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ACOUSTIC FLOW FIELD RESEARCH WITH SOUND INTENSITY AND LASER ANEMOMETRY METHODS

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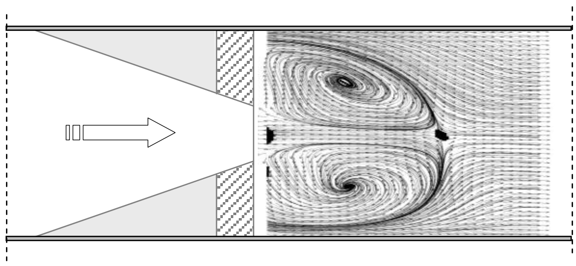
Aeroacoustics is the scientific discipline between fluid mechanics and acoustics. It considers sound generated by aerodynamics forces or motions originating from turbulent flows. Initially, experimental investigations were used to derive some empirical relations in order to estimate the noise emission of new technical products. However, owing to strongly increased computer performance, the numerical simulation of acoustic fields generated by fluid flow, computational aeroacoustics (*CAA*) has become very attractive (Ffowcs Williams, 1996).

The aim of proposed study was to obtain information on low Mach number flows around obstacles, inside a ducts and cavities using sound intensity (*SI)*, *PIV* and *LDV* techniques in order to improve physical understanding of these flows and to provide well documented test cases to validate computational aero-acoustic models (*CFD/FSI/CAA* methods). On the basis of a large number of time resolved instantaneous velocity vector fields the sound intensity and laser anemometry research techniques enables the possibility of independent determination of several main quantities of aeroacoustic parameters as: velocity fluctuations (u', v'), probability density functions and space-time-correlations of the velocity fluctuations, vorticity, average velocity profiles, and the acoustic streaming. An additional benefit of experimental studies is the opportunity to improve the theoretical calculation methods used for numerical modeling of noise in turbulent flows. A number of relevant aspects of this topic are not covered by the computation models existing today, although the noise contribution from each of the components of the acoustic flow needs to be accurately predicted. It will also be used to validate the calculations used in numerical models.

The sound wave propagating into a homogeneous gas medium creates small local disturbances in density, pressure and velocity (Fig. 1). The velocity fluctuations can be interpreted as the *acoustic particle velocity* (called also *acoustic velocity*). It is the perturbation velocity of a particle moving back and forth in the direction of the sound wave propagation. It is not the velocity of the wave propagation itself, which is called speed of sound or celerity.

Fig. 1. Disturbed flow acoustics inside waveguide visualized as a sound intensity streamlines



For low Mach-number isothermal flow we will see that aeroacoustic sound production is entirely due to mean flow velocity fluctuations, which may be described in terms of the underlying vortex dynamics. This leads to the idea of using so called *vortex sound theory*.

Vortex sound theory is not only numerically efficient but also allows us to translate the very efficient vortex-dynamical description of elementary flows directly into sound production properties of these flows in real-live conditions (Howe, 2003).

In general, sound measurements have a shortcoming together with an advantage in comparison with classical fluid mechanic measurements. The shortcoming comes from the fact that acoustic velocities and displacements are generally quite small and vary rapidly in time. For instance at 1000 Hz, for an acoustic level of 100 dB SPL the velocity amplitude is about 5 mm/s and the displacement amplitude about 10^{-6} m.

For applications with complex, inhomogeneous flows and flow-induced noise radiation, the most promising is to adopt a laser anemometry PIV and LDV technique to applied acoustics. Laser anemometry is a method which allows the non-intrusive instantaneous measurement of a field of vectors. The non-intrusive property of the laser measurements methods represents the greatest advantage against other methods using sensors for flow measurements. Laser methods can be also adapted to provide an instantaneous flow and acoustic particle velocity (Fig. 2) with the minimum disturbance of the sound field. The noninvasive nature combined with the small measuring volume of an PIV and LDV systems makes the techniques ideally suited to measure the acoustic particle velocity in the boundary layer. Sophisticated acoustic surveys of the acoustic boundary layer has also determined that the layer thickness is very small and is dependent on the frequency ($\delta_{ac}=(2\nu/\omega)^{1/2}$). For example, the audible range corresponds to oscillatory boundary layers from 0.02 mm (at 20 kHz) to 0.5 mm depth (at 20 Hz) and to acoustic velocity amplitudes from 5 10^{-8} m/s (at 0 dB) to 5 10^{-2} m/s (at 120 dB).

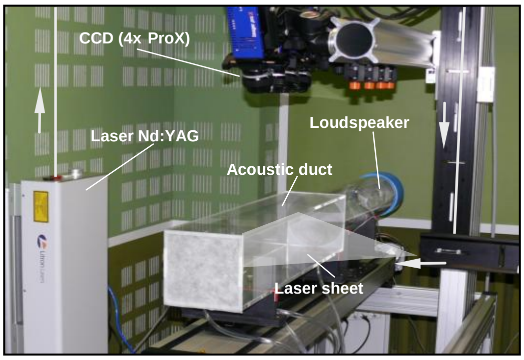
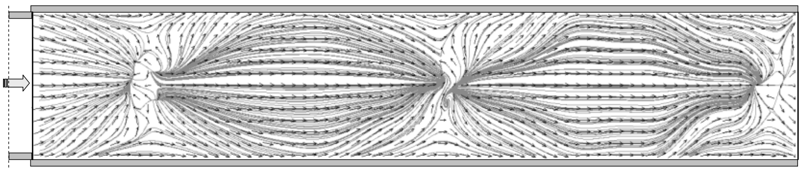


Fig. 2. Experimental setup and acoustic velocity distribution inside the square waveguide measured with PIV technique



We have extensive experience in applying the method of SI, but we can see that this method has one disadvantage: lead can not be measured very close to the sound source (eg at a distance of roughly <1 mm). Just in this region, so called *hydrodynamic acoustics near field* the sound is born and radiated to the environment. Since SI is the size of vector ($\boldsymbol{I_a}=p\,\mathbf{v}$), to describe the stream intensity we need to know the value of *particle acoustic velocity* **v.** Measurements of this magnitude can be made using PIV and LDV techniques renames as an *Acoustic*-Particle Image Velocimetry (*A-PIV*) and as *Acoustic*-Laser Doppler Velocimetry (*A-LDV*).

References

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