CMC Research at NASA Glenn

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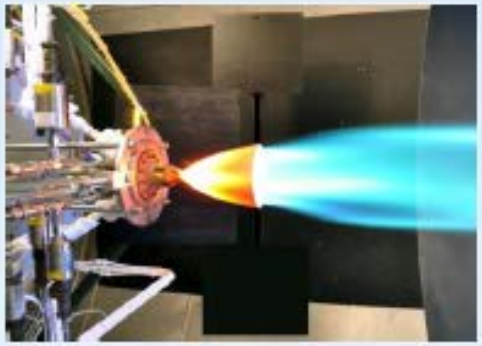
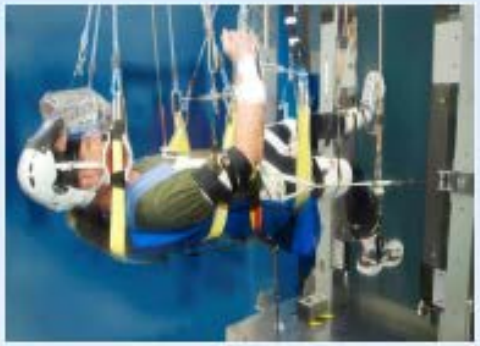
NASA Glenn Core Competencies

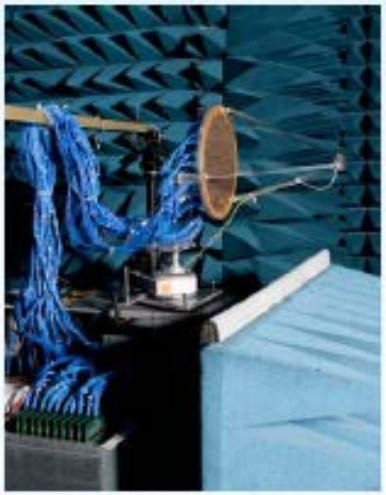
Air-Breathing Propulsion



In-Space Propulsion and Cryogenic Fluids Management



Physical Sciences and Biomedical Technologies in Space

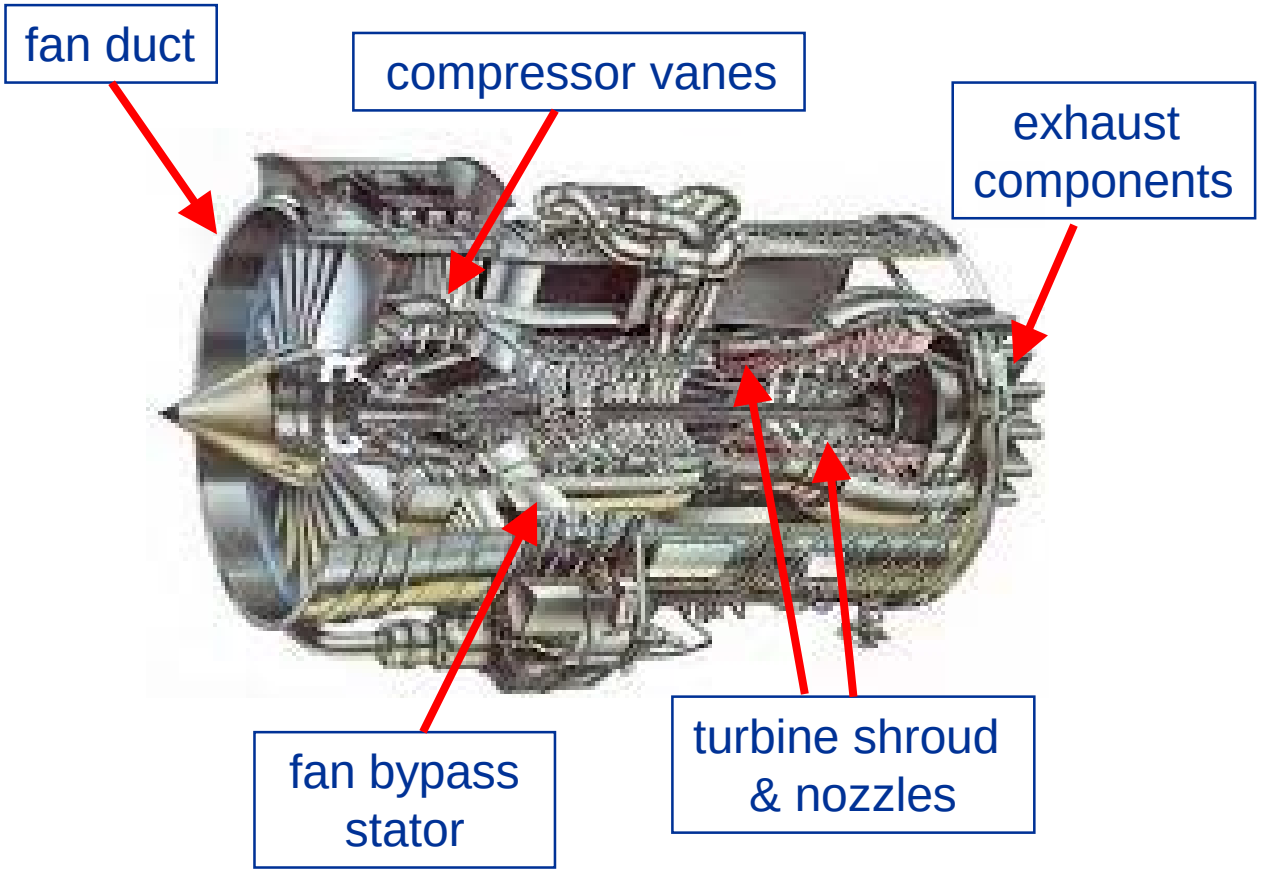


Communications Technology and Development

Power, Energy Storage and Conversion

Materials and Structures for Extreme Environments

Lightweight, high temperature composite materials improve engine efficiency



Use of these materials in critical engine components reduces emissions, fuel burn and weight

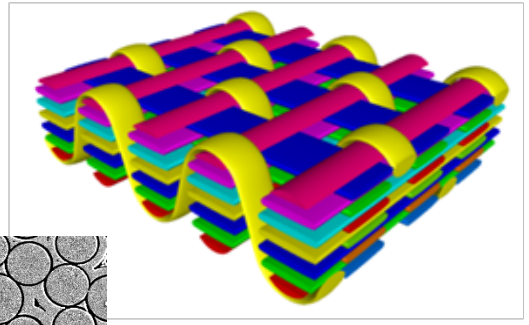
CMC Research at NASA Glenn

- CMC Development & Characterization
  - 2700ºF CMC development
  - measure effects of engine environment on durability
- CMC / EBC Durability: Modeling & Validation
  - predict durability & failure modes based on understanding of fiber, matrix & EBC interactions (multi-scale models)
- Additive Manufacturing
  - for turbine engine components and electric motor applications

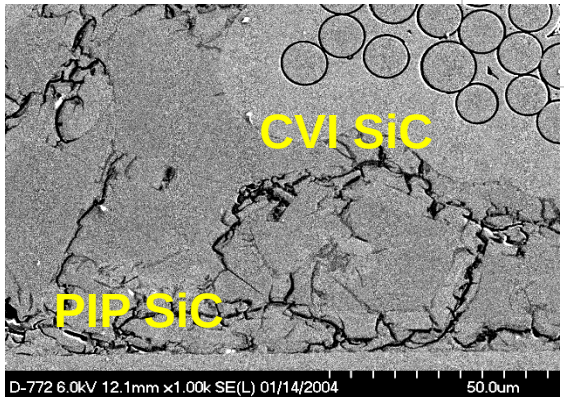
NASA 2700°F CMC combines three technology advancements

- **Creep-resistant Sylramic-iBN fiber**

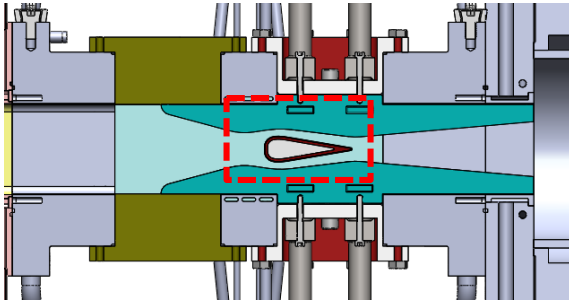
- **Advanced 3D fiber architecture**



- **Hybrid CVI-PIP SiC matrix**



Durable CMC / EBC material demonstrated in 2700ºF turbine environment



Turbine test rig used by P&W / UTRC

Challenge

A durable 2700°F Ceramic Matrix Composite with Environmental Barrier Coating would reduce cooling air required for turbine engine components, increasing engine efficiency and reducing fuel burn and emissions

Approach

- Fabricate turbine vane test article from 2700ºF CMC recently developed in TTT
- Coat CMC test article with Environmental Barrier Coating, using two different EBC processing methods
- Evaluate durability of CMC / EBC subelements in a TRL 5 rig test simulating a turbine environment, at temperatures to 2700ºF

Spall of EB-PVD coating after 7 hours of 2700F cycles

Durable slurry-coated test article after 15 hours at 2500 / 2600 / 2700ºF

Significance

For the first time, a durable CMC/EBC material system was demonstrated at TRL 5 in a 2700ºF turbine environment. Engine implementation could reduce fuel burn 6% in B737-size aircraft

Accomplishment

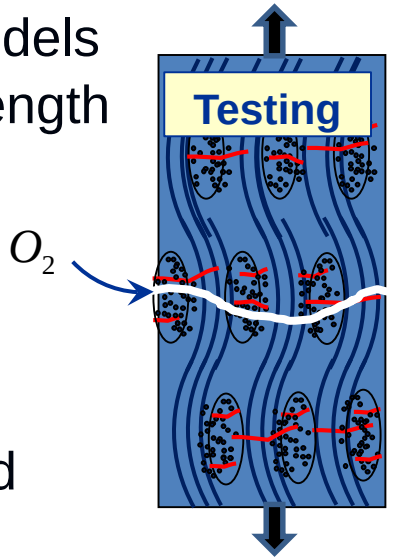
Demonstrated 15-hour durability for a CMC/EBC system with minimal spallation of the coating under simulated engine operating conditions at temperatures to 2700ºF

Modeling Environmental Effects on SiC/SiC CMCs

Objective: Determine oxidation mechanisms and develop models for the mechanical-oxidation-creep interactions that affect strength and life of SiC_f/BN/SiC CMCs

Approach:

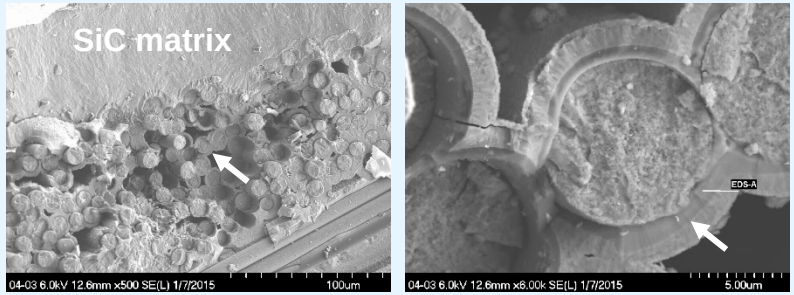
- Perform parallel and correlative *experimental* and *numerical analysis* studies.
- Build on the numerical solution methodology developed previously for the oxidation of C/SiC CMCs.



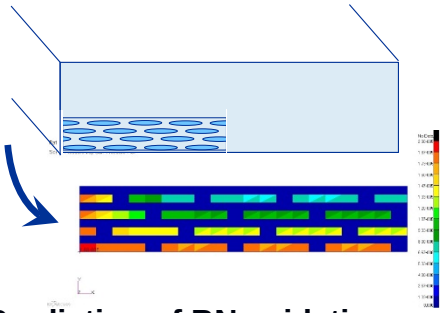
Testing and **Characterization** iterate **Modeling and Validation**

Notched CVI SiC/SiC Sample:

- **Pre-cracked to 250 MPa**
- **Held 300 h, 815°C (air), 172 MPa**



Fracture surface: oxidation of BN interphase near surface of specimen



Prediction of BN oxidation patterns at 30 h, 815°C (air)

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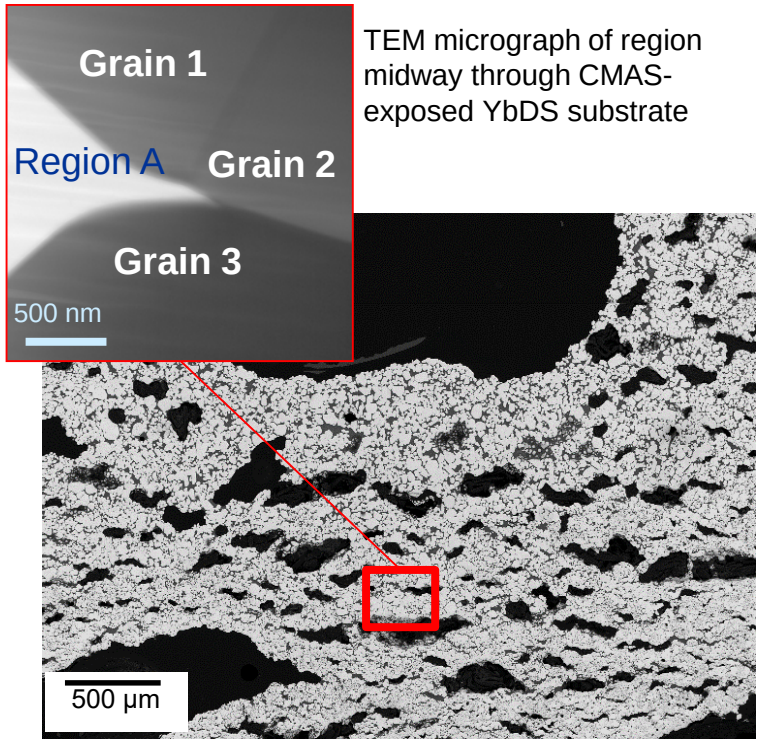
Development of CMAS-resistant EBCs

PROBLEM: Above 1100°C, molten calcium-magnesium-aluminosilicate (CMAS) can degrade environmental barrier coatings via thermochemical interactions, resulting in premature EBC failure

APPROACH:

- Understand causes of EBC degradation by characterizing thermochemical interactions of CMAS with ytterbium disilicate (YbDS) EBC
- Expose hot-pressed YbDS substrates to CMAS at 1200-1500ºC for 1- 50 hour durations
- Evaluate CMAS/YbDS interactions using transmission electron microscopy (TEM), selected area diffraction (SAD) and energy dispersive spectroscopy (EDS) for microstructural and compositional analysis



TEM micrograph of region midway through CMAS-exposed YbDS substrate

CMAS/YbDS substrate after 1500ºC-50h

OBSERVATIONS:

- CMAS infiltrated YbDS substrate, suggesting ytterbium disilicate is not effective as a standalone CMAS-resistant EBC
- TEM study revealed no apatite ($Ca_2Yb_8(SiO_4)_6O_2$) phase formation, supporting results from previous characterization

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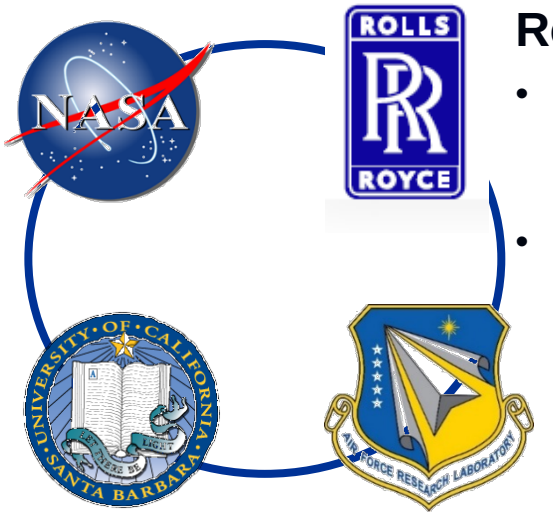
Consortium Established for CMC/EBC Environmental Durability Testing, Modeling & Validation

NASA Glenn

- Conduct mechanical testing of mini-composites at 2200-2700°F in air and steam environments
- Optimize EBC/CMC interface based on bonding and crack deflection
- Develop and validate models for mini-composite properties, durability and failure modes



Rolls Royce HTC

- Fabricate CMC mini-composites using industry fabrication processes and constituents
- Define relevant material operating conditions; stress, temperature, environment

Univ. California Santa Barbara

- Microstructural characterization of damage progression using Digital Image Correlation, Acoustic Emission measurement and SEM
- NASA Space Technology Research Fellowship

Air Force Research Labs

- Damage characterization using Digital Image Correlation and AE methods
- Microstructural characterization by High Energy x-ray imaging (w/ UC Berkeley) and automated serial sectioning of test specimens with data reconstruction

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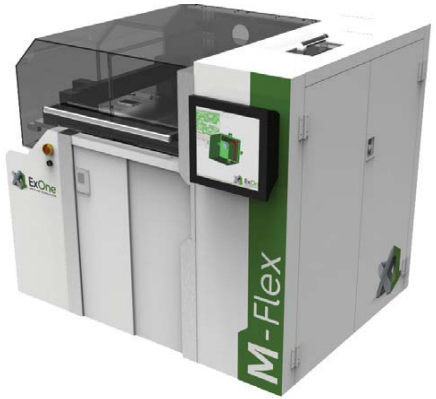
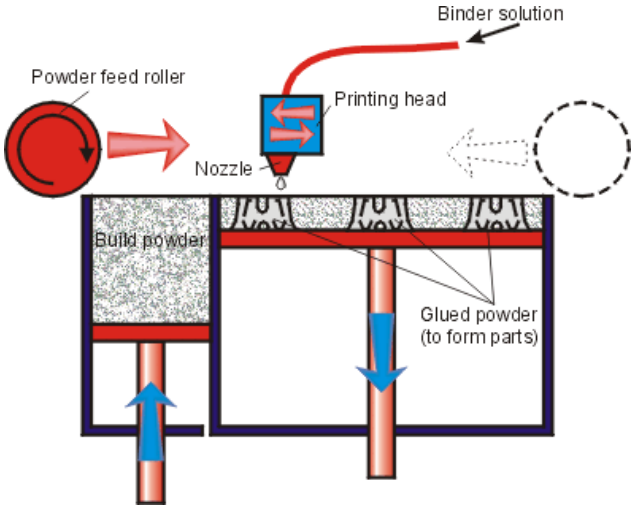
Additive Manufacturing: GRC Composites Research



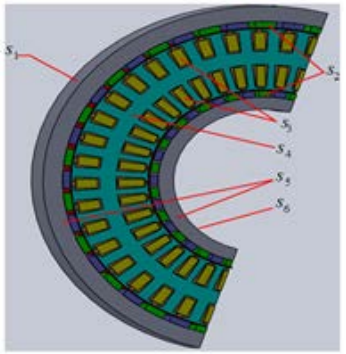


ExOne M-Flex Binder Jet machine:

Powder bed process with *tailored binders* and *chopped fibers* for CMC fabrication

n-Scrypt direct printing machine:

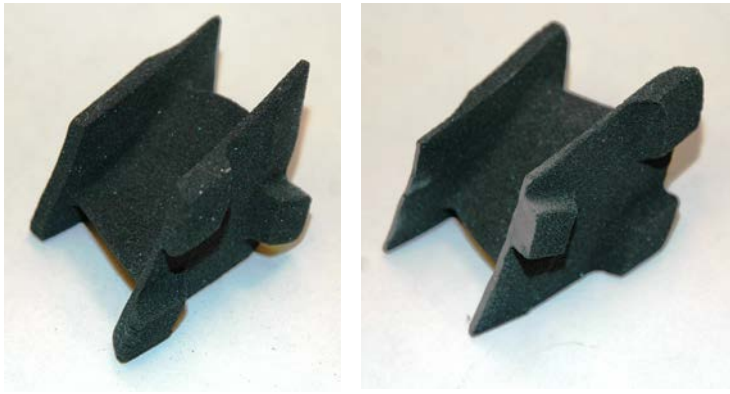
- Multi-material systems
- Ceramic pastes, electronic pastes, adhesives, solders, plastics



Multi-material stator for high power density electric motor

The first CMC turbine engine components by additive manufacturing

high pressure turbine nozzle segments



first stage nozzle segments

cooled doublet nozzle sections

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SiC/SiC CMCs have 20% chopped SiC fiber