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Technical Comments

Brief discussion of previous investigations in the aerospace sciences and technical comments on papers published in the Journal of Aircraft *are presented in this special department. Entries must be restricted to a maximum of 1000 words, or the equivalent of one* Journal *page including formulas and figures. A discussion will be published as quickly as possible after receipt of the manuscript. Neither the AIAA nor its editors are responsible for the opinions expressed by the correspondents. Authors will be invited to reply promptly.*

Comment on "Navier–Stokes Computations of Limit-Cycle Oscillations for a B-1-Like Configuration"

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FIGURE 6 of Ref. 1 shows that the Navier–Stokes computations[1] predict the general experimental data trend[2] in regard to the measured rapid loss of damping when $\alpha = 8$ deg is approached. The discrepancy is the huge underestimation of the measured loss of damping, which would result in underpredicting the experimental limit-cycle amplitude[2] by one order of magnitude. According to Ref. 3, this would be the expected result when not considering the effect of the hugely different leading-edge radius on the inner, fixed wing glove and the outer wing with its variable leading-edge sweep. The larger leading-edge radius of the inner wing glove delays the start of the formation of a leading-edge vortex more than the lesser leading-edge radius of the outer wing.[4] This causes the leading-edge vortex formation to be similar to that for a double-delta wing, where the larger effective sweep angle of the inner wing causes its vortex formation to lag behind that of the effectively less swept outer wing. It is discussed at length in Ref. 3 how this interaction between inner and outer wing leading-edge vortices started to occur when $\alpha = 8$ deg was approached. The undamping effect of this vortex interaction was the result of the sensitivity of the spanwise location of the vortices not only to the streamwise angle of attack but also to the rate and direction of the angular change.

It should be of great interest to find out why the full Navier–Stokes equations were not able to predict the large effect that the difference in leading-edge radii had on the vortex generation of the inner, fixed and outer, moveable portions of the wing.

References

[1]Hartwich, P. M., Dobbs, S. K., Arslan, A. E., and Kim, S. K., "Navier–Stokes Computations of Limit-Cycle Oscillations for a B-1-Like Configuration," *Journal of Aircraft*, Vol. 38, No. 2, 2001, pp. 233–247.

[2]Dobbs, S. K., Miller, G. D., and Stevenson, J. R., "Self-Induced Oscillation Wind-Tunnel Test of Variable Sweep Wing," AIAA Paper 85-0739-CP, April 1985.

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Reply to Comment on "Navier–Stokes Computations of Limit-Cycle Oscillations for a B-1-Like Configuration"

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ERICSSON offers an intriguing interpretation of the limit-cycle oscillation (LCO) phenomenon observed for the B-1 aircraft at transonic maneuver. He contends that the oscillatory motion of the outer wing is strictly in response to an aerodynamic phenomenon. This aerodynamic phenomenon is described as the interaction of a fully formed leading-edge vortex on the outer wing panel with a nascent leading-edge vortex over the inner fixed-wing glove. This explanation implies that any aerodynamics/structures interaction the LCO phenomenon is of secondary if any relevance. This contention is different from the explanation of the B-1 LCO phenomenon as a fluids/structure interaction offered in the article in question.[1] Ericsson concludes his Comment with his expectation that future solutions to the full Navier–Stokes equations (as opposed to the thin-layer approximation employed in the referenced article) will be required to capture the vortex interaction he suspects to be the causative agent of the B-1 LCO.

The authors of the subject paper wish to respond as follows. Consider the computational flow visualization of surface and off-surface flow shown in Figs. 1 and 2 (also Figs. 1 and 2 in Ref. 1). These transonic ($M_\infty = 0.975$) solutions were computed for a simplified B-1 configuration at an angle of attack of 7.38 deg, with and without a static aeroelastic response, respectively. Neither solution indicates an impending formation of a leading-edge vortex over the inner wing glove. These flow-visualization images are considered representative for the 30 flow solutions computed for angles of attack between 7.38 and 9 deg in an attempt to pinpoint the LCO solution among a multitude of dynamic aeroelastic solutions for which the four leading structural modes were carried. As for the accuracy of

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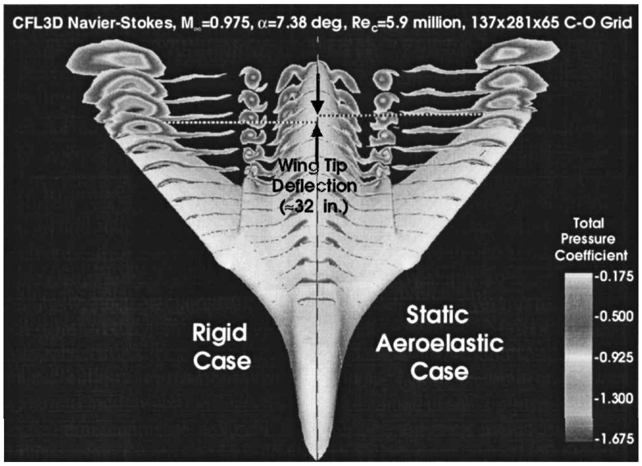

Fig. 1 Computed vortical flow over a B-1-like configuration with and without static aeroelastic structural response.

the depicted flow solutions, it is encouraging to see that the static tip deflection of the outer wing is captured in good agreement with flight-test data. Comparisons of measured (wind-tunnel) and computed surface pressure for the static aeroelastic cases agree well; for the dynamic cases it appears that the computations capture the phase angles better than their magnitudes.

The authors of Ref. 1 feel that improved numerical accuracy will better capture the fluid/structure interaction and will thus increase the magnitudes of the computed unsteady pressure, which, in turn, will lead to increased amplitudes in the structural response of the outer B-1 wing. In the absence of any improvements in temporal accuracy, one might expect to obtain better correlations with either flight or wind-tunnel data by repeating the presented computations with a much reduced time-step size. Although this would considerably increase the computational expenditure of such a fluid/structure modeling, the costs would still be far lower than those associated with the full Navier–Stokes solutions suggested by Ericsson.

Time-accurate solutions to the full Navier–Stokes equations are also quite challenging. For example, the computational grid would need to grow by one to two orders of magnitude from the roughly 2.5 million grid points used in the referenced article to adequately resolve the viscous terms in all coordinate directions. Grid adaptation approaches can be expected to reduce the associated prohibitive computational expenditure. Even the best of those grid adaptation methods are at too early a stage of their development to make such a formidable computational endeavor feasible in the foreseeable future.[2]

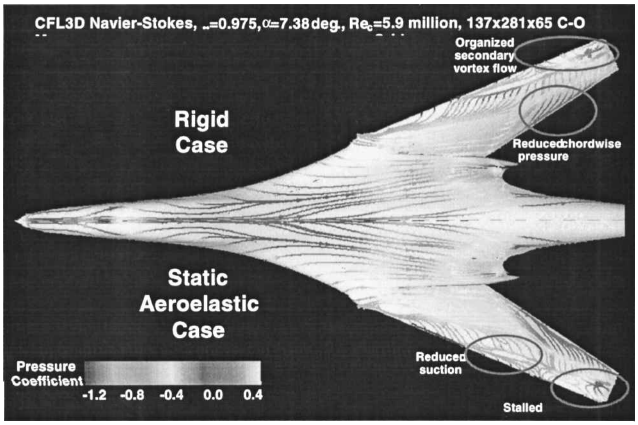

Fig. 2 Computed surface flow over a B-1-like configuration with and without static aeroelastic structural response.

For the sake of the argument, let us assume that time-accurate solutions to the full Navier–Stokes equations of second-order spatial and temporal accuracy were feasible. Whatever the results of such solutions, they are liable to be still considered inconclusive. Other comments (Spalart, P. R., private communication Long Beach, CA, June 2001) received on Ref. 1 suggested that the turbulence model is suspected to be inadequate and thus to obfuscate the true vortex/structure interaction. For instance, it has been suggested to supplant the Baldwin–Lomax turbulence model in Ref. 1, with modifications suggested by Degani and Schiff for vortical flows, with an improved version of the Spalart–Allmaras[3] turbulence model. If improvements of the B-1 LCO results are sought in the near term and at an acceptable computational cost, a repetition of such simulations with alternate and/or improved turbulence models appears to be more viable than solutions to the full Navier–Stokes equations with a potentially still inadequate turbulence model.

References

[1] Hartwich, P. M., Dobbs, S. K., Arslan, A. E., and Kim, S. C., "Navier–Stokes Computations of Limit Cycle Oscillations for a B-1-Like Configuration," *Journal of Aircraft*, Vol. 38, No. 2, 2001, pp. 239–247.

[2] Pirzadeh, S. Z., "An Adaptive Unstructured Grid Method by Grid Subdivision, Local Remeshing, and Grid Movement," AIAA Paper 99-3255, Nov. 1999.

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