A Low Mach Number, Adaptive Mesh Method for Simulating Multi-phase Flows in Cryogenic Fuel Tanks

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ABSTRACT

A new computational fluid dynamics algorithm is presented for simulating sloshing and evaporation in a cryogenics fuel tank. The numerical method represents the (complex) deforming liquid/vapor interface as an idealized sharp interface. The new algorithm is an extension of the following research [6, 8, 9] for simulating multi-phase flows with phase change in an *open* computational domain to simulating multi-phase flows with phase change in a *sealed* domain (such as in a Cryogenics Fuel Tank). A unique aspect of the new algorithm is that *both* liquid and vapor are modeled with a low-Mach number approach inspired by Duarte et al [3] and Xia et al [10]. During the evaporation/condensation process, vapor density in vapor region(s) is(are) automatically adjusted, uniform in space, in order to preserve vapor mass. In contrast to treating the vapor as a fully compressible fluid [5], the present approach can guarantee mass conservation and positivity of density without reducing the order of accuracy of the numerical method and without having to take into account the acoustic time step constraint. It is remarked that Godunov's theorem (see also [4]) restricts numerical methods for fully compressible flows to first order accurate at extrema; the restriction is not an issue for the present low-Mach number method. Potentially, the momentum and temperature equations can be discretized with space-time spectrally accurate methods as described by the authors' past work [6].

The following validation studies have already been completed with promising results: (i) agreement has been established between numerical simulations of an evaporating droplet and experiments [1] in open and sealed domains, and (ii) convergence under grid refinement, as additional levels of adaptive mesh refinement are added, has been established in open and sealed domains. Two evaporation models have been validated within the context of the new low-Mach number multi-phase flow, mass transfer algorithm: the first model is described in [7] for evaporation into multi-component gases, and the second model is described in [5] for evaporation into pure vapor. The presented low-Mach number framework allows for more sophisticated sharp interface evaporation models; see, e.g. [2].

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