Two-phase flows — overview

In engineering and environmental flows, it is common for multiple non-interpenetrating phases to coexist. Examples of such flows include liquid-fueled combustion systems, coating applications, and breaking waves, to name just a few. The immiscible nature of the two fluids creates compelling challenges to modelers, in particular due to the discontinuity in fluid properties and the tension force that arise at the phase interface. In addition, interfacial instabilities and topology changes can lead to a wide range of dynamical scales, which are often intricately coupled with the surrounding turbulence. Despite these difficulties, two-phase flow modeling is rapidly progressing thanks to the continuous development of high-performance computing, along with high-fidelity numerical schemes.

The two-phase flow group at the 2014 CTR Summer Program comprised six teams, which addressed key issues in multiphase flow research through the advancement of numerical algorithms in the project of Le Chenadec *et al.*, through the investigation of physical modeling in the projects of Herrmann and McCaslin *et al.*, and through the exploration of specific two-phase flow applications in the projects of Bravo *et al.*, Ma *et al.*, and Yu *et al.*

Le Chenadec *et al.* developed algorithms for identifying features automatically in Volume-of-Fluid (VOF) simulations. In particular, they proposed a tagging strategy for identifying interfacial structures undergoing topology changes, and applied it to a high-resolution dataset of a hydraulic jump. Such information is a prerequisite when attempting to model the subgrid dynamics that arise during break-up and coalescence, hence this algorithmic development should rapidly become widely adopted.

In their project, McCaslin *et al.* analyzed an extensive direct numerical simulation (DNS) database of turbulence interacting with an interface under tension. They characterized the scales of interfacial corrugations, pointed out the important role played by the Kolmogorov critical radius (also known as Hinze scale) both at short times and under statistically stationary conditions, and highlighted the backscattering action of the surface tension force. That dataset was also used as reference by Herrmann in his large eddy simulation (LES) modeling project. Using a two-scale representation where the fluid velocity is modeled on a LES mesh while a fully resolved realization of the phase interface is carried on a DNS mesh, he was able to show the importance of the sub-filter turbulent modeling on the development of interfacial corrugations.

Each of the three teams in the applications subgroup pushed the boundaries of two-phase flow research by tackling a different challenge. Bravo *et al.* tackled the challenge of high interface complexity by simulating the turbulent atomization of Diesel fuel issued from a realistic nozzle. In this flow, interfacial scales range from the micron for the smallest drops, to 10 μm for ligaments, to 100 μm for near-nozzle instabilities. Performing such a simulation requires the combination of very large unstructured meshes, a novel high-fidelity VOF scheme, and Lagrangian tracking of under-resolved structures. Ma *et al.* tackled the challenge of high pressure flows by simulating transcritical and supercritical mixing in Diesel engine applications. To that end, they extended the double-flux model to systems with real-fluid state equations, and were able to maintain robustness and accuracy through the use of a WENO discretization. Finally, Yu *et al.* tackled the challenge of high scale disparity by focusing on a coating application called jet wiping. Jet wiping refers to the use of a high-speed gas jet impinging on a liquid film to obtain a very thin and uniform coating. In such a flow, the ratio of film thickness to jet dimension is such that local grid adaption is indispensable. Using recently advanced numerical schemes, they convincingly established the feasibility of first-principle modeling of jet wiping.

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