_5$	0.0009
0.20	0.0311$_5$	0.0308	-0.0003$_5$	0.0310$_5$	-0.0001	0.0324	0.0012$_5$
0.25	0.0366$_5$	0.0362	-0.0004$_5$	0.0364	-0.0002$_5$	0.0380	0.0013$_5$
0.30	0.0423	0.0415	-0.0008	0.0419$_5$	-0.0003$_5$	0.0442	0.0019
0.35	0.0478	0.0472	-0.006	0.0476	-0.0002	0.0511$_5$	0.0033$_5$
0.40	0.0530	0.0526	-0.0004	0.0530	0	0.0582	0.0052
0.45	0.0592	0.0584	-0.0008	0.0586$_5$	-0.0005$_5$	0.0662	0.0070
0.50	0.0656	0.0641	-0.0015	0.0640	-0.0016	0.0736	0.0080
0.55	0.0727	0.0704	-0.0023	0.0696	-0.0031	0.0822	0.0095
0.60	0.0794	0.0778	-0.0016	0.0757	-0.0037	0.0916	0.0122
0.65	0.0856	0.0867	+0.0011	0.0838	-0.0018	0.1016	0.0160
0.70	0.0918	0.0894	-0.0024	0.0886	-0.0032	0.1126	0.0208
R = 12.0							
0.002	0.0105	0.0108$_5$	+0.0003$_5$	0.0107$_5$	+0.0002$_5$	0.0110$_5$	+0.0005$_5$
0.004	0.0106$_5$	0.0109$_5$	0.0003	0.0109$_5$	0.0003	0.0111$_5$	0.0005
0.006	0.0108	0.0111	0.0003	0.0111	0.0003	0.0113	0.0005
0.008	0.0109$_5$	0.0112$_5$	0.0003	0.0112$_5$	0.0003	0.0114$_5$	0.0005
0.01	0.0111	0.0114	0.0003	0.0114	0.0003	0.0116	0.0005
0.02	0.0119$_5$	0.0122$_5$	0.0003	0.0122$_5$	0.0003	0.0125$_5$	0.0006
0.03	0.0130	0.0131$_5$	0.0001$_5$	0.0131	0.0001	0.0136	0.0006
0.04	0.0140	0.0140$_5$	0.0000$_5$	0.0139	-0.0001	0.0146	0.0006
0.06	0.0161$_5$	0.0159	-0.0002$_5$	0.0156	-0.0005$_5$	0.0166$_5$	0.0005
0.08	0.0182$_5$	0.0178$_5$	-0.0004$_5$	0.0175	-0.0007$_5$	0.0187$_5$	0.0005
0.10	0.0202	0.0198	-0.0004	0.0194$_5$	-0.0007$_5$	0.0207	0.0005
0.15	0.0254	0.0248	-0.0006	0.0246$_5$	-0.0007$_5$	0.0260$_5$	0.0005$_5$
0.20	0.0311	0.0301	-0.0010	0.0300$_5$	-0.0011	0.0316$_5$	0.0005$_5$
0.25	0.0368	0.0355	-0.0013	0.0356	-0.0012	0.0377	0.0009$_5$
0.30	0.0426	0.0412	-0.0014	0.0412	-0.0014	0.0441	0.0015
0.35	0.0483	0.0468	-0.0015	0.0465	-0.0018	0.0505	0.0022
0.40	0.0538	0.0522$_5$	-0.0015$_5$	0.0518	-0.0020	0.0575	0.0037
0.45	0.0592	0.0584$_5$	-0.0008	0.0577	-0.0015	0.0652	0.0060
0.50	0.0648	0.0645	-0.0003	0.0634	-0.0014	0.0738	0.0090
0.55	0.0713	0.0707	-0.0006	0.0694	-0.0019	0.0828	0.0115
0.60	0.0781	0.0776	-0.0005	0.0755	-0.0026	0.0919	0.0138
0.65	0.0863	0.0864	+0.0001	0.0829	-0.0034	0.1013	0.0150
0.70	0.1001	0.0990	-0.0011	0.0968	-0.0033	0.1226	0.0225

Table III (Cont'd.)/

Table III (Cont'd.)

C_L^2	C_D	C_D	ΔC_D	C_D	ΔC_D	C_D	ΔC_D
	Square Tips	Large End Plates		Small End Plates		Wing Tip Tanks	
R = 12.7							
0.002	0.0102	0.0111	0.0009	0.0106_5	0.0004_5	0.0108_5	0.0006_5
0.004	0.0103	0.0112_5	0.0009_5	0.0108	0.0005	0.0110	0.0007
0.006	0.0104_5	0.0114	0.0009_5	0.0109_5	0.0005	0.0111_5	0.0007
0.008	0.0106	0.0116	0.0010	0.0111	0.0005	0.0113	0.0007
0.01	0.0107	0.0117_5	0.0010_5	0.0113	0.0006	0.0115	0.0008
0.02	0.0117	0.0126_5	0.0009_5	0.0123	0.0006	0.0124	0.0007
0.03	0.0127	0.0136_5	0.0009_5	0.0133	0.0006	0.0134	0.0007
0.04	0.0137	0.0145_5	0.0008_5	-0.0142	0.0005	0.0144	0.0007
0.06	0.0157_5	0.0162	0.0004_5	0.0159_5	+0.0002	0.0164_5	0.0007
0.08	0.0178	0.0179	0.0001	0.0178	0	0.0185_5	0.0007_5
0.10	0.0199	0.0196	-0.0003	0.0196	-0.0003	0.0207	0.0008
0.15	0.0252	0.0250	-0.0002	0.0247	-0.0005	0.0260_5	0.0008_5
0.20	0.0306	0.0308	+0.0002	0.0303	-0.0003	0.0317	0.0011
0.25	0.0360_5	0.0364	$+0.0003_5$	0.0359_5	-0.0001	0.0374	0.0013_5
0.30	0.0418	0.0416	-0.0002	0.0415	-0.0003	0.0437	0.0019
0.35	0.0474_5	0.0468_5	-0.0006	0.0467	-0.0007_5	0.0502	0.0027_5
0.40	0.0532	0.0523	-0.0009	0.0523	-0.0009	0.0574	0.0042
0.45	0.0593	0.0586	-0.0007	0.0580	-0.0013	0.0657	0.0064
0.50	0.0648	0.0651	+0.0003	0.0637	-0.0011	0.0741	0.0093
0.55	0.0706	0.0717	0.0011	0.0690	-0.0016	0.0827	0.0121
0.60	0.0770	0.0788	0.0018	0.0762	-0.0008	0.0910	0.0140
0.65	0.0845	0.0872	0.0027	0.0852	+0.0007	0.1010	0.0165
0.70	0.0974	0.1050	0.0076	0.0988	+0.0014	0.1126	0.0152

Table IV/

Table IV

Without Transition Wires

R (Approx)	Slope of C_D——C_L^2 Curves (Smoothed) Square Tips a	Large Plates b	Small Plates c	Tip Tanks d	Slope Ratios b/a	c/a	d/a
12.7	0.1005	0.0875	0.092	0.104	0.871	0.916	1.035
12.0	0.1025	0.090	0.094	0.103	0.878	0.917	1.005
10.0	0.1075	0.095	0.098	0.102	0.884	0.912	0.949
8.1	0.1045	0.1005	0.104	0.105	0.962	0.995	1.005
4.1	0.110	(0.112)	(0.117)	(0.123)	(1.018)	(1.064)	(1.118)
2.0	0.115	(0.125)	(0.116)	(0.129)	(1.087)	(1.009)	(1.112)
1.05	0.109	0.111	0.117	0.125	1.018	1.074	1.030

With Transition Wires and Square Tips

	Slope of C_D——C_L^2 Curves (Smoothed) No Wires a	Thin Wires b	Thick Wires c	Slope Ratios b/a	c/a
0.5	0.138	0.1145	0.099	0.830	0.718
1.1	0.109	-	(0.097)	-	(0.89)
1.5	-	0.995	0.1075	-	-
2.0	0.115	0.110	-	0.957	-
4.1	0.110	0.110	-	1.00	-
	Slope of C_L——α Curves			Slope Ratios	
0.5	0.0541	0.0537	0.0554	0.992	1.025
1.1	0.0544	-	0.0555	-	1.020
1.5	-	0.0558	0.0554	-	-
2.0	0.0550	0.0556	-	1.011	-
4.1	0.0560	0.0561	-	1.002	-

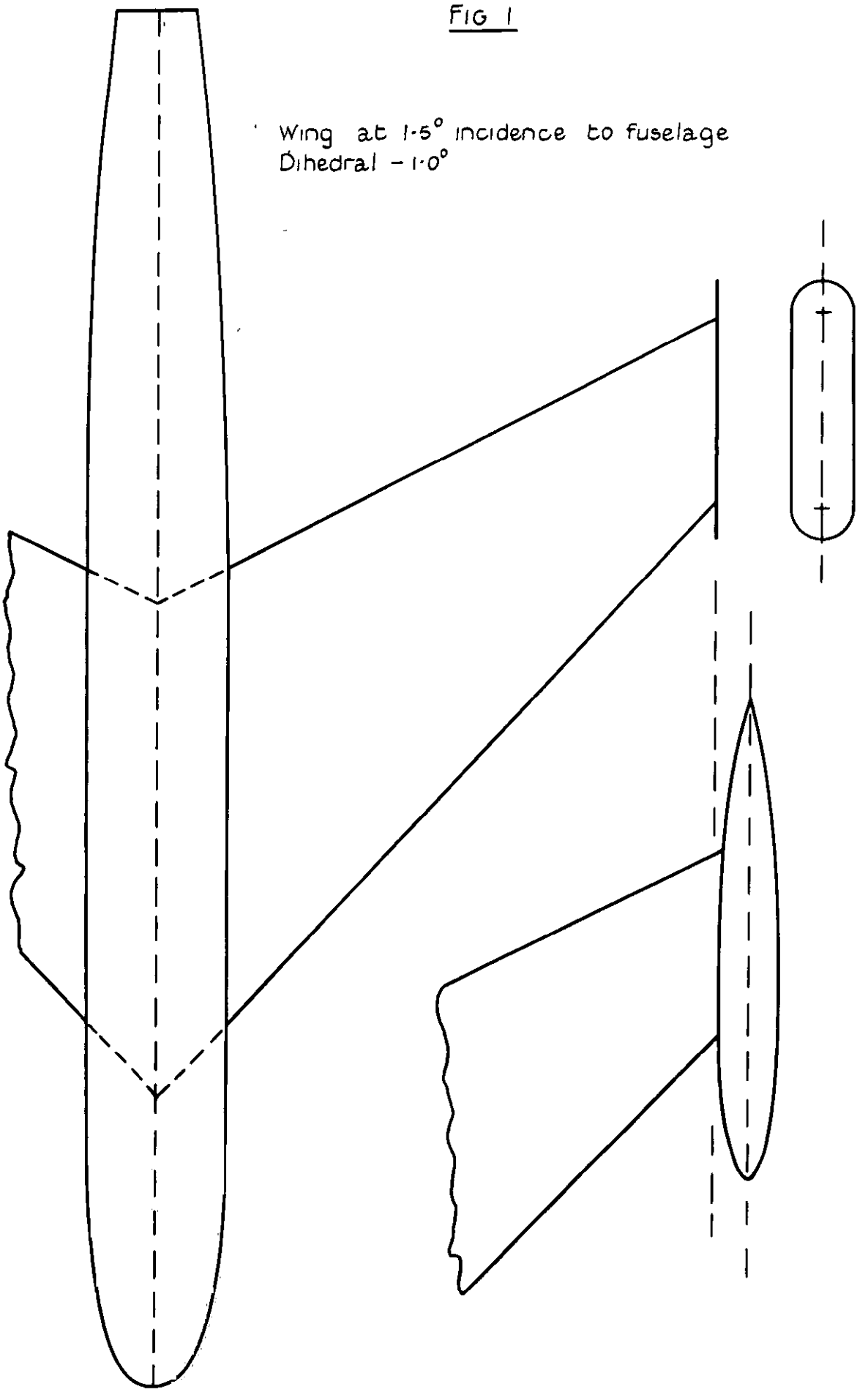
Values of C_{Dmin} (Smoothed Curves)

0.5	0.0126	0.0142*	0.0166
1.1	0.0111	(0.014)*	0.0146
1.5	-	0.0138	0.0142
2.0	0.0105	0.0124	-
4.1	0.0102	0.0116	-
High R	0.0103		

*Wires not thick enough.

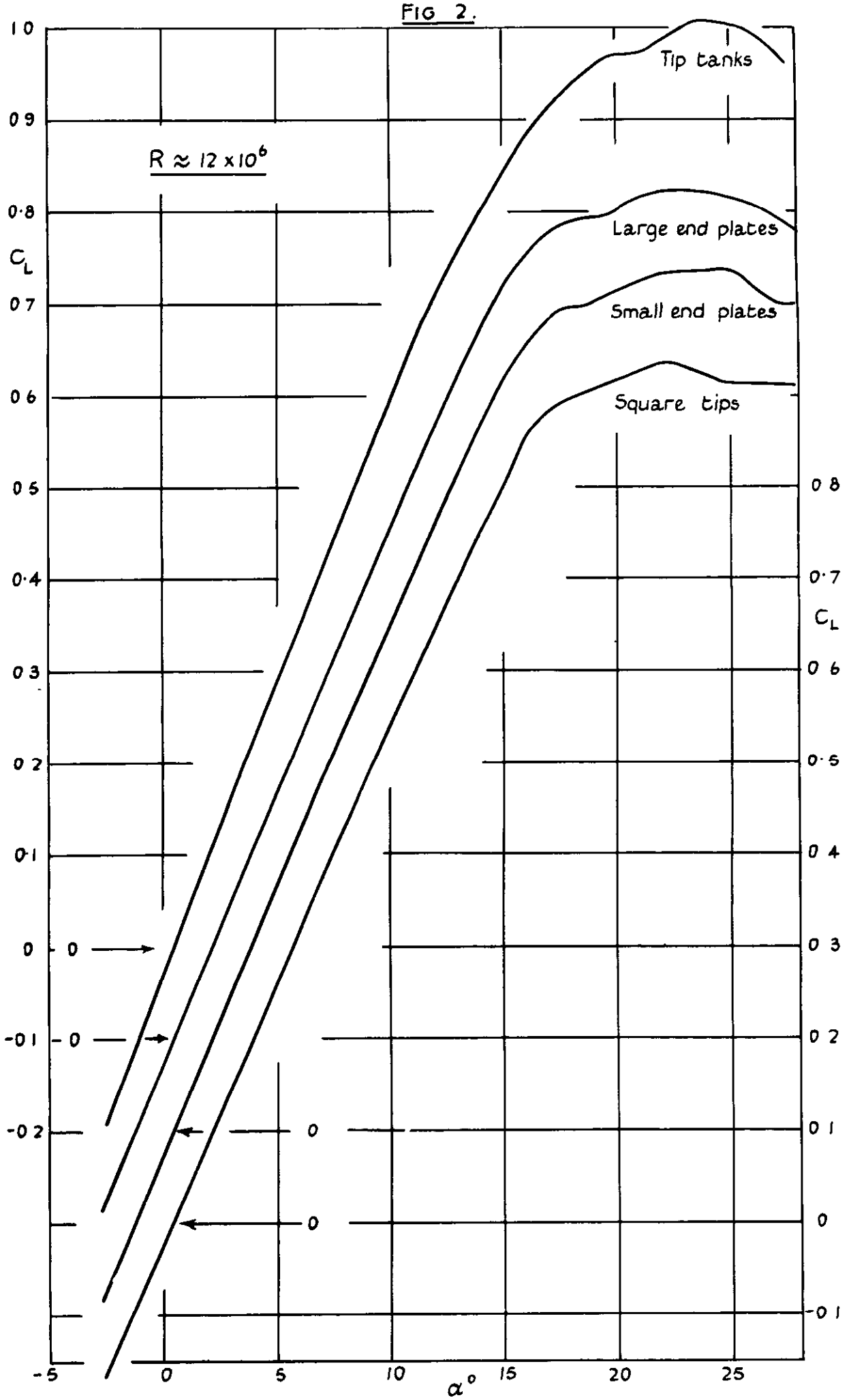
Bracketed values are where it is difficult to decide what the value actually is.

FIG 1



Arrangement of large end plate and tip tank.

FIG 2.



Curves of C_L vs α

FIG. 3.

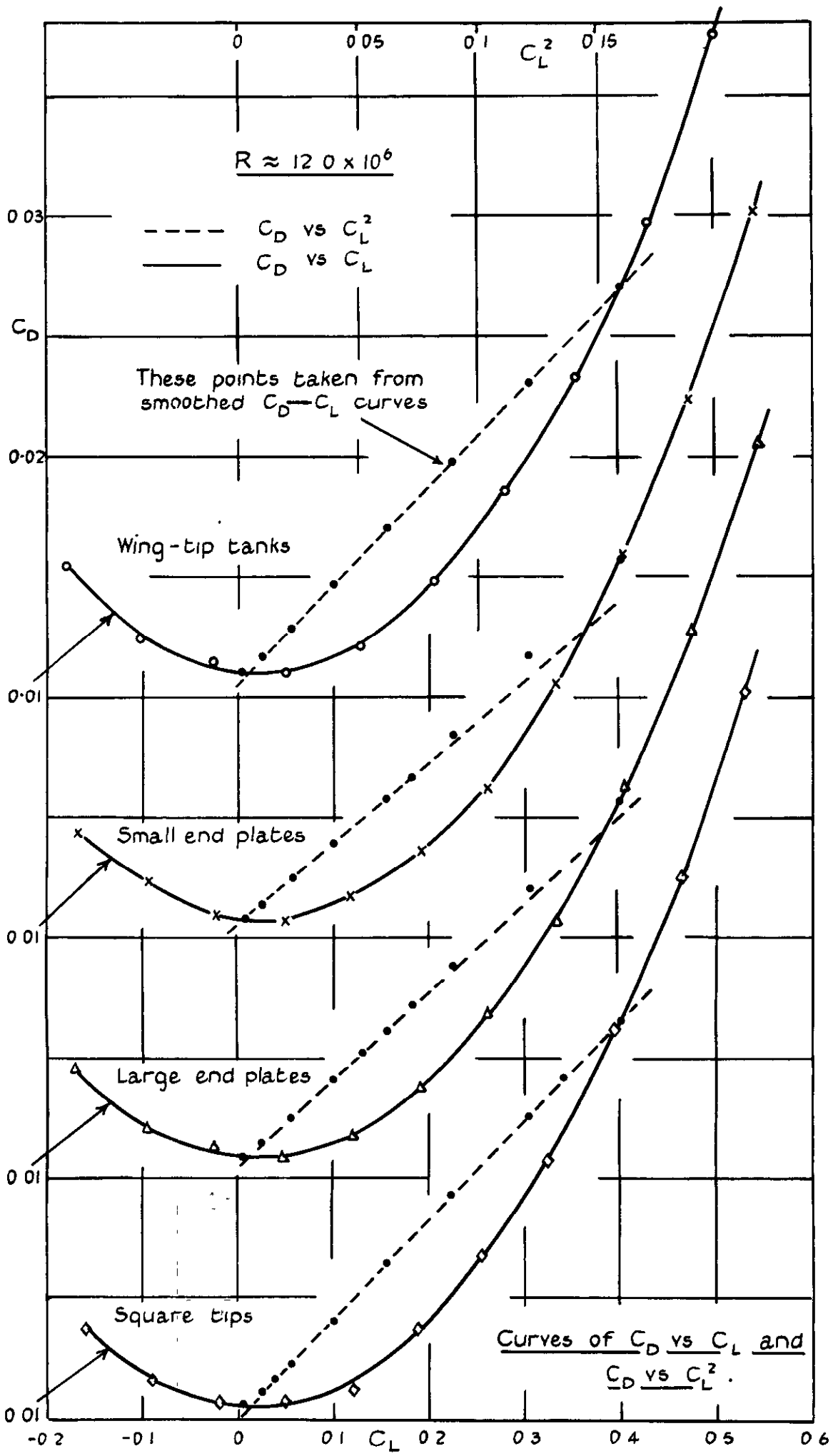
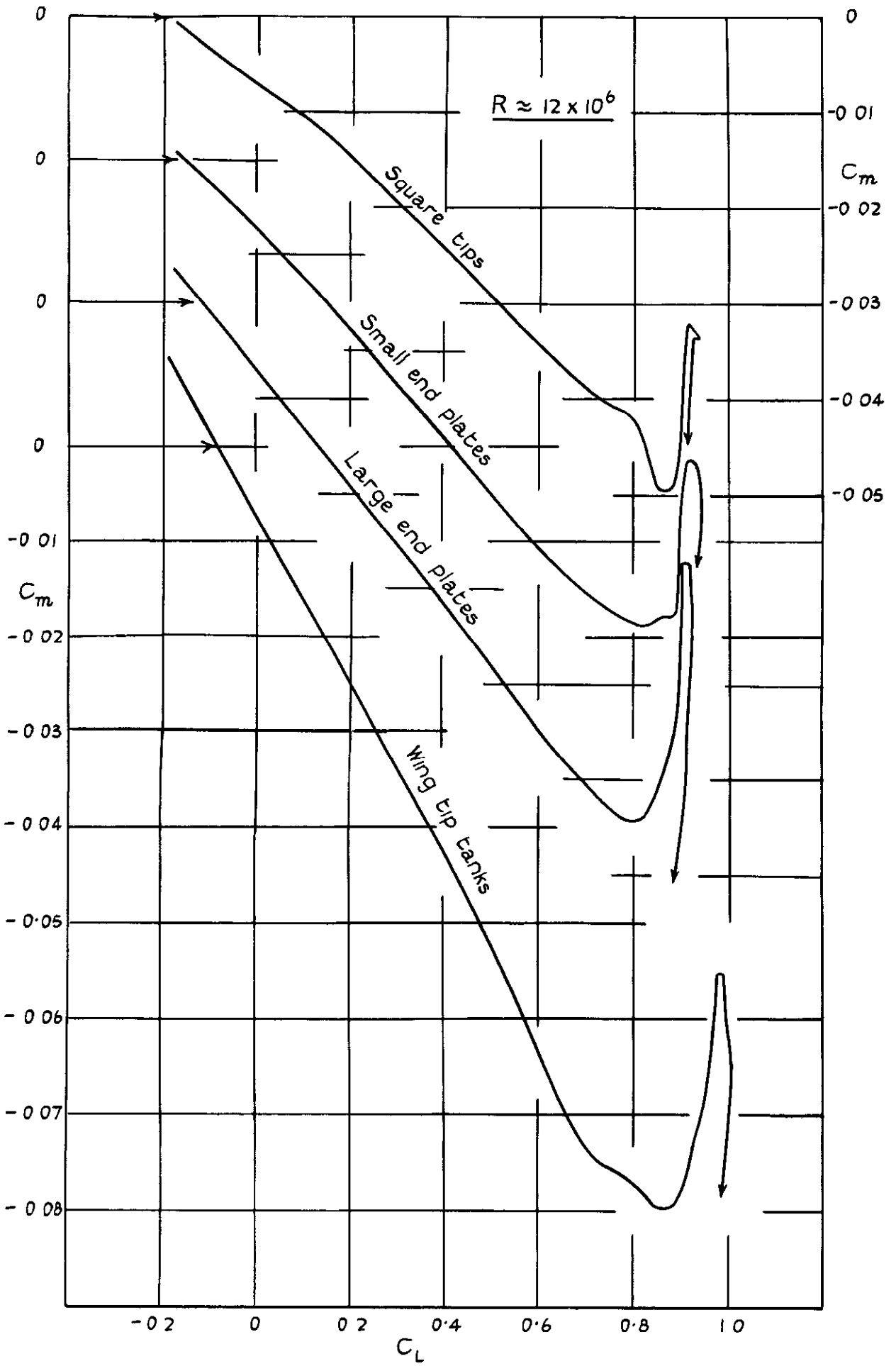
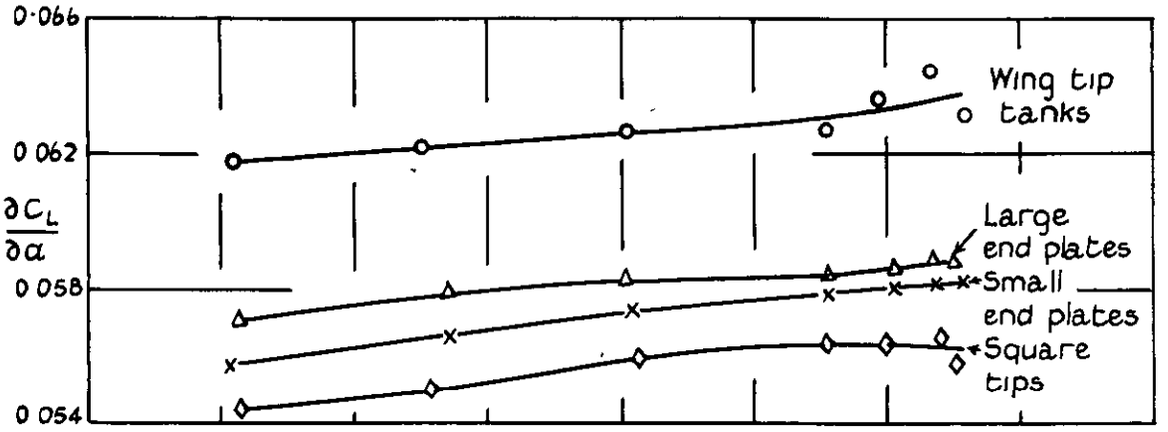

0
0 05
0 1
C_L^2
0 15
R ≈ 12 0 x 10⁶
0 03
C_D vs C_L^2
C_D vs C_L
C_D
These points taken from smoothed C_D—C_L curves
0·02
Wing-tip tanks
0·01
Small end plates
0 01
Large end plates
0 01
Square tips
0 01
Curves of C_D vs C_L and C_D vs C_L^2.
-0 2
-0 1
0
0 1
C_L
0 2
0 3
0 4
0 5
0 6

FIG 4

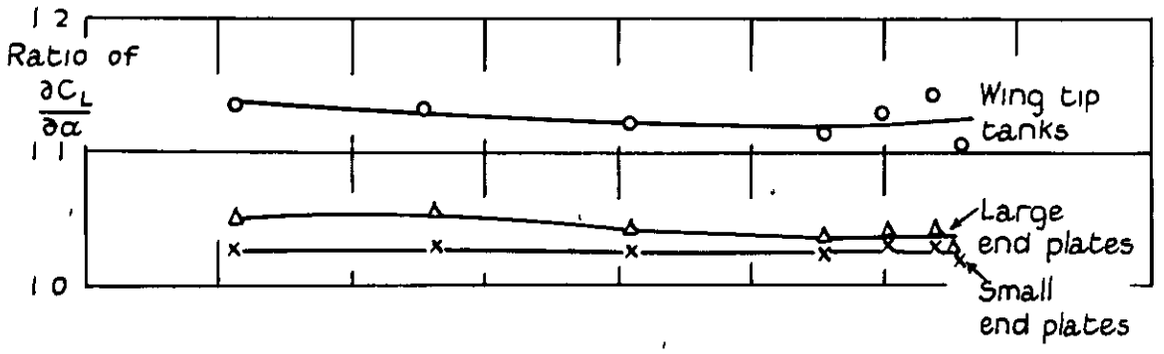


Curves of C_m vs. C_L

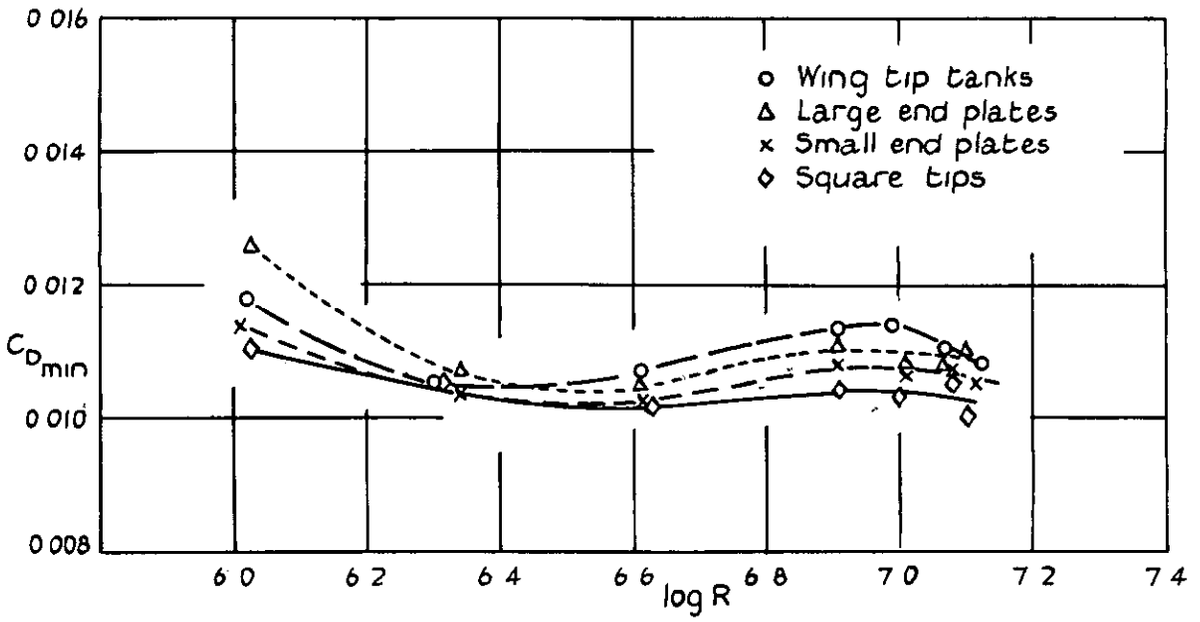
FIG 5.



Slope of $C_L - \alpha$ curves.



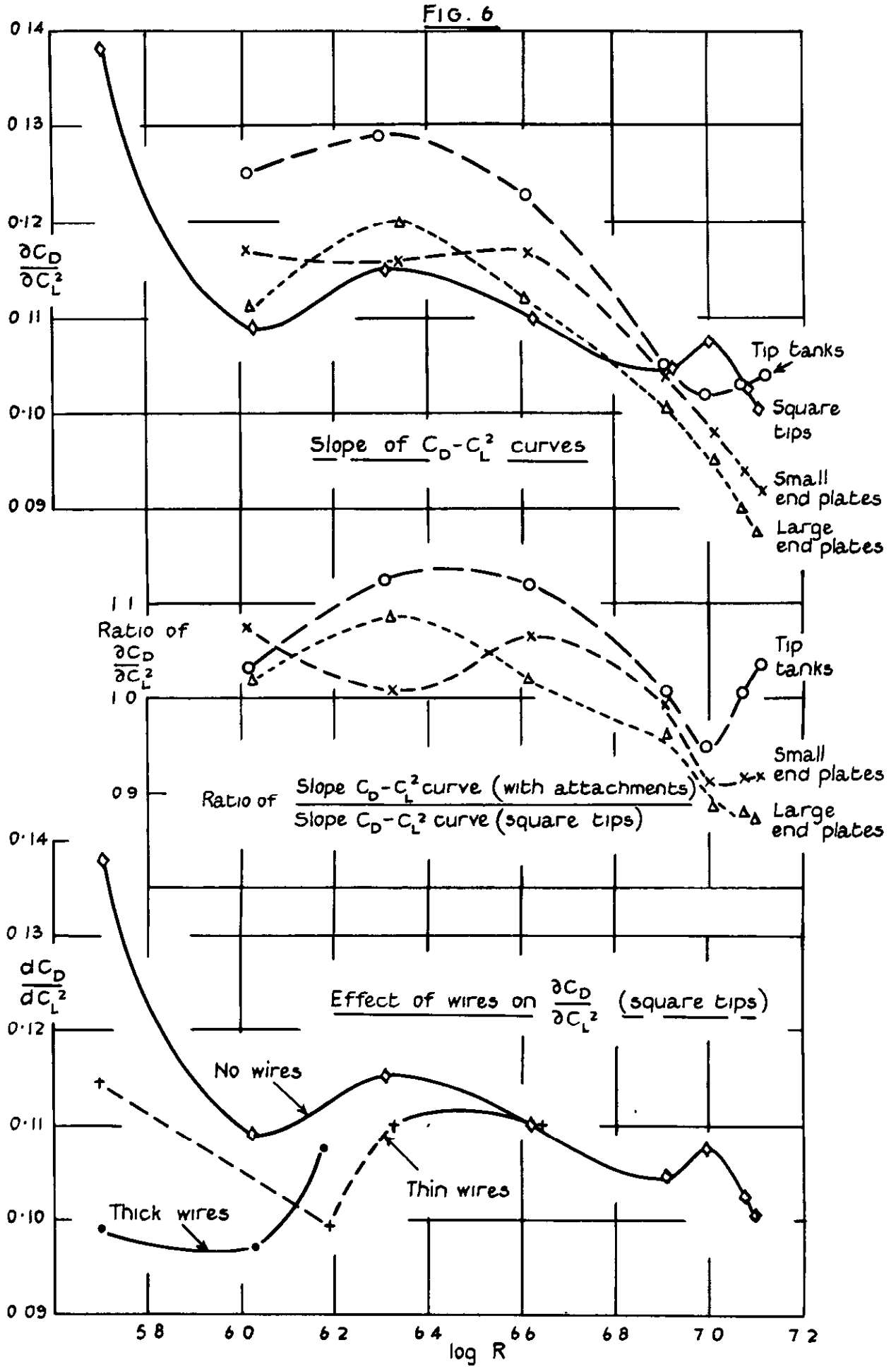
Ratio of $\frac{\text{Slope } C_L - \alpha \text{ curve (with attachments)}}{\text{Slope } C_L - \alpha \text{ curve (square tips)}}$



Minimum drag coefficient

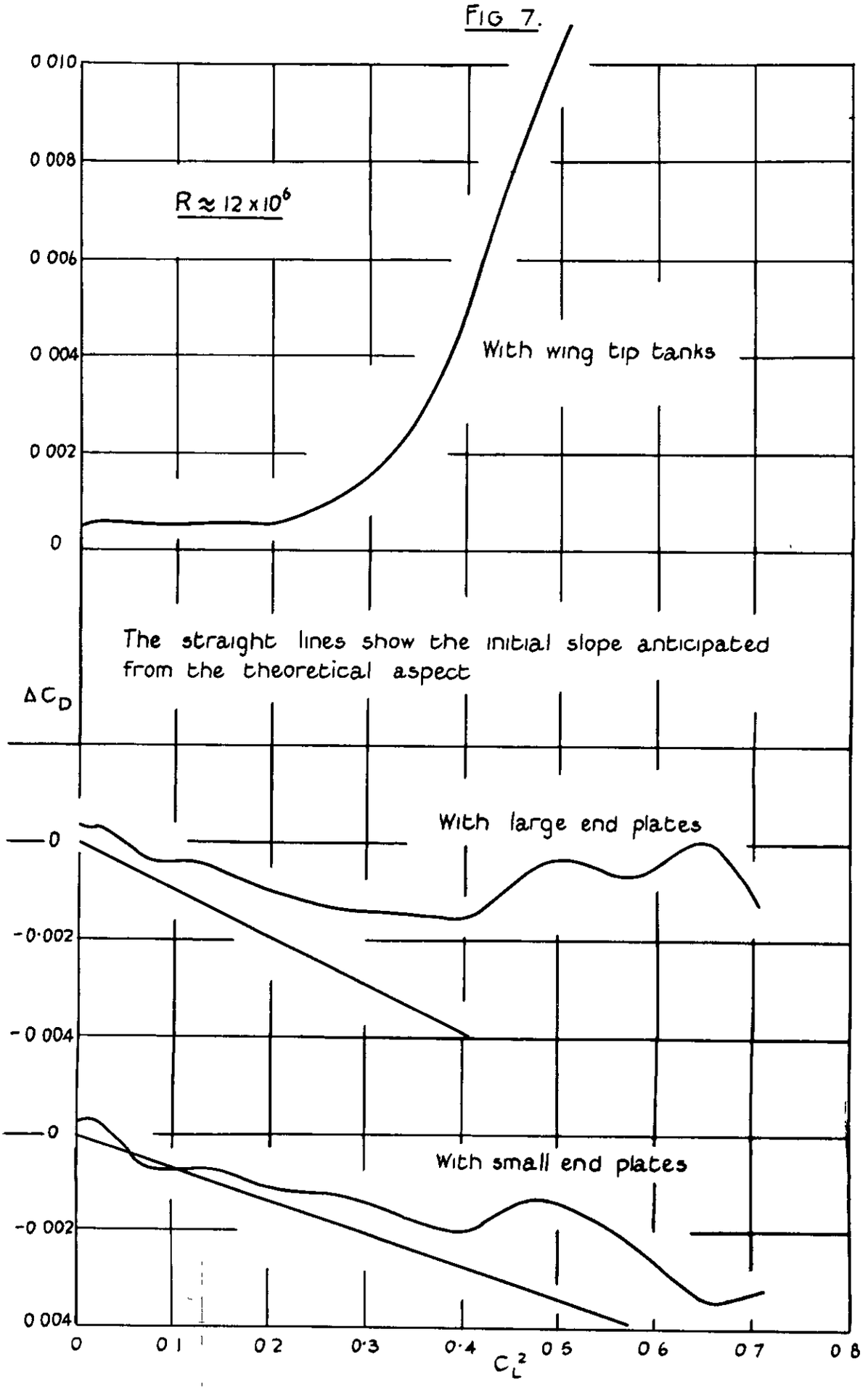
Curves of $\frac{\partial C_L}{\partial \alpha}$ and $C_{D_{min}}$ vs R

FIG. 6



Curves of $\frac{\partial C_D}{\partial C_L^2}$ vs R

FIG 7.



Curves of ΔC_D vs C_L^2

APPENDIX

Comparison Between the Measured Lift and Drag and Calculated Values for the Wing with Tip Tanks

- By -
Dr. J. Weber

It has been shown above (p. 3) that the changes of both lift slope and induced drag of the wing with endplates can be predicted with reasonable accuracy from the theory of Ref. 2. In the following, a similar comparison will be made for the wing with tip tanks where the calculation method of Hartley[3] 1952, is available.

Calculating the theoretical lift slope of the wing with tip tanks by the method of Ref. 3, one obtains 1.15 times the lift slope of the wing alone. This value is only slightly higher than the experimental values given in Fig. 5, the mean of which through the Reynolds number range is 1.13. A small discrepancy of this order must be expected as a consequence of viscosity effects, particularly in the sweptforward junctions between wing and tanks. Thus the large effect of the tanks on the lift slope which is found experimentally, can be explained by the theory; this confirms the findings of Spence and Holford[4], 1953.

The calculated lift includes the effect of the tanks on the wing load and the load on the centre part of the tanks themselves. The change of the tail load on the tank due to the downwash from the wing is very small in the present case ($\Delta C_L/\alpha^\circ = 0.0005$) and can, therefore, be ignored.

The theory of Ref. 3 gives a 25% reduction of the induced drag due to the tanks. On the other hand, the drag of the tanks themselves can be expected to rise with α^2. Therefore, the final result depends on how these two opposing effects counteract one another; it cannot be predicted without also knowing the drag of the tanks. In the present case, the two effects appear to cancel one another and the drag remains nearly constant at low C_L-values. At higher C_L-values, however, a large interference drag arises, mainly from unfavourable boundary-layer effects in the sweptforward junctions where large adverse pressure gradients behind increased suction peaks appear. Similar effects have been observed in Ref. 4.

Additional References

No.	Author(s)	Title, etc.
3	D. E. Hartley	Theoretical load distributions on wings with cylindrical bodies at the tips. C.P. No. 147. June, 1952.
4	A. Spence and J. F. Holford	The low speed effects of wing tip stores. R.A.E. Technical Note No. Aero. 2279. 1953.

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