Advanced Integrate with Ansys optiSLang and Mechanical Software

Powering Innovation That Drives Human Advancement

# Hands-on – Robustness Evaluation

# Steel Hook

Release 2023 R1

Please note:
- These training materials were developed and tested in Ansys Release 2024 R1. Although they are expected to behave similarly in later releases, this has not been tested and is not guaranteed.
- The screen images included with these training materials may vary from the visual appearance of a local software session.
- Although some workshop files may open successfully in previous releases, backward compatibility is somewhat unlikely and is not guaranteed.

# Agenda

| Session | Slide Set | Time | Topic |
|---|---|---|---|
| 1 | 0 | 5’ | Agenda |
| | 1 | 25’ | Introduction to Ansys optiSLang |
| | | 10’ | Ansys optiSLang in the Ansys Learning Hub – Find your Examples |
| | | 15’ | Q/A |
| | 2 | 30’ | Sensitivity Study and Optimization – Theoretical Background |
| 2 | 3 | 75’ | Hands-on – Process Integration, Sensitivity Study and Postprocessing<br>Steel Hook – optiSLang inside Workbench |
| | | 15’ | Q/A |
| 3 | 4 | 40’ | Hands-on – Optimization<br>Steel Hook – optiSLang inside Workbench |
| | 5 | 20’ | Robust Design Optimization – Theoretical Background |
| | **6** | **40’** | **Hands-on – Robustness Evaluation<br>Steel Hook – optiSLang inside Workbench** |
| | | **15’** | **Q/A** |

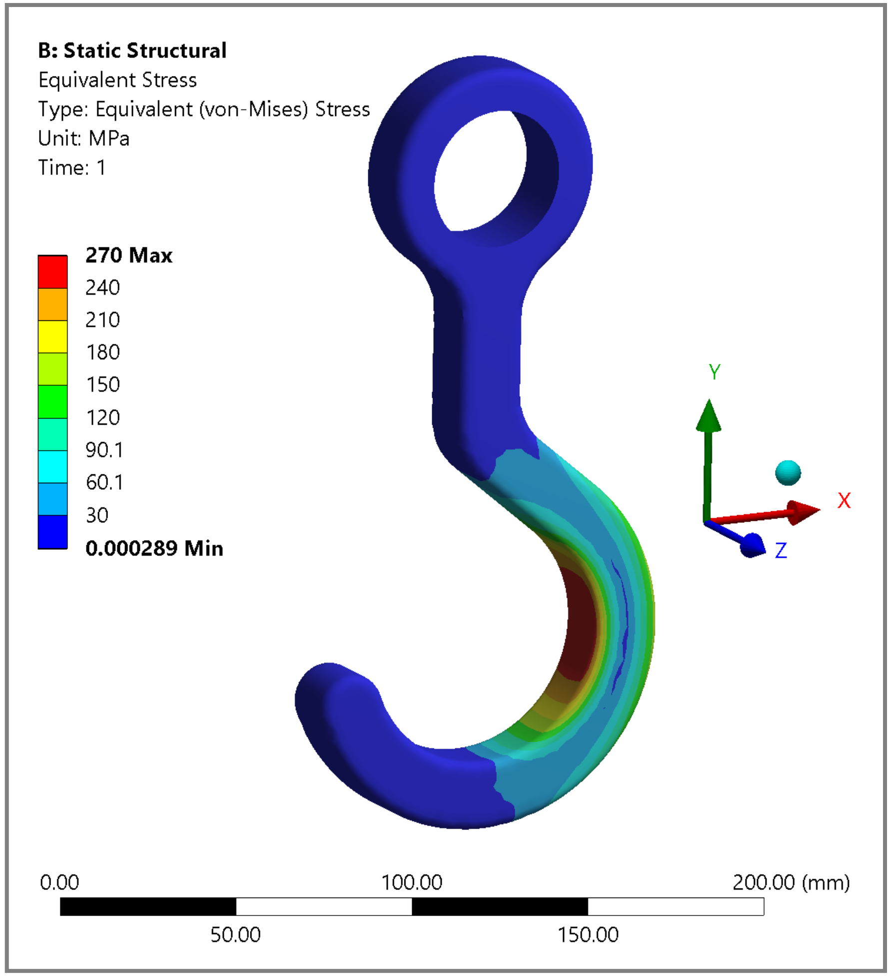
# The Robust Design Optimization Task

**Deterministic Optimization**

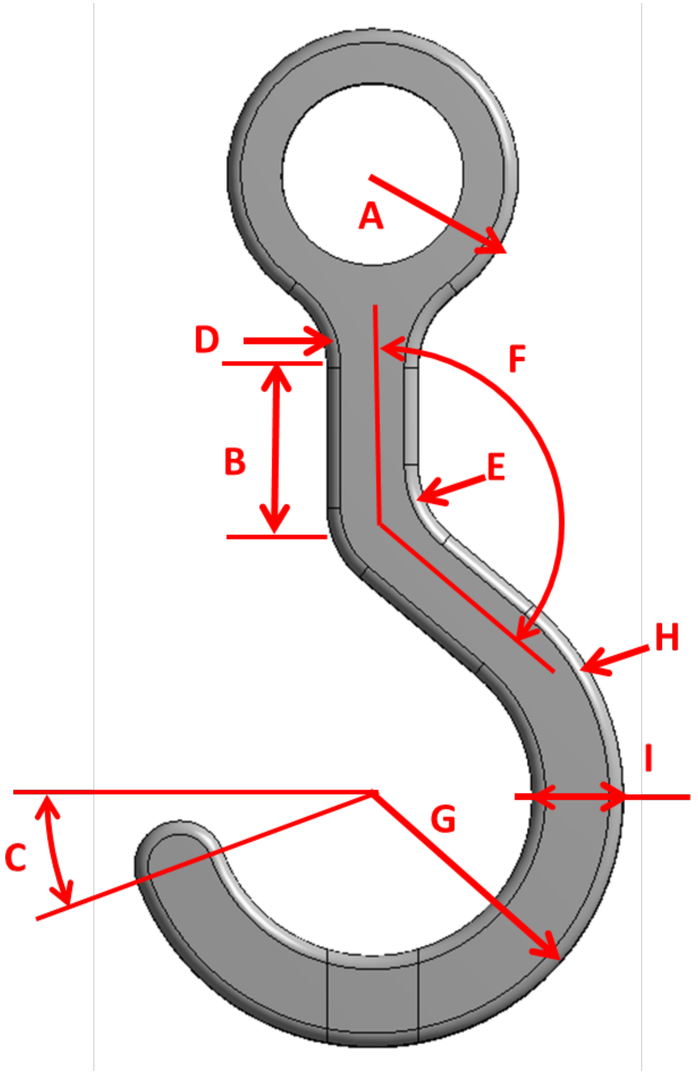
- Minimize the mass
- The maximum stress should not exceed 300 MPa
- 10 geometry parameters are varied for the design variation

**Robustness requirement**

- Proof for the optimal design that the failure stress limit does not exceed the 4.5 sigma safety margin
- 15 scattering parameters are considered (geometry and material properties and the load components)



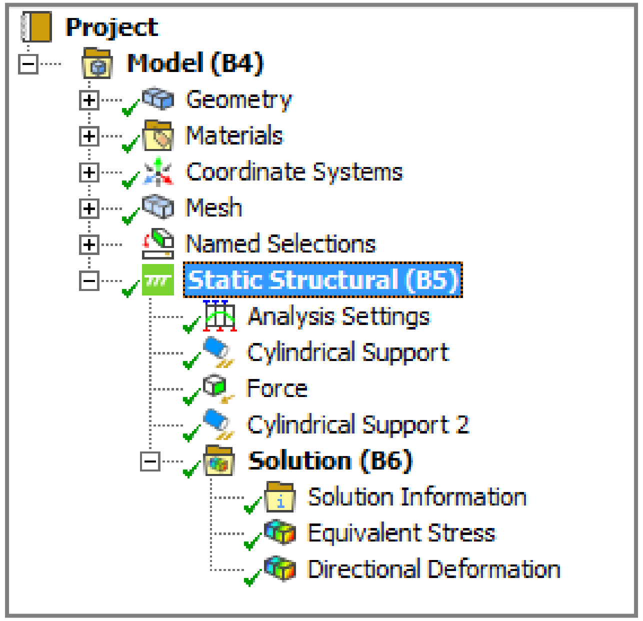
# The Geometry Parameters

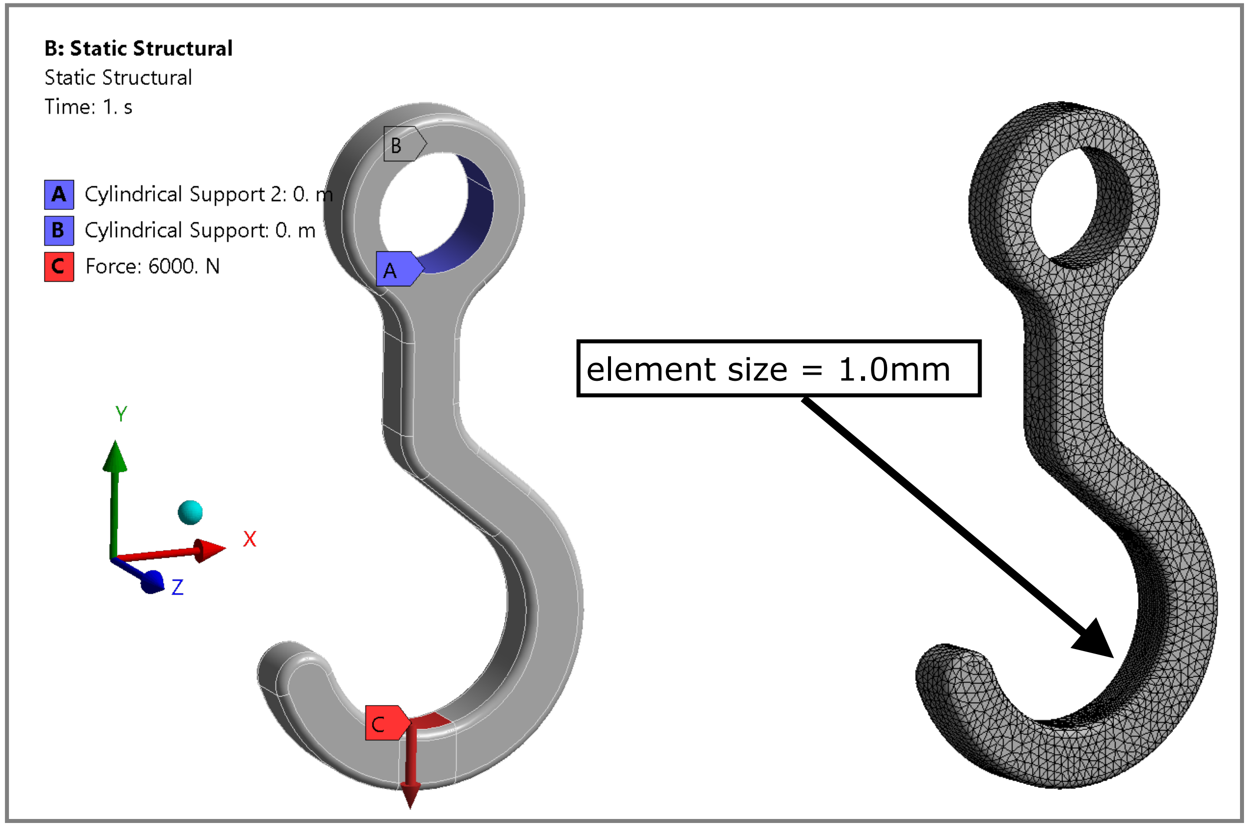



| | | |
|---|---|---|
| A | Outer_Diameter | 28-35 mm |
| B | Connection_Length | 20-50 mm |
| C | Opening_Angle | 10-30 ° |
| D | Upper_Blend_Radius | 18-22 mm |
| E | Lower_Blend_Radius | 18-22 mm |
| F | Connection_Angle | 120-150 ° |
| G | Lower_Radius | 45-55 mm |
| H | Fillet_Radius | 2-4 mm |
| I | Thickness | 15-25 mm |
| | Depth | 15-25 mm |

# Boundary Conditions

- Load F=6000 N
- Cylindrical support, tangential direction is free
- Small elements in region with maximum stresses



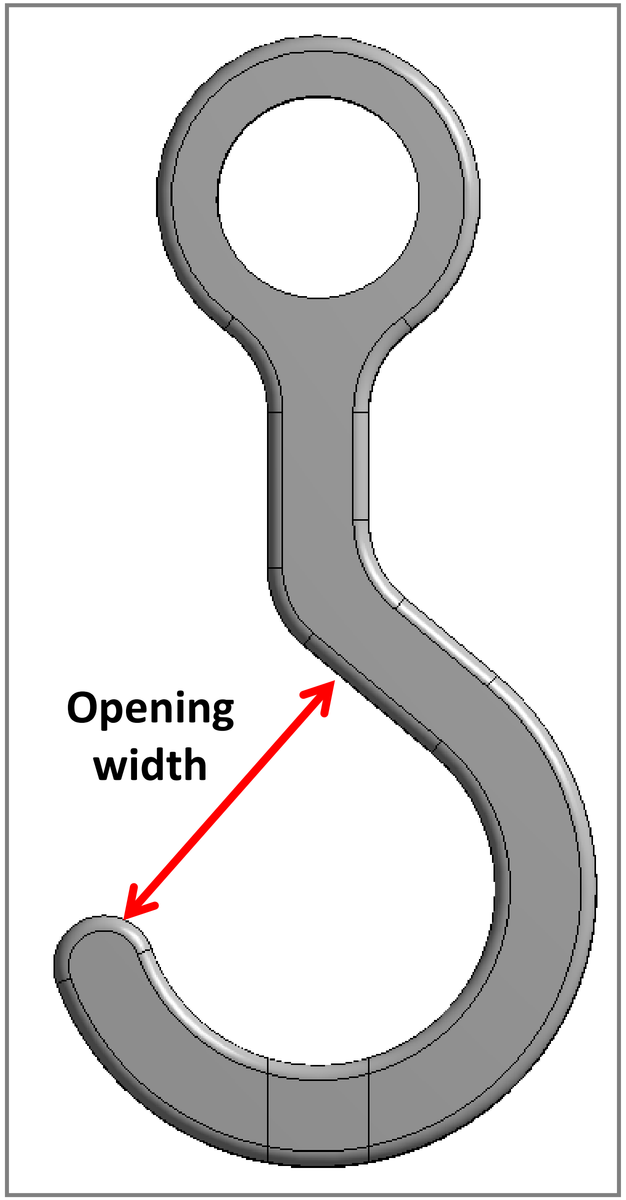



# Responses and Criteria

- Total **mass** of the hook should be minimized
- **Maximum equivalent stress** value should not exceed 300 MPa within a 4.5 sigma safety margin
- **Opening width** (undeformed) of the lower half circle should be minimum 50 mm in the nominal design

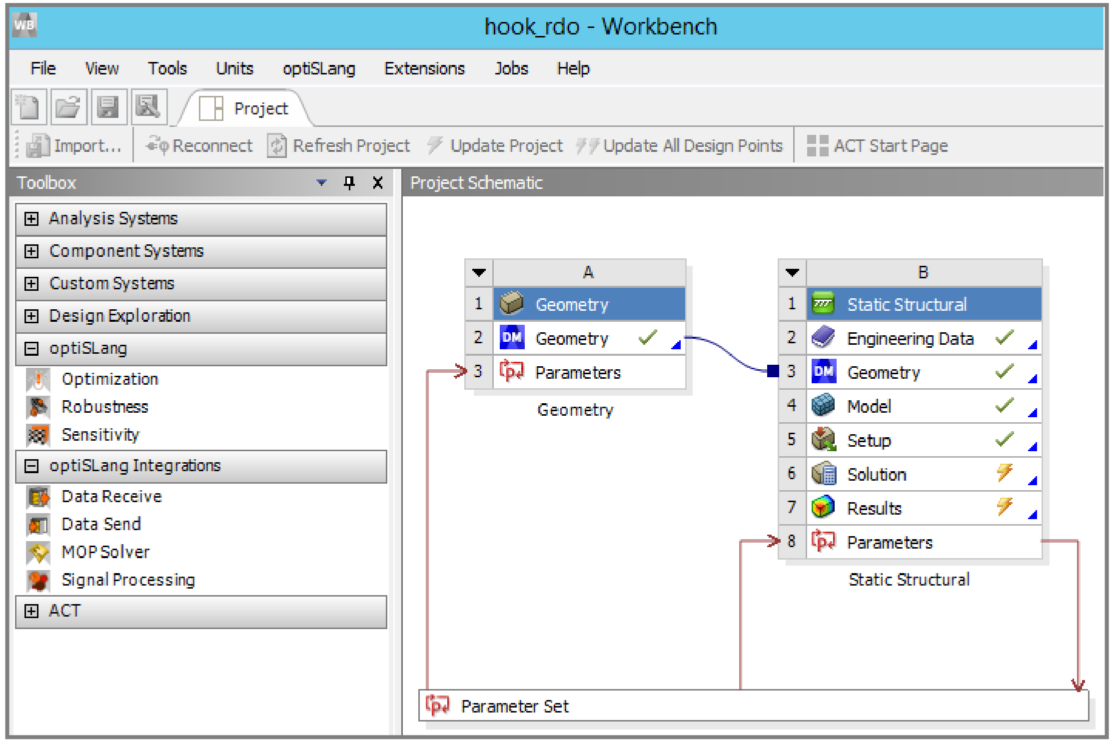
Initial nominal values

- Mass 1100 g
- Maximum stress 270 MPa
- Opening width 64 mm



# Solver: Ansys Mechanical

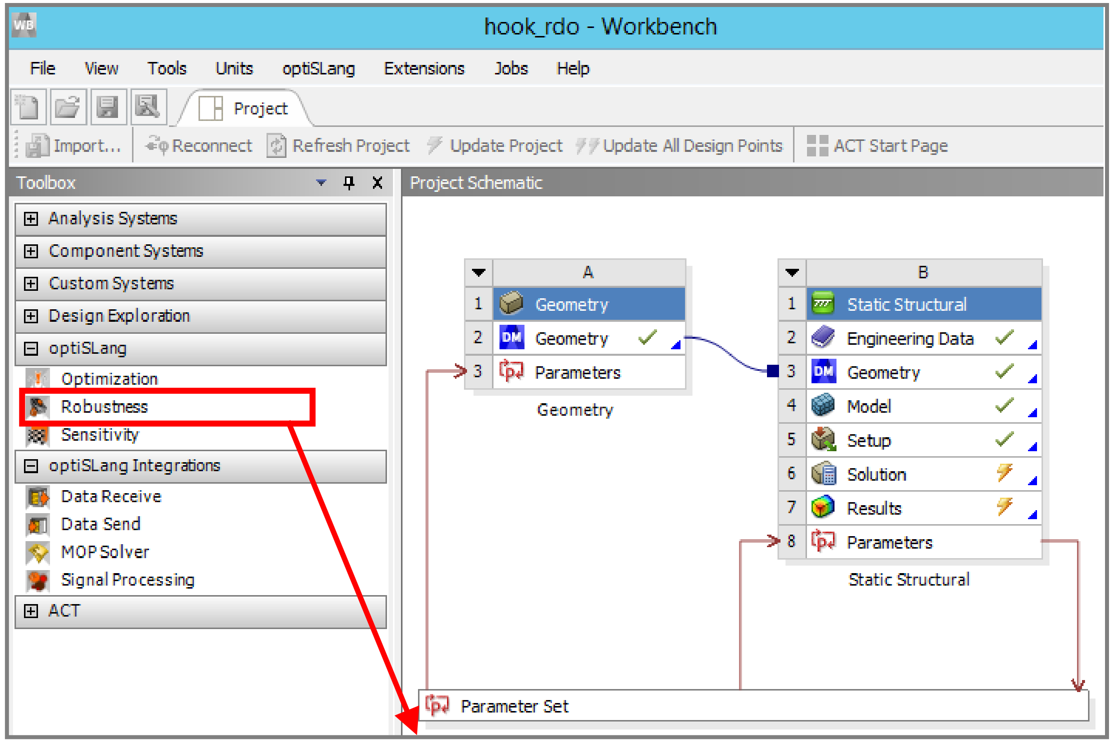
- Open the ready to use Workbench project hook_rdo.wbpz
- In ANSYS Workbench ANSYS Mechanical is used as solver



# Robustness Evaluation of the Initial Design

# Robustness Analysis

- Create a new robustness system



# Definition of the Parameter Bounds

- Define optimization parameters as "Optimization + Stochastic"
- Define the lower and upper bounds for later optimization

| Name | Parameter type | Reference value | Constant | Resolution | Range | | Range plot |
|---|---|---|---|---|---|---|---|
| Thickness | Opt.+Stoch. | 20 | ☐ | Continuous | 15 | 25 | |
| Upper_Blend_Radius | Opt.+Stoch. | 20 | ☐ | Continuous | 18 | 22 | |
| Depth | Opt.+Stoch. | 20 | ☐ | Continuous | 15 | 25 | |
| LowerRadius | Opt.+Stoch. | 55 | ☐ | Continuous | 45 | 55 | |
| Connection_Angle | Opt.+Stoch. | 130 | ☐ | Continuous | 120 | 150 | |
| Connection_Length | Opt.+Stoch. | 40 | ☐ | Continuous | 20 | 50 | |
| Outer_Diameter | Opt.+Stoch. | 32 | ☐ | Continuous | 28 | 35 | |
| Opening_Angle | Opt.+Stoch. | 20 | ☐ | Continuous | 10 | 30 | |
| Fillet_Radius | Opt.+Stoch. | 3 | ☐ | Continuous | 2 | 4 | |
| Lower_Blend_Radius | Opt.+Stoch. | 20 | ☐ | Continuous | 18 | 22 | |

# Definition of the Parameter Uncertainties

- Geometry parameters are assumed to be normally distributed  having standard deviations between 0.2 and 2
- The mean values are automatically taken from the reference values

| Name | Parameter type | Reference value | PDF | Type | Mean | Std. Dev. | CoV | Distribution parameter |
|---|---|---|---|---|---|---|---|---|
| Thickness | Opt.+Stoch. | 20 | | NORMAL | 20 | 1 | 5 % | 20; 1 |
| Upper_Blend_Radius | Opt.+Stoch. | 20 | | NORMAL | 20 | 1 | 5 % | 20; 1 |
| Depth | Opt.+Stoch. | 20 | | NORMAL | 20 | 1 | 5 % | 20; 1 |
| LowerRadius | Opt.+Stoch. | 55 | | NORMAL | 55 | 1 | 1.81818 % | 55; 1 |
| Connection_Angle | Opt.+Stoch. | 130 | | NORMAL | 130 | 2 | 1.53846 % | 130; 2 |
| Connection_Length | Opt.+Stoch. | 40 | | NORMAL | 40 | 1 | 2.5 % | 40; 1 |
| Outer_Diameter | Opt.+Stoch. | 32 | | NORMAL | 32 | 1 | 3.125 % | 32; 1 |
| Opening_Angle | Opt.+Stoch. | 20 | | NORMAL | 20 | 2 | 10 % | 20; 2 |
| Fillet_Radius | Opt.+Stoch. | 3 | | NORMAL | 3 | 0.2 | 6.66667 % | 3; 0.2 |
| Lower_Blend_Radius | Opt.+Stoch. | 20 | | NORMAL | 20 | 1 | 5 % | 20; 1 |

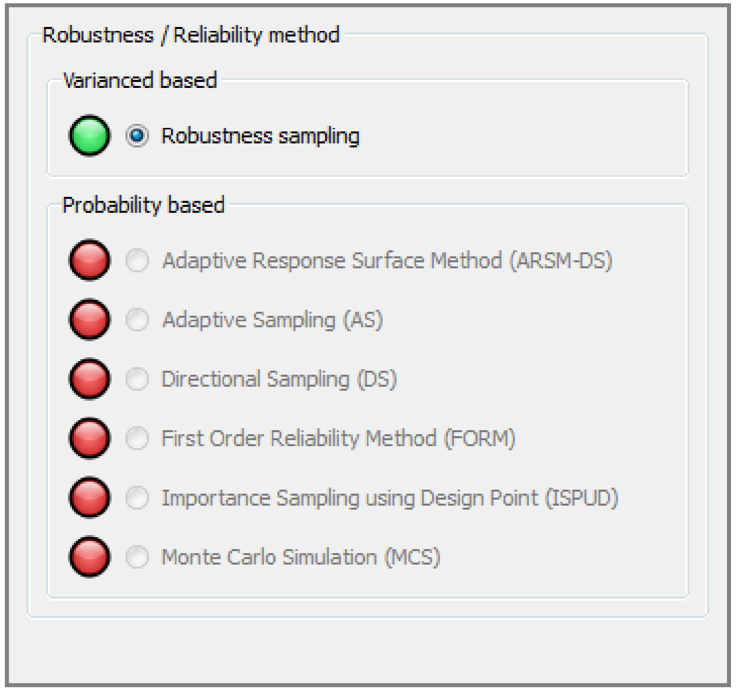
# Definition of the Parameter Uncertainties

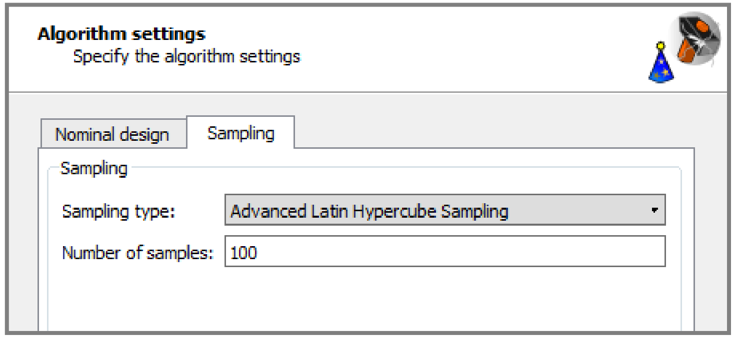
- Load and material parameters are defined as pure stochastic
- Load components are assumed to be normally distributed
- Material parameters are modelled as log-normal random variables to avoid negative values

| | Name | Parameter type | Reference value | PDF | Type | Mean | Std. Dev. | CoV | Distribution parameter |
|---|---|---|---|---|---|---|---|---|---|
| 11 | Young's_Modulus | Stochastic | 2e+11 | | LOGNORMAL | 2e+11 | 1e+10 | 5 % | 26.0203; 0.0499688 |
| 12 | Force_X_Component | Stochastic | 0 | | NORMAL | 0 | 100 | 100 % | 0; 100 |
| 13 | Force_Y_Component | Stochastic | -6000 | | NORMAL | -6000 | 600 | 10 % | -6000; 600 |
| 14 | Force_Z_Component | Stochastic | 0 | | NORMAL | 0 | 100 | 100 % | 0; 100 |
| 15 | Density | Stochastic | 7850 | | LOGNORMAL | 7850 | 157 | 2 % | 8.96807; 0.019998 |
| 16 | Poisson's_Ratio | Stochastic | 0.3 | | LOGNORMAL | 0.3 | 0.015 | 5 % | -1.20522; 0.0499688 |

# Robustness Analysis

- A variance-based robustness evaluation is performed
- Limit state functions are not necessary
- Keep the default method selection and the sampling settings

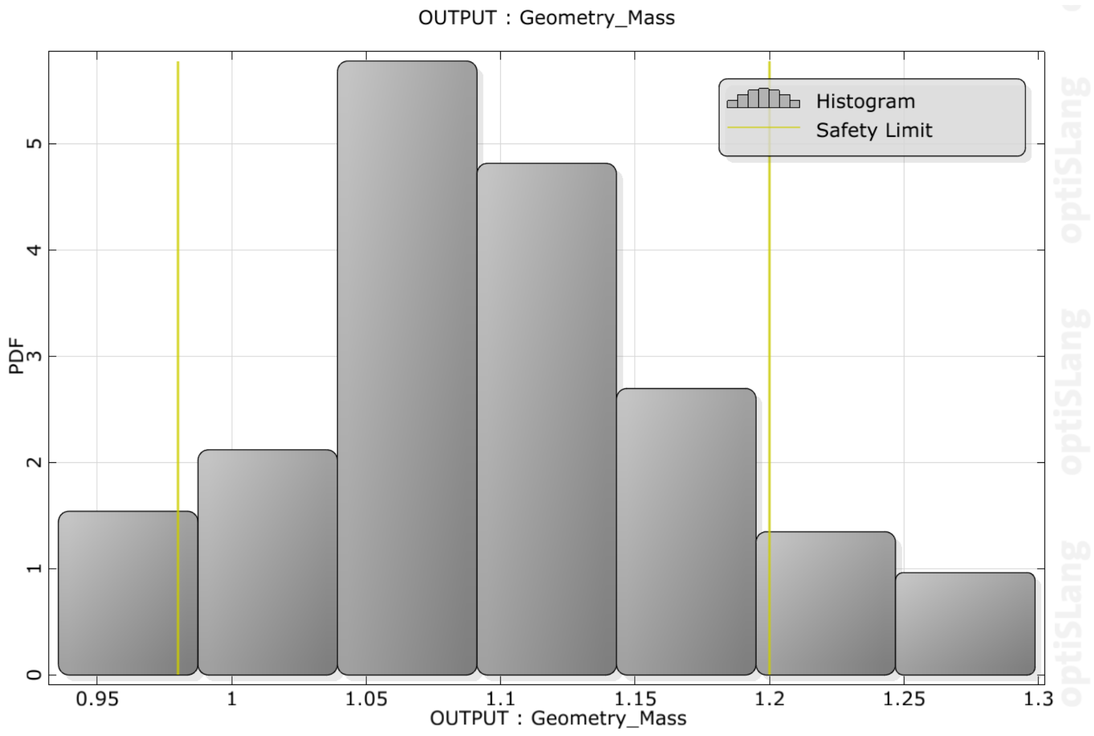


# Robustness Evaluation

Statistical Evaluation of the Mass:

- The range of 980g - 1200g is within the 80% quantile
- The scatter of the mass value is not relevant for the safety assessment



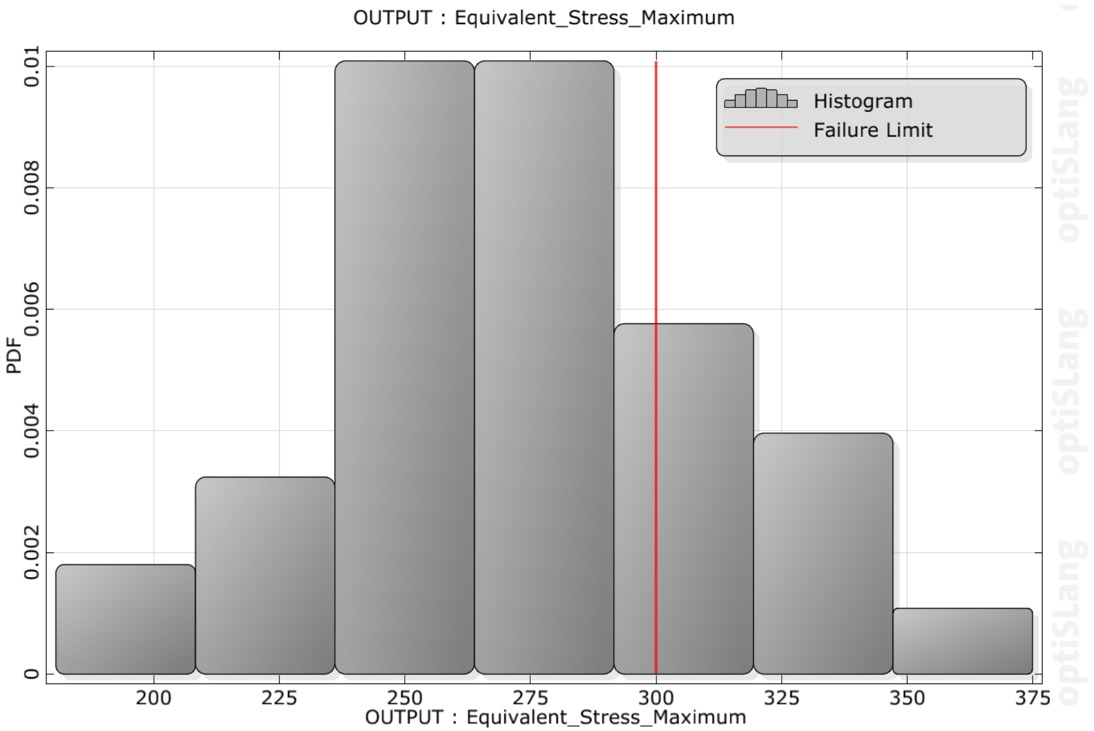

| Limit : Safety Limit | | | |
|---|---|---|---|
| | Lower value = 0.98 | Upper value = 1.2 | Total |
| P_rel: | 0.07 | 0.1 | 0.17 |
| Sigma-Level: | 1.55751 | 1.29856 | |

# Robustness Evaluation

Statistical Evaluation of the  Maximum Stress:

1. Failure stress of 300 MPa is exceeded with a probability of about 26%
2. The Sigma-Level is far from 4.5

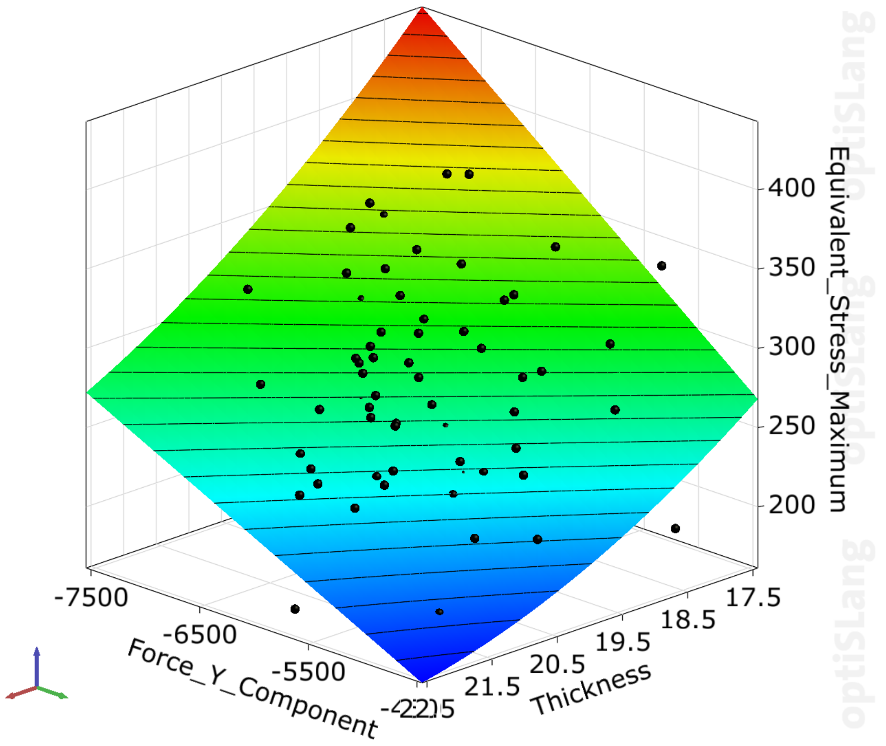
Further reliability analysis is not necessary; the design is not robust to stochastic changes.

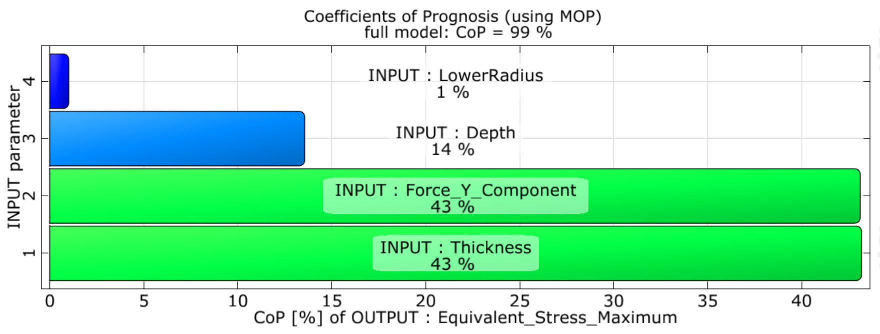



| Statistical data | | | |
|---|---|---|---|
| Min: | 180.573 | Max: | 374.927 |
| Mean value: | 273.697 | Standard deviation: | 40.2629 |
| CoV: | 0.147108 | | |
| Skewness: | 0.264513 | Excess kurtosis: | -0.104477 |
| Limit : Failure Limit | | | |
| | Lower value = not set | Upper value = 300 | Total |
| P_rel: | 1. | 0.26 | 0.26 |
| Sigma-Level: | 2. | 0.653292 | |

# Robustness Evaluation

- The force in main loading direction and the thickness are the most important input parameters for the maximum stress
- It is difficult to reduce the scatter of force uncertainty
- The design should be changed in order to reduce the mean value of maximum stress and to fulfill the robustness requirement



# Robustness Evaluation – Summary Initial Design

- Variance-based robustness evaluation has shown:
  - Probability of exceeding the stress limit is too high
  - Significant reduction of the input scatter is not likely

- Design improvement to do in the next step:
  - Iterative Robust Design Optimization
  - Modify the design and reduce the mean value of the maximum stress using deterministic optimization
  - Check the robustness

- Deterministic constraints for the first optimization step:
  - Mean stress + 4.5 * mean stress * CV ≤ 300
  - Mean stress ≤ 180

# Contacts

If you have any questions on this tutorial, do not hesitate to contact:

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