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Plenary Presentation

A COMPUTATIONAL FRAMEWORK FOR MODELING HIGHLY NONLINEAR MULTI-PHASE FLUID-STRUCTURE INTERACTION PROBLEMS

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ABSTRACT

The implosive collapse of a gas-filled and submerged structure and its subsequent effect on the structural integrity of a near-by system is a transient, high-speed, multi-phase fluid-structure interaction problem 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 arises not only in underwater engineering applications, but also in 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 corresponding computational model is a formidable challenge. It requires accounting for all possible interactions of the external fluid—namely, water—the internal gas, and the given nonlinear structures. It also requires incorporating in the computations material failure models, and capturing the precise effects on the pressure peaks of many factors such as the rate of structural collapse, hydrodynamic instability at the fluid/bubble interface, and cavitation when it occurs in the external fluid. This talk describes a high-fidelity computational framework for modeling this problem whose key components include: (a) an embedded multi-phase CFD (Computational Fluid Dynamics) method based on the exact solution of local, one-dimensional two-phase Riemann problems, (b) an effective tabulation and interpolation method based on truncated tensor products (sparse grid) for enabling the evaluation of the Riemann invariants and/or alleviating their computational cost, (c) an analytical approach for enforcing the kinematic transmission condition at the embedded fluid-structure interface, (d) an energy conserving algorithm for enforcing the equilibrium transmission condition at that same embedded interface, and (e) a staggered and yet numerically stable and time-accurate algorithm for efficiently time-integrating the coupled fluid-structure equations of equilibirum. Each of these computational topics is discussed with particular attention to achieving, wherever possible, second-order spatial and temporal accuracy. Finally, unique features of this computational framework are highlighted for several three-dimensional multi-phase fluid-structure interaction problems associated with underwater implosion, and validation results obtained jointly with collaborators at Northwestern University and the University of Texas at Austin are presented.