A HIGH-FIDELITY COMPUTATIONAL FRAMEWORK FOR THE ANALYSIS OF FAILURE DRIVEN BY MULTI-PHASE FLUID-STRUCTURE INTERACTION

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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, nonlinear, multi-phase fluid-structure interaction problem. It is characterized by ultrahigh compressions, shock waves, large structural displacements and deformations, self-contact, and possibly the initiation and propagation of cracks in the structure. This problem is a major area of concern in many underwater engineering applications. It is also relevant to other applications such as the extracorporeal shock wave lithotripsy procedure where shock waves are generated to break a kidney stone into small pieces that can travel more easily through the urinary tract and pass from the body. The development of a computational framework for this problem is a formidable challenge. It requires not only incorporating in the computations material failure models, but also accounting for all possible interactions between the nonlinear structure and the external and internal fluids. The numerical simulation of this problem is equally challenging because it typically requires capturing various phenomena that occur at multiple length and time scales. To this effect, this lecture will describe and analyze a robust, high-fidelity computational framework for modeling and simulating failure driven by multi-phase fluid-structure interaction. The key components of this computational framework include: (a) a higher-order embedded boundary method for multi-phase CFD computations based on the exact solution of local, one-dimensional two-phase Riemann problems, (b) an effective method of tabulation and interpolation based on truncated tensor products (sparse grid) for enabling the evaluation of the Riemann invariants and/or alleviating their computational cost, (c) a semi-analytical approach for enforcing the kinematic transmission condition at an embedded fluid-structure interface, (d) an energy conserving algorithm for enforcing the equilibrium transmission condition at such an interface, and (e) explicit and implicit staggered and yet numerically stable and time-accurate algorithms for efficiently time-advancing the solution of the coupled fluid-structure equations of equilibrium. The salient features of the proposed computational framework will be highlighted with the simulation of several three-dimensional multi-phase fluid-structure interaction problems associated with underwater implosion and featuring crack propagation. Validation results will also be presented for some of these simulations.