Development of High Efficiency Hot Gas Turbo-Expander for Optimized CSP Supercritical CO_2 Power Block Operation

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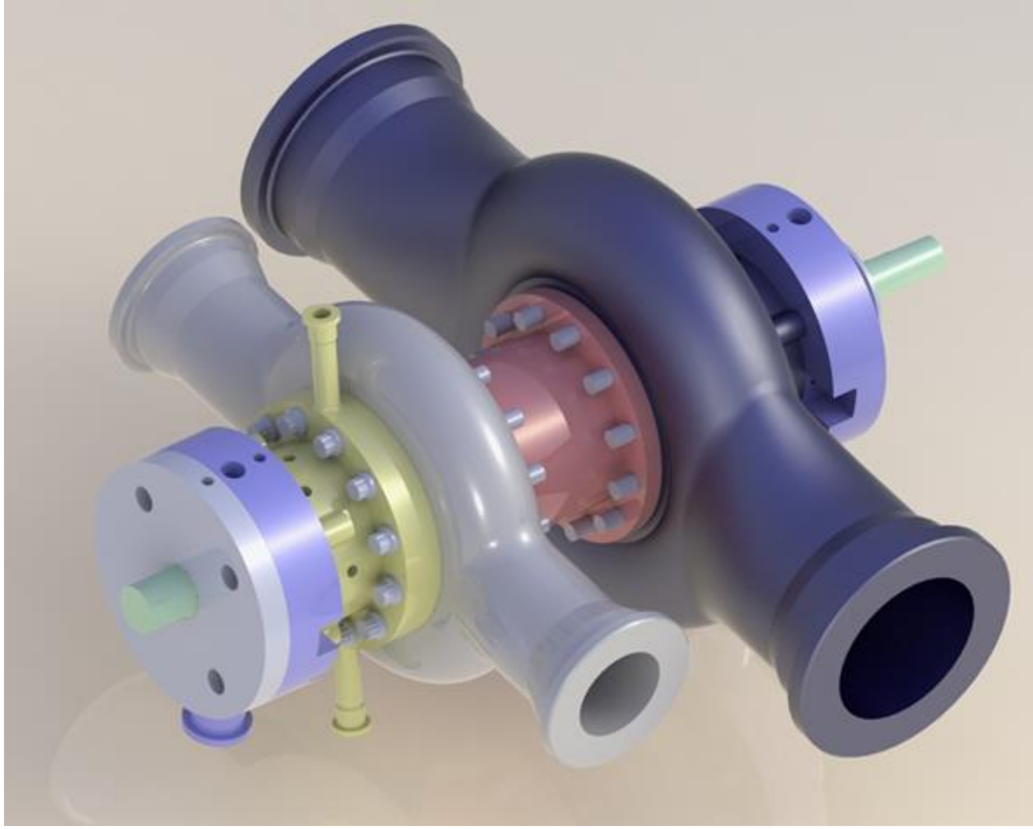

The 4th International Symposium - Supercritical CO_2 Power Cycles
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Sunshot Program Overview

SunShot
U.S. Department of Energy

Team: Southwest Research Institute, GE, KAPL, & Thar

3-year, \$8.5M program to develop & test an expander & recuperator for sCO2 power generation from CSP.

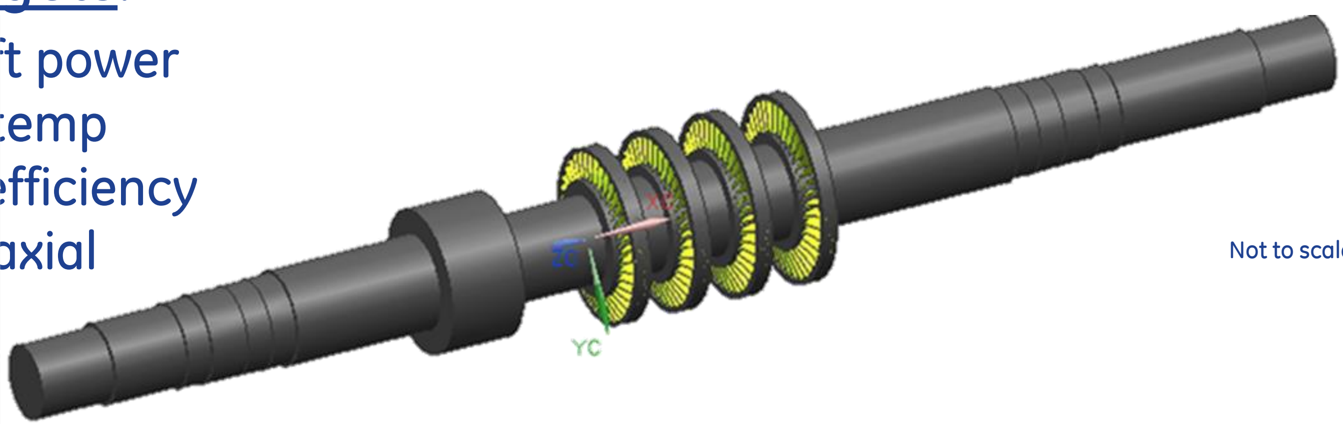
Schedule: Expander final design complete.

System targets:

- 10MWe net module size
- 50% net thermal efficiency

Expander targets:

- ~14MW shaft power
- >700C inlet temp
- >85% aero efficiency
- Multi-stage axial



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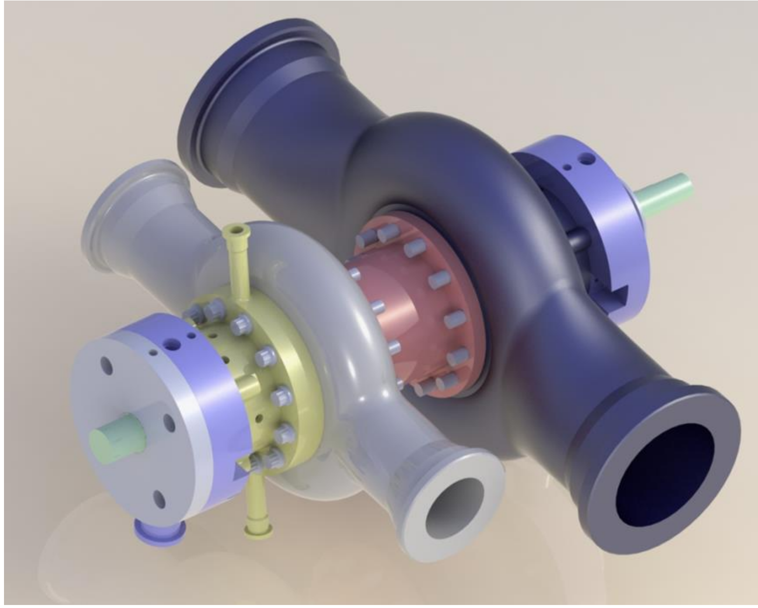
Prior Experience

GE Global Research
- sCO2 Systems
- Thermal Management

SWRI
- Test Loop Design
- Turbomachinery Design
- Advanced Analysis

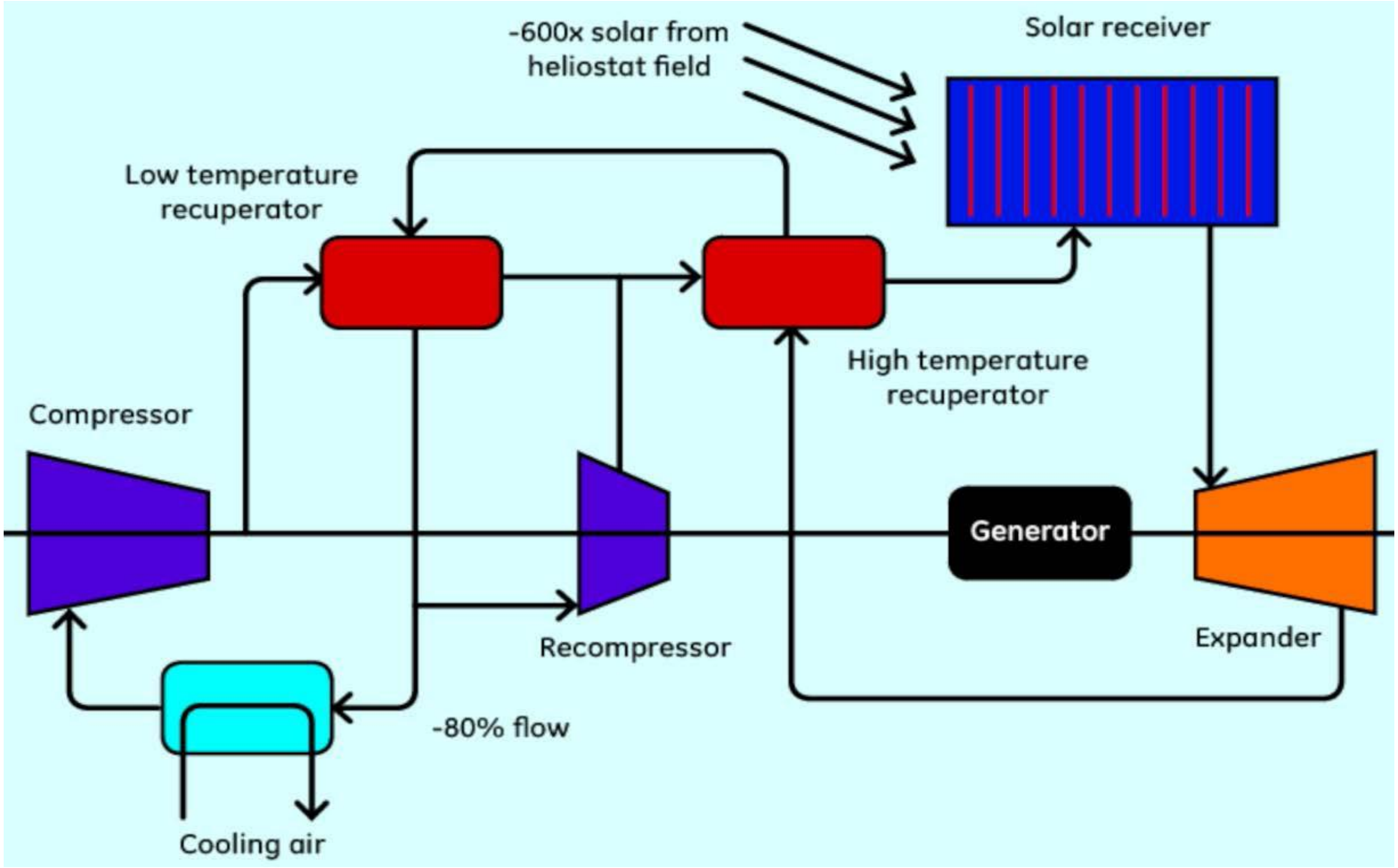
GE Power & Water
- USC steam materials
- High pressure casing
- High-power density flowpath

GE Oil & Gas
- CO2 Compressors
- Dry Gas Seals
- Rotordynamics



GE Aviation
- Manufacturing

Target Power Cycle



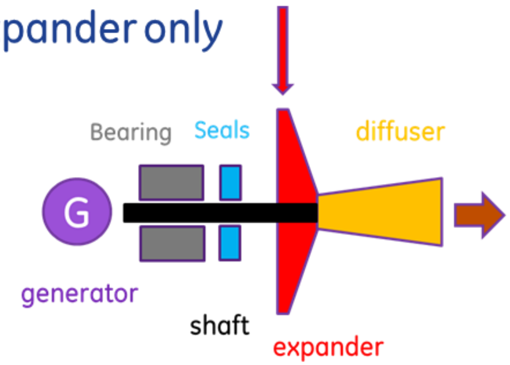
Turbo-machine layout options

Option	Generator	Compressor	Turbine	RPM
High speed, Optimal	A. IC B. PM	A. Single stage centrifugal B. Multi stage pump	A. Radial B. Axial	Optimized for compressor
High speed, expander only	A. IC B. PM	None	A. Radial B. Axial	Optimized for expander
High speed, Geared	A. IC B. PM C. 3600 rpm	A. Single stage centrifugal B. Multi stage pump	A. Radial B. Axial	Both expander and compressor run at optimal speed
3600 rpm integrated	3600 rpm	Multi stage pump or compressor	Multi stage Axial at 3600 rpm	3600 rpm
3600 rpm – expander only	3600 rpm	None	Multi stage Axial at 3600 rpm	3600 rpm

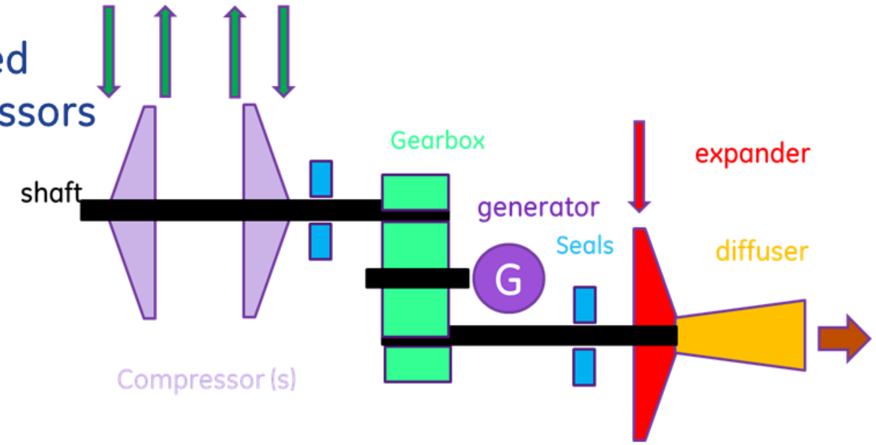
IC: Inductively coupled, PM: Permanent magnet, 3600 / 1800 rpm synchronous generator

Preliminary Layouts & Down-select:

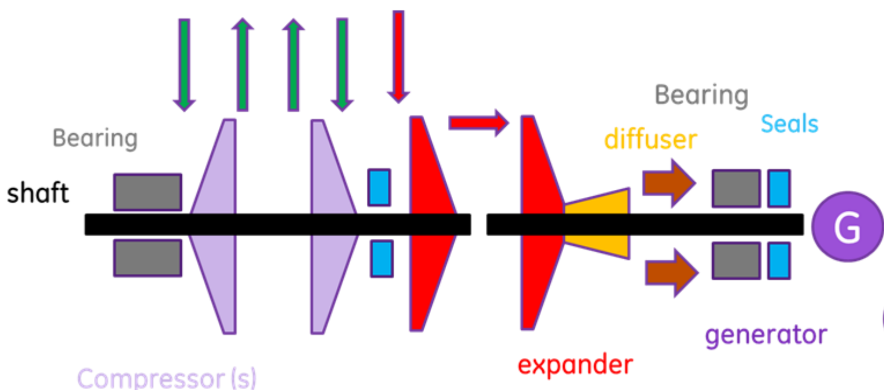
1. Expander only



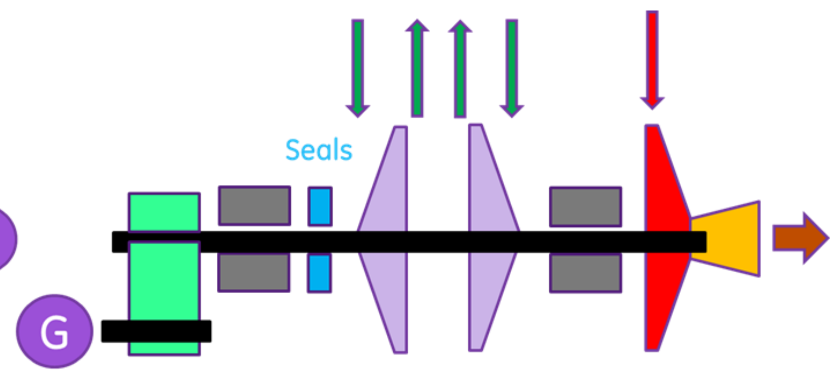
2. Geared Compressors



3. Dual Shaft



4. High Speed Geared

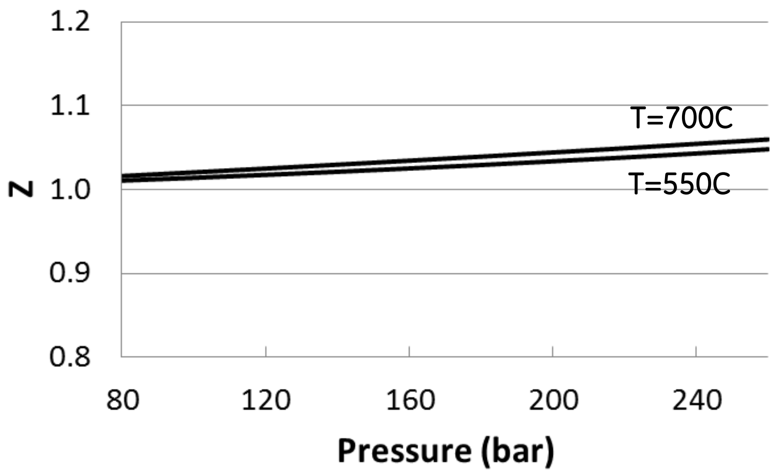


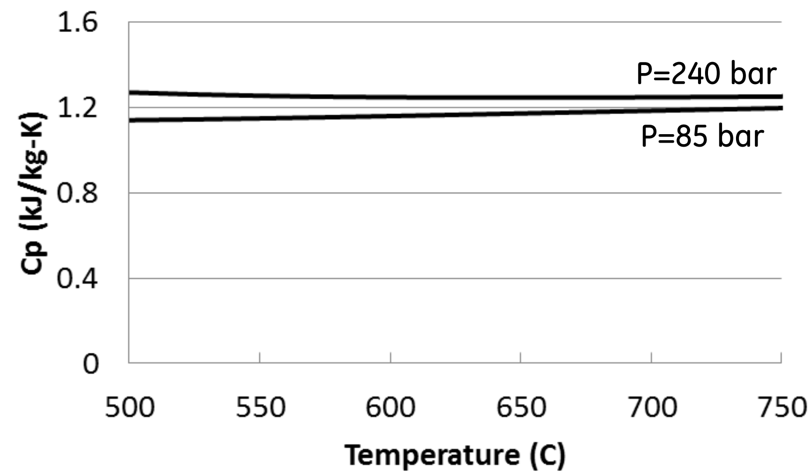
Overall design & modeling philosophy

1. Correlations & methods originally developed for steam & air will be valid for conceptual design for CO_2 in expander region because it is nearly an ideal gas.

Ideal Gas: $\frac{PV}{RT} = 1$

Calorically Perfect Gas: Cp=const





2. Need to include higher margins, particularly for non-ideal gas regions (end seals) and fluid-structure interactions.

3. Validate results with CFD.

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Aerodynamics

Mean-line 1D: Excel

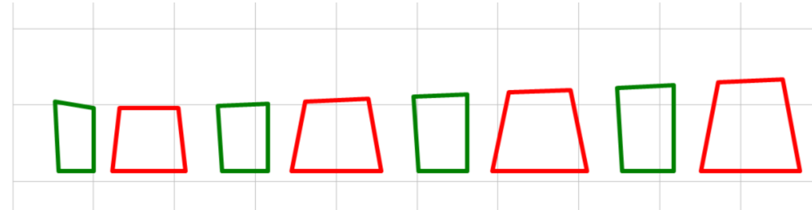
- GE proprietary loss model
- Ideal gas CO_2 properties

2D/3D: TP3, CAFD

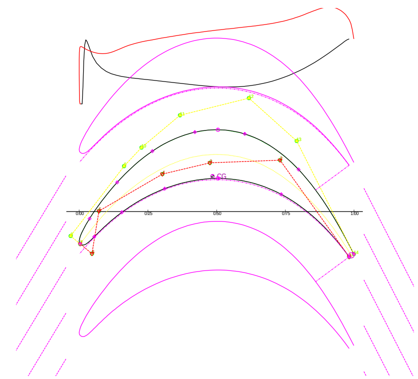
- GE proprietary design tools
- Ideal gas CO_2 properties

CFD: TACOMA, ANSYS CFX

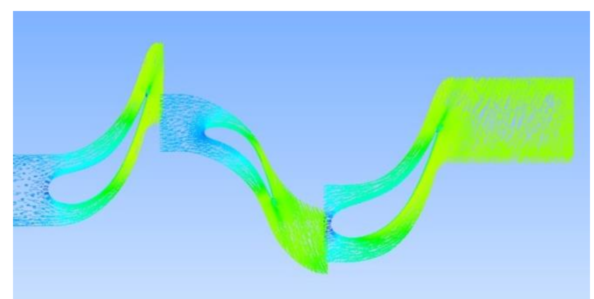
- Real gas tabular CO2 properties
- Used to validate mean-line and 2D/3D design code predictions
- Good agreement for efficiency and flow function



1D Mean-line flow path



2D Airfoil shapes

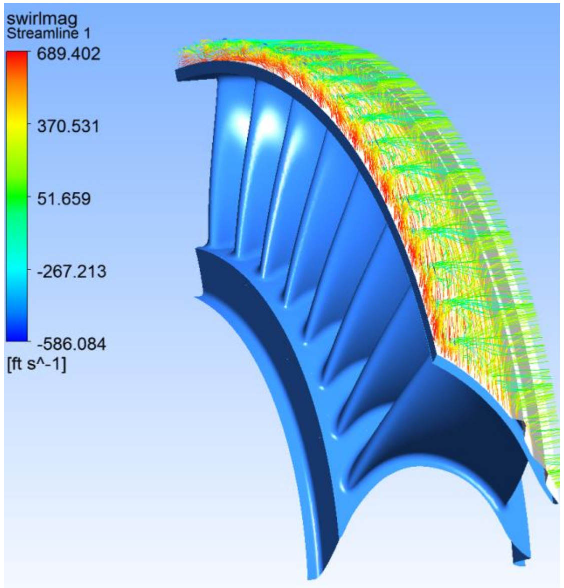


CFD Analysis

Seals

Labyrinth: Labflo, ANSYS CFX

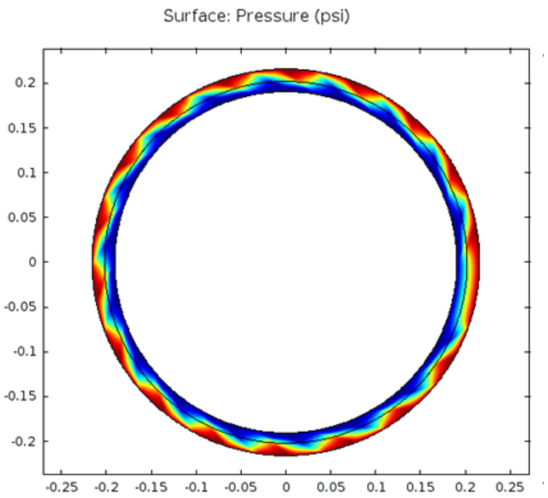
- GE proprietary model validated for steam & air
- Applied CO2/air scaling factors
- CFD predicts significantly higher leakage
- Need conservatism in conceptual design phase (aero & rotordynamics)



CFD analysis of interstage laby seal flow in CO2

Dry Gas Seals

- Commercially available at the required pressure but limited to low temperature and small diameter.
- GE developing tools to predict performance & lifing under the PREDICTS program

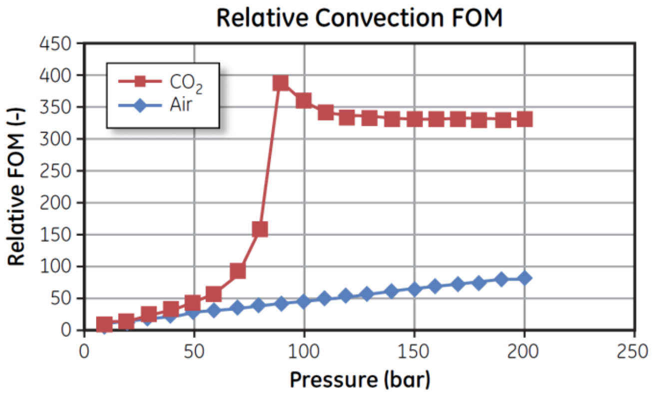


DGS Face Pressure Distribution from CFD

Heat Transfer

Challenges

- Need to cool shaft from turbine exit (>500C) to DGS & bearing max T (<200C) in short axial span
- sCO2 has high convective heat transfer



Empirical Correlations

- Shaft FEA model in ANSYS
- Gazley HTC correlation applied as boundary conditions

Conjugate Heat Transfer

- Coupled CFD, heat transfer, and shaft FEA in ANSYS

Result

- Agreement within 10%
- FOCUS program to develop & test advanced thermal management techniques to maintain gradients

Shaft Temperature Contours

Gazley HTC Boundary Condition

Conjugate HT

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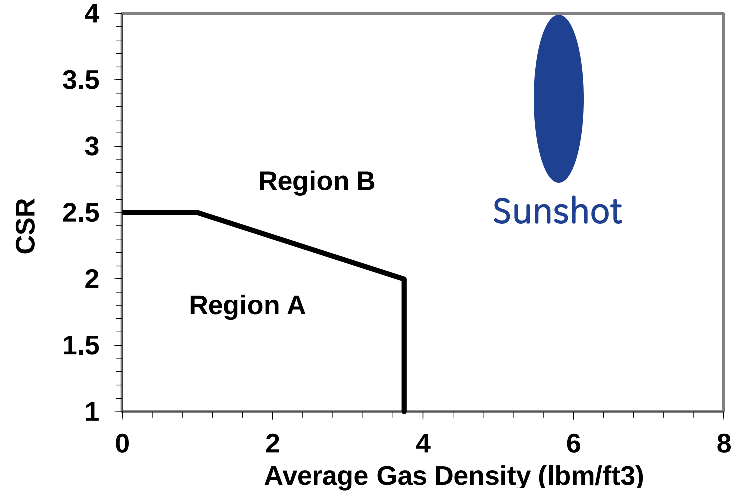
Rotordynamics

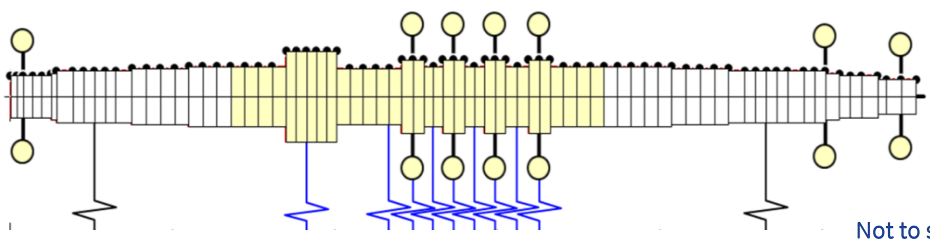
Challenges
- High gas density
- High operating speed
- Low critical speed (large L/D)



$$CSR = \frac{Operating\ Speed}{1st\ Undamped\ Critical\ Speed}$$

Interstage laby seals
- Texas A&M code
- Real gas CO2 properties

Balance piston seal
- Texas A&M code
- Perfect gas properties



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Result
- Due to uncertainty in seal damping, we used a factor of safety 10x API level II minimum (final logdec > 1.0)
- PREDICTS program developing mid-span gas bearing

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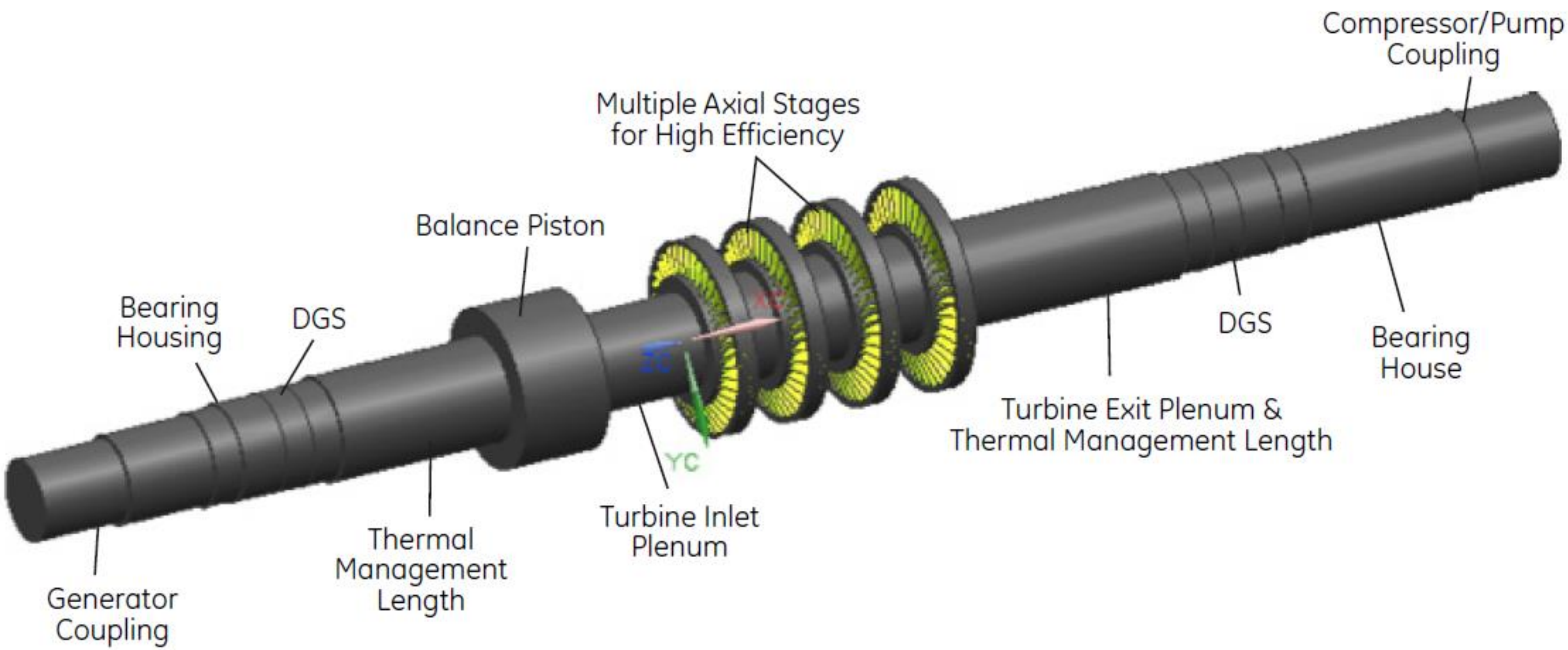
Final Rotor Design



Summary

- sCO_2 turbine design completed by the SunShot project team to meet the program objectives
- The design demonstrates key sCO_2 turbine design features – compact & low cost
- Design tools & prior experience in various products cover the operating range of a sCO_2 turbine
- Integration of these diverse technologies into a single machine is challenging but required to achieve high efficiency
- High power density enables compact design and requires development of custom high performance turbo-machinery components

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