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REVIEW ARTICLE

Marker-Based, 3-D Adaptive Cartesian Grid Method for Multiphase Flow Around Irregular Geometries

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Abstract. Computational simulations of multiphase flow are challenging because many practical applications require adequate resolution of not only interfacial physics associated with moving boundaries with possible topological changes, but also around three-dimensional, irregular solid geometries. In this paper, we highlight recent efforts made in simulating multiphase fluid dynamics around complex geometries, based on an Eulerian-Lagrangian framework. The approach uses two independent but related grid layouts to track the interfacial and solid boundary conditions, and is capable of capturing interfacial as well as multiphase dynamics. In particular, the stationary Cartesian grid with time dependent, local adaptive refinement is utilized to handle the computation of the transport equations, while the interface shape and movement are treated by marker-based triangulated surface meshes which freely move and interact with the Cartesian grid. The markers are also used to identify the location of solid boundaries and enforce the no-slip condition there. Issues related to the contact line treatment, topological changes of multiphase fronts during merger or breakup of objects, and necessary data structures and solution techniques are also highlighted. Selected test cases including spacecraft fuel tank flow management and liquid plug flow dynamics are presented.

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Key words: Multiphase flows, irregular geometry, interface tracking, adaptive Cartesian grid, non-conforming boundary methods, contact line treatment.

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Contents

1 Introduction

Fluid flows involving interactions between liquids and gases can be observed in a wide range of engineering applications. When capillary effects become significant, physical mechanisms and geometric characteristics associated with the interface need to be accurate resolved. In such circumstances, numerical simulations of interfacial flows are required to resolve the location of the interface based on the conditions arising from surface tension, viscous stresses, and pressure distributions, and distinctive material properties of the constituents. As reviewed by multiple authors [1–6], there exist numerous methods for tracking the location and the shape of the interface as well as for applying proper treatments around the interface. The computational techniques for treating moving interfaces are typically categorized into three separate groups:

- Lagrangian methods [7, 8] that modifies the grid to match the interface location,
- Eulerian methods [4, 9–13] that extract the interface location with the help of a scalar function on a stationary grid,
- Eulerian-Lagrangian methods [5, 14–18] that utilize a separate set of grid representing the interface on a stationary grid. Grid that represents the front can move freely based on the solution obtained on the stationary grid.

Once the location is known, various methods are usually employed for establishing the interfacial conditions, which impose the discontinuous pressure and viscous stresses across the interface as a result of the surface tension forces. In the literature [1, 2, 4, 19], these methods can be observed in two separate groups:

- Continuous interface methods [5, 14, 15, 20, 21] (CIM) that solves one set of equations by smearing out the flow properties around the interface,
- Sharp interface methods [12, 22–27] (SIM) that impose the conditions directly on the interface by considering different sets of equations for different phases.

With the fast progress made in recent years, various combinations of the interface tracking methods and interfacial conditions models have been proposed in order to capture