Acoustics'08
Paris
June 29-July 4, 2008
www.acoustics08-paris.org

Aeroacoustic simulation of automotive ventilation outlets

Jean-Luc Adam[a], Denis Ricot[a], Flavien Dubief[a] and Christine Guy[b]

[a]Renault SAS, 1 avenue du golf, 78288 Guyancourt, France
[b]Ligeron, Les Algorithmes Bâtiment Euclide, 91194 Saint Aubin, France
jean-luc.adam@renault.com

In this work we have numerically studied aeroacoustics of automotive ventilation outlets. Simulations are performed with PowerFLOW CFD software based on Lattice Boltzmann method (LBM). Low dissipative LBM scheme lets to compute aeroacoustic sources generated by turbulence fluctuations and to propagate them in the same simulation. In the first step we validate the ability of LBM for propagating acoustic waves in ducts and radiating them at open end terminations. In the second step, aeroacoustic simulations on automotive vents will be presented and compared with experimental data obtained from a DoE (Design of Experiment). The DoE is based on an idealized outlet with varying parameters (number and length of grid blades, grid spacing ...) which gives 18 distinct geometrical configurations. All these configurations have been simulated with PowerFLOW and measured with a new test facility (built in the Renault Research Department). The large number of tested geometries give a clear idea of the capability of PowerFLOW to correctly simulate the generation and propagation of aeroacoustic sources for a complex geometry. Results will be presented and discussed.

1 Introduction

As car manufacturers are doing large efforts, mostly focused on engine noise, to reduce noise level heard by passengers, aeroacoustic sources are becoming more and more important. Among these sources, ventilation noise represents a non-negligible contributor. For that reason, Renault has invested an important effort through the last years for a better understanding of acoustic ventilation mechanisms and to improve acoustic performance of these systems.

In ventilation and air conditioning devices, acoustic sources are mostly dominated by the blower. Nevertheless, as performance of these blowers is increasing, secondary sources are now emerging such as ducts and outlets where turbulent flow can be responsible of aeroacoustic noise. Therefore, if one wants to get a correct acoustical design of the ventilation system it is necessary to take into account each of the subsystems that compose it and particularly ventilation outlets.

Automotive vents are quite complicated components because they require some mechanisms (toothed wheel, orientation grilles) in order to perform its function that is to orient the flow towards the car passenger. Those mechanisms, and their coupling, are the main responsible for the aeroacoustic noise generated. Experimental characterization of the vents is interesting to get the global SPL emitted but it is difficult to go more inside the aeroacoustic sources even with sophisticated measurement devices. Moreover, the design process is becoming more and more based on numerical tools, which makes experimental characterization less suitable. For these reasons, we have concentrated our efforts on performing a numerical characterization of the aeroacoustic behavior of automotive ventilation outlets.

In a previous work, [1] it was tried to get an analytical expression of the aeroacoustic emission based on the theory formulated by Nelson and Morfey [2]. Despite its great interest, this theoretical formulation can be hardly generalized to a wide panel of outlet geometries. On the other hand, during the last decades, the exponential growth of computers performances has made possible the developpement of Computational Fluid Dynamics for industrial purposes. First, CFD was limited to steady-state formulations that was not very efficient for aeroacoustic problems. Since the beginning of the 2000s aerodynamic software providers are now proposing the unsteady solvers that are required for aeroacoustical purposes. Among them PowerFLOW by Exa Corp., based on a particular numerical scheme called Lattice Boltzmann Method (LBM), has become a leading actor mainly for automotive industry. The ability of this solver to simulate unsteady aerodynamic fields and to propagate weakly compressible acoustical waves [3] makes it a good candidate for aeroacoustic issues.

In this article, we present an example of application of LBM on aeroacoustic characterization of automotive ventilation outlets. We first validate the ability of PowerFLOW to propagate acoustic guided waves and then we realize, within a single simulation, the generation and propagation of aeroacoustic sources inside an automotive vent. One of the interests of this work is the number of geometrical configurations that have been tested in the context of a Design of Experiment.

2 Acoustic propagation with LBM

It is not the purpose of this paper to give a rigorous demonstration of the ability of the LBM numerical scheme to correctly propagating acoustic waves. For a theoretical point of view one may refer, as a beginning, to some works realized at Renault Research Department [3][4][5].

In this paragraph, we are validating, with two examples, that we can propagate acoustic guided waves and make them being diffracted at an open-end termination. The chosen examples are an unflanged circular pipe and a simplified automotive vent. The numerical setup, shown Fig. 1, is quite simple. There is no aerodynamic flow. The terminations are only excited upstream by an acoustic wave and we are looking at the reflected wave on the interface of the termination. The reflected wave can then be characterized by the reflection coefficient:

$$R = \frac{P_{reflected}}{P_{incoming}} \tag{1}$$

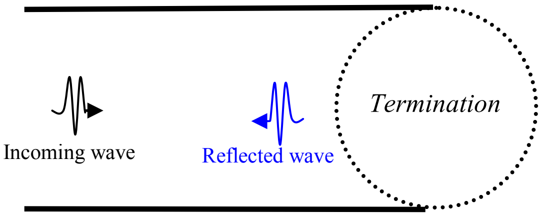

Fig. 1 : Acoustic validation principle

2.1 Circular unflanged pipe

This case is interesting because we can find in literature [6] some analytical expressions approximating the reflection coefficient. The studied geometry is a circular pipe with a diameter of 50 mm and 300 mm length. The excitation source is white noise upstream of the pipe. As we can see on Fig. 2 and Fig. 3 PowerFLOW results are in a quite good agreement with theory. Concerning the amplitude, difference is less than 1 dB, and phase result is as good as what can be obtained with a standard measurement.

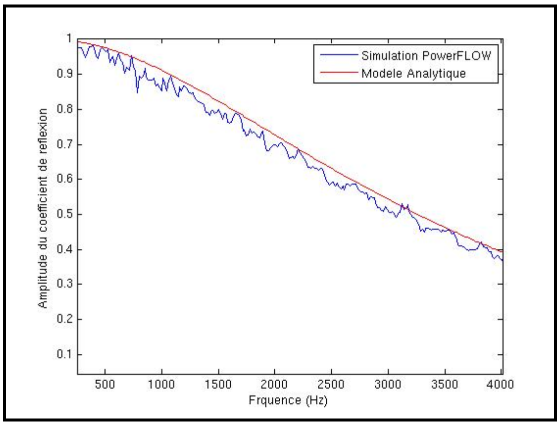

Fig. 2 : Reflection coefficient magnitude of a circular unflanged pipe (red curve is theory, blue curve is PowerFLOW simulation)

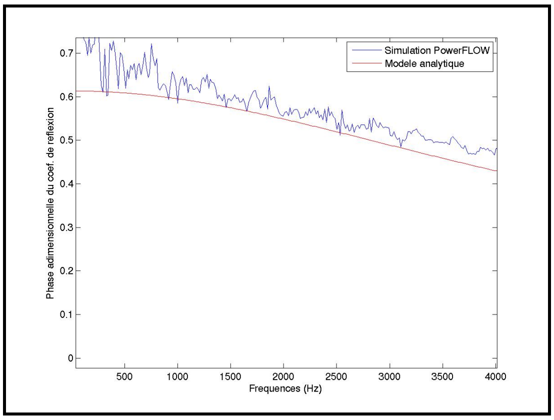

Fig. 3 : Reflection coefficient phase of a circular unflanged pipe (red curve is theory, blue curve is PowerFLOW simulation)

2.2 Simplified automotive vent

As explained, the Design of Experiment have been realized on a simplified geometry of automotive ventilation outlets shown in Fig. 4. Therefore, it was important to ensure that PowerFLOW was able to deal with an acoustic field propagating in such a complex environment. Fig. 5 shows the reflection coefficient calculated with LBM and compared with result obtained by the acoustic BEM solver Sysnoise. Naturally, using Sysnoise for this type of application had been previously validated with experimental data (not shown in this paper). As we can see on Fig. 5, Lattice Boltzmann simulation gives an accurate evaluation of the reflection coefficient even for a complicated configuration. The difference between Sysnoise and PowerFLOW results is less than 1.5 dB, which can be considered as a good approximation. On Fig. 6 one can observe the acoustic field inside the duct and its diffracted part at the interface. As expected, it can be noticed that we get an omnidirectionnal radiation of the acoustic energy outside the vent.

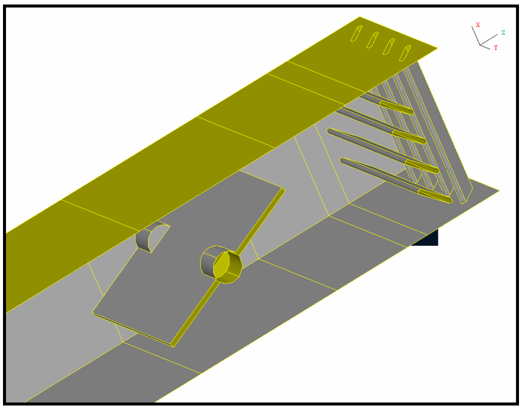

Fig. 4 : Simplified automotive vent

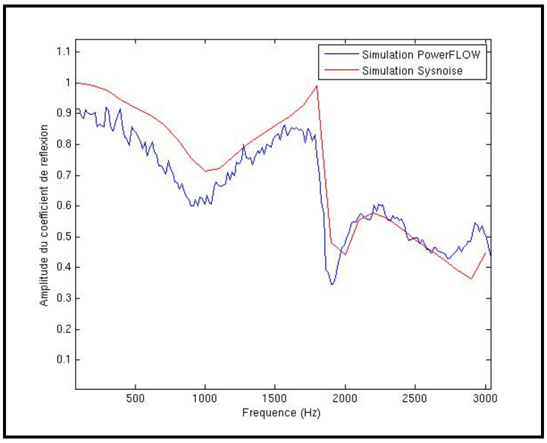

Fig. 5 : Reflection coefficient magnitude of a simplified vent (red curve is theory, blue curve is PowerFLOW simulation)

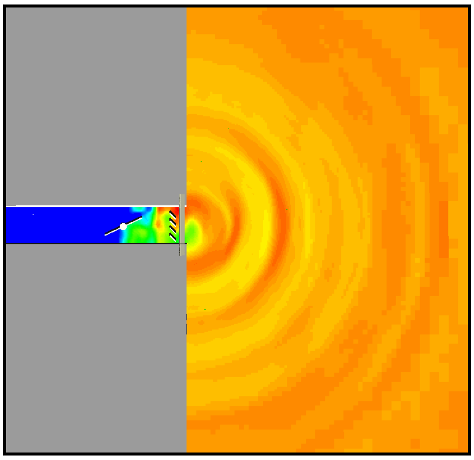

Fig. 6 : Instantaneous acoustic field through the simplified vent (two different scales inside and outside the duct)

3 Experimental setup

3.1 Introduction

The experimental data required to validate and compare with the numerical results was obtained thanks to a new test facility at Renault Research Department. This testing device was built and used by the same people (the authors) who performed the numerical simulations which is important to get a better understanding of the physics of the problem. It also permitted to detect some problems *in the experimental setup* who first lead to give results that were quite different of numerical data.

3.2 Test bench

The test device is a classical facility for in-duct measurements. A quiet flow is generated with a blower. The flow is then passing through an acoustically treated chamber connected to the duct on which the ventilation outlet is mounted (Fig. 7). In order to not to be disturbed with the noise emitted by the blower, this first part of the bench is installed in an isolated room. Then the ventilation outlet is placed in another room, coupled to the first one, which is acoustically treated to be as quiet as possible (Fig. 8). In this configuration it is possible to study the aeroacoustic field radiated by the outlet.

Fig. 7 : Blower and expansion chamber generating the quiet flow isolated in a separated room

Fig. 8 : Duct termination with automotive outlet connected to the blower but placed in an acoustically treated room

3.3 Design of Experiment

As mentioned in the introduction, a Design of Experiment was realized in order to identify the main design parameters that are responsible for the aeraoacoustic generated noise and pressure loss of automotive vents. Seven varying parameters were found to be of interest. Each parameter could take 3 different values. An orthogonal Taguchi plan with 18 different configurations (Fig. 9) was set up which could give the linear influence of each design parameter on the chosen responses.

In this paper, only individual results comparing simulation and measurement for one configuration are presented. It gives nevertheless a good idea of the capabilities of Lattice Boltzmann Method for aeroacoustic problems. The authors have also done a statistical analysis of both experimental and numerical plans, but it is not exposed in this short communication.

In order to ensure a perfect matching between experimental and numerical realization of the plan, the physical geometries were realized by sintering from the CATIA numerical geometries (Fig. 9).

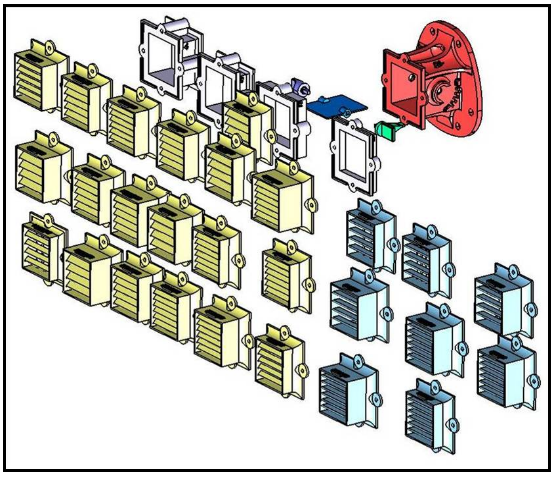

Fig. 9 : 18 geometrical configurations for the DoE

4 Aeroacoustic numerical results

In this paragraph, we present a brief overview of experimental and numerical results. There is no statistical analysis of the DoE but individual analysis of different geometrical configurations. We present successively aeroacoustic terms generated upstream and downstream (i.e. in the quiet room) of the ventilation outlet.

It is also important to indicate that numerical and experimental results are presented in density. Both are Power Spectral Density, but numerical simulation gives a smaller physical time simulated which leads to a poor frequency resolution.

4.1 Upstream source term

Fig. 12 and Fig. 13 illustrate the good agreement found between measurements and simulations. Another important result to underline is that, for some configurations, we got a whistle (around approximatively 200 Hz), which was the result of an aeroacoustic interaction between the valve and the grilles. We observed this phenomenon experimentally and it appeared naturally for the same numerical configurations.

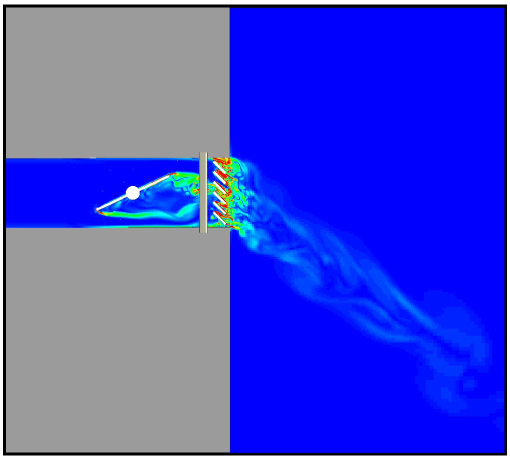

Fig. 10 : Unsteady vorticity flow field visualization

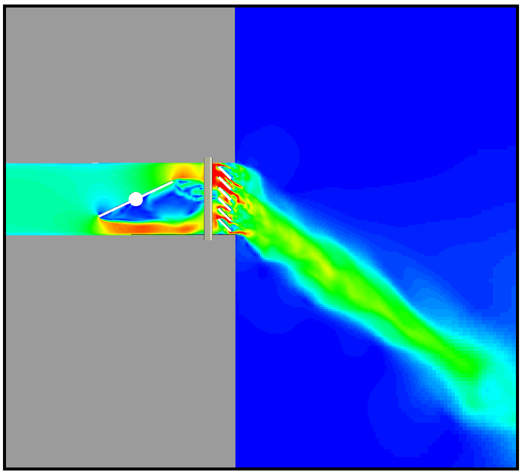

Fig. 11 : Unsteady velocity flow field visualization

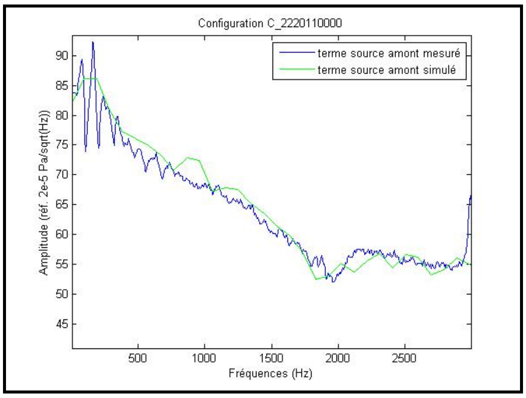

Fig. 12 : Aeroacoustic upstream source term for one configuration (experimental is blue curve, numerical is green curve)

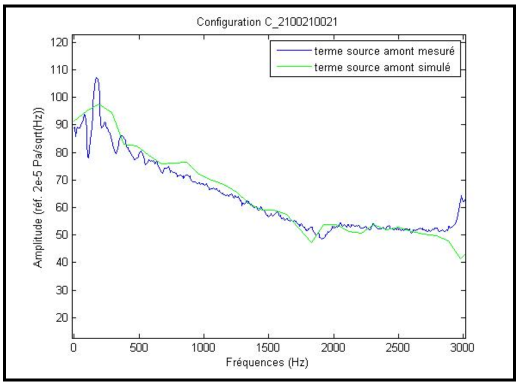

Fig. 13 : Aeroacoustic upstream source term for another configuration (experimental is blue curve, numerical is green curve)

4.2 Downstream source term

We also get good results for the radiated source term downstream of the ventilation outlet. What is interesting to notice here is the particular form that the acoustic spectra is representing (Fig. 14 and Fig. 15). These fluctuating behaviors are due to the acoustical response of the outlet when the valve is inclined as we saw it on paragraph 2.2. Those results give a strong evidence for the aeroacoustic capabilities of PowerFLOW and Lattice Boltzmann Method.

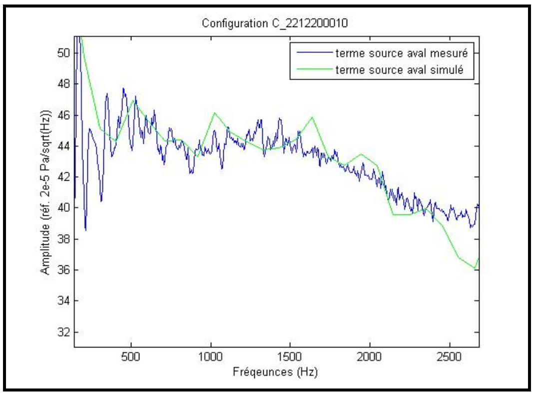

Fig. 14 : Aeroacoustic downstream source term for one configuration (experimental is blue curve, numerical is green curve)

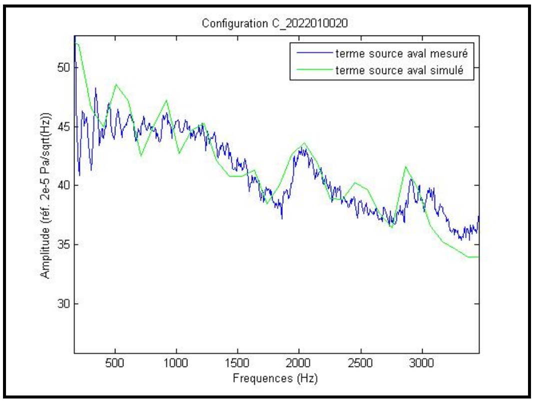

Fig. 15 : Aeroacoustic downstream source term for another configuration (experimental is blue curve, numerical is green curve)

4.3 Identified limitations

For some configurations, we found numerical results that were well correlated with experimental data but only until a frequency around 2000 Hz (Fig. 16). In fact, it was shown that this limitation was mainly due to a lack of spatial meshing resolution. Indeed, simulating the same geometry at the same spatial resolution but with a higher speed (in order to artificially increase the frequency cut-off of the simulation) we retrieve a good correlation until 3000 Hz .

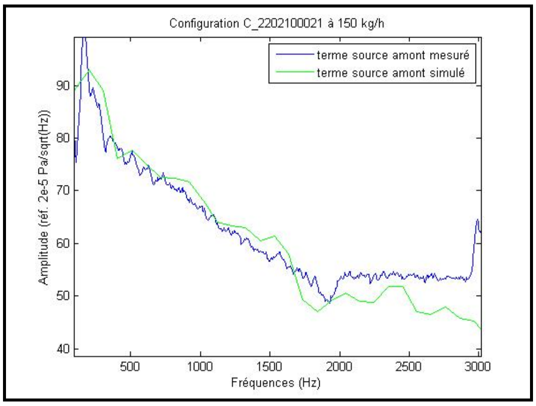

Fig. 16 : Aeroacoustic upstream source term for one configuration with limited correlation

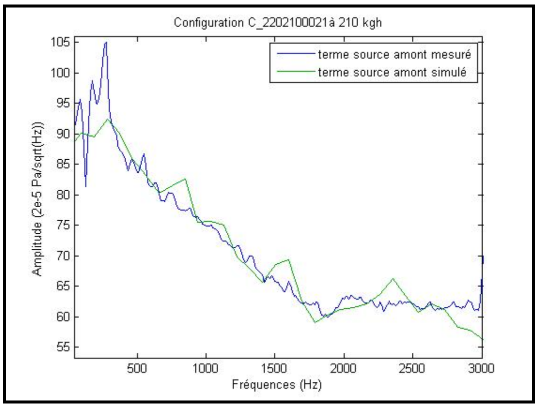

Fig. 17 : Same aeroacoustic upstream source term than Fig. 16, but with artificially increased resolution

5 Conclusion

In this study, it was demonstrated that the Lattice Boltzmann Method and PowerFLOW commercial code could accurately capture and propagate aeroacoustic sources in complex and industrial configurations. The authors want also to highlight that the same people realized the experimental part and the numerical part of this study. This particularity is an important element because of the sensitivity of aeroacoustic sources to experimental setup (geometry variations and measurement techniques).

References

[1] S. Guérin, E. Thomy, M.C.M. Wright, "Aeroacoustics of automotive vents", *Journal of Sound and Vibration 285*, 859-875 (2005)

[2] P.A. Nelson, C.L. Morfey, "Aerodynamic sound production in low speed flow duct", *Journal of Sound and Vibration 79*, 263-289 (1981)

[3] S. Marié, D. Ricot, P. Sagaut "Accuracy of Lattice Boltzmann Method for Aeroacoustic simulations", *AIAA-paper 2007-3515* (2007)

[4] S. Marié, D. Ricot, P. Sagaut, "Comparison between Lattice Boltzmann Method and Navier-Stokes high order schemes for aeroacoustics", *submitted to Journal of Comp. Physics* (2007)

[5] D. Ricot, V. Maillard, C. Bailly, "Numerical simulation of unsteady cavity flow using Lattice Boltzmann Method", *AIAA-paper 2002-2532* (2002)

[6] A.N. Norris, I.C. Sheng, "Acoustic radiation from a circular pipe with an infinite flange", *Journal of Sound and Vibration* 135, 85-93 (1989)

[7] M.L. Munjal, "Acoustics of ducts and mufflers", *John Wiley & Sons* (1987)