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Title

Numerical simulation of phase change induced by pressure variations in cryogenic tanks

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Abstract

Phase change phenomena in compressible flows are of interest for a large number of space applications among which acoustics drop interaction in combustion chambers, cavitation in pumps or pool cavitation in tanks. In particular, cavitation at the wall in tanks, characterized by fast bubbles growth in a superheated liquid, can be a great concern for cryogenic fluids storage in upper stages or fuel depots. Indeed, one cooling strategy, adopted in particular for conditioning the propellant before ignition, consists in depressurizing the tank by venting the propellant, in order to create vapor and reduce the liquid propellant temperature [2,5]. The tank thermal control is in the end strongly affected by phenomena arising at the bubble scale, and in the contact line region, that need to be predicted. In order to study these phenomena, without making use of sub-grid models for the phase change mass flow rate that bring huge uncertainties in the final result, thermal gradients at the interface need to be solved with a direct numerical simulation (DNS). However, usually DNS solver for phase change phenomena are based on incompressible assumptions suitable for the description of boiling and condensation in isobaric conditions [3,4]. On the other hand, for the simulation of pool cavitation, a compressible two-phase flow solver, including phase change, is required and, to the author knowledge, these approaches are only partially addressed in the literature. The objective of the present work is to fill this modeling gap. An innovative numerical algorithm for the DNS of compressible two-phase flows with phase change is presented. The solver is based on a level set/ ghost fluid approach, solves the complete set of Navier-Stokes conservation equations making use of a semi-implicit projection scheme [1]. Cubic equations of state are used for the description of both the liquid, the vapor and the saturation conditions at the interface. In this paper the solver is introduced with particular attention devoted to the phase change modeling. Several validation test cases are described in order to assess the validity of the approach. Finally, the focus will be on the analysis of the cavitation of a bubble at the wall in micro-gravity conditions in a closed tank considering different depressurization levels.

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