# Multiphase flow - overview

For the second consecutive summer program, topics covering multiphase flows have been combined into a separate group. Unlike in previous years, however, the focus has shifted away from models describing particle- or droplet-laden flows to numerical methods and models that directly take into account the complex phase interface geometry and dynamics of liquid/gas flows. This approach results in the following modeling and numerical challenges that the individual projects address.

For subcritical flows, the phase interface constitutes a discontinuity in material properties. If, in the incompressible limit, the jump in density across the phase interface is large, inconsistencies between the solution of the interface position and the momentum equation can result in severe numerical instabilities. To address this problem, the project of Moureau and Desjardins proposes a novel second-order ghost-fluid method coupled to a conservative level set method. Their method shows improved robustness and accuracy in the challenging case of a slow-moving liquid jet atomized by a fast-moving gaseous co-flow.

The project of Herrmann, Lopez, Brady, and Raessi considers the case of phase interface dynamics in non-isothermal environments. In this case, the surface tension force is a function of both the local phase interface curvature and the local temperature. This results in so-called Marangoni forces that might impact the atomization of liquids in combustion applications. They propose a numerical method to include the Marangoni forces into a balanced-force algorithm that tracks the position of the phase interface using the Refined Level Set Grid method. The resulting numerical method is validated predicting the thermocapillary motion of deformable drops and bubbles.

Many applications of liquid/gas flows, for example, atomization, are characterized by a vast range of time and length scales. The project of Herrmann and Gorokhovski addresses the question of how to model these flows if not all scales can be resolved. They set forth a subgrid model for the phase interface dynamics in large eddy simulations (LES). Instead of modeling the unclosed terms that result from filtering the Navier-Stokes equations, they propose to maintain a fully resolved realization of the phase interface geometry on a separate high-resolution grid. Explicit filtering of the interface geometry then directly yields the formerly unclosed terms. To maintain the fully resolved phase interface representation, they suggest a model to reconstruct the subgrid component of the velocity vector needed to advect the phase interface.

In compressible flows, the phase interface still constitutes a discontinuity. However, unlike in the incompressible limit, a complex equation of state is required to describe the two phases. In the project of Hu, Adams, Johnsen, and Iaccarino a new non-iterative, one-step Riemann solver for both strong and weak interface interactions with general equation of state is proposed. The solver takes into account phase-change phenomena in thermal non-equilibrium, assuming they are much slower than the interaction described by the Riemann solver. Several different 1-D examples demonstrate the robustness and accuracy of the proposed solver.

Unlike subcritical flows, supercritical flows do not exhibit a discontinuous change in the material properties. The thermodynamic and transport properties of supercritical fluids are in fact intermediate between those of a gas and a liquid and must be described by a real gas model. Due to the strong non-linearities present in the real gas model, there is no guarantee that low-pressure LES models are applicable. The project of Selle and Ribert addresses this question by performing *a priori* and *a posteriori* analysis of temporal jets and homogeneous isotropic turbulence for supercritical fluids. They report that some turbulence properties are indeed impacted by the thermodynamic condition. While the *a priori* analysis of a selection of subgrid models yields promising results, the *a posteriori* results indicate that subgrid-scale dissipation is over-predicted and that the employed numerics lack the sufficient robustness to handle the high-density gradients typical of supercritical flows.

The final project in the multiphase group, by Le Lostec, Fox, Simonin, and Villedieu, follows the tradition of the Summer Program and addresses particle-laden flows. They analyze the performance of two quadrature-based Eulerian methods for the particle phase. The advantage of quadrature-based formulations is that unlike existing Eulerian models that consider only unimodal or close-to-equilibrium particle velocity distributions, quadrature-based methods allow for multimodal distributions. They assess the performance of their methods in two canonical test cases: crossing jets and a Taylor-Green flow, yielding encouraging results.

Marcus Herrmann