Aerothermal Effects of Interfacial Leakage and Film Cooling Schemes with Endwall and Leading Edge Contouring

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Project Awarded (5/1/2002, 36 months)

$459,007 Total Contract Value ($430,619 DOE)

Gas Turbine Technology Needs and Project Objectives

- Improved performance and reliability
  - More effective cooling of turbine first stage passage
    - Improve schemes for injection of endwall coolant
    - Realize cooling benefits of leakage flows
    - Understand effects of component misalignment
  - Reduced secondary flows
    - Improve with endwall axial contouring and airfoil/endwall fillets
    - Realize benefits of reduced secondary flows on film cooling effectiveness
    - Record the effects of film cooling on secondary flow
- Less engineering time/cost to produce designs
    - Enhance closure model for the heat/mass transfer analogy
    - Experimental support of CFD model development

Approach – Measurement of the following (by year) y1 y2 y3

	y1	y2	y3
Qualifying data for test facilities	x		
Aerodynamic losses		x	
Effects of leading edge/corner fillets on mass transfer		x	
Aerodynamic losses with steps on a contoured endwall			x
Heat transfer with steps and gaps on the contoured endwall		x	x
Mass transfer coeffs. with a step ahead of the blade row			x
Film cooling effectiveness with steps and gaps - contoured			x
Film cooling effectiveness in the straight endwall rotor			x
Documentation of results in conference and journal papers		x	x

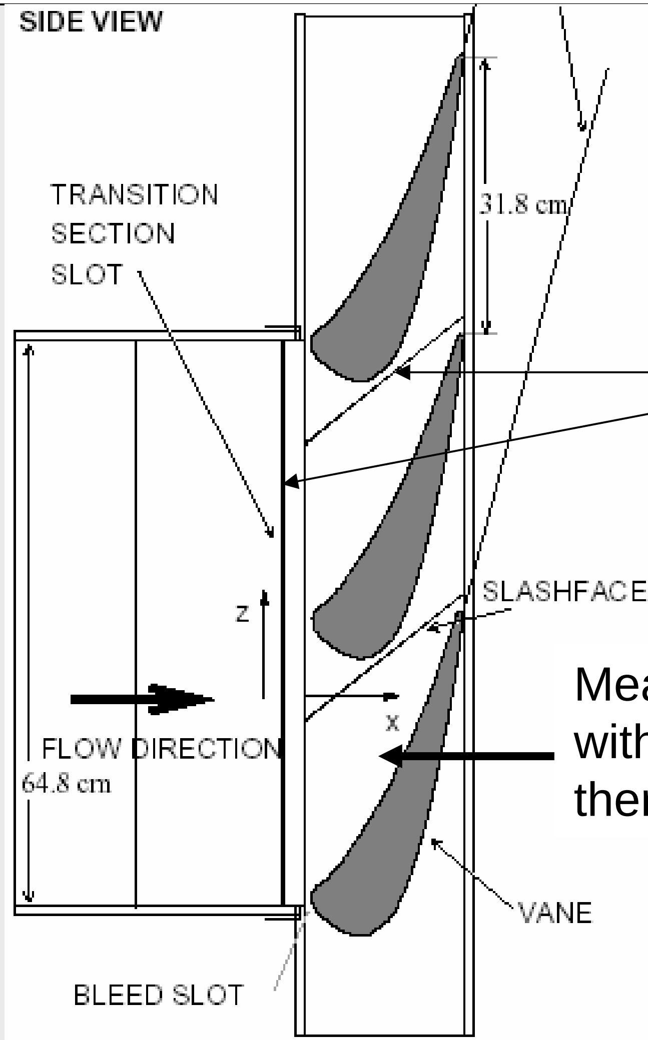
Accomplishments

The program has been completed

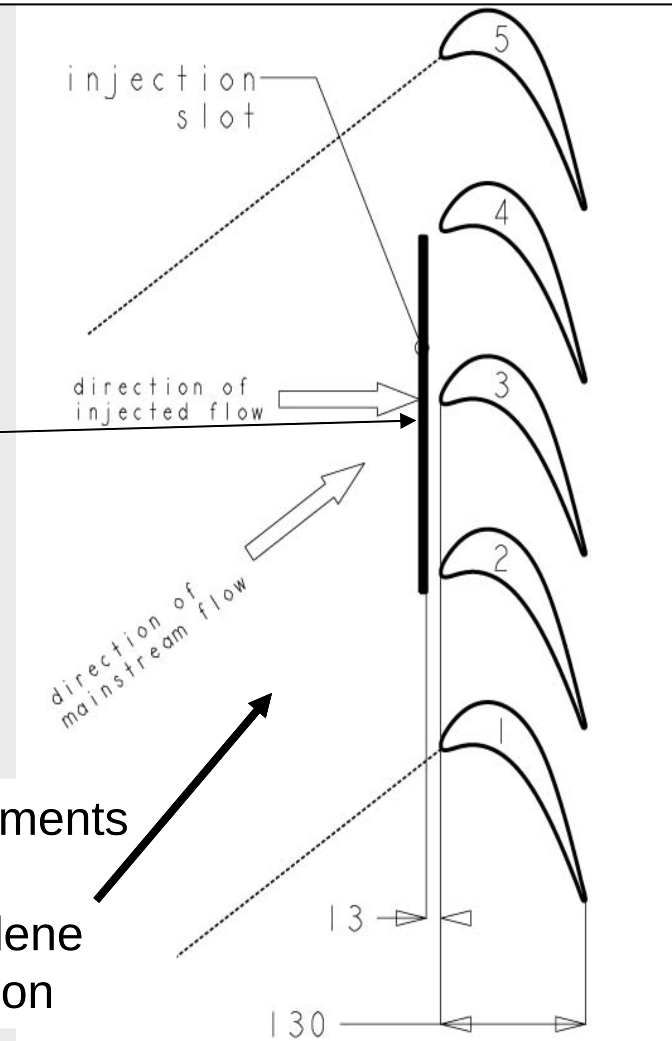
- Measurements of endwall and airfoil surface heat and mass transfer coefficients, film cooling effectiveness values and net heat transfer change
- Heat and mass transfer analogy improved
- Misalignment and leakage study
  - Some endwall visualization
    - Strong effect of leakage flow through the slashface
  - 2^n factorial study of aerodynamic loss
    - Quantified the various leakage and misalignment effects
  - Heat transfer coefficients
    - Documented the leakage, step and gap influences on heat transfer
  - Film cooling effectiveness values
    - In some cases, the steps improved effectiveness
  - Documentation of results (IGTC05 and 06, NHTC05, IMECE05, IHTC06, ASME/ATI06, journals)

Test Facilities

Vane cascade



Rotor blade cascade



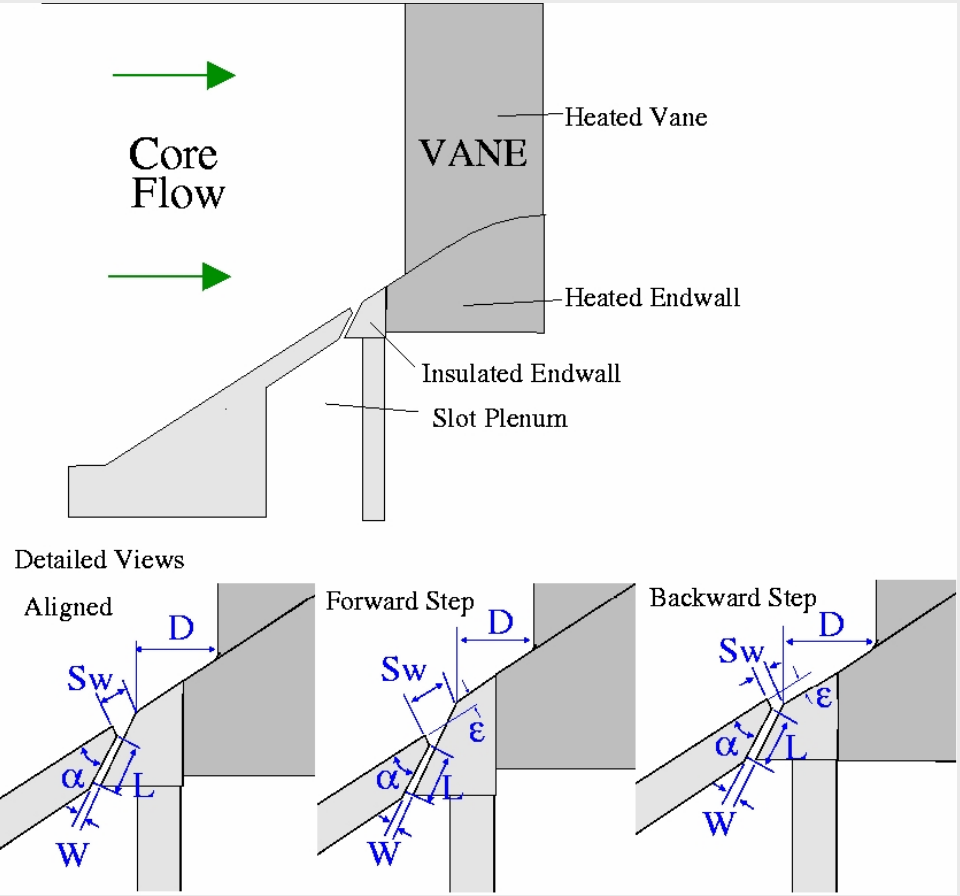
Slots for gaps, steps and injection

Measurements with traversing thermocouple

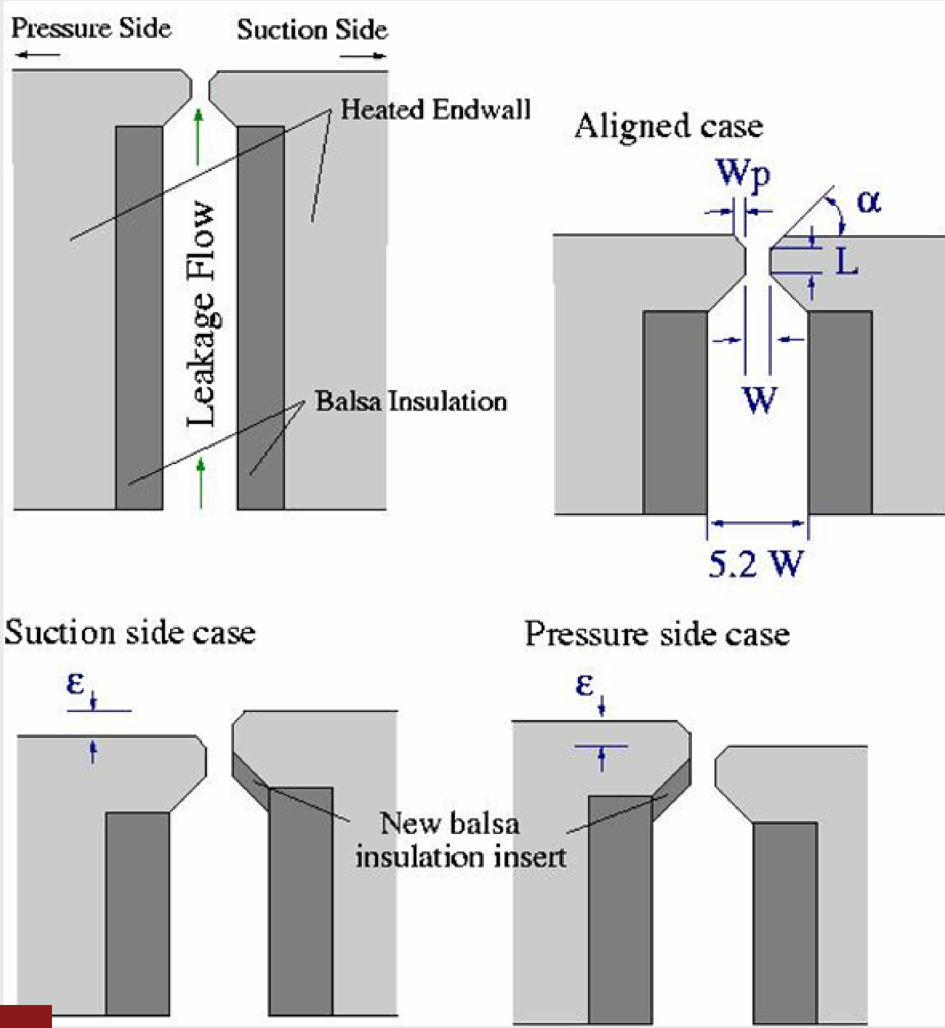
Measurements with Naphthalene sublimation

Technical Results – Vane Cascade Geometry

Transition section geometry showing leakage path and steps sizes (ε)



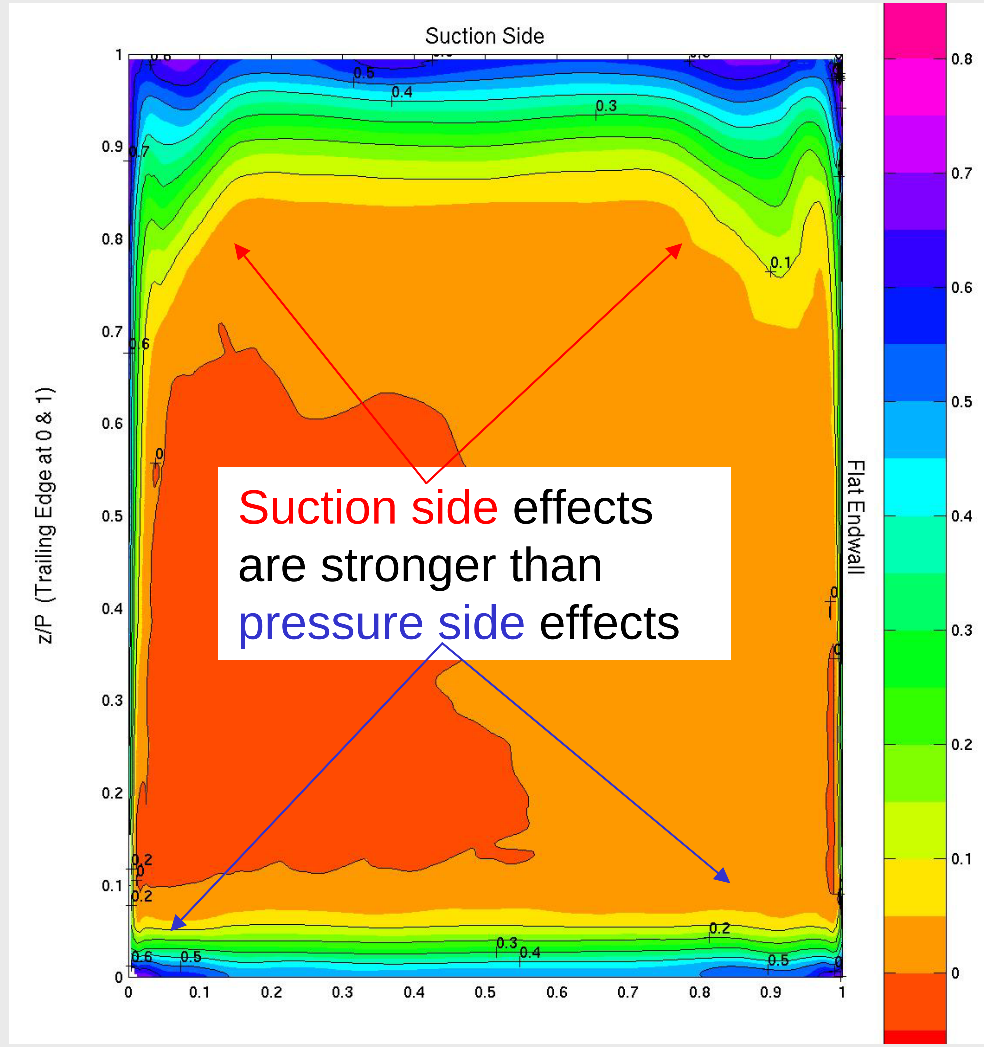
Slashface gap showing steps sizes (ε), and passage insulation



Technical Results – Vane Cascade Total Pressure Loss

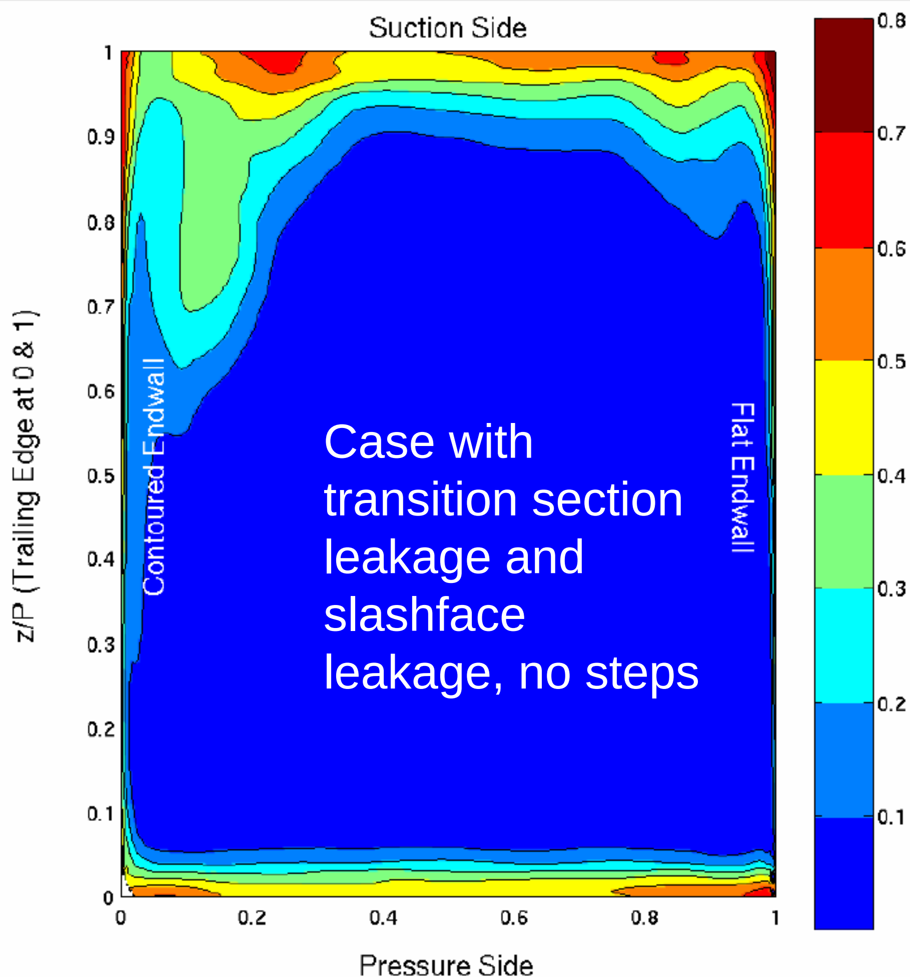
- Pressure loss (right) is typical for a contoured passage
- Cases with component misalignment and leakage; 2^n factorial study (below)

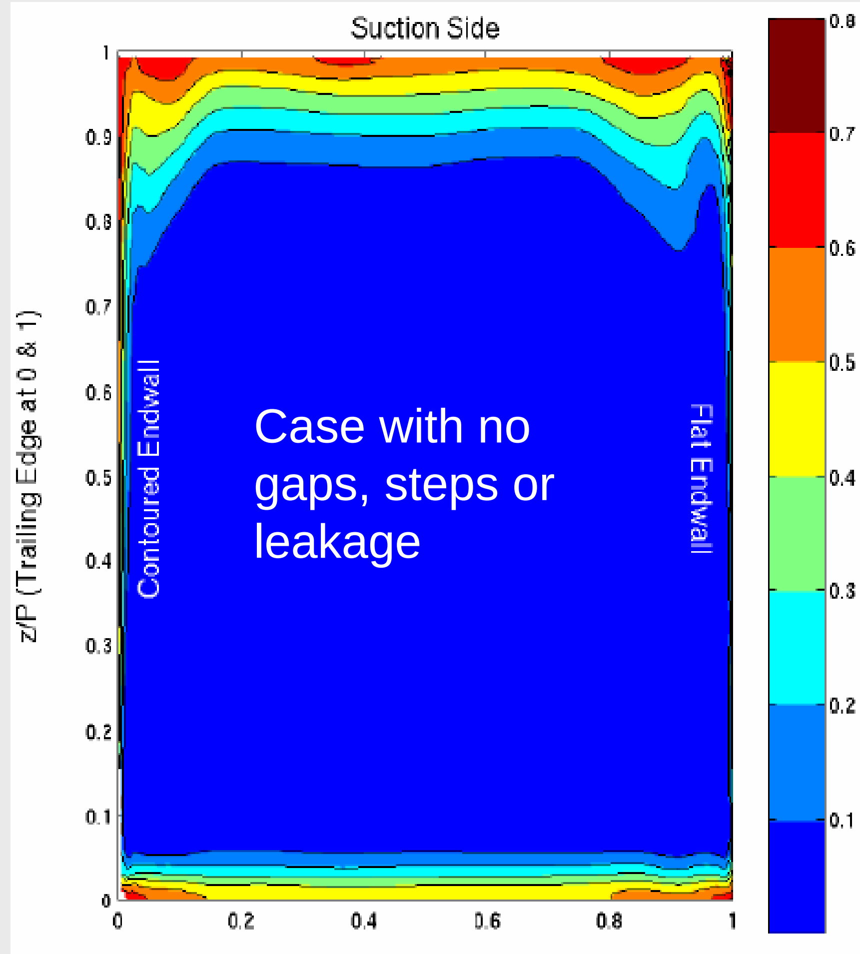
Parameter(s)	Effect	% Effect on loss
TS step	-0.00302	-3.7
TS MFR	-0.00060	-0.7
SF MFR	0.01711	21.1
TS step & TS MFR	0.00115	1.4
TS step & SF MFR	-0.00071	-0.9
TS MFR & SF MFR	0.00102	1.3
TS step & TS MFR & SF MFR	-0.00158	-1.9
Min Significant Effect	0.00283	3.5
Curvature	-0.00923	
Min. Significant Curv.	0.00233	



Passage pressure loss contours (contoured endwall-left edge, flat endwall-right edge, suction side-top, pressure side-bottom)

Technical Results – Vane Passage Total Pressure Loss



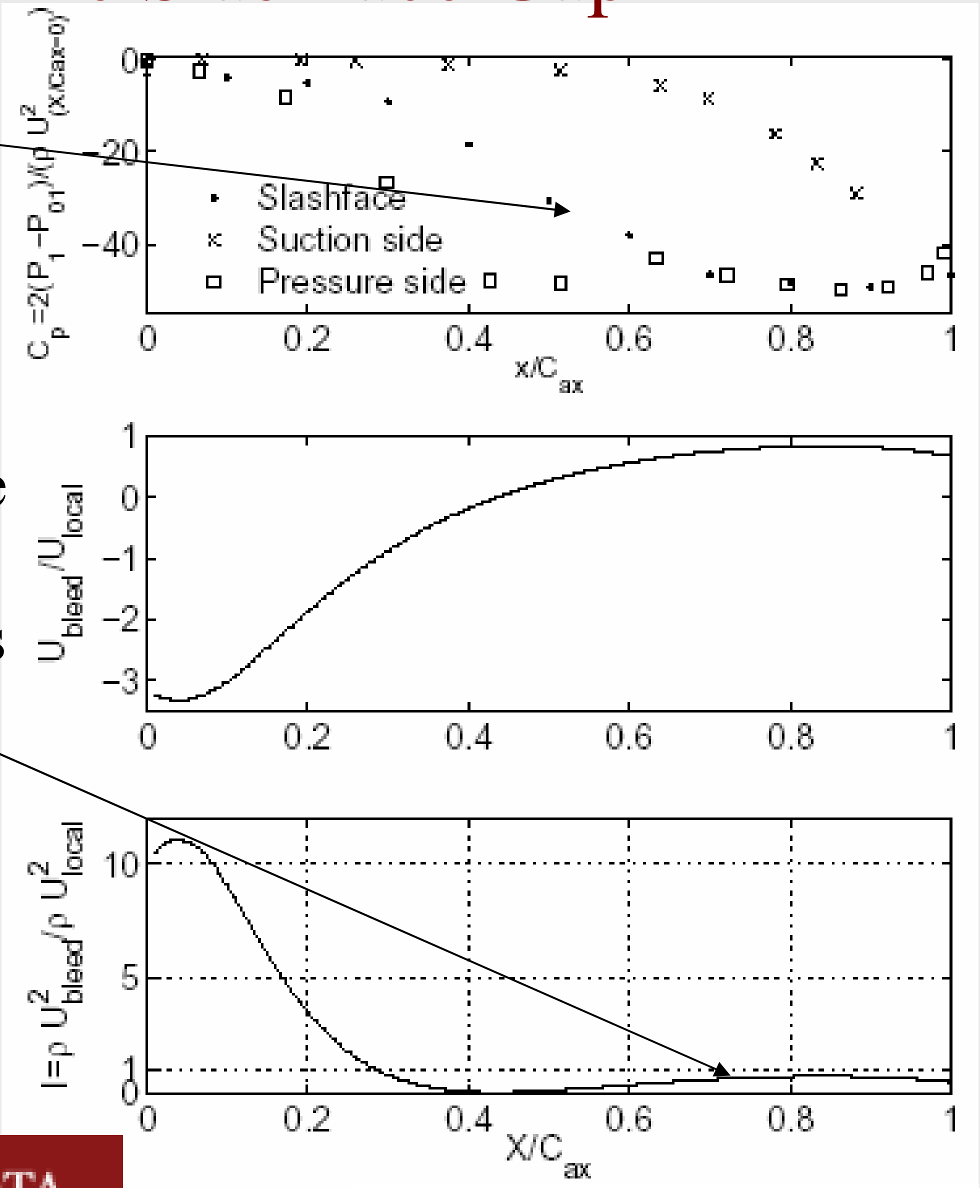


Passage pressure loss contours-
(contoured endwall-left edge of each fig., flat endwall-right edge, suction side-top edge, pressure side-bottom edge)

Technical Results – Vane Cascade

Description of the Slashface Gap

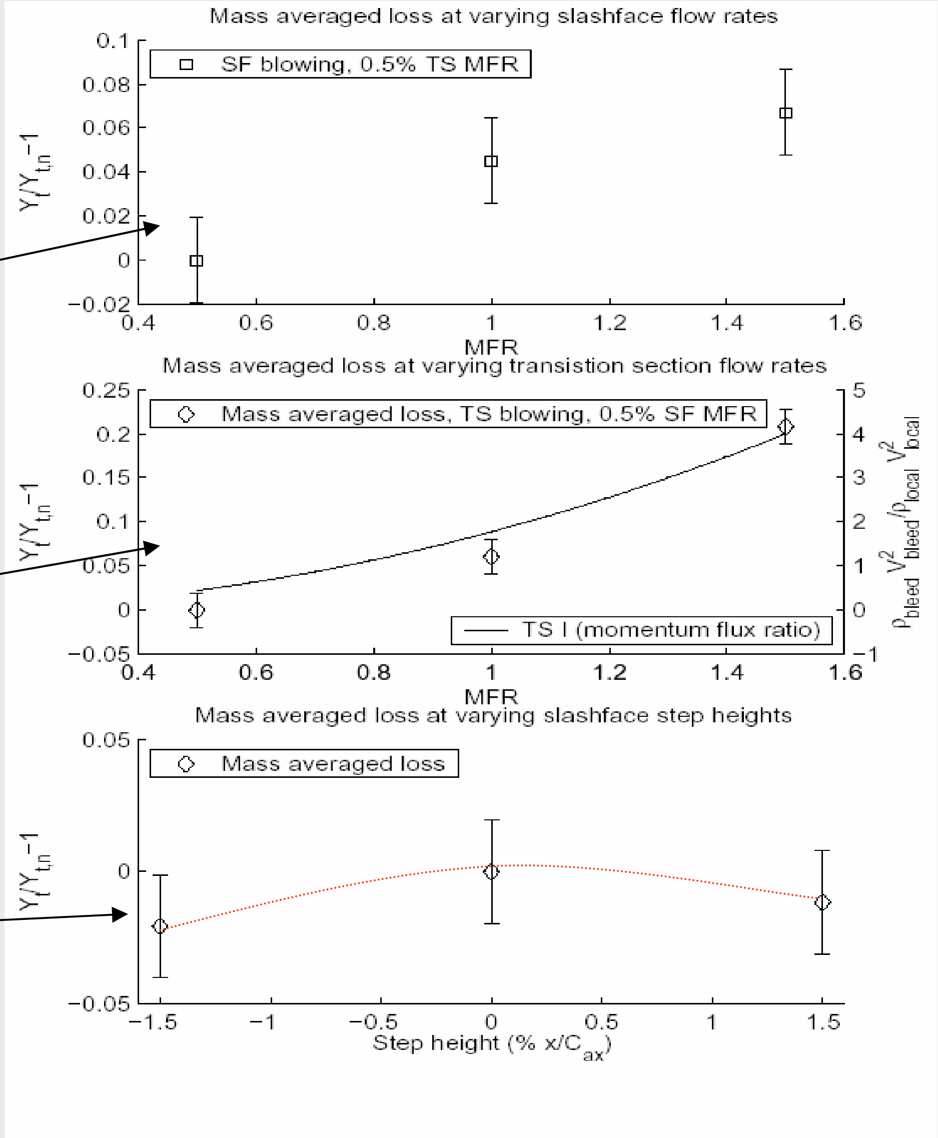
- In-passage static pressures taken along the slashface gap (compared to suction and pressure surface pressure profiles)
- Ingression of flow into slashface gap for upstream 42% of axial chord – computed from pressures
- Substantial momentum flux into passage from gap for downstream portion of passage. This flow is likely to affect passage secondary flows



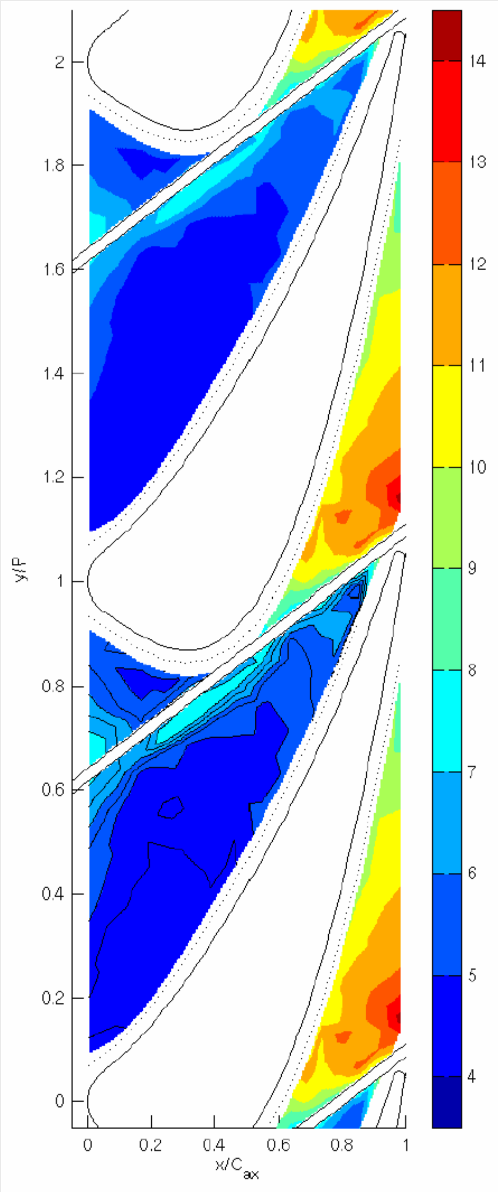
Technical Results – Vane Passage Total Pressure Loss

Single Parameter Variations

- Plot of cases compared
- Interfacial gap flow rate
  - Loss increases at decreasing rate with increased mass flow
- Transition section slot blowing
  - Loss increase closely follows momentum flux
- Interfacial gap step
  - Slight reduction in loss for steps up and down



Technical Results – Endwall Heat Transfer

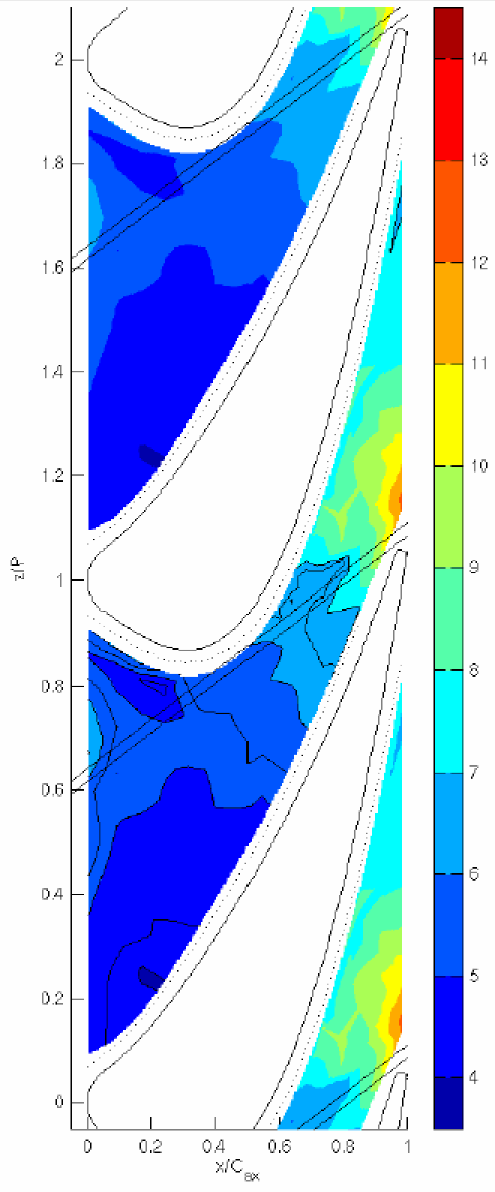


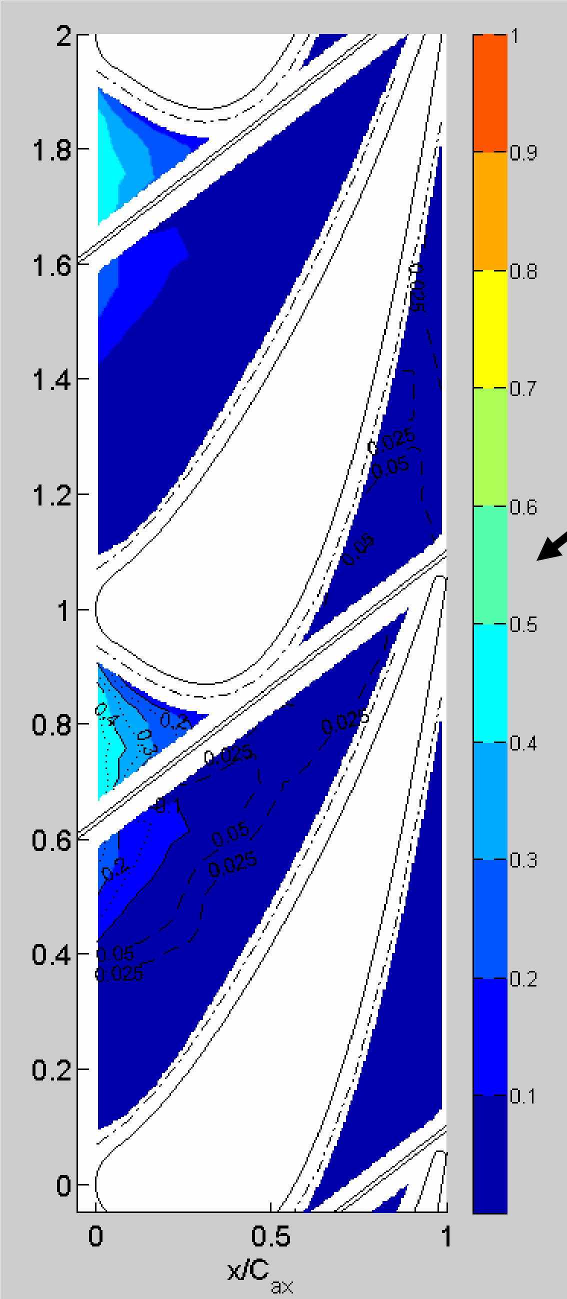
Smooth case vs Nominal case

Left- Smooth passage without leakage

Right –no steps but nominal blowing through transition section and slashface gaps

Plotted:
Stanton Number x 1000

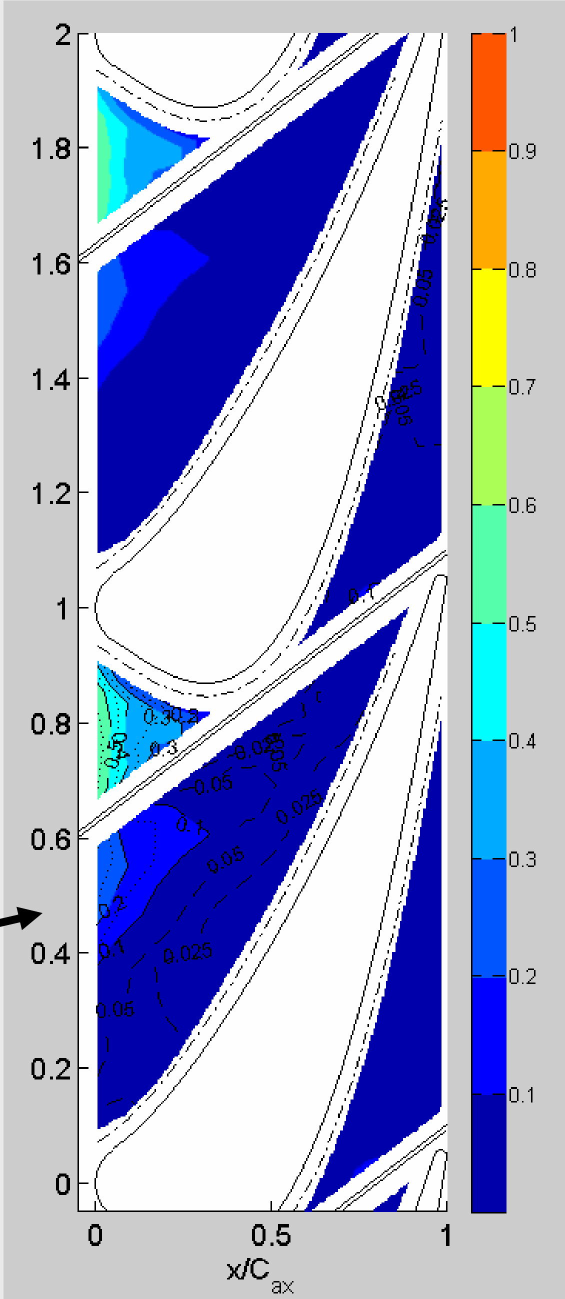




Technical Results – Endwall Film Cooling Effectiveness

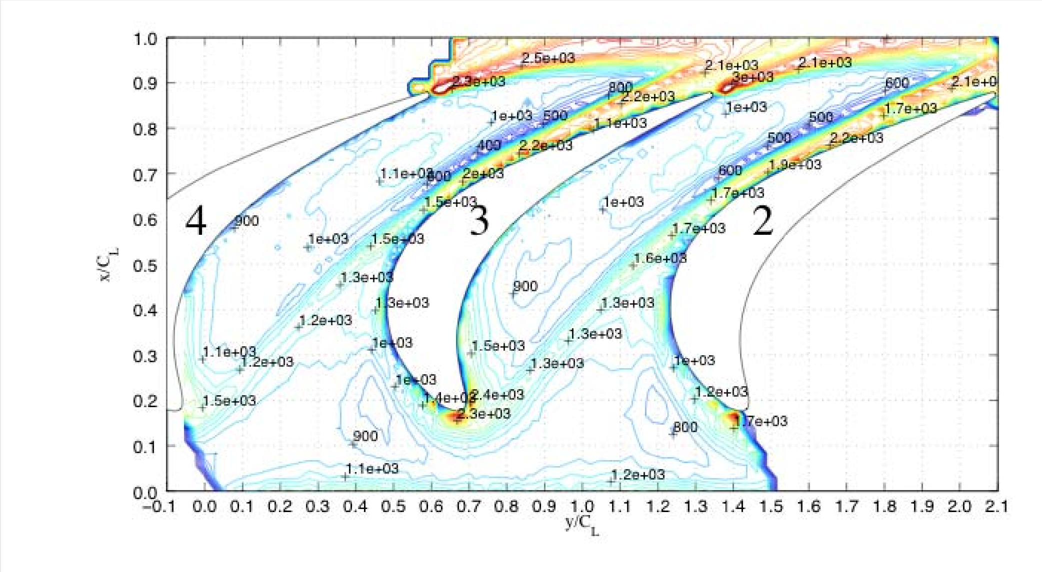
-Nominal configuration (no steps but blowing through transition section and slashface)

-Same, but with backward facing slashface step configuration



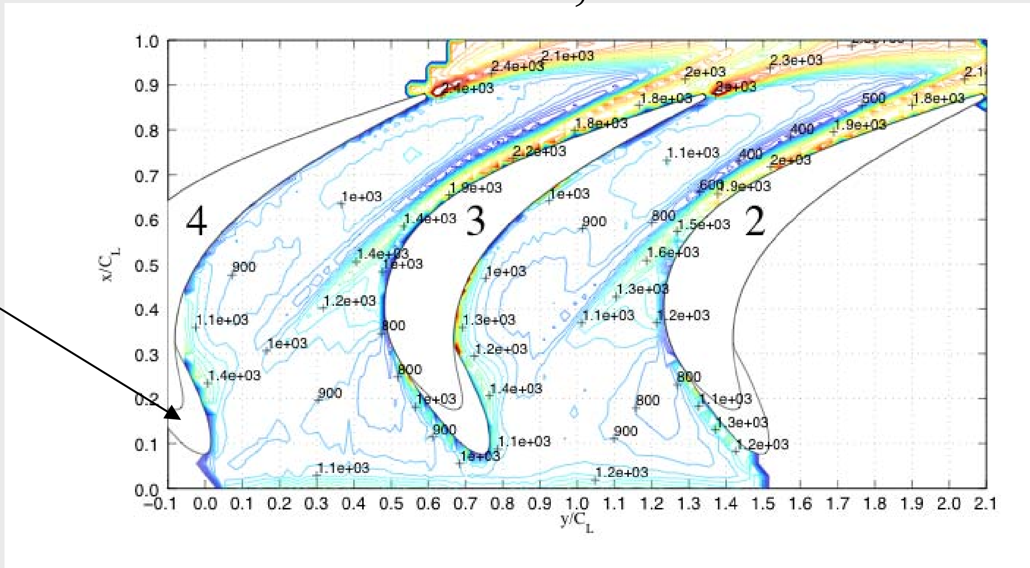
Technical Results Rotor cascade –

Sherwood number Distributions in the rotor cascade– low FSTI



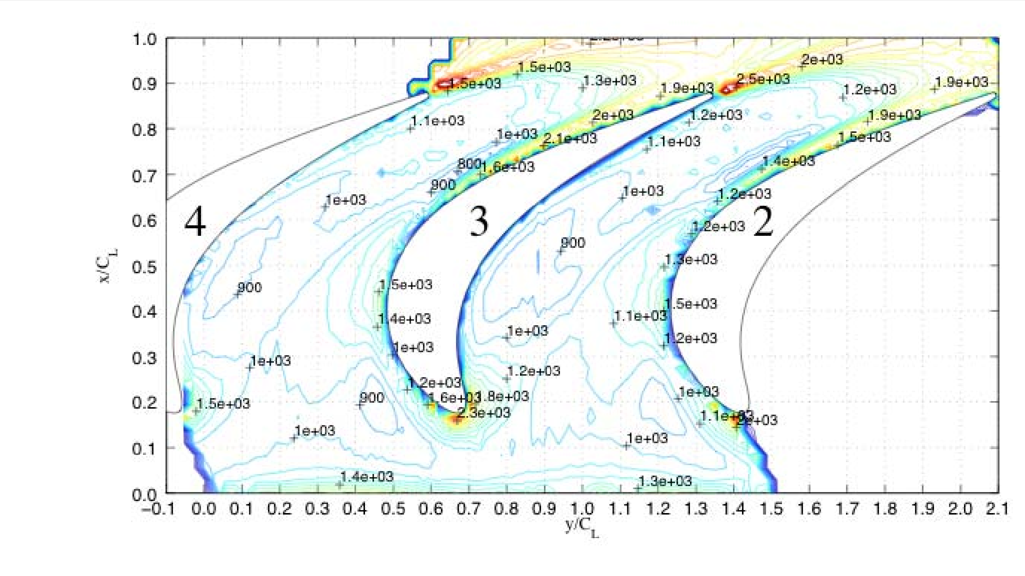
Re=5.77×10^5, Tu=0.2%

Results show the effects of fillets on the endwall heat transfer (on the secondary flows) when the FSTI is low



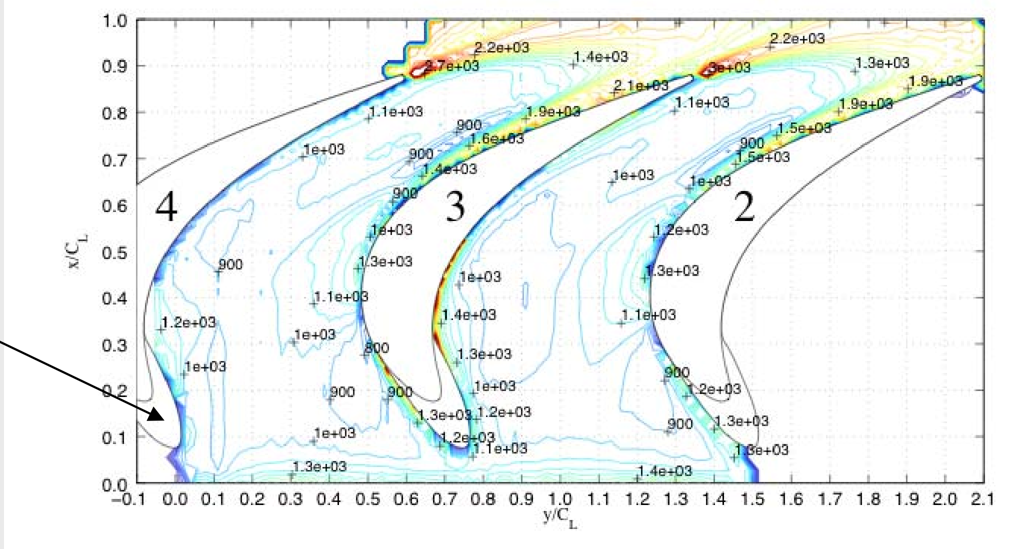
Re=5.65×10^5, Tu=0.2% and fillets

Technical Results – Sherwood number Distributions in the rotor cascade – high FSTI



Re=5.67×10[5], Tu=8.5%

Results show the effects of fillets on the endwall heat transfer (on the secondary flows) when the FSTI is high



Re=4.97×10[5], Tu=8.5% and fillets

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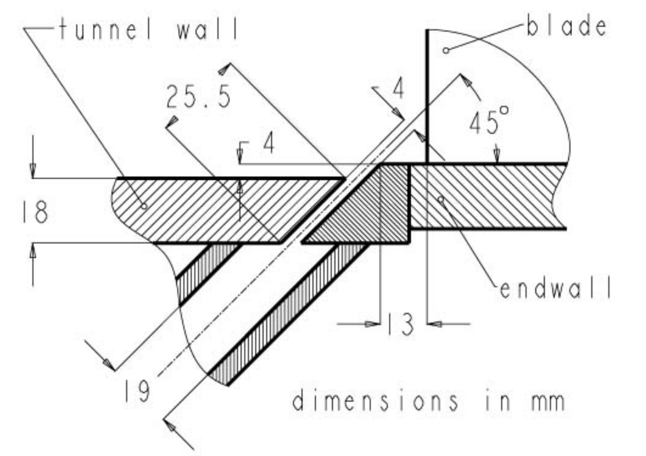
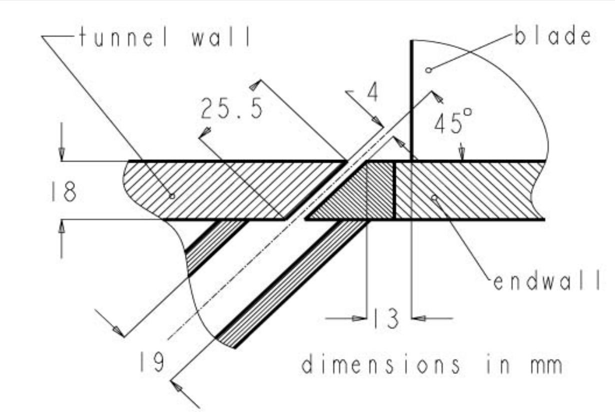
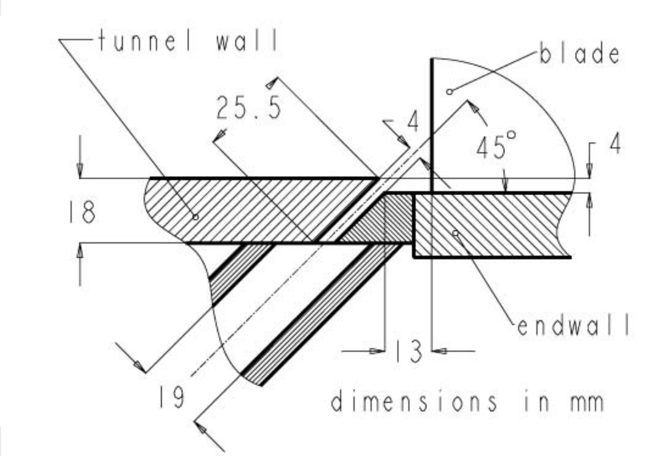
Technical Results –

Rotor Cascade Injection Geometry







Step up

(forward facing)

No step

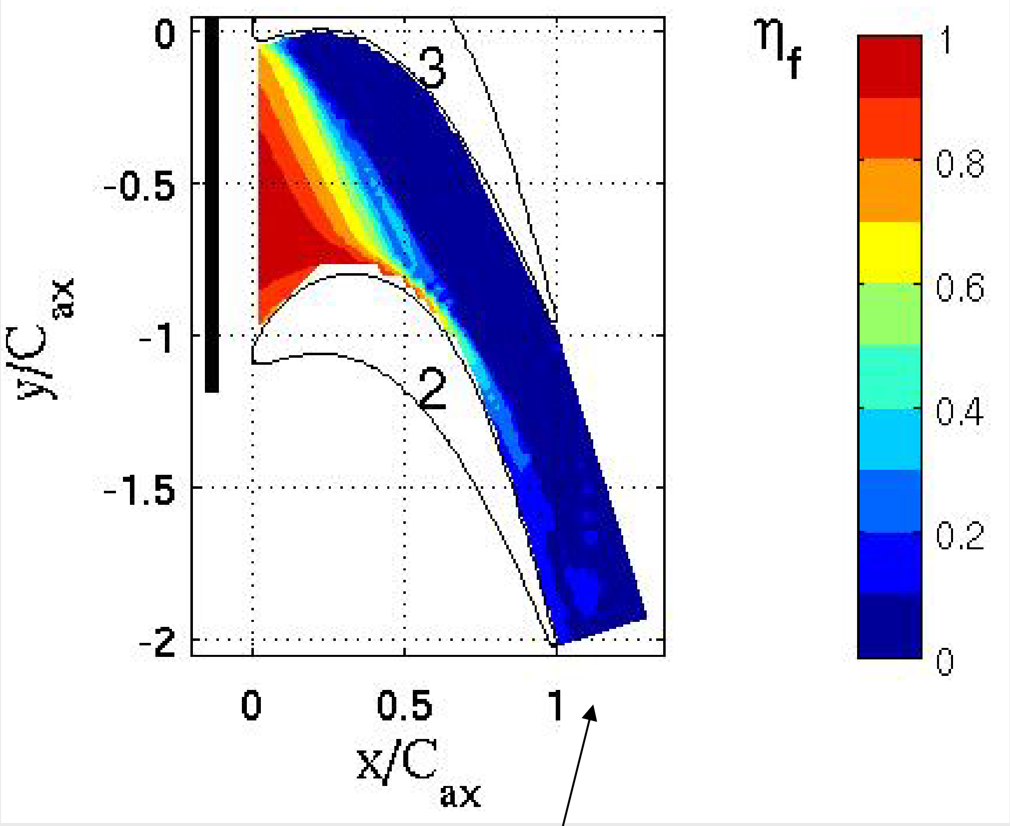
(flat endwall)

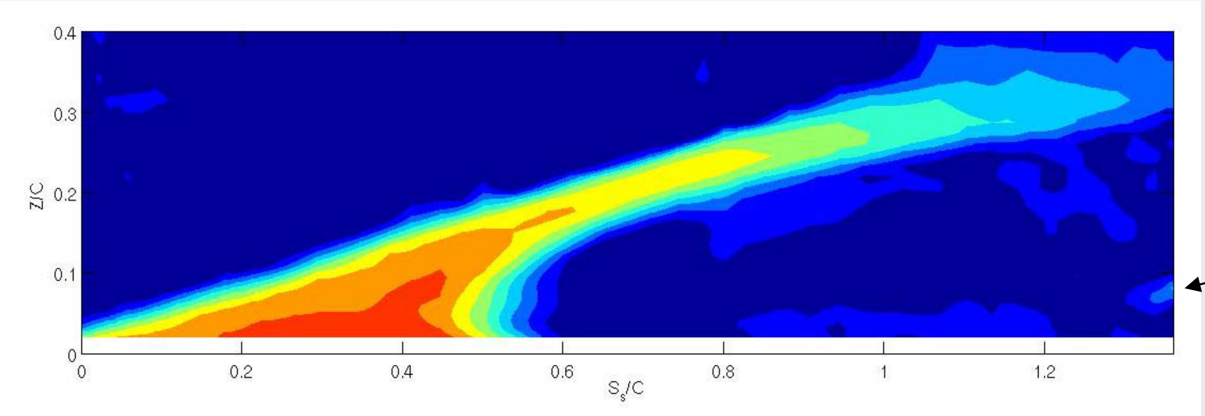
Step down

(backward facing)

Technical Results – Adiabatic cooling effectiveness on endwall and suction surface wall

Rotor Cascade





Endwall and

Suction wall

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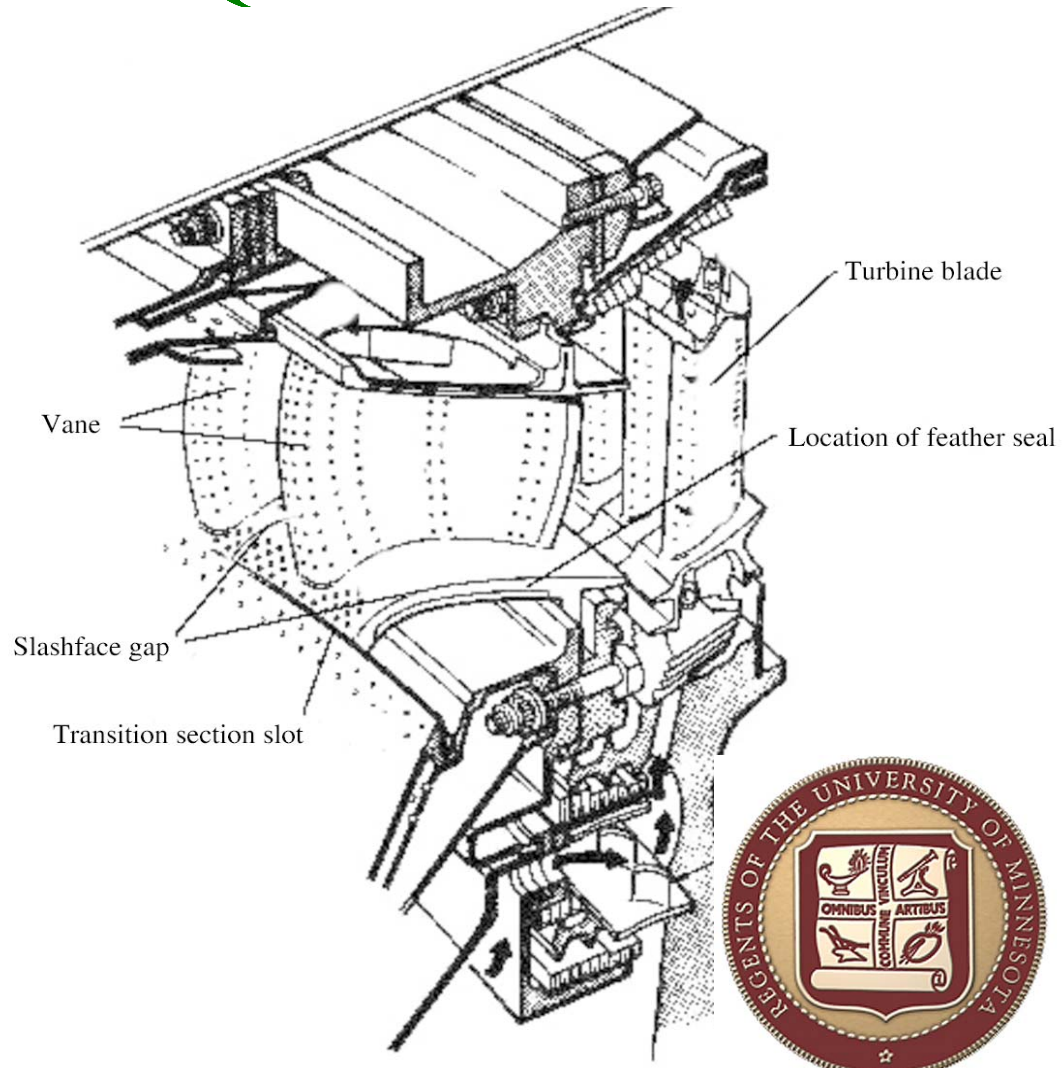
Summary

- The work has provided detailed documentation of passage losses
  - Performance with contouring is described
  - Effects of gaps and steps are documented
  - Effects of injection are documented
- The work has provided detailed documentation of heat and mass transfer coefficients on the endwall
  - Effects of fillets are documented
  - Effects of freestream turbulence intensity are documented
- Results provide an improvement in the application of the heat/mass transfer analogy for turbine design

Publications

- Han, S., Goldstein, R. J., GT2005-68590, Int'l Gas Turbine Conference, Reno, NV.
- Piggush, J., Simon, T.W., GT2005-68340, Int'l Gas Turbine Conference, Reno, NV, rec. for J.
- Piggush, J. D., Simon, T. W., 2005 National Heat Transfer Conference, San Francisco, CA.
- Piggush, J. D., Simon, T. W., IMECE2005-83032, Orlando, FL.
- Piggush, J. D., Simon, T. W., GT2006-90575, Int'l Gas Turbine Conference, Barcelona, SP
- Piggush, J. D., Simon, T. W., GT2006-90576, Int'l Gas Turbine Conference, Barcelona, SP
- Simon, T. W., Piggush, J. D., 2006, Special Section on Turbine Reliability in the AIAA Journal of Propulsion and Power
- Papa, M., Goldstein, R.J., Gori, F., GT2006-90576, Int'l Gas Turbine Conf., Barcelona, SP
- Papa, M., Goldstein, R.J., Gori, F., 13th Int'l Heat Transfer Conf., Sydney Australia 2006.
- Papa, M., Goldstein, R.J., Gori, F, ASME-ATI Conference, Milan, Italy, May 14-17, 2006 prep.
- Papa, M., Goldstein, R.J., Gori, , International Journal of Heat and Mass Transfer. In prep.

QUESTIONS?



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