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Ralf Voß, Henning Almstedt

Probabilistic assessment of the potential creep damage at the surface of steam turbine rotor shafts

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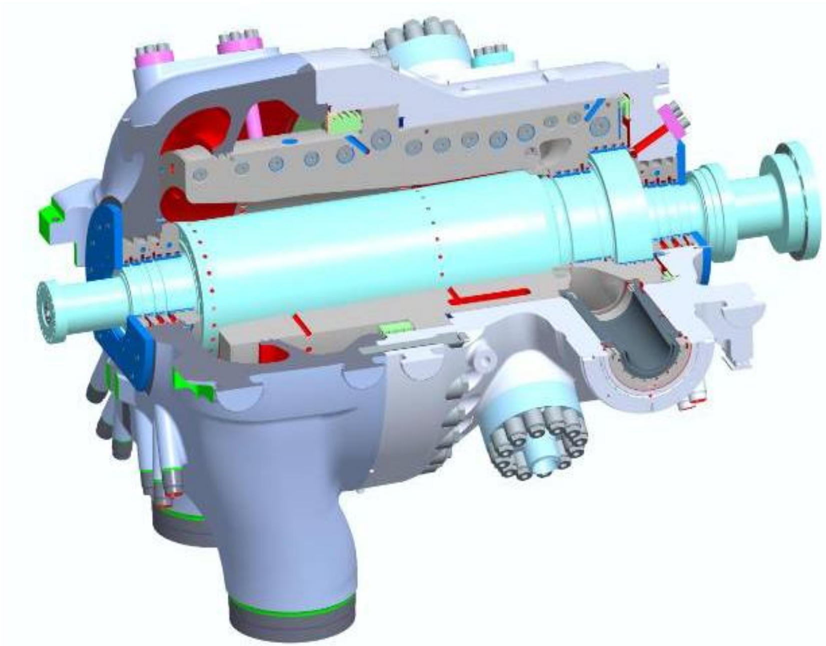

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Motivation

Requirements from steam turbine customers:

- Due to changes in the energy-mix **increased flexibility** necessary:
  - Increasing number of start-ups
  - Faster start-ups
  - Part-load-operation

- **Increasing cost-pressure** on steam turbine manufacturers (e.g. US: low gas price → efficiency less important; EU: power plants are less time in load-operation → worse ROI)

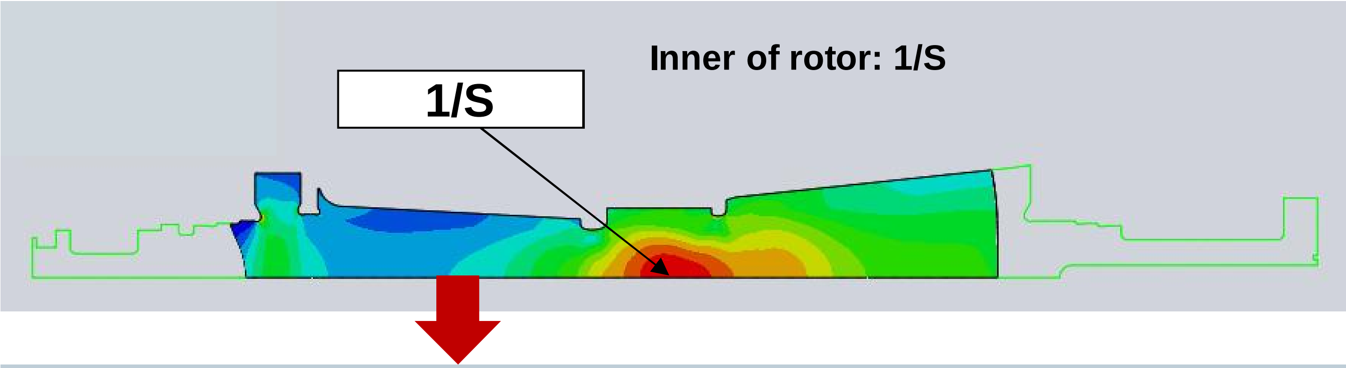
→ Increasing mechanical utilization of steam turbine components required

Deterministic design rules

State-of-the-art in the design of steam turbines: Deterministic mechanical design methods using „Worst-Case“-assumptions:

- Nominal steam temperature and pressure
- Minimum material parameters (e.g. creep rupture strength)

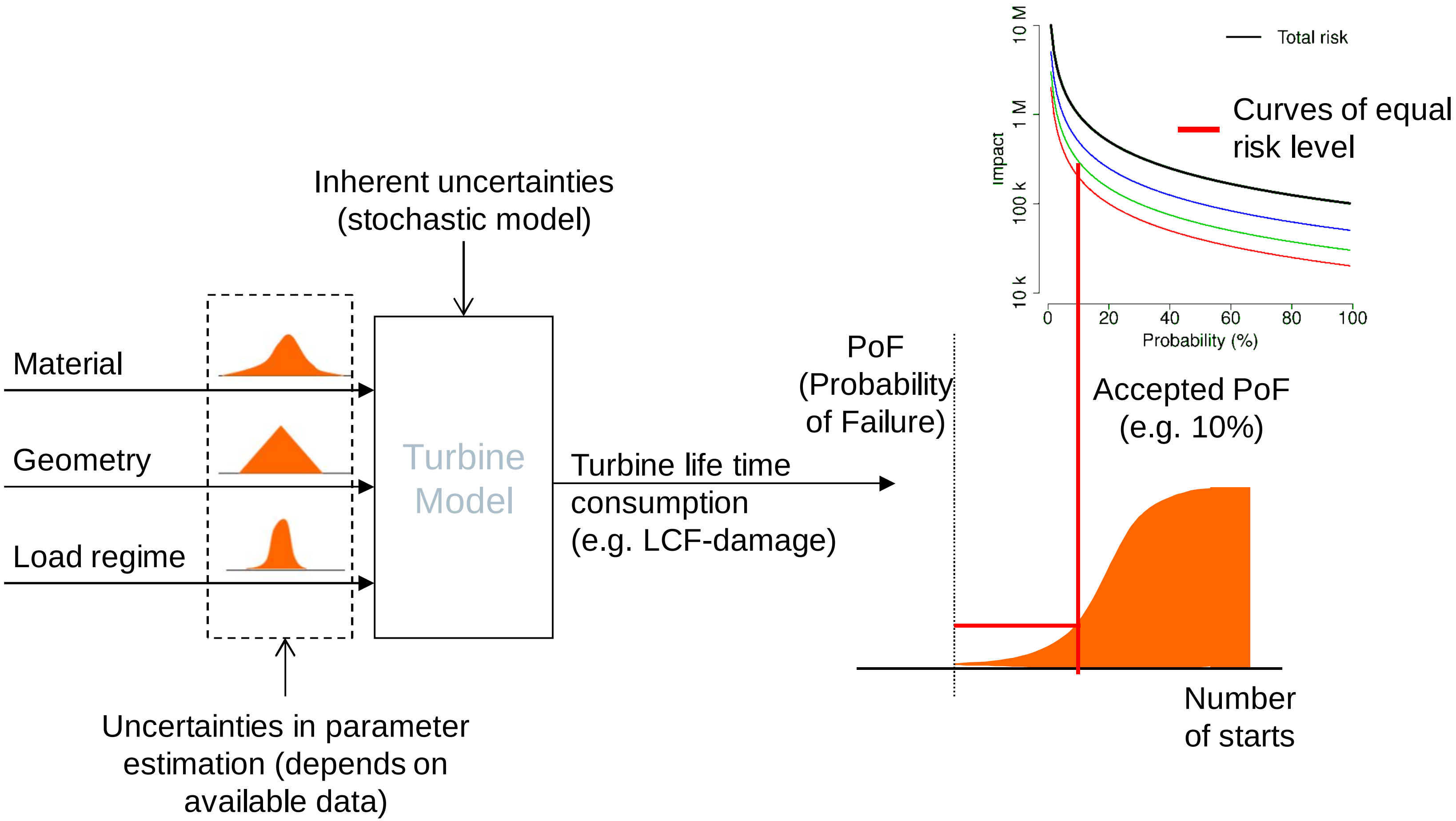
Judgement: $\sigma_{Calc} \leq \frac{R_{m2E5}}{S} \Leftrightarrow \frac{\sigma_{Calc}}{R_{m2E5}} \leq \frac{1}{S}$



- Is this really the limit?
- What risk of failure belongs to this utilization?
- How robust is the result when inputs variate?

Implementation strategies of Probabilistic Design

Approach 1: Development of Probabilistic Design methods that are **released in internal design rules or norms**



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Implementation strategies of Probabilistic Design

Approach 1: Development of Probabilistic Design methods that are **released in internal design rules or norms**

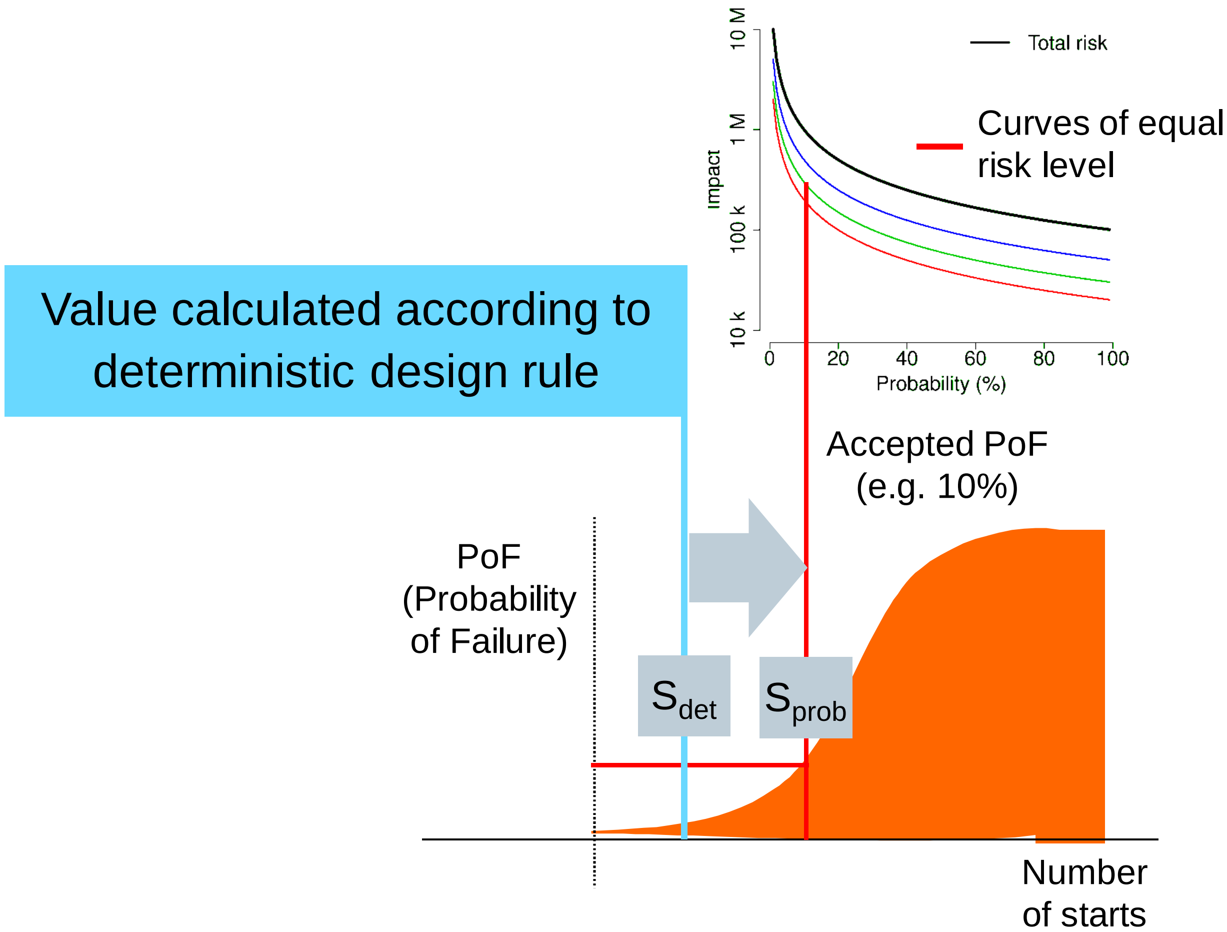
Necessary aspects for realization:

- Update of design rule:
  - Calculation procedure
  - Acceptable risk level
- Development of adequate tools
- Knowledge building in affected areas (e.g. mechanical design department)

→ Challenging and time-consuming implementation process!

Implementation strategies of Probabilistic Design

Approach 2: Usage of Probabilistic Design methods to determine **risk-based safety factors for deterministic design**. The design rules are updated with those new safety factors.



Implementation strategies of Probabilistic Design

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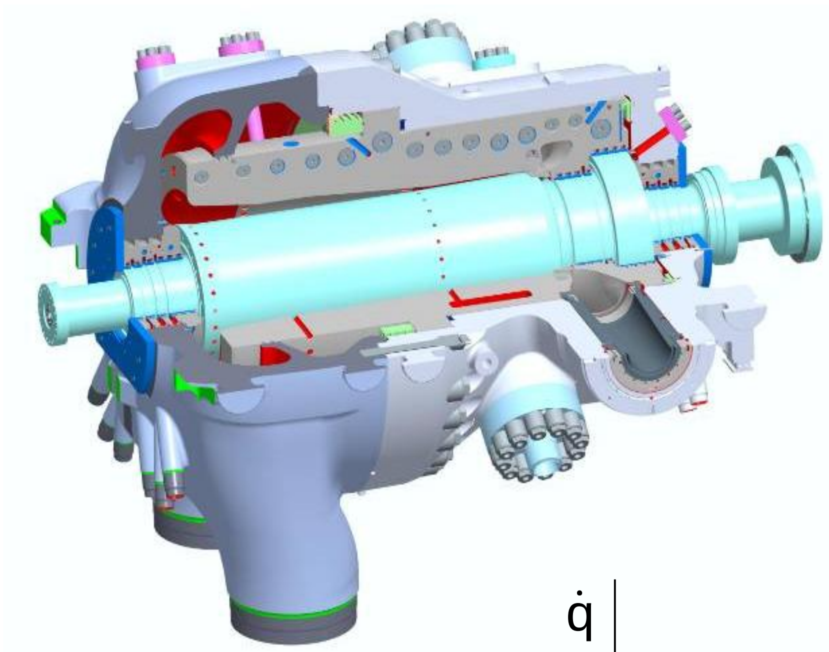
Approach 2: Usage of Probabilistic Design methods to determine **risk-based safety factors for deterministic design**. The design rules are updated with those new safety factors.

Aspects for realization:

- Update of design rule:
  - ➢ Safety factor
- Some conservativities still need to be kept (due to simplifications)
- Changes in boundary conditions of probabilistic calculations need to be checked regularly

→ Quick implementation possible (but potential for further improvement)!

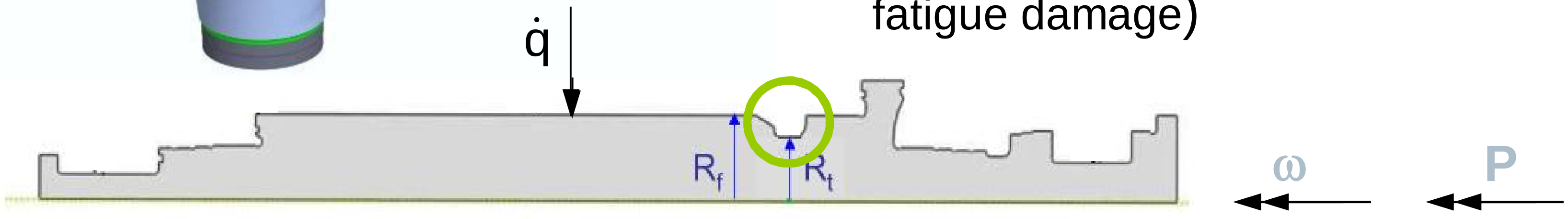
Exemplary application: Introduction



Background:

High-temperature rotors are exposed to life-time consumption in the inlet stress-relieve groove due to:

- D_c: **creeping (steady state effect)** and
- D_f: Temperature gradients during start up and shut down **limiting the number of start-ups** (low-cycle-fatigue damage)



$$D = D_f + D_c < 1$$

$$\boxed{D_c \leq S_{\det}}$$

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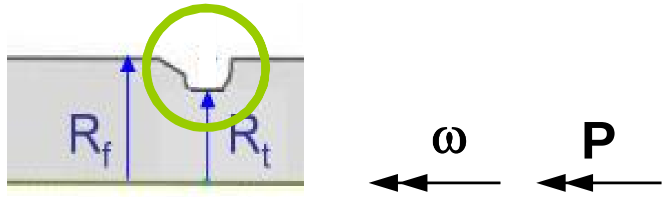
Exemplary application: Mechanics

Approach: Simplification by a cylinder

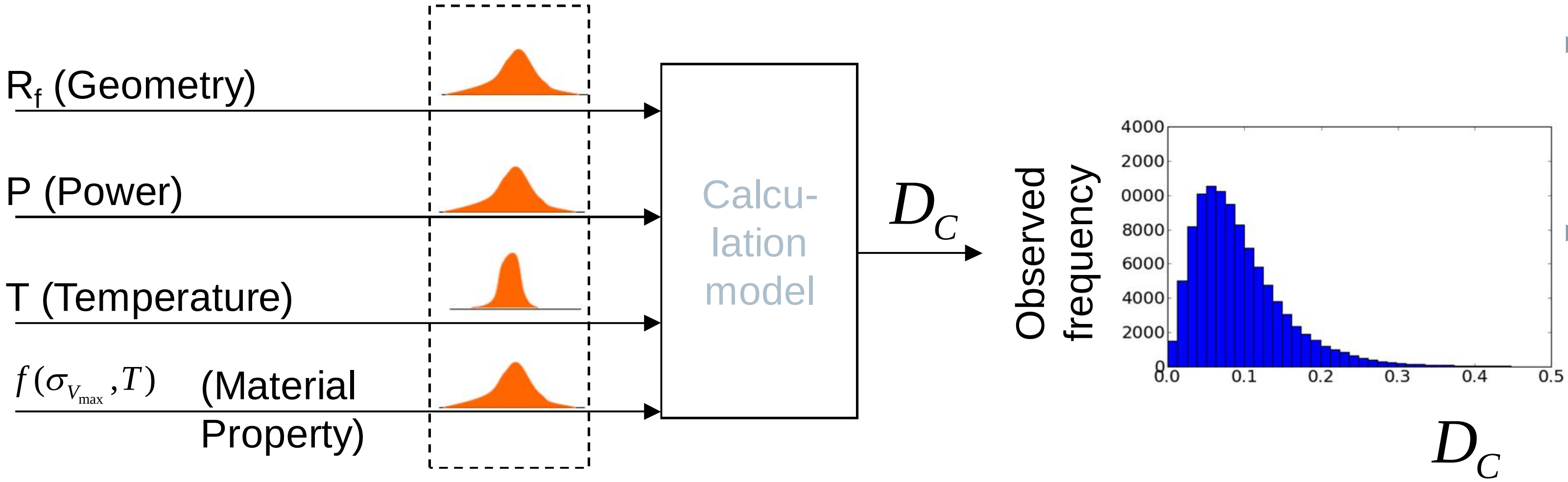


$$\sigma_{V_{\max}} = \sqrt{\underbrace{\left(\rho\cdot\pi^2\cdot f^2\cdot R_f^2\right)^2}_{\text{Centrifugal force (50/60Hz)}} + \underbrace{3\cdot\left(\frac{P}{\pi^2\cdot f^2\cdot R_t^3}\right)}_{\text{Torsion caused by transmittable power}}}$$

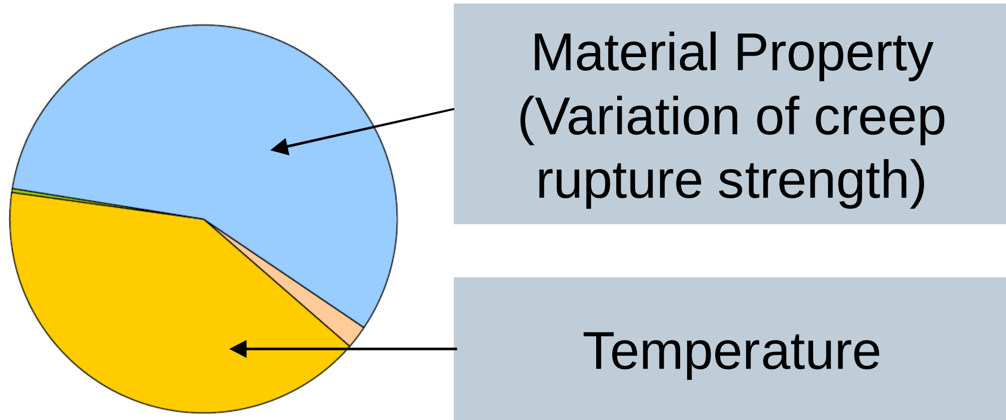
$$\Rightarrow D_C = f(\sigma_{V_{\max}}, T, Operation\ \ Time)$$

Exemplary application: Sensitivity analysis

Sensitivity analysis using Monte-Carlo-Simulation:



Normed share of rang correlation coefficient according to Spearman:

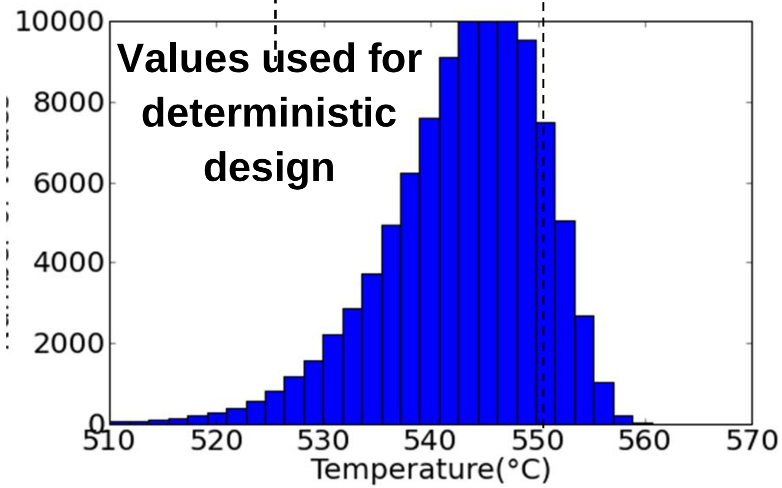


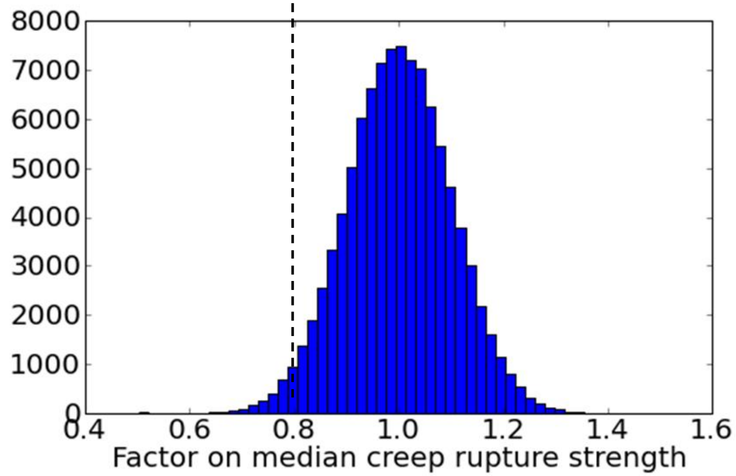
Exemplary application: Probability of Failure

Application to a statistical load regime:

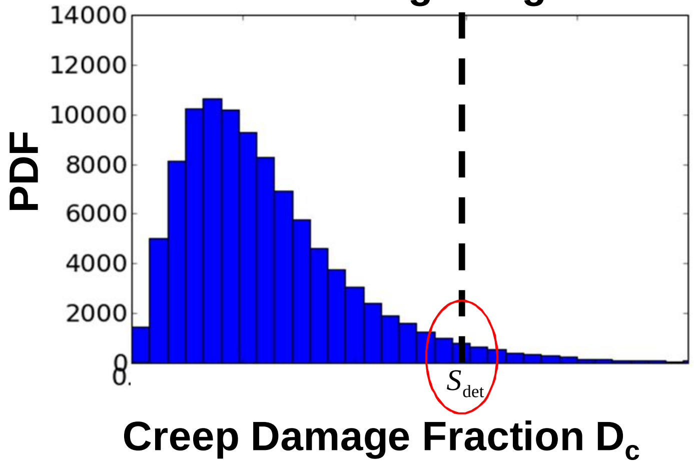
T_nom = 550ºC[1)]

Sig_min = 0.8*Sig_median (Mpa)





Design target[1)]



Share of values above S_{det} (here: 1.3%)

[1)]: Siemens-internal values differ from these values!

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Exemplary application: Probability of Failure

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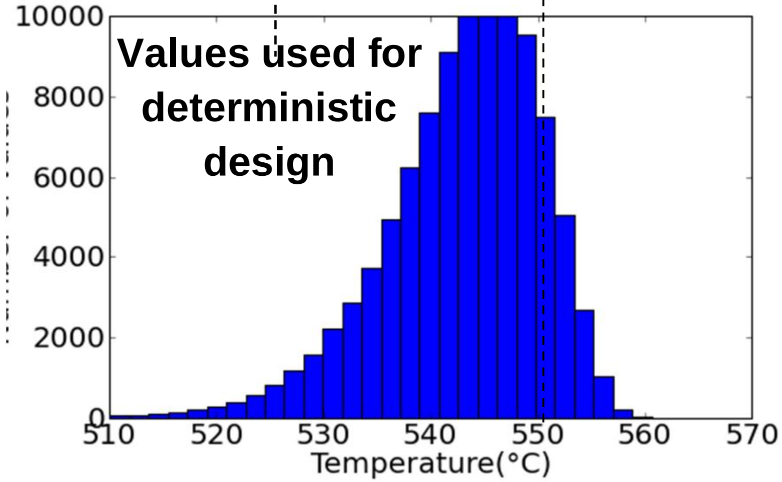

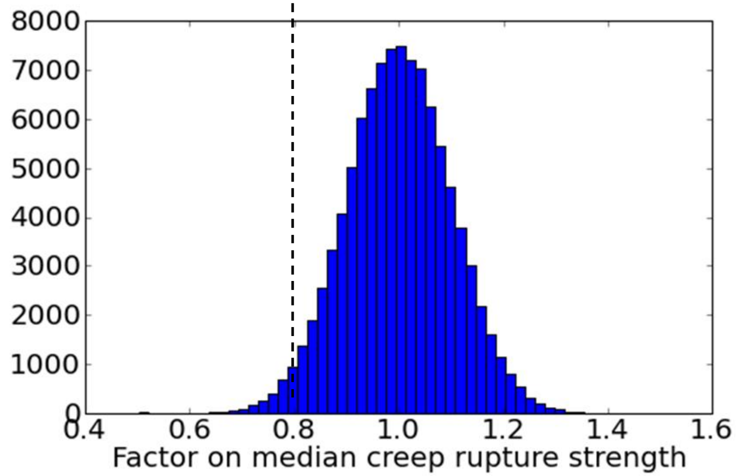

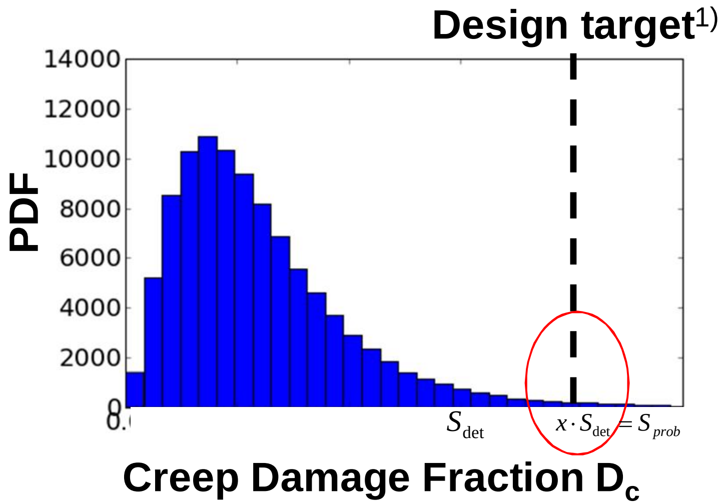

Share of values above S_{det} (here: 3.8%)

[1)]: Siemens-internal values differ from these values!

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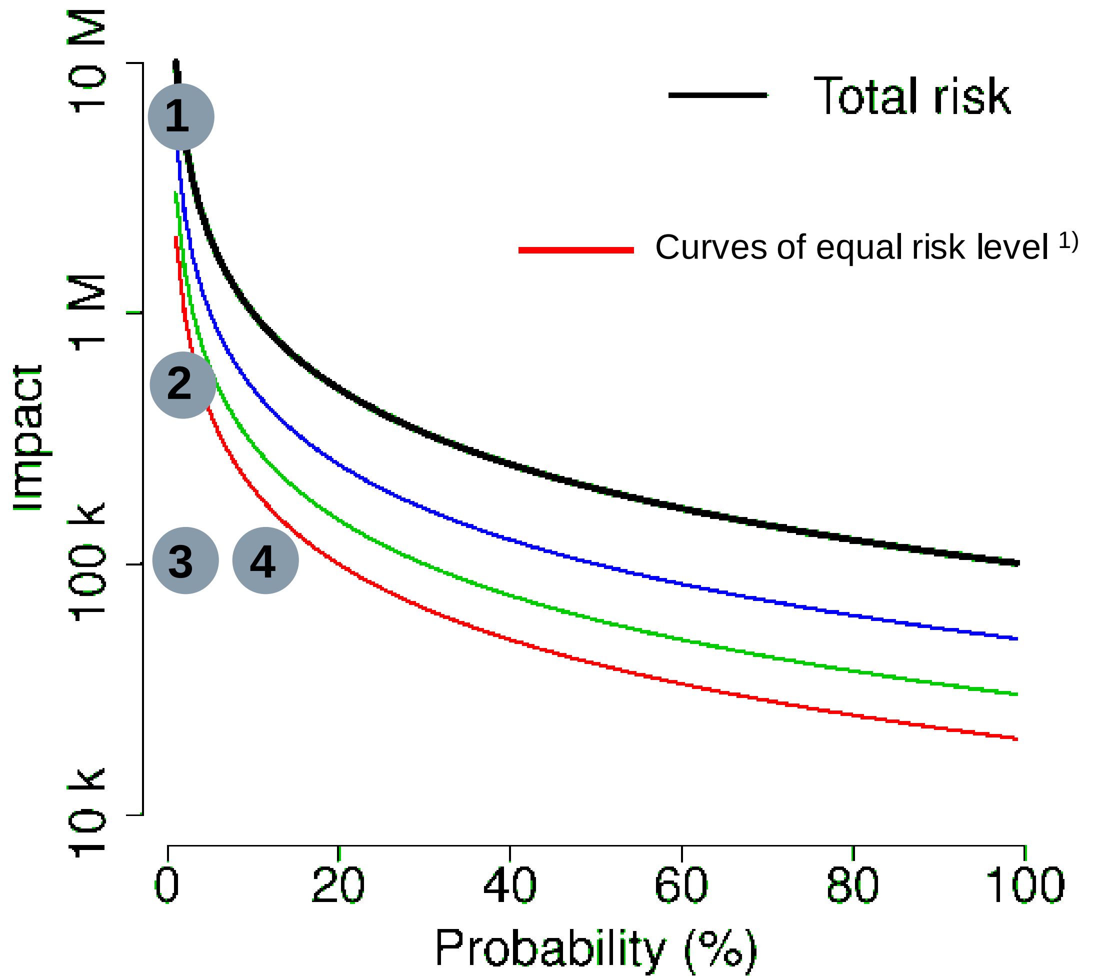
Exemplary application: Probability of Failure

Scenario 1

Scenario 2

Scenario 3

Scenario 4



1): Siemens-internal value differs from this value!

Exemplary application: Probability of Failure

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Challenges:

- Adequate determination of the input variations and frequent verification of changes in the variations
- Development of efficient and problem-specific simulation methods
- Determination of an acceptable risk level (Health&Safety, financial)

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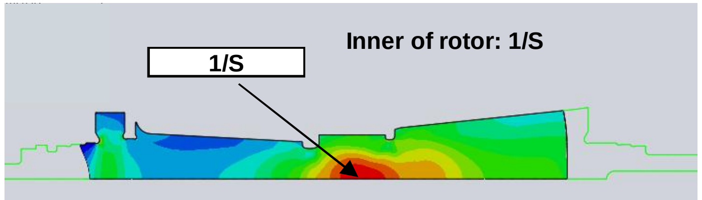
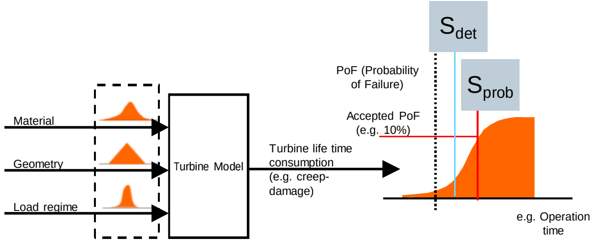
Resume

Resume:

- Presentation of limitations of deterministic mechanical design rules



- Introduction of two implementation strategies of Probabilistic Design



- Exemplary application: Analysis of the potential creep damage at steam turbine rotor shafts
  - ➢ Sensitivity analysis
  - ➢ Probability of Failure
  - ➢ Risk assessment
  - ➢ Challenges of the approach