Adaptive Finite Elements for Fluid-Structure Interaction in ALE, Fully Eulerian, and EALE Coordinates

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We investigate novel formulations for fluid-structure interaction problems and compare them to the arbitrary Lagrangian-Eulerian (ALE) framework. The well-established ALE approach provides a simple procedure to couple fluid equations with structural deformations. In such a setting, the fluid equations are transformed to a fixed reference domain. However, the moving mesh becomes the critical part for large structural deformations or contact with walls or other structures. To overcome this deficiency, we present the novel fully Eulerian approach. The idea is the opposite way to the ALE method. The fluid equations are kept in their natural coordinates and the structure is transformed into the Eulerian framework. However, the interface is allowed to intersect mesh cells, which is the major challenge of this method. Finally, as third technique, the fully Eulerian approach is coupled with the ALE method (EALE). This gives us the possibility to set up elastic structure deformations in different coordinate systems, which is interesting for hemodynamic applications. Each problem is formulated in a monolithic fashion that allows to compute sensitivities for a posteriori error estimation and gradient-based optimization, where examples are provided. Time discretization is based on finite difference schemes whereas the spatial discretization is done with a Galerkin finite element scheme. The nonlinear problem is solved with Newton's method. The performance of our developments is demonstrated with the help of numerical tests.