BRAINS - the concepts behind a quick and efficient tool for prediction of exterior and interior railway vehicle noise

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BRAINS (Bombardier RAIlway Noise Software) is a validated acoustic prediction software for interior and exterior noise of railway vehicles. It was originally developed to meet the specific needs in the industry for quick decision making in tender and early design phases. Over the years the tool has evolved by extending the modelling scope and level of detail now making it a cornerstone of the complete acoustics management process. One key feature is that BRAINS handles exterior and interior noise predictions with the same model input data as basis thanks to an efficient computational framework. It interacts with the Bombardier acoustics source and material database and can also import data from specialised software such as TWINS. For exterior noise BRAINS is well positioned to be used for the emerging field of “virtual acoustic authorisation” as an alternative to physical testing. It incorporates TWINS rolling noise input as well as other sources represented by 1/3-octave band sound power and directivity. For interior noise the calculations are based on an SEA model for the interior volume into which the transmitted acoustic power is determined from source strength models combined with transmission functions derived from analytical, statistical and empirical formulations.

1 Introduction

For a world leading rolling stock manufacturer it is essential to be at the forefront when it comes to the acoustic design of its products and with that obligation comes a need to have a toolbox of adequate prediction tools to achieve this. As there is no commercial prediction tool suited to this need available on the market each acoustics engineer typically had their own basic spreadsheet tool for making complete noise predictions on vehicle level. In specialised areas, however, there is commercial software with TWINS [1] for rolling noise as the most well-known example.

Within Bombardier there was ten years ago a decision to develop a software replacing all these local or personal spreadsheet tools with one common tool taking the best methods within the company and integrate them in a user-friendly interface. The benefit of using the same tool at different engineering sites is evident in that it greatly simplifies workload sharing and knowledge exchange. The first version of the BRAINS tool (Bombardier Railway Noise Software) appeared 2002 and was targeted primarily for quick predictions in early design phases. Since then a vast amount of efforts have been invested in the software and its capabilities have been subject to a continual expansion. This paper mainly focuses on the exterior noise calculation capabilities but gives a short overview also on the interior noise calculation aspects.

2 Computational framework

One of the unique features with BRAINS is that it handles interior and exterior noise calculations with the same model basis using the same acoustic source data and vehicle parameters for both cases. Figure 1 shows an example of the two views for a typical BRAINS model. For the interior noise calculation additional data is given (panel transmission loss, room absorption, structure-borne noise transfer functions, etc). Calculations are in both cases performed in 1/3-octave band spectra (50-10000 Hz). It interacts with the Bombardier acoustics material database. The modelling is based on a hybrid approach combining analytical, statistical and empirical formulations and pre-calculated transfer functions from other more specialised simulation packages, such as Odeon, Sysnoise, Nastran and VA1. Furthermore, BRAINS is now the common framework in which different calculation results can be imported to, superimposed and visualised. Much effort has also been spent on the user interface to facilitate modelling by building efficient interfaces and various time saving and error checking features.

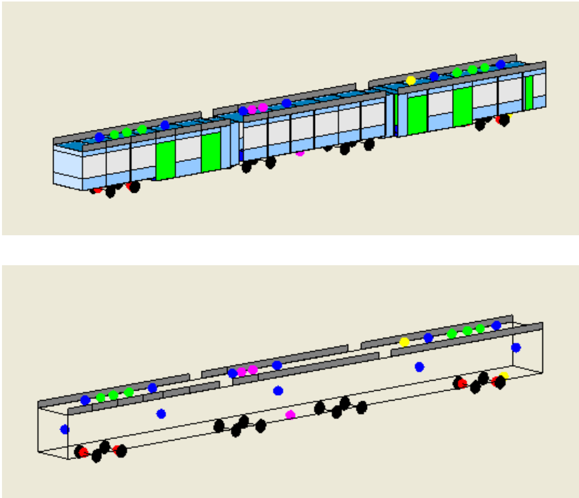

Figure 1: Two views of a BRAINS train model: interior noise analysis (top), exterior noise analysis (bottom). The coloured dots represent point sources.

3 Exterior noise

In this calculation mode the train model is represented by a number of point sources defined by their *xyz*-coordinates, 1/3-octave band sound power spectra and radiation directivity pattern. The outer boundaries of the train body plays a role for diffraction and shielding effects that are taken into account. The radiation from the point sources is made over a reflecting ground.

BRAINS calculates sound pressure time histories at chosen wayside microphone positions, from which standard descriptors such as $L_{Aeq,TP}$ and L_{Amax} are derived. It is also possible to view the results in various spectral formats and source ranking lists.

3.1 Point source models

Point sources can be positioned in the underframe, on the roof and on the sidewall (see Figure 2). Sources located on the sidewall are for example ventilation and cooling air inlets/outlets. Roof sources can be HVAC units or auxiliary equipment and sources in the underframe can be traction motors and gears. Considering the different boundary conditions, half sphere radiation is by default assumed for roof and wall sources and full sphere radiation for underframe sources.

Directivity is modelled by defining a ratio between monopole and dipole contribution in the principal coordinate directions. A fit to an experimentally derived directivity pattern can be made in BRAINS by adjusting the monopole-dipole ratio (see Figure 3).

Note that the point sources offer flexibility in that a set of point sources can mimic the behaviour of a source with larger physical extension (e.g. diesel engine or a converter box with cooling inlet and outlets on different sides).

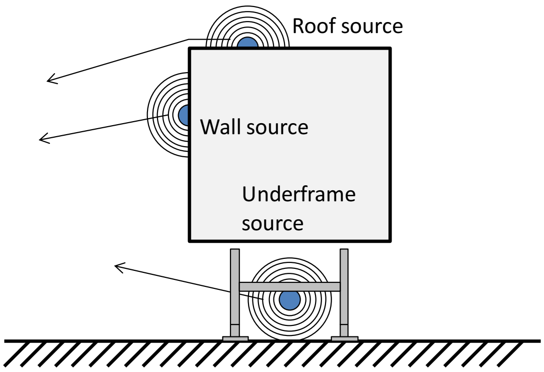

Figure 2: Location of sources for exterior radiation

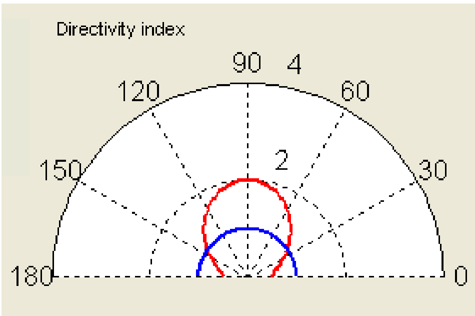

Figure 3: Composite directivity index from combination of monopole and dipole (red line). Monopole (directivity index = 1) as comparison (blue line).

3.2 Wheel-rail source models

Noise radiation from wheel and rail is tightly integrated with the TWINS software [1]. The sound power for each wheel-rail contact is taken from a TWINS calculation.

The wheel is in BRAINS represented by one point source at the height of the axle. Half of the sound power is assumed to contribute to the wayside radiation (and the other half goes backwards into the bogie) for both nearside and farside wheels and rails (see Figure 4). This means that the nearside wheels are considered acoustically transparent, which is a simplification that is considered to have a minor influence. For the directivity BRAINS assigns half of the emitted sound power with dipole directivity and half with monopole directivity. This should be in line with the assumptions in TWINS where axial modes have dipole and radial modes have monopole directivity.

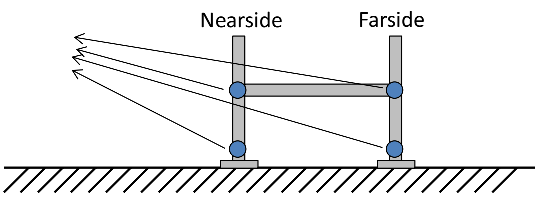

Figure 4: Radiation from wheel-rail sources. Nearside wheel assumed transparent for radiation to the wayside.

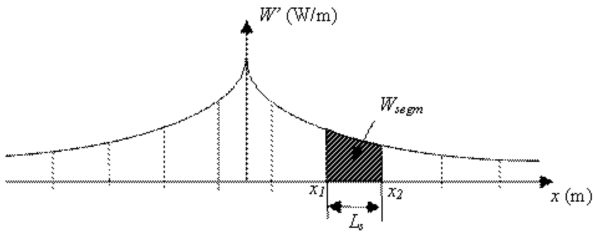

Figure 5: Distribution of track sound power into finite segments based on the track decay rate, The wheel-rail contact is located at x=0.

The rail and sleeper sound power derived from TWINS is summed up to a "track" sound power, which is distributed longitudinally according to the track decay rate (see Figure 5), which can be based on TWINS calculations or on measurements. The sound power for each finite segment is integrated and assigned to a point source in the middle of the segment at the top-of-rail height. A length of 5m (used as default) has been found appropriate as a balance between computation time and spatial resolution.

Roughness wavelength spectra for rail and wheel together with a contact filter function sets the excitation. As contact filter can be chosen a Remington model [2], a "Silent Freight/Silent Track" model [3] or any user defined 1/3-octave band wavelength spectrum. TWINS wheel and track sound power spectra shall be calculated for unit roughness excitation which means that re-scaling to the wave length roughness spectra is readily done in BRAINS.

As an option the TWINS sound power spectra can be calculated without influence of train speed, which is defined in BRAINS instead. It is obviously easier to have one speed-independent TWINS model instead of separate ones for each train speed. The main effect lost is the frequency splitting of rotating wheel modes but this has a marginal effect on the overall levels.

3.3 Interior source models

The contribution from interior sources inside the bodyshell can normally be neglected for exterior noise. One exception is locomotives where high power equipment inside a machine room may radiate through ventilation grilles on the sidewalls. BRAINS can handles this in an automated way. First the sound field inside the machine room is calculated according to the procedure for interior noise calculation outlined in Section 4. Secondly, the emitted sound power through the grille is calculated using a transmission loss spectrum for the grill. As a last step this transmitted sound power is assigned to a wall source as described in Section 3.1. Alternatively it is of course also possible to determine this sound power outside BRAINS and assign it to a wall point source directly.

3.4 Propagation model

A standard Delany-Bazley ground reflection model [4], analogous to the SPLM module implemented in TWINS, is used. The ground is supposed to be horizontally flat without discontinuities in the surface properties.

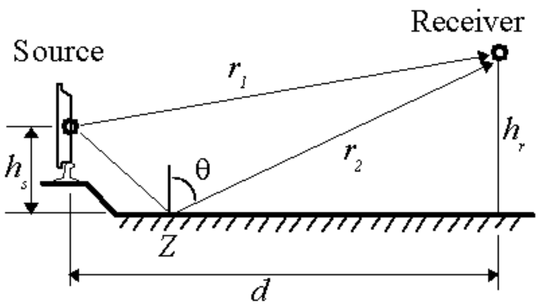

Figure 6: Ground reflection model.

The ground reflection normally has very little effect on the overall dB(A)-value unless the sources are distinctly tonal. In the spectra, however, there can be a noticeable influence for frequencies below 500 Hz (see Figure 8).

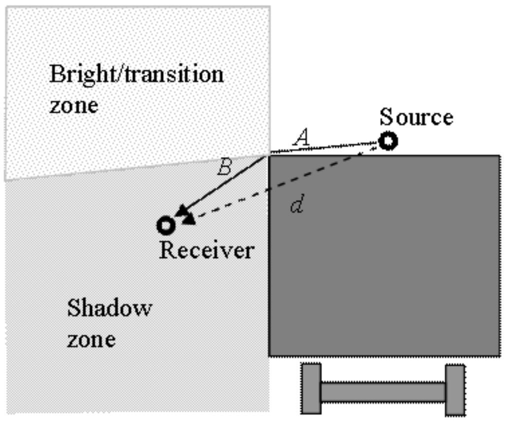

Figure 7: Diffraction model.

For roof sources diffraction due to the roof-sidewall edge is accounted for using standard formulas for insertion loss (see e.g. [5]). The edge position is by default given by the bodyshell coordinates but can be defined explicitly to consider roof fairings. As illustrated in Figure 7 there will be a shadow zone below the line of sight and a transition and bright zone above. In the bright zone the radiation is unaffected. The extension of the transition zone is frequency dependent and is wider for lower frequencies.

Bogie skirts are taken into account by adding an insertion loss in the propagation path to the wayside. The insertion loss depends on the extension of the skirt compared to the vertical position of the source. The implemented insertion loss 1/3-octave spectra have been interpolated from a set of scale model measurements [6].

3.5 Installation effects

For many sources the issue of "installation effect" is highly relevant. With this effect is meant the necessary model adjustments to a source measured in laboratory compared to the situation when it is mounted in a train. The installation effect can be categorized as either aerodynamic or acoustic. The first type includes changed inflow conditions for fans resulting in a change in source sound power. The acoustic installation effect includes modifications in the propagation path compared to free field propagation. As an example, a traction motor mounted in a bogie experiences a totally different environment with shielding and reflections. To accurately model such an effect is outside the scope of a tool like BRAINS but it is possible to calculate this effect separately and apply a correction to the source sound power spectrum. The two installation effects included in BRAINS are the roof diffraction and the bogie skirt insertion loss described above.

3.6 Parameter studies

BRAINS can either be run interactively or in batch mode, which is particularly useful for parameter studies. One small example is given below where a passby noise $L_{Aeq,TP}$ spectrum has been calculated for a set of ground parameters. BRAINS is then called upon from a Matlab script looping through the relevant parameters and storing all the calculation results. It is also possible to link this batch mode feature to a mathematical optimization procedure in Matlab.

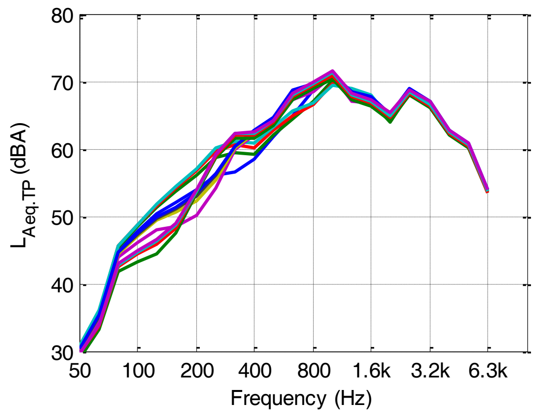

Figure 8: Calculated passby noise spectrum for a range of ground parameter variations. Ground level 0.5-1.5m below top of rail, flow resistivity 100-1000 rayls.

3.7 Validation cases

BRAINS has been used for numerous rolling stock projects over the years. The cases for which there is a full set of rolling noise input data (i.e. wheel and rail roughness plus track decay rate) are scarce. For the tram in [7] roughness was known and decay rate calculated. In Figure 9 the good agreement can be seen. The passby noise is dominated by rolling noise with some minor contribution from the drive units.

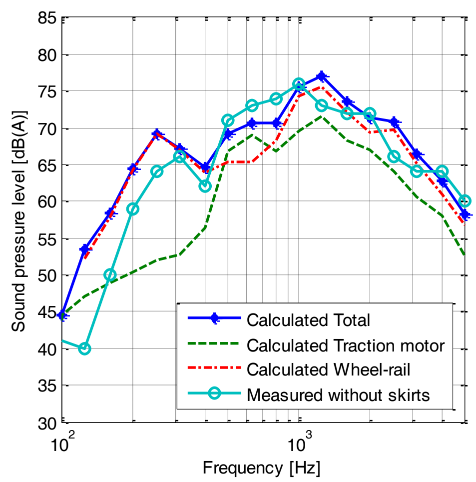

Figure 9: Passby noise calculation (60 km/h) with BRAINS for tram with full set of roughness data (see [7] for details).

The second example below is a German 4 car EMU where calculated passby noise has been compared with measurement data from a TSI Noise test. Here the track data was available together with the wheel roughness. The difference in $L_{Aeq,TP}$ between calculation and measurement is less than 1 dB. The spectra in Figure 10 are in the important frequency ranges in good agreement and it is expected that by tuning the TWINS wheel and track parameters the spectral agreement can be further improved.

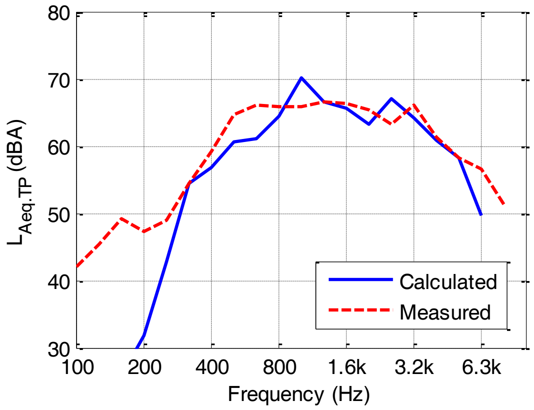

Figure 10: Calculated and measured passby noise spectrum for a 4 car EMU at 80 km/h.

4 Interior noise

As mentioned in the introduction one key concept with BRAINS is that the same model is used for exterior and interior analyses. This means that all the sources described in the previous section are applied also for *interior* noise calculations. The interior noise calculation model is based on an SEA formulation for the energy balance of interior cavities as described in some detail in [8]. The energy fed into the cavities comes from air-borne or structure-borne sources.

Air-borne sources may be located outside or inside the interior cavities. In case of interior sources (e.g. HVAC air supplies), the source power is directly injected into the cavity.

For air-borne sources located outside the carbody, as represented by dots on the roof and in the underframe in Figure 1, the transmitted power depends on the exterior sound field and the transmission loss (TL) spectra of the 2D panel elements. Such spectra can either be imported from a database or calculated by a special module inside Brains, enabling calculation of TL spectra for realistic carbody elements, including orthotropic double walls with acoustic short circuiting effects [9].

The sound field outside the (floor/wall/roof) surfaces depends on the type of operation. For the sound field around a train running on surface track analytical expressions are used, which were calibrated to full scale measurements. For tunnel operation pre-calculated level differences from ray-tracing analysis, calibrated to full scale tests, are applied. The set of these pre-calculated functions can be replaced by functions calculated for a specific tunnel geometry when considered necessary.

For structure-borne noise a semi-empirical energetic transfer function approach is used which is gradually updated with new results based on testing and simulations using FE/SEA models.

5 Certification

The revised TSI Noise issued 2011 [10] introduced an option to use simulation to prove compliance but the text is quite vague on the situations when this is allowed and not. The recently launched EU-project Acoutrain [1] has as a goal to develop criteria for calculation tools to be used for acoustic certification in the future. Despite the present lack of established common practice there are some cases where calculations have been used to demonstrate compliance for variants of an existing TSI approved rolling stock.

An example of how BRAINS was used for this purpose is the passby noise certification of a 3 car EMU based on a 4 car EMU, which previously had been certified based on full scale measurements. In this case the wheel roughness data was missing so a full validation was not possible but following the procedure outlined below the simulation convincingly proved that the 3 car EMU would not have a higher noise level than the 4 car EMU when running on the same track. It shall be noted that in this case it was evident that rolling noise is the dominant source and all other sources were of secondary importance for the passby noise. In Figure 11 is shown the measured and calculated time history and spectral content of the passby noise for the reference train using the wheel roughness as tuning parameter. In the next step, a calculation is performed with one of the intermediate cars removed. In Figure 12 can be seen that the passby noise level $L_{Aeq,TP}$ is decreased by 0.1 dB.

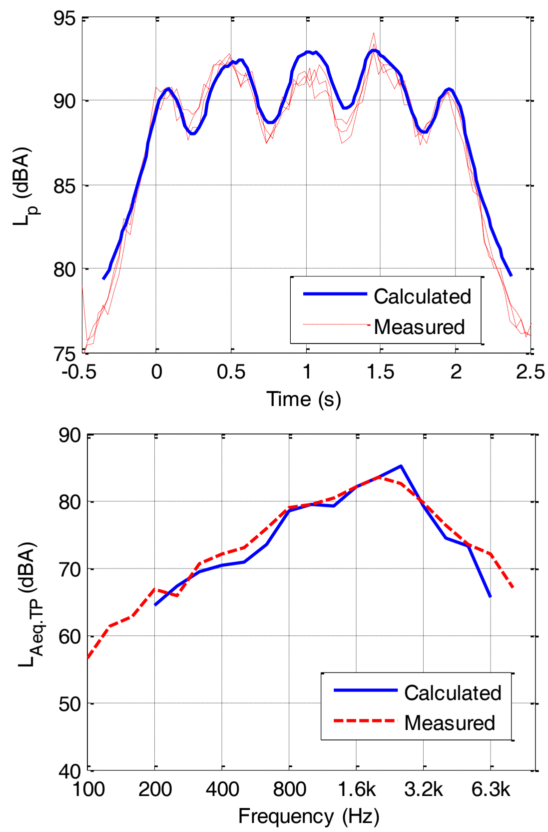

Figure 11: Comparison between measurements and calculation with calibrated model at 190 km/h. Passby noise time history (top), $L_{Aeq,TP}$ spectrum (bottom).

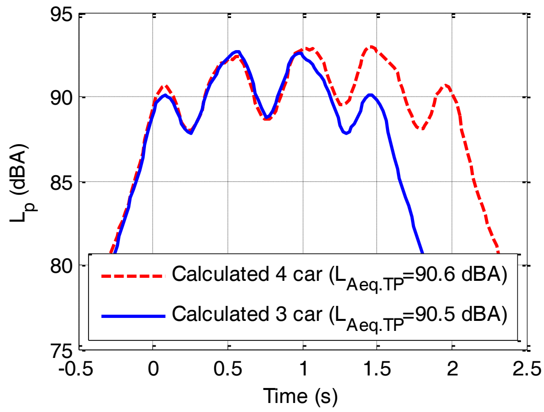

Figure 12: Calculated passby noise for reference formation EMU (top) and modified formation EMU (bottom).

6 Conclusions

A description of the BRAINS (Bombardier Railway Noise Software) has been given with the focus on its capabilities for exterior noise calculations. The methods and assumptions used and the limitations are presented. An example where BRAINS has been used in TSI certification comparing two members of a vehicle family is presented.

Besides being an indispensable tool for Bombardier for the in-house daily work in designing vehicles fulfilling the requirements of customers and legislation it can also be used externally to demonstrate compliance especially for the situations in the TSI Noise applicable for a “simplified method” and thus reducing the number of physical tests.

Acknowledgments

All valuable input from BRAINS users and colleagues within Bombardier is greatly acknowledged.

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