High Temperature Additive Architectures for 65% Efficiency DE-FE0031611

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UTSR Project Review Meeting
Orlando, FL
November 6, 2019

This material is based upon work supported by the Department of Energy under Award Number **DE-FE0031611**

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

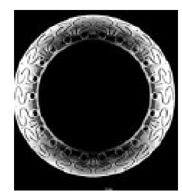
Cost
- Eliminate casting tooling
- Metal only where needed

Improving state-of-the-art

Processing sciences


Alloys


Design

Advanced Manufacturing Works - Greenville

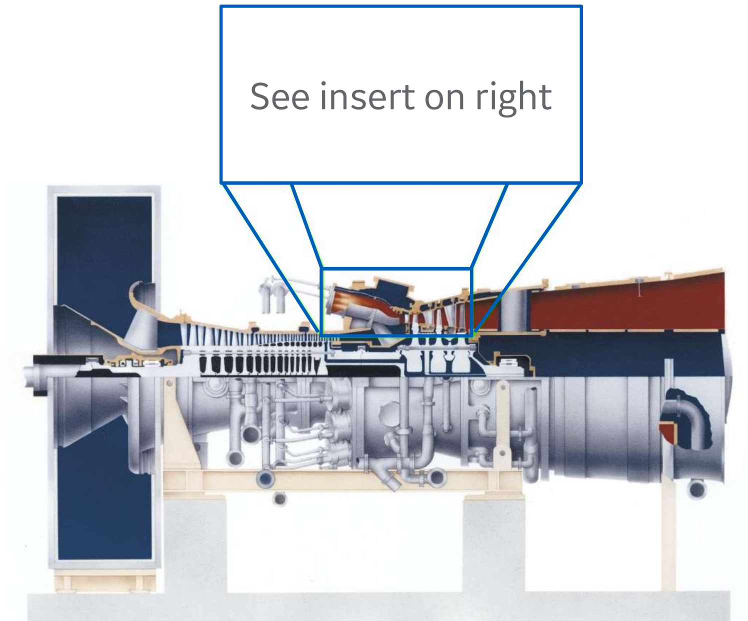
Merging design and manufacturing technology to deliver better products

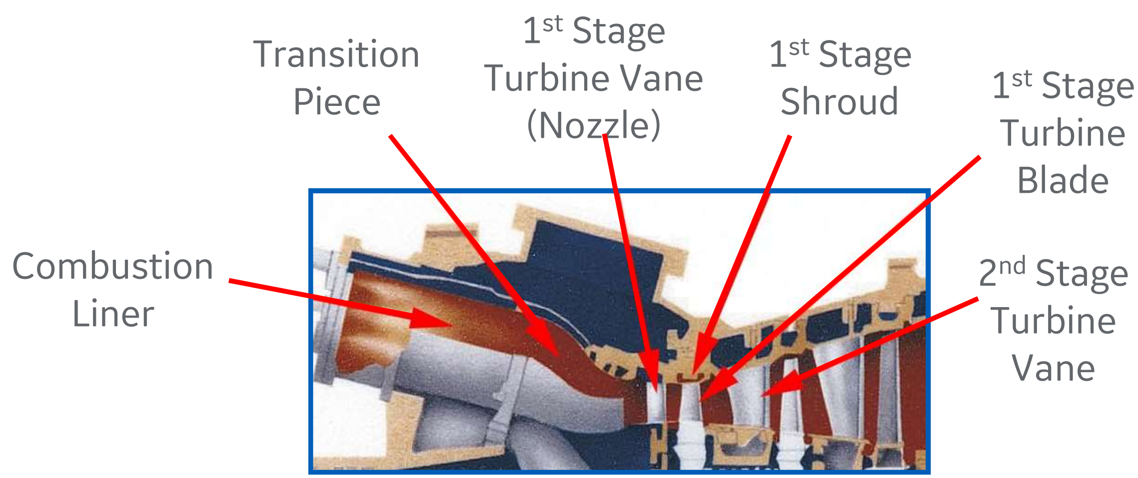
Additive
- >10,000 parts shipped
- 1st GT parts produced/fielded

Ceramics
- 1st fielded CMCs
- Thermal coatings

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

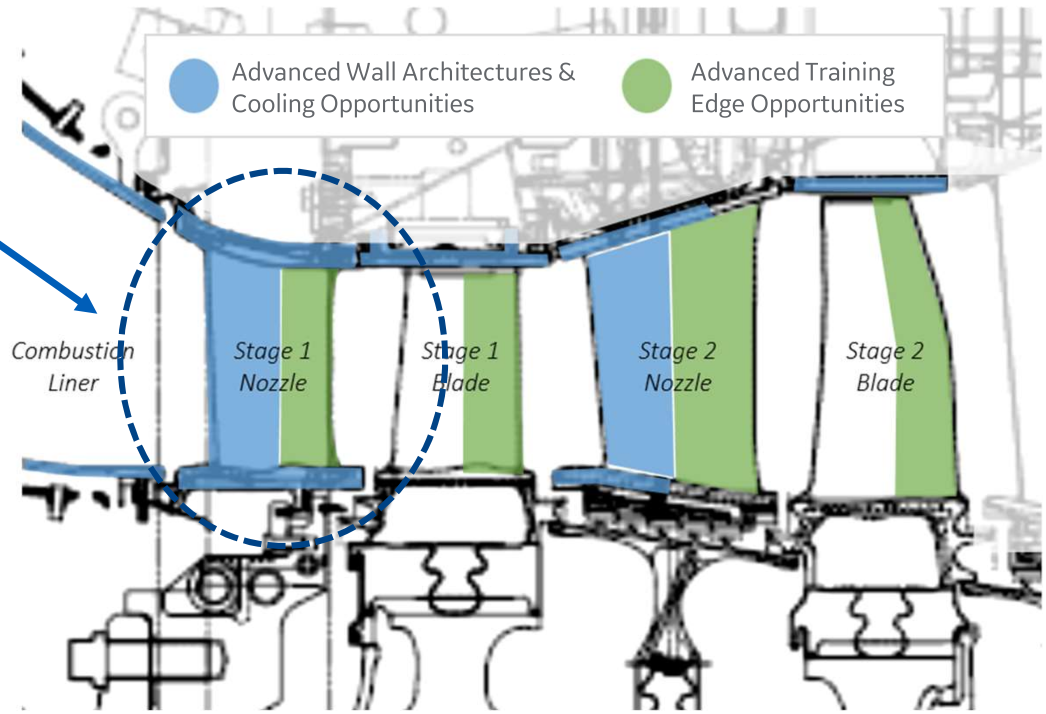
Industrial Gas Turbine Terminology





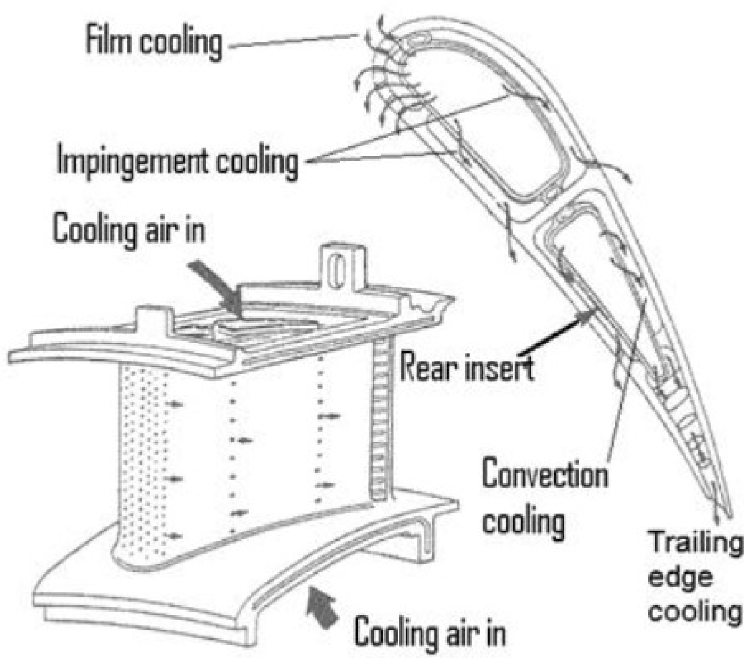
Turbine Section Advanced Manufacturing Opportunities

Component
we are focusing on
in this project

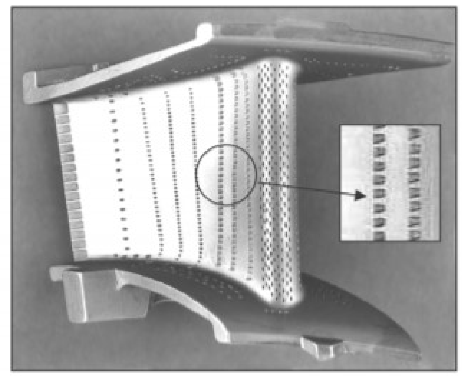


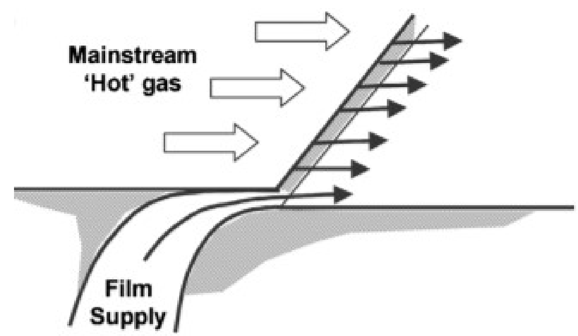
Turbine Vane Conventional Cooling Fundamentals

Internal Cooling Flow Circuit



Surface/External Film Cooling





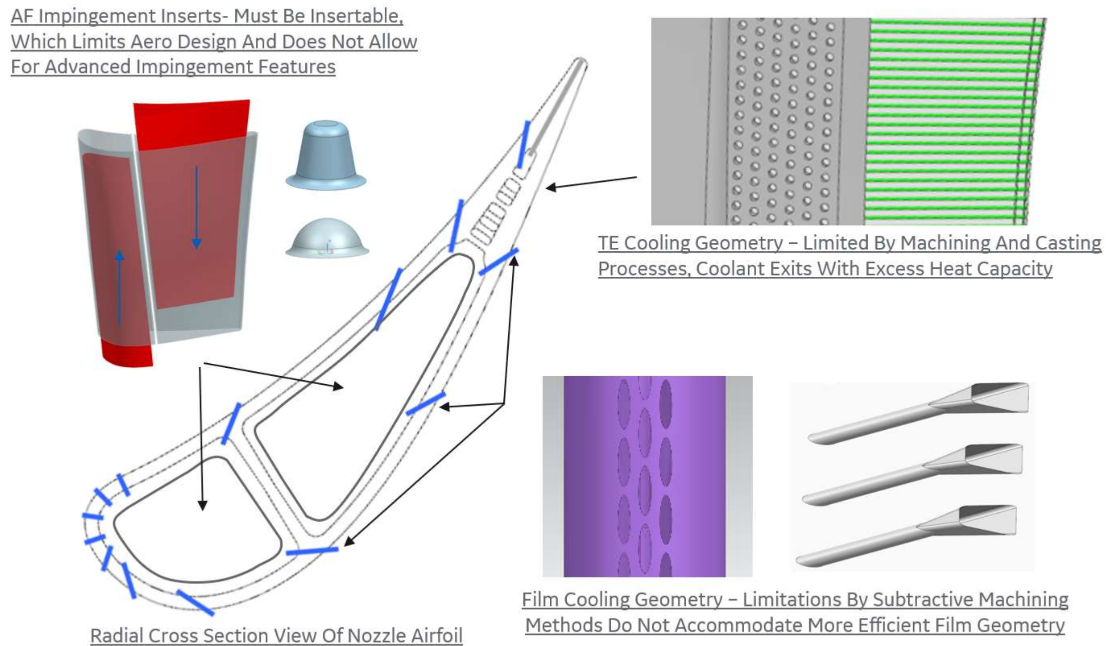
Nozzle Design - Today's Technology – "Design what you can make"

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

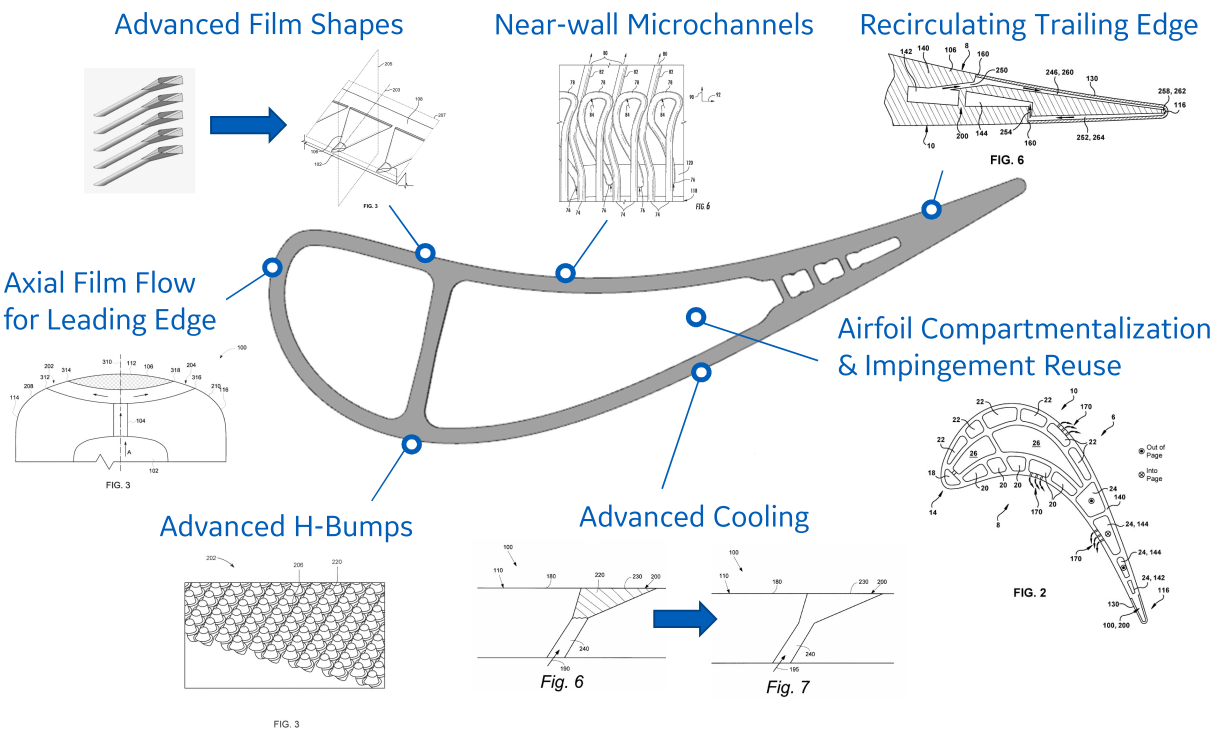
Design Challenges

- 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

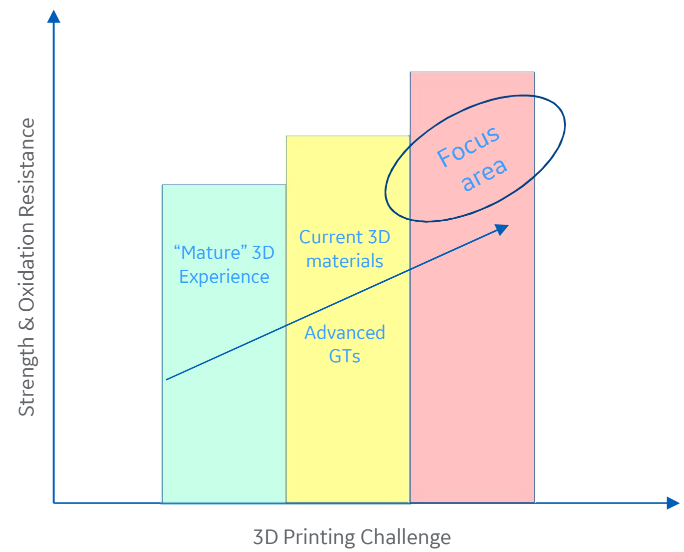


Nozzle Design – Tomorrow's Technology – "Make what you can design"

Conceptual Design & Feasibility



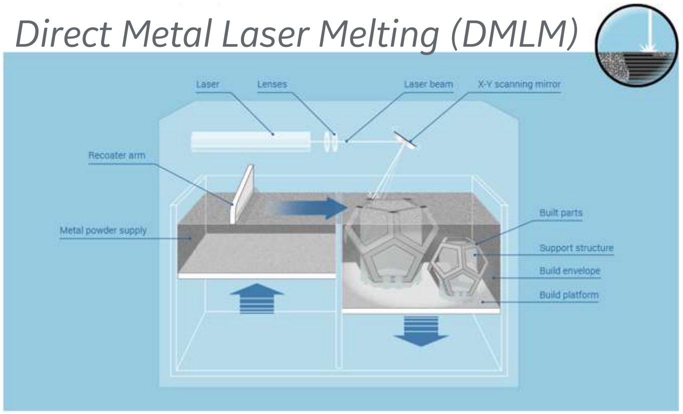
Additive Modalities & Materials



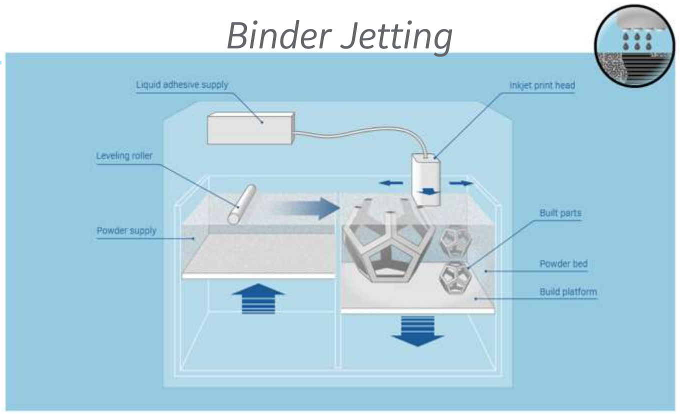
Program focus will be on high-temperature alloys, and additive modalities that enable their use

Additive Modality Comparison

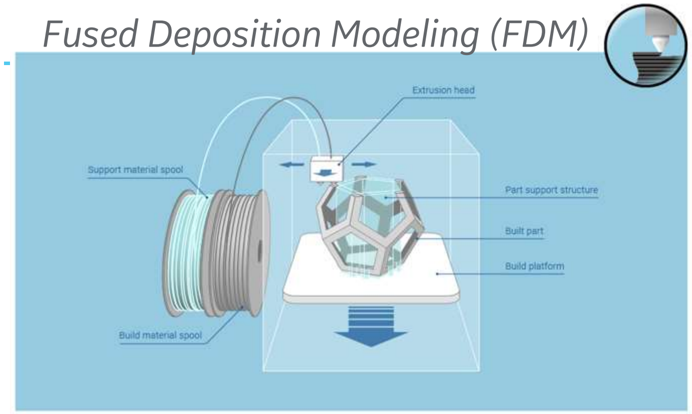
Direct Metal Laser Melting (DMLM)



Binder Jetting



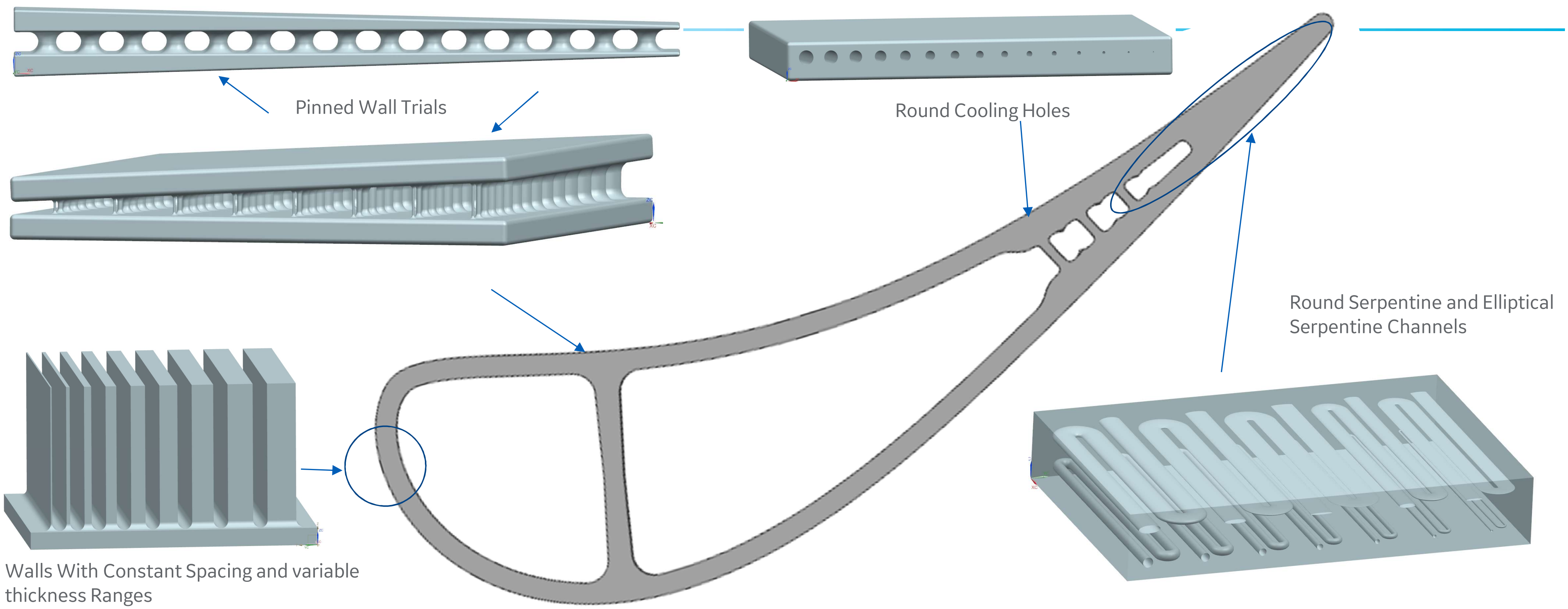
Fused Deposition Modeling (FDM)



Additive Modality	Advantages	Limitations
DMLM	- Excellent Dimensional Control - Excess Powder More Easily Removed	- Susceptible To Strain Age Cracking - Support Structures Needed & Orientation Dependent
Binder Jet	- 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
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



Artifact Coupons Create Relatively Fast And Lower Cost Learning Of Modality Capabilities And Challenges

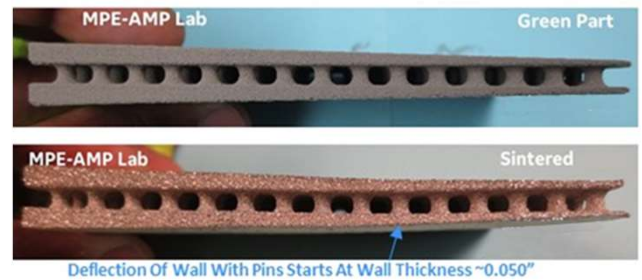
Airfoil Design & Artifact Coupon Print Trial Summary

Artifact Coupon Print Trials

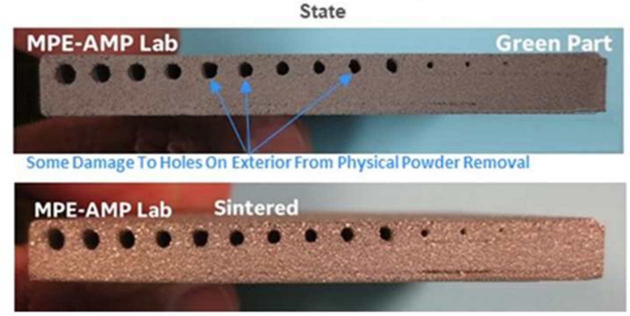
- Contained specific simplified features representative of the advanced airfoil design.
- Designed to determine what features could be achieved without significant risk in production scale-up.

Pinned wall coupon

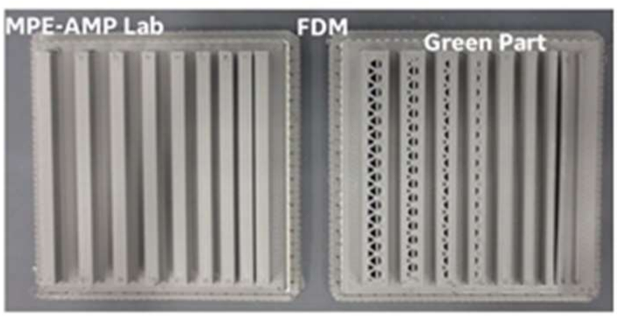
Binder Jet Trials

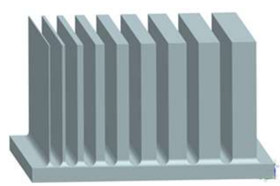


Variable Hole Diameter Coupon Showing Green & Sintered State



FDM Trials





Wall thickness Coupon

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.

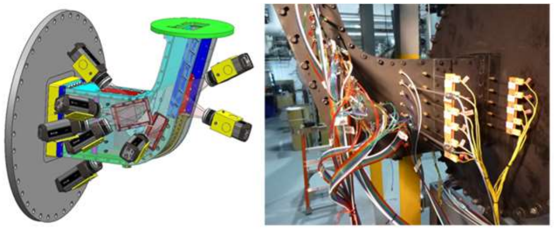
Test Plan and Key Technology Gaps

Technology Gaps

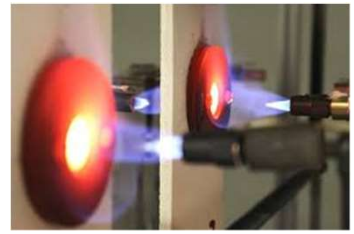
1) Cooling Technology
   - Empirical thermal correlations for additive cooling features needed.
     - HTCs
     - Film cooling effectiveness

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)



GER / GEP Film Cooling Test Rig



High Temperature Jet Thermal Shock Testing Rig

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.

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Questions?