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Experimental Measurements of a Non-Equilibrium Thermal Boundary Layer Flow

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APS-DFD
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AWARD'S: 1258702, 1258594, 1258697

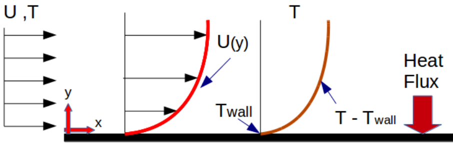
Complex Thermal Boundary Layers

Complex Boundary Layers brought about from;

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

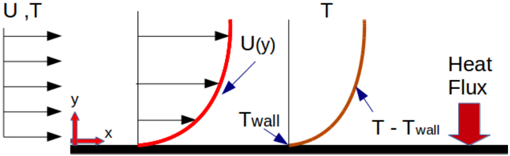
In many engineering applications one or several of these effects are important

Equilibrium Boundary Layer



http://science.howstuffworks.com/

Creating High Quality Datasets



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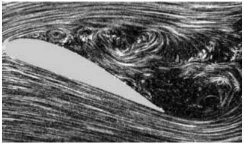

http://en.wikipedia.org/wiki/flow/separation

- Need to create test-bed for developing equilibrium/non-equilibrium flows
- Require experimental data sets to improve/validate models
- Requires controlling all boundary conditions

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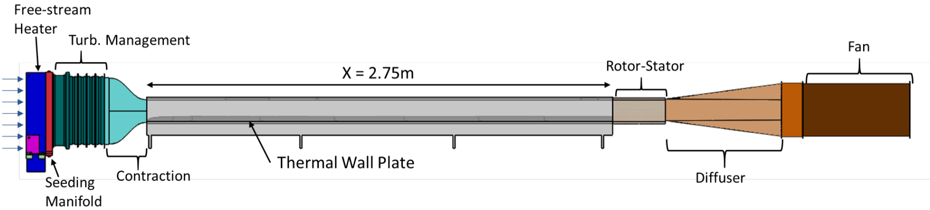
Experimental Facility

Non-Equilibirum And Thermal boundary layer Tunnel (N.E.A.T.)

- 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

D. Biles et al., UNH, APS-DFD 2016
drummond.biles@gmail.com

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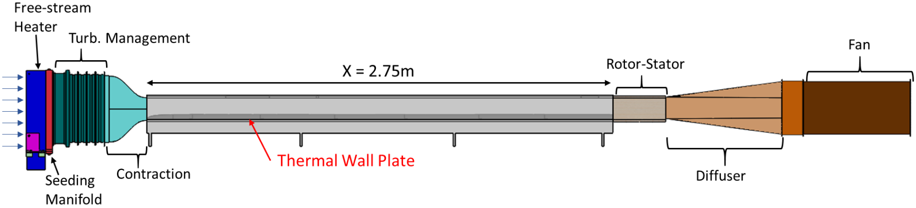

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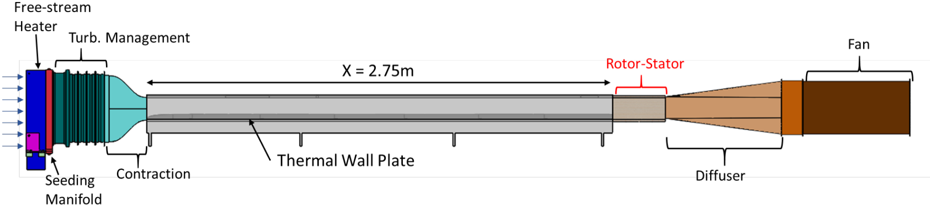
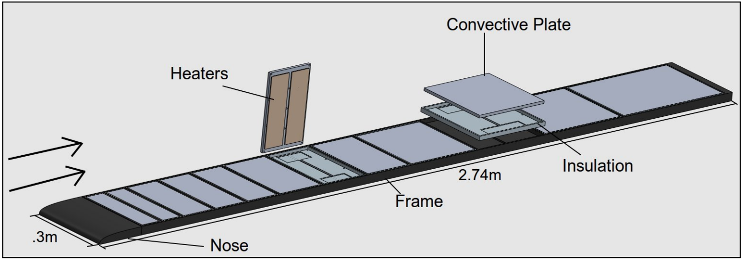


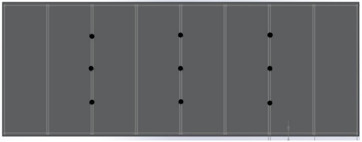
UNH Thermal Boundary Layer Wind Tunnel

Sectioned Thermal Wall Temperature Plate



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

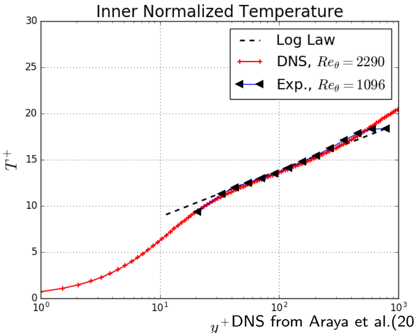
Front Convective Plate



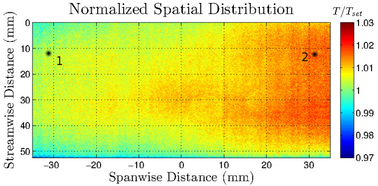
* Blackwell, B. F., *The turbulent boundary layer on a porous plate*

Validation of Wall Plate Design

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



DNS from Araya et al.(2012)



Thermocouple #1 = 50$^o C$ Thermocouple #2 = 50.01$^o C$

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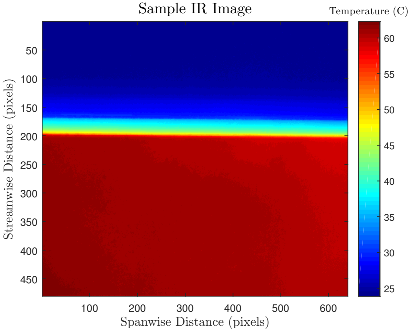
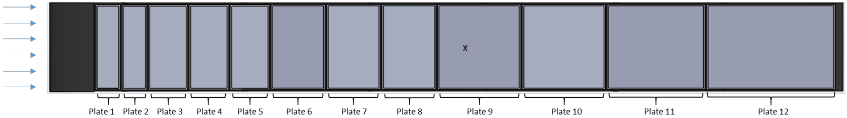
Thermal-Jump

Utilize sectioned design to manipulate stream-wise wall temperature

- Thermal jump
- Thermal gradient
- Non-unifrom stream-wise heating
- Time dependant wall temperature





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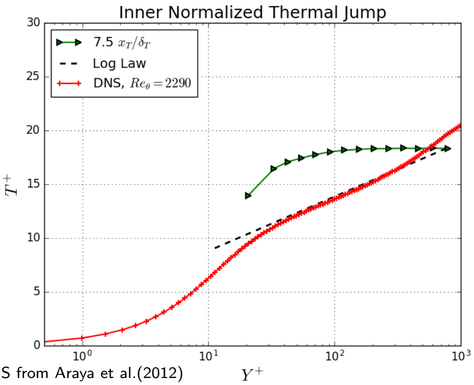

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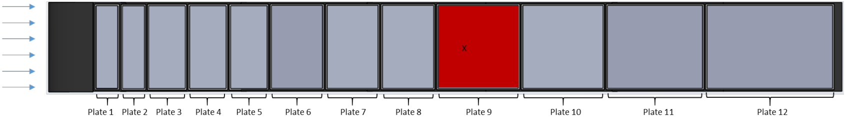
- Type J Thermocouple
- $\delta_T / TC_{diam} = 16$
- Wall Temp $= 40°C$
- $Re_\theta = 1139$
- $T^+ = \frac{T_w - T}{T_w - T_\infty} \frac{u_\infty}{u_\tau} Pr^{2/3}$
- $T^+ = 2.195 ln(y^+) + 13.2Pr - 5.66$



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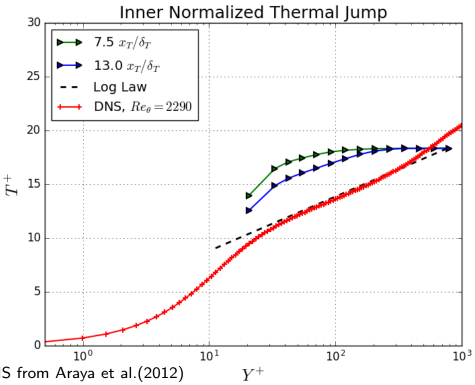

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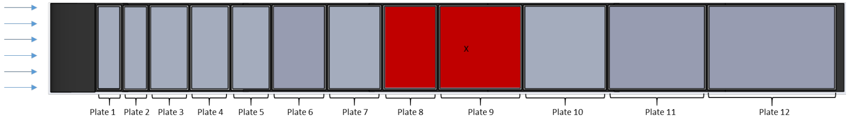

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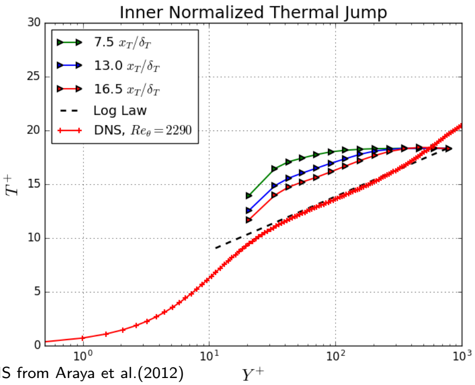
Thermal-Jump



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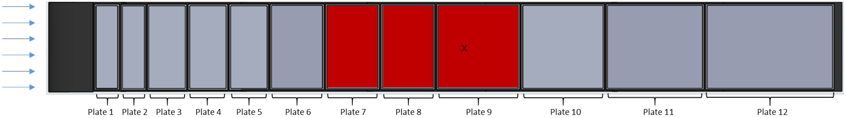

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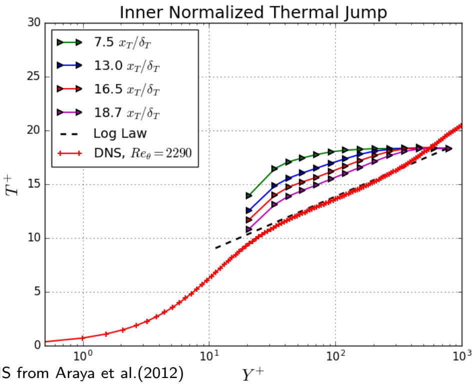

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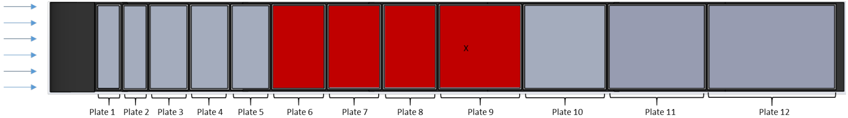

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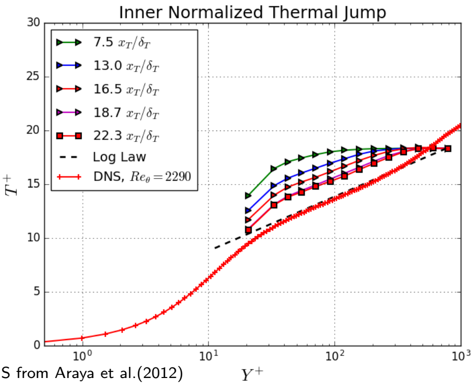

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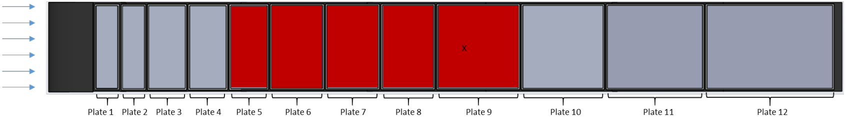

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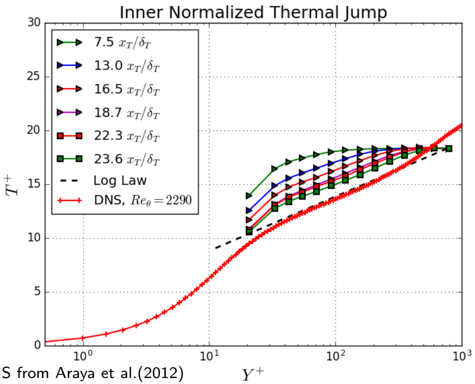

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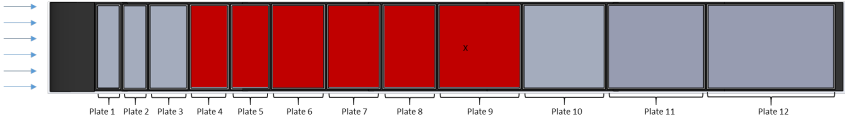

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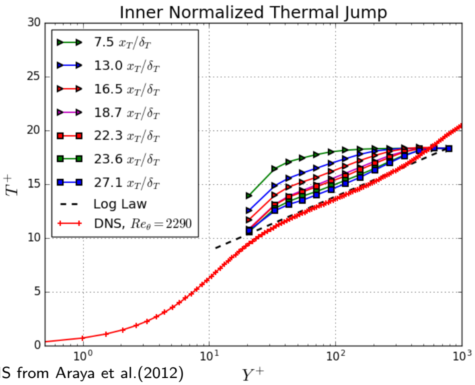

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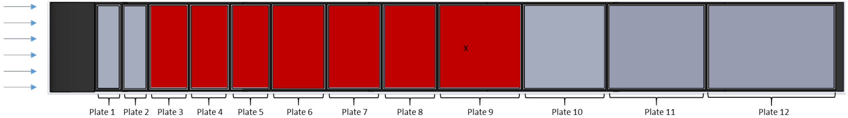

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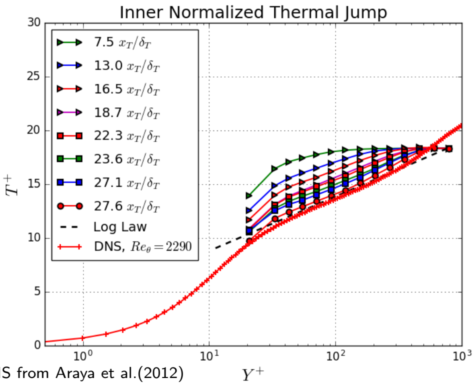

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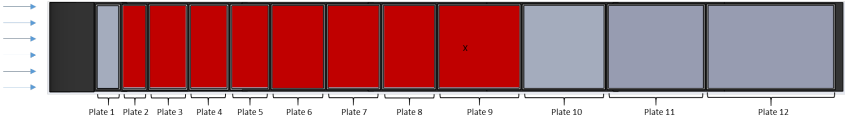

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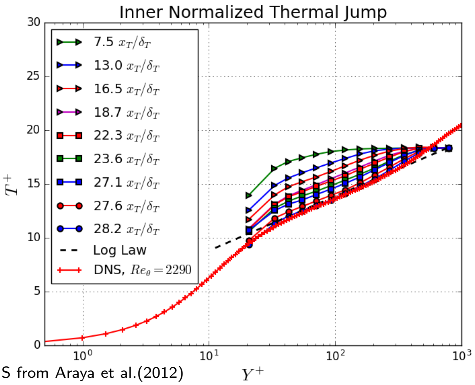

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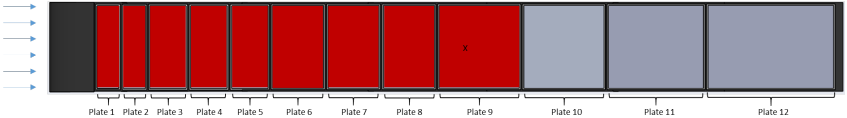

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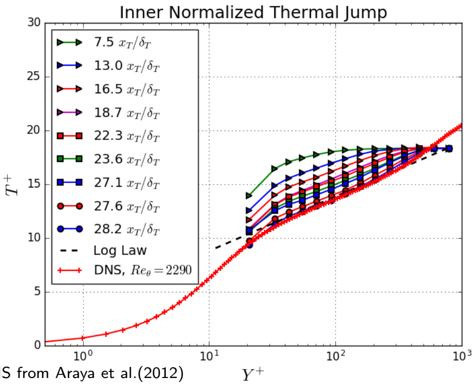

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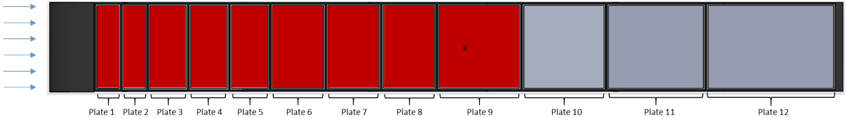
Arguments to understand development length of the thermal field

- Thermal field must first diffuse through sublayer
- Thermal field is then rapidly mixed turbulence



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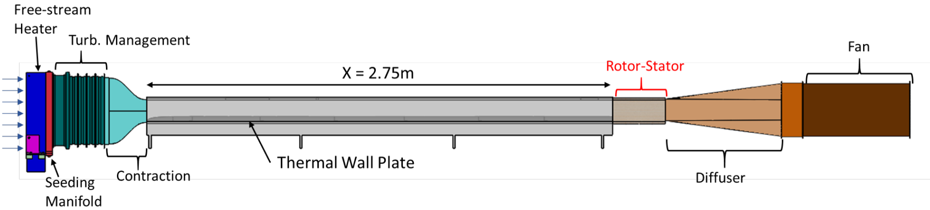
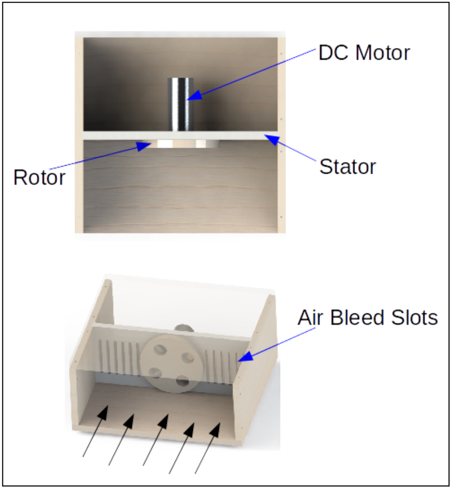
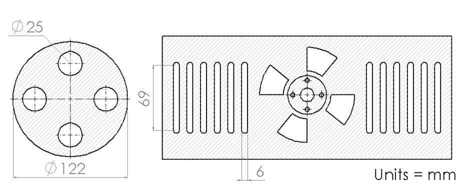


UNH Thermal Boundary Layer Wind Tunnel

Rotor-Stator Design



- Slotted Rotor-Stator design
- Rotor outer diameter = channel height
- Adjustable number of air-bleed slots
- Rotor speed adjustable from 1Hz to 85Hz



[1]

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

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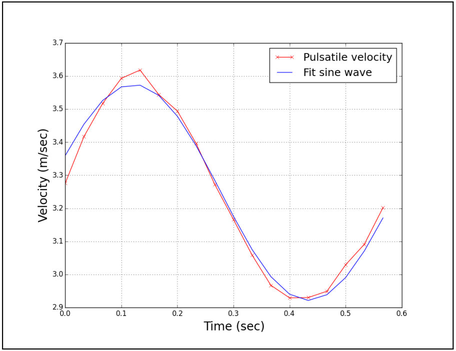

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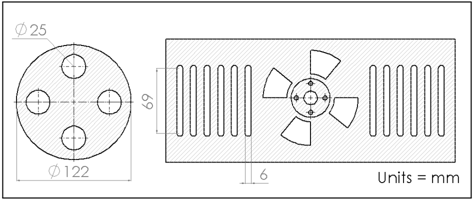

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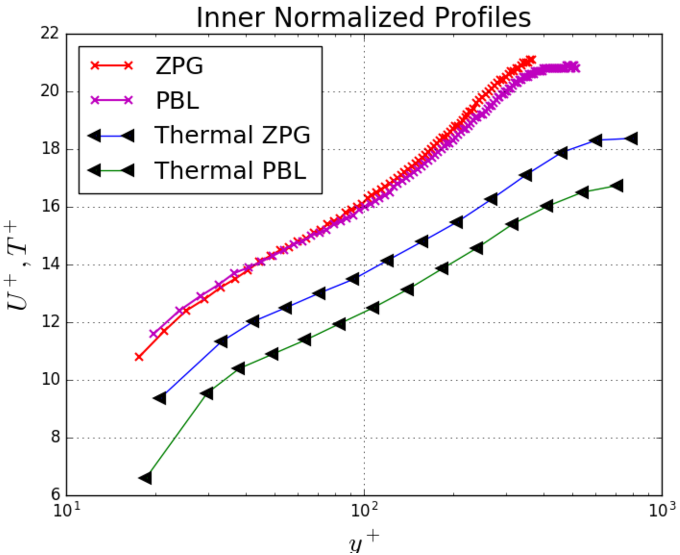
ZPG vs Pulsatile Flow



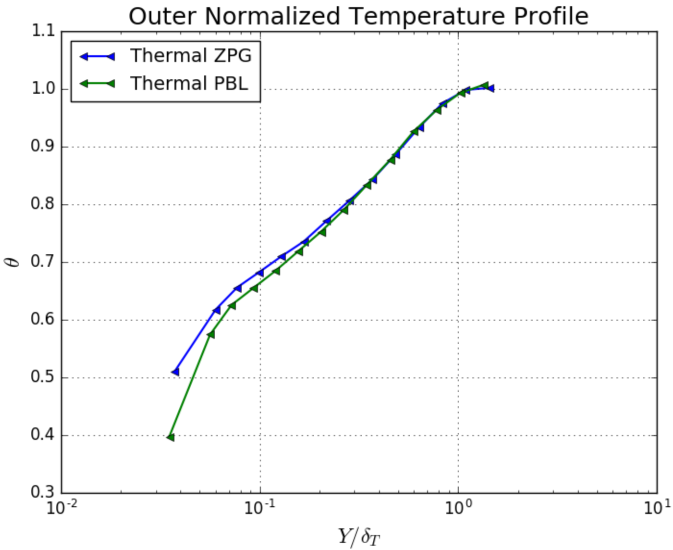
ZPG

- $Re_\theta = 1139$

Pulsatile

- $Re_\theta = 874$
- Freq = 6Hz

ZPG vs Pulsatile Flow



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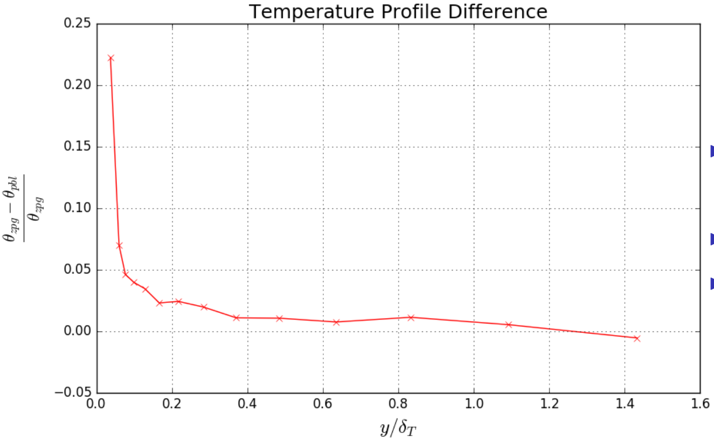

ZPG

- $Re_\theta = 1139$

Pulsatile

- $Re_\theta = 874$
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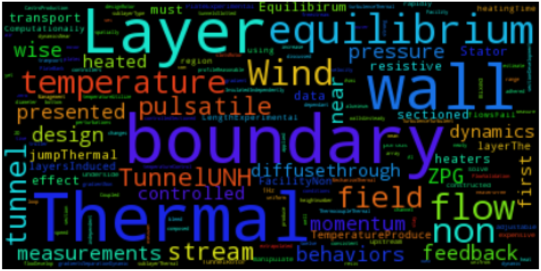
Conclusions

- Pertubations of the thermal boundary layer persist downstream based on the diffusion time scale
- The mean dynamis of momentum tranpsort stay consistent between ZPG and Pulsatile flow, yet the pulsatile flow changes the mean thermal transport dynamics with increase effect in the near wall region.

Future Work

- Measure temperature field in a range of pulsatile flow (1 - 10Hz)
- Coupled temperature and velocity measurements

Questions??



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