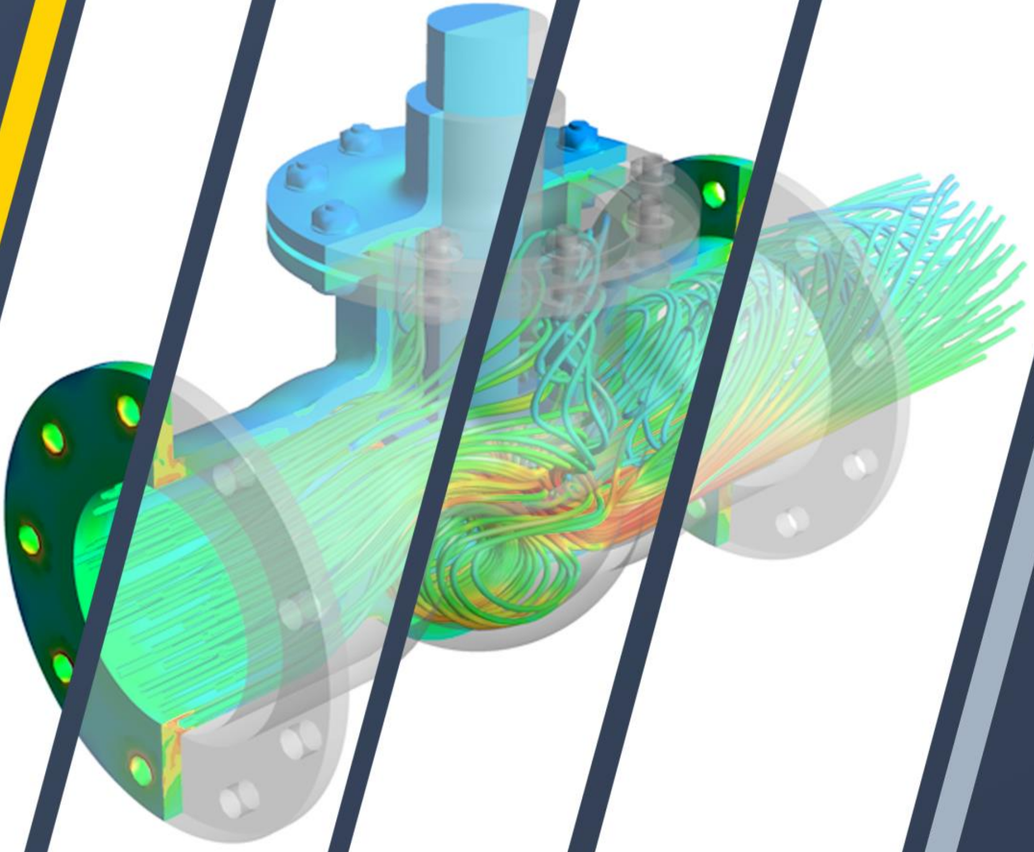
Lecture 03: Post-processing for Rotating Machinery



ANSYS CFX Rotating Machinery Modeling

Release 2019 R3

Outline

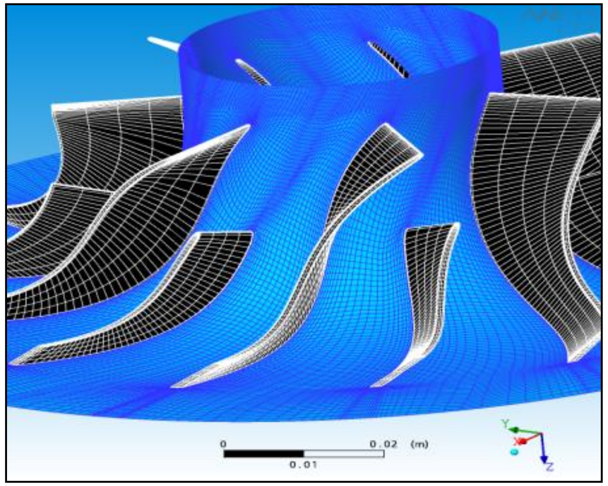
- Quantitative results
- Qualitative results
- Post-processing guidelines
- Turbo-specific post-processing in CFD-Post
  - Turbo topology
  - Turbo coordinates
  - Turbo post-processing tools
  - Reports

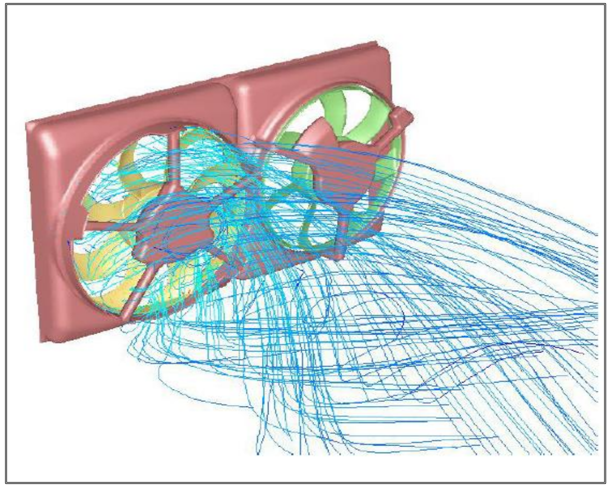
Rotating Machinery Post-Processing

- Quantitative Results
  - Efficiency
  - Pressure loads
  - Mass flow rates
  - Torque and power
  - Head rise
  - Total pressure, Total Temperature ratios

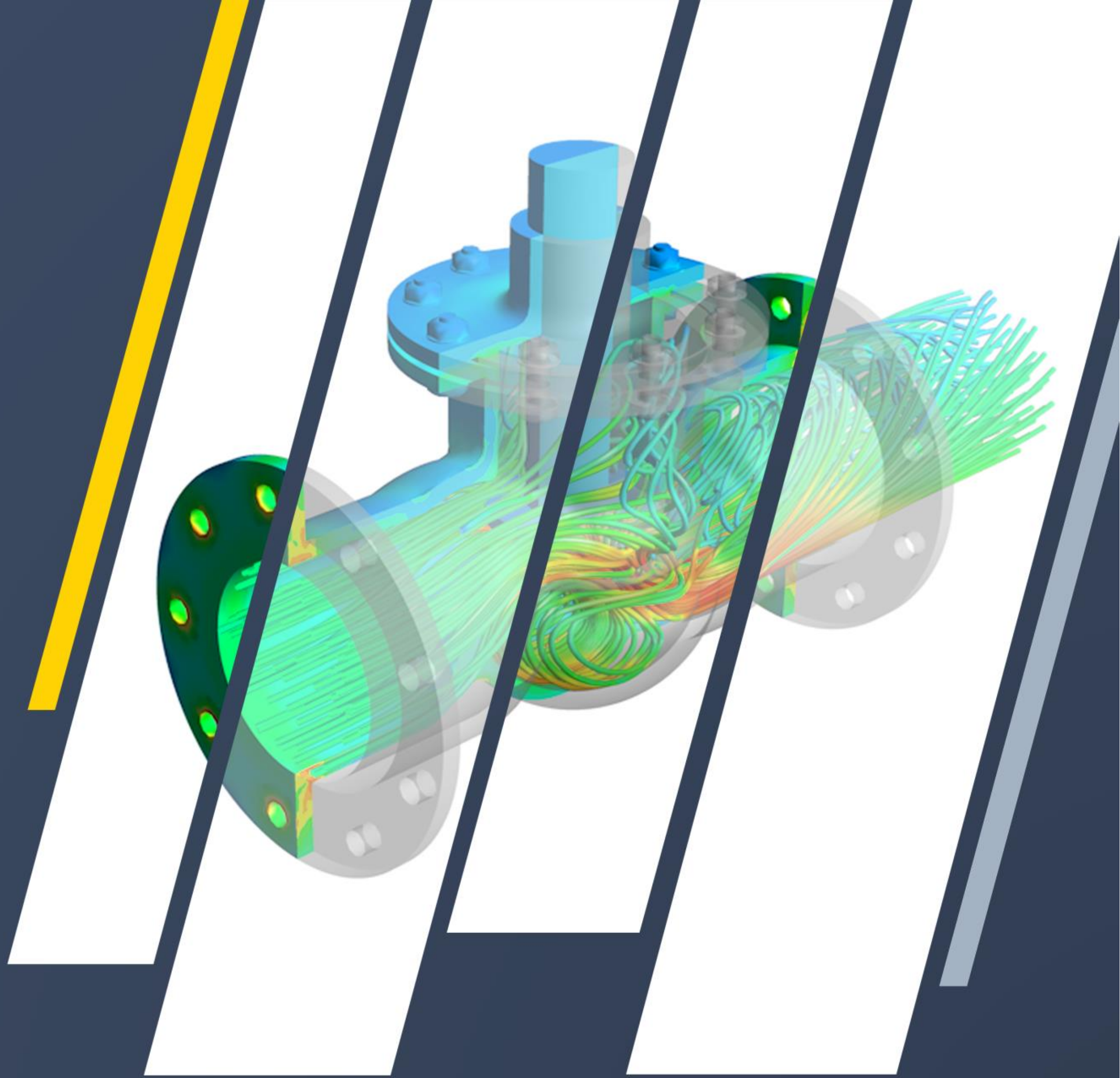
Machine Performance

- Qualitative Results
  - Contour plots
  - Velocity vector plots
  - Pathline plots
  - Animations



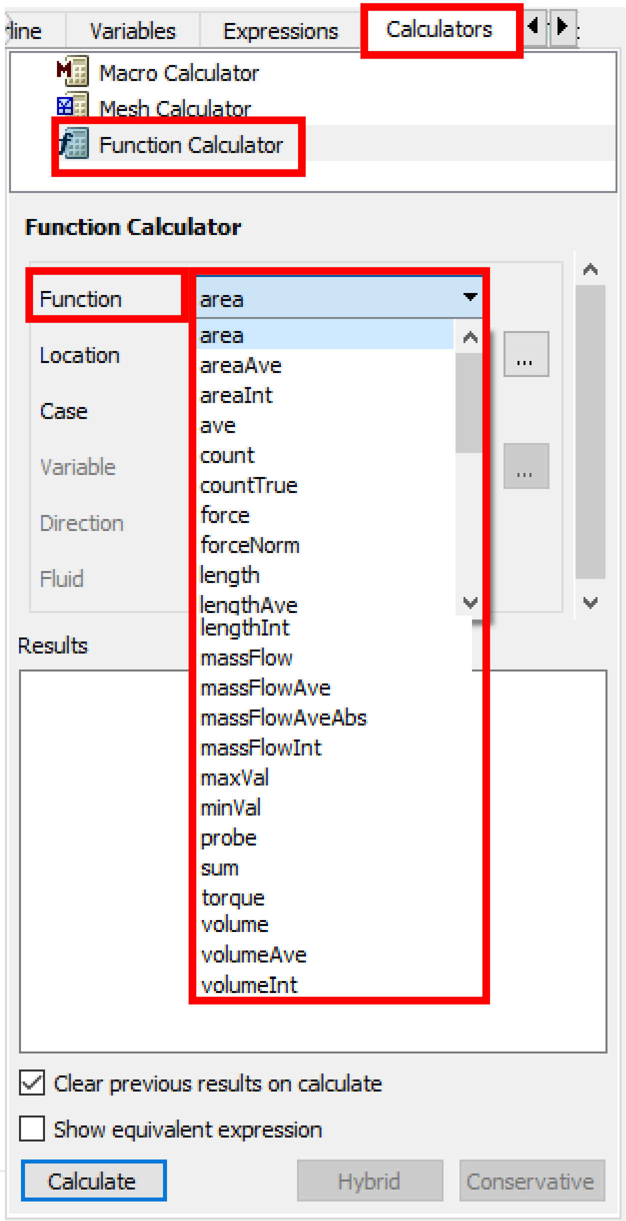


Quantitative Results



CFD-Post Function Calculator

- Compute averages, fluxes, min, max, and integral sums for any variable on location using Function Calculator
  - Select desired function
    - ➢ Integrals, averages, mass-flows, forces, torques, etc.
  - Select Location
    - ➢ Any physics or mesh 2-d locator (inlets, outlets, walls, etc.)
    - ➢ Any locator created in CFD-Post (lines, planes, isosurfaces, etc.)
- Click Calculate



Averaging Concepts

- Often it is desirable to calculate averaged quantities:
  - Ex. Average Total Pressure at the inlet and outlet for calculating Pressure ratio
- Most common types of averaging are mass weighted or area weighted
- Mass Weighted Average
  - Used at inlets outlets and internal 2D regions
    - ➢ For most quantities
    - ➢ Not used for Static pressure

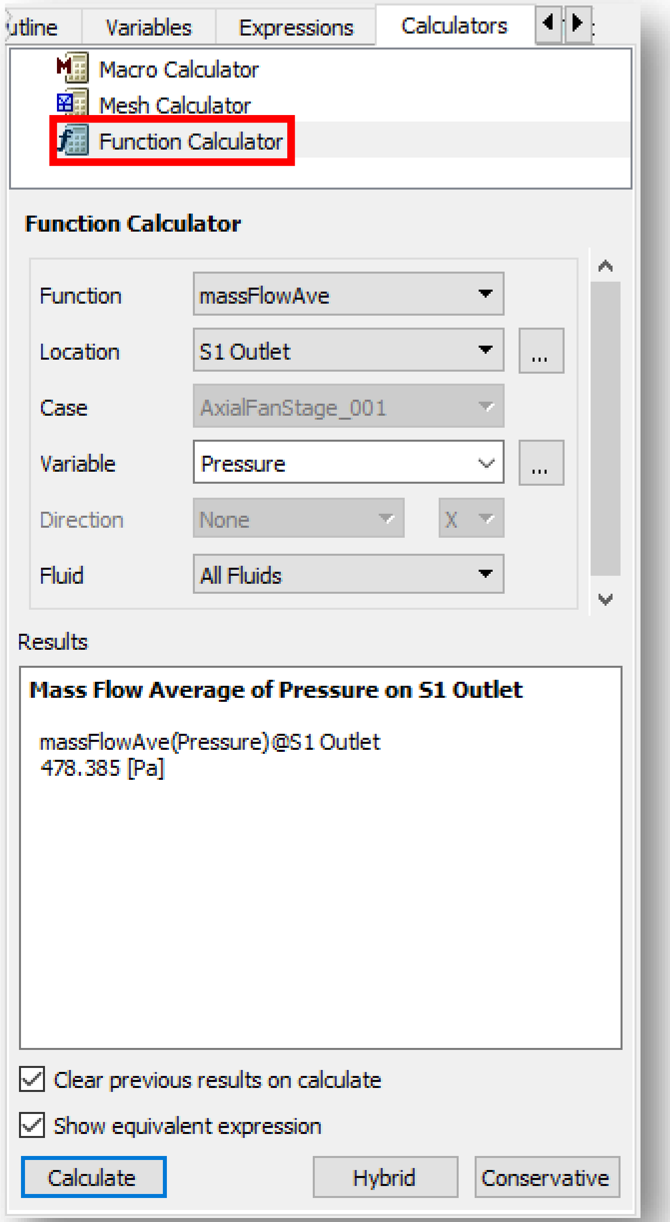
$$\bar{\phi}_m = \frac{\int_A \phi \, d\dot{m}}{\dot{m}}$$

- Area Average
  - Used to average
    - ➢ Pressure at any boundary
    - ➢ Any quantity on walls

$$\bar{\phi}_A = \frac{\int_A \phi \, dA}{A}$$

Function Calculator Averaging Example

- In the example to the right:
  - The mass weighted average of Pressure is calculated at the outlet
  - The CEL expression is shown first (enable by checkbox at bottom)
  - The value is shown second (475.385[Pa] [Pa])



CEL for Other Quantities

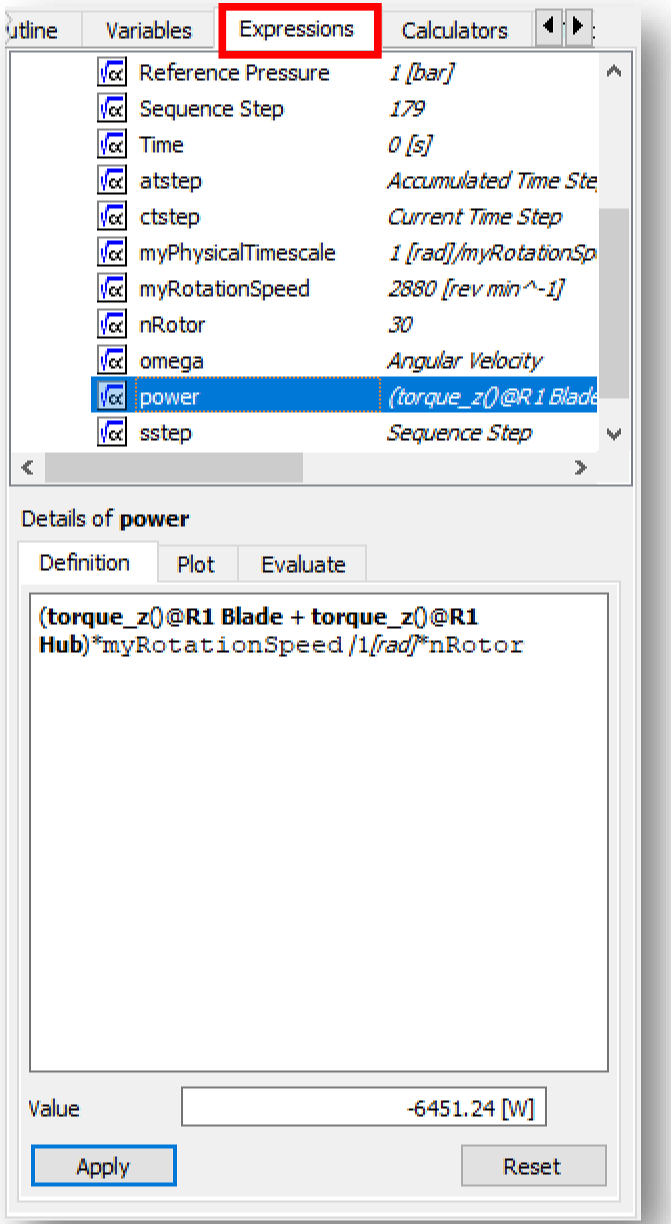
- CEL expressions created in the Expressions Tab can be used to calculate different quantities
  - Example: Shaft power is the product of the rotor torque and the rotational speed

```
power=(torque_z()@R1 Blade + torque_z()@R1 Hub)
                    *myRotationSpeed /1[rad]*nRotor
```

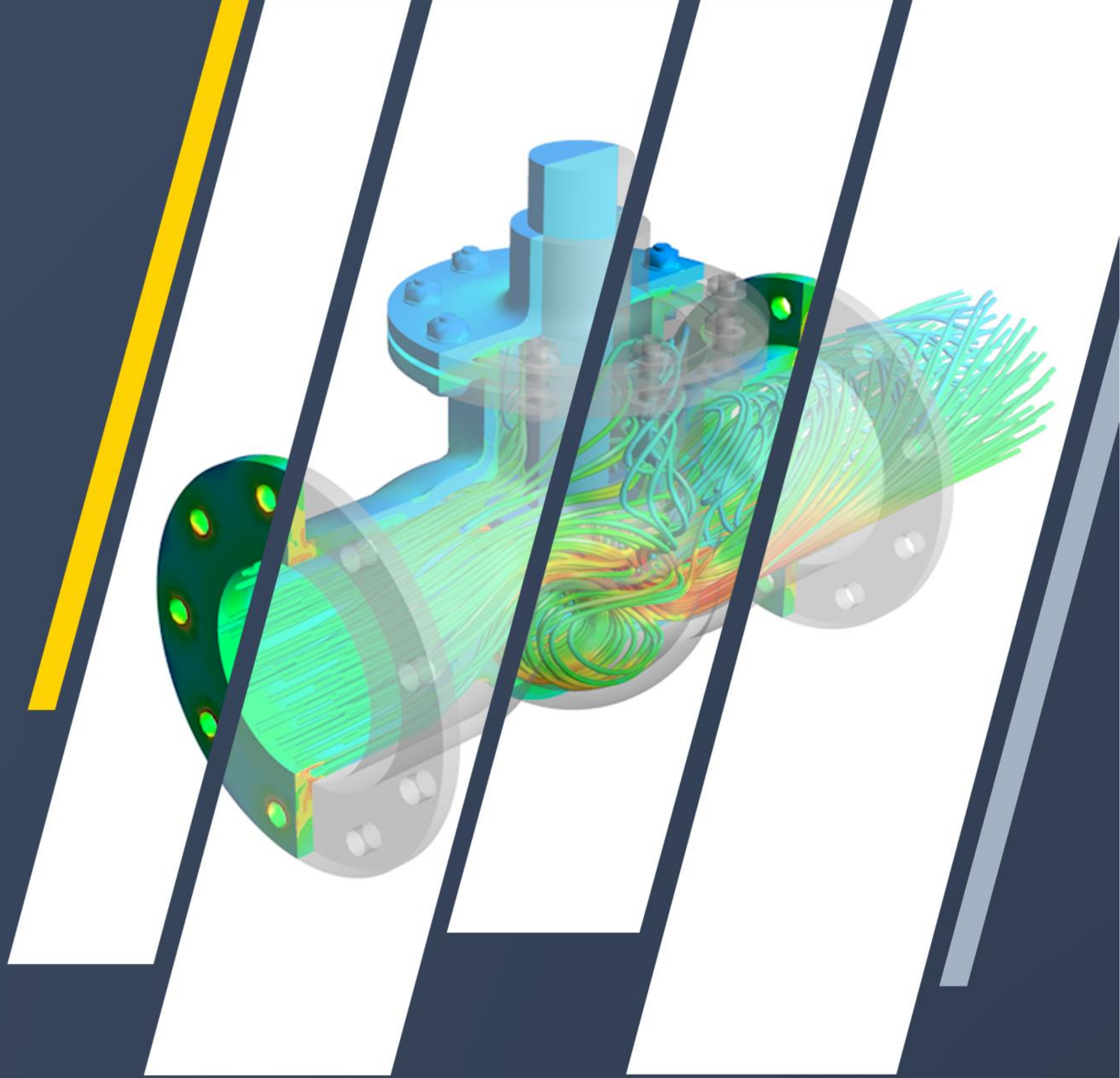
`torque_z` → a built-in function

`myRotationSpeed=2880[rev/min]` → user defined CEL

`nRotor=30` → user defined CEL for the number of rotor blades

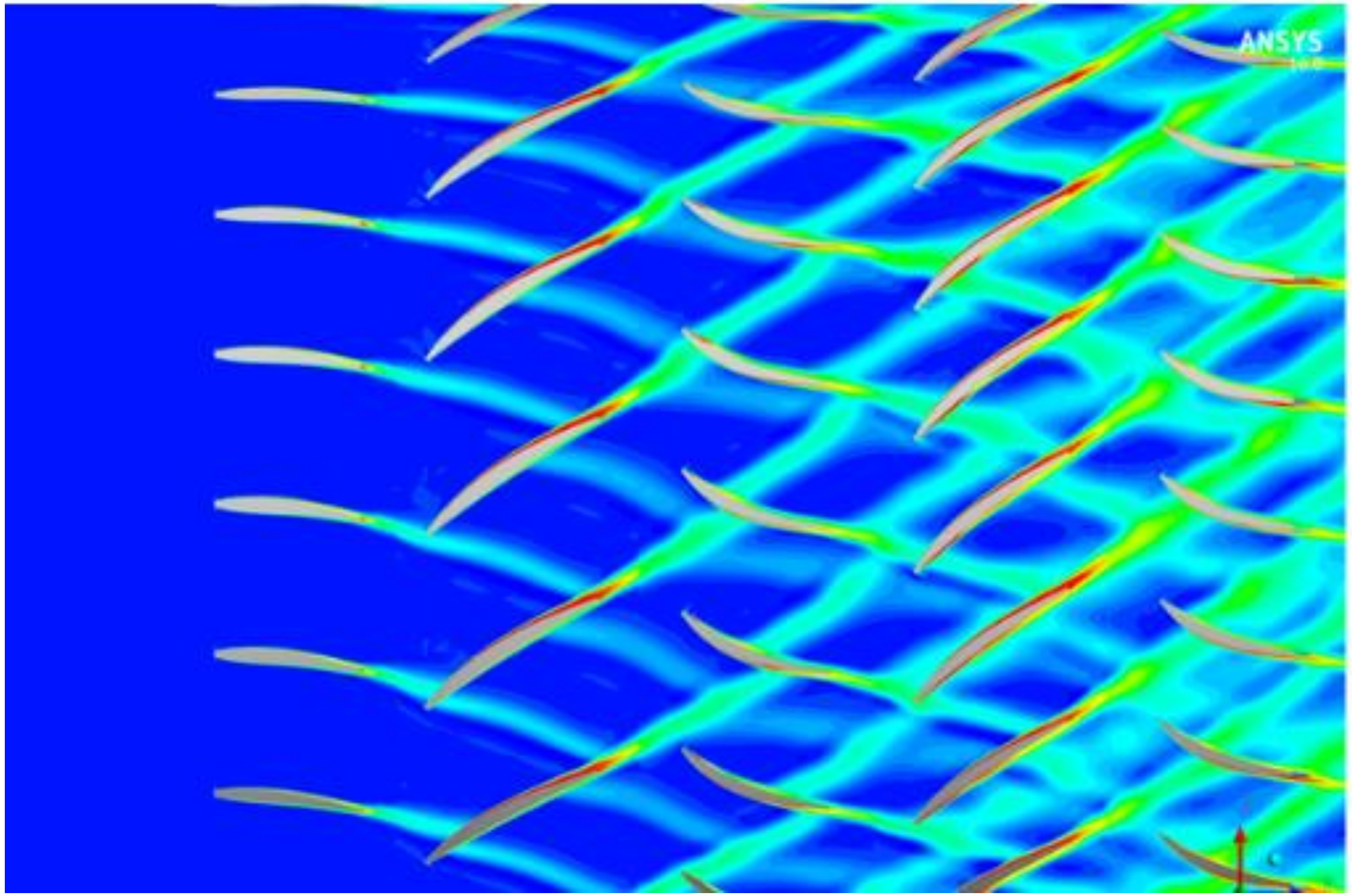


Qualitative Results



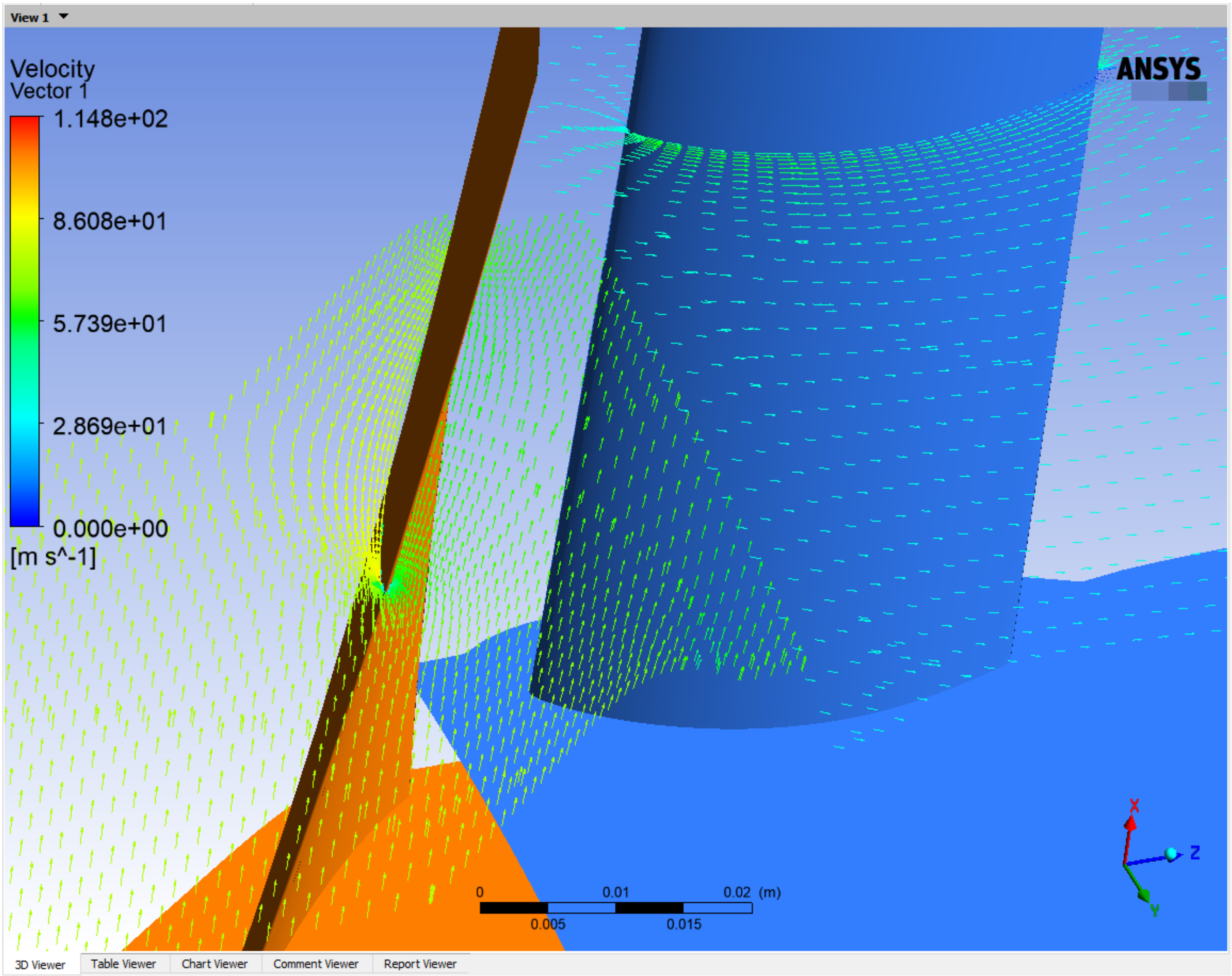
Qualitative Results: Contour Plots

- Contour plots can provide qualitative information for flow field analysis
- Many turbo-specific field functions, including:
  - Relative frame velocities (including components), velocity angle, vorticity, total pressure, total temperature, Mach number
  - Rothalpy
- Can create custom variables for problem-specific quantities (e.g. pressure coefficient, loss factor, etc.)

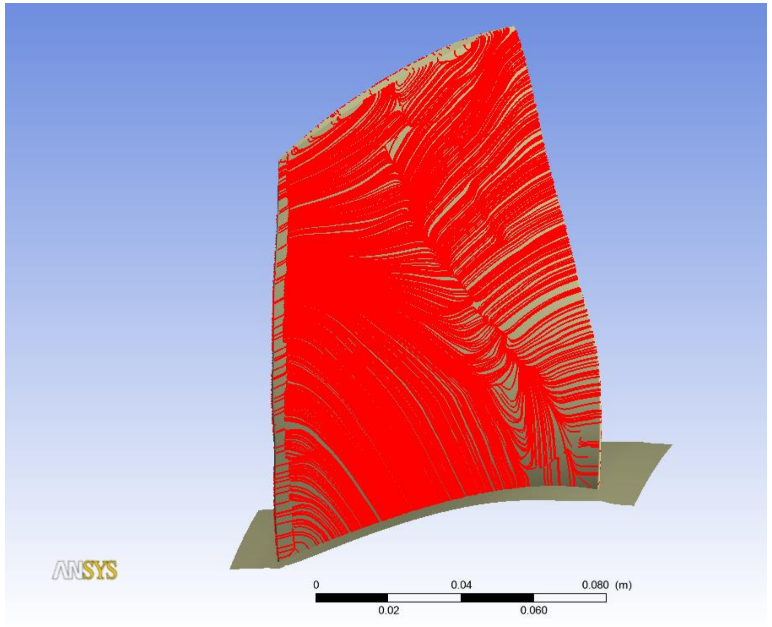


Qualitative Results: Velocity Vector Plots

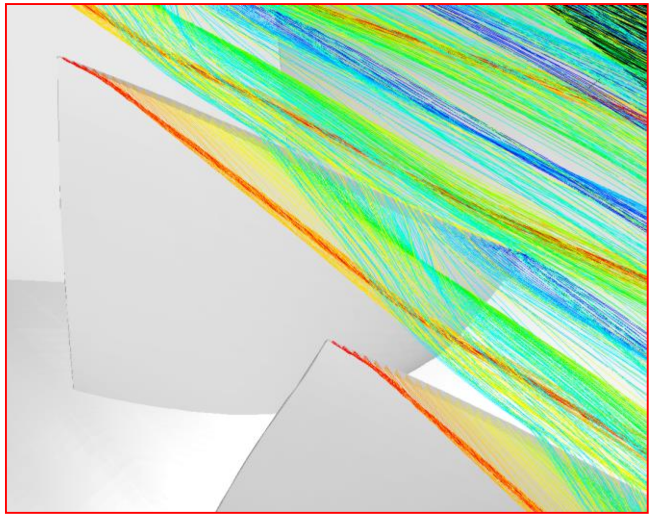
- Velocity vector plotting
  - Useful for displaying flow patterns in CFD domain
    - ➢ Show velocity vectors in relative or absolute frame of reference
      - Relative makes more sense
  - You can also create custom vector fields (e.g. pressure gradient)
  - There are separate field variables for relative, rotating, and absolute frame quantities

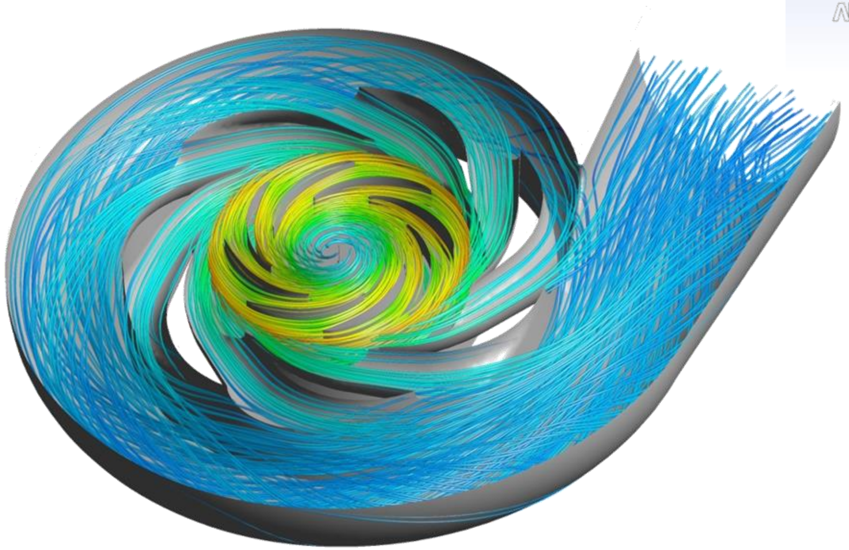


Qualitative Results: Streamlines, Particle Paths and Oil Flow Lines



- Streamlines, particle paths and oil flow lines are calculated using <u>relative velocities</u> by default
- You can disable this in the GUI if desired
  - NOTE: Absolute velocities may cause pathlines to collide with walls since the grid is fixed

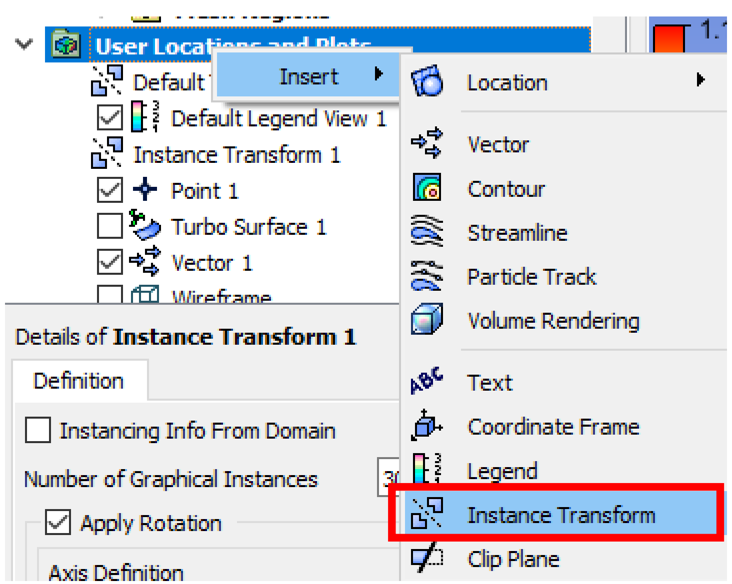


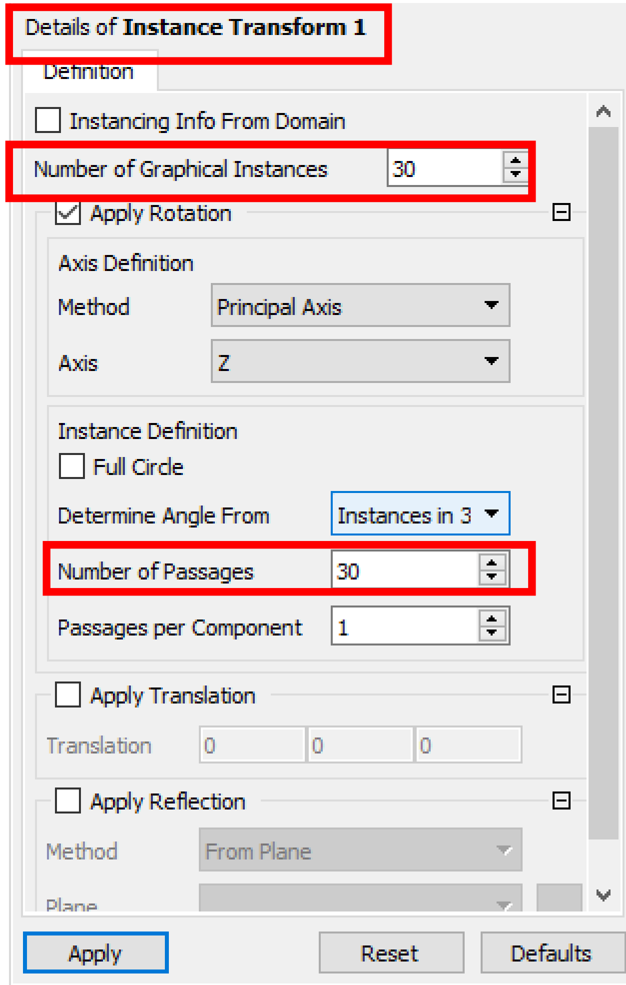


Instance Transform (1)

Instance Transform can be used to illustrate the entire wheel (or any number of desired blades) by rotating a single blade passage

1. Insert an Instance Transform in the Outline (RMB on User Locations and Plots)
2. Set the number of Passages and the number of Graphical Instances

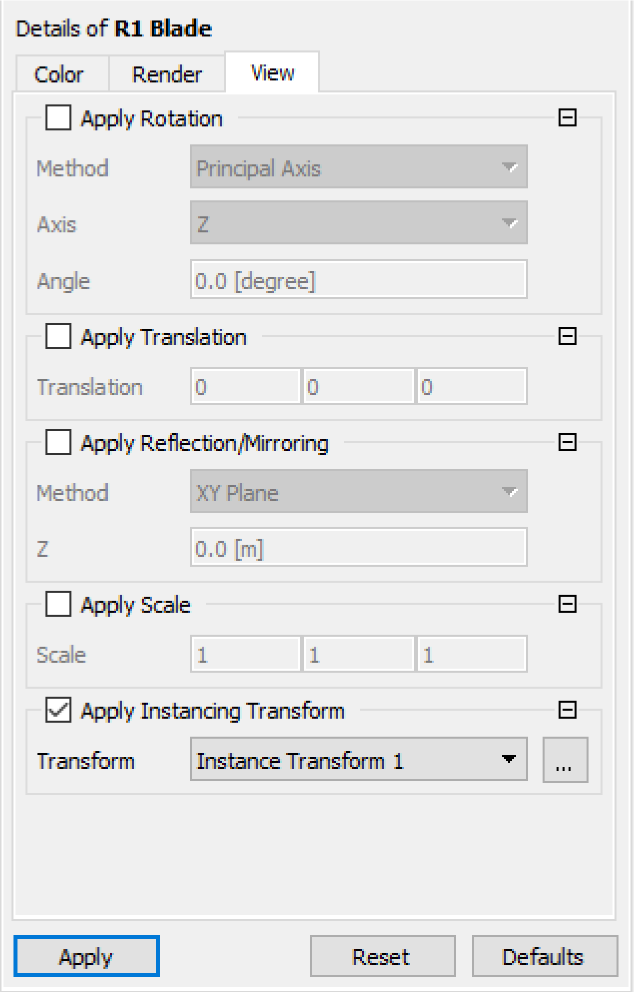


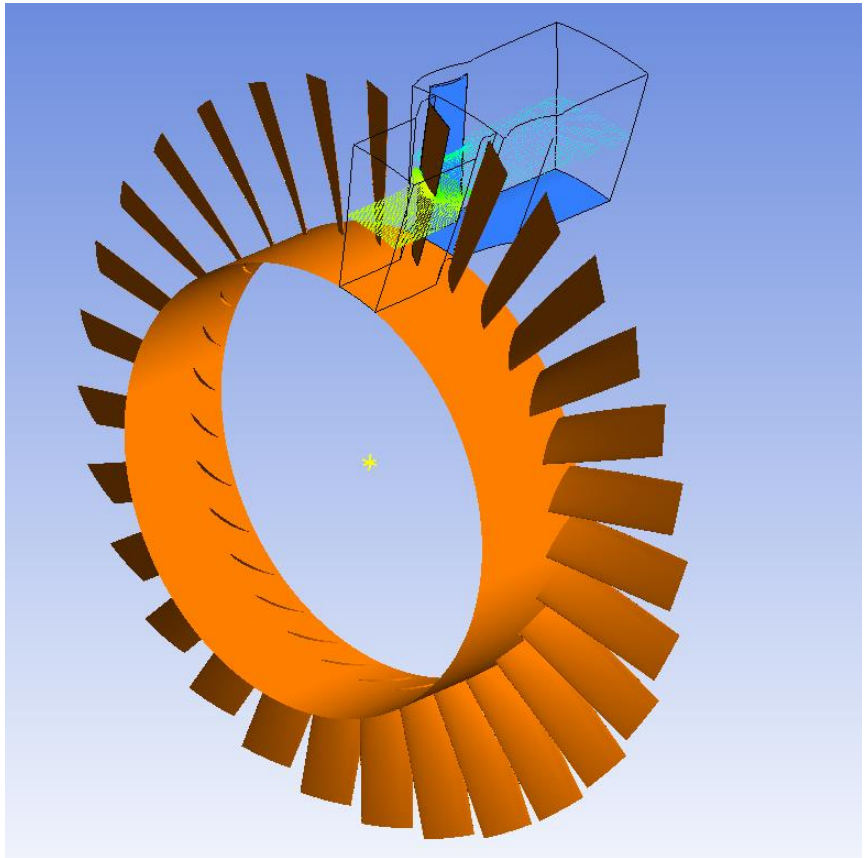


Instance Transform (2)

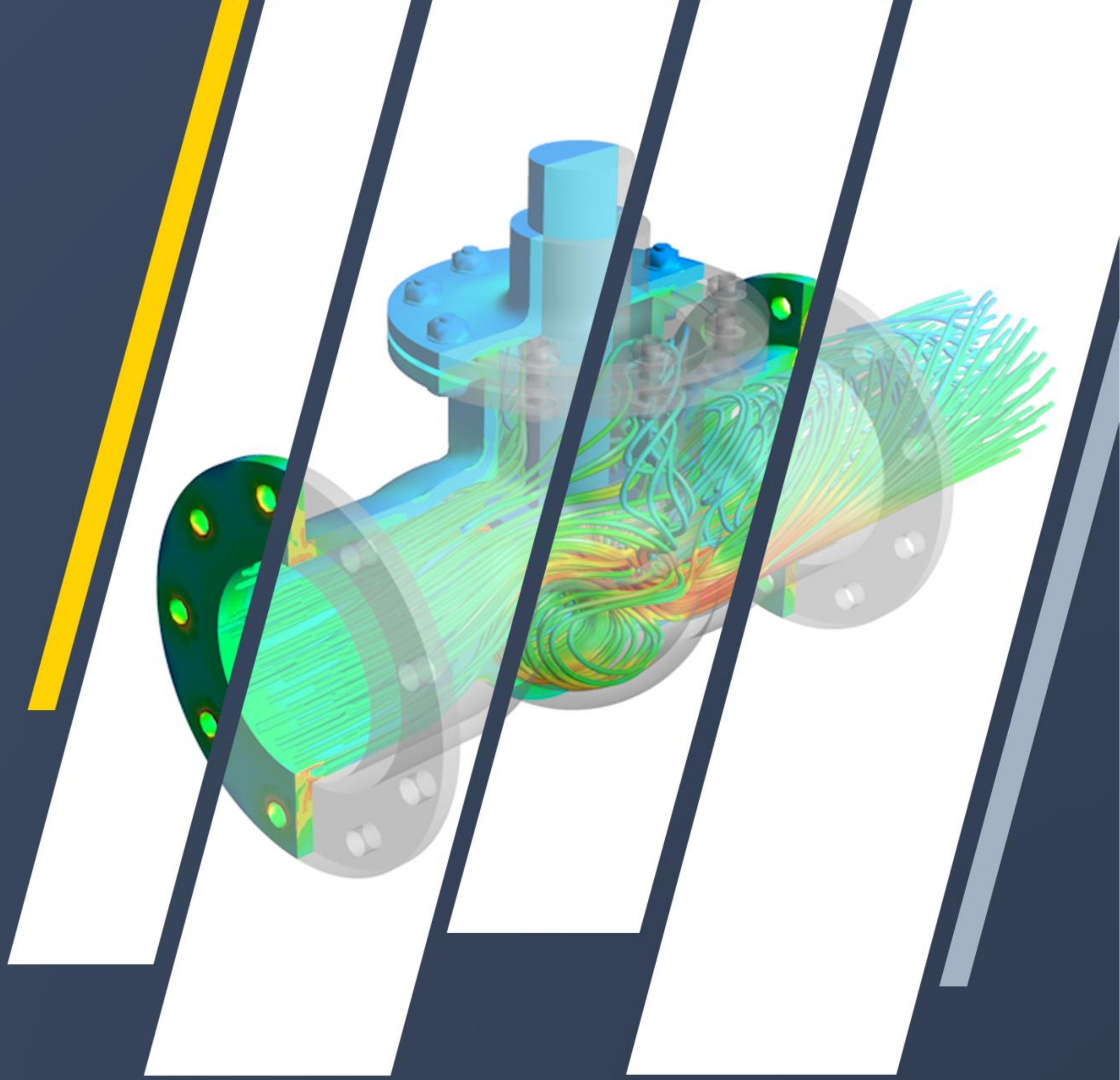
3. Activate Instance Transform in the View tab of any graphical object

   In the example shown, Instance Transform 1 was activated for the rotor blade and the rotor hub.



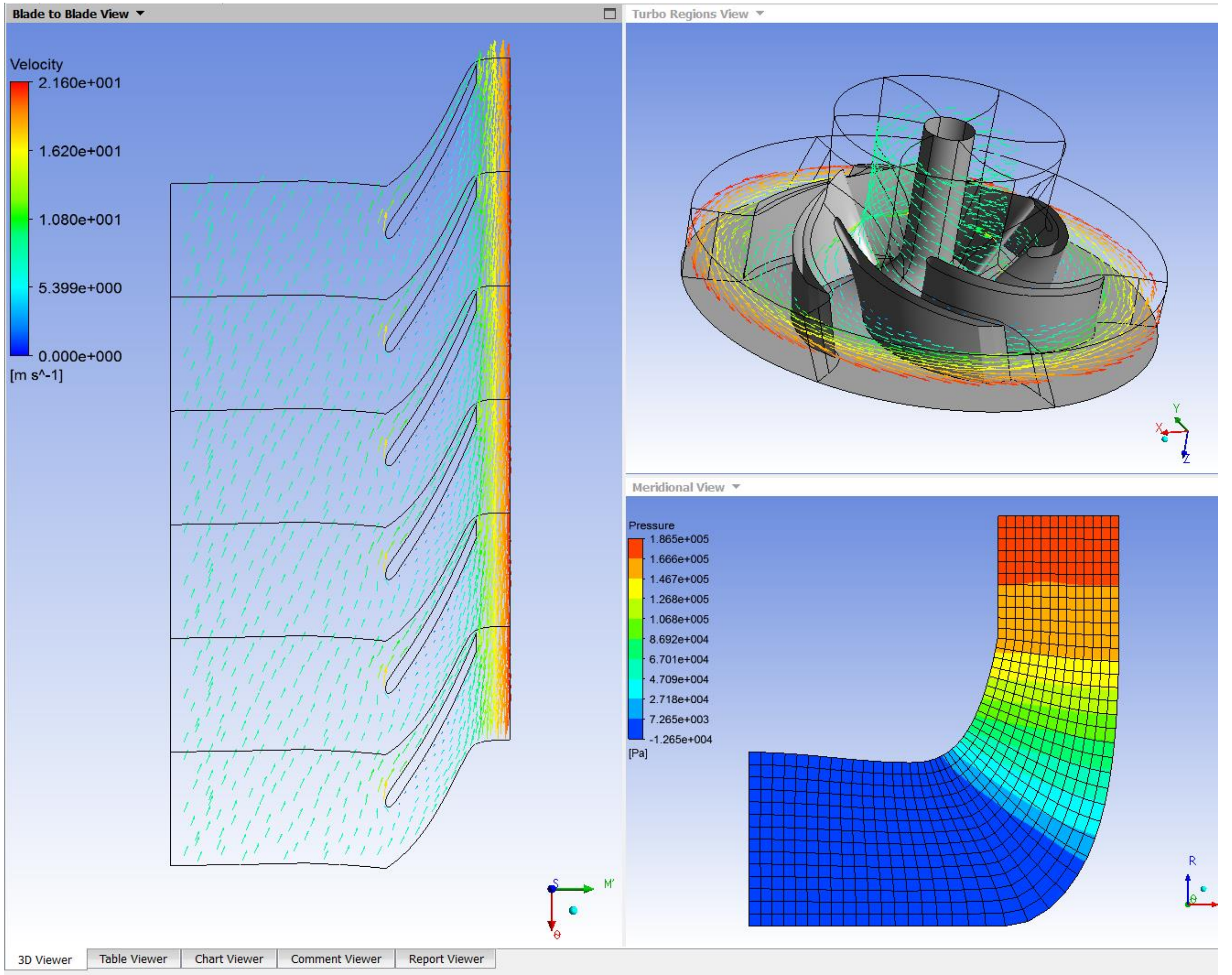


CFD-Post
Turbo Post-processing



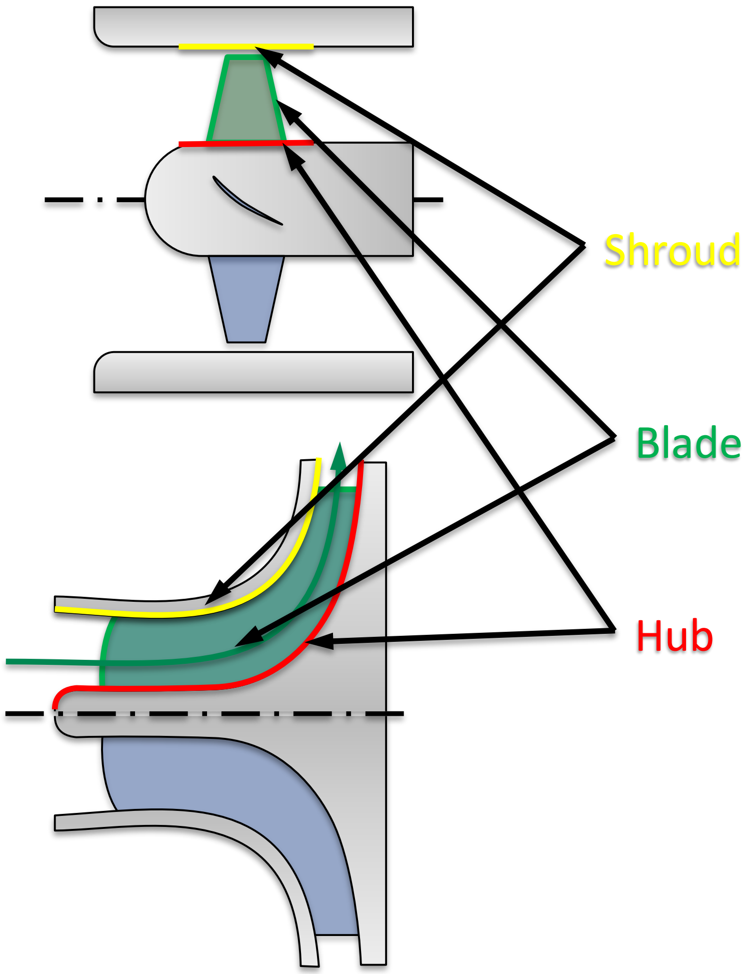
CFD Post Turbo Post-processing

- In addition to a complete set of general plotting and analysis tools, CFD Post has built-in turbo post-processing tools that can provide a wealth of plotting features
  - Blade-to-blade plots
  - Meridional “throughflow” plots
  - Turbo specific charts, such as Blade Loading charts



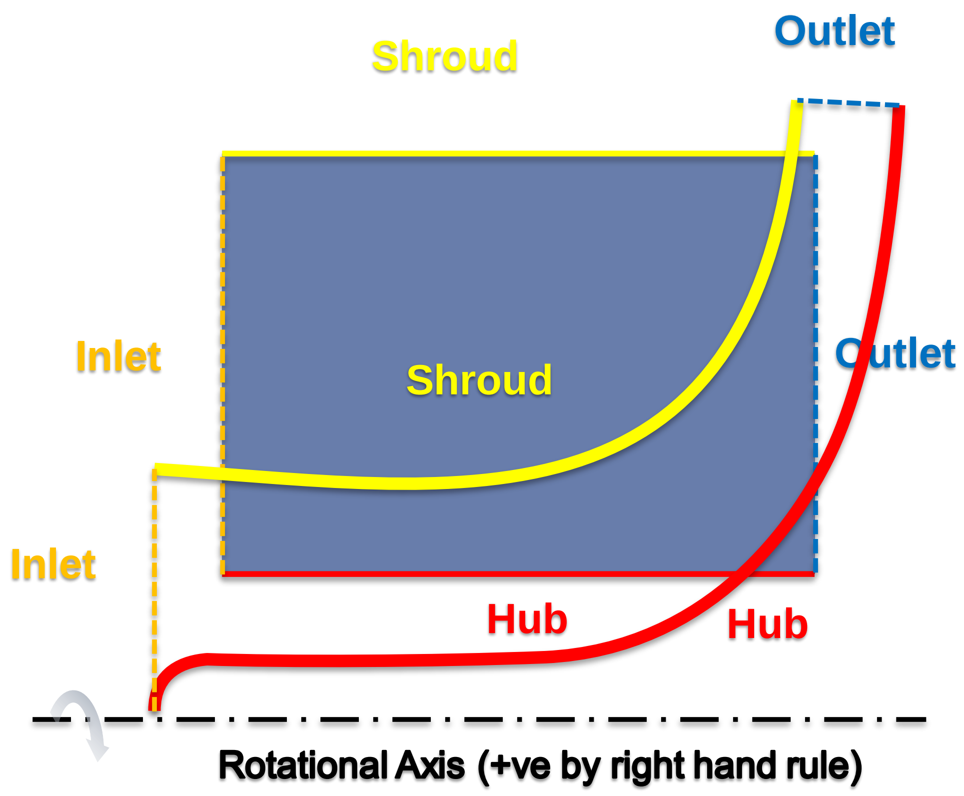
Topology

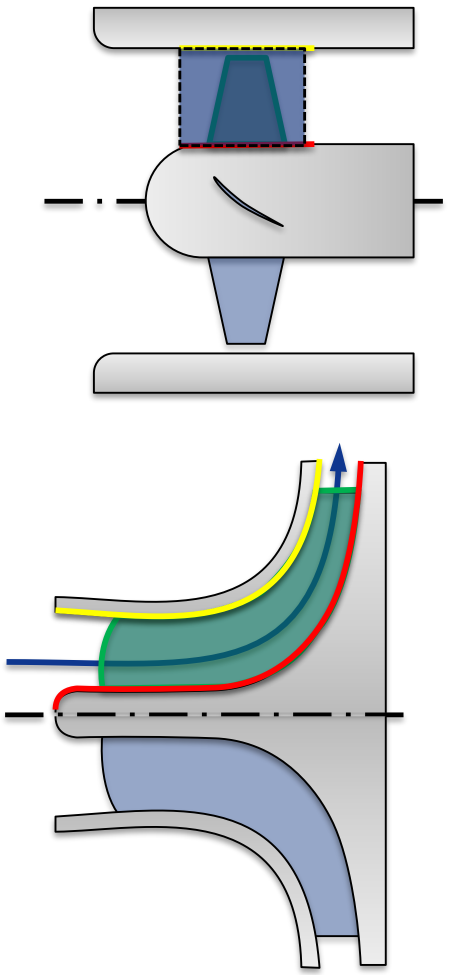
- Turbo Post takes advantage of the fact that all turbomachinery is topologically consistent
  - Just variations on a theme
  - Lends perfectly to design systems and parametric models
- Machines differ by changing
  - Hub/shroud shape
  - Blade leading and trailing edge shape and location
  - Blade wrap or angle
  - Number of blades
  - Rate of rotation

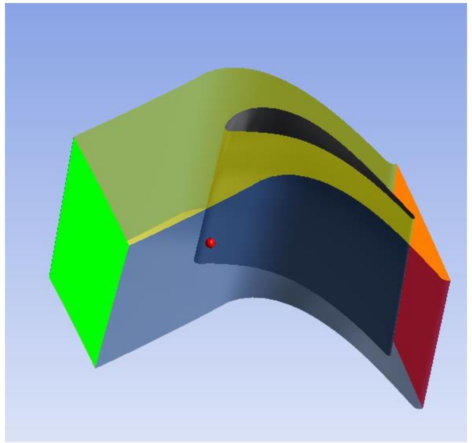


Terminology and conventions

- Meridional Passage







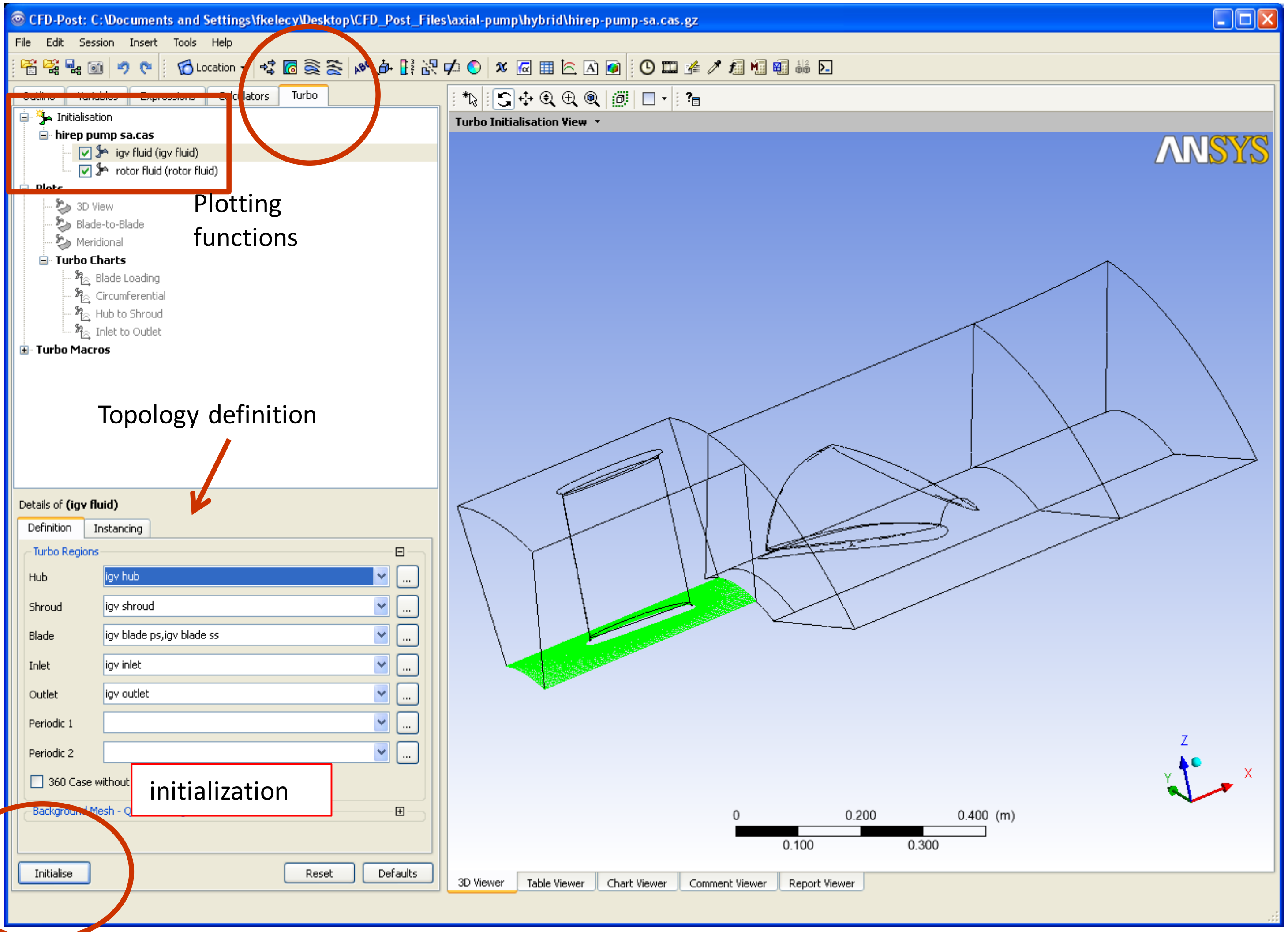
CFD Post Turbo Post-processing

- CFD Post provides for the setup of a turbo topology for each fluid zone
  - Axis of rotation
  - Hub, shroud, inlet, outlet, blade, periodic surfaces
- After specification of turbo topology, turbo post-processing is initialized and the plotting becomes available in the interface
- Turbo topology is set up automatically if you use Turbo-Pre

CFD Post Turbo Interface: Initialization

NOTE: Multiple blade
Rows can be defined

- CFD Post will automatically try to find the regions defining the hub, shroud, inlet, outlet, blade, and periodics
- If CFD Post does not find the correct regions, the user can define the correct regions as shown



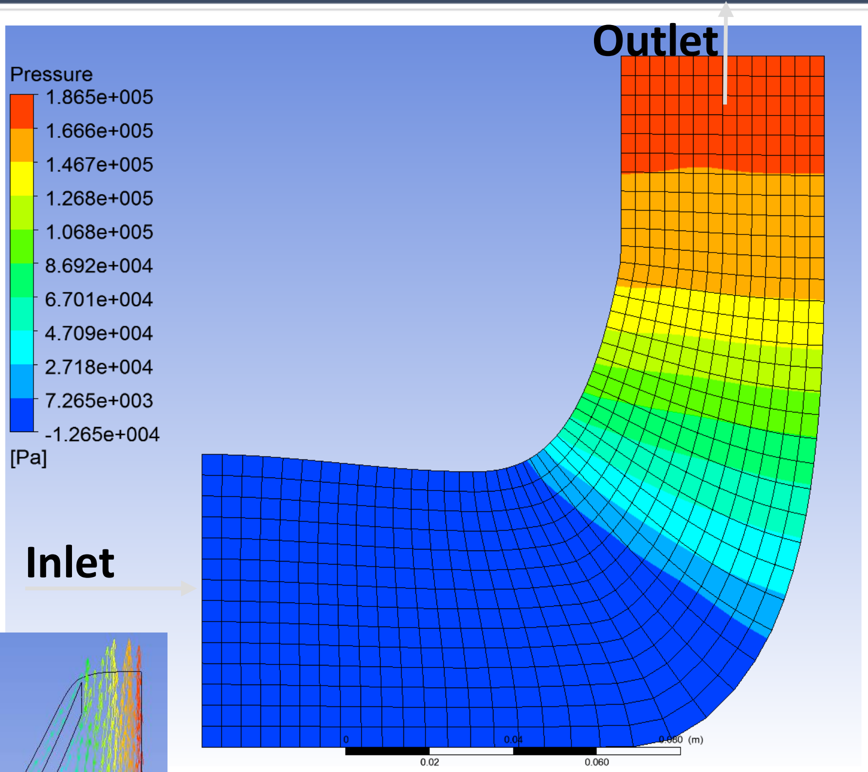
Turbo Specific Qualitative Post-Processing

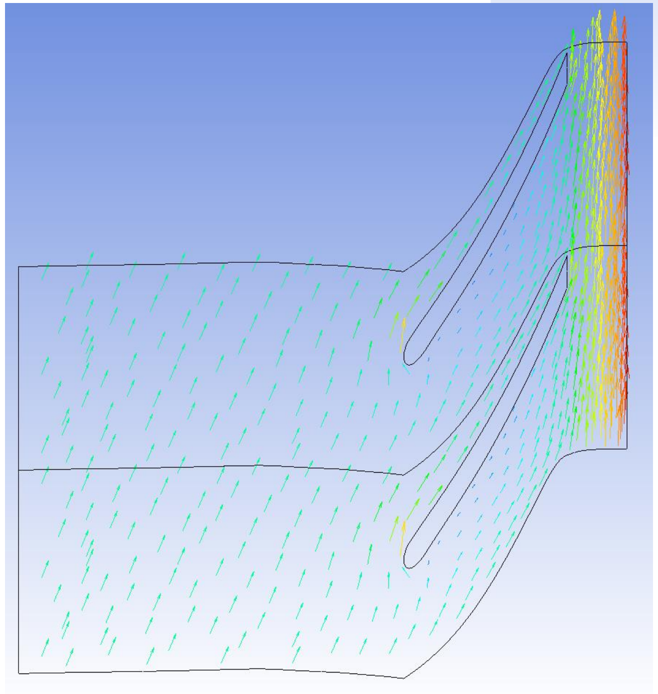
- Turbo specific qualitative post-processing provides visual insight into the flow field and guidance to help make design improvements
- Twisting nature of blade geometry often makes result visualization difficult in 3-D space
- Results are easier to visualize in 2-D transformed space
  - Meridional view
  - Blade-to-Blade view

Turbo Specific Views

- Meridional view
  - Plot in axial-radial space (r-z)
  - Circumferential averaging reduces 3D data to single meridional plane
- Blade-to-Blade view
  - Unrolled into meridional distance m’ and angular (θ) coordinates
    - ➢ (m’-θ) transformation is angle preserving with less distortion

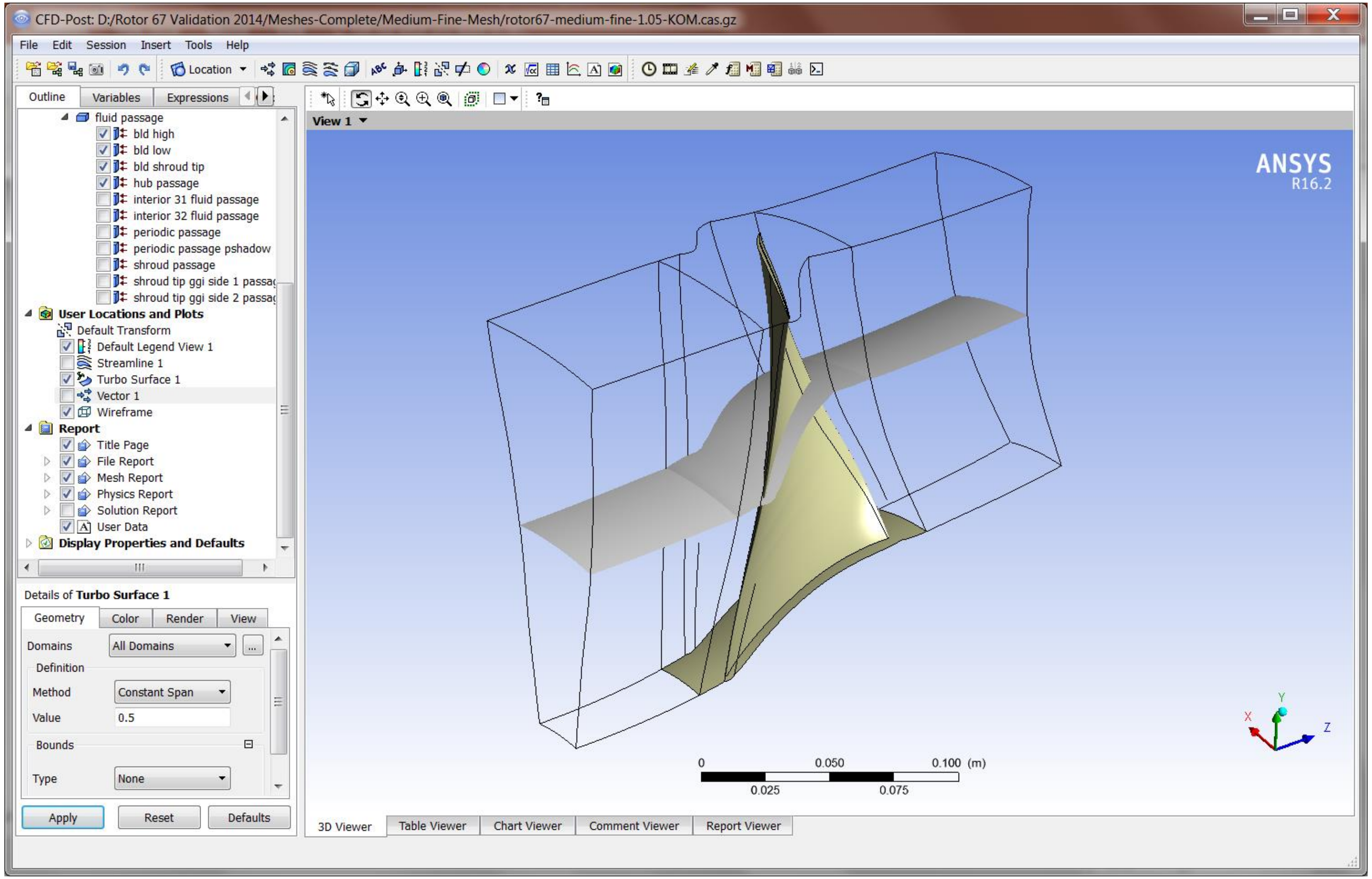
$$m' = \int \frac{dm}{r} \qquad m = \int \sqrt{dr^2 + da^2}$$





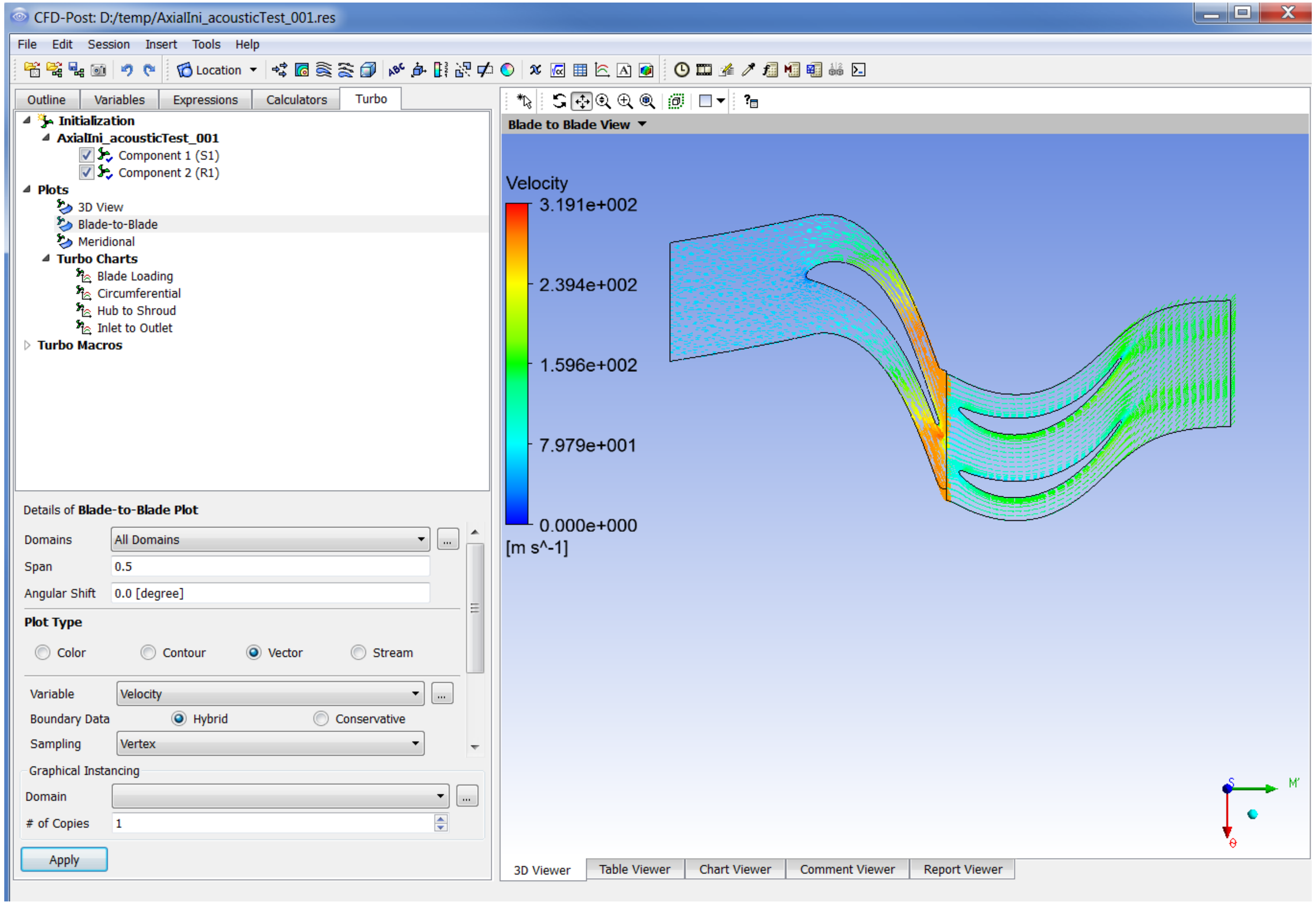
Turbo Surface Locations

- Create surface locations based on the turbo topology
  - Constant Span
  - Constant Streamwise Location
  - Constant Blade Aligned
  - Constant Blade Aligned Linear
  - Constant Theta
  - Cone
- Can plot contours, vectors, etc. on these surfaces



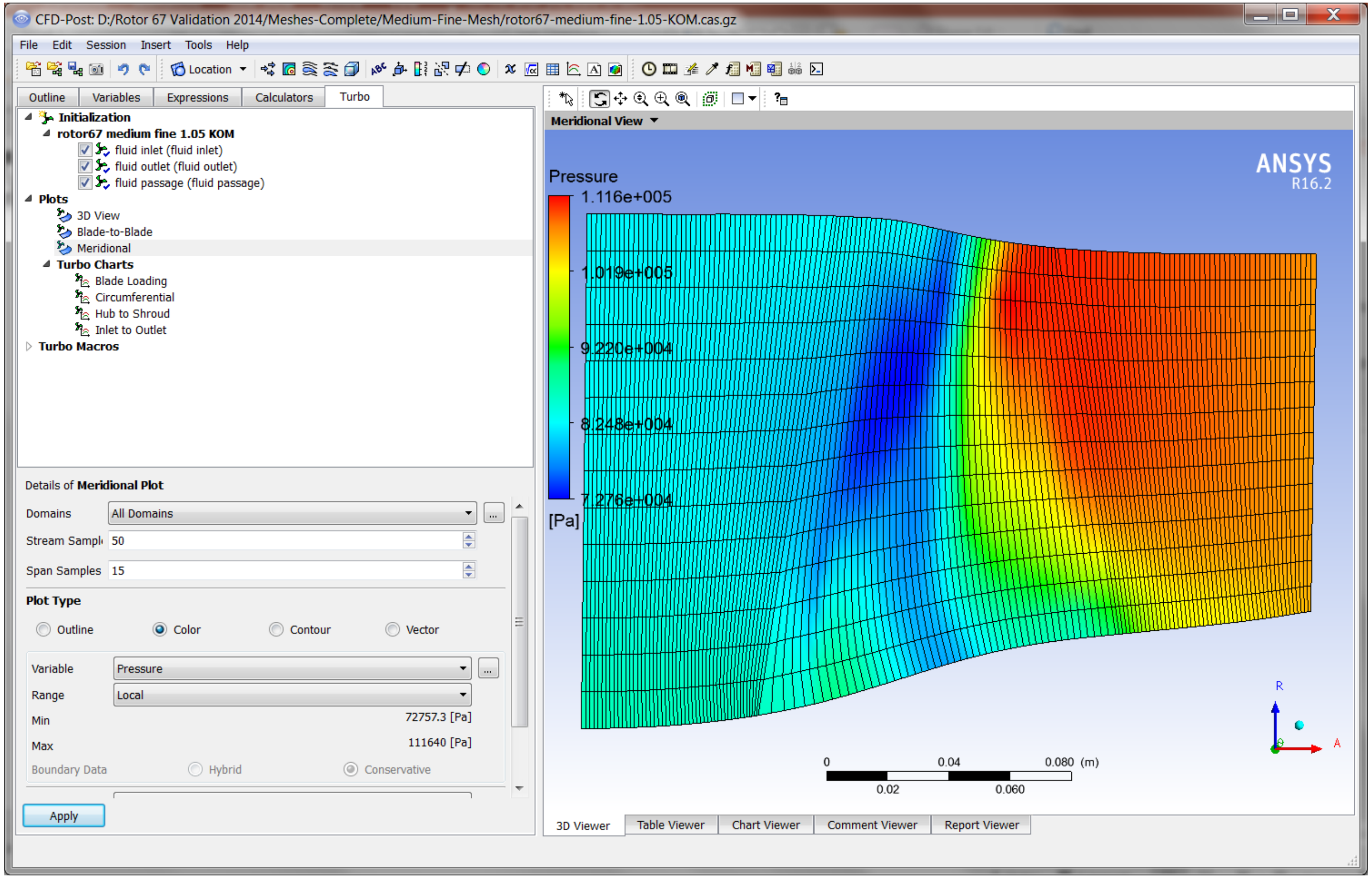
Turbo Blade-to-Blade Plot

- Creates a contour map by defining a turbo surface at a constant spanwise location and "unrolling" the surface on a plane in M'-Theta space
  - Angle preserving view
- Contours, Vectors, Steamlines can be plotted
- Allows the flow variations around a blade to more easily be analyzed versus a 3D surface rendering



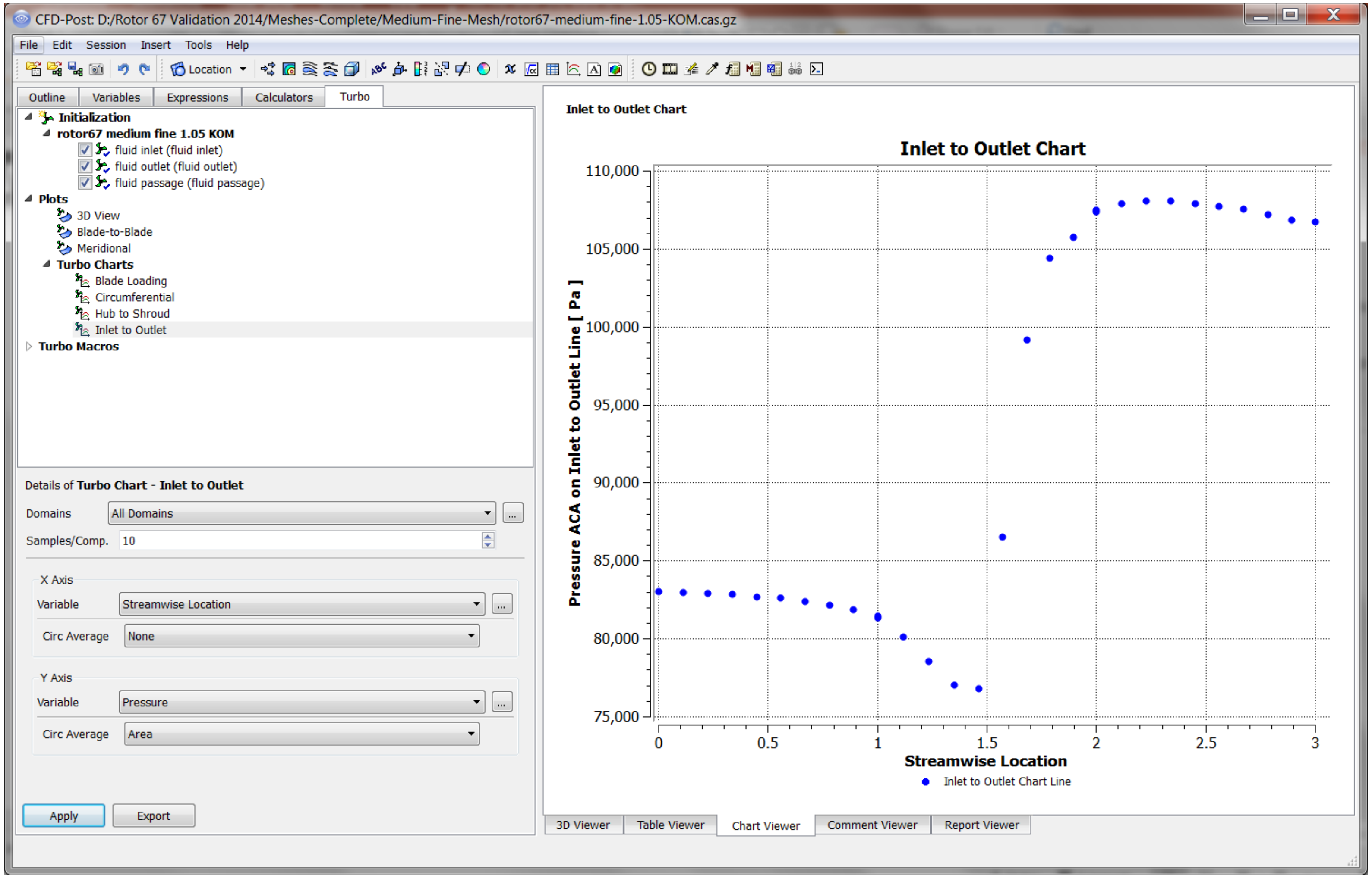
Turbo Meridional Contour Plot

- Creates a map by defining an theta-averaged (r,z) solution and displaying it as a side view map
- Shows circumferentially averaged flow variations in the streamwise direction through the flow passage



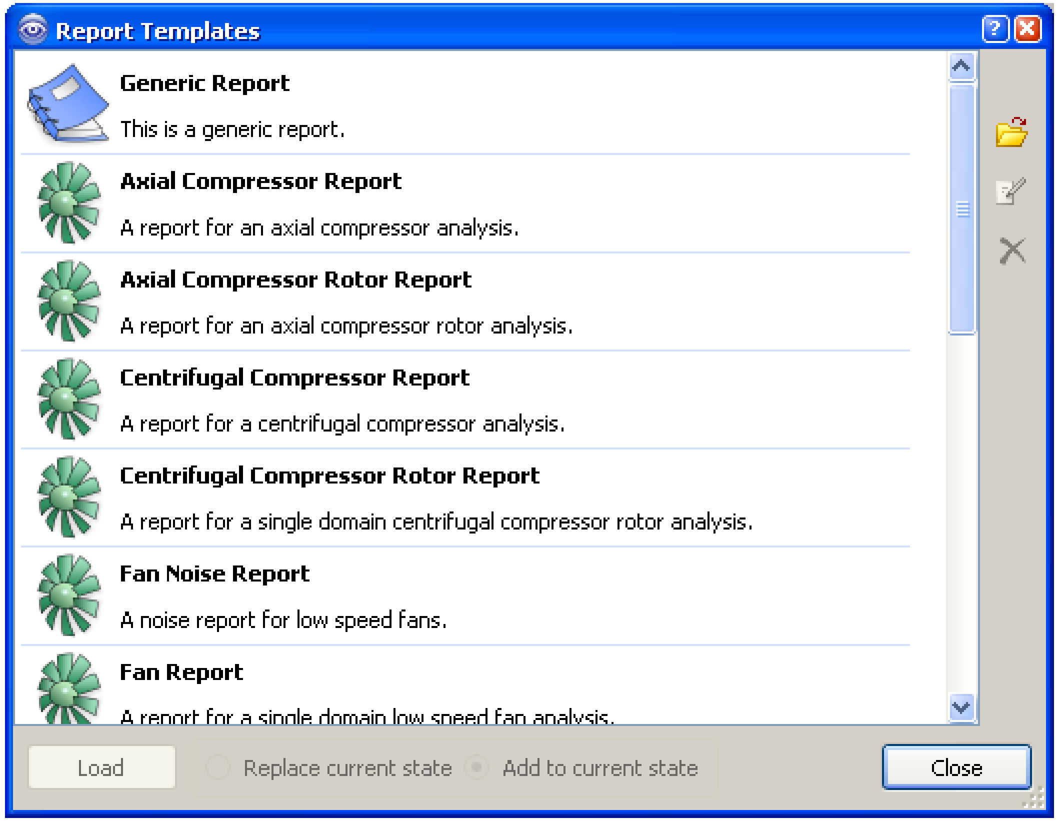
Turbo Charts

- Create plots of turbo quantities
  - Blade Loading
  - Circumferential
  - Hub to Shroud
  - Inlet to Outlet
- Show average flow variations at specific flowpath positions with streamwise, spanwise, or periodic orientations

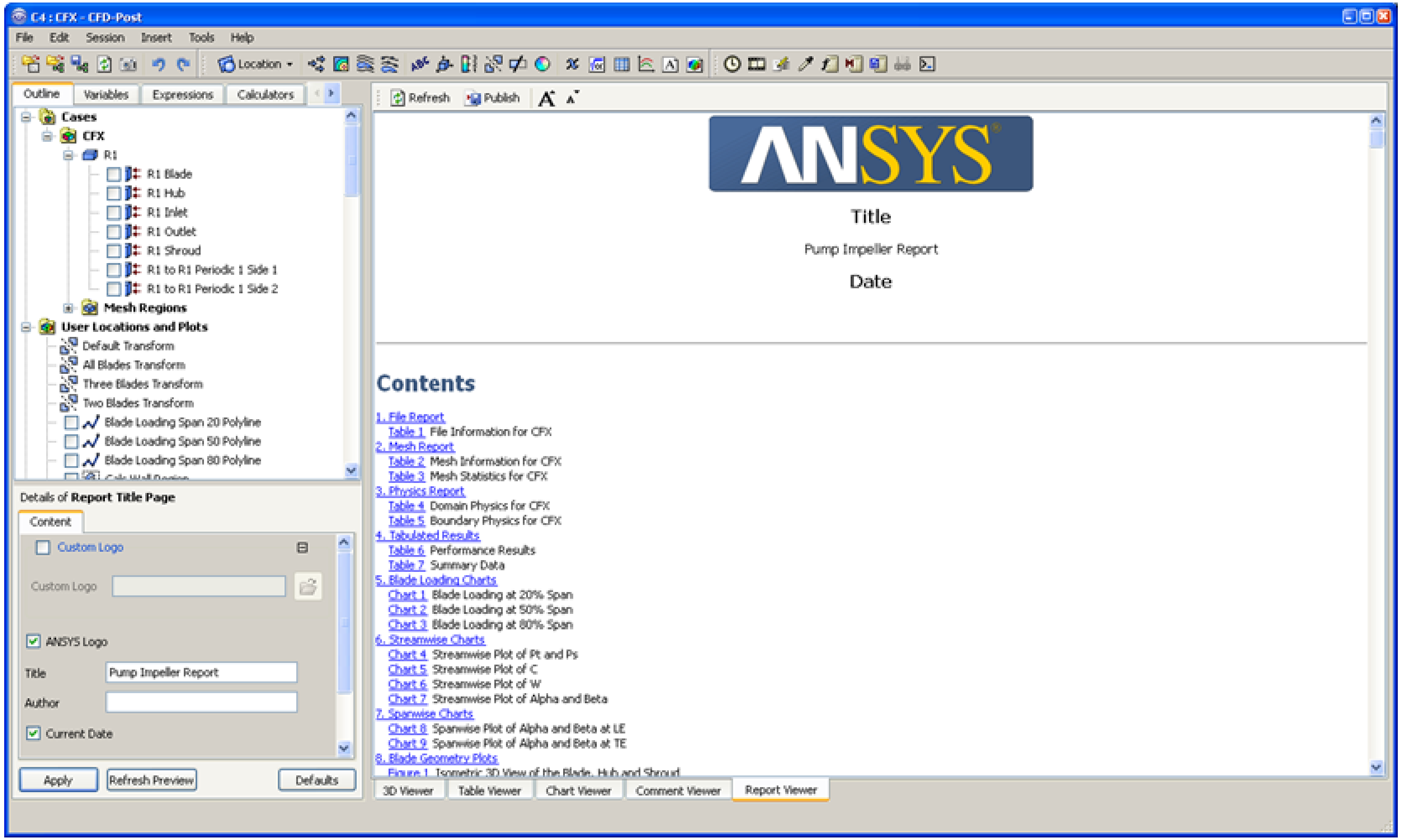


Turbo Reports

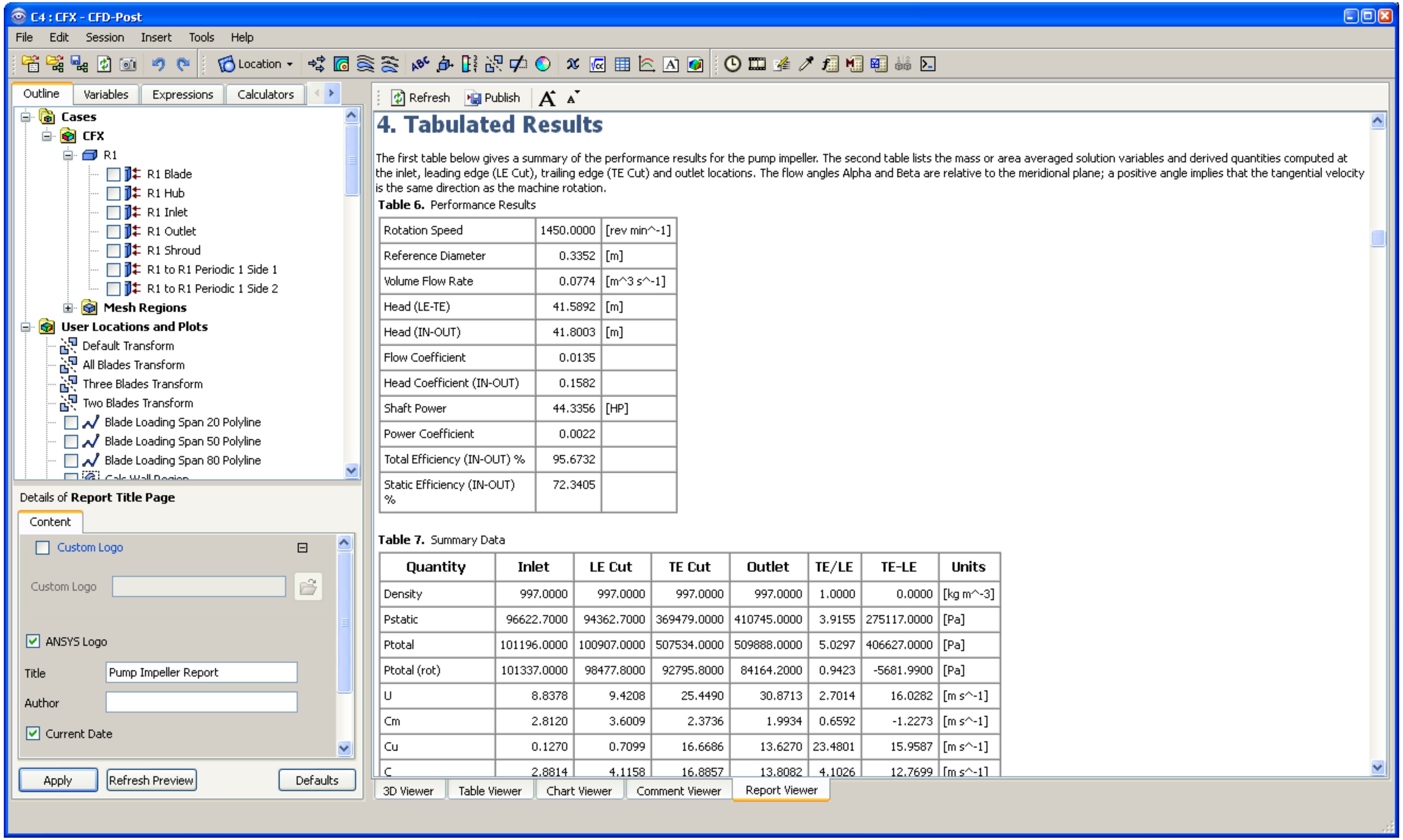
- Turbo Reports
  - The turbo reports are designed for single and multiple blade row fluid analyses
- Turbo reports attempt to auto-initialize Turbo mode
  - If auto-initialization fails, user must initialize Turbo mode manually and re-run the turbo report
- Pump report shown as an example in following slides



Automatic Reports in CFD-Post …



with Performance Tables, …



4. Tabulated Results

The first table below gives a summary of the performance results for the pump impeller. The second table lists the mass or area averaged solution variables and derived quantities computed at the inlet, leading edge (LE Cut), trailing edge (TE Cut) and outlet locations. The flow angles Alpha and Beta are relative to the meridional plane; a positive angle implies that the tangential velocity is the same direction as the machine rotation.

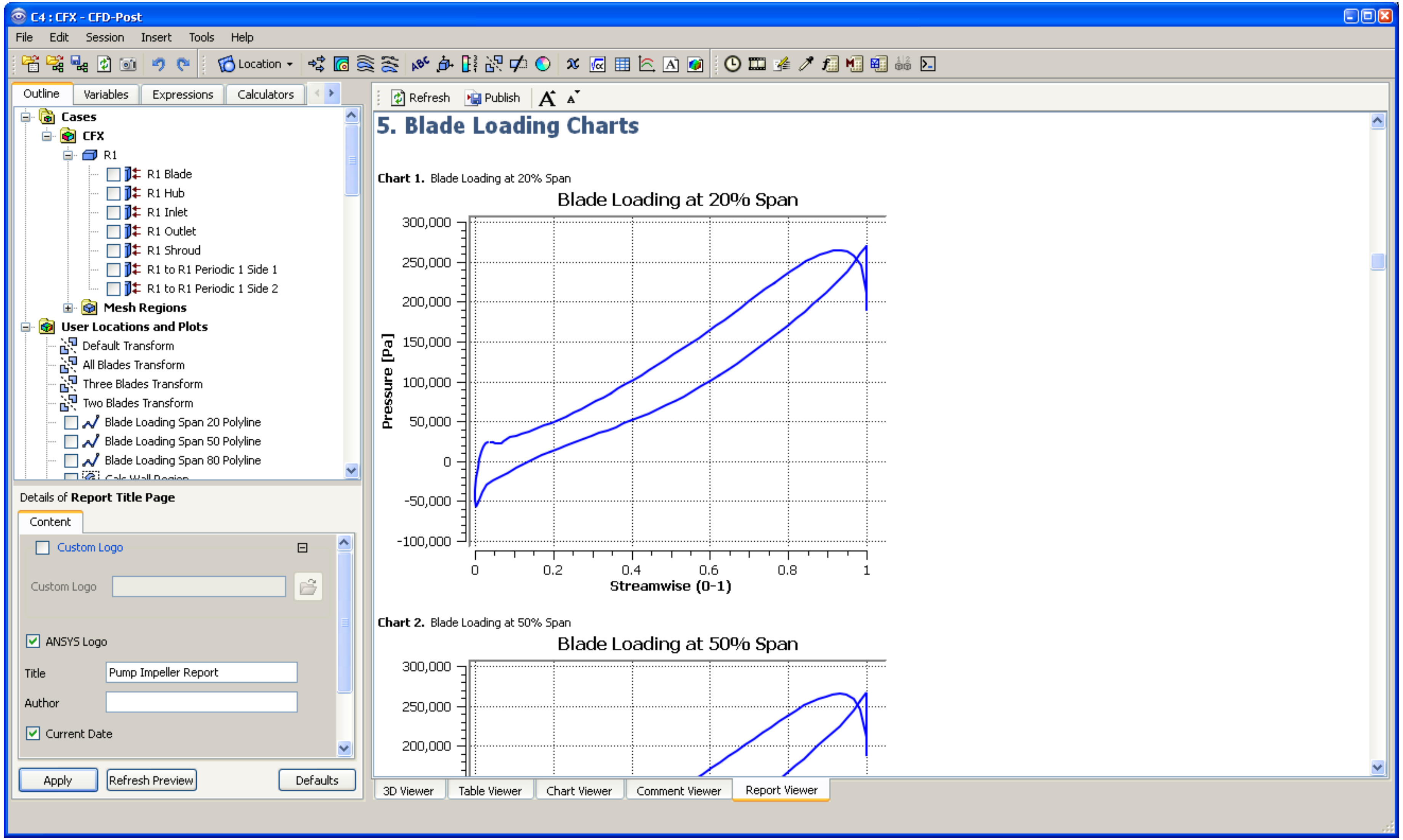
Table 6. Performance Results

Rotation Speed	1450.0000	[rev min^-1]
Reference Diameter	0.3352	[m]
Volume Flow Rate	0.0774	[m^3 s^-1]
Head (LE-TE)	41.5892	[m]
Head (IN-OUT)	41.8003	[m]
Flow Coefficient	0.0135	
Head Coefficient (IN-OUT)	0.1582	
Shaft Power	44.3356	[HP]
Power Coefficient	0.0022	
Total Efficiency (IN-OUT) %	95.6732	
Static Efficiency (IN-OUT) %	72.3405	

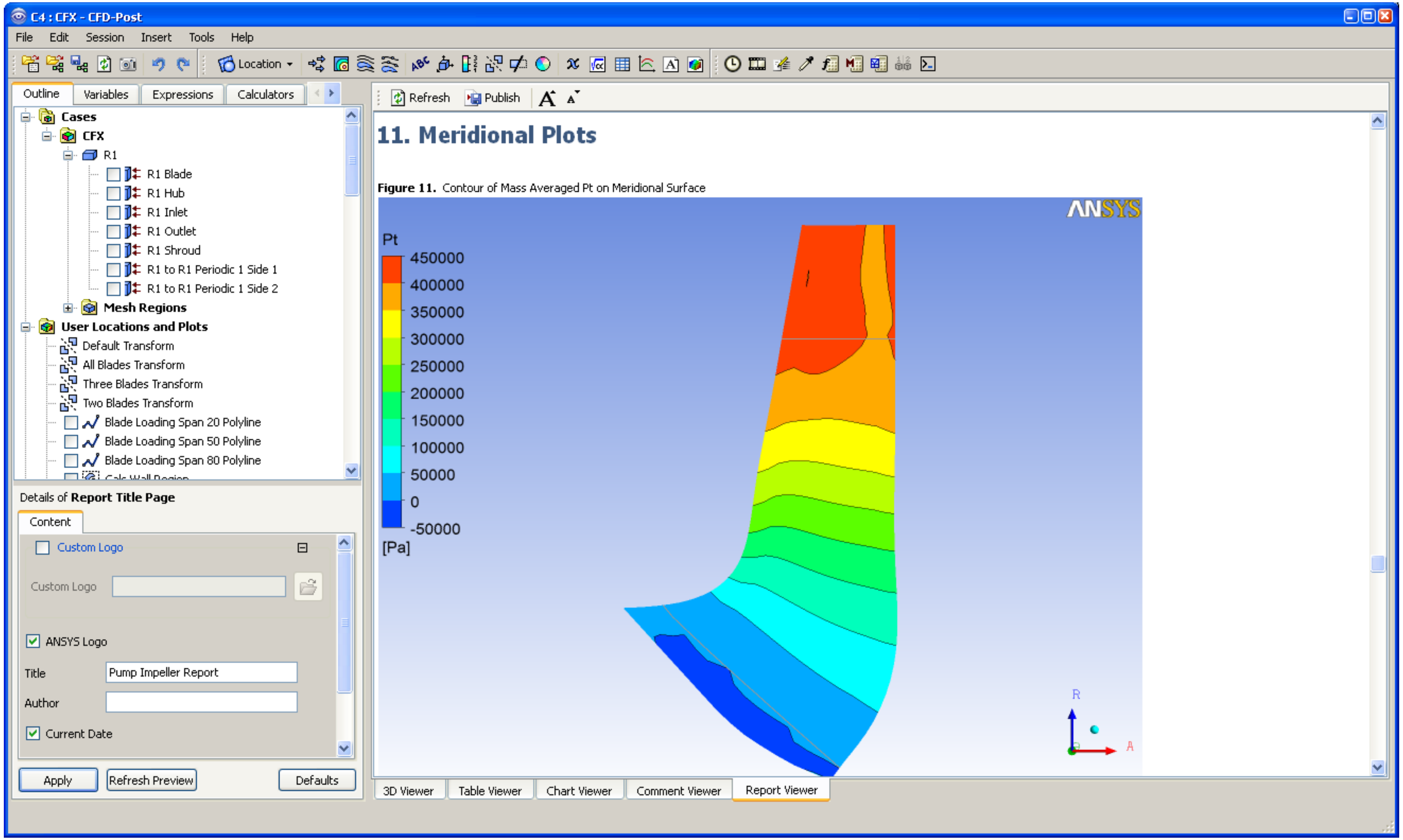
Table 7. Summary Data

Quantity	Inlet	LE Cut	TE Cut	Outlet	TE/LE	TE-LE	Units
Density	997.0000	997.0000	997.0000	997.0000	1.0000	0.0000	[kg m^-3]
Pstatic	96622.7000	94362.7000	369479.0000	410745.0000	3.9155	275117.0000	[Pa]
Ptotal	101196.0000	100907.0000	507534.0000	509888.0000	5.0297	406627.0000	[Pa]
Ptotal (rot)	101337.0000	98477.8000	92795.8000	84164.2000	0.9423	-5681.9900	[Pa]
U	8.8378	9.4208	25.4490	30.8713	2.7014	16.0282	[m s^-1]
Cm	2.8120	3.6009	2.3736	1.9934	0.6592	-1.2273	[m s^-1]
Cu	0.1270	0.7099	16.6686	13.6270	23.4801	15.9587	[m s^-1]
C	2.8814	4.1158	16.8857	13.8082	4.1026	12.7699	[m s^-1]

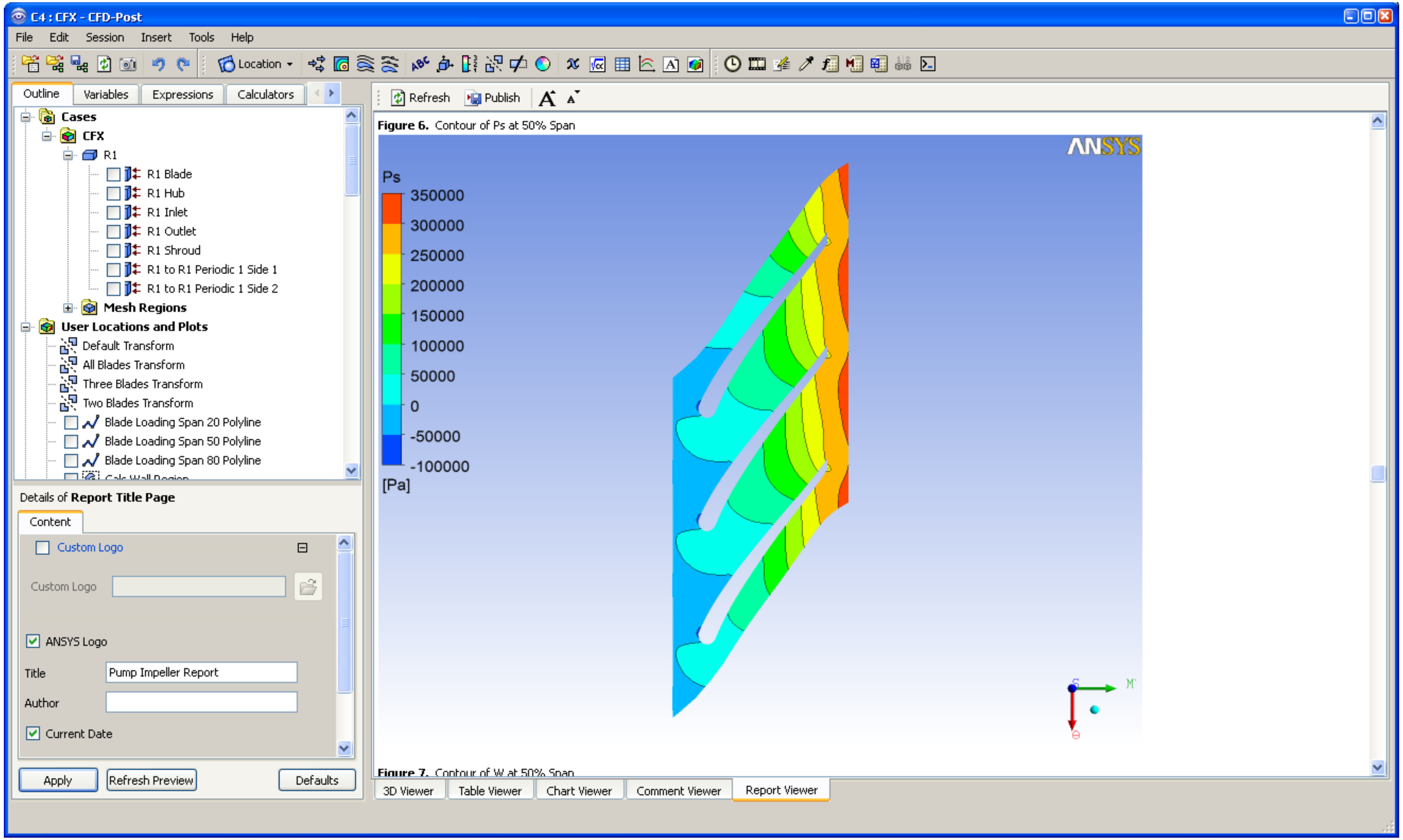
with Blade Loading Charts, …



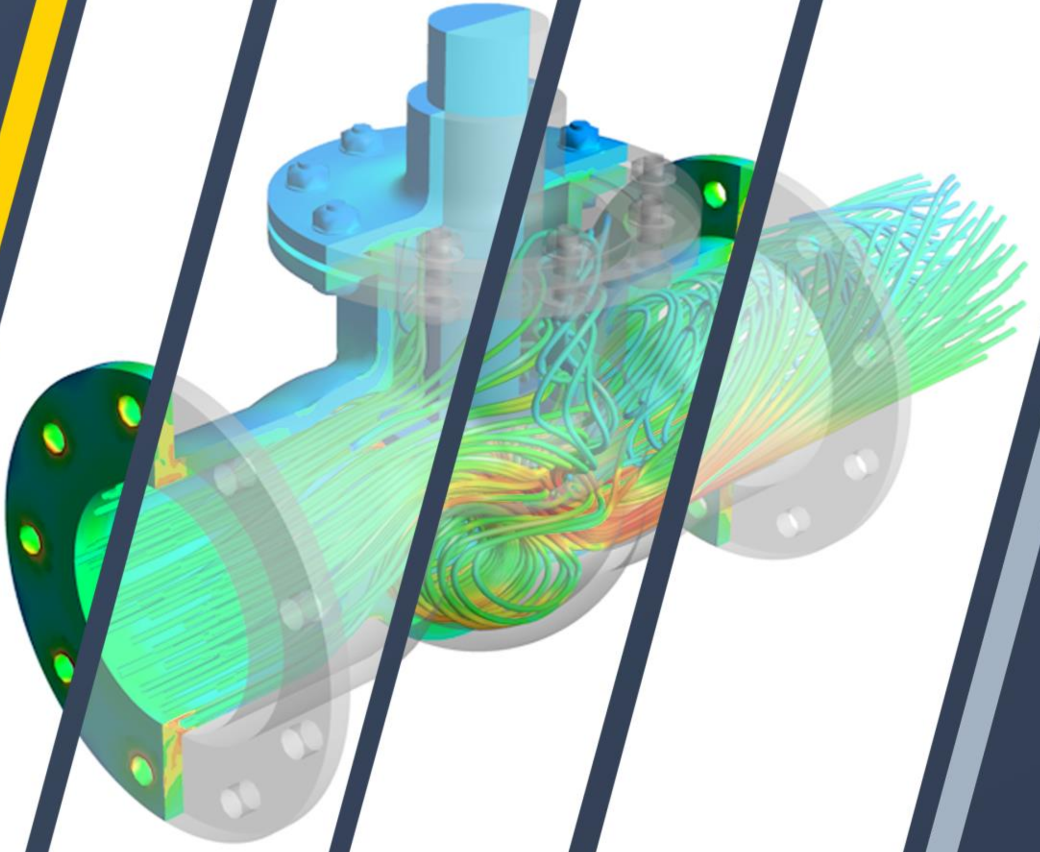
with Meridional Plots, …



with Blade-to-Blade plots, etc.



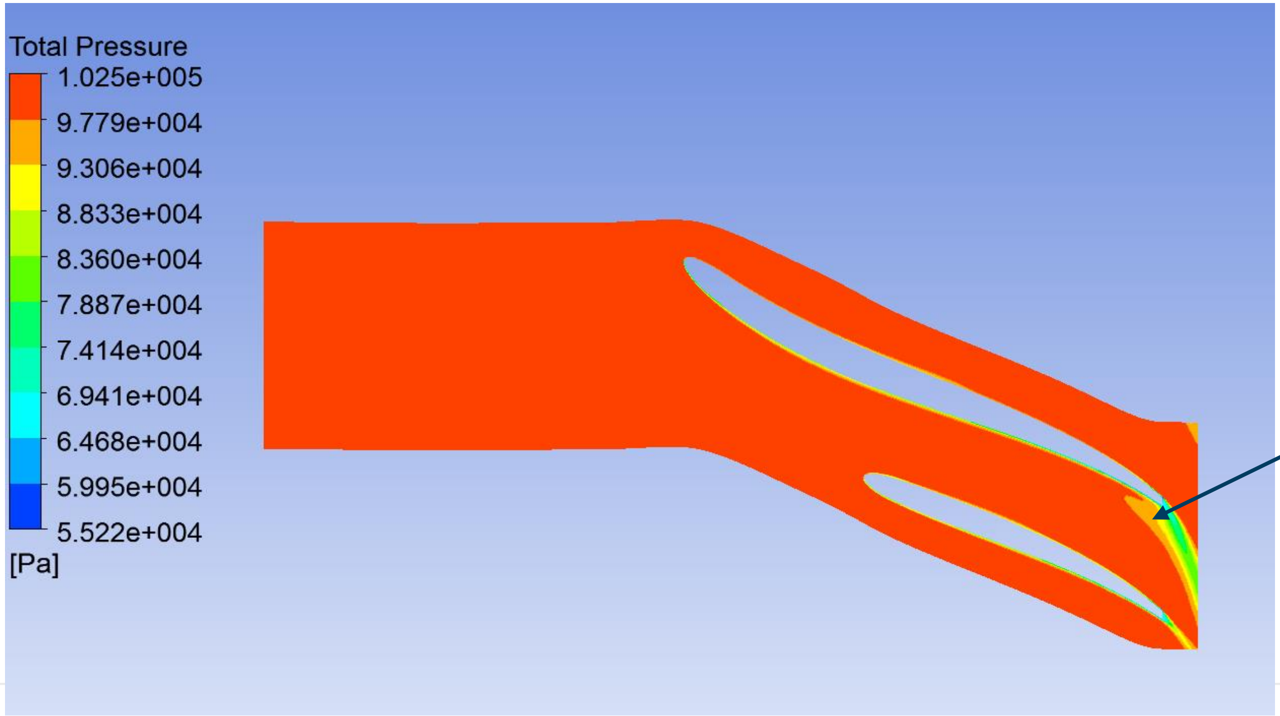
Rotating Machinery Post-processing Guidelines



Guidelines

Suggestions on key parameters to examine qualitatively:

- Rotating frame total pressure (Pt,r) is a useful quantity to identify losses
  - Invariant in the rotating frame for isentropic flow
    - locations of low Pt,r indicate loss
  - Be careful near stationary walls
    - stationary walls perform work on the flow in the rotating frame and increase apparent Pt,r

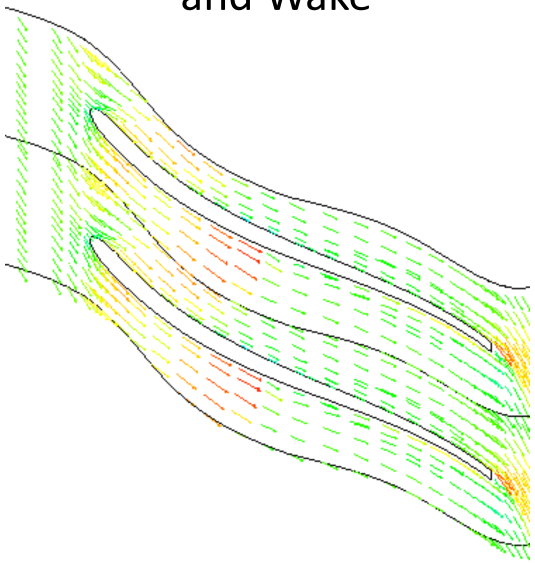


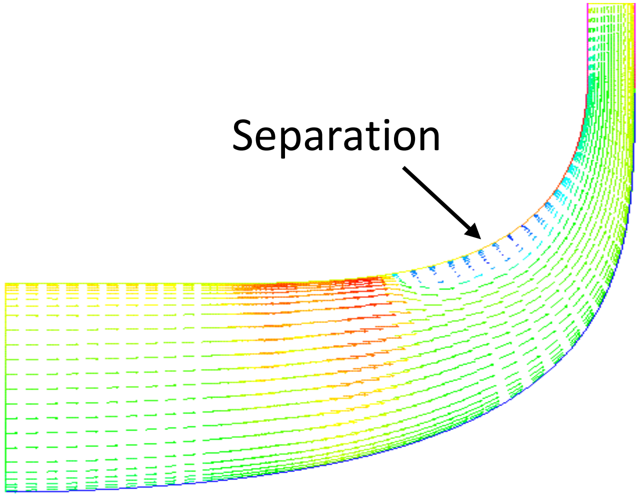
Rotating Frame Total Pressure reduces in wakes and separation regions

Guidelines

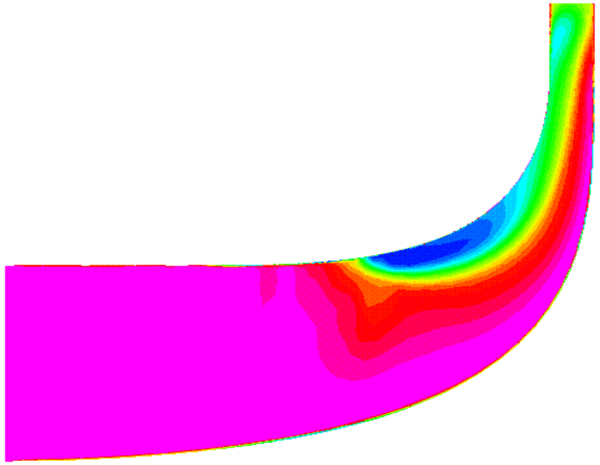
- Closely examine velocity vectors and contours for:
  - Areas of flow recirculation and separation (revise geometry to remove, if possible)
  - Areas of uneven or unnecessary acceleration and deceleration
  - Jet-wake flow in radial compressors and pumps
    - ➢ reduce and/or redistribute the wake to lower diffuser loss

Velocity Vectors Showing Suction Side Re-Acceleration and Wake

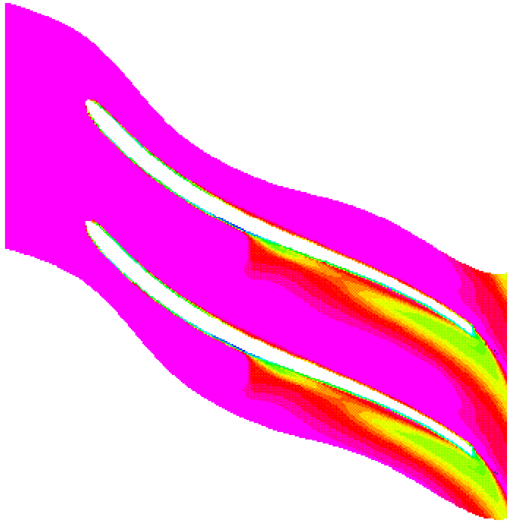




Velocity Vectors Showing Shroud Separation



$P_{t,r}$ Showing Loss



$P_{t,r}$ Showing Loss

Summary

- Wide range of Turbo-specific Post-processing tools available in CFD-Post
  - Function Calculator
  - CEL
  - Contour plots
  - Vector plots
  - Streamlines and surface pathlines
  - Turbo surfaces
  - Turbo Blade-to-Blade Plot
  - Turbo Meridional Plot
  - Turbo Charts
- Many other tools available in CFD Post
  - Templates
  - Tables
  - Custom variables and expressions
  - Automated reports