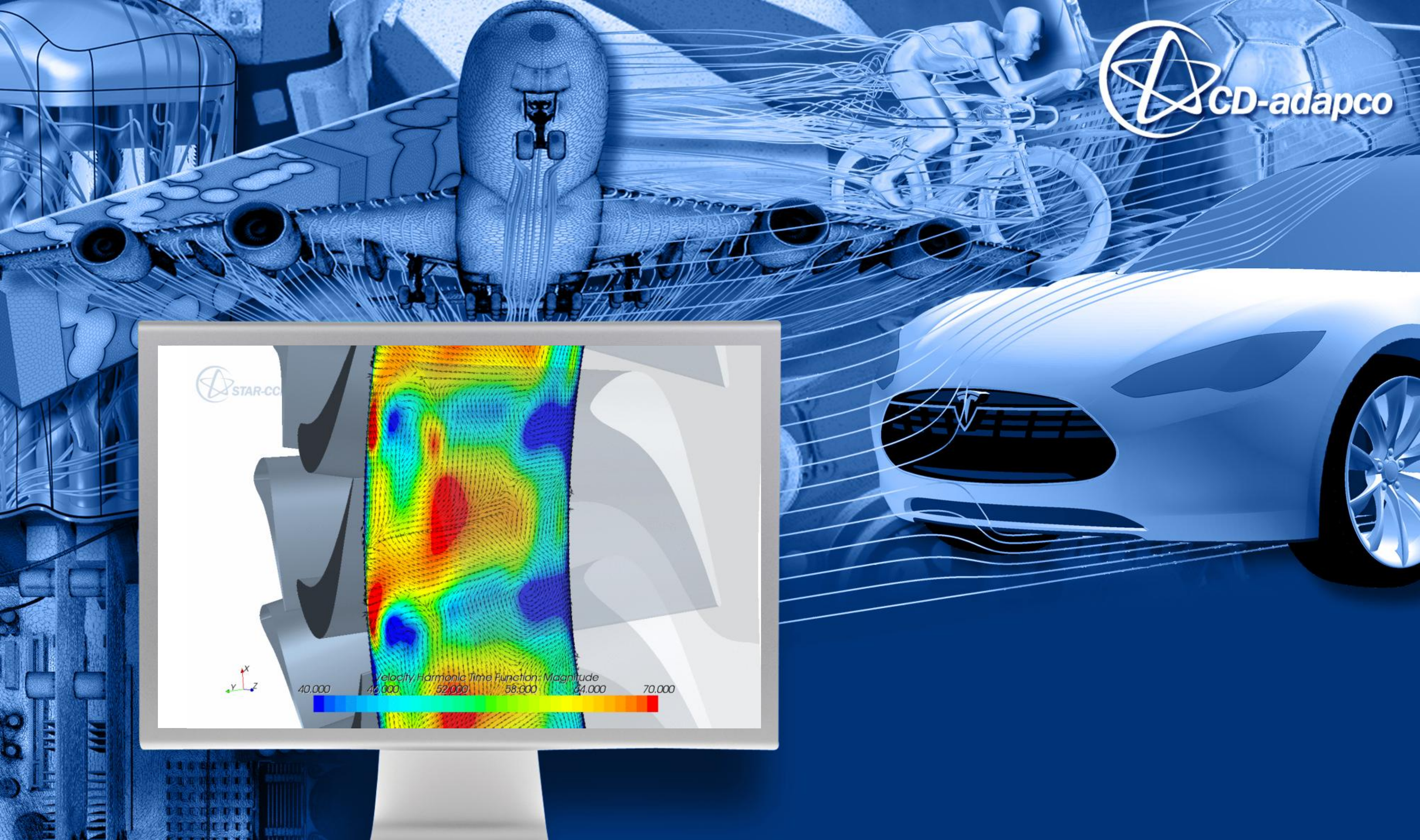
CD-adapco



Turbomachinery Simulation using STAR-CCM+

Usage From Across the Industry

CD-adapco

SULZER

VOITH

SIEMENS

Snecma
SAFRAN Group

GE

LIEBHERR

BorgWarner

WG
WOOD GROUP

Schlumberger

EBARA

NIIGATA

ALSTOM

Solar Turbines
A Caterpillar Company

ebmpapst

Pratt & Whitney
A United Technologies Company

КЛИМОВ

HITACHI
Inspire the Next

Belcan

SANDEN
Delivering Excellence

MAN

Honeywell

ROLLS ROYCE
Rolls-Royce

Hamilton Sundstrand
A United Technologies Company

САТУРН
АВИАЦИОННЫЕ ДВИГАТЕЛИ

CAMERON

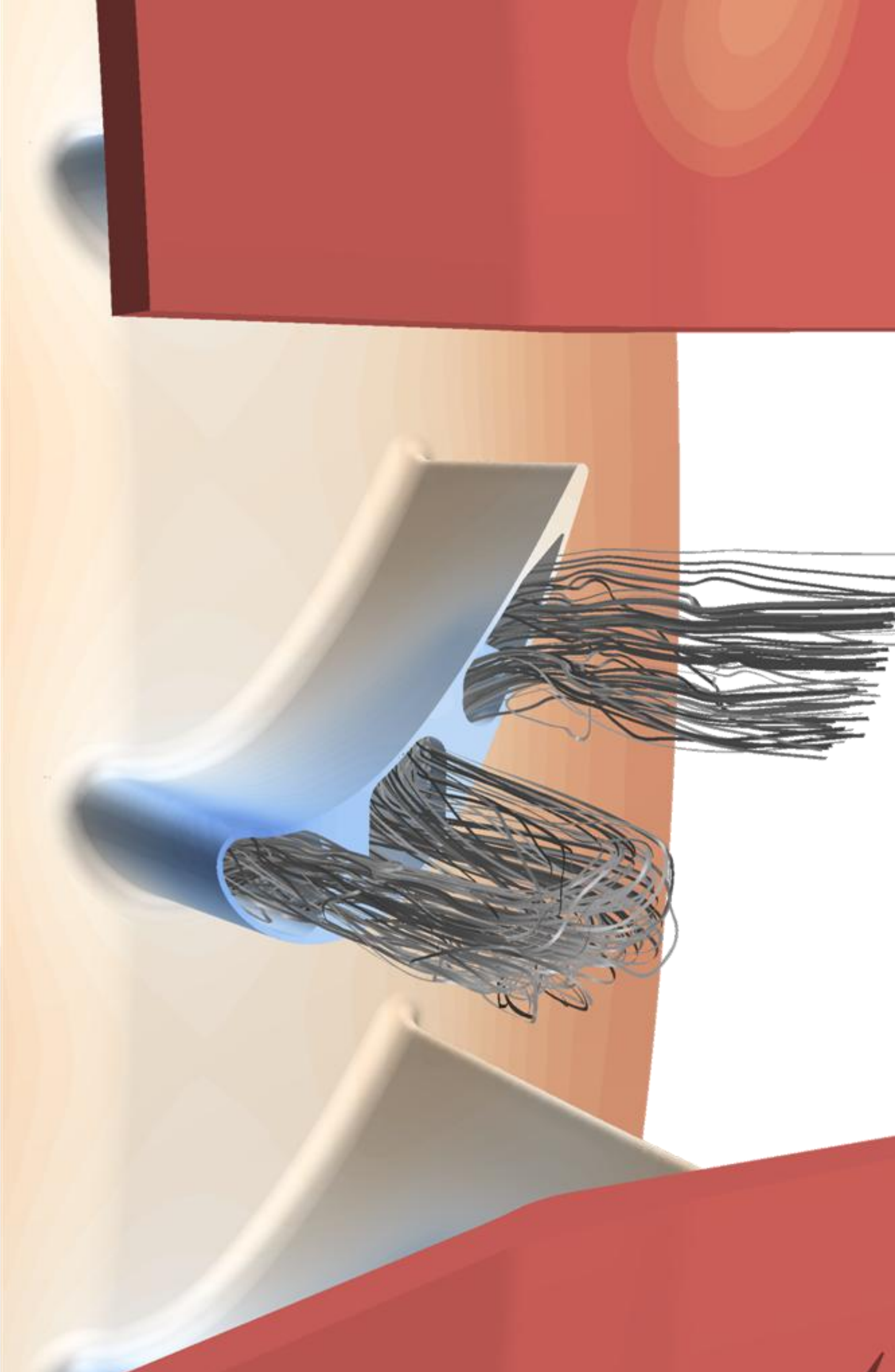
Outline

- **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

Conjugate Heat Transfer

Key Capabilities

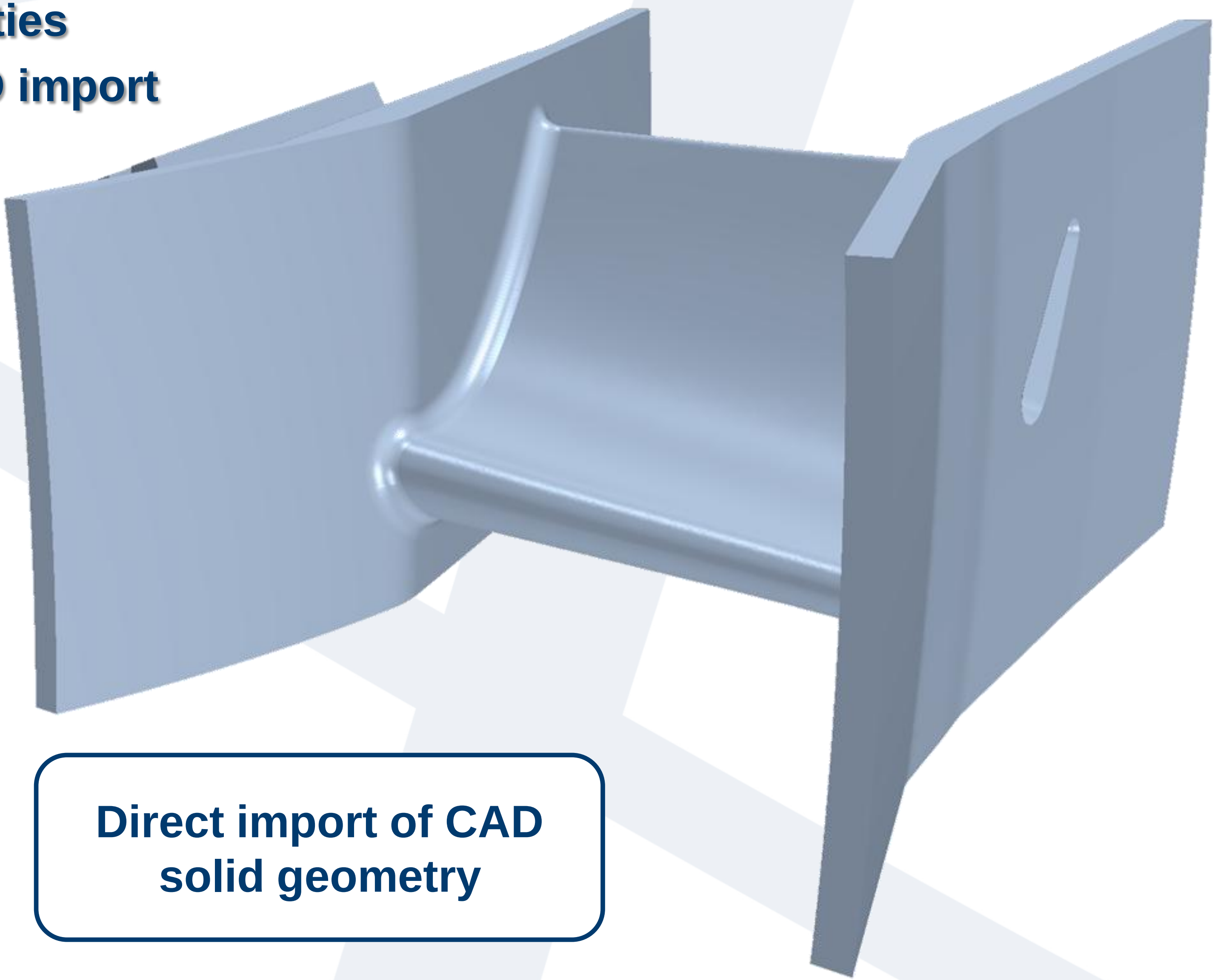
- Direct CAD import
- 3D CAD editing
- Meshing
  - Polyhedral cells
  - Conformal interfaces
  - Automatic prism layer generation



Cooled Turbine Blade

Key Capabilities

- Direct CAD import

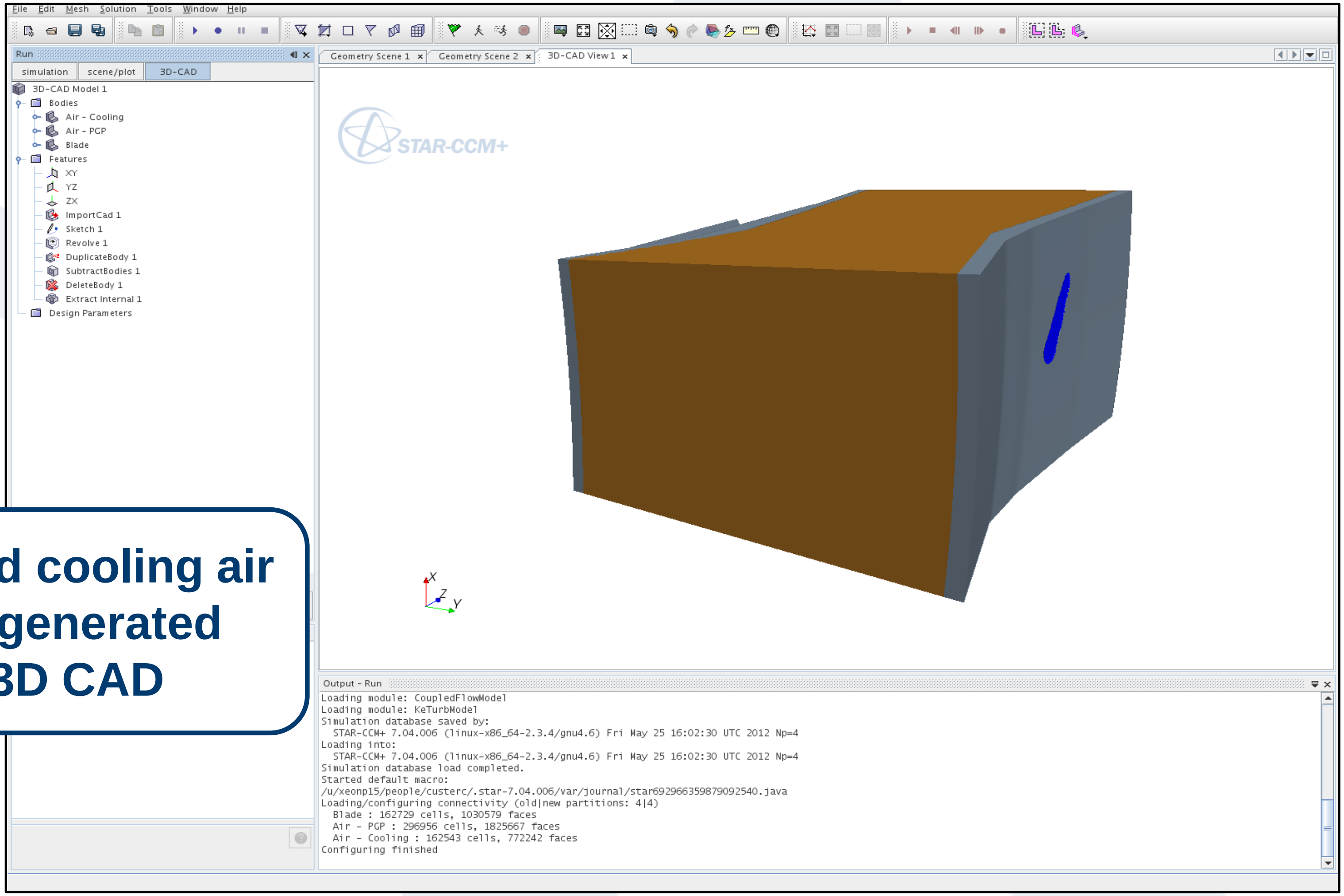


Direct import of CAD solid geometry

Cooled Turbine Blade

Key Capabilities

- 3D CAD editing



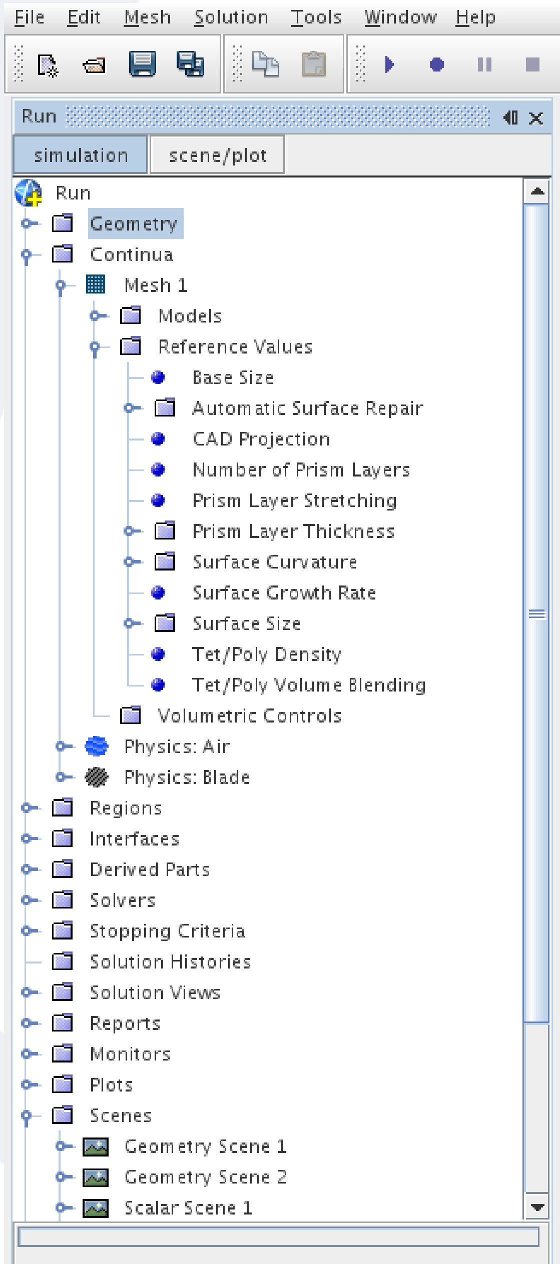
External and cooling air volumes generated using 3D CAD

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**



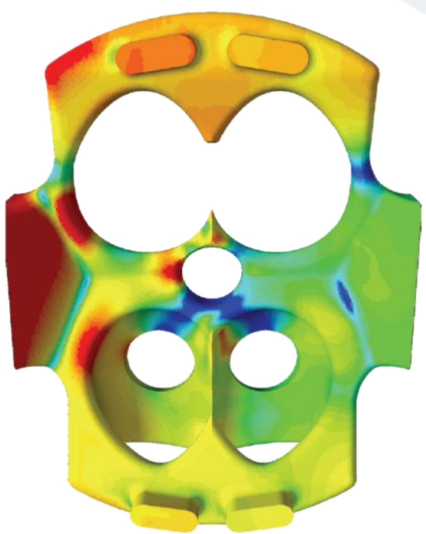
Cooled Turbine Blade

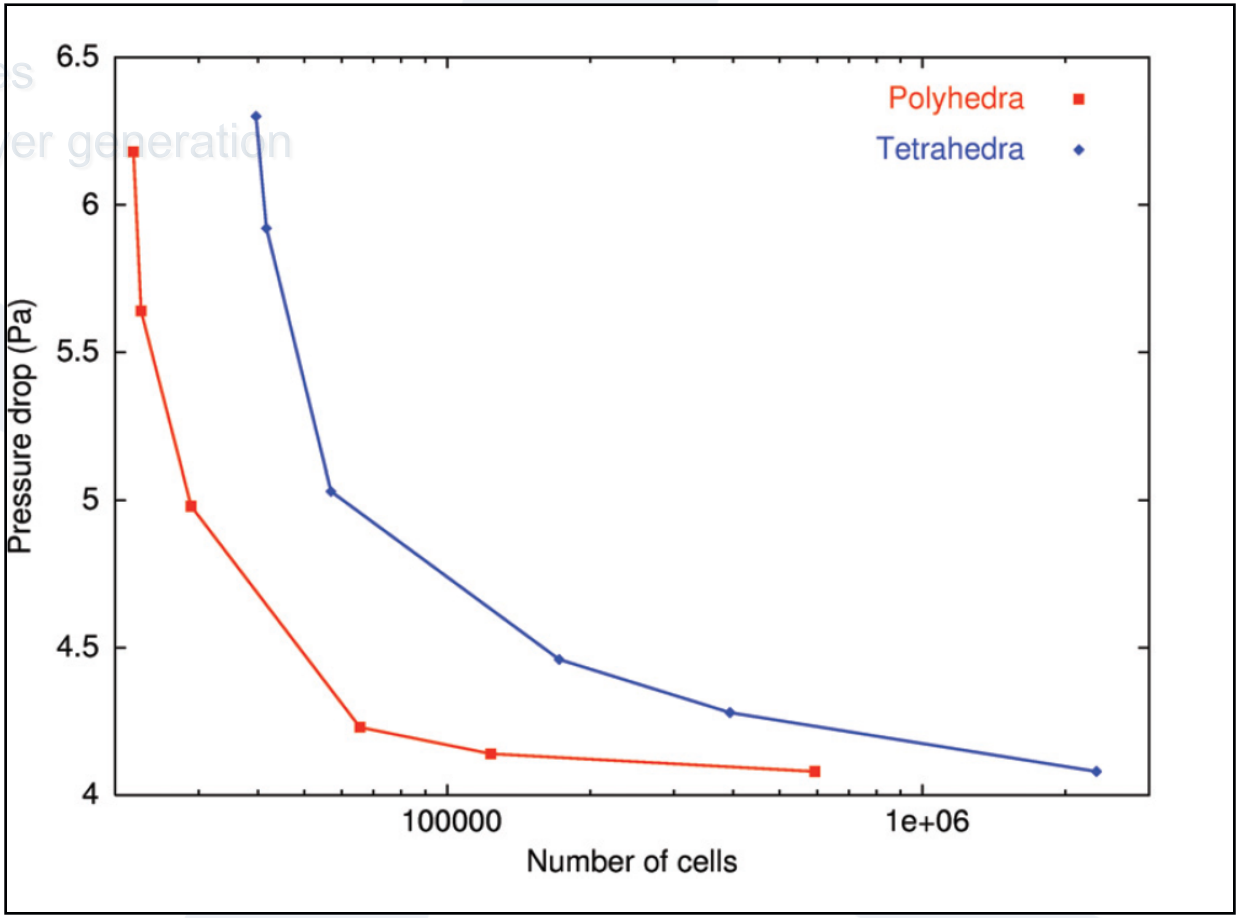
CD-adapco

Key Capabilities

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

Fewer cells required



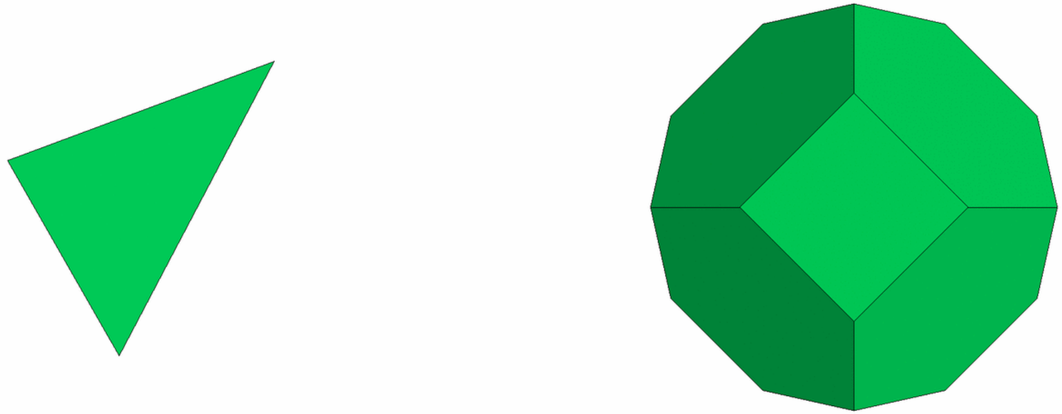


Cooled Turbine Blade

Key Capabilities

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

Good for swirling flow



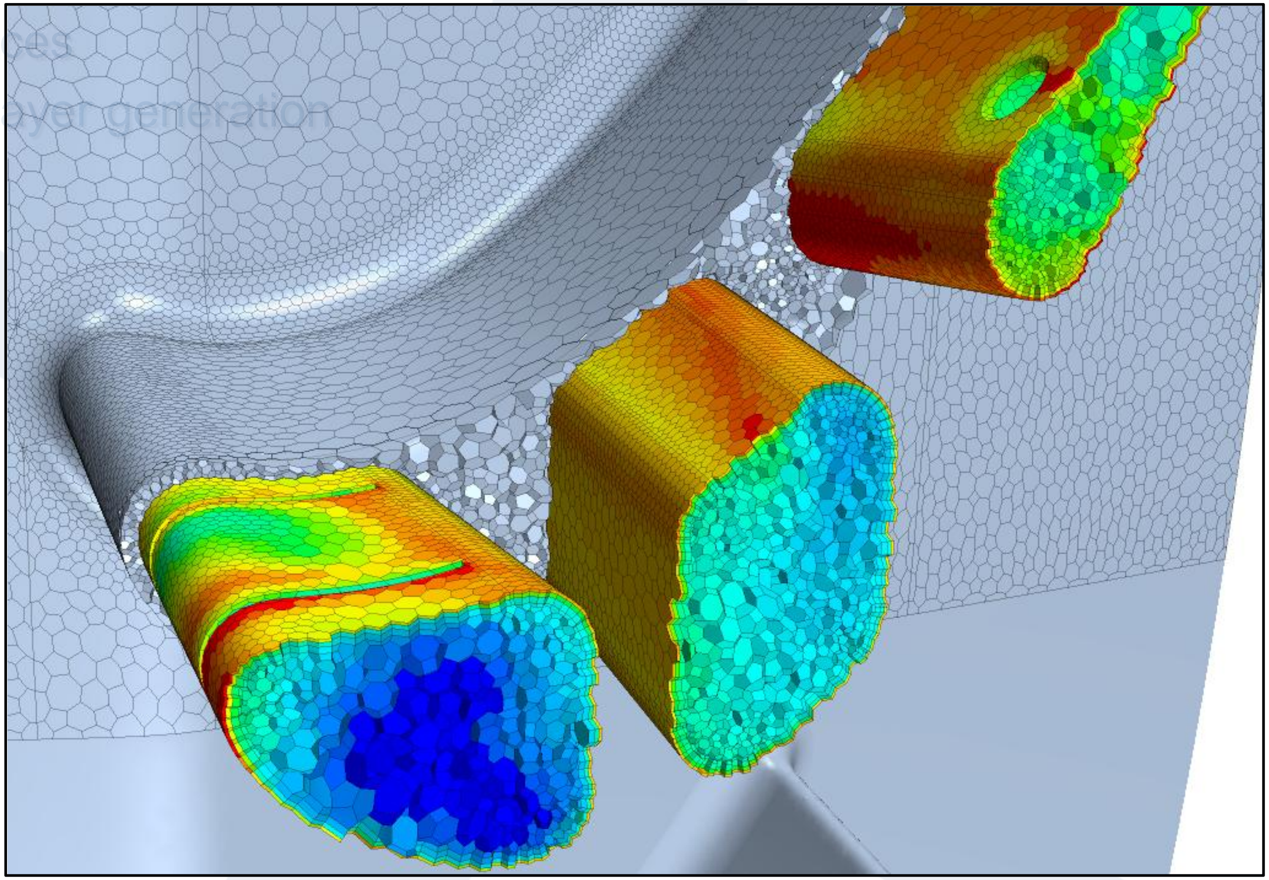
Polyhedral cell faces are orthogonal to the flow regardless of flow direction

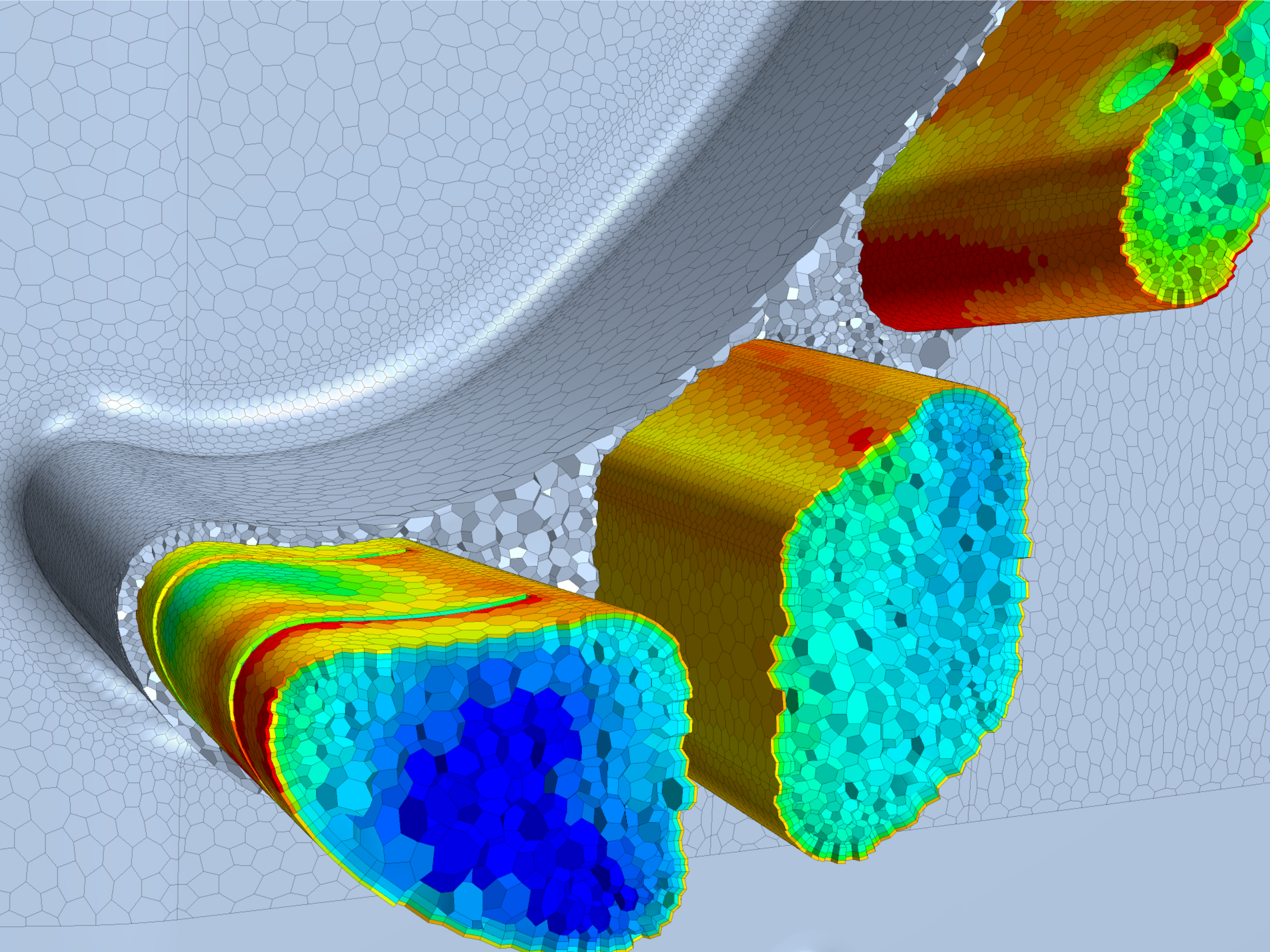
Cooled Turbine Blade

Key Capabilities

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

High quality cells, even with complex geometry





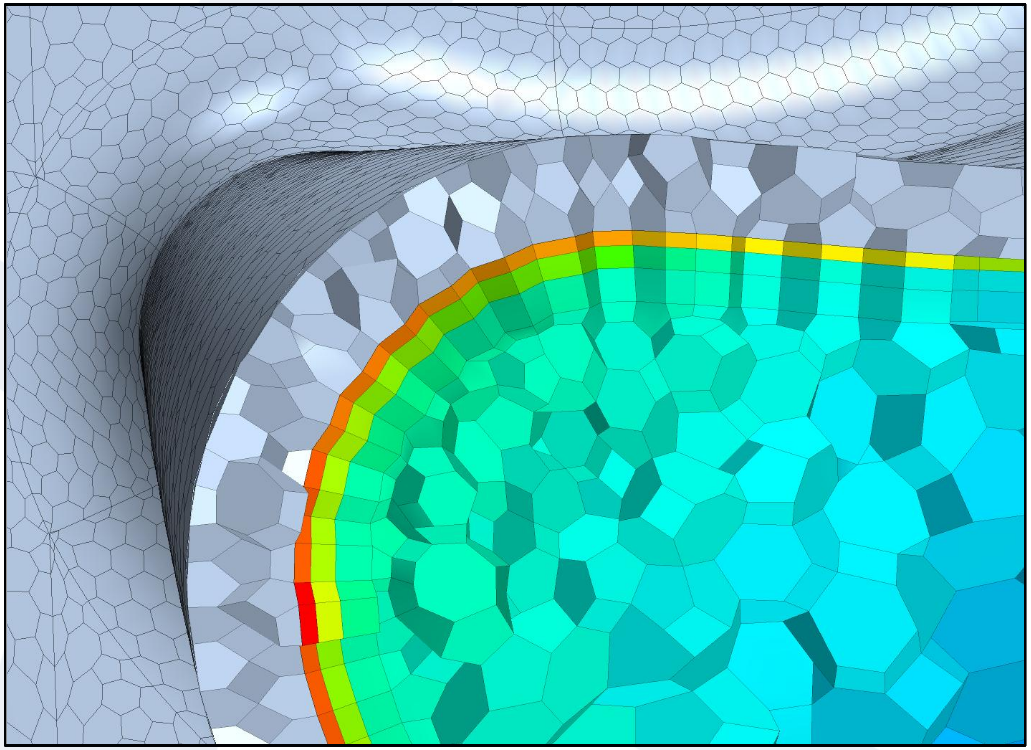
Cooled Turbine Blade

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**

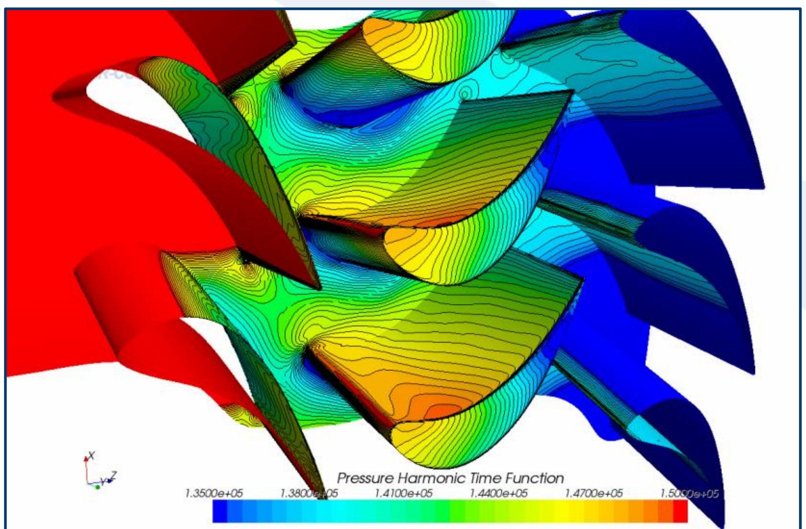
Harmonic Balance Basics

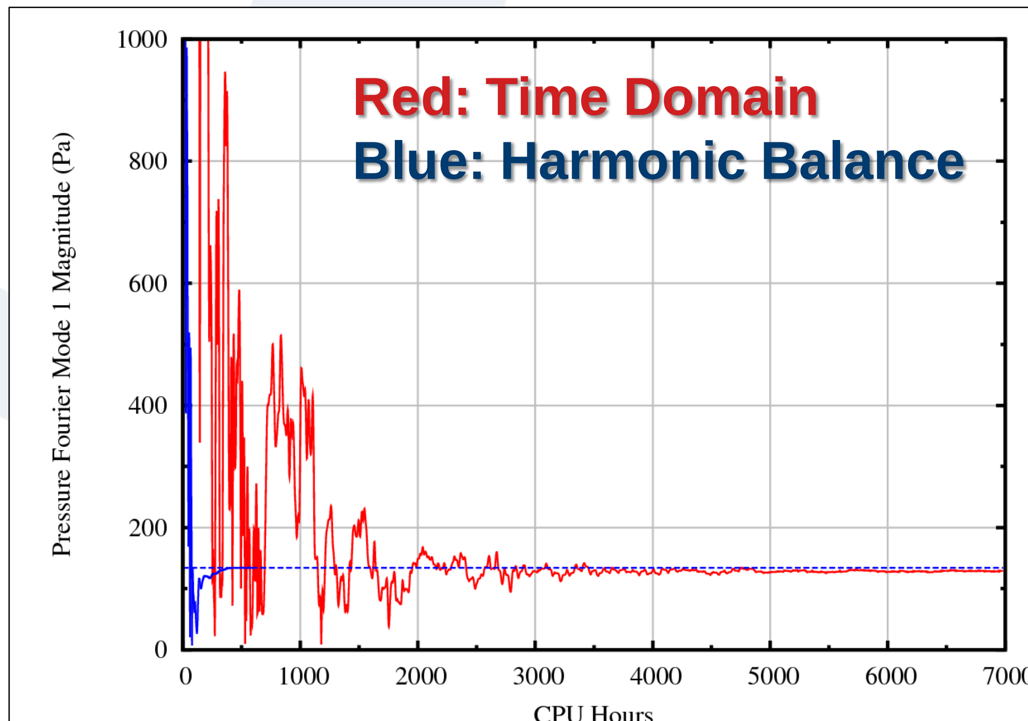
- The harmonic balance method takes advantage of the periodic nature of a turbomachine
- Solves a set of equations that converge to the periodic, unsteady solution
- Full non-linear solver
- All unsteady interactions captured

Harmonic Balance Key Benefits

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

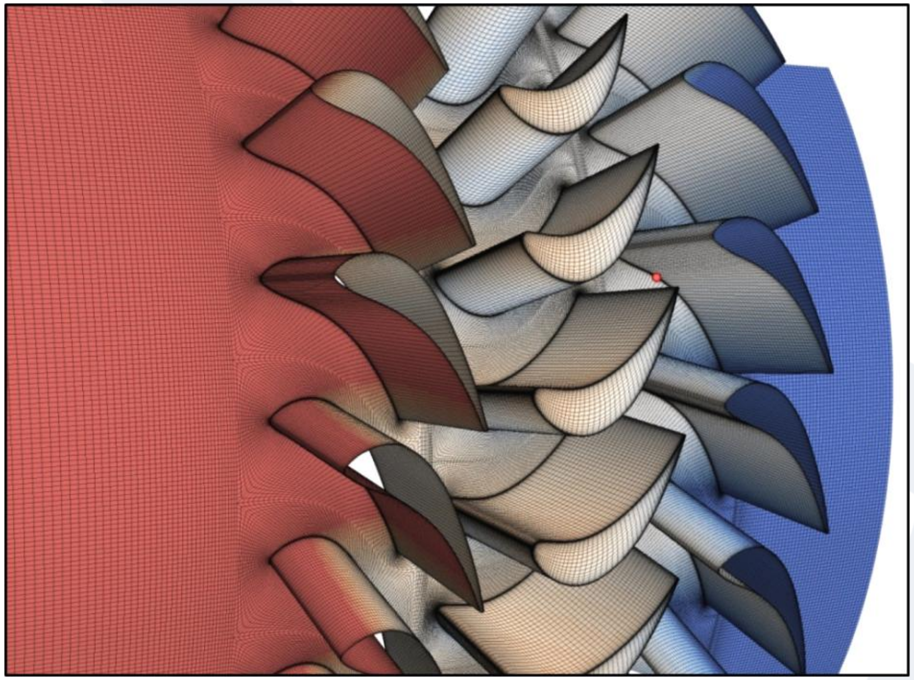




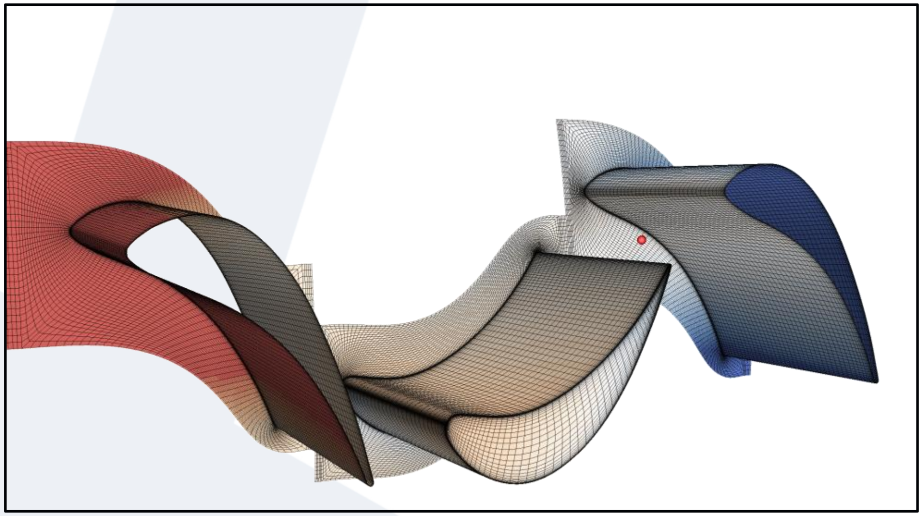
Harmonic Balance Key Benefits

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



Time Domain

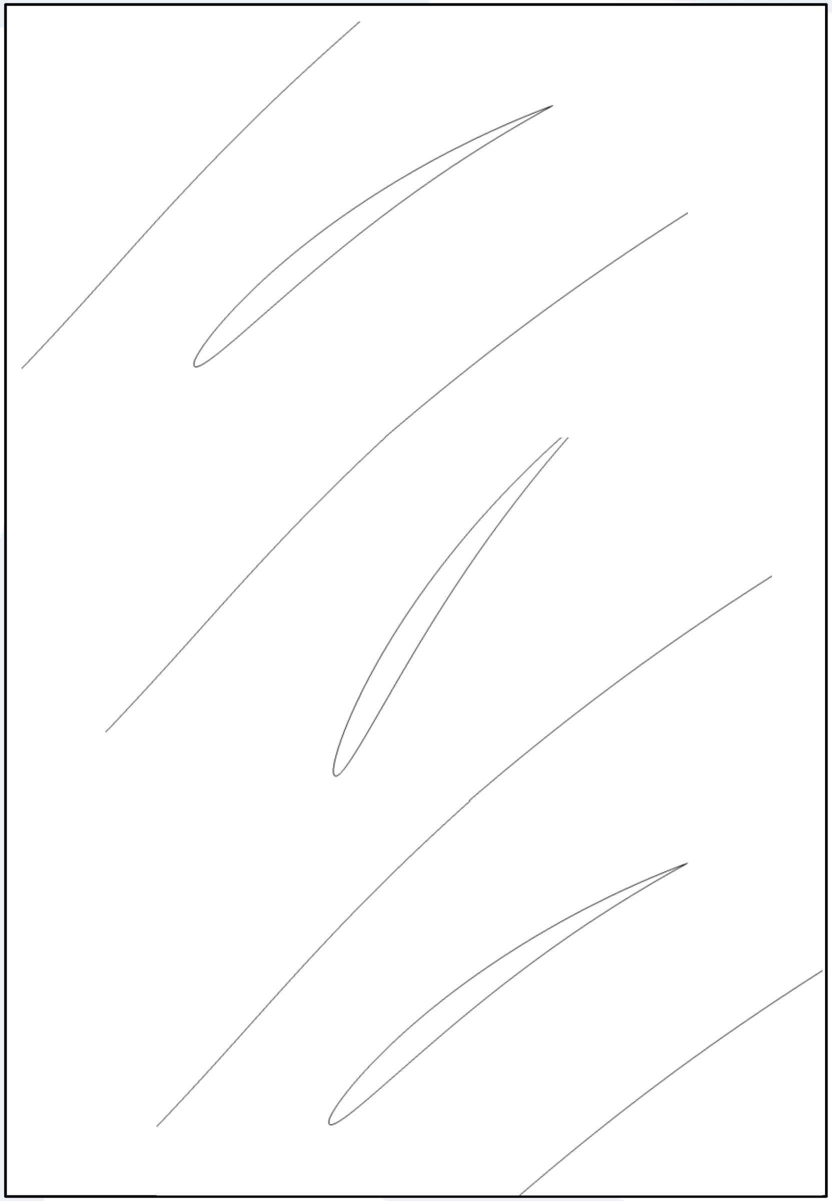


Harmonic Balance

Harmonic Balance Key Benefits

Specify blade vibration

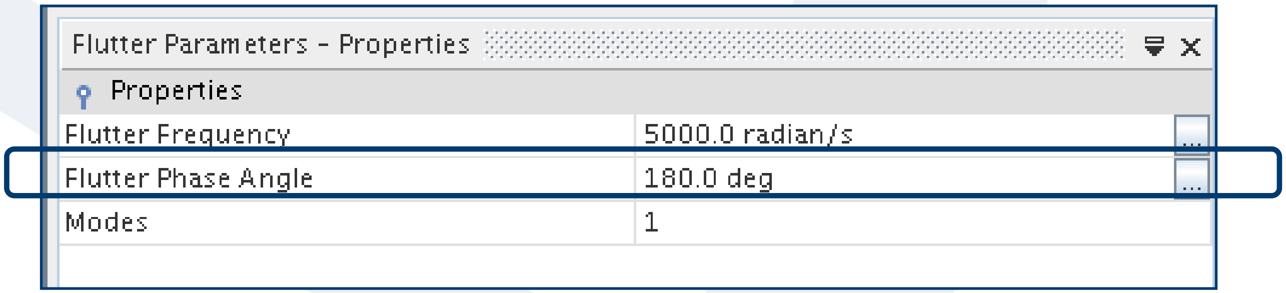
- The vibration of each blade is staggered. This is known as the "Interblade phase angle"
- To determine stability a simulation must be run for each phase angle
- Traditional unsteady solvers require manual set up of motion for each phase angle



Harmonic Balance Key Benefits

Specify blade vibration

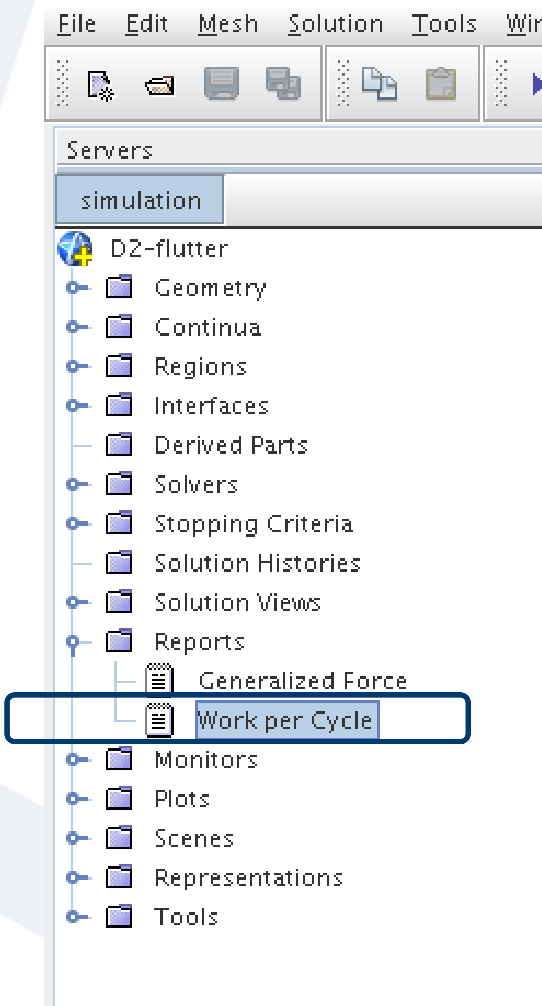
- Interblade phase angle is a simple input to the HB solver



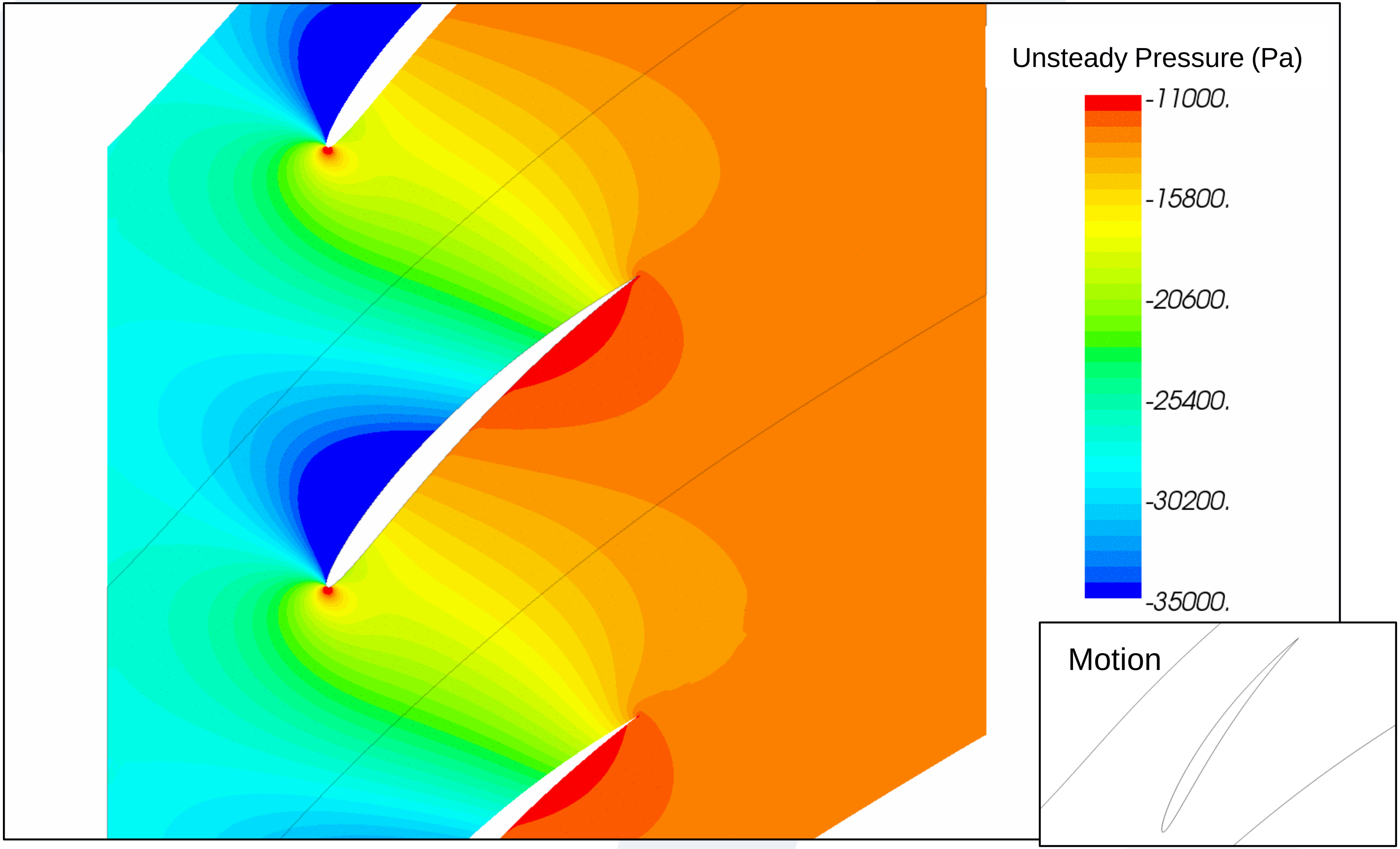
Harmonic Balance Key Benefits

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

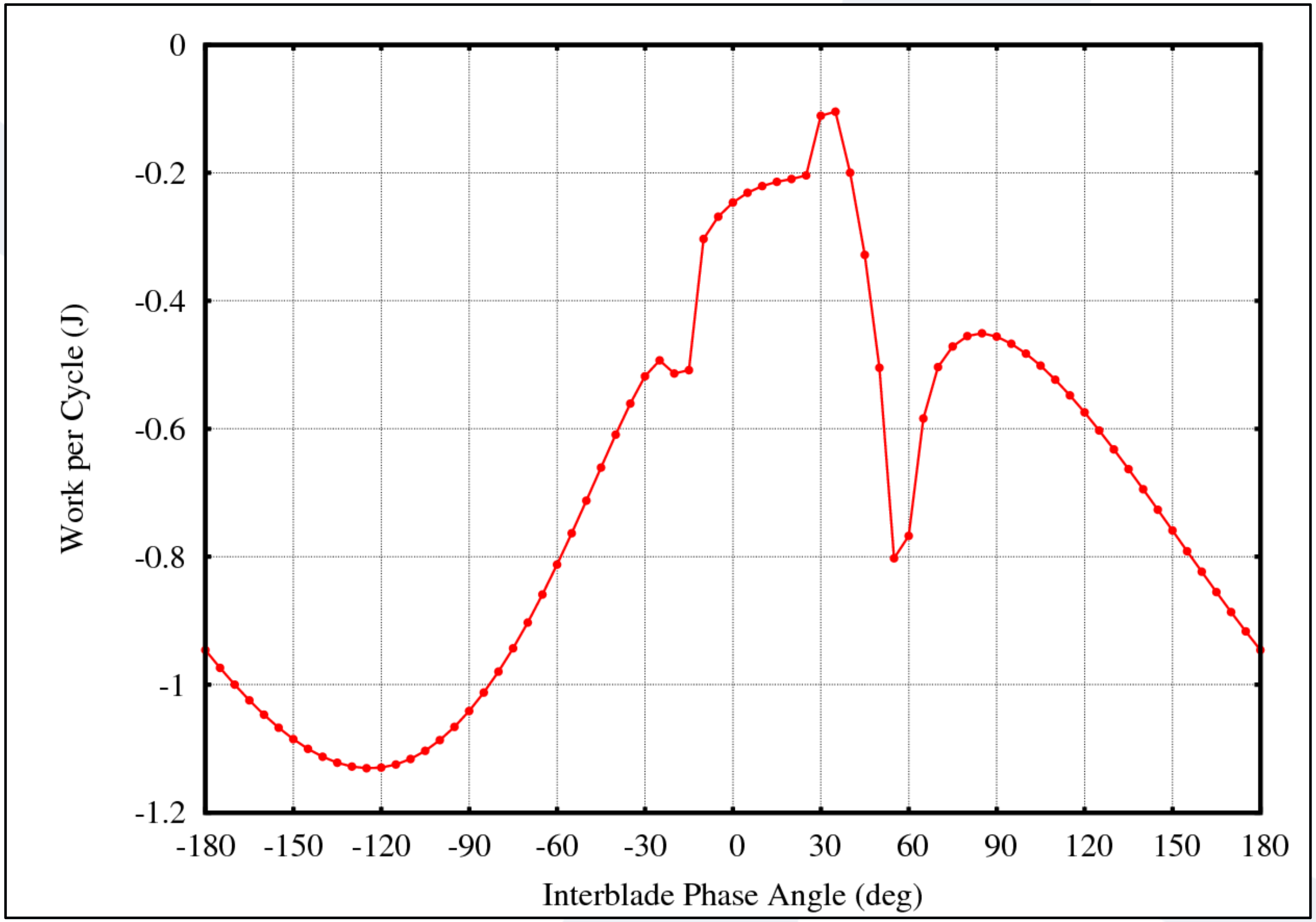


Example: Vane Flutter



Example: Vane Flutter

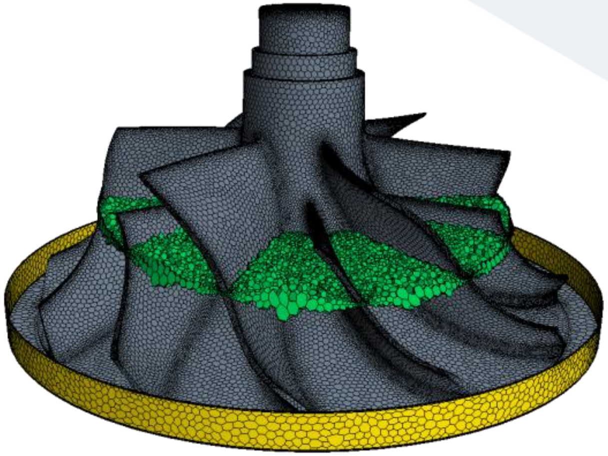
- Work per cycle map shows this vane will not flutter



Performance Mapping

Key Benefits

- Complex geometry handling
- Polyhedral cells
- High quality mesh
- Prism layer generation
- Harmonic balance solver

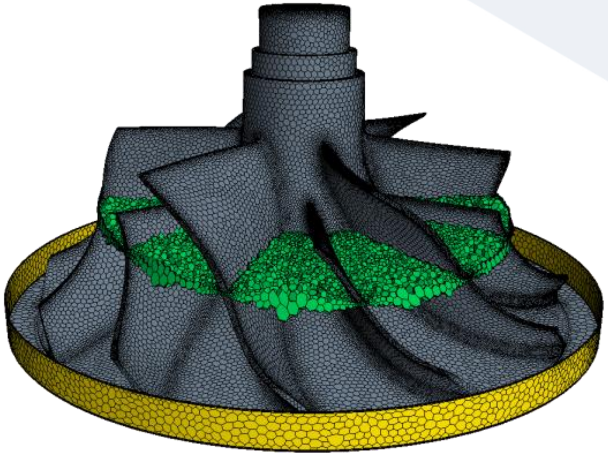


Performance Mapping

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



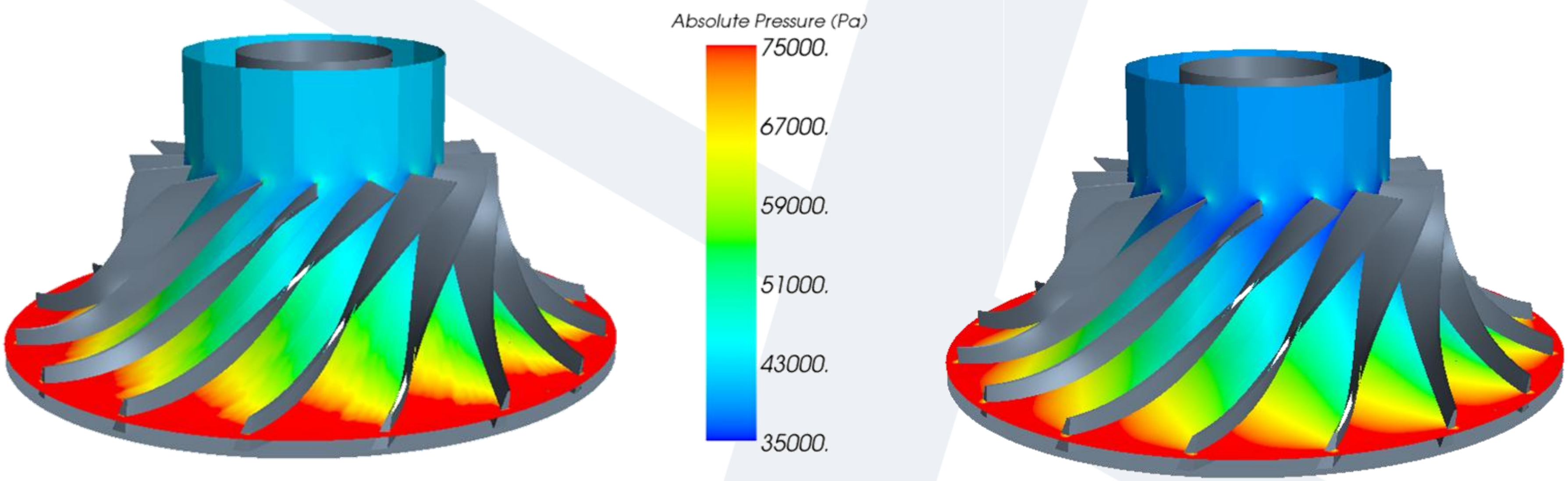
Performance Mapping

Key Benefits

- **Grid sequencing initialization**

Time to initialization:
80 seconds

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

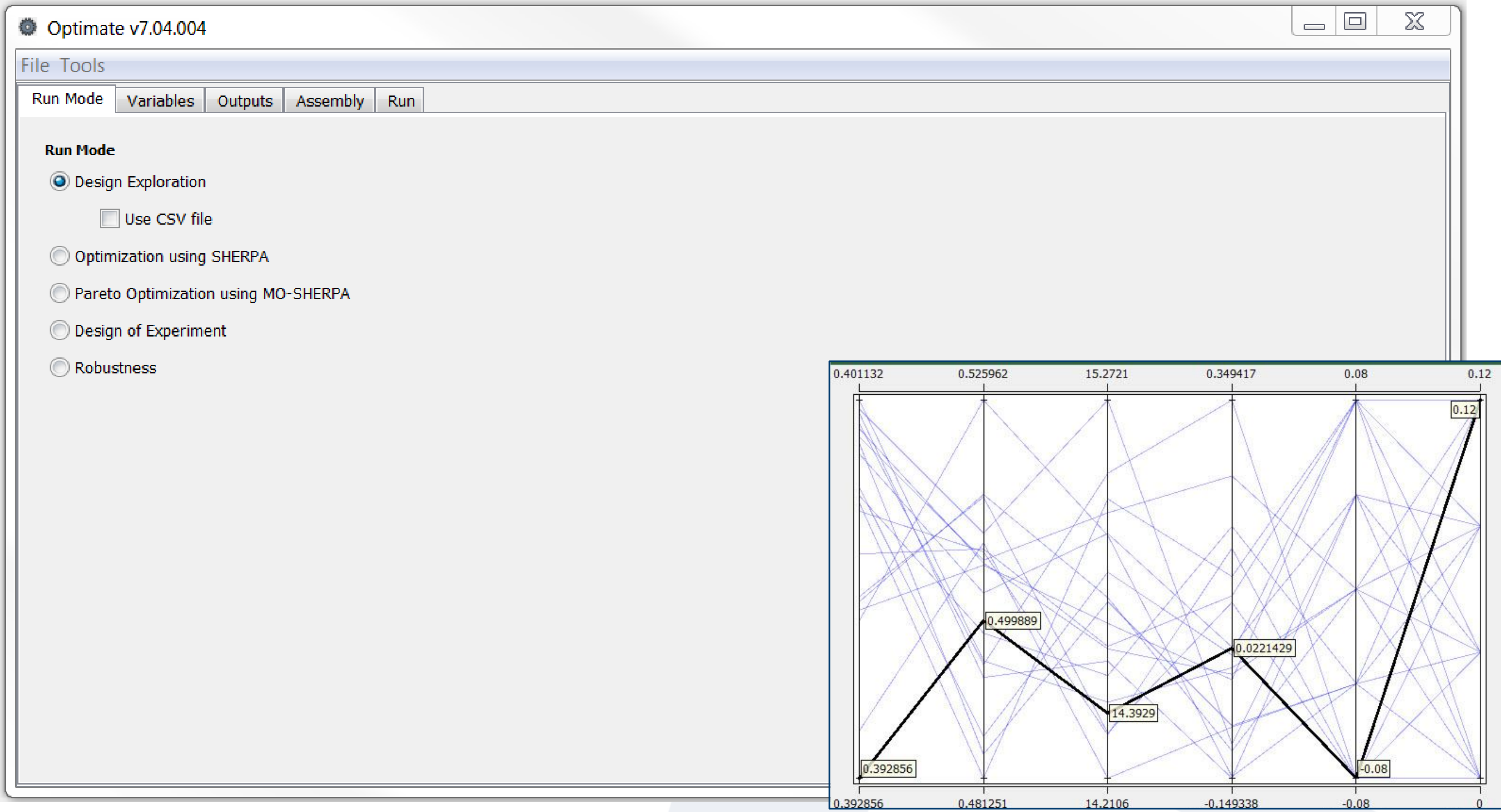


Initialization **Converged Solution**

Performance Mapping

Key Benefits

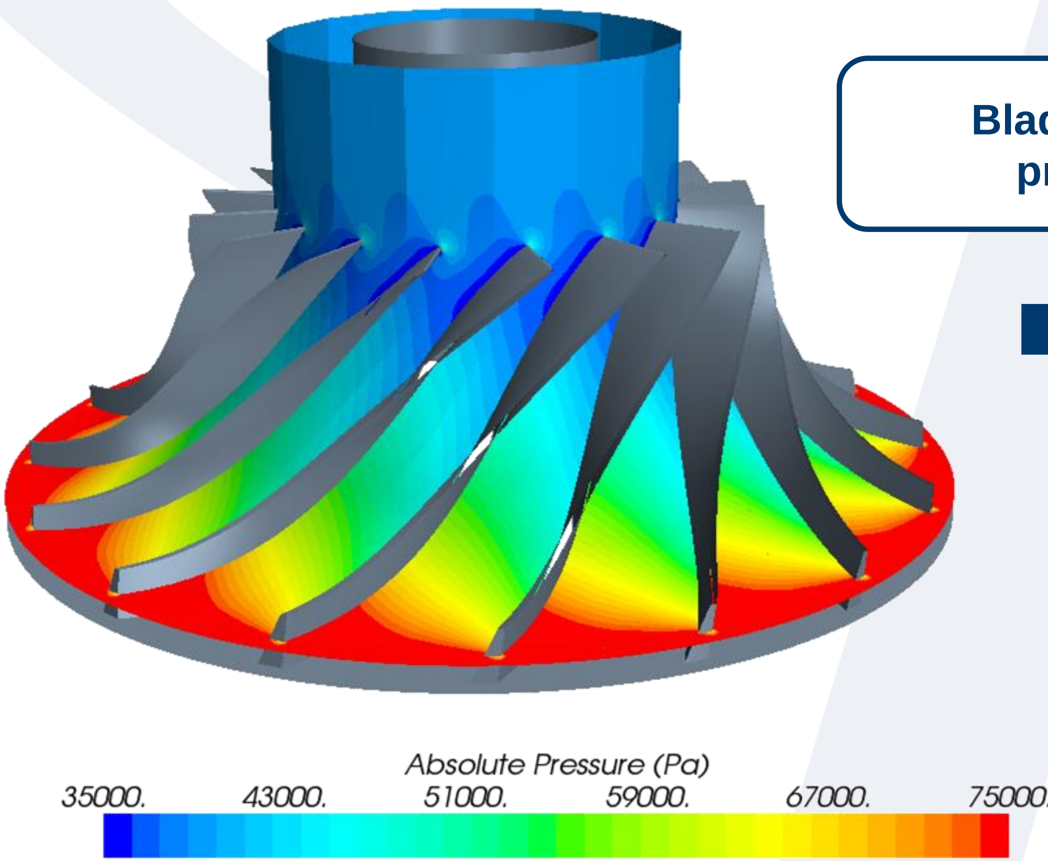
- **Efficiency optimization with Optimate+**



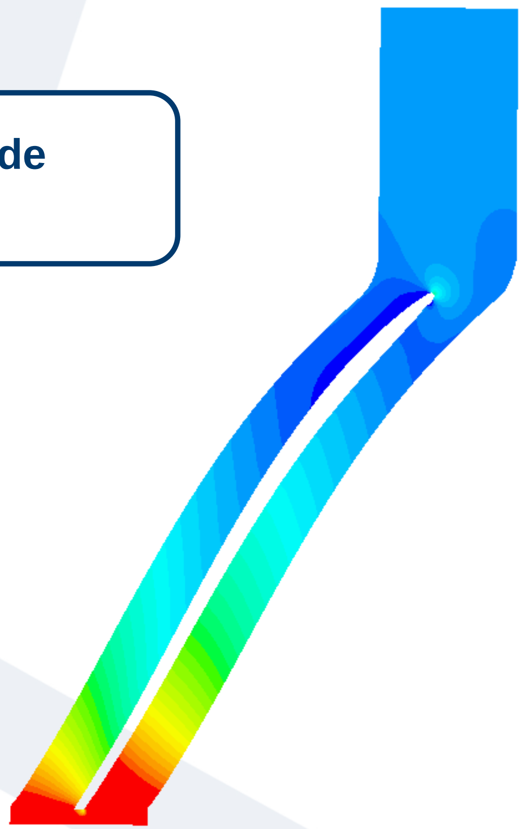
Performance Mapping

Key Benefits

- **Turbomachinery specific post-processing**



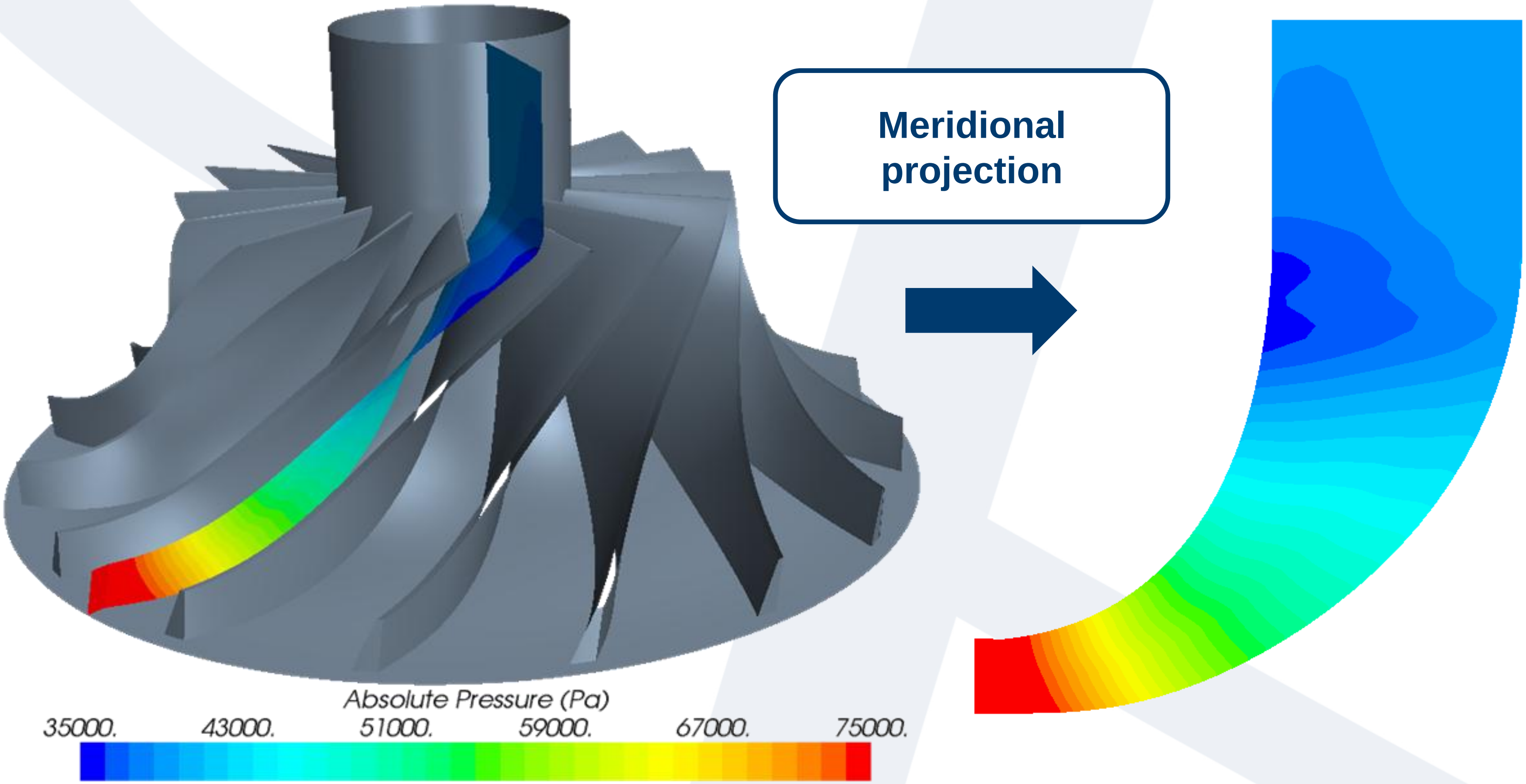
Blade-to-blade projection



Performance Mapping

Key Benefits

- **Turbomachinery specific post-processing**

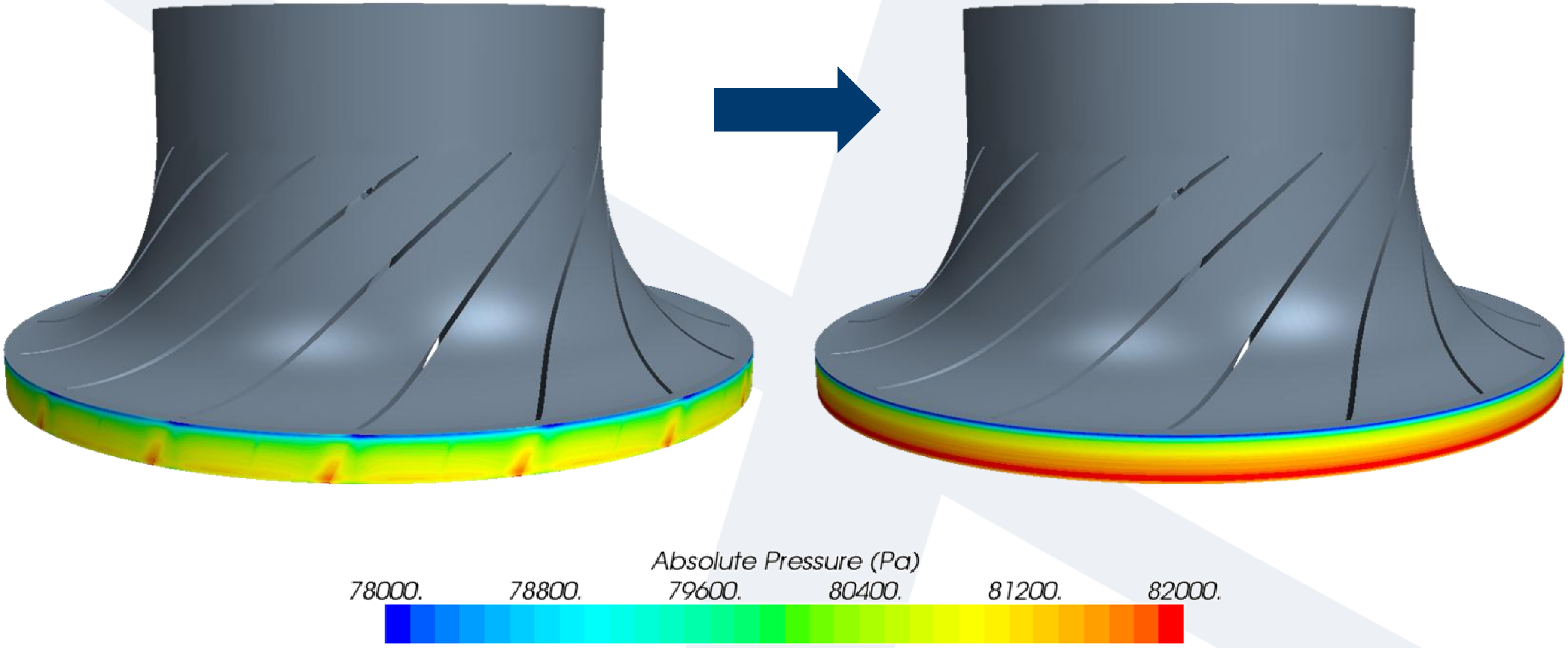


Performance Mapping

Key Benefits

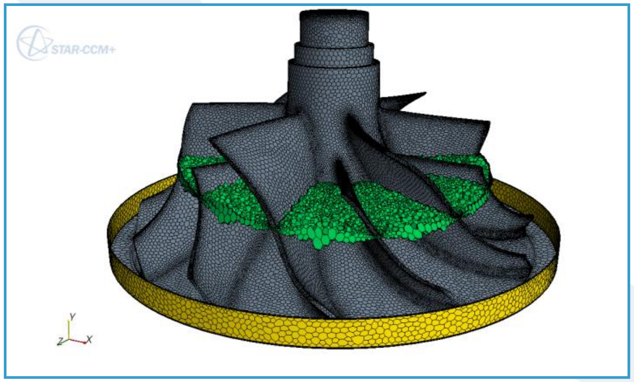
- Turbomachinery specific post-processing

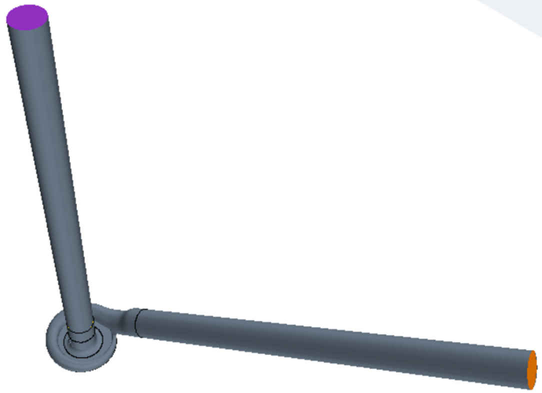
Circumferential Averaging

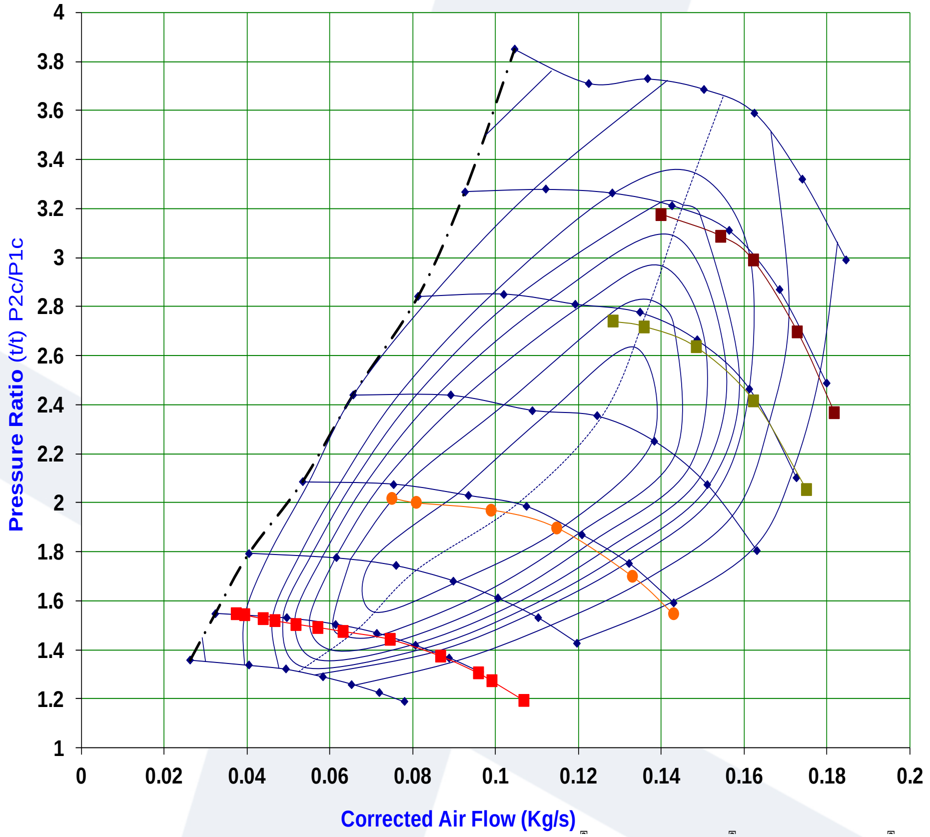


Validated Simulation: Radial Compressor

- **Comparison with rig measurements**
  - Full performance curve
  - RPM range

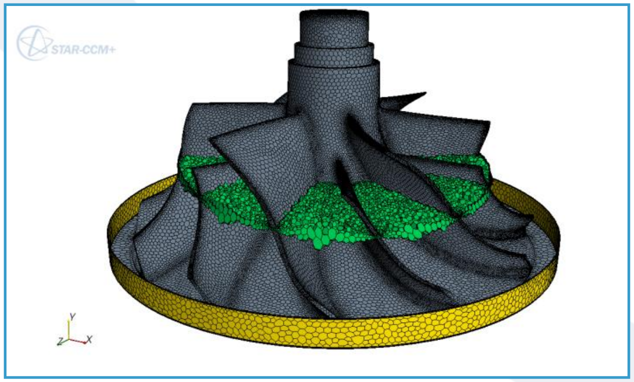


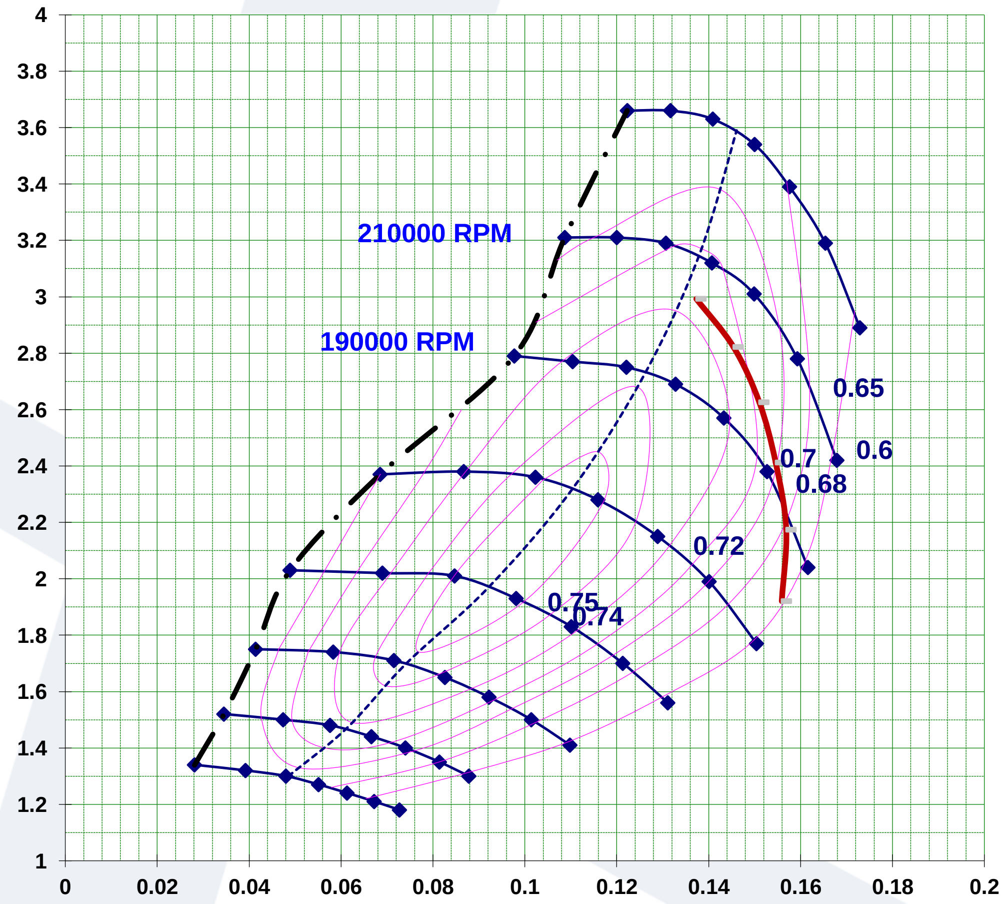




Validated Simulation: Radial Compressor

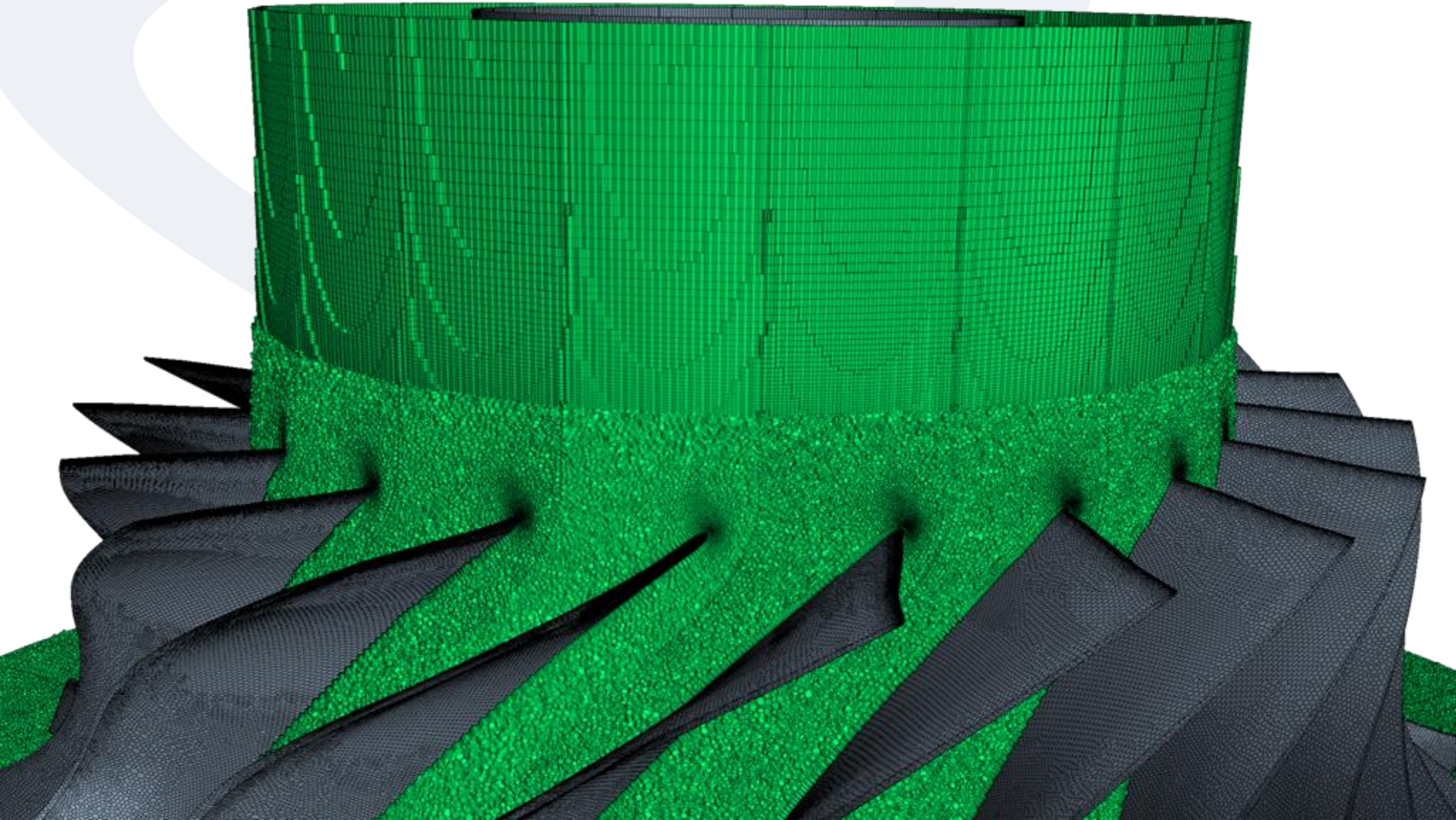
- **Installation effects**
  - Curved inlet duct
  - Diffuser outlet





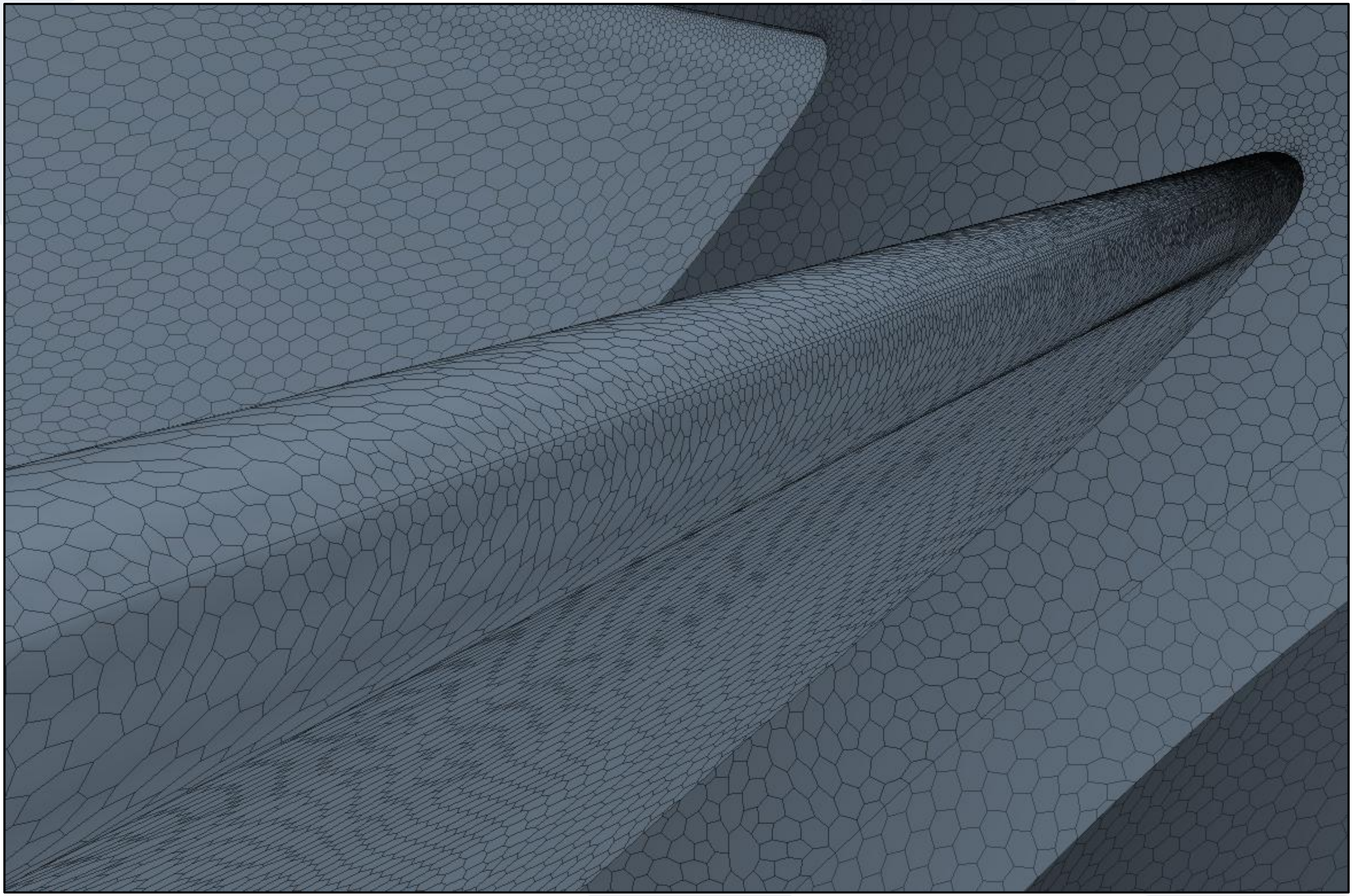
Turbomachinery Meshing Guidelines

- Polyhedral mesh with extruded inlet/exit as needed



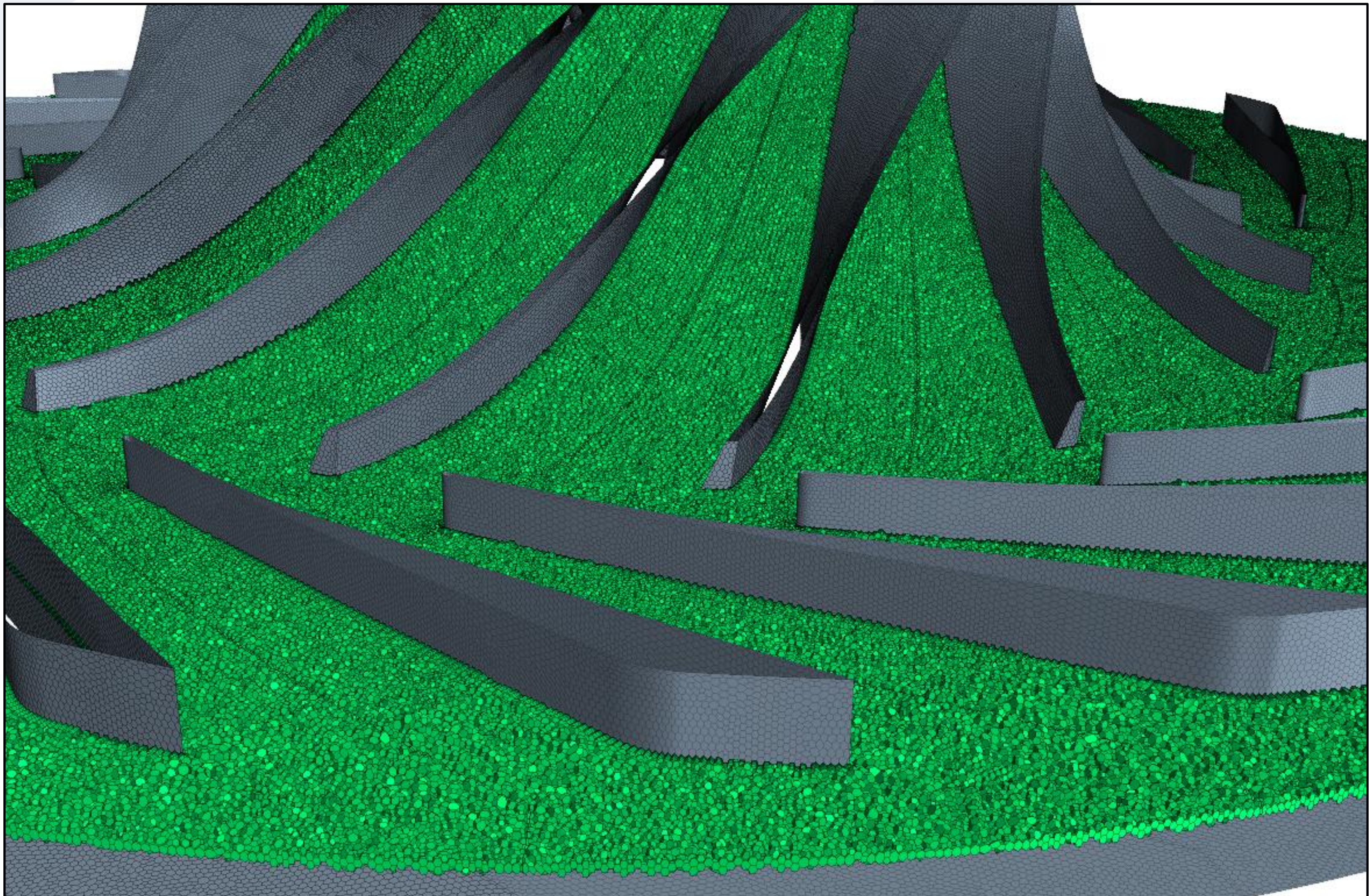
Turbomachinery Meshing Guidelines

- High resolution of leading and trailing edges



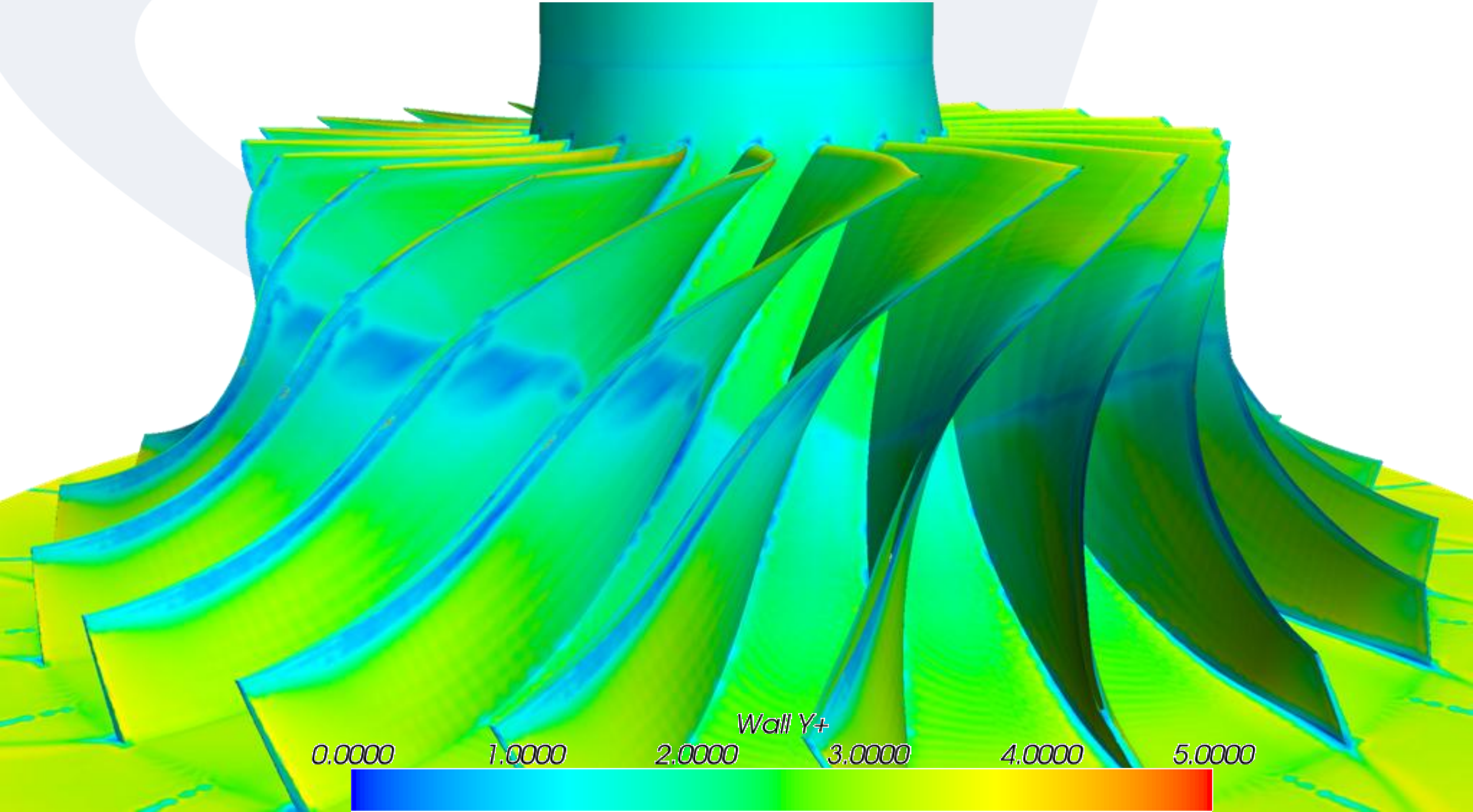
Turbomachinery Meshing Guidelines

- Uniform cell sizing in the primary gas path



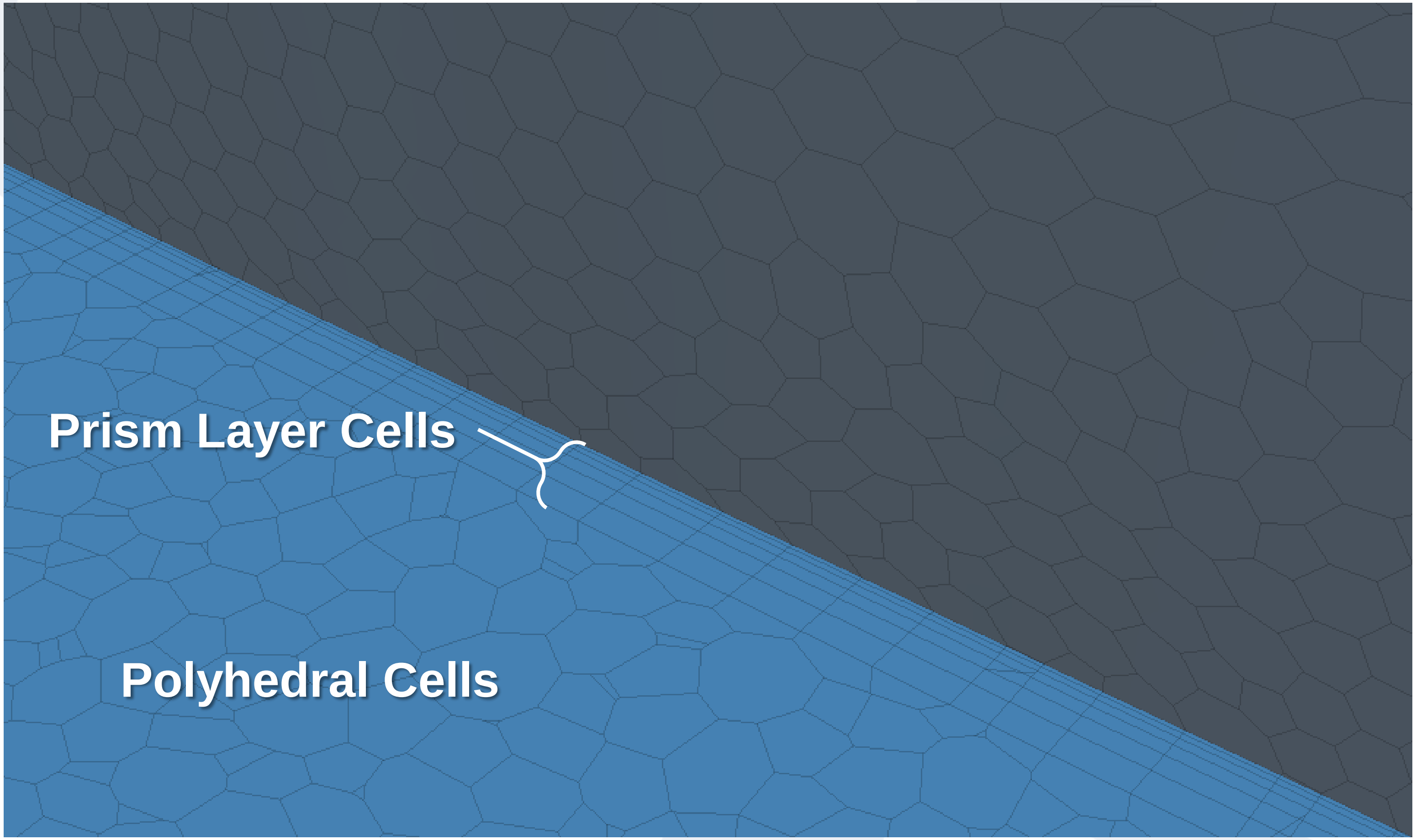
Turbomachinery Meshing Guidelines

- **All y+ algorithm with y+ values less than 5**



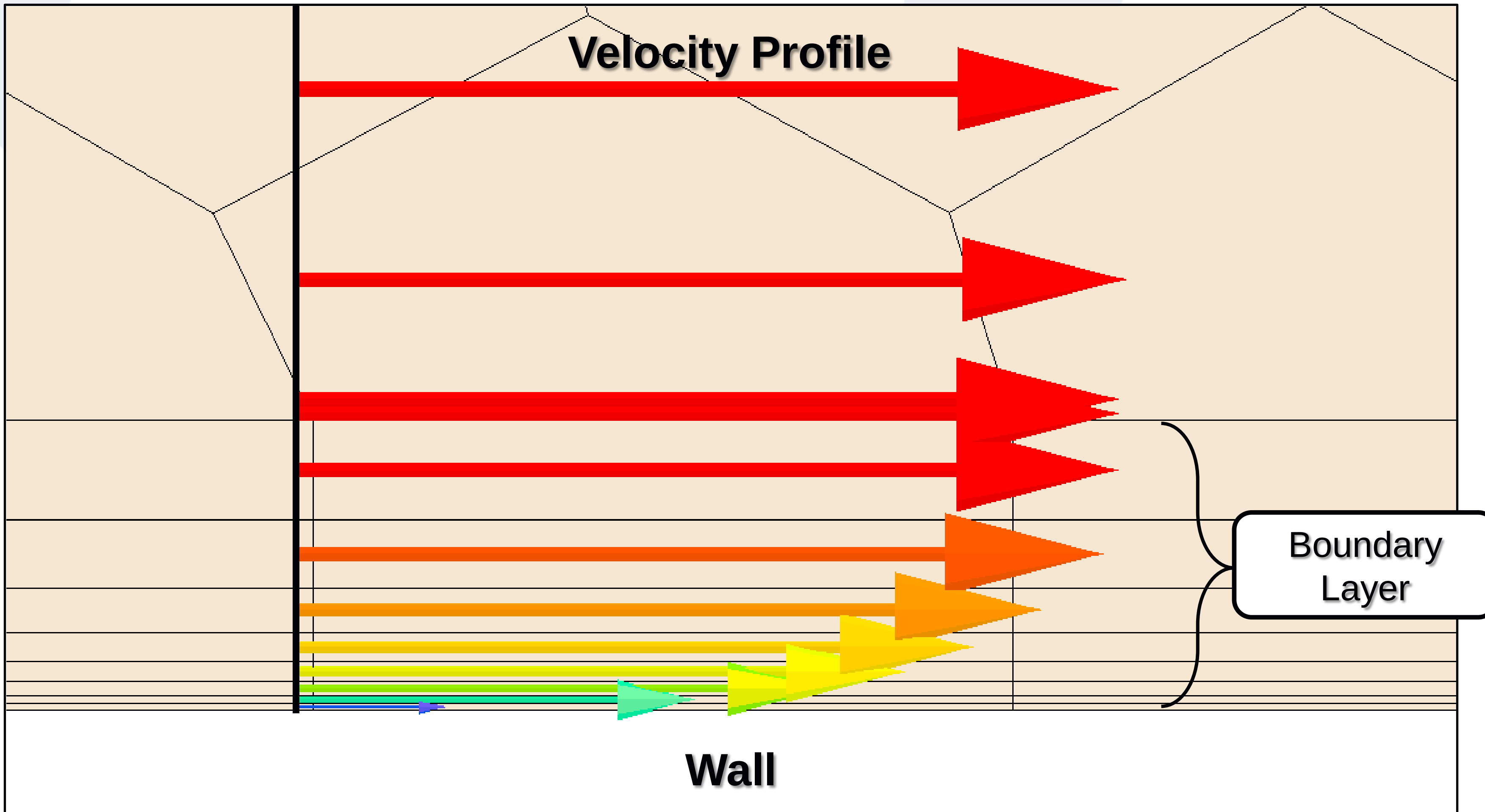
Turbomachinery Meshing Guidelines

- Last prism layer similar size to the first poly cell layer



Turbomachinery Meshing Guidelines

- At least 5 prism layers to resolve the boundary layer



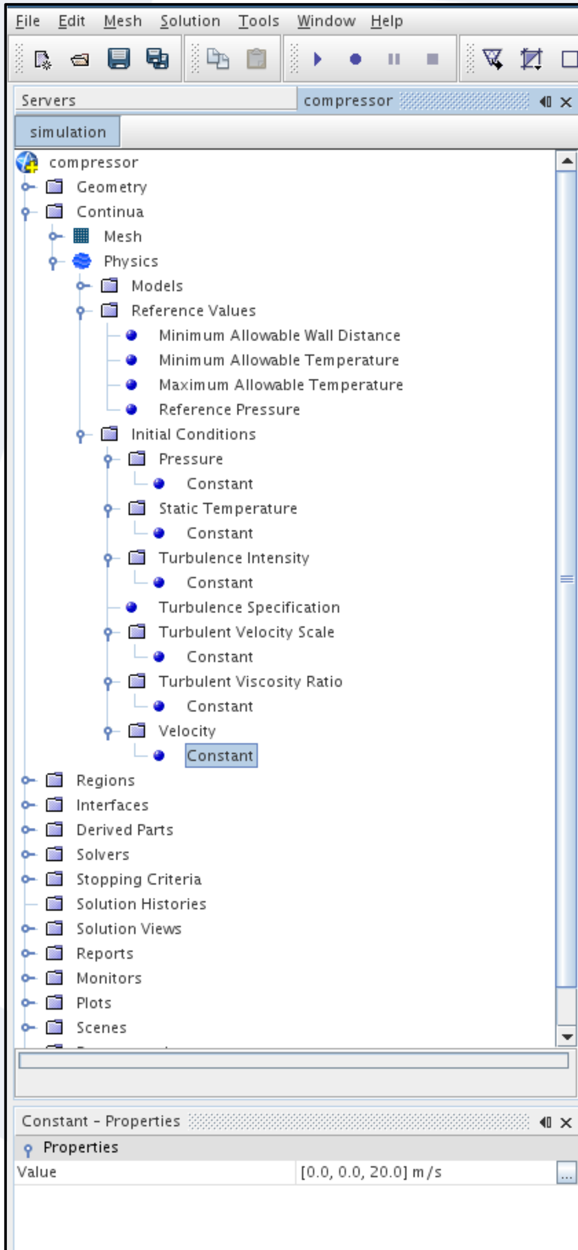
Turbomachinery Solution Guidelines

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



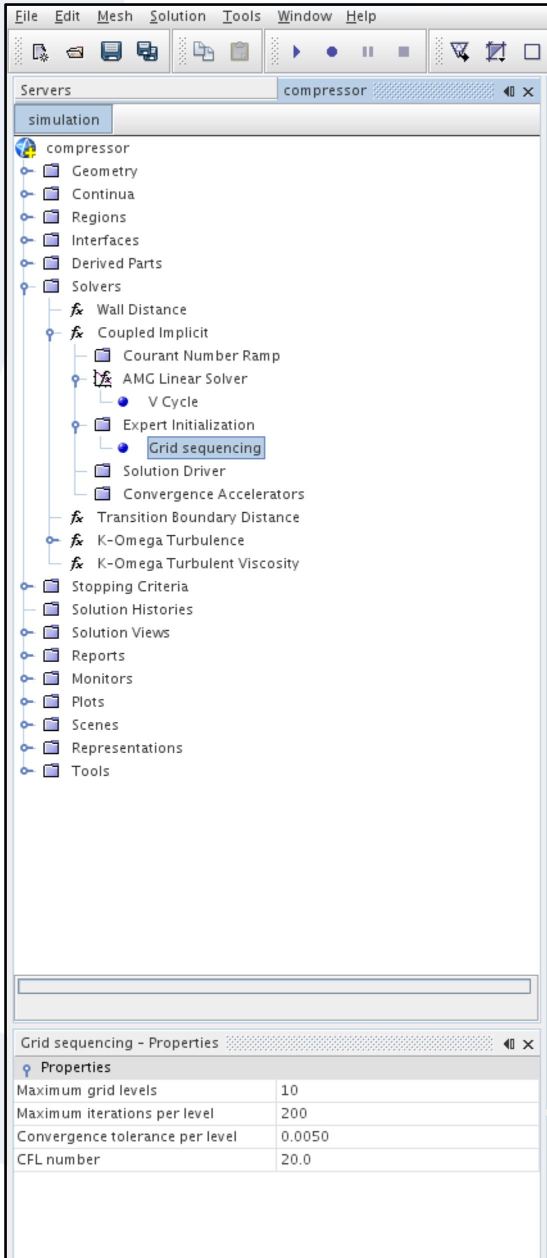
Turbomachinery Solution Guidelines

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

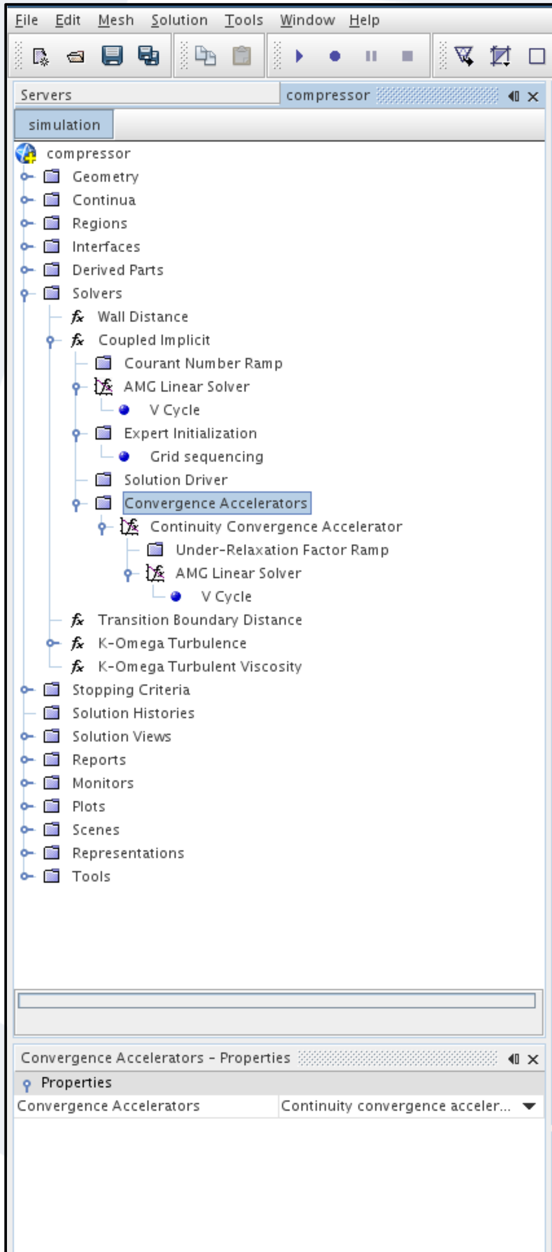
- Max iterations per level: 200
- Convergence tolerance: 0.005
- CFL number: 20



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



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