COMSOL CONFERENCE INDIA 2012

Effects of Structural Forces on the Dynamic Performance of High Speed Rotating Impellers.

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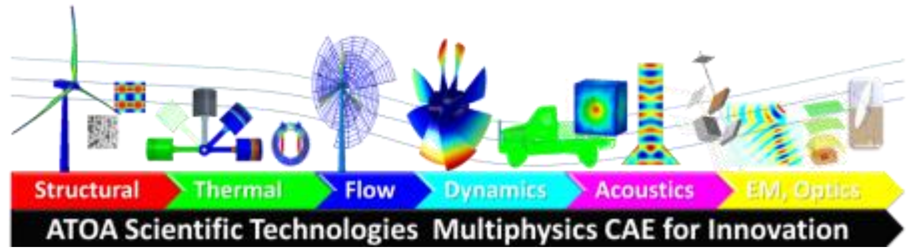
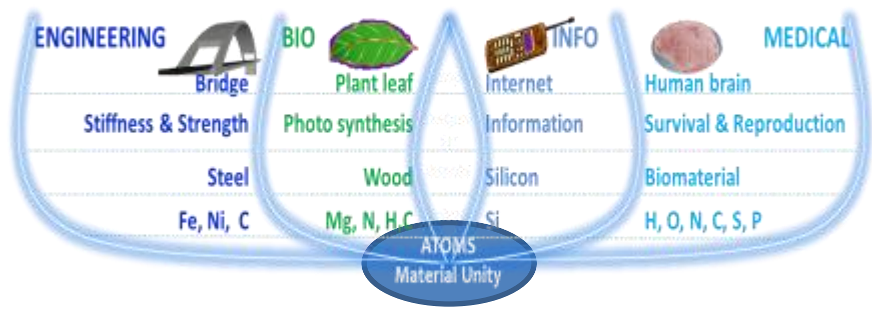
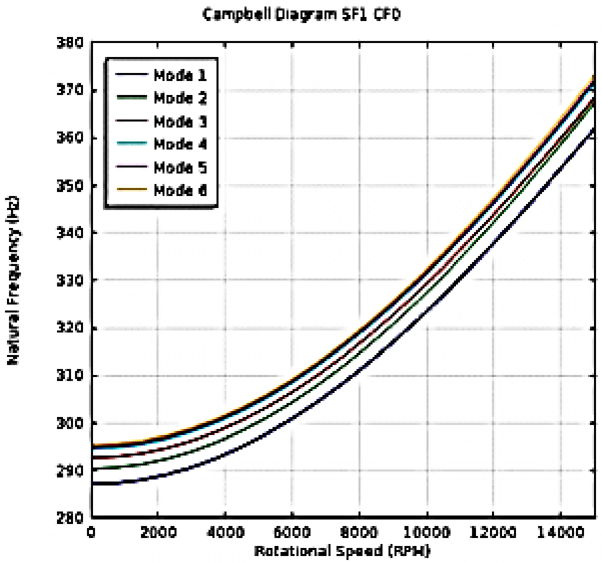




Introduction

- Rotor dynamics- Applied Mechanics-Study of Behavior and Diagnosis of Rotating Structures.
- Includes Rotating Structures - Jet engines, Gas Turbines, Pumps- Computer Storage Disk, Micro Turbines.
- Rotating-Rotor, Supporting Stationary-Stator.
- Campbell Diagram-Plot of Whirl Freq. vs Spin Speed.

Pic- Gas Turbine source- wikipedia.org



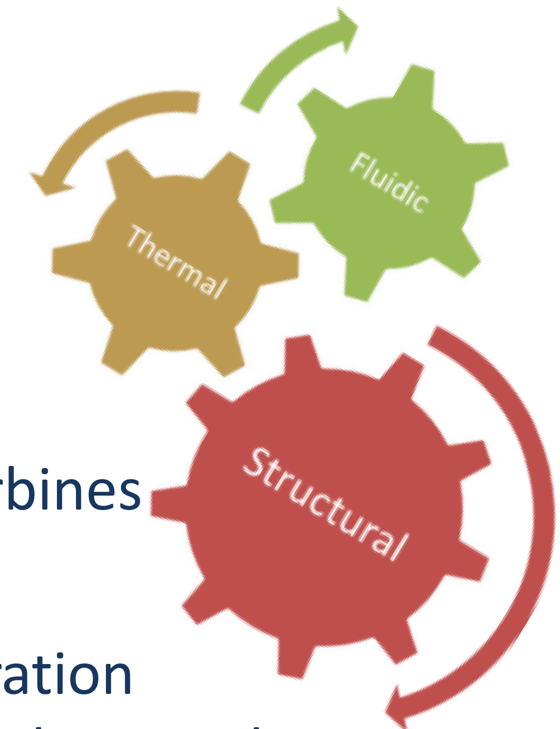
ROTOR DYNAMICS LOADS

- Traditional Rotor dynamics - Linear Structural Loads- Dominant.

For safe and efficient performance

- Nonlinear Structural Loads
- Thermal Loads
- Fluidic Load

Application- Micro and High Performance Turbines



- Objective- “To Evaluate Dynamic And Vibration Performance Of High Speed Rotors Efficiently Considering Coriolis Forces With Centrifugal Force”.

Multiphysics Rotor Dynamics

- Beam and Shell elements used in Most common Traditional Rotor Dynamics softwares.
- For Complex Geometry - 3D Rotor Dynamics- For improved accuracy. Eg. Impeller
- 3D rotor dynamics
  - The stress stiffening and softening effects
  - Coupling effects of shaft and rotor
  - Actual and Accurate geometry based modelling

  can be leveraged.
- 3D CAD geometry based Multi Body Rotor Dynamics - for accurate performance prediction.

Governing Equations

- Fundamental Physical Law governing Vibration- Newton's Second Law.
- DE- The Force Balance Equation- Linear Dynamic System - First Principle Motion Equations.
- Linking The Inertial, Damping, Elastic And External Forces, Along With Mass, Damping And Stiffness Properties, As Given Below

$$m\ddot{x} + c\dot{x} + kx = f(t)$$

Where,

[K], Global stiffness matrix

[x], Displacement vector of all the nodes

[C], Global Damping matrix

$$[M][\ddot{x}]+[C][\dot{x}]+[K][x]=[R]$$

$[\dot{x}]$, Velocity vector

[M], Global Mass matrix

$[\ddot{x}]$, Accelerati on vector

[R], Global force or load vector, where, R is f(t)

Comsol Implementation

- To calculate Centrifugal Force **(F_{cent})** and Coriolis Forces **(F_{cor})** following eqn

$$F_{cent} = -\rho\Omega^2 \mathbf{e} \times \mathbf{e} \times (\mathbf{r} - \mathbf{r}_0)$$

$$F_{cor} = -2\rho\Omega \mathbf{e} \times \mathbf{v}$$

$$F_x = -\rho\Omega^2(e_y(e_x y' - e_y x') - e_z(e_z x' - e_x z')) - 2\rho\Omega(e_y v_z - e_z v_y)$$

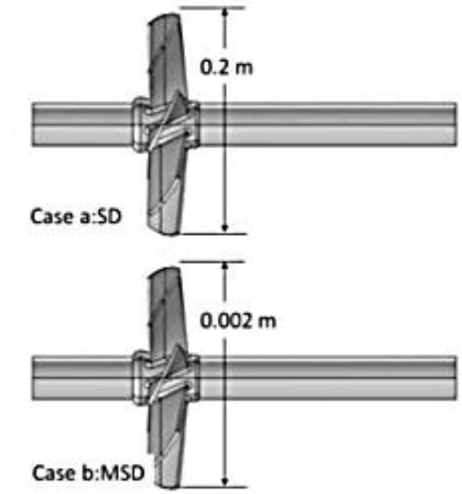
$$F_y = -\rho\Omega^2(e_z(e_y z' - e_z y') - e_x(e_x y' - e_y x')) - 2\rho\Omega(e_z v_x - e_x v_z)$$

$$F_z = -\rho\Omega^2(e_x(e_z x' - e_x z') - e_y(e_y z' - e_z y')) - 2\rho\Omega(e_x v_y - e_y v_x)$$

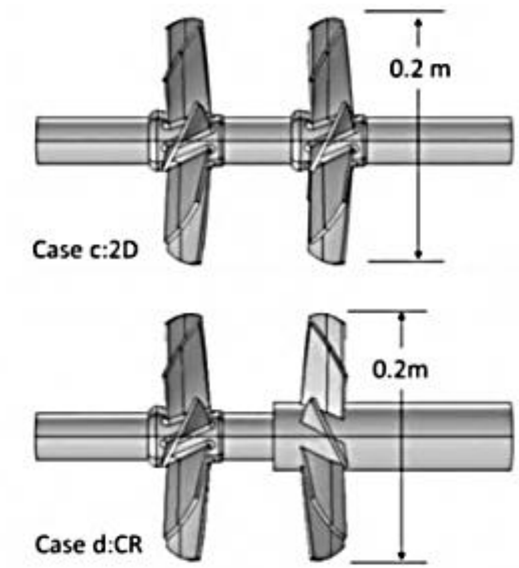
Where

- **'Ω'** fixed angular velocity for a system rotating about a fixed unit-length axis **'e',**
- **'r'** and **'v'** are the position and velocity of a material element, respectively,
- **'ρ'** is its density and **'r_0'** is any point on the axis of rotation. The model rotational axis is **'z'** for this simulation

Design of Experiment



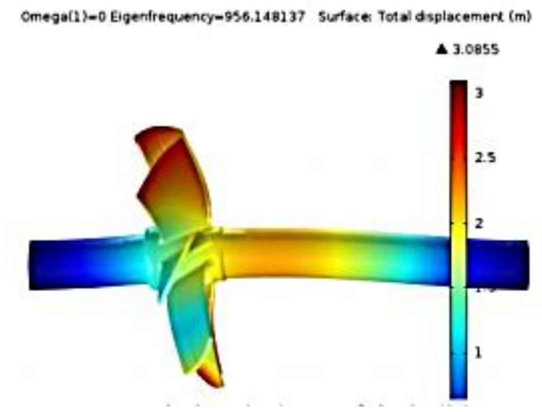
- Case a: Single disk rotor,
- Case b: Micro single disk rotor,
- Case c: Double disk rotor,
- Case d: Counter Rotating Rotor

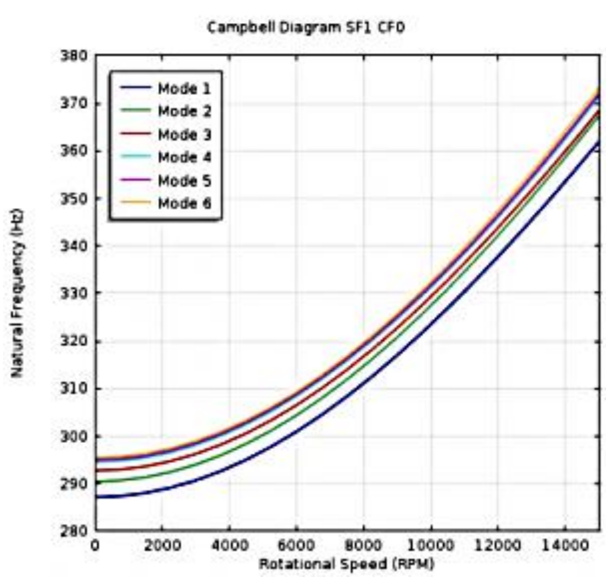


- Assumption-Rigid Bearing and Flexible Shaft/Rotor.
- The vibration characteristics- for a rotational speed about 15000 RPM. (75000RPM-MicroTurbine).

Design of Experiment

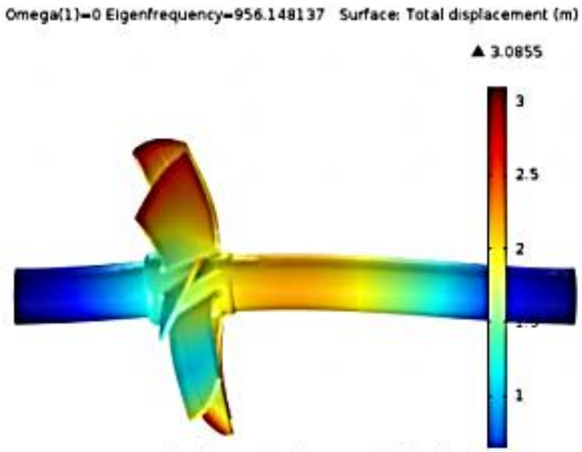
- Determine the natural frequency and mode shapes for critical speeds. Effect of Coriolis force, Scale Effect investigated.
- Total of 8 DOE runs considered for vibration performance evaluation and comparison.
- Using Campbell diagram-Vibration Performance investigated as function of rotating speed.
- These cases were selected to finalize the concept for a new turbine.

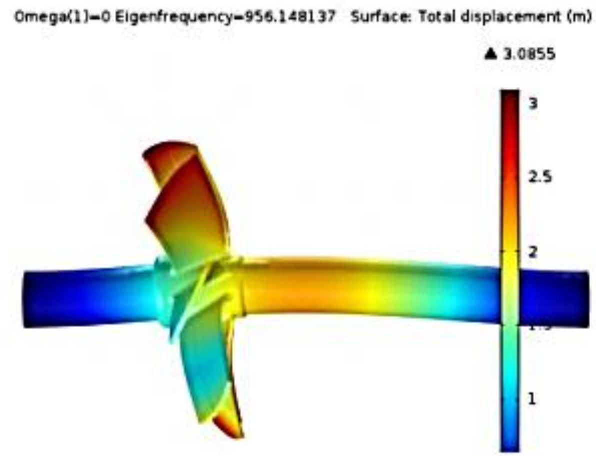


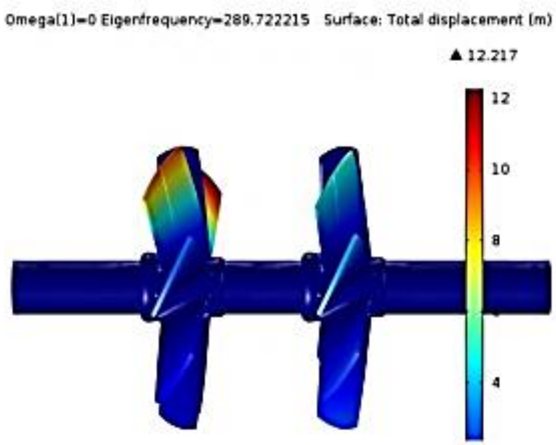


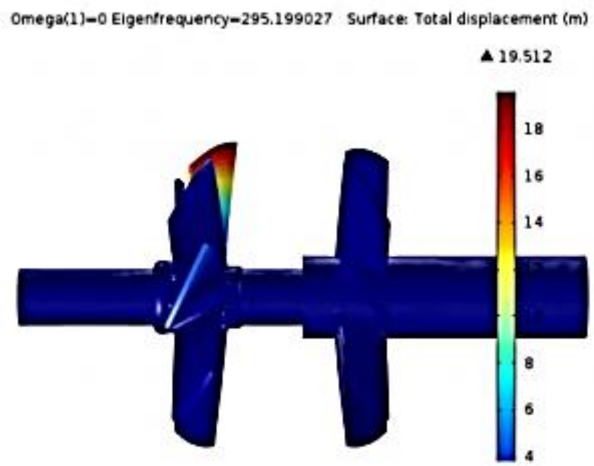
Result and Discussion

Mode Shapes of 4 Cases

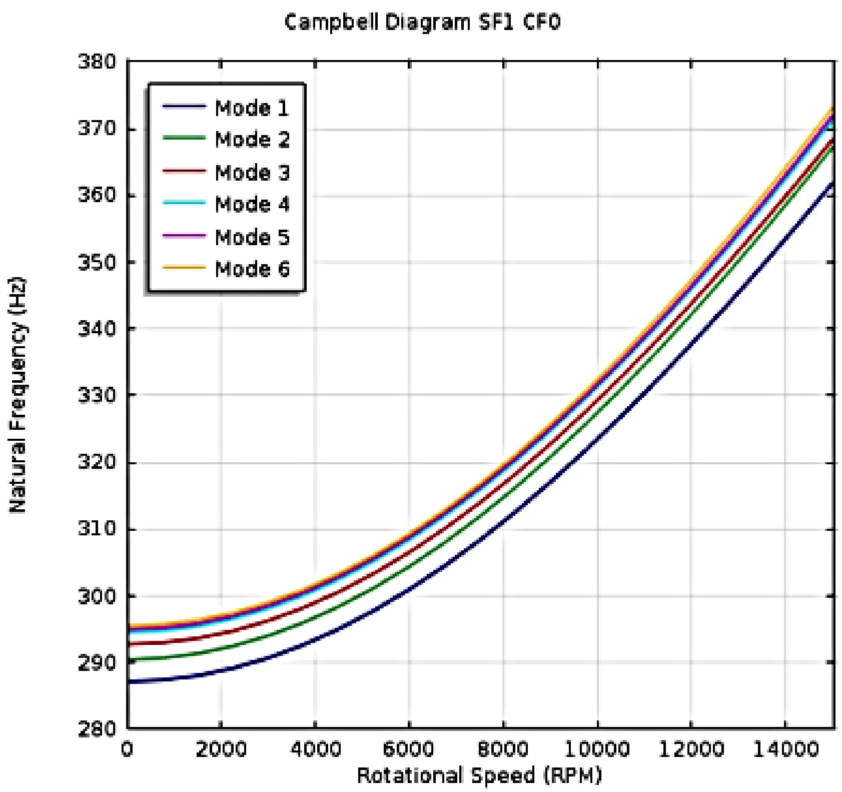




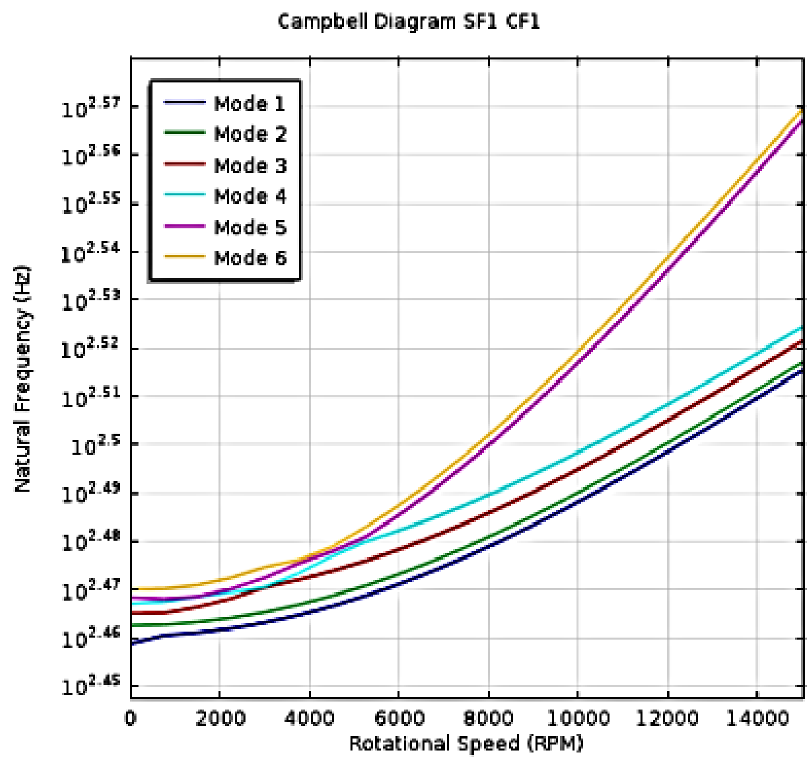




Campbell Diagram of single disk rotor



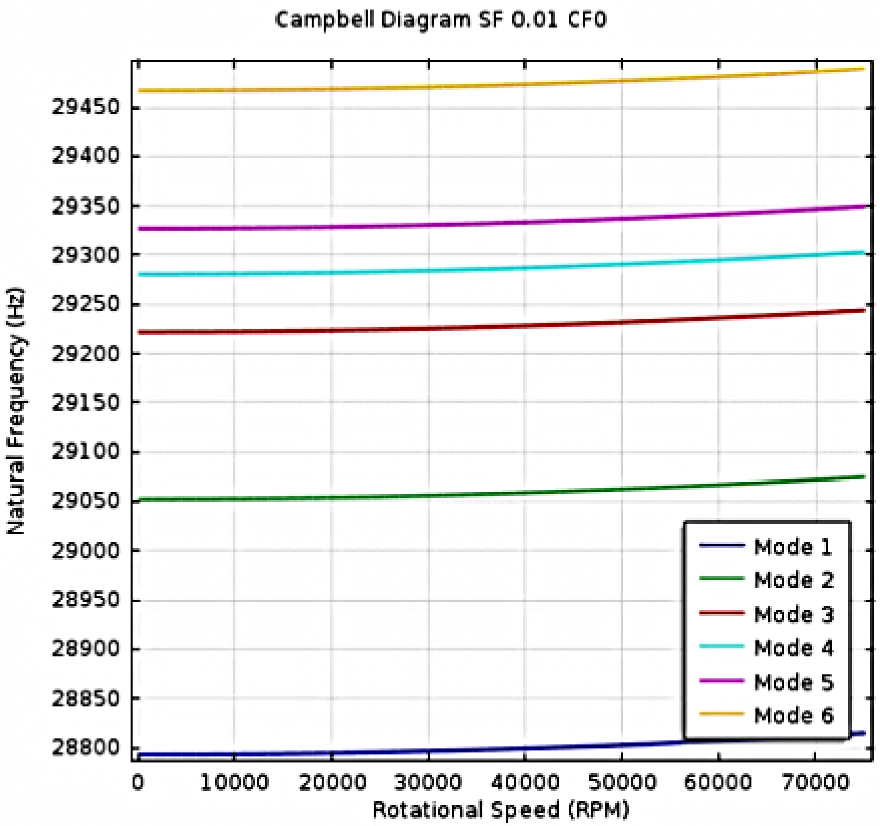
a)without effect of Coriolis forces



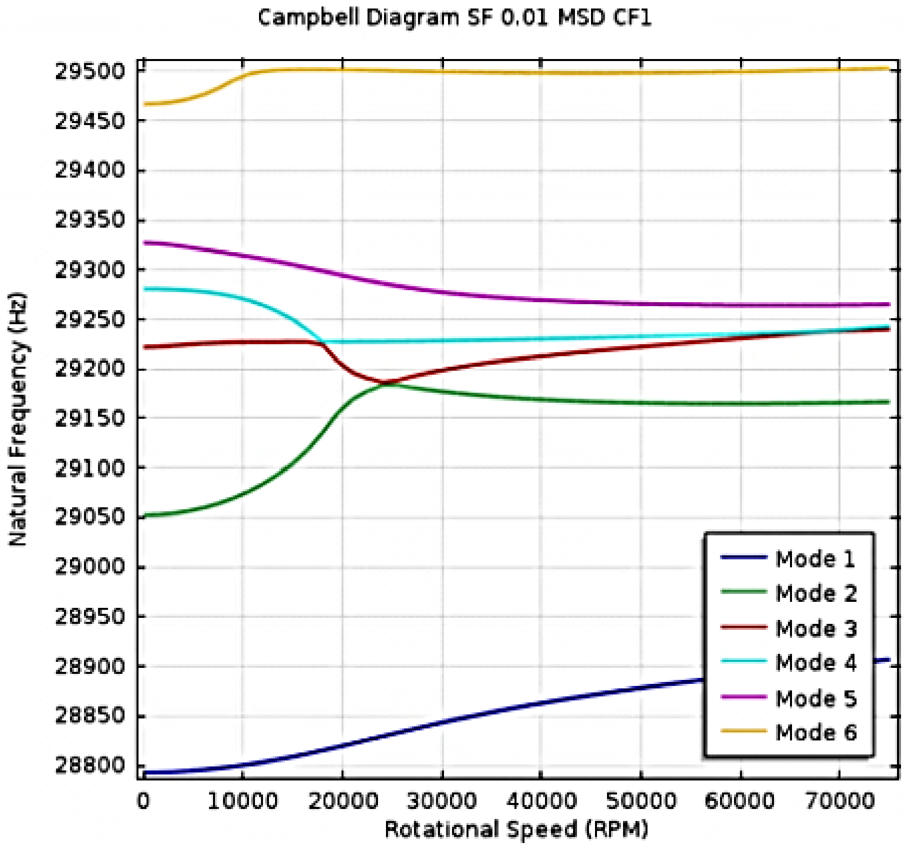
b)with the effect of Coriolis forces.

- Change in Behavior - High Speed with effect of Coriolis Forces

Campbell Diagram of micro single disk rotor



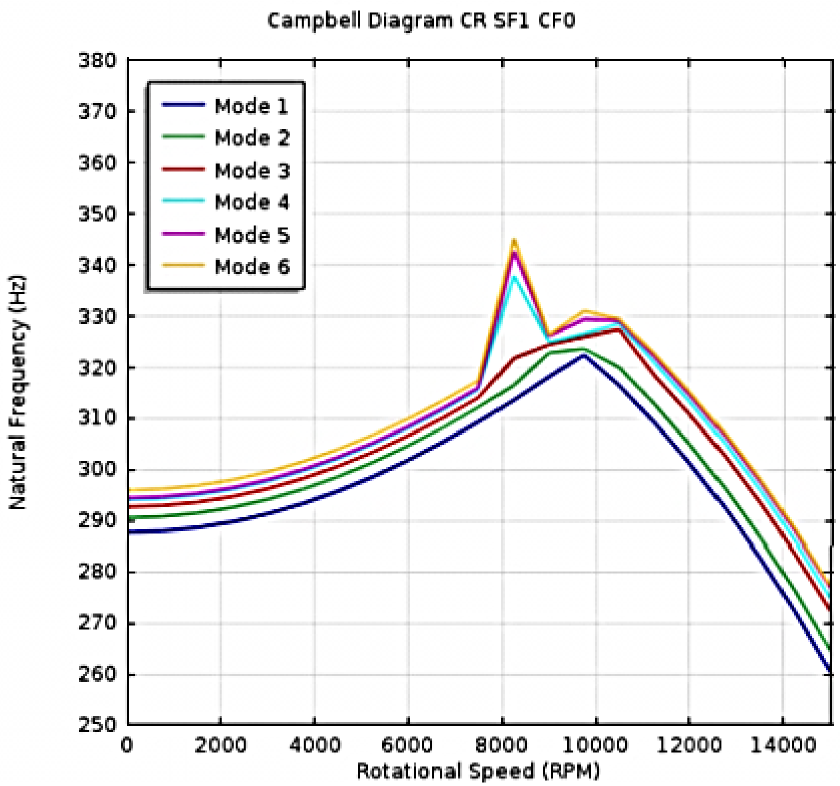
a)without effect of Coriolis forces



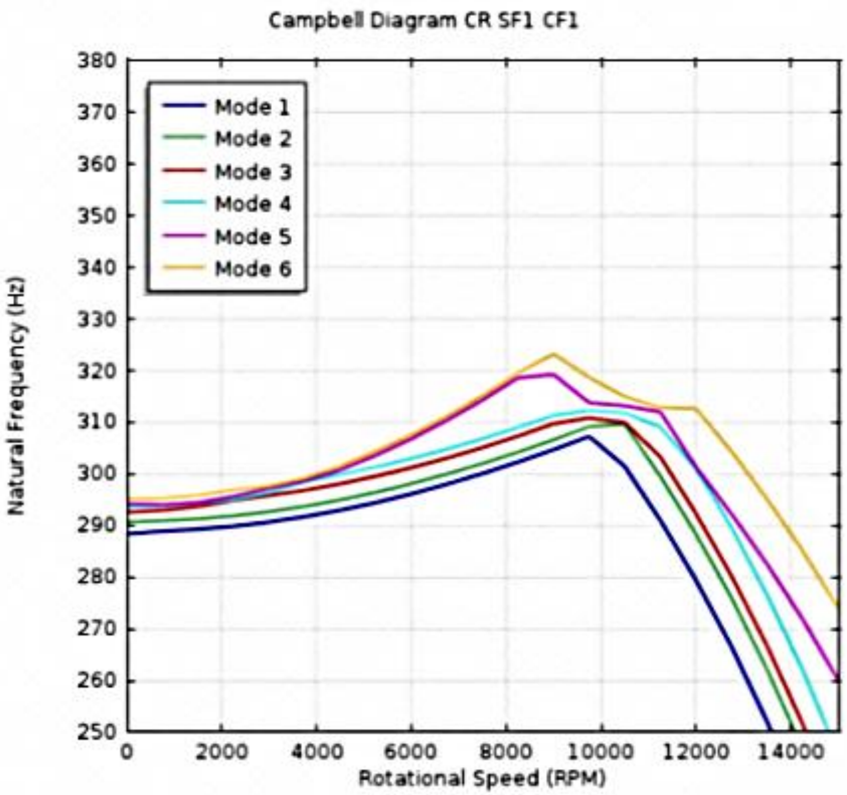
b)with the effect of Coriolis forces.

- Natural frequency almost constant -lower rotational speed without the effect of Coriolis forces.
- With effect of Coriolis forces - significant changes in pattern -increased rotational speed

Campbell Diagram of Counter Rotating disk rotor



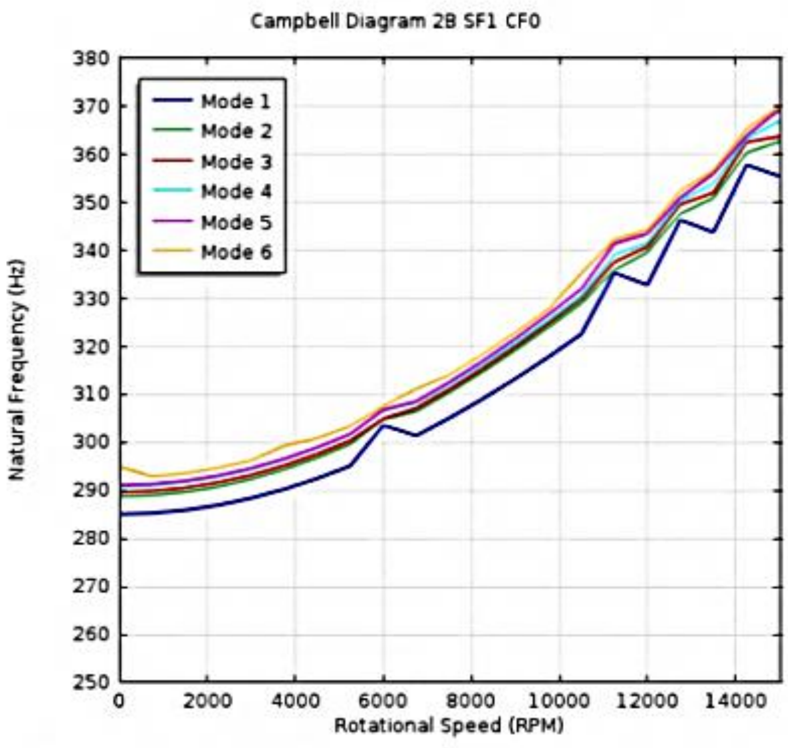
a)without effect of Coriolis forces



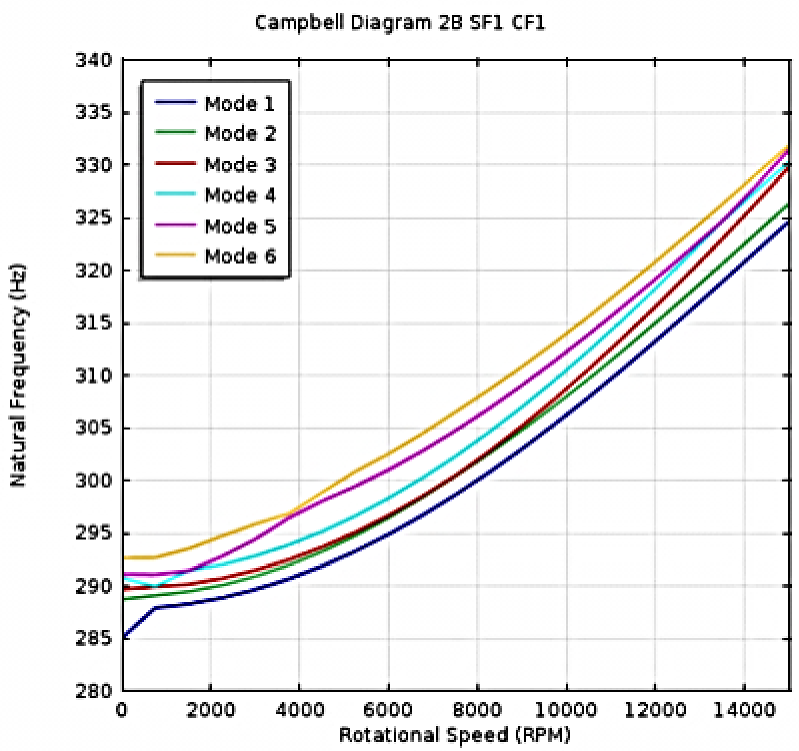
b)with the effect of Coriolis forces.

- Dual frequency behavior observed.
- Coriolis effects observed at high speed

Campbell Diagram of Double disk rotor



a)without effect of Coriolis forces



b)with the effect of Coriolis forces.

- The natural frequency increases with rotation speed.
- The Coriolis force effect at high rotational speed.

Conclusions

- The overall vibration characteristics as a function of structural forces were investigated and reported.
- The single disk rotor was shown to increase frequency with rotation speed.
- The Coriolis forces were shown to lower the frequency at higher rotational speeds.
- The counter rotating disk was shown a dual frequency vs rotation speed behaviour.

Scope for Future Work

- The effect of fluidic (aero and hydro) and thermal forces along with structural forces will be investigated in the future work .

Thank You

Questions??