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

Joseph E. Grady and Michael C. Halbig
NASA Glenn Research Center

Mrityunjay Singh
Ohio Aerospace Institute
Cleveland, OH, USA

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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

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

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.

Addition of 10% chopped fiber (AS4) increased modulus 40%.
Processing approach was refined to optimize properties of high temperature polymer composites.

Initial composites were porous.

Process improvement reduced porosity 20%

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

Reduction of moisture content in FDM polymer filament resulted in lower porosity and improved composite properties.
PMC Component Applications

- Compressor Guide Vane
- Acoustic Liner
Fabricated Compressor Inlet Guide Vanes with High Temperature Polymer Matrix Composites

- Ultem 1000 ($T_g = 423^\circ F$) with chopped carbon fiber
- First Polyetherimide composite fabricated
Structural integrity of inlet guide vane was evaluated under aerodynamic loading

Other FDM composites being evaluated:

<table>
<thead>
<tr>
<th>Matrix (+C fiber)</th>
<th>Use Temperature (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultem 1000</td>
<td>350</td>
</tr>
<tr>
<td>Ultem 9085</td>
<td>275</td>
</tr>
<tr>
<td>ABS</td>
<td>200</td>
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</table>
Fused Deposition Modeling Simplifies Acoustic Liner Fabrication

Current manufacturing approach requires metal forming, bonding and drilling

Fabricated with monolithic Ultem 9085 thermoplastic ($T_g = 367^\circ F$)
Fabrication of full-scale engine access panel demonstrated

- Inner surface incorporates acoustic treatment
- Corner detail shows acoustic perforations
- Panel location

19”
Fused Deposition Modeling enables fabrication of advanced acoustic liner concepts

Acoustically-tuned passages provide broadband noise attenuation

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.

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

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

Panels and test coupons fabricated for mechanical property measurements
The first CMC turbine engine components by additive manufacturing

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