

Enhancement of Full-Vehicle Road Noise Simulation Including Detailed Road Surface and Innovative Tire Modeling

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ABSTRACT

The time to market in the automotive industry is constantly decreasing pushing the carmaker companies to increase the efforts in numerical simulations and to decrease the number of prototypes. In the NVH field, this time constraint reflects in moving the well-established finite element simulations towards the so called “full-vehicle simulations”. Specifically, the CAE techniques should be able to predict the complete behavior of the vehicles in mission conditions, so to reproduce some usual tests, such as the “coast down” test on different roads.

The aim of this paper is to present a methodology to improve rolling noise simulations exploiting an integrated full-vehicle approach. An accurate modeling of all the subsystems is needed, with particular attention to the wheels and the suspension systems. Therefore, the paper firstly covers the modeling approach used to obtain the FE models of tires and suspension system. A particular focus is on the modeling of tires, since the typically used “modal models” are replaced by internally developed simplified FE models. Secondly, the rolling noise simulation approach is presented, by showing an easy-to-use tool developed to automatically set up the chosen full-vehicle simulation. The final aim is to have a quick technique to predict the overall behavior of the vehicle.

The proposed methodology is assessed by means of a numerical-experimental comparison for a coast down test on cobblestone road. The comparison involves the acceleration at front and rear hubs to prove the effectiveness of the tire modeling. Moreover, the Sound Pressure Level (SPL) at the driver’s right ear is compared, which is the main target of the simulation.

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INTRODUCTION

The automotive industry is facing the problem of an increasingly competitive market. This situation pushes OEMs to meet customers’ requirements by both decreasing the time to market and increasing the overall quality perception. Vehicle noise and vibration is considered to be an important part of quality perception, but in view of the decreasing time of design cycles and vehicle cost reduction, CAE engineers are pushed to develop new methodologies to address NVH numerically as much as possible. The number of hardware prototypes wants to be constantly reduced, thus increasing the need for reliable NVH simulations able to predict the behavior of the real vehicle.

In this context, being able to simulate the full vehicle in rolling conditions is an increasing need where the main objective is to reproduce the usual tests performed by OEMs to assess NVH performances, such as the “coast down” test on different roads.

If it is crucial for a good estimation to have a proper modeling of the various components involved in the full-vehicle simulation, on the other hand, a quick and accurate modeling of the excitation coming from the road is needed. Indeed, a full-vehicle simulation should be able to distinguish between different excitations. For this reason, this paper wants to deal with the modeling of important subsystems, the tires and the suspension, which are crucial for sound and vibration performances, together with a proper modeling and simulation of the excitation coming from the road surface. It is worth specifying that in this paper, only the structure-borne noise is going to be investigated. The airborne noise is out of the scope of this work since different simulation methodologies would be required to do that. Moreover, the frequency range to be investigated is usually higher and the simplified modeling of the tire proposed would be inappropriate.

Several authors have dealt with full-vehicle simulations for NVH applications. In particular, an interesting SIMULIA technology brief is focused on the importance of a proper modeling of rolling noise in full-vehicle [1]. In [2], a full-vehicle approach is proposed and a

standardized vertical displacement (ISO-2631) is applied to the wheel centers, without modeling the tires. A similar approach was used in [3], but a frequency spectrum corresponding to coarse road surface, is applied to modal models of tires. In [4], the application of the displacement from the road is limited to the wheel and the results are forces at the spindle center. Finally, interesting considerations on real experienced surface excitation based on rolling velocity are presented in [5].

The present paper is organized as follows. In the first section, the FE modeling of the full-vehicle is presented. Secondly, the simulation setup is explained, focusing on the way of dealing with road surface. Finally, the last section addresses the presentation and discussion of the results coming from the proposed simulation in terms of both acceleration at the wheel hub and SPL at the driver's right ear.

FULL-VEHICLE FE MODEL FEATURES

The aim of this section is to present the FE model used in order to run the full-vehicle simulation fully investigated in the next section. Indeed, if the use of the so called "trimmed body" models is a well-established and validated technique, the full-vehicle modeling still presents several open points. First, the modeling of tires is illustrated. Secondly, the suspension system modeling characteristics are presented and briefly compared with experimental tests.

Simplified Modeling of Tire

Usually in the automotive industry tires are accounted for by means of the so called "modal models" provided by tire manufacturers. These models are very easy to use and are certified by the suppliers. Nevertheless, such models suffer from an almost complete disconnection of their characteristics from the physical description of the tire, since both geometric and material characteristics are lost. This reflects in limiting the carmaker companies to be able to request only certain modal features to the supplier, with no link to the mechanics of the tire itself.

In addition, modal models for road noise mission simulations need to have a sufficient number of scalar points in the contact patch area for a proper application of the excitation from the road. Nevertheless, usually, the modal models are provided with limited information in this area.

The mentioned reasons have motivated an activity which has been published in [6] and which is going to be summarized in the following steps.

1. Initial FE Model Creation

The starting point is a geometric FE model of the tire, built by using the main geometric features, e.g. the width of the tire tread, which can be obtained from supplier data or from measurements. The other information needed is the composition of the tire, which is easily readable on the tire sidewall. According to this information, the FE model is characterized by means of a multilayer representation of the tire. Indeed, only two-dimensional (2D) elements are used to have a

simple model and the properties of such elements are set up by using the PCOMP card in Nastran [7], which defines the properties of an n-ply composite material laminate.

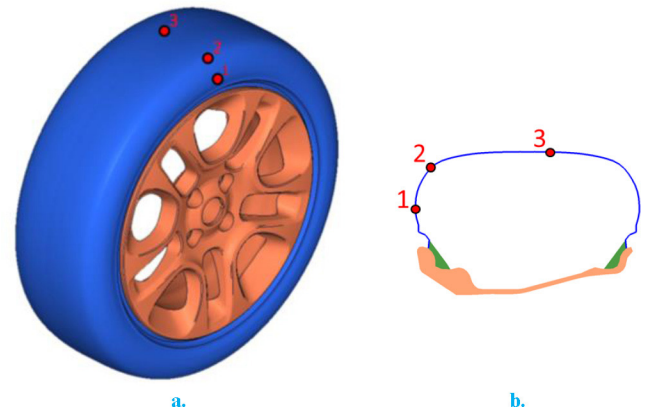


Figure 1. Example of tire with inertance measurement points indicated.

The bead area is simplified and modeled with solid elements to properly couple the 2D tire elements with the 3D rim elements, as visible in Figure 1b. The definition of the ply sequence is based on the information available on the sidewall of the tires. The thickness of the various layers is at this step hypothesized, based on literature data, since it is going to be slightly modified later on in the optimization process. On the other hand, the total thickness of the tire along its cross section is measured and the thickness of the outer layer (external rubber), is varied to meet the measured value.

2. Optimization of Tire Properties

Once the initial geometric model is created, an optimization process is set up. Since one of the main features of the proposed methodology is to perform as few measurements as possible, only three point inertances were used in the optimization process as comparison terms, as visible in Figure 1. The objective functions are then formulated as the root-mean-square errors between experimental and numerical FRFs. The point inertances are computed and measured assuming the complete wheel with tire inflated and constrained hub, but no static crushing is included.

Inflation is numerically modeled with a static subcase in the Nastran software, the "STATSUB" card, with a constant pressure applied to the internal surface of the tire.

The variables included in the optimization process are the following:

1. Young's modulus of steel cords;
2. Young's modulus of nylon cords;
3. Young's modulus of polyester cords;
4. Young's modulus of rubber;
5. Volumetric fraction of nylon cords w.r.t. the rubber matrix;
6. Volumetric fraction of steel cords w.r.t. the rubber matrix;
7. Volumetric fraction of polyester cords w.r.t. the rubber matrix;
8. Thickness of the steel cord layers;
9. Thickness of the nylon cord layers;



10. Thickness of the polyester cord layer;
11. Steel cord orientation angles;
12. Density of the rubber.

These variables are used to modify the properties and materials of the different layers in the FE model, where the cord layers are characterized by an equivalent material determined by using classical formulas of mixtures, as suggested in [8]. In addition a set of constraints is set up, including the value of some easily identifiable eigenfrequencies, whose deformed shapes are visible in Figure 2, and the overall mass of the wheel, which was measured before the experimental tests.

The optimization process is set up using the commercial software modeFRONTIER and the optimization algorithm is chosen to be the MOGA-II, see [9]. Being a genetic algorithm, the population dimension and the number of generations are imposed to be 32 and 300 respectively.

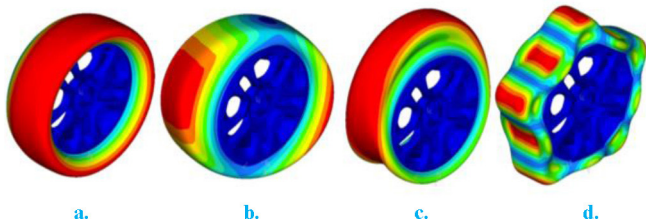


Figure 2. Deformed shapes of constrained eigenfrequencies: a) 1st mode; b) 3rd mode; c) 5th mode, which is the first vertical one; d) 17th mode.

3. Vertical Preload on Tire

After the optimization process, the best individual is chosen and its properties are used in the following steps of the modeling methodology. In particular, the deformed shape of the tire under a vertical static load has to be determined. To do so, the “static loaded radius” is measured on the wheel under the maximum permissible laden weight.

A nonlinear static approach is used to simulate the preload, by means of the SOL400 solver in Nastran. The hub is clamped and a rigid plane is used to compress the tire until the measured static loaded radius is reached. The obtained geometry is then used for the following simulations.

4. Tire Cavity Creation

The importance of a proper modeling of cavity modes has already been shown in [10]. In particular it is crucial to model the cavity in rolling conditions. Since the cavity modes are split in two, due to the effect of rotational speed, two cavity FE models are created inside the deformed tire geometry to model this phenomenon. The material of the two cavities have a modified speed of sound equal to $c_0 \pm v$, being c_0 the speed of sound in air and v the tire tangential velocity.

5. Gyroscopic Effects

Another relevant effect in rolling conditions is the influence of the gyroscopic forces on the tire [11]. To do that, an external DMIG (Direct Matrix Input at Grid) matrix is created and then applied to the simulation. The computation of this matrix is done by using a tool included in the in-house CRF-FCA Veiprod5 software which automatically generates the matrix, having the FE model of the sole tire as input. For more details, please refer to [6].

6. Rubber Softening

The last effect included in the tire modeling, due to its strong relevance, is the softening effect of the rubber caused by the increased temperature of the tire. The determination of the softening factor - i.e. ratio of the Young's moduli of the rubber in static and rolling conditions - is done by tuning the frequency shift of the first vertical mode. Typically, values range between 2 and 3.

Suspension Modeling

The front suspension system used in the vehicle studied in this activity is a McPherson strut. A previous validation activity was performed to optimize the FE model of the sole suspension. The model wants to be accurate but also computationally cheap. Therefore, the main features are:

- Coil spring of the shock absorber modeled as a spring-and-damper structural element (CBUSH element in NASTRAN);
- Strut mounts modeled as spring-and-damper structural elements with linearized properties;
- Spherical joint modeled as rigid elements constraining only relative translations.

Some tuning was performed on FE materials and properties to meet the measurement data obtained by a suspension test bench. The comparison was performed on point inertance at the wheel hub in the y and z directions, which are the transversal and vertical vehicle directions respectively. The suspension test bench can be seen in Figure 3 together with the corresponding FE model. The comparison of point inertances is shown in Figure 4 in the frequency range 0-250 Hz.



Figure 3. Front suspension test bench (a) and FE model (b).