



Abstract for **Invited Plenary Presentation** at the
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Current Challenges for HTCMC Aero-Propulsion Components

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In comparison to the best metallic materials, HTCMC aero-propulsion engine components offer the opportunity of reduced weight and higher temperature operation, with corresponding improvements in engine cooling requirements, emissions, thrust, and specific fuel consumption. Although much progress has been made in the development of advanced HTCMC constituent materials and processes, major challenges still remain for their implementation into these components. The objectives of this presentation are to briefly review (1) potential HTCMC aero-propulsion components and their generic material performance requirements, (2) recent progress at NASA and elsewhere concerning advanced constituents and processes for meeting these requirements, (3) key HTCMC component implementation challenges that are currently being encountered, and (4) on-going activities within the new NASA Fundamental Aeronautics Program that are addressing these challenges.



Current Challenges for HTCMC Aero-Propulsion Components

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Background

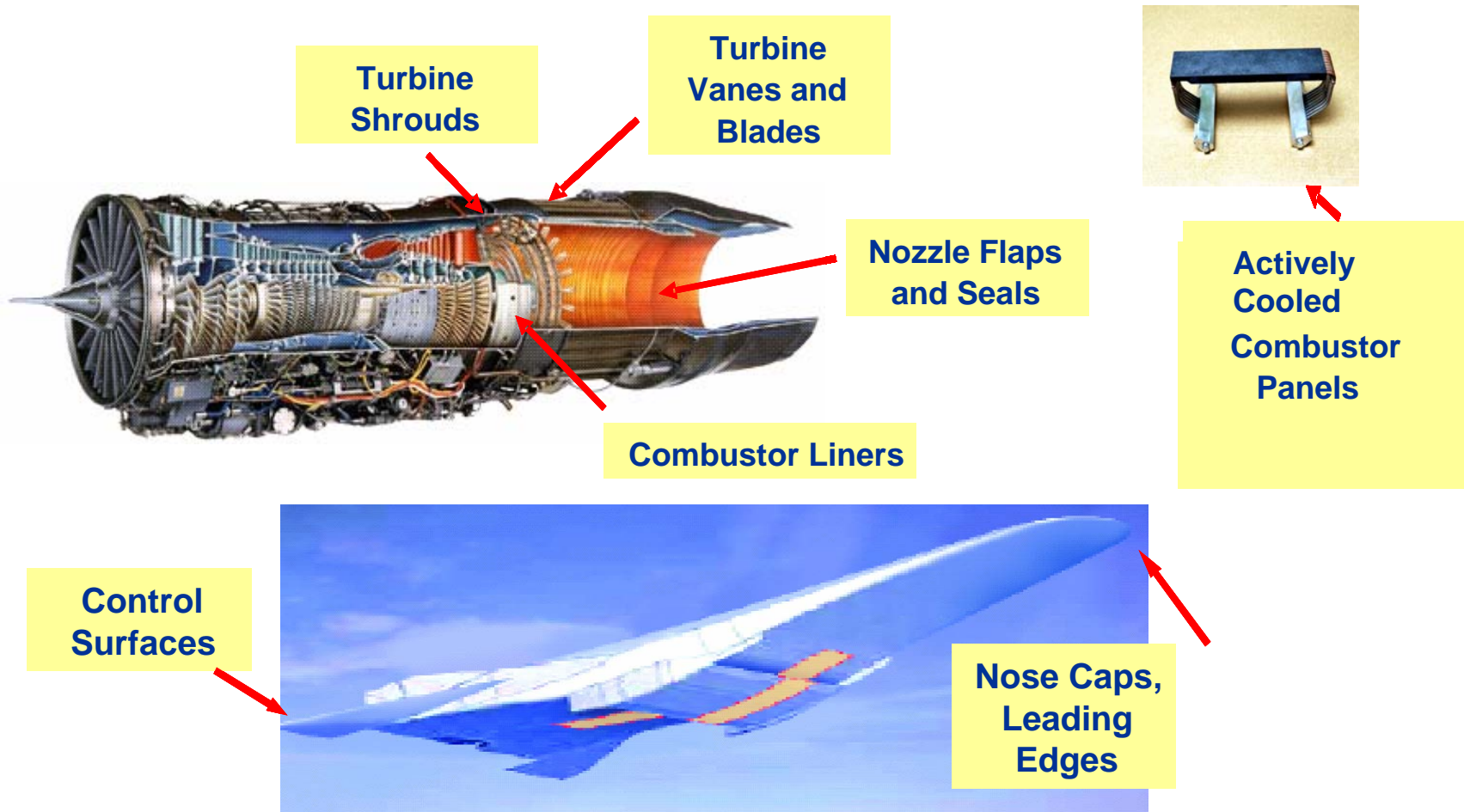
A major thrust under a variety of recent NASA and DoD aero-propulsion programs is to develop and demonstrate ***advanced lightweight components with optimized structural and environmental durability at service temperatures significantly higher than current metallic alloys***

Potential Benefits:

- ***Higher engine efficiency and thrust***
- ***Reduced weight and emissions***
- ***Longer and more reliable component life***
- ***Enabling of other aerospace applications not attainable with metals***

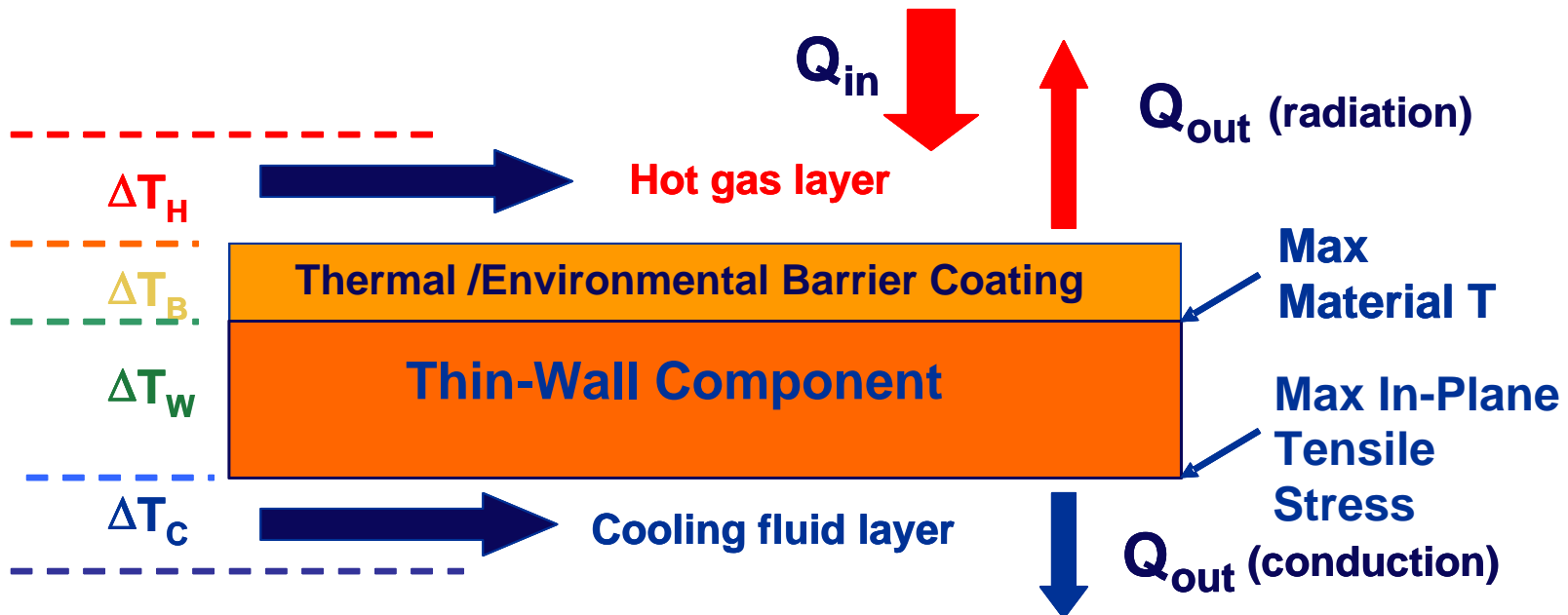


Lightweight High-Temperature Structural Materials are Needed for Multiple Aero-Propulsion Components





Typical Function of a Structural Material In a Hot Aero-Propulsion Component



Key Component Property Needs:

- **Low Density, Low Permeability, High Emissivity**
- **High Maximum Temperature Capability**
- **High Tensile Stress Capability In-Plane and Thru-Thickness**
- **High Thermal Conductivity Thru-Thickness to reduce thermal gradients and stresses**



Advantages of SiC Fiber / SiC Matrix (SiC/SiC) High-Temperature Ceramic Matrix Composites

versus Superalloys:

- Lower density (~30% metal density)
- Higher temperature capability (>1100°C)
- Lower thermal expansion

versus Monolithic Ceramics:

- Non-catastrophic failure
- Higher toughness, better damage tolerance
- Capability for larger and more complex shapes

versus Carbon Fiber Composites (C/SiC, C/C):

- Higher oxidative durability, more predictable life
- Lower permeability

versus Oxide/Oxide Ceramic Composites:

- Higher strength, temperature capability, creep-rupture resistance, thermal conductivity, emissivity
- Lower permeability

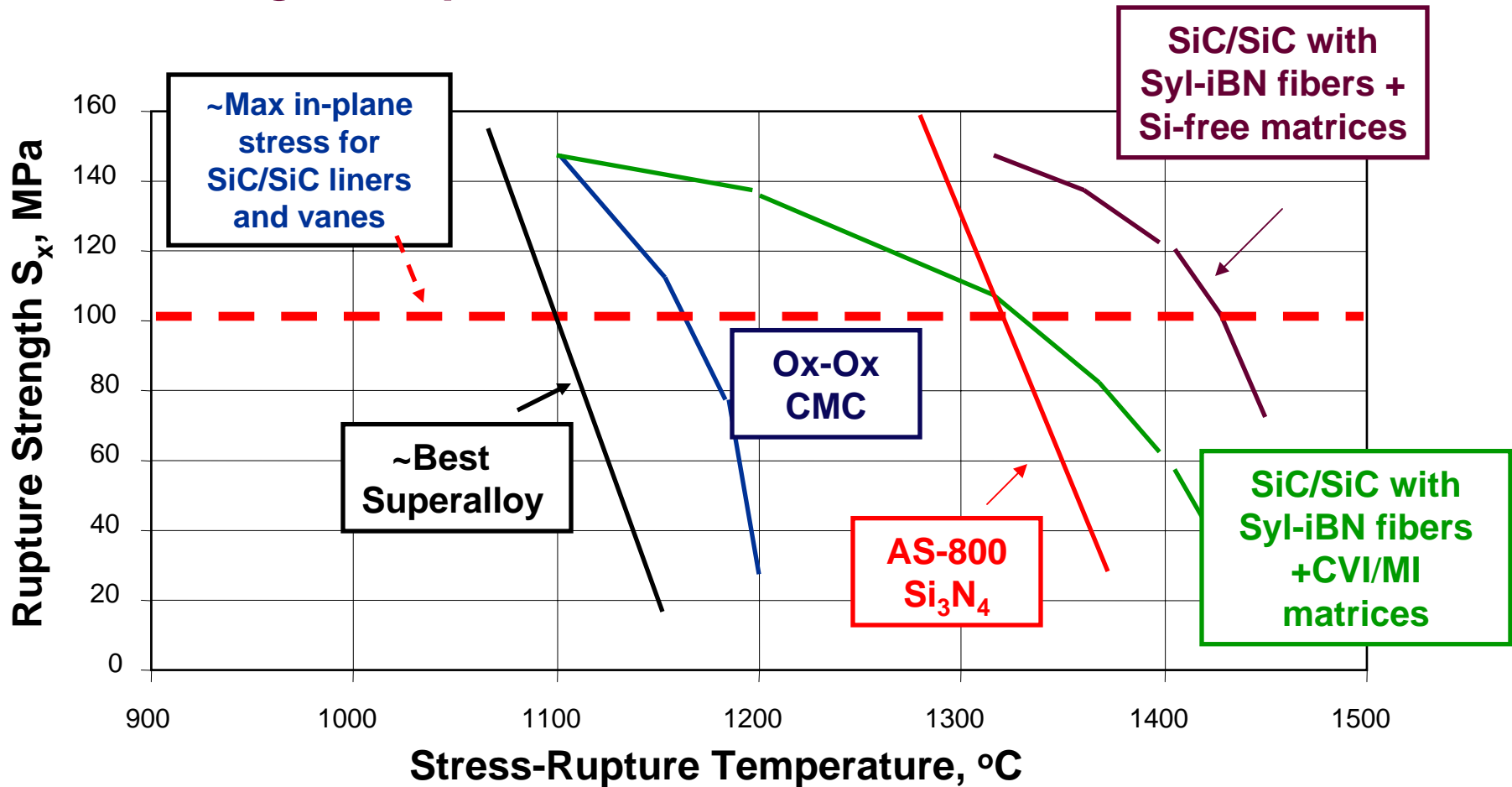


NASA Advancements in SiC/SiC Constituents and Processes that address Key Property Needs for Aero-Propulsion Components

- ***Sylramic-iBN fiber*** (creep resistant stoichiometric SiC with protective in-situ grown BN coating and thermal stability >1600°C)
- ***Improved 2D and 3D Fiber Architectures*** (stress-free and high thermal conductivity)
- ***Improved CVI SiC Matrices*** (higher thermal conductivity and creep-resistance)
- ***Hybrid CVI + PIP SiC Matrices*** (silicon-free for thermal stability >1500°C)
- ***Advanced Environmental Barrier Coatings (EBC)*** (thermal stability >1500°C in combustion environments)



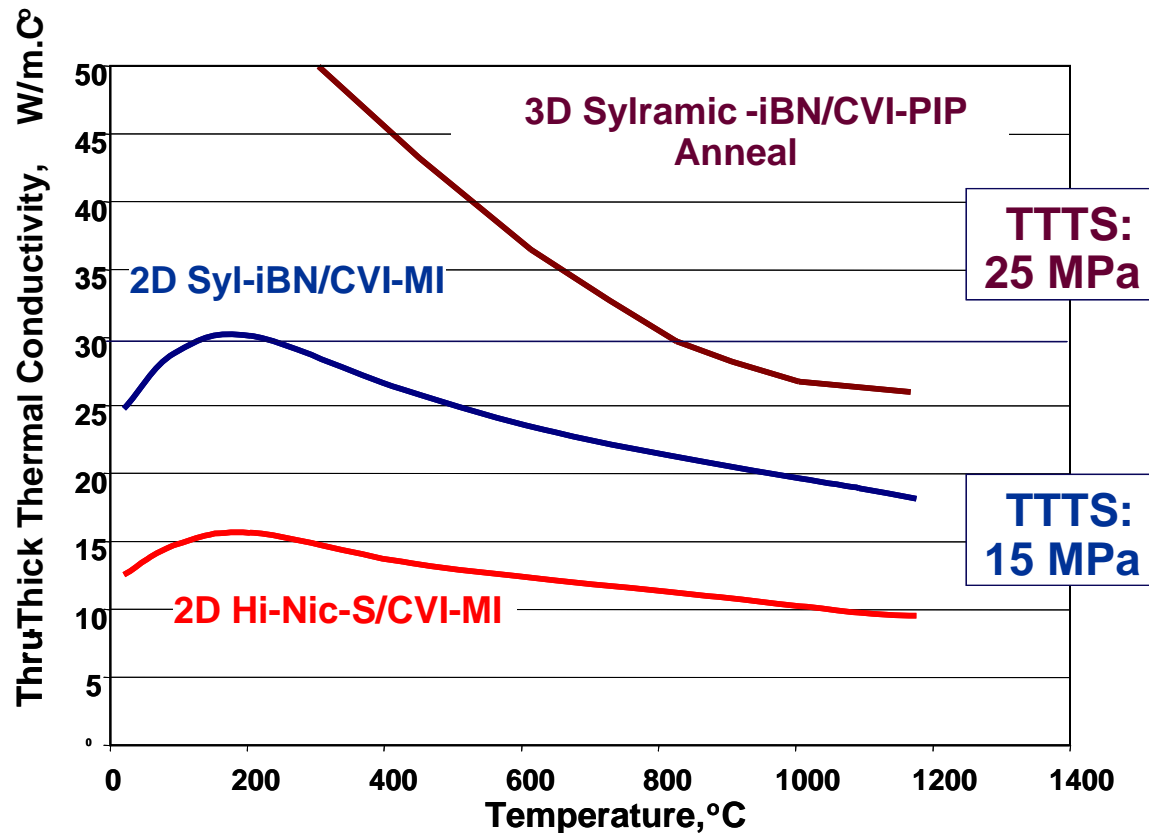
500-Hour Rupture Strength in Air for Reusable High-Temperature Structural Materials



Thermostructural capability for NASA SiC/SiC system is state-of-the art with upper use temperature of ~1450°C (2640°F) for liners and vanes



Fiber and Architecture Effects on SiC/SiC Thru-thickness Properties

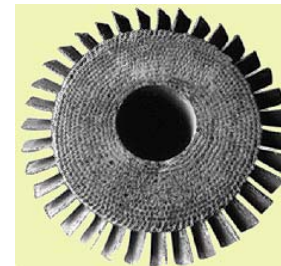


3D Architectures and Sylramic-iBN Fibers Significantly Improve SiC/SiC Thru-thickness Conductivity and Thru-Thickness Tensile Strength (TTTS)



NASA and DOD have produced a Variety of Prototype SiC/SiC Aerospace Components

- **Combustor liners**
- **Turbine vanes and blades**
- **Turbine shrouds**
- **Thrusters**
- **Nozzle Flaps and Seals**
- **Heat exchangers**
- **Integral Rotors**



✓ ***But Multiple Challenges Still Exist Before Aero-Propulsion Components Based on High Performance SiC/SiC HTCMC Can Become Actual Products***



Objective / Outline

- Present brief overview of key current R&D ***challenges*** that need to be addressed for viable SiC/SiC aero-propulsion components:
 - ***Performance:***
 - ***Higher matrix cracking strength***
 - ***Producibility:***
 - ***Complex-shaped fiber architectures***
 - ***Design Methodologies:***
 - ***Creep and Finite Element (FE) lifing models***
 - ***Affordability:***
 - ***Lower material and fabrication costs***



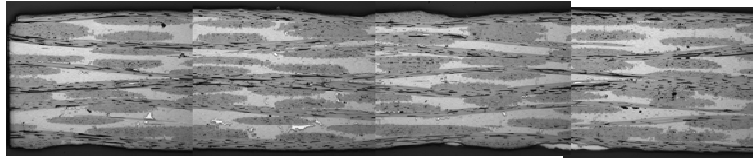
Challenge: *Higher Matrix Cracking Strength*

- Generally it is currently assumed EBC are prime-reliant and SiC/SiC components can be designed with service-related stresses below matrix cracking to minimize environmental attack.
- Thus, besides the development of reliable EBC, the challenge also exists to understand the sources of matrix cracking and minimize their influence.
- For highly dense matrices, such as those formed by melt infiltration, the *fiber architecture* plays a strong role in the initiation of thru-thickness matrix cracks.
- NASA is currently studying this effect using *Acoustic Emission* and a variety of Sylramic-iBN fiber architectures.

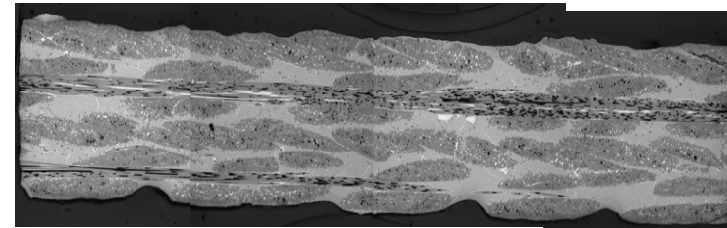


SiC/SiC Matrix Cracking vs. Fiber Architecture

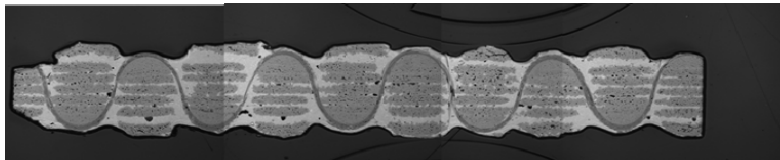
2D Five-harness Satin



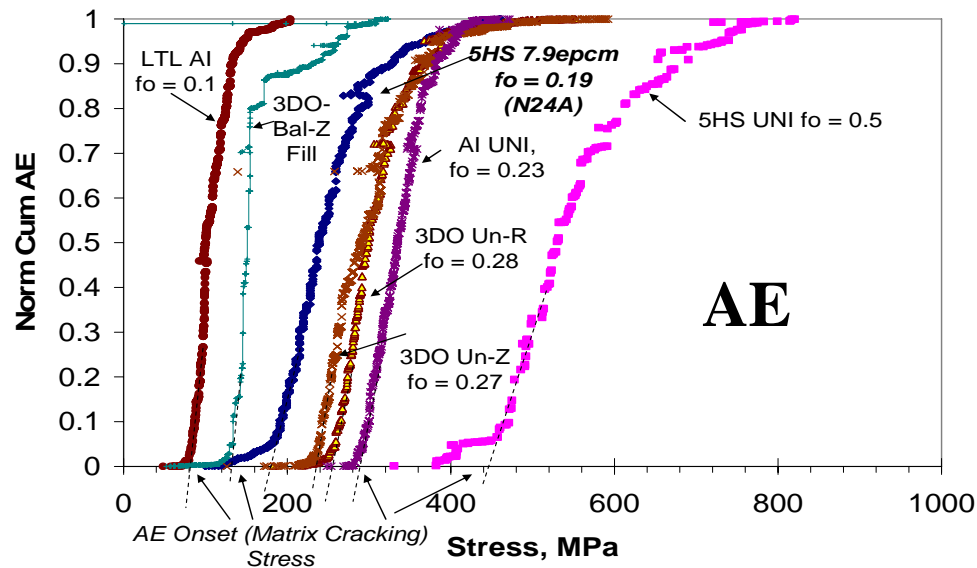
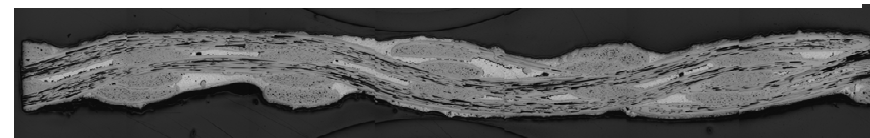
Braid



3D Orthogonal



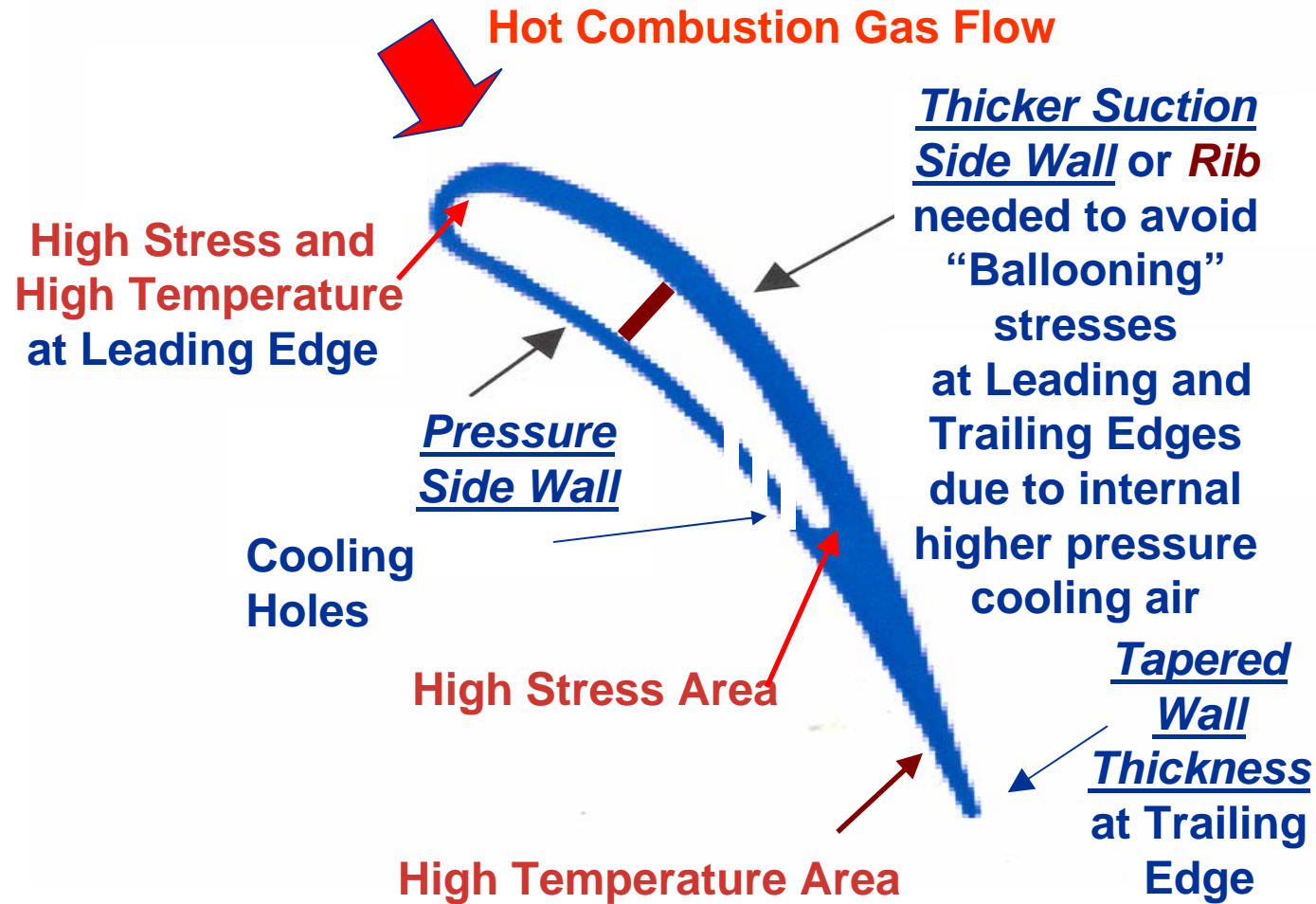
Angle Interlock



The in-plane onset stress for thru-thickness cracking can be increased from 100 to ~300 MPa by proper architecture selection



Challenge: *Fiber Architectures for Complex-Shaped High-Performance Components such as Turbine Airfoils*





Current Producibility Issues for Complex-Shaped SiC/SiC Aero-Propulsion Components

- Fiber architectures for aero-propulsion components must not only provide structural properties required at practically all locations in component, but also meet the component shape requirements. 3D is preferred because of better delamination resistance and thermal conductivity.
- ***Currently for complex-shaped SiC/SiC components such as vanes and blades, it is practically impossible for any single 2D or 3D architecture to simultaneously achieve all structural and shape requirements***
- Some key areas of concern include ***bending and residual stresses in high-performance high-modulus SiC fibers***, and architectures that can simultaneously provide ***smooth component surfaces, T-sections at reinforcement ribs, and thin trailing edges.***

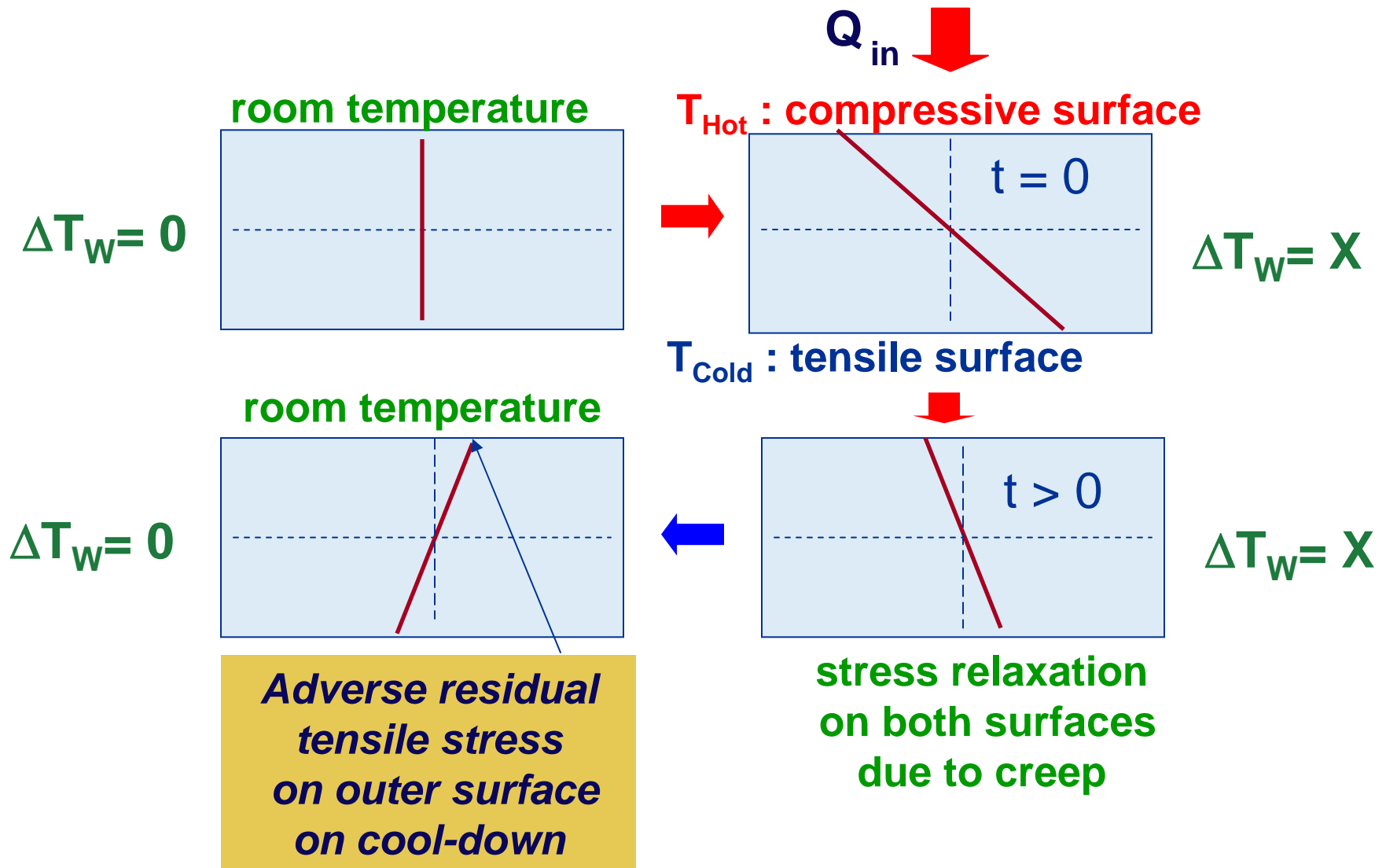


Challenge: *SiC/SiC Design Methodologies*

- For SiC/SiC to be reliably implemented in aero-propulsion components, there has to exist ***design and lifing data bases*** for selection of constituent materials, processes, and architectures that will yield components with directional strength properties safely below predicted component stress states at the end of the desired component service life.
- These needs have been difficult to address due to such issues as the ***high cost for obtaining design and lifing data bases***, the problems in ***matching the architectural requirements for structural properties with those for component shape requirements***, and the ***current lack of robust modeling approaches for converting the numerous CMC lifing mechanisms into Finite Element codes***.



Mechanistic Modeling Needed for Creep Effects





Challenge: *SiC/SiC Component Affordability*

Cost is still a major issue:

- High cost for high performance SiC fiber
- Constituent, composite, and EBC vendors are often different and single organizations, complicating production time, availability, and resulting in multi-tiers of profit taking
- Considerable hand-labor required for complex shapes
- Process technologies are continually being optimized
- Quality control at every process step is costly
- Reliable life-cycle cost-benefit analyses need to be conducted to determine economic viability



Summary

- **SiC/SiC systems with high performance fibers** are capable of outperforming the best superalloys and ox/ox CMC systems in weight-savings, structural capability, upper use temperature, and thru-thickness thermal conductivity.
- However, these systems currently face **a variety of key challenges** that need to be overcome before they can be widely implemented in hot-section aero-propulsion components:
 - **3D fiber architectures** that not only yield high matrix cracking strengths both in-plane and thru-thickness, but also are conducive for the fabrication of complex-shaped components. If the proper SiC fibers are selected, such as Sylramic-iBN, 3D systems should also provide improved thru-thickness thermal conductivity and impact resistance.
 - **Advanced lifing design methodologies** that can not only account for environmental effects, but also residual stress effects due to creep.
 - **Lower cost materials and processes** and a more stream-lined vendor base for improved affordability and wider market interest.



Outlook for SiC/SiC Components

- SiC/SiC systems will continue to be considered for a variety of hot aero-propulsion components due to their capability to outperform monolithic ceramics in damage tolerance and metallic superalloys in upper use temperature and reduced weight.
- Commercialization of SiC/SiC technologies within the next 5 to 10 years is likely for medium to large-sized components that are thin-walled and relatively simple in shape (combustor liners, transition pieces, seal rings, shrouds, etc.).
- For the more complex-shaped and higher performing components, such as turbine vanes and blades, some of the key technical and economical challenges discussed here are currently being addressed under the new NASA Fundamental Aeronautics Program.

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