MODULE DESCRIPTION

Multiphase Flow Module
Engine CFD Applications

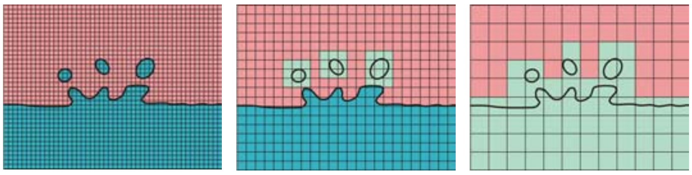
Volume-of-Fluid Hybrid Model Multi-Fluid Model

Figure 1.

FIRE provides three basic models for the simulation of the multiphase flows. The models are classified according to the available grid resolution with respect to the interface length scales, as shown in **Figure 1.**

- Volume-of-Fluid (VOF) is used when there is enough resolution to resolve all interface details.
- Hybrid Model is used when the available resolution can resolve large-scale interface details, while the unresolved small-scale effects are modeled.
- The Multi-Fluid Model is used when the surface details cannot be resolved and the interface interaction terms are modeled.

Summary of the most important features of the FIRE multiphase flow module:

- Robust capability to simulate *N*-phase flows.
- Simulations can be performed on unstructured grids including arbitrary interfaces, sliding, moving boundaries, multiple frames of reference, and mixing planes.
- Arbitrary number of phases can be specified within the momentum equilibrium (homogeneous flow) inside the *N*-phase mixture.
- Capability of the coupling between the multi-fluid and VOF models in the same multiphase flow simulation, resulting in the great flexibility for model development and implementation.
- Possibility to include multiple porosity regions with non-uniform volume fraction distribution.
- Compressibility effects available for multiphase isothermal flows.
- Available cavitation, evaporation/condensation (boiling) models.
- Cavitation, boiling, and VOF models can be used with more than two phases.
- User functions available for the implementation of the customer specific models.

Presented application samples were performed using the multi-fluid model.

APPLICATION: Diesel Injector

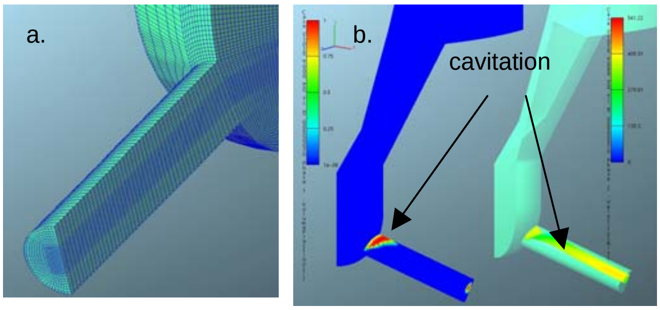

Figure 2.

Inlet pressure of Diesel injectors can reach levels of up to 2000 bars. The resulting pressure drop across the injector generates very high fuel velocities that inevitably cause cavitation. Cavitation has two main effects: a.) possible erosion of the material in the injector, and b.) influence on the atomization process. The simulation results can help improve the injector design. Sometimes simulations is the only available tool to help understanding the flow within the injector due to very small nozzle dimensions (nozzle diameter is usually a fraction of a millimeter). Similar situation occurs in some types of high-pressure gasoline injectors [1].

The results of flow simulation in the Diesel injector are shown in **Figure 2** [2]. The cavitation region can be clearly seen around the top edge of the nozzle. The predicted form of the cavitation region has also a typical shape as observed in the experiments.

APPLICATION: Gasoline Swirl Injector

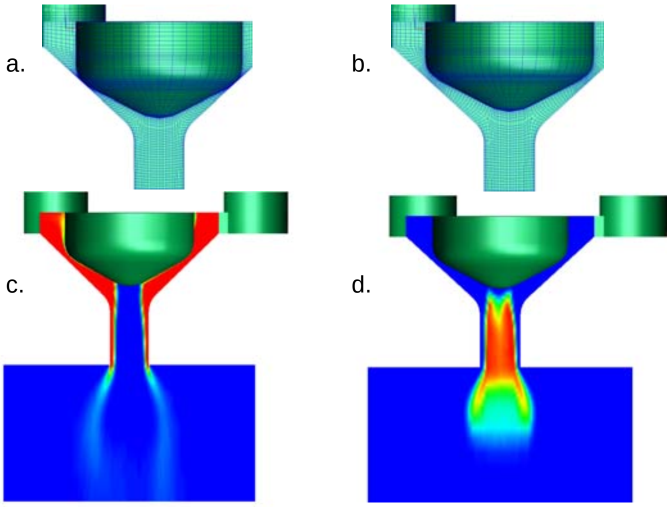

Figure 3.

Swirl injector geometry and its features have been known for some time. Due to its good atomization characteristics it has been recently used in gasoline direct injection engines. Four separate inlets into the injector cause swirl motion of the fuel within and outside the nozzle [3]. High shear rates between the fuel and air cause surface instabilities and formation of the droplets. It is interesting that the flow can reach very low-pressure levels in the core of the swirl. Pressure can reach levels below the saturation value and if that happens, direct evaporation occurs.

The simulation of such flow in the swirl injector is shown in **Figure 3** [4]. The calculation started with the needle in closed position proceeding with the needle opening. The two extreme positions of the needle are shown in **Figure 3.a** and **Figure 3.b**. The formation of the liquid swirl is seen in **Figure 3.c** with vapor generated within the swirl core, **Figure 3.d**.

APPLICATION: Injector/Spray Coupled Simulations

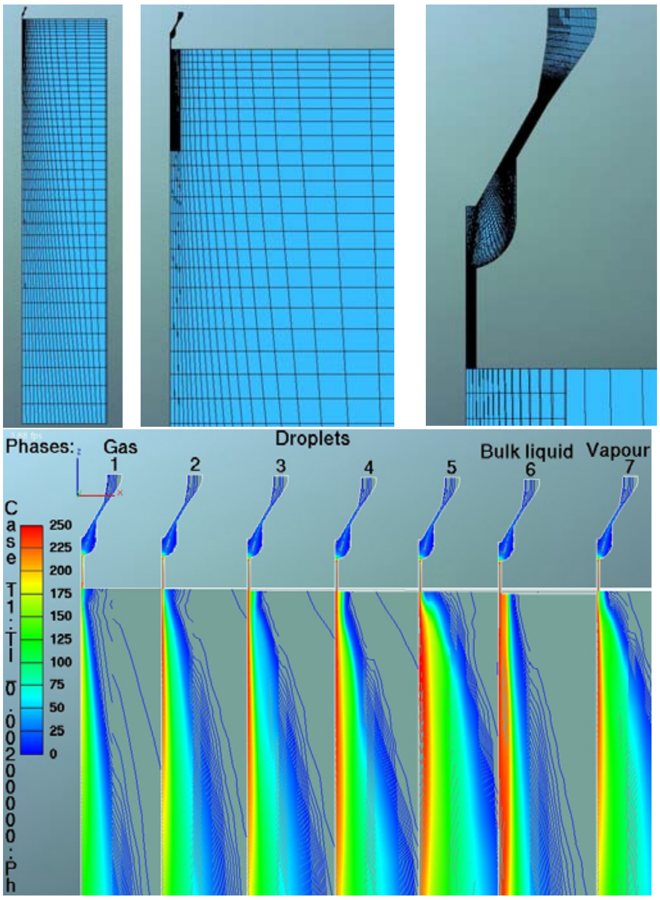

Figure 4.

Spray simulation is usually performed with the discrete particle simulation model in Lagrangian frame. Even though this method provides remarkably good results, it is limited to low fuel volume fraction areas away from the injector. The multi-fluid model does not have this limitation and its use in the nozzle proximity has a very good perspective ([5], [6]). **Figure 4** shows the geometry that was used in the simulation and the resulting calculated velocity fields [7]. The simulation included the flow within the injector and consisted of gas, bulk liquid, its vapor, and four (4) droplet classes.

Figure 5 shows the comparison between the measured and predicted spray penetration lengths. A remarkably good agreement can be observed. Even though the method is still under development, it is evident that it has some very promising features.

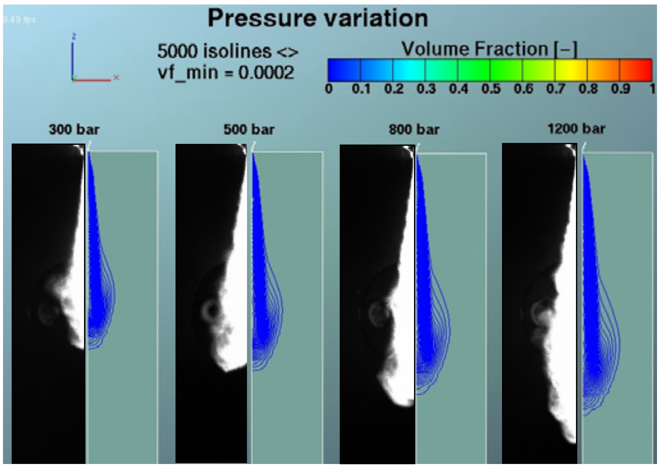

Figure 5.

REFERENCES

1. Greif, D., Monteverde, B., Alajbegovic, A., "Simulation of Cavitating Flows in Gasoline Injector," International Conference on Liquid Atomization and Spray Systems, Sorrento, July 2003.
2. Alajbegovic, A., Greif, D., Meister, G., "Multiphase Flow Simulations of Injector Flows," 2nd MIT Conference on Computational Fluid and Solid Mechanics, Boston, Massachusetts, June 2003.
3. Alajbegovic, A., Meister, G., Greif, D., Basara, B., "Three Phase Cavitating Flows in High Pressure Swirl Injectors," International Journal of Experimental Fluid and Thermal Science, 26 (6-7), 2002, pp. 677-681.
4. Meister, G., Alajbegovic, A., Lai, M.C., Yoo, J.H., "Transient Simulation of DGI Engine Injector with the Needle Movement," SAE-2202-01-2663, SAE Powertrain & Fluid Systems Conference, November 2002.
5. v. Berg, E., Alajbegovic, A., Tatschl, R., Krueger, C., Michels, U., "Multiphase Modeling of Diesel Sprays With the Eulerian/Eulerian Approach," European Annual Conference on Liquid Atomization and Spray Systems, Zurich, September 2001.
6. v. Berg, E., Alajbegovic, A., Greif, D., Poredos, A., Tatschl, R., Winklhofer, E., Ganippa, L.C., "Primary Break-up Model for Diesel Jets Based on Locally Resolved Flow Field in the Injection Hole," European Annual Conference on Liquid Atomization and Spray Systems, Zurich, September 2002.
7. v. Berg, E., Edelbauer, W., Alajbegovic, A., Greif, D., Poredos, A., Tatschl, R., "Coupled Calculation of Cavitating Nozzle Flow, Primary Diesel Fuel Break-Up and Spray Formation with an Eulerian Multi-Fluid Model," International Conference on Liquid Atomization and Spray Systems, Sorrento, July 2003.