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A VARIATIONAL APPROACH FOR FLUID–SOLID INTERACTION PROBLEMS USING IMMERSED DOMAINS

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ABSTRACT

In the present work a model to tackle the fluid–solid interaction problem employing the concepts of immersed domains is derived from a well–known governing variational principle from the continuum mechanics. The goal of this work is to present a general formulation in which an augmented fluid, composed by the real fluid and a fictitious fluid that overlaps with the solid domain, interacts with an immersed solid. The formulation is general and is very close from the immersed finite element method [3,4,9] and from the immersed continuous method [8] due to the appearance of a volume force defined over the fictitious fluid domain. One of the major differences is that in the present work the volume force in the fluid domain emerges as a reactive force due to the imposition of the continuity in the velocity field along the whole overlapped domain by means of a Lagrange multiplier. Another difference lies in the manipulation of the mass conservation for the artificial fluid. In this respect, we generalize the problem eliminating the restriction to compressible fluid–compressible solid of the immersed continuous method and the incompressible fluid–incompressible solid of the immersed finite element method.

In last decades, numerous works have been oriented to the development of techniques to deal with the fluid–structure interaction problem. In particular, in the last ten years new formulations arose that allowed to accommodate quite complex situations [2,4,5,7]. With a different standpoint, Peskin's work on the immersed boundary method (IBM) [6] became a basic reference for techniques in order to face the problem using the ideas of immersion of domains. In subsequent years the fictitious domain method (FDM) [1,2] was presented that formulates the problem using distributed Lagrange multipliers along the corresponding boundaries. Posteriorly, other generalizations of the FDM appeared, such as the immersed finite element method (IFEM) that may be viewed as a generalized class of fictitious domain methods for fluid mechanics in which the immersed domain, in this case a solid, is subjected to deformations and displacements. It must be remarked that in the IFEM approach no Lagrange multipliers are used. Furthermore, no longer is the IFEM formulation valid when the fluid is incompressible and the solid compressible. In a recent work, the immersed continuous method (ICM) was stated as a special case that remains valid only for the compressible fluid–compressible solid interaction problem.

In the present approach, the Euler–Lagrange equations of the system are straightforwardly reached as result of relaxing the continuity of the velocity field in the whole fictitious fluid domain by means of a Lagrange multiplier. Thence, the continuity of velocities and tractions at the fluid–solid coupling interface can be attained, showing the equivalence between this and the classical formulation by means of consistency arguments. Here we propose a fictitious domain method for the fluid–solid interaction problem in which the fictitious fluid has similar compressibility properties as the structure under consideration in order to conciliate the arbitrariness in the compressible character of both elements. Finally, a numerical approximation of the problem restricted to fluid–rigid solid interactions is carried out and several examples are presented, as the one shown in figure 1 to show the capabilities of the formulation for this situation. In this situation we study the interaction of a rigid valve with a transient flow.

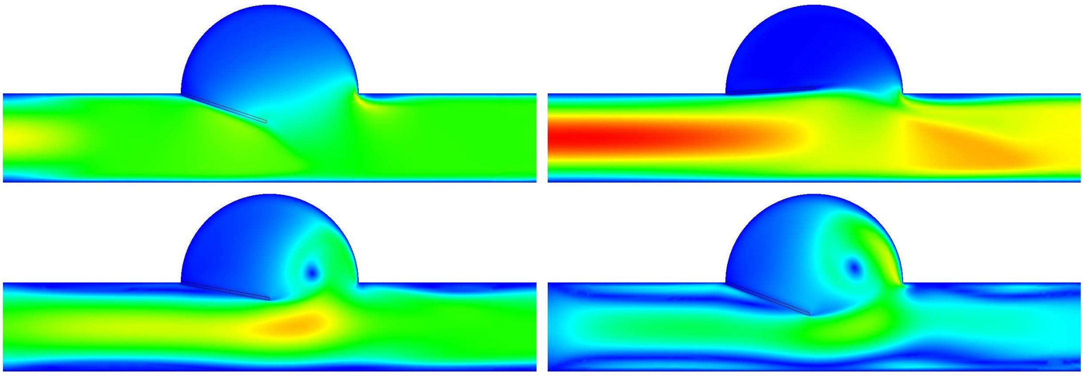

Figure 1: Time evolution of the fluid–valve interaction problem.

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