Experimental and Numerical Investigation of Flow-induced Sound for Impinging Jets on Simplified 3D Geometries

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Introduction

This work carries on the investigations of subsonic impinging jets on small simplified obstacles[1] extending the range to completely three dimensional geometries. The test cases idealise typical automotive components (like screen wipers or cooling ribs). The main focus is on the localisation of sound sources, on the mechanism of sound generation, and on the influence of obstacle geometries. In this work we apply the Lattice-Boltzmann method (LBM). Due to the compressible and inherently transient nature of LBM, the method belongs to the class of aeroacoustic direct method, that is fluid turbulence and acoustic waves are solved concurrently. In this work we use the code 'PowerFLOW' which has been validated for a wide variety of engineering flow applications and recently used also for aeroacoustics [2]. In [3] the numerical approach is described, references to classical LBM theory are listed and more detailed results of this investigation are presented.

Configuration

The impinging flow has a mean velocity of 40 m/s and a temperature of 25°C equal to the environment. Figure 1 shows the profiles and their idealised geometrical environment.

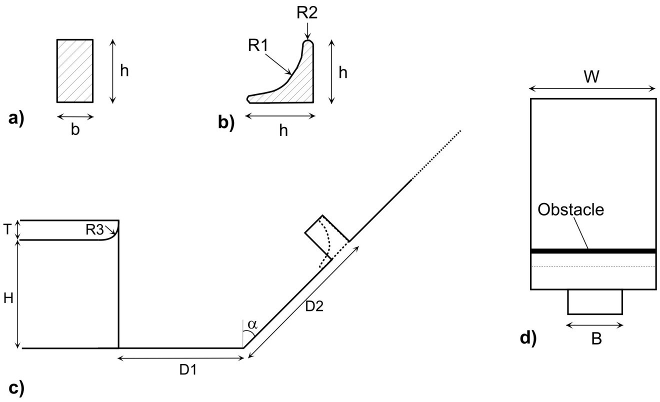

Figure 1: a) rectangular profile, b) wiper profile, c) geometrical environment (profile), d) geometrical environment (top view). $h = 15\,\text{mm}, b = 10\,\text{mm}, R1 = 13\,\text{mm}, R2 = 0.7\,\text{mm}, R3 = 1.75\,\text{mm}, D1 = 50\,\text{mm}, D2 = 60\,\text{mm}, H = 50\,\text{mm}, T = 10\,\text{mm}, B = 200\,\text{mm}, W = 800\,\text{mm}, \alpha = 45°$.

Numerical and Experimental Set-up

Figure 2 shows the domain discretisation used in this study. The domain is subdivided into 8 regions with voxel size doubling at each region crossing. The total number of elements is 21 millions. However, considering that in larger voxels the solution is calculated less frequent, the computational effort corresponds to about 8 million elements of the same smallest size. In particular a surrounding region with larger viscosity (ν_2) has been used to reduce spurious wave reflections at numerical outflow boundaries. The calculation was run for 150 ms after an initial phase of 40 ms which is necessary to obtain statistically steady data. The calculation took overall 2043 CPU hours on Opteron-type Machine.

The aeroacoustic wind-tunnel of the applied physics department has been used for validation purposes. A fluid dynamics validation is conducted with single probe hot wire anemometry and two dimensional laser Doppler anemometry. The acoustic validation is aimed to compare overall sound pressure levels in near and far field, sound spectra, location of sound sources and wave propagation. It is conducted with capacitive microphones and laser interferometry.

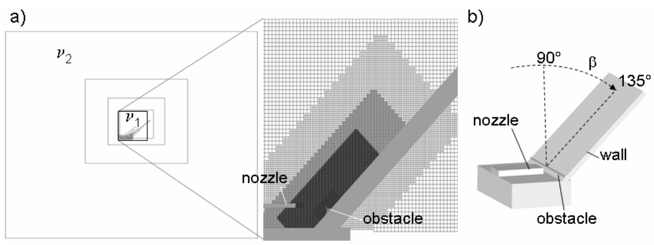

Figure 2: Domain discretisation. a) Voxel size ranges from 0.6 (interior) to 76 mm. (exterior). The lines indicate doubling of Voxel size. The exterior has a fluid viscosity ν_2 100 times higher then the interior ν_1 b) three dimensional view of the configuration with angular location β of microphones

Results

The acoustic waves and the source regions are clearly visible by post-processing the simulated pressure field with band-pass filters (Figure 3). For frequencies lower than 800 Hz the source region can be easily localised near the obstacle, while at higher frequencies it can be localised more and more in the region of flow-reattachment behind the obstacle. The comparison with laser interferometry in figure 4 shows similar results. Moreover, both simulation and experiment show a region of interference close to the nozzle about between 70° and 90°. Angles β are measured clockwise from the obstacle position starting from the horizontal direction. This interference is due to the nature of the main sound source due to the obstacle (dipole) and the reflections due to the nozzle itself.

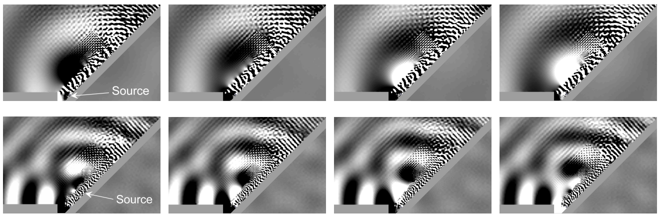

Figure 3: Simulated instantaneous pressure field for 800 Hz (above) and 1700 Hz (below): sequence of 4 pictures over $\approx$ 0.2 ms from left to right.

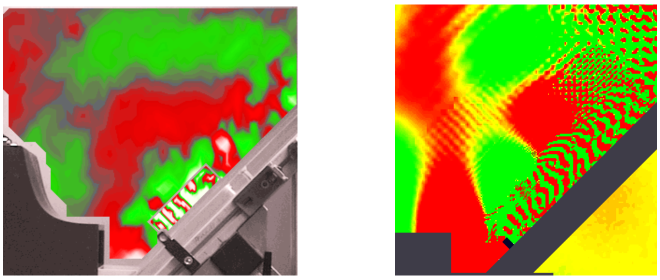

Figure 4: Qualitative comparison of pressure fluctuation fields measured with Laser interferometry (left) and simulated with LBM (right) for 1700 Hz

Figure 5 summarises the simulated and measured overall sound pressure level (OASPL) in the significant frequency range (150–5000 Hz) for both geometries over different probe locations. The locations are further marked s1 and s2 for distances of respectively 0.5 and 1 m from the obstacle. For the small distance (s1) and angles β larger than $\sim 100°$, we can observe that the pressure fluctuations are affected by hydrodynamic fluctuations (pseudo sound), therefore the OASPLs are very large. In the region dominated by acoustic pressure fluctuations (s2 and s1 for angles smaller than $\sim 100°$) we observe a very good agreement of OASPL trend and a underestimation of typically 3-5 dB. Moreover the wiper profile shows a lower OASPL than the rectangular profile at all locations. This is confirmed experimentally. Globally the noise generated is broad band, showing however peaks in the low-middle frequencies.

Conclusion

Using regions with artificial high viscosity spurious sound wave reflections at the numerical boundaries are made negligible. Experiments and simulations show differences in the OASPL of the investigated obstacles and reveal that the shaped wiper profile is quieter than the rectangular one. In far field, at 1 m from the obstacle, this difference yields between 3 and 5 dB in the experiments and between 1 and 2 dB in the simulation. The sound directivity is predicted very well and shows a continuous, but slight, level increase in flow downstream direction as in the experiments. It is also confirmed that the turbulence kinetic energy is not a measure for the OASPL: LBM overpredicts the turbulence level (more energy in the resolved turbulence scales, smaller separation regions) but understimates about 3-5 dB the OASPL

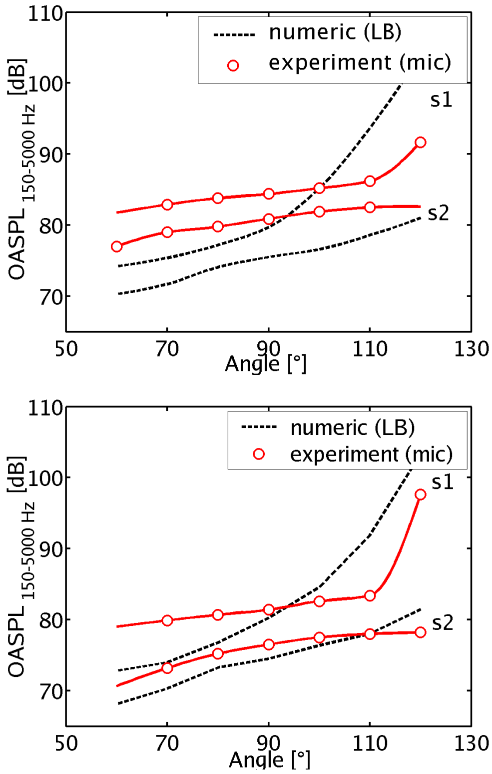

Figure 5: Comparison of OASPL for rectangular profile (above) and wiper profile (underneath) over different microphone positions.

levels. The selective frequency analysis shows the characteristic dipole-like sound propagation. Moreover, high frequency sound is mostly generated in the reattachment region behind the obstacle. In conclusion this investigation shows that LBM has good capabilities for predicting subsonic aeroacoustic problems and provided deep insight into the physics of subsonic jets impinging on obstacles.

References

[1] M. Zucchini, M. Fischer, Experimentelle und numerische Untersuchung der strömungsinduzierten Schallentstehung an 2D-Geometrien auf Oberflächen, Fortschritte der Akustik, (DAGA 2005), p. 637-638

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[3] M. Zucchini, M. Fischer, B. Crouse, G. Mercier, S. Cyr, Aeroacoustic investigation of low Mach number jet impinging on simplified 3D geometries using Lattice-Boltzmann Methods, submitted to Acta Acustica, 2006