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 highly-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
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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
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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)
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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
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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
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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
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Tool Chain

1. Geometry generation
   - Airfoil parameterization:
     - Automated fitting of initial geometry
     - ~ 5 radial sections
     - ~ 20 parameters for stacking axis and stagger
     - ~ 80 parameters to describe airfoil

2. Mesh generation

3. CFD simulation
   - 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
1. Geometry generation

2. Mesh generation

3. CFD simulation

CFX / TRACE:
• Steady state mixing plane
• SST turbulence model
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Tool Chain

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
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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)
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Application Example 2

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
2. Mesh Generation
3. CFD Simulation

→ Significant improvement of film cooling effectiveness for constant blowing ratio

Baseline:

![Graph showing film cooling effectiveness improvement](image-url)
Aero Optimizations based on CAESES
Conclusion and Outlook

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)