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RAILWAY PASS-BY NOISE USING IMPROVED SEPARATION METHODS

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ABSTRACT

The noise emitted by a train during a pass-by is the combination of track and vehicle noise. Equipment noise and aerodynamic noise are inherent to the vehicle and speed. As for rolling noise, the radiation mechanism is shared between the wheels and the track.
The current TSI certification obliges all rolling stocks circulating on trans-European network to comply with strict noise limits, especially for pass-by noise. During design phase, simulation tools are used to predict and optimize rolling stock noise levels before final certification tests.

In the context of EU-funded project FINE-2 started in 2019 and ended in 2023, a consortium of the railway companies ALSTOM, CAF, SIEMENS, DB, SNCF and TALGO worked together in Work Package 7 dedicated to noise sources separation. One of the purposes was to support the development of innovative techniques done by TRANSIT consortium in order to separate the sound power level and directivity of the different types of acoustic sources during a train pass-by at constant speed. During this work, three large test campaigns were organized with commuter, regional and high-speed trains.

This paper describes the outcomes of this work, and the simulation/correlation of train pass-by noise using detailed noise source input obtained from field tests.

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1. INTRODUCTION

The exterior noise levels emitted during the pass-by of trains can be a critical topic, especially in the current context of increasing development in railway transportation. Pass-by noise is mainly driven by the vibrations generated at the contact between the rail and wheel, which is designated as rolling noise. Other contributions, such as traction noise (motor, gearbox) and aerodynamic noise (at high speeds) may also significantly contribute in some cases. Nevertheless, it is common that the noise contribution from the track is dominant over the vehicle.

The current European rolling stock homologation restricts the pass-by noise levels below a certain threshold through the enforcement of the TSI Noise [1]. Since the track contribution (rails and sleepers) plays a major role on the total pass-by noise, a minimum track quality is required by EN ISO 3095 [2] regarding relevant acoustic parameters (rail roughness i.e. irregularities generating noise, and Track Decay Rate i.e. the propagation of the vibration within the rail). However, this does not assure that the track contribution is negligible and does not provide an objective quantification of newly designed vehicles. In addition, for a same train running on different tracks complying with these limits, the pass-by levels can vary in a range of at least 6 dB, an order of magnitude which is very significant from the noise perception point of view.

To overcome the limitations of current certification method, innovative methods have been developed by the consortium TRANSIT in collaboration with EU-funded FINE-2 project. This work aimed at:

- Separating the noise contributions (e.g. track noise from train noise) with the help of different selected techniques, valid in [100-8000] Hz range.
- Transposing to a destination track by correcting the track contribution to a track with reference characteristics and recomposing the total pass-by noise.

To achieve these targets, a relevant understanding of the contribution of the different noise sources and the use of reliable simulation tools to model pass-by noise of a train is essential.

2. TRANSIT SEPARATION METHODS

In the previous EU-funded project Roll2Rail [3] (2015–2017), several methodologies were developed to separate the contributions of vehicle and track to rolling noise. Among them:

- Advanced Transfer Path Analysis (ATPA), able to quantify the track contribution by mean of a complex experimental setup of around 30 accelerometers and a microphone. This method requires to perform static tests prior to the pass-by to identify detailed track transfer functions.
- Pass-by Analysis (PBA), able to quantify with a simple instrumentation both vehicle and track contributions. This method requires to perform several pass-by measurements, in order to identify the rolling noise transfer function (with hypothesis of dominance of rolling noise over other sources).
- TWINS-based method, based on the well-known simulation tool but using measured inputs of track and wheel characteristics and track vibration during pass-by of the train.

In FINE-2 project (2019–2023), these methods were further developed and simplified by TRANSIT, divided in 2 work packages [4] [5]. Among the improvements, distribution functions from static tests were introduced in PBA method to separate different contributions of rolling noise. An additional method was also developed:

- Array method, based on standard delay-and-sum beamforming with additional processing (deconvolution technique and spatial averaging). This method uses a 75-microphones antenna, able to identify individual sources.

These 4 methods were evaluated during 3 test campaigns:

- On a commuter train in October 2021.
- On a regional train in March 2022.
- On a high-speed train in September 2022.

The noise separation of individual sources could be achieved [6] [7] and sound power levels (SWL) of individual sources could be extracted from measurements of passing trains, as per schematic in Figure 1.

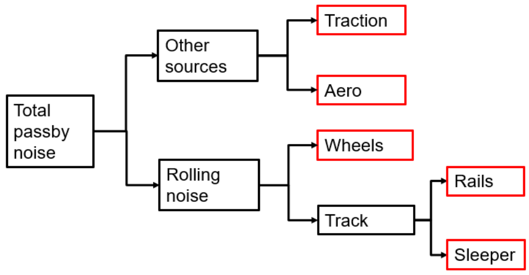

Figure 1. Train pass-by noise decomposition.

Track noise contribution could be identified by ATPA, PBA and TWINS-based method, see comparison in Figure 2 for one trailer bogie (red box) of the regional train at 80 km/h, showing similar levels but relatively different spectra. For confidentiality, all data were normalized to a value of LpAeq,tp [2] of 75dBA at 80 km/h for all rolling stocks tested. Array method could only give an evaluation of the complete rolling noise, including wheels, so results could not be compared.

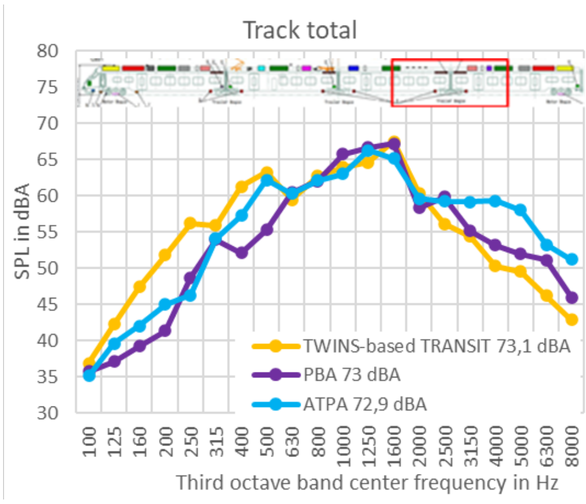

Figure 2. Track noise contribution obtained at standard 7.5m-distance from track center by the different techniques for the regional train at 80 km/h.

Wheels contribution could be evaluated by TWINS-based method and PBA method. Figure 3 shows this comparison for one trailer bogie of the regional train at 80 km/h ; most accurate evaluation is done by the TWINS-based method.

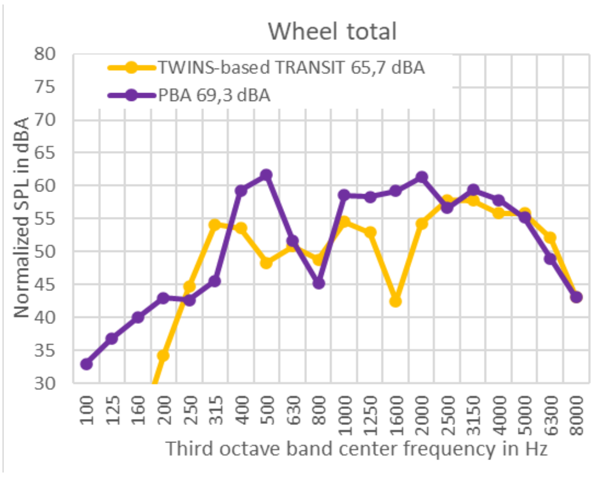

Figure 3. Wheel noise contribution obtained at standard 7.5m-distance from track center by the different techniques for the regional train at 80 km/h.

Array method could provide other sources contributions like aero-acoustic sources (for the leading cabin, pantograph, and inter-car gaps) and traction equipment. Noise maps were established on a focal plane at about 6m from the microphone. Sound power of individual sources could then be estimated considering free field propagation law with hypothesis of monopoles. The evaluation of source directivity by the array was not successful in this project.

3. PASSBY NOISE SIMULATIONS USING ADVANCED SEPARATION METHODS RESULTS

3.1 Simulation tools for homologation

Virtual homologation could be a significant improvement in terms of cost and validation planning impact. In this perspective, the use of reliable simulation tools that model the pass-by noise and could identify objectively the vehicle noise contribution alone would be essential.

Exterior noise simulation tools have been used for several decades by train manufacturers to ensure that design of their trains is fitted to respect their customer and homologation requirements. Because it is in the interest of train manufacturers and operators to have a fine estimation of the pass-by noise, improvements in that domain have been continuously undertaken to enhance the prediction accuracy of the models. However, correlation of pass-by noise as showed in this paper is only rarely performed due to the lack of accurate inputs. This section details the work performed about pass-by noise correlation in this project. This also shows accuracy evaluation of the complete method.

3.2 Commuter train campaign noise correlation

For the commuter train test campaign, TWINS-based method was applied to identify sound power levels of rolling noise components, for the two central non-motorized bogies of the trainset (red box in Figure 4).

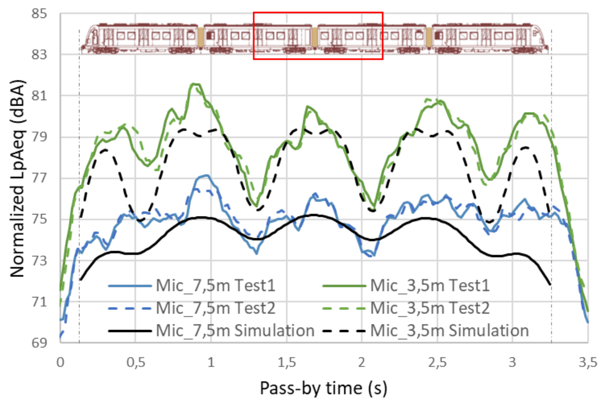

Figure 4. Correlation of pass-by noise level evolution LAeq versus time for the commuter train at 80 km/h at 3.5m and 7.5m distance from track center.

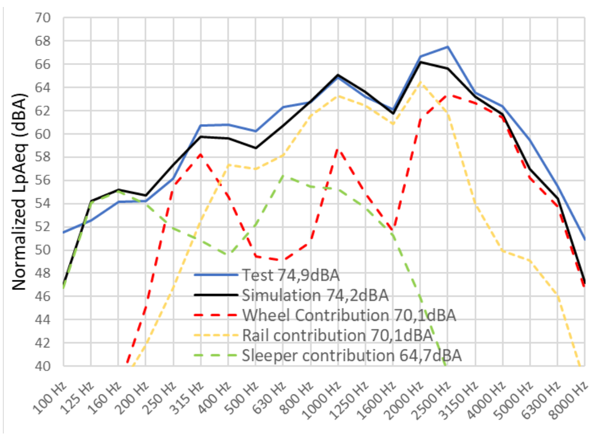

Figure 5. Correlation of pass-by noise level LAeq in third octave band for the two central bogies of commuter train at 80 km/h at 7.5m distance.

These inputs were fed into TraiNoiS (exterior noise simulation software from CAF) and SITARE (exterior noise simulation software from ALSTOM, a standard model was used [9]) to predict pass-by noise of the train in the corresponding topography. Figure 4 shows the correlation in time domain between tests and simulations at 3.5m and 7.5m distances from track centerline. As no traction sources were included in the model, there is an underestimation of noise prediction for first and end cars equipped with motorized bogies and traction equipment. Figure 5 shows the same comparison in third octave band for the 7.5m-distance; the figure also includes contribution of individual rolling noise components, showing predominance of wheel noise at high frequency, rail noise at mid & high frequency, and sleeper noise at low frequency.

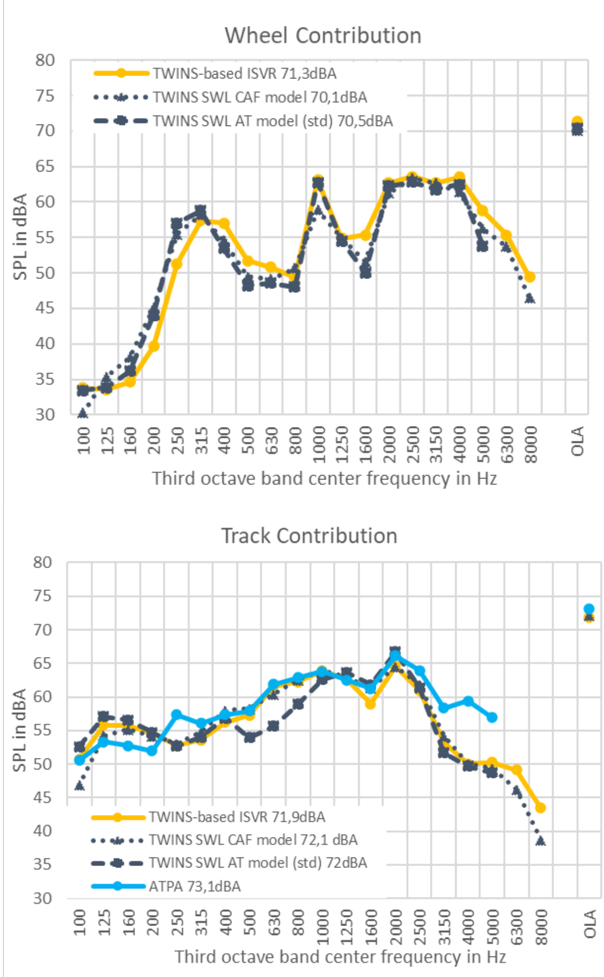

Figure 6. Comparison of track and wheel noise contribution obtained in simulation and through separation methods for the commuter train at 80 km/h.

Figure 6 shows the comparison of wheel and track contributions for the central trailer bogies, between ALSTOM and CAF simulations, and ATPA and TWINS-based separation methods results. Because of the chosen approach to use a standard model by ALSTOM (not reflecting precisely the train and topography geometry and properties), some discrepancies can be seen in the simulation results in the frequency range [500:800] Hz, but the overall noise predictions remain very similar.

3.3 Regional train campaign noise correlation

For the regional train test campaign, more in-depth analysis could be performed, as the sound power input data came from the 4 different separation methods. Simulations were performed using models from CAF, ALSTOM and SIEMENS MOBILITY. Depending on the set of data used for the simulation of a pass-by, an evaluation of the sensitivity of the results to the inputs could be performed. The simulation that showed best fit to the measurement results used the following inputs:

- Rolling noise from TWINS-based method corrected with measured rail vibration.
- Traction and equipment noise from component test bench measurements, as PBA and beamforming seem to give slightly less accurate results.
- Aero-acoustic sources (needed at high speeds only) from the array method.

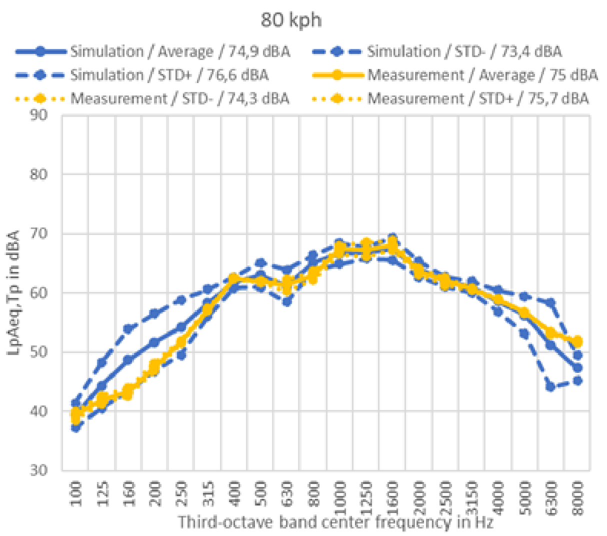

Figure 7. Statistics on simulation results using different input combinations compared to LAeq,tp pass-by measurement for the reginal train at 80 km/h.

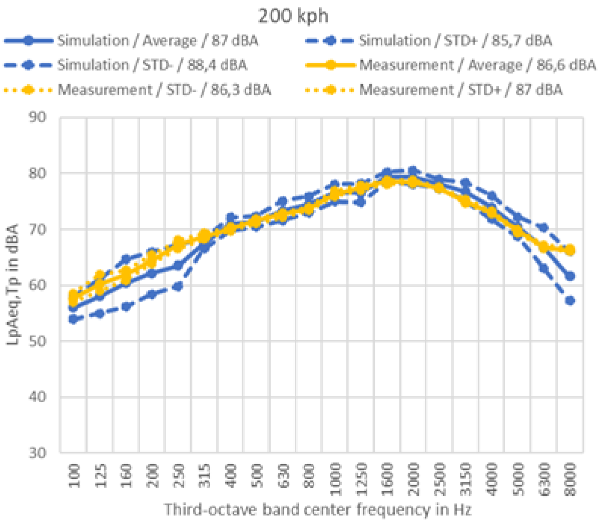

Figure 8. Statistics on simulation results using different input combinations compared to LAeq,tp pass-by measurement for the reginal train at 200km/h.

Figure 7 and Figure 8 show the simulation results at 80 and 200 km/h as a statistic view (average and standard deviation) considering different inputs combinations. It is noticed that the simulations reasonably match the measured data, although the predictions can vary significantly depending on the considered inputs. There is a higher variation in the low frequency range because there is not a good agreement between the separation methods for track and wheel contribution at 80 km/h (see Figure 2 and Figure 3), and different source modelling and propagation hypothesis could be taken for the aero-acoustic noise sources contributions at 200 km/h.

3.4 Simulations accuracy assessment

For all 3 test campaigns, a global assessment was done about the prediction accuracy of the pass-by noise calculated by simulation tools when compared to measurement data.
As shown in Figure 9, a statistical approach with different inputs combinations was used to give an overview of prediction accuracy of the simulation models. Except for the high-speed train campaign at maximum speed, where significant deviations were noticed especially in third-octave bands spectra (not dominant), the overall noise reconstruction of simulated values are generally below 1 dB from measured values.
For all test campaigns at all speeds, it was found that rolling noise significantly dominates all other types of noise sources (traction, and even aerodynamic at high speeds).

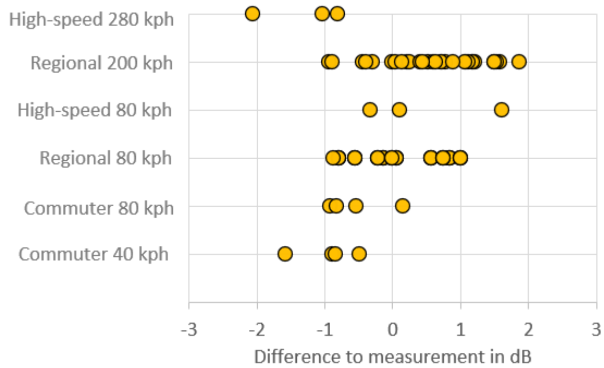

Figure 9. Difference between exterior pass-by simulation models results and LAeq,tp measurements for the 3 test campaigns performed.

4. TRANSPOSITION PERSPECTIVES

The transposition of pass-by noise measurement from one track to another track could bring significant advantages:

- For homologation purposes (TSI NOISE [1]), transposition to a reference track with virtual characteristics could be useful for rolling stocks manufacturers to ease homologation process (measurement could be performed theoretically on any kind of track) and better assess performance of their vehicle objectively.
- For operators, transposition to an existing track could be useful to evaluate pass-by noise in their network and infrastructure, to anticipate and design effective mitigation measures when needed.

Another idea to obtain more objective identification of vehicle noise could be the subtraction of the track contribution evaluated by advanced separation methodologies from the total pass-by noise measured. However, this process could be subject to large errors due the often predominance of track noise over vehicle noise.

Although transposition techniques could only be tested in this project with same vehicle in two tracks with very similar characteristics (only 2dB difference in total pass-by noise), it gave promising results. To really demonstrate transposition techniques feasibility, further tests should be organized to measure pass-by of the same rolling stock on significantly different tracks.

Some work is presented in FINE-2 final deliverable D7.5 [8] to propose possible applications of noise separation methods for a track contribution normalization of train pass-by noise. Transposition could be performed partly, based on rail roughness and track decay rates differences between two tracks. Other possibility could be to use simulation models to transpose the track contribution to a track with reference characteristics and recompose the total pass-by noise of a train. This proposition is summarized in the Figure 10 and would consist in subtracting from a pass-by measurement result a "delta", representing the difference of track noise contribution between the measured location and a virtual reference track.

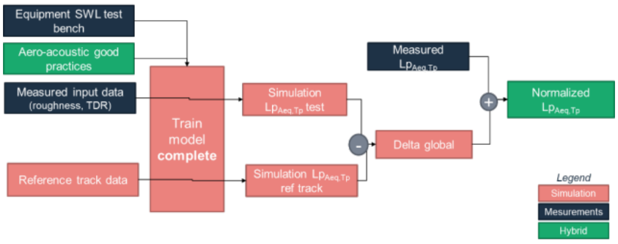

Figure 10. Transposition proposal using full simulation scheme enabling the normalization of train pass-by noise on a track with reference characteristics.

As rolling noise remains the most important source, the uncertainty in separation and transposition is particularly sensitive towards the overall noise. Even if currently the known uncertainties of track decay rates and roughness measurement data are small enough, a transposition could increase uncertainties of the pass-by noise results. It is then particularly important to consider these uncertainties in the transposition process and add them to the final result.

5. CONCLUSIONS

The 4 separation methods (ATPA, PBA, TWINS-based and array method) developed by the TRANSIT consortium could be successfully used as input to train exterior noise simulation models. The agreement between measurements and simulations is good ; considering different sets of input data from the separation methods, simulation results are generally below 1 dB from measured values, which proves that train exterior noise models provide valid and accurate results. Further developments need to be done to improve and simplify the separation methods tested, especially in view to develop and demonstrate the use of transposition techniques for potential future homologation.

6. ACKNOWLEDGMENTS

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