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A staggered fully explicit lagrangian Finite Element Method for Fluid-Structure-Interaction problems

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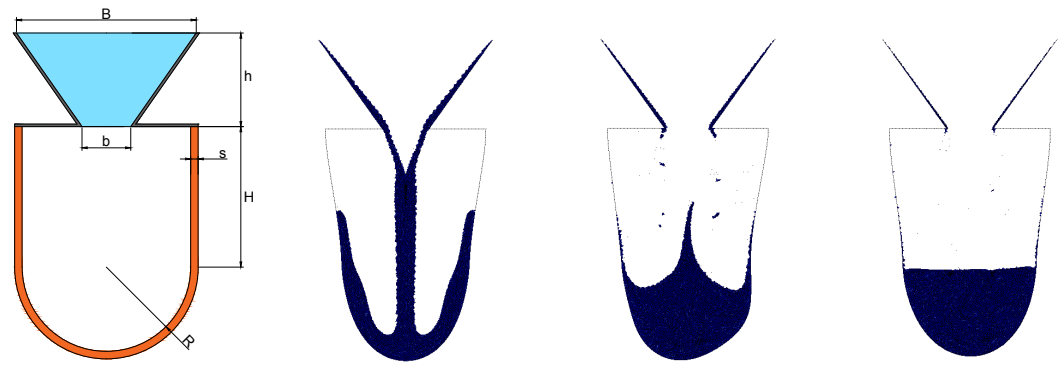
ABSTRACT

The efficient numerical simulation of Fluid Structure Interaction (FSI) problems is a topic of great relevance because of the wide range of applications in many engineering fields. Several approaches have been presented in the literature to address these problems. A possible strategy is to include the fluid and the structure subdomains in a unified model to be solved monolithically. Another strategy is the staggered (or partitioned) approach, where the two subdomains are solved independently and then coupled exchanging data through common interfaces. Moreover, different formulations depend on the kinematic description of the two material subdomains. In general, on the fluid side the Eulerian description is preferred to avoid mesh distorsion, but it requires surface tracking algorithms to identify the evolving boundaries.

Here we present a staggered and fully lagrangian approach for FSI problems. The fluid subdomain is modelled through the Particle Finite Element Method (PFEM) [1]: its lagrangian formulation is particularly suitable for the description of free surface flows and FSI problems with large structural displacements, i.e. when the fluid boundaries can vary significantly. The boundaries are automatically defined by the position of the mesh nodes, with no need for interface tracking algorithms. When the mesh gets too distorted, a Delaunay Triangulation is applied to redefine element connectivities.

A distinctive feature of the proposed approach is that the solid domain is modelled with the explicit Finite Element Method (FEM) implemented in the commercial software Dassault Systèmes SIMULIA Abaqus/Explicit. This will allow to include in the model all its advanced functionalities, such as the wide library of material constitutive relations and the possibility to introduce crack propagation and contact.

The explicit coupling algorithm is based on a Domain Decomposition Method, namely the Gravouil and Combescure (GC) algorithm, initially proposed for structural dynamics [2], and then extended to FSI problems, for example in [3]. According to the GC algorithm, the fluid and structural domain are solved independently, as if there was no interaction between them. The two staggered analyses are then synchronized by considering a system



(a) Test case geometry (b) $t = 1.50\ s$ (c) $t = 3.50\ s$ (d) $t = 10.0\ s$

Figure 1: Filling of an elastic membrane. Geometry of the problem and snapshots of the simulation at different time instants [4].

of constraint equations at the fluid-structure interface, which impose the continuity of the velocities through the definition of interface tractions. These tractions, that play the role of lagrangian multipliers, are then applied as natural boundary conditions to correct the solutions of the two subdomains. This method allows to use different time steps and nonconforming meshes in the different domains, which is crucial for the efficiency of an explicit solver involving different materials. It has been demonstrated that this algorithm preserves stability of each sub-problem, since the numerical energy variation at the interface is either null or strictly dissipative.
The obtained fully explicit solver is appealing for its possible application in a large variety of engineering problems with fast dynamics and/or a high degree of non-linearity. The approach has been validated in [4] considering several test cases presented in the literature. For instance, figure 1 shows the results of the simulation of a viscous fluid falling onto a thin and highly deformable elastic membrane. The comparison of all the considered test cases with the available analytical, experimental and numerical solutions showed a good agreement, confirming the robustness of the proposed method.

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