presented at the 12th Weimar Optimization and Stochastic Days 2015
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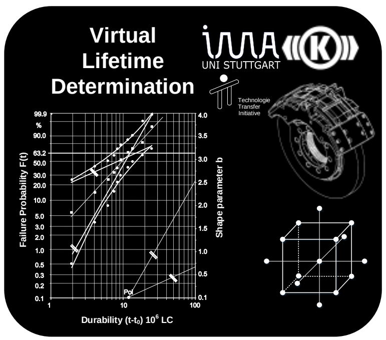
STOCHASTIC SIMULATION APPROACH FOR REALISTIC LIFETIME FORECAST AND ASSURANCE OF COMMERCIAL VEHICLE BRAKING SYSTEMS



12. Weimar Optimization and Stochastic Days 2015

M. Sc. Martin Dazer
Dipl.-Ing. Stefan Kemmler
Prof. Dr.-Ing. Bernd Bertsche

Dr.-Ing. Tobias Leopold
Dipl.-Ing Jens Fricke

Institute of Machine Components
Reliability Engineering

Knorr-Bremse Group
Systeme für Nutzfahrzeuge GmbH

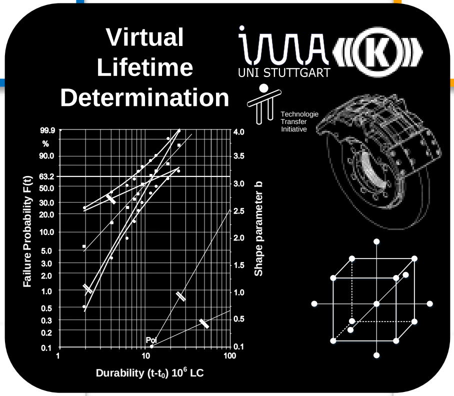
Technology Transfer Initiative

06.11.2015

Research Cooperation

KNORR-BREMSE

UNI STUTTGART



Technologie Transfer Initiative

University of Stuttgart
Germany

Agenda

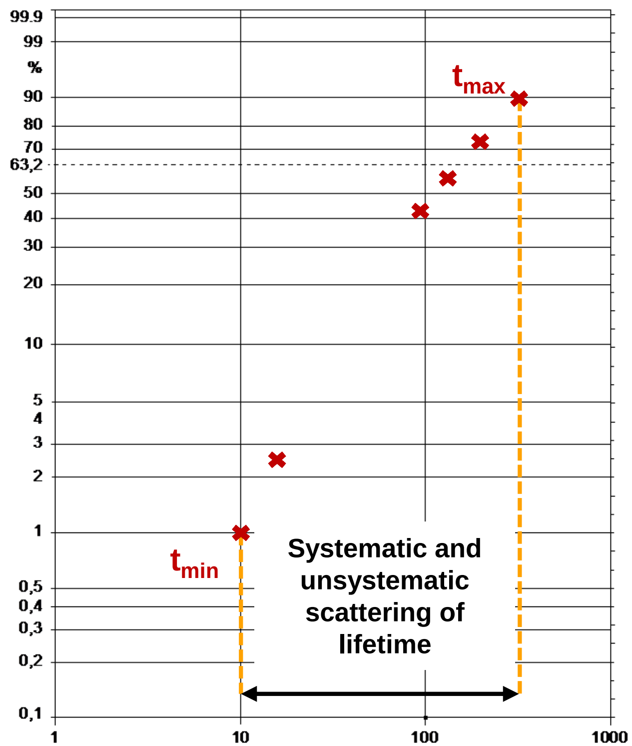
1. Motivation
2. Application example: brake caliper
3. Simulation process
4. Design of Experiments
5. Result evaluation
6. Summary and Outlook

Virtual Lifetime Determination of commercial vehicle braking systems

1. MOTIVATION

1. Motivation

Real durability tests

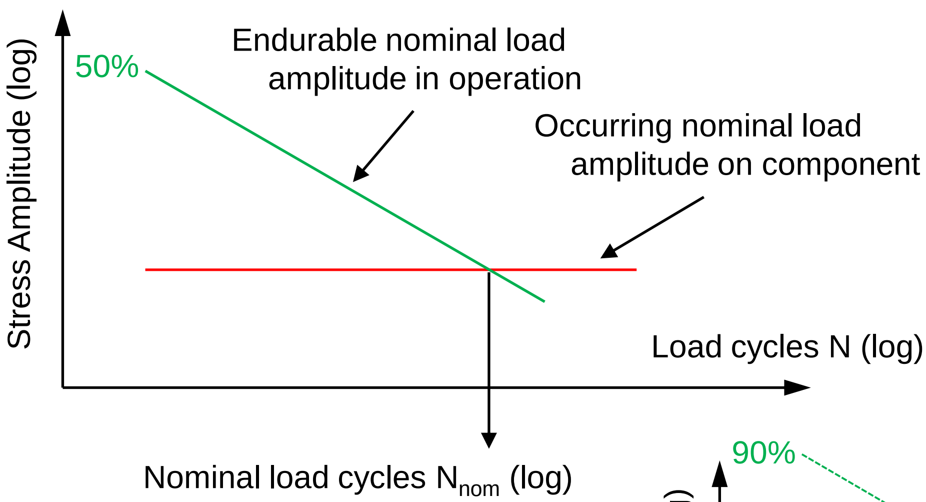


Scattering produces a characteristic lifetime distribution

Identification of specific product properties:

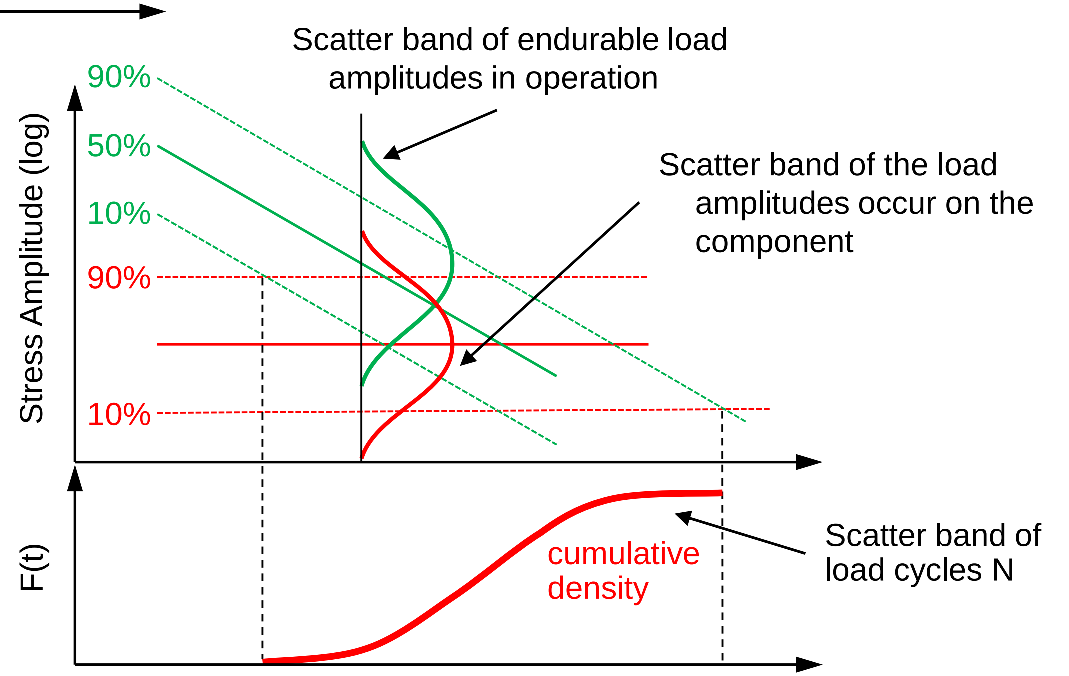
- Failure mechanism
- Lowest and longest cycle times
- Failure distribution
- Control of correct target-engineering by requirements

1. Motivation



Motivation:
Realistic lifetime prediction through stochastic simulation of stress and strength

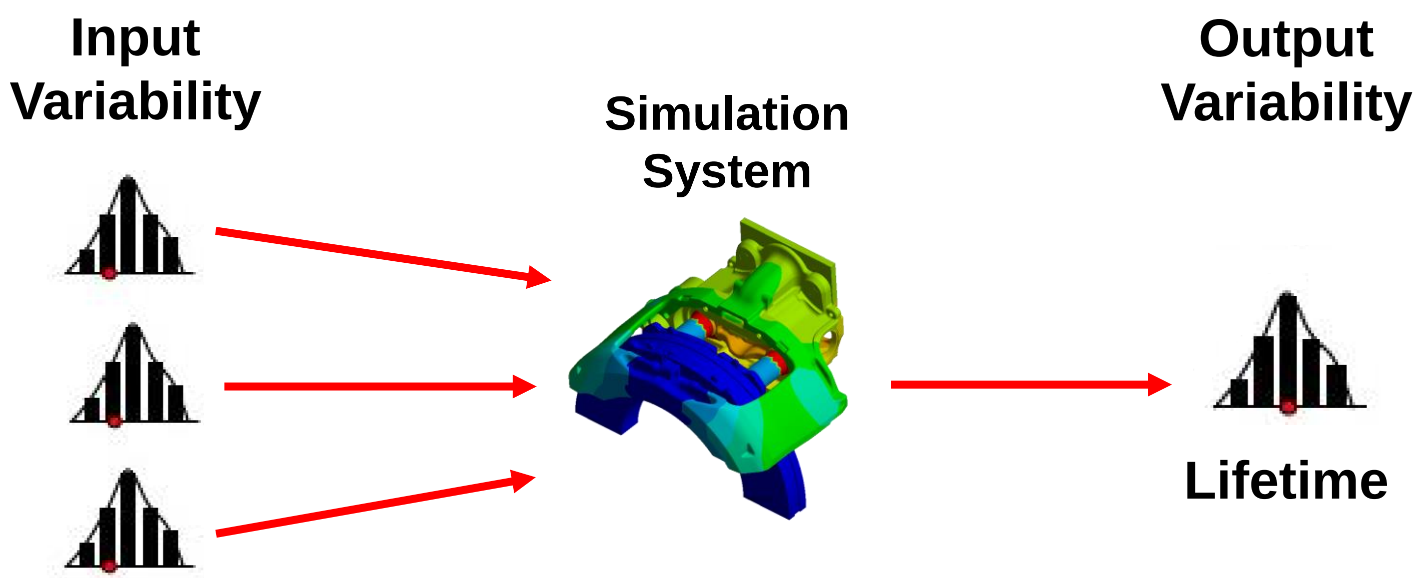
Stochastic Simulation



Source: Bertsche 2004

Prof. Dr.-Ing. B. Bertsche; M. Sc. Martin Dazer

1. Motivation



- Parameter variations of the product lead to variations in product properties as a result of internal correlations.
- This can cause functional or structural failure and the deterioration of product quality.

Aim: Realistic forecast of time to failure

Prof. Dr.-Ing. B. Bertsche; M. Sc. Martin Dazer

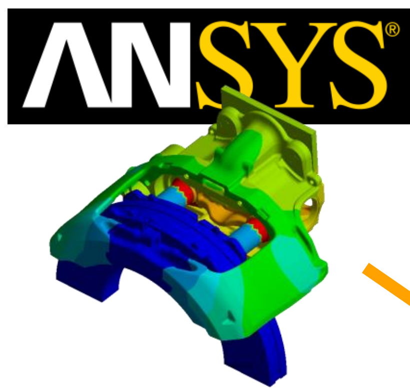
1. Motivation

Parametric CAD-Model

- Mapping the caliper geometry
- Changes in the geometry

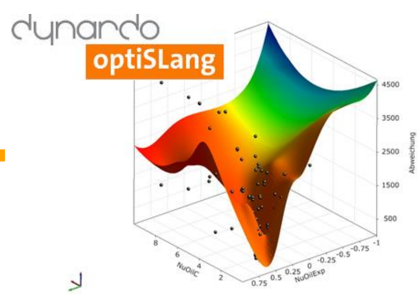
FEA-Simulation model

- Mapping of damage-related effects
  - Stress amplitudes
  - Strain amplitudes



Parameter study

- Automatic simulation of the established DOE
- Statistical evaluation



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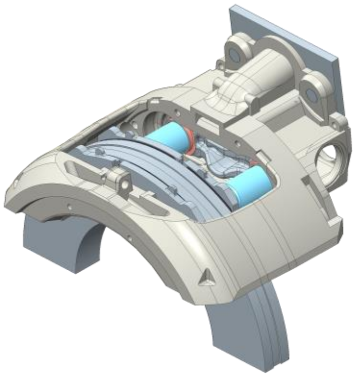
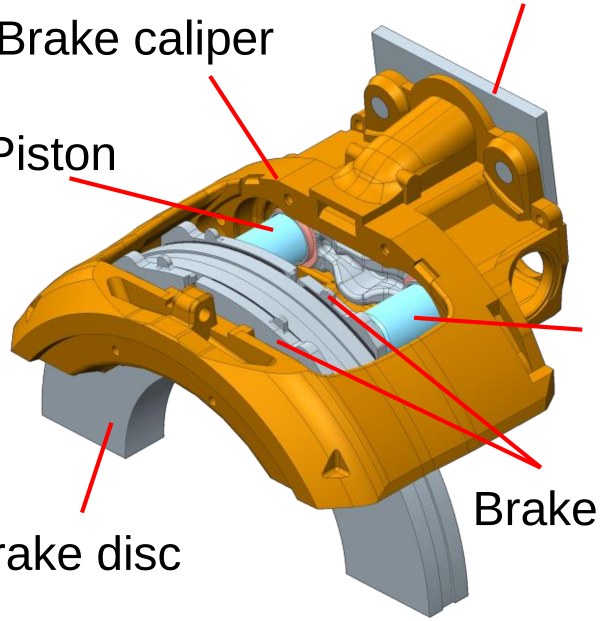


Virtual Lifetime Determination of commercial vehicle braking systems

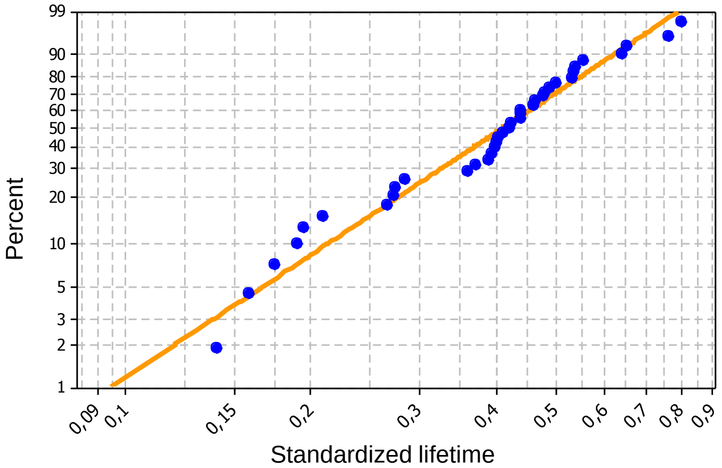
2. APPLICATION EXAMPLE BRAKE CALIPER

2. Application example Brake caliper



Application example:
Brake caliper

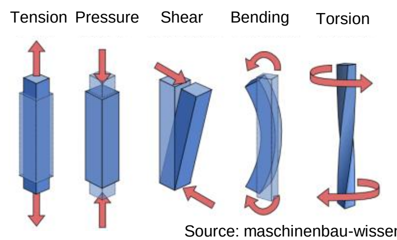
- Have to withstand high loads in case of overload
- Therefore tested with high loads
- Failures in Low-Cycle-Fatigue range (LCF)



Virtual Lifetime Determination of
commercial vehicle braking systems

3. SIMULATION PROCESS

3. Simulation process



Source: maschinenbau-wissen 2015

Definition of claim and the associated amplitudes

Loadcase simulation

Load definition

Material properties

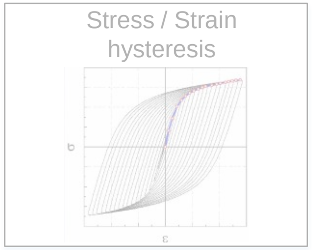
Stochastic Simulation for variance determination

Deterioration

Strength

Carrying Capacity

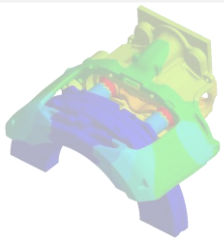
Lifetime distribution



Source: Haibach 2005

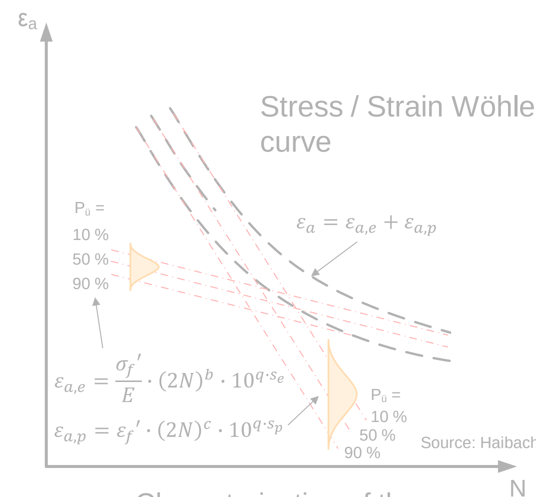
Characterization of the relevant material properties

The level of deterioration related stress and strain amplitudes



Identification and consideration of non-homogeneous loading states

Source: SOFEA 2015



Source: Haibach 2005

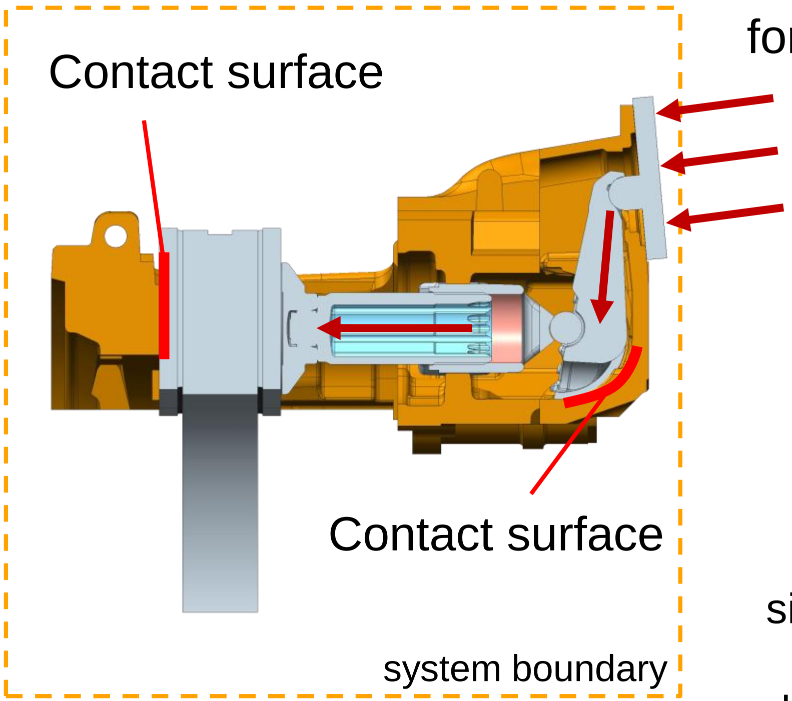
Characterization of the strength model

3. Simulation process – load definition

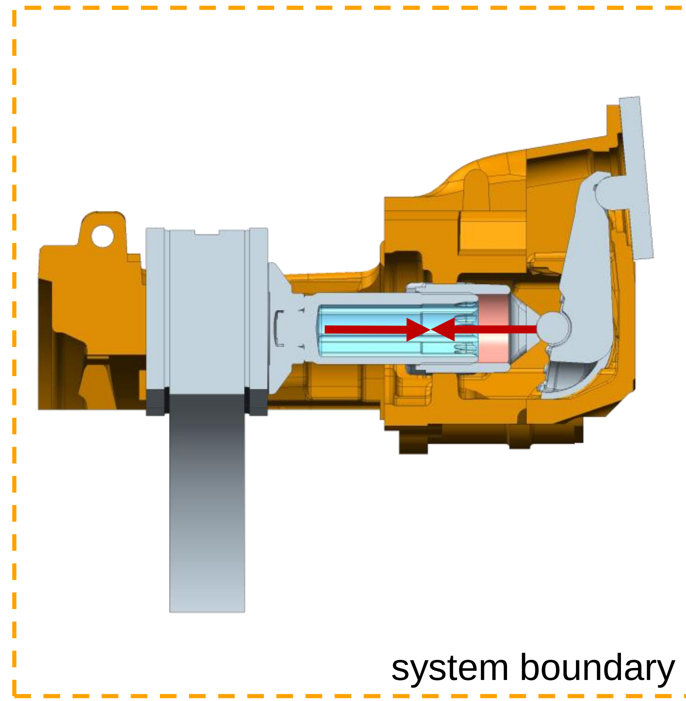
Real force flow in the brake caliper

Clamping force

Simulated force flow in the brake caliper



System simulation to determine deterioration



Clamping force causes high FE-calculation time

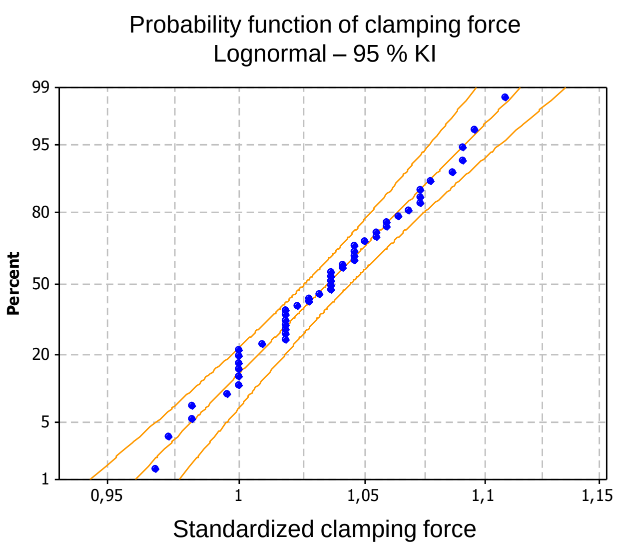
Same damage state

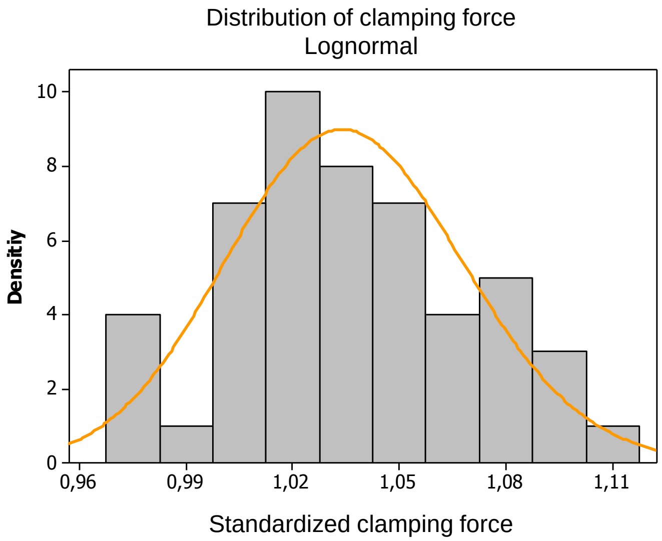
Bolt pretension for lower FE-calculation time

Prof. Dr.-Ing. B. Bertsche; M. Sc. Martin Dazer

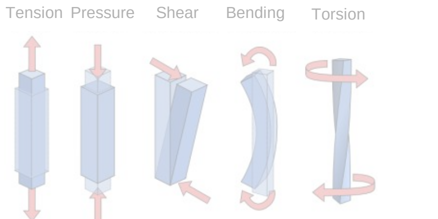
3. Simulation process – load definition

- There are variations in the clamping force occuring through hysteresis effects
- Load spectrum is determined from test reports
- Best-Fit: Lognormal distribution





3. Simulation process



Source: maschinenbau-wissen 2015

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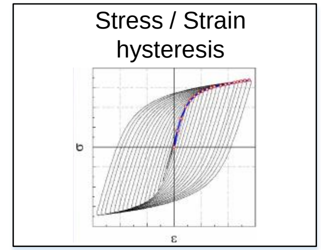

Source: Haibach 2005

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Carrying capacity

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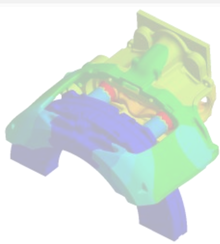
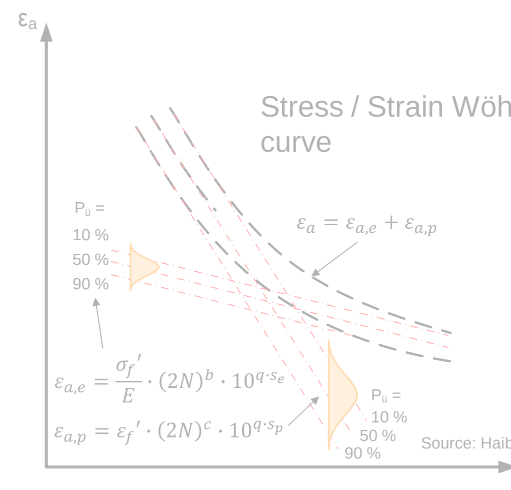


Identification and consideration of non-homogeneous loading states

Source: SOFEA 2015

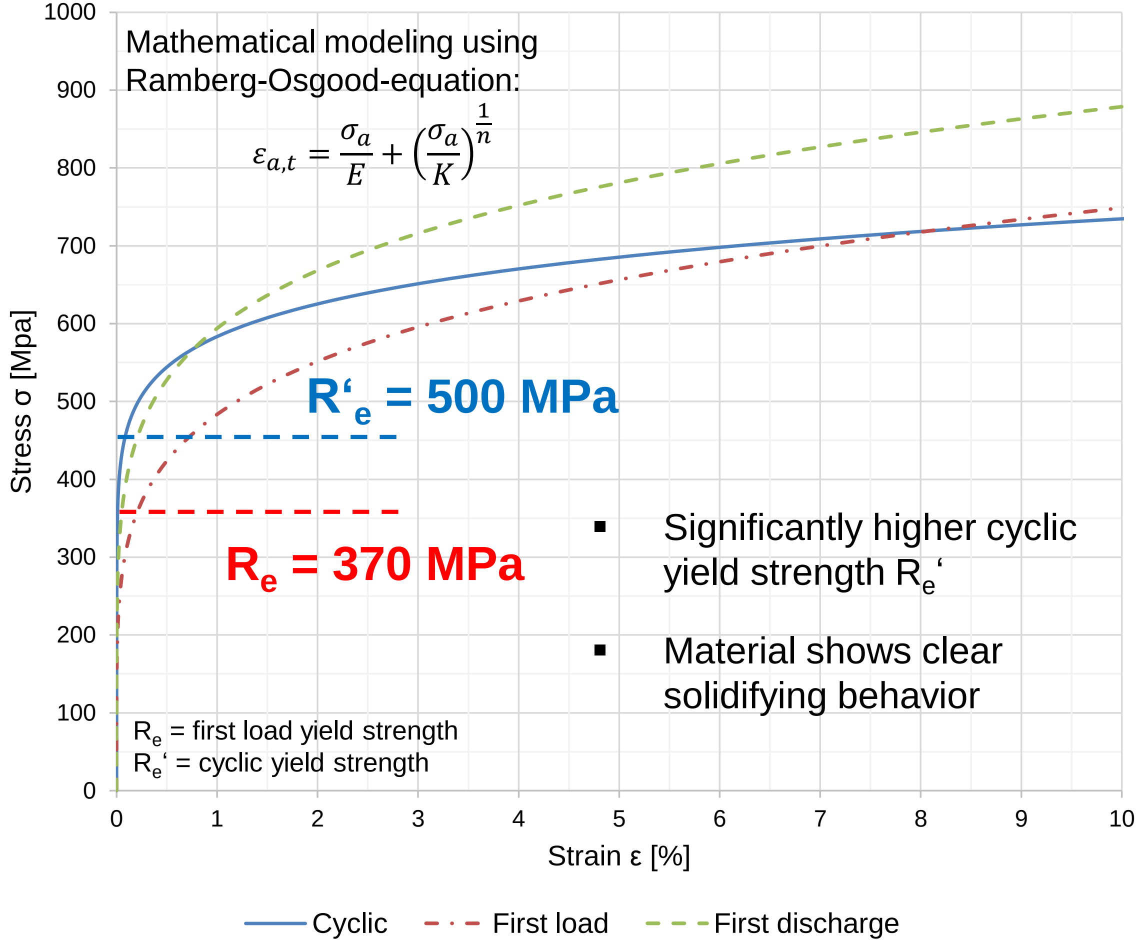


Source: Haibach 2005

Characterization of the strength model

3. Simulation process – material properties

Material behavior GJS-600-6



- Significantly higher cyclic yield strength R_e'
- Material shows clear solidifying behavior

General Ramberg-Osgood-equation:

$$\varepsilon_{a,t} = \frac{\sigma_a}{E} + \left(\frac{\sigma_a}{K}\right)^{\frac{1}{n}}$$

Modelling the fist load curve:

$$K = 1160$$
$$n = 0{,}19$$

Modelling the first discharge curve:

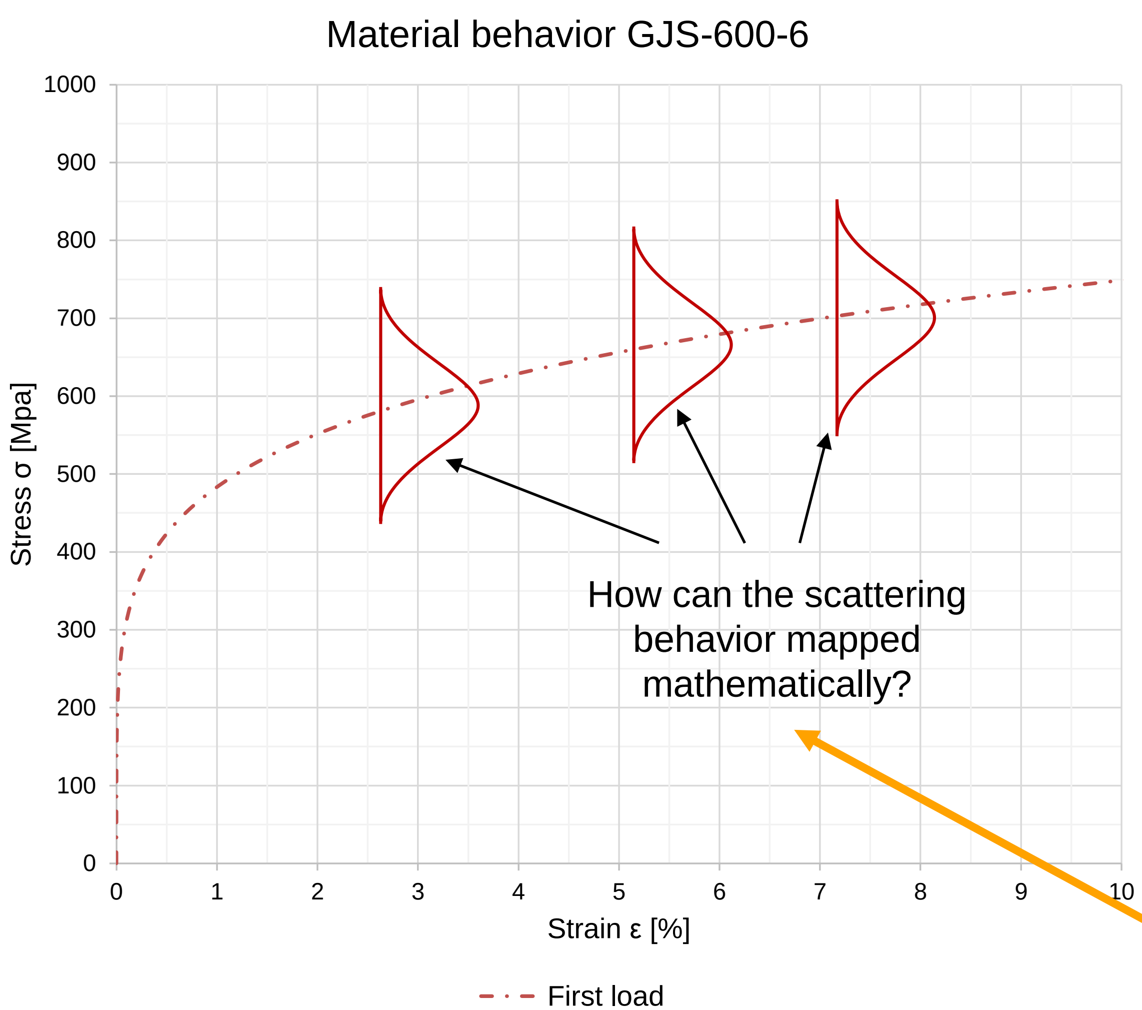
$$K'' = 1300$$
$$n'' = 0{,}17$$

Modelling the cyclic curve:

$$K' = 924{,}9$$
$$n' = 0{,}1$$

Nominal material behavior

3. Simulation process – material properties



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Modelling the cyclic curve:

$$K' = 924{,}9$$
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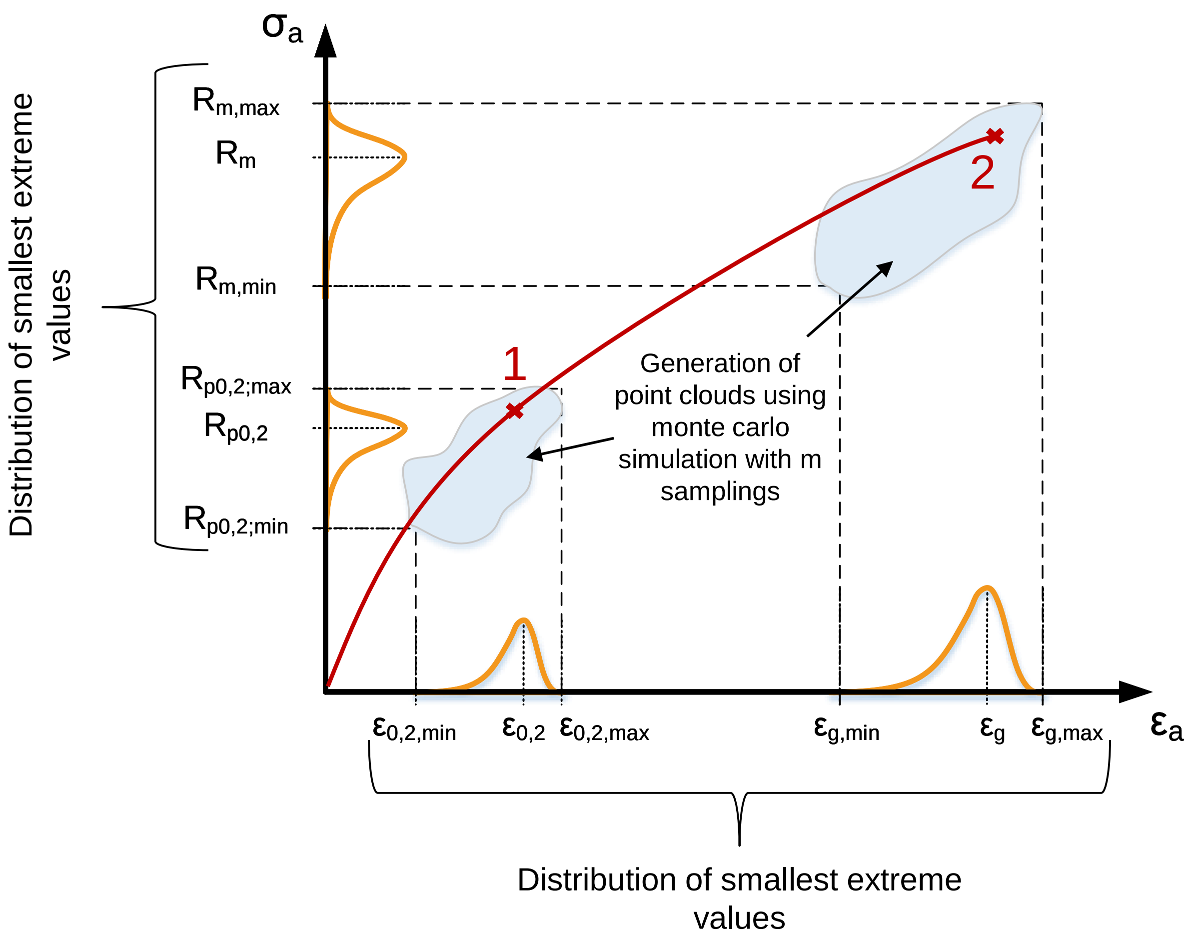
Nominal material behavior

3. Simulation process – material properties

- Only data from the static tensile test available
  - Mathematical derivation of the scattering of *n* and *k*



- Determination of the limits and the distribution of *n*, and *k*:
- Using two interpolation points solving Ramberg Osgood iteratively for *n* and *k*

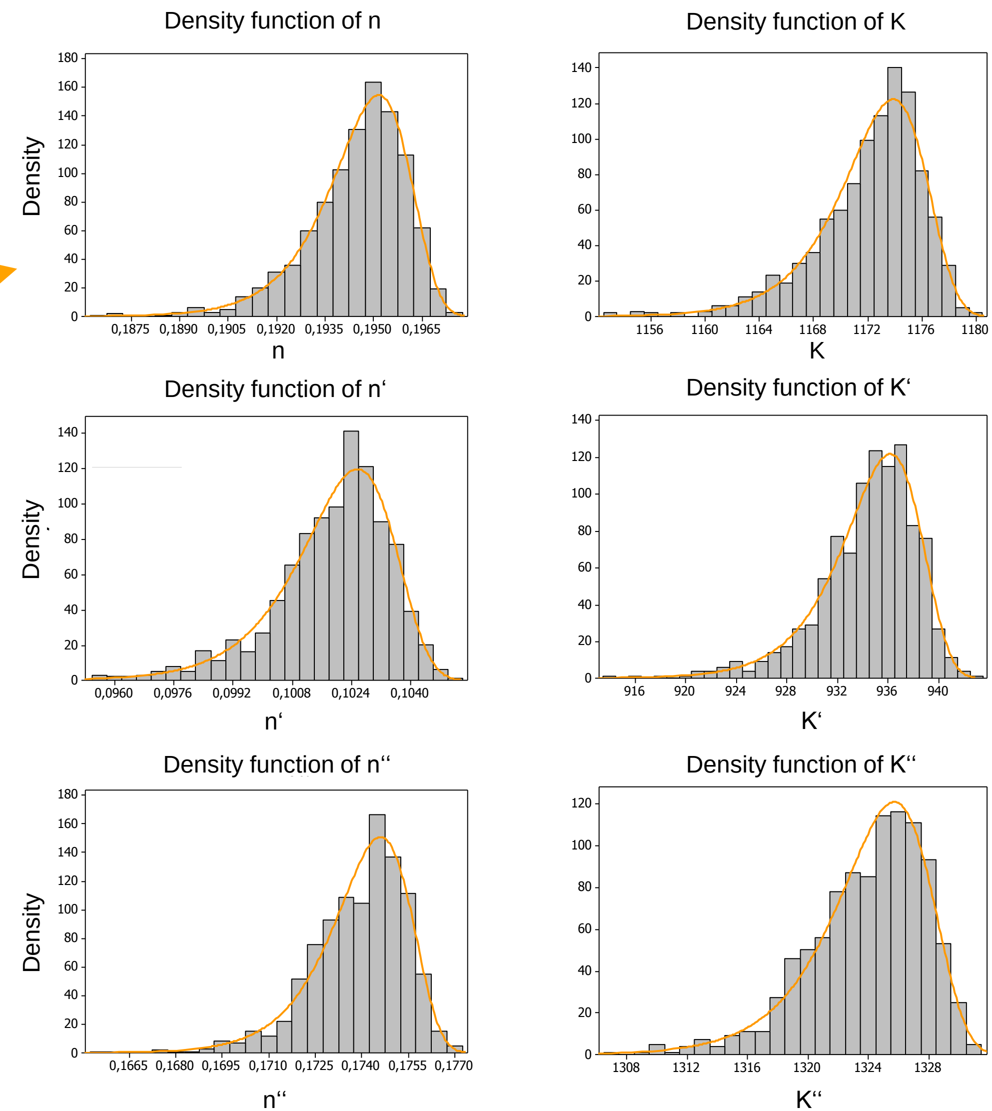
Loop to *j*, *i* = *m*

$$\varepsilon_{0,2_i} = \frac{R_{p0,2_i}}{E} + \left(\frac{R_{p0,2_i}}{K}\right)^{\frac{1}{n}}$$

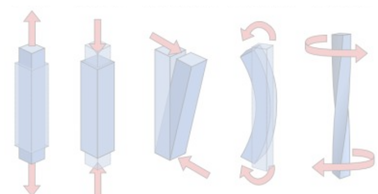
$$\varepsilon_{g_j} = \frac{R_{m_j}}{E} + \left(\frac{R_{m_j}}{K}\right)^{\frac{1}{n}}$$

3. Simulation process – material properties

- Determination of the variance of *K* and *n* using 1000 Monte Carlo Samplings
- Best fit for initial loading *K* and *n* with Weibull distribution
- Proportionate transfer of variance at *K'*, *K''*, *n'* and *n''*



3. Simulation process



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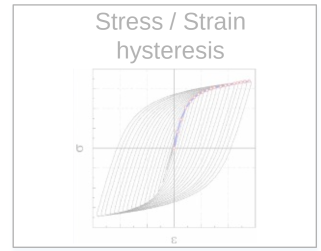

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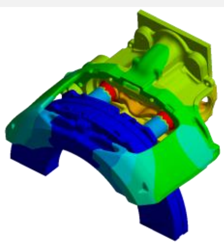

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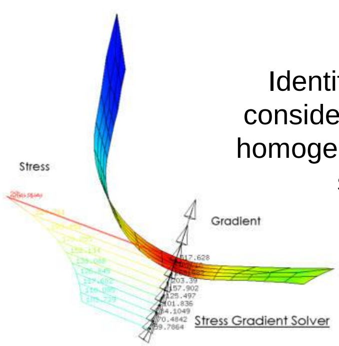

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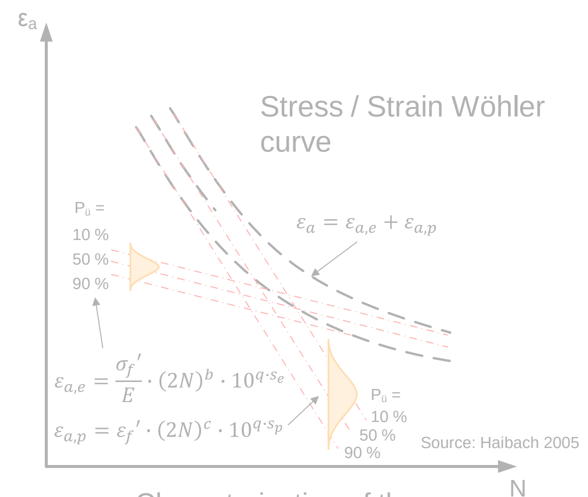

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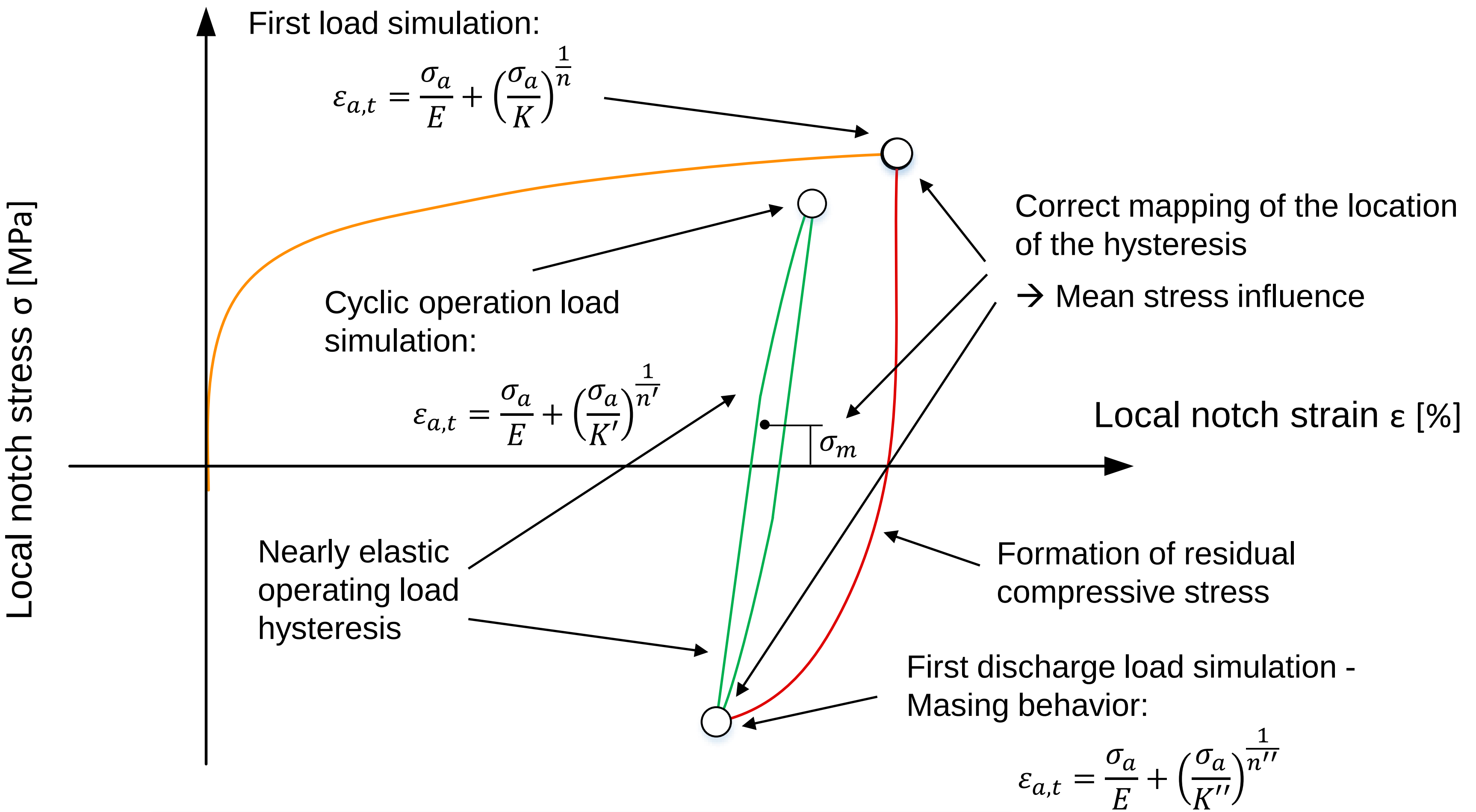
Characterization of the strength model

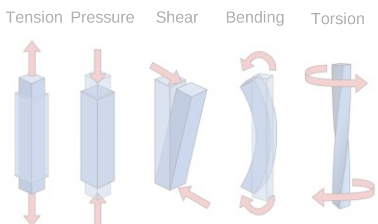
3. Simulation process – deterioration



Accelerated **R**epresentative **S**imulation **P**rocess (**ARSP**)
for deterioration calculation at constant load

Abstract representation

3. Simulation process



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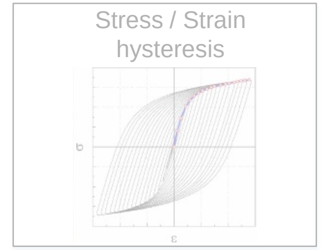

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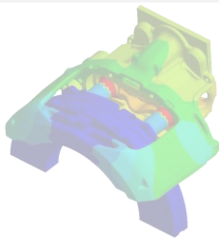

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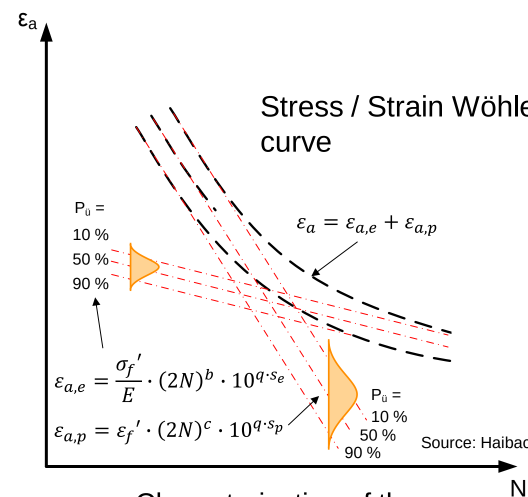
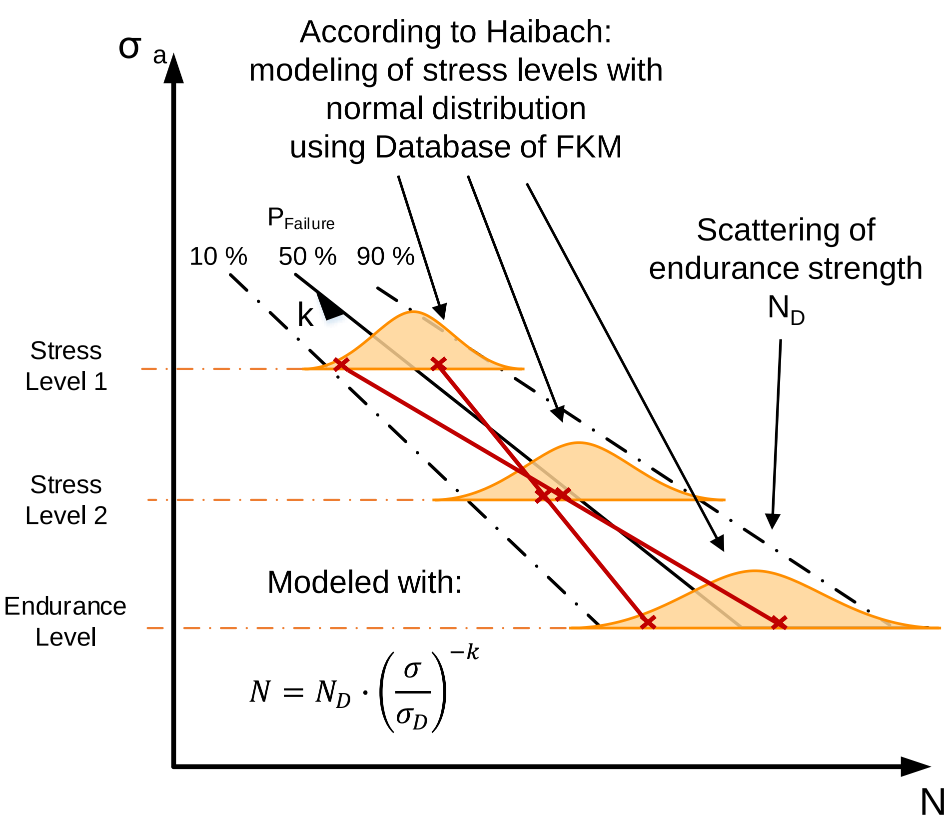


Source: Haibach 2005

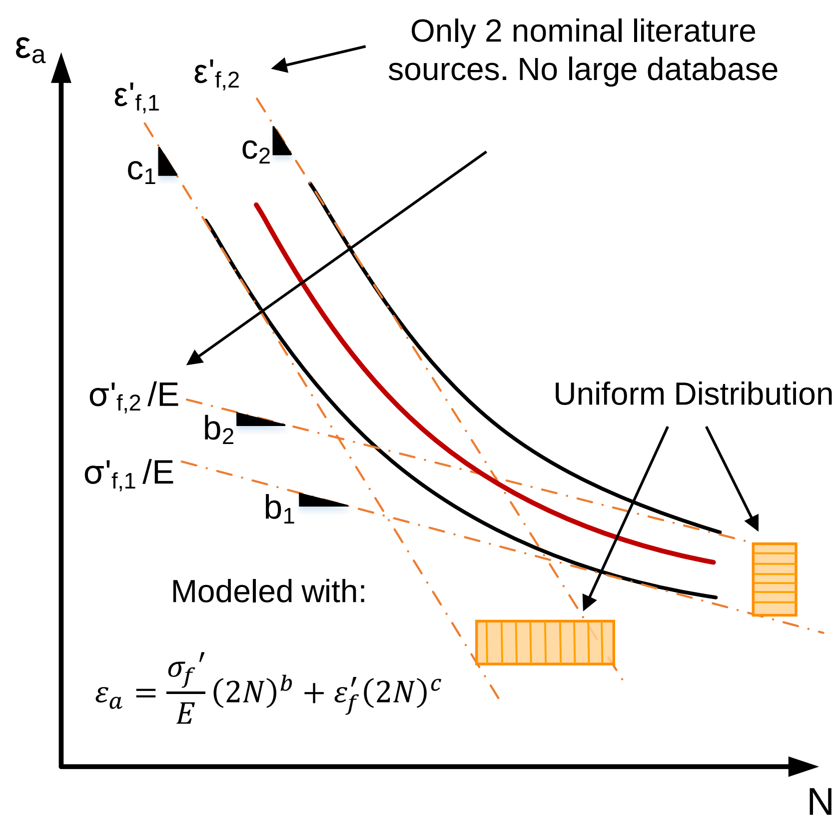
Characterization of the strength model

3. Simulation process – strength

Stress Wöhler curve



Strain Wöhler curve

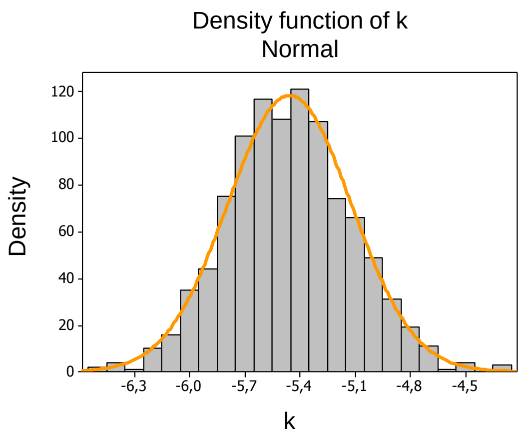


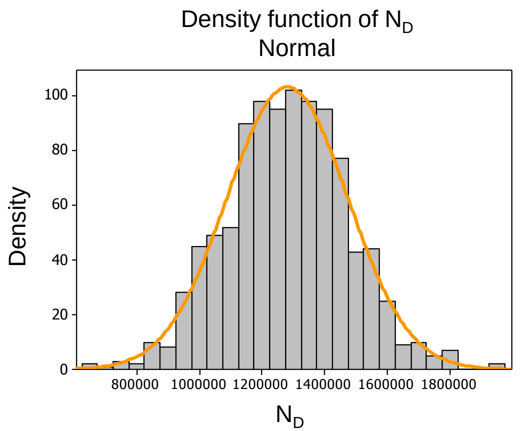
Determination of scattering of *k*: Monte Carlo Simulation using 3 interpolation points

Determination of scattering of σ'_f, ε'_f, *b* and *c*: Using uniform distribution between σ'_{f1} and ε'_{f1}

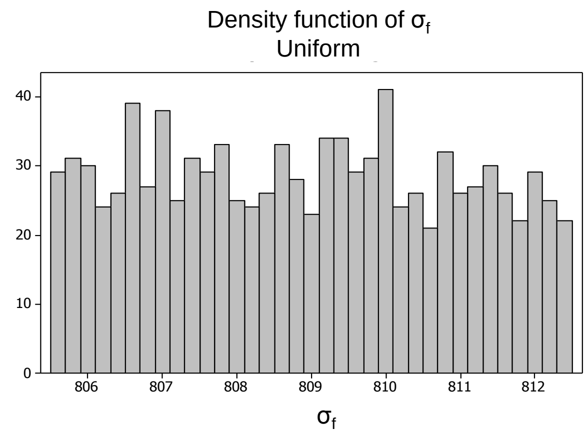
3. Simulation process – strength

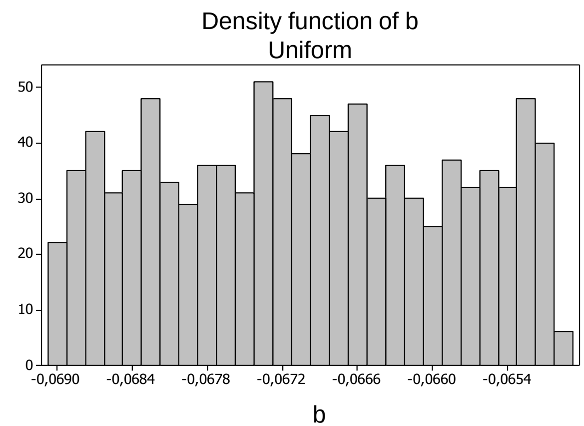
Result for variance of *k* and N_D of Stress Wöhler curve





Result for variance of σ'_f, ε'_f, b and c of Strain Wöhler curve





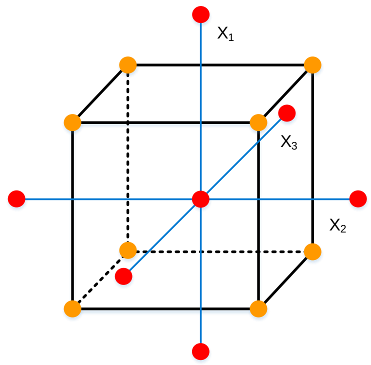
Compatibility condition according to Haibach:

Already determined

Using uniform distribution

$$n' = \frac{b}{c}\ ;\ k' = \frac{\sigma'_f}{(\varepsilon'_f)^{n'}}$$

Completely determined

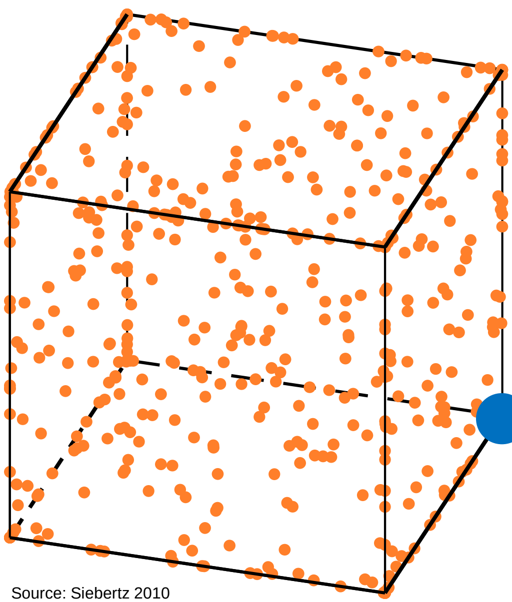


Virtual Lifetime Determination of
commercial vehicle braking systems

4. DESIGN OF EXPERIMENTS

4. Design of Experiments

Spacefilling
latinhypercube sampling



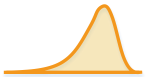
Source: Siebertz 2010

Optimal cover of the
parameter space

- Design Parameter

Using 3σ Normal Distribution

- Material Model



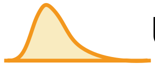
Using Distribution of smallest extreme values

- Strength Model

Stress: Using Normal Distribution

Strain: Using Uniform Distribution

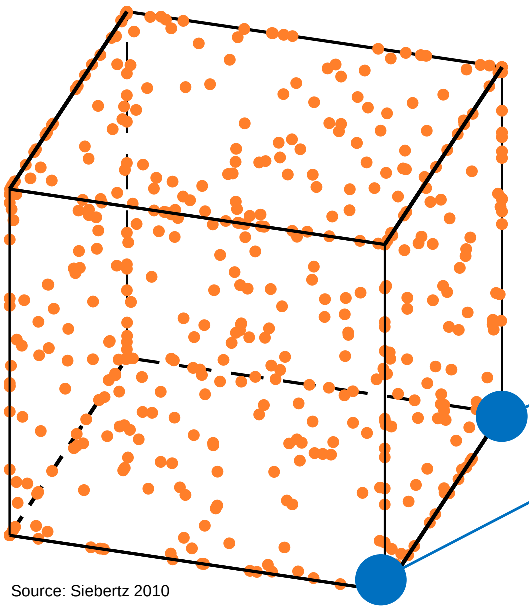
- Load Spectra



Using Lognormal Distribution and **ARSP**

4. Design of Experiments

Spacefilling
latinhypercube sampling



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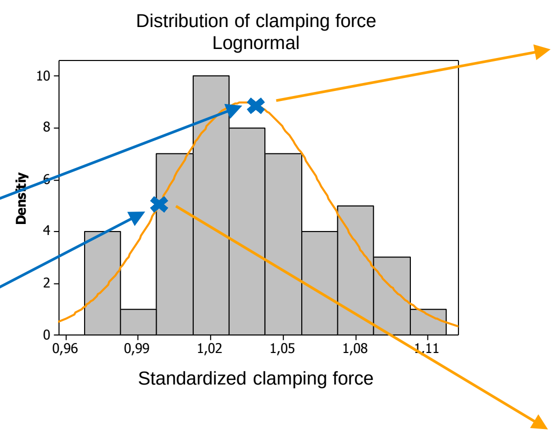
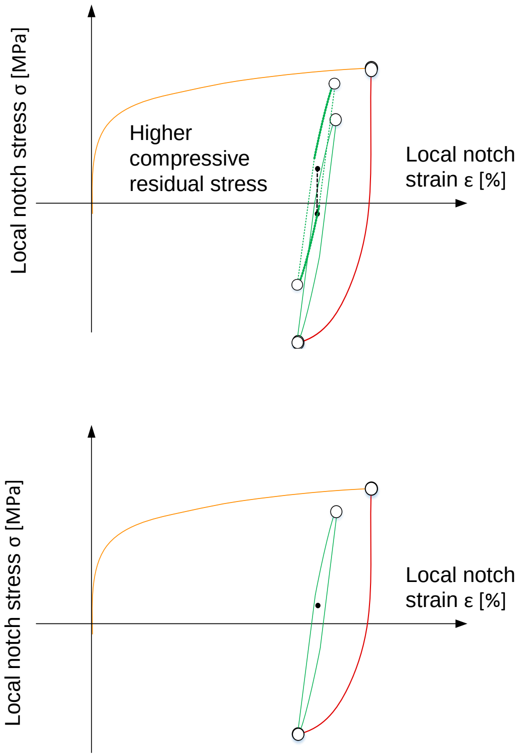
Optimal cover of the parameter space

Load Spectra

Using Lognormal Distribution and **ARSP**





Integration of the load spectrum through parametric study

Prof. Dr.-Ing. B. Bertsche; M. Sc. Martin Dazer

4. Design of Experiments

Sampling of

- Design Parameter
  - Material model

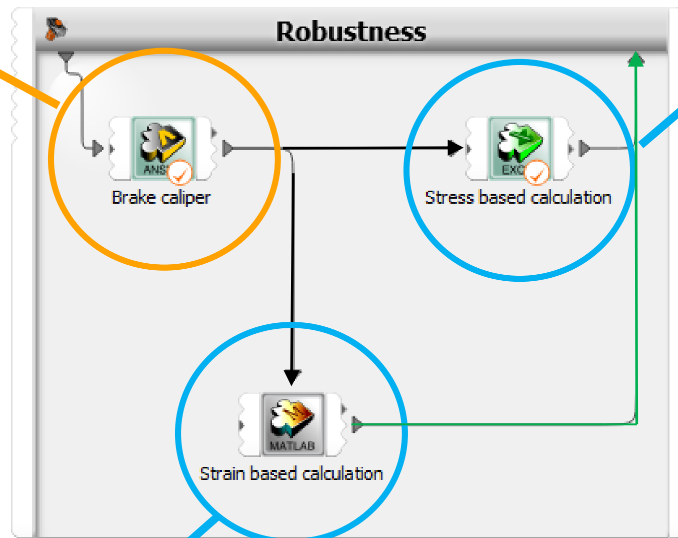
Sending deterioration outputs from FE-Simulation

Workflow Step 2

Sampling of

- Stress strength model
- Calculation of lifetime

Workflow Step 1



Workflow Step 3

Sending deterioration outputs from FE-Simulation

Workflow Step 2

Sampling of

- Strain strength model
- Calculation of lifetime

Workflow Step 3

Workflow Step 4

Sending back results to

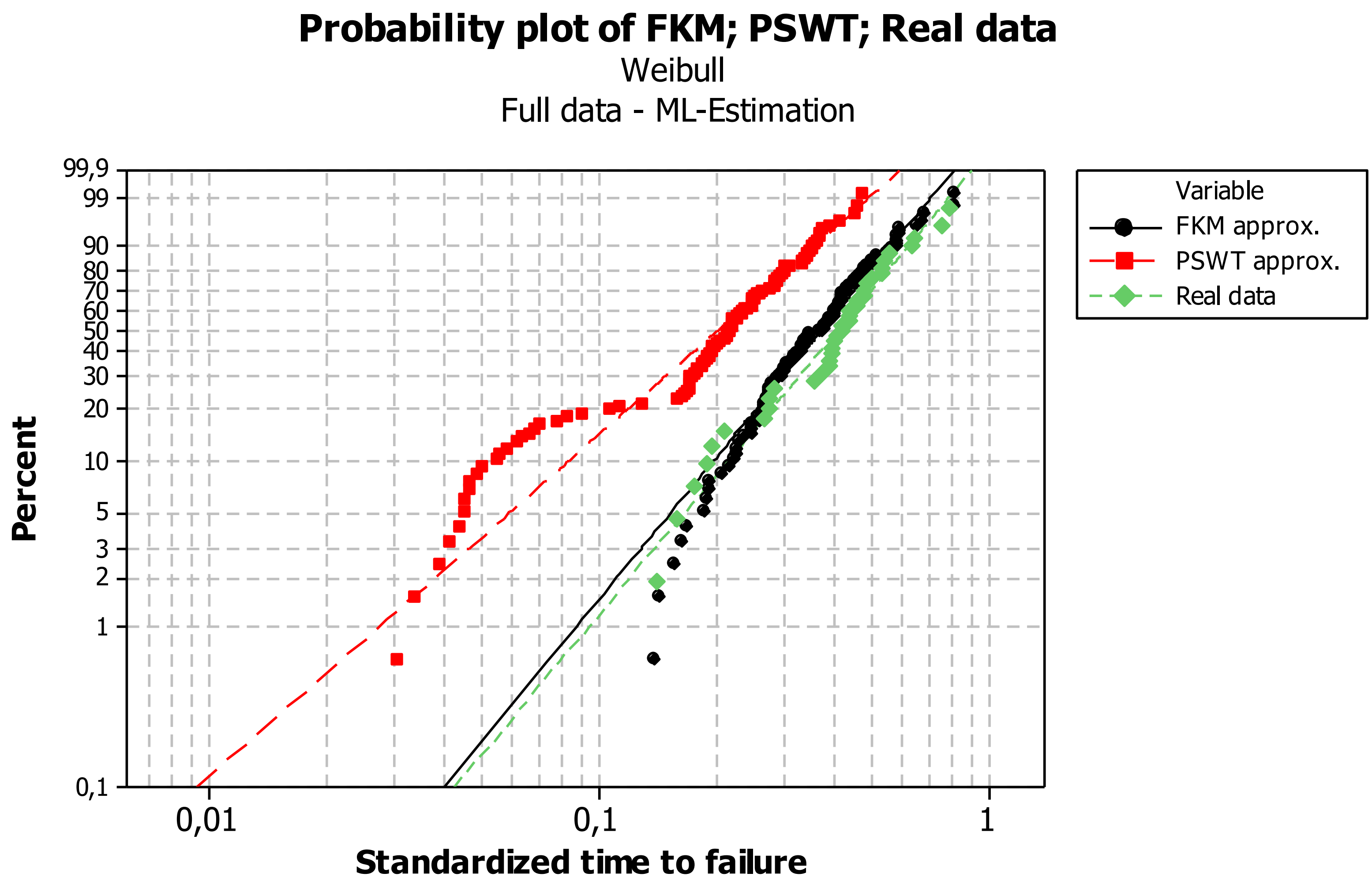
Robustness Analysis for Postprocessing

Prof. Dr.-Ing. B. Bertsche; M. Sc. Martin Dazer

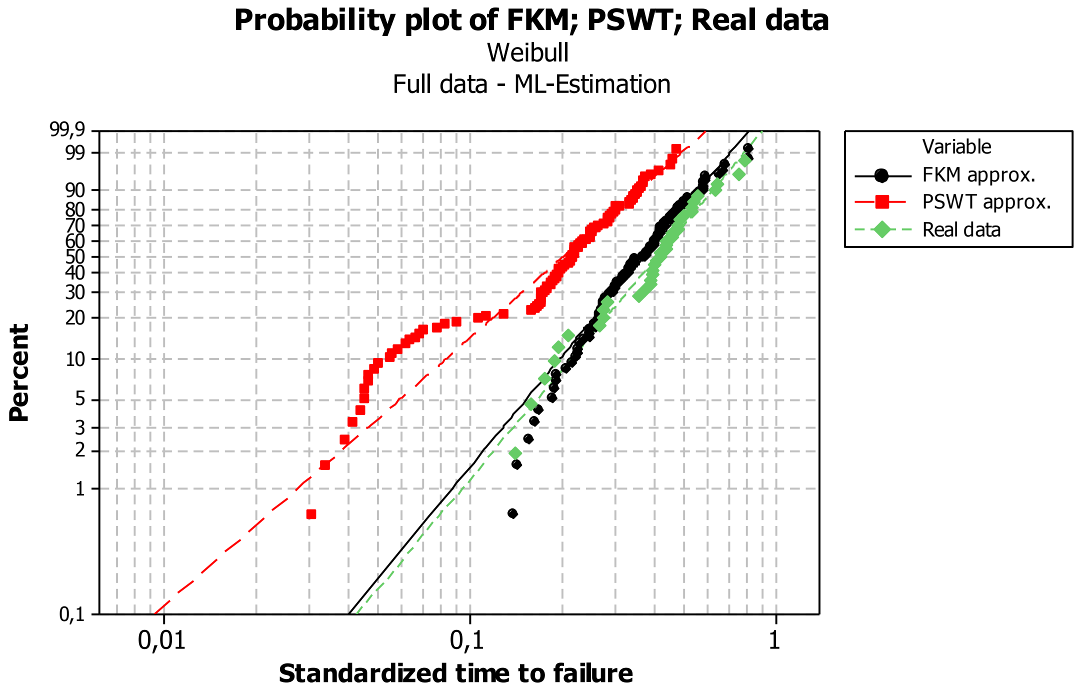
Virtual Lifetime Determination of
commercial vehicle braking systems

5. RESULT EVALUATION

5. Result Evaluation



5. Result Evaluation



- Very good approximation using stress based FKM algorithm
- Nearley same Weibull shape parameter b
- Small deviation in characteristic life time T
- Larger deviation on upper levels using strain based PSWT

- Pronounced Differences to conservative side for PSWT → Additionally insufficient fit
- FKM approximation slightly overestimates the real life time

Reason for this behavior:

Increasing plastic component of strain amplitude

Virtual Lifetime Determination of
commercial vehicle braking systems

6. SUMMARY AND OUTLOOK

6. Summary and Outlook

- Mapping of systematic uncertainties of
  - Design Parameter
  - Material model
  - Strength model
  - Load
- Development of a Accelerated Representative Simulation Process
- Succesfull development of a virtual lifetime distribution
  - Check of reproducibility
  - Future investigations to the influence of plastic compontents in strain amplitudes for deterioration calculation
  - Investigations to the strain based strength model

Increase of maturity level in early design stages!

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THANK YOU FOR YOUR ATTENTION!