GRADIENT BASED SHAPE OPTIMIZATION OF STRONGLY COUPLED FLUID-STRUCTURE INTERACTION PROBLEMS

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In this paper gradient based shape design optimization of strongly coupled fluid-structure interaction (FSI) problems between a viscous, incompressible fluid and an elastic solid undergoing large displacement is investigated. This topic has received much interest in recent years, see, e.g., [1,2], and the authors have previously demonstrated in [3], that gradient based approaches can be applied efficiently for FSI problems involving low Reynolds number flows using the $k-\omega$ two-equation turbulence model. It is the aim of this work to extend the methodology to FSI problems involving high Reynolds number flows, which has not been covered before in the literature.

The viscous incompressible turbulent flow is described using the Reynolds-Averaged Navier–Stokes equations (RANS) together with algebraic or one- and two-equation turbulence models. The turbulence models used will include both the algebraic Baldwin-Lomax turbulence model, the Spalart-Allmaras one-equation model and two-equation models such as the Wilcox 1988 and 1998 $k-\omega$ turbulence models and the shear stress transport (SST) $k-\omega$ turbulence model, see [4]. Both the Spalart-Allmaras model and the SST model have demonstrated their success in high Reynolds number flows in aerodynamics. The solution for state of the 2D/3D stationary fluid-structure interaction problem is obtained using both Galerkin, Streamline-Upwind/Petrov-Galerkin and Pressure-Stabilized/Petrov-Galerkin FEM, and due to the large displacements allowed, the finite element mesh of the fluid domain has to be updated as part of the solution algorithm. The mesh is updated by solving an auxiliary elastic problem for the fluid mesh, considering the fluid as a linear elastic solid and imposing the calculated solid displacements found from the coupled problem as nodal displacements. The resulting nonlinear equations are solved using Quasi Newton methods and design sensitivity analysis is performed using the direct differentiation approach. The use of an inexact Jacobian matrix in the analysis leads to an iterative but very efficient scheme for sensitivity analysis [5,1,3] which is further improved by using inverse update methods for the approximate Jacobian.

Several 2D and 3D gradient based shape optimization examples will illustrate the potential of the proposed methods for FSI problems involving flexible structures and high Reynolds number flows.

References

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