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PRACTICAL AERODYNAMIC DESIGN OPTIMIZATION BASED ON THE NAVIER-STOKES EQUATIONS AND A DISCRETE ADJOINT METHOD

Final Report

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The subject grant NCC–1–279 from NASA Langley Research Center began on 12/5/97 and end on 1/31/99. The technical grant monitor was W. Kyle Anderson of NASA Langley. The principal investigator was Dr. Bernard Grossman and the work was carried out at Virginia Tech and NASA Langley by Eric J. Nielsen, while pursuing his Ph. D. degree at Virginia Tech. Work related to the grant is listed in References 1–3. The technical details are summarized below:

Compressible and incompressible versions of a three-dimensional unstructured mesh Reynolds-averaged Navier-Stokes flow solver have been differentiated and resulting derivatives have been verified by comparisons with finite differences and a complex-variable approach. In this implementation, the turbulence model is fully coupled with the flow equations in order to achieve this consistency. The accuracy demonstrated in the current work represents the first time that such an approach has been successfully implemented.

The accuracy of a number of simplifying approximations to the linearizations of the residual have been examined. A first-order approximation to the dependent variables in both the adjoint and design equations has been investigated. The effects of a "frozen" eddy viscosity and the ramifications of neglecting some mesh sensitivity terms were also examined. It has been found that none of the approximations yielded derivatives of acceptable accuracy and were often of incorrect sign. However, numerical experiments indicate that an incomplete convergence of the adjoint system often yield sufficiently accurate derivatives, thereby significantly lowering the time required for computing sensitivity information.

The convergence rate of the adjoint solver relative to the flow solver has been examined. Inviscid adjoint solutions typically require one to four times the cost of a flow solution, while for turbulent adjoint computations, this ratio can reach as high as eight to ten. Numerical experiments have shown that the adjoint solver can stall before converging the solution to machine accuracy, particularly for viscous cases. A possible remedy for this phenomenon would be to include the complete higher-order linearization in the preconditioning step, or to employ a simple form of mesh sequencing to obtain better approximations to the solution through the use of coarser meshes.

An efficient surface parmeterization based on a free-form deformation technique has been utilized and the resulting codes have been integrated with an optimization package. Lastly, sample optimizations have been shown for inviscid and turbulent flow over an ONERA M6 wing. Drag reductions have been demonstrated by reducing shock strengths across the span of the wing.

In order for large scale optimization to become routine, the benefits of parallel architectures should be exploited. Although the flow solver has been parallelized using compiler directives. The parallel efficiency is under 50 percent. Clearly, parallel versions of the codes will have an immediate impact on the ability to design realistic configurations on fine meshes, and this effort is currently underway.

Further development of mesh movement strategies which enable large changes in the geometry are needed. Finally, another area that requires future work is the incorporation of multipoint optimization capability for designing geometries that perform well at off-design conditions.

References

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2. Eric J. Nielsen and W. Kyle Anderson, "Aerodynamic Design Optimization on Unstructured Meshes Using the Navier-Stokes Equations", AIAA 98-4809, September, 1998.
3. E. J. Nielsen, "Aerodynamic Design Sensitivities on an Unstructured Mesh Using the Navier-Stokes Equations and a Discrete Adjoint Formulation", PhD. Dissertation, Virginia Polytechnic Institute and State University, December, 1998.