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

Progress Review– Phase II
November 1, 2017
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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

**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 Demonstrated 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)

- PDR
- MRL 4
- TRL5
Technical Approach
Task Details
Nozzle Design Overview

Patented Pending Geometry
Cooling Circuits

Cooling Air Supply

LE Impingement

Patented Pending Geometry

Design #1

Design #2

LE

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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
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

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**

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

**Nozzle TE-to-Sidewall strength**
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

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

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**Instrumentation Summary**

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- **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 2400°F*
- Alumina-Silica matrix with Alumina-Silica fibers
- Alumina matrix with Alumina-Silica fibers
- Alumina matrix with Alumina fibers

**Ti$_2$AlC**

*Static Oxidation Tests up to 2200°F*
- Alumina scale former
- Ductile >1900°F

**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