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Project Objectives & Technical Approach

Overall Objective

Develop a feasible Conceptual Design for Advanced Additive turbine inlet components that enable 65% CC efficiency through analytical methods and feature print trials.

Technical Approach

Phase I – Discovery

• Generate Advanced Wall Architecture and Airfoil Concepts enabled by Additive Manufacturing.
• Identify and evaluate Additive Methods and Materials that enable desired geometry through Coupon Print Trials.
• Down-select a Primary Concept and Additive Method/Material and backup for future evaluation.
• Develop Test Plan for future execution.
Agenda

Additive at GE
Nozzle Design Overview
Airfoil Design & Artifact Coupon Print Trial Summary
Additive Modality Comparison
Proposed Test Plan to address Phase I gaps
Impact of Additive at GE

**Performance**
- Removes traditional mfg. constraints
- Enables “near surface” cooling

**Speed to Market**
- Model to part directly
- ~18 month cycle

**Cost**
- Eliminate casting tooling
- Metal only where needed

**Improving state-of-the-art**
- Processing sciences
- Alloys
- Design
Advanced Manufacturing Works - Greenville

Merging design and manufacturing technology to deliver better products

**Additive**
- >10,000 parts shipped
- 1st GT parts produced/fielded

**Ceramics**
- 1st fielded CMCs
- Thermal coatings

**Process optimization**
- Automation/CMT/Digital
- Hot Gas Path Special Processes
- Reduced cost and lead time
Industrial Gas Turbine Terminology

See insert on right

Combustion Liner

Transition Piece

1\textsuperscript{st} Stage Turbine Vane (Nozzle)

1\textsuperscript{st} Stage Shroud

1\textsuperscript{st} Stage Turbine Blade

2\textsuperscript{nd} Stage Turbine Vane
Turbine Section Advanced Manufacturing Opportunities

Component we are focusing on in this project
Turbine Vane Conventional Cooling Fundamentals

Internal Cooling Flow Circuit

Surface/External Film Cooling
Nozzle Design - Today’s Technology – “Design what you can make”

Design Philosophy
• Raise Combustion Temperature to increase Engine Output/Performance.
• Manage cooling techniques to increase performance while maintaining part life.
  ➢ Impingement Cooling
  ➢ Film Cooling
  ➢ Thermal Barrier Coatings
  ➢ High Temp Advanced Alloys

Design Challenges
• Overcool the Nozzle to mitigate TBC Spall Risk
• Traditional manufacturing methods overcool some regions to cool hotter areas on the Nozzle
• Developing high oxidation resistant materials is costly
Nozzle Design – Tomorrow’s Technology – “Make what you can design”

Conceptual Design & Feasibility

Advanced Film Shapes
Near-wall Microchannels
Recirculating Trailing Edge

Axial Film Flow for Leading Edge
Advanced H-Bumps
Advanced Cooling
Airfoil Compartmentalization & Impingement Reuse

Additive Modalities & Materials

Program focus will be on high-temperature alloys, and additive modalities that enable their use

“Mature” 3D Experience
Current 3D materials
Advanced GTs

Strength & Oxidation Resistance

Focus area
3D Printing Challenge

November 11, 2019
Additive Modality Comparison

**Direct Metal Laser Melting (DMLM)**
- Excellent Dimensional Control
- Excess Powder More Easily Removed
- Susceptible To Strain Age Cracking
- Support Structures Needed & Orientation Dependent

**Binder Jetting**
- No Support Structures & Orientation Independent
- Not Susceptible To Strain Age Cracking
- Machine Cost ~50% Lower Compared To DMLM
- Excess Powder Removal Difficult Due To “Green State” Fragility And Smaller Powder Particle Size
- Dimensional Control Difficult During Sintering

**Fused Deposition Modeling (FDM)**
- No Excess Powder To Be Removed
- Not Susceptible To Strain Age Cracking
- Machine Cost ~80% Lower Compared To DMLM
- Dimensional Control Difficult During Sintering
- Support Structures Needed For Printability
- Lower Feature Fidelity And Higher Surface Roughness

Each Modality Presents Opportunities And Challenges When Producing Complex Geometries
Airfoil Design & Artifact Coupon Print Trial Summary

- Pinned Wall Trials
- Round Cooling Holes
- Round Serpentine and Elliptical Serpentine Channels
- Walls With Constant Spacing and variable thickness Ranges

Artifact Coupons Create Relatively Fast And Lower Cost Learning Of Modality Capabilities And Challenges
Airfoil Design & Artifact Coupon Print Trial Summary

Artifact Coupon Print Trials
- Contained specific simplified features representative of the advanced airfoil design.
- Designed to determine what features could be achieved without significant risk in production scale-up.

FDM Trials

Binder Jet Trials
- Pinned wall coupon
- Wall thickness Coupon
- Deflection of wall with pins starts at wall thickness ~0.050"
- Variable hole diameter coupon showing green & sintered state
- Some damage to holes on exterior from physical powder removal
## Print Results Summary

### Binder Jet

**Challenges**
- Trapped Powder.
- Significant Distortion In Some Areas.

There is line of sight to producing complex features in Binder Jet.

**Going forward**
Further refinement to demonstrate dimensional quality, high yield and powder removal capability.

### DMLM

**Challenges**
- Strain Age Cracking

DMLM is favorable for producing full nozzles with complex cooling geometries.

**Going forward**
Part geometry and build orientation will be defined to minimize or eliminate strain age cracks.

### FDM

**Challenges**
- Trapped Powder.
- Significant Distortion In Some Areas.

The least favorable option for producing Nozzles with complex cooling geometries.

**Going forward**
Will not be pursuing FDM for complex geometries at this time.
Test Plan and Key Technology Gaps

Technology Gaps
1) Cooling Technology
   - Empirical thermal correlations for additive cooling features needed.
     - HTC
     - Film cooling effectiveness

2) Wall Architecture Technology Bench Testing
   - Jets Testing Rig needed to validate Phase I assumptions and design benefits.

3) Additive Material Properties.
   (analogous to Cast properties vs Forged properties)
Summary

The road to 65% CC efficiency is challenging

Additive Manufacturing is a paradigm shift in design for manufacturing.
   Early Career Engineers are the experts in additive manufacturing and design.

In this program GE....
   • Studied Advanced Wall Architecture and Airfoil Concepts enabled by Additive Manufacturing.
   • Identified and evaluated Additive Methods and Materials.
   • Developed a Test Plan for future execution.

DMLM and Binder Jet are being pursued for further development on complex turbine components.
Questions?