Multiphase flows – overview

Many flows of technical relevance contain more than one phase. This poses a set of unique physical and numerical modeling challenges that were addressed in the projects partaking in this year's summer program. According to the chosen modeling strategy, the projects can be divided into two broad categories: projects that aim to resolve the flow dynamics around the phase interface and are thereby limited to relatively small scale detailed studies, and projects that aim to model it using the spray equation, thereby allowing engineering scale analysis. This year's projects were evenly divided between the two categories, with four projects in each.

In the resolved flow category, the project of Desjardins and Moureau addresses the challenge of maintaing numerical stability in large density ratio flows exposed to high shear when tracking the phase interface location by a level set method. They propose two different approaches, one based on improving the consistency between interface and momentum transport, the other by introducing distinct velocity fields in each of the phases in the spirit of the ghost fluid method. Both methods are demonstrated to yield significant improvement over traditional methods.

In the project by Pepiot and Desjardins one of the phases is a non-deformable solid in the form of a dense particle laden flow. They present a direct numerical simulation approach based on a conservative immersed boundary scheme that resolves the boundary layer flow around each particle. The approach allows for large numbers of moving and colliding objects without the need to use boundary fitted meshes. In the stationary case, their method shows good agreement with prior work. In the non-stationary case, they find that drag forces experienced by the moving particles can be different from the stationary case, implying that drag models based on the stationary case alone might have to be modified.

The project of Hu, Adams, Herrmann, and Iaccarino addresses the issue of scale-dependent dynamics of material interfaces. They propose a scale-separation algorithm to split the interface into regions that are resolved and those that are not resolved by the local mesh. If the interface dynamics are deemed resolved they apply a conservative compressible sharp interface approach. If the dynamics are not resolved, a mechanical equilibrium model is introduced and coupled to the resolved interface model. Simulation results for shock-bubble interactions show considerable richer interface and flow structures compared to traditional single scale approaches.

The project by Herrmann proposes a dual-scale approach for phase interface dynamics due to surface tension forces in the context of Large Eddy Simulations (LES). It couples a flow solver resolved scale to a sub-grid scale that is resolved by a level set interface tracking approach. The sub-grid scale phase interface motion due to surface tension forces is modeled using a local Taylor analogy. Good agreement of model results with theoretical and fully resolved simulations are obtained at a fraction of the cost.

In the second category of projects modeling the dynamics around the phase interface using Eulerian formulations of the spray equation, the project of Chalons, Fox, and Massot introduces a new high-order moment formalism for particle trajectory crossings in the framework of gas-particle LES. They propose a new generation of quadrature with improved singular behavior and are able to limit the number of moments necessary for multi-dimensional configurations without loss of accuracy in the spatial fluxes.

The project by Boileau, Chalons, Laurent, Chaisemartin, and Massot introduces a new generation of numerical methods based on relaxation schemes that are able to treat both the general and pressure-less gas dynamics limit of the spray equation. The method is able to treat vacuum zones and natural singularities in a robust manner. Verification using analytical and reference numerical solutions demonstrates the potential of the method for Eulerian spray DNS and LES.

The mesoscopic Eulerian formalism for non-isothermal dilute turbulent two-phase flows is the focus of the project by Dombard and Selle. They analyze two different numerical methods addressing numerical challenges associated with preferential concentration and long time memory of inertial particles. They perform DNS of a planar temporal jet and find that that the impact of random uncorrelated motion heat flux on the mean quantities is moderate, but that a more precise model for the random uncorrelated motion kinetic energy is needed.

The final project in the multiphase group by Fréret, Thomine, Réveillon, Chaisemartin, Laurent, and Massot tests the ability of a Eulerian multi-fluid model and its related dedicated schemes and algorithms to capture all stages of turbulent spray combustion. These include spray dispersion and segregation, vaporization dynamics leading to fuel mass fraction topology, and eventually flame propagation in 2D and 3D forced isotropic homogeneous turbulence. They demonstrate that the muti-fluid model gives results with the same level of accuracy as a baseline solution obtained with Lagrangian droplet tracking.

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