Advances in Arbitrary Lagrangian/Eulerian techniques for analysis of flows in flexible channels with the FEM

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ABSTRACT

Partitioned fluid-structure interaction (FSI) approaches have been often preferred over their monolithic counterparts due to the considerably higher computational cost of the latter ones, in spite of their robustness. This was attributed, among other, to the poor conditioning of the linearized system describing the coupled problem. Nevertheless, recent advances in the development of powerful linear solvers prove that the this issue is less crucial now.

Another challenge in defining a monolithic FSI approach originates from the difference in the kinematic variables used for describing the fluid and the solid: velocity and displacement, respectively. To ensure that the nodes where fluid and the solid are encountered in contact, in the past the so-called “unified Lagrangian approaches” were proposed. They relied on either adopting velocity-based solid model (thus, fitting arbitrary velocity based fluid) [1] or describing the fluid in terms of incremental displacements [2]. Being Lagrangian, these were mainly advantageous for FSI involving free surface flows, but not well-suited for channel flows.

In the present work possibilities of using monolithic models for flows in flexible channels are explored. The ides is to treat the fluid-solid interaction problem using a single Arbitrary Lagrangian/Eulerian (ALE) framework, where the sub-domains (fluid and solid) differ in terms of mesh-moving strategy following the ideas of [3]. The overall ALE setting allows treating the solid in a Lagrangian way, while modeling the major portion of the fluid in the Eulerian way. The fluid elements that "join" the Eulerian fluid and the Lagrangian solid can be naturally described using a true ALE formulation.

In terms of the kinematic variables, two approaches to the FSI problem are considered here. The first one relies on a unified velocity-based formulation in the fluid and the solid domains, where these sub-domains are distinguished via the constitutive equation only. Moreover, the variable heterogeneity of the monolithic system is thus reduced. Second approach relies on introducing a mixed-kinematic ALE element for the layer of fluid elements adjacent to the solid. “Mixed-kinematic” refers to possessing both the nodes characterized by displacement degree of freedom (nodes in contact with solid) and the velocity degree of freedom (nodes in contact with the rest of the fluid). In either approach, due to using a single kinematic variable at the nodes where the fluid and the solid are in contact, no additional FSI interface equations are needed.

The model is particularly advantageous for the simulation of bio-mechanics problems involving blood flow in arteries where the artery deformation is not negligible [4].

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