TECHNISCHE UNIVERSITÄT DRESDEN

Fakultät Maschinenwesen | Institut für Strömungsmechanik | Professur für Turbomaschinen und Strahlantriebe

Probabilistic LCF - investigation of a steam turbine rotor under transient thermal loads

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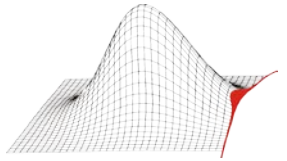
Siemens AG
Steam Turbines
Mülheim an der Ruhr

Dresden, 09.10.2014



Probabilistic Design of Steam Turbine Components – Design Citeria

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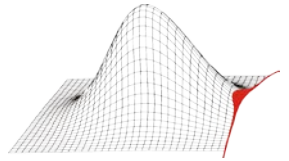
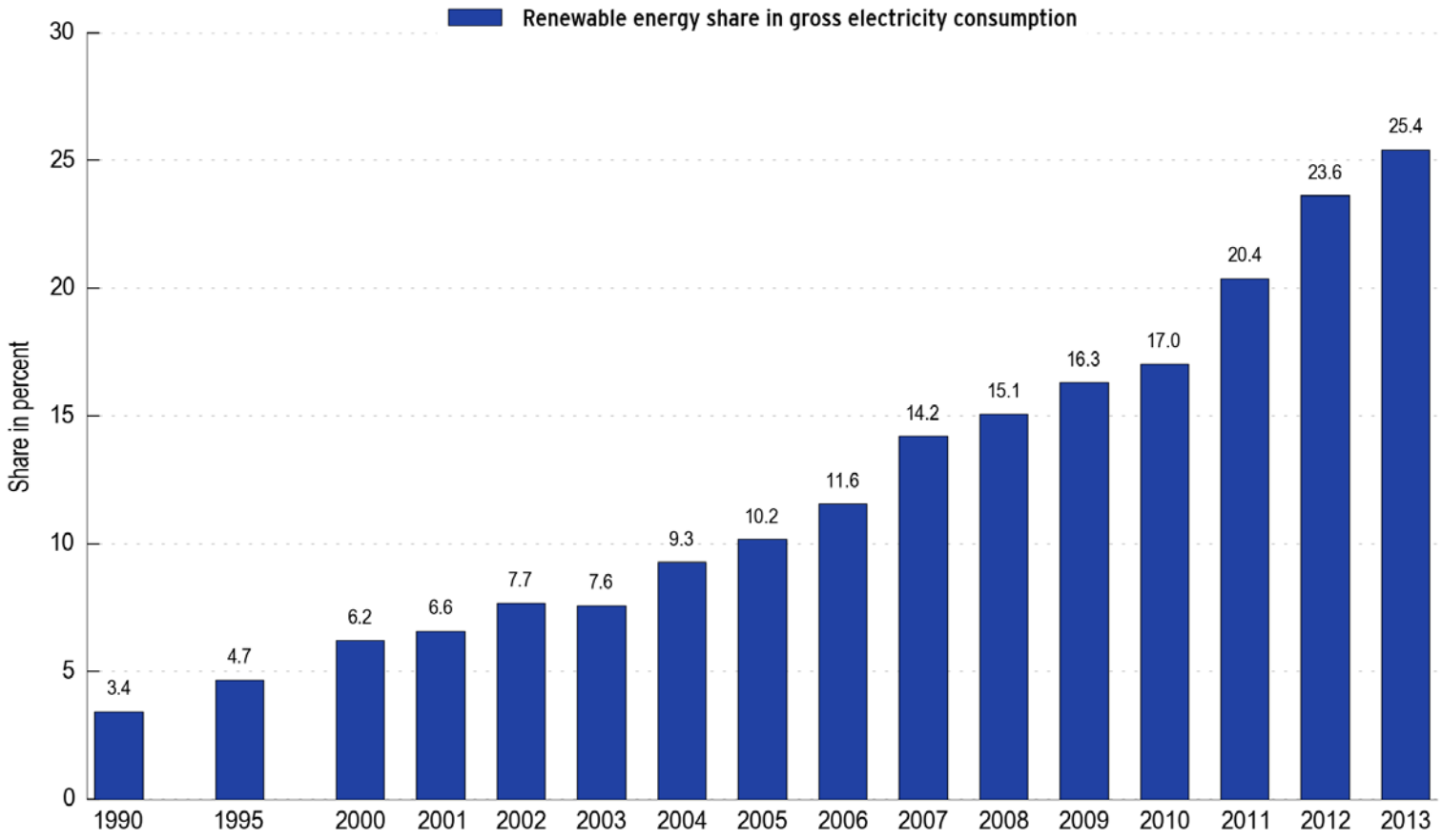
SIEMENS

AGTURBO

Federal Ministry for Economic Affairs and Energy

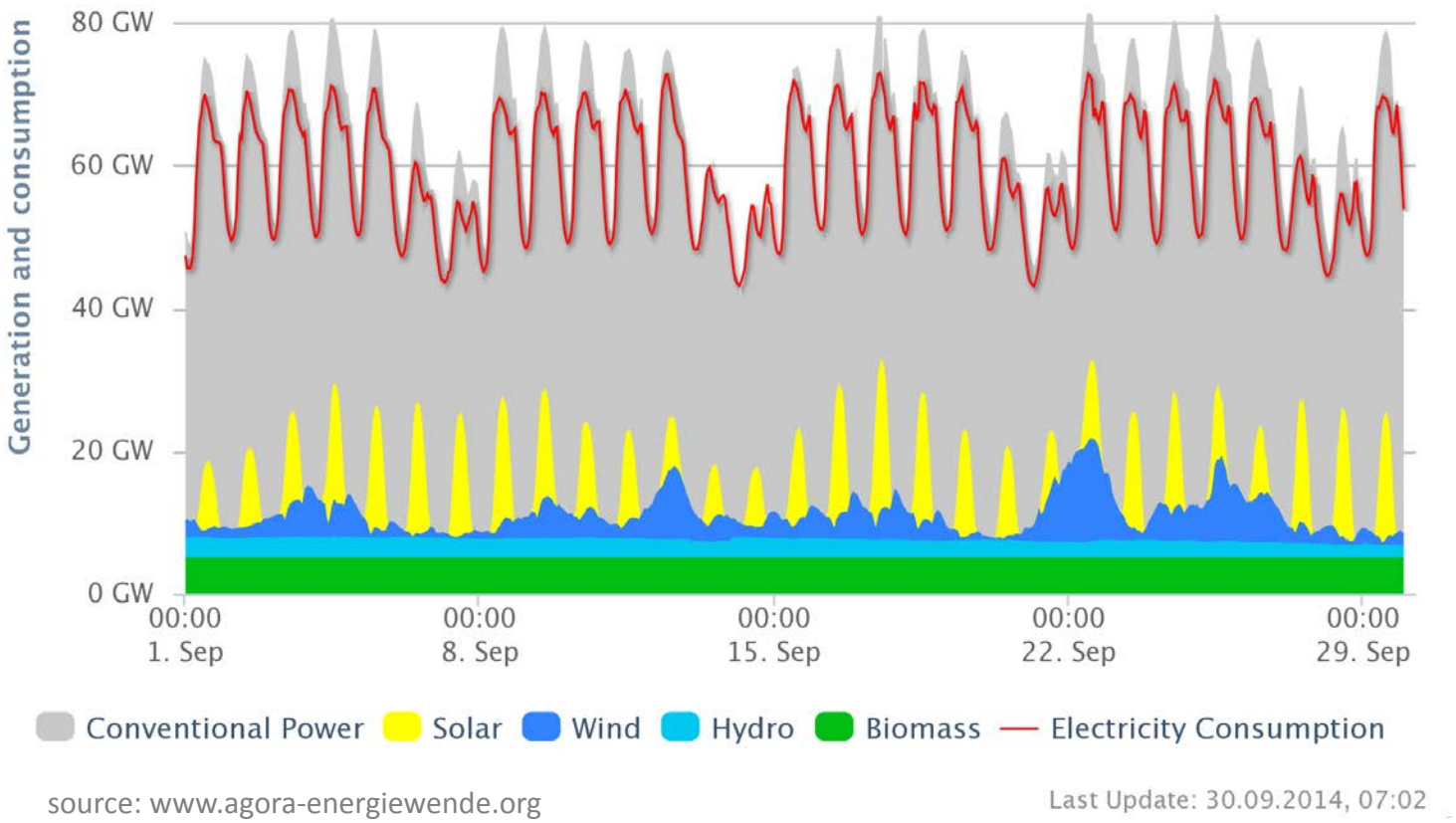


Development of renewable energy shares of gross electricity consumption in Germany



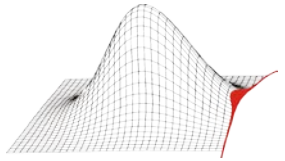
ZSW according to Working Group on Renewable Energy-Statistics (AGEE-Stat); as at February 2014; all figures provisional

source: www.bmwi.de



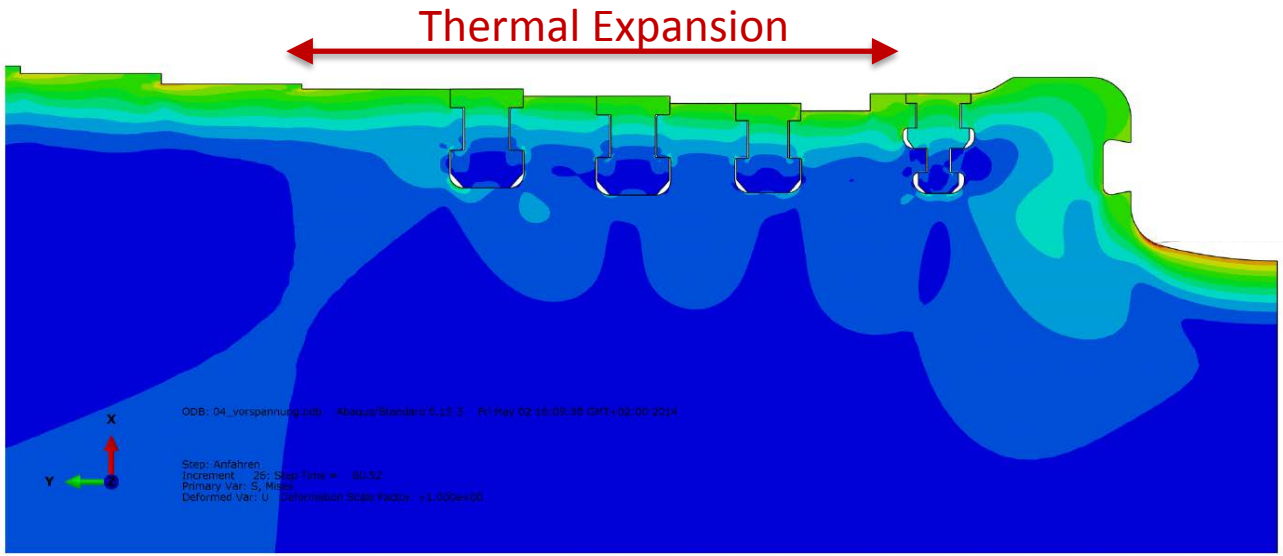
- Solar and wind power are subjected to power fluctuations, which need to be compensated
- → conventional power plants need to respond fast, flexible and reliable on power fluctuations in order to stay competitive and to guaranty a robust electricity grid

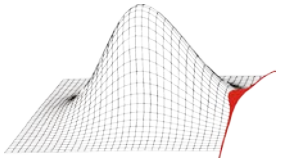
Project Scope



- Investigation of thermo – mechanic low cycle fatigue in steam turbine rotors
- Investigation of sensitivities to identify the main drivers of rotor LCF
- Use of probabilistic methods in order to take the impact of scattering or not well known boundary conditions on rotor lifetime into account

With knowledge about the system's behavior it is possible to modify the design or to adjust the operation profiles in order to optimize the rotor lifetime.





probabilistic system analysis

Deterministic model

Distribution of input parameters

Correlations between input parameters

Probabilistic methods

Development of an FEM - Model

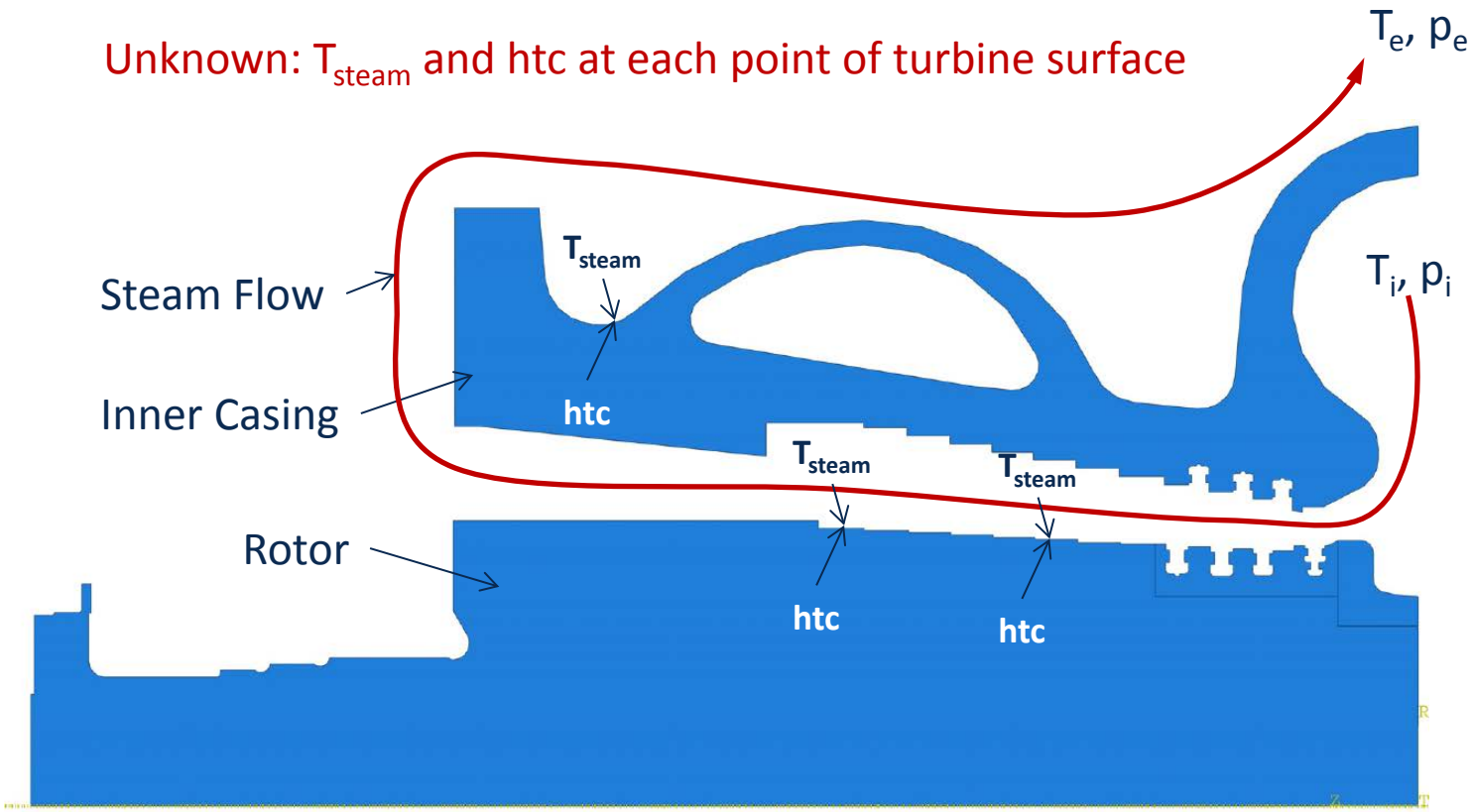
Operating data
- steam temperature (t)
- steam pressure (t)

FEM →

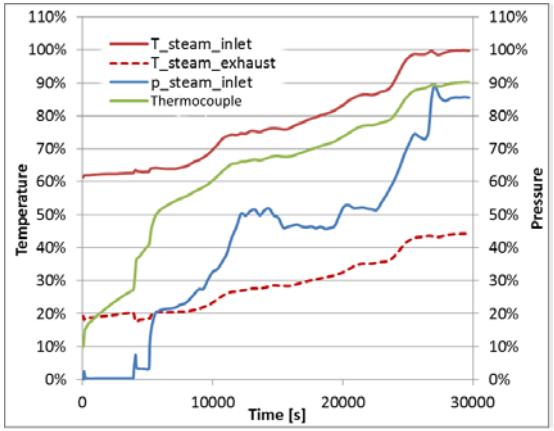
- Metal temperatures (t)
- Mises Stress

→ lifetime

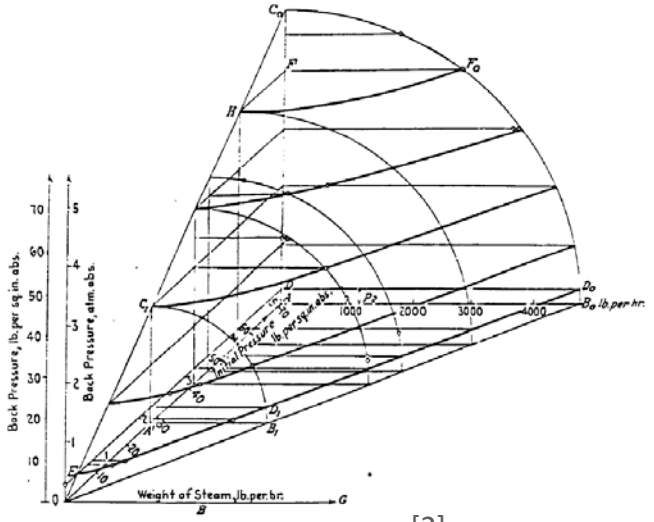
Unknown: T_{steam} and htc at each point of turbine surface



Operating data

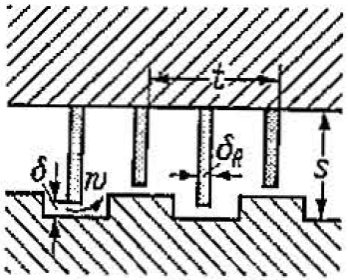


Calculation of local p_{steam} and T_{steam} by use of Stodola's cone law and 1d through flow modelling

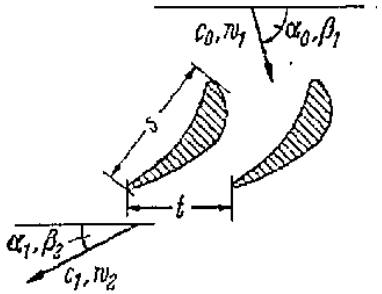


[2]

Calculation of local heat transfer coefficients, using Nusselt correlations



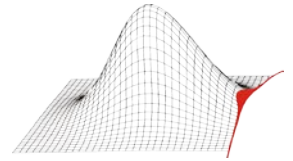
[1]



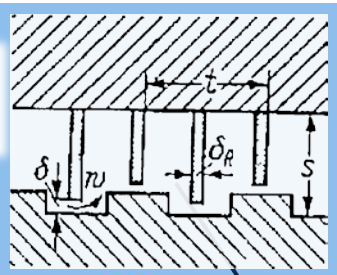
[1]

[1] Traupel, W., 1977, Thermische Turbomaschinen 1, 1, Springer, Berlin; Heidelberg
[2] Stodola, A., Loewenstein, L.C., 1927, Steam and Gas Turbines, McGraw-Hill, New York

Nusselt Correlations



Nusselt correlation for labyrinth seals adapted to Siemens design



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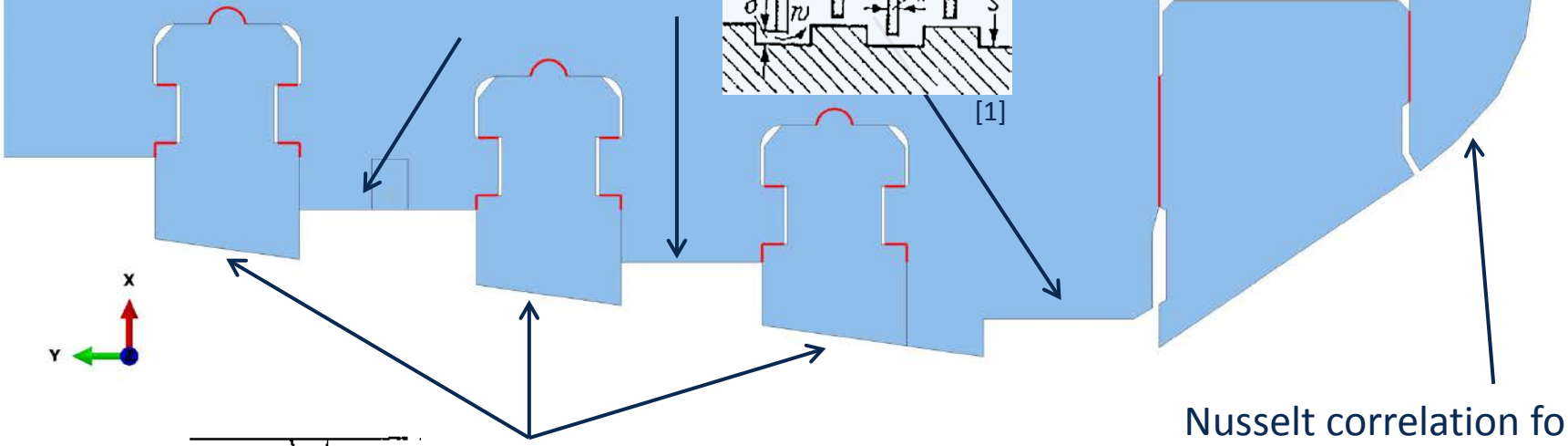
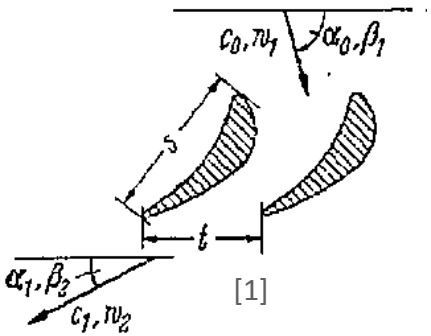


Nusselt correlation for turbulent duct flow or flat plate



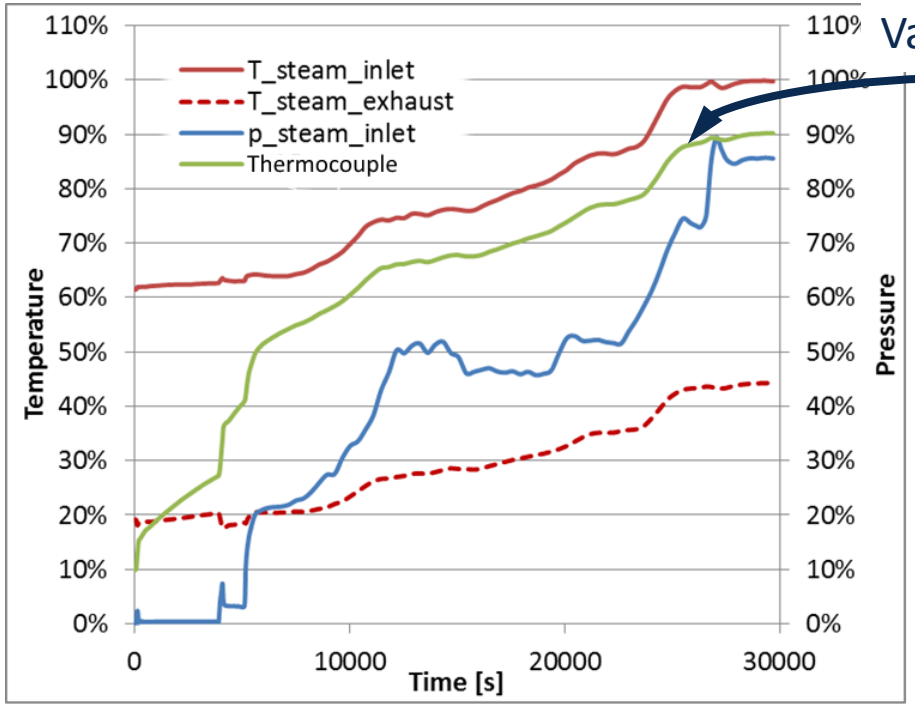
[1]

Nusselt correlation for blades adapted to Siemens design

[1] Traupel, W., 1977, Thermische Turbomaschinen 1, 1, Springer, Berlin; Heidelberg.

Model Validation

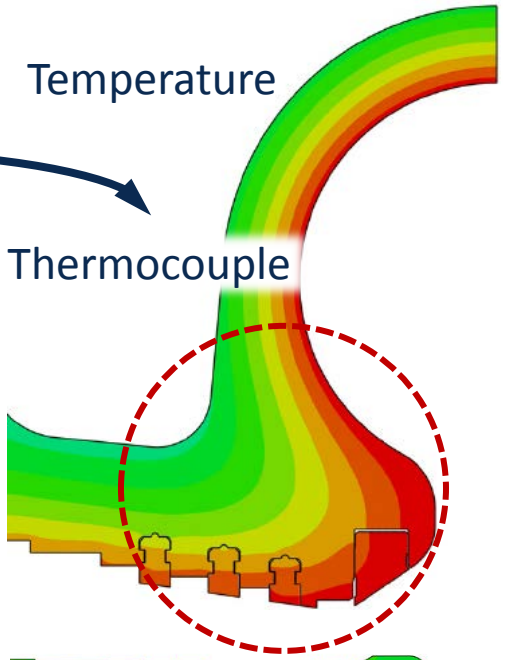
Operating Data

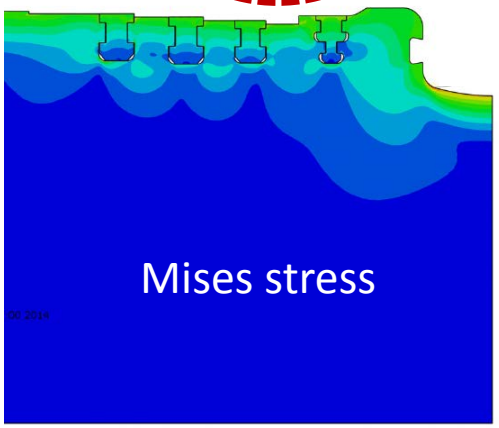


Validation!

Temperature

Thermocouple

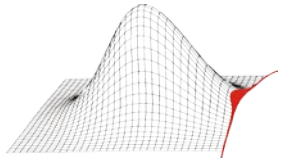


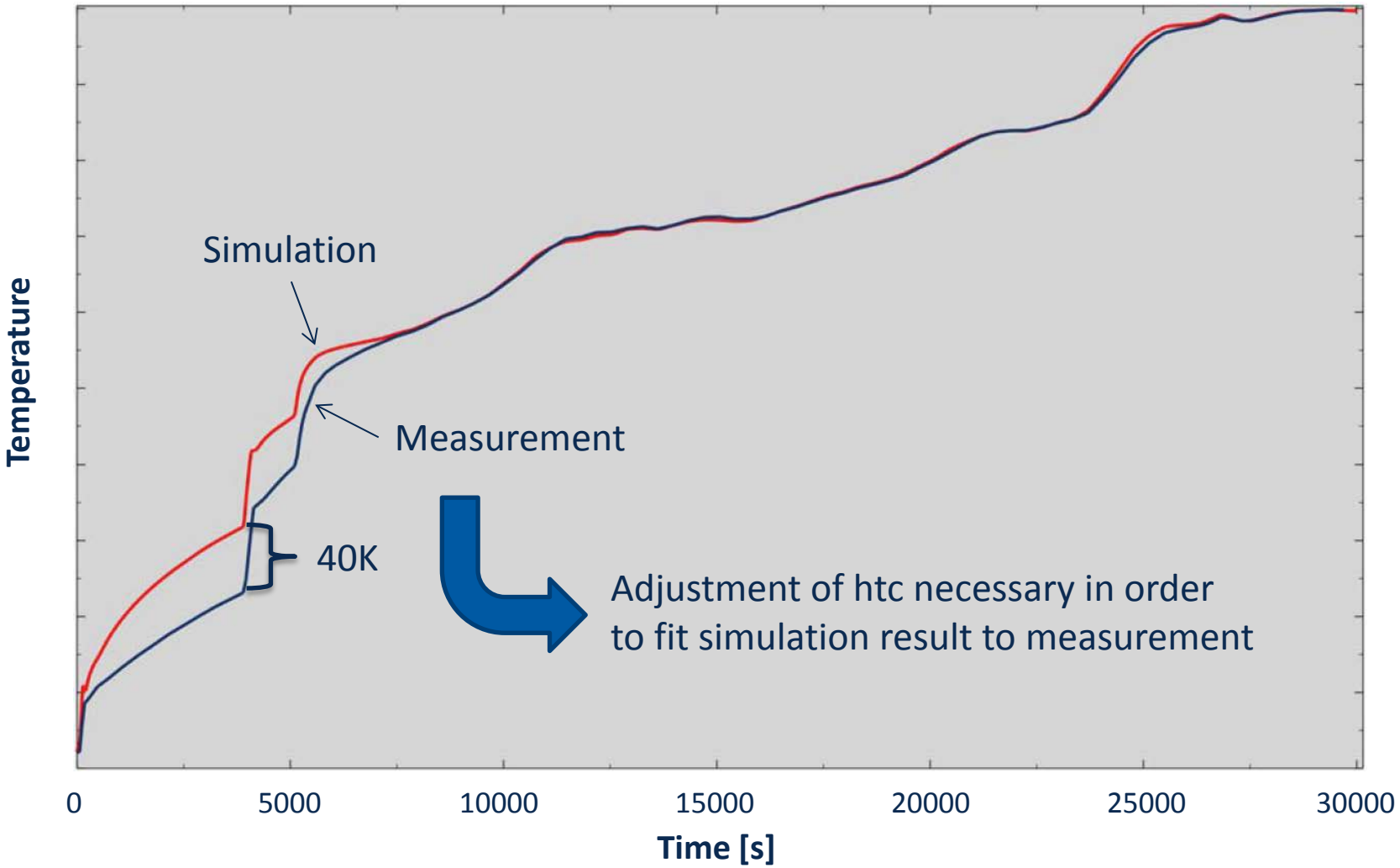


HTC (x,t)

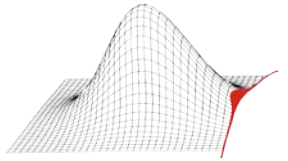
T_{steam} (x,t)

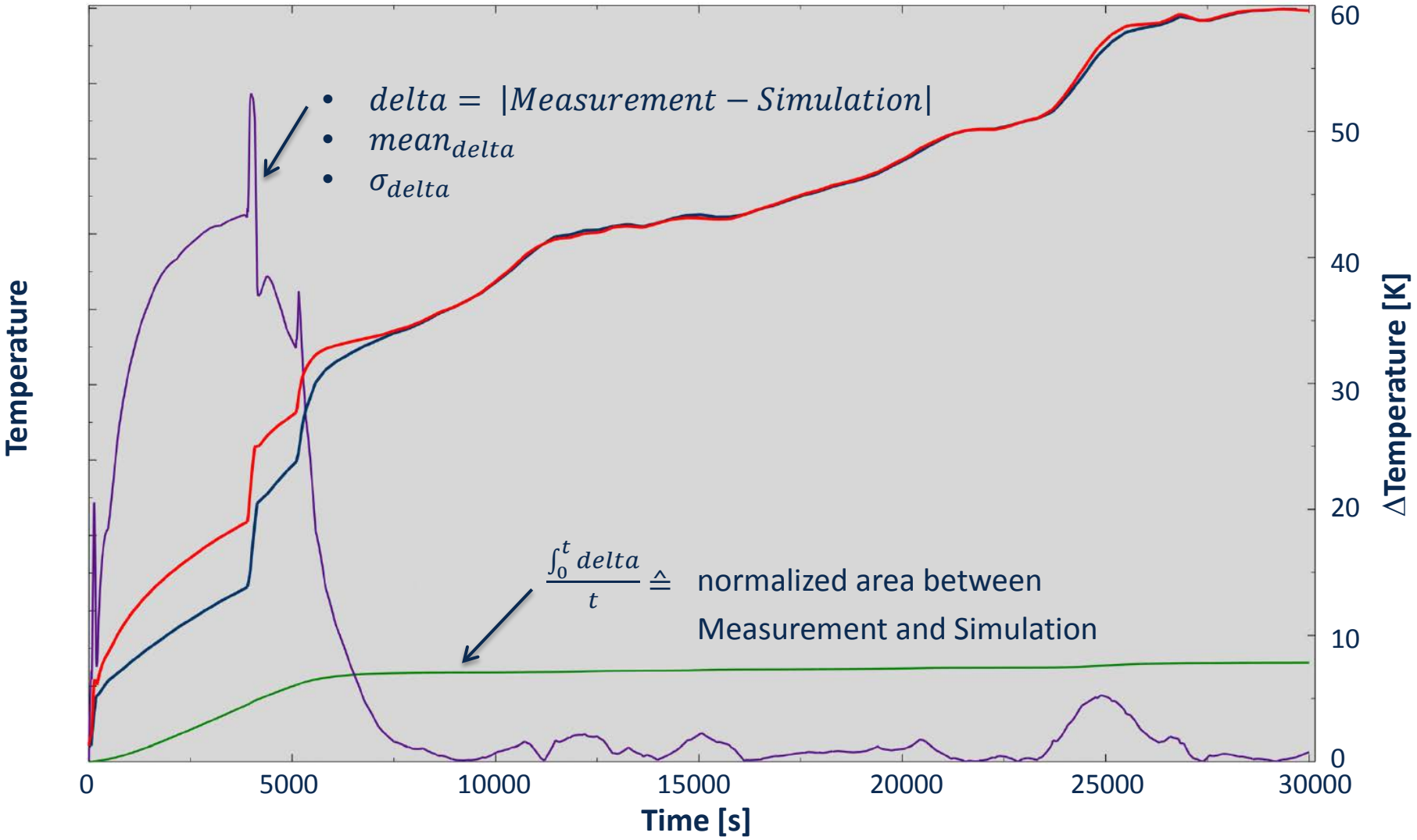
Simulation vs. Measurement



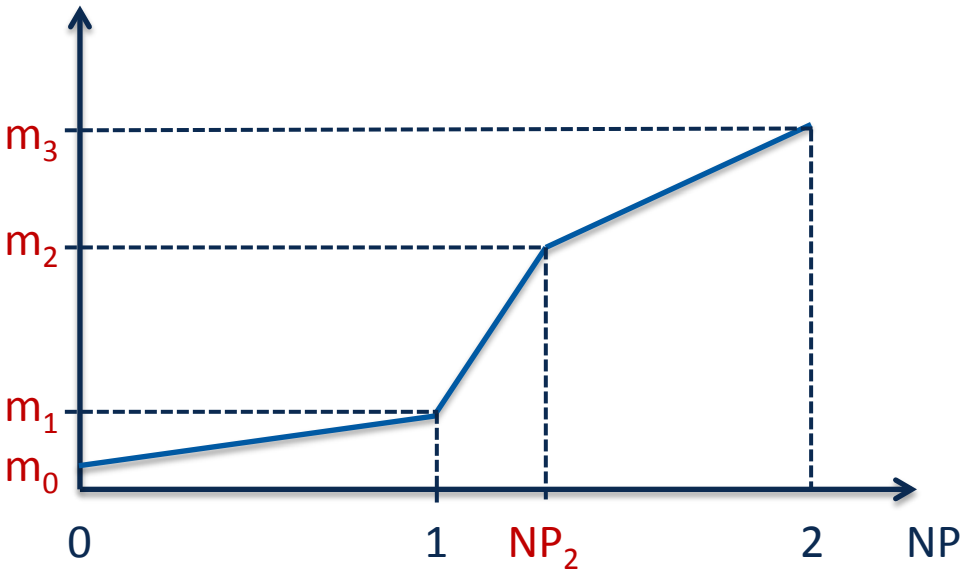


Validation – Target Values





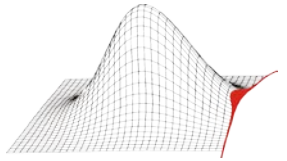
Validation – correction curve

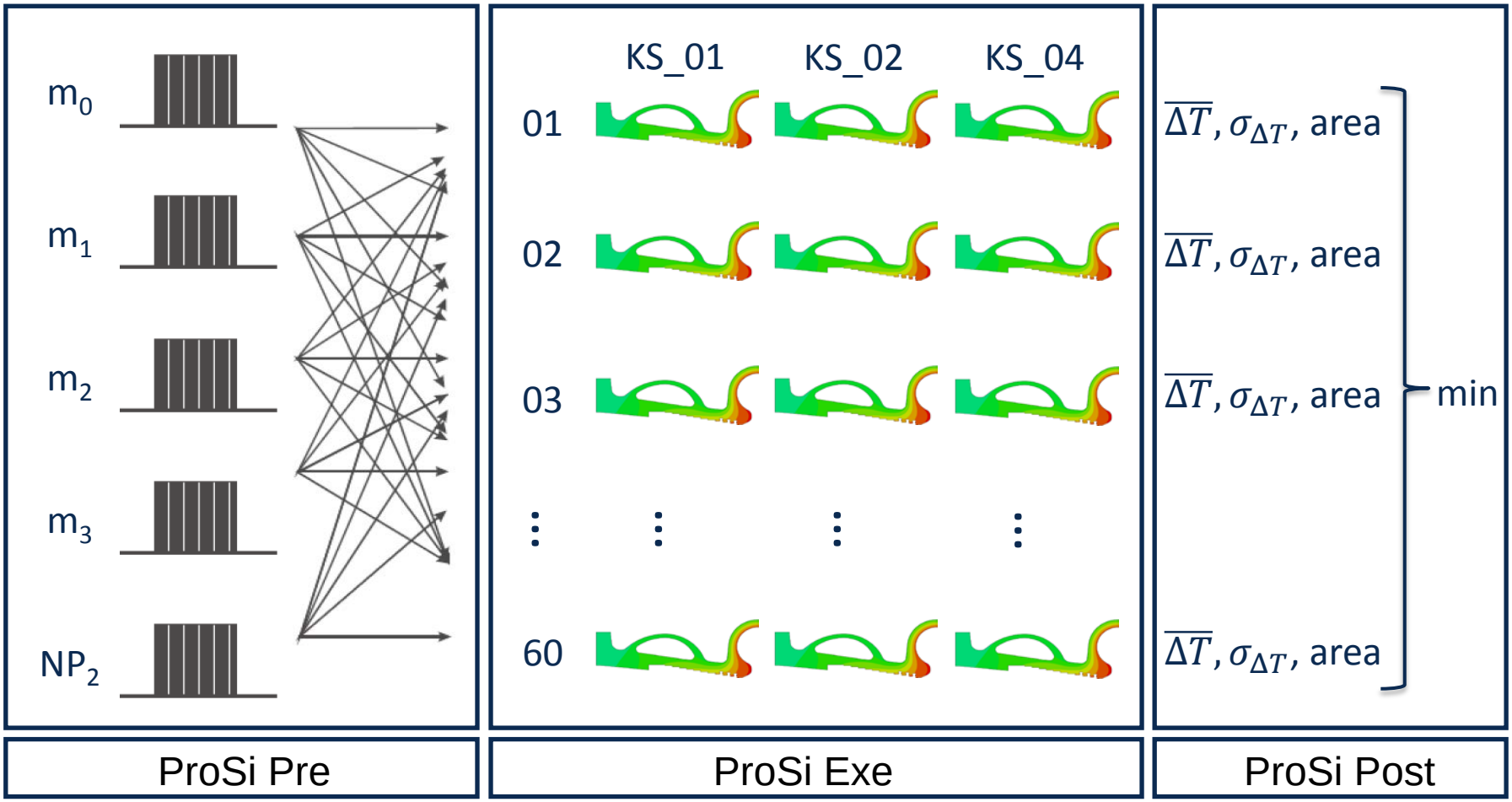


NP = relative rotational speed + relative power

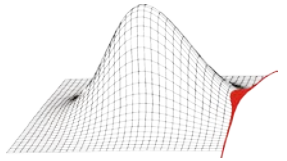
Correction curve referring to the Siemens in- house htc - correlation

Monte-Carlo-Simulation





Comparison of System Behavior



Spearman rank correlation coefficient

	m_0	m_1	m_2	m_3	NP2
01_area	0.40	0.11	-0.53	-0.20	0.01
01_stdev	0.47	0.12	-0.16	0.05	0.05
02_area	0.63	0.13	-0.43	-0.22	0.06
02_stdev	0.69	0.21	-0.14	-0.02	0.05
04_area	0.32	0.04	-0.47	-0.16	0.03
04_stdev	0.35	-0.01	-0.11	0.10	0.03

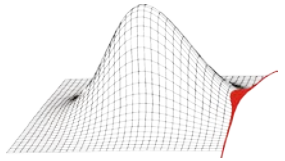
COI (Coefficient of importance)

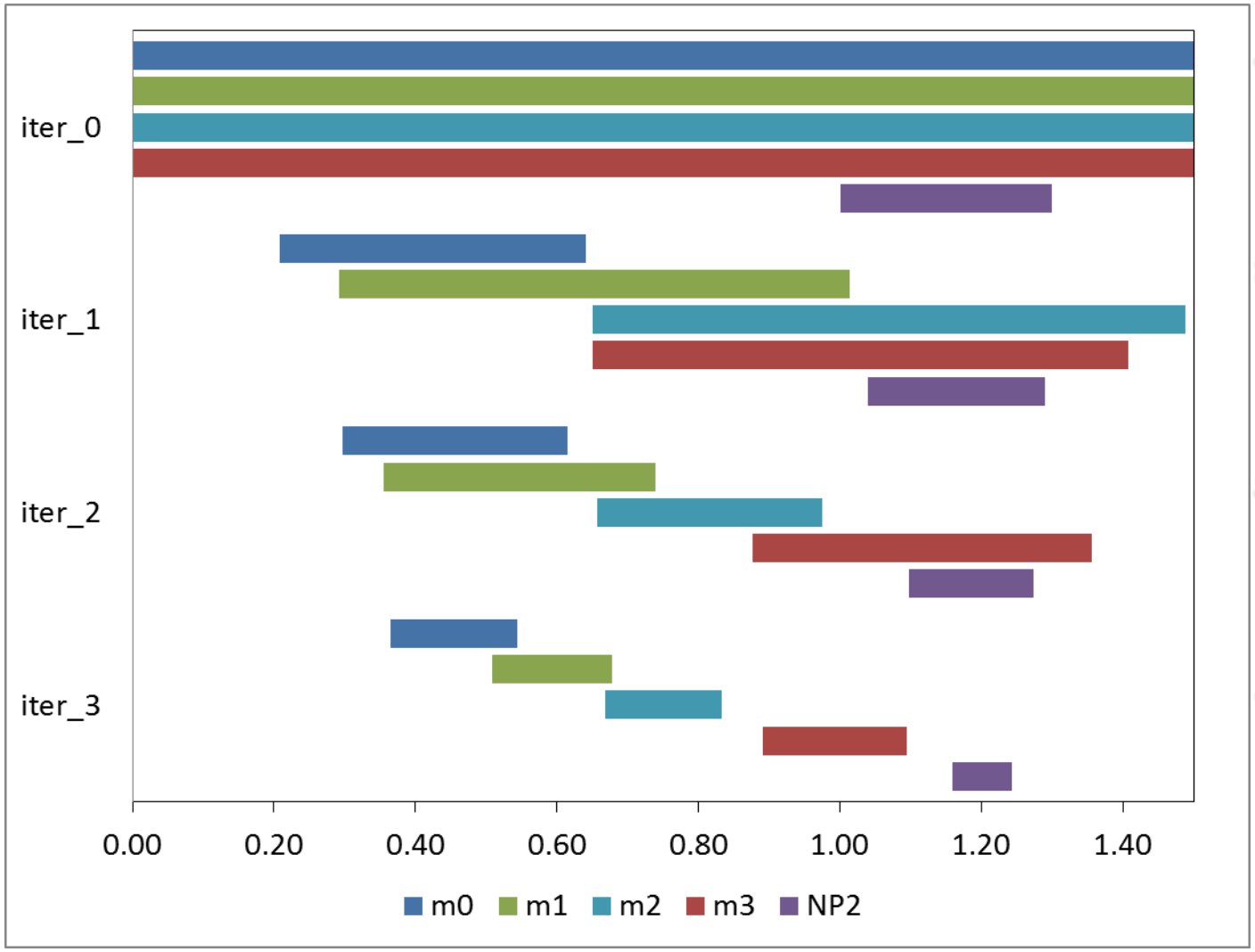
3. order response surface without (upper)/ with (lower) mixed terms

	R^2	m_0	m_1	m_2	m_3	NP2
01_area	0.57 / 0.99	0.05 / 0.15	0.08 / 0.19	0.37 / 0.27	0.02 / 0.05	0.00 / 0.04
01_stdev	0.38 / 0.99	0.15 / 0.29	0.13 / 0.30	0.11 / 0.18	0.01 / 0.06	0.01 / 0.05
02_area	0.63 / 0.99	0.28 / 0.29	0.03 / 0.13	0.31 / 0.22	0.02 / 0.05	0.01 / 0.02
02_stdev	0.57 / 0.99	0.47 / 0.38	0.06 / 0.22	0.05 / 0.12	0.01 / 0.04	0.01 / 0.04
04_area	0.53 / 0.99	0.08 / 0.23	0.09 / 0.22	0.29 / 0.23	0.02 / 0.06	0.00 / 0.04
04_stdev	0.35 / 1.00	0.17 / 0.37	0.13 / 0.33	0.07 / 0.12	0.02 / 0.05	0.01 / 0.04

all three cold starts show similar behavior

Stepwise Reduction of Distribution Limits



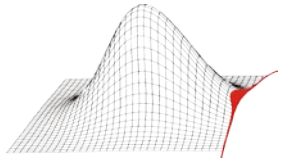


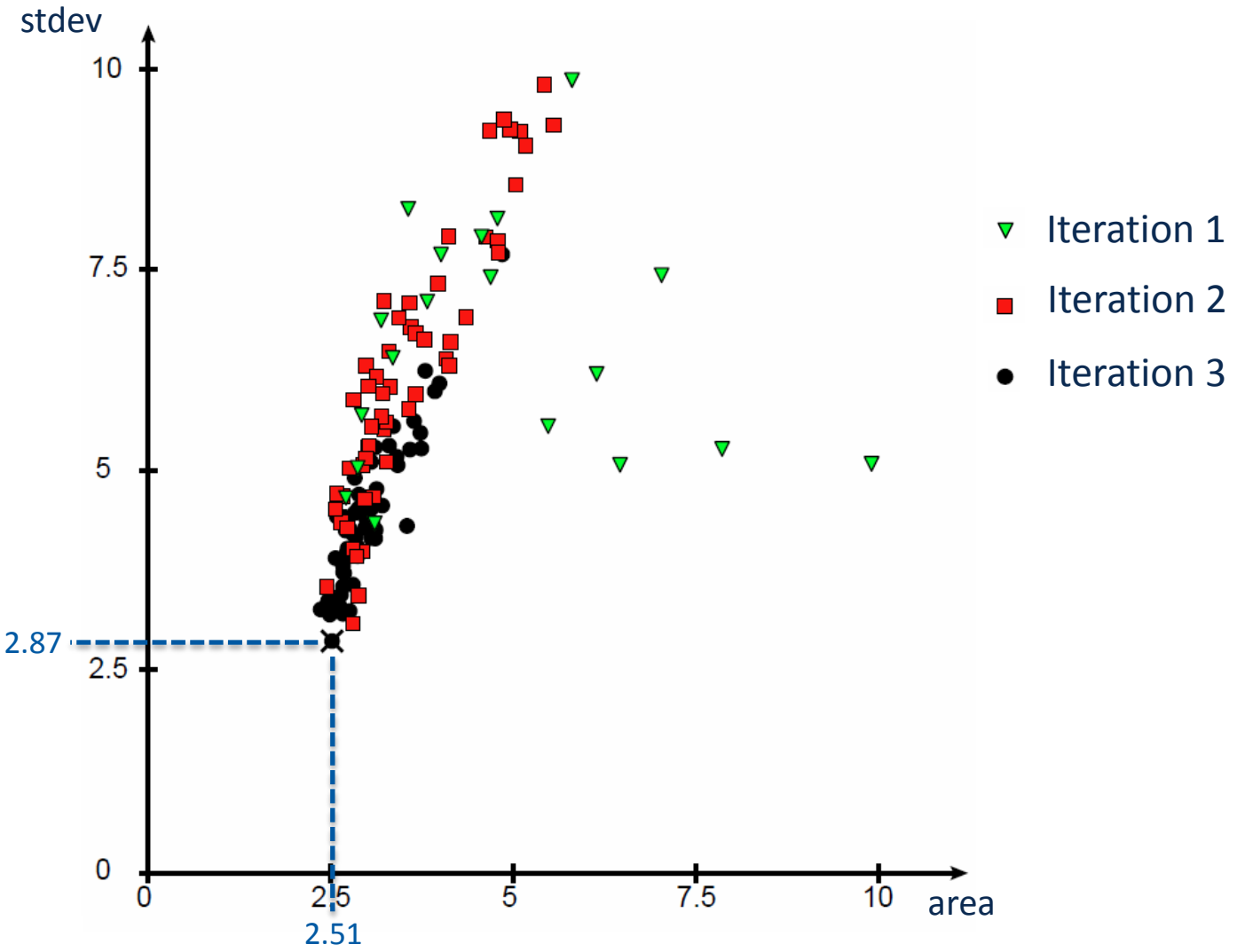
Selection of the 6 best Realisations

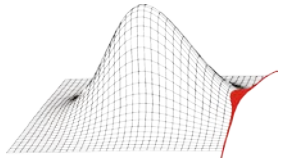
Selection of the 6 best Realisations

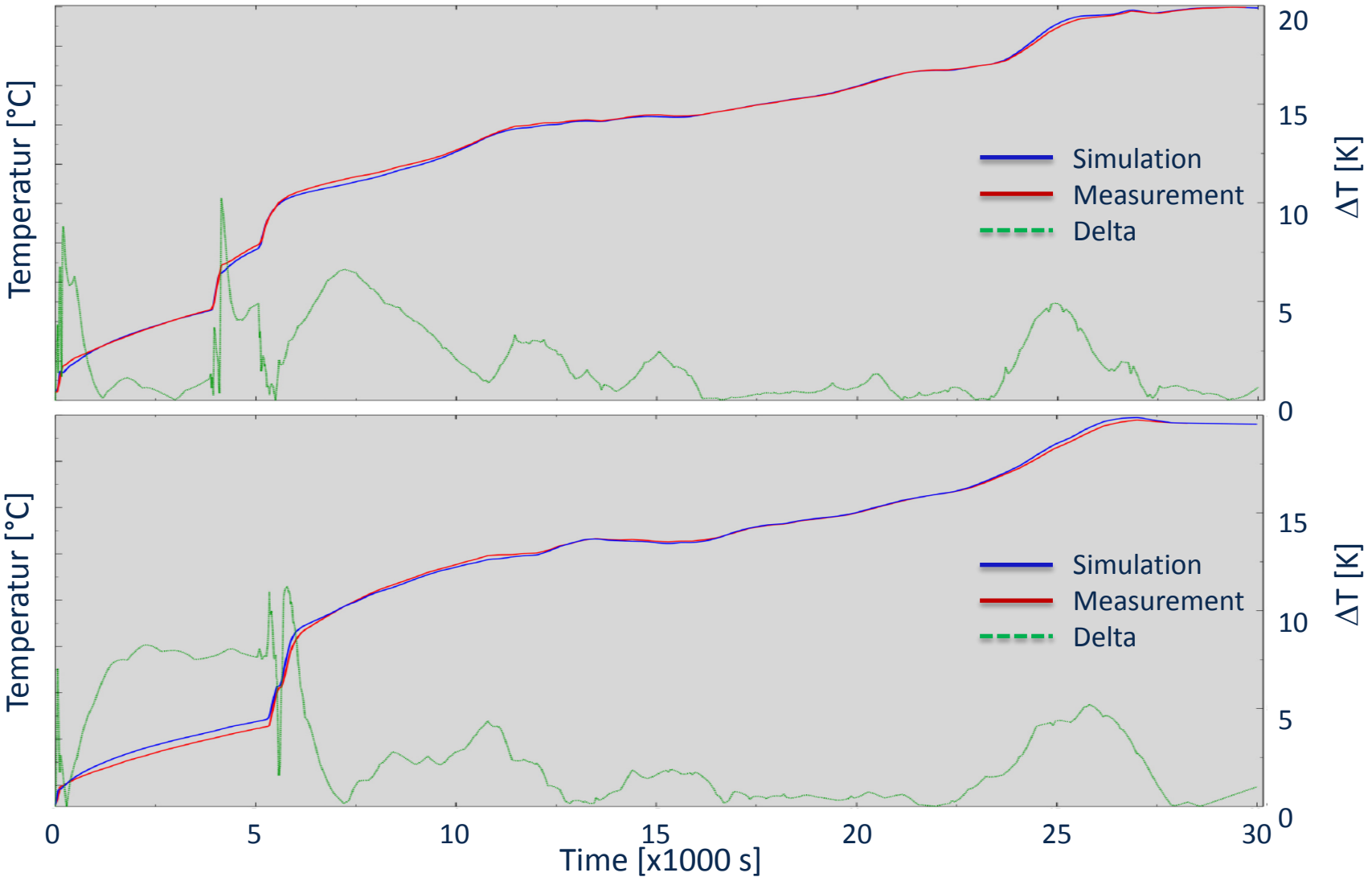
Selection of the 6 best Realisations

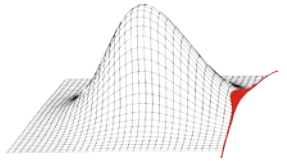
Iterations 1 - 3

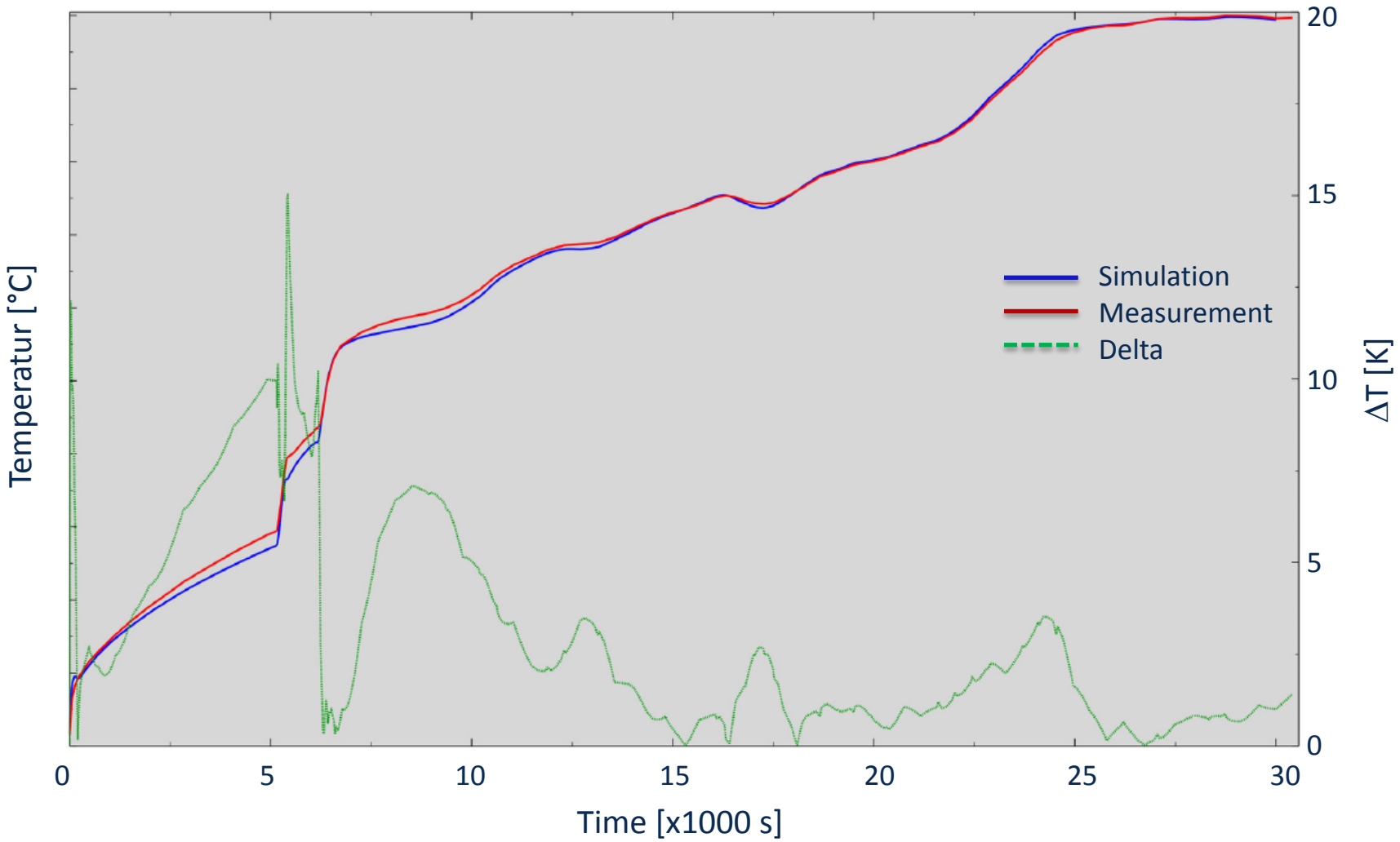







Temperatur [°C]
ΔT [K]
Simulation
Measurement
Delta
0
5
10
15
20
Temperatur [°C]
ΔT [K]
Simulation
Measurement
Delta
0
5
10
15
20
25
30
Time [x1000 s]




Temperatur [°C]
ΔT [K]
Time [x1000 s]
0
5
10
15
20
25
30
Simulation
Measurement
Delta

Next Steps

- Transfer of the findings to the rotor - model
- Probabilistic Investigation of rotor lifetime during transient operation, taking scattering boundary conditions, material properties, geometries, operation profiles, … into account