



# ADVANTAGES OF A THERMOMECHANICAL TIRE MODEL FOR VEHICLE DYNAMICS

The TameTire model developed by Michelin represents a breakthrough in vehicle dynamics simulation. The module by IPG has been integrated into its CarMaker simulation platform and extended by new functions. Even at a very early development stage, the tire can be incorporated into the parameter space of the vehicle-tire interaction, both for achieving targets and for tolerance studies.

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**MOTIVATION**

The ability to mathematically predict tire behavior that is relevant to various driving conditions is an important tool for improving existing tire makes and models in terms of their handling and driving dynamics properties. Numerous test results prove, how much the characteristic data of tire force and moment depend on the test conditions under which they occur. The current state of technology in tire modeling has been based on mathematical models which are adapted to indoor test rig measurements and thus offer only limited application potential.

The new mechanical and thermal tire model TameTire calculates the development of longitudinal and lateral forces as well as the self-aligning torque for a given combination of tire slip angle and slip at different tire pressures, camber angles, wheel loads and speeds as well as different track and ambient temperatures [1, 2].

**LIMITATIONS OF PREVIOUS MODELS**

Conventional mathematical models like MF (Magic Formula) version 5.2, also known as “Pacejka,” are widely used in the area of vehicle dynamics simulation and are currently considered “state-of-the-art”. The tires are measured on tire test rigs using standardized measuring procedures (for example “Time”). The mathematical tire model is then parameterized accordingly. Consequently, the characteristics measured this way, basically apply only to the test conditions. The tire forces and moments outside the measurement range can only be extrapolated as approximations [3], without considering thermal effects. Tire properties, however, heavily depend on temperature. Exemplary measurements show that the lateral force drops by 13 % and slip stiffness even by 32 % in a sine (seven periods). Consequently, the simulation results are not always consistent with those of physical track tests.

Furthermore, mathematical models do not represent the influence of speed, although the loss and shear modulus of the rubber compound heavily depend on the load frequency and thus on speed. The tire’s grip decreases with increasing speed [4]. In addition, the transfer behavior is limited, which leads to inaccurate predic-

tions of transient driving conditions (for example steering input, ABS/ESP braking). Last but not least, the models overload the user with abstract parameters which are difficult to link with physical properties. This, for example, is necessary when investigating target functions for tire-vehicle interaction.

**PRINCIPLE AND THEORY OF TAMETIRE**

Essentially, the new software is based on three different models [5]. The mechanical model (1) is based on the “brush element”-approach, in which the total force is assumed as the sum of the shear forces of the tread elements in the adhesion and sliding areas of the contact patch. The new software also considers the deformation of the tire structure while cornering, i.e. the torsion of the tire casing (side-walls) by the self-aligning torque as well as belt bending due to the lateral force.

Also included are the properties of the rubber compounds such as shear modulus and friction models (2) which directly influence the stiffness of the tread. The friction model considers the rubber properties for calculating the friction coefficient (relative slip between the tire and track surface), for example. The thermal model (3) calculates the contact temperature as well as the surface and inside temperatures of the tread, considering the convection to the air, thermal conduction to the track, frictional heat as well as the viscous heat generated in the tread.

**ADDITIONAL I/O SIGNALS OF THE TAMETIRE MODEL**

MF-Tire uses slip ratio, slip angle, camber angle and wheel load as input signals and delivers the respective circumferential and lateral force, self-aligning and roll resistance torque, camber torque and the effective rolling radius as outputs. The new software complements these inputs by vehicle speed, ambient and track/road temperature, initial temperature, inflation pressure and time. Additional outputs are surface, tread and belt temperatures as well as the loaded radius. Various calculation options offer the possibility of adapting the performance accuracy ratio for uses ranging from detailed all the way to real-time-capable application.

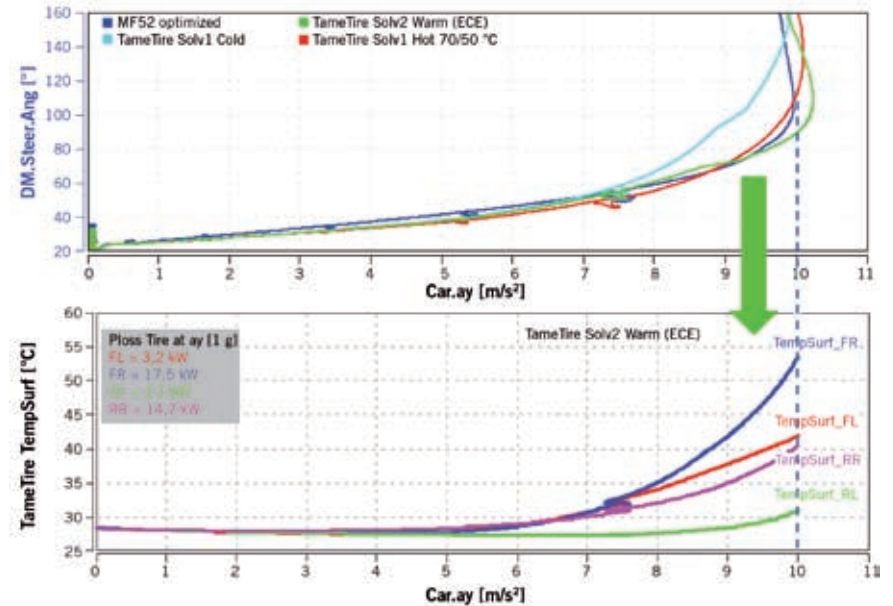
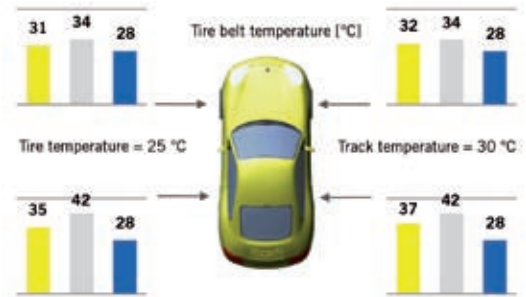
## INTEGRATION OF TAMETIRE INTO CARMAKER

The new software has been integrated into the CarMaker vehicle dynamics simulation by IPG in order to model the interaction of the vehicle-tire system and to realistically simulate the complex control loop of driver, vehicle and road. This creates additional functions and applications. CarMaker's tire standstill model, for instance, extends the working range. The GUI-based test automation enables extensive track test catalogues to be run and offers tools for parameter studies. Inflation pressure tolerances and tread stiffness values in combination with vehicle parameters can be automatically investigated overnight. With CarMaker, the virtual driver (IPG Driver) for realistic simulations of complex closed-loop maneuvers is able to systematically modify and manipulate tire inflation pressures or temperatures during the test run. Directly from the cockpit, systematic adjustments of operating parameters or a defined pressure loss to test tire pressure monitoring systems, are implemented in the test run. A status observer can query all TameTire parameters with millisecond-accuracy to ensure event-based testing. The loss power model from CarMaker delivers the corresponding performance summary based on rolling resistance, lateral and longitudinal slip, self-alignment and deformation of the tire for the purpose of performing fuel consumption analyses.

## VIRTUAL TRACK TEST

To evaluate the capabilities of the new model in comparison to MF-Tire 5.2, extensive drive tests were conducted using a sports car (rear-mounted engine, rear-wheel drive) fitted with Michelin PilotSport 235/35ZR19 tires for the front axle and Michelin PilotSport 295/30ZR19 for the rear. The open-loop maneuvers included steady-state circular driving, sine sweep/step steer, ABS braking (HIL), power off (ISO 9816) and brake in turn (ISO 7975). The closed-loop tests encompassed lane change (ISO 3888), slalom (18 m/36 m) and the Hockenheim handling course. To improve the comparison with physical track testing, various tire warm-up procedures were investigated:

① Temperature distribution after different warm-up procedures



② Vehicle self-steer effects and tire temperature evolution during steady-state circular test with a radius of 100 m

- : Michelin procedure: two laps (14 km) and high-speed course at 120 km/h
- : Daimler procedure: 400 s at 200 km/h, straight on [3]
- : ECE 13H procedure on ESC regulation: two left- and two right-hand turns with a radius of 15 m and a lateral acceleration of 6 m/s<sup>2</sup>, followed by four sine sweeps.

This leads to varying, partially non-symmetrical tire temperatures, ①. For this study, the ECE 13H warm-up procedure was selected. The individual results and findings are presented in greater detail below.

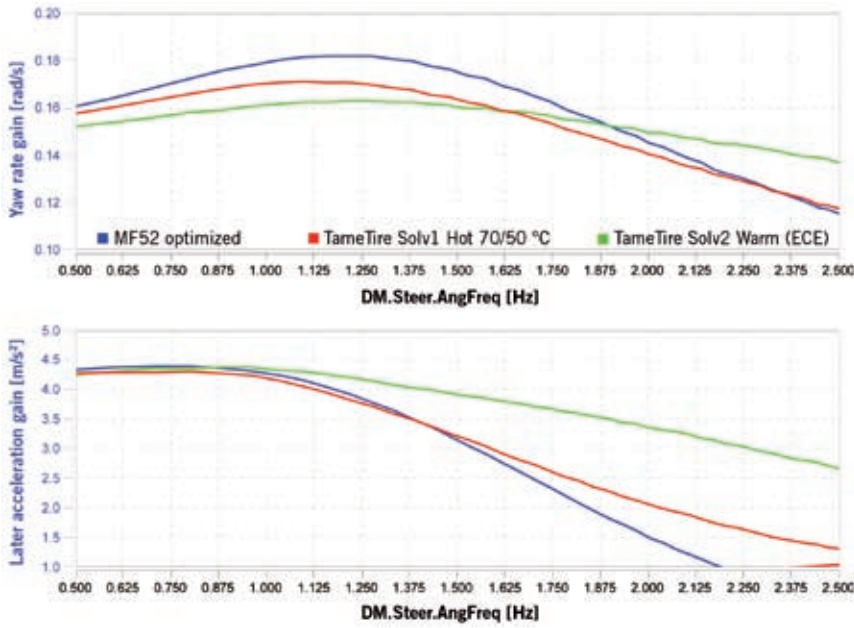
② shows the significant influence of temperature on the vehicle's self-steer effect, the non-symmetric change of the surface temperature as well as the energy dissipation (loss power) of all four tires which leads to varying tire behavior – compared to the properties of MF-Tire

which remain unchanged. The following parameters are brought to bear when it comes to sine sweeps for transient vehicle behavior:

- : vehicle speed: 100 km/h
- : linear increase of steering frequency from 0.2 to 4 Hz
- : steering wheel amplitude corresponded to the steering wheel angle, achieving a steady-state lateral acceleration of 4 m/s<sup>2</sup>.

Again, the temperature-dependent behavior, particularly at high steering frequencies, is evident, ③. The behavior of the warm TameTire differs from MF-Tire above 1.5 Hz and exhibits a clearly different behavior when the tire is cold.

The ISO lane change test was run in two variants: 1) At a speed of 144 km/h and ten consecutive lane changes on a straight. 2) At incremental speeds from 120 km/h up to the limit, as in a real-world track test.



③ Vehicle yaw and lateral acceleration gain generated with the sine sweep test

After each single test, the driver drove back to the initial position to start the next test in a flying mode. In both variants a clear change of tire temperatures as well as the influence of slip stiffness on the front and rear axles can be noted.

Unlike TameTire, MF-Tire always results in the same tire behavior. The model comparison of the side slip angle of the rear axle at 120 and 146 km/h, ④, which can be attributed to temperature and speed effects, is remarkable. At 120 km/h it is significantly higher with MF-Tire and at 146 km/h clearly lower. At a constant side slip angle, MF-Tire delivers constant lateral force across the entire time. The measurements show, however, that the lateral force decreases after a maximum at constant side slip angle. This effect is modeled by the new software equally well as the influence of vehicle speed on grip.

**HOCKENHEIM HANDLING COURSE**

Some automobile manufacturers use the lap time on the Hockenheim handling course as an evaluation criterion. The first lap was used as the warm-up lap. While MF-Tire exhibited consistent lap times, lap time with TameTire changed by 0.87 s after just a few laps. In addition to the notable increase of tire temperature, the temperature spread, the median energy dissipation (loss power) and thus the grip for all tires

exhibited clearly different values, ⑤. The influenced vehicle behavior with clear oversteer tendency is documented in the lap curve by a 65 % increase of the side slip angle on the rear axle as well as by a 15 % reduction of the steering angle, ⑤.

**PHYSICAL PARAMETERS**

Another advantage of the new model is the use of physical parameters, which are easy for the user to understand, instead of abstract mathematical parameters. This integrates the tire into the parameter space as a tuning and tolerance element in order to investigate the vehicle-tire interaction with respect to a target function. Contrary to this approach, mathematical models merely “look at” tires as a “black box,” which precludes any variations of parameters.

The scalable TameTire parameters on the other hand offer these possibilities:

- : tread properties: tread depth, shear stiffness in X- and Y-axial direction, friction coefficient
- : belt compliance
- : torsional stiffness of the tire casing (carcass)
- : stiffness in X-, Y- and Z-axial direction (they influence transient behavior (X, Y)) and the static tire radius (Z)
- : tire inflation pressure (may be varied as a parameter as well as an input signal).

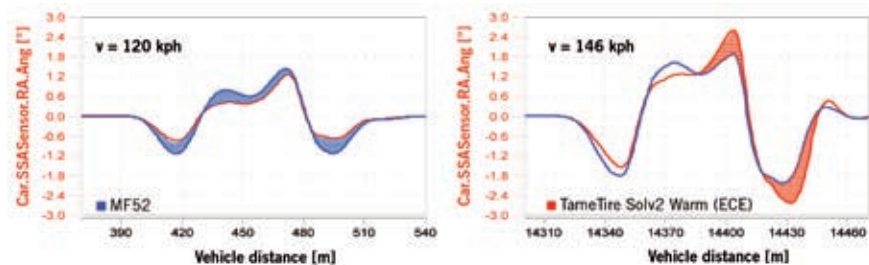
The publication [5] very clearly shows the influence of the parameters on the tire properties. To show this influence in an exemplary manner, the sine sweep test was repeated using different parameters. The green curve in ③ corresponds to the reference tires; the brown curve shows the modified tire. The test aimed to achieve a higher degree of yaw speed gain and to retain the gain level at high frequencies. This was achieved by making the following modifications:

- : front axle: belt compliance -10 %, torsional stiffness -20 %
- : rear axle: tread depth +10 %, torsional stiffness +20 %.

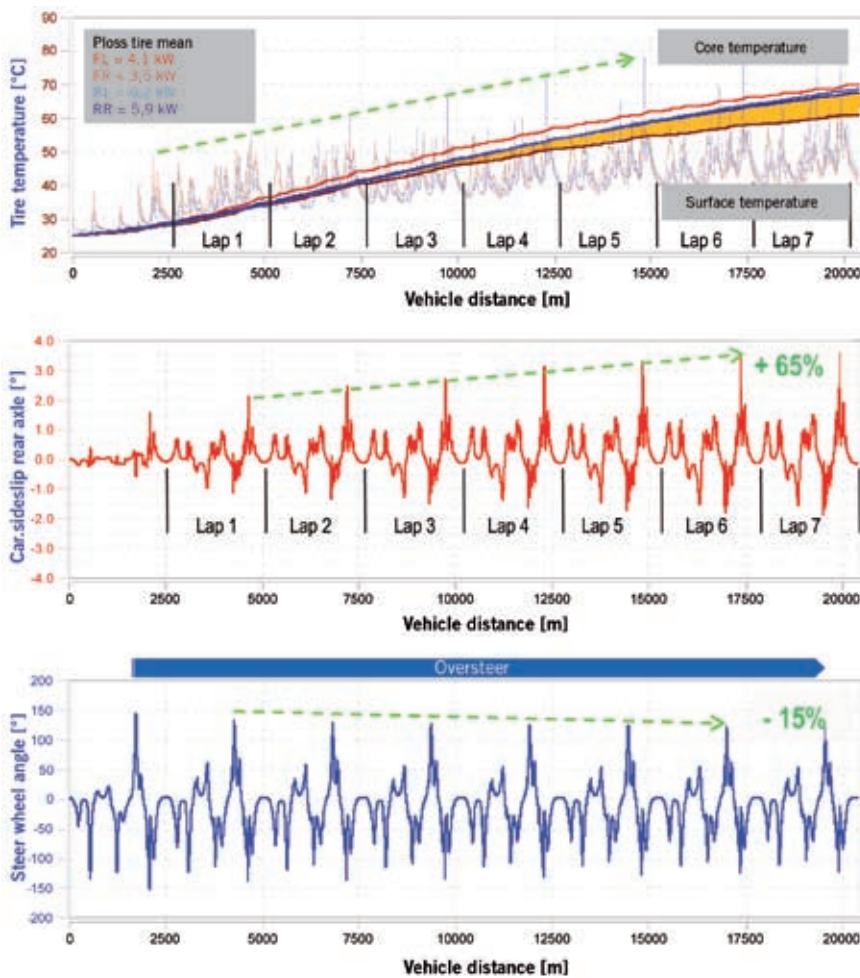
As expected, a significant influence of rear axle stability was also observed in the ISO lane change.

**SUMMARY AND OUTLOOK**

The TameTire tire model, integrated into the simulation platform CarMaker by IPG, increases the accuracy and quality of vehicle dynamics simulation – both in steady-state and transient modes. It creates the prerequisites for realistic reconstruction of a wider range of track tests and test conditions, thus opening up new diverse application options. Even at a very early development stage, the tire can be



④ Comparison of rear axle sideslip behavior during ISO lane change for MF-Tire vs. TameTire



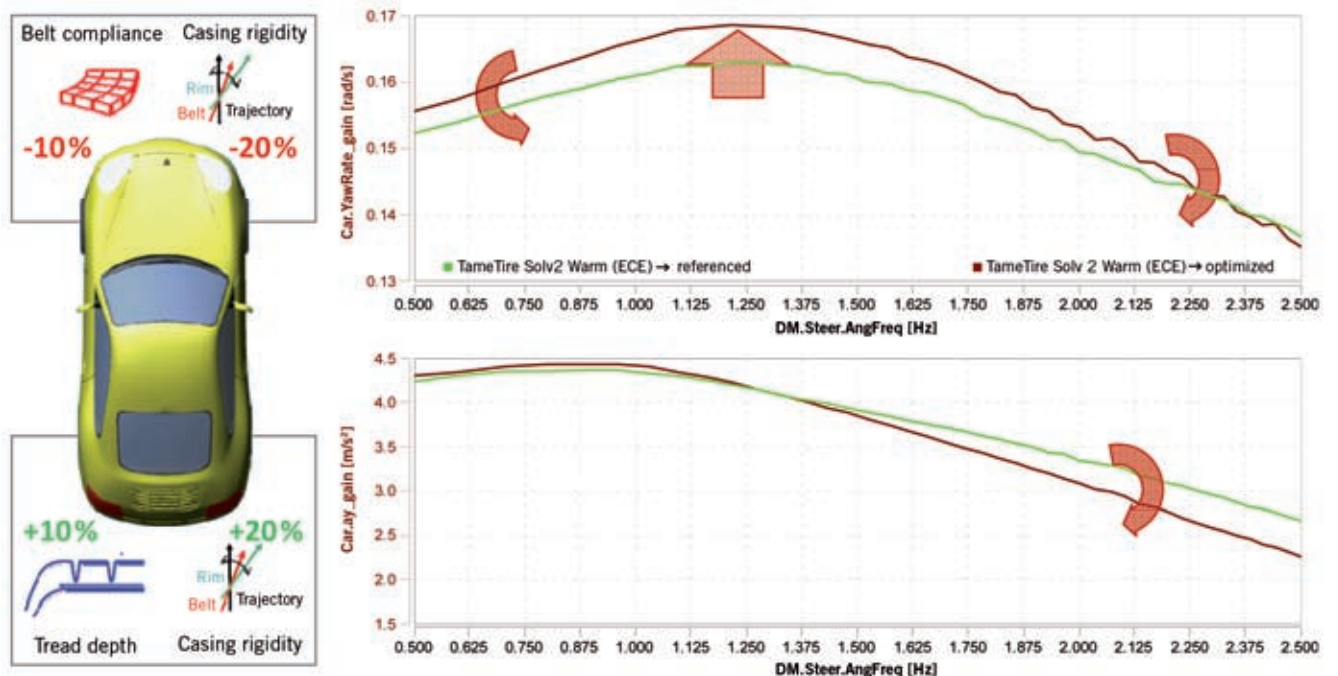
5 Tire surface and core temperature, rear axle sideslip behavior and driver's steering effort at Hockenheim

incorporated into the parameter space of the vehicle-tire interaction, both for achieving targets and for tolerance studies. In addition, TameTire is suitable for test tire pressure monitoring systems.

The study described here was subsequently continued with ABS/ESP on a hardware-in-the-loop (HIL) test rig to investigate further transient effects. The new software has recently been made available worldwide by IPG as a fully integrated model in CarMaker and as a stand-alone model. Michelin and IPG are developing additional functions and possible uses in close collaboration.

REFERENCES

[1] Février, P.; Fandard, G.: Thermal and Mechanical Tyre Modelling for Handling Simulation. In: ATZ-worldwide 110 (2008), No. 5, pp. 26-31  
 [2] Buisson, J.: Michelin Indoor Characterization for Handling Applied Mathematical Formulae. 15. Aachener Kolloquium Fahrzeug- und Motorentechnik, Aachen, October 9-11, 2006  
 [3] Durand-Gasselien, B.; Dailliez, T.; Moessner-Beigel, M.; Knorr, S.; Rauh, J.: Assessing the Thermo-mechanical TameTire Model in Off-line Vehicle Simulation and Driving Simulator Tests. IAVSD 2009, Stockholm, August 17-21, 2009  
 [4] Schick, B.; Bunz, D.: Vehicle Yaw Stability when Braking at High Cornering Speeds. In: ATZworldwide 106 (2004), No. 11, pp. 8-11  
 [5] Durand-Gasselien, B.; Dailliez, T.: New Handling Simulation Opportunities Yielded by the TameTire Tire Model. 15th International Conference on Vehicle Dynamics, SIA, Lyon, September 23-24, 2009



6 Modification of physical scaling parameters and the influence on the vehicle transient behavior