Lib-ICE: A C++ object-oriented library for internal combustion engine simulations - spray and combustion modeling

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Abstract

The Internal Combustion Engine Group has developed a set of applications and libraries (Lib-ICE) for CFD modeling of IC engines using the OpenFOAM® technology. This presentation provides an overview of the Lib-ICE capabilities to simulate the gas-exchange, fuel-air mixing and combustion processes in SI and Diesel Engines. Specific developments were carried out in the fields of:

- Mesh management: to handle the motion of complex grids in presence of high boundary deformations and topological changes [1]. The possibility to dynamically refine the grid was also included [2].
- Spray modeling: to extend the capabilities of the OpenFOAM spray library including new models for atomization, secondary breakup and spray-wall interaction [1,3].
- Combustion modeling: to provide a set of models that can be used both for development and for diagnnostic purposes [4].

The proposed models were employed to simulate three different real engine cases:

- Diesel Combustion in a direct-injection engine with complex injection strategies. A comparison between computed and experimental data of in-cylinder pressure, heat release rate and pollutant emissions is provided for a wide range of speed and loads.
- Low-temperature combustion in an optical engine. Experimental data of in-cylinder pressure and mixture fraction distribution at auto-ignition time are used to validate the proposed approach.
- Combustion in a SI-Engine. The intake stroke was simulated to initialize the gas motion at intake valve closure time. Combustion simulation is then performed including chemical equilibrium calculation for the burnt gas composition and evaluating the effects of different models to compute the turbulent flame speed.

Table 1: Spray models available in OpenFOAM and Lib-ICE.

Injection	Blob, Huh, Hollow-Cone, Pressure-Swirl
Atomization	Huh-Gosman, Wave, LISA, Bianchi
Breakup	TAB, ETAB, KH, KH-RT, Reitz-Diwakar
Evaporation	Frossling
Heat-Transfer	Ranz-Marschall
Wall-impingement	Bai-Gosman, Naber-Rutland
Collision	Nordin, O'Rourke
Turbulent dispersion	RAS, LES

Table 2: SI combustion models available in Lib-ICE. For all of them, burnt gas composition is calculated assuming chemical equilibrium. The possibility to predict knock is included using the Shell-Model

Weller	Transport equations for the normalized fuel fraction b and the flame wrinkling factor Ξ.
Zimont	Transport equation for the normalized fuel fraction b. The flame wrinkling factor Ξ is computed via Zimont approach.
ECFM-3Z	Transport equations for the normalized burnt fraction c and the flame surface density Σ. Handles stratified combustion.

Table 3: Diesel combustion models available in Lib-ICE.

TITC	Tabulation of ignition delays + Eddy Dissipation Model (4 species)
CTC	Shell Model + Characteristic Time-scale Combustion Model (chemical equilibrium, 11 species)
PSR	Detailed chemistry + in-situ tabulation (ISAT) + dynamic reduction (DAC)

Table 4: Pollutant emission models available in Lib-ICE

Soot	Hiroyasu model.
NO_x	Extended Zeldovich

References

[1] T. Lucchini et al., Proceedings of the COMODIA 2008 Conference, Sapporo, 2008.
[2] T. Lucchini et al., SAE Paper 2010-01-0179.
[3] T. Lucchini et al., SAE Paper 2009-24-0015.
[4] G. D'Errico et al., SAE Int. Jou. of Fuel and Lubricants 1, 452-465.