testing procedure outside Michelin

Tyre 2015
4th International Tyre Colloquium
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TameTire Model
Quick Overview
A bit of history

Situation during the F1 period.

- Teams had Pacejka tyre models, that were insufficient for their needs.
- Internal models at the time were not fast enough for vehicle dynamic simulations.

McLaren feedback (2001):
« tyre temperature is known to have a significant effect on tyre characteristics with maximum performance only available in a small temperature band. The current model (Pacejka), which is called by many of the simulations used to analyse car performance, takes no account of temperature effect. This is due to an inability to model the thermal behaviour of a tyre ».

As a consequence a new tyre model was created:
TameTire = Thermal and Mechanical Tire Emulator
**Motivation: limitations of the Pacejka formulae**

- No thermal effects, although tire performance is strongly temperature dependent
  - Not able to predict tire performance for different track designs
  - No tire transient mechanism modifying vehicle performance and balance
  - Tire ranking not consistent with on-track ranking
  - Limitations in the prediction of vehicle set-up effects
  - Tire models very dependant on testing procedure

- No speed effect, although compound properties are frequency dependant
  - Limitation, especially for x and x-y combined conditions

Thermal effect: up to 30% difference
The model

Mechanical model

Rubber properties

Thermal model

Contact model

The model consists of several components:

- **Mechanical model**
- **Rubber properties**
- **Thermal model**
- **Contact model**

### Components:

- **Adherent part**
  - Casing torsion
  - Rim
  - Speed
- **Sliding part**
  - Belt bending
  - Tread pattern

### Key Parameters:

- **Rubber shear modulus** $G^*$
- **Friction coefficient**
- **Contact temperature**
- **Friction heat**
- **Convection to air**
- **Tread depth thermal equation**

### Forces and Moments:

- $F_X$
- $F_Y$
- $M_Z$

### Further Notes:

- Internal temperature of the tread
- Conduction to the track
- Tread shearing
- Internal Heating
- Convection to air

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*Tyre 2015 by M. Grob*
The model: Scaling Factors

- Trajectory
- Side slip angle
- Twisting angle
- Casing torsion
- Belt bending
- Tread shearing and friction
- Tread shearing and friction
- Belt bending
- Casing torsion
- Trajectory

Factors:
- \( \lambda_{KT} \)
- \( \lambda_{zz} \)
- \( \lambda_{xx} \)
- \( \lambda_{yy} \)
- \( \lambda_{zz} \)
- \( \lambda_{Kxx} \)
- \( \lambda_{Kyy} \)
Model input

- Angular velocity (w) & Speed (V)
- or Slip Angle & Slip ratio
- Camber angle (IA)
- Vertical force (Fz)
- Tyre pressure (P)
- Logitudinal speed (V)
- Air temperature $T_{\text{air}}$
- Ground temperature $T_{\text{track}}$
- Surface and internal temperature ($T_S$ & $T_I$)
- Time (t)

Model output

- $F_x$, $F_y$
- $M_z$
- $M_x$, $M_y$
- Rolling Radius
- Loaded radius ($R_L$)
- Surface temperature ($T_S$)
- Internal temperature ($T_I$)
Model validation
Model validation

Application of the following procedure to validate our model:

- Check TameTire testing procedure on a third party machine
  - Visit to NTRC (USA) to perform the TameTire testing procedure on several passenger car tyres (Michelin & competitor tyres)

- On vehicle testing
  - Steady state
  - Braking
Cornering Stiffness at cold temperatures

Fy @ 80kph & Z=6700N at intermediate temperatures

Transient @ 10kph at hot temperatures

TameTire vs Michelin’s measurement == TameTire vs NTRC measurement

Tyre 2015  Auteur/Sce : M.Grob  Classification: D4  Conservation : YC+3  Date de création : 19/04/2015
Measurement vs model
On vehicle results versus TameTire predictions

Once the flat-track vs model correlation is verified (Y, X and X-Y) we proceed to on track testing with on vehicle measurement.

Equipment:
- Vehicle: 308 110HP
- 4 Kistler wheel force transducers
- RT systems
- 2 Lasers
- GPS
- Primacy 17"
- Continental Sport Contact 17"

Manoeuvres:
- Steady state manoeuvres
  - Several laps at different speeds (65 → 85kph)

Simulation:
- CarMaker 4.5 + MF5.2 (Primacy 17'’ & Sport Contact 17’’) vs
- CarMaker 4.5 + TameTire (Primacy 17’’ & Sport Contact 17’’)

[Diagram of racing track]
On vehicle results versus TameTire simulations on CarMaker

Speed: 80 kph (Steady State)

<table>
<thead>
<tr>
<th>Tyre</th>
<th>Yaw speed [°/s]</th>
<th>Rack displacement [mm]</th>
<th>Slip angle @ CDG [°]</th>
</tr>
</thead>
<tbody>
<tr>
<td>ContiSportContact</td>
<td><img src="image1" alt="Graph" /></td>
<td><img src="image2" alt="Graph" /></td>
<td><img src="image3" alt="Graph" /></td>
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<tr>
<td>Primacy 3</td>
<td><img src="image4" alt="Graph" /></td>
<td><img src="image5" alt="Graph" /></td>
<td><img src="image6" alt="Graph" /></td>
</tr>
</tbody>
</table>
On vehicle results versus TameTire simulations on CarMaker

Speed : 80 kph (Steady State)

TameTire is overall better correlated to measurement than MF5.2
Model validation

Pure tyre validation ➔ successfully achieved

On vehicle validation vs simulation

- Steady state: ➔ successfully achieved
  - On vehicle testing vs total vehicle simulation on CarMaker

- Braking:
  - No precise braking model at our disposal ➔ braking with a trailer
Braking tests with a trailer

Braking tests performed on Michelin’s test trailer on a 245 / 35 R 20 Pilot Alpin 4

The braking force $F_x$ is controlled until the desired maximum slip ratio (~50%) is reached

To increase the clarity of the following graphs a Pacejka fit is performed on the experimental data

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Test plan

<table>
<thead>
<tr>
<th>Effect</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inflation pressure</td>
<td>{1.5 ; 2.5 ; 3.5} bar</td>
</tr>
<tr>
<td>Tread thickness</td>
<td>{1.6 ; 8} mm</td>
</tr>
<tr>
<td>Tyre temperature</td>
<td>30 -&gt; 125 °C</td>
</tr>
</tbody>
</table>
Braking with TameTire

Temperature effect on braking

Winter tyre: temperature effect

- Ti = 35°C
- Ti = 115°C

Friction coefficient $\mu$

Slip Ratio (%)
Pressure effect on braking

Winter tyre: inflation pressure effect

- P = 1.5b
- P = 2.5b
- P = 3.5b
Braking with TameTire

Sculpture height on braking

Winter tyre: tread depth effect

Hs = 1,6 mm

Hs = new tyre
Another example of SF wear
Model Validation: Conclusion

Through a pure Y measurement we obtain a tyre model that is valid for X, Y and X-Y data.

The TameTire model allows for physical tyre sensitivity studies (Scaling Factors).
- What type of tyre do I need to achieve a given F&M?

TameTire is also a model that allows vehicle dynamics tunning.
- Impact of tyre evolution on vehicle dynamics
- What type of tyre do I need to meet a/several vehicle dynamics metrics (SS, Gain for Transient State)?

TameTire is also a model that allows vehicle dynamics tunning.
- Tunning braking systems
TameTire’s Future
V3 new features

- **TameTire 3.0 has been successfully integrated into CarMaker 4.5 and newer versions**

- **TameTire 3.0 is ~ 30% faster than TameTire 2.2**

- **Better compatibility with Real-Time simulator**
V3 new features: an improved RR model

Integration of a new rolling resistance model based on the ISO 28580 indoor test

\[ F_{RR} = C^{RR, ref}_{RR} \cdot Z \cdot \left( \frac{P}{P_{\text{ref}}} \right)^{\alpha} \cdot \left( \frac{Z}{Z_{\text{ref}}} \right)^{\beta} \]
### V3 new features: Increased database

<table>
<thead>
<tr>
<th>Brand</th>
<th>Tyre Line</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michelin</td>
<td>PSS</td>
<td>235/35 ZR19</td>
</tr>
<tr>
<td></td>
<td></td>
<td>295/30 ZR19</td>
</tr>
<tr>
<td>Michelin</td>
<td>P. Sport 2</td>
<td>235/35 ZR19</td>
</tr>
<tr>
<td>Michelin</td>
<td>P. Sport 2</td>
<td>295/30 ZR19</td>
</tr>
<tr>
<td>Michelin</td>
<td>Lat. Tour HP</td>
<td>255/55 R18</td>
</tr>
<tr>
<td>Michelin</td>
<td>Lat. Sport</td>
<td>255/55 R18</td>
</tr>
<tr>
<td>Michelin</td>
<td>Lat. Alpin</td>
<td>255/55 R18</td>
</tr>
<tr>
<td>Michelin</td>
<td>Lat. Sport 3</td>
<td>255/55 R18</td>
</tr>
<tr>
<td>BFGoodrich</td>
<td>G Grip*</td>
<td>225/45 R17</td>
</tr>
<tr>
<td>Michelin</td>
<td>Alpin 5</td>
<td>225/45 R17</td>
</tr>
<tr>
<td>Michelin</td>
<td>P. Alpin</td>
<td>225/45 R17</td>
</tr>
<tr>
<td>Michelin</td>
<td>Primacy 3 ST (AS)</td>
<td>225/45 R17</td>
</tr>
<tr>
<td>Michelin</td>
<td>Primacy 3 (EU)</td>
<td>225/45 R17</td>
</tr>
<tr>
<td>Continental</td>
<td>Conti Sport Contact</td>
<td>225/45 R17</td>
</tr>
<tr>
<td>Bridgestone</td>
<td>Turanza ER300</td>
<td>225/45 R17</td>
</tr>
<tr>
<td>Bridgestone</td>
<td>Potenza S001</td>
<td>225/45 R17</td>
</tr>
<tr>
<td>Michelin</td>
<td>Primacy HP</td>
<td>205/55 R16</td>
</tr>
<tr>
<td>Michelin</td>
<td>Energy Saver</td>
<td>205/55 R16</td>
</tr>
<tr>
<td>Michelin</td>
<td>Energy Saver+</td>
<td>205/55 R16</td>
</tr>
<tr>
<td>Michelin</td>
<td>Primacy Alpin</td>
<td>205/55 R16</td>
</tr>
<tr>
<td>Michelin</td>
<td>Alpin 5</td>
<td>205/55 R16</td>
</tr>
<tr>
<td>Michelin</td>
<td>E. Saver</td>
<td>195/65 R15</td>
</tr>
<tr>
<td>Michelin</td>
<td>E. Saver +</td>
<td>195/65 R15</td>
</tr>
<tr>
<td>Michelin</td>
<td>Alpin 3</td>
<td>195/65 R15</td>
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<tr>
<td>Michelin</td>
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<tr>
<td>Kleber</td>
<td>Dynaxer HP3</td>
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<tr>
<td>Michelin</td>
<td>E. Saver</td>
<td>175/65 R14</td>
</tr>
<tr>
<td>Michelin</td>
<td>E. Saver +</td>
<td>175/65 R14</td>
</tr>
</tbody>
</table>

### Increased/upgraded database with competitor tyres

- Michelin Primacy HP 205/55 R16
- Michelin Energy Saver 205/55 R16
- Michelin Energy Saver+ 205/55 R16
- Michelin Primacy Alpin 205/55 R16
- Michelin Alpin 5 205/55 R16
- Michelin E. Saver 195/65 R15
- Michelin E. Saver + 195/65 R15
- Michelin Alpin 3 195/65 R15
- Michelin Alpin 5 195/65 R15
- Kleber Dynaxer HP3 195/65 R15
- Michelin E. Saver 175/65 R14
- Michelin E. Saver + 175/65 R14
Michelin’s vision for TameTire

Our answer for Tire Modeling: TameTire

• Regularly used within Michelin for Tire Development
• Used outside Michelin for:
  ▪ Vehicle dynamics simulations
  ▪ Virtual chassis design and set-up, virtual development loops
  ▪ HIL and Driving simulators (driver in the loop)

• Key advantages
  ▪ Physically based real time model with thermal dependancy
  ▪ Competitive/Robust tools around TameTire modelling:
    ▪ Virtual Scaling Factors
    ▪ Real Tire characterization process is robust
    ▪ Representative tire database available
  ▪ Customer Oriented Model
    ▪ Integration of customer needs for future developments
    ▪ Measurement process for tire characterization successfully tested on external machine (NTRC)
  ▪ Easily integrated into different softwares and OS
    ▪ CarMaker, CarSim, Rfactor, LapTime softwares, Matlab…
    ▪ Windows & Linux 32 or 64 bits.
Michelin’s vision for TameTire

**TameTire is opened towards our customers**

- **Efficient Customer Support**: Strong IPG-Michelin partnership
  - IPG Customer support for Licensing and technical implementation
  - Michelin Customer support for Physical and Numerical implementation
  - Strong reactivity and technical competencies

**Continuous Improvement & Progress Strategy**

- A **living model**, periodically updated
- Merging multiple tire performances models
  - XY-Forces and Torques, steady-state and transient, Rolling Resistance
  - TPMS (Rolling Radius, evtl. Eigenmodes in the future…)
- **New features added regularly**
  - Enhanced thermal model
  - Pressure = f (temperature)
  - Integrability for different environments (simulators, HIL benches…)
  - Fstudent database
Thank you for your attention!