# Detailed Flow and Thermal Field Measurements on a Scaled-Up Stator Vane

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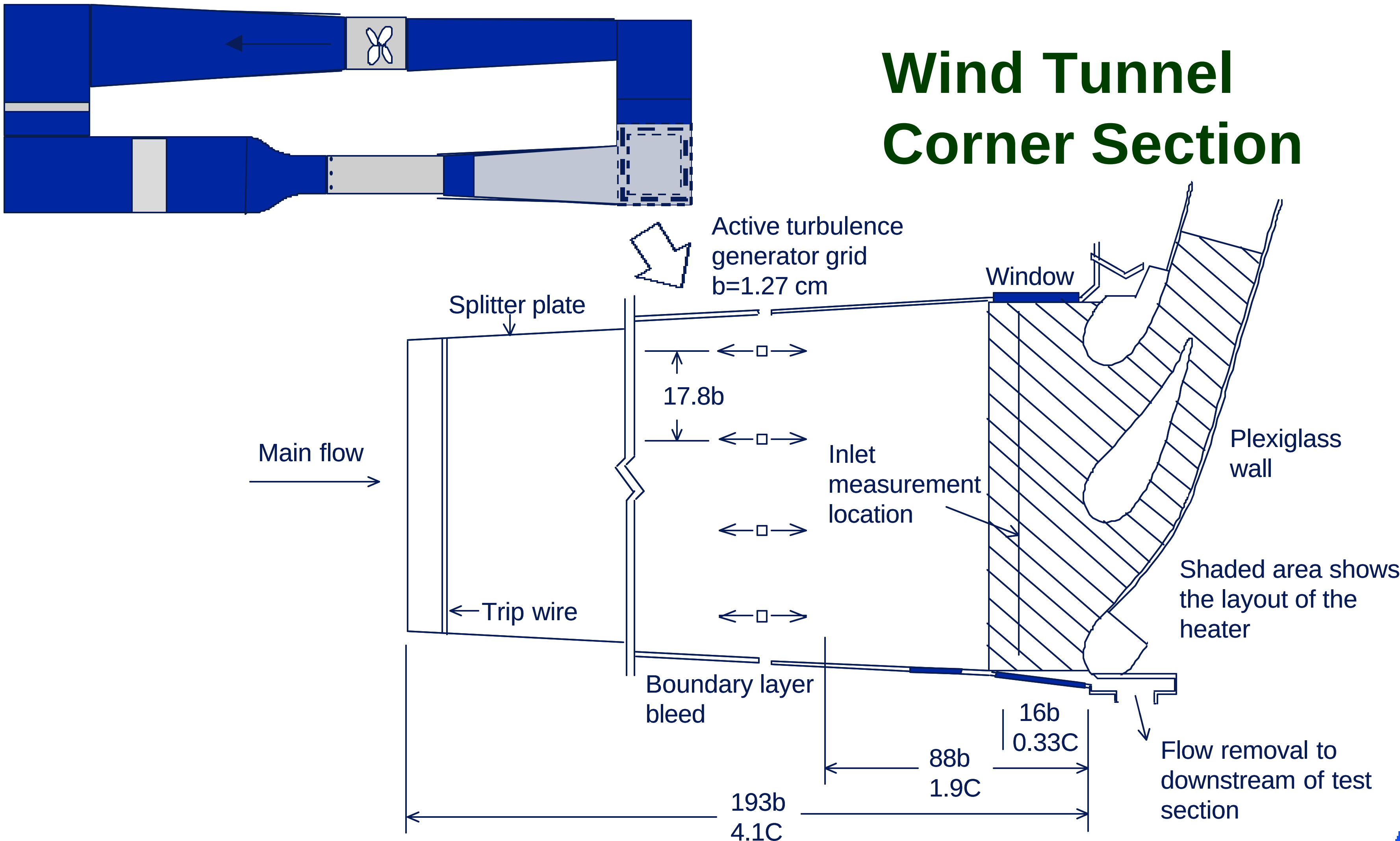
# Research Objectives

- Provide vane heat transfer and detailed flow and thermal field data to benchmark computational flow codes for various levels of difficulty
- Provide a better understanding of turbine vane boundary layers through detailed measurements
- Provide a better understanding of freestream turbulence and length scale effects on vane heat transfer

# Experimental approach provides increasing levels of difficulty

| Task | Description | Organization |
|---|---|---|
| 1 & 2 | Two-dimensional dry airfoil with and without high turbulence | UW-Madison Va Tech |
| 3 & 4 | Two-dimensional film-cooled airfoil with and without high turbulence | UT-Austin |
| 5 & 6 | Three-dimensional dry airfoil with and without high turbulence | UW-Madison Va Tech |
| 7 & 8 | Three-dimensional film-cooled airfoil with and without high turbulence | UT-Austin |

# Stator Vane Test Section Geometry

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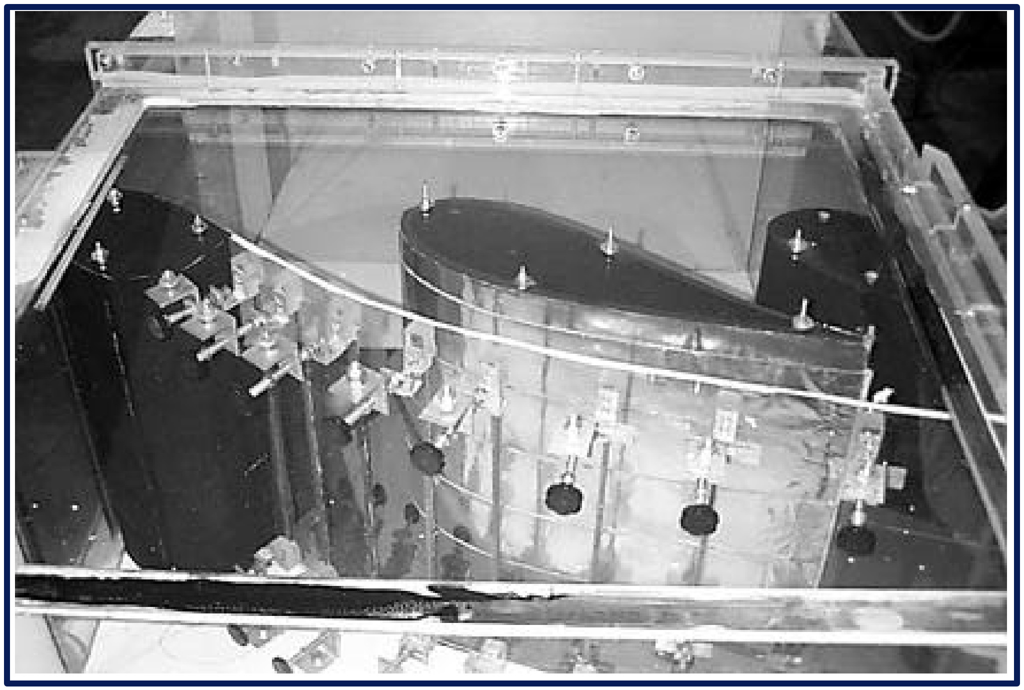
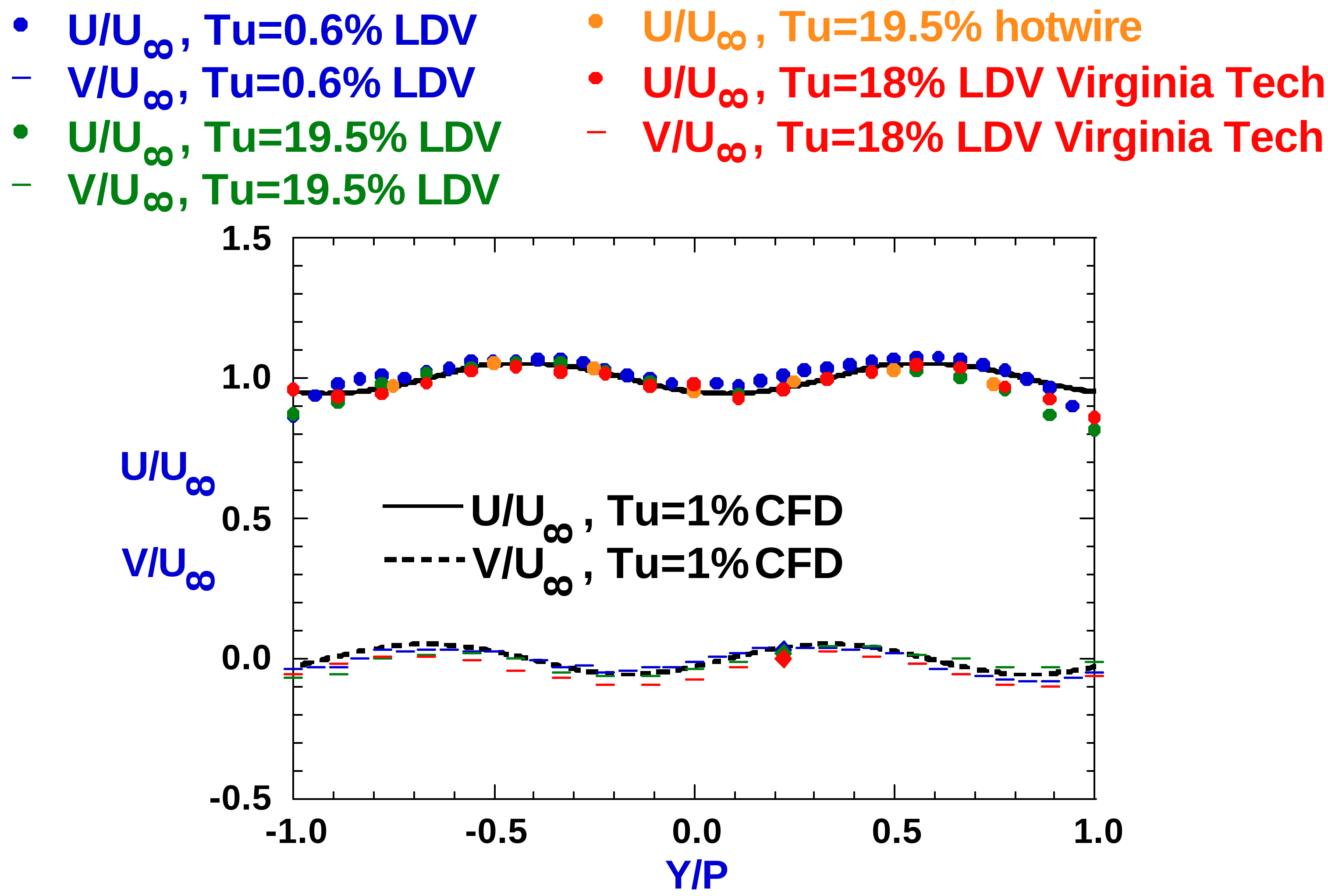
# Experimental Setup and Instrumentation

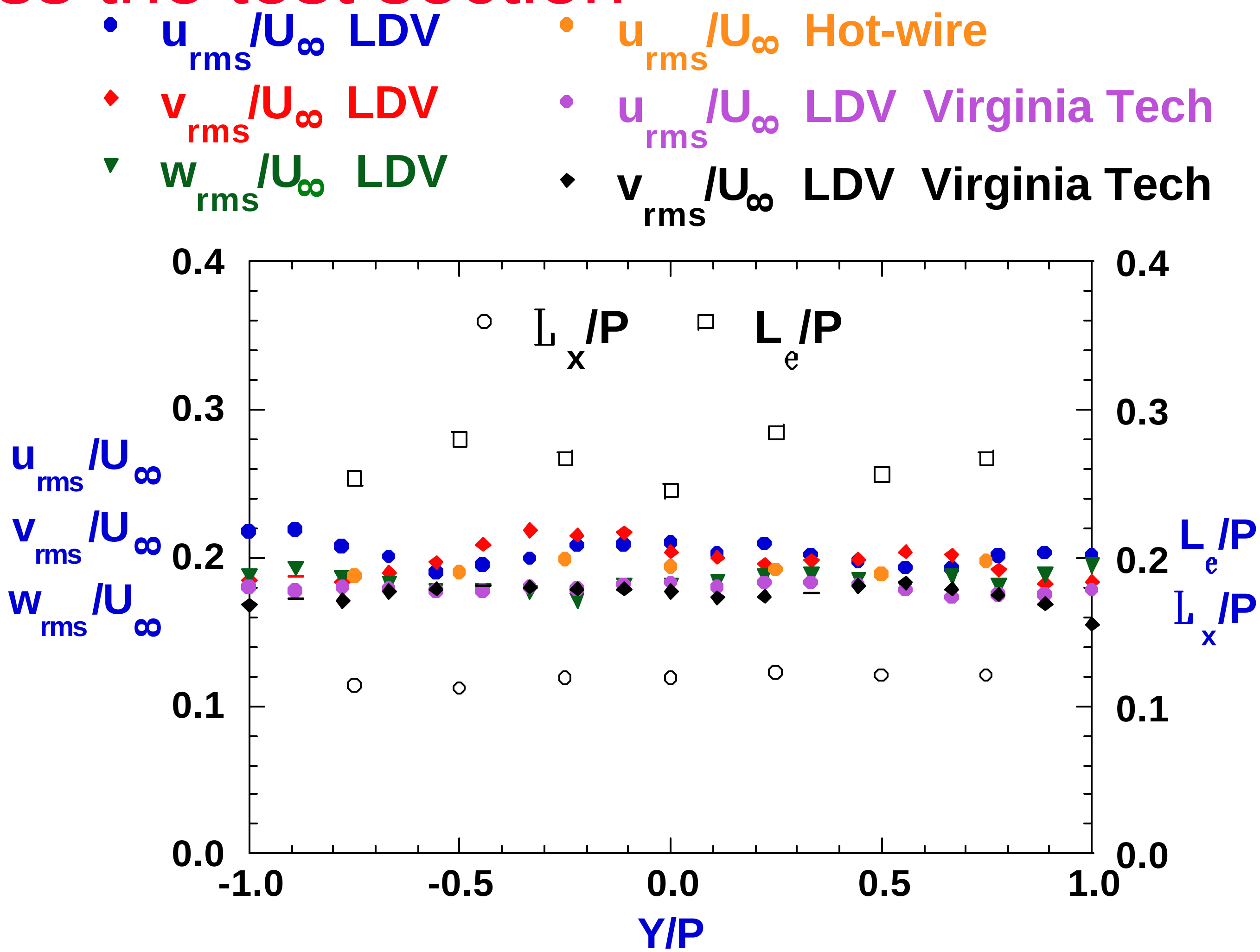


- **Pressure Taps**
- **Thermocouples**
- **2-D fiber-optic LDV system**
- **Hot-wire anemometer**
- **Infrared camera**

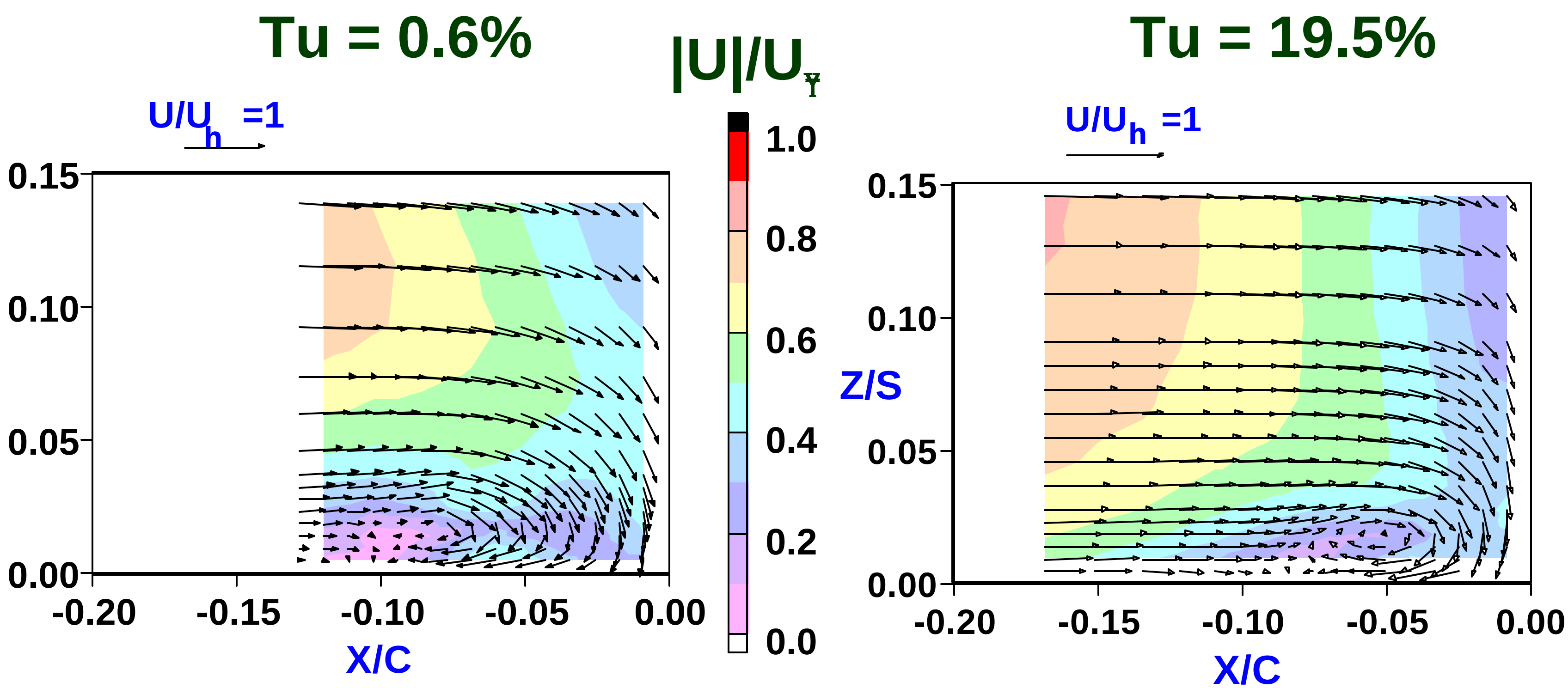
# The mean velocities at X/C = -0.33 are unaffected by the high turbulence level



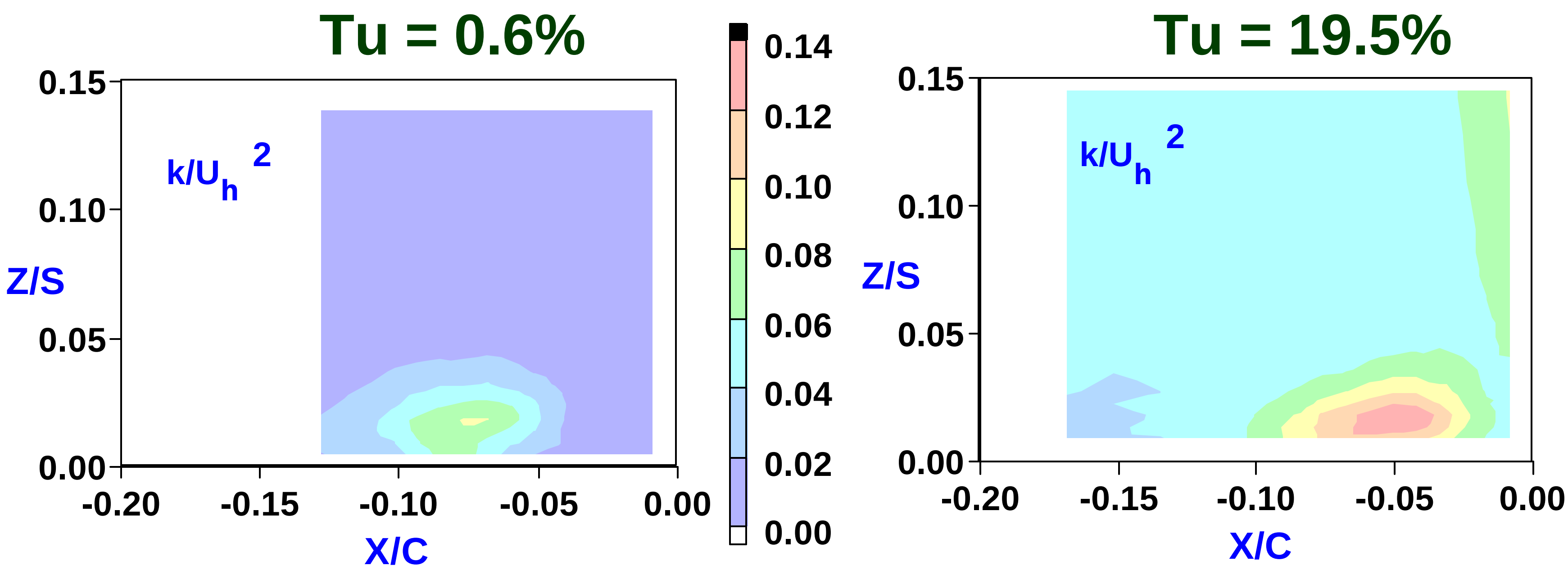
# Turbulent quantities at X/C=-0.33 are uniform across the test section



# The leading edge horseshoe vortex moves downstream at elevated turbulence conditions



# High levels of turbulent kinetic energy are observed at the center of the vortex

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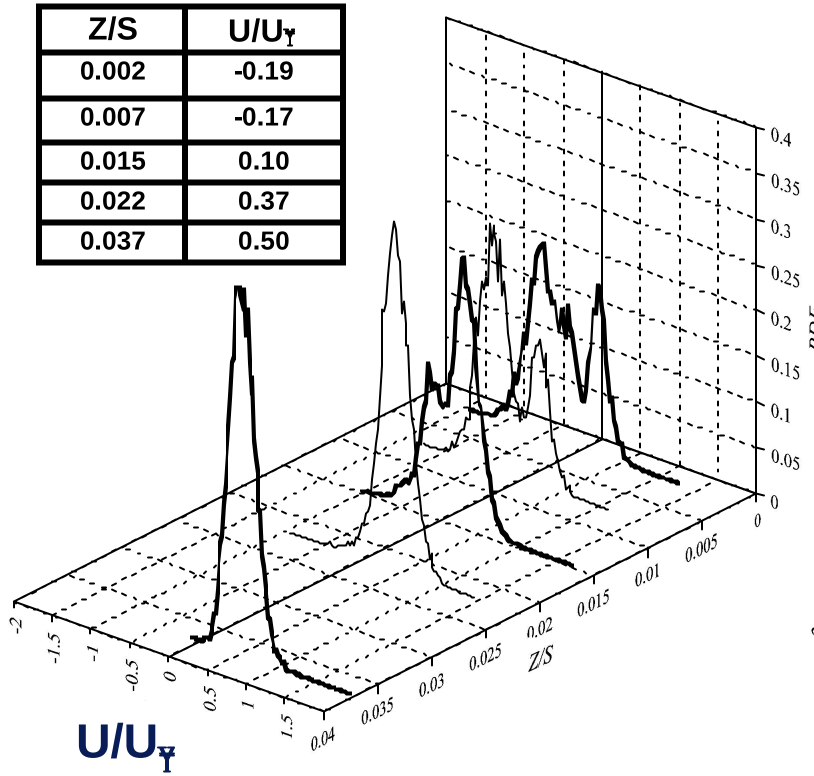
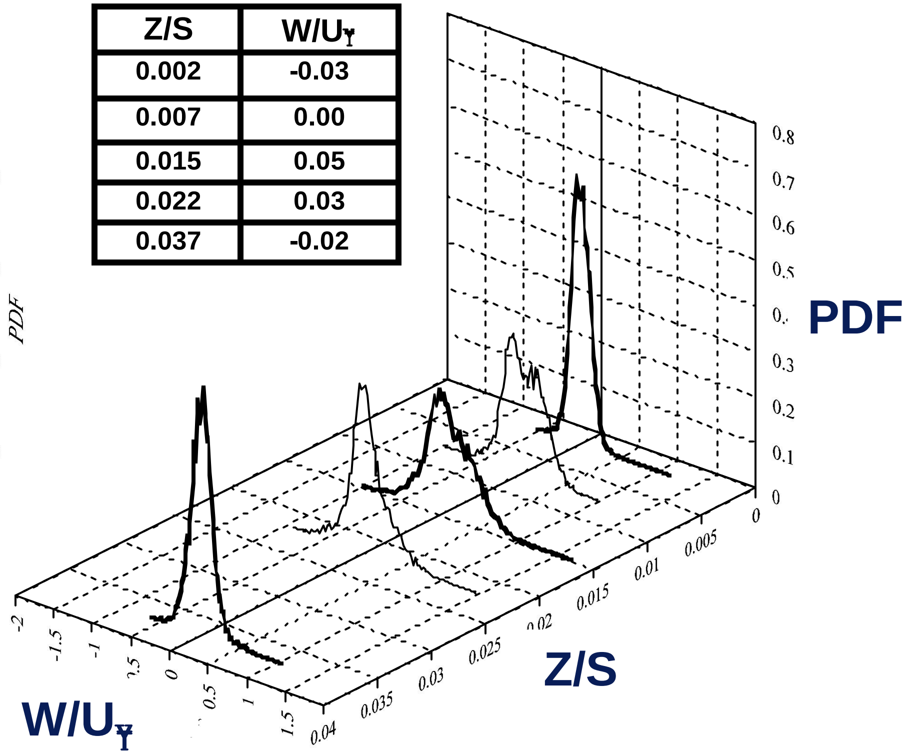
# The horseshoe vortex is unsteady at elevated turbulence levels

## Probability Density Functions (PDF)

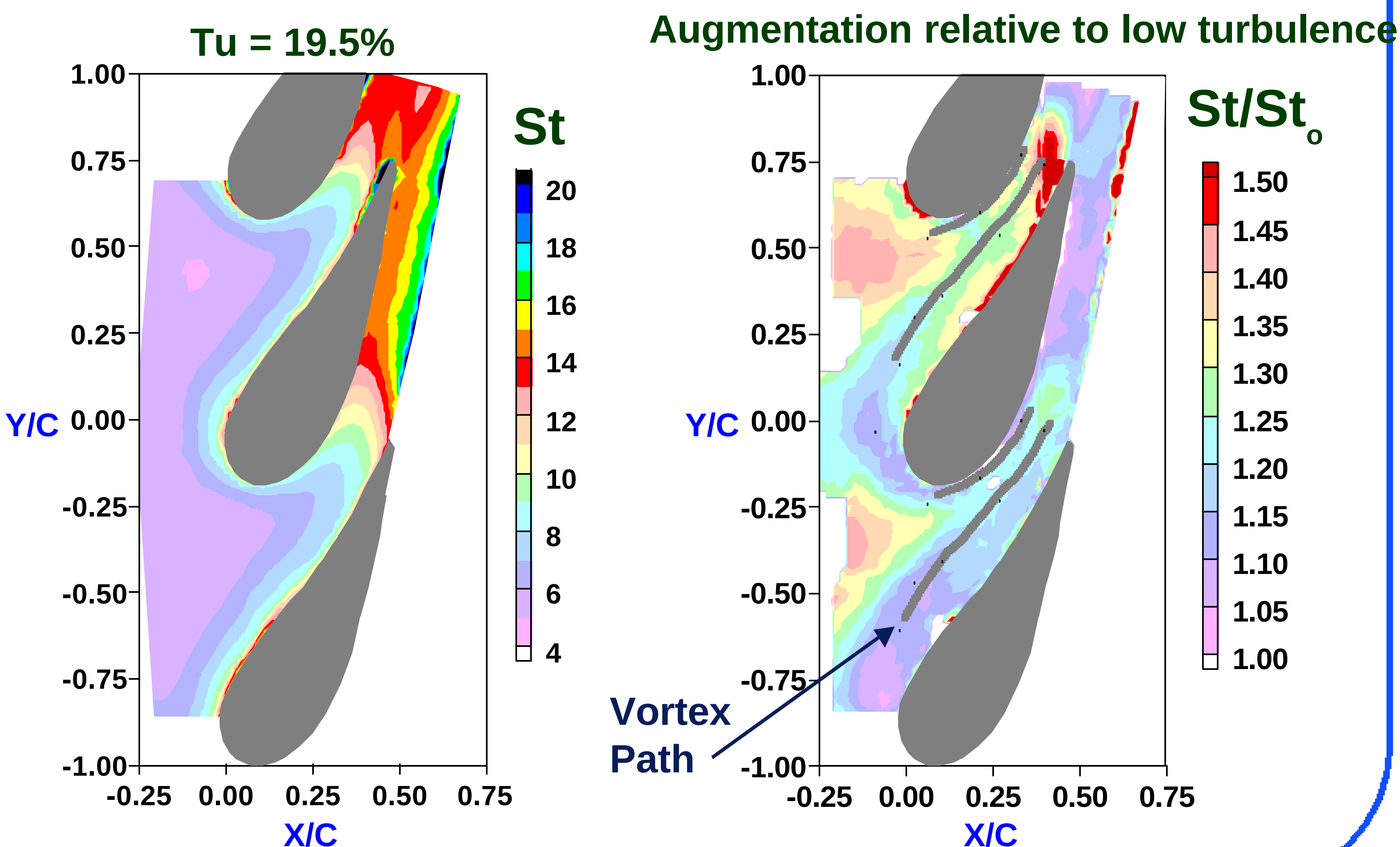
| Z/S | $U/U_\tau$ |
|---|---|
| 0.002 | -0.19 |
| 0.007 | -0.17 |
| 0.015 | 0.10 |
| 0.022 | 0.37 |
| 0.037 | 0.50 |




| Z/S | $W/U_\tau$ |
|---|---|
| 0.002 | -0.03 |
| 0.007 | 0.00 |
| 0.015 | 0.05 |
| 0.022 | 0.03 |
| 0.037 | -0.02 |



# Endwall heat transfer increases with high levels of freestream turbulence

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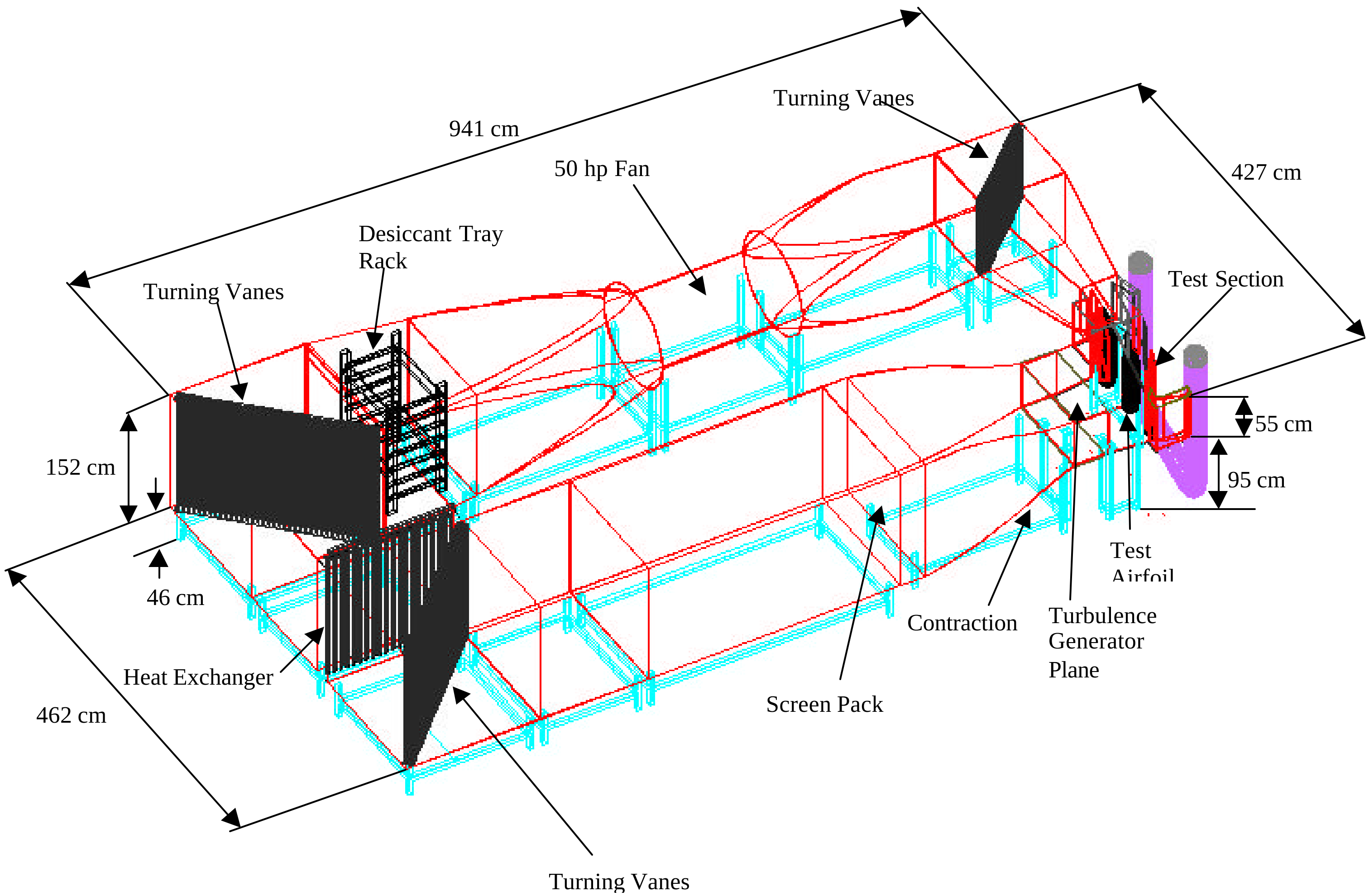
# Conclusions from VT work

- **High turbulence levels occur at the center of the leading edge and passage vortices**

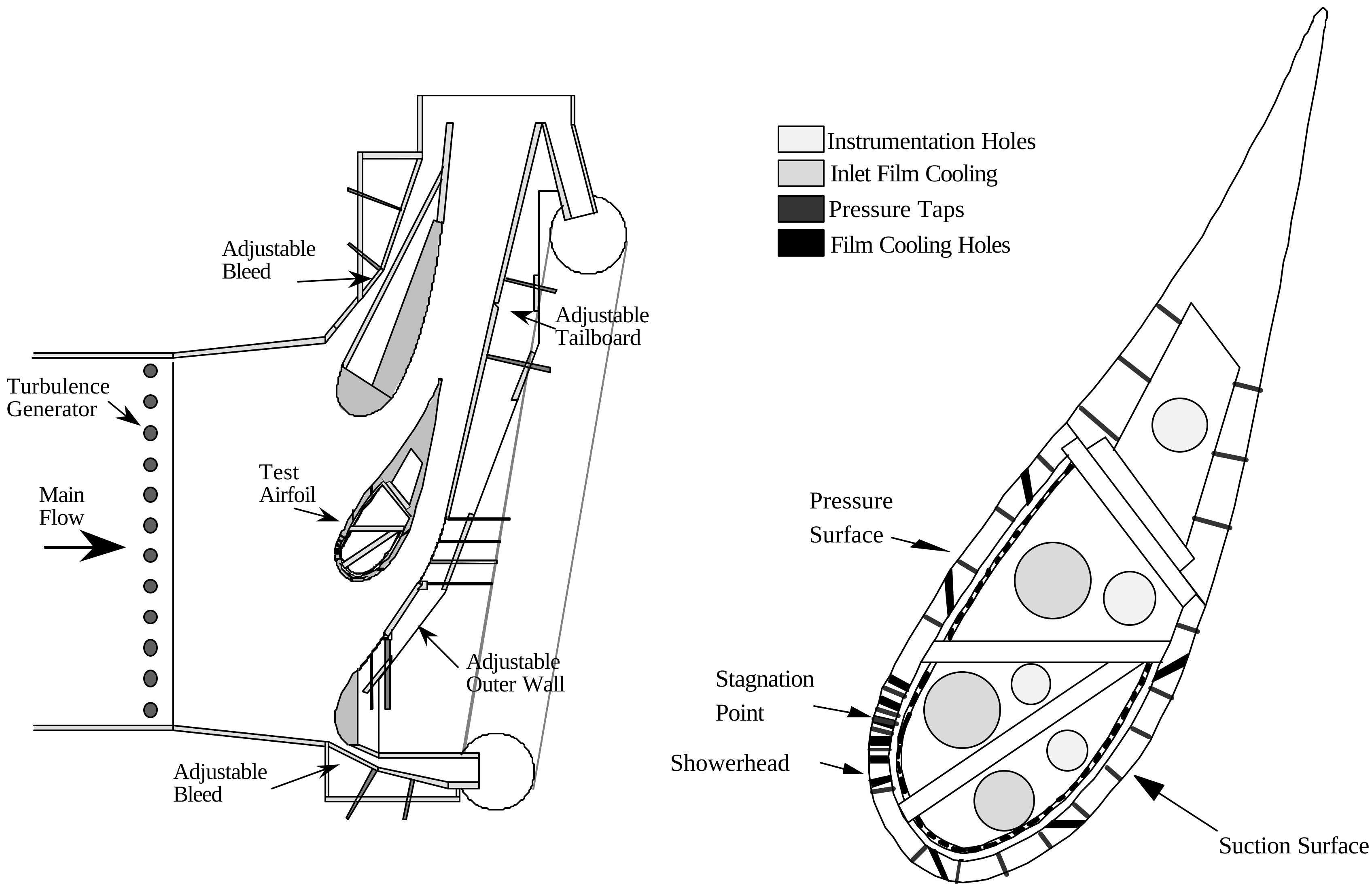
- **Leading edge horseshoe vortex is highly unsteady for both low and high freestream turbulence levels**

- **High freestream turbulence increases endwall heat transfer with only small augmentations in regions where secondary flows are strong**

# Turbine Vane Facility



# Test Section

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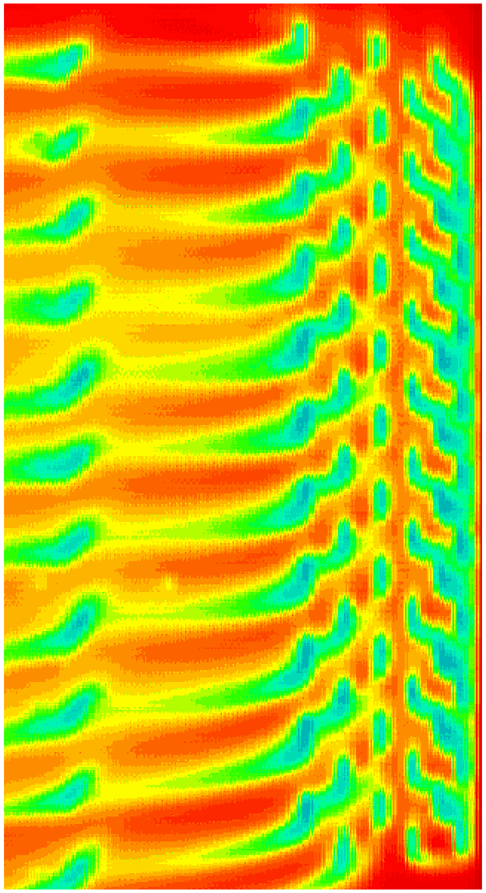
# Surface Temperature Image using Infrared Camera

with Low Turbulence and Blowing Ratio of 0.5

- Thermal imaging
  - IR camera measures thermal field in FOV
  - *NIH Image* captures thermal image in FOV
- Calibration precision errors
  - Standard error of fit
  - ± 1K (T > 270 K) - ± 2.5 K (T< 235K)
- Camera spatial resolution
  - 2.8 mm x 2.8 mm



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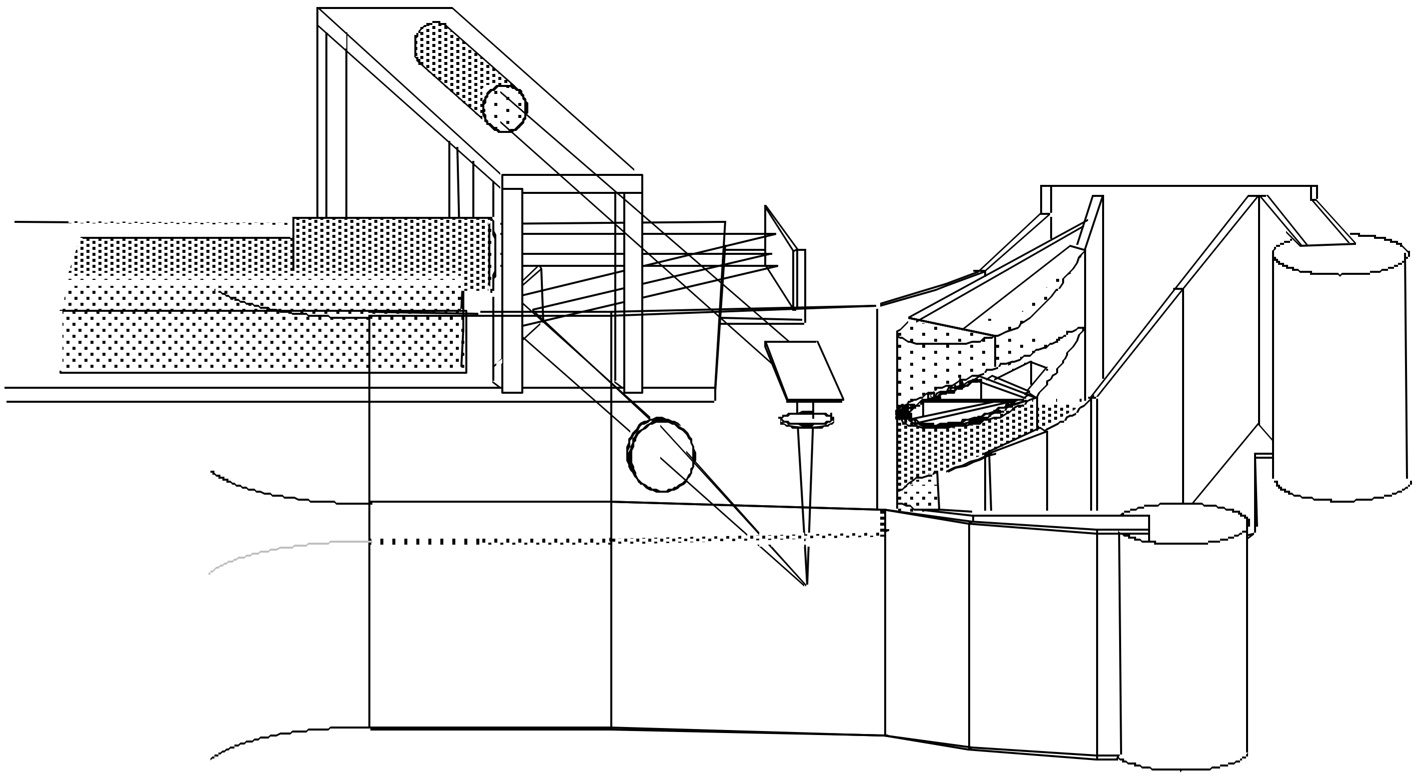
# Three Component LDV Layout

## Argon Ion Laser, All Beams Collected by Side Scatter



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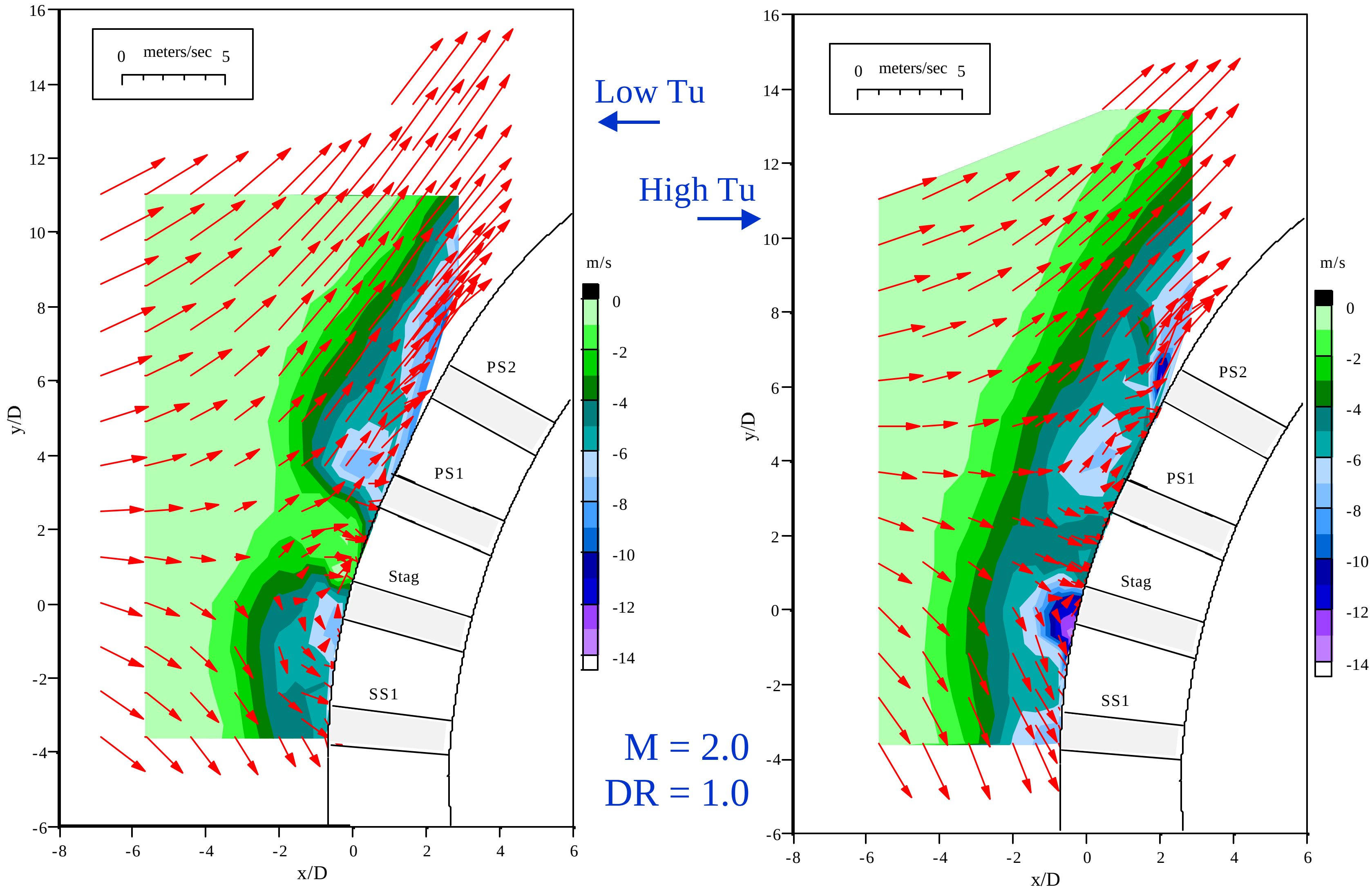
# Velocity Field @ Low and High Tu

Indicates increased lateral spreading in stagnation region with high turbulence.

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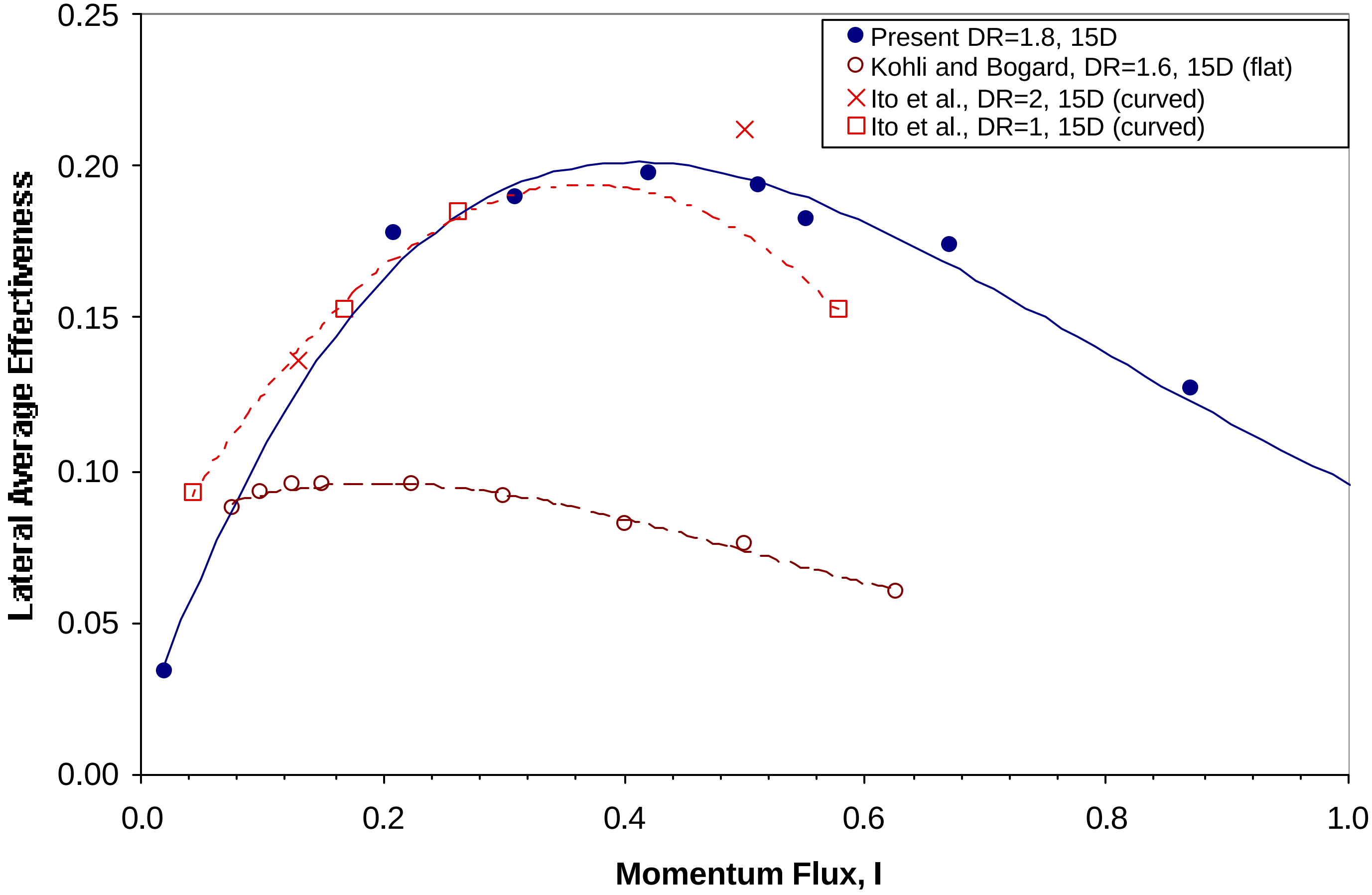
# Comparison of Suction Side Film Cooling with Previous Studies

Indicates strong similarity with convex wall studies with little influence of steep injection angle and strong favorable pressure gradients.

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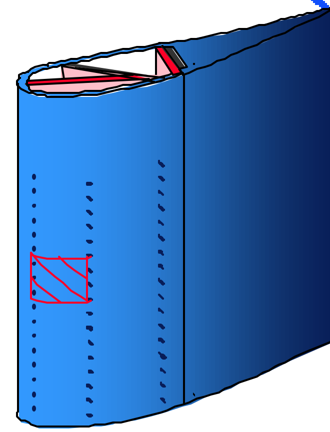
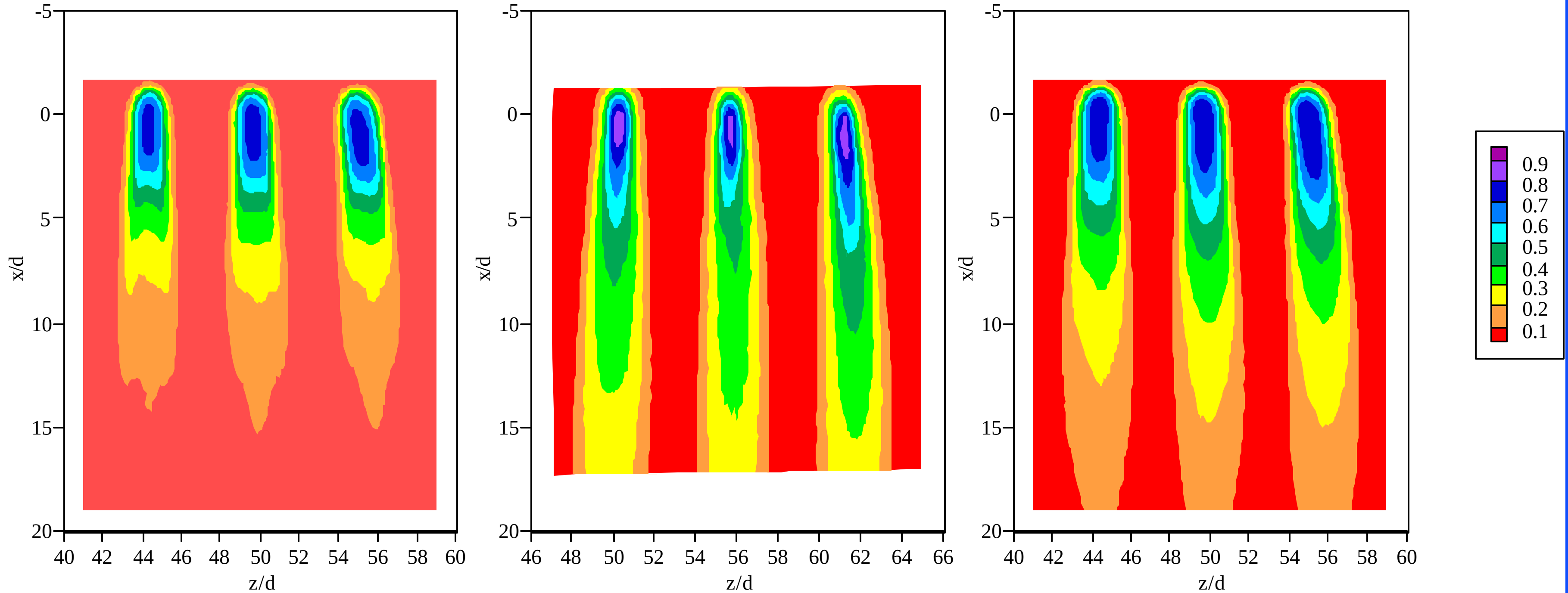
# Suction Side Film Cooling

## Adiabatic Effectiveness Contours



Indicates the increased rate of decay for the adiabatic effectiveness at low density ratios with matched blowing ratio or matched momentum flux




$M$=0.40, $I$=0.14, DR = 1.1

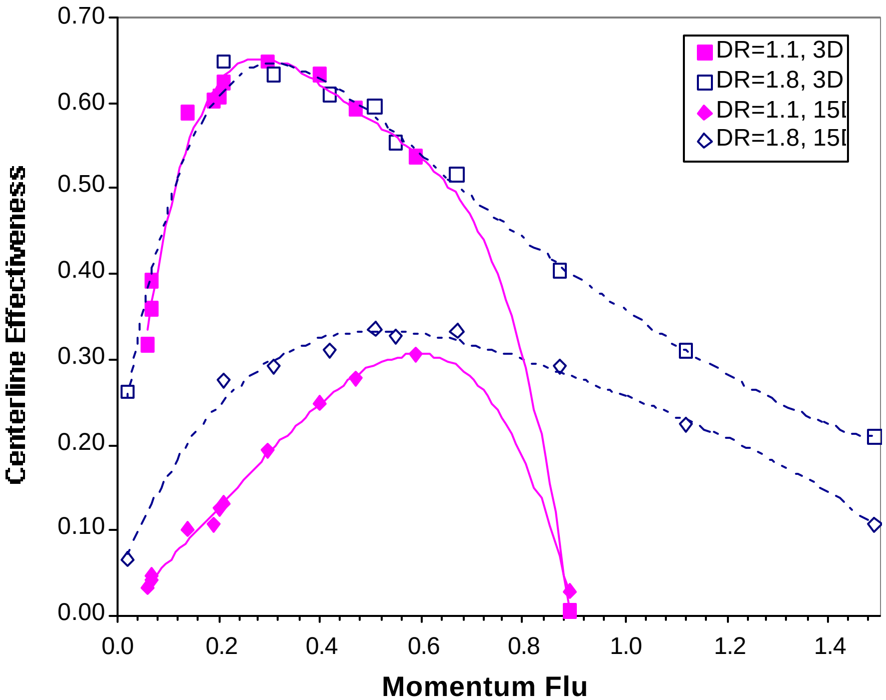
$M$=0.61, $I$=0.20, DR = 1.8

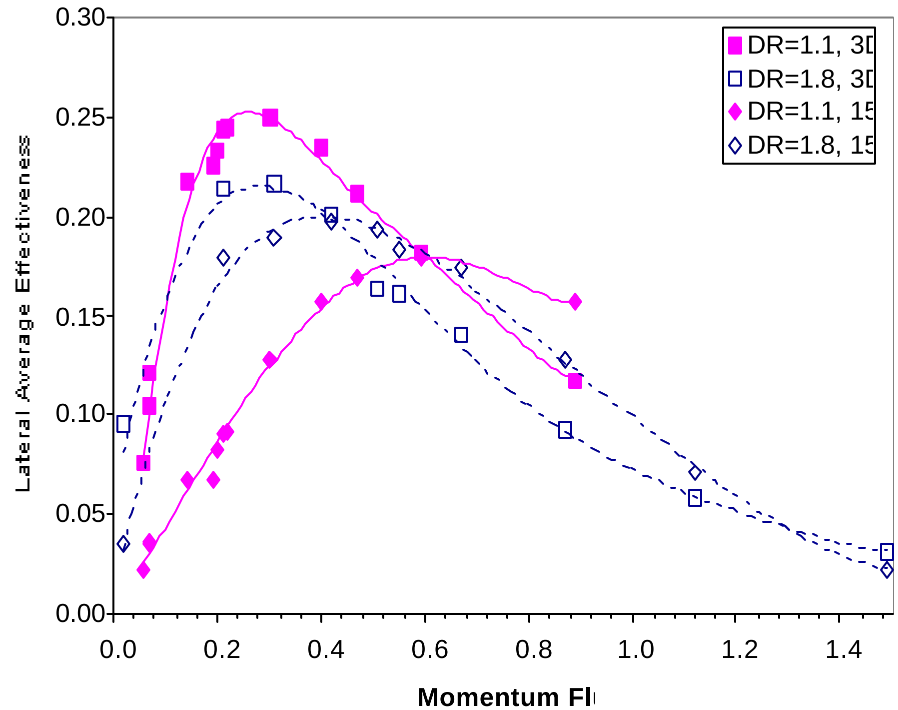
$M$=0.57, $I$=0.30, DR = 1.1

# Suction Side Film Cooling

## Density Ratio Effects @ Low Turbulence

Indicates that near the hole and low momentum flux, the adiabatic effectiveness scales well with the momentum flux.  However, the low density ratio coolant jets tend to display an increased decay rate and separate at a lower Momentum Flux.

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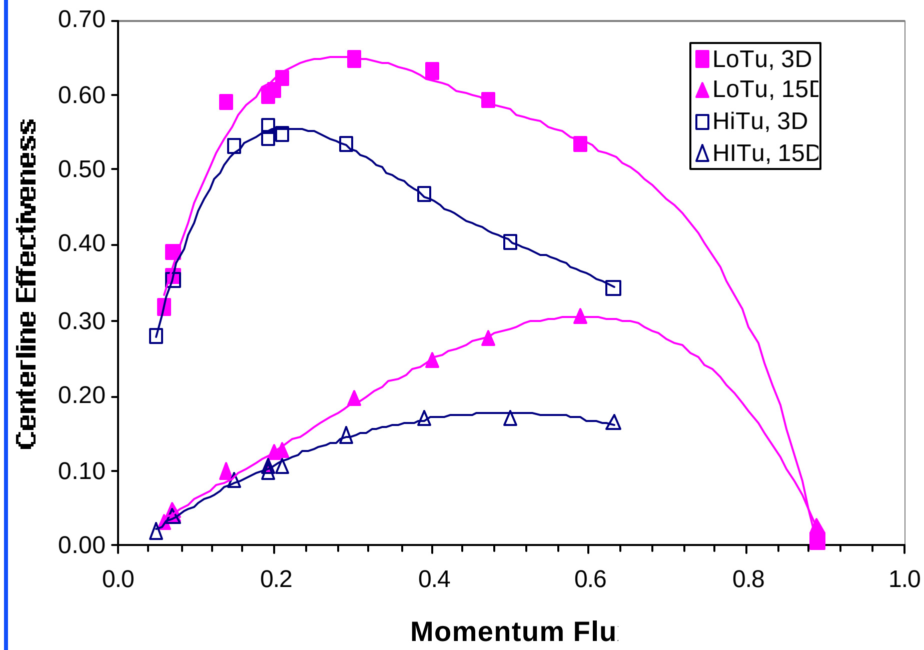
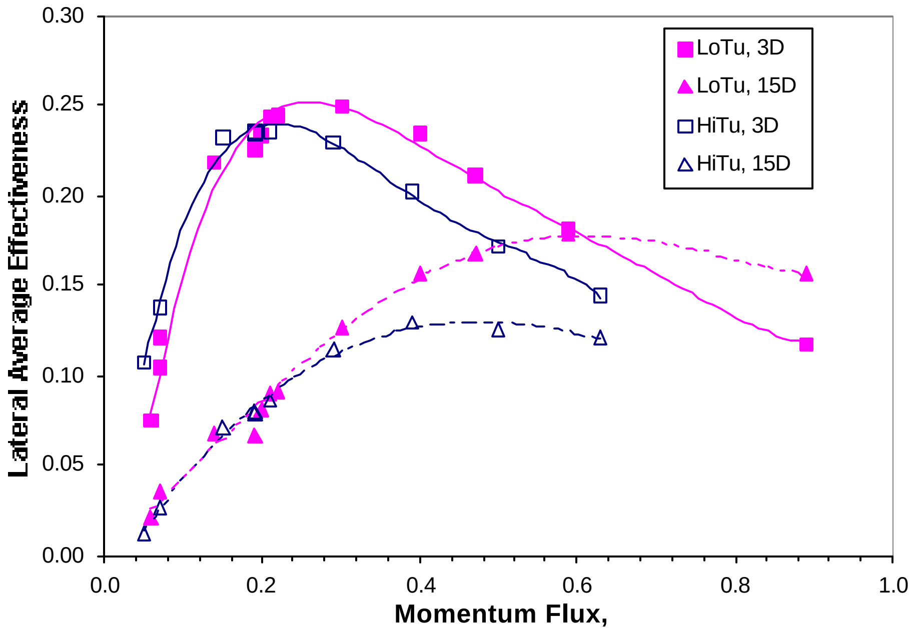
# Suction Side Film Cooling

## Turbulence Effects @ DR = 1.1

Indicate that for low momentum flux ratios, the turbulence has little effect on film cooling and for high momentum flux ratios, the turbulence has a negative effect on film cooling.  These trends are opposite those for a flat plate.



# Summary of UT work

- **Three component velocity field measurements were completed within the hole pattern of the showerhead showing details of the interaction of jets with the mainstream.**
- **Studies of the suction side cooling were completed with a focus on the first row holes where there is very strong curvature that significantly increases adiabatic effectiveness.**
- **Studies using large and small coolant density ratios showed scaling of performance with the momentum flux ratio of the jets.**
- **Very high mainstream turbulence caused little degradation in performance at low blowing ratio, but a decrease at higher blowing ratios.**

# Collaboration with Industry

- **Flowfield measurements presented to Pratt & Whitney in November, 1998**
- **Research meeting at Pratt & Whitney in September, 1999**
- **Roger Radomsky from the University of Wisconsin interned at Pratt & Whitney during the fall semester 1998**
- **Marcus McWaters from the University of Texas interned at Pratt & Whitney during the summer semester 1999**