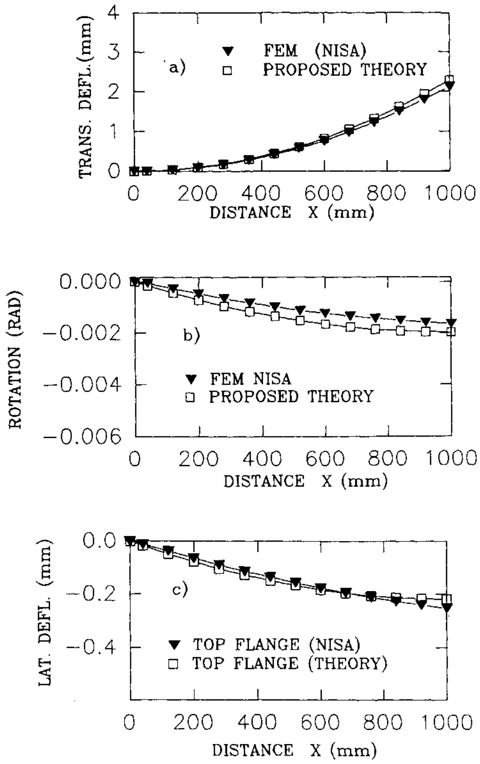

Fig. 3 a) Transverse deflection, b) rotation, and c) lateral deflection vs length for example 3.

length of the beam; Fig. 3b shows the rotation ϕ along the beam length along the length of the beam. Results of the finite-element calculations are also shown. Fig. 3c shows the lateral deflection of the top flange u_z^t along the length of the beam. The convergence of the results at the loaded end (right side) is due to a kinematic constraint condition used to enable concentrated loading at the beam end.

Conclusion

The proposed analytical theory is the first hand-calculation-type theory to be presented which can predict out-of-plane coupled deformation of transversely loaded composite beams. Numerical studies confirm the coupled deformation modes. Agreement between the theory and the finite-element results is remarkably good considering the simplicity of the theory. Parametric studies have shown maximum differences between the theory and the finite-element results to be up to approximately 15% for transverse deflections and up to approximately 25% for rotations and lateral deflections. The theory should be useful to designers wishing to perform preliminary studies of open-section stiffener sections. The theory is currently being extended to predict behavior under torsional loading, the next step in the development of a generally anisotropic beam element.

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Viscous Subsonic Flow Computation for Wings with Flaps for High-Lift

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Introduction

ANALYSIS of viscous flow over high-lift systems for large aspect ratio transport wings is one of the important problems of aircraft aerodynamics. The problem of viscous flow over clean wings was considered in Ref. 1. In the present Note, the method of Ref. 1 has been extended for analysis of multielement wings comprised of multicomponent airfoils at high-lift and includes a model for ground effect, compressibility, trailing-edge separation, and curved basic flow.

First attempts to validate the method by comparing computed results with measurements are reported. Within the

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limits of the assumptions used, the theoretical results compare well with those of experiments and the computing time requirements are modest.

Method

The overall method is an iterative procedure combining a three-dimensional inviscid lifting surface theory with a two-dimensional multielement airfoil analysis procedure including boundary-layer effects and a model for rear separation. Ground effects are included by means of a reflected image technique and the final viscous solution is improved by means of a curved basic flow analysis.

Consider a wing of high, but finite aspect ratio and lo sweep. Here, the flow around a wing section is approximately two-dimensional. But, contrary to the infinite rectangular wing, the effective basic flowfield at each section is not identical with the oncoming parallel flow, but changed by velocity differences, induced by the different vortex systems of finite and infinite wings, respectively. In general, the effective basic flow at a wing section is slightly curved and the average angle of attack is smaller than the wing incidence. If the effective basic flow were known at each section, the spanwise lift, pitching moment, and drag distributions could be obtained by applying a proper two-dimensional airfoils method to each section. If, on the other hand, the spanwise lift and moment distributions were known, one could determine the induced velocities, and therefore, the basic flow at each section by a reverse application of lifting surface theory. In the current work both methods are combined within an iteration process, starting with a reasonable first approximation for the lift and moment distributions. After computing the basic flow at each section, an advanced two-dimensional multielement airfoil method (in-

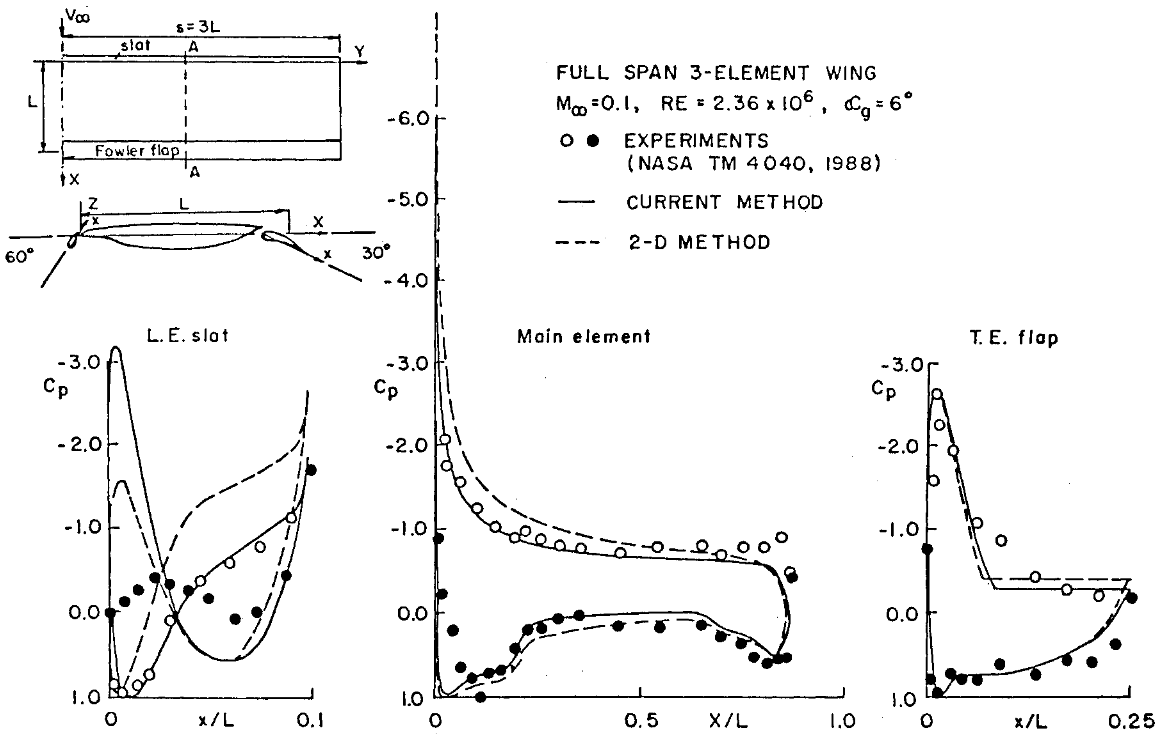

Fig. 1 Three-element rectangular wing configuration and pressure distributions at section A-A for incidence α = 6 deg.

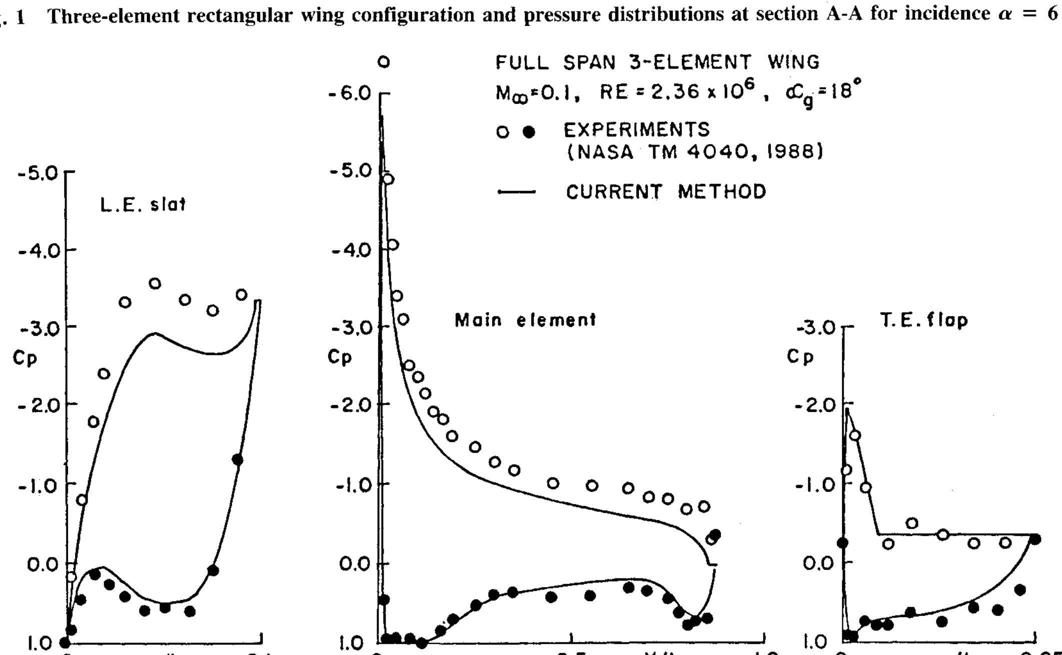

Fig. 2 Pressure distributions at section A-A for incidence α = 18 deg (for wing of Fig. 1).

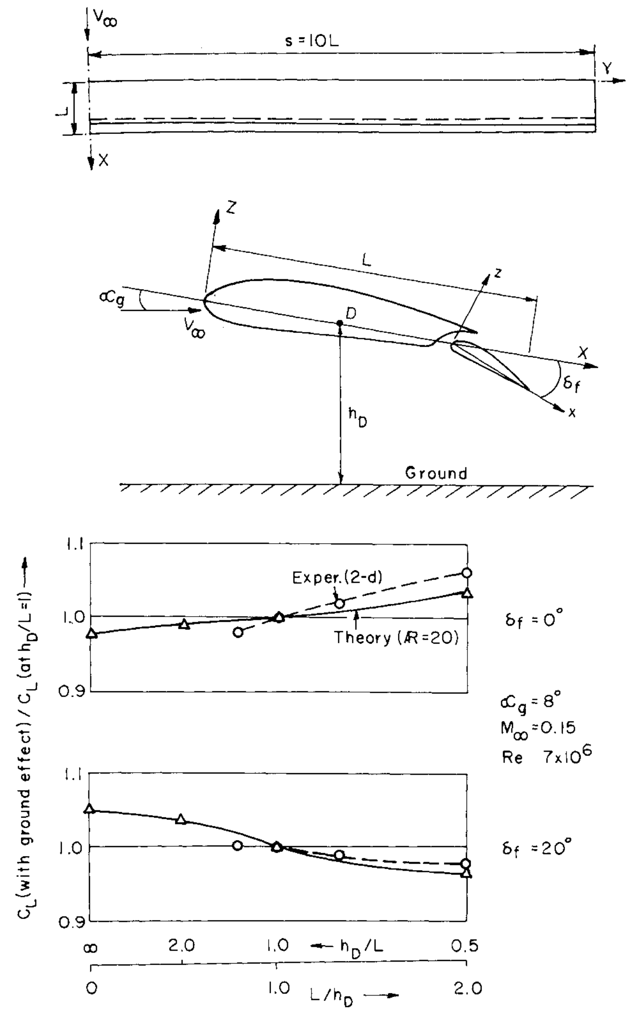

Fig. 3 Two-element rectangular wing configuration and lift coefficient vs ground distance for two flap deflections δ_f.

cluding thickness, viscosity, ground effects, and compressibility correction for subsonic flow) is applied to each section to get the next approximation for the lift and moment distributions, which in turn is then used to recalculate the basic flows at the sections, etc., until the lift distribution converges. The first approximation for the spanwise lift and moment distributions is obtained by normal application of the inviscid lifting surface method. The method adapted for the three-dimensional inviscid analysis is the well-known lifting surface method of Truckenbrodt,[2] extended by Hummel[3] for including ground effects. The two-dimensional flow at each spanwise station is analyzed using an extended version of the two-dimensional multielement airfoil method of Jacob and Seinbach[4] which takes into account the effects of boundary layers, rear separation, ground, curved basic flowfield and, for subsonic velocities, the effects of compressibility. The overall program has been coded in FORTRAN and the current program is a multicomponent version of the program reported in Ref. 1. The details of the method are given in the full article.[5]

To validate the current method against experimental data, the rectangular wing shown in Fig. 1 was analyzed at several α_g values. The wing was represented by six span-wise stations and the leading-edge slat, main element and trailing-edge flap were represented by 50, 90, and 60 surface points, respectively. Plotted in Figs. 1 and 2 are computed and measured pressure distributions at $Y/L = 0.45$ (section A-A) for $\alpha_g = 6$ and 18 deg, respectively. As can be seen, the results of the current method compare fairly well with the measured pressure, except on the lower side of the leading-edge slat for $\alpha_g = 6°$. There is the possibility that a large separation bubble exists here which is not properly taken into account in our method. As the flow incidence is increased, the bubble decreases, and for $\alpha_g = 18$ deg (Fig. 2) the pressure distributions on the lower side of the slat compare very well. Also, the separated flow region on the trailing edge is well-predicted. In Fig. 3 the effect of height-over-ground on lift is shown for a high-aspect ratio wing with a slotted flap at two flap deflections. Also plotted are the results from the two-dimensional measurements.[6] The results compare well qualitatively. Notice that for $\delta_f = 20$ deg, both theory and experiment show decreasing lift when the wing approaches the ground. Finally, Fig. 4 shows some computed results for a rather realistic wing-landing configuration. The results look reasonable and the computing time requirements are modest. Further effort should be aimed at extensive validation and improvement of the method.

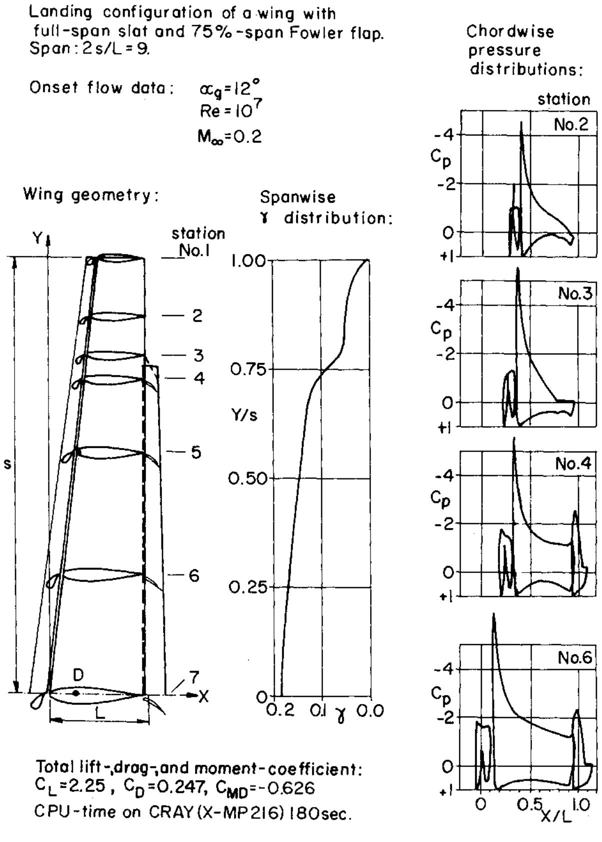

Fig. 4 General three-element wing (landing configuration). Computed spanwise lift and chordwise pressure distributions, total force coefficients, and required computing time.

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