

Novel Modular Heat Engines with Supercritical CO₂ Bottoming Cycle Utilizing Advanced Oil-Free Turbomachinery: PHASE 2 Update

GE Research Center

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BACKGROUND

APPLICATION AND MOTIVATION

- Natural Gas Compressor Stations
- Utilize waste heat | sCO₂ 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 CO₂ bearings
- Hermetic casing; free of CO₂ emissions
- Immersed generator in high density CO₂

TECH RISKS

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

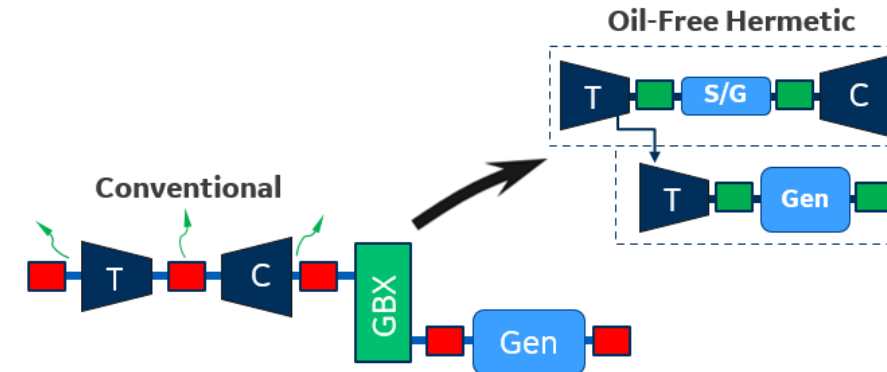
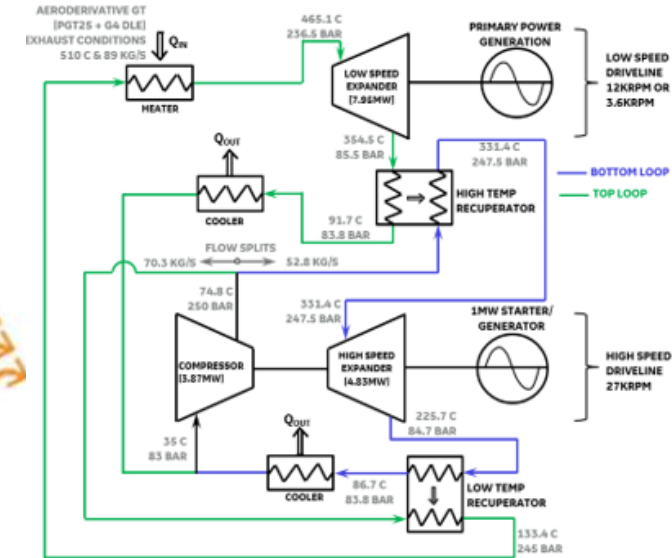
OTHER POTENTIAL APPLICATIONS

- Concentrated solar power cycles
- Nuclear power cycles

NG COMPRESSOR STATION



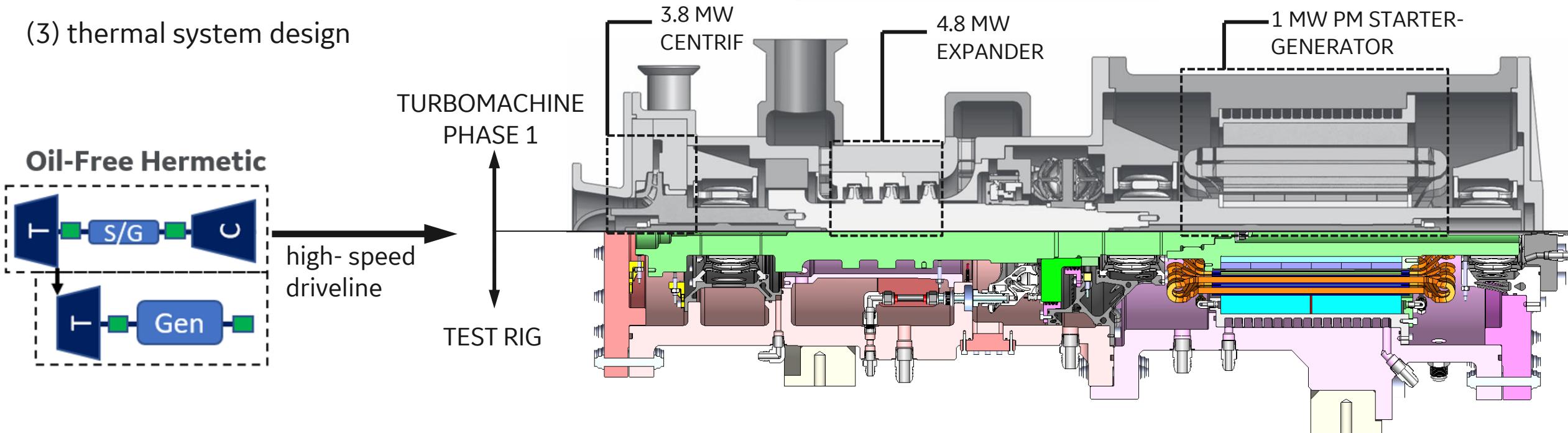
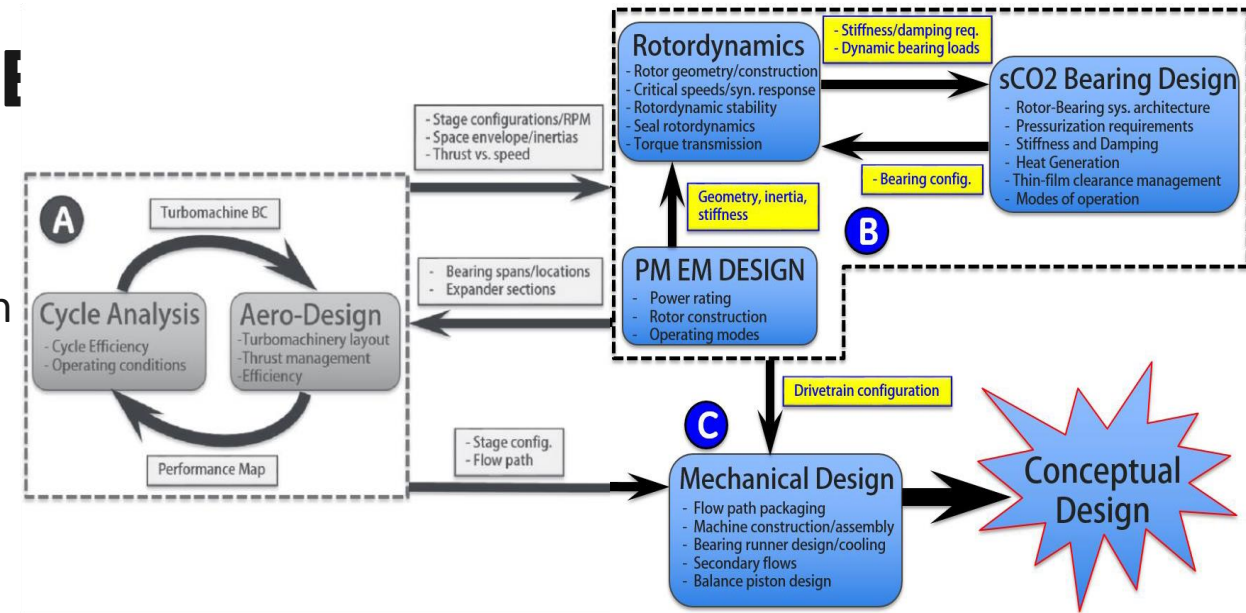
GT
WASTE
HEAT



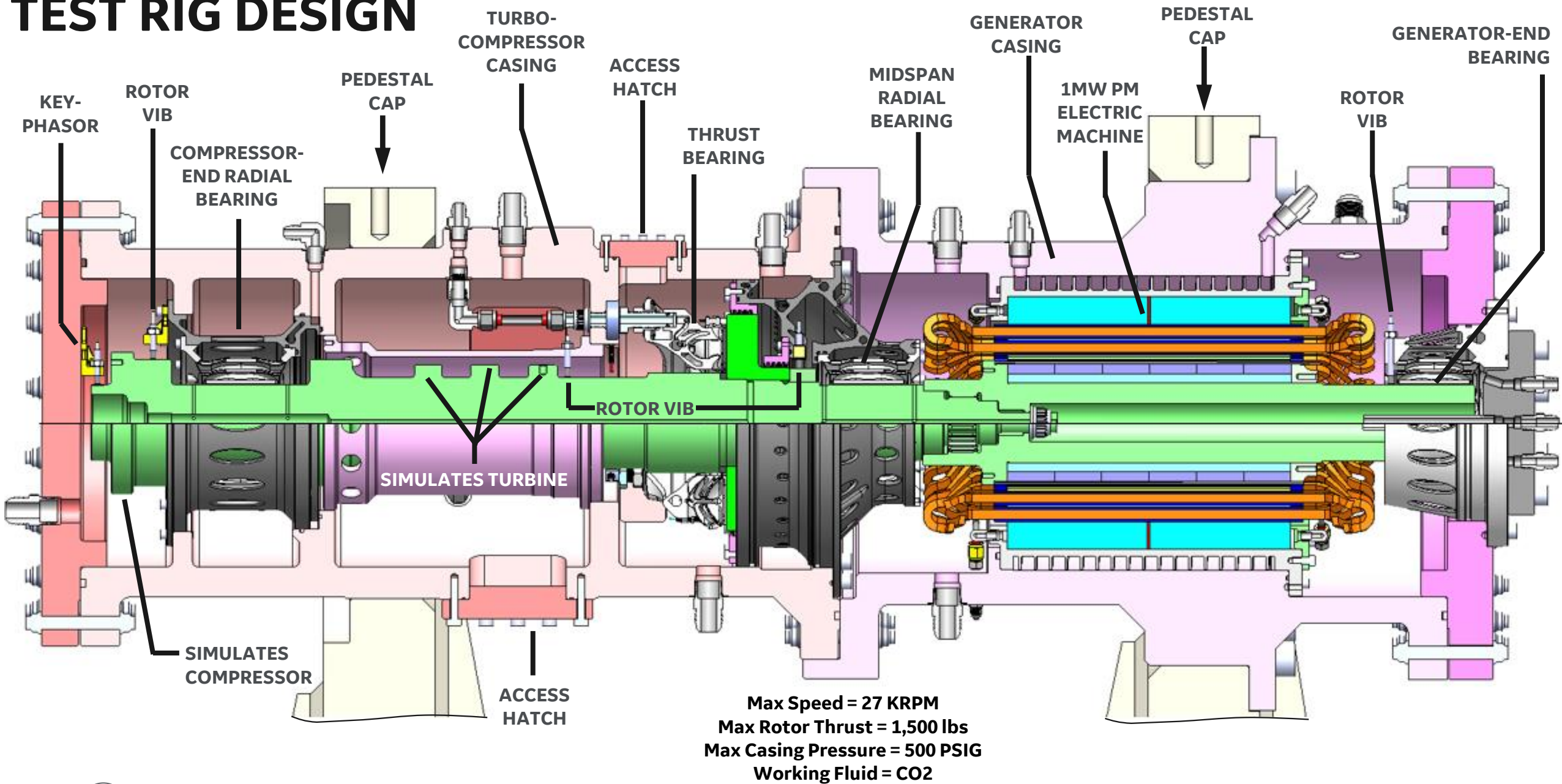
PHASE 2 SCOPE AND OBJECTIVE

- Develop design practices and methods
- Benchmark mechanical systems & electric machine design

- (1) drivetrain rotordynamics
- (2) thrust bearing load capacity
- (3) thermal system design



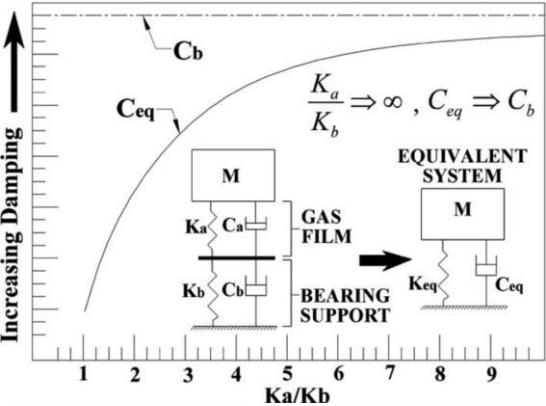
TEST RIG DESIGN



KEY ENABLING TECHNOLOGY: CO₂ GAS BEARINGS

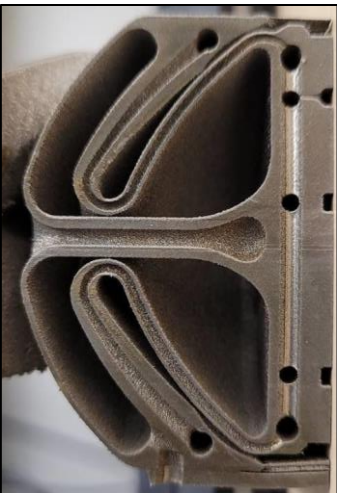
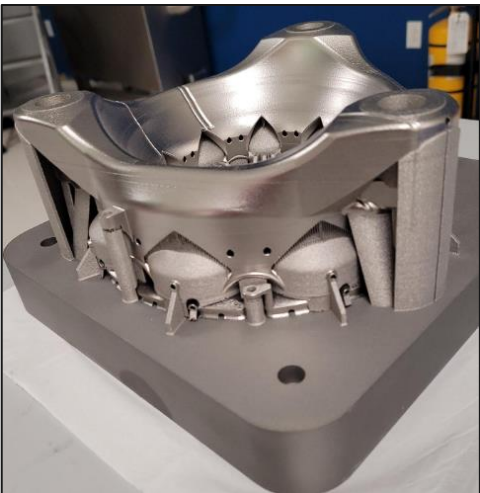
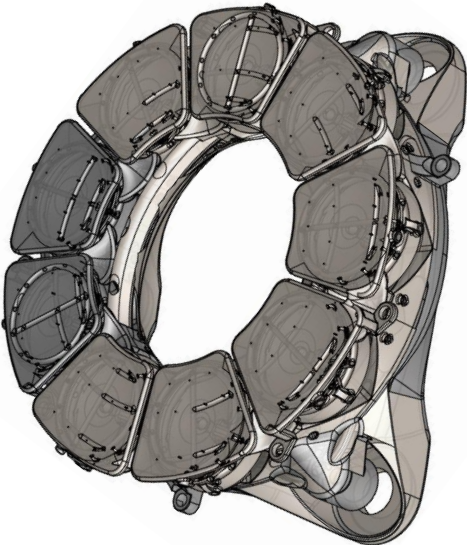
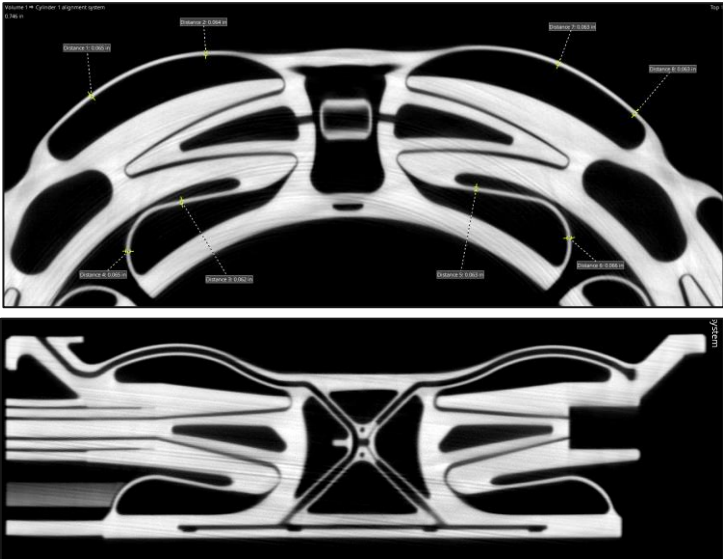
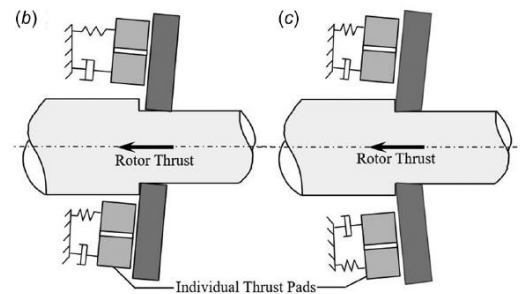
RADIAL BEARING SYSTEM

- Compliant tilting externally pressurized pads
- Hermetic squeeze film dampers
- Additively Manufactured
- Damping & misalignment capability



THRUST BEARING SYSTEM

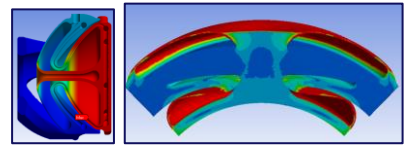
- Compliant externally pressurized tilting pads
- Additively Manufactured
- Load capacity & misalignment capability



Schedule and Tasks

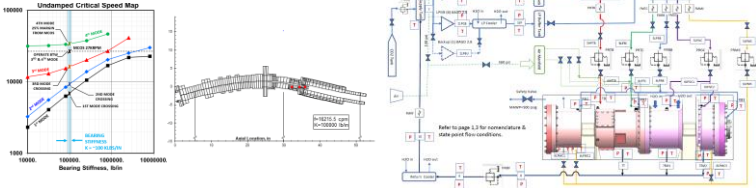
BEARING DESIGN

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



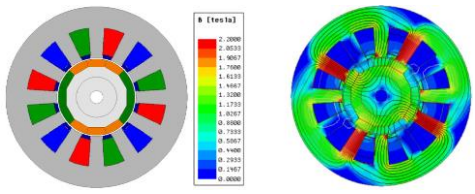
TEST LOOP AND RIG

- 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 & bearing cooling scheme
- EM cooling scheme/design
- final thermomechanical analysis



ADDITIVE COMPONENT BUILDS

- design for additive manufacturing
- coupon builds-comps
- full component builds
- quality inspections



IN PROGRESS

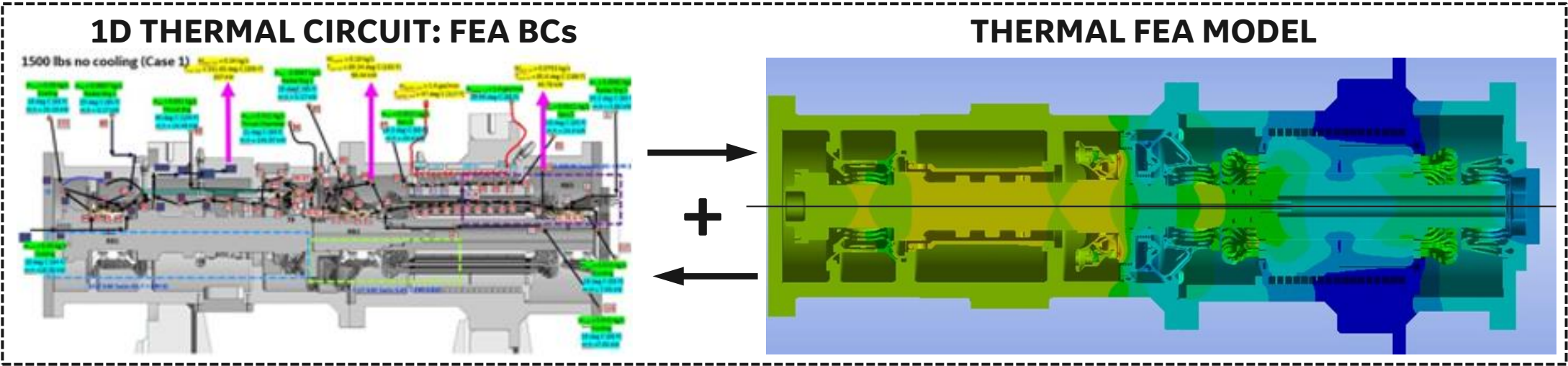
Program Activities	GE Research	Year 1				Year 2				Year 3				Year 4			
		Quarter: 1	Quarter: 2	Quarter: 3	Quarter: 4	Quarter: 1	Quarter: 2	Quarter: 3	Quarter: 4	Quarter: 1	Quarter: 2	Quarter: 3	Quarter: 4	Quarter: 1	Quarter: 2	Quarter: 3	Quarter: 4
Task 1: Project management Coordination, schedule &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

◆ Denotes Milestone ▼ Denotes Deliverable

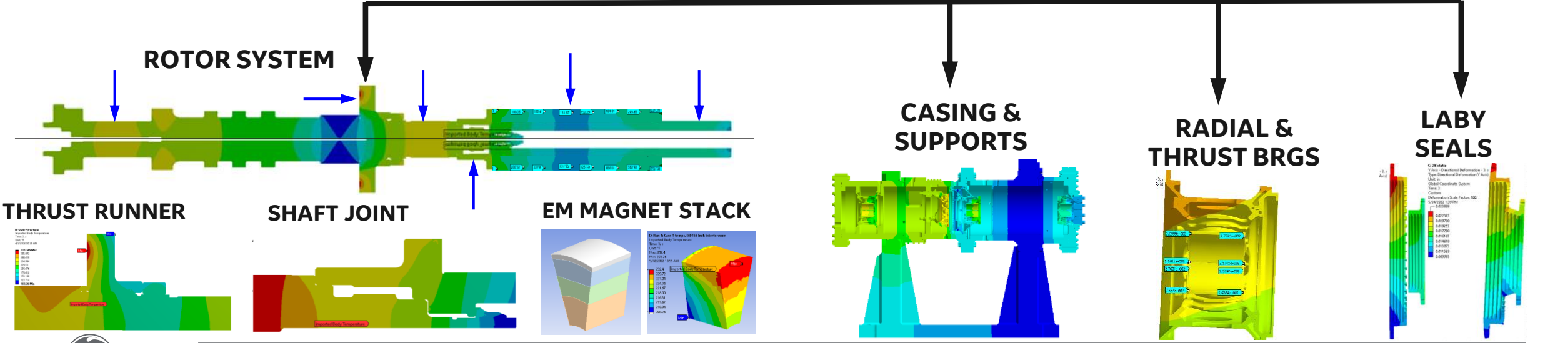


THERMAL SYSTEM DESIGN

THERMAL MODELS



TEMPERATURE MAP



ROTOR DYNAMICS ANALYSIS

Undamped Critical Speed map

- Varying bearing stiffness
- Select appropriate K based on
 - Operating speed range
 - Critical speed margins
 - 1-G deflections

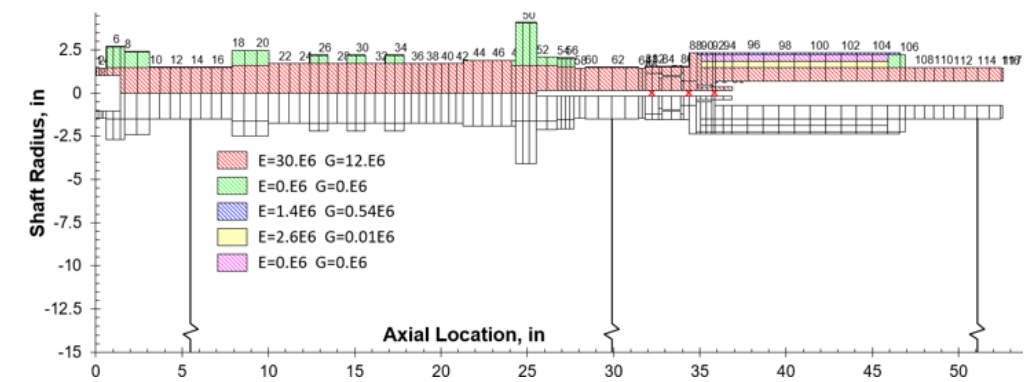
Damped Eigenvalues

- Bearing support damping study
- Revisit bearing support K and refine
- Establish bearing requirements [K] and [C]

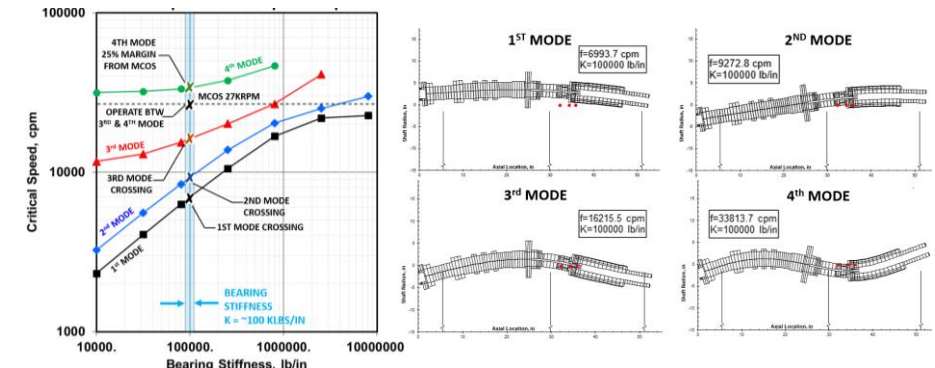
Synchronous Response

- Rotor vibration magnitudes
- Amplification factors
- Dynamic bearing loads
- Deflected rotor shapes

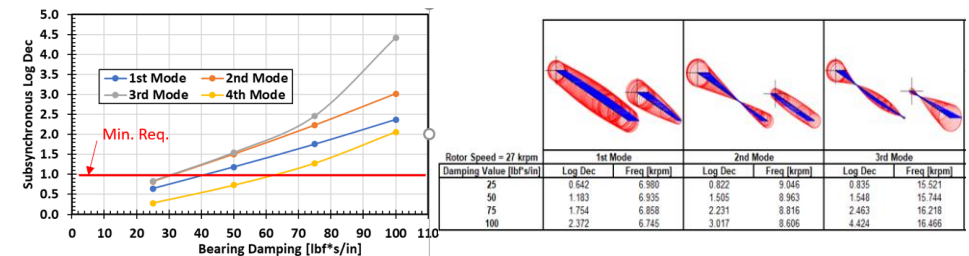
ROTOR MODEL



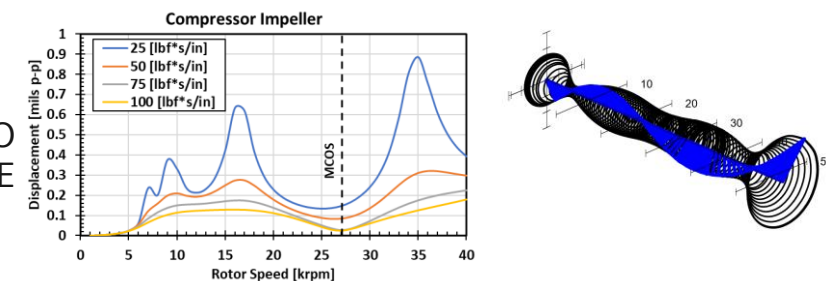
UNDAMPED CRITICAL SPEED MAP



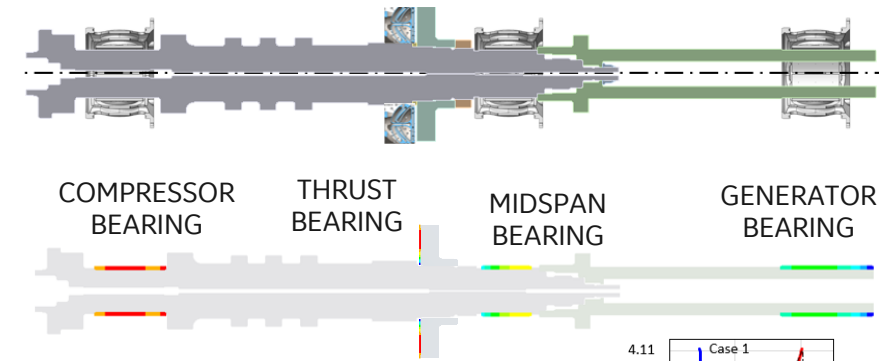
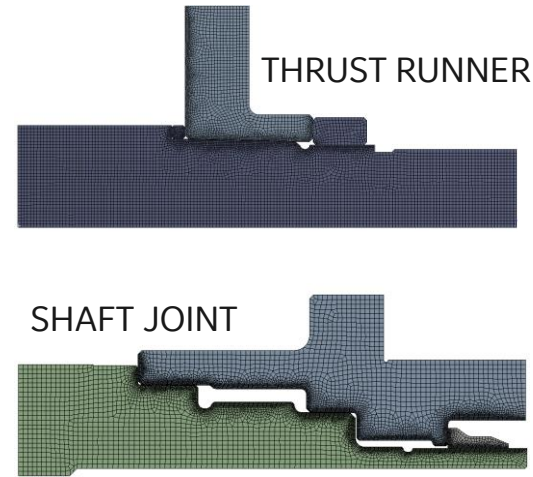
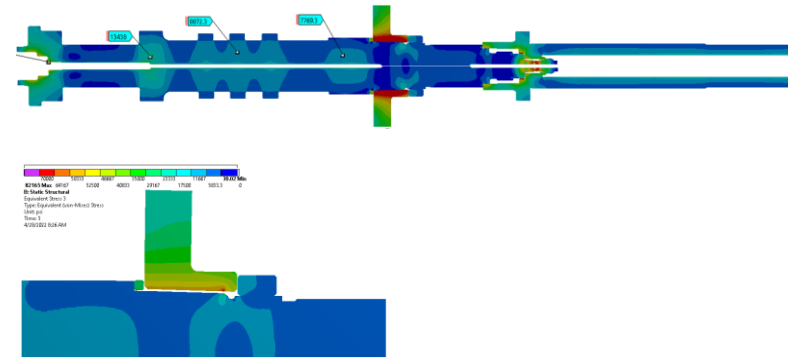
DAMPED ROTOR EIGENVALUES



SYNCHRONOUS RESPONSE TO ROTOR UNBALANCE

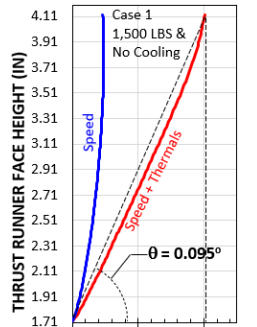


ROTOR DESIGN



BEARING SURFACES

- Radial deflections
- Out of plane warping
- Used for bearing analysis



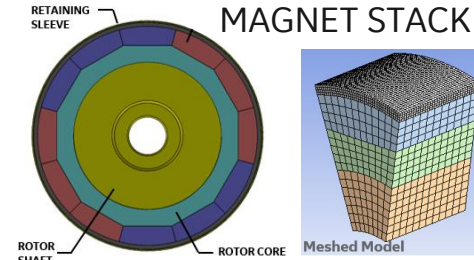
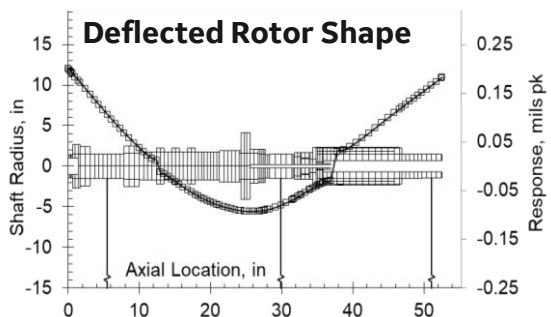
SEALS AND CLR CLOSURES

- Thrust runner deflections
- Combine with laby seal deflections
- Cold clearances vs. operating



SHAFTING DESIGN

- Shaft stresses
- Assembly/disassembly hydraulic loads
- Thermal/mechanical deflections
- Rotordynamic deflected shapes

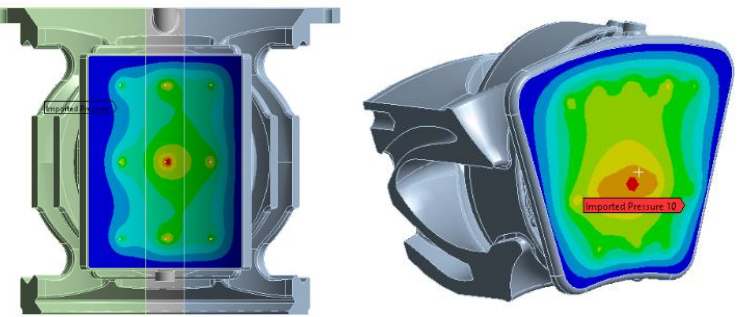


ROTATING COMPONENTS

- Component stresses
- Contact pressures
- Establish component fits
- Spline Design



BEARING SYSTEM ANALYSIS



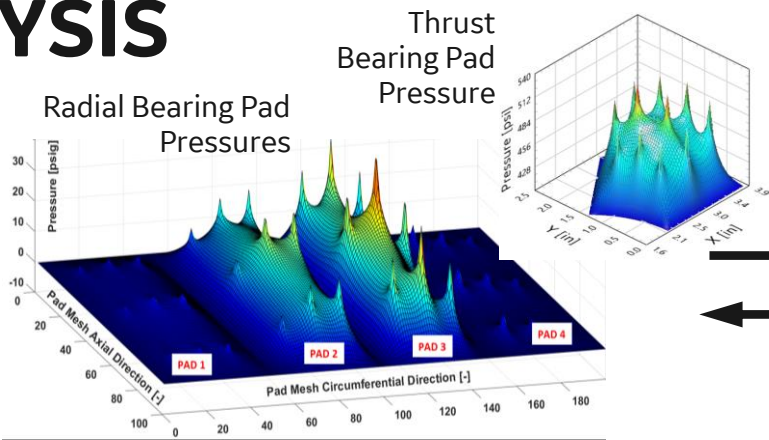
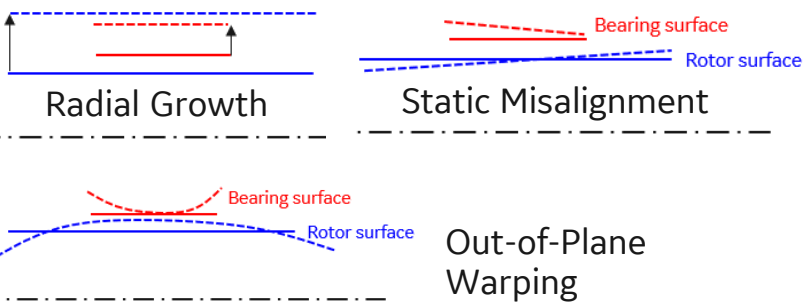
STRUCTURAL ANALYSIS

MEAN STRESS

- Assembly tolerance stacks
- Supply pressure
- Gas film pressure
- Rotor- housing deflections

ALT. STRESS

- Bearing dynamic load: force
- Bearing dynamic load: moments



GAS FILM & BEARING [K] [C]

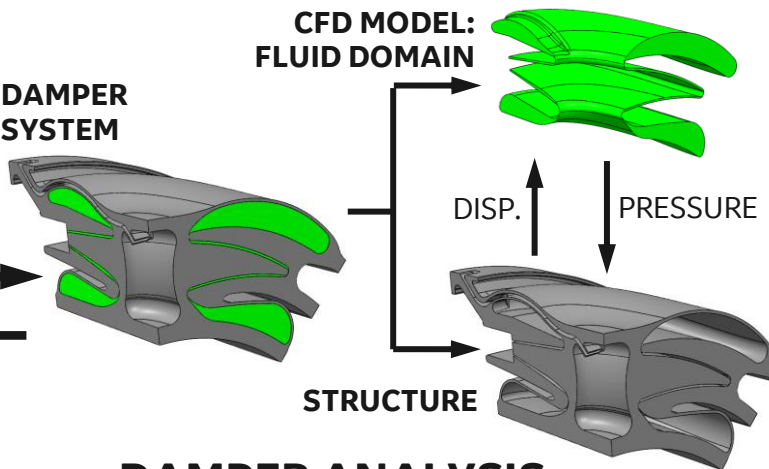
GAS FILM

- Film clrs (cold vs. operating)
- Supply pressure
- Pad orifice layout

BEARING SYSTEM

- Bearing support K values
- Support damping (HSFD)
- Pad orifice layout

Speed rpm	Kxx lb/in	Kxy lb/in	Kyx lb/in	Kyy lb/in	Cxx lb-s/in	Cxy lb-s/in	Cyx lb-s/in	Cyy lb-s/in
3600	100790.5	4140.61	-682.86	99407.37	48.87	1.46	0.88	47.45
6000	100723.8	7511.07	-926.53	99445.39	48.25	2.47	1.48	47.09
8000	1.01E+05	9848.31	-1495.92	1.00E+05	47.57	3.16	1.8	46.65
15000	1.05E+05	16650.43	-2854.91	1.04E+05	44.28	4.69	1.37	44.25
27000	1.04E+05	30669.99	-2243.34	1.01E+05	40.02	9.41	-1.02	41.5



DAMPER ANALYSIS

TOOLS

- FSI: Unsteady CFD + 3D Transient FEA
- Reduced order model

PARAMETERS

- Plunger design
- Damper clearances
- Fluid type

OUTPUT

- Dynamic pressures
- Component stresses
- Damping values



NEXT STEPS

- Finalize Detailed Drawings
- Procure Equipment
- Preparation of test platform

- Piping and Electrical
- Instrumentation
- DAQ systems
- Control systems
- Gas supply skid

