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Skirts and barriers for reduction of wayside noise from railway vehicles—an experimental investigation with application to the BR185 locomotive

A. Frid*

Center of Competence Noise and Vibration, Bombardier Transportation, Intercity Trains, SE-721 73 Västerås, Sweden

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Abstract

An experimental investigation to determine the noise reduction efficiency of a number of combinations of vehicle mounted noise skirts and trackside low barriers has been carried out. A 1:4-scale mock-up of the German BR185 locomotive was built. Special care was taken to achieve a realistic representation of the wheel/rail sources, using rotating acoustic source wheels able to imitate the radiation from structural modes and acoustic rail ducts with independently adjustable vertical and lateral slots. The acoustic insertion loss (IL) equivalent to a full-scale microphone position at 25 m distance from the track was determined for the different source components separately. The total IL was obtained from sound power spectra calculated with the TWINS software. Results for the design speed ($v = 120\,\text{km/h}$) and a case with a lower speed ($v = 100\,\text{km/h}$) are presented to illustrate the effect of speed on the acoustic IL. The tests were performed in open-air free field conditions. The experimental procedure used in the present investigation gives detailed information on the relative contributions from different source components, which is valuable for further design studies. For the eight combinations reported here, the overall reduction achieved was in agreement with results in the literature. The IL was 2–3 dB(A) for cases with only vehicle skirts and the case with only low track barriers. The combined configurations had insertion losses of 7–13 dB(A).
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1. Introduction

Vehicle skirts, wayside barriers or a combination of these are potentially effective for reducing wayside noise from railway vehicles. Up to now, however, such solutions have been considered too costly, too heavy, not fitting within the gauge, complicating maintenance, etc. and thus have

*Tel.: +46-21-317-000; fax: +46-21-128-803.
E-mail address: anders.r.frid@se.transport.bombardier.com (A. Frid).

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Fig. 1. Deutsche Bahn's Adtranz*-built BR185 locomotive (*now Bombardier).

not been widely used. However, with the current rapid development in noise legislation, shielding solutions will be necessary in the foreseeable future to achieve the required noise levels when measures like wheel and rail damping devices and "low roughness" brake blocks have been introduced [1]. In the literature there are many theoretical and experimental studies of noise reduction from shielding. A good overview including an extensive number of references is provided in Refs. [2,3]. The general conclusions are that a vehicle skirt alone is not very efficient due to the low position of the wheel/rail source. A high ground barrier is efficient but not attractive from other points of view. A combination of vehicle skirts and low ground barriers seems to be a "compromise" with the highest potential. The crucial point then is to close the gap between the skirt and barrier as much as possible to avoid noise "leaking" out. For vehicles employed in international traffic which have to comply with several national loading gauges this will clearly be an especially challenging constraint. For freight wagons this problem was clearly demonstrated in the Silent Freight project [2].

The aim of this study has been to assess the acoustic efficiency of different combinations of vehicle-mounted skirts and low ground-mounted barriers applicable to the new BR185 locomotive shown in Fig. 1 (an upgrade of Deutsche Bahn's in-service BR145 locomotive). In total, 8 skirt/barrier combinations were tested. An acoustic 1:4-scale model of the locomotive was built to determine experimentally the acoustic insertion loss (IL) given by the different skirts and barriers. The sound power of the acoustic sources (wheel and track) were calculated with the TWINS software [4,5] and generalized in the physical experiments. Eigenfrequencies and modes for the wheel were calculated with FEM and the most important modes were identified and simulated in the experiments. The choice of working with scale models was partly due to a shortage of full-scale test objects and partly due to a more convenient and flexible test procedure offered by the use of the innovative wheel and rail sources and the hybrid numerical/experimental approach described in the following section.

2. Experimental approach

The most commonly used efficiency criterion for noise shields is the "IL". The IL for a shield is simply the difference in sound pressure level (SPL) at a receiver point with and without the noise shield. Because it is a relative figure, the IL is normally easy to determine experimentally. No knowledge of the acoustic source is necessary, as long as it does not change between the two measurements. A situation with several sources that can have different relative contribution with changing operating conditions (such as the wheel and rail in rolling noise) calls for a more sophisticated approach. One way is to excite directly all sources simultaneously in one measurement with their proper relative strengths. A second option is first to measure the acoustic transfer functions for each source separately and afterwards to add the contributions based on calculated, measured or estimated source strengths. The method applied in this study, using separate wheel and rail excitation, gives an insight into transmission paths from individual sources. This makes it easy to see the effects of different running conditions such as speed and track parameters on the IL, by combining measurement data with TWINS calculations. Four separate test series were performed for each skirt/barrier configuration:

1. Vertical rail radiation (both rails at the same time).
2. Lateral rail radiation (both rails at the same time).
3. Nearside wheel radiation.
4. Farside wheel radiation.

In acoustic measurements it is often practical to work with scale models without losing accuracy due to the simple scaling laws for airborne sound waves. For instance, the typical frequency range of interest for rolling noise (0.5–5 kHz) is equivalent to 2–20 kHz in a 1:4-scale test. The model of the BR185 locomotive includes all major parts considered to have an influence on the acoustic field. It contains one bogie (including bogie frame, wheels, gearbox, traction motors), relevant parts of the carbody and 2.5 m of track (see Fig. 2). Selection of absorption materials for the scale tests was made so that the absorption factors for the scale test frequencies corresponded to the absorption factors for the actual absorption material at full-scale frequencies. Sponge sheets used in previous experiments [6] on road traffic noise were used to represent the ground (grass). The scale model (with a different carbody top) was used in a related investigation on the sound field outside the sidewall of a wide-body EMU [7].

The measurements were performed on top of the roof of the ABB Corporate Research building in Västerås (see Fig. 3) under free field conditions. A microphone was placed at an equivalent full-scale standard type test position (25 m from centre of track, 3.5 m above railhead). A second

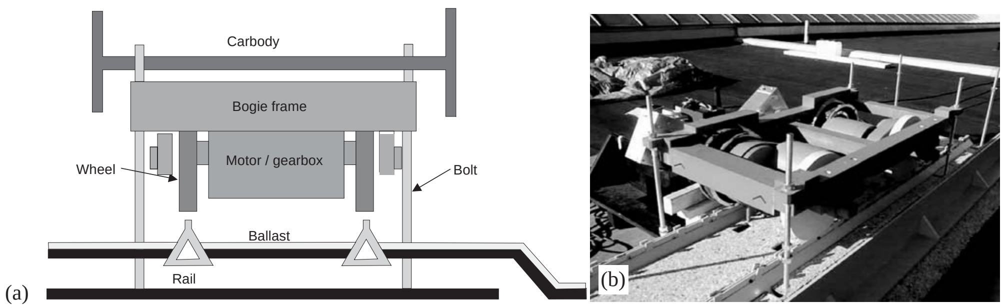

Fig. 2. (a) Close-up of scale model in Fig. 3 with different parts labelled. The bolts are for adjusting the vertical position of the parts and have negligible influence on the sound field and (b) photo of scale model without carbody top.

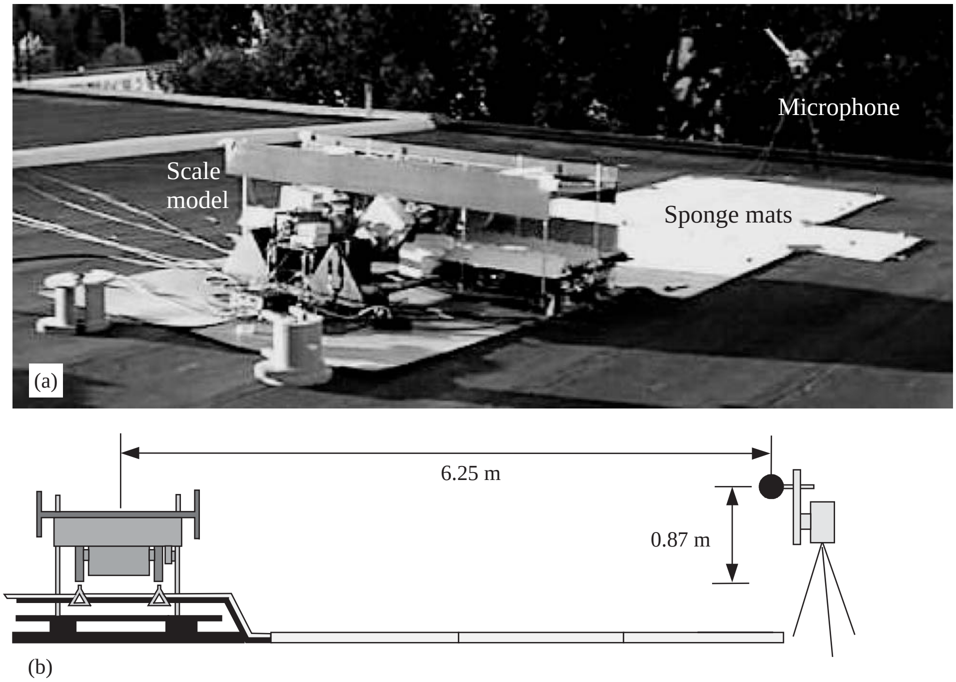

Fig. 3. Measurement site with scale model, sponge mats and wayside microphone. (a) Photo from a backside view; (b) side view.

microphone was placed in the bogie space and was used as a reference for scaling of source sound powers. The wayside microphone was rotated around a small (20 cm diameter) circle in order to average out accidental interference between direct and ground reflected sound waves.

3. Rail sources

The acoustic rail source consists of two longitudinal triangularly shaped ducts with longitudinal slots on the top and at the sides. Sets of 3 loudspeakers are placed under the ducts at each wheel–rail contact (see Fig. 4). The slot widths are adjustable so that the spatial decay along the rail can be tuned. The decay was estimated by measuring the sound pressure just outside the slots along the whole slot length (2.5 m).

4. Wheel sources

The two acoustic source wheels in Fig. 5 were designed and built to simulate the radiation from selected structural modes at arbitrary frequencies. The amplitude and phase of the 4 groups of small loudspeakers on the disc and on the rim can be controlled to represent $n = 0, 2, 3, 4$ nodal diameter and $m = 0, 1, 2$ nodal circle modes. During the experiments, the two source wheels were

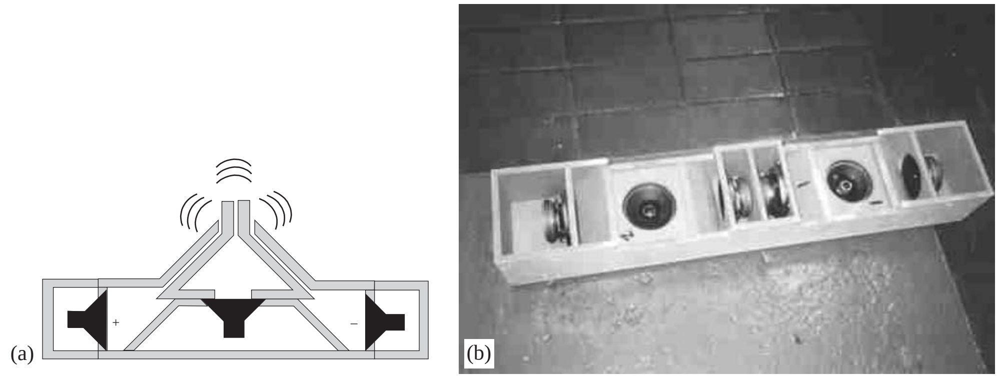

Fig. 4. (a) Cross-section of acoustic rail source at wheel–rail contact position. The two outer loudspeakers are driven with opposite phase to create a dipole-like radiation from the two lateral slots. (b) Photo of loudspeakers for one "wheelset".

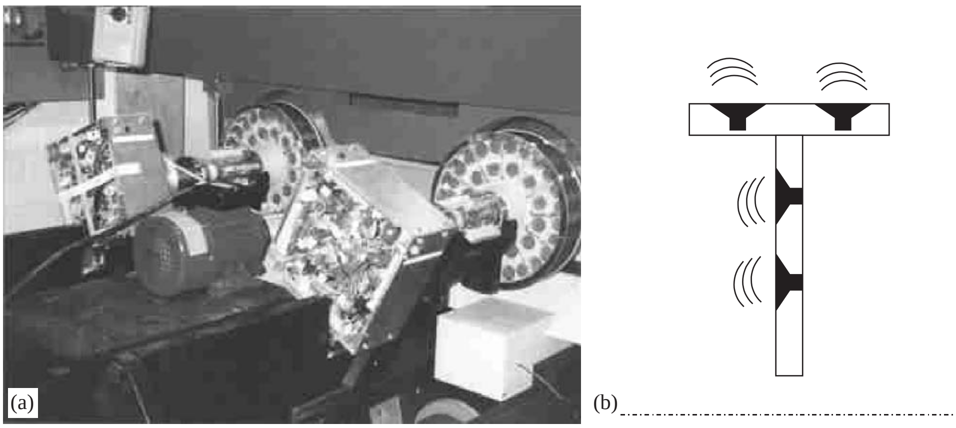

Fig. 5. (a) Acoustic source wheels; (b) cross-section of acoustic wheel with four groups of loudspeakers.

placed at the nearside and farside positions, respectively, and wooden dummy wheels were placed at the positions for the other two wheels. An averaging effect was accommodated by a rotation of the wheels.

5. Source strengths

The TWINS software was used to calculate sound power from wheel and track (rail plus sleeper). TWINS calculates sound powers in 1/3-octave bands including the distribution between lateral and vertical radiation for the rail and radial, axial and rocking motions for the wheel. The calculated sound powers are shown in Fig. 6(a). Observe that the diagram refers to the radiation from one wheel and one *infinitely* long rail. A correction of the rail sound power to account for the

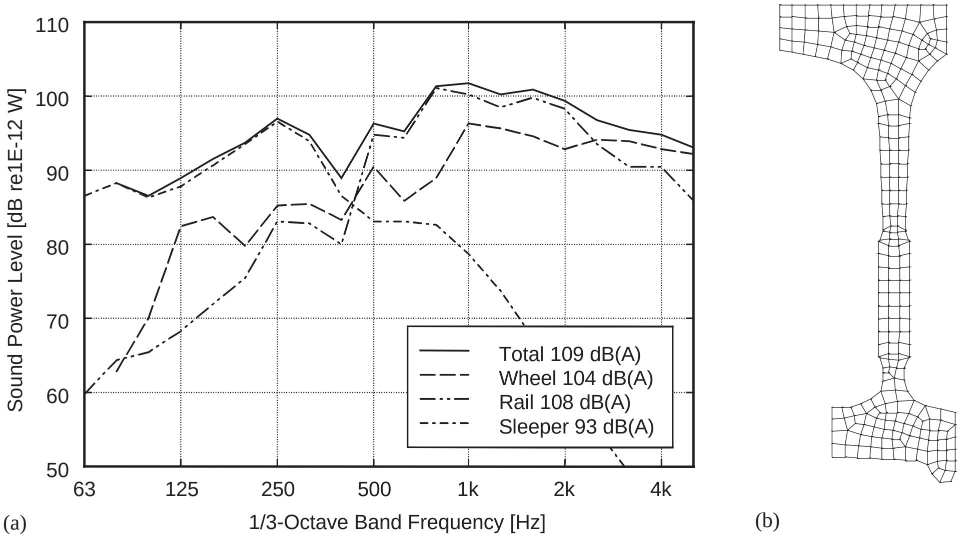

Fig. 6. (a) Calculated wheel and rail source strengths for BR185 locomotive running on Silent Freight reference track. Model includes one wheel–rail contact, a single wheel and an infinite rail; (b) cross-section of FE-model of BR185 wheel.

Table 1
Eigenfrequencies (full-scale) and mode shapes used for the acoustic wheel sources

1/3-octave band (Hz)	Number of modes	Selected mode types in 1/3-octave band	
500	1	$Ax_{(0,3)}$ 542 Hz	
630	0	—	
800	0	—	
1000	4	$Ax_{(0,4)}$ 1012 Hz	$Rad_{(1)}$ 1046 Hz
1250	2	$Ax_{(1,2)}$ 1129 Hz	
1600	3	$Rad_{(2)}$ 1626 Hz	
2000	6	$Ax_{(2,2)}$ 2135 Hz	
2500	4	$Rad_{(0)}$ 2411 Hz	$Rad_{(3)}$ 2647 Hz
3150	6	$Ax_{(2,4)}$ 2937 Hz	
4000	11	*	
5000	9	*	

Index m, n for axial modes refers to nodal circles and nodal diameters, respectively. Index for radial modes refers to nodal diameters.

finite length of the scale model was made when scaling measurement data. Track parameters for a typical European track (the Silent Freight reference track) [8,9] were used.

The cross-section of the wheel FE-model is shown in Fig. 6(b). The cheek-mounted brake disc was not included due to indications that such discs add damping but otherwise have negligible influence on the modal properties of the wheel [10]. Due to a time-consuming procedure of changing the mode settings and performing the measurements, a limited set of eigenmodes was selected (listed in Table 1). The intention was to achieve a similar mix between axial and radial radiation as in the TWINS calculation. The 1/3-octave wheel sound power of Fig. 6(a) has been allocated to the wheel modes in Table 1. In case there is more than one mode in a 1/3-octave band, the 1/3-octave wheel sound power has been split evenly between the modes. The many, high order eigenmodes in 1/3-octave bands 4 and 5 kHz are represented by $Ax_{(2,4)}$-modes at the centre frequencies.

The conversion to the expected full-scale operational wayside SPL was made according to Eq. (1). It applies for lateral and vertical rail contributions as well as for nearside and farside wheel contributions. The term $L_{p,background}$ compensates for possible high background noise levels. The expression in the second parenthesis represents the calculated source strength. The end correction term ($1\,\mathrm{dB} < L_{p,railendcorr} < 4\,\mathrm{dB}$ for the scale model dimensions) applies only for rail excitation and the term $3n$ ($n_{rail} = 2$, $n_{wheel} = 1$) accounts for the fact that both rails are excited simultaneously while only half of the wheels are. The term $L_{p,bogie}$ is an estimate of the actual source sound power during the measurement assuming that the bogie enclosure has a reverberant sound field [11]

$$L_p = 10\log(10^{L_{p,wayside}/10} - 10^{L_{p,background}/10}) + (L_{p,TWINS} + 3n - L_{p,railendcorr}) - L_{p,bogie}. \quad (1)$$

For the rails, Eq. (1) holds for 1/3-octave bands, and for the wheels, it holds for single eigenfrequencies. After the wheel eigenfrequency contributions have been sorted into 1/3-octave bands the four contributions can be added together as

$$L_{p,tot} = 10\log(10^{L_{p,vert}/10} + 10^{L_{p,lat}/10} + 10^{L_{p,farside}/10} + 10^{L_{p,nearside}/10}). \quad (2)$$

Note that this is *not* the expected pass-by SPL for the BR185 locomotive at 25 m. It is merely a value that allows for comparison between the skirt/barrier cases in a relative sense. When these SPL have been established for the reference case and for a skirt/barrier case i the IL can either be expressed in total (as in Eq. (3a)) or component-wise (as exemplified in Eq. (3b)).

$$IL_{tot(i)} = L_{p,tot(ref)} - L_{p,tot(i)}, \quad IL_{rail,lat(i)} = L_{p,rail,lat(ref)} - L_{p,rail,lat(i)}. \quad (3a,b)$$

6. Skirt and barrier configurations

Three different vehicle skirts and three different barriers were built for the scale model. They are briefly described below. In principle the skirt S1 (see Fig. 7) and barrier B1 (see Fig. 8) are conventional designs initially approved from clearance and maintenance aspects. Skirts S2 and S3 (see also Fig. 7) are derivatives of skirt S1. As shown in Fig. 9, barrier B2 has essentially the same

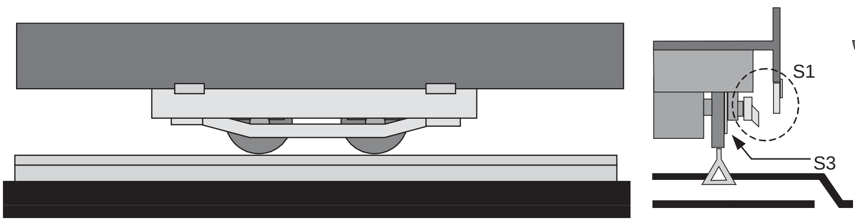

Fig. 7. Front and side view of baseline skirt model (S1) with one carbody-mounted and one bogie-mounted part. Alternative skirt models S2 and S3 are included in side view only.

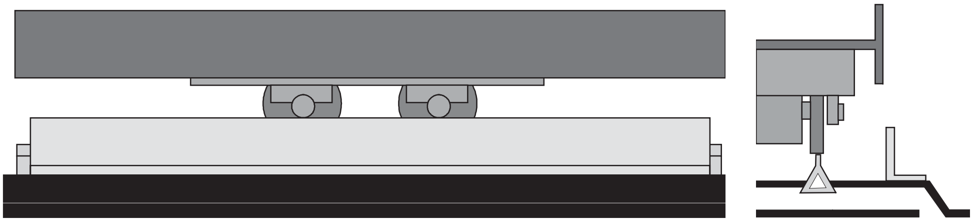

Fig. 8. Front and side view of DB low barrier model (B1).

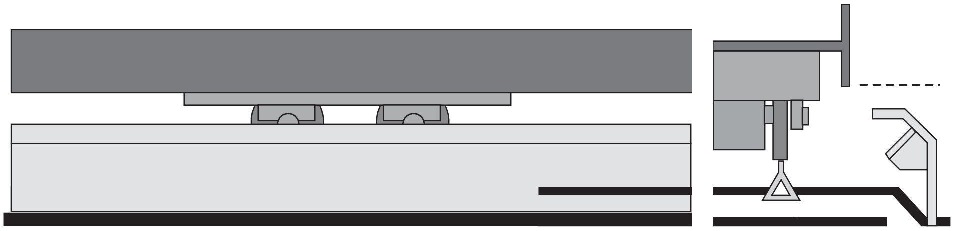

Fig. 9. Front and side view of model B2 similar to Skanska Soundtrack barrier. Barrier B3 is extended up to the dashed line.

Table 2
Combination of skirts (S1, S2, S3) and barriers (B1, B2, B3) tested marked with ×

	B0	B1	B2	B3
S0	×	×	×*	×*
S1	×	×		
S2	×	×		
S3	×	×		

The reference case is S0 + B0 (no skirt and no barrier). Asterisks indicate that no carbody underfloor absorption was present.

geometry as the commercial Skanska Soundtrack barrier and B3 is a higher variant of this (extended to reach up to the lower edge of the carbody). All skirts and barriers had absorption sheets fitted to the inside surfaces and parts of the carbody underfloor. The test configuration matrix is listed in Table 2.

7. Results

The overall A-weighted IL values at two speeds are given in Fig. 10(a). Not surprisingly, the high barriers and the combined solutions are most effective ($IL > 7\,\mathrm{dB(A)}$). The IL changes very little when the speed increases from 100 to 120 km/h. The growing importance of wheel radiation at higher speeds is seen as a slight increase in IL for the skirt cases and vice versa for the barrier cases. Graphs showing the IL in 1/3-octave bands are given in Figs. 10(b)–(d). The IL for each

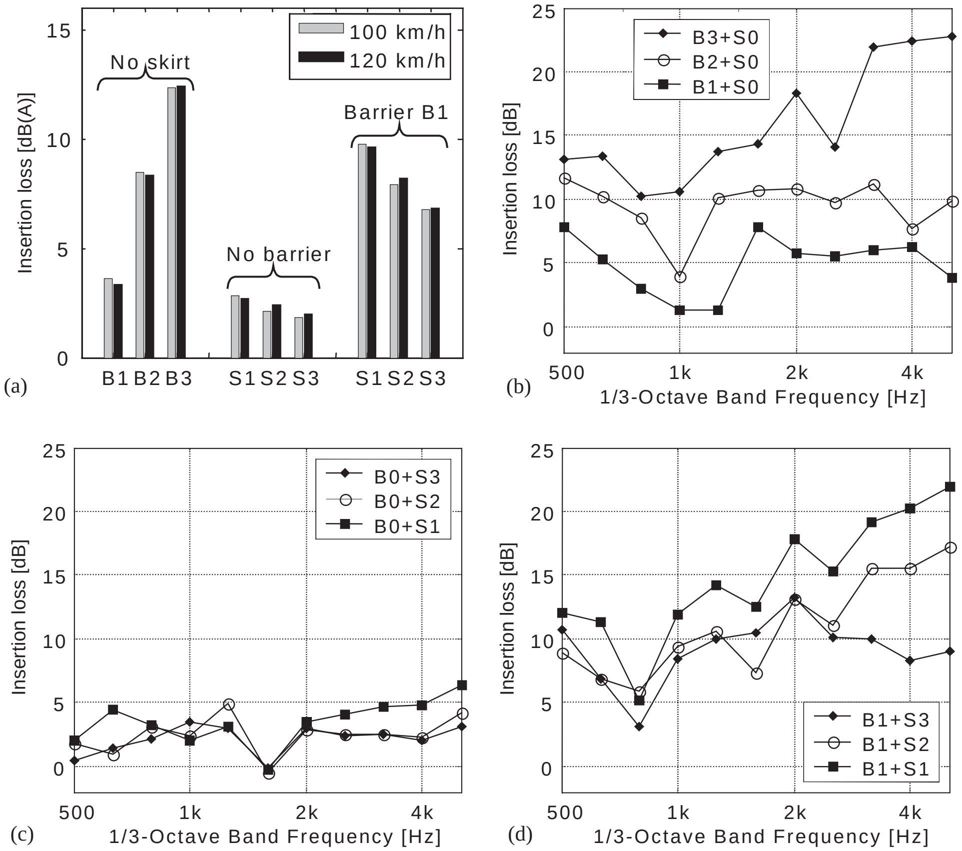

Fig. 10. (a) Estimated total IL (dB(A)) at 100 and 120 km/h for all tested combinations. (b)–(d) Estimated total IL (dB) at 120 km/h in 1/3-octave bands.

individual source for two different configurations is presented in Fig. 11. Here the nearside and farside wheel radiation have been added and the lateral and vertical rail radiation have been added. For most cases, the IL increases with frequency. This is particularly evident for the "barrier" or "combined" cases. The source spectra in Fig. 6(a) show that the rail is dominant at frequencies below 2 kHz. One conclusion is that barriers (which are closest to the rail) are expected to have high IL below 2 kHz and skirts (which are closest to the wheel) should have high IL above that frequency. An inspection of the graphs in Fig. 11 confirms that this is the case. The IL for individual wheel modes is shown in Fig. 12. It is not sufficiently obvious to be able to draw any conclusion regarding the effect of wheel mode type.

8. Conclusions and recommendations

This experiment has provided some useful results about the effectiveness of a variety of sound barriers and skirts. The results were in general agreement with past experiences and results reported in the literature. The objective was to evaluate the so-called 'Baseline Adtranz skirt

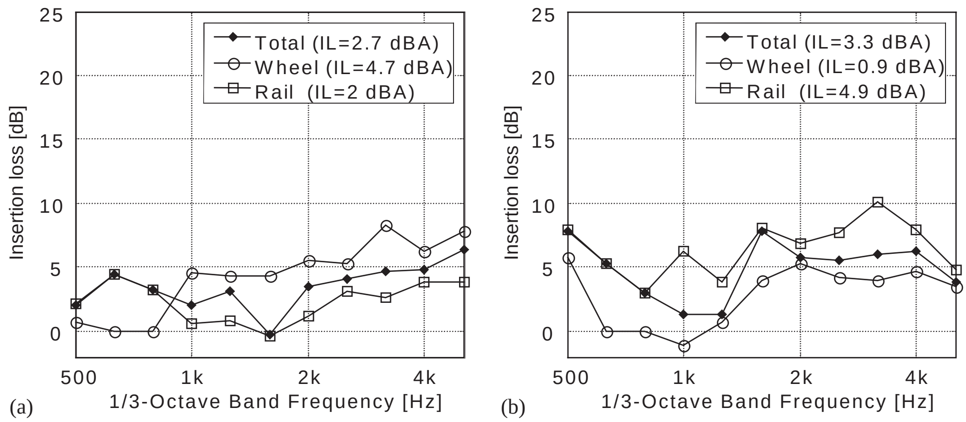

Fig. 11. Estimated IL 1/3-octave spectra (dB) for wheel and rail sources for two different configurations. (a) Skirt S1 and no barrier; (b) barrier B1 and no skirt.

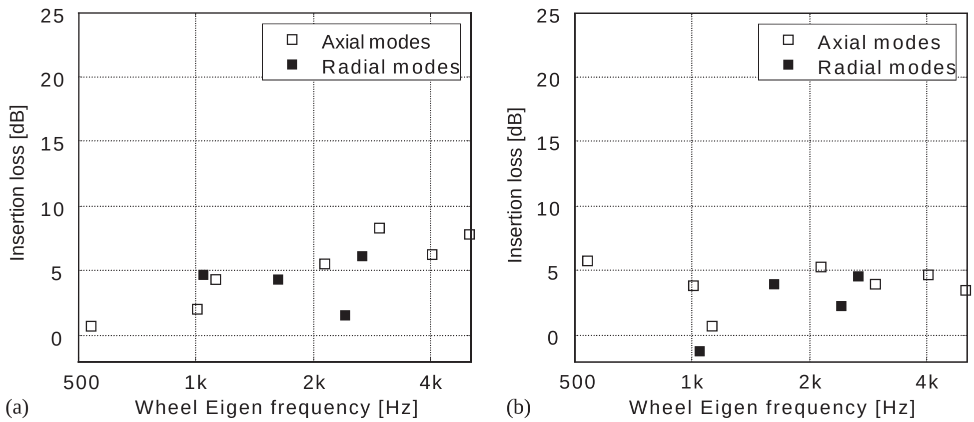

Fig. 12. Estimated IL for individual wheel modes for two different configurations. (a) Skirt S1 and no barrier; (b) barrier B1 and no skirt.

design' for the BR185 locomotive in terms of acoustic IL. This skirt was shown to meet the requirements of the noise specification. The skirt itself had an IL of 3 dB(A) and when combined with the dB low barrier the IL increased to 10 dB(A). It should be noted that the clearance between the scale model barrier and skirt was less than would be realistic at full scale. However, it is reasonable to assume that the 8 dB(A) reduction in the requirements is within reach. In the experiments, all the inside parts of the skirts and barriers were covered with absorptive material and a successful transfer of the results to the full-scale condition presumes that the same amount of absorption-covered area will be used.

The special feature of the present investigation is the realistic representation of the sources and the separate excitation of these sources, which allows both the component-wise *and* total IL to be evaluated. The outdoor measurement site was not ideal with respect to background noise, especially for the configurations with high IL. As described in Eq. (1), it is possible in principle to make a correction for background noise. However, the results presented in this report are not adjusted for background noise and as a consequence the IL values for the most effective shields are somewhat underestimated. It is recommended that future investigations be carried out in a sufficiently large semi-anechoic acoustic room. Another possible enhancement would be to have a longitudinally moving wayside microphone to simulate a train pass-by. It would then be possible to determine whether the maximum sound level is found to be perpendicular to the mid-section, which has been assumed in the present study. It is also possible to evaluate IL in terms of transit exposure level (TEL) and other descriptors involving integration of the wayside microphone signal during the pass-by. TEL represents the total acoustic energy measured at a wayside position during a pass-by, normalized to the pass-by time.

Use of the SPL in the bogie for normalization of the actual source sound power levels is a very quick but also an approximate approach. A more accurate normalization would be to measure, in an acoustic laboratory, a relation between acoustic source power and output voltage.

Finally, based on the spectral composition of wheel and rail source strengths and IL, it is possible to optimize the skirt and barrier designs to make them more effective for certain wheel modes or rail vibration types, etc.

Acknowledgements

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