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[N996] Tyre/road noise modelling: the road from a tyre's point-of-view

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ABSTRACT

We have assessed the influence of the tyre profile on the sound reducing properties of the road surface. We were not looking for the quietest tyre profile, but have assessed whether the distinction between a quiet and a noisy road surface depends on the tyre profile. With the hybrid tyre/road noise model SPERoN, we tried to incorporate the tyre profile influence by introducing an improved (quasi-3D) contact model using the 3D tyre profile information.

With this model we performed various analyses on different groups of roads. We also made a qualitive comparison with Kropp's contact model.

From the model analyses, we found that the tyre profile does have an influence on the contact pressure that is calculated as an input parameter for the regression model. However, the difference in noise production of the various tyres does not strongly depend on the tyre profile itself. However, using the new approach we could make a unified model for both slick and profiled tyres.

The comparison of the new 3D contact model with Kropp's model revealed that both models predict similar trends with respect to the assessment of the sound quality of road.

KEYWORDS: tyre/road noise, tyre profile, contact model, hybrid model, 3D model

INTRODUCTION

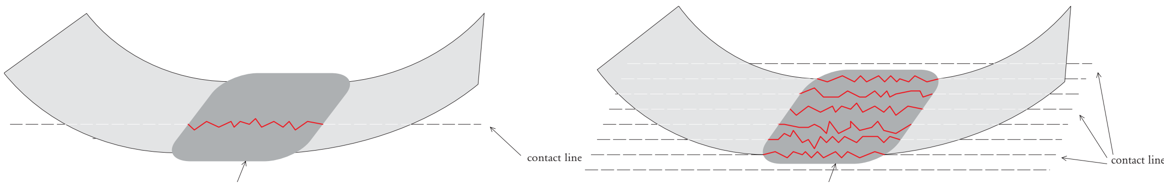
The objective of the SPERoN model [1] is to act as a tool to evaluate the acoustic quality of existing road surface textures, to develop new low-noise road surface textures, and not to investigate and develop low-noise tyres. The first version of the SPERoN model did not include specific tyre profile parameters. The reason for this is that it is rather complex to deal with the tyre profile and it still unclear to what extend the tyre profile influences the tyre/road noise generation. Furthermore, it is difficult to obtain tyre profile data. Not including tyre profile data means that the model is strictly only valid for slick tyres. This is the case for most tyre/road noise models [2] nowadays.

In the case of the SPERoN model, the approach described above meant that there were two versions of were developed, one version for slick tyres, and one version that used a slick tyre contact algorithm, but had different statistical model coefficients to improve the predictive value for profiled passenger car tyres. The objective of the research presented here, was to investigate the importance of including the tyre profile and consequently bridge the gap between the models for slick and profiled tyres.

Next we will describe the 3D contact algorithm that was developed to include the tyre profile. We will present noise prediction results for the new model and we will make a comparison of the new contact model with the contact model used by Kropp [3].

3D CONTACT IMPLEMENTATION IN THE SPERoN MODEL

To improve the predictability of the SPERoN model we tried to incorporate the influence of the tyre profile. An important characteristic of the SPERoN model is the contact force computation. The contact model used for this computation is based on a formulation introduced by Clapp [4]. To make a 3D variant of this formulation, we compute the static contact force on a number of parallel contact lines (see Figure 1). The tyre tread profile information on these contact lines (see Figure 2) is superimposed on the texture profile information on this line and then the contact force distribution is calculated.



(a) 2-dimensional contact (b) stochastic 3-dimensional contact

Figure 1: In (a) the contact between tyre and road is 2-dimensional, which can be considered as a more simple description of a 3-dimensional contact where the texture profile is identical in parallel contact lines. However, in realistic situations the road texture will not be deterministic but stochastic (i.e. randomly distributed texture in parallel contact lines) as in (b).

A schematic view of the SPERoN model with this quasi-3D contact model is given in Figure 3. Details of the implementation can be found in reference [5].

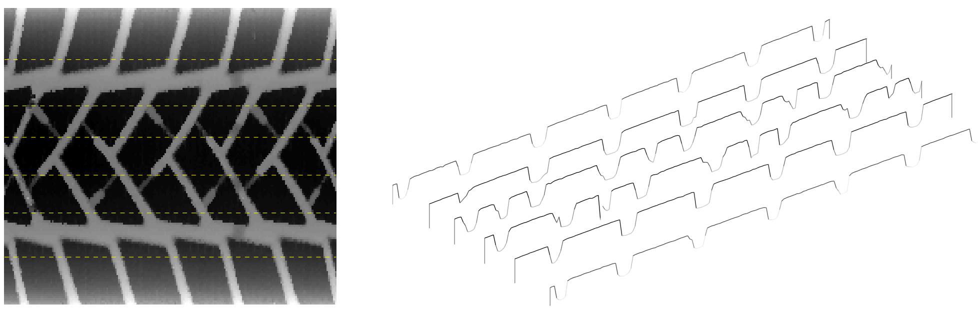


Figure 2: Tyre profile with selected slice lines (left) and profile depth information of the corresponding slices (right).

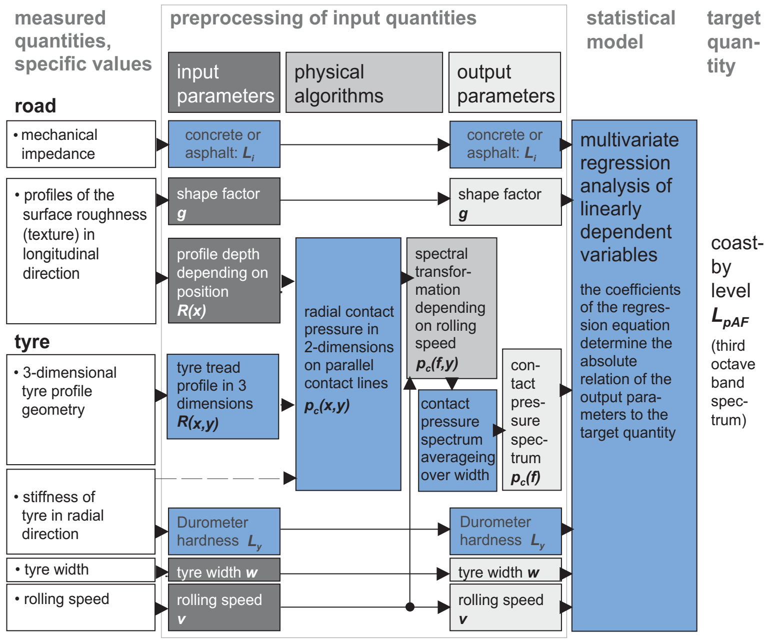


Figure 3: Enhanced SPERoN model with 3D tyre profile information. (It also includes parameters for road mechanical impedance and tyre hardness parameter, but these are not discussed here).

RESULTS

Next we will describe the results of the predictions with the new contact model and we will make a comparison of this contact model with the contact formulation used in the tyre/road noise model of Kropp.

Model predictions: profiled tyres, various roads

To investigate the improvement of this model, we made a comparison between the new 3D contact model, the original 2D contact model, and a 3D contact model with only road information (so without tyre profile information). We performed multivariate regression analyses to obtain the model coefficients. As regression model inputs, we used the coast-by noise measurement results for 14 profiled tyres on 21 road surfaces obtained at the Sperenberg test site [1]. The tyre group consisted of collection of 13” and 15” tyres normally available on the market. The road surfaces under test were varying from very smooth (SMA 0/3) to very coarse (surface dressing 5/8).

A good measure to compare statistical models is the average residue. The residue shows what part of the total observed statistical variation remains unexplained. Therefore, a lower residue signifies an improvement to the statistical model.

The average spectral residues for the investigated contact models are displayed in Figure 4. Compared with the results for the contact model with 2D and only 3D road information, the results show a slight improvement (i.e. a reduction of the residue) in the frequency range between 500 and 1000 Hz. However, in the frequency range below 500 Hz, we see a higher residue for the combined road+tyre profile, as compared to the model with only the road.

It is important to note that for the road information only one road texture profile was available for all tyre slices. Hence, we have combined 2D road information with 3D tyre information. Therefore, it is fair to compare the 3D (road+tyre) results with the 2D (road) results to investigate the improvements by including the 3D tyre profile. If we do that, we see a significant decrease of the residue in for the frequency bands between 500 and 1000 Hz. This means an improved explanation of noise induced by the road texture and the tyre tread.

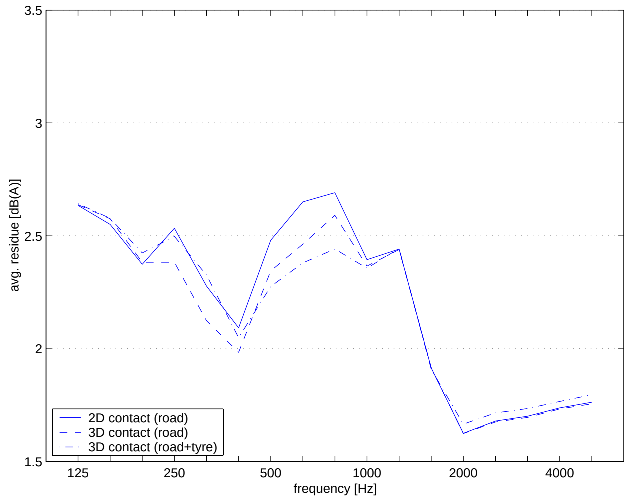


Figure 4: RMS residues for regression models with different contact models.

Model predictions: profiled tyres, smooth roads

Next we performed regression analyses with these same contact models on a collection of only smooth roads including a very smooth grinded concrete surface. This road collection was chosen because we expected the tyre profile to be of greater importance on smooth roads.

First we looked if we could explain the differences between the different profiled tyres. The residues of the statistical model are displayed in Figure 5.

Again, the residual spectra show that the 3D contact model does explain some of the variance between 500 and 1000 Hz. However, outside of this region, the variance explanation decreases. So the model is not very suited to explain the noise generation differences between the various profiled tyres. Note that the results for the 2D and 3D contact models, with only road information, give similar results. This is not surprising: for smooth roads, the road texture influence on the rolling noise generation is less important.

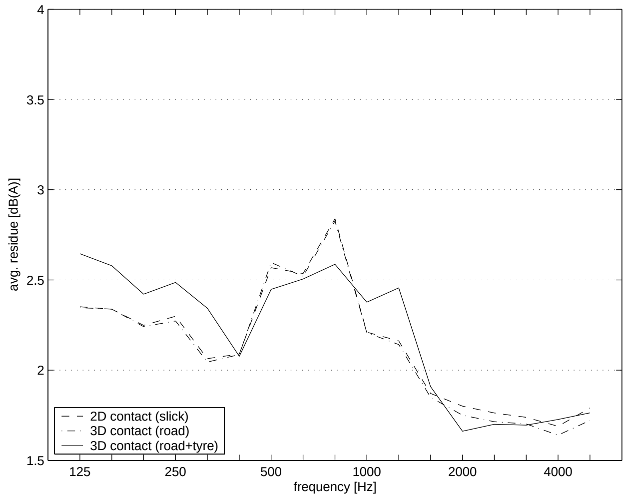


Figure 5: RMS residues for different contact models, for profiled tyres on smooth roads.

Model predictions: all tyres, smooth roads

Next we looked specifically at the residues for a model where the results for all tyre types are included. This constitutes a unified model for slick, grooved and profiled tyres. The residues of the corresponding statistical model are displayed in Figure 6.

The results for this analysis are more encouraging. Here, the 3D road/tyre contact model gives much improved results over the whole frequency range above 400 Hz, compared to the 2D and 3D contact models with only road influence. But more importantly, it demonstrates that now there is no longer any need to distinguish between slick and profiled tyres.

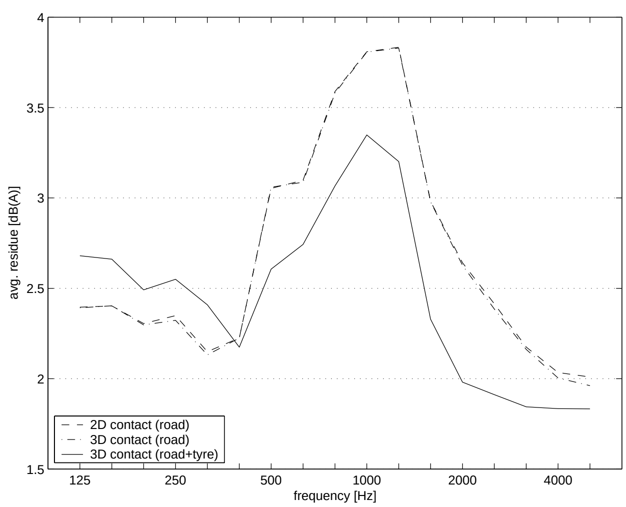


Figure 6: RMS residues for different contact models, for all tyres on smooth roads.

Comparison with Kropp's model

In the SPERoN model, a static contact model is used to calculate the contact forces between tyre and road. From a physical point-of-view however, it is apparent that the contact forces not only depend on the geometry of tyre and road profile, but also on the dynamical properties of both tyre and road. To assess the influence of a dynamic contact formulation instead of a static formulation, the results obtained with the SPERoN model were compared with the results obtained using Kropp's tyre/road interaction model [3].

In Kropp's model, the tyre profile is not incorporated directly as geometrical data. A different approach is used. The effect of the profile is assumed to be a variation of the contact stiffness. The change in contact area can be represented by a change in contact stiffness. If the contact area is smaller then the deformation amplitude will be higher, or in other words, the contact stiffness will be lower. This means that for slick tyres, the contact stiffness will be constant over the tyre's circumference and that the contact stiffness of profiled tyres will be lower than the contact stiffness of slick tyres. For profiled tyres, the contact stiffness is not constant over the circumference.

We made a qualitive comparison between the results obtained with the SPERoN model and with Kropp's model. We addressed the following issues: tyre profile effects, vehicle speed effects, and road texture effects. Because of space limitations, we will only present the conclusions here. Details of the analyses can be found in reference [5].

In general, despite a few obvious dissimilarities (e.g. spectrum shape), we conclude that the models give comparable results. In both models, the influence of the tyre profile on the generated noise is predicted to be small. We have also looked at the speed exponents that express the dependence of the tyre/road noise on the vehicle speed. Both models predict a speed exponent of about 3 in the frequency range which dominates the A-weighted coast-by level. Finally, we have assessed the predictive quality of the models with respect to the influence of the road texture. We found that with both models, the ranking of the sound production of roads is predicted well.

CONCLUSIONS

The SPERoN model was developed as a tool to assess the noise reducing properties of road surfaces. The influence of the tyre profile on the noise reduction of road surfaces has been studied. To that end, the SPERoN tyre/road noise generation model was enhanced with a quasi 3-dimensional contact formulation that incorporates the tyre profile geometry.

We found that the tyre profile does have an influence on the contact pressure that is calculated as an input parameter for the regression model. But, the noise production differences between the profiled tyres could only be marginally explained by including the tyre profile. Nevertheless, with this approach we were able to make a unified model for both slick and profiled tyres.

The results obtained with the SPERoN quasi three-dimensional contact model were compared with results obtained with Kropp's contact model. This comparison showed that both models predict similar trends with respect to the assessment of the sound quality of road textures.

We conclude that the profile differences have no influence on the rating of the acoustic quality of road surface textures because a normal tyre population will always have a certain spread in properties and vibration and radiation properties. This means that we do not have to incorporate the tyre profile of passenger car tyres explicitly in the SPERoN model, to be able to assess the acoustic performance of road surface textures. This is a positive effect, since incorporating the tyre profile is a very complicated and time-consuming procedure. However, this is most likely not the case for truck tyres.

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