A Fully Non-Metallic Gas Turbine Engine Enabled by Additive Manufacturing

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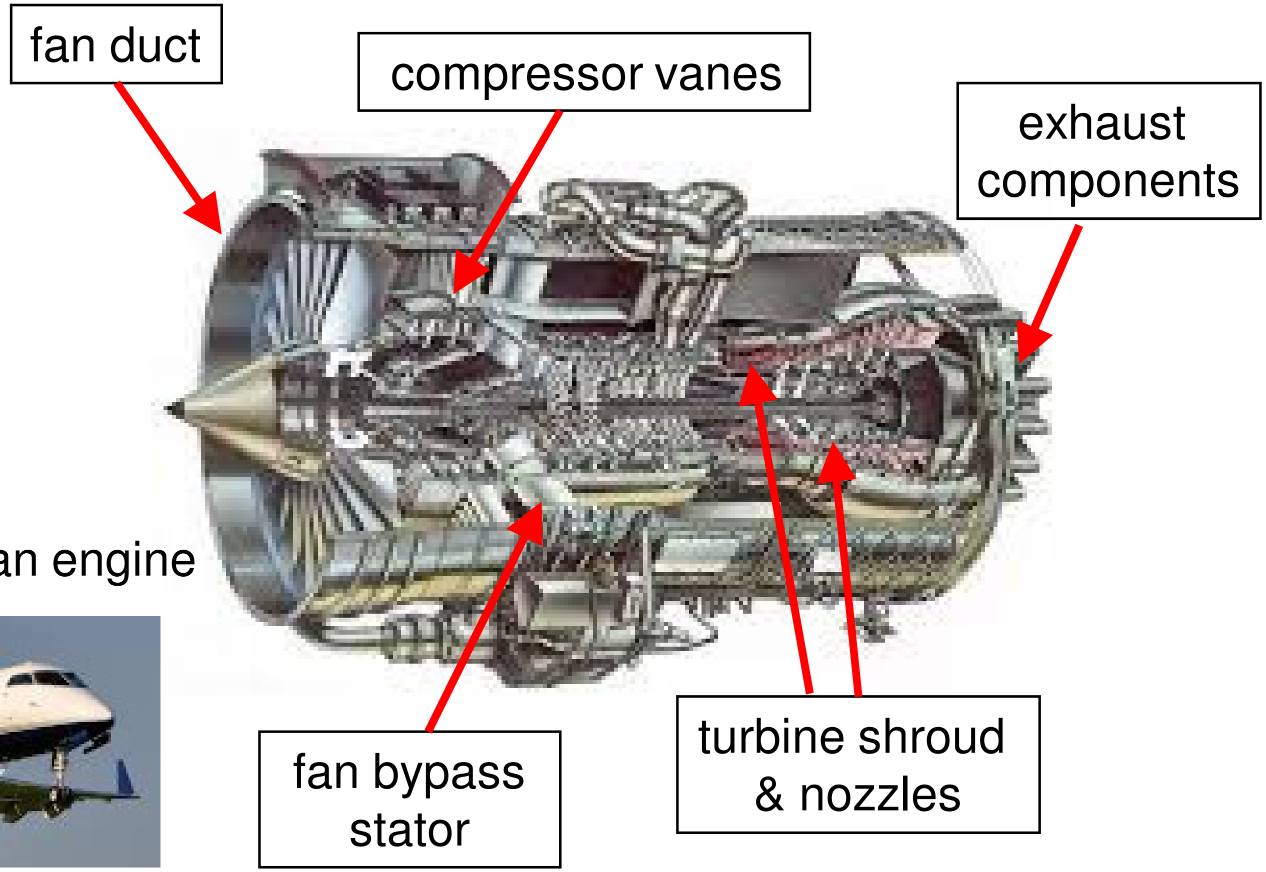
Presentation Outline

- Project Background
- Development of Additive Manufacturing processes for composite materials
- Component applications
- Next Steps

Lightweight, high temperature composite materials improve engine efficiency



Business Jet size turbofan engine

Use of these materials & manufacturing technologies in critical components will reduce emissions (8%), fuel burn (5%), engine weight (15%) for business jet size engines

Project Summary

Objective:

Conduct the first comprehensive evaluation of emerging materials and manufacturing technologies that will enable fully non-metallic gas turbine engines for reduced aircraft emissions, fuel burn and noise.

Approach:

- Assess the feasibility of using additive manufacturing technologies to fabricate gas turbine engine components from polymer and ceramic matrix composites.
- Fabricate and test prototype components in engine operating conditions
- Conduct engine system studies to estimate the benefits of a fully non-metallic gas turbine engine design in terms of reduced emissions, fuel burn and cost

Project Team

- **RP+M** (Additive Manufacturing): Tom Santelle, Clark Patterson
- **Honeywell Aerospace** (Engine Systems & Components):
  - Mike Vinup, Natalie Wali, Don Weir
- **Ohio Aerospace Institute**
  - Ceramic Processing: Mrityunjay Singh
  - Polymer characterization: Eugene Shin
- **NASA Glenn Research Center**
  - Engine Systems Analysis: Bill Haller, Sydney Schnulo, Bob Plencner
  - Materials Characterization: Kathy Chuang, Mike Halbig, Bob Draper
  - Component Rig Testing: Phil Poinsatte, Doug Thurman
- **NASA Langley Research Center** (Acoustic testing): Mike Jones
- **NASA Aeronautics Academy Students:** Chao Lao (Cal Poly), Jeremy Mehl (Princeton), Morgan Rhein (Purdue)

Polymer Matrix Composites

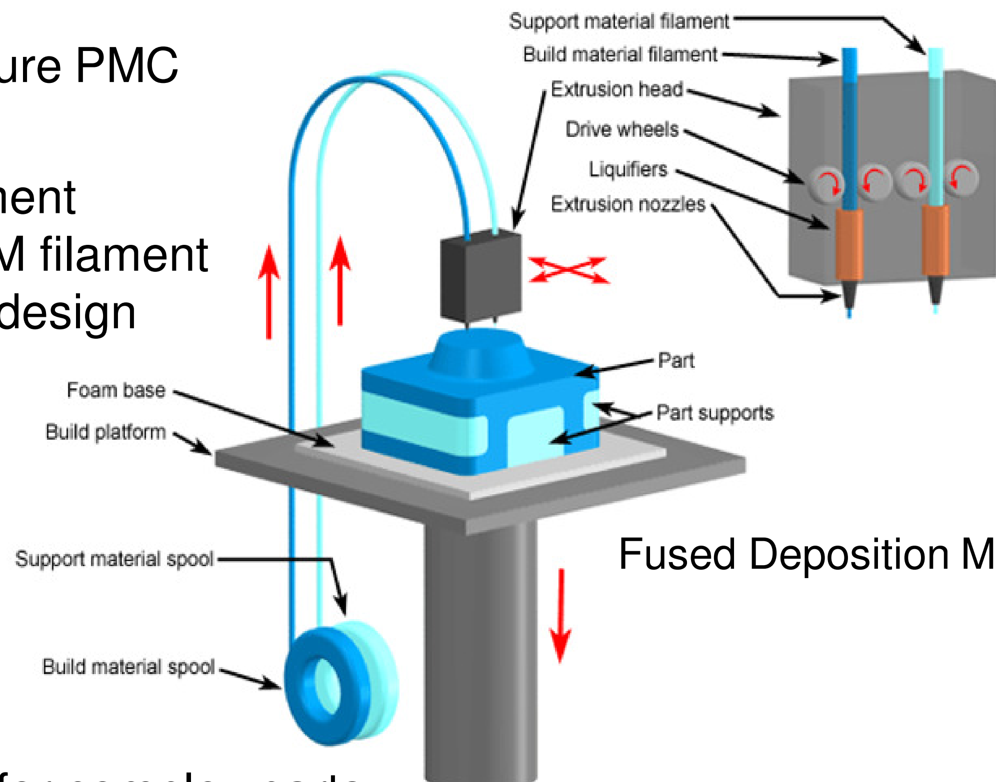
- Fabrication Process
- Material Characterization
- Component Demonstrations

Fused Deposition Modeling for Polymer Matrix Composites

Melts polymer filament and deposits it layer-by-layer following CAD files

Fabrication of high temperature PMC was enable by:

- Chopped-fiber reinforcement
- Moisture reduction in FDM filament
- Versatile printing pattern design

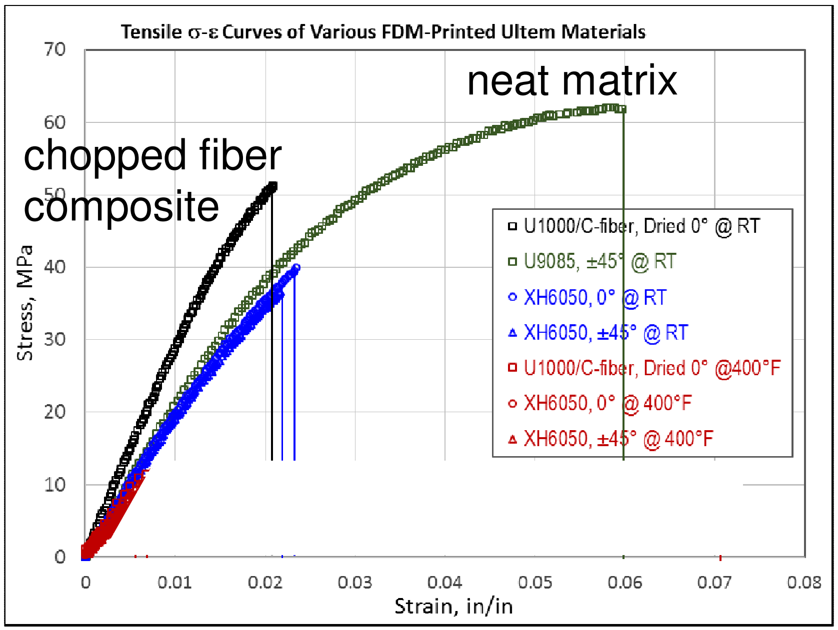


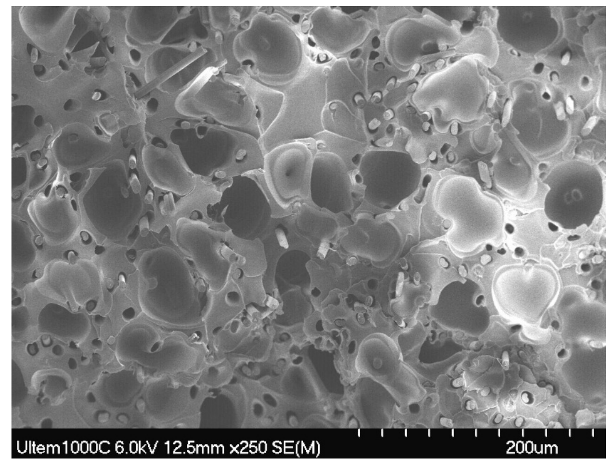
Fused Deposition Modeling

Benefits:

- Quick turn around time for complex parts
- Shorter component production and testing cycle
- Reduced cost of low production volume components

Fiber reinforcement increases modulus of high temperature polymers

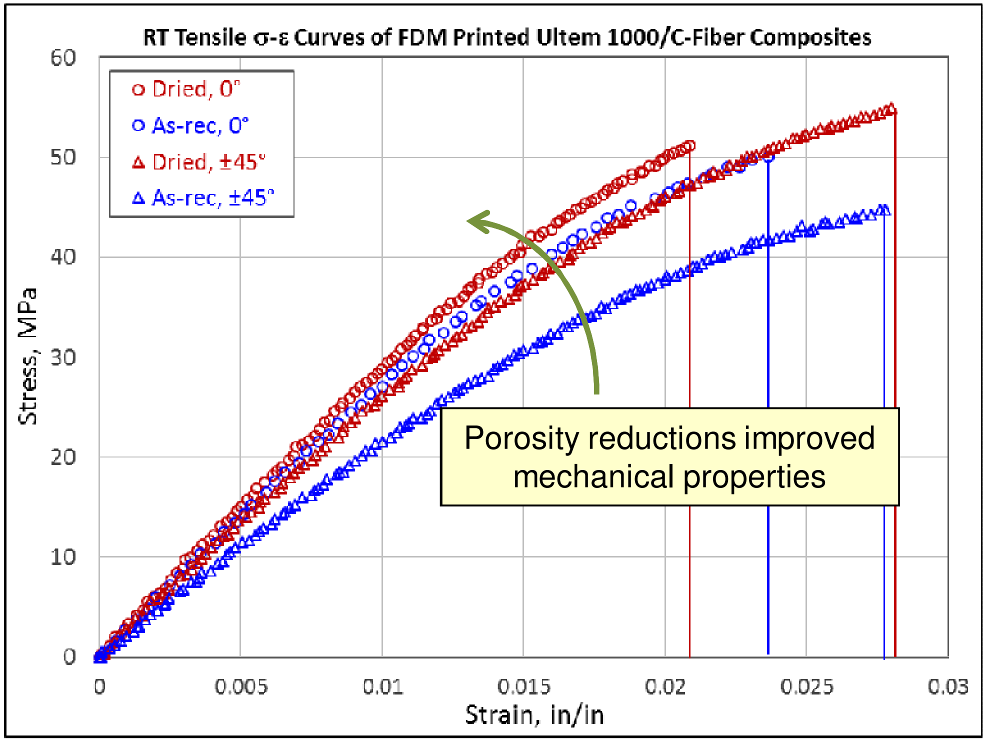




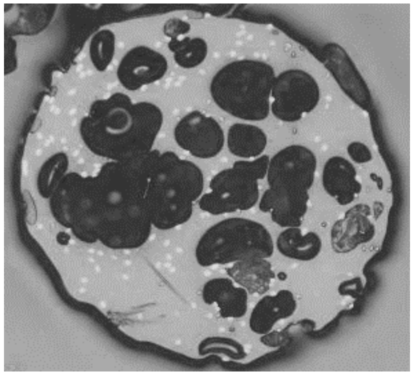
fibers are visible in composite fracture surface

Addition of 10% chopped fiber (AS4) increased modulus 40%

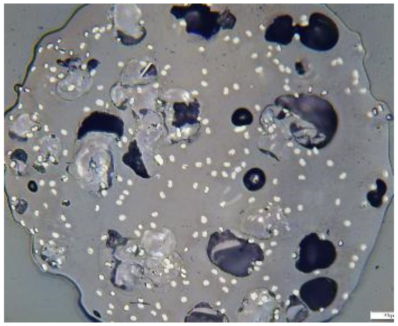
Processing approach was refined to optimize properties of high temperature polymer composites



Reduction of moisture content in FDM polymer filament resulted in lower porosity and improved composite properties



Initial composites were porous



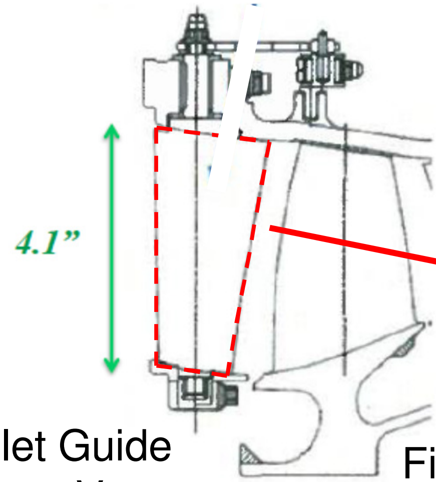
Process improvement reduced porosity 20%

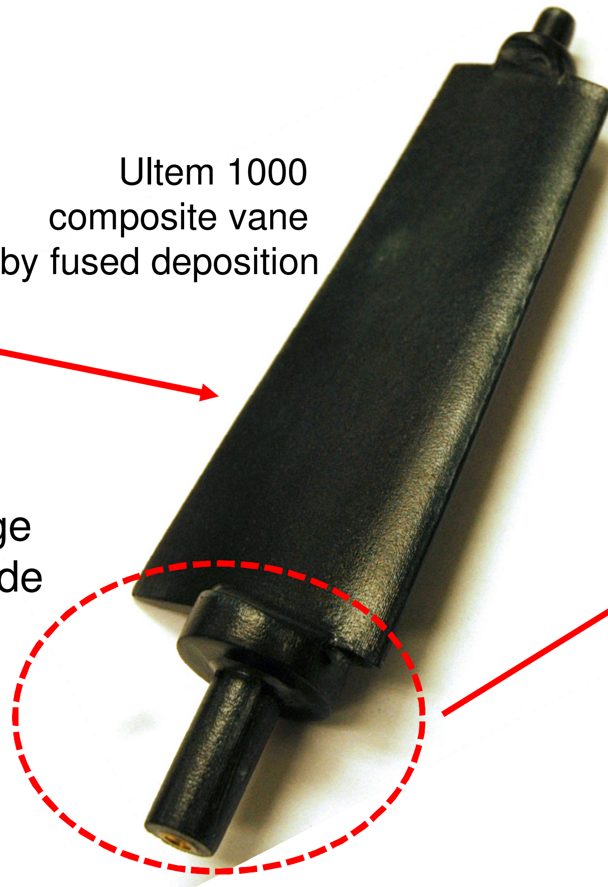
27% modulus increase and 20% strength increase measured for +/- 45° composites

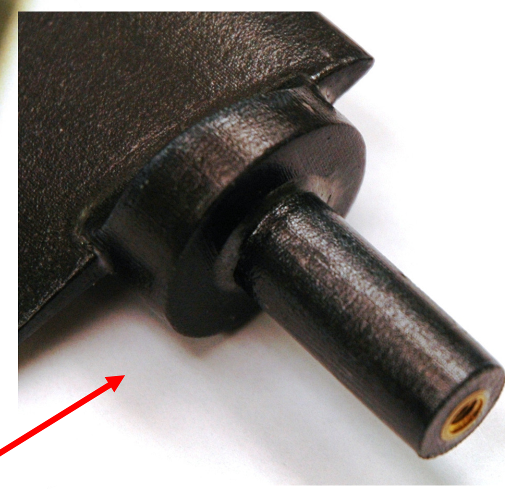
PMC Component Applications

- Compressor Guide Vane
- Acoustic Liner

Fabricated Compressor Inlet Guide Vanes with High Temperature Polymer Matrix Composites





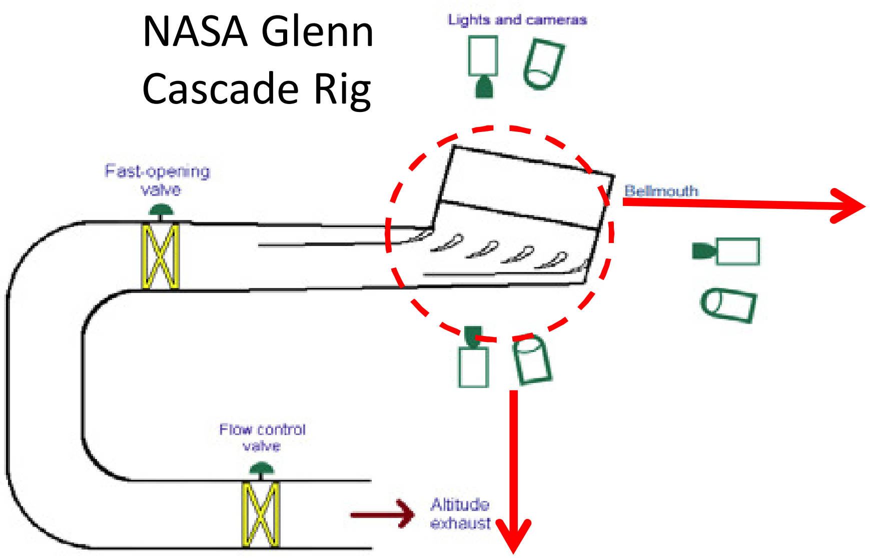


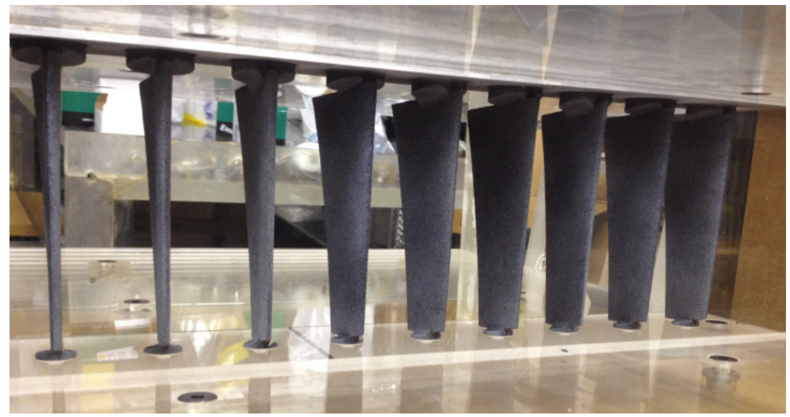
400^{0}F operating temperature

- Ultem 1000 (T_g = 423^{0}F) with chopped carbon fiber
- First Polyetherimide composite fabricated

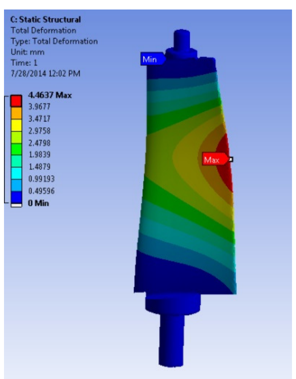
Structural integrity of inlet guide vane was evaluated under aerodynamic loading

NASA Glenn Cascade Rig

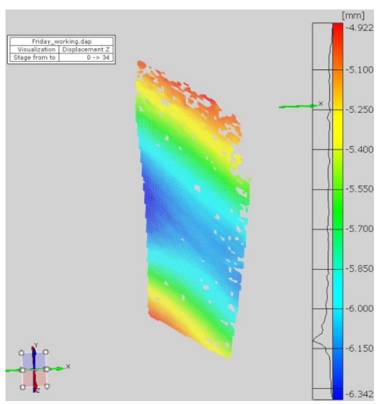




Vane Configuration in Cascade Rig



Stress Analysis

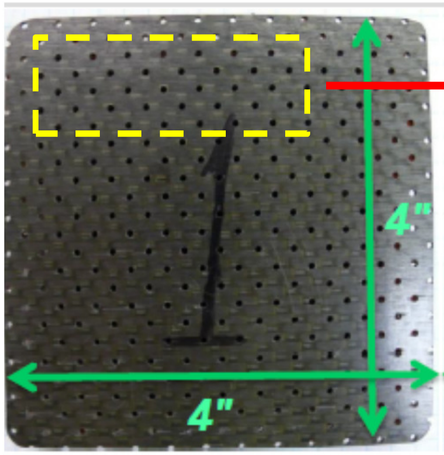


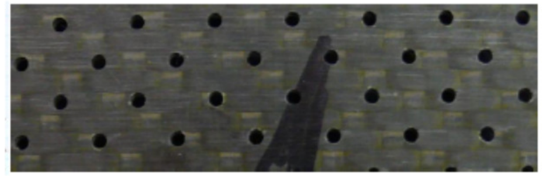
Deformation Measurements

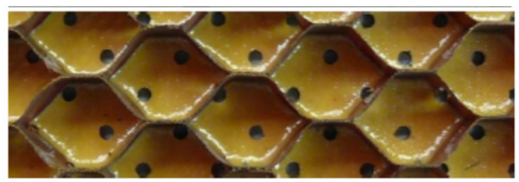
Other FDM composites being evaluated:

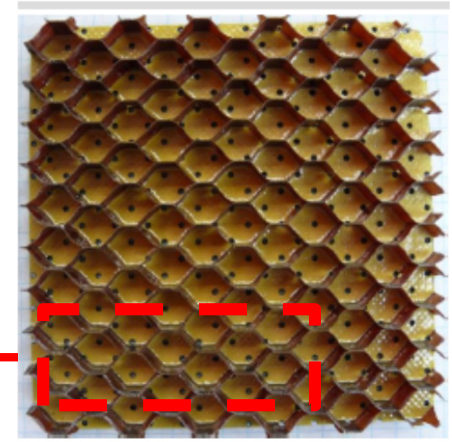
Matrix (+C fiber)	Use Temperature (^oF)
Ultem 1000	350
Ultem 9085	275
ABS	200

Fused Deposition Modeling Simplifies Acoustic Liner Fabrication







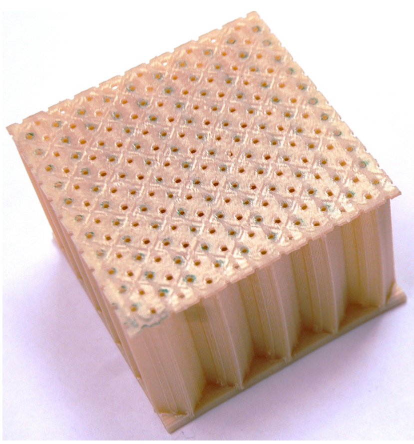


Perforated Facesheet

Bonded Structure

Honeycomb

Current manufacturing approach requires metal forming, bonding and drilling

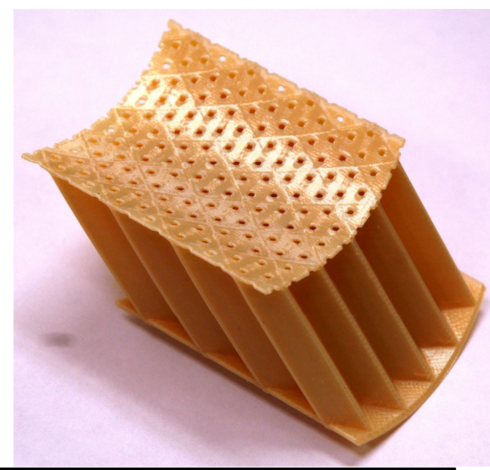


standard liner configuration

integral facesheet/honeycomb structure is fabricated in one step using Fused Deposition Modeling

200^{o}F operating temperature

complex geometries

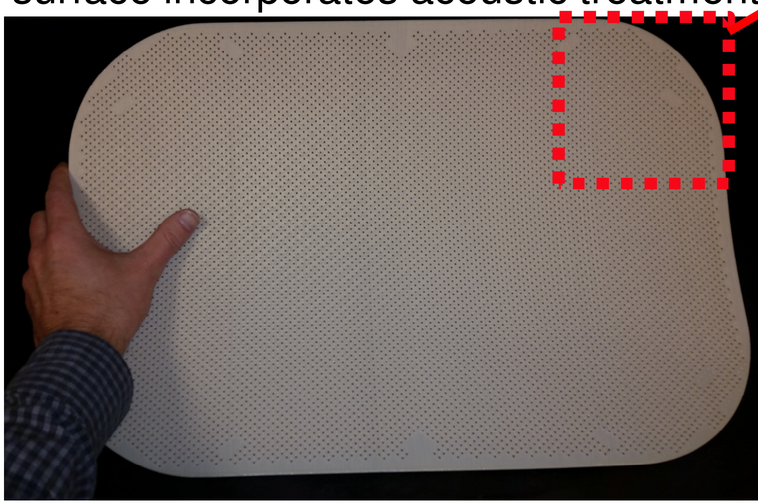


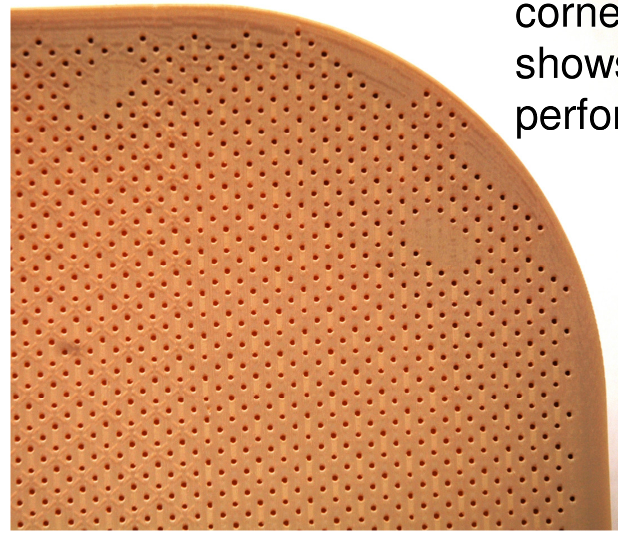
Fabricated with monolithic Ultem 9085 thermoplastic (T_g = 367^{o}F)

Fabrication of full-scale engine access panel demonstrated

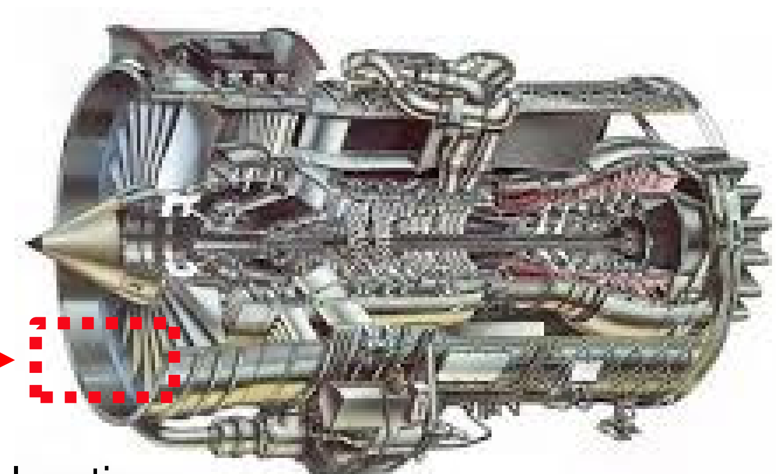
19″

inner surface incorporates acoustic treatment



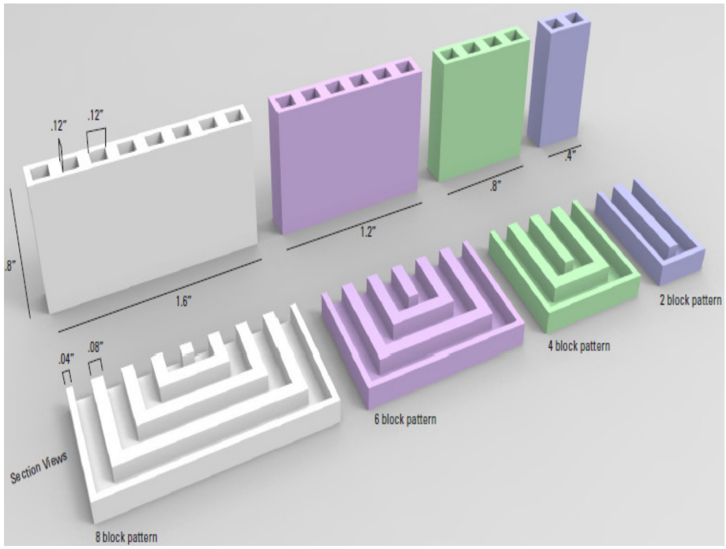


corner detail shows acoustic perforations



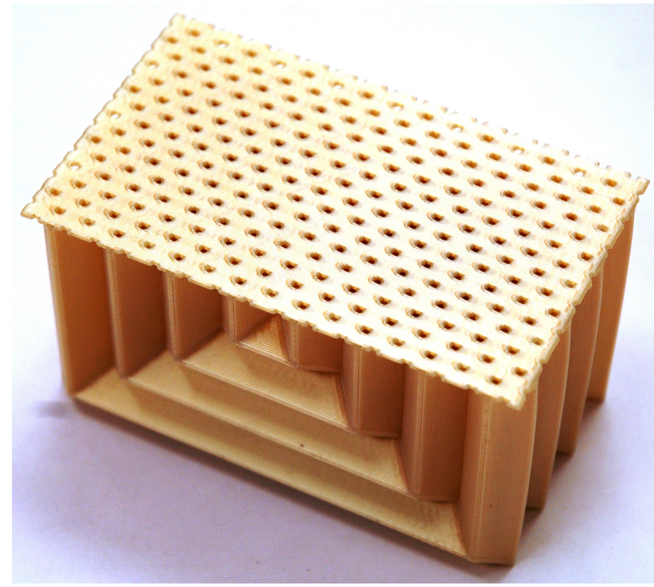
panel location

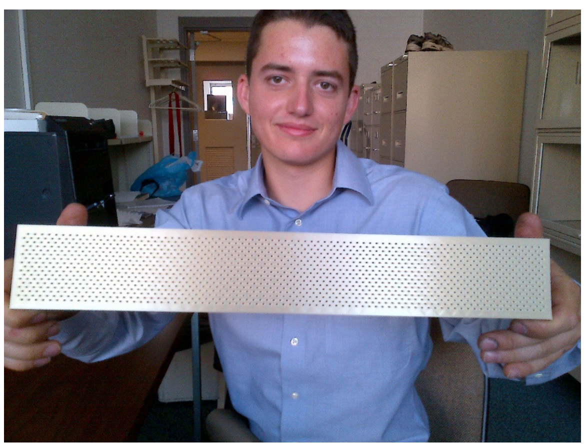
Fused Deposition Modeling enables fabrication of advanced acoustic liner concepts



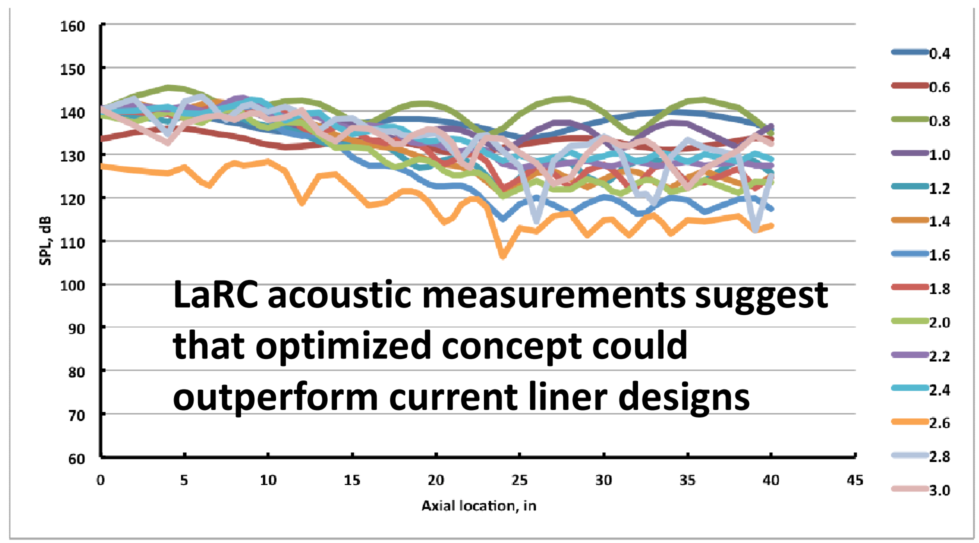
Acoustically-tuned passages provide broadband noise attenuation

FDM sample of advanced liner





Fabricated 16x2 inch test article



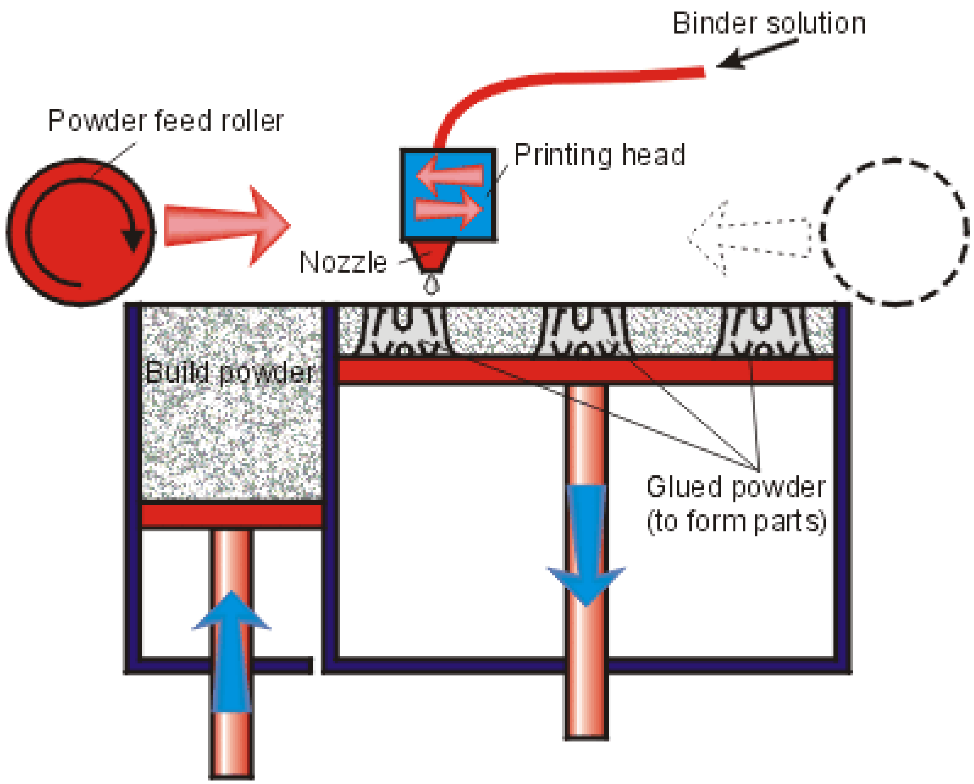
LaRC acoustic measurements suggest that optimized concept could outperform current liner designs

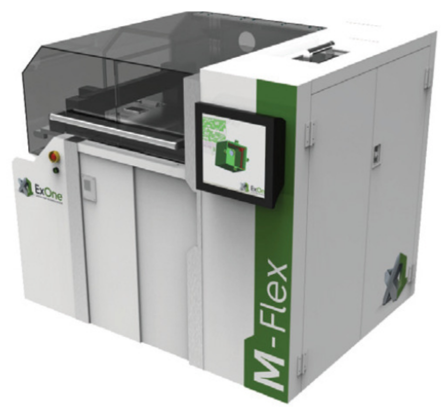
Ceramic Matrix Composites

- Fabrication Process
- Material Characterization
- Component Demonstration

Binder Jet process was adapted for fabricating Ceramic Matrix Composites

An inkjet-like printing head moves across a bed of ceramic powder depositing a liquid binding material in the shape of the object's cross section





ExOne's M-Flex print machine

Binder jet printing allows for powder bed processing with *tailored binders* and *chopped fiber reinforcements* for fabricating advanced ceramics

Powder composition is key to Binder Jet processing for structural ceramics and composites

optimization of powder spreading and bimodal distribution of powders is critical

Constituents

- **SiC powders**: Carborex 220, 240, 360, and 600 powders (median grain sizes of 53, 45, 23, and 9 microns)
- **Infiltrants:** SMP-10 (polycarbosilane), SMP-10 w/ SiC powder, phenolic (C, Si, SiC powder loaded), pure silicon
- **Fiber reinforcement**: SiC chopped fiber; 7 micron mean dia, 65-70 micron mean length, 350 GPa Modulus

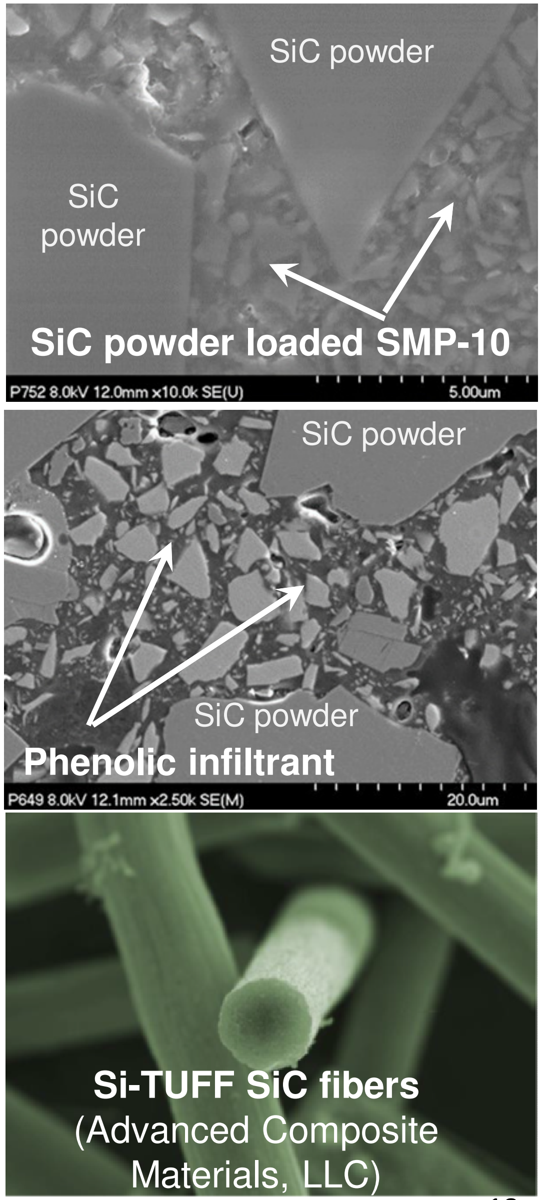
Microstructure

- Optical microscopy
- Scanning electron microscopy

Properties

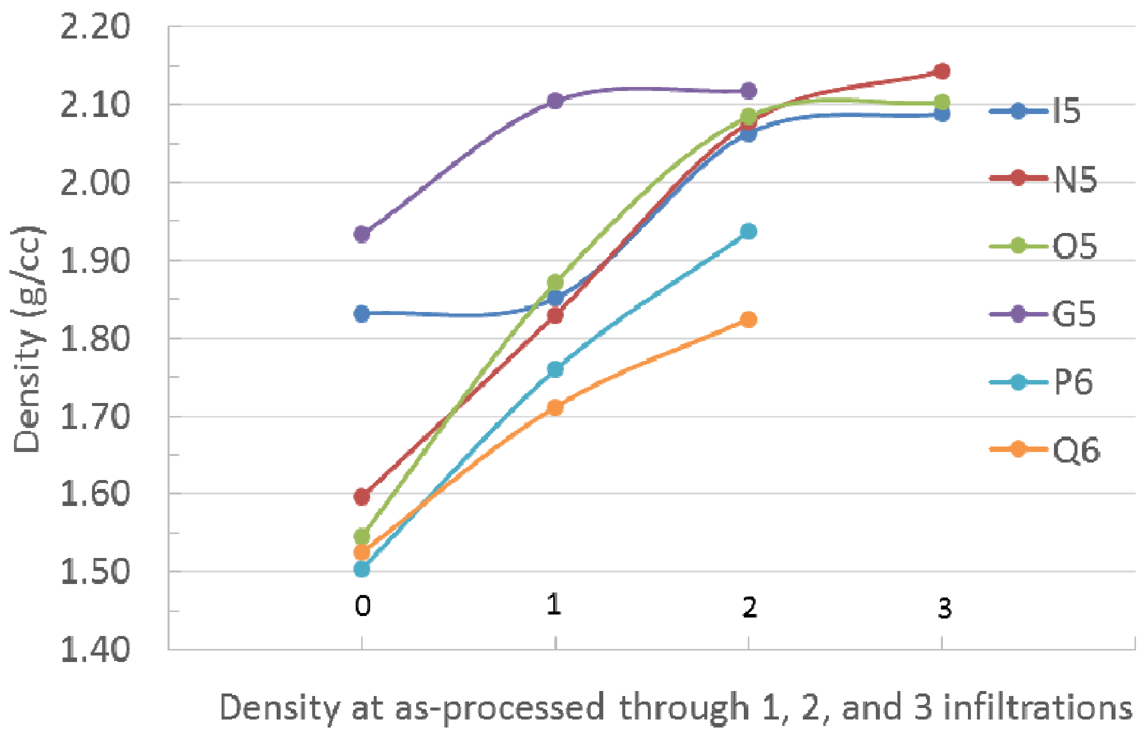
- Material density (as-manufactured and after infiltration)
- Mechanical properties

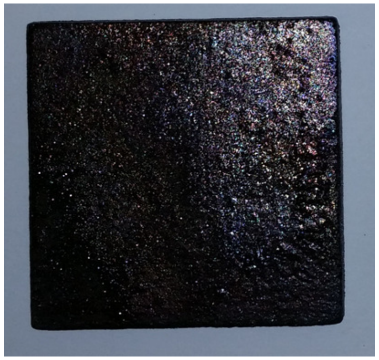
Processing, microstructure, and property correlations provide an iterative process for optimizing CMC materials



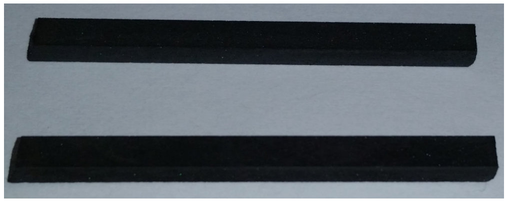
Optimization of Binder Jet process for ceramics

multiple infiltrations with SiC powder-loaded polymers increase material density



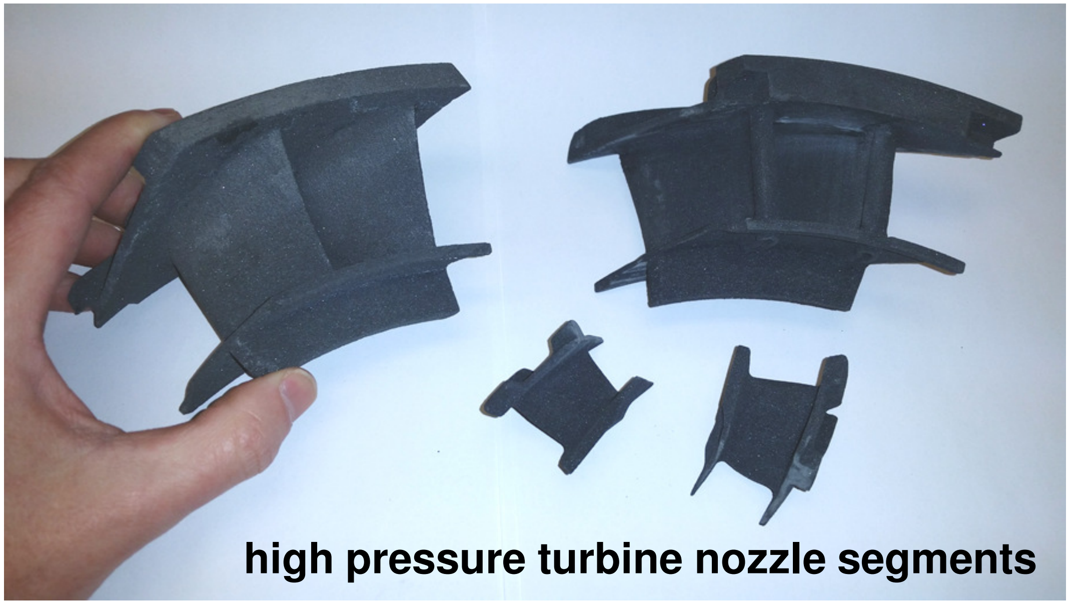


Panels and test coupons fabricated for mechanical property measurements

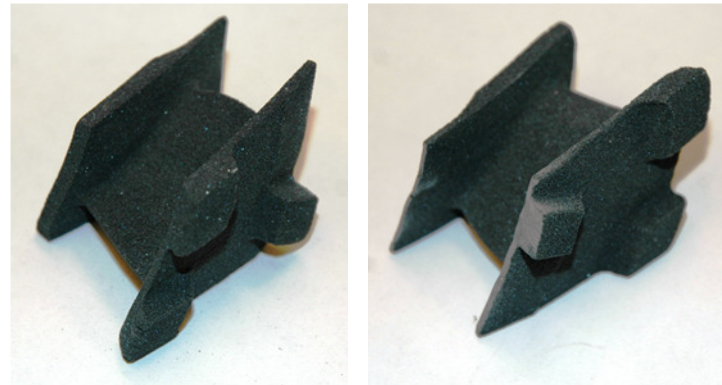


Infiltrations increased density 30%
by optimizing composition of ceramic powders used

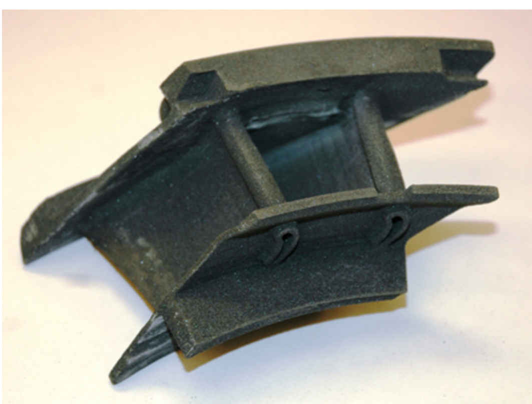
The first CMC turbine engine components by additive manufacturing

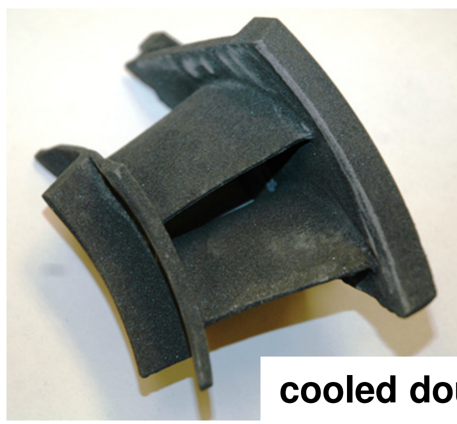


high pressure turbine nozzle segments



first stage nozzle segments





cooled doublet nozzle sections

SiC/SiC CMCs have 20% chopped SiC fiber

Next Steps

Optimize Processing & Improve Properties

- **Constituent Optimization:** utilize spherical shaped SiC powders for improved packing
- **Pursue Alternate Densification Approaches:** add carbon powder to powder bed for conversion to SiC during infiltration with molten silicon.
- **Fiber Coatings:** investigate the effect of fiber coatings for optimization of fiber/matrix bond strength
- **Reduce porosity** in polymers using higher temperature thermoplastic filaments (FDM) or thermoset polymers (Selective Laser Sintering)

Thermomechanical Testing

- Optimize fiber volume fraction based on property measurements

Turbine Engine Components

- Test components in relevant operating conditions to increase TRL