Modeling tools for the development of the Silent and Safe tyres.

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Summary
Within the project 'Stil Veilig Wegverleer', translated as 'Silent and Safe Roadtraffic' the tyre-road interaction is studied by the means of different simulation and test methodologies. Different simulation tools are developed capable of predicting the tyre-road interaction on noise, and hydroplaning / wet grip. An overview of these simulation methodologies is given. The simulations form the basis for the any tyre development and especially for the tyre-road optimization of the current project..

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1. Introduction

In modern society the road traffic noise is a major environmental issue. Above 50 km/h one of the main contributors to the road traffic noise is tyre-road noise. This orginates mainly from the contact pressure variations produced by the tyre tread pattern and macrosopic road texture. Hence, a smooth road with smooth tyre can potentially improve this issue but this will decrease the vehicle occupant's safety while driving on wet road.

Therefore a balance between safe and silent tyre-road performance is required. More over most research by tyre and road industries is done in isolation, which limits the understanding of the complex interaction. Therefore a multidisciplinary research project called Silent and Safe Roadtraffic (Dutch: 'Stil Veilig Wegverkeer') is started on the tyre-road interactions noise and wet grip.

The project is a collaboration between Apollo Tyres Global R&D B.V., Reef Infra B.V., University of Twente (Tire-Road Consortium), Province Gelderland and Stemmer Imaging. It is sponsored by the partners and subsidized by the Regio Twente, Province Overijssel and European Regional Development Fund. The objectives of the project are:

- Fundamental research on noise & wet grip (*knowledge*)
- Development of silent & safe tyre, roads and tyre-road combination (*valorisation*)
- By wich the roadtraffic becomes more silent & safe (*sustainable society*)

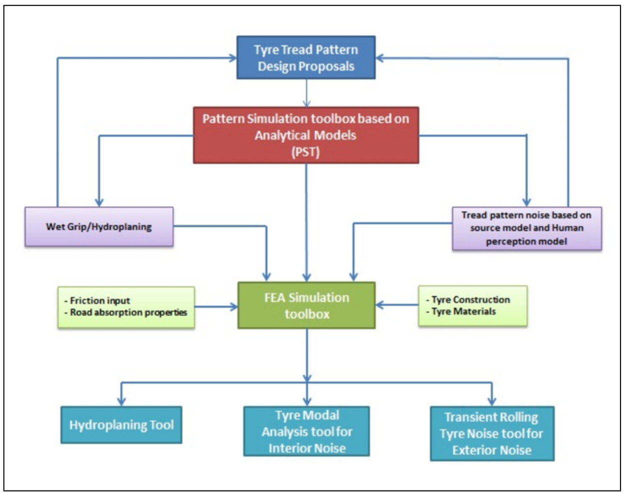

Figure 1. Overview of modeling tools.

Within this project a through and systematic investigation was planned to understand two aspects of tyre-road interaction grip and noise. The project is subdivided in four phases:

- Equipment(2011-2013); Development of new measurement equipment
- Research & Modelling (2011-2015); Development of knowledge, simulation & test tools
- Development (2013-2015); Optimization of tyres & roads using the new insights and tools
- Production & Demonstration (2015); Producing & demonstrating the optimized tyre-road configuration.

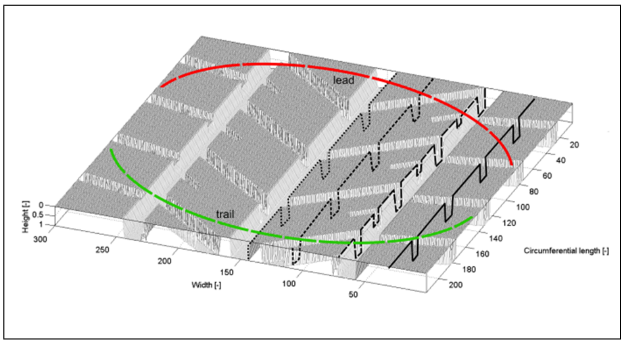

Figure 2. Source model with leading (red) and trailing edge (green) of tyre road contact.

2. Goal

The goal of the Research & Modelling part is to develop modelling and test methologies which help as engineering tools in the development of silent and safe tyres and roads. The development procedure needs to be renewed using these modelling. After clarifictation of this strategy, the different modelling tools developed in the Research & Modelling part are subsequently discussed:

Noise modelling tools

- Interior noise & human perception.
- Structural tyre vibrations.
- Exterior tyre-road noise.

Wet grip modelling tools

- Hydroplaning simulation
- Rubber-road hysteresis friction model.

These tools have been validated with experimental setups which were developed within the project scope. Most of the tools developed are in agreement with the measurements. The advantage of these simulation tools is that they provide insights into the physics of the tyre-road interaction, which can not be achieved using experimental set-ups.

3. Modelling tools

Figure 1 shows an overview of two broad classifications of tools being developed. The usage of the tools are for different stages of the development process: conceptual ideas & (virtual) prototyping.

To address the above challenge, two types of tools were developed. The first for evaluating conceptual ideas is based on analytical models for quick screening purposes. The second for (virtual) prototyping is based often on finite element methods to gathering more insight and detailed optimization. The scheme of the tools for designing new tyre is shown in Figure 1. At the conceptual design stage a variety of theory based analytical tools were developed predicting quickly faily accurate results. These analytical models are part of the overall balance optimization module called the Pattern Simulation Toolbox (PST). The

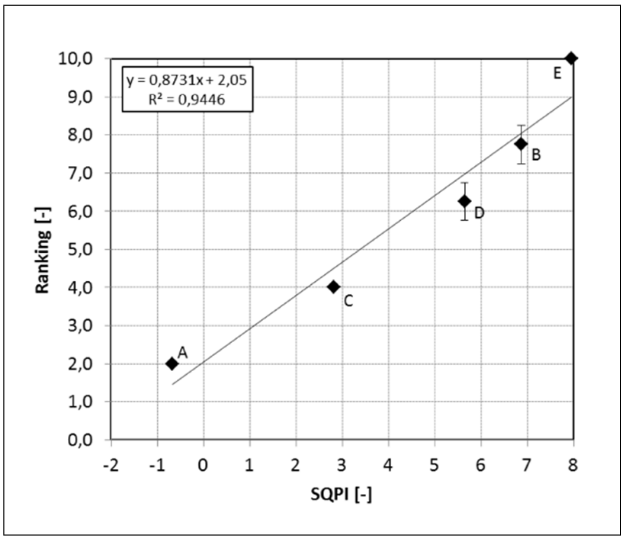

Figure 3. Obtained ranking of jury evaluation versus the calculated Sound Quality Preference Index (SQPI) using measured tyre sounds.

two analytical model developed within this project are shown here. Also other performances like snow grip are incorporated. The Interior noise & human perception model and the rubber-road hystersis model are examples of these analytical models.

With the balanced design proposals the finite element models (FEM) toolbox is used. The more complex physics of tyre-road interaction can be studied in more detail using these finite element based tools which allows to incorporate also more details like the tyre construction, tyre material behavior, frictional characteristic between road-tyre interactions, road absorption properties, etc. These tools are more time consuming and are therfore tyically used to optimize certain performances or obtain better understanding of the physics. The structural vibrations, exterior tyre-road noise and the hydroplaning simulation are examples of the finite element based simulations.

4. Noise modelling tools

4.1. Interior noise & human perception.

Tyre noise is generated by the complex interaction between tyre and road. Various excitation sources can be distinguished, one of them includes the impact of the tread pattern on a road surface. In order to reduce the sound at the source, a source model has been developed [1]. The model estimates the interior sound using the geometry of the tread pattern and footprint edge as shown in Figure 3

The human sound perception of the interior noise is determined by the noise characteristics: level, tonalness and modulation also called drumming. The new source modeling approach predicts the correct trends of the three tyre tread pattern noise characteristics.

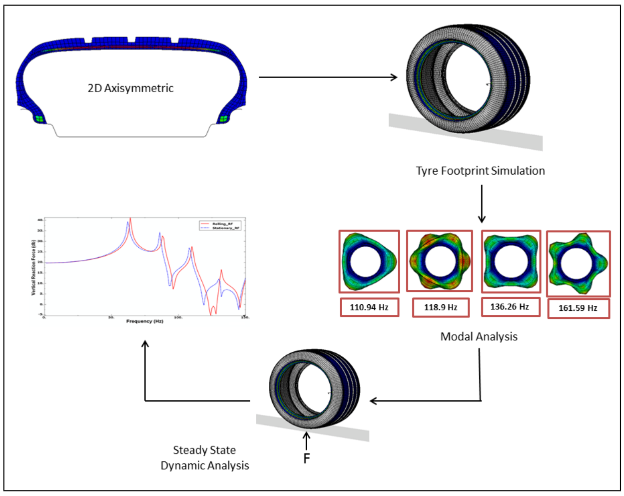

Figure 4. Structural tyre vibration simulation flow.

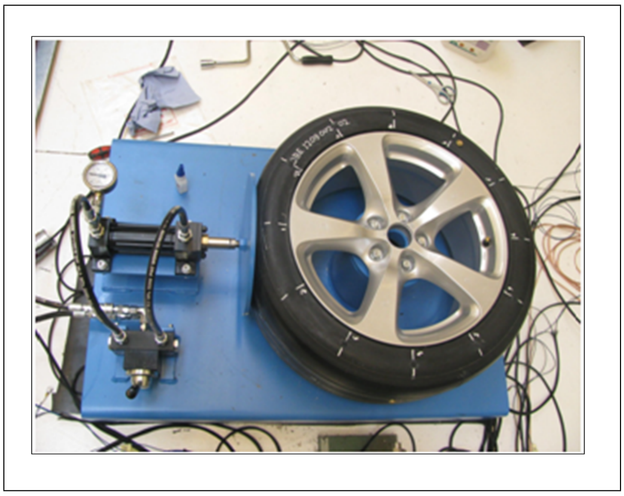

Figure 5. Experimental Tyre Modal Analysis setup.

From the noise characteristics dedicated Sound Quality Metrics are defined: for level the Standard Deviation (STD), for tonalness the Order Prominence (OP) and for modulation the Multi Order Modulation (MOM). Using these Sound Quality Metrics a human perception model is obtained, predicting the human perception of tyre tread pattern noise correctly (R^2=0.94) [2].

Using this quick and efficient tool today designer is able to make decision on how tyre tread pattern will perform regarding tyre-road noise. However, being quick the model predicts only the trends. For an absolute vaue also other proerties like the tyre construction, viscoealastic material behaviour, dimensions, etc. needs to be taken into account.

4.2. Structural tyre vibrations.

The tyre structural vibration is generally excited by the tread patterm (explained above) or road irregularities. It is one of the main reason for vehicle interior noise and vibration problems. The structural tyre vibrations tools is based upon the Finite Element Method (FEM). It is capable of predicting the dynamical response of tyre structure taking tyre construction details, tyre material and various operational conditions into account. Modal results in terms of Eigen frequency and Eigen modes of tyre give better insight into how vibrations are transferred from the road through the tyre and towards the spindle. This tool can efficiently predict the low frequency tyre vibrations and transmissibility of the tyre.

Figure 4 shows workflow of the tool. Starting from a cross section a revolution algorithm uses the rotational symmetry to produce the finite element model. The modal analysis simulation can be done in static loaded (see figure 5) or loaded rotating condition. It is also possible to model and predict effect of air cavity inside tyre which has significant effect on interior noise if cavity resonance is being transmitted to the interior of vehicle [3].

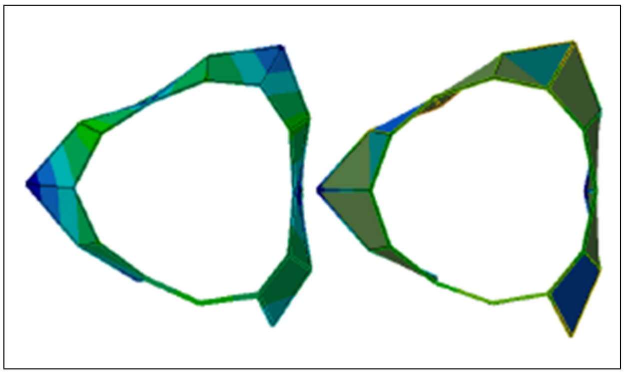

Figure 6. Experimental determined mode (left) and simulation (right) comparison using MAC within 5% deviation.

An validation experiment is executed of loaded tyres as shown by figure 5. Commercial acoustic software is used to co-relate experimental results with that of simulation results. Based on Modal Assurance Criterion theory it is possible to compare test and simulate result accuratey. Using test modal vectors (ψ_{test}) and FE modal vectors (ψ_{FEA}), the MAC matrix can be built [4]. An example of a correlated mode can be seen in Figure 6. It is found that the trends of the model corresponds quite well with the experiments.

Although this tool is computationally expensive it gives overall understanding of how low frequency tyre vibration will influence interior vehicle noise. Today designer can tune tyre construction based on knowledge generated by such virtual prototyping tools.

4.3. Exterior tyre-road noise.

In order to predict accurately the exterior tyre-road noise a Finite Element Method (FEM) based commercial code is used to calculate the vibrations of a transient rolling tyre. The detailed tyre is rolling on the

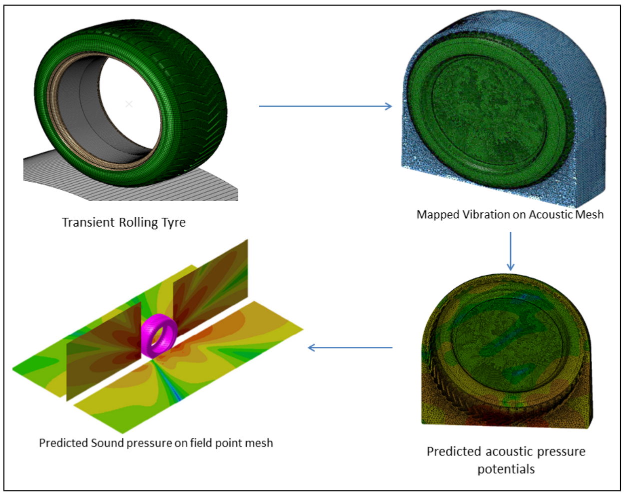

Figure 7. Exterior tyre-road noise simulation flow

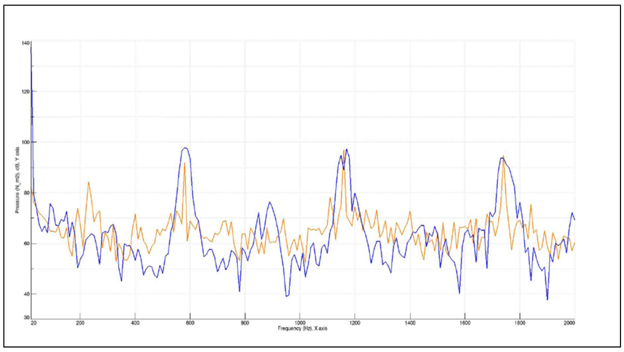

Figure 8. CPX front of simulation (blue) and experiment (yellow).

road texture as shown in Figure 7. These structural vibrations are mapped to a stationary acoustic mesh to carry out the acoustic radiation using the Finite Element Method âĂŞ Automatic Matched Layer acoustic solver. The acoustic potentials (pressure, velocity) are calculated from which different post-processing possibilities are available. For finding the solution outside the FEM domain, a Kirchhoff Surface Integral approach used.

To compare the simulation results with experimental results an experiment is executed. The noise from different treaded tyres running on a smooth drum in a anechoic room is measured at the CPX microphone locations specified in the ISO11819-2. Figure 8 shows the experimental and simulation result for the CPX front microphone location, near the leading edge. The tread impact frequencies and overall behaviour are clearly seen to correspond quite well.

This tool generates a lot of knowledge and gives insight by various post processing capabilities in order to make better design decisions. The only drawback of such full scale simulation is, it is computationally very expensive and takes time to produce results.

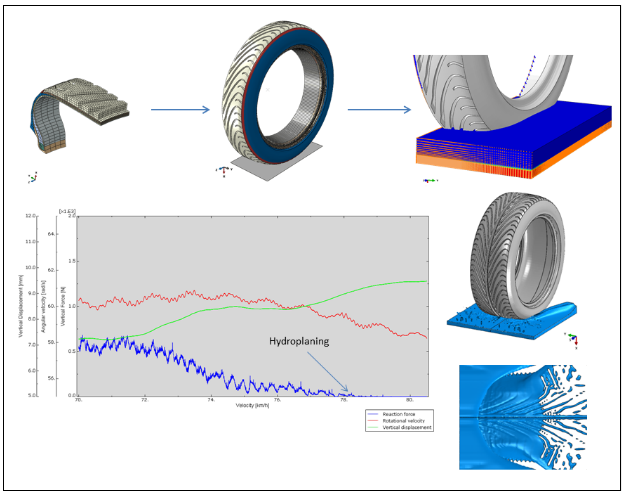

Figure 9. Hydroplaning simulation flow.

5. Wet grip modelling tools

5.1. Hydroplaning simulation tool.

Hydroplaning occurs at higher speeds (>100 km/h) and at high water levels (>3-5 mm). The tread blocks of the rolling tyre penetrates these water layers to establish tyre-road contact. This contact needs to be established before the tread blocks leave the contact patch. If the speed or water layer is too high no real contact between tyre and road can be established resulting into loss of frictional forces. Due to this braking and steering capability of the vehicle is lost; this phenomenon is called hydroplaning.

Hence, at the initial design phase it is very important to know the influence of conditions like inflation pressure of tyre, footprint aspect ratio, tire wear, water layer height, road texture, road porosity. Given these input parameters it is most importantly to determine at which vehicle speed hydroplaning will occur.

The hydroplaning tool is based on Explicit Finite Element Method. It combines Coupled Eulerian-Lagrangian approach to model Fluid Structural interaction. Figure 9 shows the simulation flow of this tools [5].

The example shown is form an experiment where one tyre is at different inflation pressures and rotation directions. Four configurations have been simulated and experimentally tested. Figure 10 shows the valiation result of this excercise. The simulation results are seen to correlate very well with the experiments.

5.2. Rubber-road hystersis friction model.

A model based on multiscale contact mechanics calculating the rubber-road friction is implemented. The material wet grip friction coefficient between rubber block and asphalt as a function of slip velocity, contact stress and tyre temperature (background tem-

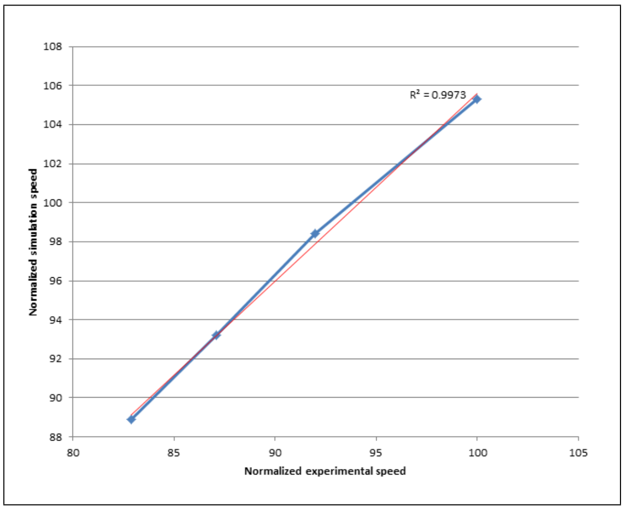

Figure 10. Validation of the hydroplaning simulation using 1 tyre at different inflation pressures and mounting directions.

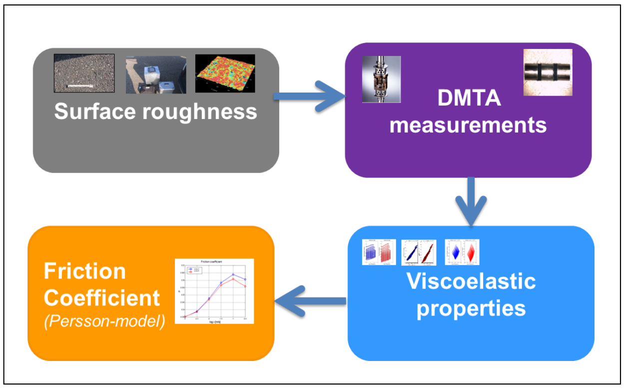

Figure 11. Rubber-road hystersis friction simulation flow.

perature) is predicted using the road textre and viscoelastic material behaviour into account.

The road identations at different road texture length scales correspond via the slip velocity to different frequencies and induce different stresses, which can be calculated via multiscale contact mechanics. The calculated stresses at different length scales will be used to identify new viscoelastic input. The new viscoelastic input will be used to recalculate apparent contact area for each length scale and corresponding stress values and so on until convergence. When solutions are found, a new iterative procedure has to be applied to define flash temperatures for each length scale and finally to calculate friction coefficient [6].

6. Conclusions & Recommendations

Various modeling tools developed within the project scope are predicting the noise and wet grip/hydroplaning performances of the tyre-road interactions. The tools correlate well with test procedures developed within project scope. The tools are implemented in the development process at the different stages to enable the engineers to make the best optimized compromise of the various performances. Furthermore the tools generate physical insights, not possible with experiments. The tools will be used to develop, within the project, various silent and safe tyre-road combination(s).

Acknowledgement

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