Experimental and numerical analysis of the generation of a turbulent flow field in a free stream jet and its correlation to acoustic radiation and wall pressure fluctuations

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Introduction

A turbulent circular free stream jet is generated using an axial symmetric fan driven by a brushless actuator with variable frequency leading to typical core-velocities of around 10 m/s (Re = 99000). The flow is propagated through a pipe (radius = 80.5 mm) system significantly damping the noise from the fan. Turbulence is generated using different sets of turbulence generators [2, 3, 4] in the tunnel (length approx. 3 m) consisting of meshes, rods, blades and spikes. The turbulent flow field downstream of the pipe outlet is measured using two-axis hot wire anemometry [1] with a temporal resolution of 48 kHz. The CTA probe is positioned using an automated three-axis traversing system. The turbulent jet impinges on a wall in the distance of 0.55 m from the pipe outlet. 12 Microphones are positioned on a flat plate mounted on the wall in the center-line of the jet. CFD (computational fluid dynamics) calculations are performed for the different turbulence generators and compared to the CTA signals. An important aspect of the work is the simultaneous recording of both the CTA- and the microphone signals. This allows for the calculation of correlation patterns between turbulence and the acoustic signals. The generation of free stream turbulence in a controlled way and its correlation to downstream pressure fluctuations is the primary aim of the work.

Numerical Simulation

The numerical analysis have been performed on a hybrid mesh consisting of tetrahedral cells in the region of the turbulence generators (see figure 3) and a prismatic / hexahedral mesh in the up- and downstream area. Mesh sizes of 2 mm at the turbulence generator core lead to typical cell counts of 3 million cells). Best results have been achieved by applying a turbulent velocity profile at the tube inlet and fixing the turbulent kinetic intensity to a value of 2.6 %. The fluid leaves the calculation area through the cylindrical surface and its base plane (see figure 1. The jet impinges on the opposite circular area of the cylinder, which is defined as a hard wall. Steady CFD calculations leading to acceptable low numeric residuals were not possible for all turbulence generators. Sharp blades caused very high fluctuating fields, which could not be captured by a steady solver. Comparing experimental and numerical results, the RNG formulation of the k-ε model gave best agreement. The differences have been found to be most pronounced in the near wall region at the microphone plate. Figure 2 shows the turbulent kinetic energy on the analysis plane for a turbulence generator with 4 spikes.

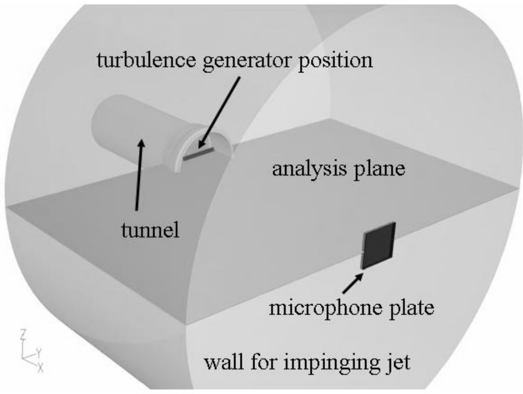

Figure 1: Geometry for the CFD simulation. A circular jet impinges on a microphone plate mounted on a wall. Turbulence generators can be applied in the outlet region of the tunnel.

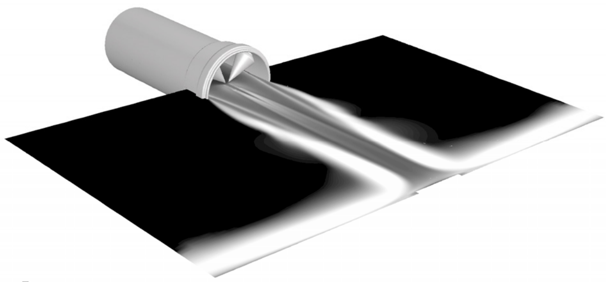

Figure 2: Turbulent kinetic energy [m^2/s^2] for a turbulent generator with 4 spikes. The simulations are performed using a steady kε-RNG model (grey scale range from 0 to 1).

Experimental Results

Signals from the 2-axis CTA (constant temperature anemometer) have been recorded simultaneously with 12 microphone signals with a sampling rate of 48 kHz. The data were acquired in the analysis plane on 492 points (streamwise tunnel direction x: 12 points, perpendicular crosswise direction +y: 41 points). All signals (CTA, microphone) have been scaled by their corresponding calibration values. For the spectral analysis they have been further numerically filtered (low pass filter 20 kHz), DC subtracted and Fourier transformed.

As an example, figure 4 compares two signals for 6 different turbulence generator setups: (1) the spectra of the CTA measurement 6 mm in front of the microphone plate and (2) the spectra of one of the microphone signals.

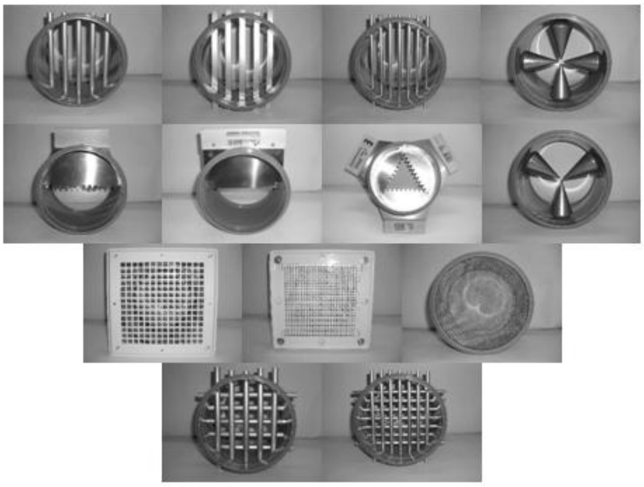

Figure 3: Different turbulence generators consisting of rods, blades, spikes and meshes. They can be mounted on top of the tunnel outlet.

All three turbulence generators (5 circular rods with diameter 12 mm, 5 quadratic rods with 12 mm side length and 7 circular rods with 8 mm diameter) were designed to have the same amount of obstruction.

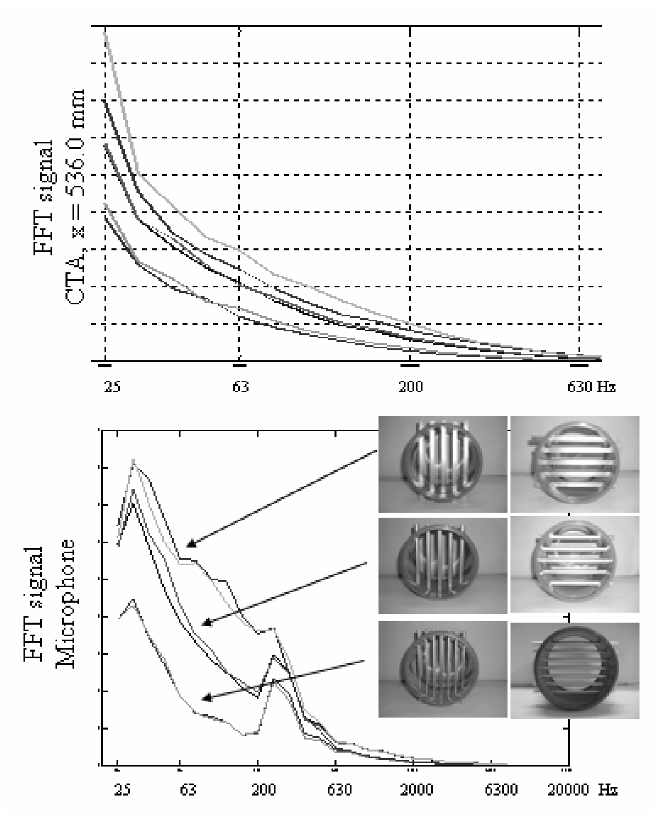

Figure 4: Comparison between frequency spectra of CTA signal (upper figure) 6 mm in front of microphone plate and microphone spectra (lower figure) for 6 different turbulence generator flow setups (y-axis FFT linear scale).

The microphone signals (lower figure 4) are clearly separated and show a peak around 250 Hz which is not observed in the CTA signals (upper figure 4). The reason for this can, however, not be found in the turbulence generator, as the peak persists, when no turbulence generator is present.

Conclusions & Outlook

Steady CFD simulations can give trends but are not ideally suited for quantitative analysis as they are not able to capture the inherent transient flow patterns. The RNG formulation of the k-ε model compared best to the experimental data (streamwise and crosswise velocity, turbulent kinetic energy). Differences in the models are most pronounced in the stagnation area of the impinging jet at the wall. For some turbulence generators (blades), a steady solution could not be achieved.

Correlations between turbulent velocity fields and microphone signals have been investigated for 11 different turbulence generators. Larger turbulence coincides with larger pressure fluctuations, the full frequency behaviour, however, could not always be reproduced. The reasons may lie in additional acoustic incoming waves, which can be attributed to dipolar and quadrupolar sound sources as well as vibrations of the turbulent generators.

Transient CFD simulations (DES) will be employed to provide frequency spectra for comparison to the experimental data. Furthermore, the correlation between simulated local velocity fluctuations and pressure fluctuations at the wall can be investigated. These results will also be compared to the experimental correlation, as CTA and microphone signals have been recorded simultaneously. The 12 microphone signals also allow for spatial correlation analysis.

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