Simulation of cavitating flows by a six-equation two-phase compressible flow model with thermodynamic relaxation

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Résumé :

We model liquid-gas mixtures with cavitation and evaporation waves by a hyperbolic single-velocity six-equation two-phase compressible flow model with mechanical and thermo-chemical relaxation. In particular, we are interested in applications to cavitating fluids in engineering devices, such as hydrofoils, fuel injectors, or pipes in industrial plants.

In these flows it is important to take into account the compressibility of both the liquid and the gaseous phase to correctly describe wave propagation phenomena and acoustic perturbations.The flow model is based on a variant of the two-phase flow model with stiff pressure relaxation of Saurel--Petitpas--Berry [JCP, 228, 2009]. Heat and mass transfer contributions are included in the model system as temperature and chemical potential relaxation terms to describe liquid-vapor transition. With respect to the classical 6-equation model in the literature we employ here a total-energy-based mathematical formulation in the numerical discretization. This allows us to easily conceive a numerical scheme that ensures consistency with conservation of the mixture total energy at the discrete level and agreement of the relaxed equilibrium pressure with the correct mixture equation of state.The model equations are solved in two dimensions by a fully-discretized high-resolution scheme. A wave propagation method based on a hybrid HLLC/Roe Riemann solver is employed for the approximation of the homogeneous hyperbolic portion of the system. Thermal and chemical source terms are handled through efficient stiff relaxation solvers that at metastable interfaces drive the two-phase mixture to thermodynamic equilibrium via the solution of simple algebraic systems of equations. We illustrate several numerical experiments that show the ability of the proposed numerical method to simulate the dynamics of cavitation pockets and evaporation fronts.

The last part of the talk will focus on more recent work on the development of a low-Mach Turkel-type preconditioning technique for our two-phase numerical model. Indeed, it is well known that classical upwind finite volume discretizations of compressible flow models experience a dramatic loss of accuracy and efficiency
at low Mach number regimes. This problem is particularly critical for liquid-gas flows due to the large and rapid variation of the Mach number, since the speed of sound may range from very low values in the two-phase mixture to very large values in the liquid medium. Some two-dimensional low-Mach channel flow tests are presented,
which demonstrate the efficiency of the proposed preconditioning correction of the numerical dissipation tensor. In particular, we show that in the low Mach number limit pressure fluctuations correctly scale with the square of the reference Mach number, in agreement with the theoretical results for the continuous two-phase flow model
in the limit of vanishing Mach number.

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