Melt Infiltrated (MI) SiC/SiC Composites for Gas Turbine Applications

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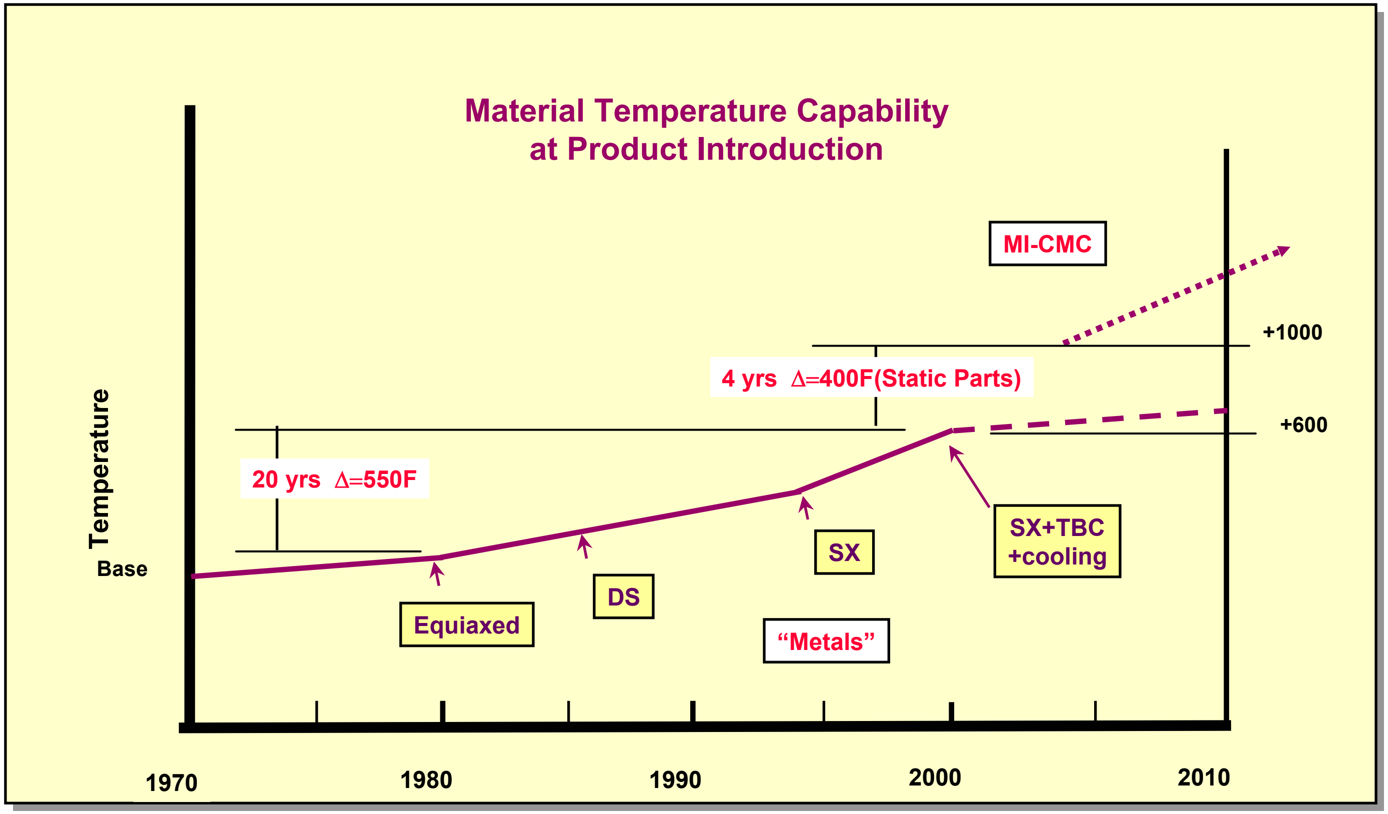
**Contract Monitor: Joe Mavec*

Outline

- Introduction
  - CMC Opportunities
  - Team Members
- Applications & Payoff
- Material System
- Pathway to Commercialization
- Current Status & Future Plans
- Summary

CMC Opportunity



- ***CMC's represent a game changing technology***
- ***DOE had the vision to start the CFCC program in early nineties***

Collaboration

Team Members

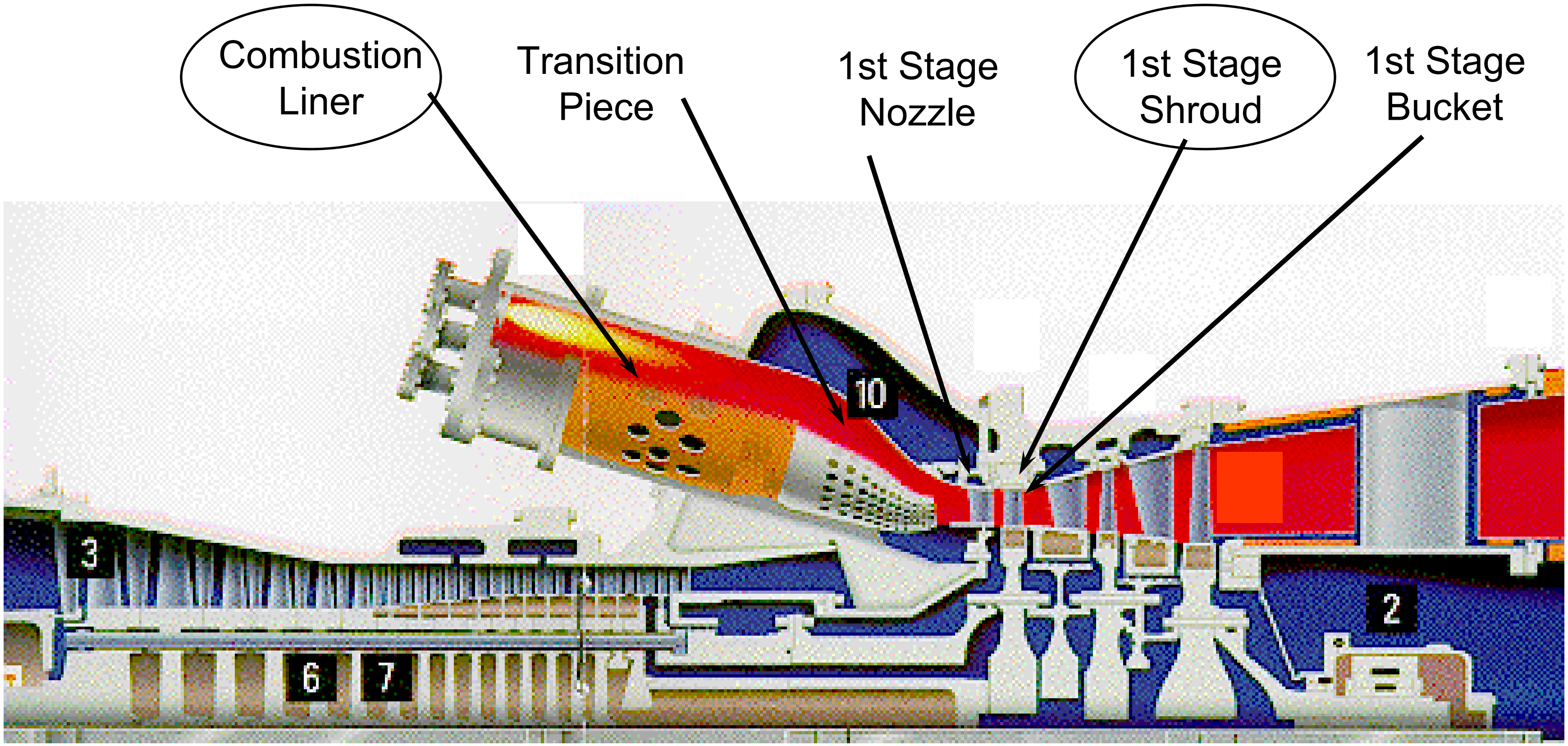
Prime Contractor:	**GE Global Research Center**
Component Fabrication:	**GE Global Research Center**
	GE Power Systems Composites (GEPSC), ***formerly Honeywell Advanced Composites, Inc. (HACI)***
	Goodrich Aerospace
End User	**GE Power Systems**
CMC Characterization:	**ORNL (Microstructural)** **Argonne National Lab (NDE)**

Leverage from other programs

CMC Material Development	**HSCT (NASA); Air Force Programs at GEAE**
Environmental Barrier Coating	**HSCT (NASA)**
Component testing	**CSGT (DOE) at Solar**

Applications

g **Industrial Gas Turbine Engine**



- ***Stationary components represent the best short-term opportunity***

Payoff & Selected Applications

- Higher temperature capability of CMCs allows reduction/elimination of air needed for cooling metallic components
  - Improvement in fuel efficiency
  - Reduction in harmful emissions
  - Higher output of machines
- Applicable to all classes of gas turbines
  - GE gas turbines range 45 KW to 280,000 KW
  - F-class & H-class machines most advanced
  - Installed base for F-class machines ~36 GW(US) & ~64 GW (worldwide) In 1999
- Initial focus on shrouds & combustor liners
  - Technology would flow to other stationary components, such as nozzles

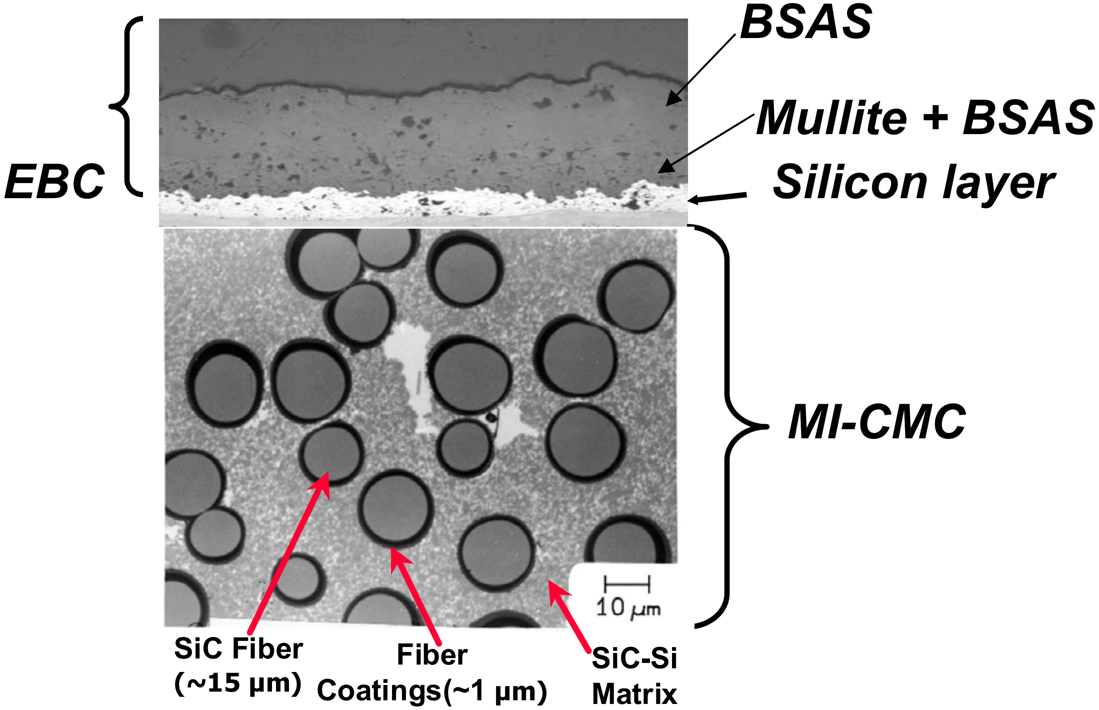
DOE-CFCC And DOE – AMAIGT focused on CMC applications in F-class machines

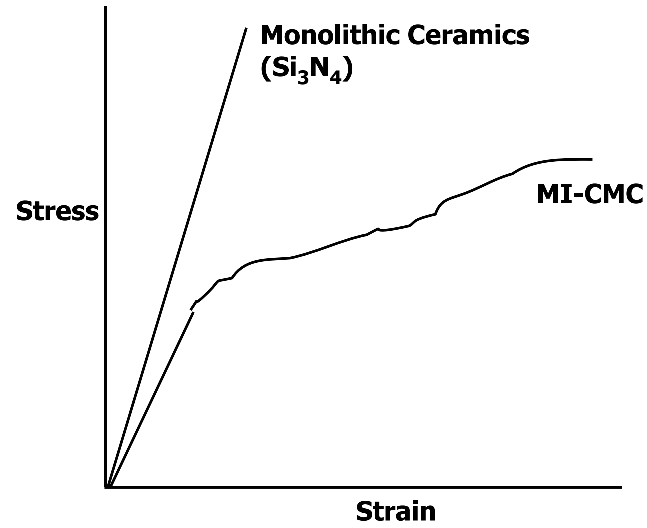
Payoff For Stationary Components

- Up to 1.1% point increase in simple cycle efficiency
- Increase in 3% output
- Market growth of 6%/year and 20% market penetration by 2020
  - US annual savings of ~290 Billion BTU of energy, equivalent to ~0.29 Billion cubic ft. of natural gas at a cost of ~$960 Million (2001 dollars)
  - Annual savings of ~4.3 Million MTCE of CO_2 emissions
  - Annual savings of ~51,000 MT of NO_x emissions
  - Extra power generation worth ~1.3 Billion dollars, further reducing the cost of electricity to customers

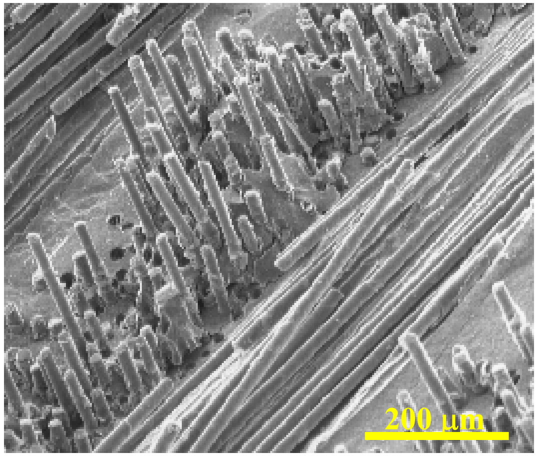
Use of CMCs offers opportunity for enormous fuel savings, reduction in emissions and reduction in cost of electricity to customers

MI-CMCs



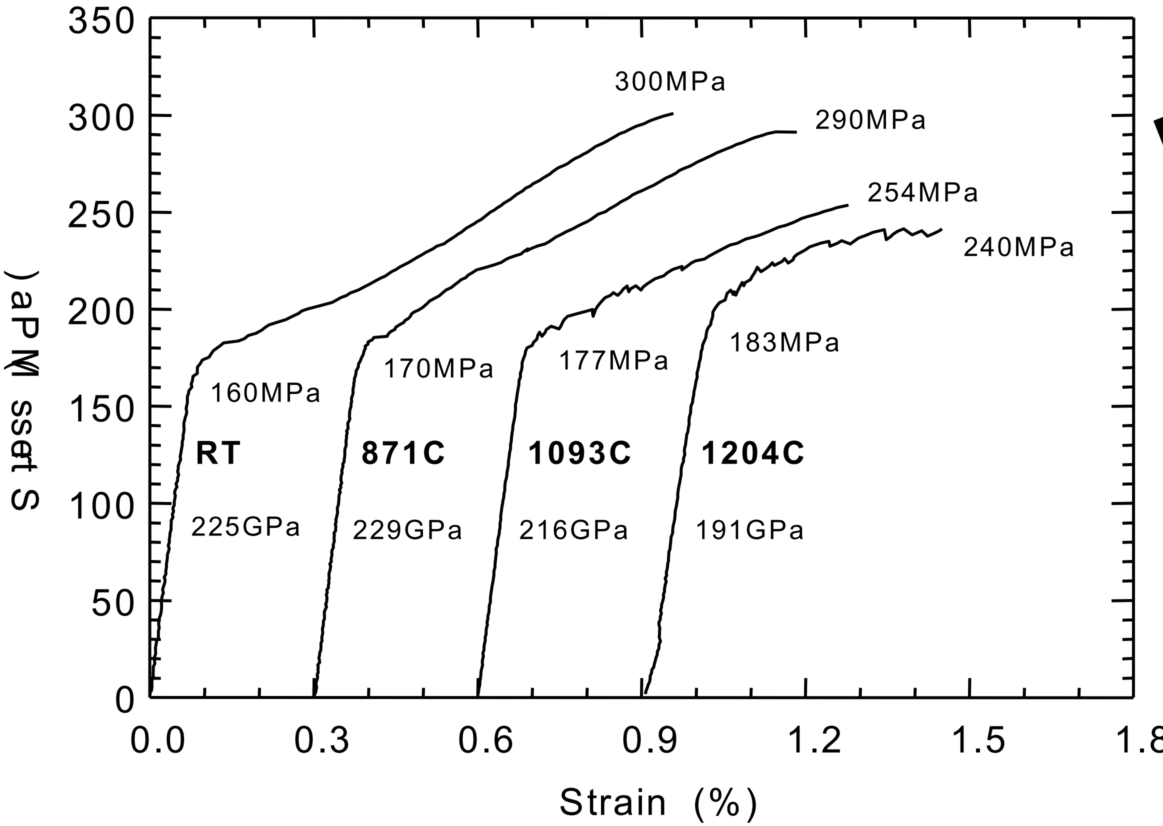


Fiber Reinforcement Increases Fracture Toughness (Damage Tolerance)



Fracture Surface

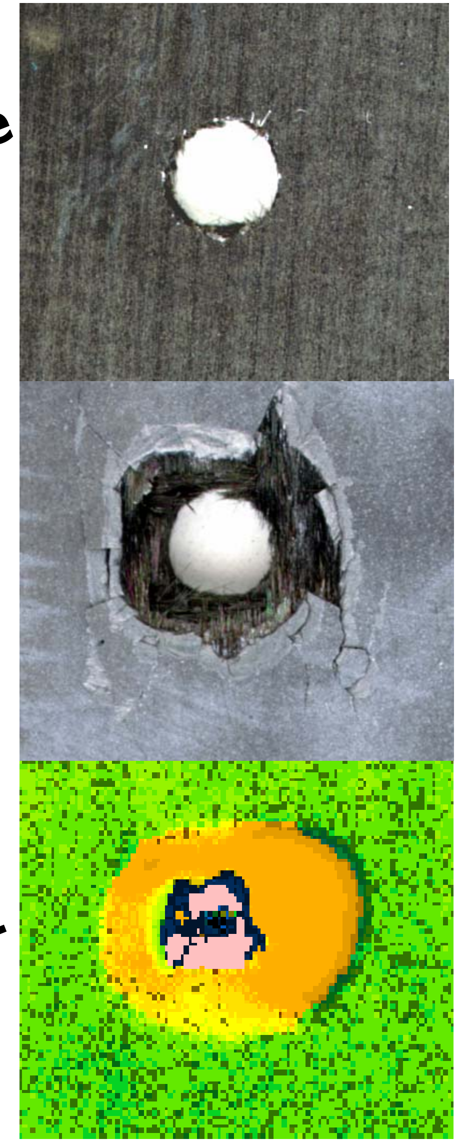
Hi Nicalon Reinforced M. I. Composites



Entrance

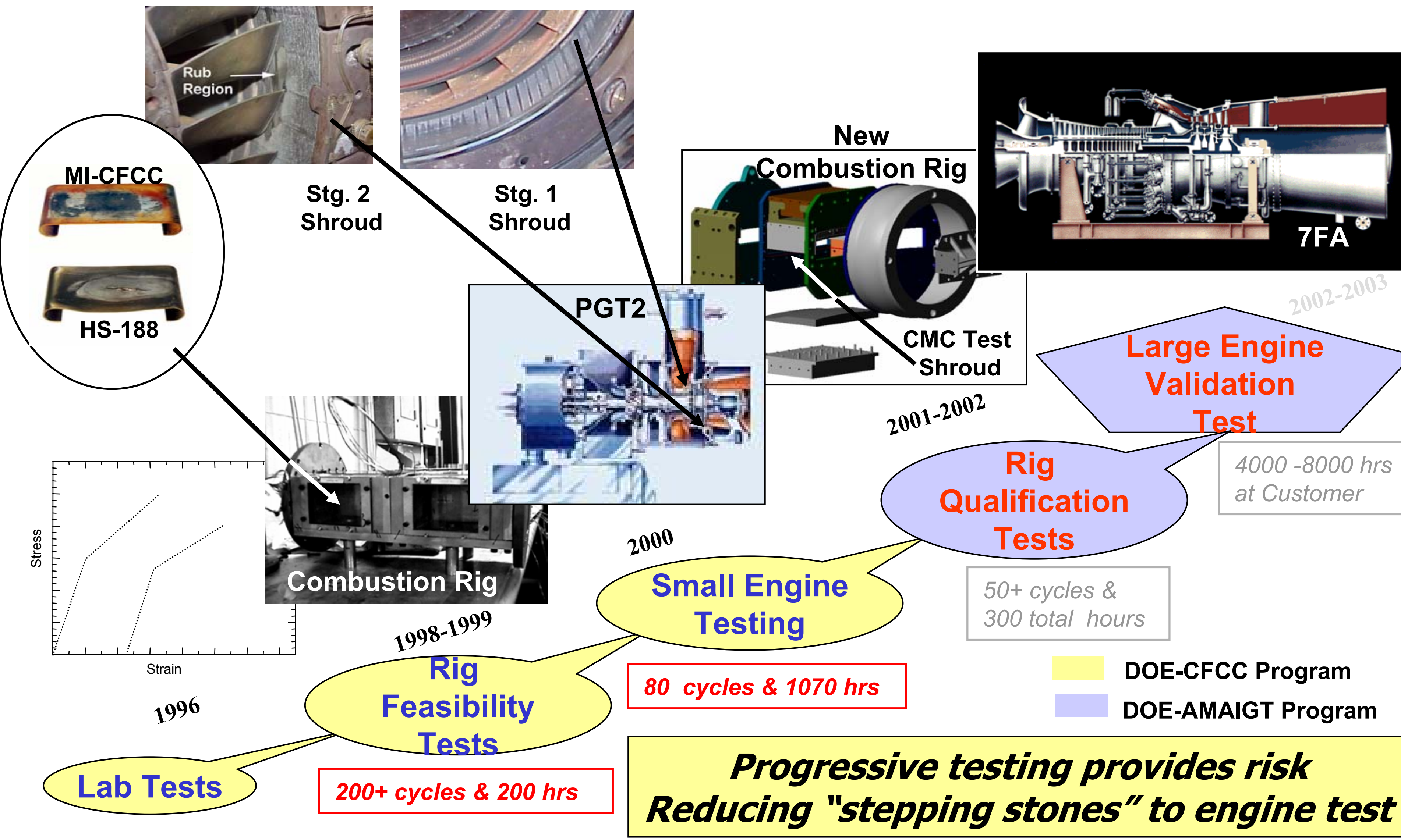
Exit

NDE



CMCs offer high temperature strength along with damage tolerance

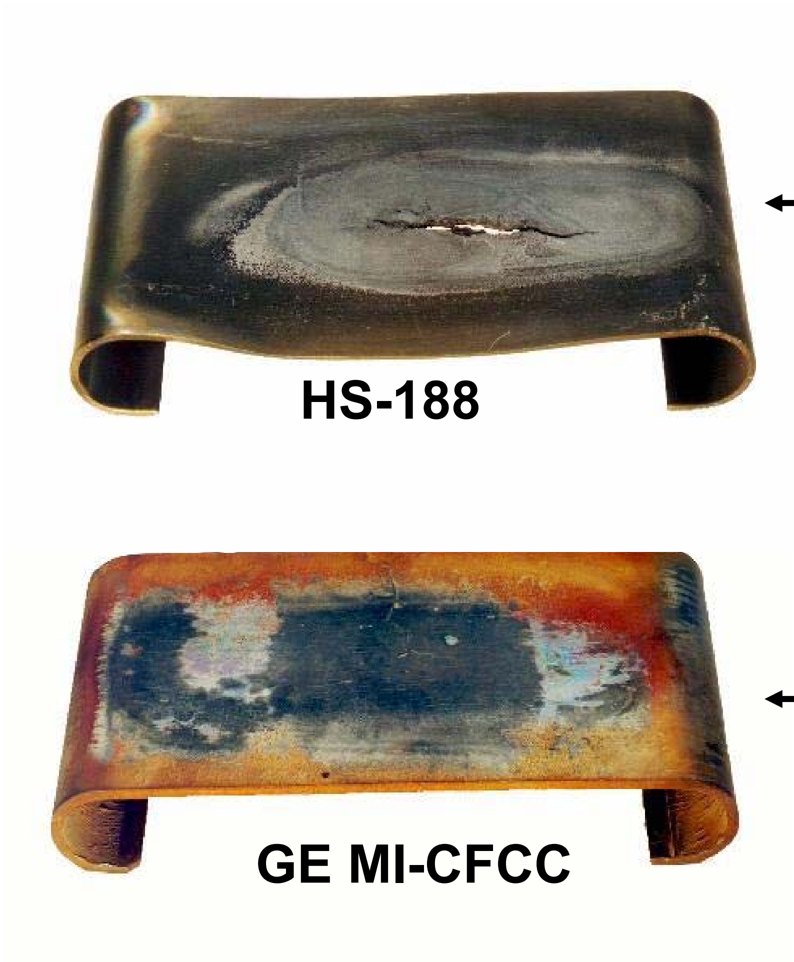
Ceramic Matrix Composites - The path into Gas Turbine Engines



Shroud Rig Component Performance

Combustors

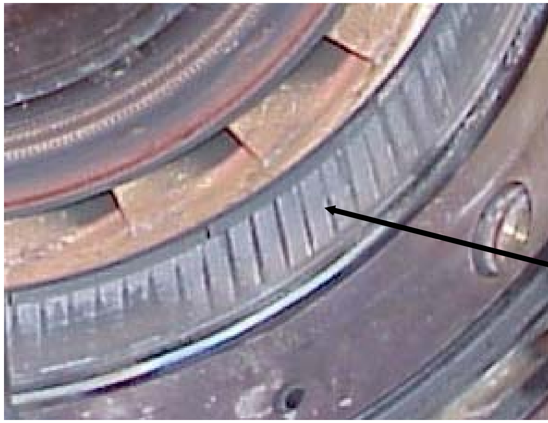
Shroud Rig Testing at 1500°C Gas Temperature



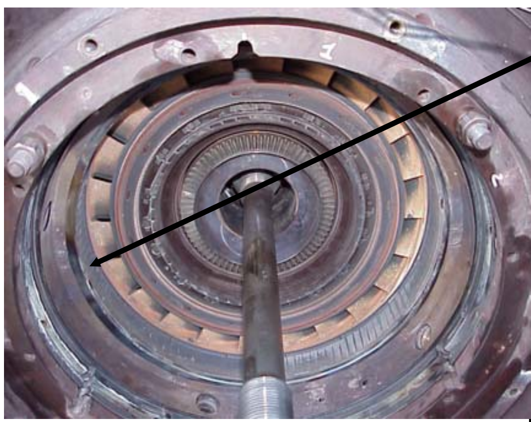
Failed after 50 cycles

Survived 200 cycles and 50 hours exposure

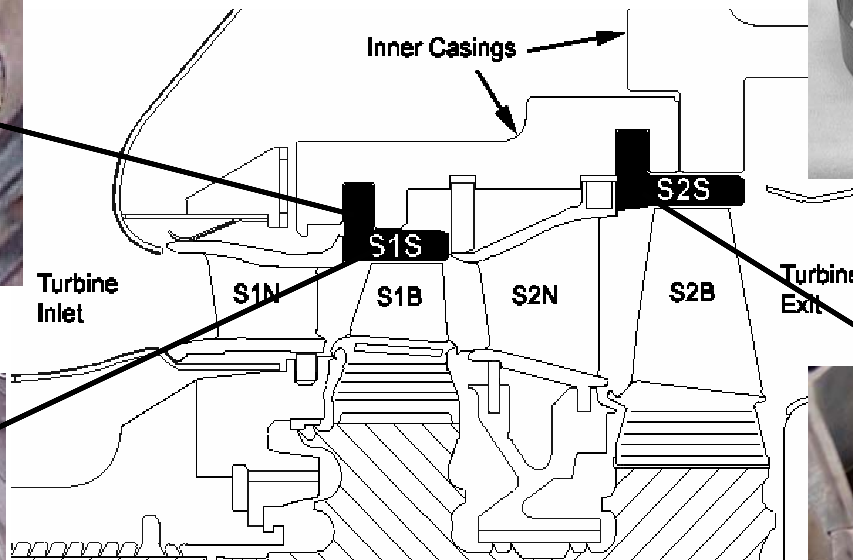
GE2 S2S and S1S Testing at GE Oil & Gas



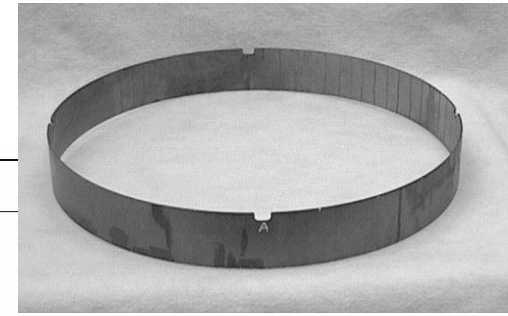
First Stage CMC Shroud



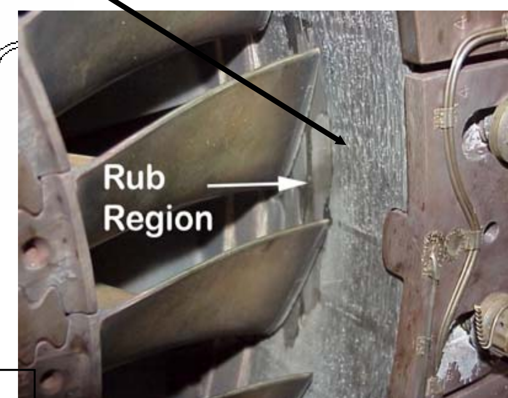
View aft looking forward



PGT-2 Turbine Cross Section
Operated at Gas Temp of ~1875F



18.5" CMC Second Stage Shroud Ring



Blade Rub on Second Stage CMC Shroud

S1S and S2S Testing:

- 1070 hrs
- S1S had 46 starts, 24 trips, 1 blade rub
- S2S had 61 starts, 27 trips, plus over 3 blade rubs

Engine Testing of Prepreg Processed Shrouds Has Been Very Successful to Date

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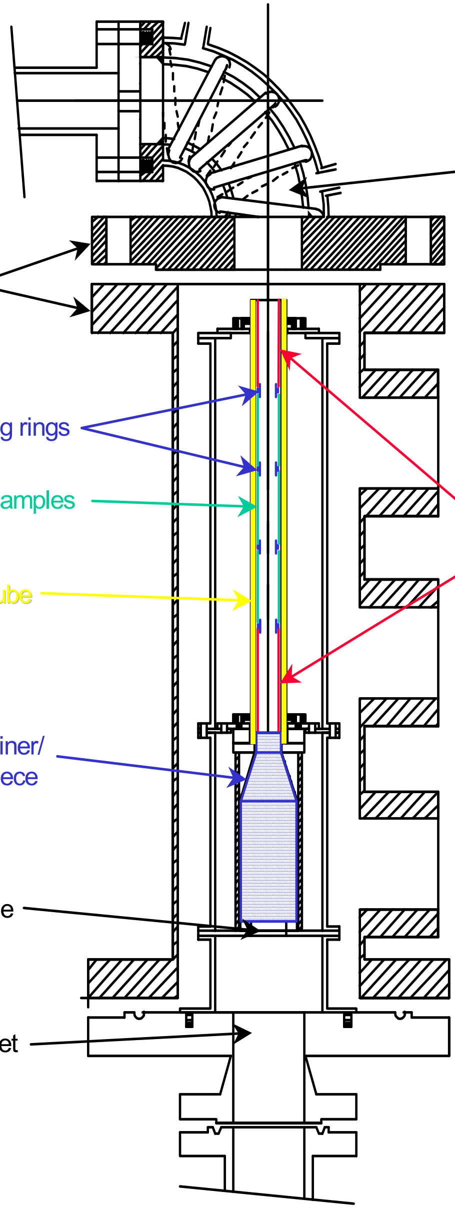
Status & Past Year Accomplishments

- Unique high pressure-high velocity rig designed and being used for long-term testing.
  - Needed to evaluate water vapor & velocity effects on CMC materials.
- Shroud system design completed.
  - Critical design features, such as attachment and blade rub tolerance, were evaluated with sub-component tests.
- Over 30 CMC inner shrouds fabricated for rig and engine testing.
  - EBC deposition process scaled up and CMC shroud coating optimized.
  - Transient IR thermography demonstrated as useful NDE technique for CMC shroud inspection.
- A new combustion rig for testing of shroud system was designed, assembled, and its operation verified.
  - Used as short-term validation of shroud system design before proceeding to engine tests
  - ~200 hours of rig testing completed on two shroud system variations.

Long-Term Rig Testing



- **High pressure – high velocity rig**
  - **Evaluate effects of water vapor and velocity**
- **Capabilities**
  - **Temperature up to 1200ºC+**
  - **Velocity of 450 ft/sec+**
  - **9 atmospheric pressure**
  - **1 atmosphere of water vapor**
  - **Up to 28 tensile test specimens**
- **Status**
  - **~3000 hours of testing performed**
  - **Another 2500 hours planned this year**
  - **Facilities would also be used for microturbine program**

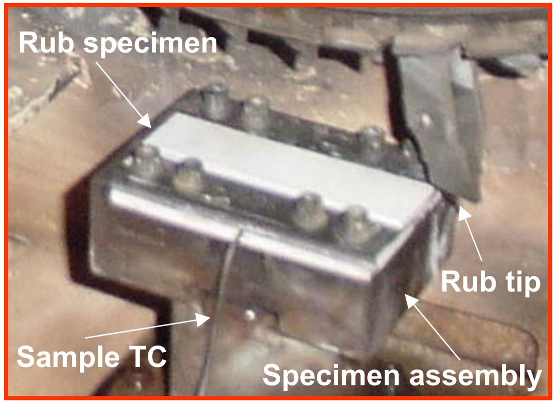
Unique material testing facility being used for long-term life testing under turbine-like conditions

Blade Tip Rub Tolerance Validation

- Rub tests of prepreg and slurry cast samples, with and without EBC, were done at RT and 1200C
  - GTD-111 blades lost mass and substrate gained mass in all tests - indicates wear of blade and deposition of metal onto CMC samples
  - No spalling of EBC coating or substantial damage to CMC observed

CMC/EBC system very resistant to blade tip rubs

Apparatus



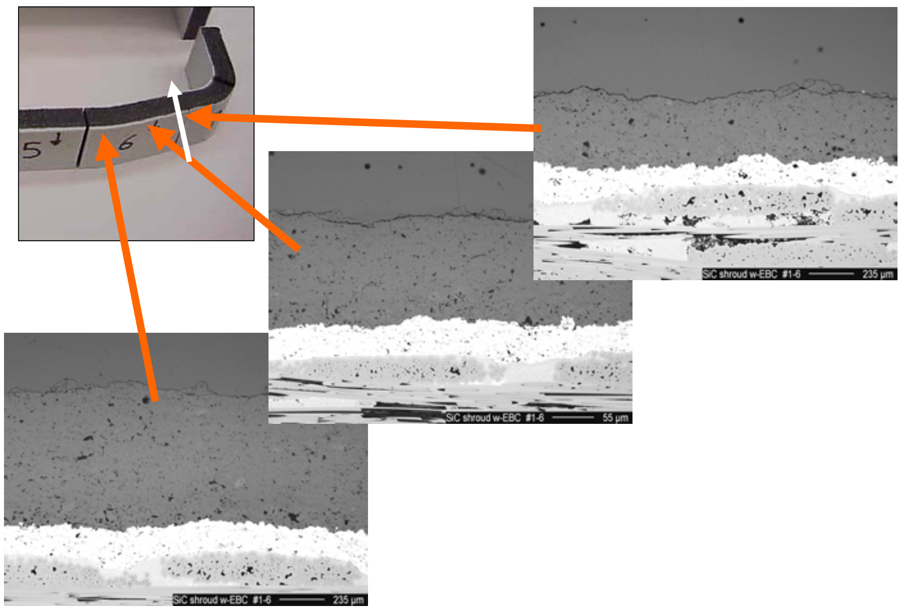
Uncoated Prepreg RT

EBC coated Prepreg 1200C

EBC Process Scale-Up and Optimization

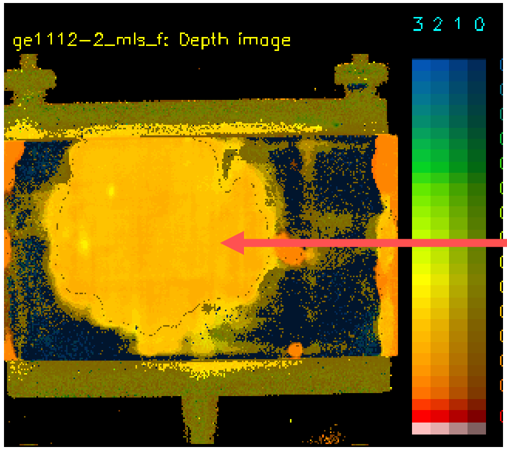
- **Process successfully scaled up to coat shroud components**

- **Quality and thickness control of EBC verified with shroud cut-ups**

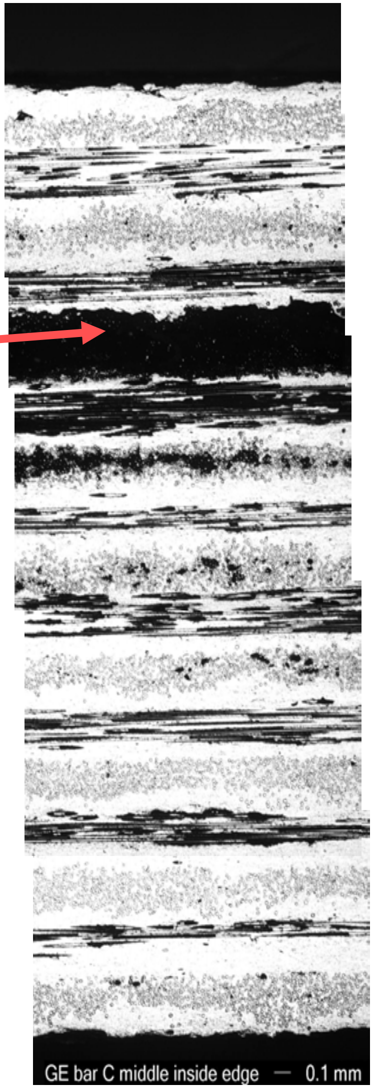


NDE by Transient IR Thermography

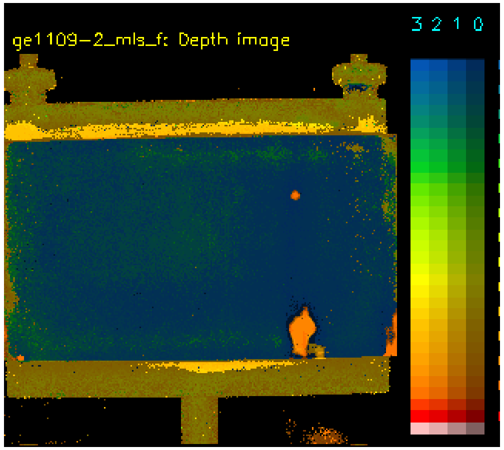
"Bad" Shroud



NDE indications verified as defects by microstructural characterization

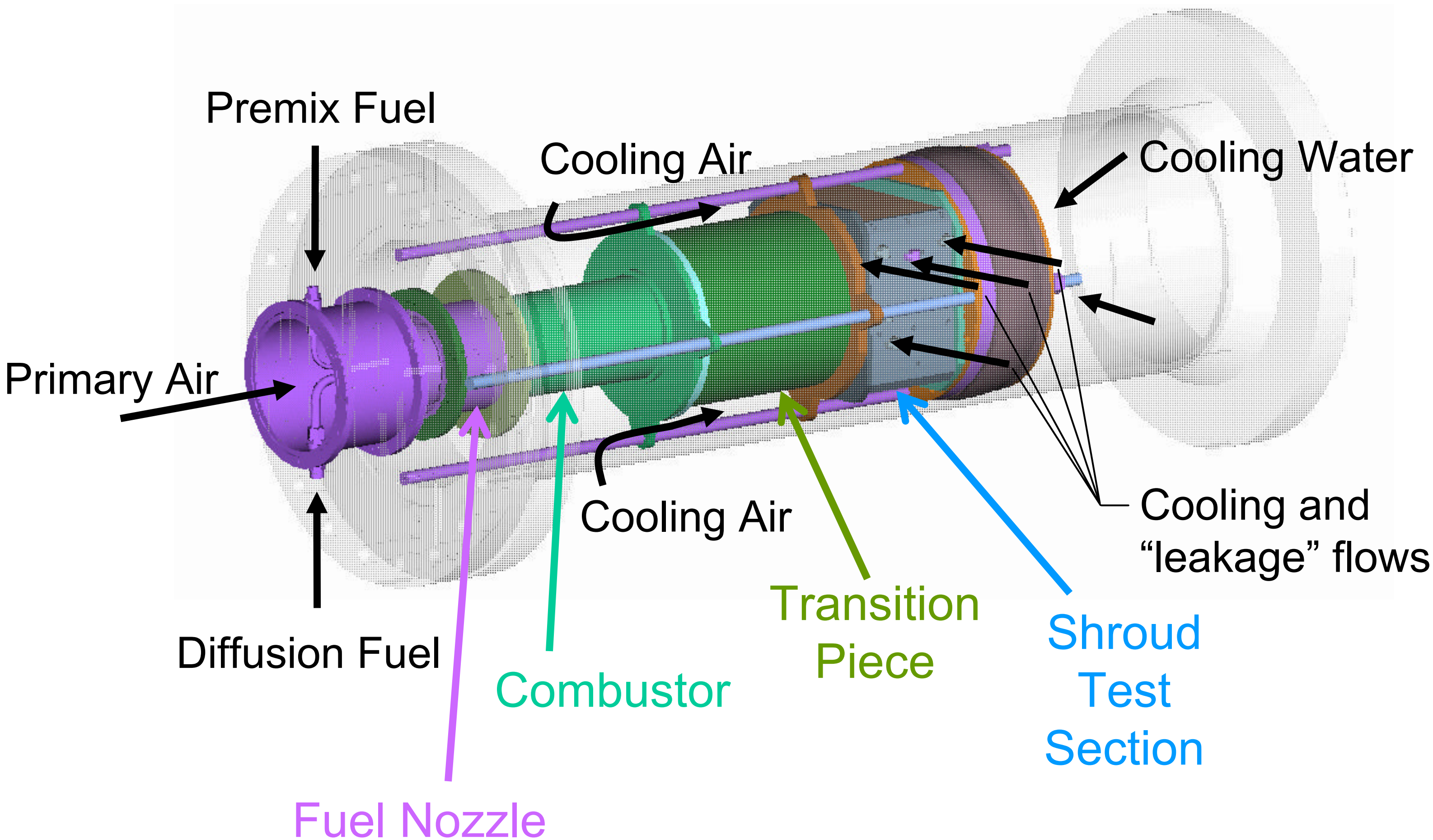


"Good" Shroud

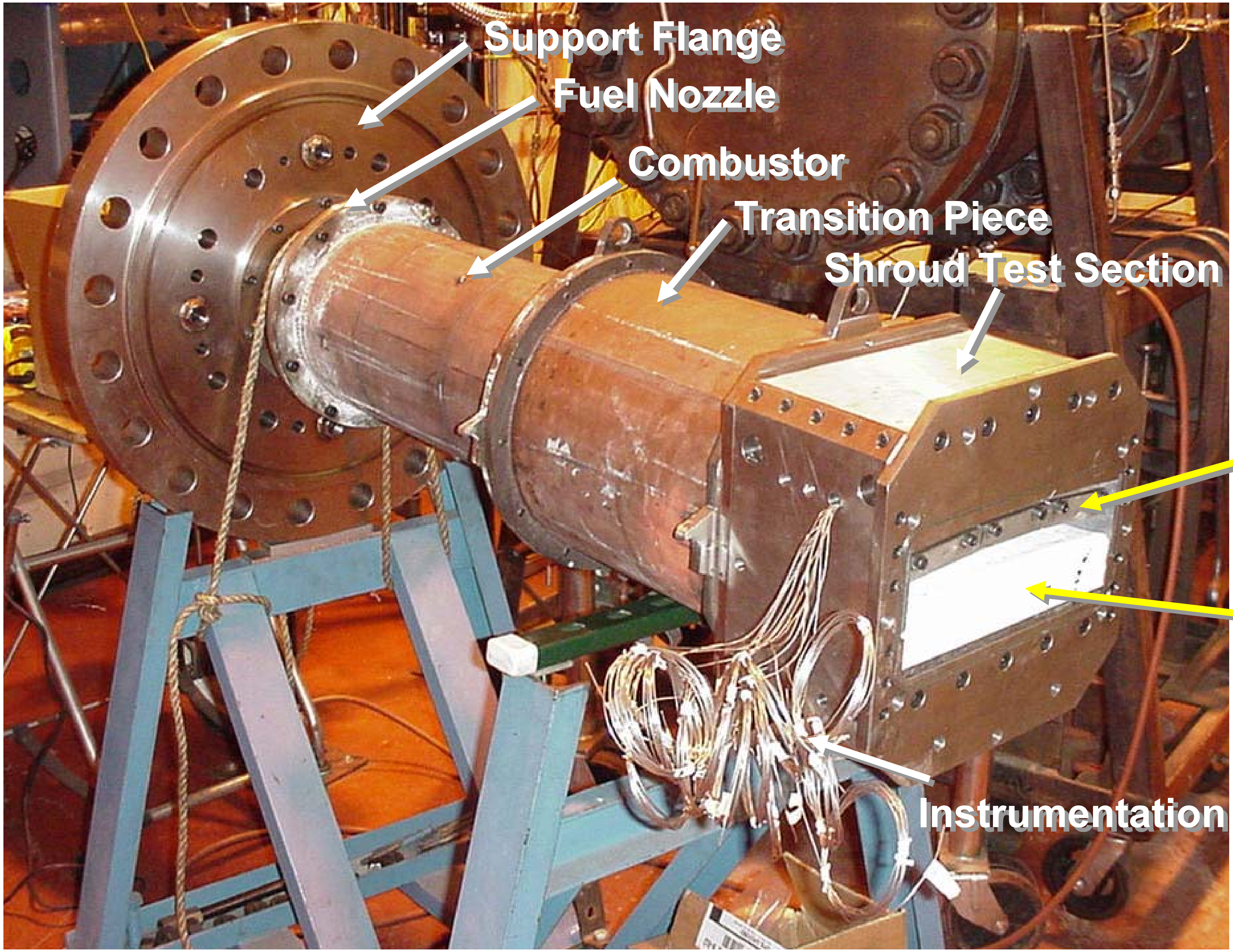


NDE of CMC Shrouds Demonstrated

Shroud Test Rig



Shroud Test Rig



Surrogate metal shrouds

Cast ceramic lower wall (replaced with CMC for durability)

Future Plans

- Shrouds
  - Engine test (4000 hours+) at a customer site starting from Fall '02 outage
- Combustor Liner
  - Combustor preliminary design completed CY 3Q02
  - Fabrication of MI-CMC combustor by CY 4Q02
  - Rig testing of combustor system starting CY 1Q03
  - Fabrication of final design and validation rig test by CY 1Q04
  - Field engine test starting CY 4Q04

Summary

- CMCs represent a game changing technology for industrial gas turbines
  - 400° F improvement over metals

- CMCs offer opportunities for enormous fuel savings, reduction in emissions, and reduction in cost of electricity to customers

- DOE's CMC programs (CFCC & AMAIGT) have taken the lead in CMC material development for their applications in gas turbines

- GE's efforts on CFCC & AMAIGT focused on shroud & combustor liners
  - Field test of first stage shroud in an F-class machine (~150 MW) planned in 2002 at a customer site
  - Combustor liner testing to follow at a customer site in 2004

GE working with DOE in a risk-reducing, step-wise approach for developing CMCs for Industrial Gas Turbines