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An Immersed Boundary Approach for Sensitivity Analysis of Fluid-structure Interactions

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Abstract

Gradient-based optimization algorithms are highly advantageous for computer intensive simulations such as fluidstructure interaction (FSI) problems. Typical simulation involves solution of the Navier-Stokes equations and their response sensitivities. Due to the use of body conformal meshes, mesh topology modification is required in structural shape optimization; however, this can be time consuming for complex structural boundaries. In this research, we introduce a method based on adding force terms to the Navier-Stokes equations to decouple the solid boundary definition from the mesh. Therefore, the governing equations can be solved on a Cartesian grid with efficient solvers. Decoupling the solid boundary from the mesh enables us to deform the solid domain without mesh modification allowing a significant reduction in computational costs. To calculate the sensitivity response of the system, the continuum sensitivity method is developed. Force terms are used to represent the solid boundaries and convective terms are removed in boundary conditions sensitivity equations because the boundaries do not depend on domain configuration. The methodology is verified using the sensitivity of laminar flow over a Joukowsky airfoil with respect to change in camber radius. The force terms are applied using the regularized Heaviside function to satisfy the no-slip condition in the solid domain.

Keywords: fluid-solid interaction; sensitivity analysis; immersed boundary method.