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Work Package 1.1

Source modelling of road vehicles

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Abstract

The state-of-the-art of acoustic source modelling of road vehicles has been reviewed. Extensive measurements and simulations have been carried out. The aim has been to identify and quantify all relevant parameters influencing the noise emission of road vehicles. The collected information has been used to construct a source model suitable to combine with point-to-point sound propagation theory to calculate day-evening-night weighted yearly average sound pressure levels of road traffic noise.

Each vehicle category is represented by two point sources, each having a specified sound power having contributions from tyre/road (rolling) noise and propulsion noise. As a minimum 3 vehicle categories are used: Passenger cars, medium heavy and heavy vehicles. Additional categories are defined. The medium heavy vehicle has two axles and the heavy vehicle has 3 or more axles but corrections are made for the number of axles. All default data refer to a reference condition: constant speed, 20 ˚C and the average of DAC 0/11 and SMA 0/11 road surfaces. Deviations from these conditions are corrected for. Default data, one constant and one speed coefficient, for rolling noise are given for each frequency band, 25-10000 Hz, using a logarithmic speed dependence. 80% of the rolling noise sound power is assigned a point source at 0,01 m and 20% is assigned a point source at 0,3 m (passenger cars) or 0,75 m (heavy vehicles). Default data, one constant and one speed coefficient, for propulsion noise are given for each frequency band, 25-10000 Hz, using a linear speed dependence. 20% of the propulsion noise sound power is assigned a point source at 0,01 m and 80% is assigned a point source at 0,3 m (passenger cars) or 0,75 m (heavy vehicles). Rolling noise is corrected for different road surfaces and different air temperatures. It is also possible to correct for wetness, studded tyres and number of axles of heavy vehicles. Propulsion noise is corrected for acceleration/deceleration.

All point sources are assigned a specific frequency dependent vertical directivity with the main purpose to take the screening of the car body into account. The lowest point source is assigned a specific frequency dependent horizontal directivity with the main purpose to take the horn effect of the tyre/road source into account. The highest point source for propulsion noise and heavy vehicles is assigned a frequency independent horizontal directivity. Propagation effects are taken into account by giving different acoustic impedances of some different road surfaces.

Key words: road traffic, source model, noise, emission, point source, tyre/road, propulsion, rolling

Contents

1 Introduction

This report deals with point source modelling of road vehicles. It summarizes the state of the art, the work carried out within Harmonoise WP 1.1 and the results and conclusions of WP 1.1.

2 State of the art of source heights

2.1 Current European models

All current European official models from Austria, France, Germany, The Netherlands and the Nordic countries use a point source at 0,3 – 0,75 m height, see e.g. [12]. The lowest height 0,3 m is to be found in the 1999 version of the French Mitra 4.0 and the highest 0,75 m from the Dutch model dating back from 1981 [1].

2.2 The new Nordic model

In the new Nordic model, Nord 2000 the following source model is used:

Table 2.1 Passenger cars. Source locations.

	Height	**Frequency range**
Source 1	0,01 m	25-10000 Hz
Source 2	0,15 m	25-10000 Hz
Source 3	0,30 m	25-10000 Hz

1) Often frequencies below 50 Hz and above 5000 Hz can be neglected.

All sources are assigned equal strength, that is the total sound power is distributed equally between them. The horizontal directivity of passenger cars is given in table 2.2. The angle φ is shown in figure 2.1.

Table 2.2 Passenger cars. Horizontal directivity, see figure 2.1.

	Height	**Frequency range**	**Directivity**
Source 1	0,01 m	1600 - 10000 Hz	-5 + 7 abs(cos(φ))
Source 2	0,15 m	1600 - 10000 Hz	-5 + 7 abs(cos(φ))
Source 3	0,30 m	1600 - 10000 Hz	-5 + 7 abs(cos(φ))

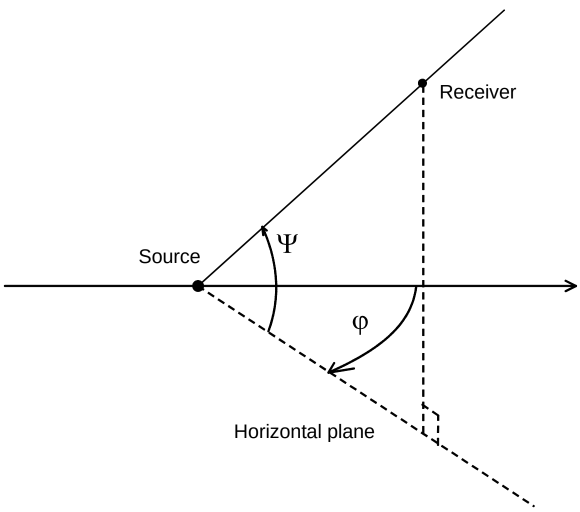


Figure 2.1 Sketch of angles of directivity

Table 2.3 Heavy vehicles. Source location.

	Height	**Frequency range**
Source 1	0,01 m	2 000-10000 Hz
Source 2	0,15 m	25(250)-10000 Hz
Source 3	0,30 m	25(250)-10000 Hz
Source 4 Vertical exhaust only	3,2 m	50-200 Hz

Table 2.4 Heavy vehicles. Horizontal directivity, see figure 2.1.

	Height	**Frequency range**	**Directivity**
Source 1	0,01 m	1600 - 10000 Hz	-5 + 7 abs(cos(φ))
Source 2	0,15 m	1600 - 10000 Hz	-5 + 7 abs(cos(φ))
Source 3	0,30 m	1600 - 10000 Hz	-5 + 7 abs(cos(φ))

The sound power is distributed equally between all sources indicated within the frequency range specified.

The vertical directivity is recognized but no corrections are made due to lack of data.

2.3 The American TNM

The American TNM model, [11], uses two source heights, one at 0 height and one at 1,5 m, with a distribution of sound power between them. The effective heights, which is a height weighted to take into account the power distribution, are given in table 2.5, [8]:

Table 2.5 Effective source heights in TNM

Vehicle	**Throttle**	**Frequency (Hz)**	**Effective height (m)**
Auto	All	< 800 > 2000	0,44 0,06
Medium Trucks 6 tyres	Cruise	< 400 >2000	0,57 0,13
Heavy trucks > 6 tyres	Cruise	<800 >1000	1,38 1,01

2.4 Some recent references

In [2] from 1999 it is concluded that the dominating noise sources from both passenger cars and heavy vehicles are located under the car body. Comparisons with propagation calculations indicate that it is not sufficient to use one source height only. As to engine noise it is indicated that the engine is well screened and the conclusion is drawn that the most important engine source is the image engine, which, accordingly, is located below the surface of the road. Measurements also show that, for passenger cars, the source is best located level with the nearest wheels, and, for heavy vehicles, on the centre axis of the vehicle.

In [4] from 2001 array measurements are reported, which indicate that the dominating source heights are about 0,5 m below 500 Hz and about 0 m at 500 Hz and above. There is no significant difference between light and heavy vehicles.

In [5, 6] from 2001 it is concluded that it is preferable to lower the source height used in the French NMTB from 0,5 m to 0,05 m.

In [7] from 2001 some measurements with barriers yield the conclusion that the equivalent source height is at 0,4 m.

In [13] a mathematical model is applied to pass-by data from 30 vehicles. It is concluded that a single low source gives a better agreement with real data than the Nord 2000 three source model with equal weighting between the sources. However, by using different weightings between the sources an even better agreement can be achieved. It should be observed that the data used refer to propagation across hard asphalt only whereas the Nord 2000 method relied on more sensitive propagation across grassland.

In [26] array measurements are used to derive the source heights given in table 2.6.

Table 2.6 A-weighted sound power levels L_W in decibels re 1 pW, per octave band and per (partial)-source at height h, for five categories of vehicles, driving on motorways with a maximal admitted driving speed of 120 km/h

centre octave-band	vehicle category									
	passenger cars		lorries mean		lorries heavy		busses		motor-cycles	
f [Hz]	*h* [m]	L_w [dB]	*h* [m]	L_w [dB]	*h* [m]	L_w [dB]	*h* [m]	L_w [dB]	*h* [m]	L_w [dB]
63	0,6 1,5	73 68	0,7	81	0,7	78	0,7	78	0,4	84
125	0,6 1,5	85 80	0,7	89	0,7	86	0,7	86	0,4	92
250	0,4 1,3	91 83	0,2 1,0	94 91	0,2 1,0	94 91	0,2 1,0	91 88	0,4 0,9	97 93
500	0,0 1,2	97 87	0,0 0,7	102 97	0,0 0,7	105 99	0,0 0,7	100 94	0,4 0,9	99 92
1000	0,0 1,0	104 92	0,0 0,7	105 96	0,0 0,7	106 98	0,0 0,7	102 92	0,0 0,4	94 94
2000	0,0 1,0	103 80	0,0 0,7	102 92	0,0 0,7	101 92	0,0 0,7	98 88	0,0 0,4	94 92
4000	0,0 1,0	94 71	0,0 0,7	93 83	0,0 0,7	92 83	0,0 0,7	89 79	0,0 0,4	89 87
8000	0,0 1,0	84 61	0,0 0,7	84 74	0,0 0,7	83 74	0,0 0,7	80 70	0,0 0,4	80 78

2.5 Discussion and conclusions

The most recent studies all point at locating the major noise sources below the body of the vehicle. The important tyre/road source is located very close to the road surface but it should also have some distribution in height due to vibrations of the tyre sides and reflections in the car body. It may be necessary to average over several heights. At low frequencies it may be necessary to add some source at a higher position.

In order to find out the best combination of different source heights it is necessary to compare calculations using different models with well defined measurements. It will be difficult to find a perfect solution. Figure 2.2 shows an example. We can see that a 0,3m high source gives a good fit to measurements up to 800 Hz whereas a 0,01 high source gives a reasonable fit at 2000 Hz and above. In between it is possible to get a good fit by weighting the two heights. As a comparison the Nord 2000 approach using 3 equally weighted sources are shown.

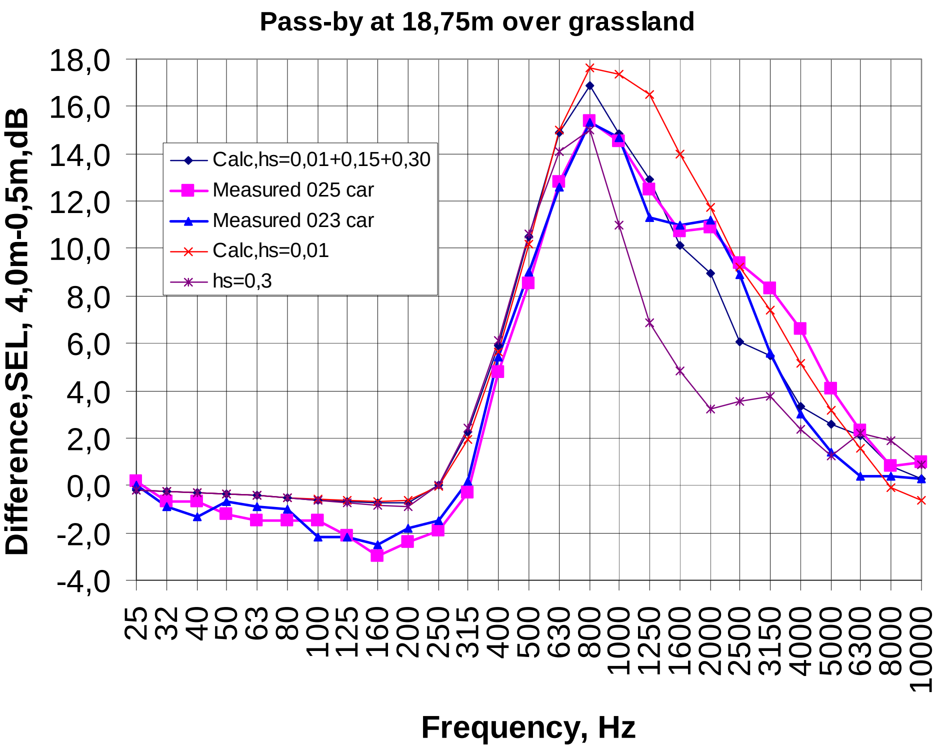


Figure 2.2 Pass-by measurements at about 70 km/h with two microphone positions at the heights 4,0 m and 0,5 m respectively. propagation over grassland with the flow resistivity 160 kPas/m². Horn effect is included above 1250 Hz.

3 State of the art of directivity

3.1 Current official models

At present there is none including complete directivity data. Nord 2000, which is not yet officially adopted by the authorities, includes corrections for the horn effect, see table 2.2 and 2.4 in 2.2 and some corrections are also used in Japan, see 3.3.

3.2 Tyre/road noise and the horizontal plane

In [9] it is shown that the horn effect at 1000-3000 Hz increases the radiation in the forward direction by 5-10 dB relative the perpendicular direction. The lower figure is applicable for tyre without car body and the higher figure includes the car body. If distance effects are included the most important angle of radiation is 45º - 60º.

3.3 Complete vehicle

In [10] A-weighted measurements are reported for actual vehicles. The results show that there is little directivity in the vertical plane up to about 45° to the horizontal plane. After that the sound power level decreases up to about 5 dB. In the horizontal plane the radiation has its minimum, as predicted by the horn effect, perpendicular to the road. At 45° it has increased 3 (heavy vehicles)-5 (passenger cars) dB. The radiation is a little higher in the backward direction. Similar data are reported in [20] and octave band data have been made available by [19]. Two examples of data are shown in figure 3.1 and 3.2. The corresponding data are also available for light and heavy trucks. The reference for the two figures is the omnidirectional sound power level + 10 dB. The measurements took place at 40 km/h which means that engine noise is fairly important and that the horn effect is not as predominant.

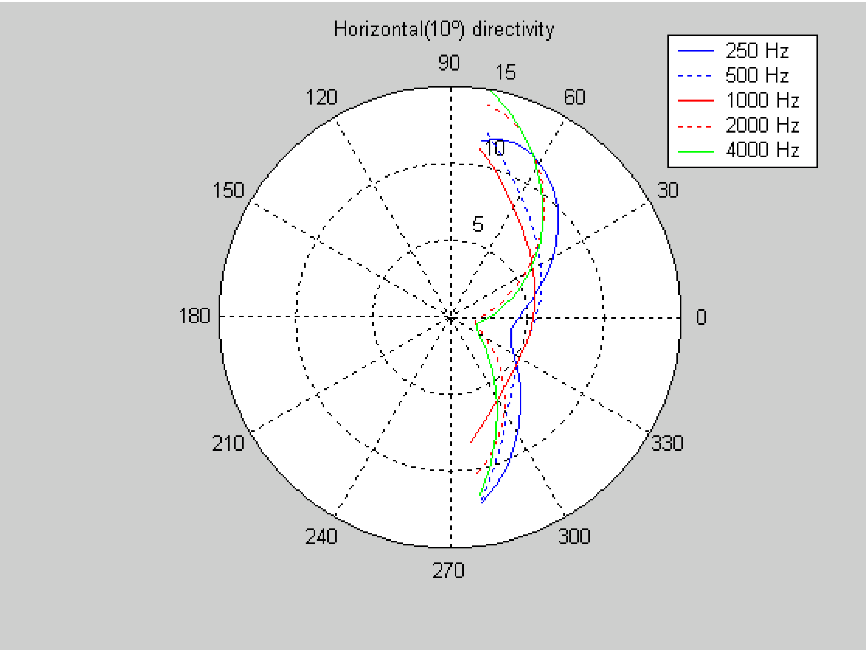


Figure 3.1 Directivity of passenger cars at 40 km/h in the horizontal plane at a vertical angle corresponding to a microphone height of 1,2 m at 7,5 m distance, from [19, 20]

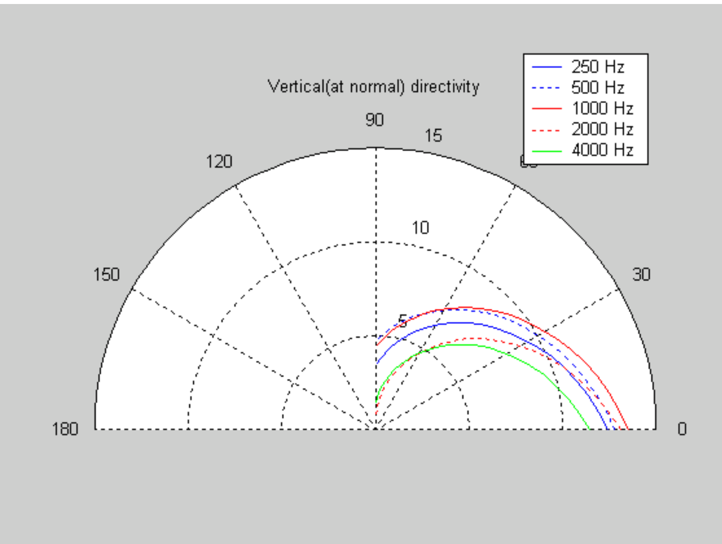


Figure 3.2 Directivity of passenger cars at 40 km/h in the vertical plane at a horizontal angle perpendicular to the car, from [19].

3.4 Conclusions

There seems to be little frequency band data available on the directivity of the sound power level emitted by road vehicles. There is, however, no doubt that the directivity due to the horn effect and to the shielding effect of the car body should be included in an accurate source model. At very high frequencies (>1250 Hz) the horizontal directivity seems to be asymmetrical. The radiation is greater in the backwards direction.

4 State of the art of source strength

4.1 General

The aim of Harmonoise is to separate emission and propagation completely and to work within a wide frequency range. This means that very much old information cannot be used, at least not without corrections. There are comparatively few data available complying with these two requirements.

4.2 Nord 2000

Nord 2000 describes the source strength as the sound power level as a function of speed for different vehicle categories. Frequency band data are available for the range 25-10000 Hz. The sound power levels have been determined from measurements of the SEL-level during pass-by and the source model has been used to calculate the equivalent omni-directional sound power level. For different vehicle categories the energy average of many pass-bys has been determined in steps of 5 km/h. Several thousands of measurements have been carried out. In figure 4.1 some results for vehicles of category 1a (normal passenger cars) are shown. In the first version of Nord 2000 only 3 vehicle categories are used: Passenger cars, dual axle heavy vehicles and multi axle vehicles. The data bank includes road temperature and type of pavement but these data are not used at present. There is no separation between different sources and all the sound power is equally distributed between the different sources used.

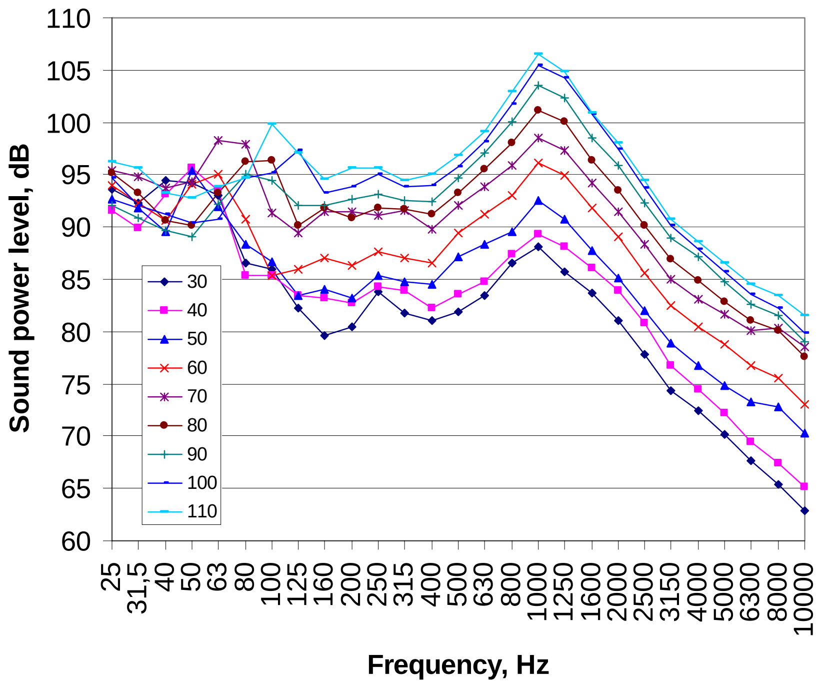


Figure 4.1 Examples of sound power levels of vehicles of type 1a on a road surface of type 2a. The parameter is speed in km/h.

4.3 The French NMPB

This model, [16], has two vehicle categories: light and heavy vehicles. The starting point is A-weighted sound power levels as a function of speed. All vehicles are assigned the same speed independent sound power spectrum. The spectrum is the same as the one standardized in ISO 717-1 for rating of airborne sound insulation and EN 1793-3 for rating of sound insulation of roadside noise barriers.

4.4 Other current European prediction methods

An overview of European methods is given in [12].

The French NMPB works with sound power levels in octave bands, 125-4000 Hz. As spectrum the standardized EN/ISO spectrum used in ISO 717/1 and EN 1793-3 is used. This spectrum is speed independent.

The German RLS from 1990 uses L_{Aeq} 25 m from the lane at 3,5 m as emission index. It is given as function of traffic flow, speed and percentage of heavy vehicles.

The Dutch model from 1981 uses the octave band (63-8000 Hz) sound power level per metre line segment. 4 types of vehicles are used: Light vehicles, light trucks, heavy trucks and motorcycles. It is given as function of vehicle flow and speed. Revised, new data from [26] have been determined as shown in table 4.1.

Table 4.1 A-weighted sound power levels LW in decibels re 1 pW, as a function of the logarithm of the driving speed v [km/h], per octave band with centre frequency f, to be applied in the prevailing more or less advanced Dutch Standard Calculation Scheme II. The values of a+ and b in L_W = a+ + b×lg(v) have been determined from measurements performed in 1996 and in 1999, [26].

f	passenger car	lorry		motorcycle
		mean	heavy	
[Hz]	25<v<170	34<v<120	23<v<120	40<v<195
	$A_+ + B{\cdot}\lg(v)$	$A_+ + B{\cdot}\lg(v)$	$A_+ + B{\cdot}\lg(v)$	$A_+ + B{\cdot}\lg(v)$
63	75,5 – 0,5·lg(*v*)	80,3 – 0,2·lg(*v*)	66,0 + 9,8·lg(*v*)	26,7 + 28,9·lg(*v*)
125	37,7 + 24,6·lg(*v*)	60,5 + 16,6·lg(*v*)	70,4 + 11,4·lg(*v*)	35,4 + 28,9·lg(*v*)
250	37,4 + 27,6·lg(*v*)	92,5 + 2,5·lg(*v*)	92,9 + 2,6·lg(*v*)	41,8 + 28,9·lg(*v*)
500	44,3 + 26,1·lg(*v*)	51,4 + 26,6·lg(*v*)	62,0 + 23,2·lg(*v*)	44,4 + 28,9·lg(*v*)
1000	50,1 + 26,8·lg(*v*)	62,2 + 22,3·lg(*v*)	68,1 + 20,8·lg(*v*)	40,9 + 28,9·lg(*v*)
2000	56,2 + 22,5·lg(*v*)	69,8 + 16,6·lg(*v*)	74,7 + 15,0·lg(*v*)	41,2 + 28,9·lg(*v*)
4000	48,7 + 22,2·lg(*v*)	64,0 + 16,2·lg(*v*)	72,7 + 12,4·lg(*v*)	37,8 + 28,9·lg(*v*)
8000	58,7 + 11,7·lg(*v*)	89,1 – 1,9·lg(*v*)	92,7 – 3,1·lg(*v*)	31,6 + 28,9·lg(*v*)
SRMI	16,9 + 27,6·lg(*v*)	38,1 + 19,0·lg(*v*)	43,0 + 17,9·lg(*v*)	14,8 + 28,9·lg(*v*)

The Nordic model, last updated in 1996, uses the sound exposure level L_{AE} at 10m during pass-by of light and heavy vehicles respectively. In addition the maximum levels are used.

The UK method uses L_{A10} at 10m from the carriageway edge, adjusted for traffic flow and speed.

4.5 The American TNM

This model, [11], uses the maximum sound pressure level (expressed in energy form) during pass-by at 15 m after propagation across generally absorptive terrain. This means that there is no complete separation between emission and propagation effects. TNM uses the A-weighted levels as starting point and include equations to calculate spectrum as a function of the A-weighted level. The following vehicle categories are used: Automobiles, medium trucks, heavy trucks, buses and motor cycles. Two operating conditions are given: Cruise throttle and full throttle. In addition two different road pavements are used.

4.6 Mathematical models

The ideal situation would be to have a complete description of the sound power emission for each of the major sources, that is for power train (engine, transmission, exhaust), tyre/road and, if relevant, aerodynamical noise. Some efforts have been made to create mathematical models describing the effects. These models have normally been based on empirical measurements and used regression analysis to obtain formulas like

$$L_{W,i} = a_i + b_i \lg(v) \quad (1)$$

where *i* indicates a frequency or a specific source. Thus we will get a very large number of coefficients.

Eq. (1) would probably work rather well for tyre/road noise. However, for power train noise, the situation may be different, particularly at low speeds where gear changes make things more complicated.

4.7 Different road surfaces

An overview is given in [27] from where table 4.2 has been taken, see next page. In the Netherlands an octave band correction is used for 24 different road surfaces for light vehicles and for 19 different surfaces for heavy vehicles, see www.stillerverkeer.nl/stillewegdekken/. Most of the road surfaces are trade marks and the speed range is limited. There is also an overview in [31].

A problem with data reported in the past is that there is no separation berween the generation and propagation of the sound. Most measurements have been carried out at about 6,5 m from the nearest tyre at a height of 1,2 m. If the surface is porous the attenuation during propagation cannot be neglected.

4.8 Different road temperatures

It is generally accepted that the road temperature will affect tyre/road noise. The sound power level with decrease with temperature. The EU Directive 2001/43/EC on tyre noise has the following correctio which is probably a little conservative:

$$L_R(\Theta_{ref}) = L_R(\theta) + K(\theta_{ref} - \theta) \qquad (2)$$

where

L_R = corrected sound pressure level, dB

θ = the measured test surface temperature

θ_{ref} = the reference temperature, 20ºC

K = the temperature coefficient:

K= -0,03 dB/ºC for passenger cars when $\theta > \theta_{ref}$ and –0,06 dB/ºC when $\theta < \theta_{ref}$

K= -0,02 dB/ºC for light trucks and vans

K= 0 dB/ºC for trucks.

Very accurate corrections are more difficult to make as the coefficient may vary between different road surfaces and tyres. There may also be a frequency dependence. A more detailed overview of the problem is given in [31].

4.9 Different tyres

The problem with different tyres is that the rank order may change from pavement to pavement. Thus it becomes very difficult to make corrections. An overview of the problem can be found in [31].

4.10 Conclusions

Most emission data does not exist in a suitable form to be used in the Harmonoise project. The only exception is Nord 2000 which uses exactly the same concept as the one planned for Harmonoise. However, as detailed sound power data can be used to calculate any other measure it is possible, at least to some extent, to use available data to verify new Harmonoise models.

Table 4.2 A compilation of road surface corrections currently applied in various European noise prediction models (EU project AR-INTERIM-CM and [27].

Legend (colour key): -2 and –3; -1 dBA; 1 dBA; 2 and 3 dBA

UNITED KINGDOM CRTN

Category	ROAD SURFACE	CORRECTIO LOW	MED	HIGH
POROUS SURFACES CORRECTION<0	Pervious road surface		-3.5	
LOW NOISE SURFACES CORRECTION<0	Impervious concrete TD<0.8 (*) Impervious asphalt TD<2 (*)	-1	<0	<0
REFERENCE SURFACES CORRECTION = 0	Impervious concrete TD=0.8 (*) Impervious asphalt TD=2 (*)	-1	0	0
NOISY SURFACES CORRECTION>0	Impervious concrete TD>0.8 (*) Impervious asphalt TD>2 (*)	-1	>0	>0
PAVE-MENTS CORREC-TION >>0				

NETHERLAND SRM II

Category	ROAD SURFACE	CORRECTIO LOW	MED	HIGH
POROUS SURFACES CORRECTION<0	Fluisterfalt	-2.6	-3.6	
	Very open double layer asphaltic concrete ZOAB 4/8-11/16	-1.4	-2.6	-3
	Very open asphaltic concrete ZOAB		-1.7	-2.3
LOW NOISE SURFACES CORRECTION<0	Discontinued concrete 4/7 (new road surfacing)		-0.9	
	Novachip (new road surfacing)	-0.6	-0.7	
REFERENCE SURFACES CORRECTION = 0	Asphaltbeton (DAB)		0	
	Stone mastic asphalt SMA 0/6	0	-0.5	
	Washed concrete		-0.1	0.4
	Concrete with surfacing treatment		0.3	0.2
NOISY SURFACES CORRECTION>0	Fijngebezemd beton		0.7	1.5
	Asphalt with surfacing treatment		1.1	1.2
PAVE-MENTS CORREC-TION >>0	Pavement	2.3	2	2

GERMANY RLS 90

Category	ROAD SURFACE	CORRECTIO LOW	MED	HIGH
POROUS SURFACES CORRECTION<0	Porous asphalt with more than 15% pores 0/8 type	0	-5	
	Porous asphalt with more than 15% pores 0/11 type	0	-4	
LOW NOISE SURFACES CORRECTION<0	Concrete with burlap cloth (smooth)	0	-2	
	Asphalt concrete without grit	0	-2	
REFERENCE SURFACES CORRECTION = 0	Non grooved asphalts, asphalt concrete		0	
NOISY SURFACES CORRECTION>0	Concrete with metal broom treatment		1	
	Concrete or grooved asphalt		2	
PAVE-MENTS CORREC-TION >>0	Cobblestones with smooth		3	
	Cobblestones with rough texture		6	

AUSTRIA RVS

Category	ROAD SURFACE	CORRECTIO LOW	MED	HIGH
POROUS SURFACES CORRECTION<0	Drainage asphalt	-1.8	-2.6	-3.1
LOW NOISE SURFACES CORRECTION<0				
REFERENCE SURFACES CORRECTION = 0	Asphaltic concrete		0	
NOISY SURFACES CORRECTION>0	Concrete or grooved asphalt	1	1.7	2.1
PAVE-MENTS CORREC-TION >>0	Granite block pavement		Constant emision	

NORDIC NMR-96

Category	ROAD SURFACE	CORRECTIO LOW	MED	HIGH
POROUS SURFACES CORRECTION<0	Porous asphalt (max 8-12 mm) newly laid	-3	-5	-5
	Porous asphalt (max 14-16mm) newly laid	-2	-3	-3
	Porous asphalt (max 8-12mm) medium aged	-1	-2	-3
	Porous asphalt (max 14-16mm) medium	-1	-1	-2
	Porous asphalt (max 8-12mm)	0	-1	-2
	Porous asphalt (max 14-16 mm)	0	-1	-1
LOW NOISE SURFACES CORRECTION<0	Cement concrete ground (grinding not	-1	-2	-1
	Mastic asphalt (SMA) (max 8-10 mm)	-1	-1	-1
	Asphaltic concrete dense smooth (≤8-10	0	0	-1
	Chip seal double (Y2) max 10-12 mm	0	-1	-1
	Chip seal double (Y2) max 14-20 mm	0	-1	0
REFERENCE SURFACES CORRECTION = 0	Asphaltic concrete dense smooth (≤12-16		0	
	Mastic asphalt (SMA) (max 12-14 mm)			
	Chip seal single (Y1) max 10-12 mm			
	Chip seal single (Y1) max 6-8 mm			
	Cement block pavement			
NOISY SURFACES CORRECTION>0	Chipped asphalt (BCS) ("hot rolled" asphalt)	0	0	1
	Chip seal single (Y1) (max 16-20 mm)	0	0	1
	Cement concrete dense smooth(≤ 12-18	1	2	2
	Cement concrete dense smooth(≤ 20-80	1	2	2
PAVE-MENTS CORREC-TION >>0	Paving stones, cobble stones (older type)	3	3	4

TABLE 7: Road surface categories

(*) TD = Texture depth. Surface correction when v≥ 75 km/h for concrete: 10* Log(90*TD+30)-20 dBA; for asphalt: 10* Log(20*TD+60)-20 dBA

5 Result summary of work carried out in WP 1.1

5.1 Vehicle categorization

This is described in [21] and the result is given in table 5.1.

Table 5.1 Summary of vehicle categories to be used in HARMONOISE. Note that this table is primarily for the data collection phase of the project. When it comes to the final model, one must take the availability of vehicle data for a certain road into consideration. See the discussion in the text and in Annex A in [21].

Main category (type)	No.	Sub-categories: Example of vehicle types	Notes
Light vehicles	1a	Cars (incl MPV:s up to 7 seats)	2 axles, max 4 wheels
	1b	Vans, SUV, pickup trucks, RV, car+trailer or car+caravan(1), MPV:s with 8-9 seats	2-4 axles(1), max 2 wheels per axle
	1c	Electric vehicles, hybrid vehicles driven in electric mode(2)	Driven in combustion engine mode: See note
Medium heavy vehicles	2a	Buses	2 axles (6 wheels)
	2b	Light trucks and heavy vans	2 axles (6 wheels)(3)
	2c	Medium heavy trucks	2 axles (6 wheels)(3)
	2d	Trolley buses	2 axles
	2e	Vehicles designed for extra low noise driving	2 axles(5)
Heavy vehicles	3a	Buses	3-4 axles
	3b	Heavy trucks(4)	3 axles
	3c	Heavy trucks(4)	4-5 axles
	3d	Heavy trucks(4)	≥6 axles
	3e	Trolley buses	3-4 axles
	3f	Vehicles designed for extra low noise driving	3-4 axles(5)
Other heavy vehicles	4a	Construction trucks (partly off-road use)(4)	
	4b	Agr. tractors, machines, dumper trucks, tanks	
Two-wheelers	5a	Mopeds, scooters	Include also 3-wheel motorcycles
	5b	Motorcycles	

(1) 3-4 axles on car & trailer or car & caravan

(2) Hybrid vehicles driven in combustion engine mode: Classify as either 1a or 1b

(3) Also 4-wheel trucks, if it is evident that they are >3.5 tons

(4) If a high exhaust is noted, identify this in the test report. Categorize this as 3b', 3c', 3d' or 4a'

(5) For example, there are some delivery trucks designed for extra low noise (meeting more stringent standards than the current EU limiting levels) combined with a driving mode called "Whisper mode" making it possible to drive in a residential area with much lower noise emission than for a conventional delivery truck. All trucks and buses especially designed in accordance with these ideas are counted in this category.

5.2 Road surface characterization

5.2.1 General

The basic principle is

- Standardized notation is introduced (DAC 0/8, SMA 0/13,PAC 4/8, etc.) to standardize the description of road surfaces;
- Reference surfaces are used to calibrate data;
- Corrections are made on tyre/road (rolling) noise in each 1/3 octave band whenever possible, otherwise all frequency bands are corrected equally.

This is a summary of the description given in [27].

5.2.2 Notation to use

The following notation should be used when collecting data on road surfaces and noise generation:

Table 5.2 Proposed standardized notation for road surfaces for the use in HARMONOISE. Note that all digits related to dimensions are in mm.

Main acronym	***Detailed acronym*** *Common variants for different aggregate compositions (maximum chipping size, etc)*	***Surface description***	***Notes***
Bituminous mixes ("asphalt" surfaces)			
DAC	DAC 0/8, DAC 0/11, DAC 0/14, DAC 0/16	Dense asphalt concrete	In DAC 0/8, the digit 8 denotes the max. chipping size. Use this principle also for other max. chipping sizes
SMA	SMA 0/8, SMA 0/11, SMA 0/14, SMA 0/16	Stone mastic asphalt	In SMA 0/8, the digit 8 denotes the max. chipping size. Use this principle also for other max. chipping sizes
OGAC	OGAC 4/8, OGAC 6/11, OGAC 8/14, OGAC 8/16	Open-graded asphalt concrete, voids 15-19 % (when new)	In OGAC 4/8, the digits 4/8 denote the dominating chipping sizes in the mix. Use this principle also for other types
PAC	PAC 4/8, PAC 6/11, PAC 8/14, PAC 8/16	Porous asphalt concrete (single-layer), voids ≥20 % (when new)	In PAC 4/8, the digits 4/8 denote the dominating chipping sizes in the mix. Use this principle also for other types
DPAC	DPAC 4/6+8/11, DPAC 4/8+11/16, PAC 6/11+11/16	Porous asphalt concrete (double-layer)	In DPAC 4/6+8/11, the digits 4/6 denote the dominating chipping sizes in the mix of the upper layer; the digits 8/11 the same for the bottom layer. Use this principle also for other types
GA	GA 5/8, GA 8/11	Gussasphalt = mastic asphalt, surface common in Germany, usually has chippings rolled into it	In GA 5/8, the digits 5 and 8 denote the range of chippings sprayed on the surface. Use this principle also for other chipping sizes.
HRA	HRA 8/11, HRA 11/16	Hot rolled asphalt, surface common in the U.K., always has chippings rolled into it	In HRA 8/11, the digits 8 and 11 denote the range of chippings sprayed on the surface. Use this principle also for other chipping sizes.
THS	THSDAC 0/6, THSDAC 0/8, THSSMA 0/6,	Thin surfacing (non-proprietary), based on either a DAC or SMA mix	In the numbers 0/6, the digit 6 denotes the max. chipping size. Use this principle also for other max. chipping sizes

	THSSMA 0/8		
ISO-S		Reference smooth surface according to ISO 10844	Since it is likely that there will (later) be also a second (rough) surface according to ISO 10844, add the -S
ISO-R		Reference rough surface according to ISO 10844	This does not yet exist but it is likely to be introduced before about 2007
Rubberized surfaces			
DACR	DACR6 0/11	Asphalt rubber = DAC surface with rubber added (>2% and <20% by weight)	In DACR6 0/11, 6 denotes the rubber proportion of the total mix (by weight), 0/11 is the range of chippings in the mix (see DAC). Rubber could be added either to the aggregate or to the binder
PERS	PERS 50, PERS 85	Poroelastic road surface (≥20 % by weight is rubber)	In PERS 50, the number 50 denotes the proportion of the mix (by weight) that is rubber
Surface dressings (often called "chip seals")			
SDS	SDS 4/8, SDS 8/11, SDS 11/16	Surface dressing (single)	In SDS 8/11, the digits 8 and 11 denote the range of chippings sprayed on the surface. Use this principle also for other chipping sizes.
SDD	SDD 4/8+8/11, SDD 8/11+11/16	Surface dressing (double)	In SDD 8/11+11/16, the digits 8 and 11 denote the range of chippings sprayed in the top layer; 11/16 is the range for the bottom layer. Use this principle also for other chipping sizes.
Cement concrete (often called just "concrete")			
CC	CC 0/8, CC 0/11, CC 0/14, CC 0/16, CC 0/22	Cement concrete (often referred to as just "concrete") – untreated	In CC 0/8, the digit 8 denotes the max. chipping size. Use this principle also for other max. chipping sizes
CCDG	CCDG 3-6	Cement concrete – diamond ground (longitudinally)	In 3-6, 3 is the width of the grooves or tines, 6 is the c-c spacing of them
EACC	EACC 0/8, EACC 0/11, EACC 0/14, EACC 0/16, EACC 0/22	Exposed Aggregate Cement Concrete	In EAAC 0/8, the digit 8 denotes the max. chipping size in the exposed layer. Use this principle also for other max. chipping sizes
CCHD		Cement concrete with Hessian drag treatment	US term is "Burlap drag". Texturing the concrete surface while fresh by dragging a jute cloth over surface
CCAT		Cement concrete with Astroturf treatment	Texturing the concrete surface while fresh by dragging an Astroturf plastic "doormat" over surface
CCTG	CCTG 5-15/30	Cement concrete with transversal grooves or tines	In 5-15/30, 5 is the width of the grooves or tines, 15/30 is the minimum and maximum c-c spacing of them
CCLG	CCLG 5-15/30	Cement concrete with longitudinal grooves or tines	In 5-15/30, 5 is the width of the grooves or tines, 15/30 is the minimum and maximum c-c spacing of them
PCC	PCC 4/8, PCC 8/11,	Porous cement concrete	In PCC 4/8, the digits 4/8 denote the dominating chipping sizes in the mix. Use this principle also

	PCC 8/16	(single-layer)	for other types
Proprietary surfaces			
xxxxx	These often have only one single composition	Various proprietary surfaces	Apply the term used by the company owning the rights to this surface
Paving block surfaces			
ILCB	ILCBd 100/200, ILCBt 100/200	Inter-locking cement block surfaces (moulded blocks)	In ILCBd or ILCDt, d denotes diagonal orientation of the blocks, t denotes transversal orientation (to the driving direction). The number 100 denotes the smallest horizontal dimension of a block, 200 the largest
PS	PSd 100/200, PSt 100/200	Paving stones, flat surface, square or rectangular cut stones	Same terminology as for ILCB
CS	CS 150	Cobble stones, old type of paving stones (rounded stones)	In CS 150, the number 150 refers to the average spacing (centre-centre, c-c) of the cobble stones

5.2.3 Reference surfaces

For comparison with measurements in other countries it is recommended to carry out measurements on a reference surface. Since the reference surface type must be one that is reasonably common in each member state, and states have different preferences and policies, it is impossible to define one and only one reference surface. Instead, it is proposed to define a “cluster” of reference surfaces having fairly similar noise characteristics. These are partly consistent with ISO 11819-1 but the maximum chipping size has been expanded downwards to 8 mm and are as follows:

DAC 0/08, DAC 0/09, DAC 0/10, DAC 0/11, DAC 0/12, DAC 0/13, DAC 0/14, DAC 0/16

SMA 0/08 SMA 0/09 SMA 0/10, SMA 0/11, SMA 0/12, SMA 0/13, SMA 0/14, SMA 0/16

A ”Golden reference” is defined within this reference cluster, which is the ideal reference surface on which the basic values of HARMONOISE are based. It is a virtual reference defined as the average of SMA 0/11 and DAC 0/11 1 year or older but not at the end of its life time. Then, depending on the actual reference surface used in a particular country and in a particular situation, one may make small corrections that normalizes the actually chosen reference surface to the “Golden reference”, see figure 5.1. The corrections are given in tabular form in clause 6. For further details see another technical report within HARMONOISE, dealing specifically with this issue [30].

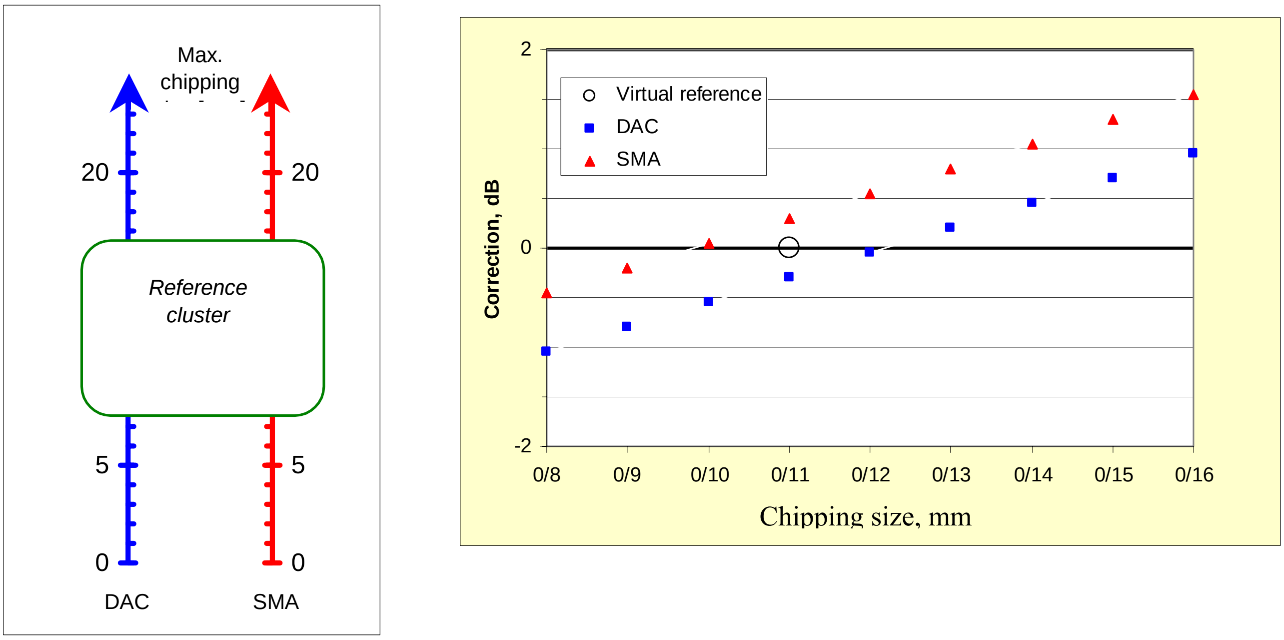


Figure 5.1 Corrections to use for different reference surfaces

5.2.4 Road surface characterization

When collecting new data the information given in table 5.3 should be recorded.

Table 5.3 Information to record when collecting data.

Measure or description	Example	Notes
Basic surface type , see 5.2.2	DAC, SMA,	Man
Maximum chipping size	11 mm, 16 mm	Man
Grading curve of mix	(Percent passing by sieve size)	Opt
Age of the surface	4 years	Man
Total traffic exposure (No. of axles passing)	3 300 500 axles	Opt
Composition of traffic (% of heavies, % of studded tyres)	11 % heavies, 55 % of tyres are studded in wintertime	Opt
Posted speed limit	70 km/h	Man
Type of road, measured lane	Motorway, 2x3 lanes, rightmost lane	Man
Grade (longitudinal slope)	2,5 %	Opt
Condition of surface (subjective, incl homogeneity)	Surf in partly worn cond., tracks visible but not deep, lateral variation clearly visible, binder worn away in wheel tracks only	Man
Surface texture - MPD (ISO 13473-1) Surface texture - L_{T63} (ISO 13473-2) Surface texture - L_{T4} (ISO 13473-2)	1,03 mm 0,87 mm 0,57 mm	Opt Opt Opt
Sound absorpt coeff as a function of freq (ISO 13472-1)* or impedance	Sound absorp coeff versus frequency or impedance or parameters according to a certain impedance model	Opt
Unevenness (CEN prEN 13036-x)	2,2 IRI	Opt

* Applicable only to potentially porous surfaces. Man = Mandatory. Opt = Optional

5.2.5 Corrections to use

Road surface corrections to apply on tyre/road noise depend on:

- Surface type (> 100 surface types, but only a few will be included in the first Harmonoise model)
- Vehicle categories (light and heavy)
- Speed (a + b log expression)
- Frequency band
- Directivity
- Age of surface

It is assumed that the changed directivity of porous surfaces relative harder surfaces is explained by a different propagation effect, which is automatically included in the propagation model by assigning a different impedance to the road surface. Thus the directivity of the noise radiating from the vehicle will be assumed to be constant for all road surfaces.

5.2.6 Impedance and propagation effects

A problem with many road surface measurements is that the measurements have been made with a microphone height of 1,2 m. In that case there may be a significant propagation effect, particularly for porous surfaces, and it is no longer possible to distinguish between generation and propagation effects without taking the propagation effect into account. In figure 5.2 it is shown that the one parameter impedance model, see [38], with a flow resistivity of 3 MPas/m^2 gives a good fit to measured values on an ISO test road surface (in principle $\alpha \leq 0,1$ between 400-1600 Hz). In figure 5.3 it is shown that there is a significant difference between a measurement at 3,0 m and one at 1,2 m. The difference is limited to about 2 dB for the ISO surface but for a porous asphalt following the Hamet impedance model, see [38], it is as great as 6 dB. The major sound source has been assumed to be at the height 0,01 m above the road surface. For normal road surfaces the one parameter model have been shown to work well, [2, 13] although it is not physically correct at low frequencies. Flow resistivity values between 20 and 200 MPas/m^2 have been used.

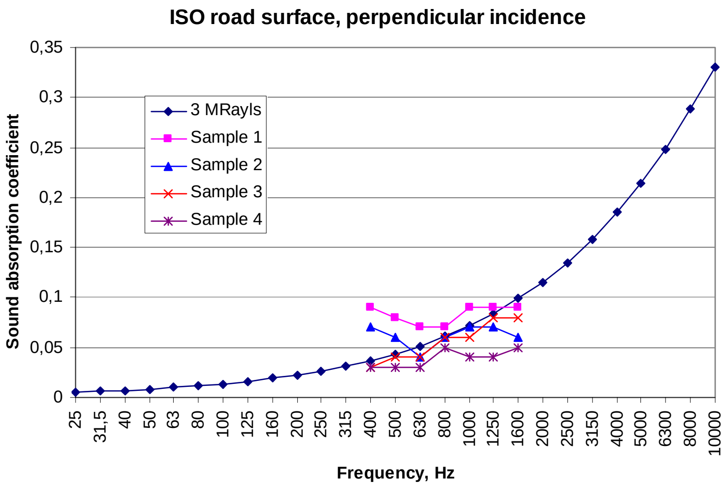


Figure 5.2 Calculated and measured sound absorption for a road surface according to ISO 10844 for pass-by measurements.

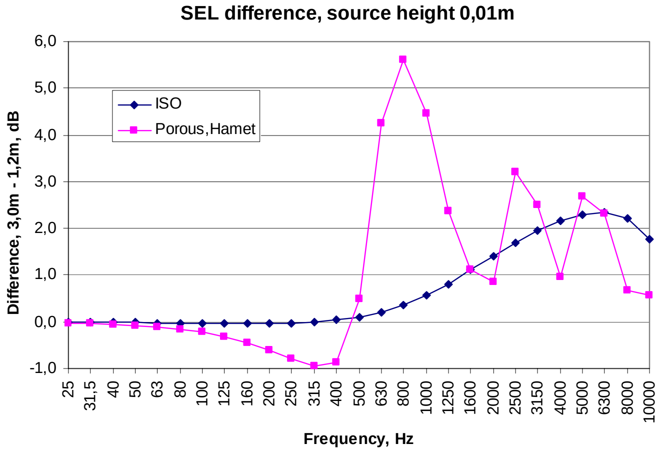


Figure 5.3 Calculated differences between the SEL at 3,0 m and 1,2 m during pass-by tests on an ISO surface and a porous surface.

The conclusion of the above is that the one parameter model works well for road surfaces at least as hard and dense as the ISO surface and that measurements carried out at 1,2 m height must be handled with care. It should be noted that the Dutch measurements referred to above have been carried out using a microphone height of 5 m which should have minimized propagation effects.

The road surface will not affect the generation of propulsion noise. However, in addition to the propagation effect outlined above there is a possibility that multiple reflections between the engine compartment and the road surfaces will affect the apparent sound radiation. In [2] a measurement over grassland indicates that this effect might be important at high frequencies above 2000 Hz. This could be taken into account by entering a correction based on the diffuse sound absorption coefficient, which can be calculated from the impedance. However, in Harmonoise only a straightforward calculation using the impedance will be used.

5.3 Source heights

In [22] TRL and TNO reports some array measurements clearly indicating that the source height of tyre/road noise is very close to the road surface and that the engine noise has its origin close to the bottom of the car body. Two examples are given in figure 5.4

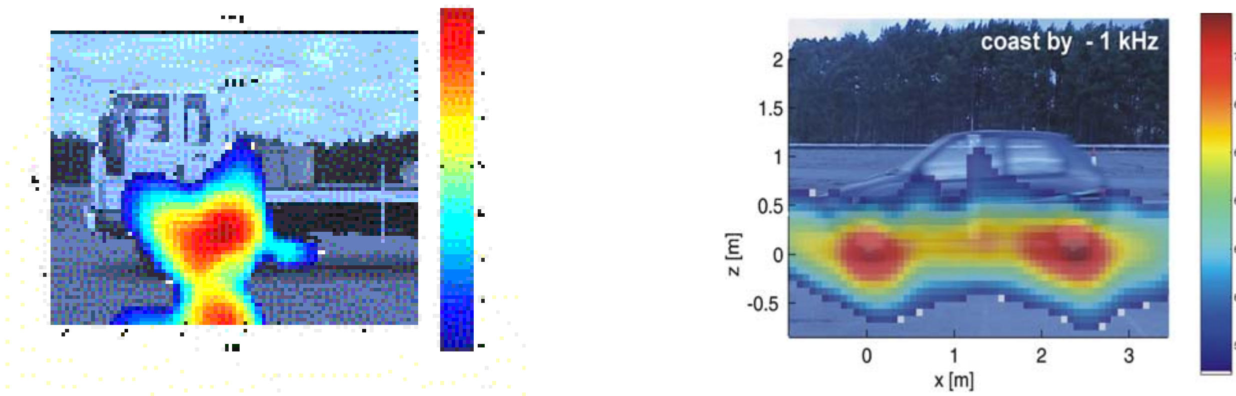


Figure 5.4 Array measurements indicating the source height for engine and tyre/road noise respectively, from [22].

In [18] TUG reports CPX intensity measurements in the laboratory on tyres rotating on drums. These measurements also indicate that the main source is close to the tyre/drum interface. In addition it is shown that there is little difference between the wheel alone and the wheel mounted in a wheelhouse.

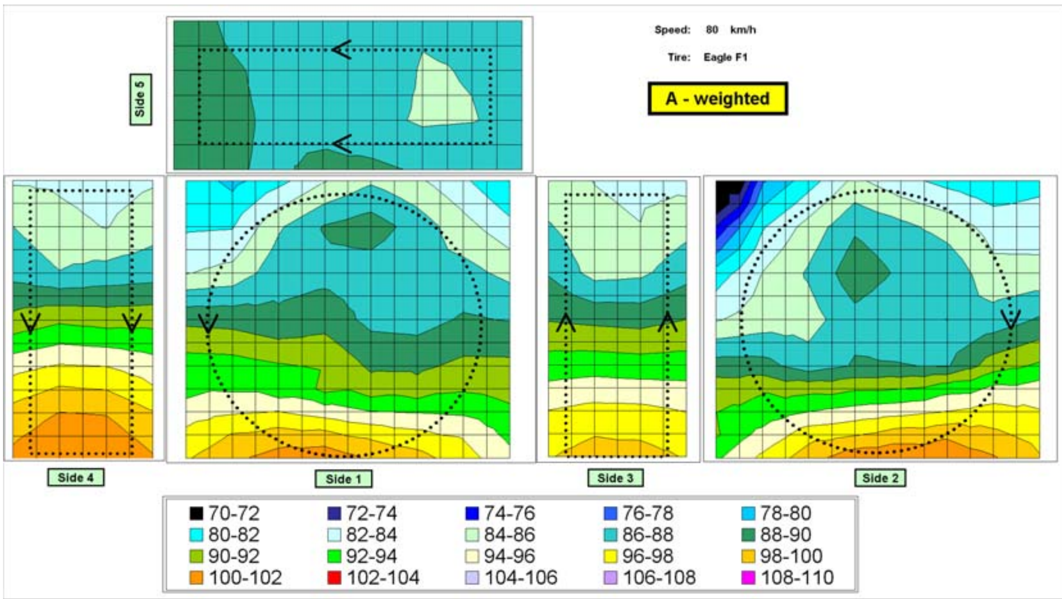


Figure 5.5 Intensity measurements on a tyre rotating on a drum indicating a low source height, from [18].

In [23] SP shows that a source height of 0,01 m for tyre/road noise and 0,3 m for engine noise gives a good fit between measured and calculated sound propagation patterns. Some of the results are shown in figure 5.6 where measured results are compared with calculations according to Nord 2000. We can see that a source height of 0,01m gives a very good fit above 400 Hz. At 1250-2000 Hz the fit improves if the horn effect is taken into account by carrying out the calculations corresponding to a L_{pFmax} maximum at 45º in stead of for at the shortest distance. At low frequencies it looks worse. For very low frequencies background noise may have influenced the measured levels. At 200-250 Hz the measurements indicate a lower level at 4 m than at 0,2 m. This could possibly be explained by a low frequency source at the bottom of the car body or higher. We can also see that there is a significant difference between the heights 0,3m and 0,5m. It is obviously not possible to draw any further conclusions until a more elaborate source model for the weighting between engine noise and tyre/road noise is available. The results are not 100% consistent with those of figure 5.8 but they are probably more reliable as the propagation path is much better defined. In figure 5.8 there was a ditch and sloping ground whereas here it is perfectly flat with a runway perfectly level with surrounding ground.

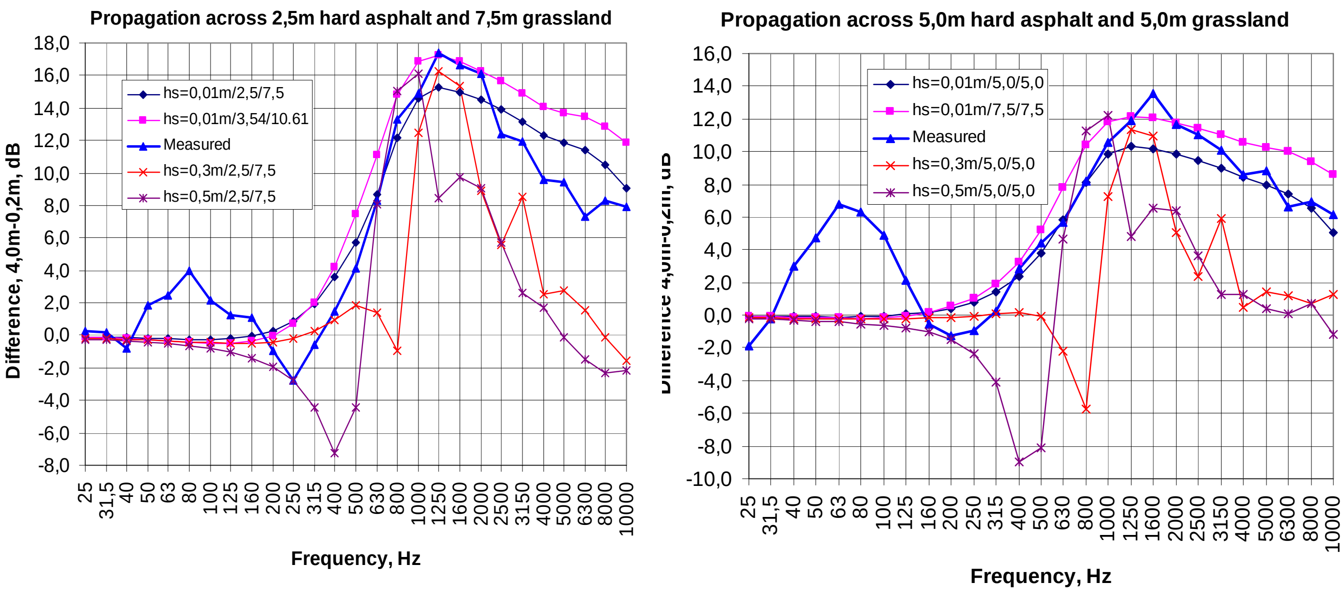


Figure 5.6 Cruise-by propagation pattern for a passenger car at 90 km/h. L_{Fmax} was measured. The ground impedance corresponded to a flow resistivity of 100 kPas/m^2 according to the one parameter model of NT ACOU 104.

In figure 5.7 another example is shown. In this case the transfer matrix, see [13], were solved and the sound power distributed between the two heights 0,01m and 0,3 m. The best solution was obtained by putting all noise emission at 0,01m above 500 Hz. Below that frequency the source height rises apart from the lowest frequencies where the long wavelength relative the small height differences makes it impossible to draw any conclusions.

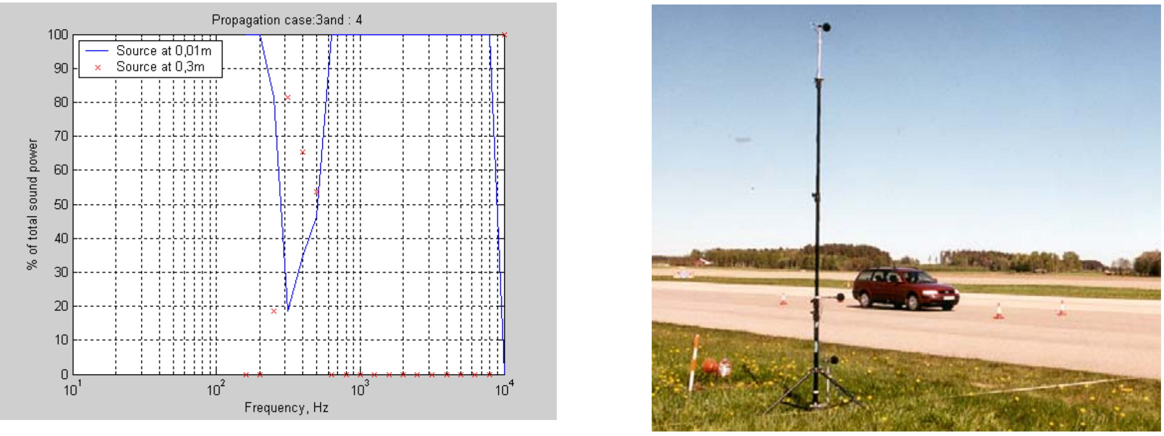


Figure 5.7 Derivation of source heights from a pass-by test. The sound is propagated over 7,5m very hard asphalt and 2,5m soft grassland and the microphone heights used are 0,2 m and 4,0 m.

Figure 5.8 shows another test site. The width of the road to the firs grass was 2,6 m, the ditch was 6,1 m wide with its deepest point 0,7 m below the level of the road surface. The flat grassland was 0,2 m below the road surface and the microphones were 9,75 m from the ditch that is 18,45 m from the nearest wheels. The ground impedance was measured and it turned out to be quite soft, the flow resistivity was 160 kPas/m^2. The calculations were carried out according to the latest Nord 2000 method using the two source heights 0,75 m and 0,01 m.

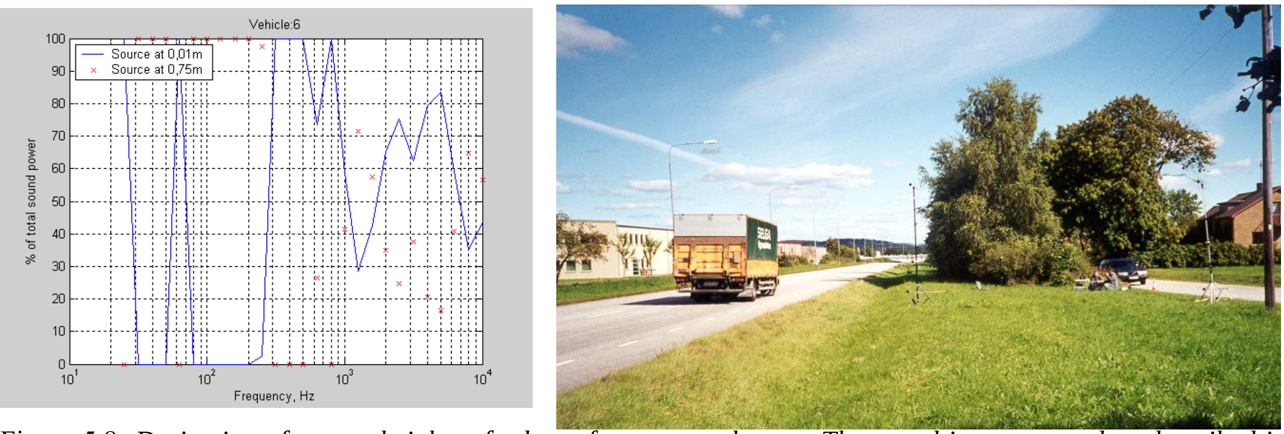


Figure 5.8 *Derivation of source heights of a lorry from a pass-by test. The sound is propagated as described in the text and seen on the photograph. The microphone heights used for the calculations are 0,5 m, 2 m and 4,0 m.*

It is not easy to draw any firm conclusions from the above. For computational reasons the number of sources for each vehicle type should be restricted to two. To avoid extreme interference dips at close distances the sound energy should be spread out in height. After intense discussions in WP 1.1 it was decided to select 0,01 m for the major tyre/road noise source and 0,3 and 0,75 m respectively for propulsion noise for light and heavy vehicles respectively. It was also decided to take reflections in the car body/wheel house into account by allocating 20% of the power output from each primary source to the other source. Further investigations in the future may warrant changes in these numbers. Above we have not specifically investigated the effect of high exhausts on trucks. These exhausts will be located about 3,5 m above the ground and a reasonable approach in these cases could be to assign all frequencies with midband frequency at and below 315 Hz to this high location as exhaust noise is a typical low frequency phenomenon.

5.4 Source strength and distribution between propulsion and tyre/road noise

Many measurements, see [24], have been carried out on vehicles in real traffic. CPX measurements have been used to separate different noise sources from each other. Some examples of measurement results are shown in figure 5.9-5.10.

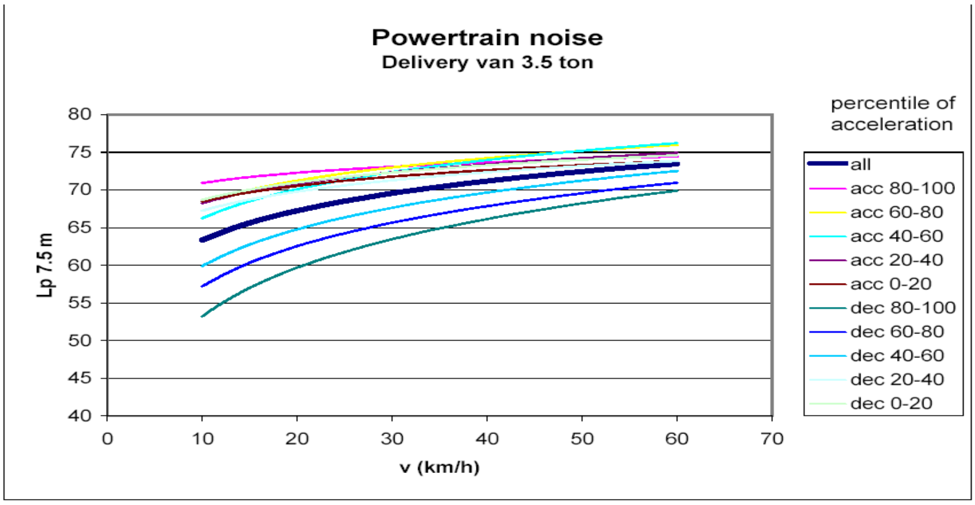
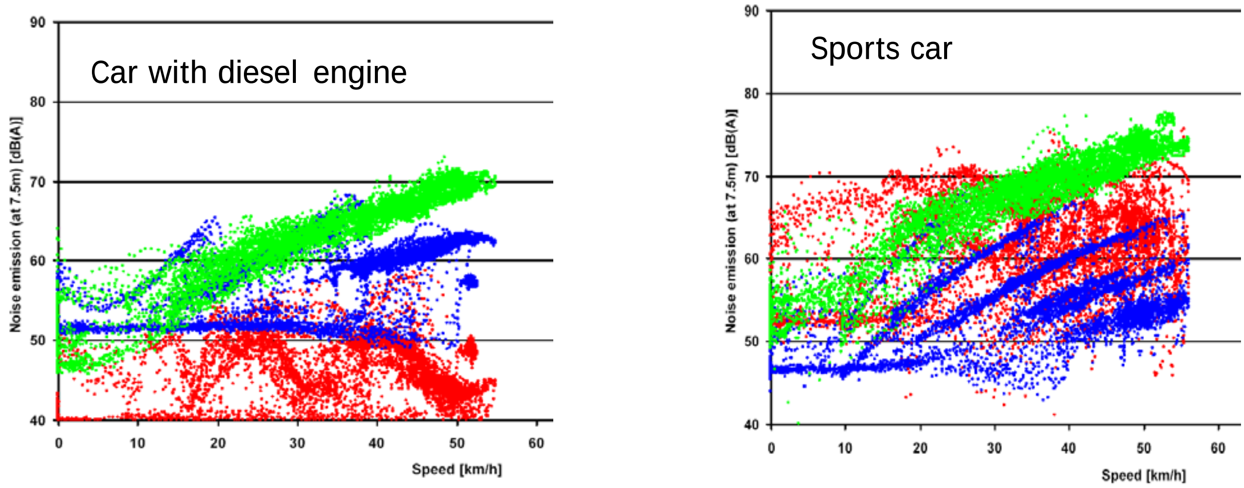


Figure 5.9 A-weighted sound pressure levels at 1,2m/7,5m as a function of speed and acceleration.



green= rolling noise, blue = engine noise, red = exhaust noise

Figure 5.10 A-weighted sound pressure levels at 1,2m/7,5m as a function of speed and acceleration.

Measurements of the type shown in figure 5.9 and 5.10 have been analyzed in 1/3 octave bands and transformed into equations yielding the sound power levels for the different conditions.

As it turns out that a linear speed relationship fits better than a logarithmic one for power train noise we get

$$L_{W,prop,z,m,i}(v_{eng},load) = A_{z,m,i} + B_{z,m,i}\left[\frac{v - v_{ref}}{v_{ref}}\right] + 10\lg(f_{z,m,i,prop}(\phi,\theta) + C_{z,m,i}(v_{eng},load) + C_{region,prop,z,m,i} \tag{5.1}$$

where

m = vehicle category index

i = 1/3 octave band index

z = height index (normally values refer to z= 0,3 – 0,5 m but there may be high exhausts with z = 3,5 m)

and for tyre/road or rolling noise

$$L_{W,roll,z,m,i}(\phi,v) = A_{z,m,i} + B_{z,m,i}\,\lg\left[\frac{v}{v_{ref}}\right] + 10\lg(f_{z,m,i,roll}(\phi,\theta) + \alpha_{road,m,i}(\phi,\theta) + \beta_{road,m,i}\,\lg\left[\frac{v}{v_{ref}}\right] + C_{weather,road,z,m,i} + C_{region,roll,z,m,i} \quad (5.2)$$

where

z = 0,01 m (at least for high frequencies)

In [22] different methods to determine power train noise is analysed. One method is to carry out both cruise-by and coast-by measurements and then subtracting one from the other. Some results are shown in figure 5.11.

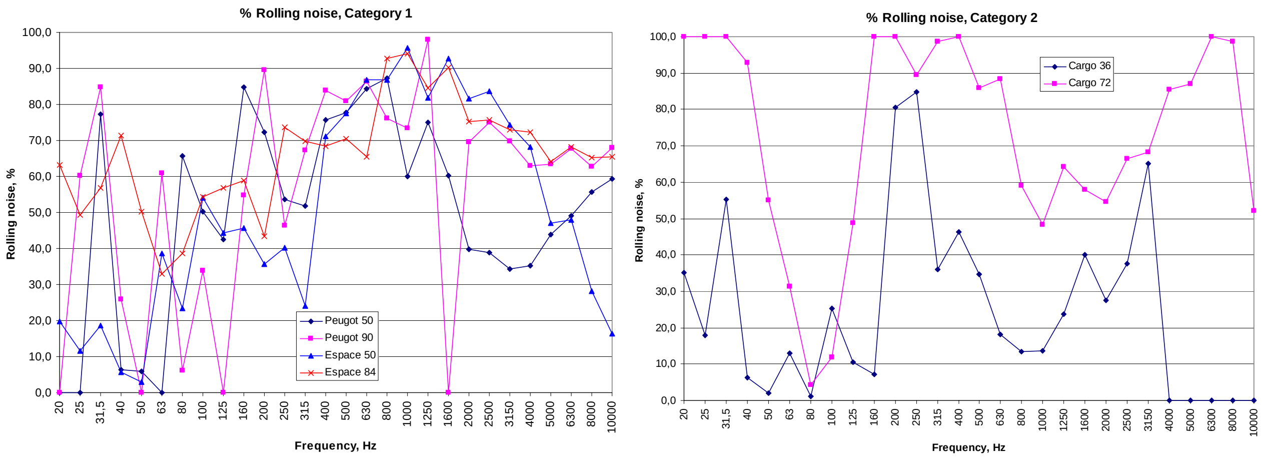


Figure 5.11 Ratio rolling noise for two category 1 vehicles and 1 category 2 vehicle. The category 1 vehicles are one Peugot 106 with diesel engine and one Renault Espace with petrol engine. The category 2 vehicle is a Ford Cargo with diesel engine.

Figure 5.11 shows that engine noise dominates around 80 Hz where the engine has its firing frequency and that rolling noise for passenger cars dominates strongly around 1250 Hz where the horn effect has its maximum.

As the Harmonoise measurements have been carried out on a limited number of vehicles the results have been used to obtain speed coefficients and ratios between different contributions only. The absolute values have been obtained from large scale statistical measurements carried out primarily in the Netherlands and Scandinavia (Nord 2000) using a fitting procedure. For light vehicles the values have been corrected to the reference surface according to the final proposal. The Danish Nord 2000 measurements were carried out on DAC 0/16 road surfaces with an average air temperature of 12ºC. To get to the reference conditions the levels have to increase 0,3 dB due to the DAC and decrease 1,25 dB due to the chip size. The temperature causes a subtraction of 0,5 dB. Totally the Nord 2000 levels should be corrected downwards by 1,5 dB. Tyre/road (rolling) noise for category 2 and category 3 vehicles has been assumed to be the same with the correction that the level increases as 10lg(number of axles). The result of these fitting procedures are shown in figure 5.12-5.14. From these figures it is evident that the speed coefficients do not match the Nord 2000 data bank very well for speeds below 50 km/h.

This might be explained by the fact that different combinations tyres/roads have been used in the different studies. In fact the speed coefficients seem to vary greatly between different countries, Looking at A-weighted levels and passenger cars only the following observations can be made:

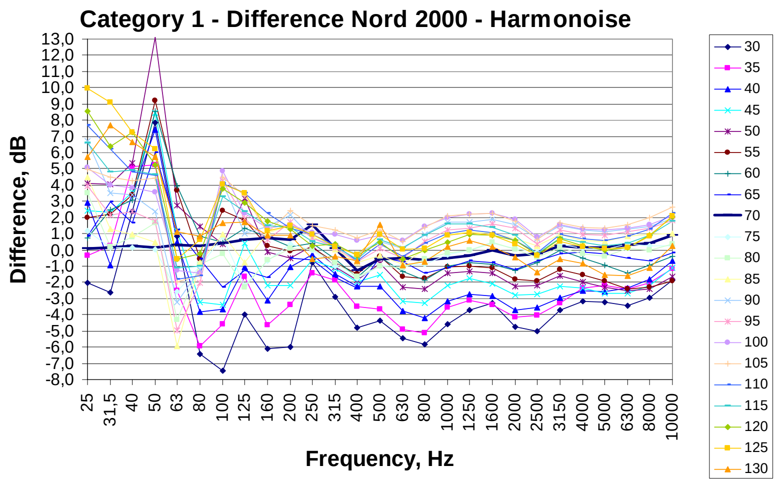


Figure 5.12 Difference between Harmonoise reference and Nord 2000 data base for category 1 vehicles

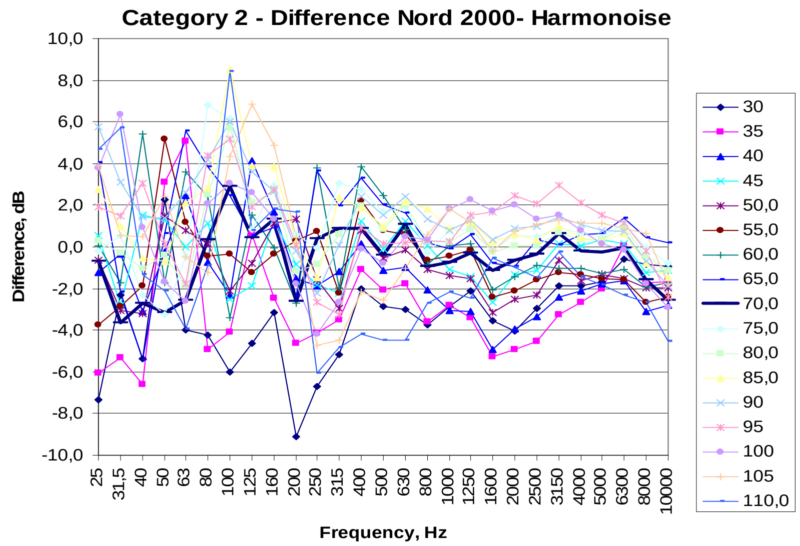


Figure 5.13 Difference between Harmonoise reference and Nord 2000 data base for category 2 vehicles

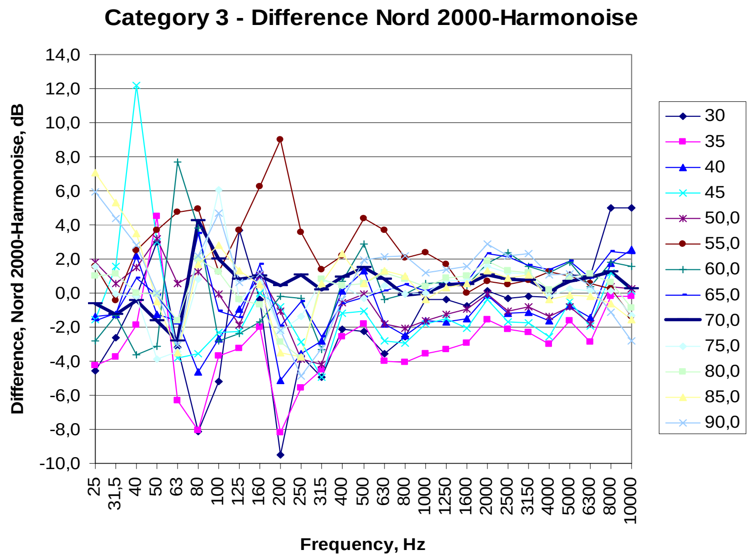


Figure 5.14 Difference between Harmonoise reference and Nord 2000 data base for category 3 vehicles

- The German RLS 90 has 22,3 for L_{Aeq} that is 32,3 for L_{WA} (this coefficient is for 50-110 km/h)
- The Harmonoise proposal used in figure 5.12-5.14 with coefficients from M+P results in 30,6 for L_{WA}
- Nord 2000 has 36,4 for the Danish data and 37,6 for the Swedish data
- The current Dutch method has 24,8 for L_{WA}.
- The Current 1996 years Nordic model has 25 for L_{EA} that is 35 for L_{WA}.
- For very heavy vehicles Nord 2000 yields 31 and the Dutch model 18! The 1996 Nordic model has 40!

A number of explanations are possible. In [31] indications are given that speed coefficients may range from 15-70 although they are typically within the range 30-40. For prediction methods it is also possible that something different from the speed of the individual vehicle has been used. The ongoing European project SILVIA, see [39], also works with this problem and hopefully this project will provide further guidance on this issue. If the differences in speed coefficients cannot be explained the Imagine project may have to determine suitable regional coefficients to use.

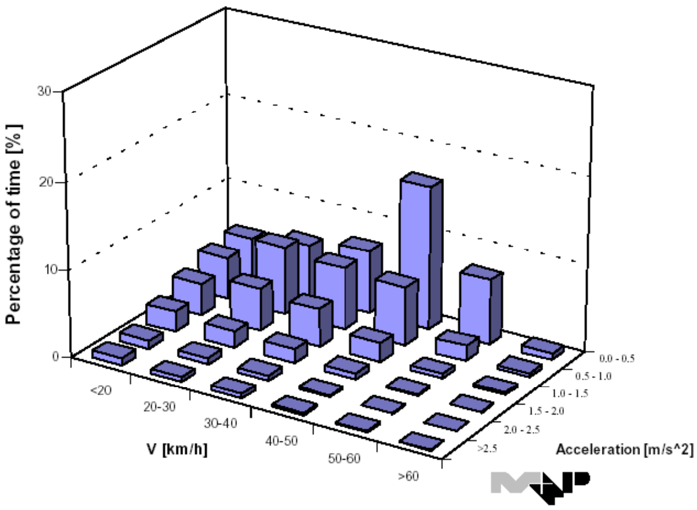


Figure 5.15 Examples of accelerations in real traffic.

In [34] it is proposed to correct for acceleration/deceleration using the formula

$$\Delta L_{acc} = C \cdot a \text{ ; } -2 \text{ m/s}^2 \le a \le 2 \text{ m/s}^2 \quad (5.3)$$

where a = the acceleration/deceleration in m/s^2 and the coefficient C is given by table 5.4. The table is based on measurements carried out in the Netherlands, primarily at speeds around 30 km/h. It is also proposed to treat gradients accordingly, that is to regard the downward component of the gravity as acceleration/deceleration. According to eq. (5.3) a vehicle is always quiter during deceleration. This is not quite true. Heavy vehicles occasionally use engine braking, in particular when driving downhill, and in such cases the engine noise is at least as high as during the corresponding acceleration. In such cases it is recommended to use the unsigned value of the deceleration thus making acceleration equivalent with deceleration.

Table 5.4 Acceleration/deceleration coefficient

Vehicle category	*C*
Category 1a	4,4
Category 1b	4,0
Category 2	5,6

5.5 Influence of road surface wetness

In [14] it is shown that a road surface with a film of water (=wet in the following) increases the A-weighted sound power level up to about 4 dB. A damp road surface has little effect on the noise emission. For passenger cars the increase is highest at low speeds while the opposite is the case for multi-axle heavy vehicles. The report also contains frequency band data. The increase for wet surfaces is most significant above 2000 Hz. In [17] procedures for determination of the correction factors are given. An example of measurement results is given in figure 5.16. In figure 5.17 the effect on spectrum is shown.

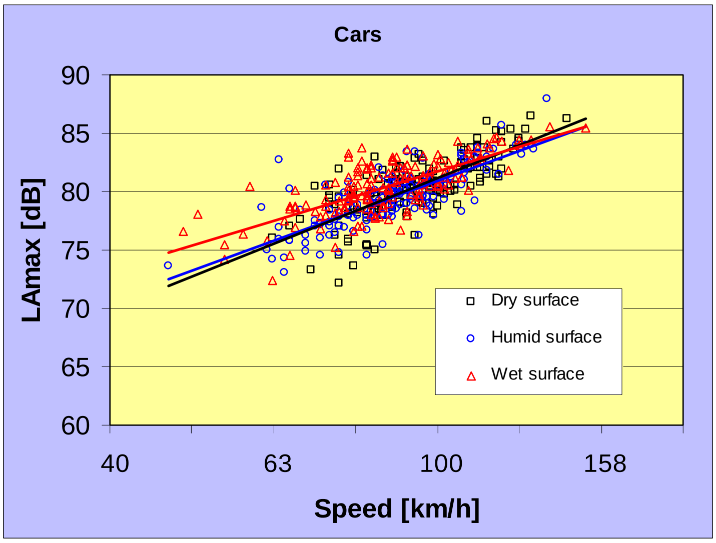


Figure 5.16

L_{pAFmax} during cruise-by by a passenger car as a function of speed and dampness.

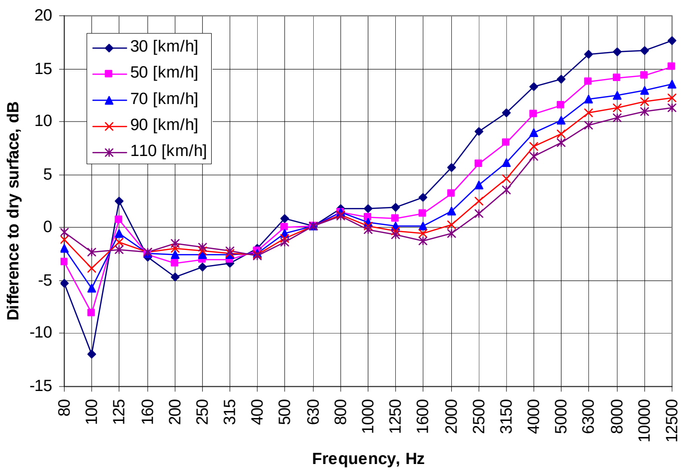


Figure 5.17

Difference in spectra for a passenger car between a wet surface and a dry surface

Ignoring frequencies below 1250 hz the curves shown in figure 5.17 can be approximated by the following equations:

$$\Delta L_{wet} = 10\lg\left(\frac{110}{v}\right) + 20\lg\left(\frac{f}{2000}\right), f \geq 2000 \text{ Hz}, 30 \leq v \leq 110$$

$$\Delta L_{wet} = 5\lg\left(\frac{110}{v}\right), f = 1600 \text{ Hz} \qquad (5.4)$$

$$\Delta L_{wet} = 2{,}5\lg\left(\frac{110}{v}\right), f = 1250 \text{ Hz}$$

For heavy vehicle the results are given in figure 5.18.

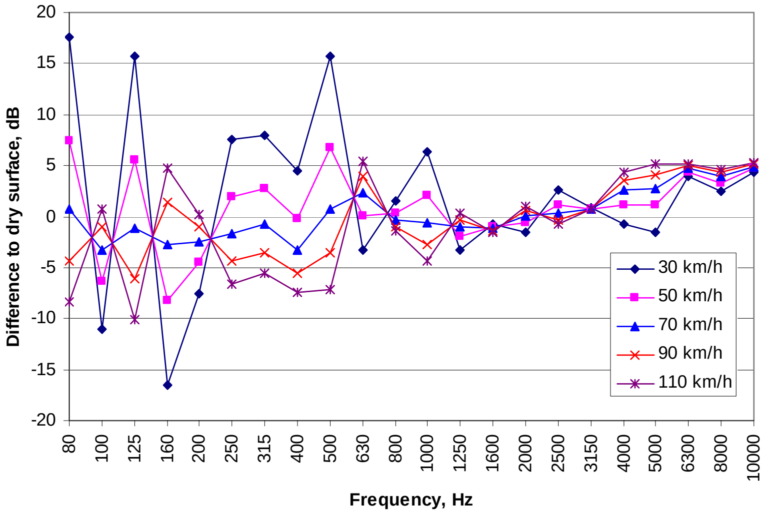


Figure 5.18

Difference in spectra for a twin axes heavy vehicle between a wet surface and a dry surface

For the heavy vehicle the result is very different from that of the passenger car. The speed dependence is more or less the opposite and the general impression is that the data may not be as reliable. There is also data available only for a light heavy vehicle. Thus it seems to be reasonable not to introduce any correction for heavy vehicles at this stage.

5.6 Influence of ageing

Newly laid surfaces are in general quieter than older ones. The deterioration becomes stable after 2 years. If a 2 years old non-porous surface has the A-weighted reference level ΔL_{A2} dB relative the reference road surface then the level ΔL_{AT} for T<2 years is given by

$$\Delta L_{AT} = \Delta L_{A2} - 0{,}2T^2 + 1{,}2T - 1{,}6; T \leq 2 years \quad (5.5)$$

For porous surfaces like PAC, PCC, PERS and OGAC the corresponding equation becomes

$$\Delta L_{AT} = \Delta L_{A0}(1 - (0{,}25T + 0{,}016T^2)), T \leq 7 years \quad (5.6)$$

where ΔL_{A0} is the A-weighted sound pressure level relative the reference surface at the time T=0 years.

As Harmonoise does not work with A-weighted levels but with frequency bands only the above corrections will be applied equally on all frequency bands.

5.7 Influence of interrupted traffic flows

In [25] some simulations have been made to show the effect of interrupted traffic flow, e.g. in crossings. The rsults are summarized in table 5.1 which shows that the SEL-level is affected insignificantly although the mean speed decreases by a factor 2. The indication is that it might not be necessary to make any noise corrections at crossings, at least not when the traffic is moderate.

Table 5.5 Some examples of the difference between free and interrupted flow.

VEHICLE	L_{Aeq} [dB]			
	Free-flow 20m/s (25 s)	**Interrupted** (54 s)	**Interrupted** normalized to 25 s	**Free-flow** 9.2 m/s (54 s)
FORD MONDEO	73.9	70.2	73.5	62.8
VOLVO S40	75.5	70.1	73.4	63.8
VOLVO S40 Diesel	75.2	70.4	73.7	64.8
FORD Ka	73.1	68.3	71.6	62.6
TOYOTA PREVIA	74.7	69.5	72.8	64.0
TOYOTA Hi-Lux	74.5	70.2	73.5	64.8
MITSUBISHI PAJERO	75.5	71.1	74.4	66.3
MC - BMW 650	75.6	71.8	75.1	64.6

5.8 Tyres and road temperatures

No specific work within this field was scheduled by Harmonoise so conclusions have to be drawn from current knowledge. Tyres are dealt with in the EU-project SILVIA and some results are expected during 2004. With the exception of winter tyres, tyres are assumed to be dealt with indirectly by the use of regional noise emission data which will include statistically representative tyres. Temperature variations have to be dealt with as they are well proven. The tyre/road sound power level will decrease by about 0,1 dB per degree increase of the air temperature and by about 0,06 dB per degree road temperature.

As to winter tyres comparably few data are available. An overview is given in [31]. It might be difficult to use older data for two reasons. One is because temperatures have not always been recorded and reported properly and another that modern studs are lighter and smaller and thus make less noise. If summer tyres are measured during the summer they will emit much less noise than they would under winter temperatures. 20ºC lower temperatures will increase the sound power level by about 2 dB. In the Harmonoise project we will introduce a provisional correction for studded tyres based on rather few recent measurements (Nov-Dec. 2003) carried out by SP, see figure 5.19. More data will be collected in the Imagine project in 2005.

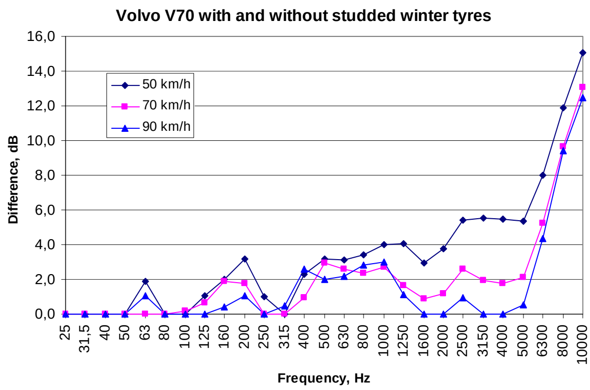


Figure 5.19 Comparison between winter and summer tyres. The measurements were carried out in Sweden in November 2003. The summer tyres were measured at 12º and the winter tyres at 5ºC.

5.9 Slip during acceleration/deceleration

A detailed report is given in [28] and [29]. Measurements have been carried out in two different ways. One was using the equipment shown in figure 5.20 yielding results like the one shown in figure 5.21. Other experiments involved measurements on real cars. By combining the different measurements with theory some equations were derived.

Figure 5.20 Test set-up for measurement of slip noise

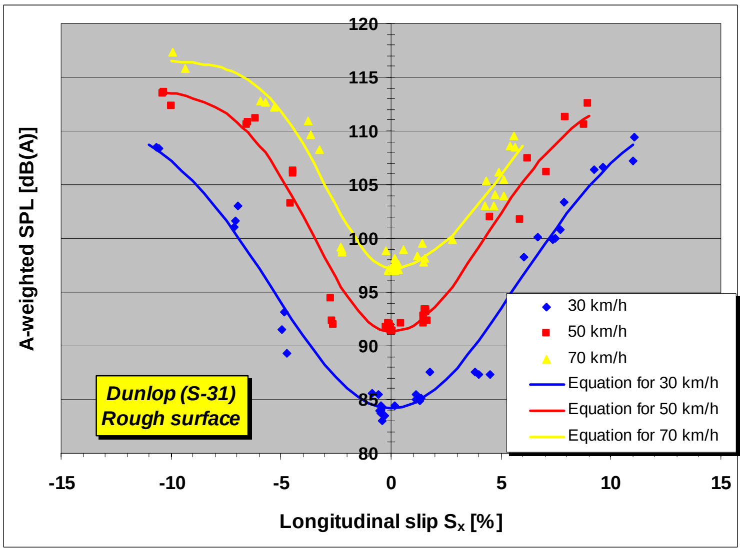


Figure 5.21 Example of test result for A-weighted sound pressure level

For slip during deceleration the following equation is valid for passenger cars and A-weighted levels:

$$\Delta L_A = (A \cdot V^3 + B \cdot V^2 + C \cdot V + D) \cdot a^2 + (E \cdot V^3 + F \cdot V^2 + G \cdot V + H) \cdot a \text{ , in dB} \quad (5.7)$$

where

V = speed, in km/h

a_2 = acceleration of the vehicle (negative for deceleration)

a = total acceleration = $a_2 + g \sin(\alpha)$

g = 9,81 m/s^2

α = road gradient (negative for downhill)

As the slip turned out to have little importance at accelerations/decelerations commonly used in normal traffic it was decided not to include any corrections in the Harmonoise source model.

5.10 Directivity

5.10.1 General

If required, the point sources should be assigned both horizontal and vertical directivity. We expect that the horn effect of the tyre/road source will affect the horizontal directivity and that the car body will screen the noise for elevated receivers. For practical reasons some simplifications should be made.

When integrated over a pass-by the integral of the directivity function should be close to zero. The horn effect has its greatest effect around 2000 Hz. The reference is the omnidirectional sound power level which, using the propagation model and integrated during a complete pass-by, yields the correct sound exposure level in the horizontal direction. It will be assumed that the vertical directivity is the same for all horizontal angles. Different directivity functions will be used for rolling and propulsion noise. It will be assumed that tyre/road (rolling) noise dominates the lowest point source and that propulsion noise dominates the higher one.

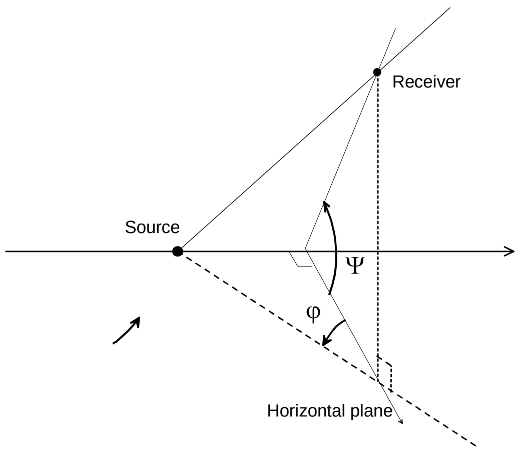


Figure 5.22 Geometry for the directivity functions (The angle ψ in the figure reflects the definition during the pass-by measurements. For practical reasons this angle is later transferred (approximation) to the true spherical coordinate, see figure 6.1).

Thus the directivity function which is a function of angles, see figure 5.22, and frequency, *f* can be written as

$$\Delta L(f,\varphi,\psi) = \Delta L_H(f,\varphi) + \Delta L_V(f,\psi) \tag{5.8}$$

ΔL_H is normalized to yield 0 dB contribution when integrated during pass-by and $\Delta L_V(0) = 0$ dB. The indices in the formulae hereafter are defined as:

$$\{H,\ V\} = \{Horizontal,\ Vertical\}$$

It will further be assumed that

$$\Delta L(f,\varphi,-\psi) = \Delta L(f,\varphi,\psi) \tag{5.9}$$

5.10.2 Vertical directivity

Autostrade has carried out measurements on real traffic using one lane of a motor way. The other lanes were blocked and the measurements were carried out during night-time. The road surface was a DAC 0/16 surface and 5 microphone positions located on an arc with the radius 7,5 m centred on the middle of the lane was used. Some of the results are shown in figure 5.23.

When interpreting the figures it is important to compensate for propagation effects. Because of the rather hard road surface these effects were limited. However, at 4000 and 8000 Hz there is a small excess attenuation which will decrease with the height of the microphone as is shown for the ISO surface in figure 5.3. For this reason the curvature upwards for these frequency bands will be ignored. This effect is most evident for category 1 vehicles at high speed. There is another effect at 63 Hz for category 3 vehicles which looks similar. This effect is most likely due to high exhausts and will also be ignored for normal heavy vehicles.

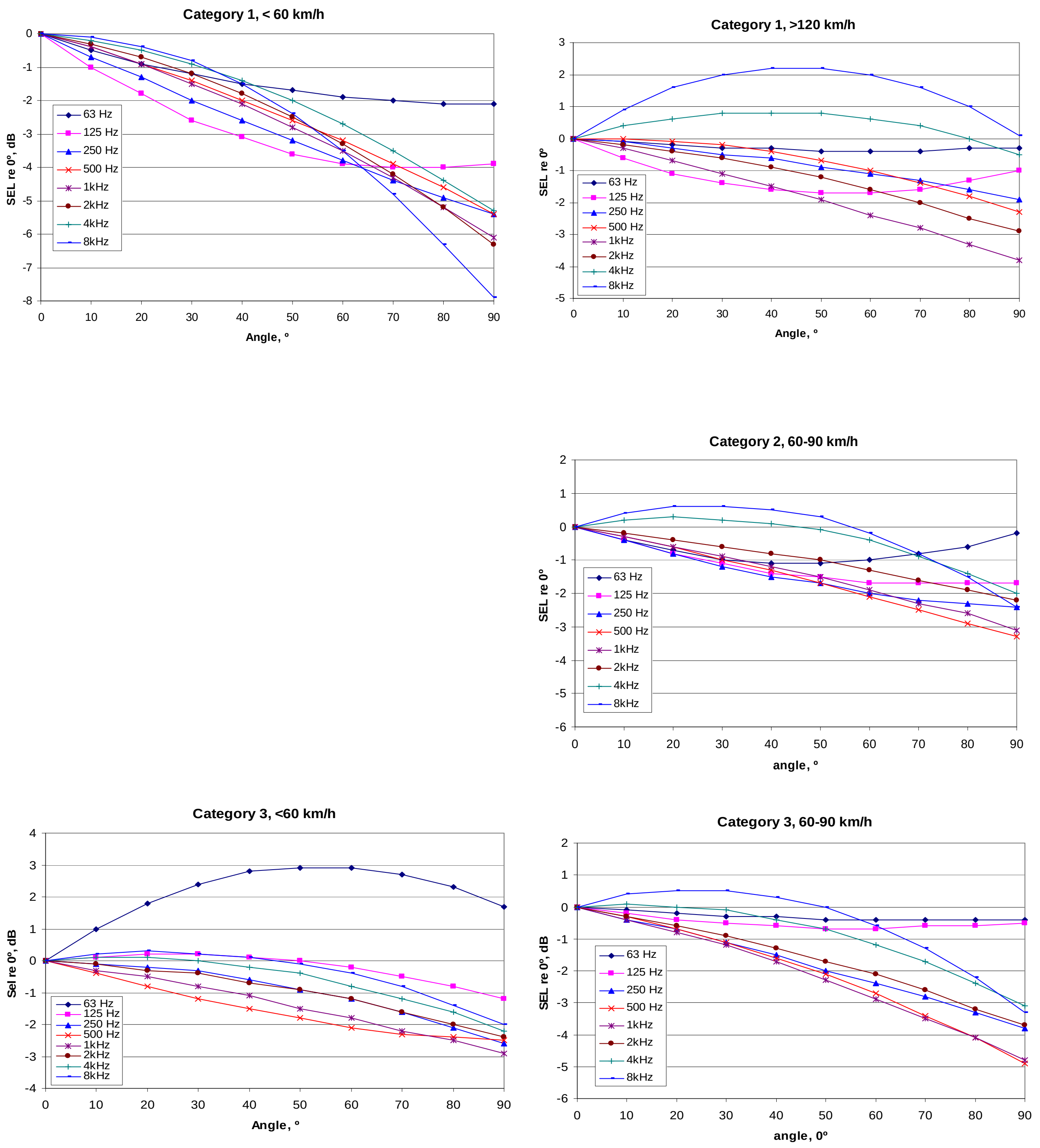


Figure 5.23 Measurements of vertical directivity on a DAC 0/16 surface using 5 microphone positions and interpolating between them.

The curves in figure 5.23 can be approximated by different functions. Some functions are shown in figure 5.24. By selecting one of these functions and multiply it by a number within the range 1-8 it is possible to obtain an approximation good enough for Harmonoise. Some such approximations are shown in table 5.6.

Table 5.6 Functions approximating the vertical directivity $\Delta L(\psi)$

	Cat 1 h_s=0,3m	Cat 1 h_s=0,01m	Cat 2 h_s=0,01m	Cat 2 h_s=0,75m	Cat 3 h_s=0,01m	Cat 3 h_s=0,75m
50,63,80	-2sin(ψ)	0	0	0	0	0
100,125,160	-4sin(ψ)	-2sin(ψ)	0	0	0	0
200,250,315	$-5(1-\cos^2(\psi)$	$-2(1-\cos^2(\psi)$	$-2(1-\cos^2(\psi))$	$-2(1-\cos^2(\psi))$	$-4(1-\cos^2(\psi))$	$-2(1-\cos^2(\psi))$
400,500,630	$-5(1-\cos^2(\psi)$	$-2(1-\cos^2(\psi)$	$-3(1-\cos^2(\psi))$	$-3(1-\cos^2(\psi))$	$-5(1-\cos^2(\psi))$	$-3(1-\cos^2(\psi))$
800,1000,1250	$-6(1-\cos^2(\psi)$	$-3(1-\cos^2(\psi)$	$-3(1-\cos^2(\psi))$	$-3(1-\cos^2(\psi))$	$-5(1-\cos^2(\psi))$	$-3(1-\cos^2(\psi))$
1600,2000,2500	$-6(1-\cos^2(\psi)$	$-4(1-\cos^2(\psi)$	$-2(1-\cos^2(\psi))$	$-2(1-\cos^2(\psi))$	$-4(1-\cos^2(\psi))$	$-2(1-\cos^2(\psi))$
3150,4000,5000	$-5(1-\cos^2(\psi)$	0	-2(1-cos(ψ))	-2(1-cos(ψ))	-4(1-cos(ψ))	-2(1-cos(ψ))
6300,8000,10000	-8(1-cos(ψ))	0	-2(1-cos(ψ))	-2(1-cos(ψ))	-4(1-cos(ψ))	-2(1-cos(ψ))

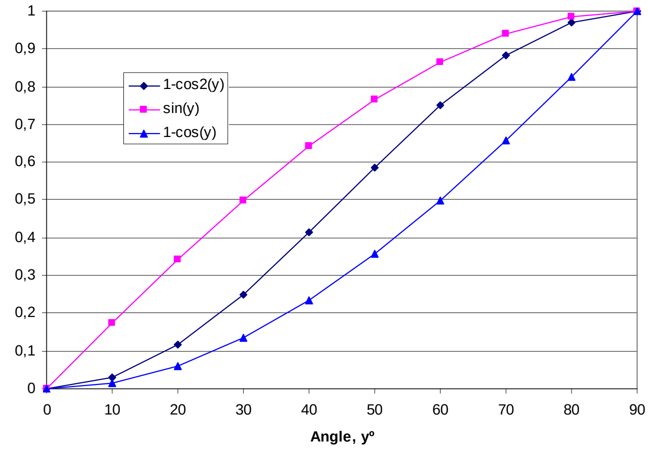


Figure 5.24 Functions used to approximate the vertical directivity.

The angle ψ in figure 5.22 is the angle used during the measurements. However, when the angle follows the vehicle it is necessary to convert it to the normal spherical coordinate as is shown in figure 6.1. Considering the uncertainties involved it has been assumed that for practical purposes the angle of figure 6.1 is approximately equal to that of figure 5.22.

For practical reasons it is not desirable to have category dependent directivites for the different heights. By considering the different weighting of rolling/propulsion noise table 5.6 can be simplified into table 5.7.

Table 5.7 Simplified functions approximating the vertical directivity $\Delta L(\psi)$

Freq./source height	hs=0,01m	hs=0,3m	hs=0,75m
50,63,80	0	-2sin(ψ)	0
100,125,160	0	-4sin(ψ)	0
200,250,315	$-2(1-\cos^2(\psi)$	$-5(1-\cos^2(\psi)$	$-2(1-\cos^2(\psi))$
400,500,630	$-3(1-\cos^2(\psi)$	$-5(1-\cos^2(\psi)$	$-3(1-\cos^2(\psi))$
800,1000,1250	$-4(1-\cos^2(\psi)$	$-6(1-\cos^2(\psi)$	$-3(1-\cos^2(\psi))$
1600,2000,2500	$-4(1-\cos^2(\psi)$	$-6(1-\cos^2(\psi)$	$-2(1-\cos^2(\psi))$
3150,4000,5000	0	$-5(1-\cos^2(\psi)$	-2(1-cos(ψ))
6300,8000,10000	0	-8(1-cos(ψ))	-2(1-cos(ψ))

5.10.3 Horizontal directivity

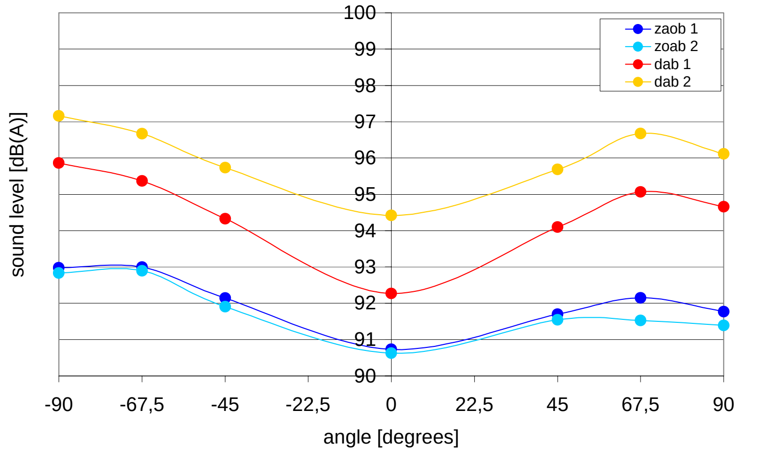


Figure 5.25 The A-weighted sound pressure level at microphone positions at the height 0,2 m in 80 km/h on four different test tracks

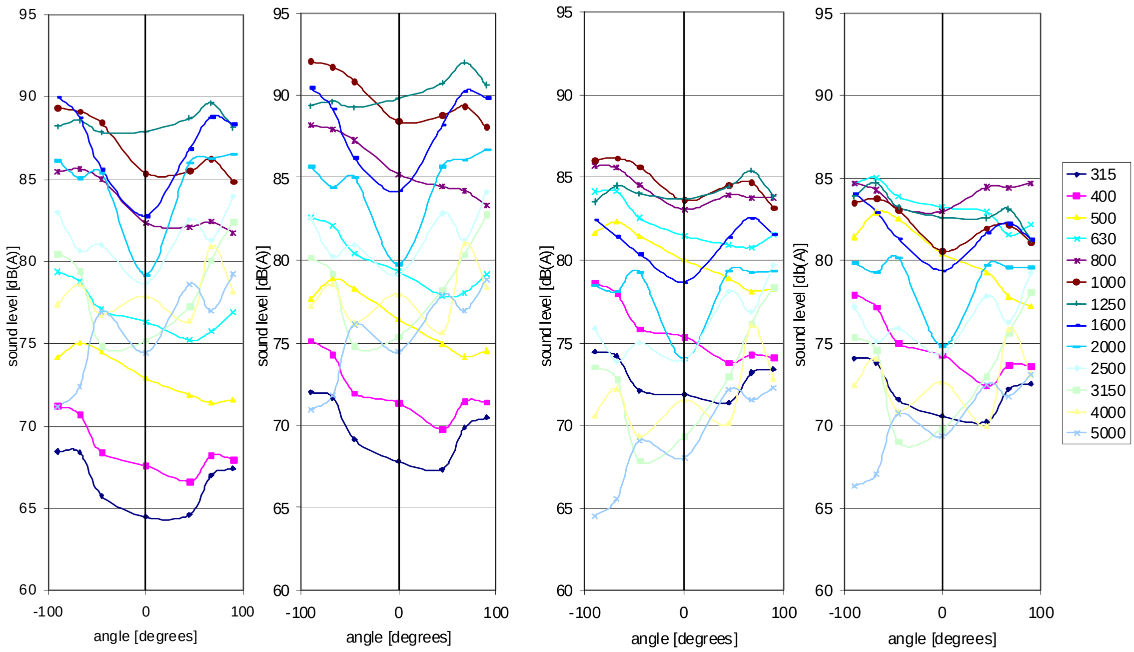


Figure 5.26 Directivity around a tyre. The two left figures refer to DAC surfaces and the two to the right to PAC surfaces. (From [])

Figure 5.25 shows some measurements indicating directivity of tyre/road noise. Figure 5.26 shows similar results but in frequency bands. It is evident that the well-known horn effect exists at least for frequencies around 2000 Hz where we can see a distinct directivity up to about 5 dB. Because the measurements in figure 5.26 have been carried out in the near field they are not necessarily representative for long distances where reflections from car body and wheel houses may have greater effects. Another problem is that there is not complete symmetry between backward and forward radiation. During a complete pass-by the two effects could in principle cancel each other.

During the project Autostrade carried out pass-by measurements on real traffic. Some results are shown in figure 5.28. 5 microphones were located on a half-sphere centred at the centre of the vehicle when it passed microphone M3. The height was 1,2 m and the microphones M2 and M1 were located 30º and 60º respectively before M3 and correspondingly M4 and M5 were located at the same positions after M3. One sample was taken every 20 ms. These samples are indicated by + in the figure. The dashed lines indicate the best fit 6 degrees polynomials of the samples and the full line is the calculated curve under the assumption that each wheel is an omni-directional source. It is not easy to draw any conclusions from these results. There is a small trend that the sound pressure level rises a little faster than it decays indicating that there are higher levels in the forward direction.

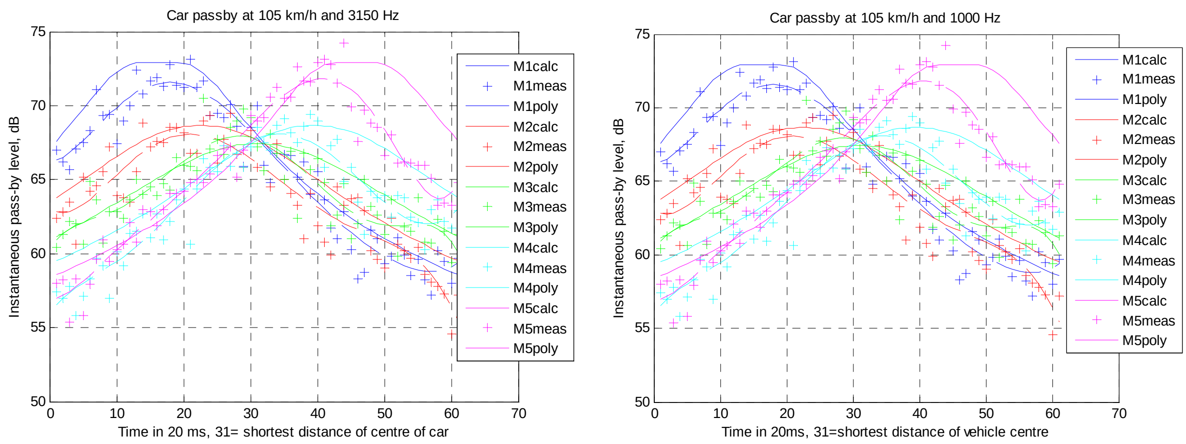


Figure 5.28. Time histories of a pass-by of a passenger car at 105 km/h.

Another way to check the directivity is to measure the difference between SEL and L_{Fmax} during pass by. If the directivity is the same for all frequencies this difference should be constant. In figure 5.29 some results are reported. A theoretical simulation shows that the difference should be about 2,5 dB if all wheels were omnidirectional. We can see that within the frequency range 1250-6300 Hz the difference is greater. Using a simulation with the directivity function shown in eq. (5.10b) the corresponding difference becomes about 3,0 dB, which is a step in the right direction.

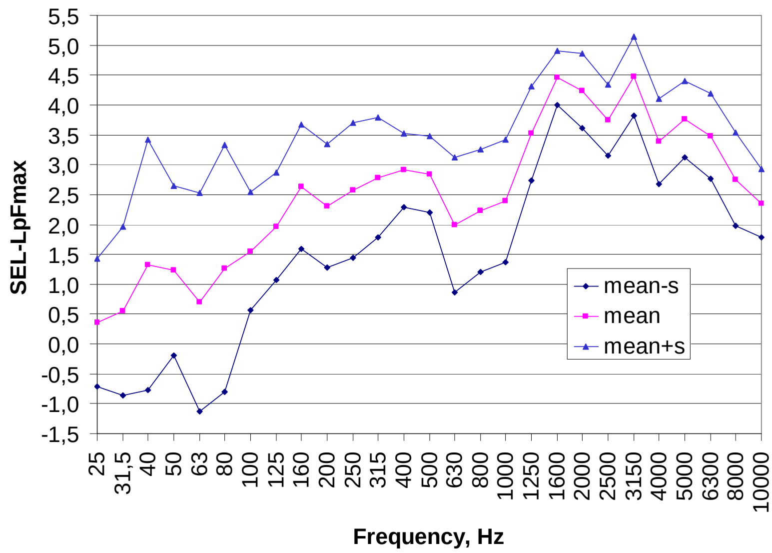


Figure 5.29 9 pass-by measurements on passenger cars at 50 ± 3 km/h and 10 m distance and 4 m microphone height. SEL integration during ± 3 a

The conclusions are not obvious. However, as we know that there has to be some kind of horn effect it seems reasonable to make at least a small correction for the frequency range 1600-6300 Hz. In Harmonoise we settled for

$$\Delta L_H(\varphi) = 0;\ f \le 1250\ Hz,\ f \ge 8000\ Hz \qquad (5.10a)$$

$$\Delta L_H(\varphi) = -1{,}5 + 2{,}5 \cdot abs(\sin(\varphi)); 1600 \le f \le 6300 Hz \qquad (5.10b)$$

As the angle ϕ is not properly defined on top of the car (5.10b) has to be modified to avoid computational problems. As it has to become 0 when $\psi = 90°$ this can be accomplished by multiplying with a cosine function. We choose the square root in order to decrease the effect at close to horizontal angles and thus get

$$\Delta L_H(\varphi) = \left(-1{,}5 + 2{,}5 \cdot abs(\sin(\varphi))\right) \cdot \sqrt{\cos(\psi)}\ ;\ 1600 \le f \le 6300\ \mathrm{Hz} \qquad (5.10c)$$

Eq. (5.10c) will be valid for the low sound source at 0,01 m only. It will be valid for both light and heavy vehicles.

For the high source positions at 0,3 m and 0,75 m respectively the directivity of propulsion noise has to be considered. In figure 5.30 the directivity of a stationary category 3 truck without and with a trailer is shown. The results indicate a slightly higher radiation in the forward direction and a significant screening effect in the backward direction.

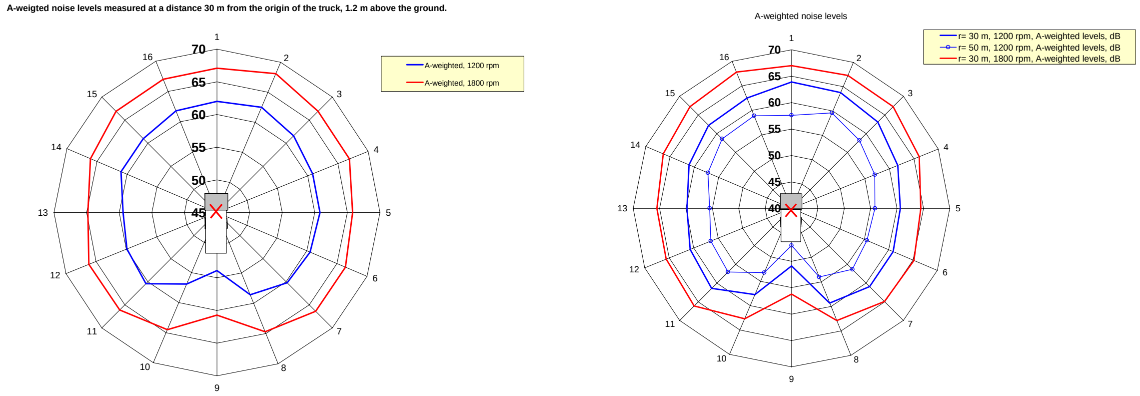


Figure 5.30 The directivity of a stationary Volvo FH 16 category 3 truck without (left) and a FH 12 with (right) trailer (Courtesy Volvo Truck Cooperation)

In figure 5.31 the frequency band values for the truck with trailer are shown.

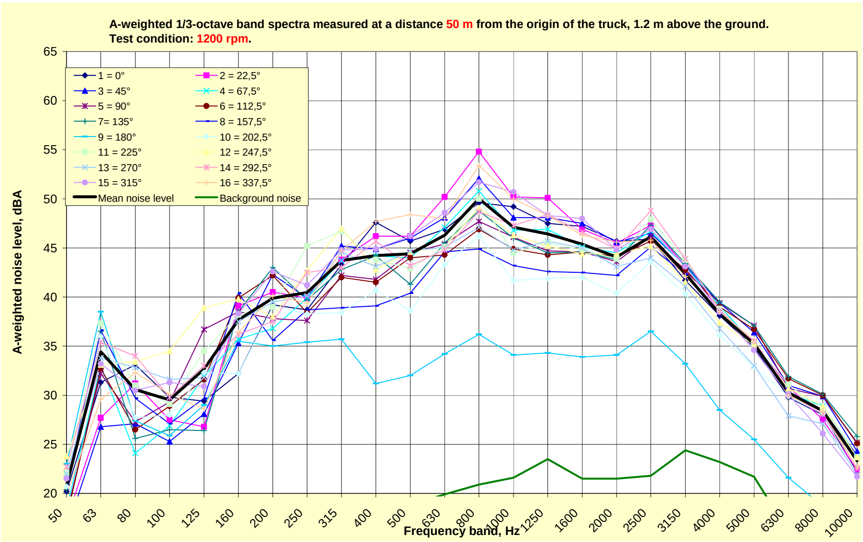


Figure 5.31 Directivity of a staionary Volvo FH 12 heavy truck with trailer measured at a distance of 50 m from the centre of the vehicle.

A reasonable approximation to apply equally for all frequencies is

$$\Delta L_H(\varphi) = 1{,}546 \cdot \varphi^3 - 1{,}425\varphi^2 + 0{,}22\varphi + 0{,}6 \qquad (5.11)$$

which is to be valid for all heavy vehicles and the source height= 0,75 m. For light vehicles and source height= 0,3 m we will assume negligible directivity, that is

$$\Delta L_H = 0 \qquad (5.12)$$

As before we have to multiply by $\sqrt{\cos(\psi)}$ to avoid problems with pass-by integration on top of the vehicle.

The two horizontal directivity functions (5.11) and (5.10c) are shown in figure 5.32.

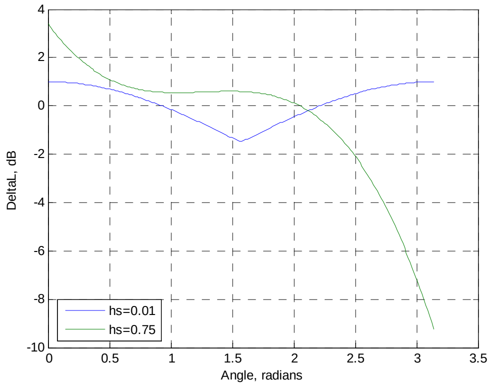


Figure 5.32 Directivity functions for source height 0,1 m and source height 0,75 m respectively.

6 Proposal for source model

The final proposal for source model is summarized as follows.

6.1 Lay-out of model

- Each vehicle category is represented by two point sources, each having a specified sound power having contributions from tyre/road (rolling) and propulsion noise.
- As a minimum 3 vehicle categories are used: Passenger cars, medium heavy and heavy vehicles. Additional categories are defined. The medium heavy vehicle has two axles and the heavy vehicle has 3 or more axles. For heavy vehicles corrections are made for the number of axles.
- All default data refer to a reference condition: constant speed, 20 ˚C and the average of DAC 0/11 and SMA 0/11 road surface. Deviations from these conditions are corrected for.
- Default data for rolling noise is given by the equation $L_{WR}(f) = a_R(f) + b_R(f)\lg\left[\frac{v}{v_{ref}}\right]$. All coefficients are given in 1/3 octave bands 25-10000 Hz. 80% of the rolling noise sound power is assigned a point source at 0,01 m and 20% is assigned a point source at 0,3 m (passenger cars) or 0,75 m (heavy vehicles).
- Default data for propulsion noise is given by the equation $L_{WP}(f) = a_P(f) + b_P(f)\left[\frac{v - v_{ref}}{v_{ref}}\right]$. All coefficients are given in 1/3 octave bands 25-10000 Hz. 20% of the propulsion noise sound power is assigned a point source at 0,01 m and 80% is assigned a point source at 0,3 m (passenger cars) or 0,75 m (heavy vehicles).
- Tyre/road (rolling) noise is corrected for different road surfaces and different air temperatures. It is also possible to correct for wetness, studded tyres and number of axles on heavy vehicles.
- Propulsion noise is corrected for acceleration/deceleration.
- All point sources are assigned a specific frequency dependent vertical directivity with the main purpose to take the screening of the car body into account.
- The lowest point source is assigned a specific frequency dependent horizontal directivity with the main purpose to take the horn effect of the tyre/road source into account.
- The highest point source for propulsion noise and heavy vehicles is assigned a frequency independent horizontal directivity.
- Propagation effects are taken into account by giving different acoustic impedances of some different road surfaces.

6.2 Vehicle categorization

See 5.2 for more details. The sub categories are to be used when collecting new data but only the 5 main categories will be used in the first version of the engineering model, see table 6.1

Table 6.1 Summary of vehicle categories to be used in HARMONOISE. Note that this table is primarily for the data collection phase of the project. When it comes to the final model, one must take the availability of vehicle data for a certain road into consideration. See the discussion in the text and in Annex A in [21].

Main category (type)	No.	Sub-categories: Example of vehicle types	Notes
Light vehicles	1a	Cars (incl MPV:s up to 7 seats)	2 axles, max 4 wheels
	1b	Vans, SUV, pickup trucks, RV, car+trailer or car+caravan(1), MPV:s with 8-9 seats	2-4 axles(1), max 2 wheels per axle
	1c	Electric vehicles, hybrid vehicles driven in electric mode(2)	Driven in combustion engine mode: See note
Medium heavy vehicles	2a	Buses	2 axles (6 wheels)
	2b	Light trucks and heavy vans	2 axles (6 wheels)(3)
	2c	Medium heavy trucks	2 axles (6 wheels)(3)
	2d	Trolley buses	2 axles
	2e	Vehicles designed for extra low noise driving	2 axles(5)
Heavy vehicles	3a	Buses	3-4 axles
	3b	Heavy trucks(4)	3 axles
	3c	Heavy trucks(4)	4-5 axles
	3d	Heavy trucks(4)	≥6 axles
	3e	Trolley buses	3-4 axles
	3f	Vehicles designed for extra low noise driving	3-4 axles(5)
Other heavy vehicles	4a	Construction trucks (partly off-road use)(4)	
	4b	Agr. tractors, machines, dumper trucks, tanks	
Two-wheelers	5a	Mopeds, scooters	Include also 3-wheel motorcycles
	5b	Motorcycles	

(1) 3-4 axles on car & trailer or car & caravan

(2) Hybrid vehicles driven in combustion engine mode: Classify as either 1a or 1b

(3) Also 4-wheel trucks, if it is evident that they are >3.5 tons

(4) If a high exhaust is noted, identify this in the test report. Categorize this as 3b', 3c', 3d' or 4a'

(5) For example, there are some delivery trucks designed for extra low noise (meeting more stringent standards than the current EU limiting levels) combined with a driving mode called “Whisper mode” making it possible to drive in a residential area with much lower noise emission than for a conventional delivery truck. All trucks and buses especially designed in accordance with these ideas are counted in this category.

6.3 Road surface characterization

See 5.2.2 and 5.2.4.

6.4 Point source model

Cars are to be represented by two sources, one very close to the road, 0,01 m, and one at 0,3 m. For heavy vehicles the high source should be raised to 0,75 m. For heavy construction equipment an additional source for exhaust noise at 3,5 m should be used. As to the power distribution between the source heights see 6.5.3 and 6.5.4.

6.5 Source strength – Sound power level

6.5.1 Reference condition

HARMONOISE will use the reference temperature t= 20ºC and a virtual reference road surface consisting of a mixture of DAC 0/11 and SMA 0/11 with an age of 2 years or more but not at the end of its life time. Corrections to other temperatures and some other road surfaces will be given, see 6.7 and 6.9. The driving condition will be cruising and corrections to acceleration/deceleration will be given. Corrections to reference conditions are summarized in 6.4.2.

Each EU member state may define a reference surface of their own and road surface corrections of their own provided that they have sufficient data to do so. They should also establish corrections between their reference surface and that of the virtual reference road surface. For more information on reference surfaces, see [30].

6.5.2 Corrections to reference conditions

The following corrections can be used:

Table 6.2 Corrections to be applied

Condition to correct	**See clause**
Acceleration/deceleration	6.11
Road surface (type, age)	6.10
Road temperature	6.8
Road wetness	6.10
Winter tyres	6.9
Directivity	6.6
Regional corrections	6.12

6.5.3 Tyre/road (rolling) noise

80% of the tyre/road noise will be assumed to be radiated by a point source 0,01 m above the road surface. The remaining 20% will be assumed to radiate from the source location at 0,3 m and 0,75 m respectively. Rolling noise for the reference condition is given by the following equation:

$$L_{WR}(f) = a_R(f) + b_R(f)\lg\left[\frac{v}{v_{ref}}\right] \qquad (6.1)$$

where v_{ref}= 70 km/h. The coefficients $a_R(f)$ and $b_R(f)$ for each main vehicle category is given in table 6.3. The values are intermediate values and a definite set of coefficients will be developed within the framework of the IMAGINE project, [37], and are expected around December 2006. The difference between category 2 and category 3 is constant. It is assumed that L_W increases as 10 lg(number of axles). The default value is that a category 3 vehicle on average has 4 axles to compare with the two axles of a category 2 vehicle. During other circumstances it may be more appropriate to use another number of axles. Heavy city buses will often have 3 axles and long distance freight traffic will on average have at least 5 axles. In Sweden where longer vehicles are permitted it is not unusual with 7 axles and there the average number is close to 6. Thus the equation to use is

$$(a_R)_{Category3} = (a_R)_{Category2} + 10\lg\left(\frac{numberofaxles}{2}\right) \quad (6.2)$$

Table 6.3 Rolling noise coefficients for the reference case (Average DAC 0/11-SMA 0/11, 20ºC)

	Category 1		Category 2		Category 3(4 axles)	
	a_R	b_R	a_R	b_R	a_R 1)	b_R
25	69,9	33	76,5	33	79,5	33
31,5	69,9	33	76,5	33	79,5	33
40	69,9	33	76,5	33	79,5	33
50	74,9	30	78,5	30	81,5	30
63	74,9	30	79,5	30	82,5	30
80	74,9	30	79,5	30	82,5	30
100	79,3	41	82,5	41	85,5	41
125	82,5	41,2	84,3	41,2	87,3	41,2
160	81,3	42,3	84,7	42,3	87,7	42,3
200	80,9	41,8	84,3	41,8	87,3	41,8
250	78,9	38,6	87,4	38,6	90,4	38,6
315	78,8	35,5	88,2	35,5	91,2	35,5
400	80,5	31,7	92	31,7	95,0	31,7
500	85,7	21,5	94,1	21,5	97,1	21,5
630	87,7	21,2	93,8	21,2	96,8	21,2
800	89,2	23,5	94,4	23,5	97,4	23,5
1000	90,6	29,1	92,2	29,1	95,2	29,1
1250	89,9	33,5	89,6	33,5	92,6	33,5
1600	89,4	34,1	88,9	34,1	91,9	34,1
2000	87,6	35,1	86,5	35,1	89,5	35,1
2500	85,6	36,4	83,1	36,4	86,1	36,4
3150	82,5	37,4	81,1	37,4	84,1	37,4
4000	79,6	38,9	79,2	38,9	82,2	38,9
5000	76,8	39,7	77,3	39,7	80,3	39,7
6300	74,5	39,7	77,3	39,7	80,3	39,7
8000	71,9	39,7	77,3	39,7	80,3	39,7
10000	69,0	39,7	77,3	39,7	80,3	39,7

1) These values refer to 4 axles. For other numbers of axles, see equation (6.2)

6.5.4 Propulsion noise

80% of the propulsion noise will be assumed to radiate from the source location at 0,3 m and 0,75 m for light and heavy vehicles respectively. 20% will be assumed to radiate from a point source 0,01 m above the road surface. Propulsion noise is given by the linear relationship

$$L_{WP}(f) = a_P(f) + b_P(f)\left[\frac{v - v_{ref}}{v_{ref}}\right] \qquad (6.3)$$

where v_{ref}= 70 km/h. The coefficients $a_P(f)$ and $b_P(f)$ for each main vehicle category is given in table 6.4. The values are intermediate values and a definite set of coefficients will be developed within the framework of the IMAGINE project, [37], and are expected around December 2006.

Table 6.4 Coefficients for propulsion noise 2004-10-14

	Category 1		Category 2		Category 3	
	a_P	b_P	a_P	b_P	a_P	b_P
25	85,8	0	97	0	97,7	0
31,5	87,6	0	97,7	0	97,3	0
40	87,5	0	98,5	0	98,2	0
50	87,5	0	98,5	0	103,3	0
63	96,6	0	101,5	0	109,5	0
80	97,2	0	101,4	0	105,3	0
100	91,5	0	97	0	100,8	0
125	86,7	0	96,5	0	101,2	0
160	86,8	0	95,2	0	99,9	0
200	84,9	0	99,6	0	102,3	0
250	86	8,2	100,7	8,5	103,5	8,5
315	86	8,2	101	8,5	104,0	8,5
400	85,9	8,2	98,3	8,5	101,6	8,5
500	80,6	8,2	94,2	8,5	99,2	8,5
630	80,2	8,2	92,4	8,5	99,4	8,5
800	77,8	8,2	92,1	8,5	95,1	8,5
1000	78	8,2	93,8	8,5	95,8	8,5
1250	81,4	8,2	94,3	8,5	95,3	8,5
1600	82,3	8,2	95,2	8,5	93,8	8,5
2000	82,6	8,2	94,9	8,5	93,9	8,5
2500	81,5	8,2	93,3	8,5	92,7	8,5
3150	80,7	8,2	91,2	8,5	91,6	8,5
4000	78,8	8,2	89,3	8,5	90,9	8,5
5000	77	8,2	87,3	8,5	87,9	8,5
6300	76	8,2	85,3	8,5	87,9	8,5
8000	74	8,2	84,3	8,5	81,8	8,5
10000	72	8,2	83,3	8,5	80,2	8,5

Propulsion noise is presumed to be independent of the road surface. The effect of porous road surfaces will be taken into account by the propagation model and a different road surface impedance. In addition it might be necessary to correct for the decrease in apparent sound power radiation due to less contributions from multiple reflections between engine compartment and road surface. However, at this stage, no such correction is made. In case of high exhausts all propulsion sound power level at and below the midband frequency 315 Hz will be assigned this source.

6.5.5 Sound power level of the whole vehicle

If one has to work with the sound power from the whole vehicle it is necessary to distribute the sound power between the lowest and the highest source. The ratio, *p*, of total sound power which is to be associated with the lowest source is given by

$$p = \frac{0{,}8 \cdot 10^{L_{WR}/10} + 0{,}2 \cdot 10^{L_{WP}/10}}{10^{L_{WR}/10} + 10^{L_{WP}/10}} \qquad (6.4)$$

where L_{WR} and L_{WP} are the rolling and propulsion sound power levels calculated according to 6.5.3 and 6.5.4 respectively.

6.6 Directivity

The point sources should be assigned both horizontal and vertical directivity. When integrated over a pass-by the integral of the directivity function should be close to zero. In this context a pass-by is defined as ± 79º. The horn effect has its greatest effect around 1600-2000 Hz. The reference is the omnidirectional sound power level which, using the propagation model and integrated during a complete pass-by, yields the correct sound exposure level in the horizontal direction. It will be assumed that the vertical directivity is the same for all horizontal angles. Different directivity functions will be used for tyre/road (rolling) and propulsion noise.

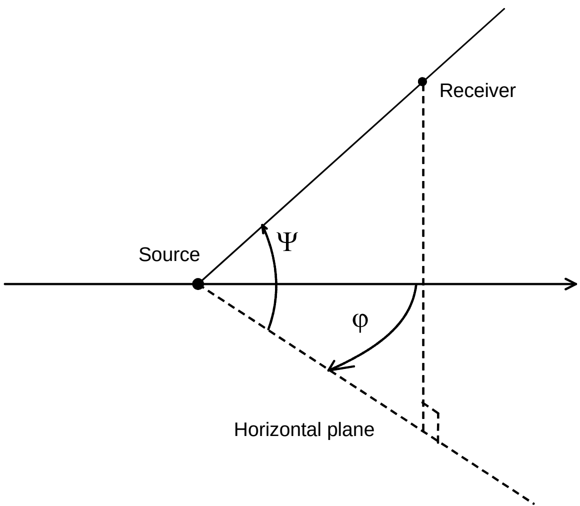


Figure 6.1 Geometry for the directivity functions (Note that the definition of ψ has been changed relative earlier chapters)

The directivity function which is a function of angles, see figure 6.1, and frequency, *f* is given by

$$\Delta L(f,\varphi,\psi) = \Delta L_H(f,\varphi) + \Delta L_V(f,\psi) \qquad (6.5)$$

ΔL_H is normalized to yield 0 dB contribution when integrated during pass-by and $\Delta L_V(0) = 0$ dB. The indices in the formulae hereafter are defined as:

$\{H,\ V\} = \{Horizontal,\ Vertical\}$ and $\{R,\ T,\ A\} = \{Rolling,\ Traction,\ Aerodynamic\}$.

It will be assumed that

$$\Delta L(f,\varphi,-\psi) = \Delta L(f,\varphi,\psi) \qquad (6.6)$$

Table 6.5 Functions approximating the vertical directivity ΔL(ψ)

Freq./source height	hs=0,01m	hs=0,3m	hs=0,75m
50,63,80	0	-2sin(ψ)	0
100,125,160	0	-4sin(ψ)	0
200,250,315	$-2(1-\cos^2(\psi)$	$-5(1-\cos^2(\psi)$	$-2(1-\cos^2(\psi))$
400,500,630	$-3(1-\cos^2(\psi)$	$-5(1-\cos^2(\psi)$	$-3(1-\cos^2(\psi))$
800,1000,1250	$-4(1-\cos^2(\psi)$	$-6(1-\cos^2(\psi)$	$-3(1-\cos^2(\psi))$
1600,2000,2500	$-4(1-\cos^2(\psi)$	$-6(1-\cos^2(\psi)$	$-2(1-\cos^2(\psi))$
3150,4000,5000	0	$-5(1-\cos^2(\psi)$	-2(1-cos(ψ))
6300,8000,10000	0	-8(1-cos(ψ))	-2(1-cos(ψ))

For the point source at the height 0,01 m the following horizontal directivity is to be used

$$\Delta L_H(\varphi) = 0;\ f \leq 1250\ Hz,\ f \geq 8000\ Hz \quad (6.7a)$$

$$\Delta L_H(\varphi) = (-1{,}5 + 2{,}5 \cdot abs(\sin(pi/2-\varphi)))\sqrt{\cos(\psi)};1600 \leq f \leq 6300 Hz \quad (6.7b)$$

For the point source at height 0,3 m the following horizontal directivity is to be used

$$\Delta L_H = 0 \quad (6.7c)$$

For the point source at height 0,75 m the following horizontal directivity is to be used

$$\Delta L_H(\varphi) = (1{,}546 \cdot (pi/2-\varphi)^3 - 1{,}425(pi/2-\varphi)^2 + 0{,}22(pi/2-\varphi) + 0{,}6)\sqrt{\cos(\psi)}$$

(in radians) (6.7d)

6.7 Corrections for interrupted traffic flow

No corrections are required for crossings without traffic lights. The calculations should be carried out like the case with an uninterrupted traffic flow although changes in speed have to be taken into account. Speed changes are in general significant in roundabouts.

6.8 Corrections for temperature

Rolling noise is to be corrected for temperature. This correction should be frequency dependent. However, due to lack of detailed data the correction to be applied equally on all frequency bands is

$$L_{WR}(\theta) = L_{WR}(\theta_{ref}) + K(\theta_{ref} - \theta) \quad (6.8)$$

where

L_{WR} = sound power level due to rolling noise, dB

θ = the measured air temperature, ºC

θ_{ref} = the reference temperature, 20ºC

K = the temperature coefficient given in table 6.5 below

Table 6.6 Temperature coefficient K for different surfaces, air temperature, from [35]

Main acronym	***Detailed acronym*** *Common variants for different aggregate compositions (maximum chipping size, etc)*	***Surface description***	***Temperature coefficient (air) (divide by 2 for vehicle categories 2-4)***
Bituminous mixes ("asphalt" surfaces)			
DAC	DAC 0/8, DAC 0/11, DAC 0/14, DAC 0/16	Dense asphalt concrete	0.10
SMA	SMA 0/8, SMA 0/11, SMA 0/14, SMA 0/16	Stone mastic asphalt	0.06
OGAC	OGAC 4/8, OGAC 6/11, OGAC 8/14, OGAC 8/16	Open-graded asphalt concrete, voids 15-19 % (when new)	0.05 (if ≤ 1 yr) 0.06 (if > 1 yr)
PAC	PAC 4/8, PAC 6/11, PAC 8/14, PAC 8/16	Porous asphalt concrete (single-layer), voids ≥20 % (when new)	Up to and incl PAC 6/11: 0.05 (if ≤ 2 yr), 0.06 (if > 2 yr) Above PAC 6/11: 0.04 (if ≤ 2 yr) 0.06 (if > 2 yr)
DPAC	DPAC 4/6+8/11, DPAC 4/8+11/16, PAC 6/11+11/16	Porous asphalt concrete (double-layer)	0.05 (if ≤ 2 yr) 0.06 (if > 2 yr)
GA	GA 5/8, GA 8/11	Gussasphalt = mastic asphalt, surface common in Germany, usually has chippings rolled into it	GA 5/8: 0.10 GA 8/11: 0.06
HRA	HRA 8/11, HRA 11/16	Hot rolled asphalt, surface common in the U.K., always has chippings rolled into it	0.06
THS	THSDAC 0/6, THSDAC 0/8, THSSMA 0/6, THSSMA 0/8	Thin surfacing (non-proprietary), based on either a DAC or SMA mix	0.10
ISO-S		Reference smooth surface according to ISO 10844	0.08
ISO-R		Reference rough surface according to ISO 10844	0.12
Rubberized surfaces			
DACR	DACR6 0/11	Asphalt rubber = DAC surface with rubber added (>2% and <20% by weight)	0.10
PERS	PERS 50, PERS 85	Poroelastic road surface (≥20 % by weight is rubber)	0.06
Surface dressings (often called "chip seals")			
SDS	SDS 4/8, SDS 8/11, SDS 11/16	Surface dressing (single)	0.12
SDD	SDD 4/8+8/11, SDD 8/11+11/16	Surface dressing (double)	0.12
Cement concrete (often called just "concrete")			
CC	CC 0/8, CC 0/11, CC 0/14, CC 0/16, CC 0/22	Cement concrete (often referred to as just	0.05

		"concrete") – untreated	
CCDG	CCDG 3-6	Cement concrete – diamond ground (longitudinally)	0.05
EACC	EACC 0/8, EACC 0/11, EACC 0/14, EACC 0/16, EACC 0/22	Exposed Aggregate Cement Concrete	EACC 0/8: 0.05 Others: 0.09
CCHD		Cement concrete with Hessian drag treatment	0.05
CCAT		Cement concrete with Astroturf treatment	0.05
CCTG	CCTG 5-15/30	Cement concrete with transversal grooves or tines	0.09
CCLG	CCLG 5-15/30	Cement concrete with longitudinal grooves or tines	0.09
PCC	PCC 4/8, PCC 8/11, PCC 8/16	Porous cement concrete (single-layer)	0.03 (if ≤ 2 yr) 0.04 (if > 2 yr)
Proprietary surfaces			
xxxxx	These often have only one single composition	Various proprietary surfaces	0.06 (depends on the type, check with Table 2, the value here is for the most common types in use 2004)
Paving block surfaces			
ILCB	ILCBd 100/200, ILCBt 100/200	Inter-locking cement block surfaces (moulded blocks)	0.06
PS	PSd 100/200, PSt 100/200	Paving stones, flat surface, square or rectangular cut stones	0.06
CS	CS 150	Cobble stones, old type of paving stones (rounded stones)	0.06

6.9 Corrections for tyres

It is recognized that different tyres yield different noise levels. One example is that a 25 mm increase in tyre width will increase the rolling noise sound power level by about 1 dB. However, in Harmonoise such corrections will be regarded as regional corrections and any corrections to the Harmonoise default values is the responsibility of the individual EU member states. For winter tyres the following provisional default corrections are proposed:

Table 6.7 Corrections for winter tyres

Tyre	Correction
Without studs	No correction
With studs	See table 6.8

Tyres without studs: No corrections; Tyres with studs, see table 6.8. The Imagine project will collect new data on winter tyres.

Table 6.8 Tyres with studs: The following correction $\Delta L = a + b\ lg(v)$:

	a	*b*
25-100	0	0
125	8,1	-4,1
160	12,5	-6,03
200	17,6	-8,5
250	7,8	-4,1
315	-3	1,73
400	0,85	0,6
500	11	-4,55
630	9,7	-3,85
800	7,8	-2,7
1000	10,9	-4,2
1250	23,7	-11,7
1600	22,7	-11,7
2000	29	-14,9
2500	35,2	-17,6
3150	42,4	-21,8
4000	41,9	-21,6
5000	37,9	-19,2
6300	32,6	-14,6
8000	28,5	-9,9
10000	32,2	-10,2

The correction is valid for $50 \leq v \leq 90$ km/h. $v < 50$ and $v > 90$ equals $v = 50$ and $v = 90$ km/h respectively.

6.10 Corrections for different road surfaces

6.10.1 General

Road surface corrections for tyre/road noise depend on:

- Surface type (> 100 surface types)
- Vehicle categories (light and heavy)
- Speed (a + b log expression)
- Frequency band
- Age of surface
- Wetness of surface

In addition, for propagation calculations, the acoustic impedance has to be adapted to the circumstances.

6.10.2 Impedance

The following impedances has been tested and are recommended for use whenever appropriate:

1. For surfaces within the reference cluster use the one parameter model with the flow resistivity 200 MPas/m^2.
2. For the ISO road surface use the one parameter model with the flow resistivity 2 MPas/m^2.
3. For porous road surfaces use the Hamet model:

$$Z = \frac{q}{\Omega} F_{\mu}^{1/2} \left[\gamma - \frac{\gamma - 1}{F_{\theta}} \right]^{-1/2} ; \quad \frac{k}{\omega / c} = q F_{\mu}^{1/2} \left[\gamma - \frac{\gamma - 1}{F_{\theta}} \right]^{1/2} \tag{6.9}$$

$$F_{\mu} = 1 + i \frac{f_{\mu}}{f} ; \; f_{\mu} = \frac{\Omega \sigma}{2 \pi \rho q^2} \tag{6.10}$$

$$F_{\theta} = 1 + i \frac{f_{\theta}}{f} ; \; f_{\theta} = \frac{\sigma}{2 \pi \rho N_{pr}} \tag{6.11}$$

Default values are σ= 5 kPasm^{-2}, Ω= 0.2, q^2 = 5, d = 0.04 m, ρ = 1,2 kg/m^3, N_{pr}= 0,71, γ = 1,4. However, it is recommended to determine the parameters for each specific road.

6.10.3 Road surfaces belonging to the reference cluster

Differences between surfaces within the reference cluster are handled by frequency and speed independent corrections as follows:

Heavy vehicles: No corrections

Light vehicles (Category 1): See table 6.9. The corrections are applied equally on the coefficient a_R in table 6.3 for each frequency band. The validity of the table is restricted to chipping sizes between 8 and 16 mm.

Table 6.9 Corrections within the reference cluster to be applied equally for each frequency band.

Road surface	Correction relative virtual reference
Virtual reference, Harmonoise default, chipping size: 11 mm, mean value of DAC and SMA	$\pm$ 0 dB
DAC	-0,3 dB
SMA	+0,3 dB
Chip size (Validity restricted to 8-16 mm)	+0,25 dB/mm above 11 mm -0,25 dB/mm below 11 mm
Age	$-(0{,}2T^2 - 1{,}2T + 1{,}6); T \leq 2 years$

Note. As an example a 2 years old SMA 0/16 road surface will have a correction of 0,3 + 5·0,25 = 1,55 dB.

6.10.4 Other road surface types

In addition to the road surfaces of the reference cluster the following road surface corrections are available

Table 6.10 Corrections for rolling noise of category 1 vehicles for some different surfaces, Dutch data

Cars (V0=70 km/h)	**valid**	**A(freq)**																										
road surface type	**speed range**	50	63	80	100	125	160	200	250	315	400	500	630	800	1k	1.25k	1.6k	2k	2.5k	3.15k	4k	5k	6.3k	8k	10k
PAC 6/16	40-130				0,8	1,3	1,3	0,9	1,3	2,5	2,8	3,1	2,8	-0,4	-3,0	-4,2	-4,3	-5,1	-5,9	-5,3	-3,7	-2,5	-2,1	-1,0	-0,1
2 layer PAC 11/16-4/8	40-130	0,7	0,2	3,6	-1,0	-1,8	-0,1	-0,9	-0,7	-1,1	-0,5	-1,5	-2,4	-3,0	-4,6	-5,8	-6,5	-7,9	-7,8	-7,2	-6,3	-5,6	-5,5	-4,8	-4,3
transversely brushed concrete	50-130				-0,3	-0,8	0,0	0,7	2,2	2,7	3,4	3,0	2,1	2,0	0,5	-0,1	1,0	1,7	1,4	0,1	-0,5	-0,5	-1,3	-1,8	-1,6
exposed aggregate concrete 7/11	50-130	-3,3	-3,1	-0,5	0,5	0,0	1,2	0,7	1,7	1,9	2,2	2,8	2,9	2,9	2,2	1,7	0,7	-0,3	-0,9	-0,9	-0,2	-0,5	-0,3	-0,4	0,4
sma 0/6	40-130				0,7	-0,1	0,3	-0,1	0,6	0,7	0,9	1,7	2,0	0,2	-1,9	-3,5	-2,9	-3,0	-2,5	-2,5	-1,8	-1,7	-6,0	-6,0	-4,8
surface dressing 1/3	50-130	0,8	-1,3	-0,4	1,6	1,7	2,0	2,4	2,8	3,7	4,3	5,0	4,8	4,4	4,1	2,3	0,2	-1,4	-1,9	-1,6	-0,5	-0,3	-0,3	0,0	0,3

Table 6.11 Corrections for rolling noise of category 2 and 3 vehicles for some different surfaces, Dutch data

Trucks (V0=70 km/h)	**valid**	**A(freq)**																						
Road surface type	**speed range**	50	63	80	100	125	160	200	250	315	400	500	630	800	1k	1.25k	1.6k	2k	2.5k	3.15k	4k	5k	6.3k	8k	10k
PAC 6/16	50-90				-0,2	-0,1	0,3	1,5	2,0	1,4	-0,1	0,0	-4,4	-5,9	-5,9	-5,1	-3,1	-2,0	-5,1	-4,9	-1,7	-1,5	-1,8	0,2	1,0
2 layer PAC 11/16-4/8	50-90	-1,8	-3,4	-1,5	-0,3	-1,5	-0,4	-0,5	-1,2	-1,1	-3,3	-4,0	-8,9	-9,4	-7,4	-6,1	-5,0	-4,7	-5,9	-5,7	-3,8	-3,6	-4,0	-2,7	-2,9
transversely brushed concrete	60-90				2,0	2,8	2,8	3,5	2,6	1,9	3,2	2,7	2,0	1,7	0,4	1,2	1,6	1,7	-0,1	-1,1	0,5	0,1	0,2	0,6	0,5
exposed aggregate concrete 7/11	50-90				-0,4	0,4	0,8	1,6	1,0	0,3	1,1	1,5	-0,4	-0,5	-1,4	-1,4	-0,3	-0,3	-2,2	-2,5	-0,7	-1,5	-1,3	-0,2	-0,2
sma 0/6	40-90				0,9	1,6	0,6	1,7	2,6	1,1	1,3	1,2	-1,5	-2,2	-2,3	-1,4	0,3	1,0	-0,9	-1,1	1,7	1,8	2,5	3,1	3,9
surface dressing 1/3	50-90	-2,4	-3,0	-1,8	0,9	1,1	1,5	2,1	0,9	1,1	2,0	2,8	0,6	-0,9	-2,1	-2,1	-0,9	-1,0	-3,1	-2,9	-0,5	-1,0	-0,6	0,3	0,4

Table 6.12 Corrections for paving surfaces, Polish data

	Paving stones		Block pavings
	Category 1	Category 3	Category 1
100	1,9	4,5	-5,4
125	7,8	6,7	-1,1
160	9,8	8,5	0,4
200	8,6	3,7	0,8
250	9,1	1,1	2,3
315	9,0	1,2	1,0
400	8,4	5,9	-1,2
500	11,3	9,8	0,9
630	10,7	9,7	-0,9
800	9,2	6,5	0,1
1000	7,8	3,1	1,5
1250	4,7	1,7	1,4
1600	1,5	0,5	0,2
2000	1,2	0,3	-0,9
2500	0,2	1,0	-2,1
3150	-0,2	0,3	-2,6
4000	0,2	-0,9	-2,2
5000	0,1	0,2	-1,7
6300	-0,6	-0,4	-2,7
8000	-0,4	1,1	-2,5
10000	-0,9	0,3	-3,0

Figure 6.2 Block paving

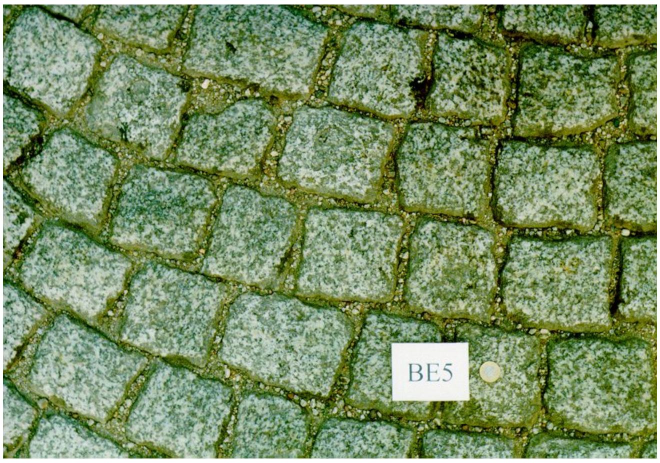


Figure 6.3 Paving stones

Table 6.13 Corrections for rolling noise for hot rolled asphalt with 20 mm chippings rolled into the surface, UK data (C1,2,3=category 1,2 and 3 respectively).

	<500	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000
C 1	0	2,2	2,8	4,2	5,3	3,4	0,1	-1,4	-2,8	-3,3	-4,1	-5,0	-6,5	-6,9	-8,5
C2, C3	0	0,4	2,1	2,2	1,4	1,1	-0,5	-1,7	-1,4	-2,3	-3,9	-3,7	-5,2	-5,3	-7,4

Note The data above refer to maximum sound pressure levels. Directivity effects may affect the sound exposure level differently.

6.10.5 Ageing

Newly laid surfaces are in general quieter than older ones. As the deterioration becomes stable already after 2 years no corrections are made unless the surface is porous where the deterioriation continues for 7 years. For porous surfaces like PAC, PCC, PERS and OGAC the equation is

$$\Delta L_T = \Delta L_0 (1-(0{,}25T - 0{,}016T^2)), T \le 7\,years \qquad (6.12)$$

where ΔL_0 is the sound pressure level for the individual frequency band relative the reference surface at the time T=0 years. The correction is made at each band frequency for the rolling noise component.

6.10.6 Wetness

Correction is only applied for wet surfaces, that is when there is a layer of water on the road. The correction is only made for high frequencies and passenger cars. The increase ΔL_{wet} relative a dry surface is given by:

$$\Delta L_{wet} = 10\lg\left(\frac{110}{v}\right) + 20\lg\left(\frac{f}{2000}\right), f > 2000 \text{ Hz}, 30 < v < 110 \qquad (6.13a)$$

$$\Delta L_{wet} = 5\lg\left(\frac{110}{v}\right), f = 1600 \text{ Hz} \qquad (6.13b)$$

$$\Delta L_{wet} = 2{,}5\lg\left(\frac{110}{v}\right), f = 1250 \text{ Hz} \qquad (6.13c)$$

No corrections are introduced for heavy vehicles as there is not yet sufficient data available to draw any firm conclusions.

6.11 Correction for acceleration/deceleration

6.11.1 Rolling noise

No correction is proposed for slip. Measurements indicate that important slip (> 5%) only occurs under such extreme conditions that there will be negligible influence on L_{den} calculations.

6.11.2 Propulsion noise

Correction for acceleration/deceleration is given by

$$\Delta L_{acc} = C \cdot a \text{ ; -2 m/s}^2 \le a \le 2 \text{ m/s}^2 \qquad (6.14)$$

where a = the acceleration (a>0)/deceleration (a<0) in m/s^2 and the coefficient C is given by table 6.14. For category 3 vehicles applying engine brake the unsigned value of the acceleration a shall be used. Such will often be the case under steep and long downhill conditions. The correction is made equally at each band frequency for the propulsion noise coefficients a_P given in table 6.4. It is also proposed to treat gradients accordingly, that is to regard the downward component of the gravity (a=10 sin(α) wher α = the angle of the ramp) as acceleration/deceleration.

Table 6.14 Acceleration/deceleration coefficient in eq. (6.14).

Vehicle category	*C*
Category 1	4,4
Category 2	5,6
Category 3	5,6

6.12 Regional corrections

The default data on tyre/road (rolling) and propulsion noise may not always be the most appropriate data to work with. Each country is encouraged to check the default Harmonoise sound power levels and, if appropriate, to elaborate regional corrections. Examples of differences, which might be important, are unusual proportions of large/small vehicles and road surfaces based on local materials deviating from those on which the corrections are based. As was indicated in chapter 5 it is also possible that different regional speed coefficients should be used. Regional corrections will be dealt with within the frame of the European Imagine project, [37]. New measurements should be carried out according to the Harmonoise test method for the whole vehicle as described in [14]. The method is based on pass-by measurements and it also gives some guidance on how to determine the sound power level from such measurements.

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