Melt Infiltrated (MI) SiC/SiC Composites for Industrial Gas Turbines

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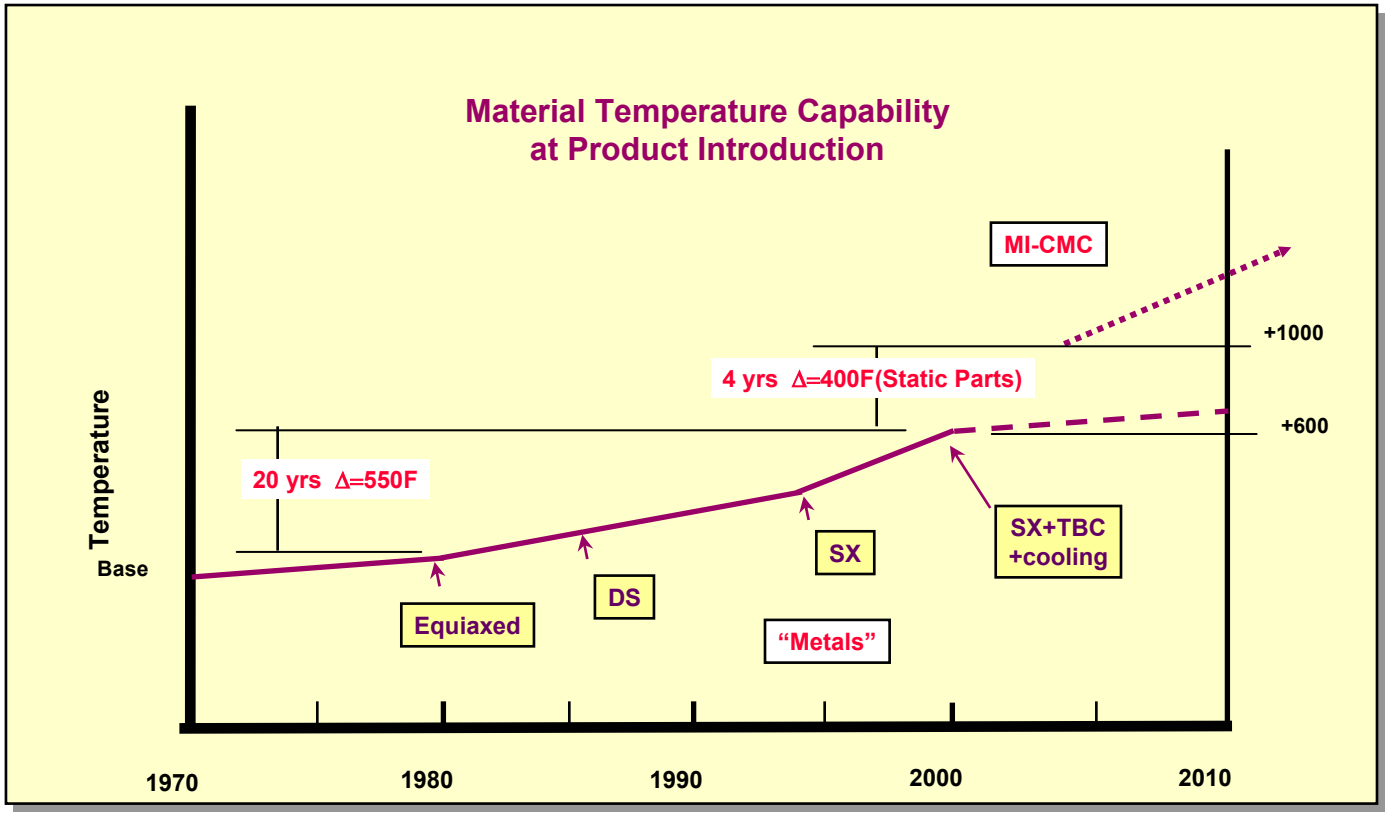
Outline

- Introduction
  - Opportunity
- Applications
- Payoff
- Pathway to Commercialization
- Summary

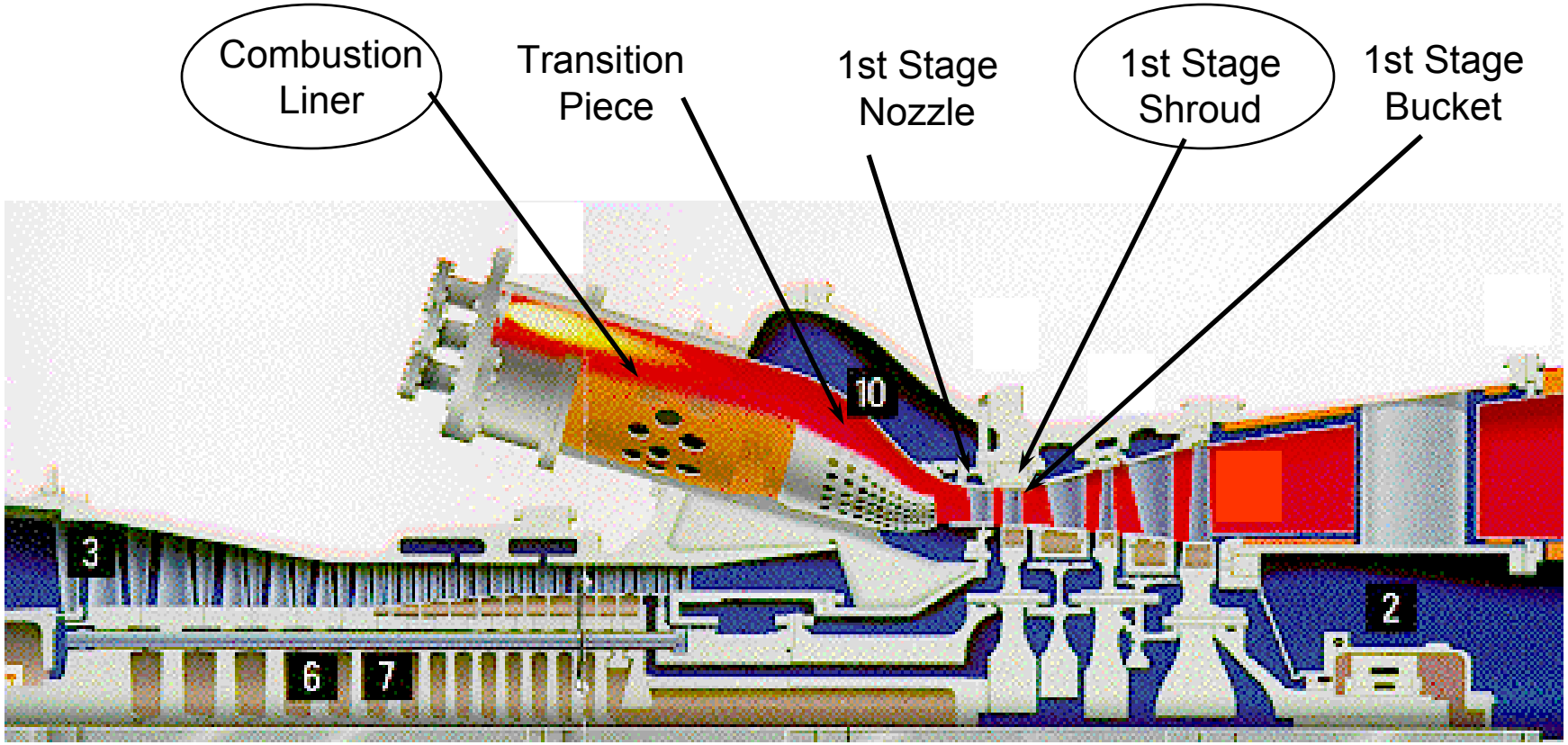
Ceramic Matrix Composite (CMC) Opportunity



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

Applications

e Industrial Gas Turbine Engine



Stationary composites 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 (simple cycle)
    - Most advanced are F-class & H-class machines used for power generation
  - F-class machines range 70-220 MW (simple cycle) & 120-350 MW (combined cycle)
    - Installed base in 1999: ~36 GW(US) & ~64 GW (worldwide)

DOE-CMC programs at GE focused on Combustors & Shrouds of F-class machines

- ***Technology would flow to other machines & other components***

Payoff For All Stationary Components

- Up to 1.1% point increase in simple cycle efficiency and 3% increase in output

- Market growth of 6%/year and 20% market penetration for all gas turbines by 2020
  - US annual savings of ~290 Trillion BTU of energy, equivalent to ~0.29 Trillion cubic feet 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 per year, further reducing the cost of electricity to customers

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

Ceramic Matrix Composites - The path into Gas Turbine Engines

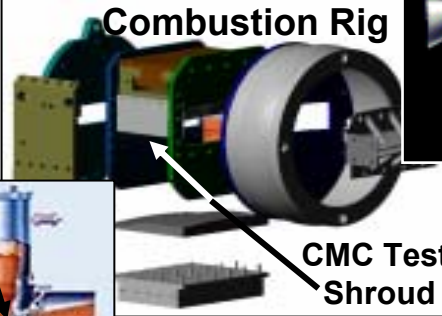
Stg. 2 Shroud

Stg. 1 Shroud

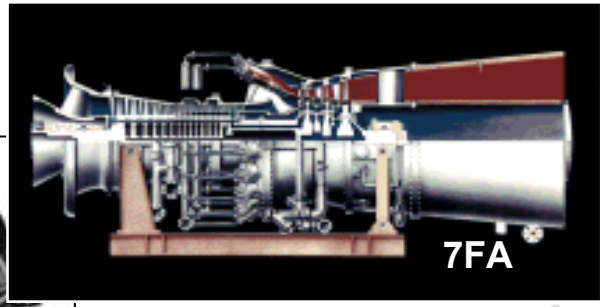
MI-CFCC

HS-188

New Combustion Rig



CMC Test Shroud



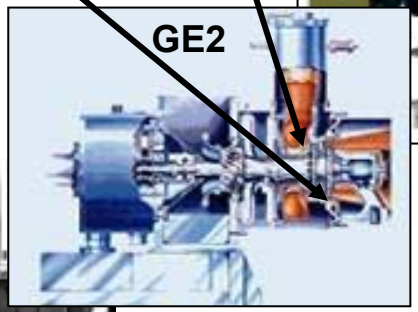
2002-2003

Large Engine Validation Test

4000 -8000 hrs at Customer

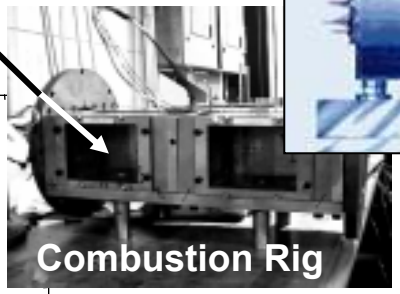
2001-2002

GE2



Rig Qualification Tests

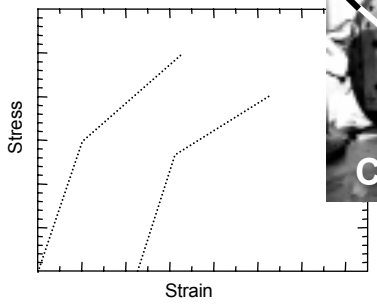
50+ cycles & 300 total hours



2000

Small Engine Testing

80 cycles & 1070 hrs



1998-1999

Rig Feasibility Tests

200+ cycles & 200 hrs

1996

Lab Tests

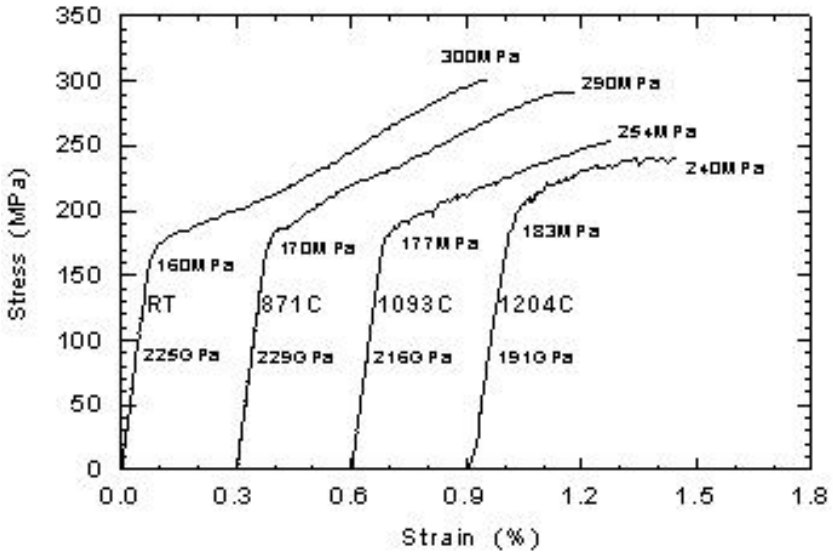
DOE Program Completed

DOE Program in Progress

Progressive testing provides risk reducing "stepping stones" to engine test

Silicon Carbide Fiber Reinforced M. I. Composites

Tensile Tests



Ballistic Damage

Entrance **Exit**

CMCs offer high temperature strength along with damage tolerance

Rig Testing of Combustor Liners

310 Flame off Cycles
25 Hours
Gas Temp. 1170^{0}c

Over 300 Flame off Cycles
Over 230 Hours
Gas Temp. 1425- 1510^{0}c

Shroud Rig Testing at 1500°C Gas Temperature

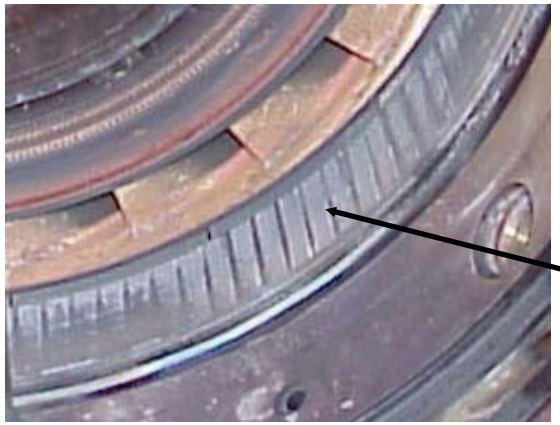
HS-188

Failed after 50 cycles

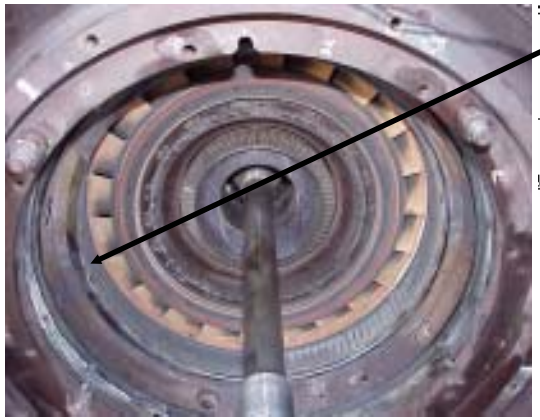
GE MI-CFCC

Survived 200 cycles and
50 hours exposure

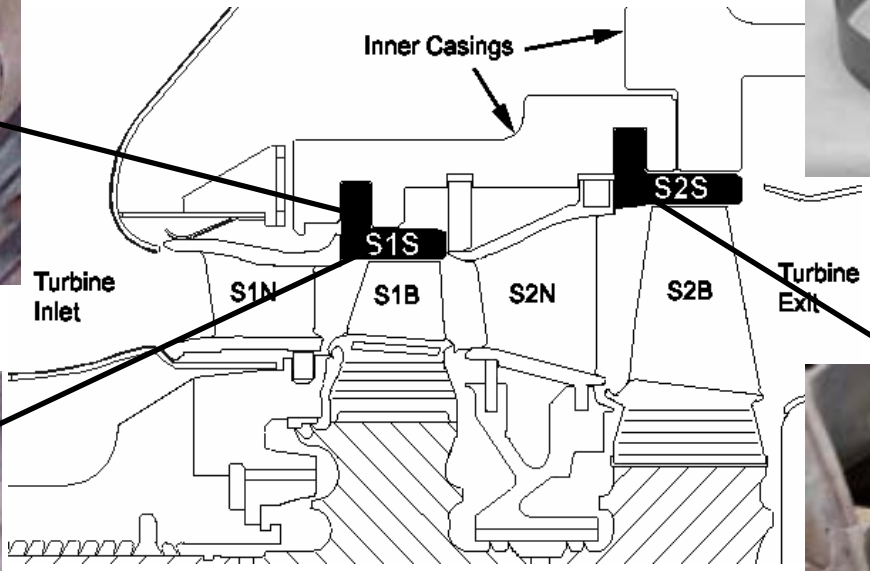
GE2 Shroud Testing at GE Oil & Gas



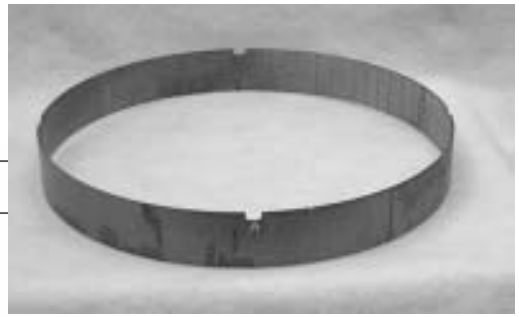
First Stage CMC Shroud



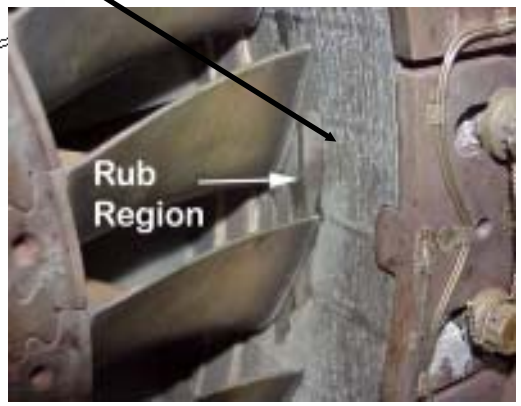
View aft looking forward



GE2 Turbine Cross Section
Operated at Gas Temp of ~1875F



18.5" CMC Second Stage Shroud Ring



Blade Rub on Second Stage CMC Shroud

Engine Testing of MI Composites Shrouds Has Been Very Successful to Date

Summary

- CMCs represent a game changing technology for industrial gas turbines
  - 400^{o} F+ improvement over metals
- CMCs offer opportunities for fuel savings, reduction in emissions, and reduction in cost of electricity to customers
- DOE's programs have taken lead in CMC material development for their applications in industrial gas turbines
- GE's efforts on DOE programs focused on shroud & combustor liners
  - Field test of first stage shroud in an F-class machine planned in 2002 at a customer site
  - Field test of combustor liners being planned

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