ME – PhD Thesis Colloquium

MECHANICAL ENGINEERING
INDIAN INSTITUTE OF SCIENCE

Numerical simulations of shock-induced bubble collapse in strain-rate-hardening and strain-rate-softening fluids

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October 6, 2022, at 2:00 PM

Venue: ME Conference Room

ABSTRACT

Cavitation bubbles subjected to incident shock or acoustic waves collapse violently and emit strong blast waves. The emitted blast waves are one of the principal reasons for the damage that collapsing cavitation bubbles cause to underwater hydraulic machinery. The collapse and blast wave emission processes have been argued to be responsible for the tissue injury in shock and sound wave based biomedical techniques such as shock wave lithotripsy and burst wave lithotripsy. Since the bubble collapse process is quite violent and short, its detailed experimental characterization is very challenging. Detailed simulations of the bubble collapse process are therefore particularly desirable and can provide the insight necessary for improvement and optimization of the aforementioned therapeutic procedures. The complexity and the multiscale character of the bubble collapse process in a complex media however, challenges even the most advanced numerical techniques for compressible multiphase flows. Here, we develop a novel constrained least-squares (CLS) based high-order unstructured mesh weighted essentially non-oscillatory (WENO) reconstruction technique that enables detailed resolution of the bubble-medium interface and its interactions with the incident and reflected/emitted strong shock, blast and rarefaction waves throughout the collapse process. The method is built upon a constraining procedure that yields pointwise estimates of the state variables that are consistently more accurate than the estimates obtained from the conventional least-squares based reconstruction over a broad spectrum of spatial wavenumbers. A specialized technique that reduces the computational burden associated with the numerical solution of the constrained least-squares system for the WENO interpolation coefficients is introduced. The constraining procedure is shown to facilitate the implementation of high-order boundary closure schemes that are consistent with the accuracy of the interior. The constrained least-squares based adaptive WENO (CLSWENO) discretization is tested in numerous challenging flow configurations that include strong shocks, complex geometries and material interfaces separating fluids with vastly distinct properties, such as air and water. Next, the CLSWENO reconstruction based multicomponent flow solver is applied to a canonical axisymmetric setup consisting of an incident shock that impacts an air bubble located next to a rigid planar boundary in a generalized Newtonian medium. Simulations reveal that the shear-thinning/shear-thickening rheology of the medium impacts the collapse and blast wave emission characteristics significantly. Specifically, the blast-wave-induced peak pressure on the rigid boundary undergoes over a three-fold increase (decrease) with the degree of shear-thinning (shear-thickening) in a generalized Newtonian fluid for which the effective viscosity can exhibit two orders of magnitude variation. The sensitivity of the peak pressure indicates that the strain-rate-softening (strain-rate-hardening) rheology can significantly enhance (diminish) the strength of the blast wave and the damage potential of collapsing cavitation bubbles.

ABOUT THE SPEAKER

Sunder Dasika is a PhD student in Department of Mechanical Engineering, IISc, Bangalore. He completed his BE from National Institute of Technology, Surat in 2015. He joined IISc as a PhD student in August 2016. His research interests include high-order unstructured mesh methods and single and multi-phase compressible flows. His dissertation work focuses on the shock-induced collapse of bubbles in complex media.