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Report

NordTyre Part 3: Results of tyre/road noise measurements

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Colofon

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Contents

1 Objective

1.1 Introduction

The Danish Road Directorate has contracted M+P and SINTEF to perform a study on the noise levels of a series of truck tyres. The study comprised the following components:

1. Selection of a representative series of 30 test tyre types. The proposed selection of tyre types is described in a report (see ref [3]).
2. The identification and compliance testing of a suitable test area with the test surfaces specified in the tender (see ref [1]) and the M+P proposal (see ref [2]). The compliance of the test area and the test sections with the requirements are given in ref [4]).
3. The performance of a series of coast-by measurements according to a procedure specified in the ECE type approval regulation for tyres, R117 (see ref [8] and the processing of the measured data to determine coast by spectra at 10 km/h intervals between 40 and 80 km/h.
4. The identification of tonal components in the tyre/road noise signals of the tested tyres on the four tested surfaces.

This report presents the results of the coast-by testing and tonal components in the tyre/road noise signals.

2 Description of measurement procedure.

2.1 Map

The test area is located on a non-used taxi way of the former military airport Twente. The picture below presents an aerial view of the airport together with the location of the taxi way, the test sections and the shelter used for the project.

figure 1 *Left: Aerial view of the test area with the test sections and the shelter. Right: Picture of the taxi way with the test sections. Picture is taken in NE direction.*

2.2 Test sections

On the taxi way the following test sections are available:

1 Thin Surface Layer with 8 mm maximum tone size and partly porous structure (TSL8)
2 Dense Asphalt Concrete 0/16 (ACsurf16[*])
3 Dense asphalt concrete 0/8 (ACsurf8[*])
4 Dense asphalt concrete 0/8 with slightly coarser texture (ISO 10844).
5 SMA11

The test area is also used for skidding testing. For this purpose the fine texture of the sections 1, 2 and 3 is smoothened artificially with a sanding device. Through this procedure, the positive texture of the protruding peaks is removed. This smoothing is the main reason that the surface of section 3 did not meet the texture requirements in the tender. Hence, an additional ISO 10844 surface with the required MPD value had to be laid. Subsequently, surface 3 is not used as test surface in the project.

Section 4 is newly laid for this project and serves as the required ISO 10844 compliant surface.

Section 5 represents the representative surface for SMA11 as is required in the tender. This surface is not laid there within the framework of testing, but is there for already more than 10 years. It serves as a high skid surface for aircraft applications (although no landing/taking-off actions are performed on that strip).

An overview of the sections and their lengths is given in figure 2. The SMA11 section is not a separate surface type, but is identical to the surface everywhere else on the strip.

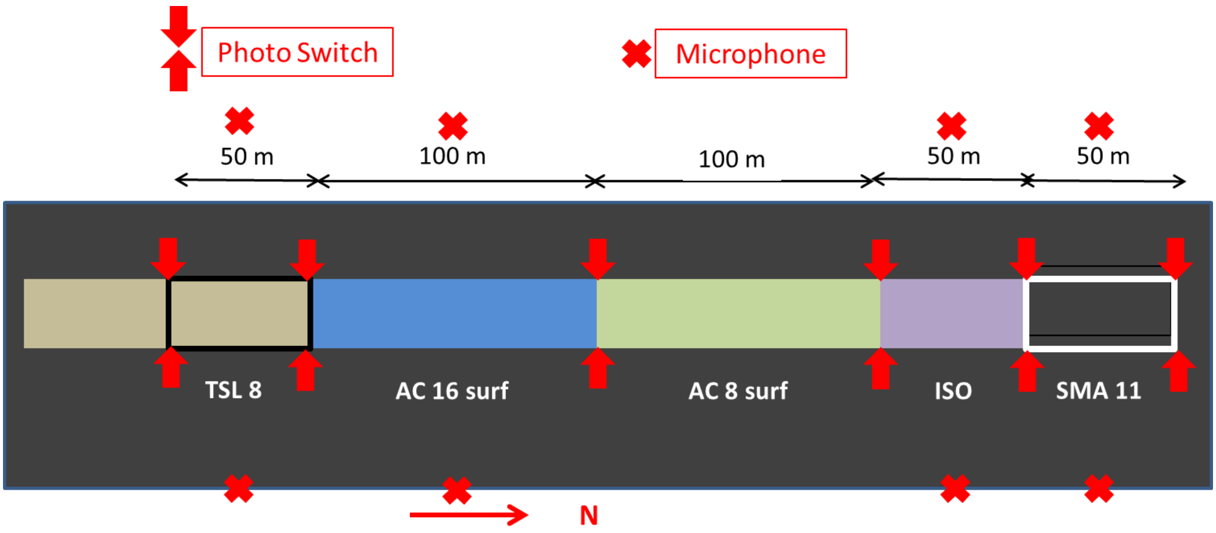


figure 2 *Overview of test section on the strip. The most left TSL8 section is only used for the last 50 m. The red crosses indicate the microphone positions. The red arrows indicate the photo switches used to detect the position and the speed of the vehicle.*

2.3 Test geometry

A series of 8 microphone stands are placed at a distance of 7.5 meters from the center of the test section. Each stand is each equipped with a microphone pair, one at 1,2 m and one at 3,0 m height. Each microphone is located half way of the 50 or 100 m long test sections at both sides of the test section (see figure 2). The cross section of the testing geometry is given in figure 3.

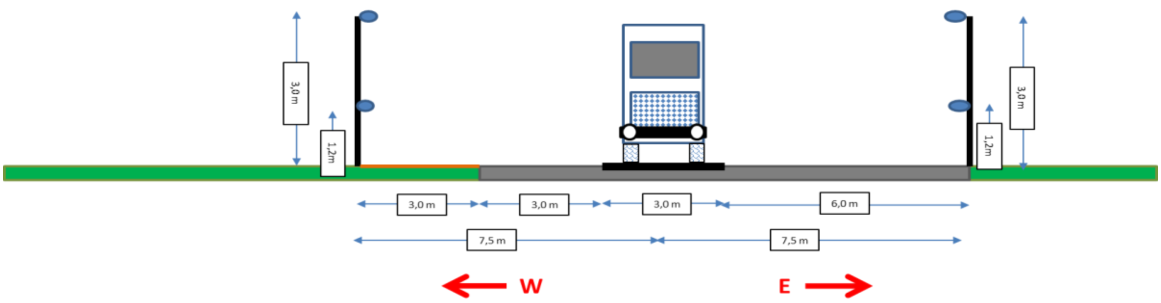


figure 3 *Cross section of the test geometry.*

The propagation area to the east side of the test sections consists of a dense SMA 11 surface up to the position of the microphone. The propagation area to the west side differs slightly for the test sections.

- At the TSL 8 section, the microphone is placed on a dense surface;
- In case of the SMA11 and the AC 16 surf sections the microphone is placed in the grass shoulder; [1]
- In case of the ISO 10844 section, the area between paved surface and microphone stand is covered with 25 mm plywood boards in order to meet the requirements of a reflective area between drive lane and microphone position as is defined in ISO 10844.

[1] The two positions in the soft shoulder at the SMA 11 and the AC 16 surf sections fit in the requirements of propagation area defined in the ISO 11819-1 SPB standard.

2.4 Test vehicle properties

The coast-by testing is performed with a 2-axle tractor capable of mounting 385 22.5 tyres on the front axle. The powertrain system allows coasting in not- engaged condition of the gear box and engine switched off.

2.4.1 Test tyres

The tyres under testing consists of a mix of steer, drive and trailer tyres, both snow/ice and non-snow/ice with original and re-treaded profiles. The drive and steer types had a width of 315 mm. The trailer types had a width of 385 mm. A total of 29 different tyre lines are tested. For one tyre type, the Nokian Hakkapellitta E, we had two sets which enables us to gain insight in the variability within a tyre type. For an extensive description of the tyres and their relevant properties the reader is referred to reference [5].

The tyres are mounted on steel rims of the size fit for the size of the test tyre.

Before performing the coast-by testing, the tyres are broken-in by driving with them over a distance of 100 to 150 km over a normal road. The position of the tyres during break-in is recorded and during the coast-by testing the tyres are mounted on the same position positions.

The air pressure of the test tyres are chosen according to the formula in R117 that includes the load capacity of the tyre and the actual load of the tyre. For the 315 size a pressure of 7,2 HPa and for the 385 size a pressure of 6,1 HPa is applied. Tyre pressure is checked in cold condition.

2.4.2 Tyre load

The test vehicle has to be loaded to achieve a specified tyre load that is based on the load index of the test tyre. In this test we have used test tyres with two different load indices. The R117 [8] requires that:

- the actual load per tyre is between 50% and 90% of the maximal load;
- the total load of the tyre set is between 70% and 80% of the maximal load.

The table below presents these requirements for the two tyre sizes used.

table I *Data and requirements for the two tyre sizes used in the test derived from R117 [8]. The grey areas indicate the relevant boundaries of the possible overlap between 315 and 385 requirements. An overlap is found between the 12.600 kg minimum load for the 385 tyre and 12.800 kg maximum load for the 315 tyre.*

Tyre size	315/70R22,5	385/55R22,5
Load index single mounting	156	166
Allowed load/tyre (=MAX_T)	4.000 kg	4.500 kg
Allowed vehicle load (=MAX_V)	16.000 kg	18.000 kg
Minimum axle load (=50% of MAX_T)	4.000 kg	4.500 kg
Maximum axle load (=90% of MAX_T)	7.200 kg	8.100 kg
Min vehicle load (=70% of MAX_V)	11.200 kg	12.600 kg
Max vehicle load (=80% of MAX_V)	12.800 kg	14.400 kg

The required loading is achieved by adding concrete blocks on the frame with a specific weight and a specific position such that the requirements for the minimum axle load of 4.500 kg (385 width) and maximum axle load of 7.200 kg (315 width) are met, together with the minimum vehicle weight of 12.600 kg (385 width) and maximum vehicle weight of 12.800 kg (315 width).

The loading chosen is 12.600 kg that is obtained by adding an extra load of 4.800 kg. The load is distributed over front and rear axle according to the values in table II.

table II *Determination of the extra load on the test vehicle and the distribution of the extra load over the front and rear axle. Requirements for the two tyre sizes used in the test is derived from R117 [8].*

	Front axle	Rear axle	Total
No extra load	5500 kg	2300 kg	7800 kg
Extra load	850 kg	3950 kg	4800 kg
Total load	6350 kg	6250 kg	12600 kg

The required axle loading is obtained with a block of 4.800 kg of concrete mounted such that 850 kg weights on the front axle and 3.950 kg on the rear axle. We acknowledge the support of DAF Trucks Netherlands for the supply of the specified block and the mounting of the system such that the correct weight distribution over front and rear axle is obtained.

figure 4 *Picture of the test vehicle and the extra load applied to meet axle load and vehicle load criteria in R117 [8].*

2.5 Measurement system

2.5.1 Coast-by measurements

The objectives of the project are to compare tyre noise levels on ISO tracks against each other and to compare levels obtained on the ISO surface with levels obtained on SMA and other surfaces. Such comparison is improved when effects from varying environmental conditions can be excluded as much as possible. We strived for this in two ways:

- To maximize the measuring efficiency such that the total measurement period is as short as possible;
- To measure the sound levels on different surfaces directly after each other.

For this a multi-channel measurement system is used that enables us to achieve a high data acquisition speed together with an optimal control of the measurement condition and direct check of back ground noise levels and required signal to background noise ratios.

The system is designed as follows:

- A series of 8 microphone stands, each equipped with a microphone pair, one at 1,2 and one at 3,0 m height. Each microphone is located half way of the 50 or 100 m long test sections at both sides of the test section (see figure 2).
- A series of six light switches, positioned at the beginning and end of each test section (see figure 2.). The distance between the light switches and the time interval between the pass-by's, defines the average speed. Because the microphones are located half way, the average speed is very close and within the required speed accuracy to the speed at the microphone position.
- The heart consists of a high speed multi-channel data acquisition system (PAK MKII) able to read the 16 signal channels with 44 kHz and 24 bits accuracy. Added to this is a high speed tacho input that is used to time the passing of the light switches.
- The 16 input channels are continuously filtered through 1/3rd octave bands and the output levels of each filter is sampled with 25 Hz and stored for later use. Simultaneously also the full signal is stored for possible later analysis.
- During the measurements the A-weighted signal is displayed for the operator as a time series for all microphones that belong to a specific section. A possible distortion by background noise is detected by checking the difference between the peak and tails of the A-weighted traces. Additional, the total A-weighted levels at 1,2 m and at 3,0 m at both sides of the section can be compared from the traces and any deviation can be noted and checked for possible errors.

2.5.2 Close proximity recording

An additional topic in the *Nord Tyre Part 3 – Truck tyre noise* is the identification of tonal components in the tyre/road noise. In the offer [2] it is proposed to base the identification on the analysis of the coast-by signals at the stationary microphones. Such identification is hampered by the Doppler shift during the pass-by event. Narrow band analysis on base of the *LAFmax* is limited because of the short duration of the signal (band width and time interval are related). Frequency shifting the recorded signal to compensate for this Doppler shift is found to be too complicated.

We have chosen to record the signal in a close proximity position (see figure 6). The relevance of this measurement lies mainly in the spectral composition and not in absolute values. Therefore an arbitrary position is decided. The tyre/road noise signal at close proximity of the front tyre is recorded as a WAV file for later analysis and possibly listening tests.

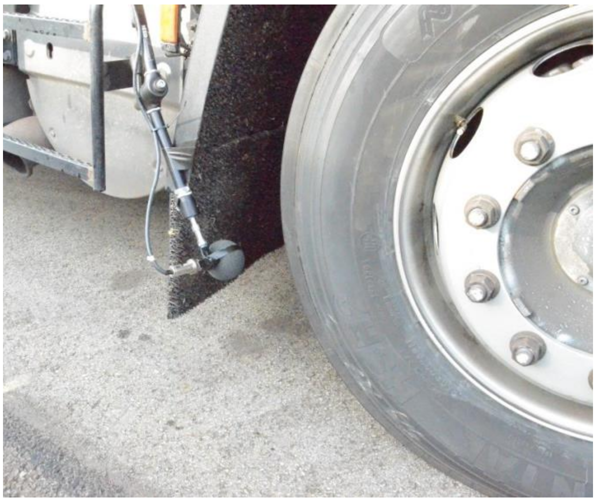


figure 6 Picture of the microphone location used for the Close proximity recording of the tyre/road noise signal.

2.6 Test procedure

2.6.1 Test protocol

The core of the procedure consists of a coast-by test with engine switched off. The vehicle speeds ranged between 40 and 80 km/h and in total 14 or more repetitions are performed.

The procedure of the testing is the following.

1. Calibration of each microphone to a level of 94,0 dB. The PAK system stores calibration factors and indicates difference in calibration factor compared to the former one. Any deviation over 0,5 dB is investigated and if necessary equipment is replaced. Calibration is repeated after 3 to 4 hours. In the majority of cases the observed difference between two consecutive calibrations is below 0,1 dB. No difference is observed above 0,5 dB.
2. The tyres are mounted on the vehicle on the same positions that they are mounted during the break-in procedure.
3. The tyres are slightly warmed up by driving for 10 to 15 minutes up and down the test track at a speed of around 60 km/h.
4. The test vehicle approaches the test sections at a designated speed. Before reaching the first test section, the gear is disengaged and the engine is switched off. The truck is coasting along the series of 4 sections with the engine switched off. After that, the engine is restarted and the vehicle approaches the end of the available lane, where the vehicle very slowly turns, in order not to cause uneven wear of the tyre.
   Over the length of the test sections of 350 m coasting speed drops with about 10 km/h in S direction to 15 km/h in N direction. The difference is explained by the gradual slope of the test area.
5. The operator controls the traces of the overall values per test section and checks for any errors or too high background levels. If left/right values or the values at 1,2 and 3,0 m deviate too much from each other this may indicate an error in the measurement chain. If the dynamic range of a microphone signal, observable from the trace on the screen is below 10 dB it may indicate background noise. In that case the measurement is discarded and the pass-by is repeated.
6. Test speeds did follow an increasing and then a decreasing order to remove any trends due to additional tyre warming.

2.6.2 Test of tyre temperature during session

We are aware that to fully warm up the test tyres an extended period of driving is required, in the order of a few hours. To include such warming-up time in the test protocol is considered not practical. It would have extended the period of the measurements considerably, leading to increasing uncertainty in the comparison of tyre/road noise levels between tyres.

To understand the possible effect of the limited warming up time, we have investigated the variation of the tyre temperature during the measurement. Repeated temperature measurements with a thermo-couple probe are performed on the tread blocks and of the side with the pointed probe pressed into the material for about 2 mm. The results are given in the graph below. It shows that after the initial warming obtained by driving over 10 km with a speed of about 60 km/h the temperature variation of the tread blocks remains within 4 °C. Air temperature was about 8°C and road temperature was about 14 °C. Of course the probe does not measure the carcass temperature, but it is can be regarded as an indication of the behavior of the tread band material.

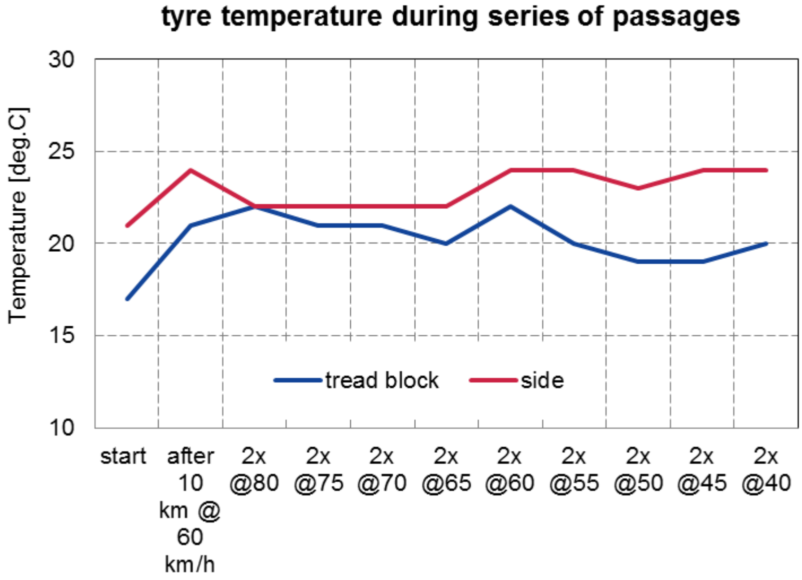


figure 7 *Development of tyre temperature during a series of pass-by's over the total test section lengths.*

3 Results of coast-by data

3.1.1 Determination of *LAFmax* and *SEL* from time series

The data acquisition and analysis system produces a continuous recording of 1/3rd octave spectra determined with a time constant of 0,125 s ("FAST"). Every 0,04 s (25 Hz) a sample is taken and stored (see 2.5.1). The *LAFmax* level and the related spectral distribution are determined by selecting the spectrum with the highest total A-weighted value from a pass-by event.

For the *SEL* determination all spectra obtained in a segment of + and -25 m around the microphone position are added and normalized to 1 s. That means that for the longer test sections, only the central area is used. This is necessary because not all test sections have the same length and variation in section length will cause variation in the *SEL* value. This hinders the comparison of *SEL* values between the test sections. The effect of truncation to 50 m length is estimated to be about 0,8 dB absolute value. For a true SEL level the determined over an infinite length the SEL levels should be increased with about 0,8 dB.

3.1.2 Determination of vehicle speed at microphone location

For every pass-by the average speed over the test section is determined by dividing the distance between light switches by the time interval between the truck passing the light switches. Since the microphones are located halfway, the average speed is nearly the same as the actual speed at the microphone location. The small error is caused by the fact that the speed reduction over the length of a section follows a power slope instead of a linear slope.

3.1.3 Regression analysis

For each combination of test section, tyre and microphone height, the recorded *SEL* and *LAFmax* levels, together with the recorded speed are put into a scatter diagram. Through the points, representing both the individual 1/3rd octave levels and the overall levels a best fitting function in the form is fitted, using the well accepted logarithmic relation between speed and tyre/road noise levels

(1) $$a + b.\log\left(\frac{v}{v_{ref}}\right)$$

With

a: constant representing the sound level at the reference speed

b: constant representing the influence of the vehicle speed

v: vehicle speed in km/h

v_{ref} reference speed of 70 km/h

From these series of regression functions we calculated the spectra at 10 km/h intercepts between 40 and 80 km/h. For all values we also determined the 95% confidence interval based on the statistical error. The values of *b* in case of *LAFmax* will be 10 higher than corresponding values of *b* in case of *SEL*. This difference reflects the fact that the duration of the sound signal of the passing vehicle is inversely related to the speed which in logarithmic terms is presented as -10.log(v/v_{ref}).

3.2 Some examples of *LAFmax* and *SEL* measurements

The graphs in figure 8 give some typical results of the scatter diagrams of *LAFmax* and the resulting regression function and 95% confidence interval around the regression function. The graphs in figure 9 display the results for the same tyre/section combination, but now for the *SEL* values.

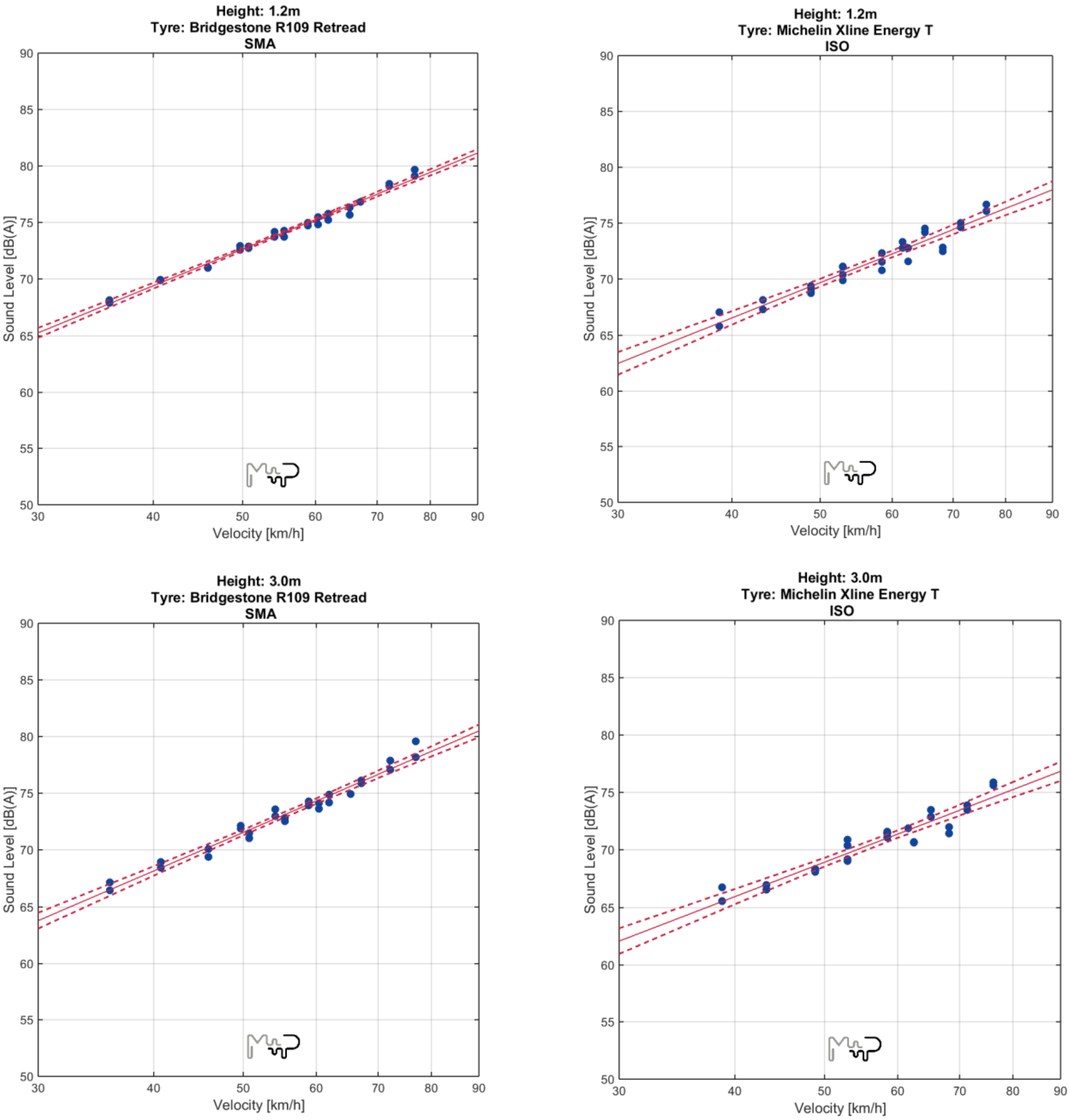


figure 8 *Examples of regression diagrams of LAFmax for two tyre types and for the ISO and SMA road surface at 1,2 and 3,0 m height.*

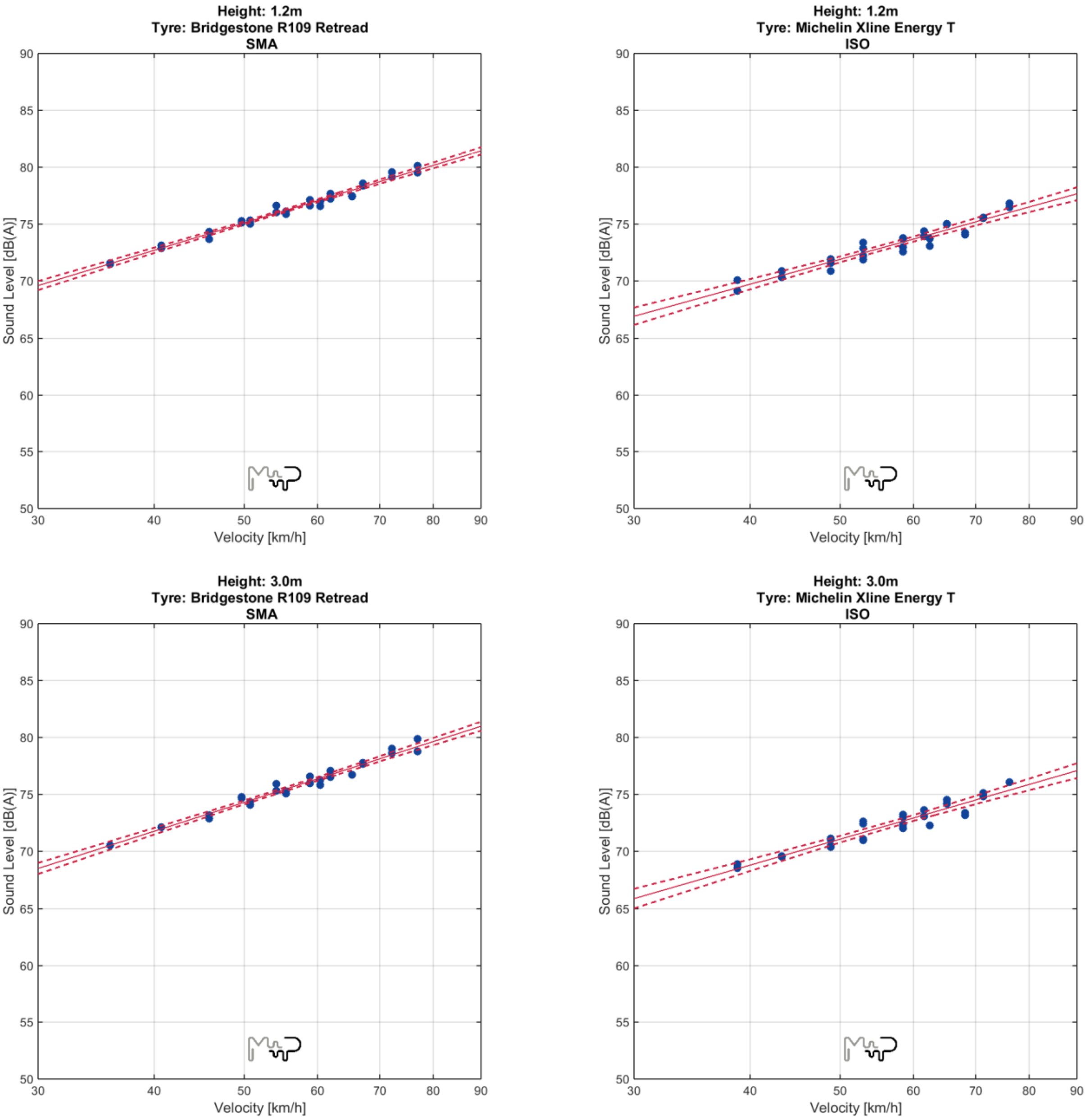


figure 9 *Examples of scatter diagrams of SEL for the same tyre/section/height combinations as in figure 9. Notice the shallower slope for SEL compared to LAFmax.*

The number of spectral regression is defined by the number of tested tyres (32), the number of heights (2) and the number of test sections (4) and both *LAFmax* and *SEL*. This amounts to a total of 512 regression diagrams. The individual regression diagrams with confidence intervals are presented in a separate database (see part 6.1 and 6.2).

Results of the regression analysis on all tyre/road combinations at 1,2 and 3,0 m microphone height for both *LAFmax* and *SEL* values are given in the directory "***figures and tables***" subdirectory "***regression analysis***" that is subdivided in "***LAFmax scatter***" and "***SEL scatter***" (see part 6.2).

3.3 *LAFmax*

The tables below (table III and table IV) present the results of the regression analysis of the *LAFmax* values. For each tyre and each surface the following values are presented:

- *a:* the value of the regression function at the reference speed of 70 km/h
- *b:* the value of the speed exponent defined as the change of the *LAFmax* level for a10 fold speed change
- *conf:* the one sided statistical accuracy of the value of *a* at 95% coverage.
- *r:* the residual standard deviation after regression. It presents the standard deviation of the individual measurement results around the regression function.

NOTE: the values of *a,* that are presented in the following tables represent the measured result at the speed of 70 km/h. Unlike the procedure in R117, the values of *a* are not corrected with -1 dB for measurement uncertainty and are not rounded down. For a fair comparison of test results with label values, such data processing on the value for *a* has to be done. This comparison is done in chapter 8 of this report.

3.3.1 Results of regression analysis of *LAFmax* at 1,2 m height

table III *The regression function has the form of a+b.log(v/vref) with vref=70 km/h. Top-left: a, top-right: b. . Bottom-left: 95% expanded statistical uncertainty at 70 km/h, bottom-right: residual standard deviation after regression.*

tyre	ISO	SMA	DAC	TSL		ISO	SMA	DAC	TSL	
Bridgestone R-DRIVE 001	78,0	78,3	77,9	76,4	< 70	37,9	33,7	38,9	39,6	< 27
Bridgestone R-STEER 001	73,7	77,1	73,1	71,8	70 - 72	19,2	23,8	20,7	16,1	27 - 29
Bridgestone R109 Ecopia Retread	75,1	77,5	74,3	72,7	72 - 74	34,1	33,3	32,5	32,7	29 - 31
Bridgestone R109 Ecopia	73,9	77,4	73,5	71,7	74 - 76	34,0	32,5	29,7	33,5	31 - 33
Continental EcoPlus HT3	73,2	76,3	72,5	71,4	76 - 78	31,5	33,0	28,4	25,4	33 - 35
Continental HDR2+	80,2	79,8	79,9	78,0	78 - 80	36,8	34,8	38,4	26,0	35 - 37
Continental HDW2 Scandinavia	80,0	79,8	79,3	76,4	> 80	36,7	35,2	33,6	21,5	> 37
Continental HSR2	71,5	76,6	72,0	70,3		22,2	23,6	26,4	24,9	
Continental HTR2	74,4	76,5	73,8	71,8		34,7	33,7	30,4	31,3	
GoodYear KMAX D	74,6	77,7	74,4	73,3		32,6	31,2	33,2	33,1	
GoodYear KMAX S	73,7	76,4	73,3	71,8		30,6	30,7	29,9	33,7	
GoodYear KMAX T session1	73,5	77,8	73,1	70,8		33,3	29,0	31,5	34,5	
GoodYear KMAX T session2	73,9	77,9	73,5	71,5		34,1	30,2	32,6	33,7	
GoodYear Ultragrip WTS	77,1	77,5	76,5	73,6		32,2	32,0	27,4	26,8	
GoodYear regional RHT II tread max	74,5	77,7	73,7	71,3		33,8	30,9	29,4	26,9	
Hankook AL10 e-cube session1	73,3	77,1	72,7	71,9		29,7	29,3	25,9	29,7	
Hankook AL10 e-cube session2	73,7	77,0	73,1	71,9		31,2	29,9	26,7	27,5	
Hankook DL10 e-cube	74,9	77,1	74,4	72,2		32,1	29,3	31,6	28,7	
Michelin XFN2 AntiSplash	78,0	77,8	76,9	73,4		29,2	31,3	24,4	24,8	
Michelin X Multiway 3D XDE REMIX	80,2	79,5	80,5	78,5		46,5	38,2	57,0	50,4	
Michelin Xline Energy D Remix	77,5	78,2	77,7	74,9		44,0	37,1	48,3	39,1	
Michelin Xline Energy T Remix	75,0	77,6	73,8	72,9		33,2	33,2	31,4	30,9	
Michelin Xline Energy Z	72,9	76,5	72,1	71,6		32,8	31,0	30,7	31,6	
Michelin Xline Energy D	76,0	78,0	75,6	73,2		36,3	34,1	35,8	32,0	
Michelin Xline Energy T	74,5	77,5	73,2	72,2		32,6	32,9	27,7	28,9	
Michelin Xmulti	73,2	76,6	73,5	71,3		33,4	32,1	29,4	37,3	
Michelin X multiway 3D XDE	79,3	78,8	78,8	76,7		34,1	33,6	34,7	28,2	
Nokian Hakkapeliitta Truck E Set1	77,8	77,7	76,9	75,8		28,9	30,4	29,8	29,0	
Nokian Hakkapeliitta Truck E set2	77,7	77,7	77,1	75,7		27,6	29,4	29,9	26,8	
Pirelli FH:01	73,4	77,3	72,9	71,7		34,7	33,4	33,3	34,2	
Pirelli ST:01 neverending	73,5	77,5	72,7	71,6		31,0	35,4	30,0	34,2	
Pneu Laurant Michelin XZE2	80,5	79,0	79,5	76,6		40,5	34,8	40,4	31,3	

tyre	ISO	SMA	DAC	TSL		ISO	SMA	DAC	TSL	
Bridgestone R-DRIVE 001	0,5	0,4	0,6	0,8	< 0,3	0,9	0,7	1,1	1,4	< 0,5
Bridgestone R-STEER 001	1,0	0,5	1,0	0,7	0,3 - 0,4	1,8	1,0	1,7	1,4	0,5 - 0,6
Bridgestone R109 Ecopia Retread	0,4	0,2	0,6	0,4	0,4 - 0,5	0,7	0,4	1,0	0,7	0,6 - 0,7
Bridgestone R109 Ecopia	0,4	0,2	0,8	0,6	0,5 - 0,6	0,7	0,4	1,2	1,1	0,7 - 0,8
Continental EcoPlus HT3	0,6	0,4	0,7	0,6	0,6 - 0,7	1,1	0,7	1,2	1,1	0,8 - 0,9
Continental HDR2+	0,7	0,3	0,9	0,9	0,7 - 0,8	1,2	0,5	1,5	1,6	0,9 - 1
Continental HDW2 Scandinavia	0,7	0,5	0,9	0,6	> 0,8	1,2	1,0	1,5	1,1	> 1
Continental HSR2	0,7	0,4	0,8	0,9		1,2	0,7	1,2	1,5	
Continental HTR2	0,5	0,3	0,6	0,6		0,8	0,5	1,0	1,1	
GoodYear KMAX D	0,5	0,3	0,6	0,5		0,8	0,6	1,0	0,9	
GoodYear KMAX S	0,4	0,3	0,6	0,5		0,7	0,5	0,9	0,8	
GoodYear KMAX T session1	0,5	0,2	0,5	0,6		0,9	0,3	0,9	1,0	
GoodYear KMAX T session2	0,5	0,3	0,6	0,6		0,7	0,5	0,9	1,0	
GoodYear Ultragrip WTS	0,3	0,3	0,7	0,5		0,5	0,5	1,2	0,8	
GoodYear regional RHT II tread max	0,5	0,3	0,4	0,7		0,8	0,5	0,6	1,1	
Hankook AL10 e-cube session1	0,5	0,3	0,5	0,7		0,9	0,5	0,8	1,2	
Hankook AL10 e-cube session2	0,4	0,2	0,5	0,6		0,9	0,5	0,9	1,1	
Hankook DL10 e-cube	0,5	0,3	0,4	0,6		0,8	0,6	0,7	1,0	
Michelin XFN2 AntiSplash	0,6	0,4	0,9	0,6		1,1	0,8	1,5	1,1	
Michelin X Multiway 3D XDE REMIX	0,9	0,4	0,7	0,7		1,6	0,8	1,2	1,3	
Michelin Xline Energy D Remix	0,5	0,3	0,6	0,7		1,0	0,7	1,1	1,2	
Michelin Xline Energy T Remix	0,3	0,2	0,5	0,6		0,5	0,4	0,8	1,0	
Michelin Xline Energy Z	0,7	0,2	0,5	0,7		1,1	0,3	0,9	1,3	
Michelin Xline Energy D	0,4	0,3	0,6	0,8		0,7	0,5	1,0	1,4	
Michelin Xline Energy T	0,4	0,3	0,6	0,5		0,7	0,6	1,0	0,8	
Michelin Xmulti	0,4	0,2	0,6	0,7		0,7	0,4	1,0	1,1	
Michelin X multiway 3D XDE	0,3	0,3	0,6	0,7		0,6	0,5	0,9	1,3	
Nokian Hakkapeliitta Truck E Set1	0,4	0,3	0,5	0,6		0,8	0,6	0,9	1,0	
Nokian Hakkapeliitta Truck E set2	0,3	0,3	0,6	0,6		0,6	0,5	1,0	1,1	
Pirelli FH:01	0,4	0,3	0,5	0,5		0,8	0,5	0,8	0,9	
Pirelli ST:01 neverending	0,4	0,3	0,7	0,6		0,7	0,5	1,2	1,0	
Pneu Laurant Michelin XZE2	0,4	0,4	0,6	0,5		0,9	1,0	1,5	1,3	

3.3.2 Results of regression analysis of *LAFmax* at 3,0 m height

table IV *The regression function has the form of a+b.log(v/vref) with vref=70 km/h. Top-left: a, top-right: b. . Bottom-left: 95% expanded statistical uncertainty at 70 km/h, bottom-right: residual standard deviation after regression.*

tyre	ISO	SMA	DAC	TSL		ISO	SMA	DAC	TSL	
Bridgestone R-DRIVE 001	77,4	78,0	77,1	75,4	< 70	40,4	37,5	36,0	37,2	< 27
Bridgestone R-STEER 001	73,1	76,5	73,0	71,2	70 - 72	20,3	23,9	19,2	17,3	27 - 29
Bridgestone R109 Ecopia Retread	74,2	76,7	74,1	72,0	72 - 74	33,4	35,1	33,7	33,9	29 - 31
Bridgestone R109 Ecopia	73,1	76,8	73,2	71,4	74 - 76	34,3	33,4	31,0	34,7	31 - 33
Continental EcoPlus HT3	72,6	75,8	72,1	70,8	76 - 78	31,7	35,6	29,2	27,8	33 - 35
Continental HDR2+	79,5	78,7	79,5	77,1	78 - 80	36,5	34,1	39,3	24,8	35 - 37
Continental HDW2 Scandinavia	79,1	78,9	78,3	75,7	> 80	36,8	36,6	30,0	24,2	> 37
Continental HSR2	71,1	75,8	71,5	69,6		26,5	25,5	26,0	24,0	
Continental HTR2	73,5	75,9	73,7	71,3		33,7	35,1	33,3	32,7	
GoodYear KMAX D	73,8	77,0	74,0	72,5		36,3	33,0	32,6	32,8	
GoodYear KMAX S	72,2	75,7	72,8	70,7		30,3	31,7	28,9	33,2	
GoodYear KMAX T session1	72,9	76,7	72,8	70,3		34,1	29,9	30,9	33,3	
GoodYear KMAX T session2	73,3	77,3	73,5	70,6		34,2	31,7	34,7	31,5	
GoodYear Ultragrip WTS	75,8	77,0	76,3	72,8		34,4	32,3	29,3	28,1	
GoodYear regional RHT II tread max	73,8	76,9	73,1	70,7		33,5	32,7	29,8	28,2	
Hankook AL10 e-cube session1	72,5	76,0	72,2	71,3		30,2	30,7	26,4	30,8	
Hankook AL10 e-cube session2	73,2	76,3	72,5	71,3		33,4	31,3	26,6	29,7	
Hankook DL10 e-cube	74,1	76,2	73,9	71,3		31,0	32,0	29,2	29,7	
Michelin XFN2 AntiSplash	77,1	77,4	76,6	72,7		29,5	32,0	24,9	25,7	
Michelin X Multiway 3D XDE REMIX	79,5	78,5	80,2	77,5		45,5	38,6	57,6	44,3	
Michelin Xline Energy D Remix	76,8	77,3	77,2	74,0		42,6	37,7	45,3	40,2	
Michelin Xline Energy T Remix	74,0	76,7	73,5	72,2		32,6	34,9	31,1	31,3	
Michelin Xline Energy Z	72,3	75,5	71,7	71,1		32,2	32,2	29,5	32,2	
Michelin Xline Energy D	75,3	77,1	75,1	72,5		34,9	34,4	36,1	29,9	
Michelin Xline Energy T	73,5	76,7	73,0	71,3		31,0	35,6	28,0	27,5	
Michelin Xmulti	72,8	75,7	73,3	70,5		33,9	33,7	32,8	37,1	
Michelin X multiway 3D XDE	78,4	77,5	78,3	75,4		33,3	33,6	32,8	25,2	
Nokian Hakkapeliitta Truck E Set1	77,1	76,6	76,6	74,9		29,2	31,0	30,9	32,0	
Nokian Hakkapeliitta Truck E set2	77,0	76,7	76,5	75,0		28,1	30,9	29,7	30,7	
Pirelli FH:01	72,8	76,2	72,6	71,0		34,5	34,3	31,8	33,1	
Pirelli ST:01 neverending	72,7	76,8	72,5	71,0		30,4	37,0	31,5	34,4	
Pneu Laurant Michelin XZE2	79,9	78,7	79,4	75,9		41,4	36,1	39,7	32,2	

tyre	ISO	SMA	DAC	TSL		ISO	SMA	DAC	TSL	
Bridgestone R-DRIVE 001	0,5	0,4	0,5	0,8	< 0.3	0,9	0,7	0,8	1,4	< 0.5
Bridgestone R-STEER 001	1,1	0,6	0,8	0,8	0.3 - 0.4	2,0	1,2	1,4	1,5	0.5 - 0.6
Bridgestone R109 Ecopia Retread	0,4	0,3	0,4	0,6	0.4 - 0.5	0,7	0,6	0,7	0,9	0.6 - 0.7
Bridgestone R109 Ecopia	0,5	0,3	0,5	0,7	0.5 - 0.6	0,8	0,5	0,9	1,1	0.7 - 0.8
Continental EcoPlus HT3	0,6	0,4	0,5	0,7	0.6 - 0.7	1,0	0,8	0,8	1,2	0.8 - 0.9
Continental HDR2+	0,6	0,2	0,7	0,8	0.7 - 0.8	0,9	0,4	1,2	1,3	0.9 - 1
Continental HDW2 Scandinavia	0,4	0,4	0,6	0,6	> 0.8	0,7	0,8	1,1	1,0	> 1
Continental HSR2	0,5	0,4	0,6	1,0		0,8	0,7	1,0	1,5	
Continental HTR2	0,4	0,3	0,4	0,6		0,7	0,5	0,6	1,1	
GoodYear KMAX D	0,6	0,4	0,5	0,5		1,0	0,6	0,8	0,9	
GoodYear KMAX S	0,6	0,3	0,3	0,6		1,0	0,4	0,5	0,9	
GoodYear KMAX T session1	0,6	0,2	0,5	0,6		1,0	0,4	0,8	1,0	
GoodYear KMAX T session2	0,6	0,3	0,5	0,8		0,9	0,5	0,8	1,2	
GoodYear Ultragrip WTS	0,5	0,3	0,7	0,6		0,9	0,5	1,1	1,1	
GoodYear regional RHT II tread max	0,5	0,3	0,4	0,8		0,9	0,5	0,6	1,4	
Hankook AL10 e-cube session1	0,5	0,3	0,5	0,7		0,9	0,6	0,9	1,3	
Hankook AL10 e-cube session2	0,5	0,2	0,5	0,7		0,9	0,5	0,9	1,3	
Hankook DL10 e-cube	0,4	0,3	0,4	0,5		0,7	0,6	0,7	0,8	
Michelin XFN2 AntiSplash	0,5	0,4	0,7	0,5		1,0	0,8	1,3	0,8	
Michelin X Multiway 3D XDE REMIX	0,9	0,4	0,8	0,7		1,5	0,7	1,2	1,2	
Michelin Xline Energy D Remix	0,5	0,4	0,5	0,7		0,9	0,8	0,9	1,3	
Michelin Xline Energy T Remix	0,3	0,3	0,3	0,6		0,5	0,5	0,5	1,1	
Michelin Xline Energy Z	0,7	0,2	0,4	0,8		1,2	0,4	0,7	1,4	
Michelin Xline Energy D	0,4	0,3	0,3	0,9		0,7	0,6	0,6	1,6	
Michelin Xline Energy T	0,5	0,4	0,4	0,6		0,8	0,7	0,7	1,0	
Michelin Xmulti	0,5	0,3	0,4	0,8		0,8	0,5	0,7	1,3	
Michelin X multiway 3D XDE	0,3	0,2	0,6	0,7		0,5	0,4	1,0	1,3	
Nokian Hakkapeliitta Truck E Set1	0,5	0,3	0,4	0,6		0,9	0,6	0,6	1,1	
Nokian Hakkapeliitta Truck E set2	0,4	0,3	0,4	0,7		0,7	0,5	0,7	1,2	
Pirelli FH:01	0,4	0,3	0,5	0,6		0,8	0,6	0,8	1,0	
Pirelli ST:01 neverending	0,4	0,4	0,6	0,6		0,7	0,7	0,9	1,1	
Pneu Laurant Michelin XZE2	0,4	0,4	0,5	0,5		1,0	1,0	1,1	1,2	

3.4 *SEL*

The *SEL* results are analyzed in a similar way as the *LAFmax* values. The results are given in the tables below. One may be surprised that the absolute values for *LAFmax* and for *SEL* at 70 km/h are so close. This is not a coincidence but can be explained by the fact that the energy average sound level over the total passage is about 3 dB below the maximum and that the effective length of the passage is about 2,5 s. Note that due to the 50 m section length the reported SEL values are 0,8 dB lower than for an infinite length.

3.4.1 Results of regression analysis of *SEL* at 1,2 m height

table V *The regression function has the form of a+b.log(v/vref) with vref=70 km/h. Top-left: a, top-right: b. . Bottom-left: 95% expanded statistical uncertainty at 70 km/h, bottom-right: residual standard deviation after regression. Note that due to the 50 m section length SEL values are 0,8 dB lower than for an infinite length.*

tyre	ISO	SMA	DAC	TSL	Legend	ISO	SMA	DAC	TSL	Legend
Bridgestone R-DRIVE 001	78,4	78,7	78,1	76,2	< 70	28,6	25,0	29,0	28,2	< 17
Bridgestone R-STEER 001	74,4	77,8	73,8	72,2	70 - 72	10,7	15,8	12,2	9,2	17 - 19
Bridgestone R109 Ecopia Retread	76,2	78,7	75,2	73,3	72 - 74	25,2	24,8	24,1	23,1	19 - 21
Bridgestone R109 Ecopia	75,0	78,6	74,4	71,6	74 - 76	24,7	24,3	21,9	20,1	21 - 23
Continental EcoPlus HT3	74,0	77,3	73,3	71,5	76 - 78	23,0	24,7	20,7	16,0	23 - 25
Continental HDR2+	80,2	80,1	79,6	78,5	78 - 80	27,0	25,6	29,0	22,2	25 - 27
Continental HDW2 Scandinavia	79,9	79,7	78,9	76,8	> 80	23,9	24,7	21,8	17,3	> 27
Continental HSR2	72,5	77,4	72,4	70,2		17,1	18,8	17,7	15,2	
Continental HTR2	75,5	77,7	75,1	72,2		26,4	25,8	24,0	22,9	
GoodYear KMAX D	75,5	78,5	75,0	73,7		25,5	23,9	24,0	24,1	
GoodYear KMAX S	74,9	77,3	74,2	72,1		23,4	22,4	22,9	23,7	
GoodYear KMAX T session1	74,4	78,9	73,9	71,0		24,6	22,6	23,2	22,5	
GoodYear KMAX T session2	74,6	78,9	74,4	71,6		24,8	24,1	25,1	21,6	
GoodYear Ultragrip WTS	77,9	78,2	77,0	74,1		24,5	24,0	19,8	18,7	
GoodYear regional RHT II tread max	75,2	78,6	74,5	71,9		25,7	23,8	22,6	20,9	
Hankook AL10 e-cube session1	74,0	77,7	73,3	72,0		22,2	22,4	18,9	19,2	
Hankook AL10 e-cube session2	74,1	77,6	73,5	71,9		23,6	22,9	18,6	18,8	
Hankook DL10 e-cube	75,4	77,9	75,1	72,5		22,5	22,3	22,1	20,5	
Michelin XFN2 AntiSplash	78,3	78,4	77,5	74,0		20,3	23,3	16,9	17,8	
Michelin X Multiway 3D XDE REMIX	79,7	79,9	79,4	78,5		30,0	27,0	37,3	37,2	
Michelin Xline Energy D Remix	78,4	78,9	78,2	75,0		34,1	27,1	35,9	30,3	
Michelin Xline Energy T Remix	76,2	78,8	75,1	73,5		23,9	24,6	24,1	22,0	
Michelin Xline Energy Z	73,3	77,3	72,8	71,7		22,5	23,0	21,9	21,4	
Michelin Xline Energy D	77,0	78,6	76,7	73,5		25,6	24,2	27,1	23,7	
Michelin Xline Energy T	75,2	78,3	74,1	72,3		22,5	23,9	20,4	17,4	
Michelin Xmulti	74,1	77,6	74,7	71,4		24,5	23,8	23,1	25,2	
Michelin X multiway 3D XDE	80,0	79,5	79,3	76,7		25,5	24,1	25,4	19,3	
Nokian Hakkapeliitta Truck E Set1	78,3	78,4	77,3	75,9		20,3	21,4	20,4	19,8	
Nokian Hakkapeliitta Truck E set2	78,3	78,4	77,4	76,1		20,3	21,1	20,8	20,6	
Pirelli FH:01	74,2	78,1	73,6	71,8		24,2	24,4	23,6	21,8	
Pirelli ST:01 neverending	74,4	78,2	73,5	71,8		22,5	25,6	21,4	21,8	
Pneu Laurant Michelin XZE2	80,7	79,3	79,5	77,1		29,4	25,1	29,4	23,8	

tyre	ISO	SMA	DAC	TSL	Legend	ISO	SMA	DAC	TSL	Legend
Bridgestone R-DRIVE 001	0,3	0,3	0,7	0,5	< 0,3	0,5	0,6	1,2	0,9	< 0,5
Bridgestone R-STEER 001	0,8	0,5	1,0	0,7	0,3 - 0,4	1,5	1,0	1,8	1,3	0,5 - 0,6
Bridgestone R109 Ecopia Retread	0,3	0,2	0,8	0,3	0,4 - 0,5	0,5	0,3	1,3	0,6	0,6 - 0,7
Bridgestone R109 Ecopia	0,3	0,2	0,8	0,5	0,5 - 0,6	0,5	0,4	1,4	0,8	0,7 - 0,8
Continental EcoPlus HT3	0,5	0,3	0,7	0,4	0,6 - 0,7	0,8	0,5	1,2	0,7	0,8 - 0,9
Continental HDR2+	0,4	0,3	0,7	0,6	0,7 - 0,8	0,7	0,5	1,2	1,1	0,9 - 1
Continental HDW2 Scandinavia	0,3	0,2	0,8	0,3	> 0,8	0,6	0,4	1,4	0,6	> 1
Continental HSR2	0,5	0,3	0,9	0,6		0,8	0,6	1,3	1,0	
Continental HTR2	0,4	0,3	0,8	0,4		0,6	0,5	1,3	0,7	
GoodYear KMAX D	0,3	0,3	0,8	0,4		0,5	0,5	1,3	0,7	
GoodYear KMAX S	0,2	0,2	0,8	0,4		0,4	0,4	1,2	0,6	
GoodYear KMAX T session1	0,4	0,2	0,7	0,3		0,7	0,3	1,2	0,6	
GoodYear KMAX T session2	0,4	0,4	0,7	0,4		0,6	0,6	1,1	0,6	
GoodYear Ultragrip WTS	0,2	0,3	0,8	0,4		0,3	0,5	1,4	0,7	
GoodYear regional RHT II tread max	0,4	0,2	0,7	0,4		0,6	0,4	1,1	0,7	
Hankook AL10 e-cube session1	0,4	0,2	0,6	0,5		0,7	0,4	1,1	0,8	
Hankook AL10 e-cube session2	0,4	0,2	0,6	0,4		0,7	0,4	1,2	0,7	
Hankook DL10 e-cube	0,3	0,2	0,6	0,4		0,5	0,4	1,0	0,6	
Michelin XFN2 AntiSplash	0,4	0,3	0,9	0,4		0,8	0,6	1,7	0,8	
Michelin X Multiway 3D XDE REMIX	0,4	0,3	0,6	0,5		0,7	0,5	1,1	0,9	
Michelin Xline Energy D Remix	0,3	0,3	0,7	0,4		0,6	0,5	1,3	0,8	
Michelin Xline Energy T Remix	0,2	0,2	0,6	0,3		0,3	0,3	1,0	0,6	
Michelin Xline Energy Z	0,4	0,2	0,6	0,4		0,8	0,4	1,0	0,7	
Michelin Xline Energy D	0,2	0,2	0,7	0,4		0,4	0,4	1,2	0,7	
Michelin Xline Energy T	0,3	0,2	0,7	0,3		0,6	0,4	1,1	0,6	
Michelin Xmulti	0,3	0,2	0,8	0,4		0,5	0,4	1,3	0,7	
Michelin X multiway 3D XDE	0,2	0,2	0,7	0,5		0,3	0,3	1,2	0,8	
Nokian Hakkapeliitta Truck E Set1	0,2	0,2	0,5	0,4		0,4	0,3	0,9	0,8	
Nokian Hakkapeliitta Truck E set2	0,3	0,2	0,6	0,5		0,5	0,4	1,0	0,9	
Pirelli FH:01	0,3	0,2	0,6	0,3		0,5	0,4	1,0	0,5	
Pirelli ST:01 neverending	0,4	0,2	0,8	0,4		0,6	0,3	1,3	0,8	
Pneu Laurant Michelin XZE2	0,2	0,4	0,6	0,3		0,6	1,0	1,5	0,9	

3.4.2 Results of regression analysis of *SEL* at 3,0 m height

table VI *The regression function has the form of a+b.log(v/vref) with vref=70 km/h. Top-left: a, top-right: b. . Bottom-left: 95% expanded statistical uncertainty at 70 km/h, bottom-right: residual standard deviation after regression. Note that due to the 50 m section length SEL values are 0,8 dB lower than for an infinite length.*

tyre	ISO	SMA	DAC	TSL		ISO	SMA	DAC	TSL	
Bridgestone R-DRIVE 001	77,9	78,5	78,2	75,6	< 70	29,7	26,0	29,0	26,7	< 17
Bridgestone R-STEER 001	74,0	77,6	74,2	71,7	70 - 72	11,2	16,5	12,0	9,8	17 - 19
Bridgestone R109 Ecopia Retread	75,5	78,1	75,4	72,6	72 - 74	25,8	26,2	25,1	24,1	19 - 21
Bridgestone R109 Ecopia	74,4	78,2	74,6	71,3	74 - 76	25,5	24,7	22,6	21,3	21 - 23
Continental EcoPlus HT3	73,5	76,9	73,3	71,0	76 - 78	24,6	26,0	21,4	17,8	23 - 25
Continental HDR2+	79,9	79,6	79,7	77,6	78 - 80	26,9	26,1	28,7	22,9	25 - 27
Continental HDW2 Scandinavia	79,4	79,3	78,7	76,0	> 80	24,8	25,2	18,3	18,2	> 27
Continental HSR2	72,2	77,1	72,4	69,9		20,0	19,8	18,3	16,0	
Continental HTR2	74,9	77,4	75,2	72,0		26,8	26,2	25,8	24,9	
GoodYear KMAX D	75,0	78,1	75,0	73,0		30,3	24,5	23,5	24,6	
GoodYear KMAX S	73,6	77,0	74,3	71,4		23,4	23,1	23,1	25,2	
GoodYear KMAX T session1	74,1	78,2	74,0	70,5		25,4	22,8	22,9	23,7	
GoodYear KMAX T session2	74,4	78,6	74,5	71,0		26,1	24,6	25,5	22,5	
GoodYear Ultragrip WTS	76,7	78,1	77,3	73,4		25,0	24,4	20,9	18,8	
GoodYear regional RHT II tread max	75,0	78,2	74,4	71,4		26,3	24,3	22,9	22,2	
Hankook AL10 e-cube session1	73,4	77,0	73,2	71,5		23,0	23,0	19,5	20,4	
Hankook AL10 e-cube session2	73,7	77,2	73,4	71,3		25,2	24,0	19,3	20,4	
Hankook DL10 e-cube	75,1	77,3	75,1	71,8		23,1	23,2	21,4	21,0	
Michelin XFN2 AntiSplash	77,7	78,3	77,5	73,5		20,1	23,8	16,2	19,1	
Michelin X Multiway 3D XDE REMIX	79,2	79,3	79,2	77,8		29,8	27,9	35,3	35,1	
Michelin Xline Energy D Remix	77,8	78,5	78,2	74,5		33,5	27,9	35,7	31,8	
Michelin Xline Energy T Remix	75,4	78,0	75,1	72,8		24,7	25,1	23,8	23,4	
Michelin Xline Energy Z	73,1	76,6	72,8	71,1		23,6	23,3	22,6	22,0	
Michelin Xline Energy D	76,4	78,1	76,5	72,9		25,5	24,8	26,3	23,4	
Michelin Xline Energy T	74,5	77,7	74,2	71,7		23,5	25,4	20,8	18,7	
Michelin Xmulti	73,9	77,1	74,8	71,0		25,4	24,1	24,9	26,9	
Michelin X multiway 3D XDE	79,6	78,8	79,2	75,9		26,3	24,5	23,5	19,2	
Nokian Hakkapeliitta Truck E Set1	77,6	77,6	77,2	75,2		20,1	22,1	20,7	21,3	
Nokian Hakkapeliitta Truck E set2	77,7	77,6	77,3	75,5		20,2	21,9	20,5	21,8	
Pirelli FH:01	73,8	77,3	73,7	71,3		25,2	24,8	23,6	22,7	
Pirelli ST:01 neverending	73,8	77,8	73,6	71,2		23,4	26,6	22,0	23,1	
Pneu Laurant Michelin XZE2	80,3	79,3	79,9	76,4		29,9	26,0	29,1	23,6	

tyre	ISO	SMA	DAC	TSL		ISO	SMA	DAC	TSL	
Bridgestone R-DRIVE 001	0,4	0,2	0,4	0,5	< 0,3	0,6	0,4	0,7	0,9	< 0,5
Bridgestone R-STEER 001	0,9	0,6	0,7	0,8	0,3 - 0,4	1,6	1,0	1,2	1,4	0,5 - 0,6
Bridgestone R109 Ecopia Retread	0,4	0,2	0,4	0,4	0,4 - 0,5	0,6	0,4	0,7	0,6	0,6 - 0,7
Bridgestone R109 Ecopia	0,4	0,2	0,5	0,5	0,5 - 0,6	0,6	0,4	0,8	0,9	0,7 - 0,8
Continental EcoPlus HT3	0,5	0,4	0,5	0,4	0,6 - 0,7	0,8	0,7	0,8	0,8	0,8 - 0,9
Continental HDR2+	0,4	0,1	0,5	0,6	0,7 - 0,8	0,6	0,3	0,8	1,0	0,9 - 1
Continental HDW2 Scandinavia	0,3	0,2	0,4	0,4	> 0,8	0,5	0,3	0,8	0,8	> 1
Continental HSR2	0,5	0,3	0,6	0,6		0,8	0,5	0,9	1,0	
Continental HTR2	0,3	0,2	0,4	0,4		0,6	0,4	0,7	0,7	
GoodYear KMAX D	0,5	0,3	0,5	0,4		0,8	0,5	0,8	0,7	
GoodYear KMAX S	0,5	0,1	0,4	0,4		0,8	0,2	0,6	0,7	
GoodYear KMAX T session1	0,5	0,2	0,4	0,4		0,9	0,4	0,7	0,6	
GoodYear KMAX T session2	0,5	0,3	0,4	0,5		0,8	0,4	0,7	0,8	
GoodYear Ultragrip WTS	0,4	0,2	0,6	0,5		0,7	0,3	1,0	0,9	
GoodYear regional RHT II tread max	0,5	0,3	0,4	0,5		0,8	0,4	0,6	0,8	
Hankook AL10 e-cube session1	0,4	0,3	0,4	0,5		0,7	0,5	0,7	0,9	
Hankook AL10 e-cube session2	0,4	0,3	0,4	0,4		0,8	0,5	0,8	0,7	
Hankook DL10 e-cube	0,3	0,2	0,4	0,4		0,5	0,3	0,6	0,6	
Michelin XFN2 AntiSplash	0,4	0,3	0,7	0,4		0,8	0,6	1,1	0,7	
Michelin X Multiway 3D XDE REMIX	0,4	0,2	0,4	0,5		0,6	0,4	0,7	0,8	
Michelin Xline Energy D Remix	0,3	0,3	0,5	0,6		0,6	0,5	0,9	1,0	
Michelin Xline Energy T Remix	0,2	0,2	0,3	0,3		0,3	0,4	0,5	0,6	
Michelin Xline Energy Z	0,5	0,2	0,4	0,4		0,8	0,4	0,6	0,7	
Michelin Xline Energy D	0,3	0,2	0,4	0,4		0,5	0,4	0,6	0,8	
Michelin Xline Energy T	0,4	0,3	0,4	0,4		0,6	0,6	0,6	0,7	
Michelin Xmulti	0,4	0,2	0,5	0,6		0,6	0,4	0,7	0,9	
Michelin X multiway 3D XDE	0,2	0,1	0,5	0,5		0,3	0,2	0,9	0,8	
Nokian Hakkapeliitta Truck E Set1	0,2	0,2	0,2	0,5		0,4	0,4	0,4	0,8	
Nokian Hakkapeliitta Truck E set2	0,3	0,2	0,3	0,5		0,4	0,4	0,5	0,9	
Pirelli FH:01	0,3	0,3	0,4	0,3		0,6	0,5	0,7	0,6	
Pirelli ST:01 neverending	0,4	0,3	0,5	0,5		0,7	0,5	0,8	0,8	
Pneu Laurant Michelin XZE2	0,3	0,4	0,3	0,4		0,6	0,9	0,9	0,9	

3.5 Spectral regression of *LAFmax* and *SEL*

In a similar way as is described for the total A-weighted *LAFmax* and *SEL* also regression analysis is performed for each 1/3rd octave band. With this one can compose the spectral composition of the *LAFmax* and *SEL* value at a certain speed. The data base comprises 1/3rd octave band values at the speeds of 40, 50, 60, 70 and 80 km/h for each tyre/road combination. In appendix A only averaged spectra over tyre types (T, S or D) at 70 km/h are given for the four test surfaces.

The data given in the data base do also indicate the statistical uncertainty in each 1/3rd octave band. In the determination of this value each 1/3rd octave band is treated as a separate, non-related data set. In reality of course, 1/3rd octave bands are related, in fact when observing the spread in individual data, the spectral shape changes less than the overall value, so the indicated 95% c.i. values are a large overestimation of the actual inaccuracy.

3.6 Repeated measurements

In order to understand the repeatability of the tests we have repeated the test program of two tyres:

- Goodyear KMAX-T
- Hankook AL10 e-cube

The tests for the Hankook AL10 e-cube tyre are repeated with a separation of two days, the tests for the Goodyear KMAX-T tyre are repeated directly after the original test.
We find the following absolute differences in total A-weighted level (see table VII). The related spectral differences are given in the graphs in figure 10 and figure 11. The original data for all test conditions are given in the tables in sections 3.3 and 0.

table VII *Results of repeated measurements on three tyre sets. Values present absolute differences in dB(A) in the coast-by level @ 70-km/h between the first and the second test. Only one height is presented.*

Tyre set	ISO	SMA	DAC	TSL
	LAFmax @ 1,2 m			
GoodYear KMAX T	0,4	0,1	0,4	0,8
Hankook AL10 e-cube	0,5	0,1	0,4	0,0
	SEL @ 3,0 m			
GoodYear KMAX T	0,3	0,4	0,5	0,5
Hankook AL10 e-cube	0,3	0,2	0,2	0,2

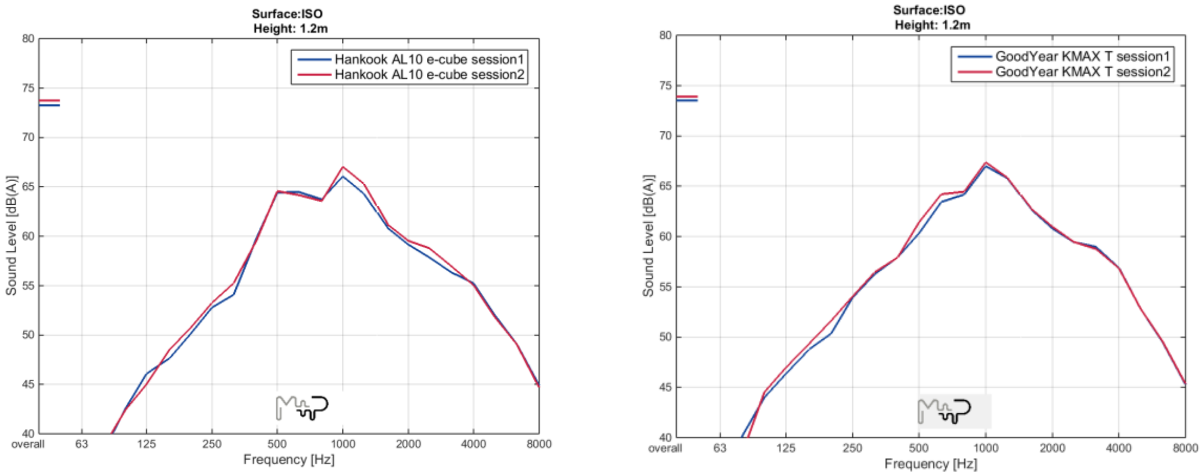


figure 10 *Results of repeated measurements of two tyre sets. Shown here is the LAFmax at 1,2 m height.*

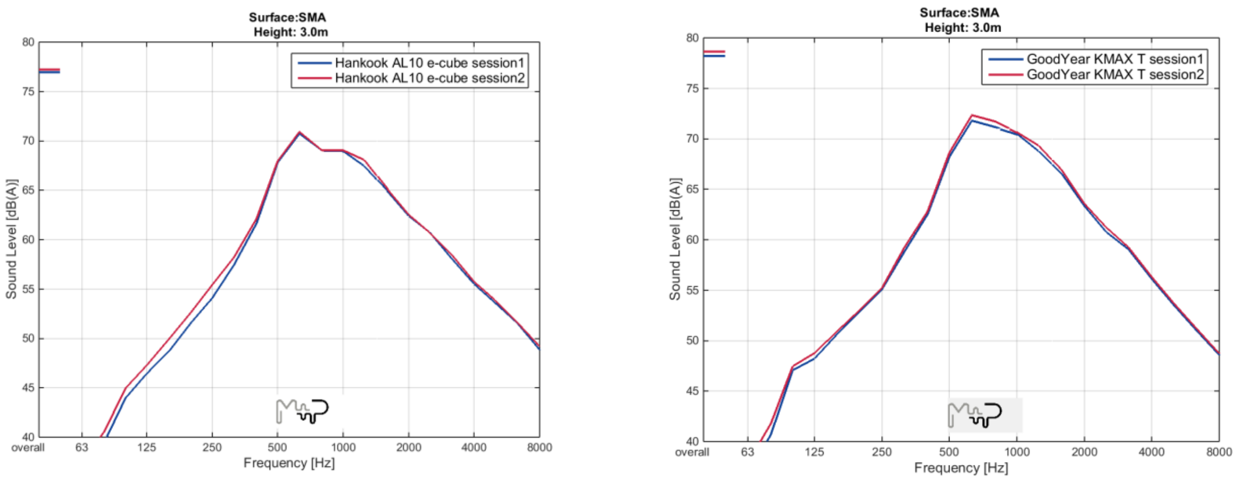


figure 11 *Results for the repeated measurements of two tyre sets. Depicted is the SEL at 3,0 m height.*

3.7 Uncertainty analysis

The sound levels obtained in the tests are subjected to all types of distorting influences that result in a deviation of the measured value from the “true” value. The GUM method [6], which is recommended by ISO for establishing the accuracy of measurements, is applied here to evaluate uncertainty in the final results. Repeated measurements are further used to estimate the overall spread in measurement outcome.

The “true” value can be regarded as the average of the measurement results of an infinite number of measurements under all allowed conditions. The testing performed in this study constitutes a small part of the infinite number and the average of this will most certainly deviate from the true value. The error analysis learns how large the expected deviation is and in what range can the true value be expected at a certain probability level.

The sources of uncertainty can have a random nature and a systematic nature. Random errors can be reduced by frequent repetitions. Systematic errors can be corrected for if the nature and coefficients are known. The deviation after correction has to be treated as a random error, but one that cannot be reduced by averaging over larger numbers.

The error analysis focusses on the results on the ISO and on the SMA surface since those are the original objectives of the NordTyre Part 3 project.

The following sources of uncertainty are distinguished:

1 Uncertainty in the representativity of the actual test surface for the average performance of all relevant ISO and all relevant SMA11 surfaces.
2 Uncertainty in the measuring chain of microphones, data acquisition, speed determination and data processing. This also includes variations in geometry of microphones and light switches.
3 Variations in the procedure of the measurements and vehicle operation.
4 Uncertainty due to environmental influences such as temperature, wind, humidity, etc.
5 Variation in properties of the tyre within a type.

Each source is analyzed in the following sections.

3.7.1 Representativity of the test surface

The properties of the road surface are a very strong influencing factor on the level of tyre/road noise. Therefore in ISO 10844 [7] the properties are defined such that for a non-specified tyre a deviation of + and – 1,5 dB can be expected due to allowed variations in the test surface. In the case of this study a strengthened requirement of MPD ≥ 0,4 mm is defined resulting in a slightly narrowed down spread estimated to be +/- 1,2 dB.

The representativity of the SMA 11 surface is discussed in [4] and from it, it is concluded that the spectral composition of the surface texture falls in the range found on Scandinavian SMA11 surfaces. The observed tyre/road noise level, determined with the two standard CPX tyres of the SMA surface used in this study is slightly lower than observed on Scandinavian surfaces, but the characteristic relation between the P and the H tyre, observed on real roads is also noticed on the SMA11 surface in this test. It is to be expected that the absolute levels of the tyres tested in this SMA11 surface will be slightly lower, but that relation between rolling levels and tyre type is conserved.

Overall a standard error due to varying surface properties of 0,6 dB is estimated.

3.7.2 Uncertainty in the measuring chain

The determination of the *LAFmax* value is subject to a series of distorting factors:

1 The intrinsic accuracy of class 1 microphones and connected data acquisition and processing system;
2 The uncertainty in the speed determination;
3 The spread in actual microphone positions rel. to the defined position;
4 The variation in properties of the propagation area.

Ad 1: A class 1 data acquisition system exhibits a maximum error of + and – 0,75 dB and thus a standard error of 0,3 dB. The determination of the *LAFmax* by sampling with 25 Hz causes a negligible error of much less than 0,1 dB.

Ad 2: the speed is determined by assessing the time difference between intercepts of the two light switches. At a speed of 20 m/s (=72 km/h) a deviation of 0,05 s in each light switch leads to a maximal error of 0,4 km/h. The standard error is less than 0,1 km/h. A second source is the effect of linear interpolation instead of exponential speed decay. The effect over a 100 m section is given in figure 12. The error is calculated to be a negligible 0,015 km/h.

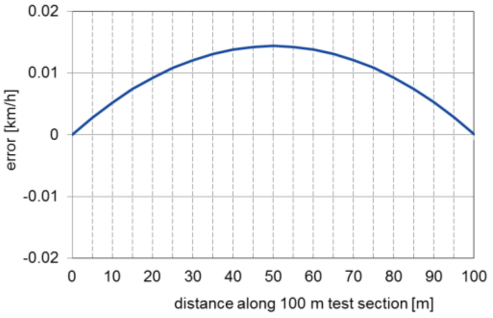


figure 12 Error in speed determination caused by linear interpolation of the speed over test section length.

Ad 3: Microphones are placed with 0,1 m accuracy. From geometrical deduction this relates to a maximum error of + and – 0,1 dB in the *LAFmax* and, assuming a line source, 0,05 dB for *SEL*. This is corroborated by a (not intended) test where one microphone is misplaced by 1,0 m and the left/right difference in *LAFmax* increased to about 1 dB.

Ad 4: The propagation area affects recorded sound levels, especially at the lower microphone height of 1,2 m. The 3,0 m height is relative insensitive as is demonstrated in the Harmonoise project. The propagation area between test surface and microphone constitutes into the east direction of dense SMA 11 surface. Into the west direction the surface differs:

- SMA 11 section: 3 m dense SMA 11 and 3 m grass
- ISO section: 3 m dense SMA 11 and 3 m dense 25 mm floorboard
- AC 16 surf section: 3 m PAC 8 and 3 m grass
- TSL 8 section: 3 m TSL 6 and 3 m grass.

For AC 16 surf and TSL 8 an effect of up to 1,0 dB can be expected at 1,2 m height in the W direction. No effect is assumed at 3,0 m. For the E direction no effect is estimated (absorption of TSL 8 is considered low in the relevant frequency range (see [4]))

Taking the root of the summed squares of the standard errors, leads to a total standard uncertainty of 0,6 dB.

3.7.3 Uncertainty due to environmental influences

Truck tyres are considered not to be sensitive to temperature variations since no correction for air temperature has to be applied on the coast-by result. In a large study [9] some effect is observed in the SPB results for heavy vehicles, so an effect may be present of about -0,04 dB/°C.

The usual target temperature is 20°C. All the measurements are performed at temperatures between 5 and 15°C. The standard uncertainty is 0,1 dB and the systematic error is estimated to be +0,4 dB. GUM prescribes that one should correct for systematic errors. Since the R117 does not allow corrections for temperature we applied no correction on the results, but levels measured between 20 and 30 °C will on average result in about 1 dB lower levels.

Wind and humidity may have an influence on the recorded sound levels of about 0,3 dB.

Overall standard uncertainty is thus estimated to be 0,4 dB.

3.7.4 Uncertainty due to variations within a tyre type

Tyres within a type will be subjected to small variations in the manufacturing process. The magnitude of this variation is not easily established since it implies repeated measurements under the same condition. In the case of car tyres, such study is done for the P and the H tyre type (defined in 11819-3 WD) [10] . For the high quality SRTT tyre a standard deviation of 0,1 dB is found and for the lesser quality AV4 tyre, the standard deviation is 0,5 dB. The difference between the higher and lower value is partly explained by the variation in rubber hardness.

In this study variability is for a part accounted for by measuring a vehicle with 4 tyres of the same type resulting in a halving of the standard uncertainty to 0,2 dB. The measurements results for the Nokian tyre also indicate that variation is relative small. The two tyre sets of the same type resulted in test results that differ between 0 to 0,2 dB.

A standard uncertainty of 0,1 dB seems a safe estimation.

3.7.5 Determination of total standard and expanded uncertainty

The total standard uncertainty in the measurements is found by taking the root of the summed squares of the individual standard uncertainties. This results in a value of 0,9 dB for the overall standard uncertainty. The expanded uncertainty at 95% coverage is 2,0 times the standard uncertainty (see table VIII). This figure refers to the total uncertainty, taking into account the normal variability in test surfaces, meteorological conditions, measuring equipment and spread within tyre properties. The thus defined uncertainty is relevant when comparing the test results found with the used tyre sets on the TPG test surfaces with test results from another location with another tyre set from the same tyre line.

If we limit the interpretation of the uncertainty to the section at the TPG and the used tyre sets, of course the value is lower in the order 0f 0,7 dB standard uncertainty. The measuring chain already has a 0,6 dB standard uncertainty. This is corroborated by the outcome of repeated measurements done for two tyres (see part 3.6). With 0,2 and 0,3 dB absolute differences they fit the uncertainty in the day-to-day influences.

table VIII Uncertainty calculation in the measurements of the coast-by levels.

Source of uncertainty	Standard uncertainty [dB]
Representativity of SMA and ISO surface	0,6
Uncertainty in measuring chain	0,6
Uncertainty in day-to-day environmental influences	0,4
Variability within tyre type	0,1
Total standard uncertainty	**0,9 dB**
Total expanded uncertainty at 95% coverage	**1,8 dB**

4 Tonal components

The detection of tonal components is done by making so called “Campbell diagrams” in which the narrow band frequency spectrum is plotted as a function of time. The level is color coded against an arbitrary reference value.

An example of two tyres are given below, one with a clear tonal content, the other with no visible tonal content. The x-axis presents the time.

We made the analysis only in one direction (TSL 8 → AC 16 surf → AC 8 surf → ISO → SMA) and only for measurements where the entry speed is between 75 and 80 km/h. The location of the different test sections is distinguishable as a step in shading in the graphs. The tonal components are distinguished by the sharp lines that follow a shallow downwards slope due to the decreasing vehicle speed over the total 350 m length. In many cases not one line but a series of harmonics can be found. In general the tones are most pronounced at the smooth AC surf sections. The coarser TSL and SMA sections suppress tonality.

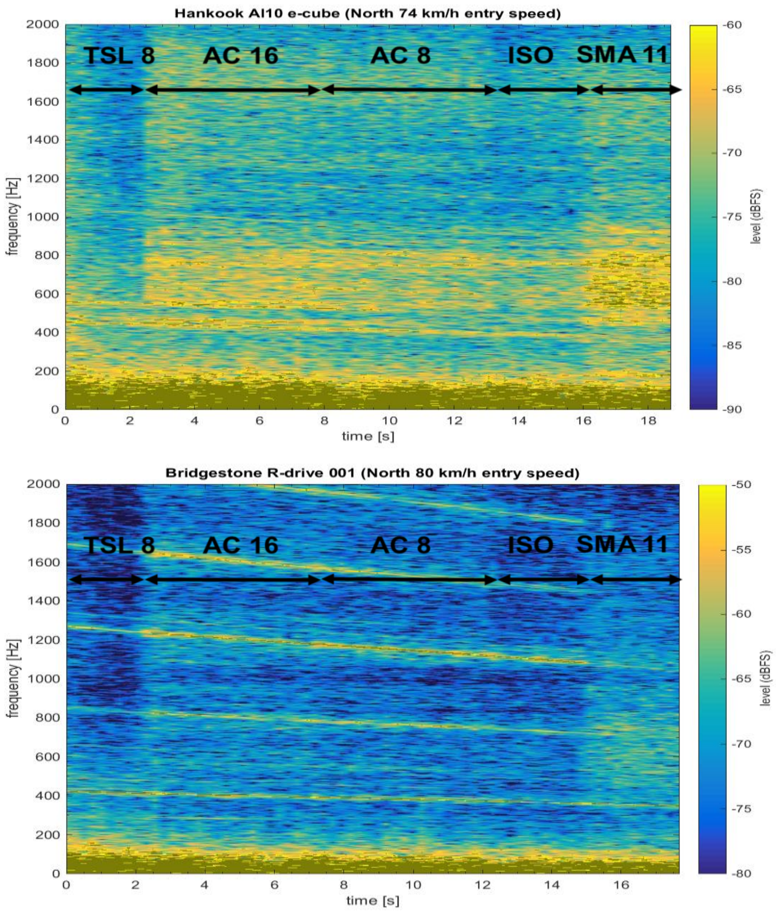


figure 13 *Two examples of narrow band analysis of close proximity signals over five sections (the non-used AC 8 surf section is included in the analysis. The sections are indicated in the graphs. top: Hankook AL 1- e-cube steer tyre, bottom: Bridgestone R-drive tyre. The latter clearly shows the tonal content and also that those components are less prominent on the trougher TSL 8 and SMA 11 surfaces.*

The spectral content for each road section is determined by taking the narrow band spectrum (FFT) over 1 sec within the passage of a section. See graphs below for the two tyres. Numerical data on the narrowband analysis are given in the data directory.

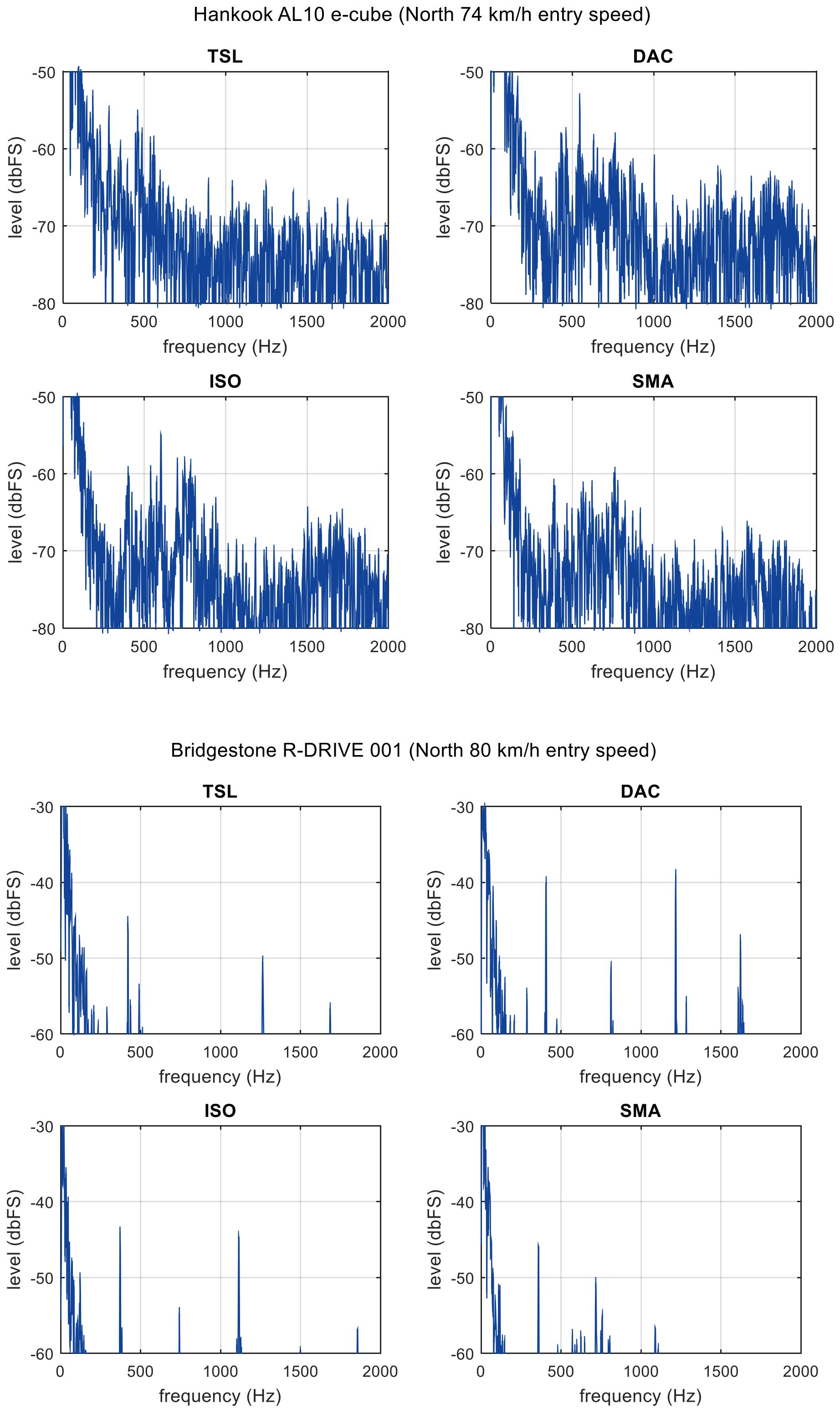
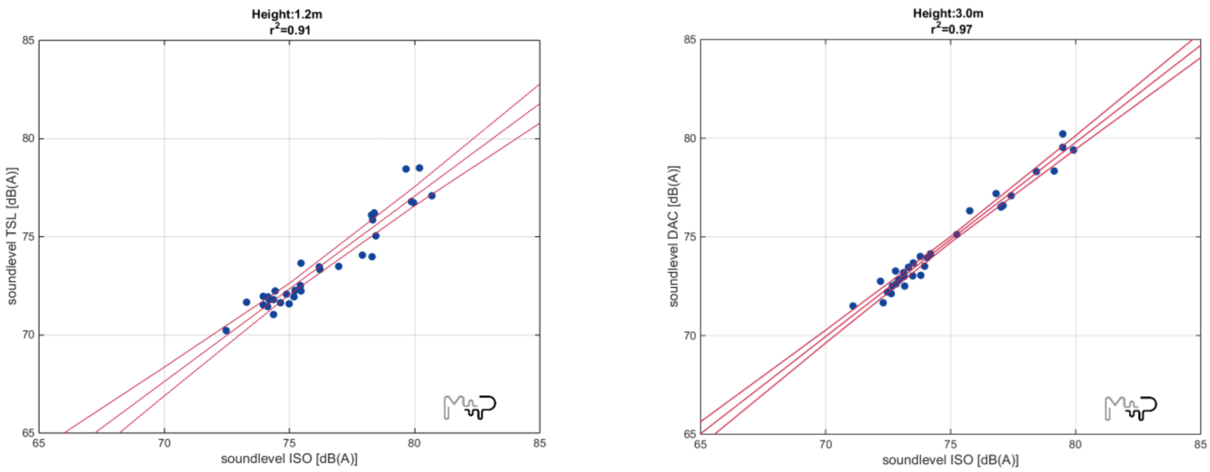


figure 14 *Two examples of narrow band analysis of close proximity signals at the four tested sections. Top: Hankook AL 1- e-cube steer tyre, bottom: Bridgestone R-drive tyre. The tonal components for the R-drive tyre at (approx.) 400, 800, 1200 and 1600 Hz are clearly recognizable in the bottom graph.*

5 Relation of tyre levels found at different surfaces

One of the relevant topics to be addressed in this study is the way levels found on the ISO surface relate to levels found at other surfaces. This refers to the issue of representativity of the ISO surface for general surfaces found in Scandinavia. In the graphs below the relation is given for all tyres, based on the *LAFmax* and on the *SEL* data. Values for slope and correlation for the total tyre set are given in table IX.



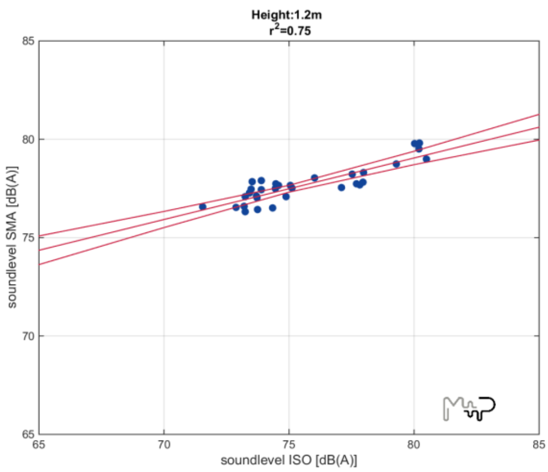
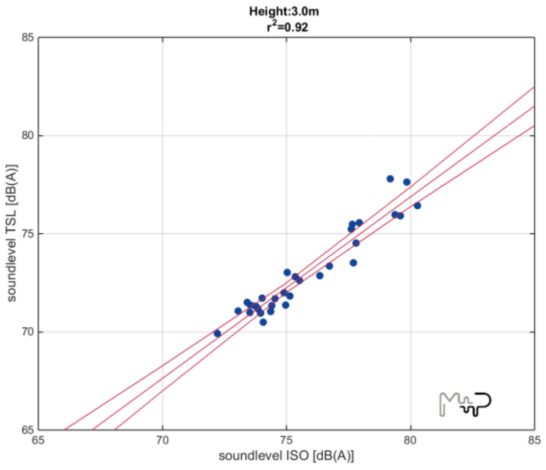
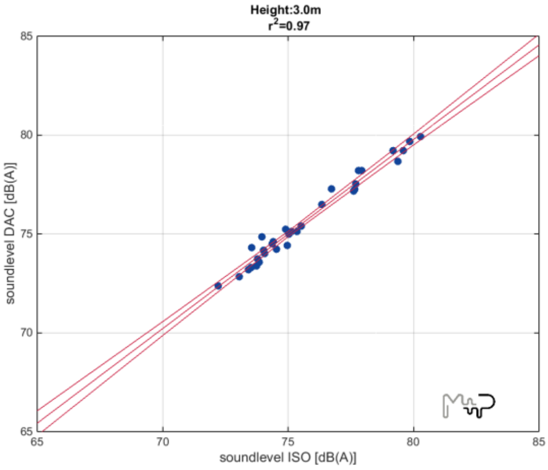


figure 15 Relation between LAFmax at 1,2 m height on an ISO surface and on other surfaces





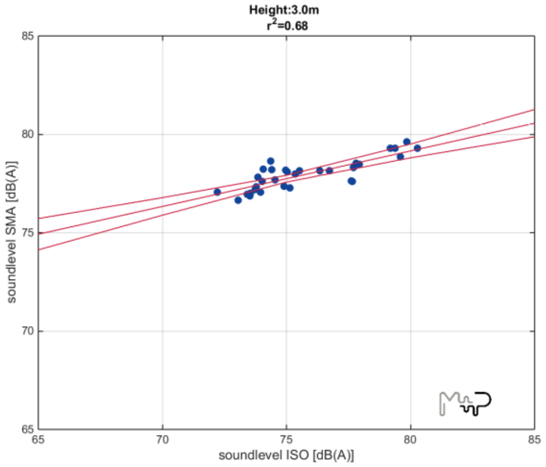
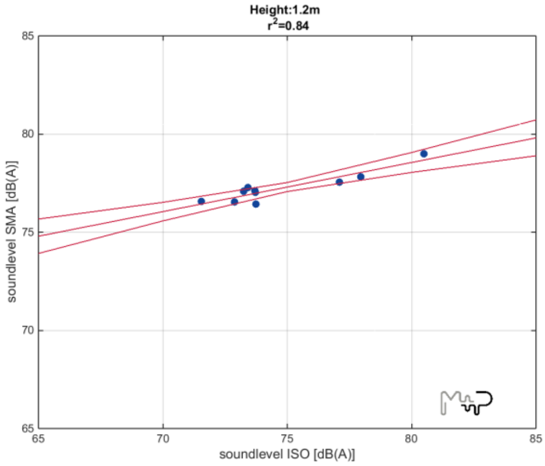


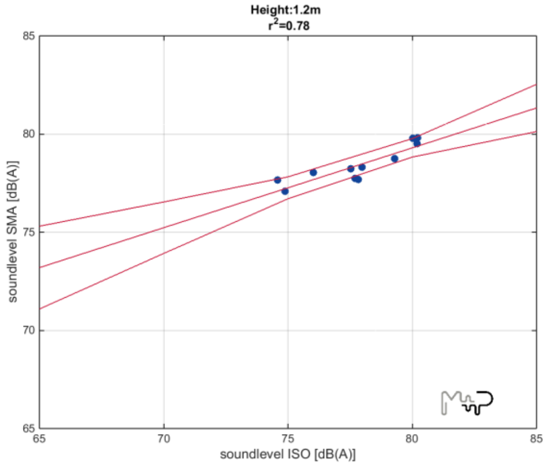
figure 16 Relation between SEL at 3.0 m height on an ISO surface and on other surfaces

table IX *Slope and correlation of the LAFmax and SEL data found on an ISO surface compared to the data found on the other surfaces. Data sets comprised all tyre types.*

LAFmax		**slope**				**correlation (r^2)**			
		ISO	SMA	DAC	TSL	ISO	SMA	DAC	TSL
ISO	1.2 m	1,00	0,31	0,99	0,85	1,00	0,75	0,97	0,91
	3.0 m	1,00	0,31	0,98	0,82	1,00	0,76	0,97	0,92
SEL		**slope**				**correlation (r^2)**			
		ISO	SMA	DAC	TSL	ISO	SMA	DAC	TSL
ISO	1.2 m	1,00	0,26	0,95	0,94	1,00	0,62	0,98	0,91
	3.0 m	1,00	0,28	0,96	0,92	1,00	0,68	0,97	0,92

In figure 17 the relation for *LAFmax* is given for the three tyre types (steer, drive and trailer) separately. Note that the steer type includes also the snow/ice versions that are characterized among others by their coarser treads pattern.





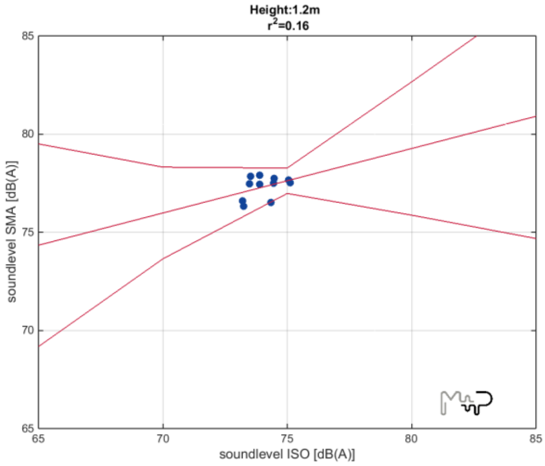


figure 17 Relation between LAFmax at 1,2 m height on an ISO surface and on an SMA 11 surface for three tyre types separate. Top-left STEER, top-right: DRIVE, left: TRAILER

6 Presentation of results

6.1 Relational database

The results of the testing of the tyres and of the coast-by values are stored in a MS-ACCESS database that can easily be approached for further analysis of the data. The database has the following structure (see figure 18).

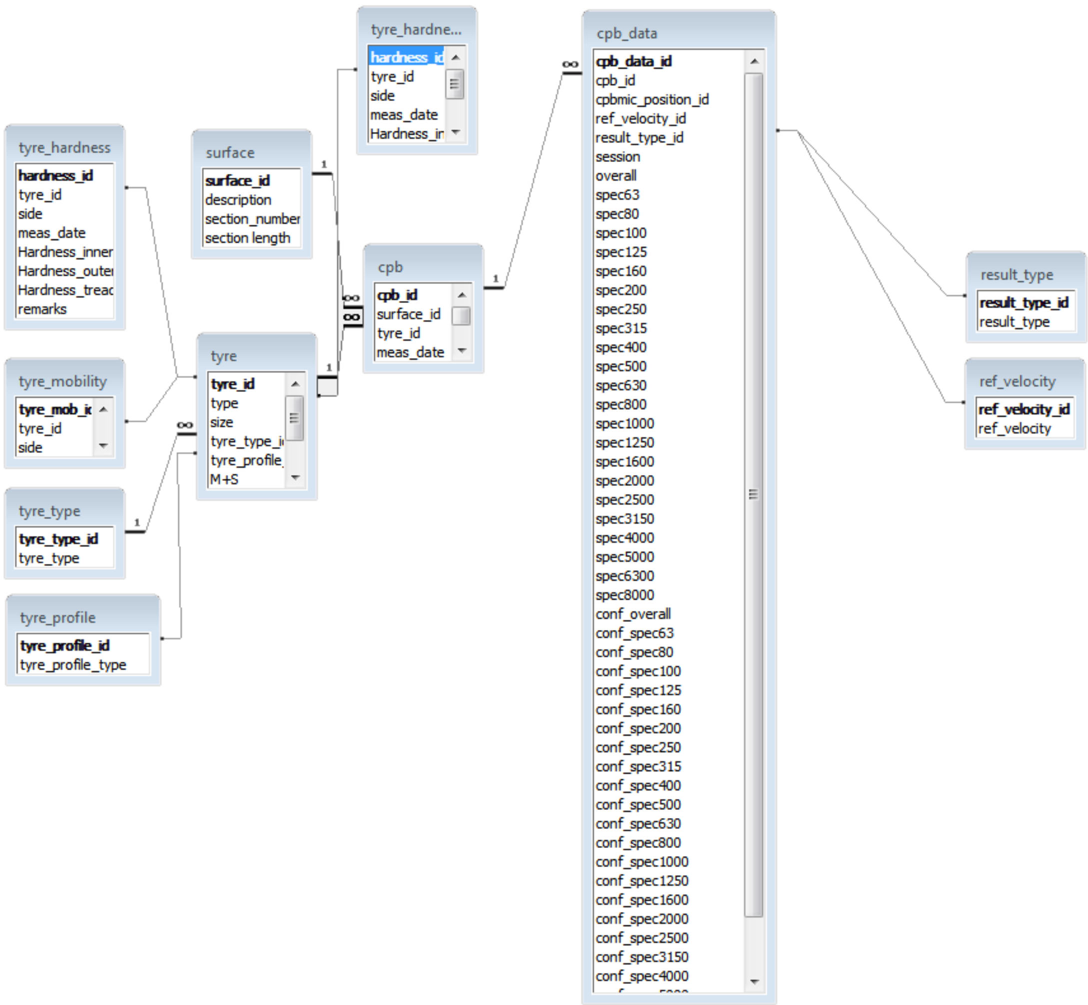


figure 18 Structure of the relational database (MS-ACCESS) used for storing and retrieving the data.

6.2 Directories with graphs and tables

The graphs and scans produced in this project are stored in the following directories (see table X).

table X *Listing of directories that contain the graphs and tables produced in the NordTyre Part 3 project.*

- tyre tread hardness
- tyre pictures
- tyre mobility
- tonality
- surface comparison
- spectral analysis
- repeated measurements
- regression tables
- regression analysis
- database
- 3-D tread profile scans
- 3-D surface profile scans

7 Discussion

7.1 Comparison of levels over surfaces

The tables with results from the regression analysis show in general acceptable uncertainty values. The statistical uncertainty at the reference speed of 70 km/h is given in the table below.

table XI *Average 95% statistical uncertainty over all tyres in the regression function at 70 km/h. Values in dB(A).*

	ISO	SMA	DAC	TSL
LAFmax @ 1,2 m	0,5	0,3	0,6	0,6
LAFmax @ 3,0 m	0,5	0,3	0,5	0,7
SEL @ 1,2 m	0,3	0,3	0,7	0,4
SEL @ 3,0 m	0,4	0,2	0,4	0,5

The *SEL* values show better accuracies than the *LAFmax* values, which is understandable from the longer signal length of the SEL determination.

The results presented in this and related reports show interesting features:

- In general tyre/road noise levels of steer tyres are lowest; trailer tyres exhibit slightly higher levels and drive tyres again slightly higher.
- The steer tyre with the snow/ice performance exhibits a higher level than the non snow/ice versions (e.g. Goodyear Ultragrip WTS). For drive tyres no such relation is observed. No specific snow/ice types for trailers are tested, mainly because such tyres are not legally required in winter time in Scandinavia.
- Tyre/road noise values in the test surfaces do differ. The average values over all tyre tests are given in the table below. As expected the TSL 8 shows the lower values, while the SMA 11 the higher ones. ISO and AC surf are about the same. Notice that the AC 16 surf is grinded, so the texture level is lower than is normally the case for this surface type.
- Interesting is that the spread found on the SMA is much smaller than the spread found at the other surfaces. This corroborate the shallower slope found in the ISO to SMA 11 relation displayed in figure 15 and in figure 16.

table XII *Average coast-by levels over all tyres at 70 km/h. Values in dB(A).*

	ISO	SMA	AC 16 surf	TSL
LAFmax @ 1,2 m	75,6	77,7	75,1	73,3
LAFmax @ 3,0 m	74,8	76,9	74,7	72,5
SEL @ 1,2 m	76,3	78,4	75,6	73,5
SEL @ 3,0 m	75,7	78,0	75,7	72,9

table XIII *Standard deviation in coast-by levels of all tyres at 70 km/h. Values in dB(A).*

	ISO	SMA	AC 16 surf	TSL
LAFmax @ 1,2 m	2,6	0,9	2,6	2,3
LAFmax @ 3,0 m	2,5	0,9	2,5	2,2
SEL @ 1,2 m	2,3	0,8	2,2	2,3
SEL @ 3,0 m	2,3	0,8	2,2	2,2

8 Comparison of label values with observed values

In a parallel report [5] data on the label values of the test tyres are presented. In this part we compare the findings of the coast-by measurements with the reported label values for tyre/road noise. From the coast-by data we selected the *LAFmax* on 1,2 m height on an ISO compliant surface (see 3.3.1) and compared these levels with the label values attributed to these tyre lines. Results are given in the graph below.

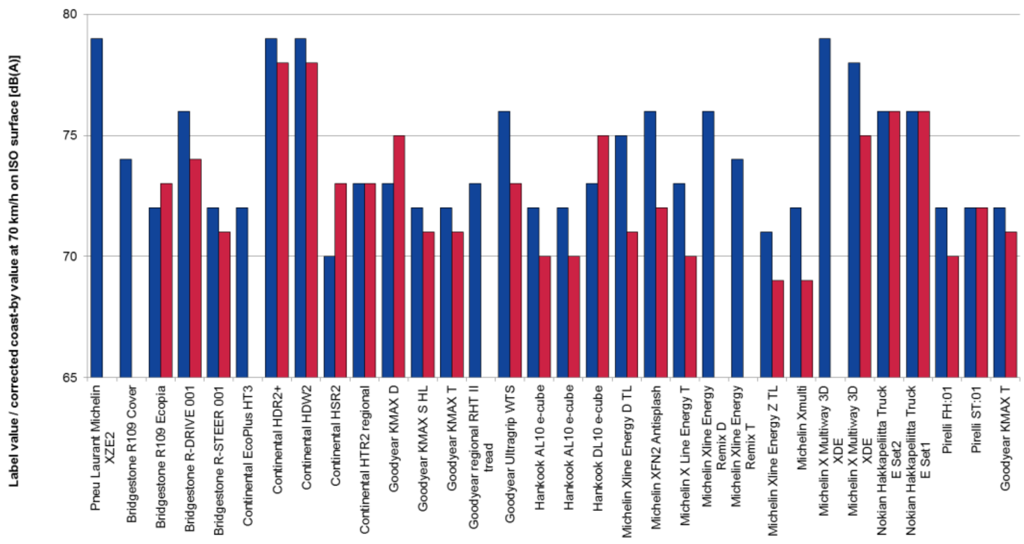


figure 19 *Label value and coast-by values at 70 km/h on ISO for the tested tyres. For the re-treaded types no label value is available.*

The data in figure 19 show a significant deviation between label values and test results on ISO at 70 km/h. The mean deviation between label value and observed value is 2,7 dB with a standard deviation around the mean of 1,8 dB.

The larger part of the deviation can be explained by the specific data processing that is applied in the R117 measuring method. The regulatory result is found by rounding down the measured test value to the lowest integer and additionally subtract 1 dB for measuring uncertainty. When we apply this procedure to the test results in this study the deviation decreases.. The average difference is now 1,2 dB with an standard deviation of 1,9 dB.

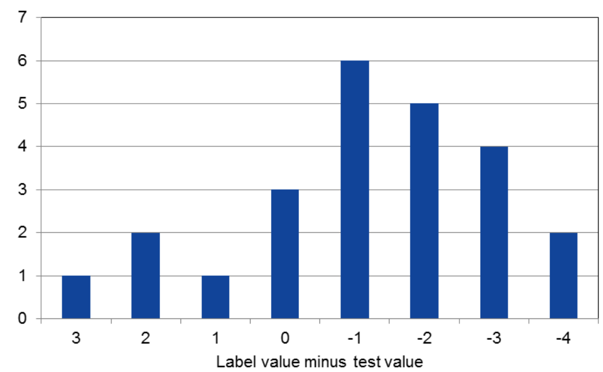


figure 20 *Distribution of differences between label values and test values. Test values are processed according to the procedure given in R 117. A negative difference indicates a higher test result compared to the label value. The average difference is 1,2 dB with an standard deviation of 1,9 dB.*

The figure below (figure 21) presents test results (after processing) against label values. It shows that the deviations between test and label values are distributed evenly over label values.

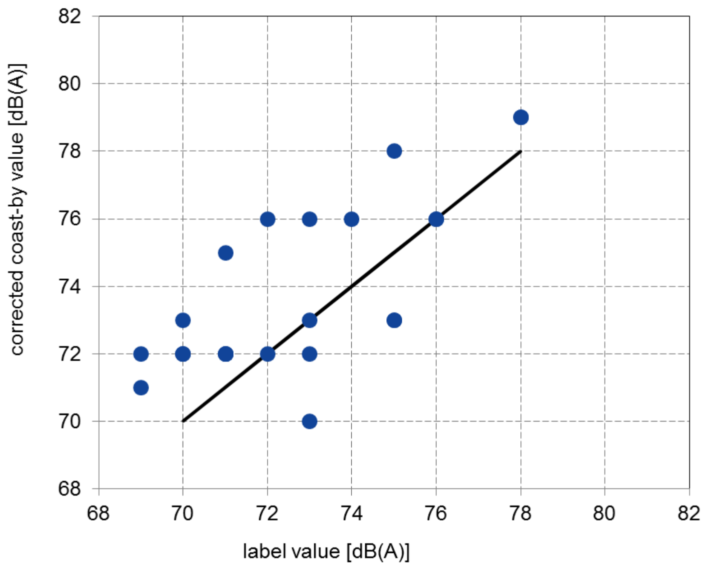


figure 21 *Label value and coast-by values at 70 km/h on ISO for the tested tyres.*

A few causes for the observed deviations between test values and label values can be identified.

- The air temperature during the measurements is substantially lower than one would expect on average. The allowed temperature range for standardized tyre noise measurements is from 5 to 40 °C and R117 defines a reference temperature of 20 °C. Air temperatures during the measurements are in the range of 6 to 11 °C. As prescribed by R117, no correction for the temperature is applied, although from other studies a correction of about 0,05 to 0,07dB/°C is to be expected [9]. Applying such a correction would lead to a 0,7 to 0,8 dB lower value at the reference temperature and even larger if the label values are determined in higher temperature ranges.
- The levels at 70 km/h are derived from coast-by events with speeds ranging from 40 to 80 km/h. This is chosen since the accuracy benefits from the larger number of data points in the scatter diagram. Further analysis on data sets with ample data points in the 60-80 km/h speed range revealed that no trend can be expected from enlarging the speed range, other than improved accuracy in level and slope.

On base of the above we find that about 75% of the observed 1,2 dB average deviation can be explained.

The test surface used here is slightly coarser than the minimum required. The MPD of the ISO test section is about 0,4 mm while a minim value of 0,3 mm is stated in ISO 10844:2014. The MPD is below the target value of 0,5 mm though. The wavelength spectrum of the ISO section also slightly exceeds the target spectrum (ref [4]). It is unclear of a net effect can be expected from this.

It cannot be concluded that there exists a structural gap between labeled values and test results from this investigation when the data are measured and processed in the same way. The initial found deviation of nearly 3 dB indicate that the measurement procedure defined in R117 leads to a structural under estimation of the rolling noise levels found in practice, even when the effect of the road surface is not included.

9 References

[1] U. Sandberg: Proposal for a Nordic project on heavy vehicle tyre/road noise – A pilot study. VTI, Final version 2012-10-28.

[2] G. J. van Blokland: Tender for Nord Tyre Part 3 – Truck tyre noise. M+P.DRD.13.01.1, November 19th, 2013.

[3] G. J. van Blokland and T.Berge, "Tyre Selection for NordTyre Part3", M+P.DRD.13.01.2, June 3rd, 2014

[4] G. J. van Blokland and T.Berge, "NordTyre Part 3: Properties of Test Surfaces", M+P.DRD.13.01.3, April 2015.

[5] G.J. van Blokland et al., "NordTyre Part 3: Properties of Tested Truck Tyres", M+P.DRD.13.01.5, April 2015

[6] ISO/IEC Guide 98-3, Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995).

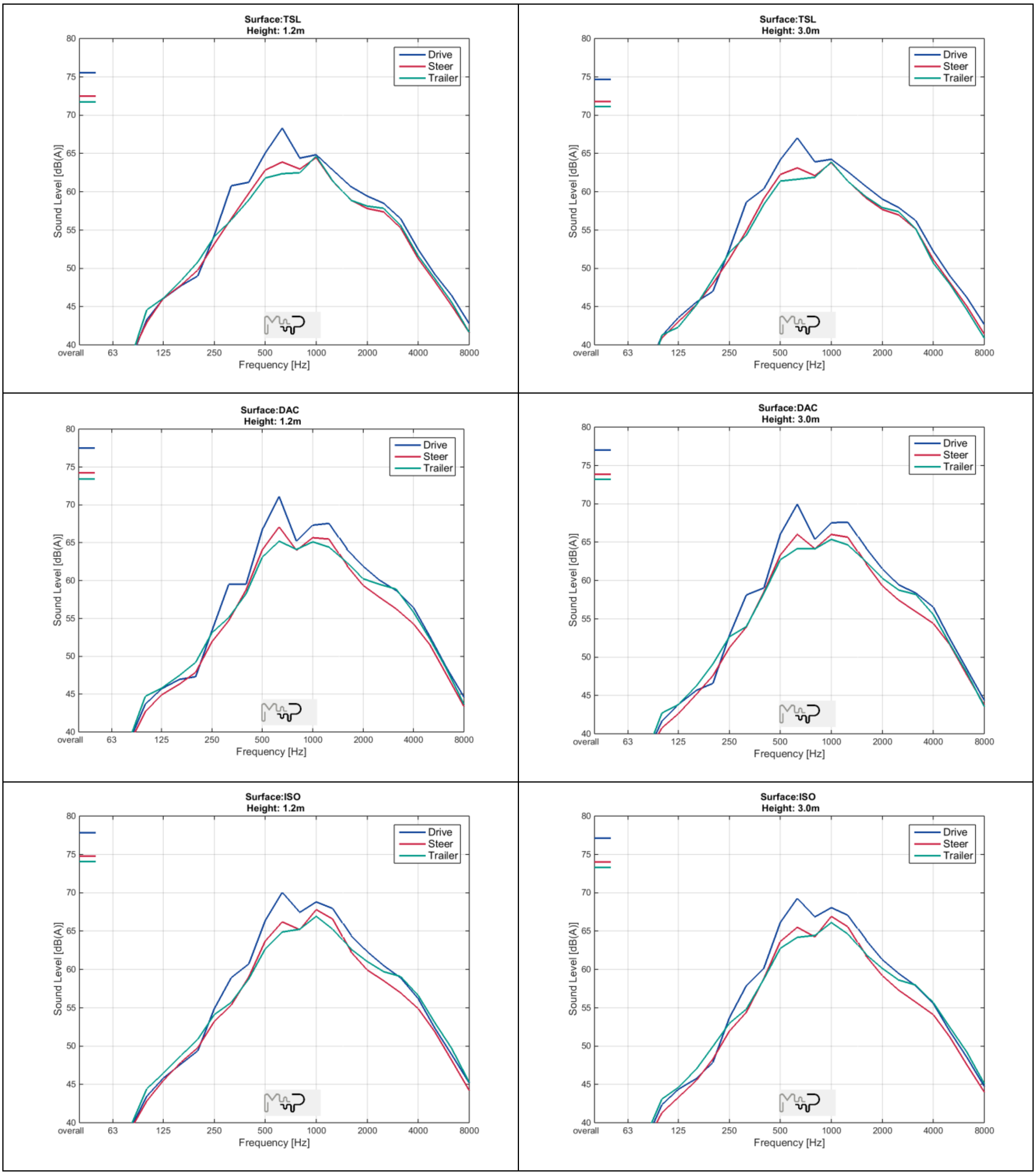
[7] ISO 10844:2014, Acoustics- Specification of test tracks for measuring noise emitted by road vehicles and their tyres, International Organization for Standardization, 2014.

[8] UNECE Regulation R117; Uniform provisions concerning the approval of tyres with regard to tyre/road noise emissions and/or to adhesion on wet surfaces and/or to rolling resistance; revision 3; February 2014.

[9] Bühlman and van Blokland, "Temperature effects on tyre/road-noise –A review of empirical research", Forum Acusticum 2014.

[10] W.Schwanen *et a*l, "Comparison of potential CPX-tyres", M+P.DWW.07.04.2 d.d. July 2007.

10 Appendix A Spectra of T, S or D tyres on test surfaces



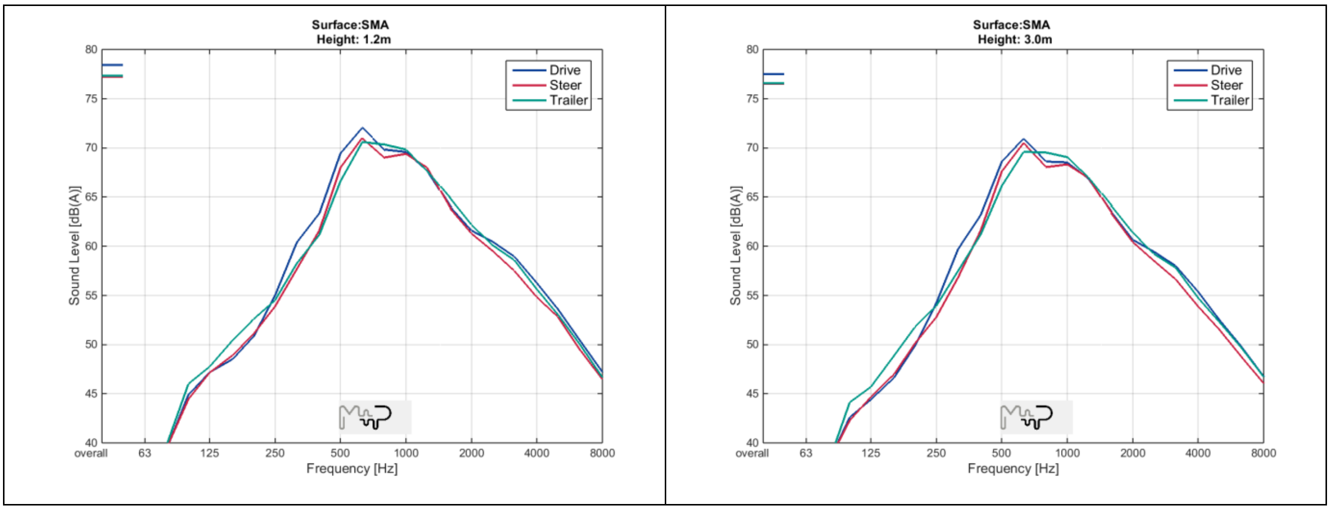
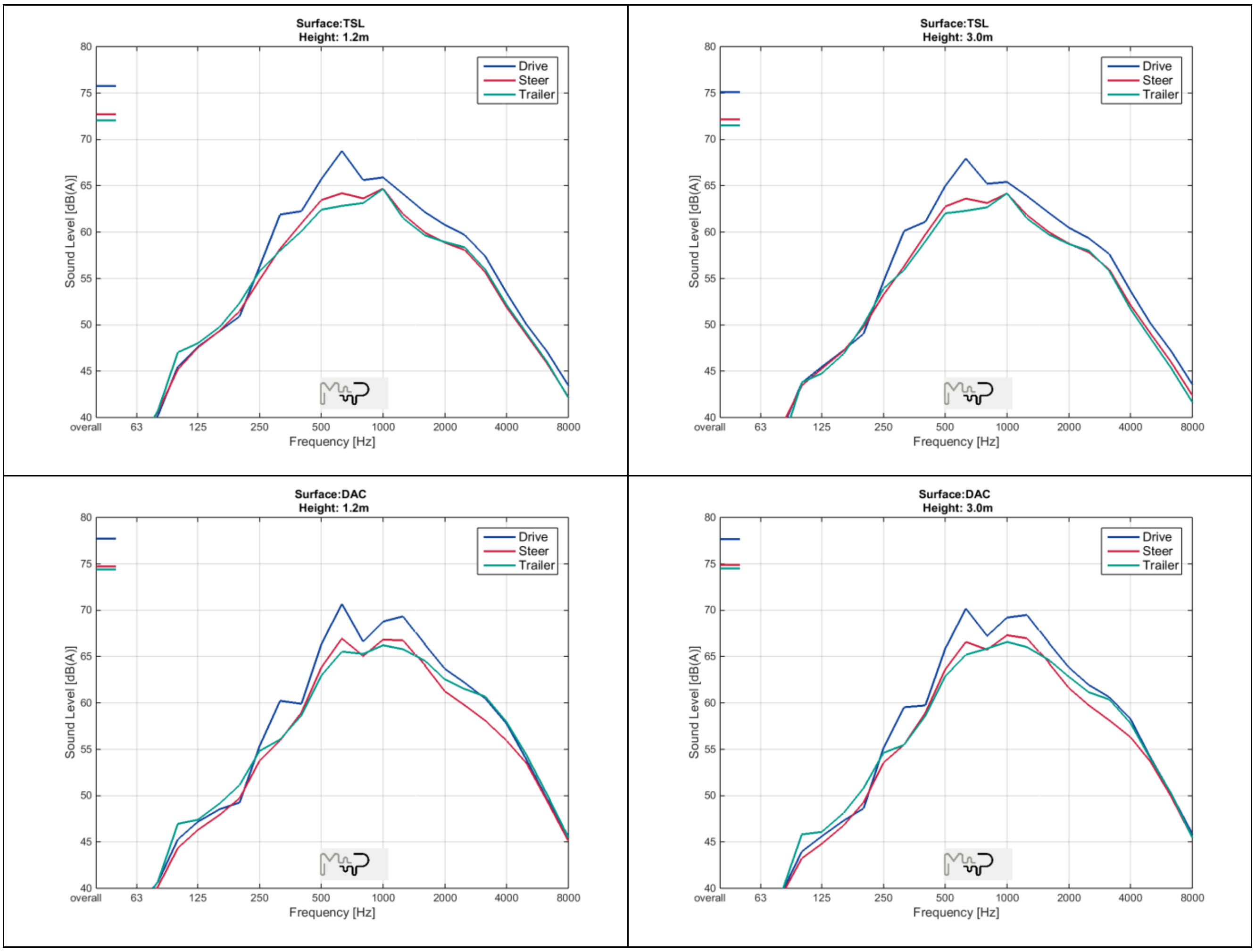


figure 22 *Spectra of LAFmax values of the three types of tyres on the four test surfaces at a height of 1,2 and of 3,0 m.*



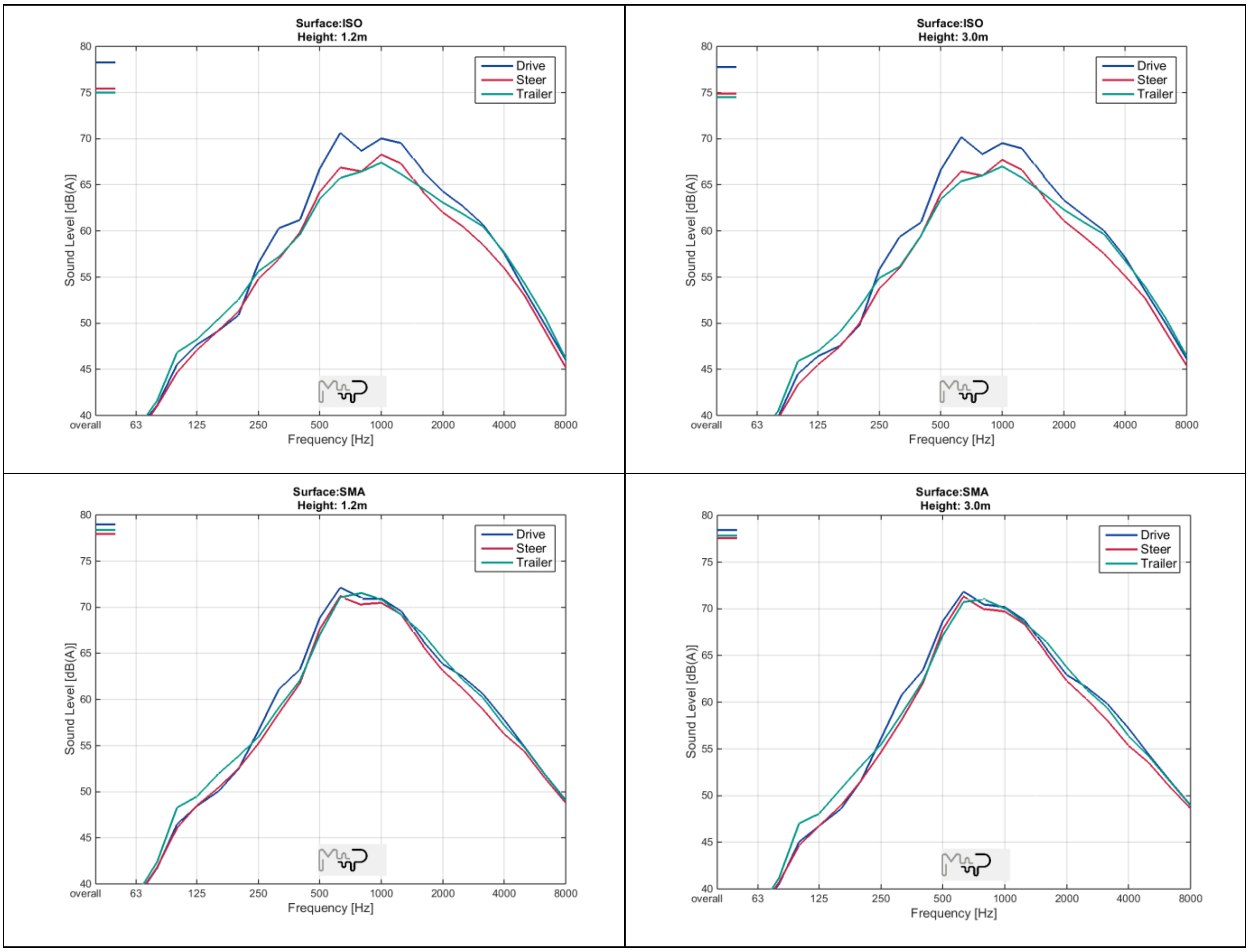


figure 23 *Spectra of SEL values of the three types of tyres on the four test surfaces at a height of 1,2 and of 3,0 m.*