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Low-Speed Wind Tunnel Tests on a Two-Dimensional Aerofoil with Split Flap near the Ground

by

J. A. Bagley, B.Sc.

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LOW-SPEED WIND TUNNEL TESTS ON A TWO-DIMENSIONAL AEROFOIL WITH SPLIT FLAP NEAR THE GROUND

by

J. A. Bagley, B.Sc.

SUMMARY

Pressure distributions have been measured on a 10% thick two-dimensional aerofoil of R.A.E.101 section fitted with split flaps deflected at 15° and 55°. Measurements were made at two distances above a ground plate, and also without the ground plate. The results have been integrated to give the sectional lift, drag and pitching-moment coefficients.

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1 INTRODUCTION

In order to verify a theoretical method for calculating the pressure distribution on wings near the ground, the experiments described in Ref.1 on a two-dimensional aerofoil were undertaken. While the model was in the tunnel, experiments were also made with split flaps fitted to the aerofoil, and the results of these experiments are described in the present note.

The data are presented merely as an addition to the literature on the subject, since no corresponding theoretical investigation has been undertaken.

2 DESCRIPTION OF EXPERIMENT

2.1 Details of model and apparatus

The tests were made in the R.A.E. No.2 $11\frac{1}{2}$ ft × $8\frac{1}{2}$ ft low-speed wind tunnel during November 1953. The model used was of R.A.E.101 section, with a chord length, c, of 30 in. and a thickness-chord ratio of 10%; it was mounted to span the vertical dimension of the tunnel. The model had previously been used in a series of tests[2] to investigate the boundary layer development and its effect on the surface pressure distribution, and in the tests[1] to investigate the influence of a ground plate. For the present tests, it was fitted with a split flap, consisting of a piece of $\frac{1}{4}$ in. plywood chamfered to have a sharp trailing-edge, fixed to the wing with wooden blocks. The flap chord was $4\frac{1}{2}$ in. (0•15c), and it was fixed to the wing with its leading-edge at 0•85c for flap angle $\beta = 15°$ and at 0•84c for $\beta = 55°$.

Pressures were measured on the wing at 52 points arranged on two parallel lines 4 in. apart around the centre of the wing; there was no provision for measuring pressures on the flap itself. The pressures were measured on two multi-tube manometers; the estimated accuracy of the C_p values quoted is about 0•01. The nominal incidence of the model was measured by a light-and-scale system, whose zero was determined by setting the model (without flap or ground plate) so that equal pressures were recorded at several corresponding points on the upper and lower surfaces. The accuracy of this system was about 0•01°.

The ground was represented in the same way as in the tests described in Ref.1. A wooden board $11\frac{1}{2}$ ft (4•6c) long spanned the tunnel vertically, and was fixed at distances H = 11 in. and H = 15 in. from the centre of rotation of the model, which was at 0•43c behind the leading-edge.

The leading-edge of the ground plate was sharpened, and a pair of pitot tubes placed just behind it so that a movement of the stagnation point to one side of the leading-edge provoked a flow separation on the other side and consequently produced a large difference in the pressures recorded by the two pitots. In this way a sensitive indication was provided of any circulation around the ground plate. The circulation was controlled by adjusting a flap at the trailing-edge of the ground so that equal pressures were recorded by the two pitots.

As long as there is no circulation around the ground board, it gives a good representation of an infinite ground; but it still differs from the real system being simulated in that a boundary layer develops along the ground plate. As long as the lift on the wing is fairly small, this boundary layer can be corrected for as described below, but at a large enough lift coefficient the boundary layer on the plate separates, and the resulting flow ceases to be a reliable representation of the prototype.

Fig.1 shows a sketch of the experimental rig used in the present experiments.

2.2 Details of tests

All the tests were made at a wind speed of 100 ft/sec, giving a Reynolds number based on the wing chord of $1 \cdot 6 \times 10^6$. Transition was not fixed; the position of transition was not measured. Tests were made for a range of nominal incidences from 0° to 8° on the wing with 15° flap angle, and from -4° to 6° on the wing with 55° flap angle. The tests were made for ground distances of 11 in. and 15 in., i.e. for $H/c = 0 \cdot 37$ and $0 \cdot 50$, and also on the wing alone, far from the ground. Owing to the correction to wing incidence for the boundary layer on the ground plate, the actual values of incidence for the various series of tests differ quite considerably.

Measurements of the velocity profiles within the ground boundary layer showed that it was no longer attached for the two highest incidences at $H/c = 0 \cdot 37$, so that the results for these two cases must be treated with considerable caution.

2.3 Corrections to experimental results

Corrections to the experimental results are needed for tunnel blockage, and for the change in flow direction at the model due to the boundary layer developed along the ground plate.

For the wing alone, without the ground plate, the standard tunnel corrections (see, e.g. Ref.3) for solid blockage and wake blockage can be applied. This gives a charge of tunnel speed, $\Delta v/V_o$, of

Flap deflection	α_{NOM}	$\Delta v/V_o$		
		Solid blockage	Wake blockage	Total
$\beta = 15°$	0°	0•0018	0•0016	0•0034
	4°	0•0019	0•0022	0•0041
	6°	0•0022	0•0027	0•0047
	8°*	0•0024	0•0082	0•0103
$\beta = 55°$	-4°	0•0019	0•0033	0•0052
	0°	0•0018	0•0033	0•0051
	4°	0•0019	0•0038	0•0057
	6°*	0•0020	0•0108	0•0128

* These values are appropriate for all cases where the wing is effectively stalled.

For the wing near the ground, additional blockage corrections are required to account for the presence of the ground plate and the supporting struts. These are discussed in detail in Ref.1. The solid blockage correction for the wing itself is also altered, since the positions of the images of the wing in the walls are altered, and the first image now represents the true ground effect and is thus not accountable as a tunnel correction.

The final tunnel corrections obtained are given in the following table.

Flap deflection	α_{NOM}	$\Delta v/V_0$		
		Solid blockage	Wake blockage	Total
<u>H = 11 in.</u>				
$\beta = 15°$	0°	0·0175	0·0097	0·0272
	4°	0·0176	0·0103	0·0279
	6°	0·0178	0·0108	0·0286
	8°*	0·0180	0·0179	0·0359
$\beta = 55°$	-4°	0·0176	0·0114	0·0290
	0°	0·0175	0·0114	0·0288
	4°	0·0176	0·0119	0·0295
	6°*	0·0178	0·0190	0·0368
<u>H = 15 in.</u>				
$\beta = 15°$	0°	0·0173	0·0094	0·0267
	4°	0·0174	0·0099	0·0273
	6°	0·0175	0·0104	0·0279
	8°*	0·0177	0·0159	0·0336
$\beta = 55°$	-4°	0·0174	0·0110	0·0284
	0°	0·0173	0·0110	0·0282
	4°	0·0174	0·0115	0·0289
	6°*	0·0175	0·0186	0·0361

* These values are appropriate for all cases where the wing is effectively stalled.

The effective incidence of the wing differs from the nominal incidence owing to the flow being inclined to the tunnel walls. For the wing without ground, the flow deflection is that induced by the images in the walls of the wing circulation, and is given by the standard formula[3]

$$\Delta\alpha = 0{\cdot}0269c^2 \ (C_L + 2\ C_m)$$

When the ground plate is introduced, the principal image of the wing circulation is that in the ground plate, and is thus no longer accountable as a tunnel correction. The remainder of the images consist of equal and opposite vortex-pairs, reasonably far away, and the correction due to these is negligible.

A correction is needed due to the boundary layer which develops along the ground plate. Measurements were made of the velocity within this boundary layer, using a pitot comb with tubes at 0·05, 0·57, 1·07, 1·58, 2·09 and 2·54 in. from the surface of the plate. Thus the displacement thickness, δ^*, of the boundary layer was found at two points below the wing leading-edge and trailing-edge for each test. The displacement surface of the boundary layer was assumed to be defined by a straight line through these points, and the flow direction at the wing was assumed to be parallel to this line.

This leads to an incidence correction:

$$\Delta\alpha = \frac{1}{c}\ (\delta^*_{TE} - \delta^*_{LE})$$

Values of δ^*_{LE}, δ^*_{TE} and $\Delta\alpha$ measured in the tests are given in Fig.2. It will be noted that δ^*_{LE} is usually greater than δ^*_{TE}, which may seem surprising at first sight - it is important to realise that this does not imply that the boundary layer thickness, δ, also decreases in the stream direction. In Ref.1, a similar phenomenon occurs at large incidences, and a check calculation of the boundary layer development under the pressure distribution induced by the wing confirmed that δ^*_{LE} could be greater than δ^*_{TE}.

As was mentioned in section 2.2, the ground boundary layer had separated at the two highest incidences for H/c = 0•37, and the values of δ^* deduced for these are likely to be unreliable, so that the incidence correction is also doubtful. However, as the whole flow pattern ceases to be representative of that round a real wing travelling close to the ground when the plate boundary layer separates, there is no point in trying to improve the estimate for $\Delta\alpha$.

The appended table shows the corrected incidence values corresponding to the nominal incidences tested.

	α_{NOM}	α		
		No ground	H/c = 0•50	H/c = 0•37
β = 15°	0°	0•06°	0•13°	-0•06°
	4°	4•13°	3•97°	3•68°
	6°	6•16°	5•85°	5•38°
	6•78°	-	-	5•95°
	7°	7•17°	-	-
	8°	-	7•72°	-
β = 55°	-4°	-3•94°	-4•04°	-4•16°
	0°	0•13°	-0•23°	-0•62°
	2°	2•16°	1•62°	0•84°
	3•5°	-	2•99°	-
	4°	4•20°	-	2•38°
	6°	6•19°	-	-

2.4 Presentation of the results

The measured pressure coefficients, with the corrections noted in section 2.3, are given in Tables 1 and 2, for β = 15° and β = 55° respectively. The results are also plotted in Figs.4 to 9.

Owing to the large incidence corrections, the results in the various figures are all obtained at different incidences, and it is difficult to visualise what changes are due to the proximity of the ground. Figs.10 and 11 have therefore been prepared, by interpolation between the measured results, to compare pressure distributions at fixed incidence at various ground distances.

It is clear that the main influence of the ground is a reduction in local velocities and a consequent increase in pressure on the lower surface, exactly as was found for the wing without flap[1]. However, in the present case there appears to be more change in the upper surface distributions when the ground is present than was recorded on the unflapped wing. This may well be due to the greater change in pressure at the trailing-edge found here, which in turn is possibly due to a modification in the shape of the separated flow region behind the flap.

The pressure distributions have been integrated to produce values of the sectional normal force, tangential force and pitching-moment coefficients, and the lift and drag coefficients have been derived from these. Since no pressures were measured on the flap itself, the flap contribution has had to be estimated. Examination of some N.A.C.A. experiments[4] suggested that the load distribution on the flap could be approximated by assuming that the load fell off elliptically from the measured ΔC_p at the flap leading-edge to zero at the flap trailing-edge. For the flap chord of 0•15c, the load on the flap (as a coefficient based on wing chord) is thus:

$$C_F = \frac{\pi}{4} \times 0{\cdot}15 \times \Delta C_p$$

(For the test results given in Ref.4 for a flap chord of 0•2c at $\beta = 20°$ and $\beta = 60°$, experimental values of the factor replacing $\pi/4$ in this expression vary from 0•61 to 0•92 over a C_L range similar to that considered here.)

Thus the contributions to the lift and drag coefficients from the flap load are respectively:

$$\Delta C_L = C_F \cos(\alpha + \beta) = 0{\cdot}1178\ \Delta C_p \cos(\alpha + \beta)$$

$$\Delta C_D = C_F \sin(\alpha + \beta) = 0{\cdot}1178\ \Delta C_p \sin(\alpha + \beta)$$

and the pitching-moment contributions from the flap load are:

$$\Delta C_m = -0{\cdot}0758\ \Delta C_p \quad \text{for } \beta = 15°$$

$$\text{and } \Delta C_m = -0{\cdot}0480\ \Delta C_p \quad \text{for } \beta = 55°$$

The force coefficients are tabulated in Table 3, and plotted in Figs.12 to 14.

It is noteworthy that the drag coefficient is almost constant with increasing lift within the range covered. The major contribution to the drag is in fact that due to the flap load; from Figs.4 to 9 it is clear that ΔC_p at the flap leading-edge is practically invariant with incidence, and this result is naturally reflected in the shape of the C_D curves.

Apart from this, there appear to be no notable features of the results. The large increase in lift measured for $\alpha > 0$ at $H/c = 0{\cdot}37$ and $\beta = 55°$ is associated with separation of the boundary layer on the ground, and is therefore probably spurious.

3 CONCLUSIONS

Pressure distributions measured on a two-dimensional R.A.E.101 aerofoil of 10% thickness-chord ratio with a split flap of 15% chord at $\beta = 15°$ and 55° have been measured away from and at two distances from a ground board.

The results, and the integrated sectional force coefficients, are presented here without analysis.

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3	Pankhurst, R.C., Holden, D.W.	"Wind tunnel techniques", Chapter 8. Pitman, London, 1952.
4	Wallace, R.	Investigation of full-scale split trailing-edge wing flaps with various chords and hinge locations. N.A.C.A. Report 539, 1935.

TABLE 1 - Pressure coefficients for wing with flap at $\beta = 15°$

(a) Without ground

UPPER SURFACE

x/c	α = 0•06°	α = 4•13°	α = 6•16°	α = 7•17°
0	0•58	-2•19	-4•41	-5•73
0•005	-0•85	-3•40	-5•07	-6•18
0•007	-0•91	-3•28	-4•94	-6•09
0•011	-0•87	-2•97	-3•86	-3•95
0•024	-0•80	-1•78	-2•67	-3•14
0•047	-0•73	-1•61	-2•10	-2•35
0•073	-0•69	-1•39	-1•77	-1•97
0•098	-0•64	-1•25	-1•56	-1•71
0•148	-0•61	-1•06	-1•30	-1•41
0•198	-0•60	-0•99	-1•17	-1•26
0•297	-0•55	-0•84	-0•98	-1•04
0•348	-0•51	-0•76	-0•88	-0•93
0•396	-0•48	-0•68	-0•79	-0•84
0•447	-0•43	-0•62	-0•70	-0•74
0•497	-0•35	-0•54	-0•62	-0•66
0•548	-0•32	-0•49	-0•56	-0•58
0•596	-0•32	-0•45	-0•51	-0•53
0•647	-0•29	-0•41	-0•47	-0•48
0•696	-0•26	-0•37	-0•41	-0•42
0•748	-0•25	-0•34	-0•37	-0•38
0•795	-0•24	-0•32	-0•34	-0•35
0•848	-0•23	-0•29	-0•32	-0•32
0•896	-0•25	-0•29	-0•30	-0•30
0•948	-0•29	-0•32	-0•30	-0•29
0•967	-0•32	-0•32	-0•30	-0•28
1•000	-0•54	-0•41	-0•37	-0•31

LOWER SURFACE

x/c	α = 0•06°	α = 4•13°	α = 6•16°	α = 7•17°
0•006	0•85	0•88	0•47	0•16
0•007	0•74	0•96	0•70	0•49
0•014	0•60	1•00	0•92	0•83
0•026	0•39	0•89	0•98	1•01
0•050	0•20	0•67	0•82	0•90
0•075	0•10	0•53	0•69	0•76
0•100	0•05	0•43	0•60	0•66
0•149	0•00	0•32	0•47	0•53
0•200	-0•04	0•24	0•38	0•42
0•298	-0•06	0•16	0•26	0•31
0•348	-0•05	0•15	0•24	0•29
0•398	-0•02	0•15	0•23	0•27
0•448	0•00	0•16	0•23	0•27
0•498	0•03	0•17	0•23	0•27
0•548	0•06	0•18	0•24	0•27
0•599	0•11	0•21	0•26	0•29
0•647	0•16	0•23	0•28	0•31
0•698	0•21	0•28	0•30	0•33
0•747	0•26	0•34	0•35	0•36
0•797	0•35	0•40	0•43	0•45
0•848	-0•54	-0•39	-0•33	-0•30
0•897	-0•54	-0•40	-0•33	-0•30
0•948	-0•54	-0•40	-0•34	-0•30
0•967	-0•55	-0•40	-0•35	-0•30

TABLE 1 - Pressure coefficients for wing with flap at β = 15° (cont'd)

(b) Ground distance H/c = 0·50

UPPER SURFACE

x/c	α = 0·13°	α = 3·97°	α = 5·85°	α = 7·72°
0	0·50	-2·40	-4·57	-1·37
0·005	-0·91	-3·30	-4·99	-1·37
0·007	-0·96	-3·21	-4·91	-1·37
0·011	-0·88	-3·01	-3·29	-1·37
0·024	-0·79	-1·75	-2·50	-1·37
0·047	-0·70	-1·48	-1·90	-1·37
0·073	-0·66	-1·27	-1·58	-1·37
0·098	-0·61	-1·13	-1·38	-1·37
0·148	-0·56	-0·93	-1·13	-1·23
0·198	-0·53	-0·85	-0·99	-1·19
0·297	-0·50	-0·71	-0·81	-1·04
0·348	-0·47	-0·63	-0·72	-0·99
0·396	-0·41	-0·57	-0·63	-0·95
0·447	-0·36	-0·50	-0·55	-0·90
0·497	-0·31	-0·43	-0·47	-0·85
0·548	-0·28	-0·38	-0·41	-0·76
0·596	-0·27	-0·34	-0·37	-0·71
0·647	-0·25	-0·30	-0·33	-0·68
0·696	-0·21	-0·26	-0·27	-0·62
0·748	-0·20	-0·23	-0·23	-0·57
0·795	-0·18	-0·20	-0·20	-0·54
0·848	-0·18	-0·18	-0·17	-0·50
0·896	-0·19	-0·16	-0·15	-0·46
0·948	-0·23	-0·18	-0·14	-0·43
0·967	-0·25	-0·19	-0·15	-0·43
1·000	-0·45	-0·26	-0·15	-0·45

LOWER SURFACE

x/c	α = 0·13°	α = 3·97°	α = 5·85°	α = 7·72°
0·006	0·92	0·81	0·35	0·79
0·007	0·83	0·92	0·60	0·89
0·014	0·71	1·01	0·87	0·99
0·026	0·48	0·94	1·01	1·01
0·050	0·29	0·76	0·89	0·84
0·075	0·20	0·64	0·79	0·75
0·100	0·15	0·56	0·72	0·67
0·149	0·09	0·46	0·61	0·56
0·200	0·06	0·40	0·54	0·49
0·298	0·03	0·32	0·44	0·39
0·348	0·04	0·31	0·43	0·37
0·398	0·07	0·31	0·41	0·35
0·448	0·09	0·31	0·40	0·34
0·498	0·11	0·32	0·41	0·34
0·548	0·14	0·33	0·41	0·33
0·599	0·18	0·35	0·42	0·34
0·647	0·23	0·36	0·44	0·36
0·698	0·27	0·39	0·45	0·37
0·747	0·32	0·44	0·47	0·38
0·797	0·40	0·50	0·54	0·45
0·848	-0·44	-0·23	-0·15	-0·31
0·897	-0·45	-0·23	-0·14	-0·31
0·948	-0·45	-0·24	-0·15	-0·32
0·967	-0·45	-0·23	-0·14	-0·33

TABLE 1 - Pressure coefficient for wing with flap at $\beta = 15°$ (cont'd)

(c) Ground distance H/c = 0·37

UPPER SURFACE

x/c	α = -0·06°	α = 3·68°	α = 5·38°	α = 5·95°
0	0·47	-2·55	-4·92	-5·90
0·005	-0·89	-3·36	-5·29	-6·15
0·007	-0·96	-3·28	-5·20	-6·13
0·011	-0·86	-3·13	-3·37	-3·71
0·024	-0·77	-1·80	-2·61	-2·87
0·047	-0·68	-1·49	-1·98	-2·14
0·073	-0·64	-1·27	-1·65	-1·79
0·098	-0·61	-1·13	-1·43	-1·54
0·148	-0·55	-0·94	-1·16	-1·25
0·198	-0·53	-0·78	-1·03	-1·10
0·297	-0·53	-0·74	-0·80	-0·85
0·348	-0·49	-0·65	-0·72	-0·75
0·396	-0·43	-0·58	-0·65	-0·66
0·447	-0·37	-0·51	-0·56	-0·58
0·497	-0·32	-0·44	-0·48	-0·50
0·548	-0·29	-0·39	-0·43	-0·43
0·596	-0·28	-0·35	-0·37	-0·38
0·647	-0·26	-0·31	-0·33	-0·33
0·696	-0·23	-0·27	-0·28	-0·27
0·748	-0·21	-0·24	-0·24	-0·24
0·795	-0·20	-0·22	-0·21	-0·20
0·848	-0·18	-0·20	-0·17	-0·16
0·896	-0·20	-0·18	-0·14	-0·16
0·948	-0·25	-0·19	-0·14	-0·11
0·967	-0·27	-0·20	-0·13	-0·10
1·000	-0·48	-0·24	-0·15	-0·10

LOWER SURFACE

x/c	α = -0·06°	α = 3·68°	α = 5·38°	α = 5·95°
0·006	0·91	0·78	0·27	0·00
0·007	0·84	0·91	0·45	0·34
0·014	0·72	1·00	0·85	0·75
0·026	0·49	0·96	1·00	1·00
0·050	0·30	0·79	0·91	0·95
0·075	0·21	0·67	0·82	0·86
0·100	0·16	0·60	0·74	0·79
0·149	0·10	0·50	0·64	0·69
0·200	0·07	0·44	0·57	0·63
0·298	0·04	0·36	0·49	0·53
0·348	0·06	0·36	0·48	0·52
0·398	0·08	0·36	0·47	0·50
0·448	0·11	0·36	0·47	0·50
0·498	0·12	0·36	0·47	0·50
0·548	0·15	0·37	0·47	0·50
0·599	0·20	0·39	0·47	0·51
0·647	0·24	0·38	0·48	0·52
0·698	0·28	0·43	0·50	0·52
0·747	0·33	0·46	0·51	0·55
0·797	0·41	0·52	0·57	0·56
0·848	0·55	0·65	0·69	0·69
0·897	-0·46	-0·23	-0·13	-0·09
0·948	-0·47	-0·24	-0·13	-0·09
0·967	-0·47	-0·24	-0·12	-0·09

TABLE 2 - Pressure coefficients for wing with flap at $\beta = 55^\circ$

(a) Without ground

UPPER SURFACE

x/c	$\alpha = -3{\cdot}94^\circ$	$\alpha = 0{\cdot}13^\circ$	$\alpha = 2{\cdot}16^\circ$	$\alpha = 4{\cdot}20^\circ$	$\alpha = 6{\cdot}19^\circ$
0	0·86	-1·12	-3·13	-5·76	-1·77
0·005	-0·36	-2·58	-4·04	-6·22	-1·77
0·007	-0·42	-2·53	-3·92	-6·12	-1·77
0·011	-0·41	-2·15	-3·77	-4·03	-1·77
0·024	-0·50	-1·92	-2·22	-3·16	-1·77
0·047	-0·52	-1·32	-1·85	-2·43	-1·77
0·073	-0·54	-1·22	-1·60	-2·05	-1·77
0·098	-0·52	-1·10	-1·44	-1·82	-1·77
0·148	-0·52	-0·99	-1·23	-1·52	-1·77
0·198	-0·54	-0·95	-1·15	-1·39	-1·77
0·297	-0·57	-0·85	-1·02	-1·17	-1·46
0·348	-0·54	-0·79	-0·93	-1·07	-1·36
0·396	-0·53	-0·74	-0·87	-0·98	-1·28
0·447	-0·50	-0·68	-0·80	-0·89	-1·16
0·497	-0·46	-0·62	-0·72	-0·81	-1·06
0·548	-0·45	-0·58	-0·67	-0·75	-1·02
0·596	-0·43	-0·57	-0·64	-0·70	-0·93
0·647	-0·43	-0·55	-0·61	-0·66	-0·87
0·696	-0·40	-0·51	-0·57	-0·62	-0·82
0·748	-0·39	-0·50	-0·55	-0·59	-0·76
0·795	-0·40	-0·50	-0·54	-0·58	-0·71
0·848	-0·42	-0·50	-0·54	-0·57	-0·66
0·896	-0·47	-0·54	-0·57	-0·59	-0·62
0·948	-0·56	-0·61	-0·63	-0·65	-0·56
0·967	-0·61	-0·66	-0·66	-0·68	-0·56
1·000	-0·87	-0·87	-0·86	-0·85	-0·60

LOWER SURFACE

x/c	$\alpha = -3{\cdot}94^\circ$	$\alpha = 0{\cdot}13^\circ$	$\alpha = 2{\cdot}16^\circ$	$\alpha = 4{\cdot}20^\circ$	$\alpha = 6{\cdot}19^\circ$
0·006	0·67	0·98	0·72	0·18	0·61
0·007	0·56	1·02	0·87	0·58	0·72
0·014	0·36	0·98	0·98	0·84	0·96
0·026	0·24	0·80	0·96	1·01	0·99
0·050	0·10	0·58	0·77	0·90	0·86
0·075	0·04	0·46	0·65	0·78	0·76
0·100	0·01	0·38	0·56	0·69	0·67
0·149	0	0·30	0·45	0·58	0·57
0·200	-0·01	0·26	0·38	0·49	0·50
0·298	0·03	0·22	0·32	0·42	0·42
0·348	0·07	0·24	0·32	0·41	0·41
0·398	0·11	0·27	0·34	0·42	0·42
0·448	0·19	0·29	0·36	0·43	0·43
0·498	0·27	0·34	0·40	0·45	0·46
0·548	0·33	0·42	0·41	0·46	0·47
0·599	0·41	0·46	0·50	0·54	0·56
0·647	0·48	0·54	0·57	0·60	0·61
0·698	0·59	0·65	0·68	0·70	0·70
0·747	0·65	0·72	0·74	0·75	0·76
0·797	0·59	0·66	0·70	0·73	0·74
0·848	-0·83	-0·84	-0·84	-0·83	-0·45
0·897	-0·83	-0·84	-0·84	-0·83	-0·46
0·948	-0·86	-0·87	-0·86	-0·84	-0·47
0·967	-0·87	-0·87	-0·86	-0·84	-0·47

TABLE 2 - Pressure coefficients for wing with flap at $\beta = 55°$ (cont'd)

(b) Ground distance H/c = 0·50

UPPER SURFACE

x/c	α = -4·04°	α = -0·23°	α = 1·62°	α = 2·99°
0	0·73	-1·50	-3·52	-5·20
0·005	-0·51	-2·61	-4·06	-5·49
0·007	-0·58	-2·55	-3·96	-5·45
0·011	-0·56	-2·19	-3·46	-3·39
0·024	-0·54	-1·44	-2·12	-2·65
0·047	-0·52	-1·23	-1·68	-2·00
0·073	-0·51	-1·08	-1·43	-1·68
0·098	-0·49	-0·97	-1·25	-1·46
0·148	-0·48	-0·84	-1·06	-1·22
0·198	-0·48	-0·79	-0·95	-1·09
0·297	-0·50	-0·72	-0·84	-0·91
0·348	-0·48	-0·67	-0·76	-0·83
0·396	-0·46	-0·62	-0·69	-0·74
0·447	-0·43	-0·60	-0·63	-0·67
0·497	-0·40	-0·50	-0·56	-0·60
0·548	-0·37	-0·47	-0·51	-0·55
0·596	-0·35	-0·45	-0·48	-0·50
0·647	-0·32	-0·42	-0·45	-0·46
0·696	-0·31	-0·39	-0·41	-0·42
0·748	-0·32	-0·37	-0·39	-0·39
0·795	-0·32	-0·36	-0·37	-0·38
0·848	-0·34	-0·36	-0·36	-0·36
0·896	-0·38	-0·40	-0·39	-0·38
0·948	-0·47	-0·46	-0·43	-0·41
0·967	-0·51	-0·49	-0·46	-0·42
1·000	-0·73	-0·68	-0·61	-0·59

LOWER SURFACE

x/c	α = -4·04°	α = -0·23°	α = 1·62°	α = 2·99°
0·006	0·82	0·92	0·56	0·16
0·007	0·74	0·98	0·76	0·46
0·014	0·62	0·99	0·94	0·80
0·026	0·44	0·91	1·01	1·01
0·050	0·29	0·74	0·88	0·92
0·075	0·23	0·64	0·79	0·85
0·100	0·20	0·57	0·72	0·78
0·149	0·18	0·50	0·63	0·71
0·200	0·18	0·46	0·58	0·65
0·298	0·19	0·42	0·53	0·60
0·348	0·23	0·43	0·53	0·60
0·398	0·26	0·45	0·54	0·60
0·448	0·30	0·47	0·55	0·60
0·498	0·37	0·49	0·57	0·62
0·548	0·42	0·53	0·58	0·63
0·599	0·49	0·59	0·63	0·66
0·647	0·56	0·64	0·68	0·71
0·698	0·65	0·73	0·75	0·77
0·747	0·72	0·78	0·81	0·83
0·797	0·68	0·77	0·79	0·84
0·848	-0·74	-0·65	-0·59	-0·53
0·897	-0·74	-0·65	-0·60	-0·54
0·948	-0·74	-0·66	-0·60	-0·55
0·967	-0·74	-0·66	-0·60	-0·55

TABLE 2 - Pressure coefficients for wing with flap at β = 55° (cont'd)

(c) Ground distance H/c = 0·37

UPPER SURFACE

x/c	α = -4·16°	α = -0·62°	* α = 0·84°	* α = 2·38°	
0	0·67	-1·66	-3·65	-2·31	
0·005	-0·59	-2·64	-4·14	-2·31	
0·007	-0·64	-2·57	-4·03	-1·64	
0·011	-0·62	-2·28	-3·28	-2·14	
0·024	-0·59	-1·34	-2·11	-1·64	Fluctuating
0·047	-0·55	-1·23	-1·65	-2·14	
0·073	-0·54	-1·07	-1·40	-1·71	
0·098	-0·52	-0·95	-1·22	-1·84	
0·148	-0·51	-0·83	-1·03	-1·74	
0·198	-0·51	-0·78	-0·96	-1·48	
0·297	-0·52	-0·69	-0·81	-1·30	
0·348	-0·50	-0·63	-0·73	-1·09	
0·396	-0·48	-0·58	-0·67	-1·03	
0·447	-0·45	-0·53	-0·60	-0·87	
0·497	-0·42	-0·47	-0·53	-0·86	
0·548	-0·37	-0·44	-0·48	-0·72	
0·596	-0·37	-0·42	-0·46	-0·70	
0·647	-0·36	-0·39	-0·42	-0·62	
0·696	-0·34	-0·36	-0·38	-0·61	
0·748	-0·34	-0·34	-0·36	-0·51	
0·795	-0·35	-0·33	-0·34	-0·46	
0·848	-0·36	-0·33	-0·34	-0·43	
0·896	-0·40	-0·36	-0·36	-0·39	
0·948	-0·50	-0·42	-0·40	-0·37	
0·967	-0·53	-0·45	-0·43	-0·35	
1·000	-0·76	-0·62	-0·60	-0·35	

LOWER SURFACE

x/c	α = -4·16°	α = -0·62°	* α = 0·84°	* α = 2·38°
0·006	0·85	0·88	0·51	0·53
0·007	0·78	0·96	0·72	0·66
0·014	0·66	1·00	0·92	0·89
0·026	0·49	0·94	1·01	1·02
0·050	0·34	0·78	0·91	0·95
0·075	0·27	0·70	0·82	0·88
0·100	0·24	0·63	0·76	0·82
0·149	0·22	0·56	0·68	0·78
0·200	0·22	0·53	0·64	0·69
0·298	0·24	0·50	0·59	0·64
0·348	0·27	0·52	0·60	0·64
0·398	0·30	0·53	0·60	0·64
0·448	0·34	0·54	0·61	0·65
0·498	0·40	0·56	0·63	0·66
0·548	0·45	0·59	0·64	0·67
0·599	0·51	0·64	0·68	0·72
0·647	0·57	0·68	0·72	0·75
0·698	0·66	0·75	0·78	0·80
0·747	0·73	0·81	0·84	0·86
0·797	0·70	0·79	0·83	0·90
0·848	-0·75	-0·59	-0·54	-0·30
0·897	-0·75	-0·61	-0·55	-0·30
0·948	-0·78	-0·61	-0·56	-0·32
0·967	-0·77	-0·61	-0·56	-0·32

* N.B. Owing to boundary layer separation on the ground plate the results for α > 0° are considered to be of doubtful reliability.

TABLE 3

Force coefficients, from integration of pressure distribution

	α	C_N	C_T	C_L	C_D	C_m
		Less flap loads		Assuming elliptic distribution of flap load		
$\beta = 15°$						
No ground	0·06°	0·427	-0·004	0·543	0·036	-0·112
	4·13°	0·880	0·056	0·983	0·042	-0·123
	6·16°	1·095	0·110	1·194	0·044	-0·121
	7·17°	1·188	0·145	1·286	0·041	-0·122
H/c = 0·50	0·13°	0·466	-0·001	0·580	0·033	-0·112
	3·97°	0·893	0·067	0·991	0·028	-0·123
	5·85°	1·085	0·116	1·181	0·030	-0·124
	7·72°	1·185	0·016	1·279	0·185	-0·210
H/c = 0·37	-0·06°	0·480	0·001	0·596	0·030	-0·120
	3·68°	0·942	0·066	1·044	0·030	-0·131
	5·38°	1·150	0·127	1·247	0·016	-0·133
	5·95°	1·204	0·148	1·297	0·012	-0·125
$\beta = 55°$						
No ground	-3·94°	0·602	-0·014	0·696	0·090	-0·160
	0·13°	0·994	0·036	1·092	0·101	-0·172
	2·16°	1·209	0·072	1·304	0·116	-0·175
	4·20°	1·421	0·123	1·516	0·130	-0·175
	6·19°	1·557	0·035	1·615	0·245	-0·250
H/c = 0·50	-4·04°	0·628	-0·013	0·726	0·091	-0·164
	-0·23°	1·001	0·036	1·095	0·089	-0·171
	1·62°	1·209	0·080	1·294	0·082	-0·163
	2·99°	1·319	0·104	1·402	0·095	-0·170
H/c = 0·37	-4·16°	0·675	-0·014	0·776	0·091	-0·170
	-0·62°	1·046	0·045	1·140	0·072	-0·173
*	0·84°	1·224	0·083	1·315	0·064	-0·170
*	2·38°	1·550	0·056	1·624	0·130	-0·207

* N.B. Doubtful results.

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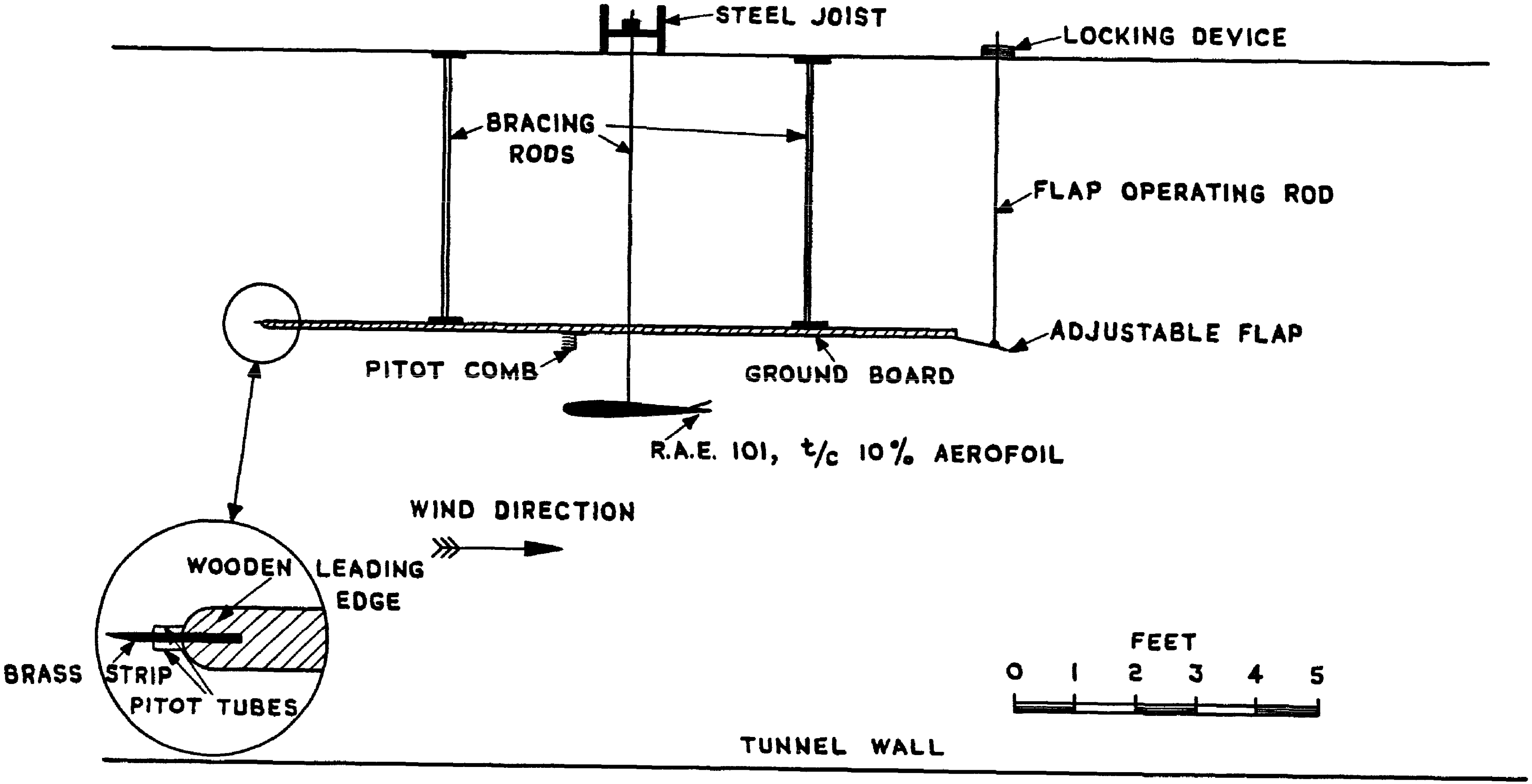

FIG. I. SKETCH OF TUNNEL RIG USED IN EXPERIMENTAL INVESTIGATION.

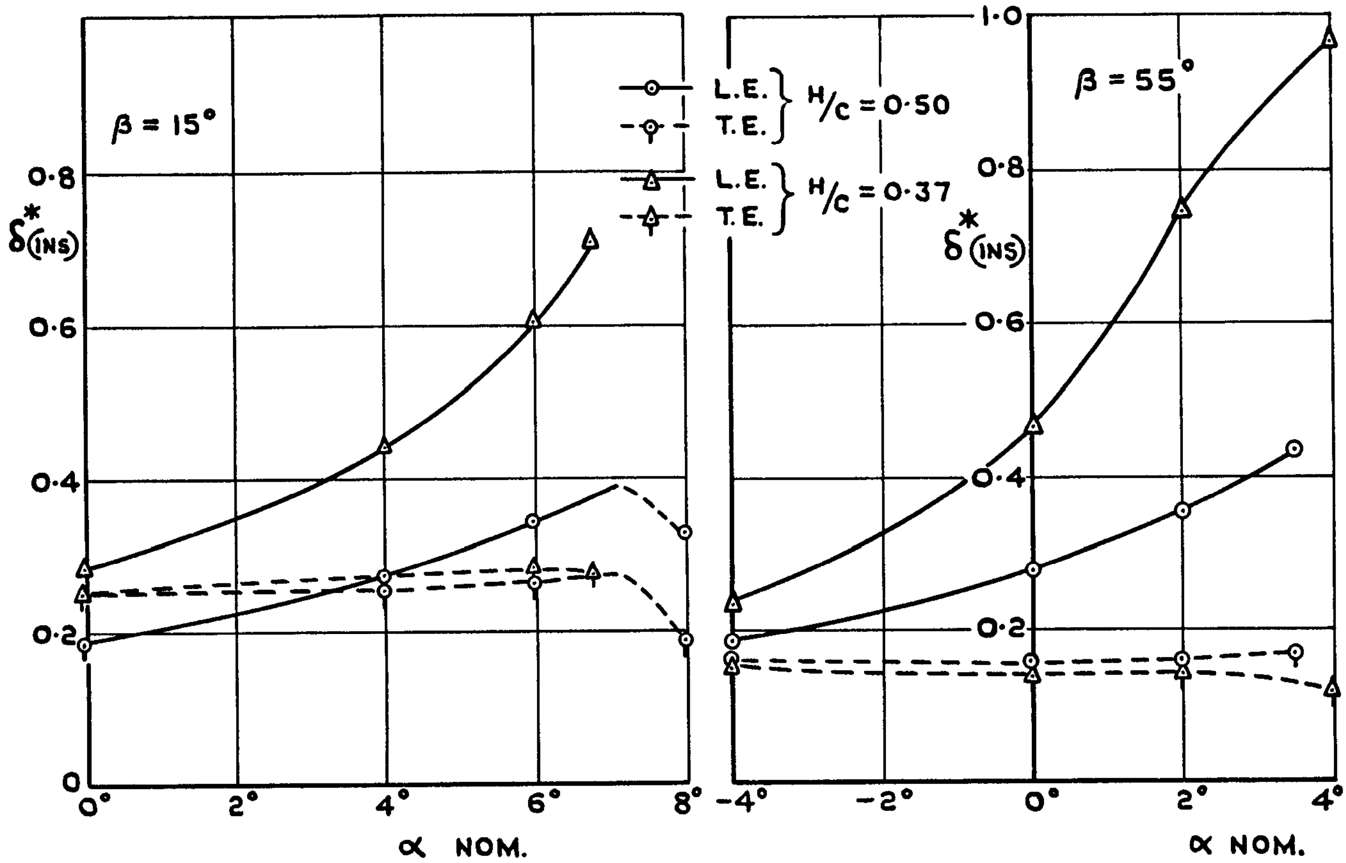

FIG. 2. DISPLACEMENT THICKNESS OF BOUNDARY LAYER ON GROUND PLATE.

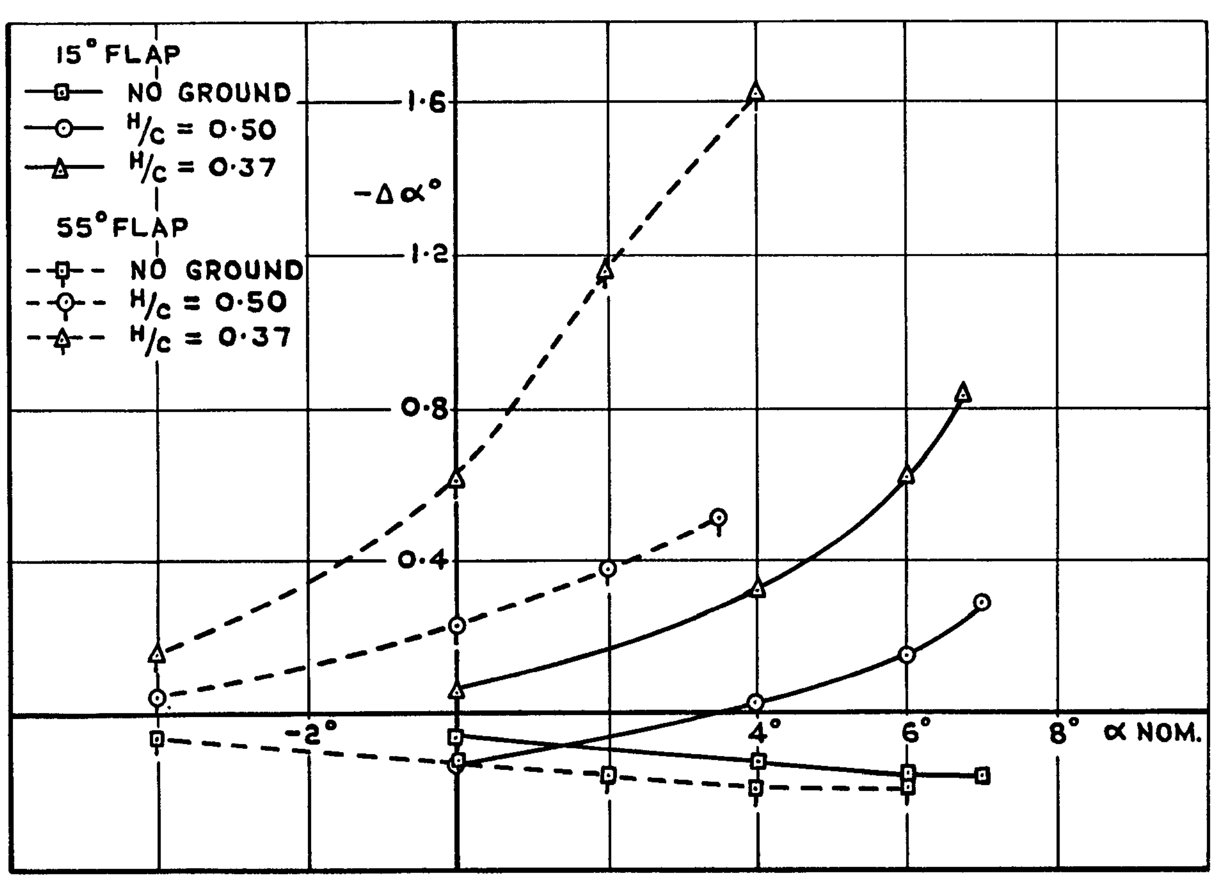

FIG. 3. CORRECTIONS TO WING INCIDENCE.

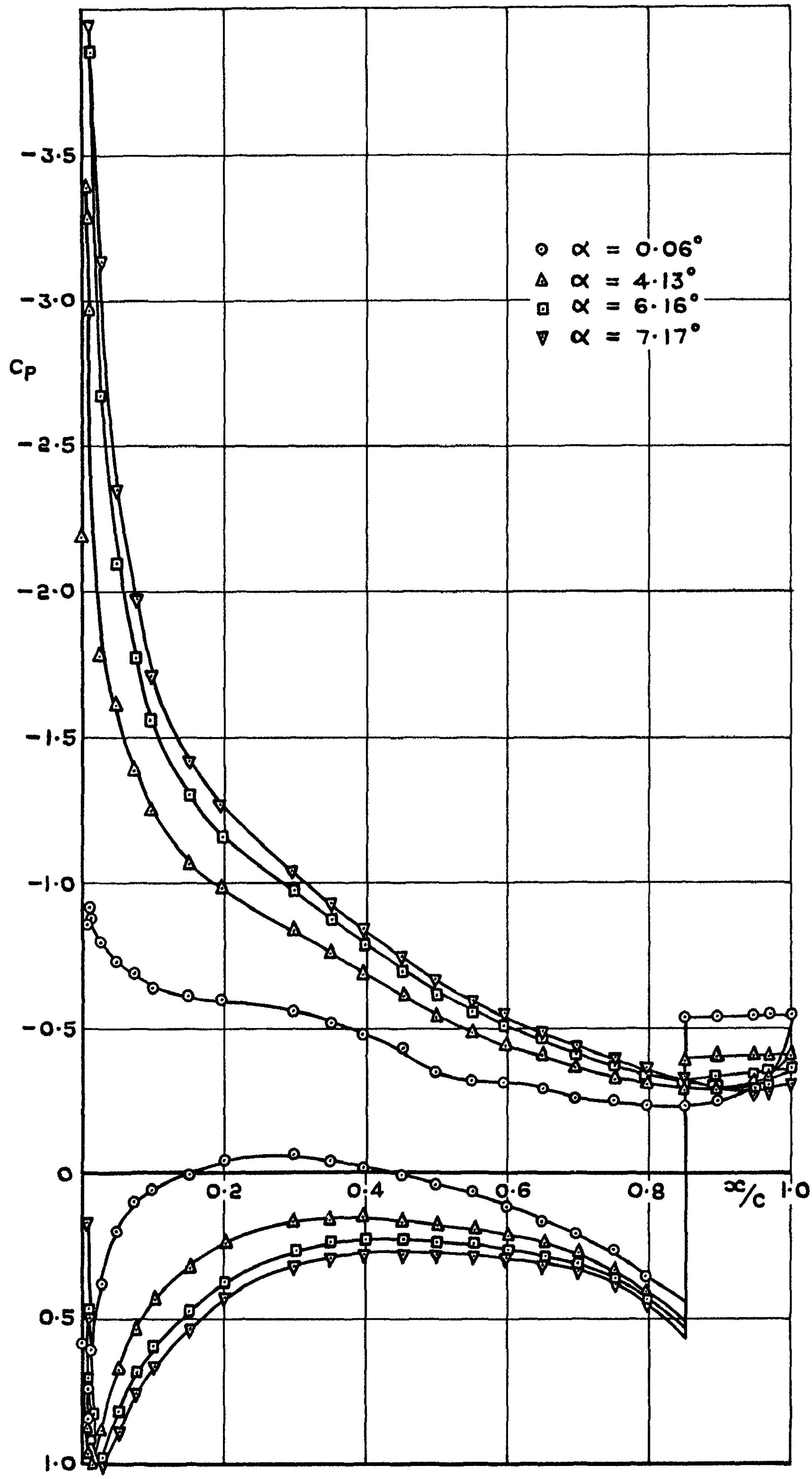

FIG. 4. PRESSURE DISTRIBUTIONS; $\beta = 15°$; NO GROUND.

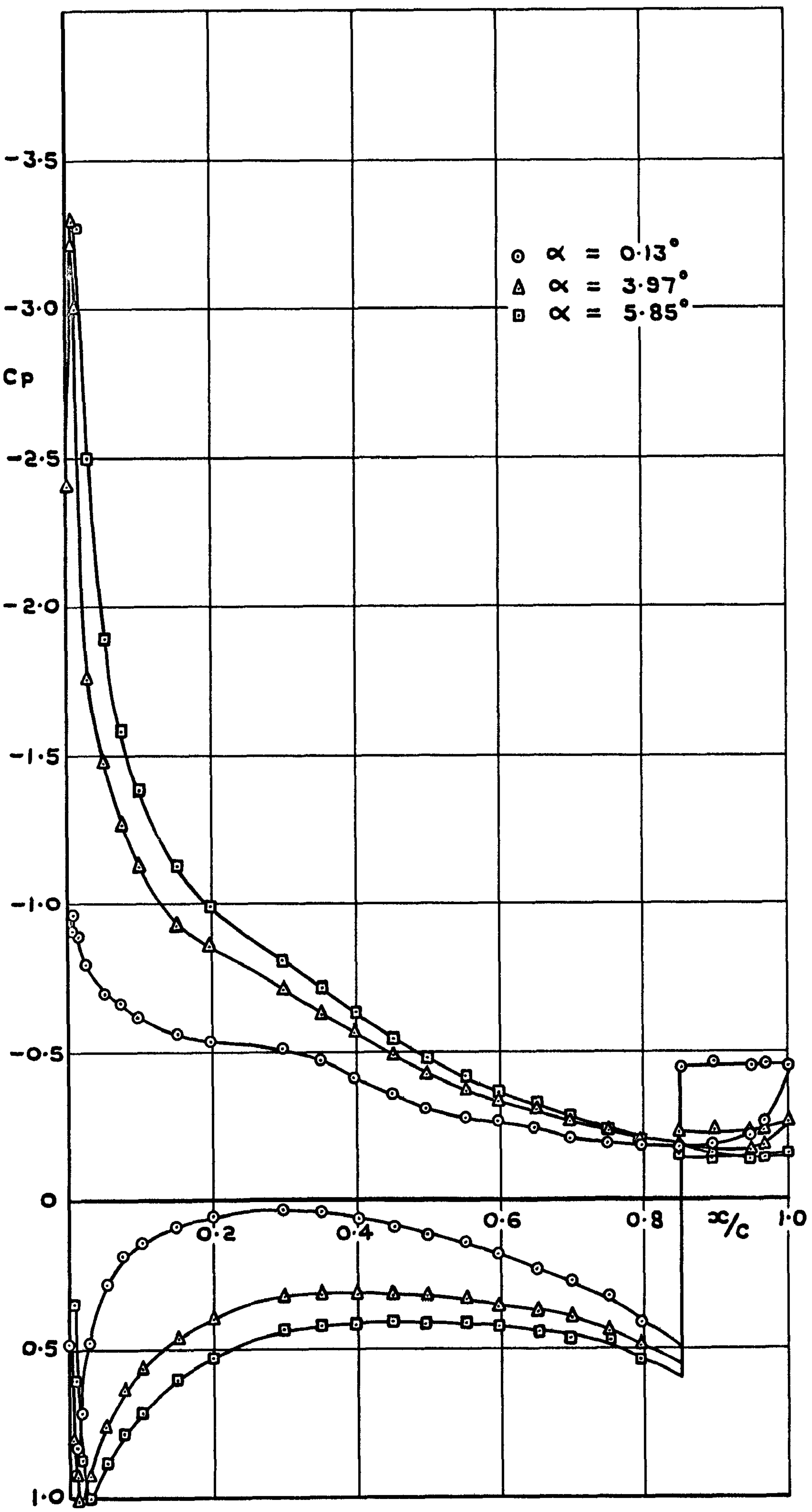

FIG. 5. PRESSURE DISTRIBUTIONS; $\beta = 15°$, $H/C = 0{\cdot}50$.

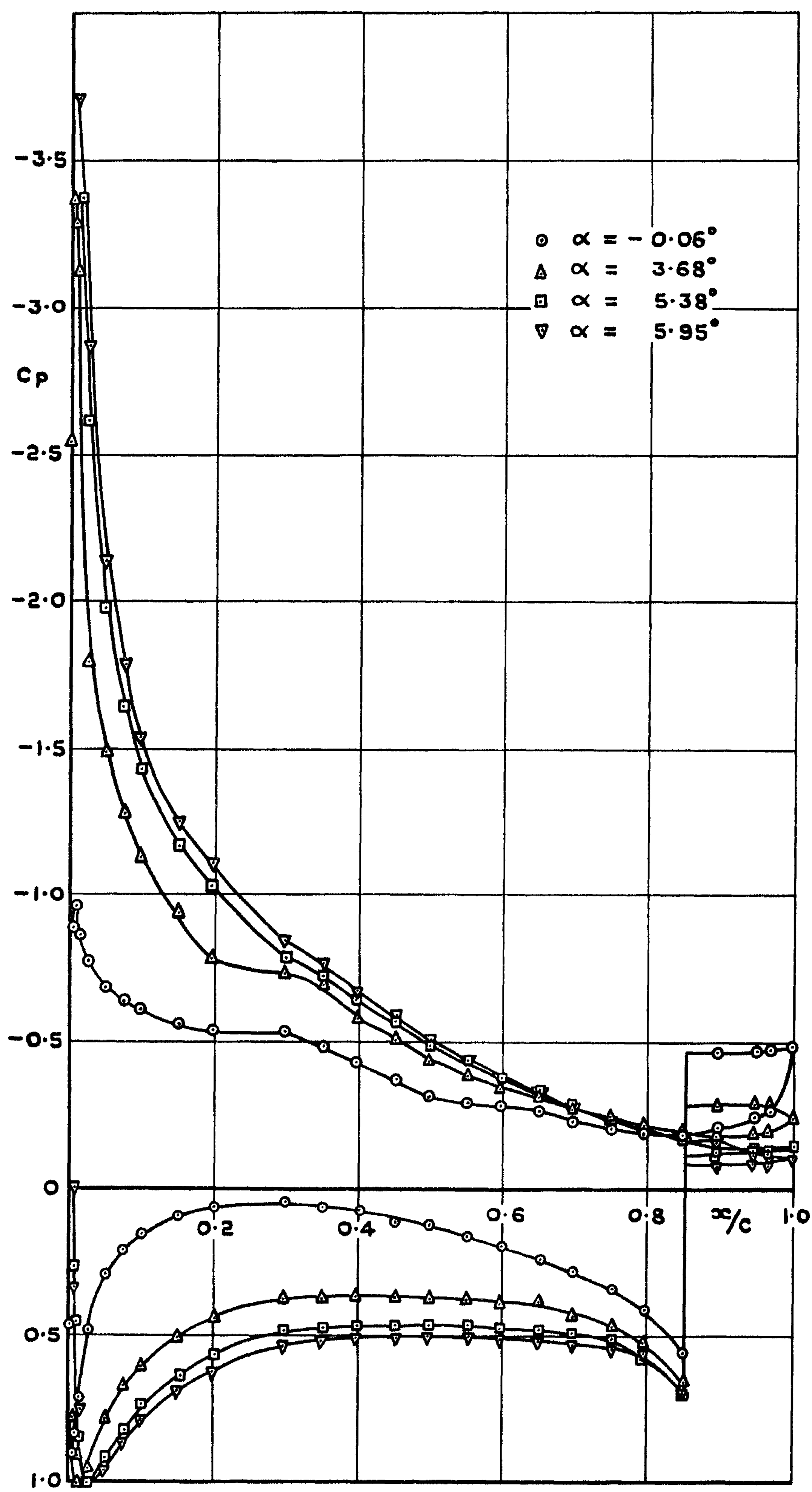

FIG. 6. PRESSURE DISTRIBUTIONS; $\beta = 15°$, $H/C = 0\cdot37$.

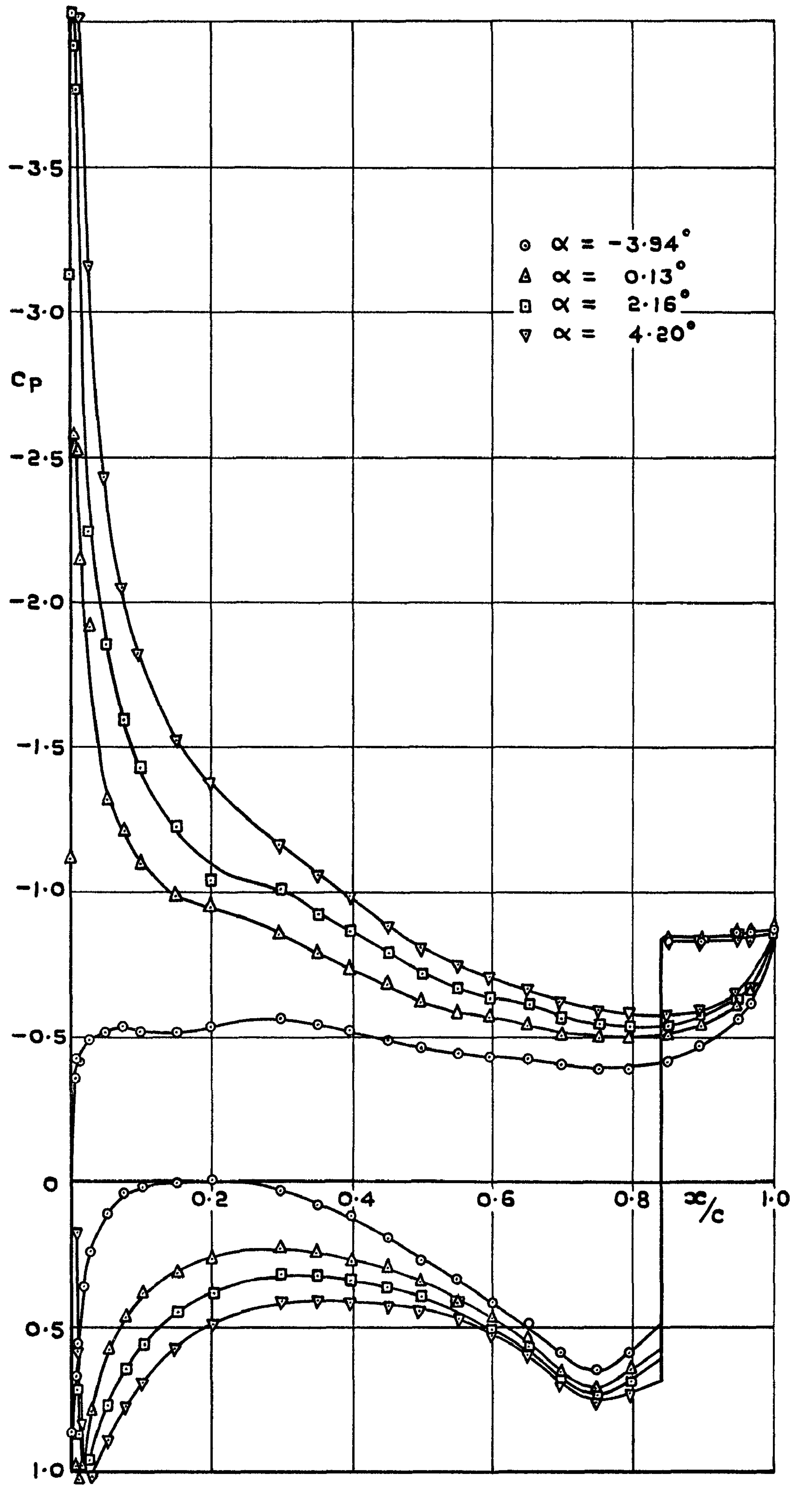

FIG. 7. PRESSURE DISTRIBUTIONS; $\beta = 55°$, NO GROUND.

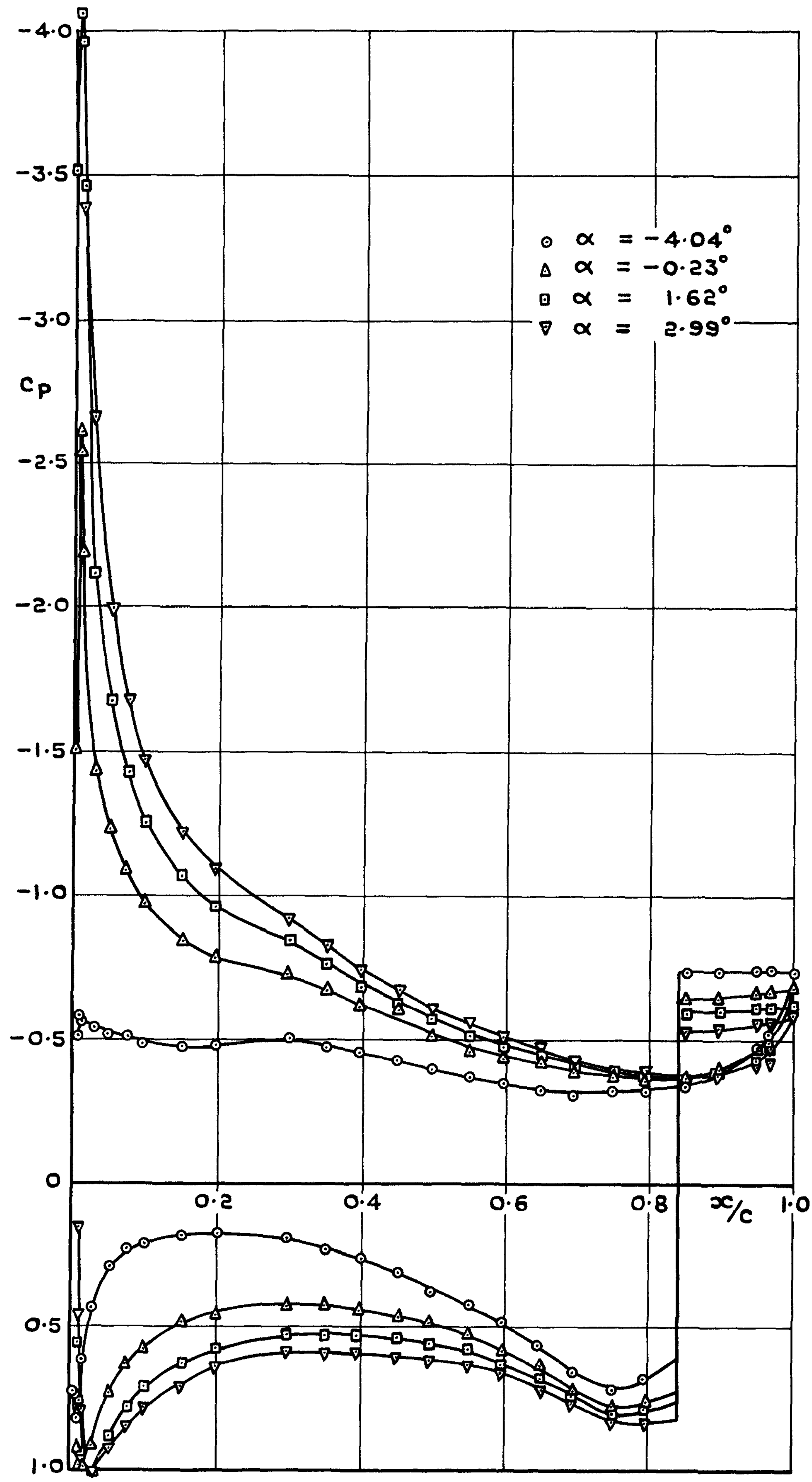

FIG. 8. PRESSURE DISTRIBUTIONS; $\beta = 55°$; $H/C = 0{\cdot}50$.

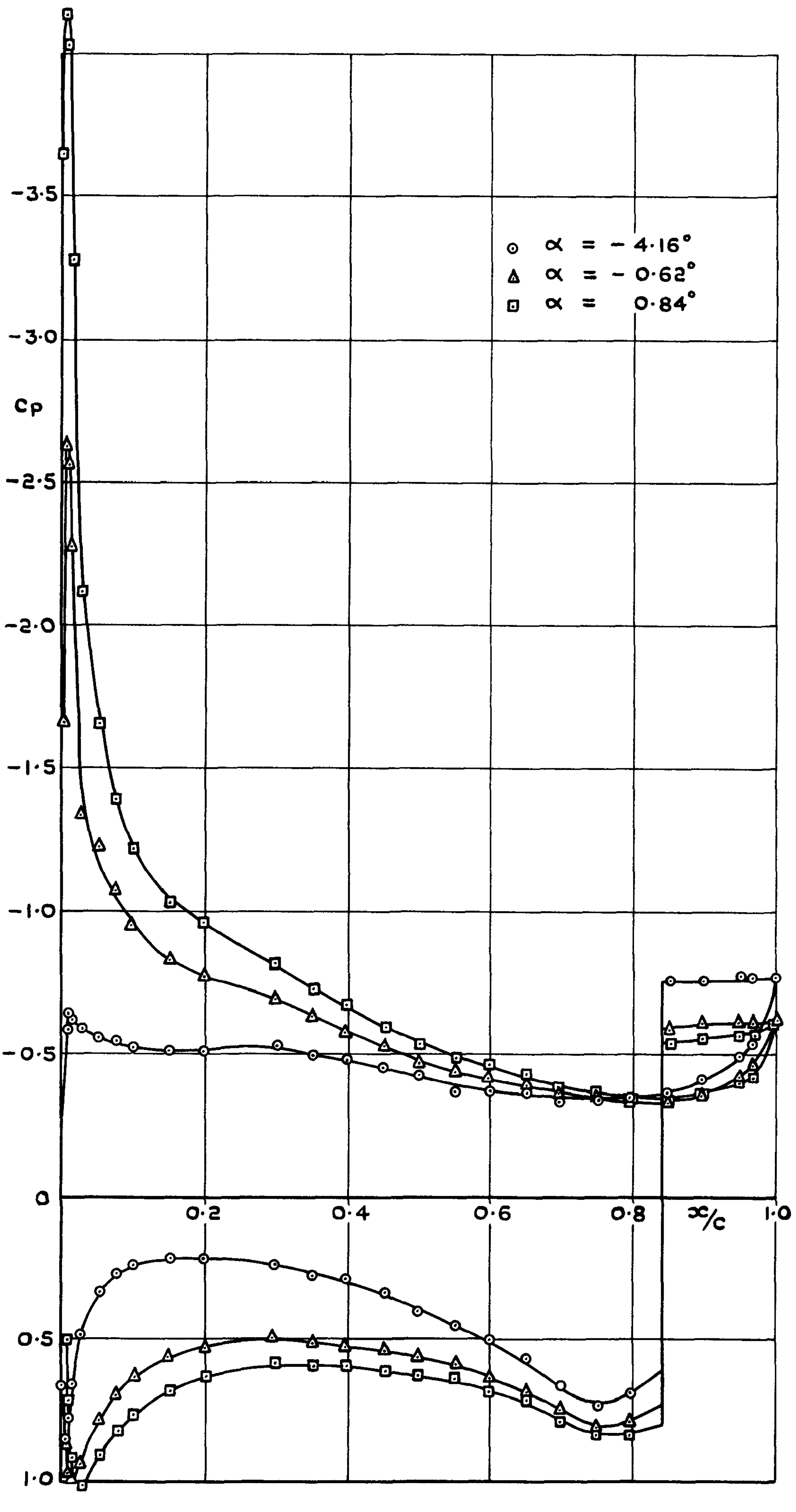

FIG. 9. PRESSURE DISTRIBUTIONS; $\beta = 55°$, $H/C = 0{\cdot}37$.

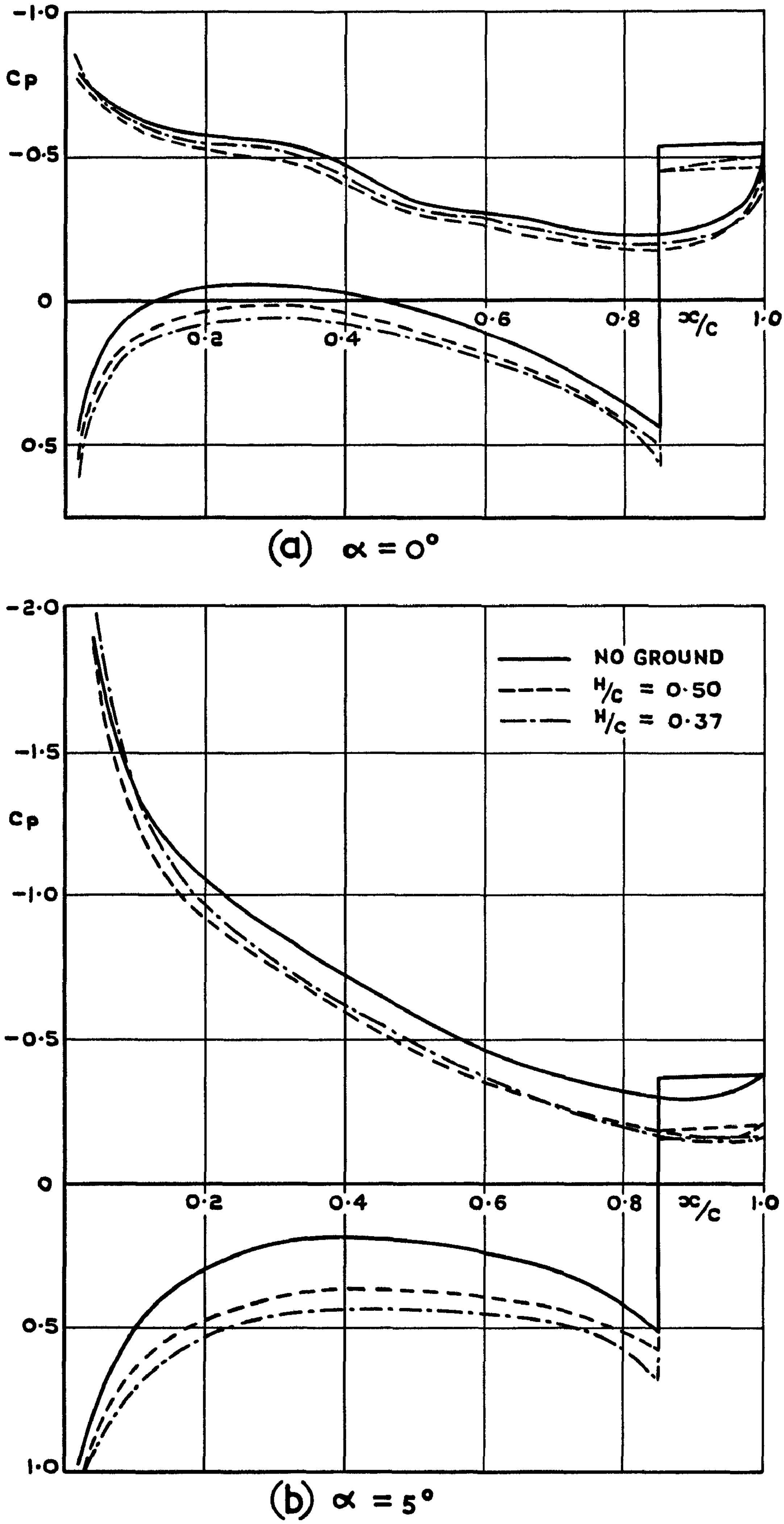

FIG. 10. EFFECT OF GROUND DISTANCE AT CONSTANT INCIDENCE, $\beta = 15°$

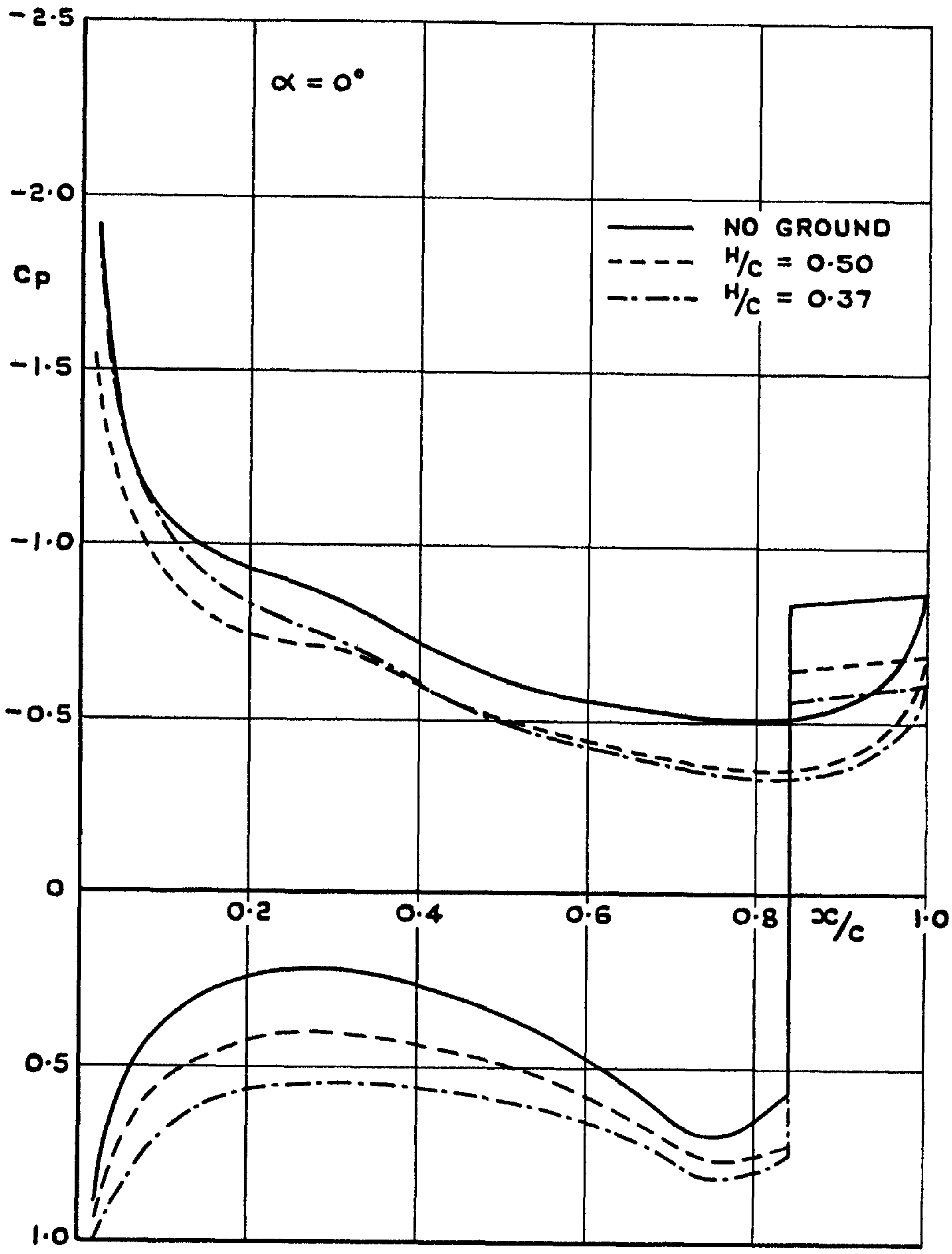

FIG. 11. EFFECT OF GROUND DISTANCE AT CONSTANT INCIDENCE, $\beta = 55°$.

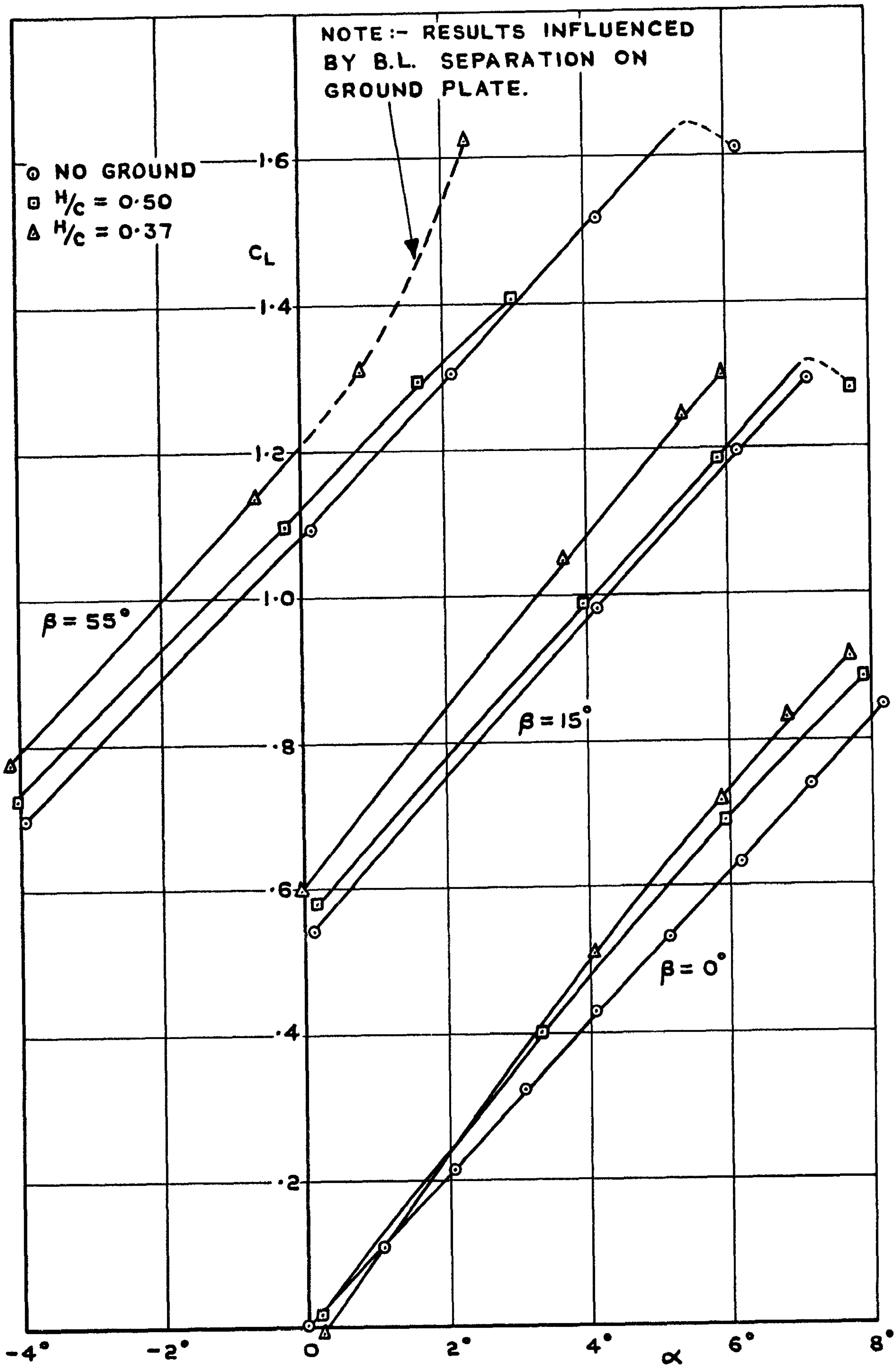

FIG. 12. LIFT COEFFICIENTS, ASSUMING ELLIPTIC LOAD ON FLAP.

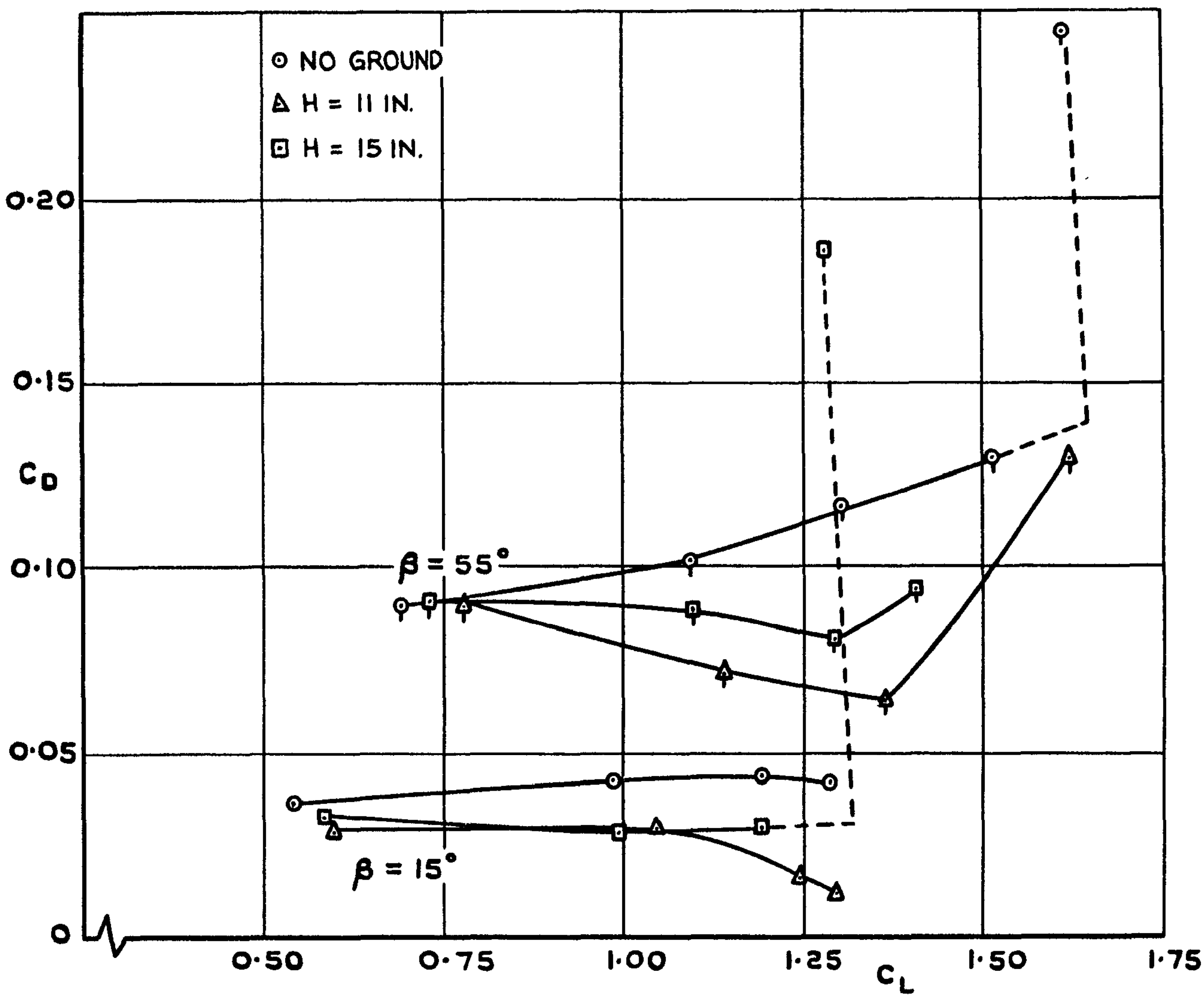

FIG. 13. DRAG COEFFICIENTS, ASSUMING ELLIPTIC LOAD ON FLAP.

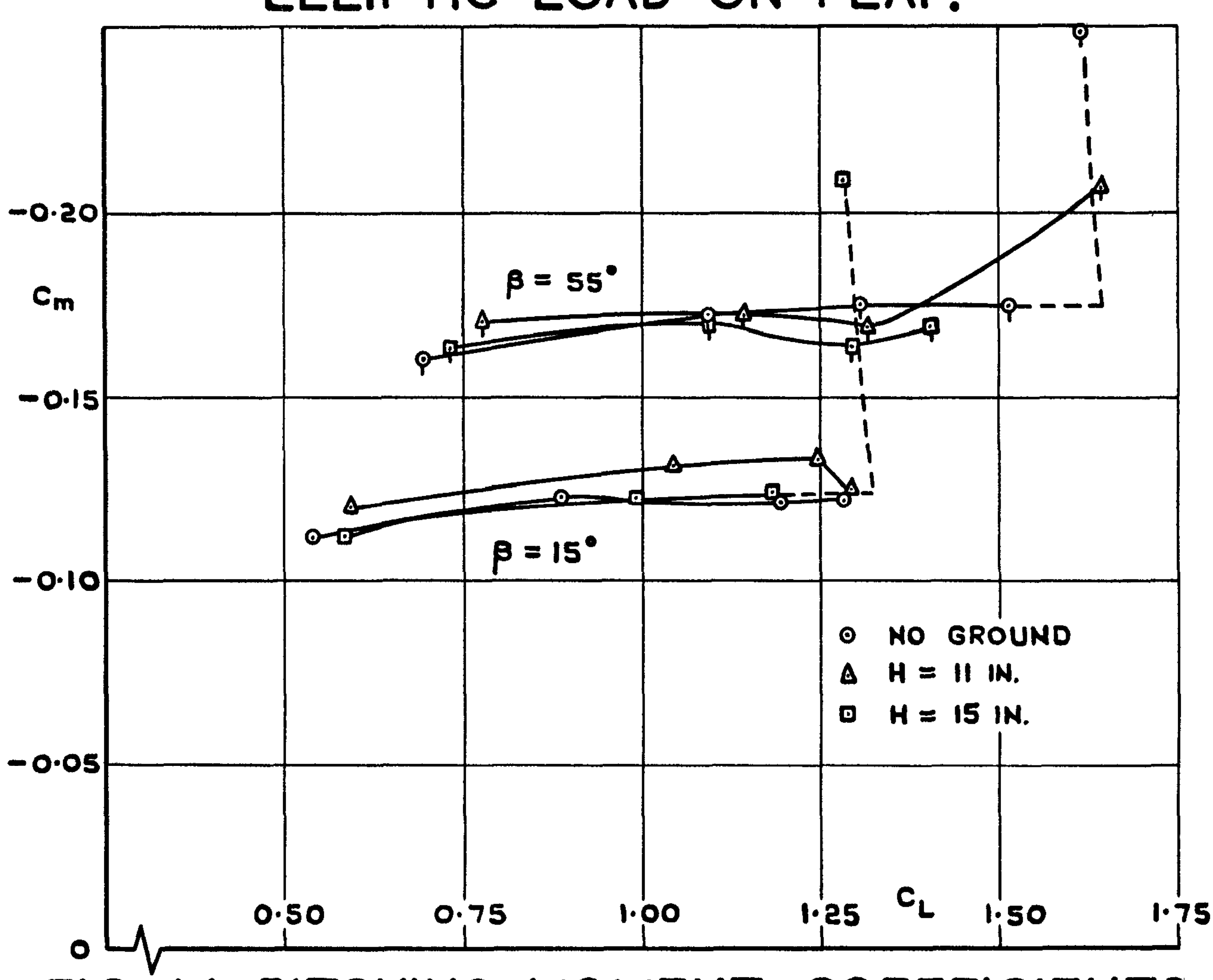

FIG. 14. PITCHING MOMENT COEFFICIENTS, ASSUMING ELLIPTIC LOAD ON FLAP.

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533.692.1:
533.694.21:
533.69.048.2:
533.682

LOW-SPEED WIND TUNNEL TESTS ON A TWO-DIMENSIONAL AEROFOIL WITH SPLIT FLAP NEAR THE GROUND. Bagley, J.A. March 1961.

Pressure distributions have been measured on a 10% thick two-dimensional aerofoil of R.A.E. 101 section fitted with split flaps deflected at 15° and 55°. Measurements were made at two distances above a ground plate, and also without the ground plate. The results have been integrated to give the sectional lift, drag and pitching-moment coefficients.

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