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Analysis of Wing Flap Configurations by a Nonplanar Vortex Lattice Method

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Abstract

A NONPLANAR vortex lattice method is described for calculating the potential flow aerodynamic characteristics of complex planforms, with an emphasis on wings with spanwise segmented partial-span flaps. A new technique has been developed for proper modeling of flow in the region between the flap edges and the wing in the case of part-span flaps. The effects of compressibility have been accounted for by the use of the Prandtl-Glauert rule with no approximation being made regarding freestream incidence, wing camber, and flap deflection. The method has been tested for a number of cases to assess its utility.

Contents

Analysis of wings with deflected flaps is of great practical importance. In the limits of linear theory, a common way of approaching this problem is to use a singularity technique with the fully linearized boundary condition and treat the flap deflection as an additional local incidence.[1,2] A more exact way of doing this is to distribute the singularities on the actual wing flap surfaces, as has been done in Refs. 3 and 4. In all these methods, near the wing flap juncture, where the computed flow quantities behave discontinuously, either a model has not been developed,[1,2] or the model suggested is restricted to single training-edge flap.[3,4] Here a nonplanar vortex lattice method has been developed with a model for the flow near wing flap juncture.

In the present work, the surfaces of lifting elements (namely, wing, flap, canard, etc.) are represented by a distribution of discrete nonplanar vortices. The configuration to be analyzed is subdivided into a network of panels and an unknown vortex singularity Γ is located along the quarter-chord line of each panel. A pair of trailing vortices along the panel edges grazes the wing flap surface and trail to infinity at a prescribed orientation from the trailing edge of the wing or flap. The strength of the unknown singularities is determined such that the flow tangency condition is satisfied at all control points.

When a flap is deflected a gap is formed in the X-Z plane. In a steady condition, the flow communicates from bottom surface (pressure side) to top surface (suction side). Thus, there is no discontinuity in spanwise loads due to geometric discontinuity and the gap carries no load. This has to be modeled so that the loads on panels both close to the gap and upstream of the gap are realistic. If this is not done, the error in computed vortex strengths (and in turn the computed ΔCp) propagates to other panels, thus affecting even the overall aerodynamic coefficients. This problem for a single trailing edge flap case has been dealt with by Rubbert.[3] As shown in Fig. 1 a, in this model the horseshoe vortices adjacent to the juncture are inset from the edge of the flap tip, similar to the treatment of a wing tip. Even though this model seems to have given correct results for the example quoted in Ref. 3, the method is impractical for arbitrarily tapered wings with complex planforms and multiple-part span flaps. Another point to be noted is that, contrary to the wing tip where the system of vortices is to only one side, the flap juncture lies between two chordwise rows of vortices. As a result, at a wing flap juncture concentrated vortices are formed at both the free edges. In the present method, the gap has been modeled by diffusing these two concentrated vortices and spreading them into a sheet of discrete vortices covering the gap. Similar to the assumption that the wake behind a trailing edge carries no load, it is assumed in this work that the vortex sheet filling the gap has a zero pressure difference across it.

Figure 1b shows the gap modeling for a wing with a deflected trailing-edge flap. The right-side trailing vortices from the column of panels on the left of inboard end of flap are deflected to fill the gap between the wing and deflected flap in the X-Z plane. Similarly, the left-side trailing vortices from the column of panels on the wing close to discontinuity upstream of the deflected flap are also deflected. The trailing

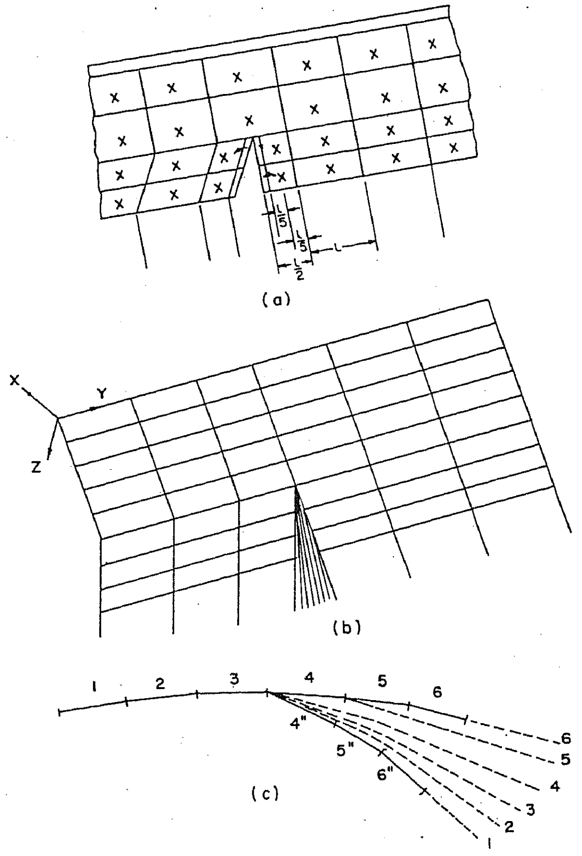

Fig. 1 Gap modeling.

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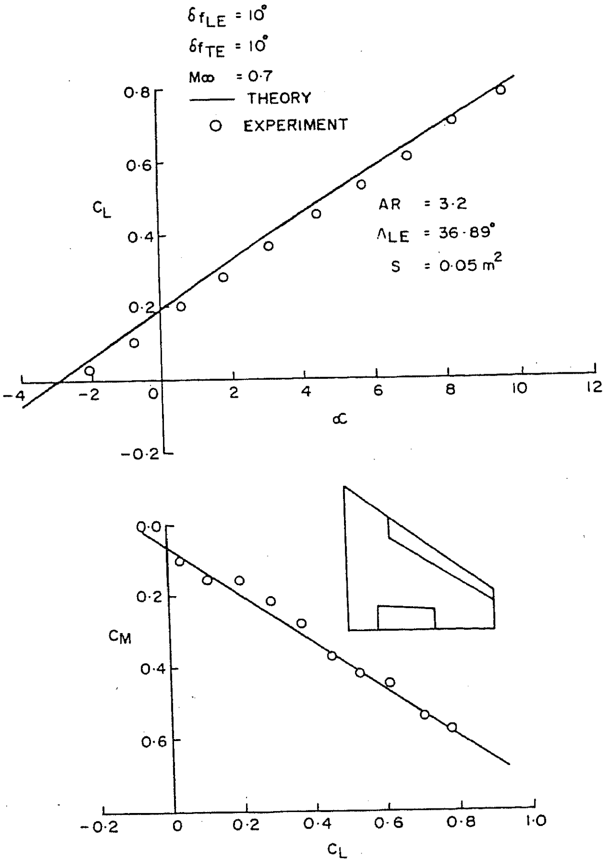

Fig. 2 Lift and moment curves for NAL-X1 wing.

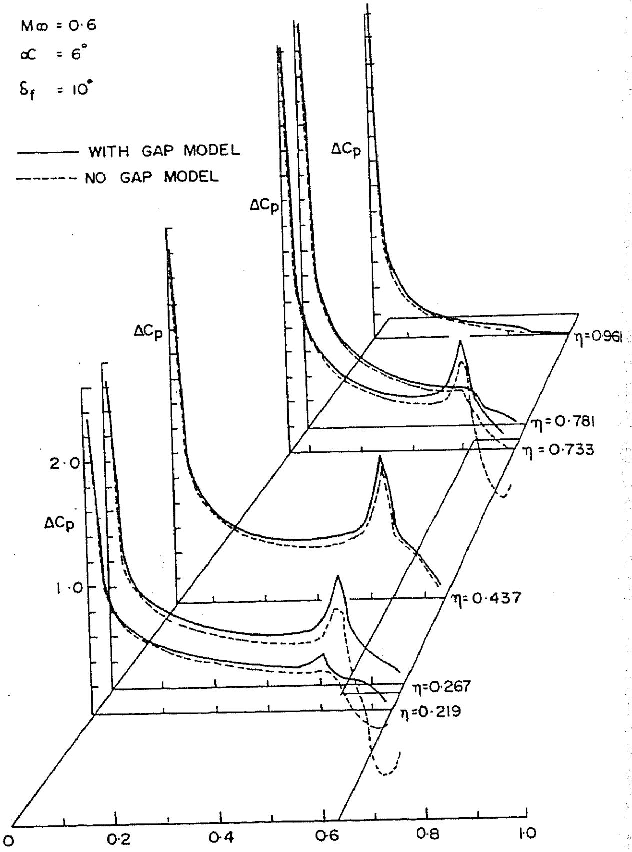

Fig. 3 ΔC^p distributions at various spanwise stations with and without gap modeling.

vortices from the panels on the flap follow the flap surface, whereas the trailing vortices from the wing are deflected by different amounts to fill the gap between the wing and flap. The vortex from the farthest panel, viz, the one close to leading edge is deflected most, while the one close to hinge line is deflected least. The left and right trailing vortices of adjacent panels above the hinge line at the geometric discontinuity are deflected by the same amount. A similar procedure is adopted for the outboard end of the flap.

Figure 1c also shows the side view of the gap modeling for a cambered wing with a trailing-edge flap. In this case, the trailing legs to be deflected in the gap are bent in such a way that the total deflection is the sum of the deflection angle due to camber and the angle the trailing vortex has to be deflected depending on the panel from which it originates.

This method has been validated against a number of wing flap systems. The results for overall lift and moment coefficients for NAL-X1 wings with deflected leading- and trailing-edge flaps compared with experimental results are shown in Fig. 2. As can be seen, the comparison between theory and experiment is good.

The Δ *Cp* distribution for a 35 deg swept-back wing with a part-span trailing-edge flap at various spanwise stations is shown in Fig. 3 with and without gap modeling. Analysis was carried out at an angle of attack $\alpha = 6$ deg, flap deflection $\delta_f = 10$ deg, and freestream Mach number $M^\infty = 0.6$. Since the wing is at a lifting condition with trailing-edge flap deflected, no part of the wing can be expected to carry a negative load. If no modeling is made for the flow near the wing flap juncture, the loads reach appreciable negative values. With the modeling of the flow near the wing flap gaps, the load distributions behave properly, as can be seen in Fig. 3.

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