



# Virtual testing within acoustic certification of rolling stock: challenges to be met

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### Summary

For the certification of new or upgraded railway rolling stock in the EU it has to be demonstrated that the vehicle noise emission level complies with the limiting values prescribed in the TSI Noise (Technical Specifications for Interoperability). Today, the conformity assessment procedure is based on tests such as pass-by noise measurements. This procedure is often seen as restrictive considering that several new rolling stocks are widely based on existing designs and minor changes have to be taken into account in terms of noise emission. ACOUTRAIN is a research project within the 7<sup>th</sup> framework programme co-funded by the European Commission aiming at simplifying and improving the acoustic certification process of new rolling stock, introducing virtual testing as an alternative and/or complementary approach.

A new procedure based on virtual testing has therefore been proposed based on the main requirement that both the real and the virtual testing procedure give equivalent results with the same level of reliability.

This paper will describe this proposal as well as the limits encountered during the project for its full validation and the challenges that should be met in the future to propose a reliable and validated virtual testing procedure.

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### 1. Introduction

Τo meet the fundamental environmental requirements covered by the NOI TSI (control of noise emission) without decreasing railway industry competitiveness, the NOI TSI process should be regularly examined to detect possible improvements. The present NOI TSI [1] & [2] certification procedure requires measurements to be carried out to characterize the noise emitted from the rolling stock for several running conditions. NOI TSI tests are claimed to be costly and time consuming. The ACOUTRAIN project was launched in this context, to examine if virtual testing (VT) could be a "good" alternative for real testing within NOI TSI, i.e. for speeding up the product authorisation while retaining the same degree of reliability and accuracy.

ACOUTRAIN is a collaborative project funded by the European Commission through the 7<sup>th</sup> PCRD dedicated to the development of virtual testing procedures that could be used in NOI TSI tests. The following sections present the basic figures of virtual testing in an acoustic certification procedure, and more particularly the essential requirements to be met to replace part of real testing by calculations. Then, the two main approaches that can be used for virtual testing implementation are detailed with their specific keypoints. Finally, the different challenges for implementing virtual testing are listed.

### 2. Virtual testing

### 2.1. Essential requirements

VT implementation does not imply any modification in NOI TSI certification criteria, as it is introduced as an alternative to conventional RT based rolling stock certification: the user could decide whether to use VT or not. The introduction of VT does not mean that experimental tests are eliminated. VT should allow complicated and expensive test procedures to be replaced by simpler and better focused test methods, dedicated to the virtual vehicle (VV) development.

To ensure that VT and RT can coexist together for the same certification purpose, some requirements have to be met:

- 1- The TSI limit value is set for predefined operational and environmental conditions as well as receiver positions. These conditions should be identical for the new virtual test procedure.
- 2- 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.
- 3- The reliability or the standard uncertainty of both procedures should be comparable.

These three fundamental requirements have the keypoints for the virtual procedure proposed within ACOUTRAIN. They have fixed the main options taken in the process, as presented below.

### 2.2. Basic figures of VT in acoustics

Virtual testing in the context of TSI NOI means that the tests required for the certification are partially carried out with numerical simulations. Thus, it requires a model to be built representing acoustically the vehicle. This model is called a virtual vehicle (VV) and consists in a set of noise sources that represent the total noise emission of the vehicle (vehicle = set of noise sources). The virtual vehicle is a central part in the concept of the ACOUTRAIN virtual testing procedure. It is the model of the real vehicle set up in a simulation tool that is used for calculating the noise levels that can be compared to the NOI TSI limit values. It is composed of data describing the vehicle noise sources that are the most important inputs to the tool. This virtual vehicle must be validated in comparison to real tests to prove that the both approaches are comparable.

Building and validating a virtual vehicle with a high degree of reliability requires time and efforts that could be reduce: many cases where certification is required correspond to an extension of approval i.e. the design of new vehicle is closely based on the design of a previous vehicle, already certified. Consequently, two parallel procedures have been developed in ACOUTRAIN: the hybrid approach, for which the virtual tests start from scratch i.e. the virtual vehicle has to be completely build; and the extension of approval for



Fig. 1: Diagram for selection of the virtual testing procedure

which an existing virtual vehicle, developed for a same design based vehicle can be re-used, with slight modification for the certification of the new vehicle. For each of these procedures, a specific control process has been proposed, mainly based on detailed validation plan of the virtual vehicle.

### 3. Building and validation of the virtual vehicle

### 3.1. Building of the virtual vehicle

The virtual vehicle corresponds to the acoustic model of the train under test, represented by a set of noise sources, handled in a so-called numerical tool. To do so, the equipment with the largest contributions in terms of noise are identified and turned into equivalent point noise sources, as illustrated in Figure 2.

The same process is carried out to consider rolling noise when it is required (for pass-by simulation): wheels, rail and sleepers are represented as equivalent point noise sources.



Fig. 2: Real noise on a DMU rolling stock

Since the simulation of the propagation of the different noise contributions is based on well known analytical formulations and is therefore well mastered, the key point of the overall procedure is the source characterization.

For the assessment of rolling noise equivalent sources, numerical approach can be used (TWINS simulation for example).

For the other types of noise source, lab tests of dismounted equipment could be used to define their equivalent noise sources. However, the integration effect in the vehicle has a large influence on the noise emitted by the different real sources and must be taken into account.

Specifications and requirements for noise sources characterization are summed-up in the final deliverable of ACOUTRAIN [3]. They highlight the importance of integration effect modelling, which has to be set depending on the source characteristics and the numerical tool capabilities.

To allow a virtual procedure, such as the one described above, to be used in a certification process and particularly in TSI Noise, each step has to be fully mastered. It has to be demonstrated that virtual testing has the same degree of reliability and representativeness as the real tests.

### **3.2.** Validation of the virtual vehicle

When a virtual vehicle is used in a certification procedure it has to be proved that it corresponds to the actual vehicle. This is done by comparing the calculation to measurement results and is called virtual vehicle validation. This means that when first creating the virtual vehicle it should be as similar to measurement results as possible.

Two different validation procedures have been developed in ACOUTRAIN, each of them corresponding to a specific use of the virtual vehicle in a VT certification procedure: the limited validation or the complete validation.

The limited validation corresponds to the validation required when a virtual vehicle is developed for the train under test: this VV should be validated at stationary and could then be used for pass-by simulation. This is the validation process to be used in the hybrid approach.

The complete validation corresponds to the validation required when a VV from another vehicle, similar to the train under test, is intended to be used for stationary and pass-by simulation for a new similar vehicle. This is the validation of the so-called reference vehicle which is a

fundamental requirement for the Extension of Approval approach.

Both validation procedures, limited or complete one, are based on comparisons between virtual test results and real test results.

The stationary and pass-by measurements should comply with tests according to ISO3095:2013 [4]. Dedicated metrics are defined for comparing the real test results and the virtual results, and specific criteria for validating VT. For the validation at stationary, required for the limited validation, three different criteria have been proposed:

- Criterion 1: maximum allowed deviation between real test results and VT results, in  $L^{i}_{pAeq;T}$  for each microphone positions shall be within +/-X dB(A), as illustrated in Figure 3.
- Criterion 2: maximum allowed deviation in  $<L_{pAeq,T}>$  Unit shall be within +/-Y dB(A)
- Criterion 3: maximum allowed deviation in <L<sub>pAeq,T</sub>> Unit for each one-third octave band shall be within +/-Z dB in the frequency range [315 Hz; 4000 Hz]



Fig. 3: criterion n°1, representation of deviation allowed per microphone around the train

And for the complete validation, additional criteria corresponding to pass-by tests are defined:

- Criterion 4: maximum deviation between measured and calculated overall pass by noise in L<sub>pAeq:Tp</sub> < +/-XX dB(A)</li>
- Criterion 5: maximum deviation between measured and calculated pass by noise spectra in one-third octave bands < +/- ZZ in the frequency range [315 Hz; 4000 Hz].

Limits values for these criteria should be fixed considering the risk that the virtual vehicle does not correspond to the real vehicle: they will then depend on the uncertainty level of the measurements and the uncertainty of the modelling (uncertainty of the inputs of the model). Combining and comparing these two sources of uncertainty to fix some limits requires more experimental results and experience. Meanwhile, preliminary proposals have been agreed by ACOUTRAIN partners and proposed in [3].

### 4. Extension of Approval

The prerequisites for applying an Extension of Approval approach consist in having a similar vehicle, compared to the vehicle under test, for which a reference vehicle (virtual vehicle validated with a complete validation process) exists. Then, the number of sources that can deviate between the reference vehicle and the vehicle under test is limited by the similarity test: as long as the two vehicles are considered as similar, an Extension of Approval approach can be performed.

## 4.1. Reference vehicle and complete validation

A reference vehicle is needed when an Extension of Approval approach is foreseen. In fact, EoA corresponds to the case where the new vehicle to be certified is largely based on an existing design, used for a previous vehicle which has already been certified with real tests. The two vehicles are considered as similar. In this context, a virtual vehicle previously created the existing vehicle could be slightly modified to be used for the certification of the new vehicle.

The virtual vehicle of the existing similar vehicle has to be declared beforehand as reference vehicle to be used for the new vehicle, where "reference vehicle" designates a virtual vehicle which has pass the complete validation procedure.

Then, use of EoA approach requires a complete validation to be carried out on one existing vehicle. It also relies on the similarity of the two vehicles, the existing and the new ones.

### 4.2. Similarity

The question of whether two vehicles are similar enough for one to act as a reference for the other has to be answered in an early phase in order to choose the right virtual testing approach.

The differences between the two vehicles have to be limited since the validation with measurement data is only performed for the reference vehicle.

Each difference between the second vehicle and the reference vehicle introduces an uncertainty to the validated reference virtual vehicle that is the basis for the new model. Its impact on the total uncertainty depends on two main factors: the contribution of the modified source to the total noise and the level of uncertainty itself.

The definition of a reference vehicle the following parameters should be restricted:

- The modification of inputs with a "large effect" on the total noise, i.e. a dominating source. This requires a ranking of the inputs taking the effect of integration and the number of sources into account. Then, a decision rule for what is considered a "large effect" is necessary.
- The number of modifications
- Input measurement uncertainty: some sources are easier to assess accurately than others. A source that can be moved to a suitable acoustic environment and easily operated with low variability has a low measurement uncertainty.
- Today the SWL-measurement is standardized and well known whereas the assessment of the integration effect belongs to the open questions. It means that at this point the modification of the sound emission of a source can be more easily and reliably assessed than a modification of the position or integration of the source.

Considering all the parameters that should be taken into account for similarity testing, a decision model is required. Table I below illustrates a first proposal of a decision model for standstill noise, ranking the different parameters that have to be checked and attributing to them weighting factors according to their importance in the similarity testing process. All the changes between the reference and test vehicles should be included in the similarity check, and reported in the same table.

STATIONARY NOISE	*	POINTS**
Ranking of the source(s) modified (the ranking takes into account the number of occurrences of this source on the train)	rank	
	1 – 3	8
	4 - 6	5
	> 6	1
Assessment of modification's uncertainty***	uncertainty	
	> 2.5 dB	7
	2.5 dB > > 2 dB	3
	2 dB > > 1.5dB	2
	1.5 dB > > 1 dB	1
Removal of source		0
Addition of shielding		0
Modification without effect on noise emission		0
TOTAL		SUM

Table I: Decision model for similarity check

A preliminary limit for similarity is a total  $\leq 15$  points. This limit corresponds for example to the fact that a change of a dominating source (= 8 points) with uncertainty > 2,5 dB (= 7 points) implies a rejection of any additional modification. It also implies that a modification of a dominating source (= 8 points) with engineering uncertainty (= 2 points) will imply that only source of rank > 6 could be modified in parallel.

For pass-by, a similar approach can be proposed.

These proposals have to be worked out in the future and evaluated by application to different vehicle types to assess how well they can determine acoustical similarity between two vehicles.

### 5. Challenges for implementation of VT

The previous sections presented a summary of the recommendations for virtual testing implementation within the TSI certification process, detailed in [3]. These recommendations are based on experience and knowledge gained during the ACOUTRAIN project but some of them cannot yet be applied: they require more experience and particularly experimental data from a variety of different vehicle designs before defining final procedures and limit values.

### Uncertainty:

Uncertainty assessment is a key point for the further development of the certification process, based on virtual testing or on real testing. If both processes should present the same degree of reliability, then their uncertainty levels should be of the same order of magnitude.

Methods for assessing uncertainty of measurement generally based process are on the recommendations gathered in [5]. Based on these recommendations, a procedure for handling variability and uncertainty in a VT process has been proposed in ACOUTRAIN Deliverable 1.6 [6]. The work carried out in ACOUTRAIN, and more specifically in the validation task has highlighted that uncertainty level of VT input and real test results are not determined. Uncertainty level assessment should be improved or developed:

- At train level: the uncertainty when testing the train is not yet known
- At noise source level: the uncertainties when testing sources (due to individual variability,

measurement method uncertainty, boundary conditions) cannot at present readily be determined.

Specific measurement processes have to be carried out for determining the variability / uncertainty levels of the main sources on a rolling stock, taking into account the intrinsic variability (the variability linked to the physical parameters of the source) and the characterization uncertainty (the uncertainty linked to the method used to characterize the source). For characterising the intrinsic variability of the sources, several sample of a same source type should be measured with a same measurement set-up. For the analysis of the uncertainty linked to measurement method, round robin tests should be performed.

Concerning real tests, round robin tests should also be performed for the real tests measurement analysis, including the track parameters characterization.

### Methodology development:

From the ACOUTRAIN project results, further experience needs to be gained with the procedure proposed for building a virtual vehicle before considering it as reliable and practical:

- Calculation and measurement procedures for source integration should be validated together with the source models established.
- The proposed methodology should be applicable for a wide variety of different vehicle designs and types of rolling stock. It is not sufficient to test the methods on only one vehicle (here the NAT). More real cases have to be tested.

Both these development tasks require experimental data to be acquired as needed for the setting up of virtual vehicle models, according to proposed ACOUTRAIN procedures. Also, application experience is required of the concept of a reference vehicle, including its validation. The proposed procedures including limit values for similarity checking, should be revised as application experience is obtained.

To meet this challenge, future work can consist of carrying out detailed investigations to determine how real sources shall be represented to meet the needs for calculation of installation effects, in particular when the source is large in relation to the distance to any interfering objects, like vehicle skirts. Development of measurement techniques for characterization of the installation effects for sources installed in vehicles or mock-ups should be proposed and tested. Round robin tests should be performed for checking the accuracy for installed sources, depending on the measurement methods used.

### Method / Process validation:

The validation of the procedures summed up in this paper and detailed in [3] could not be fully demonstrated within the ACOUTRAIN project:

- Data is lacking for validation of the procedures proposed and for a quantification of uncertainty of VT results.
- The correlation between measurement and simulation results is currently not good enough for virtual certification purposes in particular for stand-still VT.
- The concept of a virtual reference track requires further study.

To further implement the validation process started in ACOUTRAIN project, a database should be compiled, gathering different tests results: at source level and train level. Then, each new certification process should also be seen as an application case for VT: involving a characterization of the different sources, of the site and track acoustic parameters, and measurement corresponding to the one required for validation tests.

Once validation tests carried out for several vehicles and cases, an update of the criteria for validation and for similarity tests would be done.

### Process and guidelines:

Guidelines and process need to be defined after validating the reliability of the proposed VT process:

- Guidelines for Notified Bodies (legal person in charge of accreditation of the certification) for model and tool assessments need to be established,
- And more particularly, guidelines and agreed procedures for model development / source characterization need to be defined.

### 6. Conclusion

Most of the open points listed above could be answered with more experience including test data with complete set-ups to define virtual vehicles for several different rolling stocks (measurement at source level and train level). A common database should be developed so that complete sets of data can be gathered and used for the VT certification process optimization.

In parallel, after having implemented virtual testing for several example cases, a cost-benefit analysis for the different VT scenarios should be proposed to decide in which case VT is worthwhile.

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