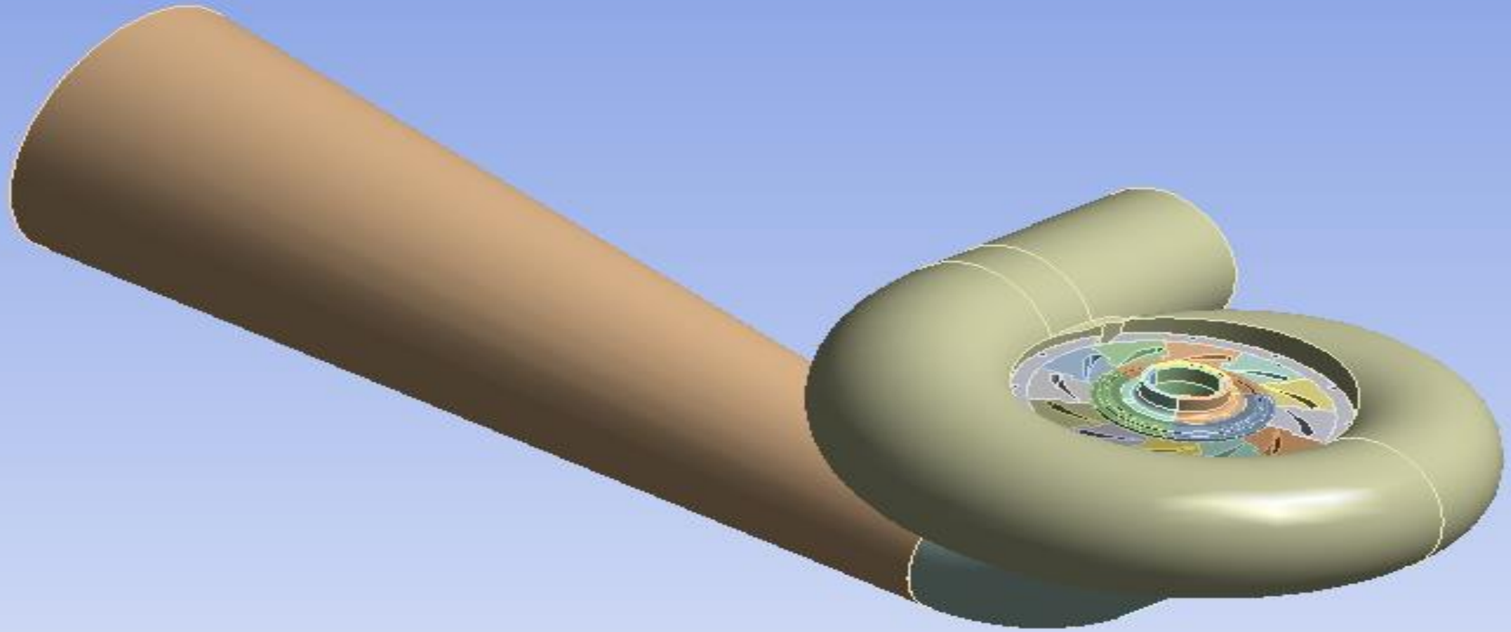

Final Project Presentation Modeling of a Francis Turbine

Authors: Anastasia Candelaria, Amneh Jaber, Basanta Rijal, Nikhil Tiwari, and Richard Aipperspach.

May 8, 2019

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Introductions

- Anastasia Candelaria – ME Graduate Student
- Amneh Jaber – ME Graduate Student
- Basanta Rijal – ME Graduate Student
- Nikhil Tiwari – ME Graduate Student
- Richard Aipperspach – ME Undergraduate Student

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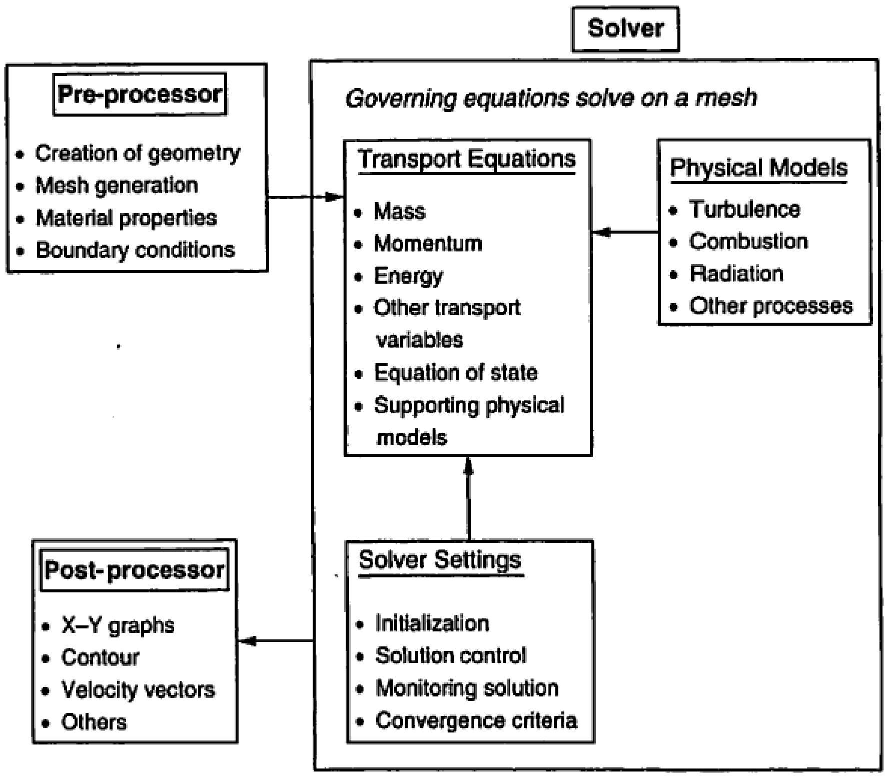
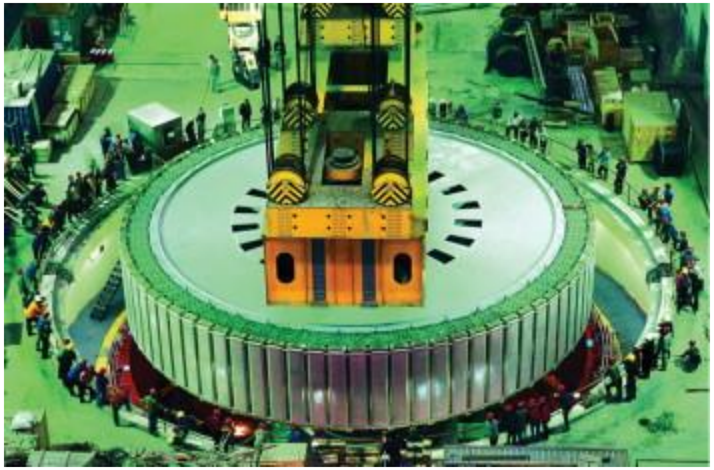
Agenda

- Francis Turbine – Richard
- Problem Description – Richard
- Geometry – Anastasia
- Named Selections – Anastasia
- Interfaces – Anastasia
- Pre-Processing
  - Mesh – Nikhil
  - Set-up
    - Solver Set-up – Basanta
    - Turbo Mode – Amneh
- Post Processing
  - Model validation – Amneh
  - Results
    - Primary – Amneh
    - Mass Inlet Study – Richard
    - Pressure Outlet Study – Richard
  - Conclusion - Basanta

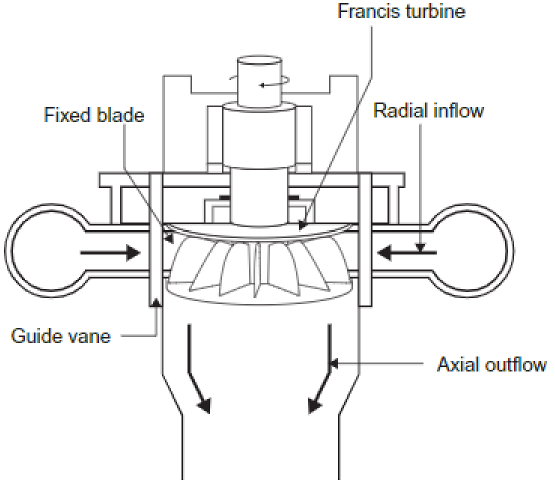


Francis Turbine Background

- Developed by James Bichens Francis [1855]
- Flow enter radial direction and exits axially
- Each turbine designed for a certain set of site conditions
- 90-95% efficient
- Range from 3 to 600 m head
- Most efficient 100 to 300 m head
- Flow rate is the limiting factor
- GE has 800MW turbine with diameter of 10 meters and 450 tons



https://www.sciencedirect.com/topics/engineering/francis-turbines



http://www.pewclimate.org/technology/factsheet/hydropower

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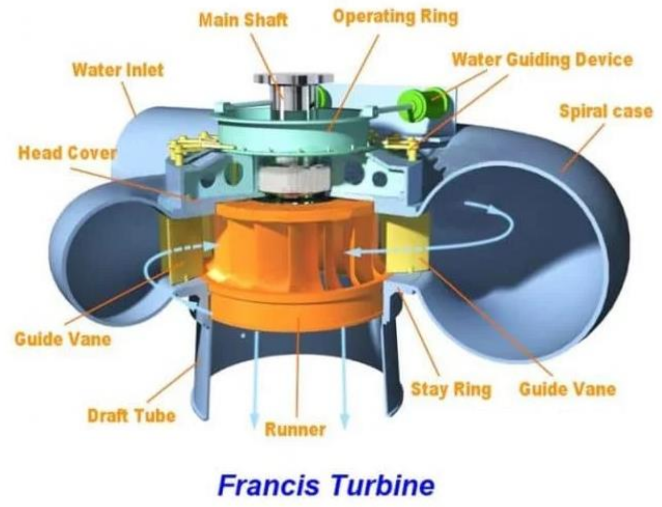
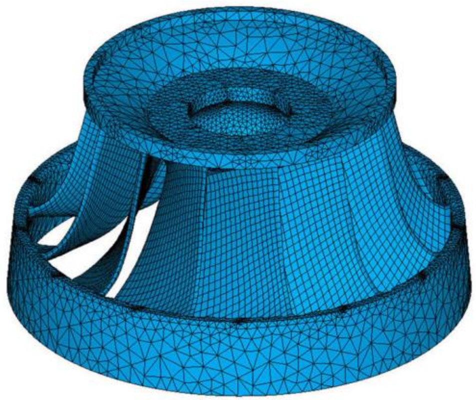
Francis Turbine Main Features

- Spiral casing – decreasing diameter to maintain flow
- Stay vanes – remove swirl from water and makes the flow more linear
- Guide vanes – maintain the angle of attack of water
- Runner blades – stationary blades that rotate the direction of water to rotate turbine
- Draft tube – tube to discharge water



https://theconstructor.org/practical-guide/francis-turbines-components-application/2900



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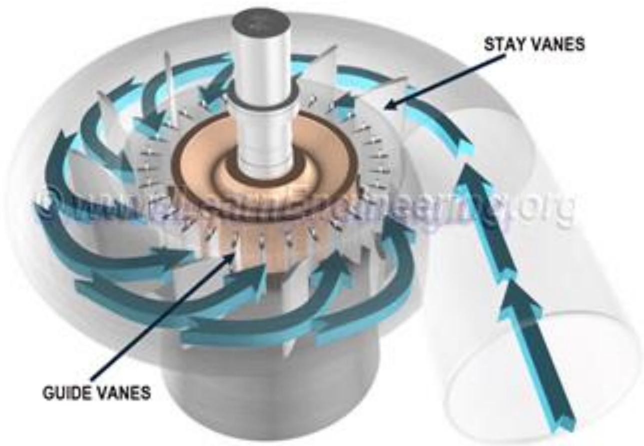

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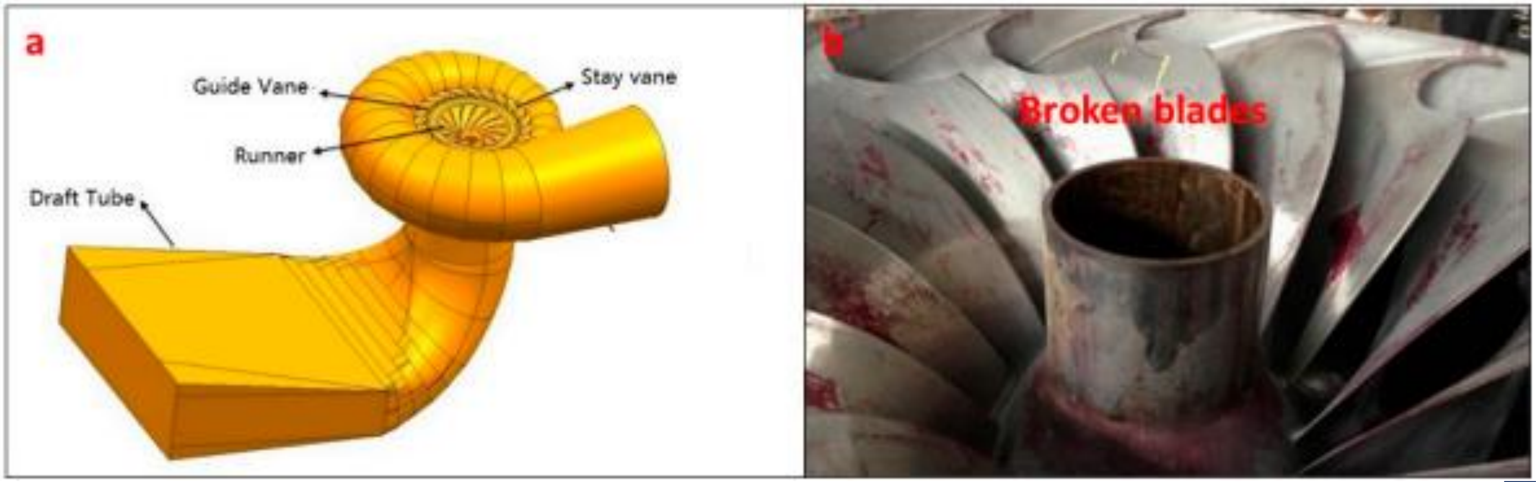
Problem Description

Main Objectives

1. Ensure mesh is independent and solution is truly converged and accurate
2. Validate model against data
3. Examine the effects of variation in mass flow and pressure



file:///Z:/adit/Downloads/energies-11-02320.pdf

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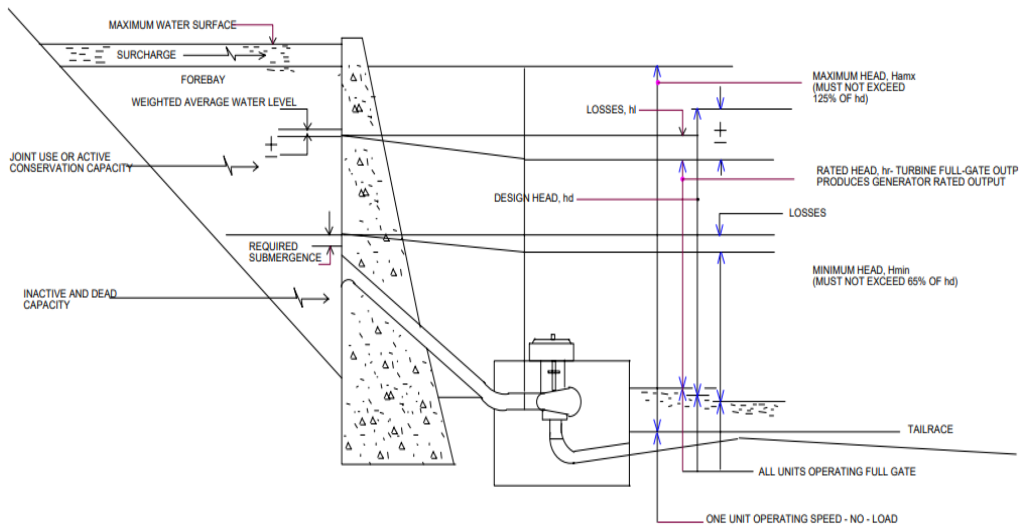
Problem Description

Cavitation – formation of empty space or cavities in liquid in area of low pressure, generally around rotor blades

- Avoid cavitation by maintaining flow throughout turbine
- Avoid bubbles and swirling
- Maintain min and max design pressures: validate model

Type of turbine	Maximum head (percent)	Minimum head (percent)
Francis	125	65
Propeller – fixed blade turbine	110	90
Propeller – Adjustable blade turbine	125	65



http://ahec.org.in/links/revised_standard/3.1%20turbine%20and%20governing.pdf

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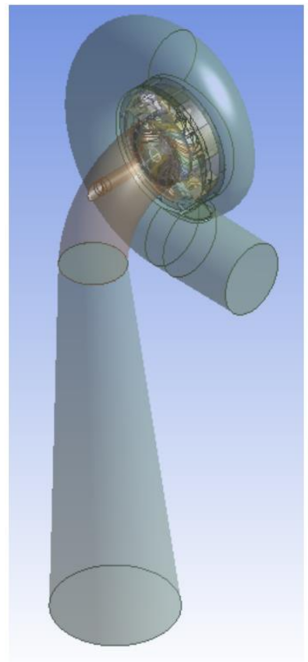
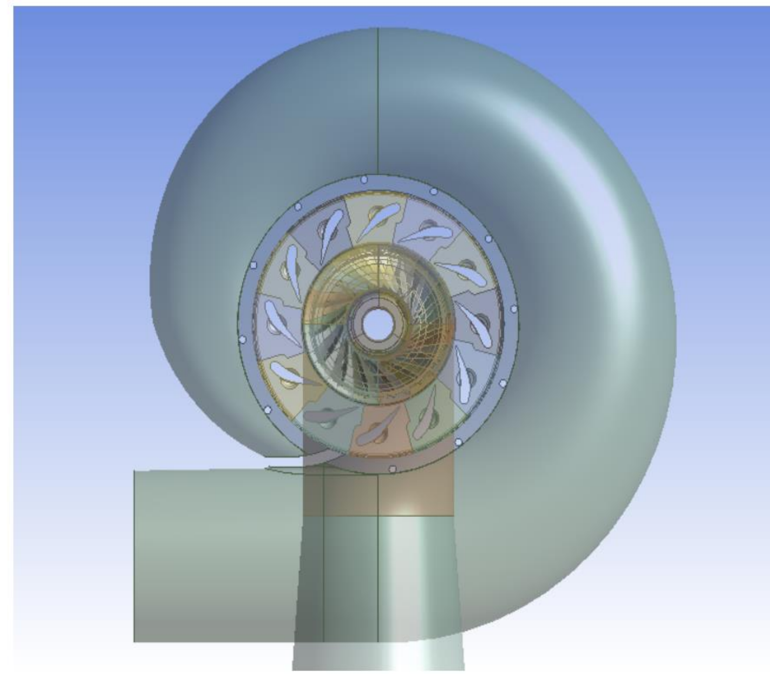
Geometry

- Optimized Geometry
  - Provided from previous study for proper validation
    - Inlet: 0.57m
    - Outlet: 1m
    - Draft Tube: 3m
    - Spiral Case: 1m
  - Made of multiple parts
  - 68% Guide Vane Opening
  - 3D Scanned
    - Accuracy 0.38mm





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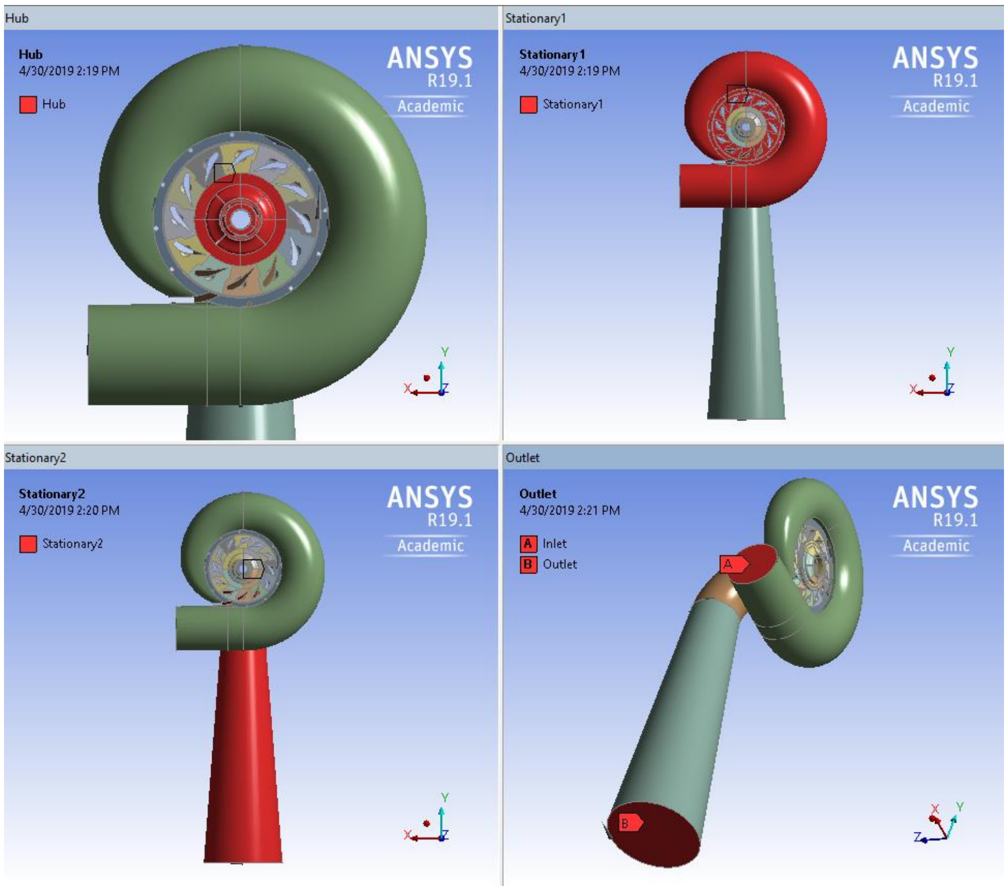
Named Selection: Components



- Hub (Rotating Part)
  - Runner
  - Rotationary Blades
- Stationary 1
  - Guide Vanes
  - Spiral Casing
  - Inlet
- Stationary 2
  - Draft Tube
  - Outlet

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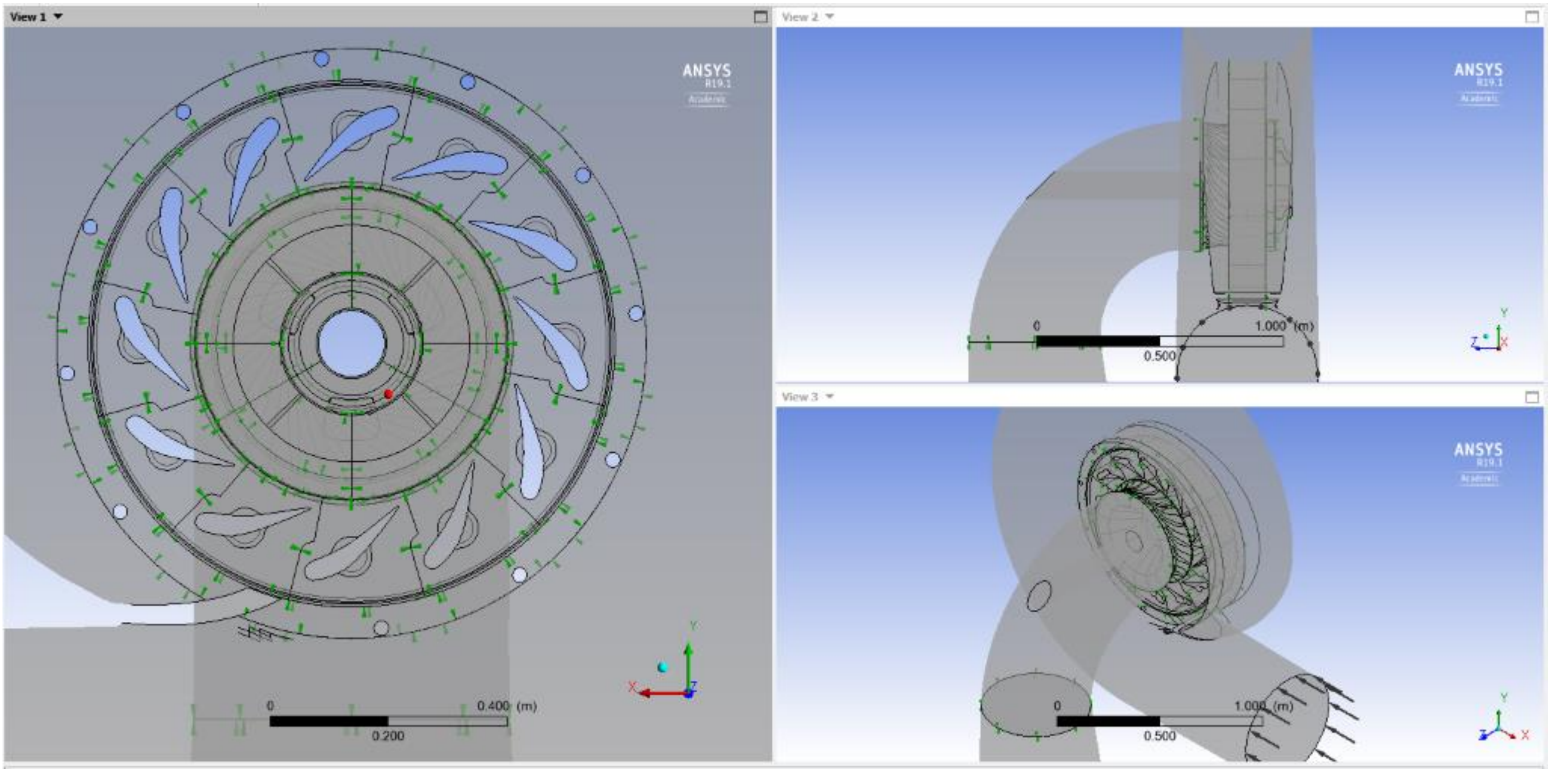
Interfaces



- 20 Overall Interfaces, between each individual part of the turbine.
- 14 Interfaces in Hub, others in Stationary components.

Pre-Processing: Mesh

- Mesh
  - Generation
  - Convergence

Pre-Processing: Solver Setup

Francis Turbine (Fluid CFX Analysis) - Simulation Settings					
Flow Analysis	**Analysis Type**	Steady State			
	Impeller	Rotationary Part Checked			
	Vane	Inlet and Outlet Checked			
Interface	Interfaces Checked				
Solver	**Solution Units**		[kg], [m] , [s] , [K] , [rad] , [sr]		
	Solver Control	**Basic Settings**	**Advection Scheme**	High Resolution	
			Turbelence Numerics	High Resolution	
			Convergence Control	Min Iteration	1
				Max Iterations	400
			Fluid Timescale Control	Timescale Control	Auto Timescale
				Length Scale Option	Conservative
				Time Scale Factor	1
			Convergence Criteria	Residual Type	RMS
				Residual Target	1.00E-03
		Equation Class Settings	Continuity / Momentum / Turbulence Eddy Dissipation		
		Advanced Options	Global Dynamic Model Control		
Materials	Standard Water (No Changes in Basic Seetings or Material Properties)				

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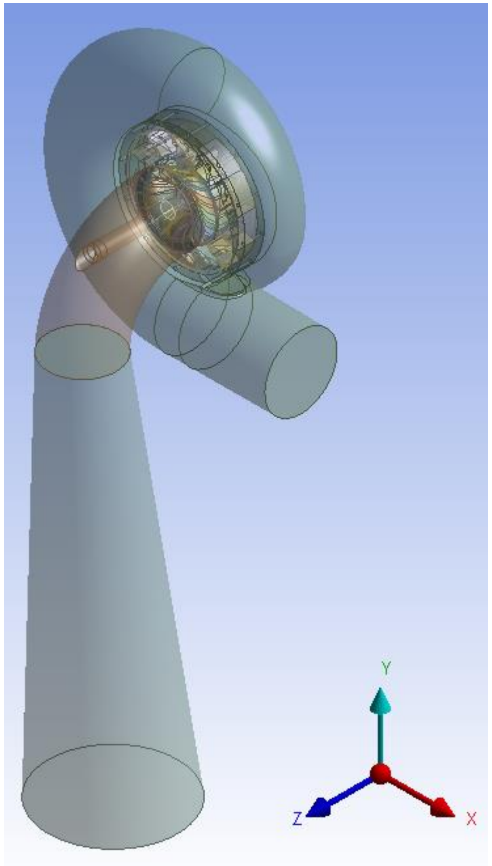
Pre-Processing: Turbo Mode Setup



- Problem: Steady State Turbulent Flow
- Machine Type: Axial Turbine
- Define Rotating and Stationary Parts
  - Rotating: -1000 rpm
  - Passages/Alignment: 15/15/15

$$f = 60Hz \qquad V = 35m/s$$

$$rpm_{real} = \frac{60\ x\ V}{\pi\ x\ D} = 1318$$

$$Z_P = \frac{f\ x\ 50}{rpm} = 2.27 \sim 3$$

$$rpm_{corrected} = \frac{f\ x\ 50}{Z_P} = 1000$$

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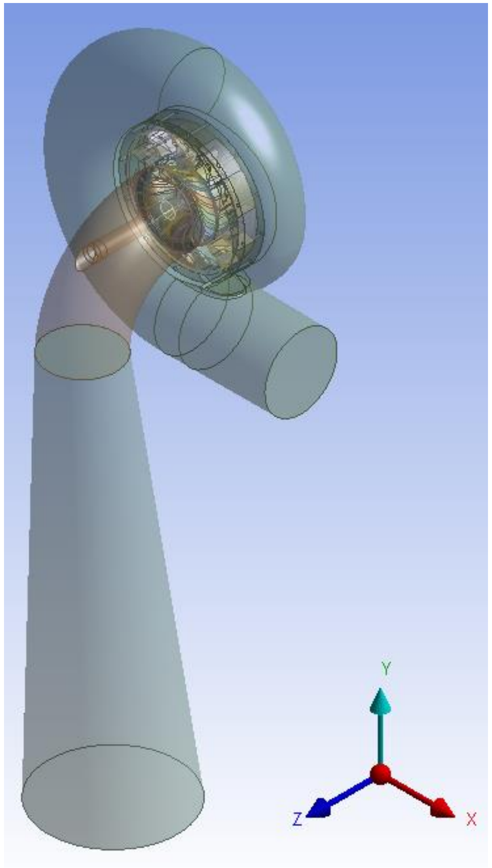
Pre-Processing: Turbo Mode Setup



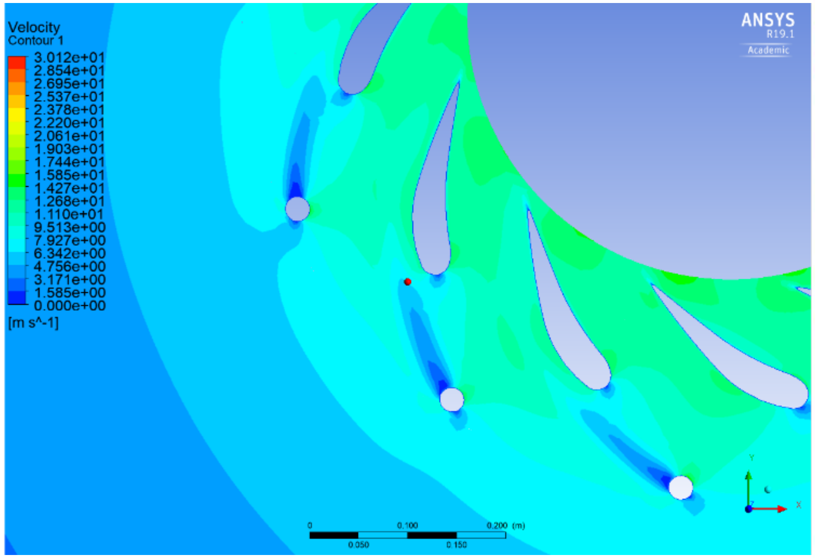
- Materials
  - Standard Water
- Turbulence
  - Shear Stress Transport (SST)
- Boundary Conditions
  - Inlet: Mass Flow 1460 kg/s
  - Outlet: 1.068 atm (0 atm reference pressure)

Post-Processing: Model Validation

- Model validates against experimental inlet conditions and the study's simulated outlet conditions.

	Experimental Inlet Velocity (m/s)	Experimental Inlet Pressure Total - (kPa)	Outlet Velocity (m/s)	Outlet Pressure Gauge - (kPa)
Study Results	5.6	407.95	2.51818	6.85
Validated Results (Propped at Max.)	5.755	437.415	2.61262	6.85
Error (%)	2.77	7.22	3.75	0.00

Post-Processing: Model Validation



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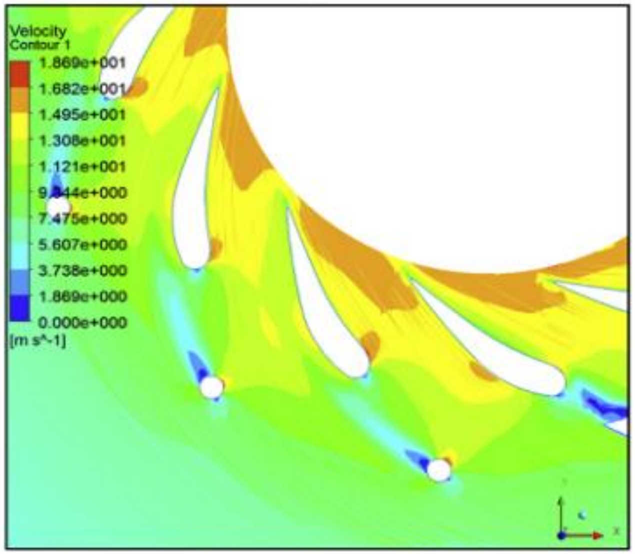

- Model validates flow near guide vanes.
  - 18 m/s max
  - 2 m/s min

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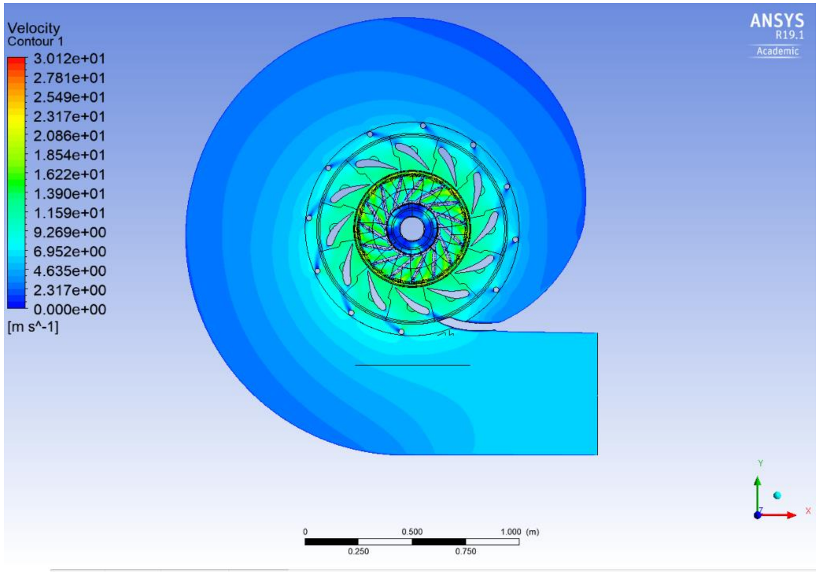
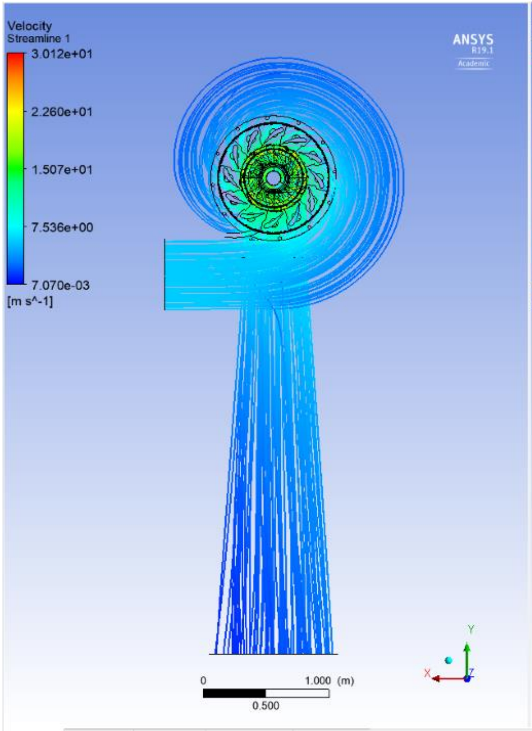
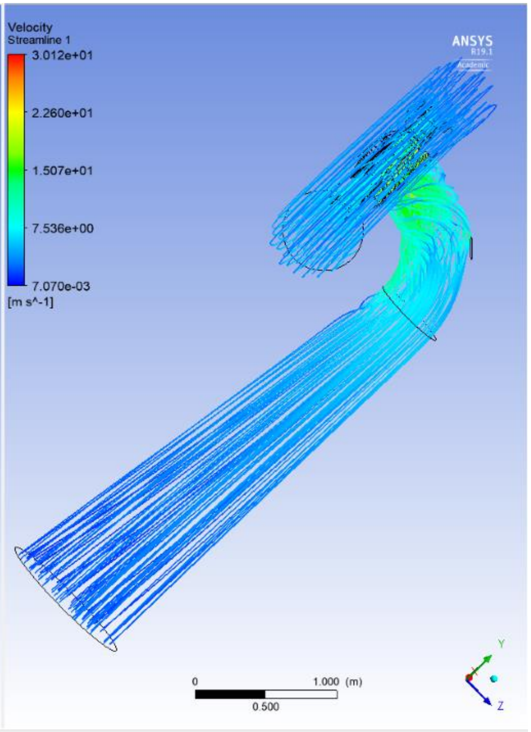
Results: Primary Case



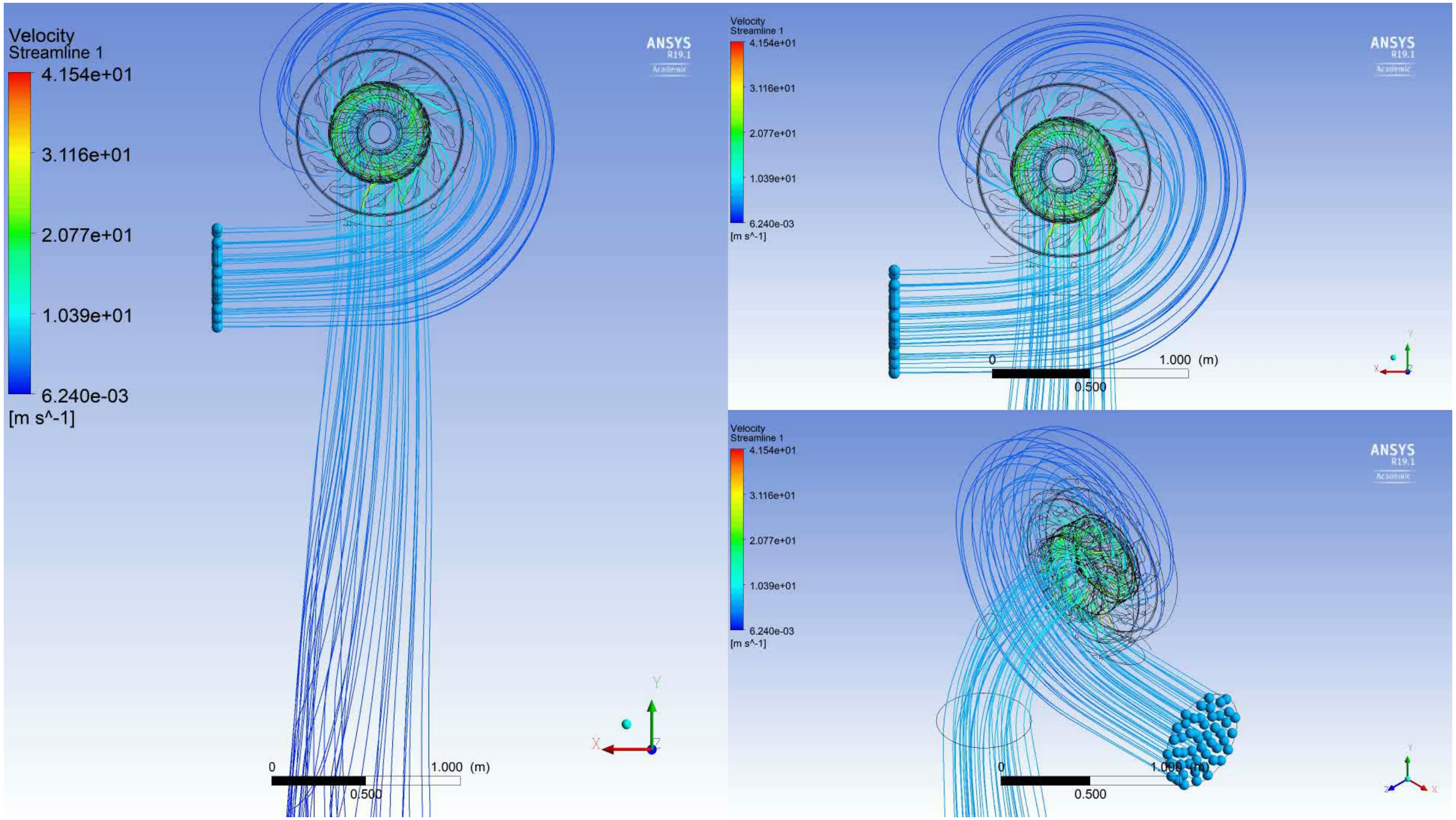
- Model shows optimal flow through the draft tube with no swirling.





- Model shows optimal flow near guide vanes

Results: Primary Case



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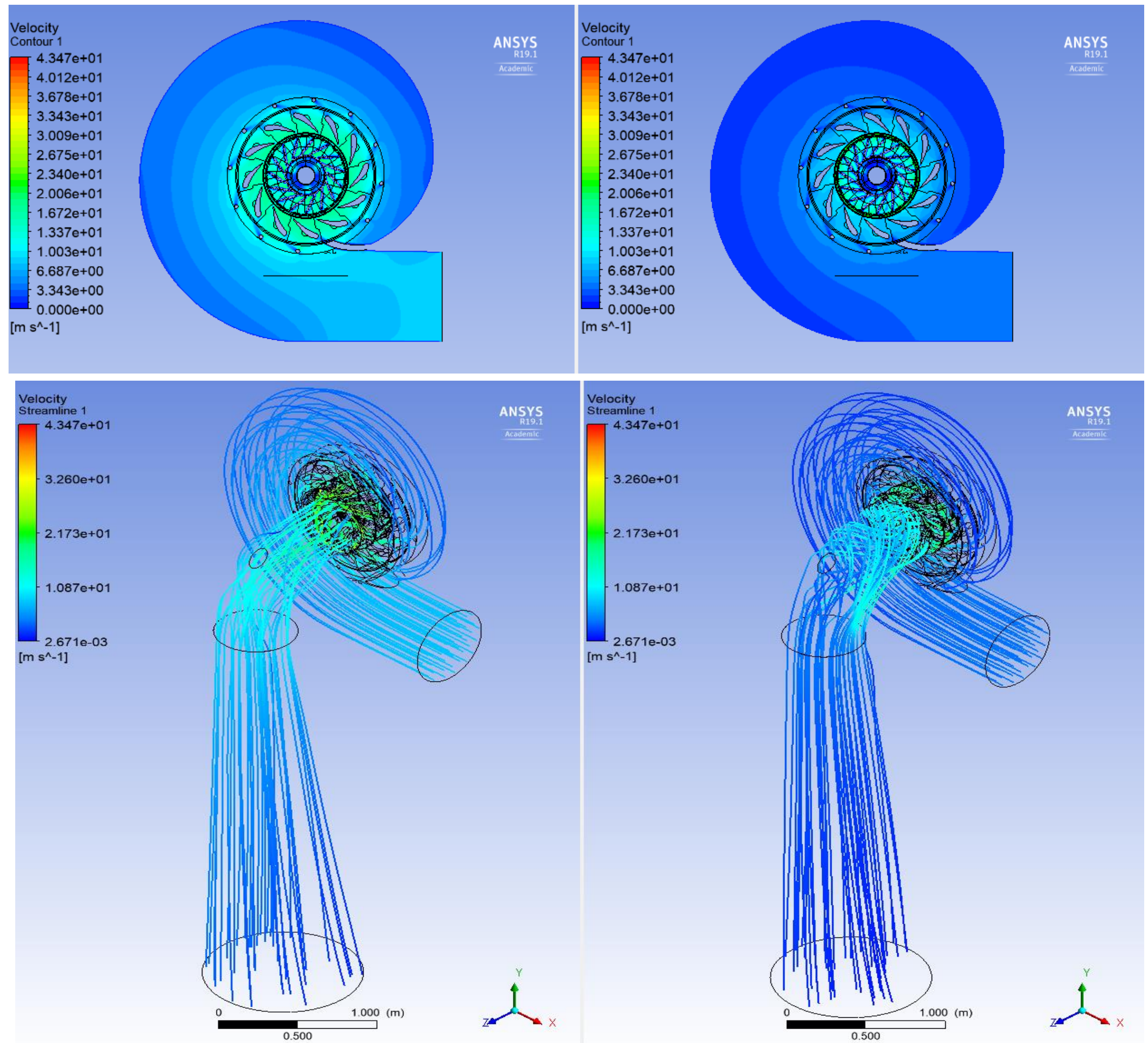
Results: Mass Inlet Study

Study 1
- Increased rate by 500 kg/s
- Generated faster velocity through the turbine

Study 2
- Decreased rate by 500 kg/s
- Generates slower velocity through the turbine
- Creates a swirling effect on the exit of the runner



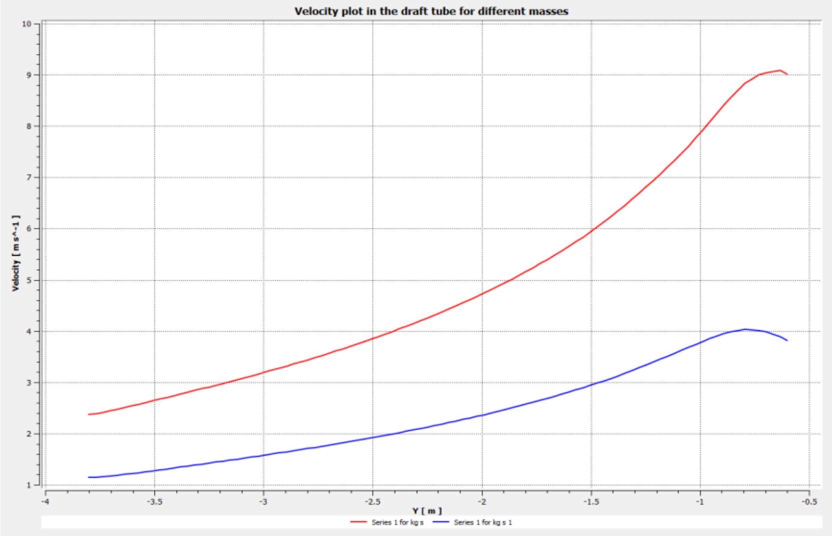
Results: Mass Inlet Study

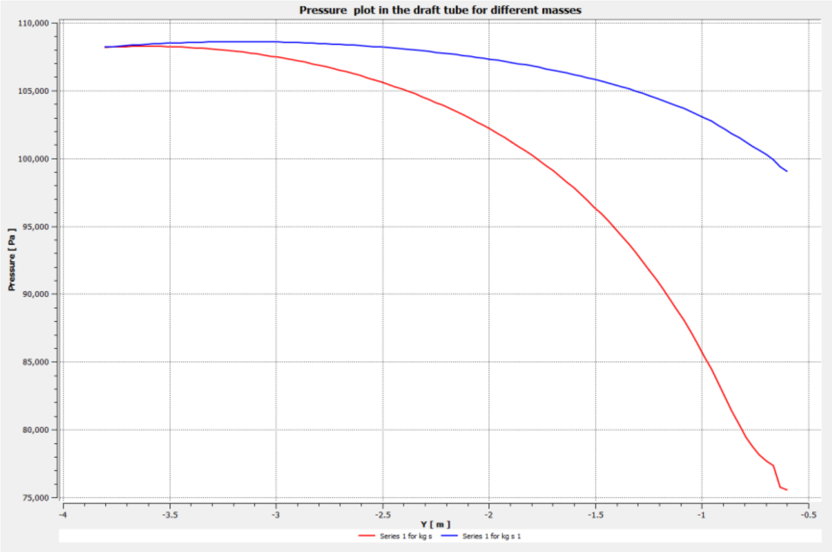
Study 1

- Generates faster velocity through the draft tube
- Increases the outlet velocity
- Decreases outlet pressure

Study 2

- Generates slower velocity through the draft tube, more linear profile
- Less impact on pressure gradient, closer to original outlet pressure, but still less





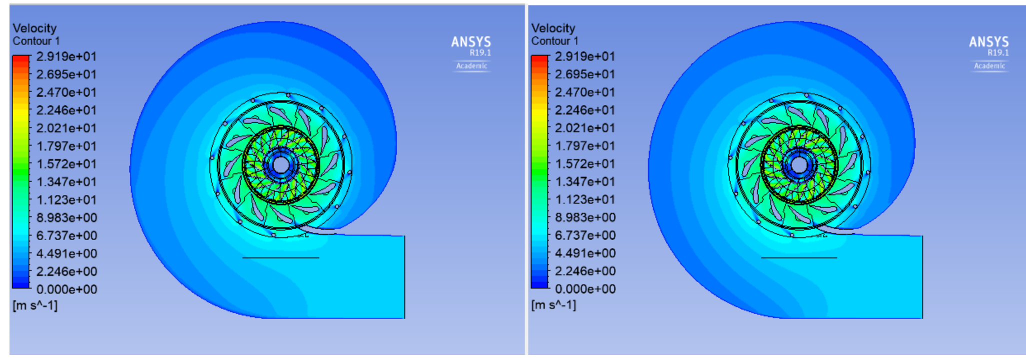
Results: Pressure Variation Study

Study 1

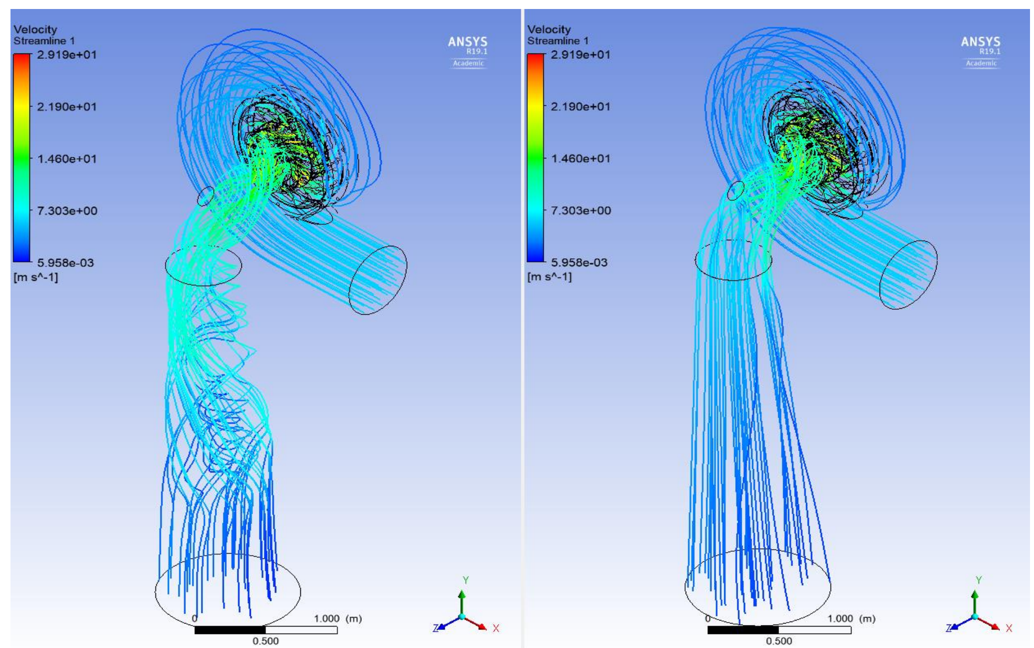
- Increased head of 3 meters
- Very little change in flow

Study 2

- Increased head of 6 meters
- Increased turbulence
- Increased eddies
- Increased swirl
- Non-uniform flow observed



Velocity & Streamline at 6m and 3m head of water



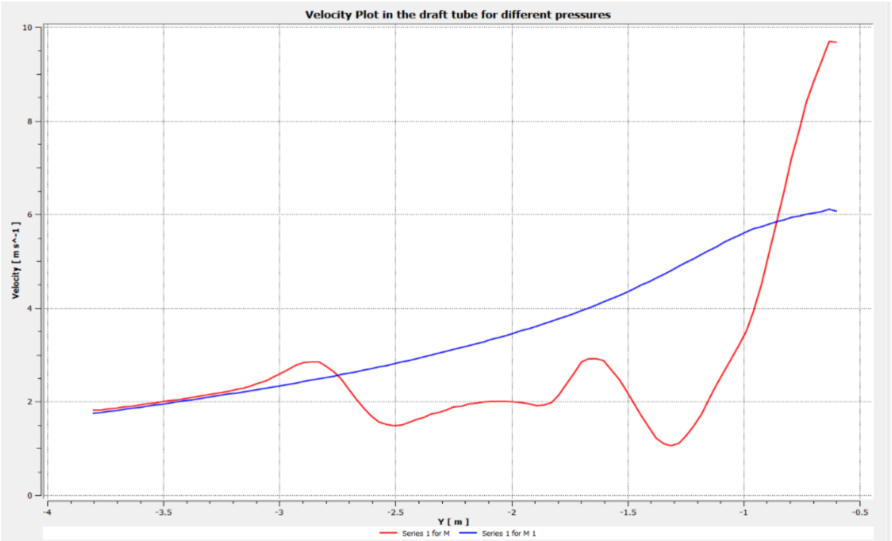
Results: Pressure Variation Study

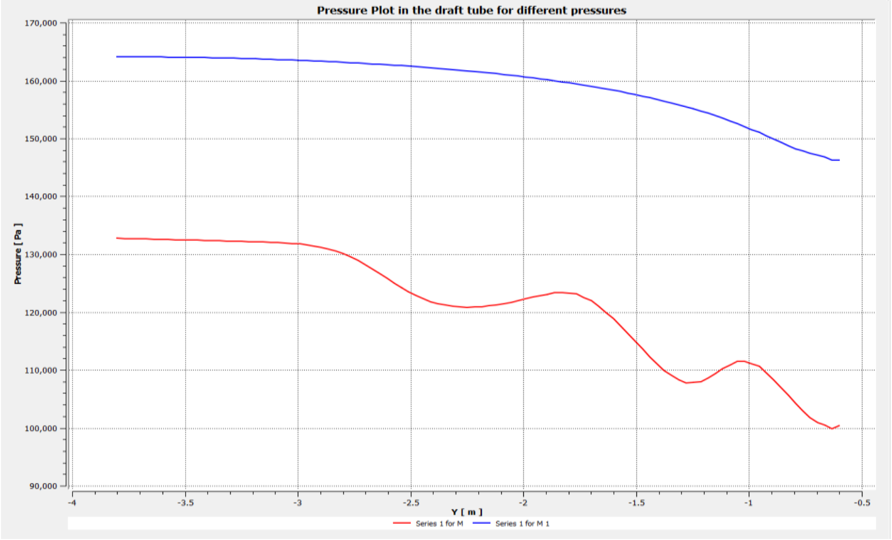
Draft tube results

- At 6 meters of head
    - Velocity erratic
    - Pressure erratic
- At 3 meters of head
    - Still smooth flow observed

Results

- At 6 meters of head
    - Velocity erratic
    - Pressure erratic





Conclusions

Goals Achieved

- Develop a grid independent Francis Turbine model.
- Validate model using previous experimental results.
  - Maintain min and max design pressures
  - Maintain boundary inlet and outlet conditions
- Explore effects of varying mass inlet and outlet pressures
  - Avoid cavitation by maintaining flow throughout turbine
  - Avoid bubbles and swirling
    - Decrease mass inlet increases cavitation and vorticities greatly
    - Increasing mass inlet increases cavitation and vorticities slightly
    - Increasing outlet pressure increases cavitation and vorticities greatly

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Questions?