STUDY OF COHERENT STRUCTURES IN COAXIAL JET NOISE USING PARTICLE IMAGE VELOCIMETRY

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ABSTRACT

A quasi-‘time-resolved’ particle image velocimetry (PIV) system is used to study coherent structures in high-speed coaxial jet flows. Results will be presented obtained at QinetiQs Noise Test Facility from jet flows at engine representative model scales, both acoustic and aerodynamic, at representative velocities and temperatures. The PIV measurement system used allows a time-space correlation to be made and enables the measurement of coherent structures in high-speed turbulent flows. These measurements were done in conjunction with both LDA and acoustic measurements, allowing for study of spatio-temporal developments in the jet, associated with jet-noise production.

Large-scale ‘coherent structures’ have been associated with noise production. As Brown and Roshko demonstrated in 1974, although single-point probes can provide time-resolved measurements, the instantaneous spatial structure and dynamics of the flow cannot be described by the turbulence statistics given by single-point probes, while flow visualization techniques such as Particle Image Velocimetry (PIV), though typically lacking temporal resolution, can provide instantaneous spatial information. Coherent structures in a flow field can be characterized by their vorticity. To obtain information on these structures the measurements need to give: 1. sufficient resolution to resolve the vortices in the flow, 2. a temporal resolution that matches the time scale of the flow, in order to study the dynamics of the structures, 3. sufficient accuracy in the velocity measurements as the errors in the velocity strongly increase the errors in vorticity as this is obtained by differentiating the velocity data.

PIV measurements in high-speed flows are generally obtained at relatively low repetition rates, which are governed by the repetition rate of the laser flashes and the data-capture rate of the cameras used. Thus, the sequential velocity measurements are unrelated and therefore do not provide a direct image of the dynamics of coherent structures in the flow, complicating identification of possible structures. To resolve this, a new high-speed PIV system was developed that enables to calculate spatial and temporal correlations from PIV data. This quasi time-resolved PIV system was used to study large-scale mixing structures found in gas turbine exhausts, which are relevant for engine efficiency and noise production. The system consists of a set of 6 Nd:YAG lasers, creating 6 independent light sheets, combined with a set of 2000x2000 pixel PIV-cameras allowing sequences of PIV-data to be captured at freely adjustable intervals between image-frames at similar intensities. Thus, a maximum of 6 high-resolution image-frames can be captured at MHz-rate. With equal time-intervals this allows for 5 velocity vector maps to be determined using standard cross-correlation processing. Furthermore, a minimum of 3 velocity vector maps can be obtained when the interval between images is non-equispaced, allowing for longer periods to be covered, enabling tracking of relatively slowly changing features. Thus the system offers time-resolved measurements, albeit over short periods (bursts), which allows time-space correlations to be determined and enables study of the unsteady dynamics of high-speed flows.

Measurements were obtained in the Noise Test Facility at QinetiQ, Farnborough, UK. This test facility is one of the world's largest anechoic chambers: 27 metres long, 26 wide and 14 metres high. This enables measurements to be taken at a representative engine model scale, both acoustic and aerodynamic. Coaxial jet flows were investigated at engine representative velocities and temperatures. The flows that are generated are typically high-speed, high-temperature and highly turbulent. In mixing areas, the flows exhibit vortices such as shown in Figure 1.

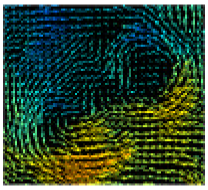

Figure 1: *Typical vortices found in flows studied*

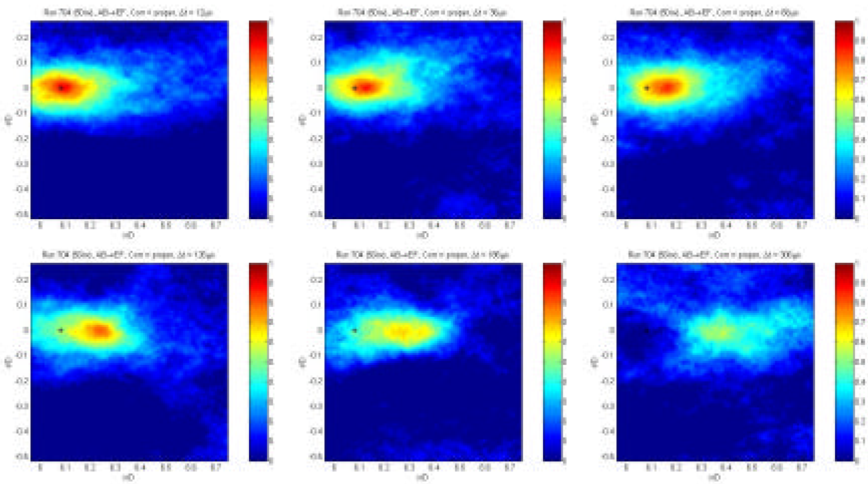

Figure 2: *Spatio-temporal streamwise velocity correlation coefficient measured at time lag t of 12, 36, 66, 126, 186, and 306 microseconds.*

To obtain data for space-time correlation image-pairs were captured at time intervals of $\tau = n\Delta t$, where Δt is the time interval between two pulses as in standard PIV, and n = 1,2,3,4,5,6,7,8,9,10,15,20,30,40,50. In the example shown here 200 sets of 3 image-pairs were recorded at each value of n, with Δt set at 3 microseconds. Figure 2 presents some preliminary results showing correlation maps obtained at different values of time lag τ ranging from 12 to 306 microseconds at a position approximately 6 diameters from the jet exit. The maps shown are calculated for the axial (streamwise) velocity using:

$$R_{uu}(\mathbf{x},\mathbf{s},t) = \frac{\overline{u'(\mathbf{x},t)u'(\mathbf{x}+\mathbf{s},t+t)}}{\sqrt{\overline{u'(\mathbf{x},t)^2}}\sqrt{\overline{u'(\mathbf{x}+\mathbf{s},t+t)^2}}}$$

For increasing time lag, the maximum correlation value is spatially convected downstream; furthermore, due to dispersion, the maximum correlation value is decreasing. The data allows extraction of space-time correlation coefficients along different directions, enabling determination of convection velocities facilitating comparison to aeroacoustic data.

Further results and analysis will be presented of two-point space-time correlations from PIV. Furthermore, spatio-temporal dynamics of coherent structures in the flow will be investigated based on the short time-resolved sequences of PIV data that have been obtained. In addition, these results will be related to data obtained simultaneously using LDA and acoustic measurements.

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