# A High Resolution Study of Non-Reacting Fuel Sprays using Large-Eddy Simulations

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**Abstract**

**Introduction** The present study deals with Large-Eddy Simulations (LES) of non-reacting fuel sprays in internal combustion engine like conditions. The motivation for the research is to gain a deeper understanding of high resolution spray simulations using the implicit Large-Eddy Simulation (iLES) approach in combination with Lagrangian Particle Tracking (LPT). The main objective is to investigate the influence of the grid size on droplet breakup and evaporation in conjunction with the implicit LES method for a well defined reference case. The chosen spray case is corresponding to the "Spray A" conditions specified within the Engine Combustion Network (ECN). This test case is experimentally investigated by several research institutes and the data is freely available through the ECN. The ambient gas density and temperature for Spray A are 22.8 kg/m3 and 900 K, respectively. The injected fuel is n-dodecane and the injection pressure is 150 MPa. The nominal nozzle diameter of the injector is 90 $\mu$m, which leads to an averaged injection velocity of approximately 590 m/s.

**Methods** The simulations are carried out with the open source CFD tool box OpenFOAM. A compressible flow solver is used and the pressure treatment is handled by the PISO-algorithm. The accuracy is formally second order in space and an implicit, 2nd order accurate time integration is used. For the turbulence modeling the implicit LES approach is applied, hence no explicit sub-grid scale model for the unresolved turbulent scales is used. Within this method the grid, or more precisely the numerical discretisation scheme, functions as an implicit low-pass filter and it is assumed that sub-filter scales will dissipate in the same manner as the numerical scheme. The liquid phase is modeled by droplets and hence LPT is used to compute the droplet motion. The box sampling method is used to determine the initial droplet location and the initial droplet size is obtained from a Rosin-Rammler distribution. Heat transfer and evaporation are modeled according to Ranz/ Marshall and Frössling correlations. Two droplet breakup models are compared in this study: the Enhanced Taylor Analogy Breakup (ETAB) and the Kelvin-Helmholtz Rayleigh-Taylor model as proposed by Reitz (1988).

**Computational domain** A fully hexahedral base mesh is used, which is refined by a 2:1 cell-splitting approach in the spray region in order to obtain appropriate cell sizes for iLES. The smallest cell size in this study is 62.5 $\mu$m, i.e. approximately $\frac{2}{3}$ of the nozzle diameter. The time step is in the order of $10^{-8}$s due to the small cell size and droplet time scale.

**Results and Conclusion** Visualizations of the flow field show that the methods used are suitable to resolve the characteristic flow structure (e.g. Kelvin-Helmholtz vortices). Comparisons to the experimental data show a reasonable agreement with respect to liquid and vapor penetration for the two finest mesh resolutions. Concerning the mesh resolution it was found that a cell size of 125 $\mu$m was sufficient to capture the turbulent motion of the spray. Both investigated breakup models performed reasonable well, even though differences in predicted droplet size were found. The differences in droplet size affect again the global spray quantities (liquid/ vapor penetration). Hence, a further investigation and tuning of the breakup model parameter is suggested for the chosen LES approach.

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