Sound Source Identification through Flow Density Measurement and Correlation with Far Field Noise

J. Panda
Ohio Aerospace Institute

R. G. Seasholtz
NASA Glenn Research Center

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Sound sources in the plumes of unheated round jets, in the Mach number range 0.6 to 1.8, were investigated experimentally using "causality" approach, where air density fluctuations in the plumes were correlated with the far field noise. The air density was measured using a newly developed Molecular Rayleigh scattering based technique, which did not require any seeding. The reference at the end provides a detail description of the measurement technique.

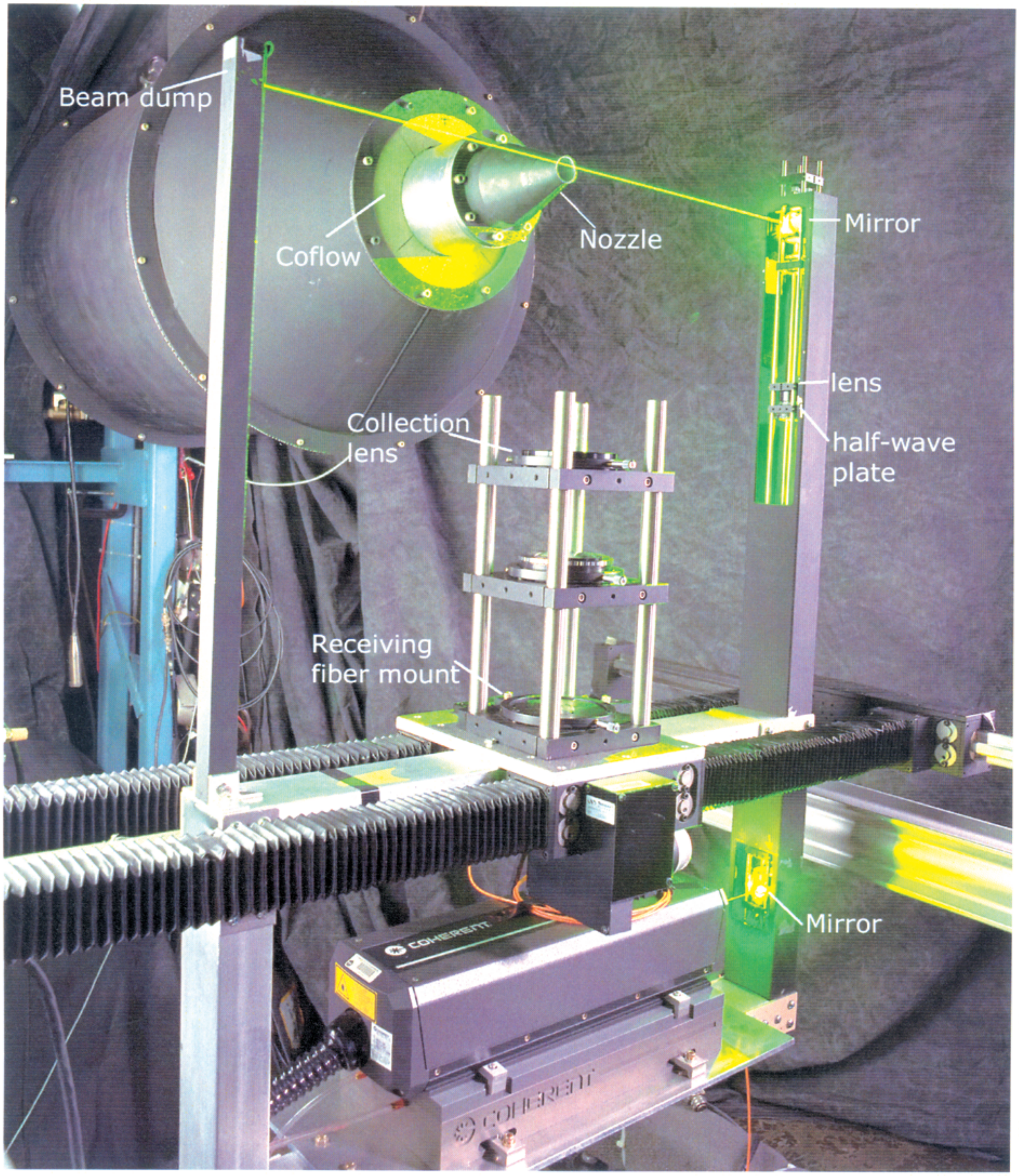

Fig. 1. A photograph of the nozzle facility and the optical arrangement.
Discussion: A narrow laser beam from a CW, Nd:VO_4 laser was passed perpendicular to the flow direction. The point measurement technique depends on collecting molecular scattered light from 1mm long probing region along the laser beam and focusing on the receiving fiber face. The optical arrangement was mounted on a X-Y traverse that allowed positioning the probe volume on a longitudinal plane. According to the Rayleigh scattering principle, intensity of the collected light is proportional to the local air density.

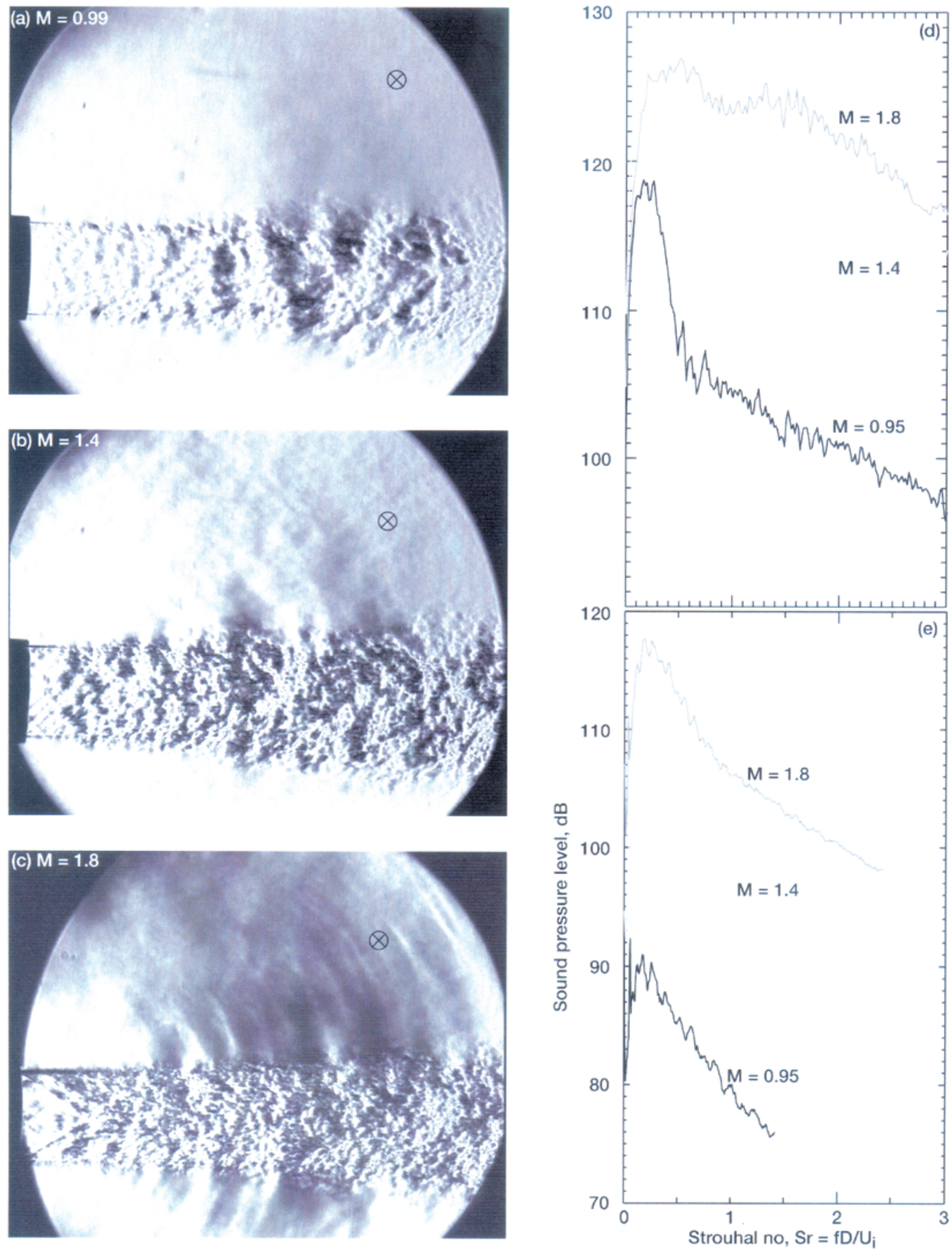

Fig. 2. (a), (b), (c) Spark schlieren photographs of fully expanded jets at indicated Mach number conditions.; (d) pressure fluctuation measured at x/D=4, y/D=2 (shown by ⊗ in schlieren photos); (e) sound pressure fluctuations at 50D & 30° to the flow direction)

Discussion: Three jets at Mach numbers 0.95, 1.4 & 1.8 were studied in details. The supersonic jets were produced from CD nozzles. Schlieren photographs show Mach wave emission in M=1.8 jet and its absence in M =0.99 jet. The M=1.4 jet is somewhat in between. An estimation of convective speed of turbulent eddies shows that it becomes supersonic with respect to the ambient sound speed in M=1.8 jet, while remaining subsonic for M=0.99 jet. The near-field microphone data show a significant increase in high frequency pressure fluctuations with the onset of 'Mach wave' emission.

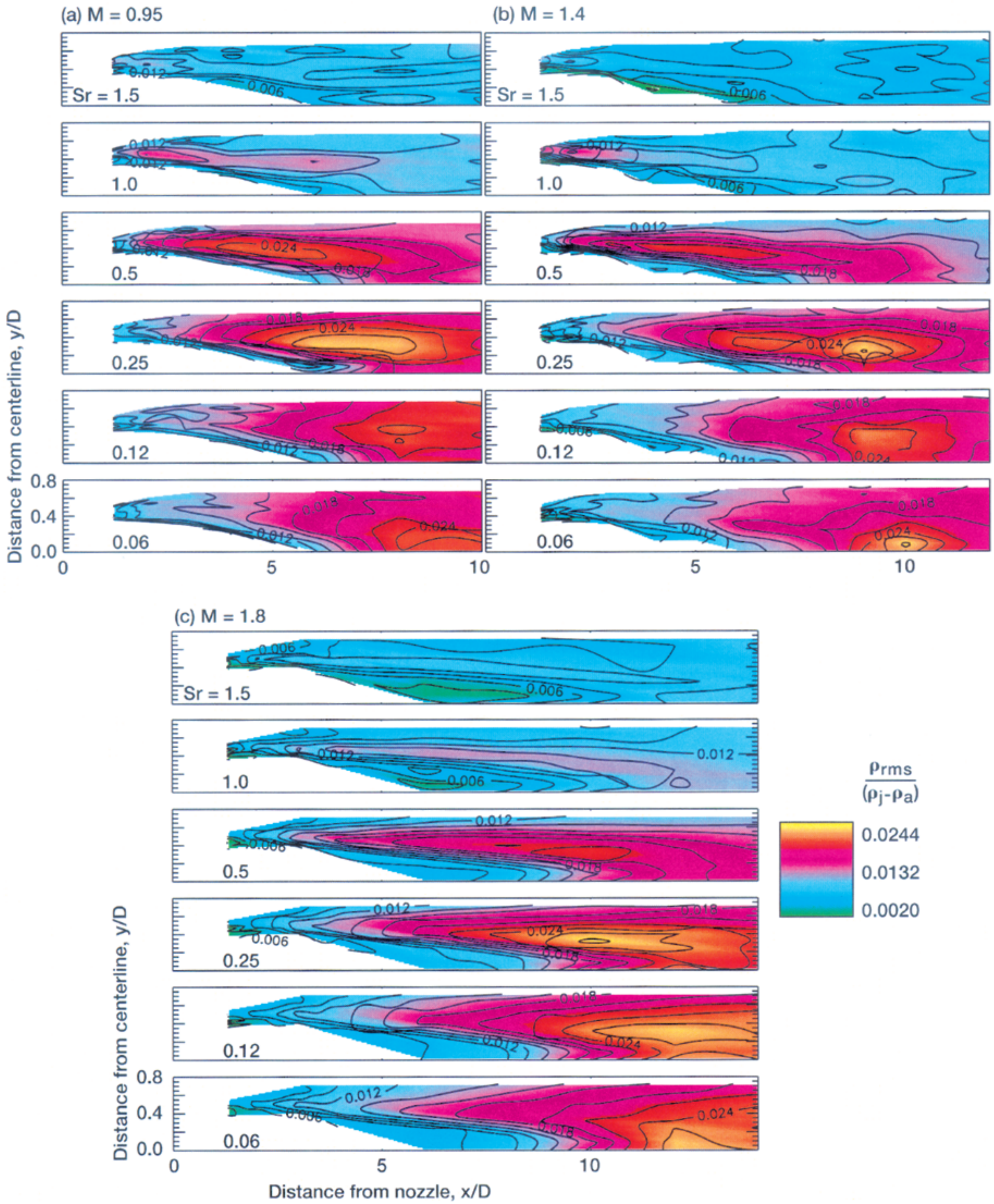

Fig. 3. The distribution of density fluctuation (normalized by ρ_{jet}-ρ_{amb}) at the indicated Strouhal frequencies (St = fD/U) for three different Mach numbers. Discussion: These data were compiled from a large number of density fluctuation spectra measured in each jet flow. The fluctuation energy in the specified St values was isolated and plotted. As expected the high St fluctuations are concentrated in the lip shear layer

near the nozzle exit, while the low St fluctuation peaks beyond the potential core. The primary observation is a similarity in the flow fluctuations irrespective of the plume Mach number. The only difference is an increased downstream stretching with the increase in the jet Mach number. In sharp contrast to this similarity in flow fluctuation, the locations of the sound sources and their measured intensity is very different. This is discussed in the following.

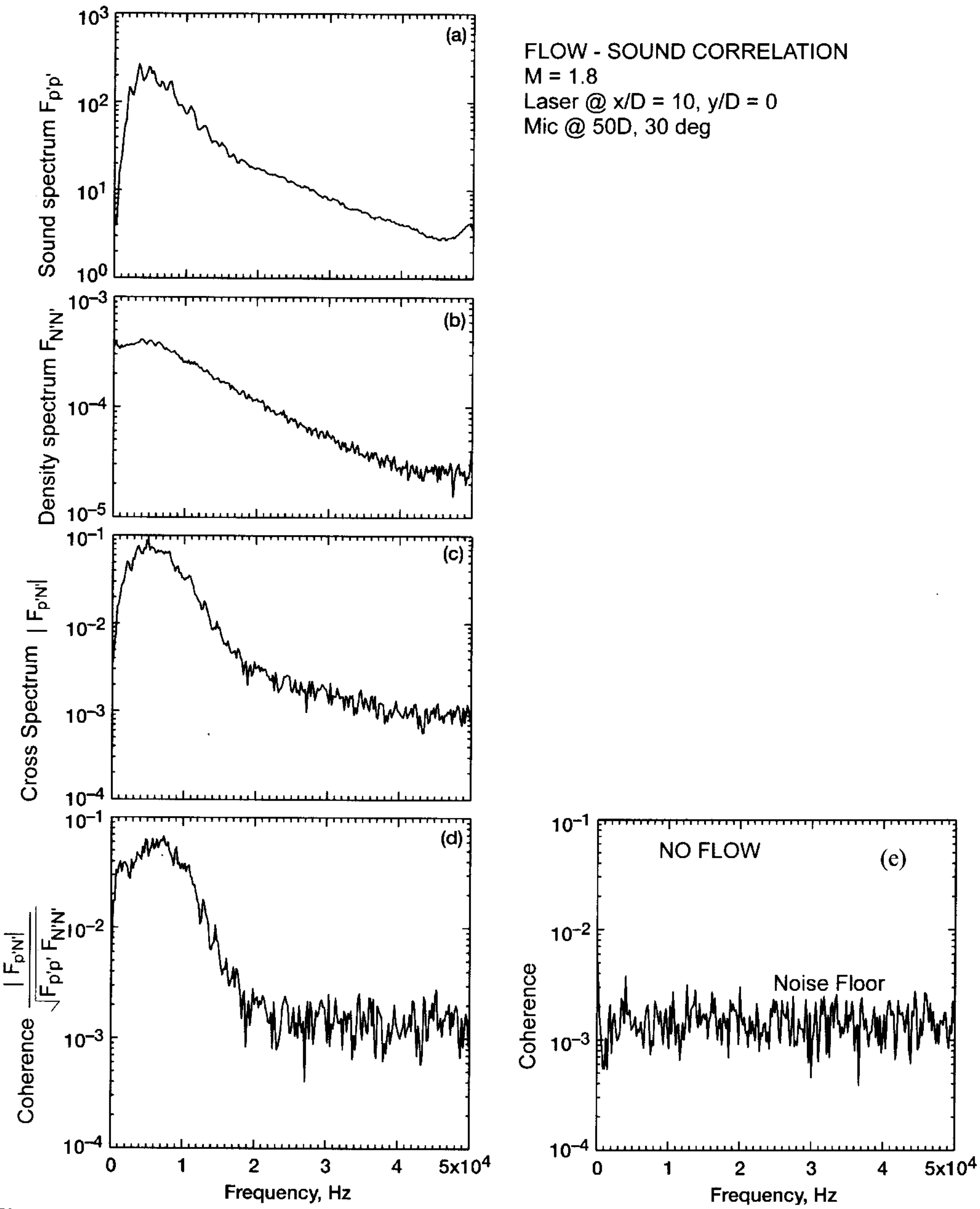

Fig. 4. Cross-correlation between flow density fluctuations and sound pressure fluctuations in M=1.8 jet, laser probe at centerline and x/D=10, microphone at farfield x/D=50, θ=30°. (a) sound pressure spectrum (b)density spectrum (c)cross-spectrum & (d)normalized cross-spectrum (coherence) (e) normalized cross-

spectrum at no-flow condition demonstrating the noise floor in cross-spectral measurement.

Discussion: The coherence (also called normalized cross-spectrum) effectively shows the correlation $\overline{\rho' p'}/(\sqrt{\overline{\rho'^2}}\sqrt{\overline{p'^2}})$ and is used for the subsequent description of correlation data. The no flow correlation data is useful in finding out noise floor in such measurements. A comparison between parts (d) & (e) of this figure shows a measurable correlation below 2KHz frequency. Above this value, the measured data falls into noise floor.

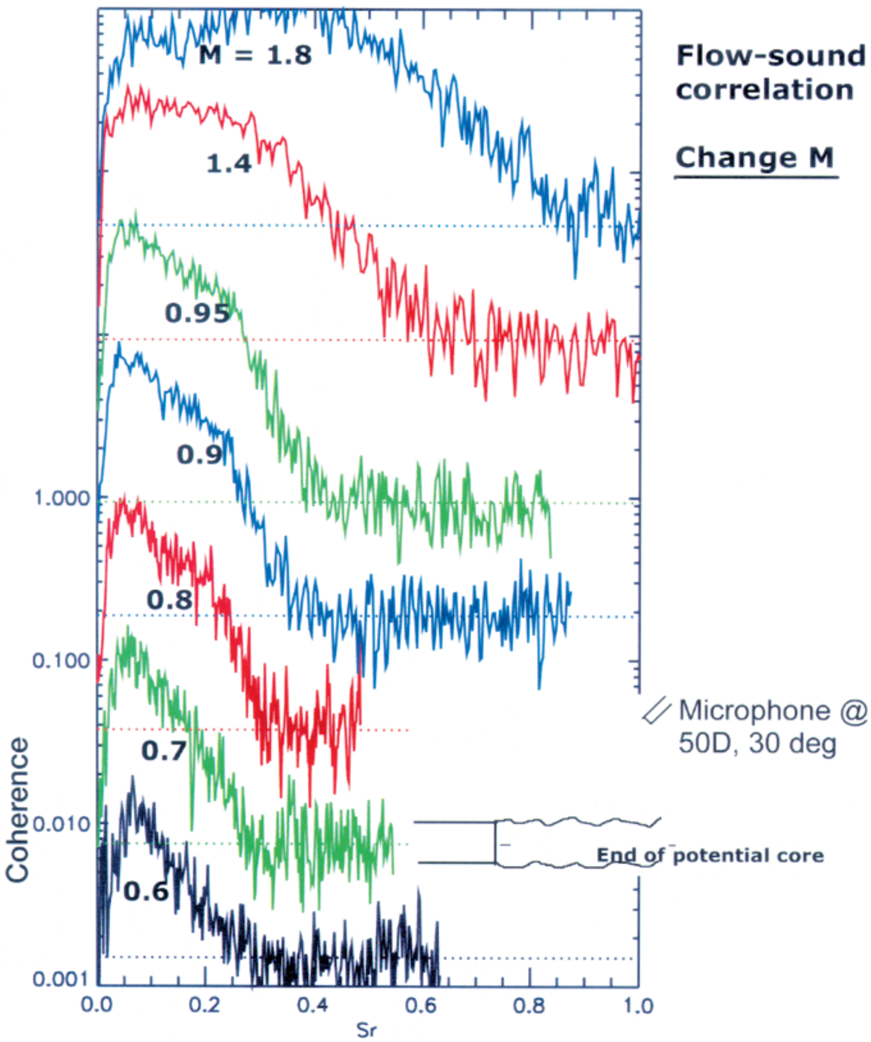

Fig. 6. Normalized cross-spectrum between flow density fluctuation and sound pressure fluctuations at different jet Mach number conditions. The probe volume was placed at the centerline & end of potential core (7D for M=0.6 jet, 9D for M=1.8 jet) & the microphone was placed at 50D & 30°.

Discussion: Some correlation in the low Strouhal number range is always measured at all Mach number conditions; indicating the end of the potential core is a low frequency noise source.

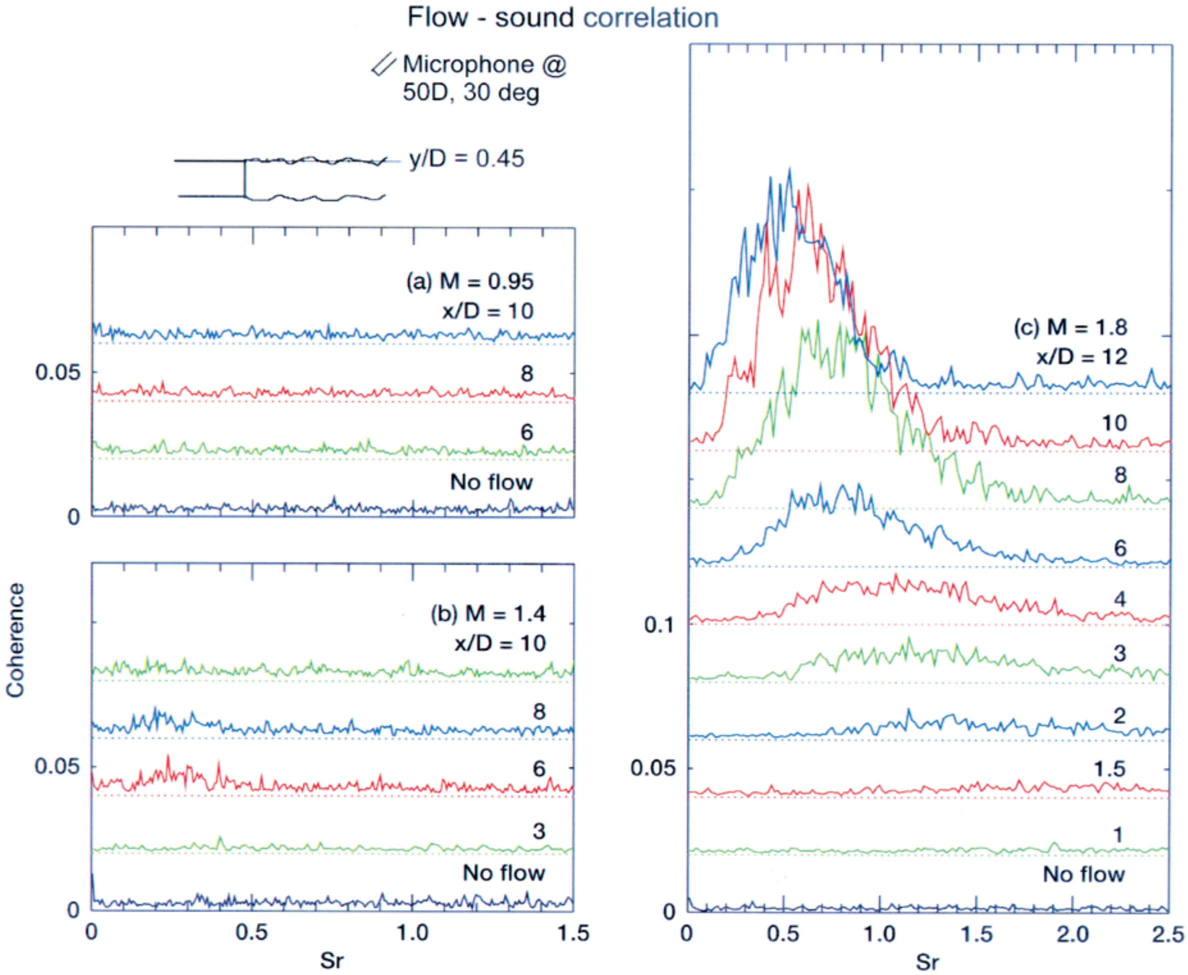

Fig. 7. Normalized cross-spectrum measured form the shear layer. The laser probe volume was moved from point to point along r/D=0.45 at the indicated x/D locations for the 3 Mach number jets and the correlation spectrum with a fixed far field microphone was measured.

Discussion: Very good correlation coefficients (up to 0.2) was measured in the supersonic M=1.8 jet while all data in subsonic M=0.95 jet falls in the noise floor (around 0.002). Small correlation values are measured for M=1.4 jet. Interestingly, the M=1.8 jet correlation data show the same trend of peak fluctuations moving to lower St frequency, with an increase in downstream distance, as expected from the Kelvin-Helmholtz instability waves. Also note that the instability waves are expected to be moving at supersonic speed in the M=1.8 jet and at subsonic speed in M=0.95 jet. All of these point out that the Kelvin-Helmholtz instability waves are directly responsible for sound generation when their speed becomes supersonic. This is also the reason for success of the instability wave based theories in predicting noise source of high supersonic jets. However, the same can not be said for subsonic jets.

J. Panda References

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