Stereo PIV measurements of flow structure of an acoustically forced swirling premixed flame

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The present work is devoted to the experimental study of the axial forcing effect on premixed non-swirling and swirling turbulent flames. During the study, $\text{Re}_{\text{air}}$ number (based on the nozzle exit diameter $d$, flowrate velocity and viscosity of the air) was varied from 500 to 8,000. The equivalence ratio $\Phi$ of air-propane mixture was varied from 0.5 to 10. For the external acoustic forcing of the flow, a system consisting of four loud speakers, connected to an amplifier and function generator. The normalized (by nozzle exit diameter $d$ and the mean flowrate velocity $U_0$ of the mixture) forcing frequency, i.e. the Strouhal number, was varied from 0.1 to 3. Forcing amplitude was defined as RMS value of voltage ($V_{\text{rms}}$) feeding the loudspeakers. The burner represented a profiled contraction nozzle. The nozzle exit diameter $d$ was 15 mm. For organization of the flows with swirl, a swirl generator was mounted in a plenum chamber of the nozzle. The definition of the swirl rate $S$ was based on the swirler geometry.

A cycle of visualisation and stereo PIV measurements were carried out for the most representative cases of the forced turbulent flames. In order to provide PIV measurements of the instantaneous velocity, the main flow, issuing from the nozzle, was seeded by TiO$_2$ particles with the average diameter of 1 µm. The ambient air was seeded by a fog generator. A Stereo PIV system consisted of a double-cavity 70 mJ Nd:YAG pulsed laser, couple of 4M CCD cameras and a synchronizing processor was used. Captured images were processed by an iterative cross-correlation algorithm with an image deformation. Due to a non-uniform seeding of the flow by tracer particles, the number of the particles present in each interrogation area (IA) was analyzed in the cross-correlation algorithm. Stereo calibration was performed by using a multi-level calibration target and a 3rd-order polynomial transform.

The Figure shows the strongly swirling lifted flame ($S = 1.0$, $\text{Re}_{\text{air}} = 4100$, $\Phi = 2.5$) with and without acoustic forcing. Direct images of the flames and instantaneous velocity and vorticity fields are shown. The main difference for the forced case is that the large-scale helical vortices, clearly visible inside of the recirculation zone of the unforced case, couldn’t be detected in forced case. By analyzing measured distributions of the average velocity and turbulent kinetic energy components it was concluded that the high-amplitude periodical axial forcing of the strongly swirling turbulent flame resulted in suppression of intensity of the backflow inside of the recirculation zone and precession of stagnation point.

Instantaneous velocity and vorticity fields of a lifted strongly swirling flame ($\text{Re}_{\text{air}} = 4100$, $\Phi = 2.5$) under acoustic forcing at 170 Hz (St = 0.6). (a) No forcing; (b) $V_{\text{rms}} = 5V$.

*Number of particles per IA wasn’t accounted.*