EC Contract No. FP7 - 284877

Virtual certification of acoustic performance for freight and passenger trains

D4.1 - Report with definition of input/output data for each global model

Due date of deliverable: 31/03/2012

Actual submission date: 26/03/2012

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Reviewed: Y

Document status		
Revision	Date	Description
1	15/03/12	First issue
2	15/03/12	Executive summary modification
3	22/03/12	Slight modifications following TMT comments
4	26/03/12	Standardisation of one-third octave band wording
5	26/03/12	Final version

Project co-funded by the European Commission within the Seven Framework Programme (2007-2013)		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Start date of project: 01/10/2011 Duration: 36 months

Collaborative project

EXECUTIVE SUMMARY

To be able to do virtual homologation, a tool to compute noise level is needed. This kind of tool already exists in some companies such as SNCF (VAMPASS tool) and ALSTOM (SITARE tool). To have a tool that could be used by everybody, it has been decided to build a tool in the project. To define this tool, we have to define the tool capabilities.

In a first step, we have summed-up the input/output of the existing tools VAMPASS and SITARE.

Then we have made the description of the minimum functionalities that a tool should have to be certified.

The last part defines the functionalities required for the tool to be developed during the project by ISVR. Different priorities have also been defined for the tool.

This document is the starting point to the realization of the tool which is going to be developed in task 4.2.

TABLE OF CONTENTS

1. INTRODUCTION

- The objective of this deliverable is to define the tool capabilities in terms of input /output data as defined in the Technical Annex for task 4.1.
- ATSA and SNCF have reviewed the input and output of respectively SITARE and VAMPPASS tool. All the participant of the task 4.1 (SNCF, ISVR, DB, BT and ATSA) have participated in the definition of the minimum requirement for a tool to be certified.
- The minimum global capability of a tool to be certified is defined in chapter 3.
- This task4.1 allowed to assign the different priorities to develop the global prediction model. It has given the entire requirement for the tool that will be developed in task 4.2 and will help to define the validation cases to certify the tool in a next step.

2. INPUT / OUTPUT OF EXISTING TOOLS

The aim of this chapter is to present the state of the art of the existing tools available in SNCF and in ATSA.

2.1 SNCF TOOL: VAMPPASS INPUT AND OUTPUT DESCRIPTION

VAMPPASS is a software dedicated to the simulation of pass-by noise, for a train under real operating conditions (acceleration, deceleration, standstill…). The outputs consist of acoustic indicators (L_{eqTp}, SEL, TEL, pass-by signature, spectrum in one-third octave band) but also sound samples for listening purposes (in multi-channels format). The simulation can also be performed in order to compute a ranking of the different noise sources, in relation to their contribution to the overall pass-by noise.

The user can manage the calculation parameters such as the ground reflection (the air flow resistivity for an impedance calculation based on Delany & Bazley model), the microphone location (see annex A.1). A scenario, defining the evolution of speed according to time has also to be defined (annex A.2).

The vehicle is considered acoustically as a set of several noise sources. Each source is defined by its location (in 2D: all the sources are in the same plane with its normal perpendicular to the track axis) and its acoustic characteristics. The shielding effect is included in the acoustic definition of sources (directivity pattern). The different inputs are given for each speed of interest during the pass-by duration (except the location which is given once and for all). Each source is also defined by its law of evolution with speed: independent of speed linearly dependent constant within speed interval or dependent on speed according to a specific law (exponential with speed or logarithmic with speed for example) (see annex A.3).

The acoustic characteristics of sources include the broad band noise given by a pressure dB spectrum in one-third band, at 1m from the source, the tonal components contributions defined by the tonal frequency and the corresponding pressure level at 1m, and the directivity which could be defined as a combination of dipole/monopole contributions or with the spherical harmonics formalism.

Several computations can be carried out (see annex A.5), depending on the required output: pass-by signal in mono-channel format; pass-by signal in multi-channel format; ranking of noise sources. For each kind of computation, global indicators such as L_{eqTp}, L_{eqTp}(A), L_{max}(A) SEL, TEL, pass-by signature are calculated as well as the time signal in mono-channel format or ambisonic format. All the output can be exported in *.txt* files.

2.2 ATSA TOOL: SITARE INPUT AND OUTPUT DESCRIPTION

SITARE is a software dedicated to the simulation of pass-by noise, for a train under real operating conditions (acceleration, deceleration, standstill…). The outputs consist of acoustic indicators (Lp_{eqTp}, TEL, pass-by signature, spectrum in one-third octave band). The simulation can also be performed in order to compute a ranking of the different noise sources, in relation to their contribution to the overall external noise.

The user can manage the calculation parameters such as the ground reflection (the air flow resistivity for an impedance calculation based on Delany & Bazley model) and the microphone location (see annex B.1).

The vehicle is considered acoustically as a set of several noise sources. Each source is defined by its location: the geometry is defined in 3D based on the extrusion of transversal sections of the train (annex B.4). The equipment based on parallelogram shapes are placed inside the train geometry. The shielding effect can be taken into account by adding skirts for the lower part (including bogie area) and also screen in the upper part. The different acoustic inputs can be given for each relevant duty point of the equipment. The user can choose the duty point he wants to use when he launches the computation. Rolling noise is based on acoustic power data computed with TWINS. Aerodynamic noise and braking noise can be defined with their law of evolution with speed (annex B.3). For the other sources the noise levels are constant with speed.

The acoustic characteristics of sources include the broad band noise given by a pressure or power level in dB with spectrum in one-third octave band. The pressure level can be defined at a distance chosen by the user. For rolling noise, the directivity is defined as a combination of dipole/monopole contributions. For aerodynamic noise the user can choose between a combination of dipole/monopole and a specific diagram of directivity.

The output for standstill computation is sound pressure level at a chosen position. For pass-by computation, different indicators can be obtained : the time history of global pressure level in dB(A), $Lp(A)_{eqTp}$, *TEL*, LpA_{max} (see annex B.6). The output can be exported in *.txt* files.

3. TOOLS CAPABILITIES: MINIMUM FUNCTIONALITIES REQUIRED FOR A TOOL TO BE CERTIFIED

The aim of this chapter is to define what should be at least the general capabilities of a global tool. It can concern an existing tool or a tool to be developed. It describes the minimum functionalities for a tool to be potentially certified. That means that, to be certified, a tool will need in a first step to have a minimum of functionalities and in a second step, it will have to give correct results when computing certain test cases.

The aim of this chapter is to define the functionalities in terms of input and output.

These capabilities are presented in 3 items:

- What are the cases to be covered by the certified tool?
- The INPUT
- The OUTPUT

3.1 CASE TO BE COVERED BY A CERTIFIED TOOL

A certified tool has to cover at least the two following cases within the present TSI:

- Stationary noise
- Pass-by noise

Starting noise does not need to be covered by the tool.

3.2 INPUT

In this chapter, we define what are the inputs to a certified tool.

3.2.1 Frequency range

The frequency range for the calculation should be minimum 100 Hz-5 kHz in third octave band. That means that the tool should be able to handle INPUT data in that frequency range as minimum even if all sources may not have data in that entire frequency range.

The frequency range depends on the application (particularly on train speed). As an example, for a case dominated by rolling noise at say 80 km/h the dB(A) level can be determined reliably using a frequency range of around 200 to 5000 Hz. Roughness data available may be limited in its frequency range for a given speed. Track decay rates will mostly be limited to a range 100 Hz to 5 kHz and existing TWINS modal parameter files only allow predictions up to 5 kHz. Indeed existing TWINS validation only goes up to 5 kHz.

3.2.2 Sound sources

General sources (independent of speed)

General sources are considered as not speed dependent. Nevertheless, it could be possible to have different functioning points (operational conditions) according to the speed of the train. Indeed, it could happen that equipment could have different rotational speed, for example, and then have different acoustic power levels. The tool should allow testing these different situations.

The minimum requirement is to define sources in the one-third octave band frequency range defined in 3.2.1.

Each sound source is to be characterised separately either by laboratory or in-situ measurements or by numerical computation.

It shall either be sound power level (Lw) or sound pressure (Lp) level at 1 meter. In the case of the sound pressure, it will be the highest sound pressure level measured all around the source at 1 m distance from the emitting surface in free field.

It shall also be a choice between 2 possible shapes of source:

- Point sources (monopole or other directivity)
- Sources defined by a global acoustic power on a given area or by the acoustic power of several surface areas.

A way to take specific directivity into account should be possible.

For traction noise, electrical equipment noise, exhaust noise, fan noise, HVAC noise, etc. source spectra have to be given for all relevant speeds. Information linking fan speed or engine speed to train speed is also required.

Rolling noise (dependant of speed)

Rolling noise is described here in a separate chapter than general sources because it has specific speed dependence.

Rolling noise includes noise from the wheels and from the whole track. It has to be described as, at least, one single equivalent source, for each wheel. This equivalent source will depend on the wheel characteristics, thus several rolling noise sources could exist on a same rolling stock. It shall also be allowed to distribute the track noise using the decay rate if this is available.

It will be characterised by, at least, one acoustic power spectrum in one-third octave band.

The acoustic power of the rolling noise can be computed by an external specific tool (such as TWINS for example).

Aerodynamic sources

Aerodynamic sources are not mandatory as input for a tool to be certified if the purpose is to make computation for speed under 250 km/h.

Aerodynamic sources can be described as point sources in the same way as general sources. The way to compute their acoustic power is still an open question.

3.2.3 Ground characteristics

Ground effect is to be modelled for example by an image-source approach.

At least, the input data are:

- Flow resistivity (in Pa.s/m²)
- Ground geometry; minimum is the height of the main reflecting ground planes relatively to the rail head.

These input data are generally used to compute the specific acoustic impedance of the ground.
The method to compute the complex impedance of the ground is still an open point. The easiest solution is to use Delany & Bazley theory but it is not the most accurate one. More complex models using flow resistivity, tortuosity and porosity will be studied also in task 4.2 to decide if a more accurate model is really necessary.
In that case, we may have additional input data:

- Tortuosity (linked to the speed of acoustic waves in the material)
- Porosity (It is the ratio between the air volume that can circulate in the material and the total volume of the material)

3.2.4 Installation effect

Installation (or integration) effect can be due to different parts of the train (train geometry, skirts, fairings, other equipment).

The shielding effect can be taken into account in the tool itself but this is not mandatory.

For the certification of the tool,

- if the shielding effect is directly taken into account into the tool, we will need to have a process to certify the method used in the tool
- if the shielding effect is taken into account apart from the global tool, we have to certify the way it is taken into account (measurement or calculation) .

That means that a pre-processing has to be defined (in WP 3) to have sources defined with the installation effect already taken into account in the source definition.

Application cases will be defined and tested in WP3 to quantify this installation effect. In WP4, these application cases will be used to define the way we can test the tools that have the installation effect included.

3.2.5 Position of the sound sources

The position of the sources has to be defined in x, y and z-coordinates.
The minimum precision should be 0.1 m.

3.2.6 Environmental conditions

Wind, temperature and humidity are taken into account indirectly but are not necessary as an input for the tool.
Reference values must be defined.in accordance with TSI (20℃, no wind)

3.2.7 Speed

When a computation on a moving train is needed, speed is an INPUT data.
It is not mandatory for the tool to be able to compute up to a given limit speed.
Nevertheless, validation cases will have to be defined for different speed intervals.

Therefore some tools could be certified for a given range of speed.

For example, we can imagine certifying a tool for standstill situation and for 3 speeds ranges:

- 40 km/h up to 100 km/h
- 100 km/h up to 250 km/h
- 250 km/h and above

We have to take care about the fact that the range below 40 km/h (except 0) will be much less reliable for the rolling noise source.

3.3 OUTPUT

3.3.1 Train stationary

The output must be at least the global value, in dBA, of the equivalent noise level: LpAeq, 60s at x=7.5m and h=1.2m

3.3.2 Train running

We consider only constant speed as mandatory.

The tool must be able to give as an output the pass-by noise at three positions: x= 7.5m, h=1.2m, x= 25m, h=3.5m and x= 7.5m, h=3.5m with the following indicators :

- LpAFMax (dBA)
- LpAF (dBA) versus time
- LpAeqTp

4. FUNCTIONALITIES REQUIRED FOR THE TOOL DEVELOPED BY ISVR

The tool developed by ISVR (Acoutrain tool) will of course have to satisfy the minimum requirements listed in the previous chapter.

Additionally, we take the opportunity of this new development to have some more options in the tool that could be useful for deeper analyses.

The aim of this chapter is to define the options we want to have in the tool developed during the project.

As in the previous chapter, these options are presented in 3 items:

- What are the cases to be covered by the tool?
- The INPUT
- The OUTPUT

4 levels of priority for ISVR tool are associated with each option; these levels are defined from level P0 to P3:

- P0: mandatory,
- P1: high priority,
- P2: medium priority,
- P3: not in this project.

Some options mentioned in priority P3 (i.e. not in the project) are listed here because it could be useful later in case of future development. Today, these options are not mature enough to be covered by the present tool.

4.1 Cases to be covered by ISVR tool

In addition to the main mandatory cases defined in the previous chapter, we define here the additional cases to be covered by the tool developed by ISVR.

4.1.1 Starting noise (P2)

To compute starting noise, it is necessary to use input data versus speed (rotation of motor and/or speed of the train). Mainly traction equipment is dominating the overall noise level. Today, in the TSI, starting noise is measured according to EN ISO 3095. Then to compute starting noise, we should refer to this procedure. Nevertheless, the indicator required (LpAFmax) could be problematic when it comes to simulation.

4.1.2 Braking noise (P3)

Braking noise will not be included because no standardized test procedure exists. Today we have too large uncertainties in the data. The idea is, in the longer term, to be able to do a computation with and without squeal noise.

4.1.3 Horns (P3)

Today, this is not relevant for a global tool. Horns are subject to big complex integration effects to be taken into account and high directivity makes it difficult to be accurate enough. It is still better to measure it in situ because of security matters.

4.1.4 Curve squeal (P3)

Curve squeal is excluded because no standardized test procedure exists.

4.2 Input

The tool being developed with Matlab, input data have to be in standard format such as text file.

4.2.1 Frequency range (P0)

The frequency range for input data and for the results should be extended to 20 kHz (compare with section 3.2.1) to possibly be able to take into account braking noise which has high frequency content, for future development.

Two different things need to be defined:

- The tool should *allow* data to be entered over a wide range (20 Hz to 20 kHz) in one-third octave bands.

- The *calculation* should be possible using data over a narrower range (in other words some of the bands can be left blank). This reduced range is something that has to be defined by the project during the validation process (what is the minimum range that is allowed for a given situation?)

4.2.2 Sources

General sources

For all sources (including sources defined in the next paragraphs), we will have the possibility to:

- Set ON/OFF the sources at standstill and during pass-by time (P0)
- Define the noise level for different speed range. That means that, according to the speed range chosen for the computation, based on a lookup table with source data, the tool will be able to choose automatically the right noise level of the source to be used in the computation. (P0)

Directivity has to be taken into account:

- Monopole/dipole ratio with possibility to define the dipole axis. (P0)
- Sources can be characterised by a surface S and by the corresponding acoustic power Lw. The tool will distribute point sources automatically on the given surface in the front plane of the train. (P1)

Rolling noise (P0)

To be able to test the influence of parameters on the rolling noise, additional input data are needed:

These input data are:

- The speed
- The wheel characteristics : Its diameter, its roughness spectrum,
- Vertical load on the wheel
- The rail characteristics: Its profile radius, its height, its roughness spectrum.
- The output of a computation such as TWINS computation: acoustic power for a reference roughness of 1µm in one-third octave band. This data is obtained with a given track decay rate that should be specified when entering the information in the tool.

To increase precision, the tool developed in the project will also allow the rolling noise to be described with 5 different sources in one-third octave bands, coming from a TWINS calculation, as an input:

- 2 for the wheel
  - Radial acoustic power (monopole)
  - Axial acoustic power (dipole in the axes of the wheel)
- 2 for the rail
  - Vertical acoustic power (line monopole)
  - Lateral acoustic power (horizontal line dipole perpendicular to the rail)
  - Possibility to model the rail using extended sources on a line. The tool will manage how to expand (P1)
- 1 for the sleepers
  - The source will be positioned under the rail in front of the wheel (monopole)

Aerodynamic noise (P0)

Aerodynamic noise sources will be defined by their acoustic power in one-third octave bands.

Data given in WP3 concerning aerodynamic sources will be acoustic power level Lw in one-third octave bands.

The type of aerodynamic source has to be identified to allow later some classification if needed:

- each bogie
- pantograph and pantograph recess
- nose
- intercoach gaps
- other identifiable sources (e.g. handrails, steps, roof-mounted equipment, louvers).

The evolution of the acoustic power according to speed is characterised by a coefficient. Each aerodynamic source will be characterised by its own coefficient. The input data will be the value Lw_0 for a given speed V_0. The speed V_0 is then also an input data. The tool should be able to extrapolate the acoustic power to have the noise level Lw_1 for another speed V_1 according the following law:

$$Lw_1 = Lw_0 + X.\log(V1 / V_0)$$

X = coefficient that can be chosen by the user;

The coefficient X could be different for each one-third octave band, so the user will have the possibility to enter either a constant coefficient with frequency, or it will be defined in a table according to frequency.

Directivity (P0)

For all type of sources, we should be able to define a specific directivity. To take into account directivity, two possibilities will be given to the user:

- Enter a monopole/dipole ratio; a default ratio can be coded in the software. It will be possible to modify the monopole /dipole ratio according frequency and choose the dipole axis (X, Y or Z).
- Directivity can be described in a text file that gives noise levels at a given radius for various angles on a sphere :

radius	teta	phi	25	31,5	40	50	63	...	1000
2	90	0	50	50	50	50	50	...	50

Coordinates of a point — Sound pressure level at that point

These sound levels are relative values.

4.2.3 Rail and wheel roughness (P0)

When defining rolling noise, it will be associated with a given roughness for the wheels and for the track. But, to be able to test the influence of parameters, it will be also an input data. The tool should allow roughness data to be entered over a range of wavelength going from 2.5 mm to 630 mm at least.

4.2.4 Track decay rate (P0)

Track decay rate will be a default data linked to the rolling noise source but it will be also an input data to test influent parameters for sensitivity analysis.

As for the roughness, this will be a necessary input to transpose rolling noise from a normal track to a TSI-Track.

4.2.5 Installation effect (P3)

The global tool developed by ISVR will not include a module to take into account the shielding effect. It will not take into account diffraction around the train (train geometry is not taken into account).

This effect will have to be calculated/measured before with a certified method/process, and directly represented into the characterisation of the sources themselves.

4.2.6 Position of the sound sources (P0)

The convention for the definition of the coordinate system will be:

- Position of the origin: the point located on the vertical axis of the coach at the level corresponding to the top of the rails (centre of the track).
- z in the vertical direction (positive upwards)
- y in the transversal direction of the train

- x in the longitudinal direction of the train (positive in the direction of motion)

4.2.7 Use of experimental data (P1)

It should be possible to have measurements as input. For instance, it will be possible to use experimental data to define the sources.

The tool will allow also importing experimental data to compare the computed results. The experimental data will have to be given in a dedicated format that the tool is able to read. This format will be defined when writing the tool on the basis of a text file.

4.2.8 Speed range (P0)

The tool will cover at least the speed range from 0 to 400 kph.

4.2.9 Braking noise (P3)

Today, we have large uncertainties in data for that kind of source. Moreover, a standardized test procedure is needed first.

Brake squeal has high frequency content. That is why for this kind of source, the software has to be able to take into account sources up to 20 kHz even if today braking noise will not be included in the software.

This kind of source is varying with time. To take into account this variation, one-third octave noise spectra have to be defined for different time steps and the software would have to extrapolate between those time steps (for future development).

4.2.10 Ground characteristic (P1)

A possibility to have 2 different types of models will be studied:

- One model based on Delany & Bazley => it will be based on flow resistivity as input data.
- One model based on more complex input data => it will be based on flow resistivity, tortuosity and porosity as input data.

4.2.11 Structure borne noise (P3)

In case of sources inside a more or less closed cavity, like on locomotives, structure borne noise can be significant but the tool will not propose a dedicated module for that. If necessary, this structure borne noise could be taken into account directly in the inputs/sources like any other source if a power level is given by the user.

4.2.12 Point calculation (P0)

The user can choose the positions of the calculation points all around the train up to 30 m from the rail in y direction and up to 4 m in z direction.

Several point positions can be chosen as an input by the user (up to at least 20 points per car). By default TSI positions will be proposed.

4.3 OUTPUT

4.3.1 Train stationary (P0)

Results will be given in one-third octave bands.

In HS-TSI, if regular spacing of the microphone is not applied, it is necessary to include a surface weighting in the energy average of the noise level. The tool will compute the average according to TSI with and without surface weighting.

4.3.2 Train running

3 cases are concerned:

- Constant speed (P1)

  Additionally to global value, the one-third octave spectra of LpAeqTp will be given (in dBA).

  LpAF(dBA) versus time every 125 ms and LpAFMax will be also given

- Starting noise (P2)

  LpAF(dBA) versus time every 125 ms and LpAFMax

- Braking noise (P3):

  LpAF(dBA) versus time every 125 ms and LpAFMax

A. ANNEX A: VAMPPASS

VAMPPASS provides pass-by noise simulations for a train under real operating conditions, i.e.:

- Acceleration, deceleration, standstill...

- Acoustic sources evolving or stationary: fan sources, engine, etc.

These simulations give access to:

- Global sound levels,

- Spectrum in 3rd octave band,

- Pass-by signatures,

- multi-channel sound samples (B-format) that allow a listening to near field (7,5m, 25m,…) pass-by in various reproduction formats (ambisonic, mono).

- Source ranking and possibility to set two receiver positions (virtual microphones)

A vehicle is defined with several sources, given their position, spectral characteristics and radiation patterns.

Operating conditions and their evolution depend on a speed scenario definition. This scenario describes the global behaviour of the speed of a vehicle in time domain.

The software also provides sound samples and the associated pressures (Mono, B-Format, Pa) simulating the pass-by of a vehicle coming from the left and going to the right on a straight way in front of a fixed receiver (at a given point).

A.1 THE PHYSICAL PARAMETERS

The user can manage:

- *Height* (h_0) is the receiver height above the ground in metres (default is 1.2 m),

- *Distance* (R_0) is the normal distance to the railway track (default is 7.5 m),

- L_0 is the starting distance from the head of the vehicle, at t=0, to the point of the way in front of the receiver. This parameter can also be set to *auto centre scenario*, meaning that the parameter L_0 is automatically set so that the front of the vehicle is in front of the receiver at the middle time of the scenario,

- *P0*is the reference pressure in Pa (default is 2.10^{-5} Pa),

- *c* is the speed of sound (default is 340 m/s),

- *Ground reflexion*: possibility to take into account ground reflection or not

- *Sigma*: it is the flow resistivity of the type of ground, for a Delany and Bazley model of the ground complex impedance (default is 300 Pa.s/m²).

A.2 Scenario

The scenario is the evolution of the speed of the vehicle in function of time, during the pass-by. A scenario is composed of pairs of time and associated speed events. Speed is assumed to evolve linearly between successive events.

A.3 Sources

The *Sources* block is dedicated to the physical definition of the source types that will be used to build a vehicle.

It is possible to *Add* a source (define a new source type), *Edit* a source (edit all the characteristics of an existing source), *Delete* a source or *Load* a source (import a source from a file *.vsrc*. Such a file is created and automatically saved in the folder Sources/ when creating a new source).

There are four different *Source Types*; each source type is defined with three main acoustic characteristics:

- The broadband component, specified by giving the level of emission of the source in dB(SPL) in third octave bands,

- The mono-frequency components that correspond to the relevant tonal components emitted by the source,

- The radiation pattern: gives information about the acoustic radiation pattern of the source

Source “independent of speed”

A source *independent of speed* is a stationary source, i.e. a source with constant acoustic characteristics (levels and directivity), independently of the scenario.

The only behaviour allowed for this type of source is to be switched on or off during the pass-by (by giving on and off time events).

Four characteristics have to be set:

- The levels in one-third octave bands of the “broadband” component,

- Monofrequency components (frequency and level),

- The directivity radiation pattern (a monopole by default)

- and the ON/OFF time events.

The levels into the third octave bands are specified in dB SPL at 1 metre away from the source, from 16Hz to 8000Hz.

The monofrequency components are defined in dB SPL at 1m from the source.

The radiation pattern of the source has to be specified. Three choices are available:

a monopole radiation pattern corresponds to the directivity of an acoustic monopole, i.e. the same radiation in every direction (omnidirectional),

a dipole radiation for which directivity has to be chosen, corresponding to the main direction of radiation.

A dipole level attenuation L is given by the law $L = \log_{10}\left(\cos(\theta+\theta_0).\cos(\delta+\delta_0)\right)$ where θ is the horizontal angle, and δ the vertical angle.

A radiation pattern can also be defined by specifying spherical harmonics coefficients, up to order 2. This corresponds to the semi-normalized 3D version. Enter the scalar coefficients W, X, Y, Z, U, V, S, T, R, and the pressure is weighted by the coefficient A (attenuation), depending on the relative positions of Source and Receiver (direction):

$$
\begin{aligned}
A = {} & W + X*\cos\theta*\cos\delta + Y*\sin\theta*\cos\delta + Z*\sin\delta \\
& + U*\sqrt{3}/2*\cos(2\theta)*\cos^2\delta + V*\sqrt{3}/2*\sin(2\theta)*\cos^2\delta \\
& + S*\sqrt{3}/2*\cos\theta*\sin(2\delta) + T*\sqrt{3}/2*\sin\theta*\sin(2\delta) + R*\left(3*\sin^2\delta - 1\right)/2
\end{aligned}
$$

The last setting consists in giving the values of *ON and OFF times*. A source of the current type is OFF (i.e. stopped) before the time t_{ON}, is ON (i.e. radiating according to the defined spectral characteristics) between $t_{ON}$and t_{OFF}, and stopped again after t_{OFF}. These times correspond to "emission time", as opposed to the "reception time" at which outputs are given (at the receiver point).

Source "constant within speed intervals"

A source *constant within time intervals* is a source type having stationary characteristics depending on the speed of the vehicle.

In other words, it is necessary to define acoustic characteristics $\{C_i\}_{i=1\ldots N}$ (levels, directivities) for some associated *speed events* $\{v_i\}_{i=1\ldots N}$. It is considered that the source has characteristics $C_n$if the speed of the vehicle is in the interval $[v_n, v_{n+1}[$.

For a speed smaller than the smallest defined speed, the characteristics are the same as for this smallest speed; and for a speed larger than the largest speed, the characteristics of the source are the one of this largest speed.

Characteristics settings are done in the same way as for the previous source type (independent of speed), except for the following differences:

the On/Off behaviour does not exist for this source type, a*s peed event* associated to the current characteristics must be defined

Every speed events should have the same radiation pattern type as the first one, but the settings can be changed (angle or coefficients). The number of monofrequency components defined for the first speed is used as a reference, meaning that the other speeds should have the same number of components. If more monofrequency components are needed, "ghosts" components can be created, with an unused frequency value and a level equal to zero (this behaviour is a consequence of the "evolving with speed" source type, see next section).

Source "evolving with speed"

This source type is defined in the same way as the previous type, "constant within speed intervals", i.e. based on characteristics defined at some "speed events".

But, for this source type, the evolution between two speed events is considered as linear.

It means that:

- Levels in one-third octave are linearly interpolated between the speed events, for each one-third octave separately.

- monofrequency components are linearly interpolated between the speed events. In order to know which frequencies have to be interpolated, an *index* value must be set, associated to each couple (frequency, level). Thus, the level and frequency corresponding to index number k at speed viwill be interpolated with the frequency and level at index number k of speed vi+1,

Radiation patterns are also interpolated:

- for a dipole, angles between two successive speed events vi and vi+1 are interpolated so that they reach the specified behaviour at the defined speed events,

- for spherical harmonic directivities, coefficients are interpolated (X(vi) -> X(vi+1), Y(vi) -> Y(vi+1), and so on...), (whatever it can mean).

If the minimum speed event is not 0, it is considered that the characteristics are constant below this speed, and equal to the one specified for the minimum speed.

On the other hand, the behaviour for a speed larger than the maximal speed event is extrapolated from the behaviour before this speed event.

Source managed with a "Law of evolution with speed"

This source type corresponds to a source whose characteristics are evolving with speed according to a law.

V0 is the reference speed at which the acoustic characteristics are defined and L(V0) represents these characteristics.

Three different laws are available:

- Linear evolution: L(V) = L(Vo) + K x (V-Vo) where K is here a coefficient in dB/ (km/h),

- Logarithmic evolution: L(V) = L(Vo) + K $\log_{10}$(V/Vo) where K is a coefficient in dB,

- Exponential law: L(V) = L(Vo) + K x $e^{(V-Vo)}$ where K is a coefficient.

This source type is only designed for "broadband" sources, i.e. it is not possible to define mono-frequency components in this case.

After choosing the law, only the acoustic characteristics at speed V0 have to be defined in the same way as for a source independent of speed.

A.4 VEHICLE

Once the required source types are defined, it is possible to build a vehicle by giving a position and a source type to the physical sources on the vehicle.

A vehicle is a set of sources, defined with their position (x: horizontal, y: vertical) and a source type. x=0 is the front (right) of the vehicle and y=0 is the bottom of the vehicle. Let us recall that the vehicle has a motion from left to right during the pass-by scenario.

A.5 COMPUTATION

The *Computation block* is dedicated to the sound pressure prediction and sound synthesis computations.

Three different types of calculation can be run:

Run Mono: computes the pressure at the receiver position due to the pass-by of the vehicle.

Run B-Format: computes the pressure at the receiver position and a B-format audio file. In this case, computation time is longer because of the need to estimate four channels at the microphone position: an omni-directional and three directional ones,

Run Source Ranking: computes a source ranking sound pressure prediction. The user can choose the source types he is interested in. As for Mono computations, each source contribution has to be computed separately from the whole vehicle process.

A.6 RESULTS DISPLAY AND EXPORTING

The results block allows:

- displaying the data analysis

- exporting data such as time signal or acoustic indicators

The computed indicators are the following:

$L(A)_{eqTp}$ is the Sound pressure level in dB(A) integrated over the interval of time T_p of the passby (i.e. between the first and the last source of the vehicle).

SEL is the Sound Exposure Level. It is defined as the A-weighted pressure level of a fictitious sound which would have, when maintained constant during 1 second, the same acoustical energy as the considered event (i.e. as the passby). We have the useful relationship giving SEL = TEL+10.log10 (T_p)

TEL is the Transient Exposure Level, corresponding to the Sound pressure level in dB(A) integrated over a time T_0 (exposure time). T_0 is a duration during which the instantaneous sound level (i.e. the signature) exceeds the minimum level value over T_p of at least 10dB(A). The TEL is then normalised over the time T_p, where $T_p<T_0$.

LA_{max} is the maximum value of the instantaneous A-weighted sound pressure level. It is the maximum value of the signature.

LdB(A) is the A-weighted sound pressure level (signature) of the whole pass-by (from t=0 to the end).

*LdB*is the sound pressure level (signature) of the whole pass-by (from t=0 to the end) in dB SPL.

Export

- *Export pressure:* the pressure in Pa at the receiver location can be exported in a text file. These files may have a huge memory size as they are text files.

- *Export signature:* signature(s) can be exported in a text file. First column is the time, and second column is the sound pressure level in dB(A).

- *Export indicators*: indicators can be saved in a text file. In case of several signals (two microphones or source ranking) they are all saved in the same file as a report.

- *Export sound sample*: the signal(s) as a RIFF PCM sound file is saved. Either as a *WAV* file for mono signals or a .*WXYZ* file with four channels, corresponding to B-Format specifications. The latter can be reproduced with dedicated software that can read ambisonic signal. In case of several signals, _mic1, _mic2 or _sourcenames are appended to the given file name (a normalization coefficient is asked for: It is due to the fact that PCM audio files standard forces to create files to contain values between -1 and 1. If no normalization is needed, sound files are automatically normalized to 0.9. If normalization is chosen, pressure will be divided by the given coefficient).

- *Export 3rd octave on Tp*: the 3rd octave levels over T_p are saved in a text file, containing two columns: the 3rd octave band centre frequencies, and the dB SPL levels. Again, in case of several signals, _mic1, _mic2 or _sourcenames are appended to the given file name.

- *Export current 3rd* octave: the current 3rd octave levels, i.e. the levels corresponding to the curve plotted in the left display, are saved in a text file containing two columns: the 3rd octave band centre frequencies, and the dB SPL levels. Again, in case of several signals, _mic1, _mic2 or _sourcenames are appended to the given file name.

B. ANNEX B: SITARE

SITARE provides external noise simulations for a train under real operating conditions, at standstill and at constant speed.

These simulations give access to:

- Global sound levels,
- Spectrum in 3rd octave bands,
- Pass-by signatures,
- Source ranking

A vehicle is defined with several sources, given their position, spectral characteristics and radiation patterns.

B.1 THE PHYSICAL PARAMETERS

The user can manage:

- *Height* (h) is the receiver height above the rail level in meters (default is 1.2 m),

- *Distance* (d) is the normal distance to the railway track (default is 7.5 m),

- *Ground reflexion*: possibility to take into account ground reflexion or not

- *Specific flow resistance*: it is the flow resistivity of the type of ground, for a Delany and Bazley model of the ground complex impedance (default is 300 krayls).

B.2 SCENARIO

We can choose between standstill and constant speed computation.

B.3 SOURCES

Different types of sources are described hereunder.

Omnidirectional point sources and sources made of parallelograms

This type of source is independent of speed, it is a stationary source, i.e. a source with constant acoustic characteristics (levels and directivity), independently of the scenario.

Nevertheless the sources can have several functioning points. The user chooses which functioning point has to be activated before launching the computation.

It can be also switched on or off at standstill or during the pass-by.

- This kind of source is characterised:
  - ♦ Either by its global acoustic power level Lw
  - ♦ by a sound power for each face
  - ♦ by its pressure level Lp at x metres
  - ♦ or by measurement data according ISO 3744 (9 pressure levels)

For sources made of parallelograms, the equipment can be made of several parallelepiped components.

Elementary sources are automatically distributed on all radiating faces (the user can identify non-radiating faces).

The distance between elementary sources can be chosen.

Air vents can be added on the equipment with specific acoustic power.

- We have 3 types of directivity :
  - ♦ Monopole for point sources.
  - ♦ Directivity of sources placed on parallelepiped
    - ▪ The directivity of the elementary sources depends on the dimension of the parallelepiped and on the position of the source on the face.
  - ♦ Directivity associated to air vent or duct outlet
    - ▪ An empirical formula based on experimental data is used

The input possibilities for noise levels are either global value or one-third octave values (ASCII file or manual input). The frequency range is generally 25 Hz-10 kHz.

Rolling noise

To compute the correct acoustic power level, the speed of the train must be specified in the software before launching the computation.

Rolling noise is separated in 3 sources:

- The wheel is defined by :
  - Its diameter, its roughness,
  - The load on the wheel
  - Acoustic power for a reference roughness of 1µm in one-third octave bands
    - Radial acoustic power Wwr
    - Axial acoustic power Wwa

Wr/Wa=cte for a given type of wheel

For wheels that are not damped, the power is assumed independent from the track.

- The rail is defined by :
  - Its profile radius, its height, its roughness
  - Acoustic power for a reference roughness of 1µm in one-third octave band
    - Radial acoustic power Wrr
    - Axial acoustic power Wra

- The sleeper is defined by :
  - Acoustic power for a reference roughness of 1µm in one-third octave band Ws

Wwi, Wri and Ws are coming from TWINS

Aerodynamic noise

The acoustic power of aerodynamic sources is entered in the software for a given speed. If the data is for another speed than wanted for the global calculation, we can enter a coefficient to make the speed correction. This correction is done with a logarithmic evolution: $L(V) = L(V_0) + K \log_{10}(V / V_0)$ where K is the input coefficient.

For aerodynamic sources, we have 2 possibilities of input:

- Data based on experimental data (Deufrako project for TGV)
  - Data are extrapolated from noise pressure levels measured at 5 m at 200 km/h
  - Various coefficient for the extrapolation are used according to the type of source :

- Pantograph,
- first bogie,
- other bogie,
- inter car gap,
- Boundary layer.

- Using known acoustic power coming from CFD or coming from experimental data. Radiation can be done on a sphere or a hemisphere. Directivity can be considered or not:
  - With directivity, the post processing of the CFD computation must be done in a proper way through an ASCII file defining the directivity for various angles.
  - Without directivity information, we can :
    - Use default directivity according the type of source (pantograph, first bogie…)
    - Give a monopole/dipole ratio according frequency and choose the dipole axis (X, Y or Z).

Brake disc noise

For this source, we have an evolution with the speed profile of the train.

The speed profile can be described through:

- A formula

$$\boldsymbol{V}(\boldsymbol{t}) = \boldsymbol{V}_0 + \boldsymbol{\gamma t}, \boldsymbol{t} \in [0, \boldsymbol{T}]$$

Or

- An ASCII file

Each speed value automatically defines a new operative point of the point source.

For each speed value determined by the software, the operating point of the source is defined. The acoustic power of the source can be interpolated between two operating points using an interpolation law of the form:

$$W(v) = W(v_0) * (v/v_0)^n$$

Disc noise sources are described by point and directional sources (ASCII file); a monopole/dipole ratio can be chosen also.

B.4 VEHICLE

To define the global geometry of the train, it is needed to have several transversal sections (.bmp file). Then we can extrude the different sections with the required length. A vehicle is made of different sections according the global geometry of the train.

Once the vehicle is defined, the sources can be positioned.

B.5 Computation

The computation menu is dedicated to the sound pressure calculation.

Two different types of calculation can be run:

- Train moving

It computes the pressure at the receiver positions due to the pass-by of the vehicle.

- Stationary train

It computes noise level at standstill at the chosen computation point.

The contribution of each source is also computed at those points.

B.6 Results display and exporting

Display

- Train moving

Various indicators are displayed:

- o The signature, the time history of global pressure level in dB (A).
- o $Lp(A)_{eqTp}$, the Sound pressure level in dB(A) integrated over the interval of time T_p of the pass-by of the whole train
- o *TEL,* the Transient Exposure Level, corresponding to the Sound pressure level in dB(A) integrated over a time T_0 (exposure time). T_0 is a duration during which the instantaneous sound level (i.e. the signature) exceeds the minimum level value over T_p of at least 10dB (A). The TEL is then normalised over the time T_p, where $T_p<T_0$.
- o LpA_{max}, the maximum value of the instantaneous A-weighted sound pressure level. It is the maximum value of the signature.

We have the possibility to obtain those indicators globally or only for wheels, for track, for equipment and for aerodynamic sources. The associated one-third octave spectrum can be also displayed.

We can also have the power level (Lw) for each bogie (rolling noise) in one-third octave.

We can also select a particular source to have its time history.

- Train stopped

One-third octave spectrum of the global noise level at a given position is displayed.

We can also visualise global noise level on a row of points (globally or for each component).

Contribution of each equipment is also given.

Export

- *Export pressure:* the pressure in Pa at the receiver location can be exported in a text file in one-third octaves bands.

- *Export signature:* signature(s) can be exported in a text file. First column is the time, and second column is the sound pressure level in dB (A).

- *Export indicators:* global indicators can be copied in a word document.