DESIGN OF A SUPERCRITICAL CO_2 COMPRESSOR FOR USE IN A 10 MWe POWER CYCLE

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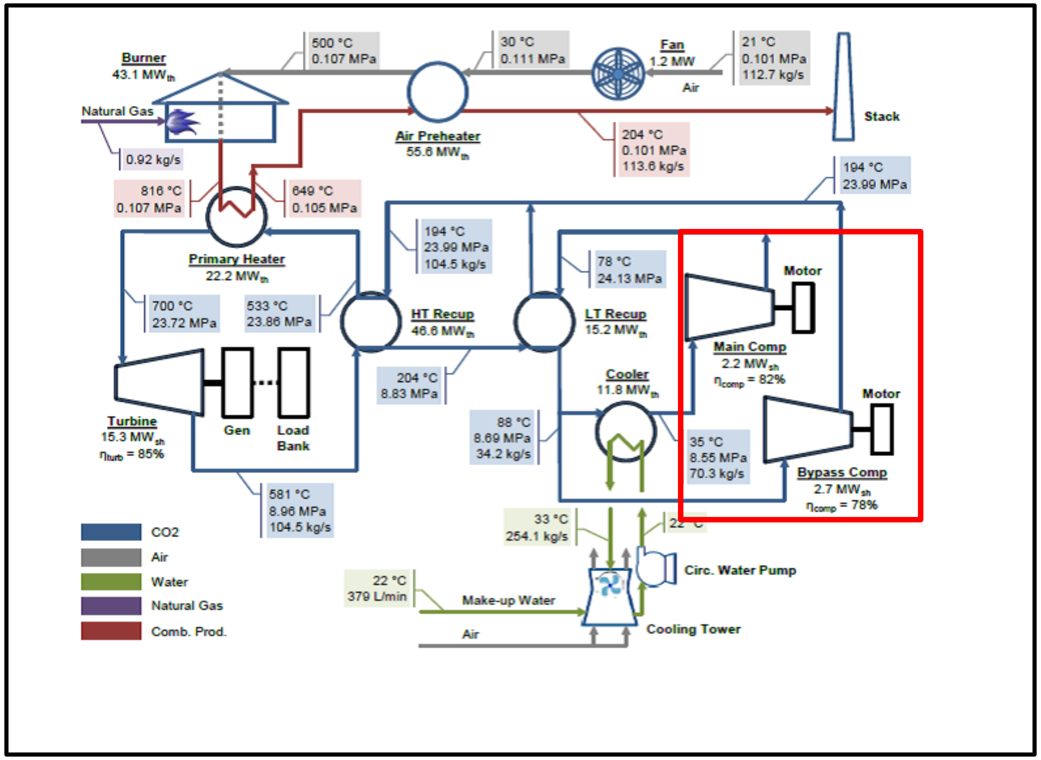
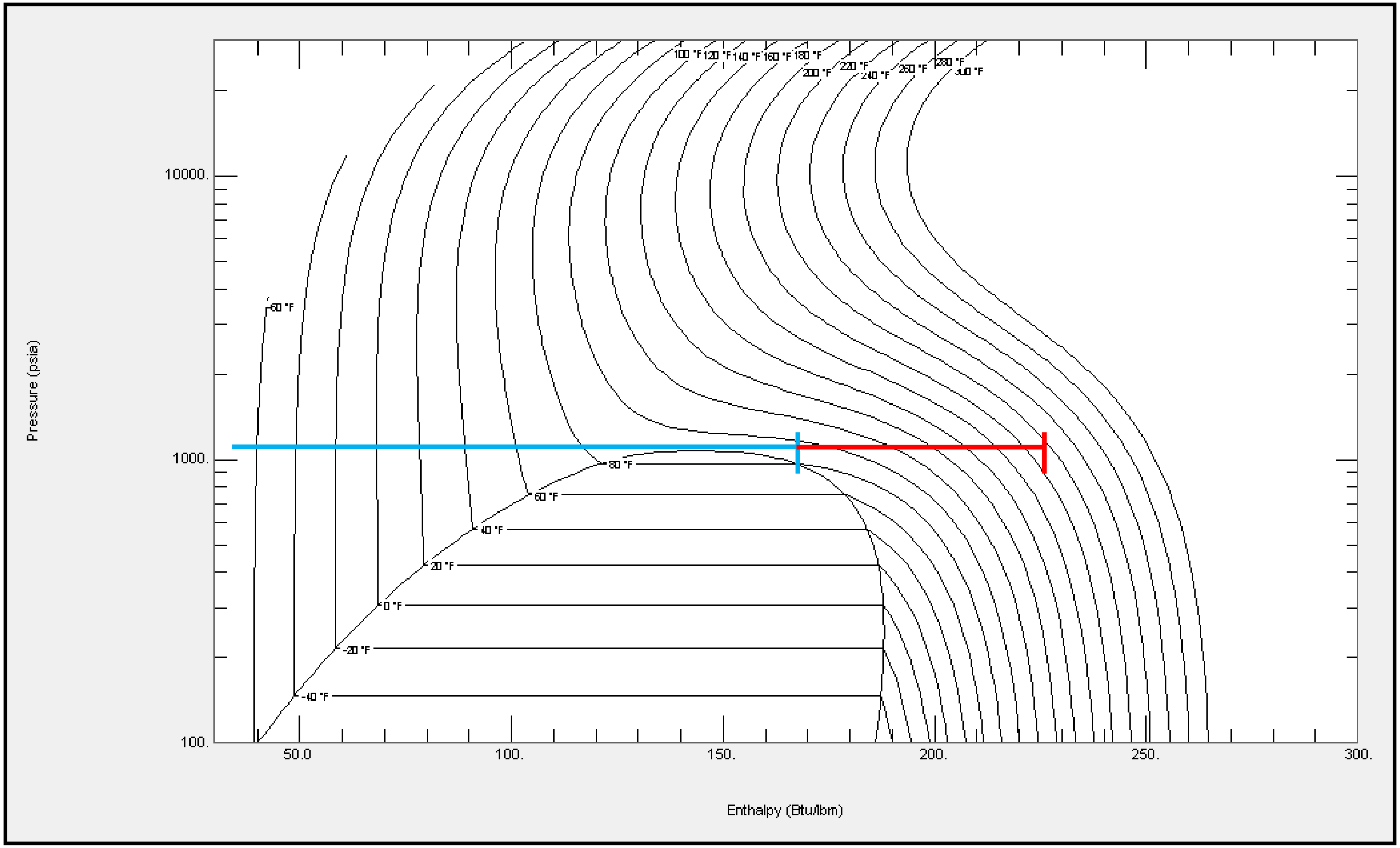
Power Cycle



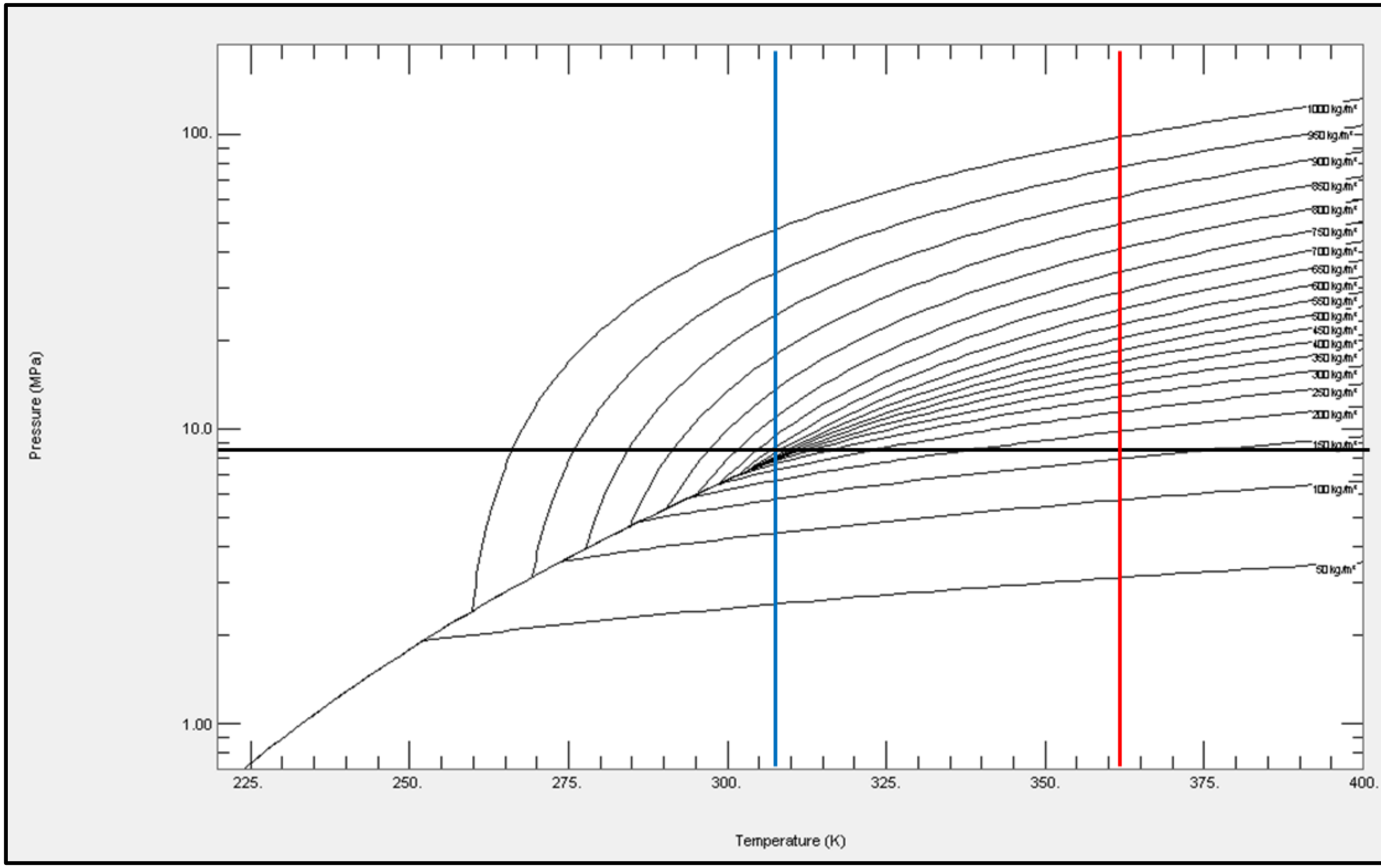
- 10 MWe, Re-compression Brayton Cycle
- Main Components
  - High and Low Temperature Recuperator
  - Main and Bypass Compressor
  - High Temperature Turbine

- Main Compressor Conditions
  - Inlet: 95ºF and 1,240 psi
  - Exit: 172ºF and 3,500 psi
  - 156 lbm/s
- Bypass Compressor Conditions
  - Inlet: 190ºF and 1,260 psi
  - Exit: 381ºF and 3,480 psi
  - 75.4 lbm/s

sCO_2 Properties

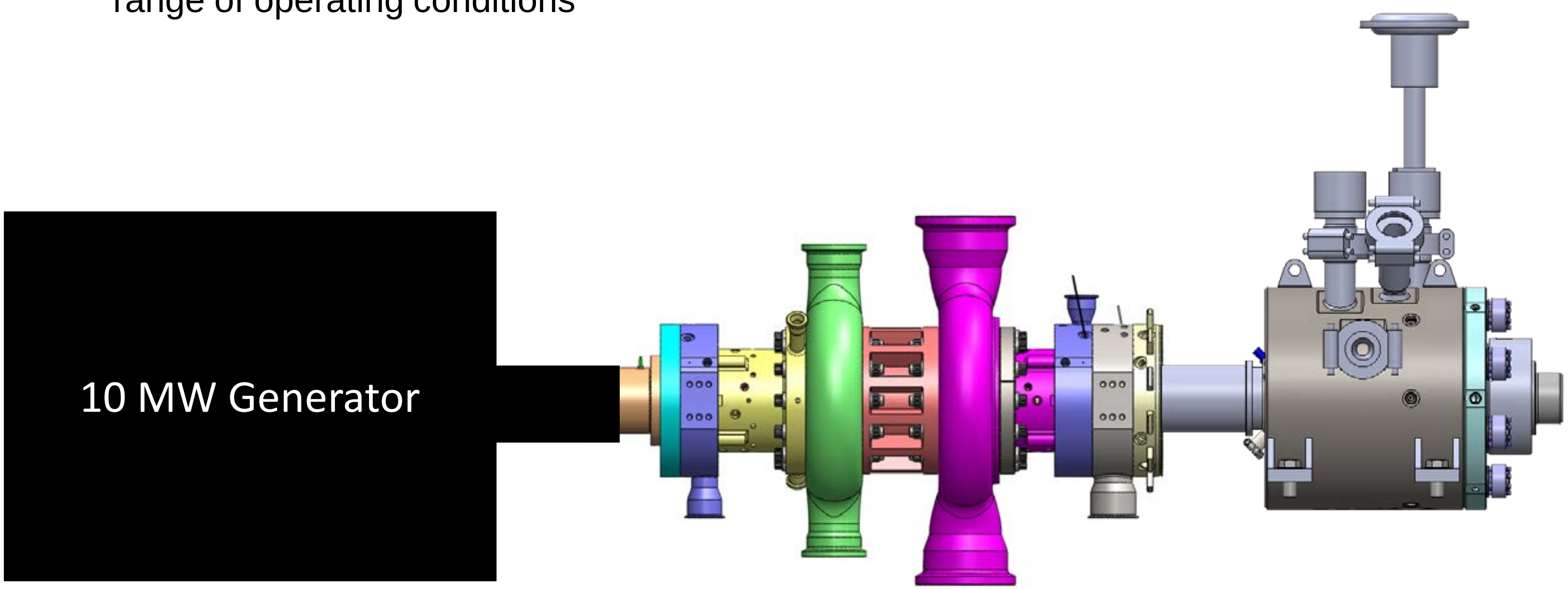


sCO_2 Properties

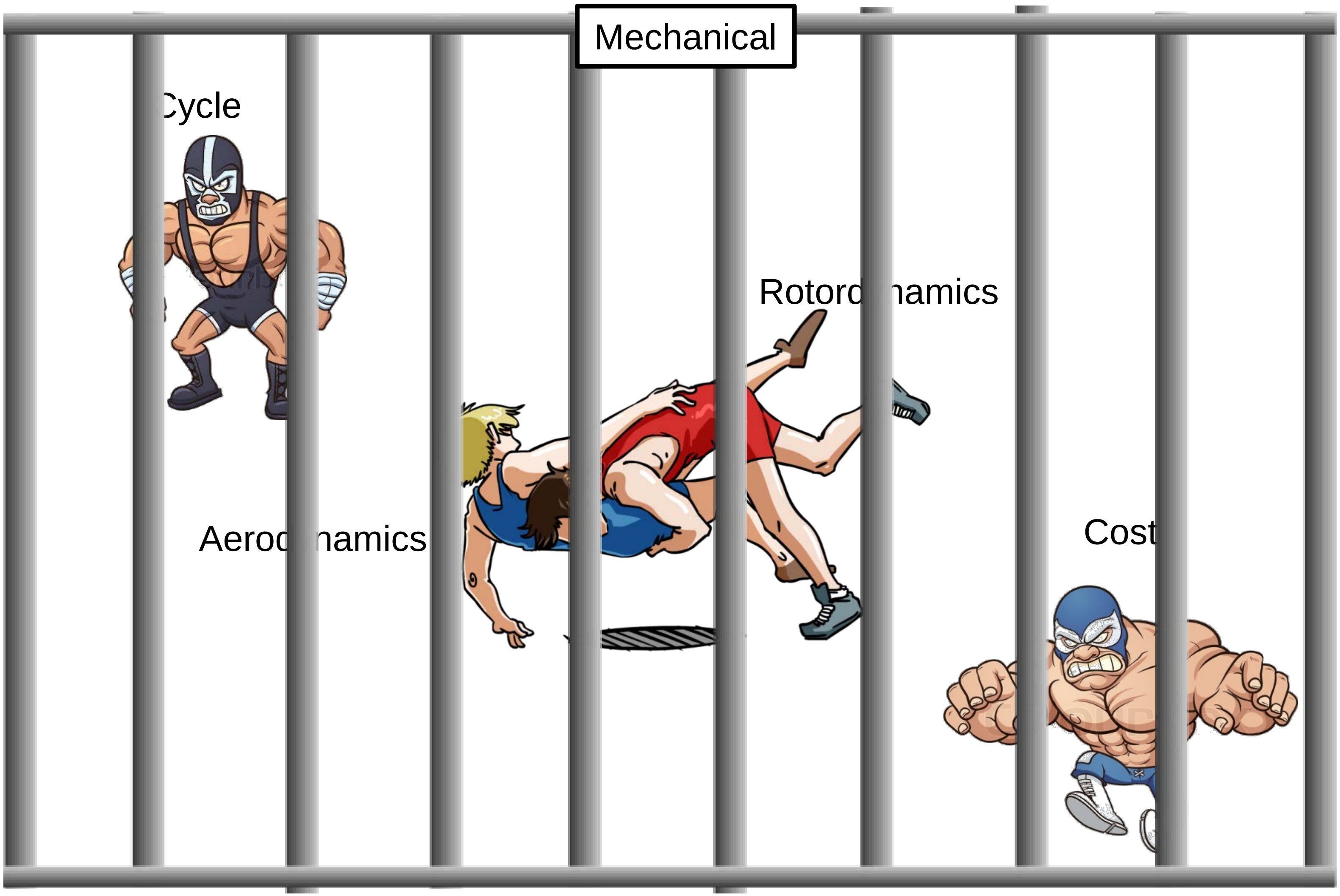


Design Goals

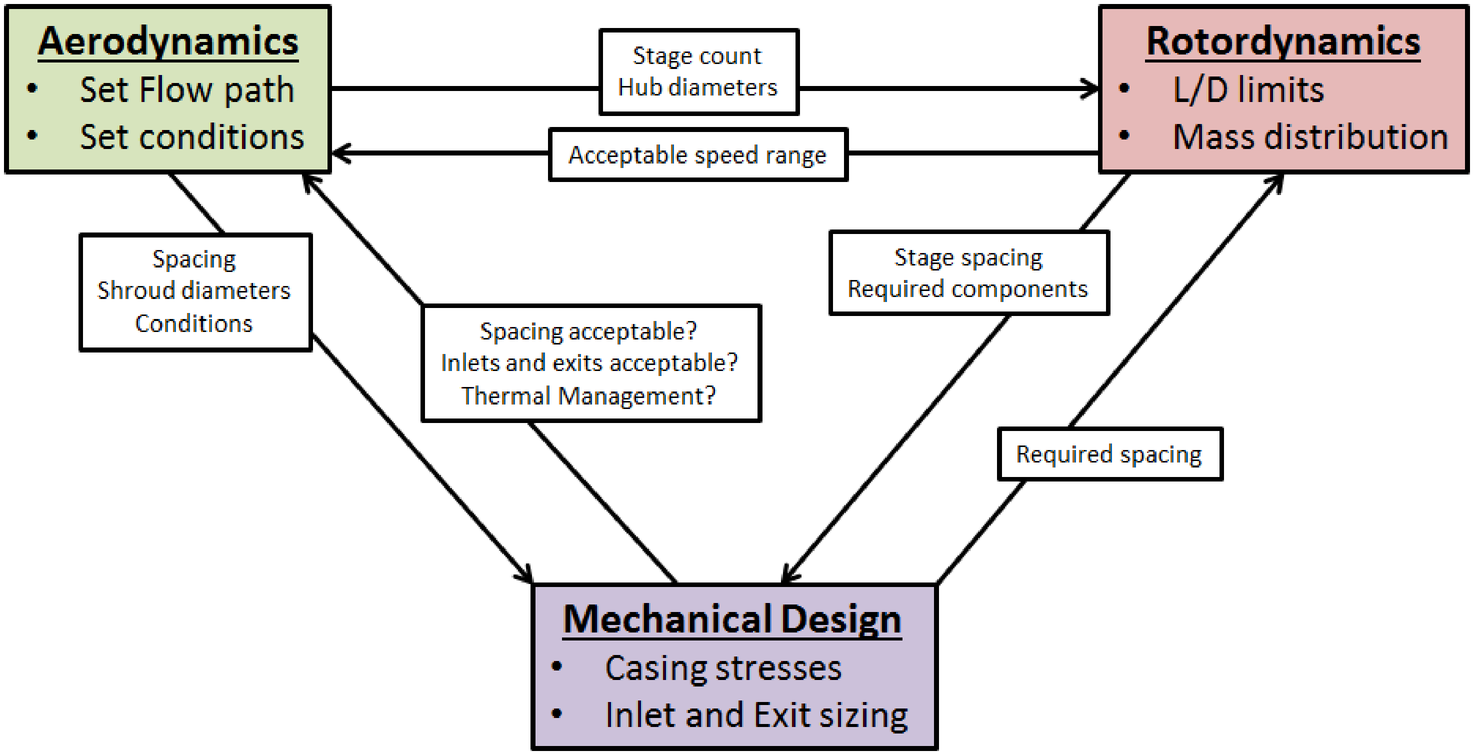
- Compressor to be directly driven by turbine
  - Only one skid required for the turbine and compressor train
  - Smaller overall footprint
  - No need for high speed gearbox
  - Compressor will be designed for operating speed of 27,000 rpm to match turbine
- Single compressor casing to house both main and re-compressor
  - Only need one high pressure casing which will reduce overall cost
- Variable Inlet Guide Vanes
  - Directly coupled means speed control in not a possibility
  - Variable IGVs are commonly used in other applications to maintain performance over a wide range of operating conditions



Design Disciplines

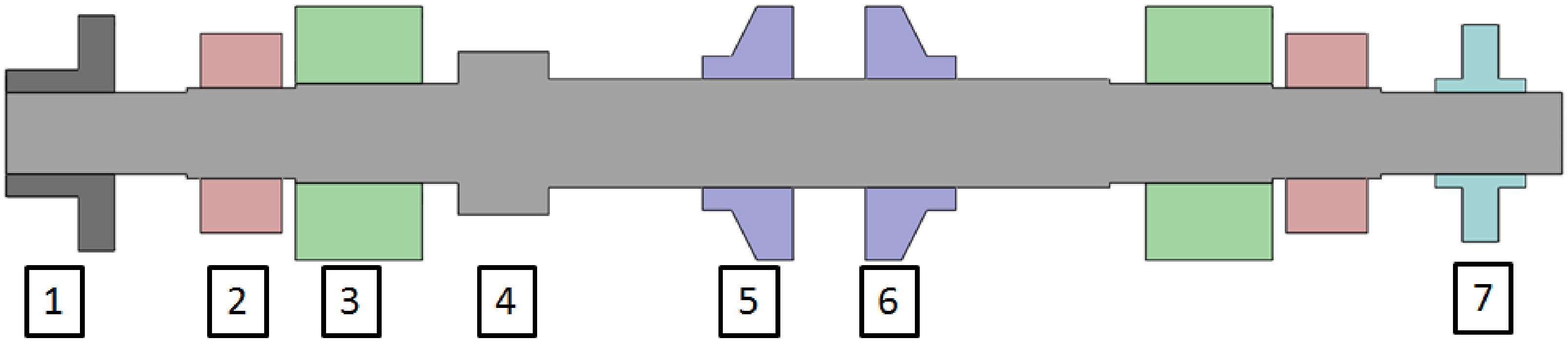


Design Disciplines



- Design must meet requirements of aerodynamics, rotordynamics, and mechanical design
- Each discipline has certain design goals that counteract each other
- Design goals
  - Fewer compressor stages to reduce the overall axial span
  - Larger hub diameters that will meet bearing span to diameter goals set by rotordynamics
  - Pushing the rotordynamic limits by balancing stage count, axial span, and key diameters to meet the overall design goals set by the cycle

Rotor Layout

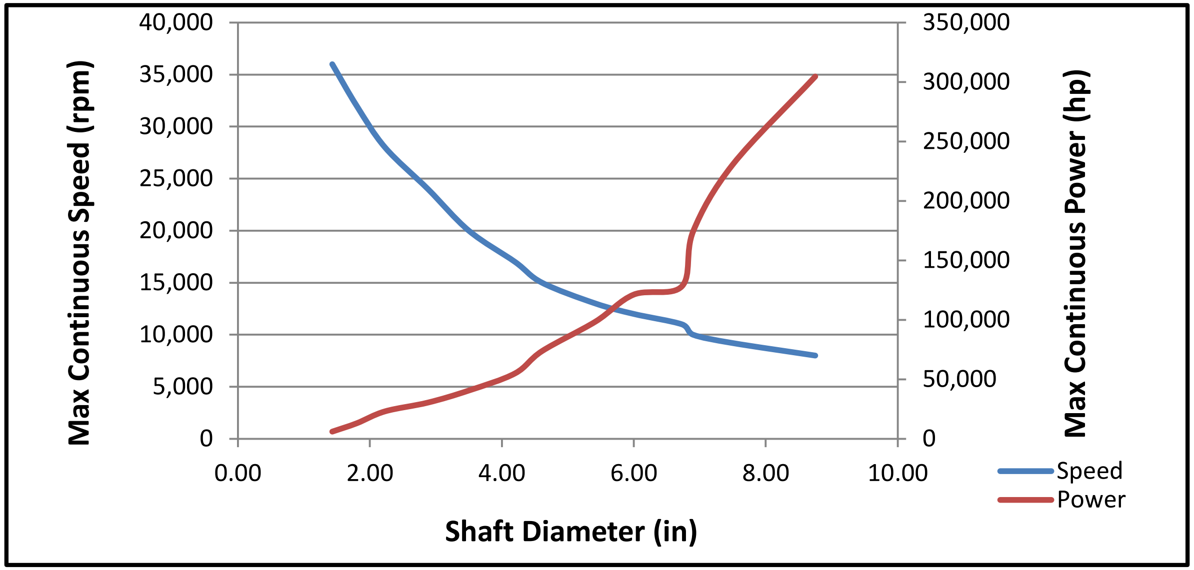


Main rotor Components

1. Coupling
2. Journal bearing
3. Dry gas seal
4. Balance Piston
5. Main / Bypass Compressor
6. Bypass / Main Compressor
7. Thrust collar and thrust bearings

- API 617
- ASME Section VIII Division 2

Coupling and Shaft Sizing



$$T = 63{,}025\frac{P}{w} = 63{,}025\frac{6570}{27000} = 15{,}336\ in - lbs$$

$$\tau = \frac{Tr}{J} = \frac{15336\ x\ 1.125}{2.52} = 6{,}857\ psi$$

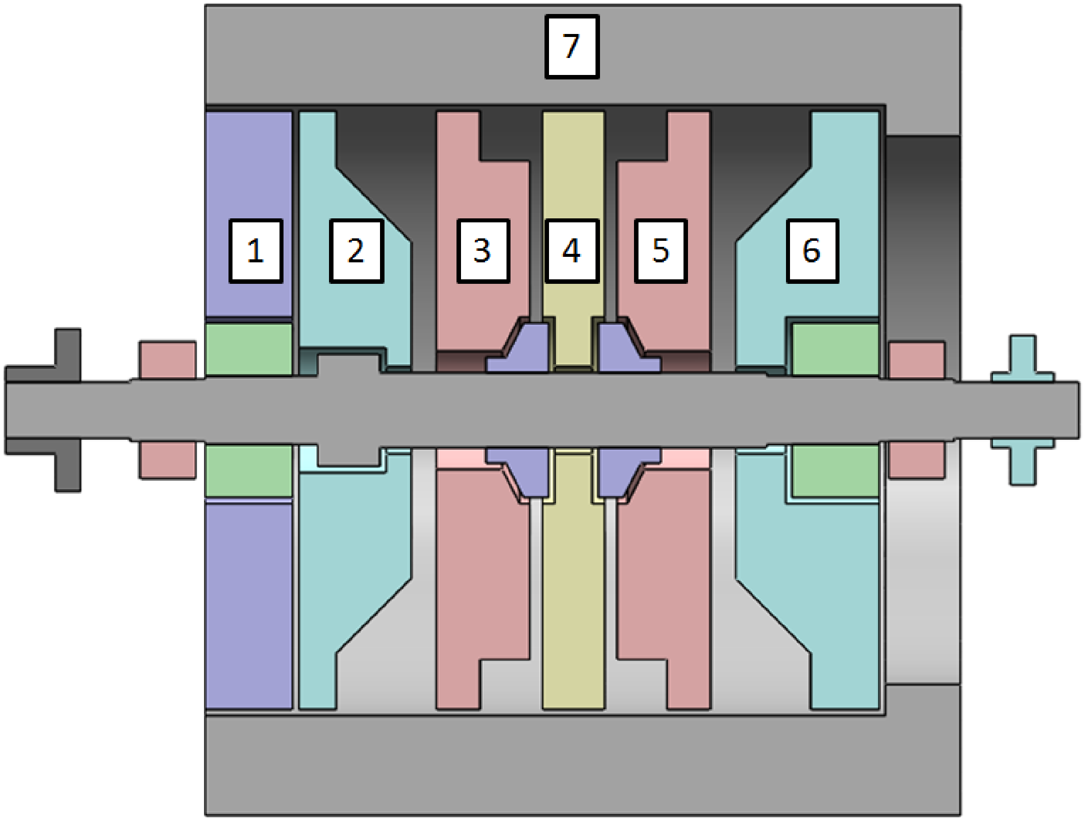
$$J = \frac{\pi r^4}{2} = 2.52\ in^4$$

$$\sigma = \frac{3+v}{8}\rho\omega^2\left[r^2 + 2R^2 - \frac{1+3v}{3+v}r^2\right]$$

3 shaft size limitations

1) Coupling size due to speed
2) Shaft minimum size due to torque
3) Shaft maximum size due to speed

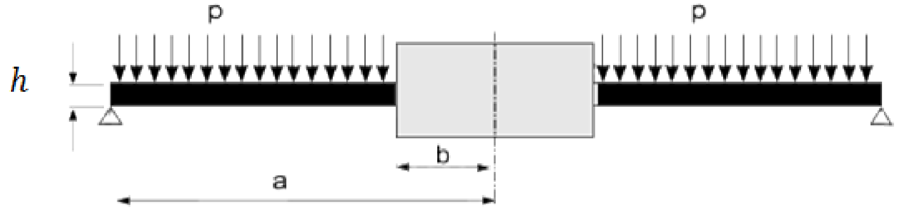
Stator Layout



Stator Components

1. End Caps / DGS Housing
2. Balance Piston Housing / Inlet
3. MC / Bypass Diaphragm
4. Division Wall
5. MC / Bypass Diaphragm
6. End Cap / DGS Housing
7. Main external casing

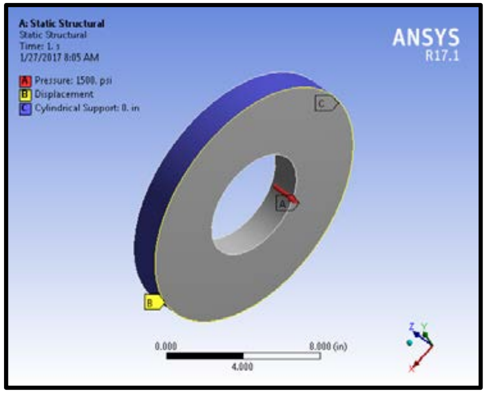
Diaphragm Sizing

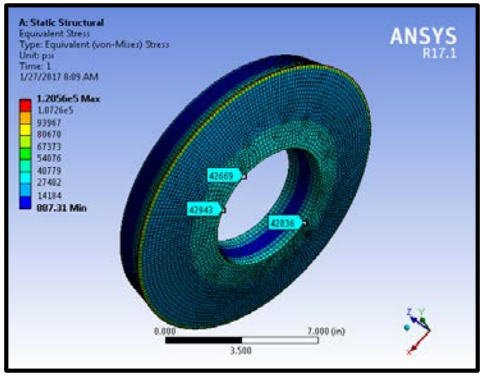


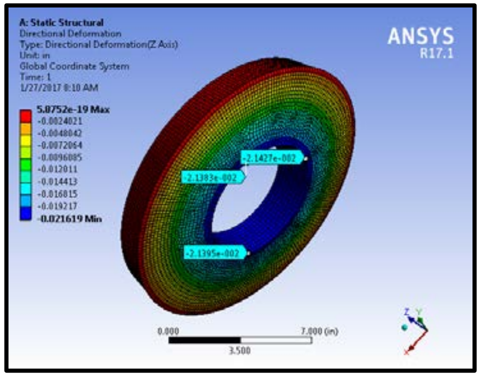
$$\sigma_{max} = \frac{k_1 P a^2}{h^2}$$

$$w_{max} = \frac{k_2 P a^4}{E h^3}$$

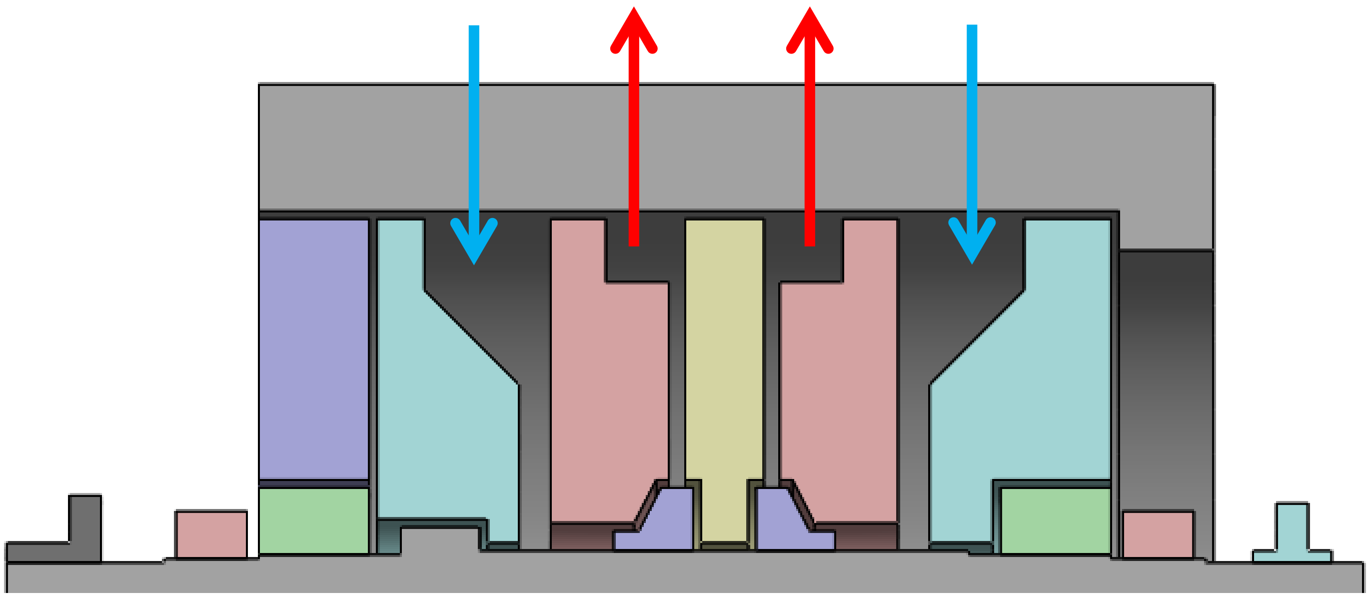
a/b	Simply Supported		Fixed Support	
	k1	k2	k1	k2
1.25	0.592	0.184	0.105	0.002
1.50	0.976	0.414	0.259	0.014
2.00	1.440	0.664	0.480	0.058
3.00	1.880	0.824	0.657	0.130
4.00	2.080	0.830	0.710	0.162
5.00	2.190	0.813	0.730	0.175







Inlet & Exit Sizing



- Meet set design velocities
  - Higher velocities lead to erosion and pressure loss
  - For shorter lengths in volutes and nozzles, velocity limits can be increased
- Lower speeds mean more axial and radial space required
- Compact machinery, look into combining volutes with other components

Axial Length

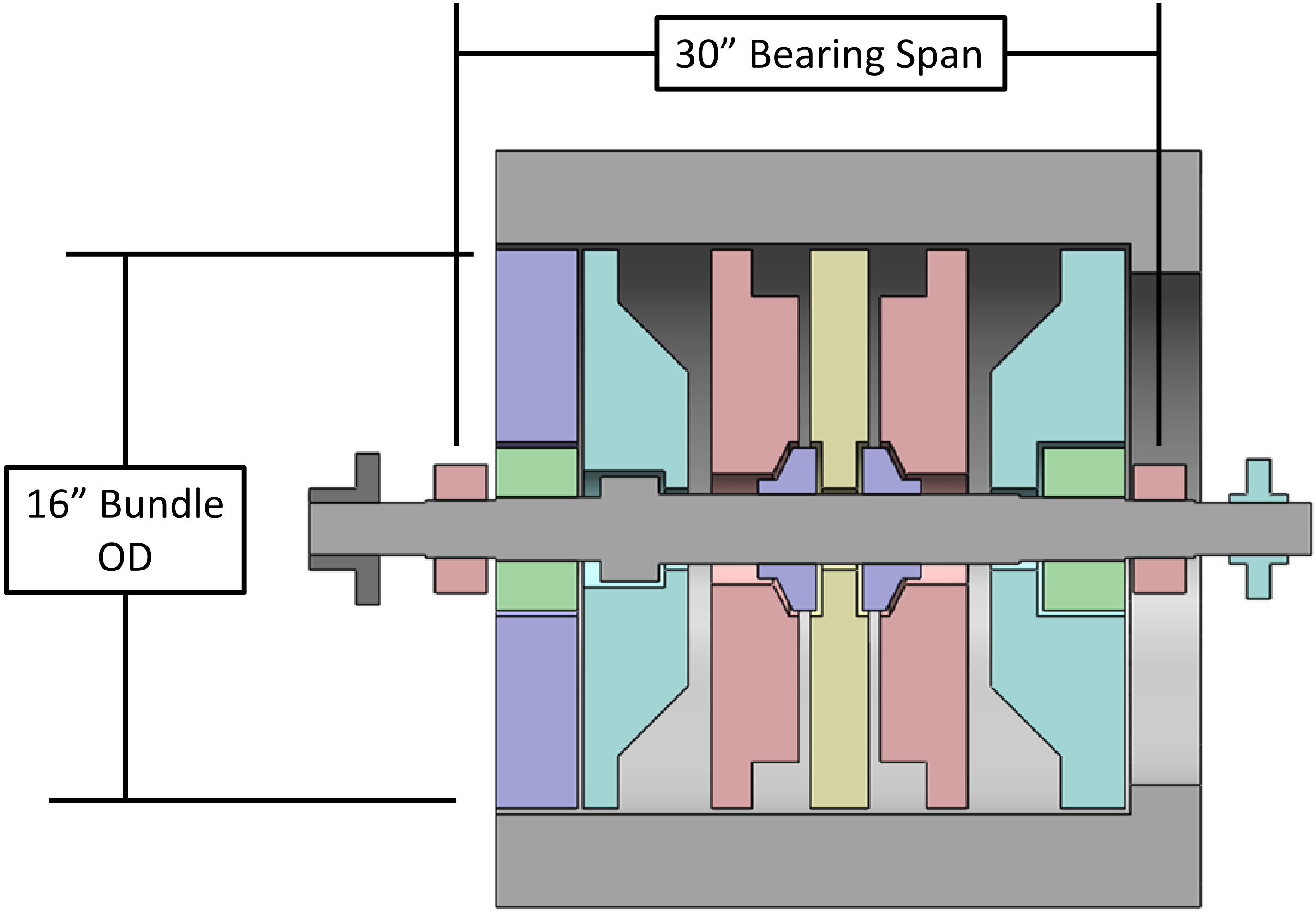
Diaphragm Axial Space

OD	Material			
in	20 ksi	30 ksi	40 ksi	50 ksi
10	11.13	9.15	7.98	7.21
12	14.92	12.27	10.69	9.77
14	18.54	15.25	13.29	12.27
16	22.06	18.15	15.81	14.72
18	25.54	21.01	18.36	17.16
20	29.01	23.87	21.00	19.63
22	32.49	26.73	23.67	22.13
24	35.89	29.53	26.33	24.63
26	39.06	32.14	28.85	26.99
28	41.67	34.29	30.96	28.96
30	43.15	35.50	32.09	29.98

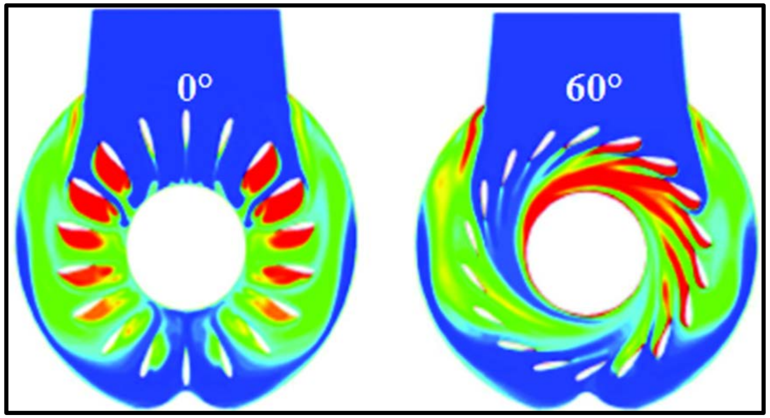
Inlet and Exit Diameters

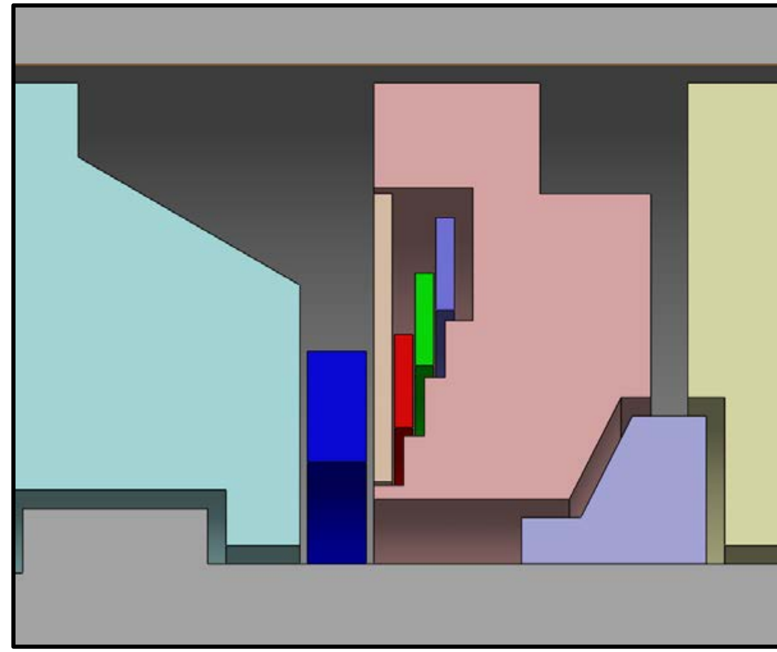
Section		Pressure		Temperature		Density	Mass Flow		Max Vel.	Min Dia.
		Mpa	psi	C	F	lbm/in^3	kg/s	lbm/s	ft/s	in
Main	**Inlet**	8.55	1,240	35	95	0.0224	70.3	155.0	80	3.03
	Exit	24.13	3,500	78	172	0.0247	70.3	155.0	80	2.88
Bypass	**Inlet**	8.69	1,260	88	190	0.0061	34.2	75.4	80	4.04
	Exit	23.99	3,479	194	381	0.0116	34.2	75.4	80	2.94
Main	**Inlet**	8.55	1,240	35	95	0.0224	70.3	155.0	150	2.21
	Exit	24.13	3,500	78	172	0.0247	70.3	155.0	150	2.11
Bypass	**Inlet**	8.69	1,260	88	190	0.0061	34.2	75.4	150	2.95
	Exit	23.99	3,479	194	381	0.0116	34.2	75.4	150	2.15

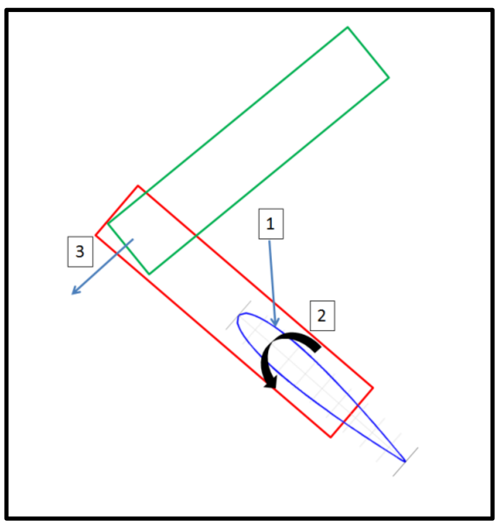
Design Envelope

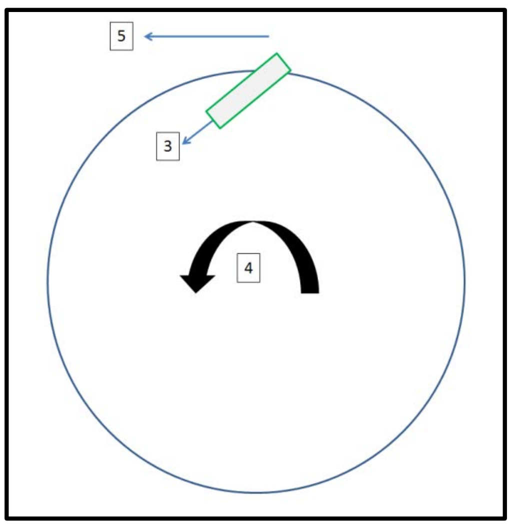


Actuator Design









Future Work

1. Final Analysis
   a) Finite element analysis on all stator and rotating components
      - Verify that stresses meet design limits
      - Verify that displacements meet design limits
      - See if diaphragm thicknesses can be reduced or need to be increased
   b) Rotordynamics
      - Verify that there is significant margin to bending modes
      - See if there is extra margin for rotor span
   c) Aerodynamics
      - Verify if number of stages is adequate for required performance
      - Check all flow path designs
2. Detail Design
   a) Complete design of internal flow paths and ports
   b) Add seals and bolts
   c) Design all external housings
      - Thrust bearings
      - Journal bearings
      - Coupling guards
3. Testing
   a) Verify performance of main compressor with variable IGVs
   b) Verify performance of bypass compressor with variable IGVs

References

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