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Regularized Euler Equations for Incompressible Two-Phase Flow Simulations

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Abstract : This paper presents an inviscid regularization technique for the incompressible two-phase flow simulations. This technique is known as observable method due to the understanding of observability that any feature smaller than the actual resolution (physical or numerical), i.e., the size of wire in hotwire anemometry or the grid size in numerical simulations, is not able to be captured or observed. Differ from most regularization techniques that applies on the numerical discretization, the observable method is employed at PDE level during the derivation of equations. Difficulties in the simulation and analysis of realistic fluid flow often result from discontinuities (or near-discontinuities) in the calculated fluid properties or state. Accurately capturing these discontinuities is especially crucial when simulating flows involving shocks, turbulence or sharp interfaces. Over the past several years, the properties of this new regularization technique have been investigated that show the capability of simultaneously regularizing shocks and turbulence. The observable method has been performed on the direct numerical simulations of shocks and turbulence where the discontinuities are successfully regularized and flow features are well captured. In the current paper, the observable method will be extended to two-phase interfacial flows. Multiphase flows share the similar features with shocks and turbulence that is the nonlinear irregularity caused by the nonlinear terms in the governing equations, namely, Euler equations. In the direct numerical simulation of two-phase flows, the interfaces are usually treated as the smooth transition of the properties from one fluid phase to the other. However, in high Reynolds number or low viscosity flows, the nonlinear terms will generate smaller scales which will sharpen the interface, causing discontinuities. Many numerical methods for two-phase flows fail at high Reynolds number case while some others depend on the numerical diffusion from spatial discretization. The observable method regularizes this nonlinear mechanism by filtering the convective terms and this process is inviscid. The filtering effect is controlled by an observable scale which is usually about a grid length. Single rising bubble and Rayleigh-Taylor instability are studied, in particular, to examine the performance of the observable method. A pseudo-spectral method is used for spatial discretization which will not introduce numerical diffusion, and a Total Variation Diminishing (TVD) Runge Kutta method is applied for time integration. The observable incompressible Euler equations are solved for these two problems. In rising bubble problem, the terminal velocity and shape of the bubble are particularly examined and compared with experiments and other numerical results. In the Rayleigh-Taylor instability, the shape of the interface are studied for different observable scale and the spike and bubble velocities, as well as positions (under a proper observable scale), are compared with other simulation results. The results indicate that this regularization technique can potentially regularize the sharp interface in the two-phase flow simulations

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