Novel Modular Heat Engines with Supercritical CO_2 Bottoming Cycle Utilizing Advanced Oil-Free Turbomachinery: PHASE 2 Update

GE Aerospace Research

TEAM

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BACKGROUND

APPLICATION AND MOTIVATION

- Natural Gas Compressor Stations
- Utilize waste heat sCO_2 Brayton power cycle
- 11pts Eff. Increase 41% to 52% cycle eff.

TECHNICAL APPROACH

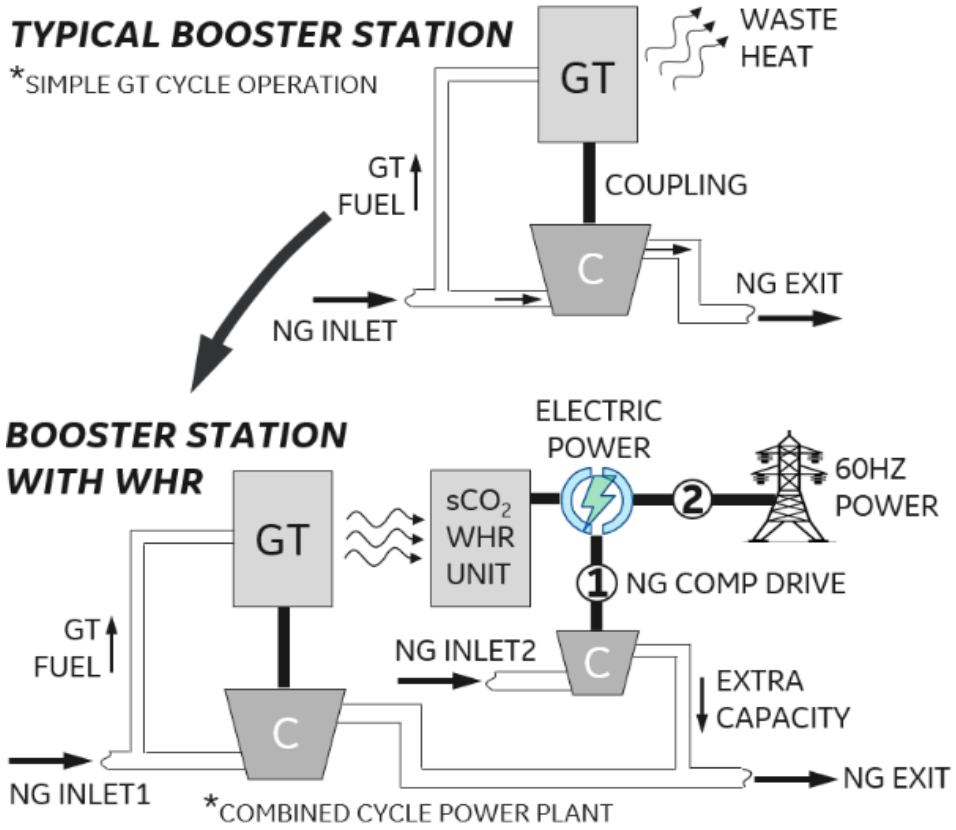
- 2 Drivetrain config. Dual spool approach
- Elimination of gearbox and use of CO_2 bearings
- Hermetic casing; free of CO_2 emissions
- Immersed generator in high density CO_2

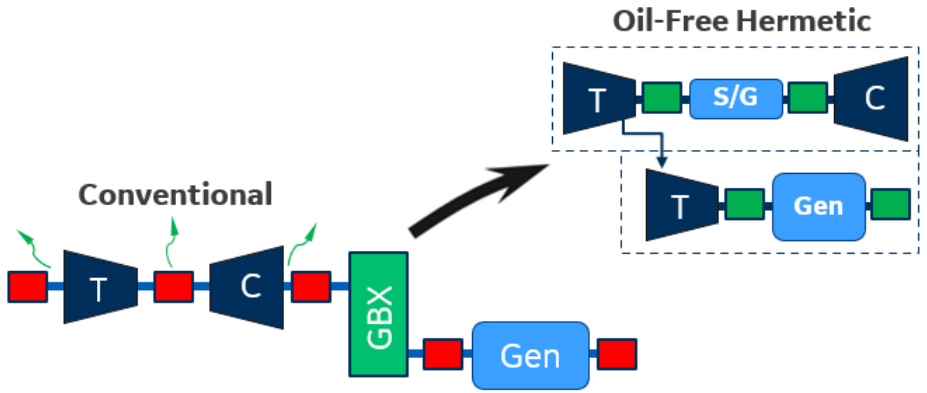
TECH RISKS

- Rotor-bearing system dynamics
- Radial bearing damping and load capability
- Thrust bearing load capacity
- Thermal stability/design of hermetic machine

OTHER POTENTIAL APPLICATIONS

- Concentrated solar power cycles
- Nuclear power cycles





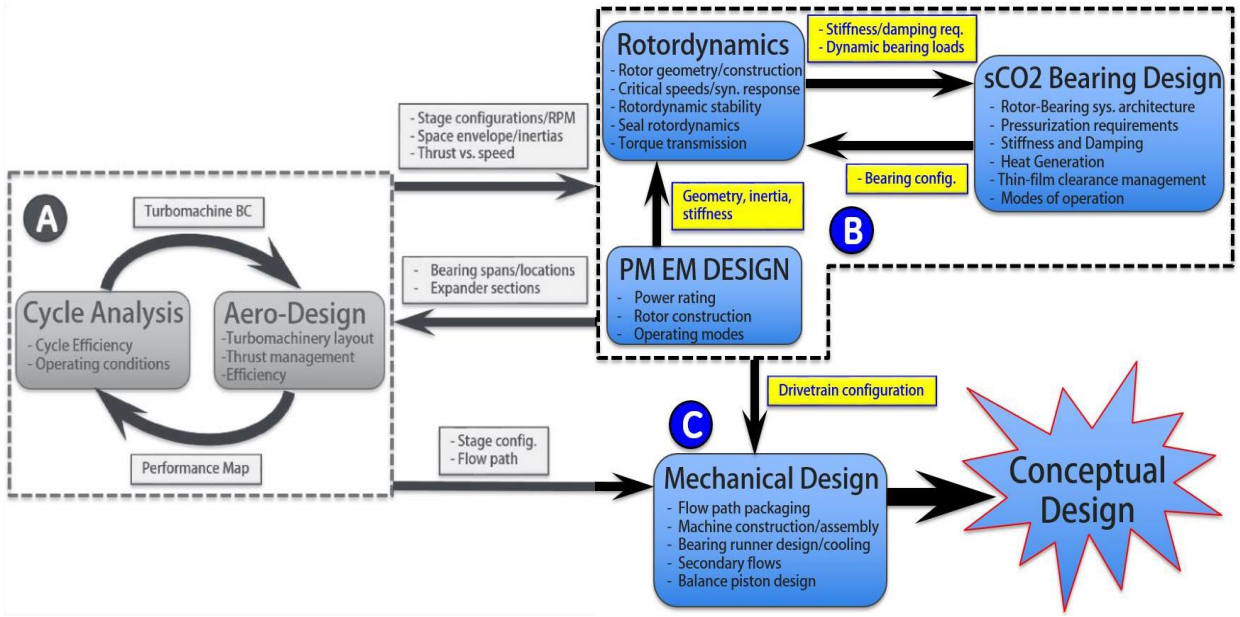
PHASE 2 SCOPE AND OBJECTIVES

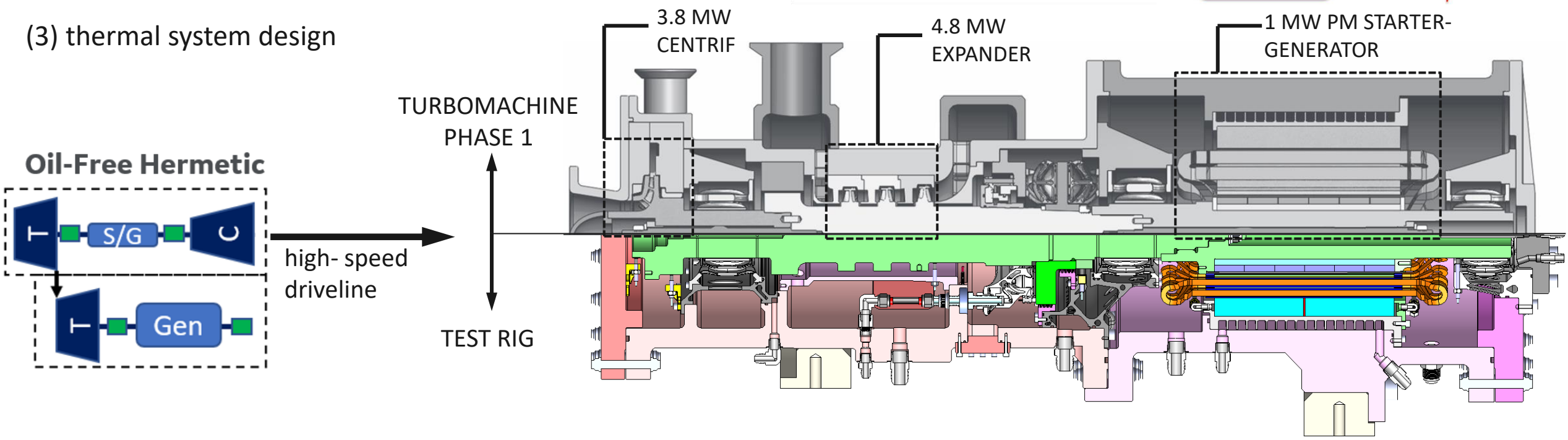
- Develop design practices and methods
- Validate mechanical/thermal/electrical systems & design

(1) drivetrain rotordynamics

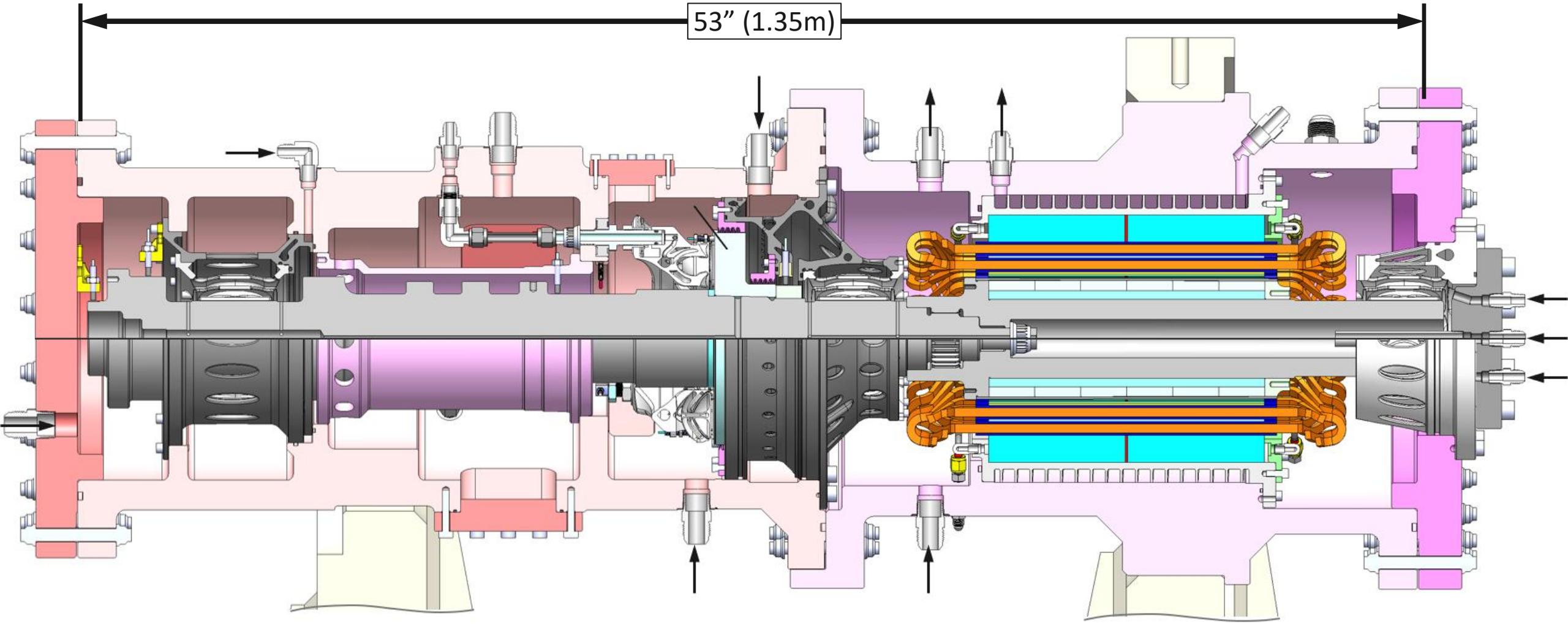
(2) thrust bearing load capacity

(3) thermal system design



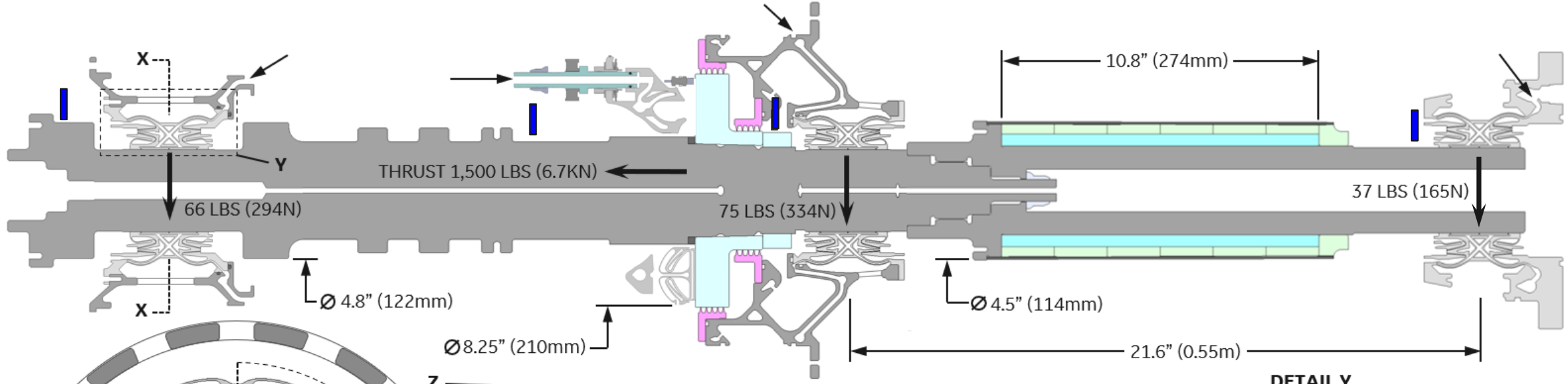


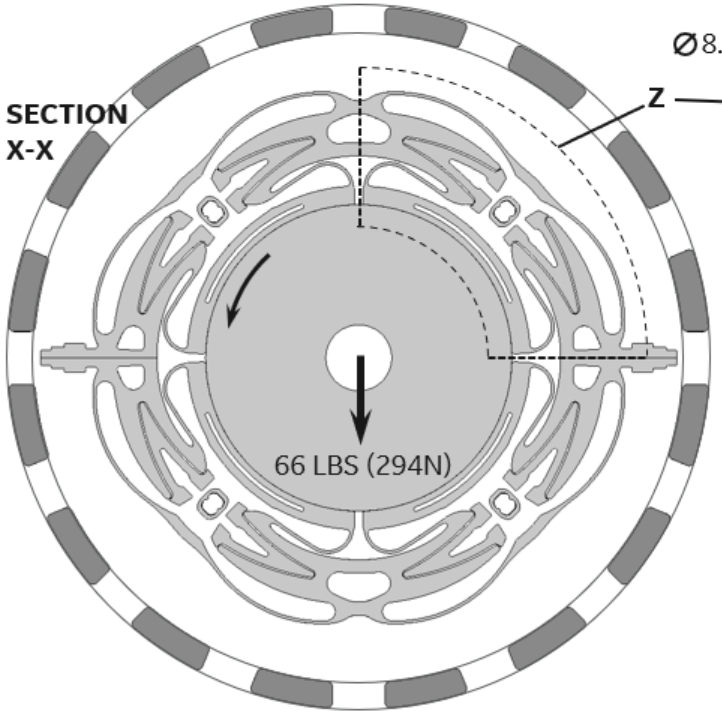
TEST RIG LAYOUT

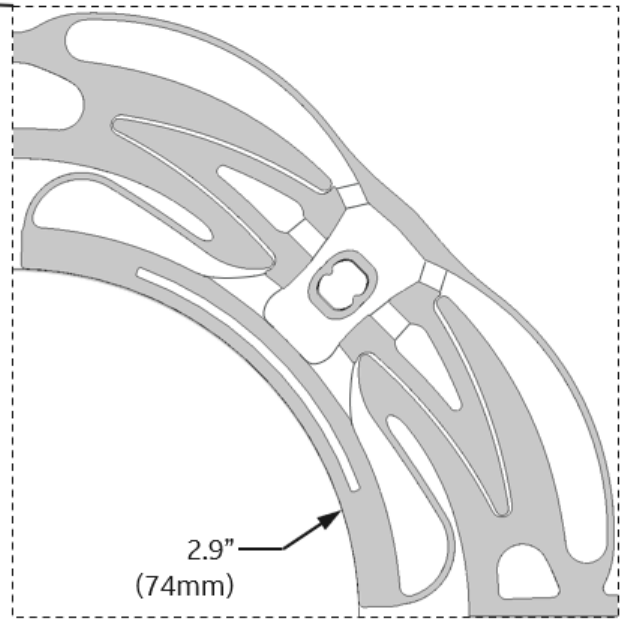


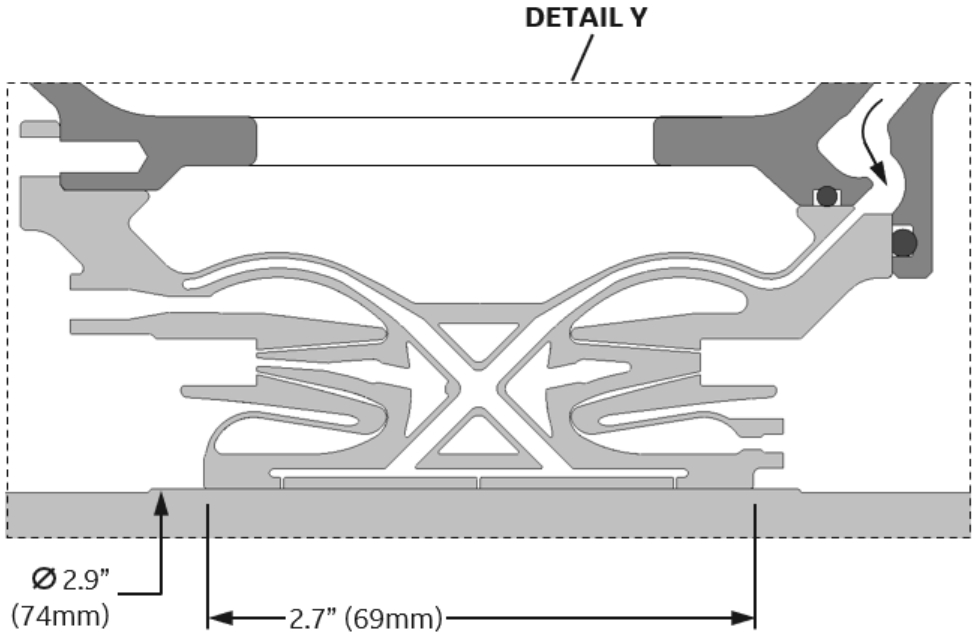
Max Speed = 27 KRPM
Max Rotor Thrust = 1,500 lbs
Max Casing Pressure = 400 PSI
Working Fluid = CO_2

ROTORDYNAMIC MEASUREMENTS AND BEARING DETAILS



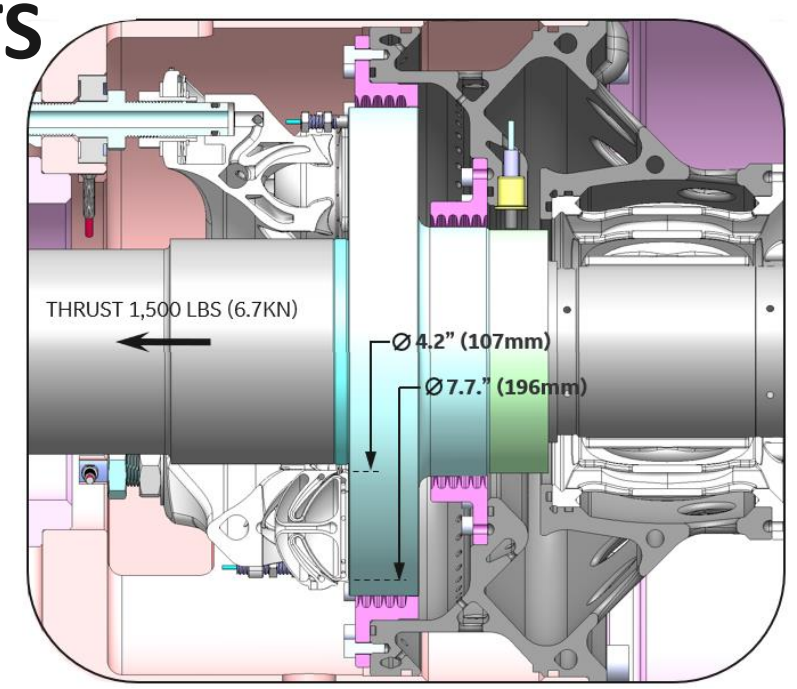


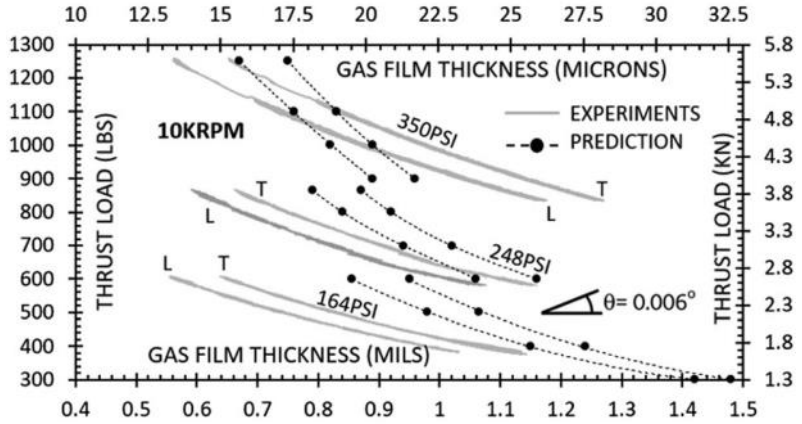


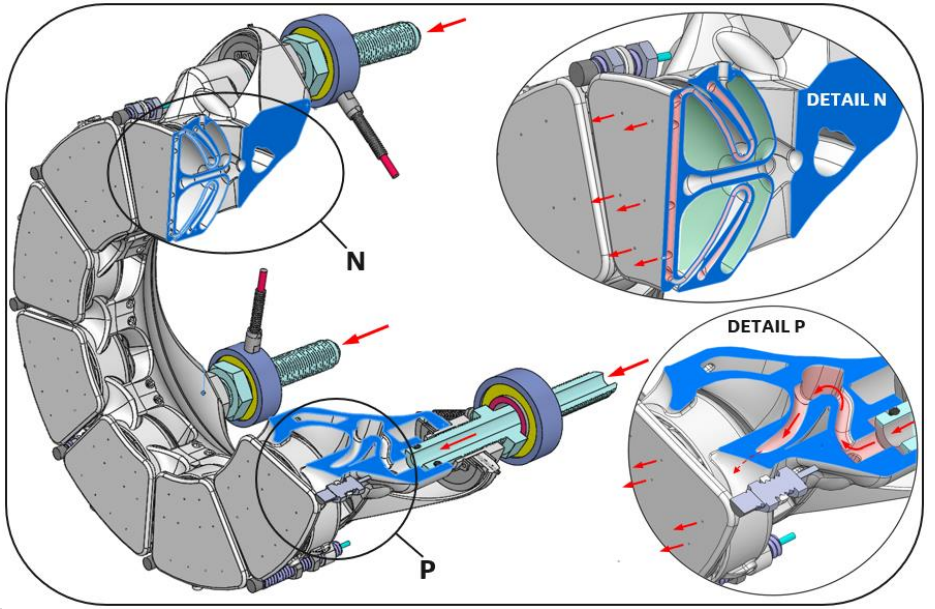


THRUST CHAMBER AND THRUST BEARING TESTS

- Thrust bearings are traditionally the weak link for gas bearings
- Test rig has ability to apply varying load through a thrust chamber
- Critical measurements are:
  - Axial load
  - Film gap
  - Thrust runner vibration/displacement
  - Flow, pressures, and temperatures
- Example measurements from, Ertas, 2021, ASME JGTP, 143/ 081024







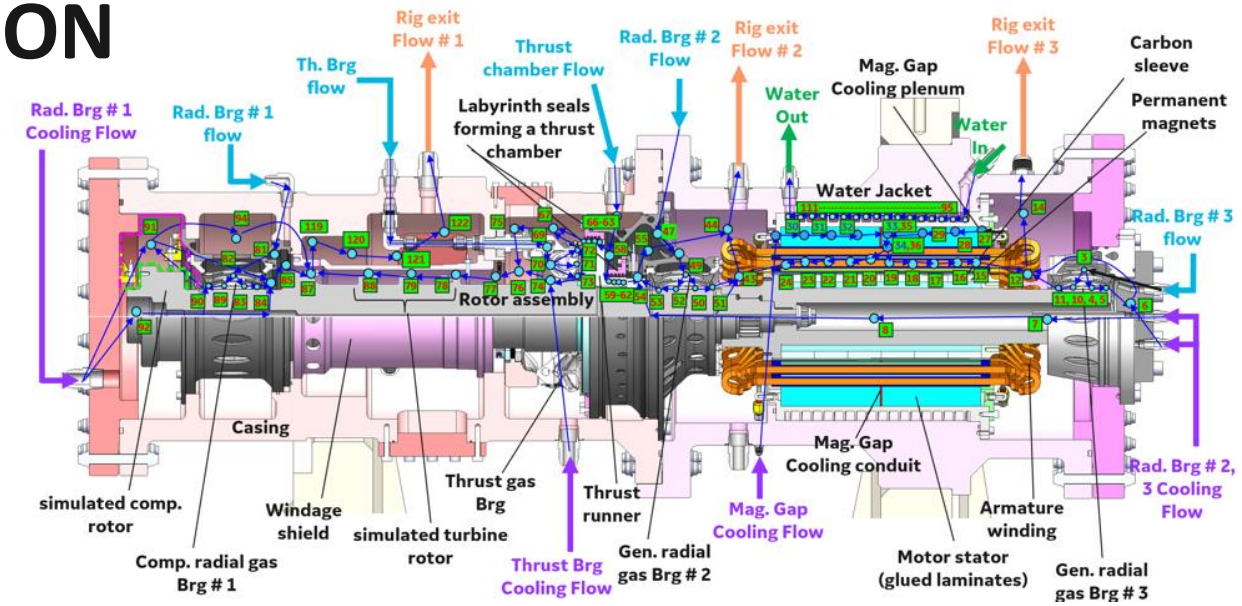
THERMAL SYSTEM DESIGN VALIDATION

- 1D Advection network iterates with structural thermal FEA model → iterates on heat flow between models, nodal and metal temperatures

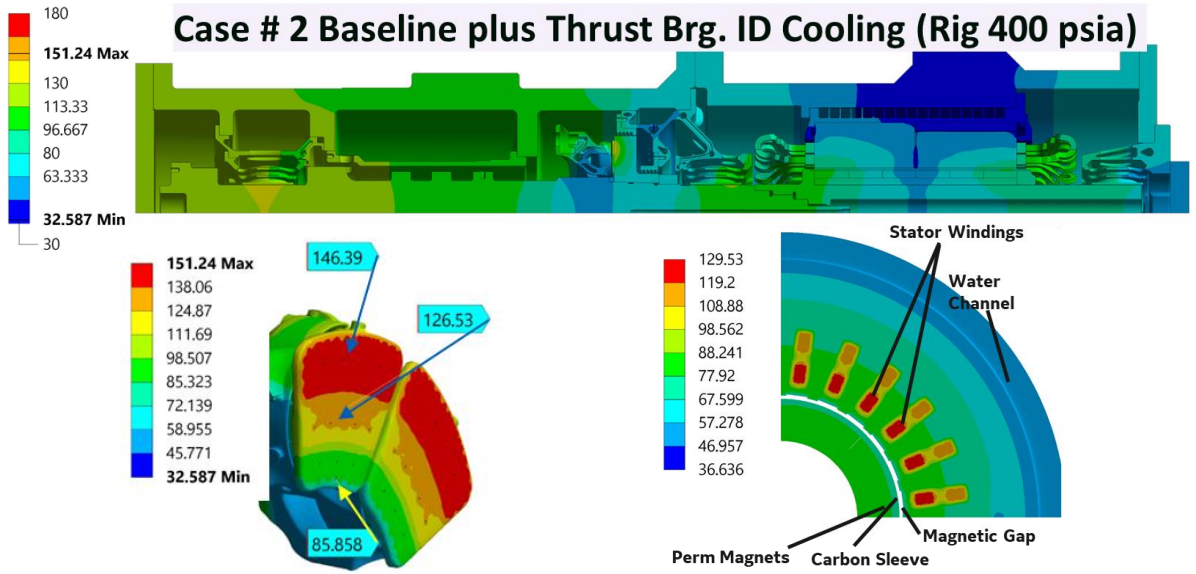
- 1D energy balance at each node accounts for:
  - rotor windage, cavity swirl
  - calculates convective HTC
  - heat gen sources in EM/bearings
  - heat sink in H_2O jacket

- Areas of concern:
  - EM temperatures
  - bearing temperatures
  - bearing and EM windage/power loss

- Experiments will allow benchmarking of thermal model



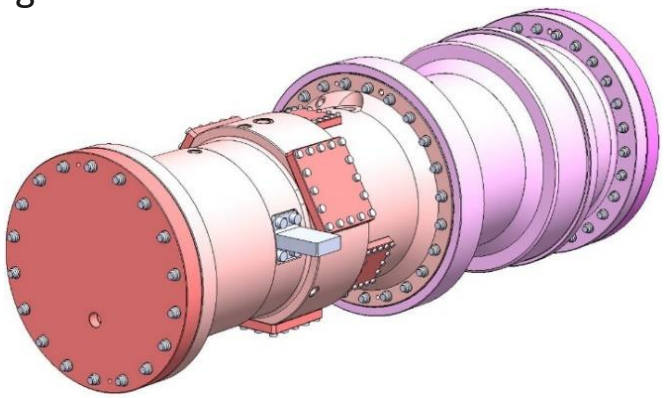
Bidkar, 2023, ASME Turboexpo PapeGT2023_103989



CASING ASSEMBLY FABRICATION & MACHINING

Casing Material

- 4340 rotor forgings located
- Casing components to be black oxide coated
- Hydraulic pressure testing



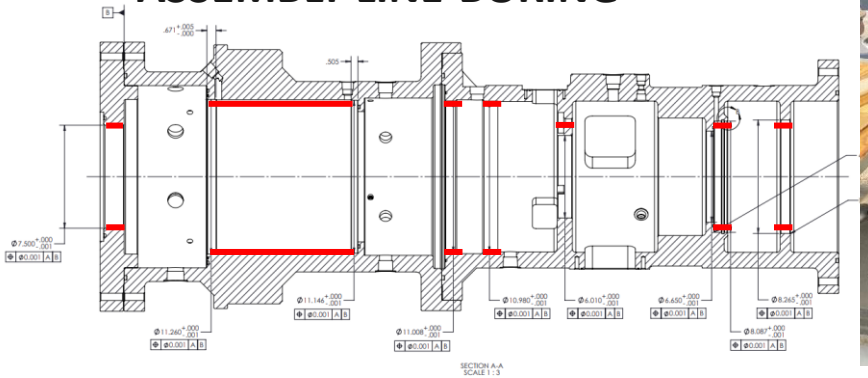
Assembly Machining

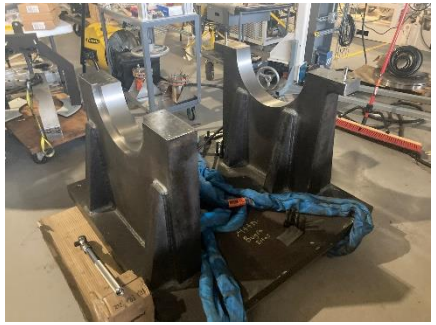
- Final precision machining to be conducted as an assembly
- Critical bores will be machined in one setup
- All radial bores to have runouts within 0.001”

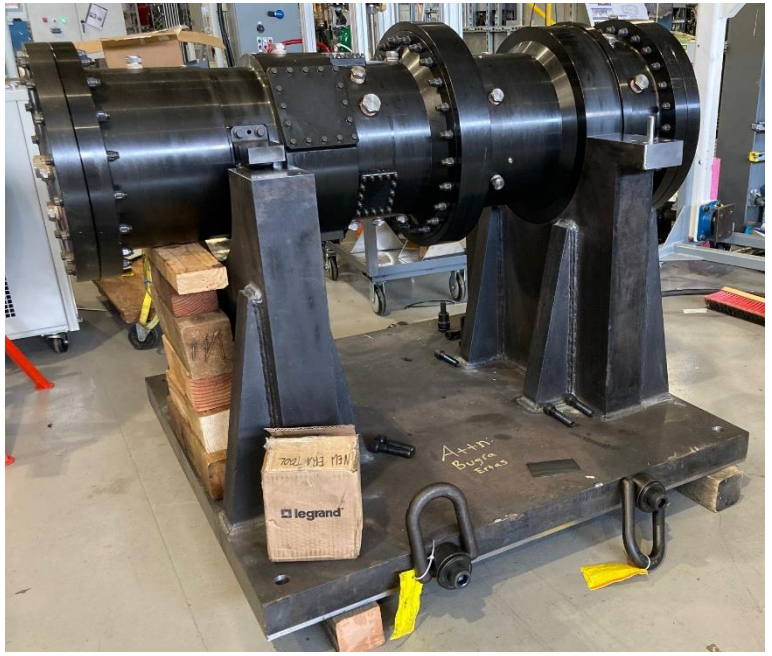
Current Progress

- Casing assembly machining completed; ready for assembly

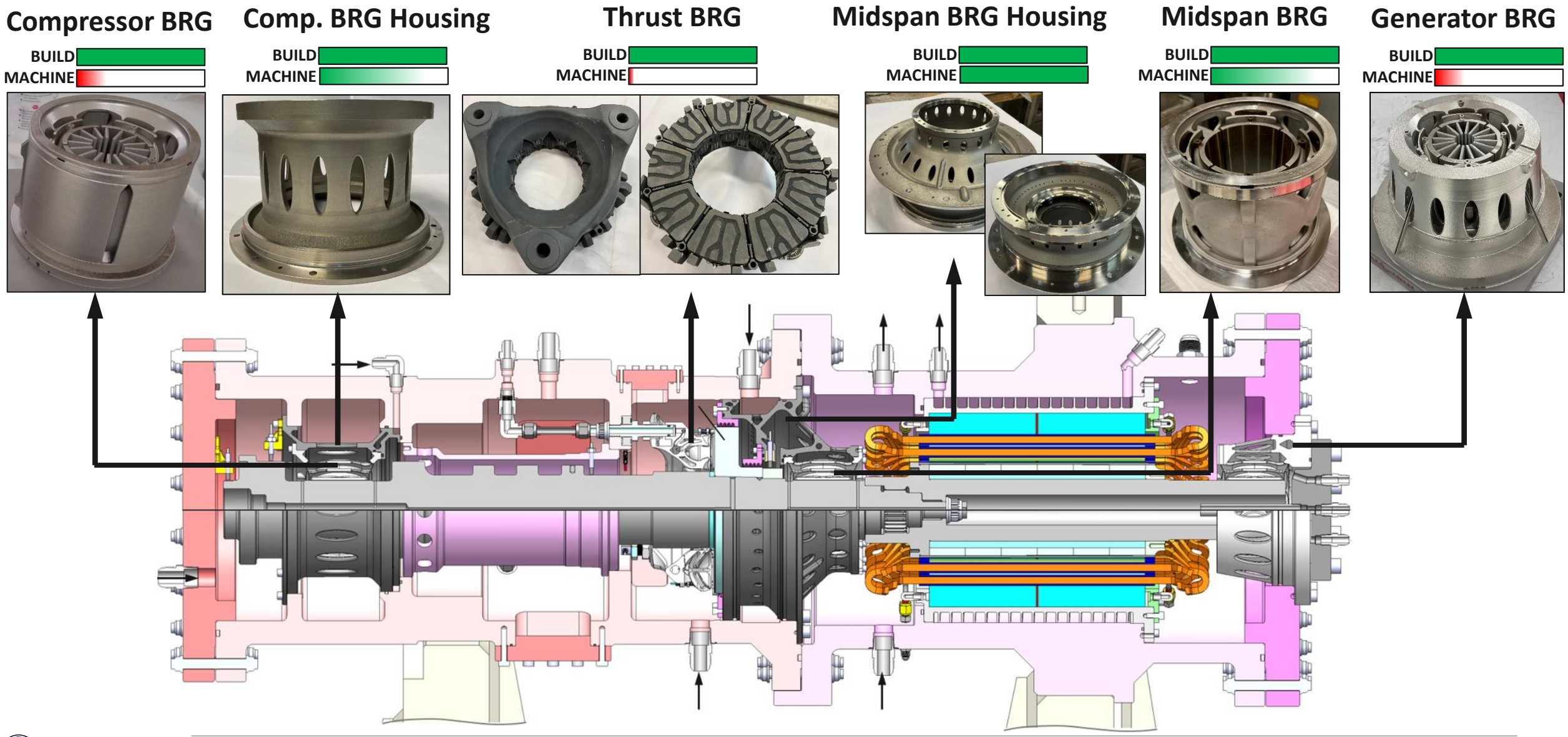
ASSEMBLY LINE-BORING







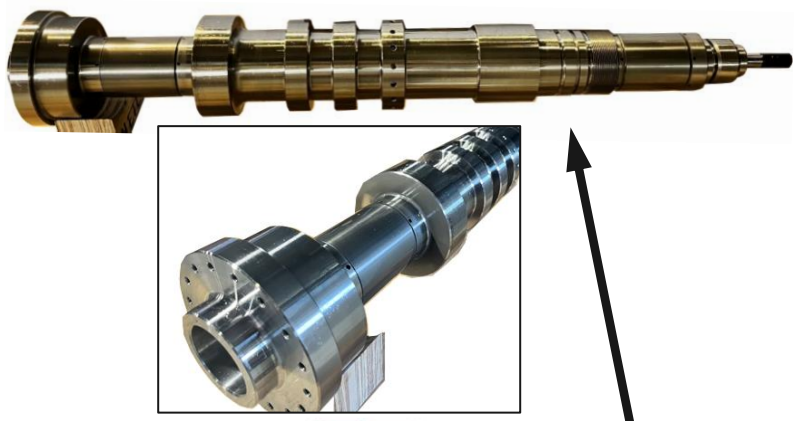
ADDITIVE MANUFACTURING PROGRESS: INCO 718 COMPONENTS



ADDITIVE MANUFACTURING PROGRESS: INCO 718 COMPONENTS

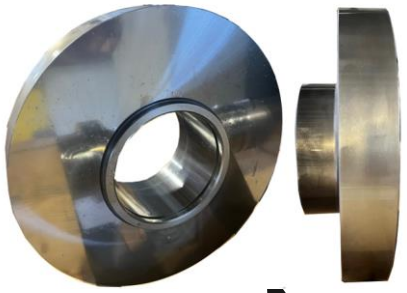
Turbo-compressor Shaft

MACHINING PROGRESS



Thrust-Runner

MACHINING PROGRESS



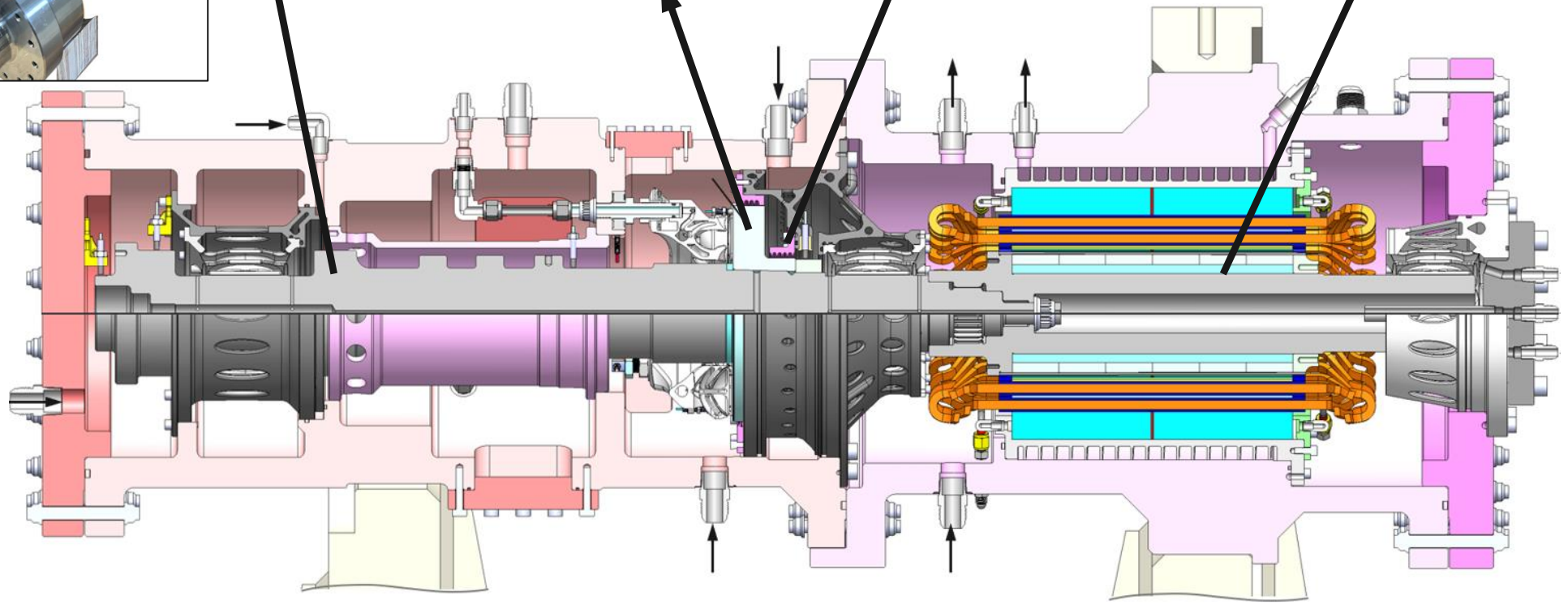
Thrust Chamber Laby Seals

MACHINING PROGRESS

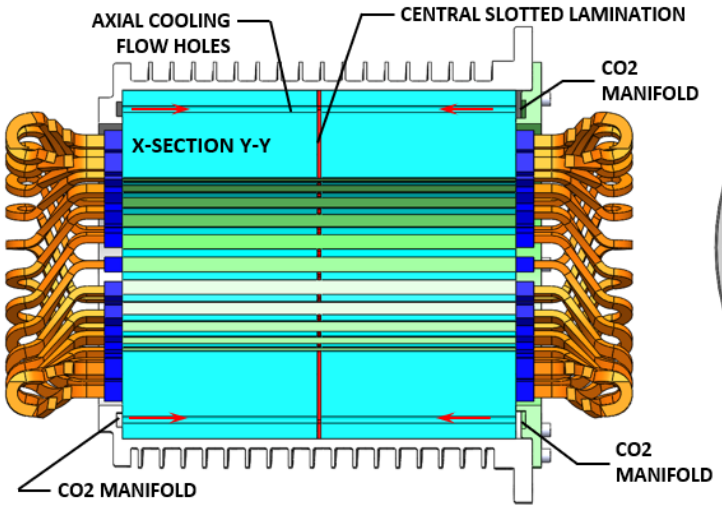
Motor-Generator Shaft

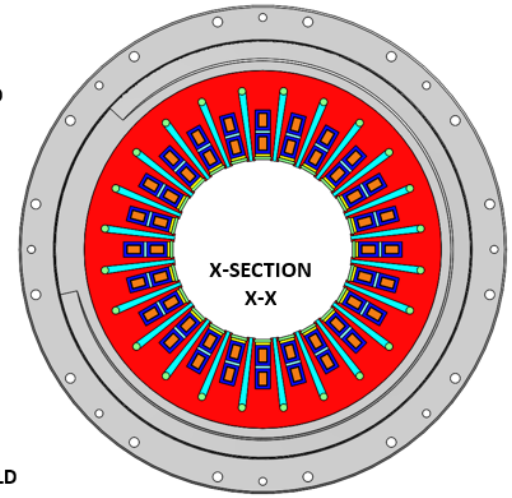
MACHINING PROGRESS

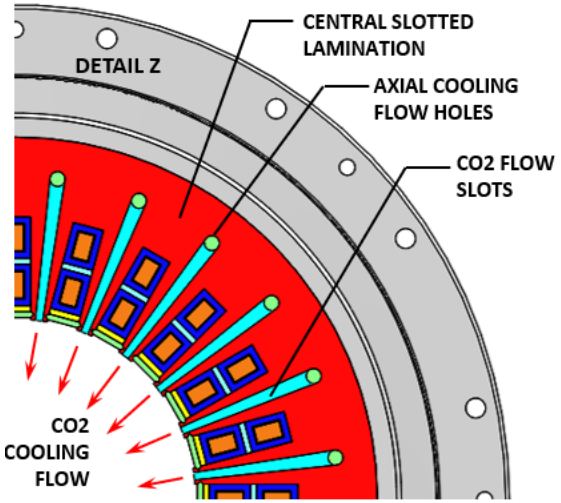
MAGNET & SLEEVE CONSTRUCTION



ELECTRIC MACHINE ARMATURE & WATER JACKET COOLING SLEEVE

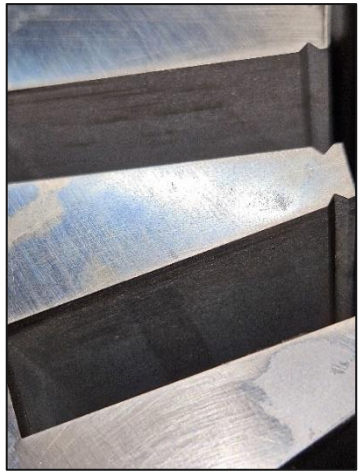






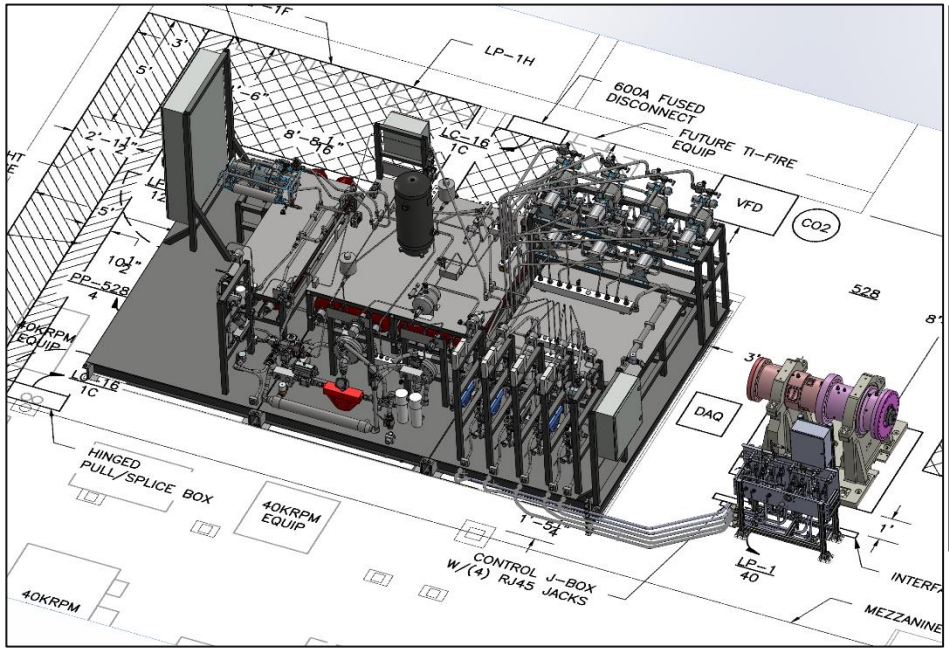
COOLING SLEEVE

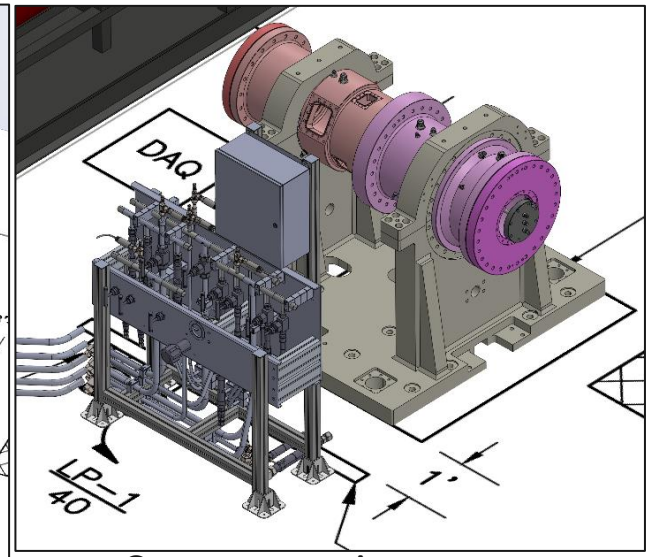
ELECTRIC MACHINE ARMATURE BEING WOUND



GAS SUPPLY SKID & TEST CELL

- CO_2 delivery powered by 8 gas boosters
- Gas boosters driven by high pressure air
- Gas boosters deliver CO_2 for:
  - Bearing pressurization
  - Mag gap cooling of EM
  - Cavity cooling
  - Bearing cooling
  - Casing pressurization
- Skid also possesses:
  - Heat exchangers
  - Pressure vessels and settling tanks
  - FMs, TCs, PTs
  - Emergency backup air system
  - H_20 cooling to EM water jacket

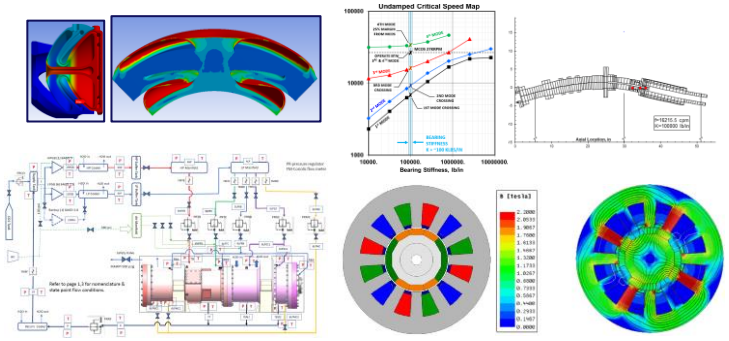




Customer witness testing this week

Schedule and Tasks

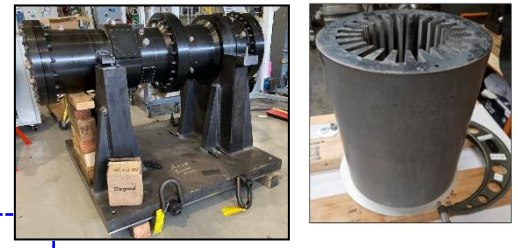
TEST RIG DESIGN
- bearing system
- structures
- electrical system
- thermal system design
- rotordynamics
- test loop



ADDITIVE COMPONENT BUILDS
- compressor bearing
- compressor bearing housing
- midspan bearing
- midspan bearing housing
- generator bearing
- thrust bearing

PARTS MACHINING AND FABRICATION
- probe brackets
- casing assembly & rotors
- Laby seals
- Bearings
- windage shield/cooling tubes/load shank

IN PROGRESS



EM VFD

EQUIPMENT PROCUREMENT
- CO_2 flow loop
- electric machine armature
- CF wound PM EM rotor
- EM VFD

IN PROGRESS

DE-FE00031617 Program Activities	2021 Quarter: 2 3 4	2022 Quarter: 1 2 3 4	2023 Quarter: 1 2 3 4	2024 Quarter: 1 2 3 4	2025 Quarter: 1 2 3
Task 1: Project Management					
Coordination, schedule, risk management, reports & publications, confr., travel	▬	▬	▬	▬	▬
Deliverable: *Quartely progress reports*	▽	▽ ▽ ▽ ▽	▽ ▽ ▽ ▽	▽ ▽ ▽ ▽	▽ ▽
Task 2: Bearing design and manufacturing					
Bearing design	▬	▬			
Bearing fabrication			▬	▬	
Milestone: *Bearing design completed*		◆			
Milestone: *Bearing fabricaiton completed*				◆	
Task 3: Test rig design and procurement					
Rig and flow loop design	▬	▬	▬		
Rig procurement and fabrication				▬	
Milestone: *Rig design reviews completed*		◆			
Milestone: *Detailed drawings released*				◆	
Milestone: *Pressure vessel and gas supply skid procured*				◆	
Task 4: Electric machine design and procurement					
Electric machine design	▬	▬			
Electric machine procurement				▬	
Milestone: *EM design reviews completed*		◆			
Milestone: *Detailed drawings released*				◆	
Milestone: *EM procured*				◆	
Task 5: Test rig and gas supply skid procurement and commisioning					
Test rig hardware machining			▬	▬	
Gas supply skid installation				▬	
Test rig assembly				▬	
DAQ and rig commisioning				▬	
Milestone: *Test rig and gas supply skid installed; commisioning completed*				◆	
Task 6: Rotating tests					
Testing					▬
Milestone: Testing completed					◆
Task 7: Power system costing					
Roll-up of latest cost data and information					▬
Milestone: *Costing completed*					◆

◆ Denotes ***Milestones*** ▽ Denotes ***Deliverables***