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

GE Global Research Center

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PHASE 1 BACKGROUND

APPLICATION AND MOTIVATION

- Natural Gas Compressor Stations
- Utilize waste heat | sCO_2 Brayton power cycle
- 11pts Eff. Increase | 41% to 52% cycle eff.
- Objective: conceptual design of cycle and turbomachinery

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

BENEFIT

Assuming 8% market penetration

→ emission-free 6.75MWh annually

→ 1.4 million metric tons of NG

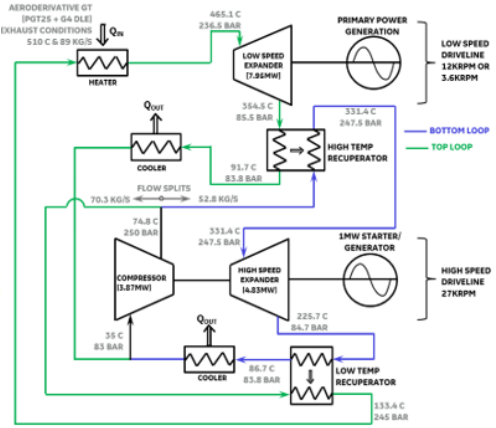
TECH RISKS → HIGH-SPEED DRIVELINE

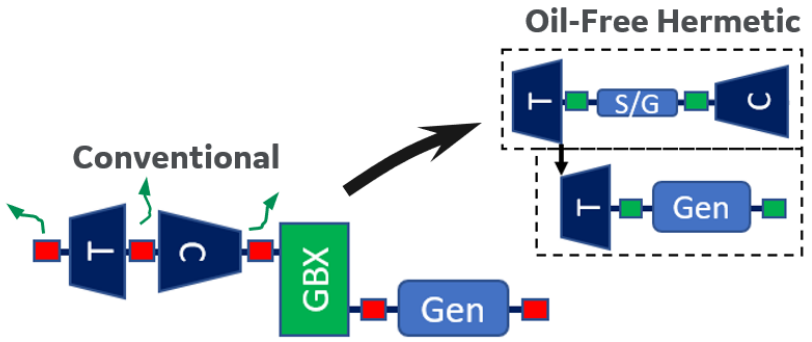
- Rotor-bearing system dynamics → high-speed operation
- Thrust bearing performance → rotor system integration
- Thermal stability → bearing systems/PM EM cavity

NG COMPRESSOR STATION

GAS TURBINE (GT)

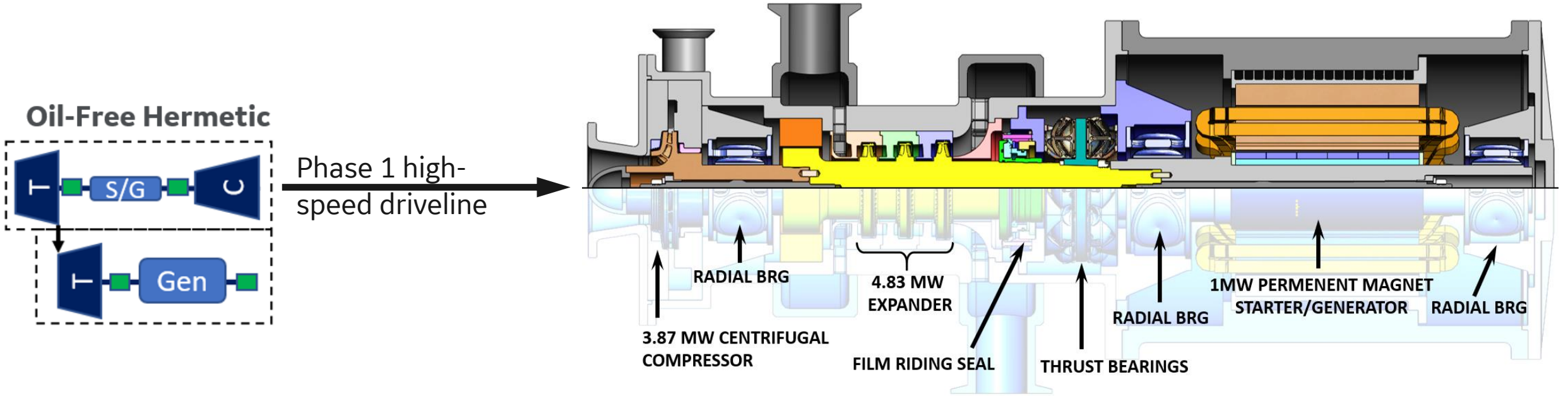
GT WASTE HEAT





PHASE 2 SCOPE AND OBJECTIVES

- Perform full-scale rotating tests on the high-speed driveline to reduce identified risks



(1) Full scale rotating test of the high-speed driveline

(2) Validation of drivetrain rotordynamics

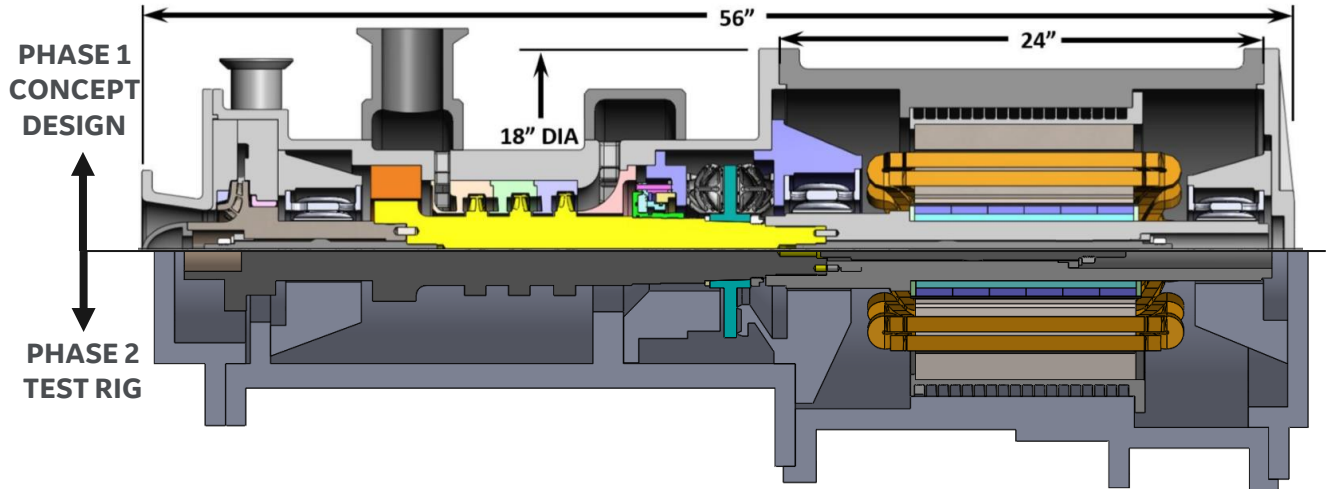
(3) Validation of thrust bearing load carrying capacity

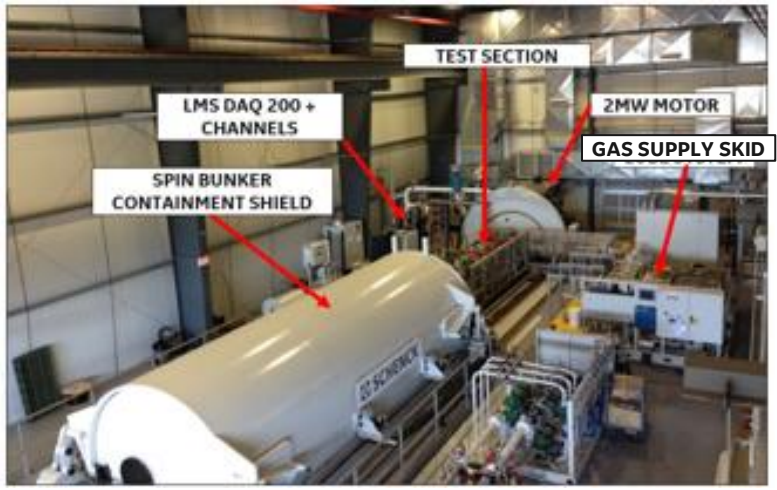
(4) Validate thermal system design and models

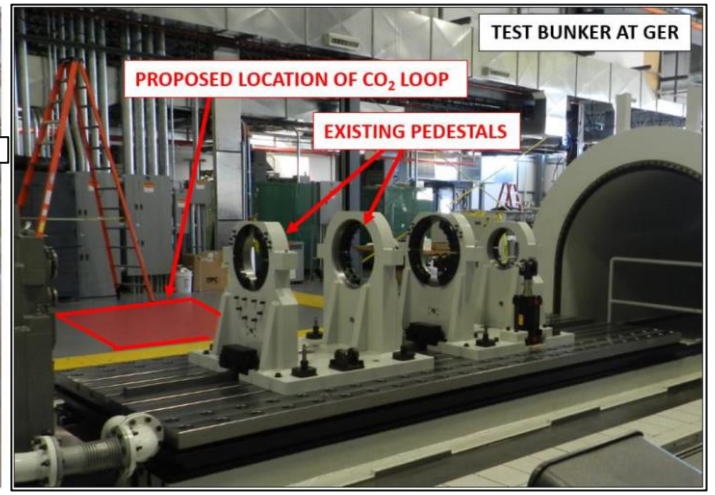
} to be performed in hermetic CO_2 environment

TEST APPROACH AND FACILITY

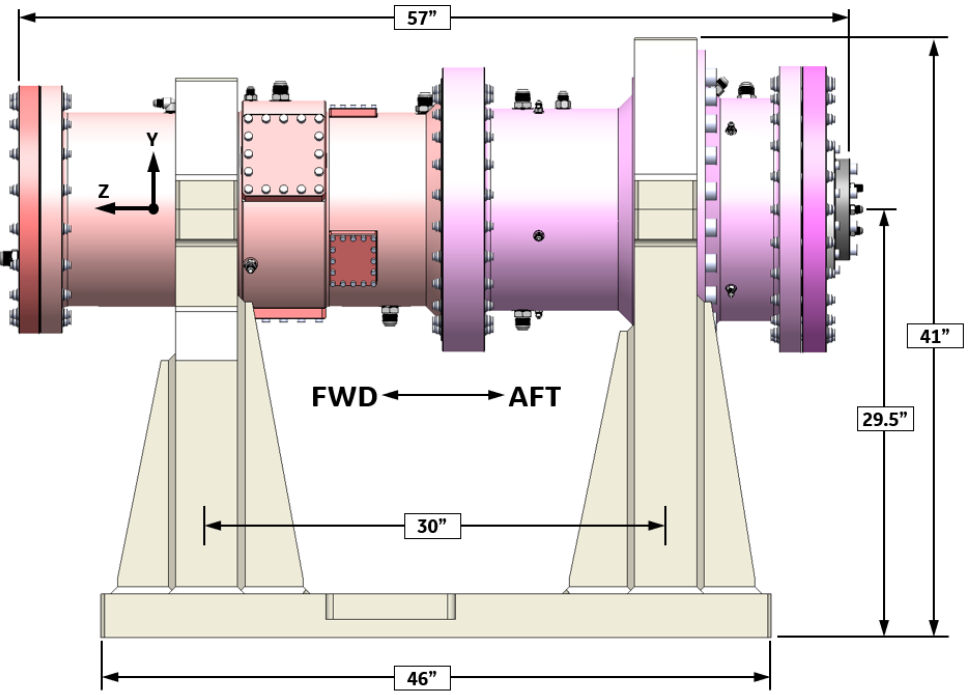
- High speed drivetrain 27krpm from Phase 1
- Equivalent rotor without turbomachinery
- Immersed PM EM in CO_2 to drive system to speed
- Utilize existing test platform at GE Research
- Key rig requirements
  - Full scale 1MW PM EM
  - Hermetic casing → 500PSIG
  - Ability to apply thrust
  - Thrust measurement system
  - Gas film measurements
  - Rotordynamic measurements
- System level technology advancement
  - Thermal model verification
  - Verifying 2nd flows and cooling schemes
  - Bearing damping and load capability



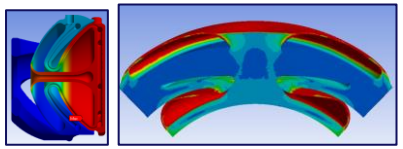




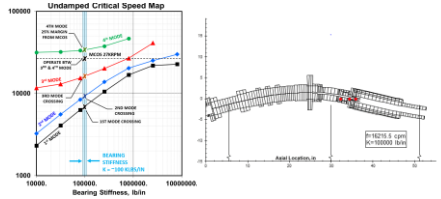
DETAILED ANALYSIS AND RIG DESIGN



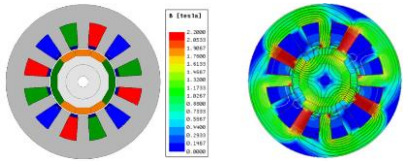
Total Test Rig (With Pedestals) = ~5,600 lbs
Max Speed = 27 KRPM
Max Rotor Thrust = 1,500 lbs
Max Casing Pressure = 500 PSIG
Working Fluid = CO2



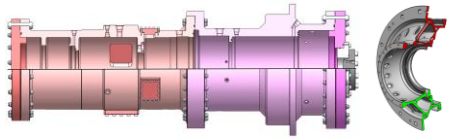
GAS BEARING DESIGN



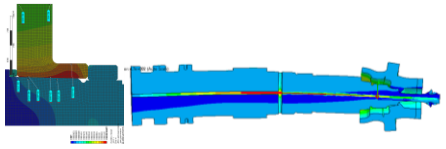
ROTORDYNAMICS



ELECTROMAGNETICS

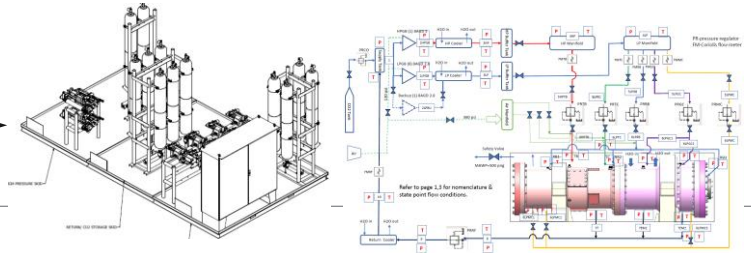


CASING & STURCTURES



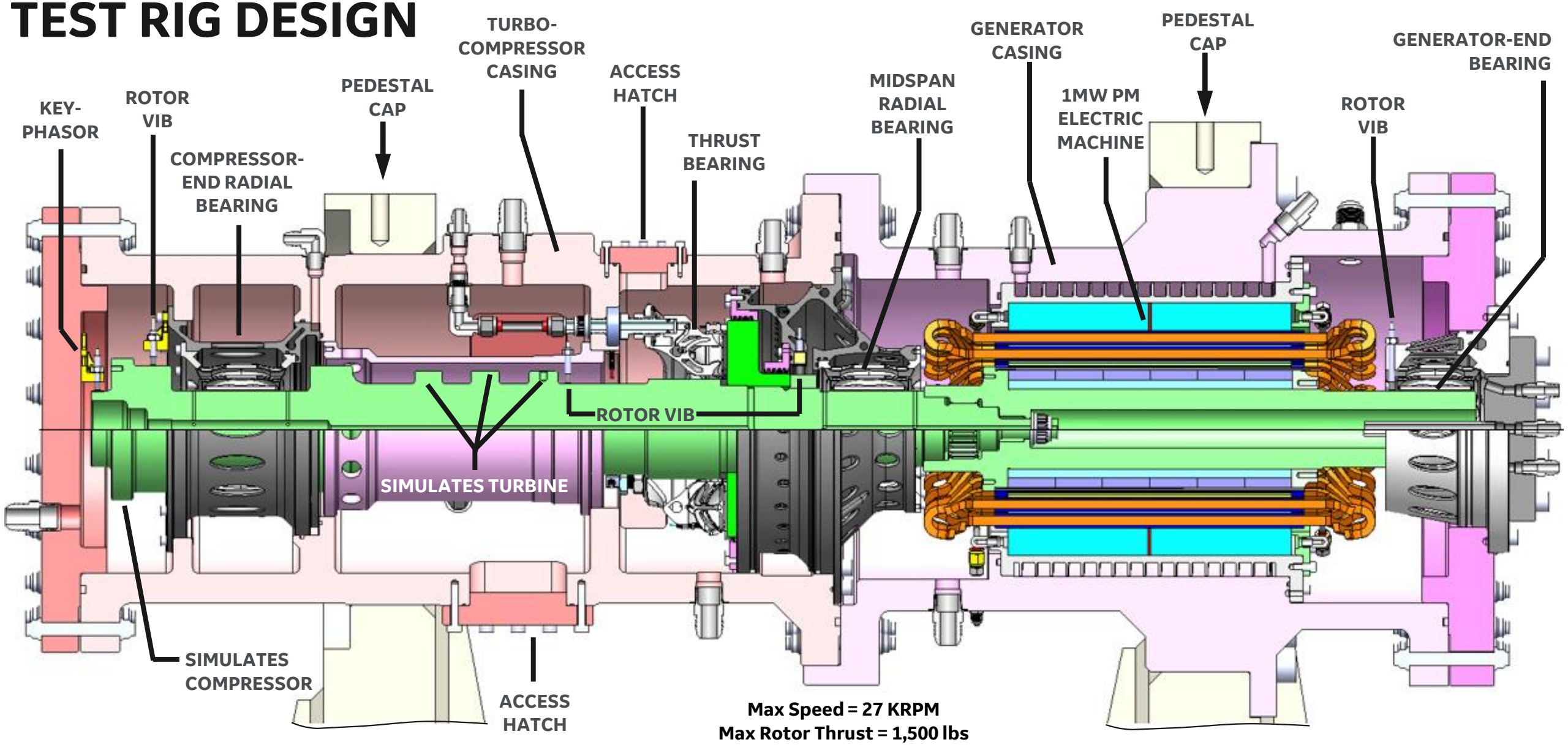
ROTATING COMPONENTS

THERMAL SYSTEM DESIGN



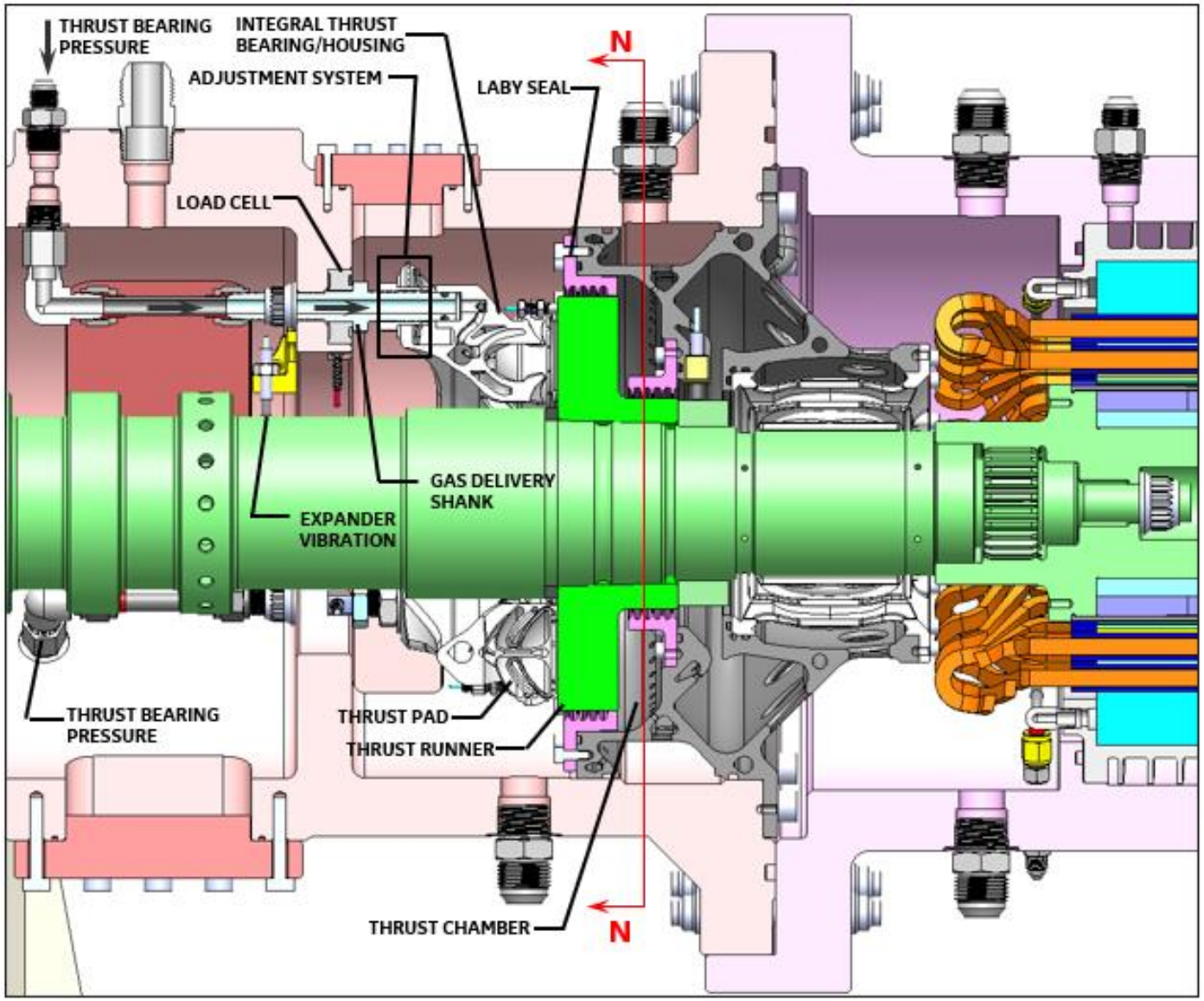
FLOW LOOP/THERMODYNAMICS

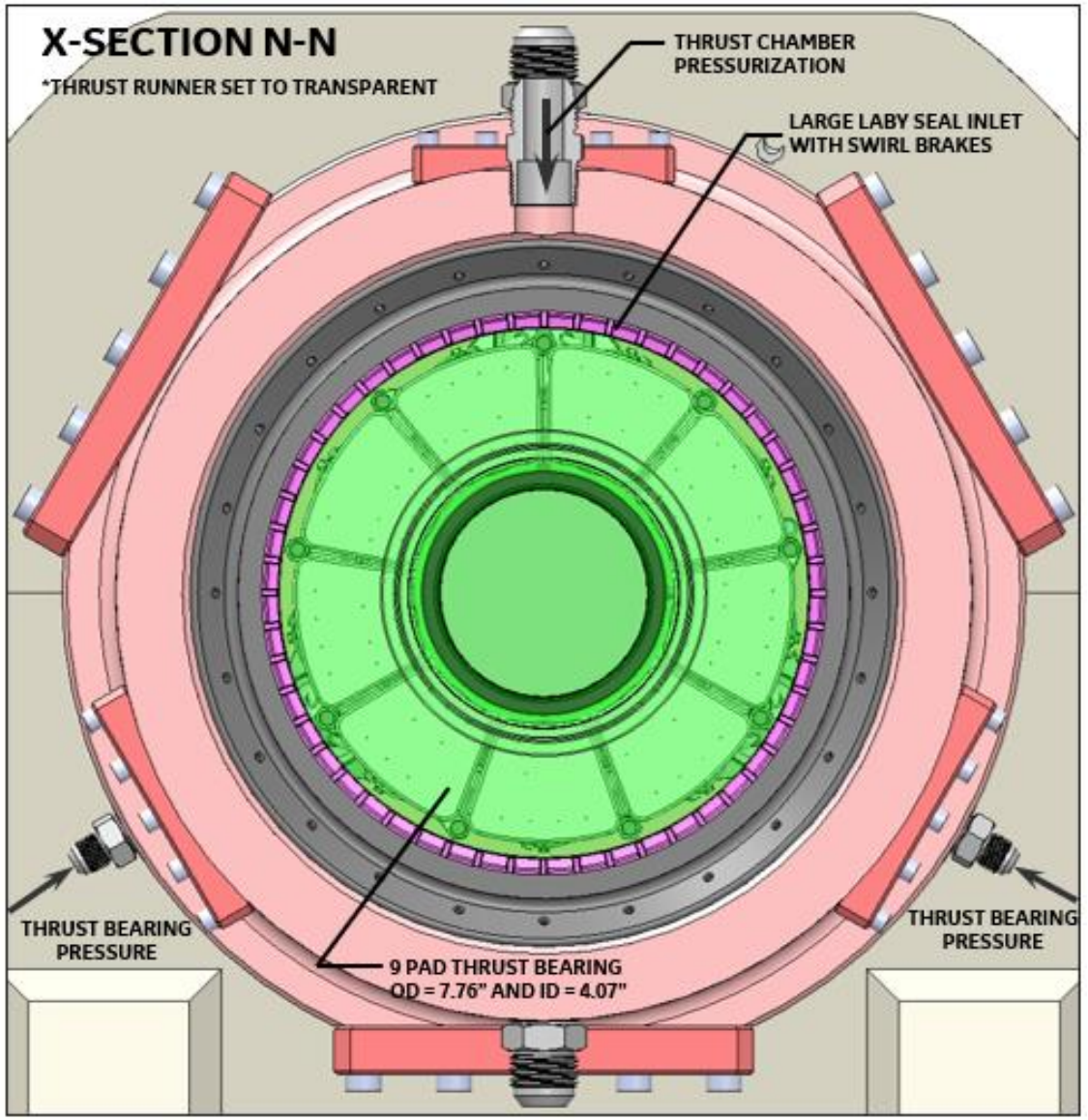
TEST RIG DESIGN



Max Speed = 27 KRPM
Max Rotor Thrust = 1,500 lbs
Max Casing Pressure = 500 PSIG
Working Fluid = CO2

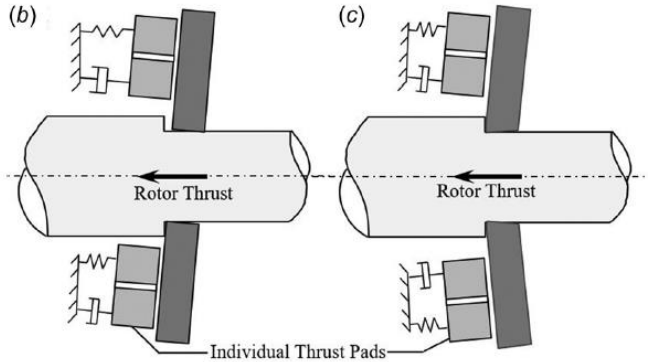
THRUST CHAMBER AND MEASUREMENT SYSTEM

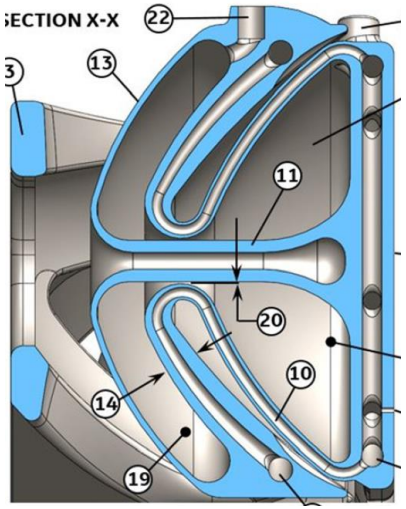




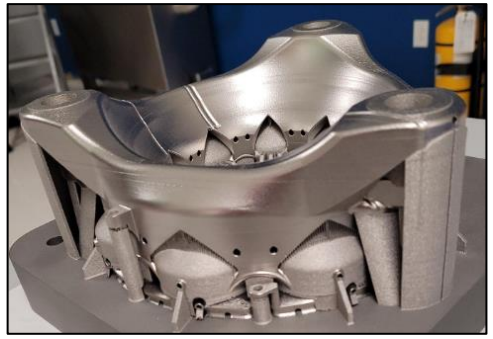
THRUST GAS BEARING

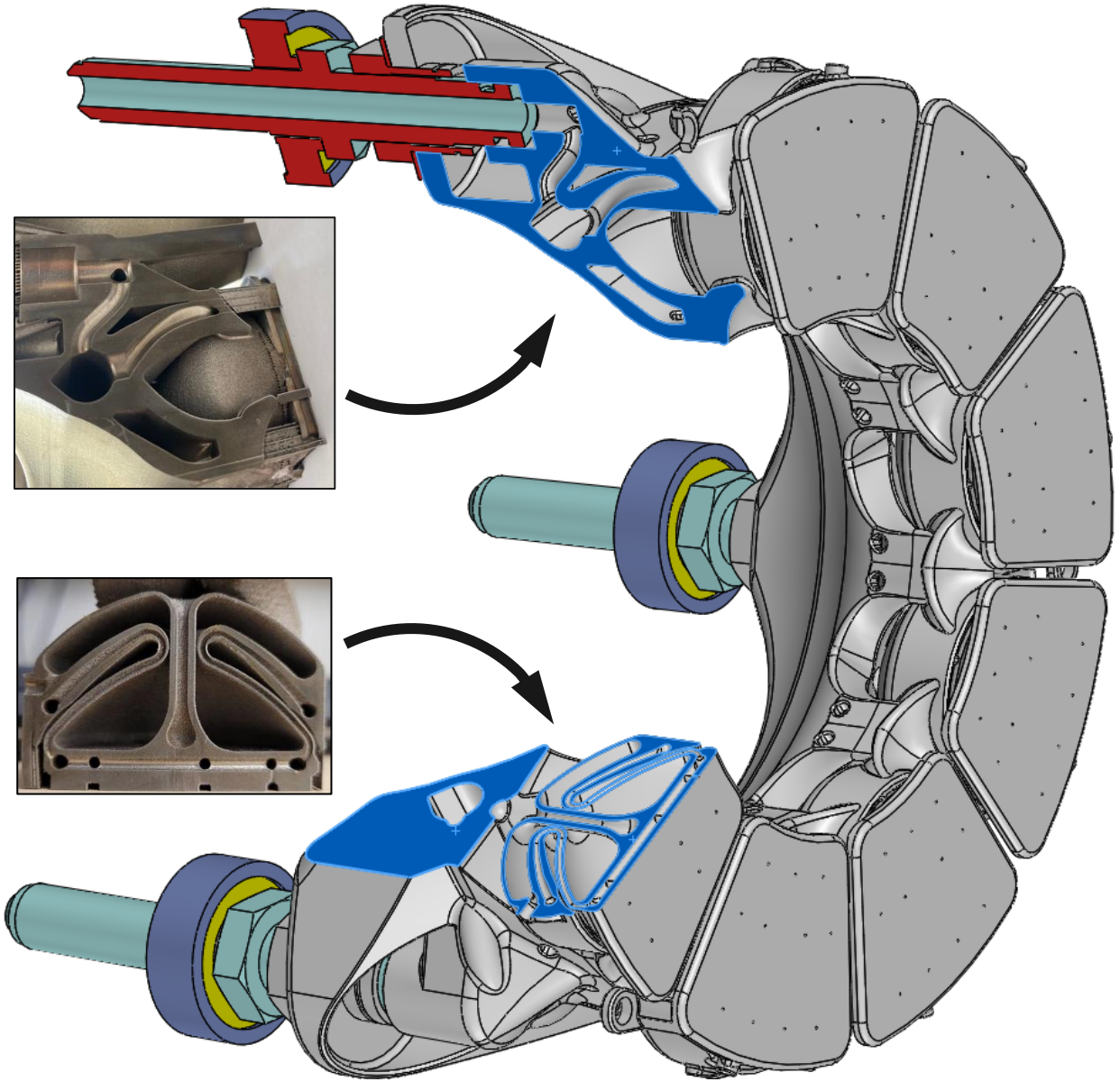
- Hybrid thrust bearing Concept
  - Individual pads
  - Angular compliance
  - Hydrostatic pressurization





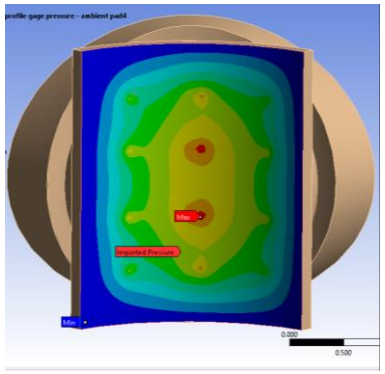
- Additive Build Trials
  - Full bearing builds trials completed
  - Inspection and build comps in progress

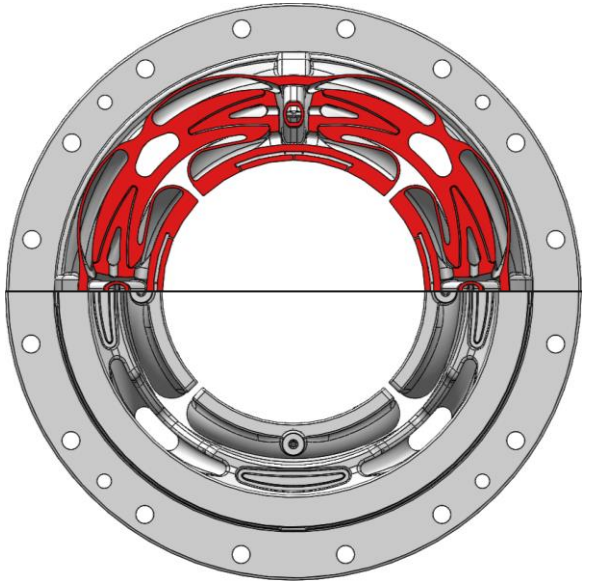


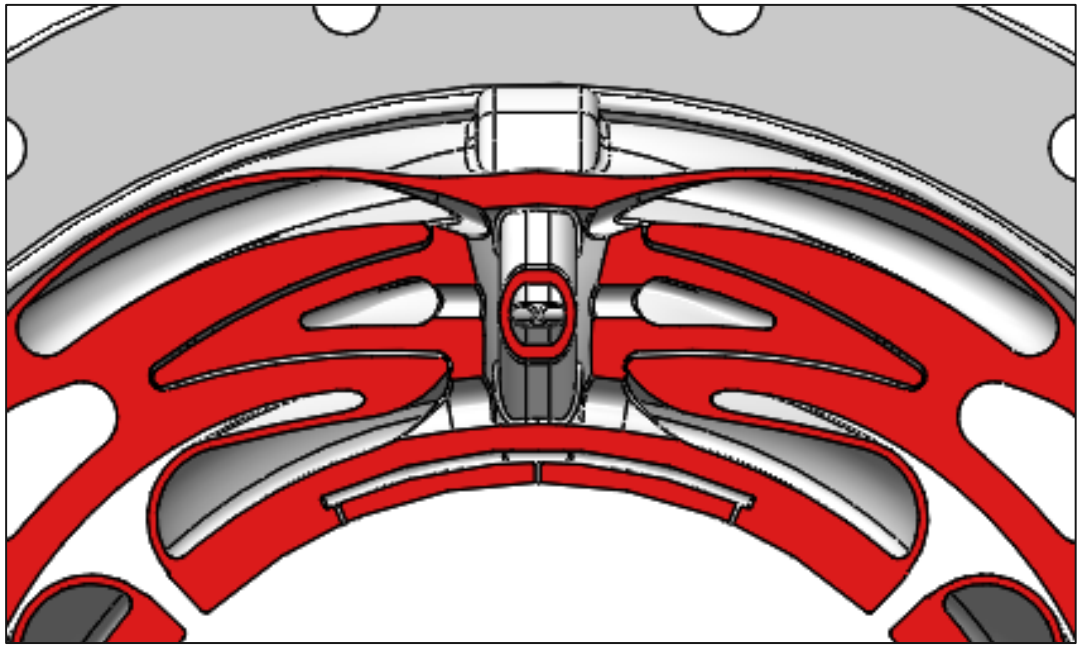


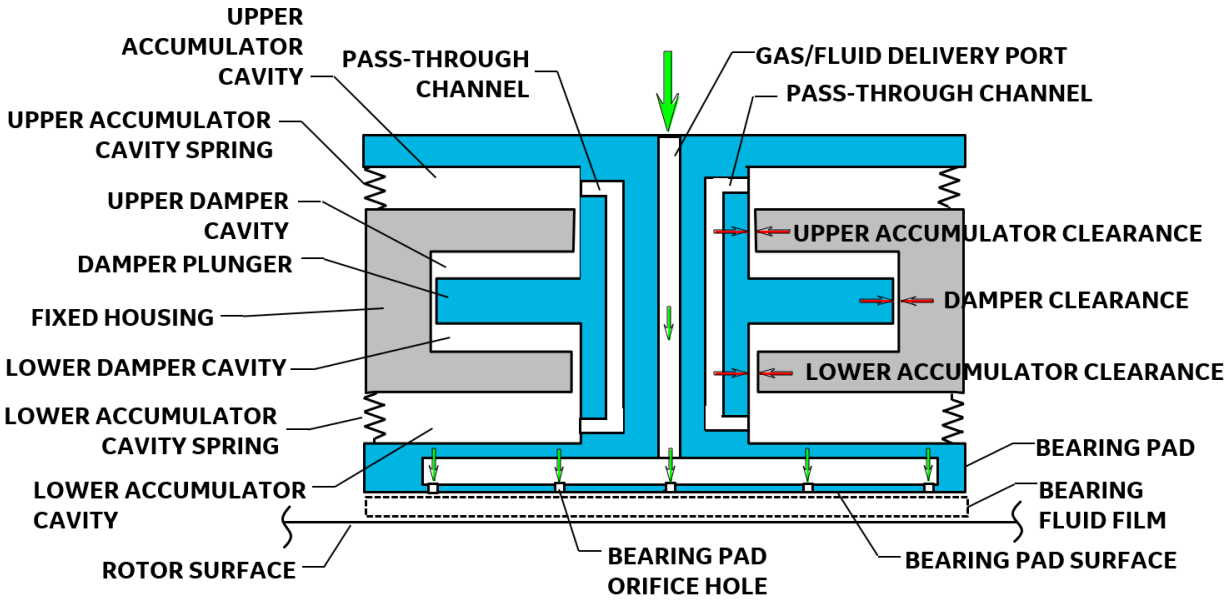
RADIAL GAS BEARING

- Hybrid Gas bearing Design Concept
  - Flexible tilting pads
  - Hydrostatic pressurization
  - Hermetic squeeze film damper
- Design aspects
  - Structural analysis/life/stresses
  - Gas film design
  - Damper design
  - Design for additive manufacturing



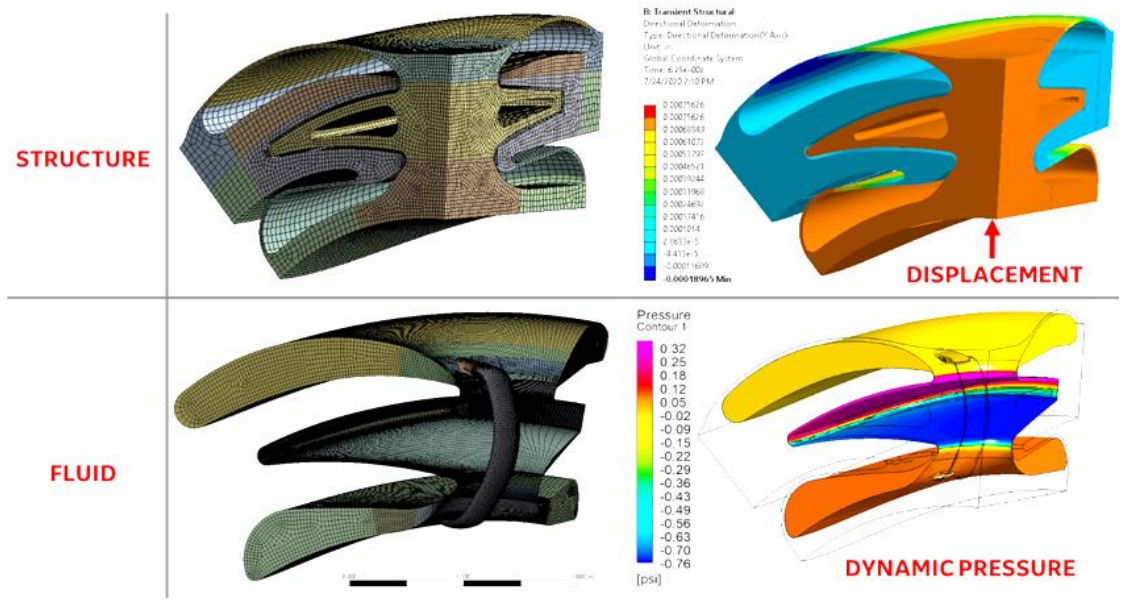




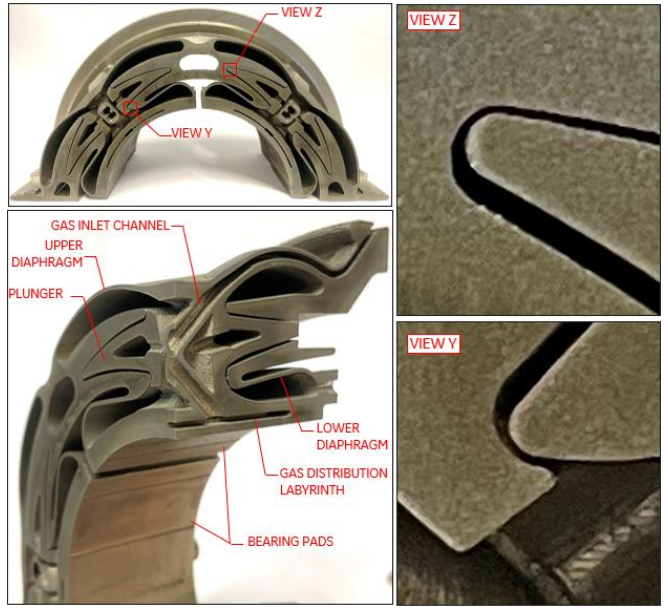


HERMETIC DAMPER & BEARING BUILDS

- Hermetic squeeze film damper design
  - Self-contained fluid damper (no lube system)
  - 2-way fluid structure integration
    - CFD ←→ Transient Structural
  - Clearance optimization
  - Enabler for reliable rotordynamic operation

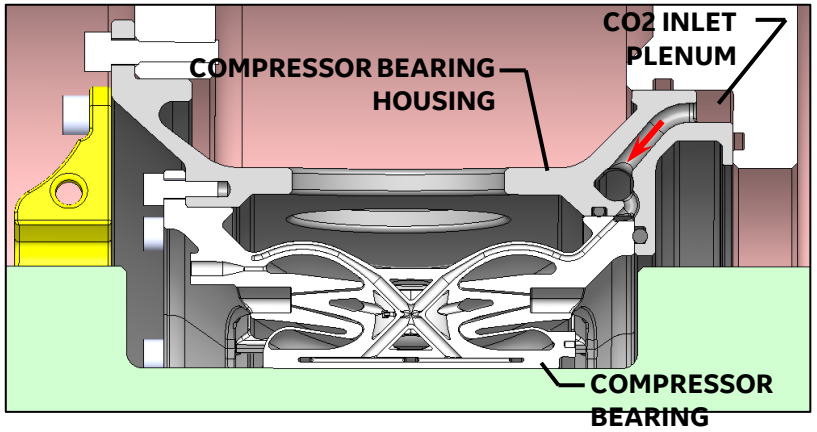


- Additive build trials
  - Damper fluid clearance control/fidelity
  - Powder removal
  - Damper fluid fill/vacuum process
  - Cut-ups and inspection
  - Currently continuing build trials



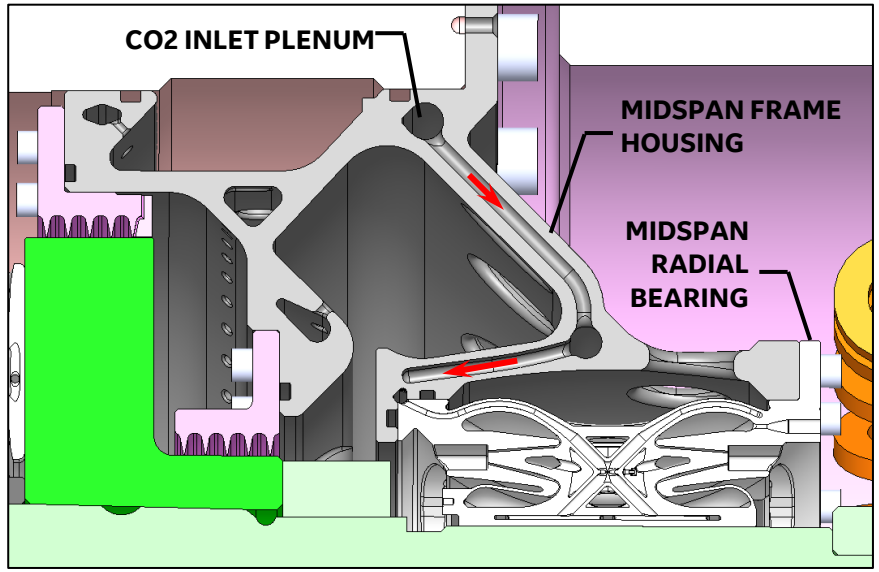
ADDITIVE BEARING HOUSINGS

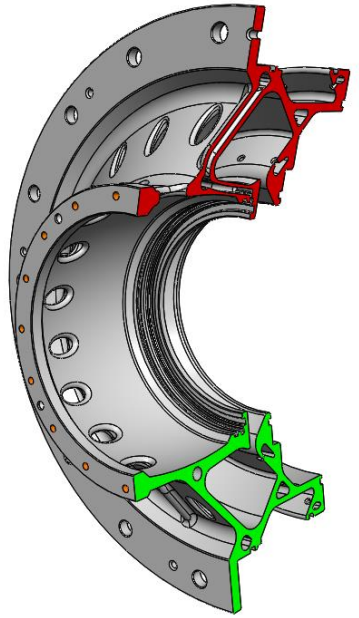
- Additive manufacturing advantages
  - Part count reduction
  - Cost reduction
  - Simplified design; improved reliability



- Compressor bearing housing
  - Radial bearing housing
  - Hydrostatic delivery circuit
  - Build trials completed; inspection ongoing

- Midframe support
  - Radial bearing housing
  - Hydrostatic delivery circuit
  - Seal holders
  - Thrust chamber boundary
  - Thrust chamber flow cavities
  - Need to start build trials





Schedule and Tasks

BEARING DESIGN
- CAD
- load capacity/dynamics
- structures/stress/life
- damper and gas film

TEST LOOP AND RIG
- loop layout and design
- casing design
- rotor design
- rotordynamics

ELECTRIC MACHINE DESIGN
- mechanical design
- assembly/installation methods
- electromechanical design rotor/armature
- VFD and control

SYSTEM THERMALS/2nd FLOW
- rotor/bearing windage
- runner design and bearing cooling scheme
- EM cooling scheme/design
- final thermomechanical analysis ← IN PROGRESS

ADDITIVE COMPONENT BUILDS
- design for additive manufacturing
- coupon builds-comps
- full component builds ← IN PROGRESS
- quality inspections

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***