Status of High Pressure and Temperature IGCC Turbine Deposition and Film-Cooling Testing at NETL

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UTSR Peer Review Workshop VIII

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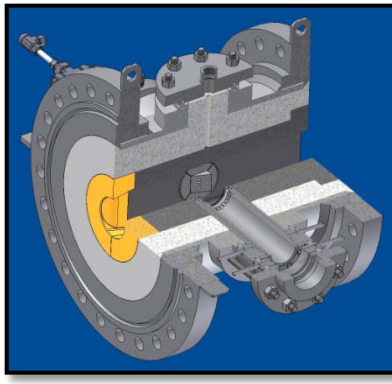
NETL NATIONAL ENERGY TECHNOLOGY LABORATORY

EPSCoR DEPARTMENT of ENERGY

Goals of the experimental program



- To match pressure, temperature and particulate loading as closely as the facility is capable of doing to simulate IGCC conditions
- To determine particulate sizing to try to match the mean particle diameter based on geometric and Stokes number similarity
- To determine particulate loading for the accelerated testing by matching the ppmw-hr loading
- To develop a system to process the flyash and seed it into the combustion rig
- To simulate the pressure surface of a NGV with straight, inclined hole film cooling (scaled 8x) with TBC coatings and shallow trench
- Focus of tests are to observe deposition rates and patterns and to attempt to measure surface temperatures, surface roughness, and observe film cooling patterns

Presentation focus is on status of testing preparation, results are forthcoming
Currently kicking-off testing phase of program (this Tuesday?)

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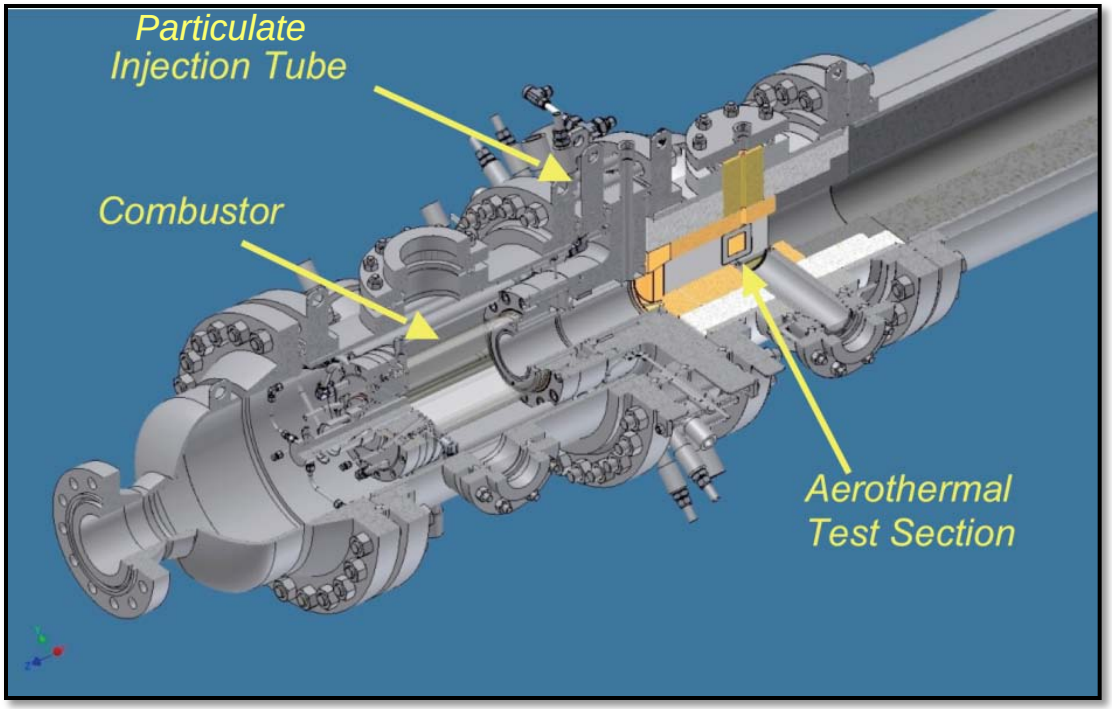
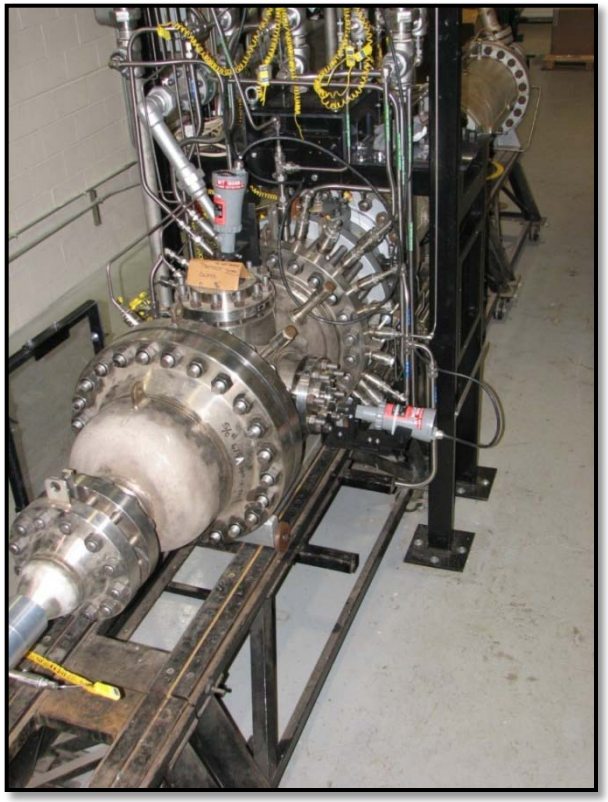
Experiments will be conducted in a high pressure and temperature combustion facility at NETL





Temperatures up to 1100 C (2000 F)
Pressures up to 5 atm
Particulate injection capability

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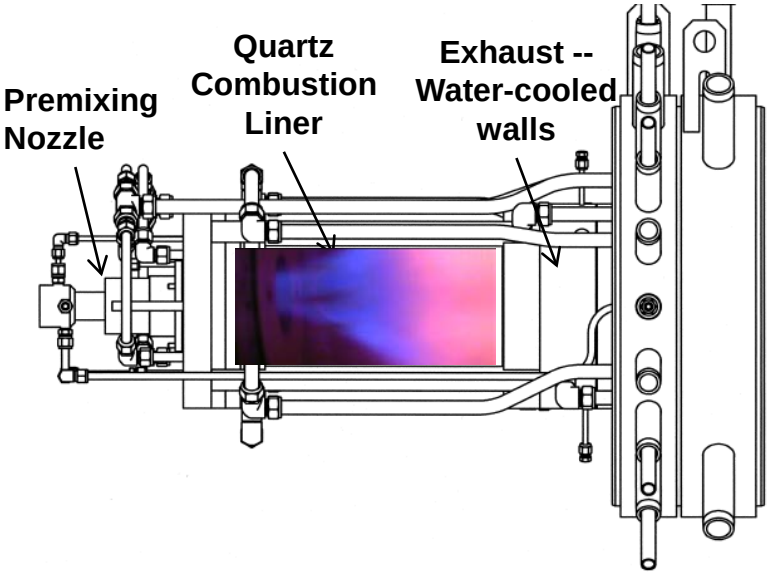
NETL combustion rig capabilities

- **Facility capabilities**
  - 2 lb/s air flow @ 700 psi
  - 800-900 F air preheat (independent control)
- **Rig capabilities**
  - 2 lb/s air flow @ 10 atm
  - Max inlet air temperature (800F)
  - Natural gas or hydrogen fuels
- **Combustor design**
  - Swirl-stabilized
  - Lean premixed gaseous fuel
  - Diffusion pilot (12 jets)
  - Quartz combustor liner
    - No dilution cooling jets
    - No upstream film cooling



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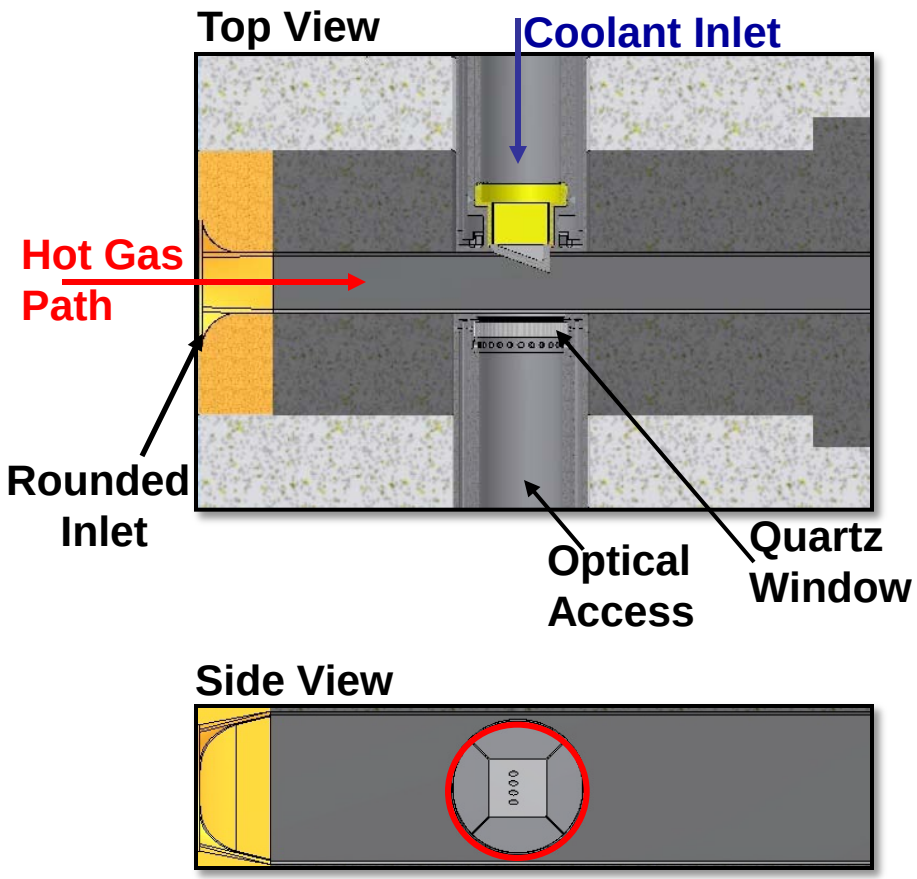
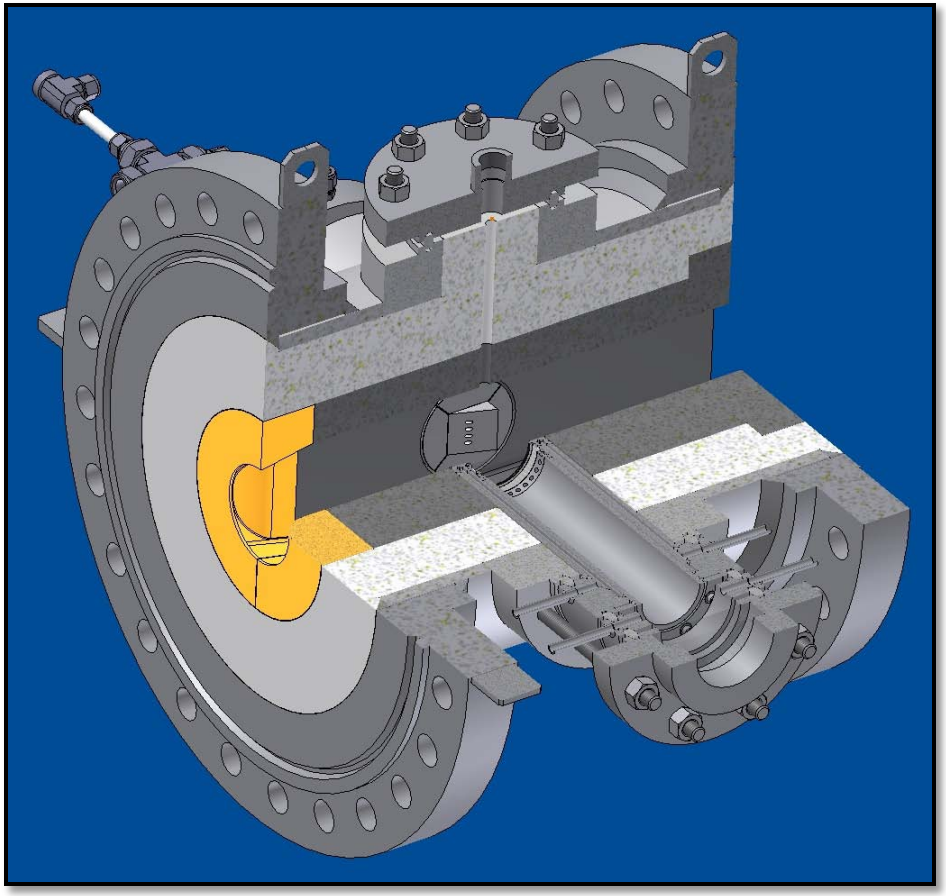
The test section was designed to allow optical access for thermal image acquisition





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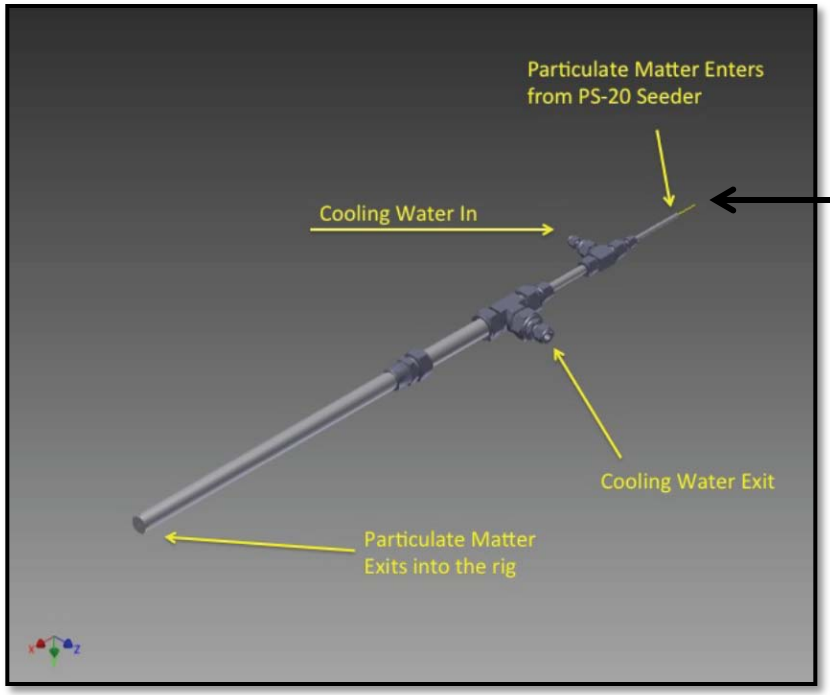
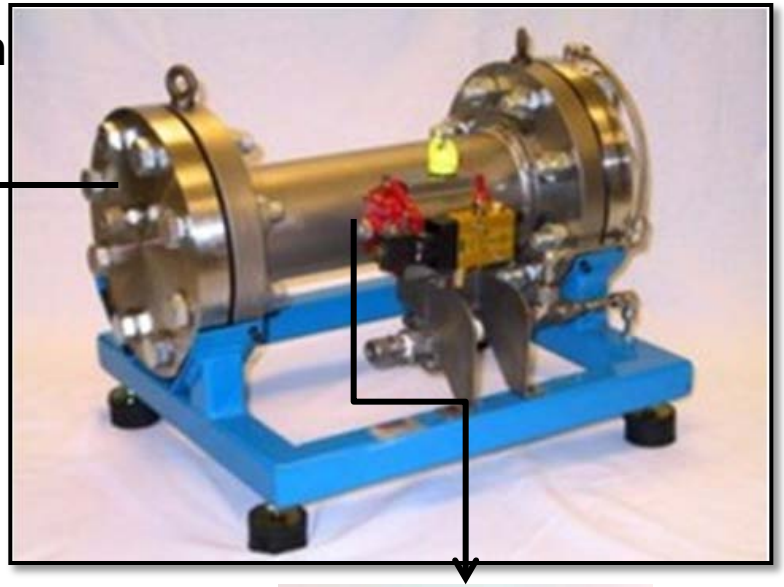
A high pressure particulate seeding system was installed to distribute ash particulate

Seeder vessel can be pressurized to 20 atm to ensure proper delivery of material to high pressure (5 atm) combustion rig





Accelerated Deposition Parameters

	Engine	Laboratory
Particulate Concentration (ppmw)	0.02	33.3
Operation Duration (hr)	10000	6
Particulate Loading (ppmw-hr)	200	200

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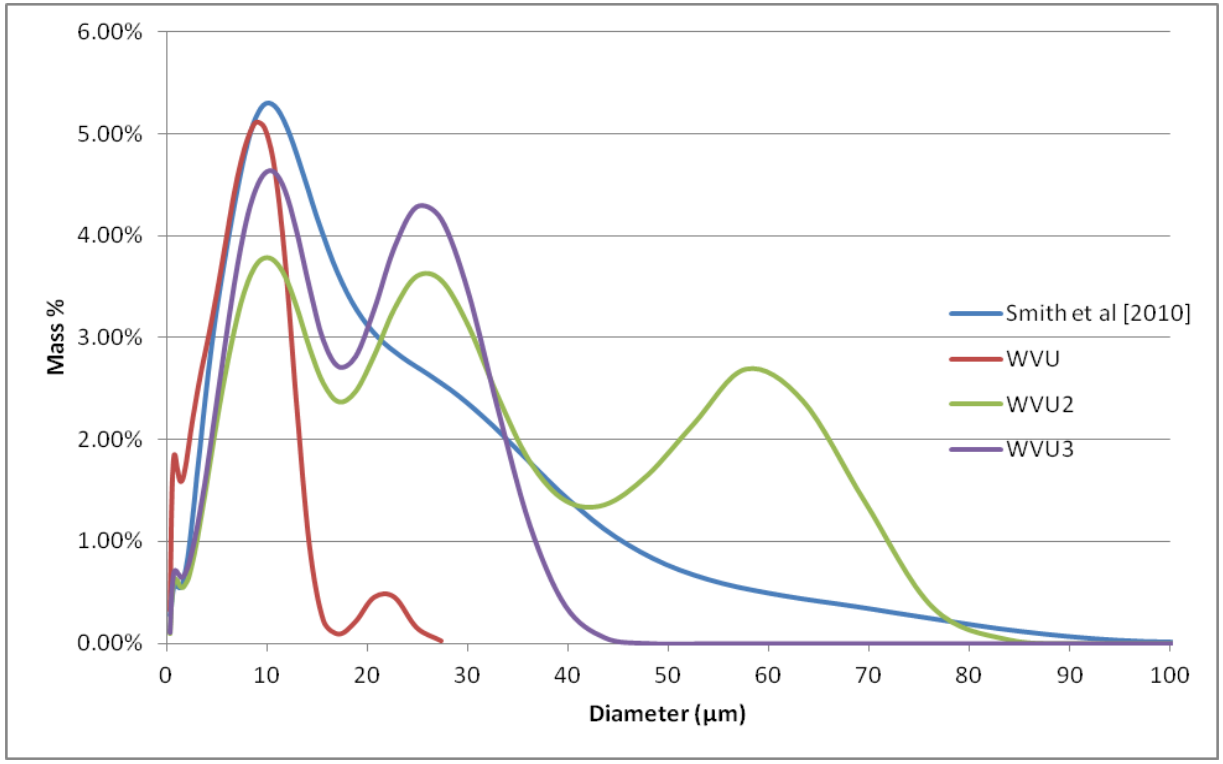
Fly ash from a local PC plant was dried, ground and sieved to match the particulate flow characteristics

www.alleghenyenergy.com



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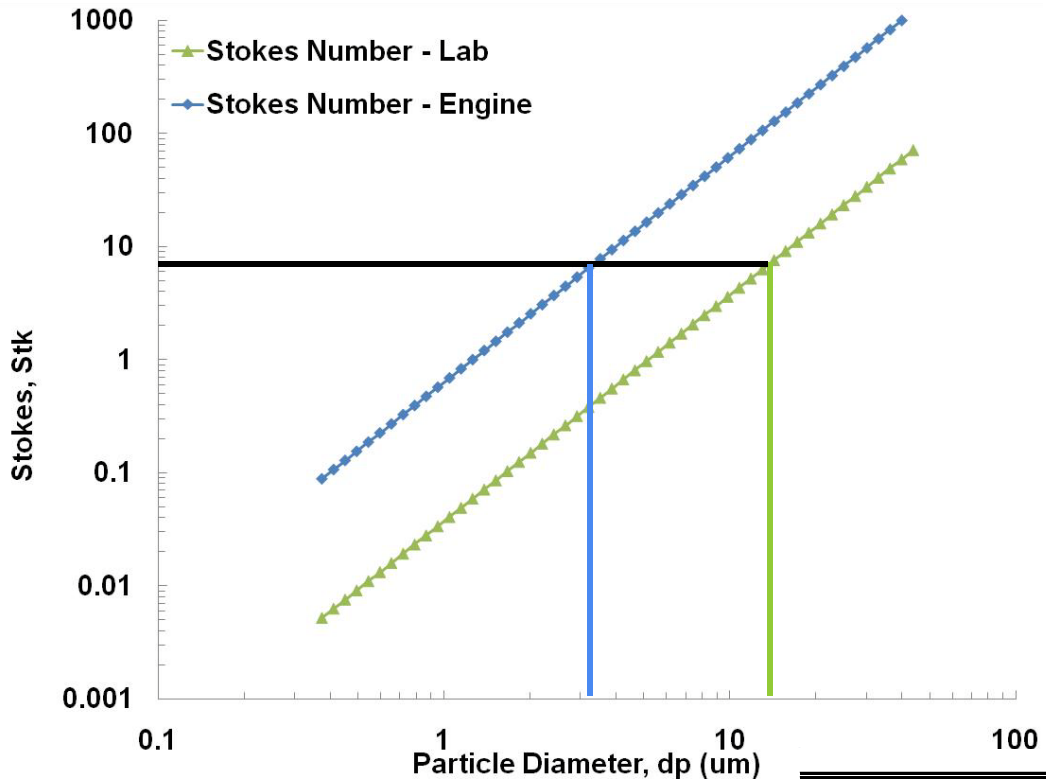
A Stokes analysis showed that particulate inertia could be scaled in the laboratory



$$\tau_p = \frac{\rho_p d_p^2}{18\mu}$$

$$\tau_f = \frac{d}{U_\infty}$$

$$\boxed{Stk = \frac{\tau_p}{\tau_f}}$$

<u>Stk<<1</u> particle follows streamlines

<u>Stk>>1</u> particle trajectory dominated by particle inertia

Median particles in engine and laboratory conditions have: Stk~ 7

	Laboratory	Engine
Mainstream Temperature, T_∞ (K)	1339	1509
Fly Ash Density, ρ_p (kg/m3)	1980	1980
Cooling Hole Diameter, d (mm)	4.0	0.5
Mainstream Velocity, U_∞ (m/s)	66	150
Mainstream Viscosity, μ	4.9×10^{-5}	5.3×10^{-5}
Median Particle Size, $d_{p,med}$ (μm)	13.0	3.2
Median Particle Stokes Number, Stk_{med}	6.3	6.3

Dennis et al. [2007], Bons et al. [2007]

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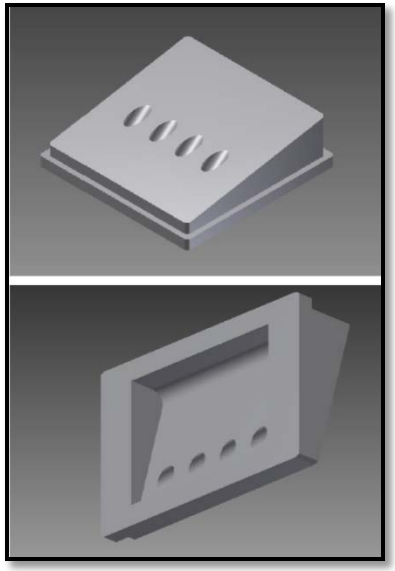
Two film-cooling coupons with 10° and 20° angled surfaces will be tested - represent pressure surface of vane

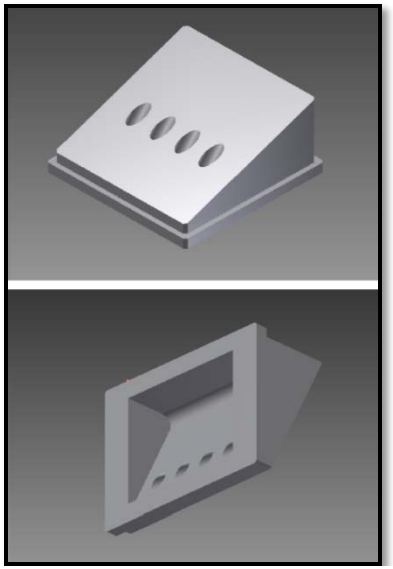
HAYNES International

Thanks to Dr. Keith Kruger

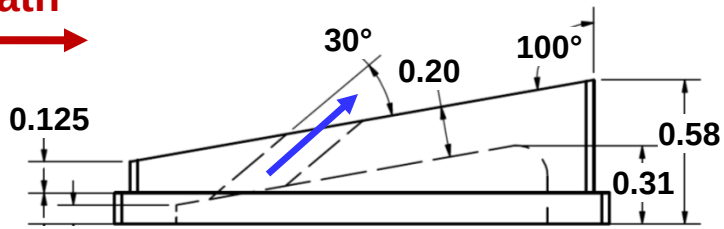


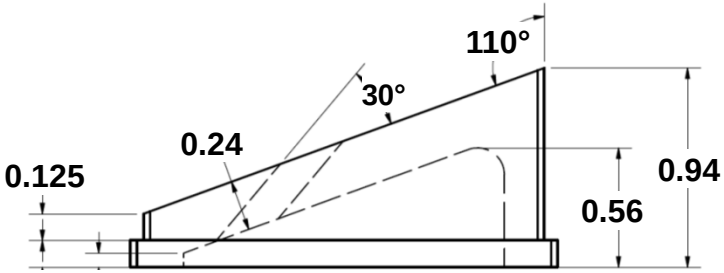
Coupon hole scaling based on:

$$\mathrm{Re}_d = \frac{\rho V_\infty d}{\mu}$$



Hot Gas Path





Dimensions in inches

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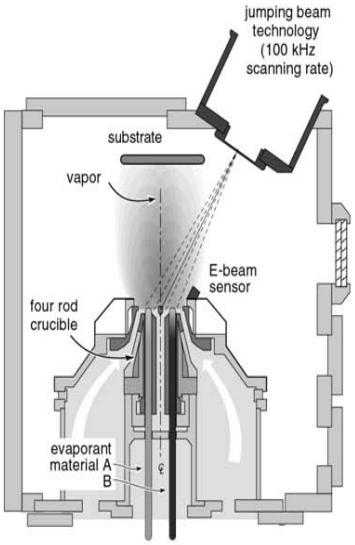
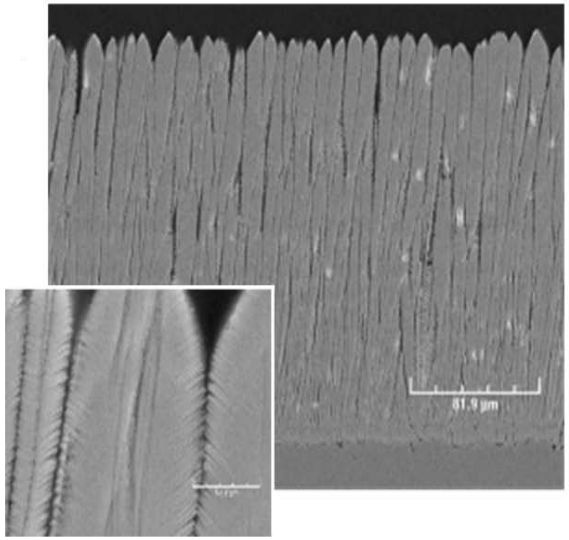
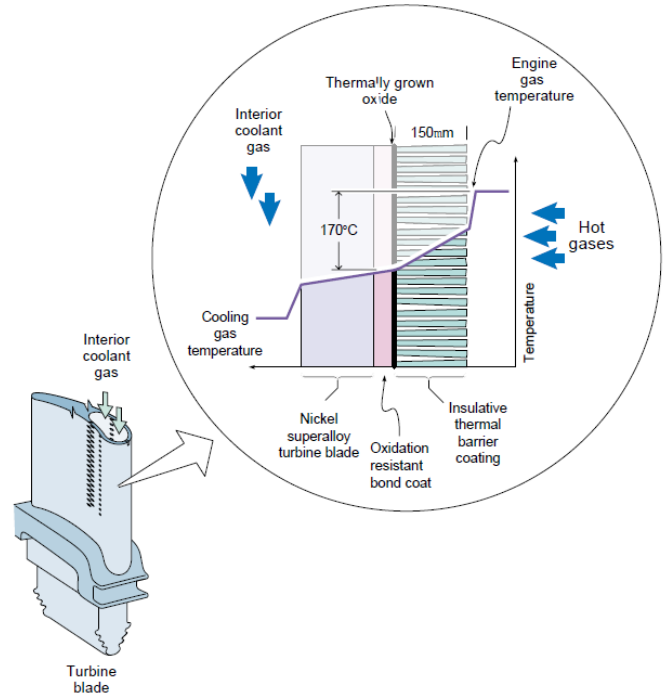
Thermal barrier coatings were applied using a direct vapor deposition (DVD) process







[Directed Vapor Technologies International (DVTI)]

	Type	Thickness
Bond Coat Layer	**γ–γ' PtAl (Dr. Brian Gleeson, UPitt)**	**~15-20 μm**
Thermal Barrier Coating (TBC)	**7% Yttrium Stabilized Zirconia (7YSZ)**	**~200-500 μm***

***In process of characterizing TBC thickness. DVTI report 300-500 μm thickness.**

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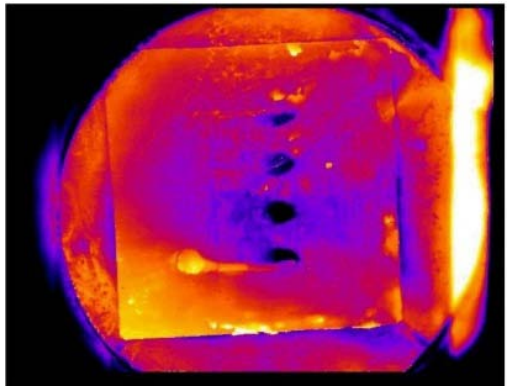
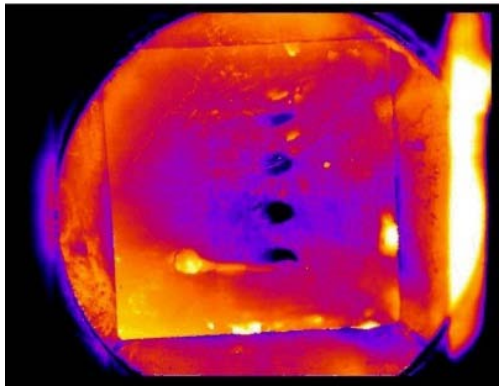
Temperature measurement and seeding issues arose after hot shakedown testing

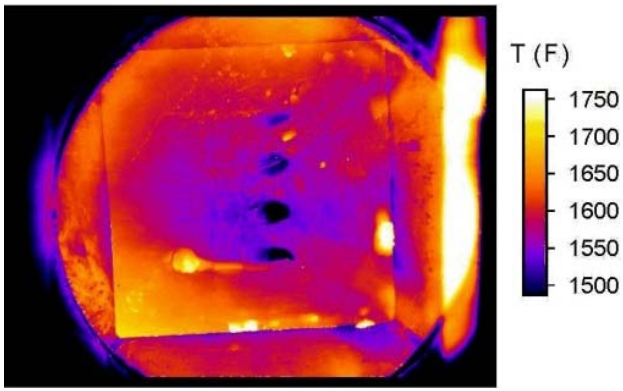
Before Particle Injection



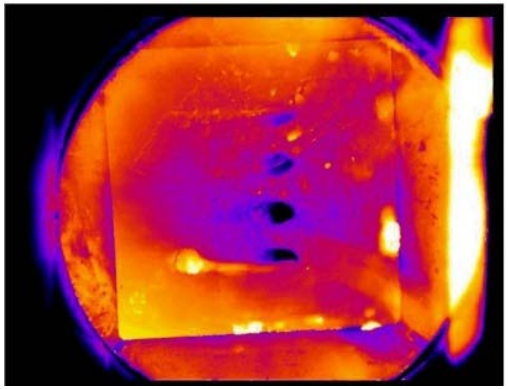
After 30 mins



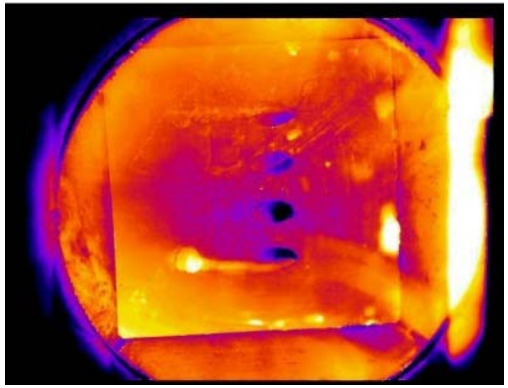
After 60 mins



After 90 mins



After 120 mins



- Devitrification
- Temperature measurement accuracy
- Low seeding injection rates

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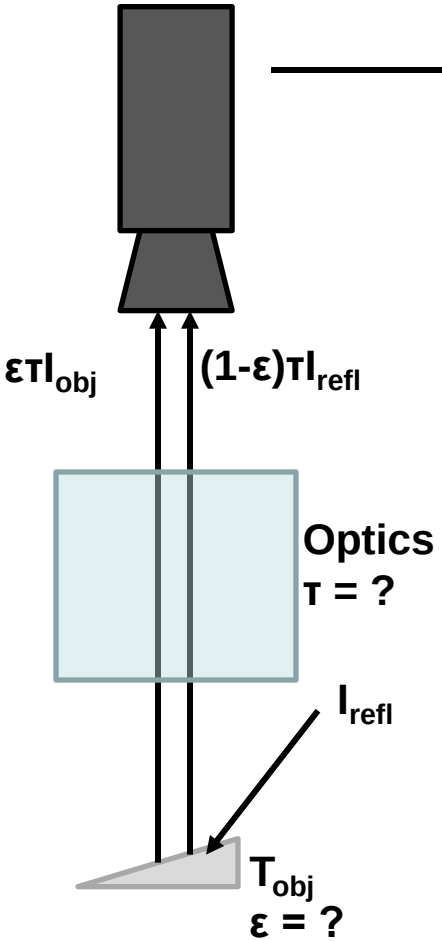
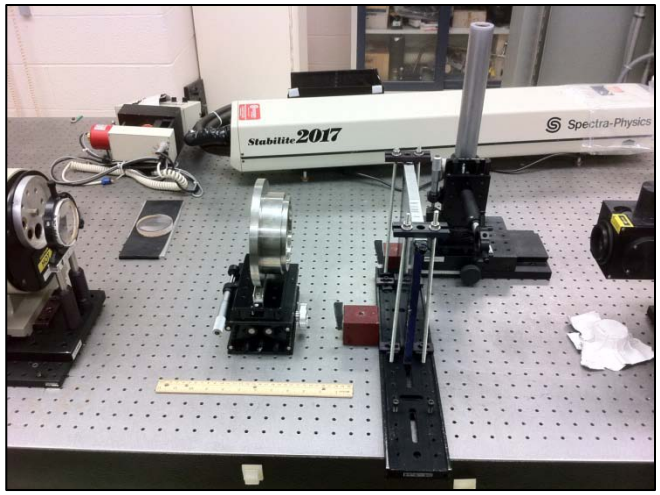
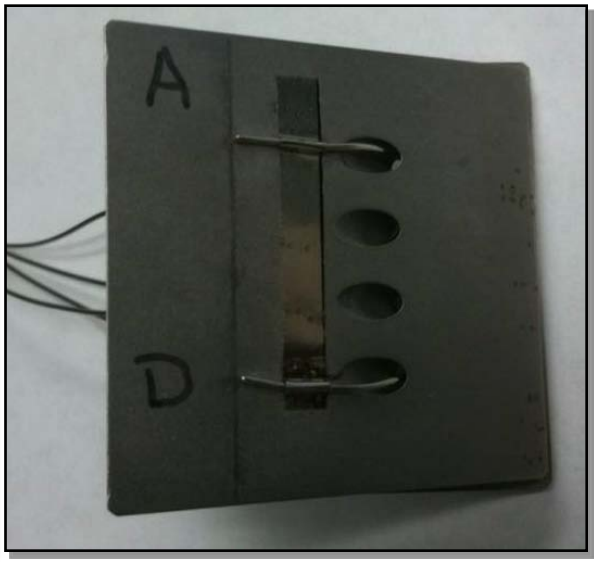
Efforts are being made to eliminate unknown variables for optical thermography



$$I_{tot} = \varepsilon \tau I_{obj} + (1-\varepsilon)\,\tau I_{refl}$$

Unknowns: ε, τ, and I_{refl}





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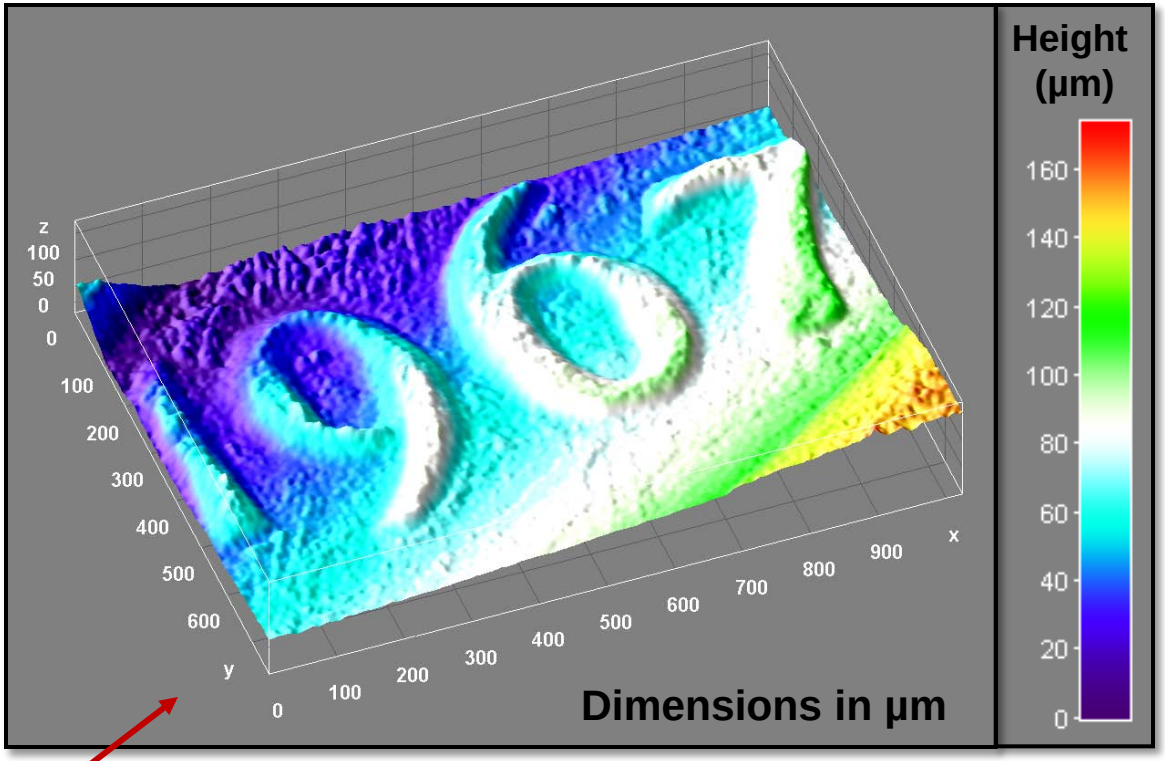
An Olympus confocal laser microscope is being used to quantify surface topography



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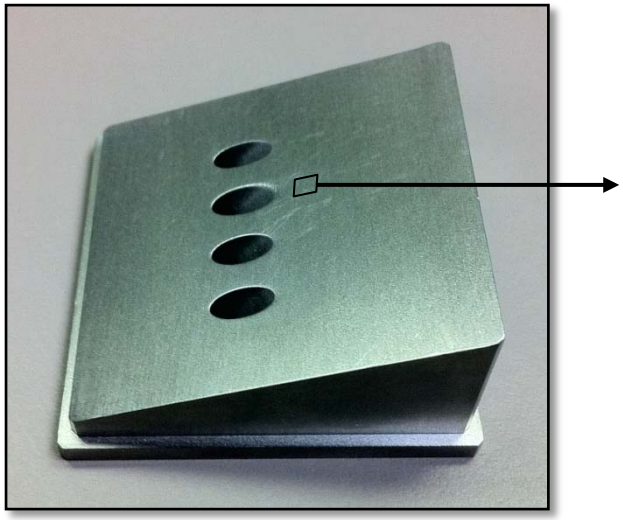
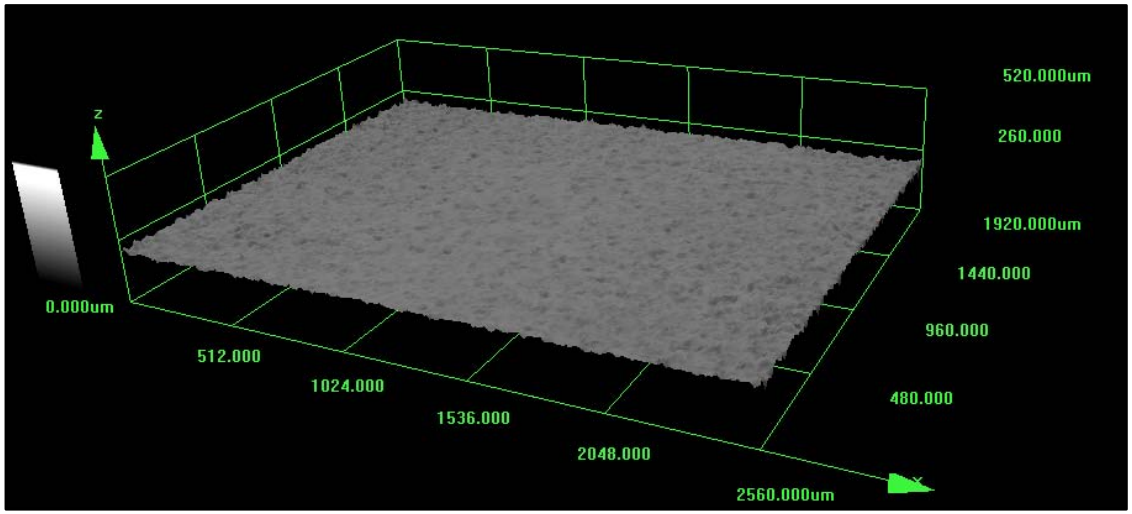
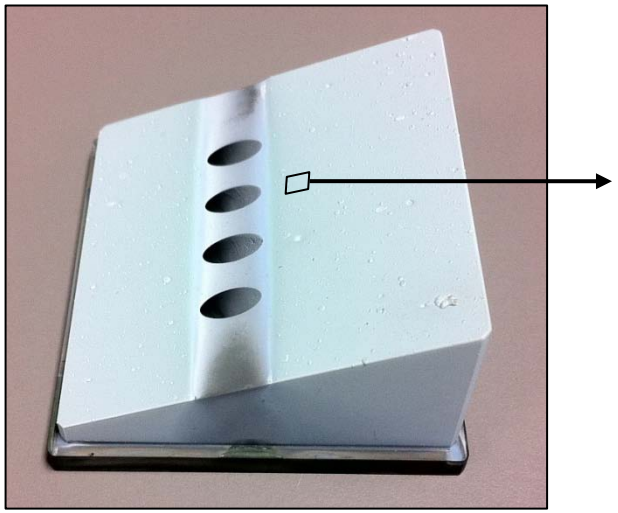
Surface scans were performed on coated and uncoated coupons before deposition

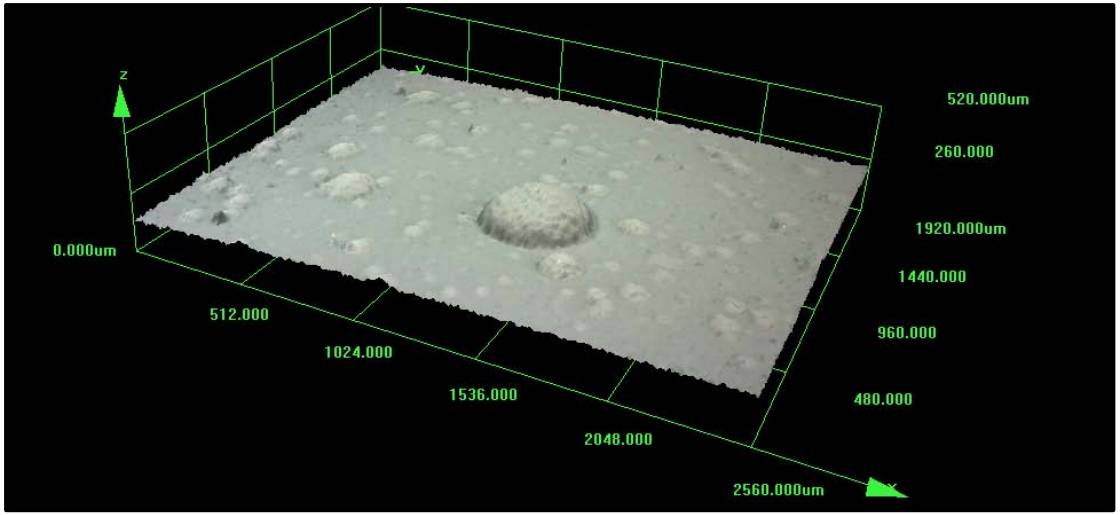
Before TBC



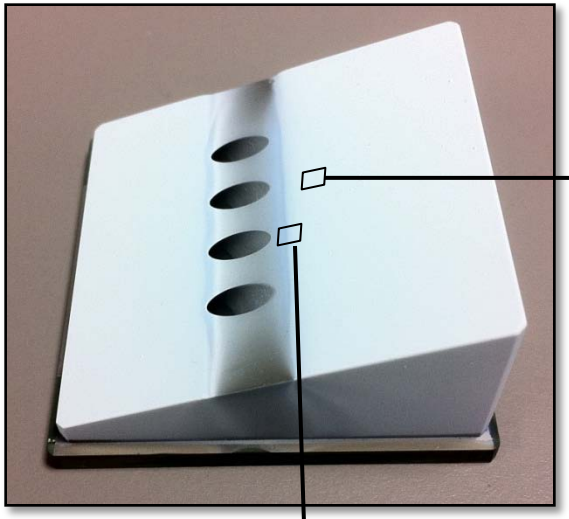


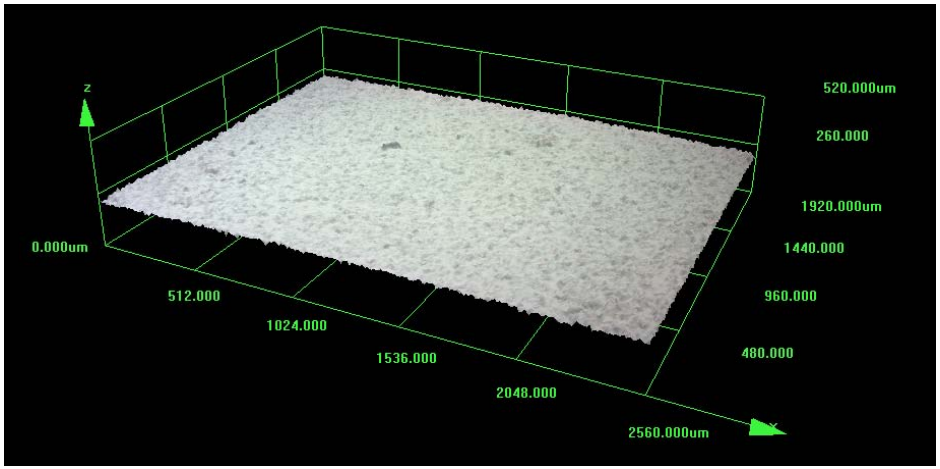
Contaminated TBC

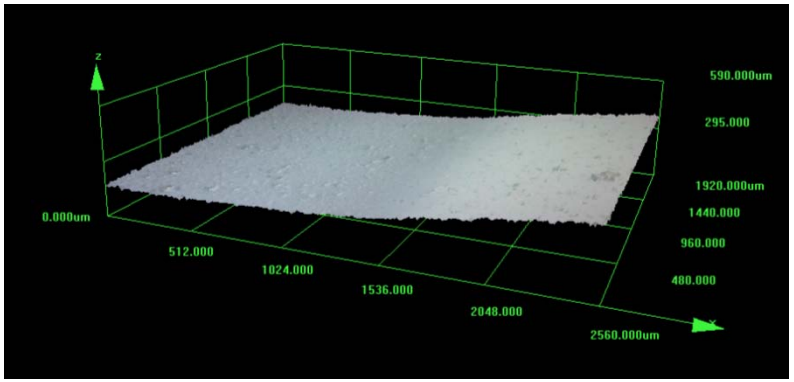


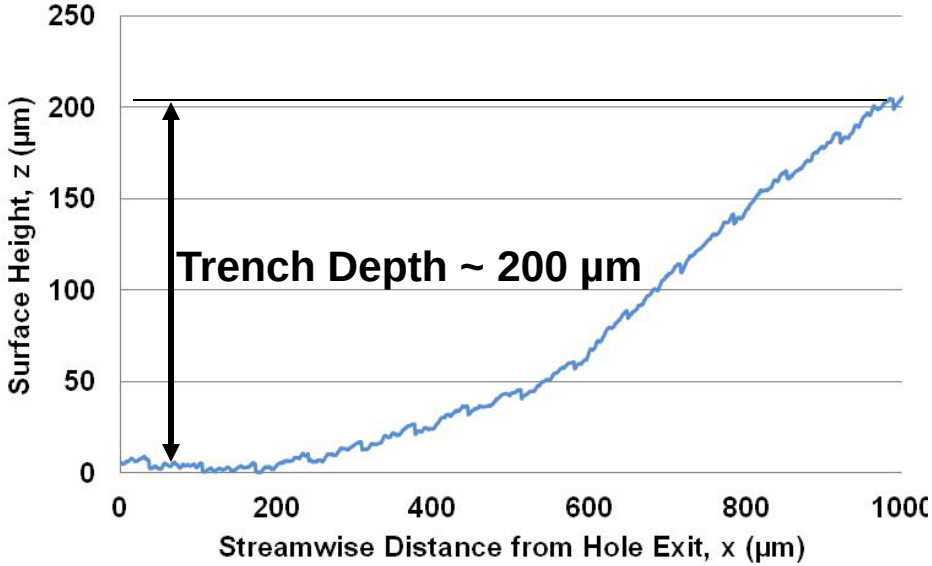


TBC coupon scans without contamination









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WVU Test Plan for Deposition Study

	Run	Blowing Ratio	Run Time (hrs)	Temperature (F)	Pressure (psig)
10° Test Article	1	1.0	3	2000	45
	2	1.0	3	2000	45
10° Test Article (Repeat Test)	1	2.0	3	2000	45
	2	2.0	3	2000	45
20° Test Article	1	1.0	3	2000	45
	2	1.0	3	2000	45
20° Test Article (Repeat Test)	1	2.0	3	2000	45
	2	2.0	3	2000	45

Non-destructive Pre-Test Roughness Scans

Run 1

Non-destructive Post Run 1 Roughness Scans

Run 2

Non-destructive Post Run 2 Roughness Scans followed by destructive tests (SEM, chemical composition)

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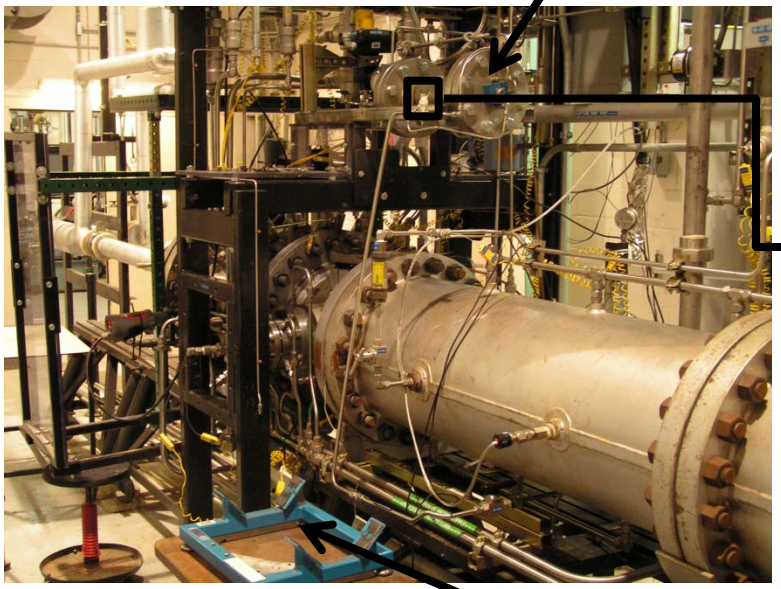
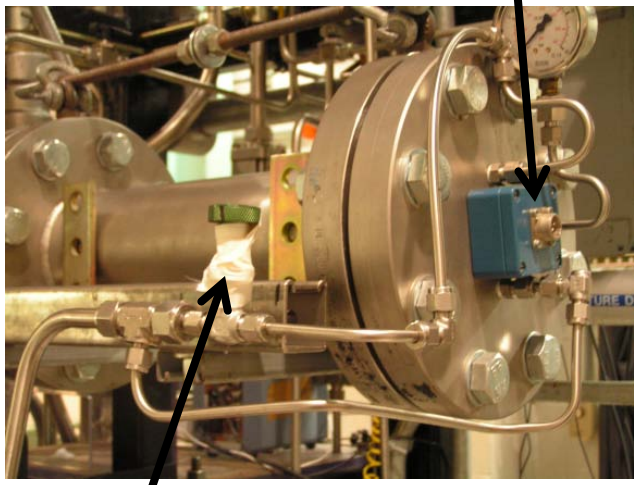
Cold flow testing is complete and desired injection rates to meet target ppmw loading have been achieved

New Seeder Position



Old Seeder Position

Increased RPM



Needle Valve

Cold flow testing completed last week.
Ready to perform full scale HOT testing.

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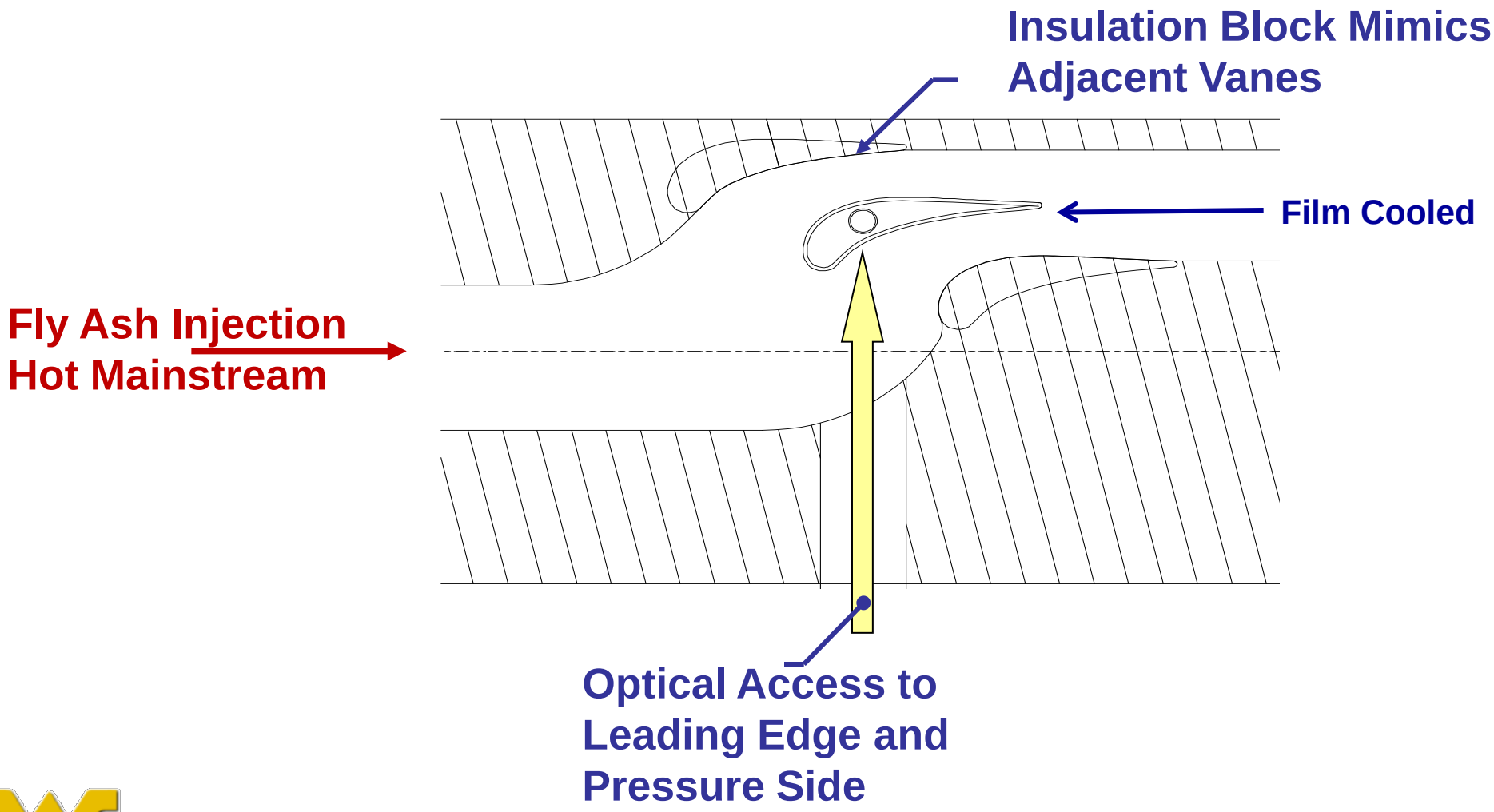
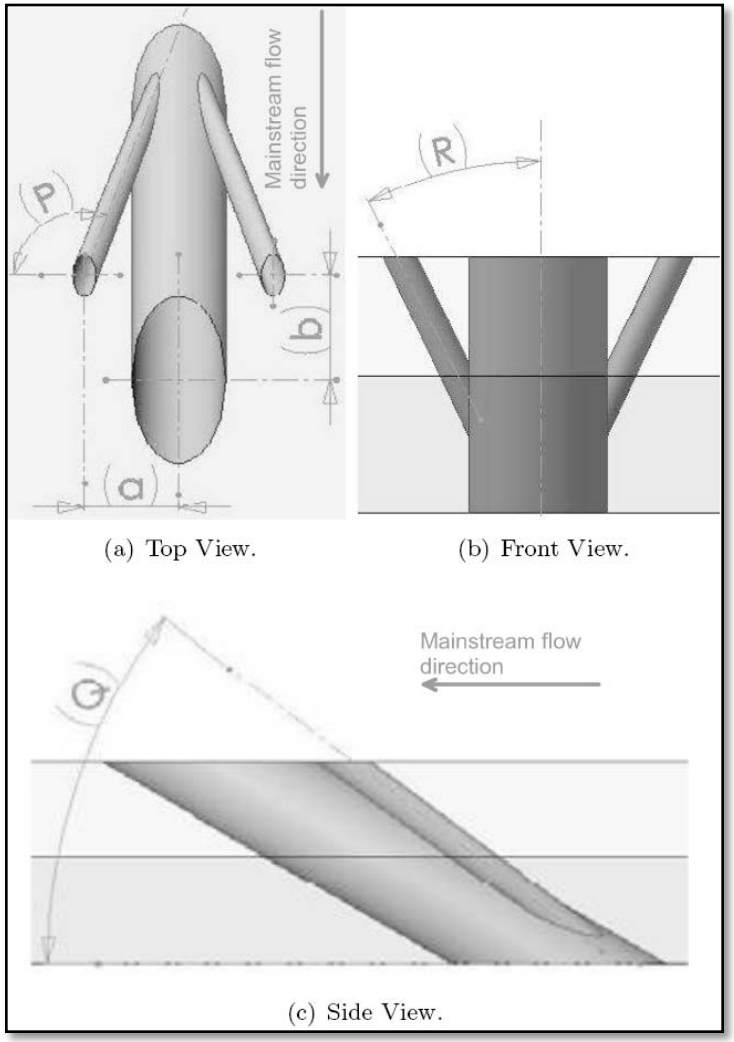
Proposed future work includes two-phase CFD modeling and 2-D linear cascade testing



[Florida Turbine Technologies, Inc.]

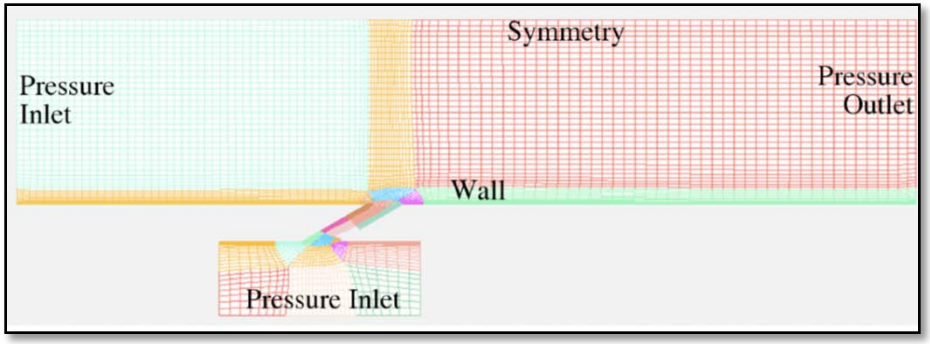
A CFD study was conducted to determine turbulence effects on anti-vortex hole cooling

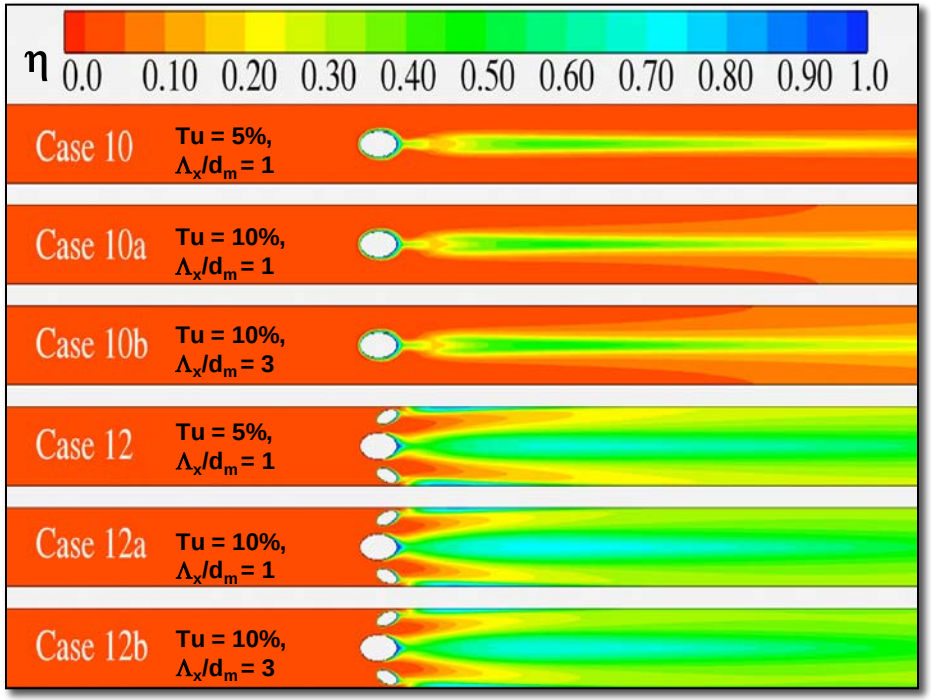


(a) Top View. (b) Front View.

(c) Side View.

Dhungel, et al [2007]





Hunley et al. [2010]

Sister hole designs can resist deposition and mitigate effects on cooling

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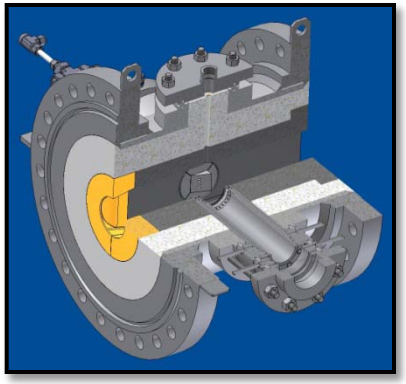
Would like to test in combustion facility - proposed for UTSR and RUA funding

Summary

- Designed and procured two test article geometries and matched flow conditions in gas turbines using Reynolds similarity.

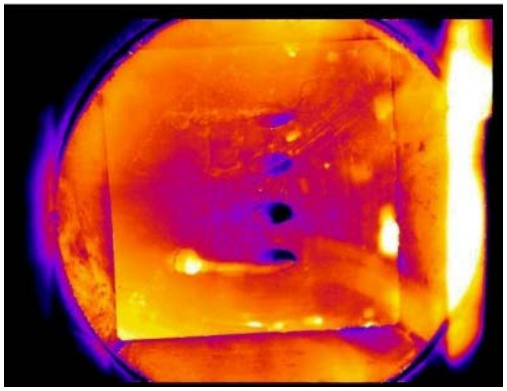


- Procured a high pressure particle seeder to seed flyash into combustion rig.

- Developed a method to process (bake, grind and sieve) flyash to achieve appropriate size distribution to scale inertial characteristics from engine to lab conditions.

- Performed shakedown testing (both cold and hot) to determine appropriate seeder and combustor operating conditions.

- Developed two measurement techniques to analyze surface temperature and characterize surface roughness on the face of the test article.



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Questions?