SENSITIVITY ANALYSIS AND DESIGN OPTIMIZATION OF AEROELASTIC STRUCTURES UNDERGOING LARGE DISPLACEMENTS

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Ever increasing requirements on weight and aerodynamic performance result in more and more flexible aircraft structures undergoing large displacements. This tendency is reflected, for example, in solar planes such as *Pathfinder* or in competition gliders. For the analysis and design of such aircraft, the interaction of the geometrically nonlinear response and the aerodynamic flow needs to be taken into account. While in recent years research on aeroelastic design optimization has focused on linear structural models [1], little work has been done accounting for geometrically nonlinear structural response [2]. The overall objective of this study is to develop a simulation-based design optimization tool for aeroelastic systems undergoing large displacements. This tool will be used to study in the influence of geometrically nonlinear effects on the aeroelastic response and on the optimum design. We propose an computational framework which is based on a three-field formulation of the quasi-static aeroelastic problem. A staggered algorithm is used to solve both the aeroelastic steady-state equations and the sensitivity equations. The flow is approximated by a three-dimensional finite volume discretization of the Euler or Navier-Stokes equations. The geometrically nonlinear structural response is modeled by a co-rotational finite element formulation. A third field describes the motion of fluid mesh as the deformations of a pseudo-structure.

The staggered algorithm for solving the aeroelastic steady-state equations follows a Newton scheme leading to the following linearized system (1) with S being the structural residual, D the residual of the mesh motion equations, and F the flow residual:

$$\begin{pmatrix} \frac{\partial S}{\partial u} & \frac{\partial S}{\partial x} & \frac{\partial S}{\partial w} \\ \frac{\partial D}{\partial u} & \frac{\partial D}{\partial x} & 0 \\ 0 & \frac{\partial F}{\partial x} & \frac{\partial F}{\partial w} \end{pmatrix} \begin{pmatrix} \Delta u \\ \Delta x \\ \Delta w \end{pmatrix} = - \begin{pmatrix} S \\ D \\ F \end{pmatrix} \quad (1) \qquad \begin{pmatrix} \frac{\partial S}{\partial u} & \frac{\partial S}{\partial x} & \frac{\partial S}{\partial w} \\ \frac{\partial D}{\partial u} & \frac{\partial D}{\partial x} & 0 \\ 0 & \frac{\partial F}{\partial x} & \frac{\partial F}{\partial w} \end{pmatrix} \begin{pmatrix} \frac{du}{ds} \\ \frac{dx}{ds} \\ \frac{dw}{ds} \end{pmatrix} = - \begin{pmatrix} \frac{\partial S}{\partial s} \\ \frac{\partial D}{\partial s} \\ \frac{\partial F}{\partial s} \end{pmatrix} \quad (2)$$

where u, x and w are respectively the structural displacement vector, the motion of the nodes of the fluid mesh, and the fluid state vector. A similar linear system (2) with the same aeroelastic Jacobian is obtained when solving for the sensitivities of the aeroelastic response $(du/ds, dx/ds, dw/ds)^T$ with respect to a design parameter s. The computational effort for solving the above linear systems is of crucial importance for the overall cost of the aeroelastic analysis and, eventually, aeroelastic optimization procedure. So far, quasi-Newton schemes have been applied frequently to solve analysis problem (1), neglecting the off diagonal terms of the aeroelastic Jacobian, while consistent Newton schemes are typically used to solve the sensitivity equations (2). In this study, we will propose alternative Newton and quasi-Newton approaches for solving equations (1) and (2), and compare their computational efficiency in the context of nonlinear structures.

References

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