ACOUTRAIN

Towards a step-change in new rolling stock certification for noise

Noise pollution is an important concern. At a European level the Environmental Noise Directive (END) requires noise mapping of large agglomerations and major routes and the development of Action Plans. It is estimated that 14 million people in Europe are exposed to levels of railway noise above 55 dB L_{den}, compared with 125 million people for road traffic[1]. In parallel, regulations controlling the noise emission from individual vehicles have been introduced. For the railway sector these were introduced from 2002 in the form of Technical Specifications for Interoperability (TSI) which limit the noise emission of new vehicles. The latest revision of the Technical Specification for Interoperability (TSI) Noise enters into force in January 2015, and Nicolas Furio, Head of Unit – Technical Affairs at UNIFE, Estelle Bongini, SNCF I&R Acoustics, Vibration and Diagnostics Research Group, and Ulf Orrenius, ACOUTRAIN Technical Leader (Bombardier), provide further information.

Although the TSI Noise is strategically important in ensuring that the railway remains an attractive means of transport in the future and in allowing the sector to grow, it also means restrictions and increased costs to individual stakeholders. The conformity assessment required in the TSI Noise is mainly based on field tests, which is often a very expensive and time consuming process. Noise measurements are required under pass-by, stationary and starting conditions as well as inside the driver's cab.

The ACOUTRAIN FP7 European Research project, coordinated by UNIFE – The European Rail Industry – aims to develop procedures and calculation tools to simplify the TSI Noise test procedures. From October 2011 to December 2014, the 15 ACOUTRAIN partners have cooperated for introducing virtual certification for noise with a reliable simulation approach.

Moreover, the ACOUTRAIN project has also contributed to the progress of other railway noise research areas such as:

Methods for separation of infrastructure and rolling stock noise contributions

Three separation methods have been proposed and tested against measured data. These methods can be used either to transpose a vehicle to a different track or to transpose to another vehicle on the same track. The concept has been extended to a proposal for transposing measured results to a virtual reference track.

Establishment of measurement procedures for new running conditions (e.g. braking and curving)

A new procedure for type testing vehicles for curving noise has been proposed, including an on-board occurrence test procedure combined with trackside pass-by test.

Development of procedures to obtain inputs for the European Noise Directive (END)

A procedure to use 'virtual testing' (VT) models and data for the definition of equivalent noise sources for the END noise mapping has been established. This procedure leads to realistic vehicle source power allocation without costly testing for application of the END.

Introducing virtual certification for noise with a reliable simulation approach

One of the main objectives of the ACOUTRAIN project consists in proposing a procedure based on VT to be used for acoustic certification purposes.

VT in a certification process means that the tests required for the

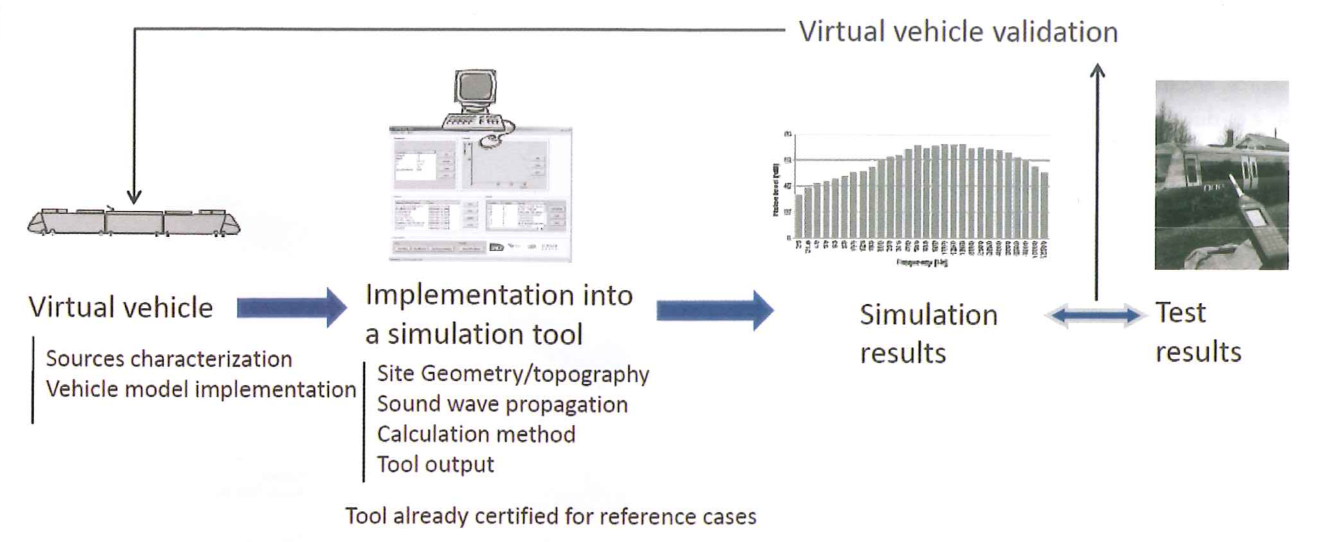

Figure 1: Virtual testing scheme, with validation and verification steps

certification are partially (or completely) carried out with numerical simulations. This means that simulation models are used for the assessment of regulatory (enforced by law) essential requirements, e.g. TSI Noise.

Therefore, VT should be an alternative to real testing: both procedures should remain as equals to improve flexibility. This essential requirement implies that:

- The TSI limit values, predefined operational and environmental conditions and receiver positions should be identical for the new virtual test procedure
- The output result from both procedures should be equivalent. It is a prerequisite that the choice of test procedure should not affect the decision to accept or reject a vehicle

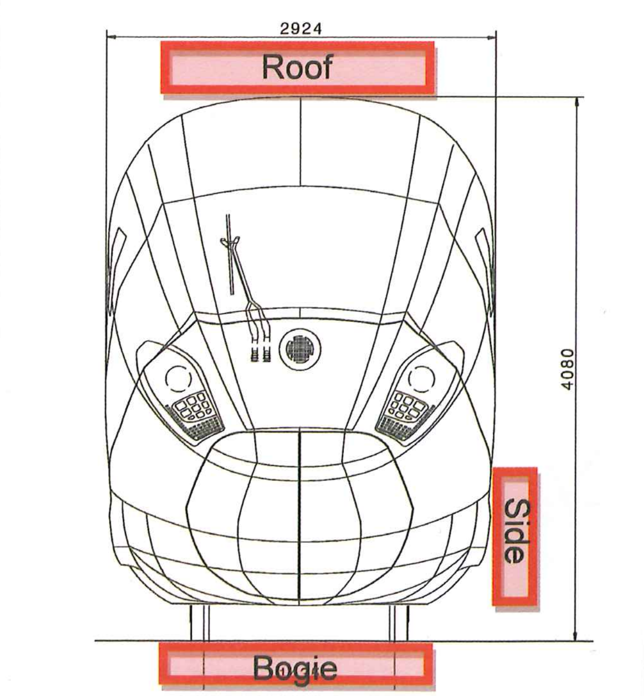

Figure 2: Vehicle profile with source positions

- The reliability or the standard uncertainty of both procedures should be comparable.

Technically, VT in acoustic consists in modelling the vehicle as a set of noise sources (train = set of noise sources) which is then called virtual vehicle (VV). This VV is handled in a numerical tool for simulating the noise of the train, at stationary and pass-by (starting noise has not been considered in ACOUTRAIN: the dominant sources for this case are traction noise sources for which acoustic behaviour during starting phase is really difficult to model). Therefore, VT will deal with:

- Simulation tools based on a specific numerical approach
- Noise source modelling: noise source characterisation and representation
- Noise source integration within the train: integration effect.

All the elements involved in the virtual process (simulation tool, models of noise sources) contribute to the reliability of the virtual test and its comparability with real test results. Therefore they will be checked either by a certification process (for the simulation tool for example) or with a validation process where virtual tests and real tests are carried out in parallel to assess their difference, as presented in **Figure 1**.

To be compared with real test results, VT should also deal with:

- Propagation of noise in a complex environment (ground effect, topology effect).
- Track characterisation.

The following sections present the ACOUTRAIN simulation tool development and the proposal for a certification process of any simulation tool; the issue of noise source modelling and characterisation and the results of the validation process carried out for some application cases within the project.

Source modelling – installation effects

Acoustic sources on a rail vehicle can be categorised in two groups: (1) noise sources associated with rail-wheel interaction, namely radiation from wheel, rail and sleepers, and (2) those of vehicle components. The latter group can be divided into sub-groups with (a) components for which fans, and other cooling devices, are the main source, and (b) components with a vibrating shell being the main source, e.g. due to electromagnetic forces (transformers, motors) or mechanical contact (gear boxes). At very high speeds components with aerodynamic sources (c) become increasingly important, e.g. bogies and pantographs. One main task of ACOUTRAIN has been to develop assessment methodology applicable to the vehicle source types, mainly cooling fans and electromagnetic sources.

For fan sources a methodology where the real source is modelled as a small number of equivalent monopole sources has been successfully applied using in-situ data on a Heating, Ventilation and Air-Conditioning (HVAC) cooling fan. Also, it has been shown that fairly simple analytical models of screens can be used to determine installation effects of roof-mounted sources. Ray tracing and energy Boundary Element Methods 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 has been suggested. For high-speed applications a computationally efficient component-based model was shown to accurately represent the spectrum of a train pantograph. Although the results are promising, more research activities are 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.

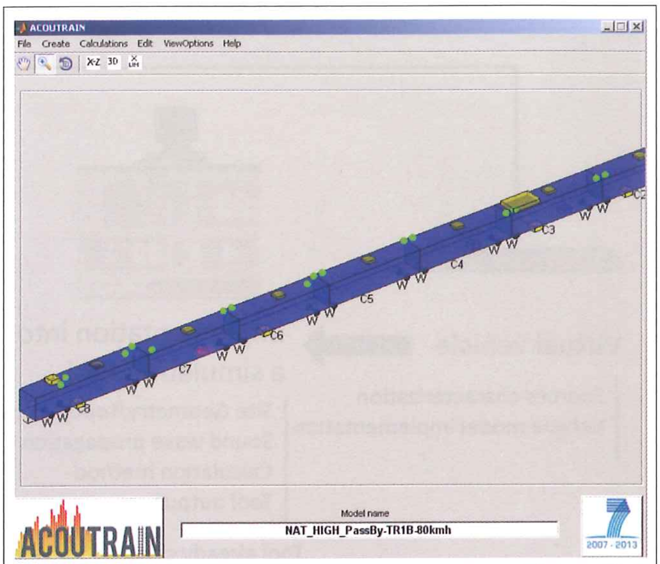

Figure 4: Example of a train model using the ACOUTRAIN simulation tool

Simulation tool development/assessment

A simulation tool, named ACOUTRAIN, has been developed within the project for pass-by and standstill noise predictions. This tool is able to compute noise levels emitted by a complete train taking into account noise coming from the different equipment. Any type of source is defined as a group of point sources and each single source is characterised by its acoustic power and directivity. Rolling noise is associated with each wheelset. The acoustic data linked to those wheelsets are obtained from the TWINS software[2].

In order to be able to use such a tool in a certification process, it is necessary to certify the tool itself. For that purpose, criteria and a methodology have been proposed. It was defined that the outputs of such a tool should be:

- Average one-third octave band spectrum for stationary calculation
- Maximum and average levels in one-third octave bands and overall sound level versus time for pass by computation.

Results for reference cases have been obtained using analytical calculations. These are based on simple monopole and/or dipole sources that radiate above different types of grounds.

A total of 13 scenarios have been computed to evaluate basic prediction performances, which are the minimum requirement for any simulation tool intended to be used for Noise TSI certification. Then a certification procedure for simulation tools has been proposed, including assessment criteria and acceptable values.

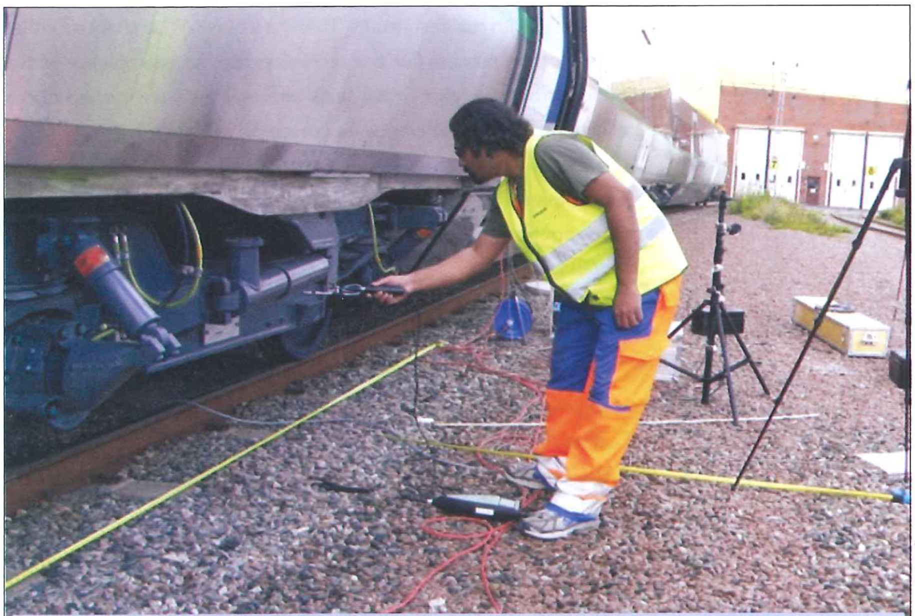

Figure 3: Scanning of sound intensity from bogie source

Procedure – validation

The VT procedure was evaluated by comparing a VV built in a simulation tool with measurements on the track. The Electricle Multiple Unit (EMU) 'NAT' manufactured by Bombardier Transportation was chosen for this purpose and the measurement campaign was performed in France by SNCF (see **Figure 5**, page 49). The VV representing the NAT was built both with the ACOUTRAIN tool and the simulation tool SITARE, which is an in-house development from Alstom Transport.

The comparison between measurement and calculation results of the NAT VV showed some significant discrepancies for stationary noise. One parameter that has proven to strongly influence the calculation results is the installation effect. The NAT has fairings

Figure 5: The NAT – field tests

on the roof and skirts that partly cover the traction motor cooling system in the bogie area. Unfortunately, the insertion loss could not be determined within the project but a test with and without skirts was made with calculations in SITARE. It was shown that skirts and fairings may have an effect of between 3-7 dB(A) depending on the microphone position. For a future certification procedure it is important to assess all kinds of shielding and account for these in the modelling of the VV.

However, the lack of suitable modelling of shielding cannot alone explain the difference between measurement and calculation results. When analysing the results it was observed that a strong peak at 315 Hz (see **Figure 6**) was leading to an overestimation of the calculated results. This could be identified as noise coming from the outlet of the traction motor cooling. During the characterisation measurement, it could not be as well isolated as when the source is mounted on the vehicle since the original ducting was not available. It can be recommended, as far as possible, to use the original systems, like ducting for cooling fans, when characterising the separate sources. This recommendation also applies for other components – for instance the transformer, which should be characterised with the original converter.

It has also been recognised that the directivity of sources has to be considered when modelling them for the VV.

The pass-by noise results, for which rolling noise is dominating, show a better agreement between calculations and measurements. By using two microphone positions for the measurement and two track decay rate (TDR) measurements as input for the calculation there is a certain spread of both results (see **Figure 7**). This gives an indication of the difficulties comparing two methods, each with an uncertainty value, which in the end limits the possibility to obtain a perfect agreement.

Recommendations for virtual testing implementation

The work carried out during the ACOUTRAIN project allows recommendations to be proposed concerning the VT implementation. Two main VT procedures have been specifically worked out in ACOUTRAIN:

- The Extension of Approval approach (EoA): in this case, the vehicle under test is largely based on an existing 'similar' vehicle. This requires that:
  - A VV has already been created for this existing similar vehicle
  - That this VV for the similar vehicle have been validated (for stationary and pass-by configurations, as presented in

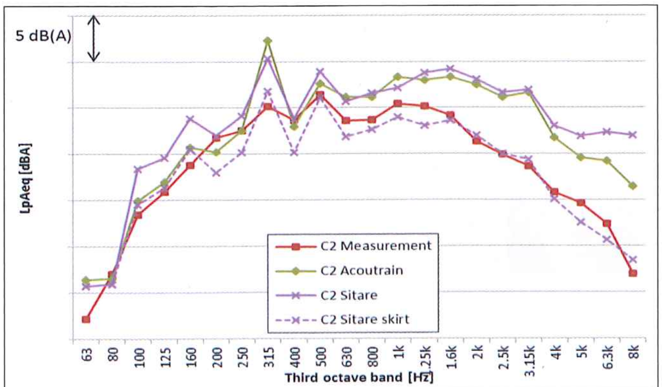

Figure 6: Third octave band analysis of the average noise level of the stationary noise

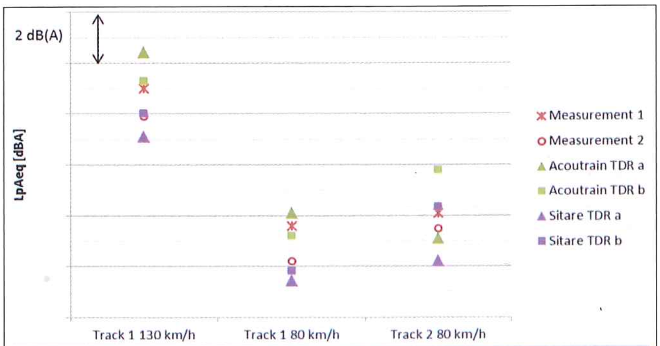

Figure 7: Comparison between measurement results of pass-by noise level at two microphone positions and the corresponding calculation results with the ACOUTRAIN tool and SITARE with two different track decay rate inputs

previous section) – this vehicle becoming then a reference vehicle
- Then the reference VV (created and validated for the similar vehicle) can be modified to correspond to the vehicle under test and used in a VT for certification.

- The Hybrid approach: in this case, no similar vehicle is identified and/or no reference vehicle has already been created and validated. A specific VV has to be created for the vehicle under test. It is validated only under stationary conditions and can be used for VT for the pass-by noise assessment.

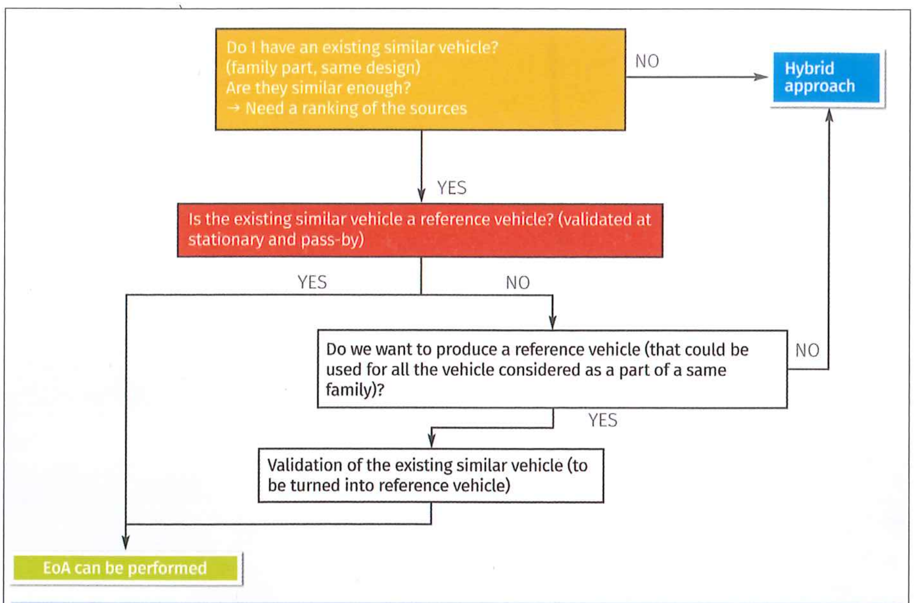

Figure 8: Selection of the best approach for VT process

As illustrated in **Figure 8**, the two main concepts that drive the choice of a VT approach, between hybrid and EoA, are the existence of a similar vehicle which has already been certified and the fact that for this similar vehicle, a reference VV exists.

A decision model has been developed in ACOUTRAIN to verify whether two vehicles are similar enough for one to act as reference for the other. This model ensures that the differences between the two vehicles are limited since the validation with measurement data is only performed for the reference vehicle, taking into account the number of modifications between the two vehicles, the nature of the modification and the uncertainty it implies. Then, for this similar vehicle, a reference vehicle potentially exists that means a VV validated at stationary and pass-by conditions, according to a specific validation process mentioned in the section above and detailed in the ACOUTRAIN VT process.

In any case, real tests for TSI certification remain an option (particularly where validation of the VV is not possible).

Conclusion

The ACOUTRAIN project consortium has developed and tested several methodologies to complete the VT procedure and make it sufficiently reliable. A lot of results are now available. Although they do not allow an application case of VT to be successfully implemented, they allow the framework of the VT process to be built with its essential requirements defined, and recommendations to be proposed for the next steps.

A certification process for simulation tools is available. For the rolling noise source, recommendations are defined to assess it reliably with the TWINS software. For the definition of vehicle specific noise sources, various methods have been tested: a process for characterising these sources is defined with specific recommendations about implementing the integration effect. However, more research should be done to better assess the integration effect of sources on the vehicle. A validation procedure has been specifically designed to assess the VT procedure in comparison to real tests. One of the key points for assuring that a VT process is as reliable as a real test process is the assessment of the uncertainty level of both procedures, which has to be worked out in the future.

Moreover, the ACOUTRAIN project also provides robust and tested methodologies for the separation of infrastructure and rolling stock noise contributions; the measurement of new running conditions (e.g. braking and curving); and the use of virtual testing outputs, within certification purposes, for defining the inputs of noise mapping as required by the European Noise Directive (END).

References

1. Noise in Europe 2014, EEA Report No 10/2014, European Environment Agency.
2. Thompson D.J, Hemsworth B, and Vincent N. Experimental validation of the TWINS prediction program for rolling noise, Part 1: description of the model and method, J Sound Vib 1996; 193: 123-35

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After a PhD in Acoustics, dedicated to a global model implementation for the simulation of train pass-by noise, **Estelle Bongini** started in 2008 to manage research projects dedicated to noise and ground vibration caused by railway traffic, at the Innovation and Research Department of SNCF. She is now in charge of the research group Acoustics, Vibration and Diagnostics at SNCF I&R, and participated to the collaborative research projects (funded by the European Commission) RIVAS – about ground vibration mitigation measures development, and ACOUTRAIN – about the virtual testing for the acoustic certification of rolling stock.

Ulf Orrenius received his MSc in Aeronautical Engineering from the Royal Institute of Technology (KTH) in Stockholm and his PhD from the Marcus Wallenberg Laboratory of Sound and Vibration Research at KTH. Since 1998 Ulf has been working with Bombardier Transportation in Sweden where he acts as a Senior Specialist in the field of acoustics and vibration. He presently acts as a Technical Leader of the FP7 project ACOUTRAIN coordinated by UNIFE. Ulf has a unique competence in the field of industrial acoustics, in particular regarding experimental and predictive methods for evaluation of noise control solutions for vehicle and aeronautical structures. His responsibility at Bombardier includes providing acoustic support in the design of vehicle and aerospace projects, development of control solutions for sources and vehicle structures, and development of predictive methods.