Assessment of noise source integration effects within a virtual certification process

Benjamin Betgen

Vibratec, 28 Chemin du Petit Bois, 69130 Ecully, France.

Ulf Orrenius, Samanthi Brunström

Bombardier Transportation, Centre of Competence Acoustics and Vibration, MLM/TSVVV, 72173 Västerås, Sweden

Summary

The Acoutrain FP7 European research project has come to an end in 2014. Its objective was to show how the classical TSI-Noise homologation process for rail vehicles, can be complemented by virtual testing for certain situations.

This paper deals mainly with noise from traction and auxiliary systems. These sources are responsible for the noise at standstill and can also contribute to pass-by noise.

Installation effects, such as screening and absorption, modify the transfer path between source and receiver in comparison with free field propagation. In Acoutrain, a prediction tool is developed to assess standstill and pass-by levels from rail vehicles. It accounts for the influence of a partly reflecting ground but does not include the prediction of integration effects close to the source. These must therefore be accounted for in the source description. Integration effects can be measured on similar existing rolling stock or predicted. It is displayed how analytical models can be used to calculate the insertion loss of screens for sources that can be represented by point sources. Ray tracing and energy BEM models are used to determine the high frequency installation effect of a source in the bogie and a practical procedure for in-situ testing of installation effects is suggested.

It is concluded that the results to date are promising but more work is needed to validate the proposed process and methods for real vehicle installations in terms of modelling accuracy and usability in a virtual testing framework for TSI certification purposes.

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1 Introduction

1.1 Background

Noise certification tests for rail vehicles according to the NOI TSI [1] are claimed to be costly and time consuming: 4 to 6 months of duration, 4 weeks of effective work. In the preliminary phase of ACOUTRAIN, a survey was made to assess the costs of applying the Noise TSI. According to the different answers received, the Noise TSI process costs around 70 k€ for an EMU/DMU certification (classic speed), and from 65 k€ to 90 k€ for a high speed train certification, depending on the network where the measurements take place.

The ACOUTRAIN project has lead to the definition of procedures and calculation tools to simplify the NOI TSI test procedures. The proposed virtual certification process is detailed in reference [2].

Within ACOUTRAIN, a software tool has been developed that permits to compute standstill or pass-by levels from several sources distributed on a train. One of the reasons for such development was the need for a certified tool. Indeed, different similar models are used already today, for example *SITARE* at Alstom, *BRAINS* [3] at Bombardier, and *VAMPPASS* at SNCF. The aim of ACOUTRAIN was not to replace such tools rather to promote the use of simulations for noise certification –which are performed anyway during the vehicle design phase-. The *ACOUTRAIN tool* as presented in reference [4] accounts for the influence of a partly reflecting ground but unlike existing tools, like *BRAINS* and *SITARE, it* does not support the prediction of integration effects close to the source. These must therefore be accounted for in the source description. This paper presents several ways to measure or compute such integration effects. Most of the addressed topics are discussed in more detail in Acoutrain deliverable 3.7 [5].

1.2 Directivity and source descriptors

Generally, vehicle sources are directive to some degree. Source components, for which the main noise generating device is a fan integrated into the component structure, may be strongly directive due to the screening of sound from the fan by the unit itself. Sources, for which the noise generation is mainly due to shell vibrations, such as transformers, motors and mechanical gears are typically less directive.
Sources may be considered as omnidirectional if the directivity index (as defined in standard ISO 3744 [6]) is lower than 2 dB. Otherwise, the directivity of the source should be taken into account. The ACOUTRAIN tool [4] permits to introduce directivity as a distribution of sound pressure on a hemisphere around the source (independently of sound power), or to use a "box source" defined by sound power per face. Reference [7] describes a procedure how to obtain these sound powers from measurements according to ISO 3744 [4]. Intensity measurements, as described in ISO 9614 [8, 9], also permit to determine sound power per face. Note however that measurement uncertainty related to 'power per face' may be higher than for overall power; for example stationary background noise or reflections can increase the sound power attributed to one face and decrease it for the opposite face.

2 Experimental methods

The above mentioned methods are suitable for characterization measurements on single sources in laboratory or in free field. Measurements that take into account the close environment of the source after integration on the train are described here. These can be dealt with independently from the source itself, i.e. by considering the transfer function from the source to the receiver (typically at 7.5 m distance and 1.2 m height from the track centre). Figure 1 illustrates such a (shielded) transfer, typical for a roof mounted source.
Transfer functions can be obtained from measurements on a mock-up or similar vehicle.

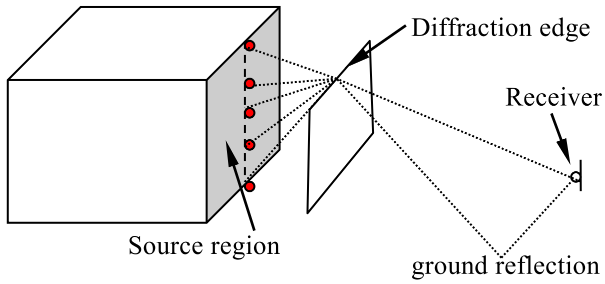

Figure 1. Sketch of a generic source-shield-receiver configuration, typical for roof mounted sources.

To determine transfer functions a reciprocal method can be applied. An artificial monopole source with known sound power level L_w is used at the receiver position and sound pressures are measured at several representative microphone positions close to the source as in Figure 1 to obtain the transfer function L_p-L_w. The details on spatial averaging are presented in reference [7].
Note that the obtained transfer function contains the 'integration effect' from the close environment of the source as well as the 'propagation effect', i.e. distance attenuation and ground reflections. The latter is not part of the source description and must be removed from the test data. The most straightforward solution consists in performing a second measurement where the source is not shielded and subtracting one transfer function from the other to obtain the 'integration part', which can also be regarded as an Insertion Loss (IL). If shields cannot be removed, an alternative consists in computing the 'unshielded' transfer function using a simple computation model (for example the ACOUTRAIN tool with one single source operating). It is important that ground reflections are dealt with identically during all computations. Also, it is recommended to identify ground properties of the test site beforehand because erroneous ground properties will lead to an erroneous estimation of integration effects (if these are obtained by subtracting computed from measured transfer functions).
The described measurements will generally be performed for a direction of propagation normal to the train. In some cases it may be necessary to take into account horizontal directivity, e.g. when shields are present which are not continuous along the train. In this case measurements should be repeated for different angles (at least at ± 45°) in order to obtain the correct integration effect.

3 Computation methods

The main scope of this paper is on the prediction of integration effects. The methods and tools used within ACOUTRAIN are briefly described in the following, see further reference [5].

3.1 Ray tracing

Ray tracing methods can be used to determine the high frequency sound pressure distribution in rooms and other applications where multiple path propagation determine the sound pressure at the receiver point. The principle is that a sound source at a given position is taken to emit numerous of sound particles in all directions at time $t=0$. The source can be made directive with the density of ray emission varying with angle. To determine the resulting sound pressures at various locations, counters are assigned registering the number of sound particles passing within a pre-defined radius. When a sound ray hits a solid object it is reflected with a reduced power in view of the absorption coefficient of the object. Reflection can be specular or more or less scattered by the reflecting object: thus, each surface in a ray tracing model is defined by its absorption and scattering coefficients and sometimes also by a transmissibility index. For out-door problems, such that of vehicle integration of noise sources, ray tracing can be used only if diffraction is satisfactory accounted for in the tool applied. For the present work, the software ODEON was used [10] which supports first order diffraction, i.e. only direct rays from the source will diffract [11].

3.2 Energy BEM

Energy BEM (EBEM) is a concept for modelling of sound radiation and distribution in closed and semi-closed spaces. Surface boundary elements are used to describe sources and absorbing and reflecting surfaces. Based on energetic quantities and energy balance its spirit is close to SEA, but unlike SEA the repartition of energy density can be predicted. Theoretical background can be found in references [12] and [13] and an application to engine shields is described in reference [14]. Standard finite element solvers dedicated to radiation are used for the computation of 'view factors' between all elements. As with ray-tracing, EBEM results are limited to analysis of broadband excitations at mid- and high frequencies as wave interference is not accounted for.

For the present work the SONOR software is applied [14] which to date does not account for diffraction, although a simplified diffraction model is a possible improvement for the future.

3.3 Analytical diffraction models

To account for the effect of diffraction of sound rays by obstacles various diffraction models are available. In ISO 9613-2 [15], calculation procedures based on Fresnel diffraction models for sound propagation to sources behind way-side screens are given. In Acoutrain, and in the following examples presented, the effect of screens has been analysed by using the so-called Geometrical Theory of Diffraction (GTD) [16], an analytical description of diffraction which is slightly more complex than Fresnel diffraction.

4 Applications

4.1 Bogie mounted sources

Transfer function measurements were made using an omnidirectional B&K 4296 loudspeaker placed in the bogie cavity of a regional train as shown in Figure 2. The sound pressure was measured at the TSI position at 7.5 m from the track centre and 1.2 m from top-of-rail.

Figure 2. Measurement set-up with omnidirectional loud speaker in a bogie centre, top: receiver position at 7.5 m, left: plywood cover as concrete slab imitation, right: ballast track configuration

ODEON (ray tracing) and SONOR (EBEM) models have been built, using the absorption properties of the ballast from reference [17] and a constant value of α=0.1 for the plywood.

At high frequencies both predictions show a satisfactory agreement with measurements. As illustrated in Figure 3 the difference between both configurations is around 4 dB. Below 1 kHz discrepancies are larger, possibly due to a modal behaviour of the sound field inside the cavity. When using the different transfer functions together with a measured sound power spectrum of a traction motor with gearbox [5] the overall sound pressure levels given in Table I are obtained. The prediction error is around 1 dBA.

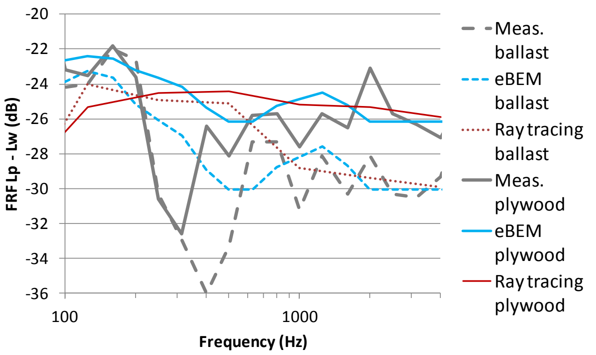

Figure 3. Measured and predicted transfer functions between source in a bogie centre and receiver at 7.5 m

Table I. Measured and predicted sound levels at 7.5 m

[dBA]	Measured	EBEM	Ray-tracing
ballast	61.7	61.5	62.6
plywood	64.0	65	65.3

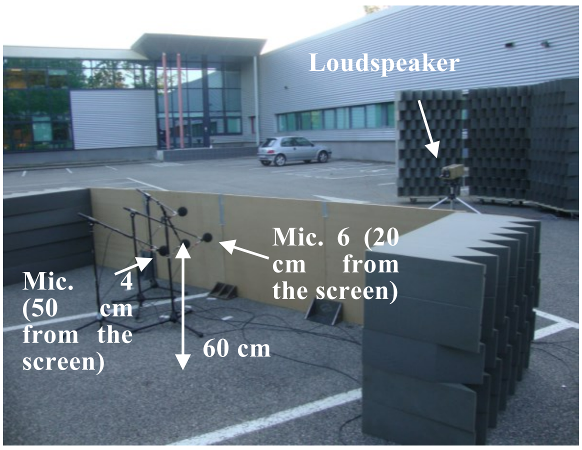

Figure 4. Measurement setup for mock-up diffraction tests

4.2 Roof mounted sources

As mentioned, the available EBEM tool does not support diffraction which excludes it for the prediction of integration effects for roof mounted sources. Instead, an analytical model as described in section 3.3 has been used.

At first, this model has been validated against transfer function measurements performed on a simplified geometry, see (Figure 4). A reciprocity approach was applied with a loud speaker at 5.5 m (for practical reasons instead of the 7.5 m position), to better represent the point source hypothesis used in the model.

Transfer functions both with and without plywood screen have been measured to determine the Insertion Loss. Figures 5 and 6 show that the analytical diffraction model is in good agreement with measurements. Reflections on the ground on both sides of the screen (assuming a constant absorption coefficient of the tarmac ground of $\alpha = 0.1$) are taken into account by an image source and image receiver, resulting in four propagation paths which can be summed up energy wise or accounting for the phase.

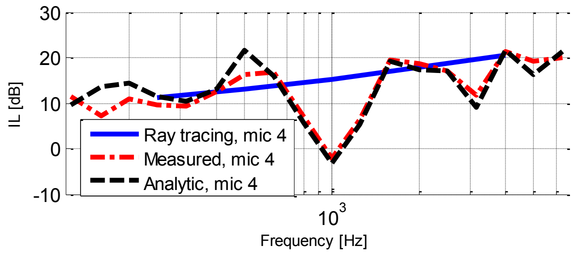

Figure 5. Measurement results and predcitions of the mock-up diffraction test (microphone at 50 cm from the screen)

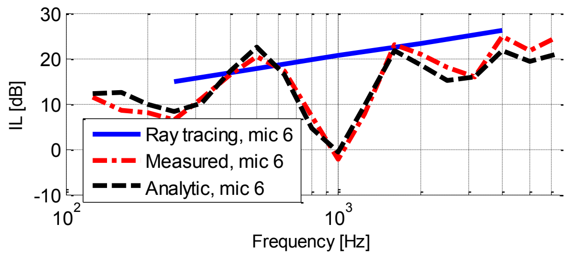

Figure 6. Measurement results and predcitions of the mock-up diffraction test (microphone at 20 cm from the screen)

The same situation has been modelled with ray tracing. A fair fit is found at higher frequencies but in average IL is clearly over-predicted, especially for the position close to the screen. This is believed to be due to the neglecting of interference effects between reflected rays and to the above mentioned limitation to ‘first order diffraction’.

In addition, loudspeaker test results on a train roof with a plywood fairing have been made available by ALSTOM. The test setup is displayed in Figure 7; note that the source is positioned on the roof and sound pressures are recorded at different distances from the train (direct measurements).

Ground resistivity has been measured as well and used for the predictions.

Figure 7. Measurement setup for transfer function measurements on a real train, above: w/o screen, below: with screen

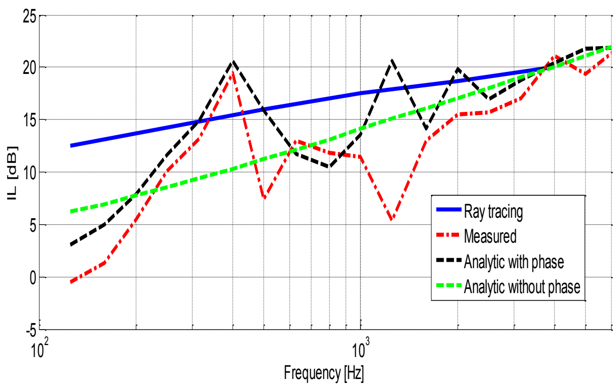

Figure 8. Insertion Loss of plywood screen on a real train

When taking phase relations into account the analytical diffraction model predicts well the first maximum of IL as shown in Fig 8. A half wavelength at 400 Hz equals 43 cm which corresponds roughly to the path difference between direct and reflected path on the source side. This means that the direct wave and that reflected on the roof, will cancel out at the top of the screen and thus maximise the obtained IL. Above roughly 500 Hz, the point source representation is no longer valid because a wavelength becomes smaller than (i) the diameter of the source and (ii) the distance between source and screen. As a consequence the computed interferences do not correspond to reality anymore and a computation which neglects all phase relations delivers better results. Again the ray-tracing model clearly overestimates the insertion loss.

When using the different transfer functions together with a measured sound power spectrum of a HVAC system [5] the overall sound pressure levels and IL given in Table II are obtained. Note that the point source position has been assumed at the centre of the real source. In comparison, analytical computations with a point source located at the upper extremity of the real source lead to predicted IL of 12.3 dB (with phase) or 11.5 dB (without phase).

Table II. Measured and predicted sound pressure levels at 7 m and IL of roof fairing

dBA/dB	meas-ured	analyt. with phase	analyt. without phase	Ray-tracing
SPL w/o fairing	61.2	61.4	61.4	61.0
SPL with fairing	51.2	48.5	48.7	44.2
IL	10.0	12.9	12.7	16.8

Conclusions

A representative virtual vehicle suitable for virtual testing has to account for integration effects of vehicle sources, such as screening or local absorption due to the ballasted track. These effects can be either calculated directly by the tool which is used for noise synthesis or identified externally and integrated in the source descriptions. The latter approach supports the use of the best suited methods although the ACOUTRAIN project has not managed to provide a validated procedure defining how to deal with integration effects for real vehicle sources. The work performed allows concluding the following:

- Measurements of installation effects by means of transfer functions or IL are useful, but require access to a vehicle with a power free catenary for safety reasons. Alternatively a representative mock up can be built around the source.
- Reciprocal measurements facilitate the determination of integration effects.
- An average of measured transfer functions can be used to determine integration effects [7]. Alternatively, a worst case estimation with a point source at the least shielded position can be adopted (rather than using the centre of the source).
- Numerical tools such as ray tracing and energy BEM can determine the high frequency installation effect of a bogie source. The use of ray tracing tools for roof mounted sources seems more delicate in view of the need for accurate diffraction models. Classical BEM would also be an alternative but the computational cost seems high in an industrial context.
- Computations using GTD have shown a very good fit with measurements for a point source setup; discrepancies were found to be much higher for a larger source. The representation of real sources close to screens is a critical point that deserves future research.

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