

Flow-Induced Noise Optimization of SUV HVAC System using a Lattice Boltzmann Method

Abdelhakim Aissaoui
Exa Corporation

Ravindra S Tupake and Vilas Bijwe
Tata Motors, Ltd.

Mohammed Meskine, Franck Perot, and Alain Belanger
Exa Corporation

Rohit J Vaidya
Tata Motors, Ltd.

ABSTRACT

For the automotive industry, acoustic comfort is of increasing importance. The market and customer expectation make the HVAC system noise quality a question to be addressed as early as possible in the vehicle development process. On one hand, the so-called traditional sources of annoyance such as engine, road-tires contact, exhaust systems and wind-noise have been significantly reduced for most traditional combustion engine vehicles. On the other hand, considered in the past as secondary noise sources, HVAC systems become the main sources for hybrid and electric and Stop-start vehicles. Previous studies have demonstrated the ability of a CFD/CAA approach based on the Lattice Boltzmann Method (LBM) to predict HVAC system noise including real and complex ducts, registers, mixing unit and blower geometries. This LBM low dissipative numerical approach has indeed been shown to accurately capture turbulent and convective mechanisms and to propagate acoustic waves in ducted systems and in free-field. For this type of HVAC noise simulations, both the turbulent flow and the corresponding flow-induced noise contribution are captured in one simulation.

The main goal of the present paper is to apply this digital solution for predicting and optimizing the flow-induced noise contributions of a production HVAC system. The validation of the numerical results is achieved by comparing the Sound Pressure Level at the passenger's ear locations to acoustic measurements performed in production vehicles. The validated method would then be used during the development as an alternative to experiment-based prototyping which is a time-consuming approach and not always easy to carry out. The validation is organized into three phases, from ducts only to full production HVAC system, in order to provide additional understanding on mechanisms involved in HVAC noise.

In this paper, our focus is on flow-induced noise contribution related to the turbulent flow generated on a detailed HVAC system. Some acoustic and pressure loss measurements are performed by Tata Motors Company on a real car. Flow and noise predictions are performed using the transient, compressible and explicit CFD/CAA solver PowerFLOW 4.4 based on LBM. Noise sources are identified for each phase and new designs numerically and experimentally tested. The final result of this project is a noise reduction of 4dB on the full HVAC system.

CITATION: Aissaoui, A., Tupake, R., Bijwe, V., Meskine, M. et al., "Flow-Induced Noise Optimization of SUV HVAC System using a Lattice Boltzmann Method," *SAE Int. J. Passeng. Cars - Mech. Syst.* 8(3):2015, doi:10.4271/2015-01-2323.

INTRODUCTION

The study presented in this paper corresponds to the most recent outcomes of a collaborative project between Tata Motors Company and Exa Corporation. The main objective of this study is to validate a digital solution in predicting and optimizing flow-induced noise contributions from HVAC systems. This would help in proposing

another alternative to support prototyping and signing off the final testing. The digital method plays a critical role at early stages of vehicle development process to reduce cost and prototype timing.

In this paper, our attention is focused on flow-induced noise contribution related to the turbulent flow generated by HVAC system vents outlets and the mixing unit of HVAC systems. At high mass

flow rate, the flow-induced contribution from the ducts and registers is the main source of noise in the mid to high frequency ranges and is more important than the HVAC structure borne and blower engine contributions. To assess the noise contribution from each system, the current work has been split into three main phases. The first phase was dedicated to the vents with the ducts only. In the second phase, additional HVAC parts were added such as the blowers and mixing unit. In the third phase, the full HVAC model incorporated in a production SUV cabin is investigated. During each phase, the original HVAC geometry is assessed experimentally and numerically. The flow-induced noise contribution is then optimized numerically and the optimal HVAC design is validated experimentally.

Details of the geometry used for each phase and the experimental process are presented in the first section. CFD/CAA methods and the corresponding geometry are then presented in the second section. In the following sections, the paper focuses on assessing the flow-induced noise contribution from different HVAC configurations. Also, a deep flow analysis is presented for each phase in order to understand the noise generation mechanisms. Finally, new designs are numerically tested and compared to the experiments.

EXPERIMENTAL SETUP DESCRIPTION

The HVAC system of the SUV was experimentally tested to obtain data to validate the computational predictions. The experimental work was performed at the semi-anechoic chamber in Pune, India through three different phases.

Phase 1 Setup

Phase 1 is dedicated to the induced noise prediction of ducts only (Figure 1), with two different vents positions (Fully open and partially open called Line Of Sight (LOS)) (Figure 2). The HVAC system is placed in a semi-anechoic room. The flow is generated with a fan located outside the anechoic room and a silencer is added to attenuate both the blade passing frequency noise and the overall sound levels. The flow generator was calibrated to deliver the mass flow at the inlet pipe in the semi-anechoic chamber to replicate the real mass flow in the cabin. The system is designed to link the flow generator to the HVAC system in such a way that the flow stays attached and that no additional flow-induced noise is added by this portion of the system. The aim is to keep the flow as laminar as possible when entering the tested system. Other sources such as the fan noise used to move the air in the system and the structure borne radiation of duct surfaces are damped and are considered negligible.

The Sound Pressure Level (SPL) is measured at 4 positions of microphones shown in Figure 1 and located about 0.98 m from the vents. The microphones are representing the driver and passenger ears positions (named Driver Outer "DO", Driver Inner "DI", Passenger Outer "PO", and Passenger Inner "PI").

During the experiments, different flow rates were tested in order to cover the different HVAC sceneries'. The mass flows are measured at each vent outlet.

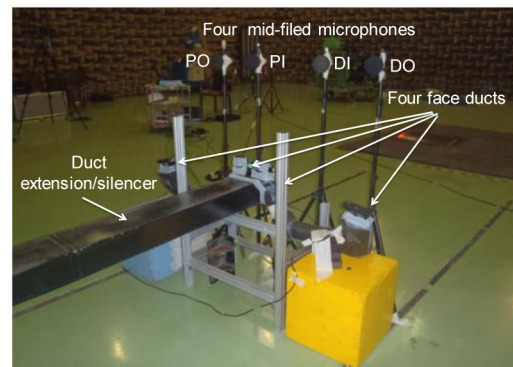


Figure 1. Tested HVAC system (Phase 1)



Figure 2. (Left) Fully open vents position; (right) partially open vents position

Phase 2 Setup

In this phase, additional HVAC parts were added to the system. The mixing unit with a twin blower was added to the Phase 1 geometry (Figure 3). In Figure 4, the schematic view of the experimental setup is presented. To ensure the assessment of noise contribution of the additional parts, test setup was built to keep similar conditions as in Phase 1. The ducts and mixing unit are inserted inside a small chamber. Heavy material was used around it to eliminate vibration noise. Flow is imposed by the flow generator to get the same mass flow used in Phase 1. The blowers are maintained fix. However, during the tests, some leakages were observed especially around the bower area. Most of them were sealed.



Figure 3. Tested HVAC system (Phase 2)

Microphones were kept in the same position to allow comparison with Phase 1 position. Additional microphones were added to understand more the noise behavior in different location.

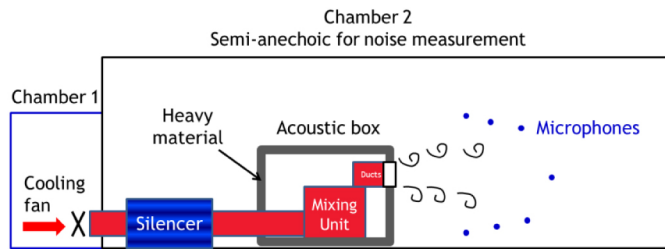


Figure 4. Schematic view of the Phase 2 experimental setup

Phase 3 Setup

In this phase the HVAC system is assessed in a production SUV. The Storme vehicle was the tested model to include the HVAC system used in previous phases. In order to cope with the new environment, the flow generator and the pipe used to link the flow to the HVAC system were taken away in this configuration. In this phase, the blower is activated to generate the flow using the fresh air mode. The positions of microphones were conserved in such away a similar distance from the vents, compared to Phases 1 and 2, but inside the cabin. To attenuate vibration from the dashboard and the cabin, heavy material was placed on the dashboard in a way it does not impact the flow path from the vents and ensure vibrations are minimized (Figure 5).



Figure 5. Tested HVAC system (Phase 3)

Experimental Measurements

Before we evaluate the delta between test and simulation, it is important to evaluate the accuracy of the experimental measurements. In this part, some parameters are assessed in order to understand their impact on measurements. This will help in understanding the differences between tests and simulations. In addition, lessons learned from this exercise will help in improving both methodologies for future programs.

Silencer Impact

The introduction of the silencer in the system, for Phases 1 and 2, is important to attenuate the noise from external sub system in the test.

The Sound Pressure Level (SPL) at two different microphone locations is presented in Figure 6 with and without the silencer. It is obvious that the impact of the silencer is mainly limited to low frequencies (below 800 Hz). Some strong peaks appear on the case without silencer within the frequency range 100-300Hz. Those peaks are significantly reduced but still visible on the case using the silencer.

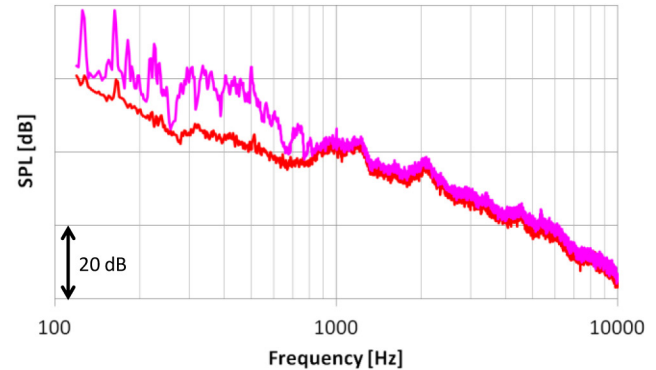


Figure 6. SPL at driver inner position. (—) with silencer; (—) without silencer

Experimental Background Noise

In Figure 7, Sound Pressure Levels from tests at different mass flow rates are presented for the driver inner microphone position. Below 400Hz frequency, some strong peaks appear at low flow rates (Q_1 to Q_3). Those peaks are similar to the ones highlighted by the silencer effect tests. Above 4000-6000Hz, the effect of the background noise is also visible for the three lowest flow rates. Therefore, only the frequency range 300-4000 Hz will be considered for the comparison between experiments and simulations.

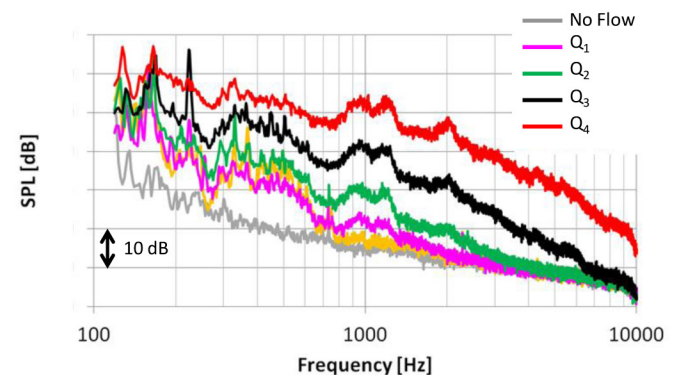


Figure 7. SPL at driver inner position for different flow rates

Microphone Windscreen Effect

In this part, the effect of the microphone windscreen is assessed. The SPL with and without the microphone windscreen are compared. The pseudo-noise, related to the effect of the flow jet, is clearly highlighted by the experiment by comparing both configurations and is limited to the frequencies below 1000 Hz (Figure 8).