Multi-Element Aerofoils in Viscous Flow

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Abstract

A NUMBER of multi-element aerofoils having up to four elements are studied both in inviscid and viscous flow. A viscous flow solution is obtained by applying the viscous inviscid interaction (VII) technique. Both direct and semi-inverse iterative modes of coupling are applied using the transpiration velocity model. The inviscid solution is compared with an exact analytical solution whereas the solution after viscous correction is compared with available experimental results.

Contents

The numerical method employs the internal singularity distribution method of Basu[1] and incorporates the Prandtl-Glauert rule for compressibility correction for the solution of the external inviscid flow. The main advantage of this method over other existing methods is the reduced computing time for comparable numerical accuracy.

In the present approach, the laminar portion of the boundary layer is calculated by the Thwaites[2] method allowing for compressibility using the Stewartson-Illingworth transformation.[3] Transition from laminar to turbulent flow in the boundary layer is predicted by the empirical criterion due to Michel.[4] Over the portion of the aerofoil where the turbulent boundary layer is unaffected by the wake of the preceding element, the development is calculated by the lag-entrainment method of Green et al.[5] using the complete second-order momentum integral equation as given by Lock and Firmin.[6] This method is also used to calculate the turbulent wake with pressure gradient. The interaction between the wake and boundary layer is calculated by the integral method due to Irwin,[7] in which reasonably simple algebraic expressions containing a total of six unknown quantities are used to describe the velocity profiles of the boundary layer and the wake. The matching of the inner and outer solutions is performed following the procedure suggested in Ref. 6. A relaxation factor, which varies from point to point, is used to avoid numerical instability and to achieve quick convergence, which is assessed by the change in lift coefficient in the subsequent iteration.

One of the most important features of the flow past a high-lift system is the existence of separated flow regions at the cavities beneath the slat and shroud and on the upper surface of the flap, possibly throughout the incidence range. The turbulent boundary-layer equations become singular in such a situation and a direct iterative method will fail. A method capable of calculating flows with embedded separated regions is developed, using the semi-inverse approach in which the velocity or pressure distribution is taken as unknown and the transpiration velocity is considered as known. The basic idea involved in the semi-inverse approach is that, at a stage when updated values of the source strength $\Sigma^{(n)}$ have been determined, two alternative estimations of U_{iw} (velocity on the wall or dividing streamline in equivalent inviscid flow) can be made with the same boundary conditions: 1) a direct inviscid calculation in the usual way, and 2) an inverse boundary-layer calculation. Denoting these two solutions by U_{iw}^{I} and U_{iw}^{V}, respectively, the convergence is judged by examining the difference $U_{iw}^{I} - U_{iw}^{V}$. If this difference is too large, a corrector is used to provide a new value for Σ and the calculation is repeated until adequate convergence is achieved.

The potential flow pressure distribution for a four-element case[8] is presented in Fig. 1 and it agrees quite well with the exact analytic solutions. Figure 2 shows the comparison of the present calculation method with the experimental result of van den Berg[9] for a two-element airfoil. Both the pressure distribution and the lift curve compare quite well with the experimental results. The small difference between the results obtained by the direct and semi-inverse methods is, perhaps, due to the different convergence criteria used in the calculation. The pressure distribution at an angle of attack of 8.4 deg and the lift curve for a Boeing four-element aerofoil are compared (Figs. 3 and 4, respectively) with experimental data obtained in the Boeing research wind tunnel[10] and with the theoretical results presented in Ref. 10. The comparison shows satisfactory agreement.

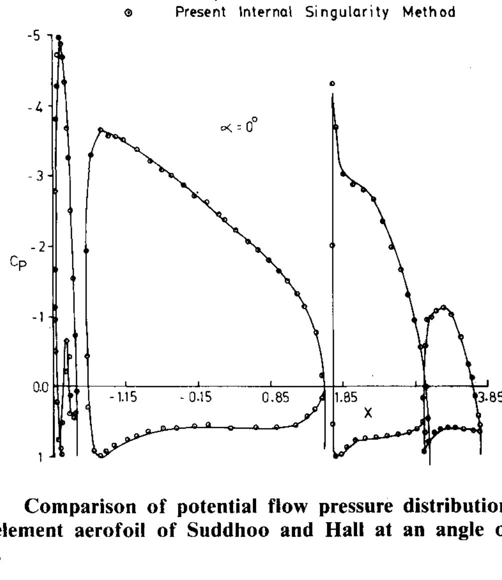

Fig. 1 Comparison of potential flow pressure distribution on the four-element aerofoil of Suddhoo and Hall at an angle of attack 0 deg.

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a)

b)

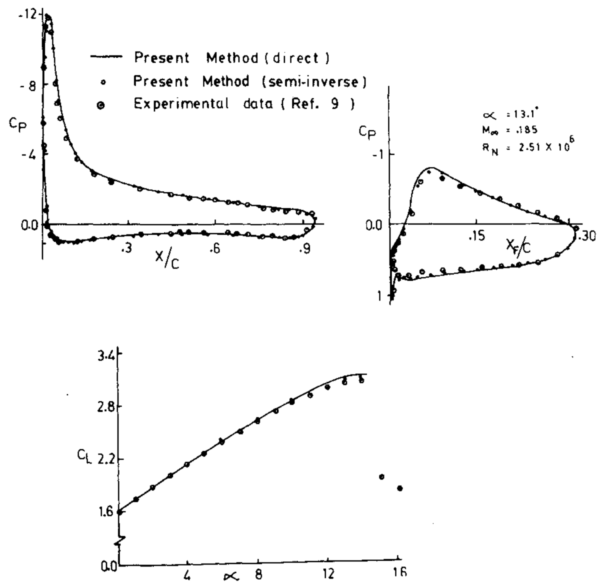

Fig. 2a Comparison of pressure distribution on NLR two-element aerofoil (gap 1.3%c, overlap 5.3%c, flap deflection 20 deg where c is the basic airfoil chord) at an angle of attack of 13.1 deg, and b) variation of lift coefficient with angle of attack.

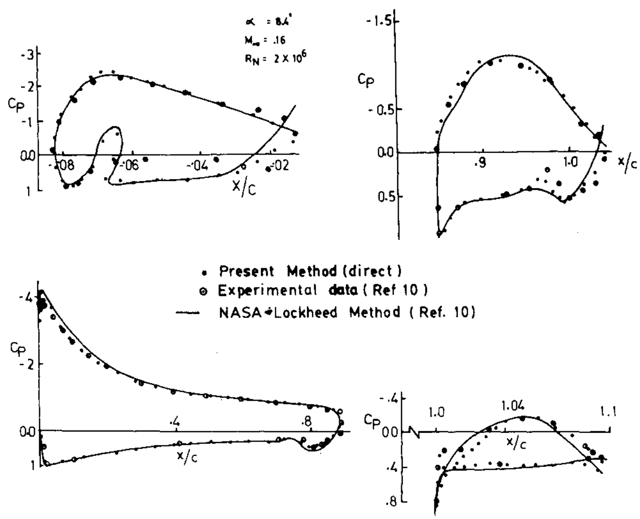

Fig. 3 Comparison of pressure distribution on Boeing four-element aerofoil at an angle of attack 8.4 deg.

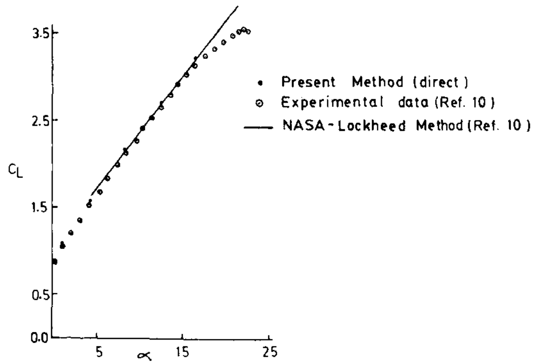

Fig. 4 Variation of lift coefficient with angle of attack for the Boeing four-element aerofoil.

Acknowledgment

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