

Vehicle Dynamics Expo Stuttgart 2008

#### Validation of Tyre Force Estimator

**TNO | Knowledge for business** 

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**TNO** Automotive

6 May 2008

## **TNO in a Nutshell**

- TNO is the Netherlands' Organization for Applied Research
- 76 years of experience
- Independent R&D organization
- 5,000 employees world-wide
- HQ in Delft, the Netherlands
- Annual turnover approx. 550 M€





# Contents

# Background

Why use vehicle motions for tyre assessment

- Tyre Force Estimator method and tool
- Validation results
- Summary

# Challenges for assessment of tyre slip characteristics

- Tyre characteristics depend on operating conditions
  - Road texture, Road curvature, Tyre temperature, Speed, etc...
- Benchmarking/Ranking of tyres important for design choices in tyre development and in vehicle setup but ranking on tyre test equipment not always consistent!
- Relation between subjective vehicle assessment and tyre characteristics more important then tyre performance assessment
- Existing tyre testing methods laborious, costly, inflexible, etc...



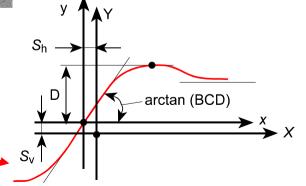
# Advantages of using vehicle motions

- Limited vehicle instrumentation
- Assessment for actual vehicle operating conditions (surface, speed, thermal load, ...)
- Easy change of tyres, can be combined with subjective evaluation
- Fast and cost effective!

**Prerequisites for success:** 

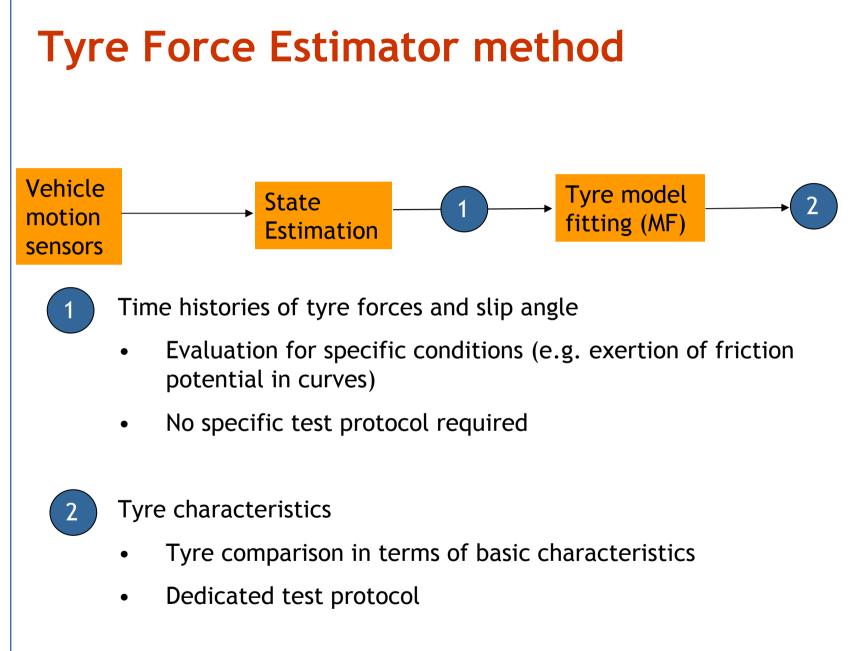
- Not dedicated to one specific vehicle
- Sufficient accuracy for ranking and basic tyre model parameter assessment
- Easy data processing



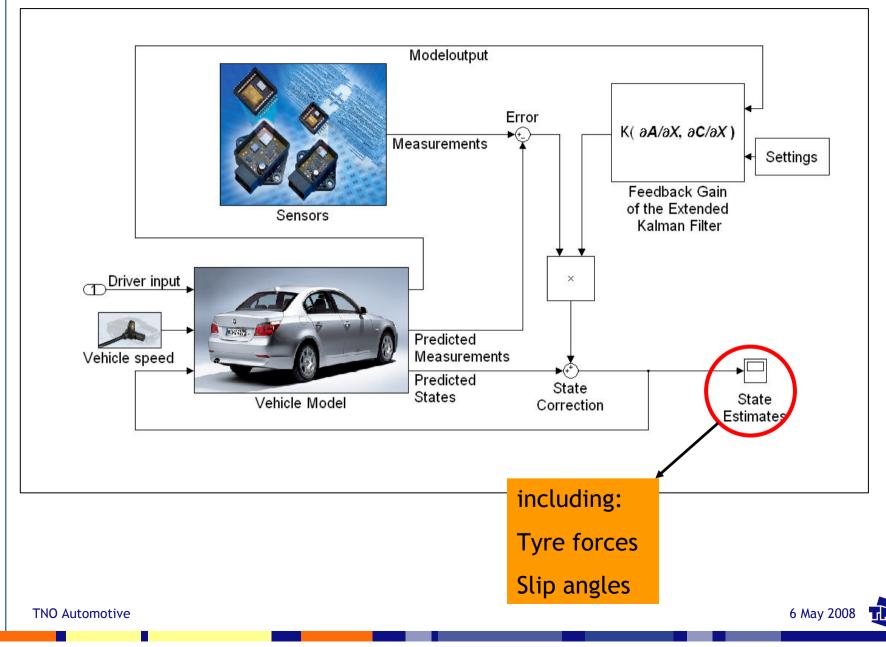


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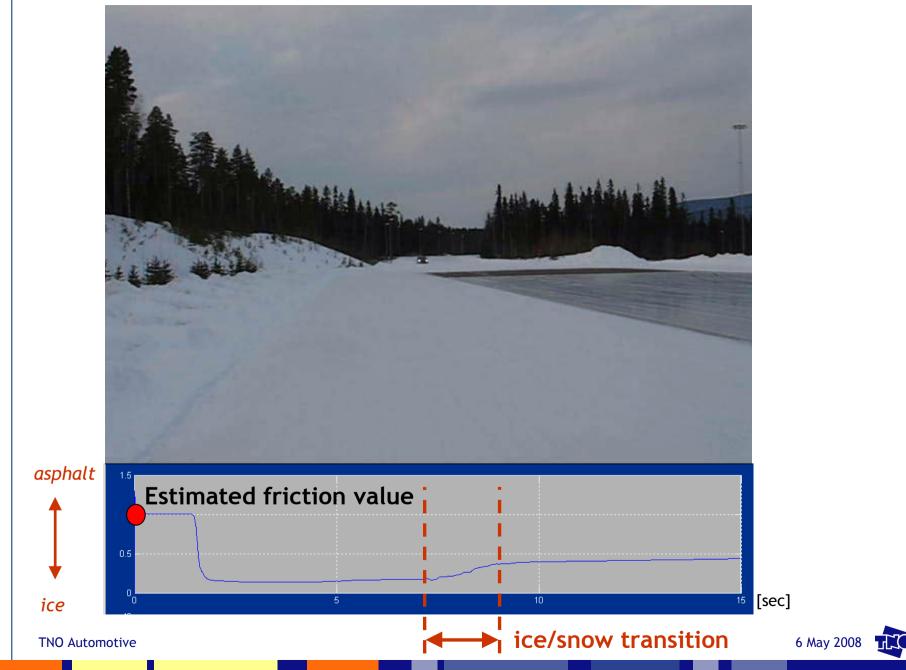




# **State Estimator concept**



#### **Example: Friction estimation**



Step 1: Define vehicle & sensor parameters

Vehicle Parameters Vehicle Parameters Vehicle Directory Select_dir gn\Projects\14390_Estimation&Control2007\Tyre_estimator\GUI\Version 5c\Vehicle_selection	Advanced_parameters
Parameters       Select vehicle       EMWS45_TNO.vdx       Fontys_18.vdx       Fontys_18.vdx       Fontys_19.vdx       Fontys_SUV.vdx       Kass [kg]       Trackwidth [m]       Tyre name       Conti-Sport       Tyre name       Conti-Sport       Tyre name       Conti-Sport       Tyre size       Ref [m]       calculate       7.5       Nass tyre [kg]       10	Sensor Vy_sensor location [m] Ay_sensor location [m] Vx_sensor location [m] Ax_sensor location [m] Close Main parameters
New filename Create vehicle_file Close	X

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. . .

Step 2: Load measurement data

Data Directory	estimator\GUI\Version 5c\Testdata_selection\BM/V545_TNO	Statom020.mat Vehicle motion data
iestdata Select testdata Nurburgring.mat 121_728001.mat randomsteer001.mat stalom020.mat Load Done	Button Group     Mat-files     Vdx-files      Show all selected graphs	$\begin{array}{cccccccccccccccccccccccccccccccccccc$
Print graphs		Legenda detta: Steering angle [deg] ay: Lat acc [m/s^2] Vx: Vehicle speed [km/h] Vy: Lat vel [m/s] Yaw rate: Yaw rate [deg/s]

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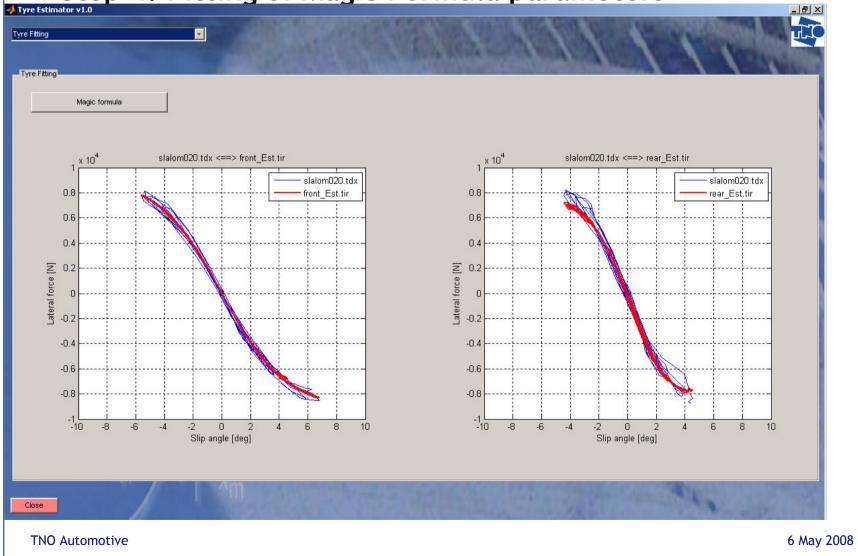
#### Step 3: Run State Estimator

Estimator Stimator	slaiom020.mat
Manoeuvre Directory Select_dir Projects\14390_Estimation&Control2007\Tyre_estimator\GUI\Version 5c\Manoeuvre_selection Estimator Select manoeuvre Vxmin [km/h] Slipmargin [deg]	Comparison of vehicle motion data
Manoeuvre.vdx 7.2 11.5 New filename Create vehicle_file	5 0 Measured Estimated 0 2 4 6 8 10 12 14 16
Run Estimator     Done     Show all graphs       Estimator graphs     Vehicle       © Comparison of vehicle motion data	
Comparison of vertical loads     Tyre     Comparison of forces and slip angle time     Comparison of forces and slip angle based on estimated slip angle	$ \begin{array}{c} & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & & \\ & $
C Comparison of Force vs. Slipangle	-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -
Close	

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#### Step 4: Fitting of Magic Formula parameters



# Validation

- 1. Dedicated measurement with vehicle equipped with wheel force transducers
- 2. Comparison of time histories of measured forces and estimated forces
- **3.** MF-Fit of measured forces
- **4.** MF-Fit of estimated forces
- 5. Comparison of force versus slip characteristics

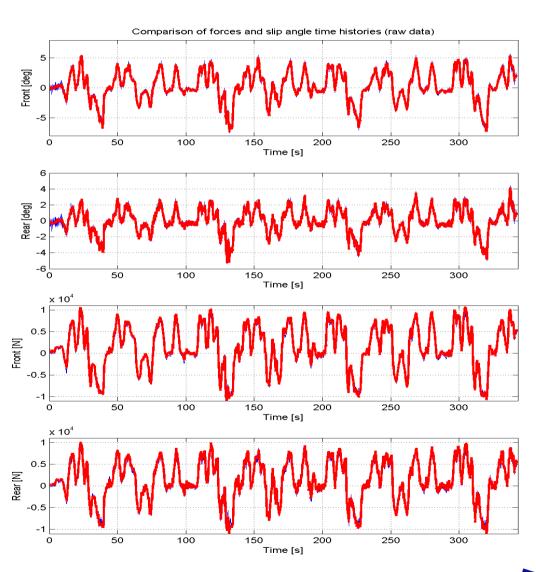
## Comparison of time histories Mini-Hockenheim @ Papenburg

Front slip angle

Rear slip angle

Front lateral force

Rear lateral force



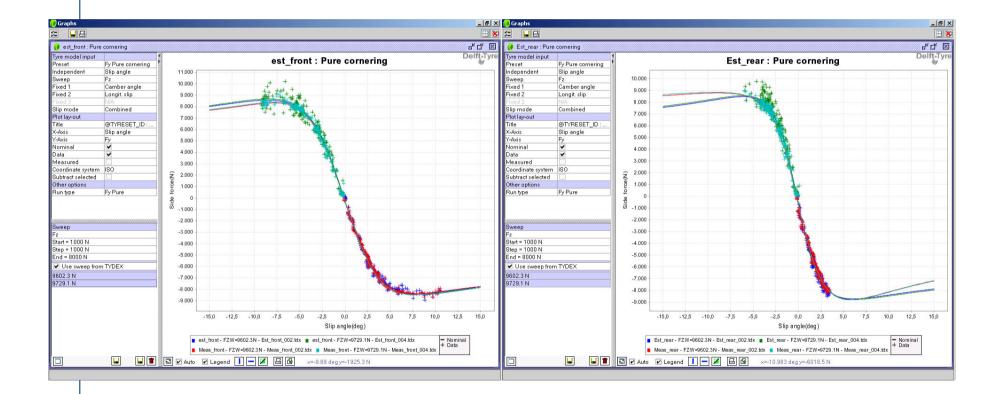


# Comparison of Magic Formula fit of measurement and estimation: Circular test

## Front axle

### **Rear axle**

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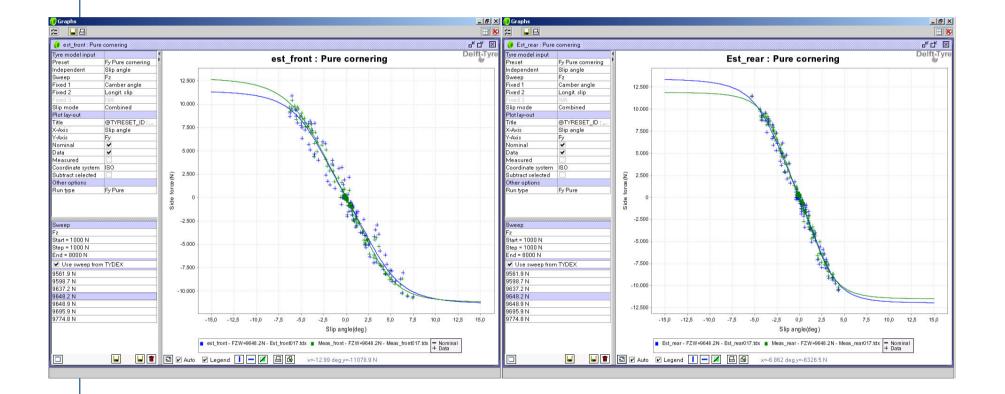
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#### Comparison of Magic Formula fit Slalom test

# Front axle

## **Rear axle**

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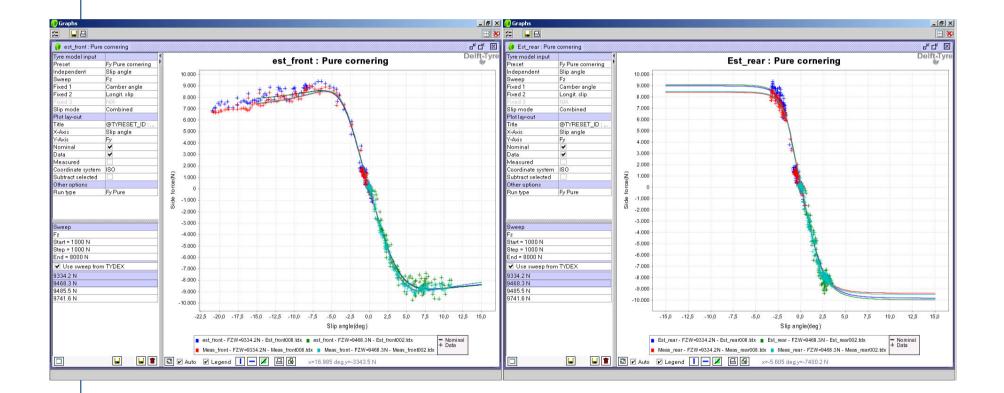
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#### Comparison of Magic Formula fit Spiral test (severe under steer)

# Front axle

## **Rear axle**

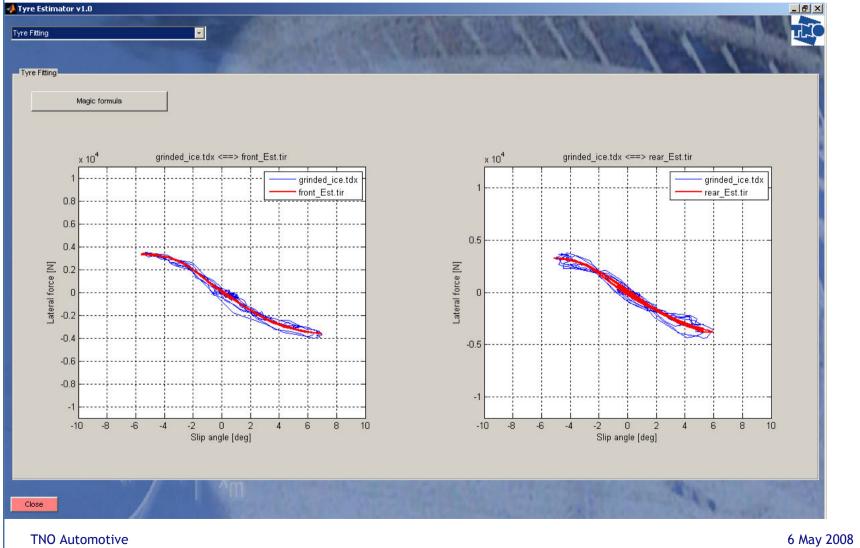
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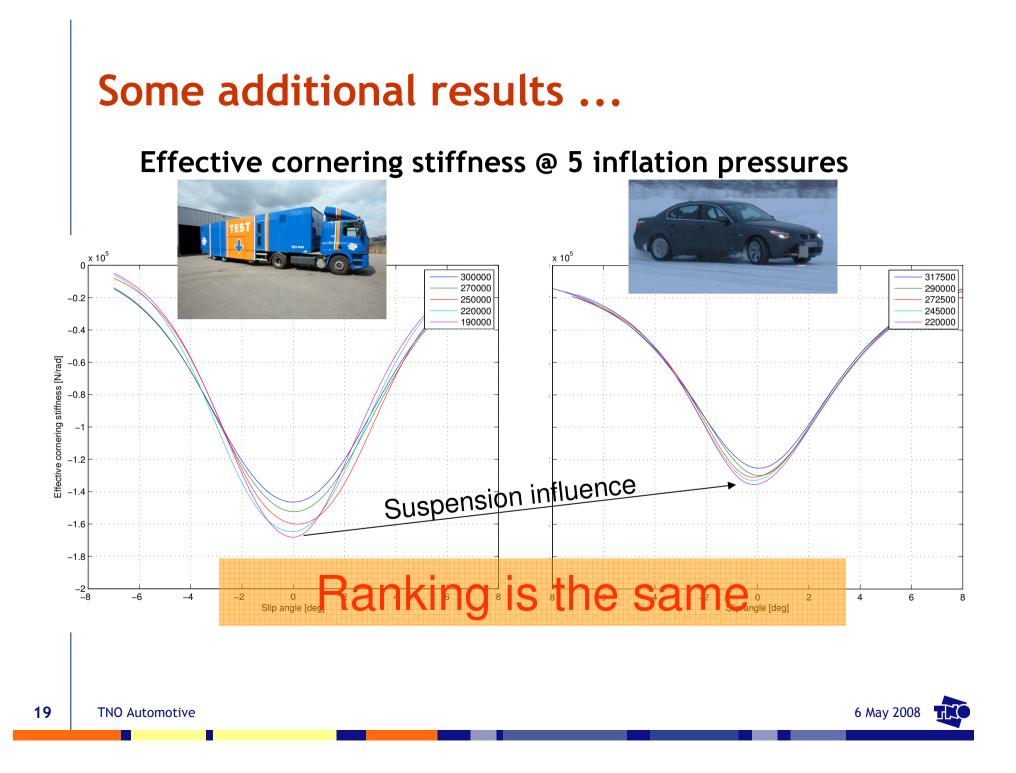


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## Some additional results...

#### Low friction



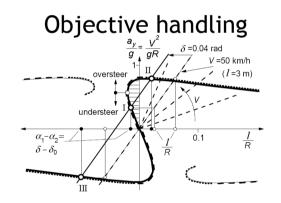


# **Tyre estimator Way of Working**

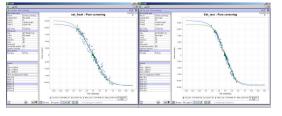
- Perform set of standard test track tests
  - Straightforward set of tests is supplied (steady-state circle, etc.)
  - Log ESC sensor data and ground speed
- Use State Estimation to calculate tyre forces
- Use MF-tool to fit tyre characteristics
  - Result is combination of tyre and suspension characteristics

#### Subjective handling





#### Objective tyre characteristics



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# Tyre estimator applications

- Tyre estimator identifies combination of tyre and suspension characteristics
  - Optimisation of tyre and suspension settings
    - tyre type, inflation pressure, tyre wear influences, speed effects, different road surface conditions
    - Suspension adjustment, camber, stabiliser, etc
  - Lap time evaluation
    - Time history of forces
    - Driver feedback
  - Subjective/objective studies
    - Relate driver assessment to estimated characteristics (of combination of suspension and tires!)
  - Input for simple vehicle model (e.g. bicycle model) or control system tuning

## Conclusion

- Tyre forces can be estimated from vehicle motions using a State Estimator approach
- The method for tyre force estimation is proven for different vehicles on various road surfaces
- Ranking capability is proven
- The method can be applied using little vehicle instrumentation, simple driving tests and processing is supported with a GUI tool

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# **Current developments**

- Truck tyres
- Racing application
- Integration with sensor systems
- Application as a check on tyre condition during vehicle testing

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