Turbomachinery Simulation using STAR-CCM+
Usage From Across the Industry

Sulzer
Voith
Siemens
Sncma
SAFRAN Group
Liebherr
BorgWarner
GE
Schlumberger
Wood Group
Alstom
Solar Turbines
ebm papst
Pratt & Whitney

Belcan
Sanden
Delivering Excellence
Hitachi
Inspire the Next
Honeywell
Rolls-Royce
Cameron
• **Key Objectives**
  - Conjugate heat transfer
  - Aeroelastic response
  - Performance mapping

• **Key Capabilities**
  - Complex geometry handling
  - Conformal polyhedral meshing
  - Harmonic balance
  - Advanced post-processing

• **Best Practice**
  - Mesh requirements
  - Solution procedure
Key Capabilities

- Direct CAD import
- 3D CAD editing
- **Meshing**
  - Polyhedral cells
  - Conformal interfaces
  - Automatic prism layer generation

Conjugate Heat Transfer
Cooled Turbine Blade

Key Capabilities

- Direct CAD import

Direct import of CAD solid geometry
Cooled Turbine Blade

Key Capabilities

• 3D CAD editing

External and cooling air volumes generated using 3D CAD
Cooled Turbine Blade

Key Capabilities

- **Meshing**
  - Automatic mesh generation
  - Polyhedral cells
  - Conformal interfaces
  - Automatic prism layer generation

- Pipelined meshing
- Simple global size settings
- Local refinement control
- Automatic solution interpolation
Cooled Turbine Blade

Key Capabilities

• Meshing
  – Automatic mesh generation
  – Polyhedral cells
  – Conformal interfaces
  – Automatic prism layer generation

Fewer cells required
Cooled Turbine Blade

Key Capabilities

- **Meshing**
  - Automatic mesh generation
  - Polyhedral cells
  - Conformal interfaces
  - Automatic prism layer generation

Good for swirling flow

Polyhedral cell faces are orthogonal to the flow regardless of flow direction
Key Capabilities

- **Meshing**
  - Automatic mesh generation
  - Polyhedral cells
  - Conformal interfaces
  - Automatic prism layer generation

High quality cells, even with complex geometry
Cooled Turbine Blade

Key Capabilities

- Meshing
  - Automatic mesh generation
  - Polyhedral cells
  - Conformal interfaces
  - Automatic prism layer generation

Cells are one-to-one connected on the solid/fluid interface

Fluid-side prism layers are automatically generated
Aeroelastic Response

Traditional simulation methods present many challenges

- **Aeroelastic analysis must be run unsteady**
- **Traditional unsteady simulation is challenging**
  - Very long run times
  - Must mesh the entire machine
  - Hard to specify blade vibration
  - Hard to extract stability information

- Harmonic balance method in STAR-CCM+ resolves each of these challenges
- The HB method is not available in any other commercial package
Harmonic Balance Basics

- The harmonic balance method takes advantage of the periodic nature of a turbomachine

- Solves a set of equations that converge to the periodic, unsteady solution

- Full non-linear solver

- All unsteady interactions captured
Rapid calculation of unsteady solution

- Unsteady simulation must be run for many time steps to converge
- HB simulation converges to the unsteady solution 10x faster
Harmonic Balance Key Benefits

Single blade passage mesh

- All blades must be meshed for an unsteady simulation
- Only one blade passage must be meshed for a HB simulation, however the solution is calculated for all blades
Specify blade vibration

- The vibration of each blade is staggered. This is known as the “Interblade phase angle”
- To determine stability a simulation must be run for each phase angle
- Traditional unsteady solvers require manual set up of motion for each phase angle
Specify blade vibration

- Interblade phase angle is a simple input to the HB solver
Work per cycle calculation

- Stability is determined by “Work per cycle”
- Traditional unsteady solver requires the solution be saved at each time step and complex, external post processing to determine this value
- Work per cycle is a simple report when using the HB solver
Example: Vane Flutter
Example: Vane Flutter

- Work per cycle map shows this vane will not flutter
Performance Mapping

Key Benefits
- Complex geometry handling
- Polyhedral cells
- High quality mesh
- Prism layer generation
- Harmonic balance solver
Performance Mapping

Key Benefits

- Complex geometry handling
- Polyhedral cells
- High quality mesh
- Prism layer generation
- Harmonic balance solver
- Grid sequencing initialization
- Efficiency optimization with Optimate+
- Turbomachinery specific post-processing

Already discussed
Performance Mapping

Key Benefits
• Grid sequencing initialization

- Drastically reduce run time
- Reduce need for ramping
- Increased simulation robustness

Time to initialization:
80 seconds

Initialization

Converged Solution
Key Benefits

• Efficiency optimization with Optimate+
Performance Mapping

Key Benefits

- Turbomachinery specific post-processing
Key Benefits

- Turbomachinery specific post-processing

Performance Mapping
Performance Mapping

Key Benefits

- Turbomachinery specific post-processing

Circumferential Averaging

Absolute Pressure (Pa)

78000.  78800.  79600.  80400.  81200.  82000.
Validated Simulation: Radial Compressor

- **Comparison with rig measurements**
  - Full performance curve
  - RPM range
Validated Simulation: Radial Compressor

- Installation effects
  - Curved inlet duct
  - Diffuser outlet
Turbomachinery Meshing Guidelines

- Polyhedral mesh with extruded inlet/exit as needed
High resolution of leading and trailing edges
• Uniform cell sizing in the primary gas path
Turbomachinery Meshing Guidelines

- All y+ algorithm with y+ values less than 5
Turbomachinery Meshing Guidelines

- Last prism layer similar size to the first poly cell layer
- At least 5 prism layers to resolve the boundary layer
Reference Values

- Set reference pressure to be near the operating point

Initial Conditions

- Set velocity to a non-zero value
- Set initial pressure to the inlet or exit value, whichever is greater
- Set temperature the inlet value
Turbomachinery Solution Guidelines

Initialization

• Use grid sequencing initialization to obtain an initial condition
• Ensure that each grid level converges
• Initialize solution using actual operating conditions (do not ramp boundary conditions or rotation rate)

Suggested GSI parameters

• Max iterations per level: 200
• Convergence tolerance: 0.005
• CFL number: 20
Turbomachinery Solution Guidelines

Solver Settings

- Use a high CFL number whenever possible, a CFL number of 20 is a good starting point.
- For cases with high and low speed flow regions, enable Continuity Convergence Acceleration.
Overview

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