Study of Helical Vortices in Swirling Jets and Flames by Tomographic PIV

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It is recognized that helical vortices are formed in swirling jet flows and promote mixing in comparison to the jets without swirl. However, influence of these vortices (including precessing vortex core) on stabilization of flames is not completely understood. Developing nowadays volumetric velocimetry techniques can provide deeper insight into this issue. The aim of the present study was to investigate 3D vortex structures in an open swirling turbulent jet and premixed methane/air flame by using a tomographic PIV system. The system performance was also tested on a laminar conical flame.

Experiment description

The jet flows were organized by a nozzle with outlet diameter of 15 mm. The bulk velocity of the air flow was 5 m/s. Different swirlers could be placed inside the nozzle to produce low- and high-swirl flows. The strength of the swirl is defined in terms of the absence/presence of a central recirculation zone in the time-averaged velocity field of the non-reacting flow. To provide PIV measurements, the flow was seeded by 4 μm AlO particles. In case of the methane-air flame study, the equivalence ratio of the mixture issuing from the nozzle was 0.7.

For calibration of the optical system, a plane calibration target was mounted above the nozzle. The nozzle and target were moved by a traverse system. A self-calibration procedure (similar to that by Wieneke, 2008, Exp. Fluids 45: 549–556) was applied to align all camera models directly by using experimental particle images (non-reacting flow) to get perfect multiple ray correspondence throughout the measurement volume. The PIV images were processed by hybrid CPU-GPU realizations of MLOS-SMART and also by MTE (Novara et al. 2010, Meas. Sci. Technol., 21: 035401) reconstruction algorithms. The server station with 2x16 AMD Opteron processors 6274, 2200 MHz (32 cores in total) with the graphics processor NVIDIA Tesla C2075 was used for the calculations. An iterative cross-correlation routine with continuous volume shifting was applied to estimate 3D velocity fields. The final size of the interrogation domain was 40 voxels with 75% overlap factor.

Examples of results

Figure 2 shows the direct image, reconstructed 3D intensity of the tracer particles (by using the bottom row of 4 cameras) and two cross-planes of the calculated 3D velocity field. Figure 3 shows the instantaneous velocity field of the swirling jet flow in a lean methane/air flame (high swirl rate 1.0) estimated by using 8 cameras.

A system of 8 cameras (ImperX IGV-B2020) was mounted as it is shown in Figure 1. The combustion causes difficulties for tomographic PIV experiment, such as non-uniform tracer particles seeding in space and luminosity of the flame, which reduce signal-to-noise ratio. In case of the low-swirl lifted flame, the bottom set of the cameras provided 3D images which were not affected by the variation of the flow density (for region below the flame). This information was used to evaluate effect of refractive index changes for the cameras in the upper row. The seeding particles were illuminated by the second harmonic of a double-head Nd:YAG pulsed laser with 400 mJ energy per each pulse. Two mirrors were used to organize multi-pass scheme for the beam (Schröder et al. 2008, Exp. Fluids 44: 305–316). The depth of the illuminated volume was 30 mm. To decrease the flame luminosity on the images, optical band-pass filters (Edmund Optics) were mounted on the used Sigma AF #50 lenses.

Fig. 1 Photograph of the experimental setup and scheme of laser beam passage

Fig. 2 Direct image, reconstructed 3D volume (10% of voxels are shown) of tracers particles, and velocity field for a laminar premixed conical propane/air flame (φ = 0.9)

Fig. 3 Direct image, and horizontal slices of the 3D instantaneous velocity field in methane/air turbulent flame (Re = 5000 φ = 0.7)