Multiphase flows - overview

This year, for the first time, projects covering multiphase flow phenomena have been agglomerated into a separate group. Traditionally, multiphase flow problems had been addressed within the combustion group, owing to the fact that most technical combustion systems rely on the liquid fuel first being atomized and then vaporized for chemical reactions to take place. This historical connection is still evident in at least two of the seven projects of this group, however, most projects move outside of the confines of combustion science and address either fundamental modeling issues in LES of multiphase flows, or numerical methods appropriate for turbulent multiphase flows.

In principle, two different paradigms can be followed when simulating particle or droplet laden two-phase flows. While the gaseous phase is typically treated in an Eulerian manner, the particles can be modeled either within a Lagrangian or an Eulerian approach. The main aim of the project of Riber, Garcia, Moureau, Pitsch, Simonin, and Poinsot is to evaluate the performance of both formulations using Large Eddy Simulation in predicting particle dispersion in a reference non-reacting, non-evaporating bluff-body configuration. It is found that the two formulations give equivalent results, and that introducing turbulence on the gas flow in the injection duct is of critical importance to obtain good comparison to the experimental data.

Treating the dispersed phase based on an Eulerian approach results in transport equations for non-diffusive scalars. This can physically lead to scalar fields containing regions of high gradients that are difficult to maintain numerically in a stable manner using standard schemes. The objective of the project of Paoli, Poinsot, and Shariff is to test the efficiency and accuracy of a semi-Lagrangian scheme to solve the Eulerian formulation of the dispersed phase. It is found that in the case of direct numerical simulation of a rod of fluid particles in a box of homogenous isotropic turbulence, positivity and conservation of non-diffuse scalars are obtained when choosing a suitable combination of high-order and low-order interpolators to reconstruct the scalar. Also, using time-steps comparable to the convective time scale, number density fields obtained from the semi-Lagrangian scheme of the Eulerian formulation compare well to a purely Lagrangian treatment of the dispersed phase.

In the project of Desjardins, Fox, and Villedieu, an Eulerian quadrature-based moment closure method is developed to solve the Williams spray equation. Traditional Eulerian transport methods that solve for selected moments of the kinetic equation have great difficulty in predicting the correct moments for finite Stokes numbers. In the proposed method based on quadrature, the kinetic equation is closed at higher-order moments using weights and abscissas that are uniquely determined from transported lower-order moments. It is shown, that this method can successfully handle flows with particle-crossing trajectories and thus is able to compute accurately the lower-order velocity moments previously obtainable only by employing a significantly more costly Lagrangian method.

In the project of Ghosal and Herrmann an attempt is made to solve the Fokker-Planck equation for particle conservation by an Eulerian method employing Laplace transforms. Unlike standard Eulerian methods based on selected moments that presume the shape of the pdf, no particulate form of the PDF is assumed. Instead, the particle distribution function is expanded in terms of a truncated series of suitable basis functions, Laplace transformed, resulting in a set of coupled advection-diffusion-reaction partial differential equations for the coefficients of the expansion. For the case of a standard evaporation law, it is shown that at least two PDEs representing four modes are required, to obtain reasonably accurate results.

Two of the projects focus on subgrid scale modeling of the dispersed phase in an LES context. In the project by Fede, Simonin, Villedieu, and Squires, modeling of the subgrid fluid velocity fluctuations along inertial particle trajectories is addressed. A Langevin model is derived which ensures that the resulting equation for the variance of the subgrid velocity along particle paths is consistent with the mean subgrid kinetic energy equation derived from the filtered Navier-Stokes system. Comparison of the model results to Eulerian/Lagrangian DNS results show that use of the model enables a match to DNS data for the particle kinetic energy. However, particle segregation is too strongly modified by the model which randomizes the particle distribution, potentially due to the fact that the chosen test case does not respect necessary criteria for stochastic modeling of the subgrid fluid velocity.

The second project by Paoli, Shariff, and Shirgaonkar addresses subgrid scale modeling of turbulent condensation. A set of Langevin equations for the droplet area, supersaturation, and temperature surrounding the droplets is proposed. This stochastic model is able to reproduce the evolution of the mean surface area, mean supersaturation, and area-supersaturation correlation, the latter being an important unclosed term in the filtered equation for the water vapor density. As such, the proposed model represents a promising subgrid scale closure model for the microphysics in LES of clouds or contrails.

Modeling of high-pressure mixing and combustion in liquid rocket injectors is the topic of the project of Cutrone, Ihme, and Herrmann. Although, strictly speaking, not a multiphase flow, since the combustion chamber is typically at a supercritical state, the simulation of the mixing and ensuing combustion is a challenging problem, since complex equations of state are required to determine the correct thermodynamic behavior of the fluid mixture. To this end, a new approach is proposed to couple a flamelet/progress variable based combustion model to the extended Peng-Robinson equation of state.

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