Overview of CMC Research at NASA Glenn Research Center

Abstract

CMC technology development in the Ceramics Branch at NASA Glenn Research Center addresses Aeronautics propulsion goals across subsonic, supersonic and hypersonic flight regimes. Combustor, turbine and exhaust nozzle applications of CMC materials will enable NASA to demonstrate reduced fuel consumption, emissions, and noise in advanced gas turbine engines. Applications ranging from basic Fundamental Aeronautics research activities to technology demonstrations in the new Integrated Systems Research Program will be discussed.

Overview of CMC Research at NASA Glenn Research Center

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Ceramics Branch

35th Annual Conference
on Composites, Materials and Structures
Cape Canaveral, Florida
January 24-27, 2011

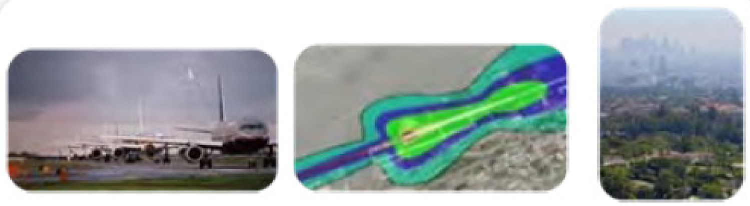
NASA Aeronautics Programs in 2011

Fundamental Aeronautics Program

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

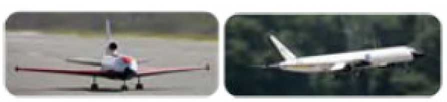
Integrated Systems Research Program

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



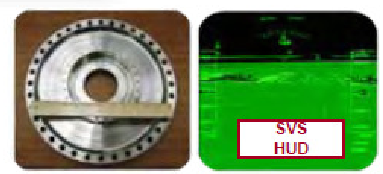
Airspace Systems Program

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.

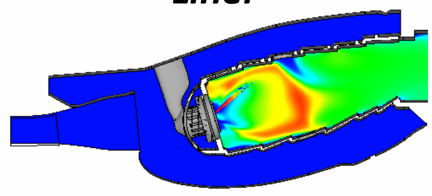


Aeronautics Test Program

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 requirements for aeronautics applications

Combustor Liner



Requirements:
- 2200-2700°F (mid-term)
- 3000 F (long-term)
- 5000 hours

Challenges:
- Recession
- 2700°F EBC
- Thermal stresses
- Attachment & integration

Benefits:
- Reduced emissions

Turbine Blade and Vane

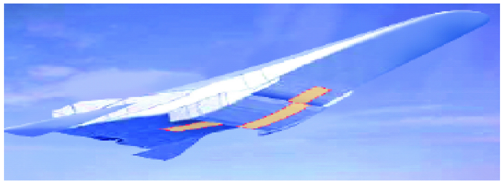
Requirements:
Near term:
- 2400 / 2700°F CMC/EBC

Longer term:
- 2700 / 3000°F CMC/EBC
- 500-3000 hours

Challenges:
- Recession
- Higher stresses
- EBC durability

Benefits:
- Reduced fuel burn

Hypersonic Airframe Components



Requirements:
- 3000°F
- 10 ksi
- 100 hours
- Reusable

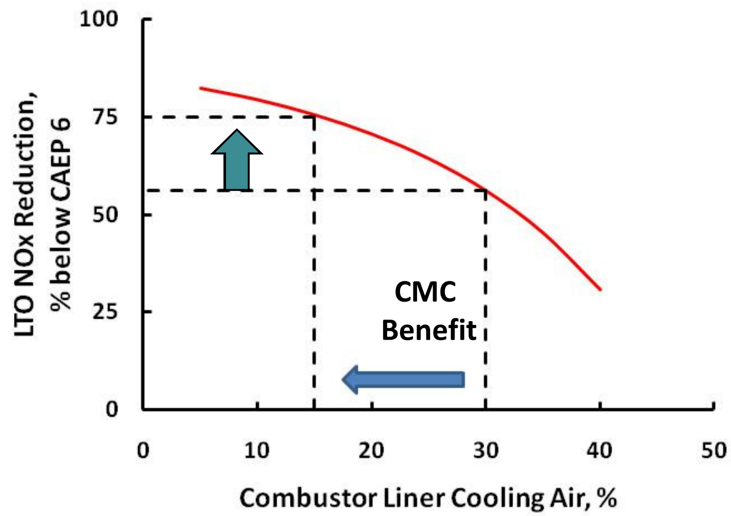
Challenges:
- Creep
- Oxidation
- EBC

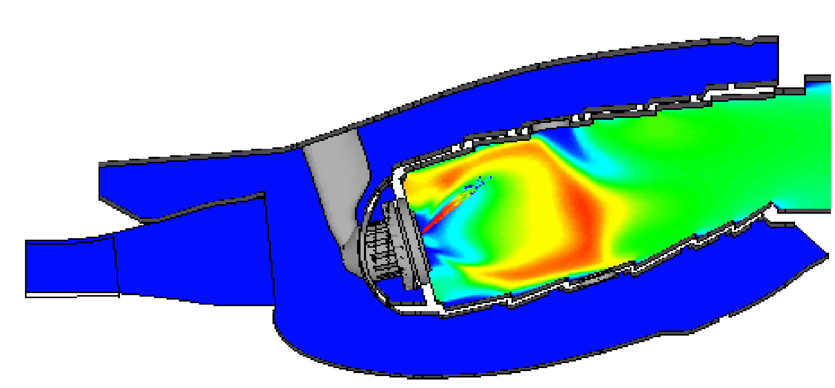
Benefits:
- Reduced cost of payload to orbit

GRC Effort is Focused on SiC/SiC Composites with Environmental Barrier Coating

CMC combustor liners reduce engine emissions for ERA

- 2700°F coated SiC/SiC will enable increased efficiency and reduced emissions
- ERA will focus on CMC durability characterization and EBC development





Low emission combustor concept

FY11-12 Plans:

- Establish creep and TMF baseline
- Model thermal gradient cyclic durability
- Evaluate effects of combustion environment
- Quantify recession of CMC and coating

50% reduction of combustor cooling air would reduce NOx formation ~ 50%

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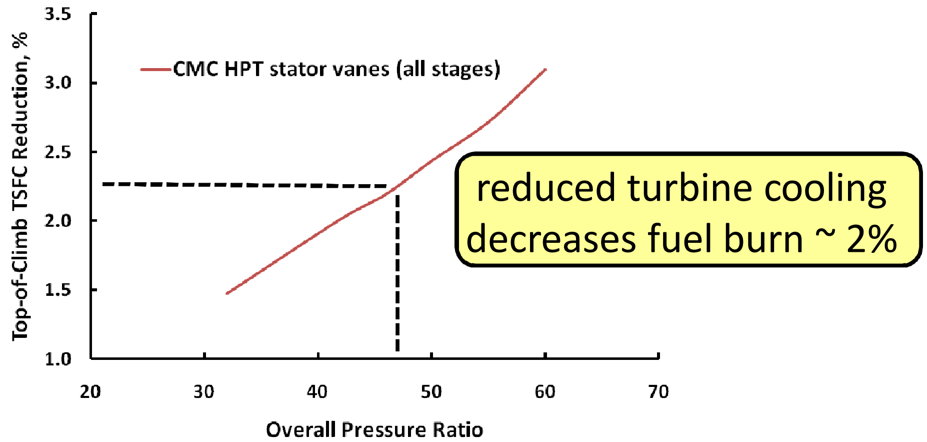
CMC turbine vanes will reduce fuel burn

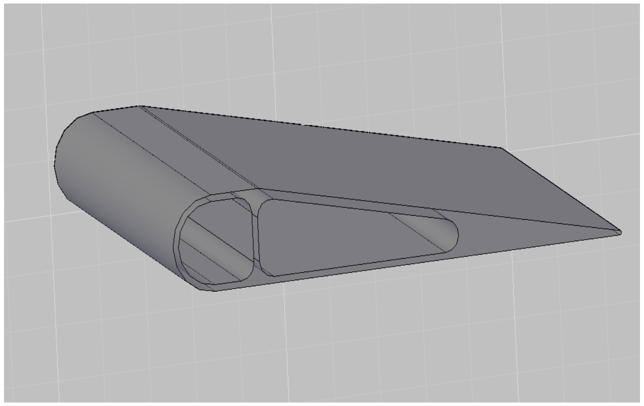


<u>Prepreg lay-up assembly</u>

- Hi-Nic type S fibers
- BN interface coatings
- Balanced ply lay-up
- $0/90^{o}$ tapes
- Fiber volume ~ 28%

<u>CVI SiC with MI SiC</u>

- Hi-Nic Type S fibers
- CVI BN fiber coatings
- 5 harness satin weave
- Fiber volume ~ 35%

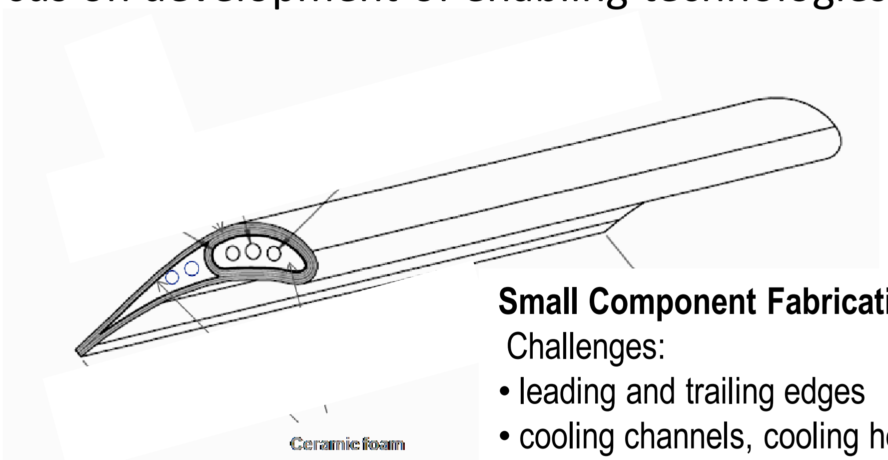


turbine vane test article

Durability of candidate CMC systems with EBCs will be compared in 2011

Enabling technologies to be developed for hybrid vane

- Objective: increase efficiency of rotorcraft engines
- Approach: use CMCs in small-engine applications (chord length ~ height ~ 1 inch)
- Focus on development of enabling technologies

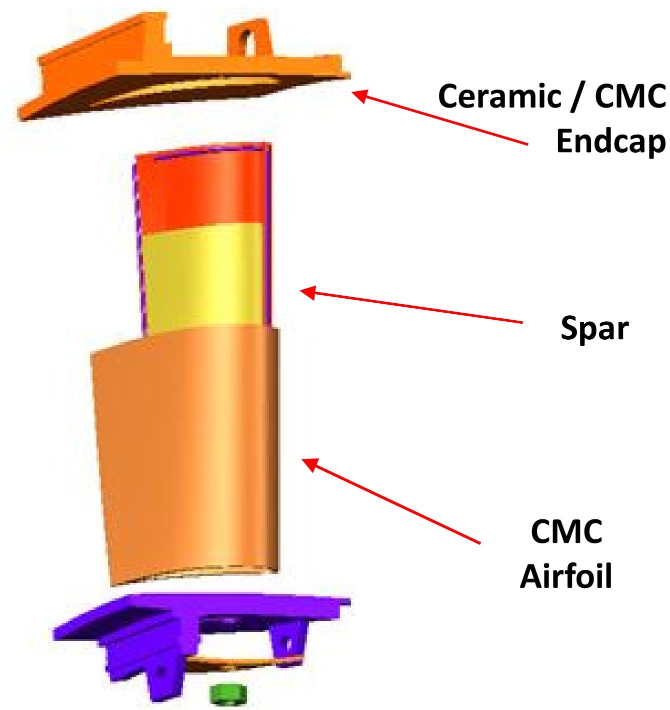


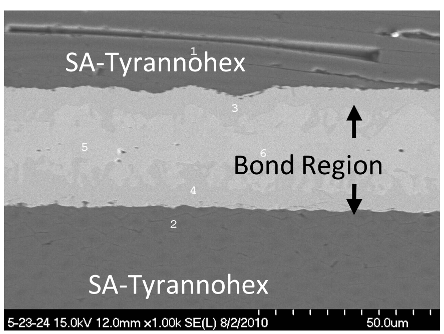
Small Component Fabrication

Challenges:

- leading and trailing edges
- cooling channels, cooling holes

HPT hybrid vane concept



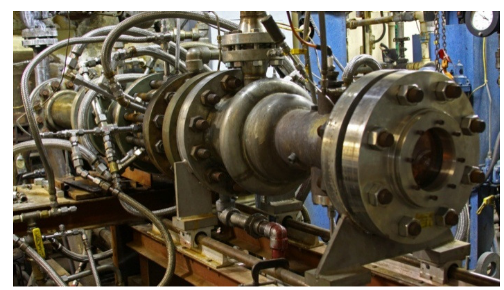


Ceramic Joining and Integration

- Challenges: joining dissimilar spar and airfoil materials

Durability Testing

High pressure burner rig



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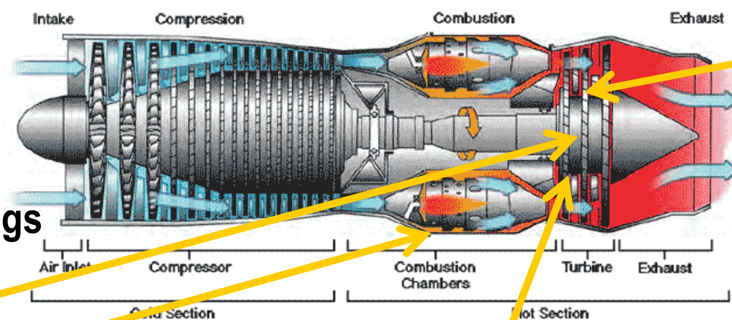
Environmental Barrier Coatings for turbine engine hot section CMC components

- *Coating Development, Including Advanced Processing*
- *Environmental Durability Testing*
- *Ceramic Material High Temperature Chemistry Research*

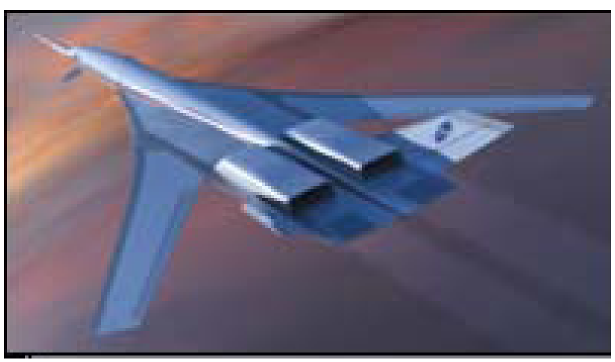


Environmentally Responsible Aviation

Environmental Barrier Coatings (EBCs) for
CMC Turbine Vanes
CMC Combustor Liners

Subsonic Rotary Wing

Metal/Ceramic Hybrid Blade Material/Coating Systems



Supersonics

Advanced EBCs for Si-based Ceramic Matrix Composite (CMC) Turbine Blades

Environmental Durability & Coatings Branch

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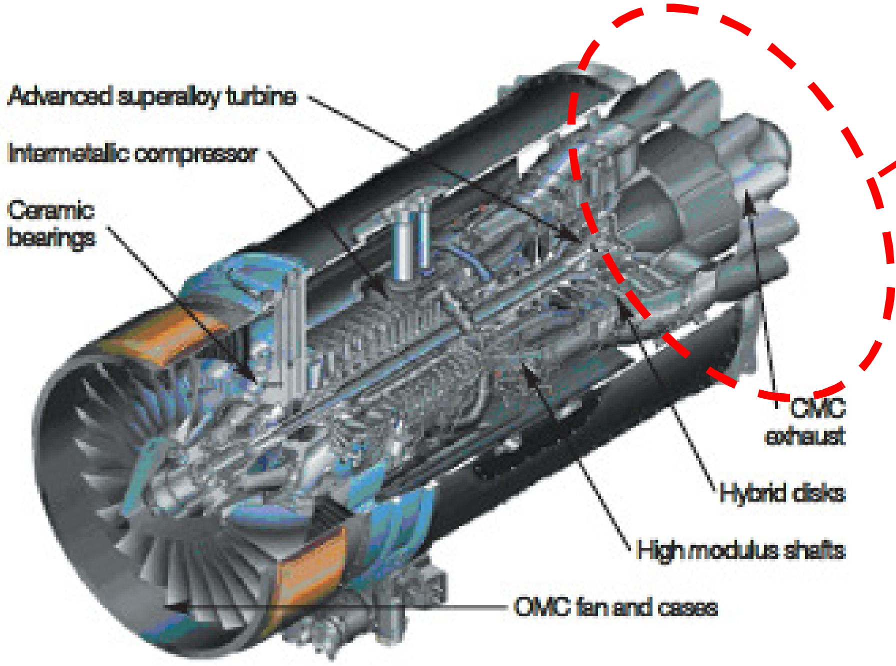
Development of CMC Exhaust Mixer for ERA Project

- NASA is teaming with Rolls Royce/LibertyWorks on CMC exhaust mixer nozzle development
- We will aero-rig test subscale components (<12” dia.) to assess their performance.
- Design of test article is in progress

18-inch dia. CMC Mixer Demo article (ATK / COIC)



- Oxide/Oxide CMC:
  - AS-N610 (Aluminosilicate matrix, Nextel 610 fabric reinforcement)
- Composition: 51% fiber, 24% matrix, 25% open porosity

Process-Property Design Tools Developed for CMC Turbine Components

Objective:

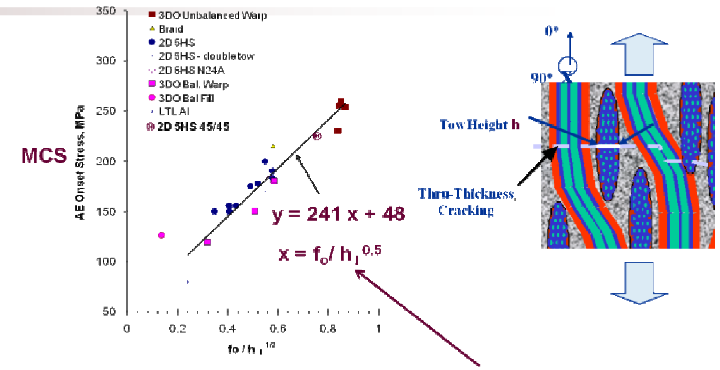
Develop physics-based tools for implementation of 3D-reinforced CMC components into turbine engines

Approach:

- Develop a semi-empirical predictive model to optimize Matrix Cracking Strength of 2D and 3D-reinforced CMCs
- Develop tools to visualize 3D fiber architectures and to understand process concerns such as fiber bending and matrix infiltration
- Use NRA contracts to evaluate the manufacturing tools for 3D-reinforced Low Pressure Turbine blade airfoils

Significance:

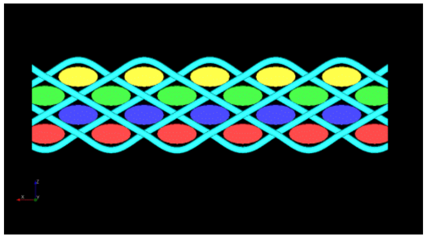
- Based on the demonstrated long-term durability of 3D SiC/SiC CMC at 2400ºF and higher, use of these materials in turbine components will increase efficiency and reduce weight, cooling and emissions

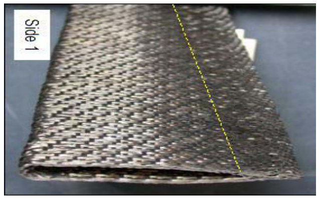


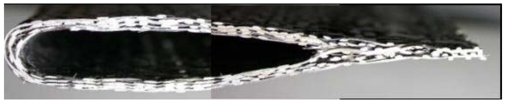
Key Empirical Architecture Factors Controlling Multi-Directional MCS:

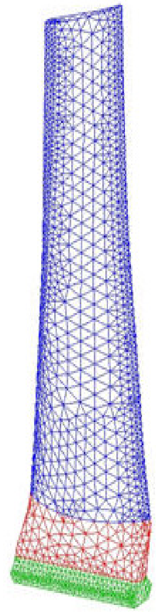
f_0 = effective fiber volume fraction in test direction
= f (0º stuffers) OR = [f (+/-θ weavers)][cos (θ)], whichever largest

h_ι (mm) = maximum height of tows perpendicular to test direction









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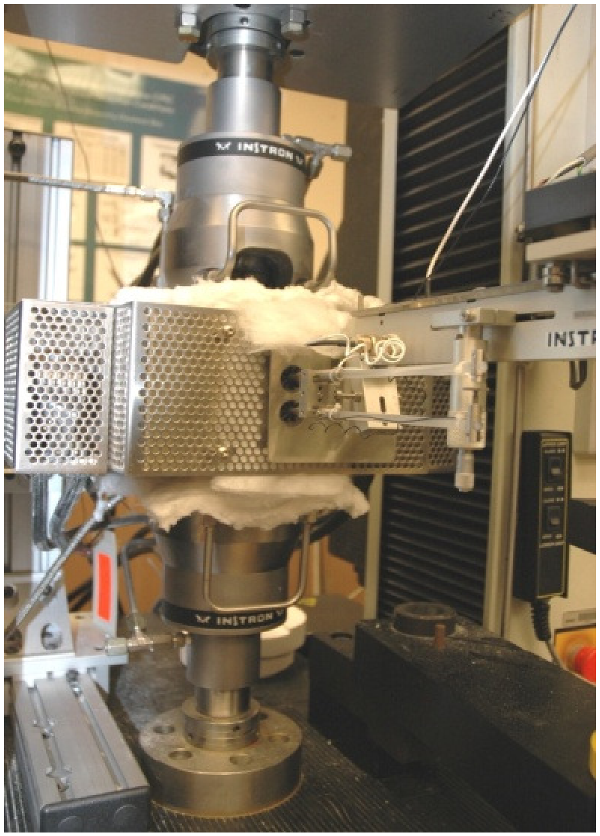
Mechanical Testing of Ceramic Composites

Long term durability testing to 3000 ℉ in air with strain measurement



- Instron 5569 / 4502 electromechanical test systems
- 3000°F custom resistance-heated furnace
- $MoSi_2$ heating elements
- High temperature capacitance contact extensometer with Hexoloy probes
- Automated rig operation & data acquisition
- 3 rigs (of 12 total) are capable of 3000°F testing

3000 ℉ / 150 hour creep tests on SiC / SiC have been completed recently

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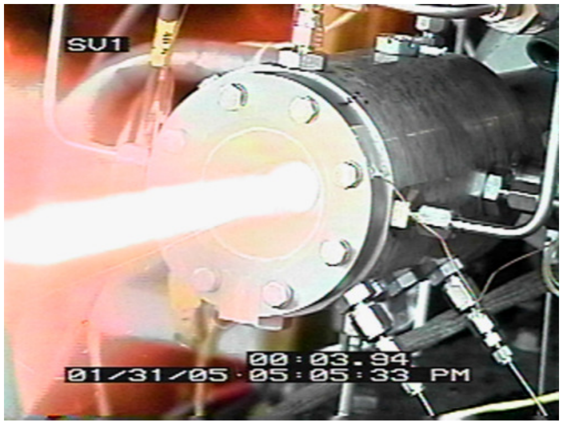
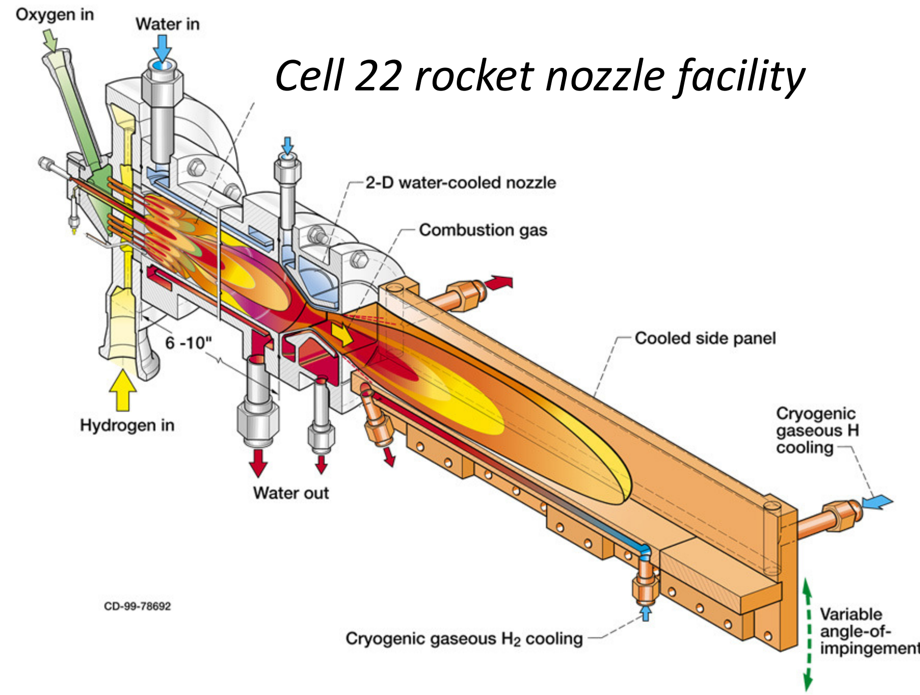
CMC Component Testing for Space Applications



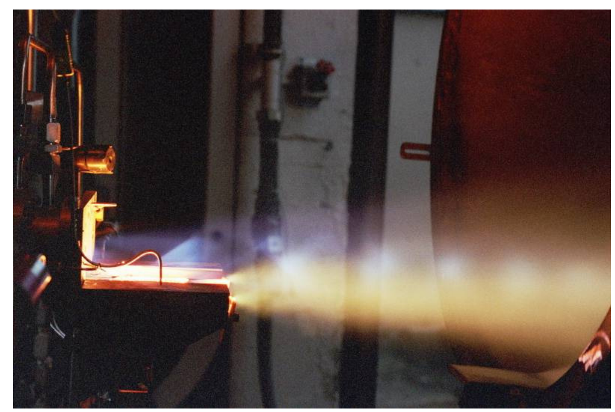
- Transpiration Cooled Liners
- Ceramic and metallic foam liners
- H_2 coolant



Cell 22 rocket nozzle facility

- Hi Nicalon SiC/CVI-SiC
- Woven coolant passages

- Radiation Cooled Nozzles
- Use temperature to 3500^{o}F



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