Ceramic Matrix Composites taking flight at GE Aviation

May 1, 2018

LEAP is a product of CFM International, a 50/50 joint company between GE and Snecma (Safran)
Presentation Outline

• CMC Materials Systems
• Product Introduction
• Technology Maturation
• Industrialization
• Raw Material Sites
• Market Potential

LEAP is a product of CFM International, a 50/50 joint company between GE and Safran Aircraft Engines
Technology Maturation & Introduction
GE Aviation: SiC/SiC CMC Engine Test Experience

2000-2009
- 1st Commercial engine test (combustor liners)
- 1st blade in military test engine
- 1st LPT blade test in F414 engine
- 1st JSF engine test
- LPT nozzle
- Multiple parts ADVENT test engine
- World record compressor exit and turbine inlet temp
- 3,000 cycles test engine
- A320neo 1st flight

2010 →
- LEAP FETT
- GE9X core test
- F414 blade 1000 endurance cycles
- Shroud in advanced helicopter

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January 22, 2018
SiC/SiC CMC Component Certification: Commercial Engines

**LEAP* Shroud**

- Factory Testing: 77 engines/builds; 12,191 endurance cycles; 8,358 hrs run time
- Joint EASA/FAA Part 33 Certification – May 4, 2016
- Fleet statistics from the field:
  - Over 500 engines delivered
  - Total engine run time >50,000 hours

**GE9x Components**

- Engine certification program in-progress
- Delivered 8 test engines to date
- Factory Testing: 350+ endurance cycles; >800 hrs run time
- Additional 22 engine sets planned thru 2019
- Targeting engine certification 1Q19

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Technology maturation
invention, application & industrialization

Global Research Center ➔ FastWorks lab ➔ Lean lab ➔ Supply chain

need ➔ idea ➔ research ➔ proof of concept ➔ product design ➔ product & process development ➔ low rate production ➔ full-scale production

(Niskayuna, NY/Cincinnati, OH) ➔ (Cincinnati, OH) ➔ (Newark DE) ➔ (Huntsville, AL Asheville, NC)

technology readiness ➔ turnkey solutions, research to production
manufacturing readiness ➔ industrialization for cost and producibility
Establishing a CMC Supply Chain
GE Aviation High Temperature Composite Supply Chain

Matrix Material

<table>
<thead>
<tr>
<th>Fibers</th>
<th>Oxide</th>
<th>SiC</th>
<th>Carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large OEM</td>
<td>Large OEM to GEA Specification</td>
<td>Multiple Suppliers</td>
<td>Multiple Suppliers</td>
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<tr>
<td>Weavering / Prepregging</td>
<td>Multiple Suppliers</td>
<td>GE Aviation Huntsville</td>
<td>GE Aviation Newark</td>
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<tr>
<td>Densification</td>
<td>Multiple Suppliers</td>
<td>GE Aviation Asheville</td>
<td>GE Aviation Newark</td>
</tr>
<tr>
<td>Coating</td>
<td>Multiple Suppliers</td>
<td>GE Aviation Asheville</td>
<td>GE Aviation Newark</td>
</tr>
</tbody>
</table>

Implementing a new SiC/SiC Supply Chain

Growing JVs

NGS Advanced Fibers Co., Ltd. is a 50/25/25 JV between Nippon Carbon Company, GE and Safran

Advanced Ceramic Coatings, is a 50/50 JV between GE Aviation and Turbocoating Corp

Industrializing

Building high-volume production facilities

Asheville, NC

Huntsville, AL

Newark, DE

GE Aviation
CMC Site Locations

Composites COE
Evendale, Ohio

Advanced Silicon Carbide Fibers
Huntsville, AL

Asheville, NC

Newark, DE

Advanced Ceramic Coatings
Duncan, SC

NGS Advanced Fibers
Toyama, Japan

Core Engine Manufacturing Sites
Joint Ventures
USG - GE partnership on Raw Material Maturation

OSD Title III Program for Domestic SiC Fiber

SiC fiber

Fiber coating

Slurry prepregging

Wet drum winding

MANTECH: Prepregging – Demonstrated technology in 2010

MANTECH: Definition of in-line processing conditions

MANTECH: TOW Transport Testbed

SBIR w/ Surface Optics: In line FTIR coating measurements

29 months into 44 mo. program for domestic SiC fiber

1 System operational in DE 3 on order for Huntsville

Full system run in 2015

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Raw Material Build out

Toyama, Japan

Huntsville, AL
Component Manufacturing – Asheville, NC

Dedicated component facility opened in Oct 2014

Delivered first production LEAP set Oct 2015

Preparing flow lines for GE9X part transition in 2018

Created LEAP flow line
Current State – 20 min TAKT
Future State – 5 min TAKT

Lay-up
Preforming
Compaction
& Densification
Machining
Inspection

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Digital Vision... Data Driven

Input material conformance

Quick validation of process changes

Process Modeling

Manage WIP

Tape Conformance

Process Health

Equipment Health

Microstructure Validation

Component Conformance

SiC fiber
Fiber coating
Slurry prepegging
Wet drum winding
Lay-up Preforming
Compaction & Densification
Machining
Inspection

Microscopy

Actual Microstructure
Target Metrics
Simulated Microstructure
FEA Model

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Cost Out – LEAP* Experience

- Created Integrated Product team
- Transitioned part to Asheville, NC
- Data analytics identifying opportunities
  - LEAN
  - Design producibility
  - Optimized processing cycles

Shroud Shipset Cost ($) vs. Year

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Establishing Capacity ... Leads to Future Opportunity

Annual Demand

- Full Campus Buildout
  - US & Japan
- Productivity & Equipment Utilization
- Huntsville, AL
- Toyama, Japan

2015  2020  2025  2030
High Temperature Composite Market Potential

2016

- Matrix Material\(^2\)
  - Other: 13.7%
  - Oxide: 31.1%
  - Carbon: 19.9%
  - SiC: 35.3%

2026

- Industry
  - Nuclear Other
  - Hypersonics
  - Brakes
  - Aero Engine
  - Missile Defense
  - Space Launch
  - Satellite / Cargo
  - Commercial Space

- Market Potential
  - 2016: $3.0B
  - 2026: $7.5B
  - ~9.5% Growth Rate\(^1\)

\(^1\)ReportBuyer (April 2017)

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Imagination at work