ME – PhD Thesis Defence

ALE-based Monolithic Finite Element Strategies for Fluid Structure Interaction Problems.

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ABSTRACT

`Fluid-structure interactions' (FSI) represent a class of engineering problems which involve a two-way coupling between the solid motion and the fluid flow. The non-linearity in the equations of fluid mechanics and large deformation structural mechanics along with the requirement to satisfy the interface conditions between solid and fluid makes it almost impossible for this class of problems to be dealt with analytically. However, with the emergence of computers, there have been significant advances in this class of problems numerically.

In this work we present new monolithic finite element strategies for solving various classes of fluid-structure interaction problems. The term `monolithic' means that the governing equations of the solid and fluid along with the interface and boundary conditions are solved simultaneously. The developed strategies are based on the Arbitrary Lagrangian-Eulerian (ALE) formulation for the fluid domain, and the Lagrangian framework for the solid domain.

First, we develop a new monolithic FEM formulation for problems involving a compressible fluid and a hyperelastic structure fully coupled with the thermal field. We develop an `energy-momentum conserving' time-stepping strategy, i.e., in the Lagrangian limit, the time-stepping strategy that we propose conserve the total energy, and the linear and angular momenta. We use a displacement-based Lagrangian formulation for the structure, and a velocity-based ALE mixed formulation with appropriately chosen interpolations for the various field variables to ensure stability of the resulting numerical procedure. Apart from physical variables such as displacement, velocity, etc., no new variables are introduced in the formulation.

Next, we present a two-dimensional monolithic FEM-based strategy for FSI problems involving partly immersed (floating) hyperelastic solids in an incompressible fluid. This strategy can be used for studying the dynamics of freely floating bodies as well as the accurate computation of hydrodynamic forces acting on them. Since the portion of the solid immersed in the fluid varies with time, one cannot use the same nodes for the solid and the fluid at the interface. The continuity requirements at the fluid-structure interface have been satisfied in a weak sense using the mortar method. The flexibility of the ALE technique permits us to treat the free surface of the fluid as a Lagrangian entity where the mesh velocity and material velocity are equal. This allows us to model the interface as a *contact* between the solid and fluid surfaces. The same strategy can be used to analyse sloshing in containers with curved or deformable walls.

Finally, motivated by micro-electro-mechanical systems (MEMS), we present a monolithic FEM-based strategy for problems involving the deformation of a hyperelastic solid and an (incompressible or compressible) fluid in the presence of an electrostatic field. The equations of electrostatics are solved on the reference configuration over both the solid and fluid domains, with voltage and electric displacement continuity imposed at the interface. The fluid is assumed to be a non-conductor of electricity so that there is no flow of charge through the fluid.

In all the formulations developed above, a hybrid formulation is used to prevent locking of thin structures. Also, in every formulation, we carry out a consistent linearization resulting in exact tangent stiffness matrices which ensure that the concerned algorithm converges quadratically within each time step. Several benchmark examples have been presented to illustrate the good performance of the proposed strategies.

ABOUT THE SPEAKER

Suman Dutta is a PhD student in the Department of Mechanical Engineering, IISc Bangalore. He is working with Prof. C. S. Jog in Faculty of Research in Technical Acoustics (FRITA) lab. He completed B.E. from Jadavpur University, Kolkata in 2016. His research interests are in fluid-structure interaction problems.