



CONCEPT STUDY FOR CONSIDERATION OF SCATTERING INPUT PARAMETERS IN STRUCTURAL DURABILITY SIMULATIONS APPLIED TO AUTOMOTIVE COMPONENTS SUBMITTED TO VIBRATION LOADS.

ECS SIMULATION CONFERENCE 2023.
SVEN MAIER^{1,2} & FLORIAN BACHMANN¹

¹BMW AG, KNORRSTR. 147, 80788 MUNICH

²TECHNISCHE UNIVERSITÄT DARMSTADT, KAROLINENPLATZ 5, 64289 DARMSTADT

CONTENTS.

1. Introduction.
2. Concept for consideration of uncertain input parameters in structural durability simulations.
3. Concept application to automotive component submitted to vibrational load.
4. Benefit of superelements within the concept.
5. Outlook.

INTRODUCTION.

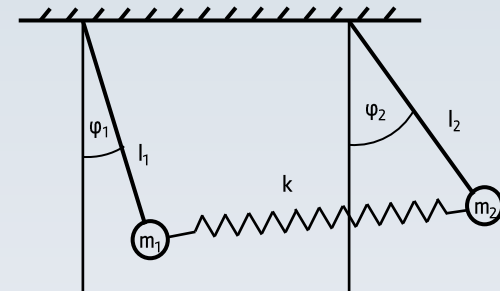
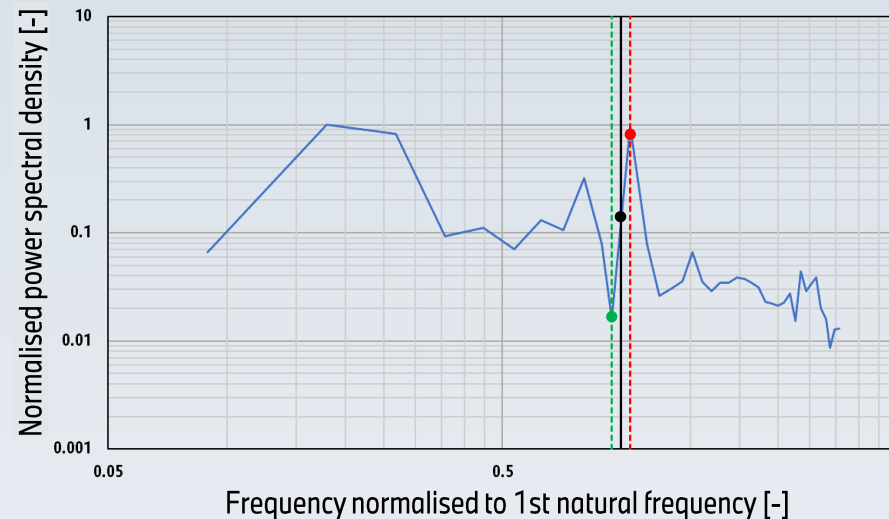
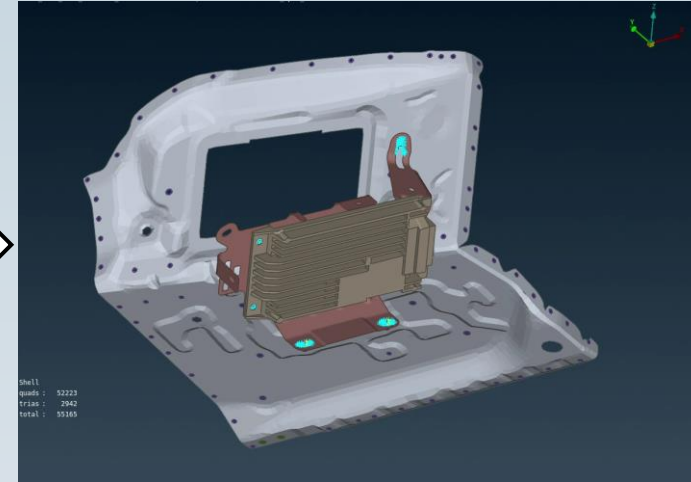
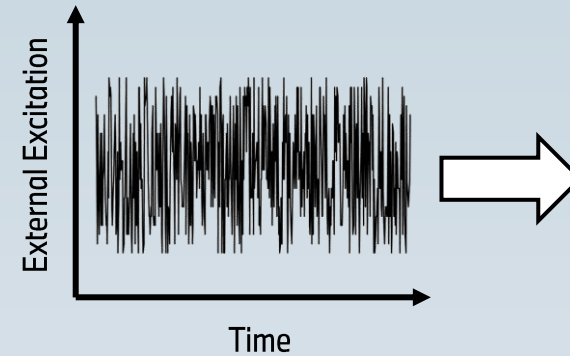
- Numerous subsystems for comfort, safety, electrification in modern vehicles.
- Mounted Parts are submitted to vibration loads (road excitation).
- Local occurrence of mass-force excitation.

State of the Art in structural durability assessment

- Reliability and safety factor concept on mainly experimental basis.

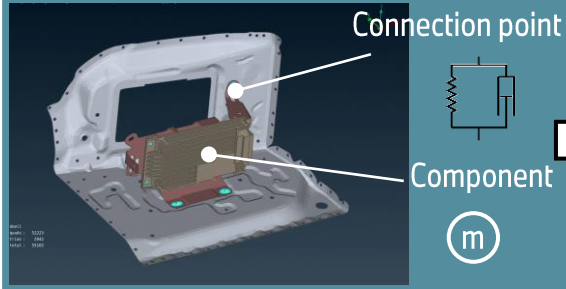
⚡ Application limited for mass-force excited components:

- Frequency-dependent power content in load spectrum.
 - Coupling vibration.
 - High impact of vibration behaviour on fatigue lifetime.
- Minor uncertainties in input parameters can significantly change the vibration behaviour.
 - Estimation of "Safe side" by means of safety factor not clearly possible.



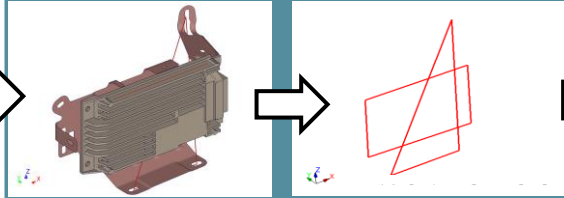
CONCEPT.

① Definition of Parameter space & target value



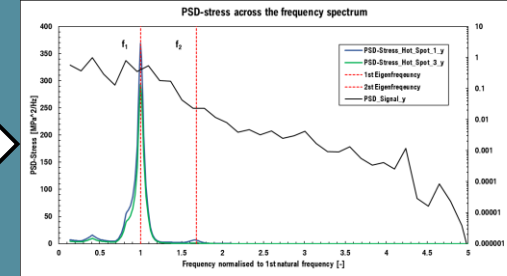
Definition & acquisition of parameter scatter bounds & distributions

② Model reduction



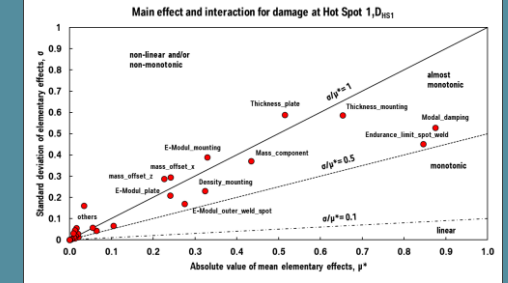
Reduction of computational time (e.g. Superelements)

③ Analysis of relevant frequency spectrum



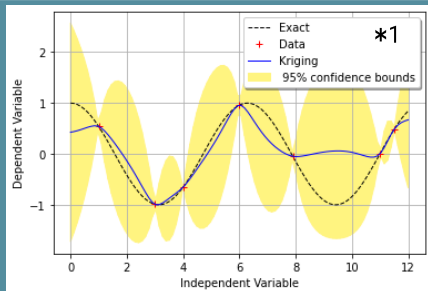
Investigation of stress across the frequency

④ Qualitative sensitivity analysis



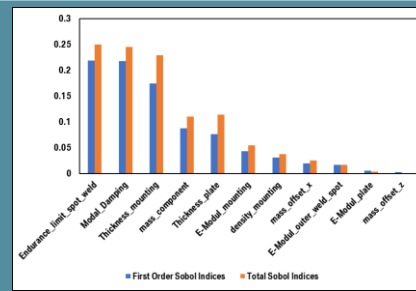
Morris plot for qualitative identification & discarding of non-influential parameters

⑤ Surrogate models



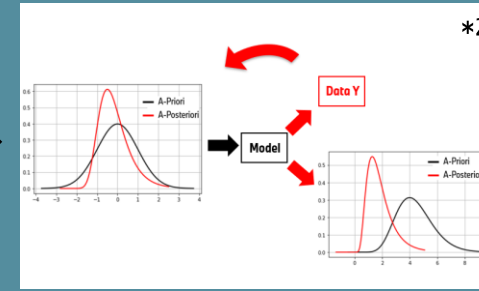
Generation of higher numbers of samples

⑥ Quantitative sensitivity analysis



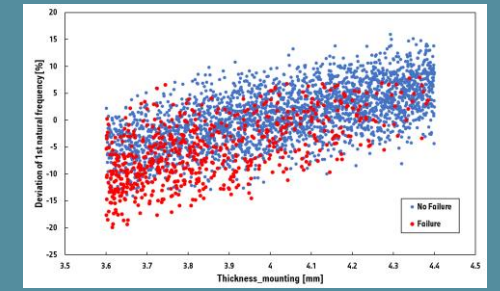
Identification of most influential parameters (e.g. Sobol Indices)

⑦ Uncertainty Quantification by means of an inverse Parameter calibration



Calibration of difficult-to-measure parameters using modal measurement data

⑧ Uncertainty Propagation and Reliability Analysis

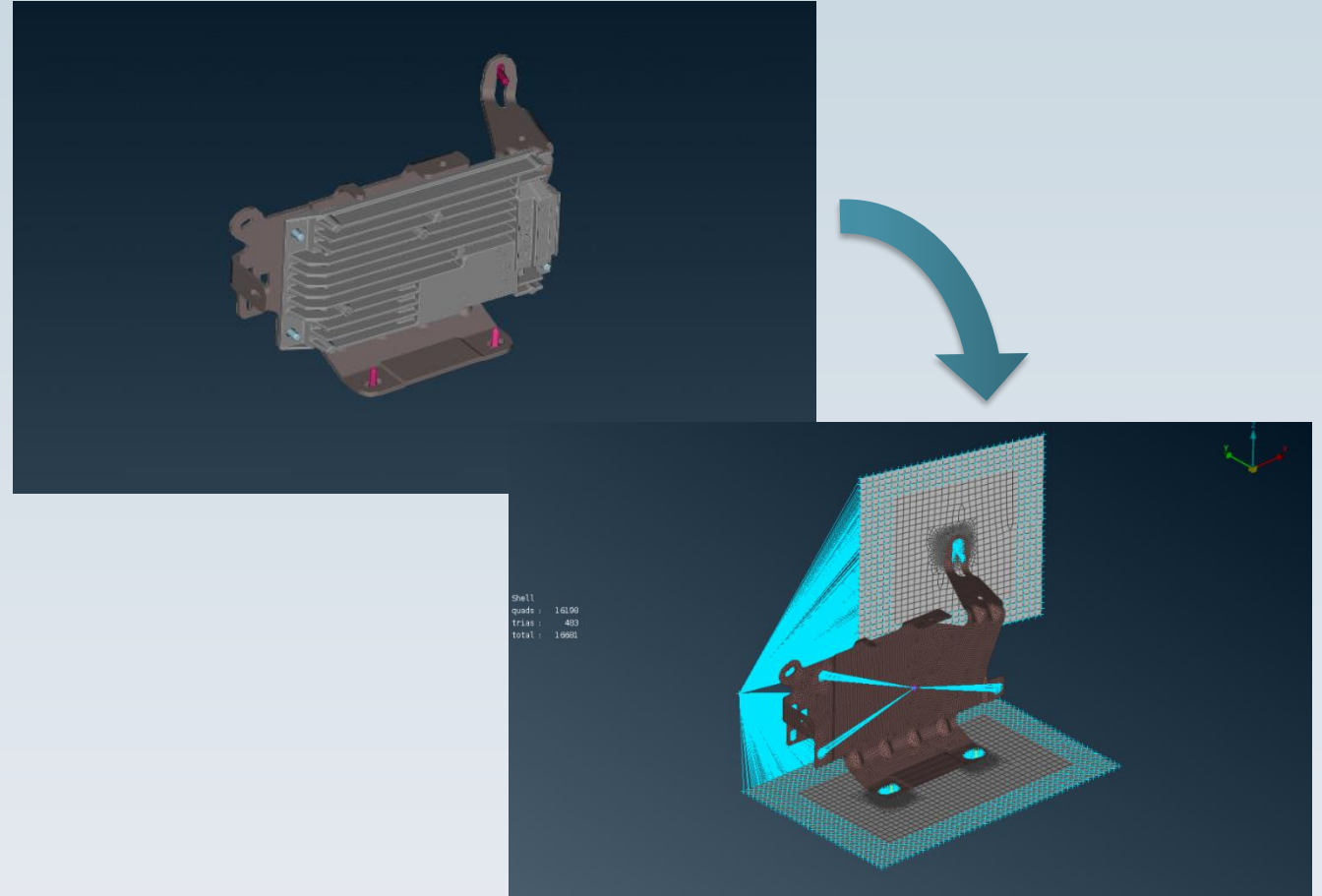


Derivation of limits for parameters & frequencies. Evaluation of the robustness

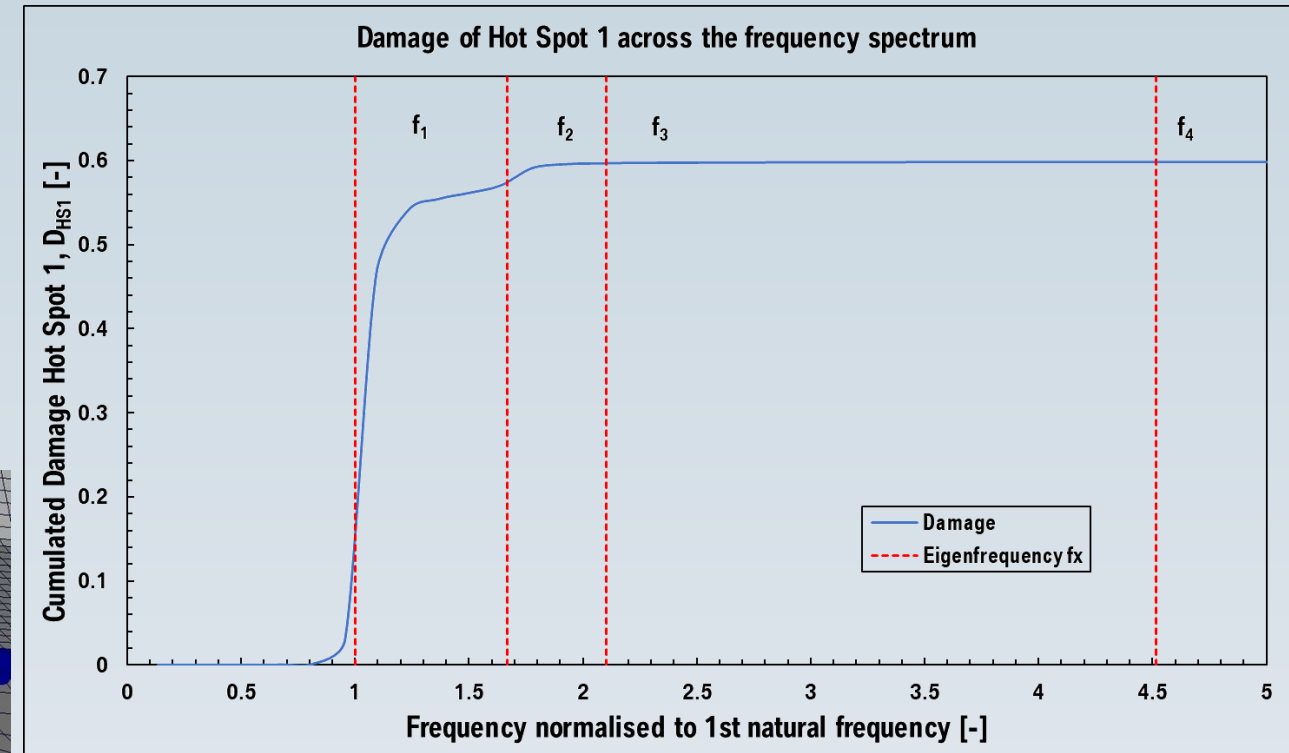
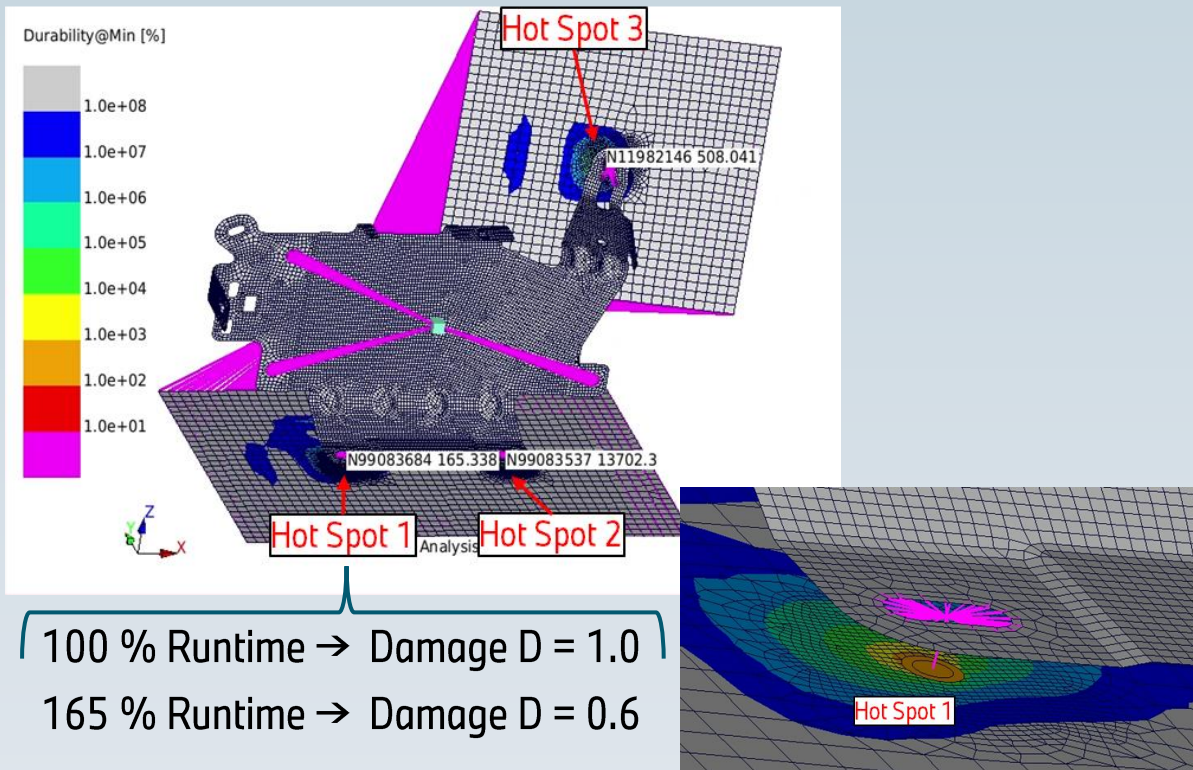
EXAMPLE AUTOMOTIVE COMPONENT SUBMITTED TO VIBRATIONAL LOAD.

FE-Model data

- Mounted component realised as point mass (with concentrated mass & mass moments of inertia).
- Connection to thin plates:
 - 0,8mm Thickness
 - Measures: 310x200mm & 200x200mm
- Connection of the mounting via CBARs und FemFat-Spots.
- Rigid constraint of the edges with RBE2 elements.
- Point excitation at the master node.



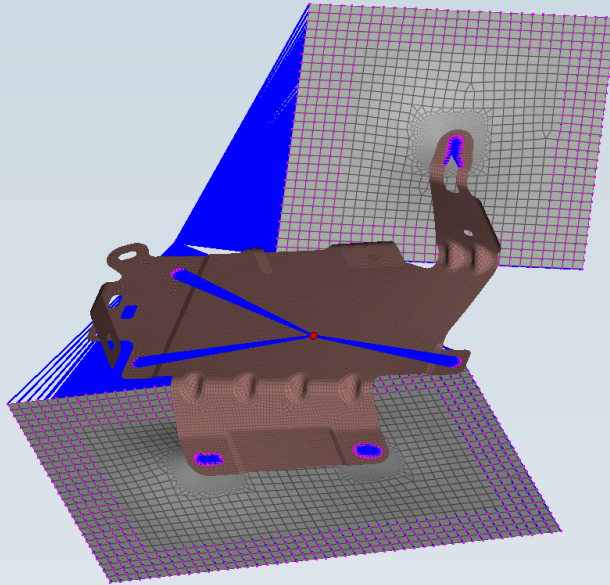
ANALYSIS OF THE RELEVANT FREQUENCY RANGE.



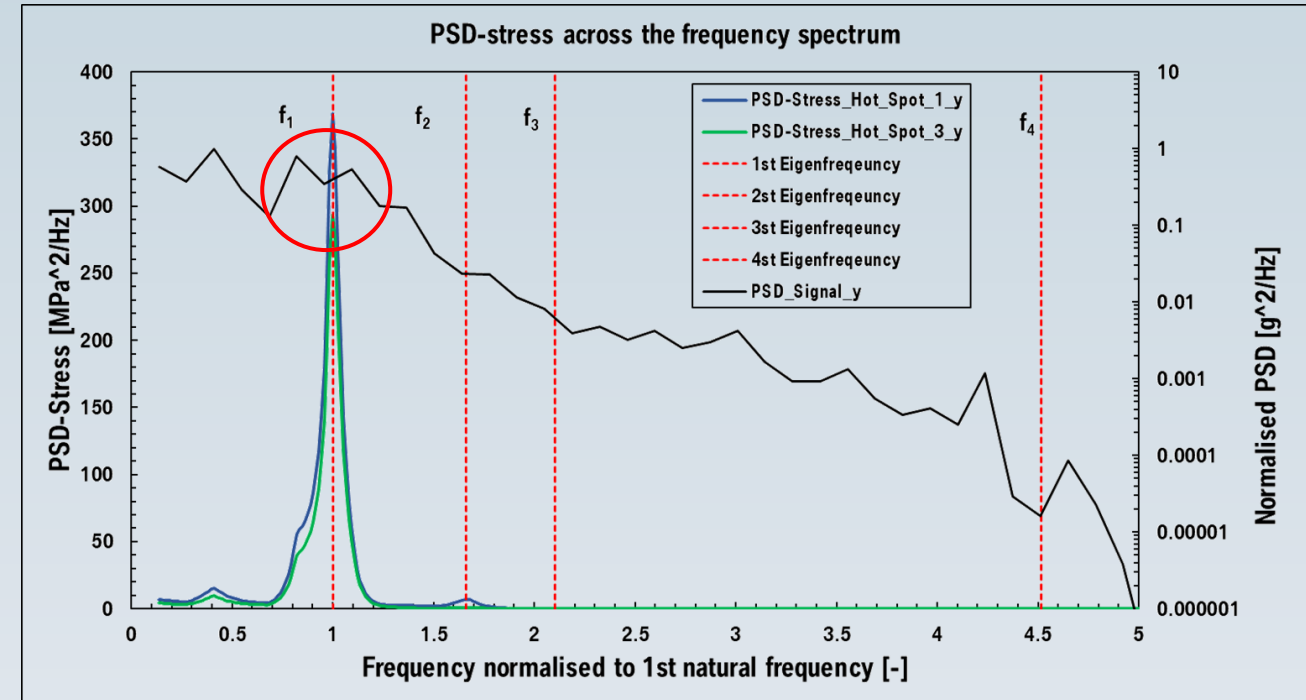
- Three Hot Spots can be identified. Hot Spot 1 (HS1) is most critical.
- Frequency spectrum at 1st natural frequency is most damage-relevant.

ANALYSIS OF THE RELEVANT FREQUENCY RANGE.

1st – 4th natural frequencies of the system



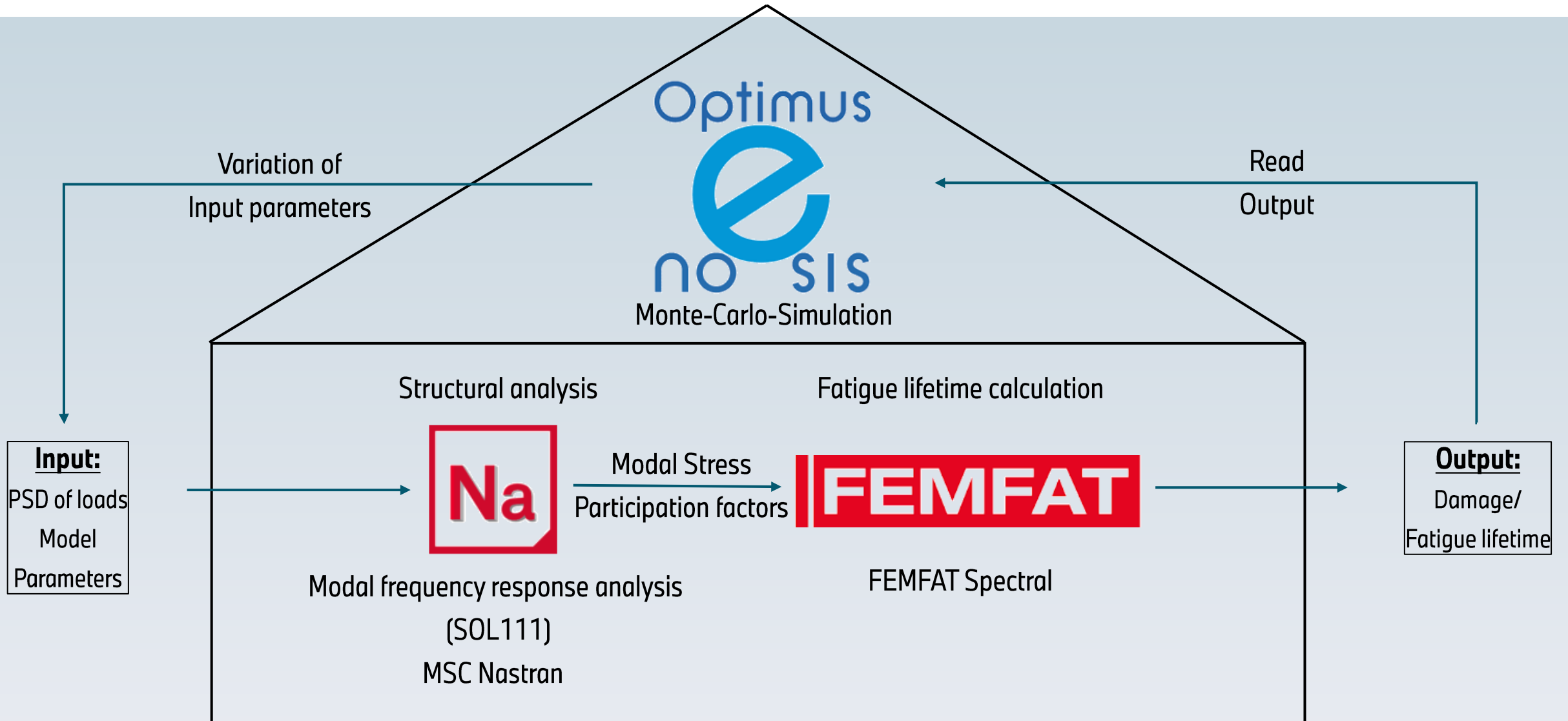
Y-Direction



- Highest PSD-Stress occur at frequency spectrum at 1st natural frequency.
- Shift in 1st natural frequency to lower and higher frequencies results in PSD-Stress increase in Y-Direction → "Safe Side"!?

WORKFLOW FOR MULTI-PARAMETER VARIATION.

SCHEMATIC CALCULATION PROCESS.

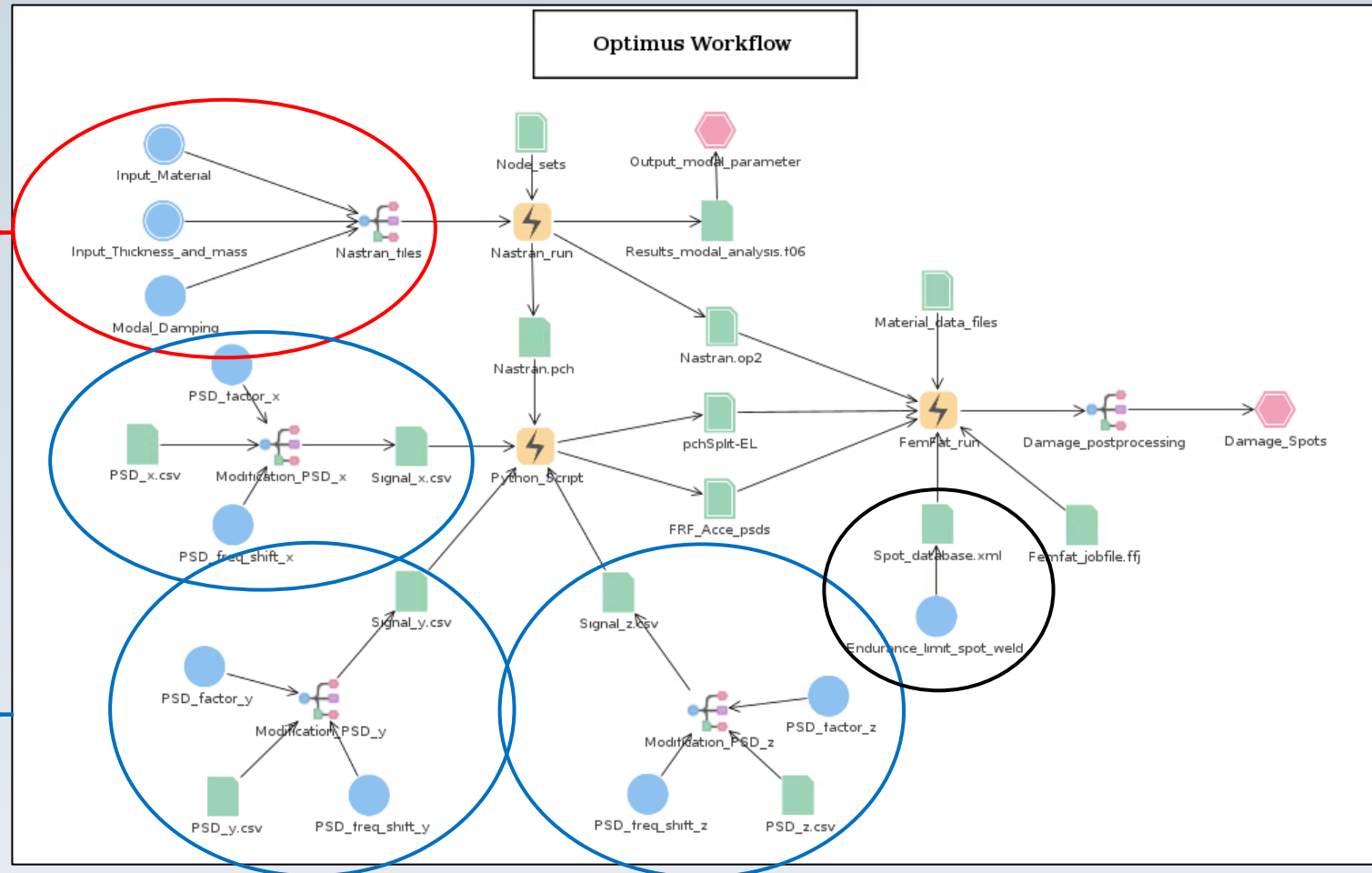


OVERVIEW PARAMETERS & OPTIMUS WORKFLOW.

- 29 uncertain parameters considered → Material, Geometry, physical quantities, Signal.
- Uniform distribution with 10% scatter assumed

- E-Modul, density, poisson, thickness of plate & mounting
- modal damping (20%), mass, mass moments of inertia, mass offset
- E-Modul of spot and connection

- Modification of the PSD signals:
- Magnitude
- Shift (-5 until 5 Hz)

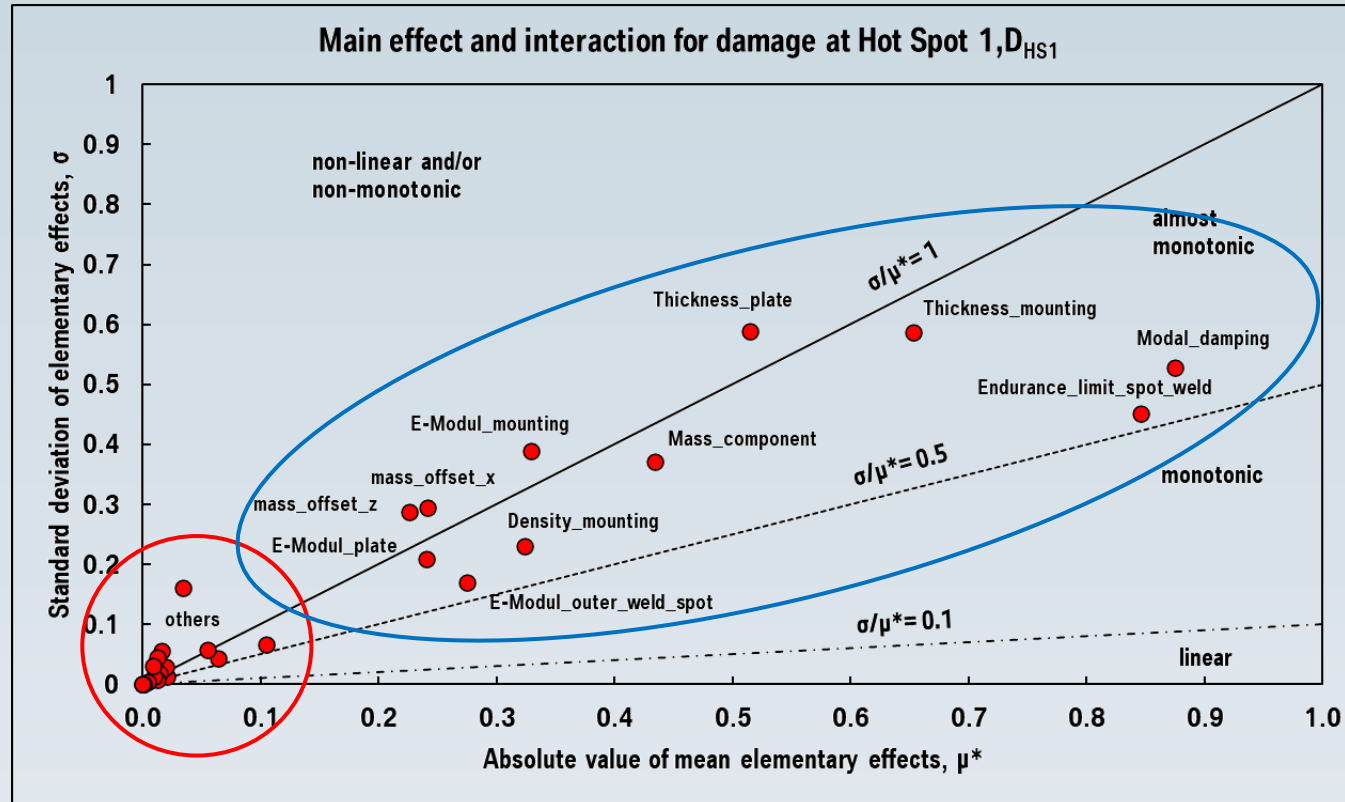


- Endurance limit of spot weld

QUALITATIVE SENSITIVITY ANALYSIS.

MORRIS-METHOD.

Exploration of Parameter space



Qualitatively most significant Parameter
Modal_damping
Endurance_limit_spot_weld
Thickness_mounting
Thickness_plate
Mass_component
E-Modul_mounting
Densitiy_mounting
E-Modul_outer_weld_spot
E-Modul_plate
Mass_offset_x
Mass_offset_z

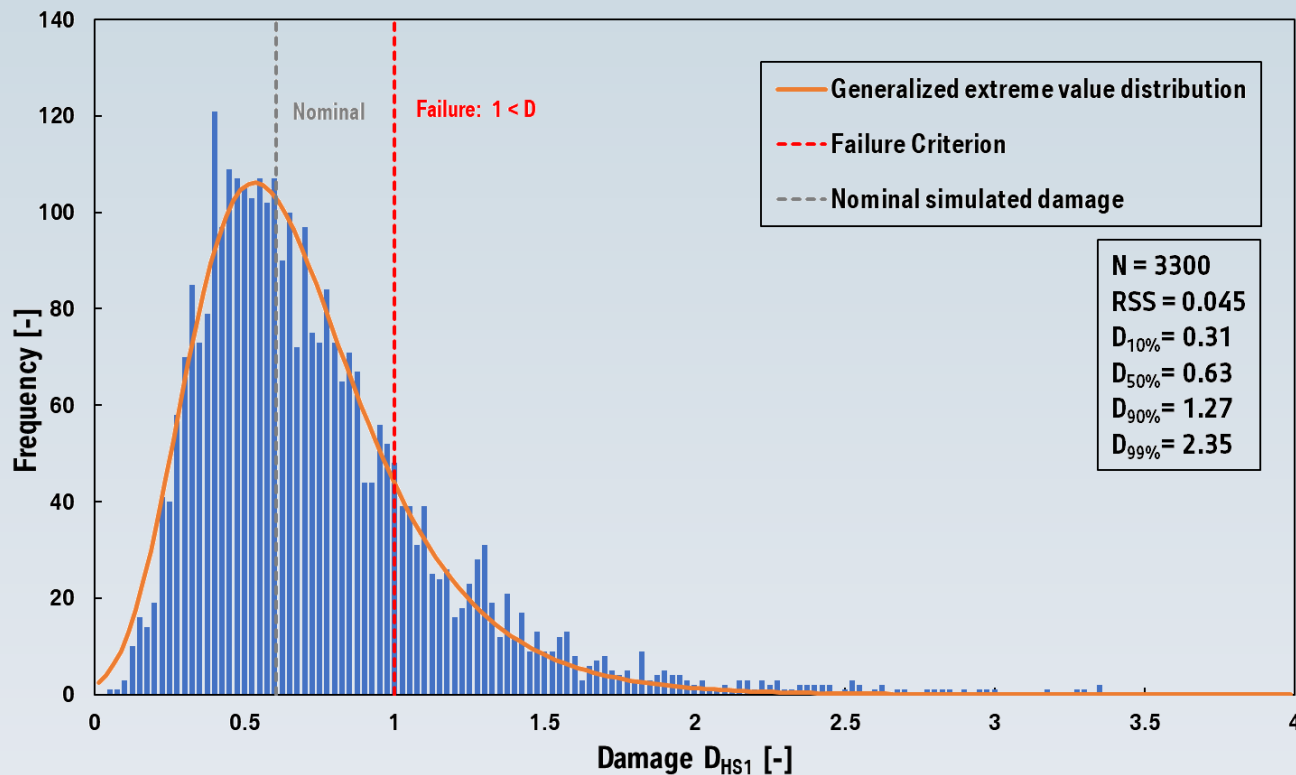
High μ^* → strong direct influence on target value (Main effect)

High σ → strong indirect influence on target value (Interaction)

- 750 samples used for calculation.
- Identification of non-influential Parameters.
- Reduction of dimensionality.

MONTE-CARLO-SIMULATION.

DAMAGE DISTRIBUTION.



- DoE - Latin-Hypercube Simulation (3300 samples).
- Scattering of the 11 Parameters (identified by Morris-Method).
- Determination of damage distribution $\rightarrow$ GEV.
- GEV: Generalized extreme value distribution.
- Probability of Failure $P_f = 0.2$

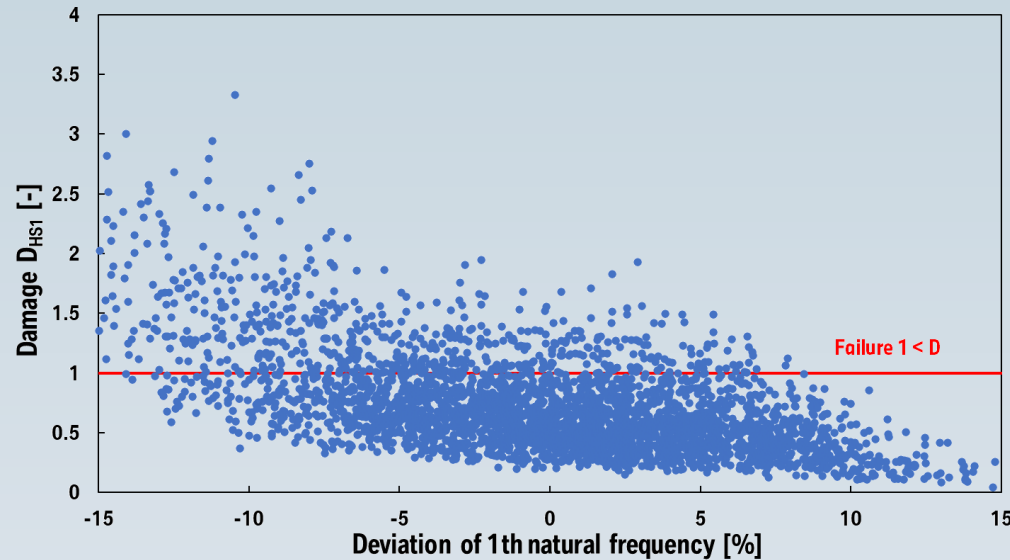
Residual sum of squares

$$RSS: \sum_{i=1}^n (y_i - f(x_i))^2$$

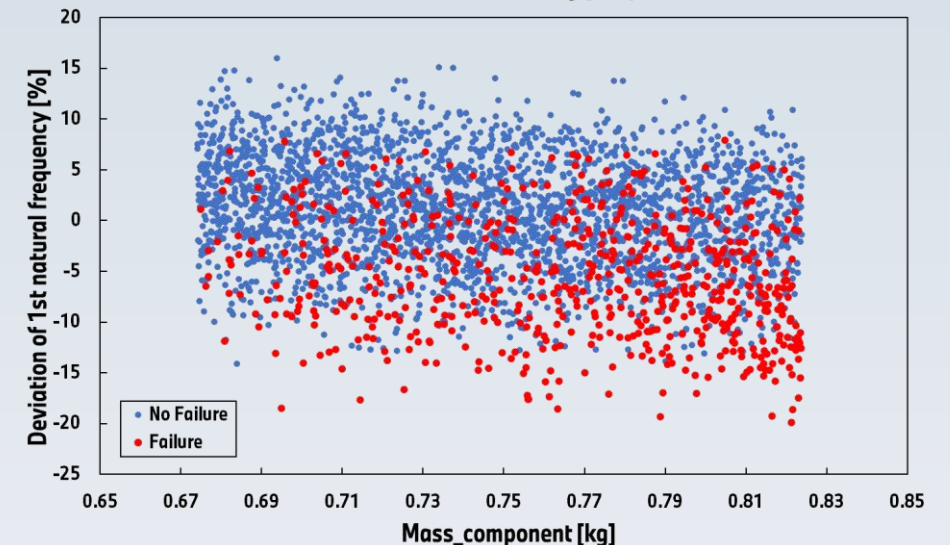
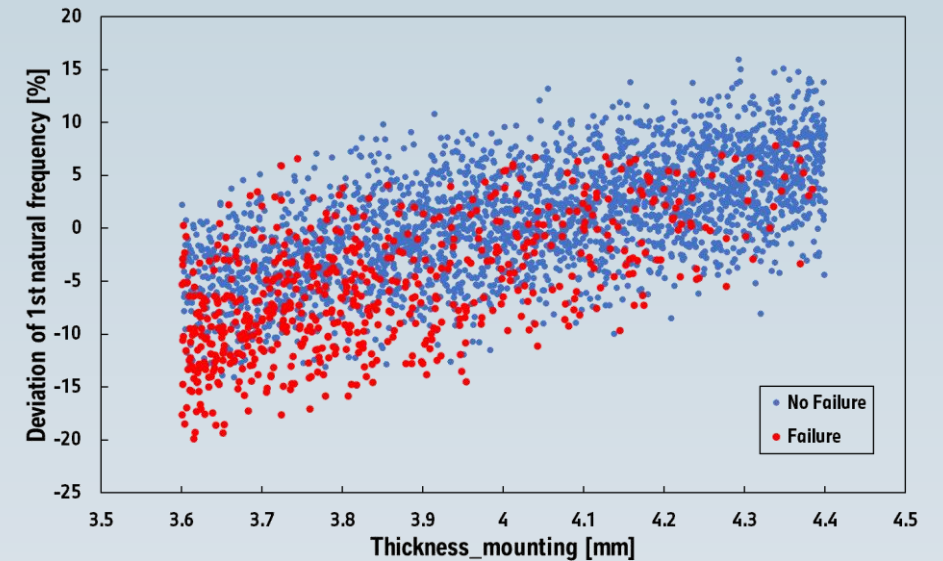
Measure of the discrepancy between the data and an estimation model

Distribution	RSS
GEV	0.045
Lognormal	0.049
Gamma	0.199
Beta	0.2
Normal	1.909

CORRELATION BETWEEN NATURAL FREQUENCIES AND DAMAGE.



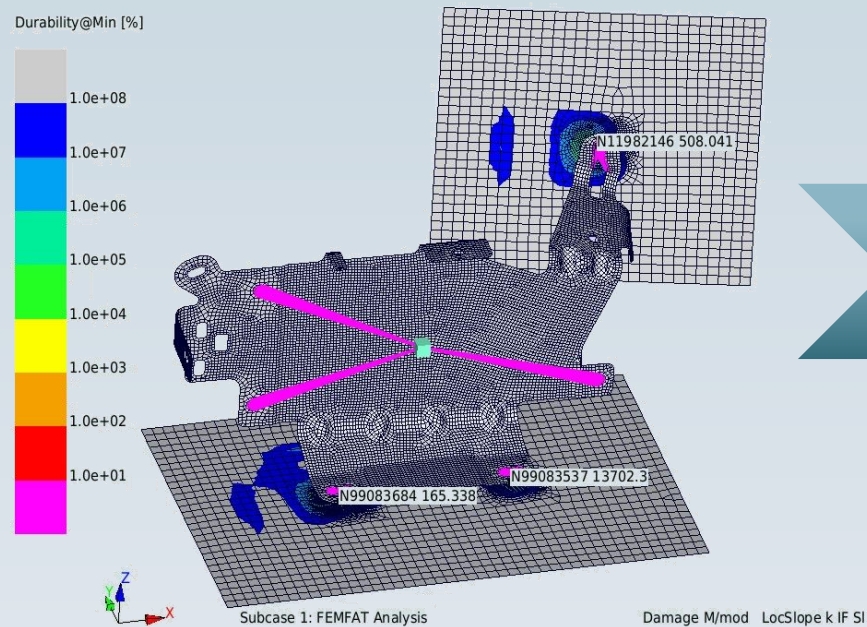
- Decrease in natural frequencies → increase in damage.
- Typically, increasing power content of the load at lower frequencies.
- Parameters with a strong influence on the vibration behavior also have a high impact on the fatigue lifetime e.g. Thickness mounting & plate, mass.
- In addition to damage, natural frequencies and eigenmodes are important assessment criterion for mass-force-excited components.



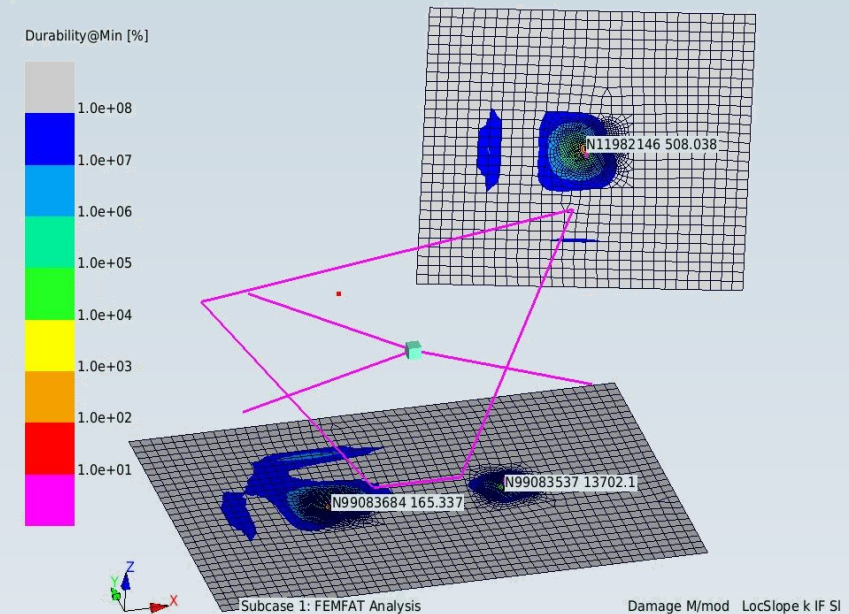
MODEL REDUCTION.

SUPERELEMENTS.

Standard FE-Model



Reduced Order Superelement Model



- Reduction of the FEM modeled mounting to a superelement with mass and stiffness matrices → 60% reduction of calculation time.
- Identical results for calculated damage.

FEMFAT SPECTRAL IN COMBINATION WITH SUPERELEMENT DATA RECOVERY.

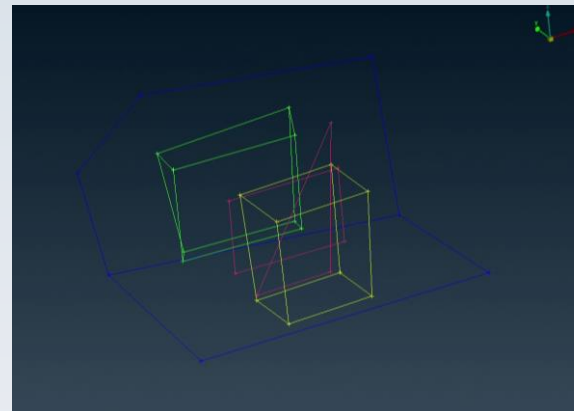
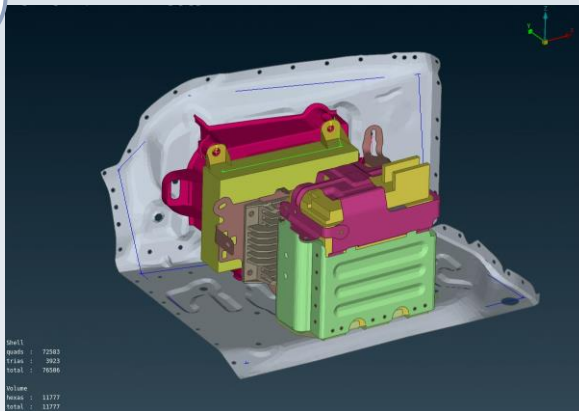
OUTLOOK.

- Many runs in Nastran for DoE
- Reduction of components and structures in superelements for full vehicle simulations
- Assessment of Hot spots envisaged
- To date, no assessment possible for Hot Spots in superelements
- Data recovery of critical areas necessary

- FemFat development team supports future evaluation of stress data recovery data blocks
- FemFat enables complete vehicle simulations with scattering input parameters

FEMFAT

Na



DoE: Design of Experiments

THANK YOU FOR YOUR ATTENTION!

