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Tyre/road noise prediction: A comparison between the SPERoN and HyRoNE models - Part 2

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The SPERoN and HyRoNE models predict the pass-by tyre/road noise of a passenger car from intrinsic characteristics of the road surface. Both models are hybrid: they combine statistical laws with physical models. With a computing time of a few minutes (very quick compared to full physical models), they provide operational tools for tyre/road noise prediction. Particular fields of interest are road surface optimisation with respect to noise at the laboratory scale, conformity of production of a new surface and acoustic monitoring of roads. They are now implemented as user-friendly stand-alone applications. The presentation will address the principles of the models, their performances and their respective main fields of application. Part 2 will address the performances of the models and their area of applications.

1 Introduction

The SPERoN and HyRoNE models predict the pass-by tyre/road noise of a passenger car tyre depending on road surface characteristics. Midway between empirical models, which aim at providing estimated relationships between measured quantities (between measured raw texture and noise levels for instance), and full physical models, which aim at simulating all generation mechanisms in detail, both are hybrid models: they combine statistical laws with physical models. They have been developed with one common objective: to provide operational tools for tyre/road noise prediction with a computation time of a few minutes (numerical tools require hours or even days).

As described in part 1 of this duplex paper [1], the philosophy that prevailed for the development of each model was very specific. The principles which have been pursued are thus quite different on several aspects. Firstly, the texture related quantity used: in SPERoN, it is the global contact force applied on the tyre tread band, which is dynamically evaluated with a rolling model; in HyRoNE, it is the enveloped local texture (for the low and medium frequency domains), evaluated through a static contact model. The texture used in SPERoN is quasi three-dimensional. HyRoNE uses bi-dimensional profiles, commonly measured by road laboratories. Secondly, in SPERoN, the contribution of each physical phenomenon is considered over the whole frequency domain of interest, while in HyRoNE each mechanism is allocated a frequency domain in which it is considered to be predominant. Thirdly, SPERoN takes the tyre parameters into account and is assumed to cover a wide range of tyre types, while HyRoNE is constructed for only one given tyre type.

All these differences make SPERoN more complex than HyRoNE, regarding its implementation as well as the amount of input data to be supplied.

This part 2 of the duplex paper on the models addresses the performances and area of applications. A first part deals with their performances in terms of accuracy and resolution. Their reasonable processing time that makes operational tools for practical applications of them is addressed in a second part. Their respective area of possible applications is presented in a third part including some practical examples.

2 Accuracy and resolution

This part deals with the model performances and focuses on their accuracy and resolution.

2.1 SPERoN

The data for the building of SPERoN's statistical sub-model is based on a comprehensive collective of several thousand coast-by measurements carried out with a great variety of tyres, road surfaces and driving speeds. Since tyre characteristics, tyre load and rolling velocity are part of the physical sub-model of SPERoN, it is not necessary to rebuild the model in the case of applying it to tyres, road surfaces and speeds which are different from those used for the determination of the statistical parameters. However, if another tyre is to be used with the model its structural dynamic parameters have to be determined by means of point mobility and tread pattern measurements as described in [1]. Based on this fact the model could be validated by applying it to a number of tyre/road/speed combinations others than the original ones.

The validation of the SPERoN model could be performed by means of coast-by data from eight impervious surfaces measured in the DEUFRAKO project P2RN. In the following Fig.1 measurements are compared with SPERoN calculations for a rolling speed of 90 km/h. The tyre used for the measurements is a Michelin Energy E3A 195/65 R15 with a tyre load of 393 kg. This tyre load corresponds to the average actual load of the four tyres which were mounted on the vehicle. The texture profiles were measured by LCPC. Informations about the different surfaces are given in [3]. The overall coast-by levels given in Fig.1 represent the sum of the 3rd octave band levels from 315 Hz to 2000 Hz both for the measured and the calculated values. The calculated levels are true for a temperature of 20°C. Therefore, the measured 3rd octave band levels were temperature corrected applying the temperature corrections given in [2] in order to adapt all values to 20°C.

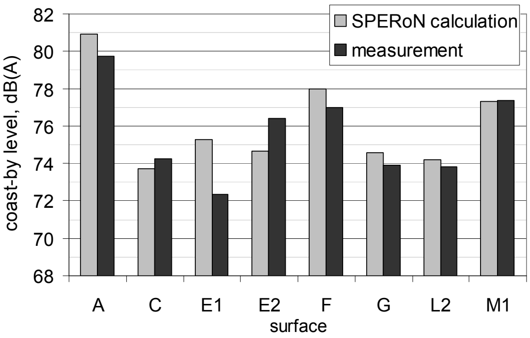

Fig.1 Comparison of measurement and SPERoN calculation results depending on the surface; *v* = 90 km/h.

The comparison of the measurement and calculation results shows that the ranking of the coast-by levels is in good agreement. The mean level difference is 1 dB(A). The maximum level difference is 2.5 dB(A) (surface E1) while four surfaces show level differences smaller than 1 dB(A).

Besides the total levels the measured and calculated spectra are in a satisfying agreement as well. In Fig.2 the measured and calculated spectra for the surface E2 and M1 are given within the frequency range from 315 Hz to 2000 Hz.

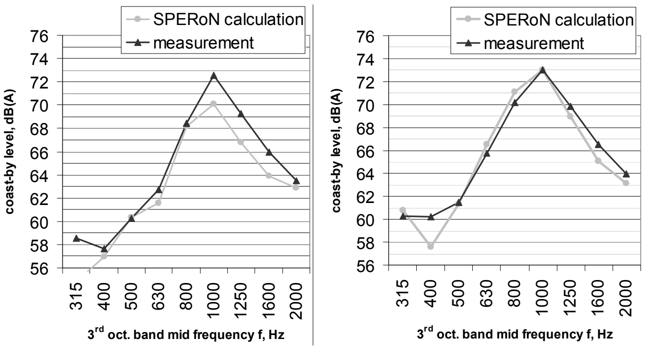

Fig.2 Exemplary spectral comparisons between measurements and SPERoN calculations for surface E2 (left) and M1 (right) ; v = 90 km/h.

As already described before, SPERoN allows for predicting coast-by levels in a wide speed range from 50 km/h to 120 km/h. Since the measurements in the DEUFRAKO project P2RN were performed in a speed range from 70 km/h to 110 km/h it is possible to compare measurements and SPERoN results as a function of rolling speed based on actual driving speeds which have been observed during the CPB (controlled pass-by) measurements. In Fig.3 this comparison is exemplary given for surface E2.

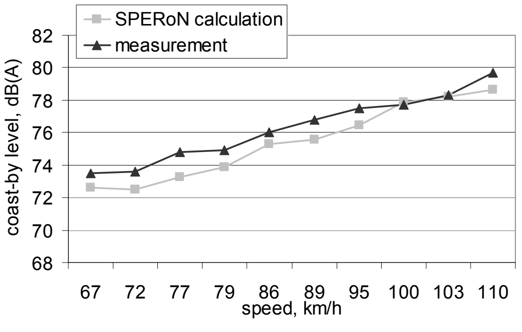

Fig.3 Measured and predicted coast-by levels as a function of the actual driving speed for surface E2.

Obviously, the SPERoN prediction holds for the whole speed-range covered in the P2RN project. The maximum difference is less than 2 dB for this surface. There is no significant change in the difference between measurements and SPERoN calculations for different speed ranges. This means that the differences are not systematic.

With SPERoN it is also possible to predict the coast-by levels for one surface and different tyres. In Fig.4 calculations for six different tyres are shown for the same surface E2, a rolling speed of 90 km/h and a tyre load of 393 kg. The two tyres on the left are both summer tyres with a width of 175 mm. These tyres give the lowest coast-by levels. The two tyres in the middle are also summer tyres with a width of 195 mm. The predicted coast-by levels for these two tyres are higher than for the smaller ones as expected. The fifth tyre has the same width as the tyres three and four but shows a higher coast-by level. The reason for this is the rougher tyre-pattern because it is a winter tyre. Finally, SPERoN predicts the highest coast-by level for the last tyre. This is a plausible result too because this tyre is the widest one in the considered collective.

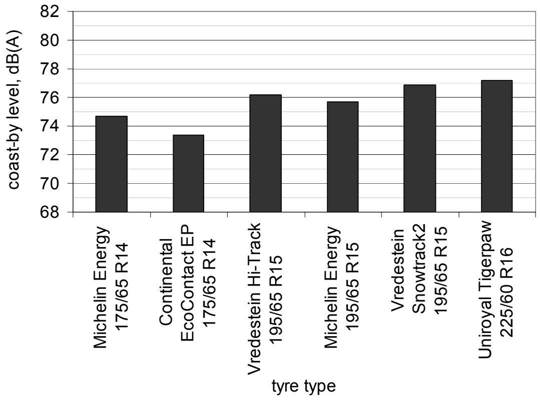

Fig.4 Predicted coast-by levels for different tyres on surface E2.

2.2 HyRoNE

HyRoNE is constructed for one tyre/vehicle combination (CPB measurement conditions). Two data sets were available for its construction and validation. The first one was made of data measured by LCPC in the frame of the French “Texture&Bruit” Prédit project. The vehicle used for the CPB measurements was a Renault Scenic 2.0 l equipped with Michelin Energy XH1 tyres. The site temperature conditions ranged from 2°C to 23°C (with an average of 12°C between the sites). The second one was made of data measured by LCPC during the DEUFRAKO P2RN project. CPB measurements were carried out using the same vehicle, but equipped with Michelin Energy E3A tyres, which have not the same tread pattern as the XH1. The site temperature conditions ranged from 16.5°C to 23.5°C (with an average of 20°C between the sites).

The model was originally constructed with the “Texture&Bruit” data set and applied to the P2RN data set for validation [4]. Eventually, it was preferred to reconstruct the model using the data set that shows the lowest temperature spread (a 20°C difference may lead to a global noise level difference of 2 dB(A)). The model was thus reconstructed using the P2RN data and for three rolling speeds (70 km/h, 90 km/h and 110 km/h). It is assumed to provide noise levels at 20°C (the average temperature between the P2RN sites). The correspondences between measured and predicted dB(A) global noise levels after construction are represented in Fig.5 for the 3 rolling speeds. The precision is observed to be quite satisfactory. The regression lines calculated between measured and predicted levels almost merge with the perfect correspondence diagonal line. The 90% confidence interval is found to be +/-2.4 dB(A) at 70 km/h, +/-2.0 dB(A) at 90 km/h and +/-2.1 dB(A) at 110 km/h.

The model was applied for validation on the “Texture&Bruit” road surfaces. Predictions are made for a 20°C temperature condition. A correction was applied to each predicted value to yield a global noise level corresponding to the site temperature condition [5]. The correspondences between measured and predicted global levels in dB(A) are given in Fig.6 (large dots). The correspondences of Fig.5 are superimposed (small dots) for comparison.

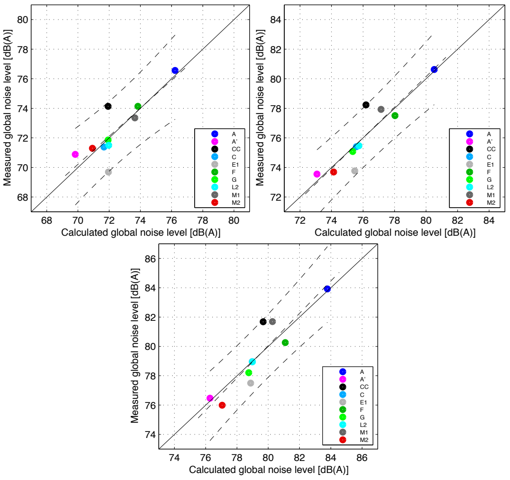

Fig.5 Correspondence between measured and predicted global levels in dB(A) after HyRoNE construction using the P2RN data set (for 70, 90 and 100 km/h).

As observed, there is a gap between the construction and the validation data sets. This gap seems to be speed dependent. It is rather high at 70 km/h and almost negligible at 110 km/h. It could be attributed to the difference in tyres between the P2RN data set (Michelin Energy E3A) and the “Texture&Bruit” data set (Michelin Energy XH1). The gap was found, by hypothesis testing, to be statistically not significant except for the lowest rolling speed 70 km/h.

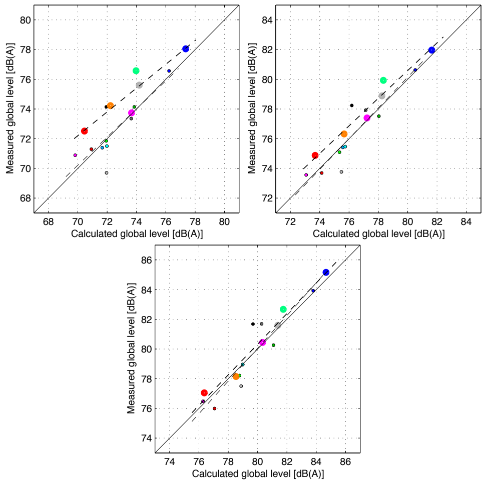

Fig.6 Correspondence between measured and HyRoNE predicted dB(A) global noise levels for the “Texture&Bruit” road surfaces (70, 90 and 110 km/h).

Apart from this gap, the spread around the validation regression line is limited. The associated confidence interval is lower than the one observed on the construction results. It amounts to +/- 2.1 dB(A) at 70 km/h, +/-1.3 dB(A) at 90 km/h and +/- 1.2 dB(A) at 110 km/h.

The 90% confidence intervals which will be kept for HyRoNE are those obtained at construction stage i.e. +/-2.4 dB(A) at 70 km/h and approximately +/-2 dB(A) at 90 km/h and 110 km/h.

3 Processing times

Another aspect regarding the model performances is the very low processing time in comparison with full physical models.

SPERoN takes about 210 sec to calculate one tyre/road/speed combination at speeds higher than 68 km/h. At lower speeds the calculation takes about 330 sec. These values are based on a mobile computer processor Intel Core Duo T2400 running at 1.83 GHz with 1 GB RAM. The difference between the two speed ranges is due to the required spatial resolution of the tyre model. The lower the speed the higher the spatial resolution must be in order to achieve sufficient time resolution and cut-off frequency for the contact force spectrum. For the same reason the number of calculated rolling loops has to be increased with increasing speed. In Table 1 the sampling frequencies and the processing times are shown.

speed, km/h	50 ... 68	69 ... 120
no. of spatial samples on 2 m tyre circumference	1024	750
sampling frequency, Hz	7110 ... 9670	7190 ... 12500
no. of rolling loops calc.	5	7
avg. processing time, sec.	330	210

Table 1. SPERoN processing times required for the evaluation of one tyre/road/speed combination.

A rough idea of the processing time required by HyRoNE is given through two examples. The first one concerns the evaluation of a road surface noisiness from 12 profiles each 1.2 m long (LCPC protocol used in the P2RN project). The processing time on a PC, equipped with a Pentium M processor at 2.0 GHz and with 1 GB RAM, is given in Table 2 for each rolling speed. As observed, it depends on the rolling speed. This can be explained by the fact that the length of the segments used for the noise evaluation depends on the rolling speed: a profile 1.2 m long is subdivided into respectively 3 and 2 overlapping segments for noise evaluation at 70 km/h or 90 km/h, and is used as it is (no subdivision) at 110 km/h.

70 km/h	90 km/h	110 km/h
65 sec	45 sec	25 sec

Table 2. HyRoNE processing times required for a noise evaluation of 12 profiles 1.2 m long.

For longer profiles, the processing times do not differ as much with the rolling speed. A noise evaluation covering a profile length of 100 m requires 10 min at 70 km/h, 7 min 30 sec. at 90 km/h and 6 min at 110 km/h.

4 Area of applications

What is understood here by area of applications is, on the one hand, the field of validity of the models, particularly the type of road surfaces that can be addressed, and, on the other hand, their possible applications.

4.1 Fields of validity

The type of road surface that can be addressed by a model depends on the characteristics of the road surface that were introduced in the model construction, and on the representation which was used to handle these characteristics. At present, the HyRoNE model is able to take account of road texture and absorption properties, while SPERoN takes account of texture only. It must be noticed that neither HyRoNE nor SPERoN take account of possible road surface mechanical impedance influence on noise at the moment.

Regarding texture input, SPERoN uses quasi 3D texture information (parallel profiles extracted from a 3D surface) while HyRoNE uses 2D single profiles. This has immediate consequences on the field of validity of both models regarding the texture characteristics. The SPERoN model can handle anisotropic surfaces. HyRoNE use is restricted to isotropic or quasi-isotropic surfaces. However, a future version could be constructed with data measured on transversely grooved pavements, with the texture profiles measured in the rolling direction.

Another restriction in the use of the HyRoNE model could arise from the tyre properties and sensitivity to noise. HyRoNE is constructed with noise measurement performed with a vehicle equipped with tyres used by French laboratories for road surface acoustic assessment (CPX measurements). Different tyres may be more or less noisy and more or less sensitive to texture. Thus, results given by HyRoNE might not fit with measurements performed with other tyres than those with which it was constructed. The differences observed in the correspondence between measured and predicted global levels for the construction and validation data sets (cf above) seem to validate this hypothesis. If needed, the model could be constructed for different types of tyres.

In contrast to this, SPERoN processes the parameters that govern the dynamic behaviour of the tyre because they are input of the model. However, each tyre taken into account in the model must be described in terms of macroscopic structural dynamics parameters. In general, these parameters are derived from point mobility measurements of real tyres. At the moment, the model is restricted to passenger car tyres.

4.2 Applications

Different types of application of the models are considered. Two main purposes are at stake. The first one addresses the design of road surfaces, at laboratory or test track scale. The second one addresses more operational considerations related to procurement process and monitoring at road scale.

Design

Regarding the road surface design, different purposes are to be distinguished: the optimization of existing road pavement laying techniques, and the development of new concepts of pavements. As mentioned in paragraph 4.1, the field of validity covered by SPERoN is wider than the one covered by HyRoNE.

HyRoNE can only handle existing techniques of isotropic road surfaces: it can be applied in optimization processes for known techniques by determining optimal parameter values regarding, on the one hand, the absorption properties of the road surface, and on the other hand, the texture characteristics.

Due to the fact that SPERoN calculations are based on a quasi 3D description of the surface, not only real road surfaces laid with existing techniques can be processed by the model. This expands the field of applications with respect to road surface design: SPERoN may be used as tool for the layout of novel low noise road surface textures that could be realized with unusual material and laying techniques.

Procurement, monitoring

Another important possible field of application of the models addresses, on the one hand, procedures enabling the characterization of road surfaces for material procurement purposes and, on the other hand, the monitoring of acoustical properties of road surfaces. Procedures have been proposed in the SILVIA project for labelling and conformity of production (COP) testing [6]. The preferred set of procedures is based on SPB and CPX methods. Another set includes procedures based on auxiliary assessment methods enabling an acoustical evaluation of a road surface from intrinsic characteristics, such as texture, absorption and mechanical impedance. Auxiliary assessment methods provided by both HyRoNE and SPERoN model may be used for homogeneity and COP testing or monitoring as far as appropriate mobile devices could provide data that are compatible with the model input format. Regarding the texture input, 2D texture measurement is quite a common practice for several aspects of road characterization. Mobile devices have been developed for some years. However, it remains in question whether these devices meet the requirements (such as sampling rate and drop-out processing) for well-suited texture measurements for noise evaluation.

4.3 Examples

In this paragraph three examples of possible use of SPERoN and HyRoNE are given. They address design of artificial texture patterns and analysis of texture influence on tyre/road noise.

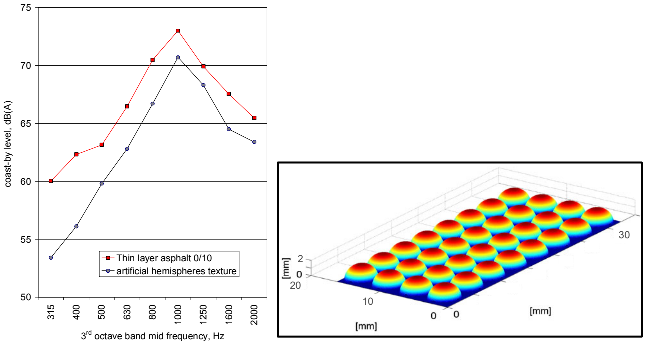

Fig.7 Coast-by level spectrum (left) for an ‘artificial’ texture (right). Red line: Measured spectrum of a real thin layer 0/10 road surface; black line: spectrum calculated with SPERoN for the ‘artificial’ surface; v = 90 km/h.

In recent years, discussions are coming up whether road surface designs based on unusual materials and laying techniques could help to exploit the reduction of tyre/road noise in a better and more reproducible way. In this context it is meaningful to test the noise reduction potential of a novel texture layout by means of a simulation tool like the SPERoN model prior to costly laying experiments. In Fig.7 an example of an 'artificial' texture with regularly embedded hemispheres with a diameter of 4 mm is shown.

The second example consists of the evaluation of the dB(A) global noise level along a texture profile. The profile, measured with a mobile device, is 32 m long (see Fig.8). The noise level is here evaluated with HyRoNE every 0.5 m (small dots) and is moving averaged over a certain distance to produce either a continuous global noise level along the profile (red line) or averaged levels on predefined segments (here every 5 m, black square).

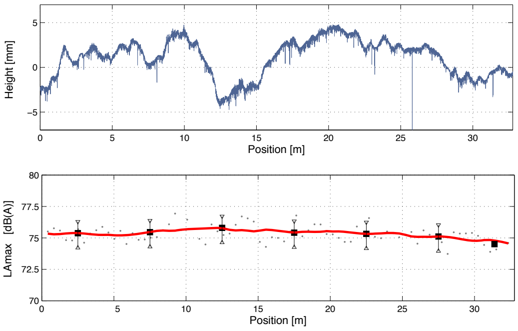

Fig.8 A profile 32 m long (top) and the corresponding HyRoNE evaluated dB(A) global noise levels (bottom).

The third example consists of the comparison of texture measurement devices regarding rolling noise purposes. Here 2D texture profile measurements have been performed on a same surface with three different systems. Three segments extracted from the raw profiles are drawn in Fig.9 to the left. The corresponding dB(A) noise levels have been estimated with HyRoNE. The pass-by noise spectra and corresponding global levels are given in Fig.9 to the right. In this case, the difference between extreme global noise levels reaches 0.8 dB(A). This comparison may be repeated on different surfaces to confirm or infirm the tendency for one device to overestimate or underestimate rolling noise levels with respect to other devices. The texture data used for HyRoNE construction have been recorded with a stationary device not adapted to a road scale assessment method, from a practical point of view. It is planned to compare this device and the associated protocol with a mobile measurement device used for skid resistance evaluations in order to assess whether the mobile device is well-suited for tyre/road noise evaluations.

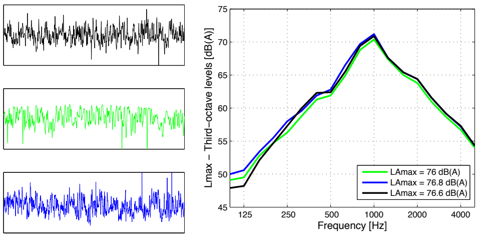

Fig.9 Left: Three segments of equal length extracted from 2D profiles measured by 3 different devices; right: Corresponding 3rd octave spectra and global L_{Amax}

5 Conclusion

The SPERoN model is rather research oriented. The pass-by noise evaluation is based on a comprehensive database and an extensive description of the road (3D texture) and tyre (3D geometry and physical characteristics). The model can handle road surface and light vehicle tyre types not used for its construction (anisotropic road surfaces in particular). It is well adapted to the development of new pavement concepts. Noise predictions are however limited to road pavements with no acoustic absorption.

The HyRoNE model is rather in-situ controls oriented (conformity of production, monitoring). The evaluation is based on a database restricted to isotropic road surfaces and a single tyre type (used for CPX measurements in France). This version cannot handle anisotropic surfaces (predictions for laterally grooved surfaces for instance would need to develop a specific version to be built). On the other hand, HyRoNE can address acoustic absorption by the pavement.

In spite of large differences in their respective philosophy and principles, the SPERoN and HyRoNE models provide pass-by noise level estimations with similar accuracies. Both require processing times of only a few minutes.

Acknowledgments

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References

[1] T. Beckenbauer, P. Klein, J.F. Hamet, W. Kropp, „Tyre/road noise prediction: a comparison between the SPERoN and HyRoNE models – Part 1", *Proceedings of Euronoise conference*, Paris, France, 2008

[2] T. Beckenbauer et al., "Effect of pavement texture on tyre/pavement noise", *Scientific report no. 847*, German Federal Ministry of Transport, Buildings and Dwellings, Bonn, August 2002

[3] F. Anfosso-Lédée, Y. Pichaud, J.F. Le Fur, "DEUFRAKO project P2RN – report on acoustic measurements, performed on LCPC Test Track in Nantes in June 2006", *Technical report LCPC 13M06151*, June 2007

[4] P. Klein, J.F. Hamet, "Tyre/road noise prediction with the HyRoNE model", *Proceedings of INTER-NOISE conference*, Istanbul, Turkey, 2007

[5] F. Anfosso-Lédée, Y. Pichaud, "Temperature effect on tyre-road noise", *Applied Acoustics*, Vol.68, pp1-16, 2007

[6] P. Morgan and al., "Guidance manuel for the implementation of low-noise road surfaces", *FEHRL report*, TRL, 2006