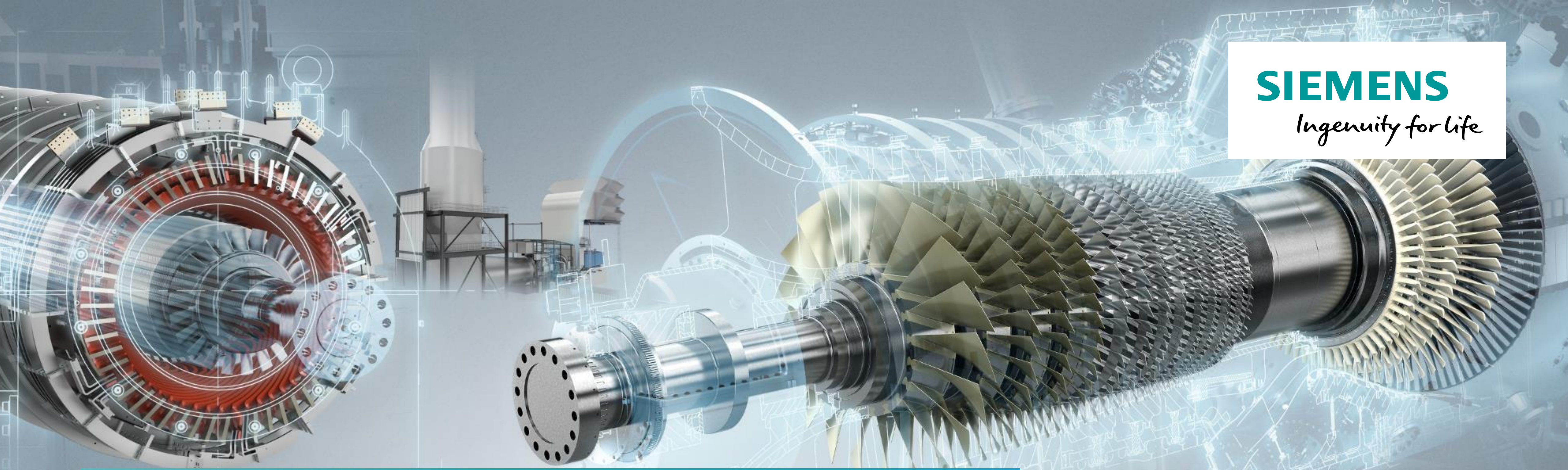


Advanced 3D Geometries for turbine Applications

Power and Gas – Large Gas Turbines, Generators

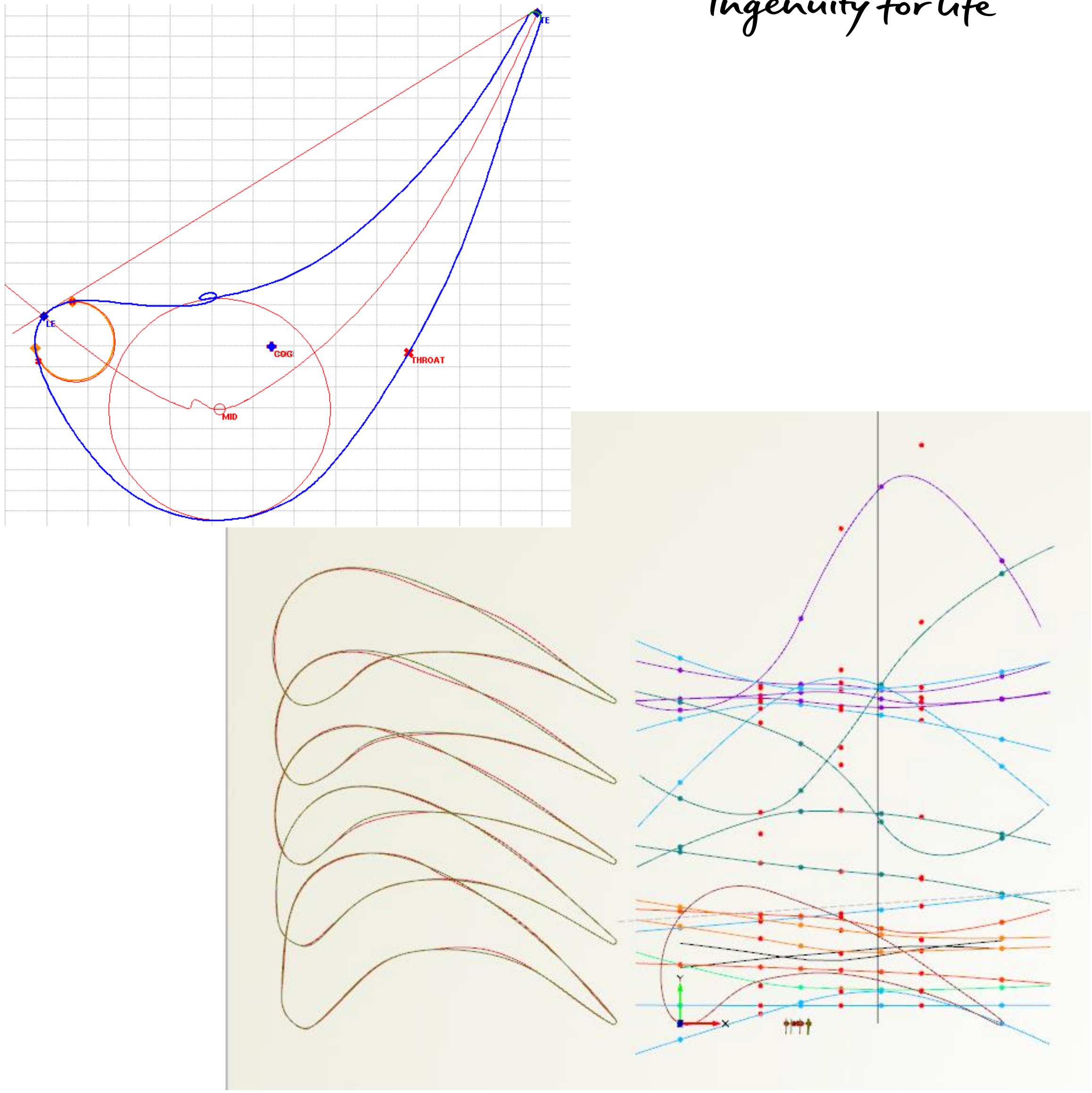
Flowpath Aero Optimization
Overview

Motivation to use CAESES:

- Difficulties with in-house tool for higly-campered, thick airfoils
- Minimize manual rework of airfoil geometries after optimization

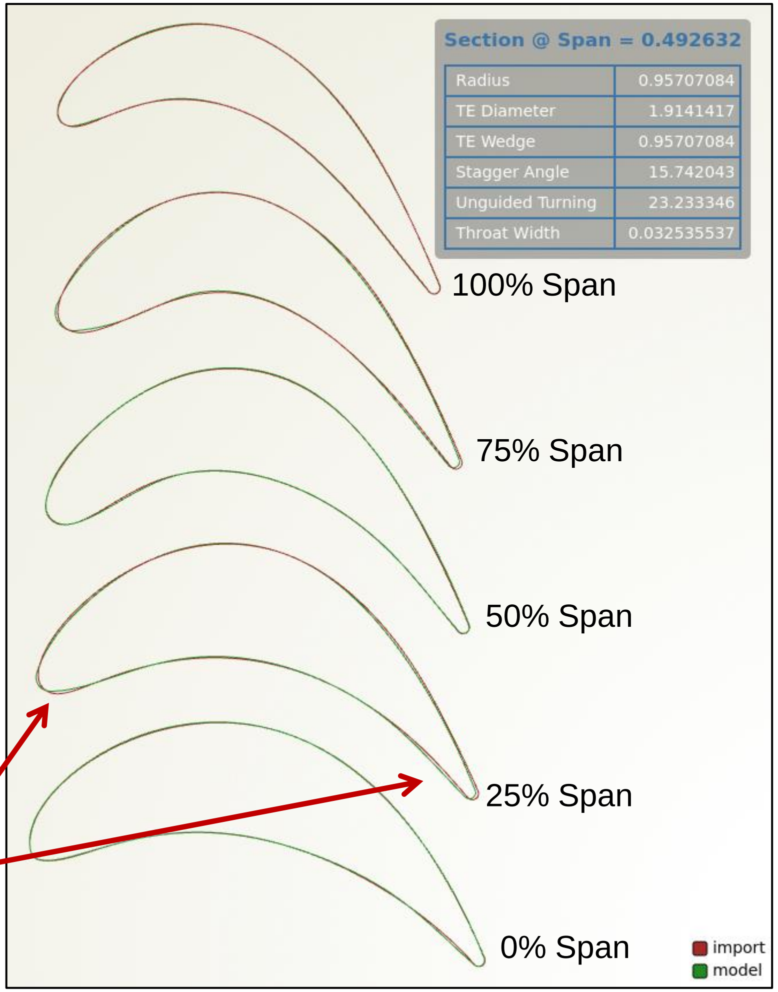
Siemens initiated project with Friendship-Systems in 2015 to develop parametric turbine airfoil model for use in turbine aerodynamic performance optimizations:

- Automated fitting routine to parameterize baseline airfoil geometry
- Manual design of airfoils inside CAESES
- Exploration of parametric design space
- Generation of non-axisymmetric endwall contouring
- Throat-area calculation and automated global restaggering



Flowpath Aero Optimization
Automated Fitting

- Prior to any optimization routine, simplified parametric model must be generated
- CAESES project automates the generation of the reduced-parameter model by fitting model to a specified baseline geometry
- Number of span-wise control points flexible and defined by user
- User is able to overlay the parametric model (green profiles) over the initial imported geometry (red profiles)
- Robustness of auto-fitting routine provides flexibility to parameterize wide range of turbine airfoil geometries



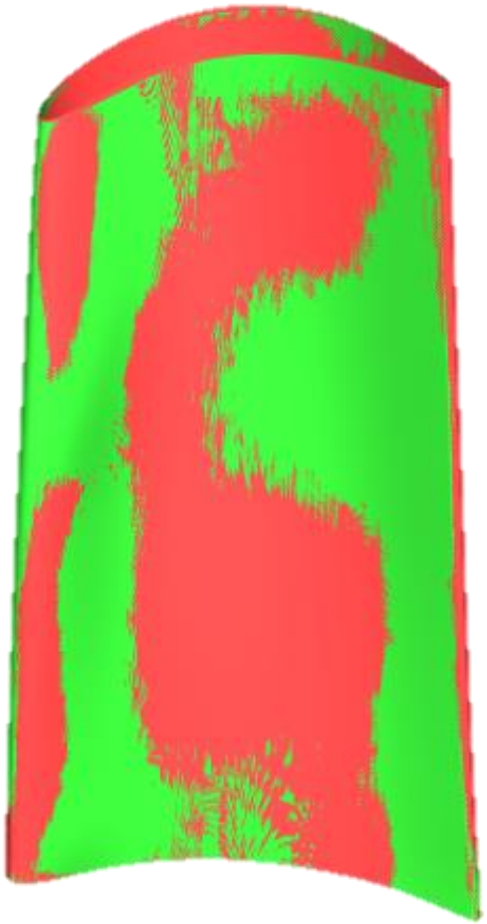
Slight deviations

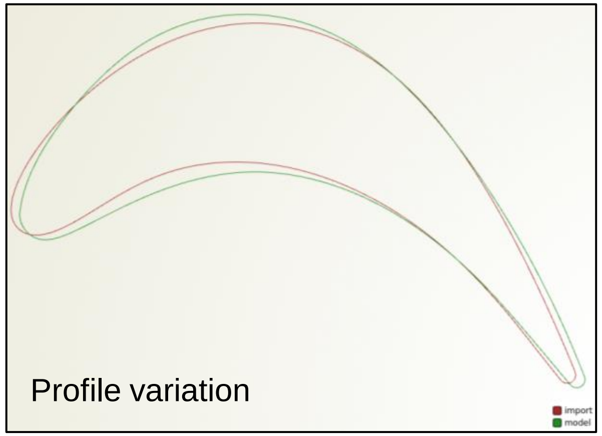
Flowpath Aero Optimization

Manual Tuning and Comparison

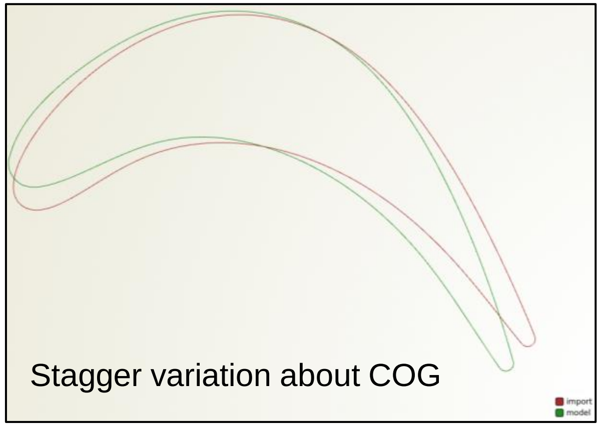
- User can manually fine-tune profile sections and/or stagger within the simplified parametric model and compare against initial geometry
- Parametric design can be viewed in 2D profiles or in 3D geometries

- 3D Effects easily added through variations to the stacking line (pitchwise and axial bow/sweep/shift)





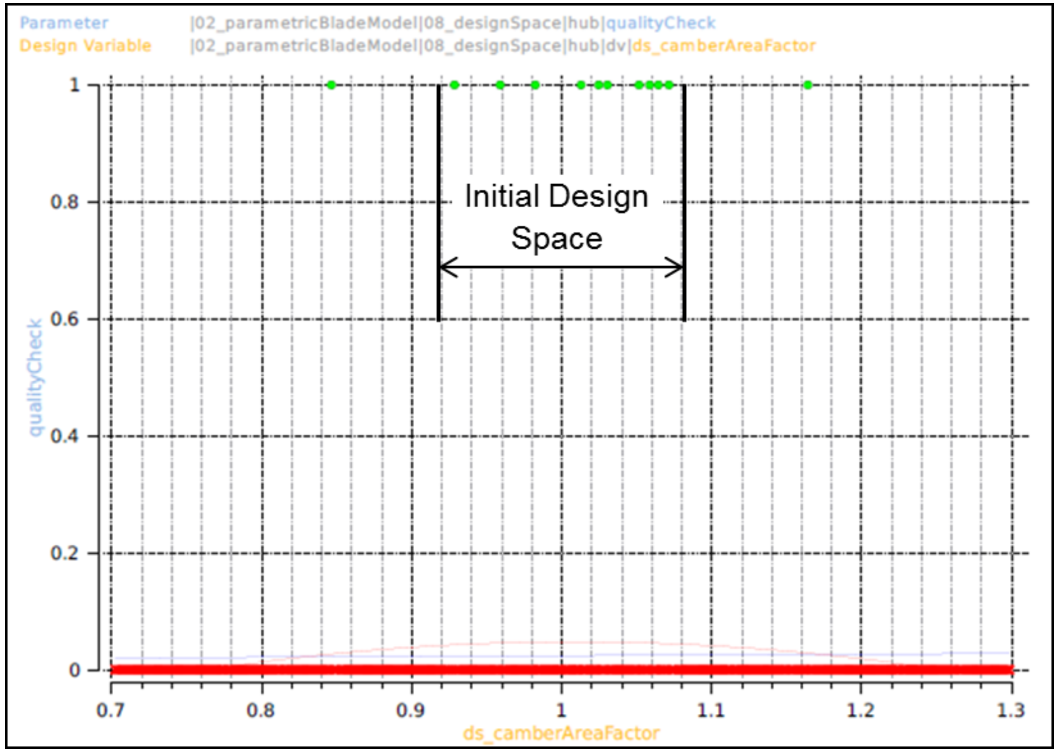
Profile variation



Stagger variation about COG

Flowpath Aero Optimization
Explore Design Space

- Design Space Exploration feature allows user to explore the valid design space by running parameter DOE inside CAESES
- Run hundreds of potential parameter combinations in matter of minutes
- “Validity” criteria based on curvature and inflection points
- Automated PDF output shows general range for each parameter which produced “valid” designs
- Streamlines setup of the initial design space allowed in aerodynamic optimizations

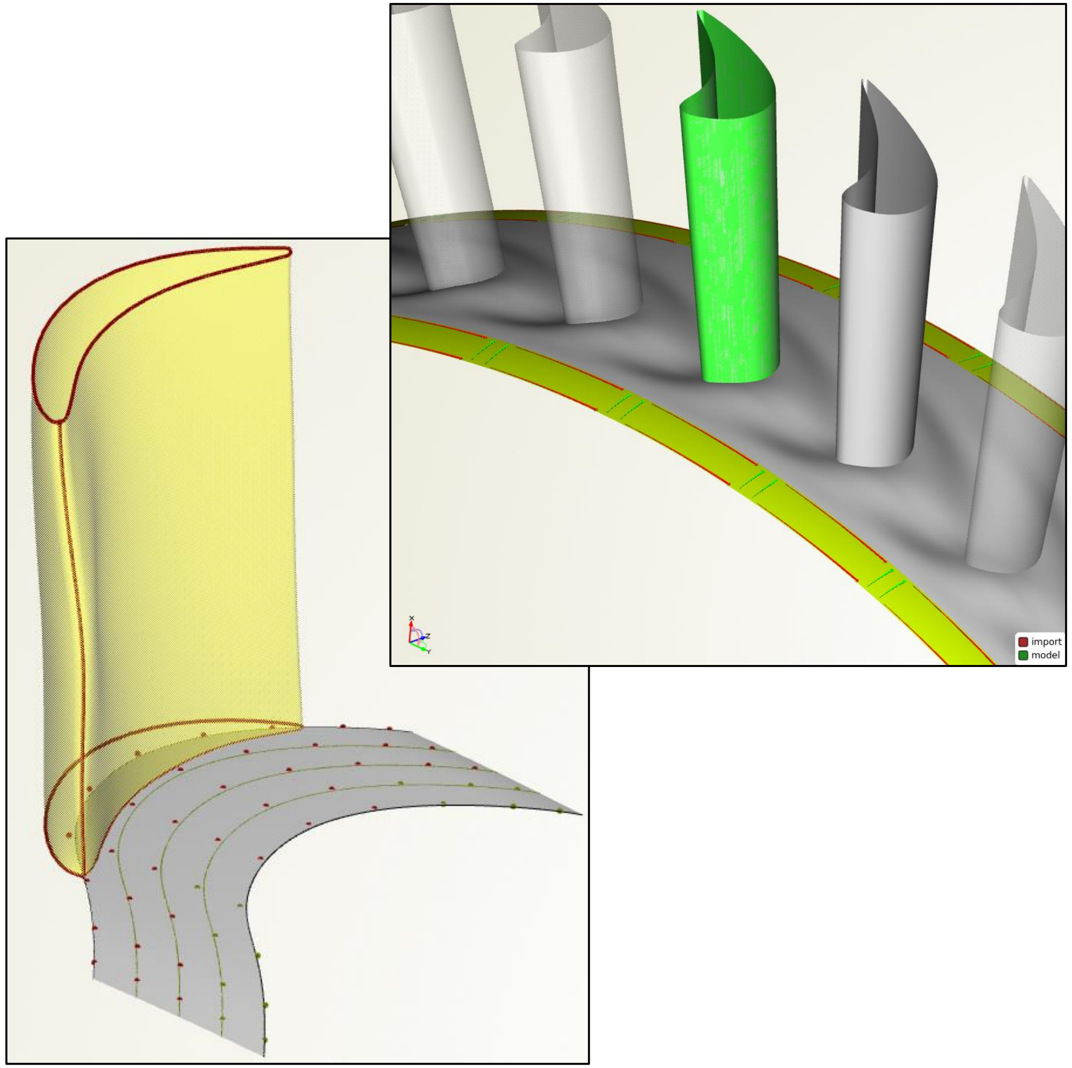


Flowpath Aero Optimization
Non-axisymmetric Endwalls

- Research has shown performance benefits by introducing non-axisymmetric contouring on endwall surfaces

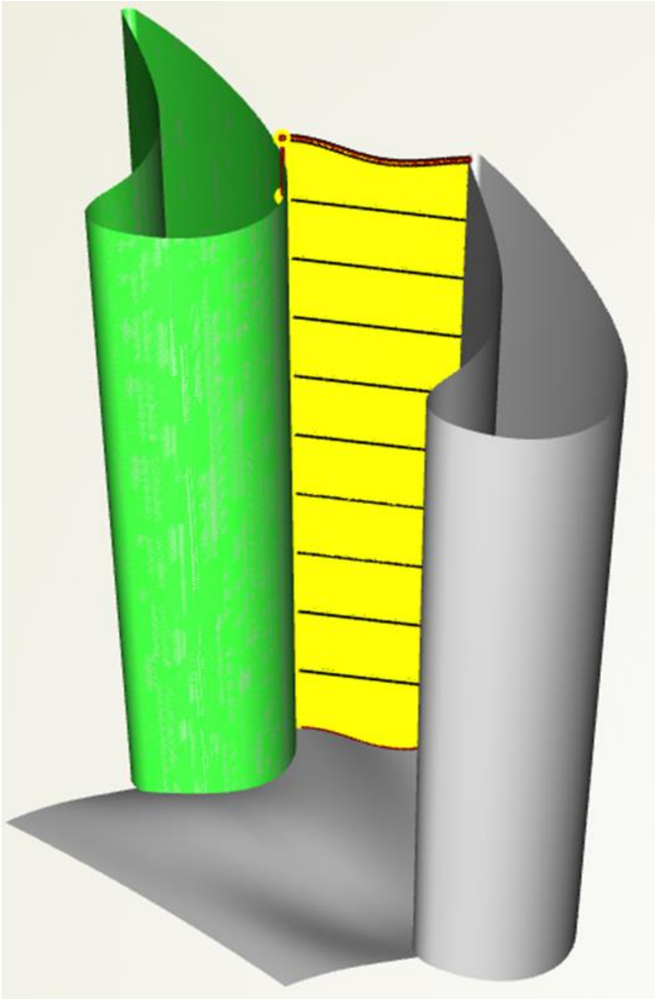
- Siemens has two options for parametric endwalls
  1. Simplified trigonometric endwall surface with one single peak and one valley per passage
     → robust and simple

  2. Independent control-point based spline surface
     → maximum geometric flexibility
     →User defined number of axial and tangential control points



Flowpath Aero Optimization
Throat Correction

- In turbine airfoil design, throat area is a key geometric parameter to consider
- CAESES model includes routine to calculate throat area of the 3D airfoil geometry (assuming airfoil pitch known)
- In cases of endwall contouring, throat area adjusted to contour
- Automated restagger feature globally rotates airfoils to match a specified throat area
- Important for optimizations where throat area changes are significant



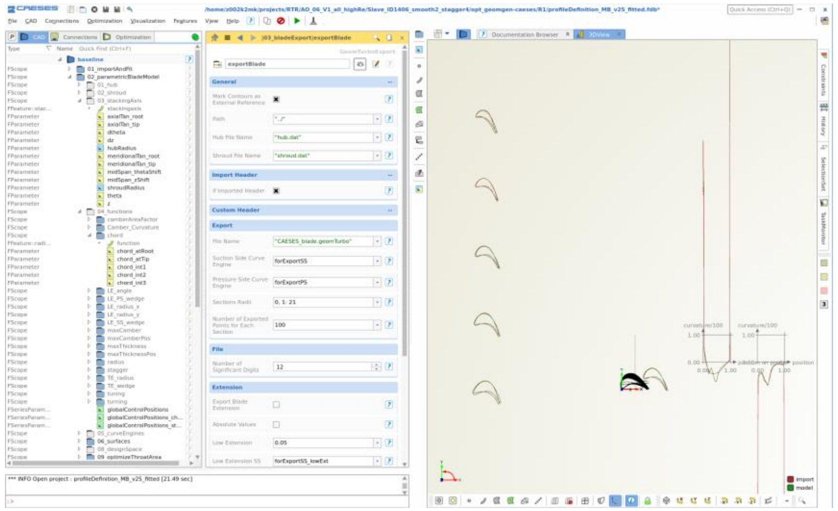
Flowpath Aero Optimization

Tool Chain

1. Geometry generation
2. Mesh generation
3. CFD simulation

Airfoil parameterization:

- Automated fitting of initial geometry
- ~ 5 radial sections
- ~ 20 parameters for stacking axis and stagger
- ~ 80 parameters to describe airfoil



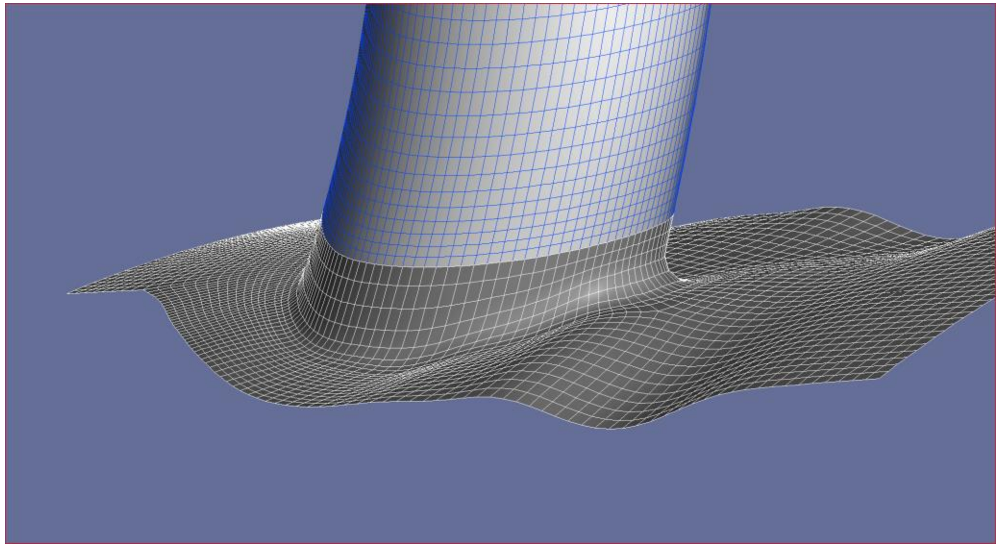
- Export geomTurbo and endwall data

Flowpath Aero Optimization
Tool Chain

1. Geometry generation
2. Mesh generation
3. CFD simulation

Autogrid meshing strategy:

- highRe / lowRe mesh including fillets, hub cavities and shrouds
- > 1M cells per row
- Butterfly o-mesh in fillets allow for non-axisymmetric endwalls



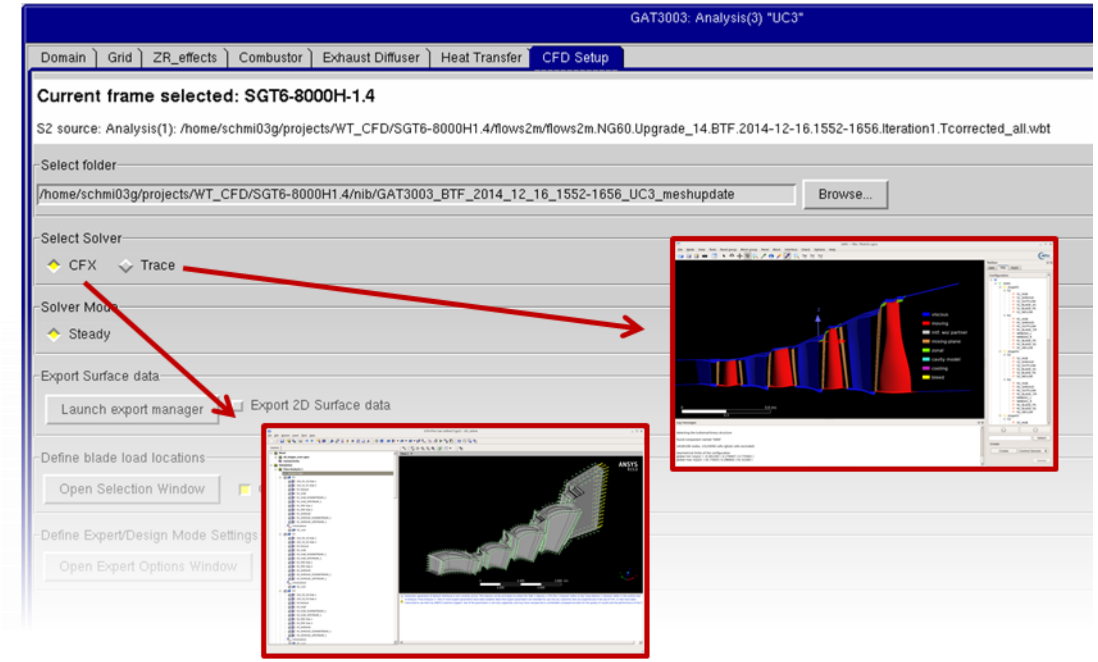
Flowpath Aero Optimization

Tool Chain

1. Geometry generation
2. Mesh generation
3. CFD simulation

CFX / TRACE:

- Steady state mixing plane
- SST turbulence model



Flowpath Aero Optimization
Tool Chain

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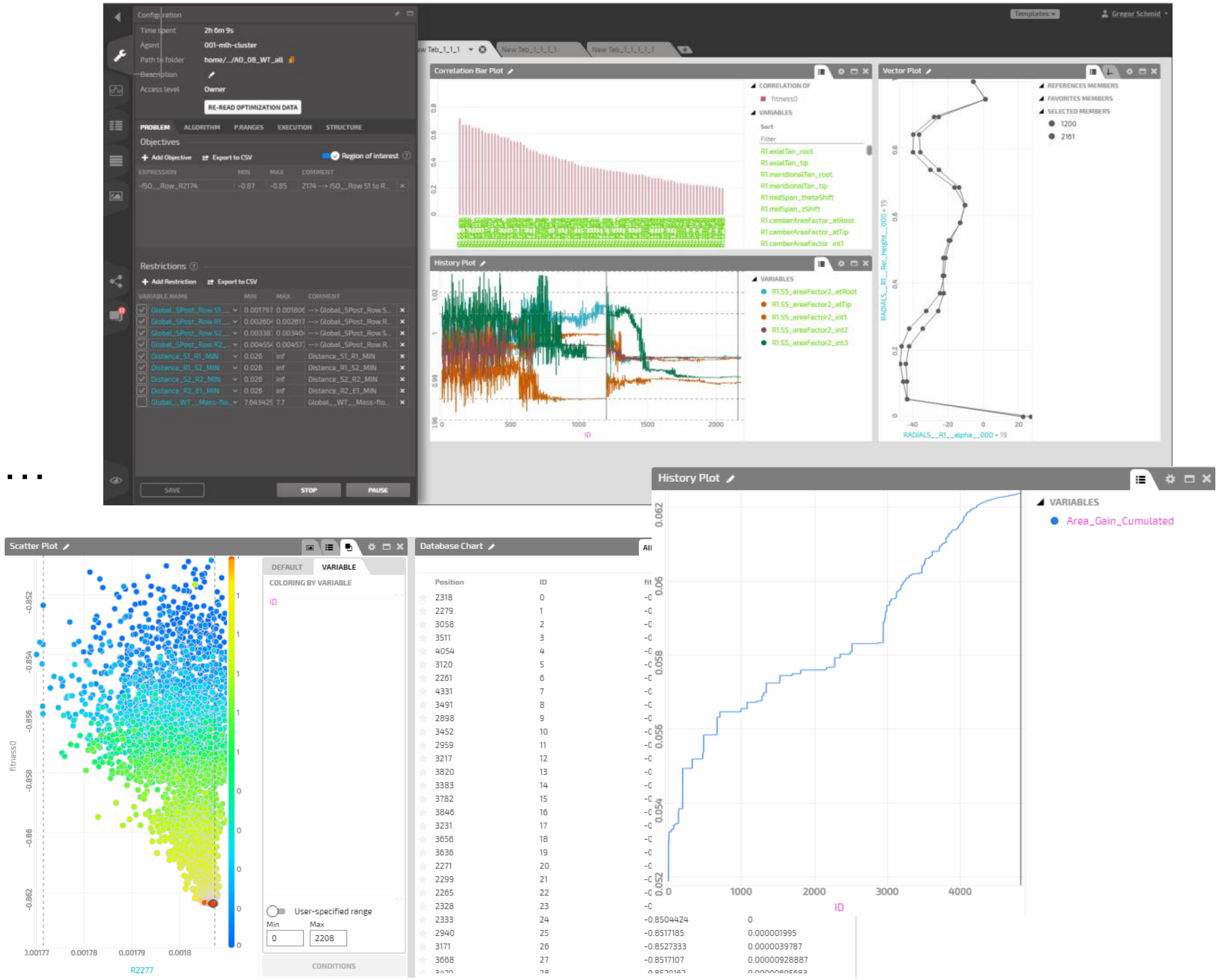
Input Files:
- Process chain
- Optimization parameters
- Optimization settings

Bunch of scripts available:
- Clean up, generate, modify members …
- analyse process chain, write out data and plots …

Interactive, web-based control of optimization:
- Generate plots and postprocess data
- Edit parameter limits, constraints

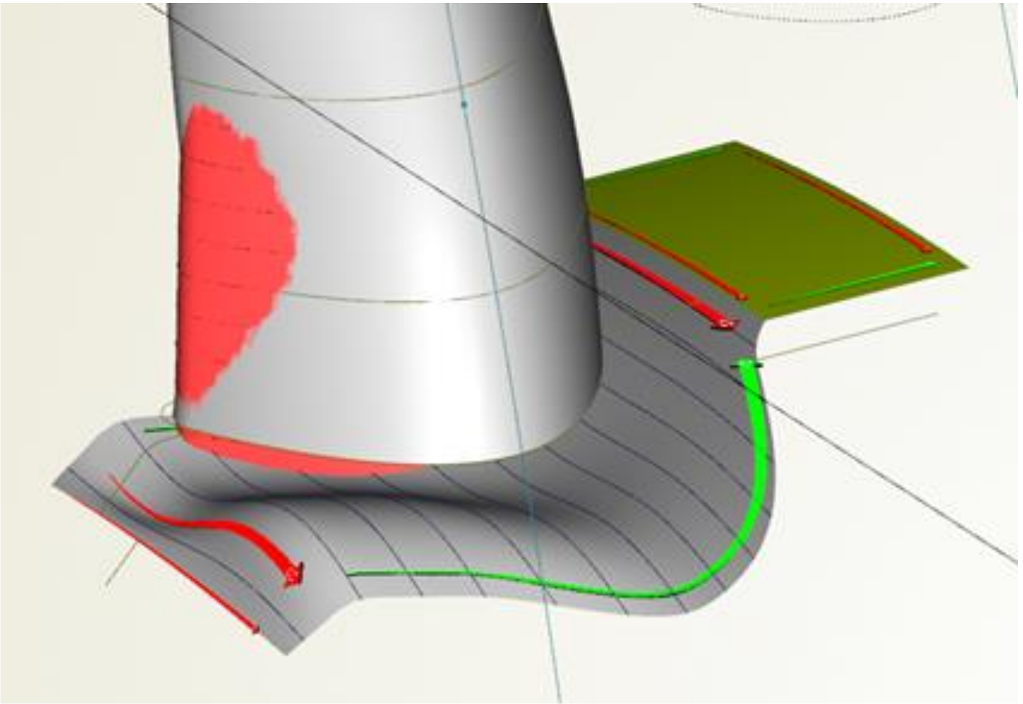


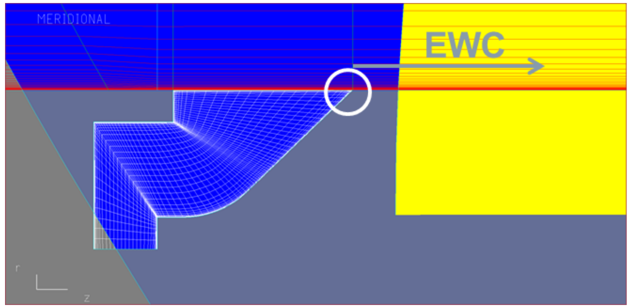
Flowpath Aero Optimization
Application Example 1

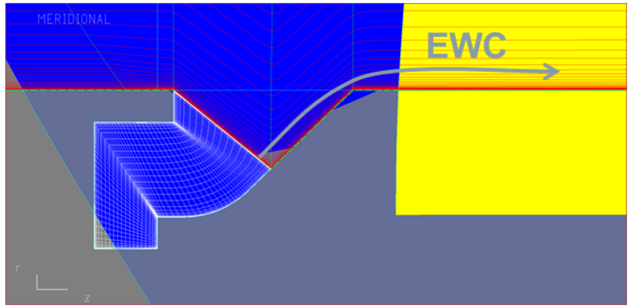
1.5 stage turbine rig:

- Reduce blade count by 20%
- Introduce non-axisymmetric endwall (EWC) and advanced blade tips
- 3D optimization with 89 parameters in total based on TRACE
- Optimization of blade1 leads to 0.9 ppts improvement
- Including EWC gave another 0.3 ppts

→ 1st stage improves by +0.2/0.3 ppts steady/transient (experiment +0.3 ppts)







Flowpath Aero Optimization
Application Example 2

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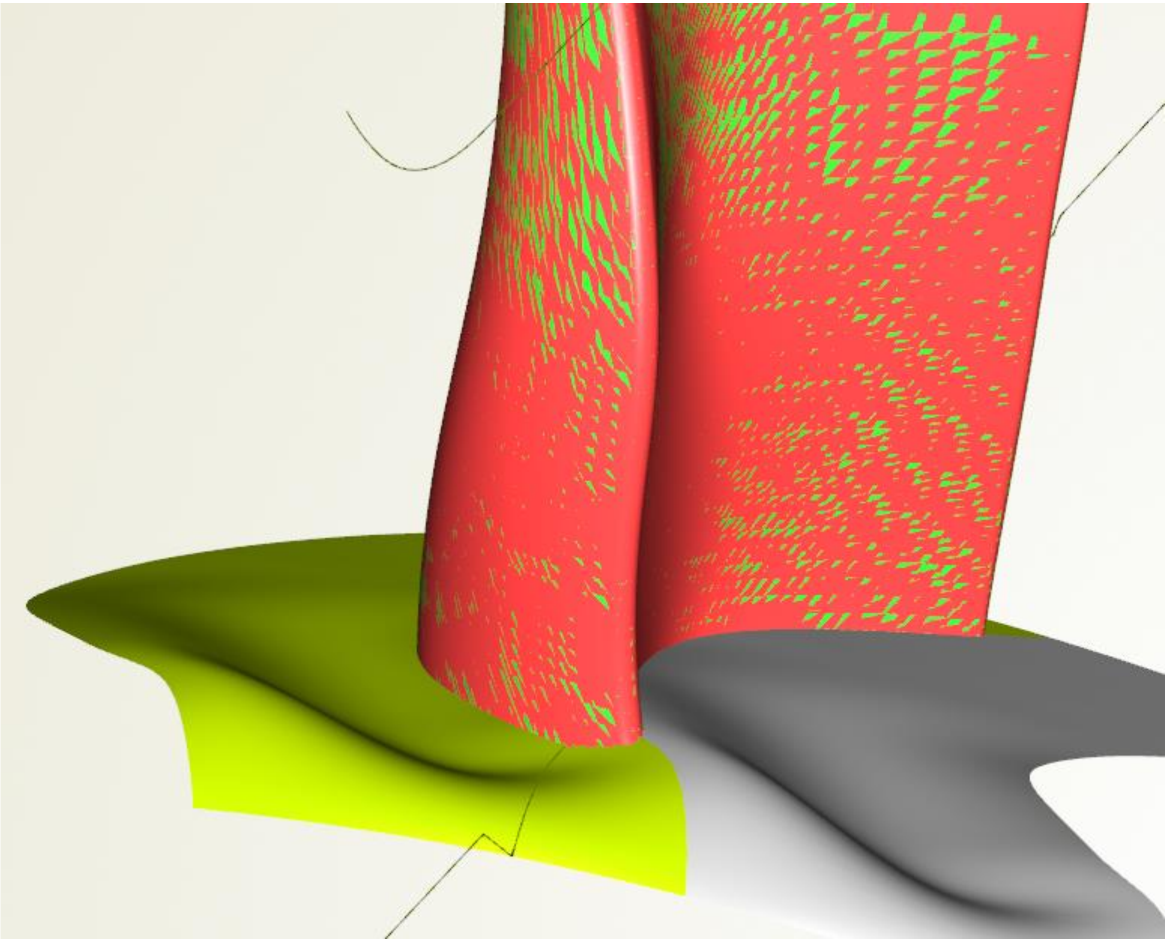
2.5 stage turbine rig:

- Significant increase of blade loading by count/chord reduction
- Airfoil optimization with ~100 parameters per blade row
- Endwall optimization with 8 parameters per surface

→ Performance improves 0.7 ppts over baseline

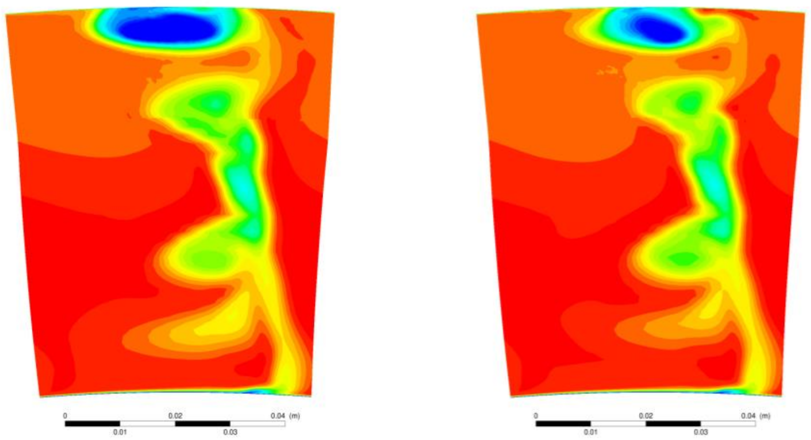


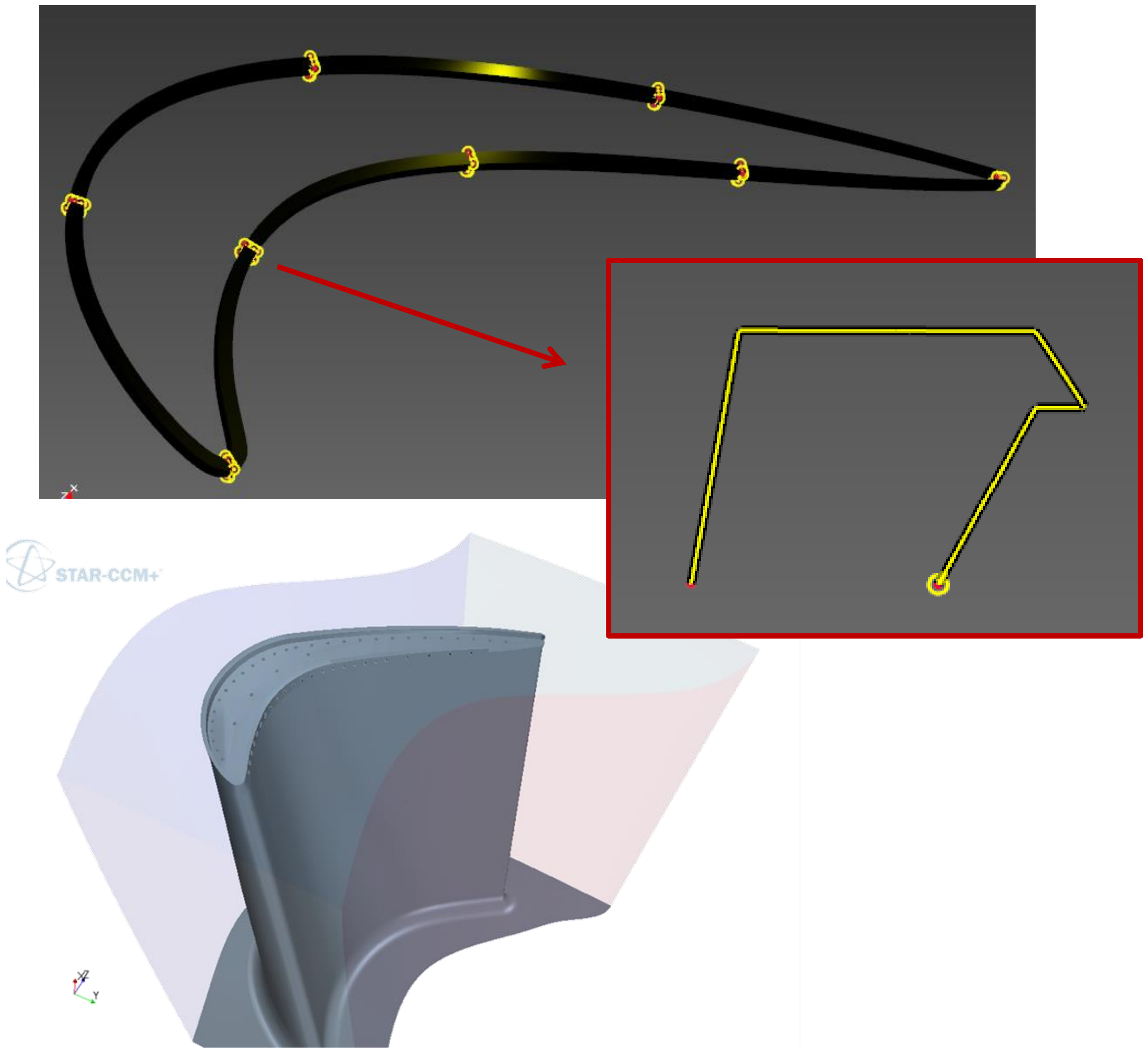
Blade Tip Optimization
Squealer Tip

Blade Tip Squealer Cavity

- Parametric cross section of squealer fence at several locations
- Include cutout at any arbitrary location
- 1.5-stage CFD setup in STAR CCM+

→ 1.5 stage efficiency improves by 0.6 ppts over baseline squealer tip





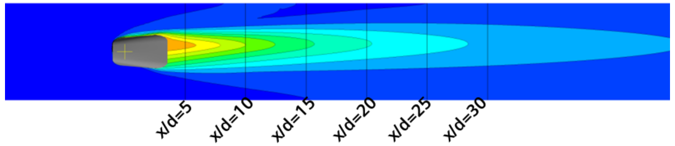
Film Cooling Hole Optimization
Diffuser Geometry

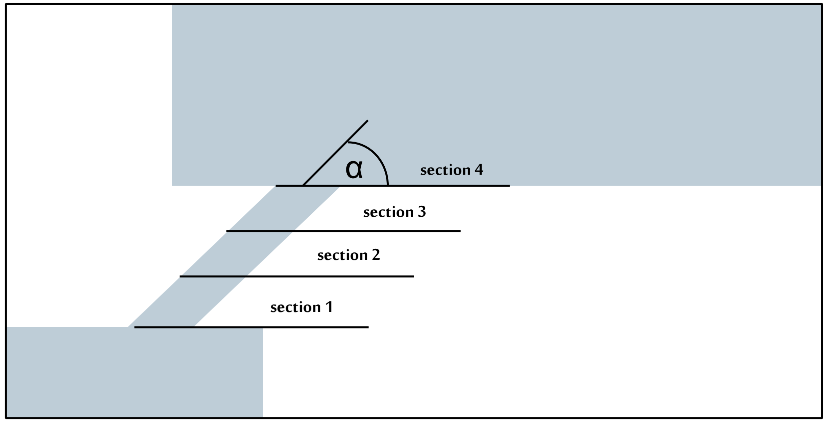
Parametrization :
- 4 sections
- 7 control points per section
- 2 angles, aspect ratio, eccentricity

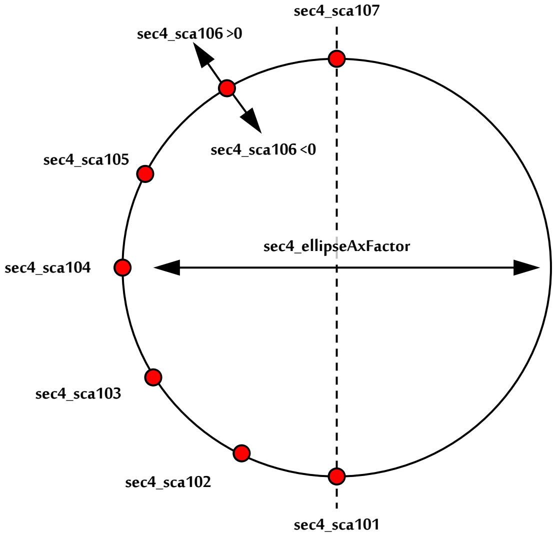
Tool Chain:
1. Geometry Generation CAESES
2. Mesh Generation
3. CFD Simulation ANSYS CFX

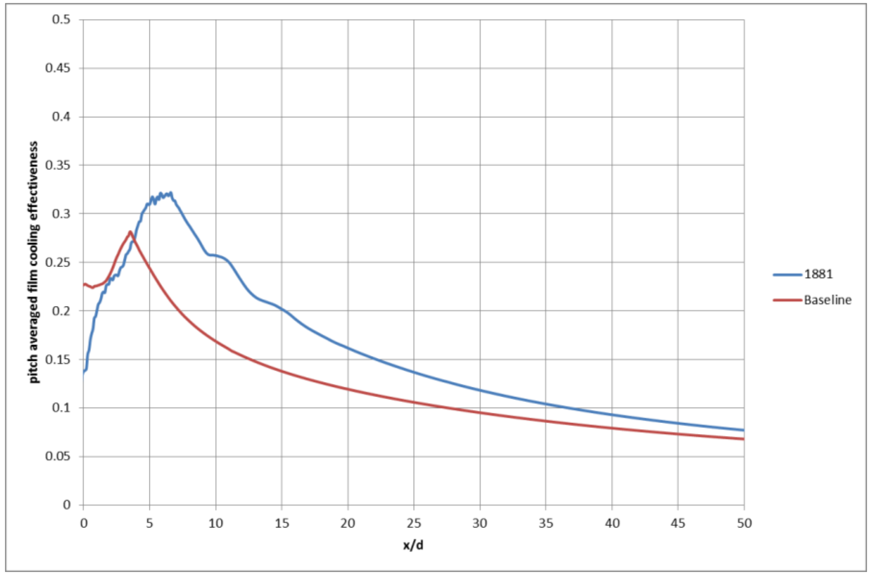
→ Significant improvement of film cooling effectiveness for constant blowing ratio

Baseline:









Aero Optimizations based on CAESES
Conclusion and Outlook

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Conclusion:

- Turbine airfoil and endwall parametrization is widely based on CAESES for production design at Siemens
- Additional functionality as automated fitting, exploration of design space and others successfully implemented in standard work flow
- Caeses has found ist way into several applications besides the main flow path design, e.g. blade tips, cooling holes, …

Outlook:

- Combine CFD with FEA for thermal and stress analysis within the optimization process chain (MDO)