3d conservative coupling method between a compressible fluid flow and a deformable structure

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ABSTRACT

In this work, we present a conservative method for three-dimensional inviscid fluid-structure interaction problems for the simulation of the impact of shock waves on solid structures. On the fluid side, we consider an inviscid Euler fluid in conservative form in order to assess the conservation issues related to coupling. The Finite Volume method uses the OSMP high-order flux with a Strang operator directional splitting [1]. On the solid side, we consider an elastic deformable solid. In order to examine the issue of energy conservation, the behaviour law is here assumed to be linear elasticity. In order to ultimately deal with rupture, we use a Discrete Element method for the discretization of the solid [2].

Body-fitted methods are not well-suited for this type of problem or even for large displacements of the structure, since they involve possibly costly remeshing of the fluid domain. We use an immersed boundary technique through the modification of the finite volume fluxes in the vicinity of the solid. This is made possible by the finite velocity of sound in the fluid, which allows to compute the fluid fluxes and modify them as a post-processing. Such an immersed boundary method originates from the seminal work of Colella et al. [3]. The method is tailored to yield the exact conservation of mass, momentum and energy of the system. The method also exhibits important consistency properties, such as conservation of uniform movement of both fluid and solid through the grid (a sort of Galilean invariance, related to Geometric Conservation Laws) as well as the absence of numerical rugosity on a straight boundary (even when not aligned with the fluid grid).

Since both fluid and solid methods are explicit, the coupling scheme is designed to be globally explicit too. Care is taken in the design of the coupling scheme in order to maintain the conservation of momentum and energy. The computational cost of the fluid and solid methods lies mainly in the evaluation of fluxes on the fluid side and of forces and torques on the solid side. It should be noted that the coupling algorithm evaluates these only once every time step, ensuring the computational efficiency of the coupling. Our approach is an extension to the three-dimensional deformable case of the conservative method developed in [4]. We will present numerical results assessing the robustness of the method in the case of a deformable solid with large displacements coupled with a compressible fluid flow. Preliminary results on rigid bodies are presented in Figures 1 and 2: this is the three-dimensional analogue of the cylinder liftoff case presented in [4, 5] replacing the cylinder with a sphere.

Figure 1: Impact of a Mach 3 shock on a mobile sphere: 30 contours of pressure at time t=0.255
**Figure 2**: Impact of a Mach 3 shock on a mobile sphere: trajectory of the center of mass in the \((x,y)\) plane

**REFERENCES**


