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AMFD – Auto Mobil Forschung Dresden GmbH
„Die Welt von morgen bewegen“

Process Reliable Parameterization of Total Vehicle Models for Driving Dynamics and Ride Comfort

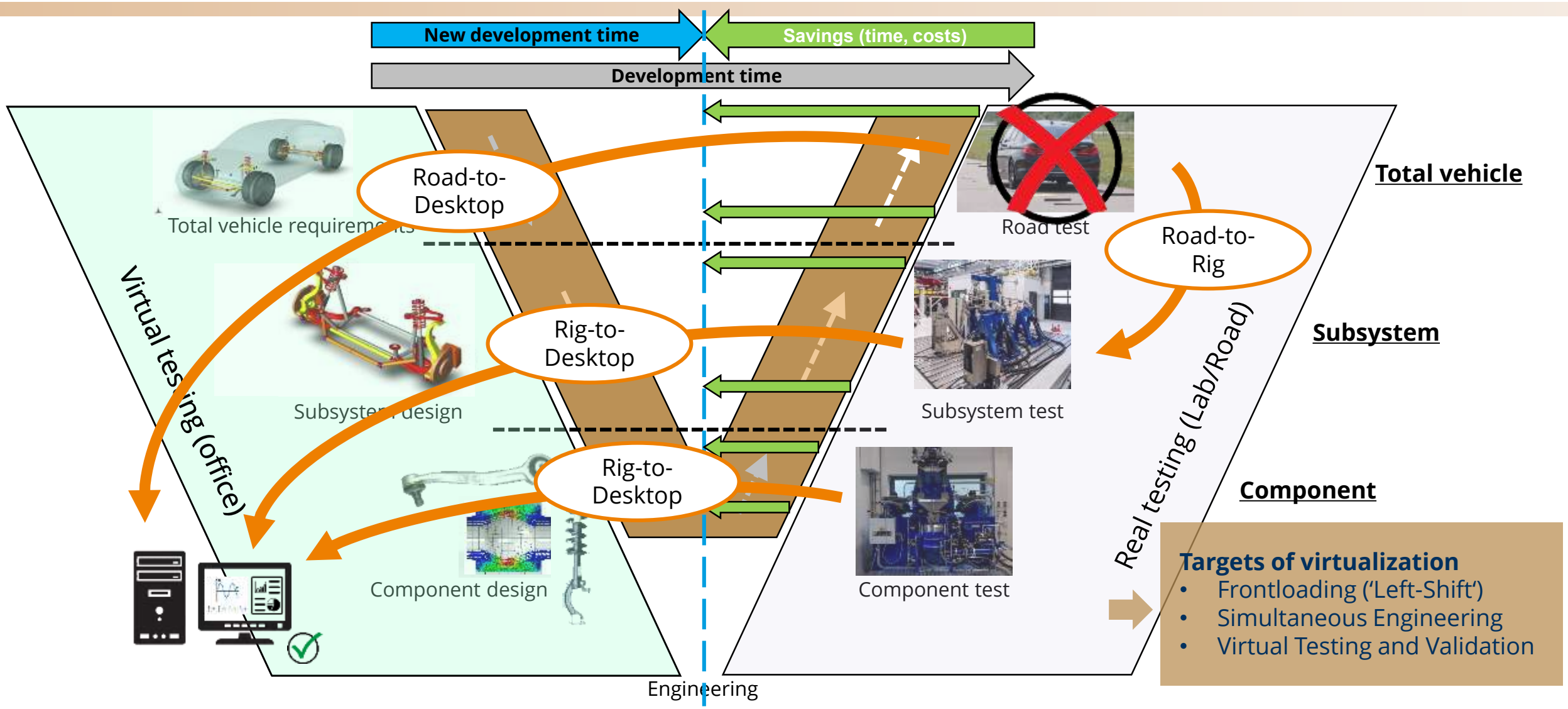
A presentation of a complete parameterization line using effective simulation methods and capable test rigs

Apply & Innovate – TECH WEEKS
October 2020

Agenda

1. Motivation
2. Solution approach
   a. Modeling
   b. Parameter identification
   c. Validation
3. Application
   a. Total vehicle level
   b. Subsystem level
   c. Component level
4. Outlook

Motivation – Virtualization in vehicle development



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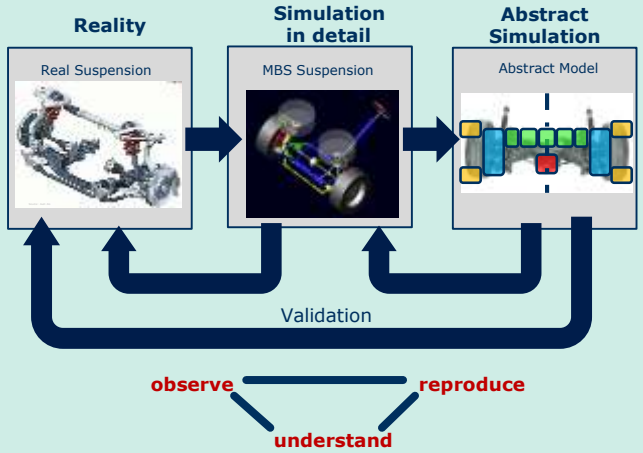
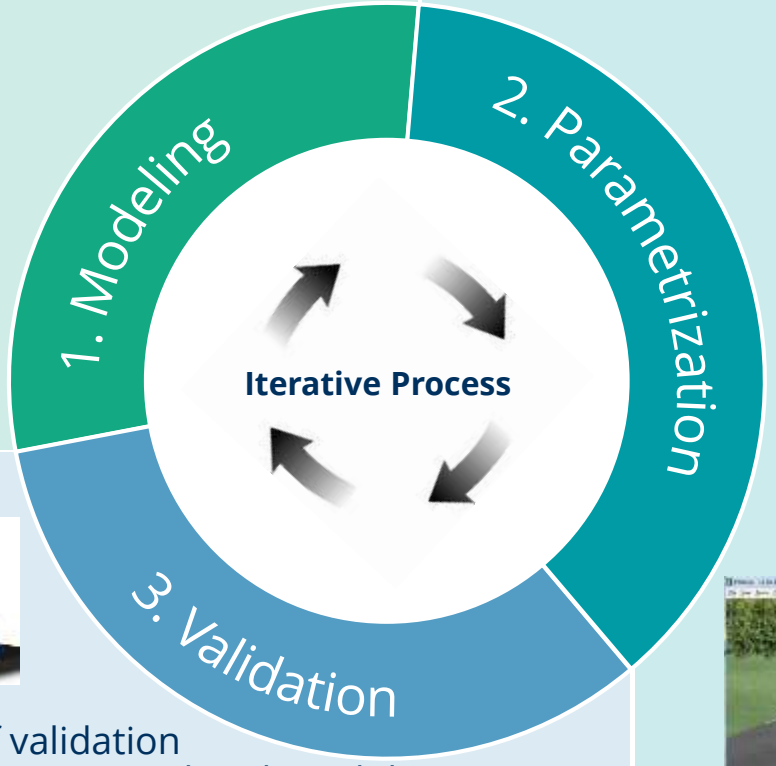
Solution approach

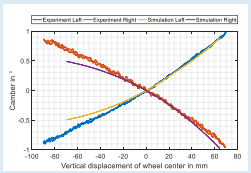
Consistent combination of modeling, parameterization and validation based on real world experiments and test rigs

- Generation of system understanding through abstraction and reduction to essential effects





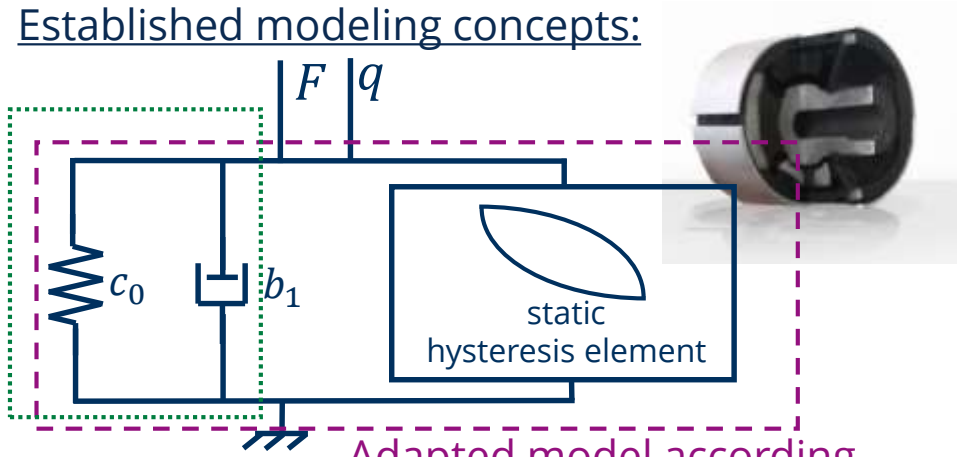
- Parameter identification corresponding to the model's level of detail



- Increasing the efficiency and accuracy of validation by simulating the environment of the specimen within the validation tests

Solution approach – Modelling

Established modeling concepts:

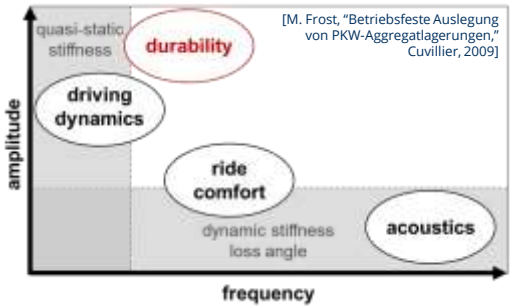


Kelvin-Voigt model

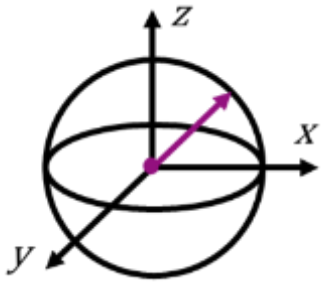
Adapted model according to DRONKA&RAUH
[S. Dronka und J. Rauh, „Modell zur Simulation von Fahrwerks-Gummilagern“, 2006]

Insufficiencies for:

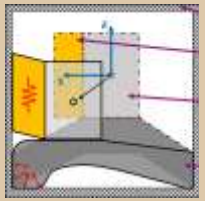
- Dynamic excitation with high amplitudes



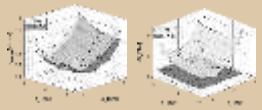
- Multi-axial excitation



Influence of stops (deformation limits)

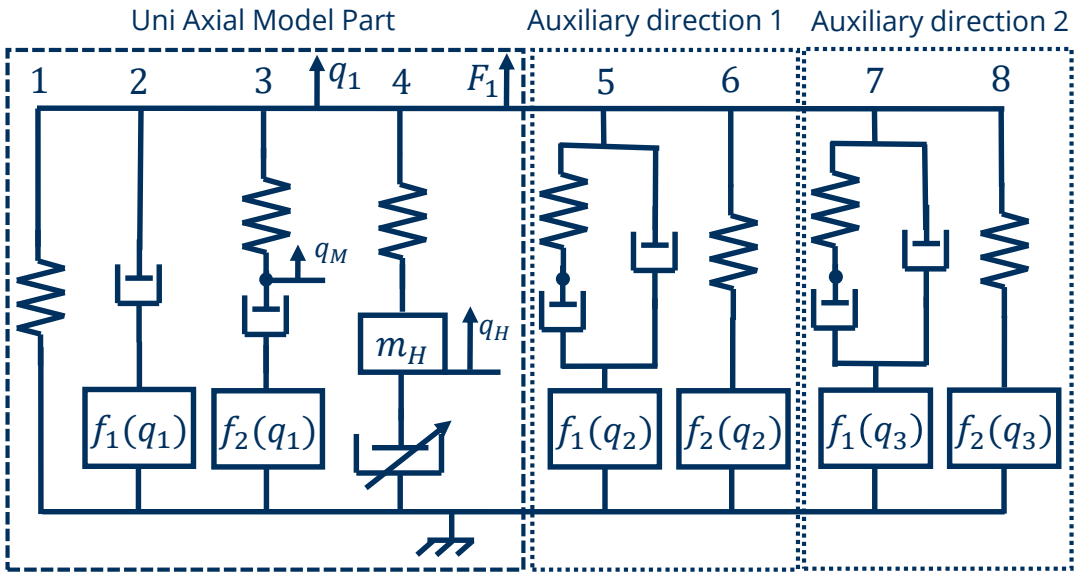


Effect chain analysis



- Increase in stiffness due to lateral deformation of the stops
- Increase in loss work due to lateral deformation of the stops
- Open hysteresis because of stick-slip-effects

New model approach to represent high loads, hydraulic damping and multi-axial excitations:



Viscous linear damping

Viscous nonlinear damping

6./8. Representation of the multi-axial stiffness components

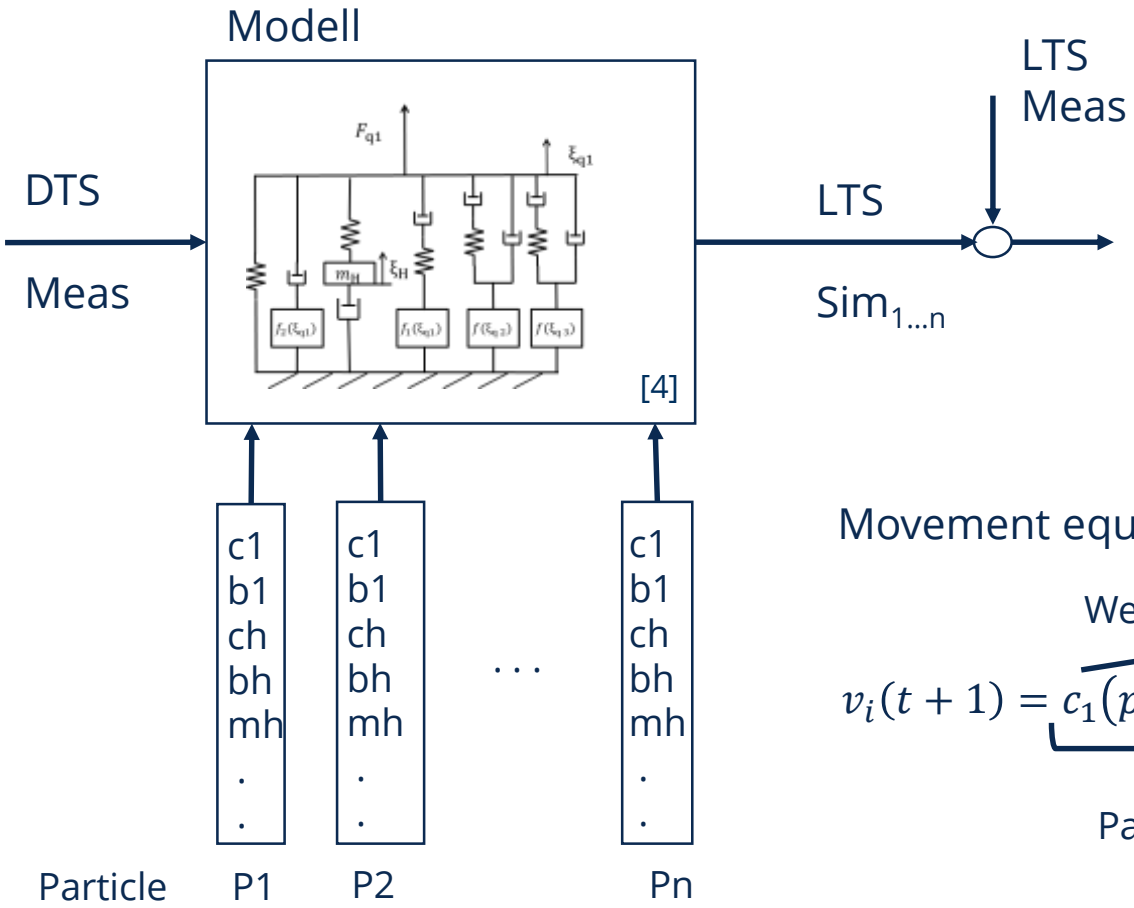
5./7. Illustration of the multi-axial dynamic components (increase in material damping due to lateral deformation and transient multi-axial dynamic effects)

$f_x(q_x)$ - nonlinear gain functions – Adaptation of dynamic parameters depending on deformations

Solution approach – Modelling (Parameter identification)

Particle swarm optimization according to Kennedy and Eberhardt

[R. Eberhart und J. Kennedy, „Particle swarm optimization“, in Proceedings of the IEEE international conference on neural networks, 1995, Bd. 4, S. 1942–1948]



Legend:

LTS Meas	Load-Time-Series measured at test rig
DTS Meas	Deformation-Time-Series measured at test rig
LTS Sim	Load-Time-Series simulated
S_{meas}	Damage sum of LTS Meas
S_{sim}	Damage sum of LTS Sim

Function for optimization:

$$0 = f(S_{rel}) \cdot \sum_{t=0}^{t=Ende} (LTS_{real} - LTS_{sim})^2$$

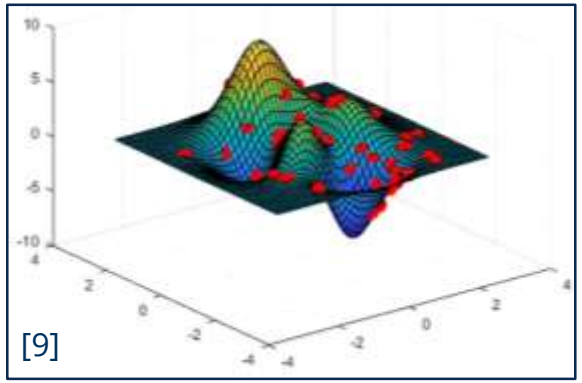
$$S_{rel} = \frac{S_{sim}}{S_{meas}}$$

Movement equation of the particles:

$$v_i(t+1) = \overbrace{c_1\left(pb_i(t) - p_i(t)\right) + c_2(pg_i(t) - p_i(t))}^{\text{Weighting factors}}$$

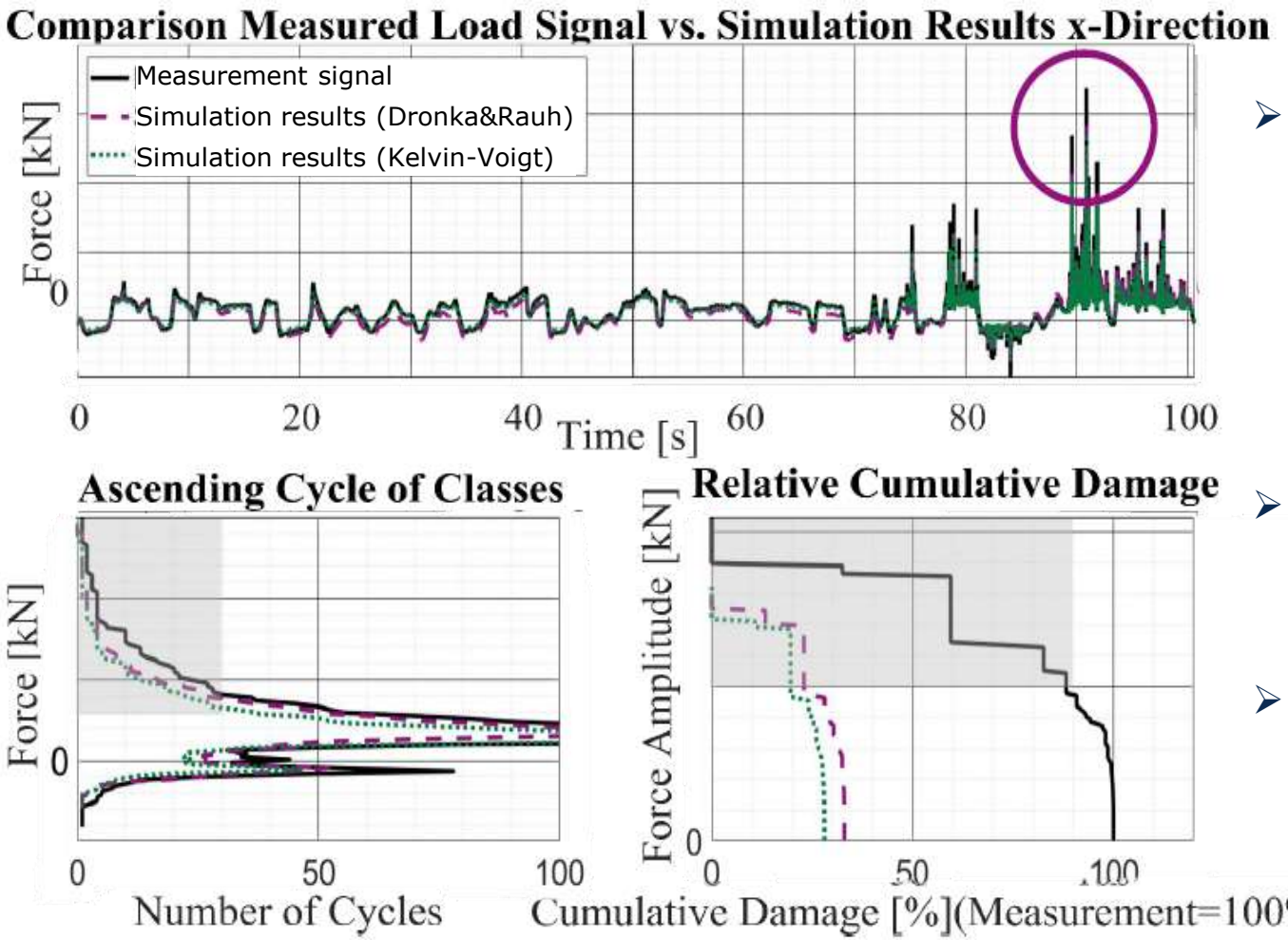
Particle experience

Swarm knowledge



Solution approach – Modelling (Validation)

Validation data acquisition

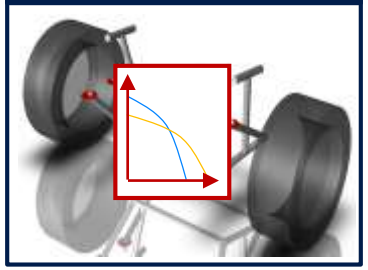


- Significant improvement of the signal quality of the newly developed simulation model compared to standard modelling
- Display of load peaks with improved accuracy
- Increase of the signal damage to approx. 104%

Solution approach – Parameter identification

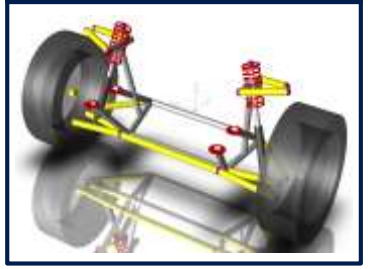
Level of detail

Characteristic Curve Based Models



Mass and inertia parameters		
Vehicle weight (axle loads)	Center of gravity coordinates	Inertia tensor
Kinematics and compliance (KnC)		
Toe, camber, longitudinal and lateral translation through parallel and anti-parallel wheel deflection		
Toe, camber, longitudinal and lateral translation caused by steering		
Toe, camber, longitudinal and lateral translation under side force		
…		

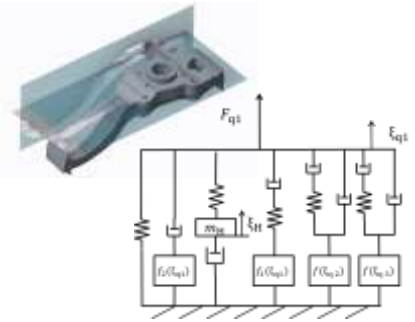
Kinematic MBS Model



Mass and inertia parameters of abstracted components		
Component mass	Center of gravity coordinates	Inertia tensor
Hard point coordinates		
Positions of joints in reference frame		
Spring an damper characteristics		
Linearized scalar parameters or look-up-tables		
…		

Elastokinematic MBS Model with CAD Bodies

Mass and inertia parameters of detailed components (Reverse engineering)		
Component mass	Center of gravity coordinates	Inertia tensor
Elastomeric bearings behavior		
Linear an nonlinear parameters for dynamic multi-axial bearing behavior		
Spring an damper characteristics		
Advanced model parameters to represent nonlinearities e.g. friction		
…		



Solution approach – Parameter identification

Concept

Implementation

Parameter Identification Process

Zero-order kinematics

Vehicle Inertia Measuring Machine

Suspension Motion Simulator

Tire properties

Whole vehicle validation

Roadsimulator

Brake properties

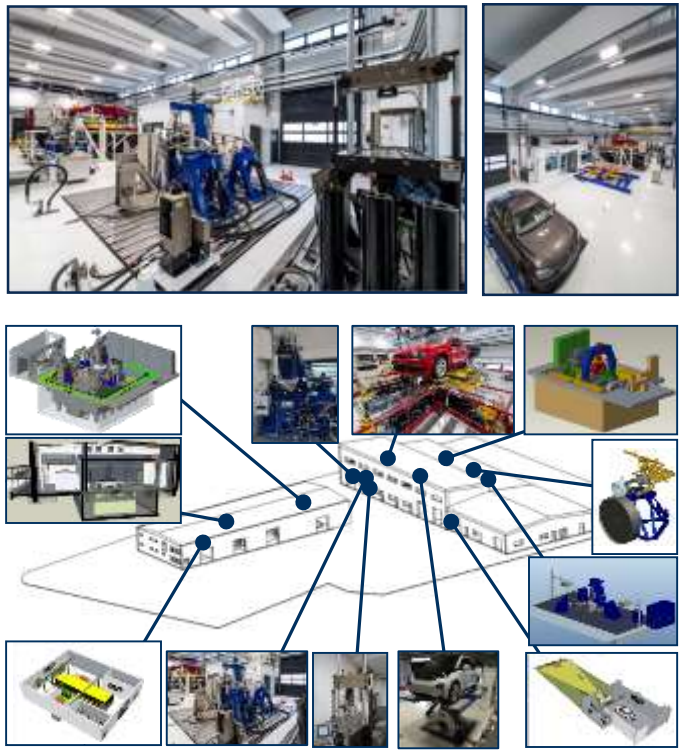
Elastic behavior

Spring / damper

...

Vehicle Test Center in Dresden

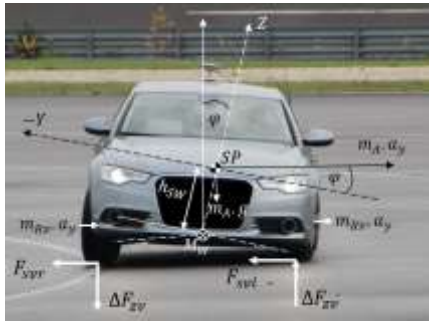
locally concentrated comprehensive test rigs



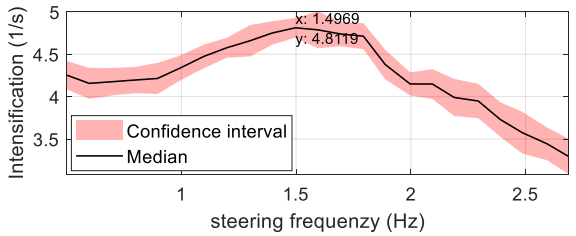
Solution approach – Validation

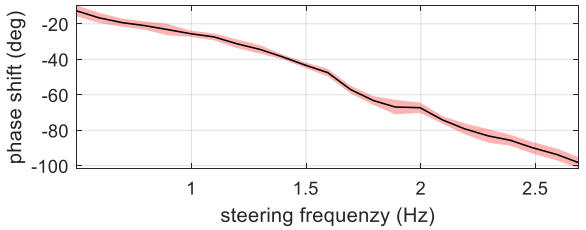
Principles of Validation:

- Repetition of experiments for statistical evaluation of measurement uncertainties
- Model effect validation by variation of the test configuration (e.g. payload) as robustness check
- Use of objective performance indicators



Yaw intensification as comparative result

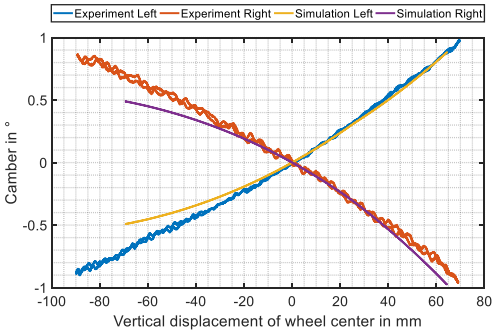




Advantage of multilevel aspect of solution approach:

- Saving of test efforts through use of data on multiple levels of detail
- Reuse of parameter identification tests for validation of sublevel models
  - ➢ KnC characteristics from total vehicle parameter identification can be used for validation of axle subsystem model

Parameter identification



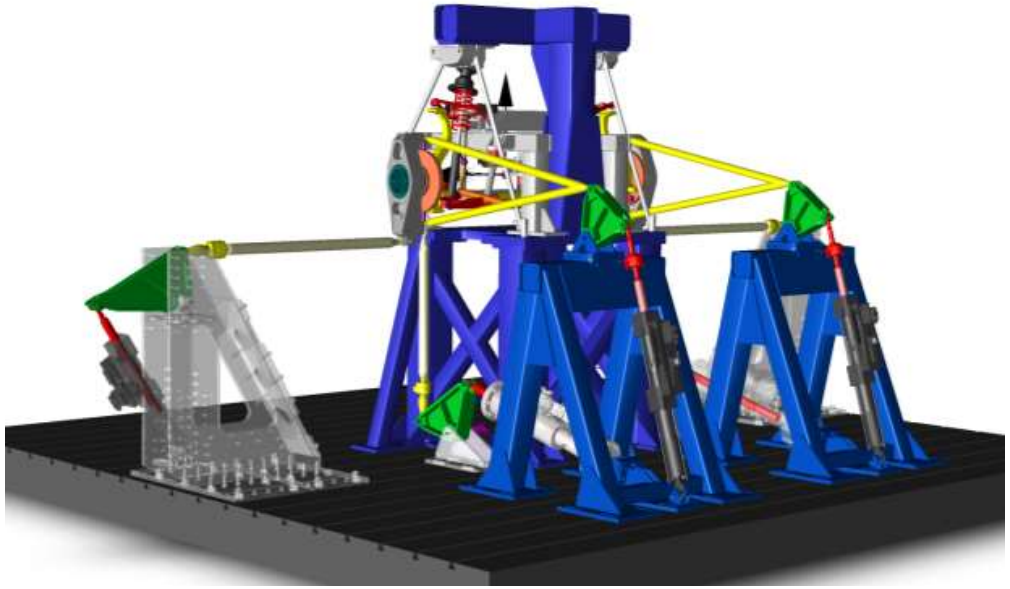
Reuse of parameter identification tests for validation

Validation

Solution approach – Validation

Digital twin of test rig:

Increasing the efficiency and accuracy of validation by simulating the environment of the specimen within the validation tests



Advantages:

- Differentiation between test rig and specimen effects
- Use of drive signals for excitation trajectories along sensitive spatial directions determined by simulative sensitivity analysis
- Increasing efficiency by model based preparation of experiments

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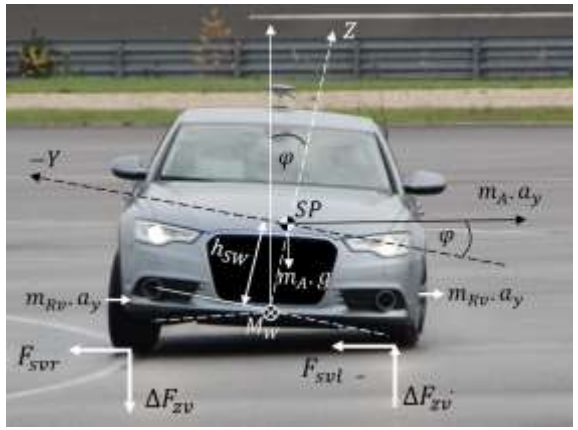
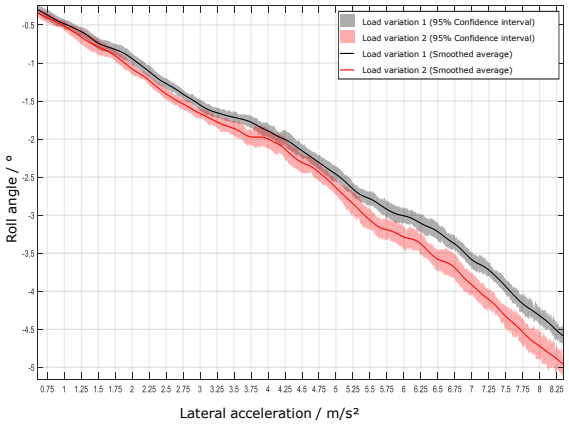
Application - Total vehicle level

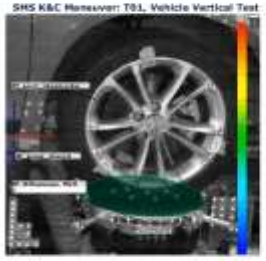
Road test validation data

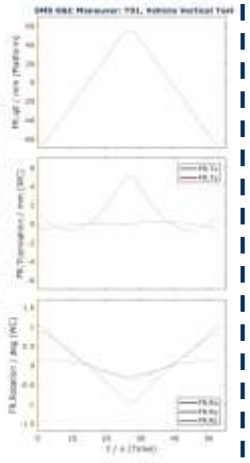




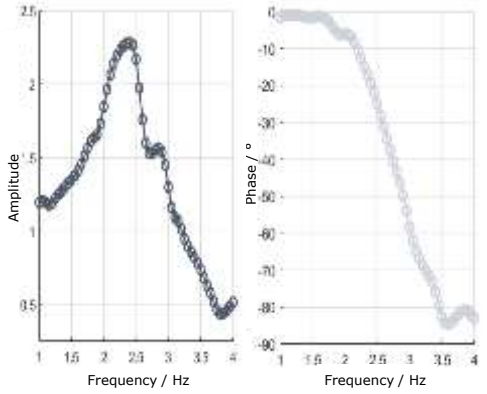
Static and dynamic K&C measuring

Static KnC





Dynamic transfer function



Inertia parameter identification

Parameters to identify (3 parameter in 3 equations)

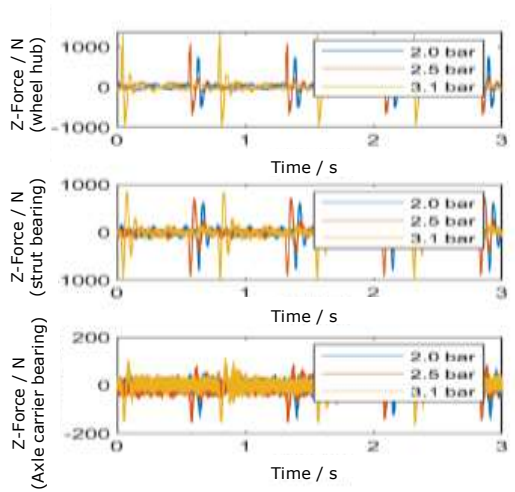
$$\frac{d\vec{L}_0}{dt} = \begin{pmatrix} -\dot{\omega}_z \cdot J_{xz} + \omega_z^2 \cdot J_{yz} \\ -\dot{\omega}_z \cdot J_{yz} - \omega_z^2 \cdot J_{xz} \\ \dot{\omega}_z \cdot J_{zz} \end{pmatrix} = \begin{pmatrix} M_{0x} \\ M_{0y} \\ M_{0z} \end{pmatrix} = \vec{M}_0$$

Obtained from motion measurement

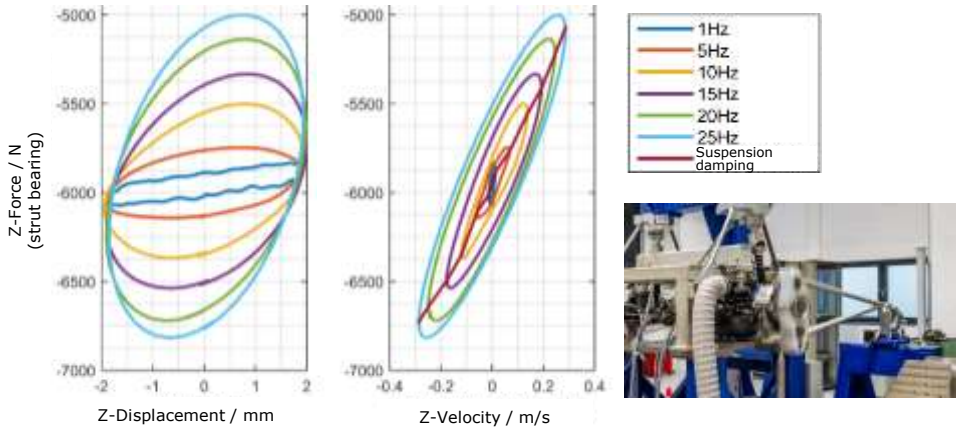
Obtained from force measurement

Application - Subsystem level

Axle Transfer behaviour

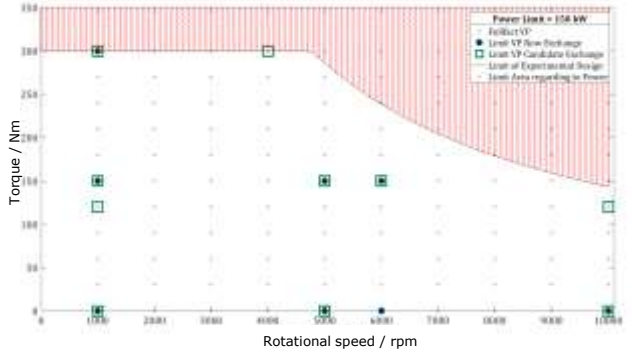


Suspension characteristics



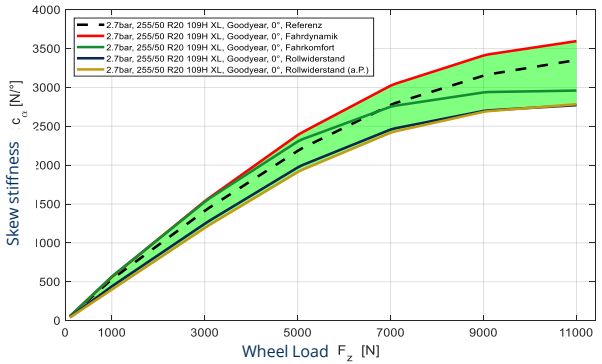
Powertrain testing

DoE based efficiency map identification

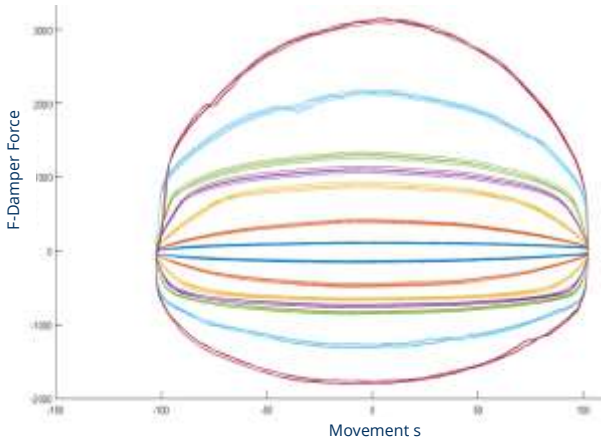


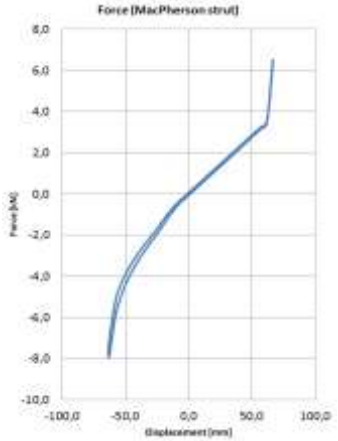
Application - Component level

Tire parameter identification

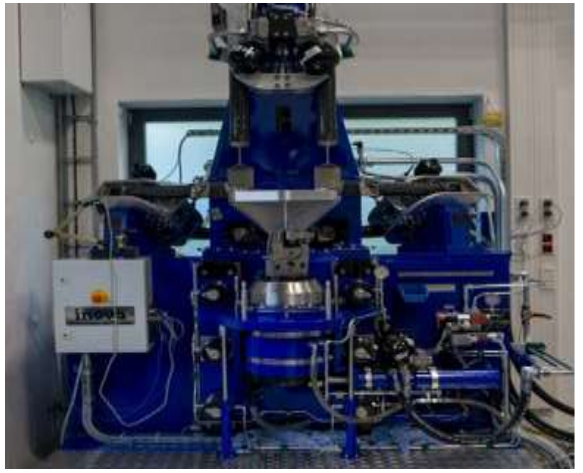


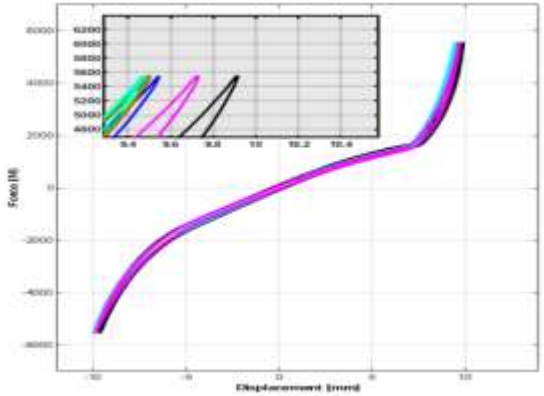
Spring and damper characteristics





Elastomeric bearings behavior





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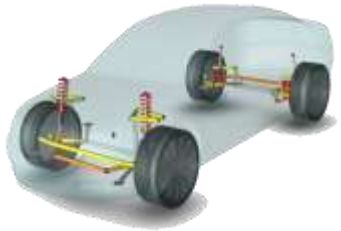
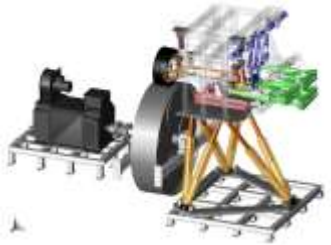
Outlook - Virtual testing und connected test rigs

Simulation environment

Component simulation



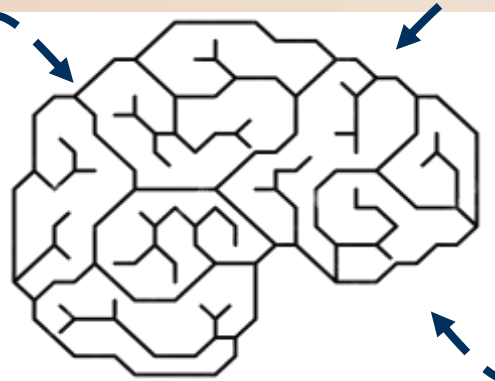
Total vehicle simulation



Virtual representation of real test rigs

Cloud data

Real-Time Processing



„Digital backbone“

Sensor Fusion

Automation & Control

Human interface

Dresden driving simulator

Analysis of the overall vehicle

Vehicle inertia measuring machine

Suspension motion simulator

Analysis of the subsystems

Powertrain test rig

Road-load simulator

Analysis of the components

Tire test rig

Elastomer measuring machine

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