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SIMULATIONS OF THE NOISE RADIATION OF HIGH SPEED TRAINS

C. Talotte*, S. Guerrand*, C. Gaumain**

* SNCF Research and Technology Department, 45, rue de Londres, 75379 cedex 09, Paris, France

** AROBAS Technologies, Consultant for SNCF, 1 rue des vergers, 69760, Limonest, France

Tel.: 33.1.53.42.92.96 / Fax: 33.1.53.42.97.84 / Email: corinne.talotte@sncf.fr

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ABSTRACT

Annoyance due to railway noise is a particularly sensitive aspect of new line projects. Experimental and numerical studies had been carried out at SNCF to characterise the noise of TGV which has two origins: rolling and aerodynamics. The knowledge of the physical phenomena linked to each kind of source, obtained through different research projects (including a specific cooperation with DBAG) allowed to define source models including mainly spectrum aspects and evolution with speed. The following step was the development of a numerical tool, for the simulation of the noise radiation of trains built from these source models. The software, called MAT2S, developed at SNCF in C^{++}, and its validation, are presented in this paper.

1 - INTRODUCTION

The noise of a TGV has two origins: rolling and aerodynamics, which becomes predominant above 300 km/h.

- Rolling noise is generated by wheel/rail interaction, which, in addition to causing airborne sound, also transmits vibrations to other parts of the train. Rolling noise had been studied for several years and predictive computations can today be carried out with the TWINS software for example (developed by ERRI). The knowledge of rolling noise phenomenon as well as the capability to use tools for its prediction can lead today to solutions.
- Aerodynamic noise research had been more recently carried out, mainly through experimental investigations, in wind tunnel as well as on line. The knowledge of the physical phenomena involved [1] allowed the characterisation of the different aerodynamic sources and the definition of basic solutions. On the other hand, numerical prediction of aerodynamic noise can not be easily achieve for industrial applications and is today limited to simple case. Advanced computations need to be carried out to obtain the aerodynamic source term (through Large Eddy Simulation method for example) and its propagation (with the difficulty to separate, in the same medium, source and propagation).

Even if it is not possible to predict accurately all the sources, database obtained through previous studies allowed to built models for the main sources of a TGV. One of the following steps of our studies was the development of a numerical tool, called MAT2S, for the simulation of the noise radiation of trains, built from these source models. The main interest of such a software is to observe the effects of simple parameters variations, and even design modifications of the train itself (by modifying the source models), on the global noise radiated by a high speed train.
We present in this paper the MAT2S software, its algorithm and the theoretical development associated, and how the sources have been modelled for a TGV.
First computation of a TGV configuration had been compared with experimental results on line. A very satisfactory comparison is presented in this paper.

2 - ALGORITHM AND THEORETICAL DEVELOPMENT

The calculation of a train pass-by signature is based on an adding principle of all acoustic sources effects. A train is built as a group of point-sources with acoustical characteristics: a spectral information (third octave band and eventually discrete frequency peaks), a directivity, a speed exponent.
The functionality of MAT2S allows to make calculation of the noise emitted by a train at one observation point or on a grid perpendicular to the train axis.
Several steps are necessary to carry out a complete calculation, as shows figure 1, an elementary step being to calculate the noise radiation of one source as shows schematically the figure 2.

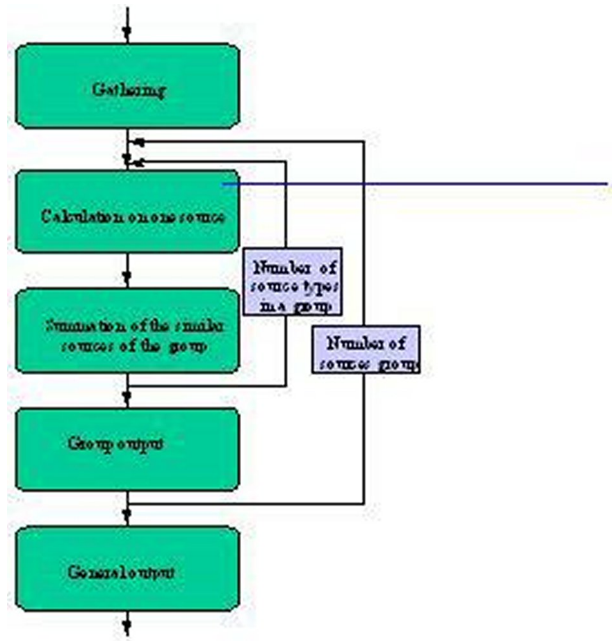

Figure 1: Algorithm of calculation.

The different steps can be roughly described as follows:

- The distance R between the emission point and the observer (that means the position of the source when the noise received was emitted) has to be known to calculate at every time, the noise received at the observation point.
- The emission parameters can be determined, once the distance R has been calculated: horizontal and vertical observation angles and Doppler coefficient
- The directivity correction is calculated from the directivity pattern defined by the user for the source
- The spherical attenuation takes into account the spherical propagation of the sound waves corresponding to 6 dB attenuation by doubling the distance
- The ground attenuation can be taken into account. Two models had been programmed in MAT2S and are proposed to the user. The Delany-Bazley's model [2] should be sufficient for most of the calculation. The Attenborough's model [3], which uses the same theory than the previous one, calculates differently the ground impedance and is more dedicated to porous material.
- The atmospheric absorption is based on the model described in the ISO 9613-1 standard. It takes into account as parameters of main influence, the sound wave frequency, the air media temperature, the air humidity and the atmospheric pressure.
- The Doppler effect has to be taken into account for high speed trains. The shift introduced by this effect between the radiated and the received frequencies is easy to calculate with a frequency peak. In the case of a third octave band description, a linear interpolation procedure had to be programmed.

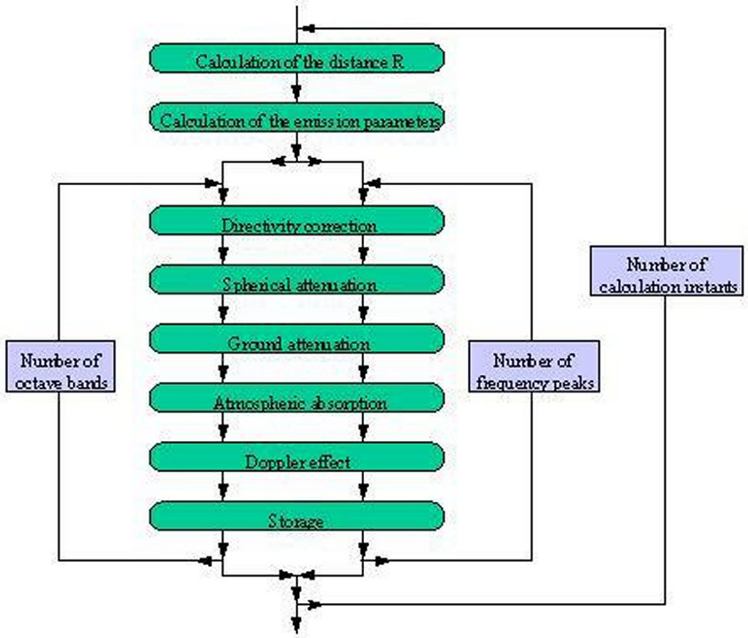

Figure 2: Algorithm of calculation for a point-source.

3 - SOURCE MODELLING

Once the MAT2S software was developed, the following work was to built source models to feed it. An important work was done to built all the models suitable to represent a train and we present in §4 a model of TGV-R.

We describe here an example of source modelling corresponding to the aerodynamic noise of the bogie area and carried out from on-board measurements results. The main difficulty of on-board measurements was to extract the acoustic signal from the aerodynamic background noise and the methodology consisted in using "phenomenological" sensors fixed near the sources and to put anti-turbulence sensors to filter turbulence and to record mainly acoustics. Using a method [4] based on a COP technique (Coherent Outpout Power), it is possible to determine if the source radiates sound and to construct its spectrum.

The aerodynamic noise of the bogie area was modelled in MAT2S by three point-sources shown on figure 3. It is probable that this description is not the best, because these three point sources are very much linked to the position of the probes during the measurement campaign but, nevertheless, the coherence between these probes and other sensors proved that sources exist nearby these probes.

The spectrum obtained from on board measurements for one of the three point sources is shown in figure 4. The purpose of modelling was then to built a spectrum in third octave-band and with some relevant peaks to describe the experimental spectrum. The experimental spectrum was decomposed in a broad band spectrum and some peaks. All the energy contained in the original peak (depending on the level as well as the width of the peak) is included in the new peak whose width is 1 Hz. The following step was to calculate the third octave band values associated to the broad band spectrum. Figure 4 shows the final spectrum compared to the measured one.

4 - APPLICATION FOR A TGV-R AND COMPARISON WITH EXPERIMENTAL DATAS

The different models used to built a configuration of TGV-R, as shows figure 5, represents the following sources: rolling, bogie (aerodynamic), fan, pantograph and its cavity.

These models are mainly based on experimental results except for the rolling noise source which was modelled from a TWINS calculation. These source models were adjusted by a comparison with measurements at 7,5 m, taken into account our knowledge of the balance of the different sources.

After this adjustment, another calculation was done at 25 m. The results were then compared to measurements completely different from those that were used to calibrate and adjust the sources. Figure 6 represents the comparison of the signatures which is very satisfying. The comparison of passby levels is also satisfying with a difference of around 1 dBA.

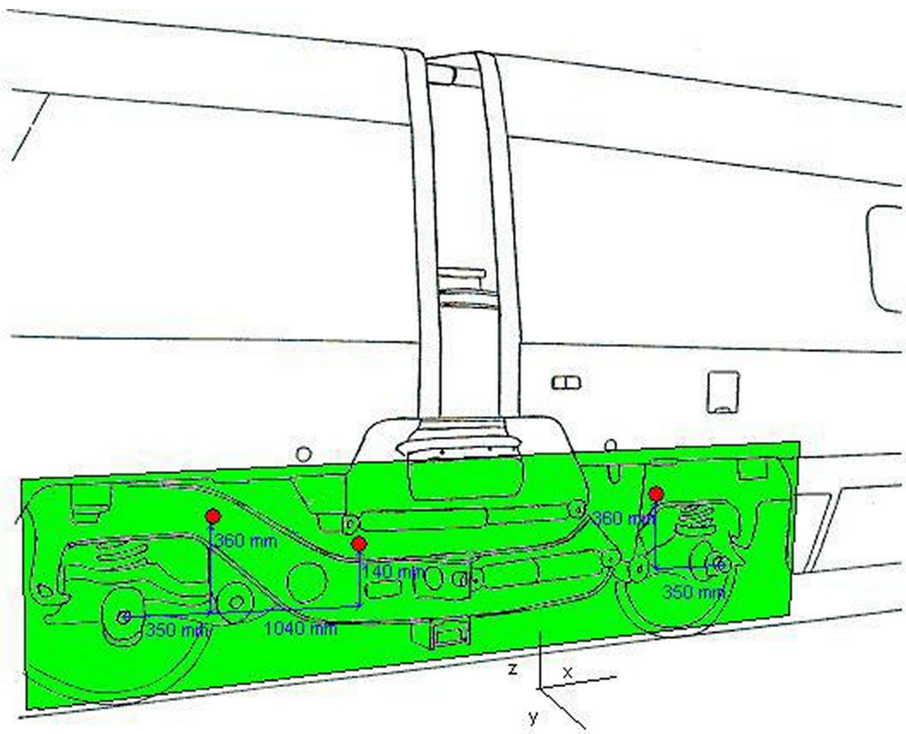

Figure 3: Location of the point-sources in the bogie area.

5 - CONCLUSION

The software use involves to model a train with its different sources and all the parameters that might influence its noise radiation, to carry out a calculation and to analyse the results.
The features of the software are:

- the capability to modify easily sources and to define a new train configuration
- the parameters included in the algorithm (directivity correction, spherical attenuation, ground effect, atmospheric absorption and Doppler effect)
- the capability to obtain the results as levels but also as spectra or signatures. The software, which is user friendly, allows to carry out parametrical studies to assess the reduction potential of the different sources and how they balance.

The comparison of the results of a first computation of a TGV configuration with experimental results is very satisfactory. Future developments will be focused on source models improvement and simulations with other trains configurations.

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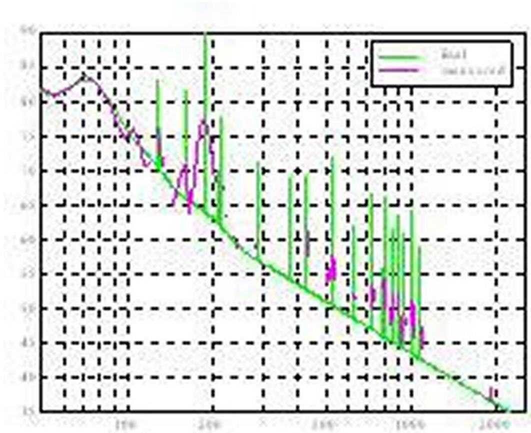

Figure 4: Comparison of measured and final spectra for modelling one point-source in the bogie area.

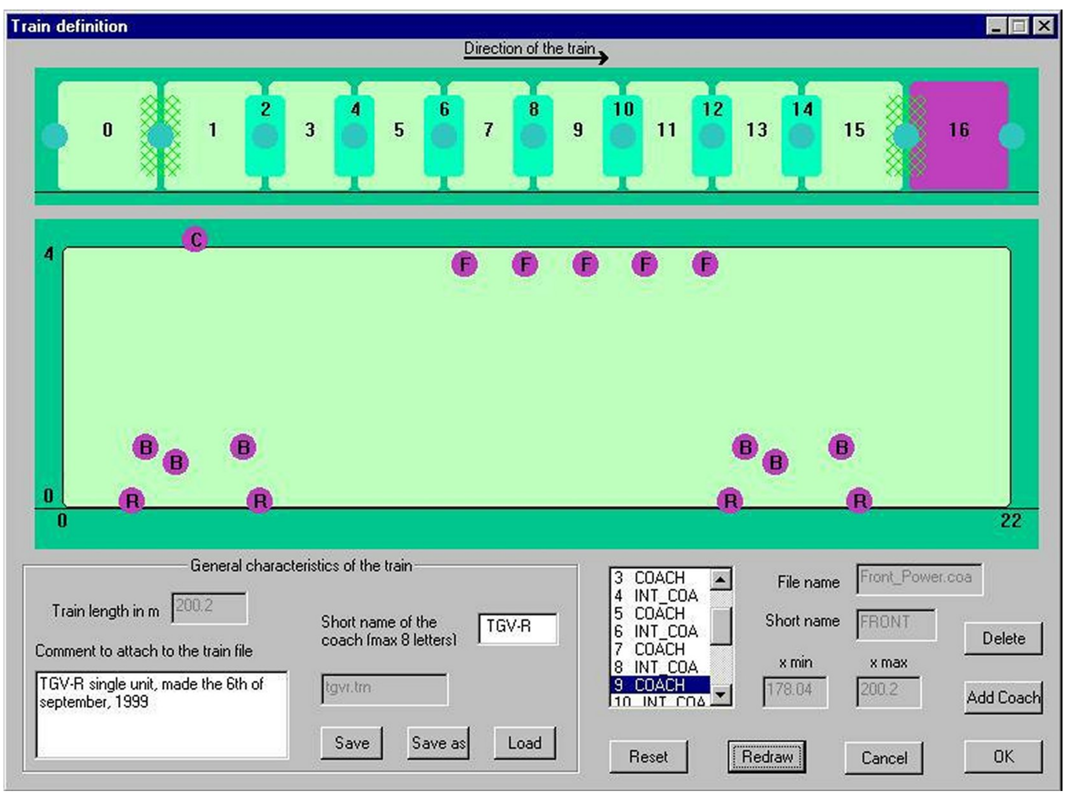

Figure 5: TGV-R "built" in MAT2S.

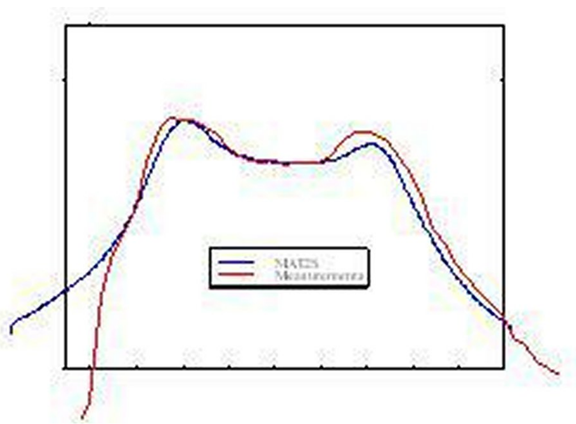

Figure 6: Comparison of MAT2S prediction to measurements.