Application of Laser-Scanning Interferometry on Aeroacoustic Problems

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Introduction

Prediction of flow-induced noise is an object of intensive ongoing research. The investigation of noise generation mechanisms and the validation of numerical results requires the mapping of sound fields in the acoustic near field. Standard microphone techniques have the problem of coarse spatial resolution, flow disturbance and dominance of the hydrodynamic pressure fluctuations.

Measuring Technique

The principle of laser-scanning interferometry is the non-invasive measurement of changes in optical length of a laser beam crossing an unsteady pressure field (see Figure 1). For detailed explanation of the measuring principle see [2] and [3].

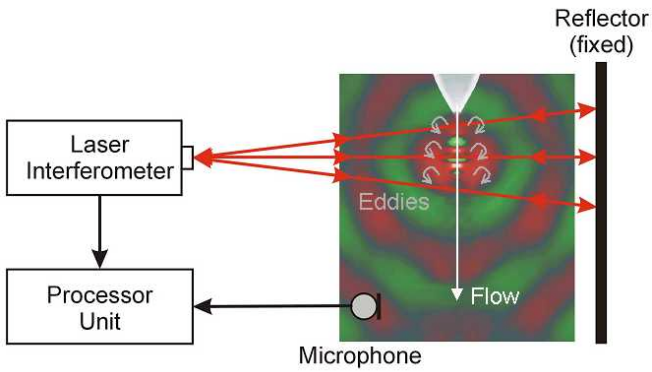

Figure 1: Laser interferometry principle

A standard scanning vibrometer PSV 200 from *Polytec* has been used for the measurement. The lower measurement limit was v_{eff} = 0.3 µm/s. Investigation of the stochastic process of noise production by turbulent flow requires referencing by signals from external microphones and averaging over a large number of data samples (typically > 100). In this way, non-correlated events are attenuated and only those turbulent structures and sound waves are highlighted which are correlated with the microphone signal. Close to aerodynamic sound sources, the hydrodynamic pressure fluctuations typically have much higher amplitudes than sound pressures. With classical point-like measuring techniques (microphones) the mapping of sound waves in the near field is not possible. With laser-scanning interferometry sound-like contributions prevail over the pseudo sound as their effective integration length is larger. This has been demonstrated for the assumption of a hypothetical coherent pressure fluctuation with a given amplitude of 70 to 82 dB and a sound pressure level of 50 dB. If the pressure fluctuations were locally measured with microphones, it would lead to a completely perturbed sound signal while with Laser interferometry one can preserve almost the original sound pressure level (see Figure 2).

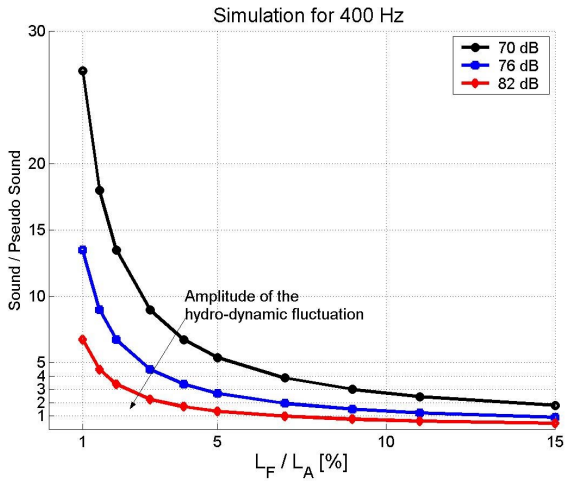

Figure 2: Influence of hydrodynamic pressure fluctuations (70 to 82 dB) on the measured values with laser interferometry for a sound pressure level of 50 dB. L_F: Integration length of hydrodynamic pressure fluctuations; L_A: Integration length of sound wave.

Application on Test Cases

The new measuring technique has been applied to one of the BOSCH aeroacoustic test cases: A turbulent jet, evolving from a nozzle of diameter D = 30 mm, with a jet Mach number of 0.3 impinges after 8 D on a flat plate which was inclined at 50°. In Figure 3 the noise production process by vortex-plate interaction and by free turbulence is visualised at a frequency of 975 Hz.

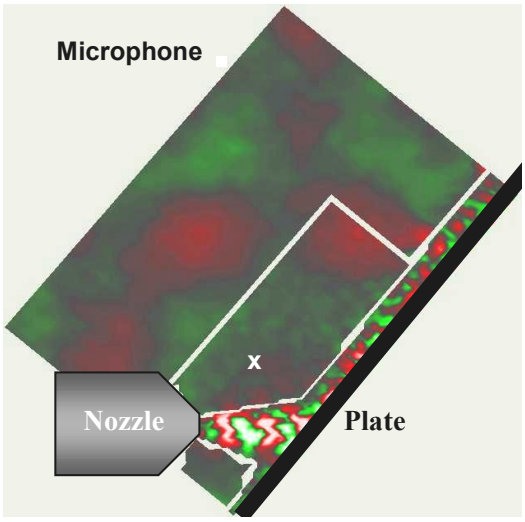

Figure 3: Visualisation with laser interferometry: sound waves and turbulent structures at 975 Hz.

In Figure 4 the spectrum of the sound correlated with the far field microphone signal is shown which has been measured close to the impingement point (marked by a white cross).

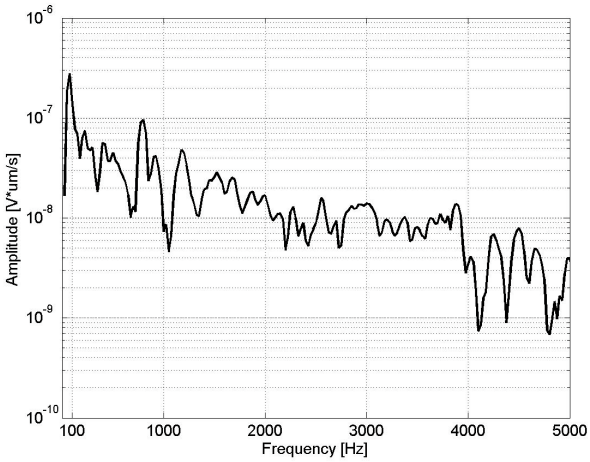

Figure 4: Sound related variable for an observer near the impinging point of a jet with a plate. Spectrum of signal from laser interferometry multiplied by the signal from a reference microphone in far field.

Comparison with CAA-results

For the same test case the sound generation process has been studied with computational aeroacoustics (CAA). Sound sources were derived from an unsteady CFD simulation (Large Eddy Simulation) using a 2D model and an expansion about incompressible flow [1]. The sound field has been modelled with Euler equations linearised around the local properties of the unsteady flow. Figure 5 shows the instantaneous sound source distribution. Figure 6 shows the spectrum of sound pressure level (SPL) in near field. The computed sound pressure levels can not be compared directly with the measured values due to the numerical 2D sound propagation. Nevertheless the computed spectra exhibit very similar spectral distribution.

Conclusions

Statistical properties of pressure fluctuations of the unsteady fluid flow or of sound waves can be mapped by means of laser-scanning interferometry. The visualisation of turbulent flow events and of the sound generated by the flow leads to a deeper understanding of aeroacoustic sound generation. The experimental data sets obtained by means of laser-scanning interferometry are useful for comparison with numerically modelled sound fields based on CFD-data. In this way, CAE tools for the prediction of flow-induced sound can be adjusted.

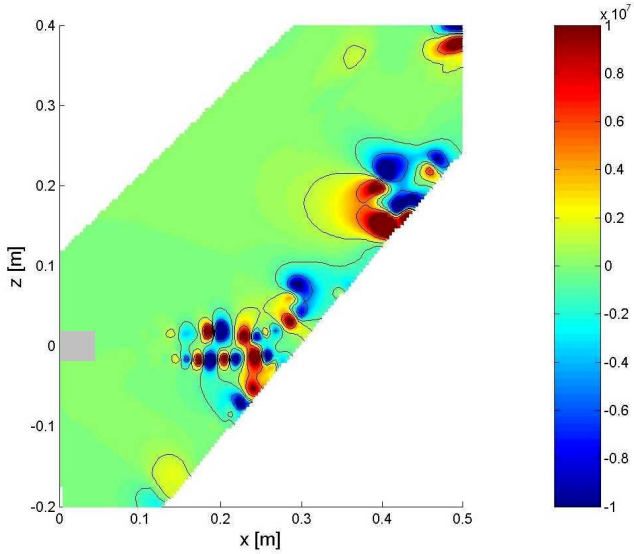

Figure 5: Instantaneous sound source distribution from a 2D LEE calculation for an impinging jet (M=0.3, plate inclination = 50°). The nozzle is in grey.

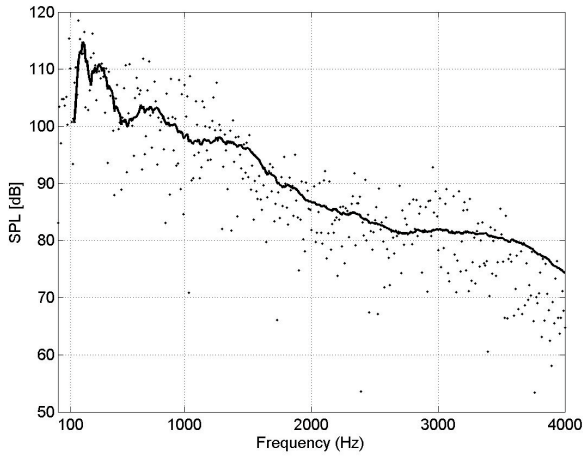

Figure 6: Spectrum of sound pressure level from a 2D LEE calculation for the same position as in Figure 4. Solid line: moving mean over one third octave around centre frequency.

Literature

[1] J.C. Hardin, D.S.Pope, An Acoustic/Viscous Splitting Technique for Computational Aeroacoustics, Theoret.Comput.Fluid Dyn, **6**, 323-340 (1994)

[2] K. Bendel, A. Gerlach, Mapping of fluid pressure fluctuations using a scanning Laser-Doppler interferometer, DAGA, CD-ROM (2004)

[3] L. Zipser et al.: „Interferometrische Messung und Visualisierung von Schallwellen und Turbulenzen“, Technisches Messen, **6**, 275-281 (2002)