Supplementary material to

Turbulent Mixing and Trajectories of Jets in a Supersonic Crossflow with Different Injectants

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All PIV measurements, referenced here, are acquired by recording 532 nm Mie-scattering image pairs with a laser pulse separation of 300 ns and processing them with the PIV software LaVision DaVis 8.4. Resulting vector resolutions are in the range of 150-210 µm. The schlieren measurements are recorded using a Z-schlieren setup with 2 m focal length parabolic mirrors.

1. Crossflow characterisation

The PIV and schlieren measurements show that the weak shock wave closest to the jet orifice impinges on the wall ~27 mm behind the jet injection point, see figure 1(a). Thus, if there is any direct influence on the jet it would manifest itself in its downstream wake probably outside of this study's region of interest.

Horizontal velocity profiles above the bottom wall are shown in figure 1(b). They indicate that the crossflow velocity is fairly constant, within 3% of the reference velocity, U_0 = 664 m/s. It decreases slightly over the field of view due to the remaining weak shocks. The maximum deflection of velocity vectors from the streamwise direction is 1.4° upwards with a maximum transverse velocity component of ~ 16 m/s or 2.5% of the crossflow reference velocity.

2. Jet properties

The properties of single jets in our facility are validated by comparing the measured Mach disk heights of free jets (no crossflow) to correlations available in the literature. In figure 2, the Mach disk heights determined via schlieren visualization are shown. The agreement with empirical correlations improves with increasing pressure ratios. The Mach disk height of the lowest pressure helium jet was difficult to determine accurately, because of relatively weak density gradients and strong turbulence present close to the jet orifice.

We also present centreline and horizontal velocity profiles from PIV measurements in figure 3. The centreline velocities in figure 3(a) show the characteristic acceleration an underexpanded sonic jet experiences as it expands after its choke point, followed by an abrupt deceleration at the Mach disk and re-acceleration. An exception is the helium jet at a low pressure ratio corresponding to J = 1 in our facility. Upon injection, the helium jet is at approximately two times ambient pressure. Thus, while the resulting Mach disk after expansion is barely detectable in schlieren images it is likely too weak or too close to the wall to be picked up properly by our PIV setup. Hence the velocity profile exhibits a seemingly continuous acceleration initially, up to $y/y_{MD} \approx 2$. The horizontal velocity

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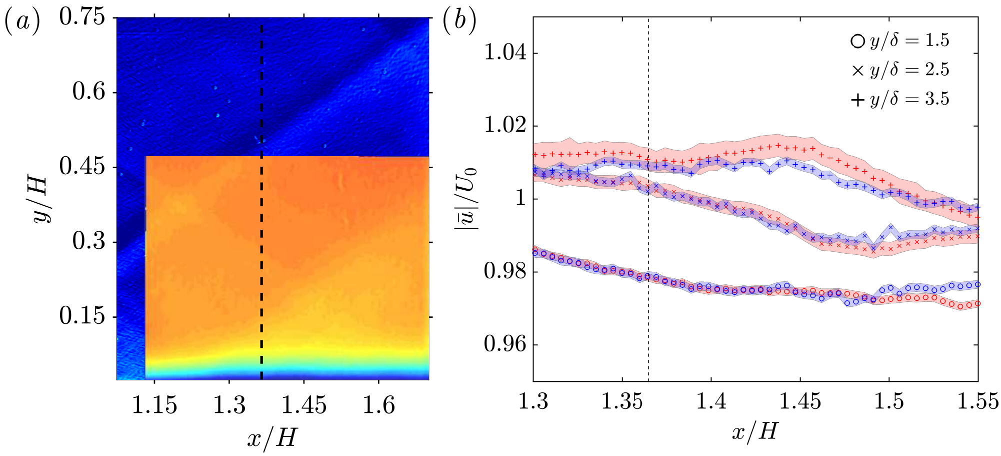

Figure 1: (a) Qualitative overlay of schlieren and PIV measurements in our test section. The schlieren image is in the background. Remaining wave structures are visible in both types of measurements manifesting themselves in sudden density and velocity changes. The dashed vertical line is the location of the injector on the bottom of the test section. (b) Horizontal velocity profiles taken at different heights above the bottom wall. Red color corresponds to a measurement magnification of 0.66, blue color to a magnification of 0.36. The dashed vertical line is the injector location on the bottom wall. Uncertainty bands correspond to a 95% confidence level and account for instantaneous (Sciacchitano & Wieneke 2016) and statistical uncertainty.

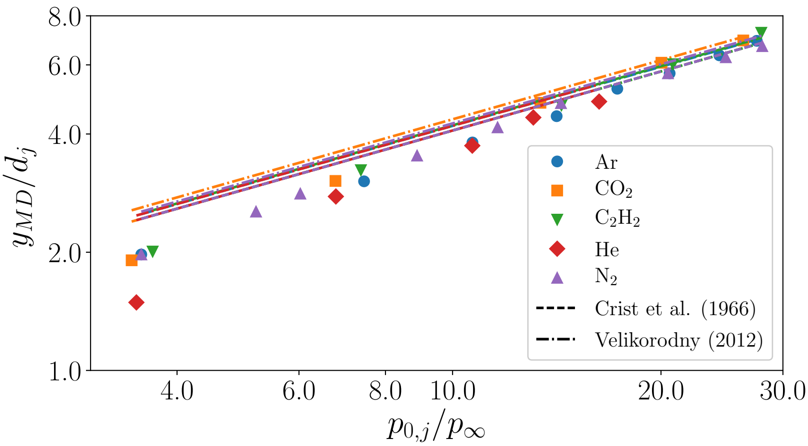

Figure 2: Comparison of Mach disk heights in our experiment to correlations of Crist *et al.* (1966) and Velikorodny & Kudriakov (2012). The agreement is very good at higher pressure ratios. At lower pressures larger deviations are visible, possibly due to the jet not actually being unconfined in the test section and experiencing a back pressure higher than the ambient pressure.

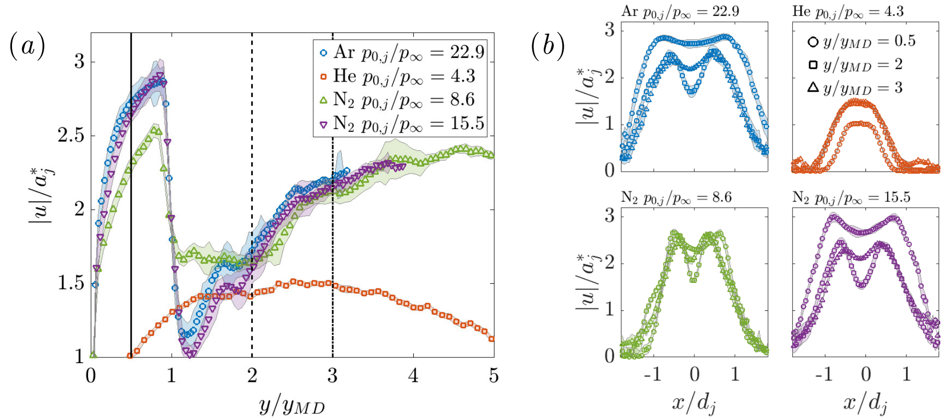

Figure 3: Velocity profiles of free jets in our setup, normalized with the sonic velocity at the choke point. The pressure ratios of the free jets $p_{0,j}$ = 22.9, 4.3, 8.6 and 15.5 correspond to J = 6, 1, 2 and 4, respectively, in the case of a supersonic crossflow at our operating conditions. (a) Centreline velocity profiles. Shaded uncertainty bands correspond to a 95% confidence level. Vertical lines correspond to the locations at which the horizontal velocity profiles are taken. (b) Horizontal velocity profiles cutting through the jets.

profiles in figure 3(b) are slightly asymmetric due to the draft created by the exhaust system that is running during experiments. Important to note is the fact that the profile,s extracted closest to the jet orifice, resemble more of a top-hat than a parabolic profile.

REFERENCES

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