The accurate and efficient numerical simulation of general fluid-structure interaction - A Unified Finite Element Method

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The accurate and efficient numerical simulation of general fluid-structure interactions (FSI) is a significant computational challenge because of the strong nonlinearities associated with the fluid flow, the structural deformation (in the case of large displacements) and, crucially, with the coupling/interaction between the two. The current gold standard for robust and accurate simulation of such problems is to use a monolithic method that strongly couples the fluid and solid models and discretizes them into a single nonlinear system at each time step (involving fluid velocity and pressure, elastic displacements and Lagrange multipliers to enforce consistency at the interface (which must either be tracked or recovered)). Such schemes are exceedingly computationally expensive however, and require sophisticated numerical schemes to ensure convergence of the nonlinear solver at each time step.

In this talk,we present a new finite element method for simulation of FSI which has the same generality and robustness of monolithic methods (and is therefore able to model a range of solid materials from very soft to very hard, for example) but is semi-explicit and therefore significantly more computationally efficient and easier to implement. Our proposed approach has similarities with classical immersed finite element methods (IFEMs), by approximating a single velocity field in the entire domain (i.e. occupied by fluid and solid) on a single mesh, but differs by treating the corrections due to the solid deformation on the left-hand side of the modified fluid flow equations (i.e. implicitly).

In addition to motivating the derivation of our numerical scheme, we will provide a description of its implementation within an adaptive finite element code and a wide range of computational examples will be presented in order to validate the method across a wide range of flows, solids and interactions.