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STEER
strengthening the effect of quieter tyres on european roads

# Improving reproducibility of tyre/road noise measurements on ISO test tracks

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## STEER: Strengthening the Effect of quieter tyres on European Roads

# Improving reproducibility of tyre/road noise measurements on ISO test tracks


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# Executive summary

An earlier report from STEER (Task 2.2 on Uncertainties) estimated a-priori the uncertainties of various sources in the tyre noise labelling procedure. It was shown there that the greatest uncertainty contributions come from three dominating uncertainty sources related to reproducibility. The purpose of this Deliverable is to explore and determine the reproducibility of tyre/road noise measurements on “ISO test tracks”.

The mentioned STEER report concluded that the greatest uncertainty contribution comes from the variation between different ISO test tracks. The second contributing uncertainty source was a tie between the effect of the test vehicle, and the effect of ambient and test track temperatures. Consequently, these are the issues explored in this Deliverable. It is recognized that there are also some other sources of uncertainty relevant here, but as they have significantly lower influence and only a marginal effect on the total reproducibility, they are not specifically treated here.

The analyses are focused on the case of testing passenger car tyres (C1), since it is for those that the reproducibility is most critical, and which have been studied much more than the heavier tyres (C2 and C3).

Although the study and analyses of the uncertainty sources serve as a background for this Deliverable, the primary purpose is to suggest how the reproducibility can be improved by improved testing procedures.

This Deliverable has confirmed that reproducibility of tyre/road noise measurements for purposes of tyre labelling is a major problem. This applies to the correction for temperature effects on the noise measurements, but even more for the lack of reproducibility of test track surfaces produced in compliance with ISO 10844.

As mentioned, the difficulty in agreeing on defined test vehicles for the various sizes of tyres has resulted in uncertainty contributions which are significant. Although it may be difficult to agree on a global test vehicle standard, we propose that discussions in the relevant forums are introduced, with the potential aim to produce a standard for test vehicles for tyre/road noise emission, adapted for a minimum influence on such measurements and for long-time use. Such vehicles would replace present test vehicles from the commercial market and be more independent of fashions of the time. They could also be tailored to be used for a wider range of tyre dimensions and loads; in that way reducing the number of needed test vehicles.

Regarding temperature influence, currently there is almost a chaotic situation as there are three major proposals on how to correct for temperature effects:

- ISO/DTS 13471-2 which (in 2021) proposes using ambient air temperature for noise corrections and a simple linear correction based on a certain temperature coefficient (dB per degree C).
- The tyre industry which supports the existing temperature correction in R117, which is more than 20 years old and based on road surface temperatures and is nonlinear. The temperature coefficients seem to be too conservative.
- The vehicle industry which suggests a new temperature correction based on air temperature, with temperature coefficients rather close to ISO, but slightly nonlinear.

This Deliverable has explored the three versions and tried to show how they are connected by suggesting a way to convert corrections between the air and road temperature options. It also reports analysis of some old comprehensive data and new data received in the last months. It is concluded that the currently best temperature correction for noise measurements on general road surfaces is a linear one based on air temperature and implying a greater correction at high temperatures than the one presently used in R117. It is also concluded that it is possible to convert corrections between those based on air and those based on road temperatures, and that it follows that the road-based temperature corrections

will be non-linear while the air-based ones are linear. Finally, it is concluded that as air and road temperatures vary substantially between various climatic regions, as soon as possible, the corrections should be improved by basing them on both air and road temperatures. But to quantify the correction coefficients, new research must be conducted.

In this Deliverable, STEER has reported all Round Robin Tests (RRT) which have been known through published work or by personal involvement. However, STEER originally proposed to make an own RRT within the project as the ones available had several constrictions making it difficult to draw the conclusions we need. Unfortunately, the budget was cut down so the planned RRT could not be conducted. Consequently, our conclusions are the best we can draw considering the partly incomplete data available.

Design and construction of test tracks for type tyre noise approval and labelling purposes are specified in ISO 10844, which to date include four editions, where the last one (2021) is under publication. After the first edition of the ISO 10844 was published (1994), two known RRT:s were conducted, one in Europe and one in Japan. When a couple of test tracks in Europe were not considered because of unacceptable performance, the rest indicated that the spread in noise levels for both the Japanese and European test tracks was between 2 and 4 dB depending on which tyre that had been used. After the 2011 and 2014 editions of ISO 10844 were published, two more RRT:s have been conducted, one by VDA in Germany and the other by ETRTO. The ETRTO study gave approximately the same results as the earlier ones, but the VDA study, including as many as 13 test tracks in Germany, Italy, Spain and Luxemburg indicated noised spreads between test tracks up to 6 dB. When the results were explored further it appeared that two of the 13 test tracks had somewhat higher sound absorption than acceptable which resulted in too low noised levels. This had not been detected in the certifications of those test tracks, It thus appears that despite the stricter requirements in the 2014 edition of ISO 10844, test tracks are constructed and used, while they may not actually meet the requirements. This calls for a more ambitious follow-up of the performance of such test tracks.

Whether the spread in noise levels is up to 4 dB or up to 6 dB, these variations are clearly unacceptable. For example, 6 dB is approximately the entire spread in noise levels between market tyres. Some of this spread assigned to tyres may therefore actually be due to the test tracks used during testing.

One should note that so far we know only about RRT:s in Europe and Japan. What results RRT:s would provide in (say) China, India or Indonesia is only subject to speculations. Studies have been made in China, but those results are not available.

Homogeneity, or rather inhomogeneity, of the test tracks is a serious problem. It has appeared that paving surfaces according to ISO 10844 often if not mostly needs iterations (initial failures must be followed by new paving operations) and despite this, it is difficult to achieve the homogeneity within the critical surface areas that is desirable. Since the noise measurement means that the peak in noise when the vehicle passes over the standardised area, it is important where on the drive lane the peak appears, and that the surface properties on that spot are important. This problem needs more attention.

One experience from the RRT:s is that in order to give clear and useful results it is not enough to include only a few (say 3-5) test tracks, but one should aim at including at least 10 tracks. The VDA study included 13 tracks, and this appeared to give a lot of useful information.

It should be noted that at the end of STEER, a Polish-Norwegian bi-national project ELANORE has started to conduct an RRT, instead of the one STEER did not get funds for. However, it appeared that due to, among others, bad luck with weather conditions, the measurements and analyses have not become available in due time for this Deliverable.

One reason for the problems of the test tracks is that the latest editions of ISO 10844 have required MPD values be within the range 0.3 to 0.7 mm. Both Sweden and Belgium have objected to this in the ISO revision of ISO 10844 which is just completed since MPD values below 0.5 mm of MPD are not suitable on highways as they would mean high risk of wet friction and hydroplaning. But such smooth textures are also difficult to produce with the high homogeneity needed while simultaneously measurements of such small MPD values give high relative uncertainties.

The unacceptably high variation in surface properties between test tracks calls for introduction of some sort of calibration procedure of test tracks, so that a correction can be added to get more uniform and reproducible noise results. To this end, a procedure named $END_T$, which used texture measurements to predict how the surface influences noise measurements, was first tried, but not with significant success.

Recently, a new procedure (or model) by the company Müller-BBM has been suggested, based on the results of all surface and noise property measurements in the RRT conducted by VDA (mentioned above). This model uses two texture and one sound absorption parameter to predict the noise emission. The result is very good, as it can be used to normalize test tracks to a common reference with relatively low uncertainty, but it is useful only within that particular RRT study. It also appears that it is very sensitive to the measurement uncertainties of texture and sound absorption on these smooth surfaces. It is, therefore, very doubtful if it is useful globally to calibrate ISO test tracks.

Instead, STEER has explored the potential use of a calibration procedure using reference tyres, that was proposed in 2017 by this main author. This procedure suggests the use of eight standardised test tyres, produced with the purpose to be long-term references, that shall be used by all test track owners to measure under strict control the noise emission at certain intervals. The results shall be compared to a global referenced and thus the test track can be calibrated to give results according to the reference noise properties (to be set by the international community). The Reference Tyre Calibration procedure was tried for the results of the VDA study which gave very good results. With such calibration, the spread in noise levels between the 13 test tracks was reduced by two-thirds of the non-calibrated variation.

Since the Reference Tyre Calibration procedure is general and only depend on the tyres and to some extent the test vehicle it is potentially a useful global procedure to reduce the uncertainties of the test tracks to acceptable levels.

At the end of the Deliverable there is a chapter with recommended actions. If these actions can be implemented in the ECE Regulation 117 as well as in the EC Tyre Labelling Regulation, the reproducibility of the noise measurement results in the tyre labelling system will be greatly improved which will substantially increase the value of the system.

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# 1 Introduction

The tyre/road noise measurements on which the label values are based are usually made by the tyre manufacturers themselves, as allowed in Regulation ECE R117 [ECE R117, 2016]. It is normal that they are made in conjunction with the type approval of new tyres. It means that the label values are influenced by the particular test track surface which is used (reference surface according to ISO 10844), as it is well known that noise emission is an effect of the tyre/road interaction.

This ECE R117 regulation describes in detail how the tyre/road noise measurements shall be conducted, and also how the reference surface on the test tracks should be constructed, where the latter, however, is based on ISO 10844:2014 [ISO 10844, 2014].

Since the label values are assumed to be generally valid, for every ISO 10844 reference surface worldwide, it follows that the label values (ideally) shall be reproducible everywhere and at any time. If they are not reproduceable it means that a fair comparison of noise properties of different tyres, from various manufacturers and made on different ISO reference tracks, cannot be made. To enable such fair comparisons is the core value of the labelling system. Consequently, this issue raises the question: how reproduceable are the label values in general? What is the uncertainty of the label values, as contributed by the unwanted influence of the ISO 10844 reference surface?

# 2 Purpose

The purpose of this Deliverable is to explore and determine the reproducibility of tyre/road noise measurements on ISO test tracks. The three dominating sources of the reproducibility problem are studied, namely the effect of the test vehicle, the effect of ambient and test track temperature, as well as the variability of the ISO 10844 reference surfaces.

It is recognized that there are also some other sources of uncertainty relevant here, but as they have significantly lower influence and only a marginal effect on the total reproducibility, they are not specifically treated in this Deliverable.

The analyses are focused on the case of testing passenger car tyres (C1), since it is for those that the reproducibility is most critical, and which have been studied much more than the heavier tyres (C2 and C3).

Although the study and analyses of the uncertainty sources serve as a background for this Deliverable, the primary purpose is to suggest how the reproducibility can be improved by improved testing procedures.

# 3 Uncertainty sources relevant to reproducibility

An analysis of uncertainty sources in the labelling system is described in the Technical Report describing the work of Task 2.2 of STEER [Goubert, 2020]. The essential outcome of that analysis of the present situation is illustrated in Figure 3-1. Note that the group named “meas. conditions” include the effects of wind and temperature, where temperature is the dominating contributor.

It appears that three groups (sources) of uncertainty dominate:

- Measuring conditions (wind and temperature)
- Test vehicle
- Test track

Due to how overall uncertainty is combined by individual uncertainties (in a "square fashion"), the overall uncertainty will depend almost entirely on the three mentioned sources. The rest of the sources together will have only a marginal effect.

It should be noted that the analyses in Task 2.2 were made at the start of the project, and that now at the end of the project we have collected more information which allows us to be more precise as well as to suggest how the uncertainties can be reduced. Nevertheless, the dominance of the three sources mentioned above has not been changed during the project.

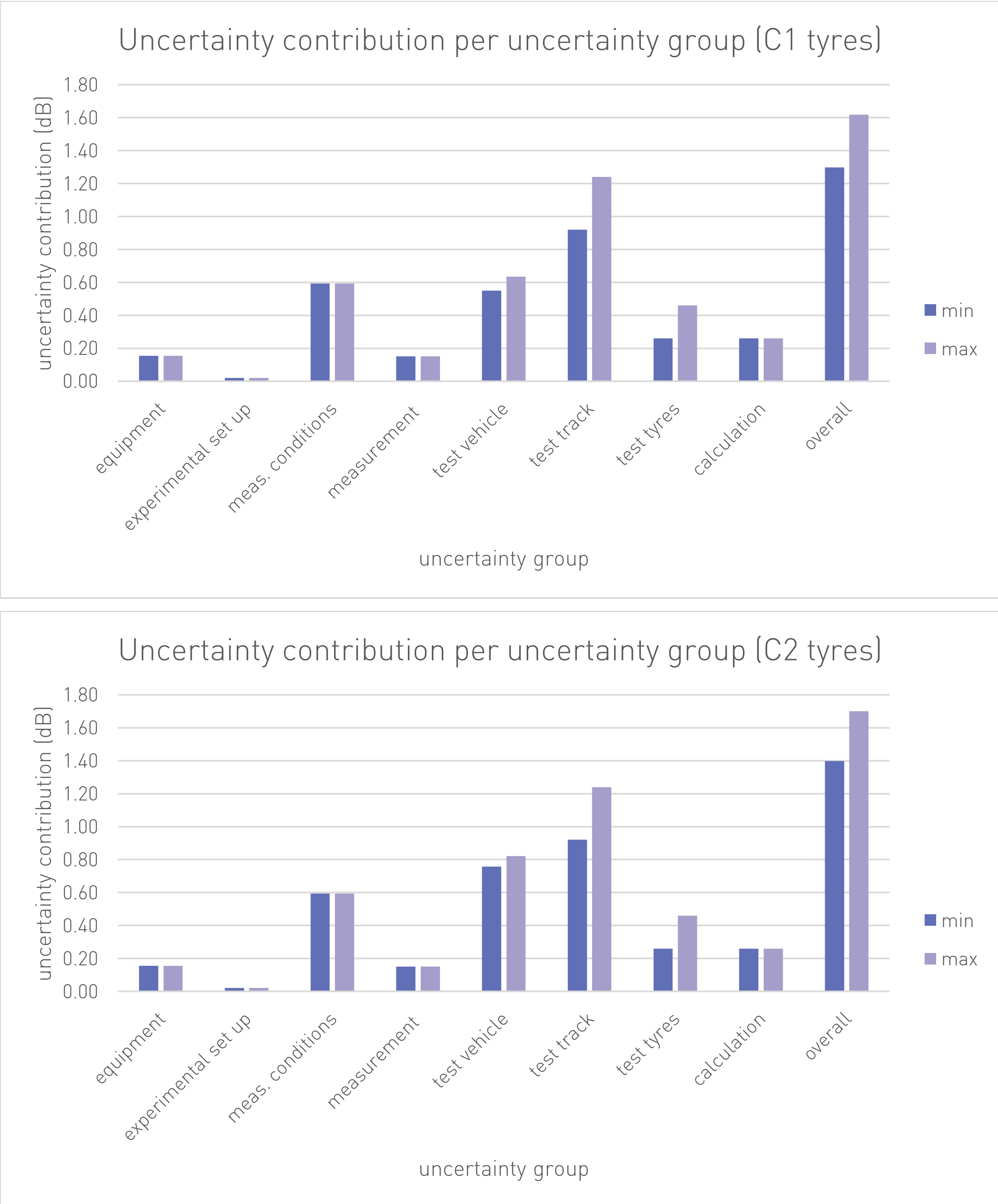



Figure 3-1: Uncertainty contributions per uncertainty group for the C1 (top) and C2 tyres (bottom). Copied from [Goubert, 2020].

# 4 Test vehicle influence on tyre/road noise

## 4.1. Description of the problem

In STEER no special analysis has been made of the influence of test vehicle on tyre/road noise measurements. Very few documents about the test vehicle influence have been made public. The only major one published is an 8-page chapter (No. 13) in [Sandberg & Ejsmont, 2002]. Among the tests reported there, is one test from 1990 by the same authors where a tyre set was tested (in coast-by) on four “light” passenger cars and another tyre set was tested on four “heavy” passenger cars on a range of speeds from 30 to 90 km/h. The cars were chosen to feature as different constructions and geometries as practical. The results are illustrated in Figure 4-1.

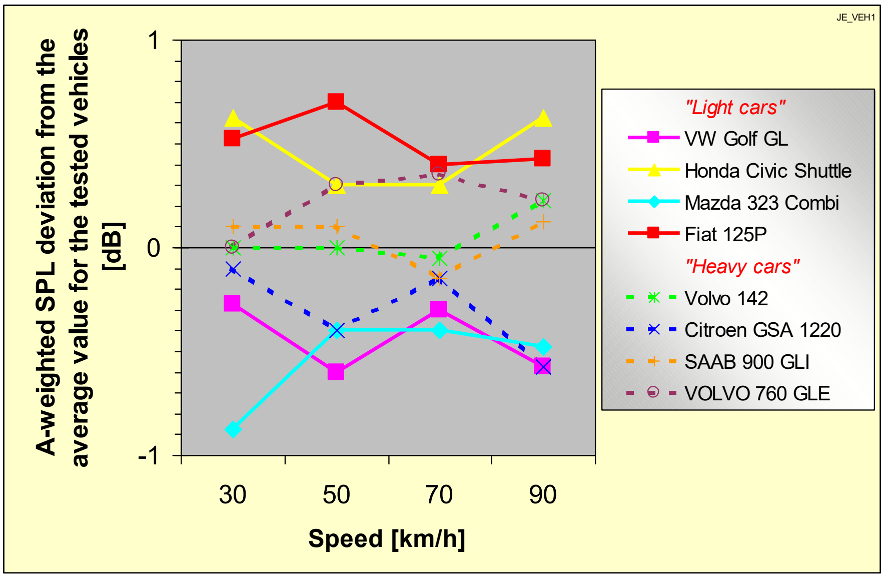



Figure 4-1: A-weighted SPL measured for the "light" and "heavy" car groups. From [Sandberg & Ejsmont, 2002].

The results indicate that the tyre/road noise (coast-by) A-weighted levels vary by approx. ±0.4 dB at 70 and ±0.6 dB at 90 km/h from the average noise level of each tyre set.

For the uncertainty contribution of the test vehicle (car), in [Goubert, 2020] a value extracted from a database from a tyre manufacturer, yielding a value of 0.60 dB is used, alternatively a value proposed by ETRTO (0.51 dB) according to [Goubert, 2020].

The values from the three sources mentioned above are thus rather consistent.

## 4.2. Suggested improvement

As shown in Figure 3-1, the contribution of vehicles to the overall uncertainty is the second highest and only the contribution to the uncertainty of the test surface is currently clearly higher. This may be a reason for why this uncertainty source has not been addressed more in depth; for example, by defining special test vehicles. However, if the test track influence is reduced, as proposed here, the vehicle influence will be relatively more important and should receive more attention.

In the current version of ECE R117, vehicle specifications include the following restrictions on the test vehicle (somewhat edited by the author):

- The wheelbase between the two axles fitted with the test tyres shall for Class C1 be less than 3.50 m and for Class C2 and Class C3 tyres be less than 5 m
- Spray suppression flaps or other extra device to suppress spray shall not be fitted
- Addition or retention of elements in the immediate vicinity of the rims and tyres, which may screen the emitted sound, is not permitted

- Wheel alignment (toe in, camber and caster) shall be in full accordance with the vehicle manufacturer's recommendations
- Additional sound absorbing material may not be mounted in the wheel housings or under the underbody
- Suspension shall be in such a condition that it does not result in an abnormal reduction in ground clearance when the vehicle is loaded in accordance with the testing requirement. If available, body level Regulation systems shall be adjusted to give a ground clearance during testing which is normal for unladen condition
- Removal or modification on the vehicle that may contribute to the background noise of the vehicle is recommended. Any removals or modifications shall be recorded in the test report
- During testing it should be ascertained that brakes are not poorly released, causing brake noise
- It should be ascertained that electric cooling fans are not operating
- Windows and sliding roof of the vehicle shall be closed during testing.

So far, the present requirements are valid for coast-by testing of tyre/road noise. Ideally, one would like to use the same special test vehicle worldwide for a certain range of tyres. To cover all tyre dimensions and their loads, probably two or three different sizes of cars/SUV:s for C1 tyres, one small truck for C2 tyres and two sizes of trucks for C3 tyres would be needed. Obviously, to define such standard test vehicles or produce special or modified vehicles that can be available worldwide and required in the regulation may increase costs and may be difficult to agree on (would US and Chinese manufacturers accept, for example a German vehicle, or vice versa?). Tyre manufacturers already have their own special test vehicles for such purposes, probably at least as many as mentioned above, but they are generally market vehicles that can be used also for other purposes.

However, it would absolutely be technically possible to decide on standard test vehicles, adapted for minimum effect on tyre/road noise, in which case one could eliminate almost all the uncertainty contributions of the test vehicles in the testing procedure.

The authors would recommend development of such standard test vehicles, if it were not for the risk that it may be strongly opposed by conservatives in the tyre industry. In fact, once a standard for such vehicles is decided on, based on modified and adapted market vehicles (for example, cars and trucks with no regular body, just chassis) it would not be significantly more expensive (if more expensive at all) to procure such vehicles, as they can be used for a very long time and corresponding market vehicles (in larger numbers) will not be needed. Too little research on the test vehicle influence and how more uniform vehicles should be constructed is available, so this is something that is needed quite urgently. As shown in Figure 3-1, this uncertainty contribution is second only to that of the test track. When the test track influence hopefully can be reduced to one-half of the present case, due to STEER proposals, then test vehicle influence will be relatively more important than currently.

It is noted that the principle of defining special test vehicles is already implemented in standards for measuring the noise properties of road surfaces (ISO 11819-2 and ISO/TS 11819-3).

It is also noted that a trend is that tyres tend to be more and more covered by body parts (for air resistance and design purposes) which may create more resonant spaces around the tyres (in wheelhouses) and thus give increased vehicle influence; furthermore, with increasing use of SUV:s and more off-road applications, ground clearance seems to be more varied than previously.

Therefore, here we propose that discussions in the relevant forums are introduced, with the potential aim to produce a standard for test vehicles for tyre/road noise emission, adapted for a minimum influence on such measurements and for long-time use. Such vehicles would replace present test vehicles from the commercial market and be more independent of fashions of the time. They could also be tailored to be used for a wider range of tyre dimensions and loads, in that way reducing the number of needed test vehicles.

# 5 Temperature influence on tyre/road noise

## 5.1. Description of the problem

As already described in a project report of STEER [Vieira & Sandberg, 2021], the influence of temperature at the tyre type approval and label noise measurements may influence the measurements by up to 2 dB. Figure 3-1 also indicates that temperature (dominant in the “measurement conditions”) is one of the three major sources of uncertainty.

Fortunately, some of the temperature influence is possible to compensate for by correction procedures. ECE R117 already includes a temperature correction; however, we think that a better correction procedure is possible. For example, a matter of controversy is whether ambient air or test track surface temperatures should be used for the correction. The findings of STEER and other actors are reported in the following sub-chapters, ending with recommendations for improved corrections by STEER.

## 5.2. The ISO/TS 13471-2 draft Technical Specification

Already in the 1990’s it was realised that a correction to noise levels for the influence of temperature was needed, and the task was assigned to a working group ISO/TC 43/SC 1/WG 27. However, the work was heavily delayed since the experimental data was insufficient and not entirely consistent. The work was finally published in 2017 as ISO/TS 13471-1 [ISO/TS 13471-1, 2017] and then it was only valid for the two reference tyres used in the CPX standard. The concept was widened to also include coast-by or cruise-by methods (but cases where tyre/road noise was not significantly “obscured” by power unit noise), and was intended for tyres in general, in the work to produce ISO/TS 13471-2. This is or should become the relevant standard document for corrections to measurements of the type made in ECE R 117. At this moment, the document is a Draft Technical Specification (DTS) [ISO/TS 13471-2, 2021]. The latest version is influenced in parts by the work presented in the STEER Project Report 3.1 (chapter 5.3 below).

When using a semi-generic correction procedure as in this case (there is no other distinction between tyres than the C1, C2 and C3 tyre dimensions), it shall be accepted that the use of an average temperature coefficient for either tyre/road noise or vehicle noise considered in this document, with a distinction between a few major road pavement categories, will lead to some over- and under-estimations of temperature corrections for individual tyres, vehicles or pavements. However, the errors of such imperfect corrections are more than balanced by the correction itself as it normalizes the results to a common and comparable scale.

First, it is determined that the most relevant temperature for the corrections is the ambient air temperature, with a reference of 20 °C. This is justified in the STEER Project Report 3.1, but also in the Inter-Noise paper presented in Chapter 5.4 below. In summary, the correction procedure is then as follows (copied from ISO/DTS 13471-2:2021 and adapted for coast-by measurements as required in ECE R117):

Temperature correction shall be applied as follows. Each measured noise level, $L_{\mathrm{Amax}}$ shall be corrected by adding the term $C_{T,\mathrm{t}}$, using Formula (1):

$$C_{T,t} = -\gamma_t (T - T_{\mathrm{ref}}) \qquad (1)$$

where

- $C_{T,\mathrm{t}}$ is the noise level $L_{\mathrm{Amax}}$ correction for temperature ($T$) for tyre class (t), in dB, to be added to the measured noise level;
- $\gamma_{\mathrm{t}}$ is the temperature coefficient for tyre class t (either C1, C2, or C3), in dB/°C;
- $T$ is the air temperature ($T$) during the noise measurement, in °C;
- $T_{\mathrm{ref}}$ is the reference air temperature = 20.0 °C.

The $\gamma_t$ (temperature coefficient) values are indicated in Table 5.1, where it should be noted that ISO 10844 test tracks would belong to road surface category “Dense asphaltic surfaces”:

Table 5-1: Compilation of temperature coefficients (excerpt from ISO/DTS 13471-2:2021).

| **Tyre class (t) →**<br>**Road surface category ↓** | **C1** | **C2** | **C3** |
|---|---|---|---|
| Dense asphaltic surfaces | -0.10 | -0.07 | -0.06 |
| Cement concrete surfaces | -0.07 | -0.06 | -0.06 |
| Porous asphalt surfaces | -0.05 | -0.04 | -0.04 |
| Other surfaces | See Note 2 and/or Appendix A in ISO/DTS 13471-2 | | |

This DTS will be subject to a final ballot during the first months of 2022. Since it was approved already in the previous version, there is no reason to suspect that it will not be approved again as the new version has been revised to take most of the ballot comments into consideration.

The DTS includes an optional Annex in which conversion between correction systems based on air (as in the DTS) versus road surface temperatures (as in ECE R117) is discussed. This is treated further in the next sub-chapter.

## 5.3. Summary of findings in STEER Project Report R3.1

### 5.3.1. Summary

This report [Vieira & Sandberg, 2021] reviews the influence of temperature on tyre/road noise emission and the existing ways to correct noise measurements for this influence to a reference condition of 20 °C. Temperatures considered are mainly air and road (test track) temperatures but also tyre temperatures are discussed.

The aim was to suggest the most relevant, accurate and up-to-date temperature corrections for tyre/road noise measured on ISO 10844 test tracks. Focus was on test conditions existing when tyre noise labelling measurements are conducted, i.e., coast-by measurements on ISO 10844 surfaces within the allowed temperature range of ECE R117.

After the existing temperature corrections in relevant standards and regulations are reviewed, the latest information about the noise-temperature relations is explored and commented. A special aim is to find a way to convert the temperature corrections from being based on air to being based on test surface temperature, and vice versa. It is recognized that, ideally, one would prefer to use tyre temperatures, but since such temperatures vary substantially in both location on and inside the tyre and with time, it is premature to use tyre temperatures for the corrections. The new research reviewed in the report suggest that tyre temperatures are more influenced by air than by surface temperatures measured as dB per degree C, even when compensating for the fact that surface temperatures generally vary more than air temperatures.

It is concluded that temperature corrections based on air temperature shall be based on ISO/DTS 13471-2 as no reason to revise that correction has been found. Using the relations measured between air and test surface (road) temperature, a corresponding correction based on surface temperature is suggested. This is compared to the presently used correction in the regulation for testing noise emission of tyres, namely ECE R117. It is found that the latter is too conservative and shall be revised to a greater correction.

The report deals essentially with C1 and C2 tyres but should ideally be updated with a review for C3 tyres, although such tyres are not primarily dealt with in the STEER project. Unfortunately, no new C3 data were available at the time of writing.

The most important issues mentioned above are treated in more detail below. Not the least, recommendations are listed in 5.3.4.

### 5.3.2. Review of the temperature correction in ECE R117

The origins of the temperature correction date back to when the first regulation on tyre/road noise was published in the EU, in directive 2001/43/EC, in 2001. It was not a recommendation from the responsible ISO Working Group (ISO/TC 43/SC 1/WG 27) but was a proposal by tyre manufacturers. When EU regulations were published in 2009, they relied on the specifications in ECE R117, thereof incorporating the same temperature correction procedure. Note that directive 2001/43/EC is no longer in force and was replaced by EC 661/2009, however, after five amendments and two corrigenda, the temperature correction procedure still refers to that of ECE R117.

In R117 it is mandatory to measure both air and surface temperature. The air temperature shall be within 5–40 °C or the surface temperature shall be within 5–50 °C. Regarding the temperature correction required in R117, a procedure for normalizing the results to a reference temperature of 20 °C is provided for tyres belonging to classes C1 and C2 only. The temperature correction is carried out by applying the following Equation, which is written in a bit different way than Equation (1), but in practice is similar:

$$L_R(\vartheta_{ref}) = L_R(\vartheta) + K(\vartheta_{ref} - \vartheta) \tag{2}$$

where $\vartheta$ is the measured test surface temperature, and $\vartheta_{ref}$ is the reference temperature of 20 °C. The coefficient K is defined according to the tyre class and the difference between measured surface temperature and the reference temperature, as shown in Table 5-2. The speed ranges and reference speeds for each tyre class are also shown in the same table. The procedure is illustrated in Figure 5-1.

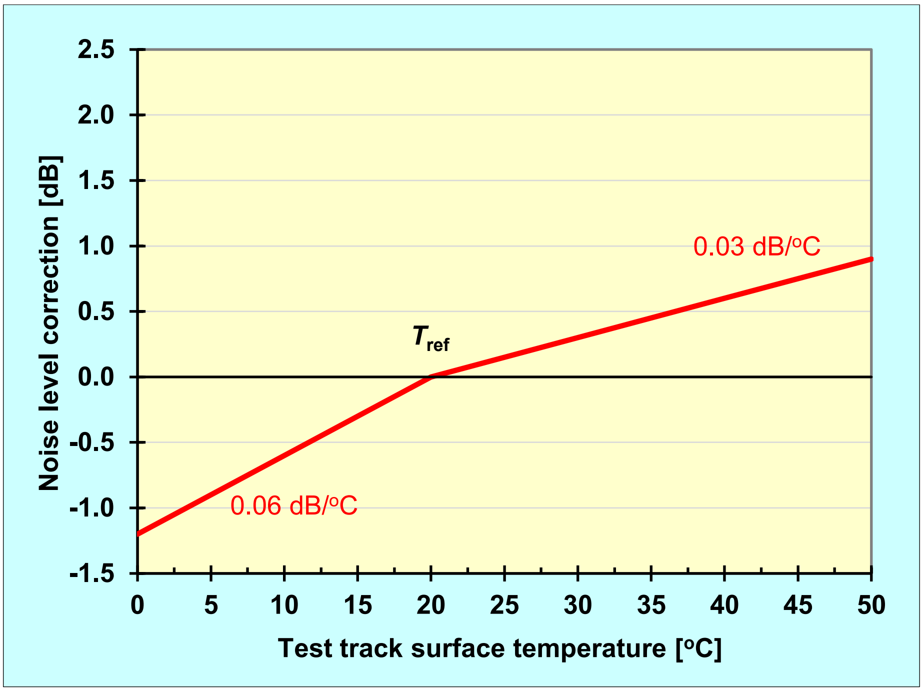



Figure 5-1: The noise-temperature relation that is used for car (C1) tyres in a number of EU and ECE regulations (see the text).

Table 5-2: Temperature correction coefficient according to ECE R117 and some test requirements. Note that the Regulation still uses the unit dB(A), which is not allowed according to ISO terminology standards. The unit shall be dB and not dB(A).

| Tyre class | Speed range | Reference speed | Road temperature $\vartheta$ | Correction coefficient K |
|---|---|---|---|---|
| C1 | 70–90 km/h | 80 km/h | $> \vartheta_{ref}$ | -0.03 dB(A)/°C |
| | | | $< \vartheta_{ref}$ | -0.06 dB(A)/°C |
| C2 | | | - | -0.02 dB(A)/°C |
| C3 | 60–80 km/h | 70 km/h | - | - |

### 5.3.3. Conversion from corrections based on air to road temperatures, or vice versa

In order to compare the temperature corrections in this document, which are based on air temperatures, with those of ECE R117, a conversion of the temperature coefficients need to be made to road surface temperatures, and vice versa. For this reason, one must define a conversion factor:

$$\gamma_{tr} = K \cdot \gamma_{ta} \tag{3}$$

where

$\gamma_{tr}$ is the temperature coefficient for tyre t, based on road temperature

$\gamma_{ta}$ is the temperature coefficient for tyre t, based on air temperature

$K$ is the conversion factor for air-to-road coefficients

The conversion factor is still subject to studies. The size of this varies within the range from 1.2 to 2.6 according to the Project Report R3.1. That document lists a number of suggested conversion factors from the literature and other known experiments. From that list it is concluded that a reasonable weighted average is 1.8.

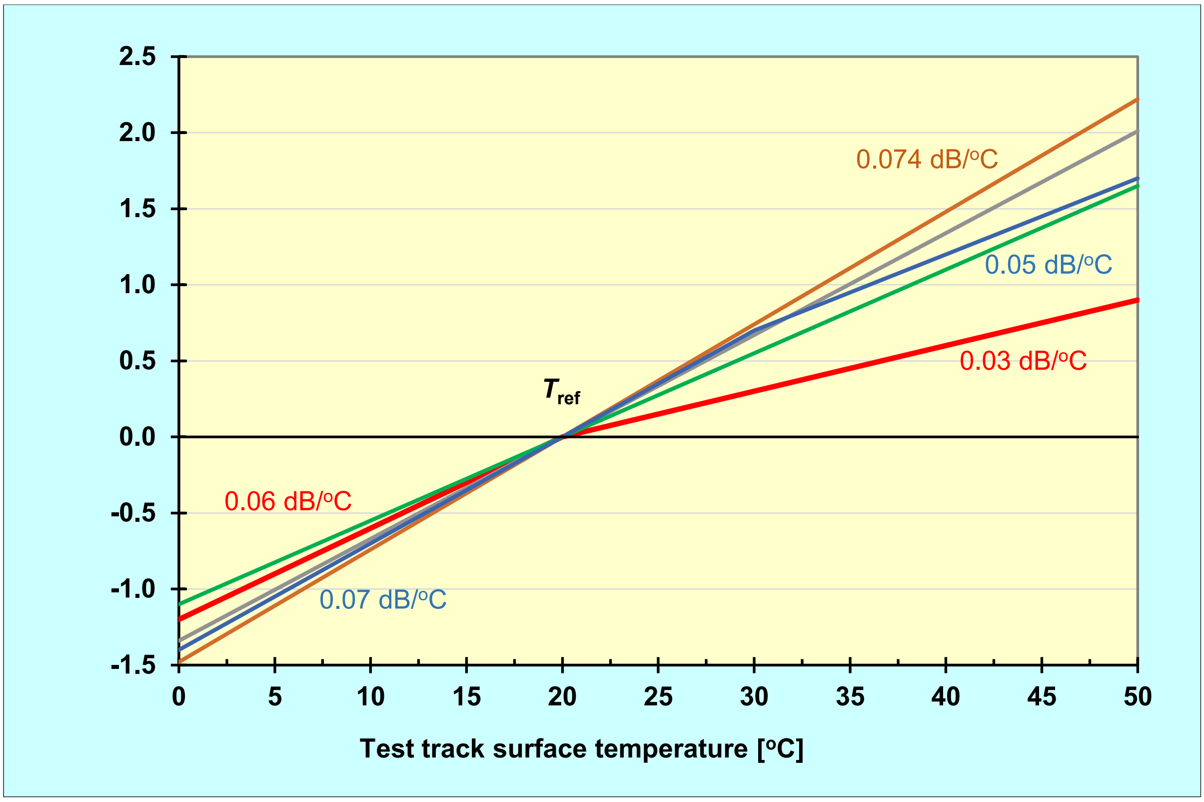
Table 5-3 shows the temperature coefficient for an ISO surface based on road temperatures if the air temperature coefficients are converted by the conversion factors discussed above. The last example is for a conversion factor 1.4 below 30 °C and 2.0 above 30 °C which results in a piecewise linear noise-temperature relation.

These coefficients are illustrated in Figure 5-2, where also the correction used in ECE R117 and related regulations are included for comparison.

Note that the last correction in Figure 5-2 and Table 5-3, compared to ECE R117, has a similar piecewise linear shape but that the STEER correction is significantly greater than the R117 at the higher temperatures.

Table 5-3: Some different conversion factors ($K$) considered in the STEER Project Report R3.1. Note that noise corrections will have the opposite sign to the temperature coefficients.

| Coeff. based on air temp. | Conversion factor ($K$) | Coefficient based on road temp. | Notes |
|---|---|---|---|
| - 0.10 dB per °C | 1.36 | - 0.074 dB per °C | Similar to unpublished Nissan data |
| - 0.10 dB per °C | 1.5 | - 0.067 dB per °C | Arbitrary chosen intermediate factor |
| - 0.10 dB per °C | 1.8 | - 0.055 dB per °C | Recommended by ROSANNE EU project |
| - 0.10 dB per °C | 1.44 and 2.0 | - 0.070 and – 0.050 | Factors rounded to get practical coefficients |



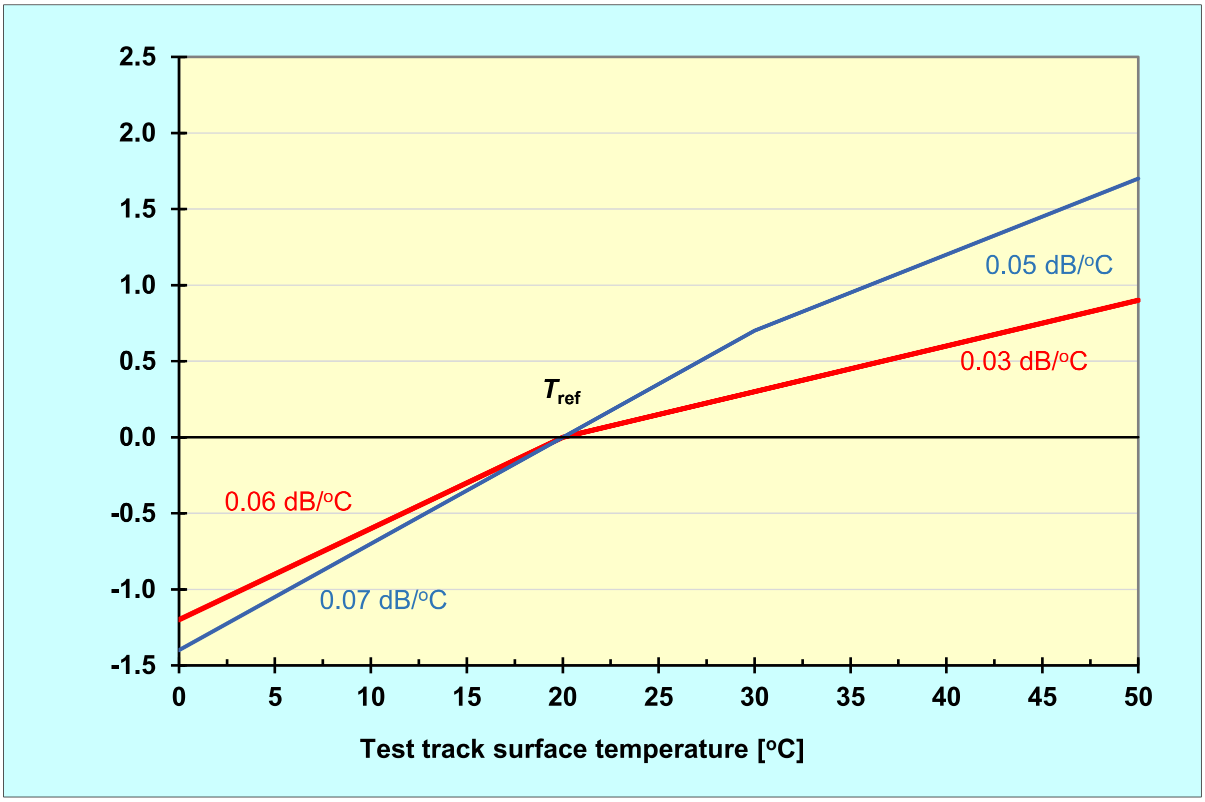




Figure 5-2: Illustrations of the noise level corrections according to the alternatives in Table 5-3 (above). The red curve is the existing correction in ECE R117, brown is K = -0.074, grey is K= -0.067, green is K = -0.055 and blue is K = -0.07 and -0.05. The diagram below shows our recommendation compared to the existing correction in ECE R117.

### 5.3.4. What temperature should be used: air or road temperature?

Based on the experimental data available and the general view of various actors and organizations, except the tyre industry, air temperatures are preferred. It seems that at the high speeds of the tyre/road noise tests for labelling purposes, the tyre temperatures are more influenced by ambient air temperature than by the road temperature. This is logical since the tyres are almost entirely exposed to high-speed air flow and turbulence, while they are exposed to the road temperature only in a rather small contact patch.

### 5.3.5. Preferred corrections based on air or road temperatures

The STEER Project Report 3.1 recommends the use of the air temperature-based correction of ISO/DTS 13471-2, which is a linear function over the appropriate range. However, if it is impossible to get acceptance for this in the tyre industry, a better alternative than no change is that the road temperature-based correction should be changed to the nonlinear one shown above in Table 5-3 and Figure 5-2 as the R117 temperature corrections are too conservative for a majority of tyres.

There is no strong support for a non-linear correction based on air temperature, on the contrary many experiments suggest that it is essentially linear. However, this does not imply that a road temperature-based correction is also linear, since the relation between air and road temperatures are not fully linear, as shown in some experiments. Especially at high road temperatures due to intense sunshine the road is heated relatively more than the ambient air. A related issue might be true at near or below freezing temperatures since the air may be colder than the road on uncloudy days or nights.

### 5.3.6. Recommendations

Finally, a set of recommendations with the aim to reduce measurement uncertainties caused by temperature being too far away from the reference temperature (20 ˚C) were suggested. In brief, they included the following measures:

- Preferably change from basing the correction in ECE R117 and ISO 13325 on surface temperature to air temperature
- If this is not politically possible, one can retain the old procedure but using a more progressive correction than today, which is part-linear; i.e., it includes two linear relations under and above a certain “knee” temperature
- Conduct research to try to find a suitable and more relevant correction based on tyre temperature for the future. In the meantime, it is envisioned that the use of an average of air and surface temperatures (maybe weighted) would improve the correction, but this must be tested further
- To facilitate the above, optionally, measures are proposed to colour the usually “black” asphalt ISO surfaces in a light greyish colour and/or to use a temperature-regulating pipe system built into the pavement to heat and/or cool the pavement by means of conventional heating or cooling systems. This may require a change in R117, but ISO/FDIS 10844:2021 has no such restrictions. A cooling or heating system is impractical to build into an existing test track so it may only be considered for new tracks.

By implementing these recommendations, it is expected that the uncertainty contribution of temperature deviating from the reference condition is reduced significantly.

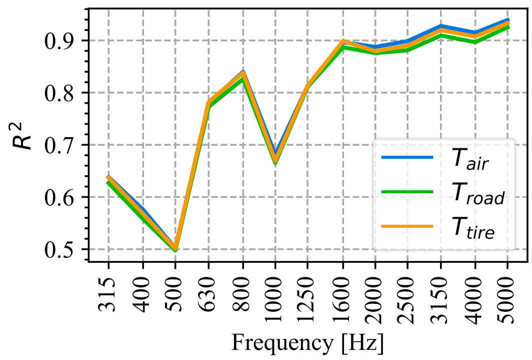
## 5.4. Summary of findings after Project Report R3.1 was finalized (Inter-Noise 21 paper)

In a recent paper, presented at Inter-Noise 2021 in Washington [Bühlmann et al, 2021], temperature effects on noise emission have been re-evaluated. This paper was produced after the special STEER report about temperature was finalized (summarized in chapter 5.3 above), and therefore contains new information not known before.

In the paper, the influence of the different temperatures on the generation of tyre/road noise is highlighted. The basic underlying assumption was that tyre/road noise is basically generated in the tyre, as it is assumed that noise is not directly emitted from the road surface; at least not to a substantial amount. Thus, it was assumed that the noise emission must depend on the temperatures in or on the tyre. Accordingly, the most relevant temperature should be the tyre temperature. Nevertheless, both air and road surface temperatures have an influence on the tyre temperature, as the thermal system tyre/road/air is connected.

The road temperature cannot be totally excluded from influence on the pavement, since the pavement stiffness, which in at least extreme cases may affect tyre/road noise generation, is influenced by temperature. The latter is, however, a negligible effect for asphalt and concrete pavements, unless the pavement is extremely soft due to a substantial content of rubber which is the case in so-called poroelastic pavements.

In the paper, different datasets collected in different projects in Switzerland have been re-evaluated, with the perspective to determine the temperature effects for the three respective temperatures *air, road* and *tyre*. In the following Figure 5-3, data from a study [Bühlmann & Ziegler, 2011] in late summer 2010 is reevaluated. In this study, the highly varying temperatures during this time of the year are used to continuously repeat measurements on the same road sections over the course of the day, from the minimum (around 06:00) to the maximum air temperatures (around 17:00)). In the left part of Figure 5-3 the (squared correlation coefficient) $R^2$ of the spectral linear regression model of the respective temperature versus the acoustic measurement value is shown as a function of frequency. In the right part, the standard error (residual variation) of the slope of the regression is shown, also as a function of frequency.



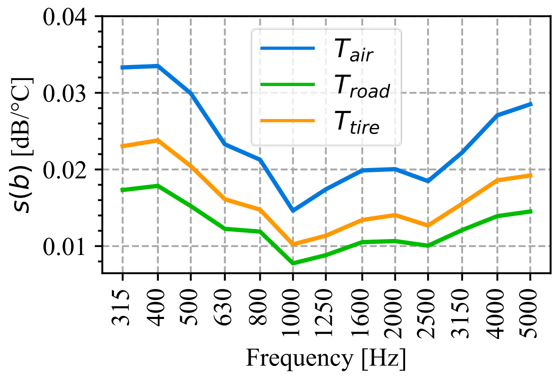




Figure 5-3 Average $R^2$ between temperatures and tyre/road noise in third-octave-band spectra (left) and residual error of the slope for the linear regression models (based on 28 tyre/pavement combinations at reference speed 50 km/h).

The left part of Figure 5-3 suggests that all the temperatures (Air, Road and Tyre) can explain the temperature effects over a large band of the noise frequency spectrum. As the measurements have been carried out during homogeneous conditions (full exposure of the pavement to solar radiation and the measurements have been performed at the same location, and thus the same climatic region). From the right graph, the standard error of the slope indicates that the air temperature has the highest error of the predicted slope. The absolute error in this graph is strongly linked to the data variation itself. Thus, the standard error of the slope does not directly correlate with the uncertainty of temperature corrections, as the slopes also differ substantially; for example, the slopes for air temperature are generally almost twice as large as those of road temperatures. When taking that into account, the air and road temperatures give approximately the same (relative) residual errors in the model.

The respective temperatures, measured during this study are shown in the Figure 5-4 below. An important information from this figure, is that the different temperatures behave differently over the course of the day. The impact of solar radiation on $T_{tyre}$ through heating-up of the pavement becomes clearly visible, as the offset of $T_{tyre}$ from $T_{air}$ starts to gradually increase after the sun rises at around 06:40. In the early morning, $T_{tyre}$ is 9 °C warmer than $T_{air}$, increasing to 15 °C in the afternoon, when the maximum offset is reached at 15:00. These observations support the assumption that it might be difficult to determine the temperature effects solely on for instance air or road temperatures, under the assumption that tyre temperatures are the most relevant for noise generation.

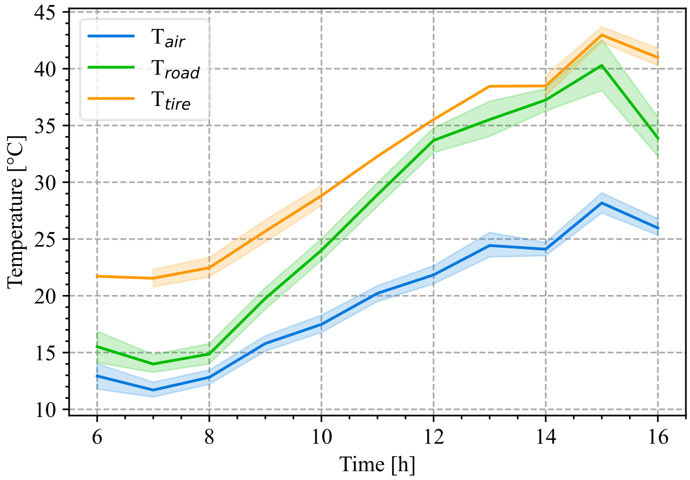



Figure 5-4: Average temperature profiles during a 9-day measurement campaign (with 95 % confidence intervals)

Furthermore, in the paper, an extensive dataset with millions of combined temperature measurements has been evaluated. The dataset has been collected during various projects between the years 2010 and 2020 in different regions in Switzerland. The data is collected at a speed of 50 km/h and covers a measurement distance of over 50'000 km. In Figure 5-5, the interdependence of the air to tyre temperatures is shown in the upper part, and the relation between the road and tyre temperatures are shown in the lower part. All the data has been separately evaluated for daytime (left graphic) and for night-time (right graphic).

The relations between the different temperatures have been investigated with different models and the *goodness of fit* (GOF) indicate that the linear model represents the data best. Between all the different temperatures, statistically significant different slopes could be found. For instance, between $T_{air}$ and $T_{tire}$ higher slopes can be found for daytime than for nighttime. The same, but to a lower degree, was observed for the temperature relations between $T_{road}$ and $T_{tire}$. The reason for the different behaviour of the slopes might be depending on the prevalence of solar radiation having a different impact on the heating of the road.

Accordingly, any correction approach based on $T_{air}$ alone, would result in a certain error if measurements over both day and night are performed, as the impact of solar radiation on tire temperature cannot be fully accounted for.

An important result emerging from the analysis in Figure 5-5 is that the tyre temperatures seem to be somewhat more closely related to road surface than to air temperatures, as the $R^2$ values are somewhat higher for road than for air temperatures. Then one shall note that these measurements were made at the speed of 50 km/h, and that at (say) 80 km/h (at which the tyre noise label is determined) the relation could be different since at 80 km/ the air turbulence which cools or heats the tyre will be about 2.5 times higher than at 50 km/h.

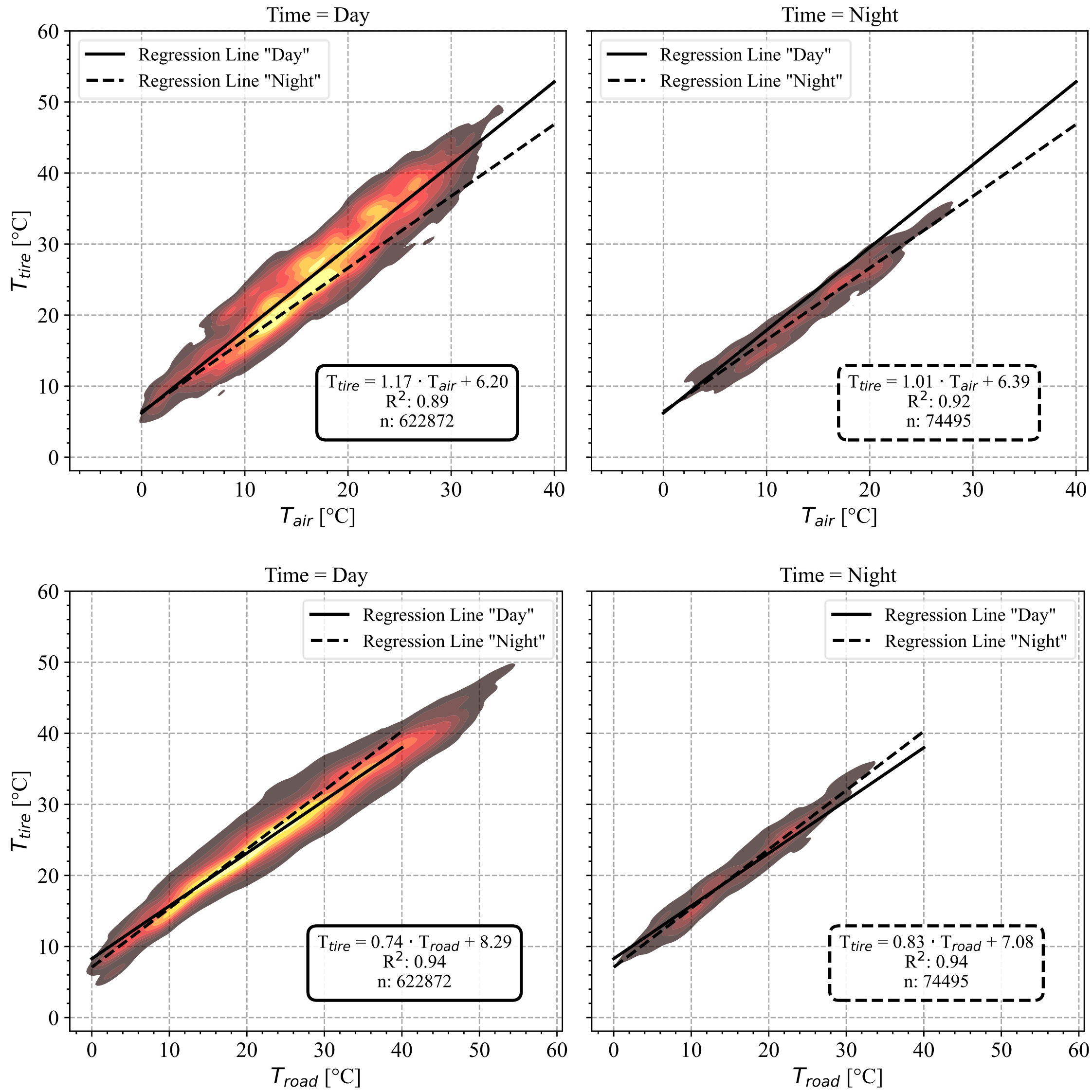



Figure 5-5: Relationships between $T_{\text{tire}}$ and $T_{\text{air}}$ (upper part), and $T_{\text{road}}$ (lower part) during daytime with varying amount of solar radiation (left) and during night-time; i.e., without solar radiation (right).

In the paper, the following recommendations have been made:

- Using air temperature or road surface temperature as a single variable in correction procedures are not the ideal solution for International Standards that require valid temperature correction mechanisms for all climatic regions around the World.
- A promising solution might be to include <u>both</u> variables to account for the different influences they have on the tyre temperature.
- An alternative is to directly integrate the tyre temperature in the correction approach. However, tyre temperatures vary due to location and time in a very complicated matter, so before introducing tyre temperatures for the correction much more research is needed
- Furthermore, it was again consistently shown, that not solely the A-weighted SPL should be corrected, but also the different frequency spectra, as the behaviour of the sound generation is different at different frequencies. However, to actually do so, more research is needed.

## 5.5. Summary of findings after Task Report 3.1 was finalized (experiment in hot climate)

In a recently published article, measurements of temperature influence on tyre/road noise were made in Qatar [Sirin et al, 2021]. It means that temperatures ranged from 20 to 43 °C (air) and 20 to 65 °C (road surface), which is interesting due to the focus on very high temperatures. Only one tyre was used, namely the tyre P1 (16" SRTT) in ISO/TS 11819-3, which was tested with the OBSI method, which is the American version of the CPX method. The tests were run on four dense asphalt surfaces having MTD values from 0.65 to 2.9 mm (MTD = Mean Texture Depth, which is numerically close to MPD values).

The relation between road and air temperatures was linear with a K factor (slope) of 1.94. The correction factor for air temperature varied between -0.030 and -0.14 dB/°C, with the lower value on the very rough-textured road and the higher value on the smooth-textured one (which had an MTD within the range allowed in ISO 10844). If one would convert the air temperature coefficient for the smoothest road surface (-0.14) to a road temperature coefficient, the latter would be -0.14/1.94 which is approx. -0.07. This coefficient happens to be similar to our proposal in Figure 5-2.

Among other results it is worth noting that this article found an inverse relation between the absolute value of the coefficient and the texture values. In terms of frequency spectra influence, the entire A-weighted spectra were influenced similarly, but with higher coefficients at the higher frequencies.

## 5.6. Summary of findings after Task Report 3.1 was finalized (views of industry organizations)

### 5.6.1. Corrections for temperature in regulations for vehicles and tyres

The UN ECE GRBP[1] "Informal Working Group on Measurement Uncertainty (IWG MU)" has, as one of its main tasks to investigate the main contributors to the measurement uncertainties when noise emission of vehicles and tyres are measured according to UN ECE Regulation 51.03 (vehicles) and Regulation 117 (tyres). Based on input from different parties including the vehicle industry (OICA[2]) and the tyre industry (ETRTO[3]), IWG MU has listed all uncertainties contributing to the overall uncertainties. The temperature influence constitutes an important part of these uncertainties as shown in Figure 5-6.

The tables show that the uncertainties related to variability of different test tracks (site-to-site variation) is the main contribution to the overall uncertainty for both M1[4] and N3[5] categories (47 %) while the temperature influence is the second largest (20 %). For the other categories, including heavy vehicles, the air temperature influence is not so important (2.4 % contribution).

In the existing regulations, only R117 gives a procedure for temperature correction, which is based on **road surface temperature**. However, there is now a proposal to UN ECE GRBP from IWG MU to include a temperature correction procedure also in R51.03 but based on **air temperature** influence (see further 5.6.2). It is likely that GRBP will approve this proposal at its 75th session in February 2022.

[1] UN ECE GRBP = United Nations Economic Commission for Europe – Working Party on ***Noise*** and Tyres (GRBP is the acronym for this group's name in French)
[2] OICA = International Organization of Motor Vehicle Manufacturers (OICA is the acronym for the name in French)
[3] ETRTO = European Tyre and Rim Technical Organization
[4] M1 = Vehicle class for light vehicles with maximum 9 seats and total weight less than 3.5 tons
[5] N3 = Vehicle class for heavy vehicles for transportation of goods with maximum engine power > 150 kW and total weight above 12 tons

| Situation | Input Quantity | estimated deviations of the meas. result (peak-peak) Lwot | Lcrs | Impact on Lurb | Probability Distribution | Variance | Standard deviation | Share [%] | Combined standard uncertainty |
|---|---|---|---|---|---|---|---|---|---|
| Run to Run | Micro climate wind effect | 1.60 | 1.50 | 1.57 | gaussian | 0.15 | 0.392 | 5.1% | 0.53 |
| | Deviation from centered driving | 0.50 | 0.50 | 0.50 | rectangular | 0.02 | 0.144 | 0.7% | |
| | Start of acceleration | 0.60 | 0.00 | 0.40 | rectangular | 0.01 | 0.114 | 0.4% | |
| | Speed variations of +/- 1km/h | 0.50 | 0.50 | 0.50 | rectangular | 0.02 | 0.144 | 0.7% | |
| | Load variations during cruising | 0.00 | 1.00 | 0.34 | gaussian | 0.01 | 0.085 | 0.2% | |
| | Varying background noise | 0.40 | 0.40 | 0.40 | rectangular | 0.01 | 0.115 | 0.4% | |
| | Variation on operating temperature of engine and tyres | 0.80 | 0.80 | 0.80 | rectangular | 0.05 | 0.231 | 1.8% | |
| Day to Day | Barometric pressure (Weather +/-30 hPa) | 0.70 | 0.00 | 0.46 | gaussian | 0.01 | 0.116 | 0.4% | 0.92 |
| | Air temperature effect on tyre noise (5-10°C) | 0.00 | 0.00 | 0.00 | rectangular | 0.00 | 0.000 | 0.0% | |
| | Air temperature effect on tyre noise (0-40°C) | 2.20 | 3.60 | 2.67 | rectangular | 0.60 | 0.772 | 20.0% | |
| | Varying background noise during measuremnt | 0.00 | 0.00 | 0.00 | rectangular | 0.00 | 0.000 | 0.0% | |
| | Air intake temperatuire variation | 1.60 | 0.00 | 1.06 | rectangular | 0.09 | 0.305 | 3.1% | |
| | Residual humidity on test track surface | 0.90 | 2.10 | 1.31 | rectangular | 0.14 | 0.377 | 4.8% | |
| Site to Site | Altitude (Location of Test Track) 100 hPa/1000m | 0.70 | 0.00 | 0.46 | rectangular | 0.02 | 0.134 | 0.6% | 1.24 |
| | Test Track Surface | 3.40 | 5.50 | 4.11 | rectangular | 1.41 | 1.187 | 47.3% | |
| | Microphone Class 1 IEC 61672 | 1.00 | 1.00 | 1.00 | gaussian | 0.06 | 0.250 | 2.1% | |
| | Sound calibrator IEC 60942 | 0.50 | 0.50 | 0.50 | gaussian | 0.02 | 0.125 | 0.5% | |
| | Speed measuring equipment continuous at PP | 0.10 | 0.10 | 0.10 | rectangular | 0.00 | 0.029 | 0.0% | |
| | Acceleration calculation from vehicle speed measurement | 0.50 | 0.50 | 0.50 | rectangular | 0.02 | 0.144 | 0.7% | |
| Vehicle to Vehicle | Production Variation Tyre and aging of tyres | 0.80 | 1.50 | 1.04 | gaussian | 0.07 | 0.259 | 2.3% | 0.57 |
| | Production Variation in Power | 0.40 | 0.40 | 0.40 | rectangular | 0.01 | 0.115 | 0.4% | |
| | Battery state of charge for HEVs | 0.00 | 0.00 | 0.00 | rectangular | 0.00 | 0.000 | 0.0% | |
| | Production Variability of Sound Reduction Components | 1.10 | 0.00 | 0.73 | gaussian | 0.03 | 0.182 | 1.1% | |
| | Impact of variation of vehicle mass | 1.60 | 1.60 | 1.60 | rectangular | 0.21 | 0.462 | 7.2% | |

| situation | Input Quantity (Uncertainty of vehicle sound emission) | For indoor | Type B: Deviations of the meas. result (peak-peak) Lwot | probability distribution | variance | standard deviation | contribution [%] | Type B Combined standard uncertainty |
|---|---|---|---|---|---|---|---|---|
| Run to run | 1) Micro climate wind effect – head wind and tail wind | | 0 | gaussian | 0,000 | 0,000 | 0,0% | 0,3 |
| | 2) Deviation from centered driving | | 0,5 | rectangular | 0,021 | 0,144 | 3,8% | |
| | 3) Speed at BB' – Target vehicle speed (+/-5 km/h), (target engine speed (+/-2%) | x | 0,4 | rectangular | 0,013 | 0,115 | 2,4% | |
| | 4) Varying background noise | x | 0,1 | gaussian | 0,001 | 0,025 | 0,1% | |
| | 5) Warming up routines between runs – operating temperature of engine and tyres (WOT) ==> See ISO 362-1 NOTE | x | 0,8 | rectangular | 0,053 | 0,231 | 9,7% | |
| Day to day | 6) Ambient temperature influence on sound transmission in air (variability in impedance) | | 0,6 | rectangular | 0,030 | 0,173 | 5,5% | 0,5 |
| | 7) Ambient barometric pressure influence on sound transmission in air | x | 0,9 | rectangular | 0,068 | 0,260 | 12,3% | |
| | 8) Ambient humidity influence on sound transmission in air | | 0,1 | rectangular | 0,001 | 0,029 | [illegible] | |
| | 9) Ambient air temperature influence on engine power (based on R85) | | 1,0 | rectangular | 0,083 | 0,289 | 15,2% | |
| | 10) Ambient air temperature effect on ICE vehicles due to tyre noise (5-40°C) | x | 0,4 | rectangular | 0,013 | 0,115 | 2,4% | |
| | 11) Barometric pressure effect on engine power (based on R85) | x | 0,4 | rectangular | 0,013 | 0,115 | 2,4% | |
| Site to site | 12) Altitude effect on combustion and sound propagation (Range: 1000 m) (95-105 kPa ) | x | 0,9 | rectangular | 0,068 | 0,260 | [illegible] | 0,5 |
| | 13) Test Track Surface | x | 1,3 | gaussian | 0,106 | 0,325 | 19,3% | |
| | 14) Microphone Class 1 IEC 61672 | x | 1 | gaussian | 0,063 | 0,250 | 11,4% | |
| | 15) Sound calibrator IEC 60942 | x | 0,5 | gaussian | 0,016 | 0,125 | 2,8% | |
| | 16) Speed measuring equipment continuous at BB | x | 0,1 | gaussian | 0,001 | 0,025 | 0,1% | |
| V to Vehicle | 17) Tyre – generic dispersion (Normal, tread depth, inflation pressure, model etc) ** | | 2,8 | gaussian | 0,490 | 0,700 | | 0,7 |
| | 18) Test mass – variation as a consequence of the definition | | | gaussian | 0,000 | 0,000 | | |
| | 19) Battery state of charge for HEVs | | | gaussian | 0,000 | 0,000 | | |
| COP | 20) Production variability | | | gaussian | 0,000 | 0,000 | | |
| Third party testing | 21) Residual surface humidity | | | rectangular | 0,000 | 0,000 | | |
| | 22) Tyre (Traction, 3PMSF) | | | gaussian | 0,000 | 0,000 | | |

Figure 5-6: Uncertainty contribution for different parameters and test conditions. Table for M1 and N1 vehicles on top and M2, M3, N2 and N3 vehicles to the bottom. Adapted from OICA (2021). The red rings points at the highest contributions (track influence) and to the temperature influence on tyre noise.

It should be noted that the test in R117 is done at speeds 70-90 km/h with a reference speed of 80 km/h. This test is primarily used for type approval of family of tyres against the sound level limits set for different sizes of tyres, and also used as a test to establish the label value for this family of tyres. The constant speed test in R51.03 is made at 50 km/h and is primarily aimed at defining the contribution of tyre/road noise for the specific set of tyres used for type approval or COP (Conformity of Production) for the specific vehicle.

Thus, these two types of regulations are not directly comparable, as the reference speed is different, as well as the loading and tyre inflation pressure can deviate from the R117 test conditions. Yet, it is not ideal that they use different principles for temperature corrections.

### 5.6.2. Coming temperature correction in Regulation R51.03

This regulation defines the maximum allowed external sound levels for vehicles of categories M and N during type approval or COP. The test procedure is based on ISO 362-1 (presently under revision) and ISO 362-3 (indoor testing).

For M category of vehicles, the test consists of a full acceleration test (from 50 km/h) and a constant speed (cruise-by) test at 50 km/h.

Until now, there has been no correction for the influence of temperature for either of these two tests. It is only stated that "*The measurements shall be made when the ambient air temperature is within the range from 5 °C to 40 °C*.". During the acceleration phase, both the tyres and the powertrain related noise sources can be influenced by temperature. So far, no real temperature correction procedure has been defined, due to this complex combination of sources. But, for the constant speed test, experience from testing of tyre/road noise at different temperatures, mainly from the vehicle industry itself, has led to a proposal for amendments to R51.03 to include a temperature correction procedure for vehicles equipped with C1 and C2 tyres [IWG MU, 2021].

Equation (4) presents the proposed correction procedure, where $L_{TR,n}$ = measured tyre/road noise level at run n.

$$L_{TR,n,\vartheta REF} = L_{TR,n} + K_1 \cdot log_{10}\left(\frac{\vartheta_{TEST} + K_2}{\vartheta_{REF} + K_2}\right) \tag{4}$$

where:

*$\vartheta_{TEST}$ = the measured air temperature during run n*

*$K_1$ = 3.4 for C1 and C2 tyres*

*$K_2$ = 3.0 for C1 tyres*

*$K_2$ = 15.0 for C2 tyres*

$\vartheta_{REF}$ = 20 °C

As the equation shows, the correction is non-linear.

Figure 5-7 gives the correction for C1 tyres, compared with the correction as given for C1 tyres in the CNOSSOS-EU[6] traffic noise calculation model. Note that measurements below 5 °C are not allowed. So, the highly non-linear curve below 5 °C is irrelevant. Note also that CNOSSOS is an average for all road surfaces, while the OICA proposal is focused only on ISO 10844 surfaces.

[6] CNOSSOS-EU specifies the following: "*A generic coefficient Km = 1 = 0.08 dB/°C for light vehicles (category 1) and Km = 2 = Km = 3 = 0,04 dB/°C for heavy vehicles (categories 2 and 3) shall be applied for all road surfaces. The correction coefficient shall be applied equally on all octave bands from 63 to 8 000 Hz*". It is based on early data collection and tentative proposals in ISO/TC 43/SC 1/WG 27. Reference: Kephalopoulos S, Paviotti M, Anfosso-Lédée F. Common Noise Assessment Methods in Europe (CNOSSOS-EU). EUR 25379 EN. Luxembourg (Luxembourg): Publications Office of the European Union; 2012. JRC72550.

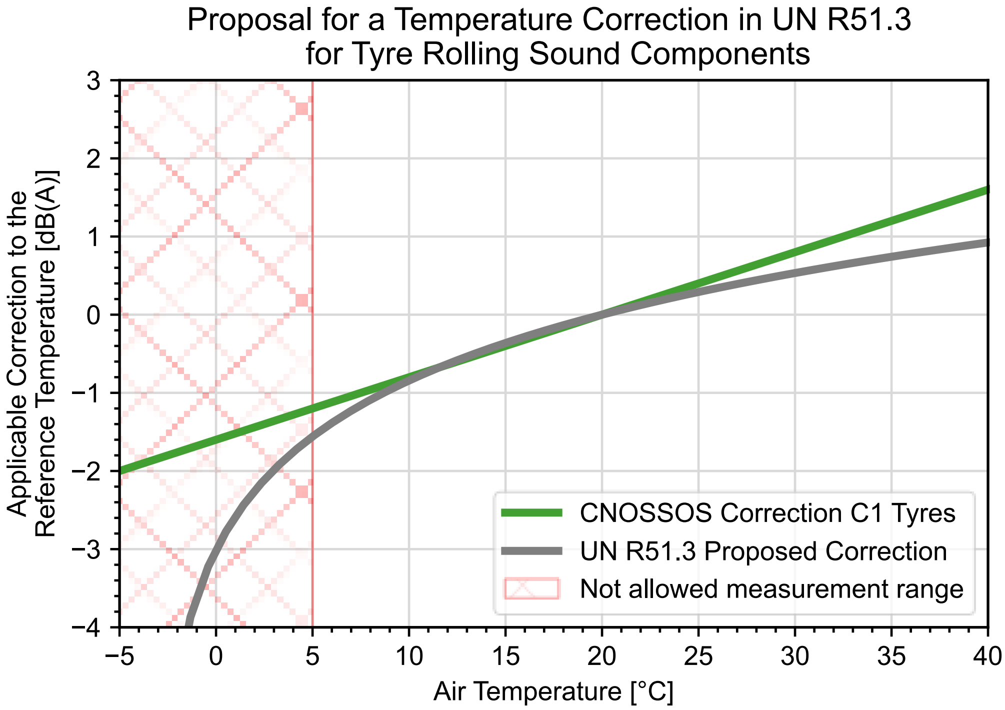



Figure 5-7: Temperature correction for C1 tyres as proposed by OICA to R51.03, compared to the correction given in CNOSSOS- EU. Diagram produced by the authors with data from OICA [IWG MU, 2021].

In Figure 5-8, the proposed temperature correction for C2 tyres (based on air temperature) as proposed by OICA is shown. The curve (dotted line) is compared with the correction curves for R117 (converted to air), ISO/CD 13471-2 and CNOSSOS-EU (CAT1 and CAT2; i.e., C1 and C2 tyres).

What data these diagrams are based on has not been presented, so from a scientific point of view it must be considered as “views” by the OICA. Therefore, STEER cannot evaluate the scientific relevance of these diagrams. For example, it is unclear whether the highly non-linear correction for C1 tyres over the allowed temperature range really is statistically justified. Note that the “ISO 13471-2” is no longer valid; it is changed to a lower slope.

To use the air temperature rather than the road surface temperature for the corrections, is probably chosen because the air temperature is more stable over time and not so influenced by clouds/shadows, etc. However, there is a well-established relationship between air and road surface temperature, as presented in the STEER Project Report R3.1.

This is also confirmed in Figure 5-9 below, compiling data from more than 700 measurements of air and road surface temperatures at different ambient conditions (summer, winter, sunny, cloudy, etc) [IWG MU, 2021]. The K factor there is 1.6. Assumably, these measurements were made at the same test track of BMW in Bavaria, Germany. It is noted that a weak trend of non-linearity is visible at the higher temperatures (over 25 °C air temperature).

In a presentation by OICA to IWG MU [OICA, 2021], the proposed correction for C2 tyres was presented partly based on recent measurements results as shown in Figure 5-10. One of the tyres seems not to be sensitive to temperature, but the others give more or less the same slope for temperature influence. The average slope for tyre sets 2-5 appears to correspond to a correction coefficient of -0.055, which fits the slope by OICA below 20 °C in Figure 5-10. It is unclear what the “LOG-REGRESSION” curve is based on since the data points in the diagram do not justify such a regression.

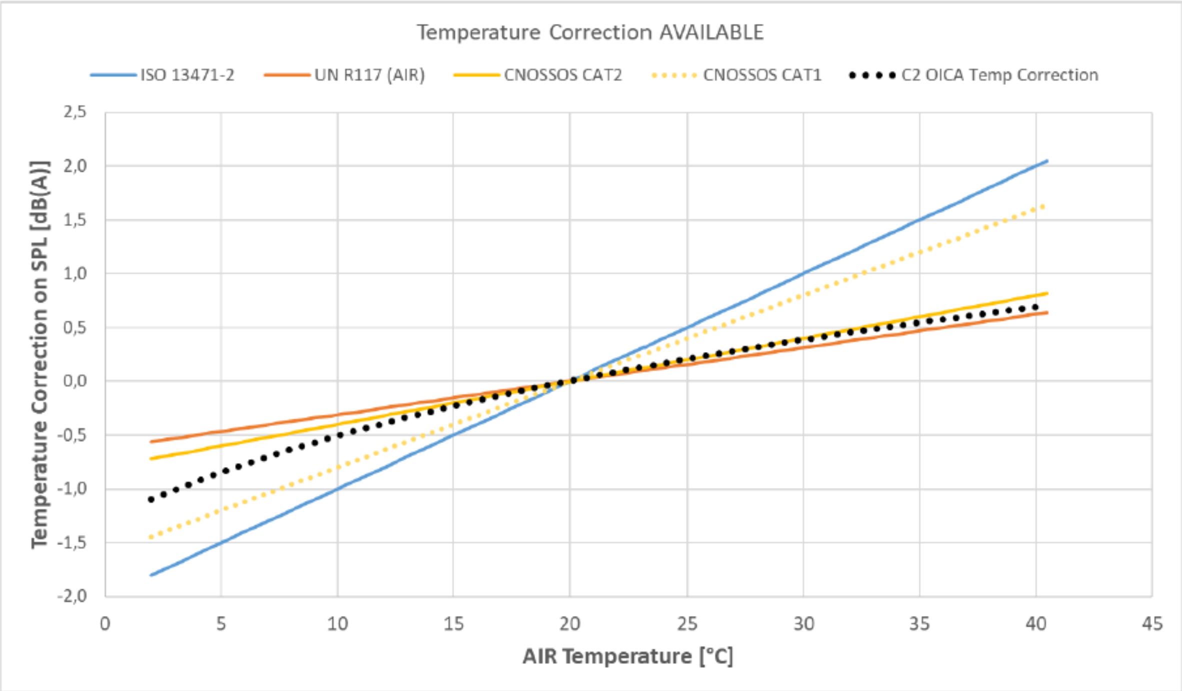



Figure 5-8: Proposed temperature correction for C2 tyres (OICA) compared to other existing corrections. From [OICA, 2021]. Note that the line for ISO 13471-2 is from an old draft not valid any longer.

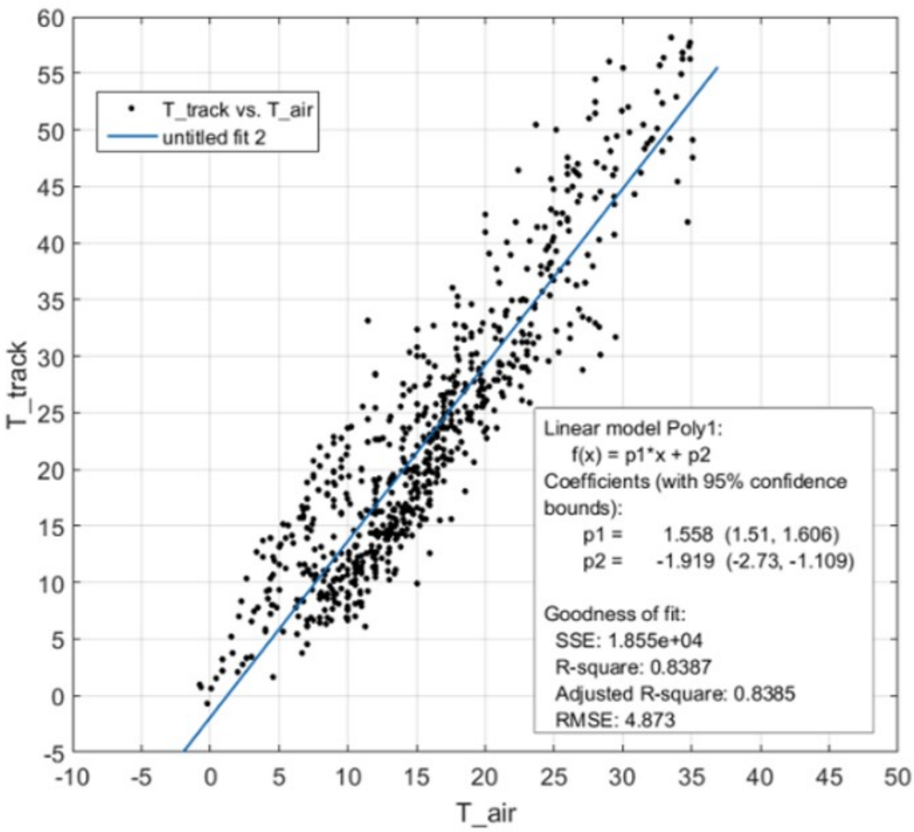



Figure 5-9: Relationship between air and test track temperature, from IWG MU, (2021). $T_{\_track} = 1.558 * T_{\_air} - 1.919$.

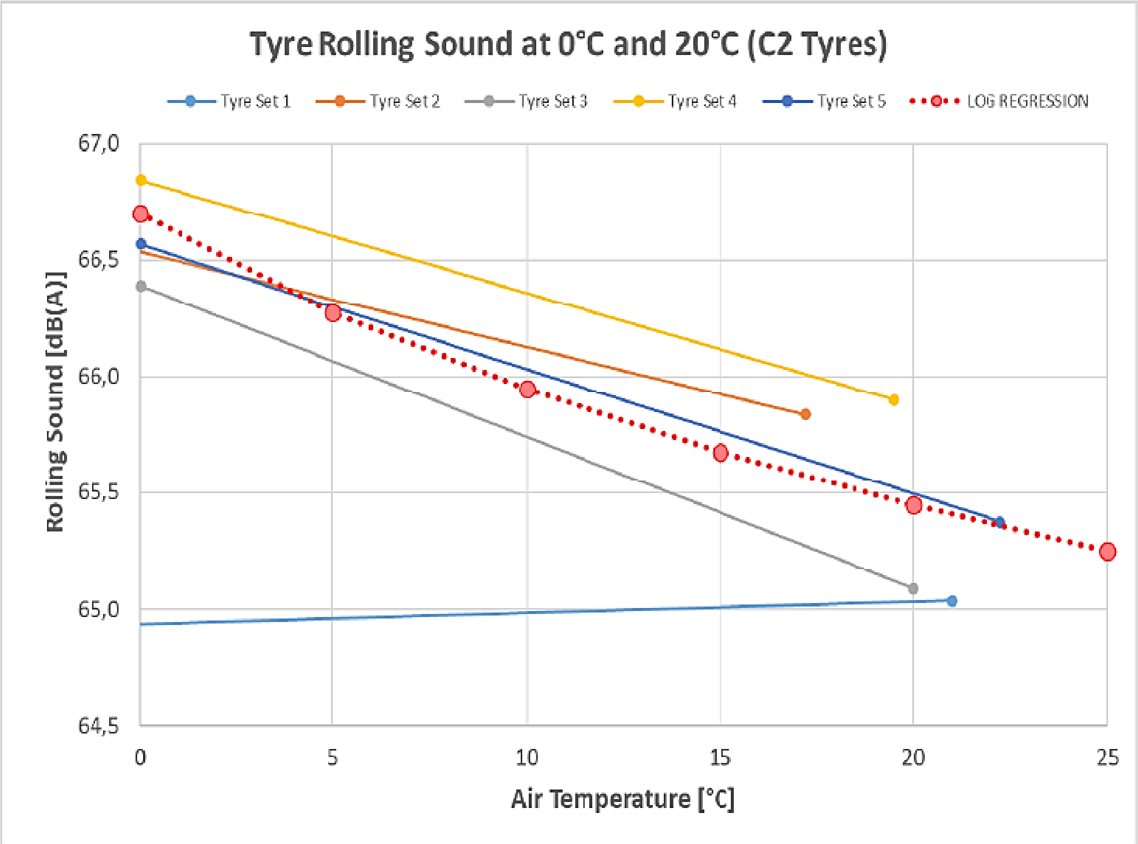



Figure 5-10: Measurement of the air temperature influence on tyre rolling sound for C2 tyres between 0 and 20 °C [OICA, 2021].

### 5.6.3. Discussions in GRBP related to ECE Regulation 117

The background and details of this regulation is described in detail in Chapter 2 of the STEER Project Report R3.1 and will therefore not be repeated here.

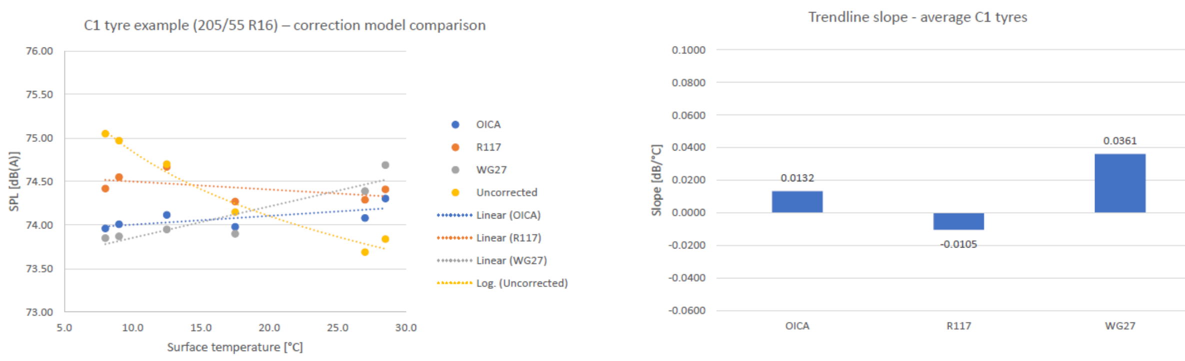
The tyre industry, through their organization ETRTO, has also produced recent investigations showing the influence of temperature on tyre/road noise for different categories of tyres, [ETRTO, 2021].

Their presentation was based on measurements of ten C1 tyres (approx. from 7 to 28 C°), three C2 tyres (from 10 to 23 °C) and three C3 tyres (from 15 to 35 °C). In the figures below, there is one example of the temperature influence given for one of the tyres of each class. In this work, ETRTO has been comparing three different correction procedures for C1 and C2 tyres and two for C3 tyres (OICA and R117 based on road surface temperatures, while "WG 27" was based on an obsolete air temperature-based correction):

- Proposal by OICA (R51.03 proposal), based on air temperature
- Existing correction in R117, based on road temperature
- Early proposal in ISO/TC 43/SC 1/WG 27, based on air temperature

The corrected results are compared with non-corrected levels and the conclusions by ETRTO are given below inside the figures 5-11, 5-12 and 5-13. Note that it is not fair to compare the early WG 27 proposal to the other ones, as the temperatures (road vs air) are very different.

› Ten tyres in the size range from 185 to 235 were analysed

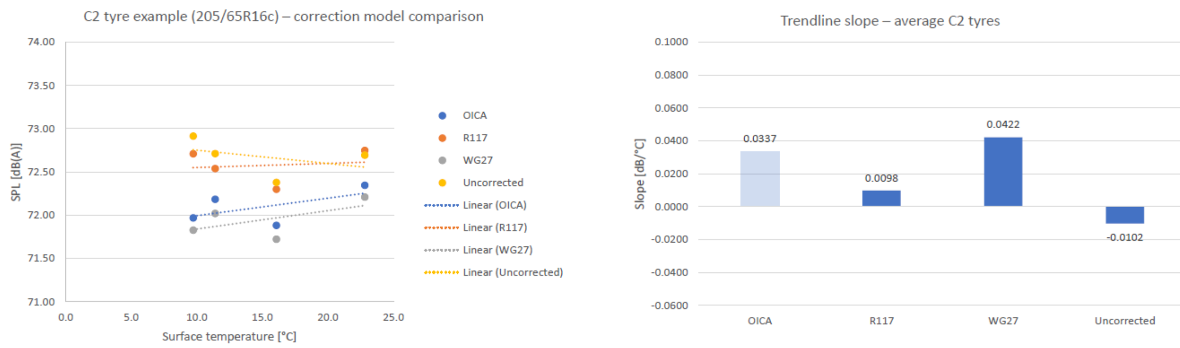



› **Correction models from OICA and R117 successfully detrend the uncorrected data**

› **The correction model proposed by WG27 tends to overcorrect the measurement results**

Figure 5-11: Measurements on C1 tyres with different 3 temperature correction procedures applied. The diagram shows the results after correction has been applied.

› Three tyres in the size 205/65R16c were analysed

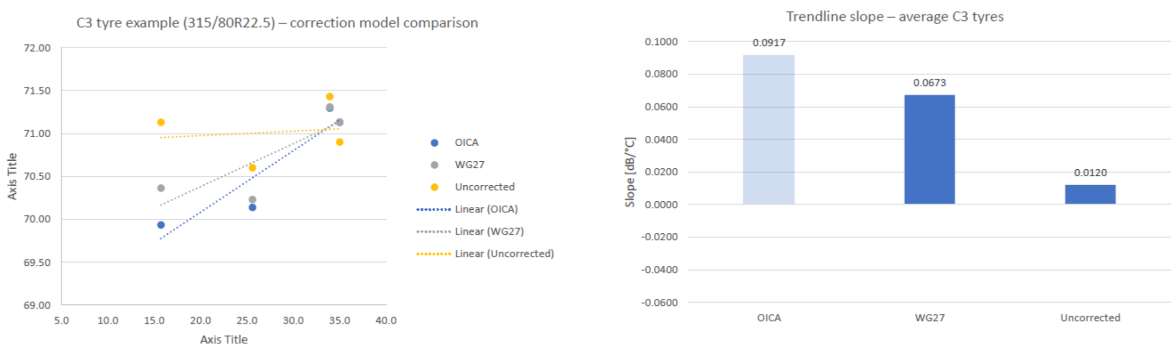



› **For C2 tyres the uncorrected data show a lower temperature sensitivity than C1 tyres**

› **Both the OICA and the WG27 model tend to overcorrect C2 measurement results**

Figure 5-12: Measurements on C2 tyres with 3 different temperature correction procedures applied. The diagram shows the results after correction has been applied.

› Three tyres in the size 315/80R22.5 were analysed




› **For C3 tyres the uncorrected data show a much lower temperature sensitivity than C1 tyres**

› **Both the OICA and the WG27 model tend to overcorrect C3 measurement results**

Figure 5-13: Measurements on C3 tyres with 2 different temperature correction procedures applied. The diagram shows the results after correction has been applied.

The main author has made a correction to the analysis of the “WG 27” data in Figure 5-11, by transferring them to road temperatures, using the final STEER proposal and the conversion factors of Table 5-3 (bottom row). In that case, the standard deviations of case “WG 27” (which actually now should read STEER), will give better corrections than OICA and R117. The standard deviations (which are a better measure than the “average slope” used in Fig 5-11) will be 0.10 dB for STEER vs 0.13 for OICA and 0.17 for R117. This is a substantial improvement especially against R117.

ETRTO has also calculated the total combined uncertainty for R117, based on the contribution to the different test parameters [ETRTO, 2019]. For the temperature influence, based on a possible peak-to-peak variation of ± 1.8 dB, based on the formula in R117 and the range of allowed temperature, the standard uncertainty for 95 % confidence interval will be ± 0.6 dB. Applying the proposed temperature correction procedure as given by OICA, this variation is reduced to ± 0.3 dB, since correction is applied for C1 and C2 tyres only [ETRTO, 2021].

## 5.7. Discussion

### 5.7.1. Global considerations by interpreting temperature effect studies

Since most studies are based on a geographically specific set of data, it must be noted that the resulting coefficients are strongly influenced by the respective climatic conditions. In particular, the direct extraction of globally valid generic corrections for air or road temperatures alone is critical. Besides, the impact of seasonal or day-to-day variation; i.e., sunny versus cloudy conditions will impact the derived correction factors.

These questions shall be properly addressed in the future, when updating or proposing new correction mechanisms for the R117 as well as R51.03. When it comes to establishing and standardising globally valid correction mechanisms (as currently proposed by OICA), studies from several climatic regions must be considered.

### 5.7.2. Noise generation mechanisms and the generic noise-temperature correction

Tyre/road noise is generated and affected by a multitude of mechanisms, which overall gives a very complicated picture of how noise is influenced by various factors under various conditions [Sandberg & Ejsmont, 2002]. In some cases, some mechanisms dominate, while in other cases other mechanisms dominate. For the influence on overall noise of temperature, it is probable that different mechanisms are influenced rather differently by temperature; maybe even in opposite ways. This is why this influence is so complicated to quantify and why different studies may arrive at different results.

Since different tyres have noise properties influenced by different generation mechanisms, and for each tyre even depending on speed and road surface, one cannot expect that all tyres would need the same temperature corrections. On the contrary, they will have different noise-temperature properties. Since it is practically impossible to determine the optimum temperature correction for each tyre separately and for each condition (speed), it is necessary to use a generic temperature correction that works the best for the majority of tyres. Well designed, it will not be very good for any particular tyre but it will be good enough for the majority, reducing the temperature influence on measured noise for almost all tyres.

### 5.7.3. Air or road temperatures?

It is only the tyre industry that prefers using road surface temperatures. The vehicle industry prefers air, the two ISO Technical Specifications use air and also the American OBSI method uses air, and they also have robust data behind that. CNOSSOS-EU also uses air temperatures for the correction. The tyre industry has not even motivated (that we know of) why road temperatures would be better.

There is a general view that the most relevant temperature to use would be tyre temperature. But tyre temperatures are extremely difficult to measure as they vary substantially from place to place and from time to time and are rarely stable in time.

The Inter-Noise paper described in section 5.4 suggests that the best model would be one that uses some kind of weighted average of air and road temperatures. This is logical since tyre temperatures obviously depend on convection to/from ambient air and conduction to/from the road surface. Heat may be transferred both ways, and it may even happen that air cools while the road heats up the tyre. The authors suggest that such a model shall be developed in the near future to replace the current ones and it could perhaps even unite the vehicle and tyre industries, and those who are measuring road surface noise properties. However, more research is needed to do this.

<u>The development of a combined approach is urgent, as it will be impractical or nearly impossible to develop globally valid correction procedures based on air and pavement temperature alone.</u>

### 5.7.4. Conversion between air and road temperature-based models

Some researchers or engineers have tested temperature influences by using air temperatures, and some have used road surface temperatures, but it is rare that somebody has compared both options. This Deliverable has attempted to convert correction factors between the two temperatures, based on the relation between air and road surface temperatures.

The STEER Task Report 3.1 [Vieira & Sandberg, 2021] suggested a conversion factor (slope of regression) air-to-road of 1.44 for lower temperatures and 2.0 for higher temperatures. More recent results from Qatar suggested 1.94 at the higher temperatures, while the OICA comprehensive results suggested 1.56 over the entire range (but dominated by the lower range and a weak trend looking to be higher at the high temperatures). The large spread of different conversion factors indicates their strong dependency on the meteorological conditions during the gathering of the underlying data (seasons, daytime, climatic regions). This phenomenon is illustrated in the InterNoise2021 paper, where the lack of solar radiation (night-time) leads to completely different slopes of the relation between different temperatures. Similar behaviour is expected for different seasons, cloud coverage or climatic regions.

Most data that have been published or have been made available to the ISO/TC 43/SC 1/WG 27 are based on air temperatures, so it is important to be able to convert to a road temperature-based model.

### 5.7.5. Linear or non-linear noise-temperature relation?

No significant data have indicated that the noise-temperature relation is non-linear over the studied range. However, as an exception, the correction suggested by OICA is non-linear, although it is unclear what (if any) data support they have for this, within the 5-40 °C temperature range.

But in R117 a so-called piecewise linear model is used, consisting of two linear relations with different slopes which are connected at 20 °C. It is also unclear what support they have for this, as nothing has been published about it. The figures in section 5.6.3 consistently suggest that there is a rather strong non-linearity. However, as the measurements behind this are not reported in a usual open scientific way, allowing external study of the results, it is difficult to judge how robust and relevant they are.

Nevertheless, from the discussion about the non-linear (general) relation between air and road surface temperature, it seems clear that there is indeed some non-linearity in a model based on road temperatures. The question is if the non-linearity is so large as the approximating piecewise linear model used in R117 suggests.

In STEER Project Report R3.1, a piecewise linear correction was proposed in Table 5.3 and Figure 5.2, for a case when road temperatures are used. The “knee” in the R3.1 was set at 30 °C. After studying the data by OICA and ETRTO reported above, the authors suggest that the “knee” is moved to 20 °C instead. With that minor modification, the proposal by STEER gives much lower standard deviation than

R117 and OICA, according to our re-evaluation of the data in Figure 5-11. Another advantage is that it is much easier to calculate the correction above 20 °C when there is only one slope to consider.

A correction model based on both air and road temperatures may automatically result in a non-linear model since at low or moderate air temperatures the noise-temperature slope may be different than at high road temperatures typical of intense sun radiation heating the surface.

### 5.7.6. Influence of road surface type

There is robust evidence that the road surface type influences the noise-temperature relation. This is reflected in the different temperature coefficients in Table 5-1 for different road surface types. Especially, there is a large difference between dense and porous asphalt surfaces. Also, the Qatar study suggests that the road surface influences the temperature coefficients; however, within the dense asphalt type where high texture gives low coefficients. As porous surfaces have high texture, and somewhat similar frequency spectra as high-textured dense surfaces, the Qatar observation is logical compared to Table 5.1, except that there are too little data available to quantify how texture (as MPD) would affect the temperature coefficients. This is something needing more research.

Of course, in Regulations R117 and R51.03, the only test track surface is an ISO 10844 surface, which is a surface having between an extremely smooth texture to a rather moderate texture, depending on the very wide texture range allowed (MPD from 0.3 to 0.7 mm). This would suggest that ISO test tracks may have higher rather than lower temperature coefficients than the average dense asphalt road surface.

### 5.7.7. Influence of speed?

In the work behind ISO/TS 13471-1 it was found that speed influences the temperature coefficient. This was based on rather comprehensive studies under controlled conditions. Thus, there is a speed factor in the temperature corrections in ISO/TS 13471-1.

For the more general case of arbitrary tyres which is relevant for the tyre/road noise tests for type approval and labelling, as well as for SPB measurements, we lack data that could justify distinguishing between speeds. Nevertheless, it would be logical if there is a speed effect, since air turbulence that may cool warm tyres at high speeds but much less at low speeds might create such effects. As the speed range covered in the R117 measuring method is only between 70 to 90 km/h, the speed effect in R117 is not important, except that the temperature coefficient should be selected based on the speed.

This issue needs more research too.

### 5.7.8. Frequency spectra corrections?

Frequency-dependent temperature corrections have been considered, and Section 5.5 indicated that it is justified. However, there is not yet enough data available to justify a quantification of such an effect. A word of caution here is justified: if a too complicated correction model is developed (for example, if speed, road surface texture and frequency will affect the correction), the risk is that too many tyres will have properties that do not fit it so well. A balance is necessary to achieve in this respect.

### 5.7.9. Correction model

STEER has found no robust indication that road surface temperature correction is better or equally good as air temperature-based correction. However, as a secondary option, STEER has converted its air-based temperature correction to a road-based temperature correction, mainly in order to see how it fits the only road temperature-based model used, namely the one in R117.

In the future as a first step, a model should be developed which makes use of both air and road surface temperature. Such a model will better fit wider climatic and meteorological conditions than the present model.

In the long-term future a model may be developed that uses tyre temperatures as a basis for correction approaches.

## 5.8. Conclusions and recommendations regarding temperature corrections

### 5.8.1. Air or road temperatures?

As a proxy for tyre temperature, it is a common view, supported by experiments, that air temperature is a better basis for temperature corrections to noise than road temperature. The exception is the tyre industry which has since “the start” used road (or rather test track) surface temperature in connection with measurements on ISO 10844 reference surfaces. Also, our own studies suggest that the subject is not that simple. Not only air but also road temperature should be considered in a model, but currently we miss the data for setting-up that model.

STEER temporarily recommends air temperature but suggests that in the near future a model shall be developed that takes both air and road surface temperatures into consideration. Nevertheless, when enough research and development has been made the optimum choice should be tyre temperatures.

### 5.8.2. Conversion between air and road temperature-based models

As long as both air and road-based temperatures are used for temperature correction to noise measurements, it is necessary to have a way to convert between them. STEER proposes a model that uses the two K factors (Equation 3) 1.44 and 2.0, where K = 1.44 is used below 20 °C and K = 2.0 is used above 20 °C [Vieira & Sandberg, 2021]. For a linear air temperature-based model, as suggested by STEER, converted to road temperature-based, the latter will be piecewise linear (two linear regressions with different slopes) which actually quite well fits the existing R117 model, but has higher slopes; i.e., correction coefficients.

### 5.8.3. Linear or non-linear noise-temperature relation?

STEER suggests that the air temperature-based model shall be linear over the appropriate range, which is from 5 to 35 °C. For an optional road temperature-based model (not preferred but corresponding to that existing in R117) STEER suggests a piecewise linear model with two linear regression lines of different slopes and connected at the reference temperature 20 ˚C.

### 5.8.4. Temperature range when measurements are possible

STEER proposes that the allowed range of temperatures during noise labelling measurements is limited to from 5 to 35 °C air temperatures and from 5 to 50 ˚C road surface temperatures. This is a small tightening of the range for maximum air temperatures from the present 40 to 35. This may be a change not well appreciated in very hot climates, although the present maximum road temperature of 50 °C (in R117) may be more restrictive. But even then, it should not be a major problem to find plenty of occasions when air temperature is below 35 °C, just as in cold climates the lower limit of 5 °C may sometimes be a problem.

### 5.8.5. Influence of road surface type

A difference in temperature coefficients for some different major road surface types is justified; see the STEER proposal in Table 5-4. The reduced coefficients for C2 and C3 tyres, compared to an earlier version of the ISO/TS, are justified by the supplementary data provided by OICA and ETRTO in Section 5.6. The reference surface specified in ISO 10844 belongs to the category dense asphaltic surfaces.

Table 5-4: Temperature coefficients suggested by STEER, based on air temperatures (introduced into ISO/DTS 13471-2:2021).

| **Tyre class (t) →**<br>**Road surface category ↓** | **C1** | **C2** | **C3** |
|---|---|---|---|
| Dense asphaltic surfaces | -0.10 | -0.06 | -0.04 |
| Cement concrete surfaces | -0.07 | -0.04 | -0.03 |
| Porous asphalt surfaces | -0.05 | -0.03 | -0.02 |
| Other surfaces | See Note 2 and/or Appendix A in ISO/DTS 13471-2 | | |

### 5.8.6. Influence of speed?

Since there is insufficient data available to include speed as a variable in the temperature correction, STEER refrains from suggesting a speed influence on the correction.

### 5.8.7. Frequency spectra corrections?

Since there is insufficient data available to include frequency band as a variable in the temperature correction, STEER refrains from suggesting a frequency influence on the correction at this moment, but it should be considered when more research has been conducted on this subject.

### 5.8.8. Correction model

STEER suggests the simple model for temperature correction to noise levels presented in graphical form in Figure 5-14.

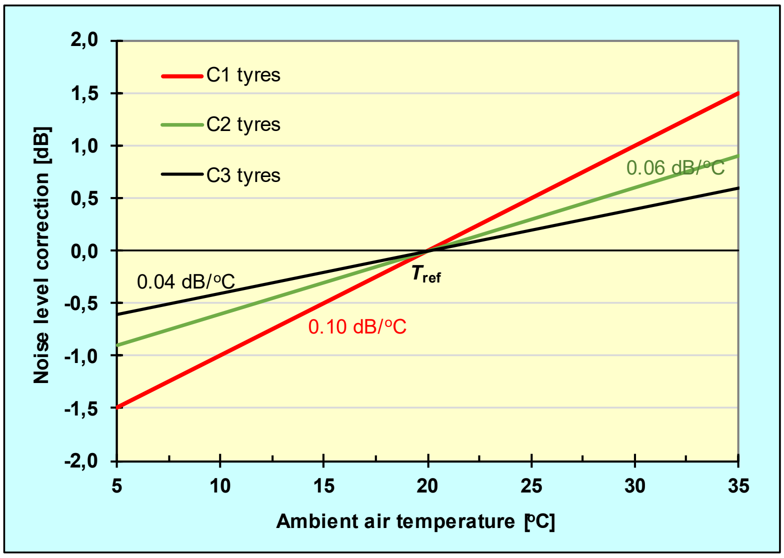



Figure 5-14: Illustration of the temperature correction model. In this case the data for dense asphaltic surfaces are used for the three tyre categories C1, C2 and C3. Coefficients for other road surface types are listed in Table 5-4.

It is suggested that R117 and ISO 13325 implement this model.

In case only road temperature-based corrections are accepted in R117 and/or ISO 13325, STEER suggests a modified correction procedure as shown in Table 5-5, which is based on the text in Section 5.8.2. A comparison of the STEER proposal and R117 for C1 tyres is shown in Figure 5-15.

It is estimated that if the proposals of STEER are implemented, the uncertainty due to the temperature influence for C1 tyres will be reduced by roughly 25 %. This is mainly due to the more accurate temperature coefficients but marginally also due to the somewhat stricter limitation to air temperatures ≤ 35 °C.

Table 5-5: Temperature coefficients suggested by STEER, based on road surface temperatures (rounded to two decimals), for dense asphaltic surfaces, including ISO 10844 reference surfaces.

| **Tyre class (t) →**<br>**Temperature range ↓** | **C1** | **C2** | **C3** |
|---|---|---|---|
| 5 – 20 °C | -0.07 | -0.04 | -0.03 |
| 20 - 50 °C | -0.05 | -0.03 | -0.02 |

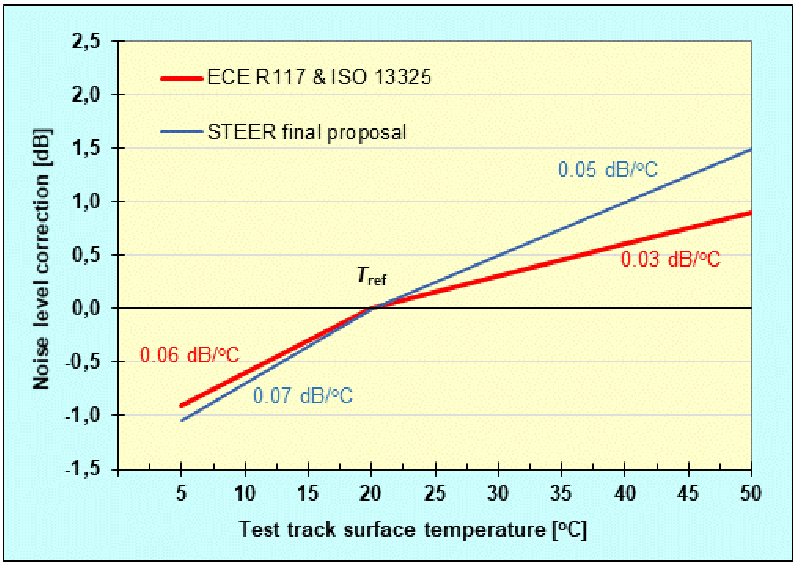



Figure 5-15: Illustration of an alternative temperature correction model for measurements of tyre category C1, in accordance with R117 and ISO 13325. In this case the road surface is the reference surface specified in ISO 10844.

### 5.8.9. The need for more research

STEER has identified the following needs for further research:

Developing a modified model which takes both air and road temperatures into account. It is hoped that this may make all temperature corrections (for roads, vehicles and tyres) uniform. Both temperatures are already measured, so it means no extra efforts by the industry except the research. In many cases, it should be possible to re-analyse old data for this purpose, and it may be useful to try putting different weights on the two temperatures, depending on the speed.

Study how the potential future model based on both air and road temperatures work in various climate zones.

Study how the temperature influence on noise depends on frequency, for various cases (tyre types, road surfaces, speed). If a uniform influence appears, it should be considered whether the correction model should include a frequency parameter.

Study how the temperature influence on noise depends on vehicle speed, for various cases. If a uniform influence appears, it should be considered whether the correction model should include a speed parameter.

Study how the temperature influence on noise depends on road surface texture, for various cases, since the texture range for the ISO-surface is large.

# 6 The history and development of ISO 10844 until now

When testing noise emission of road vehicles or tyres, such as for type approval or determination of tyre noise labels, the measurements are required to be conducted on the test track reference surface specified in ISO 10844. This reference surface is used in most, if not all, legal requirements for such measurements, such as ECE R117.

The historic background is treated in detail in Section A.IV in Annex A and is not repeated here, except for some important issues. The work to develop ISO 10844 was started in 1986 (in a working group convened by the main author) and the task was to develop a reference surface having the following properties: "….. *a test surface, which is highly reflective and induces minimum tire noise*". It was the intention that tyre/road noise on this surface would have a minimum influence on the overall vehicle noise emitted during constant speed and acceleration at speeds around 40-60 km/h according to the vehicle noise regulations at that time. The vehicle noise limits were higher at that time compared to presently which allowed vehicles of that time to emit substantially more power unit noise than presently; but yet the tyre/road noise was considered as an unwanted and disturbing contribution.

The first ISO 10844 standard was published in 1994 and met the initial intention. It contained requirements for a dense asphalt test surface with regard to texture and sound absorption as well as an optional description of how it may be mixed and laid. The maximum aggregate size was given as 8 mm but with a tolerance for up to 10 mm. In practice this pavement was similar to a stone mastic asphalt with 8 mm max. aggregate size. In 1994 there were not yet appropriate international standards for measurement of texture and sound absorption; something that initiated development of such standards. The lack of good standards to characterize road surfaces and even to measure their noise properties meant that the 1994 version of the standard had uncertainties that were acceptable when vehicle noise was measured according to regulations, but not when measuring "pure" tyre/road noise. Thus, it was good enough to implement for the vehicle noise legislations but lacking another reference surface specification, soon it was selected to be used also for tyre/road noise regulations.

The task never was to specify a reference surface for measurement of tyre/road noise, and this was stated in the scope of the standard as "…. *since the surface is not intended to produce significant tyre/road noise levels it is not particularly designed for the testing and comparison of tyre/road noise*". See Figure 6-1.

> This International Standard does not take into account the influence on tyre/road noise of purely tyre-related parameters such as tyre construction, tread pattern, inflation pressure and tyre loading. It follows that since the surface is not intended to produce significant tyre/road noise levels, it is not particularly designed for the testing and comparison of tyre/road noise.

Figure 6-1: Statement in ISO 10844:1994, under the heading "Scope".

Consequently, it was unfortunate that the standards community was not already at that time requested to develop a reference surface specifically intended for testing tyre/road noise. There were proposals for it from Sweden and UK, but these were never decided upon. Soon after, the task to update ISO 10844 was moved to another working group (ISO/TC 43/SC 1/WG 42), Instead, the tyre/road noise testing community had to live with a poorly specified reference surface for their purpose more than a decade. This poor performance for tyre/road noise testing was demonstrated by the results of the first round robin test (RRT); see more in the next Chapter. In the meantime, international standards were developed and published for measurement of both surface texture (ISO 13473-1) and sound absorption (ISO 13472-2). In 2011 a revised ISO 10844 standard was published in which the mentioned texture and sound absorption standard were implemented, along with better specifications of the asphalt mix and laying operations.

The main improvements in the 2011 edition compared to the first edition (1994) are as follows:

- The use of polymer modified binder allowed
- Flatness and smoothness defined by test method
- Measurement of texture by equipment fulfilling ISO 13473-3
- Modified texture specification, including both minimum and maximum limits
- Sieving curve normative and MPD chosen as texture descriptor
- Absorption measured by *in situ* device with specification of max 8 % in each 1/3$^{rd}$ octave band

The 2014 edition contained only minor revisions and is technically similar to the one of 2011.

The 2014 edition has been made mandatory to use in the following UN ECE regulations:

- ECE Reg.51.03 (revision 3, amendment 5)
- ECE Reg.117 (revision 4)
- ECE Reg.138 (revision 2, amendment 2)

It is stated in the standard text that the 2014 version:

- *produces consistent levels of tyre or road sound emission under a wide range of operating conditions including those appropriate to vehicle sound testing,*
- *minimizes inter-site variation,*
- *provides minor absorption of the vehicle sound sources, and*
- *is consistent with road-building practice.*

Note that it is <u>not</u> stated that it produces typical or representative levels of tyre noise. That it is *consistent with road-building practice* is arguable, as no such pavement has been paved on actual roads. This subject is treated in detail in the STEER Report for Task 2.2 (*Report of the a priori uncertainty analysis of the tyre labelling procedure*).

In the latest revision (ISO/FDIS 10844:2021), the following improvements have been made (only the most relevant for reducing variability between test tracks are listed):

- Permit modern and accurate methods for measurement of irregularity (e.g. laser methods) in addition to straightedge
- Replace sieving curve figure with equivalent tabulation of sieve values defining an aggregate grading envelope
- Replace optional calculation of $END_T$ with optional calculation of texture skewness, shape factor (g-factor) and texture spectrum

The latter is highly relevant for the introduction of the possible estimation of the influence of the test track on coast-by or cruise-by levels based on surface characteristics like MPD, g-factor and sound absorption, as proposed by the VDA in their Round Robin Test in 2016 (see chapter 7). However, as it is not implemented for normalization, the 2021 edition is not likely to provide significantly lower spread in noise properties; just a closer description of the surface properties.

To conclude, the following is a list of the different editions of ISO 10844 so far:

- ISO 10844:1994. This was the original version, not intended for tyre/road noise measurements.
- ISO 10844:2011. This was the first revision of the original version.
- ISO 10844:2014. This is still the latest published edition.
- ISO/FDIS 10844:2021. This is the final version approved for publication as the 2021 edition. However, it may still be somewhat edited by ISO.

# 7 Round Robin Tests of ISO 10844 test tracks

## 7.1. Tests by the industry in the period 2000-2020

### 7.1.1. Round Robin Test on ISO test tracks by M+P in 2005

In 2005 the Dutch consultant company M+P performed several coast-by and accelerated pass-by measurements with a test vehicle on nine different surfaces using four different tyres as part of a Round Robin Test (RRT) for test tracks constructed according to ISO 10844:1994 [M+P, 2006]. Seven of the nine surfaces were supposed to comply with ISO 10844 and were designated ISO1, ISO2, …ISO7. The other two surfaces were SMA surfaces, designated SMA1 and SMA2. Four car tyre sets were used in the tests, of which one was a slick tyre (thus not a legal tyre), one was a summer tyre, one was a winter tyre and the fourth was an off-road tyre (see Figure 7-1). The tested surfaces were located in Northwestern Europe (BeNeLux, France and Germany). It is worth noting that it is unclear how the tyres were warmed up and if the warmup process was long enough; something which is important for the results. Data about the test tracks are not published.

It should be noted that the pass-by levels were measured both at the reference position of 7.5 m, but also with near-field microphones mounted on the vehicle itself, in the CPX positions. The same test vehicle was used on all test tracks.

An analysis of the test results regarding the influence of temperature (air, road surface and tyre) is presented and discussed in chapter 5.2 in the STEER Project Report R3.1. However, in this deliverable, the results presenting the spread in the noise levels during coast-by measurements are the most relevant.


Figure 7-1: The four measurement tyres: A- Pirelli slick tyre, B- Pirelli summer tyre, C- Goodyear Eagle Ultra Grip winter tyre, D-Goodyear Wrangler 4x4 off-road tyre.

In Figure 7-2, the coast-by levels (at 7.5 m) for a speed of 80 km/h are shown for the four sets of tyres on the nine test sections.

In addition to noise measurements, the surface characteristics (texture and absorption) were also measured. However, the texture measurements were conducted with a laser profilometer which later appeared to be affected by a lot of “spikes” (disturbing transients), so the values obtained were not useful. The analysis showed that ISO4 and ISO7 had absorption values that would not have been approved according to the requirements of the present edition (2014) of ISO 10844, supported by the fact that the noise levels in Figure 7-2 indicate that these two test tracks were quieter than the “acceptable” five test tracks.

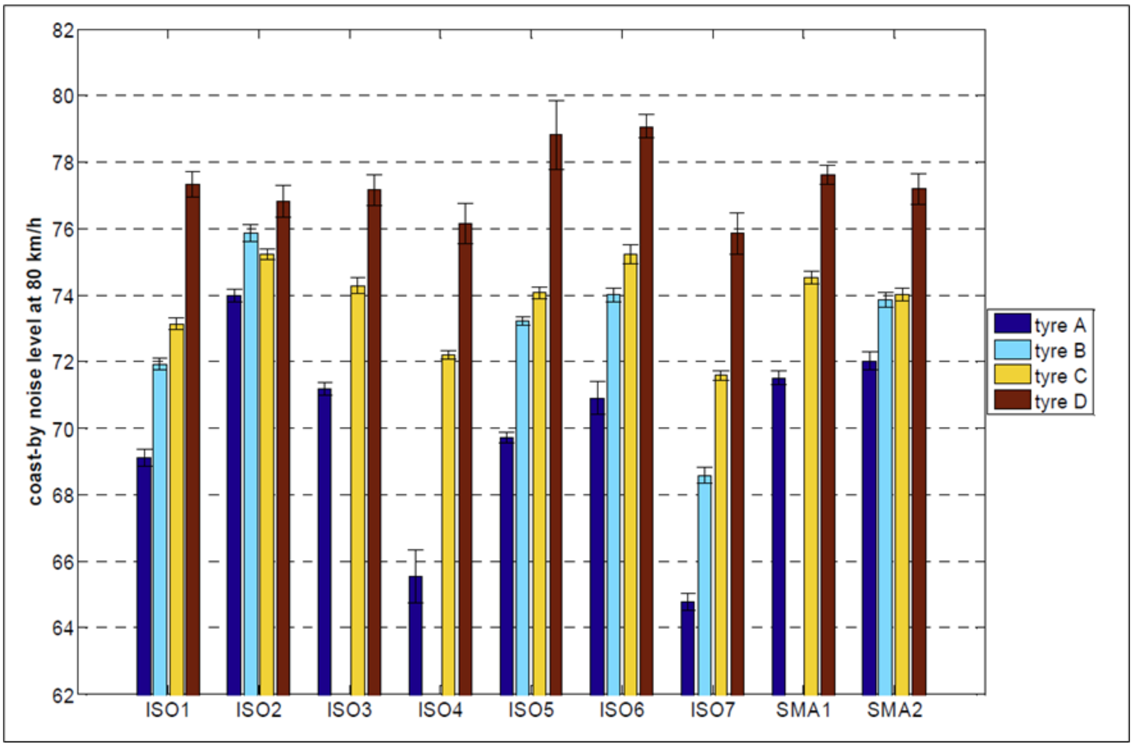



Figure 7-2: Coast-by levels at 80 km/h for all tyres at each test track; error bars show 95 % confidence intervals.

Excluding these two test track surfaces and the two SMA surfaces, the maximum difference between the remaining five test tracks in noise levels for the four tyre sets were:

- Tyre A: 4.9 dB
- Tyre B: 4.0 dB (NB, not measured on ISO3 and ISO4)
- Tyre C: 2.0 dB
- Tyre D: 1.9 dB

If all nine test tracks are included, tyre A showed a difference of 9.2 dB, and tyre D a difference of 3.2 dB. Note that Tyre A is a slick non-patterned tyre.

These results show what could be expected, namely that the tyres with the more pronounced tread patterns (C and D) are less influenced by the variation in surface characteristics between the test tracks.

A difference of 4 dB for the summer tyre is in line with newer investigations as the VDA investigation in chapter 7.1.2. Such a difference in tyre/road noise is higher than what would be acceptable, considering that only one summer tyre and five ISO test tracks were included. Non-patterned tyres are known to be the most sensitive to surface macrotexture; thus, the noise difference for tyre set A suggests that texture differences were the main reason for the differences.

This study was one of the main reasons why a revised ISO 10844 was published in 2011 (and in 2014).

### 7.1.2. Round Robin Test on ISO test tracks in Japan in 2006

To supplement the European RRT described above, eight ISO test tracks were tested in 2006 [JSAE, 2006]. As test tyres they used the tyres B and C from the European study, supplemented with two Japanese summer tyres. The test vehicle was a Japanese car used on all test tracks. Noise measurements were made on all eight test tracks at the speed of 50 km/h and on all test tracks except one at 80 km/h (R117 test procedure).

They also measured MTD and MPD as well as texture spectra, supplemented with sound absorption and friction measurement by the British Pendulum. Those results are correlated with noise measurements and also within themselves.

The noise results are shown in Figure 7-3 and Figure 7-4. It appears that among the seven or eight Japanese ISO tracks the spread in tyre/road noise levels were 1.7 to 3.3 dB at 50 km/h and 2.0 to 3.6 dB, which is lower than in the European tests. Note, however, that the Japanese diagrams include test tracks ISO4 and ISO7 in Europe which do not meet the present sound absorption requirements, so the comparison between the European and the Japanese RRT:s are a bit tricky.

### 7.1.3. VDA Round Robin Test in 2016

In this investigation, made by the German Association of the Automotive Industry (VDA), pass-by measurements (coast-by, cruise-by and acceleration) were made on 13 different ISO tracks in Europe in 2016. All test surfaces were constructed according to ISO 10844:2014 probably around or just after 2014. Thus, they were relatively new at the time of the RRT.

The main objectives of this investigation were expressed as follows:

- Assessment of tyre/road noise with OEM tyres with regard to limit value reduction to 68 dB(A) according to EU Reg540/2014 and upcoming review of the limits for tyres according to EU Reg661/2009
- Gain experience with ISO 10844:2014
- Comparative assessment of the track surface (e.g. differences)
- Physical, acoustic description of the track surface (parameters, micro/microgeometry)
- Evaluation of parameters
- Collect suggestions for future review of ISO standard
- Comparison of track surfaces in Europe among themselves and compared to Chinese test tracks (the Chinese RRT was conducted but data have not yet been released)

An electric vehicle (VW e-Golf) was used for testing. The following tyre sets were used:

- Four different typical summer tyre sets by different tyre manufacturers, size 205/55R16
- One typical summer tyre set, size 245/40R18
- One slick tyre set (without negative profile), size 205/55R16
- One SRTT tyre set, size 225/60R16

The measured values were:

Sound levels left/right [dB(A)], vehicle speed [km/h], ambient sound level (before each run) [dB(A)], air temperature [°C], surface temperature [°C], tyre temperature [°C], air pressure [mbar], air humidity [%], wind speed [m/s] and wind direction [deg].

The surface temperature ranged from 10 to 40 °C during the RRT. For each test track, the surface characteristics such as MPD, g-factor and absorption were also measured.

Driving conditions were as follows:

- Cruising-by at different speeds from 40-80 km/h (in 10 km/h steps), two runs for each speed level
- Cruising-by at 45, 55 and 65 km/h, two runs for each speed
- Cruising-by at 50 km/h, extra six runs to get noise level without regression

Passing-by at 2 $m/s^2$ acceleration, and 50 km/h at line PP' (the line between the microphones), six runs. The basic results were presented by OICA at the 1st meeting of IWG MU in Brussels 22-23 May 2019 [VDA, 2019]. There is no official report containing all measured data available, only the summary of some of the results that were presented at this meeting.

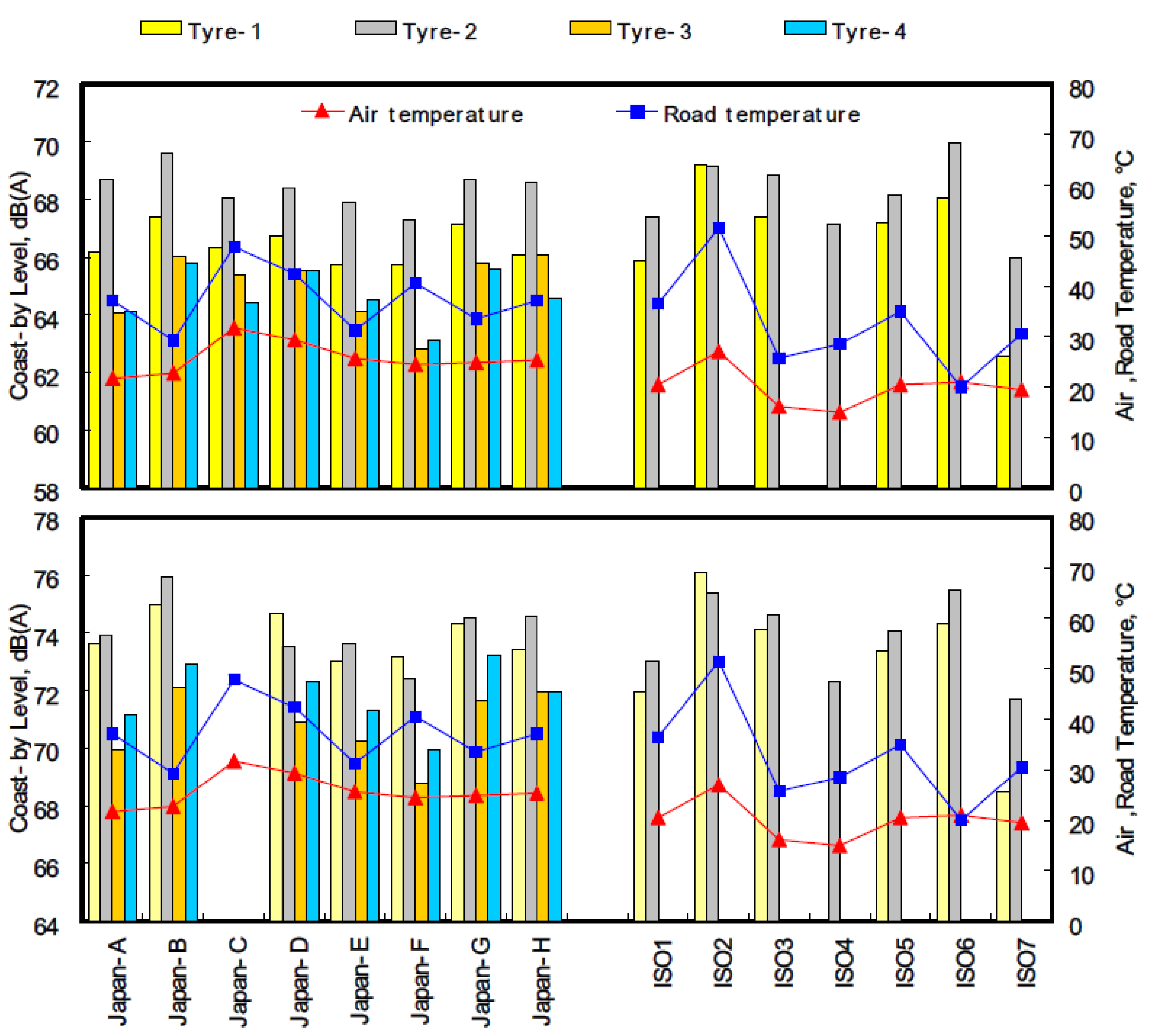



Figure 7-3: Coast-by levels at 50 km/h (above) and at 80 km/h (below) for all four tyres at each test track. The Japanese results are shown in the left part and the European in the right part (the latter only for tyres designated B and C). From [JSAE, 2006].

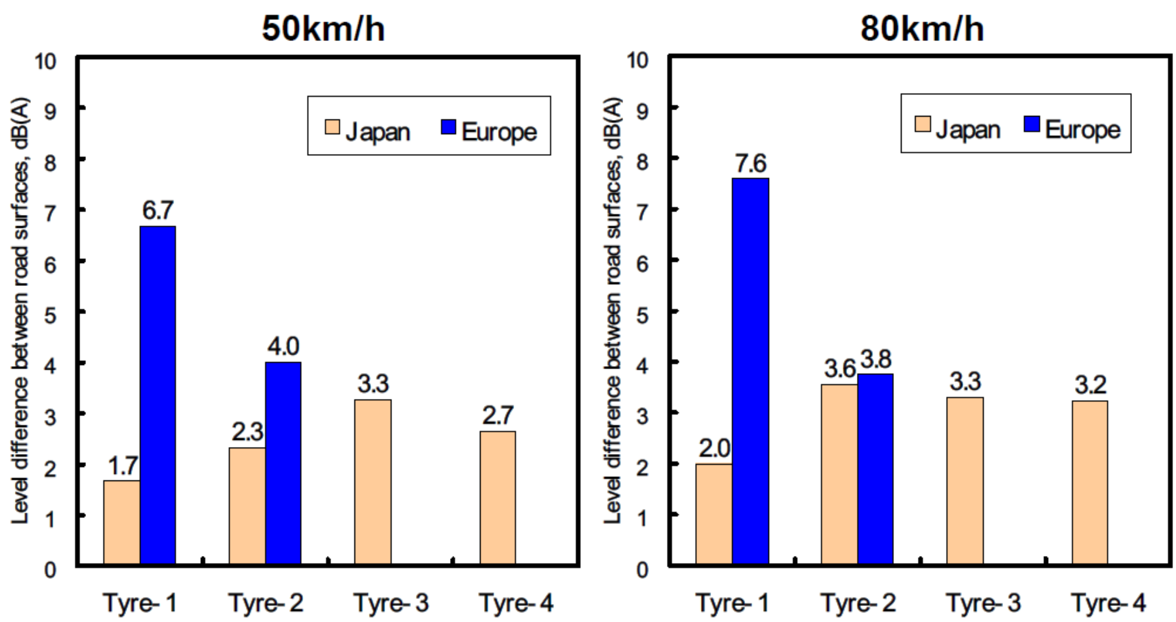



Figure 7-4: Spread of coast-by tyre/road noise levels at 50 km/h (left) and at 80 km/h (right) between the test tracks for the four tyres in Japan in orange and the European tyres B and C in blue. From [JSAE, 2006].

Figure 7-5 shows the results from cruising at 50 km/h for the 13 test tracks. The red dots in the figure (R06) are values for the SRTT tyre and the green dots (R02) are values for the slick tyre. The grey line shows the average levels for the tyres (excluding the slick tyre) on each test track.

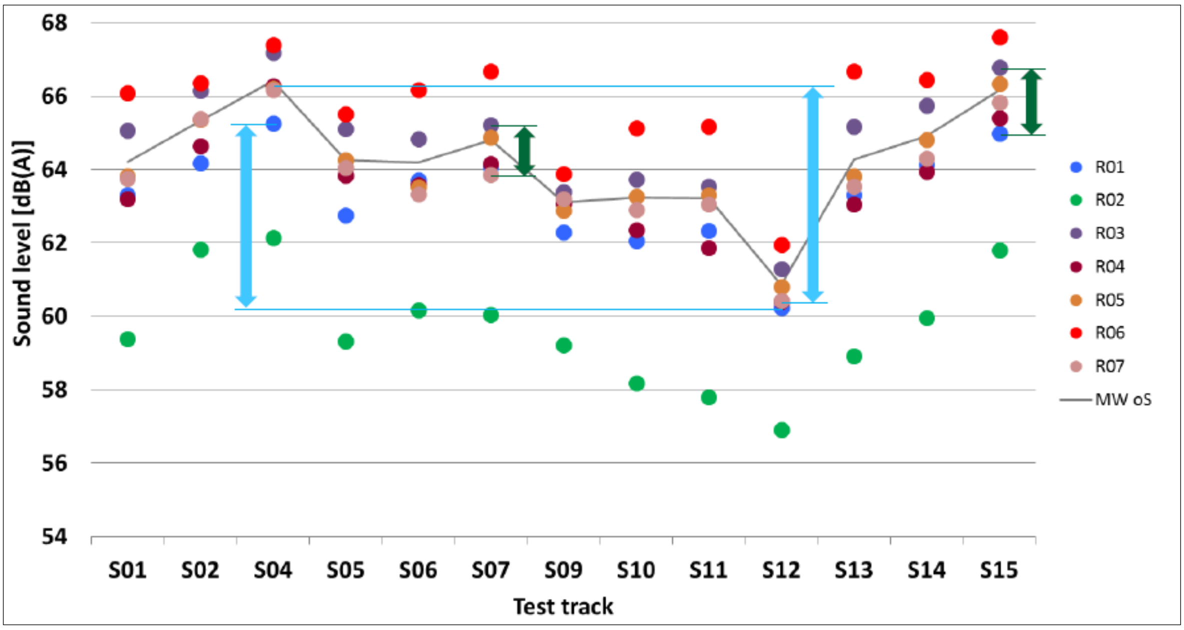



Figure 7-5: Cruise-by levels at 50 km/h, for seven tyres on 13 different ISO test tracks [VDA, 2019]. See the text for further information.

The main conclusions from this figure (excluding tyres R02 and R06 from the analysis) were:

- The sound level **spread** among the test tracks for **tyres** with tread pattern is approx. **5.0-5.9 dB** depending on tyre.
- Without the SRTT tyre, the spread among test tracks remains nearly unchanged with a range from **5.0-5.7 dB** depending on tyre.
- If test tracks S09 and S12 are not counted, due to their measured sound absorption (although they were originally certified), the spread is reduced to approx. **2.6-3.2 dB**, depending on tyre.
- The sound level **spread between the test tyres** (excl. the non-patterned one) is **1.9-3.9 dB**, depending on the test track.

Note that an analysis of the surface texture and absorption data revealed that S09 and S12 appeared not to meet the requirements of ISO 10844:2014, although they were supposed and certified to do so.

### 7.1.4. ISO/TC 31/WG 11 Round Robin Test

The main results of this RRT were presented by ETRTO at the 2nd meeting of IWG MU in Brussels 22 Nov. 2019 [ETRTO, 2019].

A small RRT consisting of five different tyres (both summer and winter, 16" and 18") and four different ISO test track was conducted. In this case, all measurements were conducted at the speed 80 km/h, to meet the requirements of R117. Figure 7-6 shows the results.

Their main conclusions were that these results, with a spread of 1.3 to 2.4 dB depending on tyre, were in line with the findings in the VDA RRT. Then it shall be noted that this study included only four test tracks while the VGA study included 13 test tracks. Of course, it is natural that differences increase when more test tracks are added to the sample.

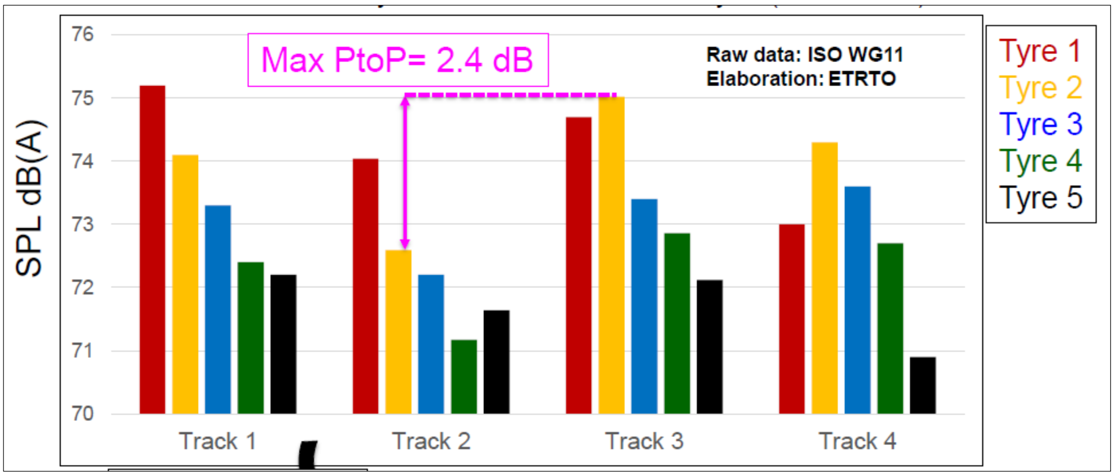



Figure 7-6: Results of the RRT by ISO/TC 31/WG 11, elaborated by ETRTO. Results show track-to-track sound level variation at 80 km/h [ETRTO 2019].

ETRTO did also get access to the raw data from the VDA study and presented the track-to-track variation at 80 km/h, which is more relevant to the STEER project and measurements according to R117. These results are shown in Figure 7-7. The slick tyre is excluded from the comparison.

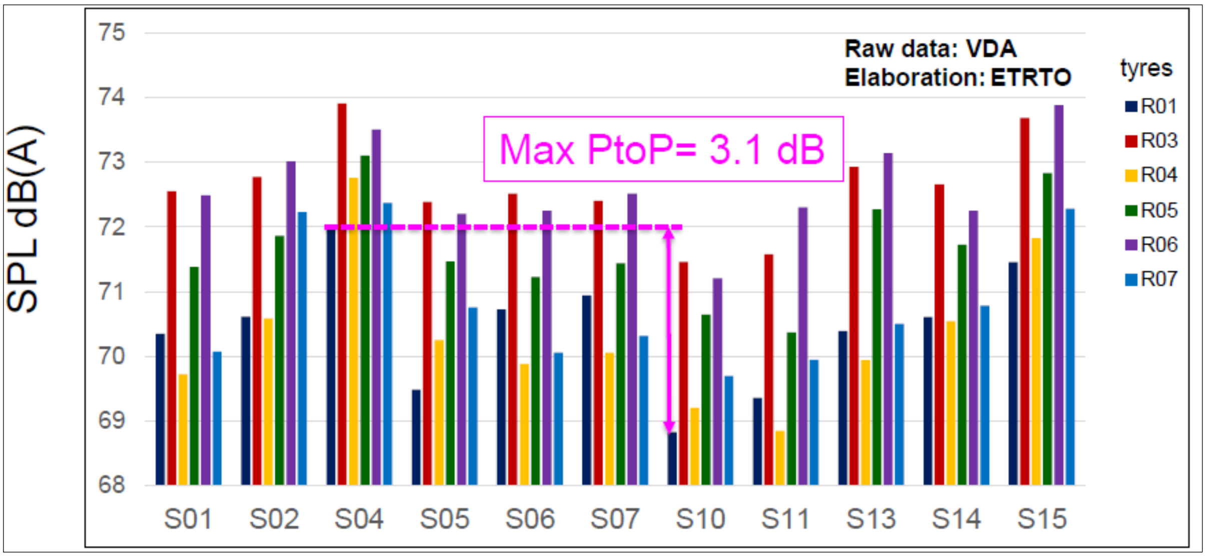



Figure 7-7: VDA RRT results elaborated by ETRTO. Track-to-track variations at 80 km/h [ETRTO, 2019].

In the VDA study, for 80 km/h as reported by ETRTO in Figure 7-7, the spread in tyre/road noise levels between the tracks seems to be 2.3 to 3.9 dB, depending on the tyre set.

For the ISO/TC 31/WG 11 RRT, the standard uncertainty (for 95 % confidence interval) was calculated to ± 1.6 dB, while it was reported as ± 1.8 dB for the VDA RRT.

## 7.2. Tests in the Polish-Norwegian project ELANORE

The ELANORE project (Improvements of the **E**U tyre **la**belling system for **no**ise and rolling **re**sistance, 2019-2023) is a joint project between Gdansk University of Technology (GUT), SINTEF and EKKOM , funded by EEA Grants for Poland and Norway - POLNOR[7].

[7] NCBiR Contract No. NOR/POLNOR/ELANORE/0001/2019-00

One part of the project is to perform noise and rolling resistance measurements on both ISO test tracks and on normal trafficked roads.

As a first part of the project, a small RRT on three ISO test tracks in Germany was performed in August 2021. At the time of this report, there is only a limited number of results available for presentation here.

The test program consisted of the following:

- coast-by measurements with a test vehicle at speeds between 40 and 90 km/h
- CPX measurements at speeds 50 and 80 km/h with the GUT CPX trailer

For the coast-by measurements, five sets of tyres were used:

- 2 summer tyres
- 1 winter tyre
- 1 all-season tyre
- 1 SRTT (P1 of ISO/TS 11819-3, which also has the name Uniroyal Tiger Paw)

All these five tyres were also used for the CPX measurement program (but only one sample of each set).

In addition, the following tyres (different from coast-by tyres) were used for CPX measurements:

- 2 summer tyres
- 2 winter tyres
- 1 all-season tyre
- 1 reference tyre (H1 of ISO/TS 11819-3 which is the market tyre Avon AV4)

Except the SRTT (P225/60R16) and the Avon AV4 (195R14C), all other sizes were 215/55R17.The labelled noise values varied from 66 to 74 dB.

The measured values included the following:

Sound levels right/left [dB], ambient noise, air and road surface temperature (before and after each test completed with one set of tyres). The CPX trailer was also equipped with the possibility to measure the air and road surface temperatures. In addition to these parameters, the MPD and g-factor values were measured using a “surface drone” provided by Müller-BBM. Besides measured values for each wheel track, the surface drone also calculated the estimated pass-by noise levels based on a modified version of the VDA equation in chapter 8.2.3:

$$L_{crs} = 60.3 + 27.7 * MPD^{1.5} - 143 \cdot \left(\frac{g \cdot MPD}{(100 \cdot 0.97)}\right)^{4.3} - 36 * \alpha^{0.9} [dB] \tag{5}$$

The test program consisted of the following noise tests (both cruise-by and CPX) run on test tracks ISO1, ISO2 and ISO3:

1) Test according to R117 for tyre inflation pressure (200 kPa) and load of each tyre (530 kg)
2) Modified R117 conditions with increased inflation pressure (230 kPa) and reduced tyre load (460 kg).

Thus, for the ModR117 condition, the inflation pressure was increased by 15 % while the load was reduced by 15 %.

Due to a lot of rain during parts of the measurement campaign, not all conditions and sets of tyres was measured on all three test tracks. Table 7-1 presents an overview of the accomplished test program.

Table 7-1: Completed test conditions for cruise-by for five sets of tyres

| Tyre No. | Tyre type | Test location | Test condition |
|---|---|---|---|
| 1 | Summer | ISO1 | R117 |
| | | ISO2 | R117+ModR117 |
| | | ISO3 | R117 |
| 2 | All-season | ISO1 | R117 |
| | | ISO2 | R117+ModR117 |
| | | ISO3 | R117 |
| 3 | Winter | ISO1 | R117 |
| | | ISO2 | R117+ModR117 |
| 4 | Summer | ISO1 | R117 |
| | | ISO2 | R117+ModR117 |
| 5 | SRTT | ISO1 | R117 |
| | | ISO2 | R117+ModR117 |

In Table 7-2, the completed program of CPX measurements is shown. Some of the missing measurements may be made in 2022.

Table 7-2: Completed CPX measurements on the three ISO tracks.

| Tyre No. | Manufacturer | ISO1 | | ISO2 | | ISO3 | |
|---|---|---|---|---|---|---|---|
| | | R117 | ModR117 | R117 | ModR117 | R117 | ModR117 |
| 1 | Summer | x | | x | x | x | x |
| 2 | All-season | x | | x | x | x | x |
| 3 | Winter | x | | x | x | x | x |
| 4 | Summer | x | | x | x | x | x |
| 5 | SRTT | x | | x | x | x | x |
| 6 | Summer | x | | x | x | x | |
| 7 | Winter | x | | x | x | x | |
| 8 | Summer | x | | x | x | x | x |
| 9 | All-season | x | | x | x | x | x |
| 10 | Winter | x | | x | x | x | |
| 11 | Avon AV4 | x | | x | x | x | |

As stated above, only a limited number of results are available to be presented here.

In Table 7-3, the expected noise levels at 50 km/h are shown. These are based on measured values for MPD and g-factor and available absorption data. The values are average of left and right wheel track and from 2 runs at each wheel track.

Yet, not verified by the owners of the test tracks, it is believed that all 3 tracks were constructed around 2015-2016 and according to the specifications of ISO 10844:2014. As this table shows, there is only a minor difference between the estimated noise level based on Equation (5). When all the measured noise levels have been analysed, they will be compared with the results in Table 7-3.

The only results analysed to be presented here, are some preliminary results for the pass-by measurements of three tyres at the two test conditions on ISO2.

Table 7-3: Estimated pass-by noise levels (50 km/h) and MPD values, based on the "surface drone" measurements based on Equation (5).

| Test track | MPD | $L_{CRS}$, dB(A) |
|---|---|---|
| ISO1 | 0.59 | 63.0 |
| ISO2 | 0.46 | 63.9 |
| ISO3 | 0.47 | 64.0 |

Table 7-4 shows these results, along with the range of air and road surface temperature during the tests. The table shows the corrected levels according to the existing procedure in R117, based on road surface temperature and correction according to the proposal for ISO/CD 13471-2.

Table 7-4: Measured and temperature corrected sound levels according to two test conditions.

| Test condition | Tyre 1 (Evergreen) | | Tyre 3 (Bridgestone) | | Tyre 5 (SRTT) | |
|---|---|---|---|---|---|---|
| | R117 | ModR117 | R117 | ModR117 | R117 | ModR117 |
| Road surface temp., °C | 34.7-38.6 | 25.8-30.0 | 38.9-39.4 | 23.0-24.7 | 23.0-25.0 | 30.3-31.8 |
| Air temperature, °C | 20.3-22.6 | 17.4-21.6 | 22.6 | 15.8-19.3 | 21.8-23.0 | 21.3-21.6 |
| No temp. corr. noise dB | 72.8 | 72.8 | 72.6 | 73.0 | 75.5 | 75.7 |
| R117 temp. corr. noise dB | 73.1 | 73.2 | 73.2 | 73.2 | 75.6 | 76.0 |
| ISO temp. corr. noise dB | 73.0 | 72.9 | 72.9 | 72.9 | 75.7 | 76.3 |

Figure 7-8 to Figure 7-10 show the results for these three tyres, with no temperature correction applied, then corrected according to R117 and then corrected according to ISO/TS 13471-2. It appears that the modified R117 condition leads to somewhat higher noise levels than the original R117 for two of the three tyres. However, when the full analysis is available, we will have data for five tyres from the pass-by tests and data from 11 tyres from the CPX tests, made on the same ISO test track.

## 7.3. Discussion

At hindsight, the RRT:s in Europe and Japan in 2005-2006 did not present so alarming spread in tyre/road noise levels as we would expect today from the original ISO 10844 edition. It appeared to be a spread from 2.0 to 4.0 dB between test tracks, depending on which tyre was considered. This is actually not worse than what the VDA and ETRTO studies arrived at more than a decade later. Yet, it is too much.

It appears that the spread between the test tracks in the VDA study is surprisingly high (almost 6 dB); in fact, not lower than in the RRT made in 2005, before ISO 10844:2014 was published. Since S09 and S12 were supposed to meet the ISO requirements, before the VDA test showed that it was not the case, it is arguable whether these surfaces should be excluded from this assessment of test track spread. If it can be justified to exclude them, the spread is still up to 3.5 dB. It is only marginally better than results of the RRT in 2005 (4 dB) reported by M+P.

Unfortunately, VDA has not allowed us to check the results they measured for the 80 km/h driving condition. Nevertheless, the results became indirectly known through the study reported by ETRTO.

It shall be noted that the results in Figure 7-5 are presented for cruise-by tests at 50 km/h and not for coast-by at 80 km/h as is the case for tyre labelling. However, the ETRTO data in Figure 7-6 revealed similar results for both testing conditions. This is not surprising since an electric car was used for cruise-by, so one can assume that only tyre/road noise was measured. It is however, not known if the light torque needed on the tyres for cruising might increase tyre/road noise, but it seems that this effect was marginal.

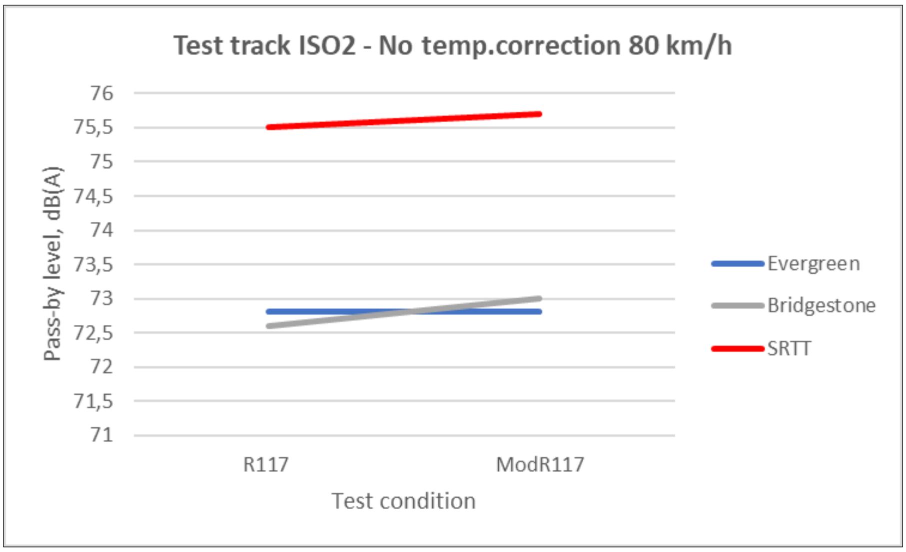



Figure 7-8: Measured sound levels on ISO2 for two test conditions and with no temperature corrections applied.

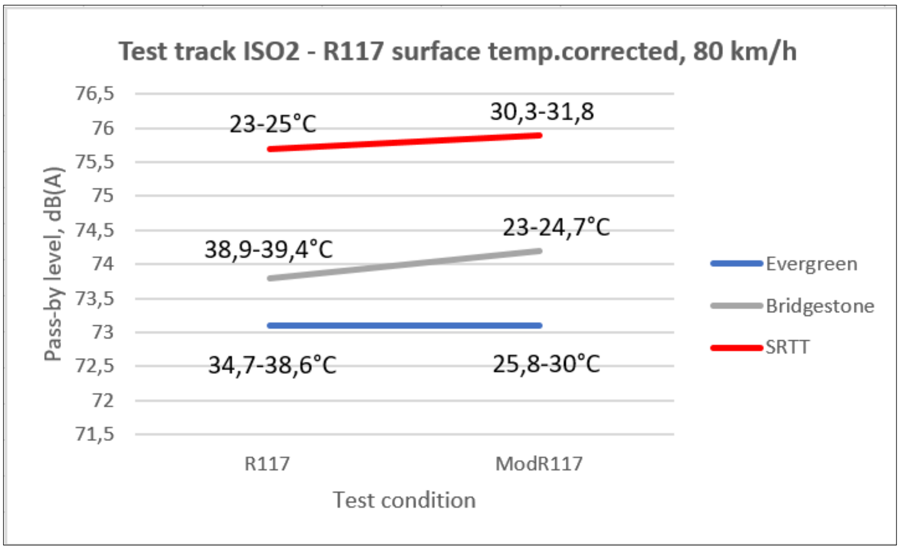



Figure 7-9: With temperature corrections according to R117 applied.

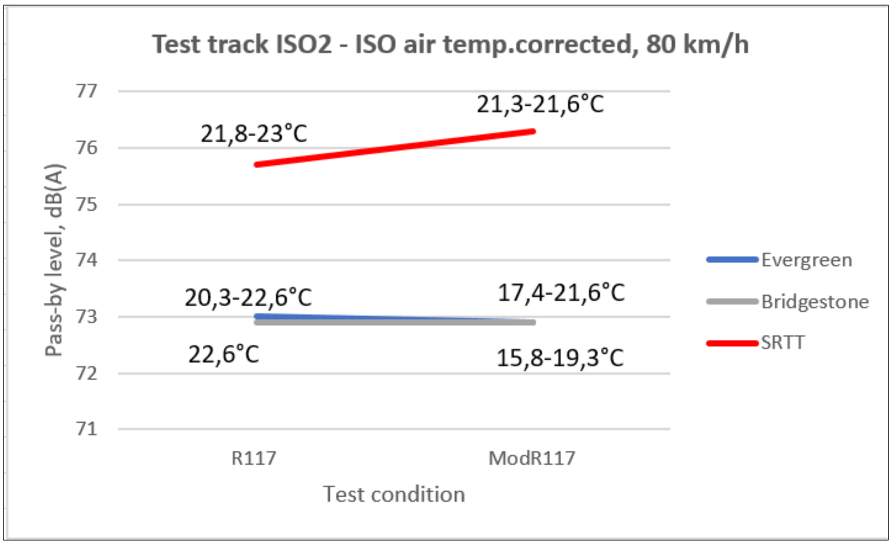



Figure 7-10: With temperature correction according to ISO/CD 13471-2 applied.

In the VDA study, for 80 km/h as reported by ETRTO in Figure 7-6, the spread in tyre/road noise levels between the tracks seems to be 2.3 to 3.9 dB, depending on the tyre set. In this case, they have excluded test tracks S03, S08, S09 and S12. With the same exclusions in Figure 7-5, for 50 km/h as reported by VDA, the test track spread is 2.6 to 3.5 dB. This confirms that the results in the RRT by VDA for coast-by at 80 km/h, which we did not get access to, is comparable to the cruise-by tests at 50 km/h. Thus, we can rely on Figure 7-5, and of course Figure 7-7, for assessing spread in noise levels between ISO tracks for measurements related to tyre labelling.

But the problem is: how can it be justified to exclude four out of the 15 test tracks originally included in the VDA test? With regard to S03 and S08, which were included in the test program but are not reported by VDA, they actually never measured on these two tracks; the reason being that the track owners of S03 and S08 cancelled their participation of the RRT.

The reason ETRTO left out S09 and S12 in Figure 7-7 was that they had too high sound absorption and thus were not meeting the specifications of ISO 10844:2014. None of the tracks in the study actually provided "certificates" for complying with the 2014 version of the ISO standard. It was assumed by the test organization that S09 and S12 in fact were "old" surfaces and therefore not complying with the ISO standard. This is probably why ETRTO left these surfaces out in their analysis. Even if they did not meet the 2014 standard, they may have been used for type approval test and for labelling of tyres. Therefore, it may be sensible to include such test tracks as an indication about the <u>actual</u> spread between test tracks.

If a test track has been built according to ISO 10844:2014 and verified to meet the requirements after construction, it would supposedly be used for tyre testing, as it is why it was built. Then one cannot exclude measured noise results of such a track just because a later test shows that the track does not fulfil the requirements, since before this would be detected, measurements could or would have been approved on that test track and be reported as tyre label values.

Another problem is that the ISO test tracks tested in these RRT:s are located only in western and possibly southern Europe. Can one rely on test tracks in (say) eastern Europe, China, India, or Indonesia being of equally high quality?

Finally, it should be mentioned that the noise properties of ISO test tracks change with time, just as road surfaces with little traffic do. The test tracks included in these measurements were of quite similar age as they were certified for ISO 10844:2014 and the RRT was measuring them in 2016.

## 7.4. Conclusions

First, it should be noted that the STEER proposal originally included conducting an own advanced RRT. However, this part of the project was cut away by budget restrictions imposed by the sponsor. Instead, the tyre and vehicle industries have made useful work that we have been able to use, for which the authors are grateful. There are also suggestions in these industries to continue and collect work of this kind in the near future.

The Round Robin Tests reported here seem to suggest that there is a stunning difference in noise levels between the test tracks of up to 6 dB if all test tracks are included. VDA had 15 test tracks in their test program but reported 13 of them. Even so, 13 tracks is a good selection; albeit it is only European locations. If test tracks such as S09 and S12, which were found not to fully comply with ISO 10844:2014, could be detected before they start operating for legal testing purposes, the spread in noise levels would be up to 4 dB.

The uncertainty calculations initially made in STEER should be updated with these data in mind.

Whether the real spread is 4 or 6 dB, it is too much. The variation between the ISO test tracks must be reduced substantially.

Another conclusion is that it seems that an original certification of a test track is not sufficient. Maybe the certification should be made twice and the track must pass both times. At least part of the certification should be repeated after one or two years (presently it should be repeated after four years).

# 8 Calibration of ISO 10844 test tracks

## 8.1. Possibilities to reduce the site-to-site variation of ISO 10844 surfaces

Attempts to reduce the variation in noise properties of ISO 10844 surfaces were made already in the first (1994) version, by specifying that texture depth (TD), later referred to as MTD (mean texture depth), shall be ≥ 0.4 mm, that residual voids shall be ≤ 8 % or that sound absorption shall be ≤ 10 %. The advice regarding design and construction of the mix also limited the surface properties.

In the presently valid edition of the Standard ISO 10844, these texture, air voids and sound absorption requirements, together with the design and construction, have been tightened, as is mentioned in Chapter 6. Also, some successful examples are presented, which however are deleted in the 2021 edition. There is also an informative Annex specifying a method to calculate the expected differences in noise levels between various test tracks, called $END_T$ (“Expected pass-by Noise level Difference from Texture level variation”). It seems, however, that the latter has not been very successful, as in the latest revision (2021) it has been replaced by calculation of texture skewness, shape factor (g-factor), and texture spectrum.

The options currently under consideration are as follows:

1. **Modelling of test track noise properties:** Very tight requirements on road surface texture, including MPD (Mean Profile Depth) according to ISO 13473-1, skewness according to ISO 13473-2 and texture spectrum according to ISO/TS 13473-4 (also the German-derived g-factor is included in the latest version, but the authors think it is not needed as the skewness is an international and common parameter describing profile asymmetry equally well).
2. **Round Robin Tests (RRT):** RRT:s may be performed at regular time intervals to determine how the track noise properties differ between each other or to a defined reference. Thereafter a correction may be made to normalize all tracks to a similar and defined reference. For examples of RRT:s see Chapter7.
3. **Calibration by using reference tyres:** By selecting reference tyres with very stable tyre/road noise properties and measuring noise emission from them at regular time intervals on every ISO test track the method can provide a relatively accurate measure of the test track noise properties. These can then be used to normalize the surface to a defined reference.
4. **3D-printed reference surface**: A durable and accurately copied hard surface from a defined ISO test surface can be applied in the wheel tracks of the test track using 3D-printing. It can be used to produce replicas of a reference surface (the same for all users worldwide) applicable and virtually identical on all test tracks. Most of the deviations in noise properties can be eliminated if this method is used. Although 3D-printing is already possible, in principle, it is not yet tried to lay such pavement replicas on an actual test track, but it is technically possible.

Very limited RRT:s have been conducted in the past, as they are expensive to perform. It is impractical and too expensive to perform on most ISO test tracks worldwide. A more practical and less expensive method is “Calibration by using reference tyres”. Therefore, the RRT option is not treated in detail here.

The 3D-printing option will likely be implemented in the future; although it may be in a future indoor method using a laboratory drum covered with the 3D-printed pavement replica. It is not further discussed here as it is not yet fully practical to implement. Discussion about the implementation of drum measurements are currently taking place in various working groups. It is expected that future work will investigate the performance of the drum method in regard to noise labelling measurements, possibly including implementation of some kind of quality verification.

## 8.2. Modelling of test track noise properties

### 8.2.1. Test track surface parameters to consider in modelling

Based on the knowledge about noise generation mechanisms, for example in [Sandberg & Ejsmont, 2021], and the limitations in design and construction for ISO 10844 surfaces, the following surface features should be included in a model adapted to ISO 10844 surfaces:

1. Macro- and megatexture represented by MPD or texture spectra. Since the aggregate mix (sieving curve) is specified, the MPD should reasonably well represent the relevant texture depth property, so spectra would not give much extra information.
2. A texture measure that takes texture profile asymmetry properties into consideration, such as skewness (or less preferred the so-called g-factor) is very important.
3. A texture measure that takes texture enveloping properties by tyres into consideration. Currently, there is no such standard method, but in the meantime, skewness can potentially represent some of the enveloping properties too (but probably not sufficiently).
4. Sound absorption in third-octave bands is an important part of a model.
5. A measure representing the tyre/road stick-slip in the contact patch. This is probably not representing a major part of the surface influence at coast-by or cruise-by conditions but should not be forgotten. For this purpose, one could use the British Pendulum Value as a temporary measure.
6. A measure representing the tyre/road stick-snap mechanism in the contact patch. The importance of this mechanism is not sufficiently explored, but potentially it may be an important effect for a smooth-textured surface with bitumen cover as typically ISO surfaces.

### 8.2.2. The $END_T$ procedure

The $END_T$ procedure was used in the 2011 and 2014 editions of ISO 10844, but was deleted in the 2021 version, since it was considered that the Müller-BBM method would be better. It is a complicated calculation procedure based on texture spectra of the surface profile which is compared to a reference spectrum. The result is a predicted difference in noise level compared to the reference surface texture.

The procedure has the disadvantage of missing the sound absorption properties and the asymmetry of the surface profile. Neither does it consider stick-slip or stick-snap motions in the tyre/road interface.

It is not considered further here as it would probably be inferior to the Müller-BBM procedure described below and that success stories do not exist, although an interesting report is available [Ammerlaan & van Blokland, 2009].

### 8.2.3. The Müller-BBM procedure (as used in the RRT by VDA)

This method appears to be suggested by the consultant company Müller-BBM and used in the VDA study reported in Section 7.1.3.

Based on the measured surface parameters explained in chapter 7.1.3, VDA developed an equation for estimation of a pass-by level at 50 km/h as shown below:

$$L_{p,cruise,50} = 60.3 + 27.7 \cdot MPD^{1.5} - 126 \cdot (g \cdot MPD)^{4.3} - 36 * \alpha^{0.9}\ [dB] \qquad (6)$$

where

$MPD$ = Mean profile depth in mm

g = g-factor, a factor between 0 and 1.

α = sound absorption factor, between 0 and 1

Figure 8-1 shows a comparison between calculated values from equation (6) and measured levels. It is assumed that the measured levels are the average of all 7 tyres. The differences between the measured and calculated data suggest an uncertainty (95 % coverage) of only (±) 0.5 dB. Such an uncertainty, if achieved generally and not just in the VDA study, would potentially be useful to normalize the ISO test tracks to within an expanded uncertainty of less than 1.0 dB, which would be a great progress.

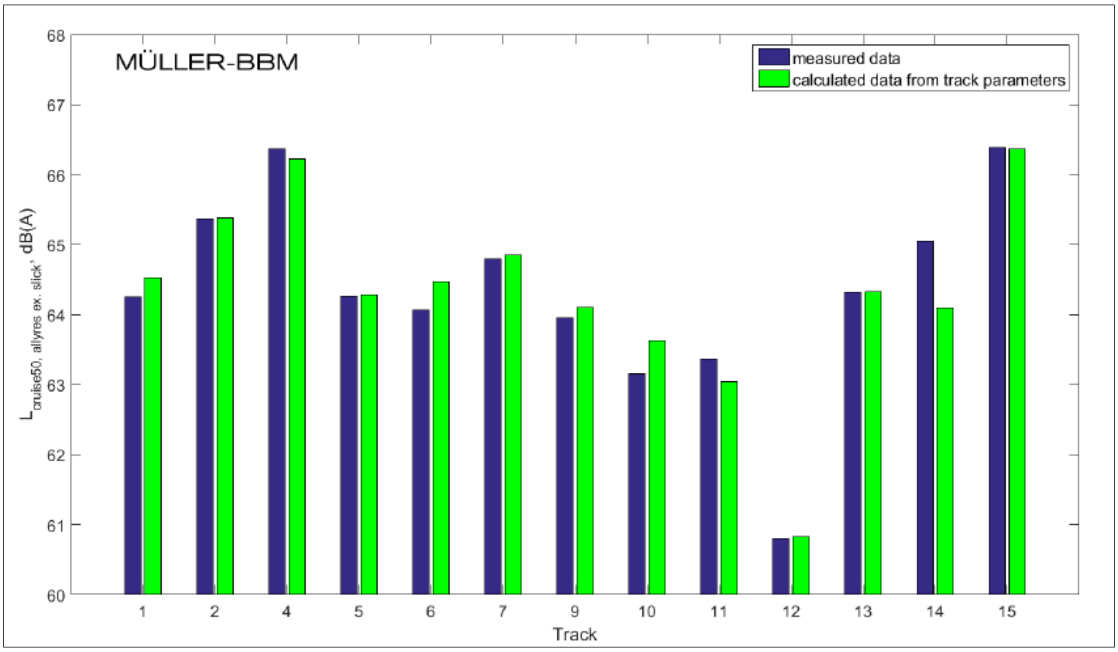



Figure 8-1: Comparison of calculated levels (green bars) according to equation (7) and measured cruise-by sound levels at 50 km/h [VDA 2019].

It should be noted that equation (6) now has been modified somewhat:

$$L_{crs} = 60.3 + 27.7 * MPD^{1.5} - 143 \cdot \left(\frac{g \cdot MPD}{(100 \cdot 0.97)}\right)^{4.3} - 36 * \alpha^{0.9}\ [dB] \tag{7}$$

However, the uncertainties will not be significantly changed.

## 8.3. Reference Tyre Calibration – the principle

It is suggested that the solution to the reproducibility problem is to introduce a calibration procedure. Such a calibration procedure has become possible recently, after a number of other ISO standards have been completed and published. Briefly, it is suggested to include:

1. Using a set of reference tyres of the SRTT 16" type, specified in ISO/TS 11819-3,
2. mounted on a relatively well-defined vehicle,
3. conducting tyre/road noise measurements according to the method in R117,
4. normalizing the resulting noise level to a reference temperature using ISO/TS 13471-1,
5. and then normalizing the final result to some defined ISO 10844 reference level.

Then the tested ISO test track will be normalized to a common reference level, reducing the spread between results on different test tracks to a significantly lower level. In this way a rather robust method can be designed.

## 8.4. Reference Tyre Calibration – description of the procedure

### 8.4.1. Reference tyres

The reference tyres must be produced to the highest possible standards and be available for a long time. As reference tyre, the 16” SRTT (Standard Reference Test Tyre) defined in ASTM F2493:20 and in ISO/TS 11819-3:2017 is suggested. This is the tyre available as a reference tyre, which has the most favourable properties for distinguishing between surfaces of this type, and at the same time have dimensions and a tread pattern similar to that of passenger car tyres. The ASTM standard defines the tyre and some of its properties, but ISO 11819-3 has some supplementing details that should be observed. The noise properties of the 16” SRTT has been demonstrated to have good correlation with noise properties of other passenger car tyres and with light traffic in general.

See further details in Annex A and its Figure 3 which shows the tread pattern of the tyre.

In order to average out a major part of the unavoidable tyre-to-tyre noise differences, due to tolerances in the production, it is suggested that eight tyres are used for the calibration; i.e., two sets of four tyres. These eight should not be from the same production batch; ideally, they should be from different production batches.

Tyres shall be loaded and inflated according to requirements in R117. Run-in and warm-up shall be according to ISO/TS 11819-3. The latter also specifies how the tyres shall be stored. It is suggested that these tyres are set aside to be used solely for this purpose, to avoid wear.

The tyres shall be checked for their rubber hardness before use, observing the method in ISO/TS 11819-3, at a temperature close to 20 °C and the result shall be within the specifications in ASTM F2493:20. If hardness has increased due to aging or use, they can be used even if hardness exceeds the maximum in the ASTM standard by up to 3 units, but then a correction for increased noise properties shall be done, according to ISO/TS 11819-3. If tyres are not used for other purposes and stored according to the advice, they may be used for such calibration purpose up to 10 years, we think. An investment in 8 SRTT:s for 8-10 years would not be a significant burden compared to other test track costs.

### 8.4.2. The test vehicle and the noise measurement procedure

In the Inter-Noise 2017 paper in which this procedure was first proposed (and which is copied in Annex A), the CPX method described in ISO 11819-2 was suggested to be used. However, in this Deliverable it is proposed to use a coast-by method of the type specified in R117 and ISO 13325.

The test vehicle shall be a four-wheel passenger car on which the tyres fit and can be loaded to the same load on all tyres. The vehicle shall meet the requirements and be driven as specified in R117; i.e., at coast-by. This includes the wheel alignment.

Ideally, the vehicle and tyre industries should agree on a particular car (for each range of tyre sizes) to be used worldwide for this purpose; or possibly cars from each continent (one, European, one Asian and one American, for each range of tyre sizes) which are assumed to influence noise emission and propagation in the same way. Preferably, it should be checked if such cars would give different tyre/road noise, to minimize the vehicle influence on noise measurements.

Note that, as 8 reference tyres are used, they need to be tested in two sets of four tyres, mounted on the same test vehicle. The direction of the driving shall be the same as normally is used for R117 testing.

Noise tests should be made in full accordance with R117 for the range 70-90 km/h. In case the test track is also used for vehicle noise tests, measurements should also be made for the reference speed of 50 km/h; in this case with the same number of runs as in R117 and within the speed range 45-65 km/h.

### 8.4.3. Temperature corrections

In ISO/TS 13471-1:2017 a quite robust procedure for temperature corrections for noise measurements on the SRTT is presented. It is based on air temperature and expressed as a “temperature coefficient” (γ) in dB per °C, and for the SRTT and a dense asphaltic surface such as the ISO 10844, the coefficients will be:

$\gamma$ = -0.11 dB/°C at 50 km/h

$\gamma$ = -0.09 dB/°C at 80 km/h

Normally, tests within the range 5 to 35 °C are allowed. However, in the case of calibrations, stricter requirements on the temperature range are needed. To reduce as much as possible the uncertainty in the temperature correction, the aim should always be to measure during a season when air temperatures are the closest to 20 °C. In no case, the range 10-30 °C (air) should be exceeded.

### 8.4.4. Reported ISO 10844 Calibration Level

The average of all measured tyre/road noise levels, by means of regression read at the nominal speeds 80 or 50 km/h, normalized to the reference air temperature of 20 °C, should be the reported value, here named “**Calibration Level**”. This represents the tyre/road noise property of the ISO surface on the test track. Measured values shall not be truncated to integers and no subtraction of the type included in R117 should be made.

### 8.4.5. Global Average Level and Test Track Correction constant (TTC)

After a large number of test tracks of varying ages have been calibrated by this procedure, one can calculate a “global average” of them all. The nearest integer dB value to this average should be selected as the “**Global Average Level**”. Then a “**Test Track Correction constant (TTC)**” may be assigned to the particular test track which is the difference between the Global Average and the Calibration Level. All tyre/road noise levels measured on an ISO test track would then be corrected by this TTC constant. The TTC may be updated at time periods according to the results of the most recent calibrations.

### 8.4.6. Frequency of calibration procedures

Since it is well-known that surface properties change with time, especially the first years, it is suggested that calibrations according to this proposal are conducted at times after laying of the surface, as follows:

- First time, when the surface is 3-6 months old
- 2nd time, when the surface is 12-18 months old
- 3rd time, when the surface is 3 years old
- 4th time, when the surface is 6 years old
- 5th time, when the surface is 9 years old
- … and so on, each 3rd year if the surface is still in good condition and if the calibration level has not changed more than 3 dB over the lifetime. It would also be practical to make an extra certification in conjunction with the first calibration.

It is expected that the TTC will change significantly during the three first years; depending on ageing and the traffic on the test track. The normalization procedure will reduce much of the effect of such changes.

## 8.5. Implementation of the Reference Tyre Calibration procedure

To check the effect of implementing the Reference Tyre Calibration procedure, data of the most comprehensive RRT we know about is used, namely the VDA study reported in7.1.3. The values presented in Figure 7-5 have been used to produce a Calibration. The average values of the tyres (the grey curve in the Figure 7-5) are used (named “All tyres”), but excluding the slick tyre, for the 13 test tracks. Then the values for the SRTT tyre (the red dots) are used for the calibration. The difference between each SRTT value and the average of all SRTT values are then used to correct the “All tyres” data; i.e., subtracting the SRTT difference values from the “All tyres” values. After this correction, a Calibrated result is achieved.

These data are shown in Figure 8-2. Remember that the slick tyre data is not included since it is not a legal tyre. The result is a dramatic reduction of test track noise differences. Table 8-1 shows some core data.

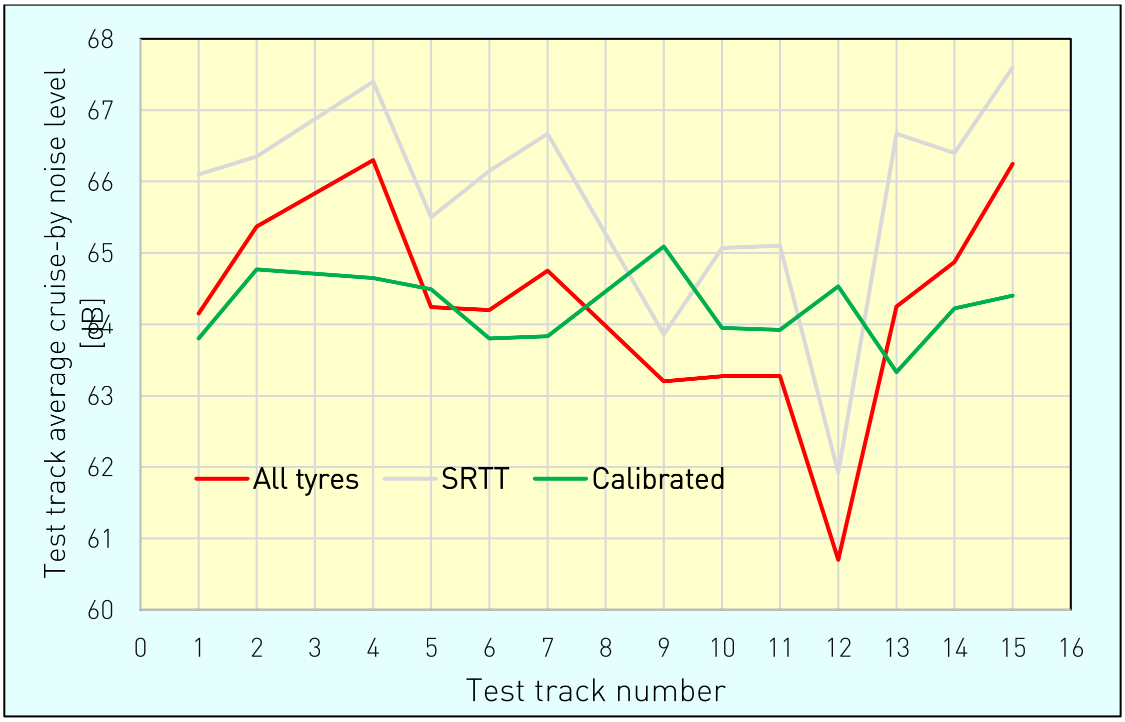



Figure 8-2: Comparison of measured cruise-by sound levels at 50 km/h for each test track (average for all tyres excl. the slick tyre in red) and the corresponding sound level for each test track after implementing the Reference Tyre Calibration procedure (calibrated data in green). The data for the SRTT tyre is shown in the background in light grey colour. See text for further explanations.

A comparison of the grey (SRTT) and red (market tyres) curves in Figure 8-2 shows that the shape of the curves are similar. This means that the SRTT is fairly representative of the market tyres in terms of noise properties of the ISO surfaces, even though it is of a much older design. The same has also been found for classification of road surfaces for high-speed (car) traffic noise in general [Kragh et al, 2015].

In principle, one can find market tyres that would have similar properties as the SRTT in this respect. They would be much cheaper. So, why not use them instead? The reason is that market tyres are available only for a few years. Furthermore, they are rarely the same over the time period when they are available, as small improvements are often made from one year to another, even though the trade name stays the same. There is no guarantee that they are sufficiently stable in time as one would expect for reference tyres, not even for a few years. This will introduce an extra uncertainty factor. A standard tyre as the SRTT is subject to more rigorous production and is intended to be stable and available for a long time. For example, the 14” SRTT (which was the predecessor to the presently considered (16”) SRTT), was available for more than 30 years.

For the label values to be comparable over many years, the ISO surface must be stable over time regarding its noise properties. A noise measurement in (say) 2030 should give the same value as a measurement in (say) 2022 for the same tyre. This is possible only if the same calibration procedure and the same reference tyre(s) for the calibration can be used over the time period, and that those tyres are not modified. The use of market tyres cannot guarantee that. Actually, over the period when the ISO 10844 has existed (27 years), a firm aim with all modifications has been that the latest ISO surface specification would also be acceptable according to the older specifications; in this way at least in principle preserving the comparability over time.

Table 8-1: The result of implementing the Reference Tyre Calibration, in summary. Note that even if it reads “All tyres” the slick tyre is excluded.

| | **Average noise level [dB]** | **Noise level difference max - min [dB]** | **Standard deviation of noise levels [dB]** |
|---|---|---|---|
| All tyres on all test tracks | 64.22 | 5.55 | 1.46 |
| SRTT on all test tracks | 65.75 | 5.68 | 1.53 |
| All tyres on all tracks after calibration | 64.21 | 1.44 | 0.49 |
| Influence of test track on noise levels after/before calibration, in % | | 26 % | 34 % |

It appears that the spread in noise levels among test tracks is substantially reduced. See further the discussion.

## 8.6. Discussion

### 8.6.1. Tightening of the ISO 10844 test surface requirements

Practical experience with laying of test tracks in the past 5-10 years have indicated that it is difficult to construct a pavement with closer tolerances than today at such low texture levels. Part of the problem is that the required texture is so low. The problems are illustrated by the practical examples of laying that are included in the present edition of ISO 10844, which are deleted in the edition of 2021 with the motivation “Avoided conflicts and confusion in interpretation of the technical requirements in the standard” [ISO/FDIS 10844:2021].

Nevertheless, it would be better and easy to move the lower limit of MPD from 0.3 to 0.4 mm. It will somewhat increase the problem for road paving companies to succeed with its paving in the first “shot”, but it would be worth it.

### 8.6.2. Homogeneity of the texture

The coast-by, cruise-by and accelerated pass-by are all methods relying on measuring a transient noise signal. Several issues make the time and spatial location of the peak A-weighted level a complicated matter:

1. Inhomogeneity of the texture is a well-known and unavoidable feature of pavement surfaces
2. Directional properties of the noise emission is a variable depending on the tyre and the surface, but perhaps most of all
3. Screening of noise propagation paths continuously changing during a pass-by, due to the vehicle body and wheelhouse resonances, and also by tyres is another complicated issue.
4. Additionally, multiple sound reflections between the vehicle underbody and the road surface is another problem influencing the noise propagating under the body from the tyres on the other side than the microphone; especially in the presence of a small patches of sound absorption.

5. Finally, a contributing factor is the distance the noise travels to the microphones when the maximum noise level is reached. It is not always when the vehicle is at the closest position that the maximum noise occurs. This factor also depends on the homogeneity of the surface texture.

An example of how noise emission may vary during a vehicle noise passage is illustrated in Figure 8-3 which is a recording of time history per 10 m of five pass-bys made with a CPX trailer with the microphones close to the tyre and moving with the vehicle. Note the big difference between the wheel tracks and the variation between 10 m segments. The difference between the five curves within a wheel track is an effect of not driving exactly in the same lateral position each time. It is clear that homogeneity is a problem both longitudinally and laterally. The variations may be caused not only by surface texture inhomogeneity but also because of small vertical vibrations ("jumping") of the vehicle when it passes over a joint between the drive lane surface and the run-in surface.

This problem is one of the reasons why reproducibility and even repeatability of ISO test track measurements of maximum sound levels are far from ideal. It means that spot measurements of noise and texture and sound absorption features are not ideal and continuous measurements over the test track length are preferred. But the best would be if the surface properties near the expected position of maximum noise levels are weighted higher than the data further away from that position.

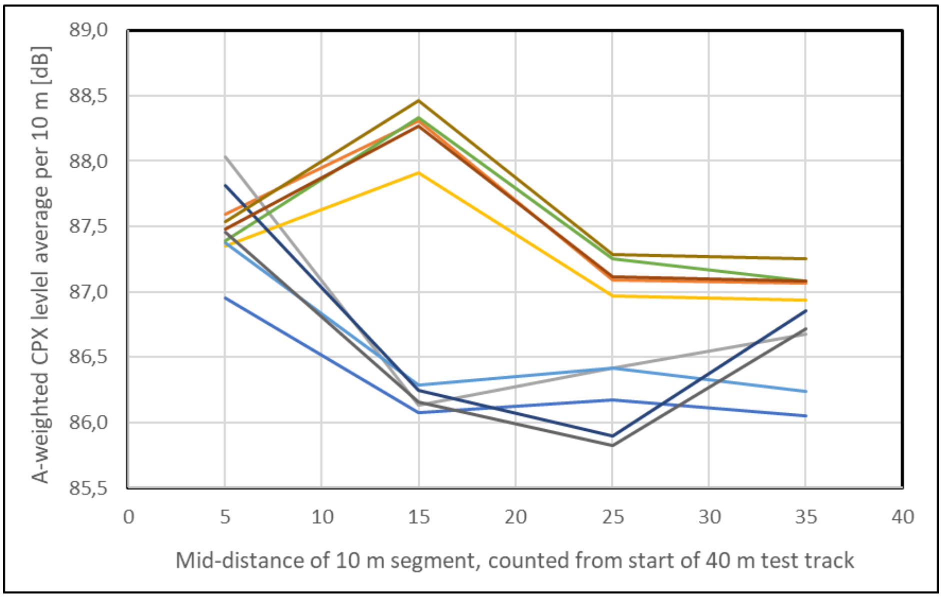



Figure 8-3: A-weighted CPX levels as a function of distance from start of drive lane (average per 10 m distance). The upper five curves are for the eastern wheel track and the five lower curves are for the western wheel track. The measurements were made on a two-month-old ISO test track laid 2020 near Skövde in Sweden.

### 8.6.3. The Müller-BBM procedure

At first sight of the results in Figure 8-1 this procedure looks like a great success. But when considering it closer, it may not be so. One disadvantage of the Müller-BBM procedure is that it misses the noise generation mechanisms stick-slip or stick-snap in the tyre/road interface, the contributions of which are unknown except that they exist. Another and much more significant disadvantage is that there are three parameters in the equation and all of them are subject to significant uncertainties. Especially the MPD parameter has a very high sensitivity to the uncertainty of its measurement at the low MPD values that most ISO test tracks have (0.3 – 0.5 mm). Further, when developing/optimizing the procedure, the uncertainties in the tyre/road noise measurements contribute to the uncertainty of the procedure.

It is difficult to make a sensitivity analysis, but it can be mentioned that only the MPD determination has an uncertainty (95 % coverage) given in ISO 13473-1 of (±) 0.08 mm. If the measured MPD is 0.40 mm (for example), it will mean that MPD uncertainty limits would be from 0.32 to 0.48 mm, which will give a spread in dB values in Equation (6) of up to 4.2 dB. And this is without the uncertainties of the g-factor, the sound absorption and, not the least, the shortcomings of the model itself.

Therefore, the Müller-BBM procedure has a potential to give so high uncertainties, potentially amounting to several dB, which would limit or even disqualify the general use of the method.

Despite this, the differences between the measured and calculated data in Figure 8-1 suggest an uncertainty (95 % coverage) of only (±) 0.5 dB according to the author's calculations. If this model would be used to normalize the 13 test tracks in the VDA study to a common reference with the mentioned uncertainty, this would really look like a great success. But then one must realize that the model is optimized for exactly the measured values and conditions in this experiment. Such optimization can be done well if sufficiently many parameters are selected, and the same equipment and the same operators are used for all test tracks. But it may not work at all for another set of data, collected with different equipment and operators on different test tracks. In fact, it is unlikely to give so good results then, unless the coefficients are recalculated to fit the new data. And this would not be useful as a general method then.

### 8.6.4. Reference Tyre Calibration

The advantage with this procedure is three-fold:

- All tyre/road noise mechanisms are covered, not only those which are causing influence by surface texture, profile asymmetry and sound absorption
- No extra test instruments are needed
- Uncertainties are low and there is no large sensitivity to any uncertainty factor which may vary from region to region

It all depends on the basic assumption that the SRTT tyre is sensitive to ISO test track surface properties in the same way as normal tyres. That this is the case has been demonstrated in many studies related to characterization of road surfaces, for example in [Kragh et al, 2015] and [Donavan, 2010], and is even the justification for selecting this tyre as a reference to represent light vehicle tyres in traffic. Nevertheless, it is unavoidable that some tyres are special and will always fall outside the general picture. It is simply impossible to produce test tracks which will rank all tyres in the same way on any of the tracks.

The Calibration procedure suggested here would be easy to implement worldwide and requires only tyre/road noise measurements, including temperature correction (plus checking the rubber hardness). It does not like the Müller-BBM procedure require any advanced surface measurements; instead requires investment in eight SRTT tyres, although this may not be needed more than one time per decade. In fact, as the tyres will be used so rarely, they and even the test vehicle can be shared by some test track owners located within reasonable distances.

The uncertainties include the following sources:

- Variation in noise levels between SRTT tyres
- Uncertainty in the temperature correction
- Influence of test vehicle
- Uncertainty of the noise measurement, if anything in addition to the above sources

The variation between SRTT tyres was studied by Donavan [Donavan, 2010]. He tested four one year old but unused (except for drive-in) SRTT:s and two 2-year-old and used SRTT:s. They all had rubber hardness (Shore A) of 64 ±1. They would most probably have come from at least two different batches. When they were tested at highway speeds (probably 50 mph) on two dense asphalt pavements, an average standard deviation of 0.24 dB between individual tyres was obtained. Approximately the same estimation has been made in the uncertainty estimations of the SRTT in ISO/TS 11819-3. For an average of eight such tyres, standard deviation would shrink to below 0.10 dB.

The uncertainty in temperature correction could amount to max. ± 0.2 dB, if we assume that the temperature coefficient may be in error by 20 % and temperatures would differ 10 °C from the reference 20 °C.

The vehicle influence should be low if a decision can be reached as to what vehicle to use. However, with the assumption that it is possible only to agree on one car in Japan, one in Europe and one in America, and if these are as similar as practical, the influence should be possible to reduce to less than ± 0.2 dB. The only uncertainty would be the difference in influence between those three vehicles and it should be possible to select them to be similar in terms of ground clearance, tyre/wheel screening, wheelbase, etc.

The average of all noise measurements from all the runs (and two sides) should have a statistical uncertainty of much less than 0.2 dB.

Overall, this should sum up to an uncertainty (with 95 % coverage) of max 0.5 dB. As this procedure is general and not optimized to fit measured data in any particular RRT, this procedure would be independent on where in the world and by whom the calibration is made.

The implementation example showed excellent performance of the procedure. The spread in noise levels between the test tracks was reduced to only one-third of the non-calibrated data. In Figure 8-1 the standard deviation between the predicted (by Müller-BBM) and measured values is approx. 0.34 dB. This is lower than the 0.49 dB by the Reference Tyre Calibration procedure. However, it is not a fair comparison, since the Müller-BBM calculations are based on a model optimized using the same data as it is implemented for and with three surface variables. The same model will not give so good results at all for other RRT:s; especially when the texture and sound absorption values are measured by other devices, as it is extremely sensitive to measurement uncertainties of texture and sound absorption. In contrast, the Calibration procedure uses a general model which will be the same for all similar RRT:s. Of course, more implementations should be tested to give a statistically robust value but the example with the VDA noise measurements was indeed very promising. It will also be possible to check the procedure (for three ISO test tracks) when the ELANORE project is resumed in 2022.

## 8.7. Conclusion and recommendations

First, it should be noted that the STEER proposal originally included conducting an own advanced RRT, which would be used for testing the implementation of the Calibration procedure. However, this part of the project was cut away by budget restrictions imposed by the sponsor.

It does not seem that the specification about how the ISO surface shall be constructed can be tightened significantly, with the aim to reduce spread in noise levels between test tracks, compared to the present situation. The exception is that the lower MPD limit should be moved from 0.3 to 0.4 mm. This would reduce the MPD variation (lowest to highest) from 133 % to 75 %. Simultaneously it would mean that surfaces which would not be accepted for highway use due to wet friction concerns would not be used for noise testing (even though many countries would not accept MPD values of less than 0.5 mm on highways).

The inhomogeneity of ISO test tracks should be addressed more than presently. However, it may practically be difficult to improve homogeneity substantially compared to now, since it is such an extreme surface. Instead, it may be worth considering the use of time averaging (like SEL, but over only the length of the ISO drive lane surface) to avoid the sensitivity to the noise peak. The present dependency on a noise peak that is influenced by surface inhomogeneity is unlucky. It is actually a similar situation as for noise characterization of road surfaces, where SPB measurements rely on noise peaks, but CPX measurements are preferred as they do not depend on spot-wise noise properties.

The Müller-BBM procedure for predicting the noise performance of ISO tracks seems to have been a success in the VDA study. However, it is because the procedure has been optimized based on the data in that study, something which is not likely to hold so well in other studies. Most of all, it is extremely sensitive to uncertainties in the MPD determination; especially for the low MPD values (0.3 to 0.5). It therefore has a potentially low reproducibility.

The Calibration procedure using reference tyres would be more generally applicable since it is not optimized for any particular set of data and is not sensitive to uncertain surface parameters. It still has uncertainties, but an estimation suggests that it may be limited to around 0.5 dB (as uncertainty with 95 % coverage). That would substantially reduce the present spread in noise levels from different test tracks around the world.

The Calibration procedure is suggested to be used for normalization of noise properties of ISO test tracks.

# 9 Overall conclusions

More comprehensive and detailed conclusions are found in Sections 5.8, 7.4 and 8.7. The following is an overall summary of the conclusions.

This Deliverable has confirmed that reproducibility of tyre/road noise measurements for purposes of tyre labelling is a major problem. This is especially due to the correction for temperature effects on the noise measurements, but even more for the lack of reproducibility of test track surfaces produced in compliance with ISO 10844. Here are the main conclusions from the STEER project related to reproducibility.

The difficulty in agreeing on defined test vehicles for the various sizes of tyres has resulted in uncertainty contributions which are significant. A standard for test vehicles for tyre/road noise emission, adapted for a minimum influence on such measurements and for long-time use would be desirable. Such vehicles would replace present test vehicles from the commercial market and be more independent of fashions of the time. They could also be tailored to be used for a wider range of tyre dimensions and loads; in that way reducing the number of needed test vehicles.

Regarding temperature influence, currently there is almost a chaotic situation as there are three major proposals on how to correct for temperature effects:

- ISO/TS 13471-2 which (in 2022) proposes using ambient air temperature for noise corrections and a simple linear correction based on a certain temperature coefficient (dB per degree C).
- The tyre industry which supports the existing temperature correction in R117, which is more than 20 years old and based on road surface temperatures and is nonlinear. The temperature coefficients seem to be too conservative at least for temperatures above 20°C.
- The vehicle industry which suggests a new temperature correction based on air temperature, with temperature coefficients rather close to ISO, but slightly nonlinear.

This Deliverable has explored the three versions and tried to show how they are connected by suggesting a way to convert corrections between the air and road temperature options. It also reports analysis of some old comprehensive data and new data received in the last months. It is concluded that the currently best temperature correction is a linear one based on air temperature and implying a greater correction at high temperatures than the one presently used in R117. It is also concluded that it is possible to convert corrections between those based on air and those based on road temperatures, and that it follows that the road-based temperature corrections will be non-linear while the air-based ones are linear. Finally, it is concluded that as air and road temperatures vary substantially between various climatic regions, as soon as possible, the corrections should be improved by basing them on <u>both</u> air and road temperatures. But to quantify the correction coefficients, new research must be conducted.

In this Deliverable, STEER has reported all Round Robin Tests (RRT) which have been known through published work or by personal involvement. However, STEER originally proposed to make an own RRT within the project as the ones available had several constrictions making it difficult to draw the conclusions we need. Unfortunately, the budget was cut down so the planned RRT could not be conducted. Consequently, our conclusions are the best we can draw considering the partly incomplete data available.

Design and construction of test tracks for type tyre noise approval and labelling purposes are specified in ISO 10844, which to date include four editions; where the last one (2021) is under publication. After the first edition of the ISO 10844 was published (1994), two known RRT:s were conducted, one in Europe and one in Japan. When a couple of test tracks in Europe were not considered because of unacceptable performance, the rest indicated that the spread in noise levels for both the Japanese and European test tracks was between 2 and 4 dB depending on which tyre that had been used. After the 2011 and 2014 editions of ISO 10844 were published, two more RRT:s have been conducted, one by VDA in Germany and the other by ETRTO. The ETRTO study gave approximately the same results as the earlier ones, but the VDA study, including as many as 13 test tracks in Germany, Italy, Spain and

Luxemburg indicated noised spreads between test tracks up to 6 dB. When the results were explored further it appeared that two of the 13 test tracks had somewhat higher sound absorption than acceptable which resulted in too low noised levels. This had not been detected in the certifications of those test tracks. It thus appears that despite the stricter requirements in the 2014 edition of ISO 10844, test tracks are constructed and used, while they may not actually meet the requirements. This calls for a more ambitious follow-up of the performance of such test tracks.

Whether the spread in noise levels is up to 4 dB or up to 6 dB, these variations are clearly unacceptable. For example, 6 dB is approx. the entire spread in noise levels between market tyres. Some of this spread assigned to tyres may therefore actually be due to the test tracks used during testing.

One should note that so far we know only about RRT:s in Europe and Japan. What results one would get in (say) China, India or Indonesia is only subject to speculations. Studies have been made in China but results are not available.

Homogeneity, or rather inhomogeneity, of the test tracks is a serious problem. It has appeared that paving surfaces according to ISO 10844 often if not mostly needs iterations (initial failures must be followed by new paving operations) and despite this, it is difficult to achieve the homogeneity within the critical surface areas that is desirable. Since the noise measurement means that the peak in noise when the vehicle passes over the standardised area, it is important where on the drive lane the peak appears, and that the surface properties on that spot are important. This problem needs more attention.

One experience from the RRT:s is that in order to give clear and useful results it is not enough to include only a few (say 3-5) test tracks, but one should aim at including at least 10 tracks. The VDA study included 13 tracks, and this appeared to give a lot of useful information.

It should be noted that at the end of STEER, a Polish-Norwegian bi-national project ELANORE has started to conduct an RRT, instead of the one STEER did not get funds for. However, it appeared that due to, among others, bad luck with weather conditions, the measurements and analyses have not become available in due time for this Deliverable.

One reason for the problems of the test tracks is that the latest editions of ISO 10844 have required MPD values be within the range 0.3 to 0.7 mm. Both Sweden and Belgium have objected to this in the ISO revision of ISO 10844 which is just completed since MPD values below 0.5 mm of MPD are not suitable on highways as they would mean high risk of wet friction and hydroplaning. But such smooth textures are also difficult to produce with the high homogeneity needed while simultaneously measurements of such small MPD values give high relative uncertainties.

The unacceptably high variation in surface properties between test tracks calls for introduction of some sort of calibration procedure of test tracks, so that a correction can be added to get more uniform and reproducible noise results. To this end, a procedure named $END_T$, which used texture measurements to predict how the surface influences noise measurements, was first tried, but not with significant success.

Recently, a new procedure (or model) by the company Müller-BBM has been suggested, based on the results of all surface and noise property measurements in the RRT conducted by VDA (mentioned above). This model uses two texture and one sound absorption parameter to predict the noise emission. The result is very good, as it can be used to normalize test tracks to a common reference with relatively low uncertainty, but it is useful only within that particular RRT study. It also appears that it is very sensitive to the measurement uncertainties of texture and sound absorption on these smooth surfaces. It is, therefore, very doubtful if it is useful globally to calibrate ISO test tracks.

Instead, STEER has explored the potential use of a calibration procedure using reference tyres, that was proposed in 2017 by this main author. This procedure suggests the use of eight standardised test tyres, produced with the purpose to be long-term references, that shall be used by all test track owners to measure under strict control the noise emission at certain intervals. The results shall be compared to a global referenced and thus the test track can be calibrated to give results according to the reference noise properties (to be set by the international community). The Reference Tyre Calibration procedure was tried for the results of the VDA study which gave very good results. With such calibration, the spread in noise levels between the 13 test tracks was reduced by two-thirds of the non-calibrated variation.

Since the Reference Tyre Calibration procedure is general and only depend on the tyres and to some extent the test vehicle it is potentially a useful global procedure to reduce the uncertainties of the test tracks to acceptable levels.

# 10 Recommendations

The STEER project recommends the following ways to improve reproducibility of tyre/road noise measurements for tyre labelling purposes (which equally well would be useful for tyre type approval measurements). Note that when further research is proposed below, this should not delay the suggested improvements which can be implemented momentarily. To reduce the present problems is too urgent to wait for results of new research. Measuring methods should always be improved when new knowledge or technical resources makes it possible, while preferably preserving traceability back in time. New research takes time but is needed to make possible improvements also later in time.

Although it may be difficult to agree on a global test vehicle standard, we propose that discussions in the relevant forums are introduced, with the potential aim to produce a standard for test vehicles for tyre/road noise emission, adapted for a minimum influence on such measurements and for long-time use. Such a standard will not come quickly, but it is time to start considering it now.

We suggest a temperature correction which should be implemented as soon as possible. However, research should be conducted to allow a further improvement in the temperature correction, so it can be based on a fusion of air and road temperatures instead of just one of the temperatures, since both of them have a profound influence on tyre temperature which should be the optimum parameter for correction.

Correction for the effects of temperature on noise measurements on measurements on general road surfaces should temporarily be based on air temperatures and be linear, but only until there is a model that accounts for both air and road temperatures. The coefficient suggested in ISO/DTS 13471-2 which is based on a synthesis of the best available experimental evidence is recommended. This implies that the existing correction in R117 is too conservative and should be changed to be more progressive; especially at temperatures above 20 °C.

However, as long as we miss enough data to present a model using both air and road temperature, it is accepted that measurements according to R117 continue to use road temperatures. But as the correction has appeared to be too conservative, it is suggested that the temperature coefficients are adapted to our suggestion in Figure 5-15, which leads to higher and more accurate temperature corrections above 20 °C.

It is recommended that increased attention is made on the inhomogeneity of ISO test tracks. An aim should be to try and reduce it, or at least trying to control it. Its influence may be reduced if the current measurement of the noise peak (maximum A-weighted level) is replaced by an integration of noise emission over a time corresponding to the 40 m long drive-lane area.

It is also recommended to change the lower MPD limit in ISO 10844 from 0.3 to 0.4 mm, since the narrower texture range will reduce the variation in noise levels between test tracks.

To reduce the unacceptably high spread in noise levels measured on different test tracks, it is recommended to introduce a calibration procedure. For global purposes, STEER recommends the Reference Tyre Calibration procedure proposed in Sections 8.3 to 8.5, which was shown in an example to reduce the variability between ISO test tracks to one third of the original variability. It is recommended that a standard procedure based on the STEER proposal be worked out and implemented when finished.

# 11 Acknowledgements

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# Annex A: Calibrating the ISO 10844 test surfaces used for vehicle and tyre noise testing

### Copy of paper at Inter-Noise 2017 in Hong Kong

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**ABSTRACT**

When measuring noise emission of road vehicles or tyres, regulations such as ECE R51, R30 and R117 and (indirectly) EU regulations (EC) 661:2009 and 1222:2009, require testing to be made on a reference surface defined in ISO 10844. The first version was published in 1994, and the most recent version is from 2014. The surface is claimed to:

- produce consistent levels of tyre/road noise emission under various operating conditions, including those appropriate to vehicle noise testing,
- minimize inter-site variation,
- provide minor sound absorption.

Originally, ISO 10844 was developed with the aim to minimize tyre/road noise, to cause as little influence as possible on vehicle noise during full-throttle acceleration, and it served well for this purpose. However, it was soon applied also to testing in conditions when tyre/road noise is the only or dominating source. Then, it appeared that various sites gave site-to-site variations up to 5-8 dB(A), probably as some users tried to produce as low noise as possible within the tolerances. The 2014 version aimed at reducing the site-to-site variation to half; i.e. about 3-4 dB(A) by applying new or updated measurement methods, allowing tightening of some technical requirements. However, even 3 dB variation is too much, which will seriously limit the efficiency of noise limits and tyre labelling system. This paper proposes a calibration procedure for ISO surfaces, by which one can quantify the differences and correct values to a global reference.

This is proposed to be based on the use of the SRTT tyre, defined by ASTM F2493:2014. Several tests have shown this tyre to give reproducible values within approximately 1 dB(A). If a number of such tyres are used; say 8, the variation between different sets will potentially be less than ±0.5 dB(A). Testing ISO 10844 surfaces periodically with such SRTT sets can then be used to determine a site-specific calibration level, to be compared to a global average reference. It is proposed to use the CPX method of ISO 11819-2 and a specific type of CPX trailer, and to observe the requirements in ISO/TS 11819-3 about reference tyres.

## A.I. Introduction

When testing noise emission of road vehicles or tyres, such as for type approval, determination of tyre noise labels or during development of new products, the measurements are usually conducted on the test track reference surface specified in ISO 10844 [1,2]. This reference surface is used in most, if not all legal requirements for such measurements, such as UN ECE Regulation 117 [3], Regulation (EC) No. 661/2009 [4], and Regulation (EC) No. 1222/2009 [5]. In many cases, there are also national variants of these regulations that also require the use of the ISO 10844 surface.

It follows that test tracks paved with a surface according to ISO 10844 exist in hundreds all over the world. For example, virtually all vehicle and tyre manufacturers own them, and there are several independent but commercial proving grounds, and some test surfaces are in the hands of universities or governmental research institutions.

The first version of ISO 10844 was published in 1994 [1]. Then a new version was published in 2014 [2]. Still, the 1994 version is required in most legal documents but the intention is to switch to the 2014 version within the next few years. Read more about this in the "History" section.

## A.II. Purpose of this paper

The purpose of this paper is to describe some of the problems with variation in acoustic properties between test sites with ISO 10844 surfaces and suggest a procedure by which one can calibrate such surfaces. This will make it possible to normalize the surfaces to a common noise level, which is expected to result in much lower site-to-site variation.

The calibration procedure has become feasible thanks to new ISO standards about measuring methods, reference tyres and correction for temperature variations.

## A.III. The principles of the surface specifications

The area traversed by test vehicles running through the test strip is covered with the specified test material, which is a dense asphalt pavement, with suitable margins for safe and practical driving. Figure 1 shows a plan of a suitable test site and indicates the minimum area which shall be machine laid with the specified test surface material. This requires certain geometrical features of the test area, where the central area on which the maximum sound levels are obtained (drive lane area) and the area over which sound propagates to the microphones have strict requirements.

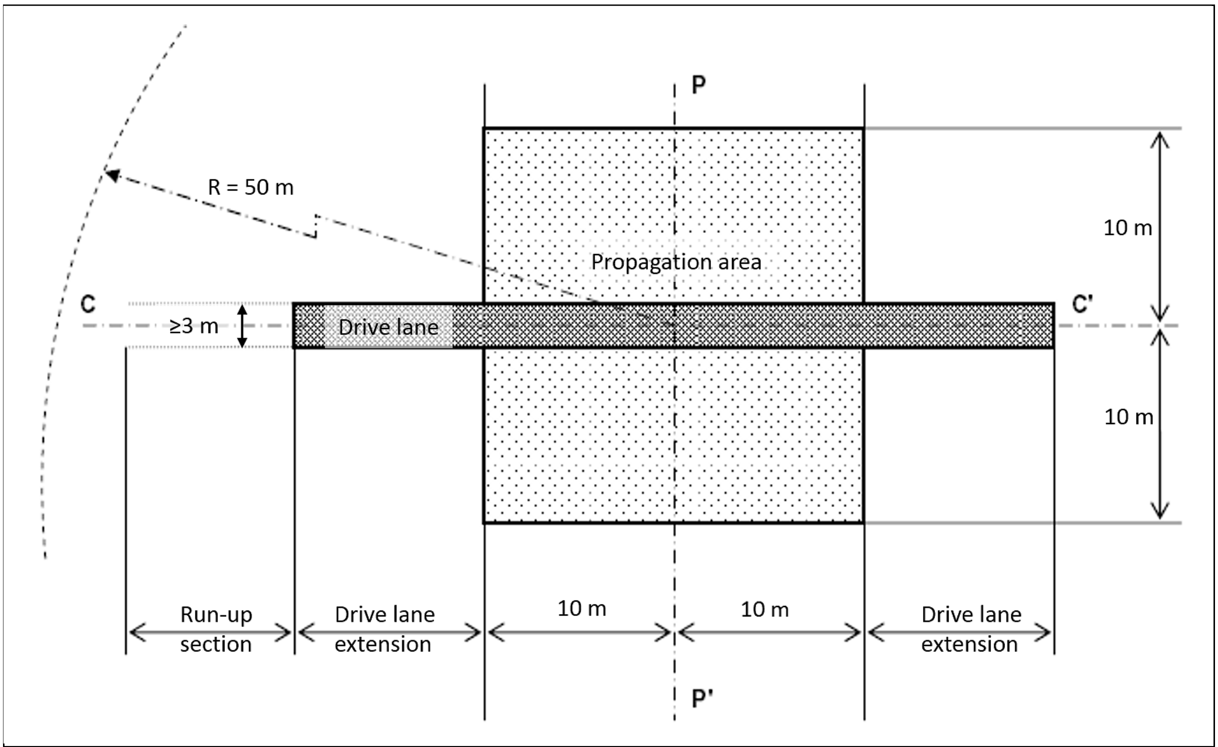



Figure 1 – Layout and dimensions of the test track, according to ISO 10844:2014 (essentially similar in the 1994 version). Note that microphones are located at 7.5 m from the centre line C-C' along the line P-P', and that drive lane extension is 10 m for light vehicles and 20 m for long vehicles. Test vehicles are driving or coasting on the drive lane from C to C'

The ISO 10844:1994 and ISO 10844:2014 specify the surface similarly in two different ways:

- By some design requirements (sometimes only guidelines), such as geometrical specifications, material and asphalt mix
- By requirements for some technical performance parameters, such as texture depth, sound absorption, unevenness and gradients

The ISO 10844:2014 version does it in a more elaborate way than the 1994 version. The performance requirements are defined by means of international standards, where available at the time of publication. Such international standards were not yet available in 1994.

## A.IV. The history of ISO 10844 development

### A.IV.I Prehistory

Published first time in 1961 as a recommendation, ISO R362 became a formal standard (ISO 362) in 1981 [6]. In 1985 it was supplemented by an alternative method, ISO 7188 [7]. Both methods were designed to measure the noise emission of road vehicles; ISO 362 with full throttle operation from 2nd or 3rd gear, and ISO 7188 combining maximum acceleration and constant speeds into "typical urban driving”. In the absence of any standard on this, in both methods it was stated that the test surface should be as follows. "*The test site shall be substantially level, the surface dry and its texture such that it does not cause excessive tire noise*" and "*...the track shall consist of concrete, asphalt or similar hard material and be free from absorbing materials such as powdery snow, long grass, or ashes*". Today, we know that this is a meaningless specification, allowing a wide range of surfaces.

In the middle of the 1980's it was recognized that tyre noise testing needed a reference surface to give reproducible results. This problem was a substantial part of the work of an ECE/GRRF ad hoc group (chaired by this main author) which resulted in the specification of two reference surfaces; one smooth-textured and the other one rough-textured; see [8] and [9]. This group aimed at obtaining surfaces which would give typical and representative tyre/road noise of actual traffic on roads as this is the only way of ranking tyres correctly with respect to their emission in actual traffic.

The need for two surfaces was acknowledged because there are two major noise generation mechanisms, one acting mainly at low and medium frequencies which would be excited by a rough texture and the other acting mainly at medium and high frequencies (frequently known as “air pumping”) and excited by smooth textures. It implies that a tyre design which is "noise-optimized" need to consider both mechanisms; i.e., excitation both by smooth and by rough textures.

Road surfaces with rough textures are not common in all countries. Consequently, it is desirable to have some flexibility as to the use of the rough reference surface. It was for this reason that this surface was not suggested as a mandatory reference in [9]. This proposal was then forgotten by the legislators in the ECE; partly as somewhat later the ISO surface work turned out to be a more appetizing option; particularly for the industry.

### A.IV.II The 1994 ISO standard

Using ISO 362:1981 transferred into ECE Regulation 51 [10], passenger cars were tested in full throttle operation; yet it was found that results were different on different test tracks. When using ISO 7188 (which, however, never was used in legal regulations) with tyre/road noise dominating at the constant speed test, surface influence was substantial. It became obvious that a much more closely specified surface was needed.

Therefore, in 1986, a new ISO working group, ISO/TC 43/SC 1/WG 27, was set-up with the task expressed as "*The test conditions defined in ISO 362 and ISO/DIS 7188 require a test surface, which is highly reflective and induces minimum tire noise. In order to improve the accuracy and reproducibility of measurements, it is necessary to give exact specifications of the condition of the texture and of the composition of the test surface. These items have not yet been subjected to standardization*".

Consequently, the task was to define a test surface which would have the following essential characteristics:

1. Be highly reflective, i.e. it must not be porous
2. Give a "minimum" of tyre/road noise (one wanted tyre/road noise to be negligible in comparison to power unit noise at full throttle acceleration)
3. Give reproducible testing conditions

The author of this paper was appointed as Convener of the group and a first meeting was held in October 1986. Then the WG worked hard until 1991 when a draft was delivered, but ISO formal procedures with ballots and revisions take time and the publication took place in 1994; just in time for the new EU regulations with reduced limit levels coming into force in 1996.

It takes too much space to describe what ISO 10844:1994 specified, but it must be mentioned that a dense asphalt pavement with maximum aggregate size 8 mm was required, with mean texture depth required to be at least 0.4 mm. Residual voids content of the paving mixture should not exceed an average of 8 %, but if it was not met, a sound absorption requirement would be the determining limit. Then the sound absorption coefficient, measured on a few bore cores, had to be maximum 0.10 between 400 and 1600 Hz. More information about the considerations behind the development of ISO 10844:1994 appear in [11].

Problems were that in the beginning of the 1990’s there were no international standards on texture measurements and the sound absorption standard was just the tube method applied in the lab. WG 27 solved the first problem by copying an existing ASTM standard (E965-87) for measurement with the volumetric patch method (a.k.a. the sand patch method) as an Annex. For sound absorption the Kundt’s tube method of ISO 10534-1 had to be accepted. This lack of appropriate measurement methods triggered the work by another ISO WG (WG 39) to develop texture measurement standards, and a WG 38 to develop sound absorption methods for use in the field. But ISO 10844 had to rely on far from ideal measurement methods. It also was based on self-certification.

The task never was to specify a reference surface for measurement of tyre/road noise, and this was stated in the scope of the standard as "*….since the surface is not intended to produce significant tyre/road noise levels it is not particularly designed for the testing and comparison of tyre/road noise*".

> This International Standard does not take into account the influence on tyre/road noise of purely tyre-related parameters such as tyre construction, tread pattern, inflation pressure and tyre loading. It follows that since the surface is not intended to produce significant tyre/road noise levels, it is not particularly designed for the testing and comparison of tyre/road noise.

Figure 2 – Statement in ISO 10844:1994 under the heading "Scope", copy from [1].

Several organizations or companies started to lay pavements on their test tracks according to various early drafts of the ISO 10844 standard in the period 1988-1991 and it became clear that the work had resulted in an unusually "quiet" pavement with a reasonable site-to-site deviation when measuring car noise at full throttle acceleration. In 1990, a round robin test (RRT) conducted with five cars driven according to ISO 362 on several test tracks documented deviations in overall vehicle noise of 2.5 dB(A) (reproducibility, 95 % probability). This was a great improvement from the 6 dB(A) reported before ISO 10844 was applied, as mentioned in Annex D of the standard [1].

When the standard was applied in the following years, now applied also for tyre/road noise testing, some road contractors attempted to make it even quieter, playing with the wide limits in the standard. Some were successful in this. An RRT conducted in 2005 on seven ISO 10844 surfaces in Europe documented deviations in tyre/road noise (coast-by at 80 km/h) of up to 9 dB(A) for a slick tyre and 7.5 dB(A) for a common "summer" tyre [12]. For example, it appeared that the quietest ISO surface was approximately 5 dB(A) quieter than a common SMA 8 surface.

WG 27 finished its task with reference surface in 1994 and received a new task: to develop temperature corrections to noise measurements.

### A.IV.III Attempts to supplement the standard with a second pavement

In 1997, Sweden proposed based on this author's suggestions, that ISO 10844 should be revised, based on the new standards for texture measurements (ISO 13473 series of standards for measurement of macrotexture by use of laser profilometers) and the ongoing development of sound absorption measurements in-situ. By means of these better measurements methods it would be possible to tighten most of the technical requirements, thus reducing site-to-site variations; something shown in 2005 to be highly justified.

Simultaneously, it was proposed to add a second and more rough-textured reference surface. Together with the existing ISO surface as a smooth surface, but with tighter specifications, the second and rougher surface would form a standard that would resemble the one proposed to GRB in 1990 (see 4.1 above), and thus be suitable to tyre noise testing with the smooth surface enhancing the air pumping mechanism and the rough surface enhancing the impact and vibrational mechanisms.

Essentially, this was approved, but as WG 27 then had other work to do (temperature corrections), the work was assigned to WG 42, which dealt with vehicle noise standards, as a sub-group designated WG 42TT.

In 2001, WG 42 proposed, including a first working draft, the formal work to improve ISO 10844 and to add a second and rougher surface, which was accepted by the noise committee.

Very unfortunately, after that, the work on the second surface was never continued. It did not seem to be popular among the industry representatives.

### A.IV.IV The 2014 version

But the improvement of ISO 10844 was necessary and after several drafts a new version was published in 2014 [2]. As suggested in 1997, it included the use of the new measurement methods on texture [13] and sound absorption [13], leading to tightened specifications; but also adding tough specifications about surface gradient and unevenness.

In the scope of the standard it reads that it specifies "*a test surface intended to be used for measuring vehicle and tyre/road noise emissions*". The latter is contrary to what the first version was intended for; even though no measures were undertaken to make it more suitable to tyre/road noise measurements, except reducing variability. Also the new title reflects the application for tyre noise measurements [2].

The 2014 version is required in the latest versions (2016) of ECE R51 [10] and ECE R117 [3].

### A.IV.V Present status and near future plans

The 2014 version of ISO 10844 is used in the newer versions of the ECE regulations for vehicle and tyre noise. WG 42 will probably be asked to revise ISO 10844 as part of the regular 3-year review of 10844:2014. An RRT for the ISO 10844:2014 was made in 2015/2016 in Germany, but the results are highly confidential. Further RRT:s are expected in Europe and in Japan in the next few years. If deviations still turn out to be large, improvements should be considered.

No RRT based on the ISO 10844:2014 has been published. However, the aim of the revision was to reduce the deviations to half that of ISO 10844:1994; i.e. to around 4 dB(A) (max-min) as measured for tyre/road noise. It is also the estimation of this author.

## A.V. The purpose and use of the ISO 10844 test track pavement

As cited above from ISO 10844:1994, the standard was not designed for the testing and comparison of tyre/road noise. It was designed for vehicle noise testing where tyre/road noise contributions should be negligible. This goal was rather well met for the time when vehicles were tested with full throttle operation and when they did not yet have to meet stringent noise limits.

This is not the case anymore. The ISO 362 has been re-designed into a new procedure labeled ISO 362-1 [15], which is intended to measure vehicle noise under more typical operating conditions than ISO 362 which was intended to measure the maximum noise a vehicle could produce. This, in combination with a trend for lower power unit noise has meant that tyre/road noise now is a very substantial contributor, and in many cases is the dominating noise in the ISO 362-1 test (or in its equivalent in ECE Regulation 51).

The aim with the ISO 10844:2014 was to give more reproducible measurements, but still to maintain the initial noise emission potential of the average ISO 10844:1994 surface, so that no noise limits had to be changed. But, as the reference surface still is intended not to produce significant tyre/road noise levels (see citation above), testing vehicle noise on an ISO surface does <u>not</u> give vehicle noise typical of traffic on common asphalt roads, according to this author’s view. Additionally, the site-to-site variation is even with the 2014 version too large to be acceptable for ISO 362-1 testing when they are the basis for vehicle noise limits.

Worse still is that when measurement standards for tyre/road noise (with the aim to measure the noise emitted by tyres) were produced, such as ISO 13325 [16] and ECE Regulation 117 [3], it was decided to use the ISO 10844:1994 surface. As the tyre labelling system [5] is based on Regulation R117, it also means that the tyre labelling suffers from this problem. As written already two times above (cited from the standard itself), ISO 10844:1994 was not designed for the testing and comparison of tyre/road noise. This now means that, on the average, one measures much “lower-than–typical” tyre noise levels, and site-to-site variations may amount to above 5 dB(A), and even above 7 dB(A) according to the RRT mentioned above. ISO 10844:2014 will make it better, but not good. Consequently, there is both a representativity and reproducibility problem with ISO 362:2014, with serious consequences for the entire vehicle noise and tyre noise limit systems, and the tyre labelling system as well.

## A.VI. The solution to the representativity problem

This author thinks that the solution to the representativity problem is to introduce a more typical road surface into the ISO 362 standard, as a second reference. As mentioned above, this was proposed already 20 years ago. It is a pity that these two decades have not provided any progress on this issue. The more typical surface could be one of the SMA 11 type (SMA 11 is Stone Mastic Asphalt with 11 mm maximum chipping size), but not designed to be one of the quieter versions of SMA 11.

But the second reference surface is not the subject of this paper; thus this issue is dropped here.

## A.VII. The solution to the reproducibility problem

It is suggested that the solution to the reproducibility problem is to introduce a calibration procedure. Such a calibration procedure has become possible recently after a number of other ISO standards have been completed and published. Using a number of reference tyres of the SRTT 16” type, specified in ISO/TS 11819-3 [17], tested with the CPX method for measurement of tyre/road noise, specified in ISO 11819-2 [18], and normalizing to a reference temperature using the procedure of ISO/TS 13471-1 [19], a rather robust method can be designed.

The rest of this paper outlines how such a method can be designed.

## A.VIII. Calibration using reference tyres tested with the CPX Method

### A.VIII.I Reference tyres

As reference tyre, the 16" SRTT defined in ASTM E2493:14 [20] and in ISO/TS 11819-3:2017 [17] is suggested. This is the tyre available as a reference tyre, which have the most favorable properties for distinguishing between surfaces of this type and at the same time have dimensions and a tread pattern similar to that of passenger car tyres. The ASTM standard defines the tyre and some of its properties, but ISO 11819-3 has some supplementing details that should be observed; especially in the application of the tyre on a CPX trailer. Figure 3 shows the tread pattern of the tyre.

It is sufficient with this reference tyre. ISO/TS 11819-3 specifies a second reference tyre, which serves as a proxy for heavy vehicle tyres. However, the use of a heavier tyre is not appropriate here since such tyres are always (?) less sensitive to road surface properties than passenger car tyres, and the 16" SRTT has been demonstrated to have good correlation with other passenger car tyres and with light traffic as a whole [21].

Figure 3 – The reference tyre (SRTT 16"); showing its tread pattern

### A.VIII.II Number of tyres and how to select them

In order to average out the major part of the unavoidable tyre-to-tyre differences, due to tolerances in the production, it is suggested that eight tyres are used for the calibration. These eight should not be from the same production batch; ideally, they should be from four different production batches. That means that there would be two tyres from each batch, and four batches in total.

### A.VIII.III The Close-ProXimity (CPX) method

The CPX method is described in ISO 11819-2 [18]. It is intended for the testing of road surface properties, using reference tyres. In this particular application, some of the requirements are difficult to meet; for example the test object's length. Figure 1 shows that the test track surface paved with the ISO mix is 40 or 60 m long (40 for light and 60 for heavy vehicles). The CPX data are normally measured and available per 20 m sections, which gives two or three measured sections per run. To account for the spread in noise data between such short sections, one should increase the number of runs to at least 10 runs per direction, per speed and per each pair of tyres. Speeds should be 50 and 80 km/h only. This would result in 10x2x4 = 80 loops or back and forth runs. If each loop takes two minutes, the measuring time would be about 160 minutes. Additionally, the mounting and change of tyres and the warm-up of the tyres will take at least as much time, ending up with a time consumption of roughly estimated six hours.

The standard requires the use of two mandatory microphone positions, but also indicates four optional positions. In this application, it is adequate with only the two mandatory positions.

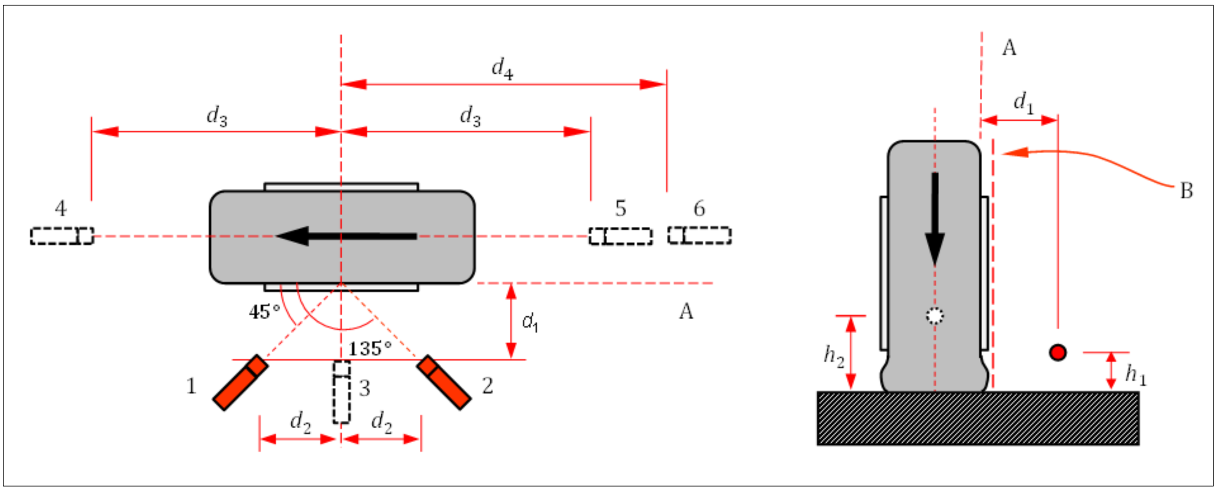



Figure 4 – Microphone positions in the CPX method. The two red microphone symbols are the ones to use here. Dimensions: $d_1$ = 200 mm, $d_2$ = 200 mm, $h_1$ = 100 mm (measured with loaded tyre).

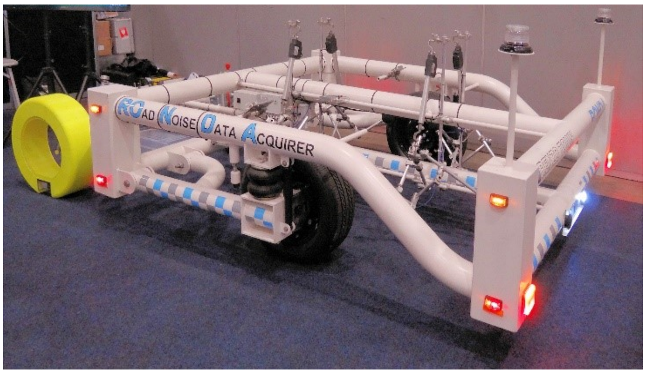
## A.IX. Proposed CPX trailer

ISO 11819-2 allows some different types of test vehicles. It could be either a towed trailer with one or two test tyres, or test tyre(s) mounted on the rear axle of a car or van. Furthermore, if it is a trailer, the trailer could be covered with an enclosure or it may have no cover at all.

In this application, one should use a trailer as it would be easier to obtain the maximum suppression of unwanted noise and have control over the acoustic surroundings of the tyre(s). It is suggested that it would be an open trailer with two tyres, of a type illustrated in Figure 5. As this has no enclosure it is more sensitive to exterior background noise and wind turbulence than an enclosed trailer. However on test tracks, the surroundings of the test area should be quiet; thus an enclosure is not needed. As the speeds would be 50 and 80 km/h, wind turbulence in the microphone should not be a serious problem, if the precautions in the standard are observed. The great advantage with the open trailer is that acoustic reflections are a minor nuisance.

The author recommends that the load and inflation settings in ISO 11819-2 and ISO/TS 11819-3 are used, since these have been used in all experiments with the SRTT. Higher load and inflation may make the SRTT less sensitive to surface properties.

The CPX trailer should always be one that is certified, as required in ISO 11819-2.



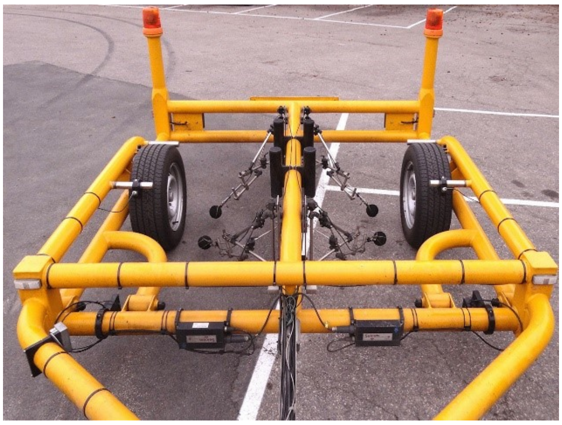



Figure 5 – Proposed type of CPX trailer; 2 test tyres in a towed open construction: ‘RONDA’ from Renzo Tonin in Australia (left) and ‘deciBellA’ from DRD in Denmark (right). Note that these are only examples of existing devices. Photos by the author.

### A.IX.I Temperature corrections

In cooperation between several organizations and companies, the two ISO working groups WG 27 and WG 33 have been able to determine a fairly robust temperature correction to measurements with the SRTT. This enabled the production of ISO/TS 13471-1:2017 in which the procedure is described in detail [19]. It is based on air temperature and expressed as a "temperature coefficient" ($\gamma$) in dB per °C, and for the SRTT and a dense asphaltic surface such as the ISO 10844, the coefficients will be:

$\gamma$ = -0.11 dB/°C at 50 km/h
$\gamma$ = -0.09 dB/°C at 80 km/h

The coefficient is simply the slope in a diagram with CPX (noise) level plotted against air temperature, and the correction may then be expressed as the opposite; see Figure 6. The correction procedure is valid if air temperatures are within 5 and 35 °C.

In order to reduce as much as possible the uncertainty in the temperature correction, the aim should always be to measure during a season when air temperatures are the closest to 20 °C.

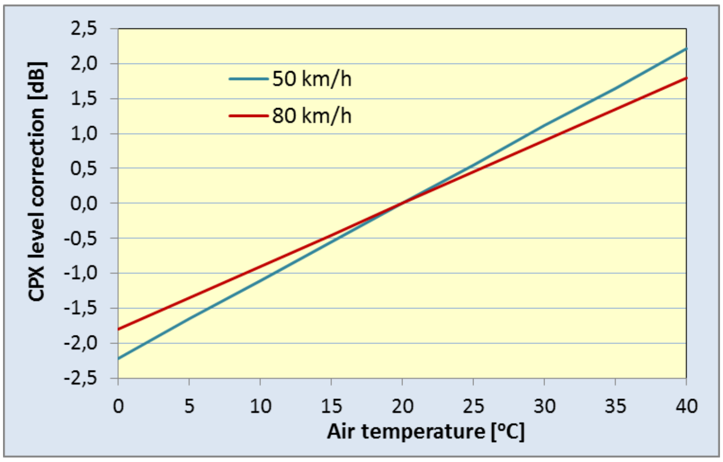



Figure 6 – Temperature correction to CPX levels for the SRTT at the two suggested speeds, for normalization of the CPX levels to the 20 °C reference temperature. Note that the air temperature should not be outside the 5-35 °C range.

### A.IX.II Reported ISO 10844 calibration level

The average of all measured CPX levels, normalized to the reference air temperature of 20 °C, should be the reported value, "Calibration Level", representing the tyre/road noise property on the ISO surface on the test track. Measured values should not be truncated to integers.

### A.IX.III Global Average and Test Track Correction constant

After a large number of test tracks of varying ages have been calibrated by this procedure, one can calculate a "global average" of them all. The nearest integer dB value to this average should be selected as the "Global Average". Then a "Test Track Correction constant (TTC)" may be assigned to the particular test track which is the difference between the Global Average and the Calibration Level. All tyre/road noise levels measured on that test track would then be corrected by this TTC constant. The TTC should be updated according to the results of the most recent calibration.

### A.IX.IV Frequency of calibration procedures

This author suggests that calibrations according to this proposal are conducted at times after laying of the surface, as follows:

- First time, when the surface is 3-6 months old
- 2nd time, when the surface is 12-18 months old
- 3rd time, when the surface is 3 years old
- 4th time, when the surface is 6 years old
- 5rd time, when the surface is 9 years old
- … and so on, each 3rd year.

This author expects that the TTC will change significantly during the three first years; depending on ageing and the traffic on the test track. The normalization procedure will reduce much of the effect of such changes.

## A.X. Estimated uncertainty

Based on the knowledge and experience obtained when developing the ISO 11819-2, ISO/TS 11819-3 and ISO/TS 13471-1, the author estimates that when calibration of an ISO surface has been done in accordance to this procedure, the maximum deviation in tyre/road noise between test tracks would have decreased to less than ±1.0 dB(A). The majority of test tracks (90 %) would probably be within ±0.5 dB(A). This would be significantly less than one half of the deviations of the present ISO 10844:2014.

## A.XI. Why not use the coast-by procedure with SRTT:s on a car?

It may feel natural to many that one should place four SRTT:s on a car and use the coast-by method. This would seem to be simpler. However, it is known from the development of the ISO 13325 method [16] and a special test made by VTI [22] that the vehicle influences tyre/road noise substantially. This depends on screening by certain parts of the body, reflections on the body and by wheel alignment (and maybe more). The CPX trailer effectively eliminates or reduces these influences. This was a reason why a trailer method was developed in ISO 13325 as an option to the coast-by method [16].

## A.XII. Development of the procedure

It is natural that the procedure is developed by the WG 42 sub-group which is in charge of the ISO 10844 standard revision. It may become a normative Annex to an updated ISO 10844, or it may be a separate standard or, to begin with, an ISO Technical Specification (TS). This author is willing to take part in that work.

It is important that proper experiments with the proposed procedure are conducted, both by a number of organizations and companies, but it is essential that also an RRT is conducted.

## A.XIII. Conclusions

Recent progress in standardization of measurement methods have made it feasible to design and use a calibration procedure for ISO 10844 test track surfaces, which can be used to normalize such surfaces to a common “global level”, thereby reducing the site-to-site variation to significantly less than ±1 dB(A). This will make all tyre/road noise measurements on such surfaces much more reliable and accurate, which will benefit all regulations where tyre/road noise is important. The cost is reasonable and highly justified as it substantially reduces all present erroneous or unfair test results.

### ACKNOWLEDGEMENT

As the author has reached a truly mature age and being partly retired, at least partly paid, this paper was produced during free time, and the sponsor is himself, for which the award is waiting in Heaven. Therefore, the author wishes to thank his wife for her, albeit reluctant, acceptance of this hobby.

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