Dual-PIV coupled with dynamic mode decomposition to unravel the structure and dynamics of a supersonic free-jet

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A distinctive feature of supersonic free-jets is the strongly coupled interaction between shear-layer instabilities and shock-cell structures that produces a resonant aeroacoustic feedback loop, referred to as *jet screech*[1]. A detailed understanding of the dominant jet screech mechanisms entails an experimental characterisation of the underlying shear-layer dynamics and coherent structures. However, measurements performed using the standard PIV technique, which is widely used to study supersonic jets, do not have the adequate spatio-temporal resolution to simultaneously resolve the relatively thin shear-layers and small temporal scales in these high-speed flows.

This study presents a novel method to enable the aforementioned experimental characterisation by using *Dual-PIV* velocity measurements coupled with their exact dynamic mode decomposition (*Exact DMD*) analysis. The *Dual-PIV* system comprises two independent, but synchronised PIV systems illuminating and recording the same field of view with cross-talk minimised using polarisation-based image separation[2]. The timing interval between these two PIV systems can be made sufficiently small to resolve down to the smallest dynamically significant temporal scale, yielding two time-resolved velocity fields at sufficiently high-spatial resolution. An *Exact DMD* analysis of these pairs of flow-field data vectors yields the best linear approximation to the mapping matrix between them and allows the determination of frequencies of interest and their corresponding spatial modes[3].

The aforementioned methodology is used to study an under-expanded supersonic free-jet at a nozzle pressure ratio of 3.4 and Mach number 1.42. The time shift between the two PIV lasers is set to 1 µs, based on the measured acoustic spectra. This time shift is also the time between the pair-wise sequential velocity fields. The presented methodology therefore has a temporal resolution of 1 MHz, and with an image resolution of 29 Mpx, it provides a high spatio-temporal resolution of the flow-field measurements. Analysis of the PIV images is performed using multigrid cross-correlation digital PIV[4]. A statistical approach is adopted to determine the adequate number of velocity snapshots required for the *Exact DMD* analysis.

The frequencies of the extracted dominant spatial modes are compared with the acoustic spectra to find coherent structures associated with the corresponding tones. Furthermore, the spatial amplification of the shear-layer instability modes in the streamwise direction is analysed with respect to the location of the shock-cell structures to quantify their interaction to produce dominant acoustic tones. These results demonstrate the robust potential of the aforementioned experimental and data decomposition technique to unravel the coherent structure dynamics in supersonic flows with high-spatial resolution.

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