

Tire Modeling from Structural Analysis to Real-Time Applications



CAE-based methods are continuously accelerating the vehicle development process. Virtual vehicle models drive over the digitized road surfaces of OEM's proving grounds, steered by virtual driver models. One of the key components of the load transfer process is the tire. The quality of the underlying tire model is crucial for the accuracy and reliability of virtual load prediction scenarios.

Fraunhofer ITWM's new tire models CDTire/3D and CDTire/Realtime have been implemented in SIMPACK to improve the accuracy and ease of parameterization for large deformations and lateral dynamics, as well as supporting comfort and durability applications in realtime systems.

INTRODUCTION

All commercially available tire models—including CDTire—were developed at a time when available computer hardware delivered only a fraction of the computational performance available today. Simplifications in the modeling process were accepted in order to ensure the applicability of the models in productive development processes. Due to these simplifications, the application range and accuracy of the load prediction was limited. Motivated by unexploited potential in the virtual development process, Fraunhofer ITWM developed a full 3D structural tire model to extend both the application range and the achievable accuracy of full vehicle scenarios.

The new CDTire/3D additionally opens the door to extended tire parameterization strategies: local geometry-based tire measurements can be used to reduce the number of tests needed to a minimum. CDTire/3D also enables the parameterization of tire types and sizes where parameterization failed in the past due to the non-availability of suitable measurements. CDTire/3D is available with SIMPACK 9.4.

MODELING CONCEPT OF CDTIRE/3D

The basic concept of this modeling approach is that the local deformation behavior of

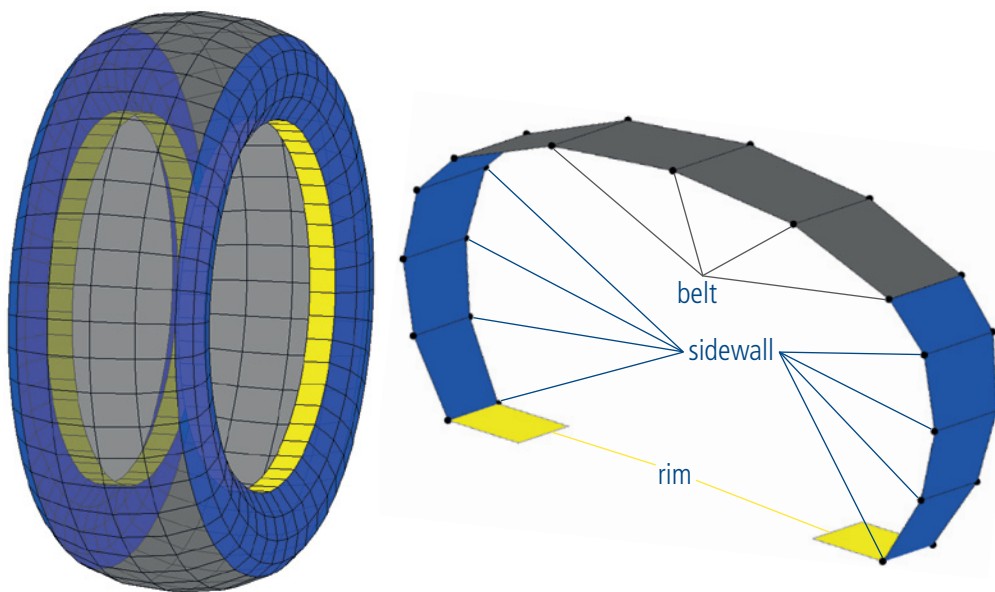


Fig. 1: Mass distribution in tire and cross section

a real tire should be identical to that of an MBD tire model. Consequently, the model must have a detailed, materialized shell representation of sidewall and belt to feature the deformation behavior of the load bearing structure. With this, one can feature both in-plane and out-of-plane (transversal) deformation behavior.

The density properties of the shell are represented by discrete mass points with every mass point having three dynamic degrees of freedom (see Fig. 1).

The elastic properties of the shell are realized by an anisotropic elastic membrane part and adaptation of the Kirchhoff-Love hypothesis for bending. The bending is implemented around all circumferential and lateral edges, and around two diagonals of each cell. To constitute the bending laws, the 4-point cells will be divided into their elementary triangles. Bending of adjacent cells relative to the edge is split into bending of two pairs of triangles. The same is done for bending around the diagonals of a cell, see Fig. 2 and Fig. 3.

COMPONENT PROPERTY LAYERS

The anisotropy of the tire is a direct consequence of the tire structure. The physical tire is built from different component layers, e.g., inner liner, carcass, steel belt layers,

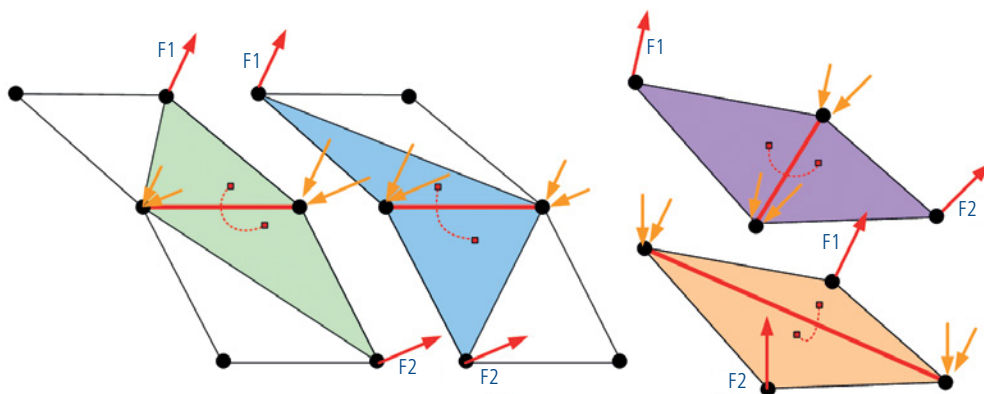


Fig. 2: Triangle pairs used for cell edge bending (left) and around diagonals of a cell (right)

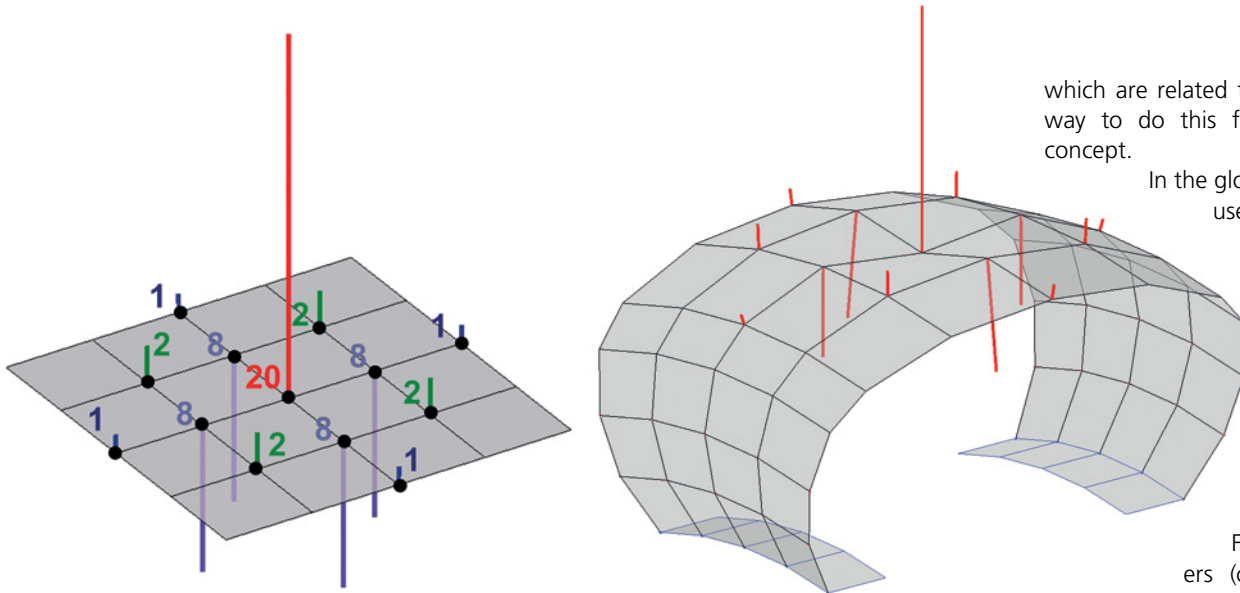


Fig. 3: Finite difference stencil of isotropic bending with unit deformation (left) and example of reaction forces to discrete deformation of belt center point (right)

cap plies, tread etc., with most of these being reinforced by synthetic cords or steel wires. Each reinforcement layer introduces directionally dependent material properties, the orientation of the cords relative to the circumferential direction is specified with an angle. All the characteristic component layers described above have a separate representation in the model. The main advantage of this description is that the model is completely configurable. One can, for example, model an arbitrary number of steel belt layers. Every steel belt layer can have a specific belt angle and specific local stiffness properties.

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This is important for modeling truck tires, which can have a varying number of steel belt layers and varying angles compared to passenger car tires, see Fig. 4.

GEOMETRY BASED MODELING

The first key entity is the cross section. The modeling starts by specifying the discrete mass distribution of the non-inflated cross section. Then, the mass-points (nodes) and the related cells must be defined. Based on the nodes and cells in the cross section, one can define every component layer’s local cross section parameters,

which are related to nodes or to cells. The way to do this follows a global-to-local concept.

In the global-to-local concept, the user first specifies a global parameter which can be seen as the average of the cross section, and then specifies the local parameters by defining weights relative to the global parameter. The specification of weights is optional.

For the reinforced layers (carcass, steel cord and cap plies), one can specify the local and component-specific stiffness and damping parameters, as well as local pre-stresses. This is done by specifying local reduction factors for the stress-free characteristic lengths of the reinforcement material (synthetic or steel wires).

CONTACT FORMULATION

The contact model is a brush-type contact model. The single bristles act as sensors; they detect road contact and their deformation results in a force transferred to the tire structure. The bristle tips can stick or slide. The number of sensors and their lengths can be specified individually for every cell in the cross section.

TIRE GROUND-OUT CAPABILITY

The Large Deformation Element (LDE) developed and validated during the last

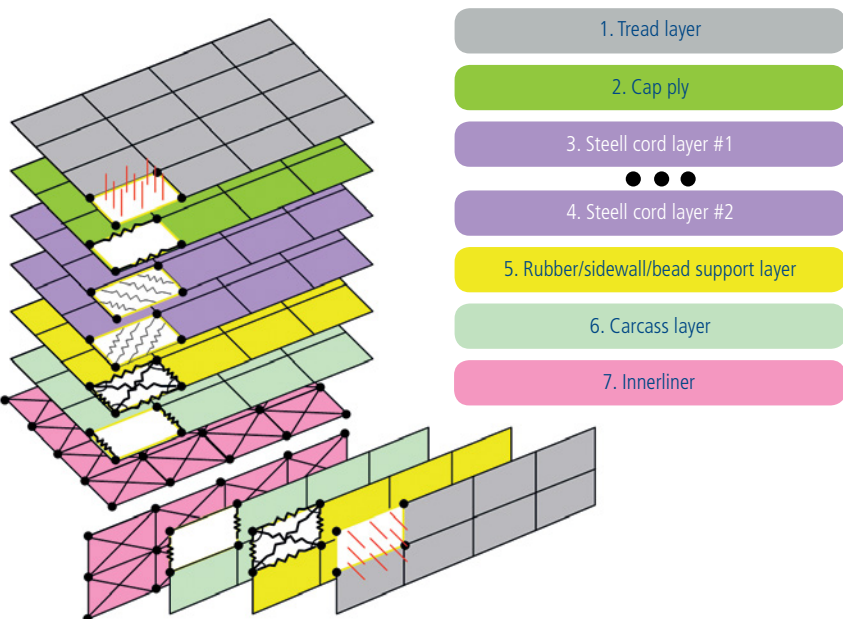
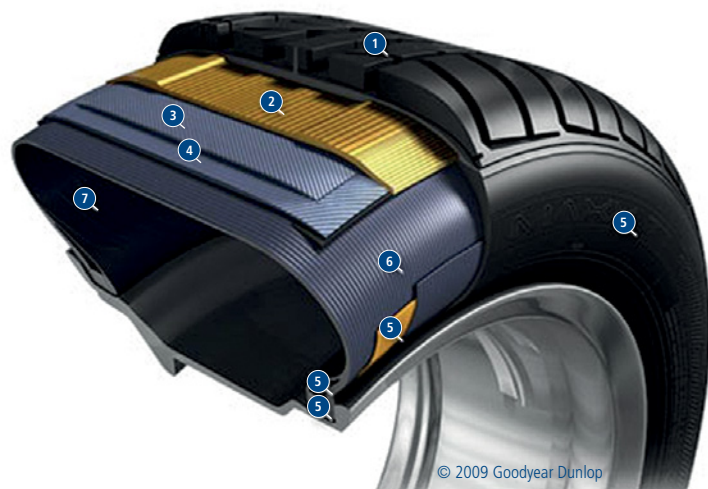


Fig. 4: Functional component layers of a tire



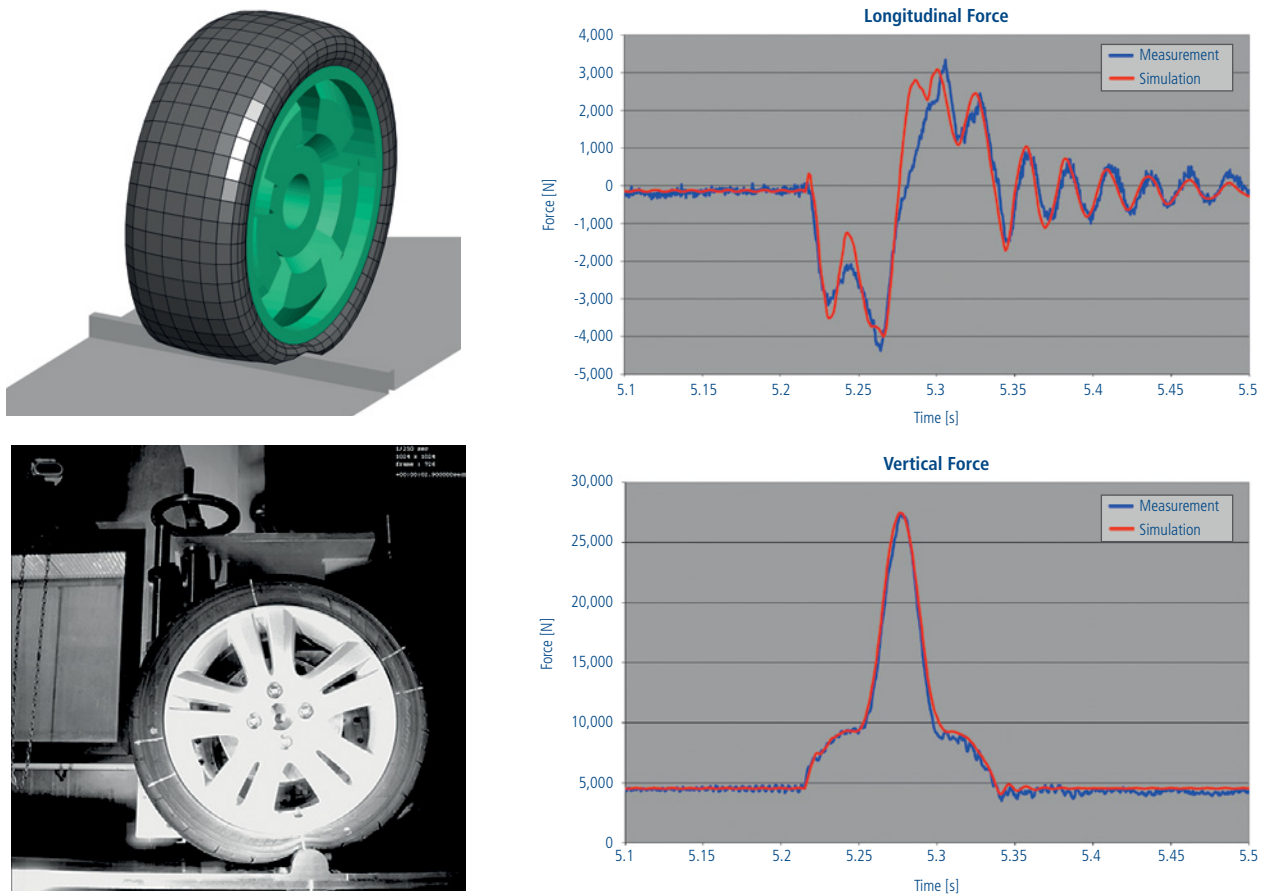


Fig. 5: Forced tire ground out simulated with CDTire/3D on Fraunhofer LDE test rig

4 years has been transferred to the new model CDTire/3D. This element models the sidewall/belt/rim contacts for very large tire deformations (see Fig. 5). As an extension, we have added the ability to distinguish between the inside and outside part of the rim as well as added support for PAX-like run-flat systems.

PARAMETER IDENTIFICATION

To determine the model parameters of CDTire in such a way that a specific tire is adapted, tire data sets and measurements must describe the physical properties of the tire. The stand-alone tool CDTirePI allows the engineer to identify the best parameter set by:

- importing measurement data from arbitrary test labs
- setting up and executing the respective test scenarios, and
- automatically comparing test and simulation results using dedicated measures (e.g., rms, range, max, etc.)

In the first step, the cross section geometry is constructed. All material properties are interpreted relative to the reference geom-

etry. The import of constructional data is supported. Functional tire components like belt, carcass and cap plies, and tread are addressed as separate entities. Their specific geometric properties (such as cord angles) are fixed during this step.

Next, certain tire (pre-strain) properties are adapted to align the cross-section geometry with measurements under inflation pressure. Both inner and outer contour and cross section mid-surface geometry can be used here.

Quasi-static stiffness tests can now be used to adapt most elastic properties. In this phase, additional geometric information like footprint shapes and deformed contour measurements can be used to resolve some parameter ambiguities introduced by pure 'spindle load' information.

If no additional measurements are available, an 80 % accurate solution can still be obtained via the structural capabilities of the model, if local information was used to parameterize it. This opens the door for tire types like large agricultural tires, where up to now, tire model usage has been difficult to

calculate due to insufficient measurements. Usually, stationary measurements can be used to identify tread and friction properties; cleat run tests assess the viscous properties. For tires too big to perform cleat runs, drop tests and/or modal analysis can be substituted.

MODEL SCALABILITY OF CDTIRE/3D

The discretization of the material shell structure is arbitrary and user selectable for side wall and belt geometry in circumferential as well as in lateral direction.

In addition to discretization scalability, users can speed up CDTire/3D by exchanging its material side wall model with an analytical discrete membrane model. If a CDTire/3D parameter set is available, the model parameters for the analytical sidewall model can be derived semi-automatically by using CDTirePI. With the analytical sidewall formulation, the simulation speed can be nearly doubled, while the accuracy is affected only insignificantly for very large tire deformations. One can switch from one formulation to another easily by setting a flag

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Fig. 6: Driving simulator at Fraunhofer ITWM

in the parameter-file. Down-scaling is therefore straightforward with this support; and the up-scaling of legacy (CDT40) parameter sets only requires little additional effort.

CDTIRE/REALTIME

For comfort and durability applications in hard real-time systems such as driving simulators (see Fig. 6), the model CDTire/Realtime was developed. While it features many of the same modeling techniques—such as the contact and analytical sidewall model of CDTire/3D—a further downscaling of the lateral discretization was necessary to achieve hard real-time. Together with very efficient memory storage, access programming in pure C/C++ and an implicit Newmark integration scheme with the choice of deterministic settings or traditional step size and iteration control, it enables simulation scenarios with extreme requirements for computational performance—such as hard real-time. An offline version of CDTire/Realtime called CDTire/HPS (High Performance Solver) is available in SIMPACK 9.4.

Meanwhile Fraunhofer ITWM and SIMPACK AG have integrated CDTire/Realime together with SIMPACK Realtime on the Fraunhofer

ITWM driving simulator RODOS (see publication Burger, M., Baecker, M., Gallrein, A., Kleer, M.: "Integration eines detaillierten, flexiblen Reifenmodells in den Fraunhofer Fahrsimulator", VDI-Berichte 2211, 14. Internationale VDI-Tagung Reifen-Fahrwerk-Fahrbahn, 2013; further see article "SIMPACK Realtime", SIMPACK News, July 2013).

Fig. 7 shows the overall integration concept of the driving simulator. The vehicle model and the tire models are running on a Concurrent iHawk 12 core real time system, where 3 cores were used for the vehicle model itself; 4 cores for the tires (one core for each tire) and 1 core for the co-simulation administrative layer. This administrative layer also organizes and coordinates the data transfer to the driving simulator, namely the chassis acceleration and orientation as an input to the robot control (via dSpace CAN bus communication) and the steering wheel angle, as well as brake and throttle pedal positions given by the operator as input to the vehicle model. Fig. 7 also shows a recorded actual maneuver with a sample rate of 1 millisecond consisting of a straight run over a series of 18 obstacles (heights varying from 15 to 25 millimeters), followed by a curve.

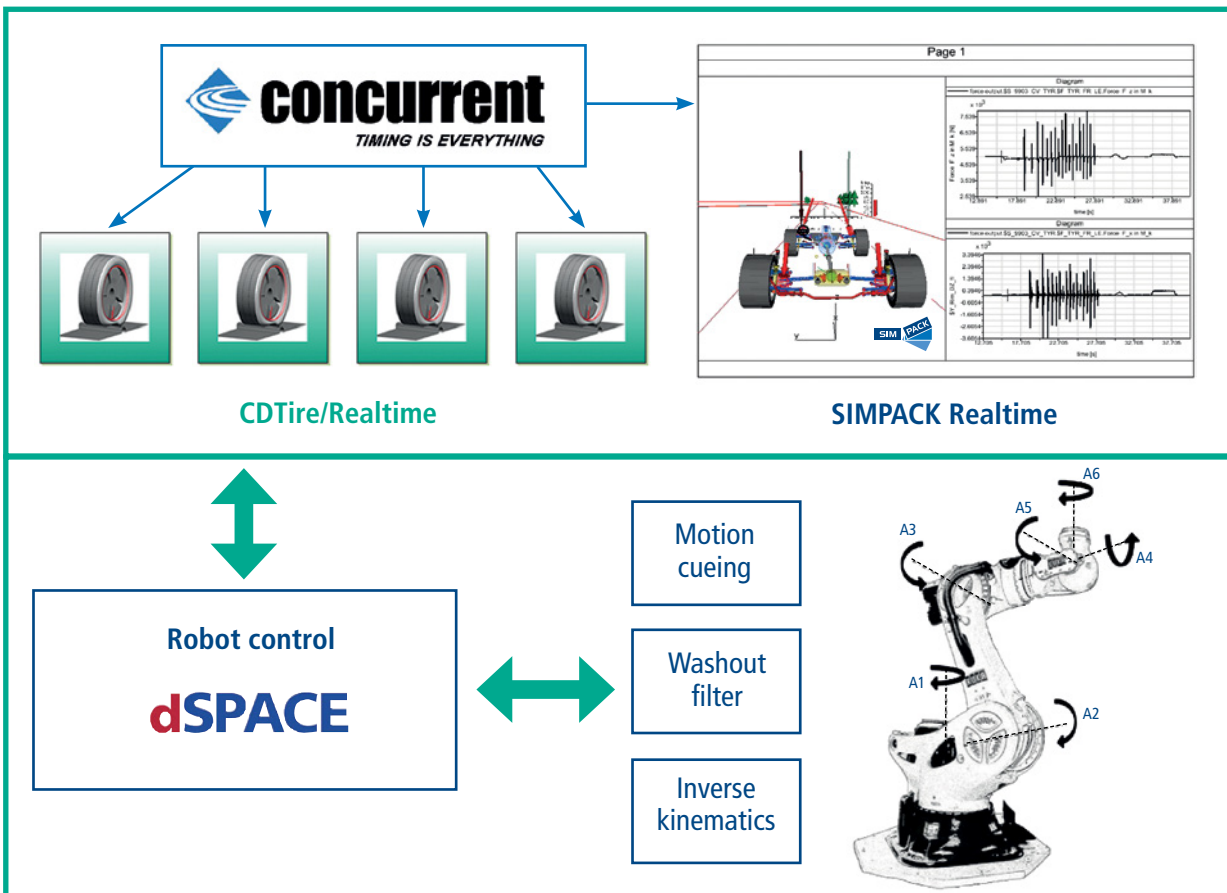


Fig. 7: Concept of Fraunhofer driving simulator RODOS