Technical Comments

Comment on "Convergence Characteristics of a Vortex-Lattice Method for Nonlinear Configuration Aerodynamics"

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IN the subject paper,[1] numerical modeling sensitivities on longitudinal force/moment properties are reported for a vortex lattice method which incorporates free vortex filaments to represent the leading-edge vortex separation. The authors are to be commended for documenting these features of their numerical method. However, several aspects of the presented results warrant technical critique.

In Figs. 6, 7, and 8 of Ref. 1, Rusak et al. document the sensitivity of their method to length scales for the wake vortices (Δx_w) as well as the wing vortices (Δx_p). The study was conducted at a 20 deg angle of attack for delta wings with aspect ratios of 0.5, 1.0, and 2.0 and included experimental values from their Ref. 21 (Ref. 2 of this Comment). The lift coefficient correlation is shown to be weak (Fig. 8a, Ref. 2), and the authors proposed an "approximate engineering formula" for selecting a length ratio value to fit the experimental results as follows:

$$\Delta x_w / \Delta x_p = 4.0/(\mathcal{R}^2 - \mathcal{R} + 0.6)$$

This expression indicates a wide variation with aspect ratio, and the authors point out that they have no reasonable physical explanation for the formula. The authors are reminded that, although empirical corrections can be useful, the correct theoretical result (subject to an assumed flow model) may not always match the "real flow" experimental values.

One reason for the differences between the subject theory and the corresponding experimental values is the particular selection of conditions ($\alpha = 20$ deg, $\mathcal{R} = 0.5$, 1.0, 2.0), as can be seen in Fig. 1. Adapted from the earlier work of Polhamus,[3] this figure illustrates experimentally determined boundaries of various vortex flow regimes as a function of aspect ratio and angle of attack and includes the three analysis points of Ref. 1. Near the boundaries, drastic changes in wing properties occur abruptly as the flow changes states. The low-aspect-ratio case of Ref. 1 falls very close to the vortex asymmetry boundary while the high-aspect-ratio case falls in the vortex breakdown regime as determined by Wentz and Kohlman.[4] However, the flow modeling in the subject method does not account for either of these effects.

As a consequence, the stated formula is strongly affected by the particular points of analysis chosen, and results in nothing more than a narrowly applicable curve fit where numerical sensitivities of the subject theory are inappropriately traded off against physical effects not modeled in that theory. Such an approach in general is to be avoided and would require a new empiricism for each new case. For example, at other angles of attack the stated curve fit would include inappropriate breakdown and asymmetry effects; even at $\alpha = 20$ deg, these effects will be overemphasized by this curve fit which essentially has only one point in or near each of the three flow regimes. A more appropriate approach in resolving this convergence problem would have been to conduct the analysis at conditions for which the theoretical modeling of the flow and the experimental "real flow" were not so disparate (i.e., well within the coherent vortex regime of Fig. 1) or, preferably, to compare the subject theory with well established theoretical methods. In any regard, this sensitivity appears to be a weak point of the subject approach which will require further analysis. (It should be noted that the cited reference for the experimental results is incorrect. The cited report only addresses $\mathcal{R} = 1.15$ delta wings; the more exhaustive planform study of Ref. 4 addresses delta wings of differing aspect ratios than the values indicated.)

A second questionable aspect of the subject computations involves the drag estimates. The authors present in Fig. 8b calculations of the induced drag normalized by the streamwise component of the normal force, $C_{D_i}/(C_L \tan \alpha)$, which range in value from 0.7 to 0.9 and show little dependence on the length parameters just discussed. Although they point out parenthetically that this value should be one, it must be emphasized that the value should be *identically* one, regardless of the number of panels or the type of panels used. This is a simple consequence of a sharp-edge flat plate at incidence with leading-edge separation supporting only normal forces. The values shown apparently indicate numerical error due to lack of convergence which result in nonnegligible and significantly erroneous axial forces.

Finally, a broader question regarding the general utility of the free vortex filament formulation for wing applications must be raised. Twenty years ago Polhamus introduced the concept of a leading-edge suction analogy for the estimation of force/moment properties on wings exhibiting separation induced leading-edge vortex flow.[5] By coupling this concept with a vortex lattice,[6] Lamar and his peers have advanced

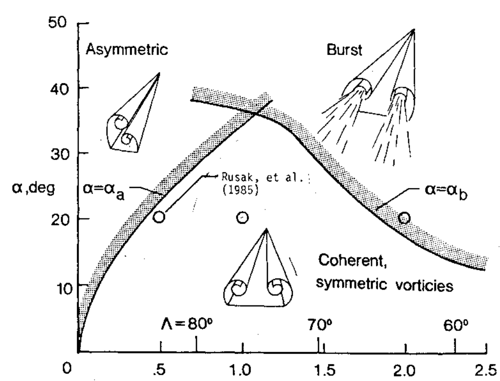

Fig. 1 Incompressible vortex flow regimes for sharp-edged delta wings.

Received Nov. 17, 1985; revision received Jan. 3, 1986.

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the method so that it is applicable for a very broad class of configurations.[7,8] This method is accurate, inexpensive, simple, and insensitive to paneling considerations.

In this context, it is difficult to understand the utility of the filament formulation. Rusak et al. indicate that roughly 170 "vortex panels" are required to solve the subject (nonlinear) problem for one angle of attack with the noted numerical sensitivities. Accurate results for a comparable case with the vortex-lattice/suction-analogy method require roughly 60 panels to solve the complete problem (which is now linear) for an entire angle-of-attack range; this solution includes the nonlinear vortex lift effects without requiring the free vortex to be explicitly modeled.

The authors also point out in Ref. 1 that local solution details, such as load distributions, have a strong dependence on numerical modeling even when the overall force/moment coefficients converge to the same value. In general, other filament methods[9,10] have also yielded less than satisfactory estimates of surface load distributions, in spite of continuing development efforts beyond the cited literature. As was recently pointed out by Hoeijmakers,[11] estimation of surface load distributions apparently requires higher order formulations, examples of which include the free vortex sheet method[12] or the NLR VORSEP method.[13]

Therefore, the filament formulation seems to be caught in an unfortunate state for wing applications; it is unduly complicated and too numerically sensitive to yield reasonable estimates of force/moment properties and is also insufficiently accurate to yield reasonable estimates of detailed load distributions. These limitations have persisted despite extensive development efforts by a variety of qualified researchers. Perhaps, future efforts could be more profitably focused at finding other problems for which the free-filament technology could more suitably be applied.

References

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Reply by Authors to J.M. Luckring

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THE authors of the subject paper[1] published an earlier paper[2] that described a combination of a so-called nonlinear vortex-lattice method (incorporating free vortex filaments to represent the leading-edge vortex separation), modeling all the lifting surfaces, and a linear source-panel method to represent the body. This method was shown to be a powerful tool for the evaluation of the nonlinear aerodynamic characteristics of complete aircraft and missile configurations that incorporate combinations of bodies and several lifting surfaces. Interactions of the bodies with the various lifting surfaces as well as the mutual interactions between the lifting surfaces themselves (canard-wing, wing-wing, wing-tail, etc.) and between their separated wakes were calculated with this method.

Working with their method, the authors have come across several of its numerical sensitivities and shortcomings and thought it was their duty to potential users to document them. This was done in Ref. 1. Luckring's Comment addresses two of these shortcomings and questions the utility of the whole formulation of the method.

One of the shortcomings documented in Ref. 1 and commented on by Luckring is the sensitivity of the lift coefficient to the ratio of the length scale of the wake vortices (Δx_W) to that of the wing vortices (Δx_p). In a later paper,[3] the authors demonstrated that this sensitivity was an inherent feature of the numerical formulation of the method. In Ref. 1 an approximate formula for the choice of the "best" value of the ratio ($\Delta x_W/\Delta x_p$) was also proposed for a delta wing of a given aspect ratio that would closely predict the experimental results for the same wing. In his Comment, Luckring correctly points out that this formula is nothing more than a narrowly applicable curve fit. It was proposed by the authors not as a major achievement but rather as an afterthought, to aid the future user of the method. There is, however, little doubt that for a fixed length-scale ratio the relation between the predicted lift coefficient and the experimentally determined value depends on the aspect ratio of the wing. For low aspect-ratio delta wings, the method tends to underpredict the lift coefficient and a high length-scale ratio seems to be best. For higher aspect-ratio delta wings, the method tends to overpredict the lift and a low length-scale ratio performs better. This is true also for angles of attack and aspect ratios other than those presented in Ref. 1.

From Luckring's second point, one has to conclude that the authors did not make their point sufficiently clear. Certainly a

Submitted Dec. 22,1985.

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