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## Simultaneous gas and spray PIV measurements in an optical engine

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### ABSTRACT

Engine internal aerodynamic reveals complex flow involving multi-scale turbulence, flow structure compression, two-phase interactions and are responsible for the mixing process and the engine performance and efficiency. Recent efforts have been made to describe in details in-cylinder flows either with temporal (HR-PIV) or spatial (Tomo-PIV) resolution. However, for gasoline direct injection engine (GDI), the dynamic coupling between gas and spray droplets should also be undertaken for a correct evaluation of in-cylinder aerodynamics. Simultaneous measurements of instantaneous gas and droplets velocities during intake and compression strokes are proposed by means of two-phase PIV based on fluorescence [1, 2]. The technique is adapted to the constraints of optical engine and associated to specific algorithms development for the liquid phase.

The engine test bench consists in a mono-cylinder GDI engine (AVL) which operates up to 3000 rpm in optical configuration with a displacement volume of 450 cm<sup>3</sup> and a compression ratio of 8.5. The optical accesses to the combustion chamber is enabled by a quartz-glass liner. The injection system is composed of a solenoid multi-hole injector Bosch fed up by a pressurized volume to ensure a stable injection pressure up to 100 bar. An injector power control module (EFS IPOD) is used to drive the injector and control injection timings in the engine cycle.

The two-phase PIV technique is based on the use of two different dyes dissolved in the seeding particle and gasoline, producing fluorescent emissions on separated spectral bands for each phase [1, 2]. The phase separation is enabled by a detection system consisting of a dichroic window distributing the collection signal on two synchronized PIV cameras (Hamamatsu 12 bits 2018×2048 pixels) equipped with Nikkor lenses (50mm f/#2) and adapted pass-band filters. Angular controls are mounted at the base of the dichroic sheet and both cameras in order to adjust with precision the common camera field of view. A refined adjustment based on a polynomial approach of 5<sup>th</sup> degree is then numerically performed from calibration grid images to ensure a perfect images overlap and to correct image distortion induced by the glass liner. Dyes excitation is performed with two lasers at different wavelengths (532 nm for the gas and 355 nm for the spray) in order to independently adjust the PIV acquisition delays to the high velocity shift between phases in the early stage of injection. The use of two wavelength also improve the spectral separation of fluorescence signal and then the phase discrimination. An original synchronisation of the laser and camera with the engine cycle is ensured by means of a programmable time board to get rid of engine speed fluctuations and guarantee a fixed working frequency for the lasers while limiting injection and fouling to the acquisition triggering.

Velocities of the gas and the liquid phases can thus be acquired simultaneously for engine conditions where the two phases are present, typically early after the start of injection [2, 3]. Prior to the correlation step, a pre-processing of the fluorescence images is performed to enhance the correlation level. A masking technique, with adaptation of the masking surface at each angular position is also used. The PIV post-processing is then adapted to the present configuration with two different algorithms for each phase. The velocity fields of the gaseous phase are obtained by a multi-pass subpixel shift correlation algorithm based on the correlation of the seeding patterns [4]. Interrogation window size of 32×32 pixels (1.85×1.85 mm<sup>2</sup>) with an overlap of 50% has been used with a vectors filtering based on a minimum value of the Signal to Noise Rate (SNR) and on a median filter which are adapted to each experimental condition. This enables to reject most of non-valid vectors. Gas phase velocity calculation for internal engine flow is validated in our configuration by means of simultaneous Mie-based PIV and fluorescence based PIV. Comparison of mean and instantaneous velocities show less than 5 % differences. The density of the liquid phase is heterogeneous with a very dense part near the injector nozzle and a dispersed part after the breaking of the liquid sheet. In the spray dispersed part, velocities are processed with a particle approach, whereas in the dense part of the spray, a specific algorithm based on pattern correlation is developed. Preferential direction and topology of the spray are taken into account through the window shape and size.

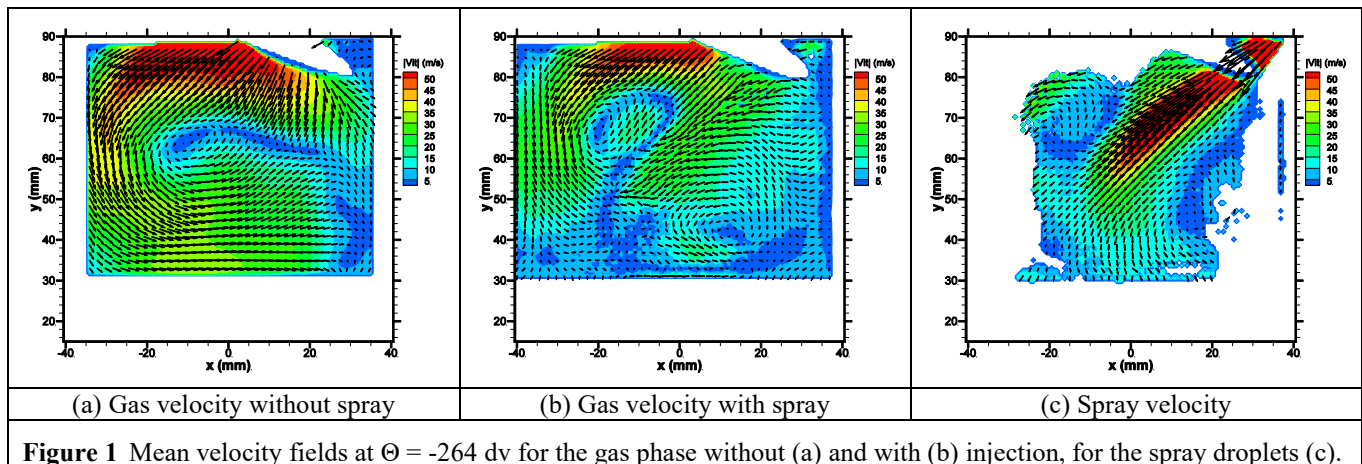
Operating conditions correspond to homogeneous combustion at partial load. The start of injection is fixed at 300 BTDC. The injection duration is adjusted for the engine rotation speed in order to fulfil the unity equivalence ratio. For the present study, measurements have been performed with engine rotation speed of 2000 rpm and injection pressure of 100 bar and 50 bar. Acquisitions are performed during intake and compression phases from 288 BTDC till 50 BTDC.

Figure 1 presents the gas velocity fields coloured by the velocity amplitude (left) without injection for an acquisition at 264 BTDC, during the intake phase. The intake valve jet is developed and forms a large-scale rotating structure, giving rise to the tumble motion. The velocity fields measured with injection is presented in the middle row for the same conditions and the corresponding spray velocity is shown on the right row. The comparison of these velocity fields show that the gas velocities are strongly impacted by the presence of the spray injection. The spray dynamics and interactions with the carrier phase must be taken into account for a correct evaluation of engine internal aerodynamics.

The tumble positions and amplitudes are extracted from  $\Gamma_1$  scalar map and analysed during the engine cycle. The tumble trajectory is modified under influence of the spray development and is limited to a vertical displacement. The spray injection also induces a reduction of the tumble intensity reaching 50% at 50 BTDC, near the compression point. The modification of injection pressure shows that the more the pressure increases the more the tumble level is reduced near the compression point. These results put forward that direct injection strongly impacts the internal aerodynamic in the present configuration.

The flow structure modifications will be described in details based on the superimposed spray and gas velocity field in the cylinder volume. Topology of the spray dynamics and its modification due to engine turbulent flow field will also be analysed by means of a comparison of the spray velocity field measured at rest and the one measured in the engine volume.

The whole results obtained in this study will help understanding the dynamic coupling between the engine in-cylinder flow and the high-pressure spray, it will also provide more realistic internal engine aerodynamic in the presence of injection for engine simulation.



## ACKNOWLEDGEMENTS

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