Modeling internal combustion engines using the OpenFOAM library

Dr. T. Lucchini, A. Onorati, G. D'Errico, G. Montenegro, A. Della Torre, L. Nocivelli

Department of Energy, Politecnico di Milano, Via Lambruschini 4, 20156 Milan, Italy

OpenFOAM represents a unique tool which can be extensively applied and customized for Computational Fluid Dynamics applications either in research and industrial environments. The consistent object-oriented structure of the code, combined with a large amount of available physical and numerical models makes it the ideal tool to implement suitable solutions for the simulation of complex problems involving moving grids, reacting and multi-phase flows. Within this context, the authors developed libraries and solvers to model flows in internal combustion engines using the OpenFOAM technology. Starting from the consolidated code structure which is publicly available, author's efforts were focused on implementation of mesh management techniques for full-cycle simulation (including automatic grid generation using snappyHexMesh), inclusion of new spray sub-models for fuel-air mixing modeling and development of combustion models based on simplified or detailed chemistry for a proper prediction of engine performance and pollutant emissions. Additional features have also been introduced to model the intake and exhaust systems of internal combustion engines accounting the presence of filtering and catalytic devices. This includes the modeling of heterogeneous surface chemistry and of filtration flows both at micro and macro scale level. In this way, suitable methodologies for CFD modeling of internal combustion engines were assessed, based on simplified or detailed models which can be oriented to design or diagnostic analysis. The presentation will show details of the developed approaches, their validation using consolidated database of experiments and their mutual interaction with the main OpenFOAM code components. Afterwards, the main results of collaboration activities with industrial partners in the field of IC engine simulations will be illustrated, including:

1) Methodology for gas exchange and fuel-air mixing modeling in gasoline, direct-injection engines to minimize soot emissions and increase combustion efficiency;
2) Simulation of flame propagation process in spark-ignition engines, with a comprehensive model which can be used to estimate effects of local flow, turbulence, mixture quality and ignition system on the combustion process;
3) Prediction of combustion in Diesel engines using different approaches, each one of them being the most suitable depending on number of injections and operating condition.

4) Simulation of surface reactions on the microstructure of catalytic devices, such as TWC or coated DPF, and upscaling of detailed information to the full scale simulation based on the porous media approach.
5) Modeling of the urea water solutions injection with improved kinematic and thermal spray-wall interaction, combined with detailed evaporation model of multicomponent droplets, to optimize Diesel DeNOx systems.