Gas Turbine Cooling Studies

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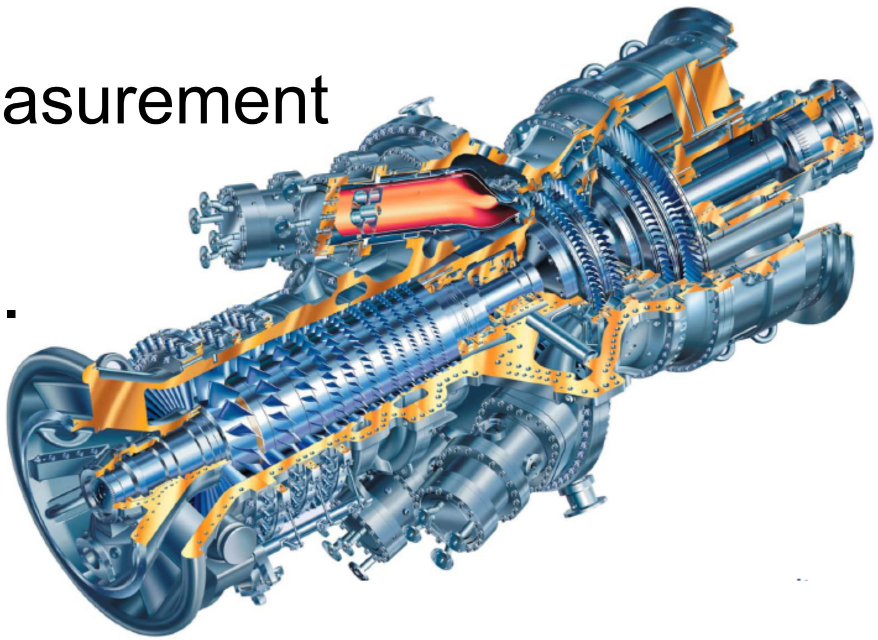
Outline of presentation

- Background on turbine cooling.
- Explanation of film effectiveness.
- Representative studies:
  - Internal cross-flow effects on film cooling
  - Coolant thermal field measurement and prediction
- New high speed facility.



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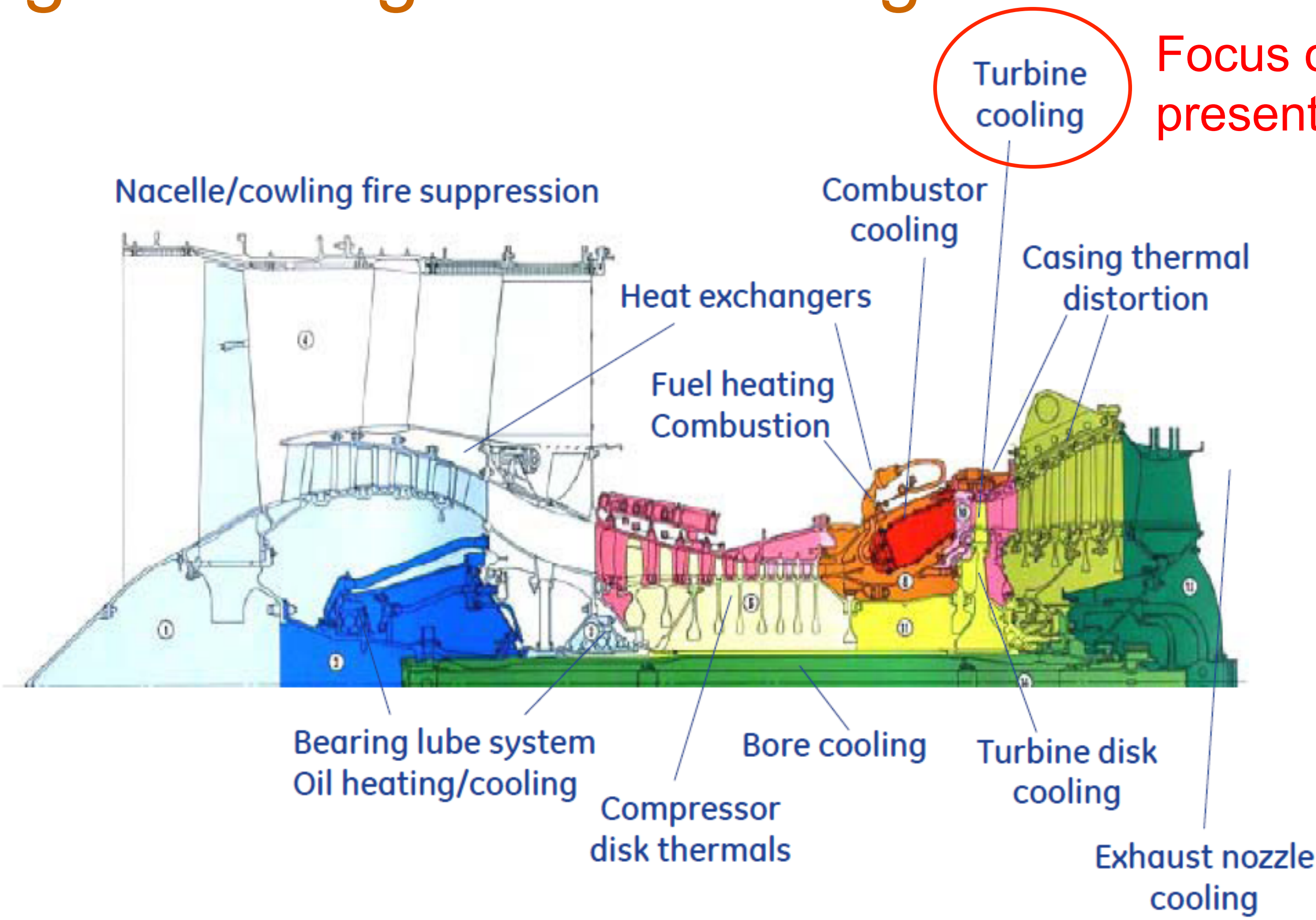
Heat transfer and cooling is important throughout the gas turbine engine

Focus of this presentation



Schematic from Bunker (ASME Turbo Expo 2013)

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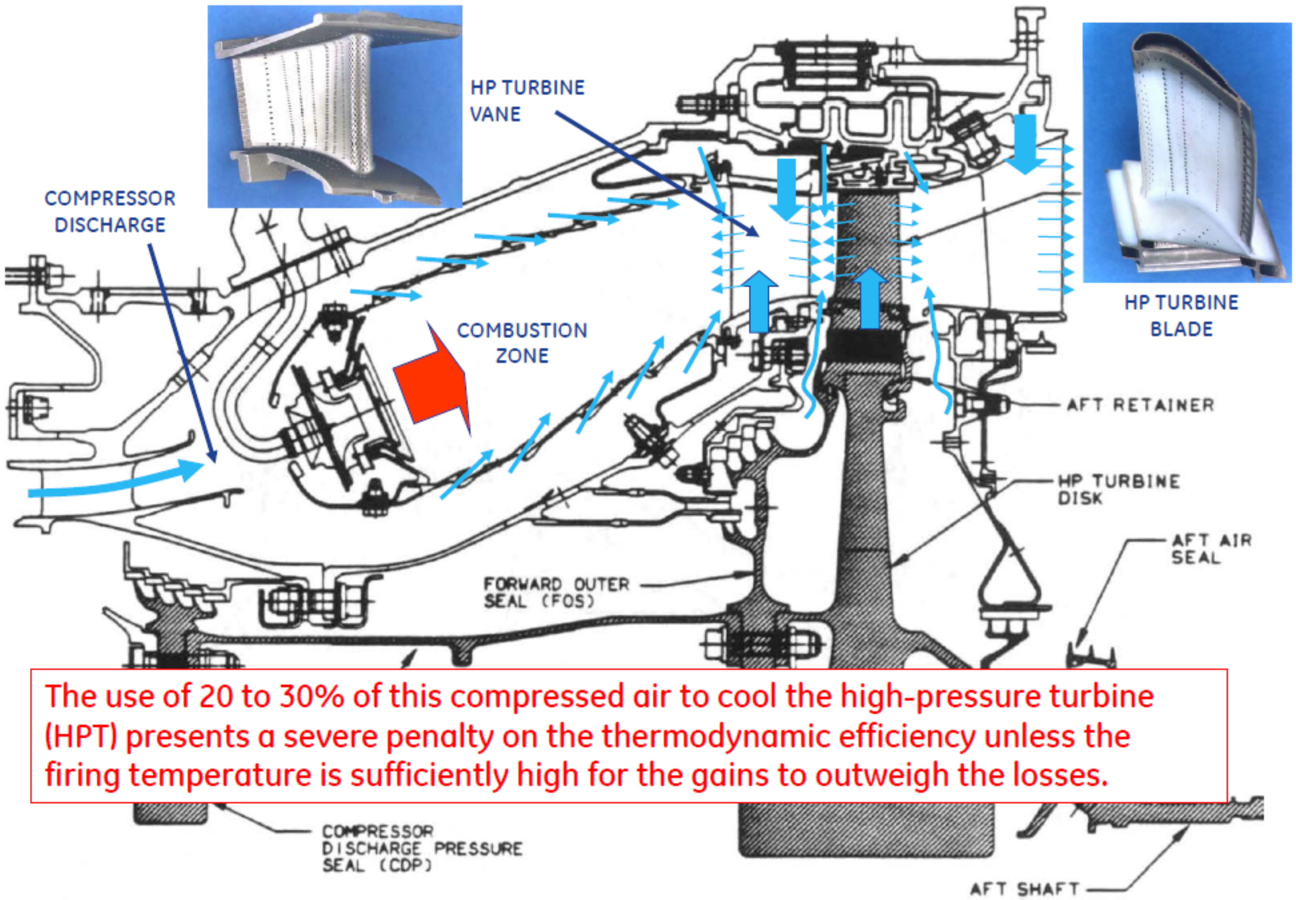
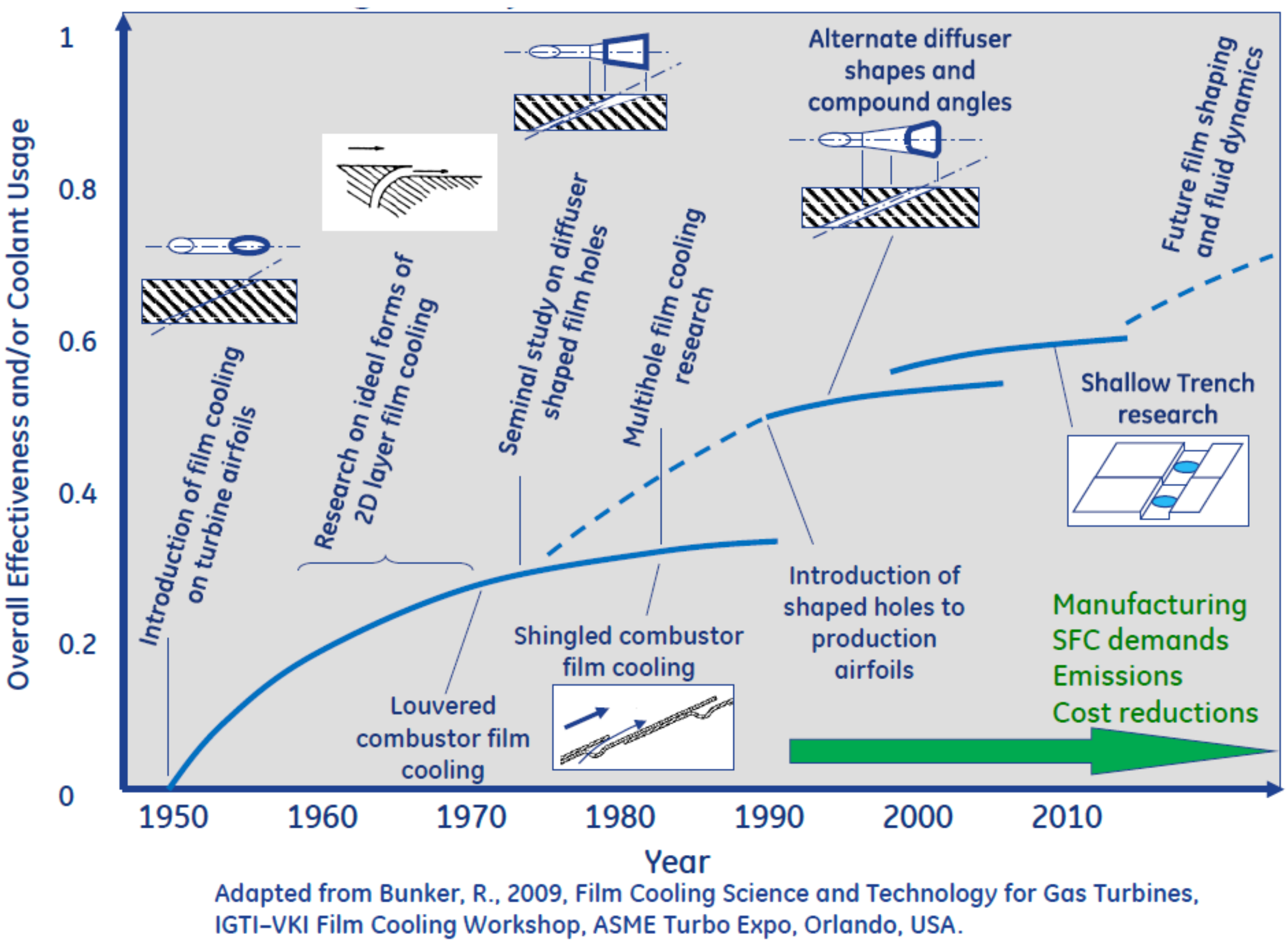
Cooling flows in the combustor and turbine section



Schematic from Bunker (ASME Turbo Expo 2013)

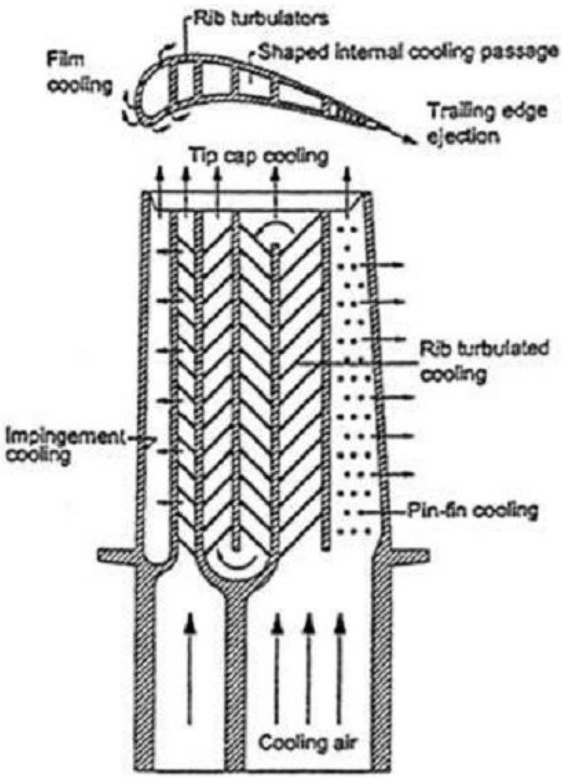
Film cooling history in gas turbines



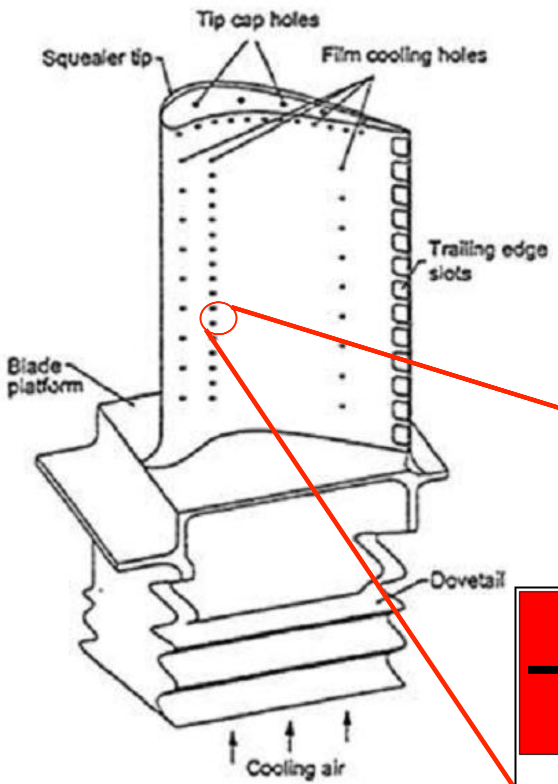
Schematic from Bunker (ASME Turbo Expo 2013)

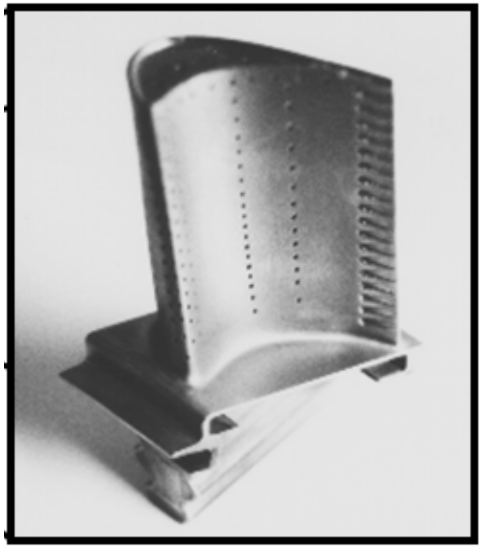
Turbine airfoil cooling:

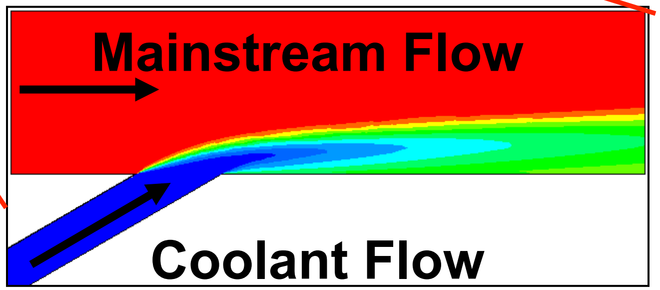
Internal cooling



Film cooling







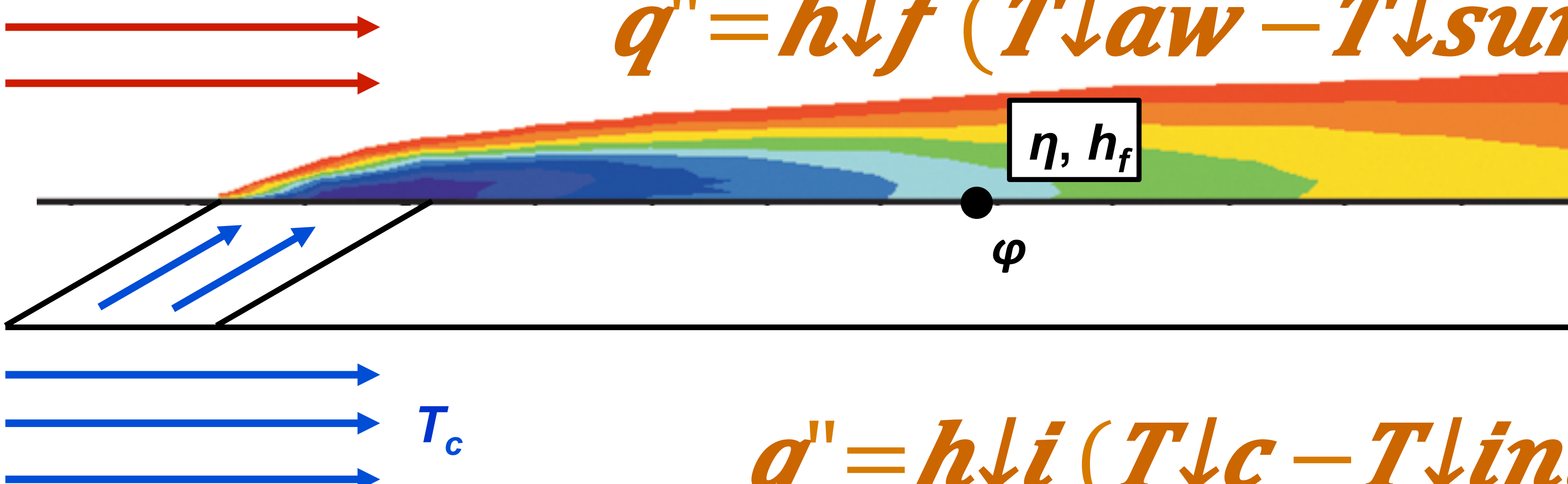
Evaluation of the performance of film cooling

Performance parameters:

Overall effectiveness: $\varphi \equiv T_{\infty} - T_{su}$

Film cooling effectiveness: $\eta \equiv T_{\infty} - T_{}$

$q'' = h_f (T_{aw} - T_{surf}$



$q'' = h_i (T_c - T_{int\, s}$

Film cooling holes in gas turbine engines are often fed by an internal crossflow

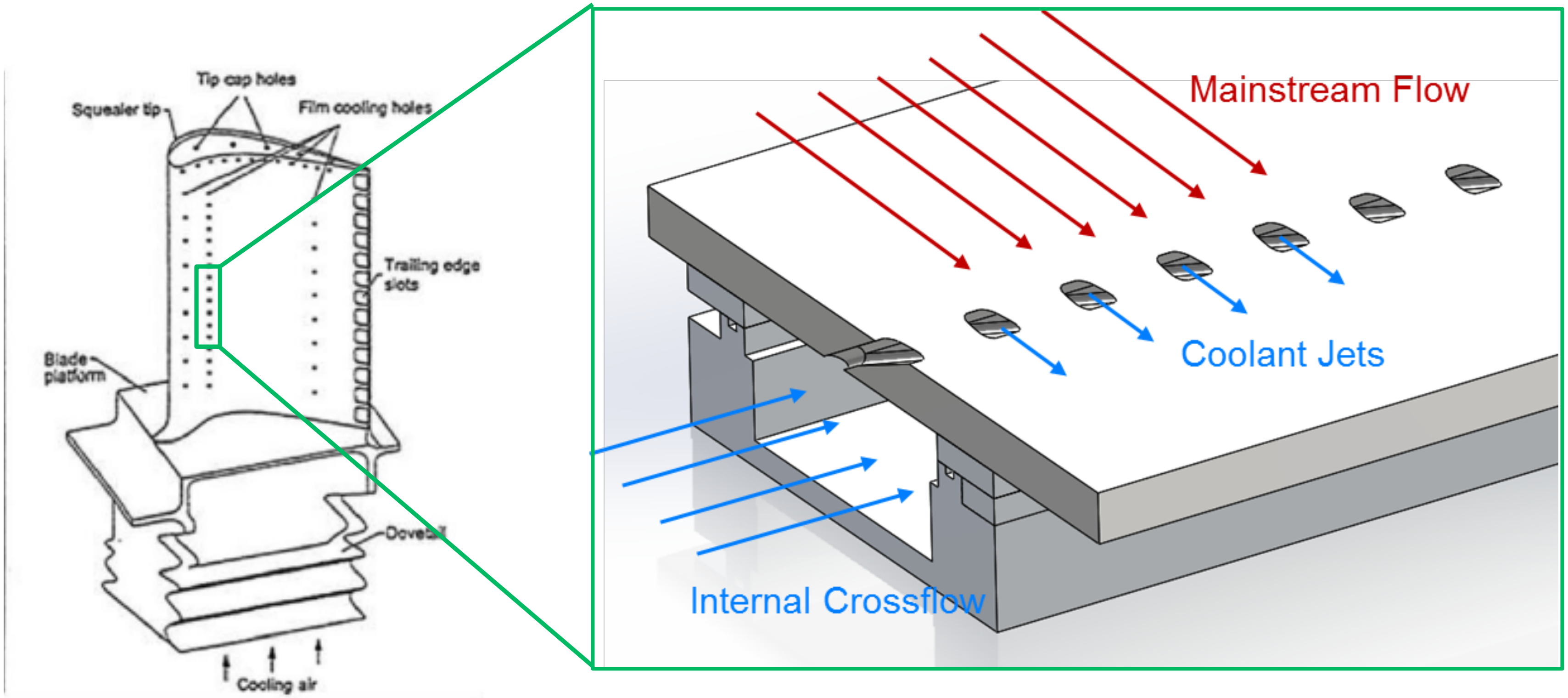
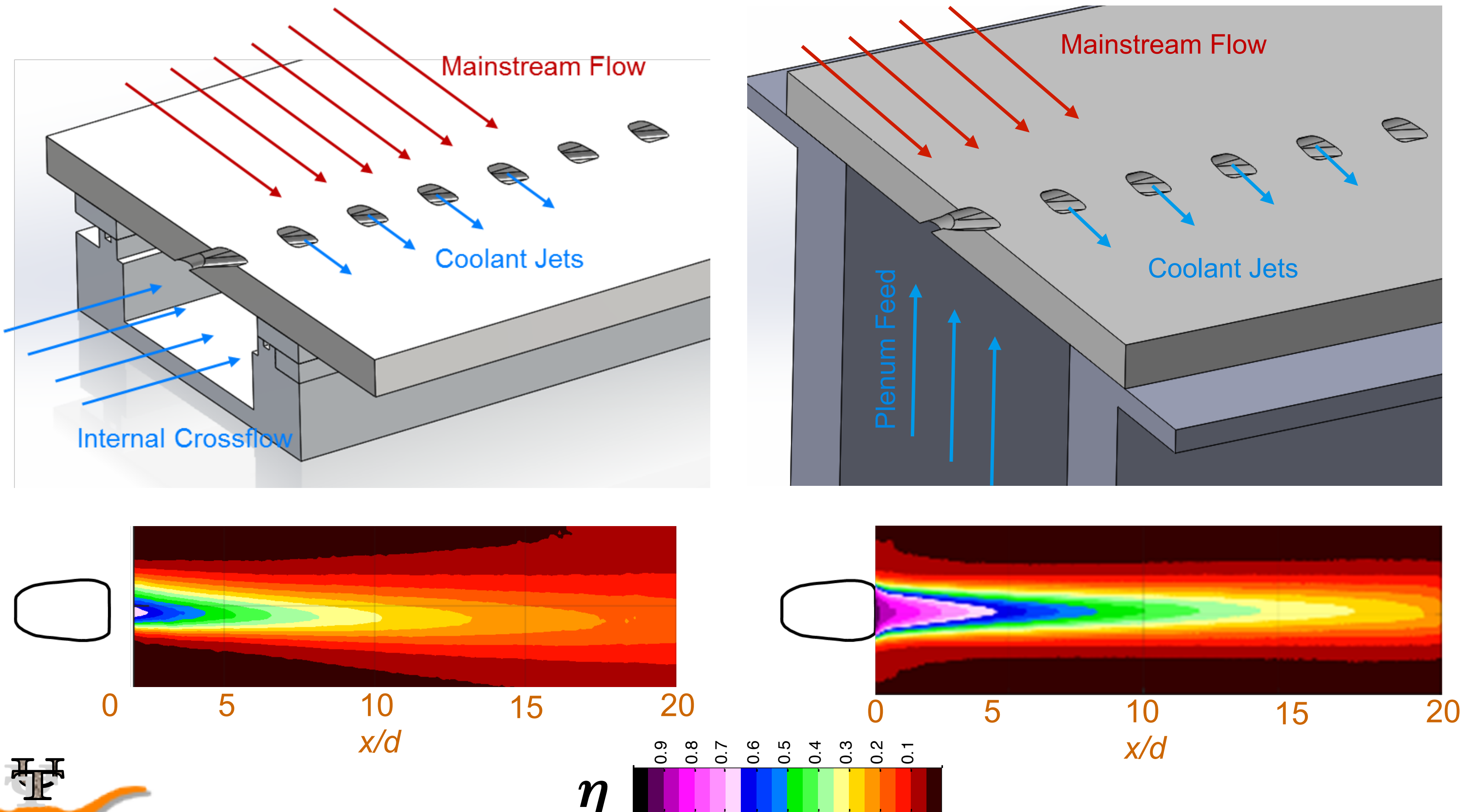


Figure from Han *et al* (2000)

Internal crossflow has been found to reduce film cooling effectiveness

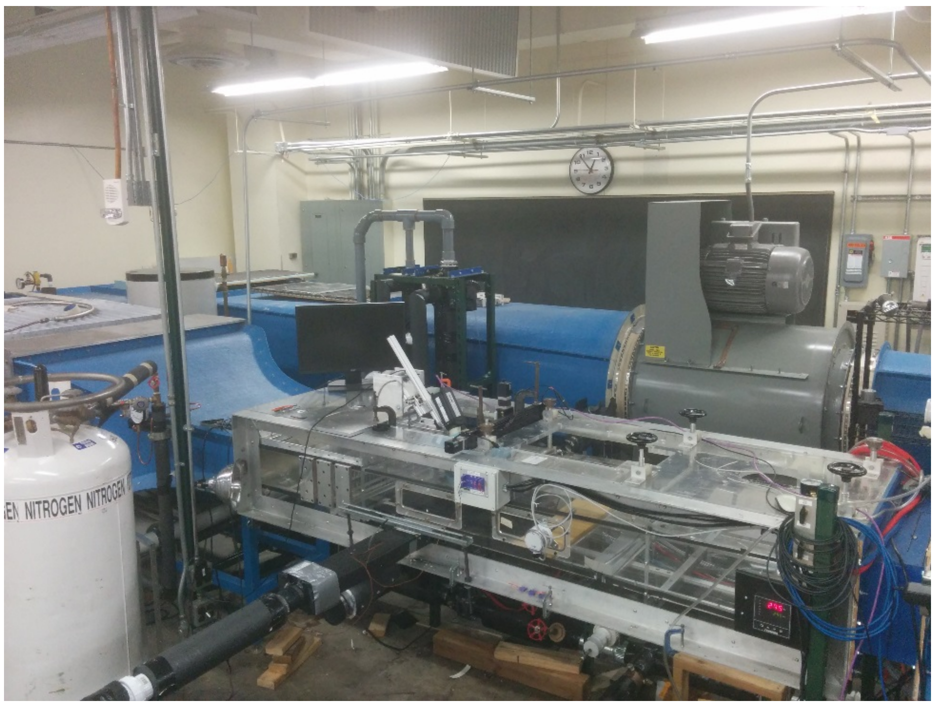
Crossflow Feed – VR_c = 0.35 **Quiescent Plenum Feed**



Data is from Wilkes et al. (2016) and Anderson et al (2015)

Motivation and Objectives

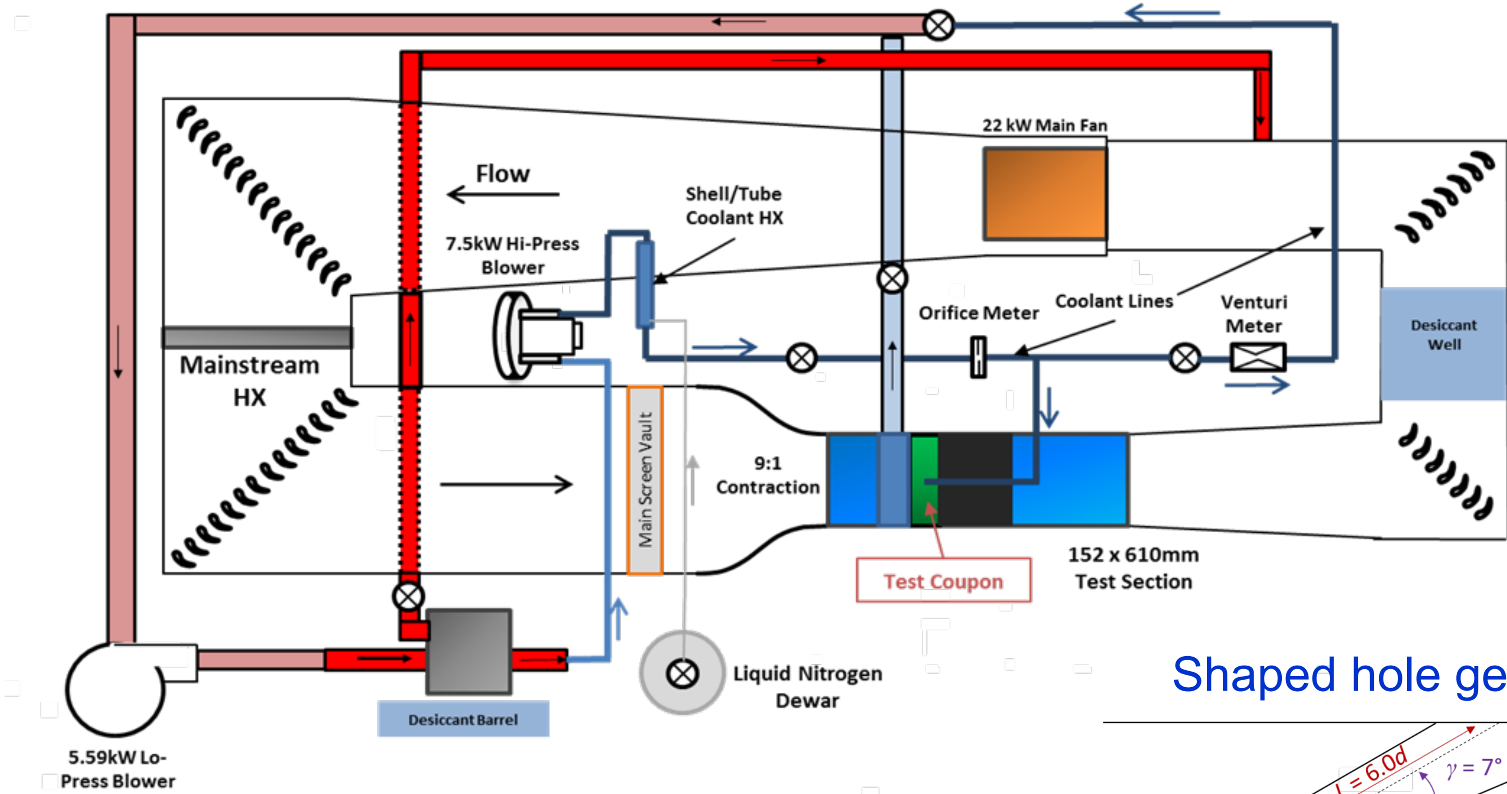
Film cooling holes are commonly fed by an internal crossflow, but the impact of the crossflow velocity is poorly understood, particularly for shaped holes.



For this study, the performance of 7-7-7 shaped holes was studied with specific objectives of:

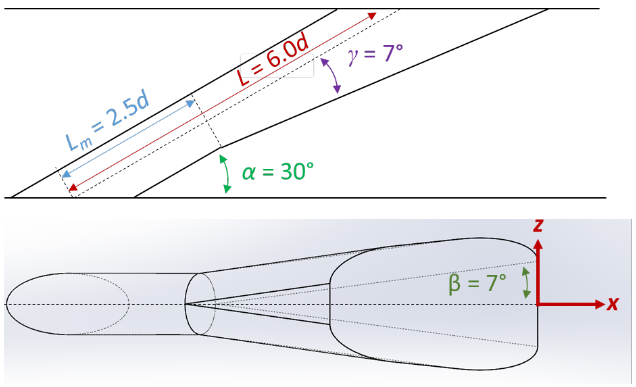
- Understanding how crossflow velocity impacts film cooling effectiveness over a wide range of conditions
- Determining which parameters govern how internal crossflow impacts film cooling performance
- Providing insight into improved film cooling design

Low Speed Recirculating Wind Tunnel Facility



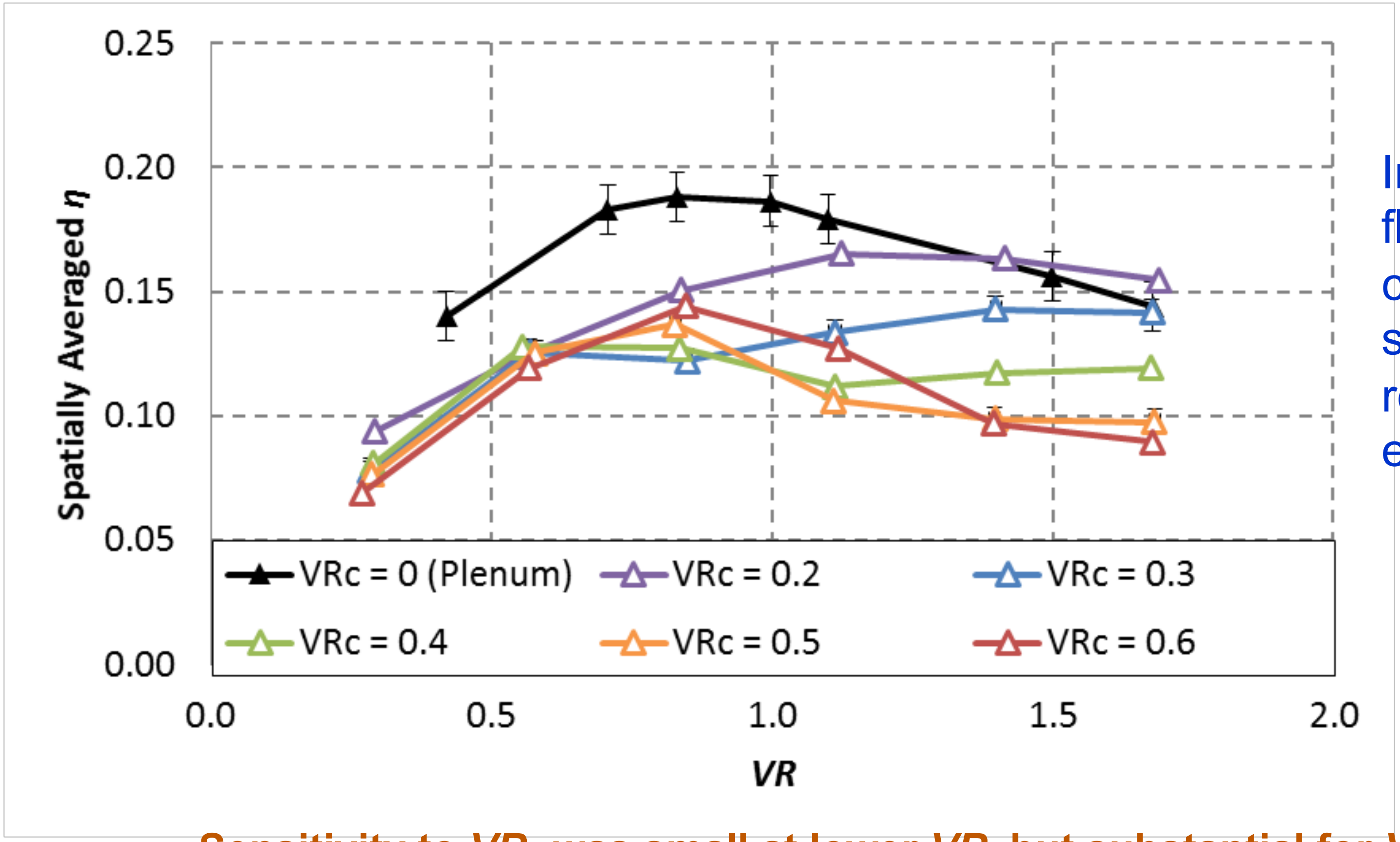
Engine condition coolant density ratios are achieved by using liquid nitrogen to cool film coolant feed to a density ratio of *DR* = 2.0

Shaped hole geometry



Internal cross-flow reduced film effectiveness, with larger decrease with increasing VR_c

Spatially average film effectiveness is the average of 4 pitches over *x/d* = 5-20



Internal cross-flow shown to cause substantial reduction in film effectiveness!

Sensitivity to VR_c was small at lower *VR*, but substantial for *VR* > 1.

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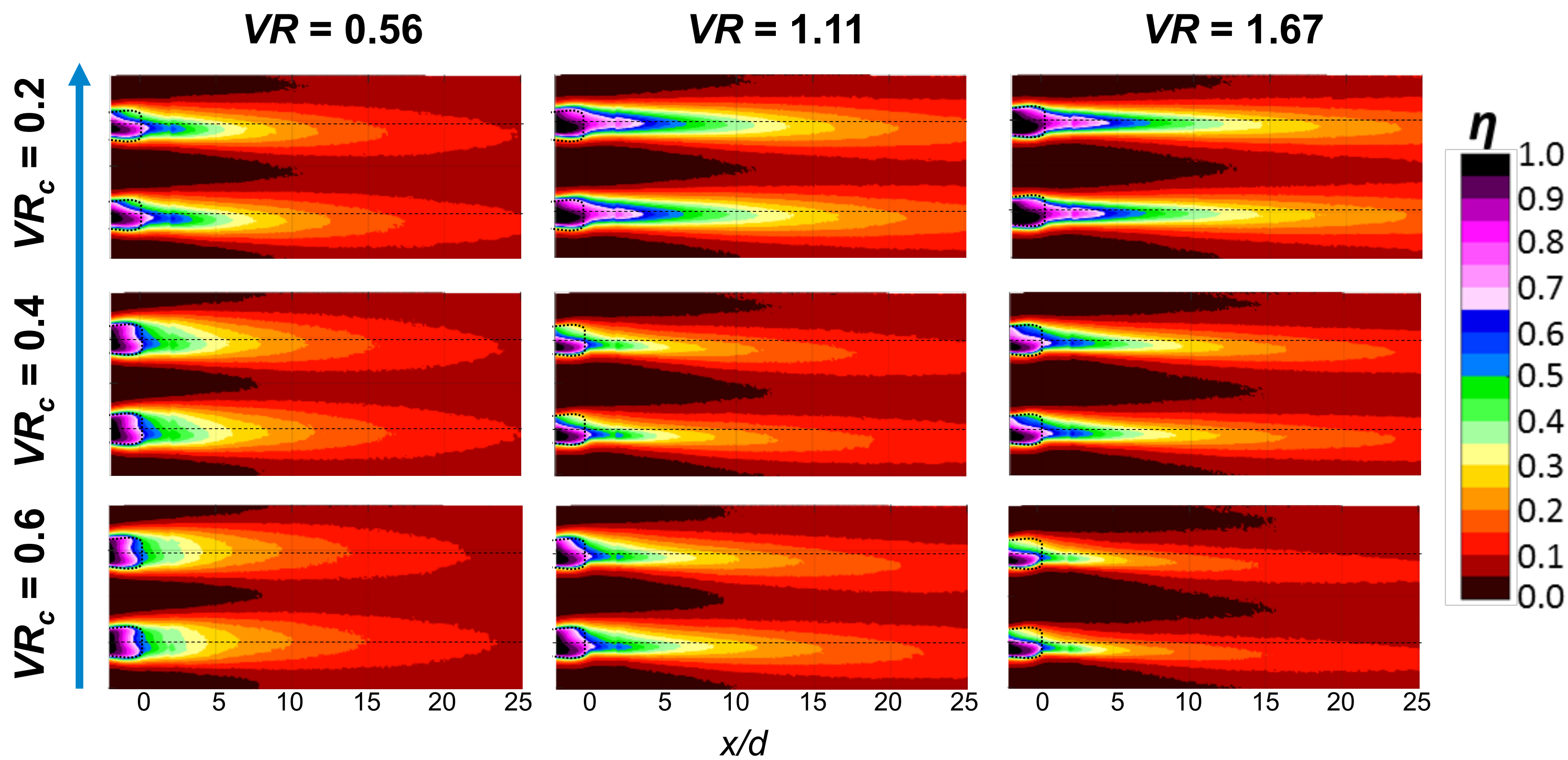
The reduction in film effectiveness appeared to be due to jet asymmetry within the coolant hole.

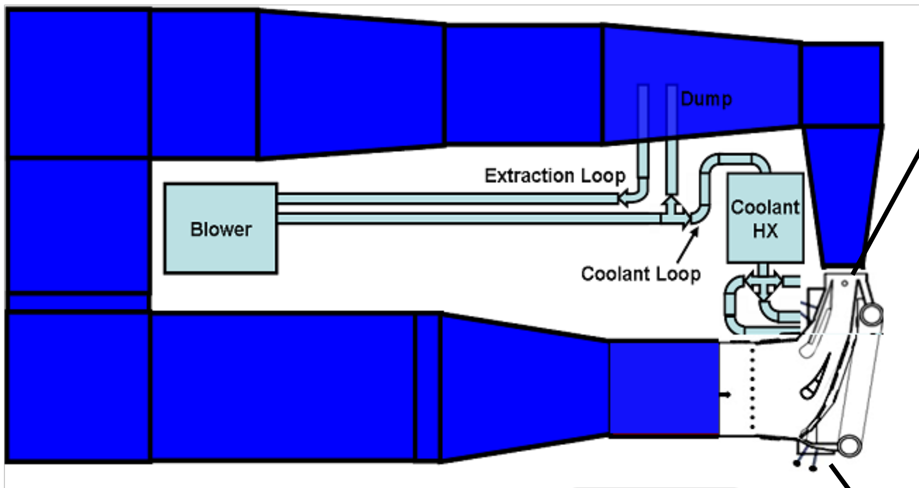


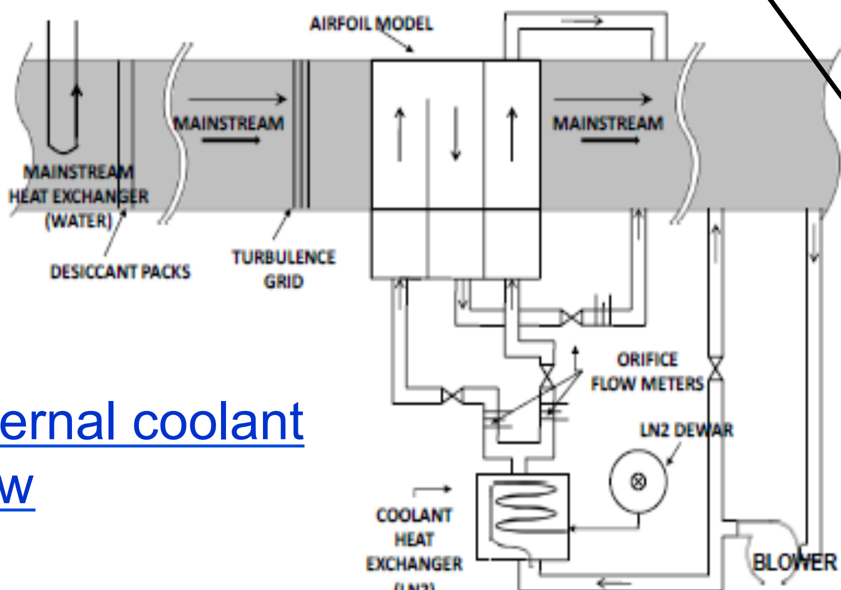
The jet trajectories deviated noticeably from the centerline of the hole

This jet movement was the result of biasing within the diffuser

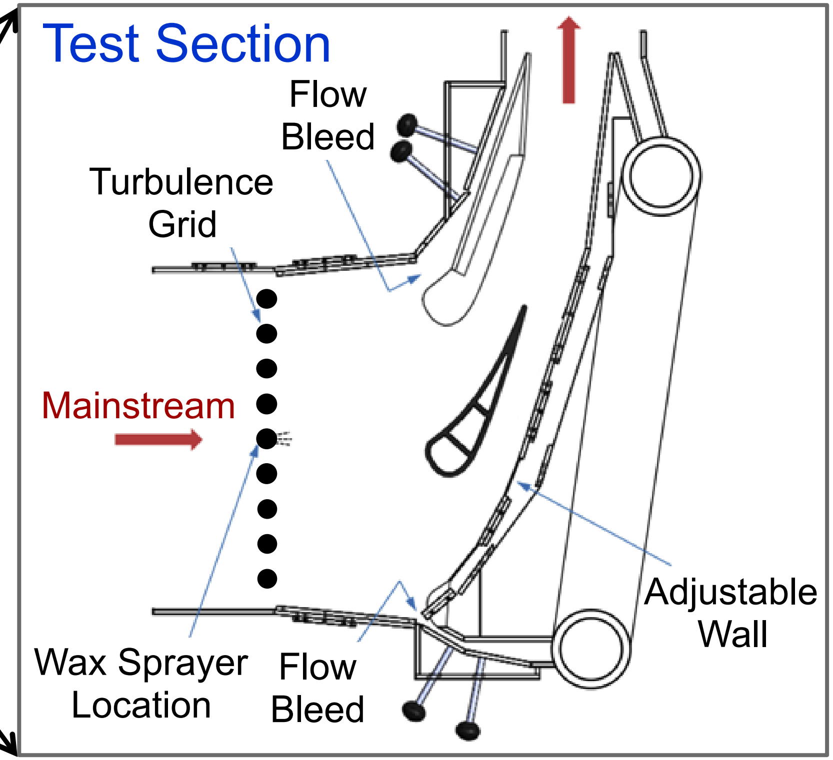
Model turbine vane test facility at the University of Texas

Wind Tunnel



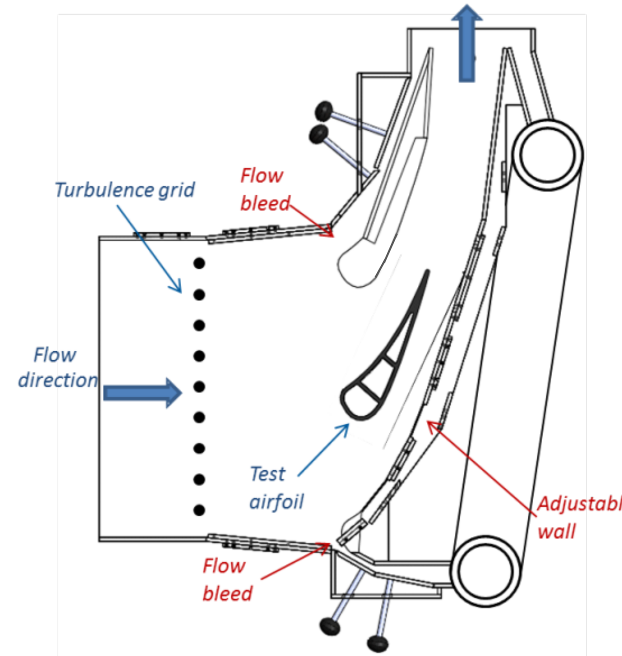


Internal coolant flow

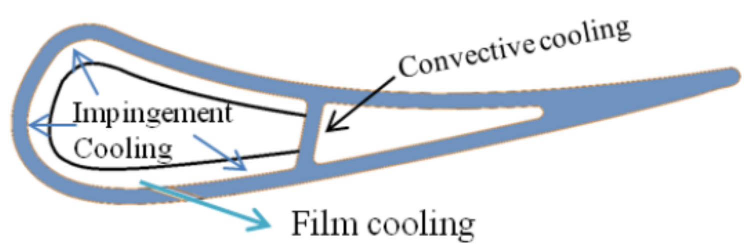


- Liquid nitrogen cooled secondary flow: DR = 1.5
- Mainstream turbulence 20%
- Reynolds number $R_c = 7\text{x}10^5$

Study to compare computational predictions with experimentally measured thermal fields for coolant jets



- Measurements were taken in a corner test section with a simulated 3 vane linear cascade of an 11.6x scale C3X vane.
- Low (k = 0.043 W/mK) and high (k = 1.0 W/mK) thermal conductivity vane models were tested, the high thermal conductivity model was designed to match the Biot number of an actual engine vane
- 2-D thermal fields were measured 0, 5 and 10 hole diameters downstream of a single row of coolant holes on the suction side of the vane



Schematic of vane model

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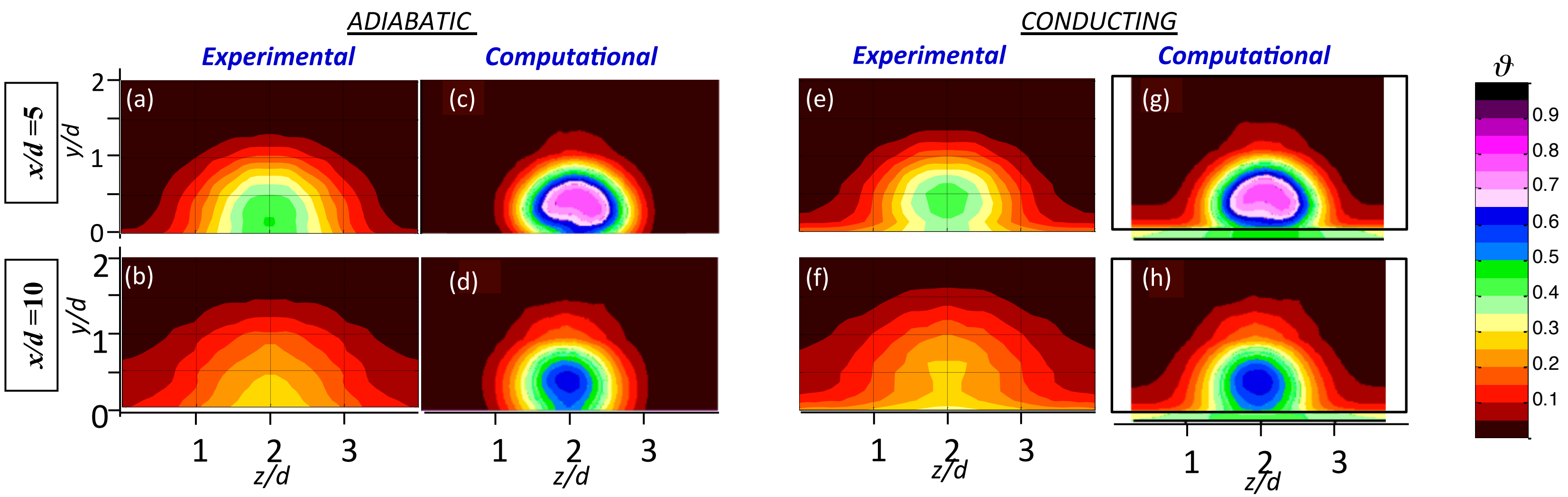
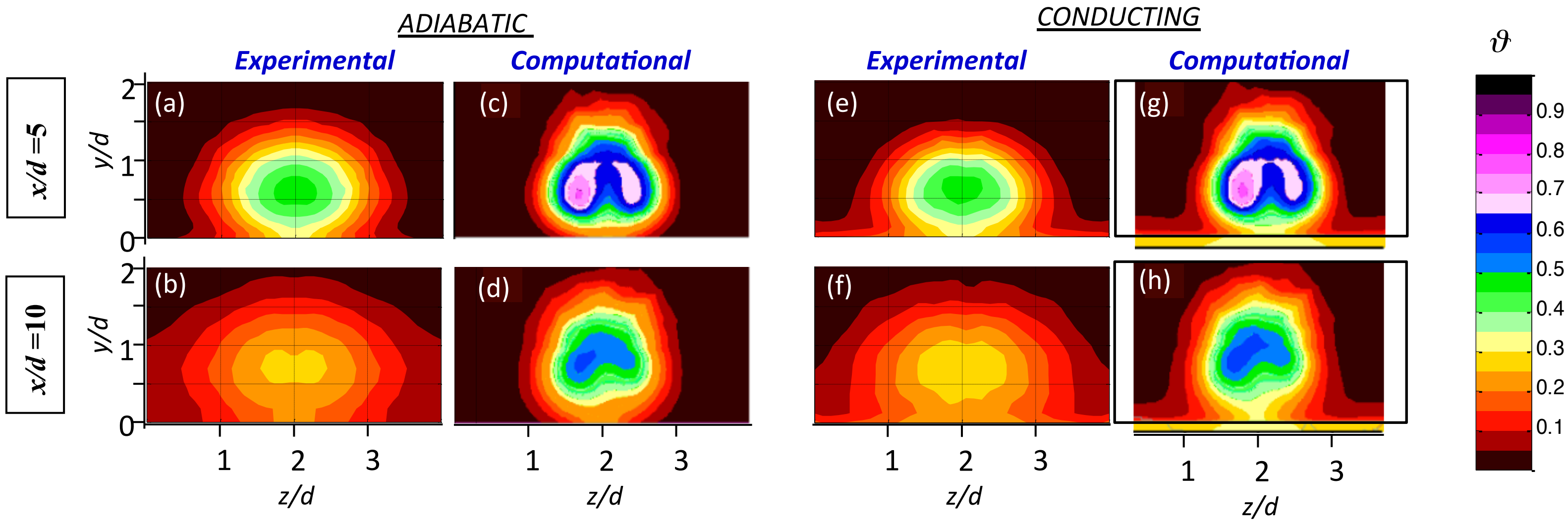
Comparison of experimental and computational thermal fields for *M*=0.65



- CFD predicts a much colder core temperature
- CFD thermal field predicted the jet core would be separated from the vane wall.
- The conducting wall has only a small effect on the over-flowing coolant jets.
- Experimental coolant jet has spread across the entire pitch by *x/d* = 10, CFD coolant jet spread only 75% of the pitch

Comparison of experimental and computational thermal fields for *M*=1.11



- CFD predicts a much colder core temperature.
- Significant coolant jet separation seen both experimentally and computationally.
- The CFD shows a split core due to counter rotating vortices– this was not observed in the experiments.
- Again, the thermal effects on the high conductivity wall were minimal on the coolant jets above the wall.

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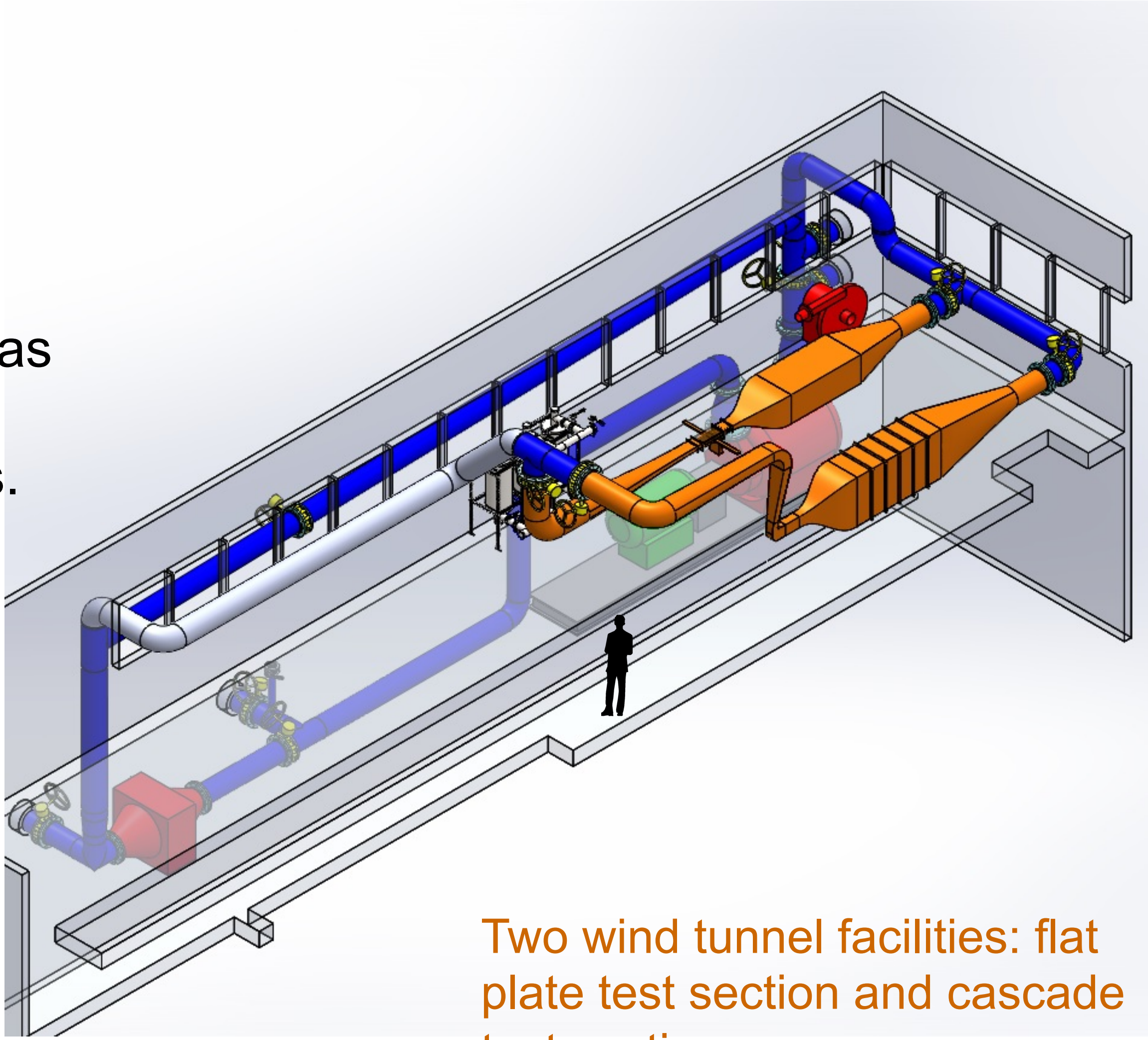
Schematic of Univ. of Texas high speed wind tunnel facility

New facility will operate in the transonic Mach number, matching gas turbine engine operating conditions.



Two wind tunnel facilities: flat plate test section and cascade test section.

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Conclusions

- Our lab has extensive experience in accurate simulation of gas turbine operating conditions in a laboratory environment. These simulations allow us to test large scale models to provide detailed spatial resolution of coolant flows. This is key to understanding the physical mechanisms involved.
- This allows development of improved turbine cooling technologies.
- It also allows development of and evaluation of improved computational models which are needed for engine designs.

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