Cornell University

Measurements in a boundary layer with intense free stream turbulence

Nicole Sharp
S. Neuscamman, S. Gerashchenko, Z. Warhaft

Cornell University

APS DFD Meeting Salt Lake City, UT

19 November 2007

Introduction

Introduction / Motivation

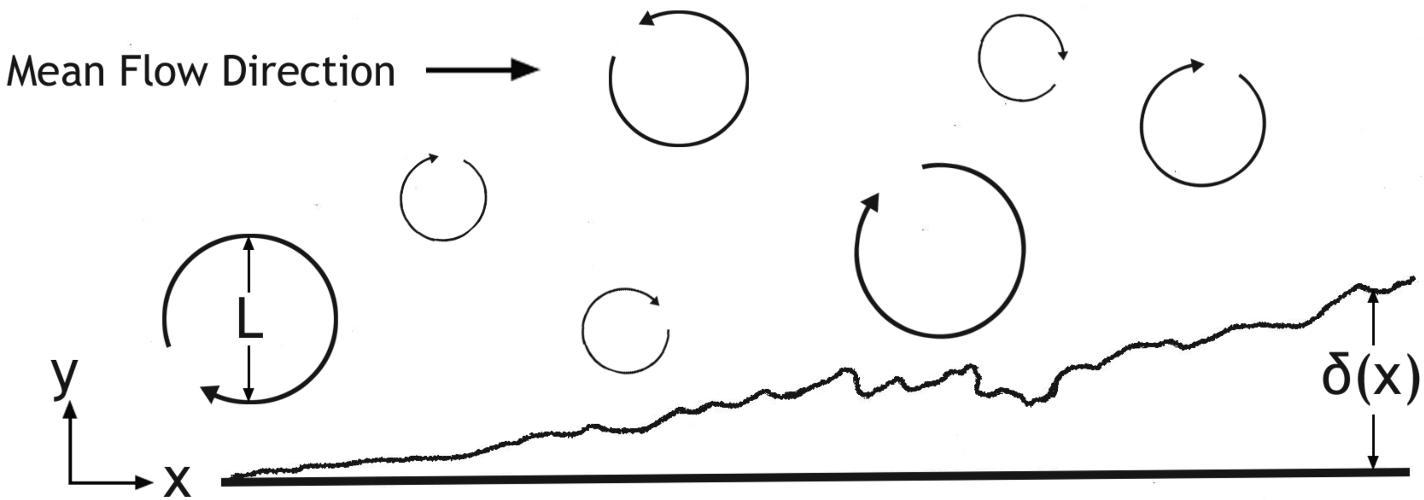
Experimental Set-up

Previous Work

Results

Conclusions

- What flow are we talking about?



FSTI = free stream turbulence intensity = $(u_{rms} / U)_{freestream}$

Motivation

Introduction / Motivation

Experimental Set-up

Previous Work

Results

Conclusions

- Simplification of flow over turbine / compressor blades

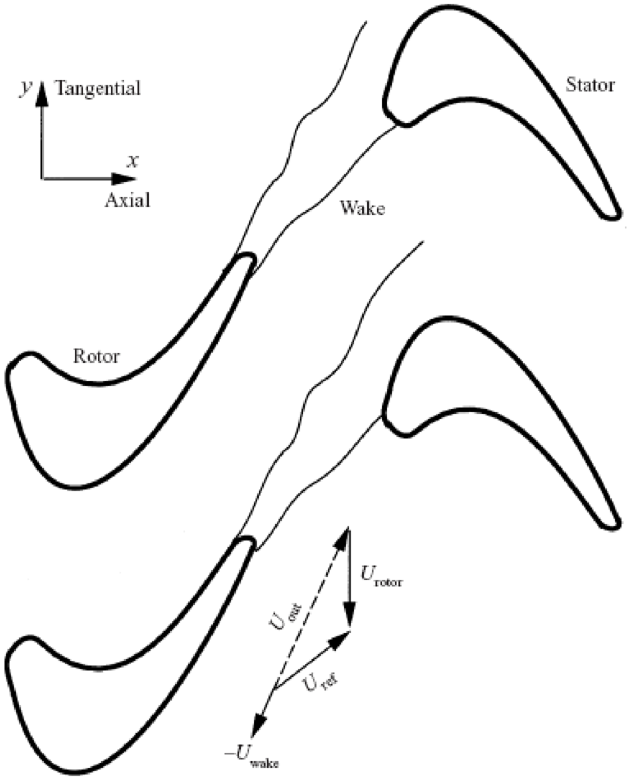
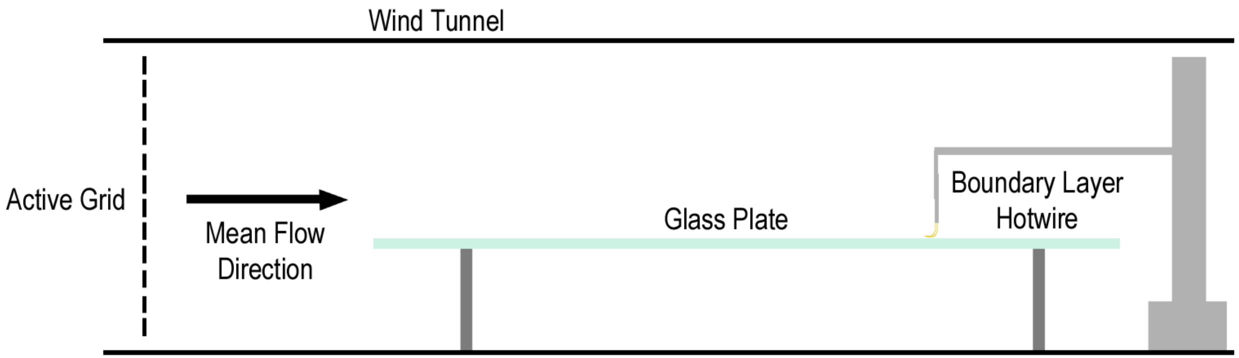


FIGURE 1. Sketch of rotor–stator wake interaction; U_{rotor}: rotor velocity in the stator reference frame; U_{out}: rotor exit flow velocity in the rotor reference frame; U_{ref}: stator inflow velocity in the stator reference frame.

Figure from Wu, Jacobs, Hunt, and Durbin. *JFM*, v. 398, 1999.

Experimental Set-Up



View From Side of Wind Tunnel

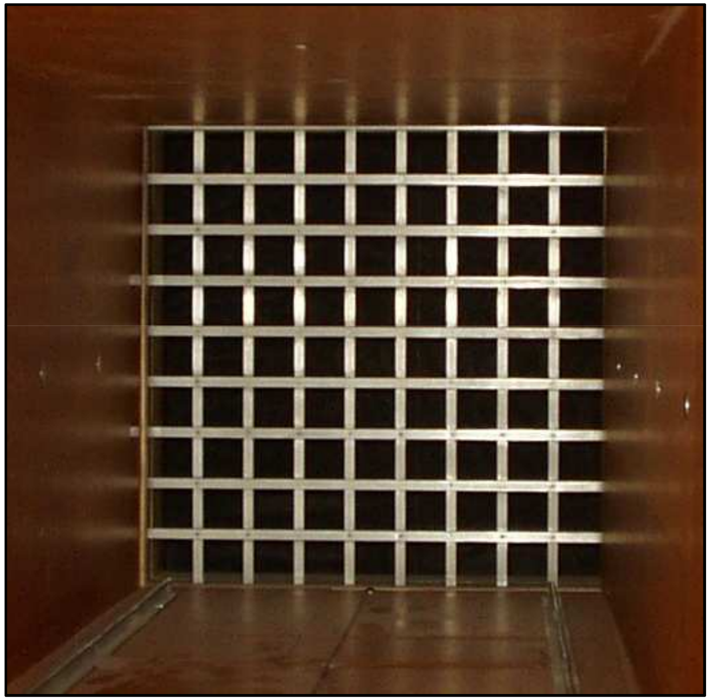
Active grid introduces large-scale turbulent eddies

→ higher Re_λ

For more on inertial particles in this flow, see Session GS.0007, “Lagrangian measurements of inertial particle trajectories in a turbulent boundary layer” by S. Geraschenko, 19 November 2007, 11:48 A.M., SLC Convention Center, Ballroom EG.

Hancock and Bradshaw (1989)

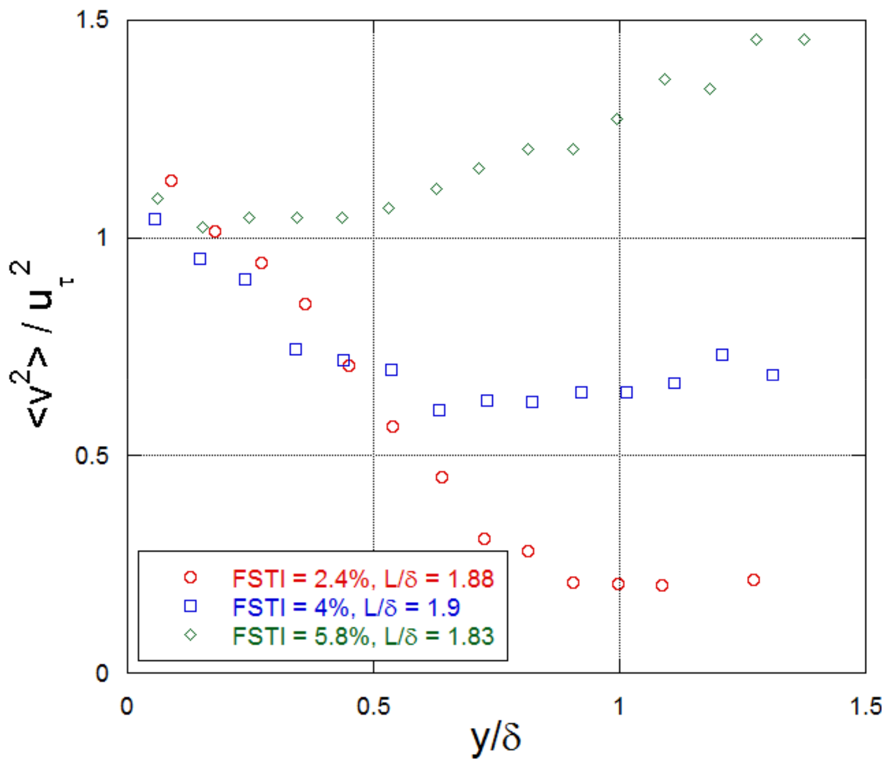
- Flow generated with biplane passive turbulence grids
- Highest free stream turbulence intensities of $u_{rms}/U = 5.8\%$
- $Re_\theta > 2000$
- Measured using hotwire anemometry



Hancock, P.E. and Bradshaw, P. "Turbulence structure of a boundary layer beneath a turbulent free stream." *JFM*, vol. 205, 1989.

Hancock and Bradshaw (1989)

- Decrease in $\langle v^2 \rangle$ from the free stream value before rising in the boundary layer region
  → Due to surface constraint (Hunt and Graham (1978))



Hancock, P.E. and Bradshaw, P. “Turbulence structure of a boundary layer beneath a turbulent free stream.” *JFM*, vol. 205, 1989.
Hunt, J. C. R., and Graham, J. M. R. “Free stream turbulence near plane boundaries.” *JFM*, vol. 84, 1978.

Thole and Bogard (1996)

- Flow generated with jets normal to the free stream
- Highest free stream turbulence intensities of 20%
- $Re_\theta \sim 600$
- $L/\delta \sim 2$
- $159 < Re_\lambda < 271$
- Measured using LDV and hotwire anemometry

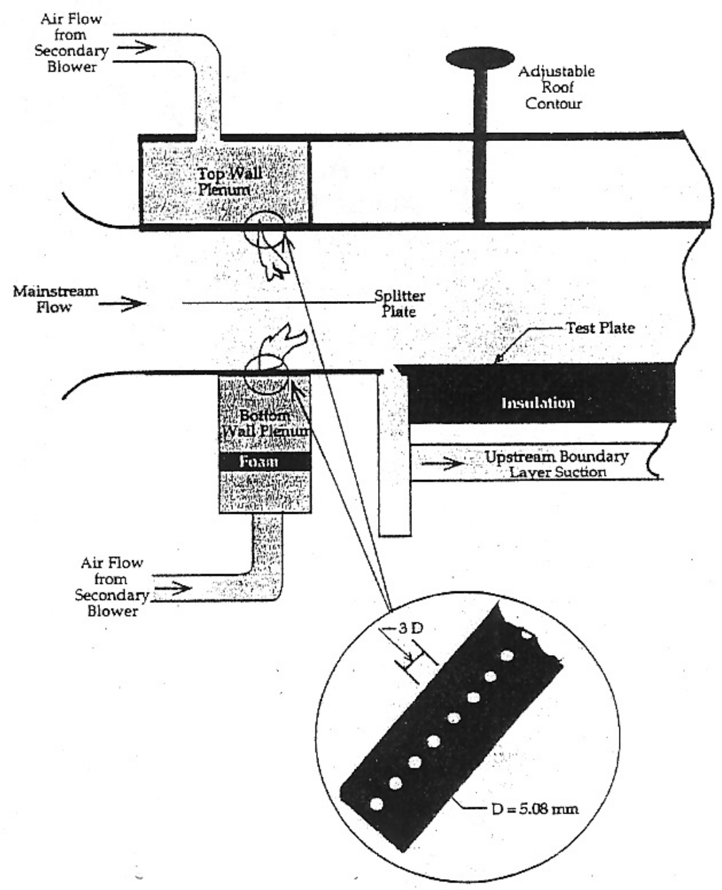


Fig. 1 Schematic of the wind tunnel test section and the turbulence generator

Thole, K.A. and Bogard, D.G. "High free stream turbulence effects on turbulent boundary layers." *J. Fluids Engi.*, vol. 118, 1996.

Thole and Bogard (1996)

Introduction / Motivation

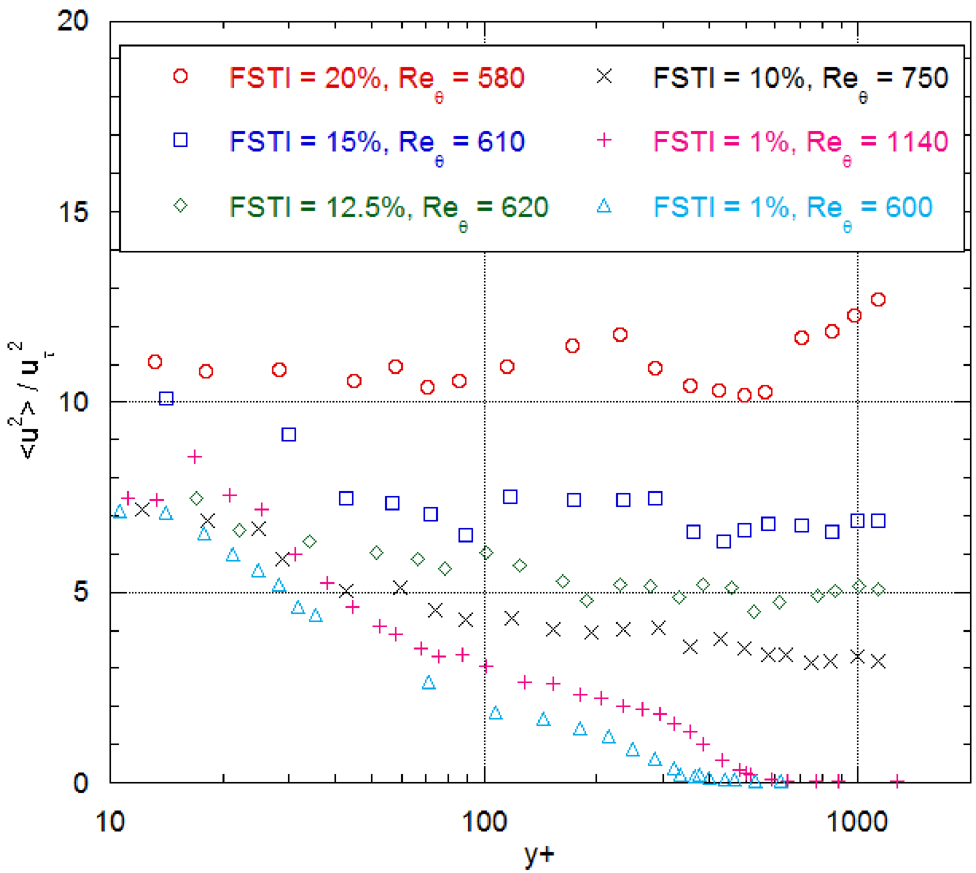
Experimental Set-up

Previous Work

Results

Conclusions

- Found collapse in near-wall $<u^2>/u_\tau^2$ values for intensities less than 12.5%



Thole, K.A. and Bogard, D.G. "High free stream turbulence effects on turbulent boundary layers." *J. Fluids Engi.*, vol. 118, 1996.

Thole and Bogard (1996)

Introduction / Motivation

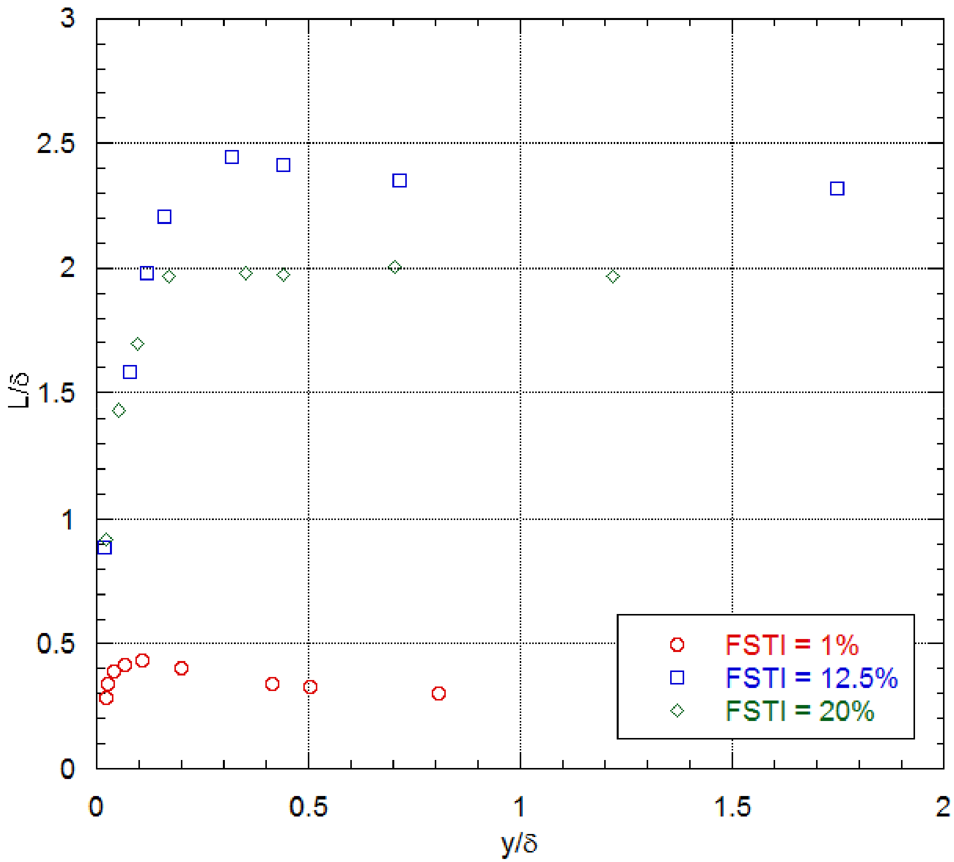
Experimental Set-up

Previous Work

Results

Conclusions

- Found that free stream integral lengthscales dominated until $y/\delta < 0.3$
- Noted integral lengthscales very near the wall are larger with high FST



Thole, K.A. and Bogard, D.G. "High free stream turbulence effects on turbulent boundary layers." *J. Fluids Engi.*, vol. 118, 1996.

Results

Introduction / Motivation

Experimental Set-up

Previous Work

Results

Conclusions

U_0 (m/s)	R_λ	FSTI	Re_θ	L/δ
2.55	140	4.6%	1080	2.37
2.39	240	11.6%	840	2.48
9.50	800	16.0%	2800	3.14

- U_0 = free stream velocity
- R_λ = Taylor microscale Reynolds number
- FSTI = free stream turbulence intensity
- Re_θ = momentum thickness Reynolds number
- L/δ = ratio of free stream integral length scale to boundary layer thickness

Normal Stresses - $\langle u^2 \rangle$

Introduction / Motivation

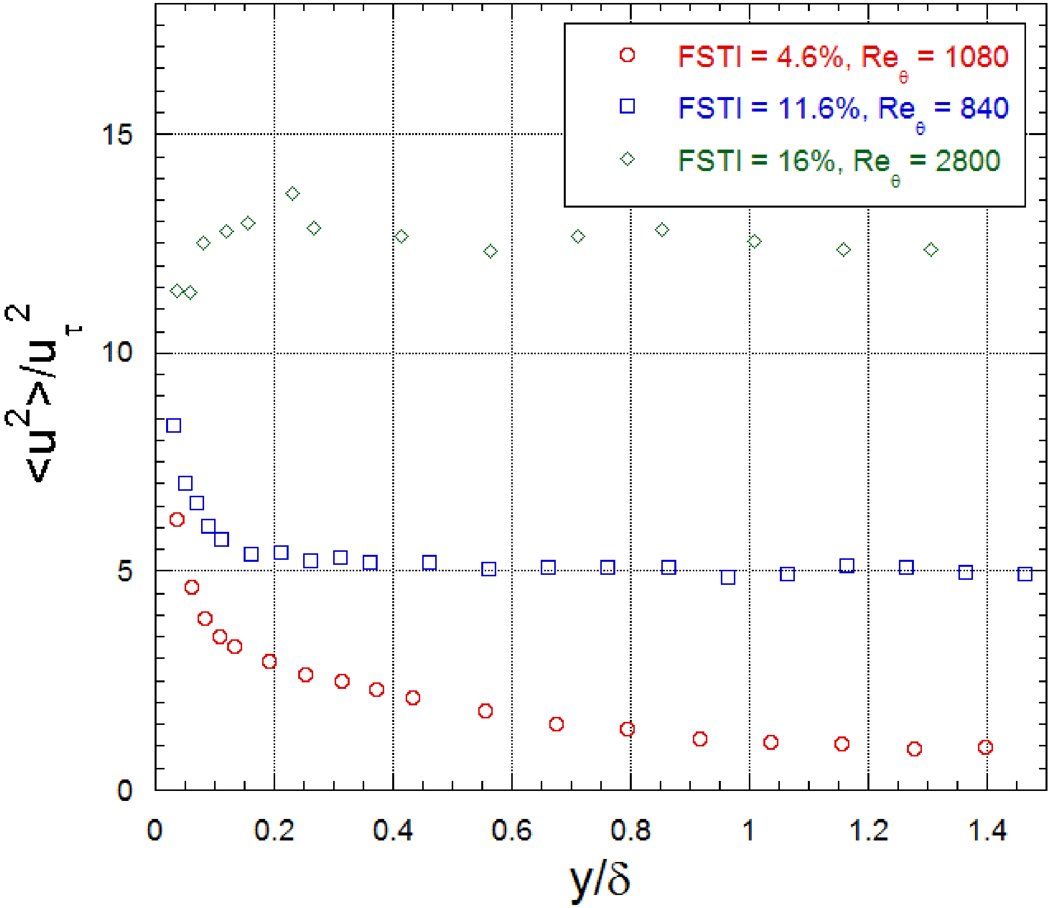
Experimental Set-up

Previous Work

Results

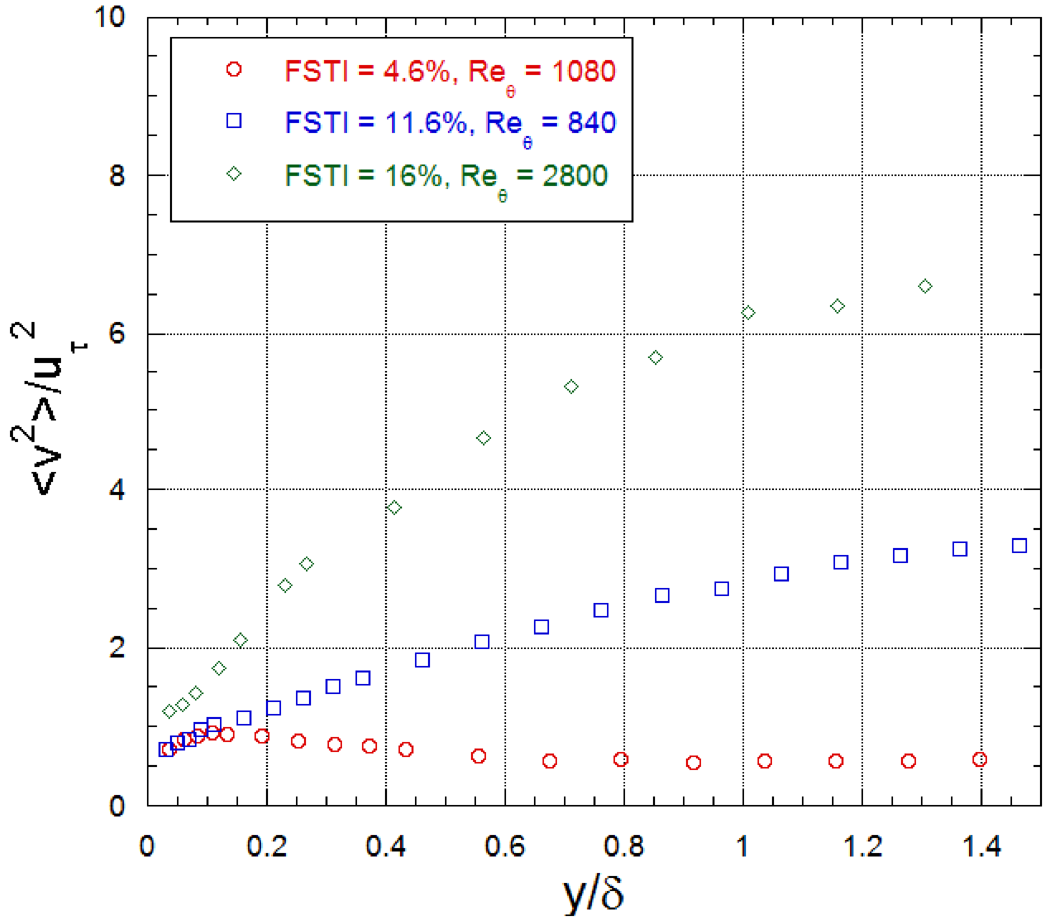
Conclusions

- Free stream $\langle u^2 \rangle$ values rise with FSTI
- $\langle u^2 \rangle$ increases inside boundary layer



Normal Stresses - $\langle v^2 \rangle$

- Free stream $\langle v^2 \rangle$ values rise with FSTI
- $\langle v^2 \rangle$ decreases inside boundary layer



Lengthscales

Introduction / Motivation

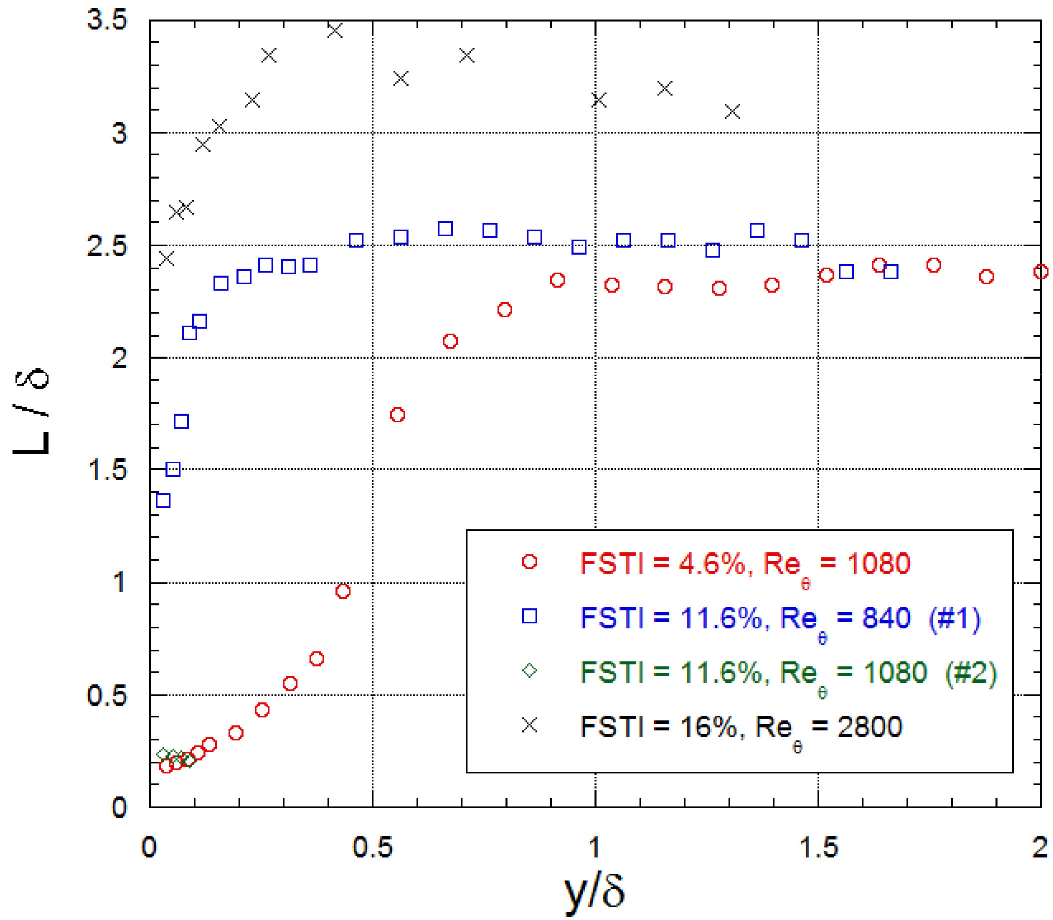
Experimental Set-up

Previous Work

Results

Conclusions

- Free stream L/δ persists well inside boundary layer *except* in low FSTI case



Lengthscales

Introduction / Motivation

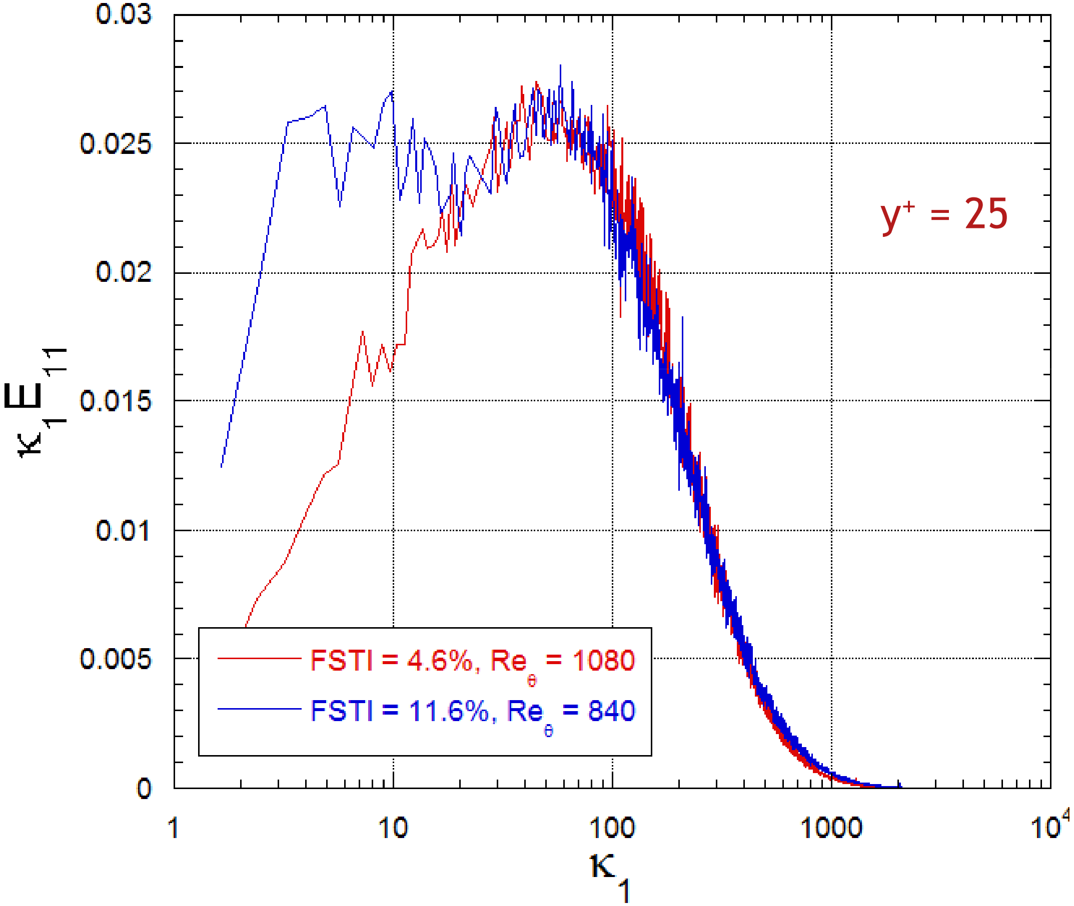
Experimental Set-up

Previous Work

Results

Conclusions

- Near-wall $\kappa_1 E_{11}$ spectra is double peaked for FSTI = 11.6% case



Evolution of Spectra

Introduction / Motivation

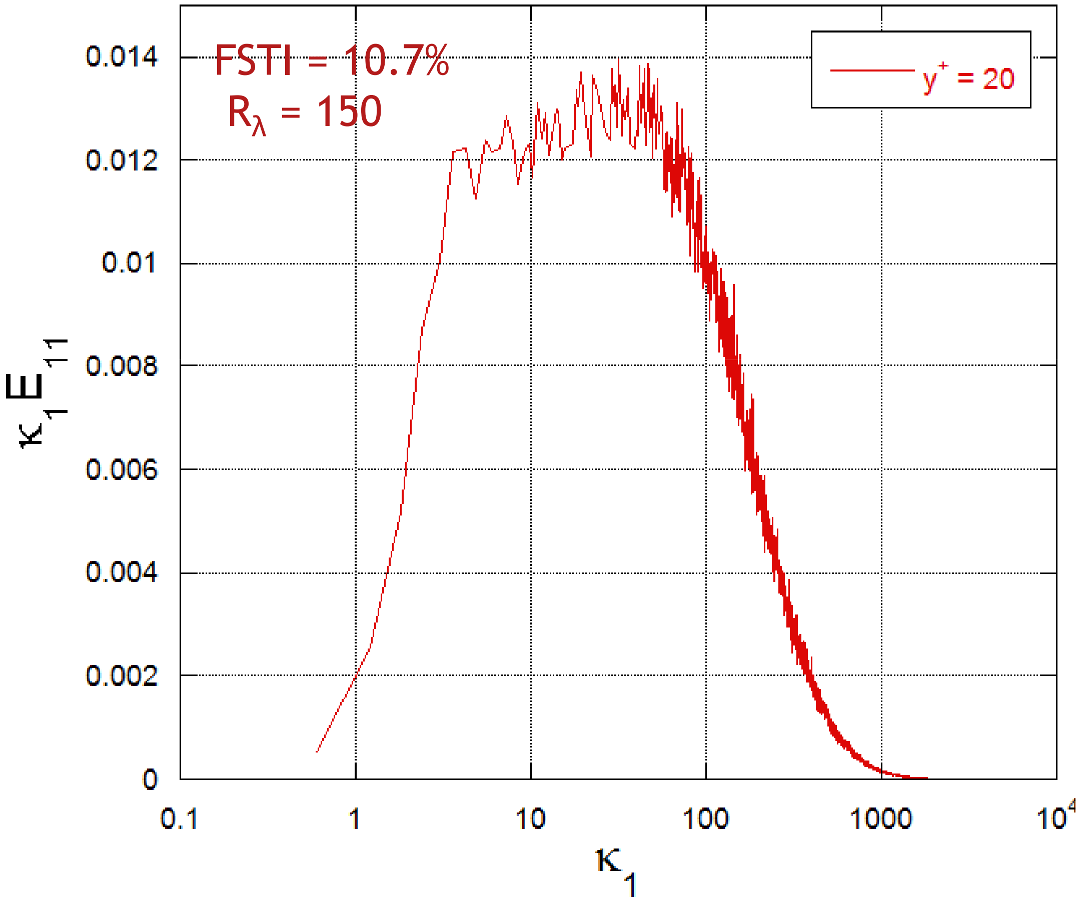
Experimental Set-up

Previous Work

Results

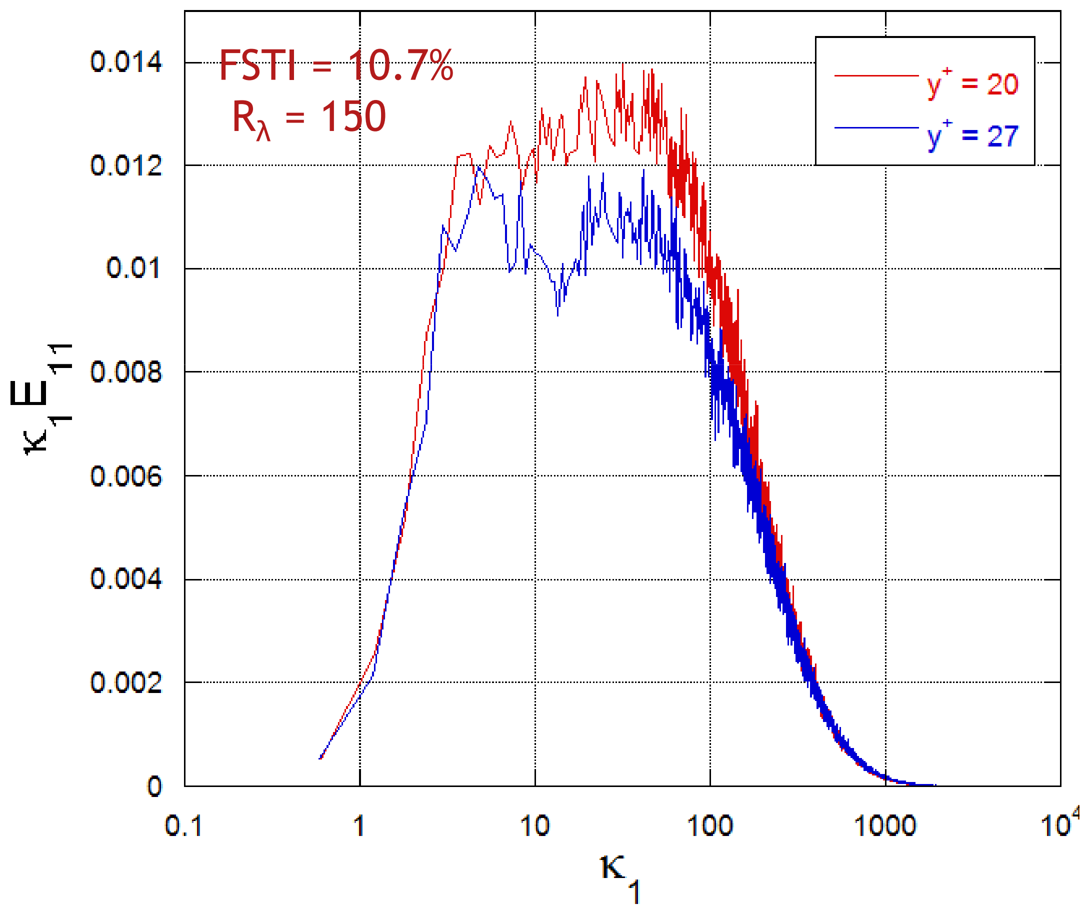
Conclusions

- Second peak decreases further from the wall



Evolution of Spectra

- Second peak decreases further from the wall



Evolution of Spectra

Introduction / Motivation

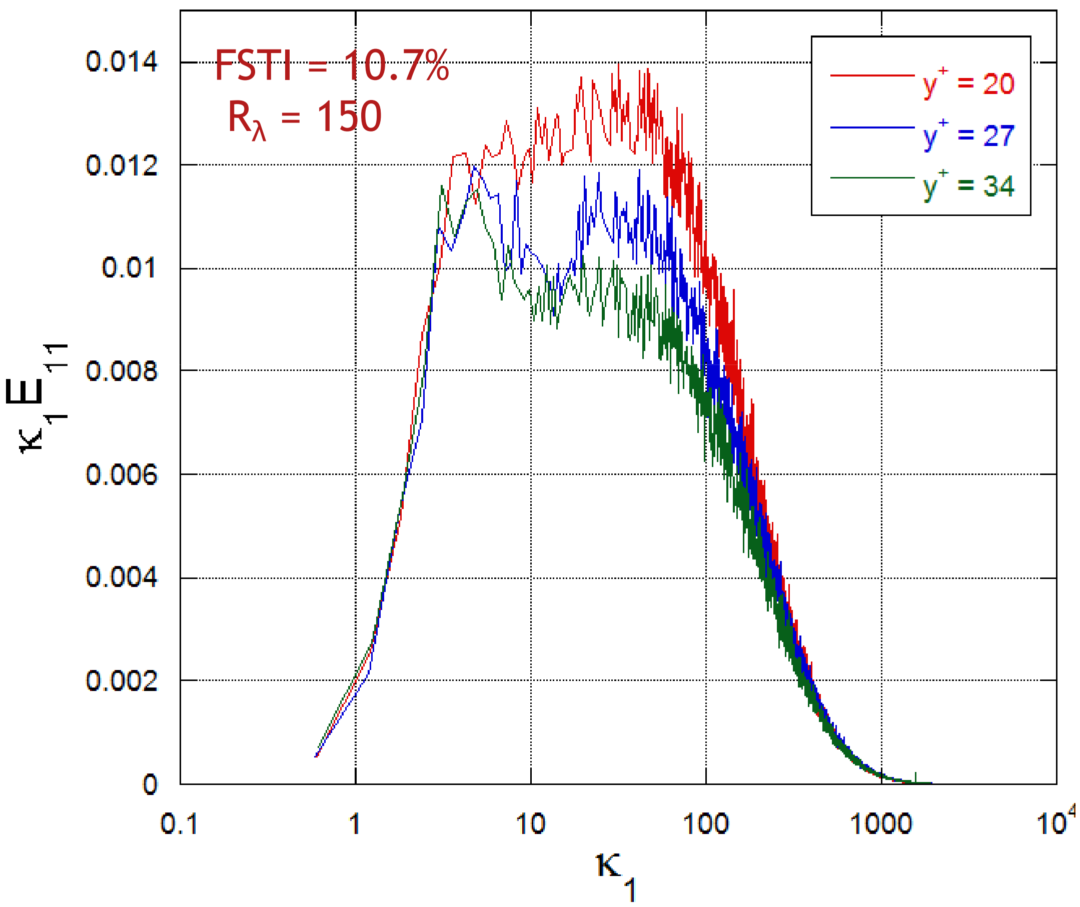
Experimental Set-up

Previous Work

Results

Conclusions

- Second peak decreases further from the wall



Evolution of Spectra

Introduction / Motivation

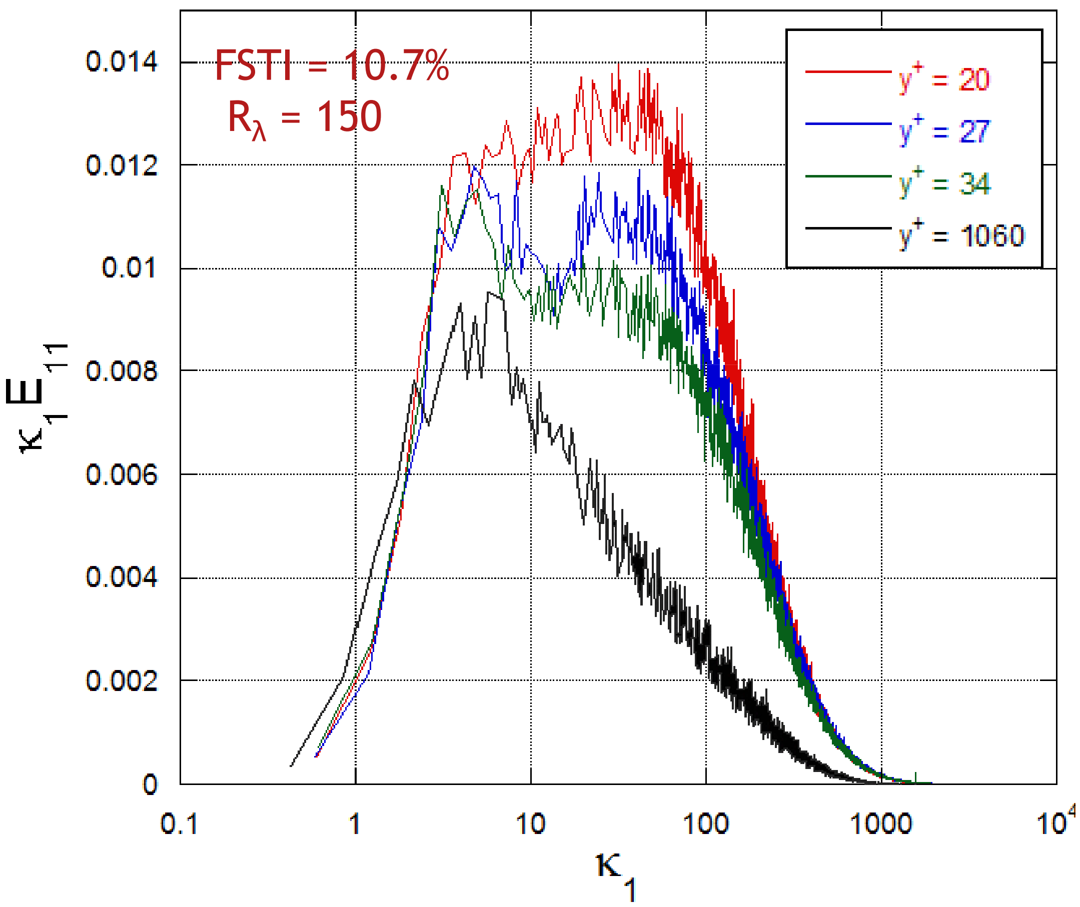
Experimental Set-up

Previous Work

Results

Conclusions

- Second peak decreases further from the wall



Evolution of Spectra

Introduction / Motivation

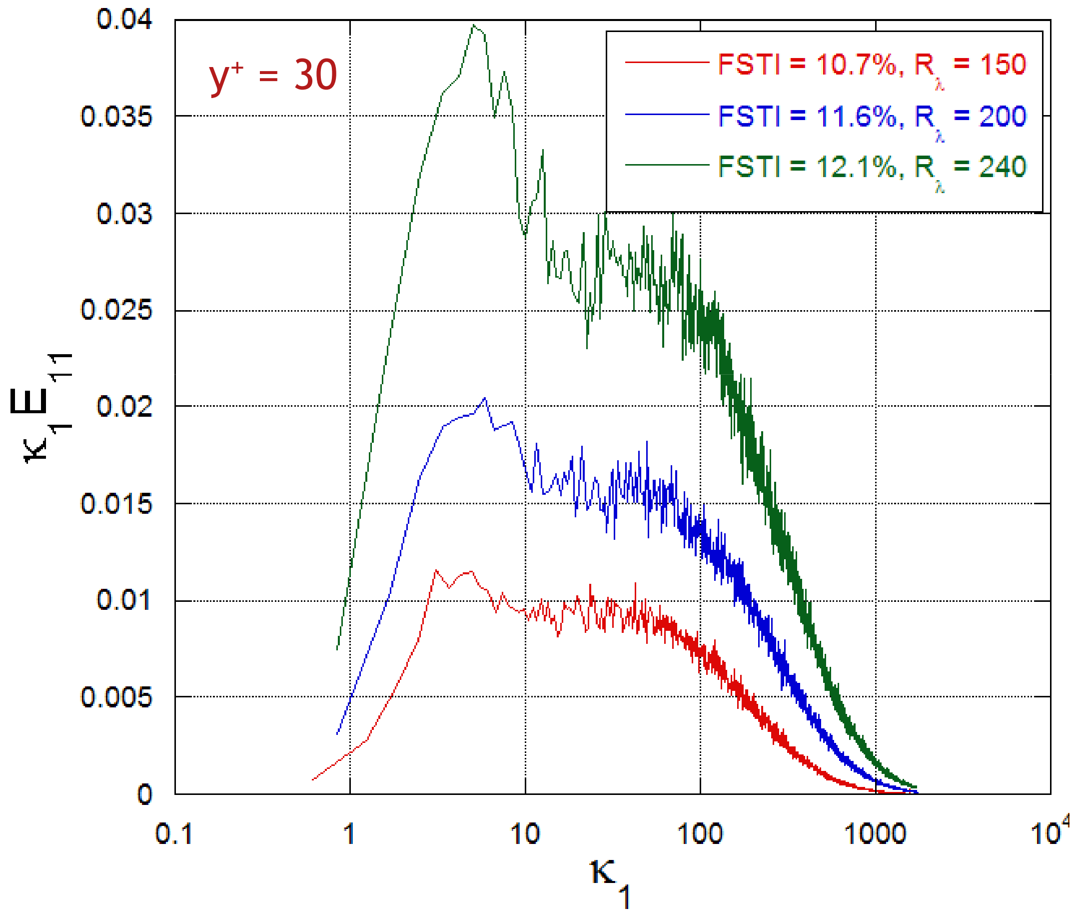
Experimental Set-up

Previous Work

Results

Conclusions

- Flow near the wall shows strong sensitivity to free stream conditions



Conclusions

- Verified trends seen by previous workers (Hancock and Bradshaw; Thole and Bogard) using a different method of turbulence generation
- Found that profile of dominant lengthscales in the boundary layer is dependent on the free stream turbulence intensity
- Observed double-peaked $\kappa_1 E_{11}$ spectra near the wall, corresponding to energy at both free stream lengthscales and boundary layer scales

Acknowledgements

The authors would like to thank the following individuals for their assistance and support:

- Sathya Ayyalasomayajula
- Juan Isaza
- Lance Collins

As well as everyone in ICTR.

This work was funded by the National Science Foundation.

Travel funds provided by the Cornell Univ. Graduate School.