Revolutionizing Turbine Cooling with Micro-Architectures Enabled by Direct Metal Laser Sintering (DMLS)

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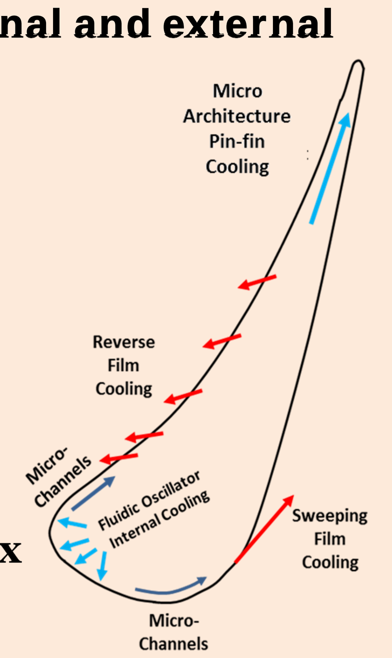
Motivation and Objective

With the development of Additive Manufacturing (AM) technique, it is now possible to design turbine vanes with complicated cooling architecture. The objects of the current project are-

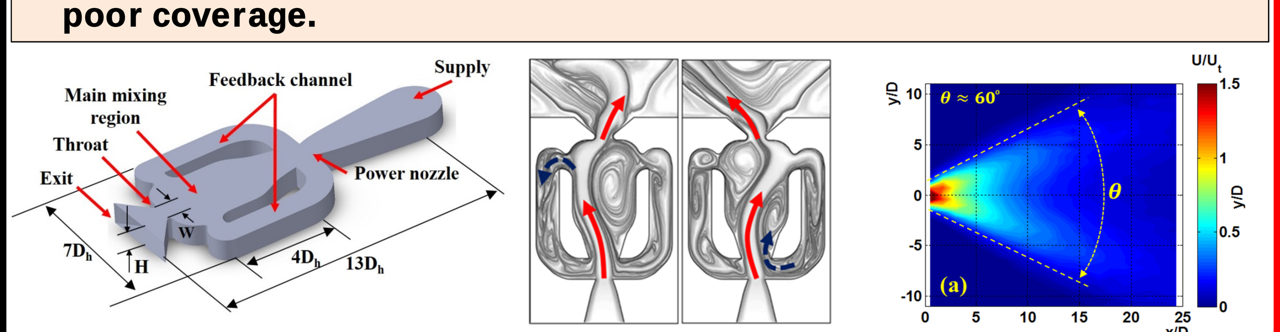
- ❑ Explore innovative cooling architectures enabled by additive manufacturing techniques for improved cooling performance and reduced coolant waste.
- ❑ Leverage DMLS to better distribute coolant through complex geometries, as well as to integrate inherently unstable flow devices to enhance internal and external heat transfer.
- ❑ Demonstrate these technologies-
  1. At Small scale-low speed
  2. At relevant Mach number in a high speed cascade.
  3. Finally, at high speed and high temperature.
- ❑ Complement experiments with CFD modeling to explore a broader design space and extrapolate to more complex operating conditions



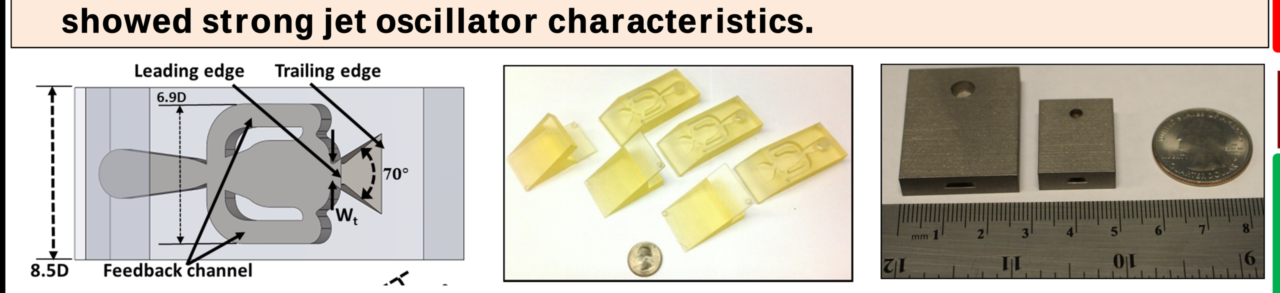
New Cooling Concepts

Sweeping Jet Film Cooling

❑ The sweeping jet motion produced by fluidic oscillators could be used to improve the spread of film cooling in regions that suffer from poor coverage.



❑ Small scale oscillators manufactured by DMLS or Polyjet technique showed strong jet oscillator characteristics.



Sweeping jet film cooling hole | Polyjet part | DMLS part

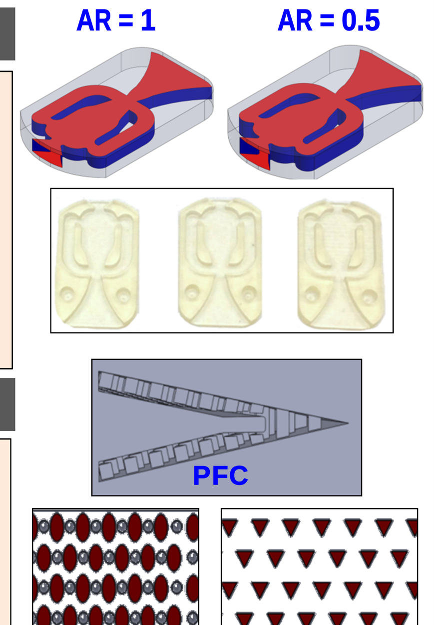
Sweeping Jet Impingement Cooling

- ❑ The oscillating impingement jet presents itself as an attractive device, especially if no external input is required to maintain the oscillations.
- ❑ The self oscillating jet has shown uniform heat transfer performance and strong oscillation behavior at small scale.

Trailing Edge Cooling

❑ Several AM enabled designs have been designed in order to improve trailing edge heat transfer without additional pressure drop. The design includes-

1. Pin-fin with clearance (PFC)
2. Elliptical pin-fin with dimple (EPFD)
3. Triangular pin-fin (TPF)

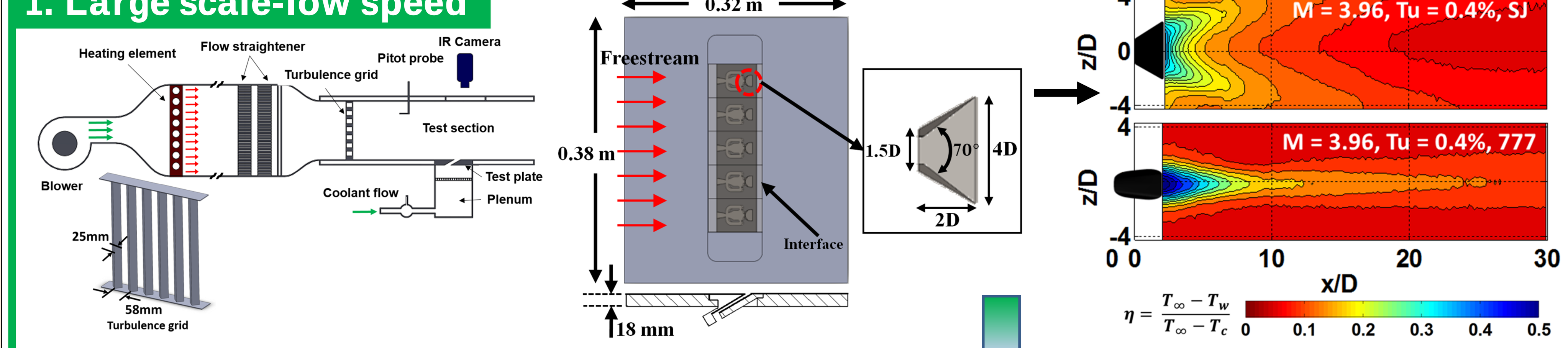


Sweeping Jet Film Cooling

A multistep (design-test-modify) method was used to develop an unsteady sweeping jet film cooling scheme

Experimental Setup ➡ Test Geometry ➡ Film Effectiveness

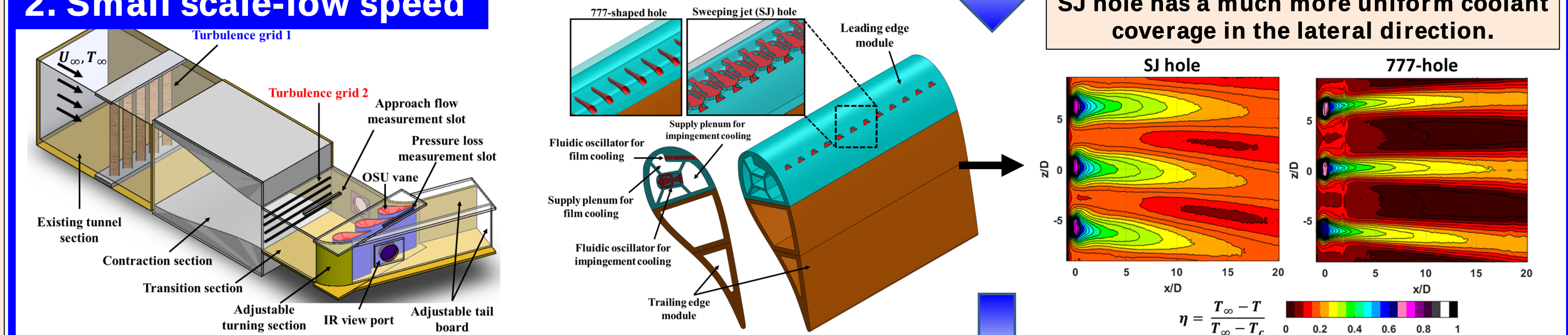
1. Large scale-low speed



$\eta = \frac{T_\infty - T_w}{T_\infty - T_c}$

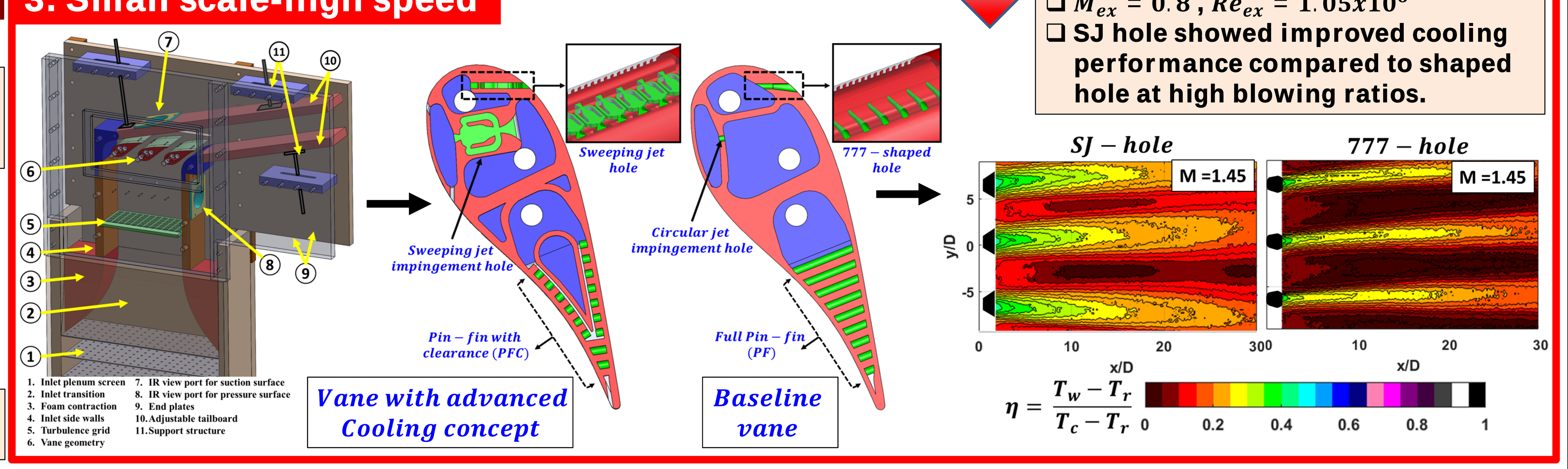
2. Small scale-low speed

SJ hole has a much more uniform coolant coverage in the lateral direction.



3. Small scale-high speed

- ❑ $M_{ex} = 0.8$, $Re_{ex} = 1.05x10^6$
- ❑ SJ hole showed improved cooling performance compared to shaped hole at high blowing ratios.

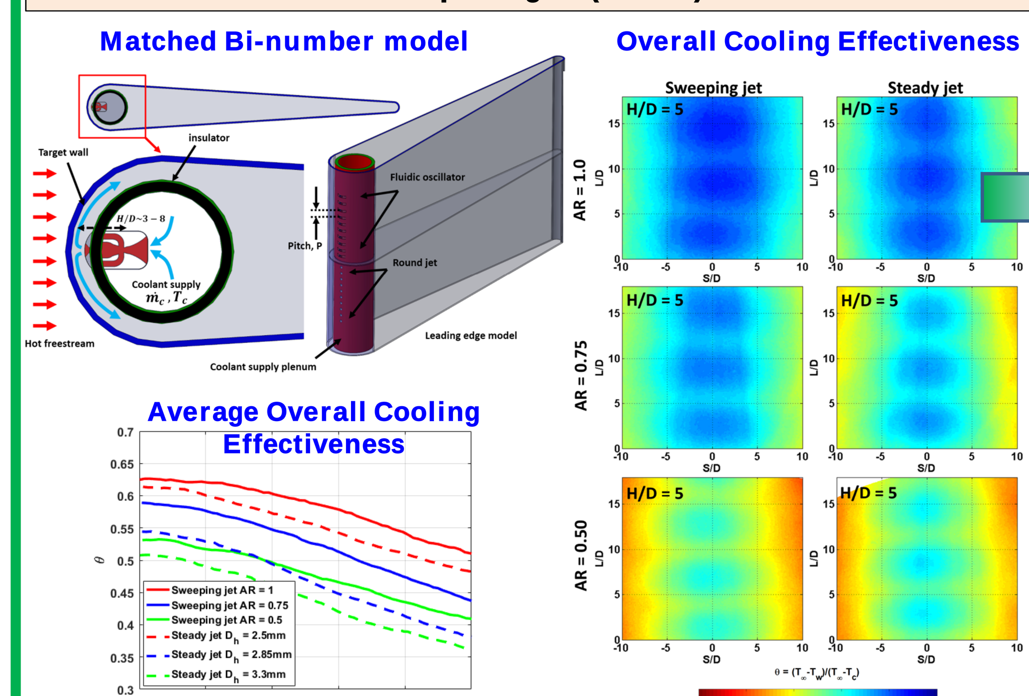


$\eta = \frac{T_w - T_r}{T_c - T_r}$

Sweeping Jet Impingement Cooling

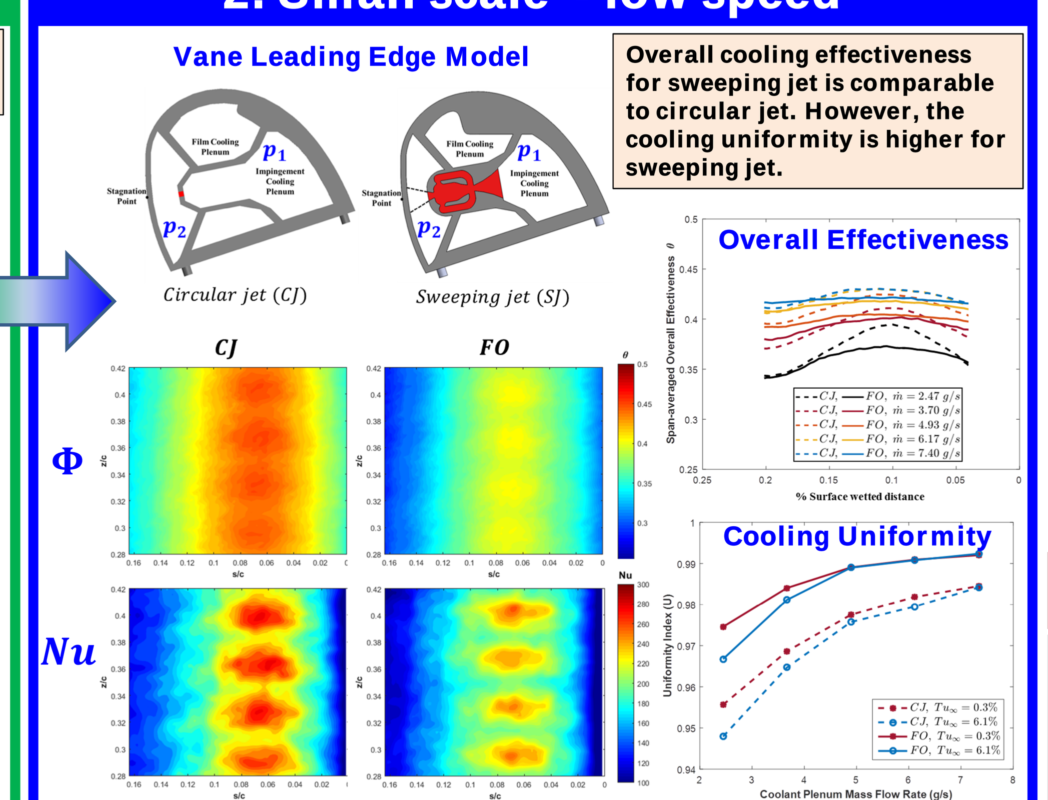
1. Large scale - low speed

Sweeping jet showed an improved cooling performance at a jet-wall-spacing of (H/D = 5).



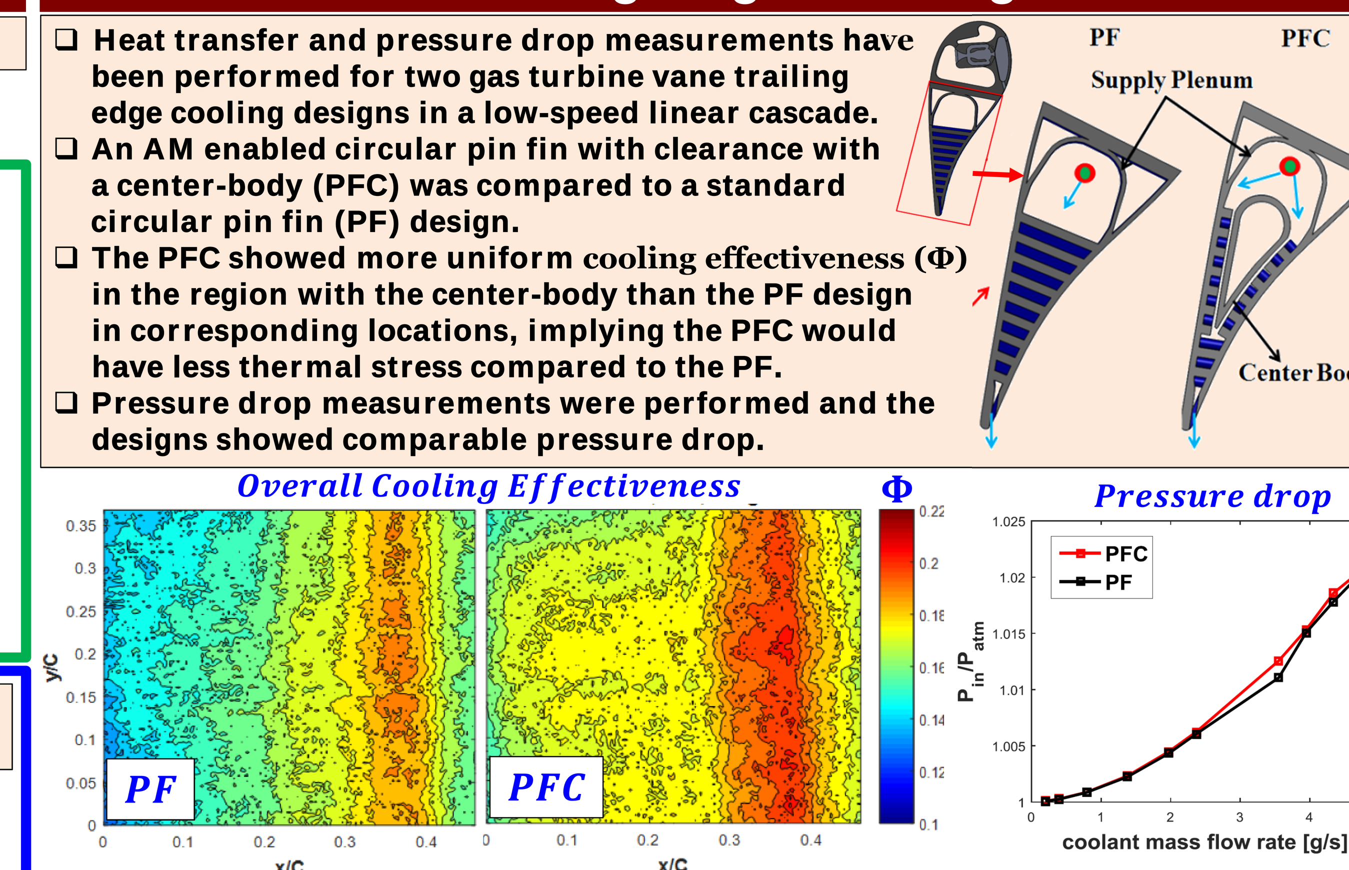
2. Small scale - low speed

Overall cooling effectiveness for sweeping jet is comparable to circular jet. However, the cooling uniformity is higher for sweeping jet.



Trailing Edge Cooling

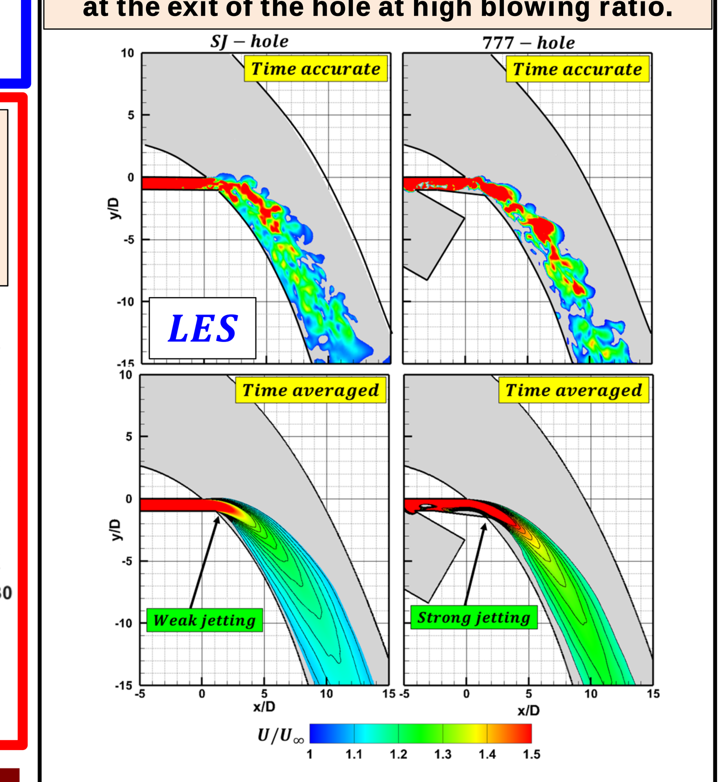
- ❑ Heat transfer and pressure drop measurements have been performed for two gas turbine vane trailing edge cooling designs in a low-speed linear cascade.
- ❑ An AM enabled circular pin fin with clearance with a center-body (PFC) was compared to a standard circular pin fin (PF) design.
- ❑ The PFC showed more uniform cooling effectiveness (Φ) in the region with the center-body than the PF design in corresponding locations, implying the PFC would have less thermal stress compared to the PF.
- ❑ Pressure drop measurements were performed and the designs showed comparable pressure drop.



Complementary CFD Work

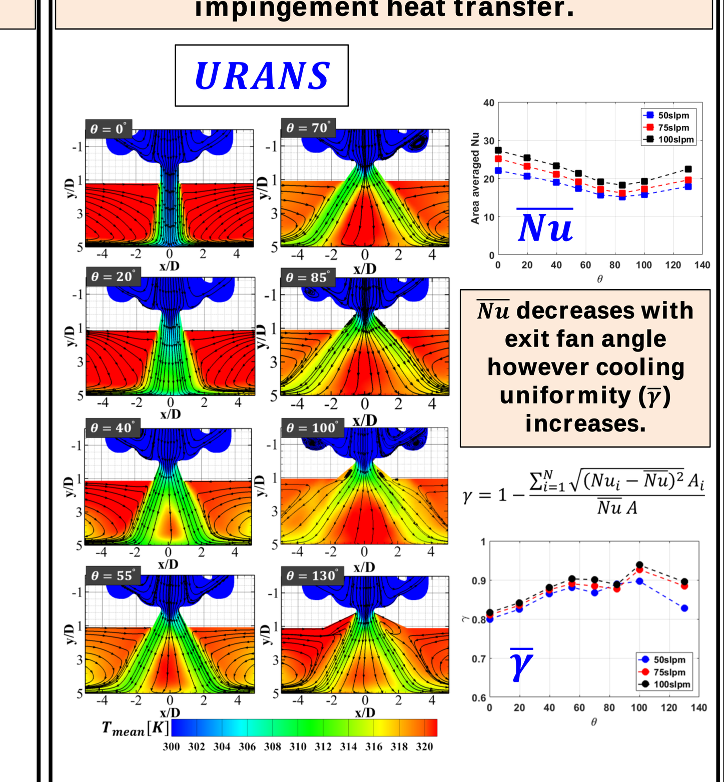
Film Cooling

SJ hole has a significantly weak jetting action at the exit of the hole at high blowing ratio.



Impingement Cooling

Exit fan angle has a significant effect on impingement heat transfer.



Conclusion and Future Work

- ❑ Sweeping jet (SJ) film cooling hole shows promising cooling performance compared to shaped hole at high blowing ratios.
- ❑ The heat transfer augmentation for SJ hole is higher than shaped hole.
- ❑ The aerodynamic pressure loss and discharge coefficient for SJ hole are comparable to shaped hole and there are scopes for optimization.
- ❑ Sweeping jet impingement can provide uniform cooling at the leading edge compared to steady impinging jet. Thus, the SJ hole reduces the potential of thermal stress development.
- ❑ The pressure drop of sweeping jet impingement hole is comparable to steady impinging hole.
- ❑ The AM enabled Pin-Fin with Clearance (PFC) design for trailing edge shows higher and more uniform cooling effectiveness with no additional pressure drop penalty than conventional Pin-Fin (PF) design.

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