NASA GRC HOTPC PMC Project Overview

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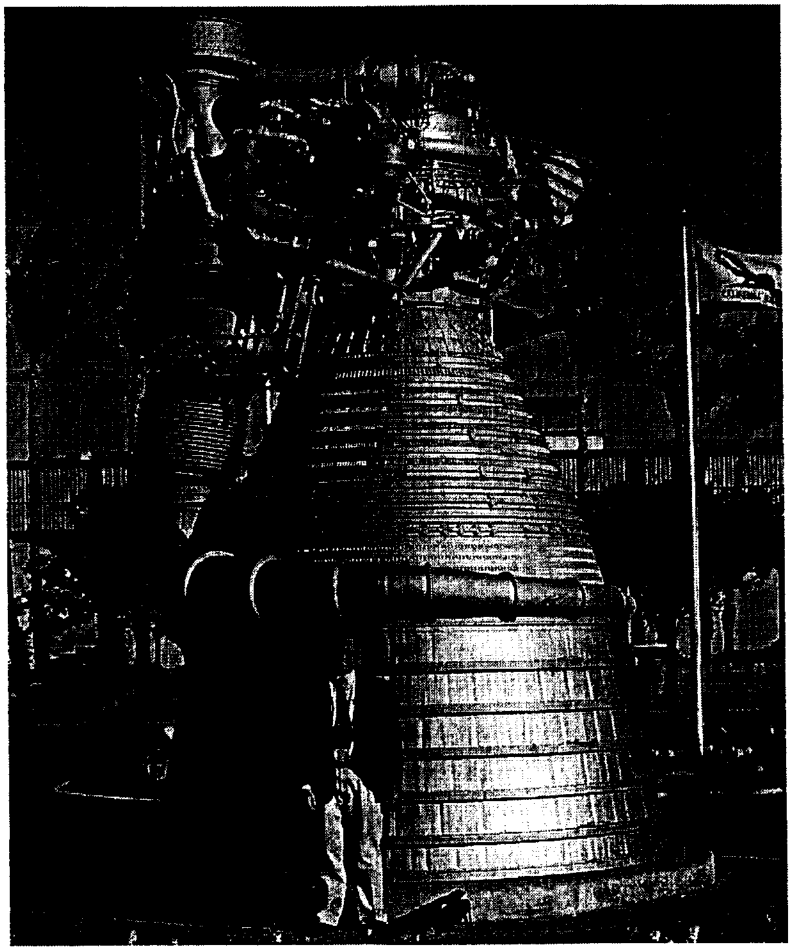
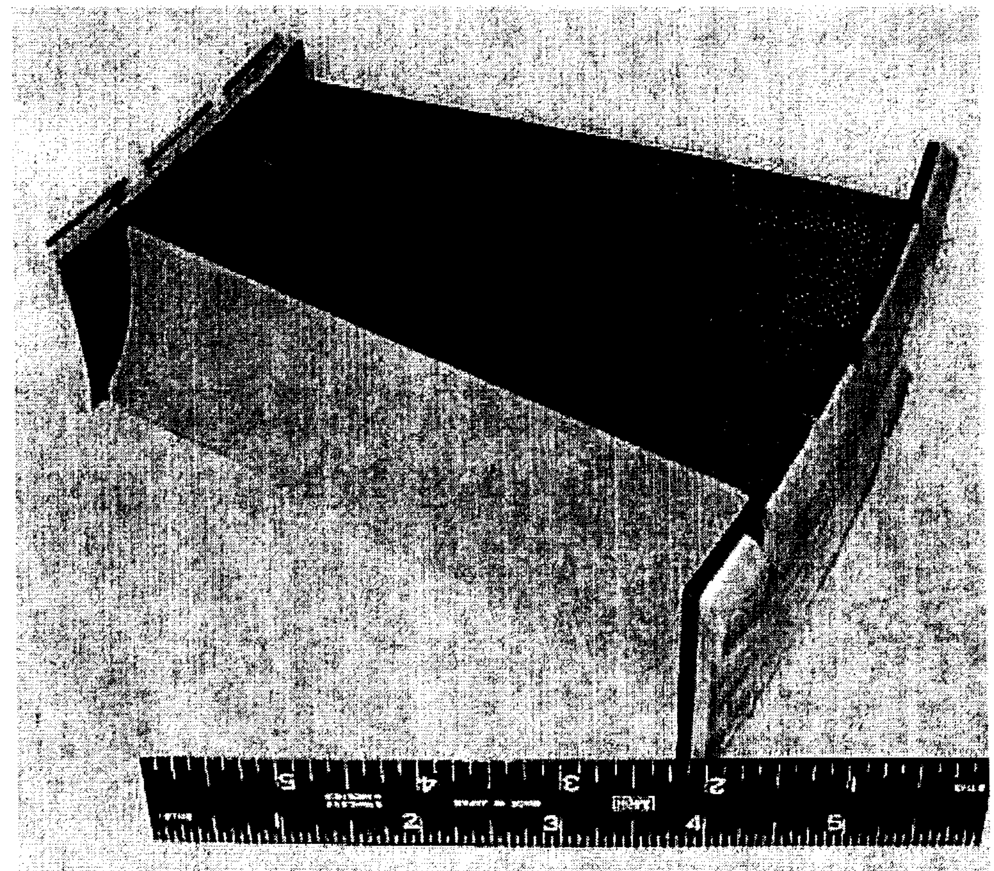
NASA GRC

A review of NASA GRCs Higher Operating Temperature Propulsion Components Project (HOTPC) on polymer matrix composites (PMCs) will be described. The summary includes research from NASA GRC in-house, university and industry's cooperative programs. Current research emphasis focuses on developing high temperature PMCs used in rapidly heated structures, erosion coatings for PMCs, nano-materials compatible with polyimide resins, and development of more durable high temperature PMCs.

Higher Operating Temperature Propulsion Components

(HOTPC): PMC Overview
Presented at *High Temple Workshop XXII*





Plasma Sprayed PMC Vane Section

Jim Sutter

January 22, 2002

Higher Operating Temperature Propulsion Components

Outline

- Program Overview
- In-House R&D
- Access to Space: Adherent, AFRL/UDRI, Boeing Rocketdyne, Canyon Composites, U. Denver, Intec, Maverick, Vanguard, & YLA
- Coatings: AADC/Rolls Royce America, Univ. Cincinnati, Drexel Univ., ECI, Maverick, Metcut, and Pratt & Whitney

Higher Operating Temperature Propulsion Components Project

Project Goal

Conduct research that leads to the development of multidisciplinary technologies for affordable propulsion engine components that will enable the system to operate at higher temperatures with reduced cooling while sustaining performance and durability.

Demonstrate the technology on an engine component, with an access to space application, through a rig or engine test.

Investment Area

Development and demonstration of technologies for higher operating temperatures with reduced cooling propulsion components will contribute to ***REVOLUTIONARY ADVANCES IN CONVENTIONAL AEROPROPULSION SYSTEMS.*** *The technology also addresses NASA Access to Space goals and other candidate turbine-based space transportation propulsion systems in the* ***AIRBREATHING AEROSPACE PROPULSION SYSTEMS.***

Higher Operating Temperature Propulsion Components

	FY00	FY01	FY02	FY03	FY04
Funding	$5.4M	$6.8M	$6.8M	$6.1M	$4.6M
FTE's	30	40	40	40	30

Engine Test SiC Pressure Sensor

Engine Test Coated PMC Exit Guide Vane

Objective:

Conduct research that leads to the development of multidisciplinary technologies for affordable propulsion engine components that will enable the system to operate with reduced cooling while sustaining performance and durability. And to utilize these high temperature technologies in access to space applications.

Approach:

- *Extend temperature capability of all classes of materials throughout the entire engine.*
- *Develop life prediction capabilities for resulting materials and components.*
- *Validate material characterization behavior and component structural performance with data from rig/engine tests.*
- *Replace standard, metallic, space propulsion, component with lighter weight advanced materials.*

Technical Challenges:

- *Developing any number of new technologies which will continue to generate affordable products.*
- *SOA materials are approaching their inherent thermal capability requiring the development and utilization of coatings: TBC's, and EBC's.*

Key Deliverables/TRL:

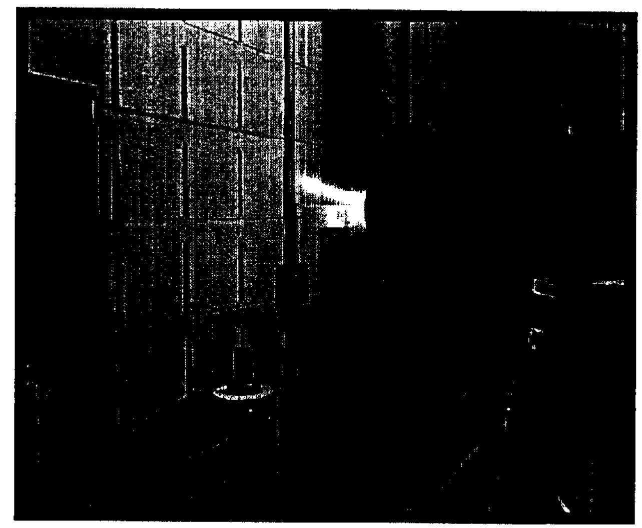
- *Engine Test SiC Pressure Sensor/TRL-6*
- *Engine Test PMC Exit Guide Vane/TRL-6*
- *Life Models for Ceramic Turbine Vane/TRL-4*

Facilities Required:

- *Durability Rigs* • *Computational Facilities*
- *Materials Characterization Labs*

Partners:

- *Boeing / Rocketdyne* • *Honeywell* • *AADC*
- *Kulite Semiconductors* • *ECI (coatings)*
- *Adherent Tech. (fibers)* • *9 Universities*



Burner Rig Test Facility

Organization & Activities

HOTPC PROJECT
Carol Ginty

Ceramics
Serene Farmer

- Cooled Ceramics (S *) *Ram Bhatt*
- Oxide Ceramics (S) *Martha Jaskowiak*
- Life Prediction and Testing of Intermetallics (S) *Jon Salem*

Metallics
Brad Lerch

- Atomistic Computational Alloy Design (S) *Phil Abel*
- Metallic and Intermetallics Characterization (S) *Brad Lerch*
- Analysis Method for RLV Thrust Cell Liners (ATS) *Rod Ellis*

Polymers
Jim Sutter

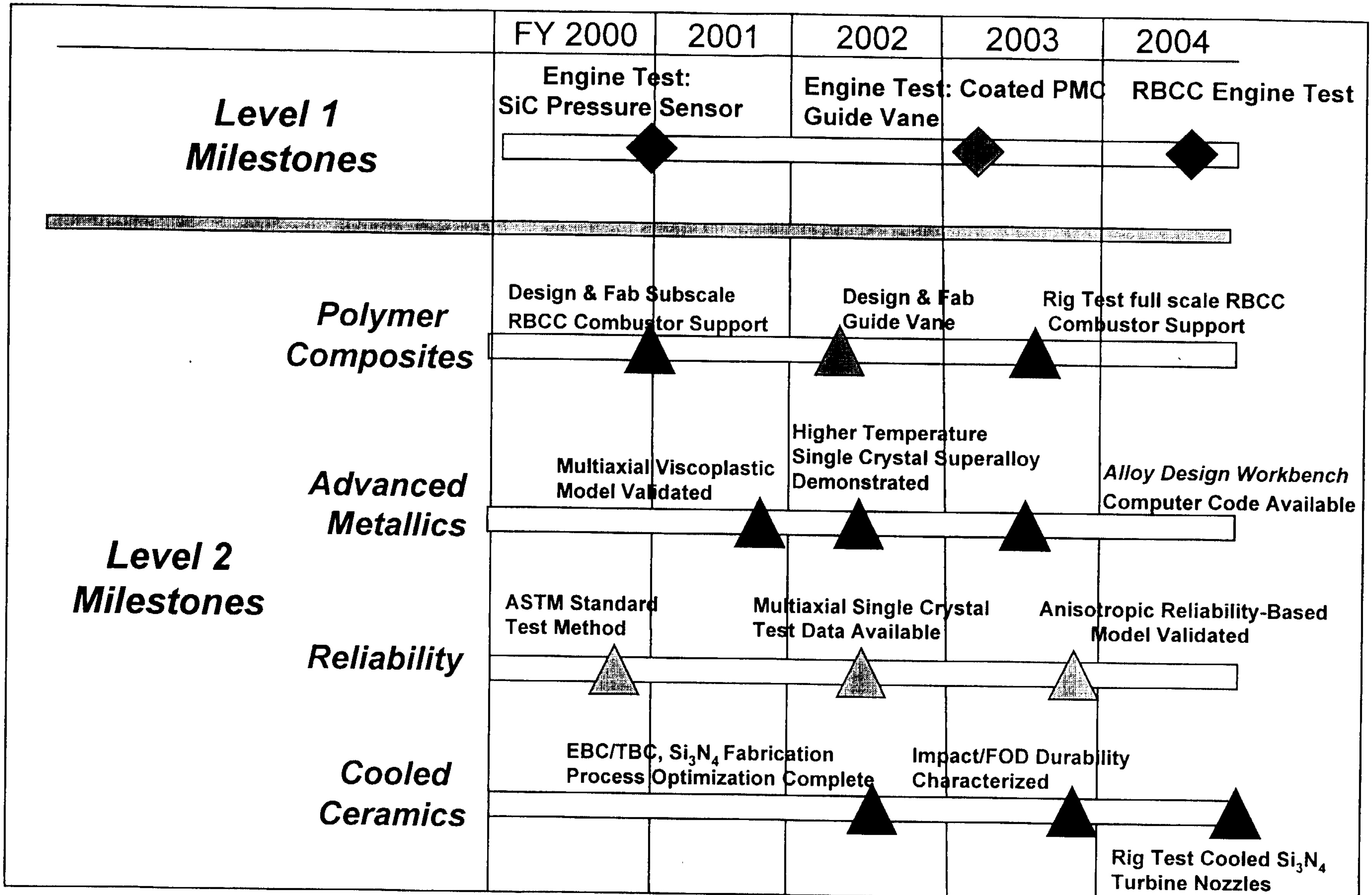
- Improved Durability (S) *Jim Sutter*
- Advanced Erosion Resistant Coatings (F) *Jim Sutter*
- RBCC Metal Component Replacement with a PMC (ATS) *Jim Sutter*

Instrumentation
Glenn Beheim

- 900°F SiC Pressure Sensor (F) *Glenn Beheim*

*S: Sustaining Activity ATS: Access to Space Activity F: Focused Activity

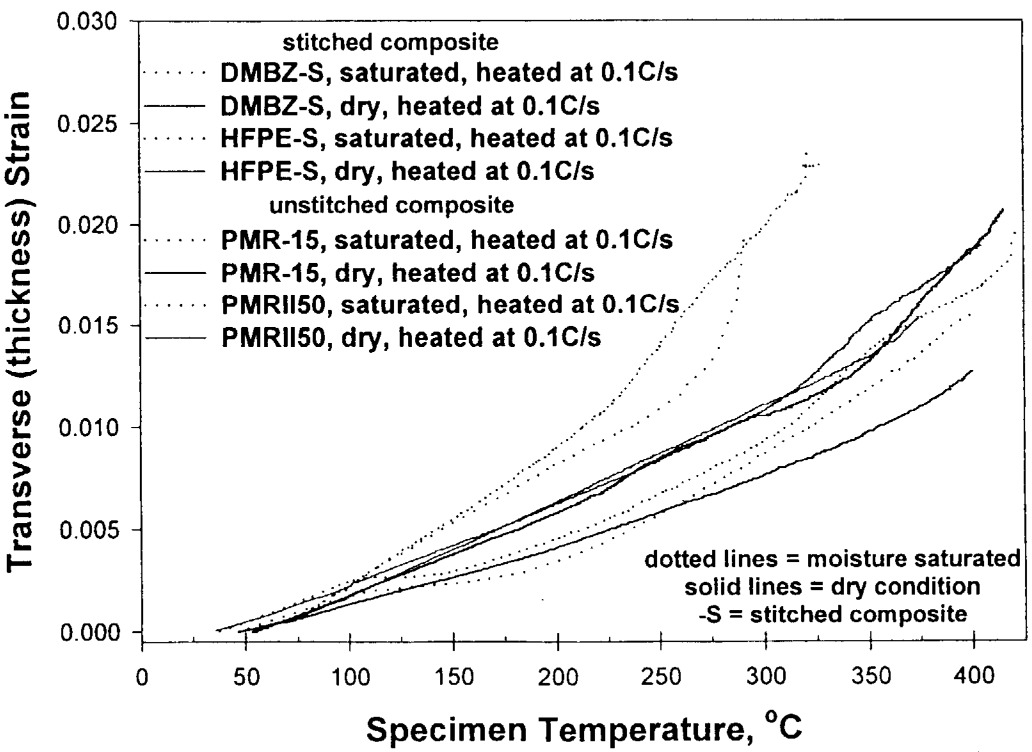
Higher Operating Temperature Propulsion Components



HOTPC PMCs – Access to Space

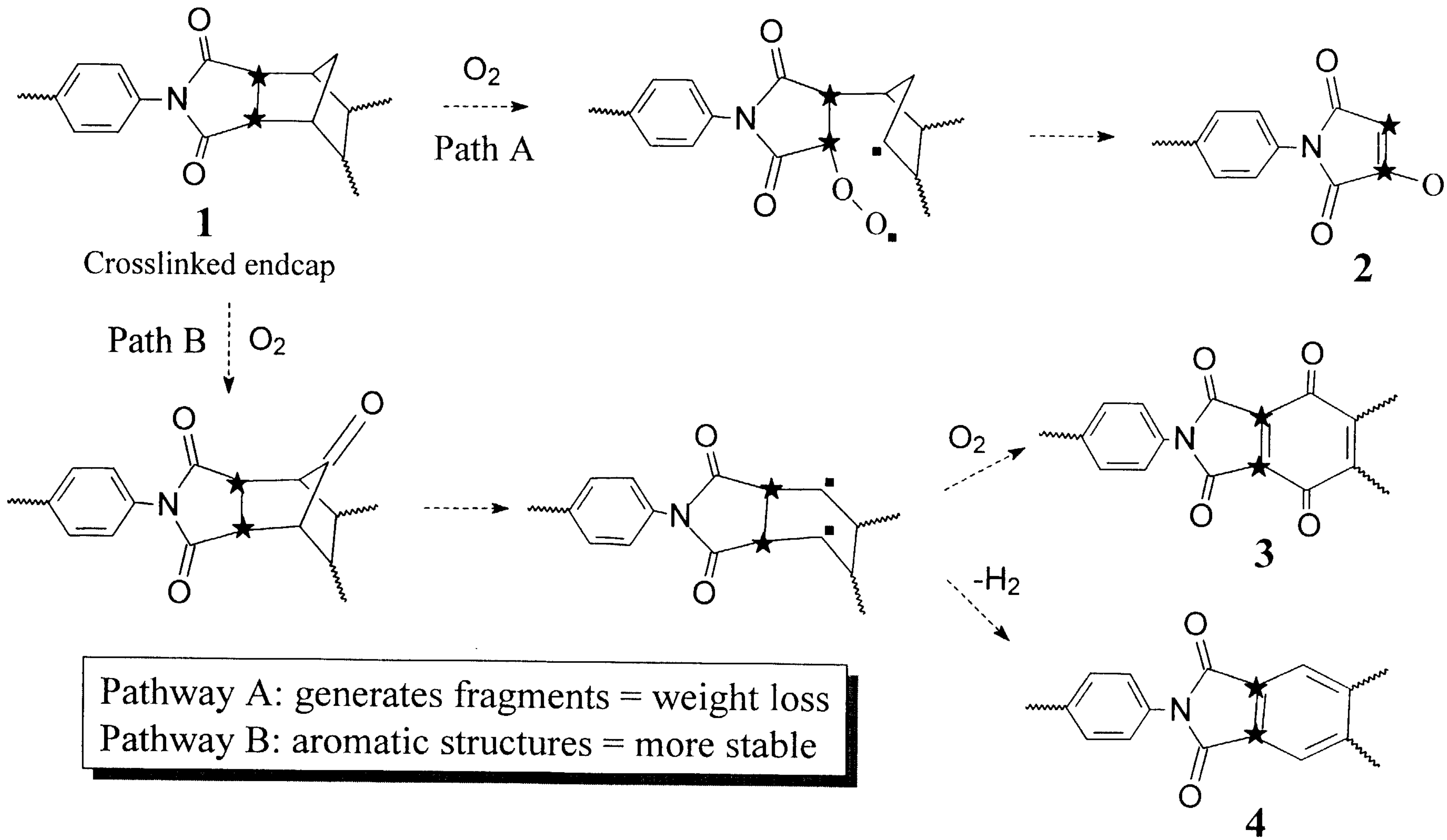
Stitched vs. Unstitched Composites

Stitched DMBZ and HFPE Composites Survive high heating rate without blistering up to 400 °C while unstitched PMCs blister at 250-300 °C



HFPE Stitched AS4 Composites (T_g = 380 °C)		
	UNC (KSI)	ILS (PSI)
RT	54.4	4409
500 °F	42.4	3513
550 °F	40.4	4063
650 °F	33.7	3184

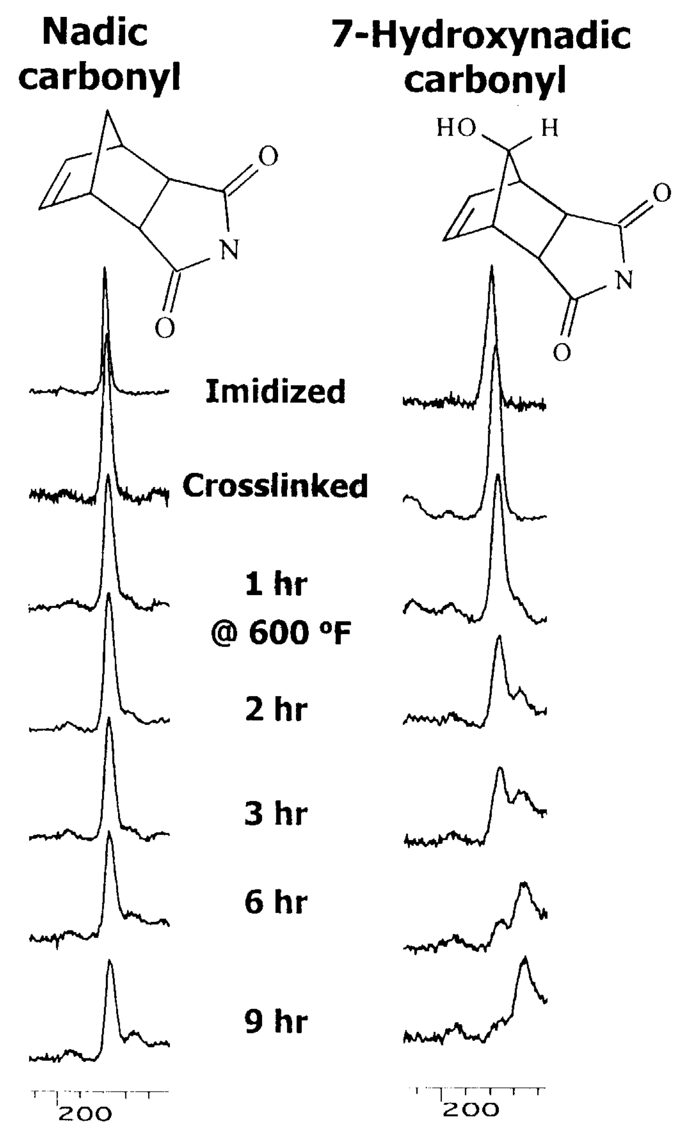
Norbornenyl Endcap Oxidation Pathway & Products



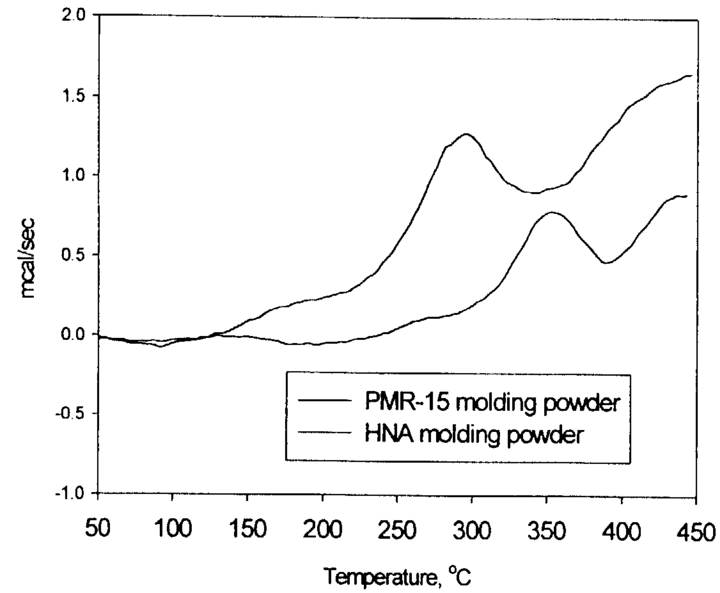
Pathway A: generates fragments = weight loss
Pathway B: aromatic structures = more stable

^{13}C Labeling Identifies Endcap Oxidation Mechanisms

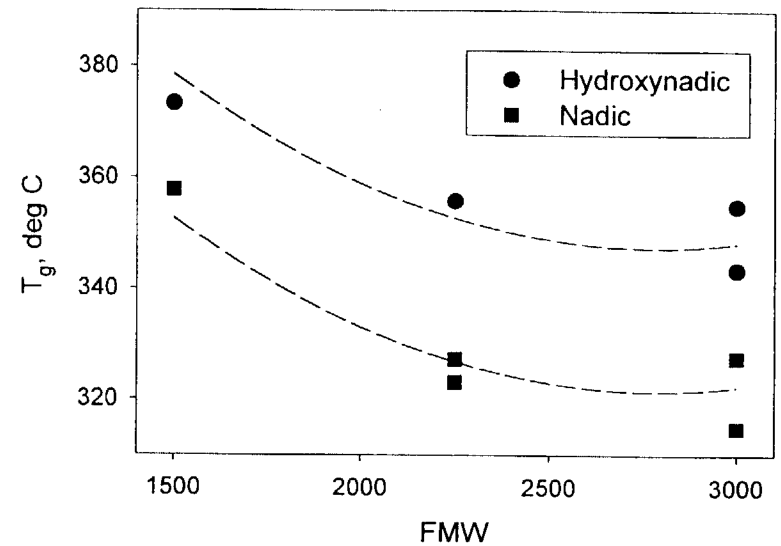
- ^{13}C Labeling identifies site-specific non-volatile oxidation products in PMR-15
- Nadic crosslink oxidizes into two types of products upon aging in air:
  - Path A: Cleavage product, accompanied by large weight loss
  - Path B: Stable, substituted aromatics, accompanied by small weight loss
- NMR shows that 7-hydroxynadic endcap favors Path B degradation
- Preliminary results indicate 7-hydroxynadic end cap is promising replacement for nadic in addition polyimides



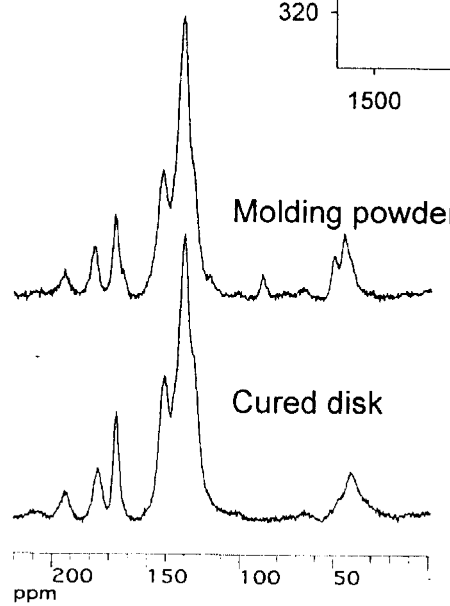
Hydroxy Modified PMR-15 Has Similar Cure + Higher Tg than PMR-15



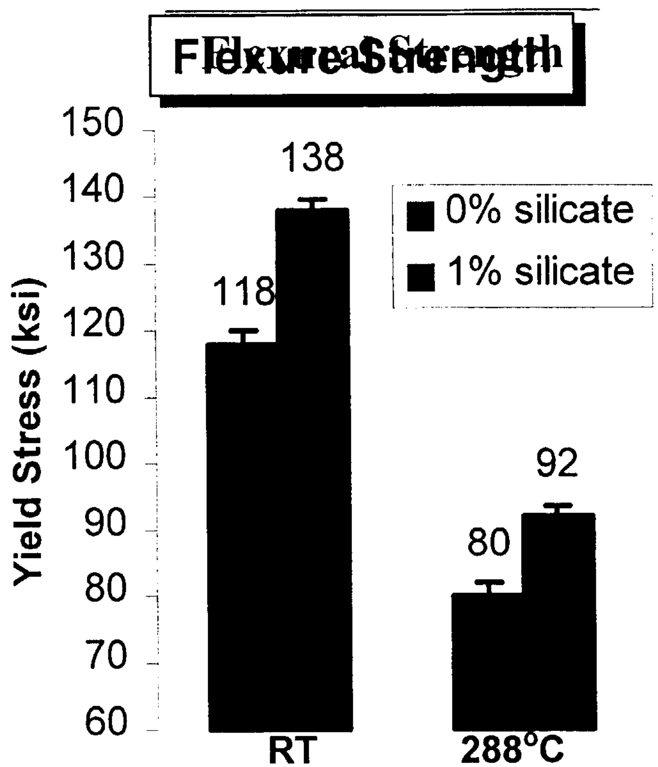
Hydroxynadic Polymers Tg = 25 °C Higher than for PMR-15

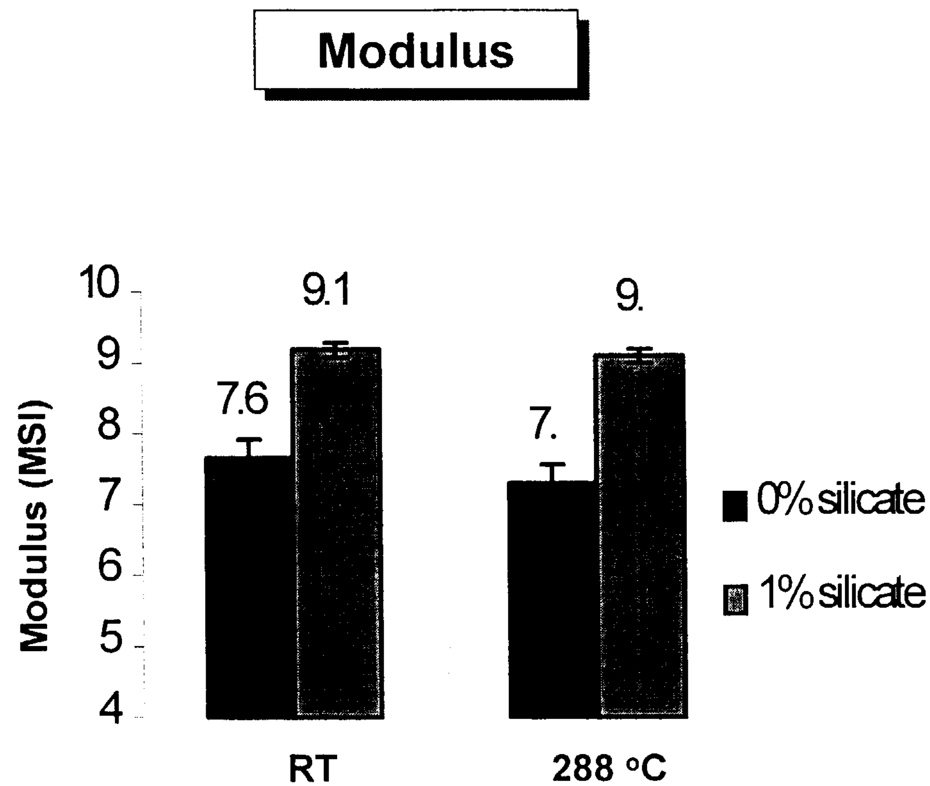


Cure temperature is about 50 °C lower than for PMR-15, but NMR shows cured structure is the same



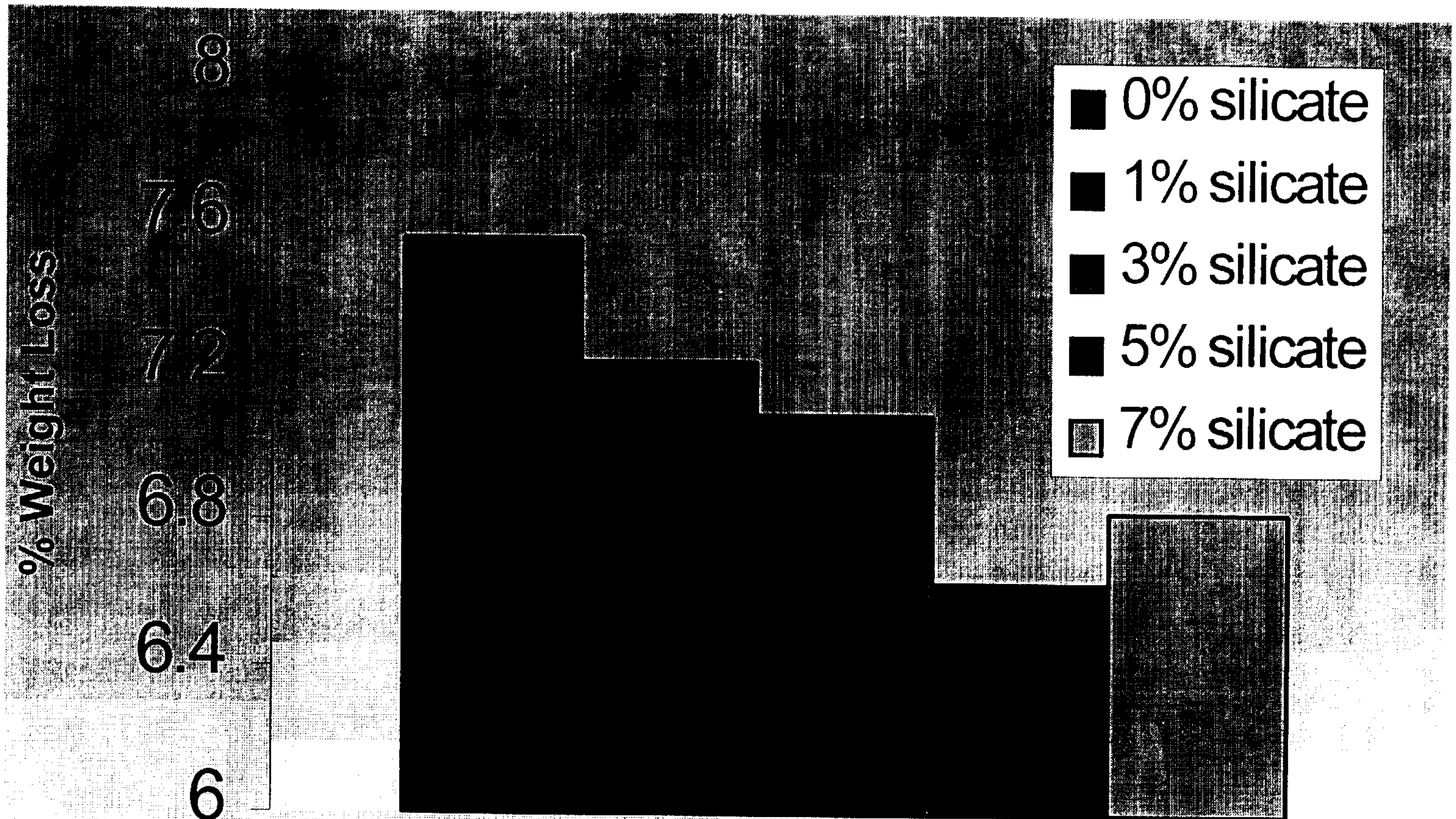
Clay Additive Improves Composite Mechanical Properties





- Silicate is PGV modified with MDA and dodecylamine (1:1)
- 8-ply T650-35 8HS/PMR-15

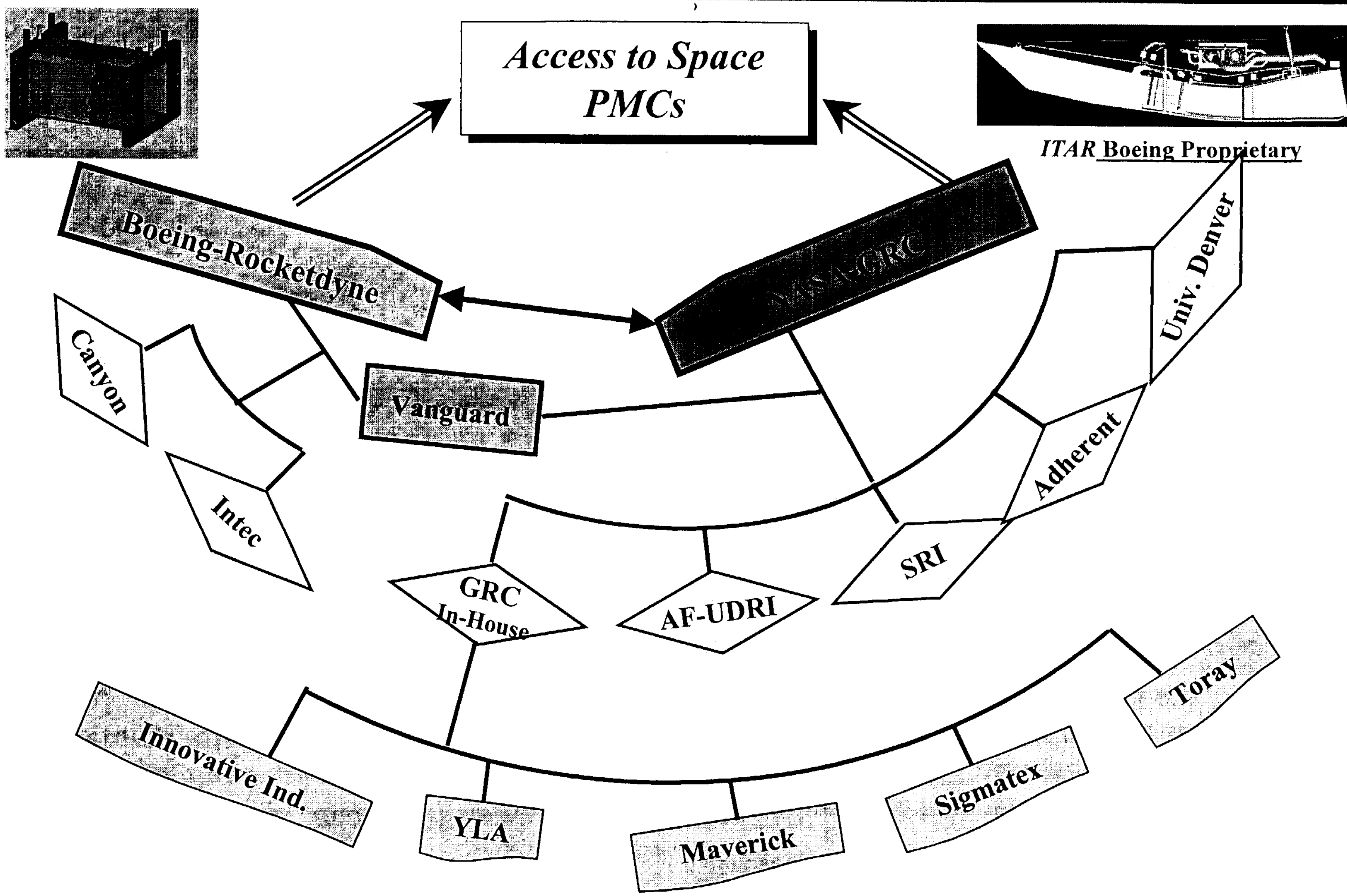
Effect of Clay Concentration on TOS of PMR-15 Neat Resin and Nanocomposite



PMR-15 Resin Aging Conditions: 1000 hr @ 288 °C

* Silicate is PGV modified with MDA and dodecylamine (1:1)

Higher Operating Temperature Propulsion Components



Higher Operating Temperature Propulsion Components

Need:

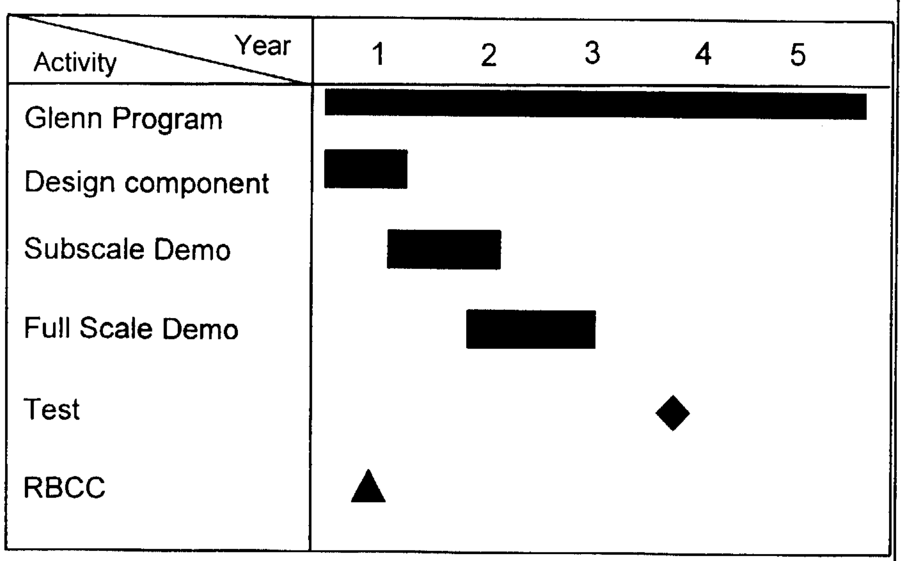
- ❑ High temp PMC replacements heavy metal manifolds, thrust chamber backup structures & turbo-pump housings
- ❑ RBCC Demonstrator thrust to weight ratio: 15:1 Flight vehicle: 30:1
- ❑ High specific stiffness & resistance to moisture related life effects under rapid heat-up

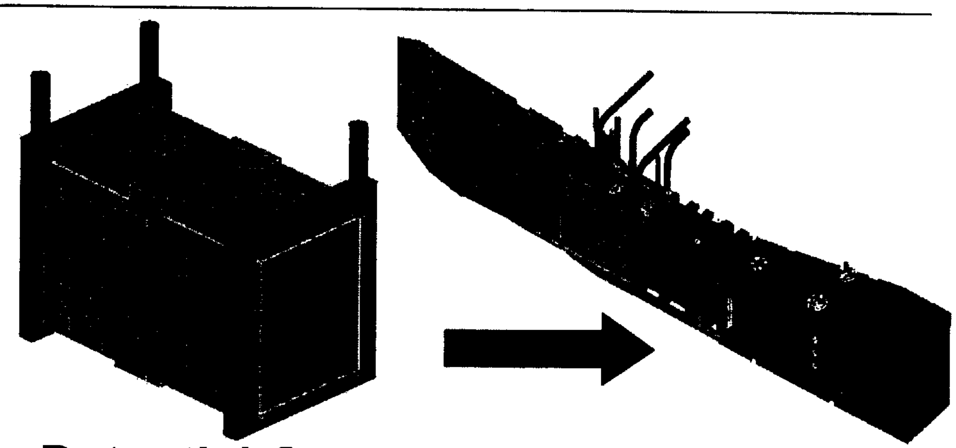
Objective:

- ❑ Develop high temperature polymer matrix composite (PMC) materials and fabrication technology suitable for manifolds, thrust chamber supports & attachments

Approach:

- ❑ Design and fab subscale component
- ❑ Subscale materials eval, environmental testing
- ❑ Perform full scale demonstration



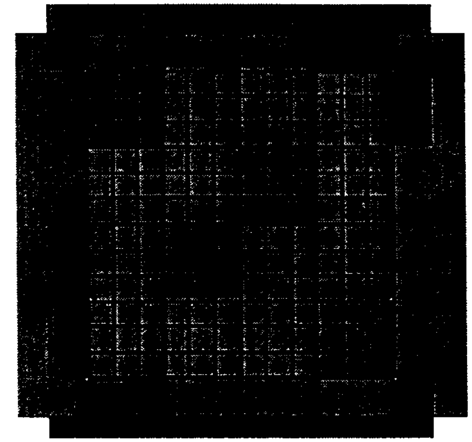


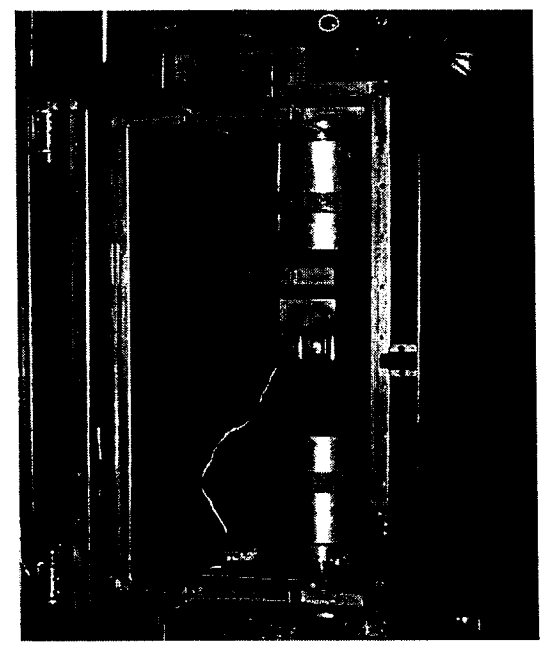
Potential Customers:

- ❑ RBCC, SLI, IPD

Micromechanical Analysis: M-Fiber 4HS PMC

- Microscopy and volume fraction measurements describe microstructure
- A finite element mesh is made of the weave unit cell
- pcGINA solution for M60j fiber: $E_{0°} = E_{90°} = 22$ Msi agrees well with experiment: $E_{0°} = 23$ Msi





Higher Operating Temperature Propulsion Components-HOTPC Project

Erosion Coatings for Polymer Composite Turbine Engine Components

Level 1 Milestone - *Build and Engine Test Coated Composite Vanes /02*

Approach

- **Build on PMC Coating Research Developed in *HITEMP* in Collaboration with AADC**
  - ***Extend technology from Composite Coupons to Components***
- **Optimize Coating Properties for Commercial and IHPTET Engine Components**
  - ***Upgrade Composite Surface for Bond Coat Adhesion - "Bottoms Up"***
  - ***Improve Bond Coat Durability to Composite & Top Coat - "Stuck in the Middle"***
  - ***Increase Wear Resistance of Top Coats - "Top Down"***
  - ***Define PMC Coating Fatigue/Life Limits based on Component Mission***
- **Perform Rig & Engine Tests on Coated Vanes - Cost Shared by AADC & RRA**

Results/ Plans

GRC research on composite surface preparation & bondcoat development leads to improved bondcoat tensile strengths

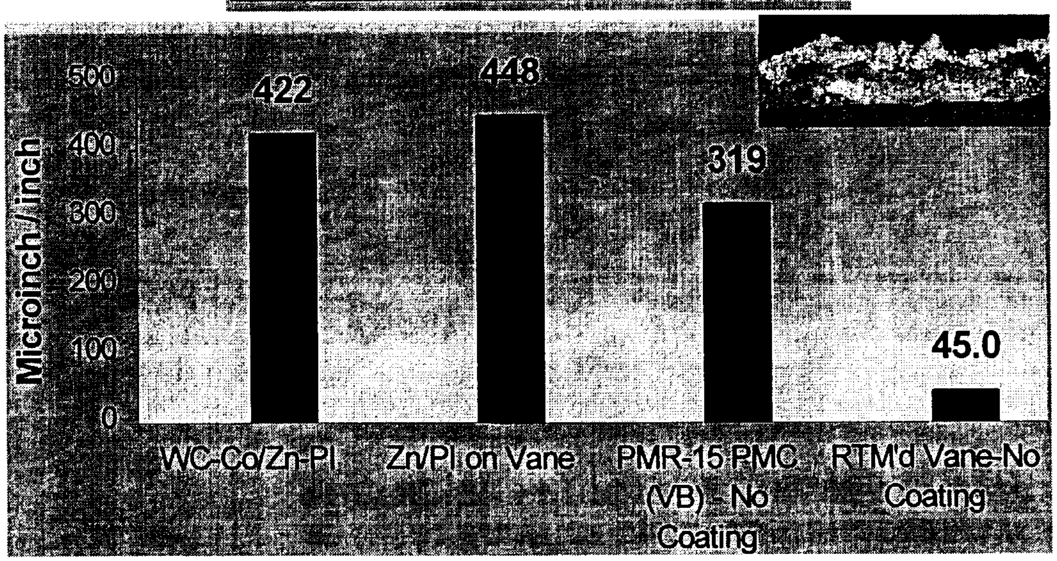
- **GRC Supplied all HT PMCs and bondcoat powders to AADC/Rolls Royce**
- **GRC developed Plasma Coating methods**

Surface Analysis for PMC Erosion Coatings

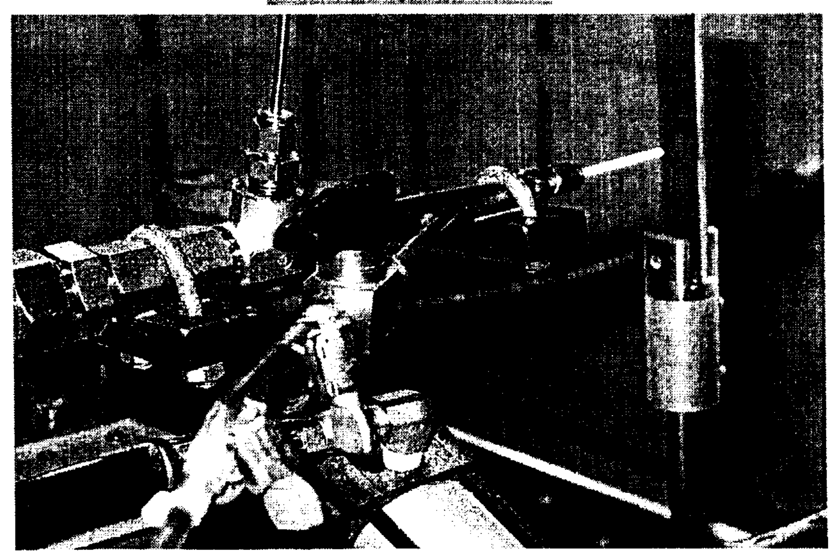
- Modified sub-mach burner rig for hot air erosion testing on PMC coatings

- Factors controlling coating surface roughness:
  - PMC manufacturing technique
  - Coating method & conditions
  - Coating particle size

Average Surface Roughness



Erosion Rig



Higher Operating Temperature Propulsion Components-HOTPC Project

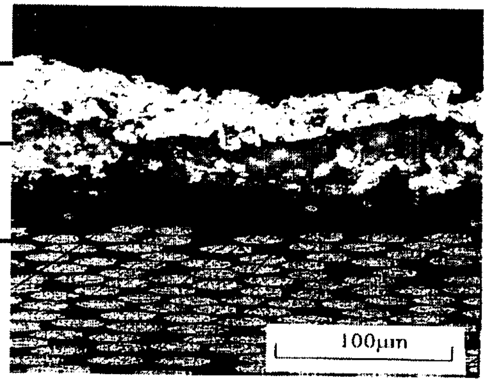
2 Coatings Evaluated

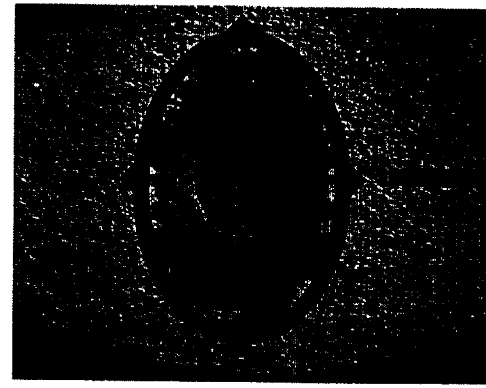
- RRA: Zn Wire Sprayed Bondcoat/WC-Co Plasma Sprayed Topcoat
- GRC: Zn+PI Plasma Sprayed BC/WC-Co Plasma Sprayed TopCoat

Top Coat

Bond Coat

Composite

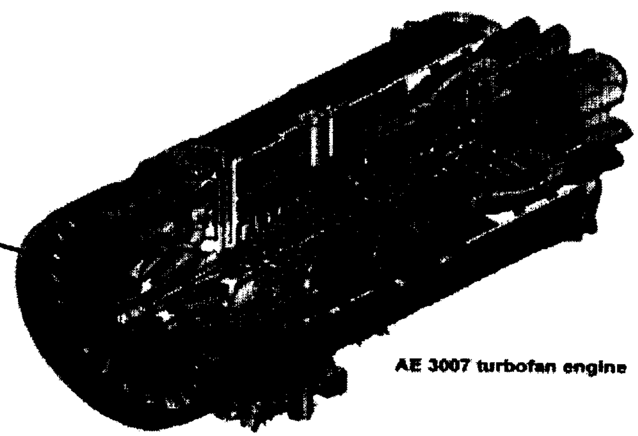




Erosion wear scar measurement tedious

PMC Coating Focused on Commercial and IHPTET Components

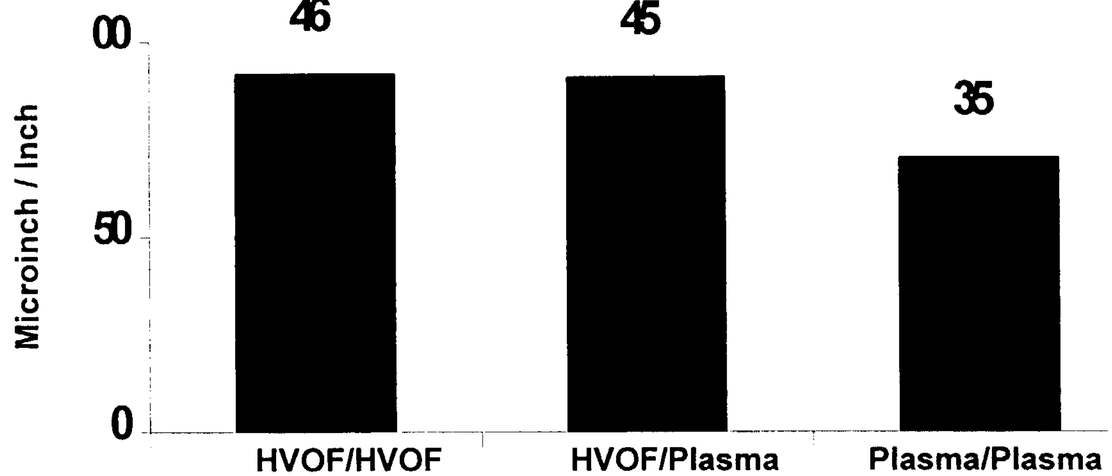
AE3007 Composite
Bypass Vane

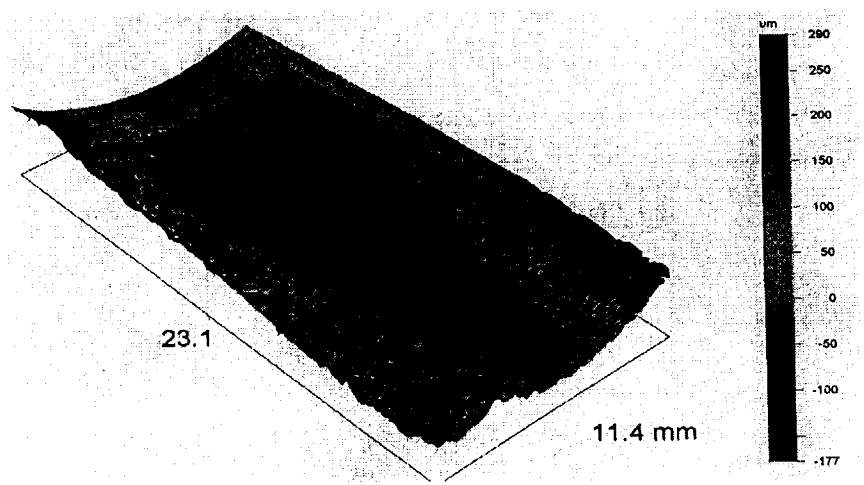


AE 3007 turbofan engine

Optimized Coating Surface Roughness

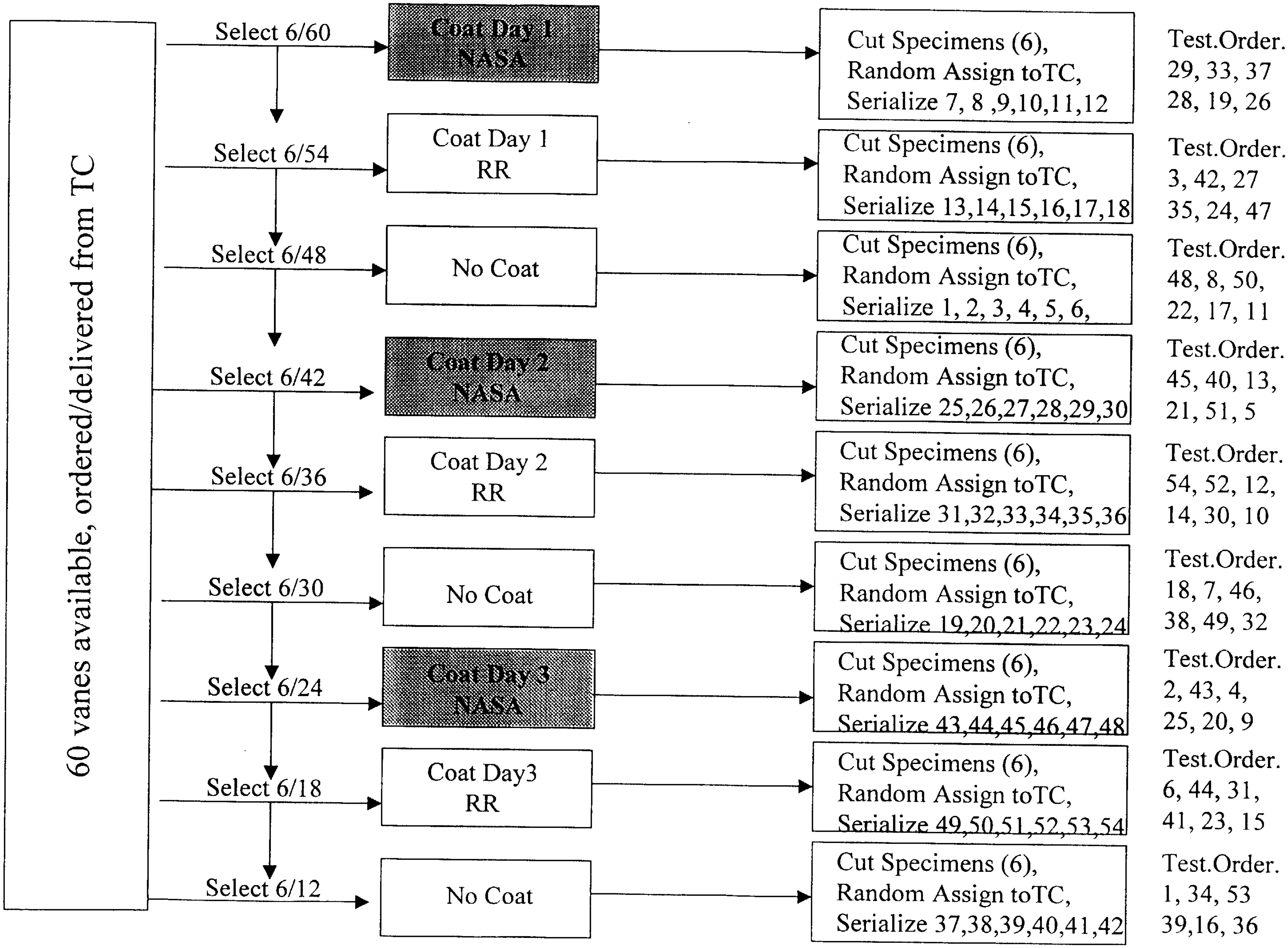
Coating Method: Average Surface Roughness



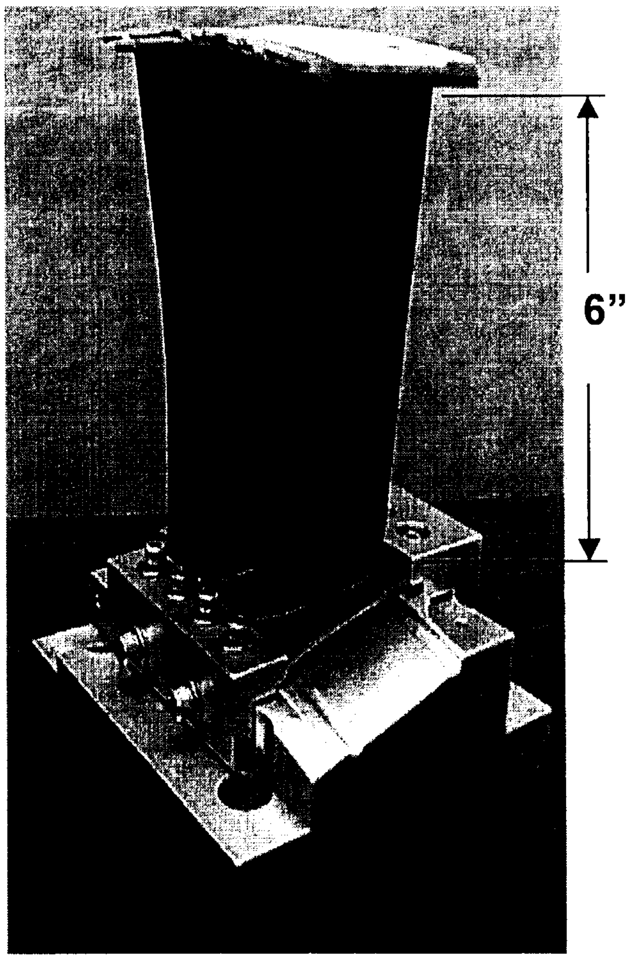


Optical Interferometer

HVOF = High Velocity Oxy-Fuel
Plasma = Plasma Spray

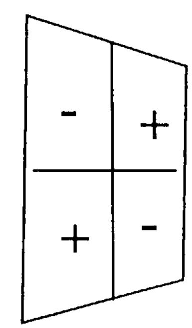

60 vanes available, ordered/delivered from TC
Select 6/60
Coat Day 1 NASA
Cut Specimens (6), Random Assign toTC, Serialize 7, 8 ,9,10,11,12
Test.Order. 29, 33, 37 28, 19, 26
Select 6/54
Coat Day 1 RR
Cut Specimens (6), Random Assign toTC, Serialize 13,14,15,16,17,18
Test.Order. 3, 42, 27 35, 24, 47
Select 6/48
No Coat
Cut Specimens (6), Random Assign toTC, Serialize 1, 2, 3, 4, 5, 6,
Test.Order. 48, 8, 50, 22, 17, 11
Select 6/42
Coat Day 2 NASA
Cut Specimens (6), Random Assign toTC, Serialize 25,26,27,28,29,30
Test.Order. 45, 40, 13, 21, 51, 5
Select 6/36
Coat Day 2 RR
Cut Specimens (6), Random Assign toTC, Serialize 31,32,33,34,35,36
Test.Order. 54, 52, 12, 14, 30, 10
Select 6/30
No Coat
Cut Specimens (6), Random Assign toTC, Serialize 19,20,21,22,23,24
Test.Order. 18, 7, 46, 38, 49, 32
Select 6/24
Coat Day 3 NASA
Cut Specimens (6), Random Assign toTC, Serialize 43,44,45,46,47,48
Test.Order. 2, 43, 4, 25, 20, 9
Select 6/18
Coat Day3 RR
Cut Specimens (6), Random Assign toTC, Serialize 49,50,51,52,53,54
Test.Order. 6, 44, 31, 41, 23, 15
Select 6/12
No Coat
Cut Specimens (6), Random Assign toTC, Serialize 37,38,39,40,41,42
Test.Order. 1, 34, 53 39,16, 36

Coating Durability:High Frequency Shaker-Table Testing



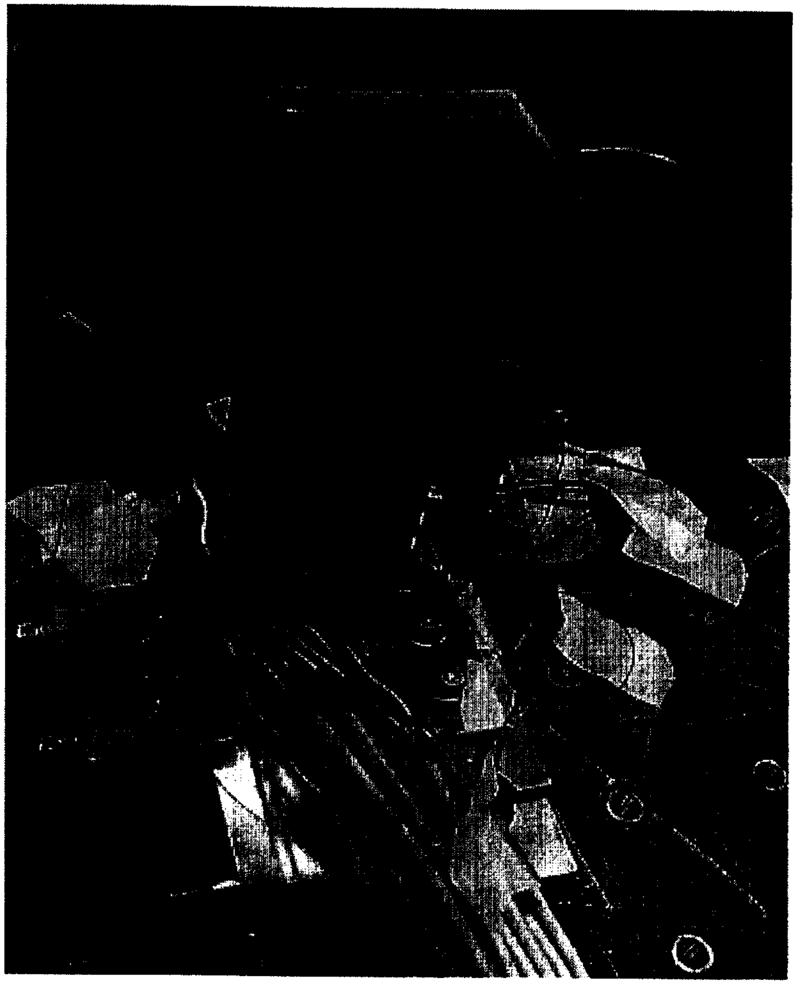
AE3007 Vane Fixture

- RRA/AADC provided data on the expected resonate frequency response for the vanes within engine speed operating ranges based on bench, rig, and engine test data. Shaker test performed at GRC simulating these conditions.
- High frequency testing confirms integrity of erosion coatings under AE3007 engine vibratory conditions
- Test fixturing was designed accommodates either individual vane segments or the three-vane packs
- High level strains recorded for 2nd Torsion mode (2T) = worst case simulation.



2T mode.

AE3007 Guide Vane Shaker-Table Testing



16 strain gages/ 6 accelerometers

- Uncoated singlet and triplet vanes were instrumented and excited at frequency ranges up to 3 kHz/accelerations $\leq$ 20G.
- Resonant frequencies, mode shapes and strain levels were determined with strain gages and accelerometers
- Modal analysis showed that both complex bending and complex torsional modes could be excited in the triplet vane.
- Complex bending modes with acceptable strain levels were simulated for singlet vane.
- Coated Singlet vane chosen for future testing. Accelerometer response will provide control feedback for dwelling at resonant frequencies.

Acknowledgements

Technical Support Team

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R&D Staff

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