Turbine Vanes and Endwalls with Realistic Surface Conditions

Virginia Tech
VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

TEXAS

***PI*: Karen A. Thole**

***Co-PI*: David G. Bogard**

***Graduate Research Assistants*:**

Nicholas Cardwell

Narayan Sundaram

Patricia Demling

Scot Wye

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DOE COOPERATIVE AGREEMENT DE-FC26-02NT41431

Tom J. George, Program Manager, DOE/NETL

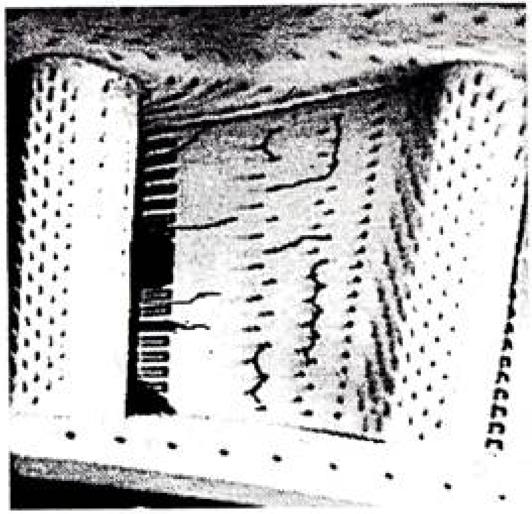
Richard Wenglarz, Manager of Research, SCIES

Project Awarded (7/1/2003, 36 Month Duration)

$572,385   Total Contract Value ($572,385 DOE)

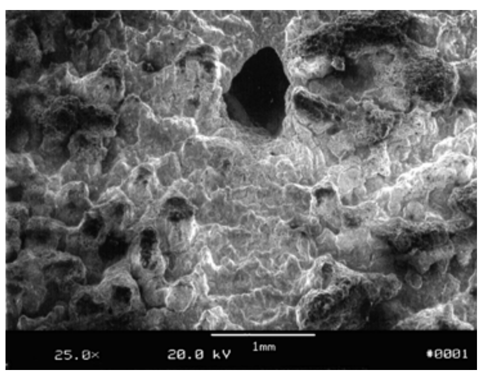
Gas Turbine Needs

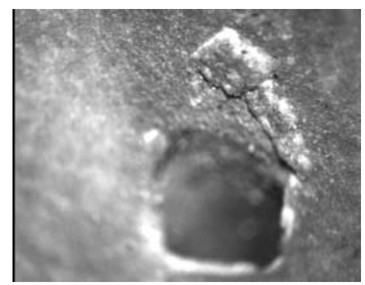
- **Account for the effects of roughness from particle deposition and corrosion resulting from the use of synfuels**
- **Account for the effects of blocked holes and gap leakages on predicting airfoil temperatures**

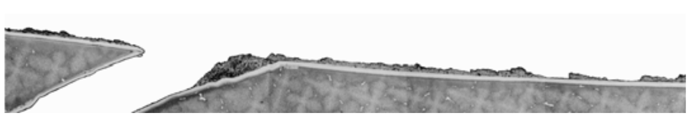


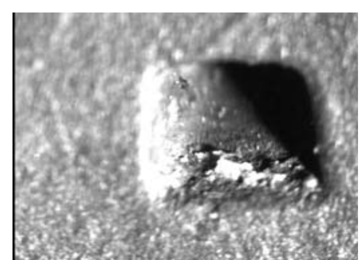
Overall Project Objectives

- Determine effects of flow leakages at component interfaces occurring due to expansions/contractions
- Determine effects of surface distortions on vane and endwall film-cooling
- Determine effects of coolant hole blockages on vane and endwall film-cooling









Problem Approach

Virginia Tech Tasks

1. Determine the effect of a leakage slot between the component interfaces on the performance of endwall film-cooling
2. Determine the effect of roughness on the performance of endwall film-cooling
3. Measure thermal and velocity fields to determine surface roughness effects
4. Determine whether film-cooling holes in slots at component interfaces can aid in directing the coolant leakage flow
5. Determine whether the performance of clean and blocked cooling holes will be improved by being placed in slots along the endwall

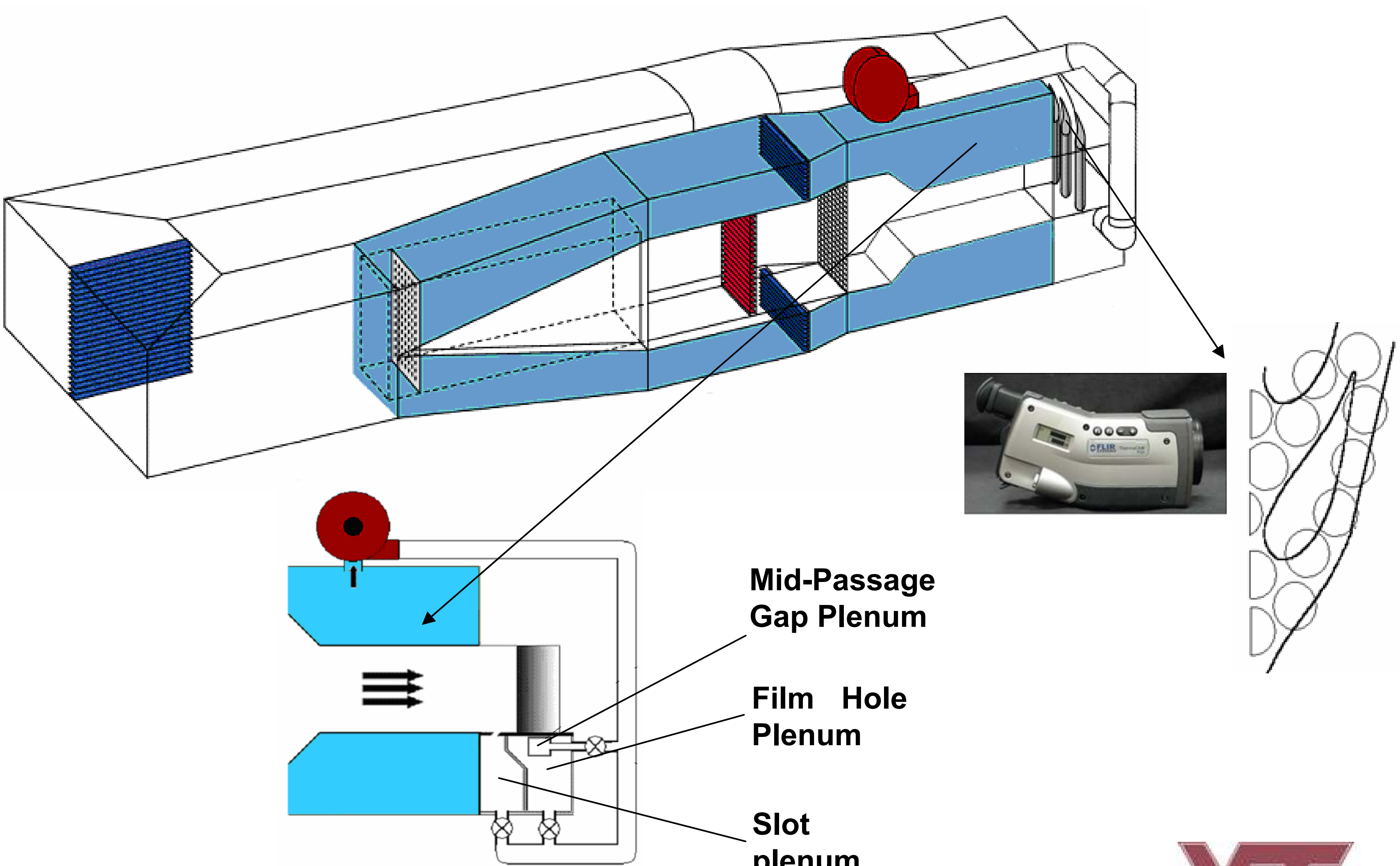
University of Texas Tasks

1. Determine roughness effect on the pressure and suction surfaces of a turbine vane
2. Measure thermal and velocity fields to determine surface roughness effects on the vane
3. Test the effects of various categories of hole blockage on film cooling performance for smooth and rough surfaces on the vane
4. Design and test transverse slots for enhanced film cooling performance with clean and blocked film-cooling holes
5. Test the performance of the transverse slot with simulated blockage of the slot by surface contaminants

Accomplishments

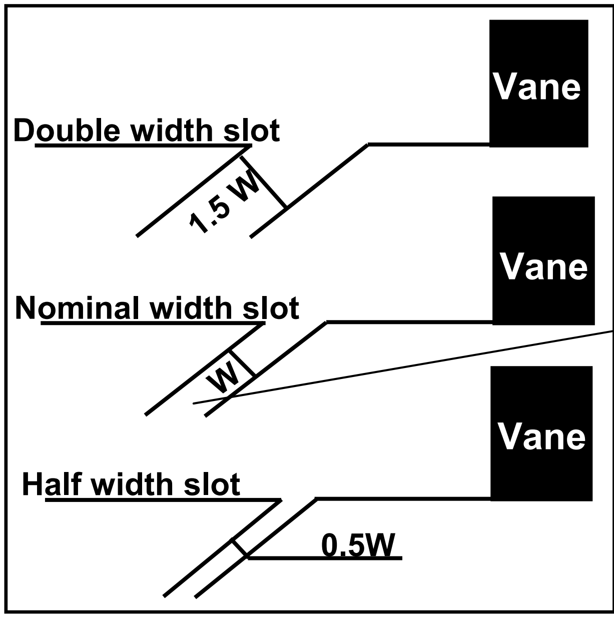
- By decreasing the upstream slot width between the combustor and turbine, improved spreading of the coolant from the slot occurs
- Modeled and evaluated the effects on endwall film-cooling performance from depositions, spallation, and hole blockages
- Found that small hole depositions can improve effectiveness in the leading edge region while hole blockages can severely reduce cooling effectiveness
- Showed a significant increase (doubling) of the heat load to the turbine vane with rough surfaces compared to smooth surfaces
- Found that roughness on the pressure side had less of an effect on adiabatic effectiveness than roughness on the suction side
- Measured degradation of film cooling performance due to obstructions upstream and downstream of the holes
- Measured a significant increase in film cooling effectiveness with a transverse slot present on the suction side of the vane

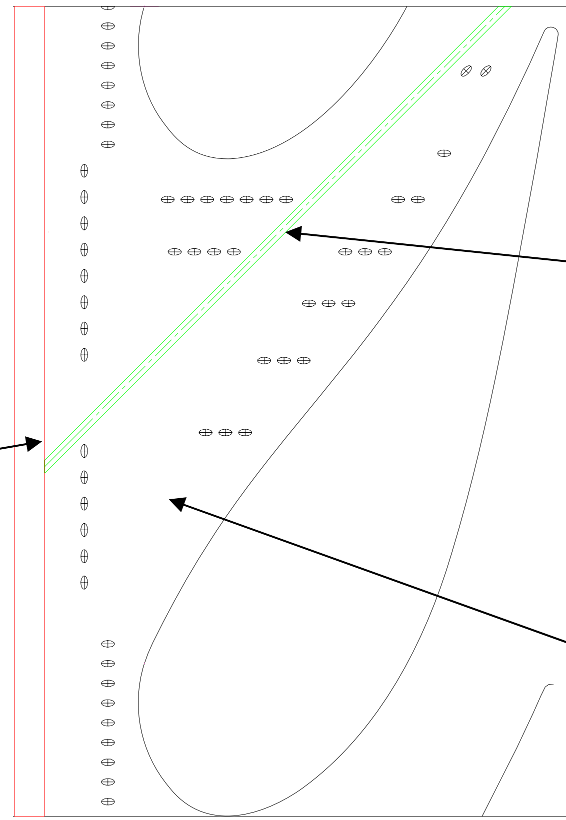
Tests were carried out in a low speed wind tunnel with measurements made using an IR camera



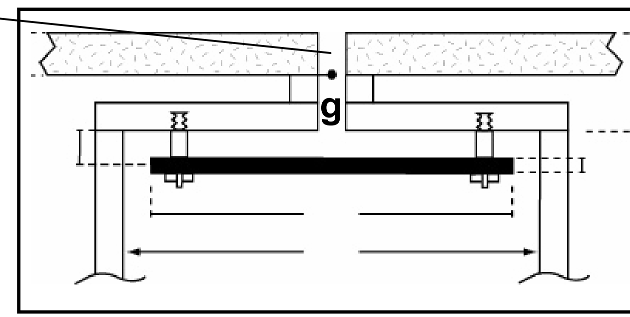
Tests were carried out on a scaled up vane simulating a realistic endwall geometry

Combustor/Vane Interface (Upstream Slot)





Vane-to-vane interface gap (mid-passage gap)

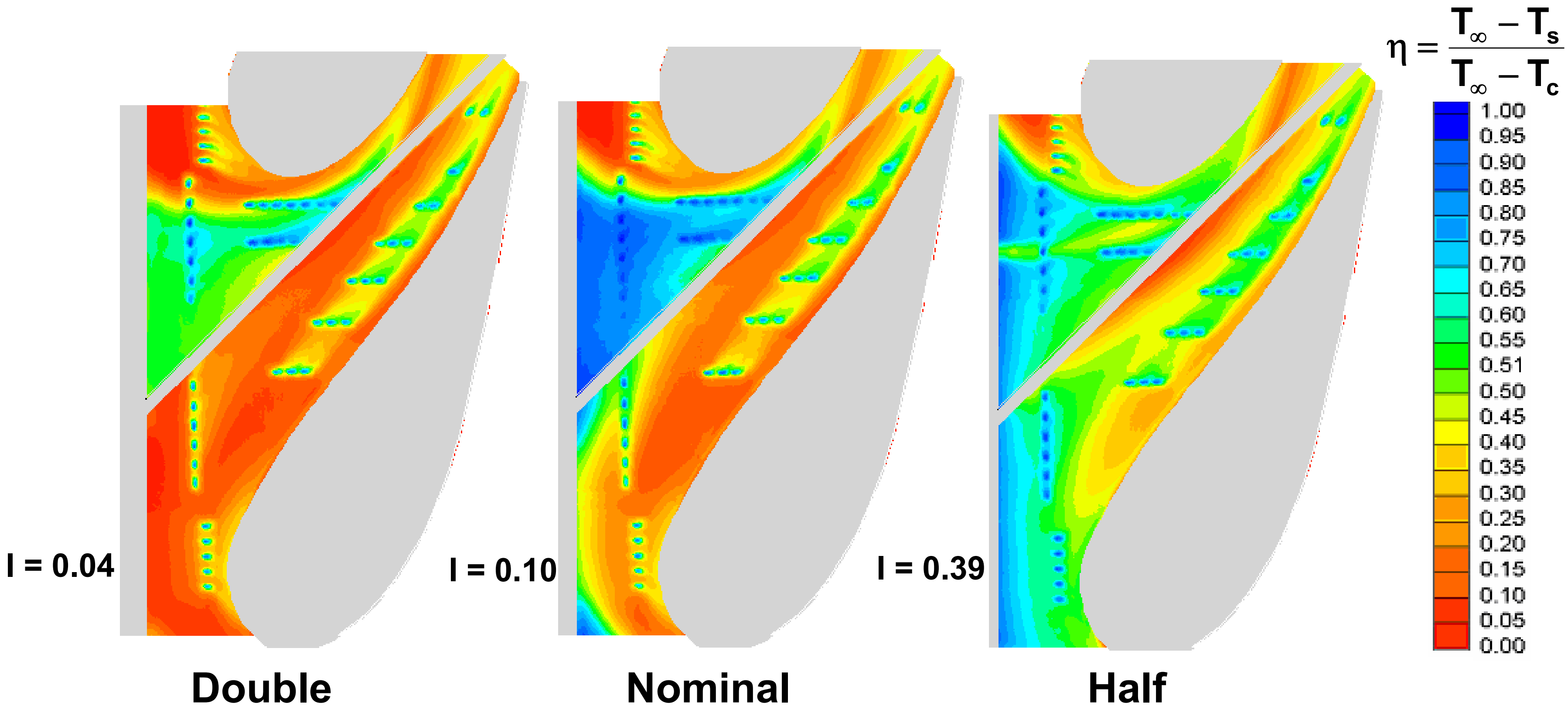


36 Grit sand paper k_s= 0.42mm at engine scale

Parameter	Dimensions
C – scaled up chord length	59.4 cm
W – upstream slot width	0.024C
g – passage gap width	0.01C

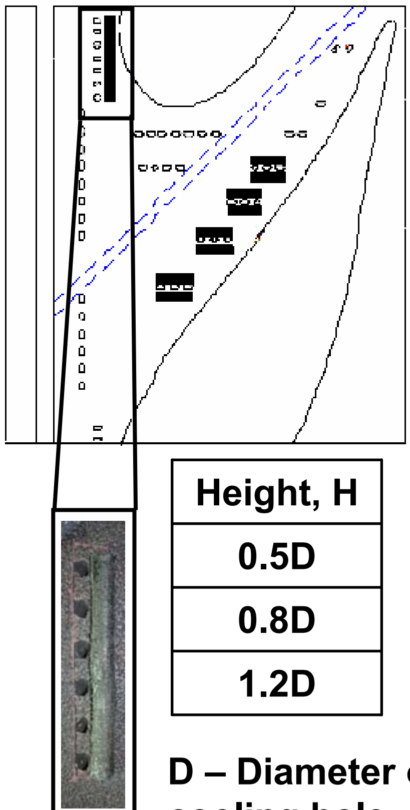
Smaller slots can lead to improved lateral spreading of vane-combustor leakage flows

0.85% Upstream slot; 0.5% Film-cooling hole; 0% Mid-passage gap



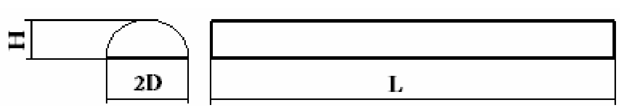
Surface deposition, hole blockage, and TBC spallation were simulated on the endwall surface

Deposition

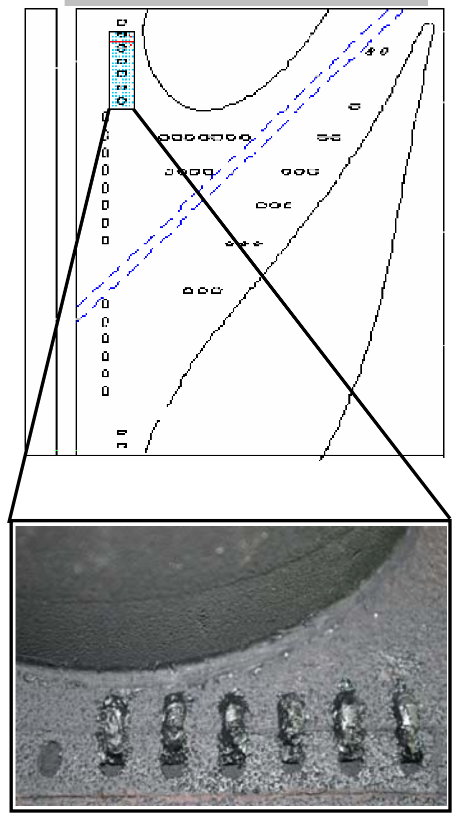


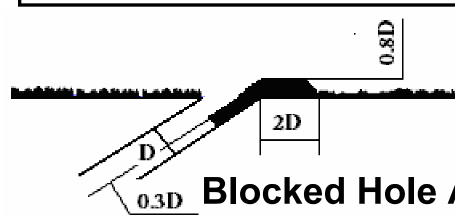
Height, H
0.5D
0.8D
1.2D

D – Diameter of film-cooling hole



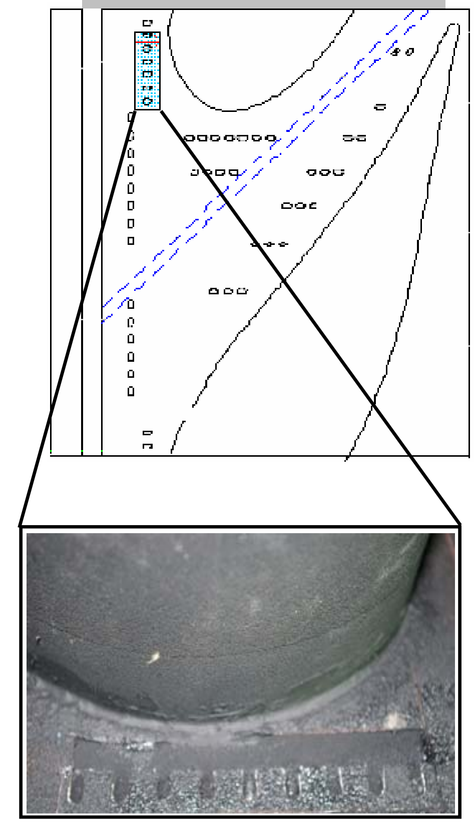
Hole blockage

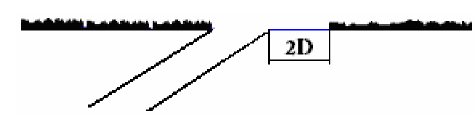




Blocked Hole Area Ratio, A2/A1 – 0.75

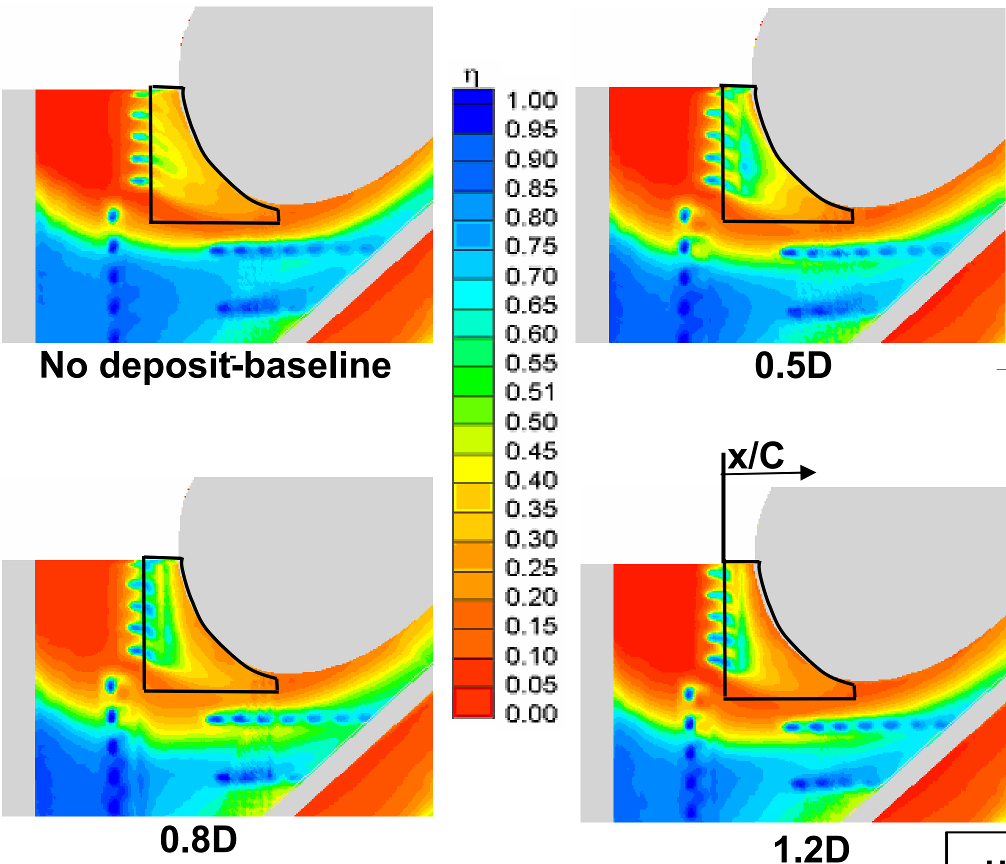
TBC spallation

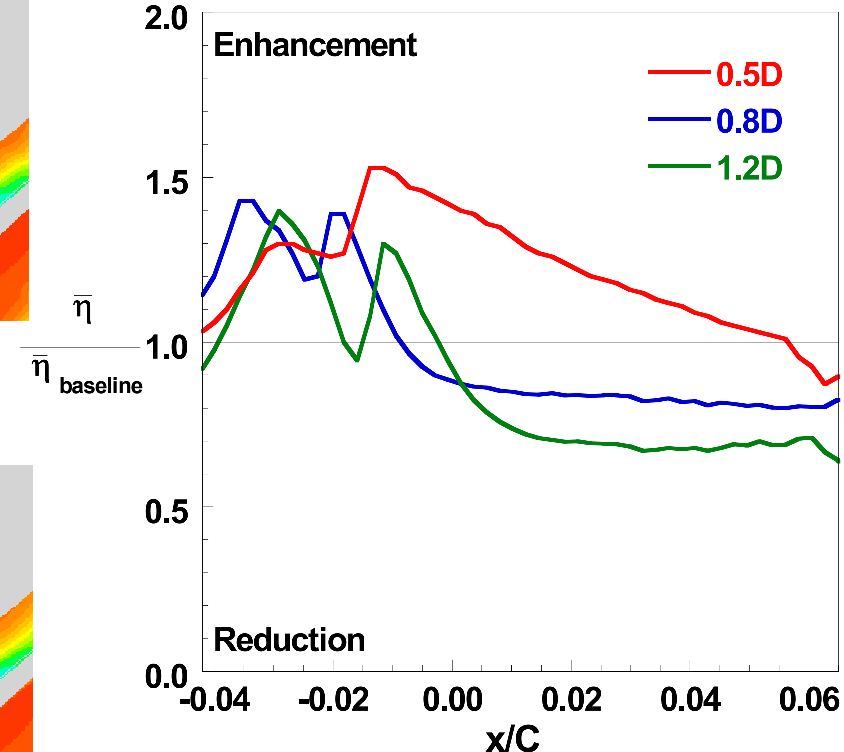




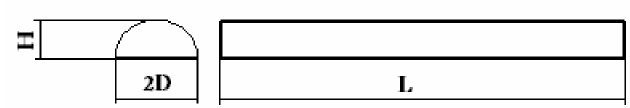
Adiabatic effectiveness was enhanced for small downstream deposits

0.75% Upstream slot; 0.5% Film-cooling hole; 0.2% Mid-passage gap



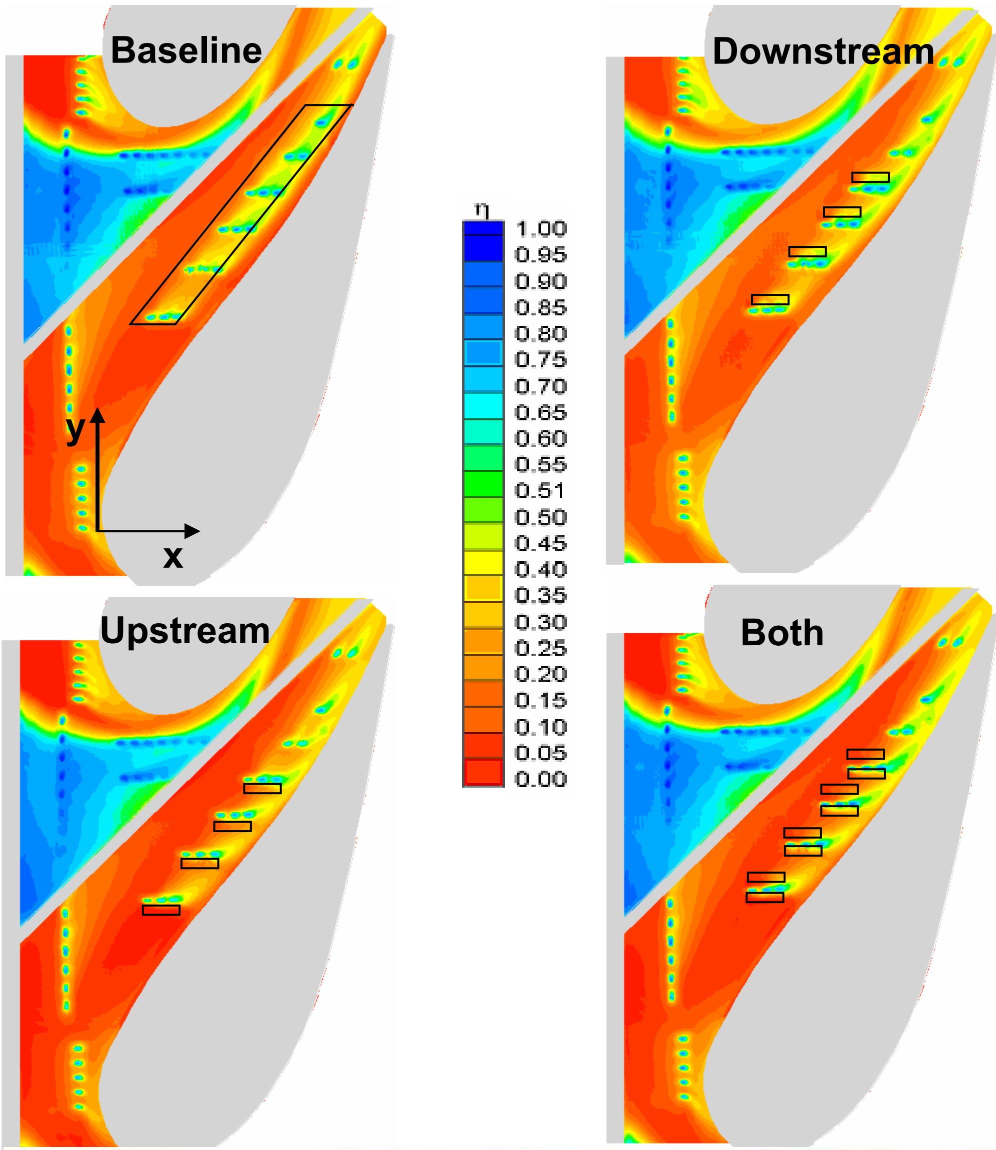


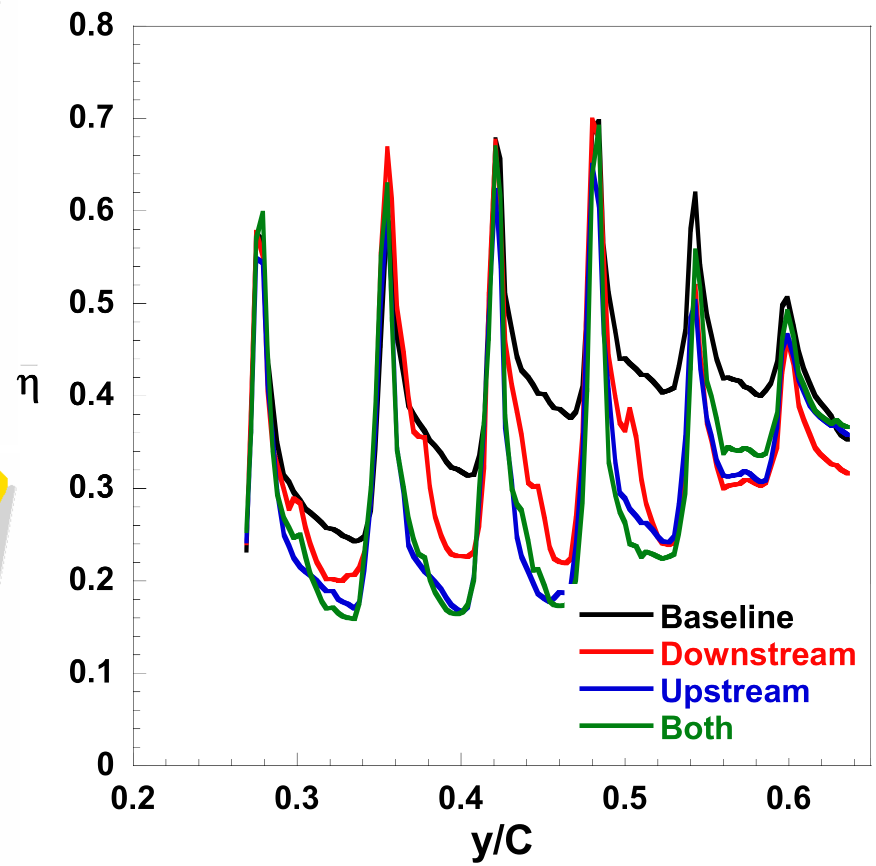
Height, H
0.5D
0.8D
1.2D



Degradation in adiabatic effectiveness was seen for deposits along the pressure side

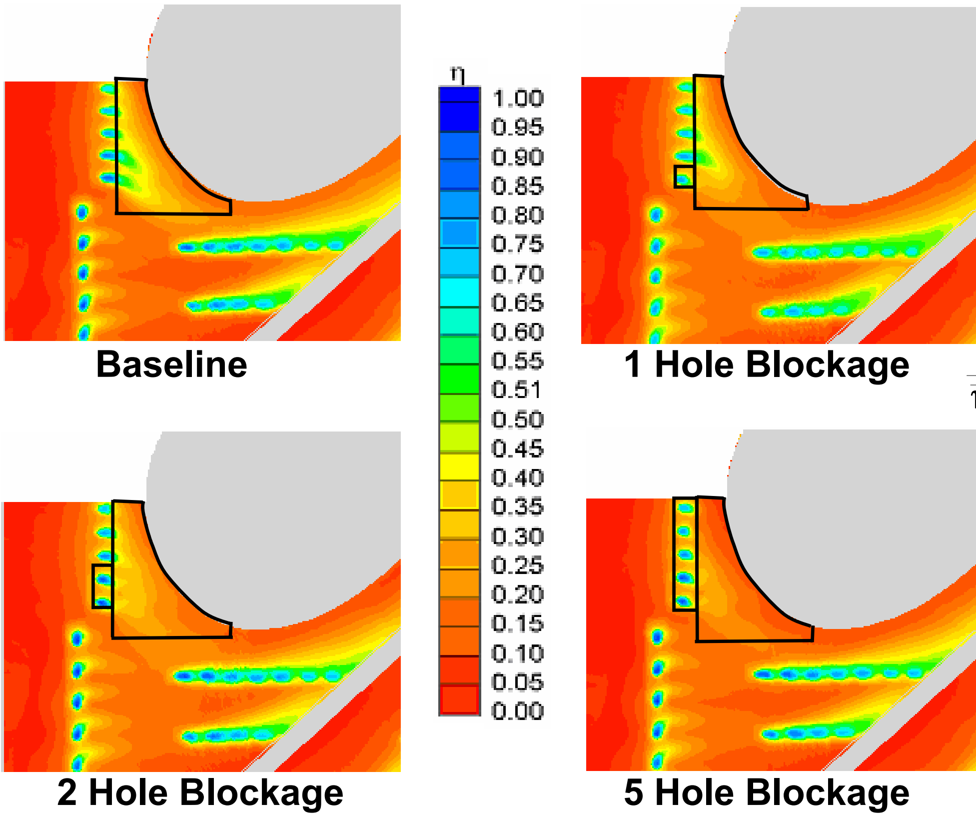
0.75% Upstream Slot; 0.5% Film-cooling hole; 0.2% Mid-passage gap; Deposit height – 0.8D

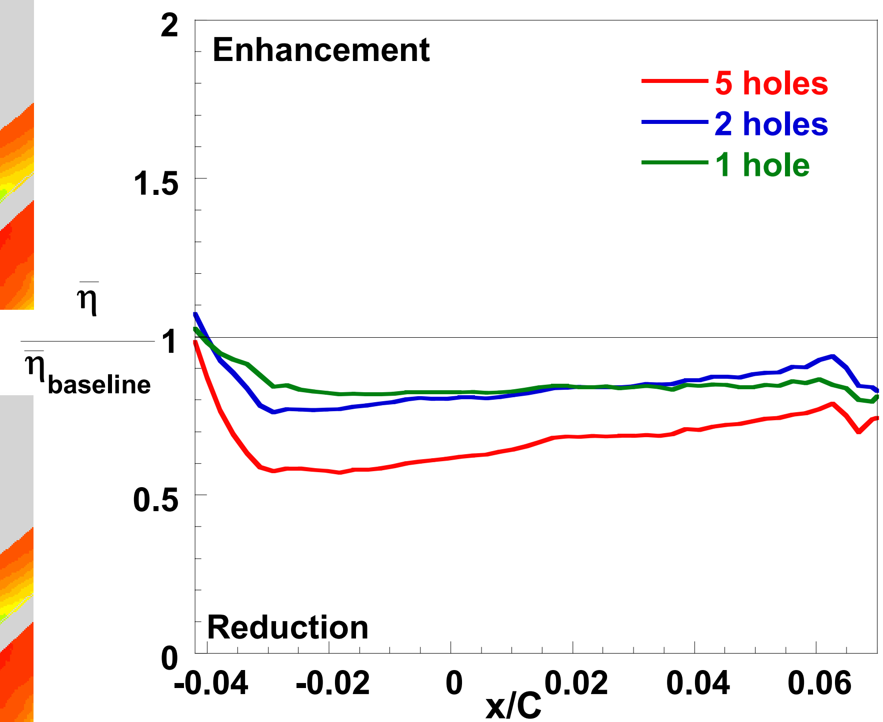


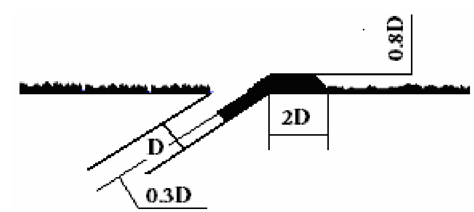


Blockage decreased cooling effectiveness in the stagnation region where blockage tends to occur

0.5% Film-cooling hole; 0.2% Mid-passage gap

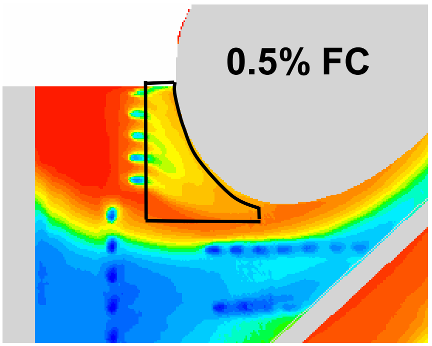




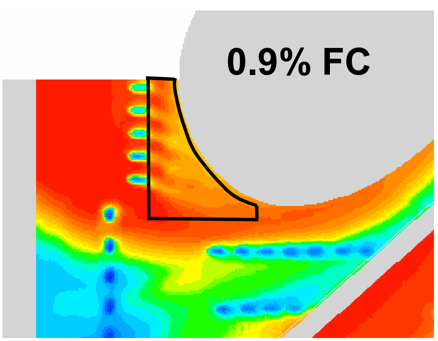


Spallation at higher blowing ratios had a greater degrading effect on effectiveness levels

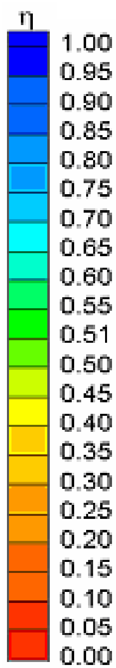
0.75% Upstream Slot; 0.2% Mid-passage gap

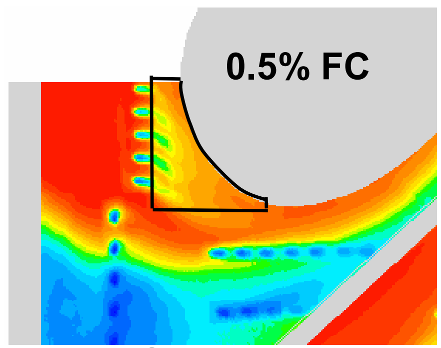


Baseline – No Spallation

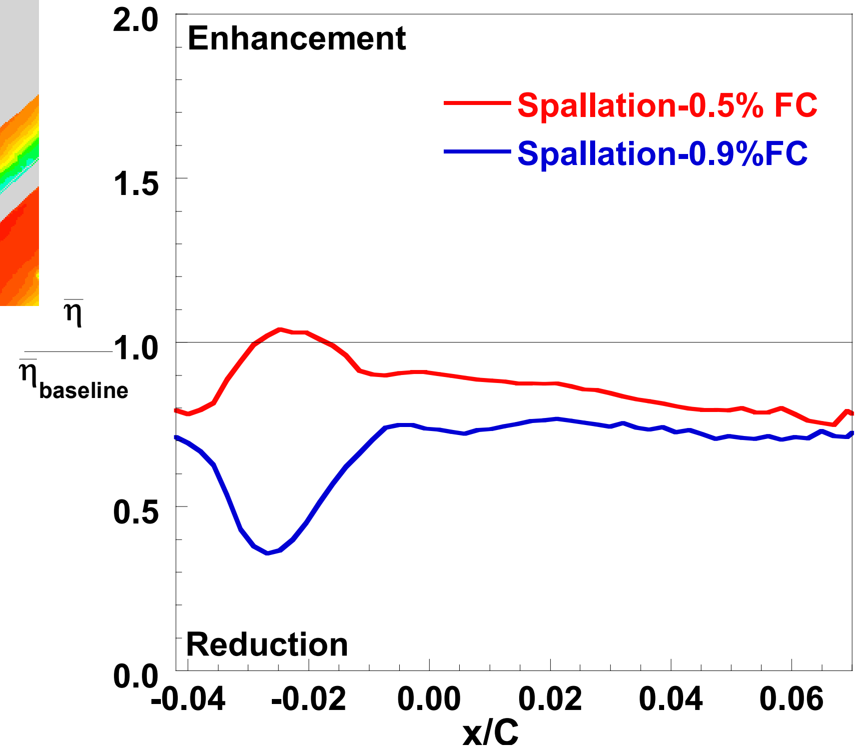


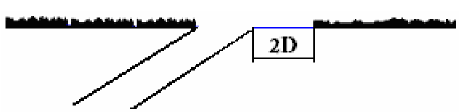
Spallation





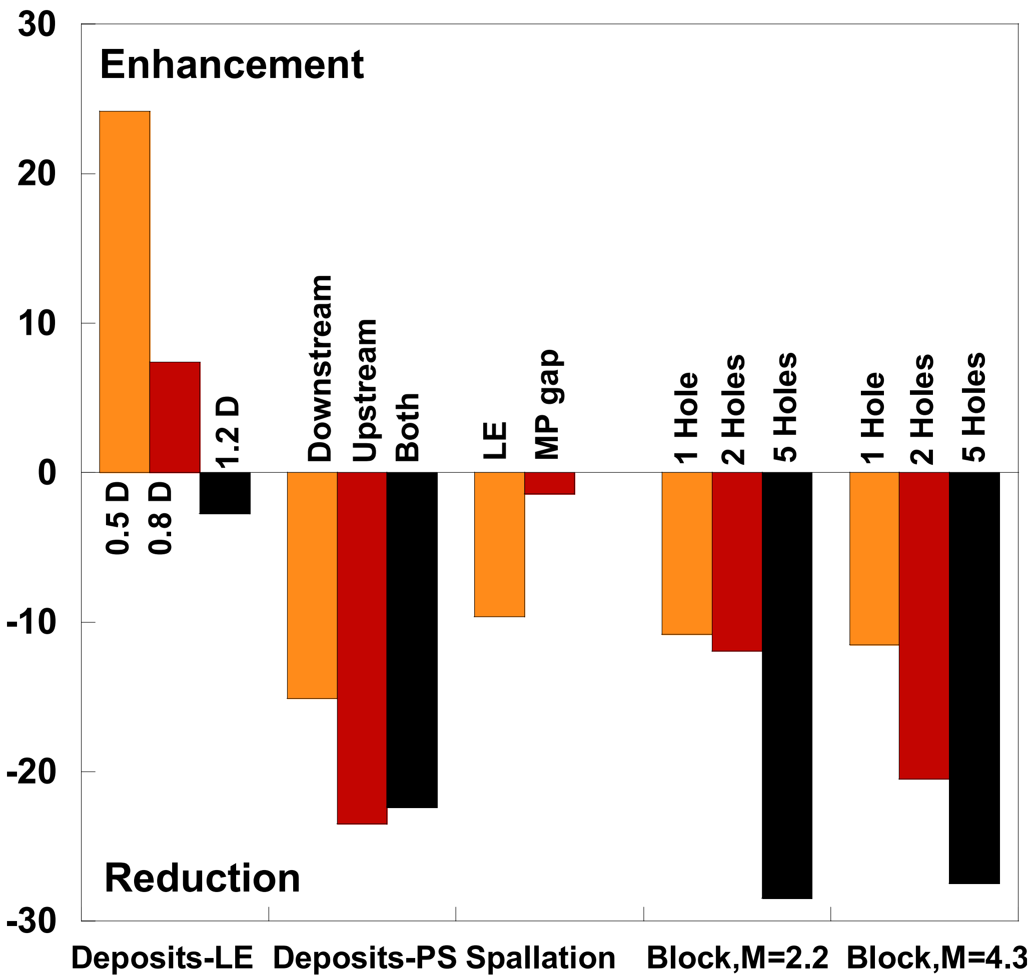
Spallation





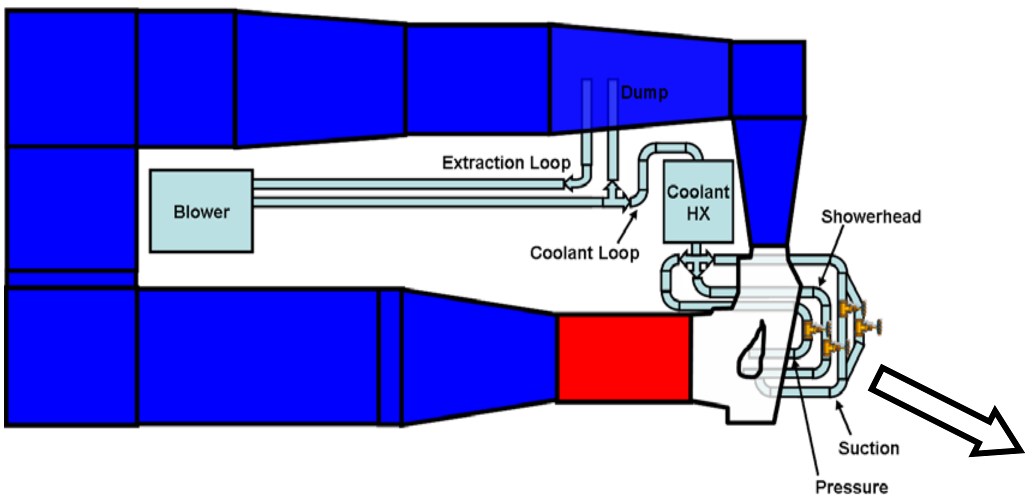
Film-cooling hole blockage resulted in the maximum reduction in area-averaged effectiveness

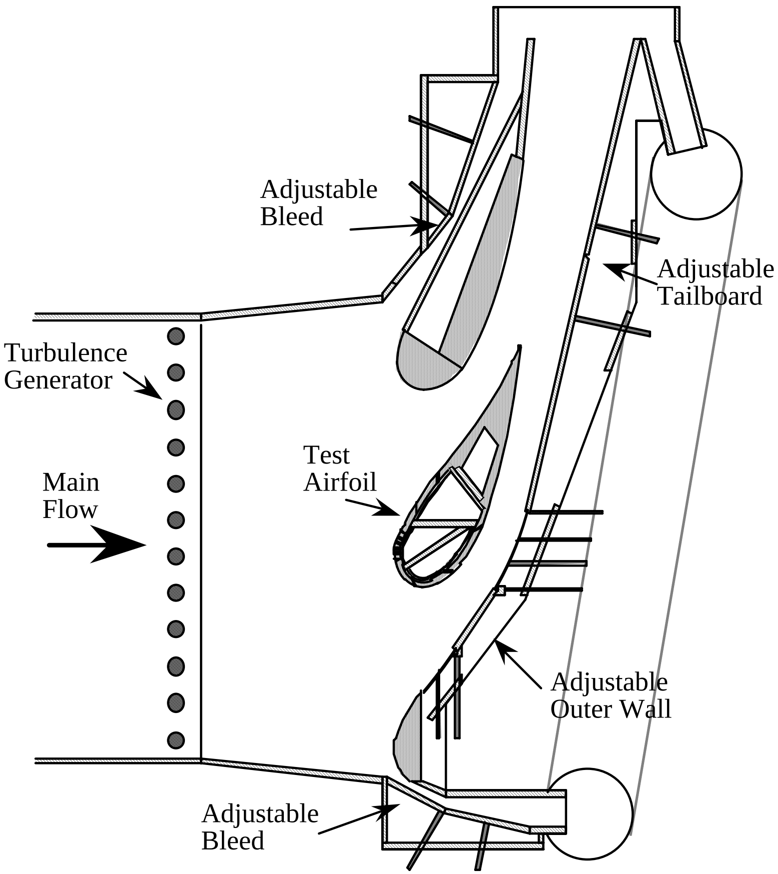
$$\%\bar{\bar{\eta}}_{Reduction} = \frac{\bar{\bar{\eta}} - \bar{\bar{\eta}}_o}{\bar{\bar{\eta}}_o}$$



LE – leading edge
PS – pressure side

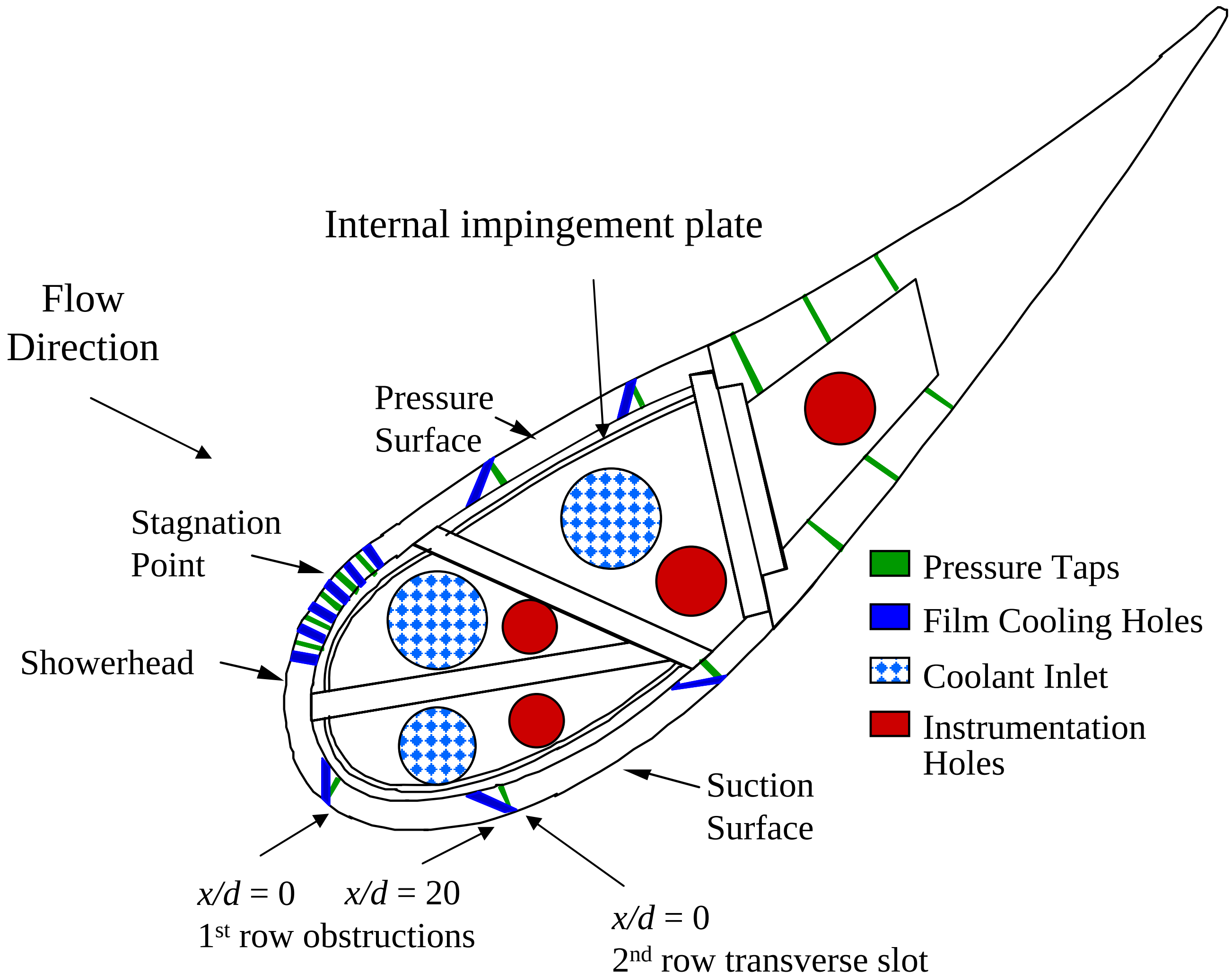
Test Facility



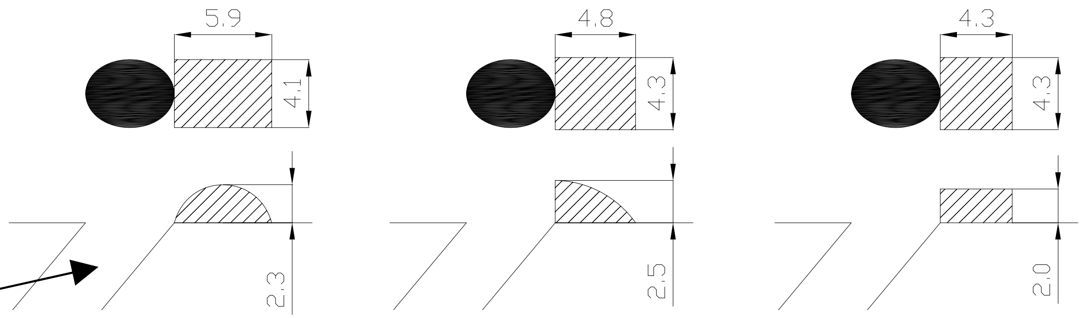


- Simulated Three Vane –Two Passage Linear Cascade
- Liquid nitrogen cooled secondary flow for *DR*
- Mainstream turbulence levels of Tu_∞ = 3.5% and 20%, Λ_f/d = 10

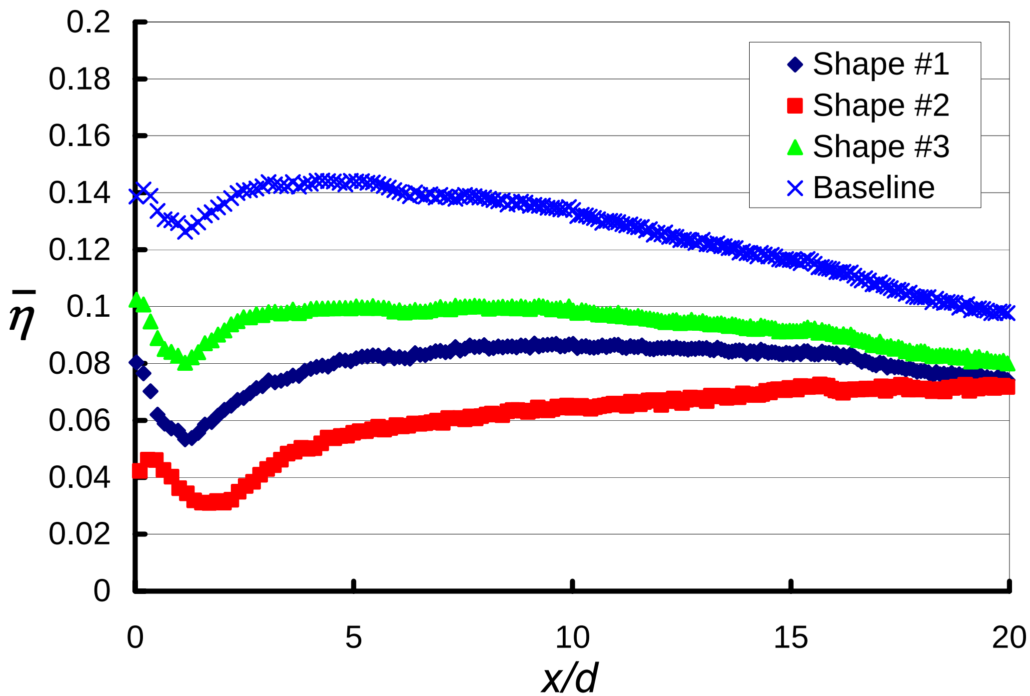
Test Section



Effects of Obstruction Shapes on Film Effectiveness

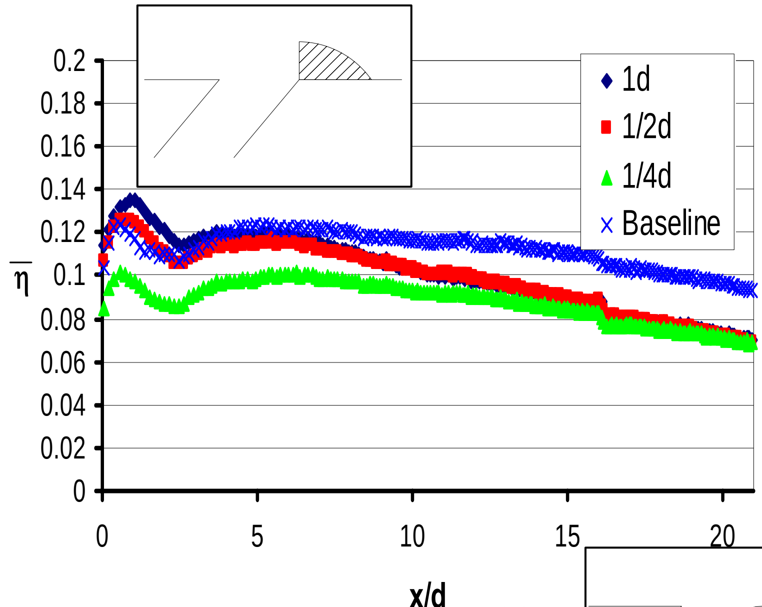


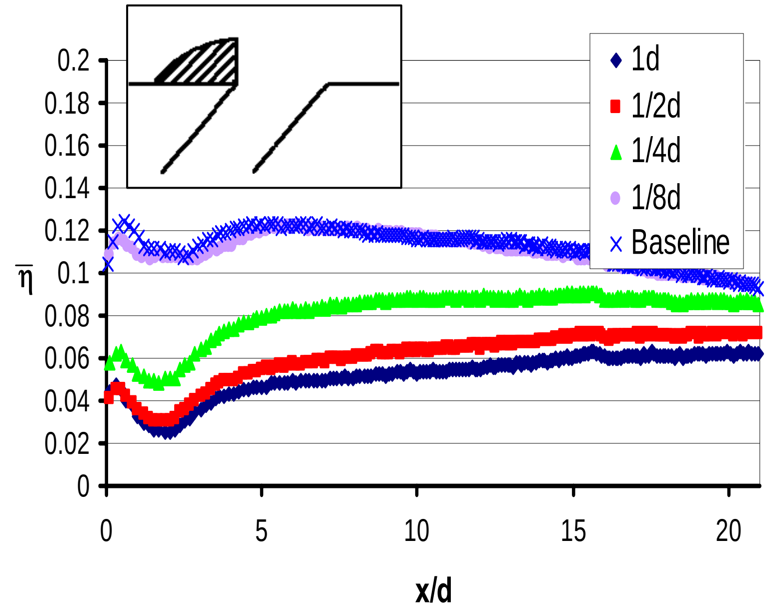
Coolant hole, 55º injection angle

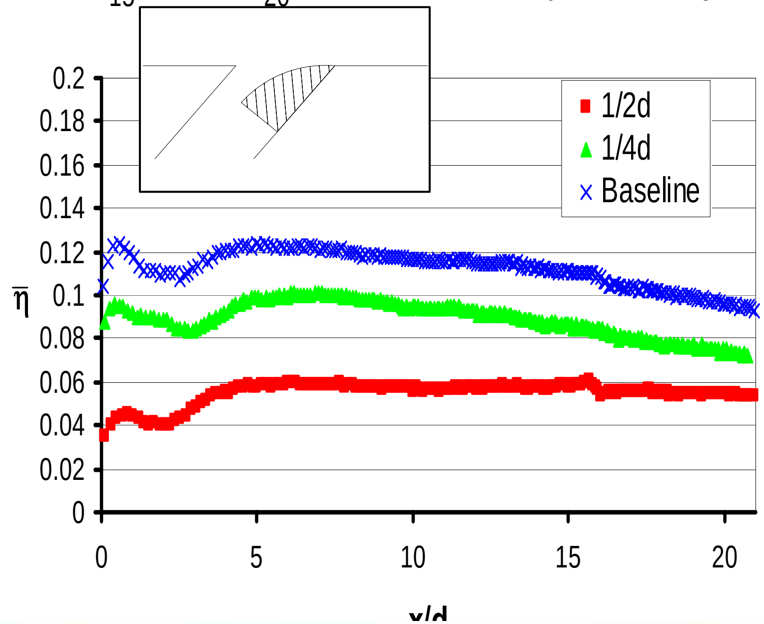


Film effectiveness for upstream positioning of obstructions

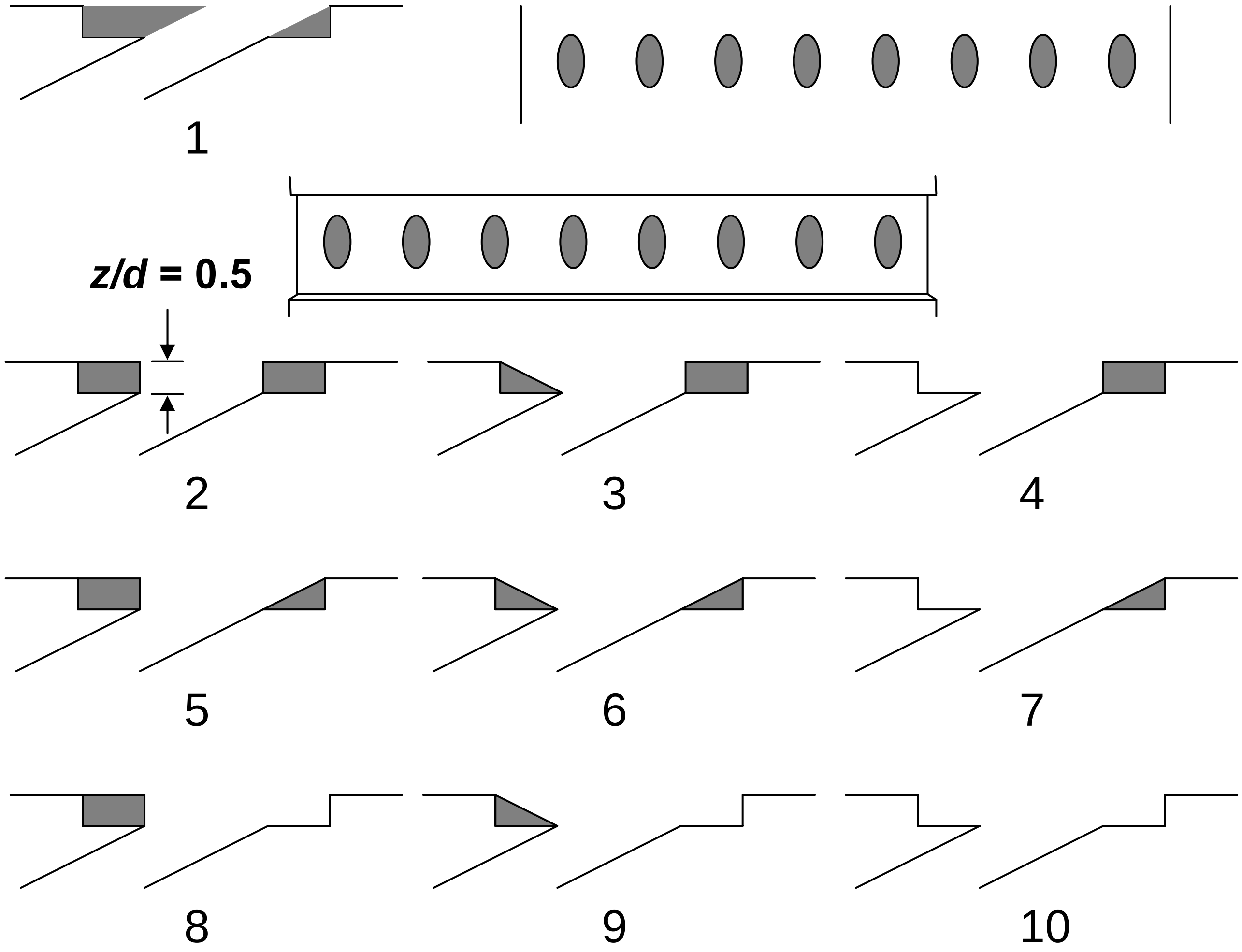
Effects of Obstruction Position and Size on Film Effectiveness



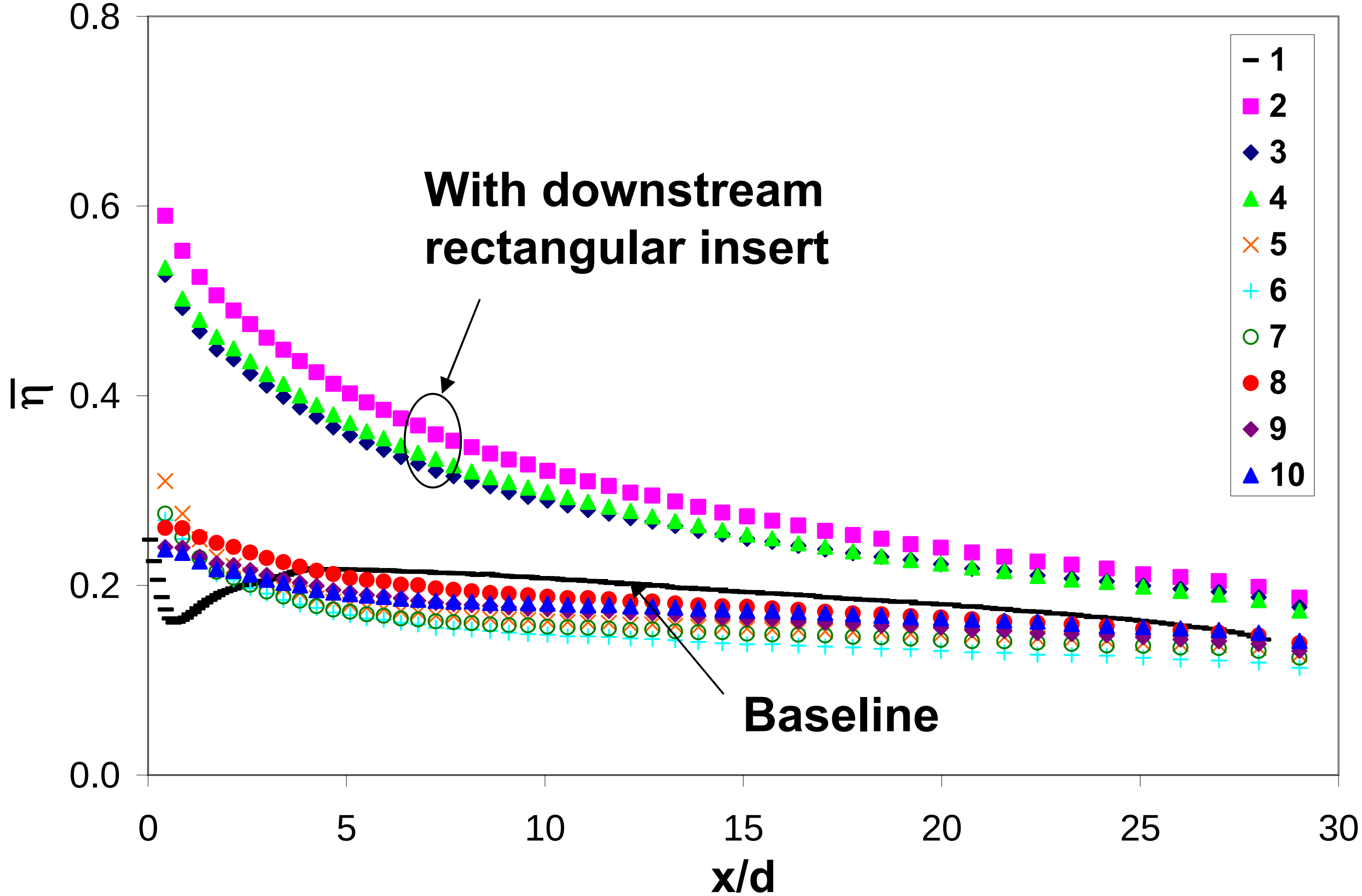




Trench Lip Configurations

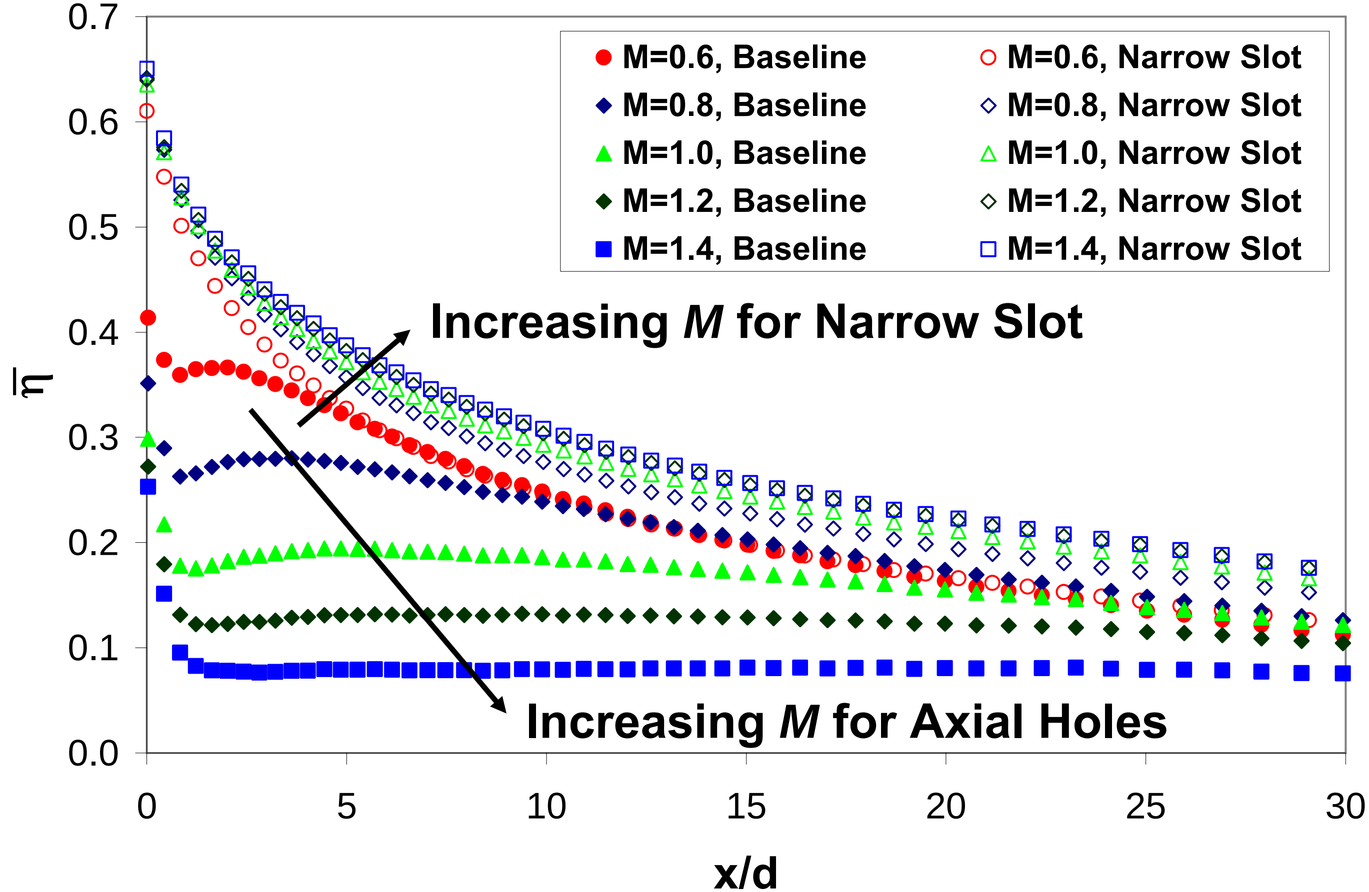


Laterally Averaged Adiabatic Effectiveness of Lip Configurations, *M* = 1.0



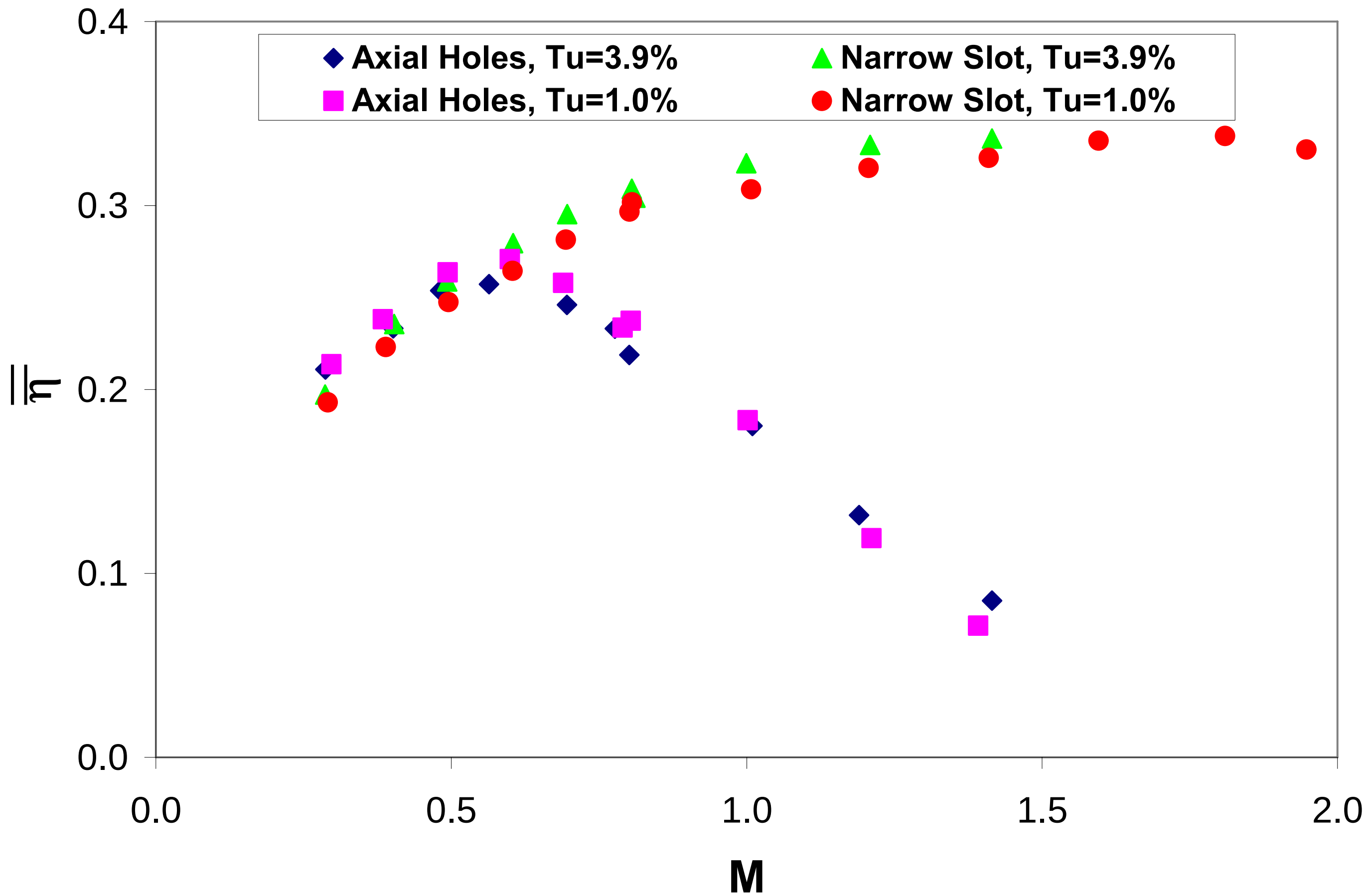
CRL

Comparison of Narrow Slot to Baseline Axial Holes

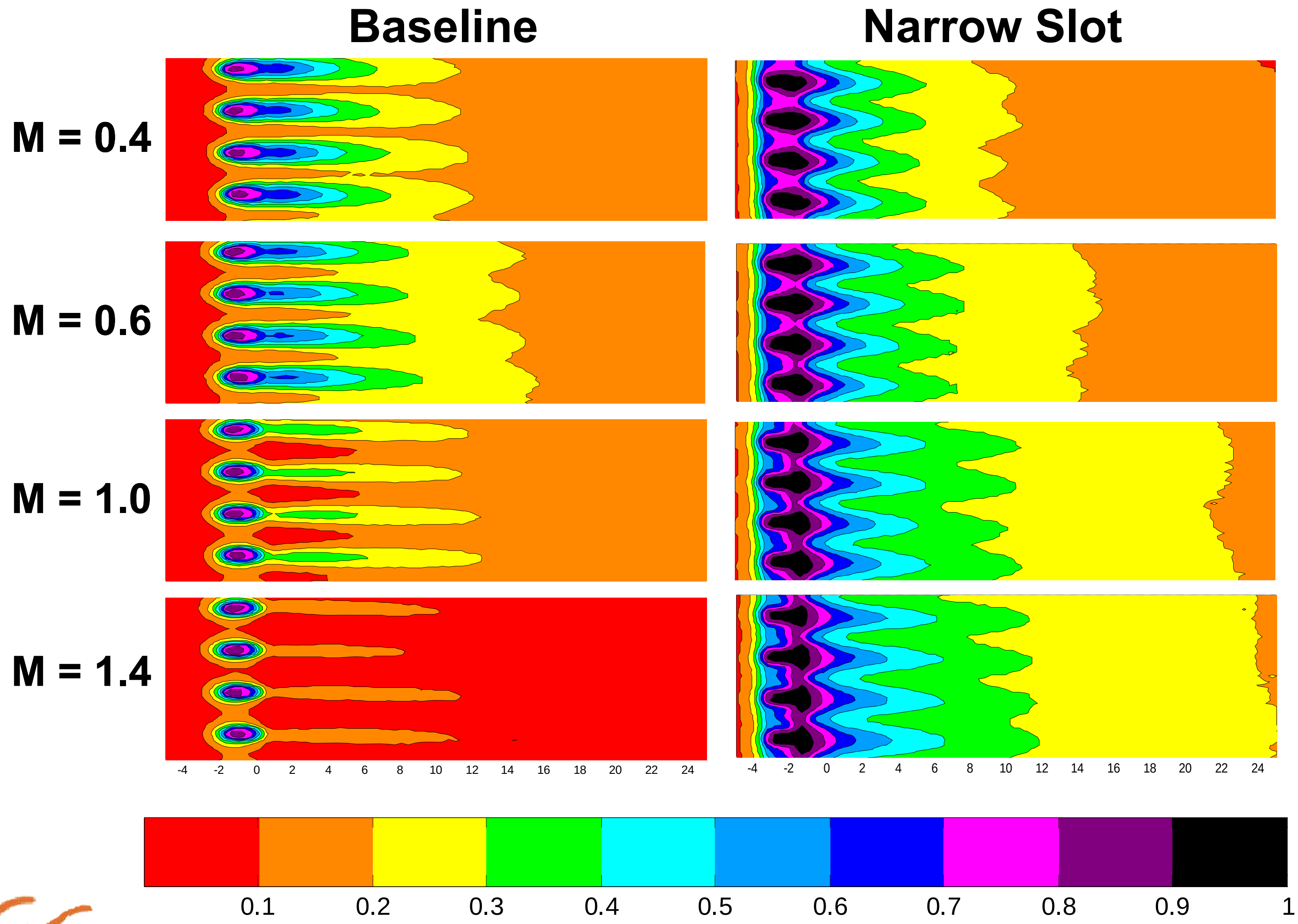


TCRL

Comparison of Narrow Slot to Baseline Axial Holes (Spatially Averaged Adiabatic Effectiveness)



Comparison of Spatial Adiabatic Effectiveness of Axial Holes and Narrow Slot



Summary

- Expansion and contraction of upstream slot widths showed varying coverage on endwall effectiveness
- Small depositions in the leading edge region of the endwall can improve cooling effectiveness while both hole blockages and spallation can reduce cooling effectiveness
- Testing of effects of obstructions to coolant holes have been completed and show significant degradation of film cooling performance, particularly for upstream obstructions
- An increase in adiabatic effectiveness due to an optimized transverse slot has been found. Testing the slot with a rough vane surface and obstructions will commence. The slot may help mitigate the negative effects of the roughness and obstructions.

Questions ?