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FAST TRANSIENT FLUID-STRUCTURE INTERACTION WITH FAILURE AND FRAGMENTATION

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ABSTRACT

Fluid-structure interaction (FSI) phenomena of various types play an important role in many areas, ranging from aeronautical and space applications, to civil and marine/offshore engineering and to the transport industry, to name just a few. The JRC has been involved for decades in the development of numerical methods for FSI modelling applied to safety studies, initially for the nuclear industry and more recently for conventional power plants (electrical machinery) and in civil engineering (building or infrastructure vulnerability to terrorist attacks).

All these studies have in common the violent blast loading resulting either from an accident or from an intentional attack. Strong pressure waves propagate in the fluid and load the surrounding structures, which typically undergo large deformations and in some cases reach complete failure and fragmentation. For this class of problems, the fluid is usually modelled as compressible and inviscid (Euler equations) and an Arbitrary Lagrangian Eulerian (ALE) formulation is adopted for the fluid sub-domain.

This allows to describe with great accuracy the coupling between the fluid (ALE) and the structure (Lagrangian), under the assumption that the fluid remains constantly attached to the structure along the normal direction to the FS interface, the so-called *permanent* FSI scenario. General and robust algorithms for this class of problems have been developed—see e.g. the FSA method in reference [1], Fig. 1a/b—and thoroughly validated over a large range of industrial applications [2] by means of the EUROPLEXUS code, developed jointly by the JRC and by the French CEA. An important practical aspect is that these algorithms are totally automatic and can deal with arbitrarily complex 3D geometry without any user intervention. The initial FSA formulation assumed nodally conforming F-S meshes at the FSI interface, but recently the algorithms have been generalized to non-conforming FSI interfaces [3], a great advantage in complex practical applications of industrial relevance.

As a counterpart of their great accuracy and robustness, the methods considered so far suffer from two limitations: on one hand, excessive deformation of the structure (in particular, extremely large *rotations*) may have deleterious effects on the automatic mesh rezoning algorithm, which tries to keep the ALE fluid mesh acceptable and without entanglements while remaining constantly attached to the structure. On the other hand, if the structure completely fails and some elements are removed from the computation via a suitable fragmentation/erosion strategy (perhaps being replaced by a cloud of debris particles) then it is technically difficult—at least in completely arbitrary 3D geometries—to “sew” the two fluid meshes (which might be non-conforming) at the opposite sides of the failing structure, and to ensure appropriate mesh rezoning.

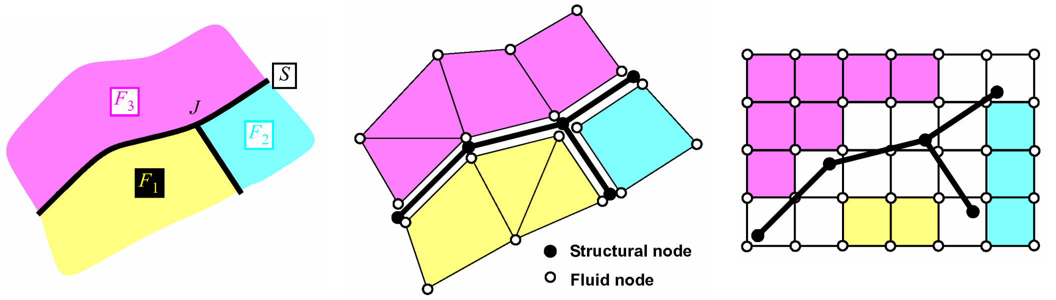
To overcome these drawbacks and to open the way to applications involving complete structural failure and fragmentation, e.g. for the simulation of terrorist attacks, a new FSI model is being developed along the following lines. The fluid and structural sub-domains are *topologically uncoupled* (independent). Each sub-domain is discretized separately and the two meshes are simply superposed, see Fig. 1c. At each time instant of the computation, a topological search is performed (by suitable optimized algorithms) of the fluid nodes which are “reasonably close” to the structure. Then, appropriate FSI coupling conditions are imposed. These are of the form:

$$\underline{v}_F \cdot \underline{n} - \underline{v}_{S^*} \cdot \underline{n} = 0 \qquad (1.1)$$

where $\underline{v}_F$ is the fluid (particle) velocity at the concerned fluid node F, $\underline{v}_{S^*}$ is the structure velocity at the associated structural *point* S^* (*not* a node, in general) and $\underline{n}$ is the local normal direction to the FSI interface. A key aspect of these methods is the automatic determination of the local normal(s) in an arbitrary 3D *discretized* geometry. To this end, much of the techniques developed for the topologically coupled models (FSA, see Fig. 1b) may be reused. Relations of type (1.1) form a system of linear constraints that are solved by a Lagrange multipliers method.

Since the fluid mesh is topologically decoupled from the structural mesh, the above mentioned limitations related to mesh rezoning and to structural failure are completely avoided. In practice, it may be convenient to adopt a Eulerian (fixed) fluid mesh, or even a “structured” one, a simplification which would allow important computational savings and optimizations. If a structural element fails and is eroded, then the corresponding constraints (1.1) are simply no longer imposed locally and the fluid may start to flow freely across the vanishing structure.

Of course, as a counterpart to its greater flexibility, the new model outlined above is expected to be less accurate than the topologically coupled one. The reason is mainly numerical diffusion, which may cause some spurious fluid flow across a non-failed structure. A quantitative assessment of the new method is being performed by comparison with the previous one, of course on problems *not* reaching structural collapse. These preliminary results indicate that the method is sufficiently precise for the class of problems of interest, so that it is going to be applied soon in large simulations of vulnerability of railway/metro stations and rolling stock to terrorist attacks.



a) Continuous FS domain b) Discretized (FSA model) c) Discretized (new model)

Fig. 1 – Two alternative approaches for the modeling of a FSI problem

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