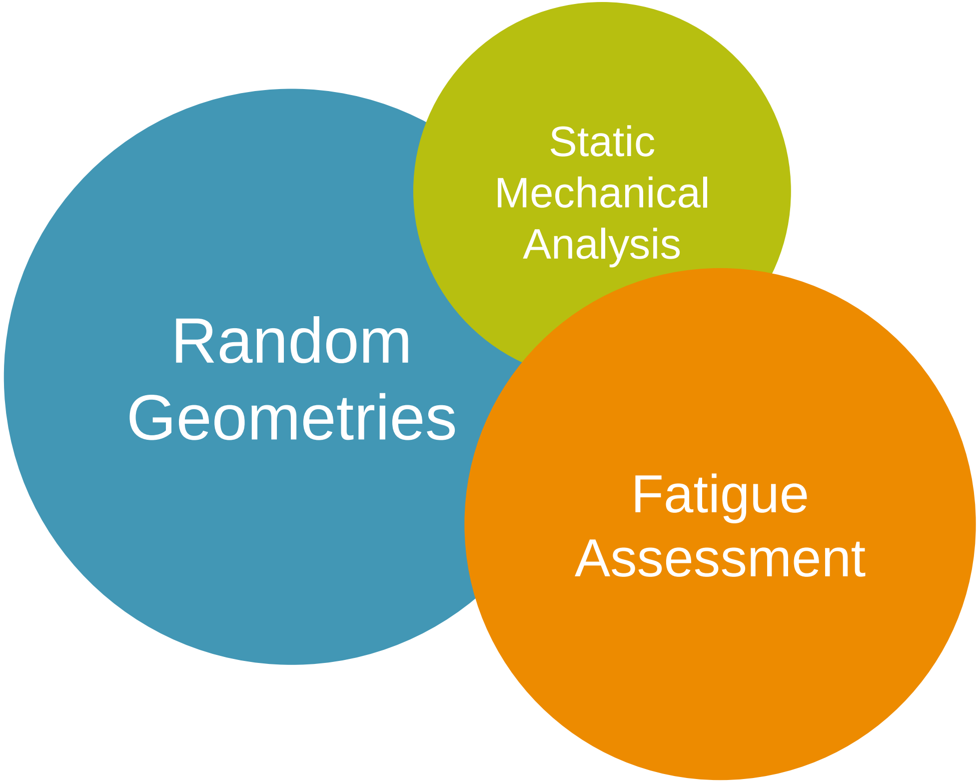
Influence of manufacturing tolerances on fatigue life estimation

R. Pschera, R. Lampert, S. Wolff

Overview

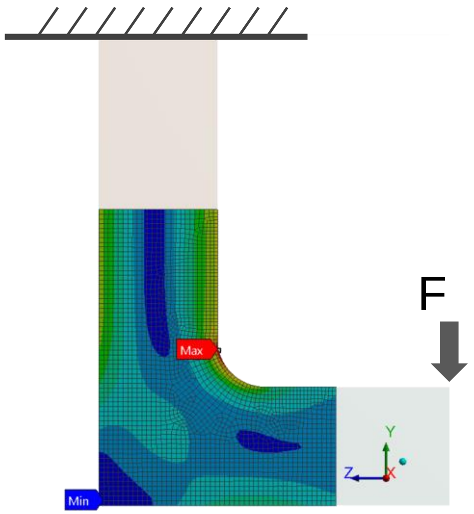


Workflow

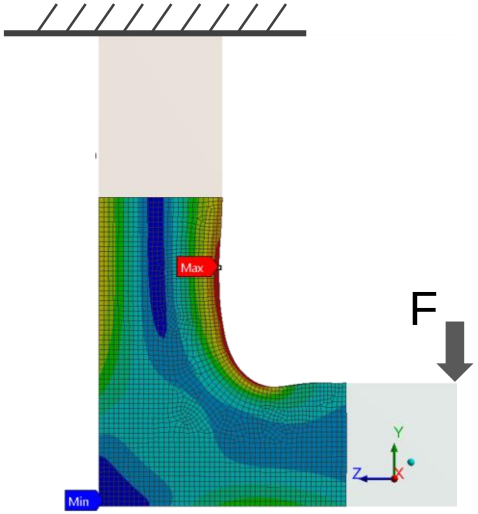
Problem and Objective

Geometry optimization can be done easily using optiSLang presuming a managed workflow

Initial System



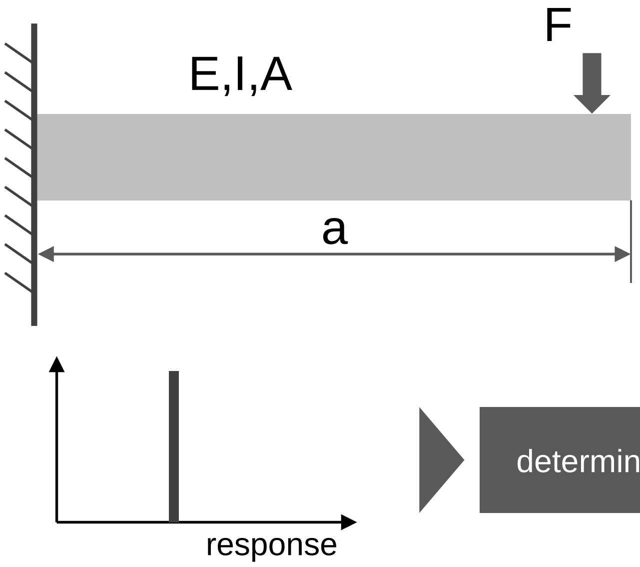
Optimized System



Geometry may be considered as a random variable. Suitable descriptions of their variations is necessary. The simulation process has to be managed in a workflow.

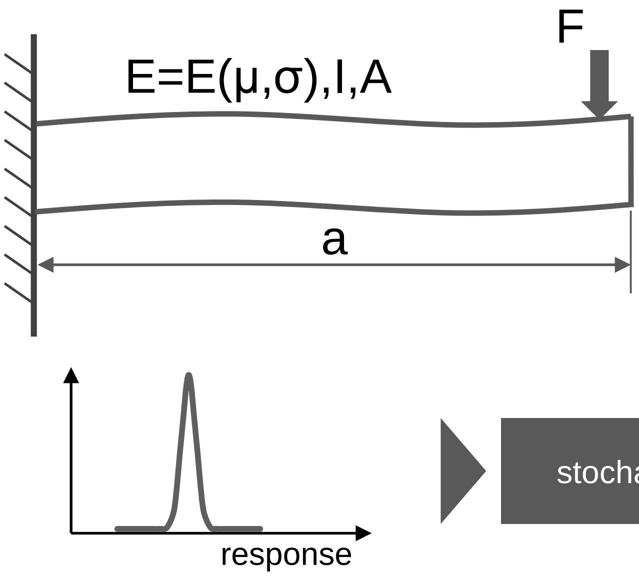
The stochastic description of a real system presumes a managed workflow and a suitable description of variations

Ideal system



deterministic response

Real system

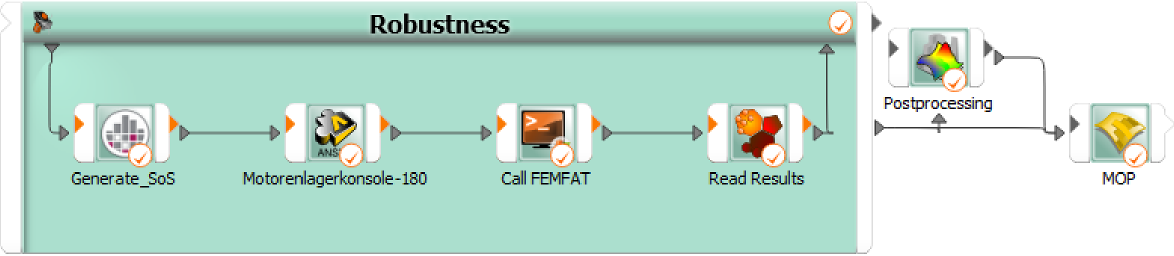


stochastic response

Material properties and geometry may be considered as random variables. Suitable descriptions of their variations is necessary. The simulation process has to be managed in a workflow.

How to Define the Robustness of a Design

- **Intuitively**: The performance of a robust design is largely unaffected by random perturbations



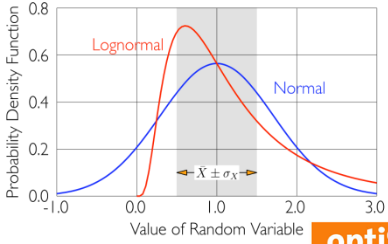
- **Variance indicator**: The coefficient of variation (CV) of the objective function and/or constraint values is smaller than the CV of the input variables

- **Sigma level**: The interval mean+/- sigma level does not reach an undesired performance (e.g. design for six-sigma)

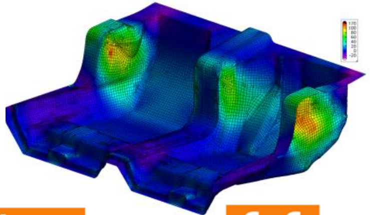
- **Probability indicator**: The probability of reaching undesired performance is smaller than an acceptable value

Robustness Evaluation using optiSLang and SoS

1) Define the robustness space using scatter range, distribution and correlation

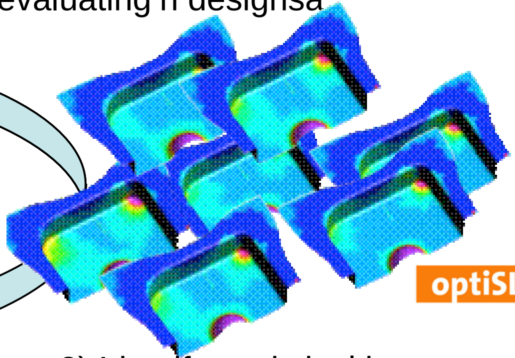


optiSLang



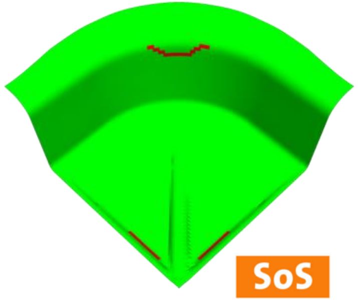
SoS

2) Sampling: Scan the robustness space by producing and evaluating n designsa



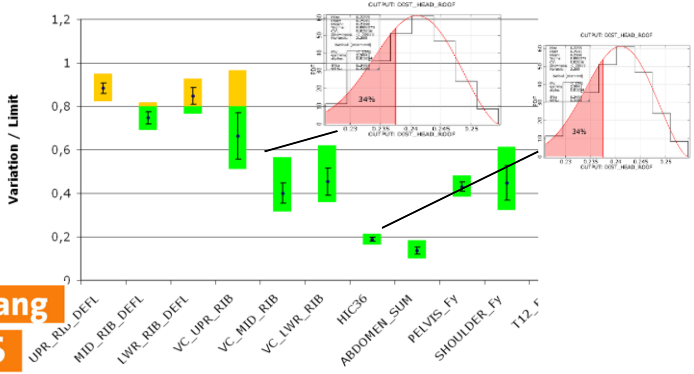
optiSLang

3) Identify statistical hot spots

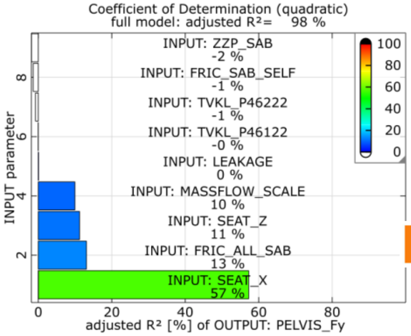


SoS

4) Check the variation



5) Identify the most important scattering variables



optiSLang

SoS

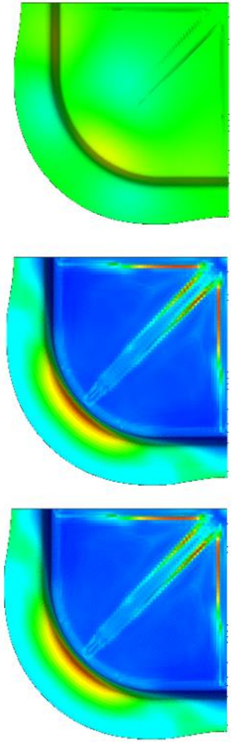
Decision process
Size of test series vs. numerical accuracy

Depending on available data:

1. **No or only a single measurement**:
   Use assumptions
   Synthetic random field model
   Test if the field variations have impact

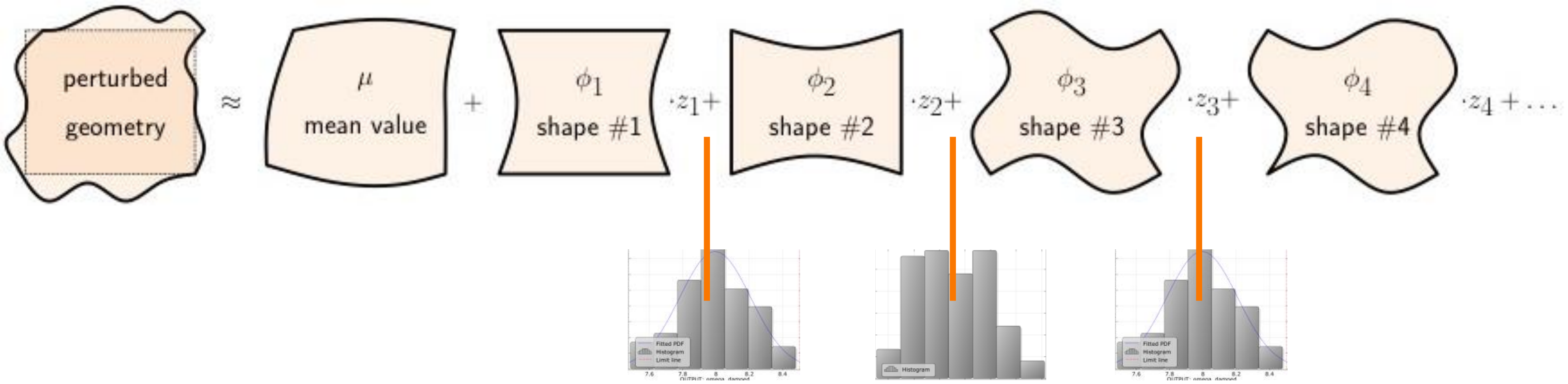
2. **Few number of measurements**:
   Assumed correlation, but empirical mean/sigma
   Synthetic random field model
   Test if “true” magnitude of variation is important

3. **Many measurements**:
   Anisotropic, inhomogeneous, Non-Gaussian
   Empirical random field model
   Model accurate statistics using large test series

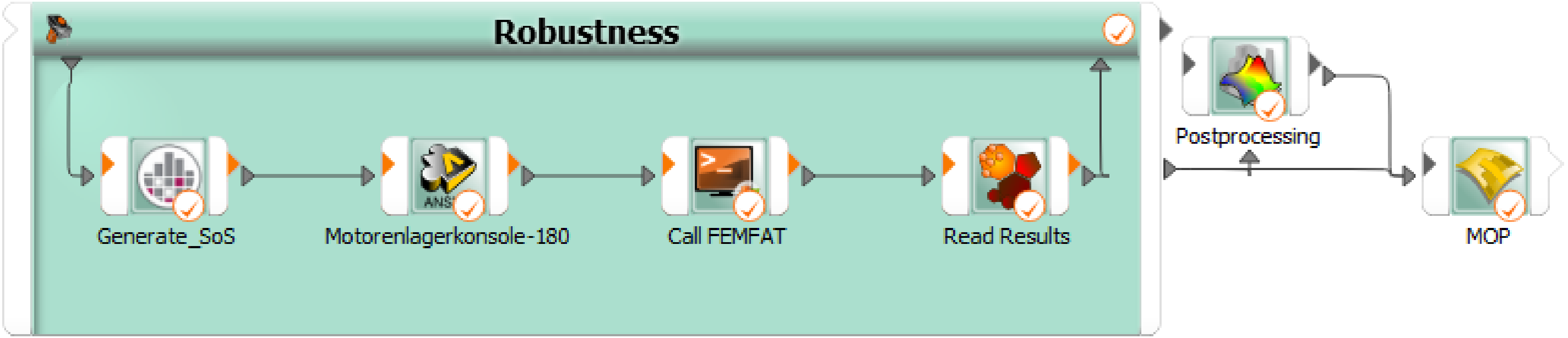


Parameterization of measured geometries
Based on measurements or virtual experiments

- Measured spatial field variations:
  - Geometries, thinning, strains, etc.
- Spatial field variations from simulation:
  - Displacements, thinning, remaining stresses, plastic strains, etc.
- New parameters “z”: describe the full variation shape pattern of the measured geometry, strain field, thinning etc.



A workflow is set up in optiSlang linking SoS, ANSYS WB and FEMFAT to evaluate robustness of the cast structure

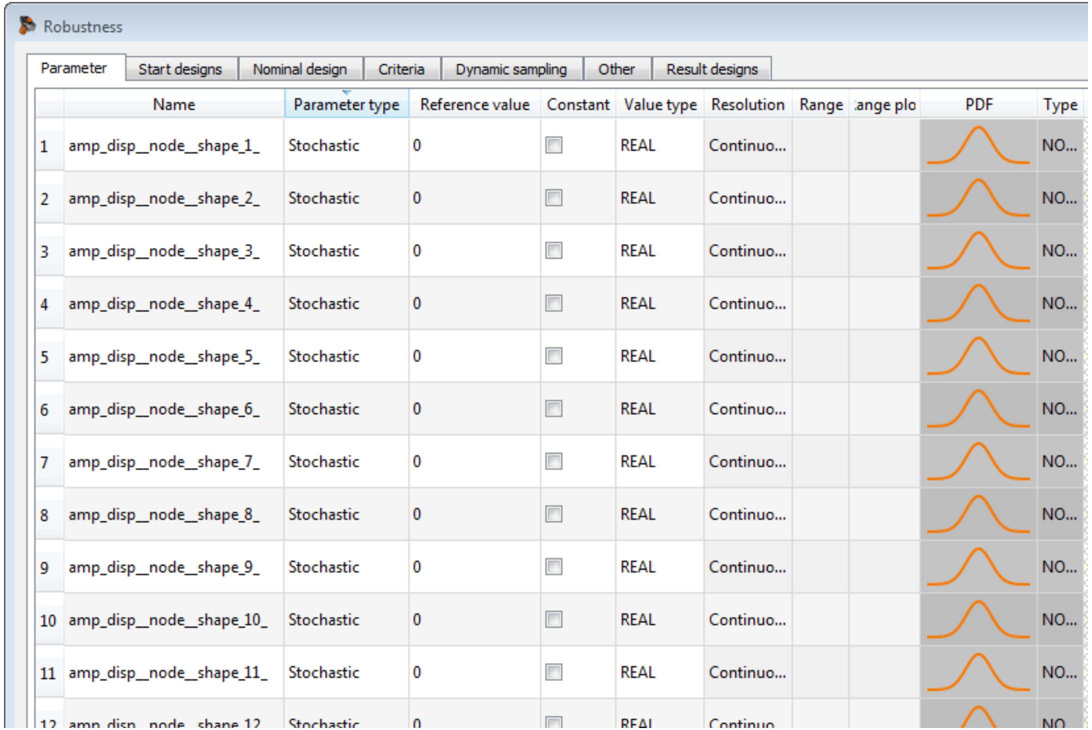


- When material, geometry, process or environmental scatter is significantly affecting the performance of important response values
- When significant scatter of performance is observed in reality
- and there is a doubt that safety distances may be too small or safety distances should be minimized for economical reasons

Fully automatic transfer of data from the each single task to another

Random Geometries

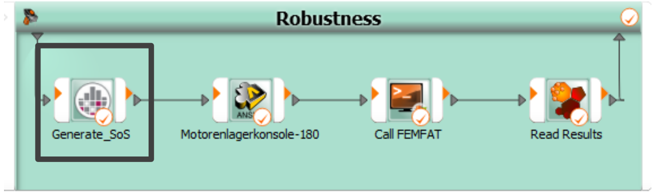
Generate random geometry with SoS



Robustness

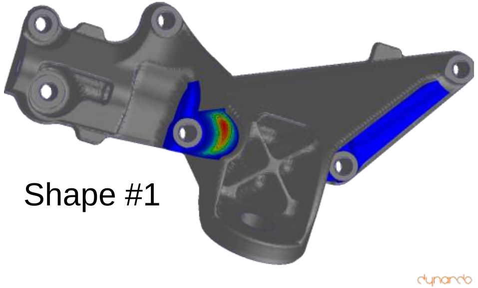
Parameter | Start designs | Nominal design | Criteria | Dynamic sampling | Other | Result designs

	Name	Parameter type	Reference value	Constant	Value type	Resolution	Range	ange plo	PDF	Type
1	amp_disp_node_shape_1_	Stochastic	0		REAL	Continuo...				NO...
2	amp_disp_node_shape_2_	Stochastic	0		REAL	Continuo...				NO...
3	amp_disp_node_shape_3_	Stochastic	0		REAL	Continuo...				NO...
4	amp_disp_node_shape_4_	Stochastic	0		REAL	Continuo...				NO...
5	amp_disp_node_shape_5_	Stochastic	0		REAL	Continuo...				NO...
6	amp_disp_node_shape_6_	Stochastic	0		REAL	Continuo...				NO...
7	amp_disp_node_shape_7_	Stochastic	0		REAL	Continuo...				NO...
8	amp_disp_node_shape_8_	Stochastic	0		REAL	Continuo...				NO...
9	amp_disp_node_shape_9_	Stochastic	0		REAL	Continuo...				NO...
10	amp_disp_node_shape_10_	Stochastic	0		REAL	Continuo...				NO...
11	amp_disp_node_shape_11_	Stochastic	0		REAL	Continuo...				NO...
12	amp_disp_node_shape_12_	Stochastic	0		REAL	Continuo...				NO...

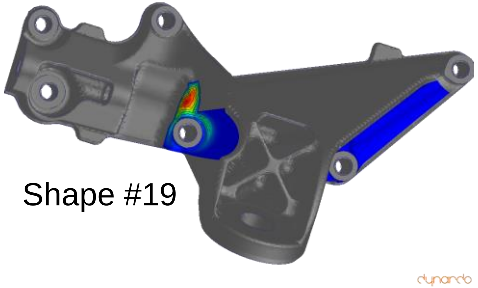


- 20 parameters as coefficient
- For 20 different spatial distributions (shapes) used
- All of them are normal distributed
- Mean value and standard deviation are obtained from analysis of measurements
- Enable displacements into negative and positive directions (Add/Remove material)

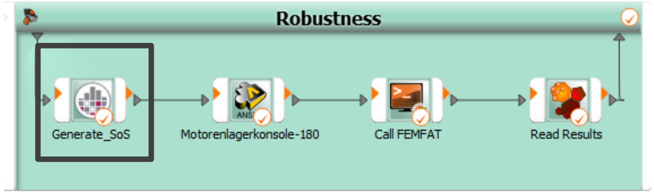
Generate random geometry with SoS: New models in 3.3.1

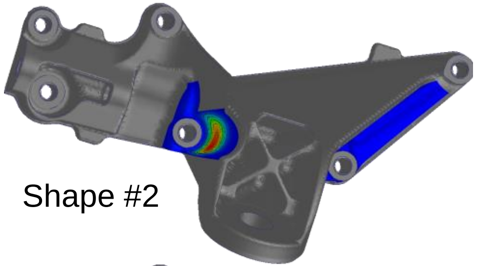


Shape #1

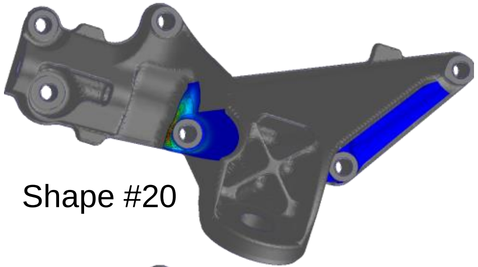


Shape #19

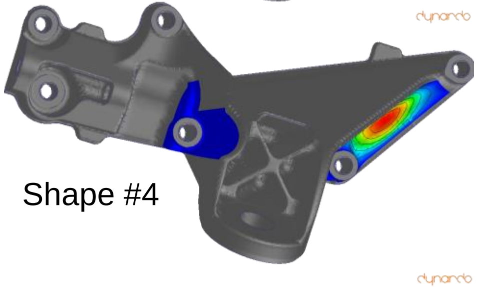




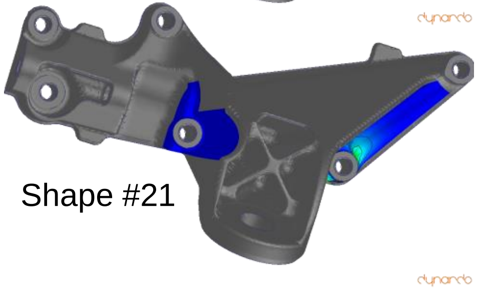
Shape #2



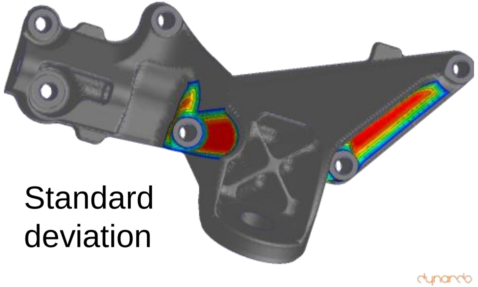
Shape #20



Shape #4



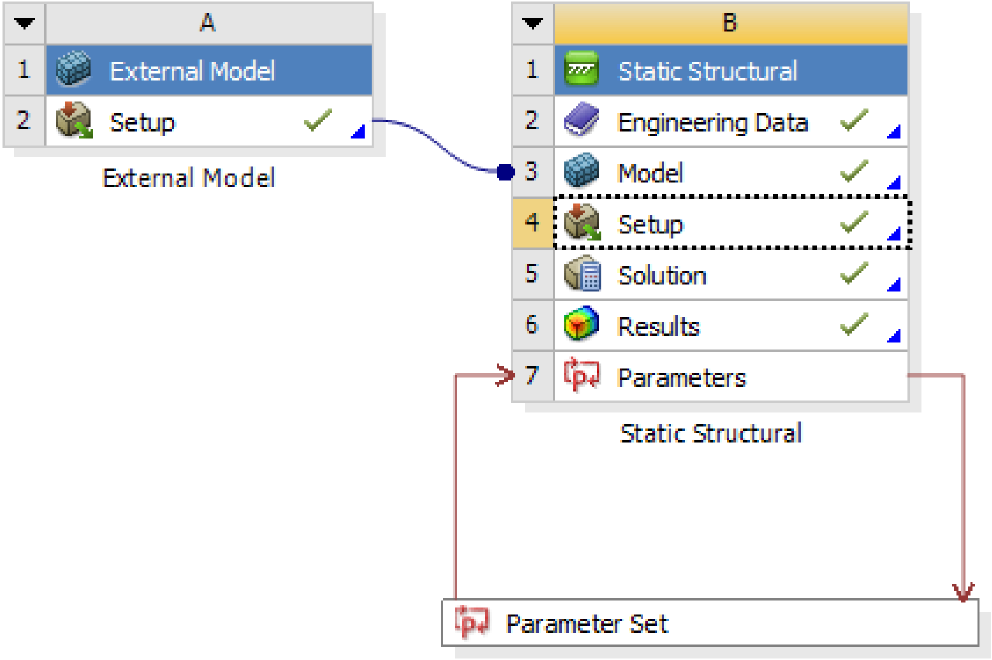
Shape #21

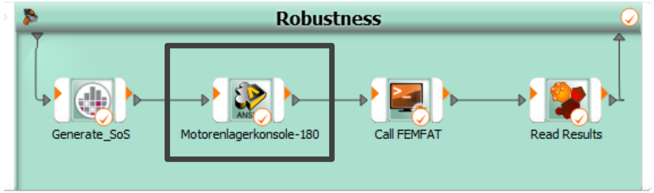


Standard deviation

Static Mechanical Analysis

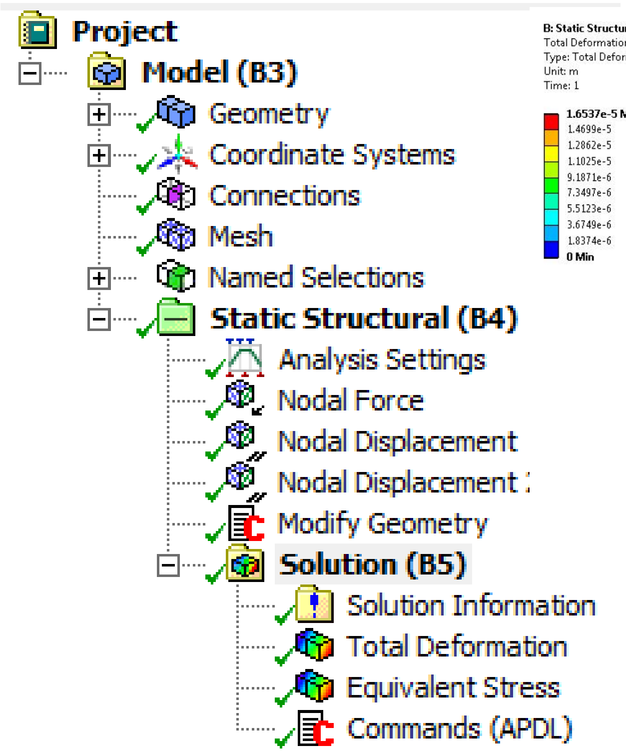
Static mechanical evaluation with ANSYS WB 18.0

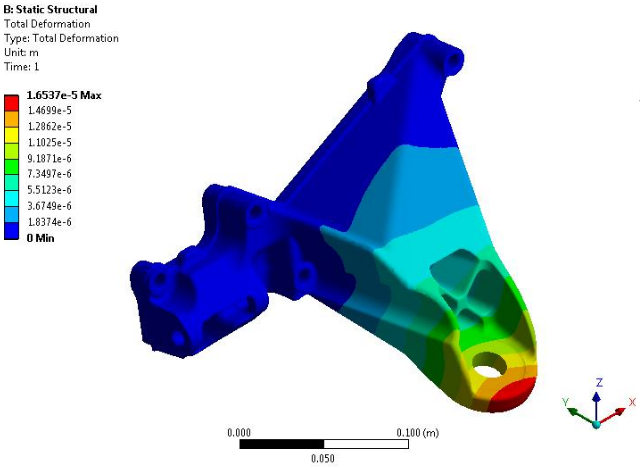


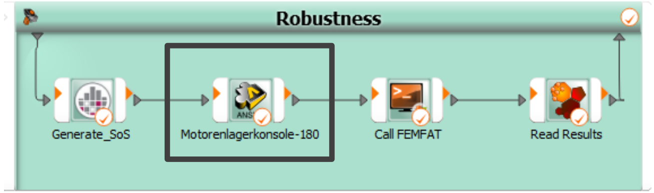


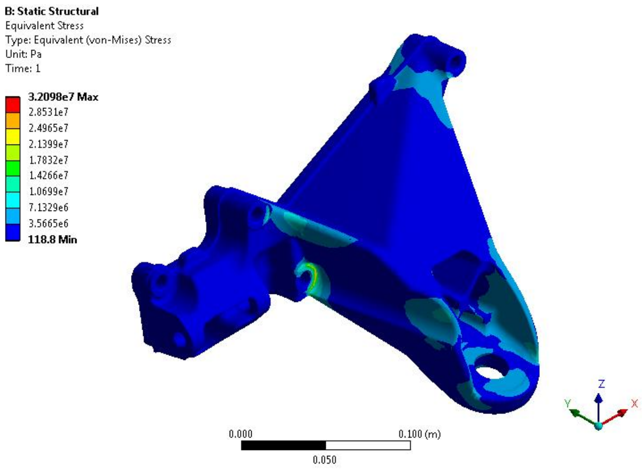
- Geometry is changed inside of the Setup component
- The result file, containing stresses is used for following fatigue evaluation
- Additional results like max. displacements and max. equivalent stresses are considered as responses

Static mechanical evaluation with ANSYS WB 18.0







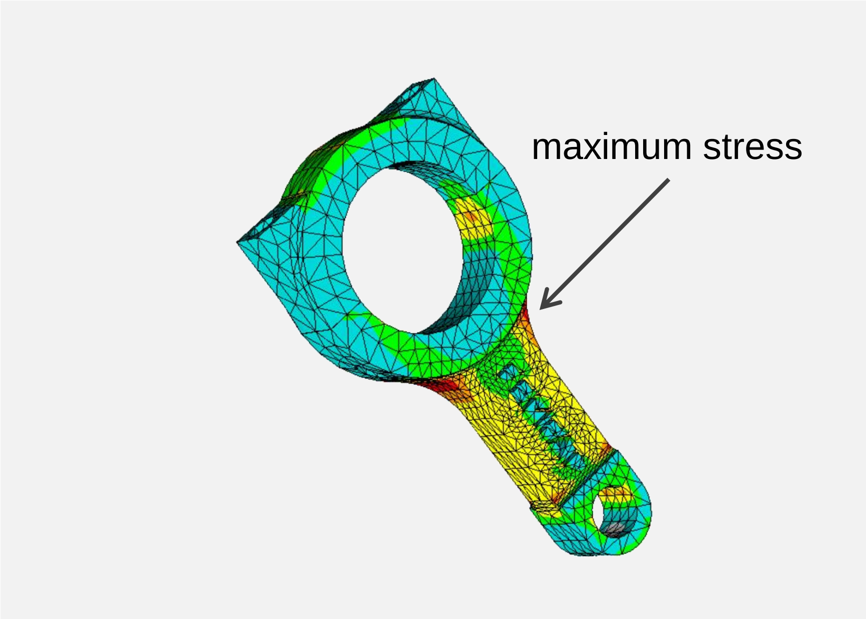


Fatigue Assessment

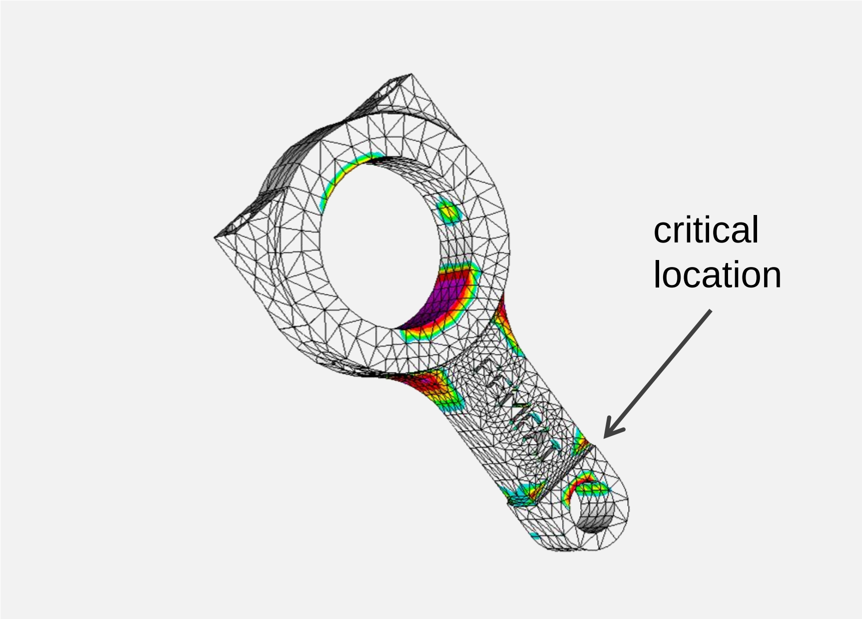
FEMFAT is developed in co-operation with computational engineers in our structural analysis department at MAGNA in St. Valentin, Austria.

The exclusive analysis of stress in a traditional way doesn‘t often reveal damage occurrence at the right point.

Traditional view



Modern life-cycle stress analysis



Only modern fatigue analysis tools are capable of predicting critical crack locations and the number of load cycles until failure.

FEMFAT Modules

FEMFAT basic

Standard/Minimum configuration; includes all the interfaces and material database, handles 2 stress states plus one assembly load case for life- or safety factor analysis

FEMFAT break

A software module for assessing static safety factors in combination with BASIC or MAX

FEMFAT heat

For low cycle fatigue analysis of components which are exposed to thermo-mechanical loads (e.g. cylinder heads, exhaust manifolds) and suffer from mechanical, creep and oxidation damage

FEMFAT strain

A software module for assessing damage from measured strains and comparing stresses from FEA and testing

FEMFAT laminate

A software module for fatigue life prediction on layered infinite fiber reinforced materials

FEMFAT max

Module for fatigue analysis of MultiAXially loaded components using time histories of loads or series of stress states

FEMFAT parallel

Take the advantage to use more than only one CPU of your multi-core workstation to speed up your analysis

FEMFAT spot

Module for predicting fatigue of spot-joints (welds, rivets) in FE-shell structures

FEMFAT plast

Module to consider the effect of mean stress and/or amplitude stress rearrangement from linear stresses when local plastic deformation occurs using Neuber correction

FEMFAT visualizer

FAST 3D post-processor to display the FE-model, fatigue results and stresses including a feature to generate animations and 3D pdf files. Unmatched for weld seam definition

FEMFAT weld

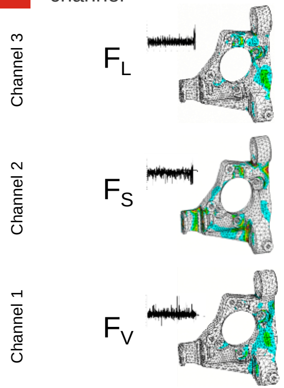
Module for fatigue analysis of welding seams for steel and aluminum using notch stress method and standards (DIN 15018, EUROCODE 3 and 9, BS 7608, IIW)

FEMFAT spectral

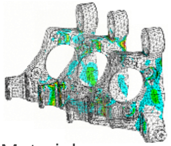
Random response fatigue analysis using PSD (Power Spectral Densities) loads

Complex loading situations can be assessed in an accurate and efficient way using FEMFAT max

1 Load history for each channel

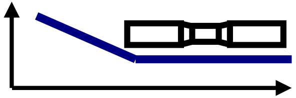


2 One stress result for each channel

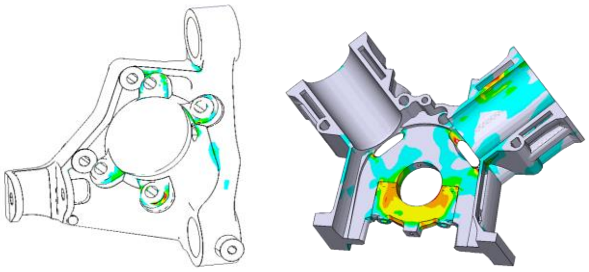


3 Material

Specimen Material Data



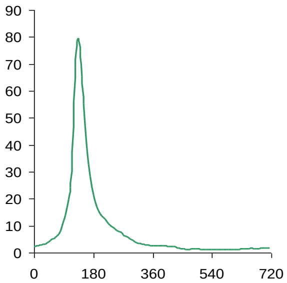
In order to analyze the interaction of all loads, all stress information is superimposed, transformed to an equivalent stress and rain-flow counted. Then the operational strength analysis begins with the help of local S/N curves including relevant influences such as notches, mean stress, isothermal temperature,…



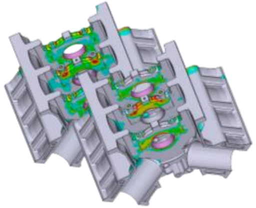
Results

- damage values,
- safety factors or
- safety factors related to a defined cycle number

1 Transient load condition in time

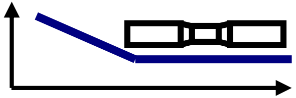


2 One stress result for each timestep

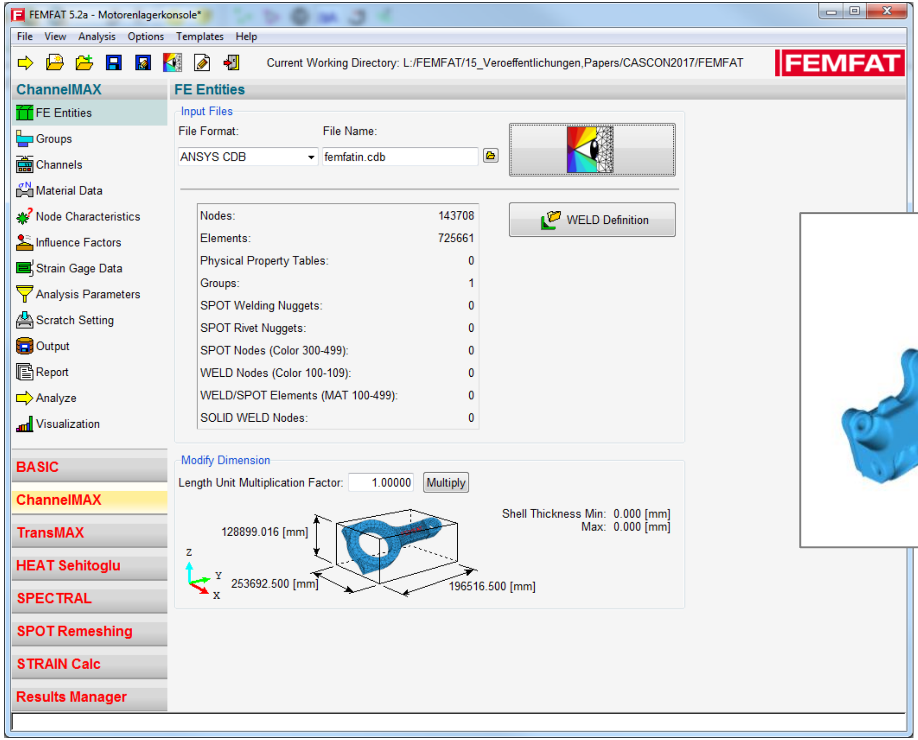


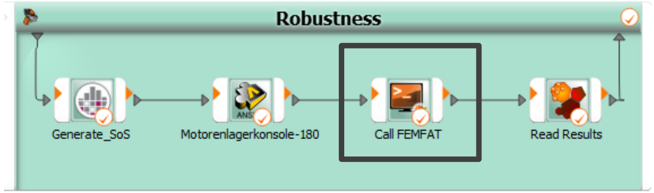
3 Material

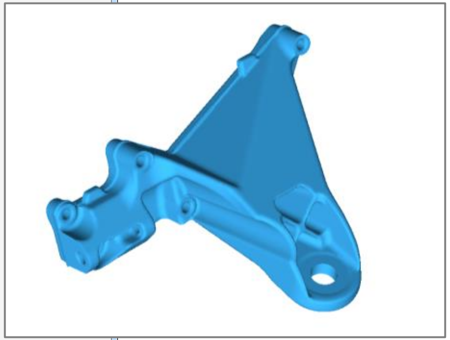
Specimen Material Data



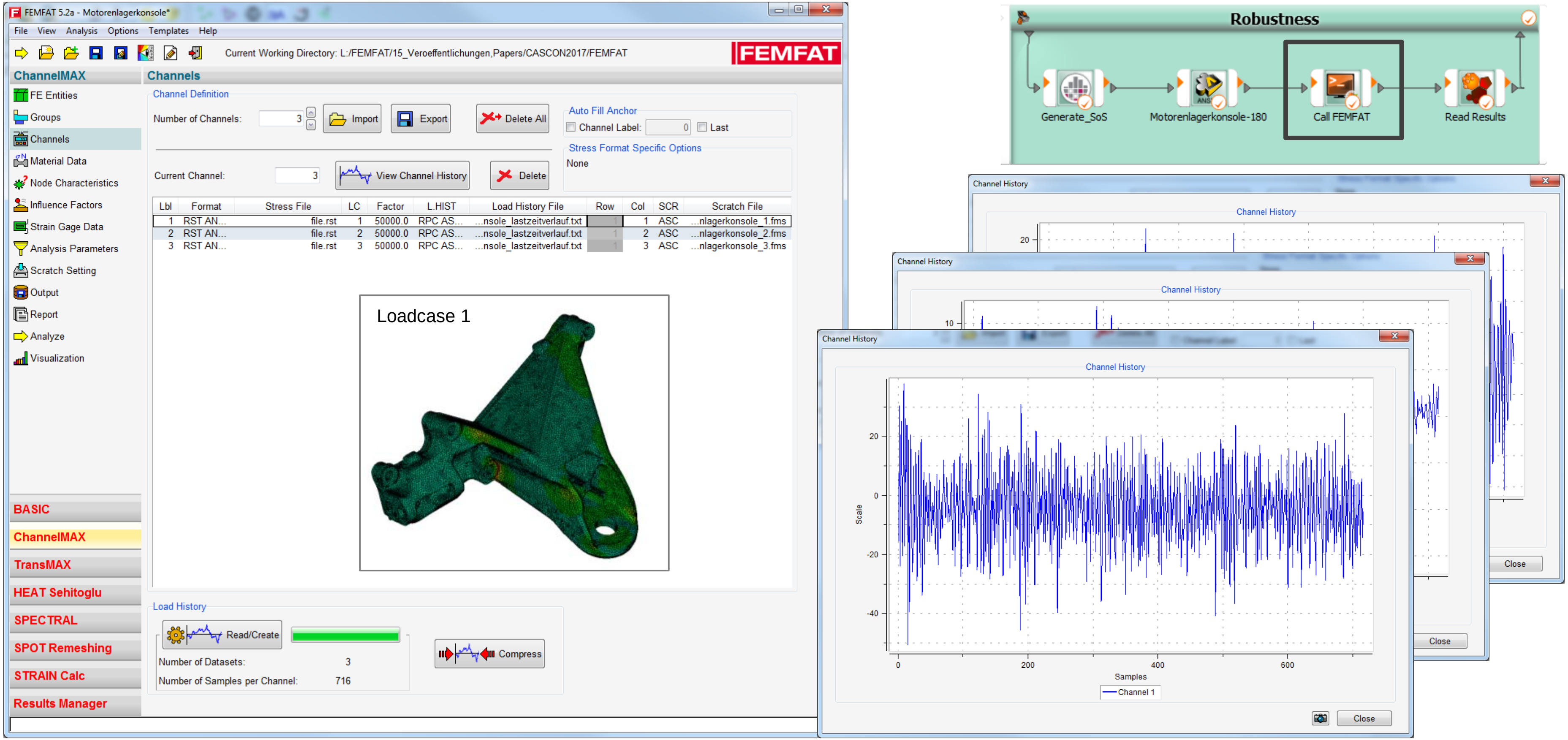
Information of structure is read into FEMFAT using the .cdb interface



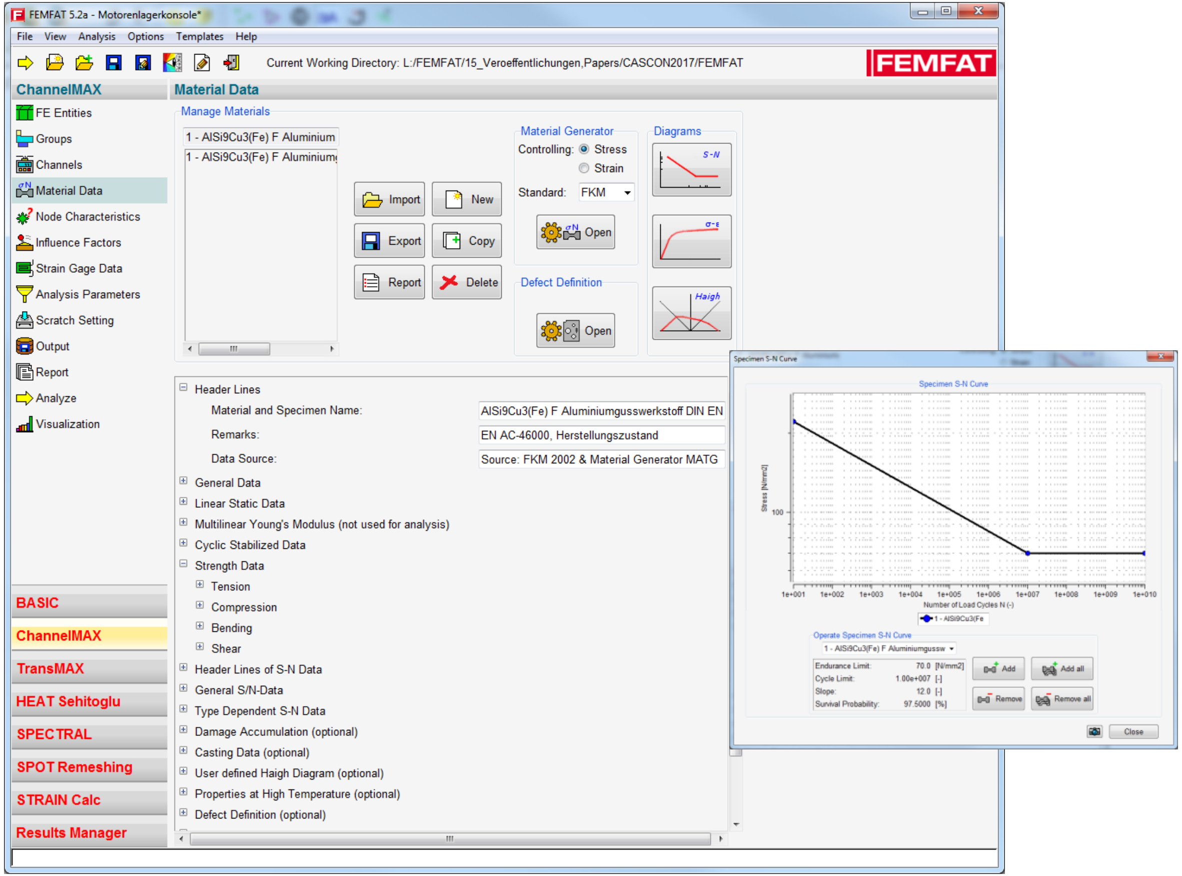


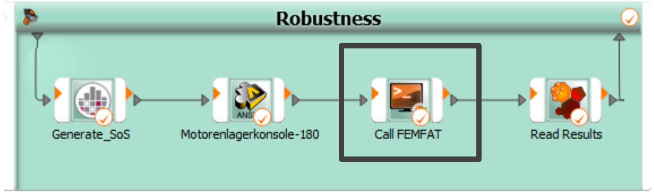


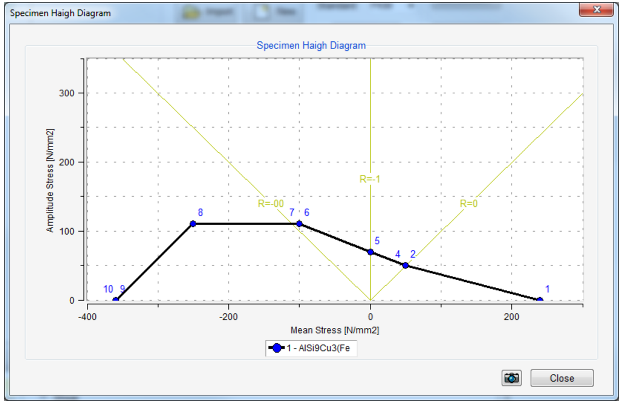
The loading is applied by unit loadcase and the channel history



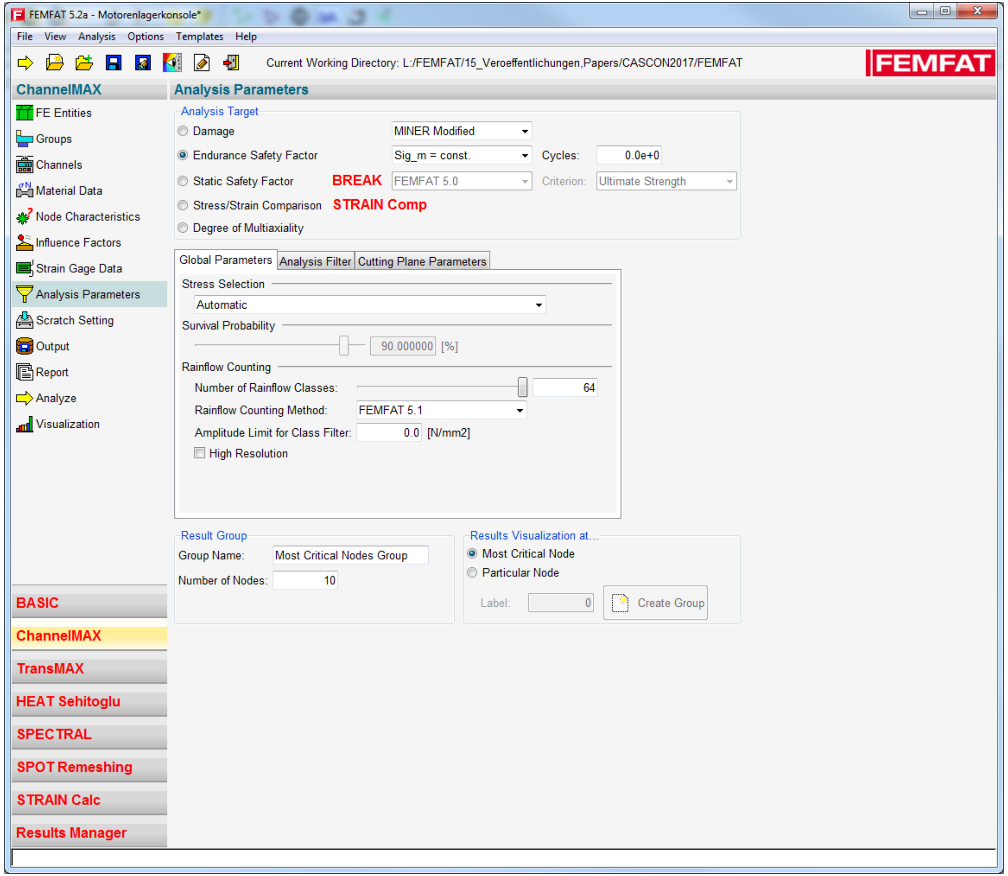
Material parameters for fatigue analysis are generated in FEMFAT and stored in a .ffd file

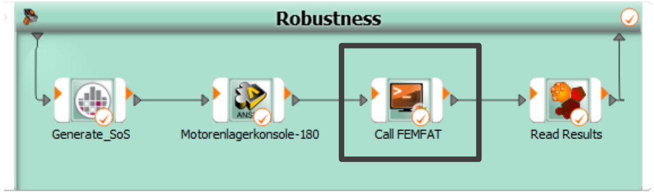






The analysis target is an „Endurance Safety Factor“ with respect to a constant mean stress.





The fatigue simulation is done using FEMFAT channelMax.
Variations are applied in the workflow by modifying the files.

MAGNA

Input

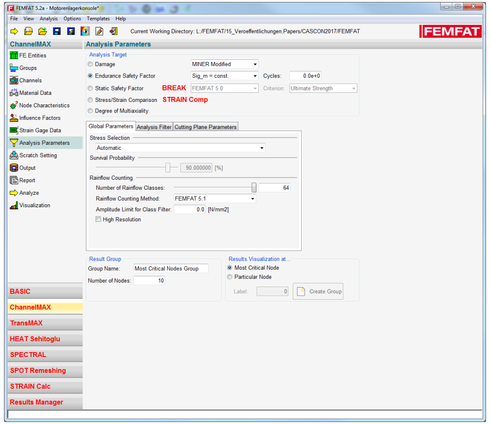
ANSYS .cdb file

ANSYS .rst file

Material file .ffd

Load history .txt

FEMFAT software
FINITE ELEMENT METHOD FATIGUE



FEMFAT max

Stored in a .ffj file

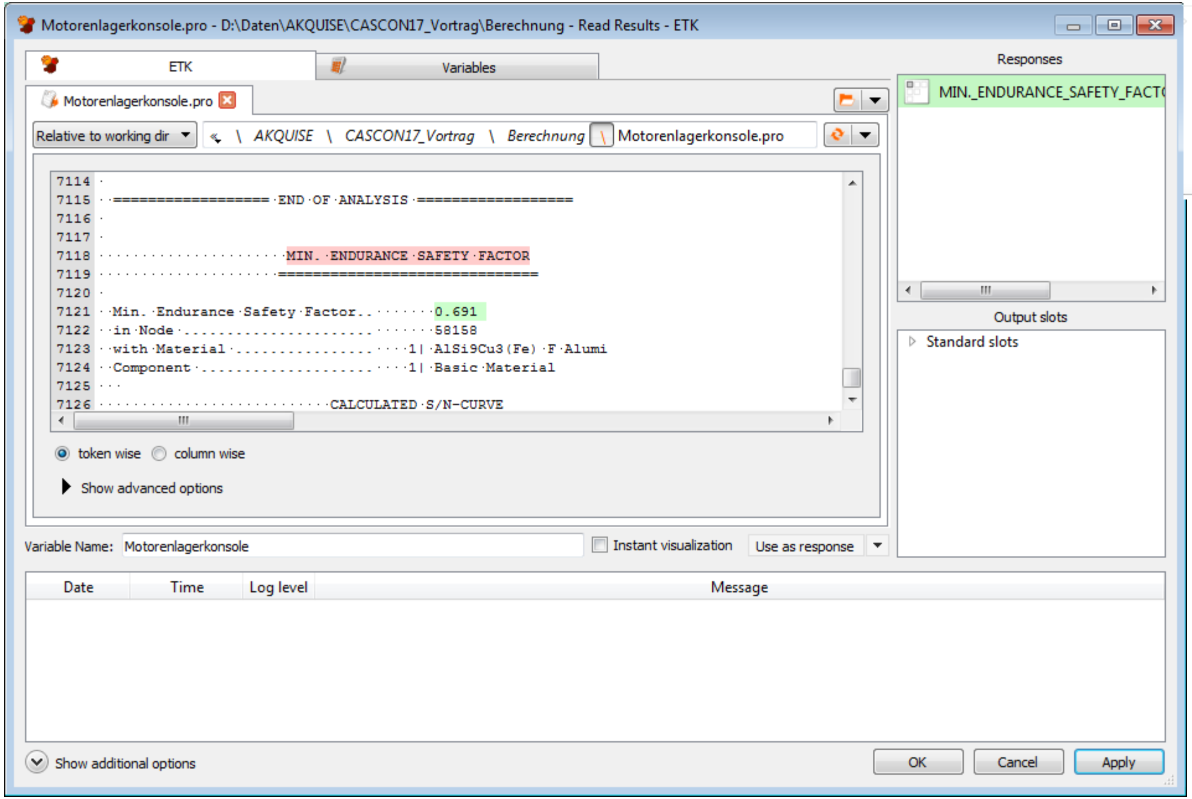
Output

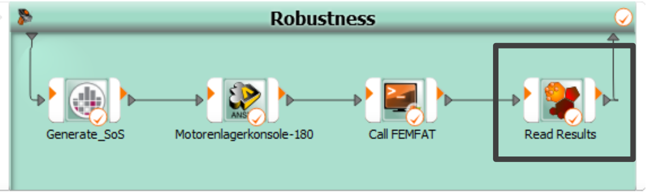
Result file .fps

Report file .pro

Read Results for Robustness Evaluation

Workflow is managed by optiSLang and the Extraction Toolkit

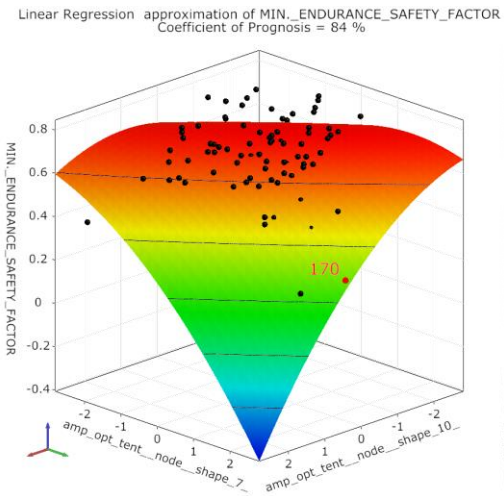


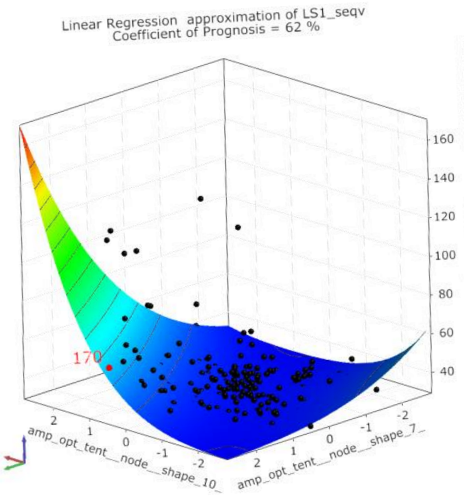


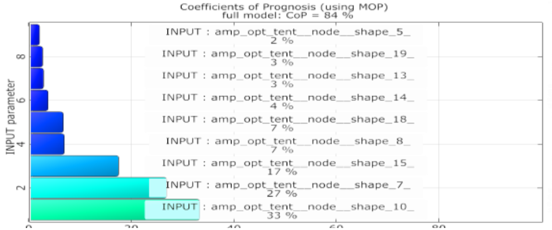
Results

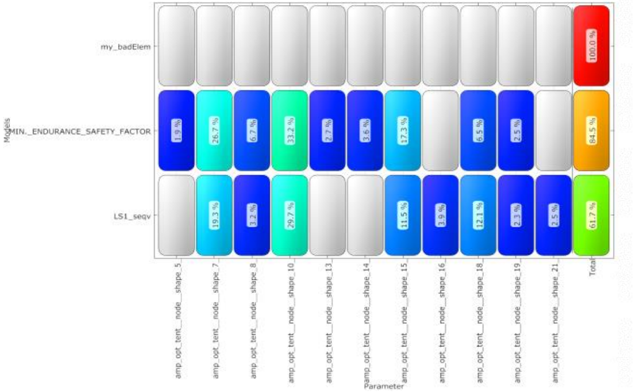
Robustness Evaluation

- Coefficient of Prognosis (CoP) and Metamodel of optimal Prognosis (MOP) for “Endurance Safety Factor” : 84%
- CoP for maximum stress: only 62% (due to varying location?)



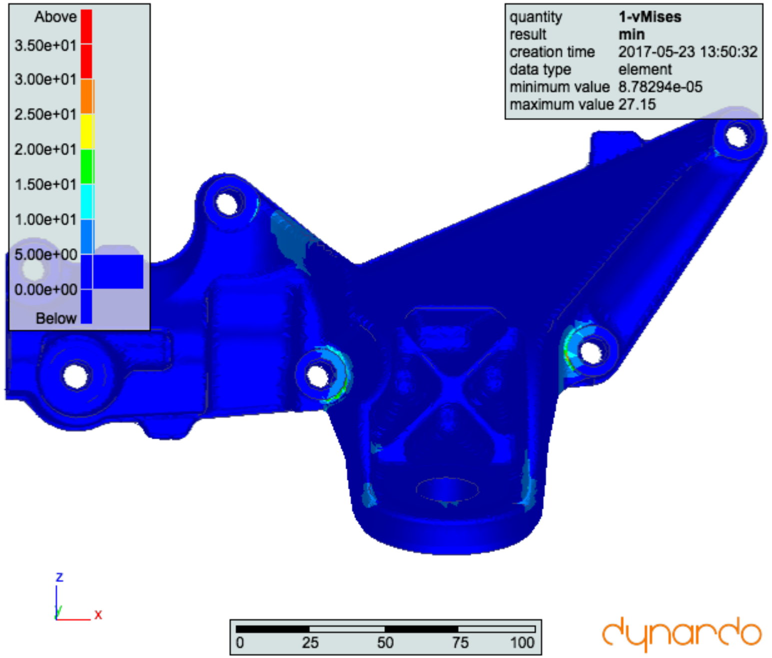


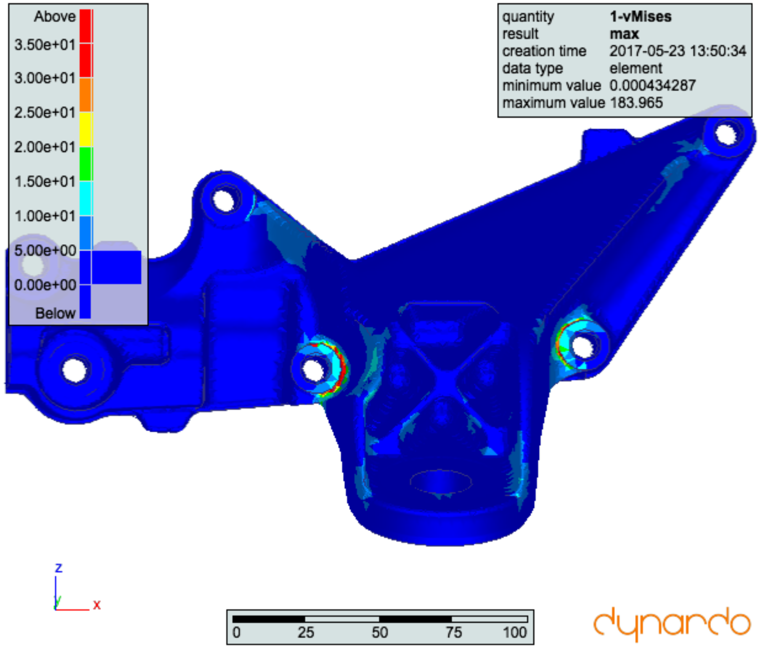




Robustness Evaluation

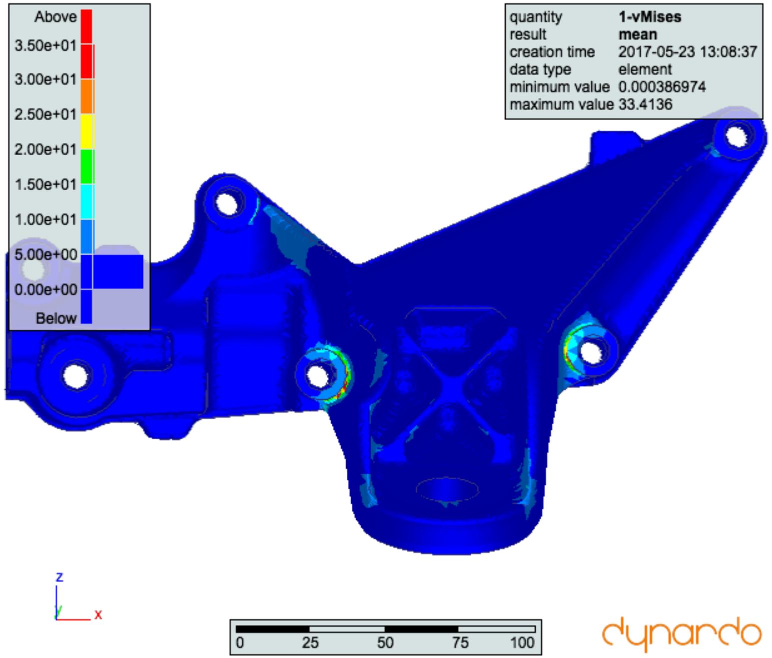
- Analysis of variation of von Mises stress due to geometric imperfection
- Left: Minimum value (safe), Right: Maximum value over all designs- unsafe

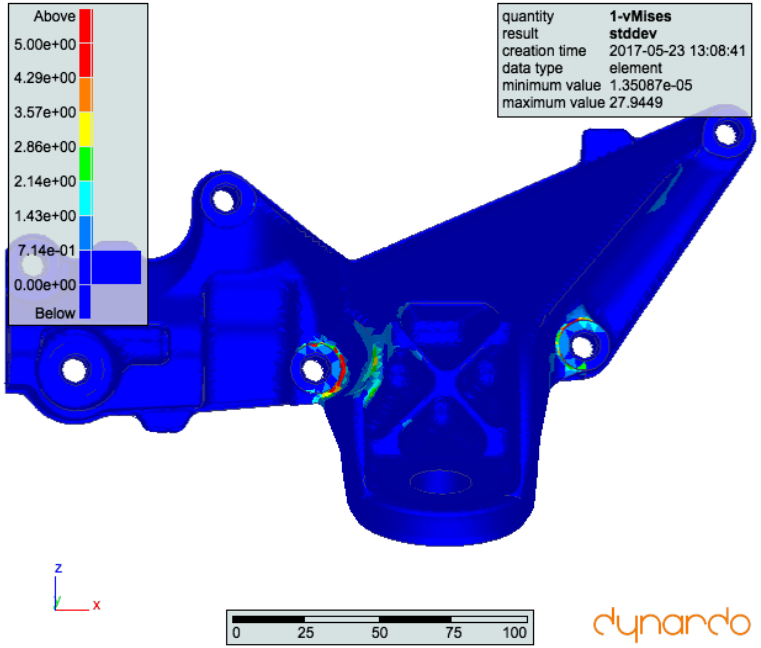




Robustness Evaluation

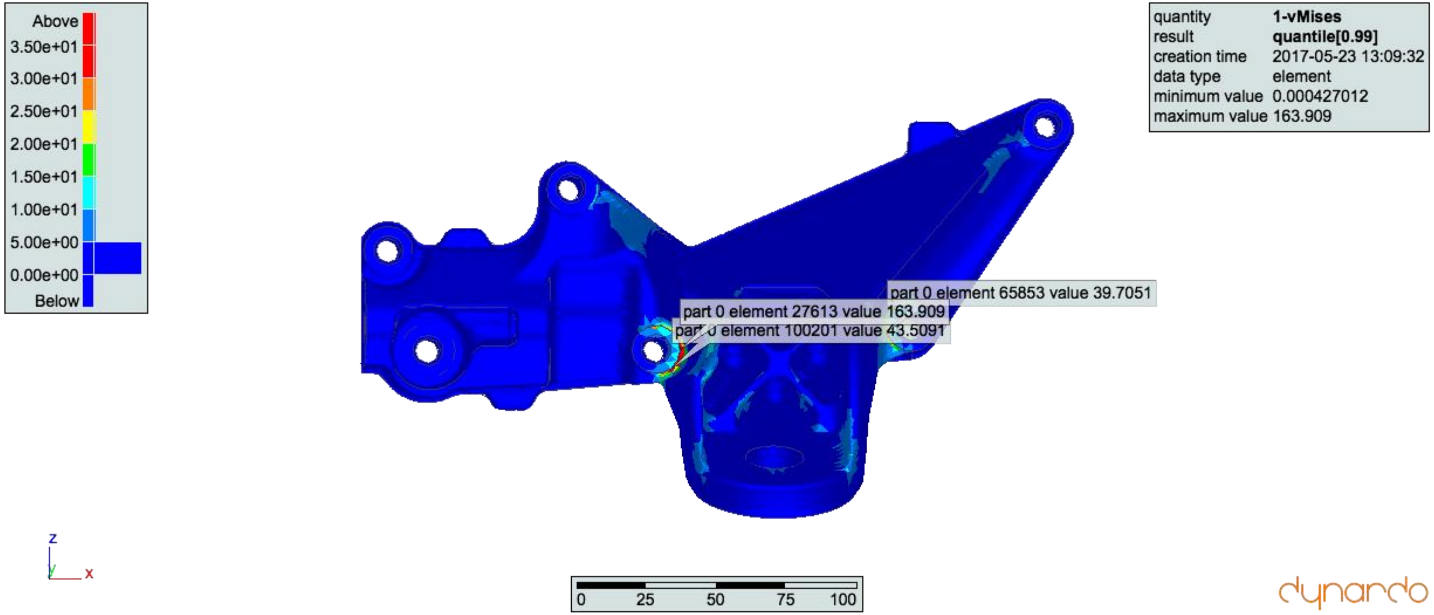
- Analysis of variation of von Mises stress due to geometric imperfection
- Expected statistical mean value (left) and standard deviation (right)





Robustness Evaluation

- Compute e.g. 99% quantile value, i.e. the v. Mises stress value which is exceeded by only 1% probability
- Detect “hot spots”, i.e. 3 potential failure locations exceeding the critical value



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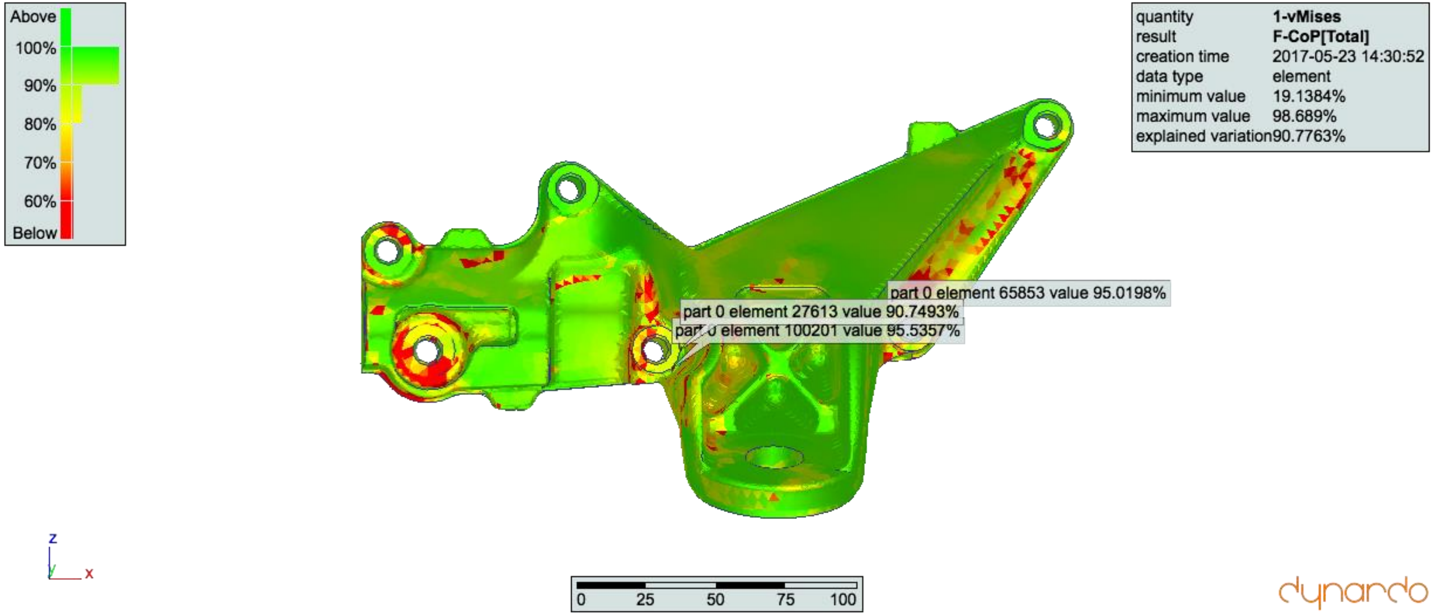
Robustness Evaluation

- Check explainability of FMOP (field meta model):
  - 90% on average (compared with 62% before)
  - 95% at hot spots



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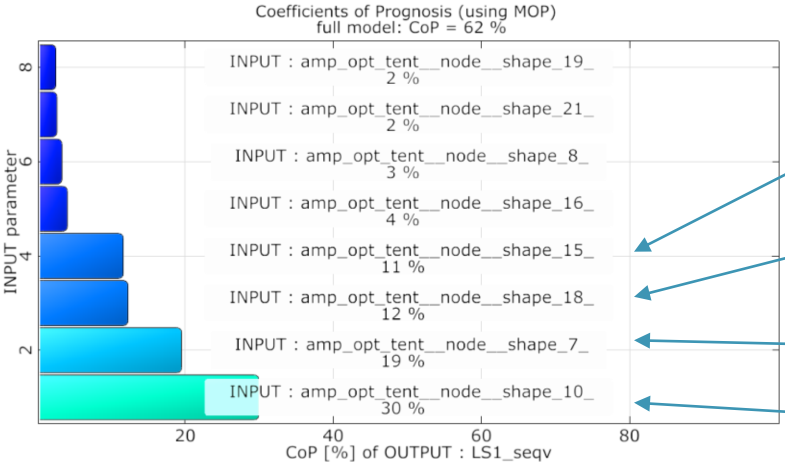
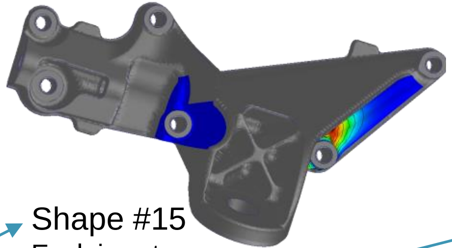
Sensitivity analysis

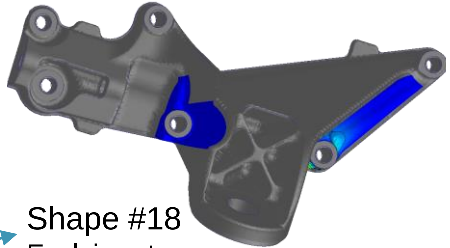
- Which geometric shape is responsible for variations ?

CoP matrix for maximum stress:
(only 62% CoP)

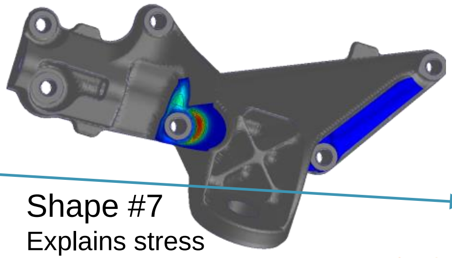




Shape #15
Explains stress variation on the right hot spot by 42%



Shape #18
Explains stress variation on the right hot spot by 18%



Shape #7
Explains stress variation on the left hot spot by 46%

Shape #10
Explains stress variation on the left hot spot by 38%

Conclusion

There are many applications for the use of random fields in engineering practise.

1. Optimisation of free form surfaces
2. Using statistics of measurements for geometry creation in simulations
3. Analysis of variations in production processes
4. Determination of the influence of different raw material suppliers

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INSPIRING **INNOVATION.**