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Three-dimensional density measurements of a heated jet using laser-speckle tomographic background-oriented schlieren

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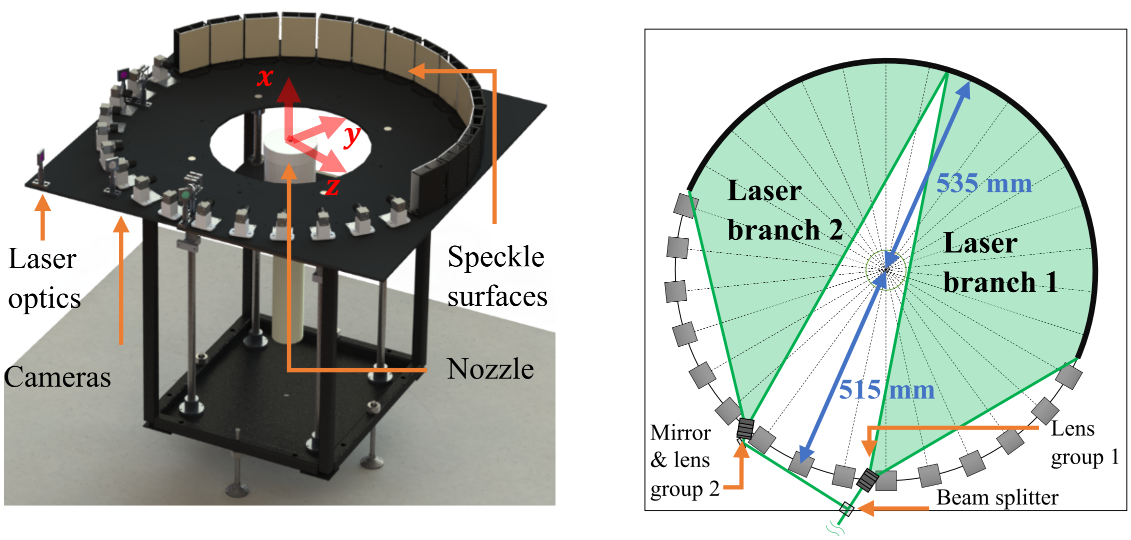
Abstract



(a) (b)

Figure 1: a) Fifteen-camera experimental rig, b) schematic of laser expansion. Optical axis of camera 1 is aligned with the global *z*-axis, and *x* is the jet axis.

Three-dimensional density field measurement techniques can be used to understand the complex heat transfer and mixing processes that occur in turbulent flows. Tomographic background-oriented schlieren (BOS) is an optical technique that can be used to measure the instantaneous three-dimensional density field in turbulent flows. Light rays propagating through the flow are deflected from their ambient path due to variations in refractive index related to the spatial density gradients. In BOS, a camera is placed looking through the flow at a reference image, which captures path-integrated information on the refractive index gradients in the form of apparent image displacements Richard and Raffel (2001). The displacements recorded simultaneously from many cameras placed around the flow form the basis of a tomographic reconstruction of the three-dimensional refractive index gradients Goldhahn and Seume (2007), from which the density field is obtained through integration of the gradients and application of the Gladstone-Dale relation.

Most TBOS experiments to date have used printed background patterns and strobe lighting to record deflections. The lighting systems often result in temporal integration on the order of many hundreds of flow time scales to achieve adequate image exposures, which prevents the observation of instantaneous turbulence structures such vortex roll-up. Defocus blurring must also be carefully managed, as the sensitivity

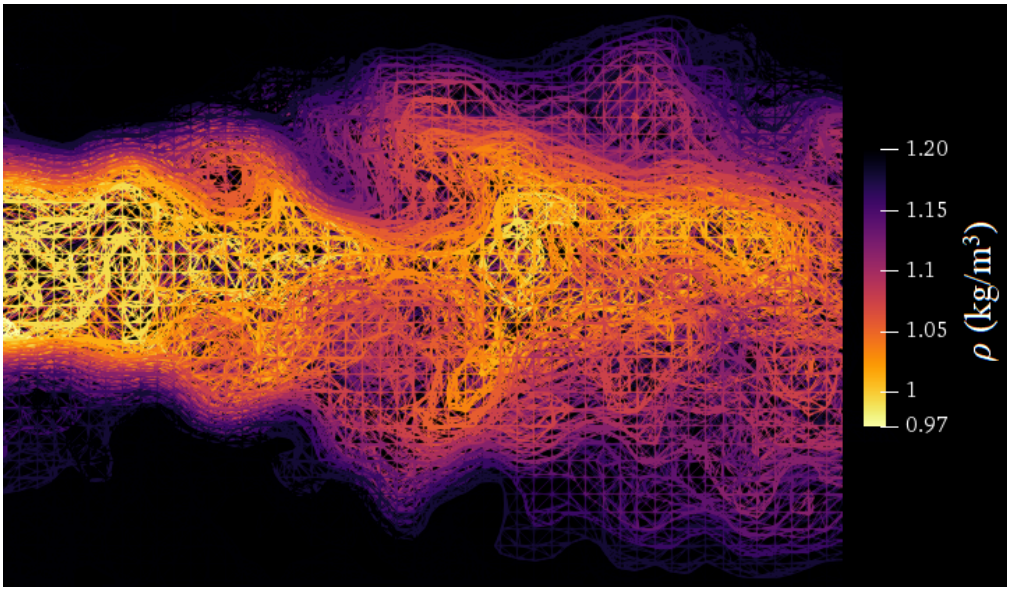


Figure 2: Longitudinal slice through reconstructed density field ρ (kg/m^3) at one time-step at $y/D = 0$. Flow is from left to right. Domain length is $0.3 < x/D < 4.6$.

to displacements is increased by focussing further away from the object. Our proposed experimental set-up shown in figure 1 uses a pulsed laser beam for both short-duration illumination and the creation of a suitable background pattern in the form of laser speckle patterns Meier and Roesgen (2013). The beam is spread to illuminate a surface that is observed by fifteen cameras that are evenly-spaced circumferentially around the flow. We present a methodolgy for selecting the optimal focal length, focus distance, and aperture by considering the compromise between displacement sensitivity, defocus blurring and speckle size. Using an optimised iterative tomographic reconstruction method Amjad et al. (2020), we demonstrate the suitability of tomographic laser-speckle BOS for the collection of turbulent density field statistics using a heated air jet. The 3D reconstructions of the density field of a heated jet show excellent reproduction of turbulence structures with spatial resolution of 840 μm (0.084D) per voxel.

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