Calculated and Measured Turbulent Noise in a Strongly Swirling Isothermal Jet

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Introduction

The most common technique, used for flame stabilization in combustion devices such as aero-engines, is the application of strongly swirling inflows. Despite the major advantage of high ignition stability, such flows constitute a large source of noise due to the strong turbulent motion and, additionally, to combustion, which acts as an energy source to amplify the noise of the turbulent motion. As it is known, that the noise level originating from an isothermal flow (turbulence noise) is much smaller than from equivalent flows including combustion, the central focus of the framework "combustion noise", in which the present work is incorporated, comprises noise generation from turbulent flames. As a first approach, in the present study the isothermal swirling flow and the noise originating from this flow have been investigated experimentally and numerically.

Objective

In order to study combustion generated noise, a new combustor has been developed at the Division of Combustion Technology at the Engler-Bunte-Institute. This burner provides the possibility to vary important geometry parameters, which are expected to influence the generation of combustion noise (figure 1).

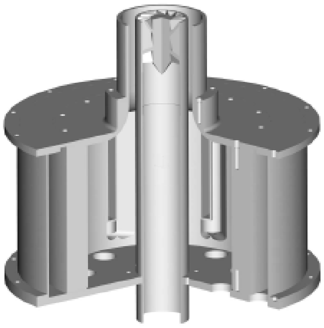

Figure 1: Sketch of the new burner. Two separate flows, central and concentric annular can be impinged with swirl by axial swirlers; in the outer flow additionally by tangential channels.

The combustor provides two inflows, central and concentric annular, with the possibility to vary the swirl intensity in each inflow. Additionally, the type of swirl generation for the annular flow can be changed from axial swirl generation to tangential swirl generation, which is shown in figure 1 and was done for the investigations shown in this work. The axial position of the swirl-generator in the central inflow can be moved upstream as a further parameter. Using this device, first experimental and numerical data from the isothermal flow have been derived.

Experiments

On the experimental side, the sound pressure level (SPL) has been measured with a microphone probe at various axial and circumferential positions to check the spatial distribution of noise. The experiments were performed in an open large environment to minimize noise reflection. As probing unit a B&K condenser microphone was used. The microphone signals were processed to get both, the wavelength integral sound pressure level and spectral resolved amplitudes of the noise.

LES Simulation

As a first approach for calculation of the flow noise the isothermal flow field was calculated in a confined configuration using the large-eddy simulation (LES) formulation for turbulence closure (e.g. [1]). The applied computational fluid dynamics code was CFX-TASCflow 2.12. As a first attempt to resolve the major features of the flow an incompressible formulation of the Navier-Stokes equations was applied. The subgrid model used in the LES formalism was the Smagorinsky model [2] with dynamically adjustment of the model constants. The three-dimensional grid was block-structured with 142 blocks and a total of 452064 nodes and comprises the internal burner geometry as well as the chamber.

As the numerical calculations preceded the experiments, the total inflow volume flux was chosen to 630 m_N^3/h. In contrast, due to limitations of air supply in the experiments, only a slightly smaller volume flux of 603m_N^3/h could be adjusted in the experimental setup later. The swirl intensity was adjusted to conceive comparable circumferential velocities in the burner exit. The inflows were chosen as pure undisturbed laminar flows. This advance can be judged appropriate, as the flow rapidly develops turbulent motion. In particular, the strong radial acceleration from the outer flow into the burner nozzle imprints its own turbulent motion due to high velocity gradients forced by the geometry.

Simulation results

From the results of the time resolved LES-simulation a total physical time of 0.15 s was analysed. Figure 2 shows two contour plots of the axial velocity in a meridian cut of the calculation domain in the vicinity of the burner outlet with a time delay of 2.8 ms. On the first sight a decrease in axial velocity in the outer annular channel can be seen for positive (upper image) and for negative y-positions (below, see arrow). This overall decrease in the local axial velocity comes together with an upstream flow (negative axial velocity, blue) at the radially inner edge of the nozzle (x=0;

y=+/-0.035). This periodically recurring upstream flow narrows the effective area for the annular outlet and, thus, temporarily increases the axial momentum flux.

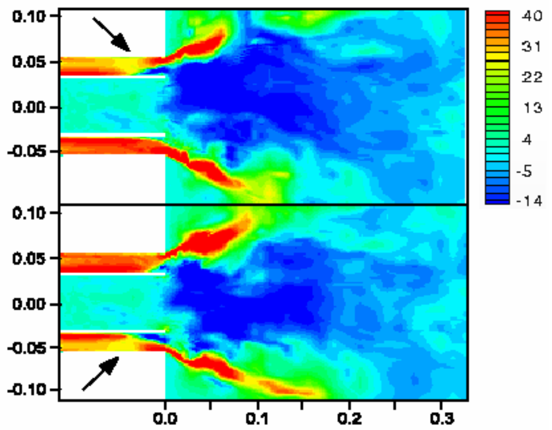

Figure 2: Contour plots of calculated axial velocity in a meridian cut in the vicinity of the burner outlet. The time difference between the two time-steps is 2.8 ms.

An important parameter for describing the swirl intensity is given by the swirl parameter S_0:

$$S_0 = \frac{\dot{D}}{\dot{I} \cdot R_0} \tag{1}$$

with $\dot{D}$ standing for the circumferential momentum flux, $\dot{I}$ denoting the axial momentum flux and R_0 standing for a reference radius, which usually is chosen as the outer nozzle radius. As the swirl parameter decreases for increasing axial momentum flux, pressure increases in the channel and in series the temporary upstream flow region is blown out of the channel. This mechanism is illustrated in Figure 3, was already suggested in [3] from experimental results and is well reproduced from the simulation.

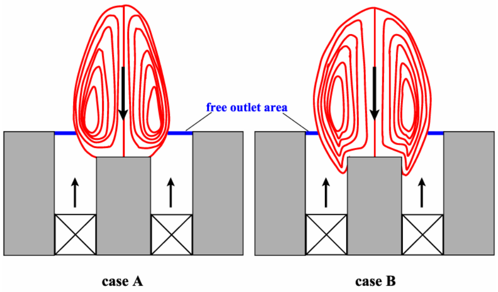

Figure 3: Mechanism of periodical blockage of an annular channel by a central recirculation zone.

Comparison of spectra

The good representation of the mechanism outlined above encourages to compare measured and calculated spectra. As the calculations so far only incorporated the incompressible Navier-Stokes equations, noise generation is not included by definition. But, because generation of coherent flow structures in the vicinity of the burner exit is suggested to constitute the major noise source, an attempt was made to compare qualitatively a spectrum of measured sound pressure level with the spectrum of calculated turbulent fluctuations of the static pressure, recorded near the chamber wall.

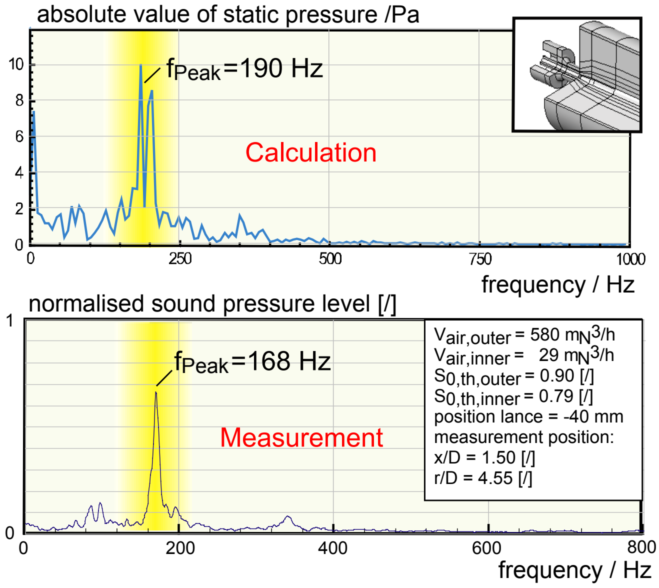

Figure 4: Qualitative comparison of a measured spectrum of sound pressure level with the spectrum of the calculated static pressure at the outer boundary of the calculation domain.

In figure 4 an example for this comparison is shown. The upper part of the image shows the spectrum of calculated static pressure and the lower part shows the measured spectrum of the normalized sound pressure level. Both spectra show a distinct tonal peak at frequencies of 190Hz (calculation) and 168Hz (measurement). Taking into account that the inflow volume flux of the calculations was slightly higher, the agreement of the preferential frequency is excellent. In combination with the observed mechanism shown for the calculations in the vicinity of the burner exit, the agreement in the spectral representation confirms the suggestion, that the major mechanism for noise generation in this configuration is identified by the periodic blockage mechanism outlined above.

References

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