Virtual certification of acoustical performances of a railway vehicle

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Summary
Environmental noise is a key issue for the growing of railway traffic. In Europe, the environment noise radiated by the railway system is constrained by : Technical Specifications for Interoperabilty (TSI) which limits the noise at source and the national legislation of various Europeans countries which limits the noise at the receiver position or imission point. The TSI noise compliance is checked for each new type of train at stand still and during pass-by. The stakeholders want to reduce the time to market of the new trains and the cost of the certification process. One technical alternative of the measurement campaigns is to calculate the stand still and the pass-by noise of the train and to compare them to the reference values of the TSI.
The paper explains how virtual certification can be introduced. The characterisation of acoustic sources, the simulation tool, and the combination of measured and calculated values are presented. Then, the example of the modification of a TGV is investigated. As a conclusion, the next steps to develop virtual certification in acoustics is discussed..

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1. Introduction

Environmental noise is one of the characteristics of a new rolling stock and is limited in Europe by Technical Specifications for Interoperabilty (TSI) [1,2] They are combined with national laws which limit the noise at the receiver over a period of 24 hours to protect residents along a railway line.

During the development phase of the new rolling stocks, train manufacturers are using simulations to prevent any risk of non-conformity. Environmental noise is forecasted at stand still and pass-by conditions to check the compliance with TSI noise limits.

The train certification is mainly based on measurement campaigns to control the dynamic behaviour, the current collection, the braking performances,… Environmental noise is measured at stand still, starting and pass-by and compared to the reference values of the TSI.

In order to reduce the time to market of the new trains and the cost of the certification process, stakeholders promote the reduction of online tests. Then, several collaborative projects have been launched in the FP7 European Program to deal with virtual certification. After the three projects TrioTrain (DYNOTRAIN, AEROTRAIN, PANTOTRAIN), ACOUTRAIN has been launched in 2011. The main objectives of the project focus onto the design of a process to apply virtual certification and the development of a simulation tool to calculate environmental noise. The work presented in this paper is based on ACOUTRAIN methodology to be applied to a real case.
Chapter 2 is dedicated to a presentation of the acoustic requirements of the TSI and national law in France. The pass-by noise modelling is described in chapter 3 and illustrated in chapter 4. The conclusion describes the following steps to include virtual certification in railway processes.

2. Technical Specification for Interoperability and national laws

For most of the European countries, residents are protected from the railway noise by European Directives and national laws.

The Directive 96/48/EC refers to the TSI which limit the noise in the different phases: standstill, starting and pass-by of the train. Measurements are performed on a TSI compliant track. This track is a quite low emission track which ensures that the rolling stock contribution is the most important one in the pass-by noise
The Directive 2002/49CE is dealing with noise mapping and actions plans. L_{DEN} and L_{NIGHT} are used to take into account the noise of each train and the number of train pass-bys.
Exposure levels are fixed in the national laws, using L_{DEN} and L_{NIGHT} or equivalent long terms indicators. In some countries, short terms indicators are also taken into account.

3. Pass-by noise modelling

The railway noise is a combination of rolling noise, equipment noise and aerodynamic noise [3]. The balance depends on the train speed:

- At standstill and below ~80km/h, equipment noise is the main source,
- From ~80km/h to ~320km/h, the rolling noise is the main one,
- Up to 320km/h, aerodynamic noise becomes the most important contribution.

The modelling of the pass-by noise must be able to take into account the three types of sources according to the train speed. The main parameters are for each source:

- the source position onto the rolling stock,
- the sound pressure level at a given position (1m) or the acoustic power,
- the frequency content in narrow band and/or in third octave band,
- the source directivity and integration effect,
- the dependence of the previous parameters with the train speed.

The main sources of equipment noise are the auxiliaries which are : HVAC (Heating Ventilation Air Conditioning), Diesel engines, cooling units including fans, compressor, electric converters, electric motors… They can be characterized at stand still. Measurements are performed with the equipment mounted on the train or in the laboratory in a mockup. In this case, the train environment must be taken into account using a scale model or a simulation tool. Several examples are given in [4]. The speed dependence is difficult to characterize as the actions of the train management system depends on a large number of parameters.

The rolling noise is due to the rolling of the wheel roughness on the rail roughness which generates vibrations of the wheel and the rail. The wheel and the track components radiate noise in the environment. Below ~40Hz, sleeper is the main source. From ~40Hz to ~1200Hz, the rail provides the main contribution. The wheels radiate up to ~1200Hz. Depending on the track components and the wheels characteristics, the rail can be the main contributor to the pass-by noise level in $L_{PAeq,Tp}$. The TWINS software has been developed twenty years ago by D. Thompson from ISVR to predict the rolling noise. A review of modelling is presented in [5]. The measurement of input parameters like rail roughness, wheel roughness and track decay rates are robust and now defined in international standards. Then, rolling noise source characteristics can be extracted from TWINS output with a good confidence.

Aerodynamic noise can be measured during the train pass-by or in a wind tunnel using a scale model. An array of microphones is needed to extract the source characteristics. Aerodynamic noise can be also predicted using Lattice Boltzman method as described in [6].

In the pass-by noise modelling, the noise propagation from the source to the receiver must be considered. In case of virtual certification, the distance is limited to 7,5m or, at a maximum of 25m. In the TSI, a flat ground and a low wind are required to perform the measurement. Then, the modelling of the propagation is simplified to take into account the reflection on a grass ground, with constant impedance, without gradient of temperature and without wind. A model and experimental validation are presented in [7].

When all the noise sources are defined, there are located onto a train map according to their physical positions. Software have been developed by rolling stock manufacturers and operators to make easier the calculation. Such software has been also developed in ACOUTRAIN project. A most sophisticated one called VAMPPASS, including sound generation and acoustic barrier has been developed by SNCF. ACOUTRAIN project (all deliverables can be uploaded onto http://www.acoutrain.eu) provides a set of data and attended results to validate others software.

4. Application case

This chapter deals with an application case of acoustic virtual certification process. According to the TSI [2], it proposes in the §7.1.5.2 that in case of upgraded or renewal of rolling stock, it is necessary to: *"to be proved that an upgraded or renewed vehicle does not increase noise with respect to the performance of the vehicle before upgrading or renewal*"**.** This definition can be similar to the simplified method to assess the conformity of the TSI noise [1]. The methodology of ACOUTRAIN which have been written in the deliverable 1.8 [6] is the scientific approach that we chose in our study.
So in this chapter, it will be presented the cases of an high speed train which has been certified and conform to the TSI [2] and a new rolling stock which has been subjected to some modification in some area of the power car. Firstly, we will present the methodology and the strategy that the acoustic engineer has chosen to demonstrate the conformity of the modified rolling stock. Secondly, a description of the high speed train model and its virtual validation will be introduced. Thirdly, the case of the modified rolling stock will be presented and open debate can be discussed about some improvement of the method and input noise source.

4.1 Methodology

The simplified method consists in an acoustic comparison between a reference rolling stock which has been certified by the notified body and compliant to the TSI noise with a rolling stock which is under acoustic assessment. The current TSI **[**1**]** refers to a "simplified" method that allows the full measurement procedure to be avoided if some requirements are met: "*The simplified evaluation shall prove that the unit under assessment complies with the applicable noise levels as set out in this TSI, for those noise cases for which the simplified evaluation is used. Virtual testing in the context of TSI NOI means that the tests required for the certification are partially carried out with numerical simulations".* Thus, it requires a model to be built representing acoustically the vehicle. This model is called a virtual vehicle (VV) and consists in a set of noise sources that represents the total noise emission of the vehicle (vehicle = set of noise sources)". Based on the ACOUTRAIN project and the deliverable 1.8 [6], the following flow chart describes the best relevant approach to use virtual certification for the case of a new rolling stock to be certified.

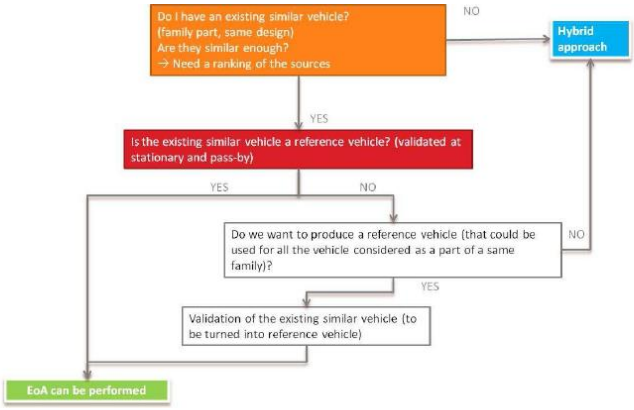

Figure 1: ACOUTRAIN flowchart

According to this flow chart, the virtual certification suggests two scenarios: the hybrid approach and the extension of approval (called EoA). When no similar vehicle exists or no reference vehicle is available for a similar vehicle, the hybrid approach consists in creating a dedicated virtual vehicle for the vehicle under test. The prerequisites for applying an EoA approach consist in having a similar vehicle, compared to the vehicle under test, for which a reference vehicle (virtual vehicle validated with a complete validation process) exists. Then, the number of sources that can deviate between the reference vehicle and the vehicle under test is limited by the similarity test: as long as the two vehicles are considered as similar, an EoA can be performed. For our study, the EoA approach is used as the rolling stock under evaluation has been certified TSI [2].

4.2 Similarity evaluation between the rolling stock

Firstly, in order to be sure that the virtual certification can be used, it is necessary to verify whether the two rolling stocks are similar enough in term of source noise.

The considered high speed train's modifications are mainly located on the carbody of the power car. Some deflector have been installed in order to improve the aerodynamic of the rolling stock when is running at high speed (320 km/h). The goal is to reduce the turbulent energy which improves the drag resistance of 3% and hence decreases the electric consumption at the end. The figure 2 shows the main card body changes and the area on the power car.

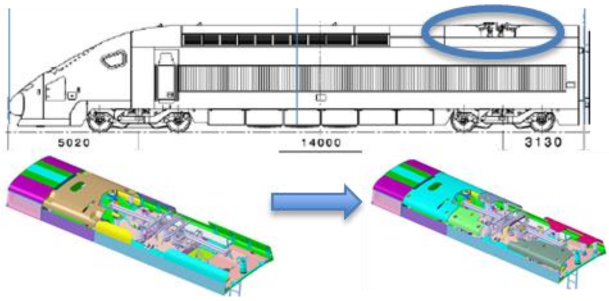

Figure 2: High speed train modifications in the pantograph aera

So in terms of acoustic sources, difference is clearly located in one specific zone. Hence due to few modifications, the virtual certification can be used and then verify the §7.1.5.2 of TSI [2] noise criteria. The next step is to build a virtual vehicle reference by simulation tools.

4.3 Virtual vehicle reference of high speed train

According the EoA methodology, the first step is to build a reference vehicle which has been certified by acoustic testing and compliant with TSI noise. The rolling stock, under the study, is a high speed train double deck built by Alstom transport which has been certified TSI noise [2] in 2011 following the acoustic standard EN ISO 3095.

4.3.1 Information of the model

A short description of the acoustic source is presented in this chapter. Firstly the rolling noise source has been calculated by a TWINS model within the software. The wheel modes have been calculated by simulation tools and the roughness wheel measured during a previous measurement campaign. No wheel roughness measurements have been performed during the certification test.

Due to of two braking system on the bogies of the rolling stock, hence two kinds of wheel roughness have been used: a roughness disc brake for the wheel which equipped the trailer bogie (located on the coach train) and a composite brake roughness for the motor bogie (located on the power car).

For the track side, the roughness of the rail and the track decay rates have been measured during the test campaign and are compliant to the TSI target. The track characteristic are presented below: track type UIC60, mono bloc sleeper, ballast track and stiffness of the pad around 500 kN/mm.

Calculation using the method of Lattice Boltzmann has been done during previous studies on a high speed train double deck. The global acoustic power values have been calculated and the results are presented in the figure 4 with a ranking of the aerodynamic source. Furthermore, the acoustic spectra in sound power have been calculated for a high speed train duplex running at 320 km/h.

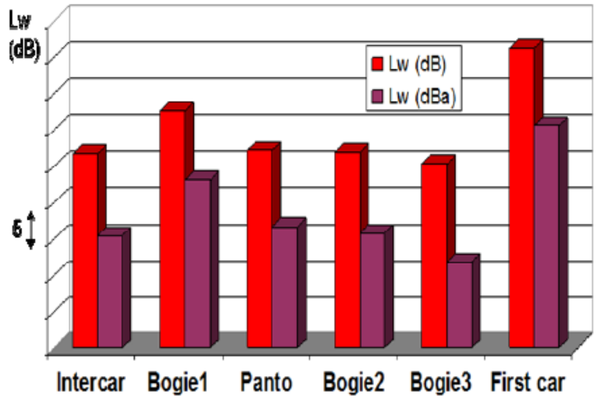

Figure 3 Ranking of the acoustic spectra (Lw) of the main aero-acoustic sources of TGV POS estimated by Lattice Boltzman method (320km/h)

From the acoustic result above, the sound power spectra have similar shape, only the amplitude are different. One frequency peak appears to be important on the intercar, but without any effect to the exterior noise. The main acoustic energy sound power is located in the frequency band between 100 Hz to 1kHz. All aero-acoustic noise sources have been used in the acoustic model for the calculation of the pass by noise and the power spectra is presented in the figure 4.

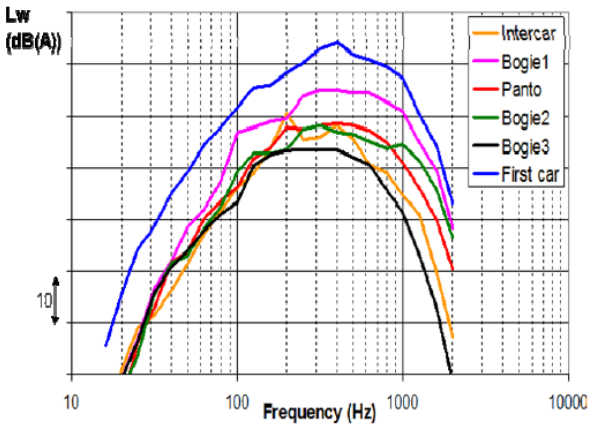

Figure 4 - Sound power spectra of the main aeroacoustic sources of TGV double deck estimated by Lattice Boltman method at 320 km/h

4.4 Tolerance and uncertainties

The uncertainties are the main point for the accuracy of the result. The uncertainties on the measurement are dealt in the standard EN 3095 annex G. For an accredited laboratory, the measurement uncertaintie is around +/-1dB. The variability factors when repeating the measurement with the same vehicle another day, with different conditions of propagation, are not considered.

Concerning the virtual model, the required accuracy of the input data should be determined by the required accuracy of the output. This means that the required accuracy level of one input parameter, e.g. a source, should depend on its influence on the total noise level. The more dominant the source contributes to the total noise, the higher its required accuracy level.

In this application case, the choice for the value of the uncertainties has been define from the ACOUTRAIN project. The table 1 presents the tolerance factor used for the verification and validation of the numerical vehicle against the test type measurement.

Indicator for pass by	1/3 octave band [350Hz-4kHz]	$L_{pAeq,\ Tp}$ global noise
Tolerance	5 dB(A)	3 dB(A

Table 1 Acceptable tolerance for correlation level between measurement and simulation results

4.5 Acoustic correlation results between measurement and simulation for the reference vehicle

This chapter presents the acoustic result regarding the comparison between measurement test and simulation. Three operating speeds of the rolling stock have been measured during the test type: 80 km/h, 190 km/h and maximum speed 320 km/h. The measurement point is located at 25m from the centerline of the track and 3,5m height. Hence below, the graph presents the noise global value indicator $L_{pAeq,Tp}$ for testing measurement and the result from simulation.

Figure 5 – Correlation measurement versus simulation

From this comparison, whatever the speed range, the correlation is good and the maximum difference is 1dB. The virtual model can be considered as an acoustic reference vehicle.

4.6 Ranking source

The second step is to do a ranking of the sources of the virtual vehicle. This feature allows to defining whether the sources are dominating or significant. A source dominate is the one which contributes the more in term of sound power compared to the total noise. A significant source is the one which contributes to the total noise level by more than 0,5 dB(A) (if you turn it on / turn it off, it changes the total noise by more than 0,5 dB(A)). “Significant” is not equivalent to “dominant”: several significant sources can contribute to the total noise. The sources can be ranked according to their contribution to the total noise of the train, from the highest contribution to the lowest ones. This ranking can be easily and precisely assessed as soon as a validated virtual vehicle is usable. The ranking could be made by the indicator of $L_{pAeq,Tp}$ calculated during the pass by. The figure 6 below shows a plot of different source contributions for the high speed train at 320 km/h on the indicator $L_{pAeq,Tp}$ measured at a distance of 7.5m from the centreline of track at height of 1.2m above the upper surface of the rail.

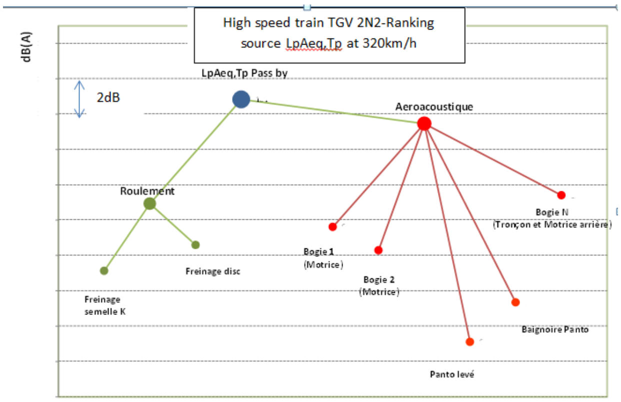

Figure 6 - Ranking of the HST source on $L_{pAeq,Tp}$ at 320km/h

From the figure above, the dominating source is the aerodynamic source from the bogie. The rolling noise is located at 4dB below the all aerodynamic sources, so it means that it is a significant source.

4.7 Modification of the reference vehicle

Aerodynamic study has been done on the power car of a high speed train in order to improve the drag resistance in the aera of the cavity of the pantograph by adding fairing (see figure 7) [7]. However during this simulation project, it has been seen that the incomplete fairing in the area of the cavity pantograph could increase the sound power of +3dB in the area of the pantograph area.

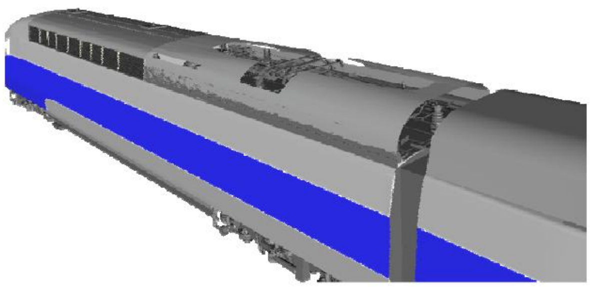

Figure 7 - Fairing on the cavity pantograph

Hence in order to validate the modification of the fairing of the power car’s pantograph a new acoustic model is created based on the reference vehicle which has been certified. The main change is located to the sound power in the area of the pantograph cavity. The total sound power has been increase of 3 dB in order to simulate the integration effect of the fairing with a worst case scenario. The result of the sound pressure with the indicator $L_{pAeq,Tp}$ gives equivalent result as the reference vehicule. So this modification has no impact in term of the pass by on the $L_{pAeq,Tp}$ indicator.

5. Conclusion

The work carried out in the ACOUTRAIN project and the software developed can be already used to perform virtual certification in acoustics. The extension of approval is the most confident application case and can be already used in the context of the simplified method of the TSI.
The same approach is already used in dynamic behavior and current collecting certification process.
The confidence in the simulation will rise with the increase of application cases. The measurement campaigns will be focused to the worse cases and extended by simulation.

References

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