Implementation of Immersed Finite Element Method for Fluid-Structure Interaction Applications

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Abstract

Introduction - Fluid-structure interaction (FSI) refers to a class of problems in which the motions of fluid and solid are coupled. FSI is of great significance in many applications such as aero-elasticity, biomechanics, and design of various engineering systems. Typically, the multiphysics involved in the FSI problems render them too complex to solve analytically, necessitating the use of numerical simulations to analyze such problems. Since the fluid and structure motion are generally analyzed in different frameworks (Eulerian and Lagrangian respectively), the typical method to analyze FSI problems is the Arbitrary Lagrangian-Eulerian (ALE) method. However, the success of ALE method frequently depends on the choice of the mesh motion technique adopted, making it practically untenable for cases where the structure has very large displacements. In this work, we present the implementation of an immersed finite element method (IFEM) [1], which is based on the use of two independent discretizations for the fluid and the structure, in COMSOL Multiphysics® software. In IFEM, the equations of the motion of the fluid are extended to cover the union of the fluid and the solid domains, such that a body force field informs the fluid of the presence of the immersed solid, thereby circumventing the need for any re-meshing.

Use of COMSOL Multiphysics - Since the IFEM uses separate discretizations for fluid and the structure; the implementation of IFEM in COMSOL software requires use of two separate Components. Specifically, the first Component models the equations of motion for fluid over the extended solution domain (i.e. the union of fluid and solid domain), while the second Component models the equations of motion for the structure defined over the reference domain of the structure. The exchange of information between the two Components is achieved by using a General Extrusion mapping. We use an implicit method for time-discretization (Backward Difference Formula), while updating the Jacobian of the system at each time step.

Results - We will present the IFEM formulation for a Neo-Hookean solid with focus on the procedure of its implementation in COMSOL Multiphysics. We will also present various benchmark cases, including the lid-driven cavity test and the Turek-Hron benchmark cases. The simulation video showing the immobility of the mesh over the solid domain while the structure deforms will also be presented.

Conclusion - In conclusion, we present the COMSOL model implementation of the IFEM

scheme for handling immersed structures with large displacements in FSI problems. The implementation involves use of two separate Components, which exchange information via a General Extrusion map. We also present our results for the standard benchmark cases: namely the lid-driven cavity test and the Turek-Hron benchmark case. We believe that with suitable optimizations our implementation can be offered as a stand-alone COMSOL model by employing the Physics Builder.

Reference

1. L. Heltai and F. Costanzo, Variational implementation of immersed finite element methods, Computer Methods in Applied Mechanics and Engineering 229 (2012): 110-127.