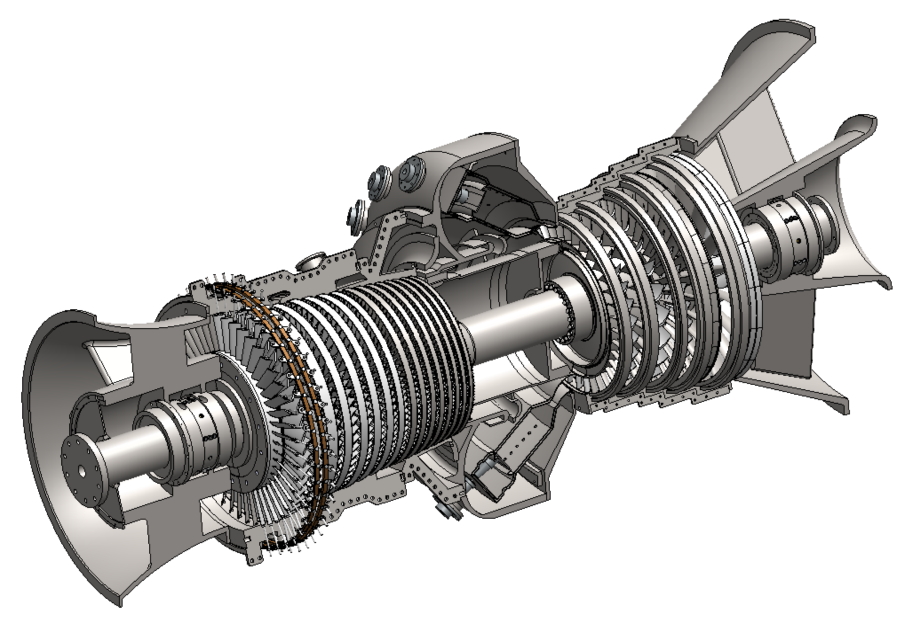

Dwight Look College of ENGINEERING
TEXAS A&M UNIVERSITY

Gas Turbine Engine Design

MEEN 646 Final Competition Project

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Students: Dung Tran
Jiataditya Mondal
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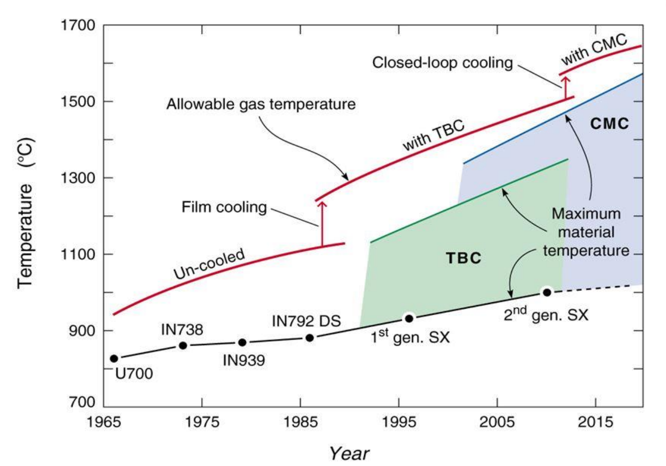
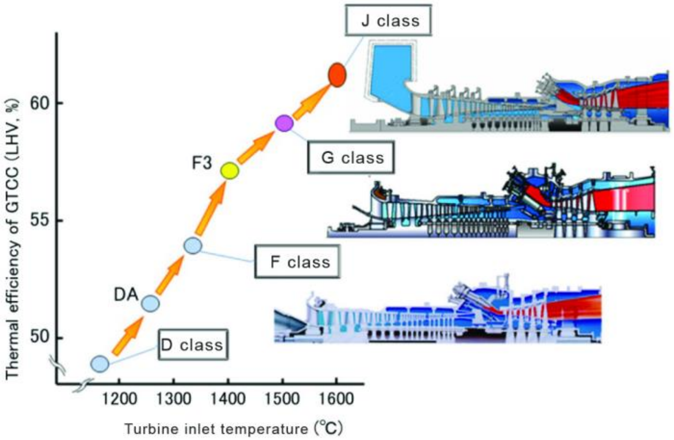
Presentation Outline

- Introduction
- Problem Description
- Compressor Design
- Turbine Design
- Combustor, Compressor Nozzle & Turbine Diffuser Design
- Bearing Design
- Gas Turbine Engine Assembly
- CFD of Blades
- Summary

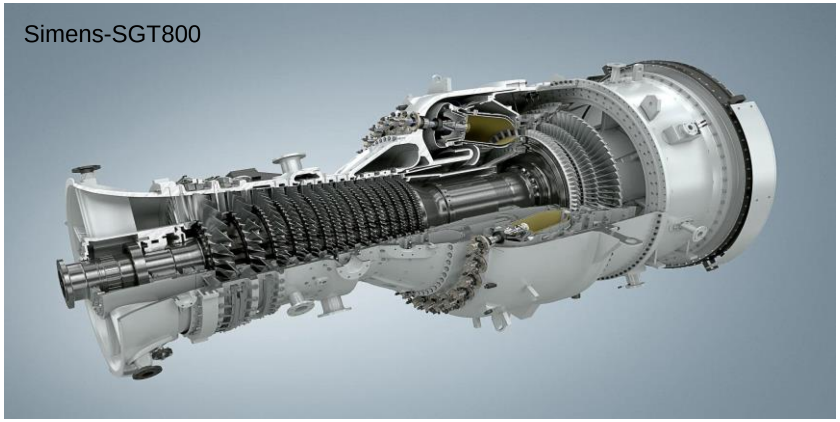
Introduction

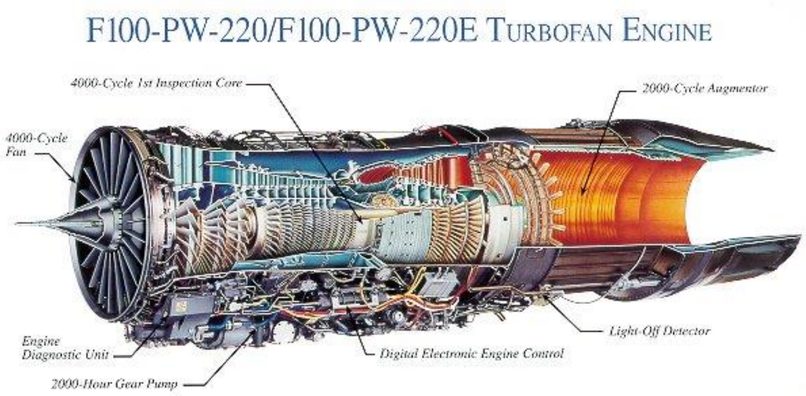
- Gas Turbine Evolution





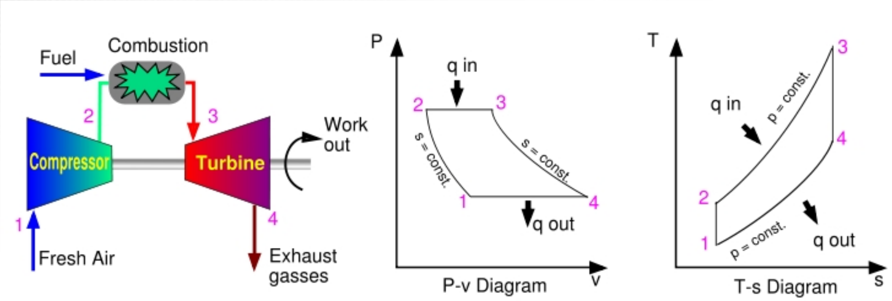
- Gas Turbine Application





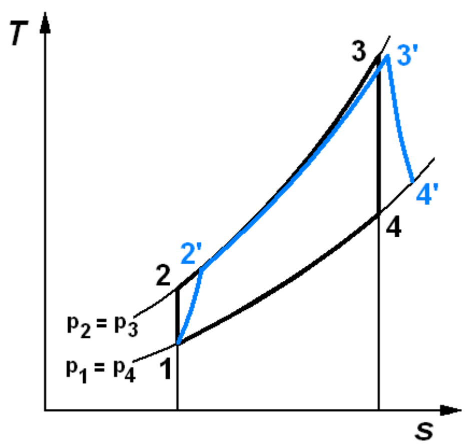
Introduction

- Thermal Process (Brayton Cycle)



Idealized Brayton Cycle

- Non-isentropic Process (Brayton Cycle)



Brayton Cycle Efficiency

Best expressed as: $\eta_{th} = 1 - r_p^{(1-k)/k}$

Where: r_p **= Compressor Ratio**

and k = ratio of specific heats of working fluid.

- **Average simple gas turbine cycle efficiency is 38% - 45%**

Project Task

- Given conditions:

Compressor

LP-Compressor			
Mass flow	$\dot{m}$	150.0	kg/s
Inlet static pressure	p_{in}	98.61	kPa
Pressure ratio	π_{LP}	1.8048	
Inlet total temperature	T_{0in}	288.21	K
Exit total temperature	T_{0out}	347.2	K
Inlet mean diameter	D_{m_in}	1.2043	m
Exit mean diameter	D_{m_out}	1.1253	m
Angular velocity	ω	469.35	rad/s

IP-Compressor			
Mass flow	$\dot{m}$	150.0	kg/s
Inlet static pressure	p_{in}	177.97	kPa
Pressure ratio	π_{IP}	1.6739	
Inlet total temperature	T_{0in}	347.02	K
Exit total temperature	T_{0out}	407.51	K
Inlet mean diameter	D_{m_in}	1.1253	m
Exit mean diameter	D_{m_out}	1.0809	m
Angular velocity	ω	469.35	rad/s

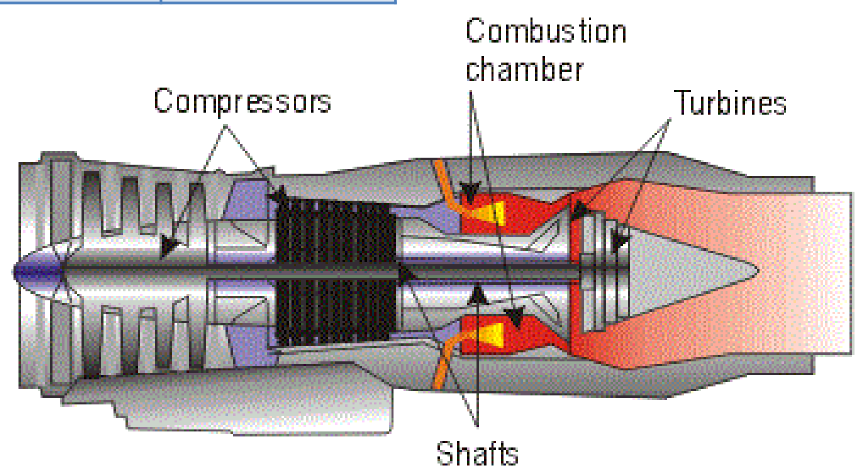
HP-Compressor			
Mass flow	$\dot{m}$	150.0	kg/s
Inlet static pressure	p_{in}	297.01	kPa
Pressure ratio	π_{HP}	3.0629	
Inlet total temperature	T_{0in}	407.51	K
Exit total temperature	T_{0out}	576.89	K
Inlet mean diameter	D_{m_in}	1.0809	m
Exit mean diameter	D_{m_out}	1.0130	m
Angular velocity	ω	469.35	rad/s

Combustion Chamber

P_{ccin}	909.74Kpa
P_{ccout}	873.35Kpa
T_{ccin}	576.89K
T_{ccout}	1222.7K
$\dot{m}$	150kg/s
$\dot{m}\_fuel$	2.97kg/s

Turbine

P_{in}(Pa)	873350
P_{out}(Pa)	102200
T_{in}(K)	1222.7
D_{m_in} (m)	1.062
T_{out}(K)	806.77
D_{m_out}(m)	1.12



Compressor Design

Aero-thermo calculations

For LP compressor

Assumptions

- Axial velocity (V_{ax}) and density (ρ) are constant through compressor
- At 1st stg rotor, $\alpha_2 = 90\ deg$
- Mean diameter is constant in each stage
- Isentropic efficiency $\eta_s = 0.9$
- Use R, k, C_p as average of inlet and outlet pressure and temperature condition

Steps

- Determine the r_hub/r_tip at the mean diameter for the 1st stage, by selecting r_hub/r_tip ratio which gives the lowest Mach No. at the tip of rotating blade.
- Determine the approximate total temperature across the 1st stage
- Estimate and calculate the rest parameters of the LP stages

Compressor Design

Aero-thermo calculations

For IP and HP compressor

Assumptions

- Axial velocity (V_{ax}) and density (ρ) are constant through compressor
- Mean diameter is constant in each stage
- Isentropic efficiency $\eta_s = 0.9$
- Use R, k, C_p as average of inlet and outlet pressure and temperature condition

Steps

- Select degree of reaction "r" and a reasonable "α_2 " for the 1st stage of the compressor.
- Solve for α_3,β_2,β_3 using the following relationships, given V_ax,U,r,α_2
- Determine the approximate temperature increment in the 1st stage
- Stage temperature distribution for IP and HP compressors

Compressor Design

Aero-thermo calculations

- Calculate stage parameters

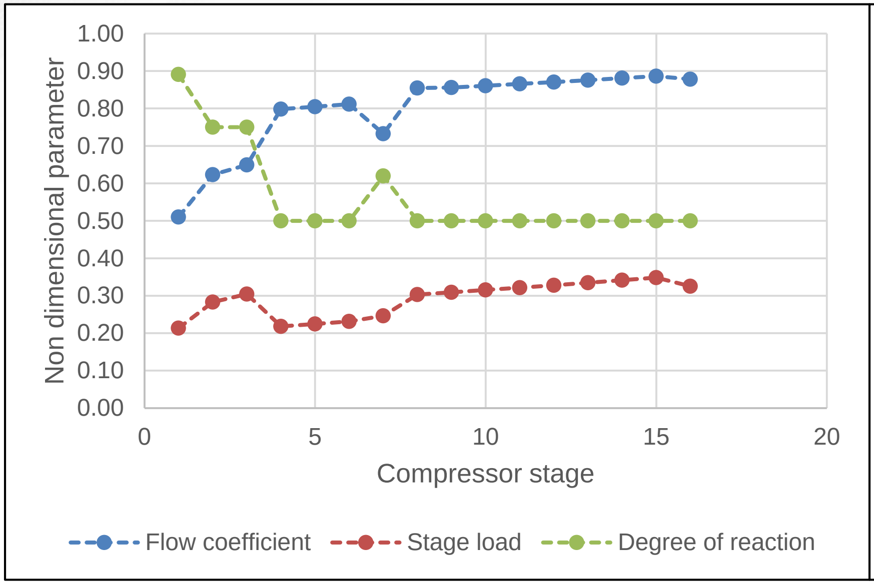
- Calculate losses
  - Primary loss
  - Trailing edge loss
  - Endwall friction and secondary flow loss
  - Flow loss in shrouded blades
  - Exit loss

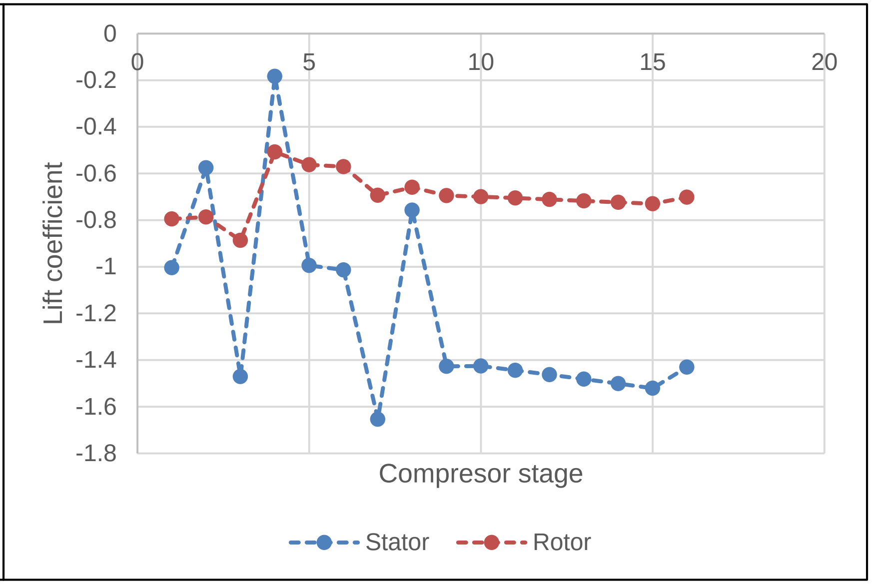
- Iterate data based on losses

→ **LP: 3 Stages, IP: 4 Stages, HP: 9 Stages**

Compressor Design

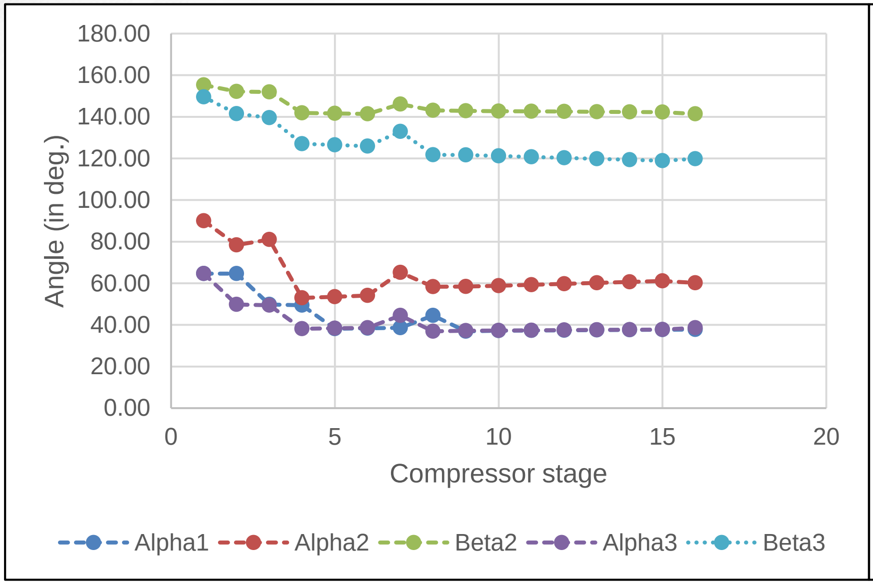
Dimensionless parameters

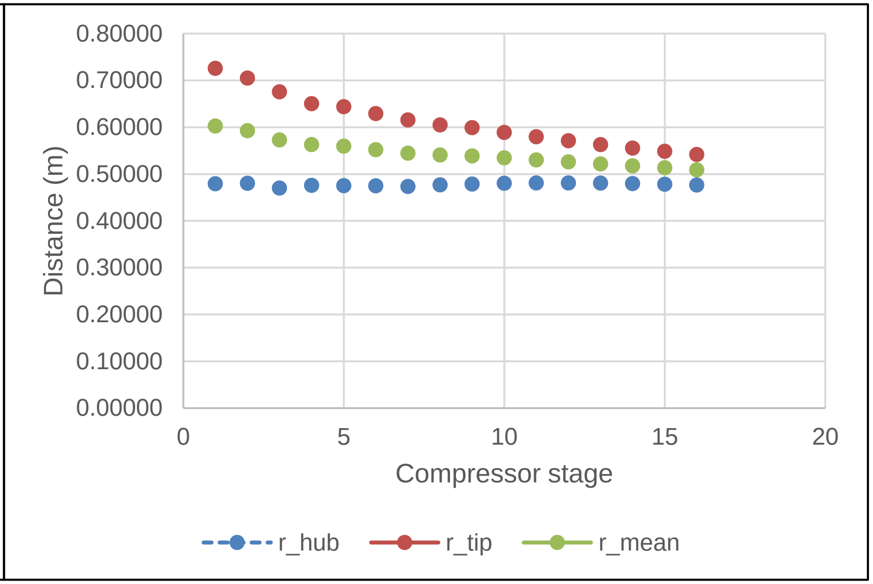




Compressor Design

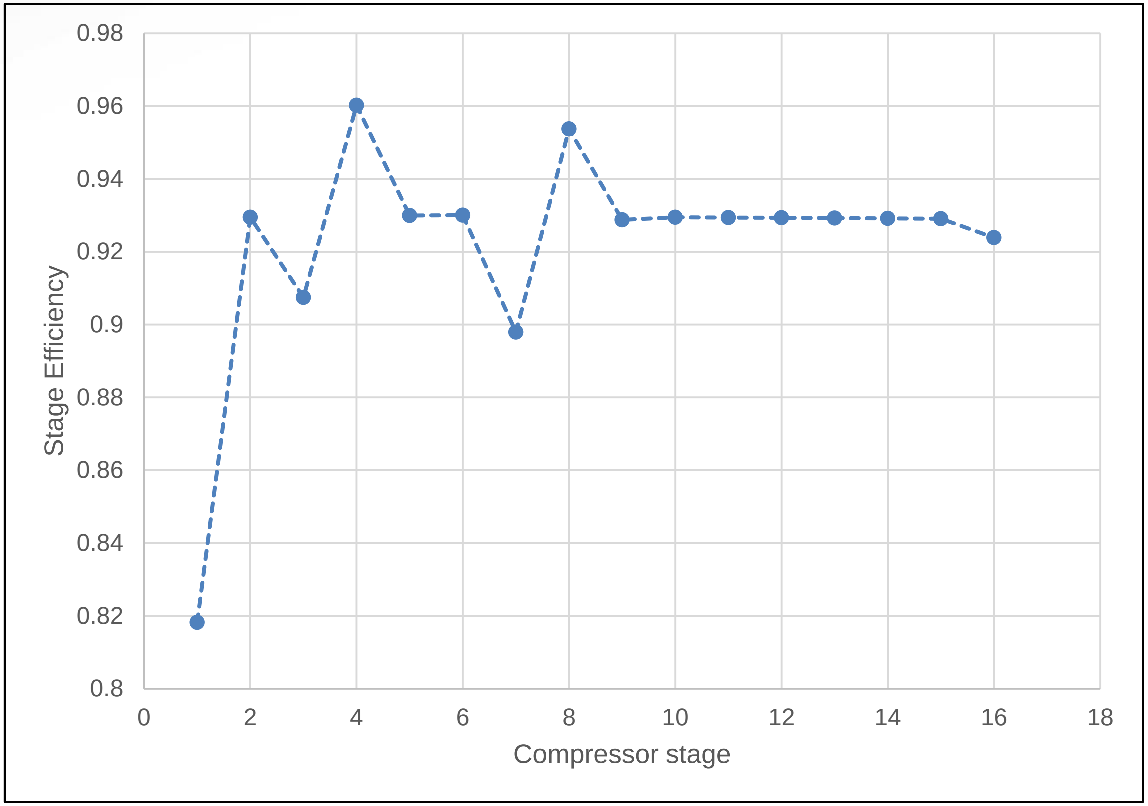
Blade parameters





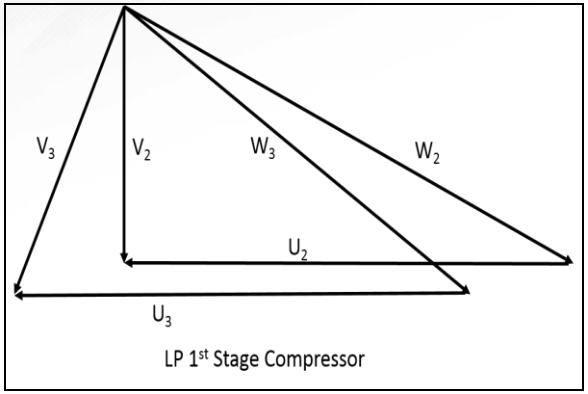
Compressor Design

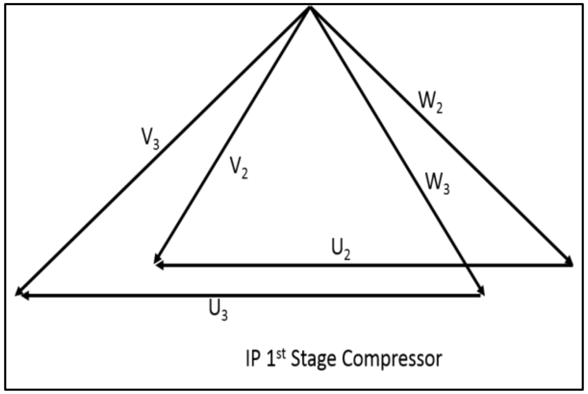
Stage Efficiency

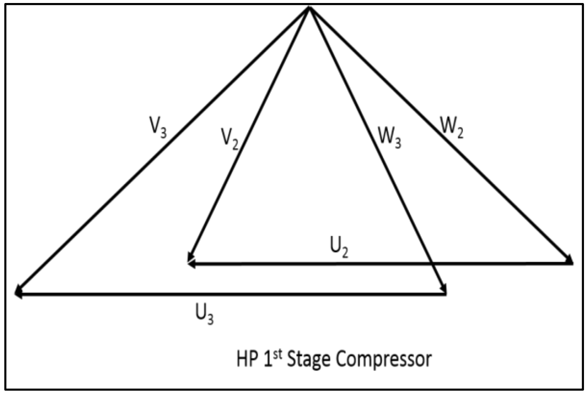


Compressor Design

Velocity triangles

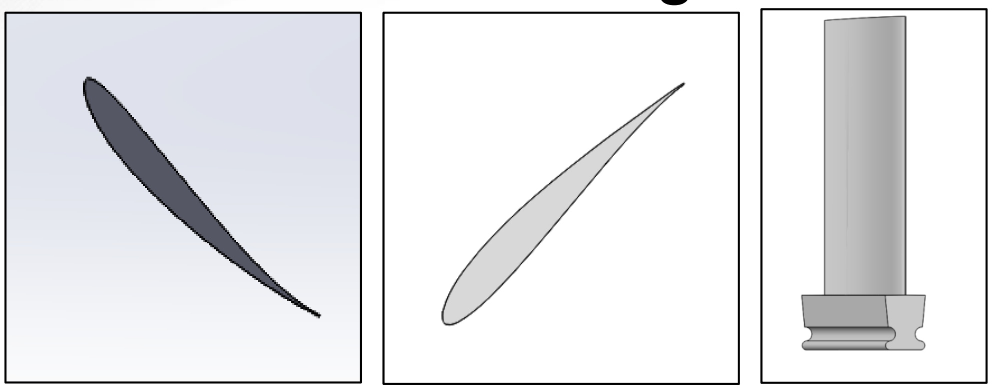




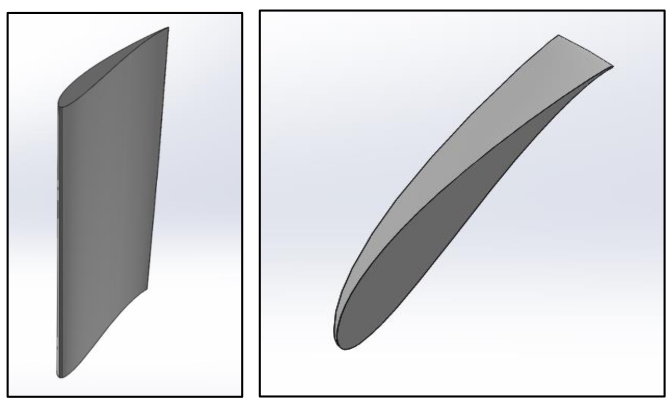


Compressor Design

Blade design



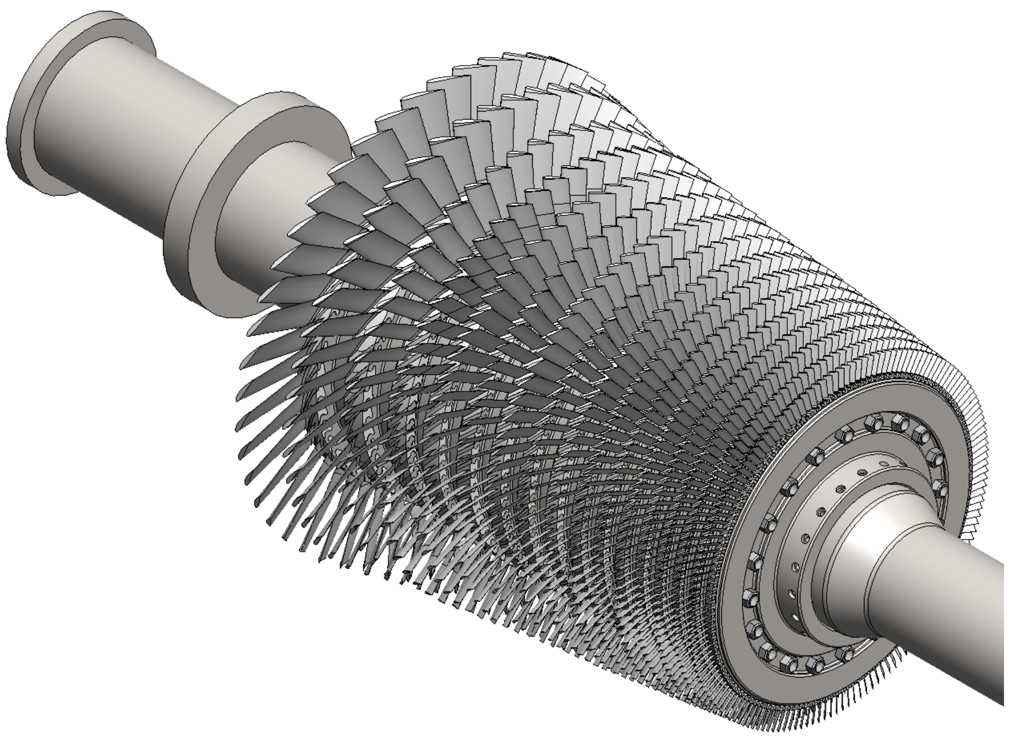
Stator(left), Rotor (right). Fir tree feature



Twisted rotor blade of stage 3

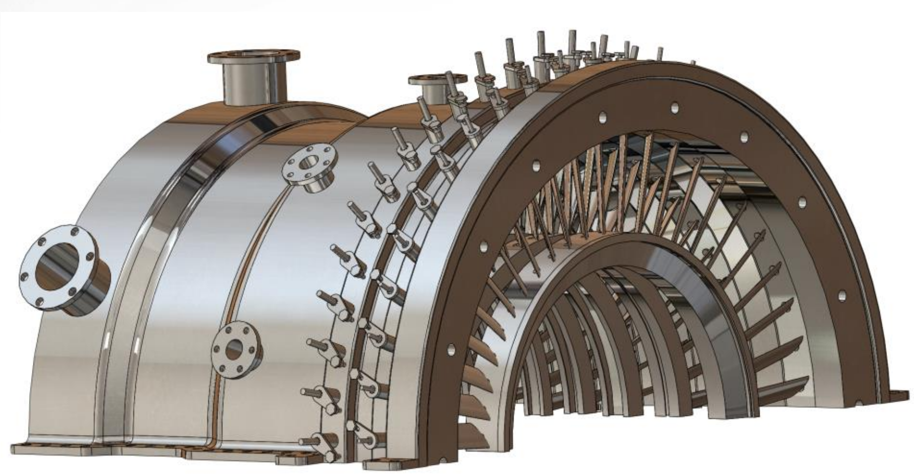
Compressor Design

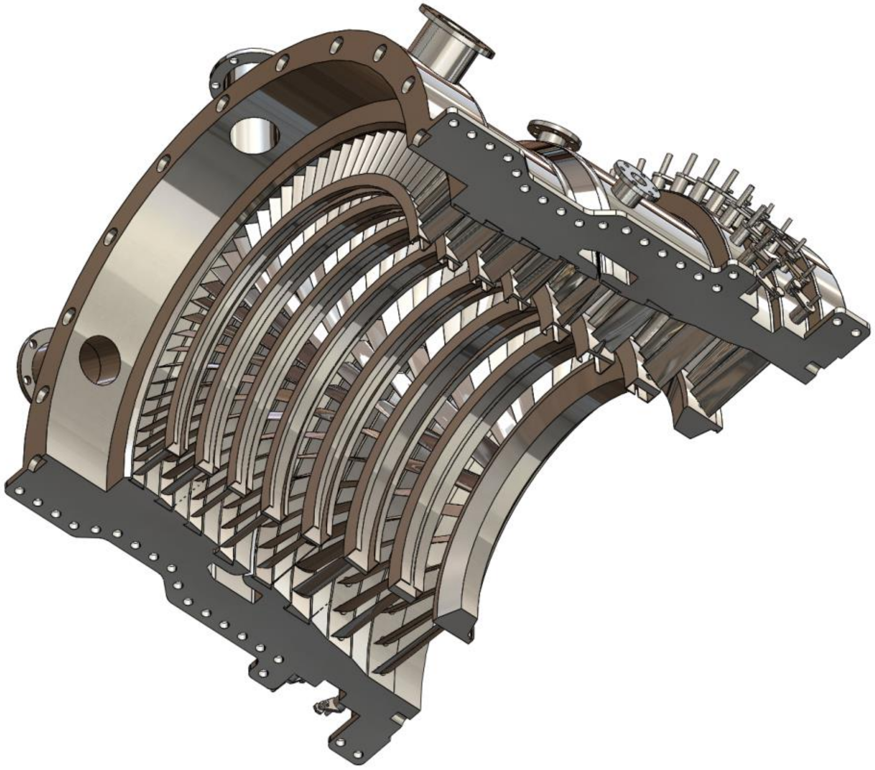
Compressor rotor



Compressor Design

Compressor casing (LP-IP)



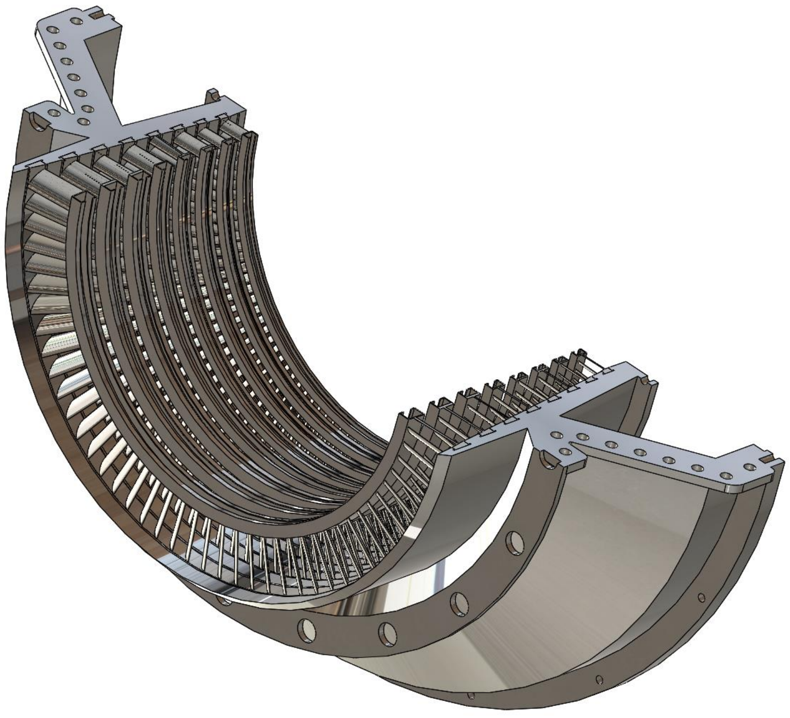
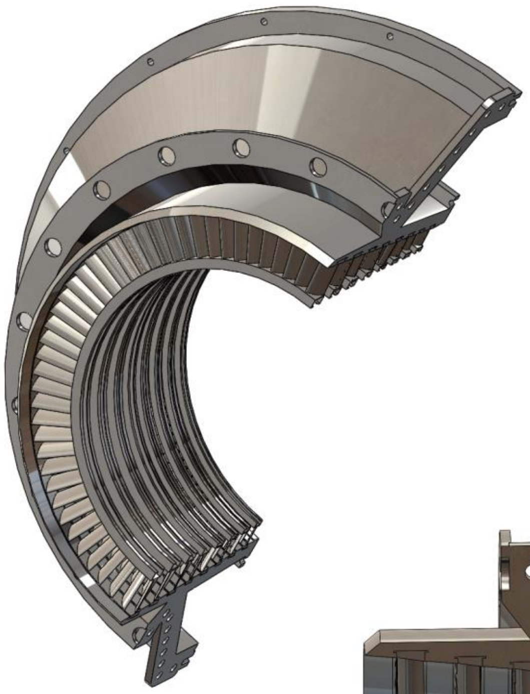
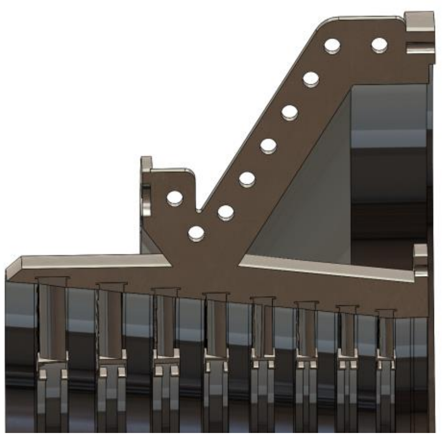


Compressor Design

IGV for 1st and 2nd stages

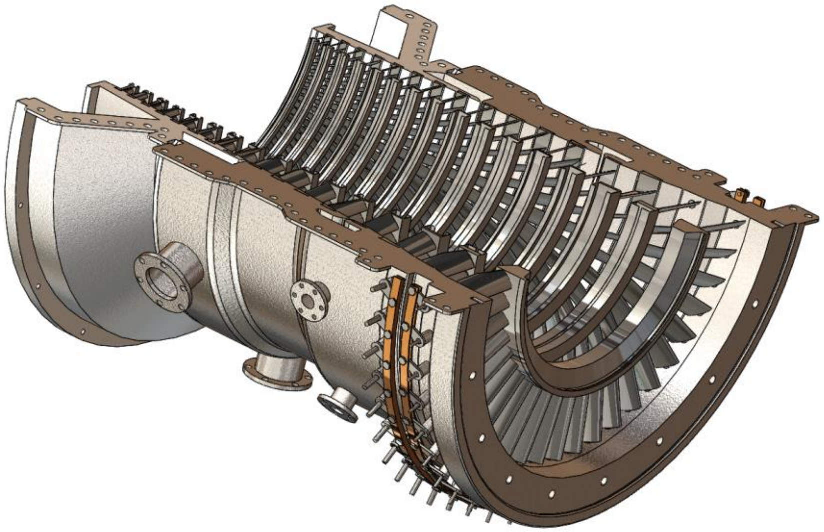
Compressor Design

Compressor casing (HP)

Compressor Design

Complete Casing Assembly



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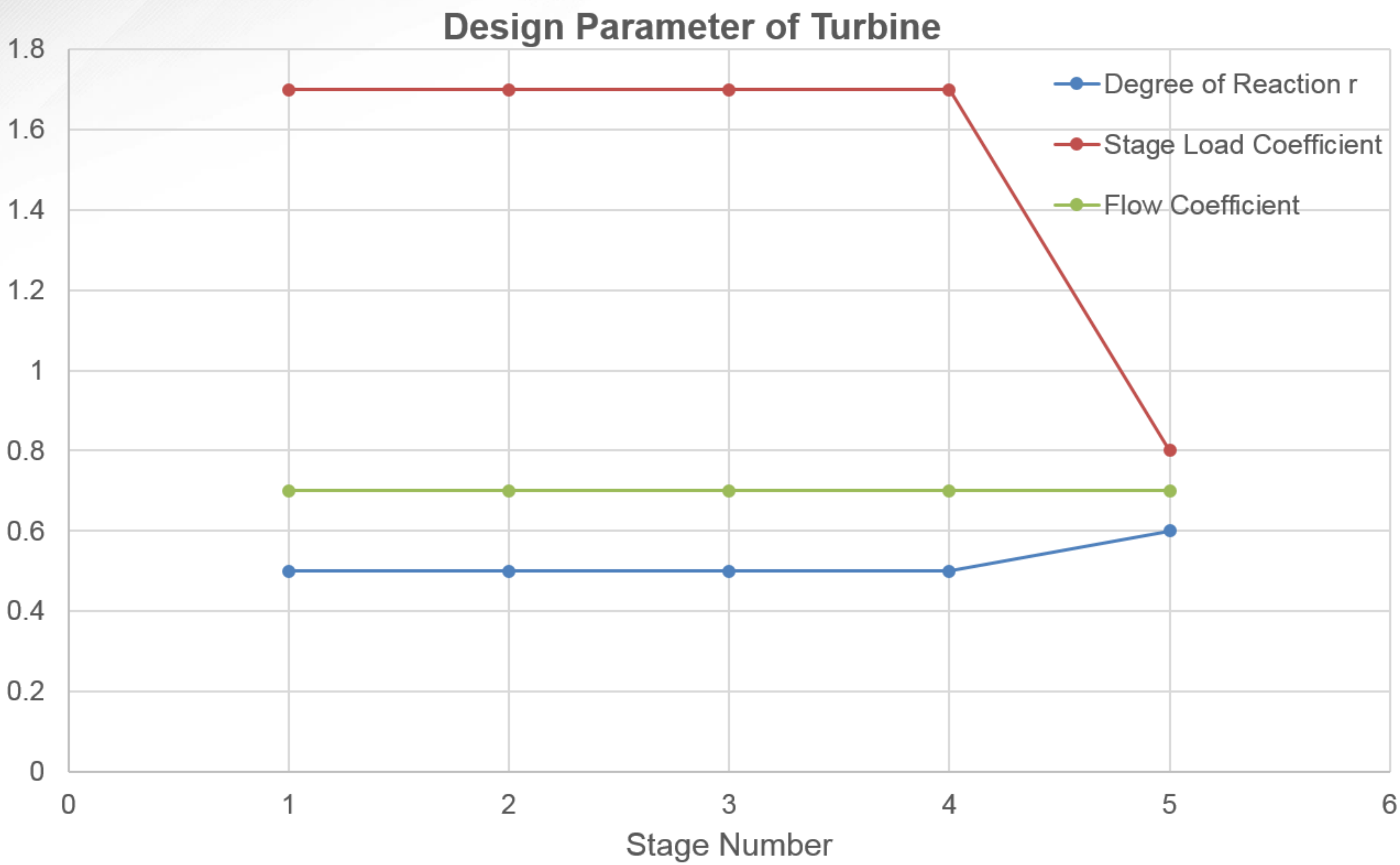
Turbine Design

- Aero-thermal Calculation
- Choose of r, λ and ϕ
- $\cot\alpha_2 = \frac{1}{\phi}\left(1 - r + \frac{\lambda}{2}\right)$
- $\cot\alpha_3 = \frac{1}{\phi}\left(1 - r - \frac{\lambda}{2}\right)$
- $\cot\beta_2 = \frac{1}{\phi}\left(-r + \frac{\lambda}{2}\right)$
- $\cot\beta_3 = -\frac{1}{\phi}\left(r + \frac{\lambda}{2}\right)$

Turbine Design

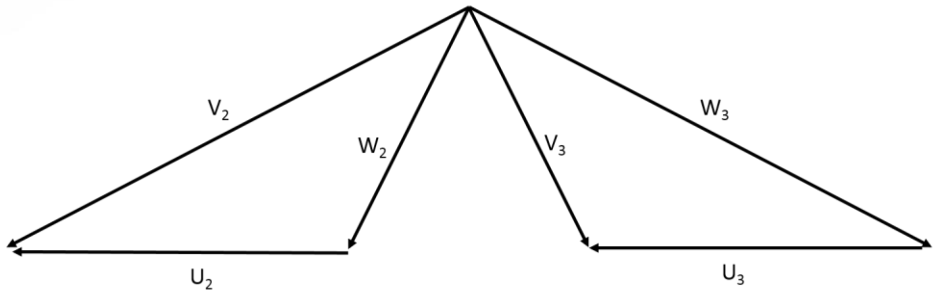


Turbine Design

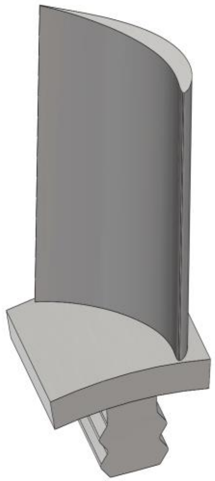
- From the velocity angle, and, we can solve the velocity triangles.
- $U = \omega * \frac{D_m}{2}$
- $V_3 = U\phi$
- $V_{ax} = V_3 * \sin(\alpha_3)$
- $V_2 = V_{ax} / \sin(\alpha_2)$

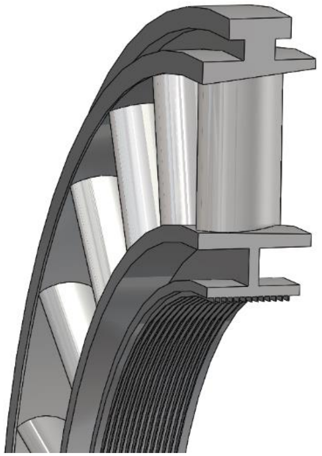
Turbine Design

- Velocity Triangle



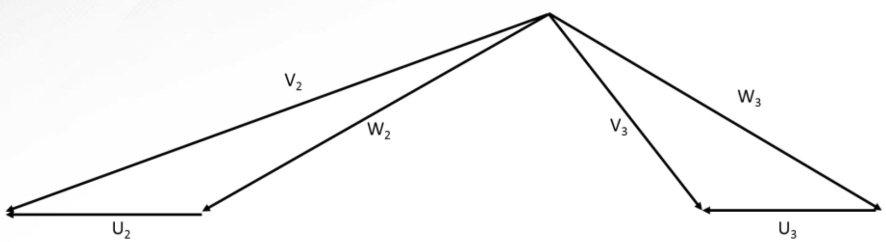
1st to 4th stage turbine



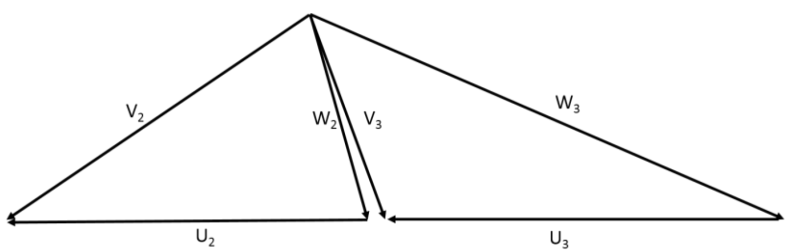


Turbine Design

- Velocity Triangle for twisted blades



4th stage turbine at hub



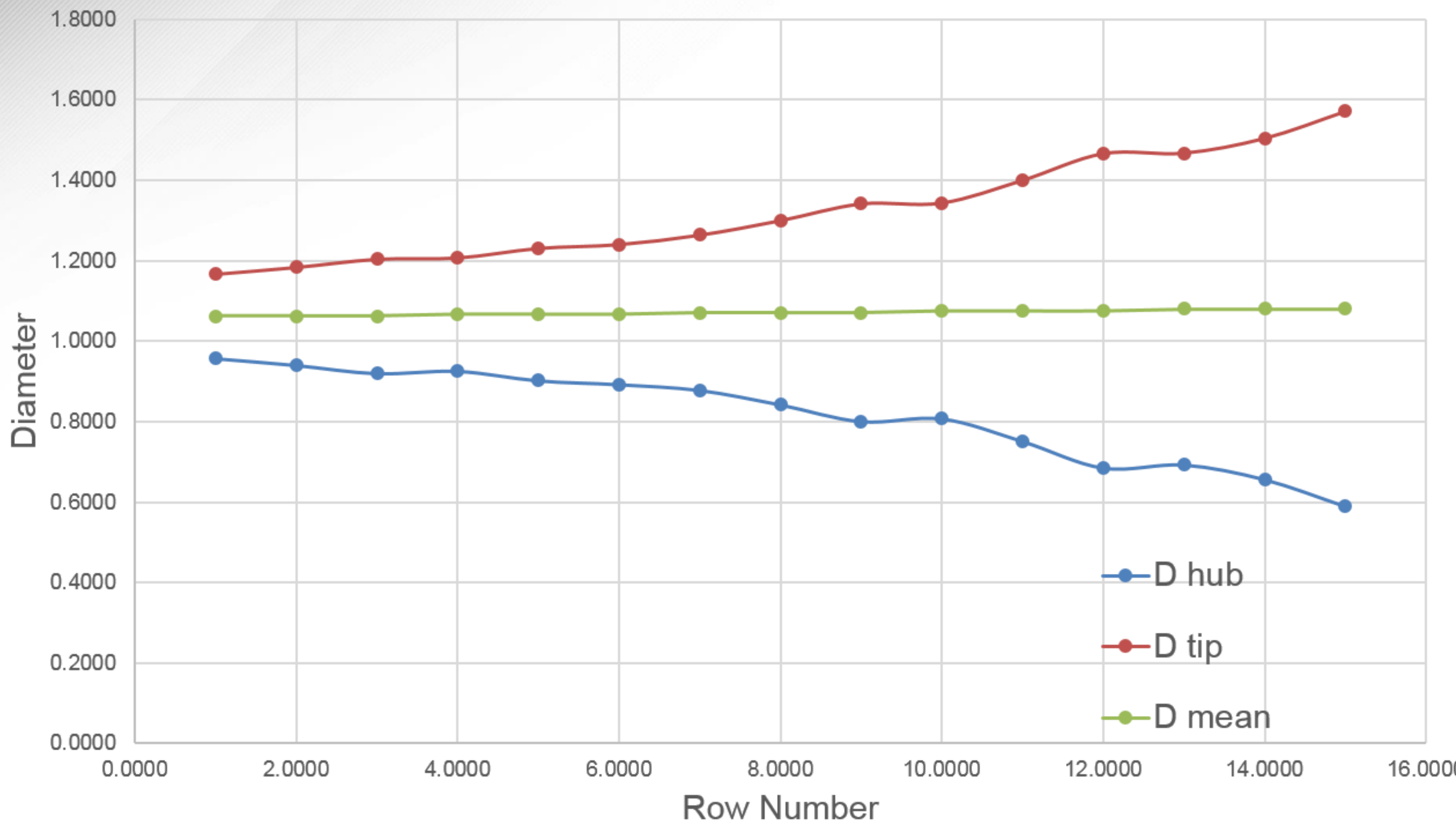
4th stage turbine at tip

Turbine Design

- Calculate thermodynamics properties at each station based on assumed isentropic efficiency and thermodynamic process:

- $P_3 = P_1\left(\frac{T_{3s}}{T_1}\right)^{\frac{k}{k-1}}$ $\qquad \eta_s = \frac{T_1 - T_3}{T_1 - T_{3s}}$
- $T_{03} = T_{01} - \frac{\lambda {U_3}^2}{c_p}$ $\qquad T_3 = T_{03} - \frac{{V_3}^2}{2c_p}$
- $T_{01} = T_1 + \frac{{V_1}^2}{2c_p}$ $\qquad T_2 = T_{02} - \frac{{V_2}^2}{2c_p}$ $\qquad P_2 = \frac{P_{01}}{\left(\frac{T_{01}}{T_{2s}}\right)^{\frac{k}{k-1}}}$
- $\rho = \frac{P}{RT}$ $\qquad A = \frac{m}{\rho V_{ax}}$ $\qquad h_{blade} = \frac{A}{\pi * D_m}$

Turbine Design



Turbine Design

- Geometry parameters

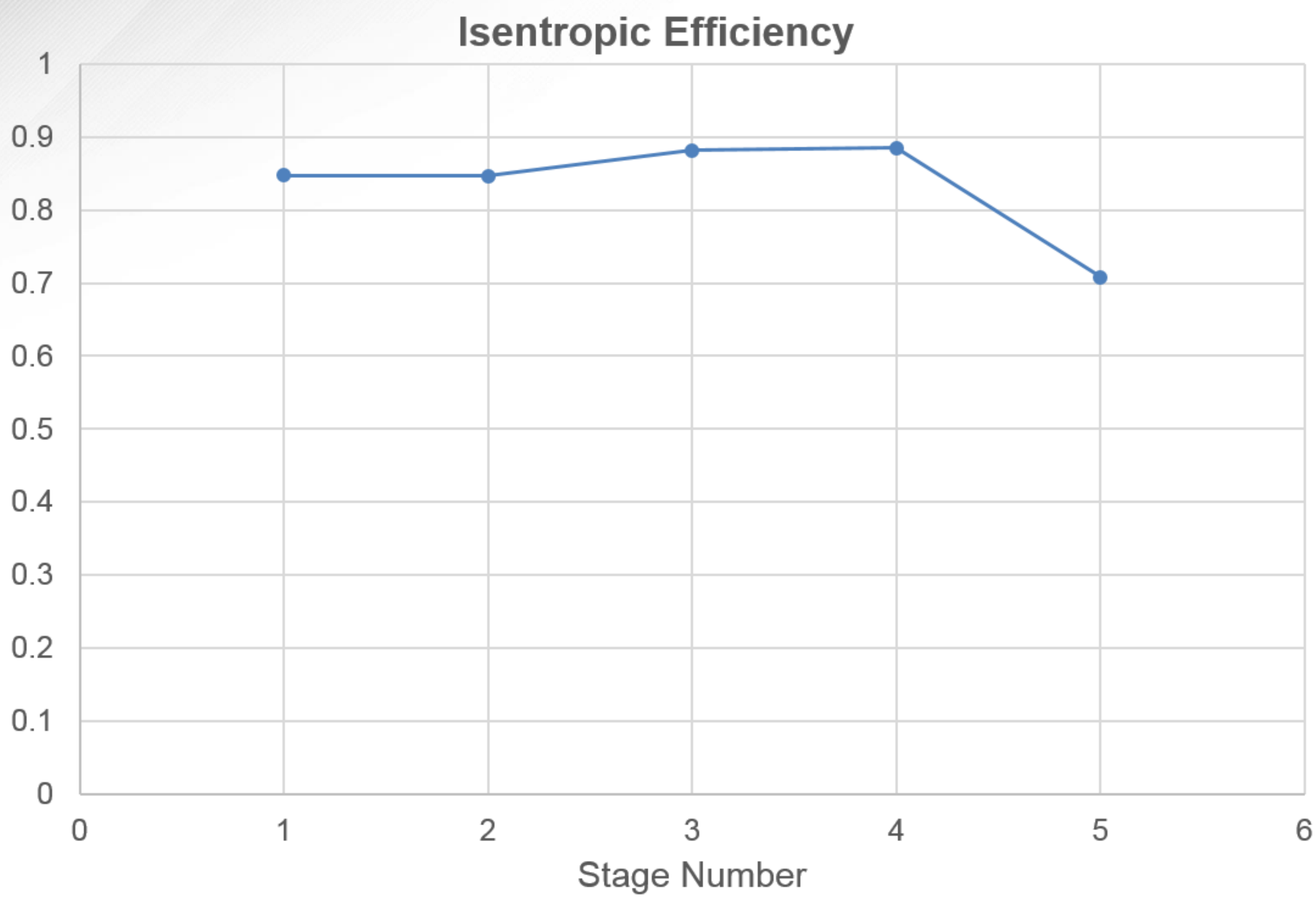
	Stage 1		Stage 2		Stage 3		Stage 4		Stage 5	
	Stator	Rotor	Stator	Rotor	Stator	Rotor	Stator	Rotor	Stator	Rotor
Solidity c/s	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Chord length c (m)	0.0941	0.1096	0.1269	0.1408	0.0702	0.0832	0.0987	0.1192	0.1352	0.1525
Spacing s (m)	0.0855	0.0996	0.1154	0.1280	0.0638	0.0756	0.0898	0.1083	0.1229	0.1386
Blade number N	35.00	30.00	25.00	22.00	43.00	34.00	28.00	21.00	18.00	15.00
Aspect ratio h/c	1.2	1.2	1.2	1.2	3	3	3	3	3	3

Turbine Design

- Profile loss
- Endwall friction and secondary loss
- Trailing edge loss, exit loss
- Clearance leakage loss

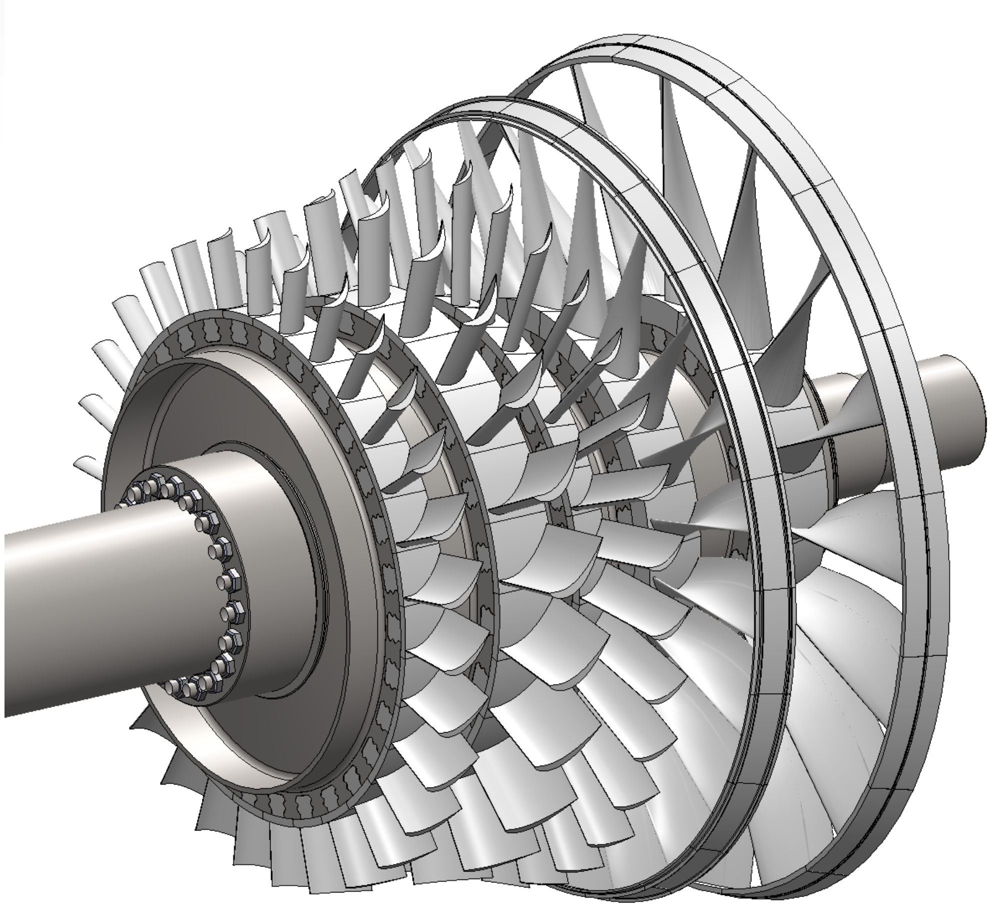
	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Z	0.18	0.1811	0.1340	0.1305	0.4121
Z_s	0.1526	0.1533	0.1181	0.1155	0.2918
η_S	0.8644	0.8564	0.8564	0.8564	0.6491
η_R	0.8245	0.8311	0.9017	0.9065	0.7380
η_{stage}	0.8474	0.8467	0.8819	0.8845	0.7082

Turbine Design



Turbine Design

Turbine rotor



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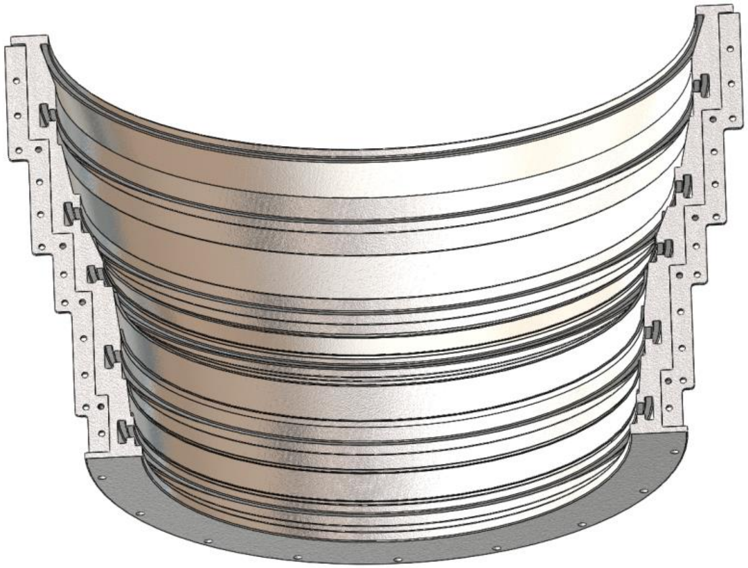
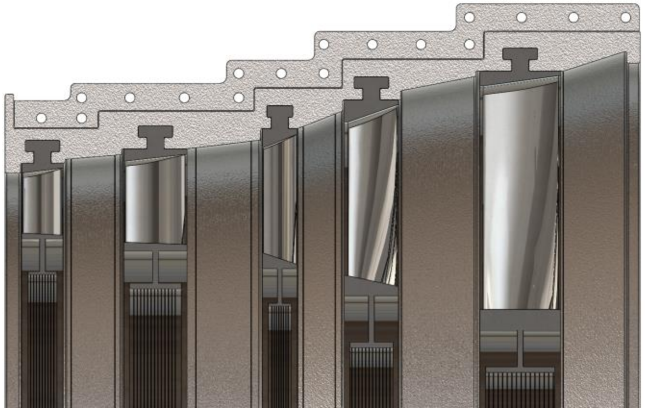
Turbine Design

Inner Casing





Rotor Stress Estimation

- Maximum stress happens at rotor root.

$$\sigma_{max} \approx 2\pi N^2 \rho_{blade} A$$

Where A is the annulus area, N is the rotational speed in rev/s.

	Material
Compressor LP, IP	Aluminum Alloy
Compressor HP	Nickel Alloy
Turbine	Nickel-based Super Alloy IN-100

Combustor Design

Equations used

- $\zeta_{CC} = (P_{ccin} - P_{ccout})/P_{ccin}$
- $m_{air} c_p T_{ccin} + m_{fuel} H = (m_{air} + m_{fuel}) c_p T_{ccout} + Q_{loss}$
- $\eta_{cc} = \frac{(m_{air} + m_{fuel}) c_p T_{ccout}}{m_{air} c_p T_{ccin} + m_{fuel} H}$

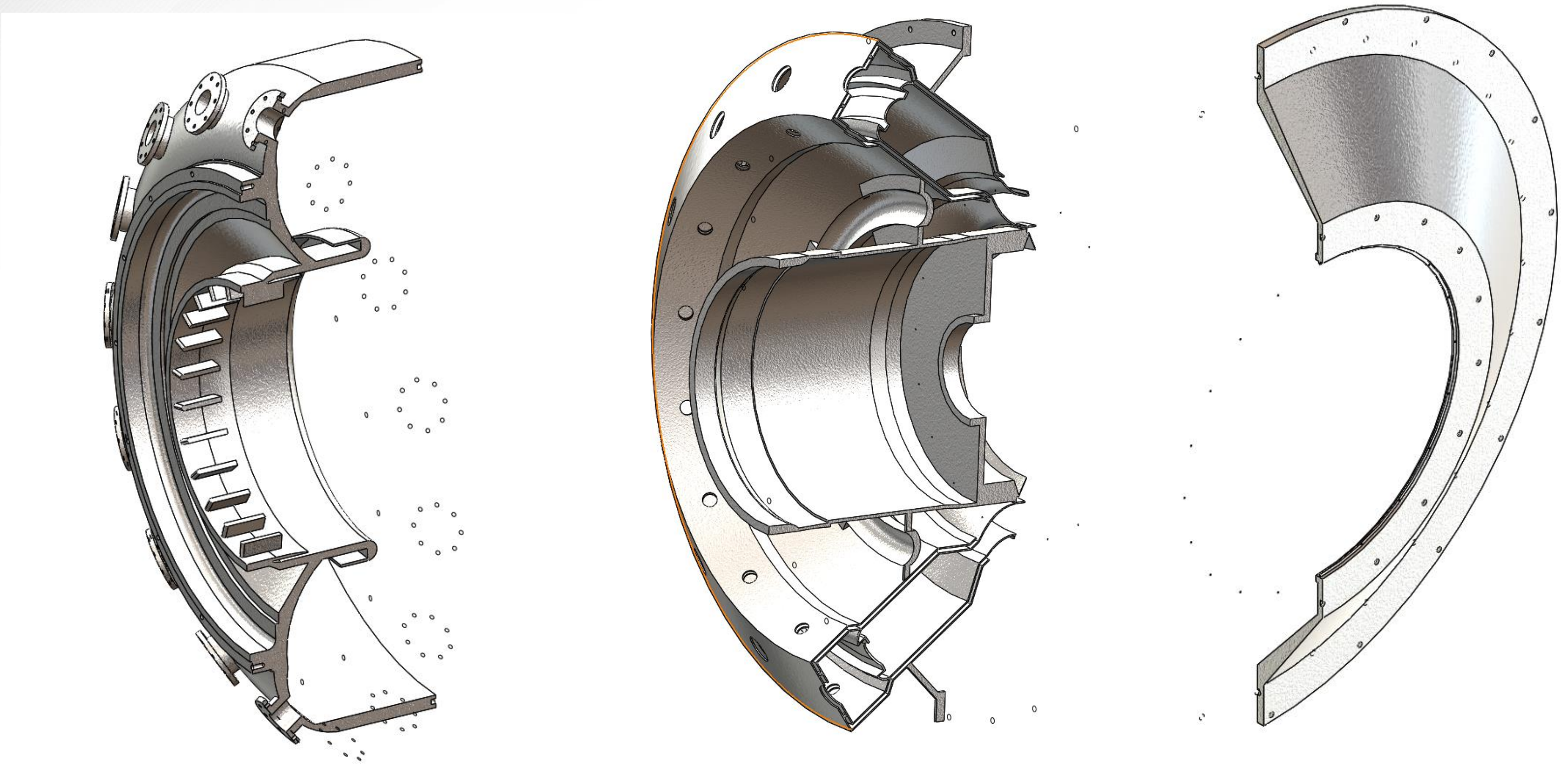
Fuel used: CH4

$\zeta_{CC} = 0.0397$

$\eta_{CC} = 0.9793$

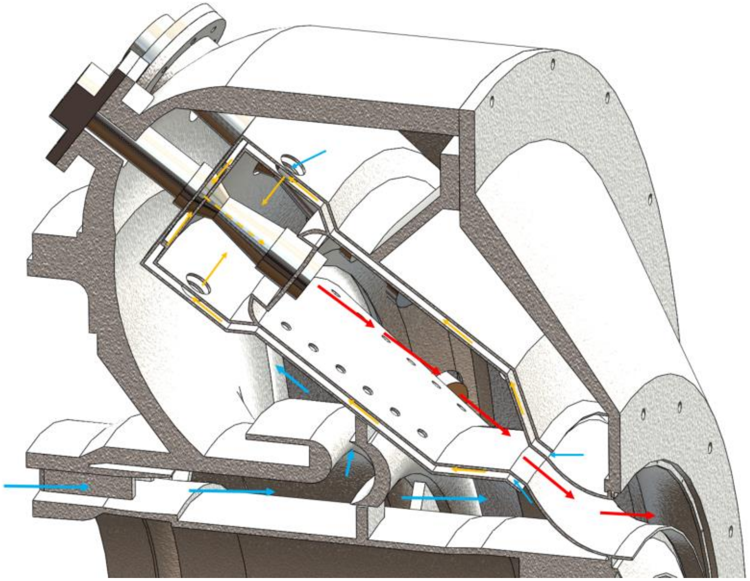
Combustor Design

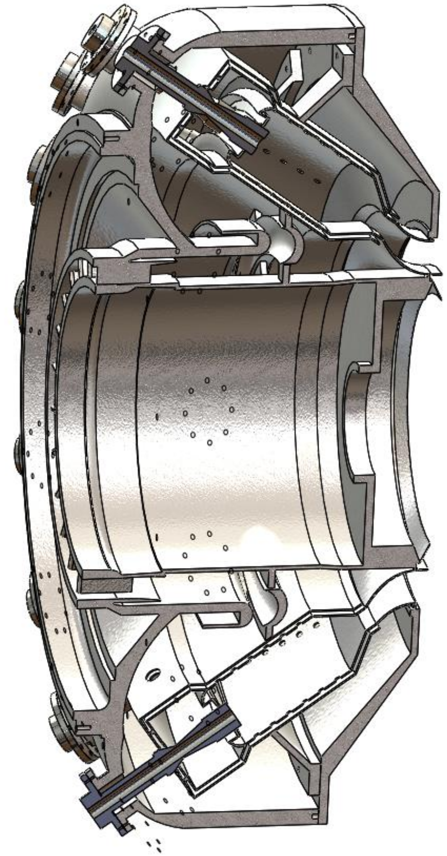
Combustion chamber parts



Combustor Design

Complete assembly





Nozzle and Diffuser Design

Governing Equation

(1) Ideal gas equation:

$$P = \rho RT$$

(2) Bernoulli equation:

$$P_0 + \frac{1}{2}\rho_0 V_0^2 = P_1 + \frac{1}{2}\rho_1 V_1^2$$

(3) Mass balance:

$$\rho_0 V_0 A_0 = \rho_1 V_1 A_1$$

(4) For compressible flow:

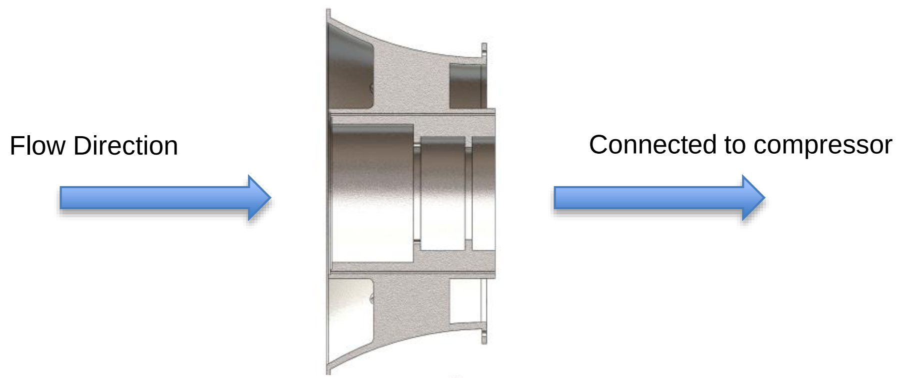
$$\frac{T}{T_0} = \left(\frac{P}{P_0}\right)^{\frac{k-1}{k}}$$

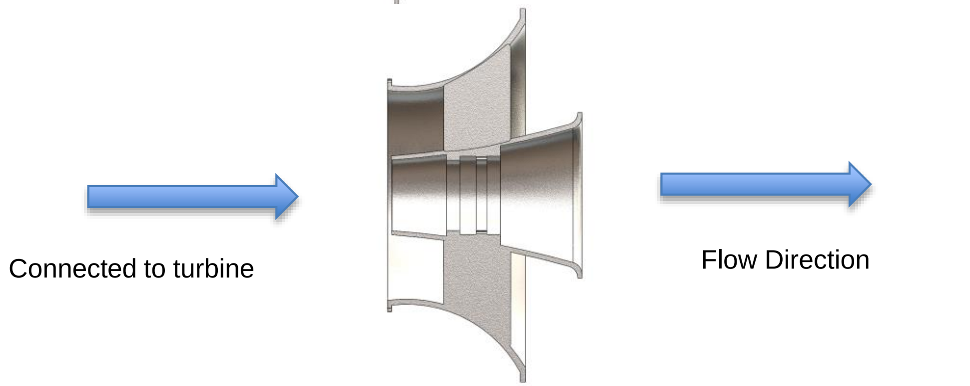
(5) Speed of sound at a certain temperature:

$$c = \sqrt{kRT}$$

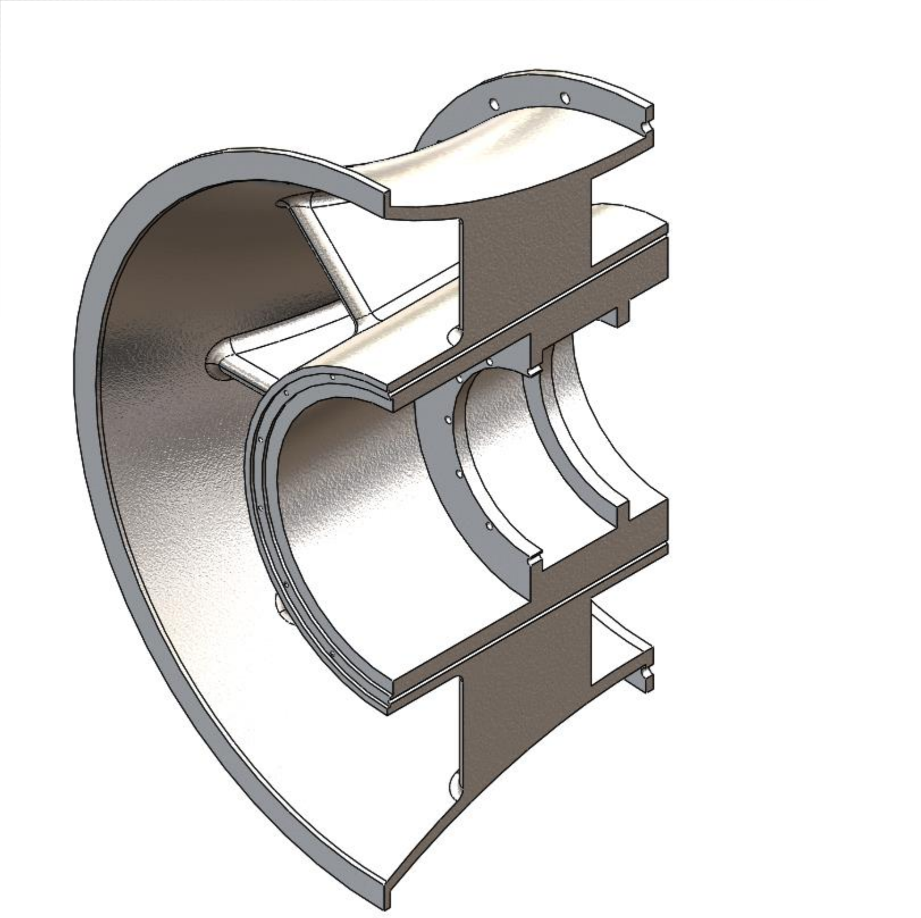
(6) Mach number relationship:

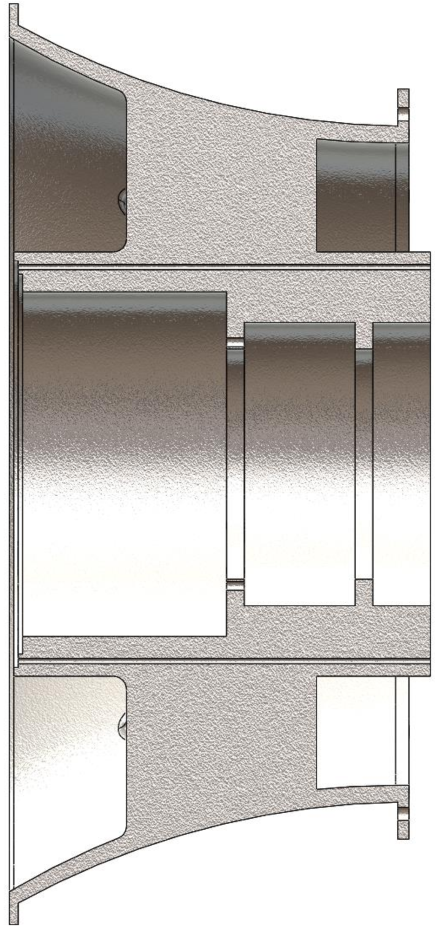
$$\frac{P_0}{P} = \left(1 + \frac{k-1}{2} Ma^2\right)$$





Nozzle Design





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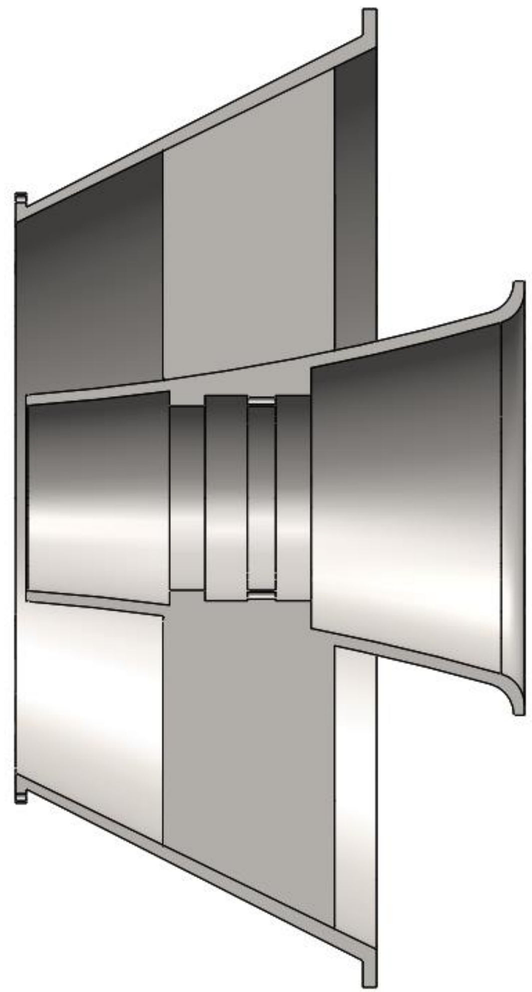
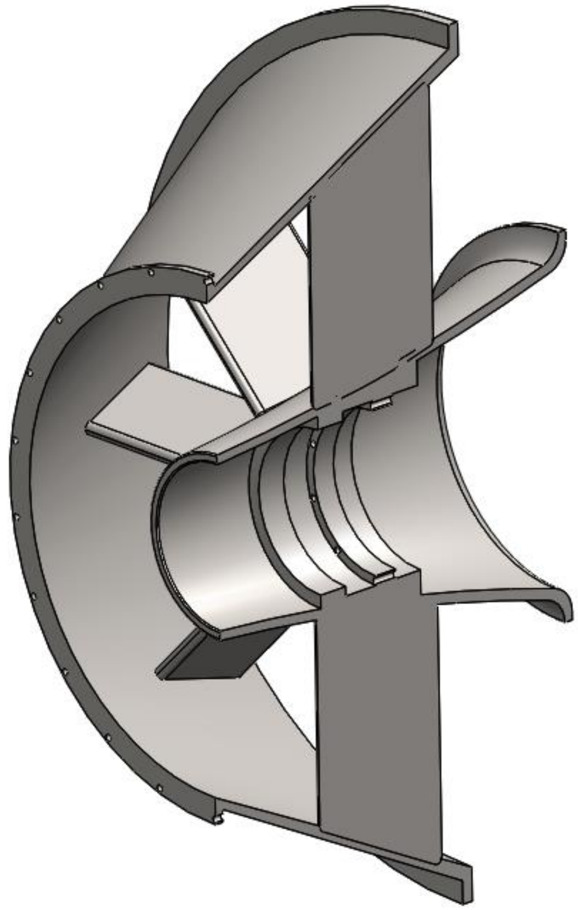
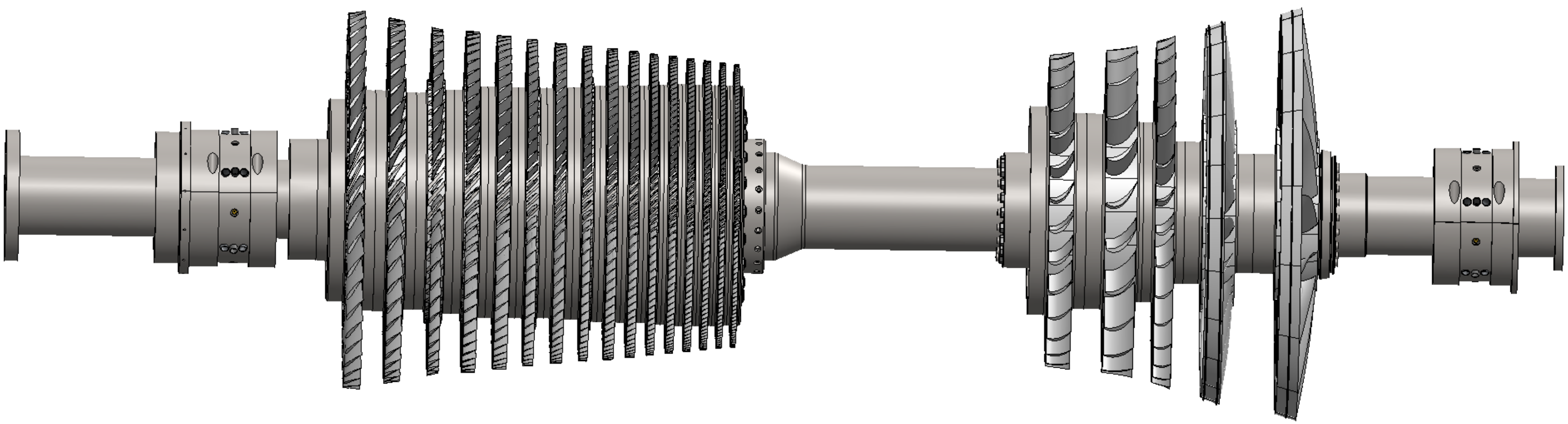
Diffuser Design



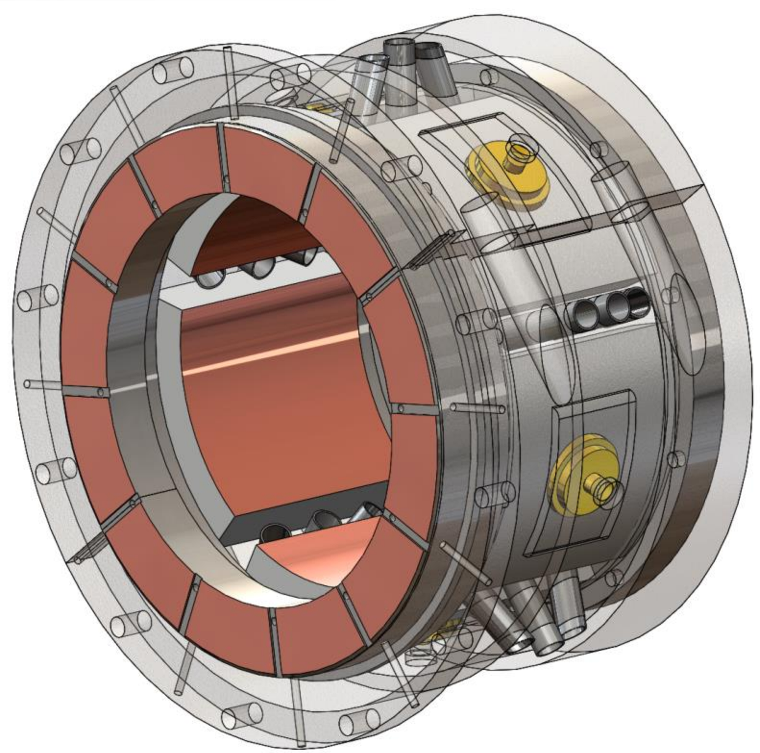


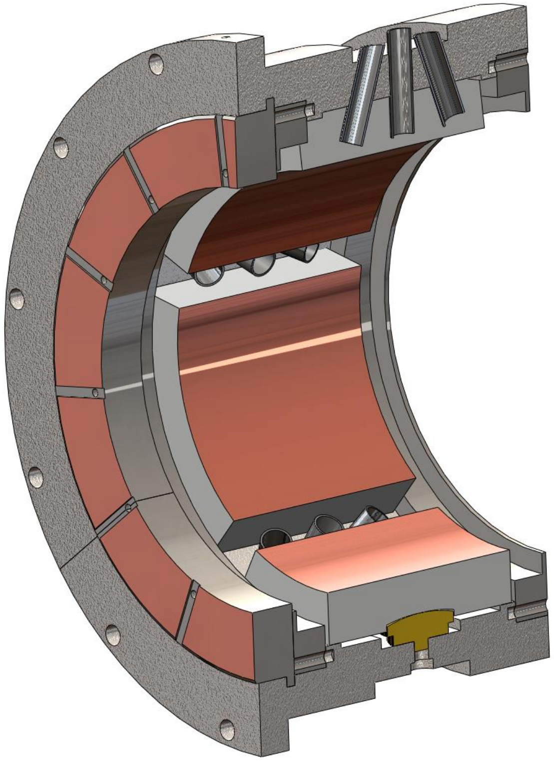
Bearing Arrangement



Bearing Design

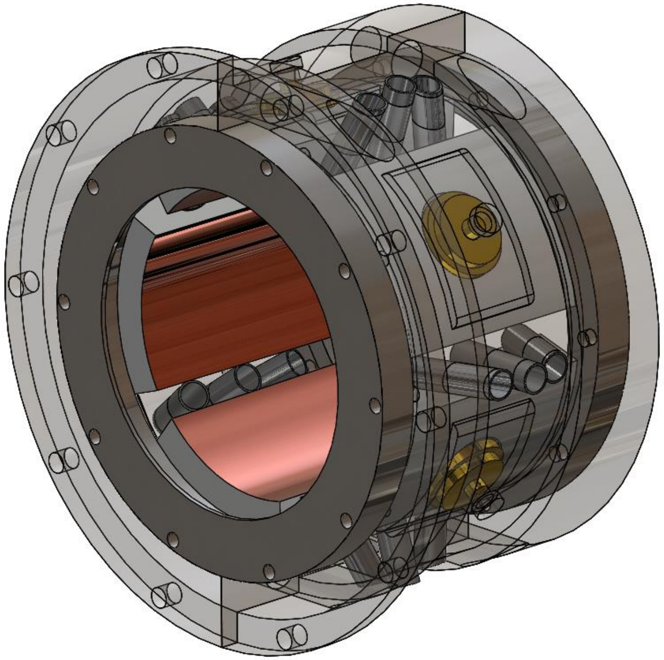
- Compressor end thrust bearing (fix pad) and journal bearing (spherical seat titling pad) – John Crane Design

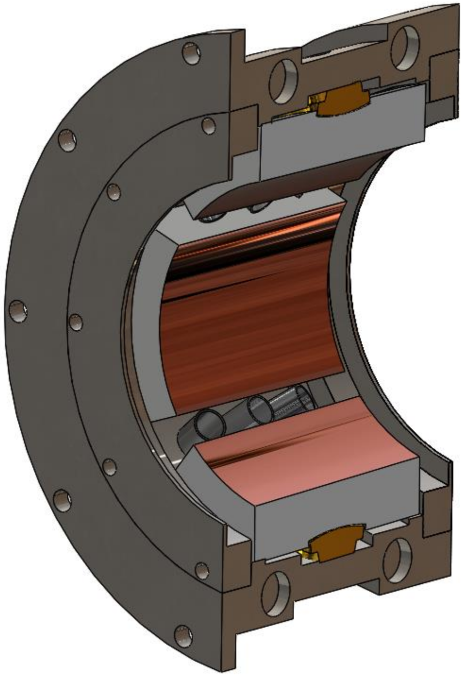




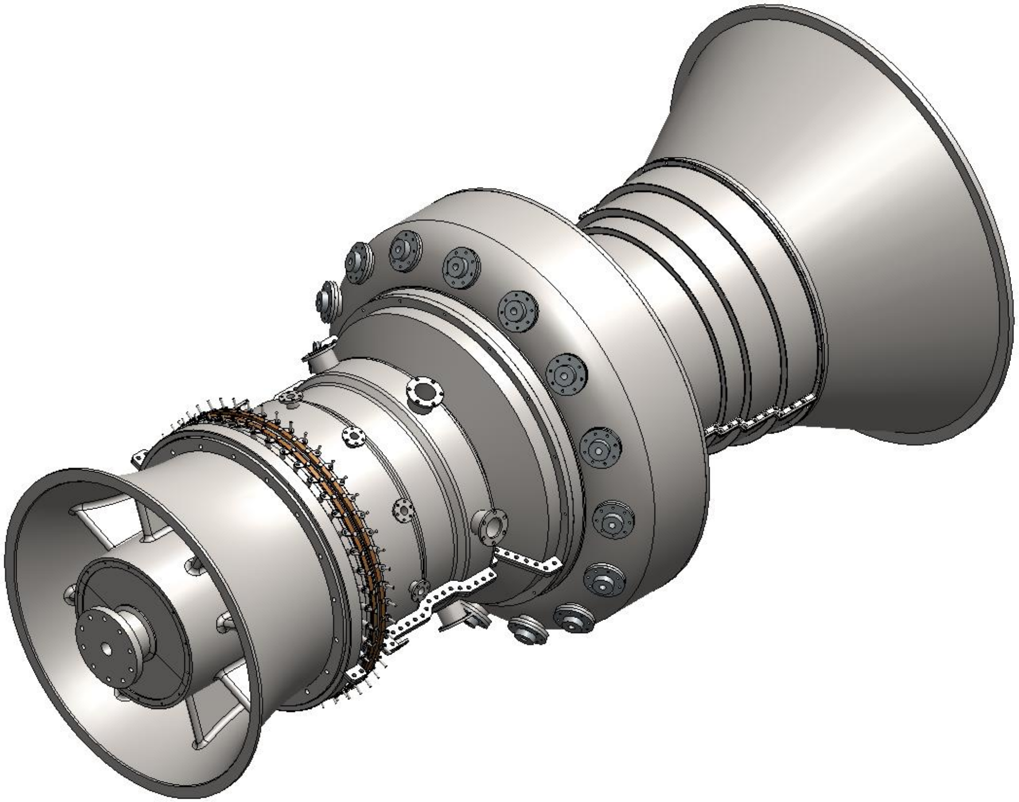
Bearing Design

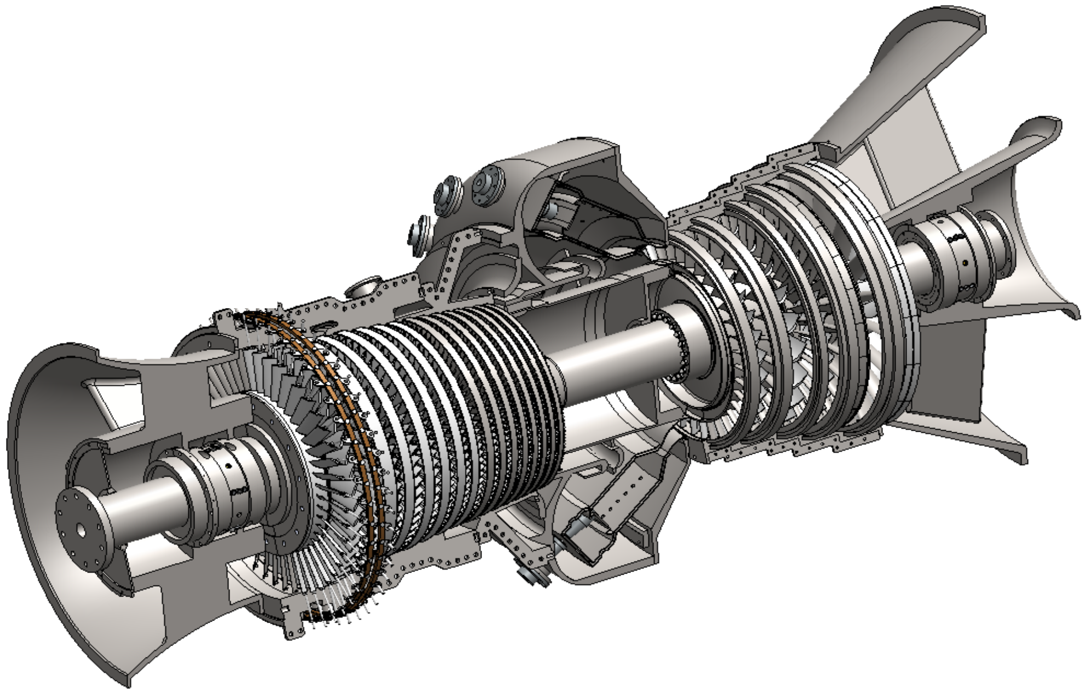
- Turbine diffuser end journal bearing (spherical seat titling pad) – John Crane Design





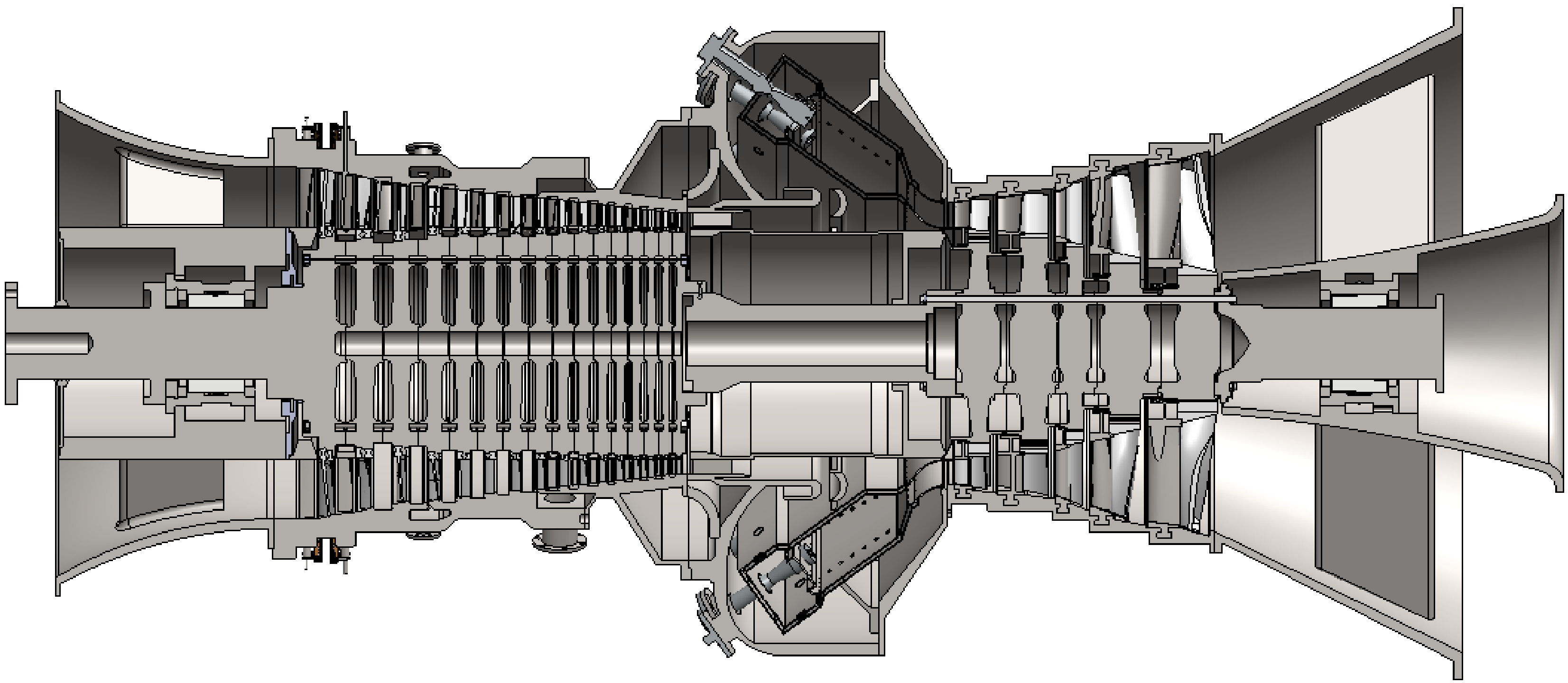
Gas Turbine Assembly





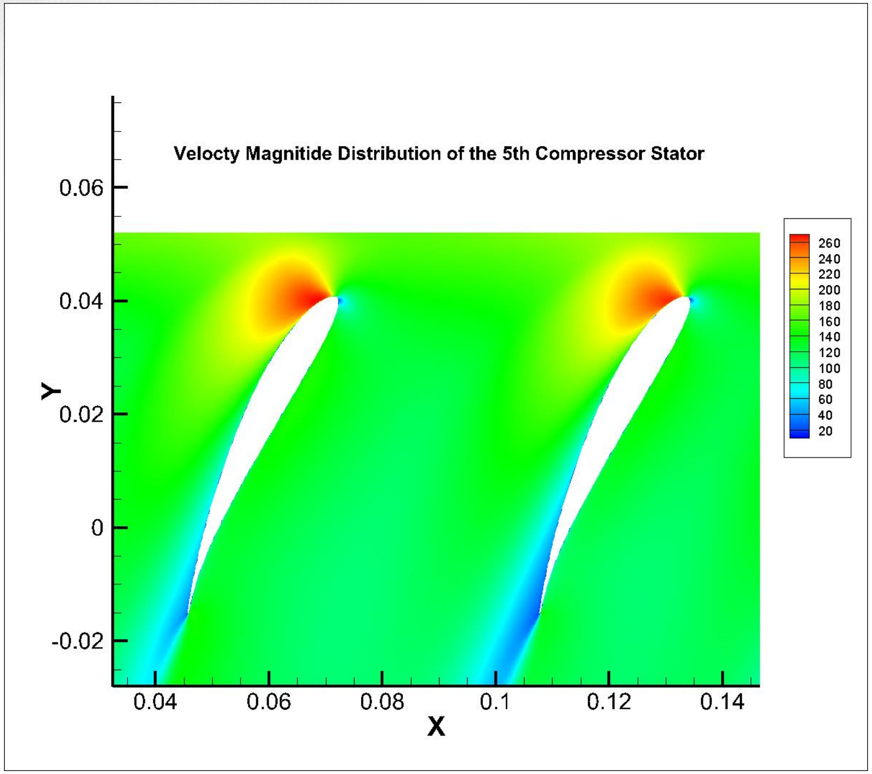
Gas Turbine Assembly

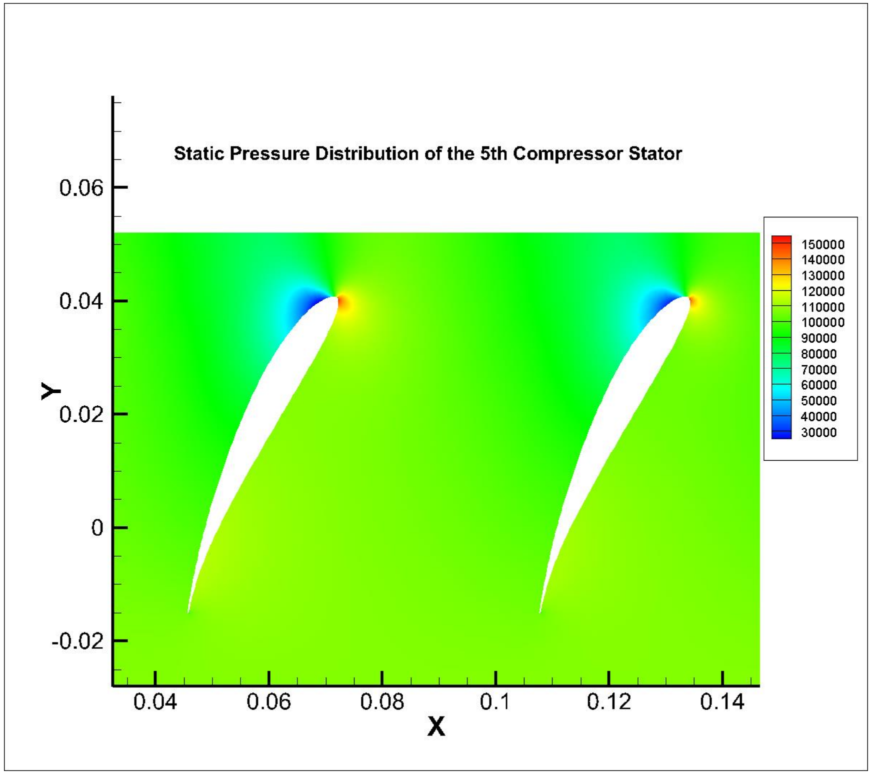
Sectional View



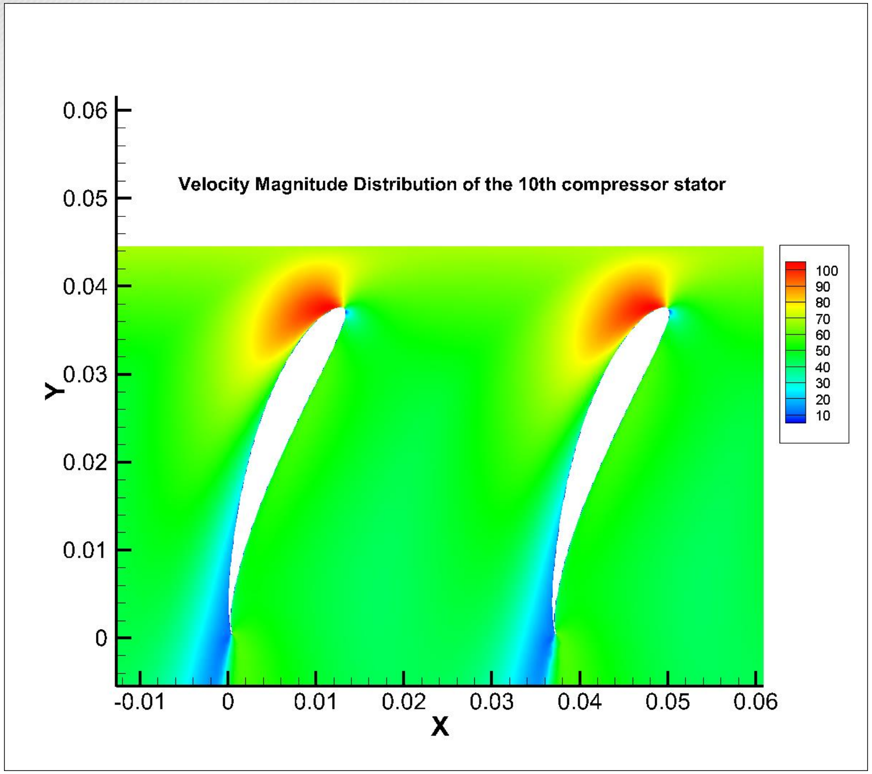
CFD of Blades

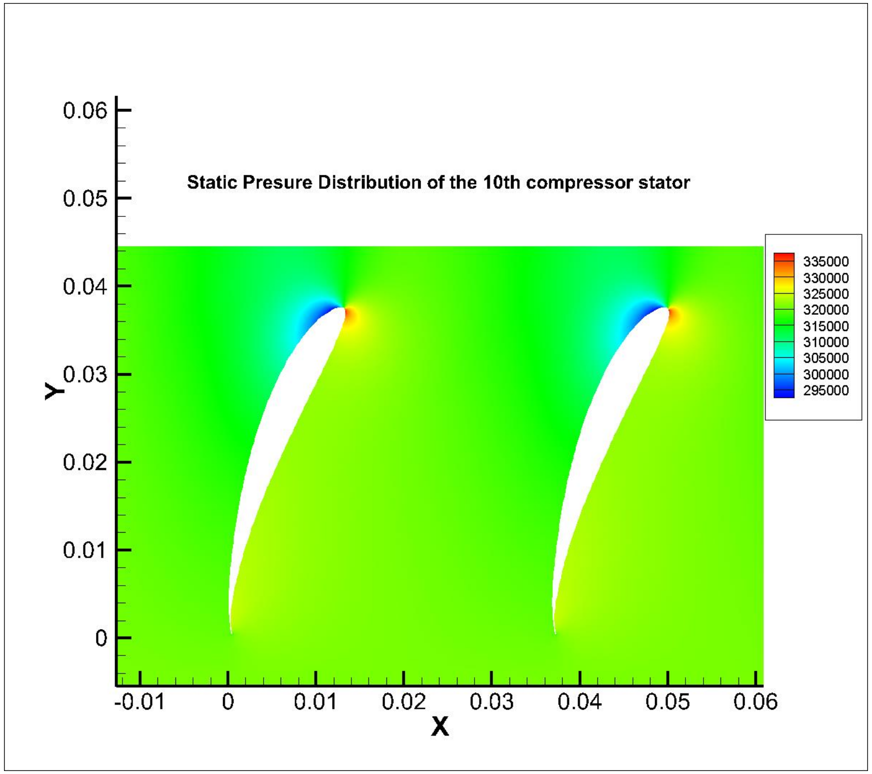
- CFD of Compressor





CFD of Blades





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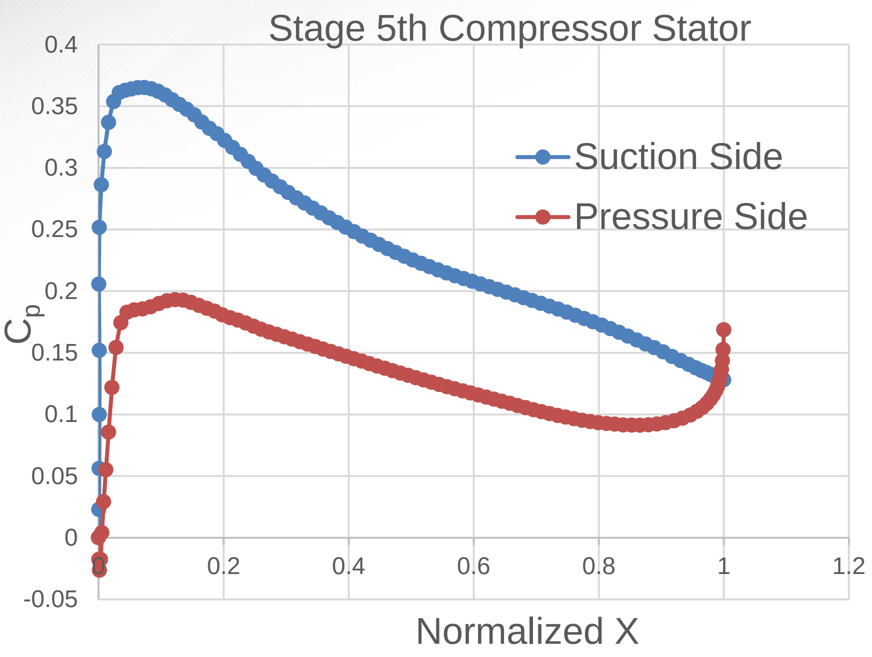
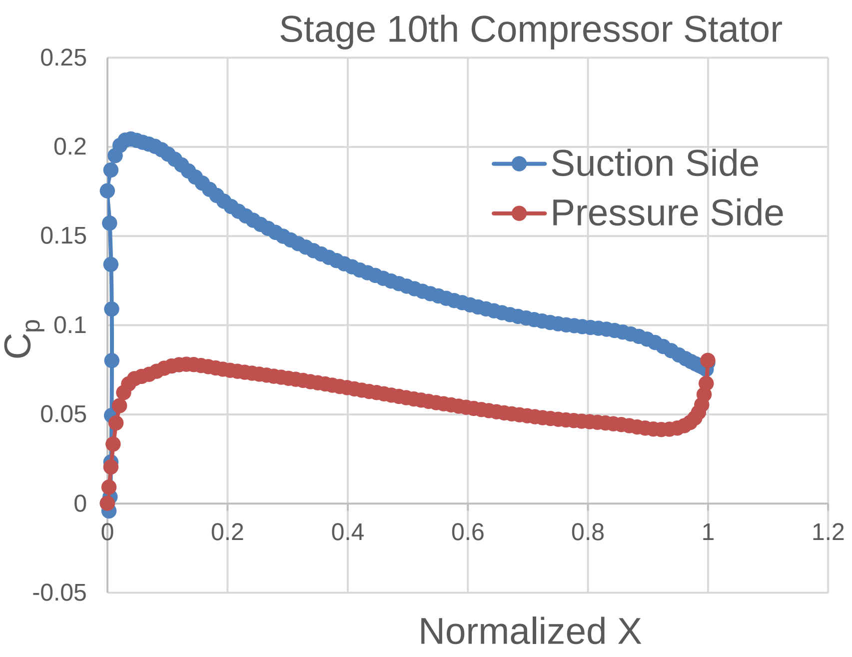
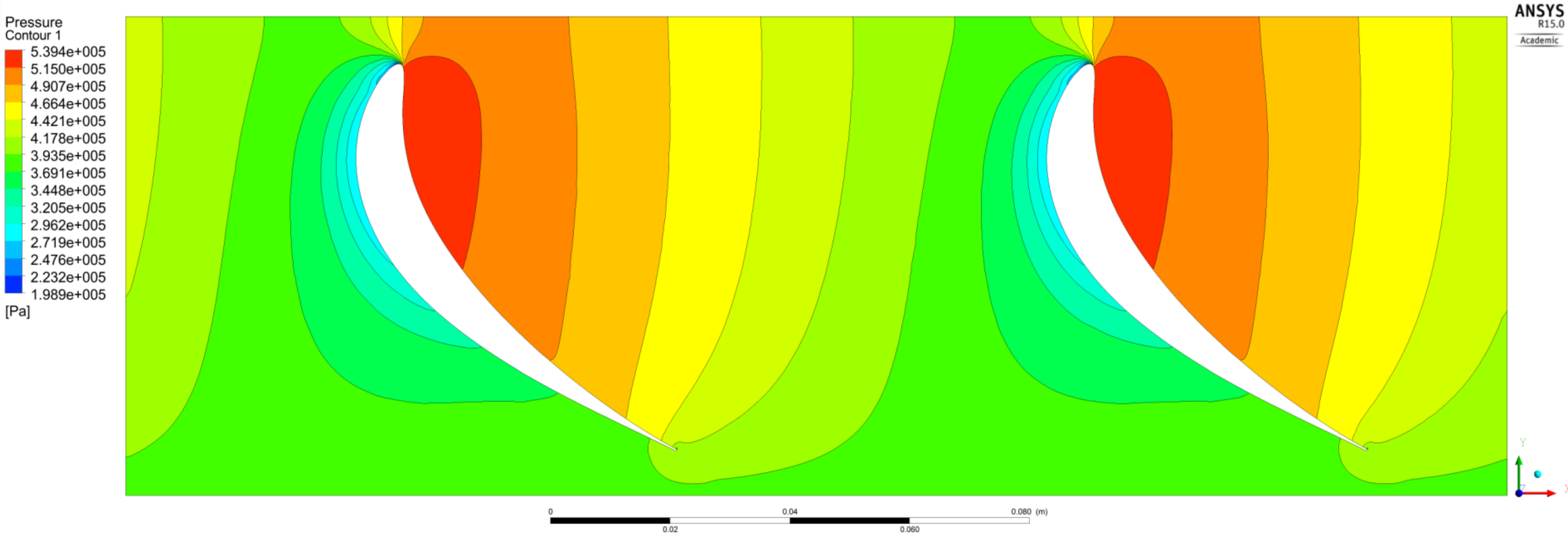


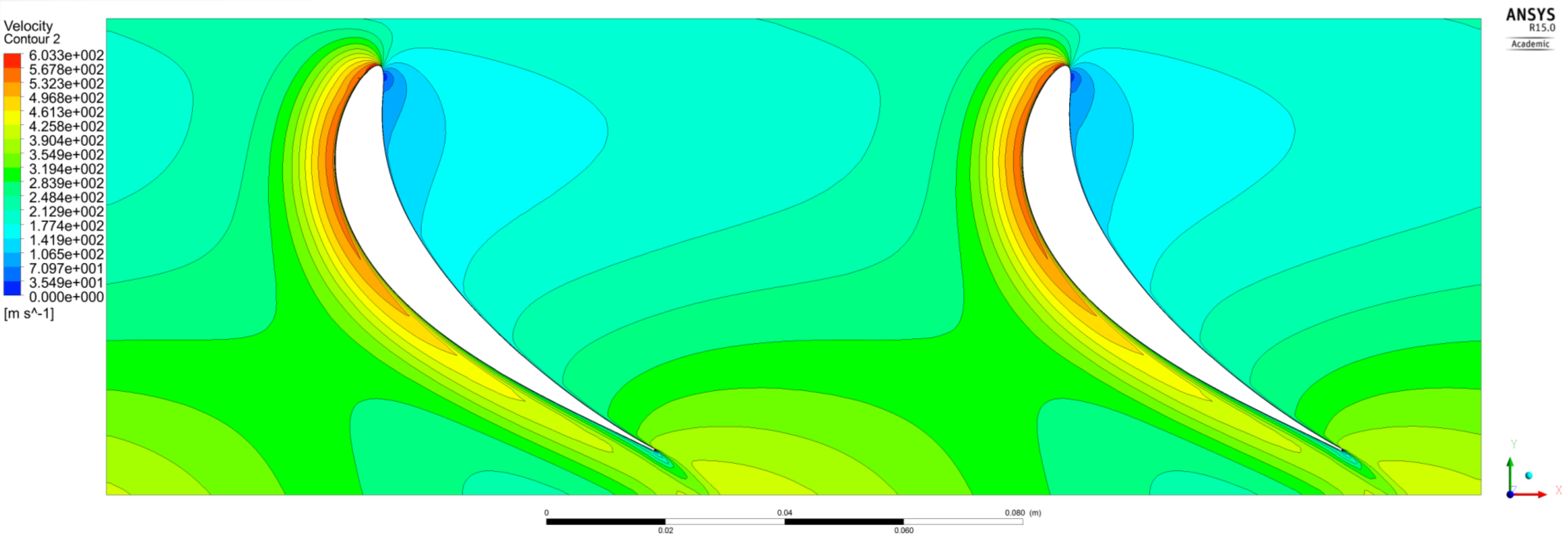


CFD of Blades

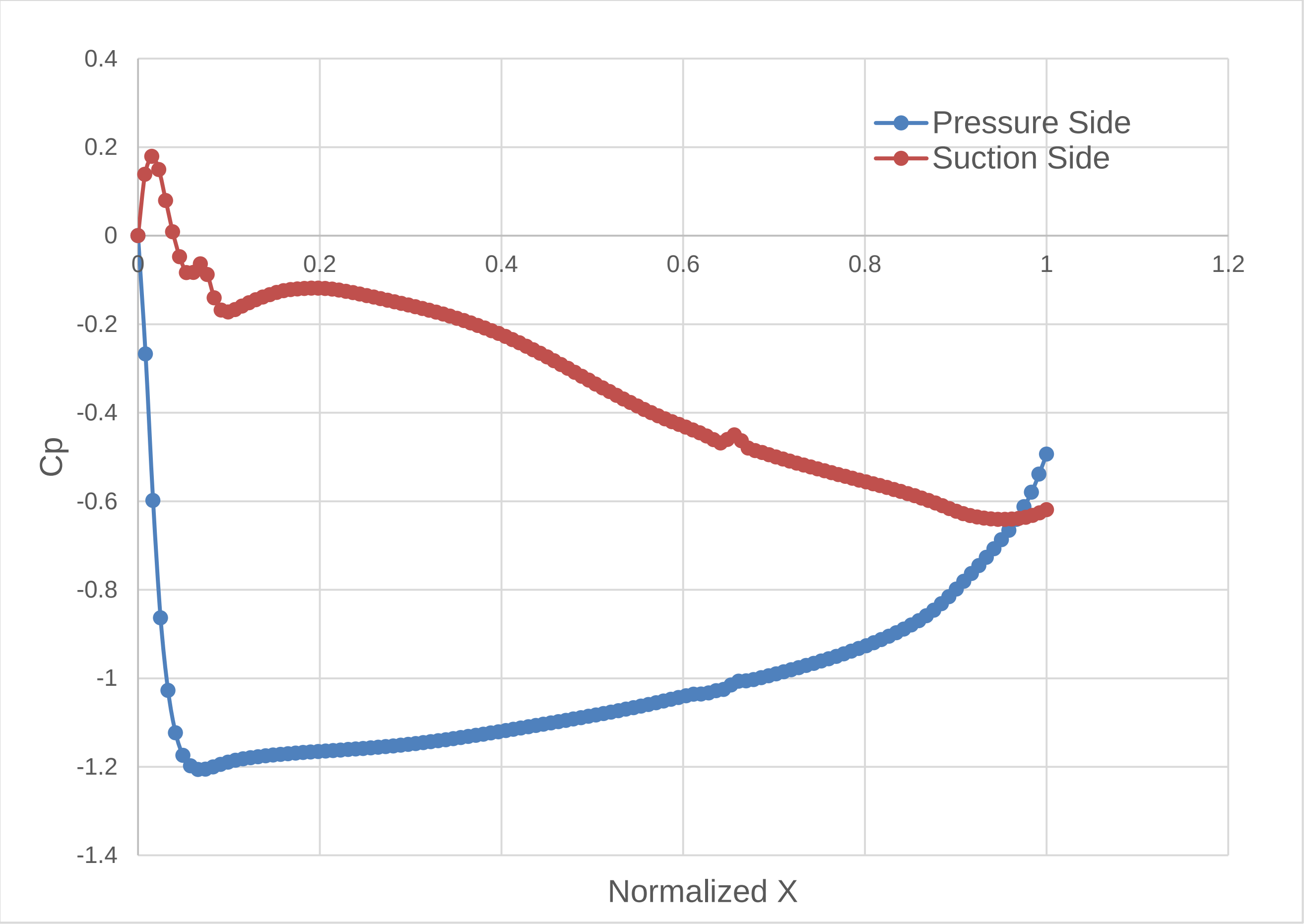
- 2nd Stage Turbine



CFD of Blades



CFD of Blades



Summary

- Aero-thermodynamics Calculation for compressor and turbine.
- Detailed mechanical design for manufacture purpose.
- Bearing assembly design for normal operation.
- CFD of blades provide pressure distribution.

Dwight Look College of ENGINEERING TEXAS A&M UNIVERSITY

Thank you!
Q&A