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Shape Optimization of Single- and Two-Element Airfoils on Multiblock Grids

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A multiblock, discrete sensitivity analysis method is used to couple a direct optimization and a flow analysis methods. The domain is divided into smaller subdomains for which the sensitivities are obtained separately. Then, an effective sensitivity equation is solved to complete the coupling of all the sensitivity information. The flow analysis is based on the thin-layer Navier-Stokes equations solved by an implicit, upwind-biased, finite-volume method. The method of feasible directions is used for the present gradient-based optimization approach. First, a transonic airfoil is optimized to investigate the behavior of the method in highly nonlinear flows as well as the effect of different blocking strategies on the procedure. A supercritical airfoil is produced from an initially symmetric airfoil with multiblocking affecting the path but not the final shape. Secondly, a two-element airfoil is shape optimized in subsonic flow to demonstrate the present method's capability of shaping aerodynamically interfering elements simultaneously. For a very low and a very high Reynolds number cases, the shape of the main airfoil and the flap are optimized to yield improved lift-to-drag ratios.

Introduction

Recently, a scheme was developed to perform discrete sensitivity analysis on decomposed computational domains (SADD).[1,2] This scheme was motivated by the need to address the computer memory issues in the direct inversion of the sensitivity equation's coefficient matrix, which becomes particularly large. Another benefit was its applicability to problems involving complex and multicomponent geometries, around which structured grids can only be generated by the use of domain decomposition techniques. The impetus for the present paper is to to couple a direct optimization and a flow analysis methods via SADD scheme, study some relevant issues, and test it through applications. One area of its potential applications is the design of high lift devices.

High lift devices, such as flaps and slats, have been used for many years to improve take-off and landing performances. Effective design of such devices currently relies on extensive wind tunnel tests. Among many reasons responsible for this reliance has been the lack of computational tools to assist the aerodynamicist in the prediction of mechanical high-lift device performance and their sensitivities to the shape perturbations. Earlier and some current design methods for multielement airfoils based on the potential flow theory have the desired characterisitic of being computationally inexpensive (e.g. Refs. 3 and 4). However, there is a need to develop more accurate yet efficient direct optimization methods to design multielement airfoils.

Direct optimization techniques have traditionally relied on finite-difference approximations of the sensitivity coefficients, which are prone to inaccuracies and quickly become expensive to compute. A poor selection of the design variable increments used in the finite-differencing may lead to inaccurate sensitivities. Another drawback is the computational cost necessitated by the repeated flowfield analyses of which at least *NDV+1* are required when using a basic one-sided finite-difference technique, where *NDV* is the number of design variables. An alternate approach to computing sensitivity coefficients is the quasi-analytical discrete sensitivity analysis.

In 1990, an aerodynamic sensitivity analysis method[5] was presented for the compressible Euler equations. This method was then applied to the design of a scramjet-afterbody configuration for an optimized axial thrust.[6] The scramjet-afterbody was again used to validate an extension of the method to the third-order accurate discretization of the Euler equations.[7] Viscous effects were later accounted for by including the sensitivities of the Navier-Stokes equations and used in optimizing a transonic airfoil.[8] Then, the issue of computational efficiency was addressed[1] by examining the solution of the sensitivity equation using a conjugate-gradient like method, known as generalized minimum residual (GMRES) method, as compared to a direct solution method. In addition, the investigation was turned to the development of the multiblock sensitivity analysis scheme SADD,[1,2] to improve the efficiency. The SADD scheme was later extended to three dimensions, where GMRES was also incorporated[9] and applied in the optimization of a nacelle near a wing.[10]

Therefore, this paper is aimed at demonstrating the following by shape optimizing a single airfoil and a two-element airfoil: (i) the aerodynamic shape optimization methodology on a multiblock domain, (ii) multiblock capability in optimizing a highly nonlinear flowfield, (iii) the simultaneous reshaping of interfering elements. For brevity, however, some details are not included herein but can be found in Ref. 11.

Constrained Shape Optimization

Aerodynamic shape optimization requires some means of systematically modifying the geometry of an aerodynamic body in the search for an optimum design. This is achieved by changing the *design variables*. There must be a direct relationship between the design variables and the surface geometry of the body in what is called the *surface representation* of the body. These design variables are incrementally changed during the optimization process which

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