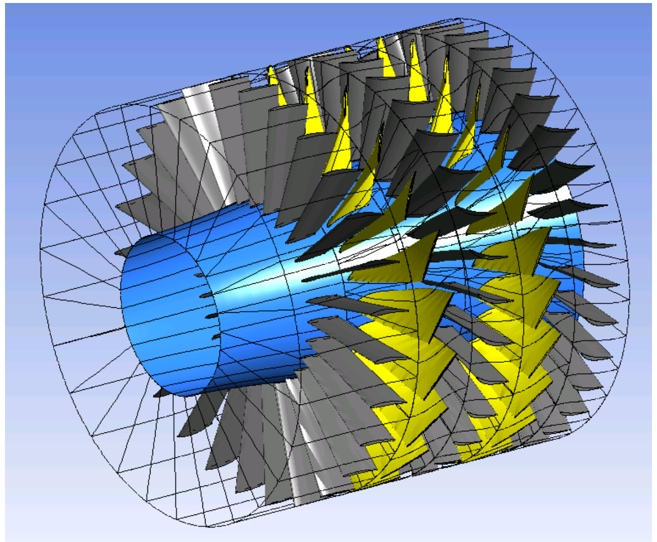
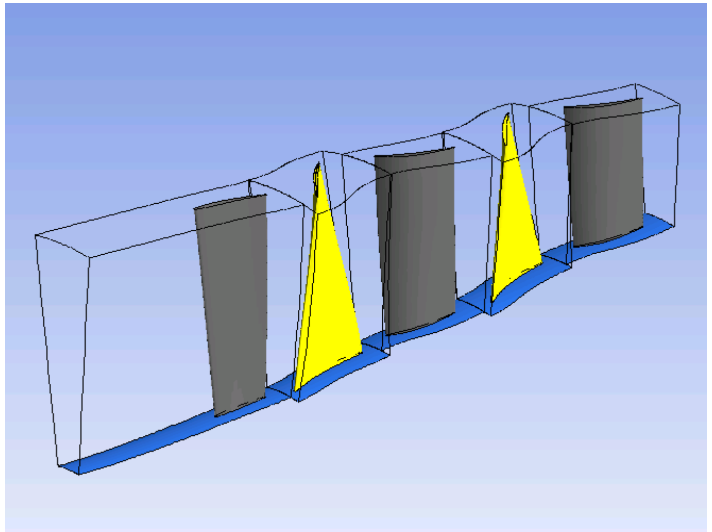
Lecture 05: Multi-Component Analysis – Transient

Release 2020 R2

Outline

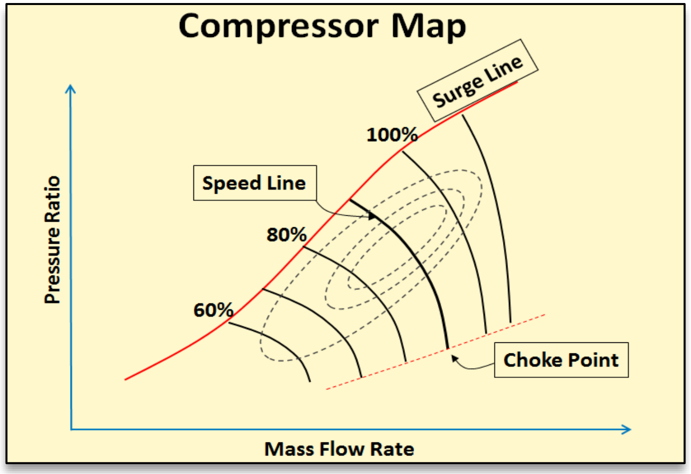
- Introduction to Unsteady Modeling
- Transient Rotor-Stator Full-annulus challenge
- Sliding Mesh Model - Fluent
  - Full-annulus Transient Rotor-Stator Simulations
  - Pitch-Change Transient Rotor-Stator Simulations
- Setting Up Transient Rotor-Stator Simulations
- Summary



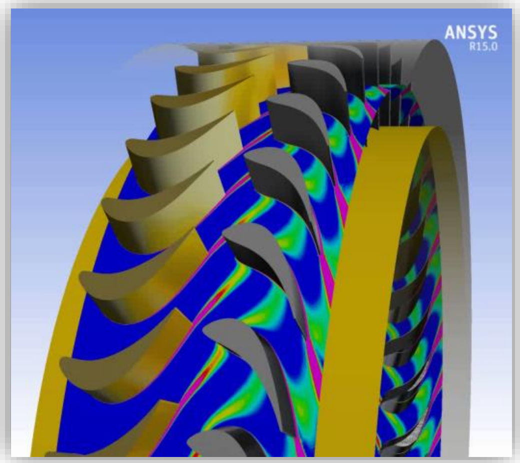


Introduction to Unsteady Modeling

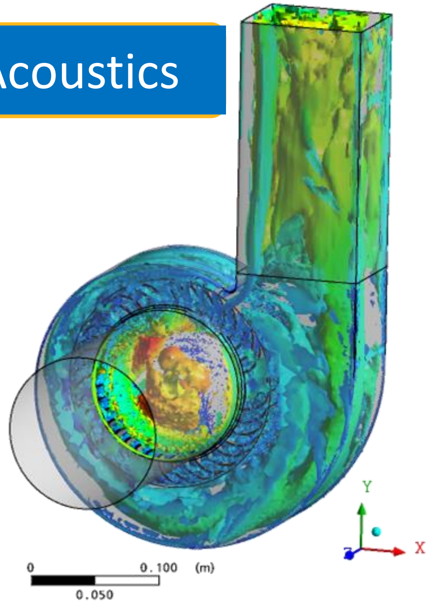
Better performance prediction



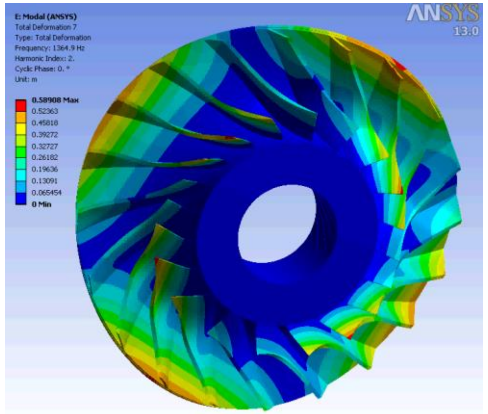
Unsteady interactions



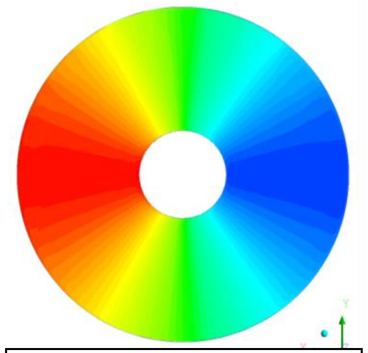
Acoustics



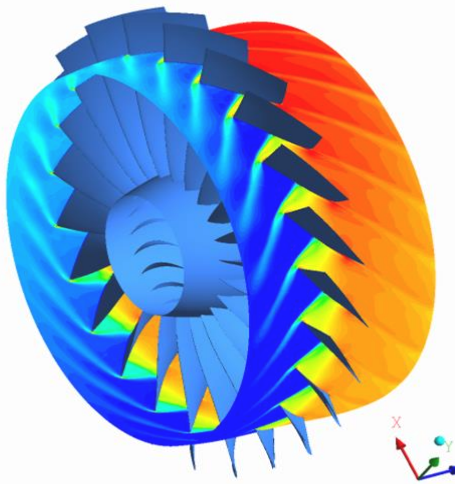
Aeromechanics



Asymmetric geometry or flow



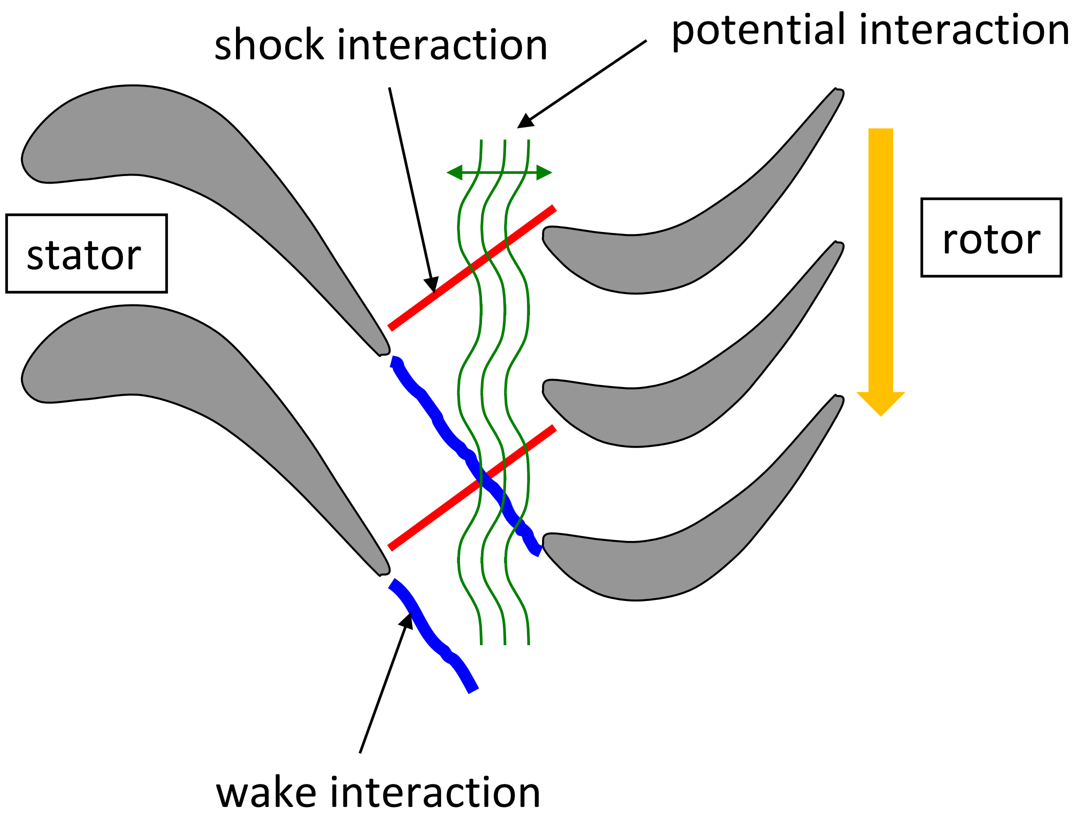
Fan Inlet Distortion P_o



...

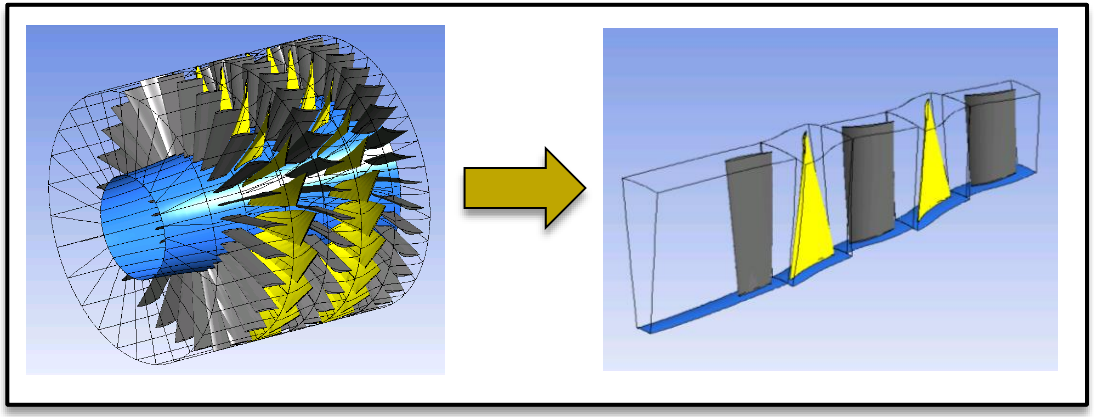
Introduction to Unsteady Modeling

- The relative motion of stationary and rotating components will give rise to unsteady interactions.
  These interactions are generally classified as follows:
  - **Potential interactions** - flow unsteadiness due to pressure waves which propagate both upstream and downstream
  - **Wake interactions** - flow unsteadiness due to wakes from upstream blade rows advecting downstream
  - **Shock interactions** - for transonic/supersonic flows, unsteadiness due to shock waves striking downstream blade row
- Both the Frozen Rotor Model and Mixing Plane Model neglect unsteady interaction entirely and thus are limited to flows where these effects are weak
- If unsteady interactions cannot be neglected, you will need to employ one of the transient methods presented in this lecture



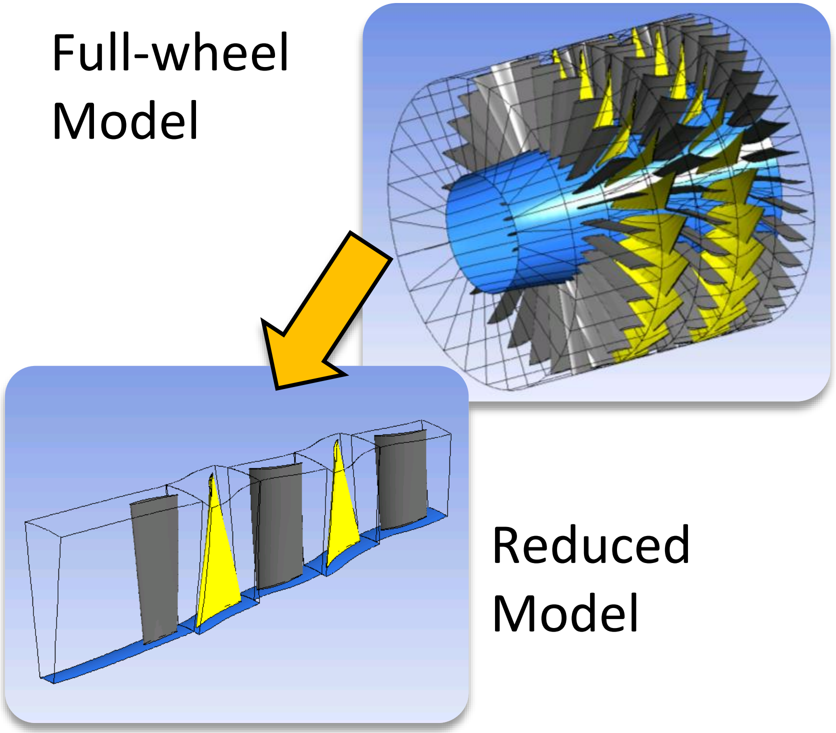
Transient Simulations

- Steady state solutions are fast and practical, however, there are cases where the unsteady effects of blade row interaction do affect performance
- Solving full anulus is impractical
  - Huge computational effort and resources are needed!
- Fluent provides rotor-stator interfaces, which allows for simulating the unsteady blade to blade interaction
  - Typically one or a few passages are modeled per component



Pitch Change Problem

- Adjacent blade rows typically have different blade counts, and often the numbers of blades of rotor and stator do not even have a common divider
- Therefore, single periodic sectors will have different pitch angles
  - The Pitch-scale and No-Pitch-Scale methods, introduced in the previous lecture for Frozen Rotor, are also available for transient simulations with Fluent
  - The Fluent pitch-change methods currently available are an approximation
    - Improve the performance accuracy of the calculation
    - Cannot predict the correct rotating-machine's frequencies, unless there exists a matching pitch for a sector with different blade numbers for rotor and stator
      - Example: For a 12-blade rotor followed by a 16-blade stator a 90 degrees sector can be modelled with 3 rotor blades and 4 stator blades



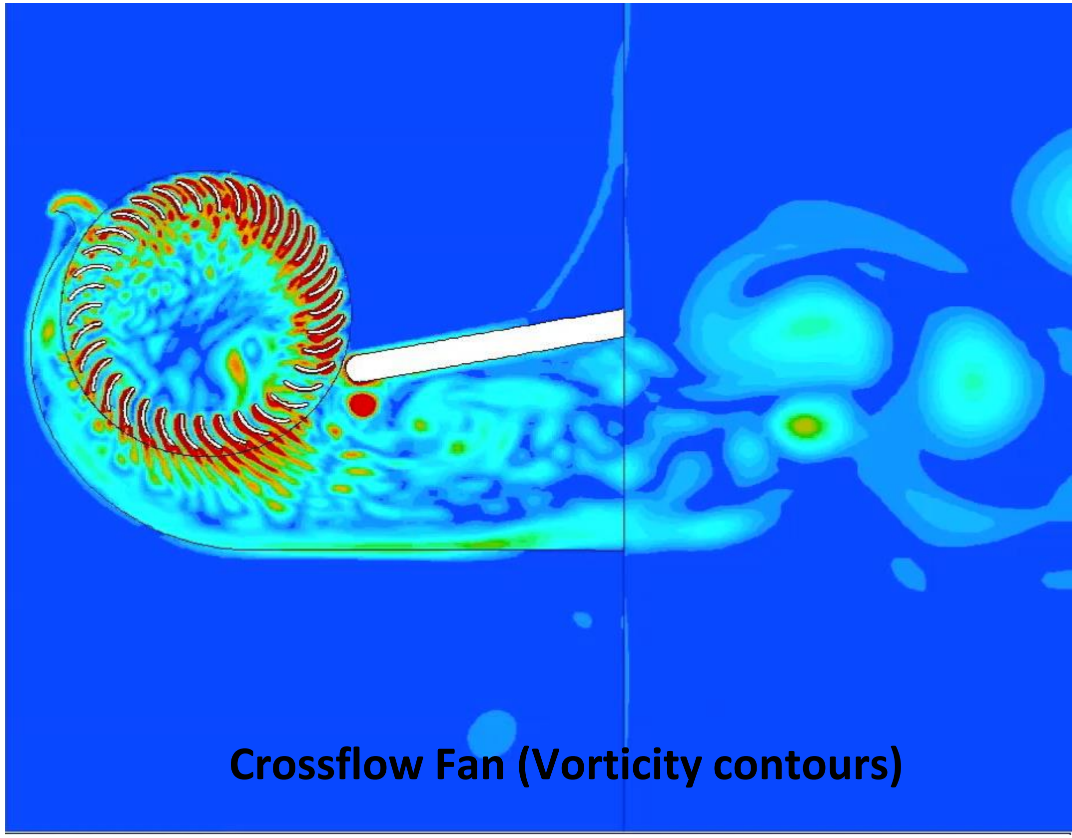
Sliding Mesh Model (SMM)

Sliding Mesh Model (SMM) - Fluent

- In Fluent, the Sliding Mesh Model (SMM) capability is used for performing transient simulations of single stage and multi-stage machines
- In Fluent SMM, a generalized moving mesh formulation is employed
  - The mesh node locations are updated according to the Mesh Motion prescribed for the zone
    - Mesh moves rigidly in space
    - A subset of the general moving/deforming mesh algorithm
  - All interfaces are recalculated as mesh positions are updated
    - Permits partial overlapping interfaces during any part of the mesh motion

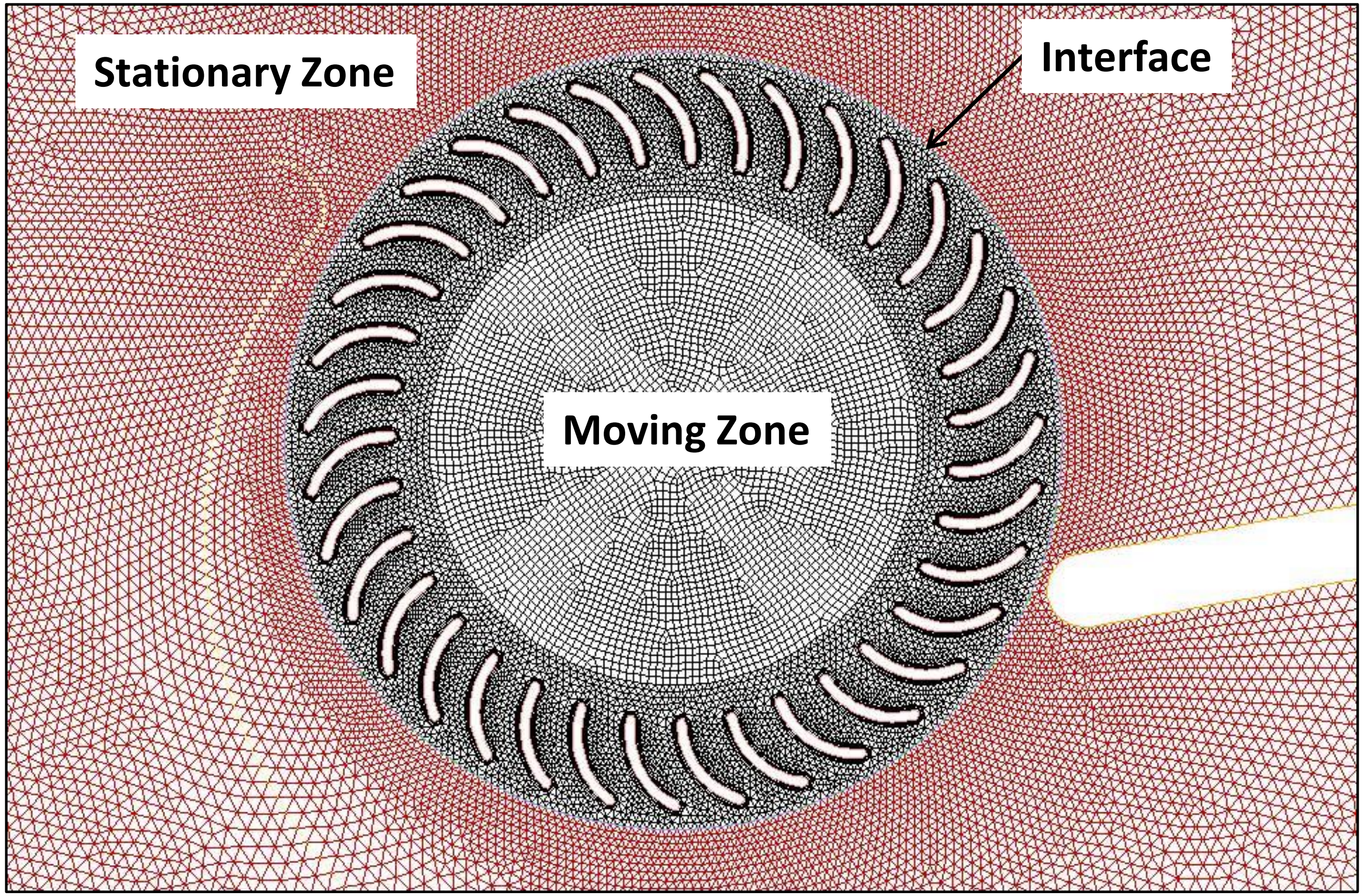
How does the Sliding Mesh Model Work?

- Like the Frozen Rotor and Mixing Plane models, we divide the domain into rotating and non-rotating zones
- The interfaces must be non-conformal, and must adhere to the same restrictions as with the Moving Frame models
  - interfaces must be surfaces of revolution about the axis of rotation
- Unlike the Moving Frame model, the cell zones move relative to one another, and thus the problem is inherently unsteady



Crossflow Fan (Vorticity contours)

Sliding Interface Example

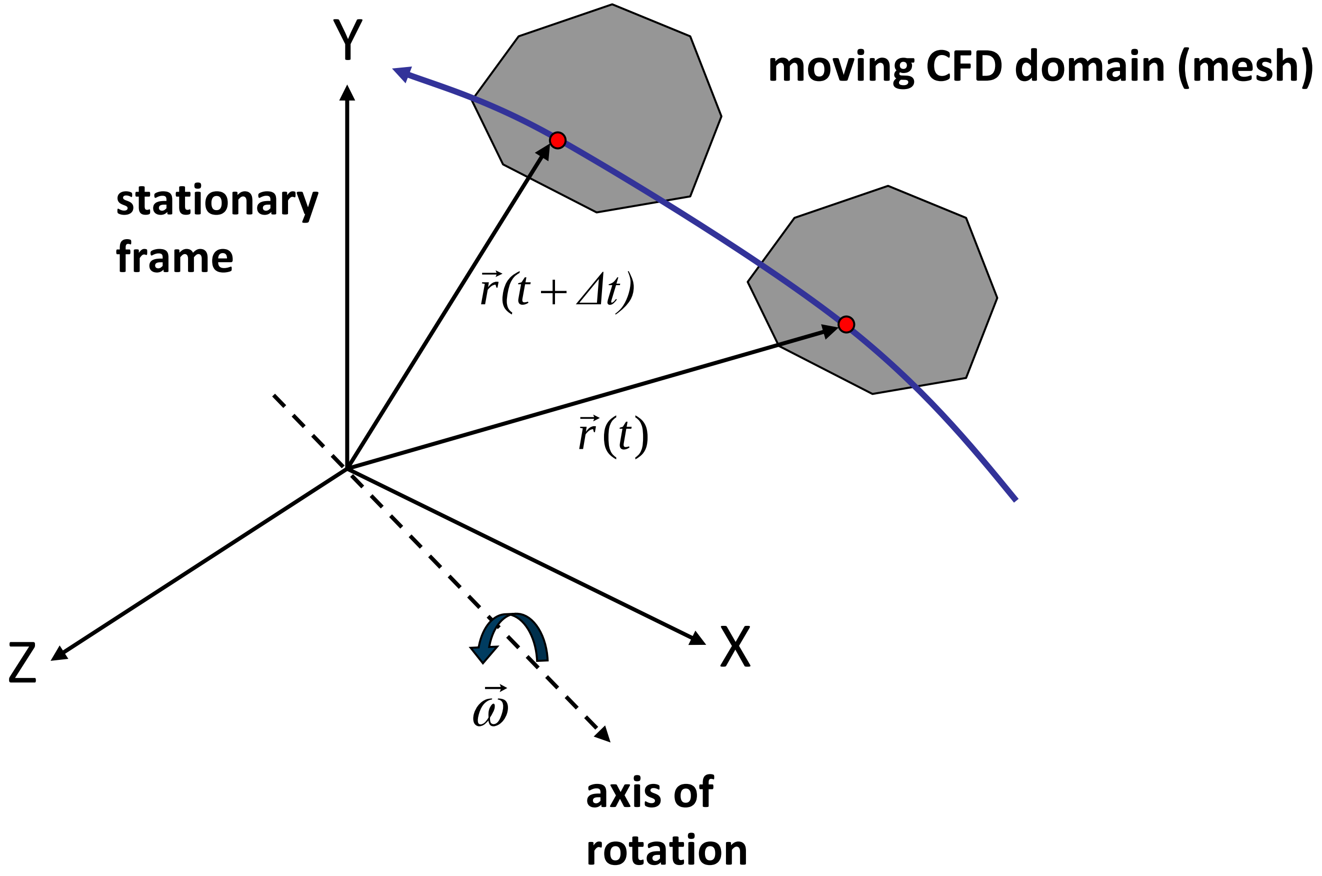


Navier-Stokes Equations: Moving Mesh Formulation

- The sliding mesh model in FLUENT uses the general moving mesh formulation
  - The motions of moving zones are tracked relative to the stationary frame
  - Meshes do NOT deform, but remain rigid throughout the range of mesh motion
  - Flux transfer occurs across the (sliding) mesh interfaces
  - NOTE: No moving reference frames are used!
- The motion of any point in the domain is given by a time rate of change of the position vector $\dot{\vec{r}}$
  - $\dot{\vec{r}}$ is also known as the grid speed
  - Note that for rigid body rotation of the mesh at constant speed

$$\dot{\vec{r}} = \vec{\omega} \times \vec{r} = \vec{U}$$

Moving Mesh Illustration



Moving Mesh Equations (1)

$$\frac{d\rho}{dt} + \nabla \cdot \rho(\vec{V} - \vec{U}) = 0$$ **(Continuity)**

$$\frac{d\rho\vec{V}}{dt} + \nabla \cdot \left[\rho\left(\vec{V} - \vec{U}\right) \otimes \vec{V}\right] = -\nabla p + \nabla \cdot \bar{\tau} + \vec{F}_b$$ **(Momentum)**

$$\frac{d\rho e_t}{dt} + \nabla \cdot \rho\left(\vec{V} - \vec{U}\right)e_t = \nabla \cdot \left(k\nabla T - p\vec{V} + \bar{\tau} \cdot \vec{V}\right) = \vec{F}_{\mathrm{b}} \cdot \vec{V} \ + \dot{\mathrm{Q}}_{\mathrm{g}}$$ **(Energy)**

Moving Mesh Equations (2)

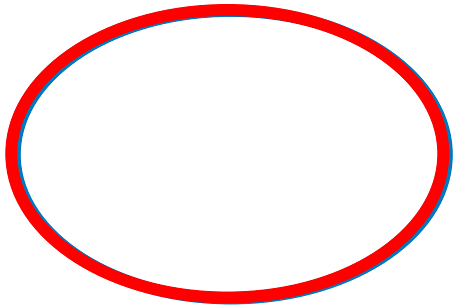
- The time derivative (d/dt) represents differentiation with respect to time following the moving control volume
- All spatial derivatives computed relative to the stationary frame
- Grid related variables are now functions of time since the mesh is moving
- Same equations are used for the Moving/Deforming Mesh (MDM) model in Fluent, except that with MDM, the mesh points have the additional freedom to move relative to each other
  - Hence, the Sliding Mesh model is a subset to the more general MDM model.
- Note that the mesh motion can be constant speed or accelerating – the equations accommodate both situations

Sliding Mesh Model Characteristics

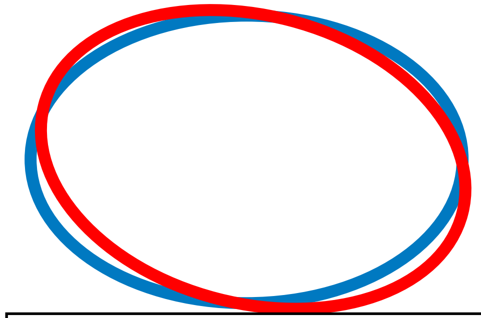
- Advantages
  - Provides the most accurate description of the flow field for situations where unsteady interactions are present
  - Can handle multiple rotating domains, each with their own unique rotational axes and speeds
  - Uses non-conformal mesh interface capability, thus enabling you to easily switch between cell zone Frame Motion and sliding mesh
- Disadvantages
  - Solution is always unsteady (even if steady solution exists in rotating frame)
  - Unsteady solutions require more CPU and disk space than steady-state solutions

Sliding Interface Rules

- Sliding interfaces are simply non-conformal interfaces which are updated as the meshes move
- They must therefore follow the same rules as Moving Reference Frame problems with non-conformal interfaces:
  - The interface between a rotating zone and the adjacent stationary/rotating zone must be a surface of revolution with respect to the axis of rotation of the rotating zone
- Many failures of sliding mesh models can be traced to interface geometries which are not surfaces of revolution!



“warped” interfaces aligned at initial time level...



...become misaligned at a subsequent time level!

Sliding Mesh Model Setup and Solution

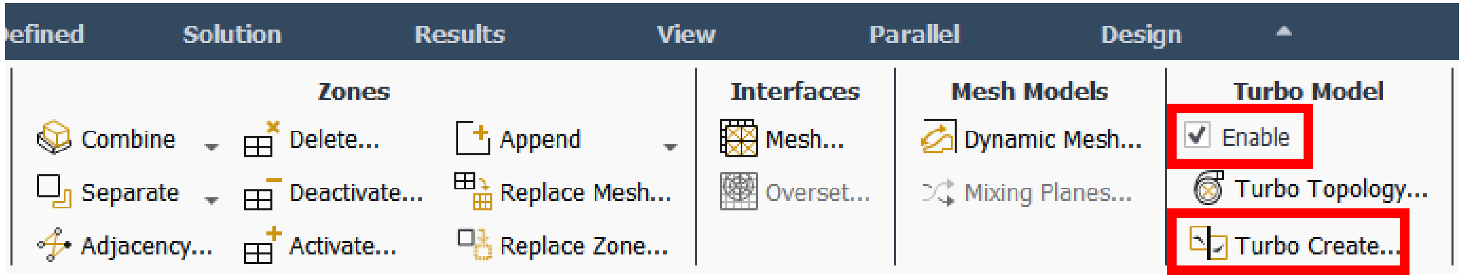
Sliding Mesh Setup, Steady-State Precursor Simulation

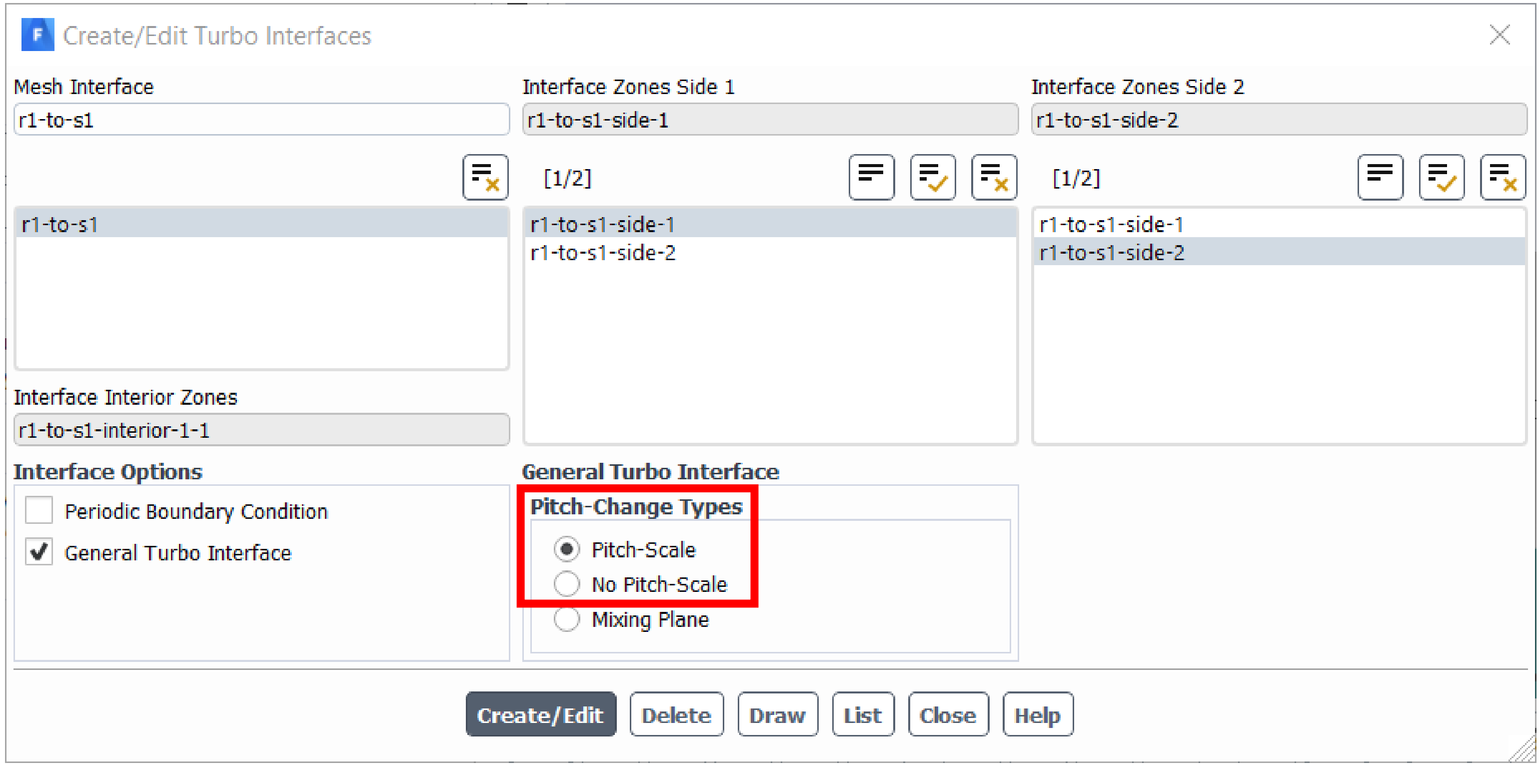
- Create a precursor, steady-state, Frozen Rotor case
  - All settings for any rotating component and all general physics and solver settings should follow the rules and best practices given in lecture 02 “Single Rotating Component Analysis”
    - Operating conditions
    - Gravity
    - Turbulence model
    - Energy equation
    - Rotation axis
    - Periodic interfaces
    - Boundary conditions
    - Generalized Turbo Interfaces (see also next slide)
    - Solver settings
    - Initialization procedure
    - Time scale factor
    - Report plots
    - …

It is always a good idea to run this steady case, as a precursor steady-state run is a good initial condition for a transient run with the same conditions

Sliding Mesh Setup, General Turbo Interface

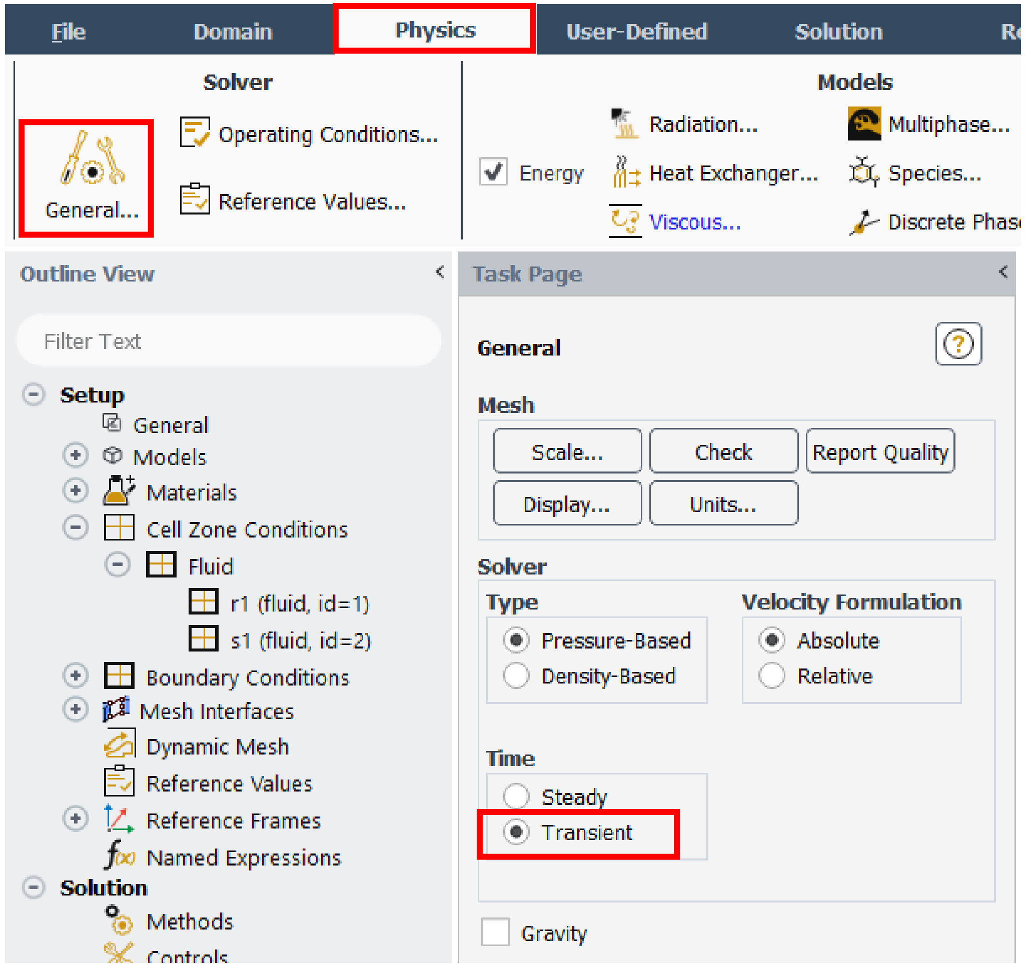
- All settings for the General Turbo Interfaces (GTI) should be made according to the best practices and methods from lecture 04 “Multi-Component Analysis – Steady”
  - For the precursor case, always use a pitch-scale or a no-pitch-scale GTI option (depending on the pitch ratio)





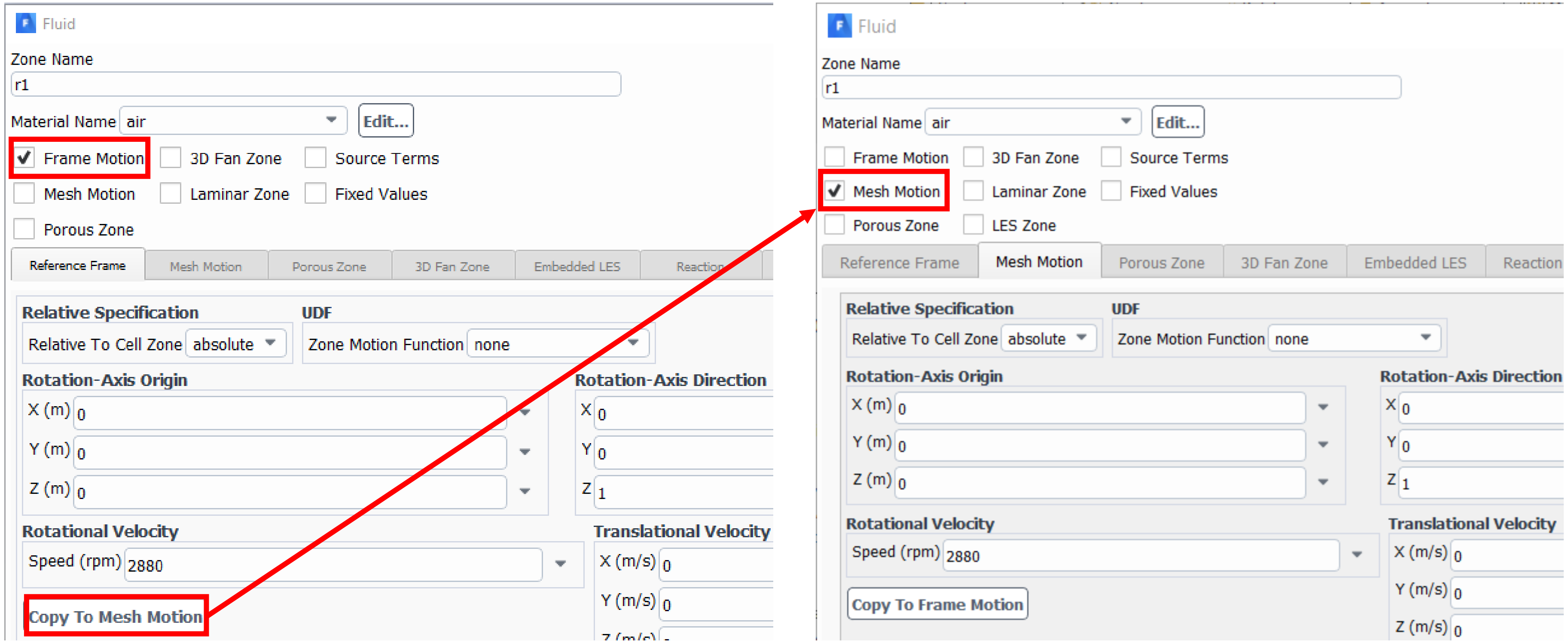
Sliding Mesh Setup, Transient Solver

- Activate the transient solver
  - Physics tab > General > Transient



Sliding Mesh Setup, Mesh Motion

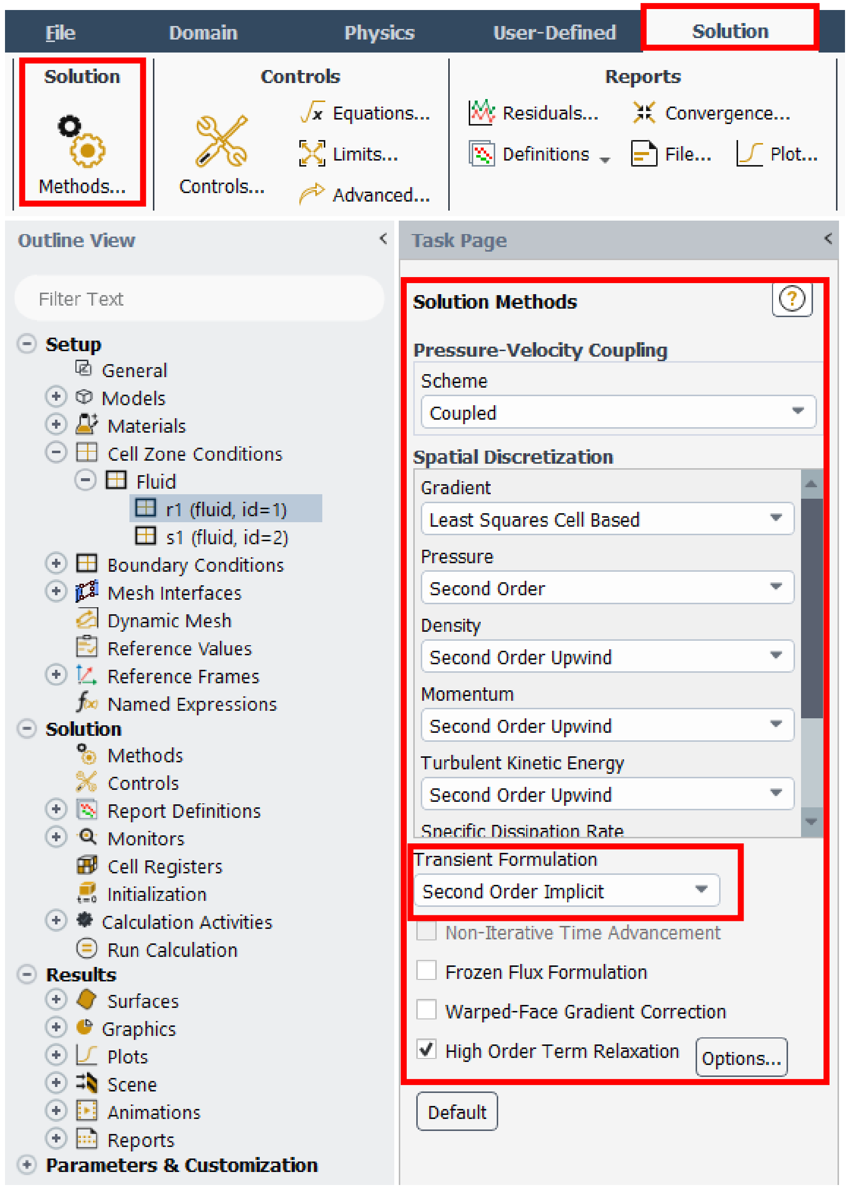
- For each rotating zone, select the “Mesh Motion” option in the Cell Zone Conditions panel
  - When starting from a steady-state setup, you can edit any zone with Frame Motion and use the “Copy to Mesh Motion” button



Sliding Mesh Setup, Transient Solver Settings

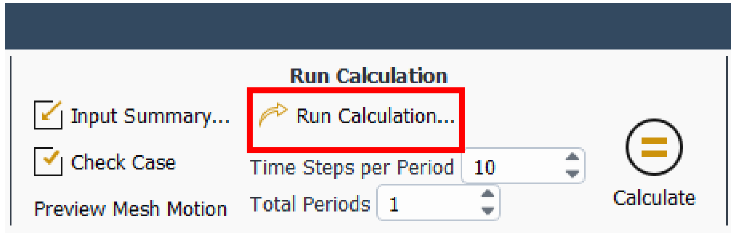
- Solution Methods
  - All basic settings as in the steady state precursor simulation

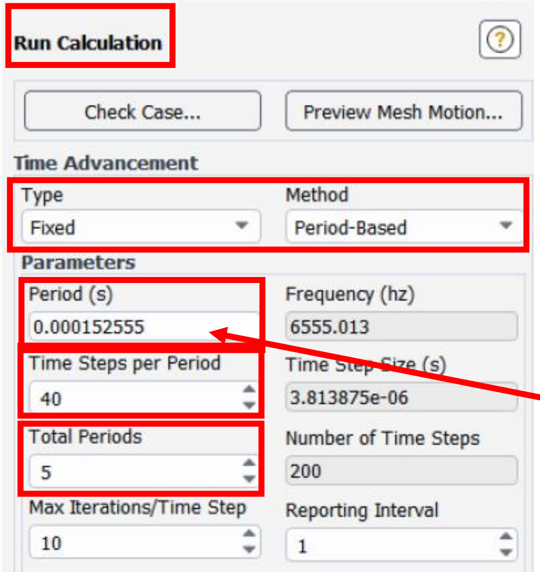
- Transient Formulation
  - Second Order implicit time discretization is recommended for more accurate results



Sliding Mesh Setup, Time Step Selection

- Select appropriate Time Step
  - In the Run Calculation panel set “Time Advancement” to “Fixed”, “Period-based”
  - Set the passage “Period”
  - Give a sufficient number of “Time Steps per Period”
    - At least 20-40
  - Set number of Total Periods
  - Leave Max Iterations/Time Step to 10
    - If the solver does not converge in 10 iterations per time step, consider decreasing the time step rather than increasing the Max Iterations per time step



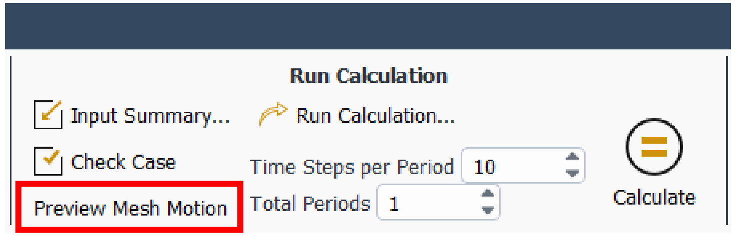


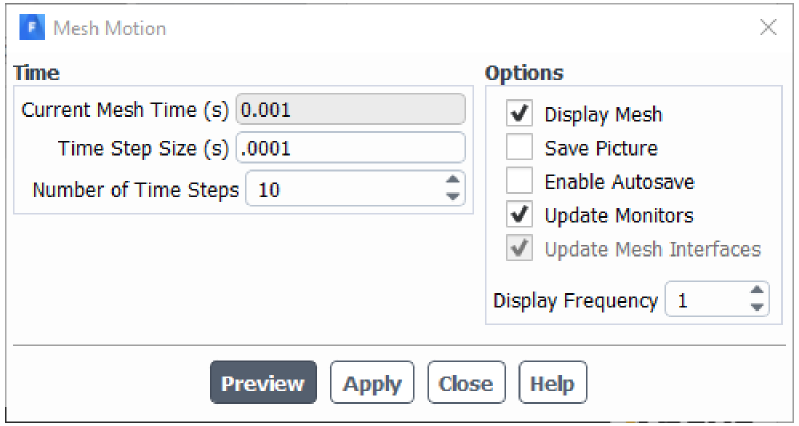
Example passage period: For a 23-blade rotor, running at 17100 (rpm) the passage period is 60 /(17100 *23)=1.5255E-4(s)

Sliding Mesh Preview

- Fluent provides a sliding mesh preview option for checking sliding mesh motion before beginning the calculation
- To use this facility:
  - Specify the time step and number of time steps (see previous slide)
  - Click on Preview Mesh Motion
- You can display the grid motion and optionally save hardcopy images of the grid motion for later animation

NOTE: Save your initial case and data files prior to running Mesh Preview so you can start from your original mesh positions



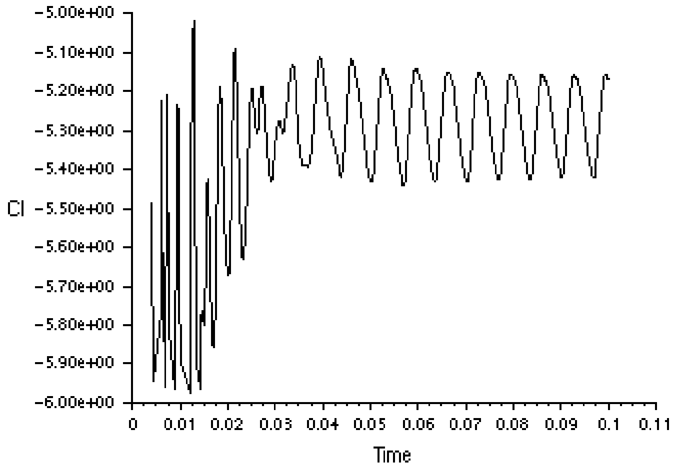


Ansys

Running Transient Rotor Stator Problems

- Advance the solution until the flow becomes time-periodic (pressures, velocities, forces etc. oscillate with a repeating time variation)
  - Usually requires several revolutions of the grid for rotating machinery cases
- Data Sampling for Time Statistics can be enabled to have Fluent save time-averaged flow field variables
- Save intermediate files
  - Solution tab > Activities > Autosave
- Create solution animations
  - This is shown in the Fluent Getting Started course in the ”Vortex Shedding” workshop of the “Transient Flow Modelling” module

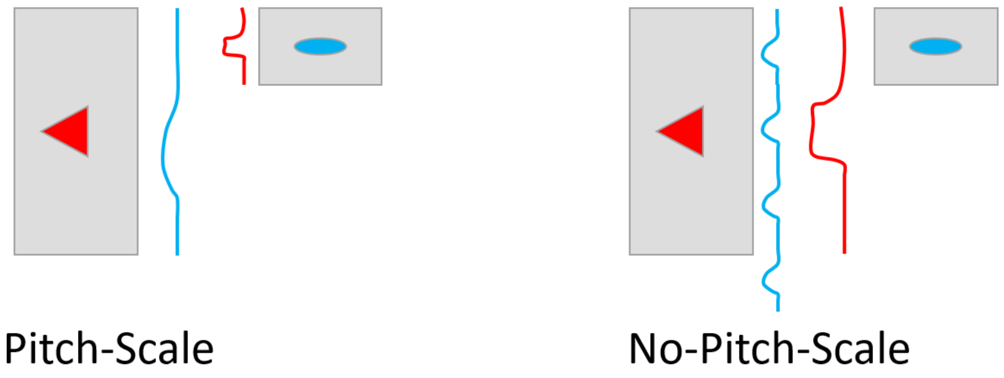
Time Periodic Flow

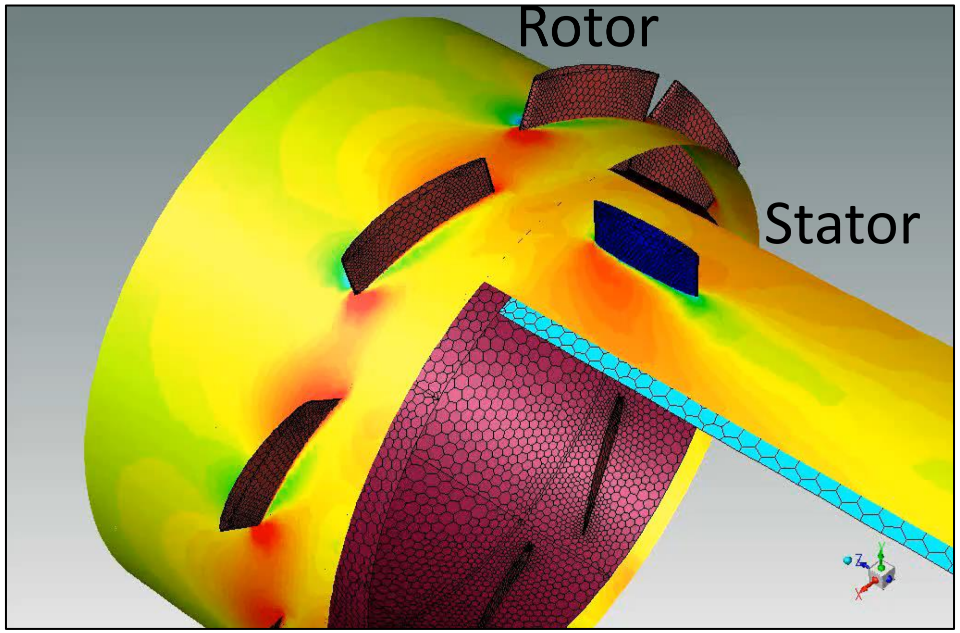


Use of GTI for Transient Rotor Stator Simulations

- Both Pitch-Scale and No- Pitch-Scale GTI methods are available for the Transient Rotor Stator

- Pitch-Scale is available for pitch-ratios <2
- Use No-Pitch-Scale for
  - Connecting 360 to 360 interfaces
  - pitch-ratio > 2
    - Suitable for connecting even a 360 degrees blade row with one stator blade passage

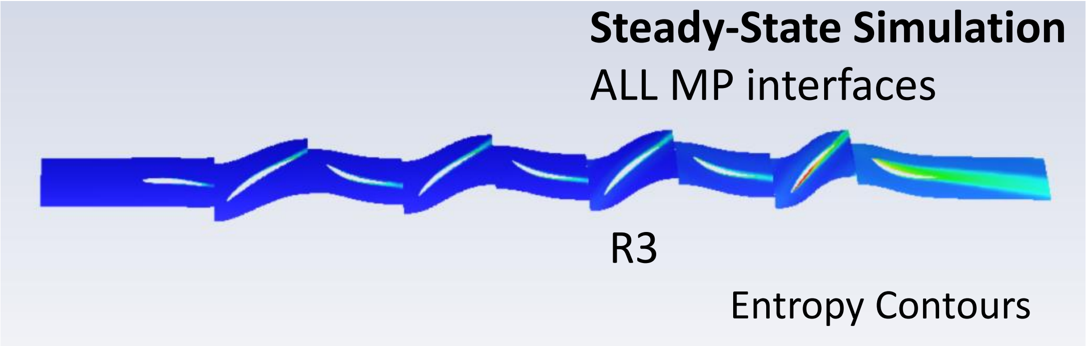


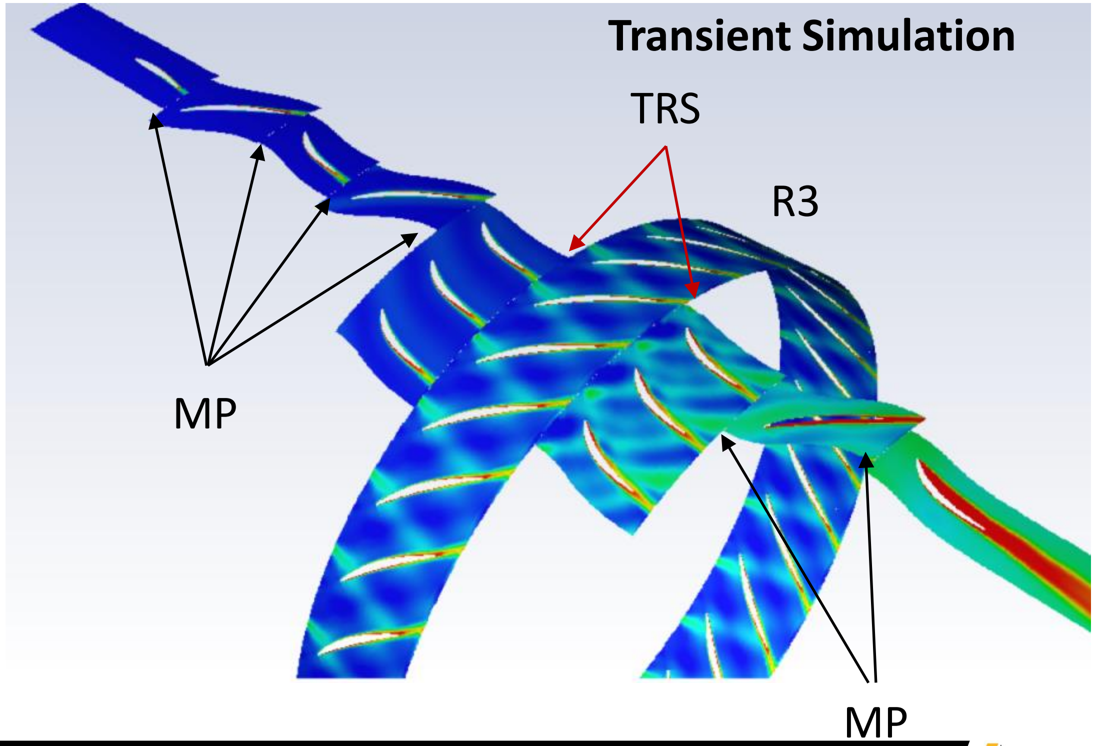


Use of GTI for Transient Rotor Stator Simulations (2)

- Ability to use Mixing Plane (MP) & Transient Rotor Stator (TRS)
- Simulation Process:
  - Run steady-state solution with only MP interfaces
    - Single passage per blade raw
  - Change MPs on R3 to (PS or NPS) interfaces
  - Switch solver from steady to transient simulation
    - Change R3 Fluid Zone motion from Frame motion to Mesh motion
    - Use: Fixed timestep, Period-Based with period equal to R3 passage period
    - Calculate solution

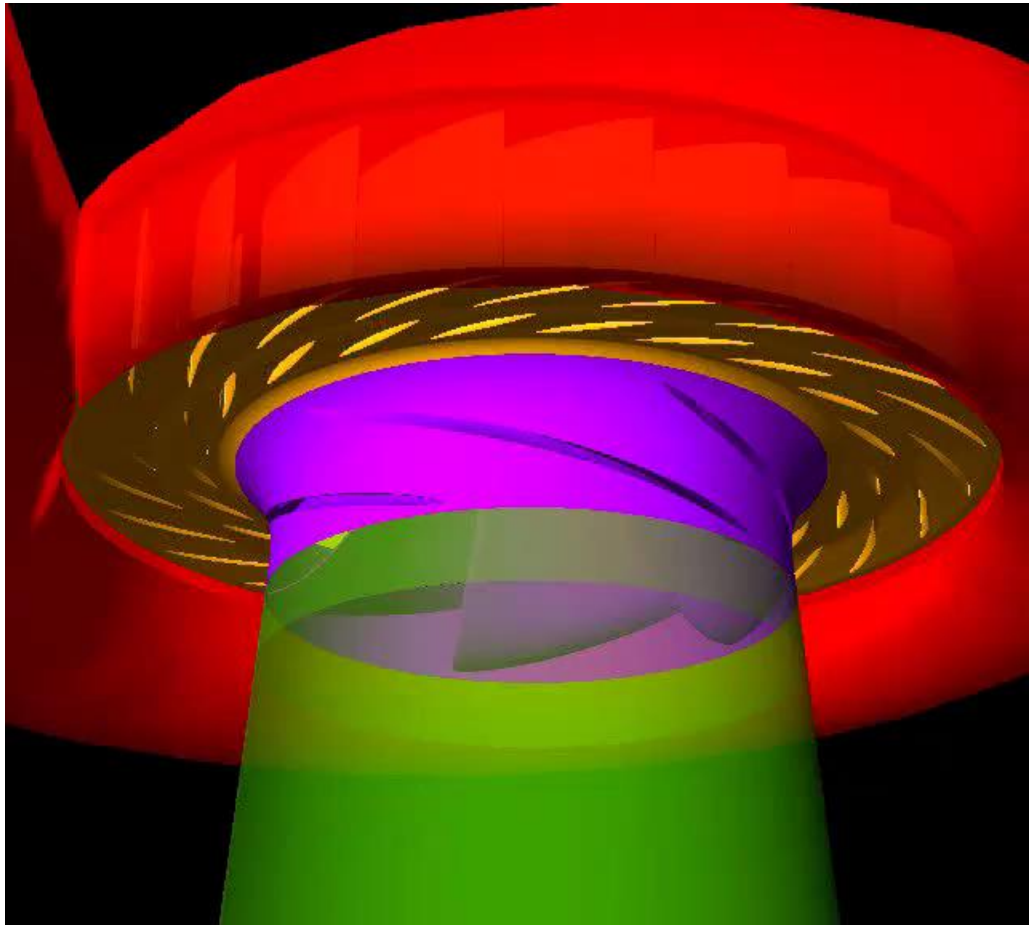
Hannover 4.5 stage compressor





Summary

- Unsteady Modeling provides the most accurate description of flows involving both stationary and rotating zones
  - Unsteady interaction in captured with no approximations at the interfaces
- The cost for doing this is the increased CPU time required for the unsteady solution
  - Run unsteady simulations only when you really need the transient interaction between components
- Sliding Mesh Method in Fluent is very easy to set up using a precursor case with Frame Motion
  - Use the precursor Frame Motion result as an initial condition for the sliding mesh calculation
  - Set time step using a fixed “Period-based” option and at least 20-40 timesteps per passage period
  - New General Turbo Interface provides a flexible and efficient framework for various combinations
    - Can handle large pitch ratios (e.g., connect 360 deg with one passage)
    - Combine steady state Mixing Plane with Transient Rotor Stator in a multi-stage machine



End of presentation