Fundamental Aeronautics Program

Supersonics Project

Recent Progress and Future Directions for CMC Research and Development at NASA Glenn

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Glenn Research Center

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Cleveland, Ohio

NASA Aeronautics Programs



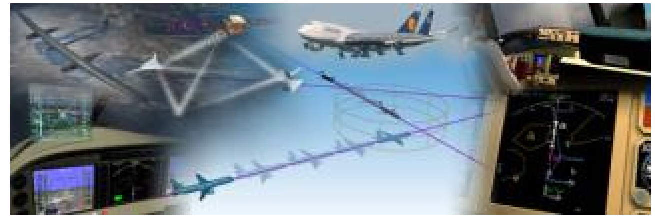

Fundamental Aeronautics Program

Conduct fundamental research that will produce innovative concepts, tools, and technologies to enable revolutionary changes for vehicles that fly in all speed regimes.

Integrated Systems Research Program

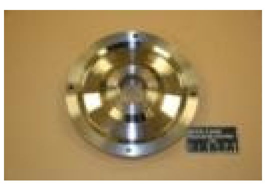
Conduct research at an integrated system-level on promising concepts and technologies and explore/assess/demonstrate the benefits in a relevant environment





Airspace Systems Program

Directly address the fundamental ATM research needs for NextGen by developing revolutionary concepts, capabilities, and technologies that will enable significant increases in the capacity, efficiency and flexibility of the NAS.

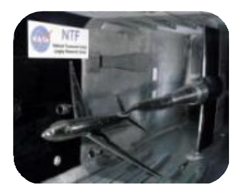
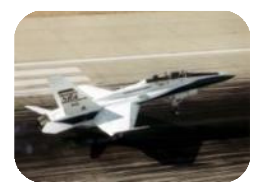



Aviation Safety Program

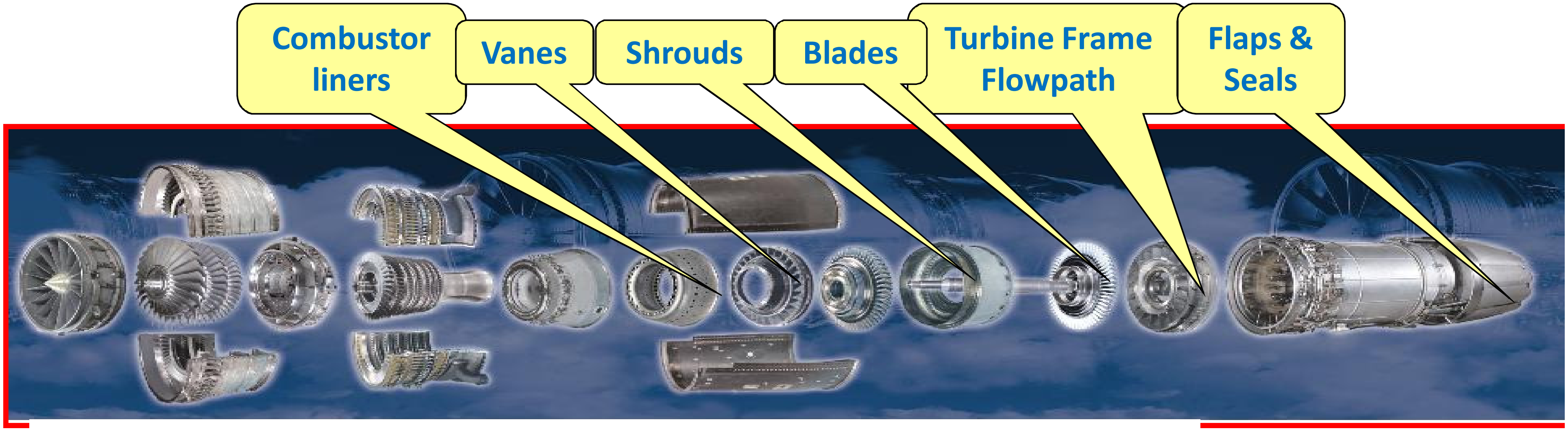
Conduct cutting-edge research that will produce innovative concepts, tools, and technologies to improve the intrinsic safety attributes of current and future aircraft.

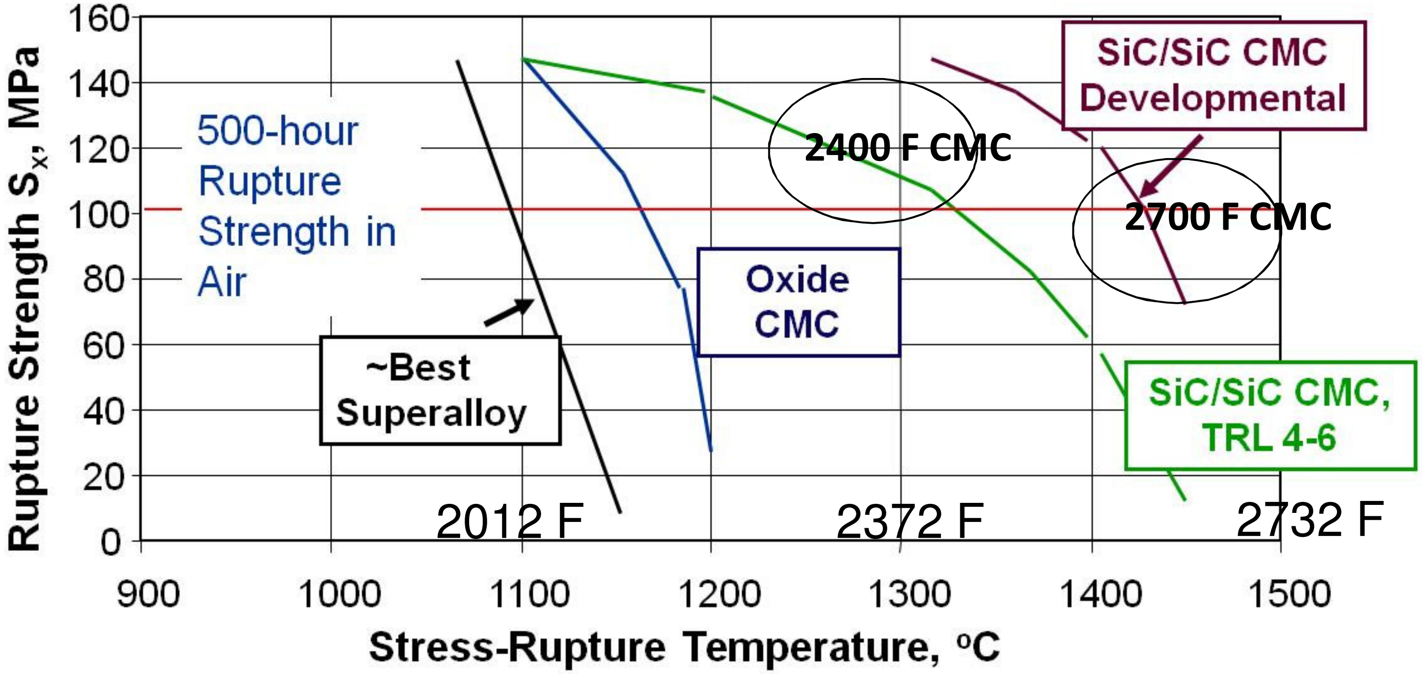

Aeronautics Test Program


Preserve and promote the testing capabilities of one of the United States' largest, most versatile and comprehensive set of flight and ground-based research facilities.

CMC Component Applications





SiC/SiC CMC offers at least 400°F advantage over superalloys at 1/3 density

Summary of Fuel Burn Reduction

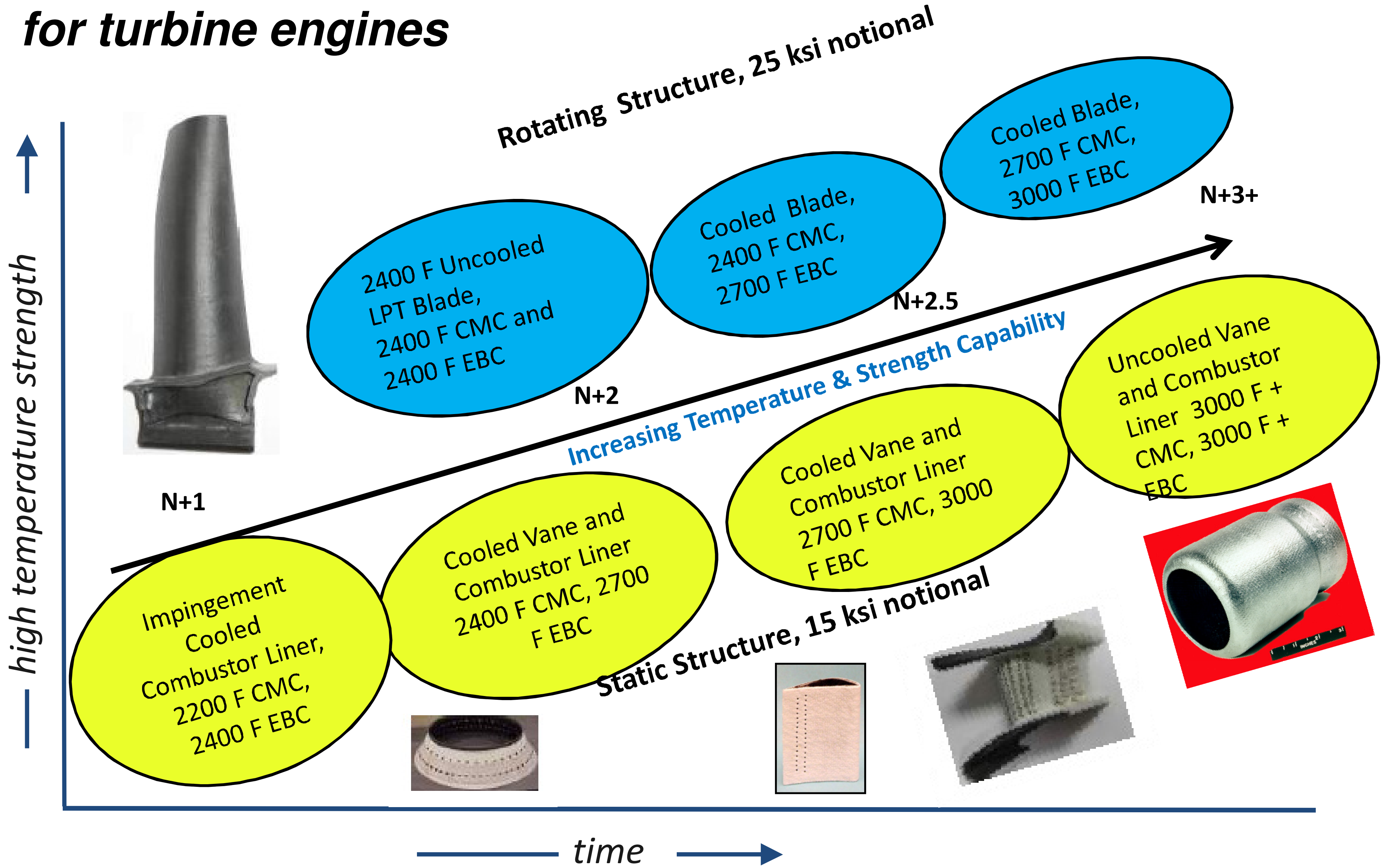
2700 ^{o}F CMC Materials

CMC Application	SFC Reduction	Engine Weight Reduction	Fuel Burn Reduction
HPT Vanes	-0.5%	-0.45%	-0.95%
HPT Blades*	-1.8%	-0.8%	-3.1%
LPT Vanes/Blades*	0	-3.6%	-0.7%
Burner ΔP (5% to 3%)	-0.75%	0	-1.25%
Overall Reduction	-3.0%	-4.85%	6.0%

Similar analysis shows a corresponding 33% decrease in NO_X emissions resulting from CMC combustor liner implementation

CMC Technology Development Roadmap

for turbine engines



Objectives of CMC Research Programs

Fundamental Aeronautics Program

longer term research, 2011-2020

Objective: High Pressure Turbine blade with 3000°F surface capability

- 2700°F CMC development underway
- 3000°F thin EBC development underway
- Development of validated life prediction capabilities for CMC/EBC systems underway

Environmentally Responsible Aviation

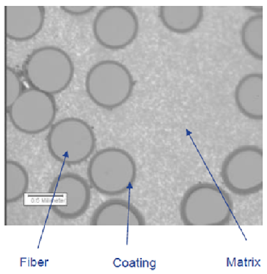
near term technologies, 2010-2015

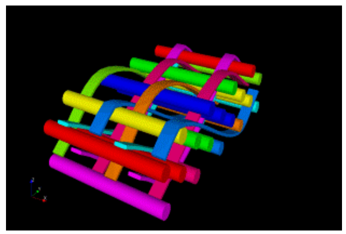
Objective: TRL 5 (rig) and TRL 6 (engine) demonstration of durable HPT vane and combustor liner by 2015

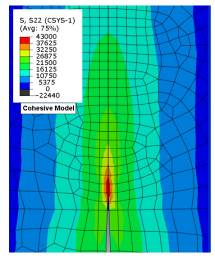
- 2400°F SiC/SiC CMC
- 2700°F EBC

CMC Research Project Deliverables

FAP / Supersonics (2011-2020): develop 3000°F CMC/EBC, optimize architecture & validate models

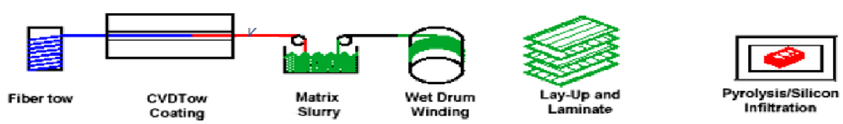


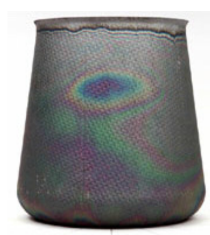


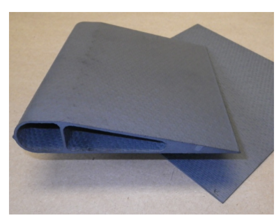


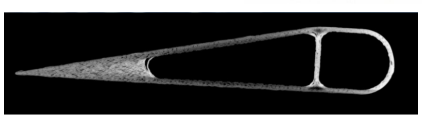
ERA (2010-2012): establish processing approach and properties, evaluate combustor & vane subelement

baseline fabrication

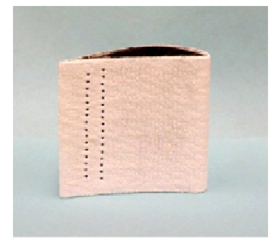


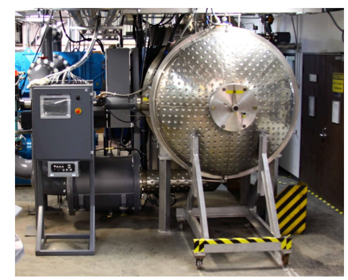






ERA Ph. 2 (2013-2015): design and fabricate components, conduct rig and engine tests to evaluate long-term durability





2011 Accomplishments

- Analyzed creep and rupture data for candidate SiC/SiC systems to understand the underlying mechanisms controlling maximum use temperature and long term durability

- Evaluated candidate processing approaches for 2700°F SiC matrix
  - focused on development of a "hybrid" matrix that combines benefits of CVI and PIP processes

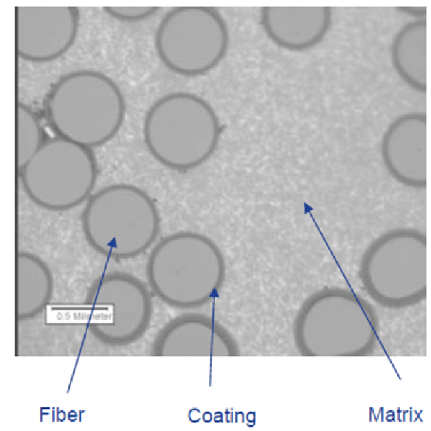
- Initiated development of a SiC fiber with 2700°F durability superior to current state-of-the-art

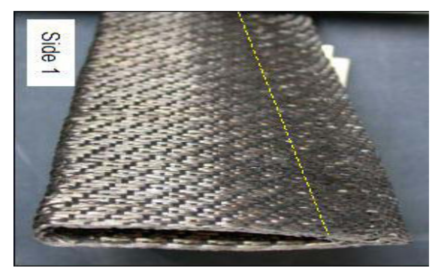
- Identified candidate 3D fiber architectures to best meet key performance requirements for 2700°F HPT vane

2700°F CMC Matrix Development

Objective: Optimize hybrid silicon carbide matrix to enable fabrication of ceramic matrix composites with high strength, thermal conductivity and creep resistance at 2700°F well beyond current state-of-the-art composites. Coordinate GRC research approach with complimentary AFRL CMC development program.

Activities Required for Milestone Completion	Due Date	Exit Criteria/Comments
Fabricate fiber preforms at TEAM vendor	04/30/12	Deliver flat panel (two 6x9 inch panels for each of six candidate 3D architectures) and airfoil-shaped preforms fabricated with current state-of-the-art silicon carbide fiber.
Infiltrate fiber preforms at Hyper-Therm vendor	06/30/12	Deliver airfoil preforms after melt infiltration. Deliver flat panel preforms after chemical vapor infiltration (CVI) coating of boron nitride and silicon carbide.
Infiltrate fiber preforms at EEMS vendor	08/30/12	Complete polymer impregnation and pyrolysis (PIP) infiltration of CVI-coated flat panel preforms and deliver hybrid matrix (CVI + PIP) composites for testing.
CMC matrix with 2700°F temperature capability developed	09/30/12	Hybrid-matrix thermal stability and improved matrix cracking stress level demonstrated at 2700°F.





fiber preform

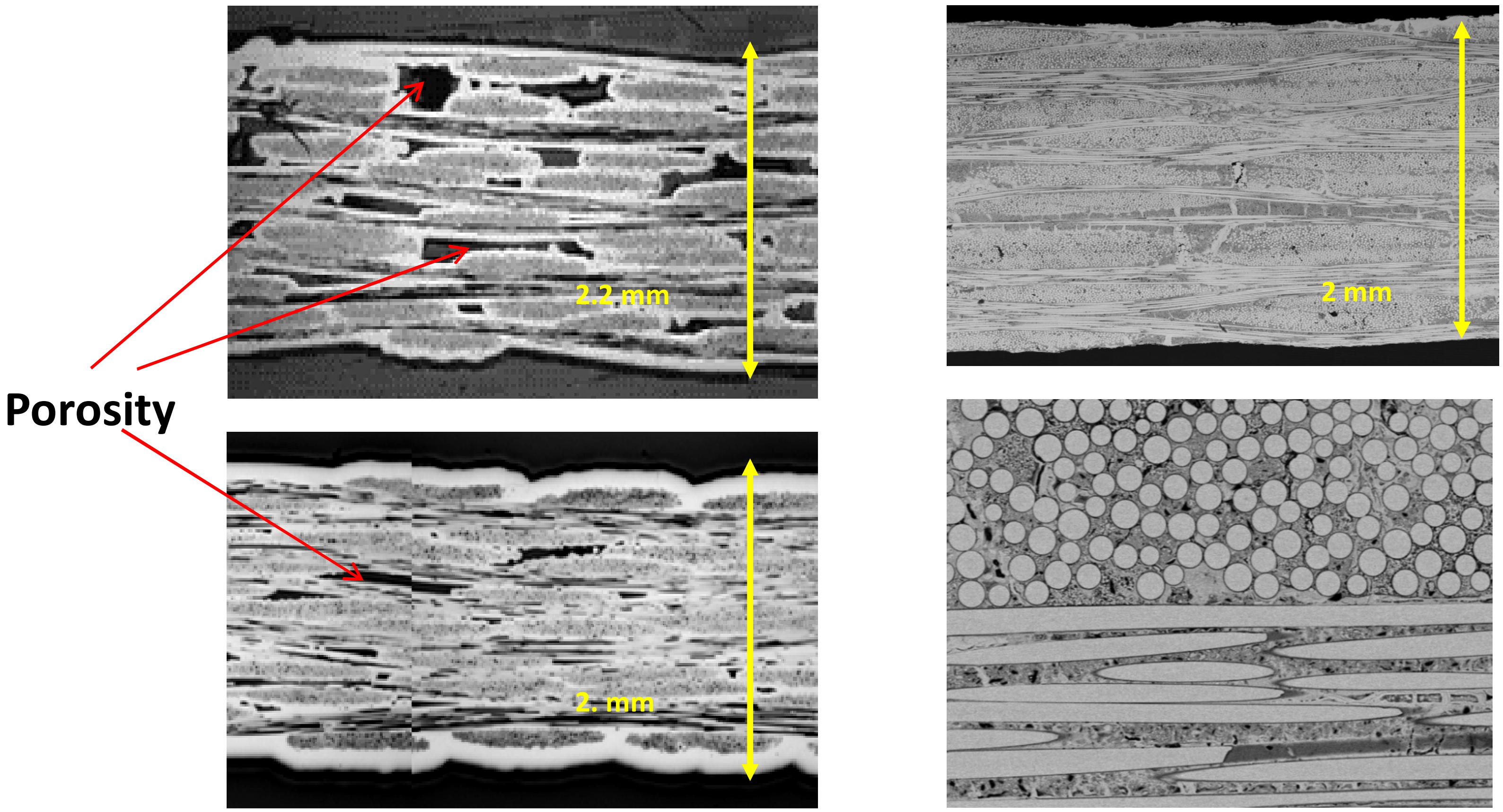
Status:

- Downselected six candidate 3-D fiber architectures for evaluation
- Shipped Sylramic fibers to vendor for weaving 3-D fiber preforms
- Reviewed CMC fabrication requirements with interface coating and PIP vendors

POC:
Ram Bhatt
3-5513

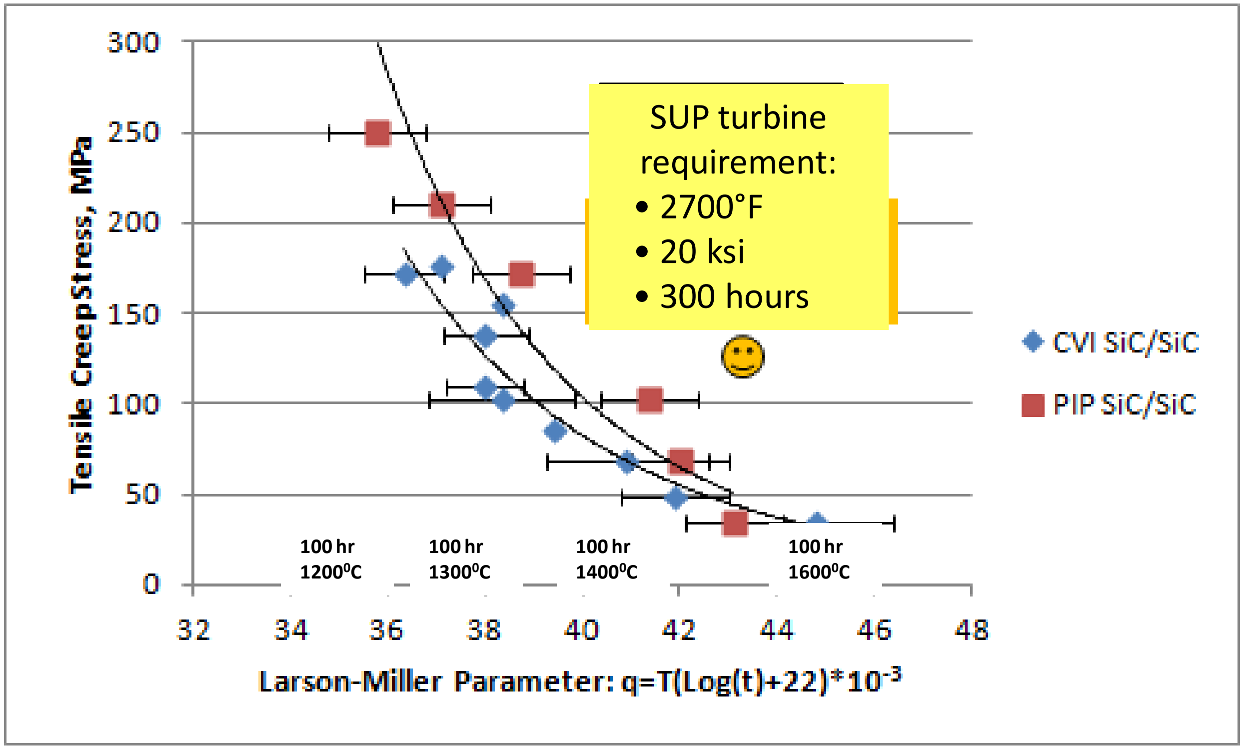
Microstructures of CVI and PIP Composites

CVI SiC/SiC | **PIP SiC/SiC**



	CVI SiC/SiC	PIP SiC/SiC
Advantages:	• Near stoichiometric matrix • Good creep-resistance	• Low cost, high fiber fraction
Disadvantages:	• High porosity, process time	• Micro-cracked matrix • Poor off-axis properties

Creep Rupture Strength of CVI and PIP Composites

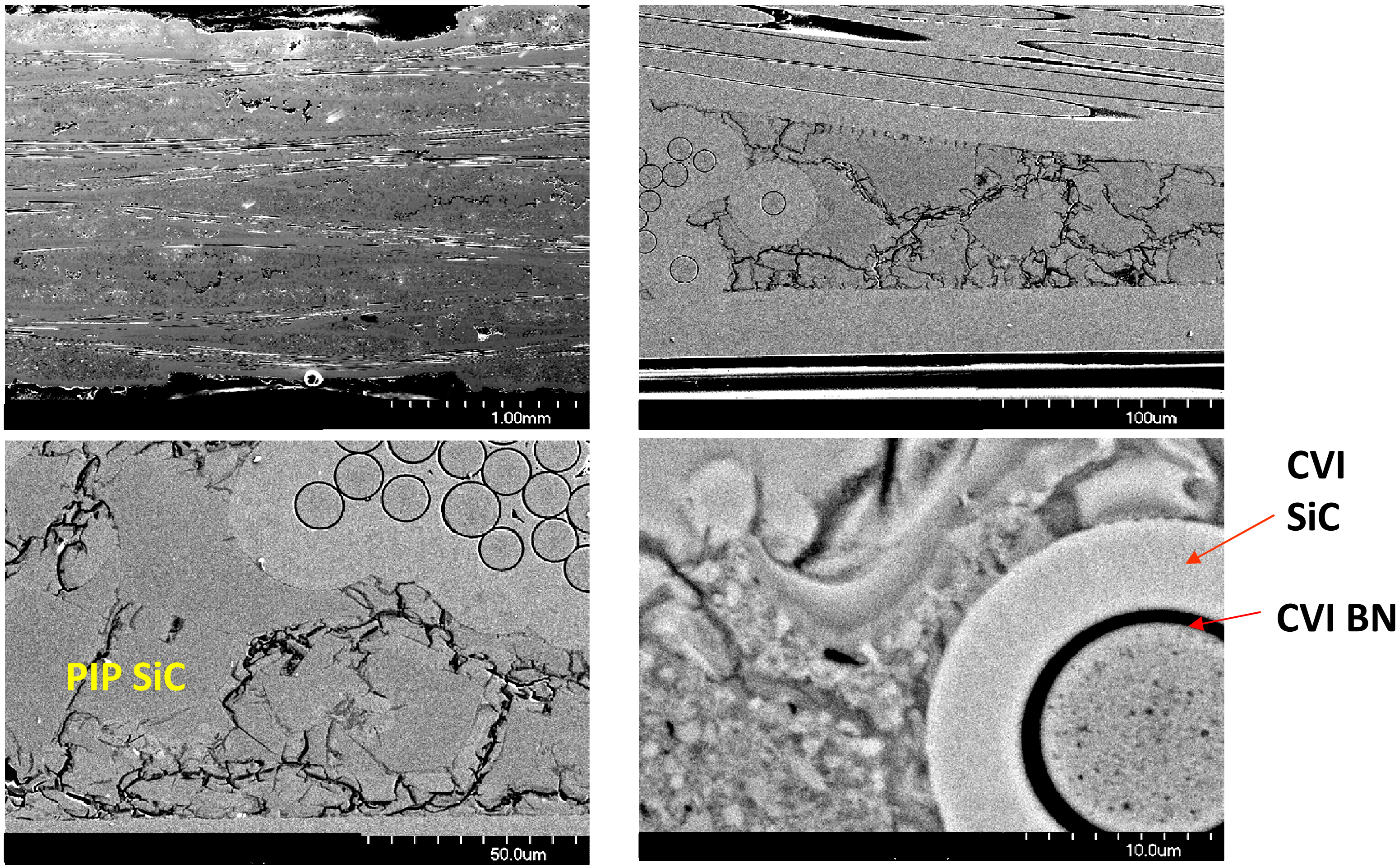


t = rupture time (hours) at constant stress

Neither material meets requirement for 2700°F turbine application due to low fiber creep resistance at higher temperatures

Above 2500°F, CVI composites show better creep rupture lives due to better load-carrying capability in the matrix

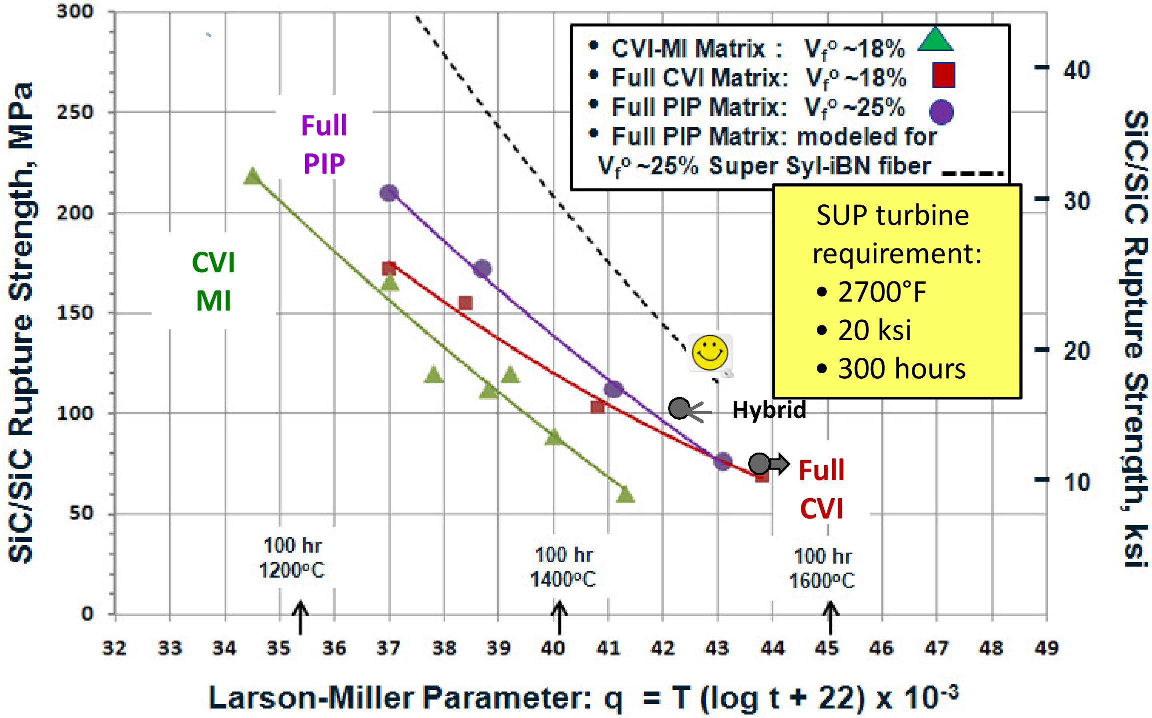
NASA Focus: Hybrid (CVI + PIP) Matrix



Advantages:

- **Reduced porosity; higher MCS and thermal conductivity**
- **Reduced matrix cracking; better oxidation resistance & off-axis properties**

Hybrid Matrix: Durability Comparison

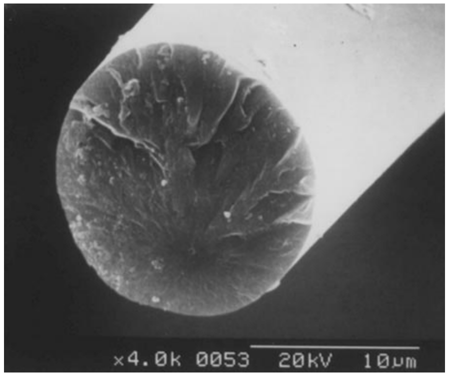


- Hybrid matrix performs better than PIP due to greater creep-resistance of the annealed CVI SiC component
- Hybrid matrix performs better than CVI due to better oxidation resistance of PIP component
- Advanced fiber is needed to meet 2700°F turbine goal

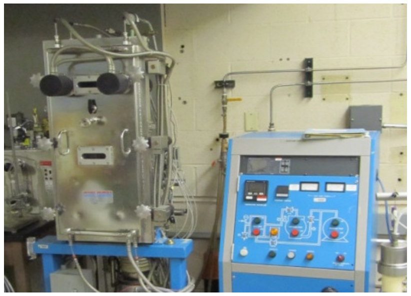
2700°F CMC Fiber Development

Objective: Conduct theoretical and experimental studies to establish fabrication processes for a 2700ºF SiC fiber and to ultimately develop a 3000ºF Ultra High Temperature SiC fiber. Assure that high-quality precursor fibers are available through collaboration with industry and Air Force Research Labs.

	Milestone	Due Date	Exit Criteria/Comments
SUP	GRC processes for 2700F Super Sylramic-iBN fiber re-established	03/12	2700F fiber properties at low and high temperatures validated
SUP	Design and demo Super-iBN fiber preforms for 2700F airfoil	04/12	Designs successfully fabricated at commercial weaver
SEED	UHT fiber and tow fabricated	06/12	UHT fiber properties at low and high temperatures measured
SUP	2700F fiber process transferred to industry	08/12	Industrial 2700F fiber properties validated
SUP	High-quality Sylramic precursor for 2700F fiber available	09/12	COI Ceramics providing high quality Sylramic fibers
SUP	2700F "Super Sylramic-iBN" SiC fiber demonstrated in lab scale	09/13	500 hour creep rupture tests completed and comparison with current SOA fiber published



UHT Fiber Sintering Furnace



Status:

- Optimal sintering process for UHT fiber established
- In-house and vendor efforts underway for sintering 2700°F fiber precursor
- Completed chemical characterization of Lox M precursor fiber to determine oxygen, titanium and iron content prior to testing
- Conducted initial AES surface analysis of baseline fiber

POC: James DiCarlo, 3-5514

Fabrication Process for 2700°F Fiber

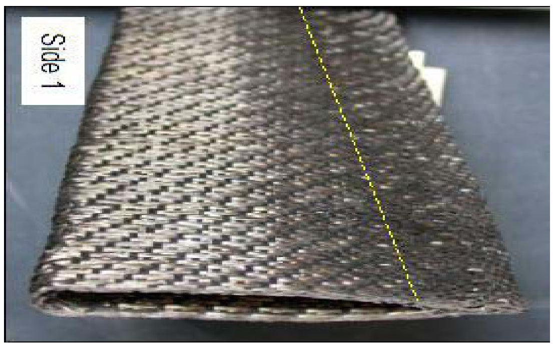
Boron-Sintered SiC Fiber Preform
(formed from commercial "Sylramic" Fiber)

→

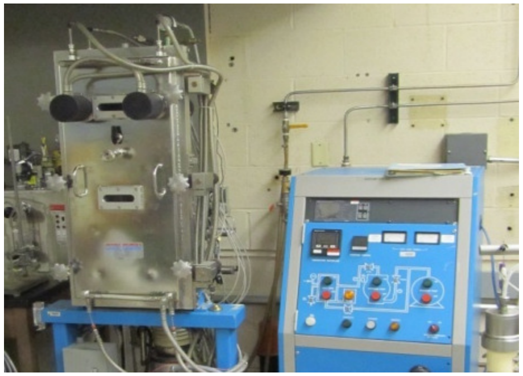
Preform Treatment in High-Pressure N_2
(Boron removal for SOA creep-rupture resistance)

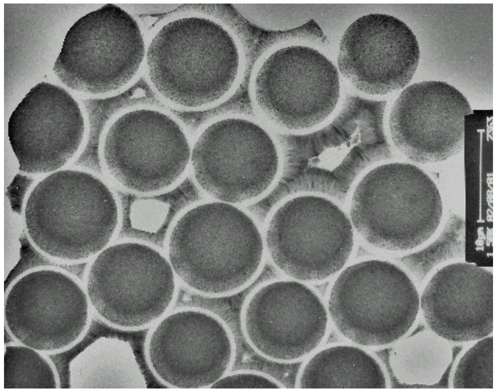
→

Super Sylramic-iBN Preform
(in-situ grown BN surface layer on each fiber for environmental protection)



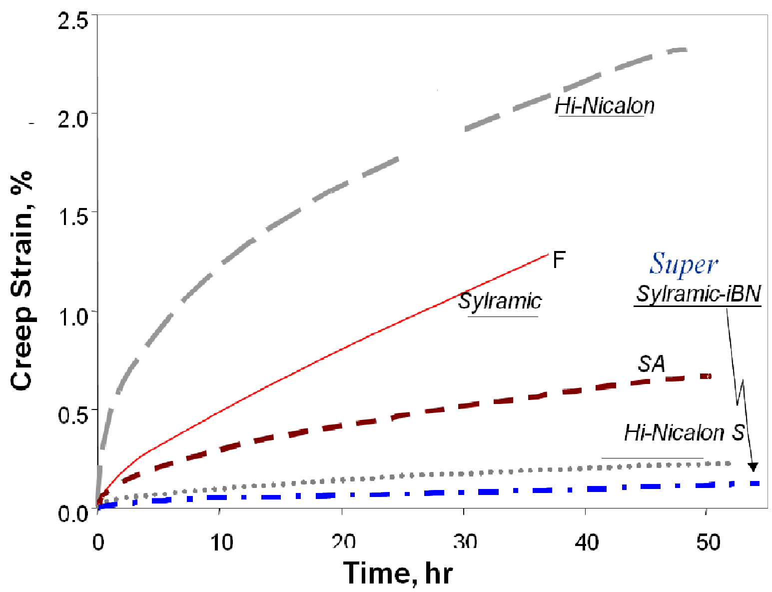
Blade Preform

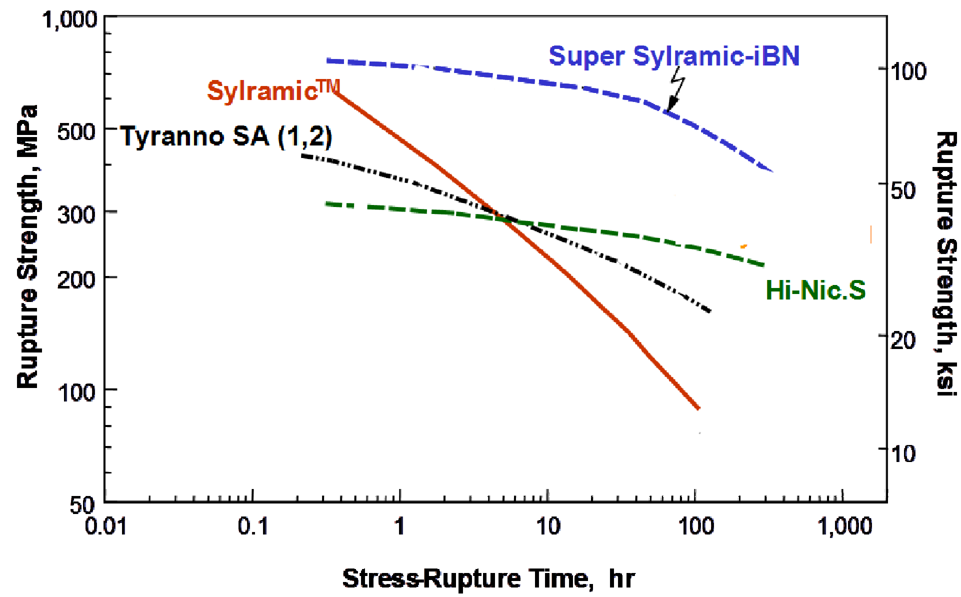

Preform Treatment Furnace


iBN coating
between every fiber

Fiber treatment process improves on 2009 NASA patent for Sylramic-iBN fiber

Creep and Rupture Resistance of SiC Fibers



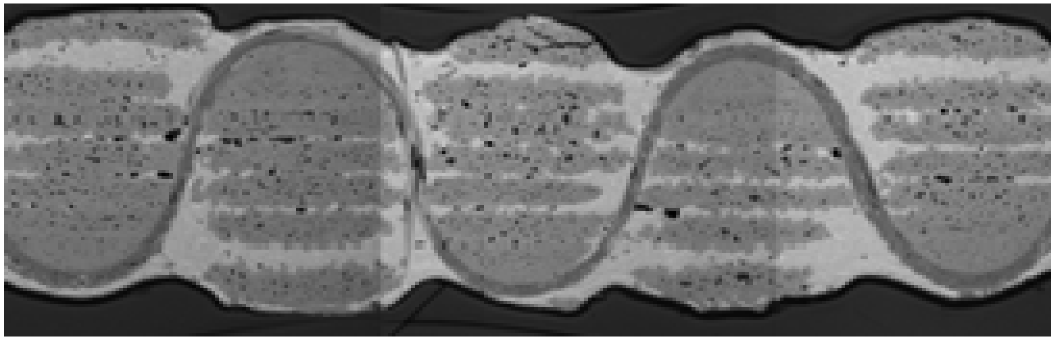


Data measured in air
at 2550°F, 40 ksi

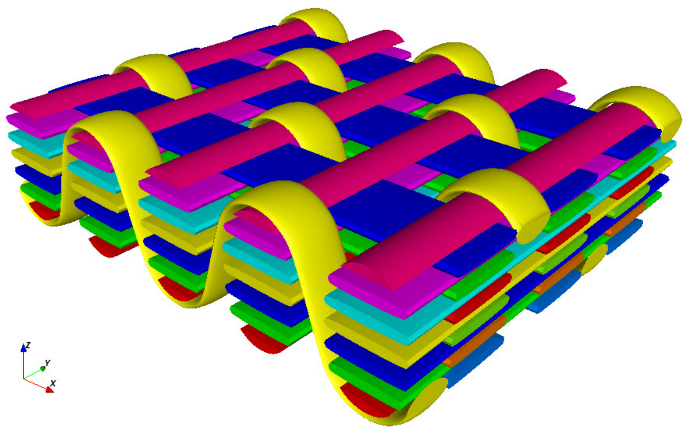
High-pressure nitrogen-treated Super Sylramic-iBN fiber shows state-of-the-art creep and rupture resistance in air with projected capability to 2700°F

3D Fiber Architectures Increase CMC Durability

for turbine applications



3D-orthogonal fiber architecture



fiber architecture analysis and visualization tool

	Repeating Unit Volume Dimensions, mm			Total Fiber Volume, %		
	H	W	L	Warp Stuffer	Fill Stuffer	Warp Weaver
Predicted	1.9	3.0	1.4	14.3	17.4	3.3
Measured	2.0	3.0	1.4	15.2	17.4	3.2

3D fiber architectures suppress delamination and increase thermal conductivity

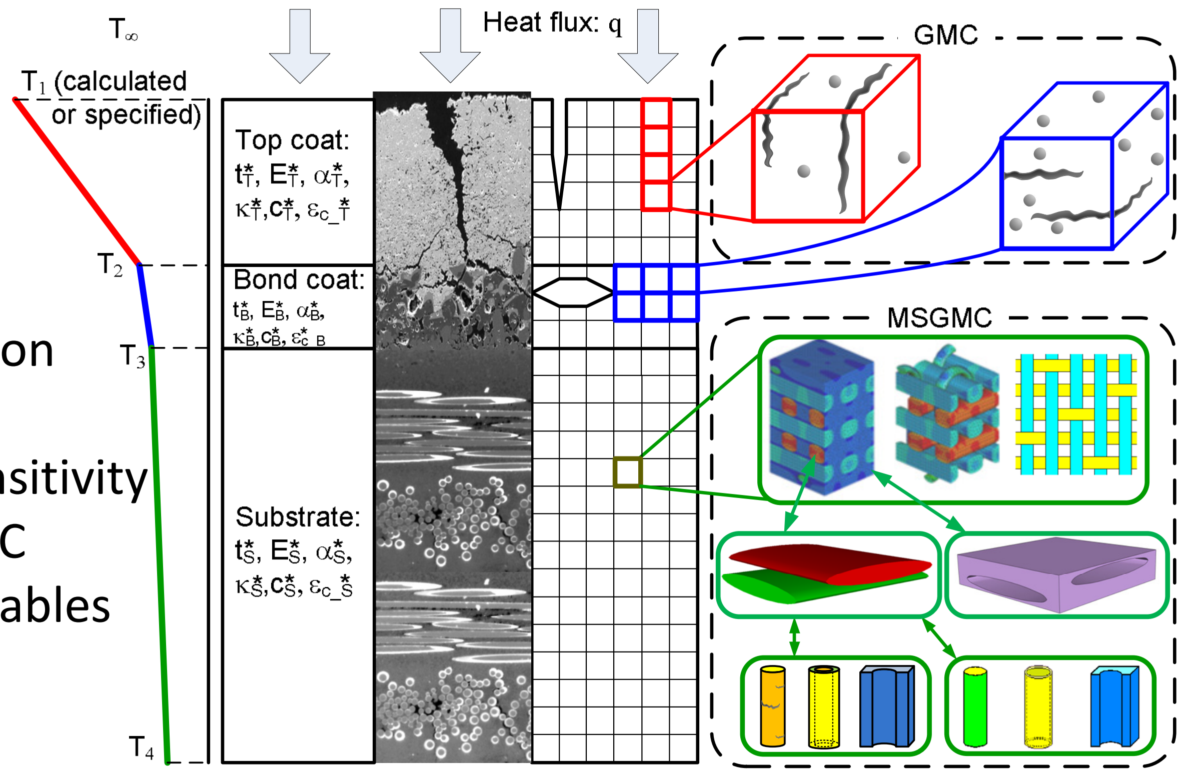
Multi-Scale Modeling Approach

for life prediction of CMC / EBC systems

Failure defined as EBC spallation resulting from a combination of:

- EBC cracking
- EBC / bond coat delamination

Objective: understand the sensitivity of failure driving forces to CMC properties and geometric variables

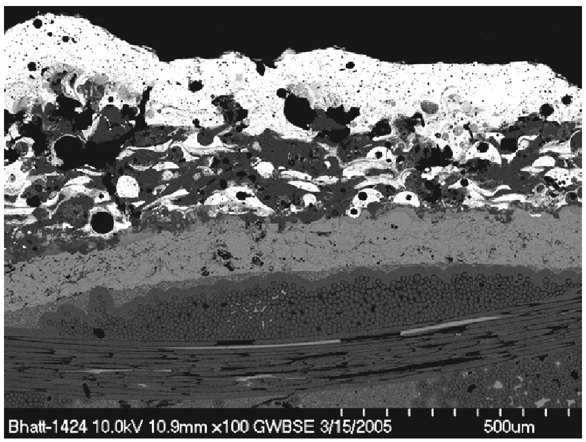


Relates constituent-level properties to CMC / EBC failure modes

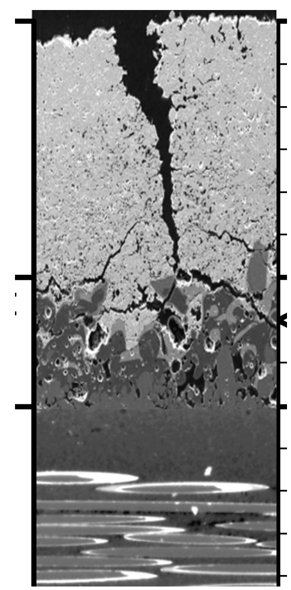
Collaboration Opportunities

- **CMC/EBC Durability Consortium** (Summer 2012)

  for the development of validated models of failure modes specific to CMC/EBC systems in turbine engine environment.



The workshop will review and disseminate results of ongoing NASA research with a focus on understanding thermal, mechanical and environmental interactions between CMC and EBC that affect failure mechanisms and durability in turbine and combustor.



- **RFI-ERA-2012** posted on NASA Acquistion Internet Service for April 20 response. Requesting info for FY15 Integrated Technology Demonstrations. Spring 2012 solicitation planned.

Summary

- **NASA CMC development is focused on meeting the requirements for turbine vanes and blades with reduced cooling. Near-term capabilities will be demonstrated in the ERA project (2015). Advanced capabilities (2700-3000°F) for increased performance are being developed in the Supersonics project.**

- **Durable CMC turbine blades with 2700^{0}F, 20 ksi, 300 hr capability will require development of SiC fibers with increased creep resistance, 3D fiber architectures and hybrid SiC matrices**

- **NASA will demonstrate an advanced hybrid matrix that meets these requirements in FY12 and an advanced fiber in FY13. We anticipate that CMC's fabricated with these constituents will have improved through-the-thickness strength and thermal conductivity, while maintaining high in-plane properties such as creep and rupture resistance.**

NASA