High Temp. CMC Nozzles for 65% Efficiency
DE-FE0024006

Progress Review– Phase II

November 1, 2017

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October 30, 2017

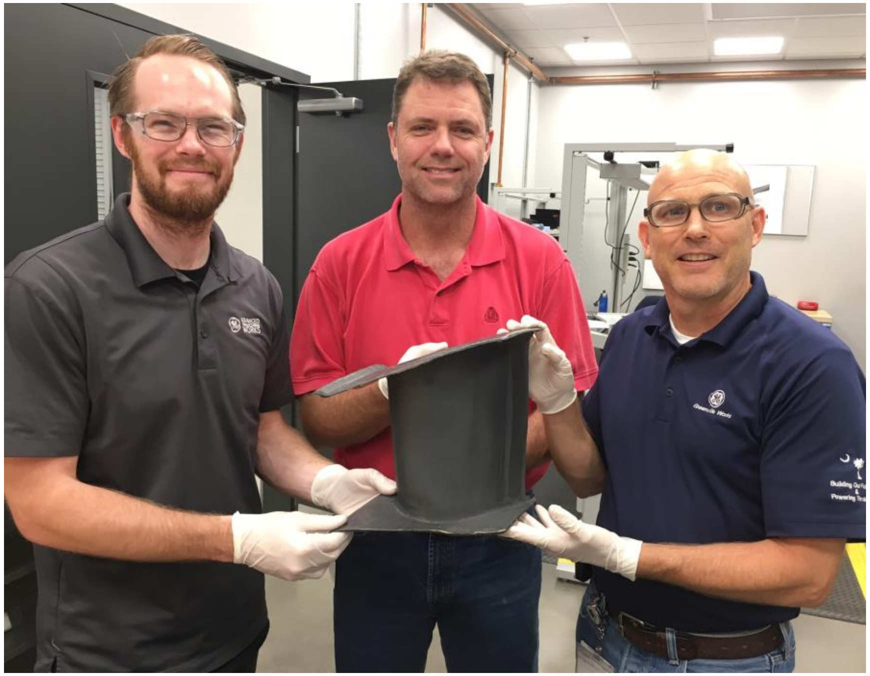
GE Solution

Cooled high-temperature CMC nozzles

- Support load following capabilities of modern grid
- Allow higher turbine inlet temperatures (~3,100°F)
- Applicable to IGCC with pre-combustion carbon capture
- Means of improvement – improved cooling designs, improved aerodynamics, better sealing, reduced leakage
- Leverage advanced manufacturing processes

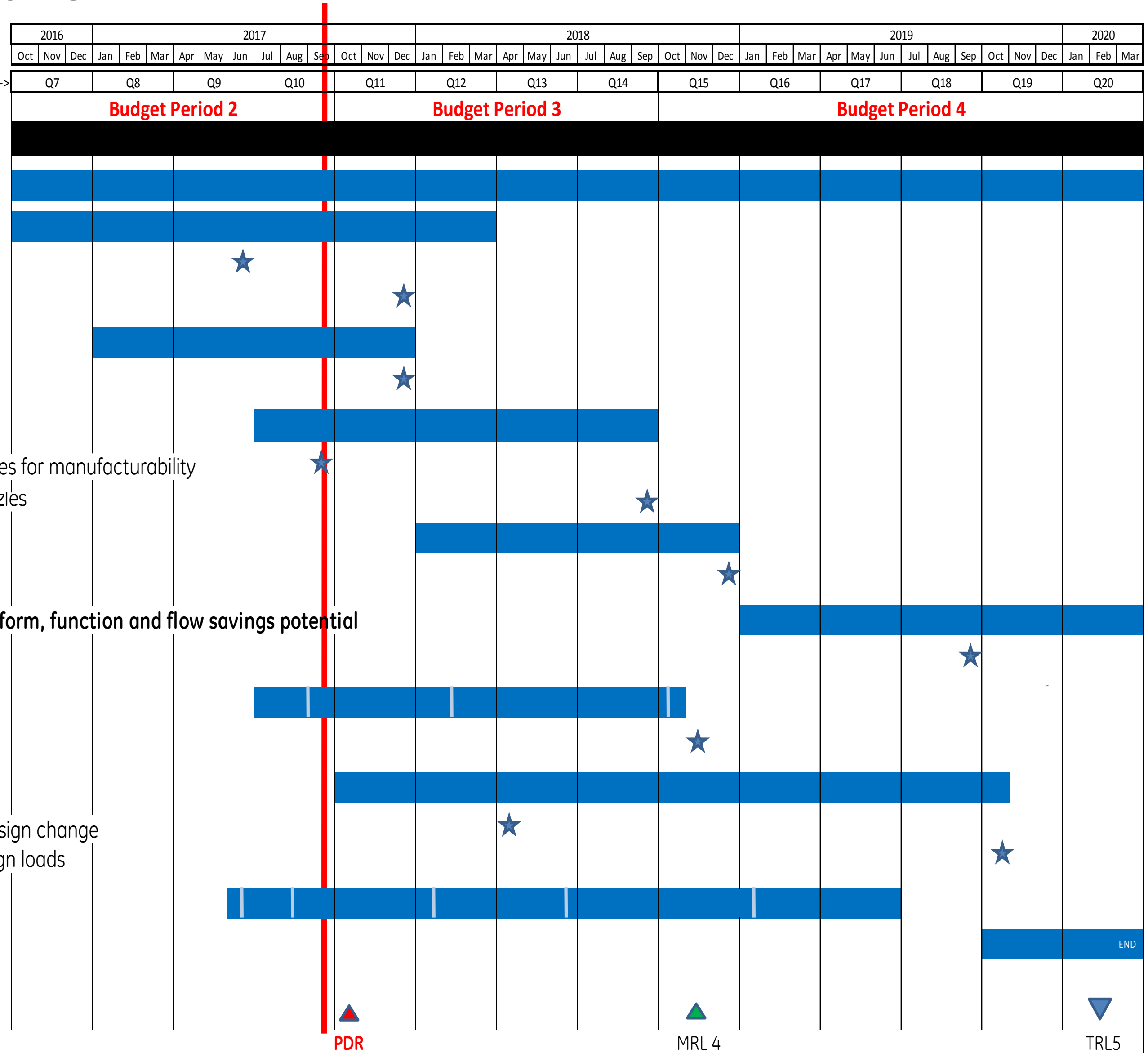
Agenda

- Schedule Update
- Nozzle Design
- Nozzle Fabrication
- Clemson Work
- Test Rig Design
- Feature Test Design
- High Temperature Seals
- Next Steps



Phase II Schedule

Project Quater -->



PHASE II - DEVELOPMENT & TESTING

Task 2.1.0 - Project Management & Planning

Task 2.2.0 - Complete design definition of CMC nozzle

Milestone 2.2.1.1 CMC preform definition

Milestone 2.2.3.1 model definition for fab

Task 2.3.0 - Design high-temperature nozzle test rig

Milestone 2.3.2.1 model release for fab

Task 2.4.0 - Fabrication of nozzles, end-walls, seals

Milestone 2.4.1.1 Define needed design changes for manufacturability

Milestone 2.4.4.1 Finished prototype CMC Nozzles

Task 2.5.0 - Fabricate nozzle test rig

Milestone 2.5.2.1 Installation complete

Task 2.6.0 - Test nozzles and seals to demonstrate fit, form, function and flow savings potential

Milestone 2.6.1.1 Demonstrated sealing

Task 2.7.0 - High temp EBC/CMC durability test

Milestone 2.7.1.1 Demontrated Durability

Task 2.8.0 - Feature test for strength and durability

Milestone 2.8.1.1 Identify results that drive design change

Milestone 2.8.3.1 Demonstrate margin to design loads

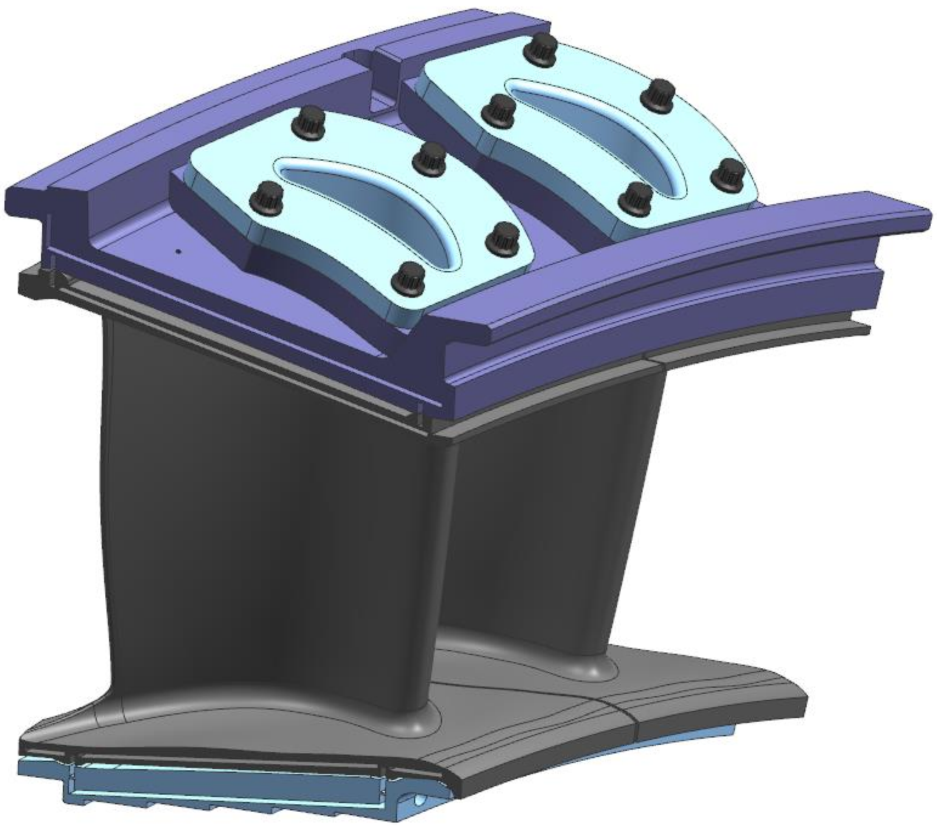
Task 2.9.0 - Full-scaled full-featured demo field test

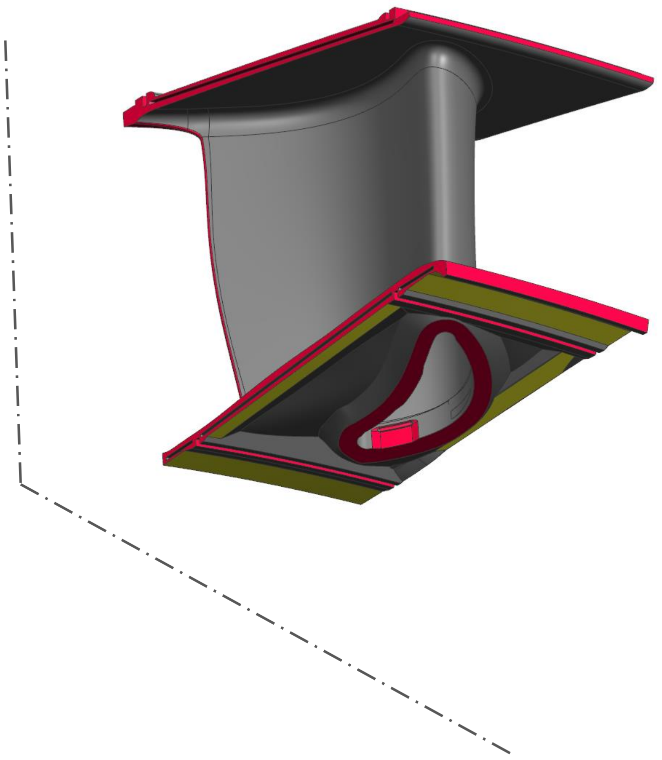
Task 2.10.0 - Conclusions and Documentation

Phase II Go/No-Go (1 per Project Year)

Technical Approach
Task Details

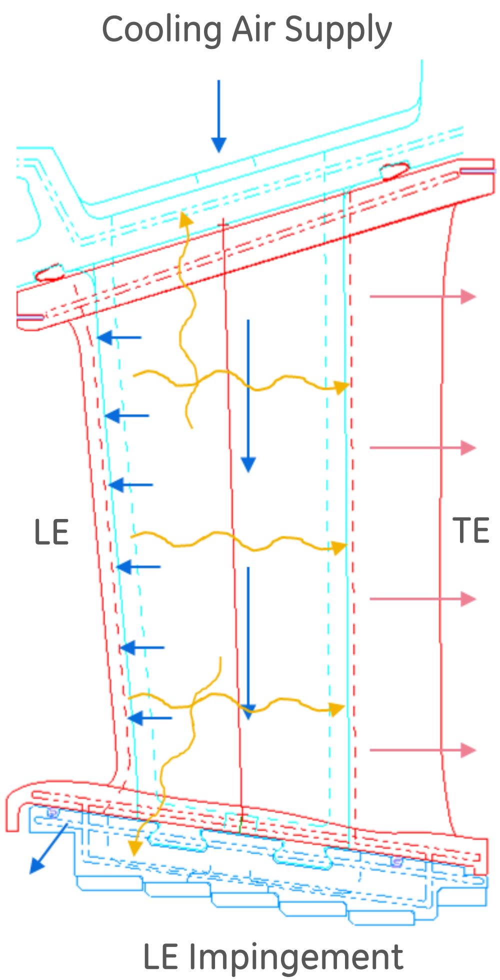
Nozzle Design Overview

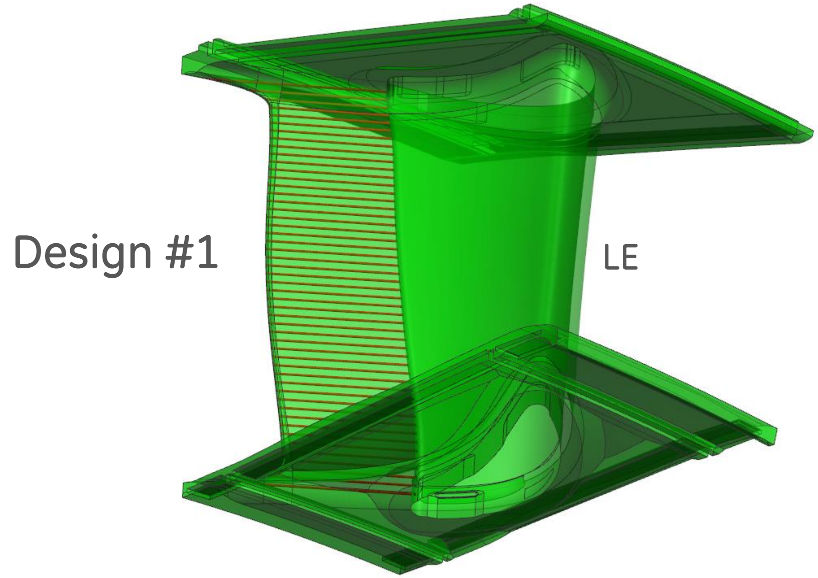


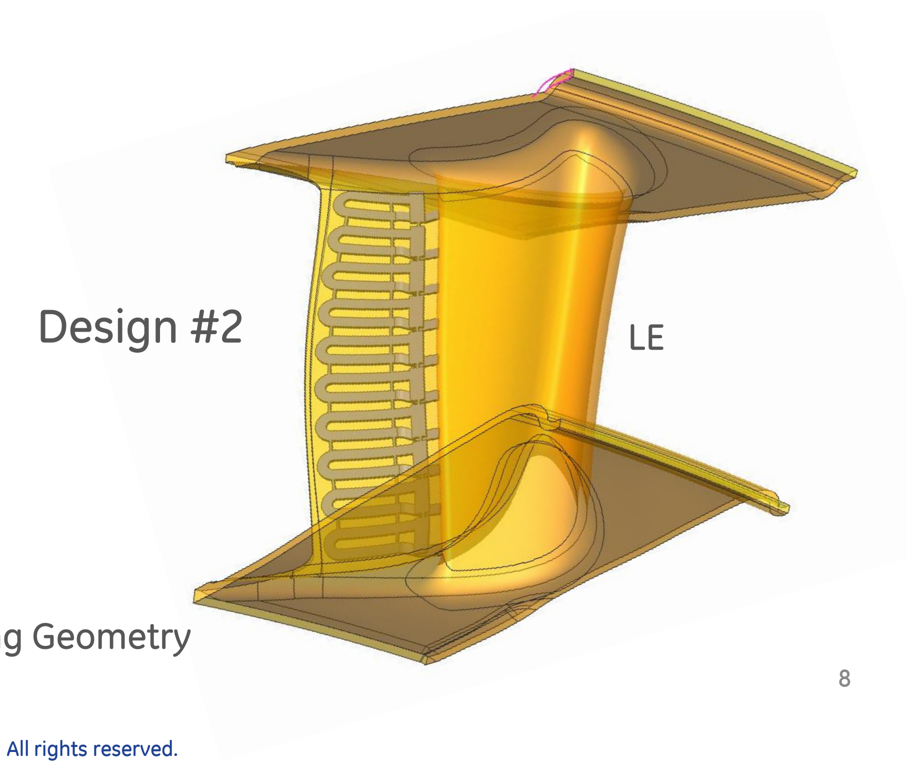


Patented Pending Geometry

Cooling Circuits



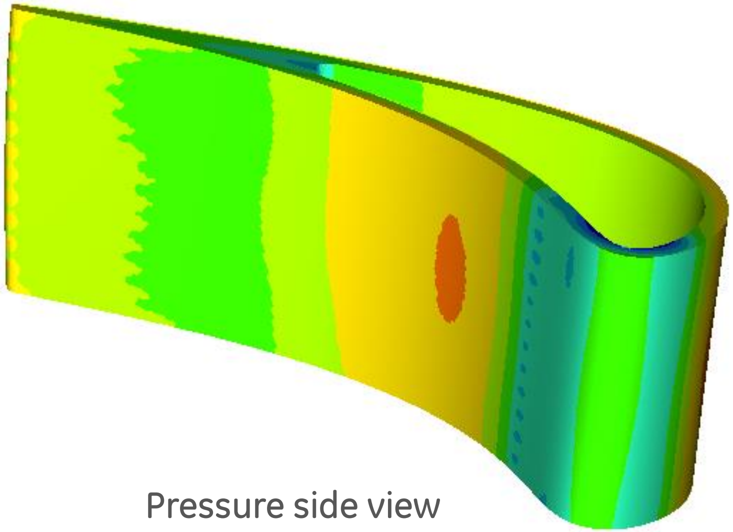


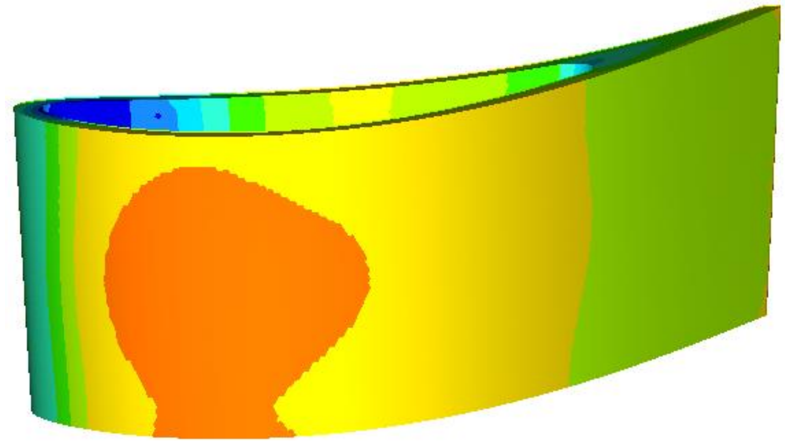


Patented Pending Geometry

TE cooling – Two workable approaches

Design #1

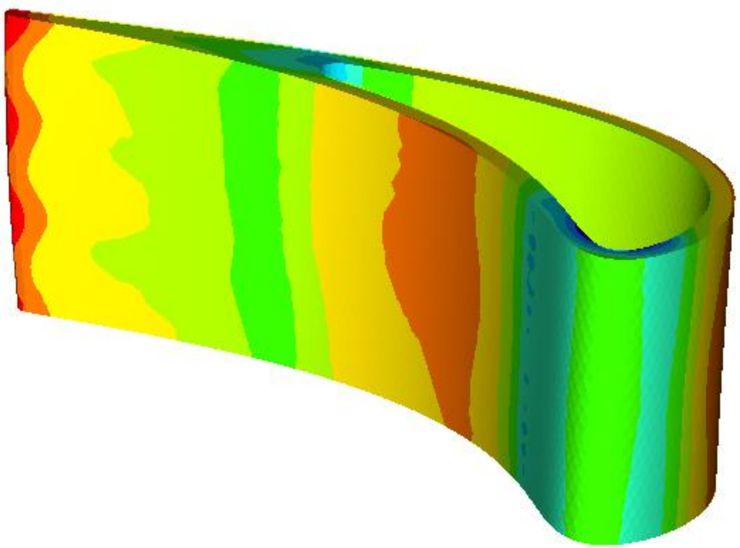


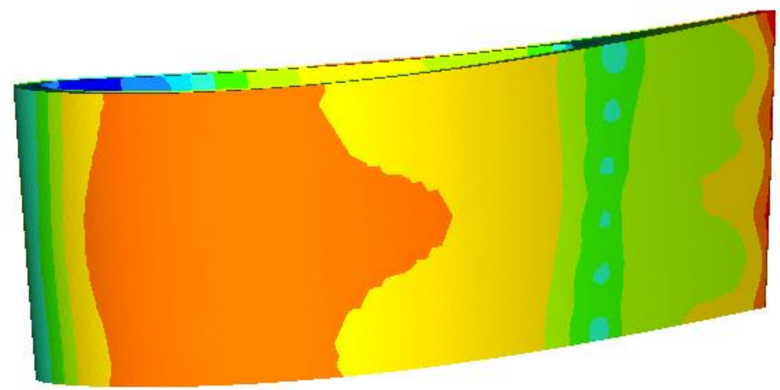


Pressure side view

Suction side view

Design #2





Temperature Contours

Initial Fabrication Learning

SN001

- Layup architecture #1
- Tooling concept proved feasible
- Need to improve thermal cycles to reduce dimensional deformation
- Resulted in well infiltrated component… excellent weight gain

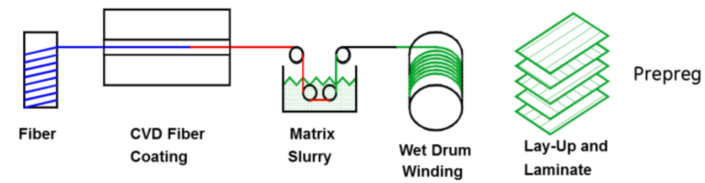
SN002

- Layup architecture #2… darting to remove excessive build up
- Altered thermal cycle to reduce dimensional deformation

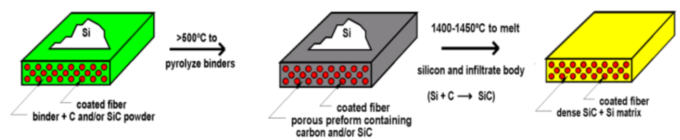
SN003

- Layup architecture #3… alternate airfoil to end-wall build
- Tool change resulted in improved compaction in TE
- Altered thermal cycle further decreased dimensional stability

Preform Fabrication



Melt Infiltration



Pre-Preg Slurry

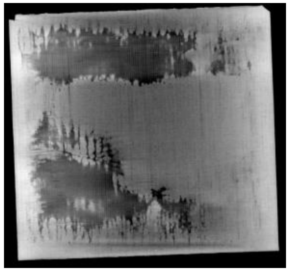
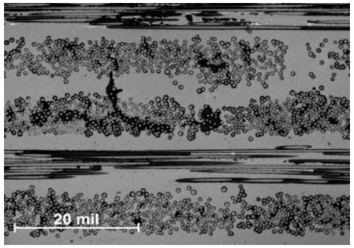
Slurry Trial Goals

- Increase infiltrability of large components
- Increase mechanical properties
- Process robustness vs strength loss/gain

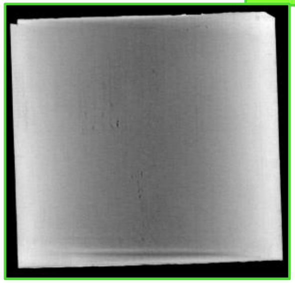
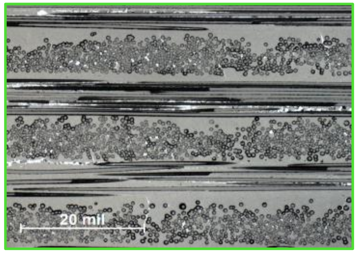
Slurry Trial Results

- Repeatable high quality infiltration
- No debit in ILT strength

Baseline - Geni2

V6

Remaining 2017 Trials

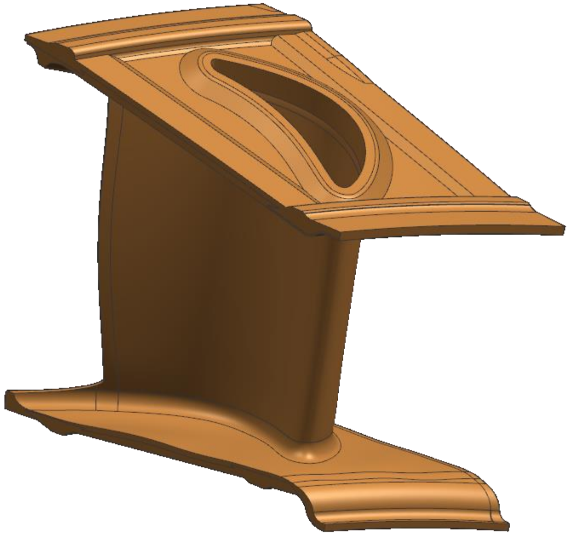
Construction

- Utilize alternate slurry formulation
- Add component features

TE Cooling build trials

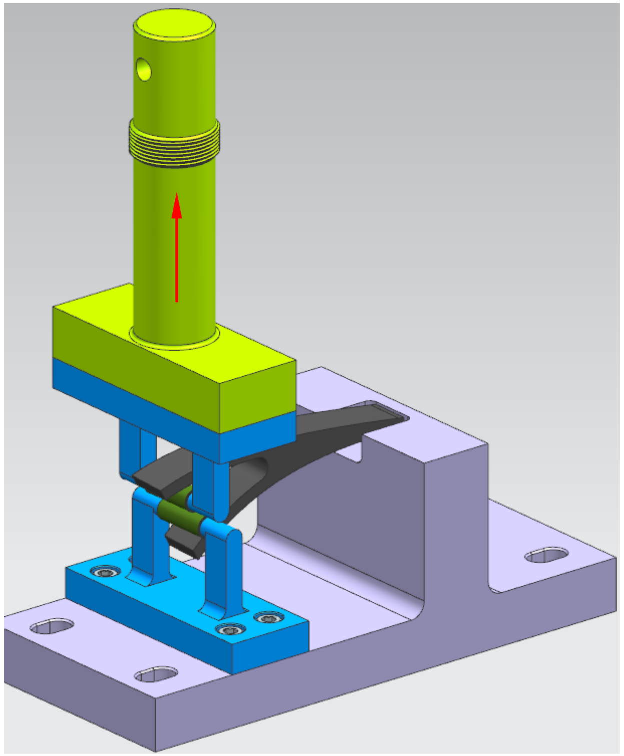
Machining Development

- CAM and fixture design
- Seal slot machining improvements

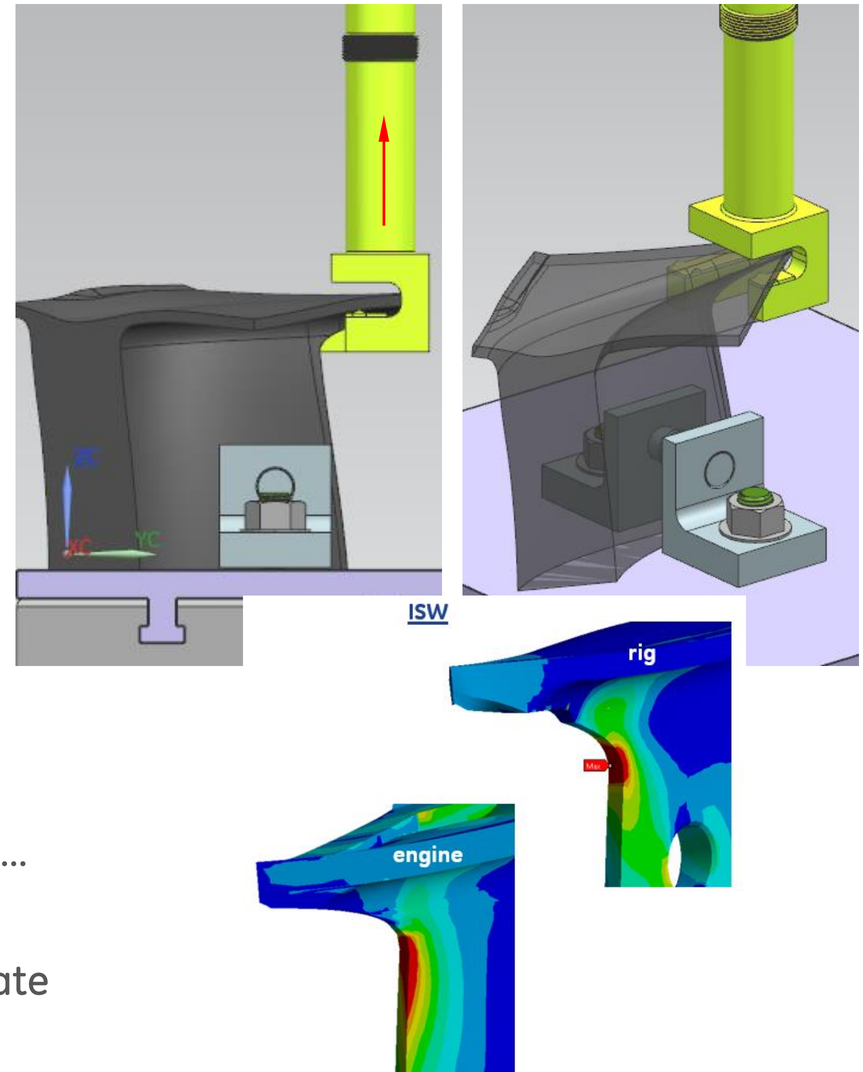


Nozzle Feature Tests

Nozzle Airfoil-to-TE strength



Nozzle TE-to-Sidewall strength

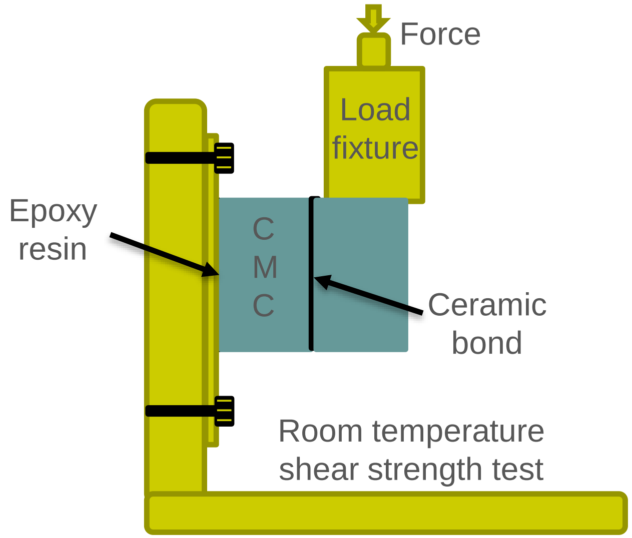


- Test Goal - simulate engine stress state… determine section capability
- Measure local strains and detect laminate damage at overload conditions

Design Bonded Joint – Clemson

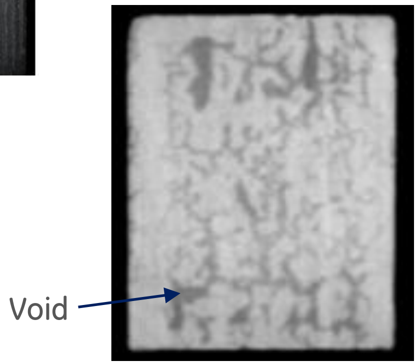
Room temperature shear testing

- Tested in-house and commercially available bonding agents
- Proprietary formulation using Si-based polymer derived ceramics with ceramic particles
- Bonded surface investigation shows some voids in the bond joint



Application

- Bond load pads to simplify airfoil layup
- Bond laminates for seal build-up areas



CT of Bond Joint

Current bond strength less than desired

Seal Surface Improvement - Clemson

Background

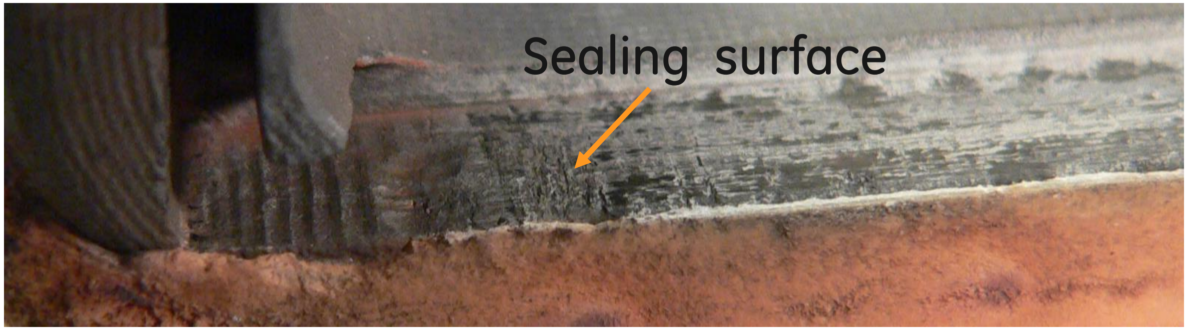
- A smoother sealing surface leaks less
- Current manufacturing method may not produce required surface finish.
- Surface finish may deteriorate during operation.

Goals

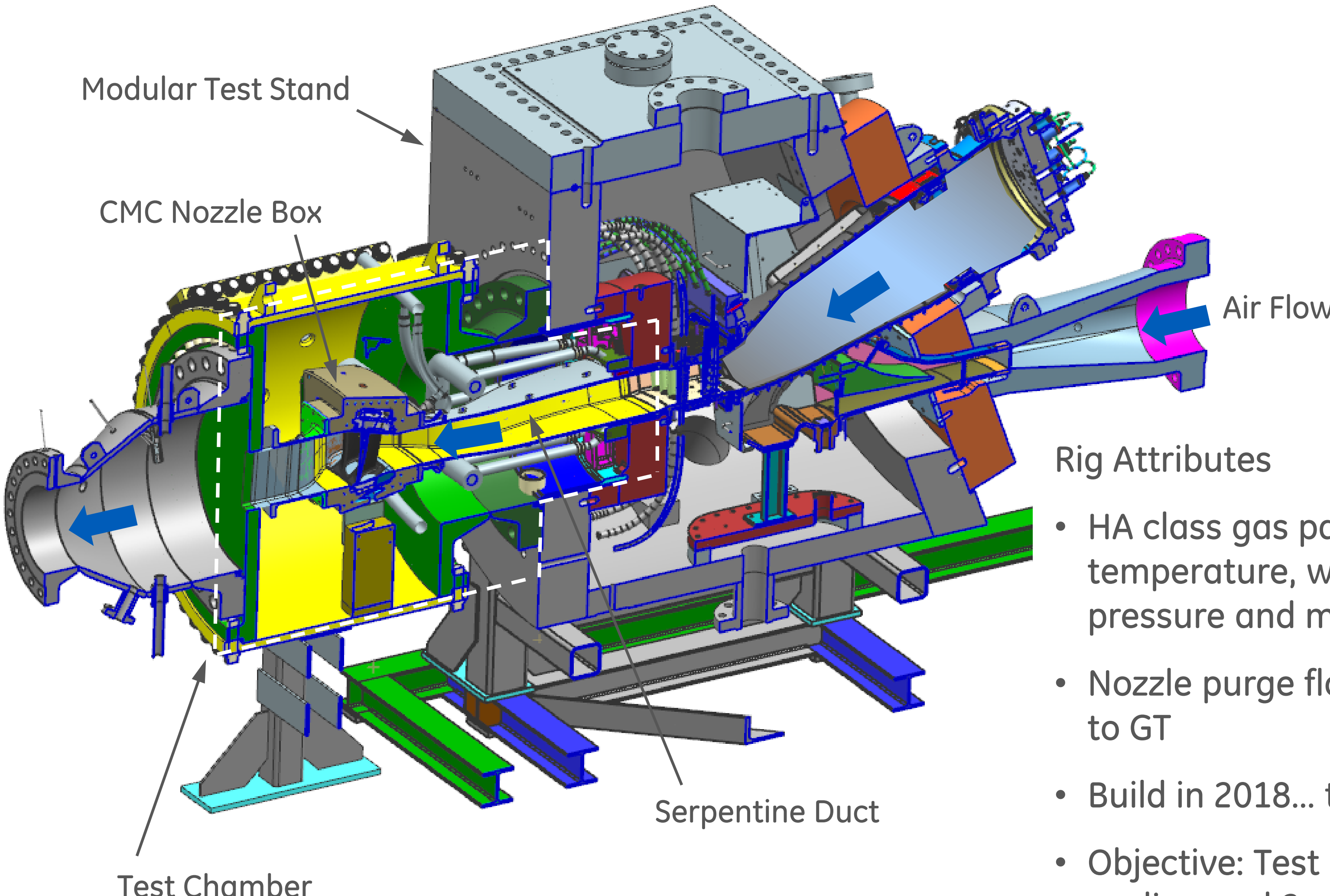
- Create a durable smooth sealing surface
- Easy application with no CMC material property degradation

Proposed Solution

Coat sealing surface with vitreous material



High-Temp Nozzle Test Rig Design

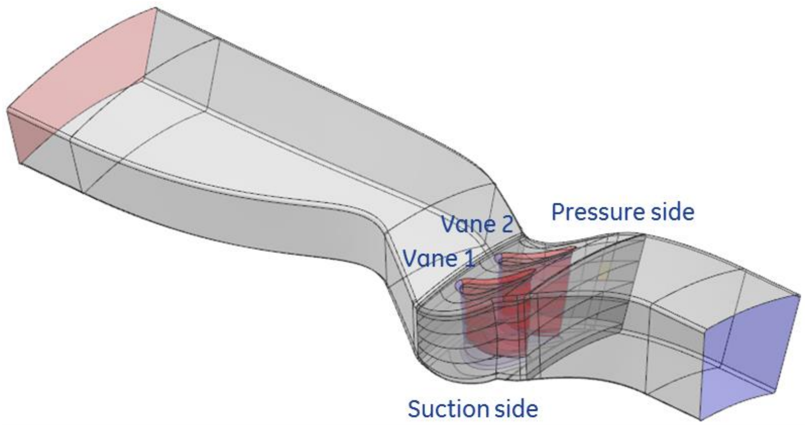


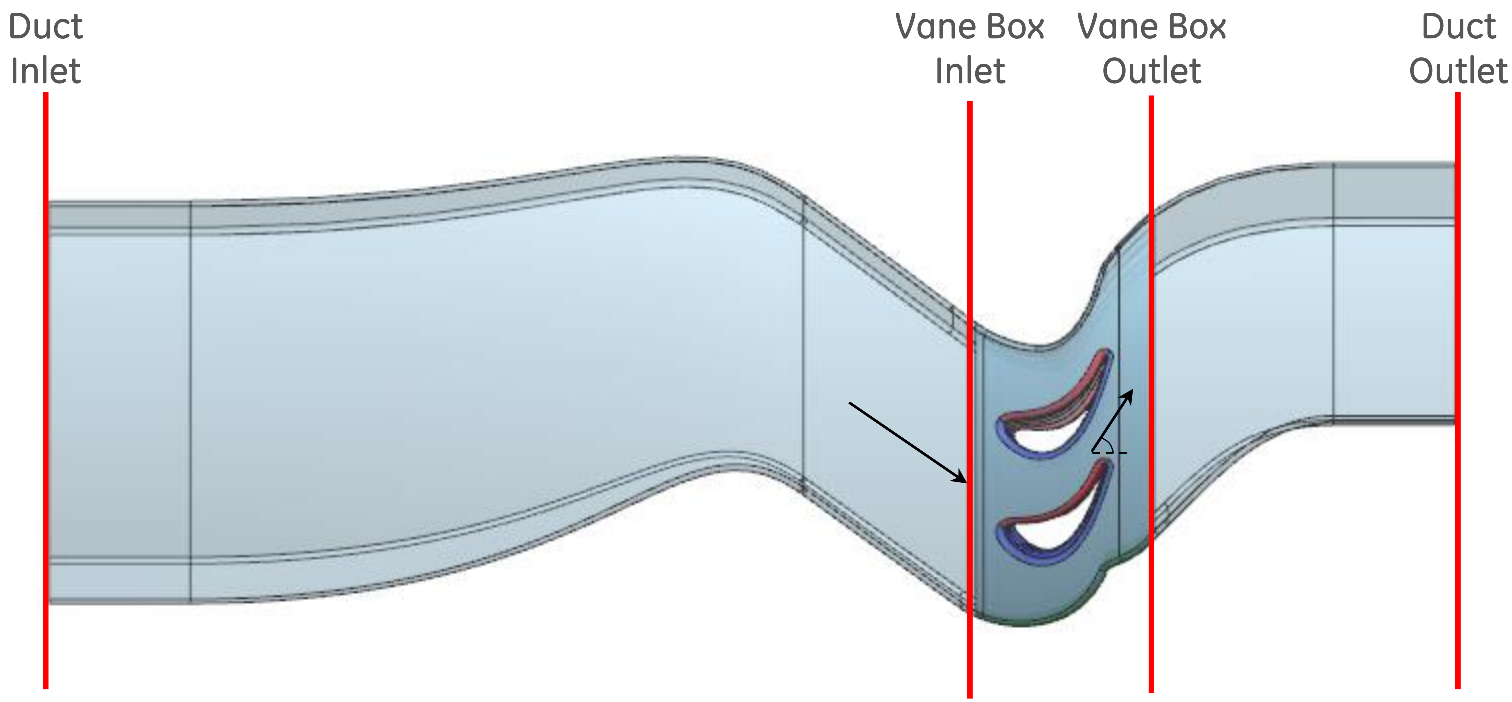
Rig Attributes

- HA class gas path temperature, with relevant pressure and mass flow
- Nozzle purge flow to similar to GT
- Build in 2018… test in 2019
- Objective: Test up to 3 sealing and 2 cooling configurations of full size CMC nozzle

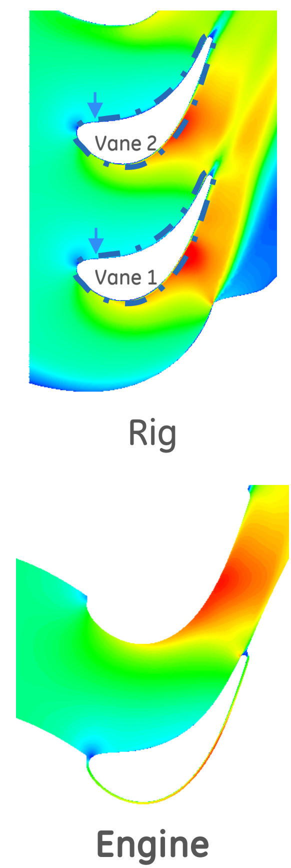
Finalized Serpentine Duct

- Pressure loading within +/-2% of relevant engine conditions
- Simulated pressures will provide engine relevant cooling and leakage flows





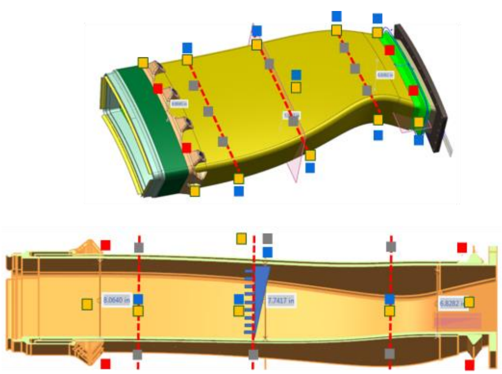
Mach Contours at 50% Span



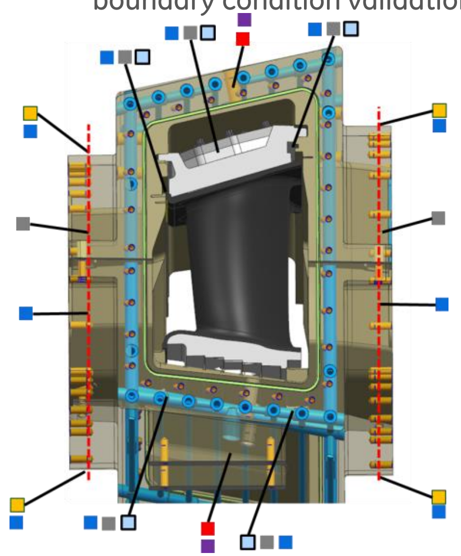
Instrumentation Summary

	PV	Serp	Rake	Vane box	Nozzles	aft duct	other	Total
Total Pressure	0	0	5	0	0	0		5
Total Temperature	0	0	5	0	0	0		5
Strain	0	0	0	0	10	0		10
Static Pressure	0	6	0	29	7	0		42
Differential Pressure	0	0	0	0	0	0		0
Water Temperature	0	8	0	2	0	0		10
Static Temperature	0	9	0	19	11	0		39
Metal Temperature	0	8	0	4	34	0		46
	0	31	10	54	62	0	0	157

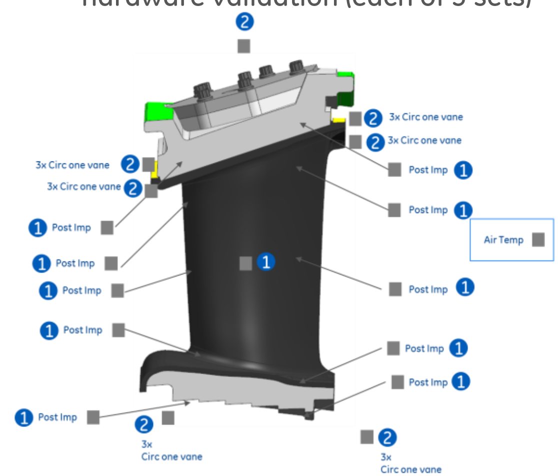
31 pcs instrumentation for health monitoring and boundary condition validation



54 pcs instrumentation for health monitoring and boundary condition validation



62 pcs instrumentation for hardware validation (each of 5 sets)



Intersegment Seal Material Characterization

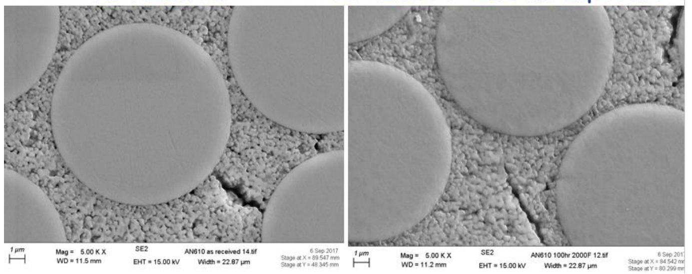
Oxide-Oxide Composites

Static Oxidation Tests up to 2400F

- Alumina-Silica matrix with Alumina-Silica fibers
- Alumina matrix with Alumina-Silica fibers
- Alumina matrix with Alumina fibers

Ox-Ox (all-Al_2O_3) Microstructures

As-received vs 2000°F -100 hr. exposure

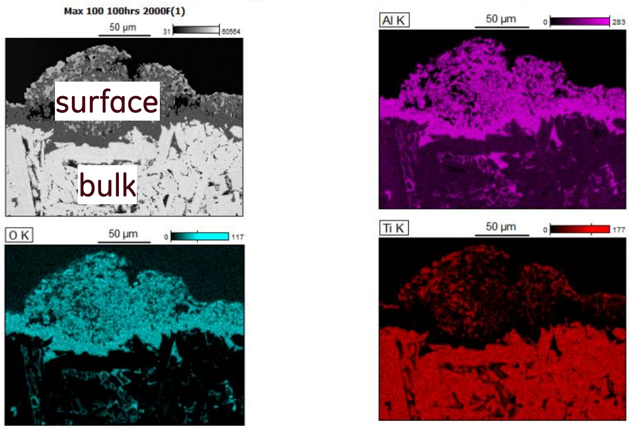


Ti_2AlC

Static Oxidation Tests up to 2200F

- Alumina scale former
- Ductile >1900°F

(Ti_2AlC) 2000°F -100 hrs



FeCrAl Alloy

Machining into test coupons for static oxidation tests

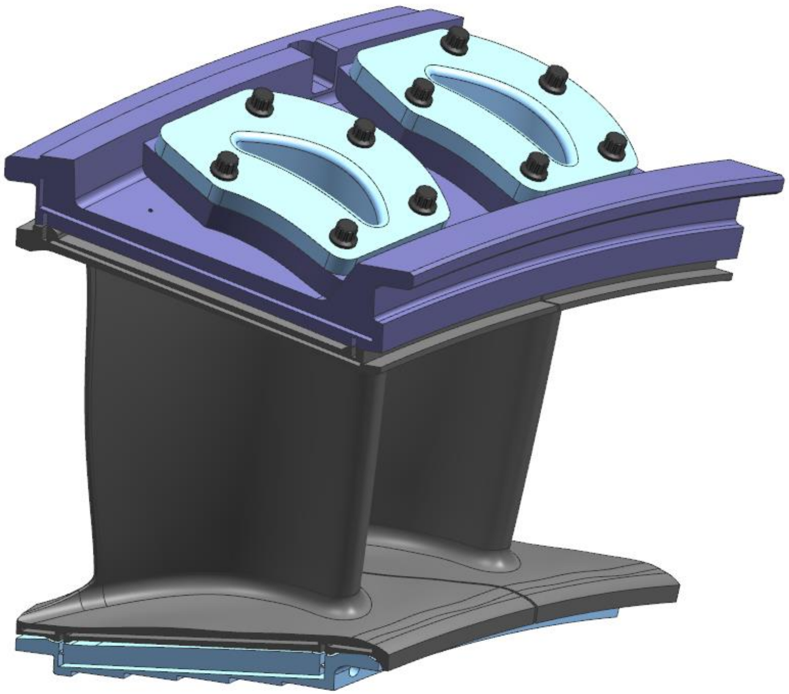
Alumina scale former

YSZ (TBC–type material APS onto substrate, strip from substrate)

Evaluating ZrO_2 infiltration to achieve higher density

Next Steps

- Complete nozzle design … Milestone
- Complete test cell definition… Milestone
- Order long lead rig materials
- Build feature test rigs
- Begin EBC testing



Q&A
Discussion