TECHNISCHE UNIVERSITÄT DRESDEN

Faculty of Mechanical Engineering · Institute for Fluid Mechanics · Professorship for Turbomachinery and Jet Propulsion

6th „Dresdner Probabilistik Workshop“

A parametric model for turbine components to consider geometric variability effects of gas-washed surfaces

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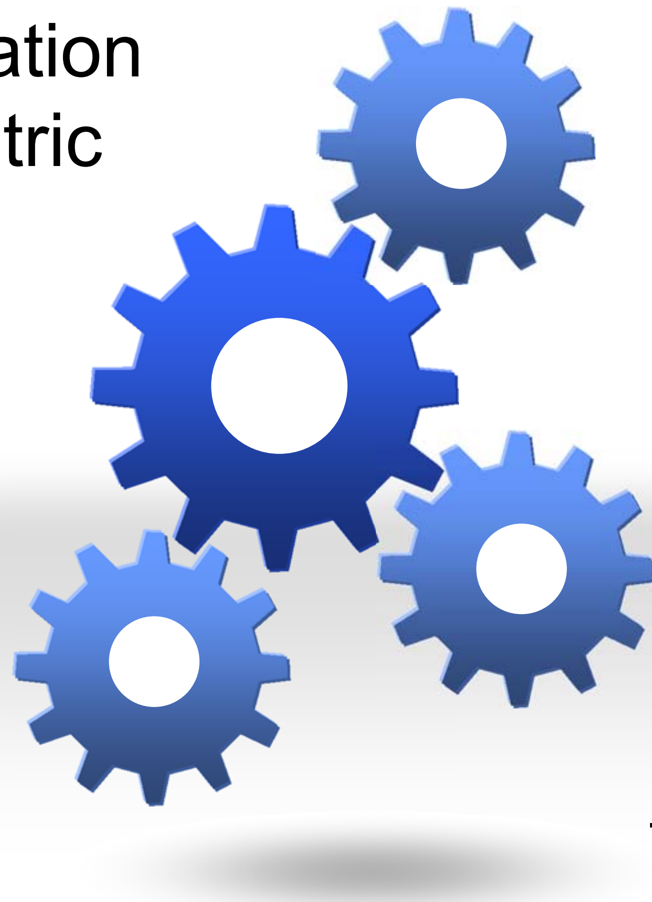
Probabilistic Simulation considering geometric production scatter



Input Parameter

- pdf‘s including statistical parameters and correlations between the input parameters

Deterministic Model

- a validated model to simulate the process which considers all phyical effects

Probabilistic Method

- E.g. Monte-Carlo-Simulation (MCS) or Response Surface Method (RSM)

Probabilistic Simulation considering geometric production scatter

Input Parameter

- pdf's including statistical parameters of geometric parameters
- correlations between the input parameters

1. Use a set of geometric parameters and correlations to rebuild manufactured geometries for classical probabilistic investigation (e.g. Monte-Carlo Simulation or Optimization)

Deterministi

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robabilistic Method

Monte-Carlo-Simulation (MCS) or Response Surface Method (RSM)

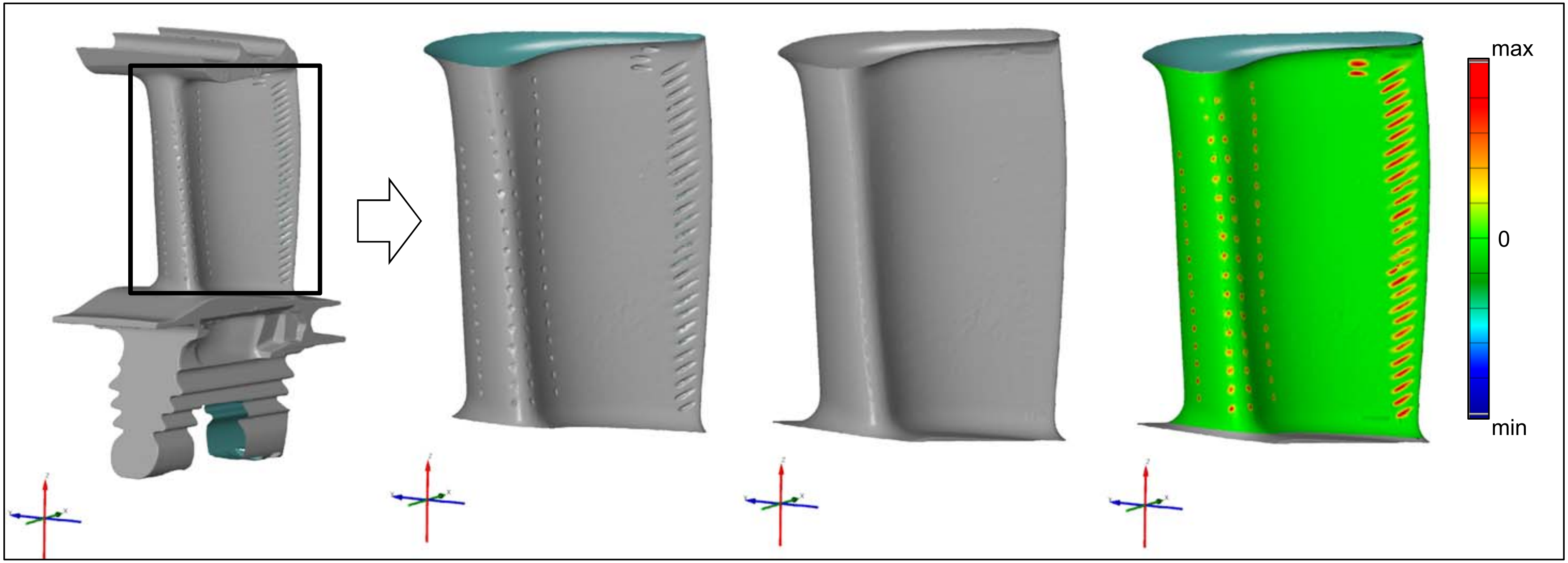


Fig1: Cooling hole smoothing algorithm

- results of the cooling hole smoothing algorithm based on a 3D-NURBS
- deviation plot on the right clarifies the local smoothing of the cooling holes

aerofoil parameterisation

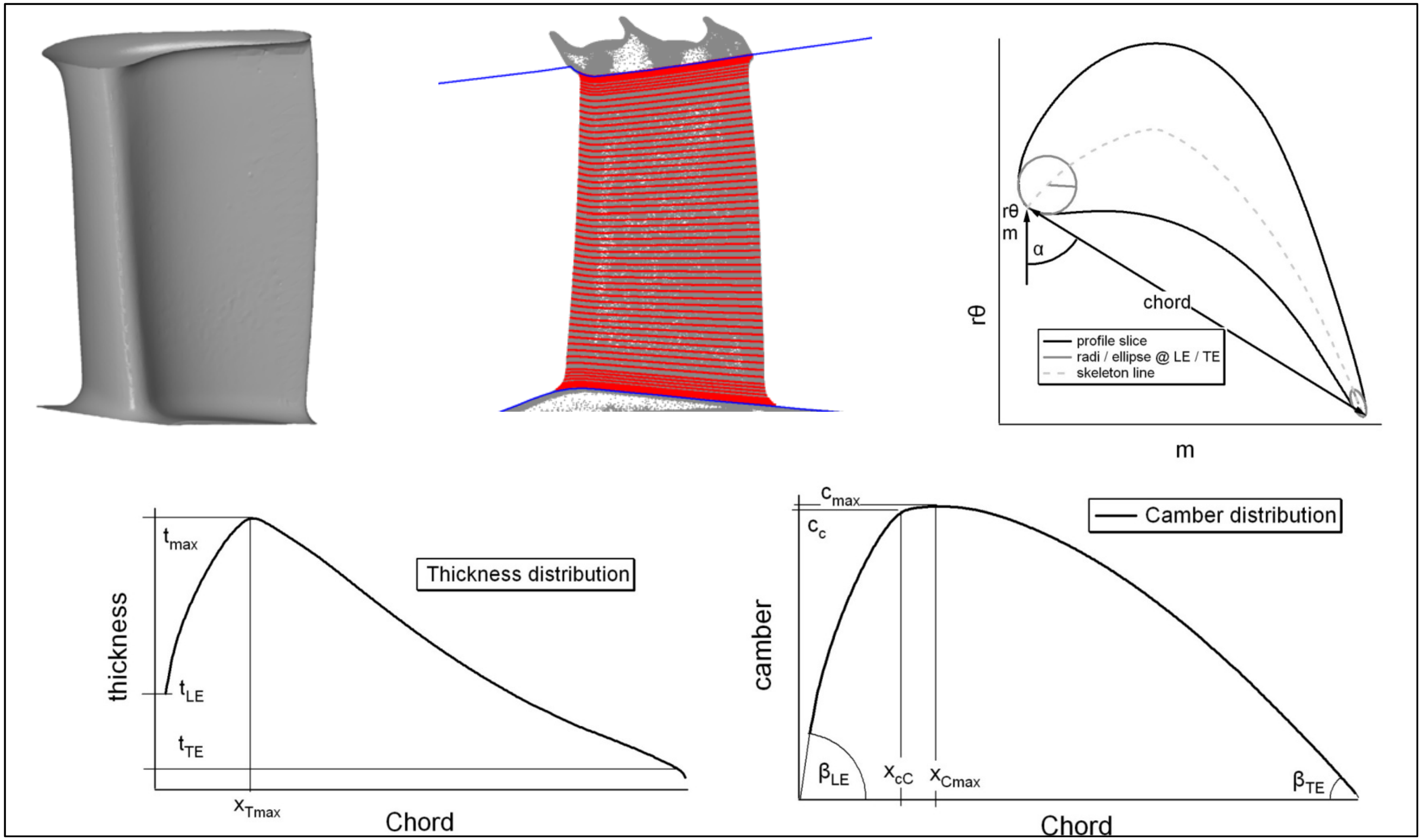


Fig2: Turbine blade parameterisation based on Lange et al. (1st Probabilistic Workshop)

- 15 parameters to describe the profile slice geometry
- 61 profile slice extraction according to the streamlines
- 915 parameters for the entire aerofoil geometry

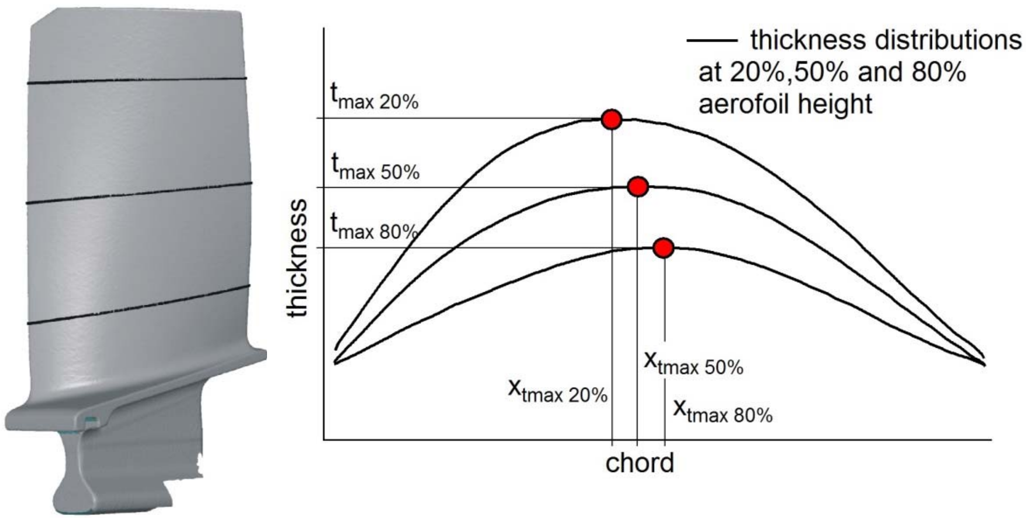


Fig3: Thickness distributions of different aerofoil slices (black) with the appropriate maximum thickness (red)

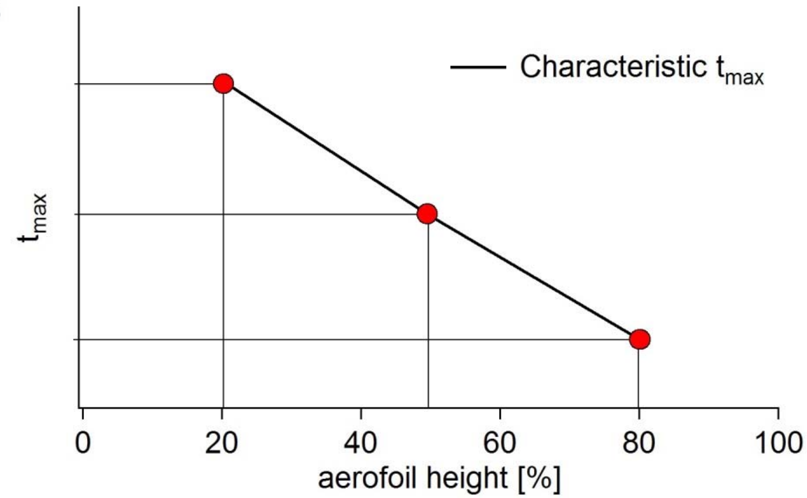


Fig4: Maximum thickness characteristic over the aerofoil height

The parameterisation of the aerofoil slices enables the comparison of the manufactured components to the intended design (manufacturing tolerances) and among each others (manufacturing scatter).

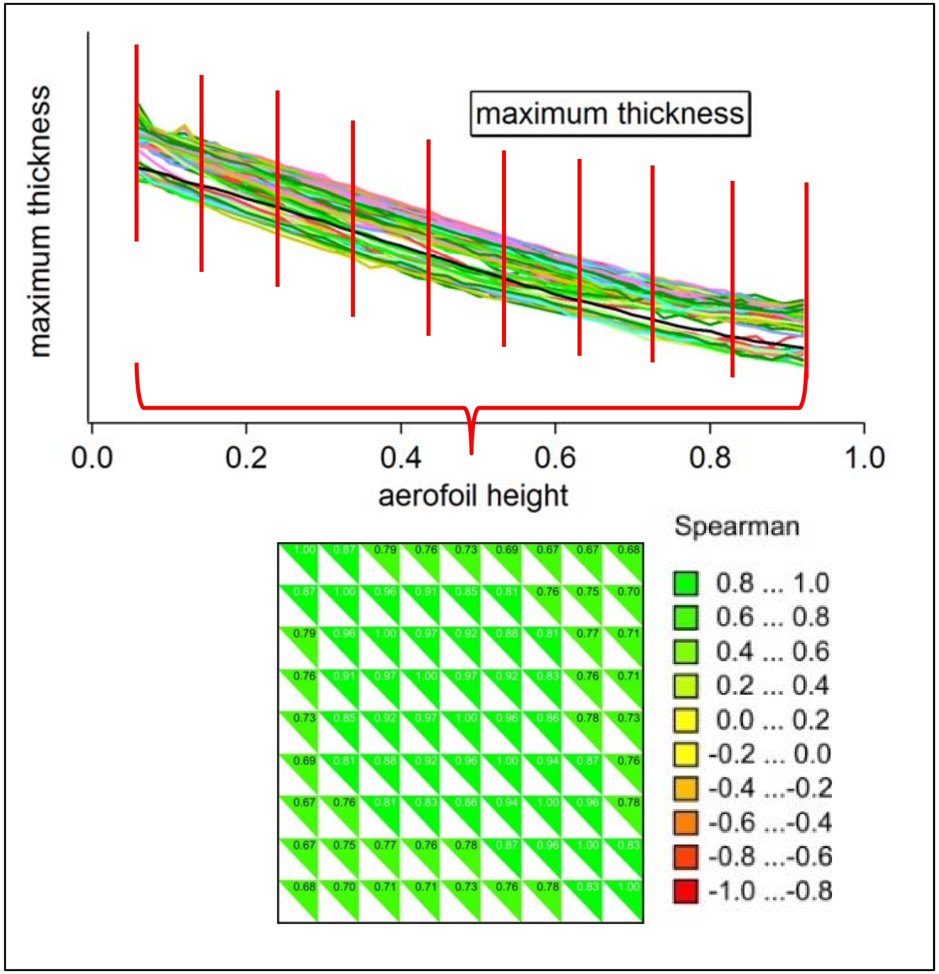


Fig5: statistical analysis

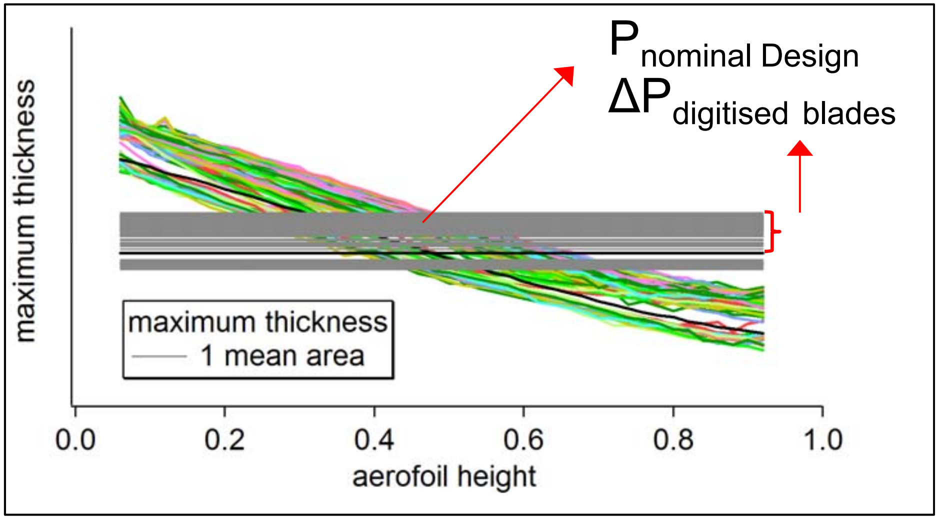


Fig6: parameter reduction – delta model

- high correlations between different areas of parameter maximum thickness
- delta model applied

profile setup

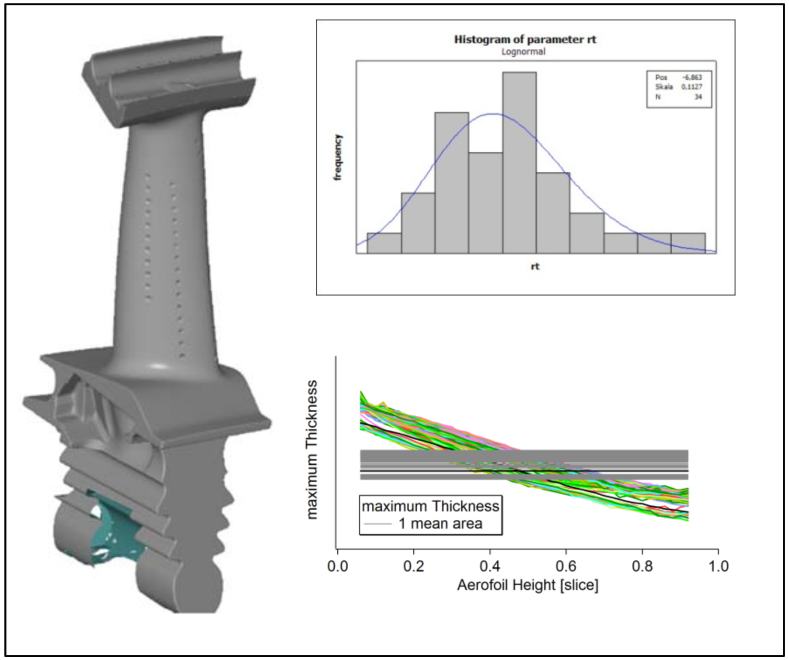


Fig7: manufactured parameter scatter

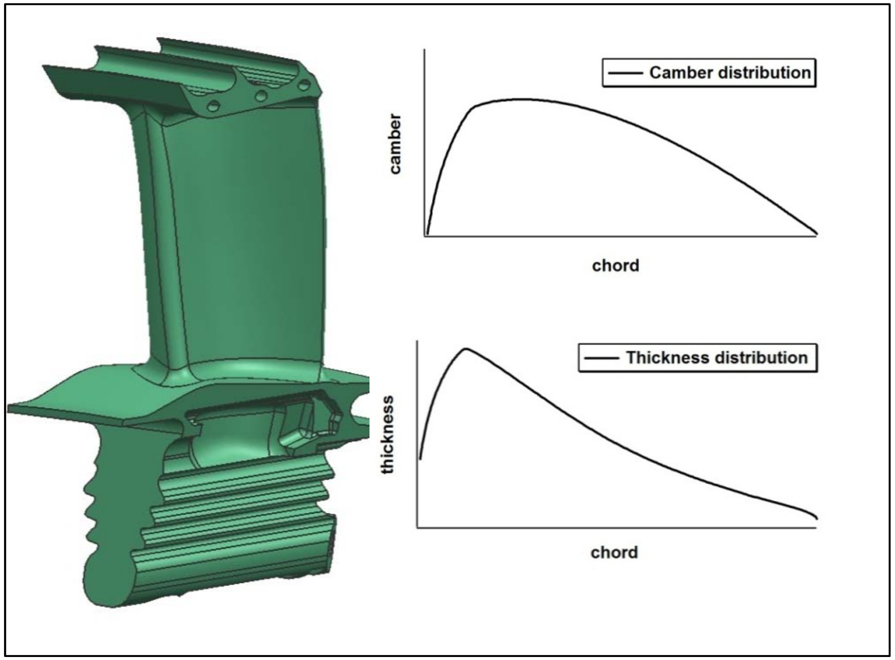


Fig8: nominal design parameters

- profile setup for probabilistic investigation:

$$P_{\text{nominal Design}} + \Delta P_{\text{digitised blades}} = P_{\text{realisation}}$$

- profile setup uses nominal design parameters + thickness and camber distribution of the nominal design (or other typical design) and the statistical parameters and correlations of the geometric parameters obtained from the digitised blades.

profile setup

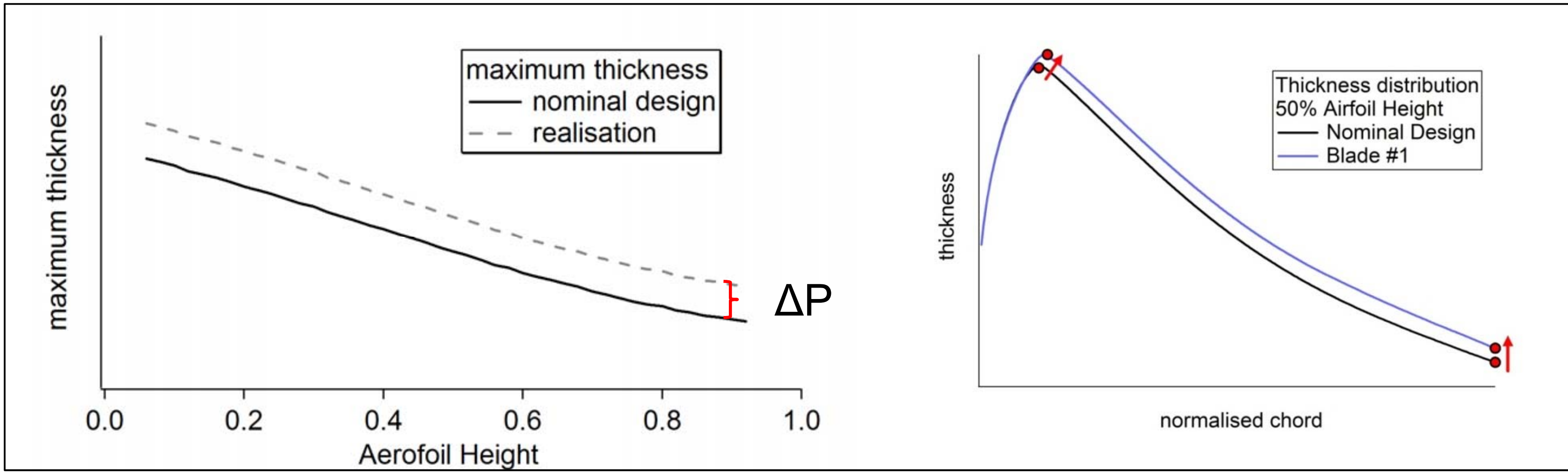


Fig9: morphing process

- Fig.9 on the top right shows nominal design and realisation thickness distributions
- nominal design thickness distribution will be morphed according to the geometric parameters at the anchor points

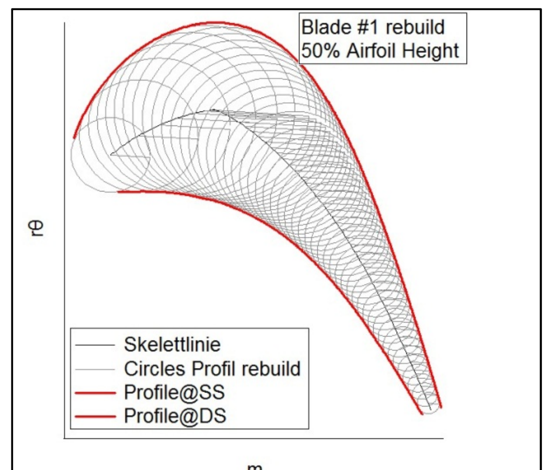


Fig10: aerofoil rebuild using rolling ball method

profile setup

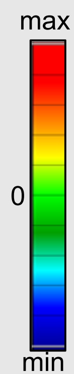
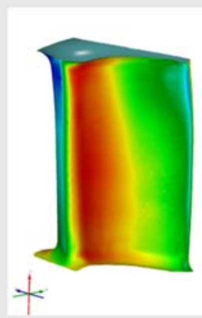
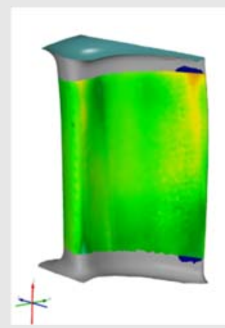
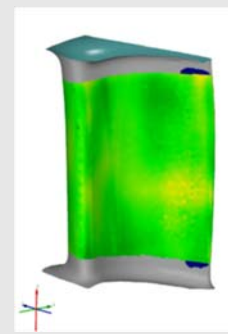
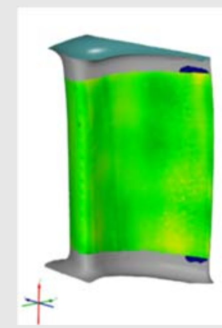
method	original	1 section setup	2 section setup	4 section setup
parameters	-	15	30	60
deviation plot profile setup vs. digitised aerofoil 				

Fig11: aerofoil rebuild

- profile setup method shows small deviations to the digitised aerofoil compared to the rebuild aerofoil
- more geometric effects can be considered with an increased number of parameters

Probabilistic Simulation considering geometric production scatter

Input Parameter

- pdf's including statistical parameters of geometric parameters
- correlations between the input parameters

1. Use a set of geometric parameters and correlations to rebuild geometries for classical probabilistic investigation (e.g. Monte-Carlo Simulation or Optimization)

2. Use real geometries to evaluate the impact of geometric variability (also with parameters) on efficiency and lifetime (sensitivity analysis)

Deterministi

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Probabilistic Method

- Monte-Carlo-Simulation (MCS) or Response Surface Method (RSM)

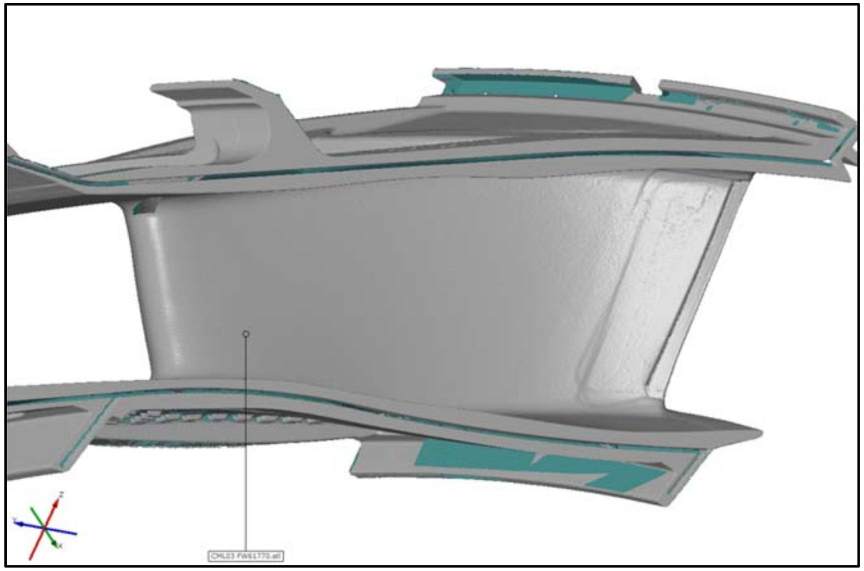

Fig12: STL-mesh of a digitised Trent900 IP Vane

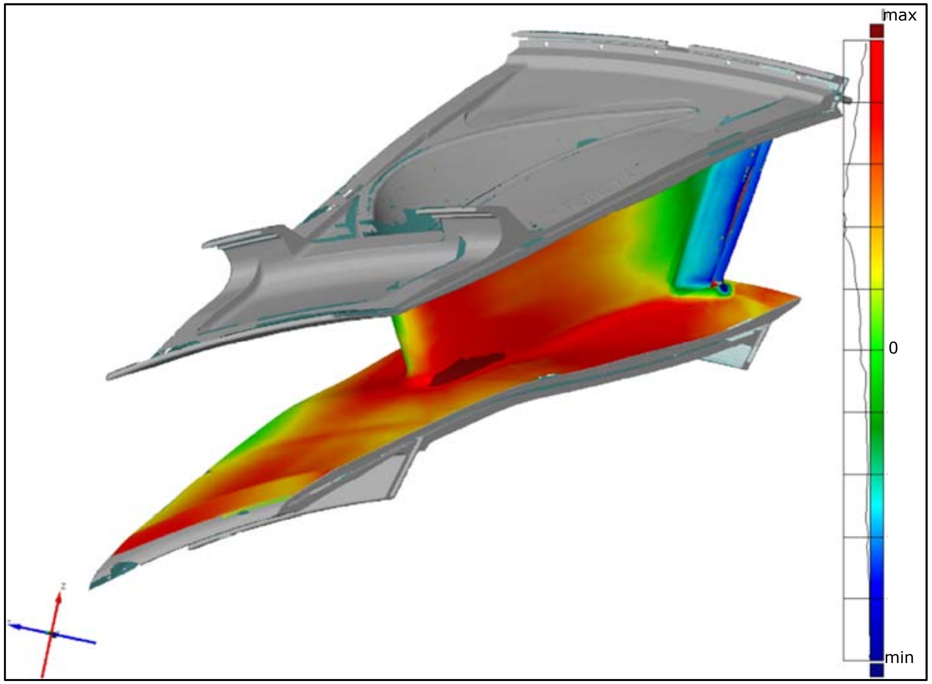

Fig13: Deviations of the manufactured component to the intended design

Main Objective:

Automated geometry rebuild (aerofoil, fillet, endwalls) of manufactured components, to consider the manufactured geometry in the simulations.

Capture statistical parameter set's (e.g. PDF's) of manufactured components for probabilistic investigations.

aerofoil rebuild

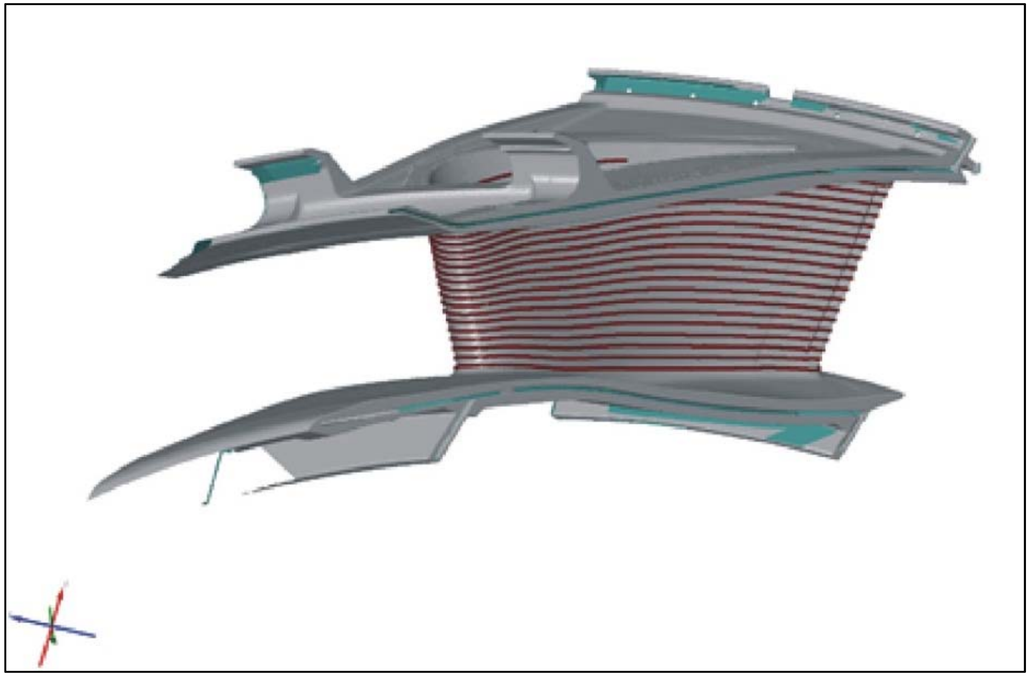

Fig14: Aerofoil slices (red)

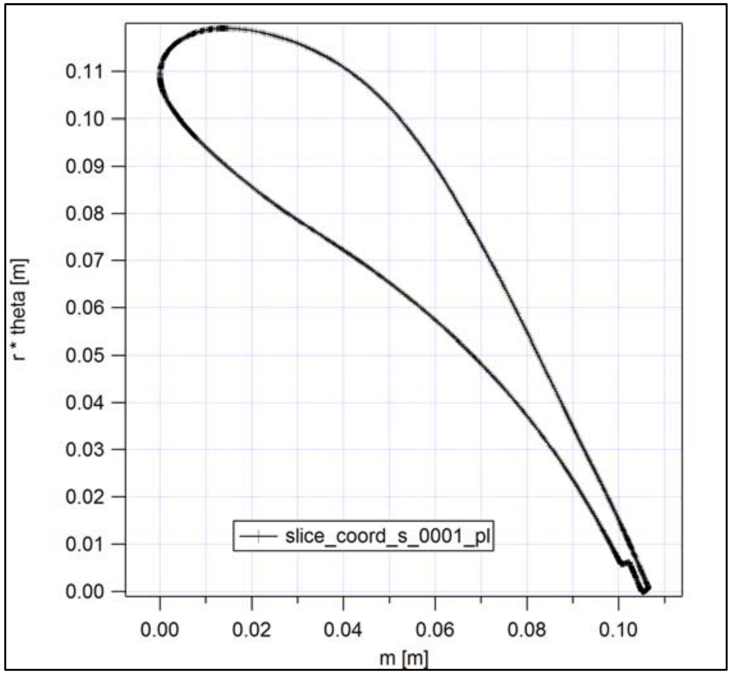

Fig15: Aerofoil slice with trailing edge slot

Aerofoil slices (red lines at Fig14) are extracted from the STL mesh based on the streampaths. The aerofoil slices (Fig15) will be parameterised and prepared for 4-patch rebuild (close trailing edge slot).

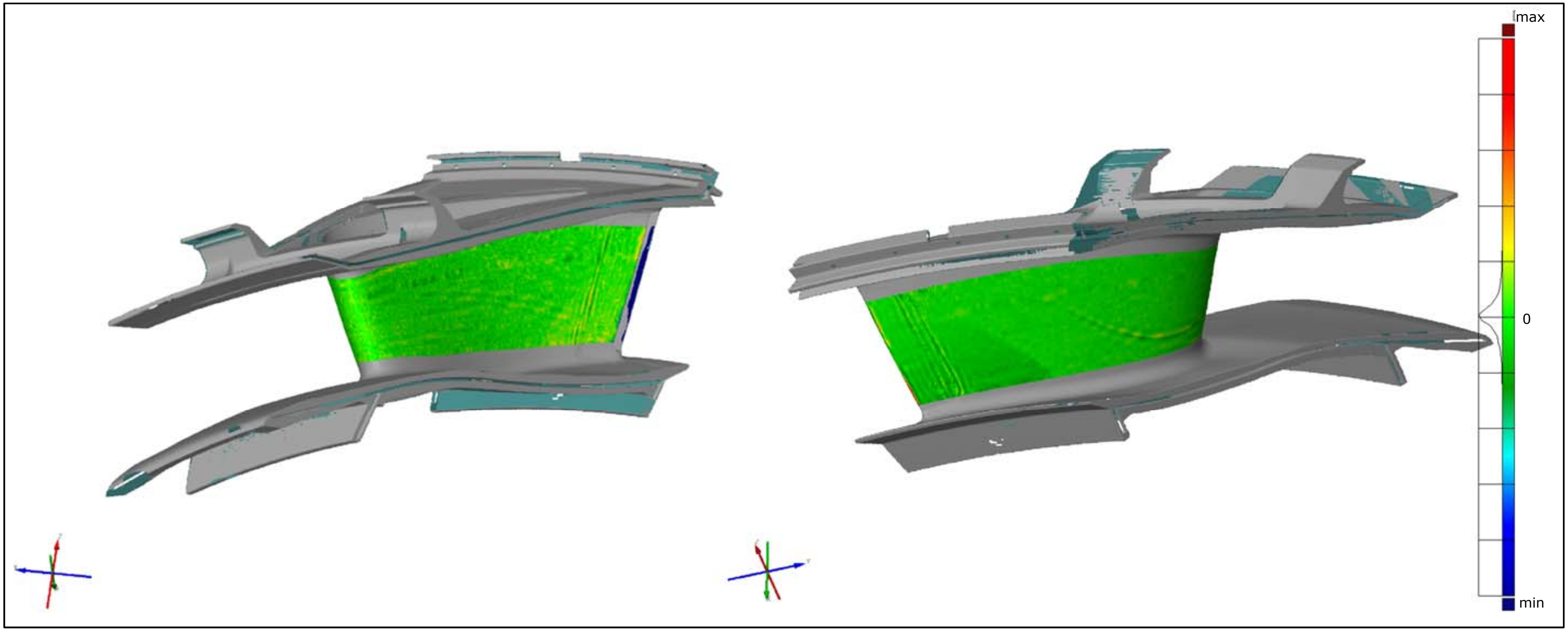

Fig16: Aerofoil rebuild of the manufactured component

The aerofoil slices are exported as 4-patch xml-file for RR-interface to CAD systems. For each patch a surface is created which will be exported as NX prt-file. Fig16 illustrates the deviations of the aerofoil rebuild to the manufactured aerofoil.

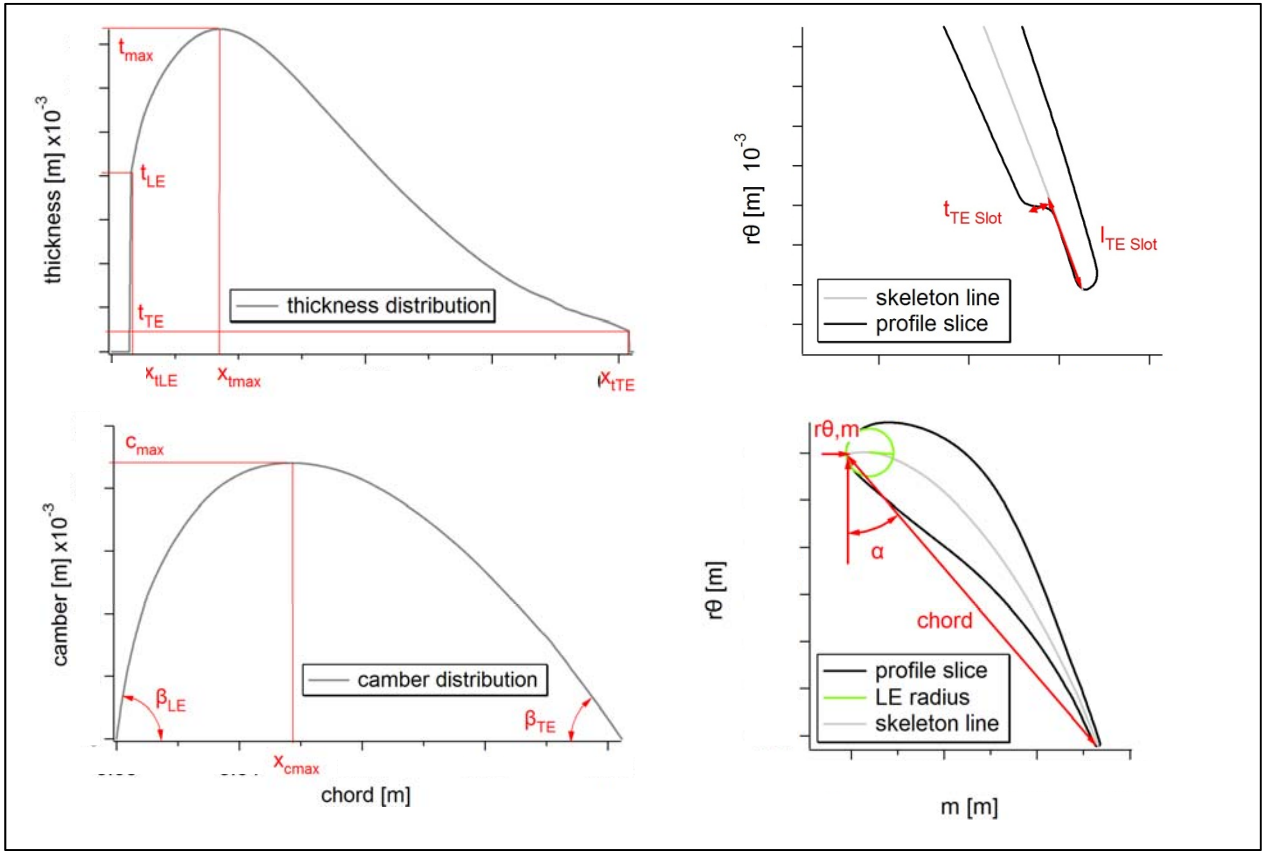

Fig17: Aerofoil parameterisation

16 “well-known” parameters are determined on each aerofoil slice using thickness and camber distribution.

fillet rebuild

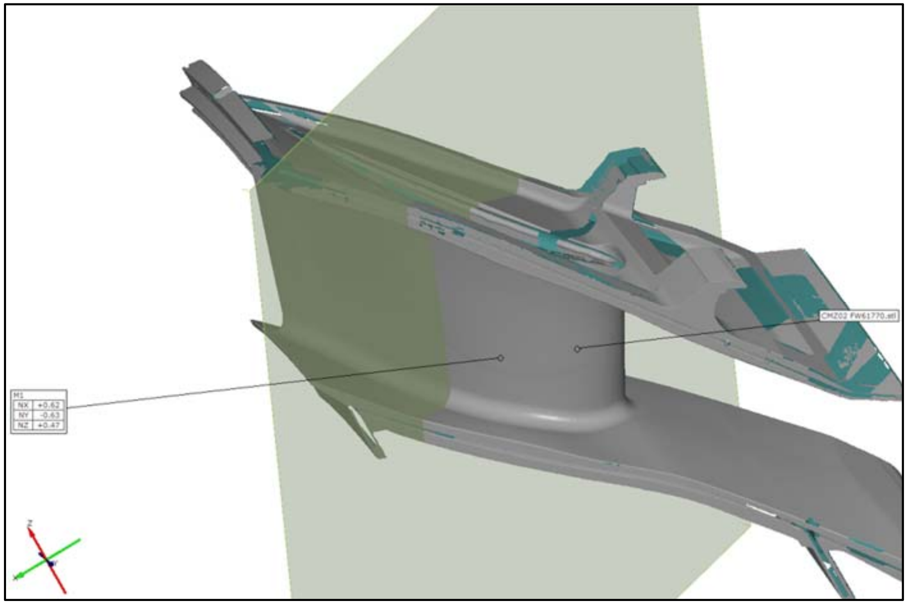

Fig18: Intersection plane (green) that is used to extract a fillet slice from the STL-mesh

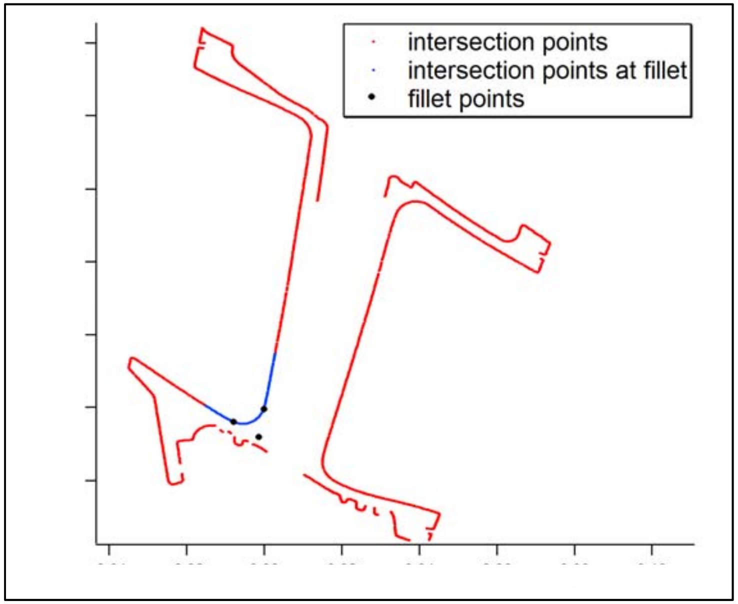

Fig19: Fillet slice (red) with fillet (blue) and fillet start/end points (black)

The start/end points of the fillet (black points on Fig19) are determined at several positions around the hub and tip fillet by extracting slices from the STL-mesh.

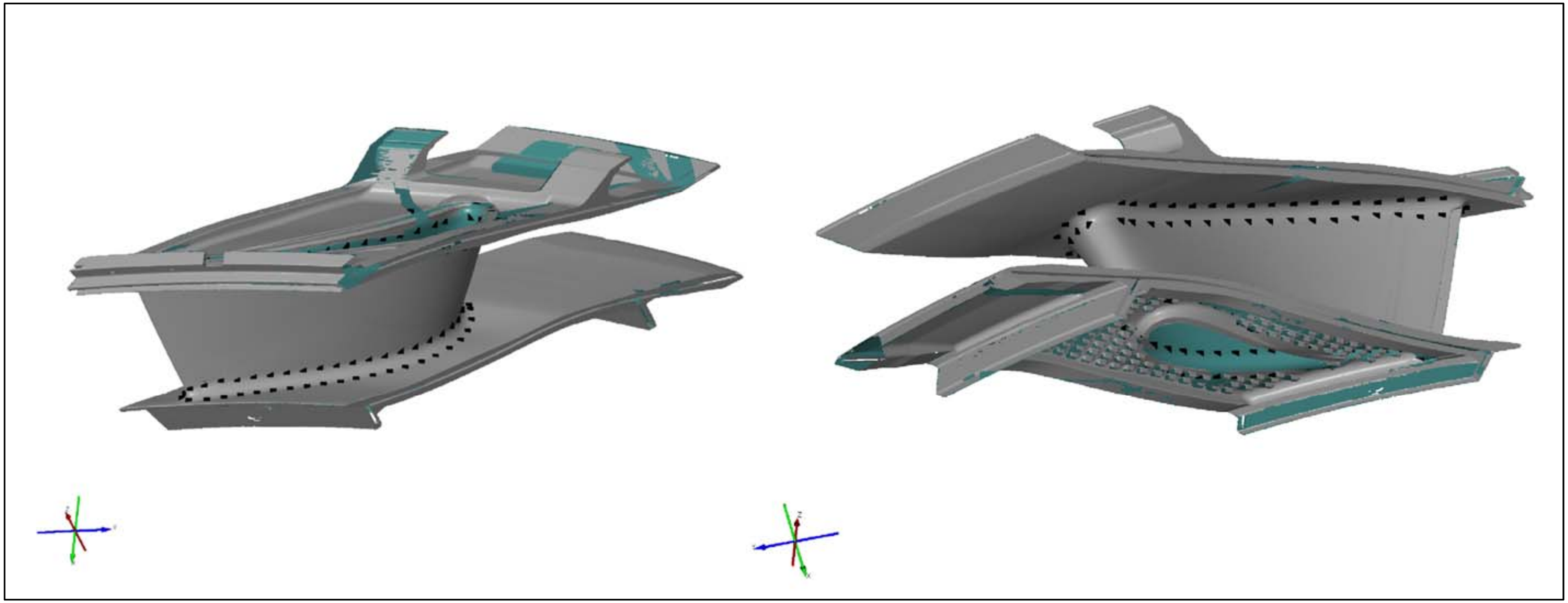

Fig20: Fillet start/end points around the fillets at hub and tip

The fillet start/end points at hub and tip (black) are exported as input-file for the Rolls-Royce fillet generator. The generator is currently adapted to use 3D coordinates.

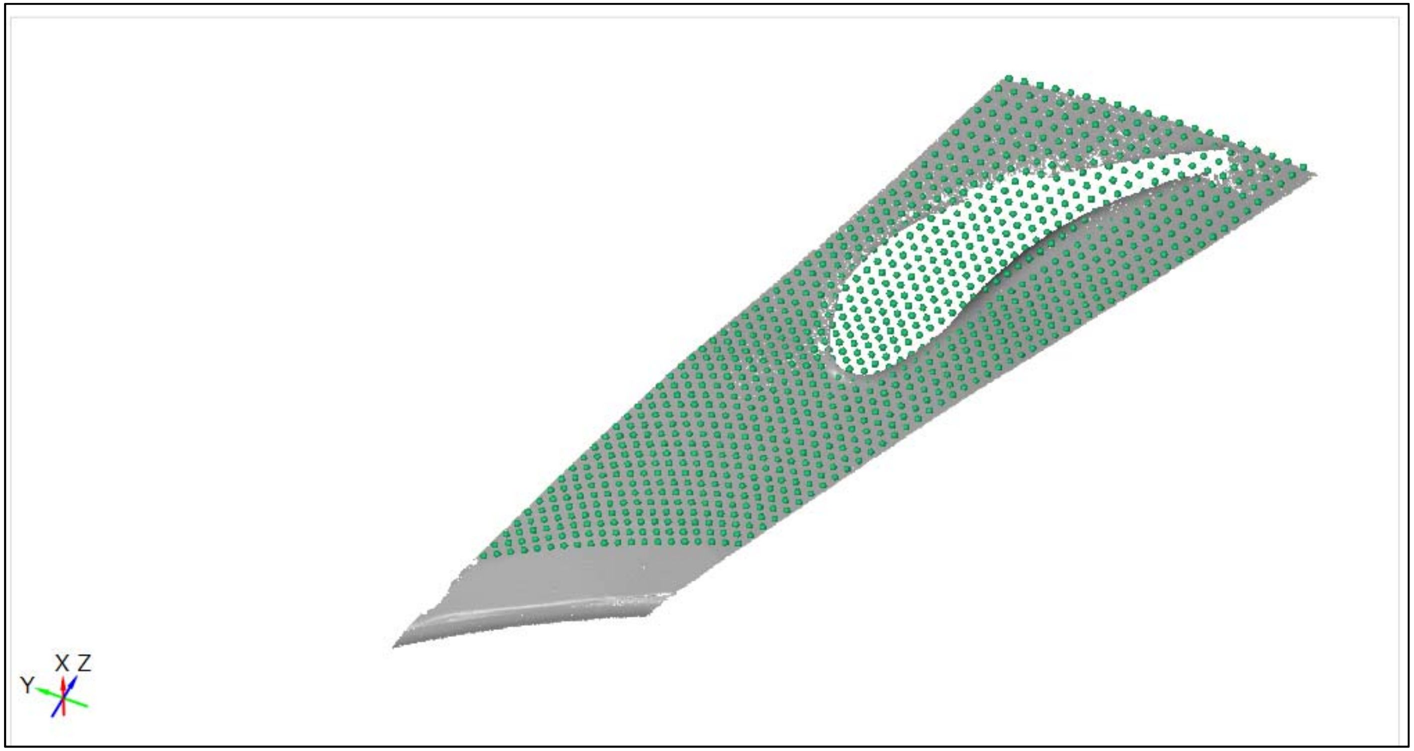

Fig21: Control points (green) that will be projected on the endwall (grey)

The endwalls are rebuilt by generating a mesh of control points (green points at Fig21). This mesh is projected on the endwalls (grey).

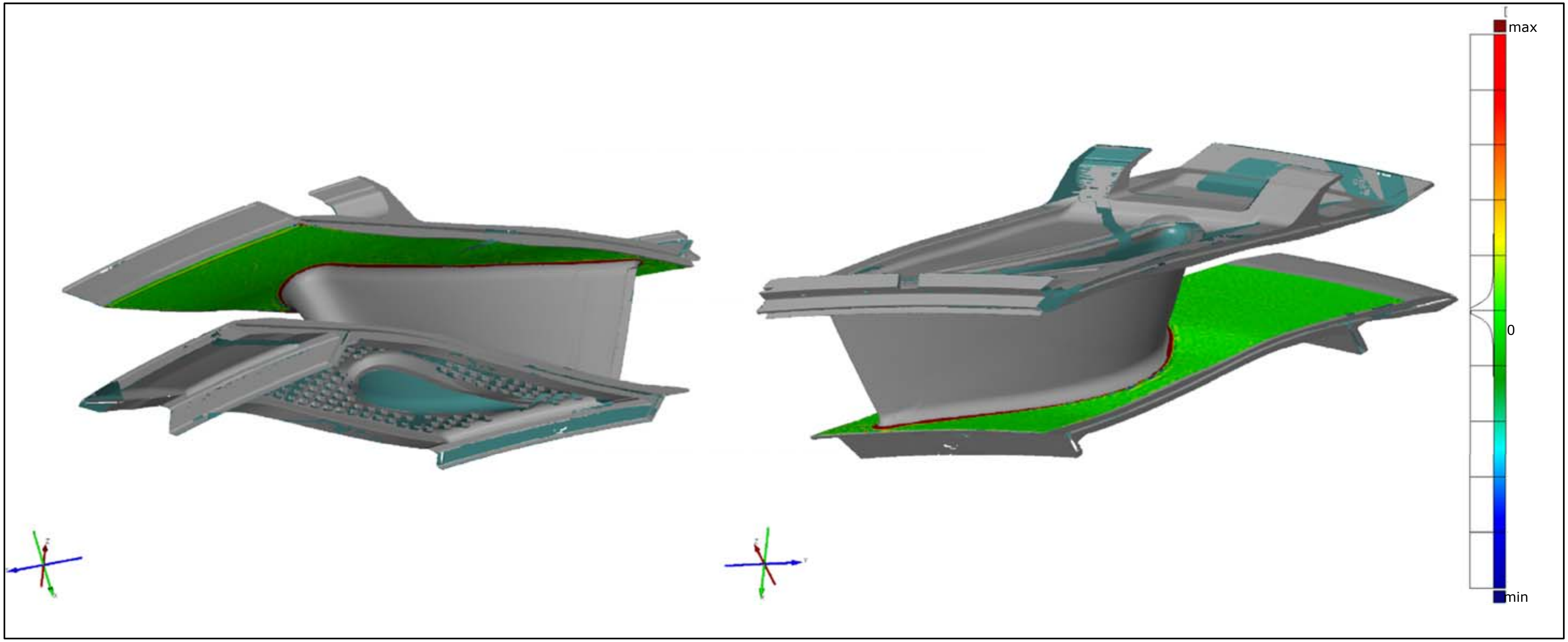

Fig22: Deviations endwall rebuild compared to manufactured endwalls

The endwall points are exported as input file for the Rolls-Royce endwall generator. Fig22 shows the deviations of the rebuild endwalls to the manufactured endwalls (surfaces created by NX).

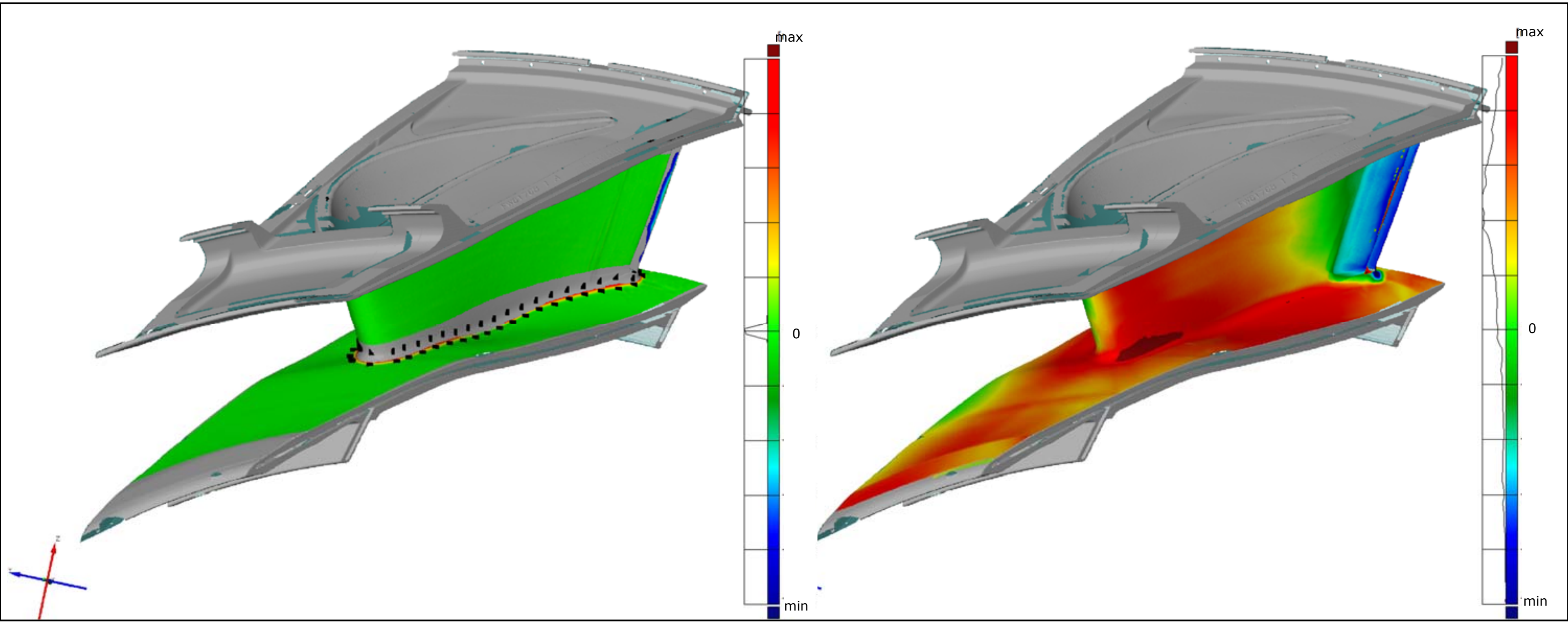

Fig23: Deviations of rebuild component compared to manufactured component (left) and intended design compared to manufactured component (right)

Fig23 left illustrates the deviations of the rebuild gas-washed surfaces compared to the manufactured surfaces. Fig23 right illustrates the deviations of the intended design geometry to the manufactured surfaces.

conclusion / outlook

- The developed tools enable the consideration of manufactured part geometries by using delta-parameters and a nominal design geometry or/and the real geometries in the design process
- The developed automated tools work without user interface and create input files for the Rolls-Royce design tools (Parablading, NX)
- The impact of the manufactured geometries on efficiency and lifetime can be determined
- New robust parts can be designed considering the production scatter by using probabilistic methods