Engineering Success by Application of STAR-CCM+ for Modern Gas Turbine Design

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B&B-AGEMA GmbH, Aachen, Germany
• Founded in 1995, located in Aachen, Germany
• Independent engineering service company

• Company Expertise
  • compressor and turbine design for steam & gas turbines
    ➢ component design & re-design, technology development, reviews, test-rig realization, advisory service
    ➢ research in cooling technologies (e.g. innovative film cooling)
  • combustion technology
    ➢ optimization of pre-mixed combustion systems
    ➢ Low-NO\textsubscript{x} hydrogen combustion
  • power plant
    ➢ CFD / CHT Analysis & Flow Optimization of power plant components (cooling tower, valve, condenser, moisture separator, etc.)
Content

• Introduction on modern GT development

• Compressor design
  ❖ 2D design tool ACF2D & interface to STAR-CCM+
  ❖ Multi-stage axial compressor

• Combustor design
  ❖ Dry Low-NOx (DLN) pre-mixed combustion
  ❖ New designed industrial gas turbine

• Cooled turbine design
  ❖ Conjugate Heat Transfer (CHT) application
  ❖ Upgrade of E-class 1st vane

• Conclusion
Example of Modern GT Development: Full Approach

Industrial gas turbine L20A
Courtesy of Kawasaki Heavy Industries

RESEARCH & DEVELOPMENT

FIELD TEST OPERATION

COMPONENT DESIGN

COMPONENT TESTING

CFD / CHT / COMBUSTION VALIDATION
**“Kawasaki L30A” Overview**

### 30 MW<sub>e</sub> simple cycle efficiency >40%

**Kawasaki GT line-up (GT2012-68668)**

- **KHI GT's (HEAVEY DUTY)**
- **EXISTENT HEAVEY DUTY GTs**
- **EXISTENT AERODERIVATIVE GTs**

Full CFD/CHT/combustion validations are of significant importance during the design process of modern gas turbines:

- to reach the advanced design specifications
- to accelerate the design process
- to reduce testing steps until product readiness
- to save money

**References:**


“Kawasaki L30A”: Examples for Modern Design Tool Application

Compressor Design:
Example: compressor performance prediction with ACF

Turbine Design:
Example: CFD analysis of a blade cooling

Combustor Design:
Example: CFD analysis of DLN combustor emissions

Industrial gas turbine L30A
Courtesy of Kawasaki Heavy Industries

World’s best Industrial GT “Kawasaki L30A”
Highest PG efficiency in 30 MW class GT’s
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- 2D Streamline Curvature Code
- Developed for heavy duty and industrial GT axial compressors
- Fast design and upgrade of multi-stage compressors
- Quality of implemented correlations proven by several existing machines running successfully
Interface ACF2D to STAR-CCM+

- All necessary input data are generated by ACF2D:
  - 3D blade geometry (currently NACA65, NACA63 and DCA)
  - Hub and shroud geometry
  - Mixingplane positions
  - TurboWizard file
- Automated hexahedral mesh generation (H-O-H structure for each row) by TurboWizard
- All mixing planes & periodic interfaces established automatically by TurboWizard
- Mesh generation for 16 stage compressor takes 30 minutes (approx. 5 GB RAM)
- 2D results from ACF2D of pressure, temperature & velocity applied as initial solution

Hexahedral mesh from STAR-CCM+ generated with TurboWizard
Initialization with STAR-CCM+

Initial distribution of static pressure, static temperature & flow vectors from ACF2D result.

Performing Grid Sequencing:
- 5 grid levels
- convergence tolerance 0.05
- CFL number 5.0
Example calculation for stages 1 to 3:

- Rotor tip clearance neglected
- Non-reflecting option in mixingplanes
- Continuous streamlines across blade rows

<table>
<thead>
<tr>
<th></th>
<th>ACF2D</th>
<th>STAR-CCM+</th>
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<tbody>
<tr>
<td>Mass flow</td>
<td>502.3 kg/s</td>
<td>505.93 kg/s ± 0.04 %</td>
</tr>
<tr>
<td>( \eta_{1R} )</td>
<td>93.56 %</td>
<td>94.68 %</td>
</tr>
<tr>
<td>( \eta_{2R} )</td>
<td>96.27 %</td>
<td>96.84 %</td>
</tr>
<tr>
<td>( \eta_{3R} )</td>
<td>96.12 %</td>
<td>97.58 %</td>
</tr>
<tr>
<td>( \eta )</td>
<td>91.14 %</td>
<td>92.40 %</td>
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</table>
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3D flow and reaction simulations with STAR-CCM+ help to identify and understand complex flow phenomena within modern gas turbine combustors. Such simulations support the detailed analyses and improvement of combustors with respect to:

- fuel/air mixing
- flame stability
- combustion efficiency
- \(\text{NO}_x\) emissions
- CO emissions
- structure cooling

Worlds best Industrial Gas Turbine „Kawasaki L30A“
Highest PG efficiency in 30 MW Class GT's.
Courtesy of Kawasaki Heavy Industries
Comprehensive numerical modeling of a modern gas turbine combustor with STAR-CCM+:

- Fuel supply
- Main combustion
- Supplemental combustion
- Air supply
- Combustor exit

Worlds best Industrial Gas Turbine „Kawasaki L30A“
Highest PG efficiency in 30 MW Class GT's.
Courtesy of Kawasaki Heavy Industries
• 1.4 million polyhedral cells (90° sector)
• standard eddy break up model (EBU)
• realizable k-epsilon turbulence model
Non-reactive flow simulation: analyses of air/fuel mixing process based on gas mixture fluid model:

- Fuel injection
- Burner inlet area
- Air/fuel mixedness as calculation result
Gas Turbine Combustor Design with STAR-CCM+

Reactive flow simulation: visualization of flame structure, analyses of reaction process / species distribution and emission behavior (e.g. NO\textsubscript{x})

- **air /fuel premixing** (streamline color: velocity)
- **supplemental combustion zone**
- **main combustion zone** (iso-surface H2O mass fraction; color: temperature)
- **combustor exit** (color: temperature)

- **air supply**
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Successful implementation of STAR-CCM+ in turbine analyses

- investigation of innovative film cooling technologies for turbine blades
- upgrade analysis of turbine designs
- failure analysis

CFD/CHT calculation procedure of a turbine upgrade analysis

- CFD calculation of multiple stages with consideration of cooling flow ejection to evaluate detailed B.C. for CHT calculation
- complex CHT calculation of single vanes and blades with detailed geometrical description and fine mesh (wall $y^+ < 1$) to evaluate thermal conditions
- combination of detailed CHT results lead to a detailed thermal turbine model
- geometrical adjustments of inner cooling structure and the impact of thermal barrier coatings can be analyzed easily and fast in a parametric study
Upgrade E-class Gas Turbine: 1st Stage Vane Analyses with STAR-CCM+

**detailed CHT simulation model**

**flow direction**

**vane mesh specification**
- Fluid: 7.04 million volume cells
- Solid: 1.04 million volume cells
- Prism layer around outside airfoil: 28 layers, 1.15e-6 m first cell height
- Prism layer inside flow path: 15 layers, 1.6e-6 m first cell height
- Local refinement area on suction side

**CHT-calculation set up**
- SST-GammaRe-theta Model
- Full conjugate calculation
- Combustion gas properties
Upgrade E-class Gas Turbine: 1st Stage Vane Analyses with STAR-CCM+

1st vane upgrade analysis with STAR-CCM+

- parametric study for:
  - redistribution of the internal cooling air
  - TBC’s of different thickness
- peak temperature reduction by 160°C
- homogenization of the temperature distribution

Benefits by application of STAR-CCM+ in upgrade design process

- accurate determination of the thermal conditions of cooled turbine parts
- fast evaluation of improved internal cooling designs
- reduction of experimental validations
- reduction of development time, effort and costs
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STAR-CCM+, with its high level of automation, meshing capabilities and high solution accuracy, is the favored commercial CAE tool to perform fast and accurate simulations as conjugate heat transfer, flow and combustion calculations.

Development time, effort and cost can be reduced significantly by the application of STAR-CCM+ within the R&D process.