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Virtual Load Case Definition for Off-Road Vehicles Based on Multibody System Simulation

ECS Simulation Conference 2023 Dynamic Simulation

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Motivation

Obtaining Full Vehicle Loads

Desired

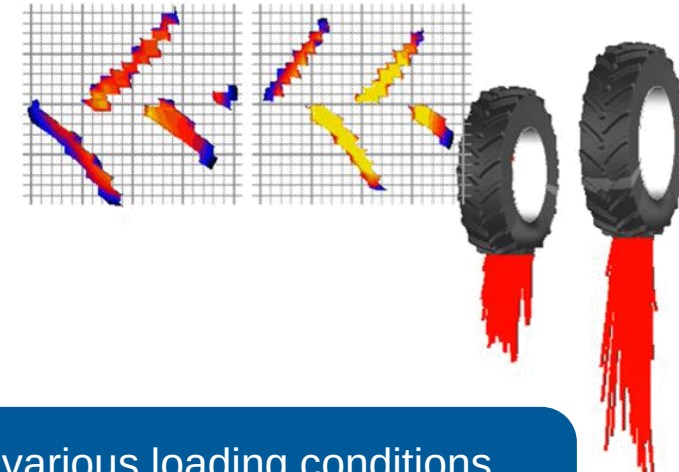
- Correct **dimensioning**, component selection
- **Lightweight**, but **safe** design
- Reduced development **cost** & **time**

Required

- **Load collectives** for virtual evaluation of design
- **Accurate**
- **Early** in development phase

Source

- a) Either **wheel hub loads** from measurements on **similar, existing vehicle (expensive)**
- b) Or **road profile** and accurate tire model to obtain loads from simulation
→ **FTire**



- More applicable for tractors due to various loading conditions (front/rear implements, front loader, ballasts, etc.)
- Harder to obtain, especially FTire parameters for tractor tires

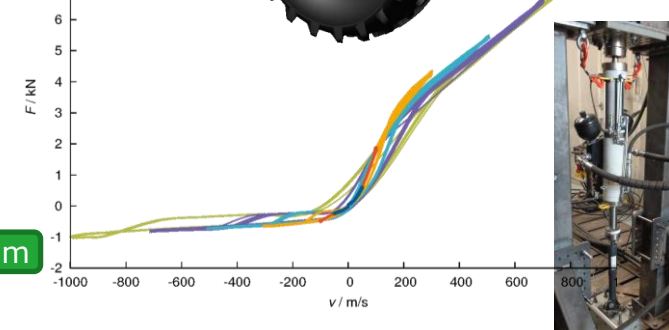


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Tractor Vehicle MultiBody System (VMBS)

Empty and ballasted tractor



90 mm x 220 mm

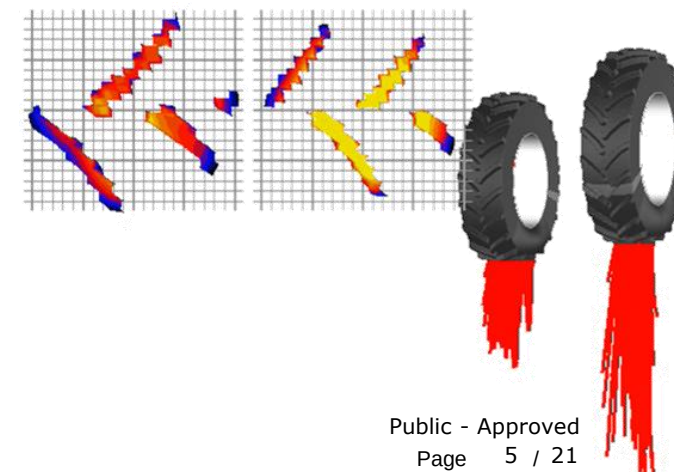


60 mm x 165 mm



47 mm x 190 mm

3 different obstacles,
traversed several
times with 3 different
velocities



VMBS Model for FTire Fine-Tuning

- **Rigid** bodies
 - Chassis frame
 - Rigid (pendulum) axle
 - Cabin
 - Implements
- Initially no flexible parts (Craig-Bampton) necessary
- **Springs and dampers** with linear and nonlinear characteristics (cabin, front/rear hitches)
- Different **ballasting** situations
- Front and rear **tire models** (FTire)
 - Initial guess for 2 tractor tires from company cosin, based on tire manufacturer data
 - **Fine-tuning** of tire parameters via comparison to measurements during traversing of cleat obstacles (tire test rigs for tractor tires hardly available)

Fine-Tuning of FTire Parameters

- 10 main parameters were varied
- Main focus (time signals during cleat traversing and Fourier spectrum):
 - Vertical accelerations near wheel hubs
 - Vehicle speed



Sensor measurement signals for front/rear left wheel hubs compared to simulated accelerations

Initial guess from cosin

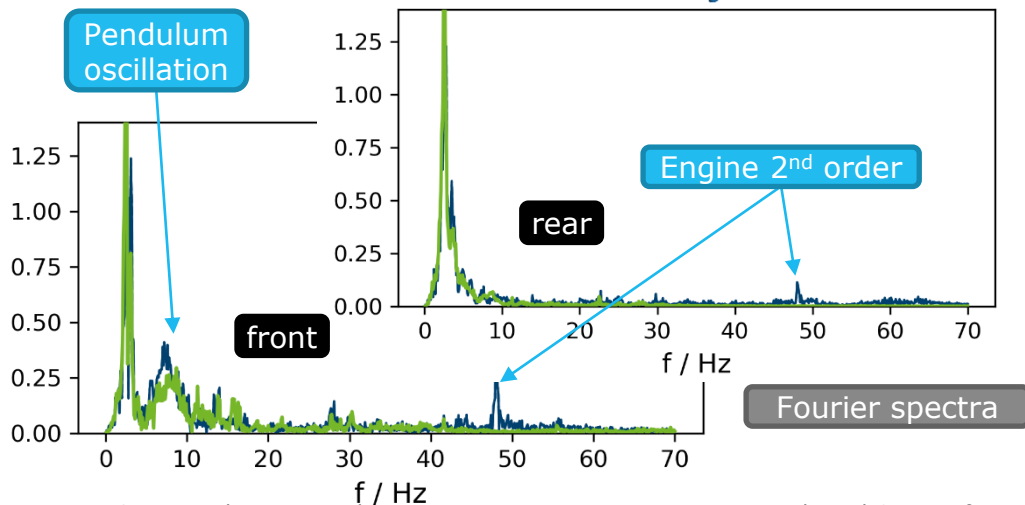
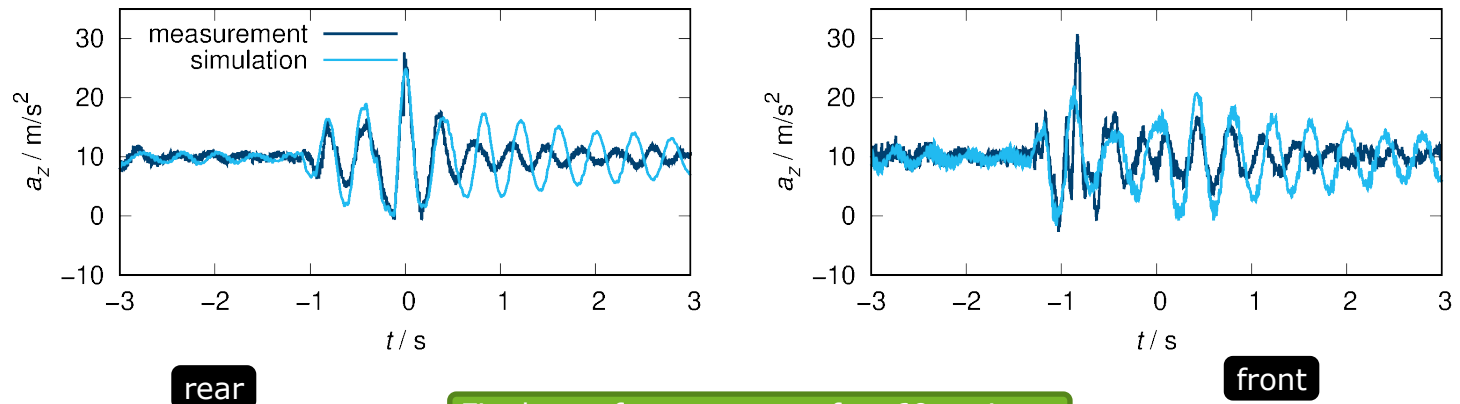


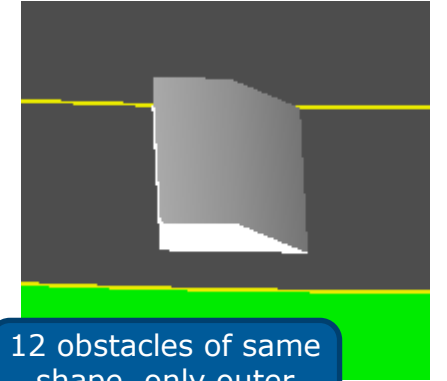
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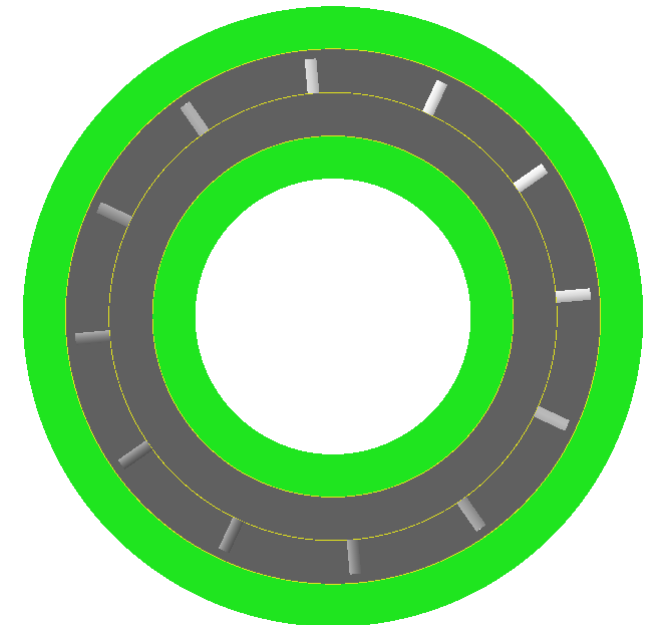
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Validation on Basis of the Merry-Go-Round

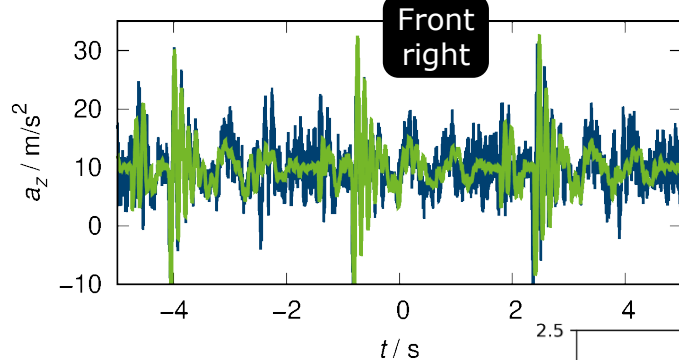
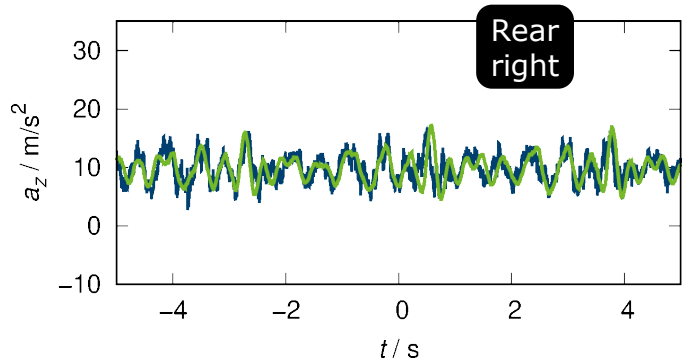
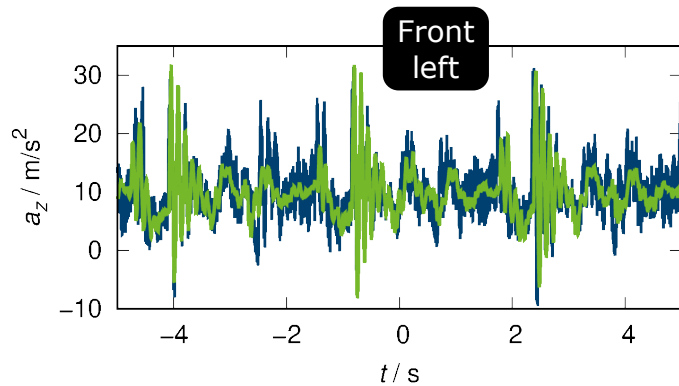
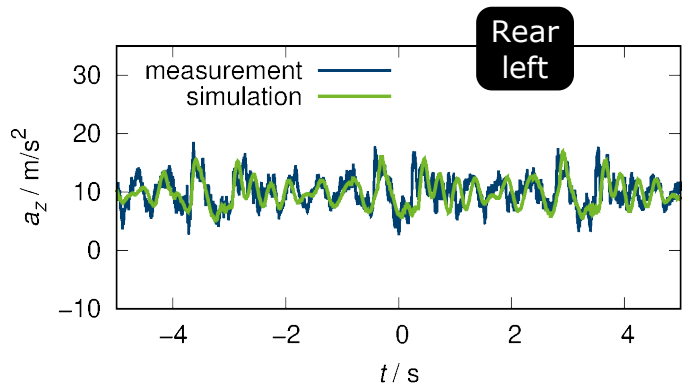
- Some features of **the tractor model** had to be added to **respect asymmetry** (rear differential, lateral stabilizers of rear hitch)
- **FTire** parameters **unchanged**



12 obstacles of same shape, only outer wheels traversing it

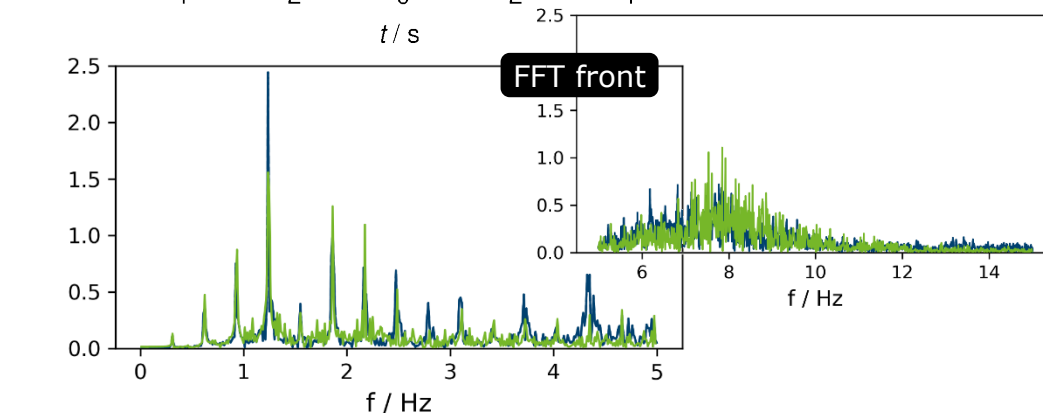
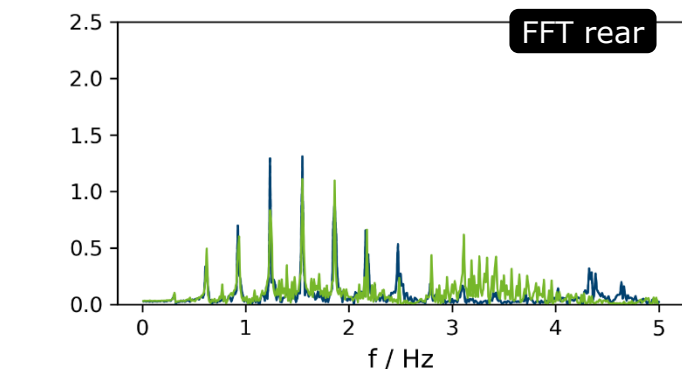


Validation on Basis of the Merry-Go-Round Comparison of Simulation with Measurement Data

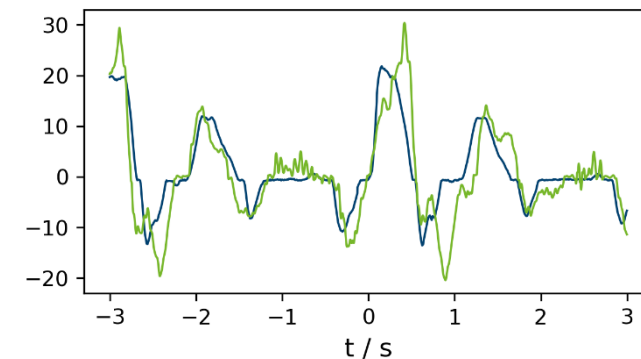


Large peaks
(important for
durability)
reproduced

Spectra
reproduced



Further example:
Rear hitch (left) stabilizer
force in kN



Estimated clearance
 $\approx 22 \mu\text{m}$

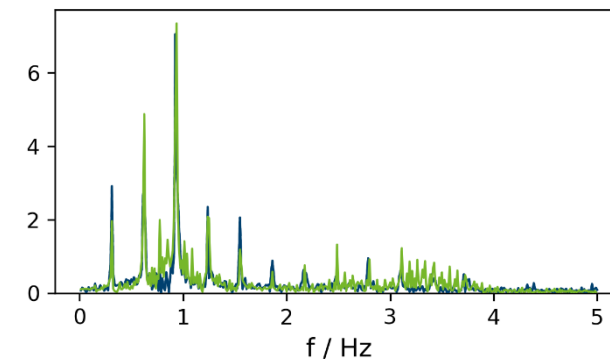


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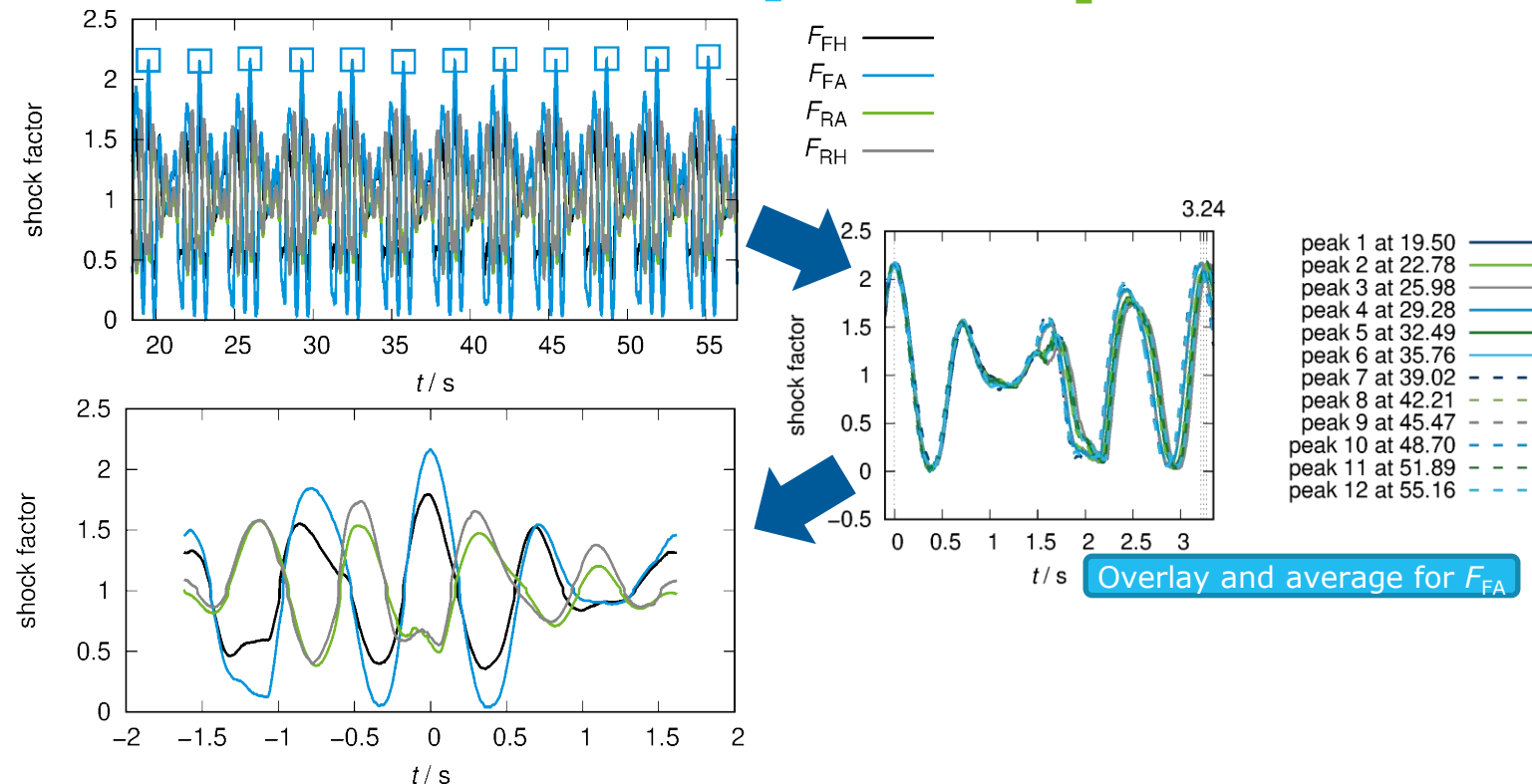
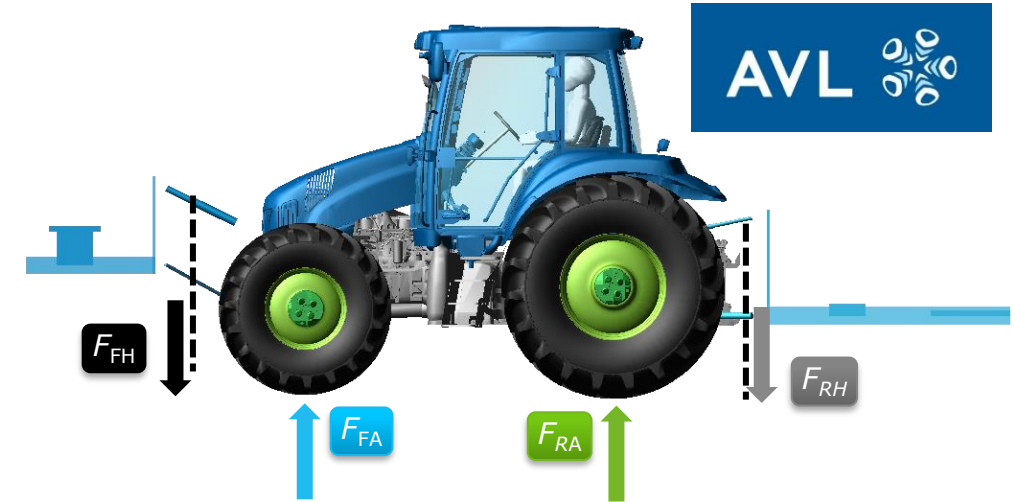
Periodic Load Creating Representative Cycle

- Estimate main contributions:

- Front axle load F_{FA}
- Rear axle load F_{RA}
- Vertical force from front hitch F_{FH}
- Vertical force from rear hitch F_{RH}

Note: if a specific component (e.g.: gearbox) is of special interest, cut loads at this component are to be used → "Marker Method", see Fuchs and Pauschenwein, ATZ heavy duty 02/2019, 52, [LINK]

- (Use shock factors for better combined visualization)
- Identify periodicity in these signals from the Merry-Go-Round simulation
- Overlay and average
- Plot curves for all main contributions together

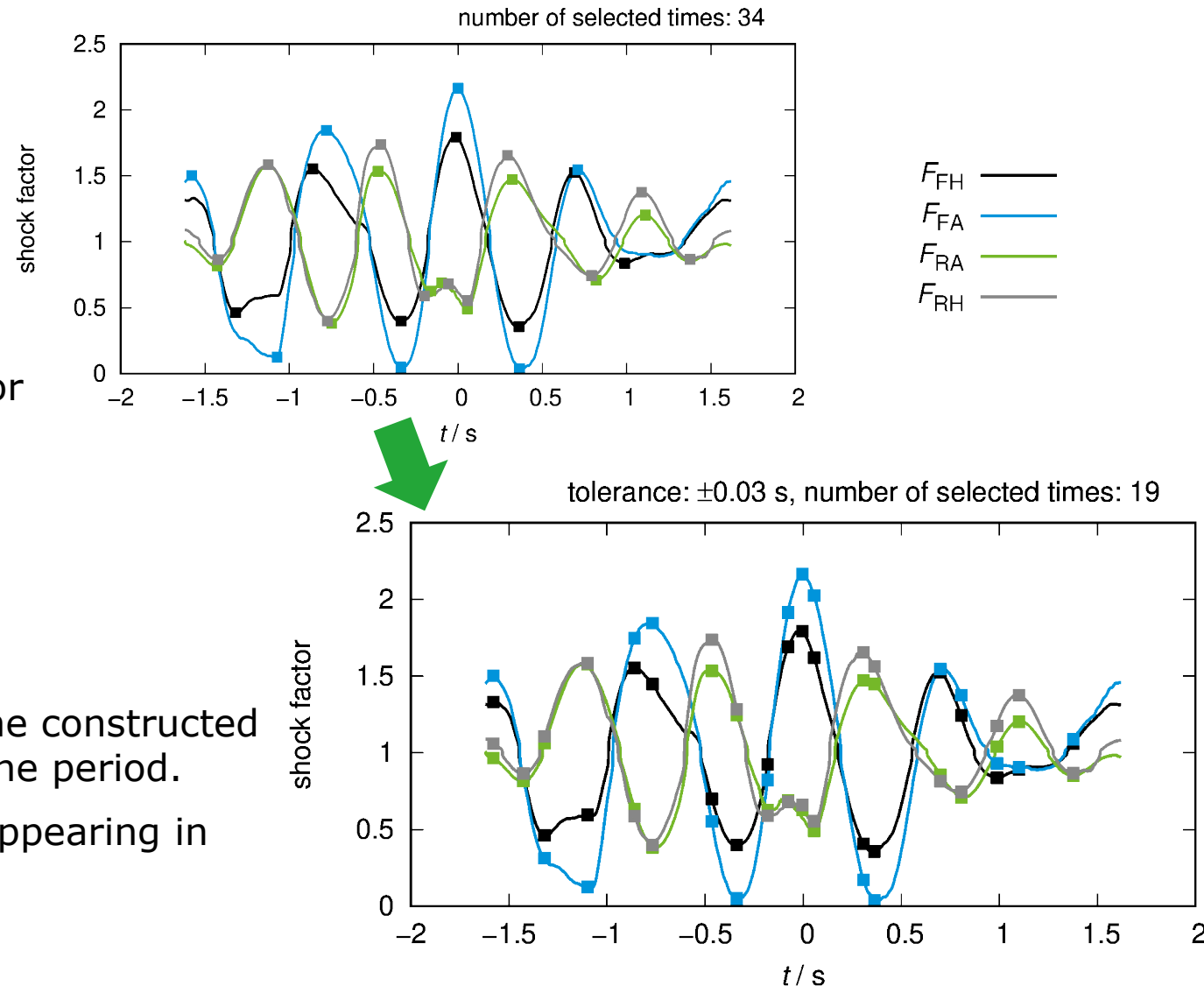


Periodic Load

Deriving Loads for Durability and FEA



- Identifying all local maxima and minima for all 4 dominant loads (→34)
- Combine time points which lie close to each other (→19)
- For each final time point – for the part of interest (e.g.: beam) – extract the loads onto the part (e.g.: the forces in the cabin suspension, individual wheel hub loads, etc.) for the selected time points, with the condition:
 - If a local extremum is close-by use this value, otherwise use the value at the time point
- Apply the loads to the FE model (inertia relief)
- Perform a Femfat TRANS MAX calculation for the constructed representative cycle to obtain the damage of one period.
- Multiply the damage by the number of cycles appearing in the whole MGR parkours



Periodic Load FEA for Testbed Conditions

On a simple hydraulic testbed, dynamic conditions (accelerations) are difficult to reproduce and/or limit the quickening of load cycles.

- 3 hydraulic cylinders available
- Focus on front chassis →
- Forces adjusted to reproduce vertical loads at front axle (FA), front hitch (FH), and rear axle (RA) exactly.
- For rear hitch (RH) small deviations are accepted

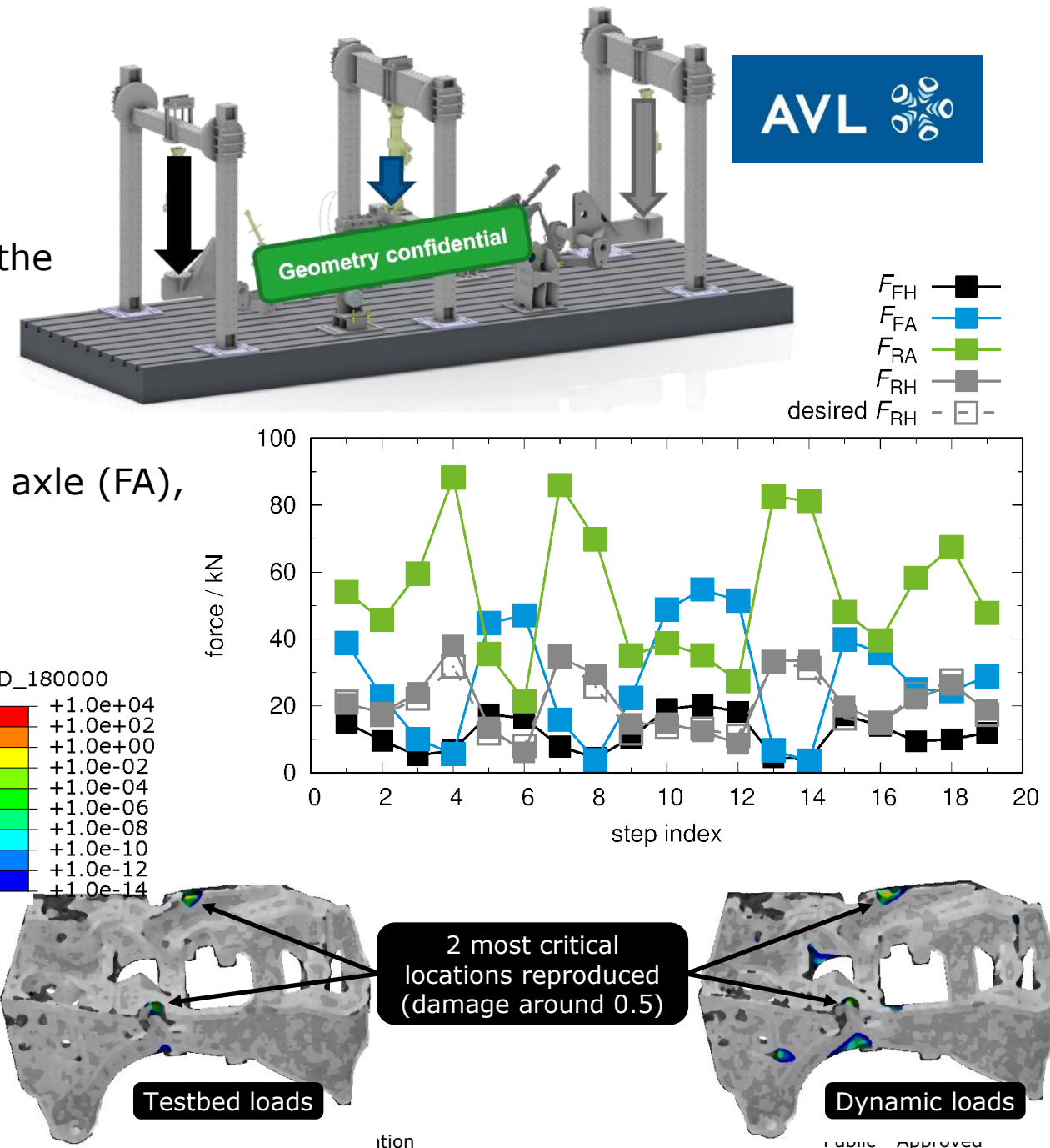
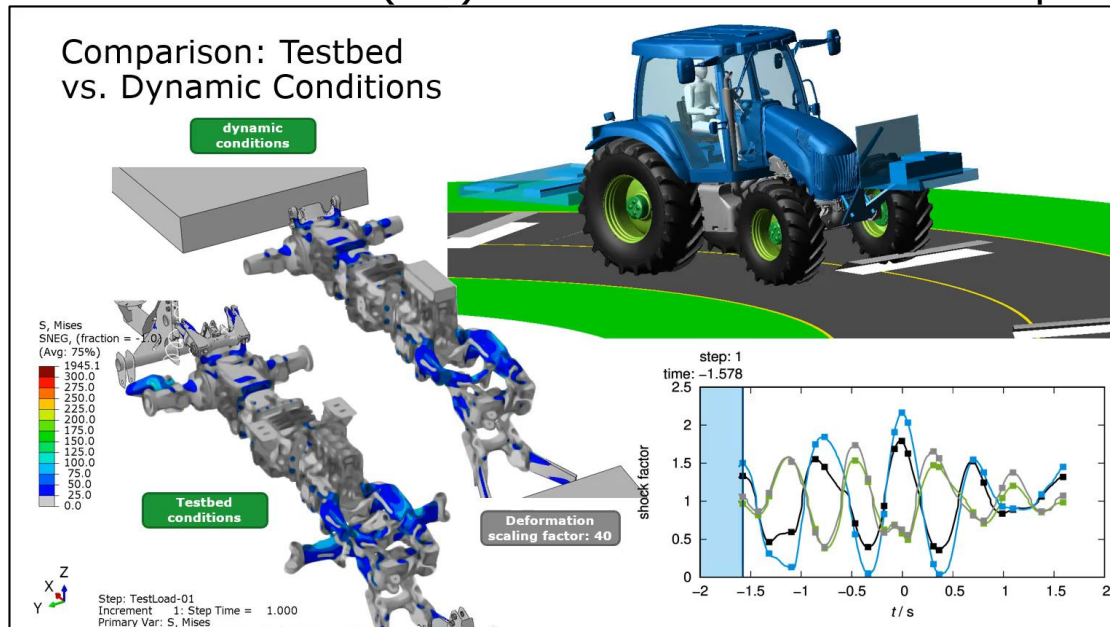


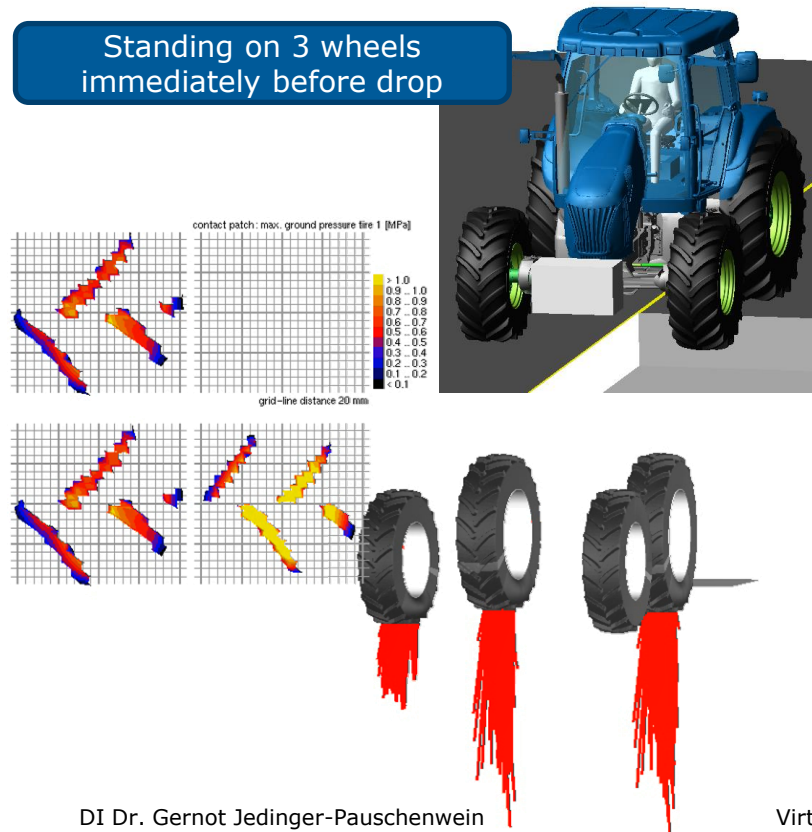
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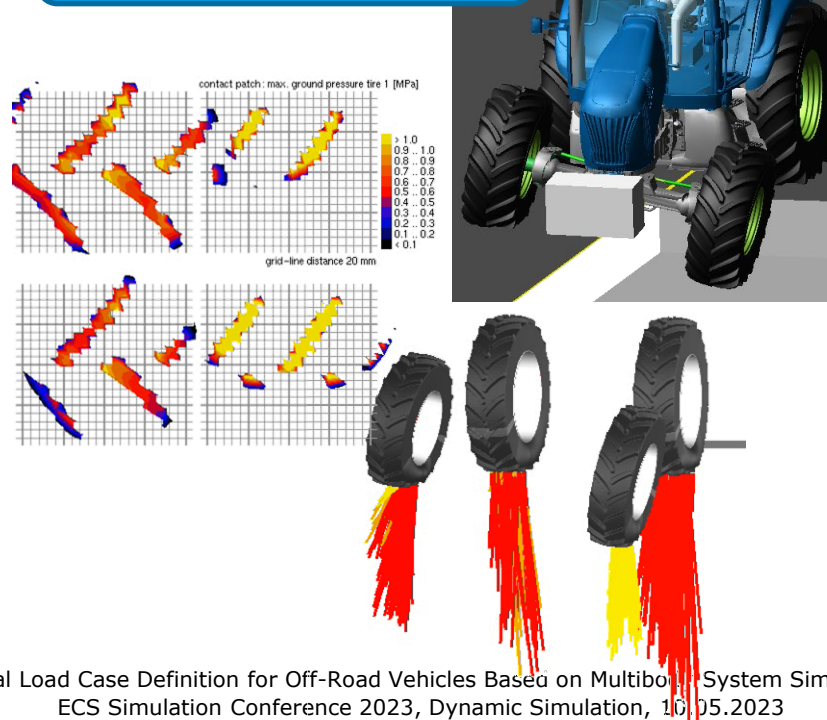
Singular Event – Pendulum Impact Description

- The tractor breaks into a big hole in the ground with one front wheel
- Pendulum axle hits stop blocks
- Tractor tilts forward (due to chosen ballasting)

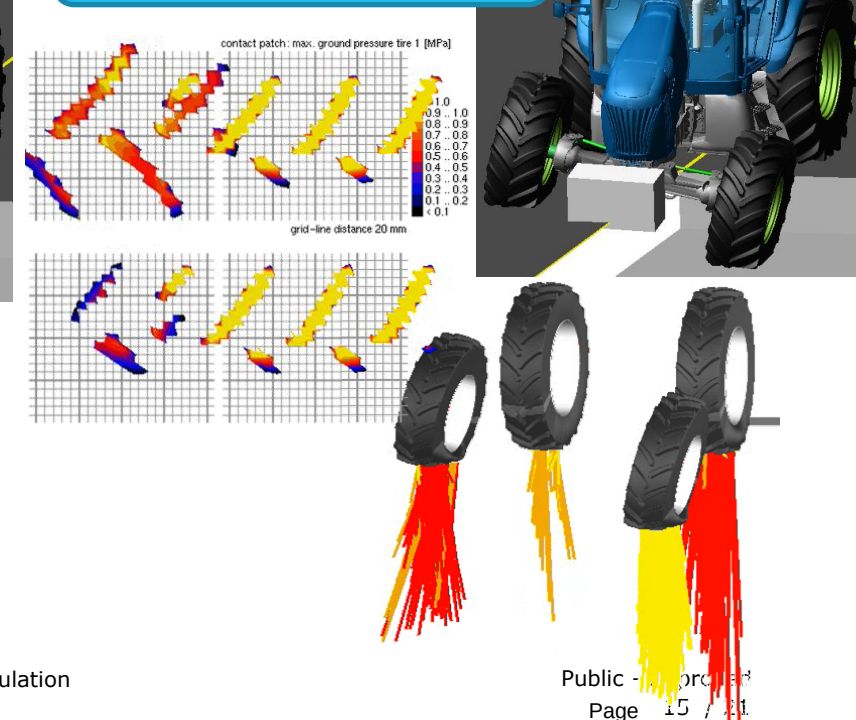
Standing on 3 wheels immediately before drop



Maximum torque at front chassis: left wheel just starts to develop contact



Maximum force at right wheel: Contact on left wheel also well established



Singular Event – Pendulum Impact Finite Element Analysis

- Global model without front axle and wheels
- Loads at $t=15.3006$ s at boundary points (see image) & inertia relief
- FEMFAT Damage analysis → critical
- Contact/sleeve evaluation → critical
- → include elastic element
- Testbed: 3 cylinders to reproduce torques at front chassis & engine flanges (to respect inertia effects correctly)

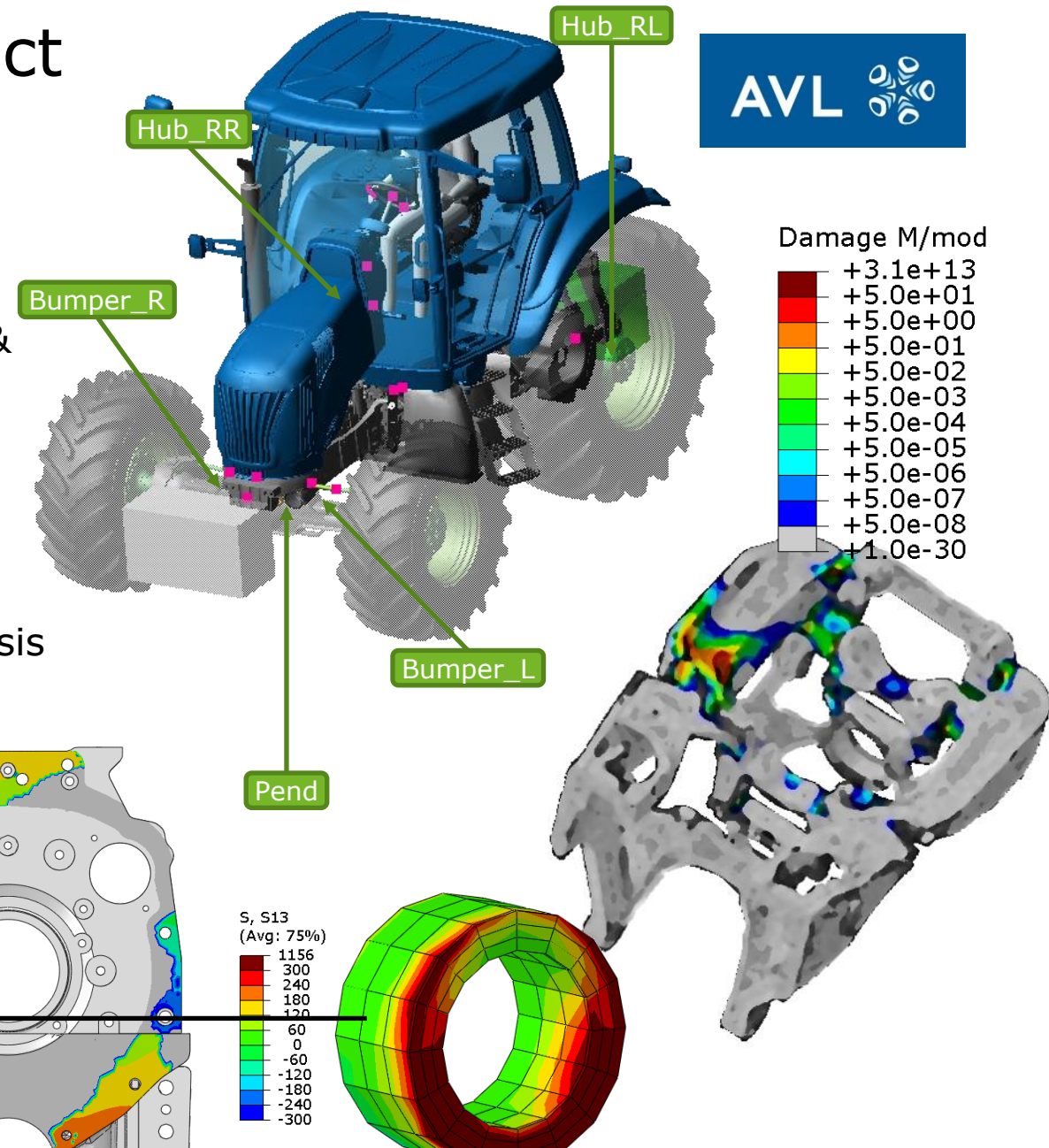
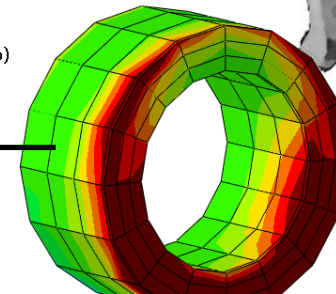
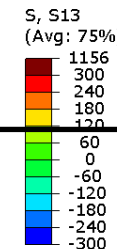
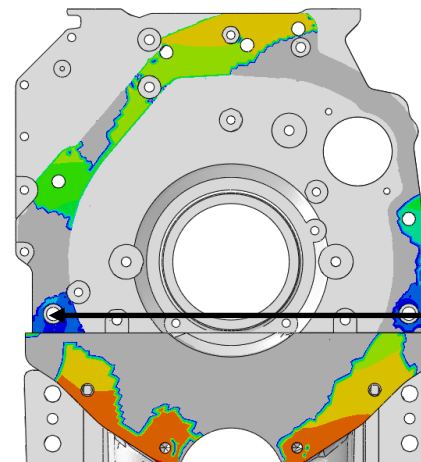
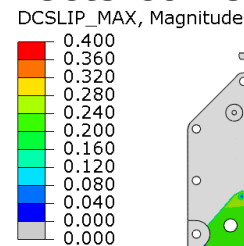
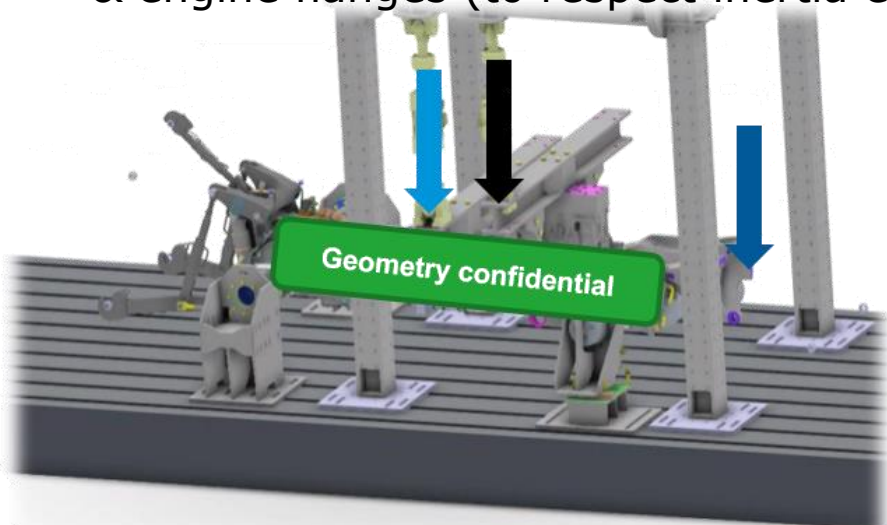


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Sketch of Random Load Evaluation

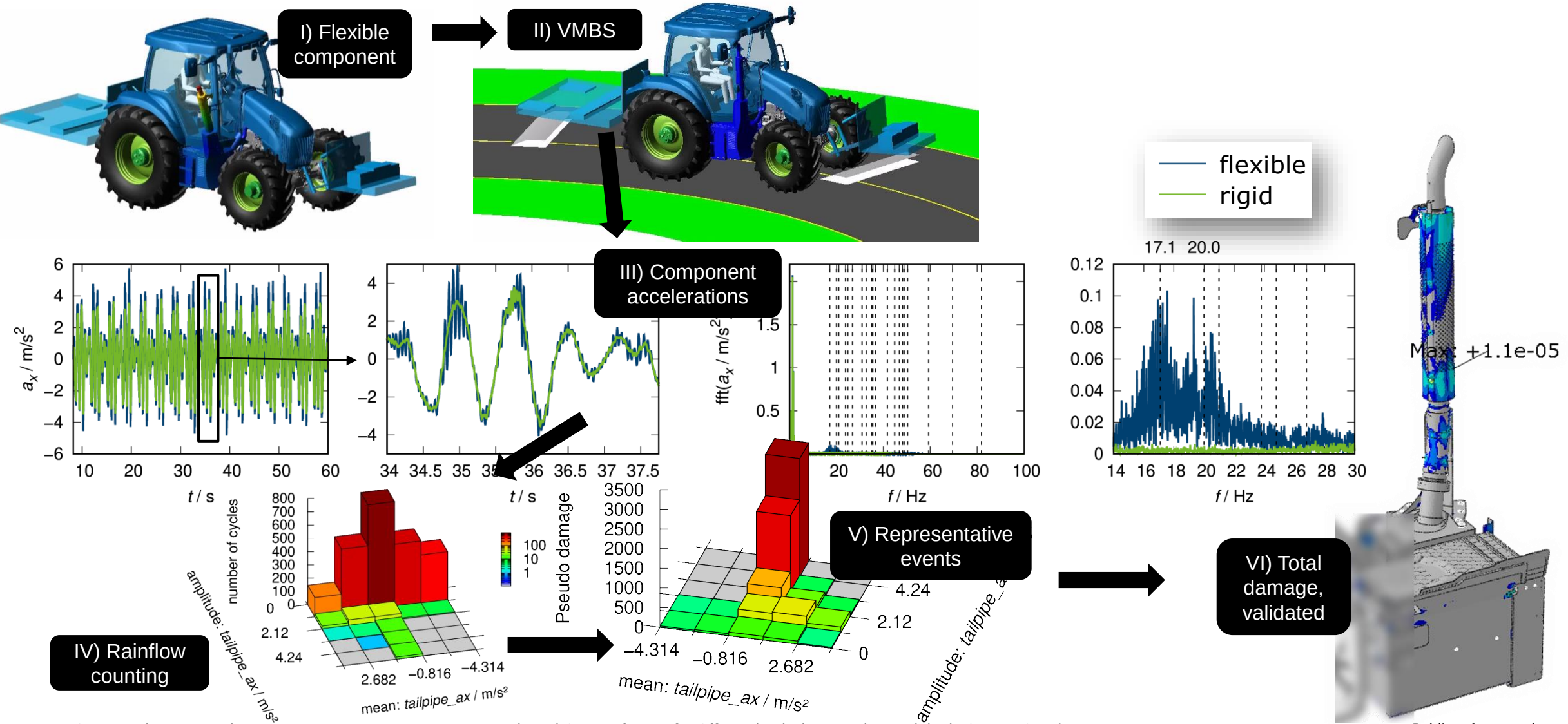


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Summary and Conclusions

- A **method** has been developed to determine
 - reliable **FTire** tire **parameters**
 - for **tractor** tires
 - **without a tire test-rig**, based on acceleration measurements during traversing cleat obstacles
- The method has been **validated** by means of a Merry-Go-Round test track
- The validated model has been used to derive **durability loads** for three different kinds of load cases:
 - **Periodic** loads onto the complete vehicle from the **Merry-Go-Round** track
 - Conditions during the **singular event** of a severe **pendulum impact**
 - A **statistically evaluated load collective** for dynamic loads of flexible tractor attachments



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Thank you for your attention!