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PIV Investigation of a Pressure-Swirl Atomizer Spray

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Abstract This contribution presents an experimental investigation of spray characteristics of a spill-return pressure-swirl atomizer for a small-sized turbojet engine by means of Particle Image Velocimetry. The nozzle was tested on a cold test bench at atmospheric pressure and room temperature. Measurements were carried out in an axial section of the spray cone with various single-camera and stereoscopic PIV configurations. Results of our measurements provide a quantitative visualisation of the spray flow fields in regimes based on the engine operating conditions. Comparison of velocity profiles obtained from the individual configurations is presented and discussed.

1 Introduction

Pressure-swirl atomizers are simple and reliable atomizing devices which have been applied in industrial burners, propulsion systems and many other engineering areas. Their common feature is the formation of a thin conical liquid sheet at the discharge orifice which spreads under a certain angle due to centrifugal forces. Disturbances propagating on the surface of this sheet cause its disruption into ligaments and finally into droplets in the form of a hollow cone spray. Current research interests have been focused on the improvement of spray characteristics of fuel nozzles since spray quality has a crucial effect on combustion stability limits, combustion efficiency and pollutant emission levels [1].

PIV is a technique with high spatial resolution allowing measurement of velocity distribution and visualisation of structures in a section of the flow field. Its application to sprays is less common than e.g. Phase-Doppler Anemometry and it is rather a challenging task. Some studies by means of PIV dealt with measurements of the internal spray structure [2] and interaction of the spray with ambient air [3].

The objective of this study was to investigate the spray characteristics of a miniature spill-return pressure-swirl atomizer for a small-sized jet engine designed for experimental aircraft and gliders (discharge orifice d_o = 0.36 mm, spill orifice d_{spill} = 1 mm; a sketch can be found in [4]). The investigation of spray characteristics of this nozzle is an important step in the engine development process. Single-camera PIV and stereoscopic PIV (SPIV) measurements were carried out in various configurations. Comparison of mean velocity distribution for selected operating regimes is presented and discussed.

2 Experimental methods

2.1 Test rig

The test rig for studying spray characteristics comprised a cylindrical collection vessel (approx. 80 cm long and 50 cm in diameter) mounted on a stand with its axis in the vertical position. The atomizer was located centrally approx. 20 cm above the vessel. The nozzle discharge orifice was oriented vertically downwards. The atomized kerosene gravitated to the bottom of the vessel, from where it was returned to the fuel tank. The atomizer was tested for various inlet pressures (150 kPa – 1 MPa) and spill line pressures based on the typical engine operating regimes. In this contribution, two regimes are presented: 200 kPa inlet pressure with 50 kPa spill line pressure (called “regime 1” hereafter) and 1 MPa inlet pressure with 400 kPa spill line pressure (called “regime 2” hereafter).

2.2 Data acquisition

A light sheet generated by a Nd:YAG double-pulse laser illuminated an axial cross section of the spray. Single-camera measurements were carried out first with a 60 mm macro lens (field of view 77 x 62 mm); the latter measurement incorporated a 28 mm lens for a larger field of view (162 x 130 mm). The camera was oriented perpendicular to the plane of the light sheet (**Fig.1**). Both SPIV configurations were symmetrical with the stereoscopic half angle θ set to 40°, which should provide a sufficient accuracy for the measurement of the out-of-plane velocity component [5]. The 28 mm lens was used also for SPIV 1 (FOV 162 x 126 mm) and 60 mm lens in case of SPIV 2 (FOV 106 x 60 mm). All CCD cameras were of the same model with 1.3 Mpx resolution. Time delay Δt between laser pulses was set according to the mean particle image displacements from 50 µs at the lowest pressure setting to 15 µs at the highest one.

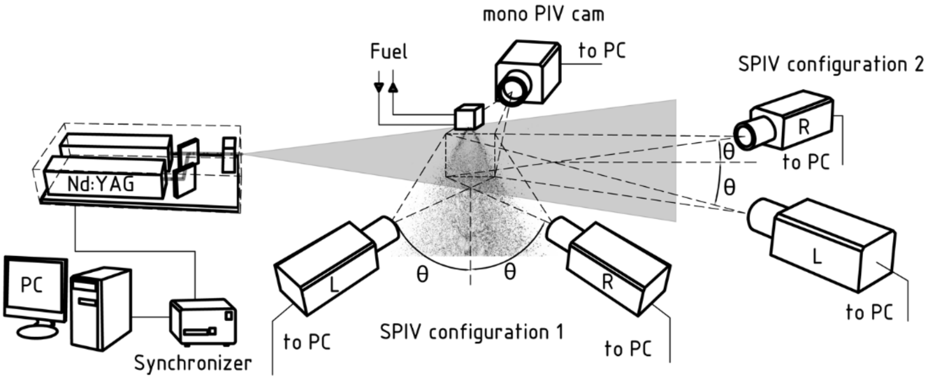


Fig. 1 Configurations of the PIV system.

2.3 PIV processing setup

Image pairs with subtracted background were interrogated in Insight 3G 10.0.2. software package (TSI, Inc.) using a two-pass multi-grid cross-correlation algorithm. The starting window size was 64 x 64 px, followed by one refinement at 32 x 32 px. A relatively large displacement between particle images in regimes with the 60 mm lens was treated by window offset in the z-axis direction. This improved the signal-to-noise ratio thanks to lower in-plane correlation loss. The resulting 2C and 3C velocity vector fields were averaged over 500 instantaneous vector fields (1500 in case of SPIV 1).

3 Results and Discussion

Sprays in general represent an optically harsh environment for PIV. In some areas the measurement was inaccurate mainly due to low seeding density, large speckles and droplet clusters (**Fig. 2**). In principle, PIV measures the displacement of all objects in the flow, either ligaments or droplets. However, quality of PIV relies very much on the size, concentration and spatial distribution of seeding particles. Excessive velocity gradients contribute to in-plane and out-of-plane loss of correlation. This phenomenon is most significant at the spray periphery. This area is formed by ligaments and large droplets with high kinetic energy. The best seeding quality was achieved in the spray core at higher pressures. This area is formed by a fraction of the smallest droplets with low velocity. Droplet velocity distribution in the spray is highly dependent on the injection pressure differential (**Fig. 3**). Single-camera PIV is unable to resolve the tangential velocity component due to perspective error and this component is lost. SPIV eliminates this problem and one can expect higher mean velocity obtained from SPIV. Comparison of the velocity profiles at various z-values downstream from the nozzle has revealed that data measured with SPIV 1 are shifted towards higher values (**Fig.4**). Tangential velocity reaches maxima close to the nozzle orifice at the highest pressure setting (up to 4 m/s). With increasing downstream distance, influence of the tangential component decreases (**Fig. 5**). In contradiction to SPIV 1, configuration SPIV 2 in average gave lower velocity values than the other three settings. This might have been either due to a calibration misalignment or acquisition settings (Δt, field of view). A relatively high residual error of this setting resulted in rejection of significant portion of reconstructed 3C vectors in area close to the nozzle orifice. Anyway, this configuration is potentially interesting since both cameras are aligned in the

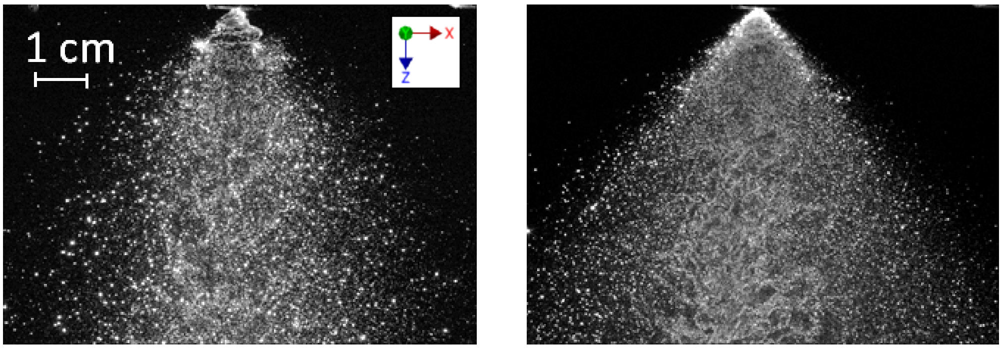


Fig. 2 Instantaneous PIV captures. Left: regime 1; right: regime 2.

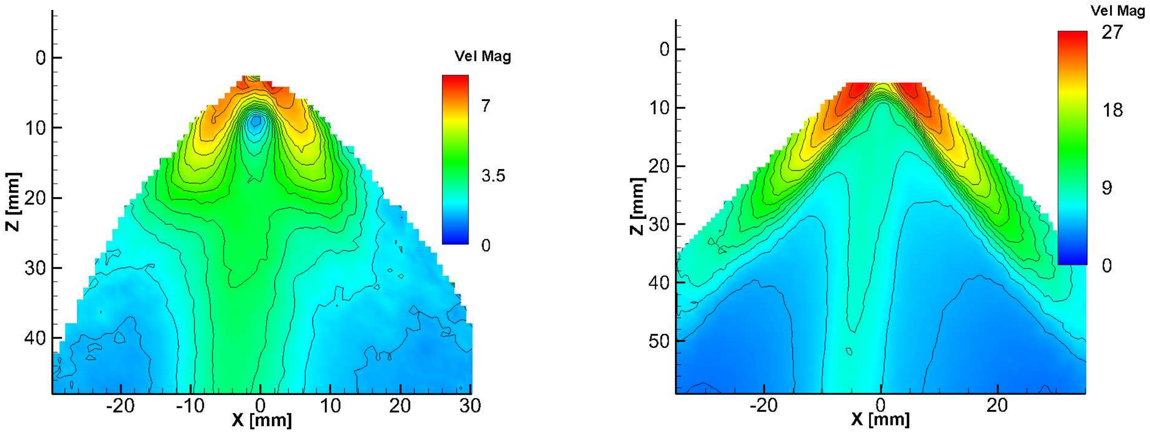
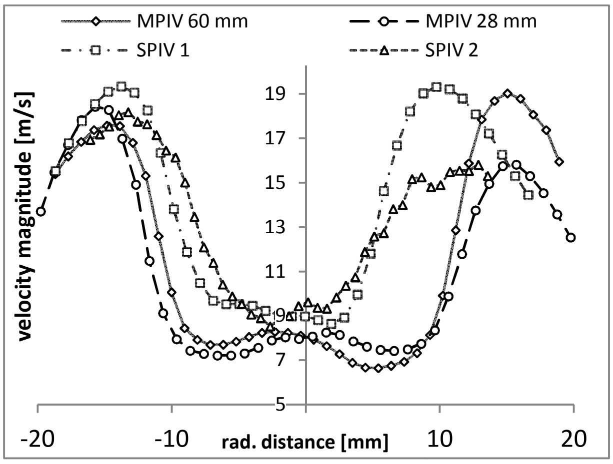
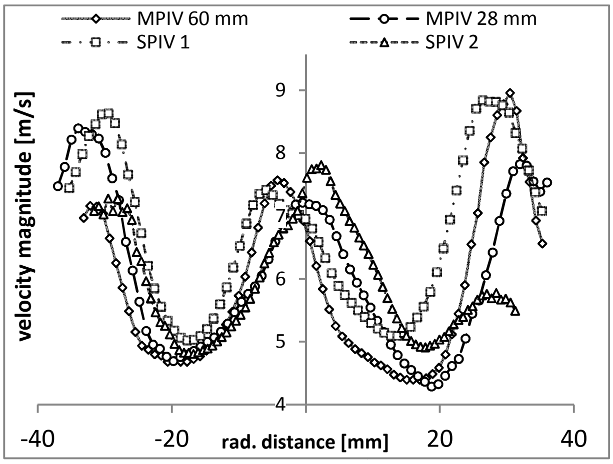


Fig. 3 Average velocity vector field from single-camera PIV. Left: regime 1; right: regime 2.

forward scattering mode (lens apertures can be set identically) and it will be exploited in future experiments. High number of valid vectors in the single-camera measurements was achieved with the larger field of view (28 mm lens). This is primarily due to smaller effective particle image diameters and shorter pulse separation times set for this configuration.





: 20±1 mm;

at z = 40±1 mm;

4 Conclusions

This study focused on investigation of spray characteristics by means of single-camera and stereoscopic PIV. Results of our measurements provide an insight into the spray flow fields. Velocity distributions obtained from single-camera measurements are in good agreement. Results of stereoscopic measurements are contradictory. SPIV configuration 1 confirmed our expectations; however, a disagreement was found in the results obtained with SPIV 2, where velocity profiles in all tested regimes exhibited lower values than in other three PIV configurations. Future investigations will focus on refinement of PIV for spray applications.

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