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Applications for Si_3N_4 in Turbine Engines and Issues for EBCs Within Them

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Monolithic Ceramic Turbine Components

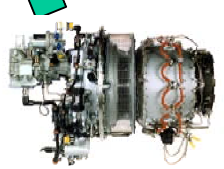
Outline

- Overview of potential markets for small gas turbine engine products, UTC product applications, and customer value propositions
- Opportunities and technology requirements
- Engine and ceramic component requirements
- EBC Issues for each major component class

Monolithic Ceramic Turbine Components

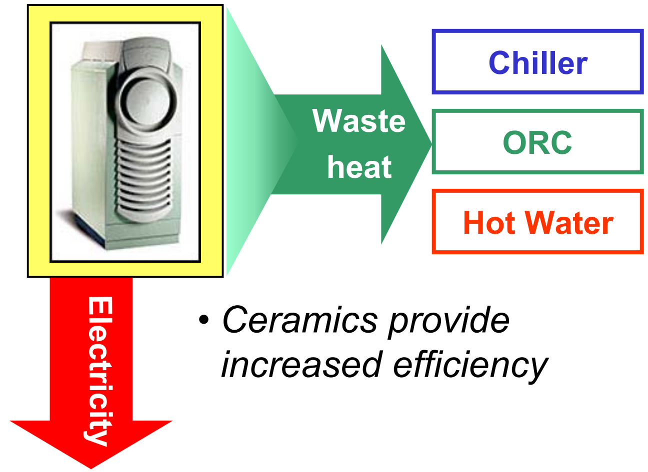
UTC Engine Applications – Axial Configuration Machines

Engines for Unmanned Air Vehicles (UAVs)



- *Ceramics enable engine size and weight reduction*

Microturbines for Cooling, Heating, and Power (CHP) Systems

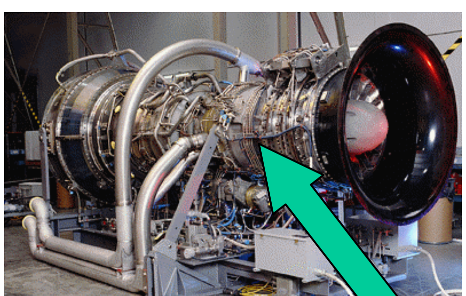


- *Ceramics provide increased efficiency*

Auxiliary Power Units (APUs)

- *Ceramics provide engine weight and operating cost reduction*

Industrial Gas Turbines



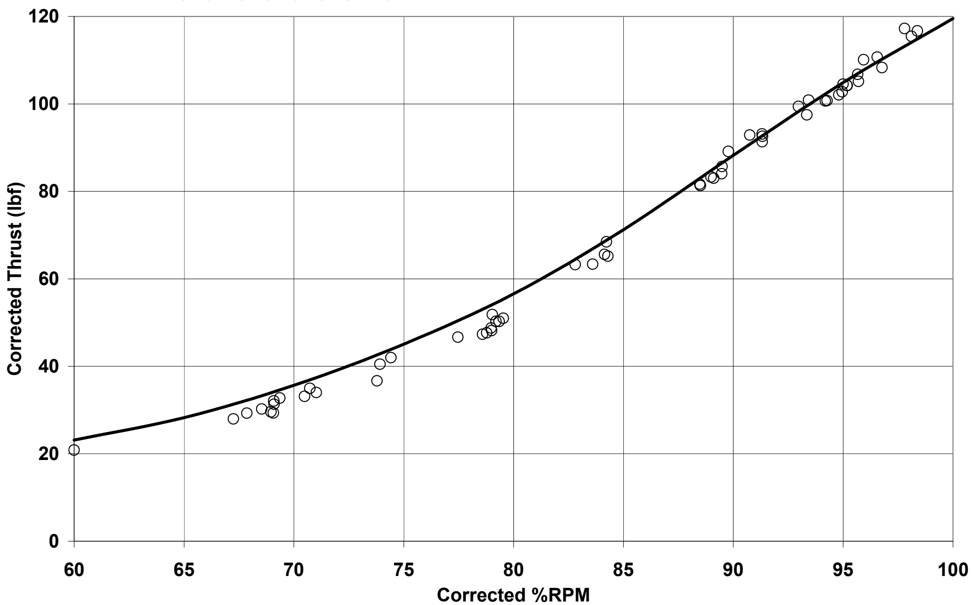
- *Ceramics enable increased efficiency and reduced emissions*

- UTC has several potential gas turbine engine applications that could employ ceramic turbine components for enhanced customer value
- Primary value achieved through higher efficiency and weight reduction
- Potential value is signficant

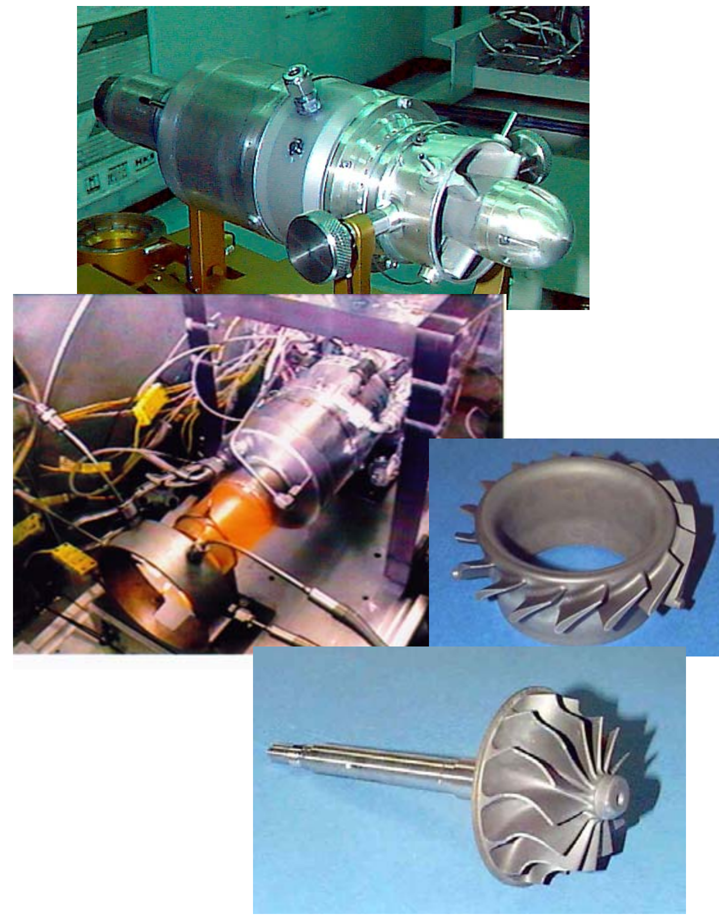
Monolithic Ceramic Turbine Components

UTC Engine Applications – Radial Configuration Machines

- ***Engine Tested With Ceramic Nozzle and Rotor from Kyocera -- Operation at T4=2300F Successful***



TJ-50 Expendable Turbojet



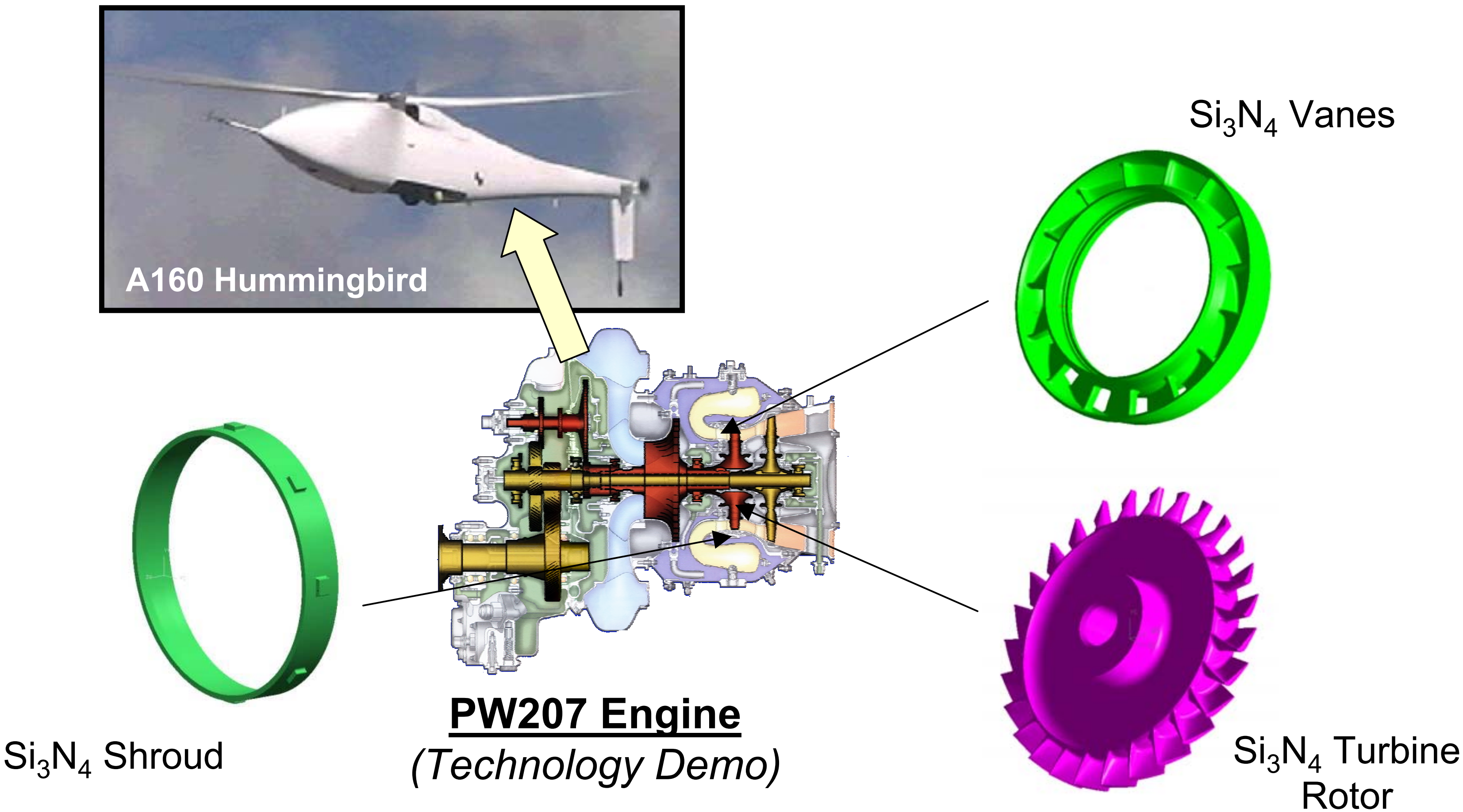
Monolithic Ceramic Turbine Components

Applications - Summary

- The potential market for gas turbine engine products incorporating ceramic turbine components is substantial
  - Ceramic turbine technology creates a strong customer value proposition
  - For UTC, significant opportunity exists for CHP, UAV, APU, and IGT products incorporating ceramic turbine technology
- Common technology requirements across diverse range of products encourages an integrated ceramic turbine technology plan to maximize leverage
- Integrated plan has been constructed to reduce critical risks for ceramic turbine technology to TRL 6 by 2006

Monolithic Ceramic Turbine Components

Ceramic HPT components to be demonstrated in gas generator



Ceramic integrally bladed rotor (IBR), one-piece vane ring, and turbine shroud HPT components are common across UTC small gas turbine engines

Microturbine Component Fabrication Progress

ST5+ Integral vane rings produced by Kyocera USA at high yield/minimal cost

- Integral vane rings address intervane sealing issues w/singlets
- Significantly reduced diamond grinding cost through slash angle elimination
- Acceptable tolerance control achieved via isopress/bisque machining method

Initial Kyocera fabrication trial yields 2 out of 3 engine quality parts, 8.5 inch OD

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Monolithic Ceramic Turbine Components

Small Gas Turbine Engine Duty Cycles Vary Considerably

APU

(12,000+ hour life)

Time (hrs)	T4.0 (F)	PR4.0
~800	> 2100	> 7
~1300	> 2000	
~2300	>1900	
~3200	>1800	
~2300	> 1700	
~2100	>1500	

UAV Engine

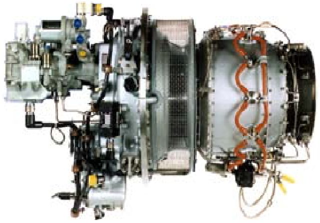
(5,000 hour life)

Time (hrs)	T4.0 (F)	PR4.0
100	> 2200	> 12
350	> 2150	
900	> 2100	
1000	> 2050	
3000	> 2000	
650	> 1800	

Future Microturbine

(30,000 hour life)

Time (hrs)	T4.0 (F)	PR4.0
~15,000	> 2000	> 6
~15,000	> 1950	



- Most of life is spent at partial power
- Less time spent at high T4

- Most of life is spent at high power (75 – 100%)
- More time spent at high T4

Engine duty cycle plays key role in determining EBC requirement

Monolithic Ceramic Turbine Components

Small Gas Turbine Engine Component Requirements

	Vane Ring			IBR			Turbine Shroud		
Characteristic	**UAV Engine**	**APU**	**Micro-turbine**	**UAV Engine**	**APU**	**Micro-turbine**	**UAV Engine**	**APU**	**Micro-turbine**
Max Temperature (F)	> 2200F	> 2100F	> 2000F	1900-2200F	1800-2100F	1700-2000F	2100-2400F	2100F	~2000F
Pressure at Entrance	> 12	> 7	> 6	8 to 10	4 to 6	4 to 5	8 to 10	4 to 6	4 to 5
Life	5,000 hrs	12,000 hrs	30,000 hrs	5,000 hrs	12,000 hrs	30,000 hrs	5,000 hrs	12,000 hrs	30,000 hrs
EBC Required? (Y, N)	Y	Y	Y	TBD	Marginal	Y	Y	Y	Y

$$\text{Recession Rate} \propto \frac{V^{1/2} \bullet P_{H2O}^{\;2}}{P_{total}^{\;1/2}} \bullet e^{-1/KT}$$

- Current application requirements will challenge the limits of current ceramic materials and process technology
- EBC's will be required for all static structures and some IBR components

Monolithic Ceramic Turbine Components – EBC Requirements

Recession is effected by pressure, temperature and velocity

$$\text{Recession rate (um/hr)} = \frac{512*\exp(-111000/(8.314*T)*v^{1/2}*P_{H2O}^{2}}{P_{total}^{1/2}}$$

Where T = temperature in Kelvin

v= velocity, m/s

P = water vapor and total pressure in atmospheres

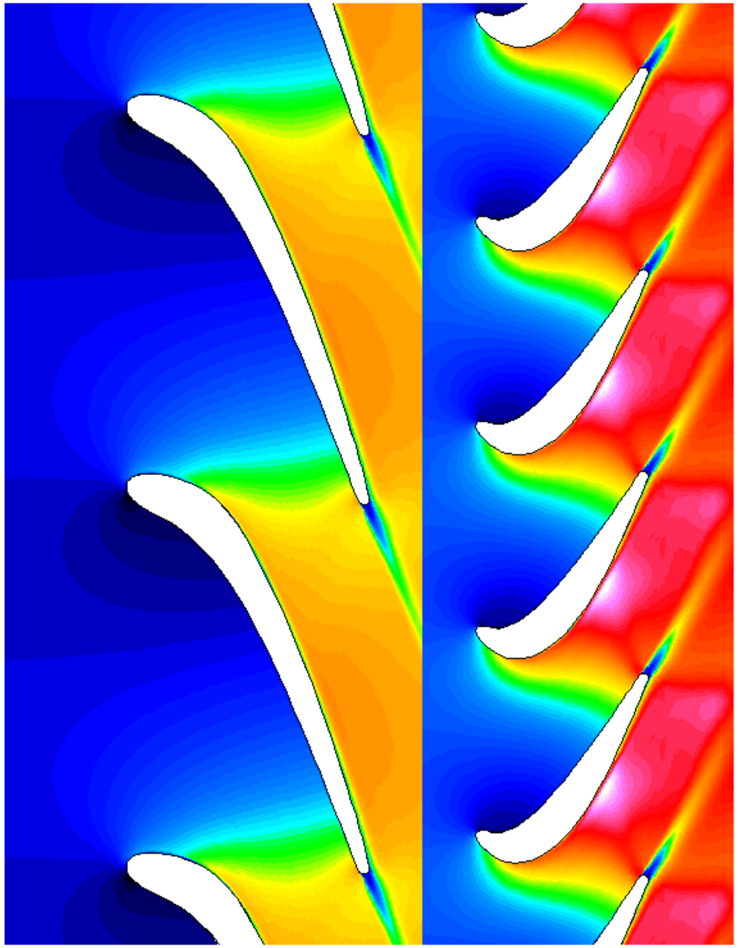
After M. Ferber, et al. adaptation of NASA/J. Smialek equation for silicon based ceramic recession

Monolithic Ceramic Turbine Components – EBC Requirements

Pressure, Velocity and Temperature vary through the turbine stage(s)

Relative Mach Number

Vanes – Stationary reference frame

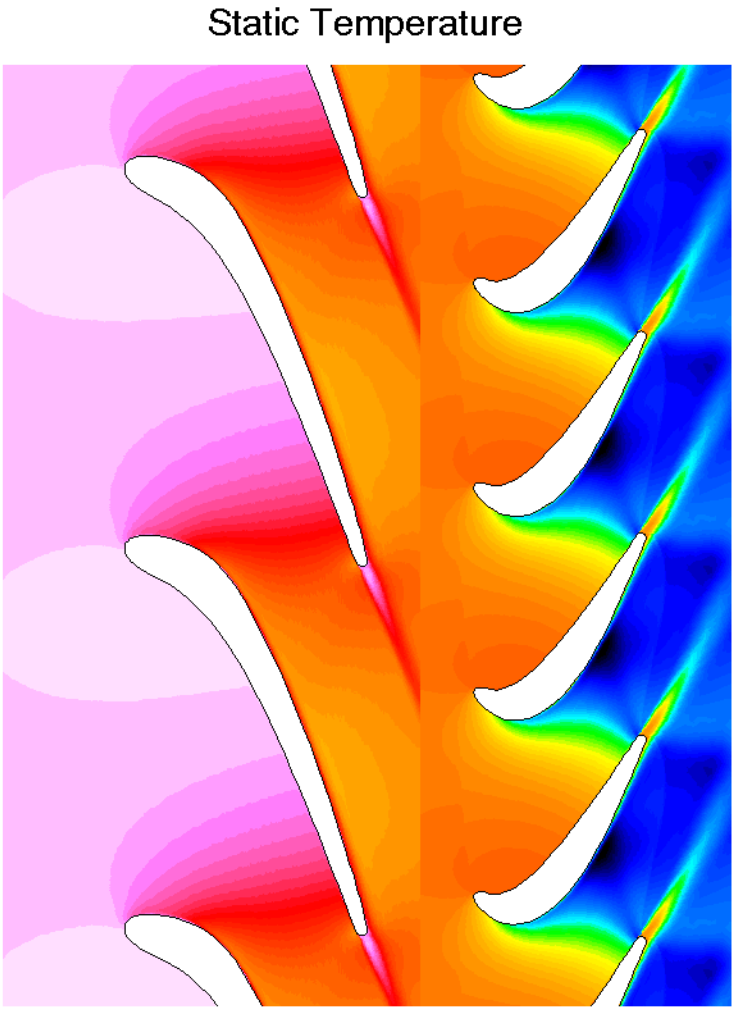


Blades – Rotating reference frame

Monolithic Ceramic Turbine Components – EBC Requirements

Pressure, Velocity and Temperature vary through the turbine stage(s)

Delta T > 250ºC



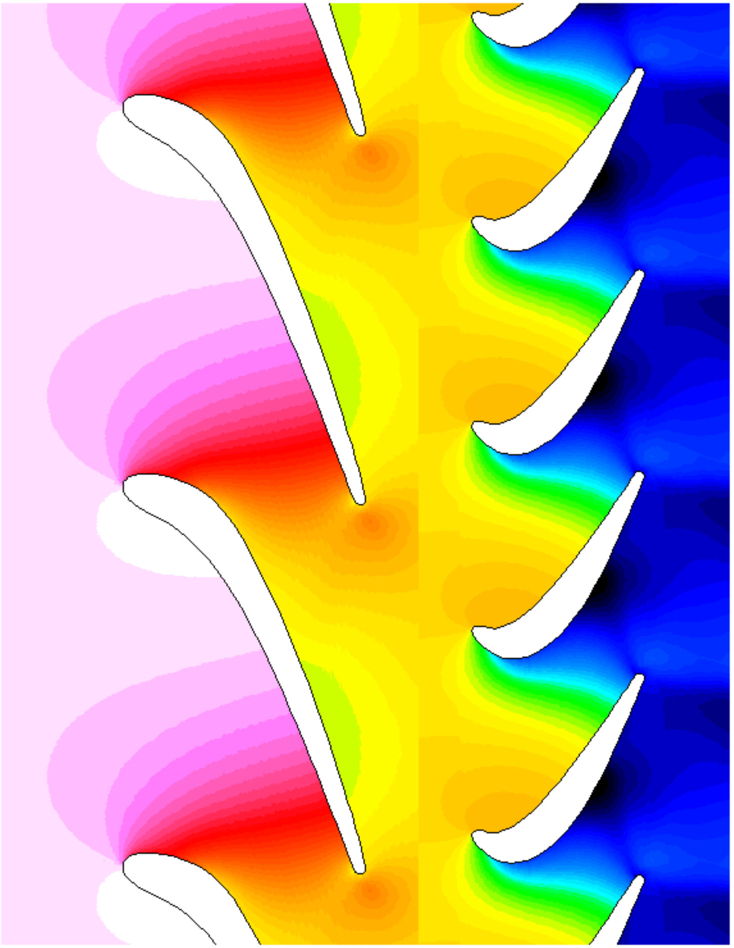
Monolithic Ceramic Turbine Components – EBC Requirements

Pressure, Velocity and Temperature vary through the turbine stage(s)

- Velocity changes & Work Extraction drop pressures

Static Pressure

> 7 Atm.



< 3 Atm.

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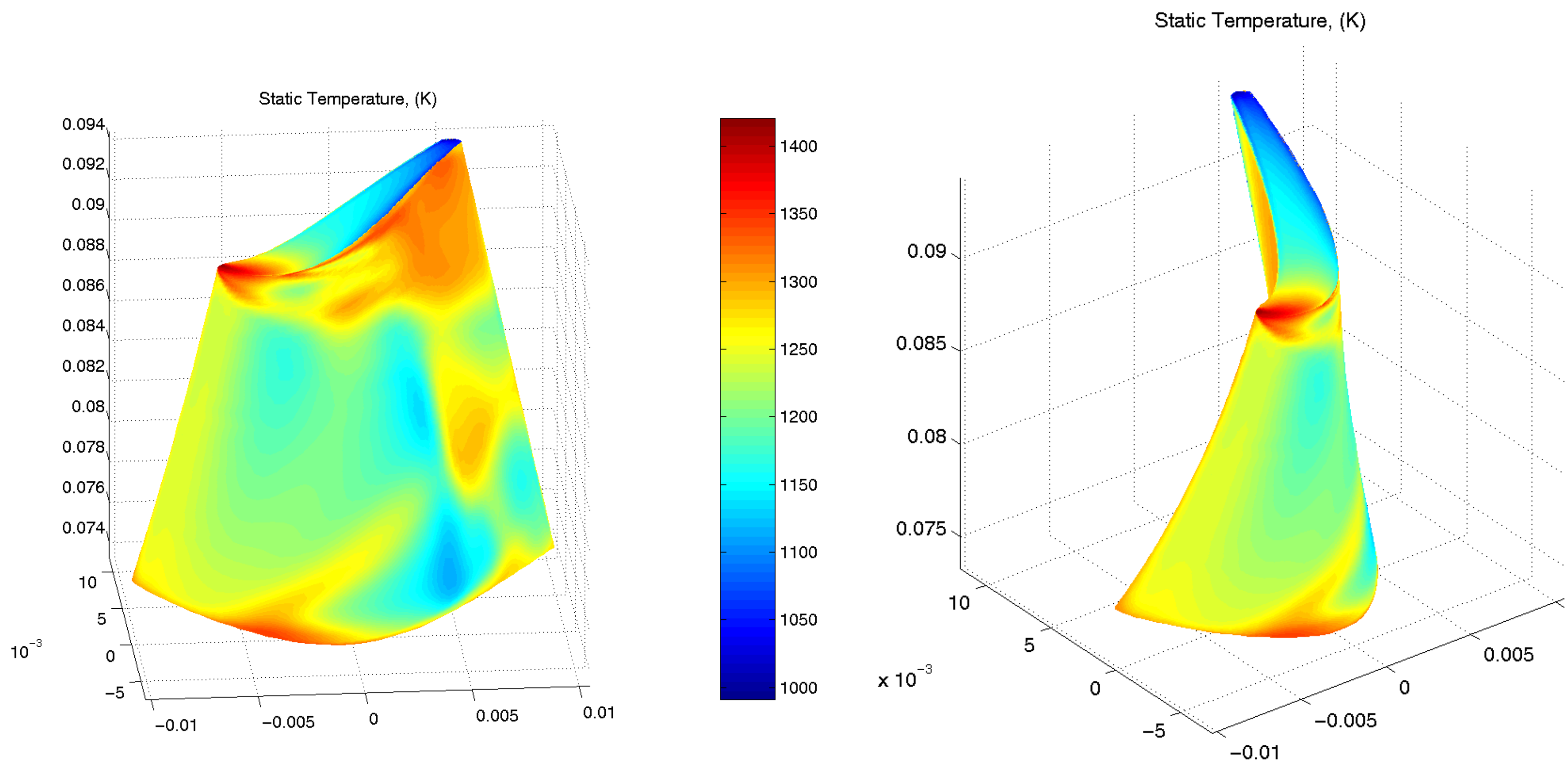
Monolithic Ceramic Turbine Components – EBC Requirements

Blade material temperatures effected by tip to shroud aerodynamics



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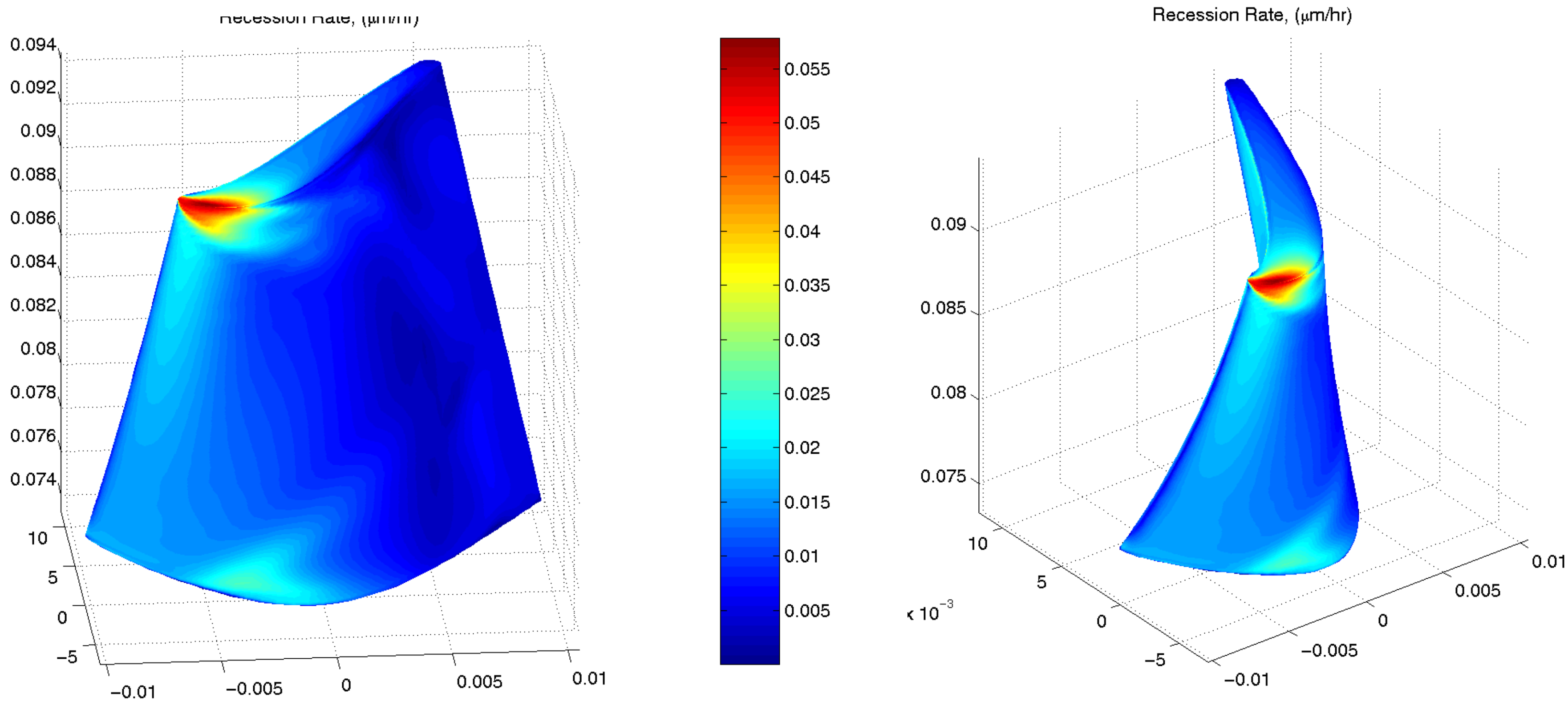
Monolithic Ceramic Turbine Components – EBC Requirements

Material recession predicted using temperature, pressure and local velocity



Monolithic Ceramic Turbine Components – EBC Requirements

Blade tip recession not seen on Allison tested AGT5 rotor blades

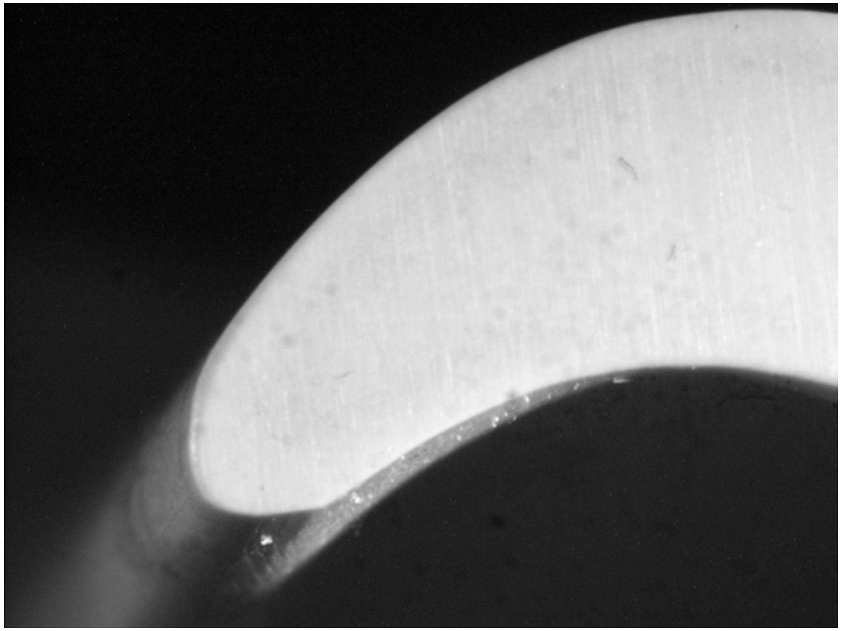
1000 hour AGT5 rotor

~ 250 hour AGT5 rotor

Photographs courtesy Rolls Royce/Allison

Monolithic Ceramic Turbine Components – EBC Requirements

Possible blade tip/leading edge recession in Solar 100 hour test



As Received AS800 Blade

AS800 Blade after 100 hour test

10x photographs courtesy Mattison Ferber, ORNL

Monolithic Ceramic Turbine Components – EBC Requirements

Blade/tip issues a concern for EBC developers

- Turbine tip shrouds (BOAS) will require EBC's due to high temperature hot streaks from the combustor
- Shroud coatings will likely need to be abradable
  - GE showed BSAS based EBC's can abrade during a CMC shroud/metal blade 2MW engine test
  - What environmentally safe grit tips are available?
- Blade tip leading edge a concern, might burn away to a "safe" geometry, not yet analyzed
  - "revised through removal" aerodynamics may continue to promote high heat transfer and further tip loss
  - Effects of enlarged tip clearances significant for small turbine engines

Monolithic Ceramic Turbine Components – EBC Requirements

Conclusions

- A broad base of potential applications exist for monolithic ceramics in turbine engines of the future
- P, T & V all change rapidly throughout the turbine hot section, and these changes effect needs/requirements for EBC's
- Local areas of high heat transfer can significantly promote recession
- Blade tip and shroud regions both present unique requirements for the EBC developer
- A systems approach – Base material as well as EBCs, are required to meet goals (particularly for blades/rotors)