Development and analysis of a Lagrange-Remap sharp interface solver for stable and accurate atomization computations

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Abstract

There exists a variety of computational models for treating multiphase flows, with increasing levels of complexity. In the direct numerical simulation (DNS) approach that is considered in the present work, the physics of the flow are all solved for directly. In the presence of complex topologies such as those encountered in atomization, the underlying equations are quite stiff, and therefore the development and improvement of numerical methods that treat these flows has been an area of active research. Among algorithms that have emerged, sharp interface methods including Volume-of-Fluid (VoF), Level Set (LS) and their combination (Coupled LS/VoF) have been shown to perform well on a variety of test cases. The application of these methods to realistic configurations such as primary atomization of a turbulent round jet is not common, and the rare convergence studies available show strong grid dependence. This suggests the need for a careful analysis of the numerical schemes predicting such flows.

The present work focuses on a Lagrange-Remap approach developped for free surface flows and involving two recent improvements which are presented in details: first, a second order unsplit Coupled LS/VoF interface capturing method designed for arbitrary grids [1], and second, a robust and conservative flow solver for incompressible Navier-Stokes equations in the presence of an liquid/gas interface [2]. The resulting approach is shown to be stable, and the interface capturing to be second order accurate. In addition, the scheme is shown to have excellent mass and momentum conservation properties.

As mentioned, these improvements rely on an unsplit geometric Lagrange-Remap approach. Firstly, the interface is advanced using an unsplit Coupled LS/VoF interface capturing method, therefore benefitting from the conservation properties of the VoF method and the geometrical accuracy of the LS method. In addition, the unsplit nature of the volume fraction advection offers meshing flexibility and reduces numerical errors known to be detrimental to split VoF methods. Secondly, the predictor and corrector steps used in the incompressible flow solver are designed so that the momentum advection and Ghost Fluid projection are carried consistently with the volume fraction transport. This improves momentum conservation and stability, even at high density ratio. Furthermore, the analysis of the polyhedral operations used during the transport of volume fraction and momentum will be presented along with a proof of the stability of the scheme.

Finally, the proposed method is applied to a series of round jet computations at realistic density ratio and moderate Weber/Reynolds numbers. Mean flow statistics, including liquid penetration length and drop size distributions, are used to quantify the impact of grid resolution in an attempt to characterize the grid dependence of the atomization process.

[1] V.H.M. Le Chenadec and H. Pitsch, A Hybrid Lagrangian-Eulerian Method for Multiphase Flow Computation, Journal of Computational Physics, *submitted*.

[2] V.H.M. Le Chenadec and H. Pitsch, A Robust and Accurate Lagrange-Remap Sharp Interface Solver for Multiphase Flow Computation, Journal of Computational Physics, *in preparation*.

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