Franco-British INTERREG European Programme

Les Sprays

11 June 2007

Introduction

Overview of the results of numerical and theoretical studies of processes in sprays.

The main focus is made on sprays found in technology of high-pressure atomisation in direct injection Diesel engine.

Structure of presentation

- Objectives
- Methods
- Results of numerical studies:
  - Penetration of cold sprays
  - Autoignition in Diesel sprays
- Conclusions

Objectives

- Development of advanced analytical and numerical models for in-cylinder processes in internal combustion (IC) engine
- Implementation of the models in KIVA II spray code
- Validation of the models against in-house measurements

Stages of research

Studies of dynamics of cold sprays (with a view of automotive, environmental, biomedical, etc applications). Modelling of processes of liquid injection, atomisation into droplets, gas-droplet momentum exchange, droplet collisions, dispersion, etc.

Studies of processes in hot sprays (Diesel engine). Modelling of gas-droplet heat and mass transfer, and fuel autoignition.

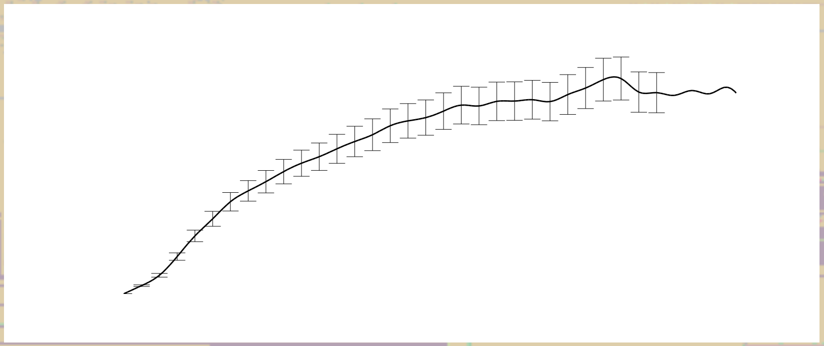
KIVA II - Methodology

- Eulerian (gas)/ Lagrangian (liquid) code for computation of flows with sprays and chemical reactions
- Liquid phase is represented by droplet parcels, characterising droplets of a given size, velocity and temperature
- Stochastic sampling technique is applied to describe droplet injection, collisions, breakup and turbulent dispersion

Stage 1 – Studies of cold sprays

- In-house measurements
- Results of studies:
  - Conventional spray breakup models
  - A new phenomenological breakup model
- Conclusions

Experimental data. Validation test case

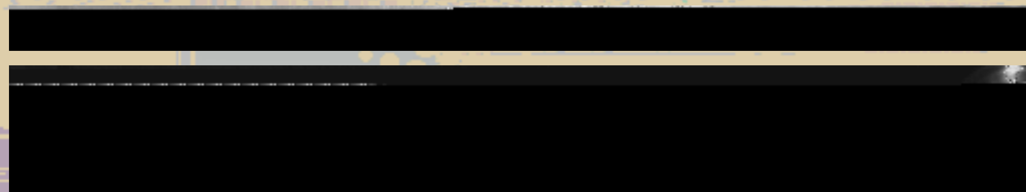


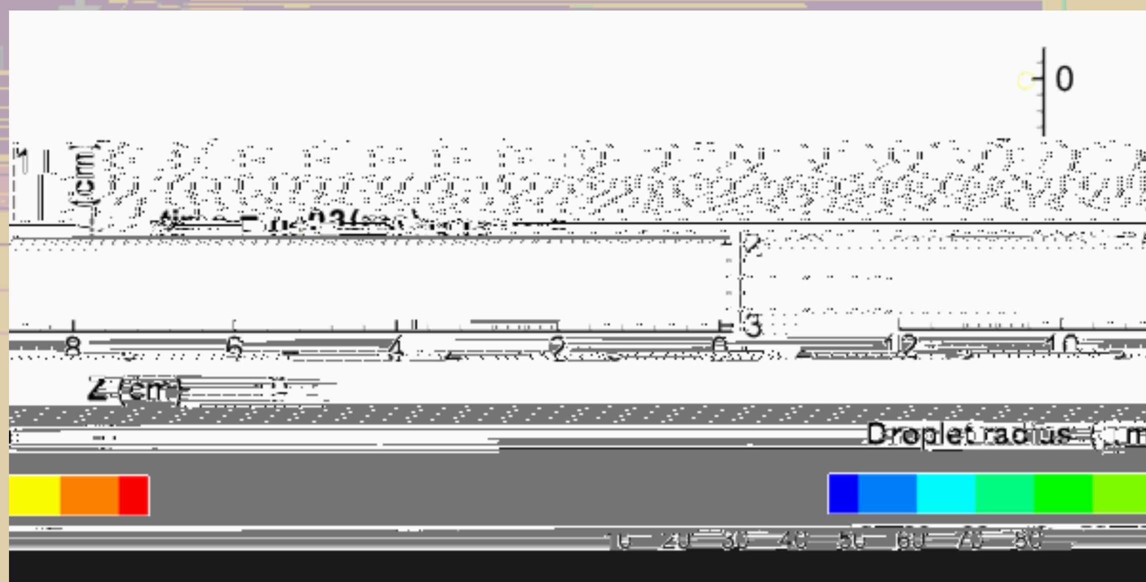
Effects of cavitation

- Effects of cavitation are described using the dimesionless criterion – cavitation number CN.
- Parameters of injected parcels (diameter and velocity) are modified depending on CN.

Diesel fuel spray (photograph by K. Karimi, University of Brighton)

Comparison with spray video





Conclusions. Cold sprays

- Several models of spray breakup has been implemented in KIVA code and validated against the in-house measurements of Diesel sprays
- A model for the breakup of accelerating sprays has been developed
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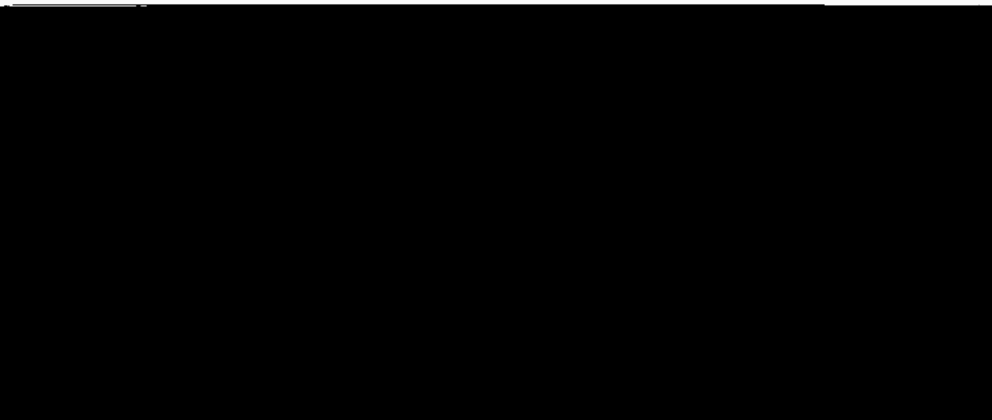
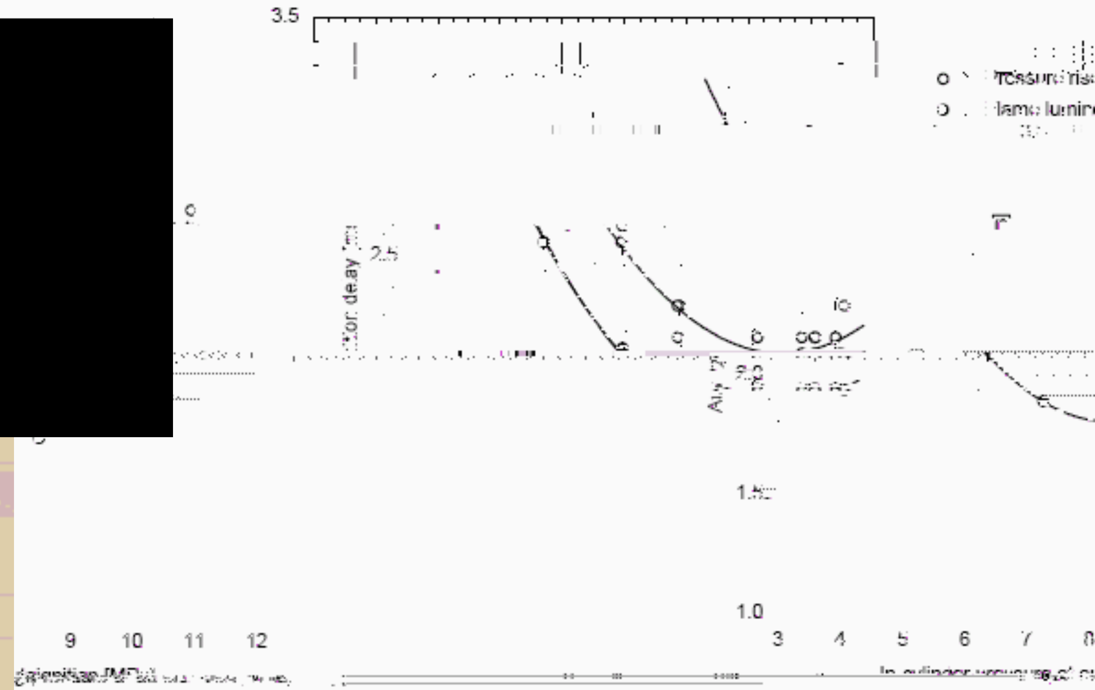
Stage 2 – Hot Diesel sprays

- Experimental observations
- Models of droplet heating and evaporation
- Shell model of autoignition
- Results of numerical studies

Measurements of autoignition delay time in Diesel sprays (Crua, 2002)





autoignition delay time comprises of the

- ignition delay of the vapour fuel, and
- delay time, spent on liquid breakup, evaporation and mixing processes

Key processes in modelling of autoignition in Diesel sprays

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Models of droplet heating and evaporation

Models of heat and mass transfer from evaporating droplets has been reviewed (Sazhin, 2006)

- Due to high diffusivity of the gas phase thermal conductivity can be considered steady-state for the gas, and transient for the liquid
- Heat transfer in the liquid and gas phases are modelled separately
- Preliminary study have shown that in presence of breakup choice of the liquid-phase model can have significant effect on the predicted rate of fuel evaporation

This study investigates the effects of heat-mass transfer on evaporation and ignition for realistic transient 3D Diesel sprays

Liquid phase models

- Infinite thermal conductivity (ITC) model – based on the assumption that there is no temperature gradient inside droplets
- Effective thermal conductivity (ETC) model

Gas phase models

- Conventional KIVA describes the heat and mass transfer from the droplet surface using approximations for Nusselt and Sherwood numbers:

$$= \left(+ \qquad\qquad\qquad \right)$$

- Abramzon and Sirignano (1998) have suggested more accurate approximations, taking into account finite thickness of thermal boundary layer around droplet, effects of variable properties, Lewis number, and the Stefan flow on heat and mass transfer between the droplet and the gas

Shell model (Halstead, 1977)

- Describes the autoignition chemistry using reduced mechanism of eight-step chain branching reactions between the fuel, O_2, products (H_2O, CO, CO_2), radicals (R), branching (B) and intermediate (Q) agents
- Originally was designed for autoignition in premixed fuels
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Basic validation case – autoignition in premixed fuel (Halstead, 1977)

Computational studies of autoignition process in Diesel sprays

Test cases:

- Single-hole injector of nozzle diameter 0.2 mm;
- Injection pressure 1600 bar;
- Fuel temperature at injector 350-400 K (estimated).

In-cylinder temperatures at TDC (K)	832	847	852
In-cylinder pressure at TDC (bar)	56	62	69
Autoignition delay time (ms)	2.37	2.04	1.78

Results – pre-ignition spray

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Directions for future studies

- Theoretical studies:
  - stability and breakup of transient jets and sprays
- Experimental studies:
  - breakup length in transient sprays
- Modelling and numerical analysis:
  - time constant for the primary atomisation in stochastic breakup model
  - computation of heat-mass transfer at supercritical in-cylinder temperatures and pressures
  - analysis of the limiting phases (kinetics and diffusion) of autoignition using Shell model
  - fuel combustion and soot formation models in KIVA

Thank you ☺