# High-Fidelity Acoustic Simulation of a Recorder Using PowerFLOW

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## 1 Introduction

Computational acoustics is a rapidly evolving field of study that relies on a variety of simulation and analysis methods to model the acoustic behavior of different systems, including musical instruments.

Among them, SOLIDWORKS Flow Simulation and ANSYS Fluent employ the finite volume method (FVM) and Unsteady Reynolds Averaged Navier-Stokes (URANS) equations, coupled with the Lighthill acoustic analogy, to simulate acoustics [1, 2]. Although ANSYS Fluent could also use the Ffowcs Williams and Hawkings (FWH) equation, this method requires an additional step to describe the acoustic field. On the other hand, PowerFLOW uses the Lattice Boltzmann Method (LBM) with the Very Large Eddy Simulation (VLES) method [3]. Fundamentally LBM solves the unsteady flow field in small time steps. Its low numerical dissipation and high accuracy make it an ideal choice for aeroacoustic simulations.

This study aims to highlight the precision and robustness of PowerFLOW simulation software to simulate the acoustics of a Turkish treble recorder. This woodwind music instrument is chosen for its modeling simplicity, serving as an optimal case study for the comparison of various simulation techniques.

## 2 Methodology

Airflow behavior in the Turkish treble recorder was initially characterized by Celik *et al.* [1], both experimentally and numerically, using SOLIDWORKS Flow Simulation, thus establishing a baseline for the current study. The referenced work examined the initial four tones produced from the head of the recorder when played in a closed position, assuming no leakage in the closed holes, under four distinct blowing speeds of 2, 4, 5.5, and 10 m/s. The numerical values of air velocity, pressure, and acoustic power level in the simulation domain were then determined.

The same recorder was simulated in ANSYS Fluent, with a Cartesian-based meshing technique used for the fluid region, with an element size of 0.001 m. The default k-epsilon model constant were chosen [4]. The less-computational expensive broadband noise source model [2] was used instead of the FWH equation.

Finally, the recorder was also simulated in PowerFLOW. The boundary conditions were defined similarly to the one used for SOLIDWORKS Flow Simulation. The computational domain was divided into nine virtual regions (VR) of progressively higher resolution, as shown in Figure 1, resulting in an effective number of voxels of around 10.9 million and a time step (dependent on the finest resolution) of 1.04 µs.

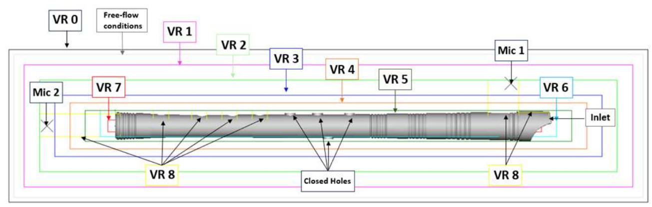
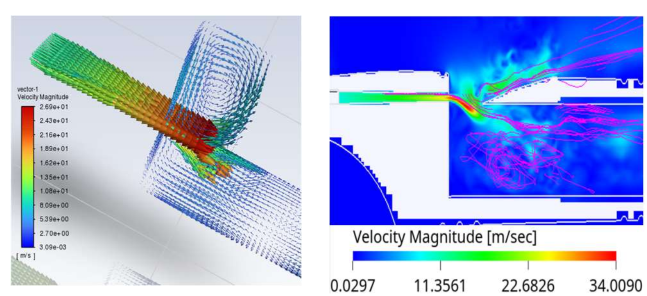



**Figure 1**: Side view of the simulation set-up.

The precise probe location of the experimental measurements was not specified in [1]. A simulation probe (Mic 1) was assumed to be placed 20 mm above the jet opening of the recorder and another probe (Mic 2) was placed 45 mm from the recorder's exit. The maximum simulated sound pressure level of Mic 1 was compared to the experimental measurements from [1], the SOLIDWORKS Flow Simulation results, and the ANSYS Fluent results. Additionally, the peak values recorded by Mic 2 were analyzed alongside measurements taken experimentally with an anemometer in the referenced work.

## 3 Results and discussion

PowerFLOW simulation, using LBM, demonstrated more distinct vortex formation, attributable to its microscopic, particle-based approach which excels in acoustic studies. Unlike the macroscopic URANS approach, LBM's time-stepping technique accurately captures complex flow physics and transient details, making it superior in resolving small vortices as shown in Figure 2.




(a) (b)

**Figure 2:** Velocity magnitude around the jet opening for an inlet speed of 10 m/s: (a) ANSYS simulation and (b) PowerFLOW simulation.

Moreover, the $\lambda_2$ parameter, which is a non-dimensional parameter representing turbulence, could only be obtained directly with PowerFLOW and reveals intricate vortex

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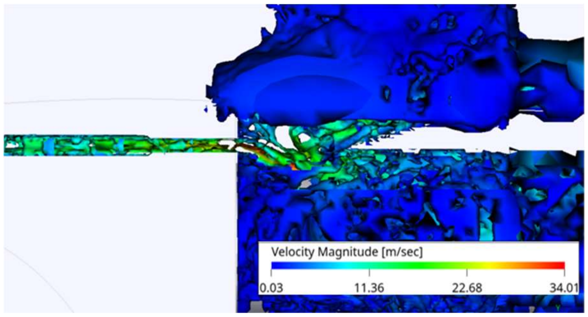


**Figure 3:** $\lambda_2$ criterion applied to the recorder.

structures within the instrument. These structures were color-mapped according to their velocity, as illustrated in Figure 3.

PowerFLOW is also used to extract the sound pressure level spectrum, an advantage not available with the other simulation methods, as illustrated in Figure 4. The maximum sound pressure level at Mic 1 is identified and compared with the values provided in the referenced article.

The results in Table 1, showing the maximum sound pressure levels at the four inflow rates, further help highlighting the superiority of PowerFLOW. Overall, the difference between the experimental and numerical results is the lowest with PowerFLOW. A comparison with ANSYS FLUENT indicates larger relative deviations from the experimental results, consistent with Oberkampf's assertion of a potential 35% error for the employed k-ε model [5]. While ANSYS Fluent shares a similar methodology to SOLIDWORKS Flow Simulation, its unique implementation of boundary conditions has resulted in diminished accuracy.

Upon examination of Table 2, it can be noted that the dominant tone frequencies simulated by PowerFLOW display a maximum difference of only 4.5% from those measured experimentally in [1]. While the referenced article did not provide a numerical comparison of the frequencies derived experimentally, this study successfully bridged this gap using PowerFLOW. This further confirms that PowerFLOW accurately replicates the recorder's note better than the other two software.

## 4 Conclusion

This research explored the application of computational acoustics, specifically the use of PowerFLOW simulation software, to model the acoustics of a Turkish treble recorder. The study highlighted the software precision and robustness, benefiting from its use of LBM and the VLES method. These findings underscore the importance of precise experimental measurements in future work to further validate the performance of LBM in accurately simulating acoustic phenomena.


## Acknowledgments

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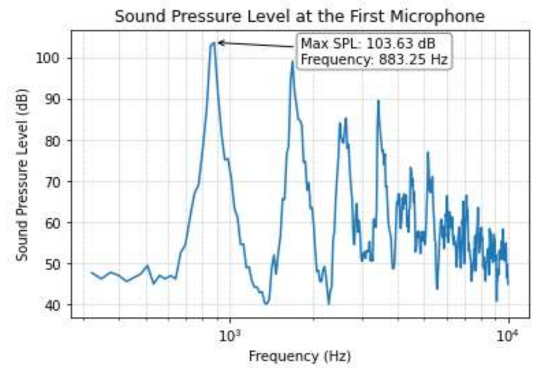


**Figure 4:** Sound pressure level for an inlet speed of 10 m/s.

**Table 1:** Comparison between experimental and simulated acoustic power levels at various inlet airflow rates. For conciseness, only the relative difference with respect to the experimental value is reported.

| Inlet speed | Experim. | SolidWorks | ANSYS | PowerFLOW |
|---|---|---|---|---|
| 2 m/s | 62.9 dB | 11.8% | 42.1% | 2.8% |
| 4 m/s | 81.6 dB | 7.1% | 29.1% | 7.2% |
| 5.5 m/s | 98.1 dB | 12.7% | 38.0% | 1.6% |
| 10 m/s | 102.6 dB | 13.3% | 30.8% | 1.0% |

**Table 2:** Comparison between experimental and PowerFLOW-simulated dominant tone frequencies, measured at Mic 2, for various inlet speeds.

| Inlet speed | Experimental | PowerFLOW | Relative diff. |
|---|---|---|---|
| 2 m/s | 879.4 Hz | 862.4 Hz | 1.9% |
| 4 m/s | 1759.7 Hz | 1686.3 Hz | 4.2% |
| 5.5 m/s | 2634.8 Hz | 2516.2 Hz | 4.5% |
| 10 m/s | 3514.2 Hz | 3426.3 Hz | 2.5% |

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