Numerical Methods and Simulations of Complex Multiphase Flows

by

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ABSTRACT

Multiphase flows are an important part of many natural and technological phenomena such as ocean-air coupling (which is important for climate modeling) and the atomization of liquid fuel jets in combustion engines. The unique challenges of multiphase flow often make analytical solutions to the governing equations impossible and experimental investigations very difficult. Thus, high-fidelity numerical simulations can play a pivotal role in understanding these systems. This dissertation describes numerical methods developed for complex multiphase flows and the simulations performed using these methods.

First, the issue of multiphase code verification is addressed. Code verification answers the question "Is this code solving the equations correctly?" The method of manufactured solutions (MMS) is a procedure for generating exact benchmark solutions which can test the most general capabilities of a code. The chief obstacle to applying MMS to multiphase flow lies in the discontinuous nature of the material properties at the interface. An extension of the MMS procedure to multiphase flow is presented, using an adaptive marching tetrahedron style algorithm to compute the source terms near the interface. Guidelines for the use of the MMS to help locate coding mistakes are also detailed.

Three multiphase systems are then investigated: (1) the thermocapillary motion of three-dimensional and axisymmetric drops in a confined apparatus, (2) the flow of two immiscible fluids completely filling an enclosed cylinder and driven by the rotation of the bottom endwall, and (3) the atomization of a single drop subjected to a high shear turbulent flow.

The systems are simulated numerically by solving the full multiphase Navier-Stokes equations coupled to the various equations of state and a level set interface tracking scheme based on the refined level set grid method. The codes have been parallelized using MPI in order to take advantage of today's very large parallel

computational architectures.

In the first system, the code's ability to handle surface tension and large temperature gradients is established. In the second system, the code's ability to simulate simple interface geometries with strong shear is demonstrated. In the third system, the ability to handle extremely complex geometries and topology changes with strong shear is shown.

The rest of the dissertation and all supplemental materials will be included on a CD-ROM