Attenuation of Hot Streaks and Interaction of Hot Streaks with the Nozzle Guide Vane and Endwall

ATS Annual Review Meeting
February 2002

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Active Participants

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Industry Partners

Pratt & Whitney, General Electric, Rolls-Royce

Overall project objectives

Determine how a combustor hot streak increases the heat load to the first stage stator vane and endwall.

Determine how surface roughness affects the film cooling performance of the turbine vane.

Determine how the hot streak is attenuated when it impacts film-cooled surfaces.

TTCRL VTExCCL

Experimental and computational approaches will provide insight to combustor hot streaks

University of Texas Tasks

1. Simulate actual operating conditions of a film cooled nozzle guide vane with particular focus on surface roughness
2. Study the effect of the hot-streak impact on the nozzle guide vane on film cooling performance.
3. Investigate the attenuation of the hot streak by interaction with the nozzle guide vane.

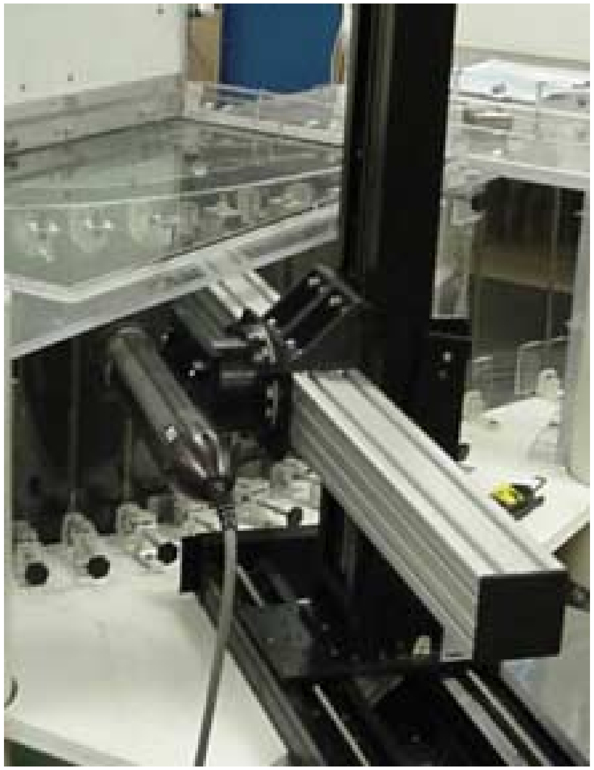
Virginia Tech Tasks

1. Measure endwall temperatures as hot streak passes through the vane passage
2. Measure endwall film cooling effectiveness with a range of temperature profiles
3. CFD simulations of hot streak/vane interactions with and without endwall film-cooling

Measurements will be performed using various techniques

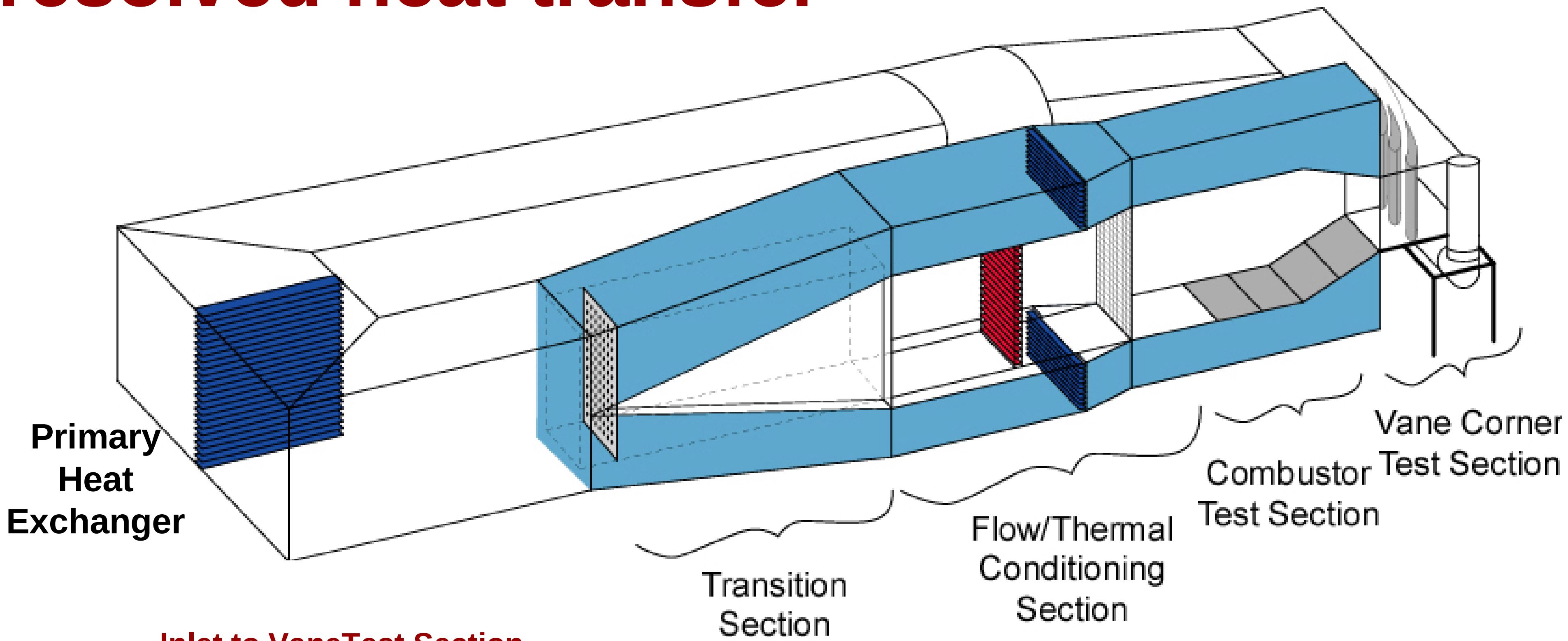
Infrared Camera

Three-Component Laser Doppler Velocimeter



Kiel Probe Rake

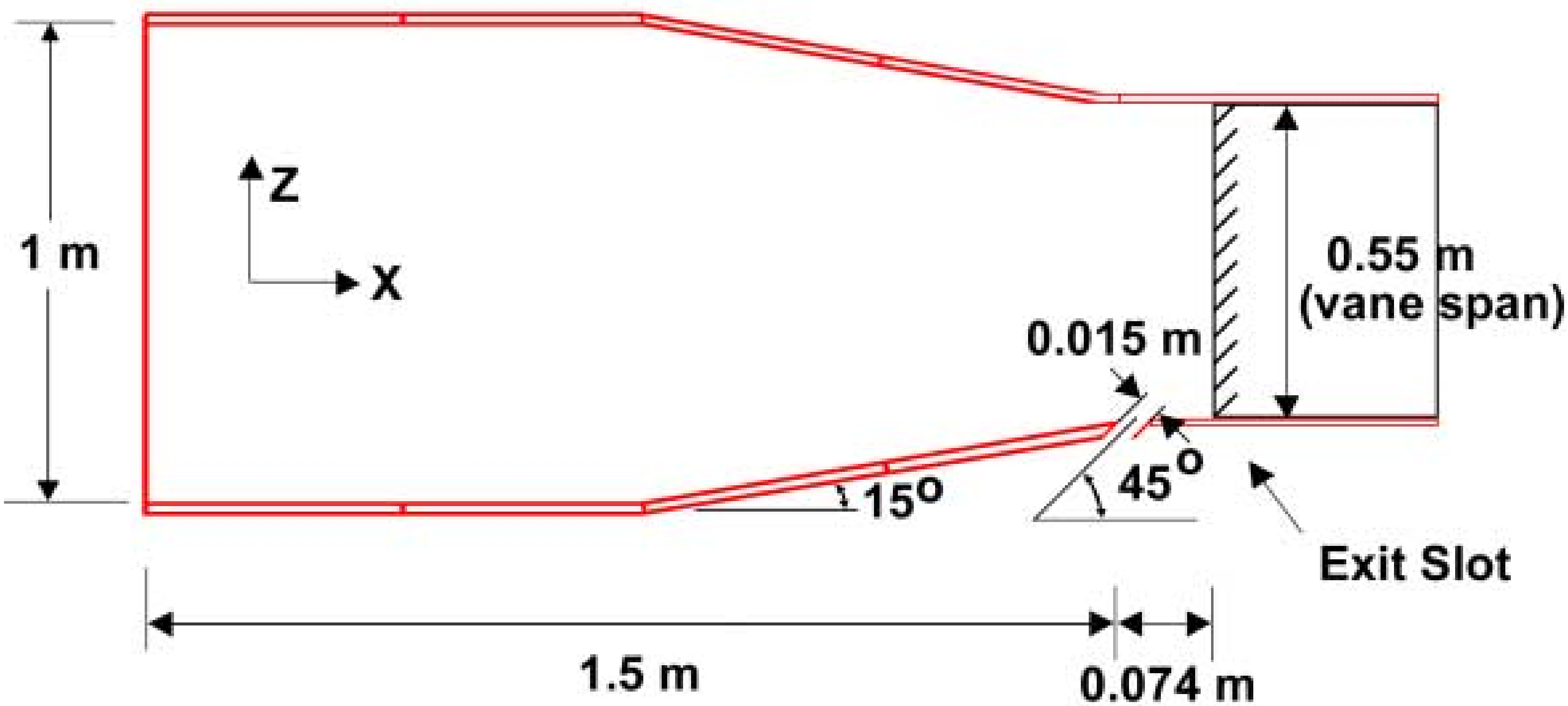
Large scale testing will allow spatially-resolved heat transfer



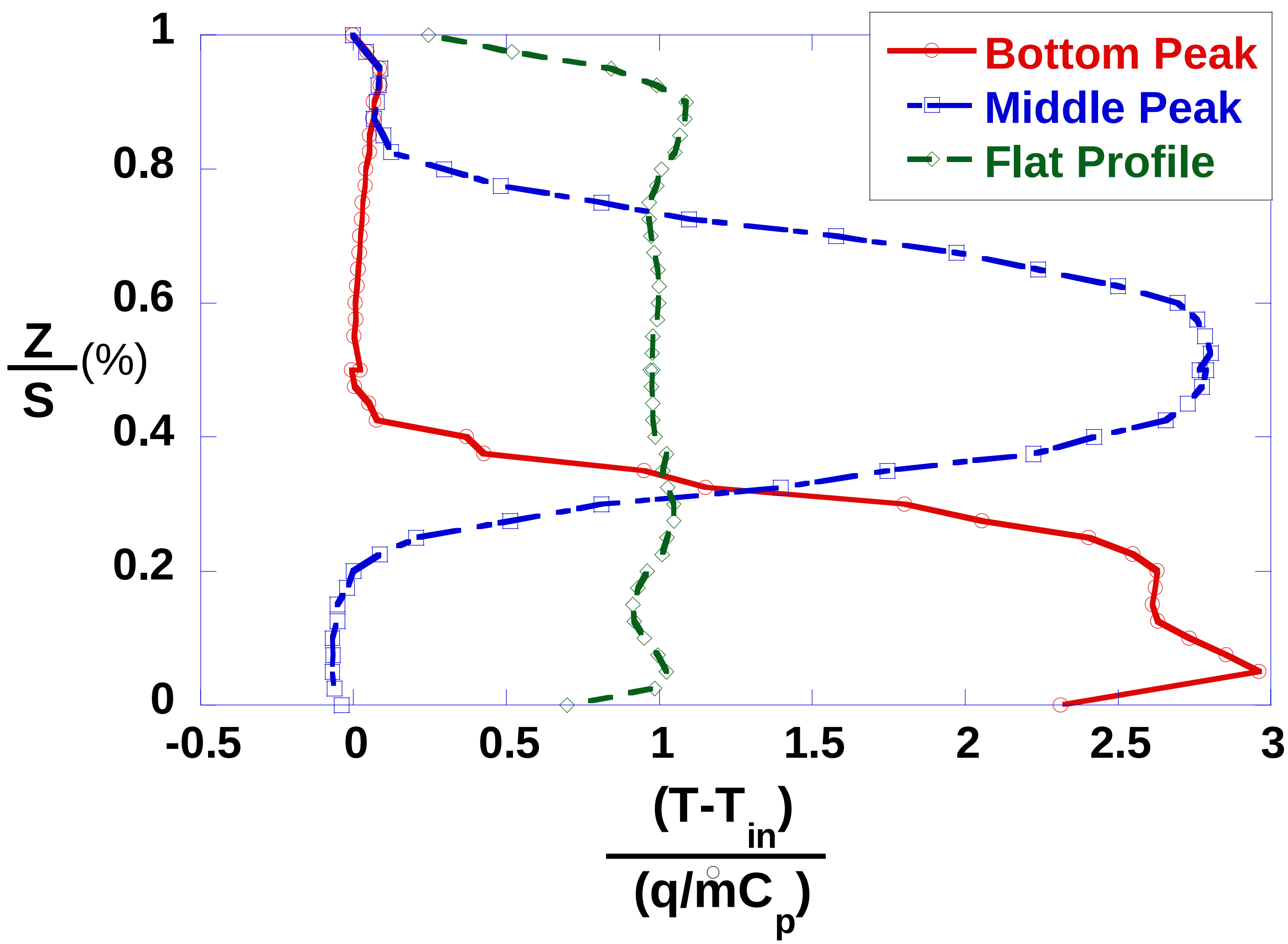
Inlet to VaneTest Section

Stator Vane Test Section

The test section includes a leakage slot at the combustor-vane interface



Preliminary Temperature Profiles



Industry Collaboration

University of Texas

- Pratt & Whitney and the Air Force Research Laboratory reviewed and discussed the design of the surface roughness used in this study
- A review meeting was held at UT with Pratt & Whitney representatives

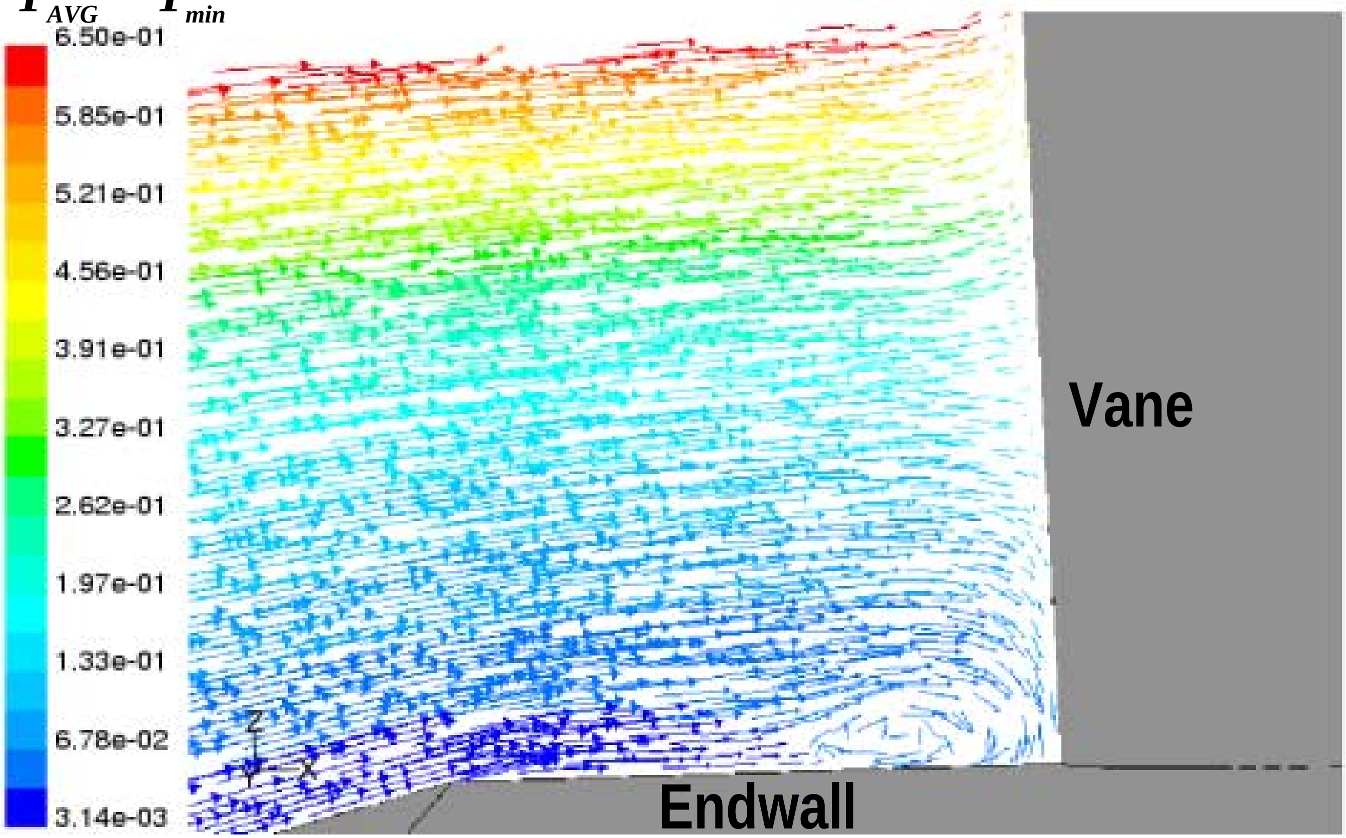
Virginia Tech

- Input for endwall cooling hole design was obtained from Pratt & Whitney, General Electric, and Rolls-Royce
- Visit and regular discussions with Pratt & Whitney

CFD Prediction of Horseshoe Vortex

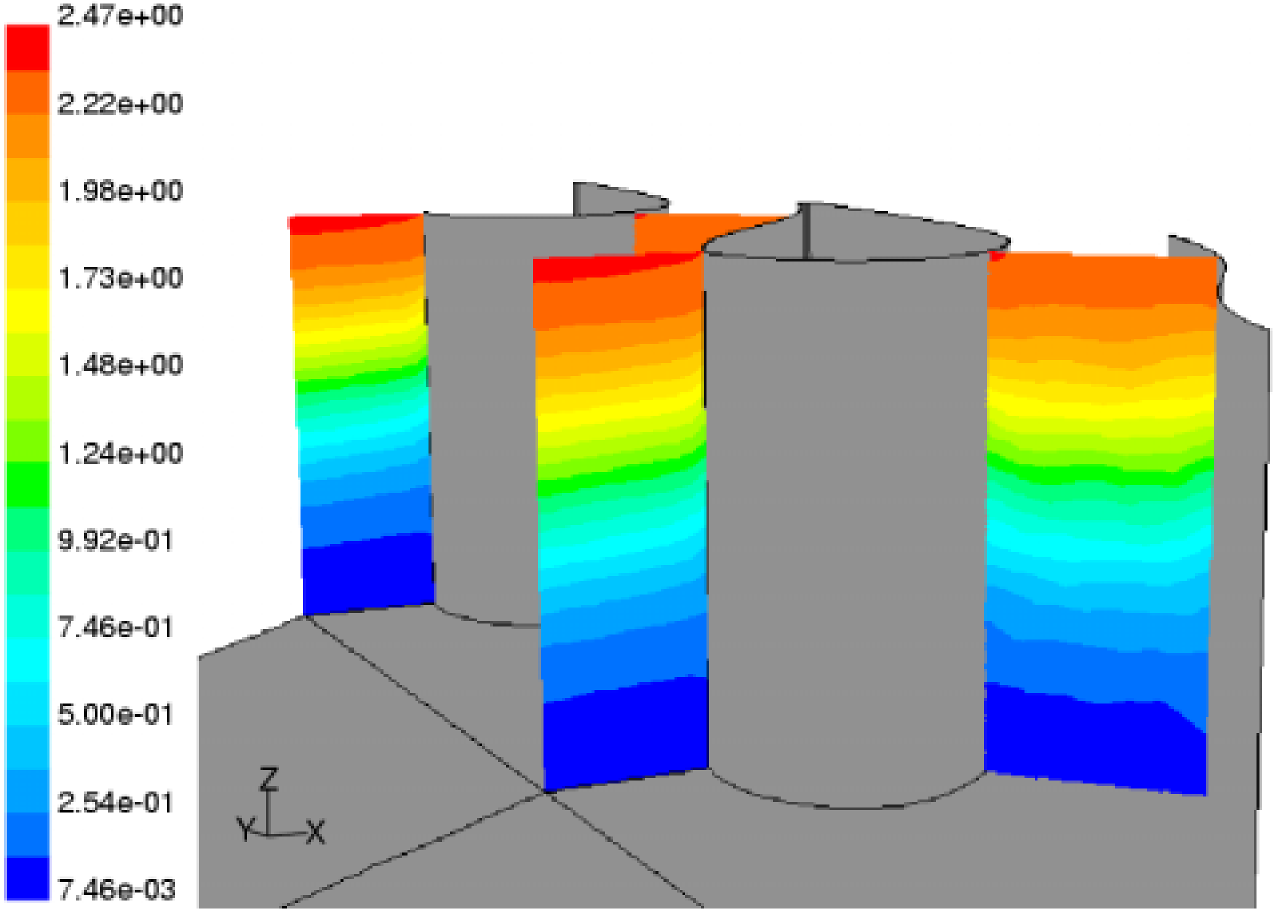
Velocity vectors are colored by non-dimensional temperature

$$\Theta = \frac{T - T_{min}}{T_{AVG} - T_{min}}$$



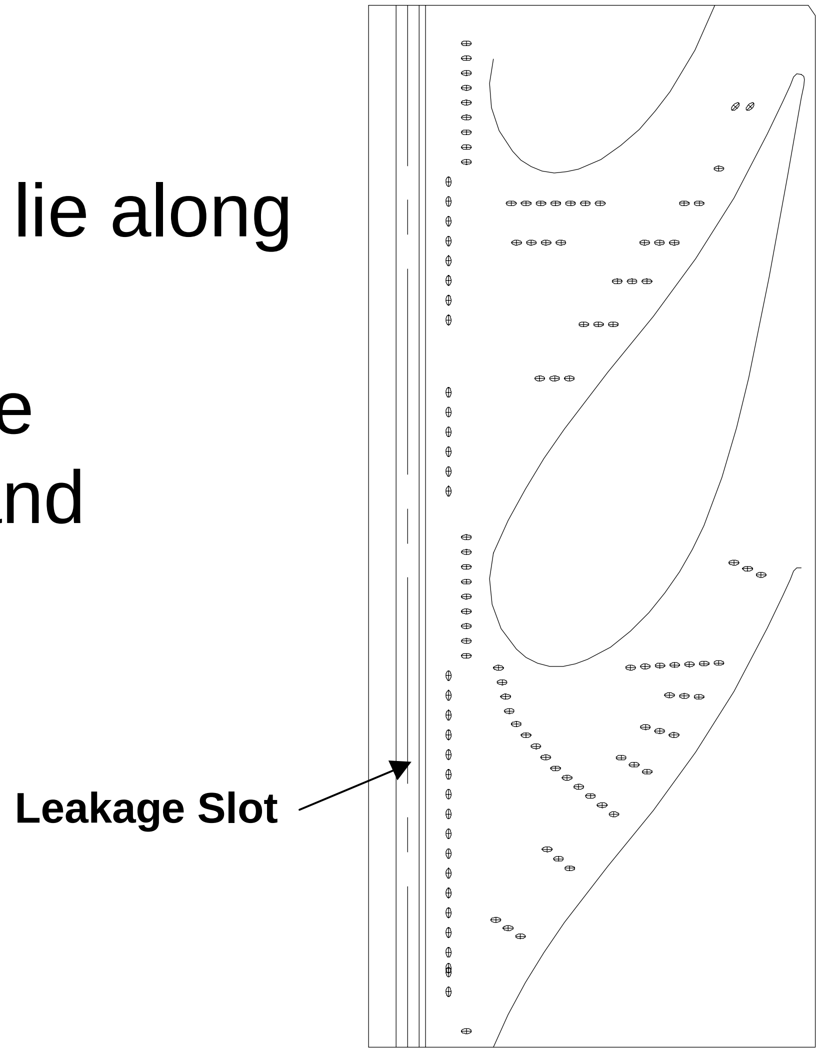
Thermal Contours in the Vane Passage

$$\Theta = \frac{T - T_{min}}{T_{AVG} - T_{min}}$$

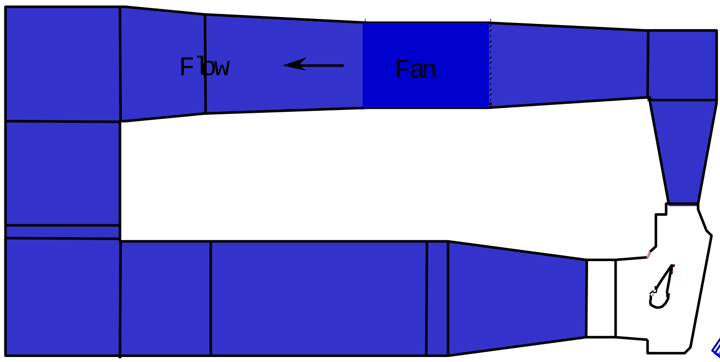


Endwall Film-Cooling Design

- Lower passage holes lie along iso-velocity lines
- Slot simulates leakage between combustor and turbine sections

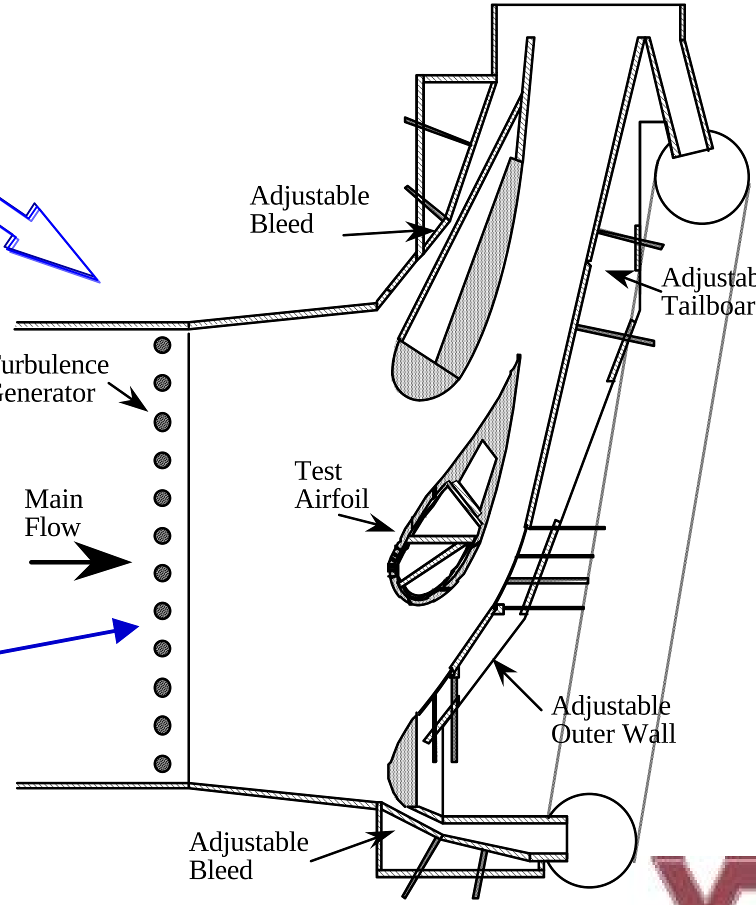


Schematic of test facility at the University of Texas



Closed loop wind tunnel

Simulated turbine vane cascade with a film-cooled center test vane.



Objectives of the rough surface study

Roughness was added upstream of a row of coolant holes on the suction side of the vane. The roughness simulated the degradation of the airfoil surface that occurs during operation of the engine. Although roughness effects have been studied on flat test surfaces, no previous studies have been done on a film cooled airfoil. The effect of roughness was studied for operation using an uncooled leading edge with low mainstream turbulence, and with a leading edge showerhead coolant flow with high mainstream turbulence.

Simulated surface roughness

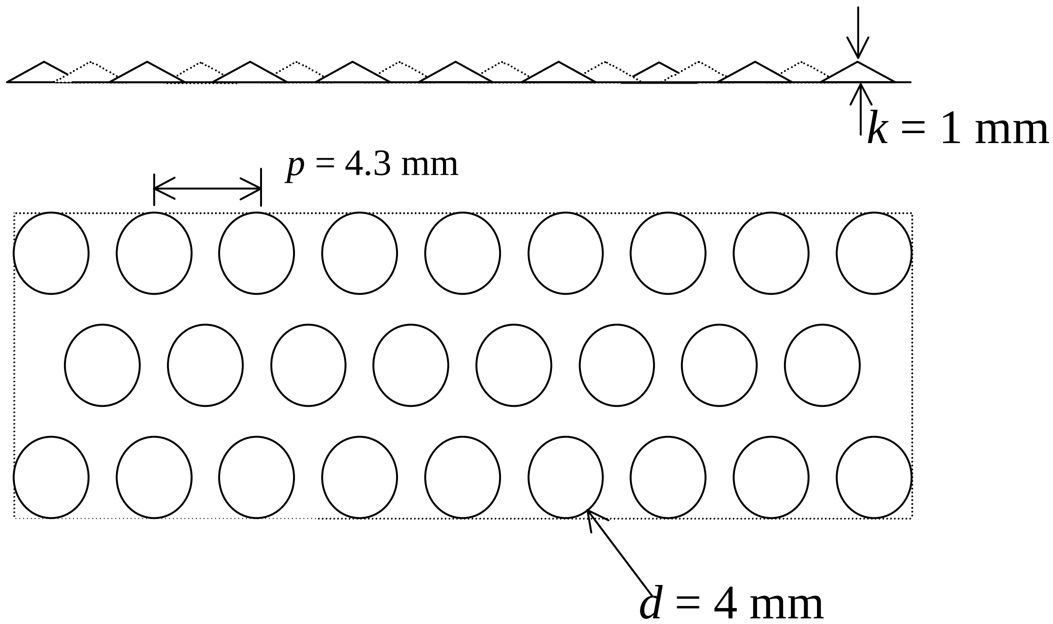
A surface roughness section was designed to simulate the roughness of a turbine after many hours of operation. The surface roughness had the following characteristics:

R_a = 20 μm, (centerline average roughness) on actual airfoil

$k \sim 5R_a$, (average roughness height)

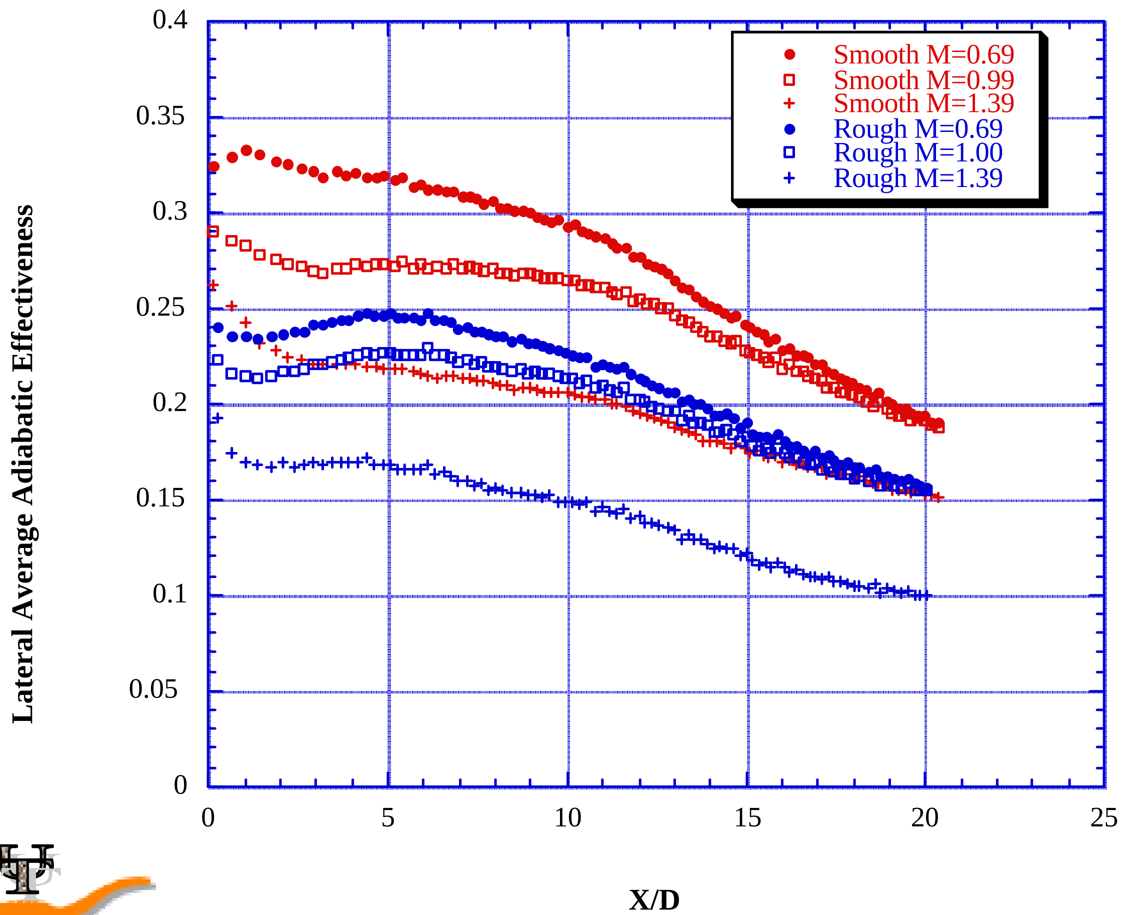
$k_s = 0.5k$, (equivalent sand-grain roughness)

Using a scale factor of 9, k_s = 0.5 mm for the simulated airfoil.



Comparison of the adiabatic effectiveness with smooth and rough surfaces

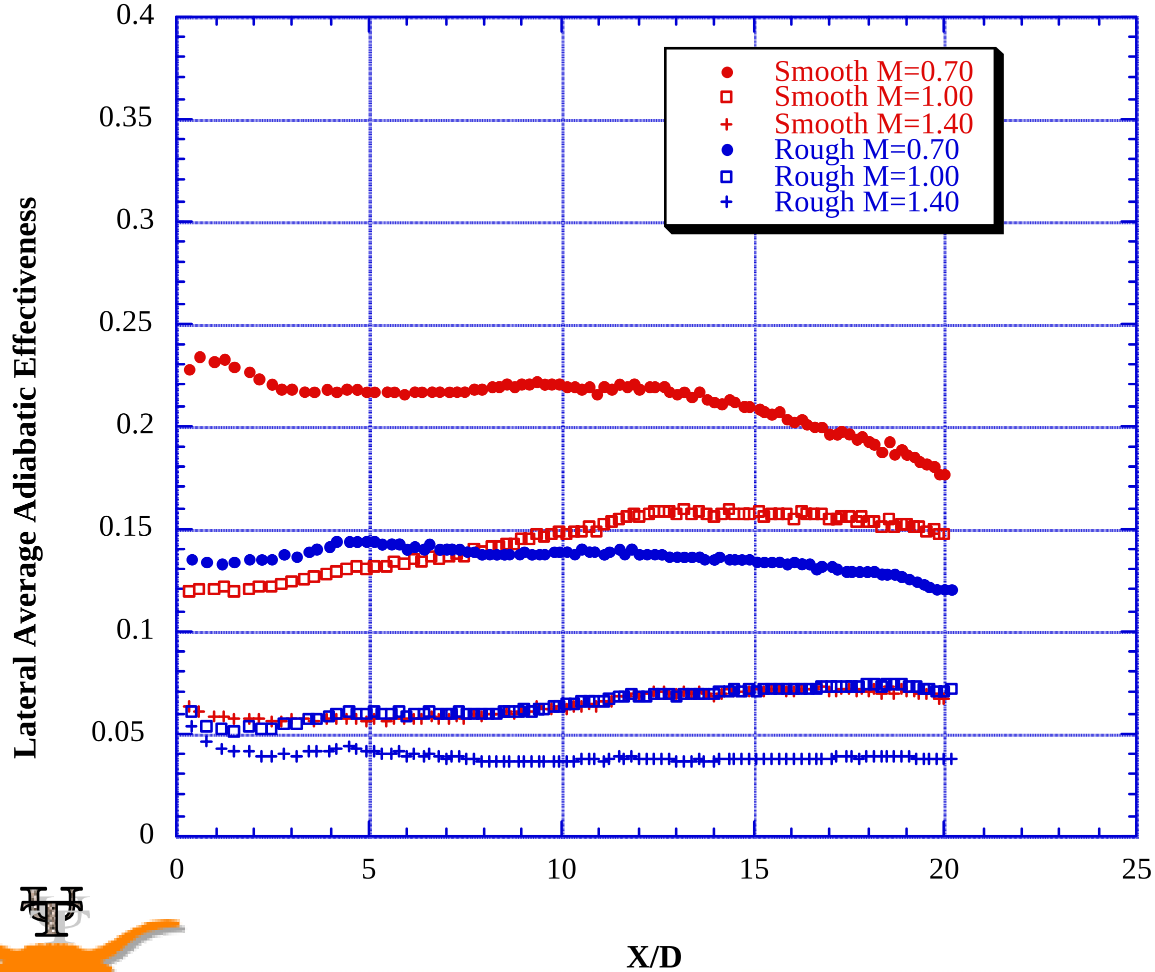
On the suction side of the vane with high mainstream turbulence and showerhead blowing at *M* = 1.6



A rough surface still causes a significant reduction in adiabatic effectiveness even with the showerhead blowing and high mainstream turbulence

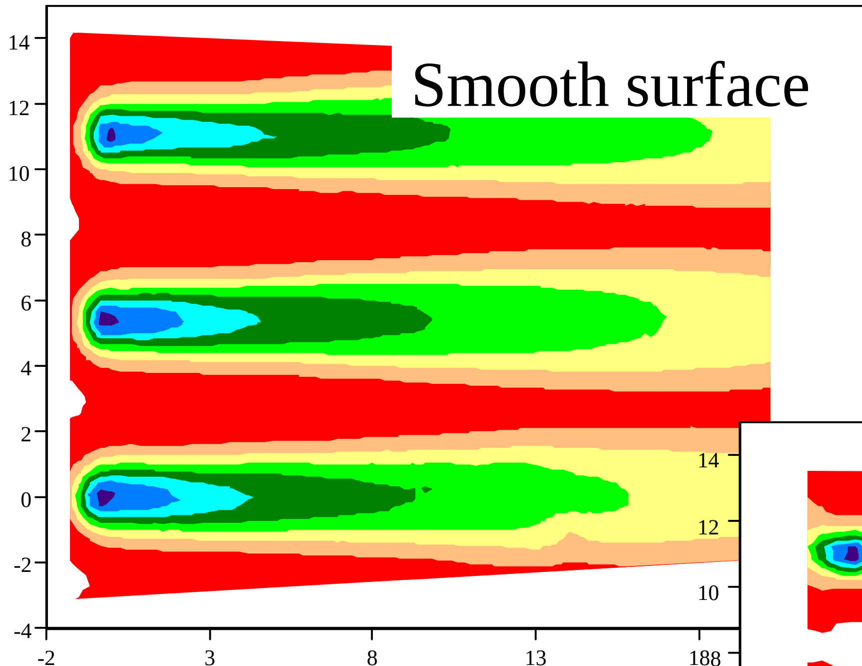
Comparison of the adiabatic effectiveness with smooth and rough surfaces

On the suction side of the vane with low mainstream turbulence and no showerhead blowing

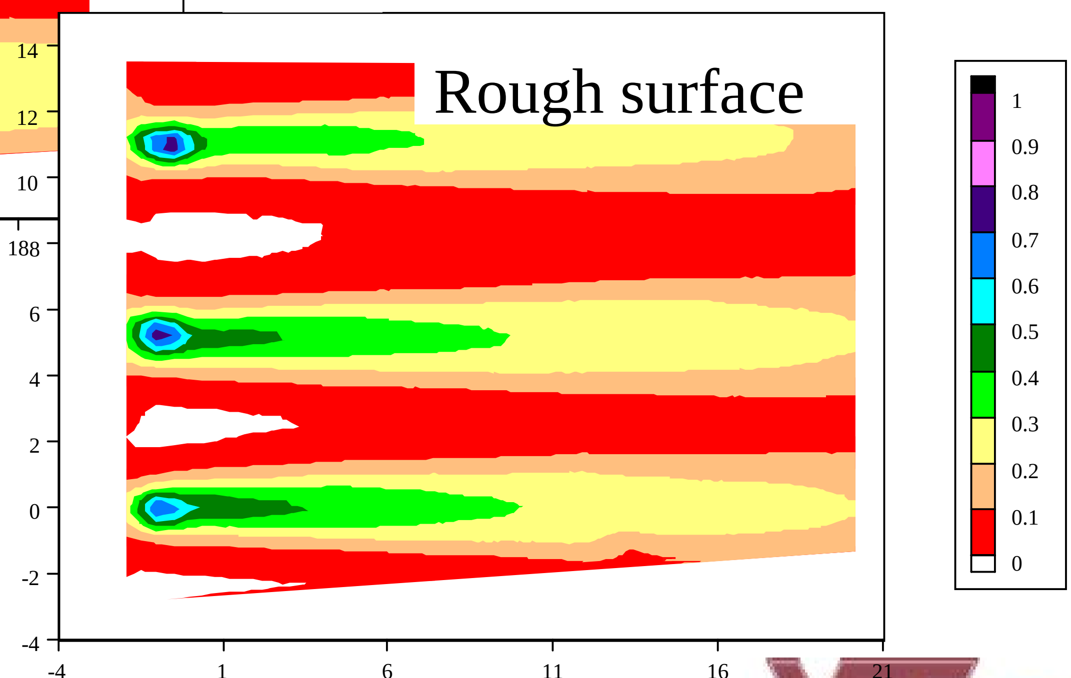


A rough surface causes a significant reduction in adiabatic effectiveness for all blowing ratios

Comparison adiabatic effectiveness contours with smooth and rough surfaces

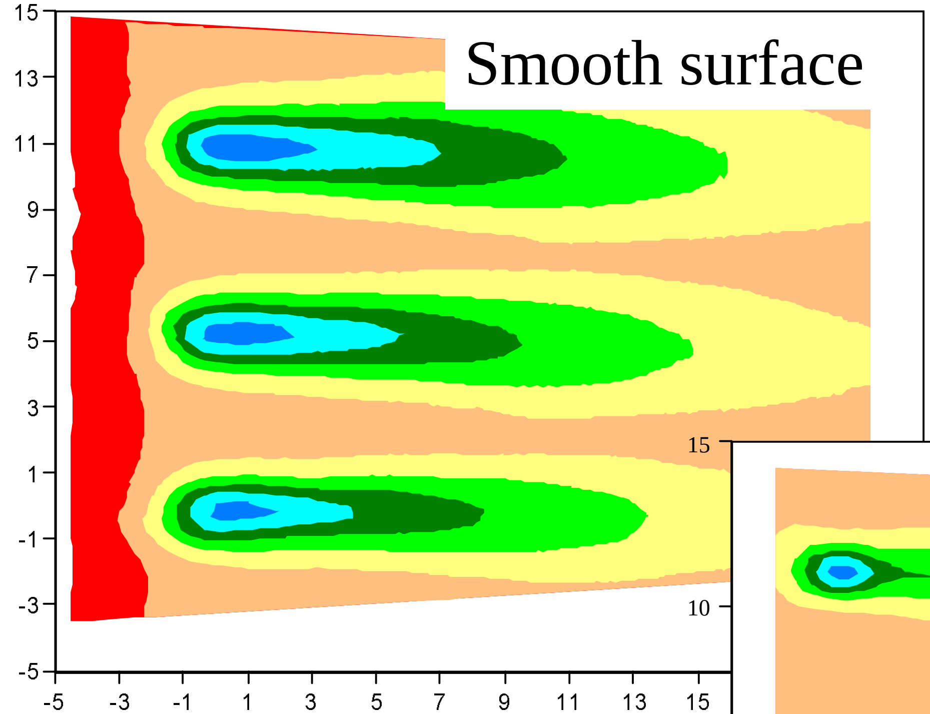


Low mainstream turbulence and no showerhead blowing

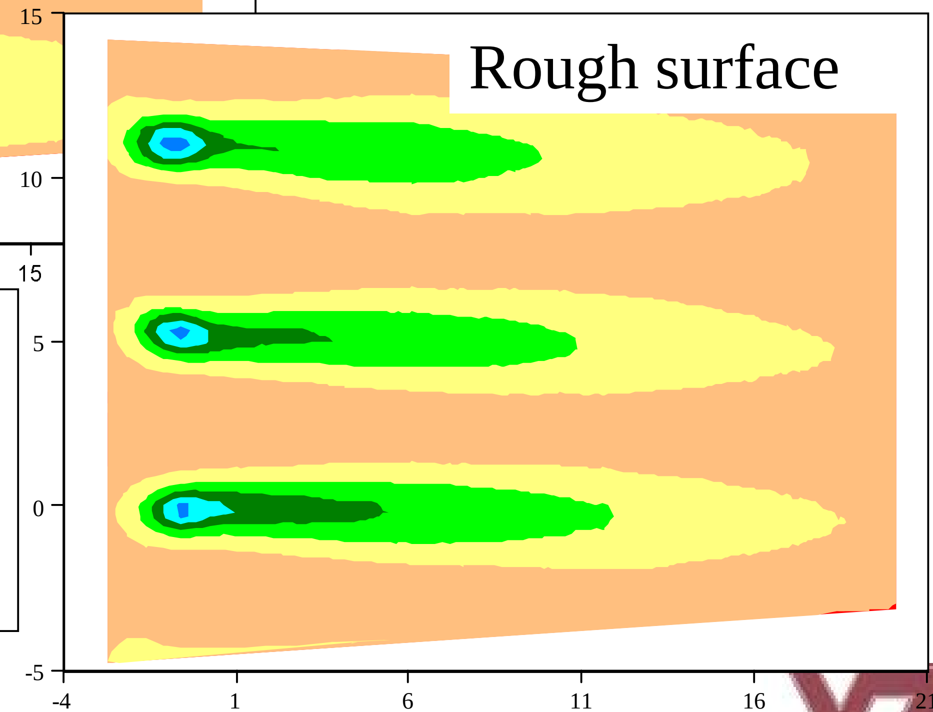


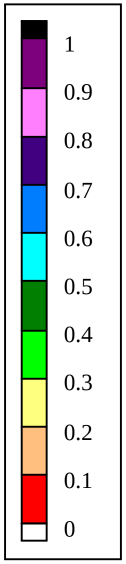
With the rough surface the coolant jets appear to have separated from the surface

Comparison adiabatic effectiveness contours with smooth and rough surfaces



High mainstream turbulence with showerhead blowing





The rough surface had little effect on the showerhead coolant, but again cause the coolant jets on the suction side to separate from the surface

Conclusions from rough surface study

Surface roughness upstream of a row of coolant holes on the suction side of the vane was found to cause a significant reduction in adiabatic effectiveness. This reduction appeared to be due to the coolant jets detaching from the surface for the rough surface condition. This may be attributed to a large momentum deficit in the boundary layer following the rough surface section, and/or increased turbulence in the near wall region due to the surface roughness.