25th International Congress on Sound and Vibration
8-12 July 2018 HIROSHIMA CALLING
ICSV25

IDENTIFICATION OF JET-NOISE SOURCE SIGNATURE FROM RAYLEIGH SCATTERING MEASUREMENTS

Bertrand Mercier
Univ Lyon, Ecole Centrale de Lyon and LMFA UMR CNRS 5509, Ecully, France, F-69134

Thomas Castelain
Univ Lyon, Université Lyon 1 and LMFA UMR CNRS 5509, Ecully, France, F-69134

Christophe Bailly
Univ Lyon, Ecole Centrale de Lyon and LMFA UMR CNRS 5509, Ecully, France, F-69134
email: christophe.bailly@ec-lyon.fr

Jet mixing noise is experimentally investigated by means of cross-correlations between density fluctuations inside the turbulent jet flow and the radiated acoustic pressure. The time-resolved density fluctuations are measured by a Rayleigh scattering device mounted in the large anechoic wind tunnel of Ecole Centrale de Lyon. An original signal processing developed in a previous study is implemented for the photon counting, combined with the use of a single photomultiplier to remove shot noise. A high-speed subsonic jet and a perfectly expanded supersonic jet with a subsonic convective velocity are considered to characterize mixing noise sources. Conditional averages are a well suited method for investigating the intermittent feature of the turbulent flow and its noise, and can provide insightful information about noise generation mechanisms. The signature of turbulent events linked to the noise emission in the downstream direction are extracted for two subsonic and supersonic jets, and interpreted with respect to expected jet noise properties. Furthermore, the use of time-resolved density fluctuations is discussed in the framework of jet turbulence and noise.

Keywords: Rayleigh scattering, density fluctuations, jet noise

1. An optical method for measuring density

The density fluctuations may be measured thanks to a Rayleigh scattering based technique [1], which is time resolved, non intrusive, quantitative and local. The principle consists in observing the elastic scattering of light by gas molecules that constitute the considered flow, small in size with respect to the laser wavelength. The power of scattered light is here measured with a photomultiplier combined with a photon counter process. It can be shown that the theoretical flux of photons ϕ_d collected in a given solid angle $d\Omega$ is directly proportional to the density by $\phi_d = k_R \sin^2(\psi)\, \rho$. A sketch is provided in Fig. 1 to introduce some notations. The constant k_R is setup-dependent, and must be determined from a specific calibration process [2]. The use of a photon counting technique raises two intrinsic difficulties, the shot noise and the pile-up effect. The shot noise is a spurious noise induced by the random detection of photons, distributed in time according to Poisson's law. The signal-to-noise ratio increases with the photon flux, but physical density fluctuations remain significantly smaller than those induced by shot noise. The latter can be, however, partly removed with a two-photomultiplier configuration [3] or by applying a suitable data treatment to a single

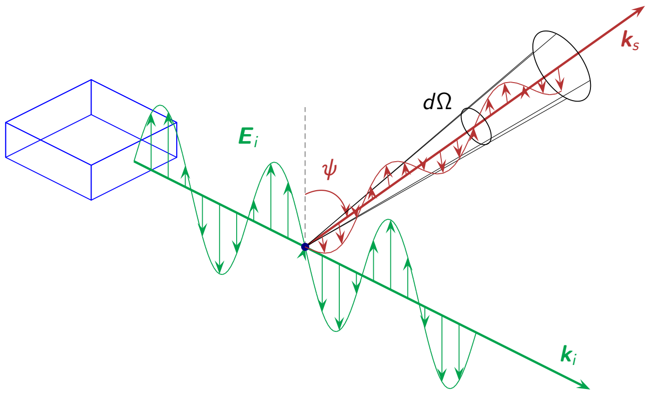

Figure 1: Sketch of the Rayleigh scattering apparatus, where ψ is the angle between the electric field vector $\boldsymbol{E}_i$ of the incident laser beam of wavenumber $\boldsymbol{k}_i$, and the direction of observation $\boldsymbol{k}_s$ for a probed volume.

photomultiplier signal [4]. Moreover, two photon detections must be separated in time by at least the pulse pair resolution, induced by a dead time of the counter or by the pulse width for a fast counter. This pile-up effect can be reduced by using a fast digitization of photomultiplier output signal combined with a software processing for the photon counting, and by applying a correction to the effective detected flux of photon [4]. Finally, some precautions must be taken to reduce background light level and to limit the presence of dust particles in the considered flow, including the entrainment for free shear flows.

2. Motivation and results

Jet noise is experimentally investigated by examing conditional correlations between density fluctuations inside the turbulent flow and pressure fluctuations measured in the acoustic far field. This optical measurement for density has been introduced by Panda *et al.* [3, 5] in aeroacoustics. In addition to the characterization of aeroacoustic sources through a direct connection between turbulent events and noise, previous studies [7, 8] on subsonic and supersonic jet noise have emphasized the need of having an independent measurement of the density in order to fully exploit time-resolved schlieren visualizations. Furthermore, a non-intrusive measurement of the density is also of interest to investigate compressible turbulent flows.

The new optical system has been set-up in the anechoic dual-stream wind tunnel of the Center for Acoustic Research at Ecole Centrale de Lyon. A complete description of the optical arrangement may be found in Mercier *et al.* [4]. Rayleigh scattering measurements have been coupled with far-field microphone acquisitions [6] in order to investigate noise production mechanisms in two high-Reynolds-number jets at Mach 0.9 and Mach 1.32. The use of conditional statistics is better suited to examine the intermittent feature of jet turbulence and its associated noise. In this study, they are performed on density signals, and are based on the detection of high amplitude events in the acoustic pressure signal. The time delay associated with the acoustic propagation, around 5ms, is taken into account to properly isolate the portions of the density signal. The result is displayed in Fig. 2 for a microphone located at $\theta = 30^{\circ}$ with respect to the jet axis in the downstream direction. Positive pressure peaks are considered and the conditional average is provided for six axial positions z/D, and for three radial positions y/D, where D is the jet diameter. The crosses indicate the point corresponding to the acoustic time delay for reaching the microphone. The identification of large changes in density may be observed near the end of jet potential core in the shear layer, and then closer to the jet axis further downstream.

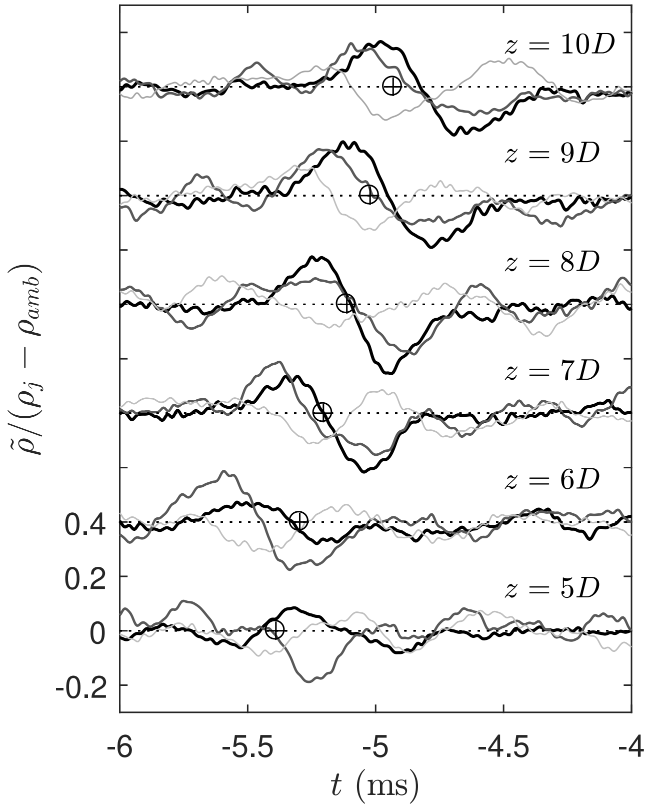

Figure 2: Conditional averaging of density signal triggered by negative pressure peaks recorded by a microphone located at $\theta = 30$ deg. in the far field, and for six axial positions z/D. In dark, for the radial position $y/D = 0$; in gray, for $y/D = 0.25$ and in lightgray, for $y/D = 0.5$.

Aknowledgments

This work was performed within the framework of the Labex CeLyA of Université de Lyon, within the program "Investissements d'Avenir" (ANR-10-LABX-0060/ANR-11-IDEX-0007) operated by the French National Research Agency (ANR), and it is also partially supported by the industrial Chair ADOPSYS cofinanced by SAFRAN-SNECMA and ANR (ANR-13-CHIN-0001-01).

REFERENCES

1. Miles, R.B., Lempert, W.R. and Forkey, J.N. Laser Rayleigh scattering, *Meas. Sci. Technol.*, **12**, R33–R51 (2001).

2. Panda, J. and Gomez, C.R. Setting up a Rayleigh scattering based flow measuring system in a large nozzle testing facility, AIAA Paper 2003-1089, 1–9 (2003).

3. Panda, J. & Seasholtz, R.G. Experimental investigation of density fluctuations in high-speed jets and correlation with generated noise, *J. Fluid Mech.*, **450**, 97–130 (2002).

4. Mercier, B., Castelain, T., Jondeau, E. and Bailly, C. Density fluctuations measurement by Rayleigh scattering using a single-photomultiplier, *AIAA Journal*, **56**(4), 1310–1316 (2018).

5. Panda, J., Seasholtz, R.G. and Elam, K.A. Investigation of noise sources in high-speed jets via correlation measurements, *J. Fluid Mech.*, **537**, 349–385 (2005).

6. Mercier, B., Castelain, T. and Bailly, C. Experimental investigation of the turbulent density - far field sound correlations in compressible jets, to appear in *International Journal of Aeroacoustics* (2018).

7. André, B., Castelain, T. and Bailly, C. Experimental study of flight effects on screech in underexpanded jets, *Phys. Fluids*, **23**, 126102, 1–14 (2011).

8. Mercier B., Castelain T. and Bailly, C. Experimental characterisation of the screech feedback loop in underexpanded round jets, *J. Fluid Mech.*, **824**, 202–229 (2017).