Surface Thermometry in Low TRL Testing of Combustor Cooling Concepts

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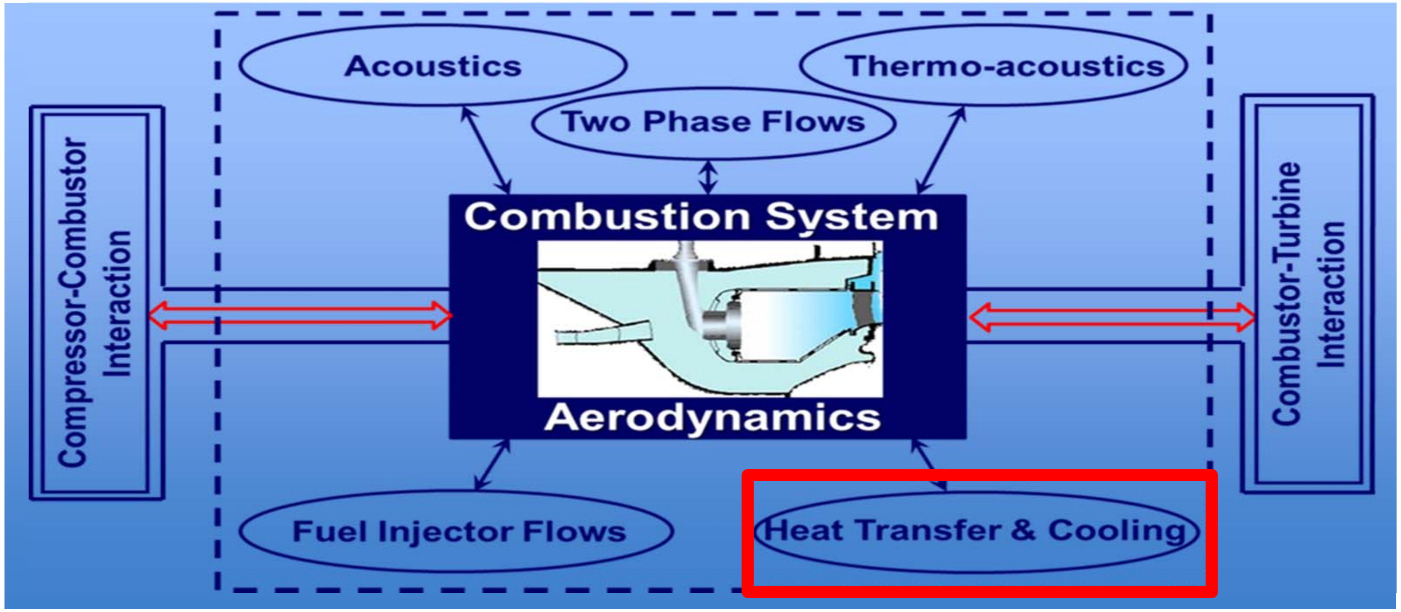
UTC in Combustion System Aerothermal Processes

- Based in Department of Aeronautical and Automotive Engineering
- Research team of 40 (academics, research fellows, research associates, research students)
- 40 active research projects
  - Combustion related ~ 32
  - Non-combustion ~ 8

UTC in Combustion System Aerothermal Processes

- National Centre of Excellence in Gas Turbine Combustion Aerodynamics opening 2018
  - Staff Accommodation & New Test Cells
  - Elevated pressure and temperature capability
  - Reacting flow facilities, sub-atmospheric facilities

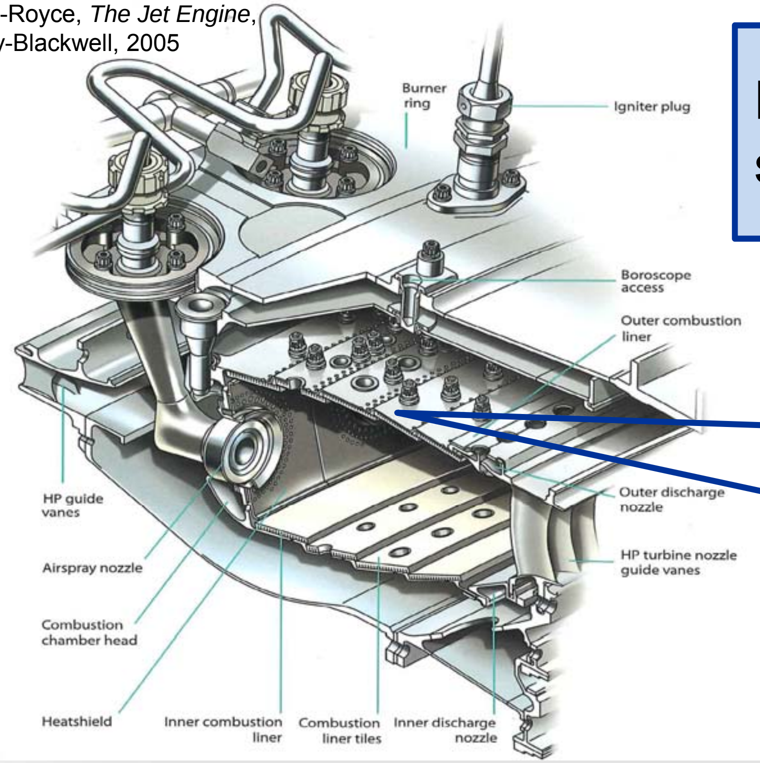
UTC Research Areas



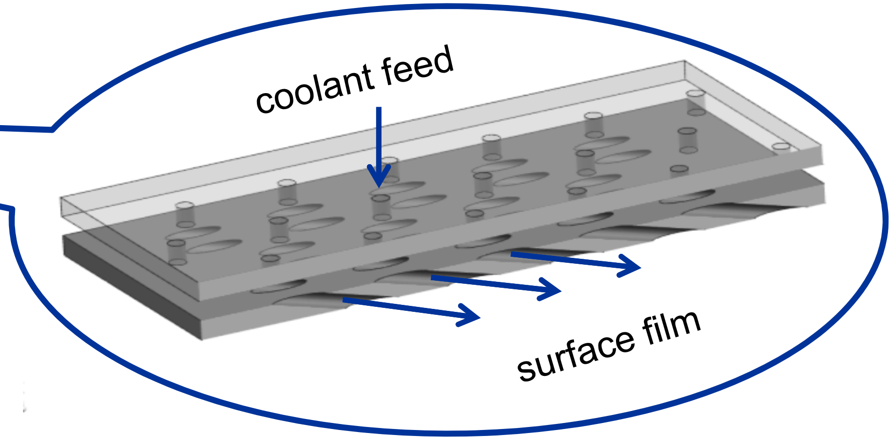
Plus: Compressors, Instrumentation, Noise, Installations…

Combustor Cooling

Rolls-Royce, *The Jet Engine*, Wiley-Blackwell, 2005

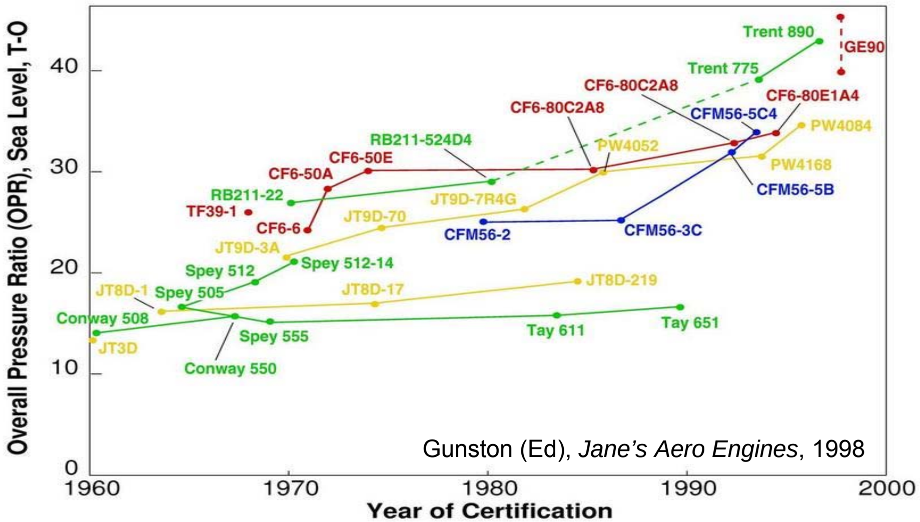


Example twin-skin arrangement with cold-side impingent and hot-side angled effusion



Considerations for Cooling

- Higher cycle temperatures
- Lean burn combustor technology uses more air (NOx)
- Reduced cooling flow budget
- More effective cooling concepts required



Gunston (Ed), *Jane's Aero Engines*, 1998

Considerations for Cooling

- Higher cycle temperatures (T30, T40)
- Lean burn combustor technology uses more air (NOx)
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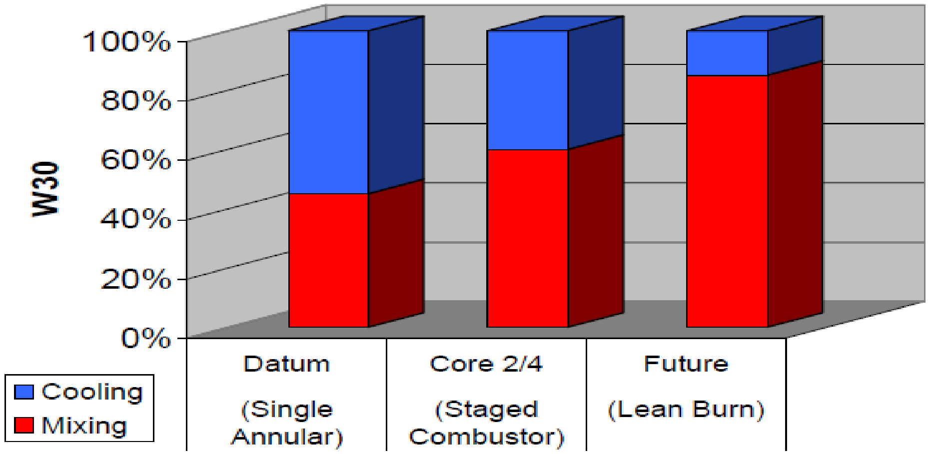
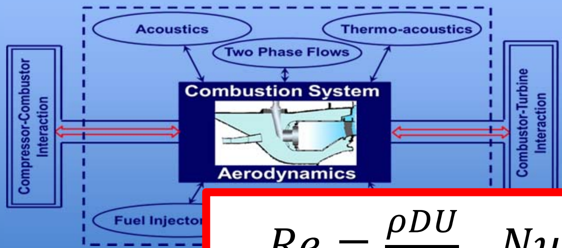
- More effective cooling concepts required



Gerrendas, Hoschler & Schilling, *Development and Modelling of Angled Effusion Cooling for the BR715 Low Emission Staged Combustor Core Demonstrator*, RTO AVT Symposium on Advanced Flow Management, 2003

Low TRL Testing of Cooling Concepts

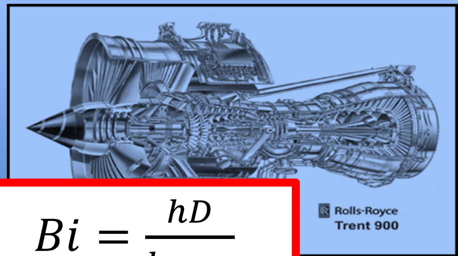
Measurement 'Friendly', Controlled Conditions



Affordable

Scaling

Complex Engine Physics
(High Pressures &Temperatures)



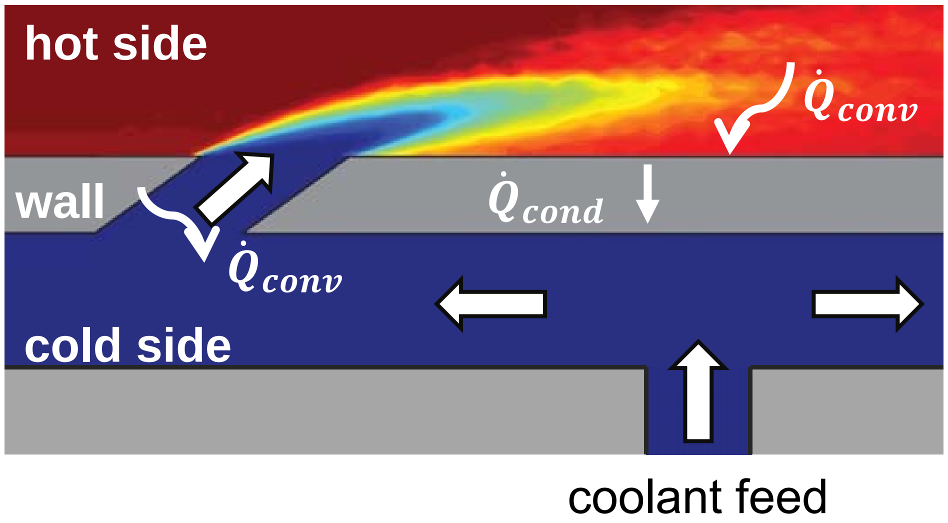
Costly & Provides Limited information

$$Re = \frac{\rho D U}{\mu} \quad Nu = \frac{hD}{k_{gas}} = f(Re, Pr) \quad Bi = \frac{hD}{k_{wall}}$$

TRL 1 – 4	TRL 5 - 9		
LUTC work	RR vetting and further work	RR Design work	Engine project work

Low TRL Testing of Cooling Concepts

- Three key test facilities
  - hot side cooling
  - internal cooling
  - overall cooling effectiveness
- Ranking cooling concepts
- Validating computational models

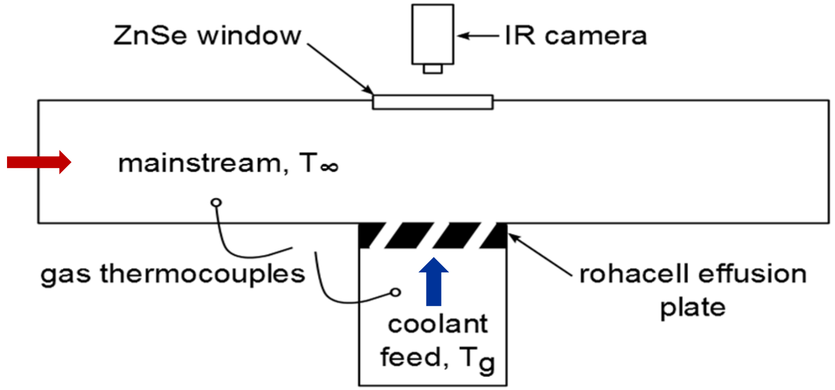


Hot Side Cooling

- Adiabatic film effectiveness measured on steady-state facility at near atmospheric conditions

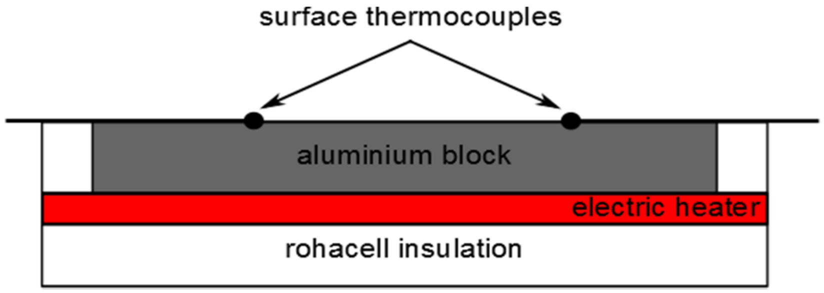
$$\eta_{aw} = \frac{T_\infty - T_{aw}}{T_\infty - T_c}$$

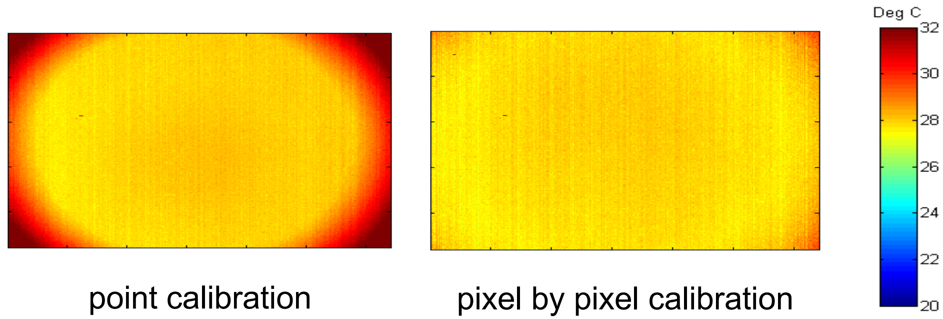
- Wall temperatures measured with IR camera
  - 2D, non-intrusive
  - IR transmissive window



Hot Side Cooling

- Pixel by pixel camera calibration with heated isothermal block and reference surface thermocouples
- Surface emissivity unknown
- Effects of transmission, background radiation and window reflections included





point calibration pixel by pixel calibration

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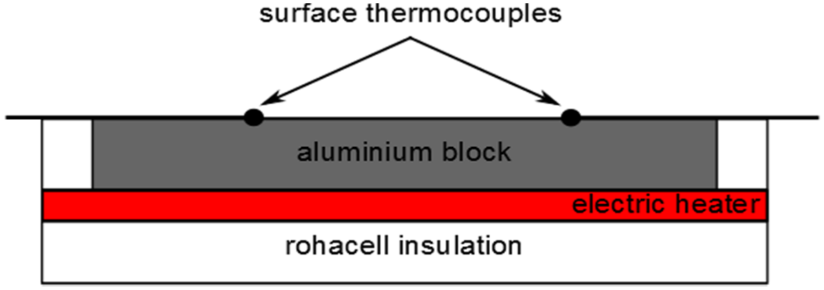
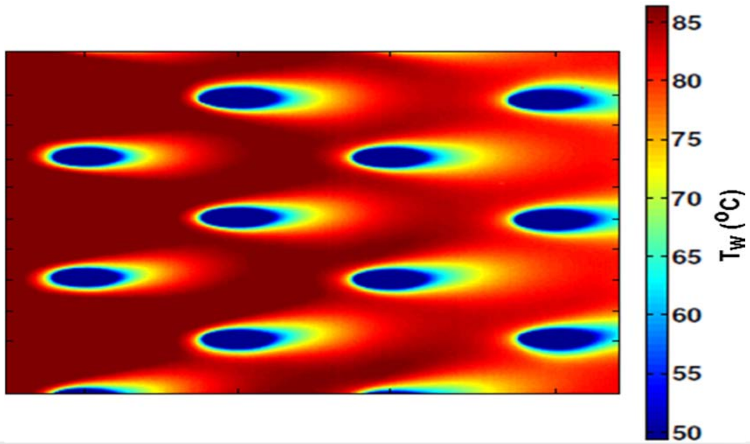


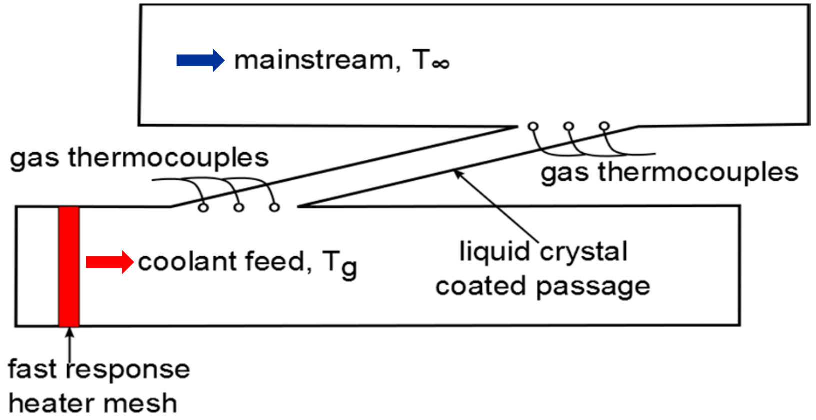


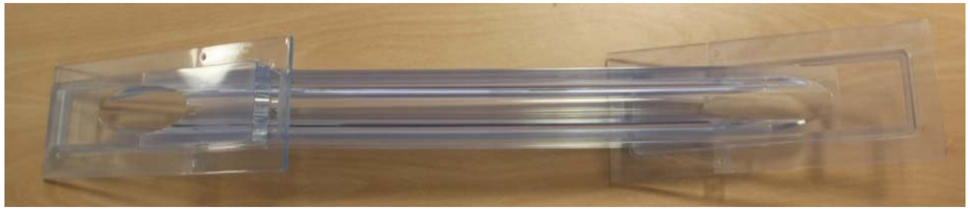
Internal Cooling

- Internal heat transfer coefficients measured at large scale using transient technique

$$\frac{T_{w,t} - T_{w,0}}{T_g - T_{w,0}} = 1 - exp\left(\frac{h^2 t}{\rho c k}\right) erfc\left(\frac{h\sqrt{t}}{\sqrt{\rho c k}}\right)$$

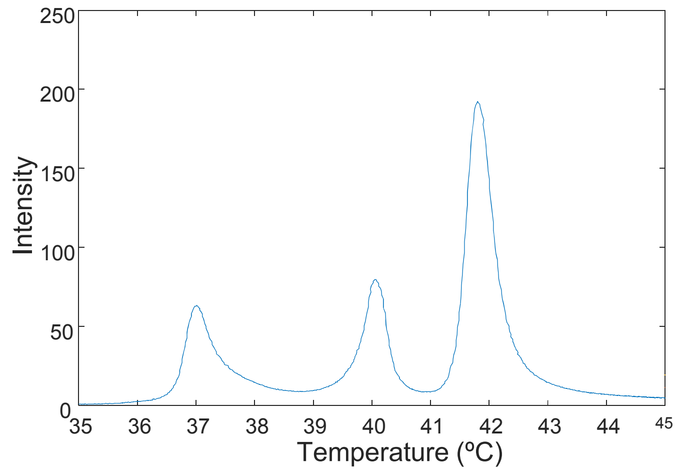
- Thermochromic liquid crystals capture wall temperature history
  - 2D, semi-invasive
  - optical access

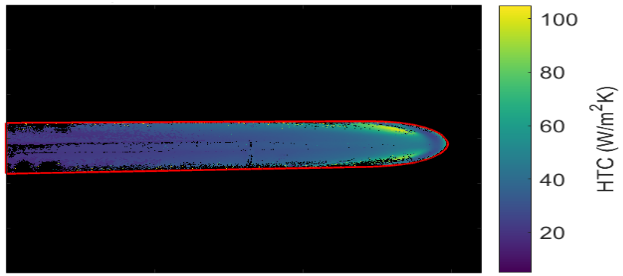




Internal Cooling

- Peak intensity related to wall tempertaure using reference surface thermocouple
- Variations in viewing/illumination angles and crystal thickness excluded, reflections lead to local data loss
- Application of phosphor thermometry could remove some of these effects





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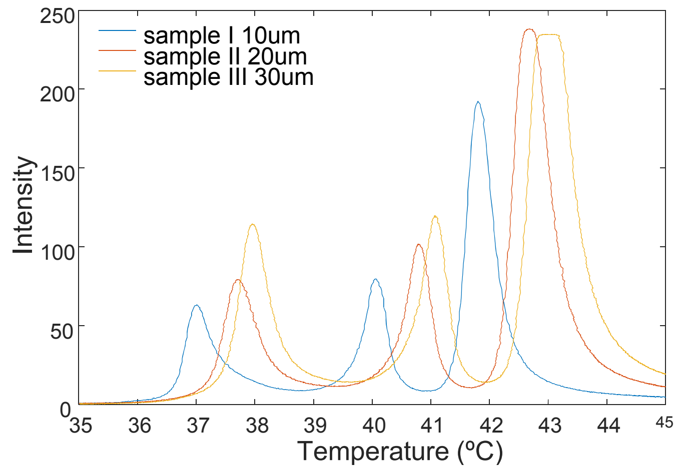
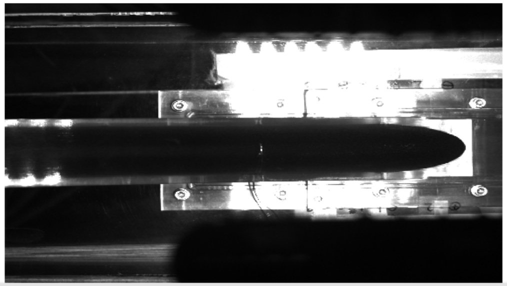


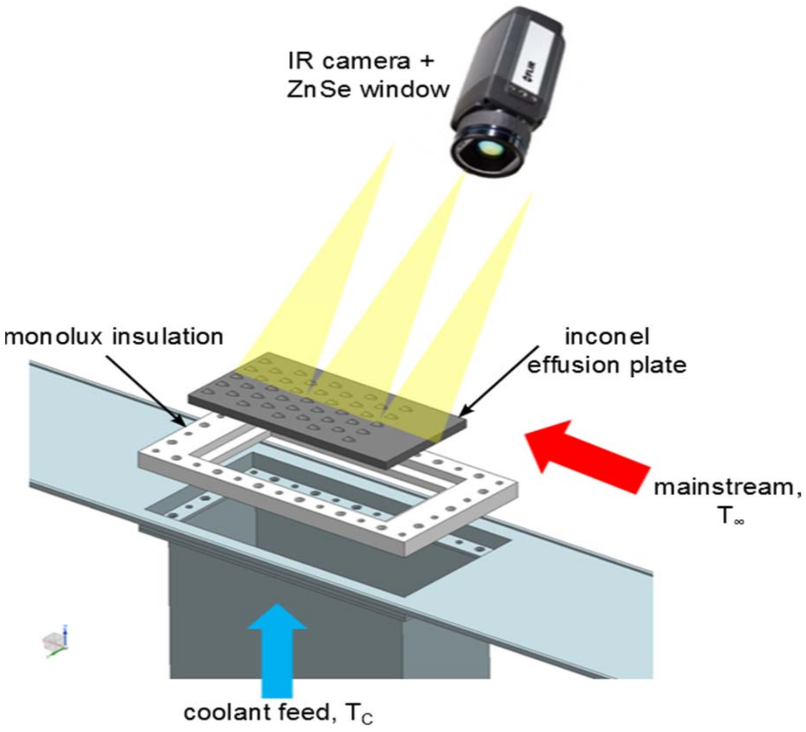


Overall Cooling Effectiveness

- Overall effectiveness measured on steady-state facility including convective and conductive heat transfer effects

$$\phi = \frac{T_\infty - T_W}{T_\infty - T_c}$$

- IR thermography used to measure spatially resolved wall temperatures
  - 2D, non-invasive
  - IR transmissive window

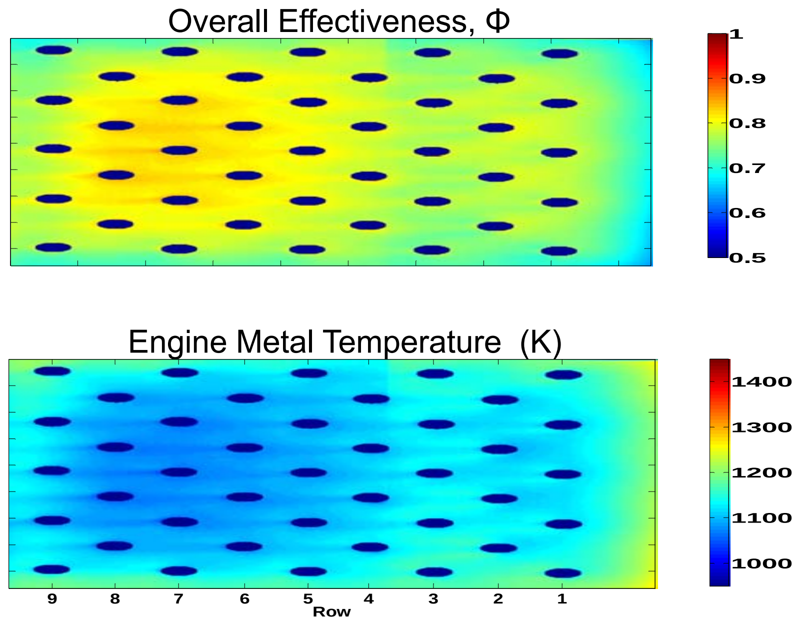


Overall Cooling Effectiveness

- Technique allows engine metal temperatures to be determined from overall effectiveness measurements

$$\phi = \frac{T_\infty - T_W}{T_\infty - T_c}$$

- Results feed into design process upstream of high TRL combustor testing



Summary

- Test facilities for low TRL testing of combustor cooling concepts
  - hot side cooling
  - internal cooling
  - overall cooling effectiveness
- Semi/non-invasive techniques used for 2D surface tempertaure mapping
  - infrared thermography
  - thermochromic liquid crystals