A hybrid adjoint shape sensitivity analysis of fluid-structure interaction problems

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Large scale shape optimization involving the solution of an adjoint system of equations is an active area of research in computational fluid and structural dynamics, particularly for aerospace applications. In this regard, it is vital to have at hand a sensitivity analysis approach which shows stability, efficiency and accuracy. This contribution addresses a hybrid adjoint shape sensitivity analysis for fluid-structure interaction (FSI) problems which benefits from the continuous adjoint method for the fluid and the discrete adjoint method for the structure. The incompressible fluid flow is modeled using the Reynolds-averaged Navier-Stokes equations. For the structure, large displacements are considered due to the interaction with the fluid domain, resulting in geometrically nonlinear structural behavior and nonlinear interface coupling conditions. In the proposed coupled sensitivity analysis, two core ideas are introduced: 1) using a strictly continuous adjoint approach to derive adjoint boundary conditions for the FSI boundary, 2) formulating a force-type objective function over the far-field boundary which does not undergo any shape change.

Our formulation eliminates the need of expensive computation of partial derivatives such as the coupling terms in the coupled adjoint analysis. Instead it requires only to exchange boundary information like in the primal FSI solution and hence easily integrates into a partitioned co-simulation environment. Furthermore, the boundary conditions for a continuous adjoint fluid simulation using a far-field force objective have been derived and compared to a regular near field approach. It has been shown that both yield the same gradient information. Last but not least, the accuracy of the proposed coupled sensitivity analysis is verified through comparison of results with those obtained using a finite difference technique.

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