Shell-fluid coupled simulation of detonation-driven fracture and fragmentation

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The experimental investigation of fracture and fragmentation of thin-plates and thin-shells subjected to impact or detonation loadings has attracted considerable interest in the past. The simplified analytic models proposed to date are often based on ad-hoc approximations and can only predict certain limited aspects of the structural response, such as the burst pressure of pipes or the dissipated energy during the petaling failure of plates.

In this work, we develop a robust computational method for the loosely coupled simulation of fracturing thin-shells subjected to compressible reactive high speed flows. The mechanical response of the thin-shell is modeled with a Kirchhoff-Love type theory in Lagrangian coordinates [1]. The conforming finite element discretization of the underlying energy functional is accomplished with smooth subdivision finite elements. We assume that cracks can only be initiated on the edges and propagate along the edges of the finite elements. After a crack is initiated the adjacent surface pieces interact only through tractions and moments, which are computed with a cohesive fracture model. This approach allows for fracture in an in-plane mode, a shearing mode, and a bending of hinge mode.

The compressible reactive high-speed fluid flow is discretized with an Eulerian finite volume method and a dynamically adaptive block-structured Cartesian grid [2]. The coupling between the moving shell and the fixed fluid discretization is accomplished with level sets and the ghost fluid method. At each time step, the distance function from the shell surface is computed on the Eulerian grid. The resulting implicit representation of the fluid-shell boundary in the deformed, and possibly fractured, configuration is used to enforce the conservation laws at the fluid-shell boundary [3]. The overall coupling approach is part of the Virtual Test Facility (VTF) software integration framework developed at the Caltech ASC Alliance Center for the Simulation of Dynamic Response of Materials.

As an application example we consider the detonation driven fracture of tube experiments, whereby a preflawed thin aluminum tube is subjected to internal detonation loading [4]. The experiment exhibits a strong coupling between the shell motion and the fluid flow in particular due to the venting of the detonation products at the crack openings.

References

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