MAGNA

FEMFAT TOOL ELASTOLOADS

In Co-Simulation with Abaqus

Fatigue Strength Analysis of Commercial Vehicle Engine Mounts

Contents

Introduction

- **Task of engine mounts:**
  - Absorption of loads caused by operation of the engine and by excitation from the road surface
  - Vibration isolation and damping

- **Large Displacements** have to be withstood

- The necessary elasticity can be obtained by using elastomeric mounts with often very **complex geometries.**

- Therefore **fatigue strength** of engine mounts **is very important** and should be considered in an early design phase before the first prototypes are built.

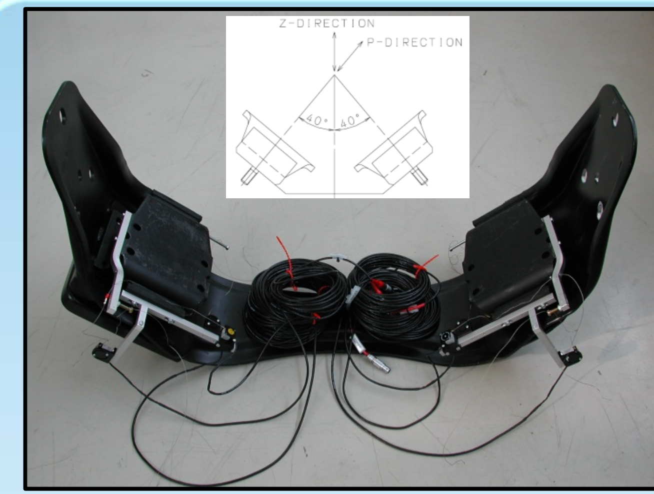
Introduction

Initial situation

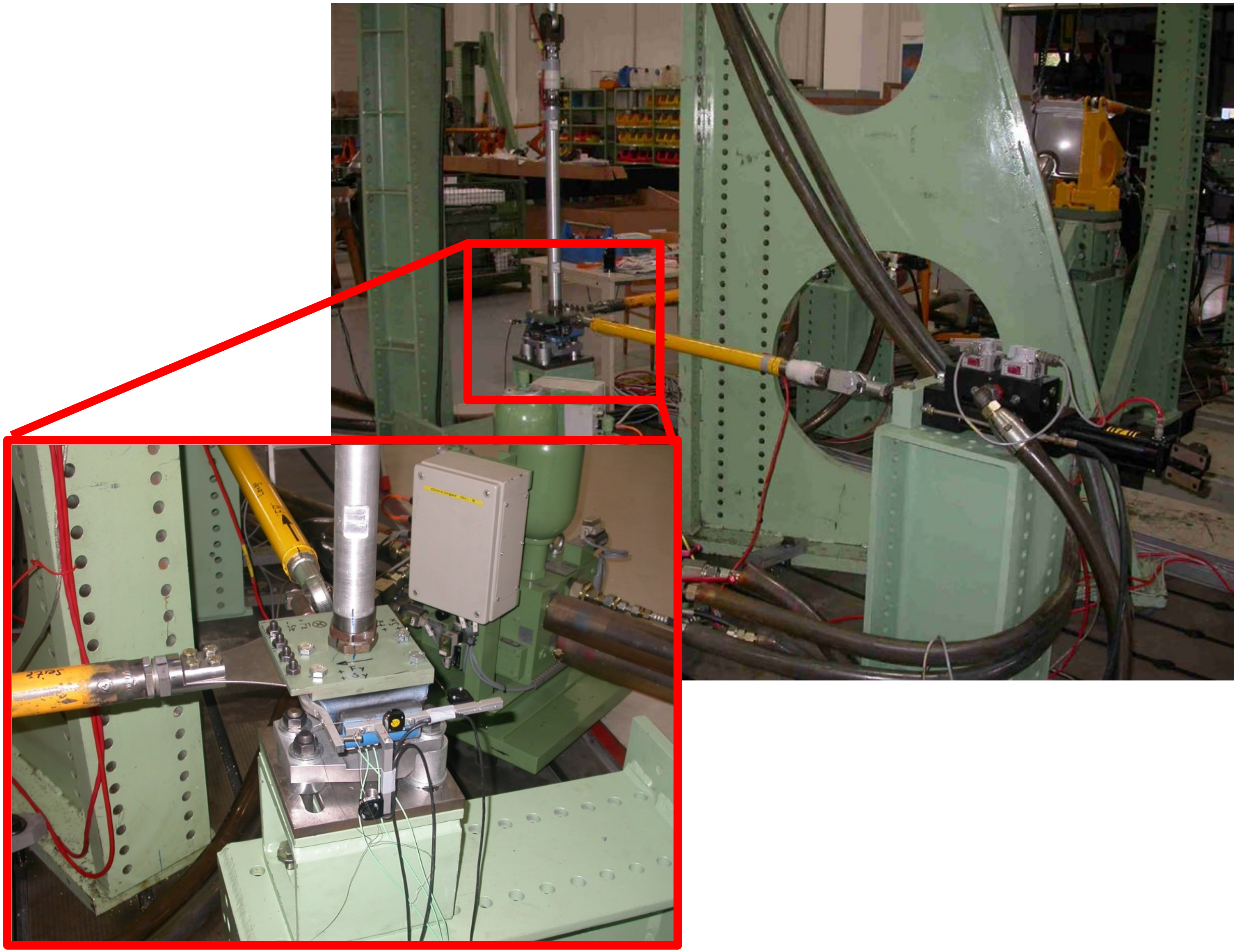
- Estimation of vibration fatigue based on single FEM simulations.
- Tasks:
  - What is the critical load cases?
  - Considering nonlinearities: material model, big displacements, contact and folds.

Objective

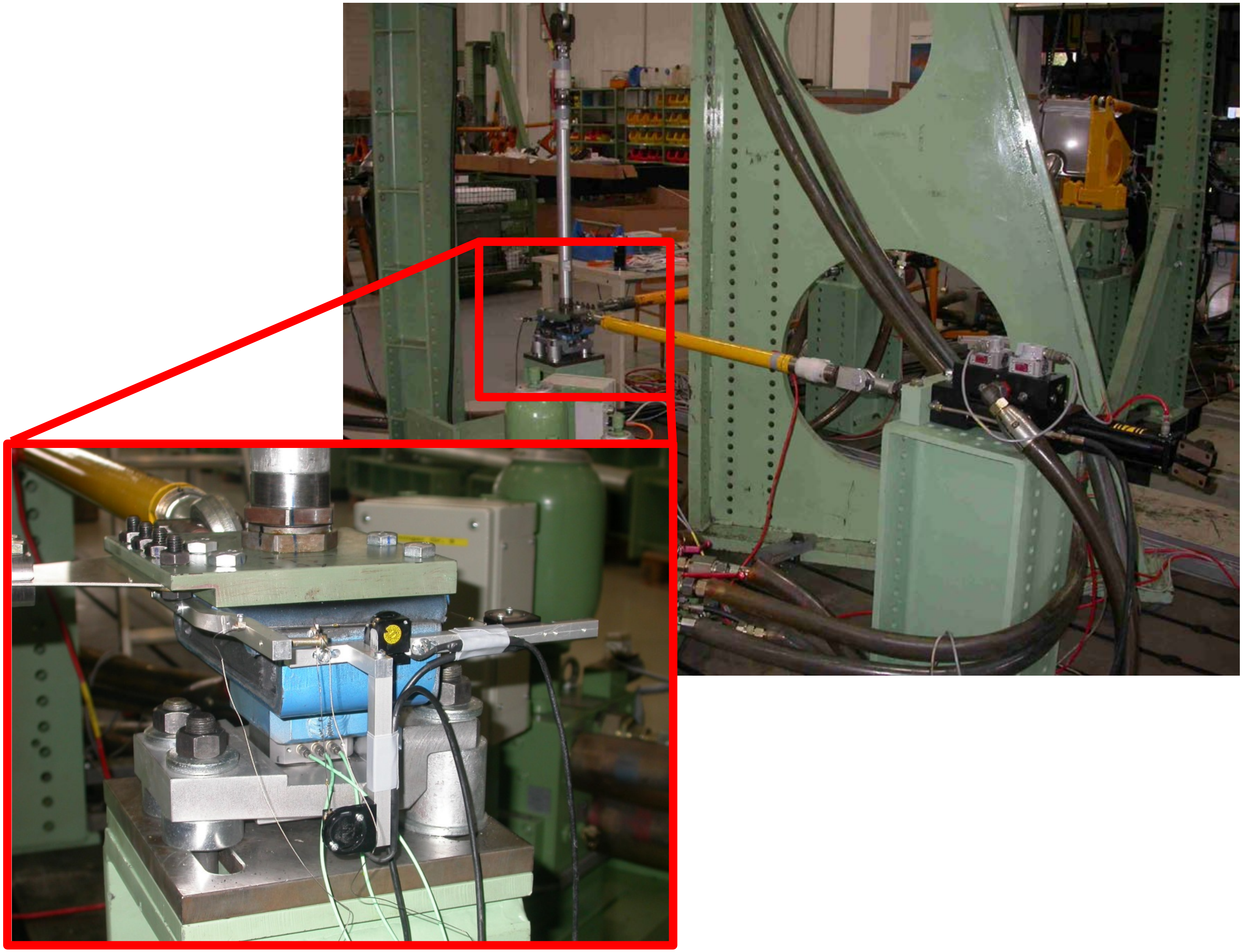
- Simulation Method which allows
  - the **assessment of vibration strength** of engine mounts
  - based on **n-dimensional-component loads**
  - **in an early development phase**
  - for meaningful results before the first prototypes have been built.



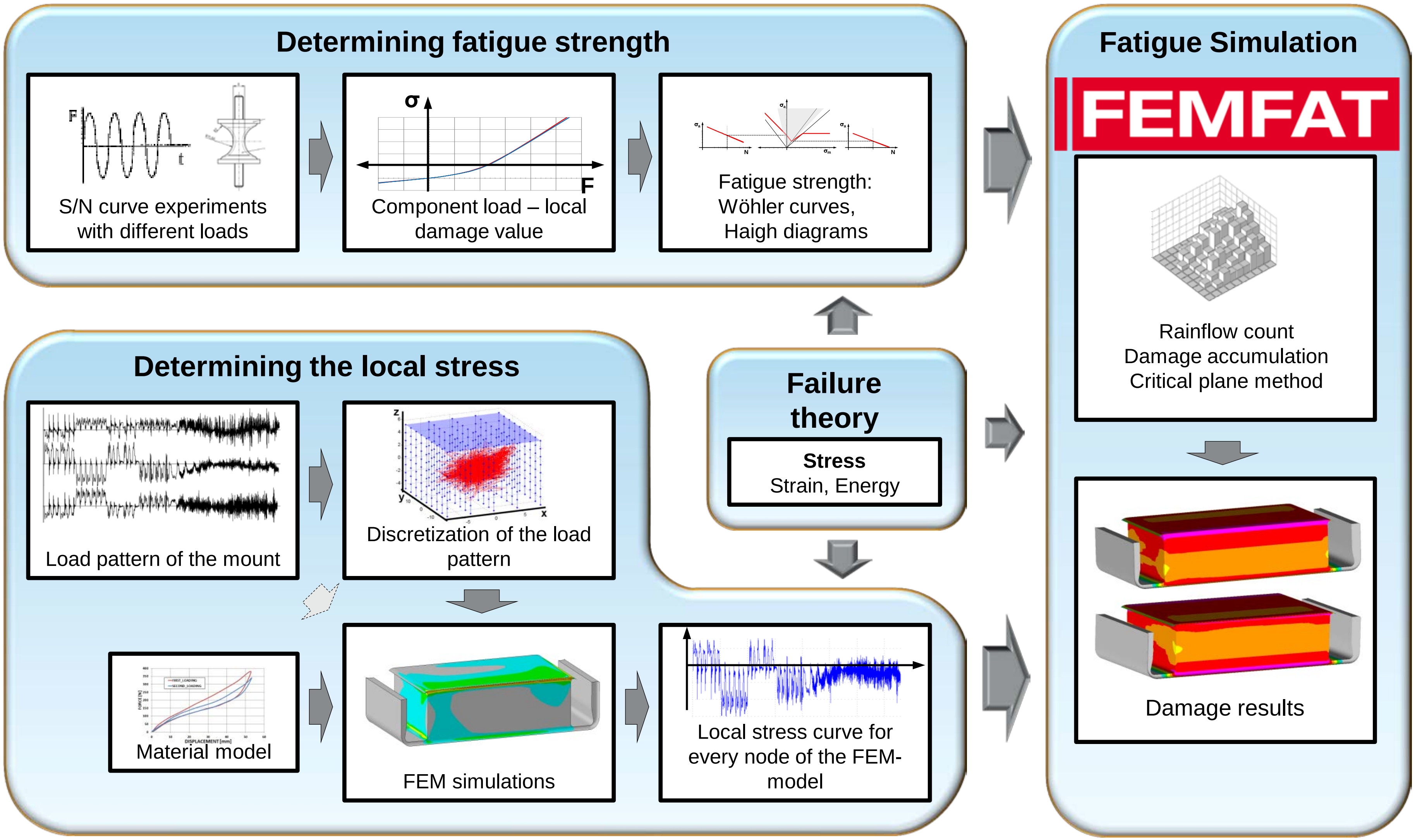
Testbench 3 Channel-Loading



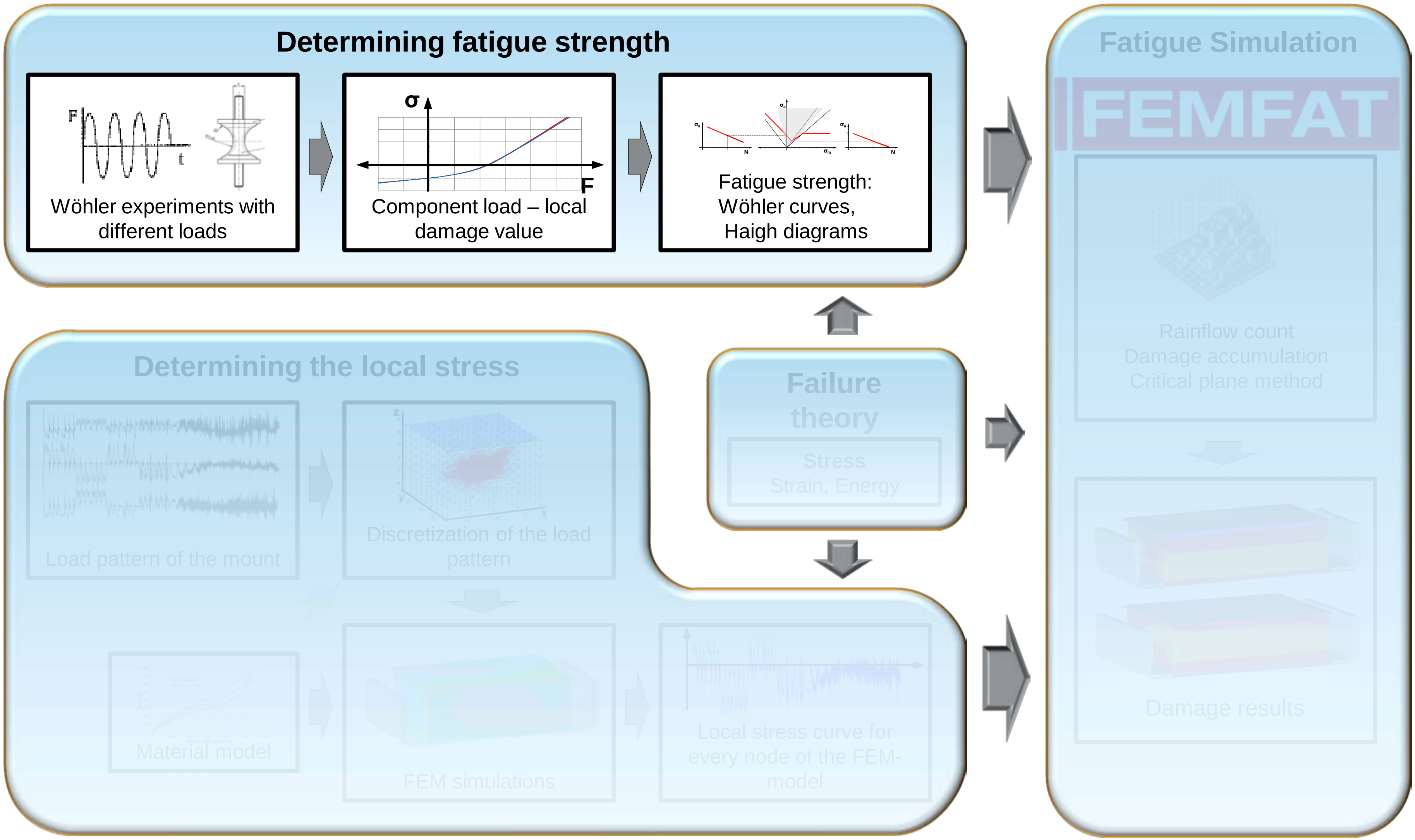
Testbench 3 Channel-Loading



Fatigue simulation method

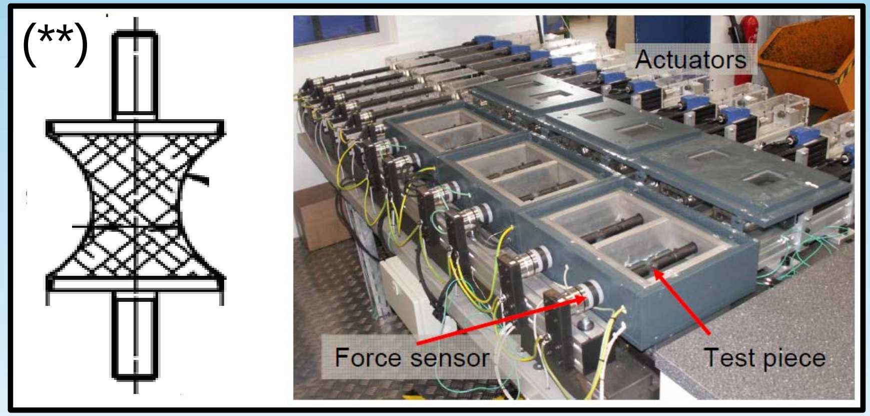


Fatigue simulation method

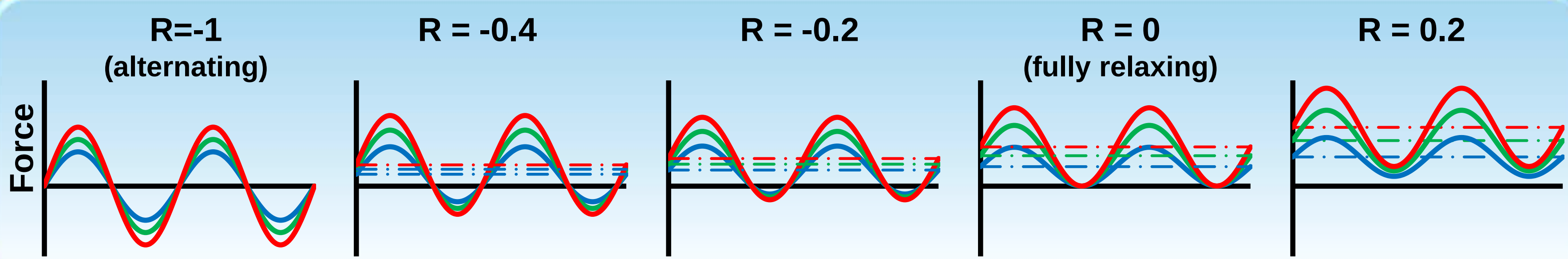


Determining fatigue strength

- **Material from literature* was used**
  - No specimen fatigue data for this engine mount material available
- **Loads from literature***
  - Several constant load amplitudes with different R-ratios tested
  - 33 tests with constant amplitude
  - At least 2 specimens per load level
- **Haigh Diagram for 1E5 LC was used for the NR material**

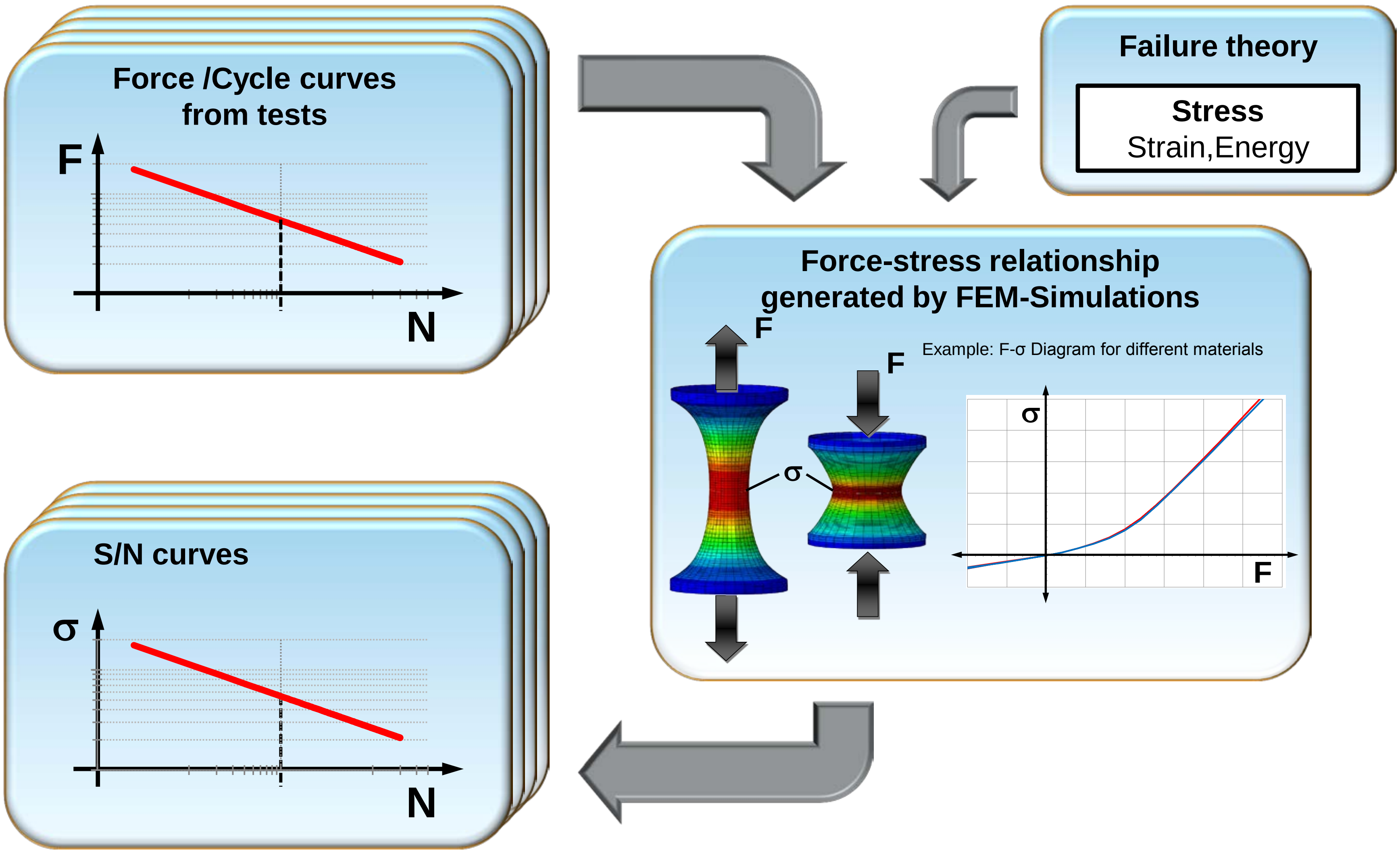


- Hourglass test samples
- Signal: Force-controlled-signal
- Load cycles until failure are counted

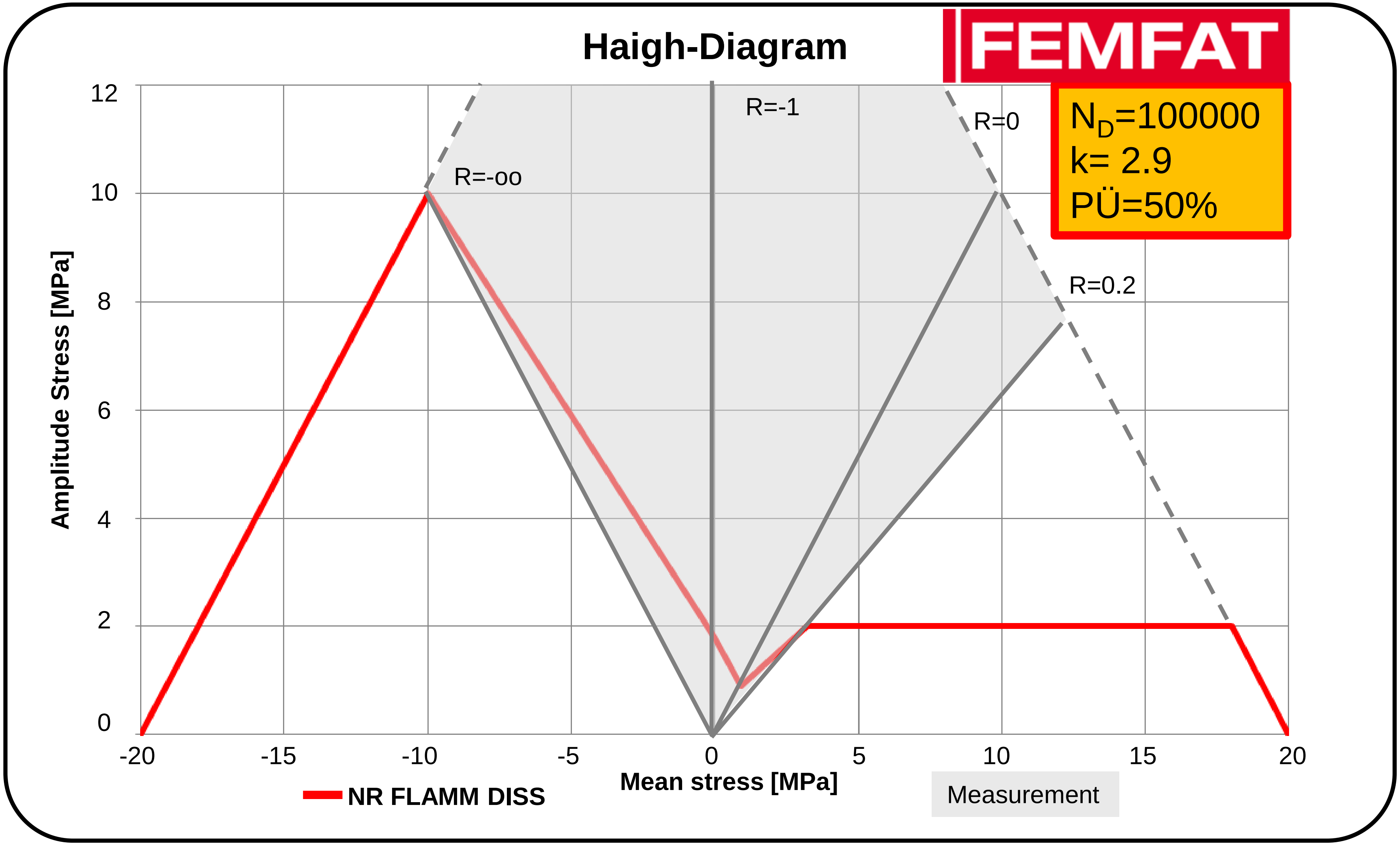


* Steinweger, T., Weltin, U., Flamm, M.: Four tests to characterize a Haigh-diagram for damage calculations. In: Austrell, P.-E. (Hg.): Constitutive models for rubber IV. Proceedings of the 4th European Conference on Constitutive Models for Rubber, ECCMR 2005, Stockholm, Sweden, 27 - 29 June 2005. Leiden: Balkema, S. 9–14.
** *Duisen, F.:* Angewandte Betriebsfestigkeitsberechnungen an ein- und zweiachsig belasteten Fahrwerkslagern. In: Bruder, T. (Hg.): DVM-Bericht 676. DVM-Tag 2009, S. 89–101

Determining fatigue strength
Force-stress relationship

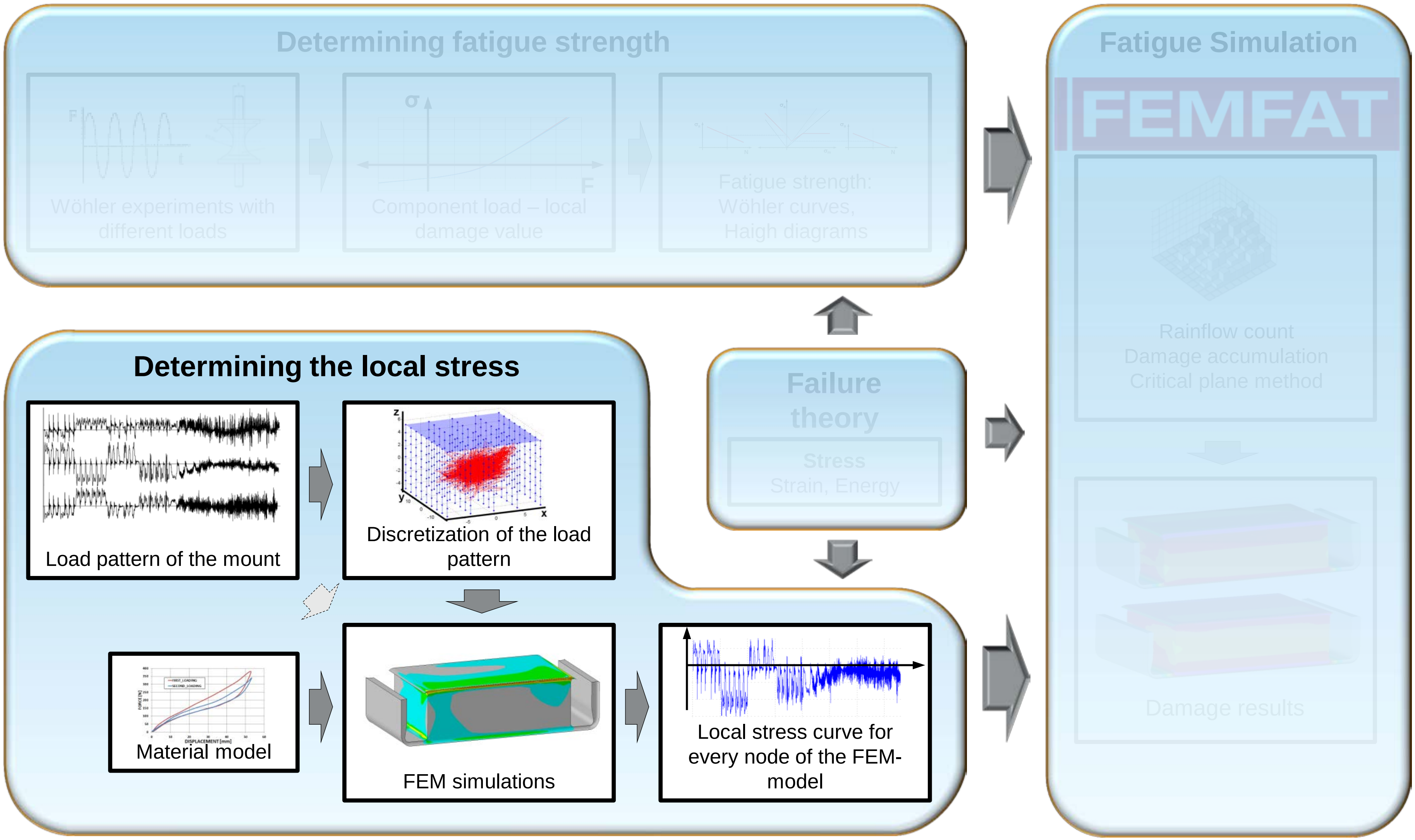


Determining fatigue strength
Haigh-Diagram

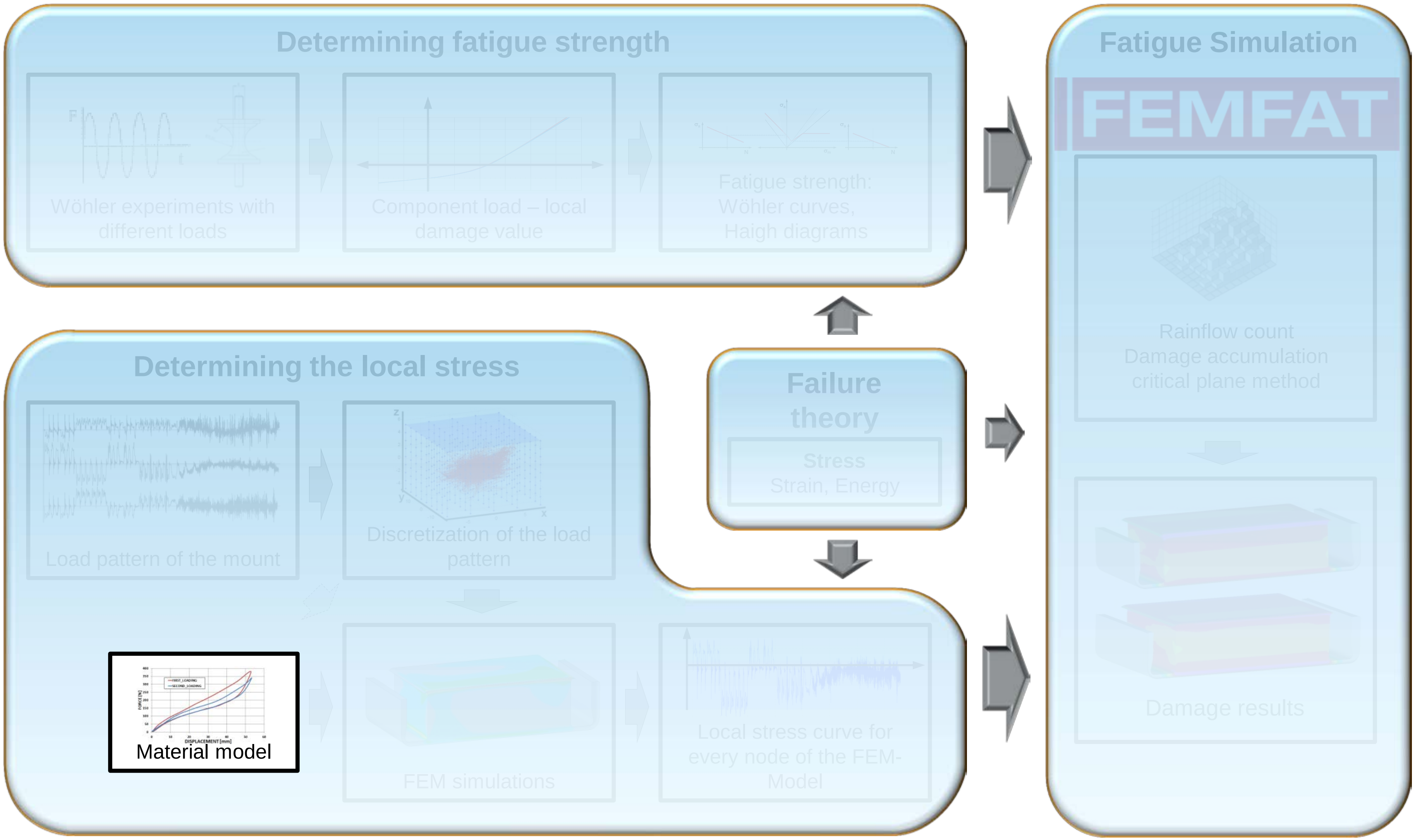


Haigh-Diagramm construction acc. Phd: Stefan Kaindl: Simulation der Schwingfestigkeit von Elastomerbauteilen 2014

Fatigue simulation method



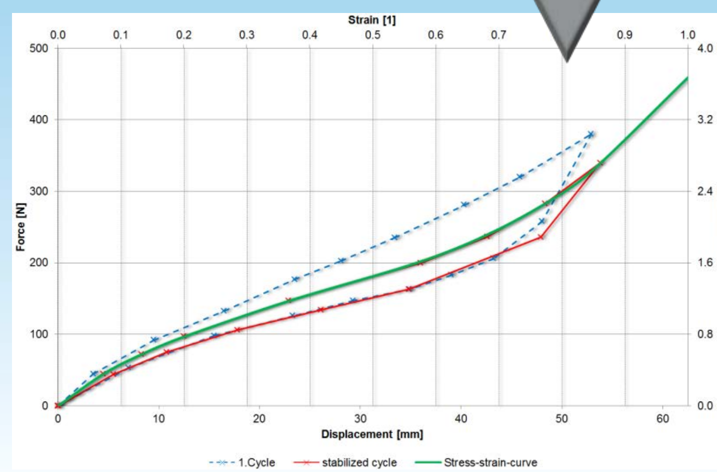
Fatigue simulation method

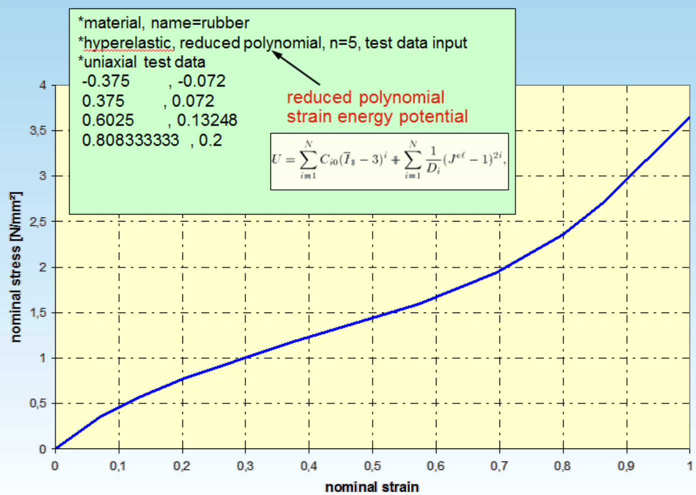


Determining the load
Material properties for FEM simulation

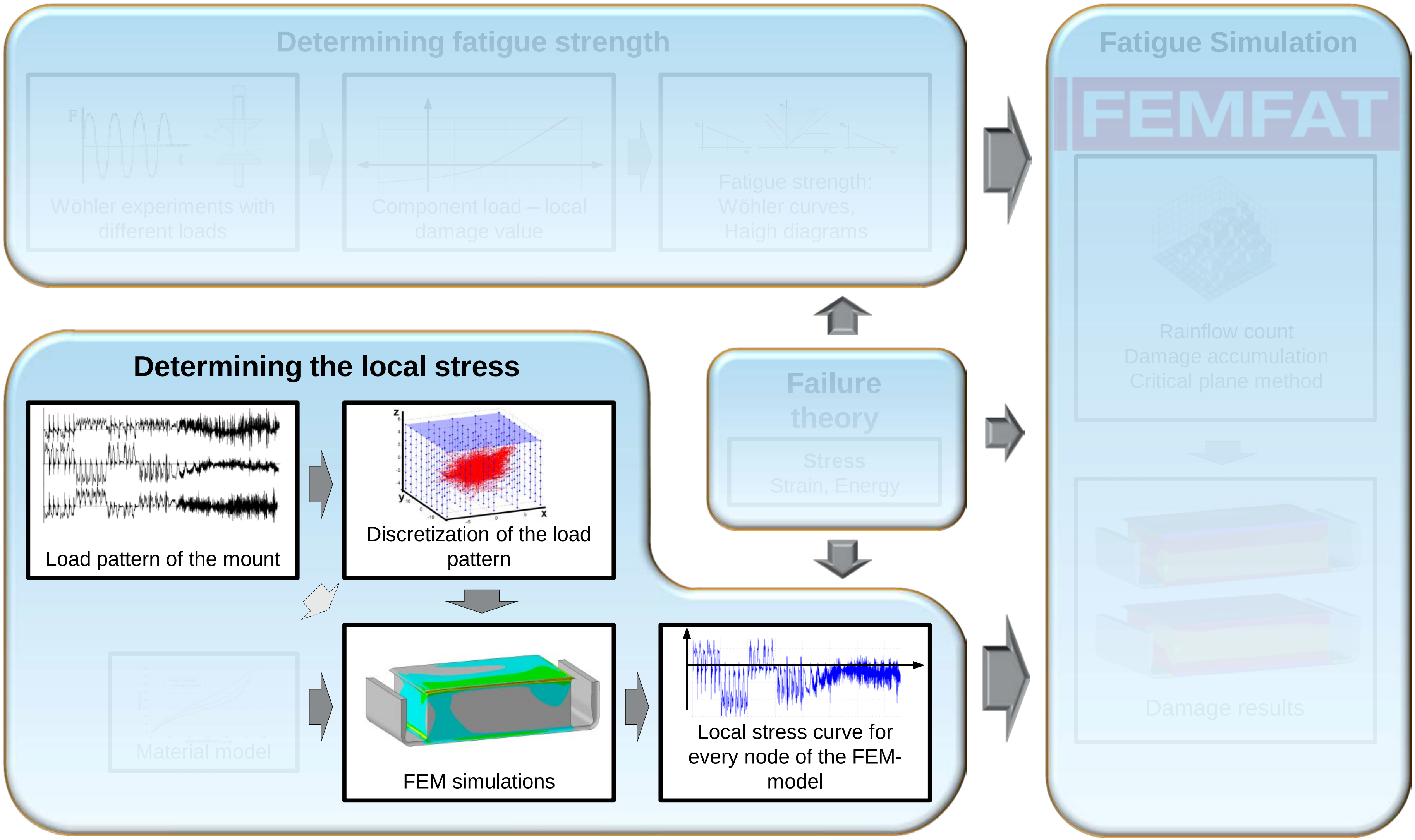
- Workflow:
  - Measurement:
    Determine the Force-Displacement Relationship with a specimen on the test bench
  - FEA:
    Calibration of the material model with the measured data

- Material properties are hyper elastic, the viscoelasticity was neglected (low Shore-Hardness of engine mount material)



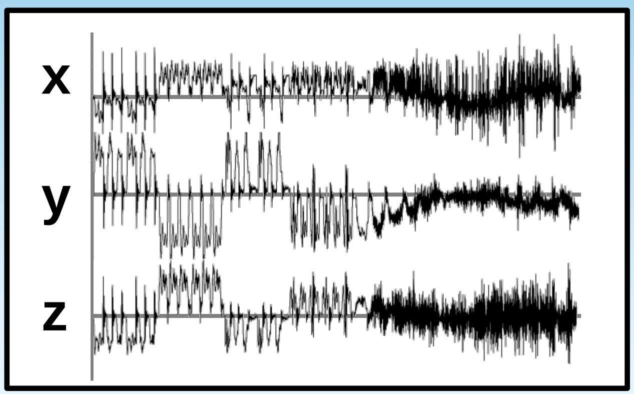


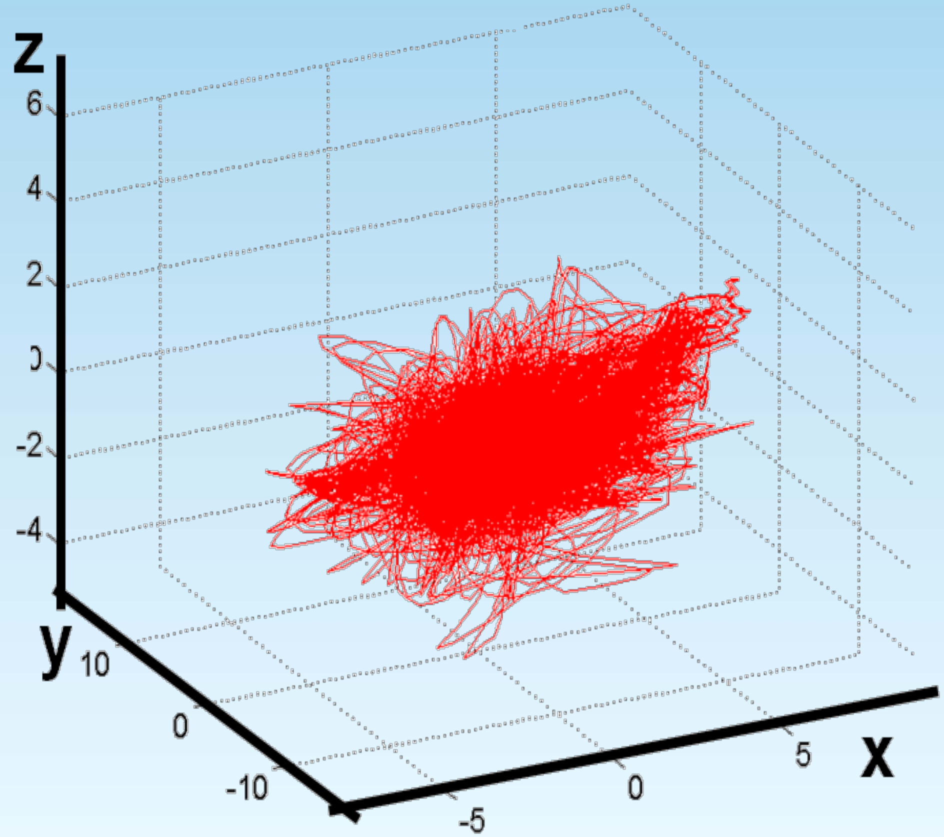
Determining the local stress



Determining the load stress
Simulation of deformations - basis

- Basis:
  - three-axis load-time signal (red curve in the right plot)
  - It is not possible to simulate such complex load history transient (analysis time, amount of data)





Determining the load
Simulation of deformations - discretization

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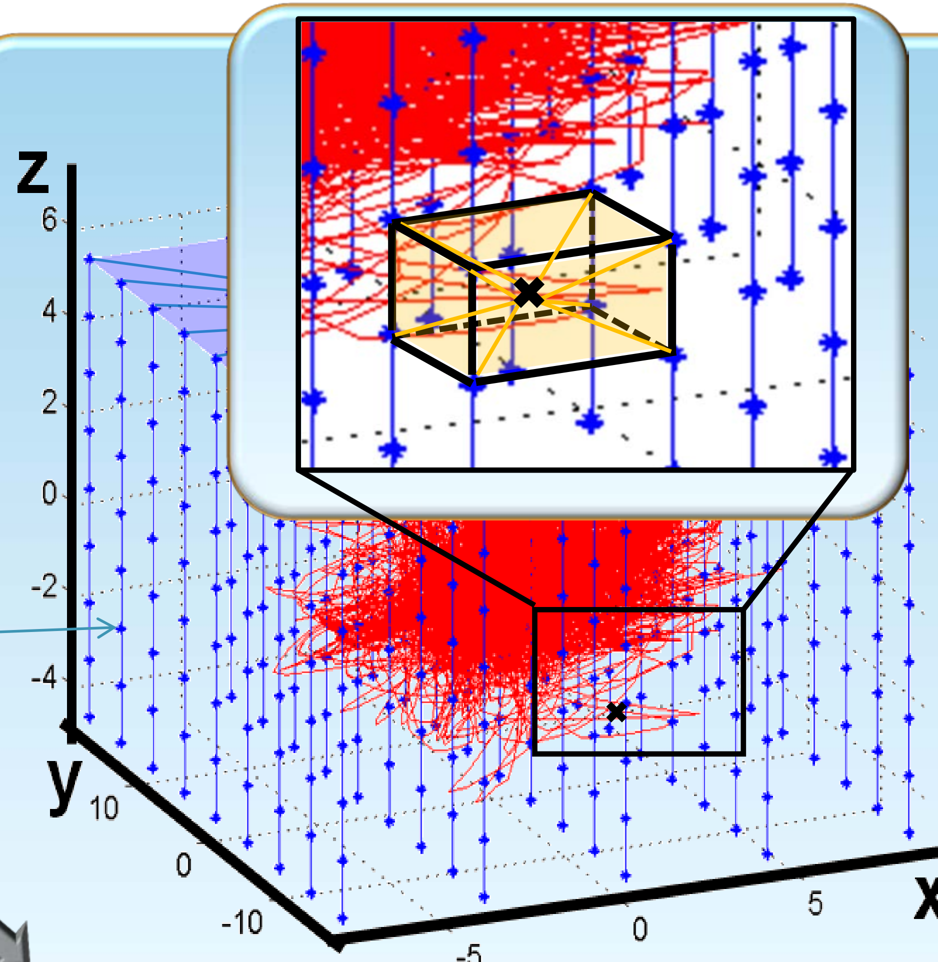
- Basis:
  - three-axis load-time signal (red curve in the right plot)
  - It is not possible to simulate such complex load history transient

- The operating space of the signal will be discretized
- This is done by enclosing it by a cuboid with a pattern of simulation results (symbolized by blue stars).
- The simulation results are generated by FEM-simulations in vertical direction (blue lines) from top (blue surface) to bottom.

- Subsequently: Interpolation for every time-point of the load-time signal



New **FEMFAT** Tool **ELASTOLOADS**

Fatigue simulation - Method and concept

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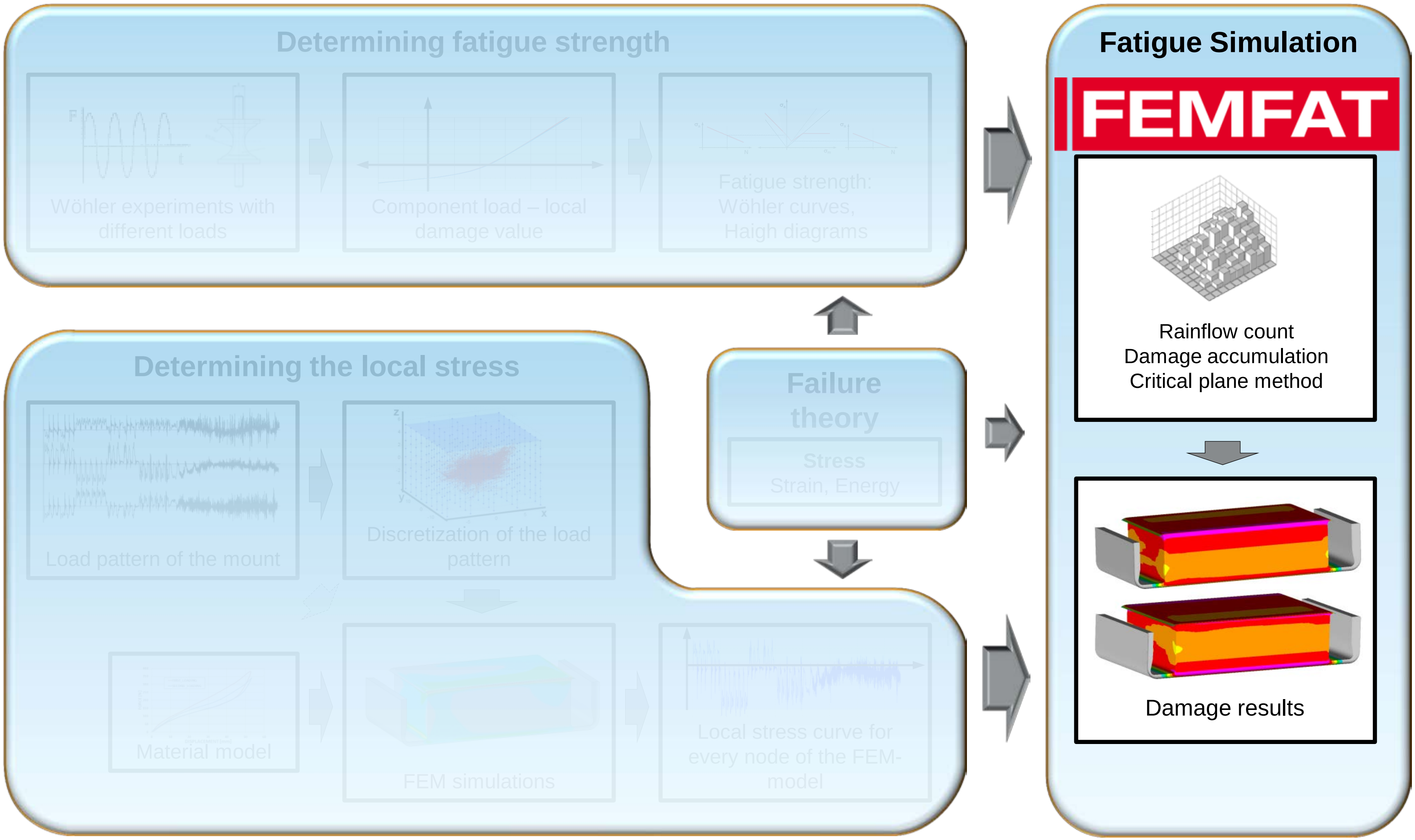
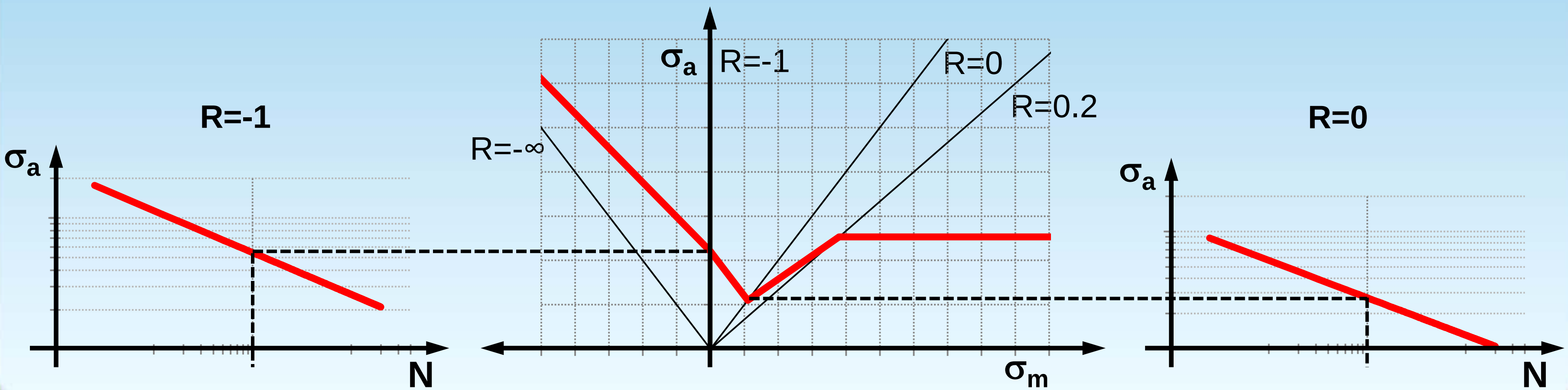


Fatigue simulation
Method and concept

- Modified channel based multiaxial fatigue analysis
  - Method of critical cutting plane
    - Rainflow-counting of 3D normal stress in critical cutting plane (acc. damage hypotheses)
  - Channel based method
    - For each FE-result one corresponding channel
    - For each channel specified interpolation factors are applied, all others are 0
  - Linear damage accumulation

▶ Influence of mean stress is taken into account based on R-ratios

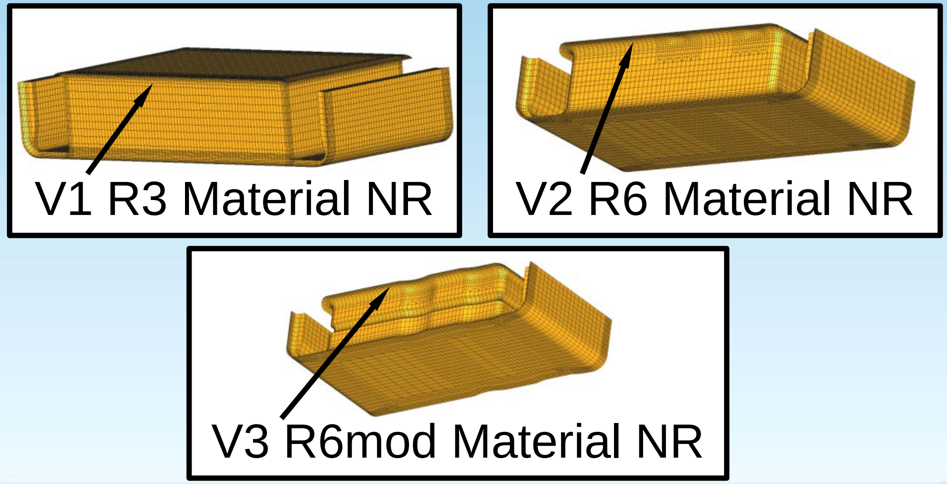


Example: 3 channel load Simulation and testing

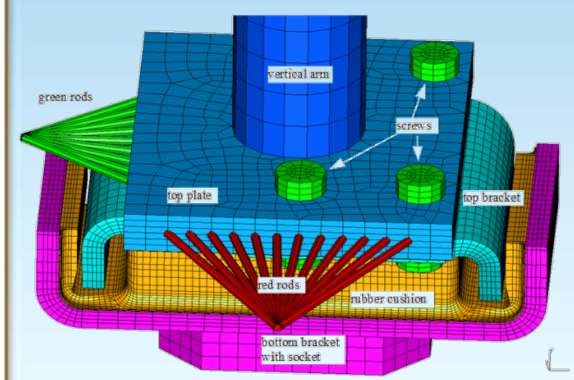
- Checking the simulation method with two different mounts and one virtually modified version

- Test
  - Excitation: by hydraulic cylinders
  - Signal measured on the real vehicle

- Simulation
  - Abaqus/Explicit solver was used because of contacts (and folds,…)
  - Consideration of the test bench including the connecting stiffnesses
  - Failure theory: Normal tension stress in critical cutting plane



FE-Model

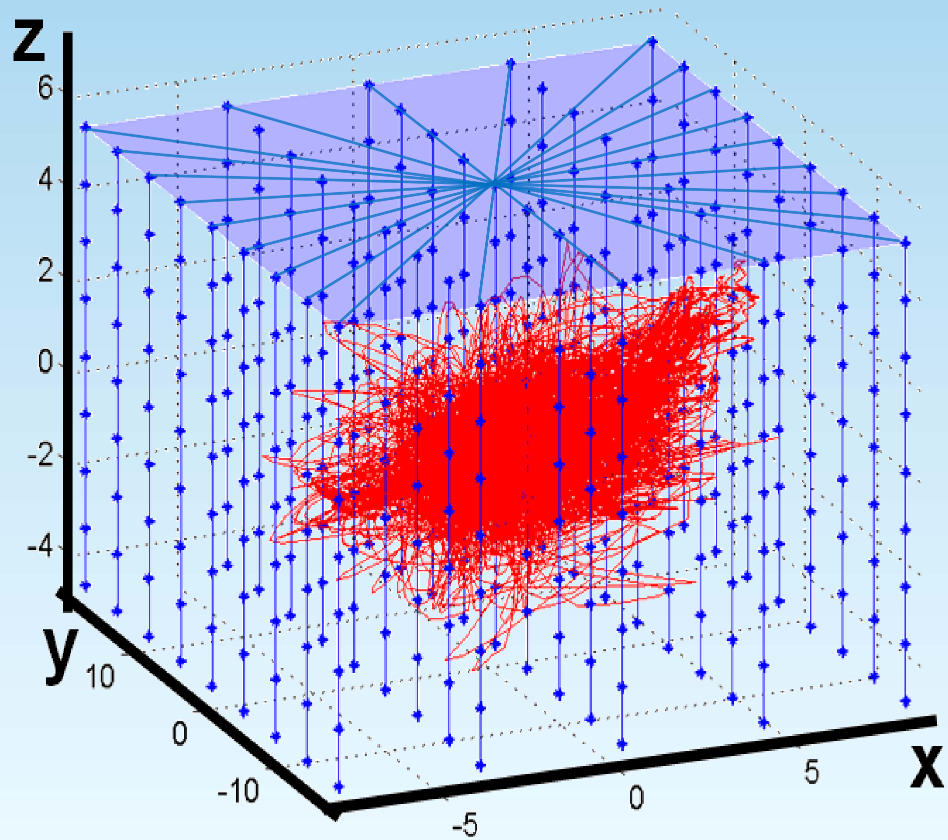


Test Bench

Example: 3 channel load
Simulation and testing

- Load: 3 channel Road-Load-Data
- 3 x 3 and 5 x 9 (higher resolution) discretization in x-y plane
- 9 and 45 FEM simulations
- 9 Increments in z-direction
- The fatigue simulation is thus based on 81 and 405 FEM results (channels) respectively

- The multiaxial fatigue simulation was done with FEMFAT channelMax
- New Tool **ELASTOLOADS** for the special needs of the presented method was used
- Failure theory: Normal stresses in the critical cutting plane



Example: 3 channel load Simulation and testing

Benchmark data

TESTING

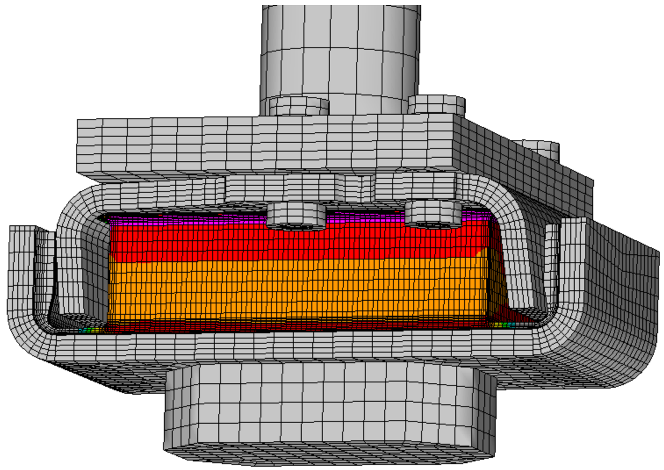
- Load: 3 channel Road-Load-Data (RLD)
- Test signal mixed from measured RLD
- Signal includes 5 different manoeuvers
- Signal ~38000 time points
- 700 Repeats = 100% Real time
- Test bench >70h for 700 Repeats
- 2 different engine mounts tested

SIMULATION

- Load: 3 channel test bench excitation
- Test bench signal directly used
- Damage analysed for 1 repeat => total repeats until crack
- Complete simulation chain takes less than < 40 h (depending on the mount and resolution)
- 3 different engine mounts simulated
- Estimation of the life increase of the third not tested mount

Example: 3 channel load
Simulation and testing

Mount R3
95000 Nodes
84000 Elements



<u>Abaqus COARSE RESOLUTION:</u>

9 Analyses

<u>Duration:</u> ~4h with 12CPUS

<u>FEMFAT COARSE RESOLUTION :</u>

75 of 81 channels,
~38000 timepoints/channel

3D cutting plane = 218/node

No channel- and node filtering

<u>Duration:</u> ~11h with 12CPUS

Total analysis time = ~15h

<u>Abaqus FINE RESOLUTION:</u>

32 Analyses

<u>Duration:</u> ~14h with 12CPUS

<u>FEMFAT FINE RESOLUTION:</u>

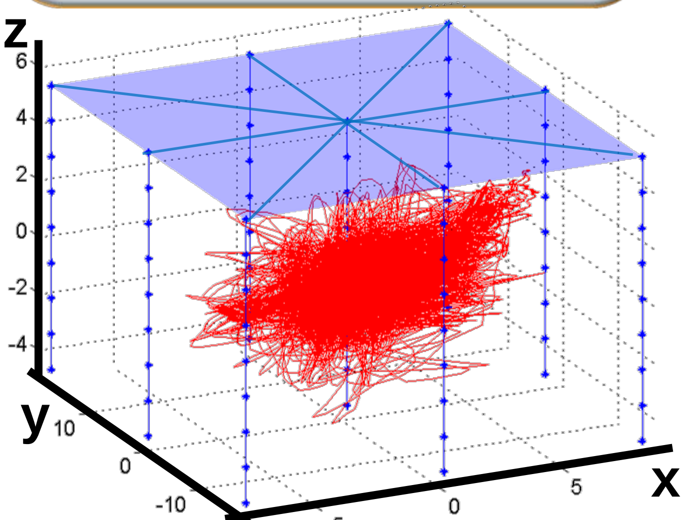
215 of 405 channels
~38000 timepoints/channel

3D cutting plane = 218/node

No channel- and node filtering

<u>Duration</u>: ~25h with16CPUS

Total analysis time = ~39h

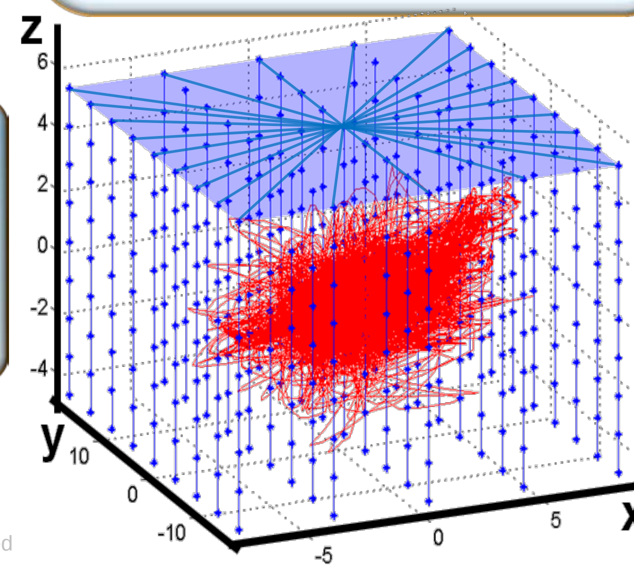


<u>TEST TIME UNTIL CRACK:</u>

TOTAL TIME = ~100h

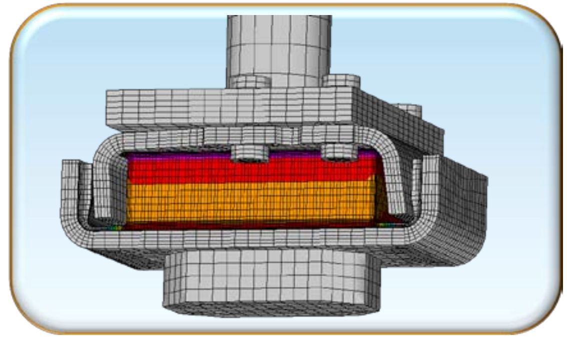
<u>TEST TIME UNTIL STOP:</u>

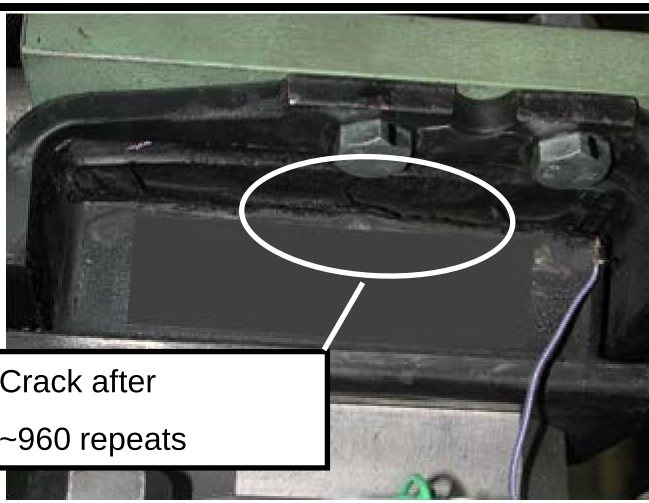
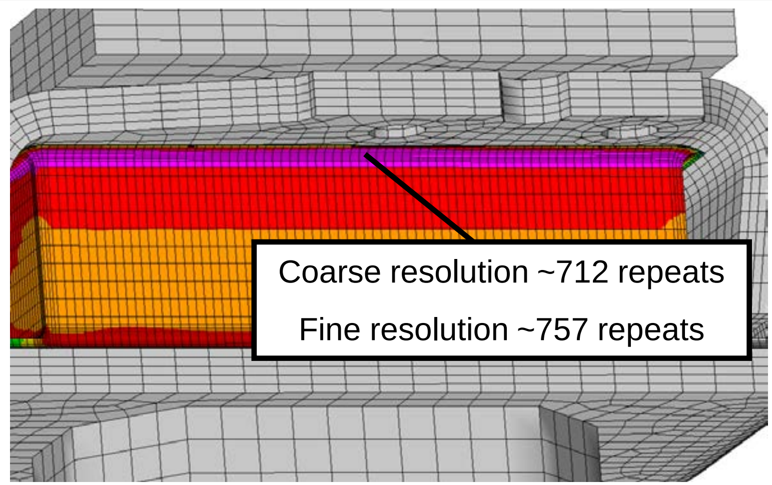
TOTAL TIME = ~ 115h



Example: 3 channel load
Simulation and testing

- The point of failure compared to test is well predicted
- The predicted repeats differ with a factor of 1.35 (coarse) respectively 1.27 (fine) from the test
- Increasing the resolution leads to a better correlation
- The crack starts in the outer radius



Damage at test	Fatigue simulation result
	

Example: 3 channel load
Simulation and testing

Mount R6
41000 Nodes
35000 Elements

Abaqus COARSE RESOLUTION:

9 Analyses

Duration: ~1.5h with 12CPUS

FEMFAT COARSE RESOLUTION :

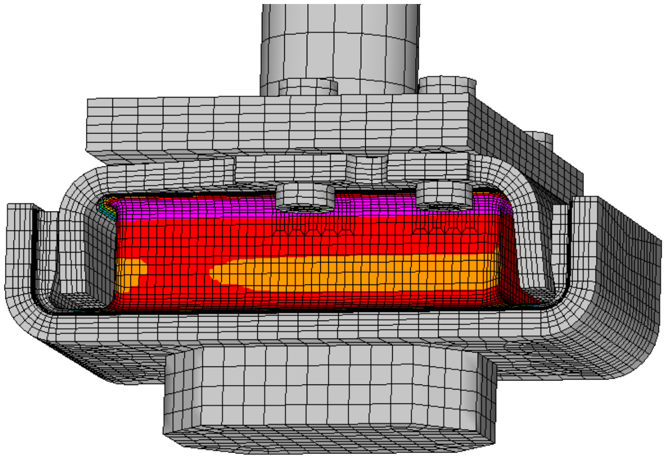
75 channels, ~38000 TP/chan.

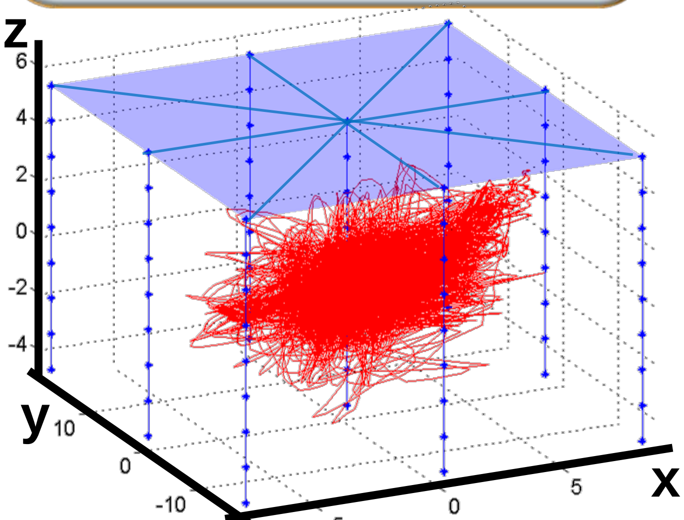
3D cutting plane = 218/node

No channel- and node filtering

Duration: ~6h mit 10CPUS

Total analysis time = ~8h





Abaqus FINE RESOLUTION:

32 Analyses

Duration: ~5.5h with 12CPUS

FEMFAT FINE RESOLUTION:

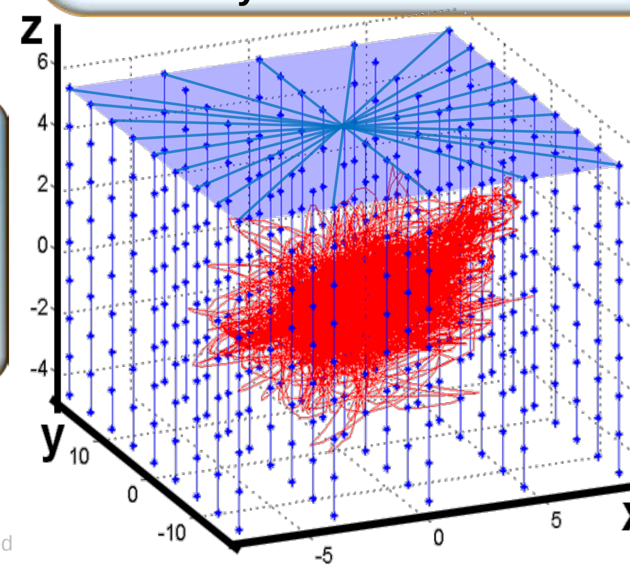
215 channels, ~38000 TP/chan.

3D cutting plane = 218/node

No channel- and node filtering

Duration: ~15h mit 10CPUS

Total analysis time = ~21h



TEST TIME UNTIL CRACK:

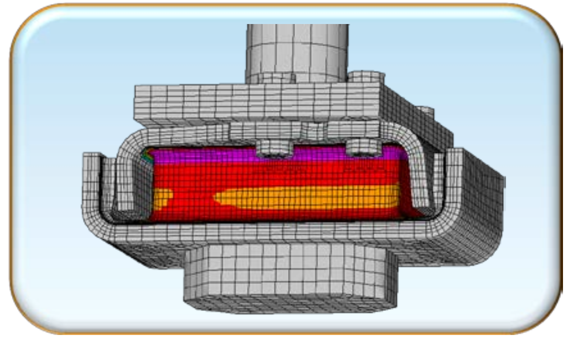
TOTAL TIME = ~170h

TEST TIME UNTIL STOP:

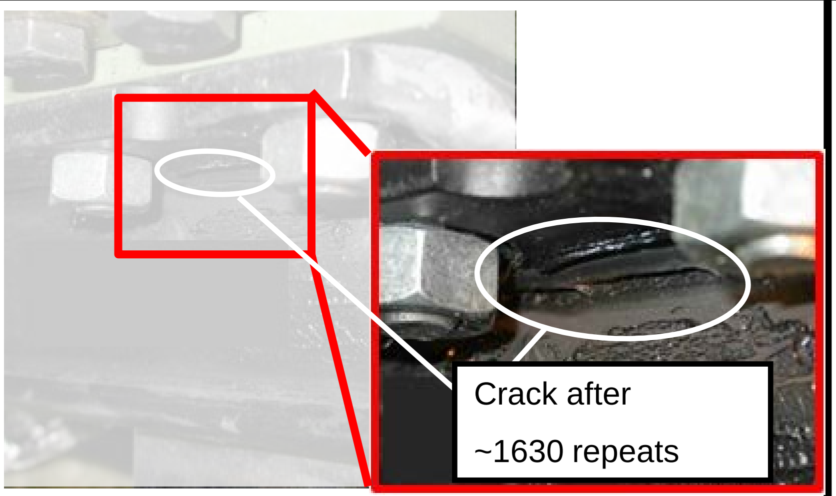
TOTAL TIME = ~ 300h

Example: 3 channel load
Simulation and testing

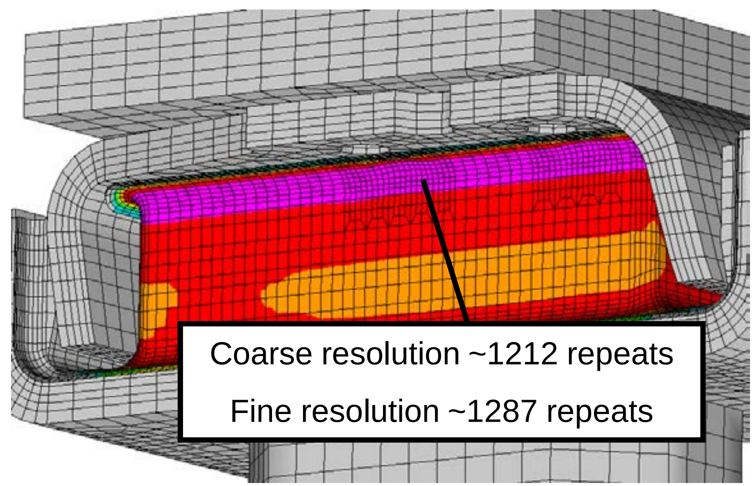
- The failure point of the test is well predicted
- The predicted repeats differ with a factor of 1.35 (coarse) respectively 1.27 (fine) from the test
- Increasing the resolution leads to a better correlation
- The crack starts in the radius



Damage at test

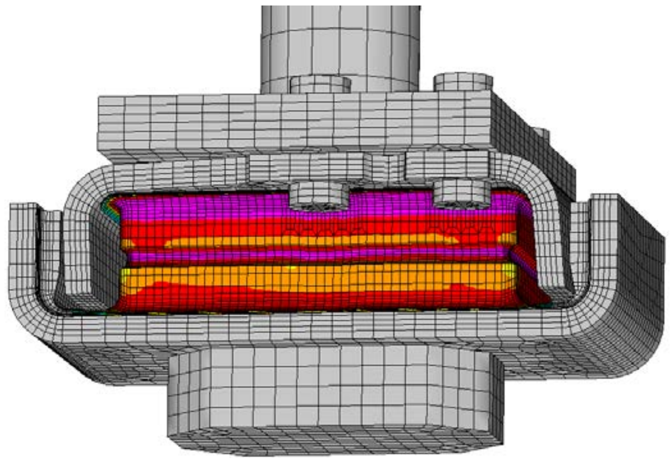


Fatigue simulation result



Example: 3 channel load
Simulation and testing

Mount R6 mod.
48000 Nodes
40000 Elements



Abaqus COARSE RESOLUTION:

9 Analyses

Duration: ~2h with 12CPUS

FEMFAT COARSE RESOLUTION :

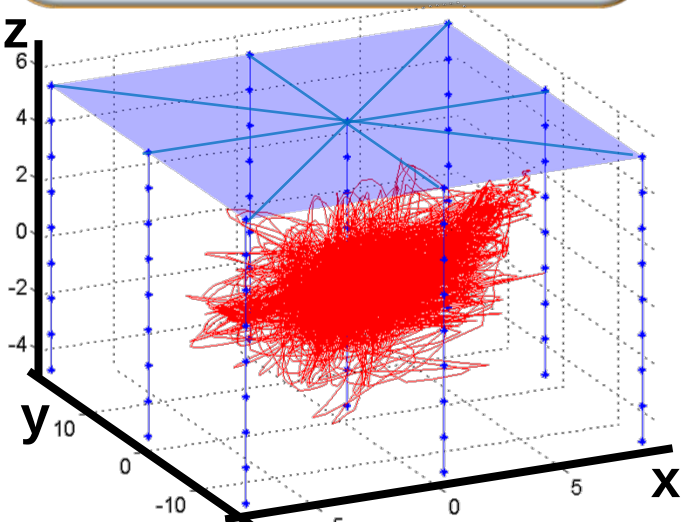
75 channels, ~38000 TP/chan.

3D cutting plane = 218/node

No channel- and node filtering

Duration: ~6h with 12CPUS

Total analysis time = ~8h



Abaqus FINE RESOLUTION:

32 Analyses

Duration: ~6h with 12CPUS

FEMFAT FINE RESOLUTION:

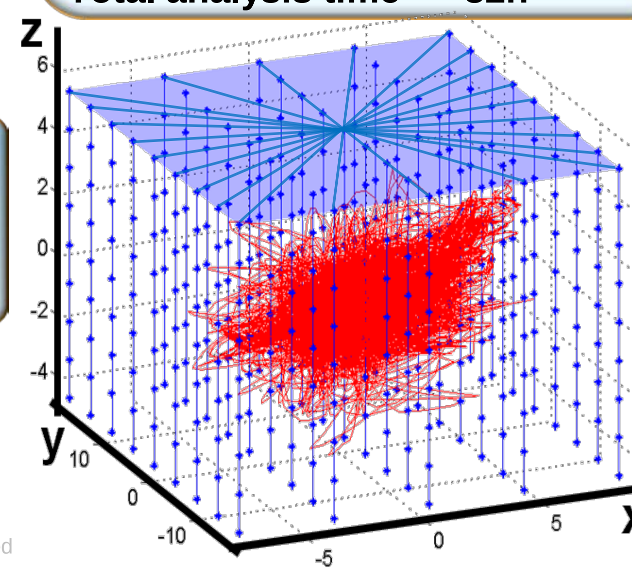
215 channels, ~38000 TP/chan.

3D cutting plane = 218/node

No channel- and node filtering

Duration: ~26h with 12CPUS

Total analysis time = ~32h

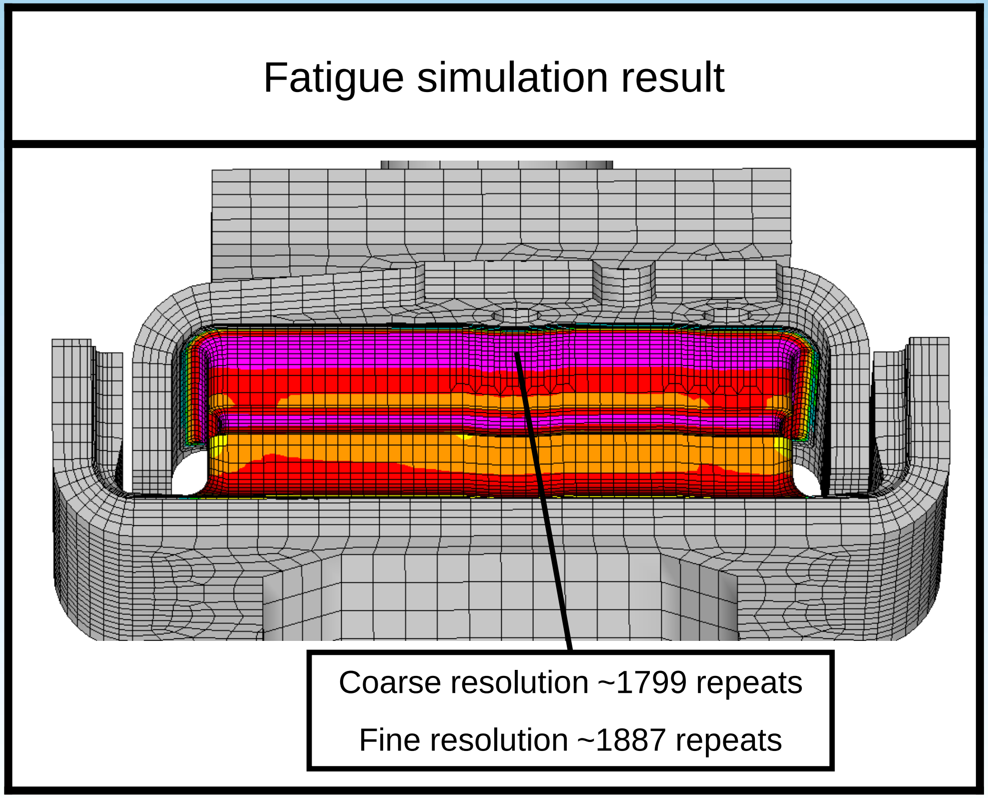


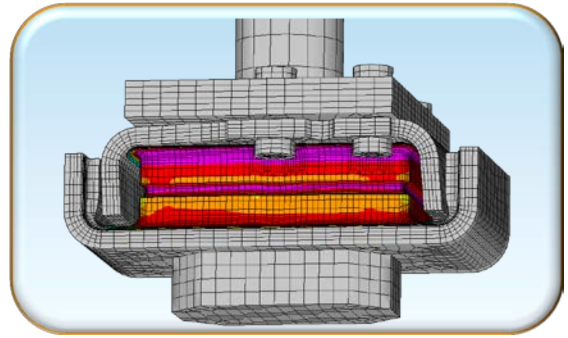
Testing:

No Data available, because only design variant

Example: 3 channel load Simulation and testing

- The failure point remains the same
- The predicted repeats increase with a factor of 1.47 compared to the mount R6 variant





Version	R3	R6	R6 mod
FEMFAT Coarse	715	1212	1799
Improvement	1	1.7	2.5

Version	R3	R6	R6 mod
FEMFAT Fine	757	1287	1887
Improvement	1	1.7	2.5

Version	R3	R6	R6 mod
Test bench	960	1630	2390*
Improvement	1	1.7	2.5*

*Estimated based on simulation results

Summary

Summary

- A method was presented which allows the assessment of dynamic strength of engine mounts in an early development phase, before the first prototypes have been built.
- The simulations show a good prediction quality even with less support points
- The prediction quality increases with higher resolution (fine resolution)
- Due to fast simulation and good prediction quality it is possible to decrease prototype numbers and tests
- Additionally the simulation time can be reduced. Due to integrated filtering with FEMFAT
  - Channel filter => reduction of time points and channels
  - Cutting plane filter => reduction of the analysed cutting planes
  - Node filter => reduction of the analysed nodes
- The method is independent of the time signal length and channels (real RLD instead of mixed signals can be used)
- The method in combination with Abaqus and FEMFAT is fully automated and approved
- Important for the prediction quality:
  - Good representation of the material model in Abaqus
  - Simulation of large deformation (folding is possible to be considered, too)
  - Determining of the fatigue strength of the used rubber material for FEMFAT

Application

- Assessment of geometric variants during the development phase
- Assessment of load spectra on the basis of local effects
- In general to consider nonlinear behaviour (local contact, non linear geometric behaviour)
- Additional axis like temperatures, inner pressure,… could be applied (4D, 5D,.. Simulation)


The future is ours to make.