

Virtual Tire Data Influence on Vehicle Level Handling Performance

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ABSTRACT

This study presents the comparison of vehicle handling performance results obtained using physical test tire data and a tire model developed by means of Finite Element Method.

Real tires have been measured in laboratory to obtain the tire force and moment curves in terms of lateral force and align torque as function of tire slip angle and vertical force. The same tire construction has been modeled with Finite Element Method and explicit formulation to generate the force and moment response curves.

Pacejka Magic Formula tire response models were then created to represent these curves from both physical and virtual tires. In the sequence, these tire response models were integrated into a virtual multibody vehicle model developed to assess handling maneuvers.

Finally, results were generated for key vehicle level handling metrics such as roll gradient, understeer gradient and maximum lateral acceleration, allowing the comparative assessment of these metrics using physical and virtual tire data.

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INTRODUCTION

Tires are key components for overall vehicle dynamics behavior, as they are the only elements that connect the car to the pavement. The tire tuning during vehicle development is aimed to achieve the ideal balance among the following characteristics:

- **Ride Comfort:** relates in general to the tire radial force transmissibility, that is translated into vertical and longitudinal load inputs to the vehicle. This characteristic needs to be balanced for different road conditions that the vehicle is expected to be subjected to (smooth road, rough road, off-road, etc.) and mass/ballast conditions of the vehicle (light vehicle vs heavy vehicle, vehicle + driver vs fully ballasted vehicle).
- **Handling & Stability:** relates in general to the tire lateral force transmissibility. The vehicle handling behavior needs to be balanced for different ballast conditions and pavement conditions as high friction pavements (regular asphalt and concrete) vs low friction pavements (wet roads, ice and snow conditions). For the tire development, requirements like aquaplaning avoidance and very-low friction (icy or ice covered roads) behavior play an important role in terms of trade-offs with the other handling characteristics.
- **Braking:** relates in general to the tire longitudinal force transmissibility. Like the handling characteristics, the vehicle braking behavior needs to be balanced for different ballast and pavement conditions.
- **Fuel Economy:** this characteristic relates to the tire internal friction that is translated as a rolling resistance coefficient (RRC) as determined by standards SAE J1269 (Rolling Resistance Measurement Procedure for Passenger Car, Light Truck, and Highway Truck and Bus Tires [1]) and SAE J2452 (Stepwise Coast down Methodology for Measuring Tire Rolling Resistance[2]). The pressure for more fuel efficient vehicles usually presents the need for lower RRC values and with that, significant trade-offs with the braking and handling performance of the tire.
- **Tire Wear:** this characteristic relates to the expected life of the tire under regular usage and also must be balanced with the other characteristics.

The tire development engineer needs to determine the right tire internal construction and inflation pressure that provides the desired balance of these characteristics, taking into account other points like construction cost, raw material availability, etc.

Traditional tire development involves building different physical prototypes with considerations of the vehicle under development and previous known tire constructions. Different samples with variations of the internal construction aspects are then sent to vehicle physical testing, where the in-vehicle tests are performed to find the best alternative to balance the characteristics previously described. In parallel to that, the same samples are tested in the laboratory to determine the tire force and moment (F&M) and RRC properties that can be used to feed full vehicle simulation models for the virtual assessment of these same characteristics. As the process is iterative, 3 to 5 loops of physical tire builds are usually required in order to achieve the desired performance.

In this sense, the traditional approach demands significant resources in terms of prototype tooling costs, laboratory test costs and the timing associated with these processes. While other areas of vehicle, and more specifically chassis system development, have been consistently migrating hardware based development to CAE/virtual assessments to reduce costs and timing and allow effective advanced development, traditional tire development still demands availability of physical vehicles that many times are available only at later stages of vehicle development, putting more pressure to the timing aspect of the development. Even when the vehicle level performance is assessed with virtual simulation models at early development stages, the tire information to feed these models would still be obtained by means of tire physical prototype builds and respective laboratory testing. This leads to penalties in terms of cost and time.

The objective of this paper is to study an alternative to the traditional tire development process, which is to develop virtual tire properties by means of a CAE (Computer Aided Engineering) simulation model of the tire. The data generated by this simulation will then be incorporated in a vehicle level simulation model, where the main performance characteristics can be assessed by means of the adequate metrics. This process can bring significant improvements to the initial steps of the tire development in terms of costs and time, eliminating or significantly reducing the need for physical prototype builds and laboratory tests, especially in the early development stages.

This work will focus on the tire force and moment data generation and the associated vehicle level handling metrics. The details on the virtual tire modeling, incorporation of these results in the virtual vehicle model and the comparison of these results against the results obtained by the tire built and measured through the traditional approach will be described in the sequence.

VIRTUAL TIRE MODEL

In order to analyze the tire dynamic responses, in general it is not necessary to consider the transient phenomena. The use of steady state behavior provides reliable results and has the advantage to save computational time when compared with time-dependence models.

In this paper, the finite element software Abaqus® was used. This is a nonlinear solver with suitable tools to simulate tire performance, as already pointed by Donatellis [3] in his works with Formule 1 tire development. Abaqus provides a procedure called Abaqus/Standard Steady State Transport (SST), a specialized analysis that uses an

Eulerian formulation and a material deformation. The tire model is an axisymmetric body traveling at a constant ground velocity and constant angular rolling velocity, as depicted in [figure 1](#). It moves at the speed of the ground velocity but does not spin with the body in the rolling motion: an observer in this frame sees the tire as not moving, although the material, of which the tire is made of, is moving through those points. This choice of reference frame allows the finite element mesh to remain stationary so that only the part of the body in the contact zone requires fine meshing (ABAQUS® - Standard User's Manual [4]). This removes the time dependence from the problem reducing considerably the computation time and providing a fast and reliable solution. The SST allows for steady-state rolling and sliding solutions including frictional effects and inertia effects.

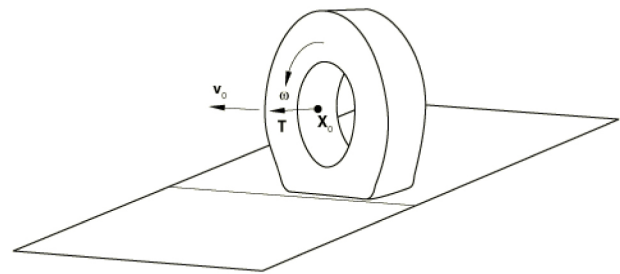


Figure 1. Tire Straight Line Rolling. ABAQUS® [4]

Using the SST procedure, it is possible to change the velocity direction (V_0) and simulate a slip angle condition, as the slip angle is a necessary condition to generate lateral force and align moments in the contact patch.

Finite Element Model

The Finite Element Model is a 3D, quad-dominant mesh, initially built as a 2D model and then revolutionized into a 3D model. With the 3D model, the SST analysis is applied to generate the F&M using a flat rigid surface created to represent the road. The [figures 2, 3, 4, 5](#) illustrate the process sequence.



Figure 2. Chart flow to create SST Tire Model

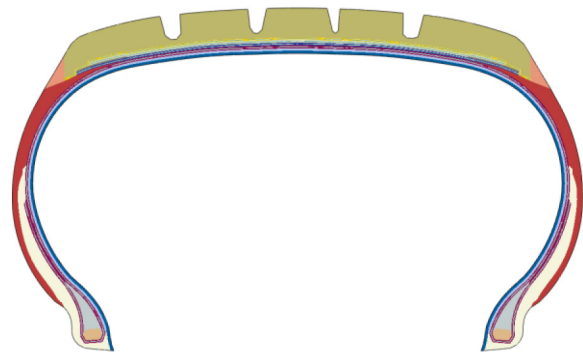


Figure 3. Two-Dimensional CAE based Tire Model Cross Section

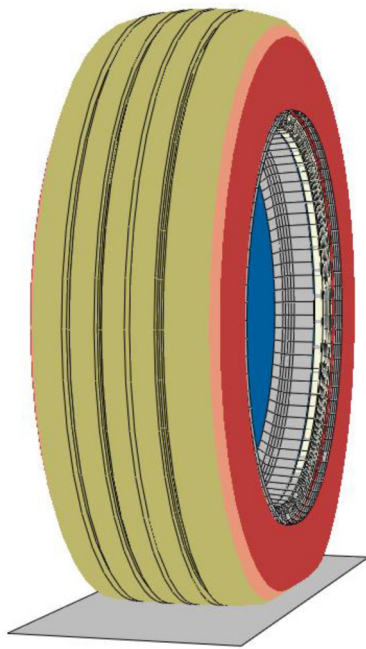


Figure 4. Three-Dimensional CAE based Tire

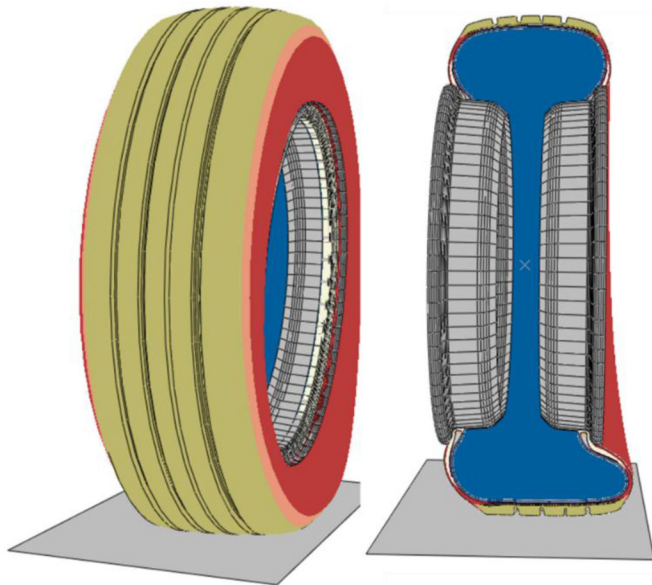


Figure 5. Steady State Transport (SST) CAE based Tire Model with 10° Slip Angle.

The reaction F&M are measured in the rigid surface to represent the forces generated by the tire deformations at the contact patch. This can ultimately be correlated against real measured tires to confirm effectiveness of the process.

Procedure and Results

To simulate a slip angle test the follow conditions were considered:

- Tire model to represent build construction of Pirelli 205/60R16 92H Scorpion ATR
- Vertical Forces = 907N; 2268N; 3628N; 4536N; 5896N; 7257N

- Longitudinal Velocity = 3.5 Km/h
- Slip Angle = 0° to 10°

These conditions were chosen to match real tire test and the results comparison is presented in figures 6 and 7.

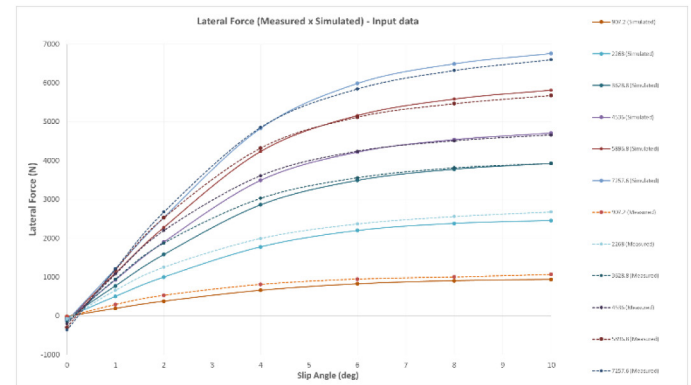


Figure 6. Comparison of CAE Based Tire (solid lines) with Measured Tire (dashed lines) for Lateral Force vs Slip Angle as Function of Normal Load

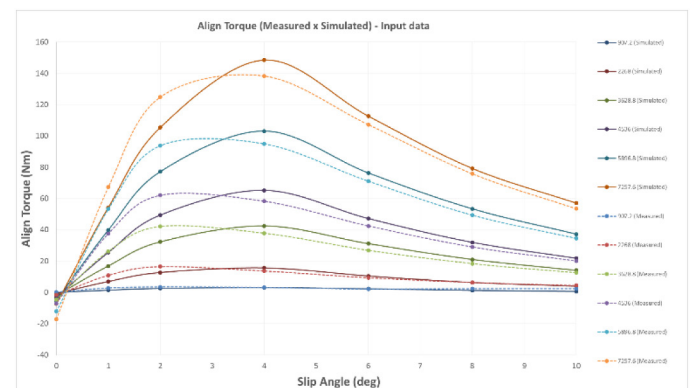


Figure 7. Comparison of CAE Based Tire (solid lines) with Measured Tire (dashed lines) for Align Torque vs Slip Angle as Function of Normal Load

Pacejka [5] works in parametric models as the tire Magic Formula, which is able to capture non-linearities in the relationship between lateral force and self-aligning torque with the tire slip angle to wide ranges of vertical load at the same time. This work will consider this approach and two different sets of parameters for the Magic Formula tire model representation were created to fit the curves from both physical and virtual tires as shown in figures 6 and 7, so that the vehicle level effects could be adequately compared in the sequence.

VIRTUAL CAR SIMULATION MODEL AND METRICS

In order to compare the two tire models (measured tire and CAE based tire), a full vehicle simulation model was created using multibody systems. ADAMS® (Automatic Dynamic Analysis of Mechanical Systems) has been considered as the reference model for this study. It is a widely accepted software for three-dimensional systems and there are several studies that demonstrate the good correlation between vehicle handling dynamic metrics simulated with ADAMS® software compared to physical measurements [6, 7]. Vilela [6], Prado et al [7] and Fernandes and Okano [8].