Improving Durability of Turbine Components Through Trenched Film Cooling and Contoured Endwalls

Principal Investigator:

Prof. David G. Bogard

University of Texas at Austin

Graduate research assistant: **Todd Davidson**

Co-Principal Investigator:

Prof. Karen A. Thole

Pennsylvania State University

Graduate research assistant: **TBD**

UTSR Peer Review Workshop

October 20, 2010

Background image: [Hamed, A., Tabakoff, W., and Wenglarz, R., 2006]

Project Objectives

a. Evaluate the degradation of performance for trench and crater film cooling configurations when subjected to active deposition of contaminants. This will be done on simulated vane and endwall models.

b. Design improved trench or crater film cooling configurations that mitigate the degradation effects of deposition of contaminants.

c. Determine the overall cooling effectiveness (including conjugate heat transfer effects) with and without thermal barrier coatings for the vane and endwall.

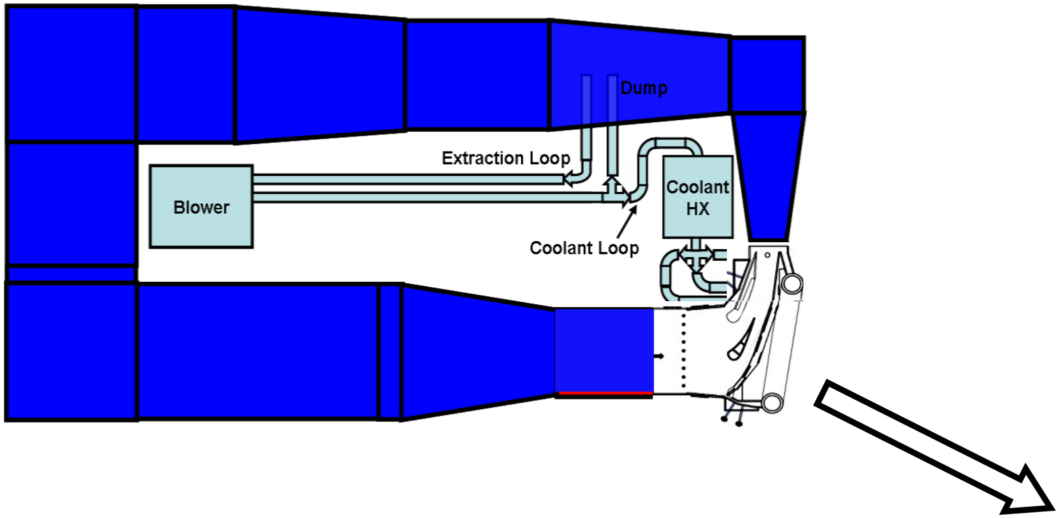
Project Objectives, continued

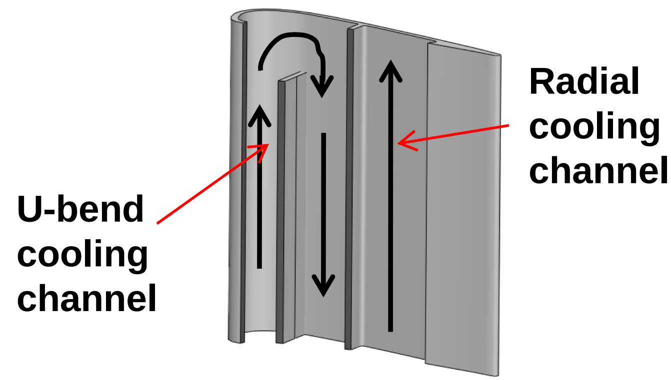
d. Develop the knowledge needed to design film cooling configurations on contoured endwalls.

e. Perform detailed velocity and thermal field measurements along the vane, endwall, and downstream wake, with and without film cooling, to provide benchmarks to evaluate CFD simulations.

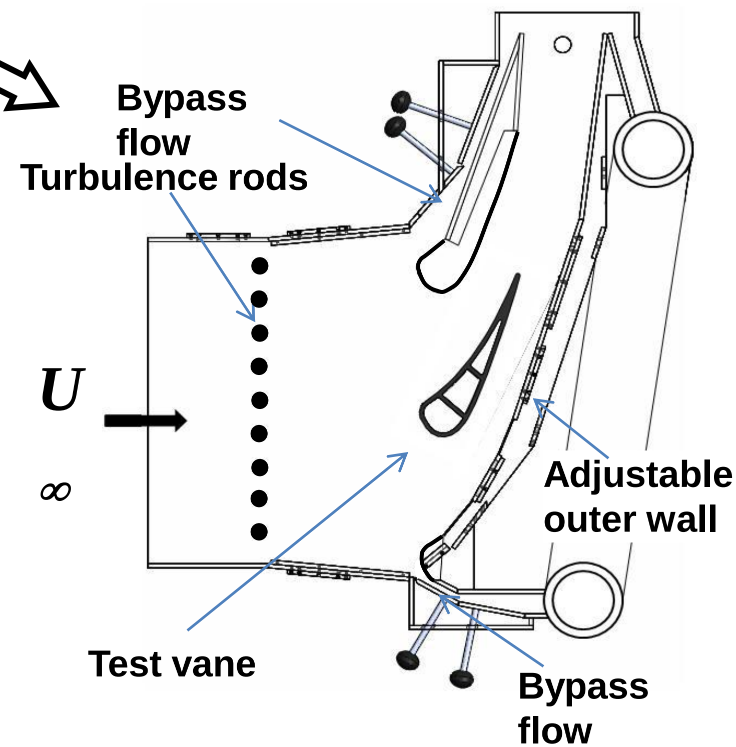
f. Develop improved cooling designs specifically for the vane-endwall junction including mitigation of deposition effects.

Simulated vane test facility at UT





Internal cooling configuration

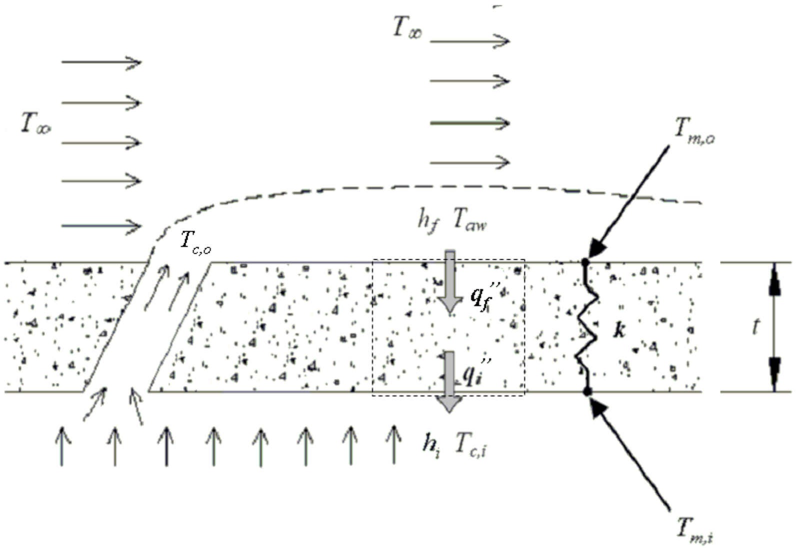


- Simulated Three Vane –Two Passage Linear Cascade
- Liquid nitrogen cooled secondary flow during overall effectiveness measurements
- Constant heat flux boundary condition on near adiabatic airfoil for heat transfer coefficient measurement
- Surface temperatures measured using FLIR P20 and P25 IR cameras

Technical Approach: use matched Biot number models to obtain overall effectiveness which includes internal cooling effects

Heat transfer through the wall:

$$q_0'' = \frac{T_{aw} - T_{c,i}}{\frac{1}{h_f} - \frac{t}{k} - \frac{1}{h_i}}$$



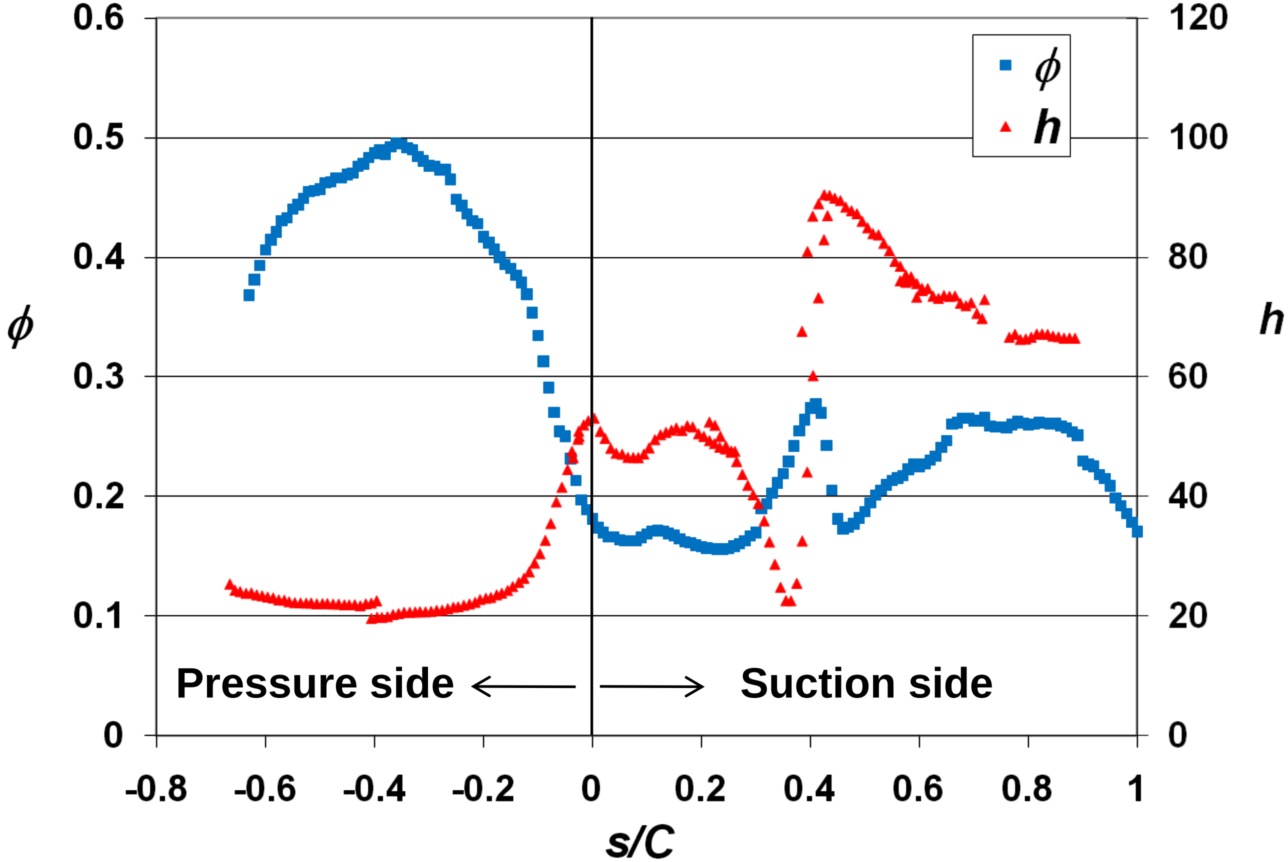
Overall effectiveness:

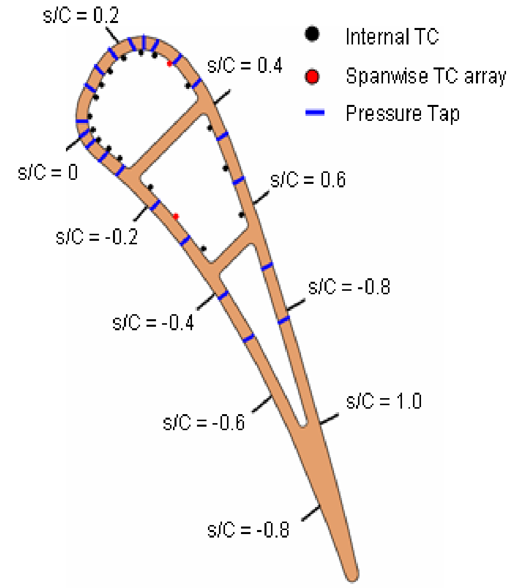
$$\phi = \frac{T_\infty - T_w}{T_\infty - T_{ci}} = \frac{1 - \eta}{1 + Bi + \frac{h_f}{h_i}} + \eta$$

Experimental model needs to match Bi and h_f / h_i

A baseline was established by measuring ϕ with internal cooling only.

From Dees' dissertation (2010)



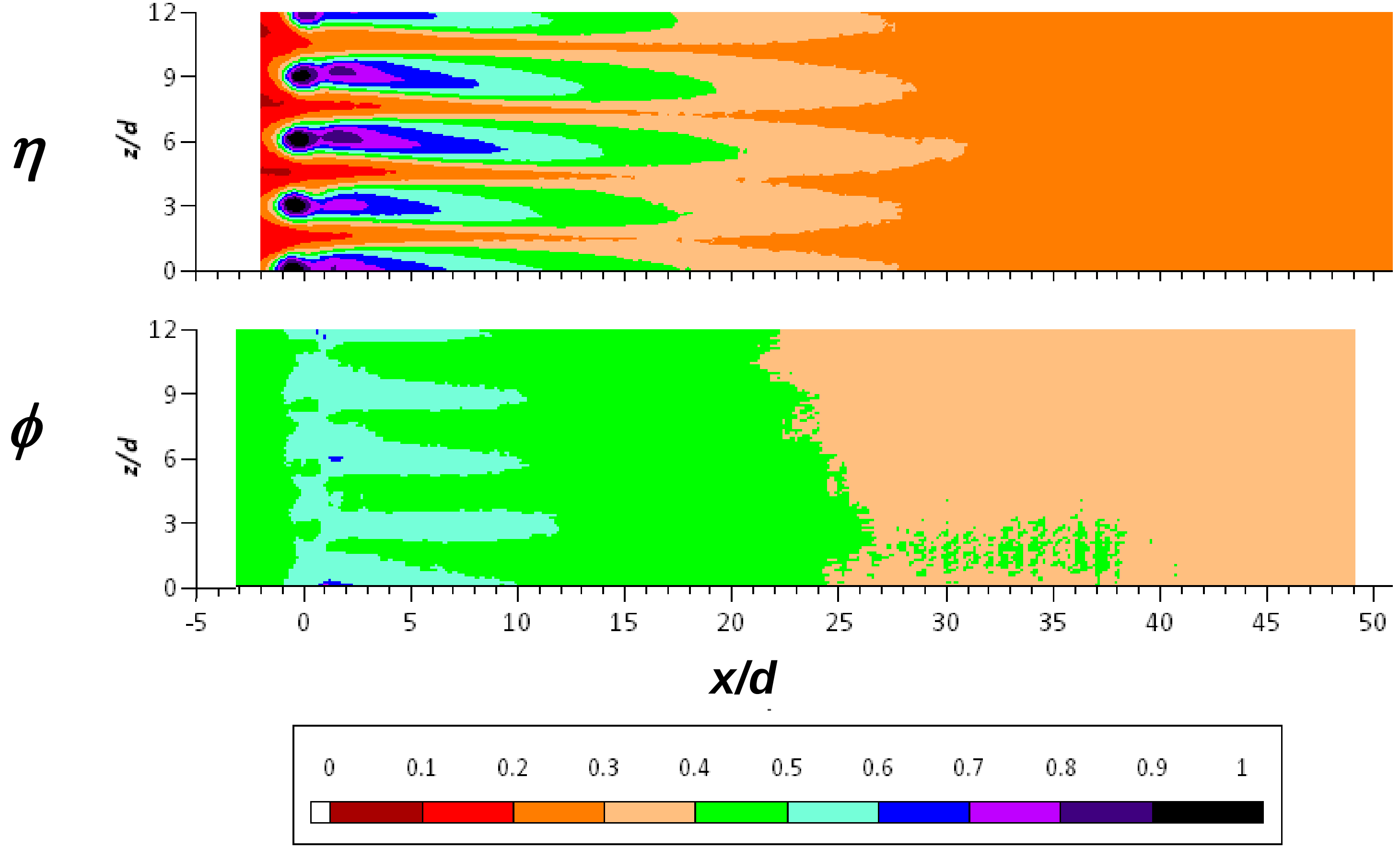


Variation in ϕ was found to correlate with variation in external heat transfer coefficient.

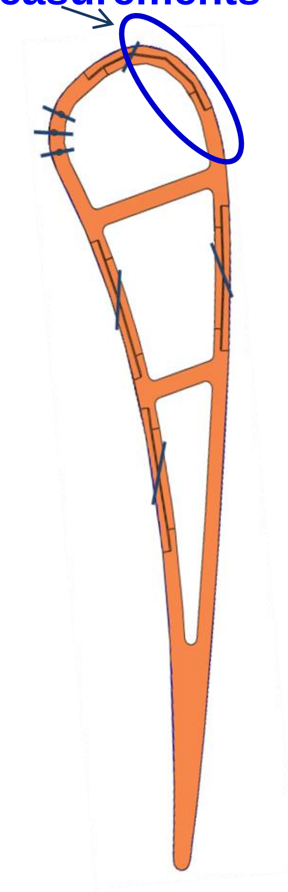
TTCRL

Comparison of η *and* ϕ contours with film cooling shows redistribution of localized cooling by coolant jets

From Dees' dissertation (2010)



Region of measurements

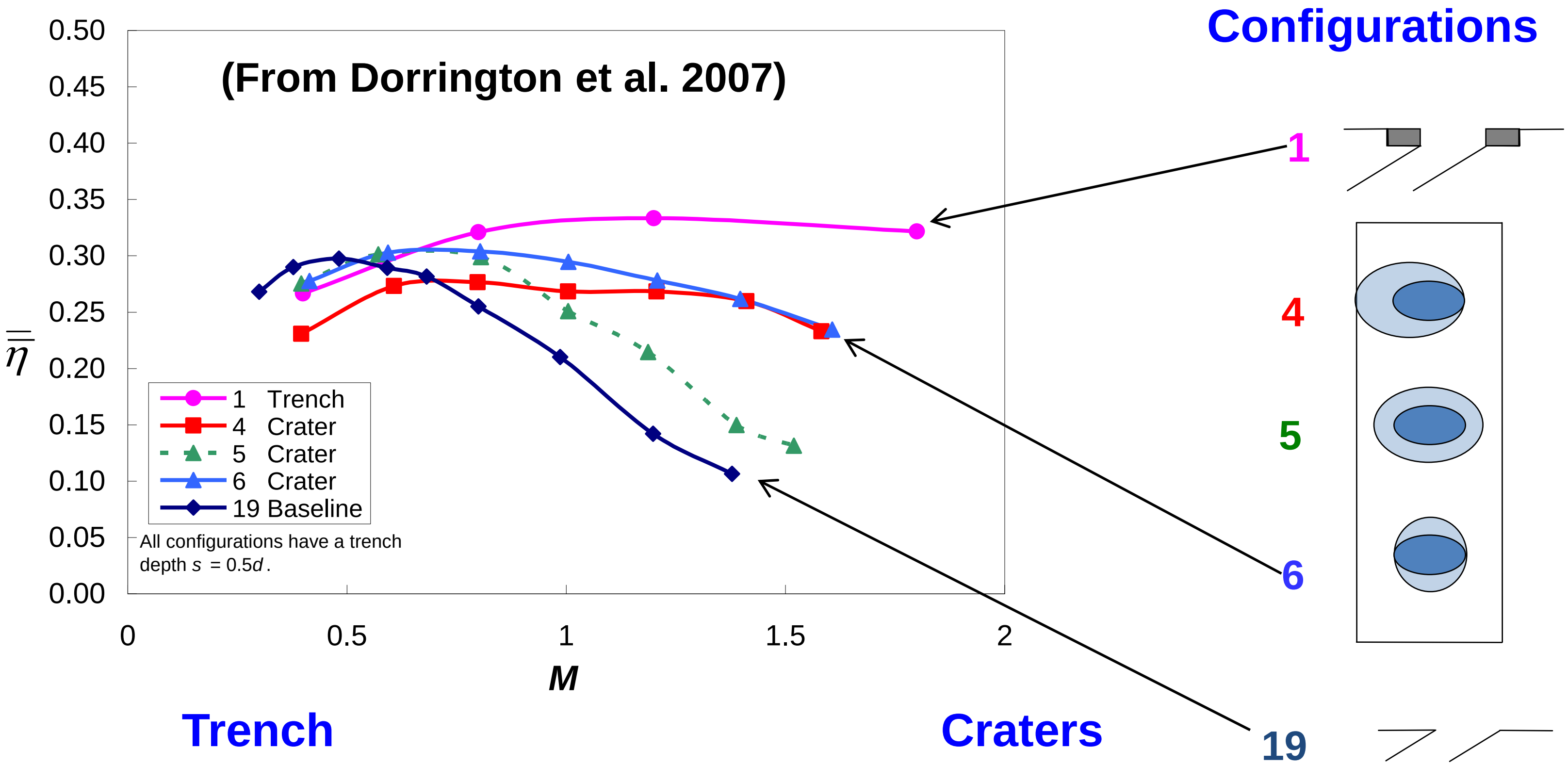


$$\eta = \frac{T_{aw} - T_\infty}{T_{c,e} - T_\infty}$$

$$\phi = \frac{T_w - T_\infty}{T_{c,i} - T_\infty}$$

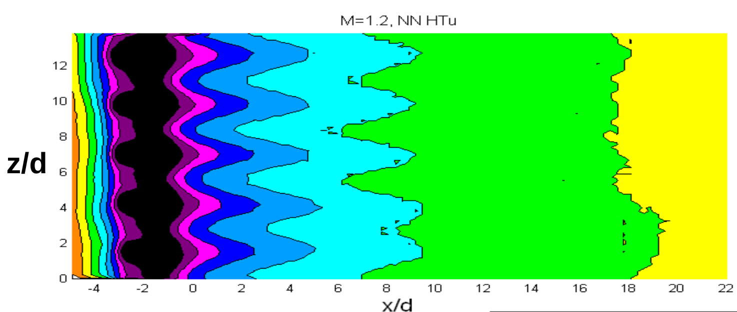
TTCRL

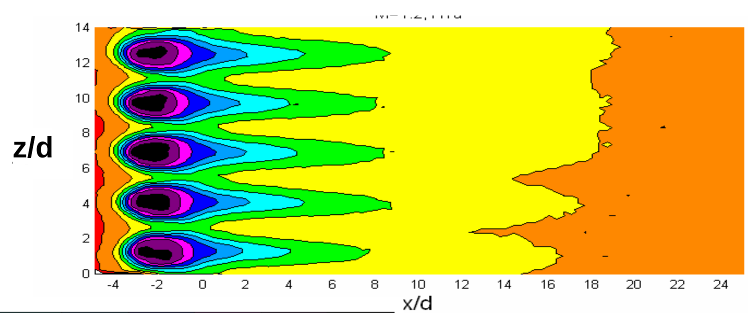
This study will evaluate trench and crater film cooling configurations

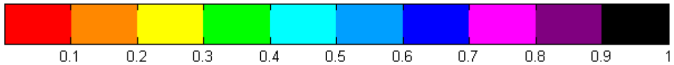


Trench

Craters

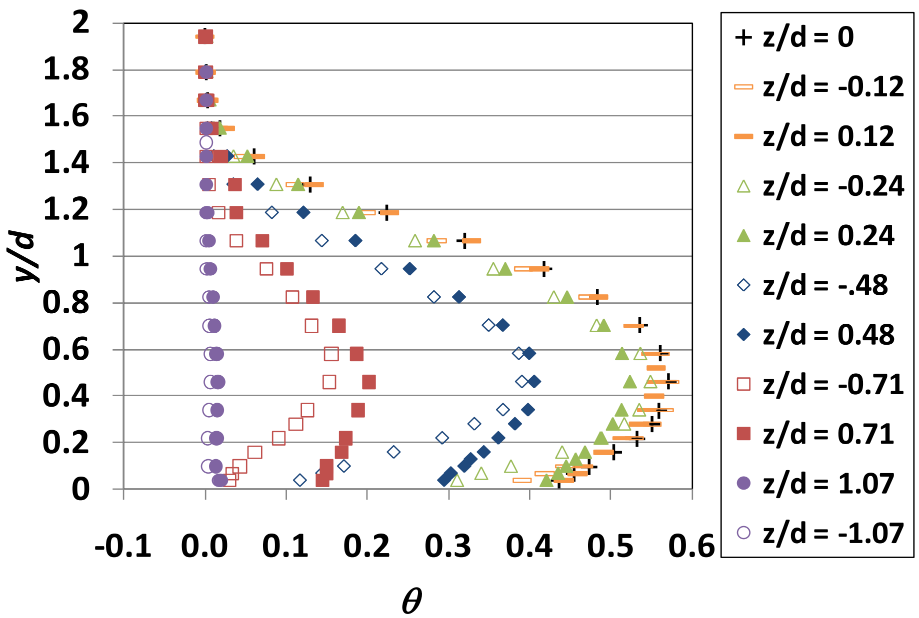






Thermal field measurements will be an important part of this study to show coolant jet details and conjugate heat transfer effects

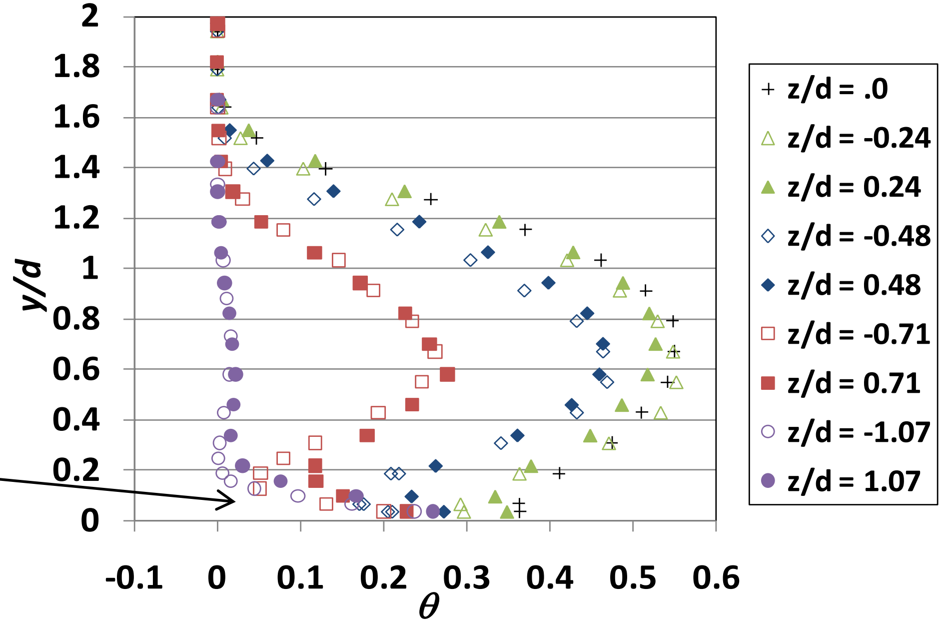
Adiabatic wall



From Dees' dissertation (2010)

I = 0.75, x/d = 5

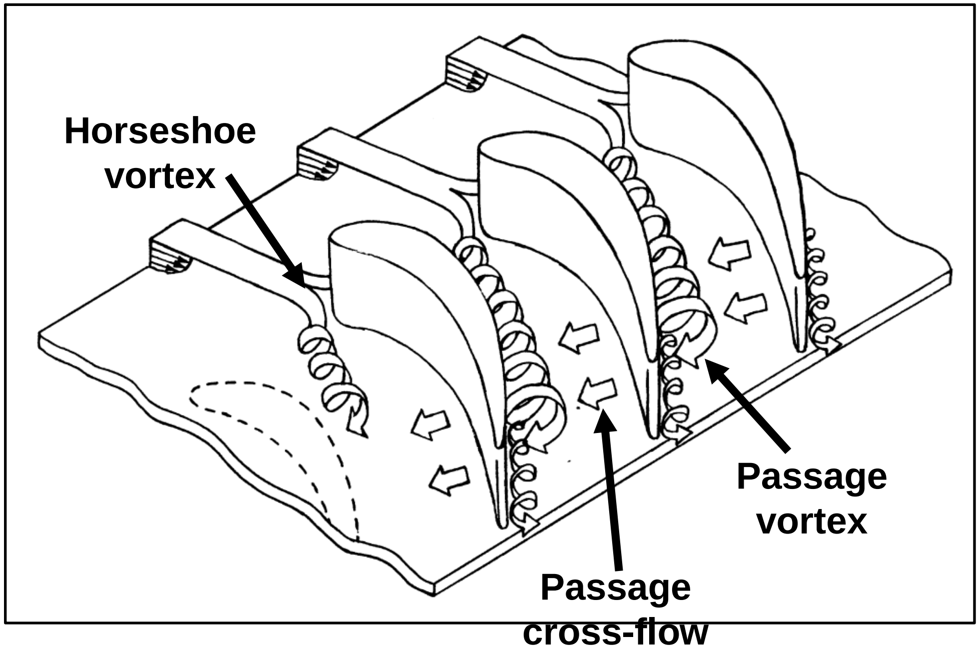
Conducting wall



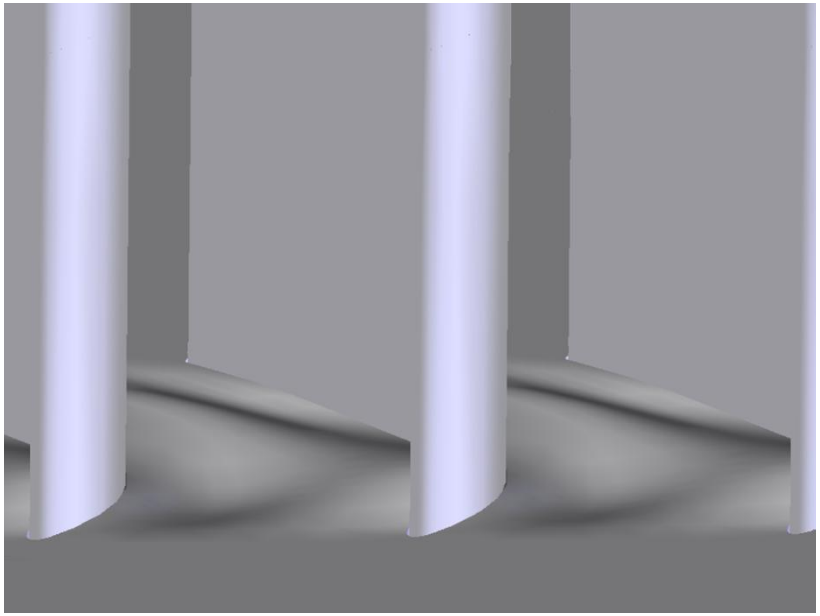
Note thermal boundary layer development

The objective of our studies is to understand the effect of deposition on non-axisymmetric contoured endwalls

Langston [1980]

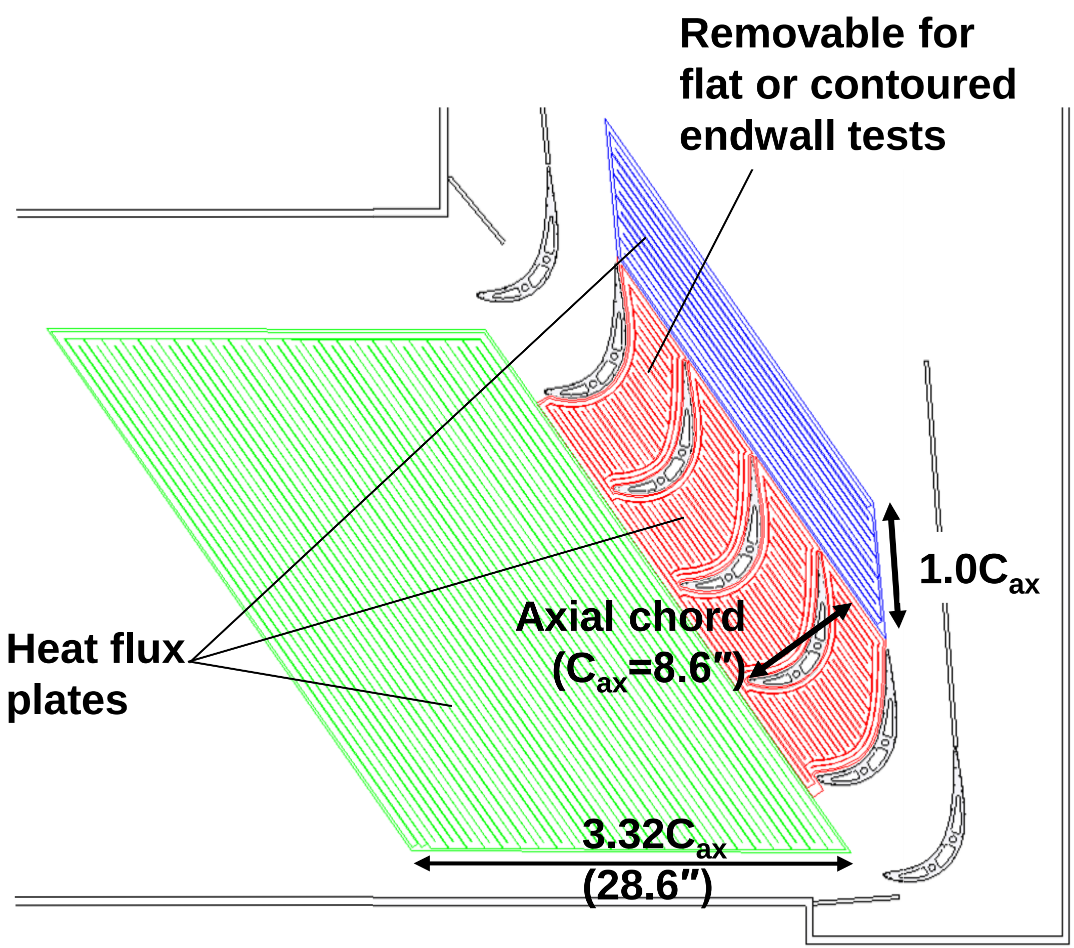


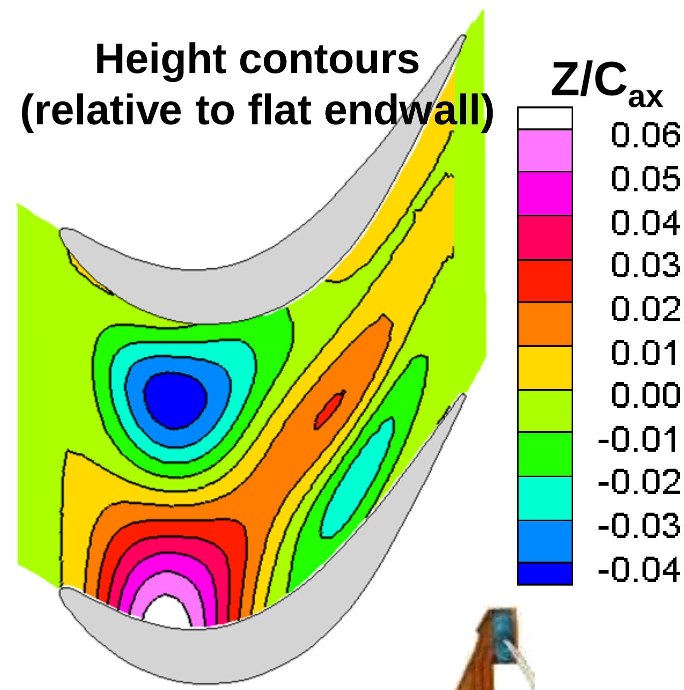
Contoured endwall

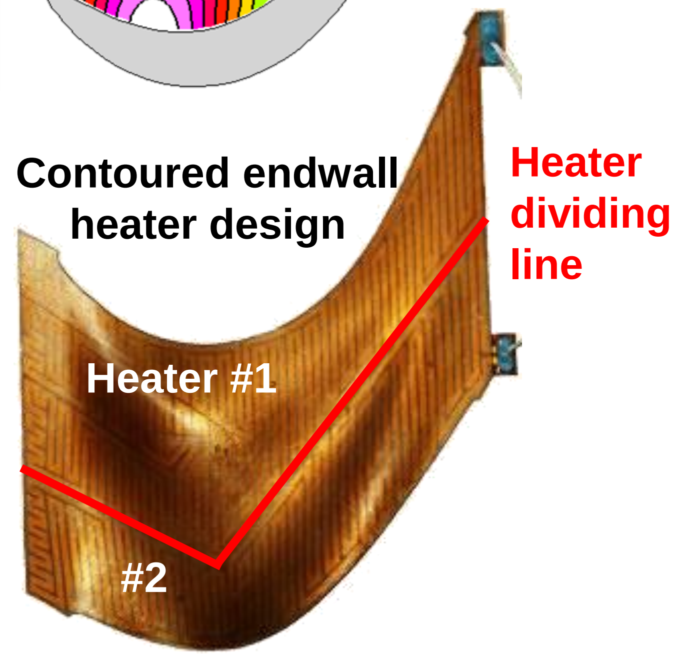


Do deposits adversely affect heat transfer and film cooling with contoured endwalls?

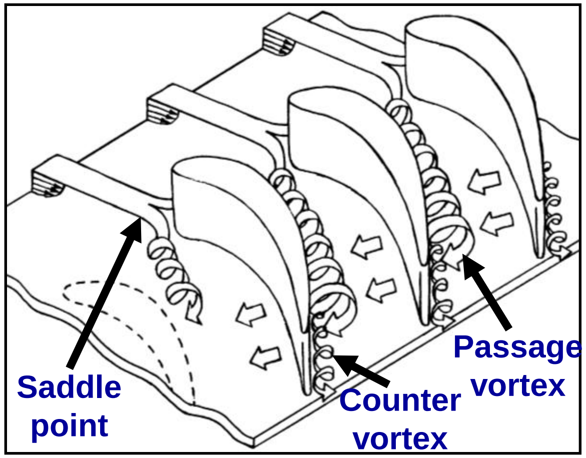
A novel heater design was developed for contoured endwalls to allow it to conform to the surface



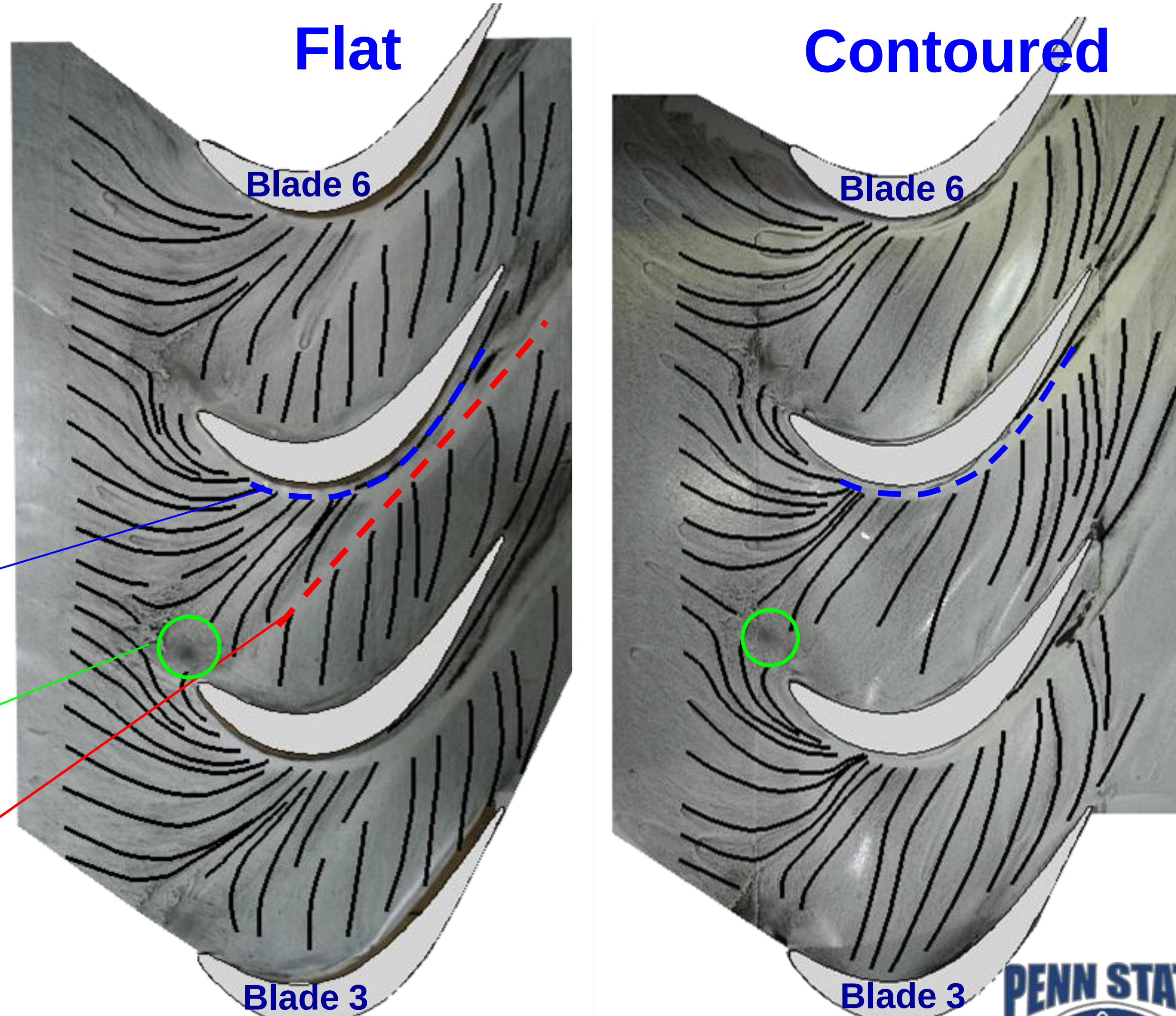




Oil flow visualization for the contoured endwall did not show a scoured region caused by the passage vortex

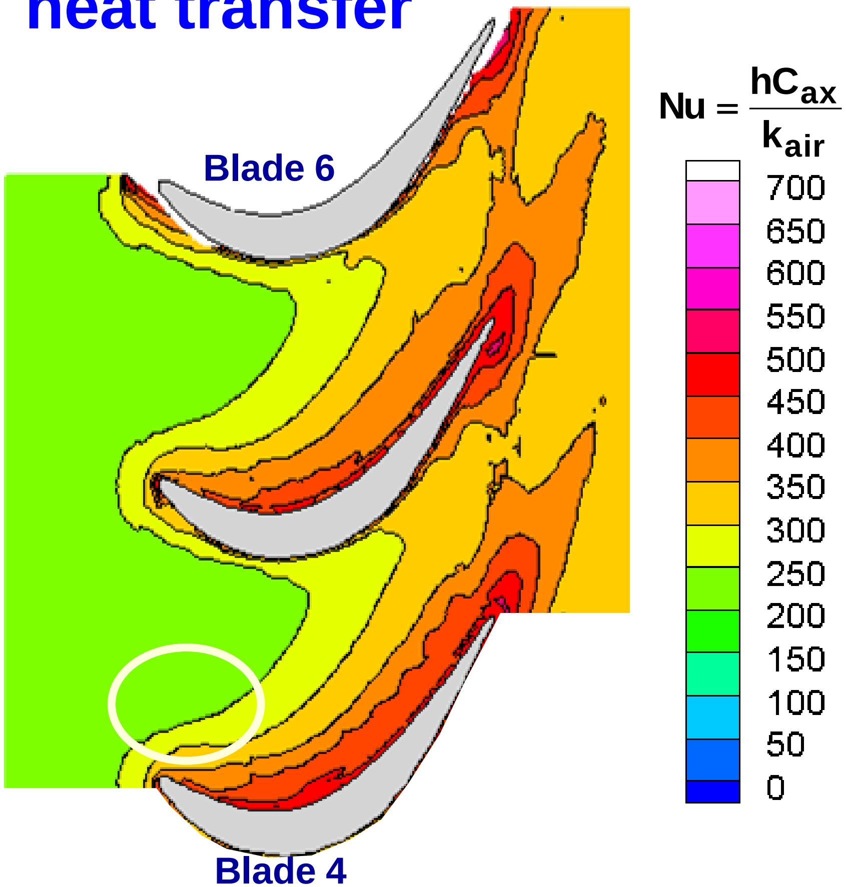


Langston [1980]

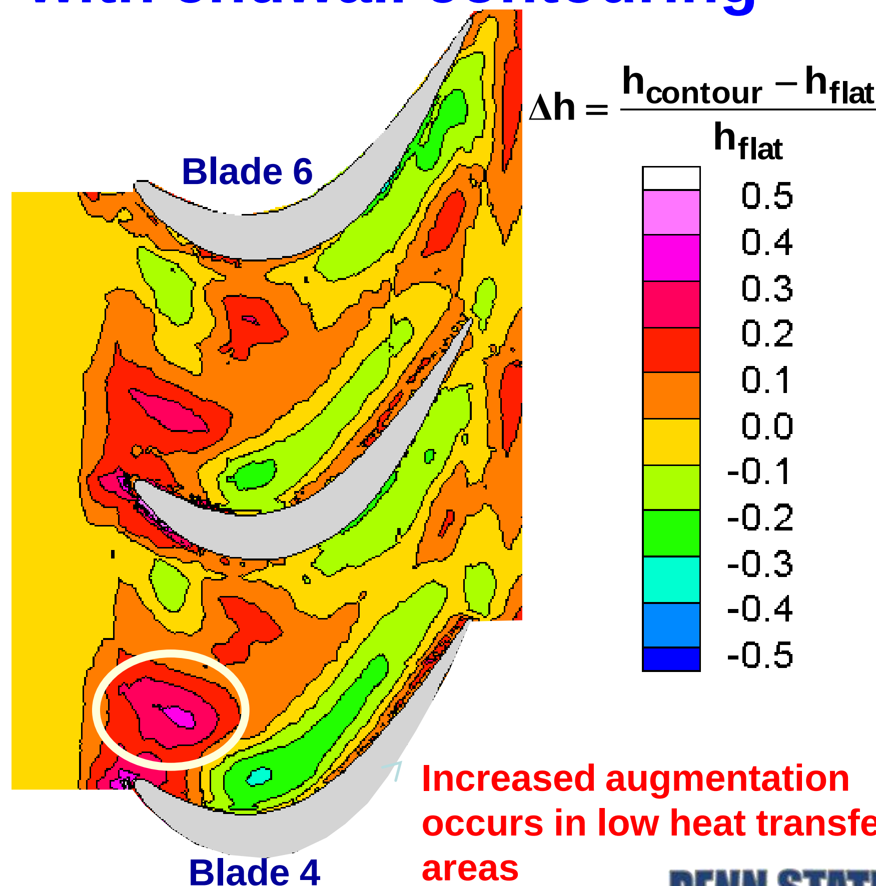


Endwall contouring reduced heat transfer by 25% in the region of high heat transfer near the pressure side

Flat endwall heat transfer

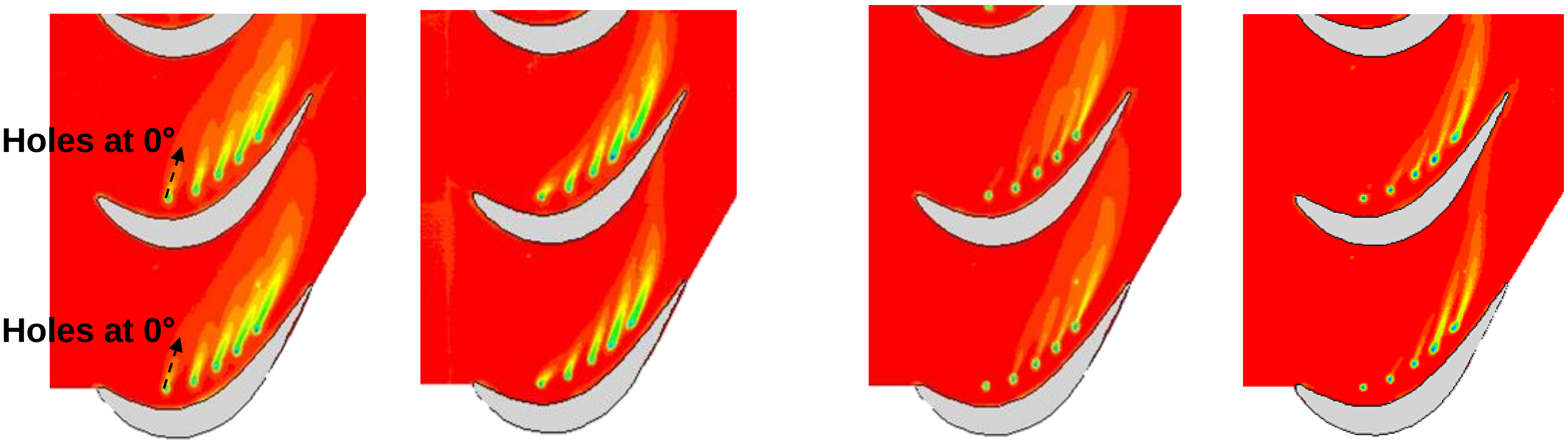


Heat transfer augmentation with endwall contouring



Coolant does not sweep across the passage as well for the contoured endwall, compared to the flat endwall

Flat	Contoured	Flat	Contoured
$\overline{M_{ideal}}=1.0$	$\overline{M_{ideal}}=1.0$	$\overline{M_{ideal}}=2.0$	$\overline{M_{ideal}}=2.0$



$$M_{ideal} = \frac{\rho_j U_{j,ideal}}{\rho_\infty U_\infty} = \sqrt{\frac{\rho_j}{\rho_\infty}\left(\frac{P_{plen} - P_{s,endwall}}{P_{tot,in} - P_{s,endwall}}\right)}$$

$$\overline{M_{ideal}} = \sum_k \left(M_{ideal}\right)_k \Big/ k$$

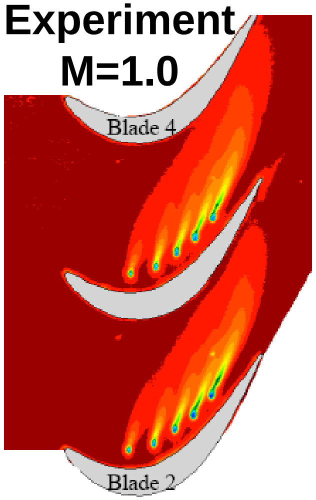
j=coolant
k=individual hole

PSU will investigate the effects of deposition on film-cooling with endwall contouring

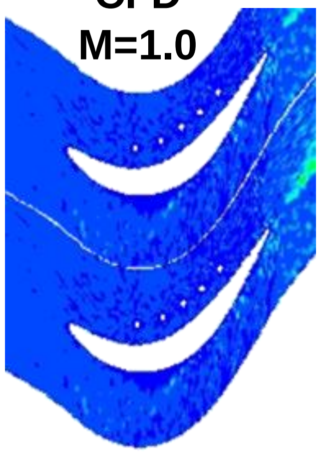
Flat Endwall

Contoured Endwall

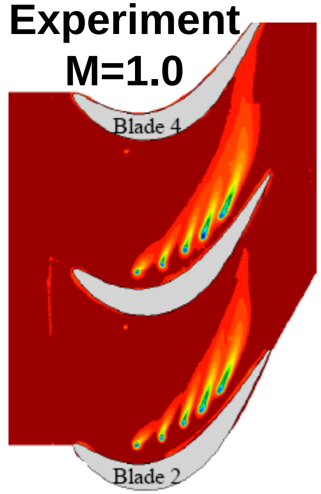
Baseline Experiment M=1.0



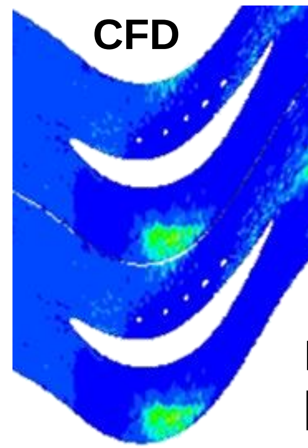
CFD M=1.0



Baseline Experiment M=1.0



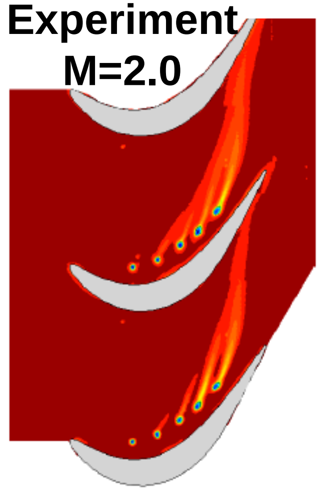
CFD

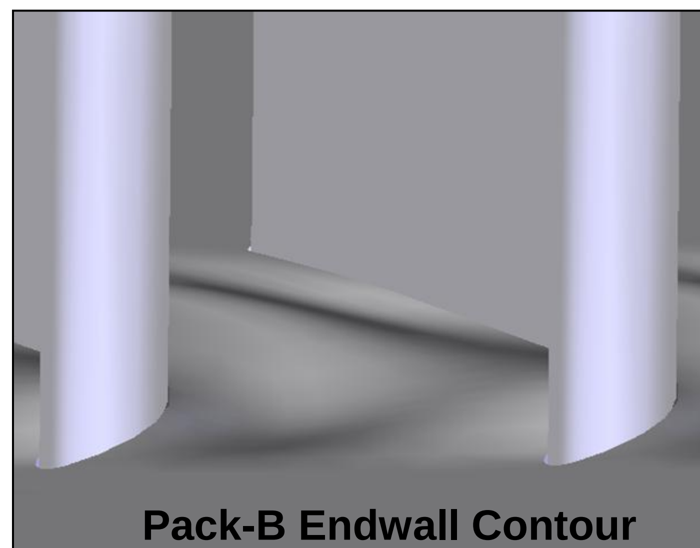


Experiments by [Lynch et al., 2010]

Baseline Experiment M=2.0

Baseline Experiment M=2.0





Pack-B Endwall Contour

Phases and Deliverables for the project

Phase	UT Deliverables	Penn State Deliverables
Phase I Planning and Project Coordination	• Agreed upon plan for frequency and mode for communication • Agreed upon test plan for initial phases of work	
Phase II - Deposition with No Film-Cooling	•Identify where vane deposits occur • Vane heat transfer with deposits • Measurements of aero-thermal BL	• Conducting contoured endwall model •Identify where endwall deposits occur • Contoured endwall heat transfer with deposits • Measurements of aero-thermal BL
Phase III - Deposition with Trenched Film-Cooling on Vane and Contoured Endwall	• η and ϕ with trenched holes on vane •Evaluation of new trench / TBC design for vane	• η and ϕ for film-cooling on a contoured endwall •Evaluation of trenched film-cooling on contoured endwall
Phase IV - Optimized Hole/Trench on Vane and Contoured Endwall	• Effectiveness measurements for an optimized hole shape / trench for vane • Results from numerous hole shape / trench hole designs for the vane	• Effectiveness measurements for the optimal hole shape / trench for contoured endwall •Measurements of aero-thermal boundary layers
Phase V - Mating of Optimized Hole/Trench on Contoured Endwall	• Measurements of aero-thermal BL's for hole shape / trench on vane • Measurements in vane wake with optimal hole shape / trench	• Evaluation of mating between vane and contoured endwall with overall effectiveness measurements using optimized hole shape / trench

Questions?

TTCRL

PENN STATE ExCCL

Background image: [Hamed, A., Tabakoff, W., and Wenglarz, R., 2006]