Construction of a Non-Equilibrium Thermal Boundary Layer Facility

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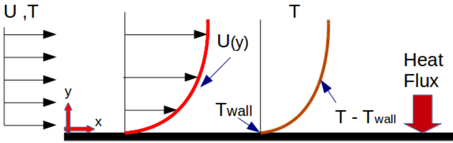
Non-Equilibrium Thermal Boundary Layers

Non-Equilibrium Boundary Layers brought about from;

- Induced pressure gradients
- Temperature gradients
- Separation
- Dynamic walls
- Unsteady flow

In many engineering applications one or several of these effects are important

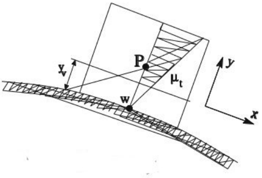
Equilibrium Boundary Layer



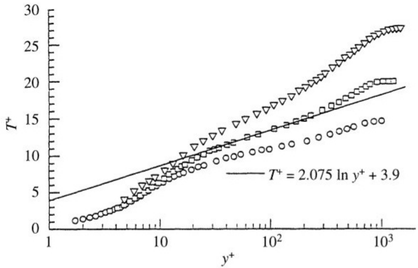
http://science.howstuffworks.com/

Modeling Non-Equilibrium Flows

- Computationally expensive to solve near wall dynamics
- Near wall dynamics extrapolated from log profile
- Reasonable estimate for equilibrium wall flows
- Fail when applied non-equilibrium boundary layers



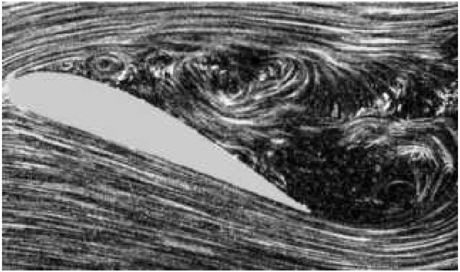
P. Bradshaw and G. P. Huang



Bradshaw et al., *The law of the wall in turbulent flow*

Creating a Non-Equilibrium Boundary layer

- Need to create test-bed for developing non-equilibrium flows
- Require data sets to improve current wall models
- Control both momentum and thermal boundary layer



http://en.wikipedia.org/wiki/flow/separation

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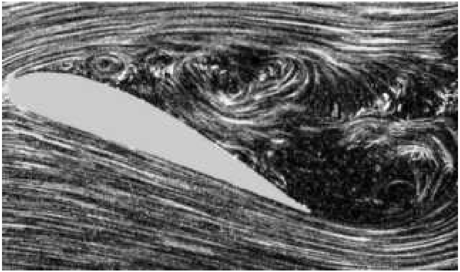
$$\rightarrow U_\infty$$

$$\rightarrow \frac{\partial U}{\partial t}$$

$$\rightarrow T_{wall}$$

$$\rightarrow T_\infty$$



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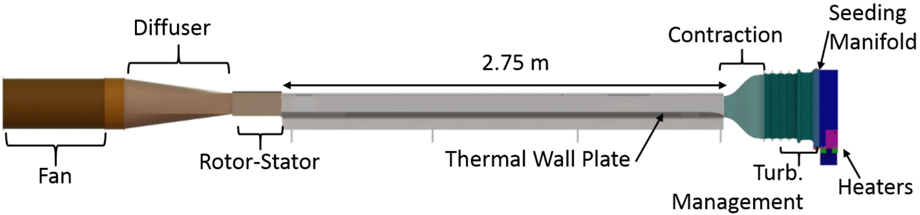
Experimental Facility

- Length=2.75m $\longrightarrow$ Development Length
- Turbulent Management section $\longrightarrow$ Free Stream Turbulence
- VFD Controlled Motor $\longrightarrow$ U_∞
- Bank of Resistive Heaters $\longrightarrow$ T_∞
- Thermal Wall Plate $\longrightarrow$ T_{wall}
- Rotor-Stator Mechanism $\longrightarrow$ $\frac{\partial U_\infty}{\partial t}$



UNH Thermal Boundary Layer Wind Tunnel

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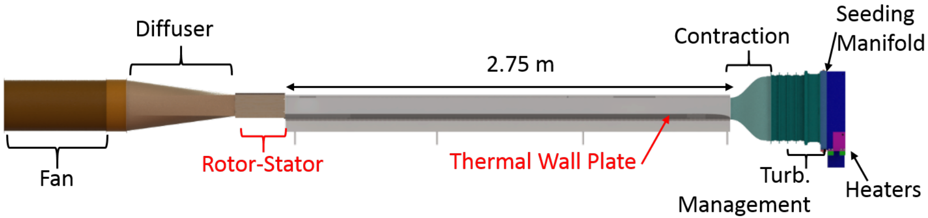
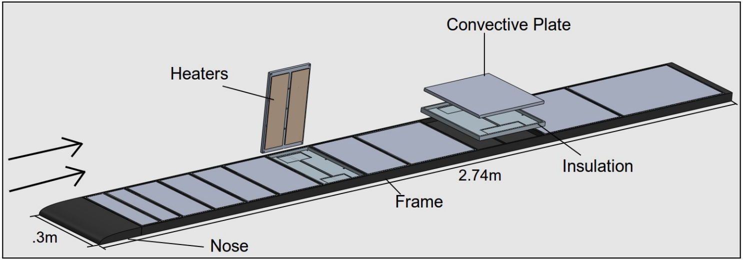


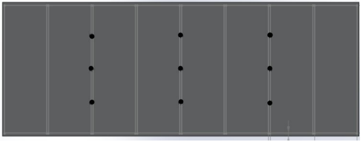
UNH Thermal Boundary Layer Wind Tunnel

Sectioned Thermal Wall Temperature Plate



- Size=0.3m x 2.74m
- Sectioned design*
- Independently heated/controlled*
- Individually Insulated

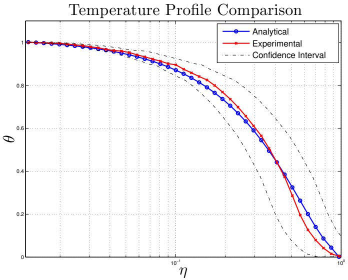
Front Convective Plate

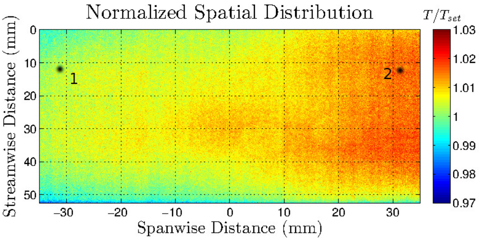


* Blackwell, B. F., *The turbulent boundary layer on a porous plate*

Equilibrium Validation of Final Wall Plate Design

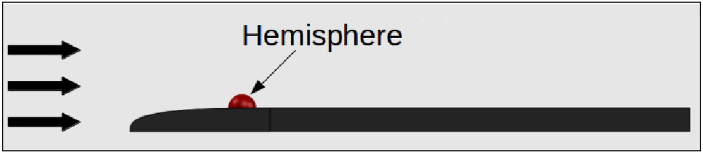
- Control set Temperature to +-0.1°C
- Produce spatially uniform temperature to +-2% in equilibrium flow
- Develop 2D equilibrium thermal boundary layer

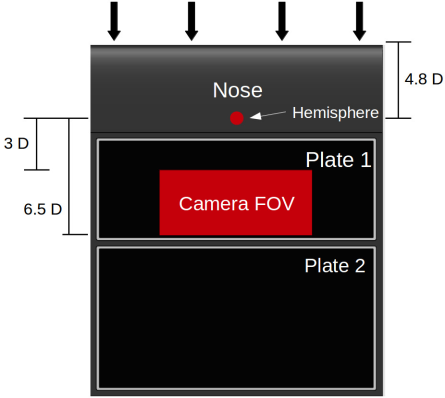




Thermocouple $\#1 = 50^{o}C$ Thermocouple $\#2 = 50.01^{o}C$

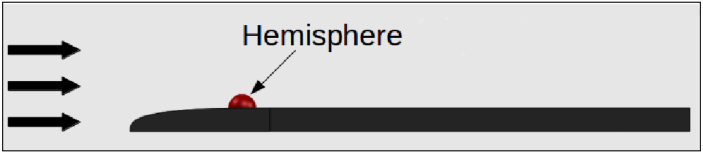
Non-Equilibrium Validation of Final Wall Plate Design



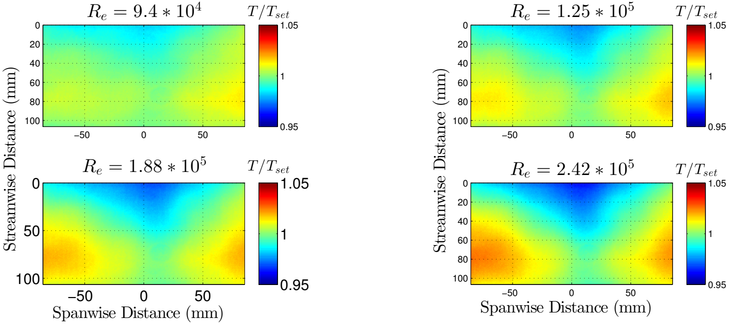


- 3cm Diameter
- Insulated Hemisphere
- $\frac{D}{\delta} = 10$

Non-Equilibrium Validation of Final Wall Plate Design



Set Temperature=60°C



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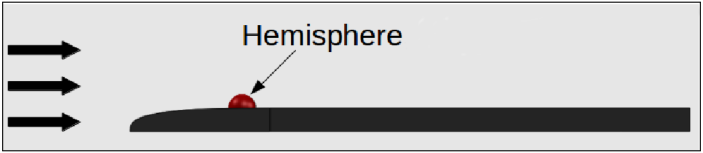
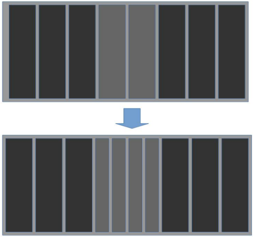
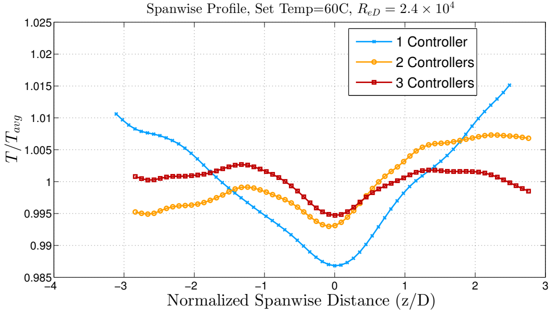
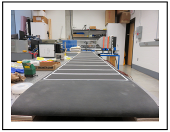


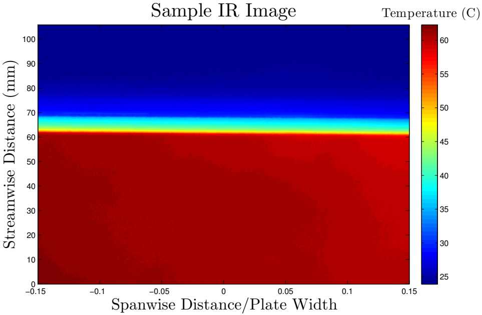




- Increase number of resistive heaters
- Increase number of controllers

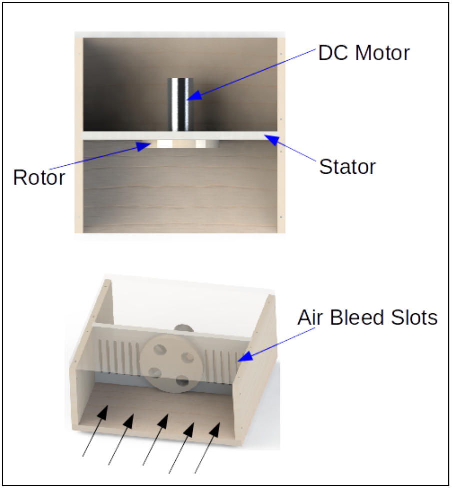
Sectioned Thermal Wall Temperature Plate



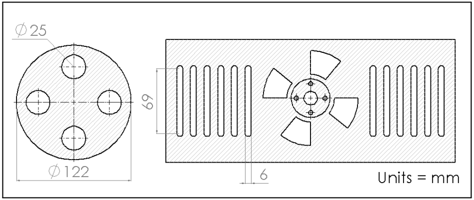


- Insulation left unpainted resulting in different emissivity and non-physical temperature

Rotor-Stator Design



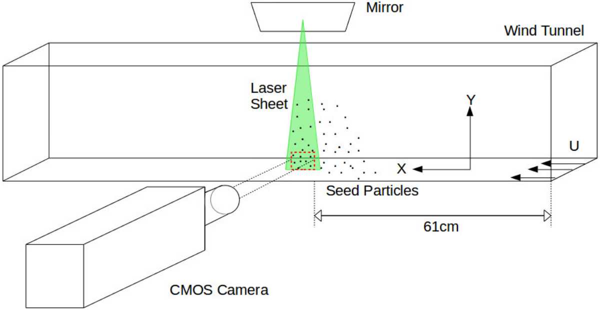
- Slotted Rotor-Stator design
- Rotor outer diameter = channel height
- Adjustable number of air-bleed slots
- Rotor speed adjustable from 8Hz to 85Hz



[1]

[1] K. Al-Asmi and I.P. Castro, *Production of oscillatory flow in wind tunnels*

Rotor-Stator Testing



- Nd:YLF 527nm Photonics laser
- 12-bit Photron SA4 CMOS camera
- Sampled at 2kHz for 6000 images
- $R_e = 7.04 \times 10^4$
- $\delta = 2.8cm$
- Tested from $60\% F_a \rightarrow 120\% F_a$ $F_a = \frac{c}{4l}, = 31.45Hz$
- 40% Fluctuating area

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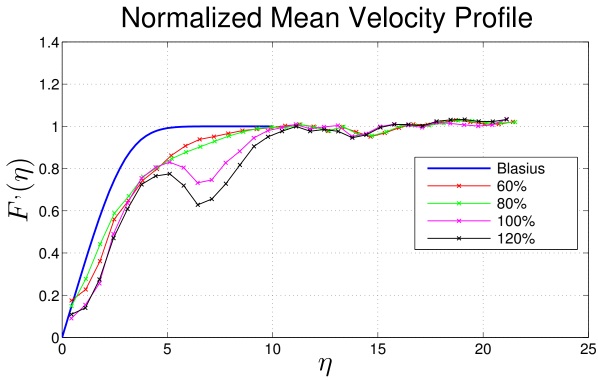

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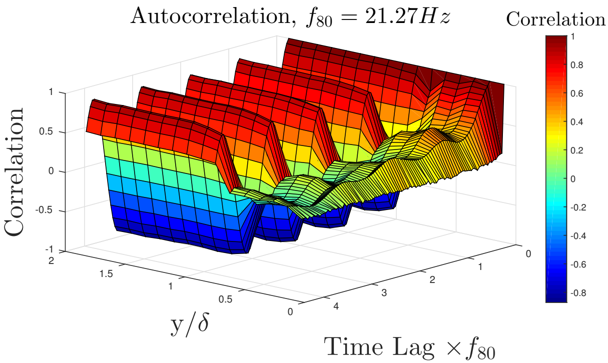

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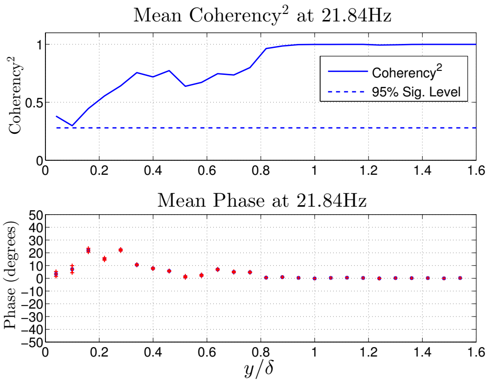

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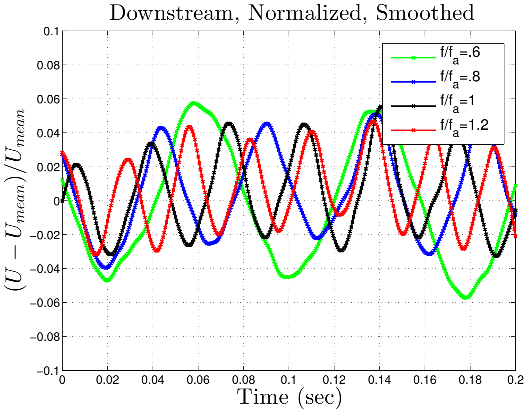

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Conclusions/Capabilities

- Thermal wall plate
  -Control set wall temperature to +-0.1^{o}C
  -In equilibrium/non-equilibrium flow produce spatially uniform temperature to +-2%
  -Produce 2D equilibrium thermal boundary layer
- Rotor-Stator mechanism
  -Produce Pulsatile flow up to +-5% of mean flow

Future Work

- Coupled temperature and velocity measurements in equilibrium environments
- Measurements in non-equilibrium environments of increasing complexity
  -flow behind a hemisphere
  -pulsatile flow
  -multiple perturbation flows