

CONSERVATIVE NUMERICAL DISCRETIZATION FOR MULTIPHASE FLOWS WITH ADAPTATIVE MOVING MESH REFINEMENT

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ABSTRACT

Direct Numerical Simulation of multiphase flows remains challenging due to the dynamic interaction between interfacial tension and fluid mechanics, as well as the need to accurately resolve thin, deforming interfaces. This work presents a computationally efficient framework that couples conservative numerical methods for multiphase flow with an adaptive, moving deformative mesh strategy, validated on the canonical vibrating bubble benchmark.

The numerical approach builds upon conservative discretization strategies; (i) an algebraic energy-preserving level-set method, which ensures mechanical energy conservation through symmetry-preserving schemes, implemented by a fully conservative formulation for convection and surface tension terms that prevents the accumulation of spurious currents and numerical instabilities, and (ii) the incorporation of conservative flux-limiting techniques formulated within an algebraic framework, enabling portable implementations on heterogeneous high-performance computing systems without compromising physical fidelity.

A key innovation lies in integrating these conservative schemes with dynamic mesh adaptation, instead of relying on fixed, uniformly refined grids. The approach, employs moving deformative meshes that automatically refine in regions of physical interest -particularly near the bubble interphase - while maintaining coarser discretization in less critical areas, reducing both memory footprint and computational overhead. Finally, the mesh refinement is driven by an adaptive metric, controlled by a variational algorithm that ensures mesh quality while it is validated against linear perturbation theory predictions.

The vibrating bubble case serves as the primary validation benchmark, demonstrating the method's ability to correctly capture the energy transfer between kinetic and surface potential energy across multiple oscillation periods. We will show how the adaptive moving mesh successfully tracks interface evolution while maintaining mesh quality throughout the simulation without requiring periodic remeshing operations.

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