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By

J. Bridgewater and K H. Wilson

Aerodynamics Division, N P L

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Influence of Wing Root Shaping on the Pressure Distribution of Swept-Wing Body Configurations

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J. Bridgewater and K. H. Wilson
Aerodynamics Divn., N.P.L.

SUMMARY

Swept wing pressure fields calculated by inviscid linearized theory are presented for symmetric wing-body configurations at Mach number $\overline{2}$. The effects of varying the inboard wing shape are investigated, with the aim of minimising the associated body waisting needed to achieve a desirable isobar pattern, and to produce a good overall area distribution.

1. Introduction

It is well established, both at subsonic and supersonic speeds, that there is an increase of pressure over the forward part of the chord near the root of a swept wing arising from the sudden angle of sweep change at the junction, and that this is most pronounced near the leading edge. This change in the pressure distribution results in loss of isobar sweep and is liable to lead to the early appearance of shock waves. These disadvantages can be overcome by waisting the shape of the body so that the extra body pressure field over the wing exactly compensates, thus enabling a favourable combined pressure field to be regained. Unfortunately this has the further disadvantage that the waisting can severely reduce the useful payload volume, as well as creating a structural problem. This note gives details of some theoretical design studies made along an alternative approach, whereby the root region of the wing is itself appreciably altered (Fig. 1) to achieve a desirable combined pressure field over the wing, so that the body waisting may be kept to a minimum. The present study is restricted to uncambered wings at zero incidence with subsonic edges, at Mach number $\overline{2}$.

2. Reference Wing-Body Configuration

As a basis from which to assess the effects produced by inboard changes of wing shape, a reference wing-body configuration has been designed according to the methods described in Ref. 1. The wing, of 63° leading edge and 54° trailing edge inboard sweep, has a rounded tip planform and has similar chordwise sections across the span, with the thickness/chord ratio varying linearly from 6% at the root to 3% at the tip. The sections are symmetric and the wing is unwarped.

* Replaces NPL Aero Note 1082 - A.R.C.31 311

The pressure distributions over this wing alone at Mach number $\sqrt{2}$ and zero incidence have been calculated from linearized inviscid theory by the computer methods of Refs. 2 and 3. Fig. 2 (full line) shows the results of these calculations, for which it has been assumed that the flow field is reflected at the body side. Note the occurrence of the usual unfavourable pressure rise towards the root, leading to loss of isobar sweep, and consequent danger of shock wave formation.

A waisted body shape was specially designed (again by the methods of Ref. 1) such that by adding the extra pressure field over the wing from this body to the wing pressures previously calculated, the undesirable pressure rise near the root was cancelled out. Details of the resulting combined pressure field over the wing with its restored fully swept isobar pattern are given by the dotted line in Fig. 2; the body shape required to produce this pressure field is shown in Fig. 9 as 'reference shape'.

3. Wing Root Shape Modifications

Using the reference wing as a basis, an inboard area of the wing extending from the root to about 40% semispan (ya) was then modified by both increasing the thickness and moving its maximum position further forward (Figs. 1 and 3).

For convenience, the extra thickness thus added was represented as the product of separate chordwise and spanwise functions. The chordwise function K is defined as the extra thickness added at the root chord, and depends solely on the non-dimensional length along the chord ξ_0. The spanwise function f is the multiplying factor whereby the extra root thickness decays smoothly outwards over the wing to a zero value at y = ya. Full details of the nomenclature used are presented in Fig. 3.

Comprehensive pressure distributions over the inboard wing region of interest have been calculated according to linearized theory at Mach number $\sqrt{2}$ and zero incidence for the following alternative modifications to the inboard shape.

Chordwise K function such that for:-

Ka, total maximum thickness increased to 12% of root chord and its location moved forward to $\xi_0 = 0.065$.

Kb, total maximum thickness increased to 8% of root chord and its location moved forward to $\xi_0 = 0.15$.

Spanwise f function such that for:-

fa, $f(y/ya) = \frac{C(y)}{Co} \cdot (1 - |y/ya|)^2$,

fb, $f(y/ya) = \frac{C(y)}{Co} \cdot (1 - |y/ya|)^8$,

fc, $f(y/ya) = \frac{1}{2} \cdot (1 + \cos \pi y/ya)$;

C(y) is the local chord and Co is the wing-root chord.

The resulting calculated pressure distributions for combinations of the above-defined functions are given in Figs. 5 and 7, and the corresponding inboard thickness shapes shown in Figs. 4 and 6.

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The effect on the pressures of thickening the root chord while keeping the same spanwise decay factor is illustrated in Fig. 5. It is evident that the root thickening has a powerful correcting influence on the pressure rise shown by the reference wing near the root, but has given rise to a localized but strong suction peak close to the leading edge at a position about 10% of root chord out from the root. It is also clear from Fig. 4 that the blunter and thicker the root leading edge, then the more pronounced is this suction peak.

Fig. 7 shows that, for a fixed new root section shape (K_b) the nature of the spanwise decay also plays an important role in determining both the peak strength and the degree of pressure recovery that can be obtained at the root itself. Although a more rapid spanwise thickness decay alleviates the strength of the peak, it unfortunately also lessens the desirable correction to the root pressure rise. The cosine decay function f_c produces the most marked effect on the pressures because it introduces the most extra volume. Of the two power functions f_a and f_b, the more rapid spanwise thickness reduction obtained from using the power 8 results in appreciably smaller changes to the root pressures.

It is worth mentioning that in practice the peak suctions would be smaller in value than obtained from the linearized theory calculations used here because of the Riegels Factor corrections which have to be applied near a round leading edge. (cf. Ref.3). It should also be remembered that one of the assumptions inherent in linearized theory is that the wing syrface is everywhere close to the plane $z=0$, and hence calculations are limited to shapes which do not become too thick near the wing root nor too blunt very close to the leading edge.

4. Final Wing-Body Configuration

The final wing-alone shape for a future experimental investigation was determined by selection from the sets of different inboard shapes and their pressure distributions given above, together with some others not quoted in this note. These various sets were combined linearly using appropriate factors so that the eventual wing-alone pressure field was of suitable form to be added to the pressure field around a body of revolution having much reduced waisting. The final configuration, designed by the method of Ref. 1, attempted to regain as closely as possible the desired combined upper-surface pressures of the original reference wing-body configuration. The resulting wing-alone and combined pressure fields over the complete wing are shown in Fig. 8. Such a design process is necessarily somewhat complicated and lengthy, and it is considered from the experience so far obtained that a practically cylindrical centre-body shape could be evolved by means of the appropriate inboard wing-shaping. The degree to which the body waisting has been successfully reduced from that of the reference configuration in the present case is shown in Fig. 9, where details of the actual root shaping have also been added for comparison.

The cross-section area distributions of the reference and final wing-body configurations are shown in Fig. 10. It can be seen that the transfer of the shaping from the centre-body to the inboard wing area has considerably improved the smoothness of the 'hump' in areas in the axial direction which, from 'Area Rule' considerations, should consequently lower the overall drag per unit volume.

5./

5. Conclusions

This theoretical design study for symmetric wing body configurations has shown that by transferring the reshaping from the centre-body to the inboard wing region it is possible to:-

(a) improve the 'Area Rule' distribution of the total configuration,

(b) obtain a thicker wing root with consequent structural gains,

(c) produce a body shape with much reduced waisting and hence greater payload volume,

whilst at the same time preserving practically the same combined wing pressure field.

The pressure changes near the root are affected as much by the inboard spanwise thickness variations as by the chordwise variations.

Careful design is needed to avoid the occurrence of a strong but localized forward suction peak which the root blunting and thickening tend to introduce at about 10% root chord outboard from the root.

6. Acknowledgements

The authors are indebted to Dr. R. C. Lock both for the instigation and continued interest in this work, and to Miss V. Stringfellow, Mr. M. D. Whitley and Mrs. R. A. Thompson for their valuable computational assistance.

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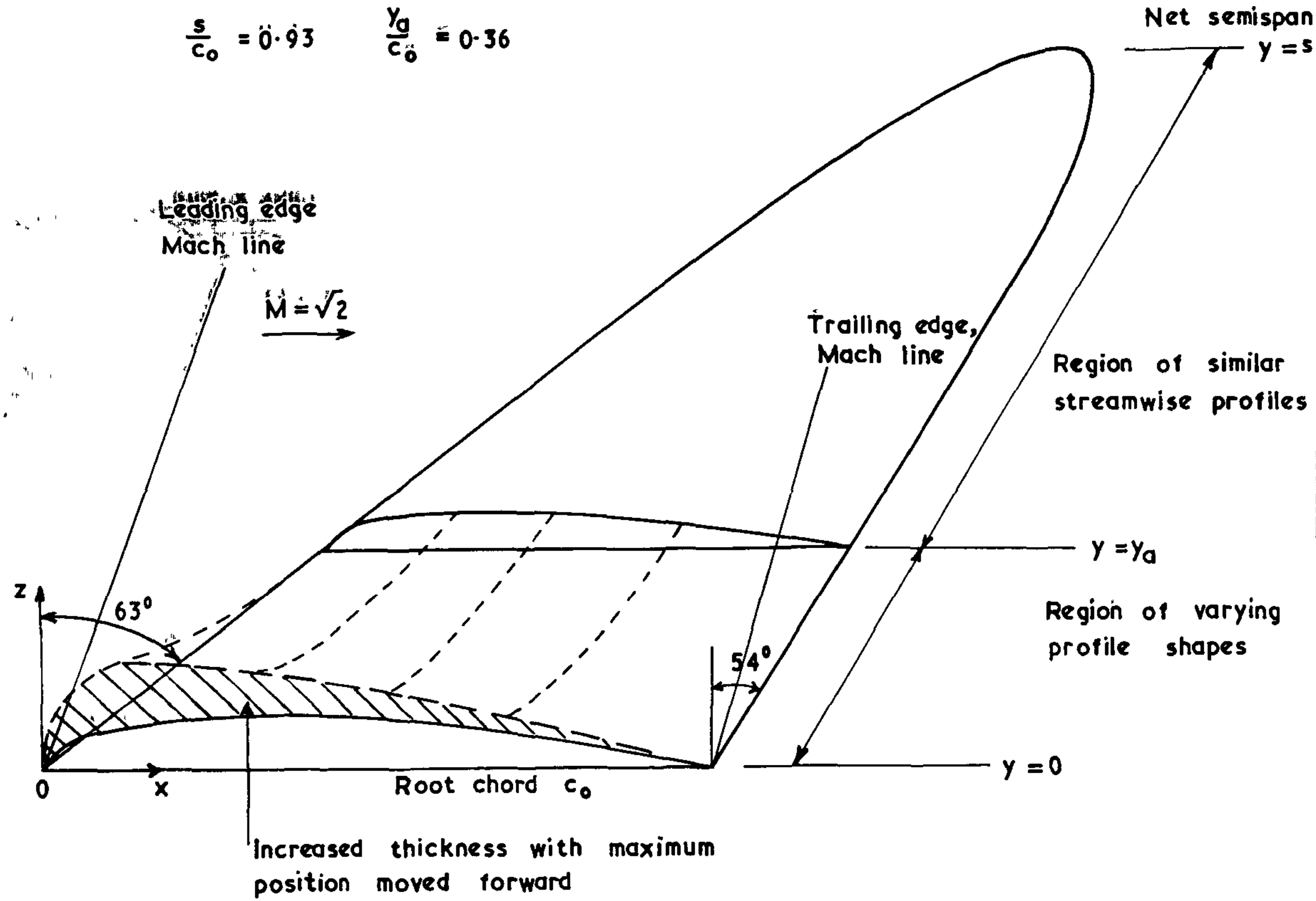


FIG. 1.

View of wing showing inboard extent of shape modifications

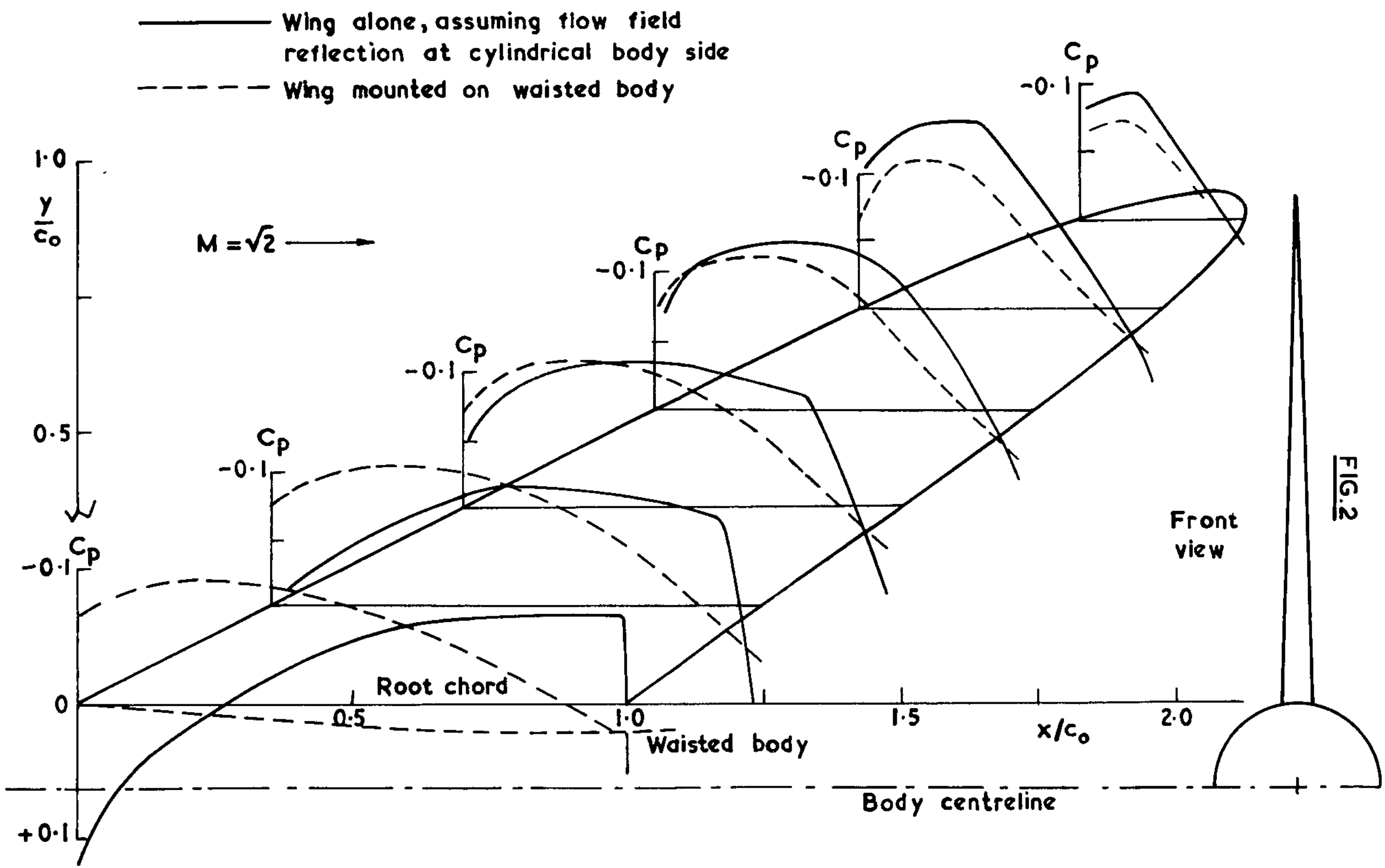
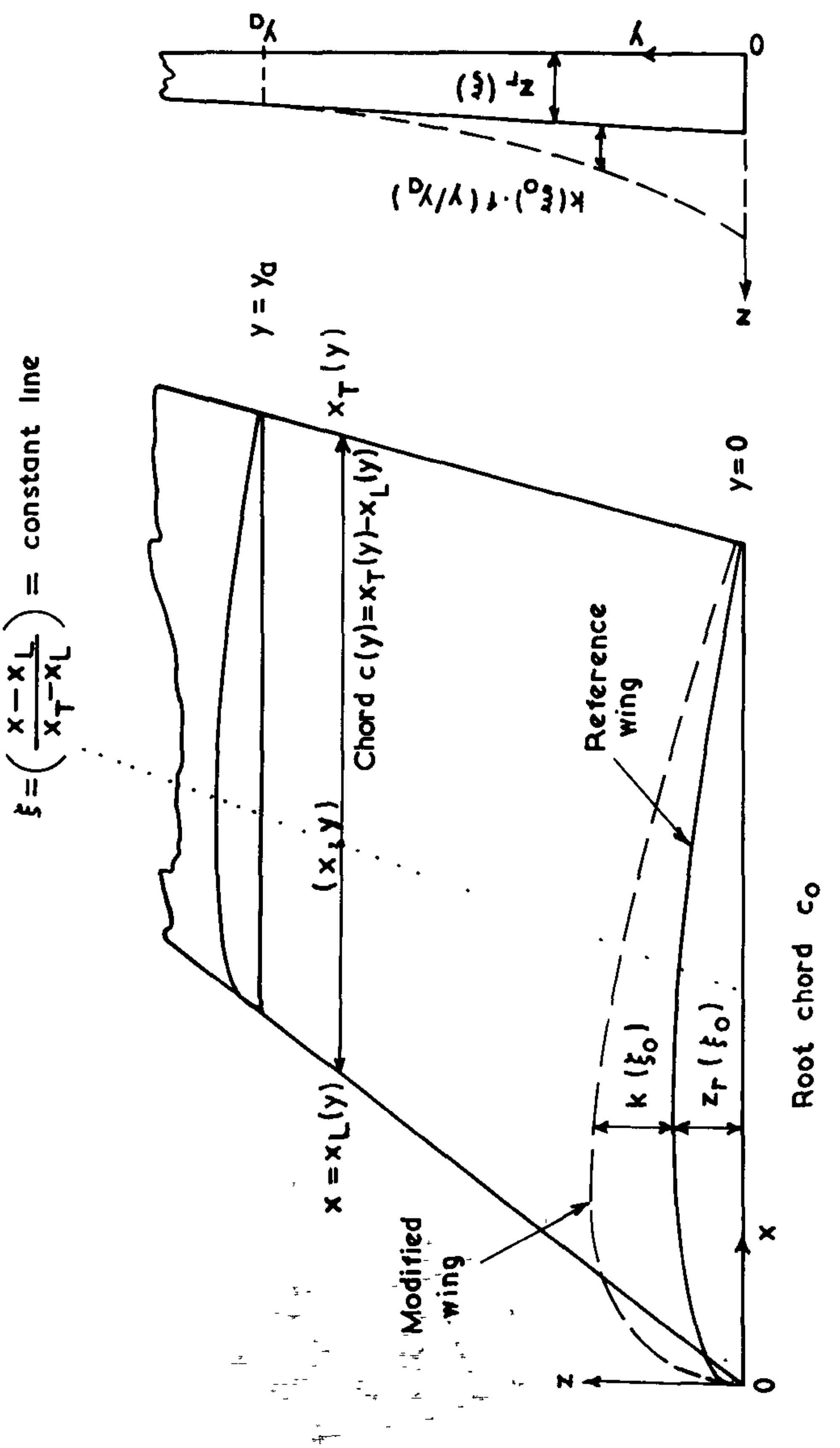


FIG. 2

Calculated pressures over reference wing having straight tapered similar streamwise sections

FIG.3



Chordwise variation K at root

Spanwise variation f close to root

$$z(\xi,y) = z_r(\xi,y) + k(\xi_0)\cdot f(y/y_a)$$

Nomenclature for geometry changes made near wing root

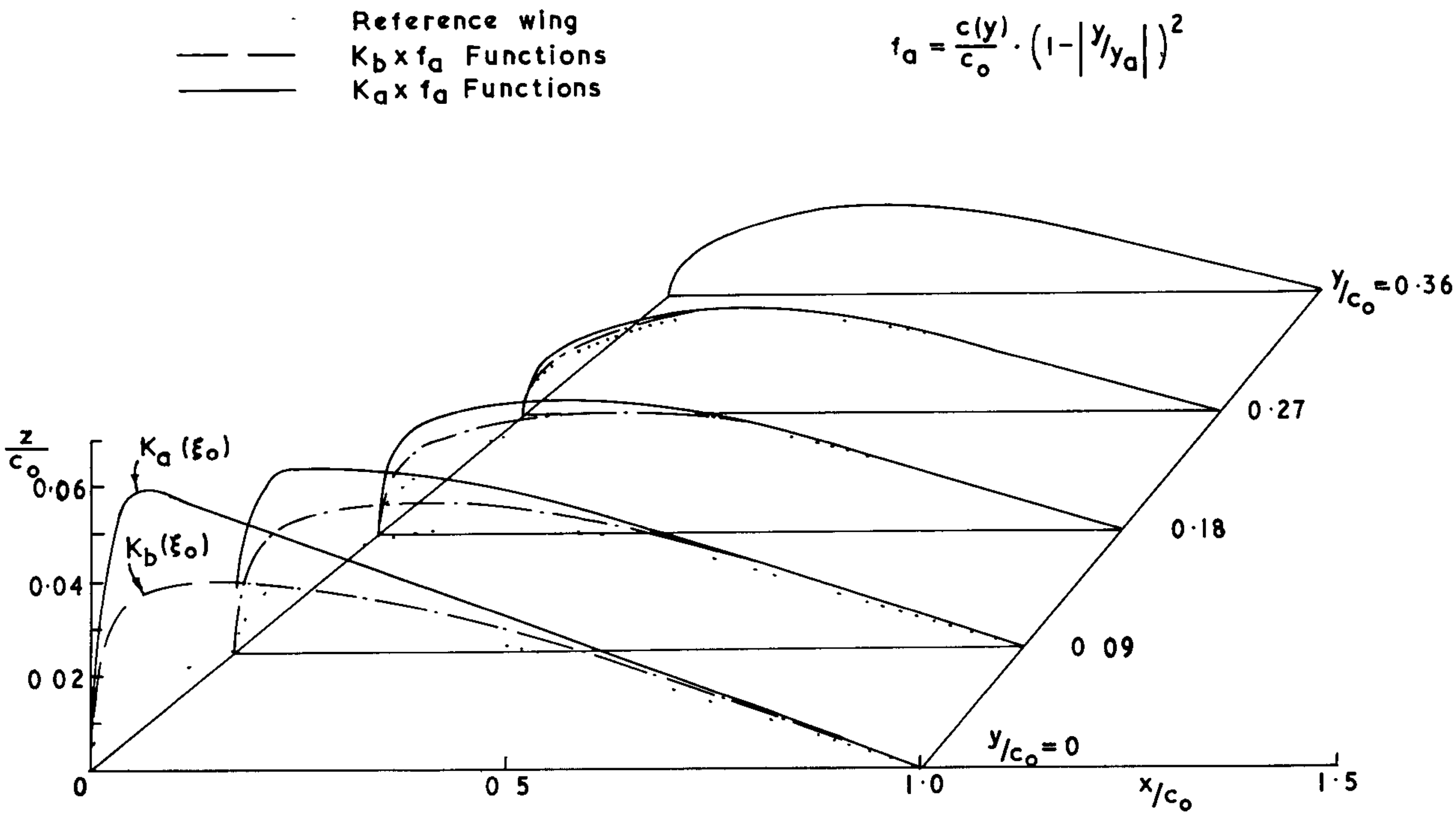


FIG 4

Geometry changes near root Variation in chordwise function.

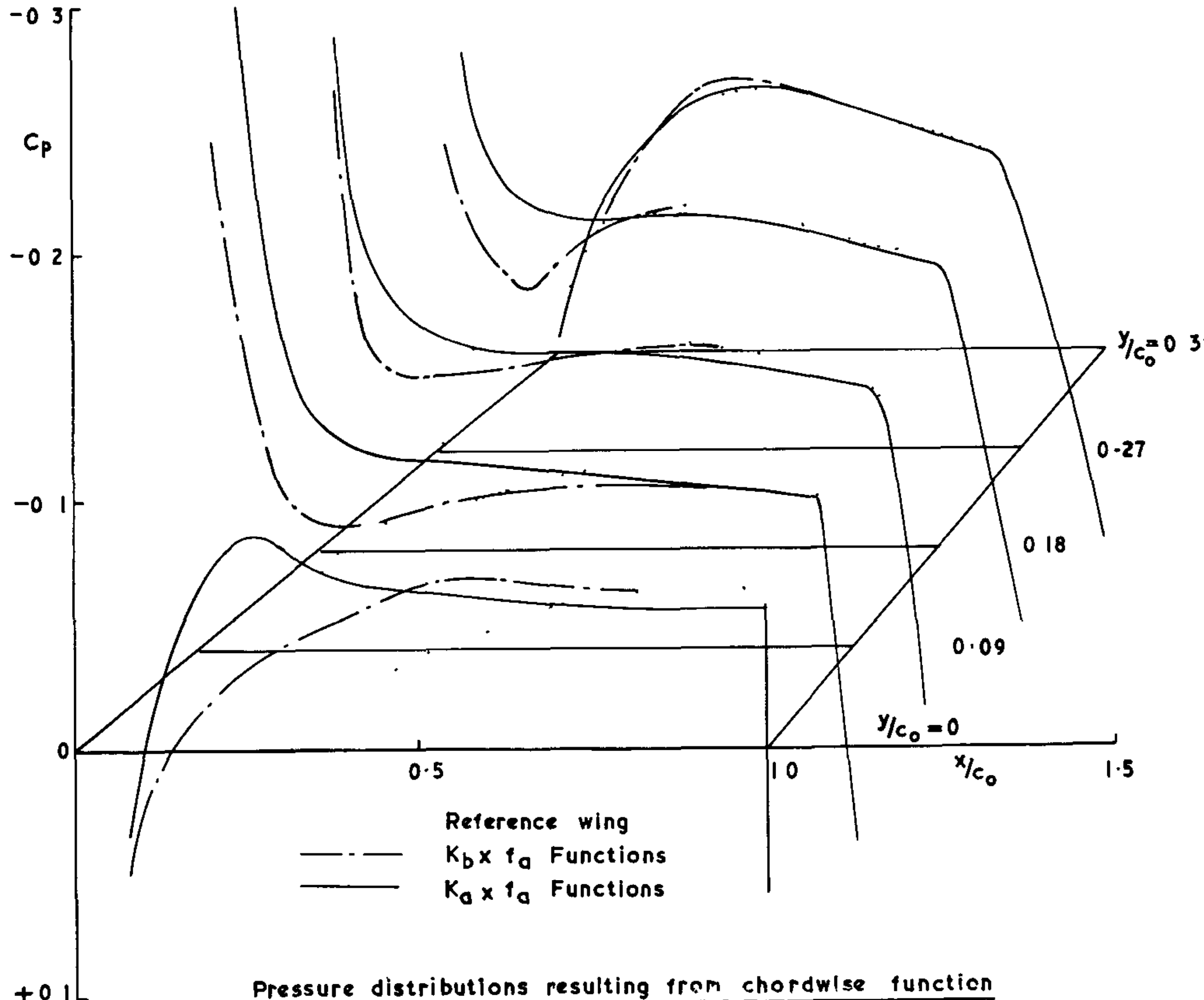


FIG 5.

Pressure distributions resulting from chordwise function changes near root (FIG 4).

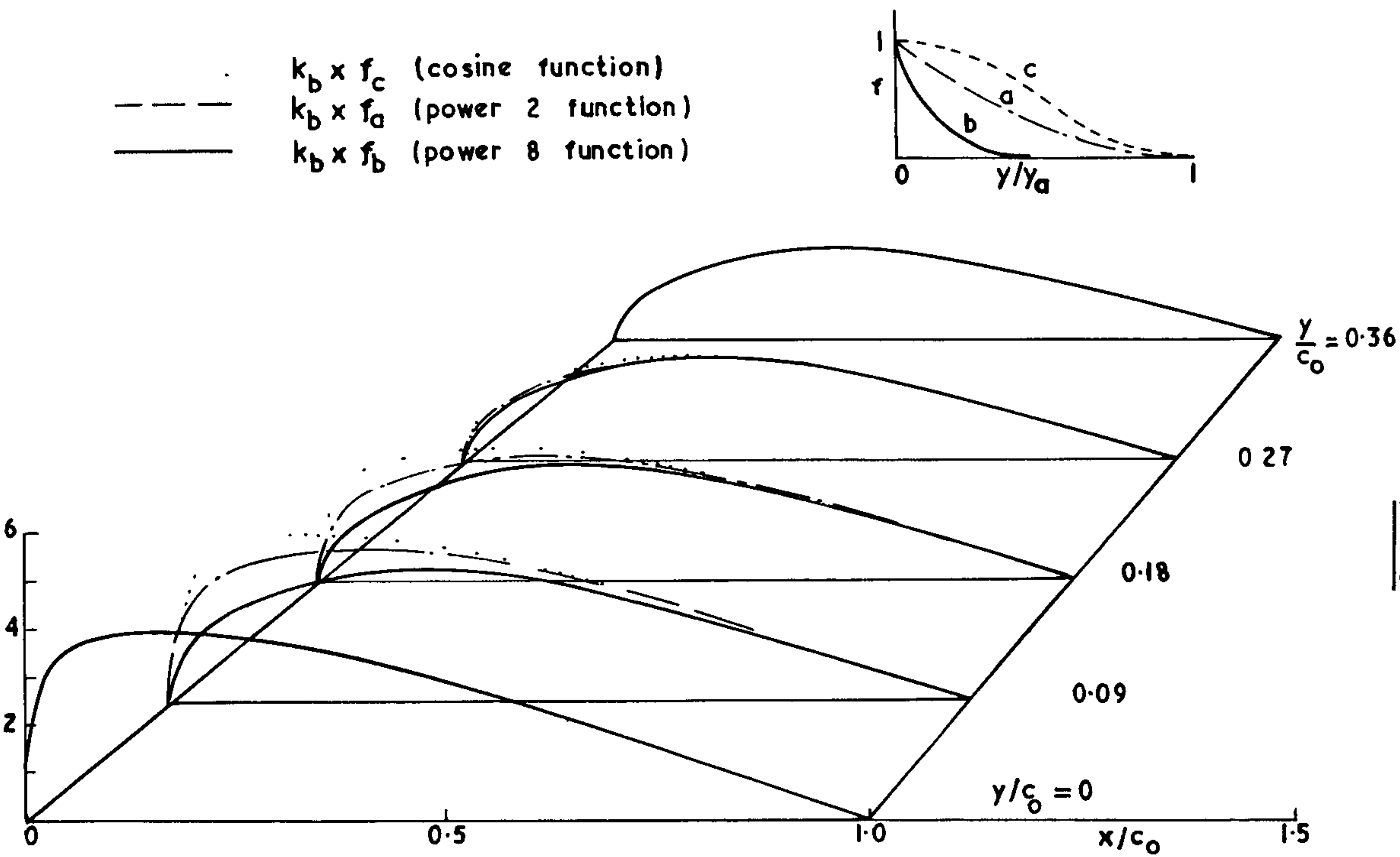
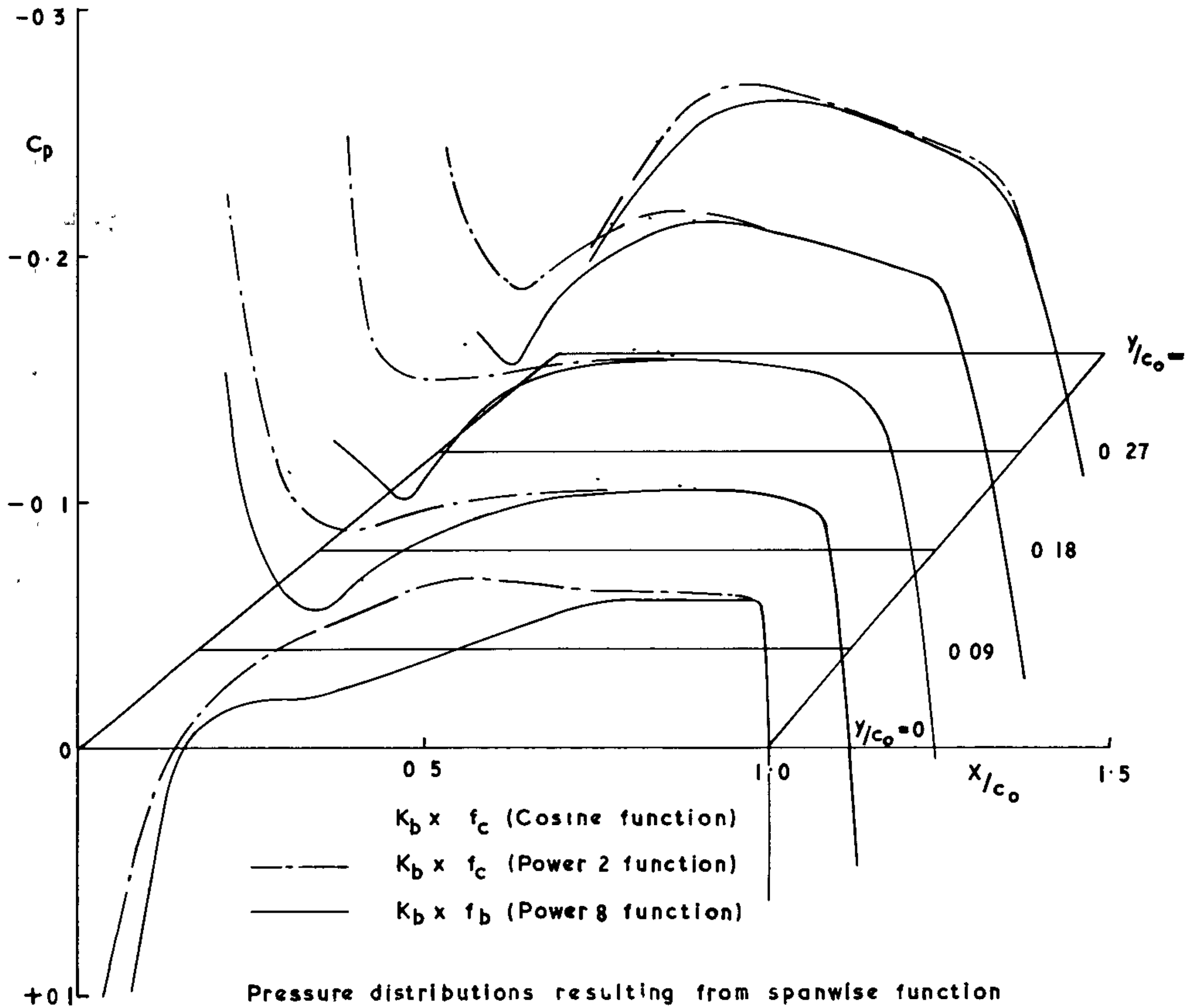


FIG. 6

Geometry changes near root · Variation in spanwise function



Pressure distributions resulting from spanwise function geometry changes near root (FIG 6)

FIG 7.

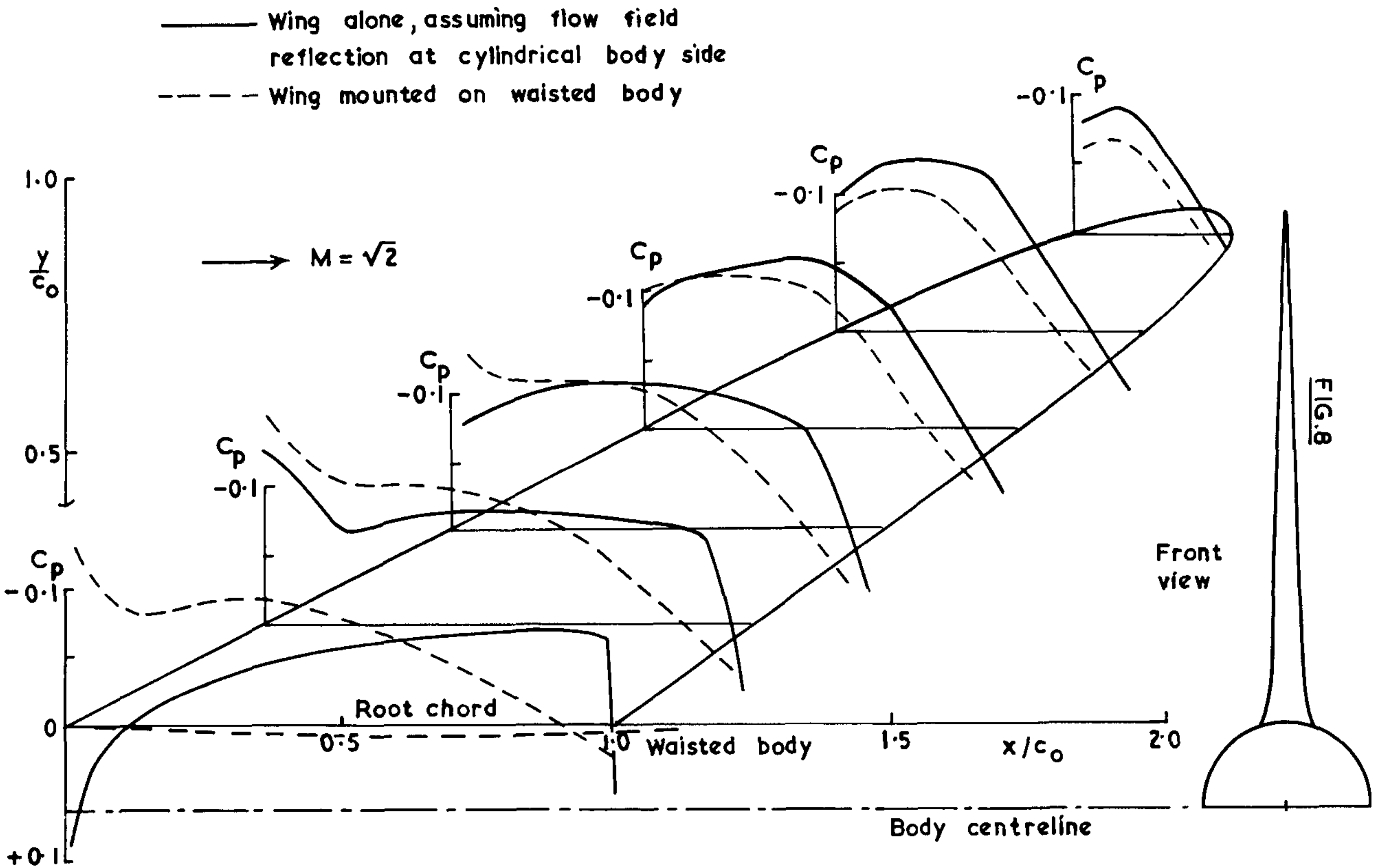


FIG. 8

Calculated pressures over final wing with modified root shaping

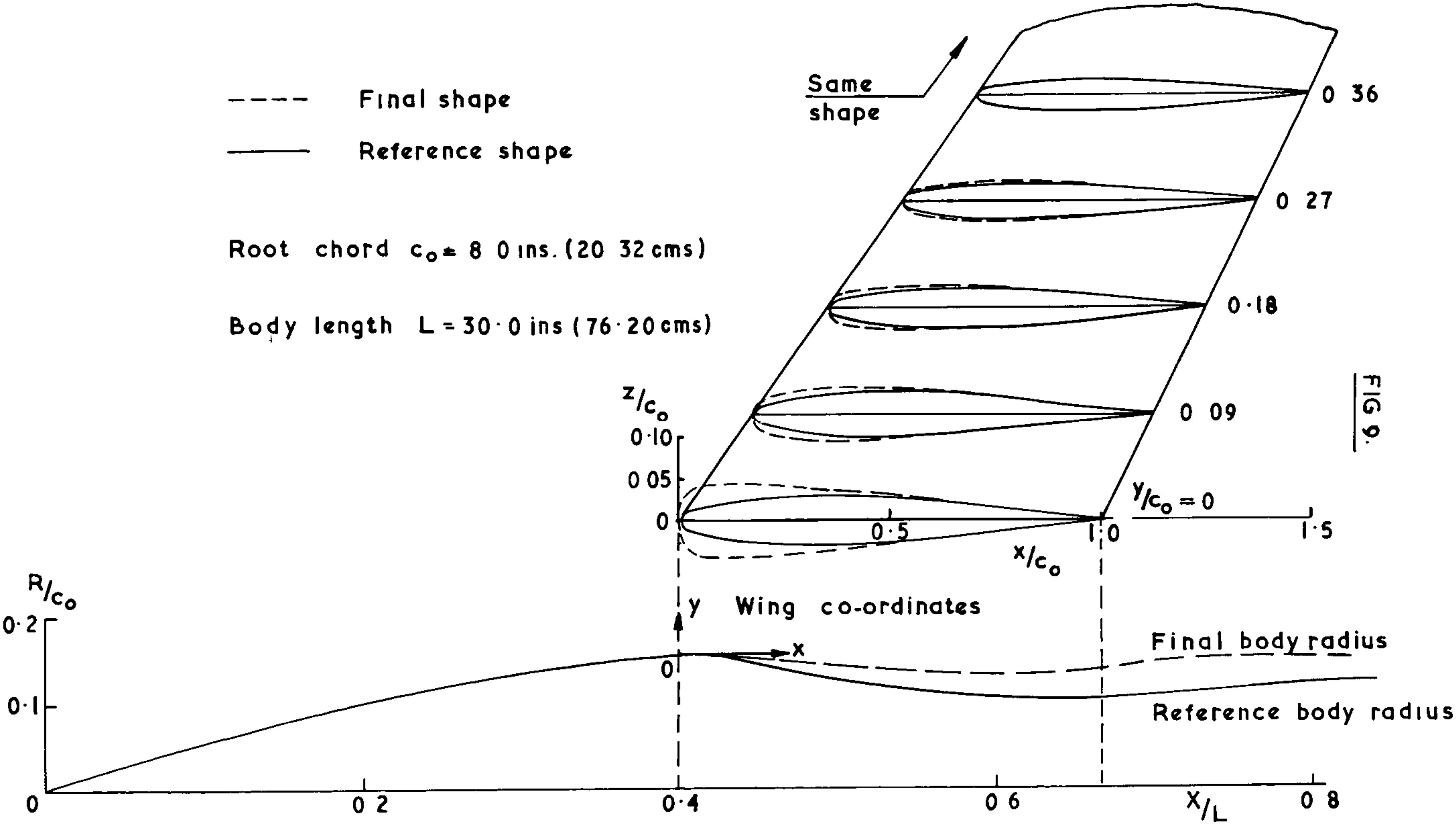
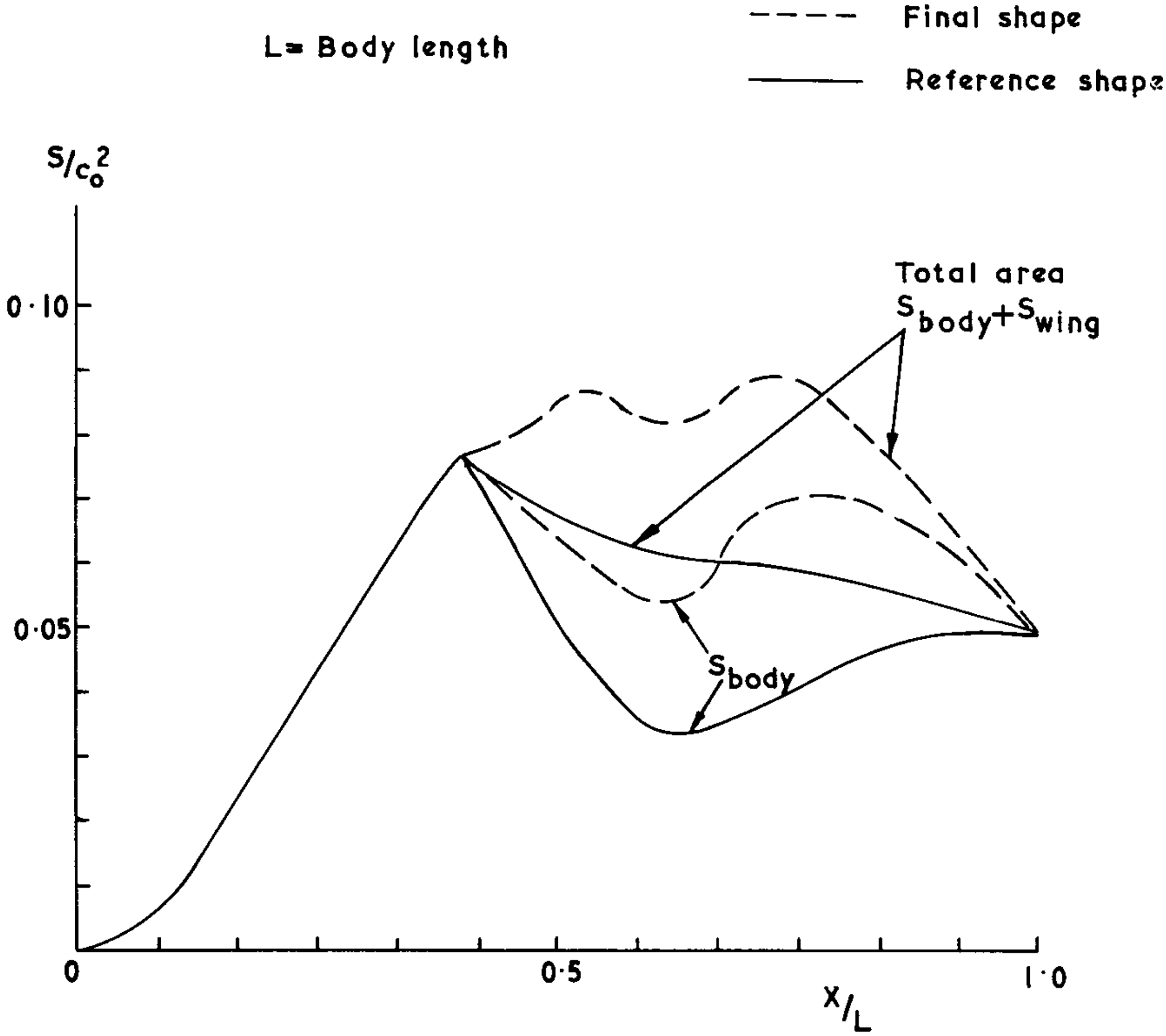


FIG 9.

Comparison of geometries of final and reference wing body configurations.

FIG.10.



Cross-sectional area distributions of final and reference wing body configurations

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