Application of Detached Eddy Simulation to Lagrangian Spray Simulations

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Abstract

Lagrangian simulations of liquid sprays involve models for many small scale processes, including primary and secondary breakup or droplet collisions in the liquid phase, and turbulence in the gas phase. For turbulence modelling, two classes of models have evolved, first, turbulence models based on Reynolds Averaging of the Navier Stokes equations (RANS models), and more recently spatially averaging Large Eddy Simulations (LES). Most common RANS models are k-epsilon- and k-omega-models, which describe turbulence in terms of turbulent kinetic energy and the (specific) turbulent dissipation rate. LES models are distinguished by the subgrid-scale-model (SGS model) involved. Studies by other authors have shown that the choice of the turbulence model has major influence on the accuracy of Lagrangian spray simulations.

While most liquid phase models are based on a RANS description of the gas phase, RANS turbulence models are not capable to capture vortex creation and break down in highly unsteady free jets. In turn, LES can describe free jet turbulence very well, but does not link to many liquid phase models properly, as it does not provide time-averaged quantities. This trade-off can be overcome by hybrid turbulence models, such as Detached Eddy Simulation (DES). Contrary to classical hybrid LES-RANS models, which decompose the domain into dedicated LES and RANS regions, DES is basically a LES approach with RANS for subgrid-scale-modelling, i.e. the turbulent transport equations are solved for the entire domain. When combined with a k-epsilon-model, DES can provide the turbulent quantities required by the liquid phase models, while maintaining LES behavior in the free flow.

In this study, the application of DES to Lagrangian spray simulations is assessed by example of a hollow-cone spray as is found in gasoline direct injection engines. The DES model is coupled to a realizable k-epsilon model, and compared to LES and RANS simulations of the same case (including standard k-epsilon, RNG-k-epsilon and realizable k-epsilon models). For all turbulence models, a mesh sensitivity analysis is performed. The influence of turbulence modeling on the spray simulation is evaluated by macroscopic properties such as liquid penetration, vortices formed etc., and by microscopic properties and turbulent quantities, such as turbulent kinetic energy (for the DES and RANS models) and dissipation rates.

Preliminary results indicate that DES can handle free jet turbulence better than the RANS models tested. The DES approach with realizable k-epsilon model shows low diffusivity of turbulent quantities (in particular when compared to the realizable k-epsilon RANS simulation, which is known for its overly diffusive behaviour), and turbulent dissipation is reduced. For the spray simulation, this leads to increased liquid phase penetration, and to a more destinct prediction of vortex structures, which are in many cases dissipated by RANS models. In contrast to the LES simulation, turbulent fluctuations can be derived from turbulent kinetic energy, leading to a more realistic prediction of turbulent interaction and turbulent dispersion. The prediction of turbulent dispersion is crucial to the formation of droplet recirculation regions, which is a known issue when coupling Lagrangian spray simulations to LES simulations. As assumed, the DES simulation appears to combine the benefits of LES and RANS simulations.

Despite the good results, the combination of DES with Lagrangian spray simulation requires further validation by synthetic validation cases. This study has shown that it might be worth the effort.

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