The TRANSIT project: innovation towards train pass-by noise source characterisation and separation tools

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Abstract

The overall goal of the Shift2Rail project TRANSIT is to provide the railway community with a proven set of innovative tools and methodologies to reduce the environmental noise impact and improve interior acoustic comfort of railway vehicles. To predict overall noise levels accurately for stand-still or during pass-by, accurate separation and characterisation of the main contributing sources is required. Methods developed in TRANSIT are based on static characterisation and on measurements during pass-by to identify the sound power and directivity of the main sources of railway noise and establish their contribution to the total measured levels. These results are the input to exterior noise simulation tools. The main obstacle for current vehicle certification methods is the fact that the track is the main contributor to pass-by noise. TRANSIT is targeting this problem by developing methods to identify the contribution of vehicle sources and to separate the vehicle and track contributions to rolling noise, based on the most promising approaches from Roll2Rail. Validation tests for all these techniques are being carried out in collaboration with the FINE-2 project. Finally, acoustic meta-material designs are being developed for specific applications, within an HVAC duct and as a horn cover, to achieve high absorption and transmission loss at target frequencies. The initial assessment is promising and will be followed by measurements in realistic conditions.

Keywords: Noise, Technical Specifications for Interoperability, Virtual testing, Meta-materials, Shift2Rail

1. Introduction

Noise and vibration levels in the vicinity of railways are a major environmental challenge for the railway sector. Populations in the vicinity of railways no longer accept the increasing annoyance; moreover, a competitive railway system requires improved passenger comfort. The Technical Specifications for Interoperability address noise reduction to some extent by requiring that all new vehicles meet noise limits in both pass-by and stationary conditions. Due to the high cost of such tests, however, it is desirable to develop virtual testing methods. Some progress has been made in a previous project Acoutrain [1] towards this by developing source characterisation methods and exterior noise simulation tools which have been validated for a few cases. These tools and models require further development to include other practically relevant situations. This includes the effect of source integration due to for example skirts or fairings.

A major obstacle for the current vehicle certification method is the fact that the track is often the main contributor to pass-by noise. Advanced measurement methods can identify the noise contributions of different sources on an operational train and provide better understanding of the relative importance of the various sources on the vehicle as well as the track. Wheel/track separation methods have been developed in the previous project Roll2Rail [2] but the validation of these methods is so far limited to a single case.

The Shift2Rail project TRANSIT is divided into four technical work streams. Most activities are focused on the experimental characterisation, modelling and separation of railway noise sources (at standstill and during pass-by). New test methods are being developed to quantify noise transmission paths from sources on rail vehicles to the trackside accounting for installation effects. In addition, innovative materials and methods for improved internal sound comfort are investigated.

2. Source and transmission characterisation for exterior noise

In the modelling approach developed in Acoutrain, Figure 1, the noise at a trackside microphone is simulated using source information for each noise source (sound power and directivity) and transfer functions from the source position to the microphone position. The source information can be measured on the equipment on a test bench and for the transfer functions simple free-field conditions were assumed, allowing for ground reflections. The main shortcoming of this approach is the omission of acoustic installation effects due to shielding by skirts, fairings and the train structure itself.

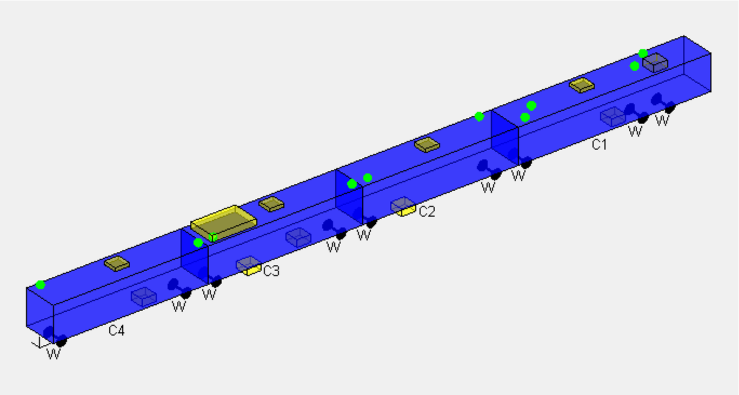

Figure 1: Examples of acoustic sources located on a train modelled using the Acoutrain approach

To address this source-transmission problem, two methods are under development. In the first, a method of source characterisation has been further developed, by introducing a new simplified procedure assuming uncorrelated equivalent monopoles. This is based on sound power measured via a standard procedure, e.g. ISO 3744 or 9614. The machine is enclosed by a virtual control surface that is divided into small areas and each area is associated with a monopole source. Transfer functions are defined from the volume velocity of each monopole source to the sound pressure at the receiver locations. A calibrated sound source is also used to measure these transfer functions. Figure 2 shows an example of tests conducted in the laboratory to validate the procedure [3].

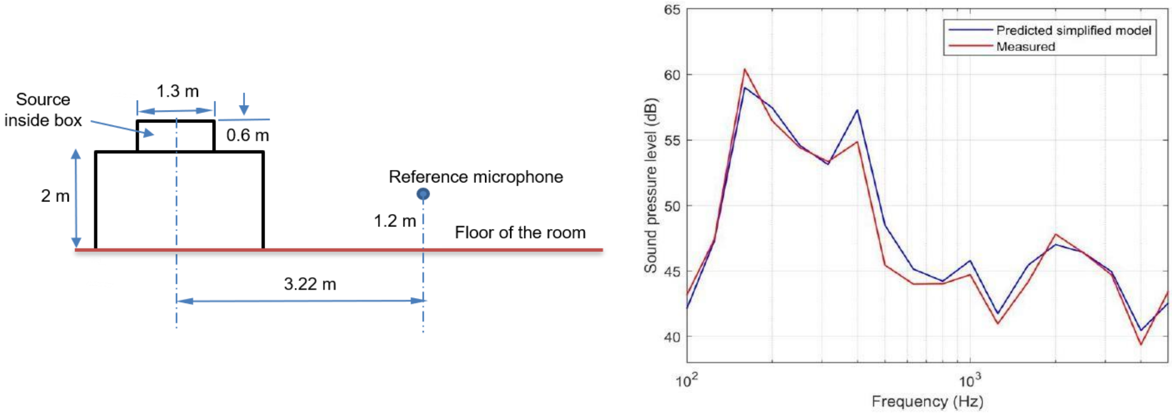

Figure 2: Laboratory test of monopole method for source and transmission characterisation. Left: mock-up with acoustic sources inside a box on top of the 'roof'; right: example result.

The second approach investigated for the source strengths and transmission is to use an acoustic array with iterative Bayesian focusing (IBF) to measure the source distribution on the surface of the source (Figure 3). The transfer functions could be measured or predicted using the Boundary Element Energy Method. Field measurements are used to verify both approaches with the equipment mounted on a train (Figure 3).

Figure 3: Left: Sound power measurement on a power converter with an acoustic array; right: static measurements of the same equipment mounted on the train.

3. Pass-by noise source separation

As well as these static source quantification methods there is a need to obtain the sound power and directivity of noise sources during a train pass-by. The main sources considered are aerodynamic noise, traction noise, equipment noise and rolling noise. Two different methods are investigated: (i) with a microphone array and (ii) with a single microphone and rail-mounted accelerometer (PBA-based).

In the microphone array method, the train pass-by is measured simultaneously with an array of microphones (at least 64 channels). Acoustic imaging techniques are then used for source separation based on beamforming, advanced spatial filtering deconvolution or inverse methods. In beamforming, the signals from the microphones are combined with appropriate time delays to 'steer' the focus in a certain direction which can follow the moving train. However, such methods only provide a relative comparison between noise sources and no information about directivity. To improve on this, a CLEANT deconvolution method and the Iterative deconvolution method have been applied. These give improved resolution of noise sources on the train, see Figure 4.

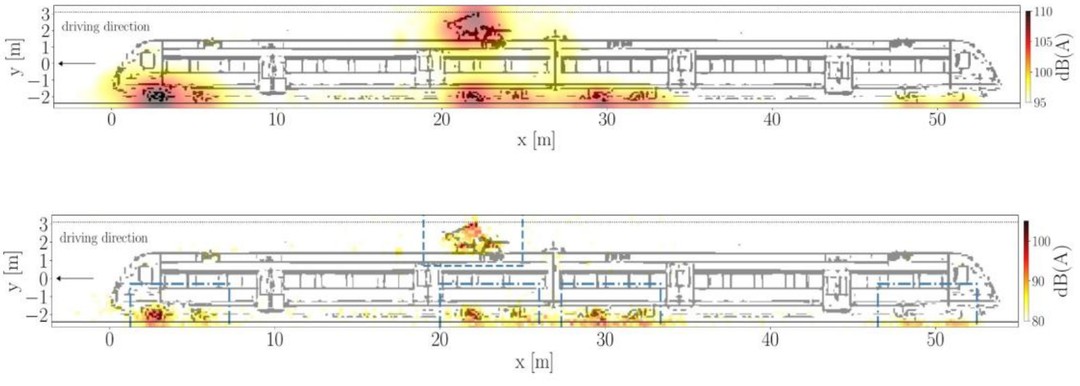

Figure 4: Example of a beamforming result (upper) and result of deconvolution (lower)

A simpler alternative has also been investigated based on the Pass-By Analysis (PBA) method [4]. This uses measured operational rail acceleration to estimate combined wheel/rail roughness levels. A vibroacoustic transfer function is derived from this combined roughness and trackside sound pressure levels. The rolling noise transfer function can be determined from the operational pass-by of vehicles which are dominated by rolling noise. The pass-by level of rolling noise is estimated from the sum of the combined roughness level and rolling noise transfer function. Other noise sources will be evident as deviations from the rolling noise transfer function; for example, aerodynamic noise can be assessed by measuring a high-speed train and comparing the transfer functions with those obtained at a lower speed (dominated by rolling noise). Rolling noise transfer functions can also be obtained using stationary measurements on track and vehicle (see next section).

4. Separation of track noise and vehicle noise

The TSI Noise specifies noise limits for new vehicles, which must be achieved on a track with a low contribution to the noise, specified in terms of track decay rate and rail roughness level. However, the track noise (and roughness) is still an important contributor to the overall level, meaning it is difficult to compare results from different sites. It is therefore important to be able to separate the contributions of vehicle and track. In TRANSIT, promising techniques from the Roll2Rail project for the separation of rolling noise contributions [2] are being further developed (simplified and/or enhanced). The methods should also be able to 'transpose' pass-by data measured on one track to another track; wheel and rail roughness separation should also be achieved. Three proposed separation methods are considered and further developed.

TWINS model (Track-Wheel Interaction Noise Software): the TWINS model for rolling noise [5] includes a series of engineering models for vibration and noise radiation of wheel, rail, and sleepers and excitation by combined surface roughness. For source separation, TWINS is used with measured rail vibration. Improvements in TRANSIT are based on recent developments in modelling sound radiation. The effect of reflections from the underside of the vehicle is being investigated, by using 1:5 scale models and boundary element calculations (Figure 5).

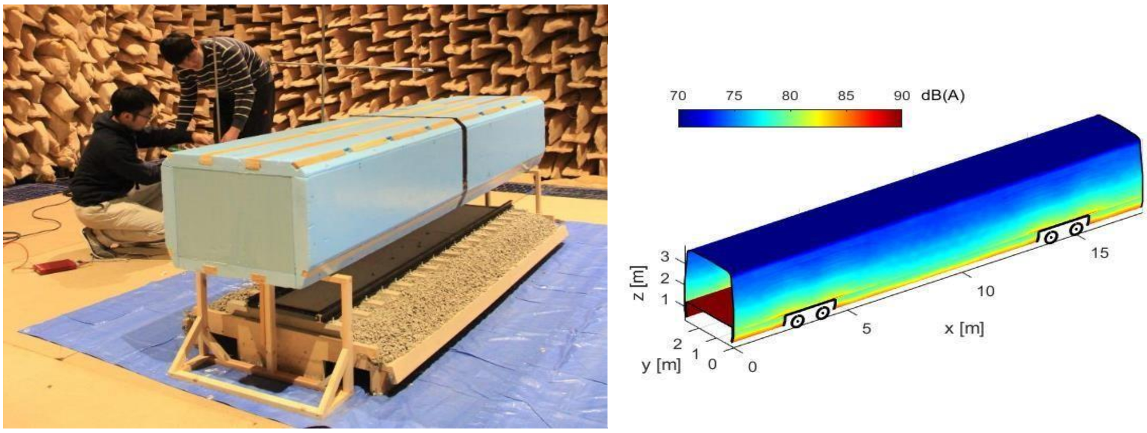

Figure 5: Investigations of the effect of the vehicle on rolling noise. Left: 1:5 scale model tests; right: boundary element model.

Pass-By Analysis (PBA): This uses sound pressure and rail acceleration signals of multiple pass-bys at different speeds [4]. From the analysis the track decay rate, combined effective roughness levels, and combined vibro-acoustic transfer function are obtained. This allows the separation of roughness excitation and combined (vehicle and track) response. Further separation of vehicle and track components is considered in the project, based on separately measured transfer functions for vehicle and track (static measurements). Two different methods are considered: the direct method (excite with a hammer) and the reciprocal method (excite with a loudspeaker). Separation of wheel and rail roughness will also be performed through PBA by monitoring mixed traffic, identifying minimum combined roughness levels in each wavelength band, and providing an upper bound for rail roughness.

Advanced Transfer Path Analysis (ATPA): This is an experimental method for obtaining noise contributions from different parts of a system, by decomposing the sound pressure at the target location as the sum of the noise contributions considered. To apply ATPA to rolling noise separation, the relevant track section is divided into subsections (Figure 6). Both static measurements (with hammer excitation) and dynamic (pass-by) measurements are carried out and combined. Each subsection (red dashed box) includes a vertical accelerometer on each rail, a horizontal accelerometer on each rail, and a vertical accelerometer on one sleeper. The four wheels of one bogie are instrumented in radial and axial directions. The aim is to simplify ATPA in terms of equipment, time, and resources. Various simplifications are being considered: measuring a reduced set of static functions and deducing the rest from calculation, assessing the use of reciprocally measured static functions, or measuring the static functions without the train present and applying some corrections.

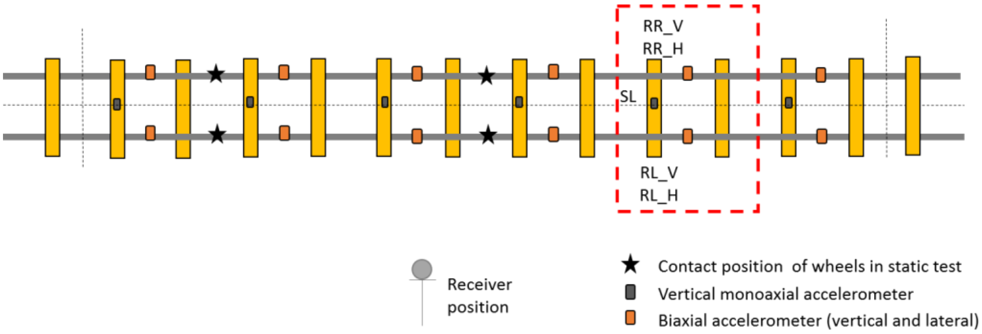

Figure 6: Diagram of instrumentation set-up for ATPA method

5. Field tests

In collaboration with the FINE-2 project extensive field measurements are being carried out to validate the various methods developed in the project, both for wheel/track separation and for the characterisation of other sources on a moving train. Three different test campaigns are organised: (i) on a metro train, focussing only on wheel/track source separation; (ii) on a regional train with various types of auxiliary equipment, traction noise and rolling noise; (iii) on a high-speed train that additionally includes aerodynamic noise.

6. Innovative designs for interior noise solutions

In the final workstream, innovative approaches and material designs are being explored for improved interior sound comfort. A feasibility study was first carried out into several potential solutions. These focused on meta-structure designs and other tailored material design. The potential for interior noise reduction and the possibility for practical implementation have been assessed and the two most promising solutions have been chosen for further development.

Noise reduction in an HVAC duct system is targeted at frequencies associated with the fans. Ultra-thin low frequency (UTLF) resonator arrays were considered in a feasibility study with the result that many single UTLF would be needed. A simplified design is proposed based on a membrane with an array of small masses and a perforated plate (Figure 7). A reduction of 15 dB has been found to be achievable at 250 Hz. The second solution aims to minimise the noise from the train horn inside the driver's cab. To achieve this, acoustic metamaterials (Figure 7) are placed in a box surrounding the horn. These are tuned to have a very high absorption at the two target frequencies, 370 Hz and 660 Hz, which reduces the sound transmission from the horn into the driver's cabin. For both solutions prototype tests will be carried out in the laboratory and in a realistic set-up.

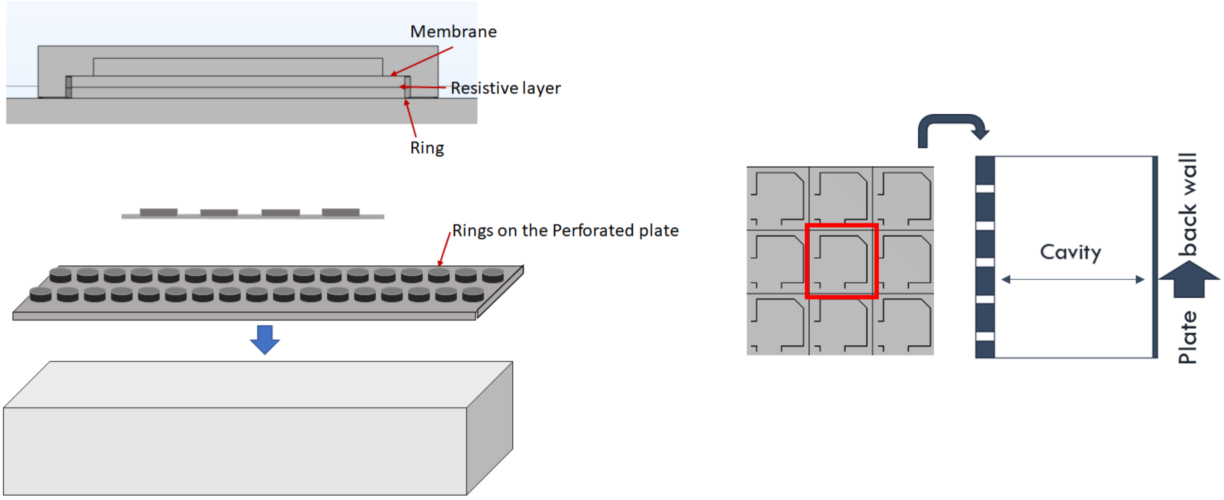

Figure 7: Left: Concept for ultra-thin low frequency resonator array for application in HVAC duct. Right: Micro-slit metamaterial backed by a cavity used for horn cover.

7. Conclusion

The main obstacle for current vehicle certification methods is the fact that the track is the main contributor to pass-by noise. TRANSIT is targeting this problem by developing methods to identify the contribution of vehicle sources and to separate the vehicle and track contributions to rolling noise, based on the most promising approaches from Roll2Rail. To predict overall noise levels accurately for stand-still or during pass-by, accurate separation and characterisation of the main contributing sources is required. Methods are developed based on static characterisation and on measurements during pass-by to identify the sound power and directivity of the main sources of railway noise and establish their contribution to the total measured levels. These results are the input to exterior noise simulation tools. Validation is being carried out in collaboration with the FINE-2 project.

Finally, acoustic meta-material designs have been developed to achieve high absorption and transmission loss at target frequencies. The initial assessment is promising and will be followed by measurements in realistic conditions.

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