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

prediction and audio synthesis of vehicle pass-by noise

Estelle Bongini[a], Stephane Molla[b], Cédric Herviou[a], Dominique Habault[c] and Franck Poisson[a]

[a]SNCF DIR, 45, rue de Londres, 75379 Paris, France
[b]Genesis S.A., Bâtiment Gérard Mégie, Domaine du Petit Arbois - BP 69, 13545 Aix-en-Provence Cedex 4, France
[c]LMA CNRS, 31 chemin Joseph Aiguier, 13402 Marseille, France
estelle.bongini@sncf.fr

The European project SILENCE is dedicated to the reduction of railway and roadway noise in urban areas. Within this context, SNCF and LMA (Laboratoire de mécanique et d'acoustique, Marseille) collaborate into the sub-project B to develop a pass-by sound simulation software. This global modelling tool will support parametric studies on the reduction of the noise of a train or a car pass-by, by providing standard indicators (time signature, equivalent sound pressure level) and sound samples. These sound samples are computed in B-Format, which allows, after a short post-processing, to provide various listening formats (mono-aural, binaural,...).
The software is now operational and the sources characterisation has been carried out on an AGC bi-mode BOMBARDIER train and a passenger car. Equivalent sources have been defined in various operating conditions. Simulated pass-by indicators (signature, Leqtp(A)) in various configurations have been compared to measured one and show very good agreement.
A perceptive validation has been carried out with listening tests, by indirectly comparing recorded samples corpus and corresponding simulated samples corpus. It shows that the arrangement made by the listeners of the simulated corpus and the arrangement of the recorded corpus are closely the same and are based on the same perceptive criteria.

1 Introduction

The european project SILENCE is dedicated to the reduction of railway and roadway noise. Manufacturers have proposed new source improvements that implie noise reductions. A suburban train like the Bombardier AGC is composed of twenty one noise sources: if noise emission of each optimised source can be estimated with numerical or analytical studies, its impact on the global pass-by noise of the train is hardly obtained. Into the sub-project SILENCE B, the software VAMPPASS (Vehicle Acoustic Modelling for Pass-by Prediction and Audio Simulation Software) has been developped. This software calculates global pass-by noise time signal from sources spectra and directivity patterns and the definition of the pass-by scenario. From the time signal, standard acoustic indicators are calculated and listening samples in various formats are provided. The first section of this paper is dedicated to the software development. In the second section, after having validated VAMPPASS, an example of parametric study is presented. It has been led to estimate the best combinations of optimised sources in term of global pass-by levels reduction and pass-by sample agreement.

2 Description of VAMPPASS

VAMPPASS has been developped to evaluate, in conception steps, which acoustic improvement will impact the global pass-by noise. It provides, from acoustic noise sources definition, standard acoustic indicators and sound sample of the pass-by. Thus time signal of the pass-by has to be calculated.

As urban circulations are concerned, the vehicle's speed can evolve during the pass-by: it can modify source definition, this evolution has thus to be supported by the software.
Users should lead parametric study: on the one hand equivalent noise sources has to be defined in such a way that real source improvement can easily be taken into account, on the other hand short calculation times are necessary.

All these constraints constitute the framework of the software.
To provide time signal in short computation times, a new synthesis method has been used. It is based on the construction of a global time-frequency plan in which evolutions of all the noise sources are given. A time-frequency description of the pass-by allows to take into account speed changes described by the scenario as well as doppler effect or ground effect (taken into account through image-source model). This plan is turned into time signal by an Inverse Short Time Fourier Transform. This "single" calculation ensures short computation times. The method is illustrated in the figure 1.

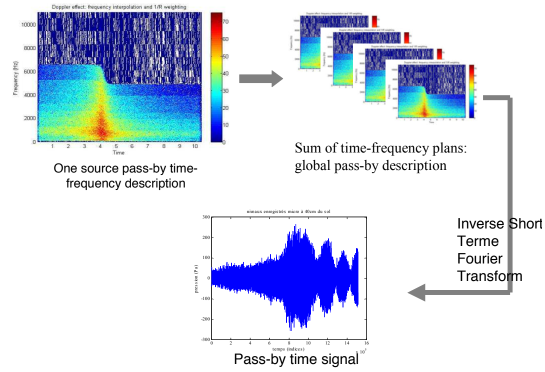


Figure 1: Synthesis method illustration

It has to be noticed that only the time-frequency plan of the pressure level is drawn: phase continuity is not ensured by this method. For energetic components at distinctive frequencies, called tonal components, an additive synthesis approach is chosen in order to improve their listening effect.

To easily implement source optimisations, a real source is represented by a unique equivalent point source. The complex sound radiation of the real source is taken into account through a directivity pattern described by spherical harmonic coefficients allocated to equivalent source. One equivalent point source can be defined for different speeds. The acoustic evolution of a source according to train speed is given through an evolution law, that can correspond to linear dependency, logarithmic dependency, step evolution with train speed...

Once the source defined and pass-by scenario given, simulation produced time signal in monoral format or the four channels corresponding to a B-Format record. This encoding format corresponds to the decomposition of the sound field on the first four spherical harmonics and allows, after a short post-processing, to obtain the signal in any listening formats (stereo, binaural...). At the same time, standard acoustic indicators are calculated: signature of the pass-by; global level (A-weighted global level); instantaneous third octave bande spectrum; time exposure level; sound exposure level and maximum level.

3 VAMPPASS used for sound design study

The synthesis method described below has been implemented in VAMPPASS. To validate this software, two dedicated studies have been led: the first one on standard indicators and the second one with perception tests. All the further studies concern an AGC train model (Bombardier) which is composed of twenty one noise sources and is presented on the figure 2.

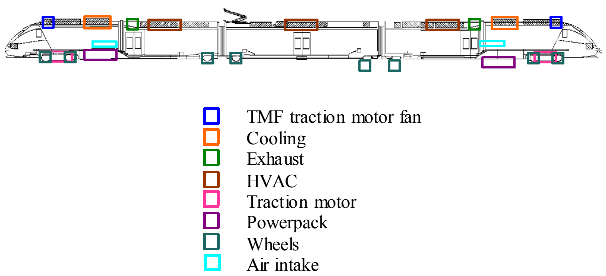


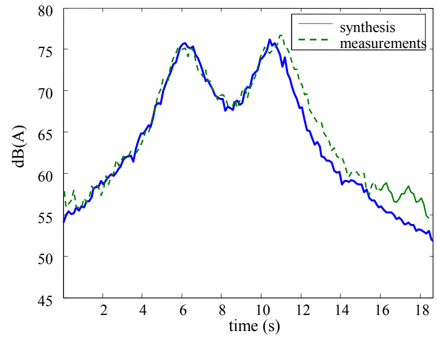
Figure 2: AGC noise sources description

3.1 Validation of VAMPPASS

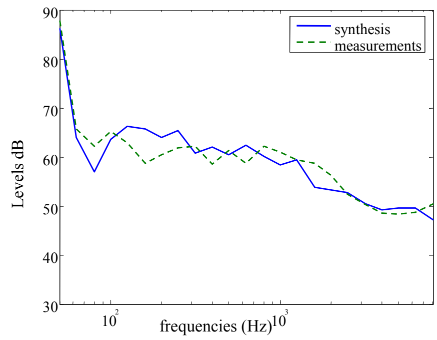
The first step of VAMPPASS validation deals with standard acoustic indicators like pass-by signature or global pass-by level. VAMPPASS simulation results are compared with recorded signals, for a same train (a Bombardier AGC), with same traction mode and at same speed. The acoustic sources on AGC have been characterized with measurements campaigns described in [1].

Figures 3 (a) and (b) and table 1 ilustrate that VAMPPASS is in good agreement with recorded pass-by signals, in terms of pass-by signature or global levels. Same kind of results are obtained at 80kph and for electric traction mode cases.

The second step in the validation process is to evaluate if VAMPPASS samples are relevant to perform listening tests. No direct confrontation between simulated and recorded samples has been led: the perceptive criterion that would probably dominate is the type of the samples (synthesized vs recorded). This study has to evaluate the relevance of using VAMPPASS samples to determine which optimisation would impact on the perception of the pass-by noise. Thus, it has to be verified that listeners will classify in the same order/way (for given instructions) recorded samples and their equivalent synthesized ones. It will ensure that the same perceptive criterion dominates to classify the two corpus.



(a) Pass-by signature



(b) Spectrum of the $L_{peq,Tp}$

Figure 3: Pass-by signature and third octave band spectra for a 30kph Diesel mode pass-by, comparison between simulation and record signal

Synthesized samples have been created in binaural listening format, corresponding to recorded ones, for several speeds and different traction modes of the AGC Bombardier. The pass-by cases used are summed up in the table 2. Rail dampers case and optimised cooling case correspond to acoustic improvements of rolling noise and cooling system presented in the next section.

Subjects have passed two series of dissimilarity tests: one for the synthesized corpus and the other for the recorded corpus. The results of the tests allow to distribute the samples of each corpus in a two-dimensions space, using a Multi-dimensionnal Scale (MDS). The spaces are then rotated, with a Principal Components Analysis in order to maximize corpus variance along the axes, see figure 4. The dominant criterion used during the tests by the subjects is the same for the two corpus and corresponds to the speed of the pass-by (along the x-axis). The dispersion of the synthesized samples on both sides of the y-axis, which can not be noticed for the recorded samples, corresponds to the use of a second perceptive criterion: for synthesized samples, subjects have splitted up Diesel mode pass-by and electric mode pass-by.
Diesel mode are characterized by low frequency contributions of the Diesel traction auxilairies. Diesel recorded pass-by can not be differenciated from electric recorded pass-by probably because another noise source masks

	simulation	measurements
Diesel 30kph		
$L_{peq,Tp}$(dB)	86	87
$L_{pAeq,Tp}$ (dB(A))	65	68
Diesel 80kph		
$L_{peq,Tp}$ (dB)	68	73
$L_{pAeq,Tp}$ (dB(A))	67	69

Table 1: Comparison between simulated and recorded global levels

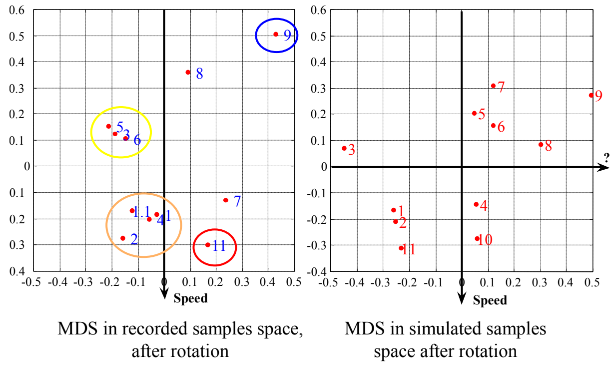


Figure 4: MDS of the two corpus

Samples	Mode	Speed (kph)	Rail dampers
1	Electric	80	NO
1.1 just recorded	Electric	80	NO
2	Electric	80	YES
3	Electric	30	YES
4	Diesel	80	YES
5	Diesel	30	NO
6	Diesel	30	YES
7	Diesel	15	NO
8	Diesel	15	NO
9	Diesel	0	NO
10 just synthesized	Diesel	80	NO optimised cooling
11	Electric	130	YES

Table 2: Samples used for listening validation of VAMPPASS

the contribution of traction auxiliaries. The only source contributing towards both traction modes is the rolling noise. Moreover, rolling noise equivalent source is not defined below 250Hz: subjects can then detect the low-frequency contributions of traction auxiliairies only for synthesized samples.

This study shows that simulated samples and recorded ones are classified with the same dominant perceptive criterion. Using VAMPPASS for listening tests is relevant. However, sources definition has a huge influence upon the classification, as it has been shown regarding the rolling noise on the second perceptive criterion for synthesized samples.

After validation tests, a study has been led, within the frame of SILENCE project, to determine the impact of the improvements proposed by the manufacturers.

3.2 Parametric study using VAMPPASS

Within the sub-projet SILENCE-E, manufacturers have proposed various improvements, for different traction noise sources. They have estimated, numerically or by measurements, the reduction brought by this optimised versions:

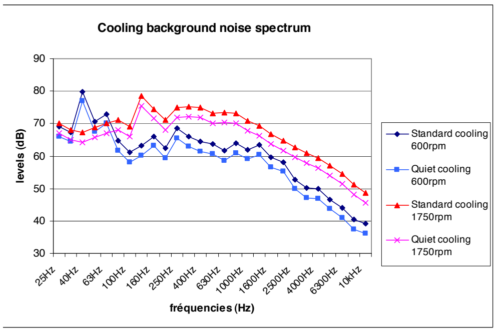
- cooling system has been modified in such a way that tonal components are removed and broad band noise is reduced by 4dB, figure 5(a);
- exhaust has been modified to reduced very low frequency contribution (under 100Hz), figure 5(b);
- powerpack compartment on AGC is an acoustic optimised version with lateral skirts and damping materiel covering the panels: a standard compartment has been created by removing the effect of some of these components, figure 5(c);
- rolling noise can be reduced by using rail dampers or a combination of wheel dampers and rail dampers, figure 5(d).

From these data, VAMPPASS simulations have been led to evaluate the impact of each of these improvements on global pass-by noise, at 30kph and 80kph. The results are summed up in the table 3. The results on the standard indicators show that :

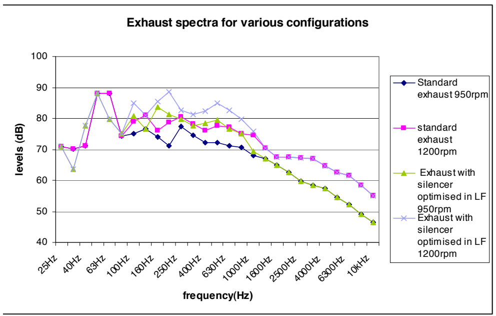
- at 30kph, on Diesel mode, optimisations leaded on only one source seem to be inefficient (less than 3dB(A)): several sources have equivalent contributions on global pass-by level;
- in Diesel mode, simultaneous improvements of dominant sources allow to reach 2.8dB(A) at 30kph and 4.2dB(A) at 80kph; however, low frequency contributions are very important in Diesel mode and global level in dB(A) should not be a relevant indicator;
- in electric mode, rolling noise reduction is relevant: wheel and rail dampers effects are efficient.

This study gives first indications concerning the impact that can be reached on global pass-by noise, with the improvements proposed by the manufacturers.

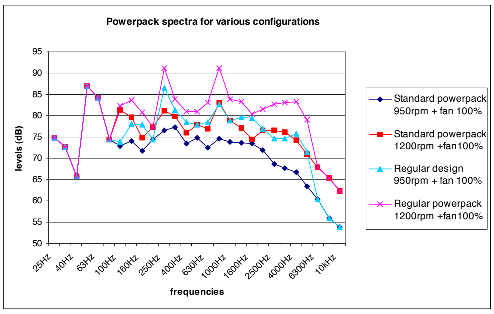
The sound samples produced in this study have then been used for listening tests, presented in [2]. During one of the tests, the subjects have to choose which sound, in a pair, was the more annoying. At the same time, indicators like loudness, sharpness, roughness and



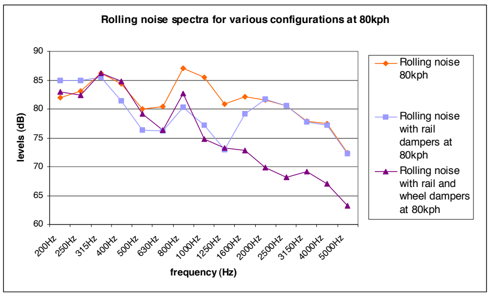
(a) Spetra of the cooling system



(b) spectra of the exhaust



(c) spectra of the powerpack compartment



(d) spectra of the rolling noise at 80kph

Figure 5: Spectra of the different noise sources, with their optimised versions

CONFIGURATIONS		$L_{pAeq,Tp}$ dB(A)
30km/h Diesel		
	standard	68,7
	noisy (standard power-pack)	69,8
	optimised exhaust	68,6
	optimised cooling	67,5
	optimised rolling noise	
	rail dampers	68,4
	wheel and rail dampers	68
	global optimisation	**67**
80km/h Diesel		
	standard	76,2
	noisy (standard power-pack)	77,1
	optimised exhaust	76,4
	optimised cooling	74,9
	optimised rolling noise	
	rail dampers	75,2
	wheel and rail dampers	74,7
	global optimisation	**72,9**
30km/h Electric		
	standard	61,9
	optimised rolling noise	
	rail dampers	58,2
	wheel and rail dampers	**57,3**
80km/h Electric		
	standard	72,2
	optimised rolling noise	
	rail dampers	68,9
	wheel and rail dampers	**67,4**

Table 3: Global level for each configuration

tonality have been estimated for each sample.
The results of this test show that, at 30kph, even if standard sample and optimised cooling sample present a difference of only 1.2dB(A) in term of global pass-by level, subjects have perceived the second one as less annoying. At 80kph in Diesel mode, rail dampers sample, presenting a difference of 1dB(A) with the standard sample, is perceived as less annoying. In electric mode, for both velocities, the reduction induced by rail dampers or the combination of rail and wheel dampers is enough to produce the sensation of "less annoying sample".
Moreover, only loudness correlates with the results of subjective assesment in pair comparisons.

These listening tests have shown that A-weighted global level, particularly for Diesel traction mode, is not the most appropriate criterion to represent annoyance perception. Sound samples are thus important data to conduct sound design studies.

4 Conclusion

VAMPPASS is a software dedicated to pass-by noise prediction. It calculates standard indicators and creates corresponding sound sample which allow to lead perceptive study. The source model used in this software allow to easily change equivalent noise source definition. Parametric studies can thus be achieved and sustain sound design of vehicle.

In addition to VAMPPASS trains models (a TGV model has been implemented), a car model is under developement.

References

[1] E. Bongini, S. Molla, D.Habault, P.E. Gautier, P.O. Mattéi, F. Poisson "Acoustic source characterisation on railway vehicle for prediction and audio synthesis of pass-by noise", *International Congress on Acoustics 2007 Madrid*

[2] B. Griefahn,T. Gjestland, A. Preis "SILENCE AD7: Transfer of evaluation of noise attenuation measures developed within the IP"(2008)