Confined vortex rings in gasoline fuel sprays: modelling and observations

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Introduction

In our earlier papers [1,2] basic properties of vortex ring-like structures in gasoline engines were interpreted in terms of the generalised vortex ring model described in [3]. The main restriction of the approach considered in these papers was that it was assumed that vortex rings developed in an unbounded domain and the effects of confinement of vortex rings inside gasoline engines were ignored. A vortex ring model taking into account the effects of confinement in a tube (a good approximation of a confinement in realistic gasoline engines) was described in our recent paper [4]. The range of validity of this model was investigated based on the comparison between the predictions of the model and the results of Direct Numerical Simulations (DNS). The main objective of the current presentation is to investigate the dynamics of sprays in realistic gasoline engine conditions, taking into account the effects of the confined vortex rings, and compare the results with experimental observations where possible. The model for confined vortex rings described in [4] will be used in our analysis.

Methods

The confined vortex ring model combines model, developed by Kaplanski & Rudi [5], with Brasseur's [6] approach to deriving a wall-induced stream function correction. In this model, using the power-law assumption for the time variation of the viscous length of the vortex ring, the time variations of the main integral characteristics, circulation, kinetic energy and translational velocity were obtained. The Fully Lagrangian Approach (FLA), suggested by Osiptsov [7], is used for the analysis of droplets in a confined vortex ring flow. The methodology used in the experimental studies of vortex ring-like structures in gasoline engines is described in [1].

Preliminary Modelling Results

The preliminary investigation of a transient axially symmetric flow of droplets in a vortex-ring flow field was performed using the one-way coupled, two-fluid approach. The carrier phase parameters were calculated using the analytical solution suggested in [5], which does not take into account the effects of vortex ring confinement. Due to the vortical nature of the flow, the mixing of inertial admixture were accompanied by crossing particle trajectories. According to the FLA, all the dispersed phase parameters, including droplet number density, were calculated from the solution to the system of ordinary differential equations along chosen particle trajectories. Two flow regimes corresponding to two initial conditions were investigated: (i) injection of a two-phase jet; and (ii) propagation of a vortex ring through a cloud of particles. It was shown that the dispersed media may form folds and caustics in both types of flow. In both cases the ranges of governing parameters leading to the formation of mushroom-like clouds of particles were identified.

Preliminary Experimental Results

An experimental study was carried out to investigate the characteristics of a gasoline fuel spray injected by a piezoelectric type fuel injector. The injector is commonly used in spray-guided, direct injection combustion systems, where the fuel spray is typically confined by the cylinder bore, during full-load engine operation or by the piston bowl volume at an engine part-load, stratified operating condition. The formation of vortex-ring like structures within the fuel spray plays a central role in efficient mixture preparation [8]. In this study, the single-hole injector was mounted in a transparent spray chamber with gas at room temperature and pressure conditions. Clear inserts were positioned within the chamber to mimic the effects of confinement within the engine and within the scope of the modelling approach. A surrogate fuel (iso-octane) was injected at pressures of up to 100 bar and with injection durations of up to 2 ms. The mean injection flow rate was measured at approximately 30 mg/ms at 100 bar fuel line pressure. The directly actuated injector needle opens outwardly producing a hollow-cone spray with a manufacturers stated nominal spray angle of 85° +/- 5°.

Several experimental techniques were carried out to study the development of the fuel spray and the vortex-ring like structures observed within the spray. Firstly high-speed photographic imaging was used to analyse the spray structure following the start of needle lift. The images clearly showed the early spray development from a thin liquid sheet, the initial formation of vortex rings close to the nozzle exit shortly after the start of injection and the subsequent evolution of these rings beyond the end of injection. The time-resolved Particle Image Velocimetry (PIV) technique was used to determine the velocity of discrete fuel droplets in the latter phases of the spray development. An example for an unconfined spray is shown in Figure 1 below for a frame rate of 8 kHz. In the final experiment, the Phase Doppler Anemometry technique was used to determine the liquid droplet velocity and size distributions within a plane of symmetry the spray that bisected the nozzle. A traversing system was used to position the measurement volume on a grid and data was collected for two components of velocity. The quantitative PIV and PDA data confirmed the presence of several complex vortex-ring like structures and revealed the distribution of particles within their structures. The experimental data highlighted the significant effects of the confinement upon the entrained gas and liquid phases and the formation of these structures.

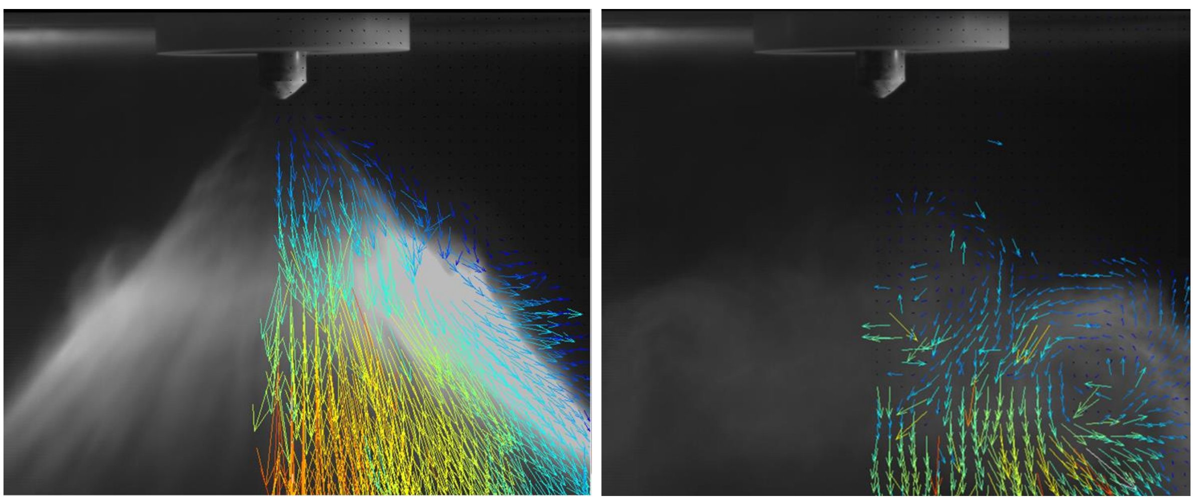

Figure 1.

Time-resolved Particle Image Velocimetry measurements of the liquid phase gasoline droplets at t = 1.375 ms (left hand side) and 3.125 ms (right-hand side) after the start of injection with a fuel injection pressure of 100 bar and an injection duration of 1 ms for an unconfined case.

References

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