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

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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

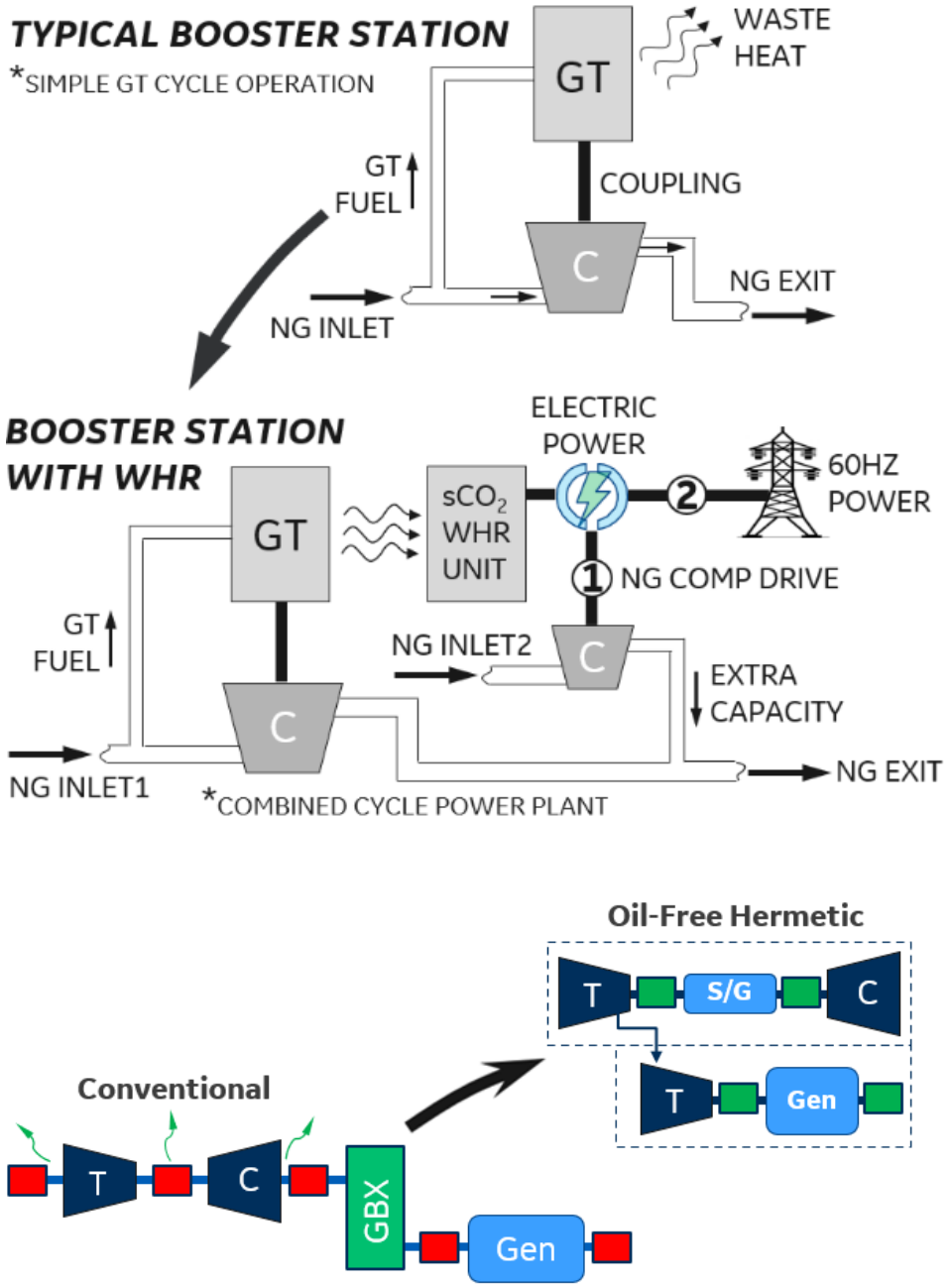
- 2 Drivetrain config. Dual spool approach
- Elimination of gearbox and use of CO_2 bearings
- Hermetic casing; free of CO_2 emissions
- Immersed generator in high density CO_2

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



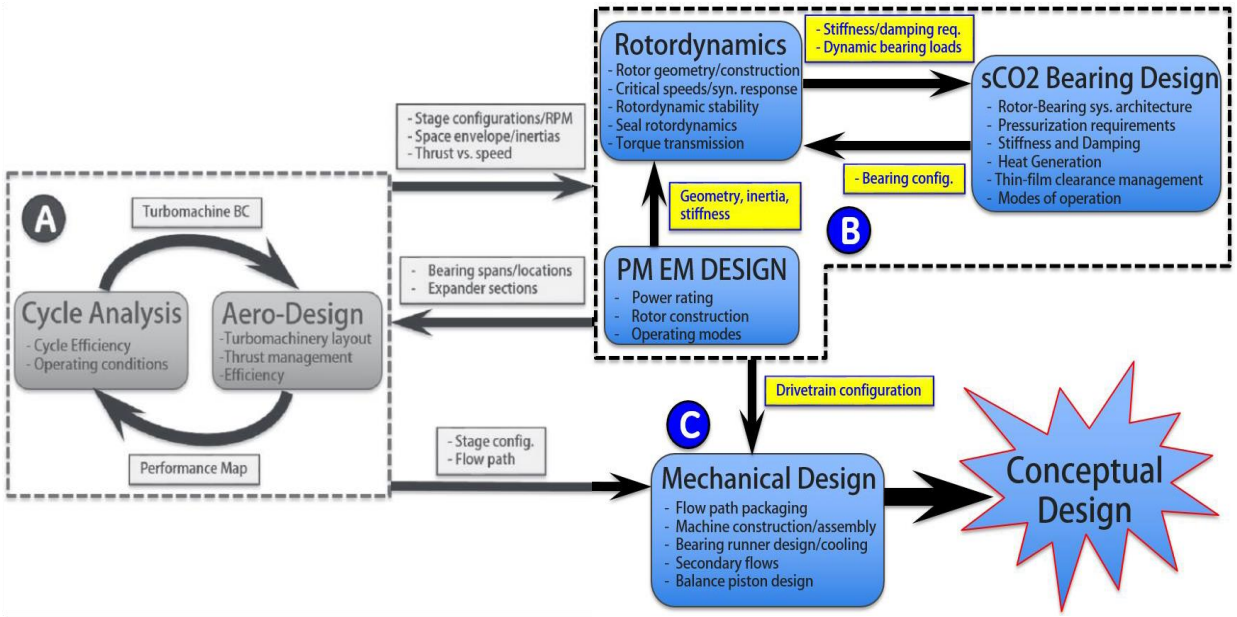
PHASE 2 SCOPE AND OBJECTIVES

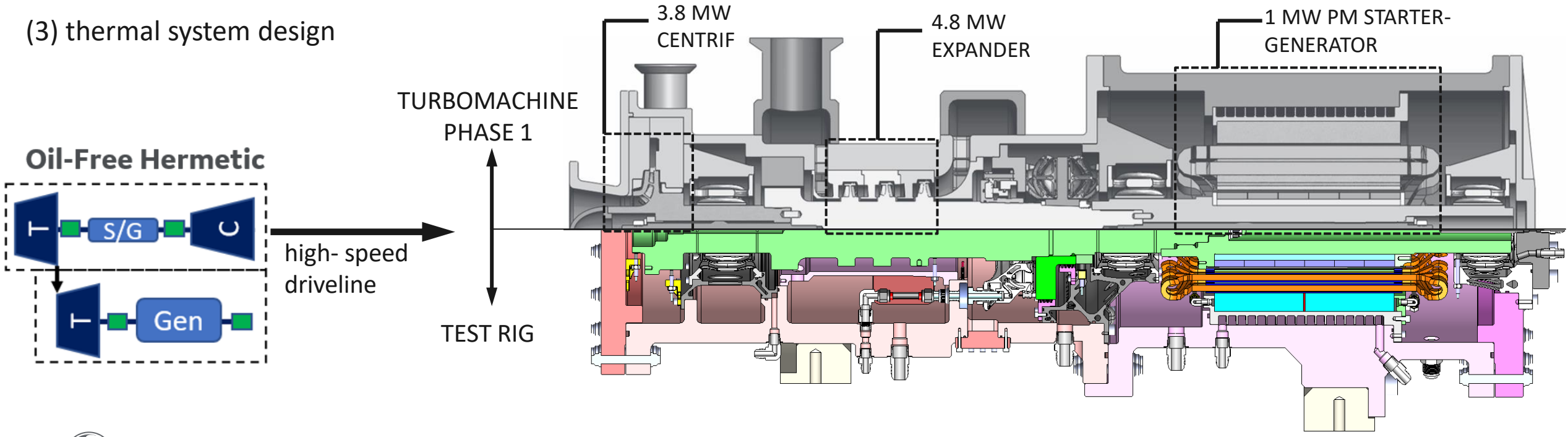
- Develop design practices and methods
- Validate mechanical/thermal/electrical systems & design

(1) drivetrain rotordynamics

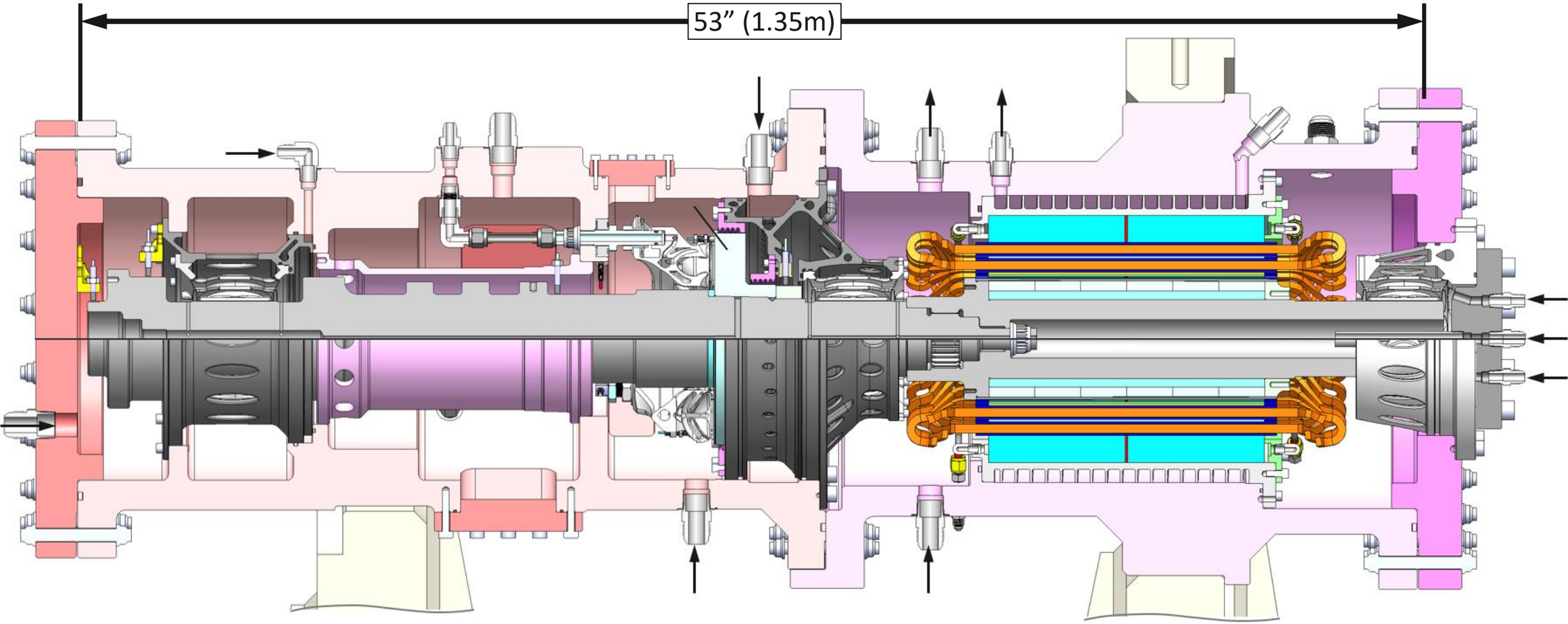
(2) thrust bearing load capacity

(3) thermal system design



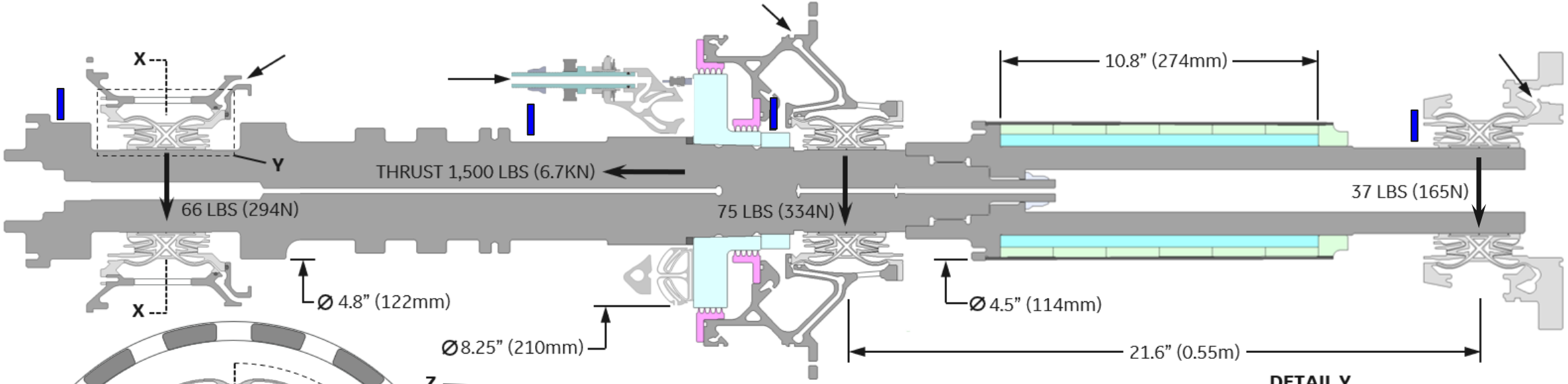


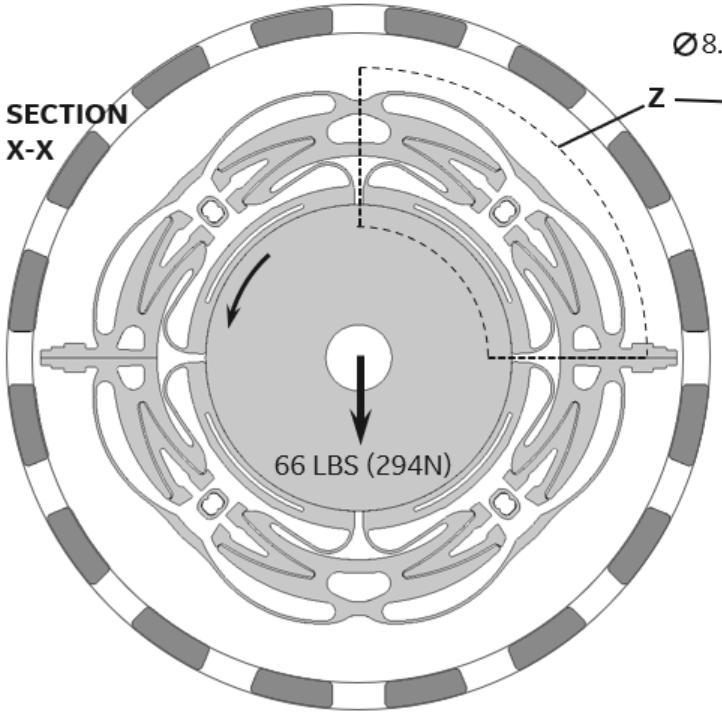
TEST RIG LAYOUT

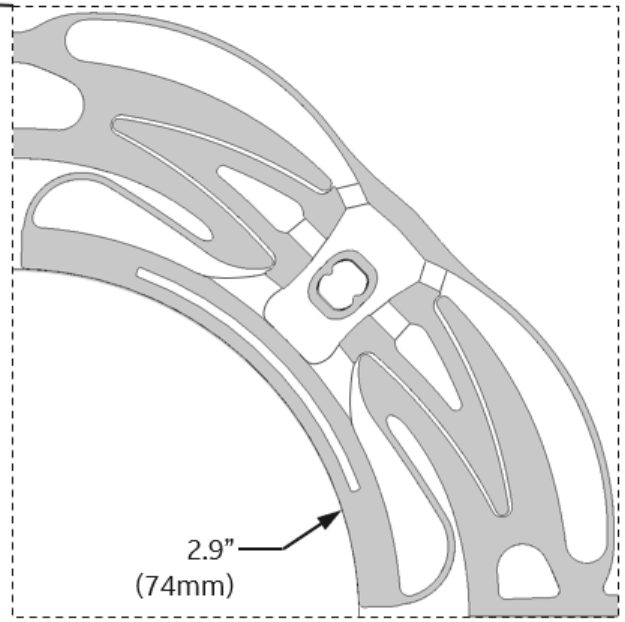


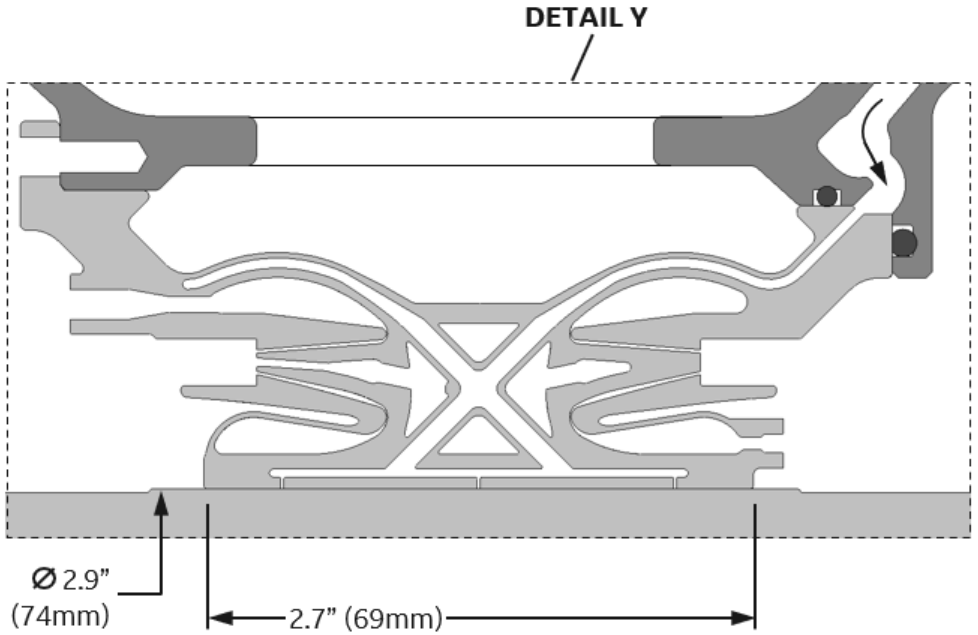
Max Speed = 27 KRPM
Max Rotor Thrust = 1,500 lbs
Max Casing Pressure = 400 PSI
Working Fluid = CO_2

ROTORDYNAMIC MEASUREMENTS AND BEARING DETAILS



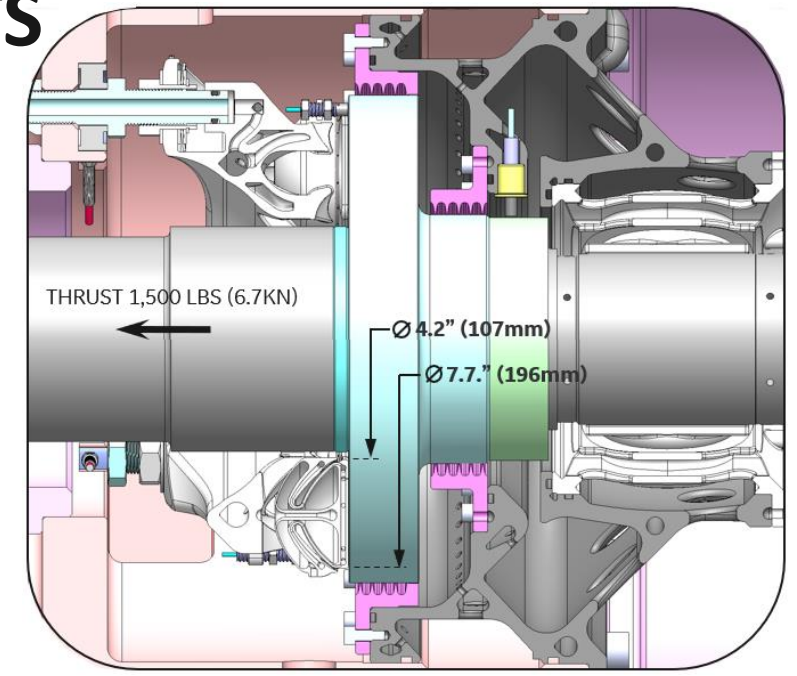


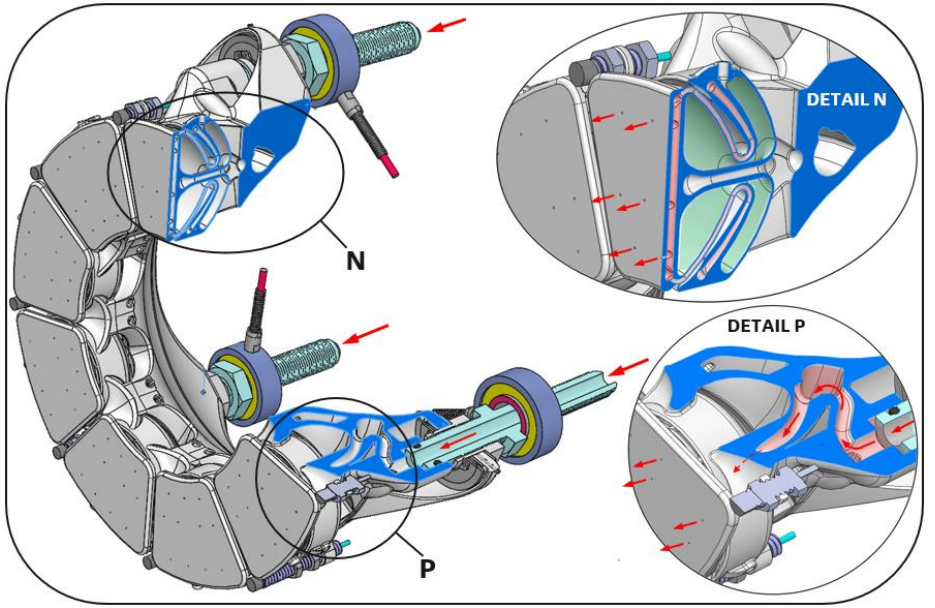


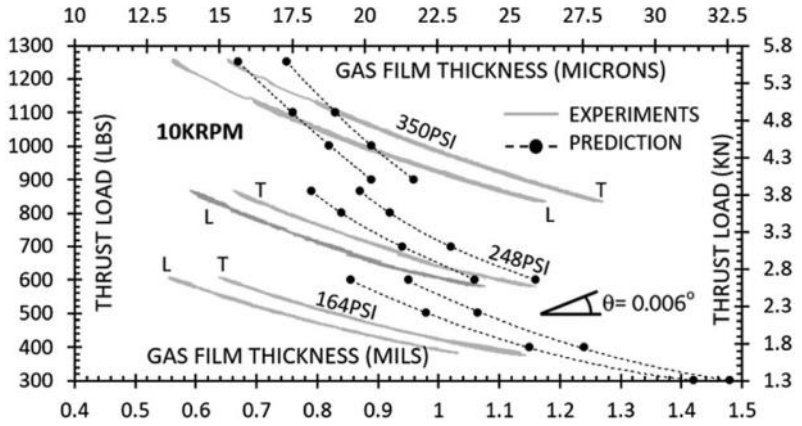


THRUST CHAMBER AND THRUST BEARING TESTS

- 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







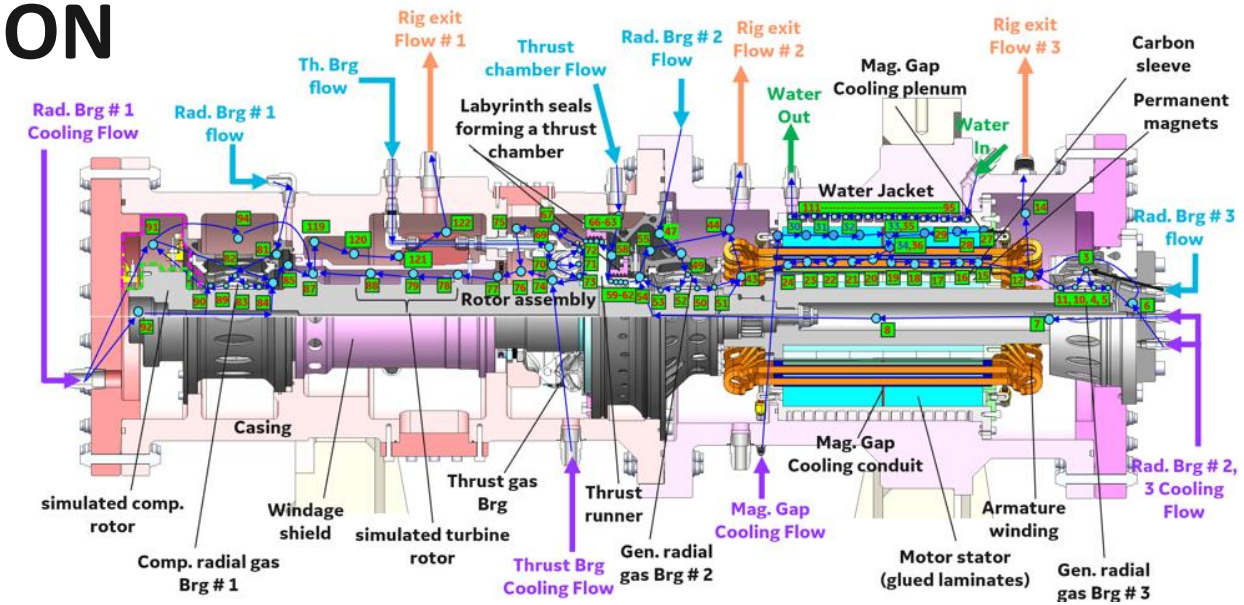
THERMAL SYSTEM DESIGN VALIDATION

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

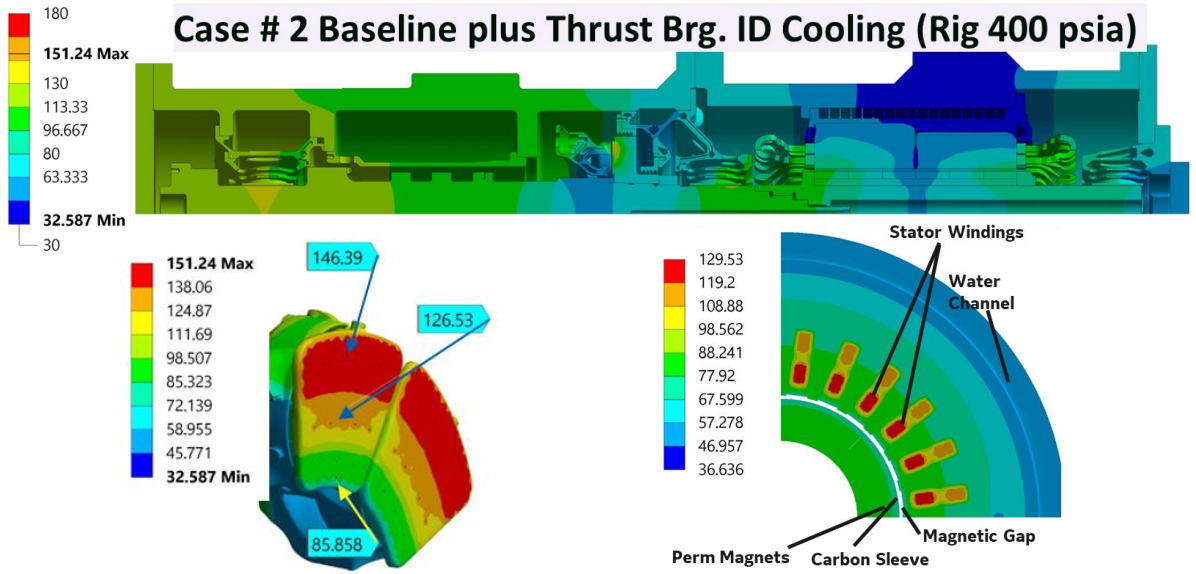
- 1D energy balance at each node accounts for:
  - rotor windage, cavity swirl
  - calculates convective HTC
  - heat gen sources in EM/bearings
  - heat sink in H_2O jacket

- 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



ADDITIVE MANUFACTURING PROGRESS: INCO 718 COMPONENTS

Compressor BRG

BUILD
MACHINE

Comp. BRG Housing

BUILD
MACHINE

Thrust BRG

BUILD
MACHINE

Midspan BRG Housing

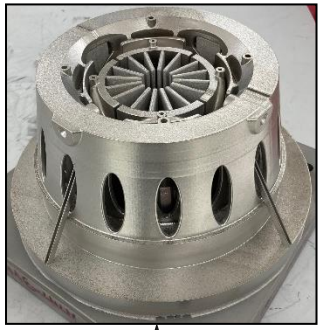
BUILD
MACHINE

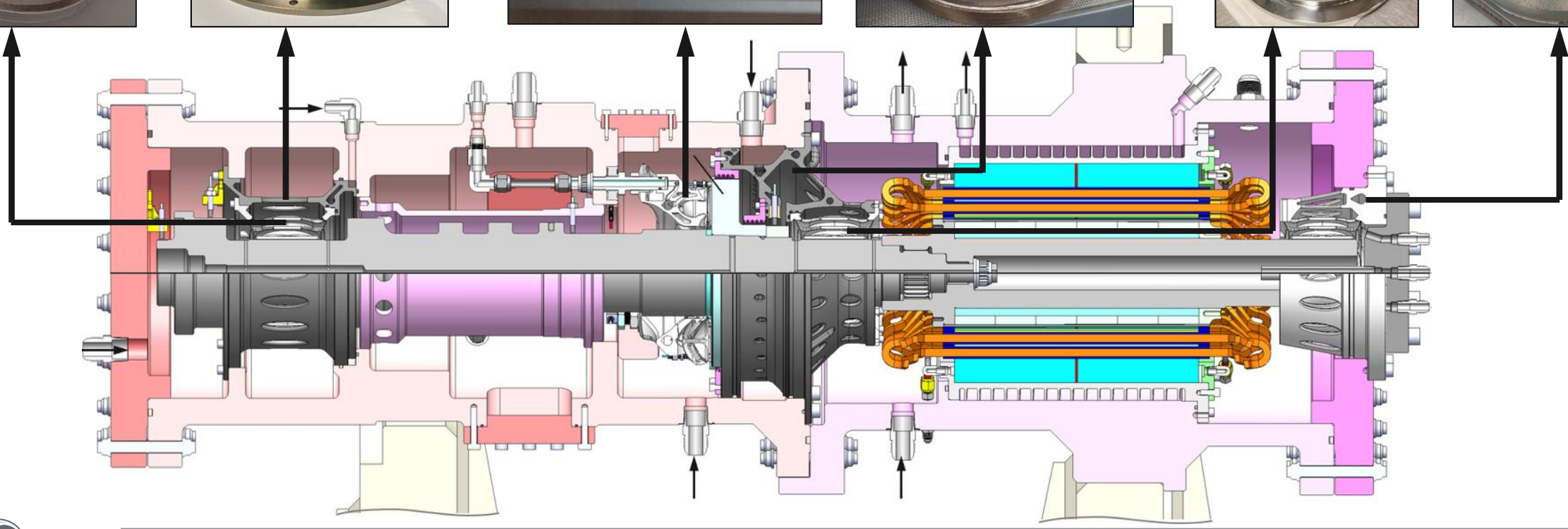
Midspan BRG

BUILD
MACHINE

Generator BRG

BUILD
MACHINE

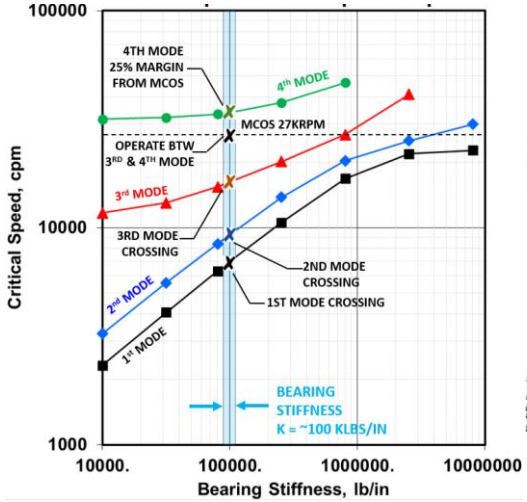


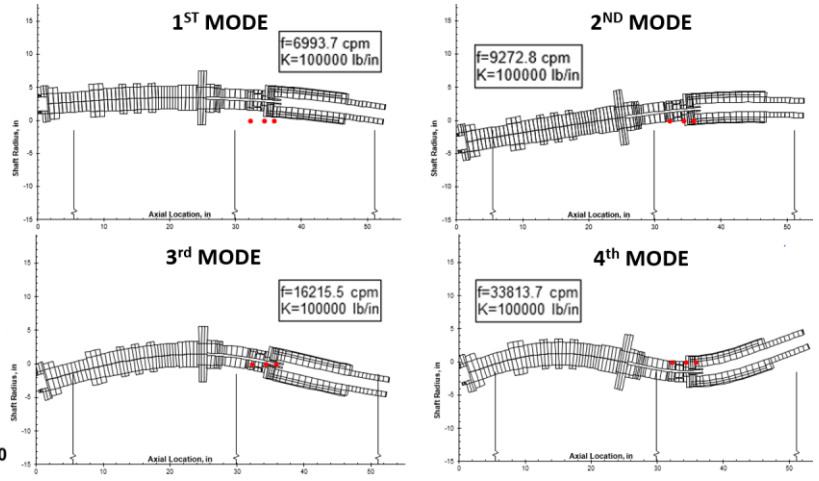


DAMPER COUPON TESTING

Rotordynamics

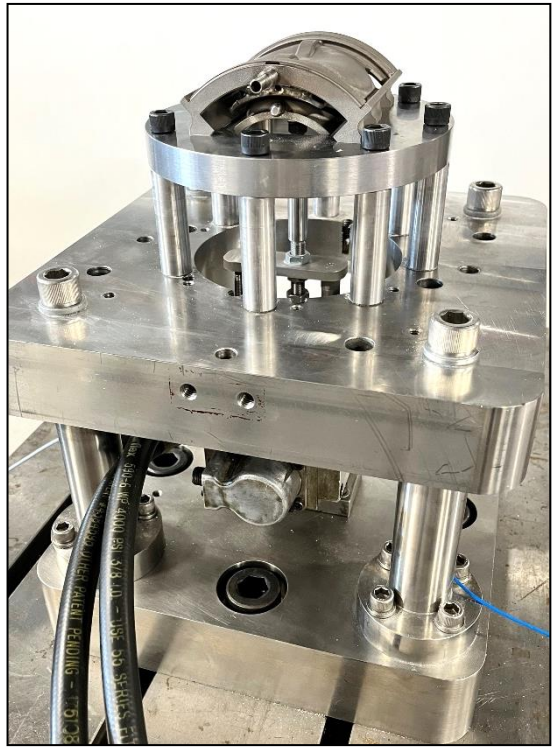
- Machine concept has high power density and requires high speed operation
- Key risk in concept is operating above third critical speed
- To mitigate this risk → 3 bearing layout
- However, for reliable operation need a certain K and C





Bearing support stiffness and damping

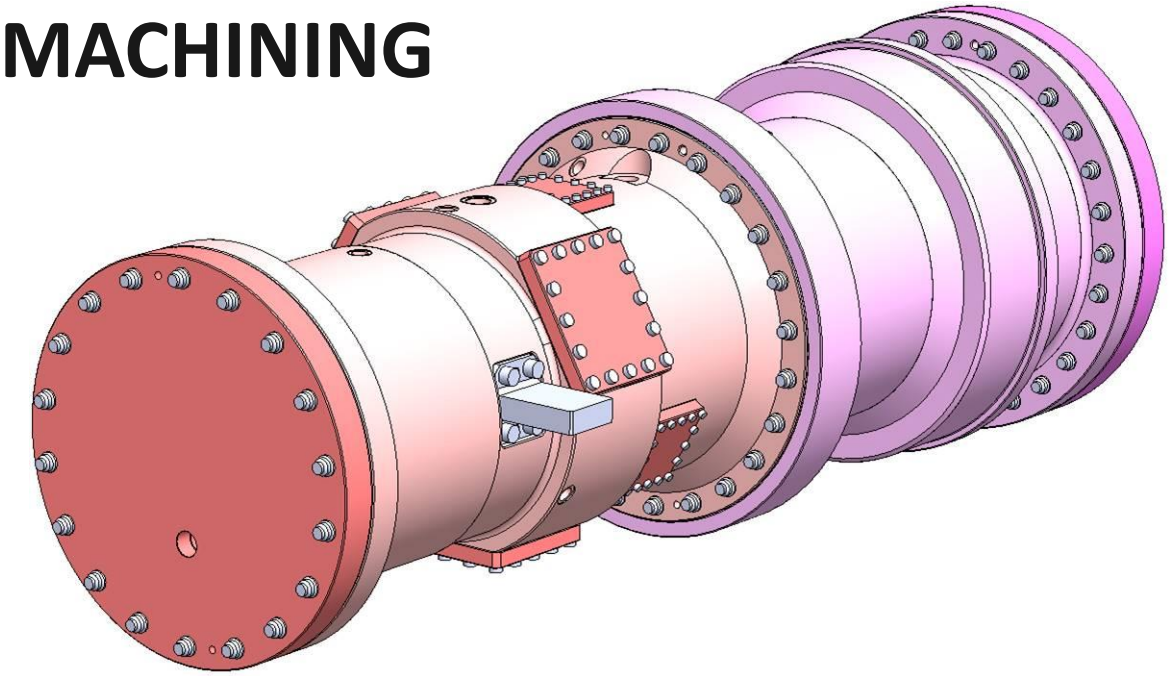
- A ¼ section bearing damper coupon has been built
- Coupon to have simple testing conducted on test bench
- Static force deflection → static stiffness
- Dynamic single frequency excitation testing → damping and stiffness



CASING ASSEMBLY FABRICATION AND MACHINING

Casing Material

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

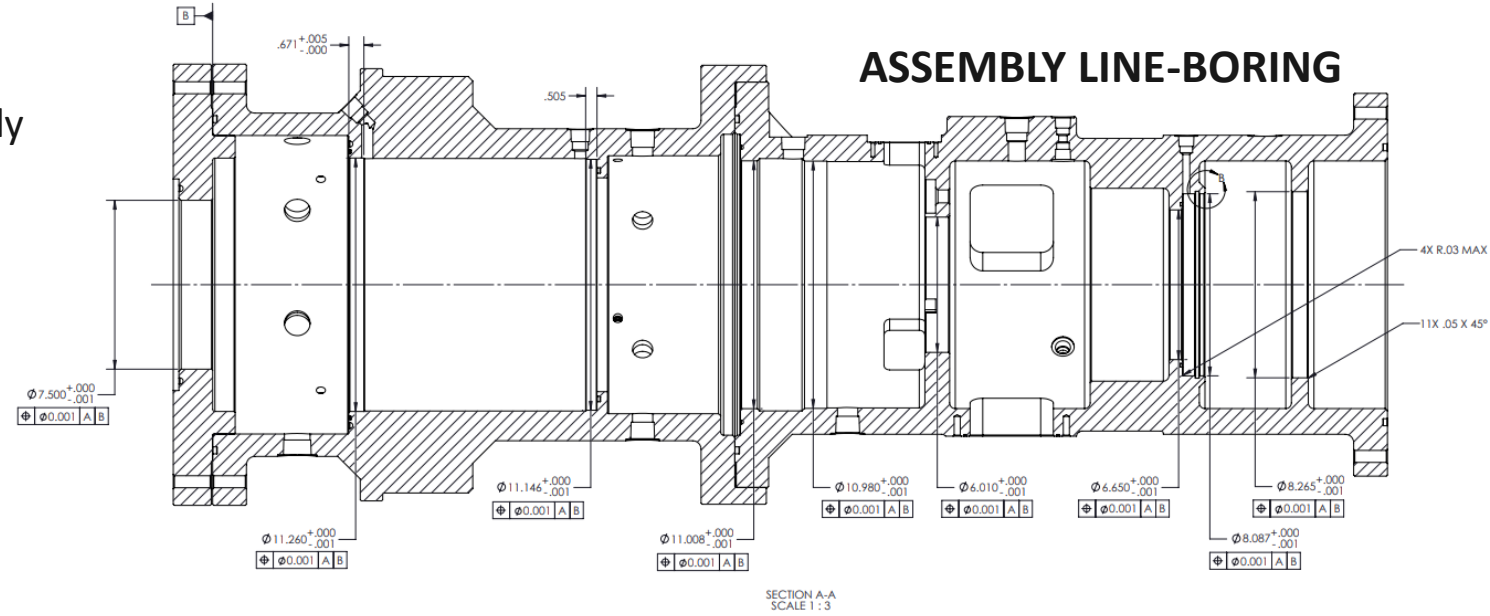


Assembly Machining

- 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

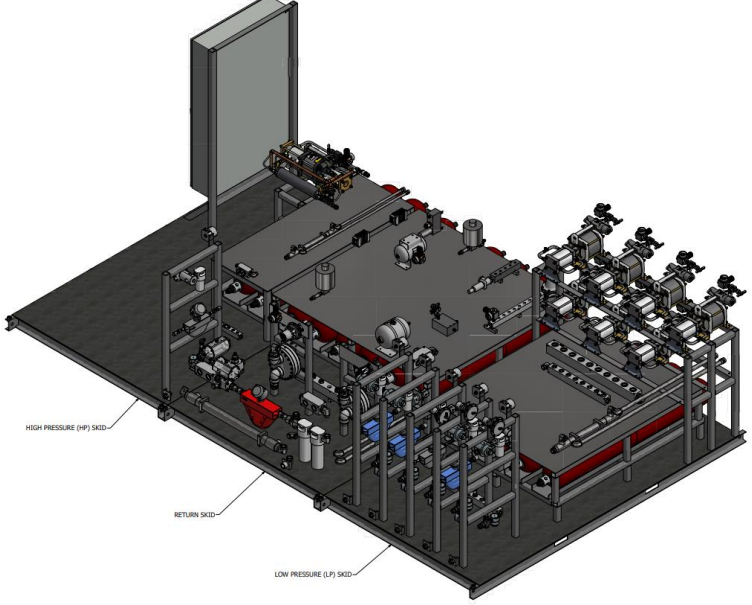
- Drawing finalized and major forgings received by vendor

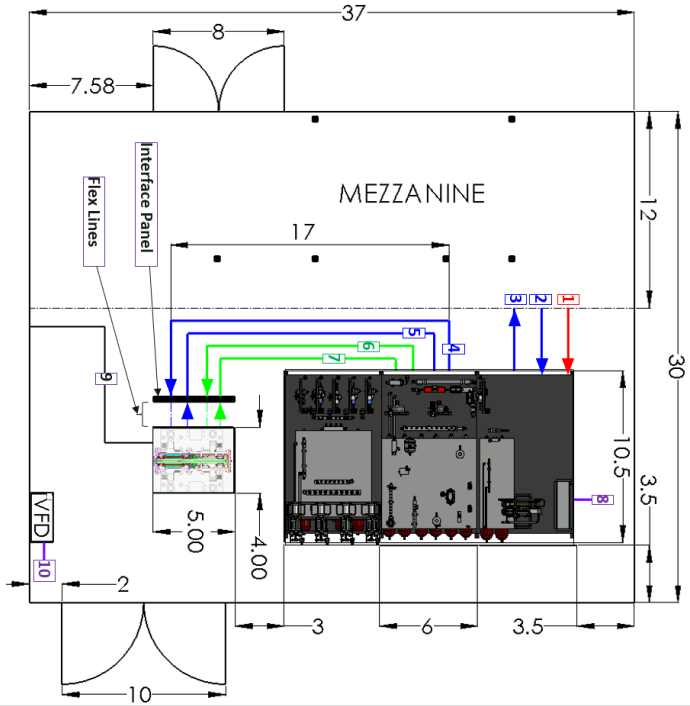


GAS SUPPLY SKID AND TEST CELL

- 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

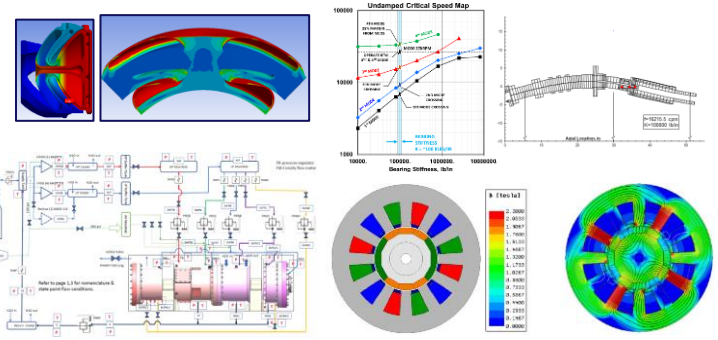
	Flow Temp Entering Rig (°C)	Case # 1	Case # 2
		Baseline	Thrust Brg. ID Cooling
		CO_2 Flow 0.65 kg/s	CO_2 Flow 0.76 kg/s
		400 psia	400 psia
Water Flow gal/min	29.44	1.4	1.4
Thrust Chamber kg/s (% rig flow)	21	0.31 (48%)	0.31 (41%)
Gap Cooling kg/s (% rig flow)	18.3	0.10 (16%)	0.10 (14%)
3 Radial Brg kg/s (% rig flow)	29 to 29.3	0.073 (11%)	0.073 (10%)
Thrust Brg kg/s (% rig flow)	40	0.031 (5%)	0.031 (4%)
Rad. Brg # 1 Cooling Flow kg/s (% rig flow)	18	0.1 (15%)	0.1 (13%)
Rad. Brg # 2, 3 Cooling Flow kg/s (% rig flow)	18	0.03 (4%)	0.03 (4%)
Thrust Brg. ID Cooling kg/s (% rig flow)	18	0 (0%)	0.113 (15%)





Schedule and Tasks

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



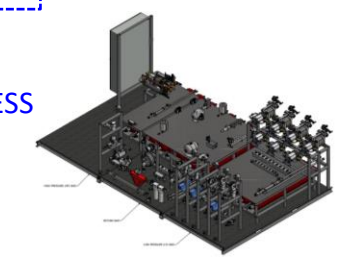
ADDITIVE COMPONENT BUILDS
- compressor bearing
- compressor bearing housing
- midspan bearing
- midspan bearing housing
- generator bearing
- thrust bearing ← IN PROGRESS

PARTS MACHINING AND FABRICATION
- probe brackets
- casing assembly
- rotor system
- laby seals
- windage shield/cooling tubes/load shank

← IN PROGRESS

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

IN PROGRESS ←



EM VFD

Program Activities	GE Research	Year 1 Quarter: 1 2 3 4	Year 2 Quarter: 1 2 3 4	Year 3 Quarter: 1 2 3 4	Year 4 Quarter: 1 2 3 4
Task 1: Project management	x				
Coordination, schedule & risk management, reports & publications, conf. travel	x				
Deliverable: *Quarterly progress reports*	x	▽	▽	▽	▽
Task 2: Bearing design & fabrication	x				
Bearing design	x				
Bearing fabrication	x				
Milestone: *Bearing design completed*			◆		
Milestone: *Bearing fabrication completed*				◆	
Task 3: Test rig design, pressure vessel & flow loop procurement	x				
Rig & flow loop design	x				
Rig procurement	x				
Milestone: *Rig design completed*				◆	
Milestone: *Detailed drawings released*				◆	
Milestone: *Pressure vessel & flow loop procured*					◆
Task 4: Electric machine design & procurement	x				
EM design & consult	x				
EM procurement	x				
Milestone: *EM design completed*				◆	
Milestone: *Detailed drawings released*				◆	
Milestone: *EM procured*					◆
Task 5: Test rig fabrication & assembly	x				
Rig parts machining	x				
Loop & rig assembly	x				
DAQ & rig commissioning	x				
Milestone: *Test rig & flow loop assembled; shake-out completed*					◆
Task 6: Full-scale rotor testing	x				
Testing	x				
Milestone: *Testing completed*					◆
Task 7: Modular heat engine costing	x				
Roll-up of latest cost data and information	x				
Milestone: *Costing completed*					◆

◆ Denotes ***Milestone*** ▽ Denotes ***Deliverable***

PROCUREMENT OF TEST HARDWARE UNDERWAY