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Large Eddy Simulation of Turbulent Cavitating Flows

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Abstract:

This talk will discuss our efforts at developing the large-eddy simulation capability for the simulation of turbulent cavitating flows. LES of cavitation is challenged by phase change modeling, acoustic stiffness, sharp multiphase fronts, strong compressibility effects, consistent accounting of nuclei, broadband turbulence and subgrid effects. We will discuss a predictor-corrector numerical method for the LES equations based on the compressible homogeneous mixture model that captures sharp fronts without dissipating the resolved turbulence. The method uses a non-dissipative and symmetric scheme in the predictor step along with a novel characteristic-based filtering scheme for the corrector step to handle shocks and material discontinuities.
LES of partial cavitation over incipient, transitory and periodic regimes will be discussed under the same conditions as experiments in a sharp wedge configuration. Physical mechanisms of cavity transition observed in the experiments, i.e., re-entrant jet and bubbly shock waves, are both captured in the LES over their respective regimes. Vapor volume fraction data obtained from the LES will be quantitatively compared to X-ray densitometry, and the results will be discussed.
Bluff body cavitation will be considered, and effects of non-condensable gas and cavitation on both large-scale shedding and small-scale turbulence will be discussed. The use of the dynamic mode decomposition to study wake characteristics will be illustrated.
Cavitation nuclei are likely to be introduced through the free-stream as well as at solid surfaces. We will present a novel approach based on Gibbs free energy minimization to obtain liquid-air interfaces over realistic rough surfaces. The methodology has the potential to predict wall-nucleation in cavitating flows.
LES of cavitation inception in the shear layer of a backstep will be presented. Statistics for both pressure and vapor volume fraction are computed and the likelihood of inception is determined. The locations of the preferred sites for cavitation are compared to experimental results and good agreement is achieved. The flow topology is investigated, and inception is found to occur in the core of the stretched tubular vortical structures with a rotation rate four times higher than the stretching rate. These results will be discussed. Cavitation inception due to the interaction of a counter–rotating vortex pair will be discussed and a three–stage process for the inception will be presented.

It will be shown that inception predictions require values of freestream vapor volume fraction that are much smaller than what is typically used in mixture simulations. However, small volume fractions result in acoustic stiffness. We will discuss a preconditioning methodology for the compressible, finite rate equations and demonstrate its efficiency for both canonical and propeller flows.

Finally, we will discuss a multi-scale methodology that combines a Lagrangian modelling of subgrid bubbles with mixture modelling of large-scale cavitating regions to ensure efficient modelling of the wide range of scales.

Keywords: Large-eddy simulation, numerics, sheet to cloud, inception, nucleation