FIVER: A Computational Framework for Compressible Multi-Material Problems with Second-Order Convergence Rate

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ABSTRACT

The simulations of underwater implosion, aerodynamics of flexible flapping-wing micro air vehicles, aeroelastic tailoring of racing cars, and high-G maneuvers of fighter aircraft share the challenge of computing fluid-structure interactions in highly nonlinear multi-material domains. Indeed, the implosive collapse of a submerged, gas-filled structure and its subsequent effect on the structural integrity of a near-by system is a transient, high-speed, multi-phase inviscid fluid-structure interaction problem characterized by ultrahigh compressions, shock waves, large structural deformations, self-contact, and possibly the initiation and propagation of cracks. Bio-inspired micro air vehicles operate in the lower Reynolds number regime and tend to have light weight flexible flapping wings. Their unsteady and turbulent erodynamics are closely linked to their structural dynamics which features large motions and deformations, and their flight characteristics are affected by environmental factors such as wind gust. Formula 1 cars and fighter aircraft operate in the higher Reynolds number regime. They perform aggressive high-G maneuvers characterized by high angles of attack, and turbulent viscous flows driven by large-amplitude structural vibrations. To this effect, this lecture will present FIVER [1—5], a robust, multi-disciplinary, computational framework for the numerical simulation of all of these highly nonlinear fluid-structure interaction problems characterized by multi-material domains, and discuss its mathematical and numerical properties. These include nonlinear stability and second-order convergence rate, including in the vicinity of the material interfaces. This computational framework includes a generic, comprehensive, and yet effective approach for representing a fractured fluid-structure interface that is applicable to several finite element based fracture methods including interelement fracture [6] and remeshing techniques [7], the eXtended Finite Element Method [8], and the element deletion method [9]. The lecture will also highlight the potential of FIVER for the simulation of complex, grand challenge, engineering problems such as the analysis of material failure driven by multi-phase fluid-structure interaction with dynamic fracture, the response of structural systems to underbody blast events, the generation of thrust by flexible flapping wings at low Reynolds numbers, and the vertical tail buffeting of fighter jets at high angles of attack.

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