VIRTUAL ITERATION FOR SET UP OF TRUCK CAB TESTS

N. Weigel, S. Weihe, V. Sing, R. Gerlach, A. Ferreiro de Souza

Daimler AG, Stuttgart-Untertürkheim

M. Speckert, A. Marquardt, K. Dreßler,

Fraunhofer-Institut für Techno- und Wirtschaftsmathematik ITWM, Kaiserslautern

Simpack User Meeting, Bonn, 20th and 21st November 2007

Overview

- Introduction and objective
  - Prediction of load data for new vehicles
  - Digital track vs. hybrid road
- MBS model
  - Axor truck cab and frame on test rig / new vehicle
- Back-calculation of invariant load data based on the existing vehicle
  - Identification of transfer function, iteration
  - Simulation results vs. measurements
- Prediction for new vehicle
- Summary and conclusion

Load data prediction

- Load data for upcoming vehicle models must often be known before a physical prototype is available, e.g. for physical testing or numerical simulation of components

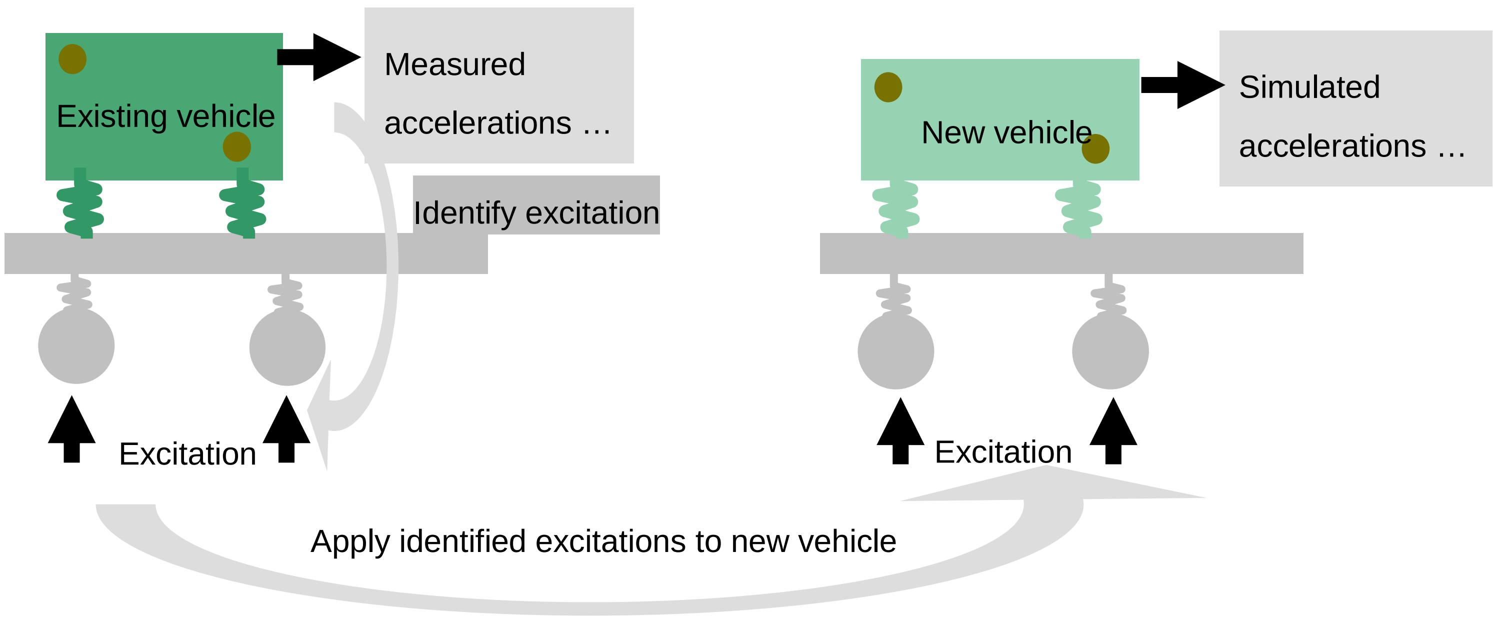
- **Digital track** is one option for load data prediction:
  Simulation of the vehicle on the test track (e.g. rough road)
  - \+ Straightforward approach
  - \+ Theoretically, no measurement is required (except for model correlation)
  - \- Accuracy of tire models very often an issue for x, y
  - \- Digital model of test track required

- Optional approach: **Hybrid road** …

Load data prediction
Hybrid road method

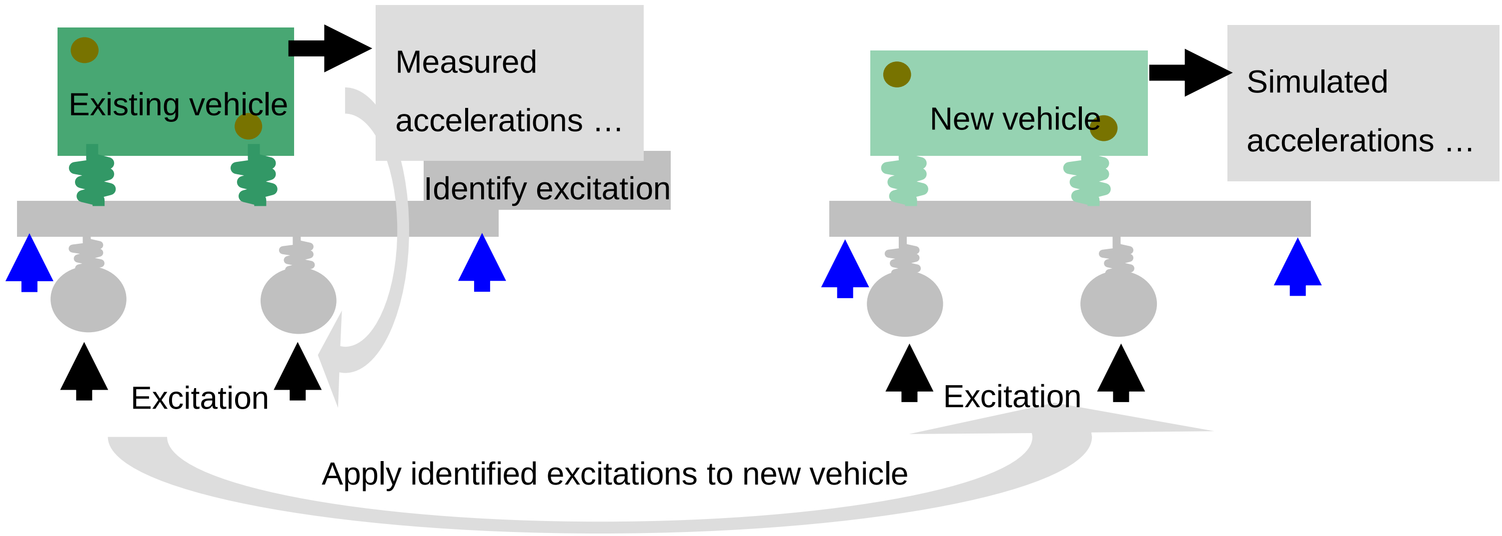
Basic idea:

1. Use measurement on an existing vehicle (WFT, accelerations etc.) to generate a „hybrid road".
   → Differences between hybrid road and actual road actually counterbalance inaccuracies in tire models.
2. Simulation of new vehicle on hybrid road yields load data.



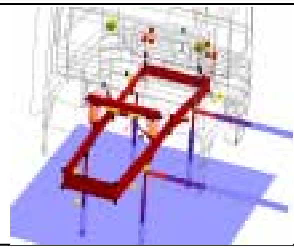
DAIMLER
Fraunhofer Institut Techno- und Wirtschaftsmathematik

Load data prediction
Hybrid road method



- It is most straightforward to identify the road excitations (black arrows) and apply these to the new vehicle, i.e. to consider the road as the „invariant“ interface.
- However, one can also consider a different interface as (quasi-)invariant and identify/transfer the excitations there (blue arrows).
- The choice of the interface depends on the similarity between both vehicles, accuracy of MBS models, acceptable compromise between modeling/simulation expense and result accuracy.
- In the present project, the frame was chosen as invariant interface.

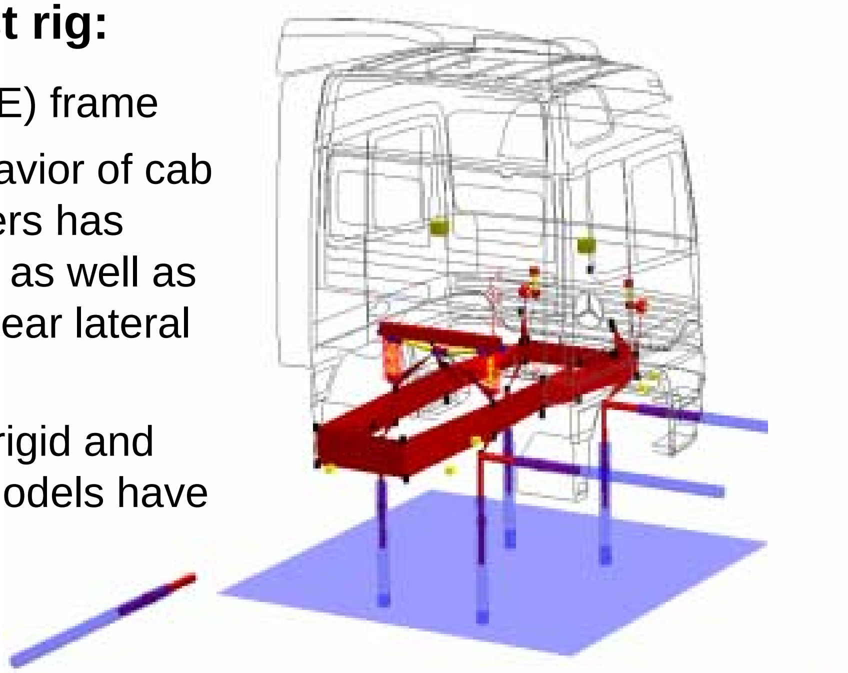
DAIMLER
Fraunhofer Institut Techno- und Wirtschaftsmathematik



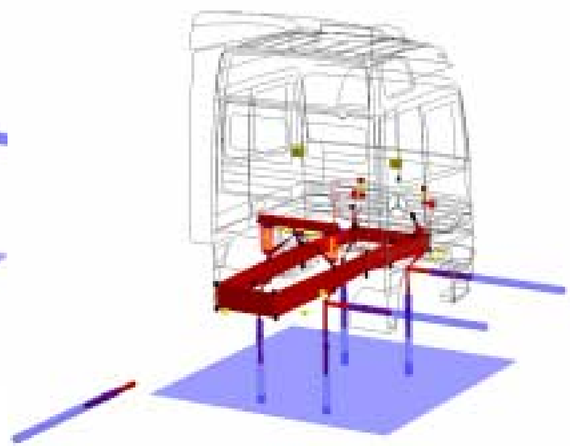
MBS models

Axor cab and frame on test rig:

- Flexible (i.e. FE) frame
- Nonlinear behavior of cab springs/dampers has been modeled as well as bump stop of rear lateral damper
- For cab, both rigid and flexible (FE) models have been used



New vehicle



Back-calculation of drives Methodology (general)

for $i = 0,1,2,\ldots$

$$u_{i+1} = u_i + \Delta u_i$$

$$\Delta u_i = H^{-1} \cdot (T - y_i)$$

S = MBS model of Axor with test rig
u = cylinder displacements
y = (MBS) calculated accelerations and spring displacements
T = measured accelerations and spring displacements (target)
e = error *T – y*

Aim: Find input *u* such that the error e is minimized

Steps: a) Identification (frequency domain)

$$\text{Set point: } y_0 = S(u_0)$$

$$y_{noise} = S(u_0 + u_{noise}) - y_0$$

$$H = \hat{P}_{y_{noise}, u_{noise}} \cdot \hat{P}^{-1}_{u_{noise}, u_{noise}}$$

b) Iteration

for $i = 0,1,2,\ldots$

$$u_{i+1} = u_i + \Delta u_i$$

$$\Delta u_i = H^{-1} \cdot (T - y_i)$$

H = linear spectral representation of system S linearized w.r.t. set point u_0 (frequency response functions FRF)

DAIMLER

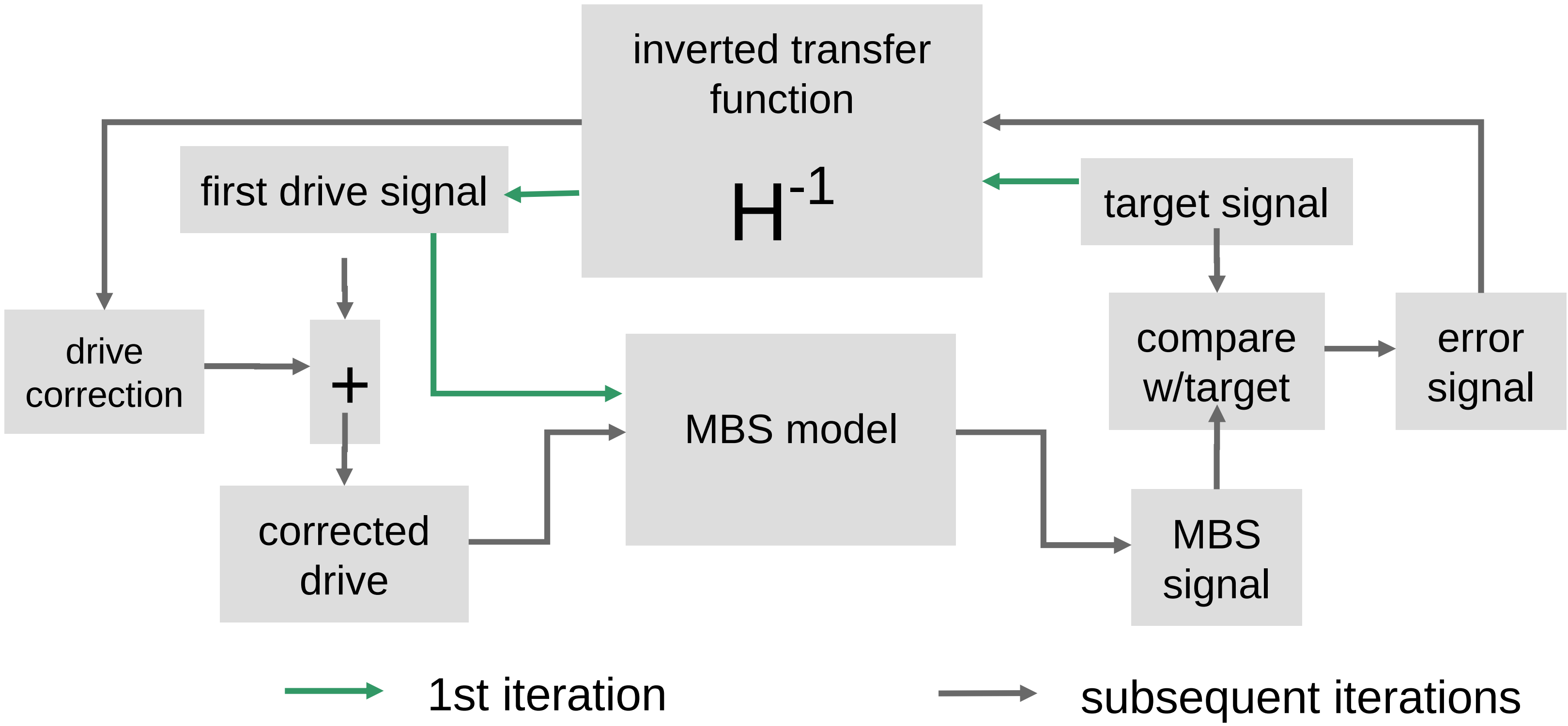
Fraunhofer Institut Techno- und Wirtschaftsmathematik

Back-calculation of drives
Methodology (general)

for $i = 0,1,2,\ldots$

$$u_{i+1} = u_i + \Delta u_i$$

$$\Delta u_i = H^{-1} \cdot (T - y_i)$$



Back-calculation of drives Methodology (special)

$$\text{for } i = 0,1,2,\ldots$$
$$u_{i+1} = u_i + \Delta u_i$$
$$\Delta u_i = H^{-1} \cdot (T - y_i)$$

Derive frame motion from measured accelerations

- Measured accelerations on frame
  - front right: x,y,z
  - front left: x,z; rear right: y,z; rear left: z
- Calculated (translational) displacements …
  - Calculate frame displacements by integration of acceleration and subsequent filtering (1Hz)
  - Use front right as reference point since all components of acceleration are known there
  - Calculate relative displacements

Describe frame motion by means of a rigid body approach

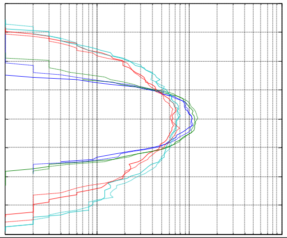
- Now describe movement of the remaining points (f l, r r, r l) as rigid body motion w.r.t. front right

Calculate angular displacements of rigid body by means of optimization

- Minimize the difference between rigid body motion of frame and motion derived from accelerations for frame points (f r, f l, r r, r l)

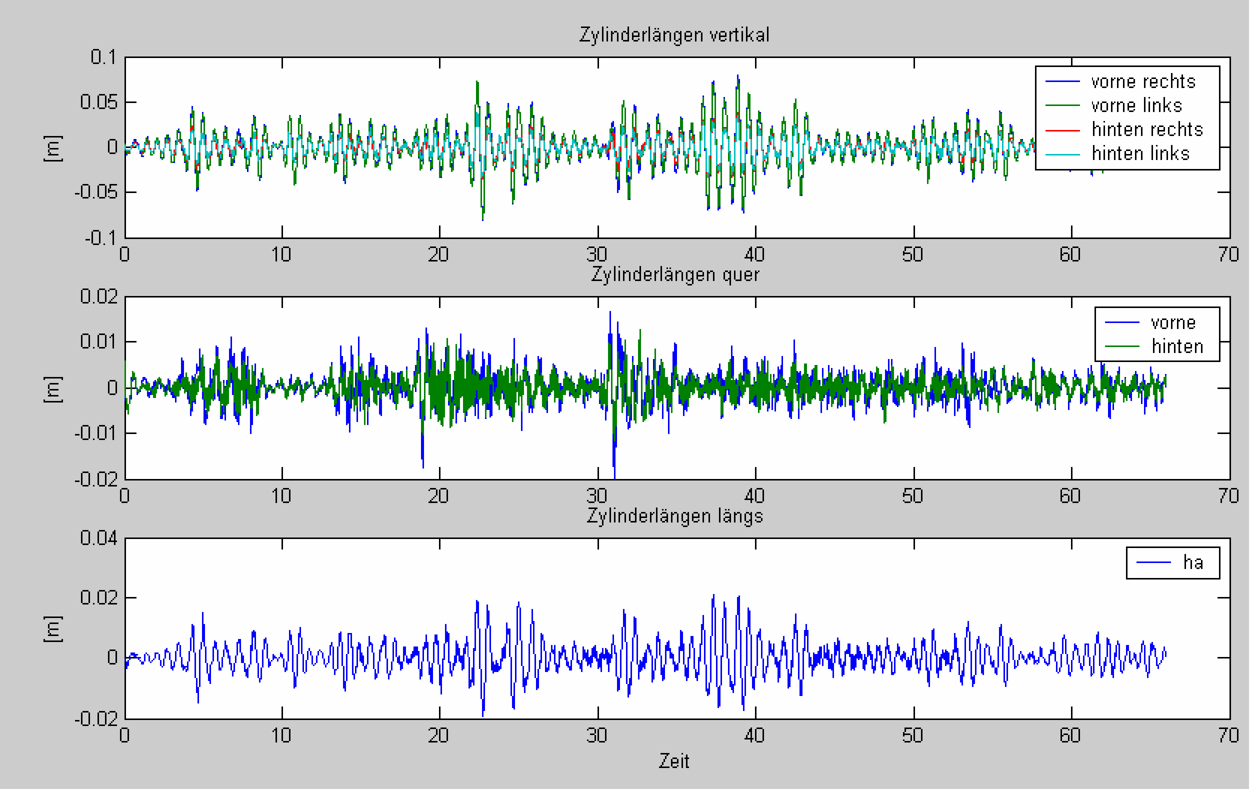
→ **cylinder displacements**

Back-calculation of drives
Results



1st drive signal

→ frame displacements calculated by means of rigid body approach have been used as set point u_0 (in this case, this is a better initial drive than $H^{-1}*T$)

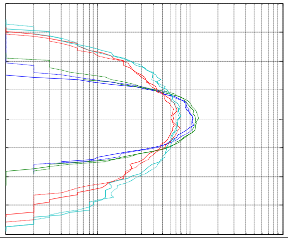


Set point: $y_0 = S(u_0)$

$$y_{noise} = S(u_0 + u_{noise}) - y_0$$

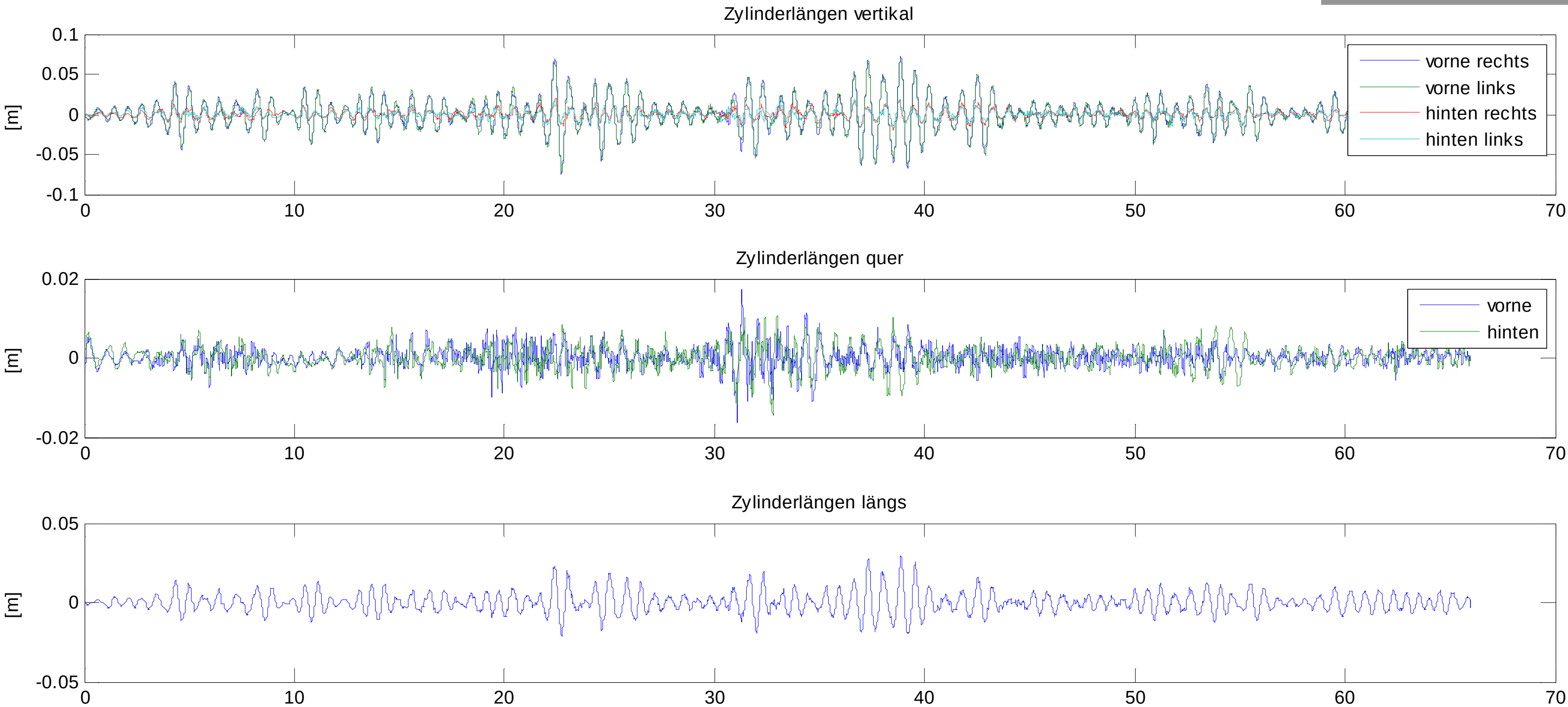
$$H = \hat{P}_{y_{noise},u_{noise}} \cdot \hat{P}^{-1}_{u_{noise},u_{noise}}$$

Back-calculation of drives
Results

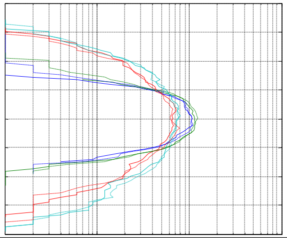


Drive signals (i.e. cylinder displacements) after 5 iterations

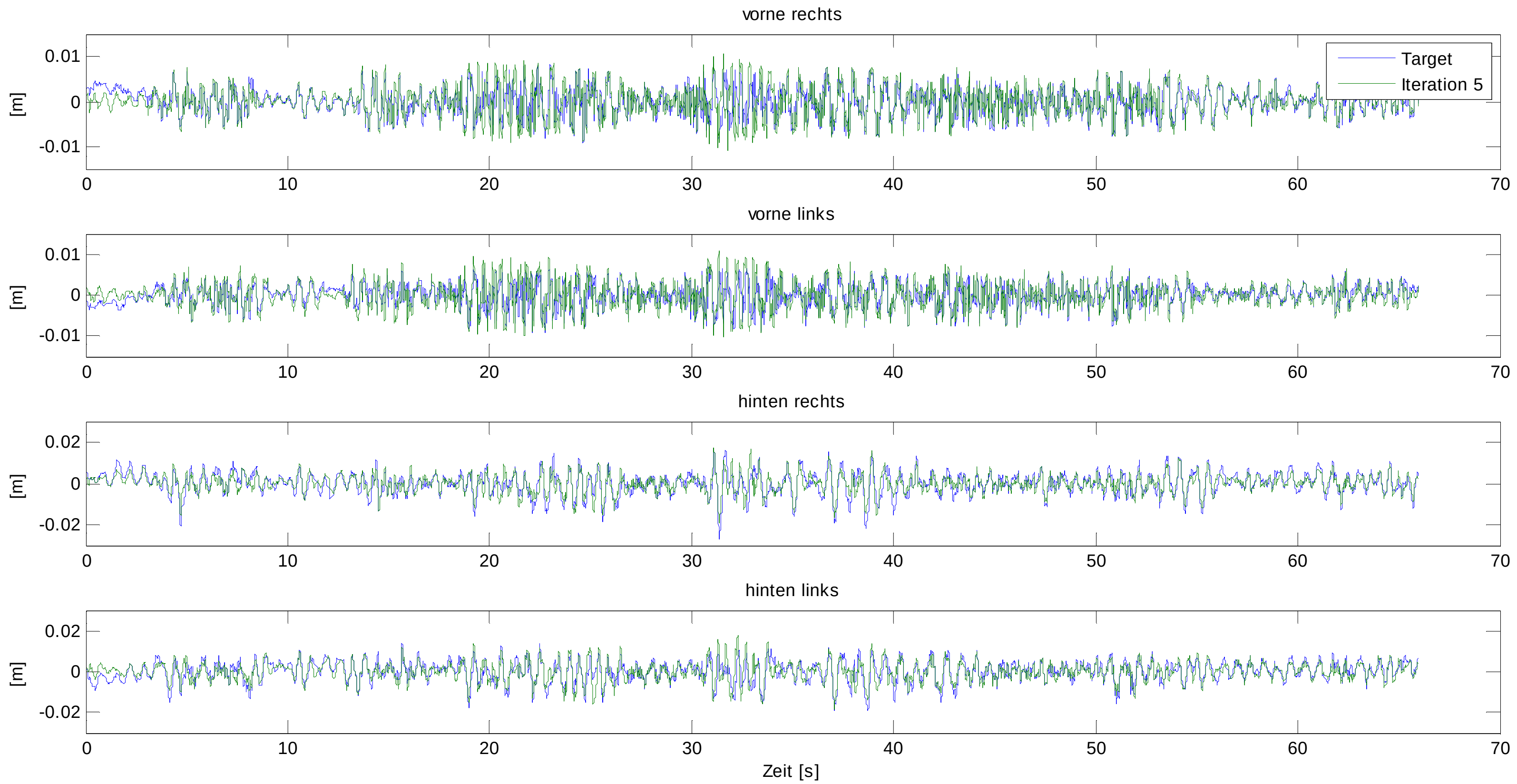
$$\text{for } i = 0,1,2,\ldots$$
$$u_{i+1} = u_i + \Delta u_i$$
$$\Delta u_i = H^{-1} \cdot \left(T - y_i\right)$$



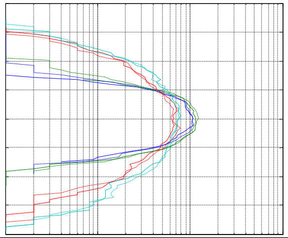
Back-calculation of drives
Results



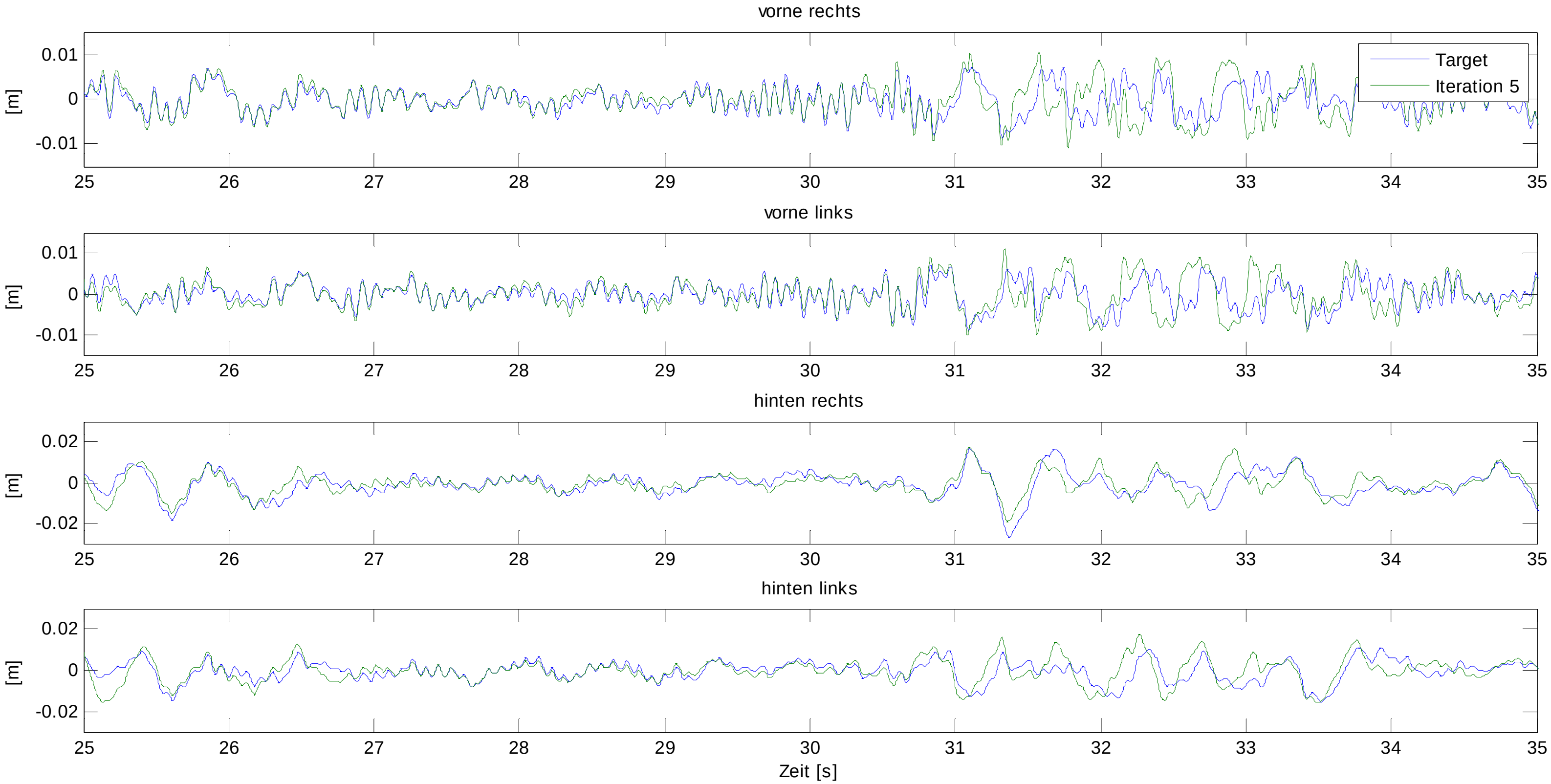
Relative displacement frame vs. cab after 5 iterations



Back-calculation of drives
Results

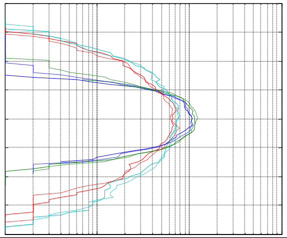


Relative displacement frame vs. cab after 5 iterations (detail)

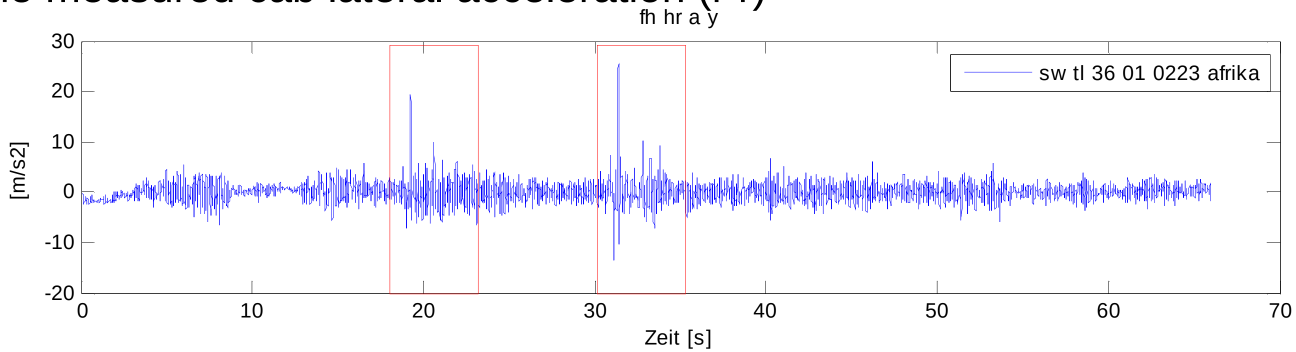


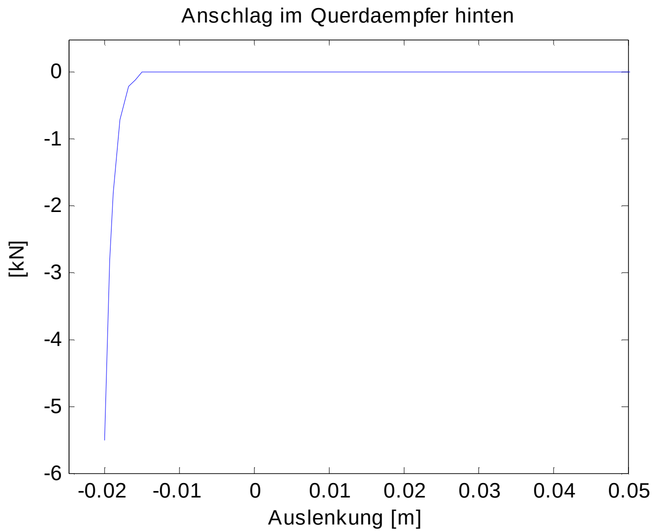
Deviation between measurement and simulation is due to inaccuracies in MBS model (especially, bump stops)

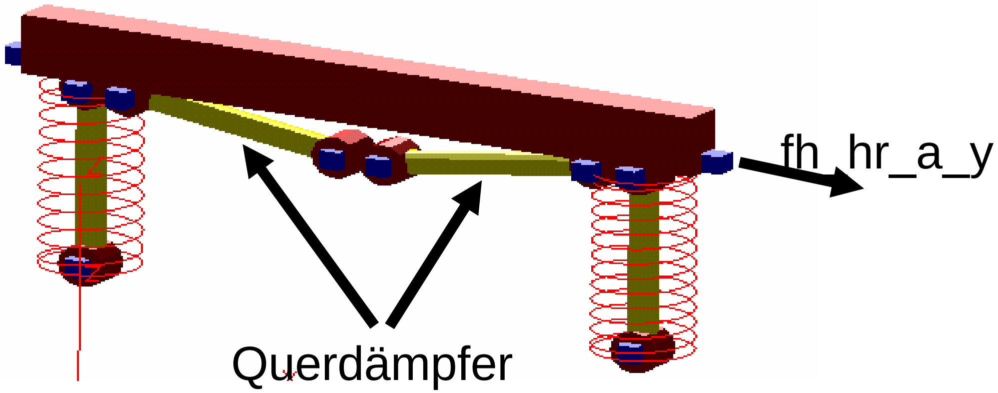
Back-calculation of drives
Simulation of bump stops



On rough road, the bump stop of rear side lateral damper is activated several times as can be seen on the measured cab lateral acceleration (r r)

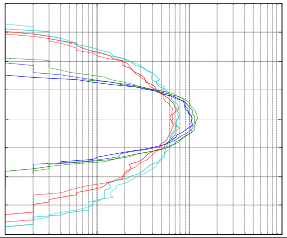






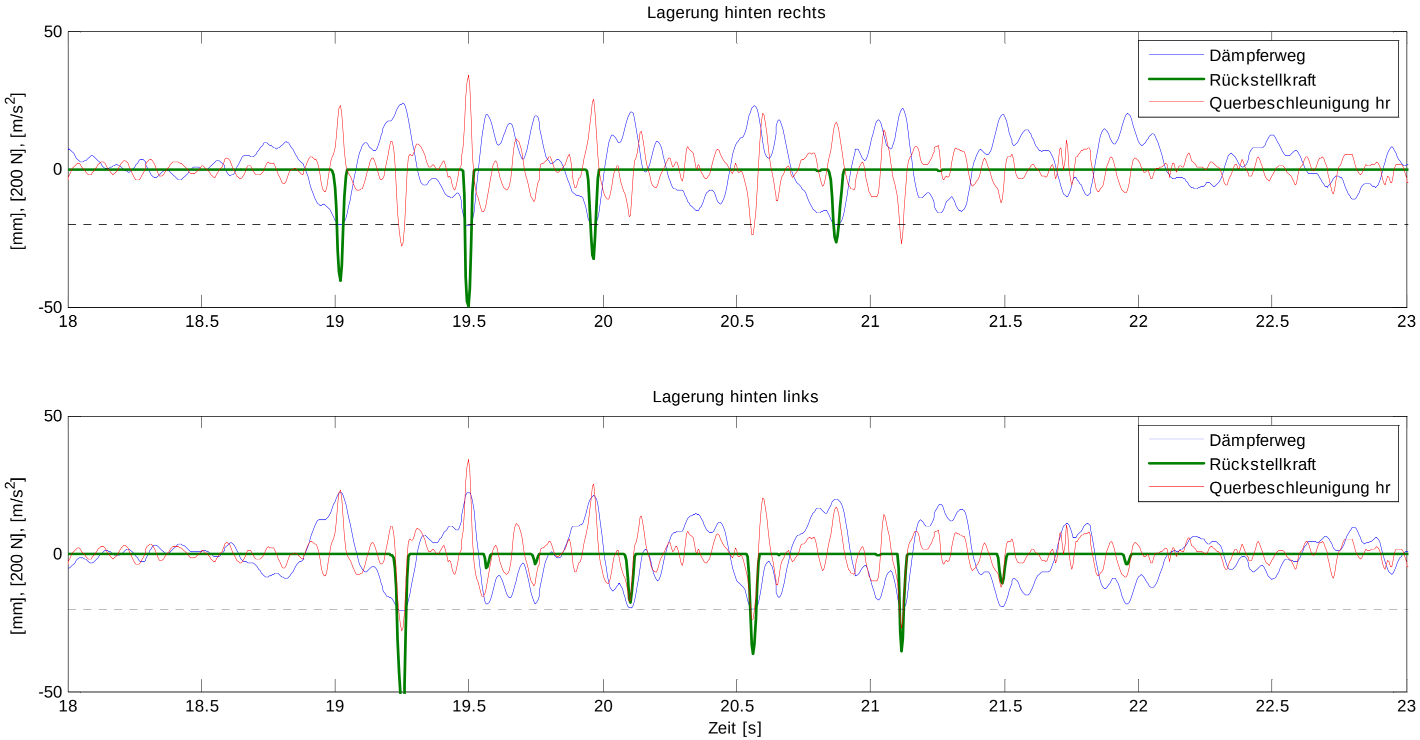
DAIMLER

Fraunhofer Institut Techno- und Wirtschaftsmathematik ITWM



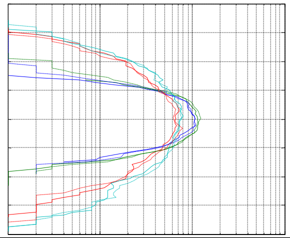
Back-calculation of drives
Simulation of bump stops

Simulated behavior of rear side lateral bump stop



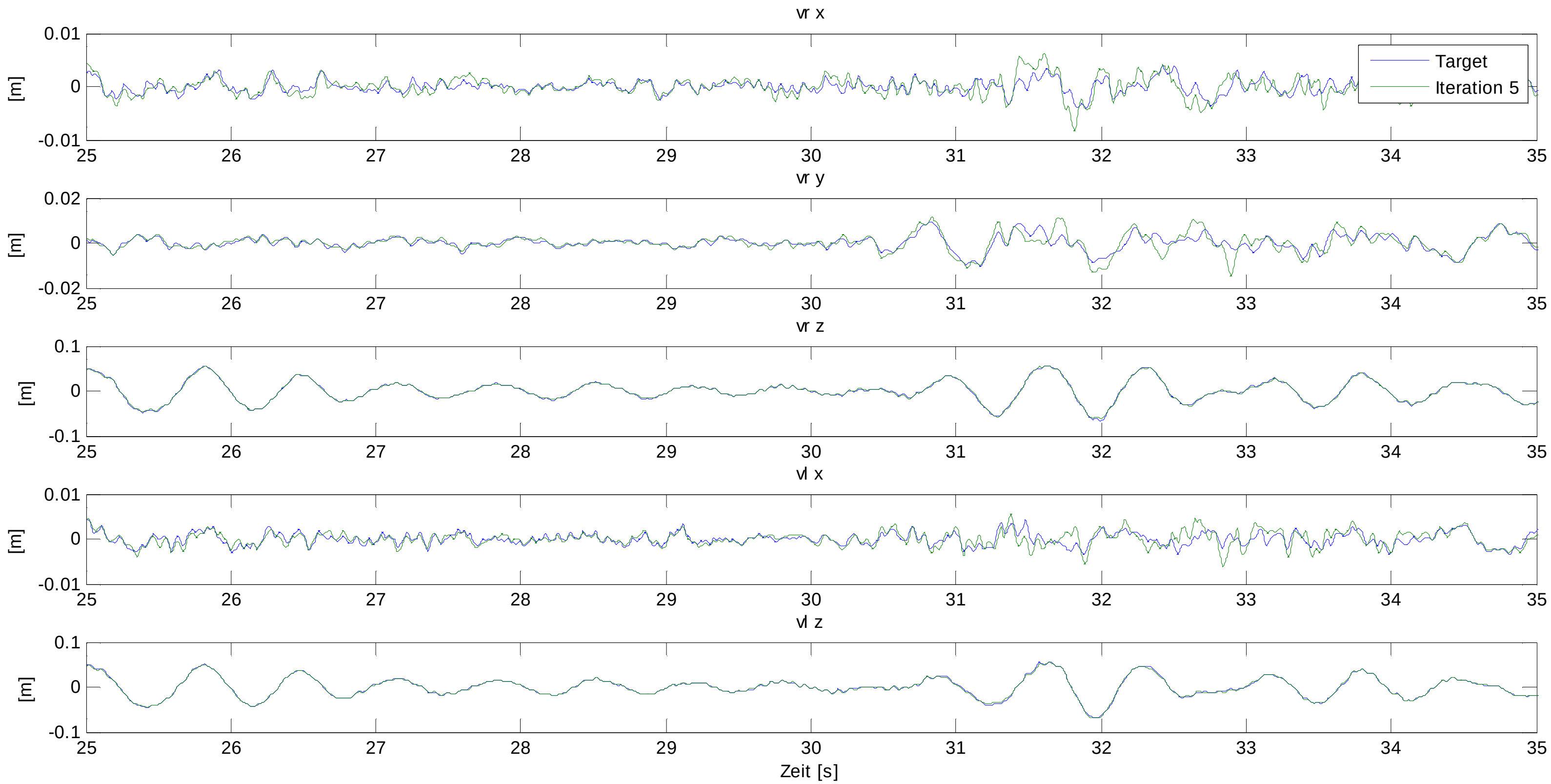
DAIMLER

Fraunhofer Institut Techno- und Wirtschaftsmathematik



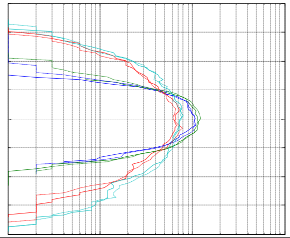
Back-calculation of drives
Results

Frame displacements (front side) after 5 iterations (detail)

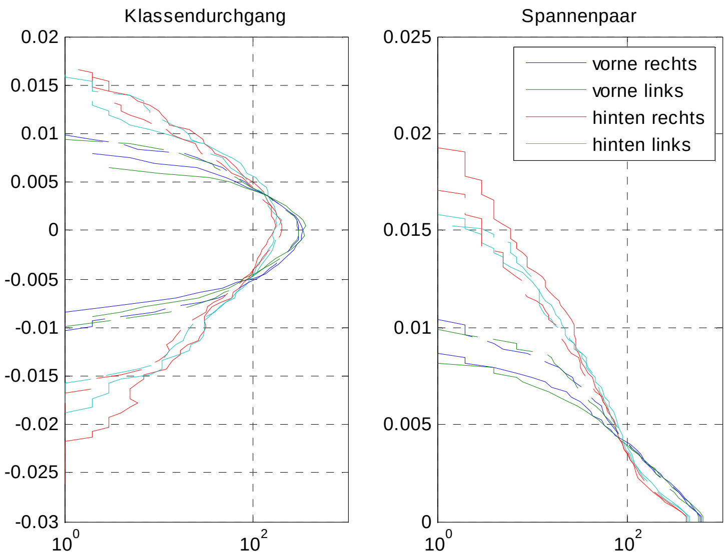


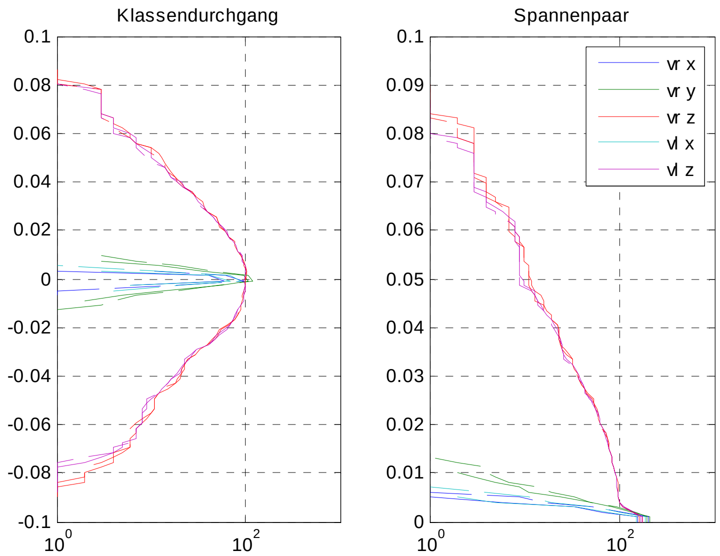
DAIMLER
Fraunhofer Institut Techno- und Wirtschaftsmathematik

Back-calculation of drives
Results

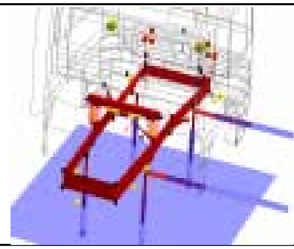


For durability testing, statistical properties of loads are often more relevant than time history…



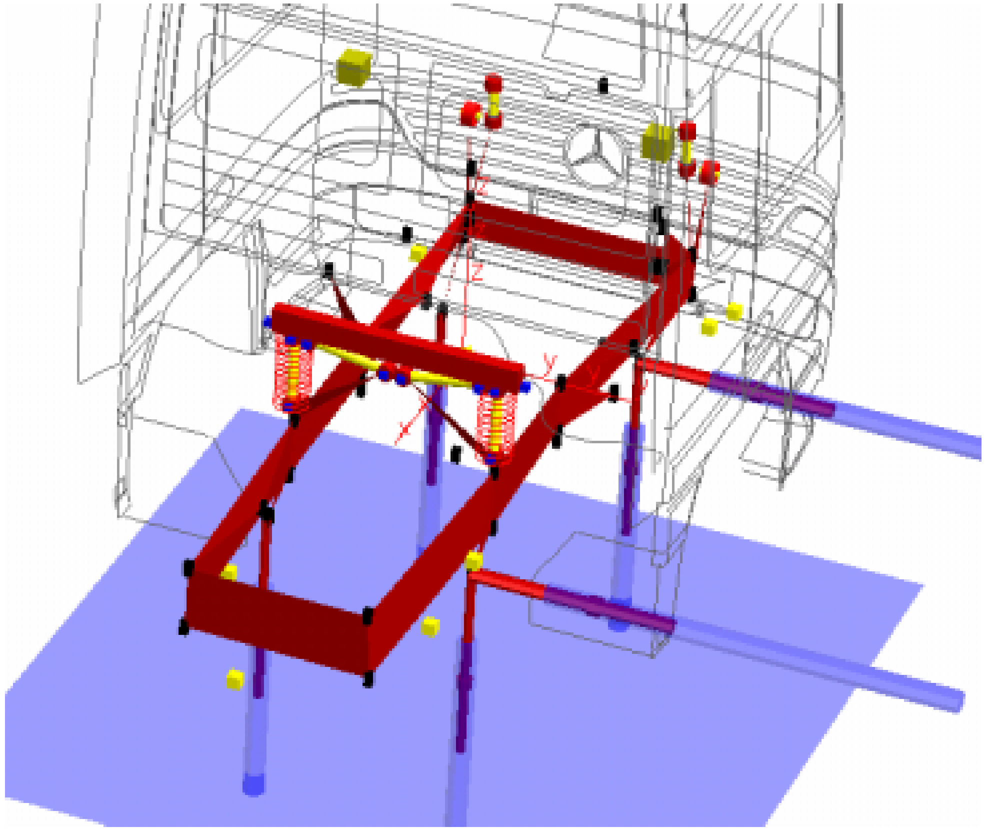


Relative displacements/frame displacements:
Target=solid line, Iteration 5=dashed line

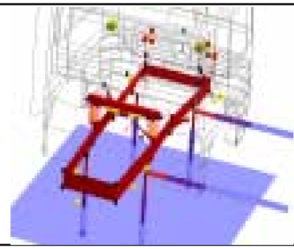


Prediction for new vehicle

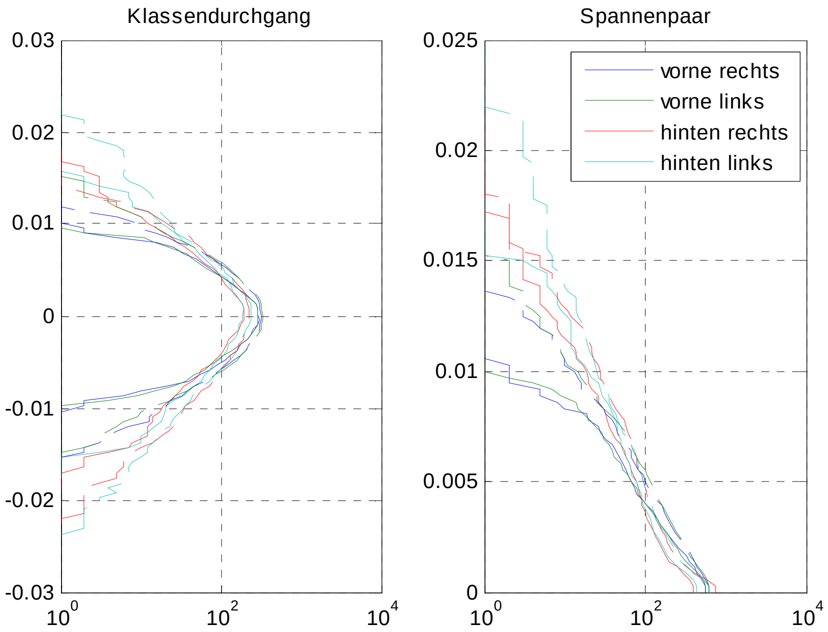
- New vehicle‘s frame is mounted on the test rig at different points than Axor (new vehicle=yellow cubes).
- The drives for the new vehicle are derived from the frame displacements at these mounting points. The elasticity of the frame has to be taken into account.
- Using these drives, cab accelerations etc. can then be computed for the new vehicle via MBS.
- Optionally, these drives can be used in a physical test rig.



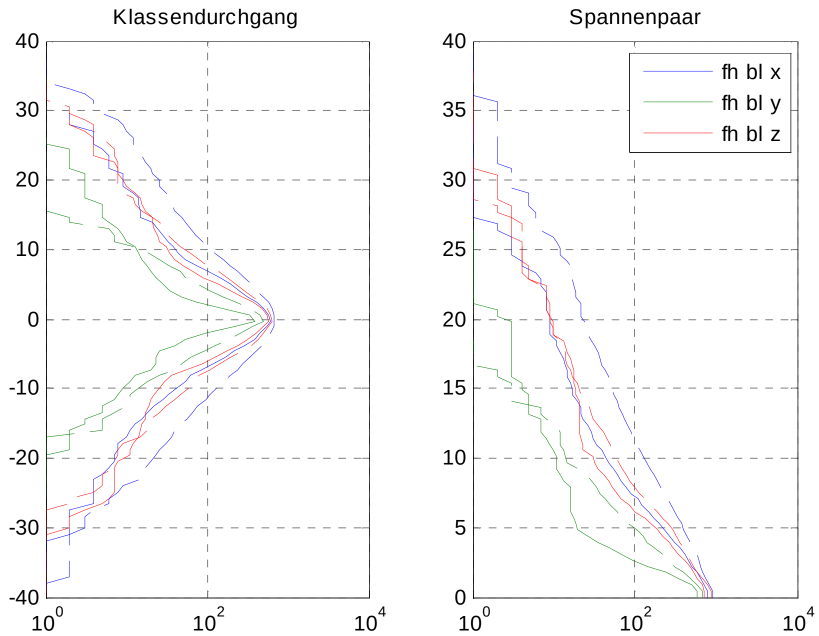
Prediction for new vehicle
Comparison of old and new targets



Relative displacements frame/cab:



Accelerations on the cab:



Axor=solid line, new vehicle=dashed line:

Significant differences due to different dynamical behaviour

Summary and conclusion

- The present methodology allows to determine load data for a new vehicle based on measurements on an existing, similar vehicle. „Hybrid road“ methodology is thus applicable to vehicles on test rigs, too.
- The choice of the interface which is assumed as invariant (i.e. same displacements for existing and new vehicle) depends on degree of similarity between both vehicles, accuracy of MBS models, acceptable compromise between modeling/simulation expense and result accuracy.

- Back-calculation (on Axor) has been carried out yielding a good agreement with measurements. Bump stop behavior is also simulated reasonably well.
- Measurements on the new vehicle should be carried out to verify assumptions regarding „invariance“ interface.

Back-calculation of drives
Co-simulation vs. offline-simulation

- Simpack-Matlab/Simulink Co-simulation
  - Easy to use
  - Higher computing costs due to online data exchange Simpack/Matlab
  - Has to be used if test rig controller/hydraulics are modeled in Matlab
- Offline-simulation
  - Matlab generates if2-file for rig cylinder input as well as num6-file for integration parameters
  - Simpack: Integration, measurements and export of results (option: matlab) take place successively
  - Matlab then reads the simulation results