Experimental study of a round jet in cross-flow at low momentum ratio

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With the final objective of optimizing the “Micromix” hydrogen combustion principle, a round jet in a laminar cross-flow prior to its combustion is investigated experimentally using Stereoscopic Particle Image Velocimetry. Measurements are performed at a jet to cross-stream momentum ratio

\[ r = \frac{\rho_j \cdot u_j}{\rho_{\infty} \cdot u_{\infty}} \]

of 1 and a Reynolds number, based on the jet diameter and jet velocity, of 1600.

The suitability to combine side, top and end views is analyzed statistically. The statistical theory of testing hypotheses, pertaining to the joint distribution of the averaged velocity along intersecting observation planes, is employed. Overall, the averaged velocity fields of the varying observation planes feature homogeneity at a 0.05 significance level. Minor discrepancies are related to the given experimental conditions.

By use of image maps, averaged and instantaneous velocity fields, an attempt is made to elucidate the flow physics and a kinematically consistent vortex model is proposed.

In the time-averaged flow field, the principal vortical systems were identified and the associated mixing visualized. The jet trajectory and physical dimensions scale with the momentum ratio times the jet diameter

\[ j \approx 1, \text{Re} = 1600 \]

and jet velocity, of 1600.

The cross-flow velocity profile has been limited to a peak value of \( u_j \approx 2.5 \text{ m/s} \). The jet nozzle is a circular pipe with inner diameter \( d = 10 \text{ mm} \). The jet had a parabolic mean velocity profile with an average bulk jet velocity of \( u_j = 2.2 \text{ m/s} \). The momentum ratio based on the mean jet exit velocity profile is \( r \approx 1 \) and a \( Re_{\text{jet}} \) of approximately 1600. One has to notice that the jet velocity profile in the \( \text{yz}\)-plane features a slightly higher jet peak velocity in comparison with the \( \text{xy}\)- and \( \text{xz}\)-plane.

Overall, Stereoscopic Particle Image Velocimetry (SPIV) measurements were performed in the Fluid Dynamics laboratory of the Royal Military Academy (BE) to visualize the velocity field. The air jet and cross-flow were seeded with oil droplets (1-3 \( \mu \text{m} \)). To visualize the jet and cross-flow interaction, a slightly higher seeding density in the jet was adopted. A single dual cavity Nd:YAG laser (Spectra-Physics PIV 400) was used. The time delay between the two laser sheet pulses ranged from 10 to 50 \( \mu \text{s} \). The resulting scattering signal was collected by two interline transfer CCD cameras (HiSense MkII – 1344 \( \times \) 1024 pixels).

250 image pairs were acquired for each experimental configuration, which, after post-processing (Dantec FlowMap software package), were temporally averaged. The interrogation region was \( 32 \times 32 \) pixels and was shifted 16 pixels (50% overlap) for each data point. The experimental analysis was performed in a blow-type low speed open-circuit wind tunnel with a test section \( 0.45 \times 0.45 \text{ m wide and 1.2 m long} \). The laser sheet has been positioned on planes parallel to the \( 0-x, y \) plane (side view) at \( z = 0, 0.25, 0.5 \) and \( 1 \text{ rd} \), on planes parallel to the \( 0-y, z \) plane (end view) at \( x = 0, 0.25, 1, 3 \) and \( 5 \text{ rd} \) featuring the CRVP and on planes parallel to the \( 0-x, z \) (top view) at \( y = 0.25, 0.5 \) and \( 1 \text{ rd} \).

The image size in physical dimensions for most recording planes was approximately \( 50 \times 35 \text{ mm} \). This yields a spatial resolution of about 1 mm. The tunnel cross-flow velocity profile has been limited to a peak value of \( u_{\infty} = 2.5 \text{ m/s} \). The jet nozzle is a circular pipe with inner diameter \( d = 10 \text{ mm} \). The jet had a parabolic mean velocity profile with an average bulk jet velocity of \( u_j = 2.2 \text{ m/s} \). The momentum ratio based on the mean jet exit velocity profile is \( r \approx 1 \) and a \( Re_{\text{jet}} \) of approximately 1600. One has to notice that the jet velocity profile in the \( \text{yz}\)-plane features a slightly higher jet peak velocity in comparison with the \( \text{xy}\)- and \( \text{xz}\)-plane.