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Effect of Production Modifications to Rear of Westland Lynx Rotor Blade on Sectional Aerodynamic Characteristics

by

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EFFECT OF PRODUCTION MODIFICATIONS TO REAR OF WESTLAND LYNX ROTOR BLADE ON SECTIONAL AERODYNAMIC CHARACTERISTICS

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SUMMARY

The RAE (NPL) 9615 aerofoil was accepted, on the basis of wind tunnel tests, as the basic blade section for the Westland WG 13 'Lynx' helicopter rotor. However, production methods necessitated a modification to the rear profile of the blades which was considered sufficient to produce changes in the aerodynamic characteristics of the aerofoil. Thus, the modified profile was tested in the wind tunnel and the experimental data are here compared with those for the original profile. The main effects of the modification are found to be a small increase in maximum lift, a small decrease in supercritical drag and a reduced range of pitching moment coefficient. These changes arise from the generation of a small increment of lift, over the rear of the aerofoil, which increases progressively from zero as incidence increases from zero.

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* Replaces RAE Technical Report 73043 - ARC 34835

CONTENTS

1 INTRODUCTION

On the basis of its measured aerodynamic characteristics, the RAE (NPL) 9615 aerofoil was adopted by Westland Helicopters as the basic blade section for the WG 13 'Lynx' helicopter, but, as a result of the type of blade construction used, the blade profile differs from the specified RAE (NPL) 9615 profile over the last 20% chord. In the method of construction used, the metal skins which form the upper and lower surfaces of the blade are joined together at the trailing-edge in the form of a short flat tab. The resulting profile is shown in Fig.1 where it is compared with the true RAE (NPL) 9615 profile, for which measured aerodynamic data already exists. It was felt that the changes in profile were sufficient to alter the aerodynamic characteristics of the blade thus the model of the RAE (NPL) 9615 aerofoil was modified to the production shape and designated RAE (NPL) 9660. This was tested, in 1971, in the 36in × 14in (0.92m × 0.36m) tunnel at Teddington so as to evaluate any changes in characteristics.

2 TEST CONDITIONS

The modified model was tested in the same wind-tunnel and under the same conditions as the basic model. In this tunnnel, the model spans the 0.36m dimension of the test section with its ends mounted in the optical glass windows. A roughness band of carborundum grains (of approximately 0.06mm diameter) was applied round the leading-edge, extending back to 2% chord on both upper and lower surfaces. Lift was obtained by integration of the measured pressure distributions and drag was obtained from wake traverse pitot readings.

The tunnel test section had slotted upper and lower walls with a slot configuration that gives effectively zero blockage (overall open-area ratio of 0.033). No corrections for tunnel interference have been applied to the results for either the modified or the basic aerofoils.

The model had a chord of 0.25 m and the tunnel operates at atmospheric stagnation pressure.

3 RESULTS

3.1 Pressure distributions

The first interesting feature of the modified profile is the change of pressure distribution in the region of the profile modifications, and this is presented in Fig.2 for a Mach number of 0.5. It is seen that at zero incidence a local increase of pressure occurs in the hollow formed by the modified profile and that the change in pressure distribution is much the same on both surfaces. However, as incidence increases, the dip in the upper surface pressure distribution progressively vanishes but that on the lower surface increases, resulting in a progressively increasing local increment of lift. Presumably, as incidence increases the thickening boundary-layer on the upper surface is separated locally by the additional adverse pressure gradient and reattaches at the trailing-edge, thereby effectively smoothing out the hollow in the profile. On the other hand, the boundary layer on the lower surface does not thicken with increase of incidence and is able to withstand the local adverse pressure gradient. The external flow can thus continue to follow the modified profile. In fact, the boundary-layer thickness on the lower surface can be expected to decrease as incidence increases, and this may account for the way in which the dip in the pressure distribution increases with incidence.

The effect, as far as the aerodynamic characteristics are concerned, is a small increment in lift that increases from zero as incidence increases, and an appreciable increment in nose-down pitching-moment which again increases from zero as incidence increases.

3.2 Lift coefficients

The measured values of lift coefficient, compared with those for RAE (NPL) 9615 are shown in Fig.3 where the first point to be noted is the higher value of maximum C_L for the modified aerofoil. Secondly, one sees that the value of $\frac{\partial C_L}{\partial \alpha}$ is greater for the modified profile, and finally that the zero lift angle is slightly different. The variation of lift increment with incidence for a Mach number of 0.5 is given in Fig.4, which also gives the lift increment produced over the last 15% chord. It is seen that the latter accounts for only a small part of the total lift increment over most of the incidence range, and the remaining part must be attributed to an increase in overall circulation, presumably caused by the influence of the new trailing-edge geometry on the position of the forward stagnation point. This is an effect commonly found with different degrees of rear-loading, even when the maximum thickness of the aerofoil is unaltered. Fig.5 gives the variation of stagnation point position (determined graphically from the detailed pressure plotting) with incidence for the two profiles at a Mach number of 0.5 and it is seen that the stagnation point does in fact move further aft as a result of the trailing-edge modifications. Now if the extra circulation simply took the form, effectively, of an increase in incidence then the upper surface pressure distributions corresponding to separation onset would be the same for each profile but would be attained at different values of incidence. In that case, the values of $C_{L_{max}}$ would differ only by the increment of lift produced locally near the trailing-edge. However, it is seen in Figs.3 and 4 that the value of $C_{L_{max}}$ is increased by an amount that is greater than the trailing-edge increment, and this suggests that the increase in circulation is not simply equivalent to an increase of incidence, but must also produce some extra lift over the rear part of the aerofoil thereby generating a higher lift for a given level of minimum pressure. This is confirmed by Fig.6 which shows the local loading for the two profiles at 0.1 c and 0.75 c. The change of loading at 0.1 c gives an indication of the effective change in incidence but the increase in loading at 0.75 c is much larger than would result from this effective incidence change.

3.3 Drag coefficients

The increase in circulation for a given value of geometric incidence is illustrated again in the pressure distributions of Fig.7. Here it is seen that, for supercritical conditions, a stronger shock wave is generated for a given incidence by the modified aerofoil and hence shock-induced separation can be expected to occur at a lower value of incidence. However, due to the increase of lift over the rear of the aerofoil, the supercritical drag at a given value of C_L is less for the modified aerofoil (see Fig.8). This means that a higher value of lift is generated for a given value of shock strength and it is the shock strength that has a major influence on drag at these conditions.

3.4 Pitching-moment coefficients

Perhaps the most important effect of the modifications is on the pitching-moment. The increment of lift generated at the rear of the profile at high incidences produces a relatively large increment in nose-down pitching moment about the quarter chord position as shown in Fig.9. The value of C_m at zero C_L is of course unaffected but C_m is seen initially to become steadily more negative as C_L rises as opposed to remaining essentially constant as it does for the RAE (NPL) 9615 profile. Only at low Mach number and high incidence is a positive value of C_m found, while C_m remains negative at all incidences for Mach numbers greater than 0.5.

All the recorded values of C_L, C_D and C_m are given in Table 2.

4 POSSIBLE EXPLOITATION

A possible way of exploiting the aerodynamic effects observed in these tests is in connection with the cancellation of nose down pitching moments produced by cambered aerofoils at zero lift. It is this nose-down pitching-moment that prevents the use of highly cambered (or rear loaded) aerofoils as helicopter rotor blade sections. In maximum forward speed flight the advancing blade tip tends to operate at approximately zero lift, and the combination of a finite pitching moment (as opposed to zero pitching moment for a symmetric section) with the high dynamic pressure of the advancing tip produces a large torsional load. This torsional load can be of much greater magnitude than that produced by the retreating tip, and of opposite sign. Hence a large fluctuation of torsional load is produced.

Suppose that the type of modification to profile shape that have been considered here were applied to the upper surface only, with the original profile retained on the lower surface. Then, at zero incidence a local down load would be generated near the trailing-edge, producing a nose-up pitching-moment which would counteract the nose-down pitching moment (due to camber) of the basic section. This local down load would progressively decrease with increase of incidence, due to the smoothing effect of the thickening boundary-layer, resulting in no loss of maximum lift. Generally speaking, reflex camber, introduced to eliminate zero-lift pitching moments, leads to a decrease of $C_{L_{max}}$.

However, the rear profile modifications as tested on RAE (NPL) 9660 would produce an increment of C_L, at zero lift, of only -0.006, which would produce an increment in $C_{m_{\frac{1}{4}c}}$ of only 0.004. More drastic changes to the profile would be required before an increment in $C_{m_{\frac{1}{4}c}}$ of really useful magnitude (i.e. 0.01 or greater) could be generated at zero lift conditions.

The effects discussed in this Report are obviously strongly governed by the boundary-layer and hence Reynolds number, but it can be noted that the Reynolds numbers for the tunnel tests lay between those typically found for full-scale main and tail rotor blades.

5 CONCLUSIONS

The production modifications to the rear profile of the RAE (NPL) 9615 aerofoil produce no real disadvantages as far as aerodynamic performance is concerned, and actually produce small benefits. There is a small increase in maximum lift, a small reduction in supercritical drag under lifting conditions, and a reduction in the overall range of pitching moment coefficient.

There are possibilities of exploiting the measured effects, to counteract the nose-down pitching-moments associated with cambered aerofoils at zero lift.

Table 1

THICKNESS DISTRIBUTION OVER REAR PART OF AEROFOILS

$\frac{X}{c}$	Zt/c	
	RAE (NPL) 9615	RAE (NPL) 9660
0.77779	0.02838	0.02838
0.81520	0.02412	0.02395
0.85355	0.02000	0.01915
0.88651	0.01613	0.01450
0.91573	0.01257	0.01020
0.94096	0.00935	0.00625
0.96194	0.00676	0.00280
0.97847	0.00469	0.00190
0.99039	0.00293	0.00190
0.99759	0.00173	0.00173
1.0	0.00130	0.00130

Table 2

RAE (NPL) 9660 AERODYNAMIC DATA

α^o	C_L	C_D	C_m
M = 0.3			
-2	-0.223	0.0097	-0.0045
0	-0.020	0.0102	-0.0062
3	0.311	0.0107	-0.0120
6	0.646	0.0119	-0.0163
9	0.939	0.0134	-0.0118
12	1.205	0.0220	-0.0053
13	1.263	0.0272	-0.0040
M = 0.5			
-2	-0.264	0.0105	-0.0058
0	-0.023	0.0099	-0.0092
2	0.220	0.0099	-0.0124
4	0.465	0.0106	-0.0146
6	0.711	0.0121	-0.0154
8	0.954	0.0147	-0.0123
10	1.1394	0.0241	-0.0022
11	1.146	0.0333	-0.0002
M = 0.65			
4	0.547	0.0111	-0.0146
6	0.834	0.0269	-0.0123
M = 0.75			
-2	-0.353	0.0140	-0.0164
2	0.323	0.0129	-0.0175
4	0.554	0.0550	-0.0478
M = 0.8			
-2	-0.383	-	+0.0092
0	-0.009	0.0139	-0.0190
2	0.299	-	-0.0473

α^o	C_L	C_D	C_m
M = 0.4			
-2	-0.242	0.0104	-0.0059
0	-0.021	0.0101	-0.0076
2	0.213	0.0101	-0.0109
4	0.439	0.0106	-0.0144
6	0.677	0.0121	-0.0166
8	0.898	0.0136	-0.0175
10	1.094	0.0167	-0.0121
11	1.159	0.0211	-0.0046
12	1.189	0.0266	0.0001
M = 0.6			
-2	-0.268	0.0113	-0.0067
0	-0.016	0.0098	-0.0096
2	0.244	0.0098	-0.0125
4	0.514	0.0107	-0.0158
6	0.711	0.0139	-0.0154
8	1.038	0.0363	-0.0053
9	0.982	0.0740	-0.0265
M = 0.7			
-2	-0.307	0.0141	-0.0126
0	-0.013	0.0100	-0.0101
2	0.285	0.0100	-0.0139
4	0.611	0.0201	-0.0172
M = 0.775			
2	0.349	0.0217	-0.0334
M = 0.825			
0	-0.007	0.0248	-0.0205
M = 0.85			
0	-0.054	-	-0.0114

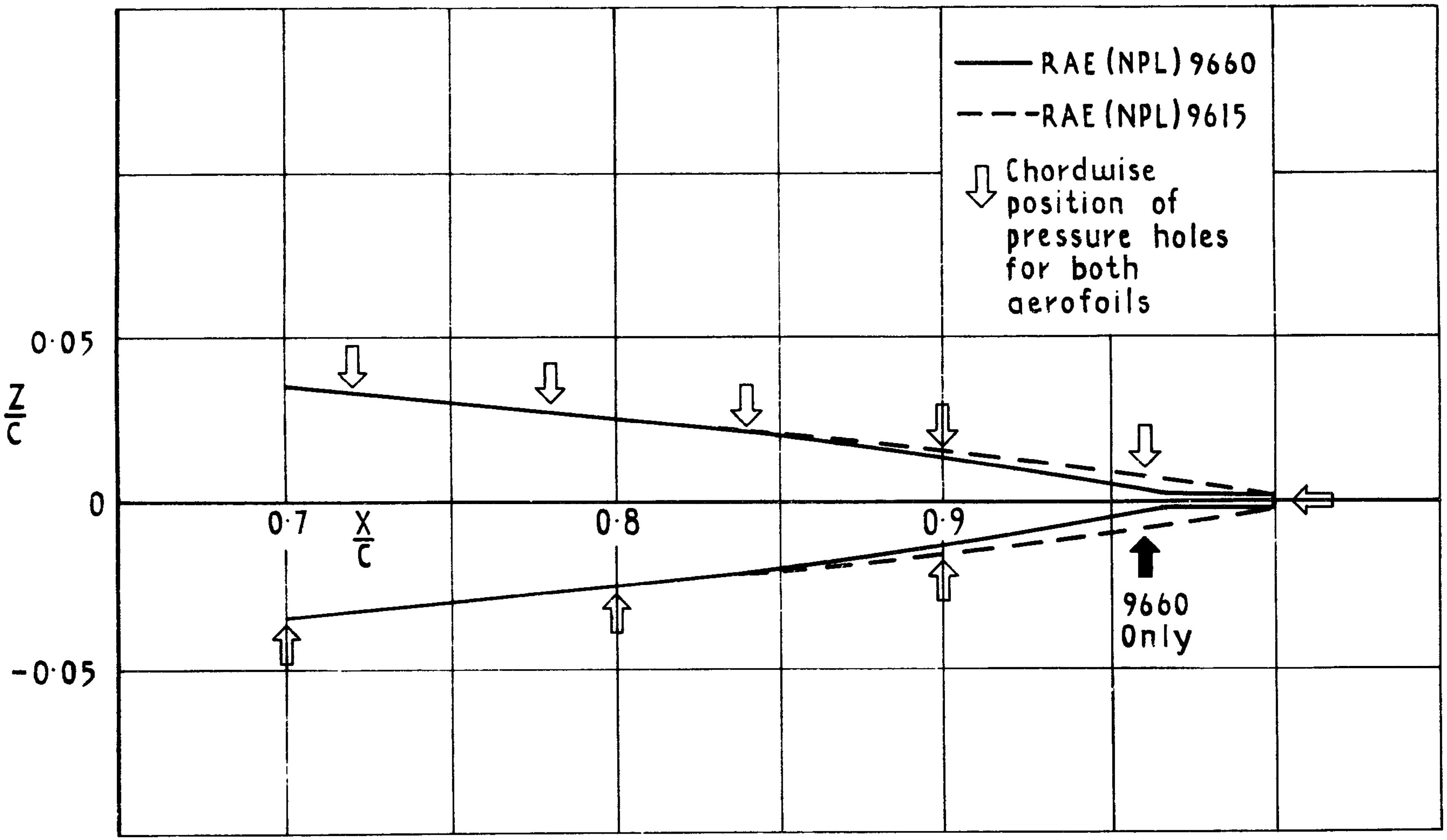


Fig. 1 Rear profiles and pressure hole positions

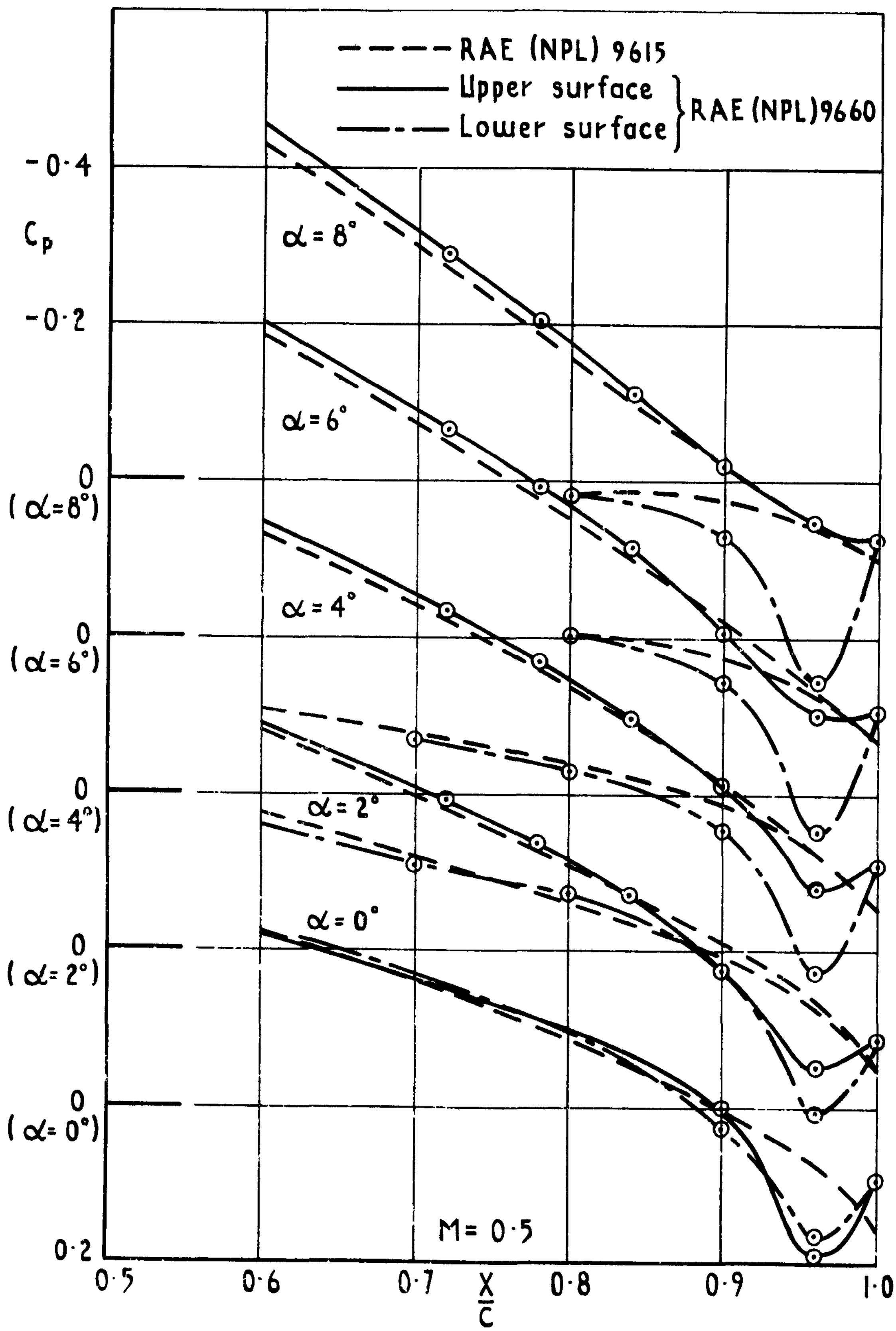


Fig. 2 Experimental pressure distributions over rear part of aerofoils

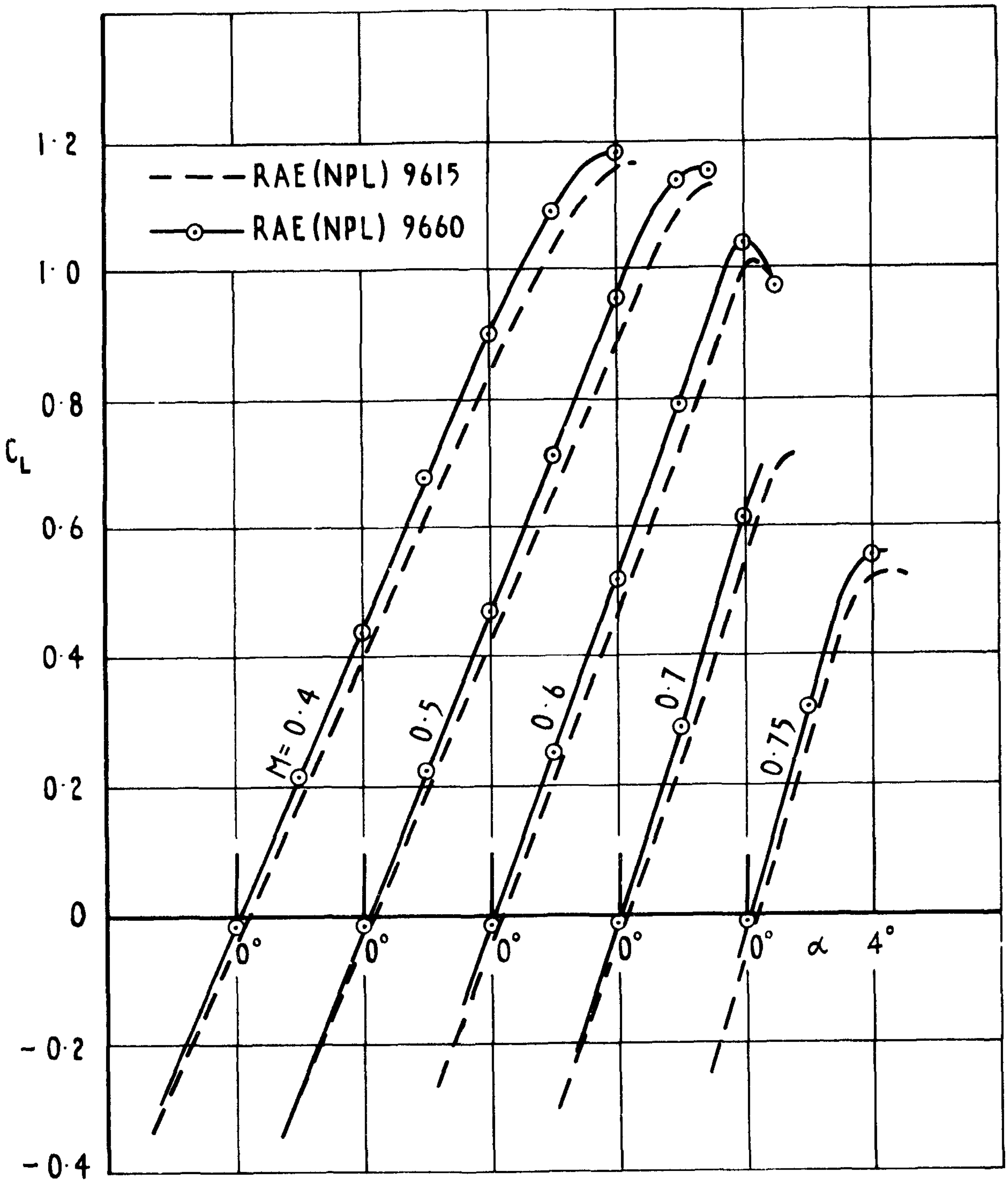


Fig. 3 Variation of lift coefficient with incidence and Mach number

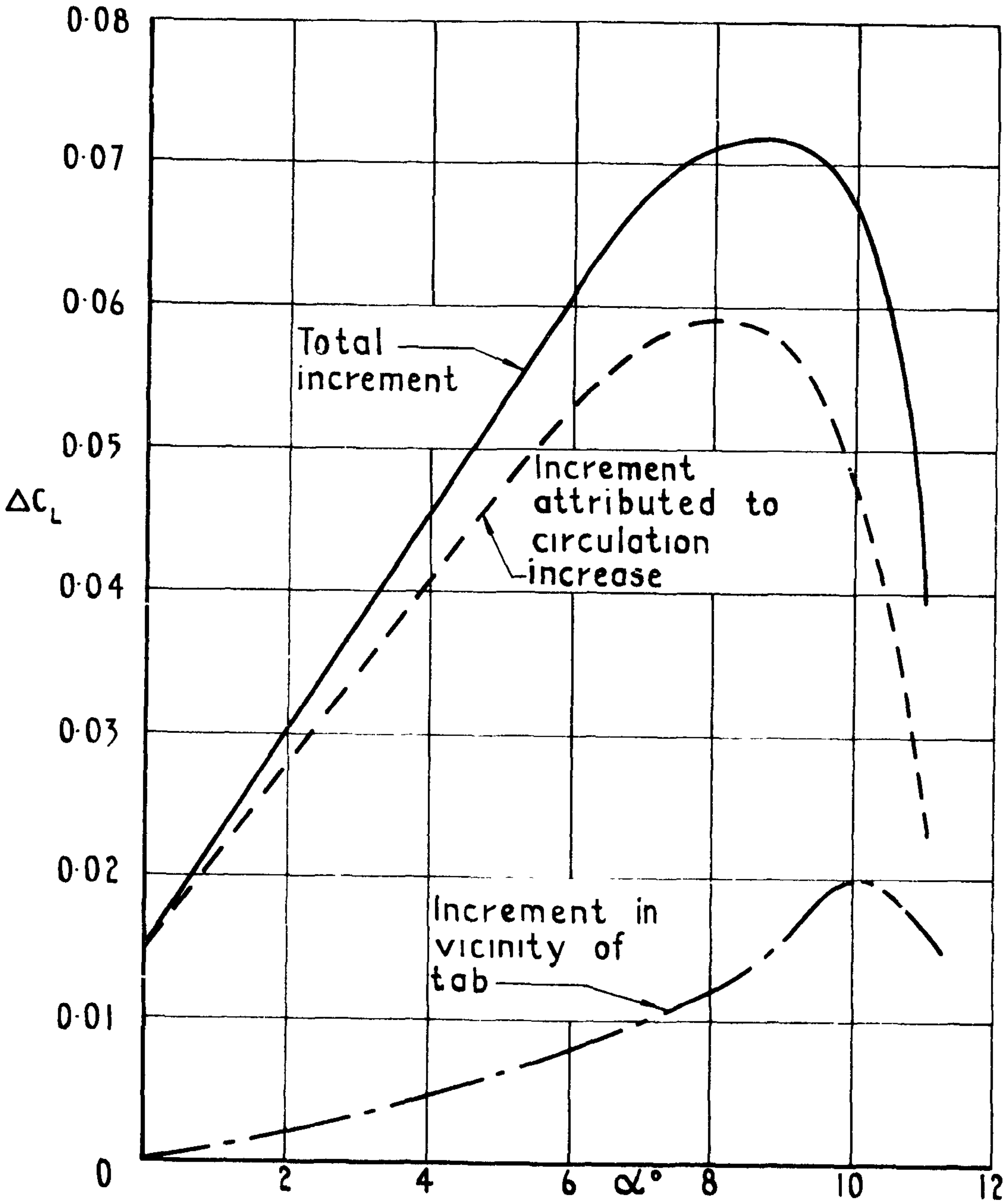


Fig. 4 Variation of lift coefficient increment with incidence

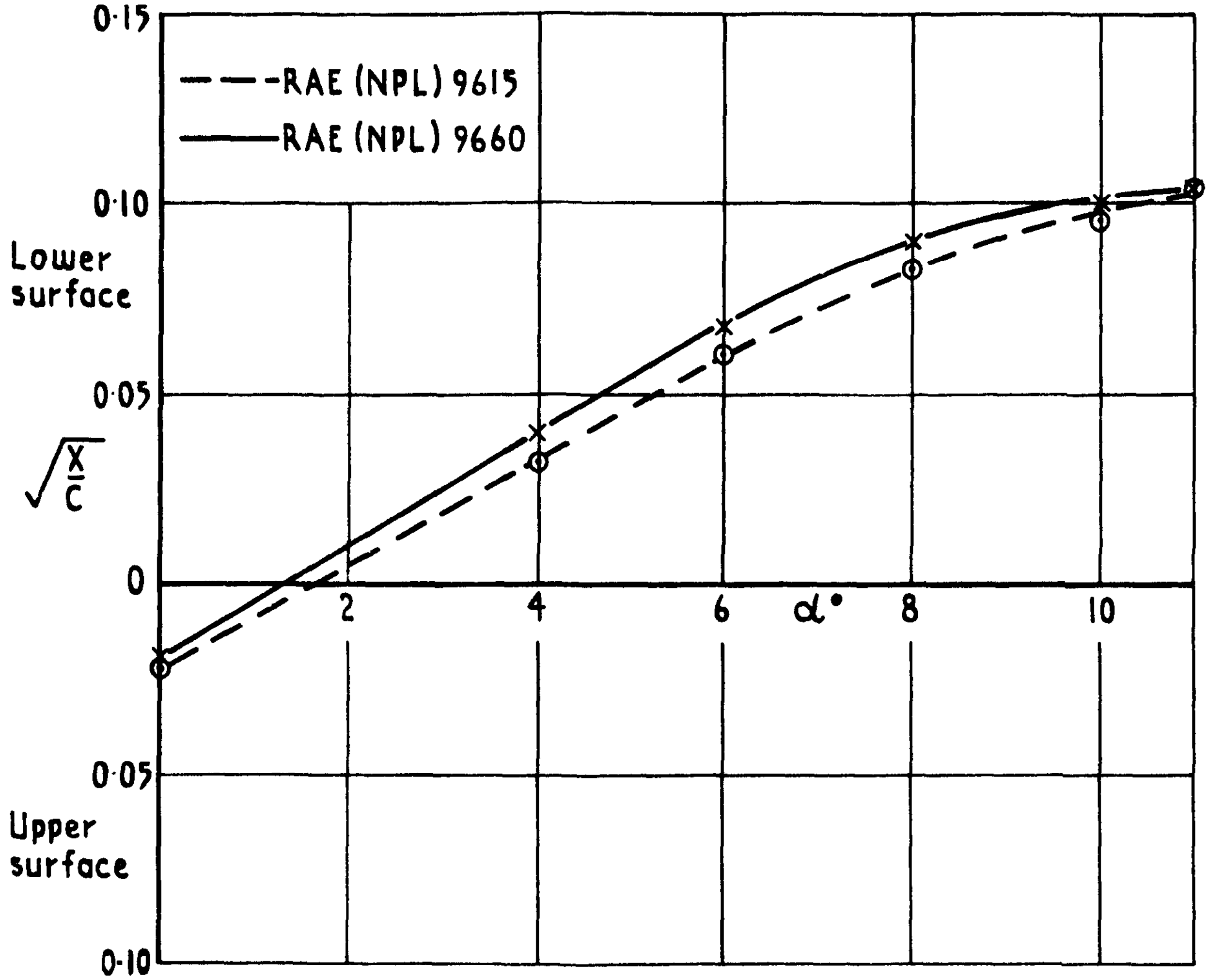


Fig. 5 Variations of stagnation point position with incidence

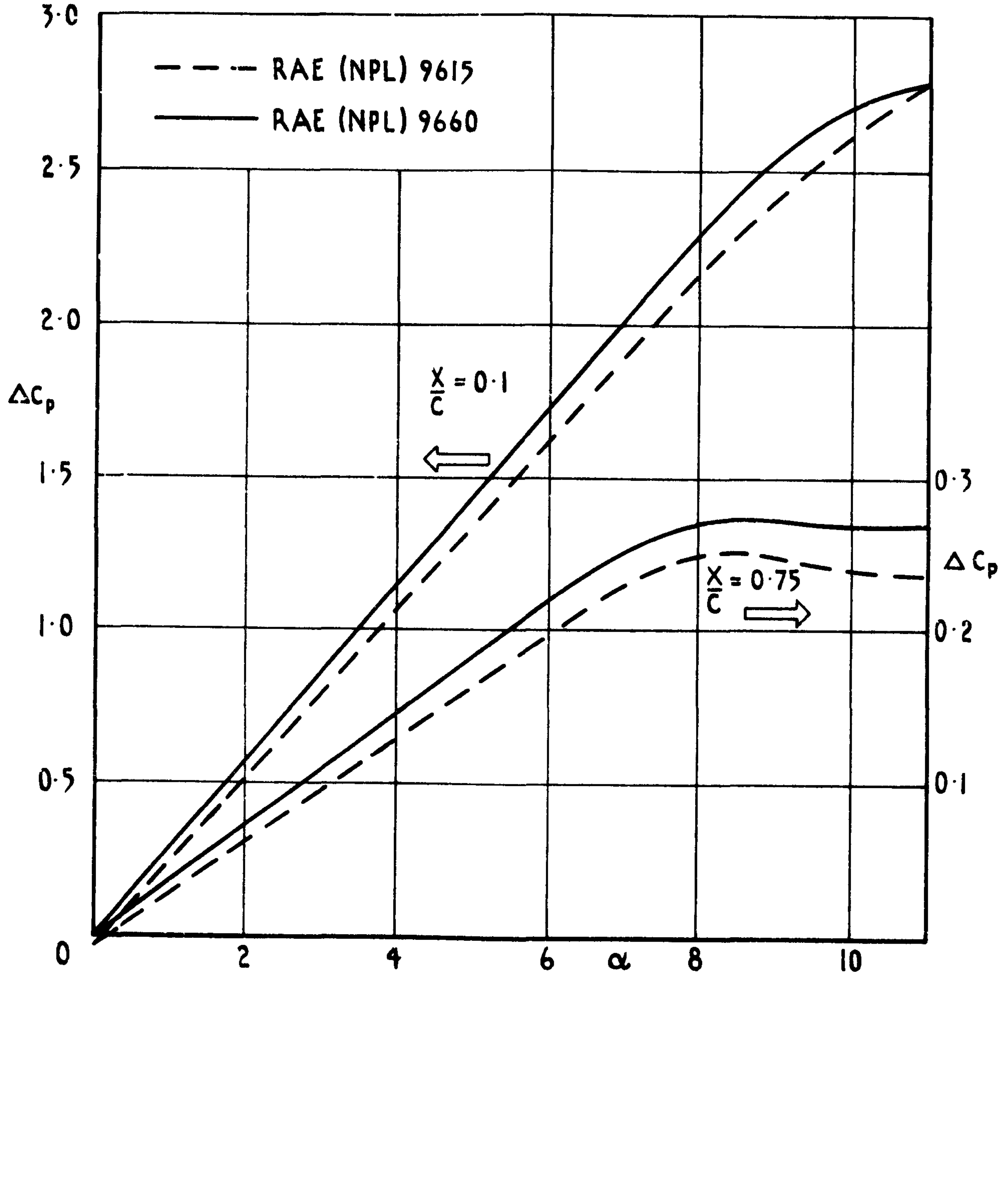
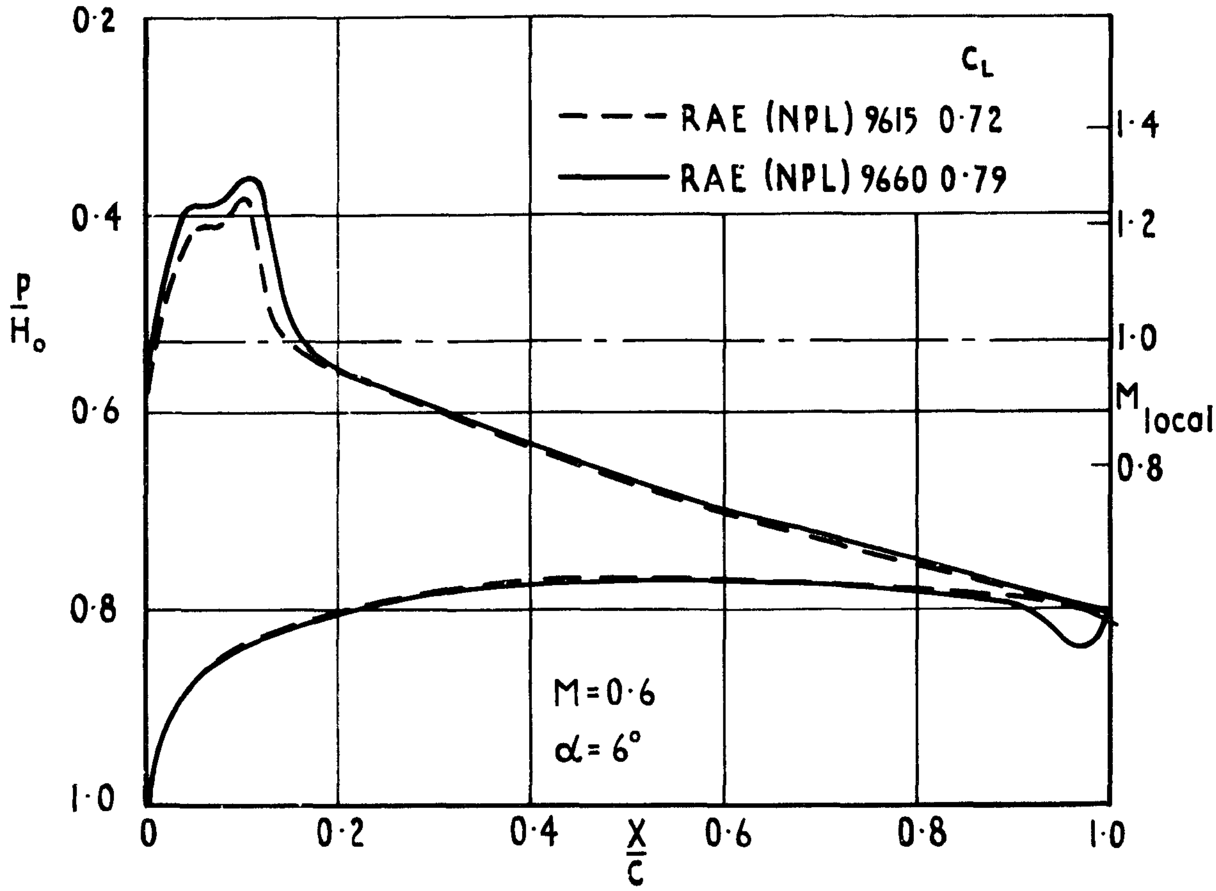


Fig. 6 Variation in local loading with incidence at two chordwise stations



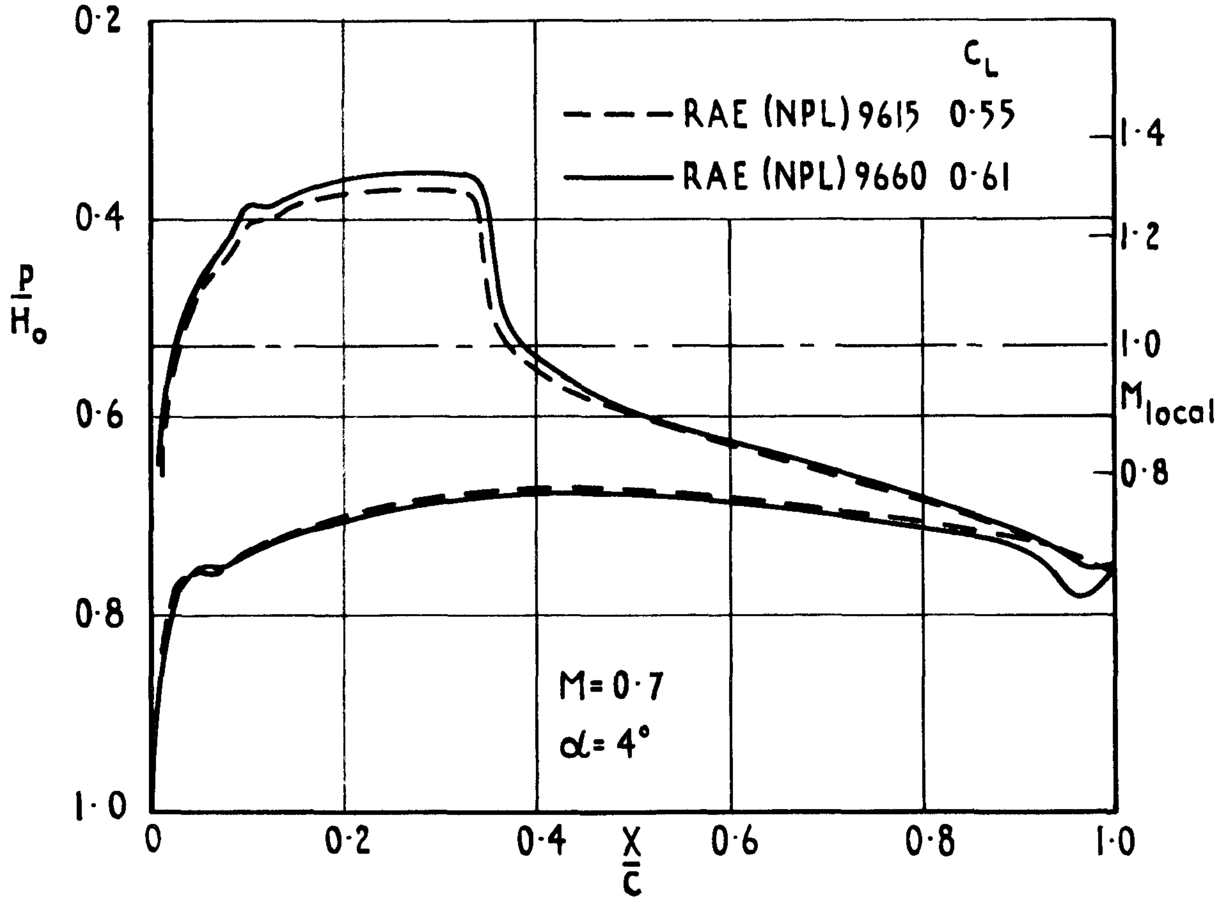


Fig. 7 Experimental pressure distributions

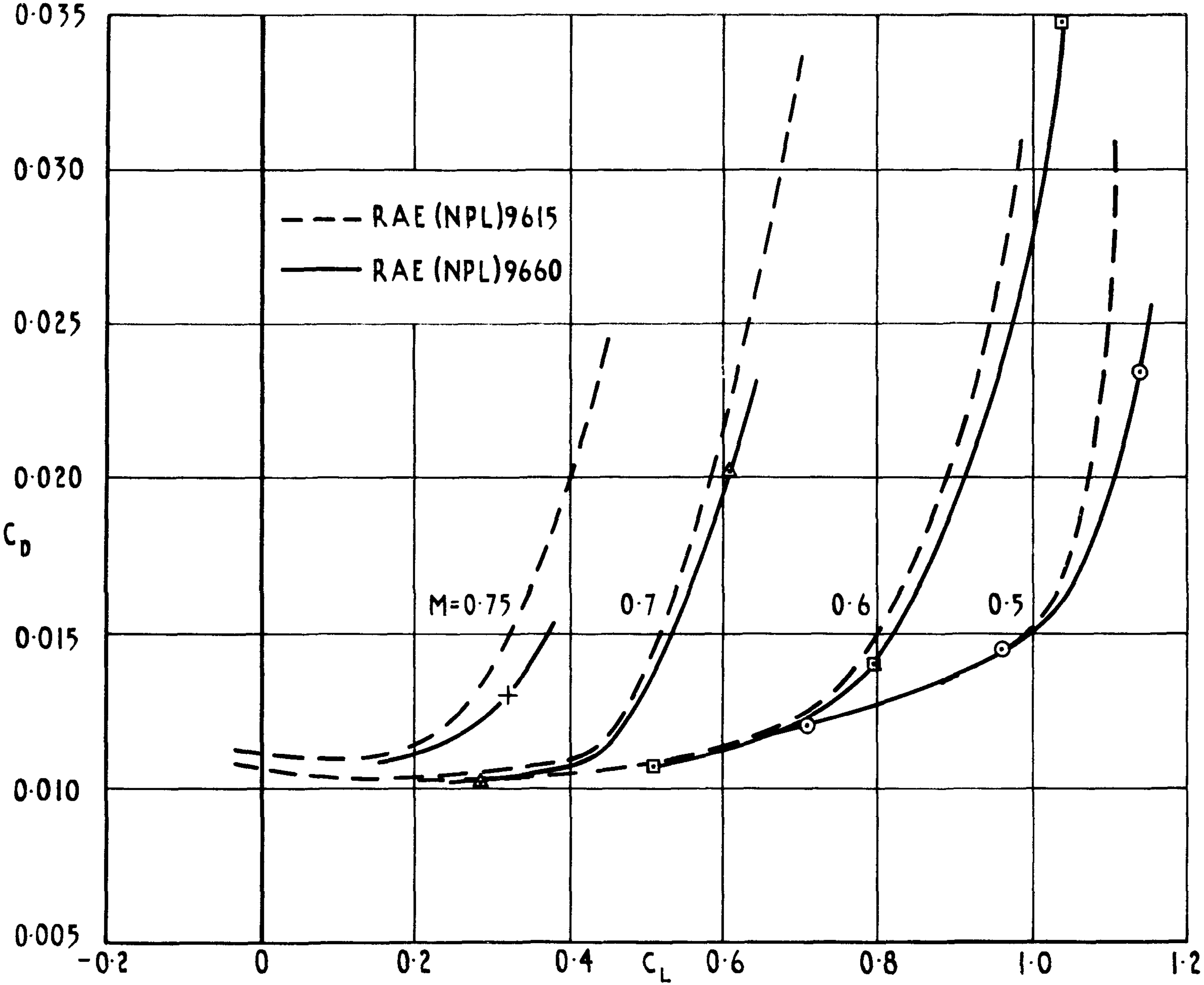


Fig. 8 Variation of drag coefficient with lift coefficient and Mach number

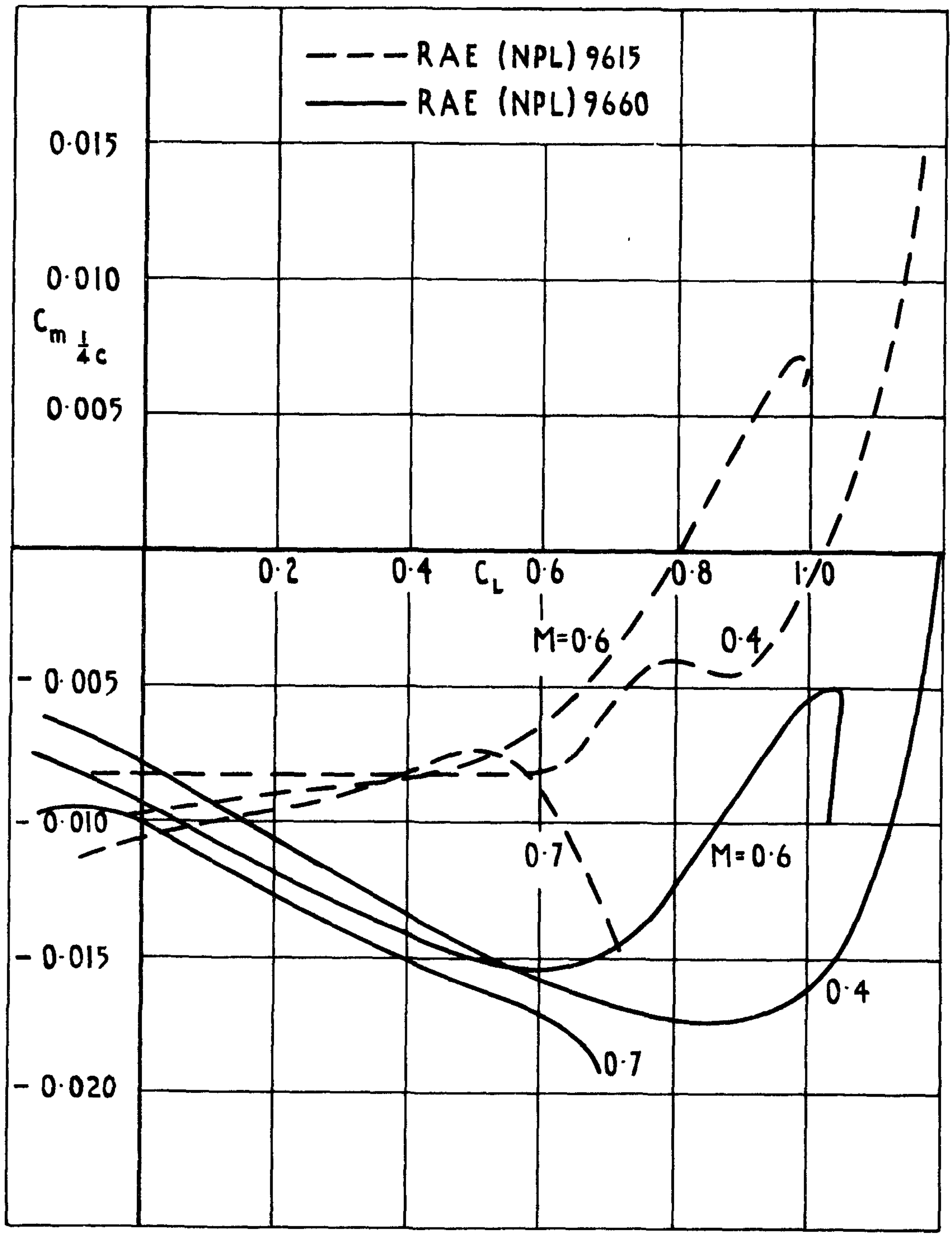


Fig. 9 Variation of pitching-moment coefficient with lift coefficient and Mach number

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