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by

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THE LONGITUDINAL STABILITY CHARACTERISTICS OF AN OGEE WING OF SLENDERNESS RATIO = 0.35

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SUMMARY

The lift, drag and pitching moment characteristics of an ogee wing of slenderness ratio = 0.35 have been measured in the 4ft × 3ft wind tunnel at RAE Farnborough and the results and analysis are presented in this paper. The analysis extends the results already obtained on a previous generalized series of planforms.

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* Replaces RAE Technical Report 71103 - ARC 33206

CONTENTS

1 INTRODUCTION

An investigation into the effect of planform shape on the subsonic longitudinal stability characteristics of slender wings was reported by Kirby in Ref.1. The ogee wings tested were of slenderness ratios $s/c_0 = 0.2, 0.25, 0.3$ and had constant planform parameters and thickness/chord ratios of 0.4756 and 4 per cent respectively. The series has now been extended by testing a further ogee wing of $s/c_0 = 0.35$ and the results and subsequent analysis, which follows that adopted in Ref.1, are presented in this Report.

2 MODEL AND TEST PROCEDURE

The non-dimensional planform and thickness distribution equations for the new ogee model of $s/c_0 = 0.35$ were the same as used for the previous ogee models; the planform being defined by,

$$\frac{y}{s} = 0.8\left(\frac{x}{c_0}\right) + 0.6\left(\frac{x}{c_0}\right)^4 - 0.4\left(\frac{x}{c_0}\right)^8$$

where y is the spanwise distance from the centre line to the leading edge, s is the semispan, x is the chordwise distance from the apex and c_0 is the centre-line chord. The thickness distribution is defined by the equation,

$$\text{half thickness} = \frac{3\sqrt{3}}{50}(x_1 - x_0)\left(1 - \frac{x_1 - x_0}{c_0 - x_0}\right)\left(1 - \frac{1}{2}\frac{x_1 - x_0}{c_0 - x_0}\right)$$

where x_1 is any point on the wing chord and x_0 is the leading edge at a particular spanwise section (Fig.1). Full geometric parameters for the series of ogee wings are listed in Table 1.

The model was hung from the standard wire rig of the overhead balance in the 4ft × 3ft low-speed wind tunnel at the RAE Farnborough. The tests were made transition free at a free stream velocity of 60.78 m/s (199.42 ft/s) giving a Reynolds number of 2.3 million based on centre-line chord.

The lift, drag and pitching moment forces were measured over the angle of incidence range -5 to +25 degrees at 1 degree intervals, and, for greater accuracy in defining the characteristics at low incidences, at every ½ degree over the range -5 to +5 degrees. The measured forces and pitching moments were non-dimensionalised with respect to qS and qSc_0 respectively, where q is the free stream dynamic pressure and S is the wing plan area. The calculated results have been corrected for wind tunnel constraint[2] and a small incidence correction of $\Delta\alpha = 0.17$ degree applied to ensure that there is zero lift coefficient at zero incidence. It was not found necessary to apply a ΔC_m correction. The fully corrected results are given in Table 2.

3 ANALYSIS OF RESULTS

3.1 Lift and normal force

The lift coefficient is plotted against angle of incidence in Fig.2. Following the method of analysis adopted in Ref.1, the coefficients of the lift and drag forces are first resolved into the coefficients of normal force (CN) and axial force (CA) where,

$$CN = C_L \cos\alpha + C_D \sin\alpha$$

and

$$CA = C_D \cos\alpha - C_L \sin\alpha \quad .$$

The normal force coefficient is then further divided into linear and non-linear components

$$CN = CN_L + CN_{NL} = a\alpha + CN_{NL} \quad .$$

The slope 'a' of the linear component is determined by locating the intercept on the CN/α axis of the curve of CN/α plotted against incidence (Fig.3), use being made of the extra points at the lower angles of incidence. Comparing the value of 'a' thus obtained with the results for the other ogees in the series shows that increasing the slenderness ratio has continued to increase the slope of the linear normal force component (Fig.4).

Furthermore the value for the ogee wing of slenderness ratio = 0.35 fits onto the curve of 'a' against the modified aspect ratio $A(1 + (0.99c)/c_0)$ which was introduced in Ref.1 to collapse the linear slopes of all planforms (Fig.5).

Subtraction of the linear force component from the overall normal force leaves the non-linear component $(CN - a\alpha)$. In Ref.1 it was shown that the variation with angle of incidence of the non-linear component of a wide range of planforms could be expressed by a single curve if $(CN - a\alpha)/A\alpha\eta$ was plotted against α/A, where η is the semispan ratio s_x/s at a semispan s ahead of the trailing edge. The results for the ogee wing of $s/c_0 = 0.35$ are compared with the correlation curve from Ref.1 in Fig.6. The present results are consistently above the curve and outside the scatter of the points used to derive that curve in Ref.1. There is evidently a limit on the range of slenderness ratio over which the curve can be applied and this range may be less for the ogee type of wing because of the rapid reduction in η when s is increased beyond about 0.3. Because of the larger proportion of linear to non-linear normal force as slenderness ratio increases, the error in the overall force coefficients resulting from use of the correlation curve is much less than that of the non-linear component, cf. Figs.3 and 6.

3.2 Drag

The value of C_{D_0}, the minimum drag coefficient, is determined by plotting drag coefficient against (angle of incidence)^2 and locating the intercept on the drag axis; the drag 'bucket' due to the transition free condition at low Reynolds number is ignored. The lift-dependent drag factor $K = \frac{(C_D - C_{D_0})\pi A}{C_L^2}$ is evaluated and given in Table 2 and plotted against angle of incidence in Fig.7 together with the values obtained for the previous series of ogee wings. The previous trend of increasing K with increasing slenderness ratio is maintained.

3.3 Pitching moment

The pitching moment coefficient, expressed about a moment centre of $0.62c_0$ is plotted against angle of incidence and lift coefficient in Fig.8a and Fig.8b respectively. Comparing the present ogee with those of the existing series shows that, as before, for a fixed moment centre an increase in slenderness ratio tends to produce a pitch-up moment.

Again, following the previous method of analysis, the pitching moment is resolved into its linear and non-linear components by the following equation,

$$C_m \frac{h}{c_0} = CN_L \left(\frac{h}{c_0} - \frac{x_a}{c_0} + \frac{\Delta h_L}{c_0}\right) + CN_{NL} \left(\frac{h}{c_0} - \frac{x_a}{c_0} + \frac{\Delta h_{NL}}{c_0}\right)$$

where $C_m \frac{h}{c_0}$ is the pitching moment about an arbitrary point distance h aft of the wing apex, x_a is the distance of the centre of plan area aft of the wing apex and Δh_{linear} $(= \Delta h_L)$ and $\Delta h_{non\ linear}$ $(= \Delta h_{NL})$ are the distances of the points of action of the linear and non-linear force components ahead of the centre of area. The point of action of the linear component is obtained by plotting C_m/C_N against angle of incidence and locating the intercept on the C_m/C_N axis at zero incidence.

The point of action of the non-linear component can then be calculated by using Δh_L in conjunction with the linear normal force component and the overall pitching moment. Values of $\Delta h_L/c_0$ and $\Delta h_{NL}/c_0$ for the $s/c_0 = 0.35$ ogee are compared with the values for the previous ogee wing in Fig.9 and show a continuing development of forward movement with increasing slenderness ratio.

3.4 Aerodynamic centre

The position of the aerodynamic centre Δh_n ahead of the centre of area evaluated by using the equation,

$$\Delta h_n = x_a - \left(h - \frac{dC_m}{dC_N}\right)$$

is given in Table 3 and plotted against lift coefficient in Fig.10. The values for slenderness ratios $s/c_0 = 0.2$, 0.25 and 0.3 are also plotted and the form of the variation with lift coefficient observed previously is still found at the higher slenderness ratio.

4 CONCLUSIONS

This test on an ogee wing of slenderness ratio = 0.35 was made to provide an extension to an existing series of ogee wings. The calculated results and subsequent analysis has followed the methods used in Ref.1. The results show that

(i) The slope 'a' of the linear normal force curve when plotted against the modified aspect ratio provides an extension to the existing data.

(ii) The function η, used in Ref.1 to correlate the non-linear normal force curves, was found to be less effective for the present ogee wing presumably because of the rapid reduction in η when s is increased beyond a slenderness ratio of about 0.3.

(iii) The induced drag factor K continues to increase with increasing slenderness ratio.

(iv) The increase in slenderness ratio moves the point of action of the linear and non-linear lift further forward and increases the pitch-up tendency.

Table 1

LIST OF GEOMETRIC PARAMETERS FOR THE SERIES OF OGEE WINGS

Slenderness ratio s/c_0	0.20	0.25	0.30	0.35
Wing centre line chord c_0	0.686 m (2.25 ft)	0.686 m (2.25 ft)	0.686 m (2.25 ft)	0.555 m (1.821 ft)
Wing semi-span s	0.137 m (0.45 ft)	0.172 m (0.563 ft)	0.206 m (0.675 ft)	0.193 m (0.633 ft)
Wing plan area S	0.0965 m^2 (0.963 ft^2)	0.1119 m^2 (1.204 ft^2)	0.1342 m^2 (1.445 ft^2)	0.1019 m^2 (1.0966 ft^2)
Thickness chord ratio	0.04	0.04	0.04	0.04
Aspect ratio	0.8411	1.0514	1.2617	1.4616
Planform parameter	0.4756	0.4756	0.4756	0.4756

Table 2

CALCULATED COEFFICIENTS

α deg	C_L	C_D	C_N	C_A	$C_{m_{0.62}}$	C_N/α	K
V = 60.78 m/s (199.42 ft/s)							
-4.94	-0.1720	0.0177	-0.1729	0.0028	0.00385	2.004	
-4.45	-0.1543	0.0155	-0.1550	0.0036	0.00358	2.006	C_{D_0} =
-3.91	-0.1317	0.0127	-0.1323	0.0037	0.00300	1.938	
-3.40	-0.1143	0.0108	-0.1147	0.0040	0.00261	1.936	0.0051
-2.88	-0.0921	0.0088	-0.0924	0.0042	0.00216	1.841	
-2.36	-0.0753	0.0080	-0.0755	0.0049	0.00175	1.832	
-1.85	-0.0545	0.0066	-0.0546	0.0048	0.00125	1.697	
-1.33	-0.0401	0.0059	-0.0402	0.0050	0.00096	1.729	
-0.82	-0.0274	0.0049	-0.0275	0.0045	0.00062	1.915	
-0.31	-0.0103	0.0044	-0.0103	0.0043	0.00039	1.909	
0.21	0.0080	0.0042	0.0080	0.0042	-0.00002	2.209	
0.72	0.0219	0.0044	0.0219	0.0041	-0.00041	1.750	
1.23	0.0406	0.0062	0.0407	0.0053	-0.00110	1.892	
1.75	0.0548	0.0069	0.0550	0.0052	-0.00129	1.805	
2.26	0.0703	0.0076	0.0706	0.0048	-0.00154	1.791	
2.78	0.0922	0.0088	0.0925	0.0044	-0.00213	1.908	
3.30	0.1144	0.0107	0.1149	0.0041	-0.00270	1.997	1.979
3.81	0.1309	0.0125	0.1315	0.0037	-0.00299	1.977	1.987
4.32	0.1482	0.0144	0.1489	0.0032	-0.00327	1.973	1.954
4.84	0.1726	0.0176	0.1734	0.0030	-0.00379	2.052	1.943
5.36	0.1921	0.0204	0.1932	0.0024	-0.00417	2.064	1.917
6.40	0.2379	0.0283	0.2396	0.0016	-0.00468	2.145	1.893
7.44	0.2841	0.0380	0.2866	0.0009	-0.00537	2.208	1.887
8.47	0.3248	0.0480	0.3283	-0.0003	-0.00597	2.221	1.883
9.51	0.3729	0.0612	0.3779	-0.0013	-0.00626	2.276	1.866
10.61	0.4285	0.0787	0.4356	-0.0016	-0.00656	2.353	1.852
11.59	0.4715	0.0941	0.4808	-0.0026	-0.00657	2.376	1.851
12.64	0.5224	0.1140	0.5347	-0.0030	-0.00605	2.425	1.846
13.68	0.5741	0.1364	0.5901	-0.0032	-0.00536	2.472	1.842
14.72	0.6202	0.1575	0.6399	-0.0053	-0.00453	2.491	1.832
15.76	0.6740	0.1843	0.6987	-0.0057	-0.00353	2.540	1.824
16.86	0.7283	0.2137	0.7590	-0.0068	-0.00252	2.580	1.818
17.85	0.7745	0.2412	0.8111	-0.0078	-0.00141	2.604	1.897
18.90	0.8308	0.2762	0.8754	-0.0078	-0.00002	2.655	1.816
19.94	0.8793	0.3088	0.9319	-0.0096	+0.00127	2.678	1.816
20.98	0.9280	0.3443	0.9898	-0.0108	0.00265	2.703	1.821
22.08	0.9865	0.3884	1.0602	-0.0109	0.00447	2.751	1.821
23.07	1.0330	0.4264	1.1174	-0.0124	0.00609	2.776	1.826
24.11	1.0789	0.4669	1.1755	-0.0145	0.00804	2.794	1.835
25.15	1.1324	0.5166	1.2446	-0.0137	0.01024	2.835	1.843
26.19	1.1767	0.5609	1.3034	-0.0161	0.01242	2.852	1.856

Table 3

α	C_L	a	$\frac{C_N}{\alpha} - a$	$\frac{dC_m}{dC_N}$	$\frac{\Delta h_n}{c_0}$	CN_{NL}	$\frac{\Delta h_{NL}}{c_0}$	η	$\frac{\frac{C_N}{\alpha} - a}{A\eta}$
0	0	1.67	0	-0.0228	0.0441	0		0.6144	
2	0.061		0.152			0.0053			0.169
4	0.139		0.294	-0.0204	0.0465	0.0205	0.0537		0.3273
6	0.221		0.419			0.0439	0.0319		0.467
8	0.308		0.530	-0.0113	0.0556	0.0740	0.0635		0.5902
10	0.399		0.670			0.1169	0.0719		0.7461
12	0.491		0.721	0.0050	0.0719	0.1510	0.0795		0.803
16	0.681		0.880	0.0189	0.0858	0.2457	0.0993		0.980
20	0.880		1.011	0.0233	0.0902	0.3529	0.110		1.1258
24	1.075		1.130			0.4733	0.119		1.258

SYMBOLS

A	aspect ratio
a	linear normal force slope
b	overall span
C_D	drag coefficient
C_L	lift coefficient
C_N	normal force coefficient
C_m	pitching moment coefficient
c_0	wing centre-line chord
Δh_L	distance linear normal force acts ahead of the centre of plan area
Δh_{NL}	distance non-linear normal force acts ahead of the centre of plan area
Δh_n	distance of the aerodynamic centre ahead of the centre of plan area or arbitrary moment centre
K	lift-dependent drag factor
p	planform parameter
q	free stream dynamic pressure
S	wing planform area
s	wing semispan
V_0	free stream velocity
X_a	distance of centre of area behind apex of wing
α	angle of incidence in degrees

REFERENCES

No.	Author(s)	Title, etc.
1	D.A. Kirby	An experimental investigation of the effect of plan-form shape on the subsonic longitudinal stability characteristics of slender wings. ARC R & M 3568 (1967)
2	H.C. Garner E.W.E. Rogers W.E.A. Acum E.C. Maskell	Subsonic wind tunnel wall corrections. AGARDograph 109 (1967)

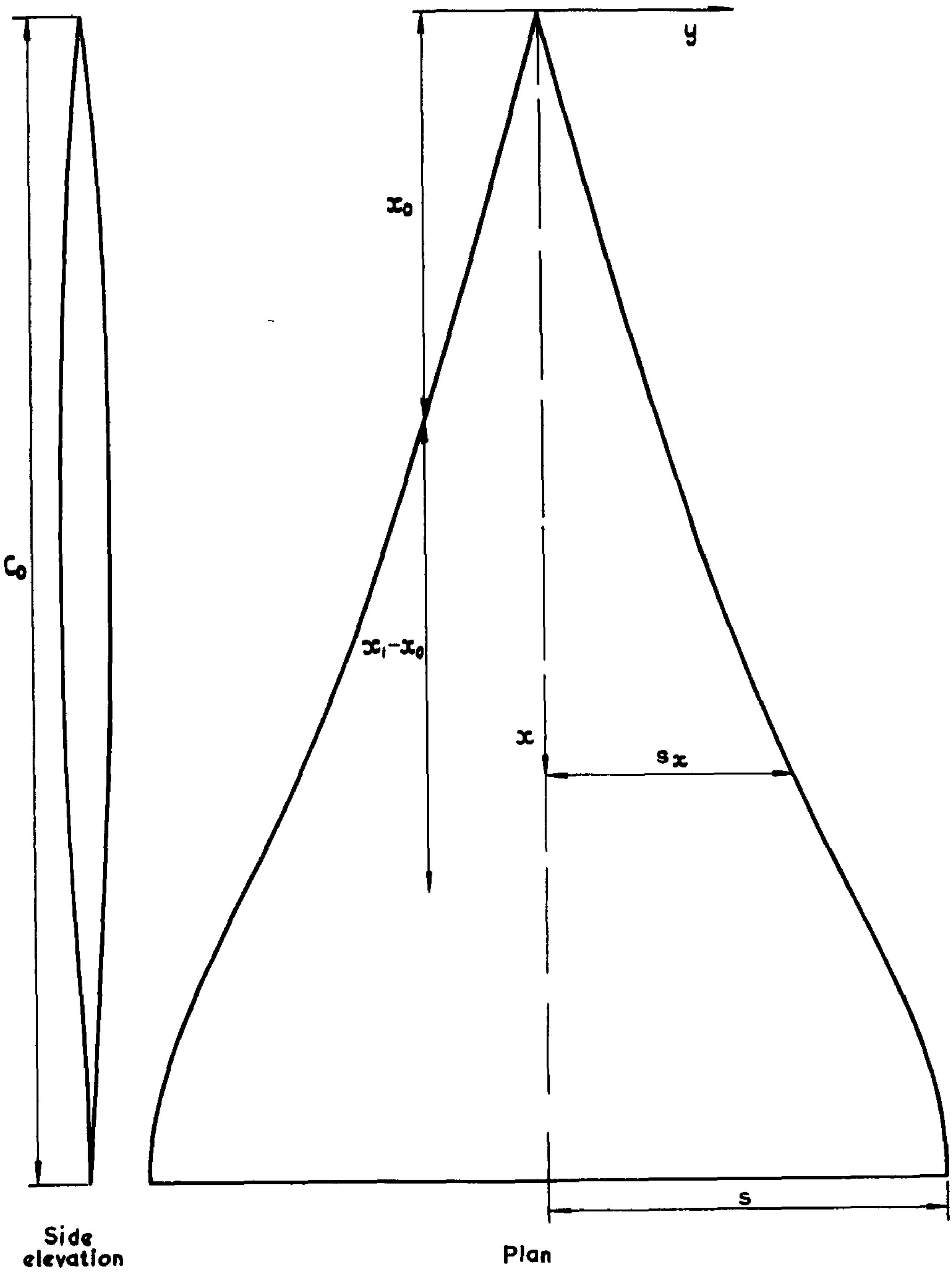


Fig.1 Ogee $s/c_0 = 0.35$ $p = 0.4756$

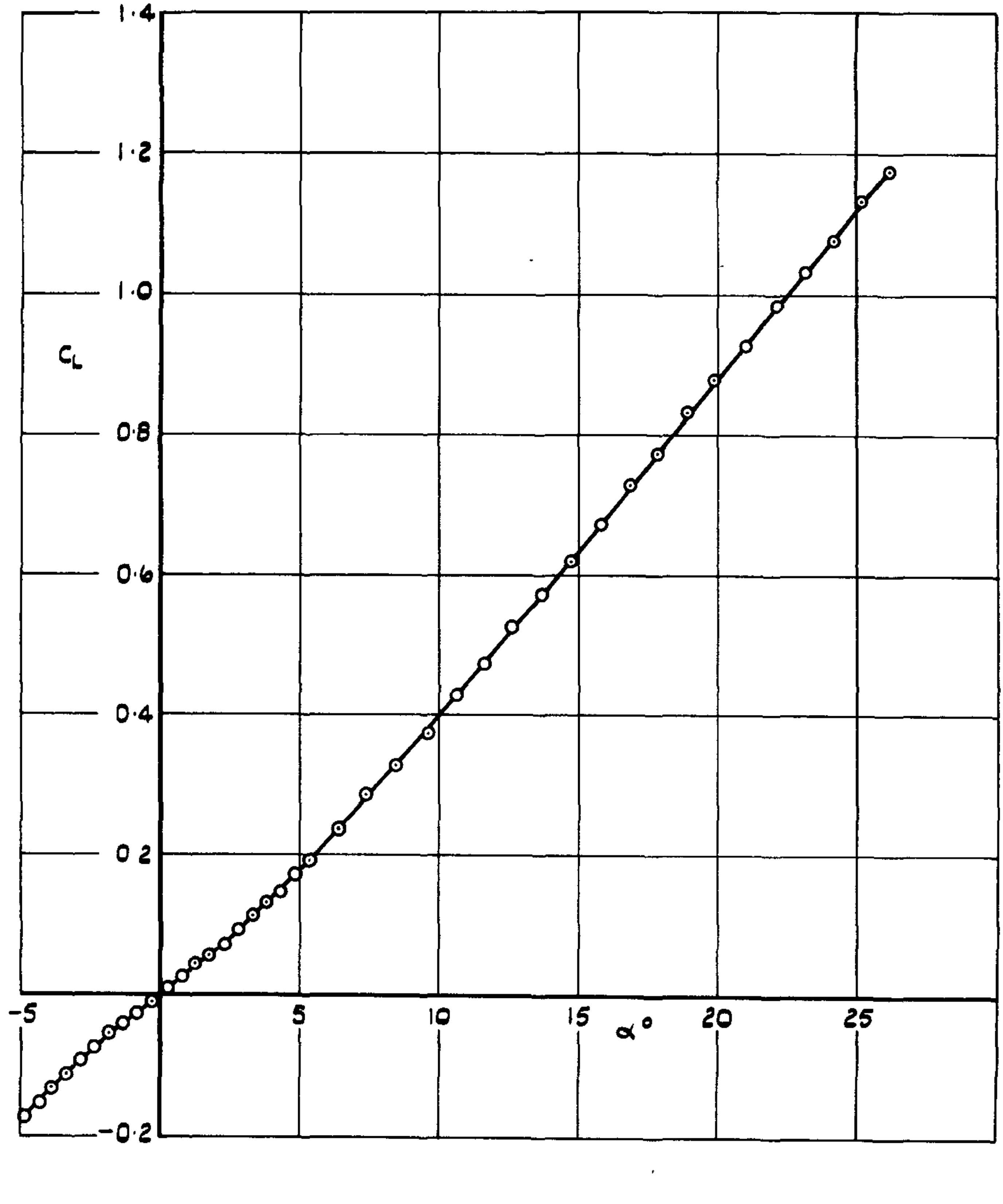


Fig 2 Lift coefficient v incidence

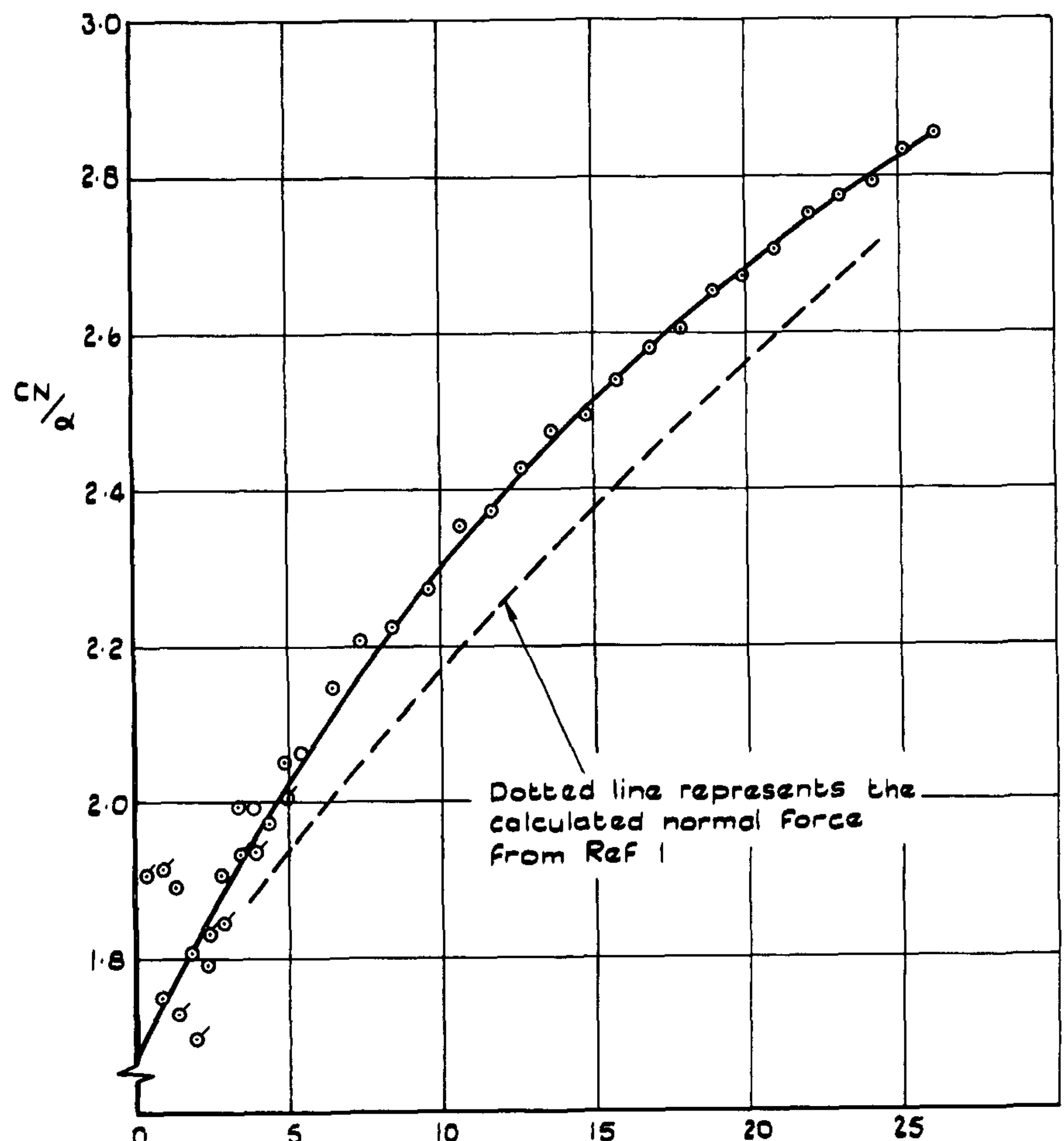


Fig. 3 CN/α v incidence

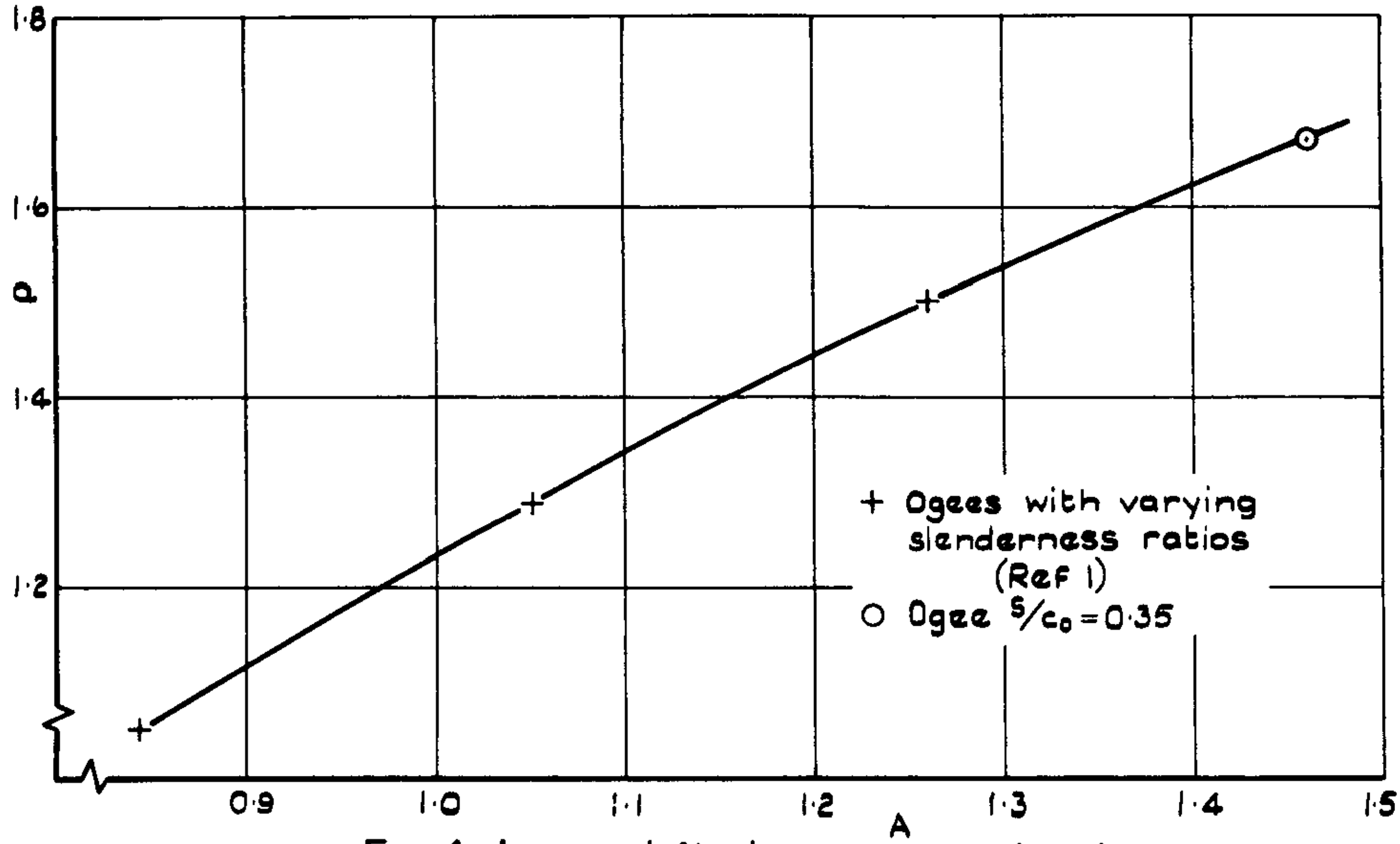


Fig.4 Linear lift slope v aspect ratio for ogees of p=0·4756

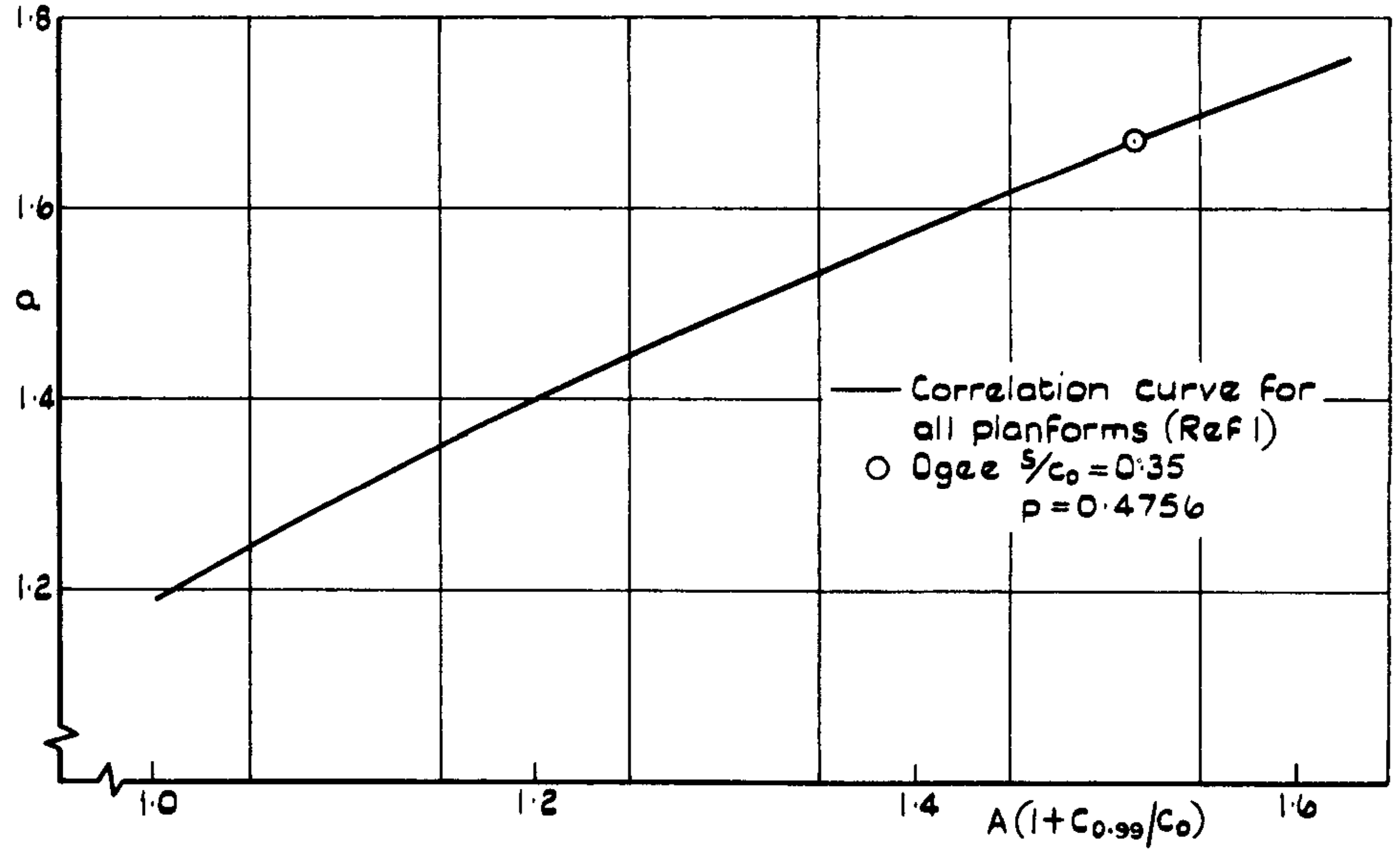


Fig.5 Linear lift slope v modified aspect ratio

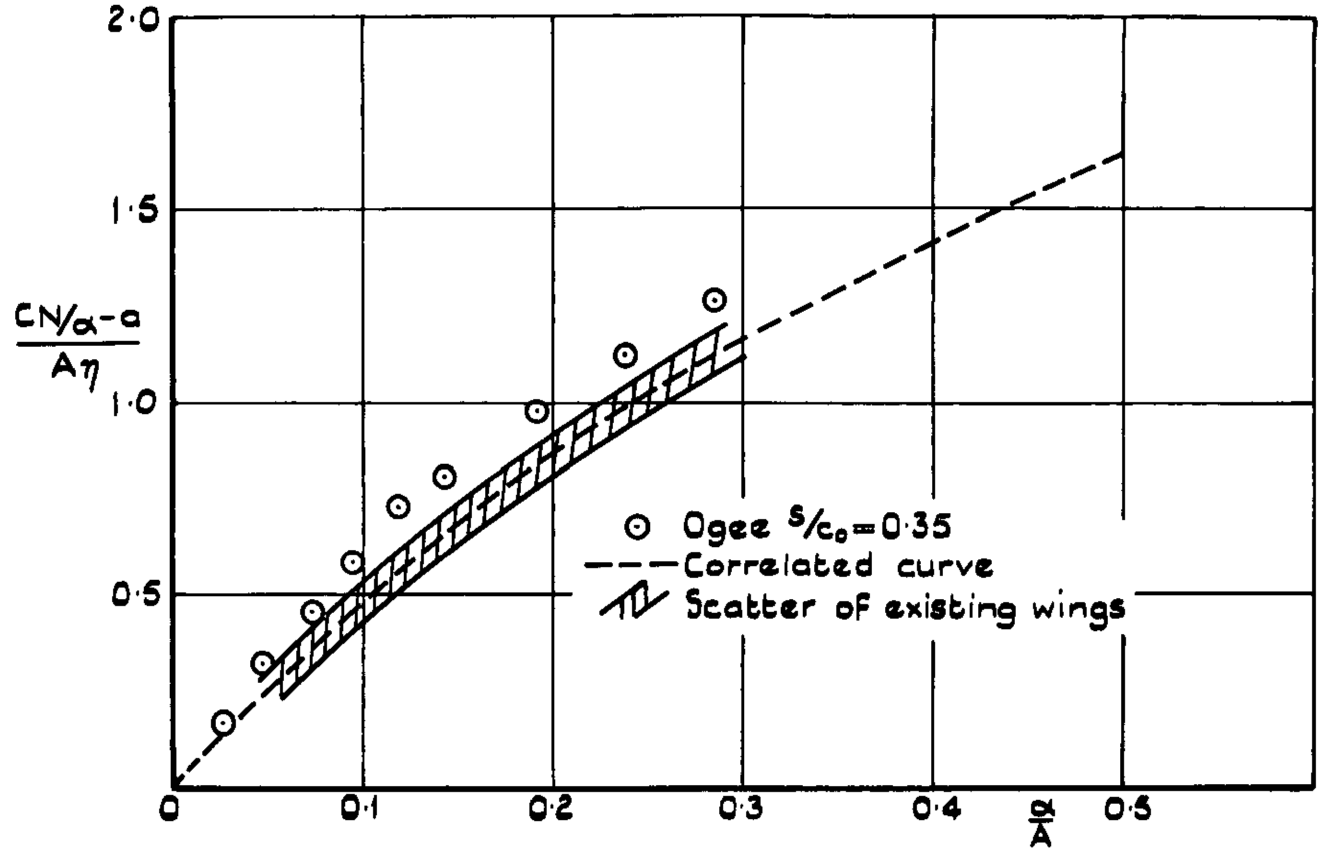


Fig.6 Correlation of non linear component of normal force

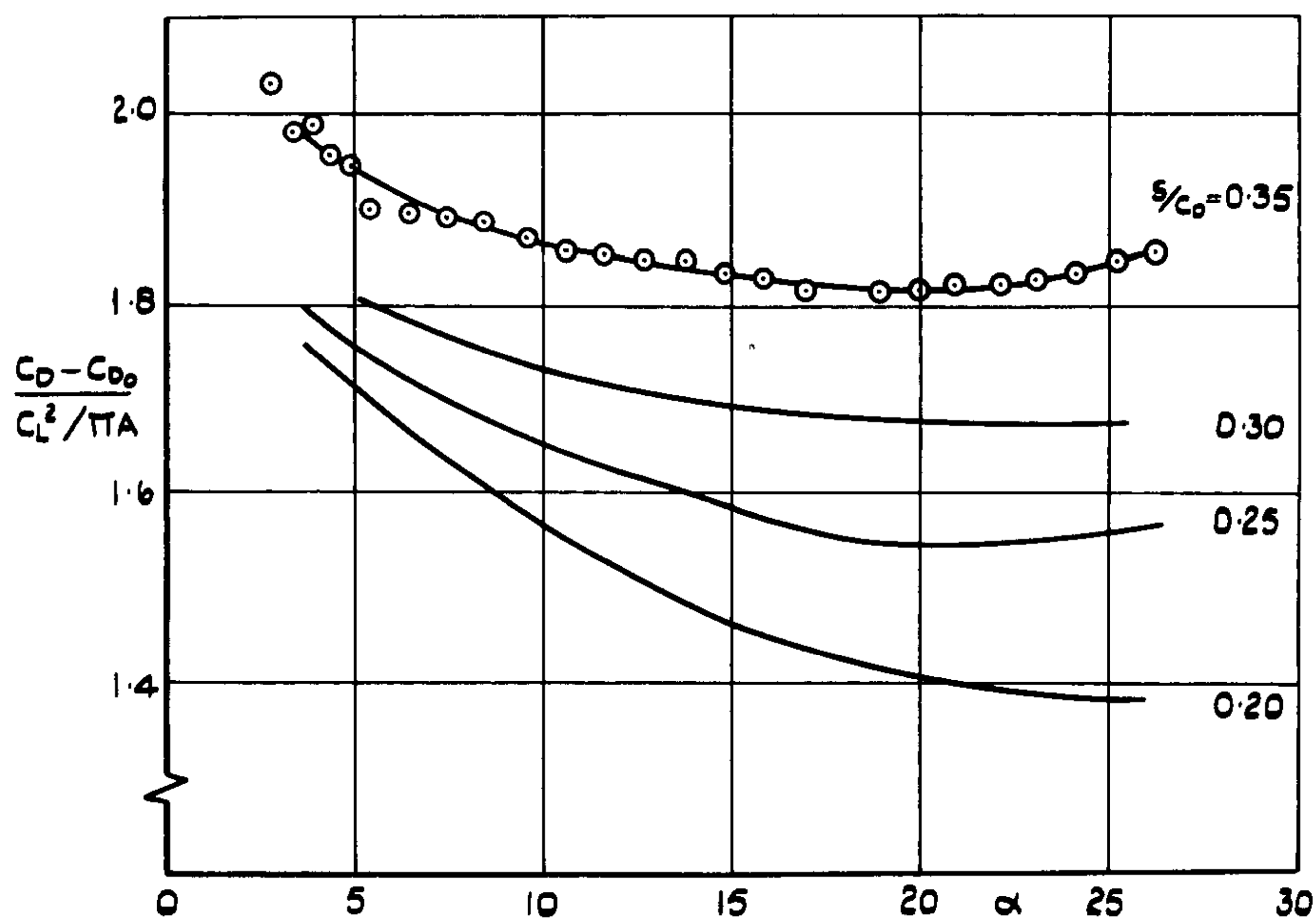
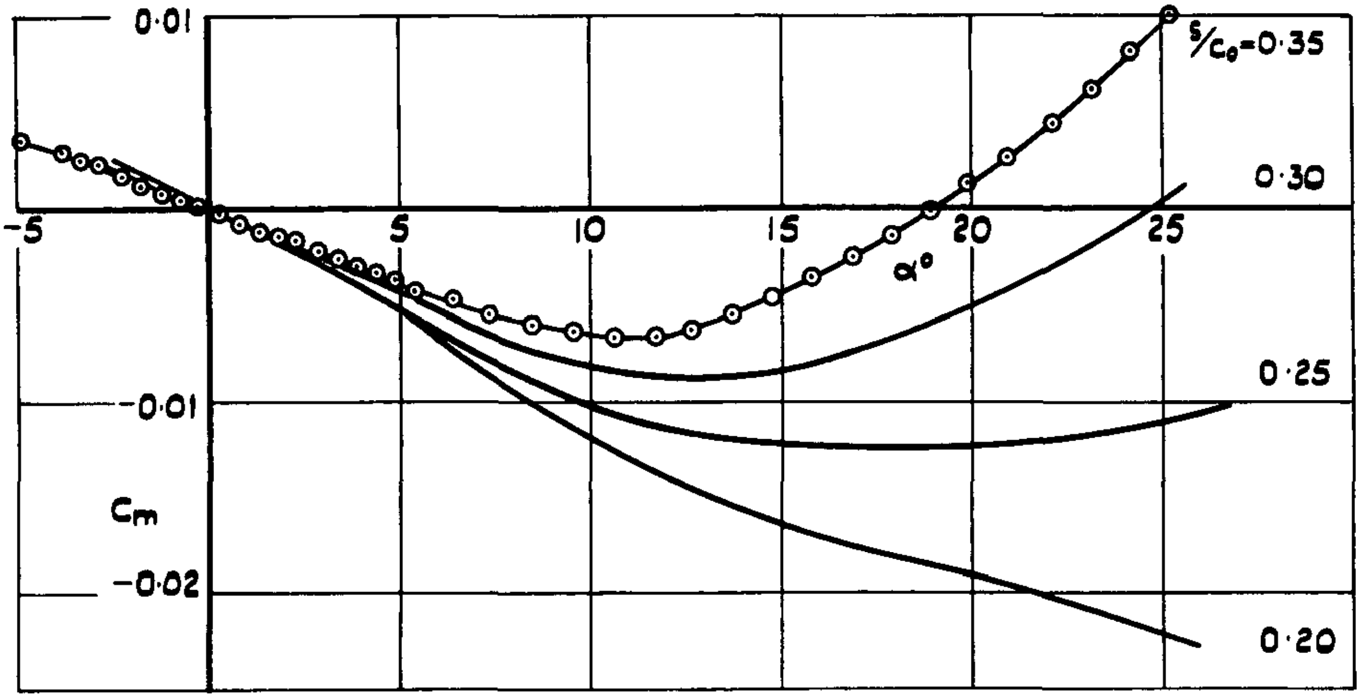
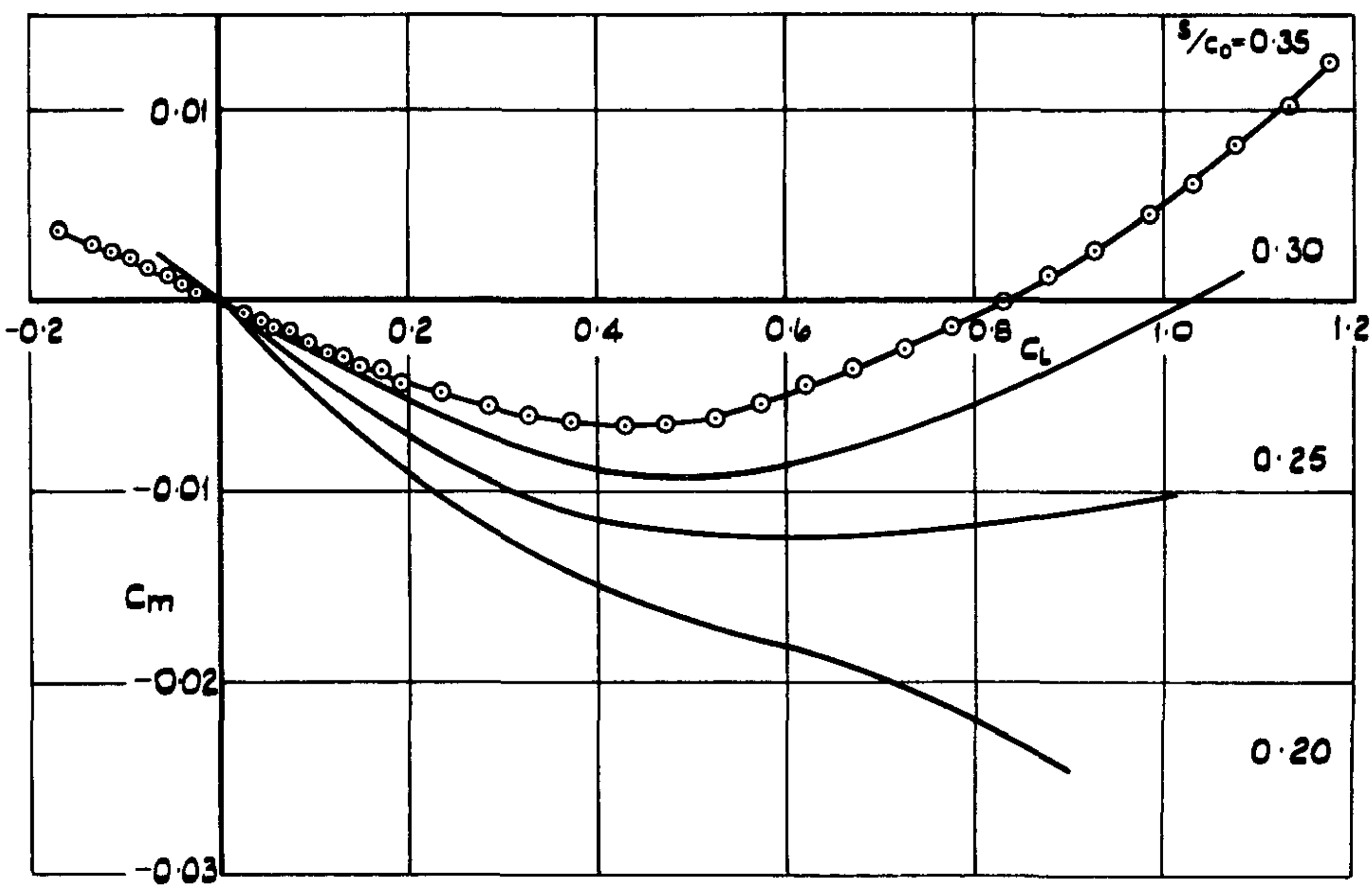


Fig.7 Lift dependent drag factor v incidence



a Pitching moment coefficient v incidence



b Pitching moment coefficient v lift coefficient

Fig. 8 a & b Effect of slenderness ratio on pitching moment coefficient of ogee wings

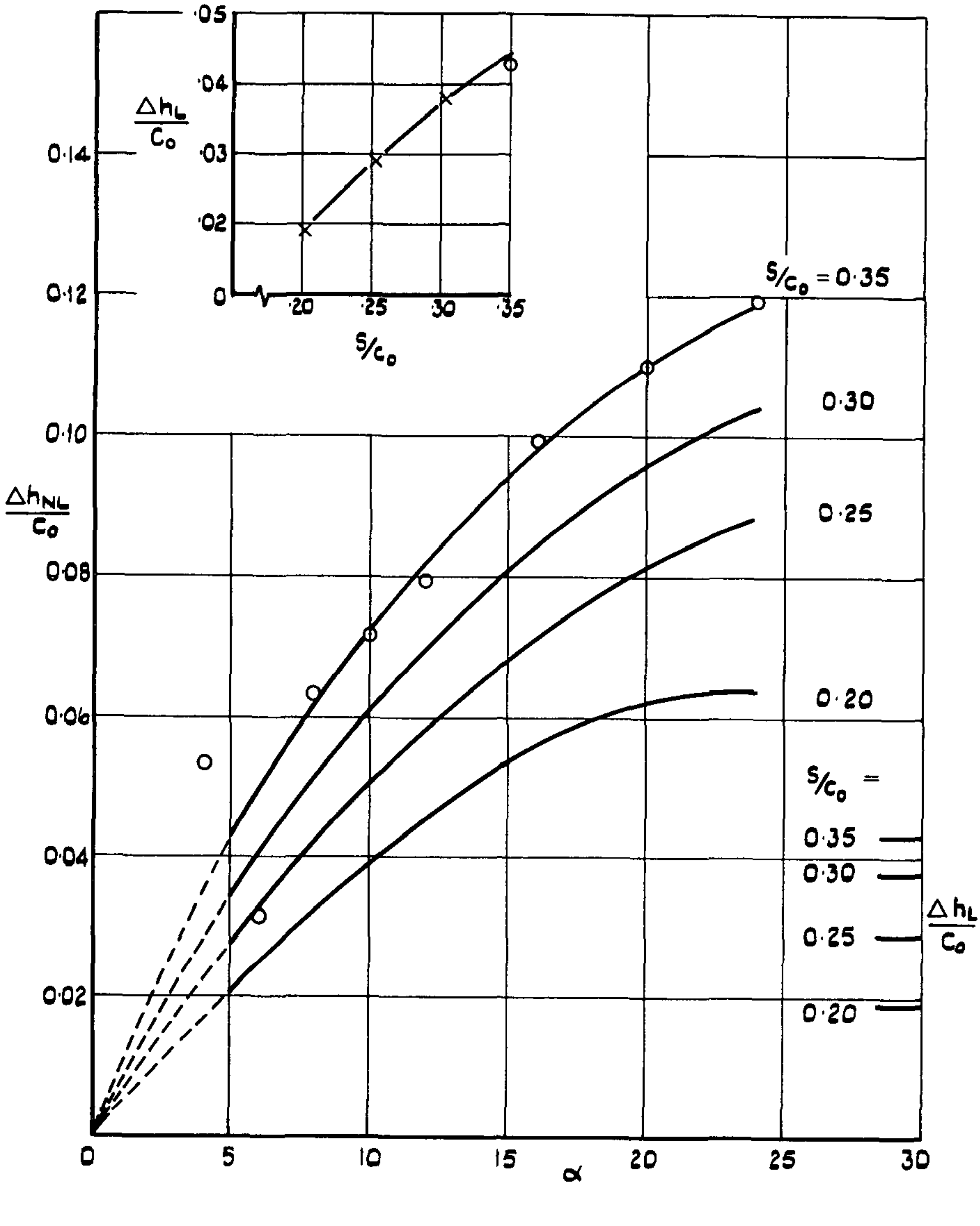


Fig.9 Distance of centre of linear and non-linear normal force ahead of centre of area

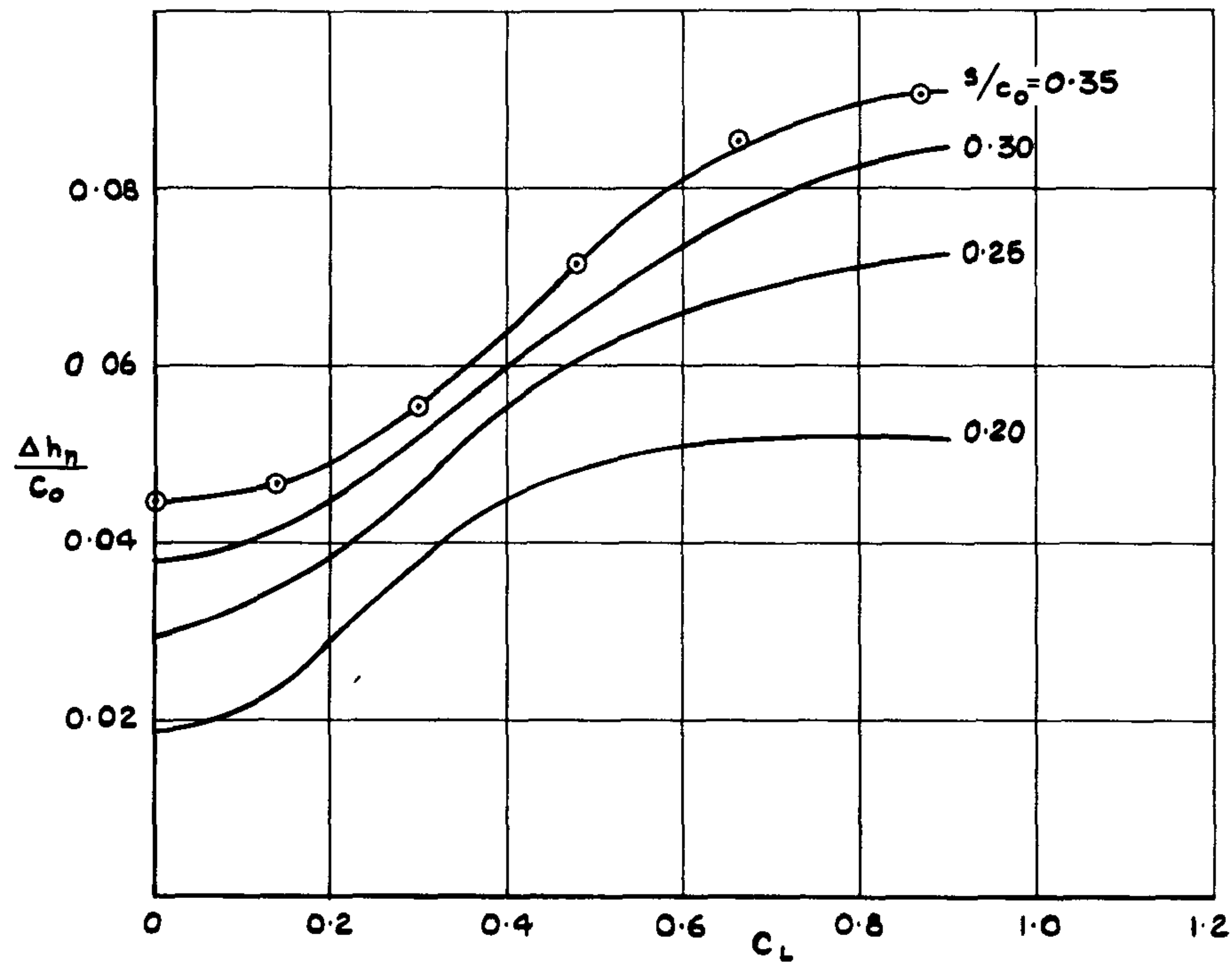


Fig. 10 Distance of aerodynamic centre ahead of centre-of-area v lift coefficient

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