Integrated Multidisciplinary Design Optimization Using Discrete Sensitivity Analysis for Geometrically Complex Aeroelastic Configurations

by

James C. Newman, III

Dr. Richard W. Barnwell, Chairman

Mechanical Engineering

(ABSTRACT)

The first two steps in the development of an integrated multidisciplinary design optimization procedure capable of analyzing the nonlinear fluid flow about geometrically complex aeroelastic configurations have been accomplished in the present work. For the first step, a three-dimensional unstructured grid approach to aerodynamic shape sensitivity analysis and design optimization has been developed. The advantage of unstructured grids, when compared with a structured-grid approach, is their inherent ability to discretize irregularly shaped domains with greater efficiency and less effort. Hence, this approach is ideally suited for geometrically complex configurations of practical interest. In this work the time-dependent, nonlinear Euler equations are solved using an upwind, cell-centered, finite-volume scheme. The discrete, linearized systems which result from this scheme are solved iteratively by a preconditioned conjugate-gradient-like algorithm known as GMRES for the two-dimensional cases and a Gauss-Seidel algorithm for the three-dimensional; at steady-state, similar procedures are used to solve the accompanying linear aerodynamic sensitivity equations in incremental iterative form. As shown, this particular form of the sensitivity equation makes large-scale gradient-based aerodynamic optimization possible by taking advantage of memory efficient methods to construct exact Jacobian matrix-vector products. Various surface parameterization techniques have been employed in the current

study to control the shape of the design surface. Once this surface has been deformed, the interior volume of the unstructured grid is adapted by considering the mesh as a system of interconnected tension springs. Grid sensitivities are obtained by differentiating the surface parameterization and the grid adaptation algorithms with ADIFOR, an advanced automatic-differentiation software tool. To demonstrate the ability of this procedure to analyze and design complex configurations of practical interest, the sensitivity analysis and shape optimization has been performed for several two- and three-dimensional cases. In two-dimensions, an initially symmetric NACA-0012 airfoil and a high-lift multielement airfoil were examined. For the three-dimensional configurations, an initially rectangular wing with uniform NACA-0012 cross-sections was optimized; in addition, a complete Boeing 747-200 aircraft was studied. Furthermore, the current study also examines the effect of inconsistency in the order of spatial accuracy between the nonlinear fluid and linear shape sensitivity equations.

The second step was to develop a computationally efficient, high-fidelity, integrated static aeroelastic analysis procedure. To accomplish this, a structural analysis code was coupled with the aforementioned unstructured grid aerodynamic analysis solver. The use of an unstructured grid scheme for the aerodynamic analysis enhances the interaction compatibility with the wing structure. The structural analysis utilizes finite elements to model the wing so that accurate structural deflections may be obtained. In the current work, parameters have been introduced to control the interaction of the computational fluid dynamics and structural analyses; these control parameters permit extremely efficient static aeroelastic computations. To demonstrate and evaluate this procedure, static aeroelastic analysis results for a flexible wing in low subsonic, high subsonic (subcritical), transonic (supercritical), and supersonic flow conditions are presented.