Additional railway noise source terms For "Calculation of Railway Noise 1995"

A report produced for Defra by AEAT

January 2007

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May 2004

Executive Summary

When the procedure "Calculation of Railway Noise 1995" (CRN) [Ref 1] was devised, the list of stock that was included was aimed at representing the majority of typical vehicles operating on the railway at that time. However, since 1995 the nature of the rolling stock fleet has changed considerably and there are many types of vehicle currently in operation that are not included in CRN. There are also several types of stock pre-dating CRN that are not included.

Within this report, data for CRN rolling noise terms for a range of vehicles agreed with Defra have been calculated by application of AEA Technology's experience in this field and by reference to its database of information on the acoustic and physical characteristics of the stock. Data have also been obtained from field measurements for the Class 390 Pendolino Brittanico, the Class 220 Virgin Voyager, the Class 221 tilting Virgin Voyager and the Class 170 Turbostar. Rolling noise source term corrections, measured previously in the field by AEA Technology for the main UK rail freight operator EWS, are also provided for an agreed set of freight wagons and diesel locomotives, and the measured "on-power" source term is also provided for these locomotives. These latter sets of data are provided with the permission of EWS.

Eventually it would be advisable to base all such terms on measurement, especially if they are to be incorporated within a revised CRN document, but the calculated values presented in this report can be considered as being sufficiently accurate for initial noise mapping purposes.

Contents

1   Introduction

When the procedure "Calculation of Railway Noise 1995" (CRN) [Ref 1] was devised, the list of stock that was included was aimed at representing the majority of typical vehicles operating on the railway at that time. However, since 1995 the nature of the rolling stock fleet has changed considerably and there are many types of vehicle currently in operation that are not included in CRN. There are also several types of stock pre-dating CRN that are not included. The following is a list of this missing stock and an indication, in parenthesis, of the number of vehicles:

[The entire registered UK passenger and freight fleet at 3 January 2004 comprised 50939 vehicles, including 35230 freight wagons of which 6506 are international vehicles not necessarily always in the UK. There are also 4647 de-registered vehicles that may be re-registered in the future.]

Diesel Multiple Units pre-privatisation
Class 142 (192), 143 (50), 144 (56), 150 (278), 153 (86), 155 (14), 156 (230), 158 (368), 159 (88)

Diesel Multiple Units near or post-privatisation
Class 168 Turbostar (46), 170 Turbostar (248), 175 Coradia (70), 180 Coradia (56), 220 Voyager (136), 221 Voyager (216)

Electric Multiple Units pre-privatisation
Class 312 (196), 313 (192), 314 (48), 315 (244), 317 (328), 318 (63), 320 (66), 321 (468), 322 (20), 325 (64), 365 (164), 411/412 (326), 421 (444), 423 (888), 442 (140), 455 (576), 456 (48), 483 (14), 488/489 (78), 507/508 (222)

Electric Multiple Units near or post-privatisation
Class 323 (129), 332 Heathrow Express (56), 333 (64), 334 Juniper (120), 350 (24), 357 Electrostar (296), 375 Electrostar (210), 377 Electrostar (404), 390 Pendolino Britannico (477), 444 Desiro (225 on order), 450 Desiro (560), 458 Juniper (120), 460 Gatwick Juniper (64)

Diesel locomotives near or post-privatisation
Class 57 (17), 66 (328), 67 (30)

Electric locomotive near or post-privatisation
Class 92 (46)

There is also a very large fleet of freight wagons not included specifically within CRN, eg BAA (143), BBA (308), BDA (533), BZA (98), MEA (437), TDA (156), TEB (56), TIA (41), HTA (1144) and KQA/KTA "pocket" wagons (75).

The numbers of vehicles shown are a good indication of the actual proportion of usage, especially for the passenger stock.

CRN source term corrections cover rolling noise and, for diesel locomotives, "on-power" noise, ie the exhaust and engine noise resulting from the locomotive being on full power. The rolling noise term can be measured under conditions specified in CRN. Diesel locomotive on-power source terms can also be measured under carefully controlled conditions. However, it is not easy to find sites where the required train types pass and which fulfil the conditions needed to obtain good rolling noise data (eg a non-corrugated rail head and no intervening track, and no intervening or reflecting structures between the track and a measurement point 15m – 25m from the track). It is, however, possible to use the known physical characteristics of a particular type of vehicle to calculate an approximate CRN rolling noise source term or to identify a vehicle with a known source term likely to be acoustically similar to the unknown vehicle.

Within this report, data for CRN rolling noise terms for an agreed range of vehicles have been calculated by application of AEA Technology's experience in this field and by reference to its database of information on the acoustic and physical characteristics of the stock. Rolling noise source term corrections, measured in the field by AEA Technology for EWS, the main UK rail freight operator, are also provided for an agreed set of freight wagons and diesel locomotives. The measured "on-power" source term is also provided for these locomotives. These measured data are provided with the permission of EWS.

Additionally, the rolling noise source term corrections for the Class 390 Pendolino Brittanico, the Class 220 Virgin Voyager Diesel Multiple Unit, the Class 221 tilting Virgin Voyager and the Class 170 Turbostar diesel multiple unit have been acquired by measurement.

2 Calculation Methodology

The baseline Sound Exposure Level (SEL) for rolling noise at 25m from CRN is speed-based:

$$SEL = 31.2 + 20 \log_{10}V(km/h) \; dB(A)$$

The fundamental source term for single vehicles is then obtained by adding a "Correction" to the baseline SEL, as presented in Table A1.1 of the procedure.

Although the corrected SELs from CRN have a range of values dependent on speed, rolling noise is a function of a limited number of parameters. The most significant of these are the number of wheels and whether the vehicle has cast-iron tread brakes or disc brakes/composition tread brakes, as cast-iron brakes lead to rough wheels and higher rolling noise emission.

The effect of the number of wheels can be clearly seen in CRN Table A1.1 where locomotives have a rolling noise correction of either 14.8 dB or 16.6 dB. The difference between these two groups is that they have 4 or 6 axles respectively ($10\log_{10}(6/4) = 1.8$ dB).

The difference between vehicles with and without cast-iron tread brakes is also clear from CRN Table A1.1. The Mk I and Mk II coaches have cast-iron tread brakes while the Mk III and Mk IV have disc brakes. It can be seen in CRN that the correction for the Mk I and Mk II

vehicles is 8.8 dB higher than for the Mk III and Mk IV. This difference can be explained by the relative values of the combined wheel and rail surface roughness for the different braking systems.

Although the number of wheels and the difference between cast-iron tread brakes and other brake types account for much of the variation between vehicles, there are other factors to consider. For example, the Mk III has a correction of 6 dB but multiple units have a higher figure. One probable explanation is that some of the wheels on multiple units are powered, resulting in rougher wheels.

The methodology adopted in calculating rolling noise corrections has been to apply AEA Technology's experience, and information from our database of measurements, to specify algorithms relating the correction to the total number of axles, the number of powered axles, and the type of braking and, in the case of the unloaded freight vehicle, its length. In this latter case, it has been found that measurements of some unloaded freight wagons in the UK indicate increased levels over the same wagons when loaded. This is contrary to the findings of the "Silent Freight" EC 4th Framework project where a tank wagon and a "Tombereau" wagon were investigated, but is nevertheless a measurable effect on some UK stock.

To validate this rolling noise prediction methodology, a comparison has been made between (a) a set of CRN corrections predicted by applying this methodology (ie "from first principles") and (b) correction values either enshrined in the CRN 1995 document or obtained by measurement in the past by AEA Technology. The results of this can be seen in Figure 1.
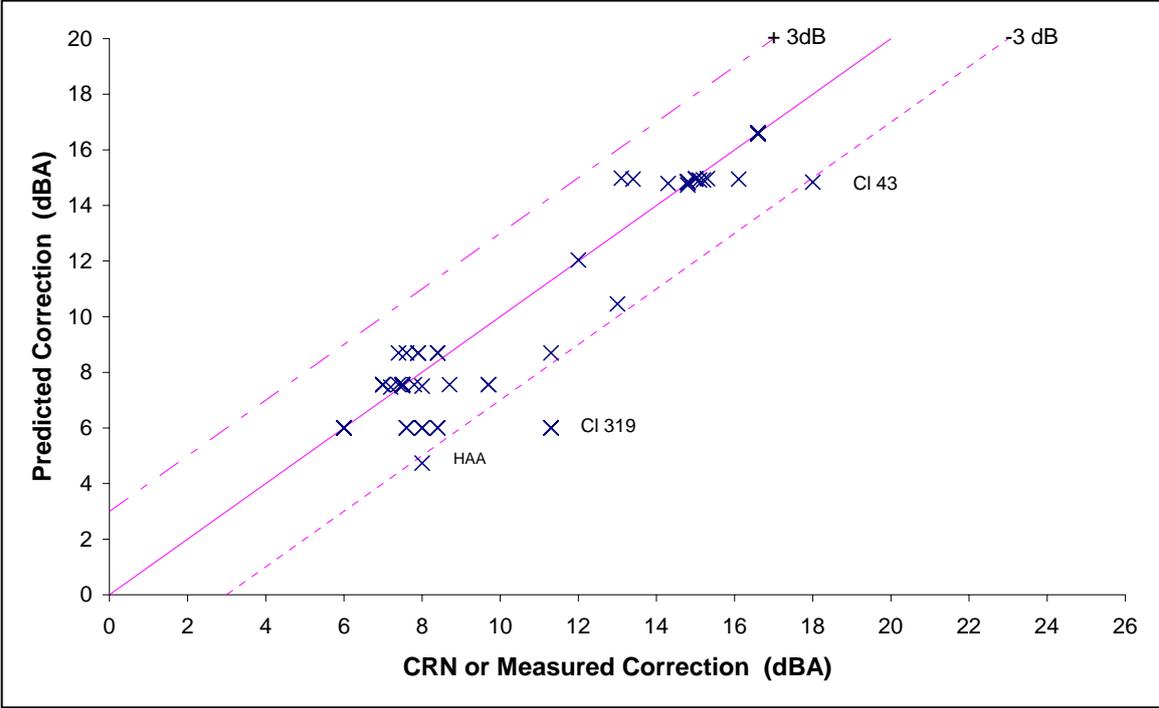

Figure 1 CRN corrections predicted using the AEA Technology methodology vs values either in the CRN 1995 document or obtained from measurement

The solid straight line represents y=x and therefore indicates the situation that would occur if the predictions using the methodology of this report agreed exactly with the CRN 1995

figures or earlier AEA Technology measurements. Figure 1 shows a good correlation, providing confidence in the methodology applied within the current study, but highlights a few anomalies:

Cl 319	Recent measurements made at several locations indicate that the correction in the CRN 1995 document is high.
HAA	Although the HAA wagon has disc brakes it also has cast iron tread brakes on two diagonally opposite wheels, which are intended to be used only when the vehicle is stationary. The correction from CRN for this wagon (8.0 dB) is high for a disc-braked two-axled vehicle, suggesting that the tread brakes may bear on the wheel when it is moving, increasing wheel roughness. Modelling the HAA wagon with 2 disc-braked and 2 cast-iron tread-braked wheels gives predicted source term corrections of 9.1 dB unloaded and 7.2 dB loaded, which can be seen to be significantly closer to the CRN value.
Cl 43 (InterCity 125/HST Power Car)	The rolling noise source term in CRN for the Class 43 locomotive is higher than for any other diesel locomotive with 4 axles. It is known that the Class 43 produces high levels of high frequency engine noise and it is considered possible that the rolling noise correction in Table A1.1 of CRN includes an element of engine noise.

If the Class 319, Class 43 and the HAA data are excluded, the root mean squared difference between the predictions and the CRN/measured data is 1 dB.

The methodology employed for deriving the CRN correction from the measured values of EWS freight wagon and locomotive pass-by noise is to capture the time-history of each event which can often consist of pass-by information from a range of different vehicle types and, always, a locomotive. Those data are then used to synthesise an event comprising solely the vehicles in question, enabling the correction to be obtained (an AEA Technology procedure known as "T-Noise"). A similar approach was used in order to extract on-power corrections for locomotives, which were acquired during dedicated measurement exercises within an EWS depot.

3 Results of calculations and separate measurements for EWS

The results of the various approaches described in Section 2 are shown in Table 1.
(* = freight vehicle data measured by AEA Technology, provided with the permission of EWS, + = On-Power correction, rather than rolling noise correction, where a negative value indicates a quieter locomotive than those shown in CRN, the majority of which have an On-Power correction of 0.0 dB). Note that the Class 444 Desiro EMU, which has just commenced testing, has been added to the list agreed previously with Defra.

Vehicle type (EMU = electric multiple unit, DMU = diesel multiple unit)	Arrangement per unit if DMU/EMU (M= motor vehicle, T= trailer vehicle) Code in brackets = variant	Brake type for prediction D=Disc T= Cast Iron Tread	No of powered axles per motor vehicle for prediction	CRN vehicle source term correction dB(A)
168 Turbostar DMU	MMMM	D	2	+7.6
170 Turbostar DMU	M(M)M	D	2	+7.6
175 Coradia DMU	M(M)M	D	2	+7.6
180 Coradia DMU	MMMMM	D	2	+7.6
220 Voyager DMU	MMMM	D	2	+7.6
221 Voyager DMU	MM(M)MM	D	2	+7.6
323 EMU	MTM	D	4	+8.7 (M) +6.0 (T)
332 Heathrow Express EMU	MTTM	D	2	+7.6 (M) +6.0 (T)
333 EMU	MT(T)M	D	2	+7.6 (M) +6.0 (T)
334 Juniper EMU	MTM	D	2	+7.6 (M) +6.0 (T)
350 Desiro EMU	MTTM	D	4	+8.7 (M) +6.0 (T)
357 Electrostar EMU	MTMM	D	2	+7.6 (M) +6.0 (T)
375 Electrostar EMU	MT(M)M	D	2	+7.6 (M) +6.0 (T)
377 Electrostar EMU	MT(M)M	D	2	+7.6 (M) +6.0 (T)
390 Pendolino Britannico	MMTM(T)MTMM	D	2	+7.6 (M) +6.0 (T)
444 Desiro EMU	MTTTM	D	4	+8.7 (M) +6.0 (T)
450 Desiro EMU	MT(T)TM	D	4	+8.7 (M) +6.0 (T)
458 Juniper EMU	MTMM	D	2	+7.6 (M) +6.0 (T)
460 Gatwick Juniper EMU	MTTMTMM	D	2	+7.6 (M) +6.0 (T)
KQA loaded Pocket wagon		T		+15.0
KQA empty Pocket wagon		T		+17.5
Class 92 locomotive Dual voltage electric		T	6	+16.6
BAA wagon Steel carrier, 4 axle				+15.2*

BBA wagon loaded Steel carrier, 4 axle				+13.4*
BBA wagon empty Steel carrier, 4 axle				+16.1*
BDA wagon empty Bolster 4 axle				+10.8*
BZA wagon loaded Steel carrier, 4 axle				+11.8*
MEA wagon empty Box mineral, 2 axle				+5.6*
TDA wagon loaded Tank, 4 axle				+17.8*
TEB wagon loaded Tank, 4 axle				+20.2*
TIA wagon loaded Tank, 2 axle				+17.8*
HTA wagon loaded Hopper, 4 axle				+7.1*
HTA wagon empty Hopper, 4 axle				+10.4*
Class 66 rolling Diesel locomotive				+13.0*
Class 66 **on-power** Diesel locomotive				-13.4* [+]
Class 67 rolling Diesel locomotive				+7.4*
Class 67 **on-power** Diesel locomotive				-10.8* [+]

Table 1 CRN source term corrections for stock not included within the current issue of the procedure.

4 Discussion of predictions

The information provided in Table 1 will enable CRN predictions to be carried out for the stock shown with an acceptable level of confidence for indicative purposes, as shown by the validation data presented in Figure 1.

In addition to the measurement of rolling noise source terms to verify the above calculations, a complete database of the current UK fleet will require measured information on on-power levels and rolling noise from the Class 57 locomotive, and on-power information for re-engined Class 43 power cars. It would also be advisable to measure the fan noise from the Class 92 locomotive in order to establish whether this is as significant a source as is the case for the Eurostar, necessitating the inclusion of an additional term in the prediction procedure.

In terms of likely impact on the mapping exercise, the Class 43 power cars on full power could be of the greatest significance. Although these are now at least 22 years old, they are still extensively used (197 units), and are unlikely to be withdrawn from service in the foreseeable future. It should be noted, however, that the measurement of full power terms for use in CRN is not a straightforward matter, as it will normally require a dedicated train set to be made available so that controlled acceleration, and preferably control over the mode of operation of the cooling system (a potentially major contributor), can be realised in an acoustically acceptable environment.

The fan noise from the Class 92 electric locomotive (dual voltage freight) may also be of some significance for accurate noise mapping, as these operate from Scotland to the south of England on the West Coast Main Line, and on the Channel Tunnel route. However, as there are only 46 in service, and as the fan noise will be significantly lower in level than Class 43 Full Power noise, they do not need to be considered as a priority issue.

As there are only 17 Class 57 locomotives, their impact on the mapping will be of even less significance, and it is therefore only appropriate to measure their full power and rolling noise levels if a complete database is required.

5   Introduction to measurements of Source Term Corrections for Classes 390, 220, 221 and 170

Following the calculations reported in Section 3, Defra requested that AEA Technology carry out a limited set of field measurements to validate the predictions and to enhance the currently available measurement database. The set of vehicles chosen was as shown in Table 2.

Class	Name	Description
390	Pendolino Brittanico (tilting) (477 vehicles in fleet)	Virgin's inter-city train for the West Coast Main Line, capable of 140 mph on appropriate track
220	Voyager (136 vehicles in fleet)	Virgin's cross country diesel multiple unit, capable of 125 mph
221	Voyager (tilting) (216 vehicles in fleet)	Tilting version of the 220, capable of 125 mph
170	Turbostar (248 vehicles in fleet)	Widely-used 100 mph diesel multiple unit, with wheels designed for reduced rolling noise by ISVR (Southampton University), constructed 1998 onwards

Table 2 Stock chosen for the measurement exercise

These vehicle classes were chosen for several reasons that made them of particular interest. The Class 390 is based on an Italian design, with distributed electrical power and a number of features that are different from typical UK stock, including tilt, and comprises around 3.5% of the passenger fleet. The Class 220 and 221 Voyagers are very powerful diesel multiple units (560 kW engines) and again comprise (with a new variant in production, the 222) around

3.5% of the total passenger fleet. The 220 has "inside frame" bogies, while the 221 has the more conventional "outside frame" but with a tilting capability. The Class 170 diesel multiple unit (315 kW engines) has wheels that were designed to reduce rolling noise in order to meet the procurement specification and comprises around 2% of the passenger fleet.

6   Measurement methodology

Measurements were carried out in a large, grassed, rear garden of a cottage on the outskirts of the small village of Cranberry (with the prior agreement of the resident) at OS map reference SJ 825362 on 2nd April 2004. The garden lies adjacent to, and on the east side of, the West Coast Main Line between Stafford and Crewe, at mileage 144ml, 339yd. This is a 4-track section with the first and second (nearest two) tracks to the measurement site being the "Up Fast" and the "Down Fast" respectively. The third and fourth tracks were the "Up Slow" and "Down Slow" respectively, but were excluded from the analysis because vehicles of known characteristics did not pass over them during the measurement period, and they could therefore not be "calibrated".

The land is flat and open, lying approximately 0.5m below the level of the rails. The line is reasonably straight at this location, with both Fast tracks appearing to have been recently re-laid with fresh ballast. The rails of both Fast tracks had evidently been recently re-ground, each still showing grinding marks either side of a smooth and narrow wear band.

Using tripods and poles, microphones were mounted at the following positions:
- Microphone 1 at 25m horizontal distance from the Up Fast (nearest track, carrying southbound trains) at 3.5m above the level of the rail head.
- Microphone 2 at 25m from the Down Fast, also at 3.5m above rail head height.
- Microphone 3 at 7.5m from the Up Fast, 1.5m above rail head height.

Microphones 1 and 2 were used for measurement, while Microphone 3 provided better resolution of the time-history of the sound recording.

The microphones (all *Bruel & Kjaer* Type 4165) were connected via *Norsonic* Type 112 pre-amplifiers and Type 336 signal conditioning frontends to a *Sony* Type PC208 digital audio tape (DAT) recorder. All microphone channels were calibrated by means of a pistonphone before and after the tests.   Rail vehicles were identified on site but, in addition, a digital video camera was used to allow later confirmation of vehicle types, numbers and speeds. Wind speeds were monitored using a hand-held anemometer to ensure that no measurements were made where wind speeds exceeded the recommended limit of 5m/s in any direction and 2 m/s from rail to reception point. Sound and video recordings were made during the pass-by of every train. The recordings were analysed at a later date in the AEA Technology Rail Acoustics Laboratory in Derby.

7 Analysis of measured data

7.1 BACKGROUND

It is rarely possible to measure CRN source term corrections directly from measurements because (a) the track is often not adequately smooth even when free from visible corrugations, (b) rolling noise from other vehicles in the train can influence the measured levels, (c) non-rolling noise sources may be present in the train[1] and (d) wheel faults can adversely affect levels.

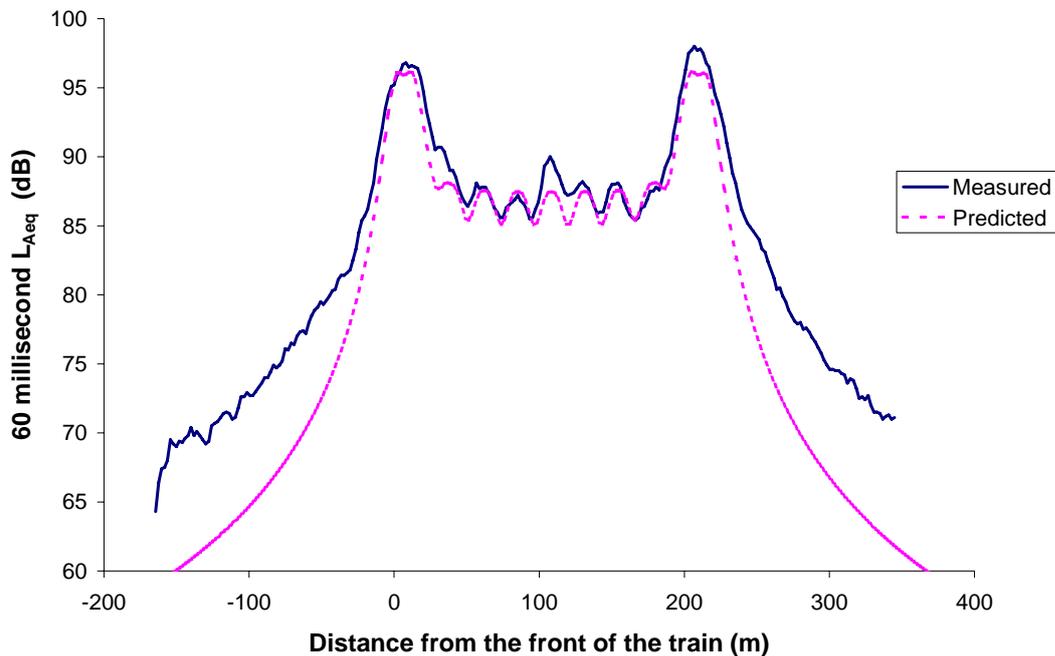Figure 2 shows a typical time history of a train pass-by at the measurement site.

Figure 2 Typical Measured and Predicted Time History of a Train Pass-by

It should be noted that, to illustrate the effects more clearly, the data in Figure 2 are for a microphone 7.5 metres from the nearest rail. For calculating the source term corrections it is necessary under the requirements of CRN to use data measured at a distance of between 15 metres and 25 metres from the nearest rail.

The "High Speed Train" (HST) illustrated in Figure 2 has a Class 43 power car at each end and eight Mk III[2] coaches in between. The Mk III coach is disc braked and the Class 43 has cast-iron tread brakes, which is one reason for the peaks in level at either end of the time history. Furthermore, the Class 43 has a diesel engine, which also contributes to pass-by

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[1] The presence of noise from traction equipment may contaminate the rolling noise signal. Because rolling noise and traction noise vary differently with speed it is important that the source term corrections for these two phenomena are considered separately.

[2] In an HST the Mk III coaches are termed "trailer cars".

noise. The rear engine provides the electrical power for the coaches, which is why the measured peak for the rear power car is slightly higher than for the front.

The small peak near the middle of the measured pass-by is common with this type of train and is associated with the buffet car.

Figure 2 also shows the time history of the rolling noise predicted using the techniques developed by Peters[Ref 2]. It can be seen that although the agreement is good during the actual train pass-by the predicted levels rise and fall more rapidly than those that are measured. This is because the predicted levels are for rolling noise while the measured levels include contributions from the noise from the diesel engines. Figure 3 compares the measured time history with a prediction that includes an engine noise component and it can be seen that the agreement is much improved.
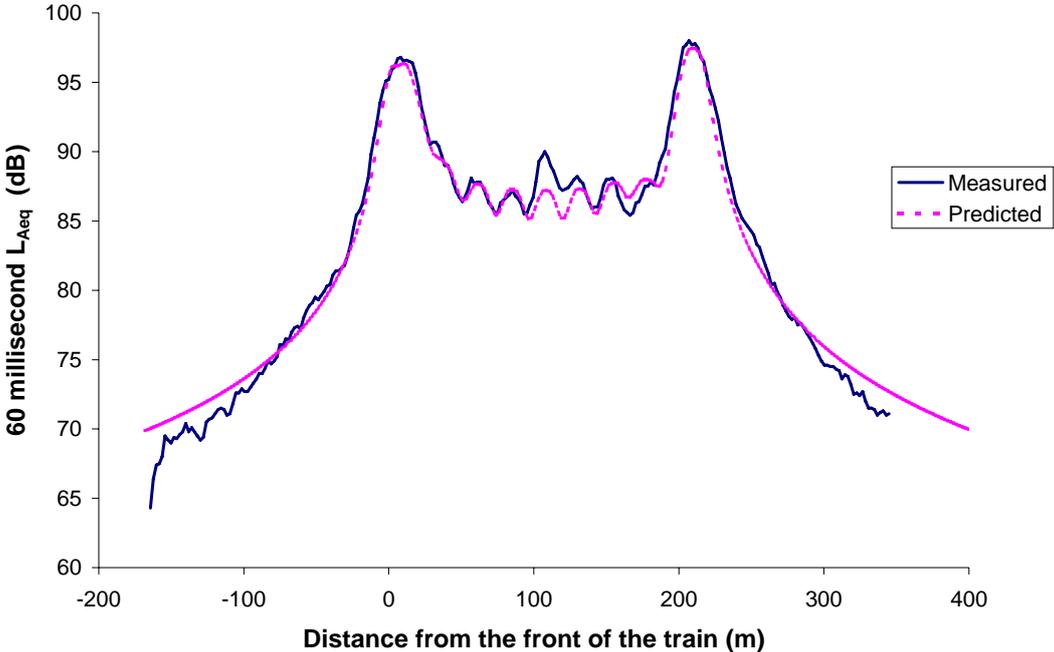

Figure 3 Typical Measured and Predicted Time History of a Train Pass-by with the Prediction including Engine Noise

7.2   SEPARATION OF CONTRIBUTIONS

The rolling noise model used here treats each wheel as an individual source. By adjusting the source term corrections iteratively to achieve a good fit between the measured and predicted time histories, the effects of individual vehicles or groups of vehicles can be removed, as illustrated in Figure 4.
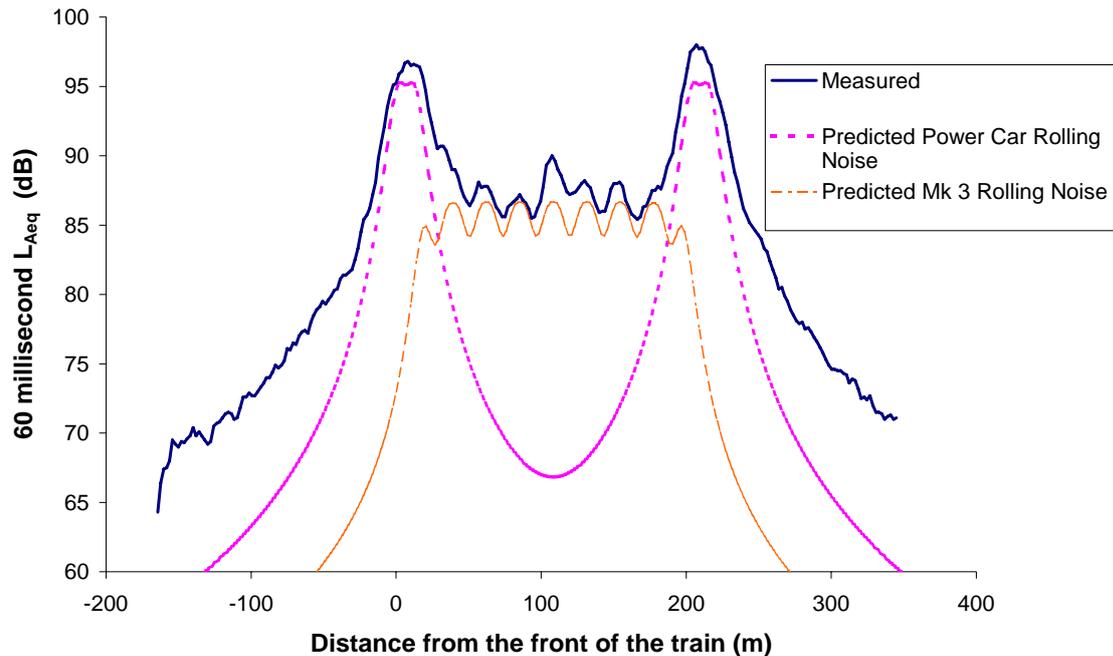
Figure 4 Predicted and Measured Time History of a Train Pass-by with the Predicted Levels for the Power Cars and Mk III coaches separated

From this example pass-by, the rolling noise source term correction for the Mk III coaches in this train (ignoring the buffet car) is calculated as being 6.0 dB, while for the power cars it is 15.9 dB. The measured Mk III source term correction is therefore identical to the value given in CRN but the power car term is 2.1 dB lower than the CRN value of 18.0 dB. The source term correction for similar locomotives is 14.8 dB. Because of the difficulties inherent in separating the measured locomotive rolling noise from that of the rest of the train and from the traction noise it is possible that the Class 43 rolling noise source term correction in CRN includes some traction equipment noise.

The same process can be used to calculate the source term corrections for the traction noise from the power cars. The values are –5.8 dB for the front power car and –4.7 dB for the rear. As the locomotive was not on full power these values cannot be compared directly with the CRN "full power" term of 0 dB. However, they do indicate that traction equipment noise can make a significant contribution to overall pass-by noise even when the engines are not on full power and the train is travelling at a speed of around 75 mph.

7.3   MEASURED DATA

It is shown in Reference 3 that for statistical robustness it is necessary to measure the noise from a number of vehicles. For example, for there to be a 90% probability of the sample mean being within +1.1 dB and –0.9 dB of the population mean it is necessary to measure the noise from at least 34 vehicles, requiring several trains to be considered.

When the time histories for some of the other trains measured at the site were examined they were found to have unusual characteristics. Figure 5 presents the time history for a second HST at the site.
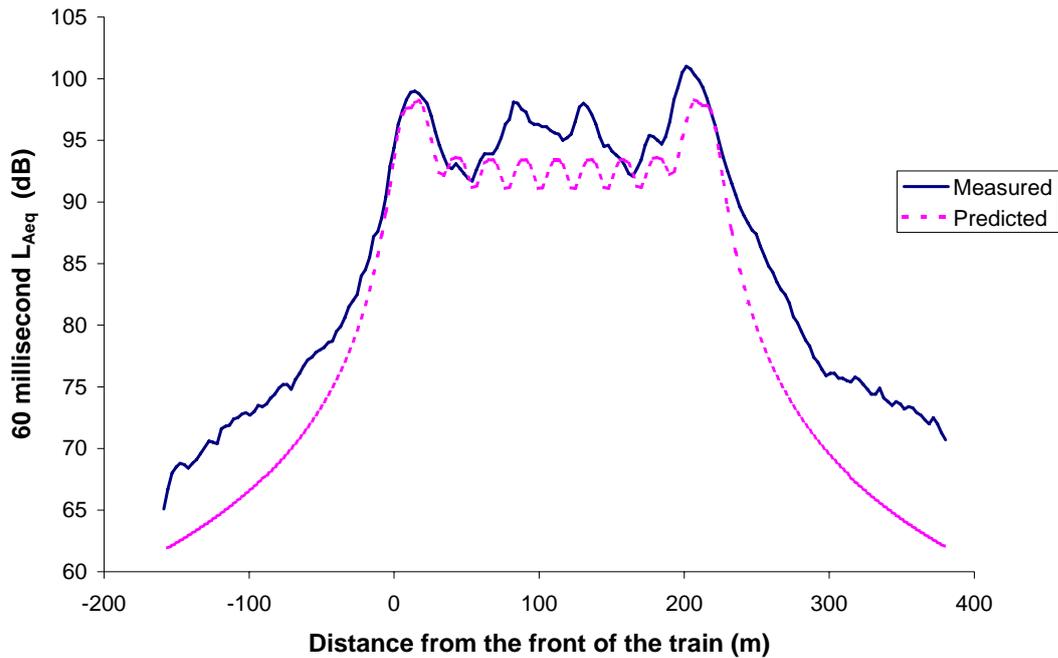
Figure 5 The Measured and Predicted Rolling Noise Time History for a Second HST

It can be seen that there are measured levels at the centre of the train that are much higher than the predicted levels of rolling noise. Further examination of the data revealed that the bogies appeared to be 'hunting'[3] for these vehicles. Examination of other data for trains containing Mk III coaches revealed that this is a fairly common problem at this location. However, there were enough data from Mk III coaches running normally to allow an accurate quantification of the acoustic condition of the track at this location, as shown in Table 3.

Track	Number of Vehicles	Average source term Correction (dB)	Standard Deviation (dB)
Up Fast	9	6.2	0.65
Down Fast	12	6.3	0.52

Table 3 Measured CRN Source Term Correction for Mk III Coaches (value in CRN is +6.0 dB)

The Table shows that, although there are less than the 34 vehicles suggested in Reference 3, the standard deviations are relatively low and there is little variation between tracks. Furthermore, measurements made at the site on other vehicles for which source term corrections were already known showed that the measured corrections were consistently close to those given in CRN. Therefore, the track quality indicated by the measurements of Mk III coaches was considered sufficiently statistically reliable.

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[3] Hunting is a lateral oscillation of the bogie that occurs when the lateral damping in the bogie is insufficient for the combination of wheel and rail dynamics at a site.

Measurements on the Class 390, Class 221, Class 220 and Class 170 showed no evidence of the bogies 'hunting'. However, it was found, with the exception of the Class 390 (which has electric traction), that there are significant levels of engine noise on some vehicles. Figure 6 is a typical example for two Class 220 units (ie 2x4 vehicles) coupled together.
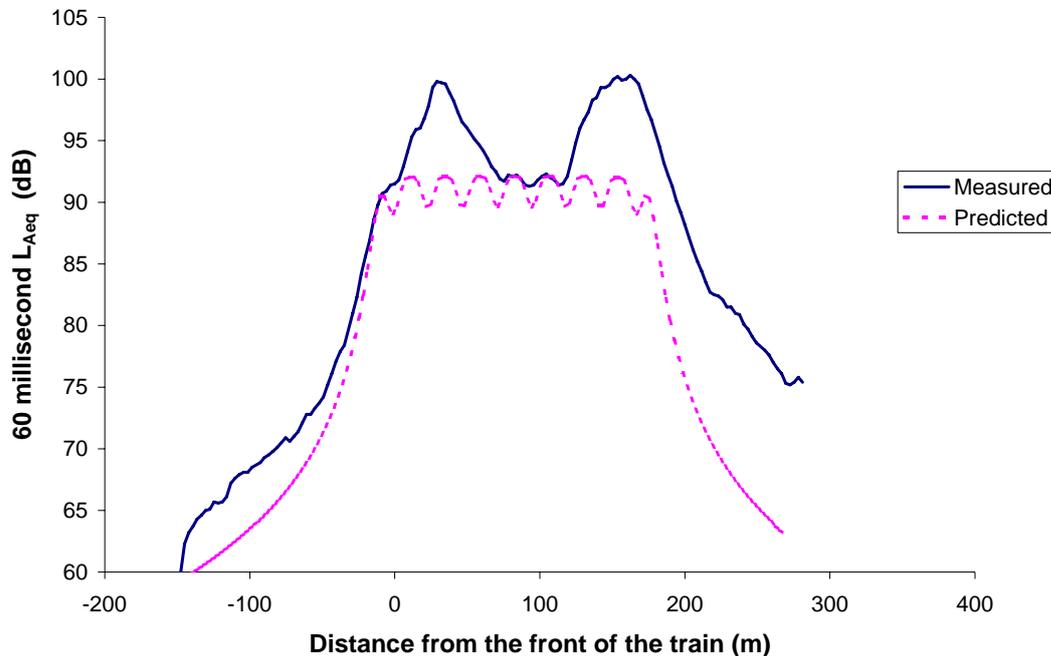

Figure 6 Typical Measured and Predicted Time History for two Class 220 Voyagers coupled together

Because the engines on each Class 220 unit provide both traction power and local power for the train air-conditioning, lighting, etc, it is possible for the engines to be running at different speeds. The peaks in Figure 6 show this effect, with wheel-rail noise only being obviously discernible at the centre of the train. The techniques indicated above allow the rolling noise and traction noise components to be separated from each other.

7.4   TRACK CORRECTION

The measured source term corrections for the Mk III coach indicate that the track is slightly noisier than it should be to meet the CRN requirements exactly. However, the difference is not large enough to justify rejection of the data, which have instead been corrected to take account of the track roughness. This correction is derived from the fact that the rolling noise is excited by the combined rail and wheel surface roughness. As the rail roughness is the same for all trains on one track and the combined wheel/rail roughness for a Mk III coach on track that would produce a CRN correction of 6 dB is dominated by the rail roughness, it is possible to produce a true correction for all other types of vehicle. The difference between the measured Mk III source term correction and the value presented in CRN is known as the Acoustic Track Quality (ATQ) which, at the measurement site, was therefore 0.2 dB for the Up Fast track and 0.3 dB for the Down Fast track. Figure 7 shows the effect of ATQ on the measured source term corrections for three different vehicles.
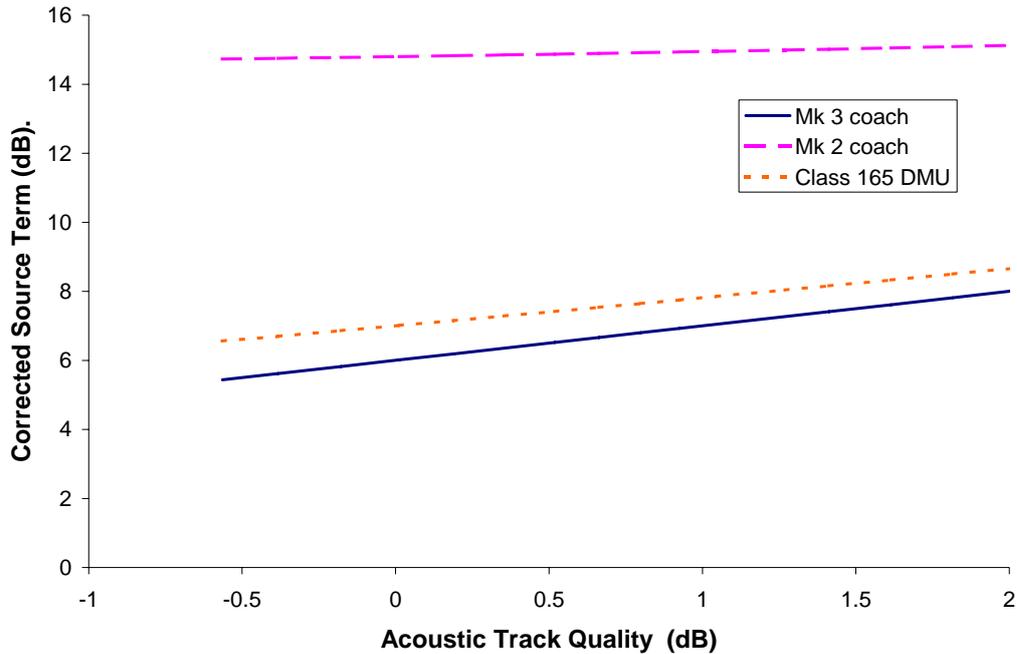
Figure 7 Effect of Acoustic Track Quality on the Corrected Source Terms

It can be seen that the corrected source term for the cast iron tread-braked Mk II coach increases less rapidly with ATQ than for the disc-braked Mk III. The source term for the Class 165 is close to the Mk III but increases less rapidly, having some driven axles and hence somewhat rougher wheels than the unpowered Mk III coach.

The data acquired during this exercise were similarly corrected for the measured ATQ values for each track under consideration at the site. The data from the two tracks were then combined.

7.5   RESULTS

Table 4 shows the measured rolling noise source term corrections for Class 390, Class 221, Class 220 and Class 170.

	Number of Vehicles	Average Source Term (dB)	Standard Deviation (dB)
Class 390	86	8.7	1.4
Class 221	10	6.0	0.4
Class 220	4	7.7	2.0
Class 170	4	7.6	0.4

Table 4 Average Measured Rolling Noise Source Terms Corrected for Acoustic Track Quality

It can be seen that, except for the Class 390, the number of vehicles is less than the 34 that Reference 3 suggests. This is because the rolling noise from a number of vehicles was contaminated with engine noise and could not be included.

The extraction of traction noise source term corrections from the measured data is difficult on an operating railway as engine condition is unknown. However, from the noisiest Class 220 and Class 221 units the traction noise source term correction was found to be of the order of –3dB (compared with typical full power correction terms for diesel locomotives of 0.0 dB in CRN). This indicates that, despite CRN's current non-inclusion of traction noise for Diesel Multiple Units, more powerful modern Units may need to be treated within CRN similarly to locomotives, with source term corrections both for rolling noise and traction noise.

The effect of the number of vehicles that were available is shown in Table 5.

	Range of Population Source Terms Based on Measured Values (dB)			
	5%	25%	75%	95%
Class 390	9.4	9.0	8.5	8.2
Class 221	8.0	6.8	5.3	4.4
Class 220	11.2	9.1	6.7	5.3
Class 170	11.1	9.1	6.6	5.2

Table 5 Effect of Number of Vehicles Available on the Possible Range of the Rolling Noise Source Terms (from the cumulative distribution)

The results in Table 5 therefore show, for example, that there is a 90% chance that the population source term correction for the Class 390 lies between 9.4 dB and 8.2 dB, and a 50% chance that it lies between 9.0 dB and 8.5 dB.

Table 6 compares the measured source term corrections with those predicted in Section 3.

	Rolling Noise Source Term (dB)		
	Measured	Predicted	Difference (dB)
Class 390[4]	8.7	7.1	1.6
Class 221	6.0	7.6	-1.6
Class 220	7.7	7.6	0.1
Class 170	7.6	7.6	0.0

Table 6 The Measured and Predicted Rolling Noise Source Terms

From these data the Class 390 is seen to be noisier than predicted while the Class 221 is quieter. It can also be seen that the Class 221 is quieter than the Class 220. This difference in characteristics has a less than 9% chance of arising by chance.

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[4] Based on a 9-car train comprising 3 trailer cars and 6 motor cars.

8   Conclusions

Source correction terms for rolling noise have been calculated for an agreed set of railway vehicles representing a large proportion of the current types that are absent from the CRN procedure. Measured data have also been provided for a range of freight vehicles, with the permission of EWS. Eventually it would be advisable to base all such terms on measurement, especially if they are to be incorporated within a revised CRN document, but the predicted values presented in this report can be considered to be sufficiently accurate for initial noise mapping purposes.

Rolling noise source term corrections have been obtained by measurement for the Class 390 Pendolino Brittanico tilting electric train, the Class 220 Virgin Voyager Diesel Multiple Unit, the Class 221 tilting Virgin Voyager and the Class 170 Turbostar Diesel Multiple Unit Intrusive traction noise elements and abnormal rolling noise behaviour have been separated from the pass-by characteristics by an iterative process that involves the fitting of idealised pass-by time histories to the measured time histories.

Although the rail head was visually in good condition at the measurement site, measurements of known vehicles (Mk III coaches) showed that it was a little rougher than "CRN" track, and the results have been corrected accordingly.

The corrections are: Class 390, 8.7 dB; Class 221, 6.0 dB; Class 220, 7.7 dB; Class 170, 7.6 dB.

The Class 390 has been shown to be noisier in rolling than predicted in Section 3. The most likely reason for this is that the wheels of the Class 390 have a higher surface roughness than expected. Although it is known that wheels on powered axles tend to have a surface roughness higher than that found on unpowered axles, and the Class 390 has a large number of powered axles, the Class 221 also has a high percentage of powered axles and yet is quieter than predicted. Therefore, it is possible that development of the surface roughness of a powered axle depends on a complex combination of factors.

The significant presence of traction noise from the Class 220 and Class 221 indicates that this noise source should be included additionally within CRN predictions if these vehicles are to be represented accurately in noise maps. Currently DMU traction noise is excluded from the CRN procedure. It is likely that this stock produces higher levels of traction noise than found with earlier DMUs because their engines are more than twice as powerful as those on older units. However, collecting appropriate data would require measurements to be taken where the trains were developing full power, which was not necessarily the case during the current measurements where rolling noise was the prime concern.

9   References

1   Department of Transport, 'Calculation of Railway Noise 1995', published by HMSO
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3   AEJ Hardy and RRK Jones, 'Reducing the Errors when Measuring Railway Noise and Vibration', Proceedings of the Institution of Civil Engineers, Transport 153, Issue 2, May 2002, pages 103-109

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