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Measurements in a boundary layer with intense free stream turbulence

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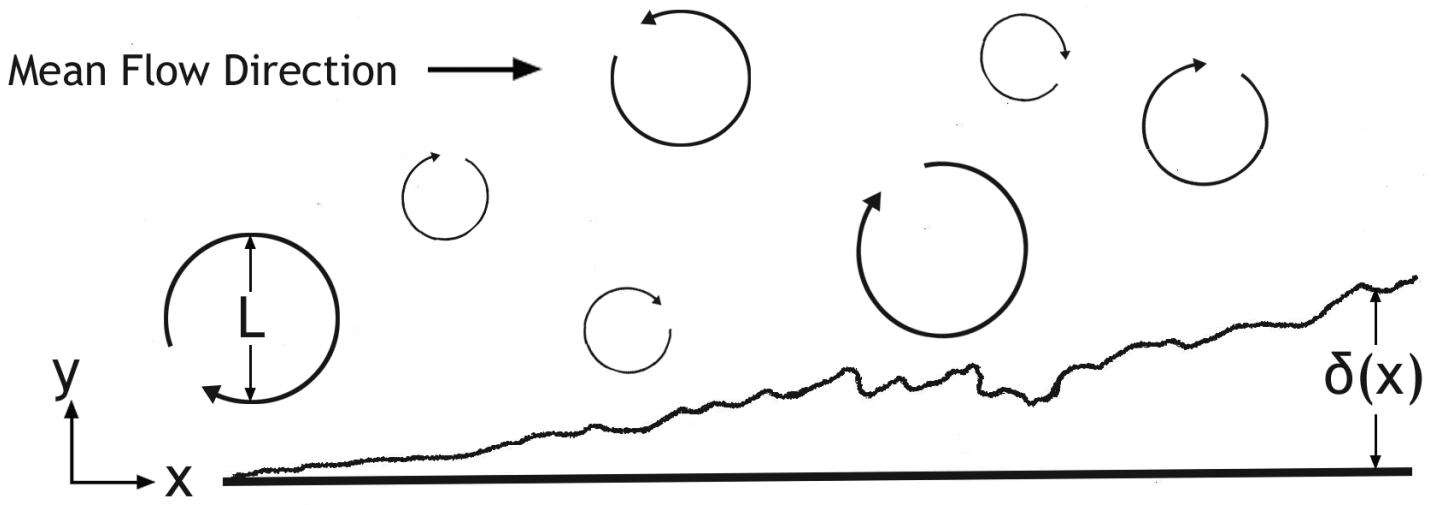
Introduction

- What flow are we talking about?



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

Motivation

- Simplification of flow over turbine / compressor blades

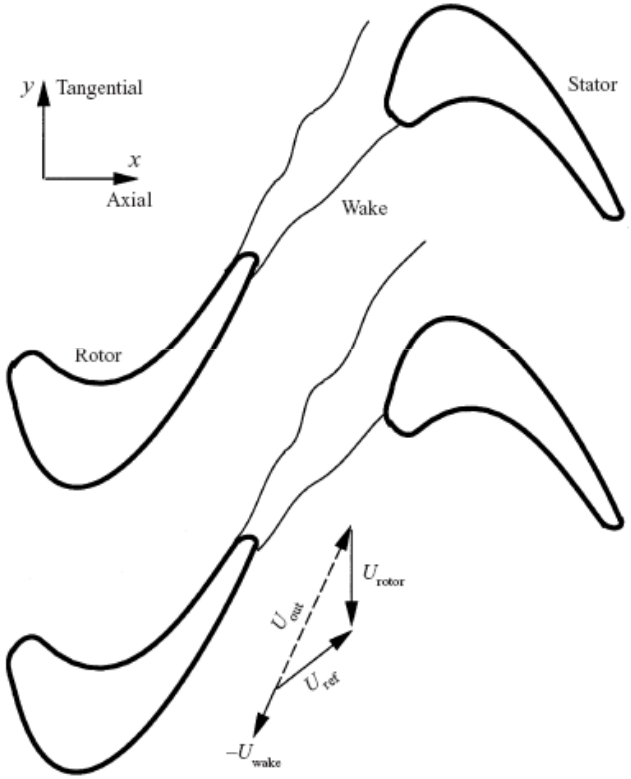
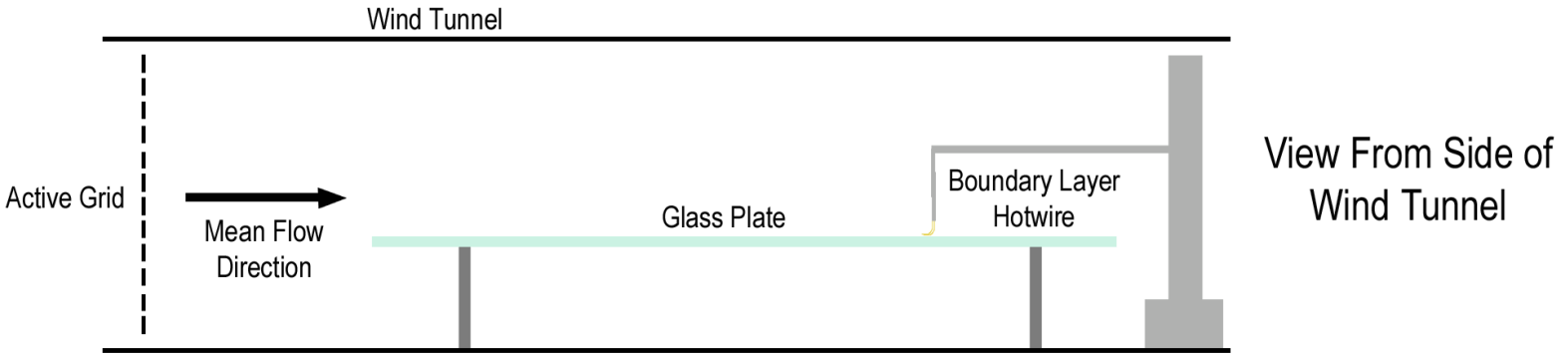


FIGURE 1. Sketch of rotor–stator wake interaction; U_{rotor}: rotor velocity in the stator reference frame; U_{out}: rotor exit flow velocity in the rotor reference frame; U_{ref}: stator inflow velocity in the stator reference frame.

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

Experimental Set-Up

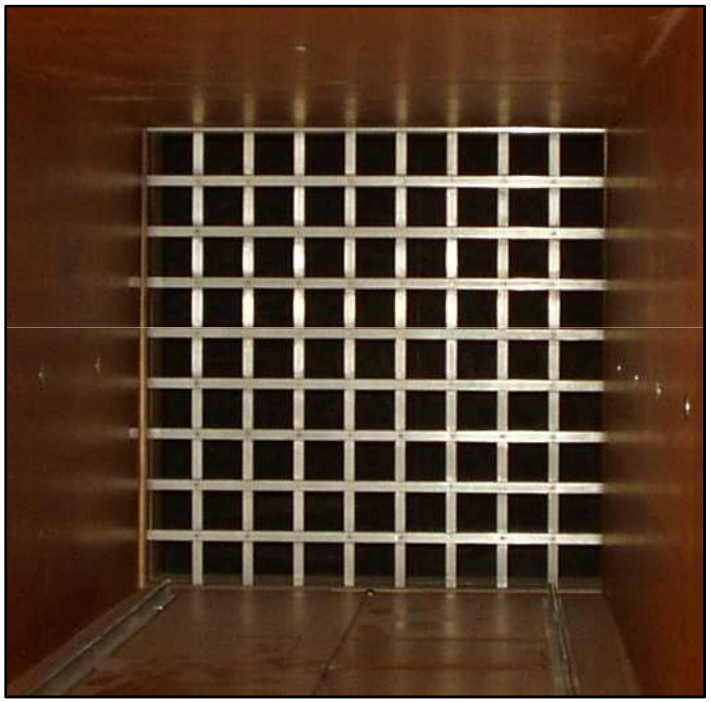


Active grid introduces large-scale turbulent eddies
→ higher Re_λ

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)

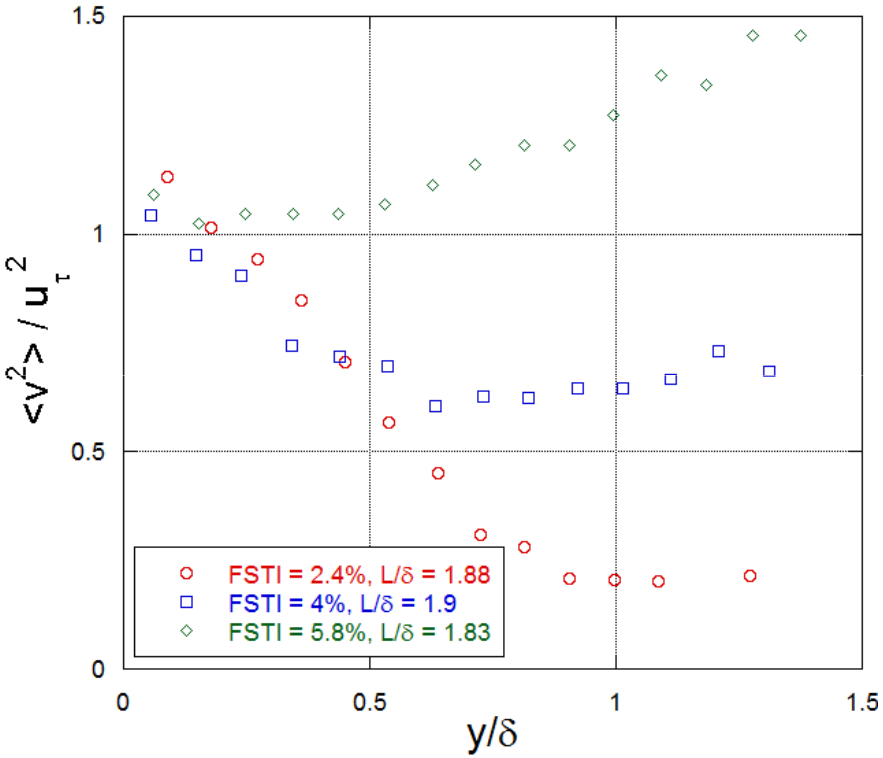
- Flow generated with biplane passive turbulence grids
- Highest free stream turbulence intensities of $u_{rms}/U = 5.8\%$
- $Re_\theta > 2000$
- Measured using hotwire anemometry



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_θ ~ 600
- L/δ ~ 2
- 159 < Re_λ < 271
- Measured using LDV and hotwire anemometry

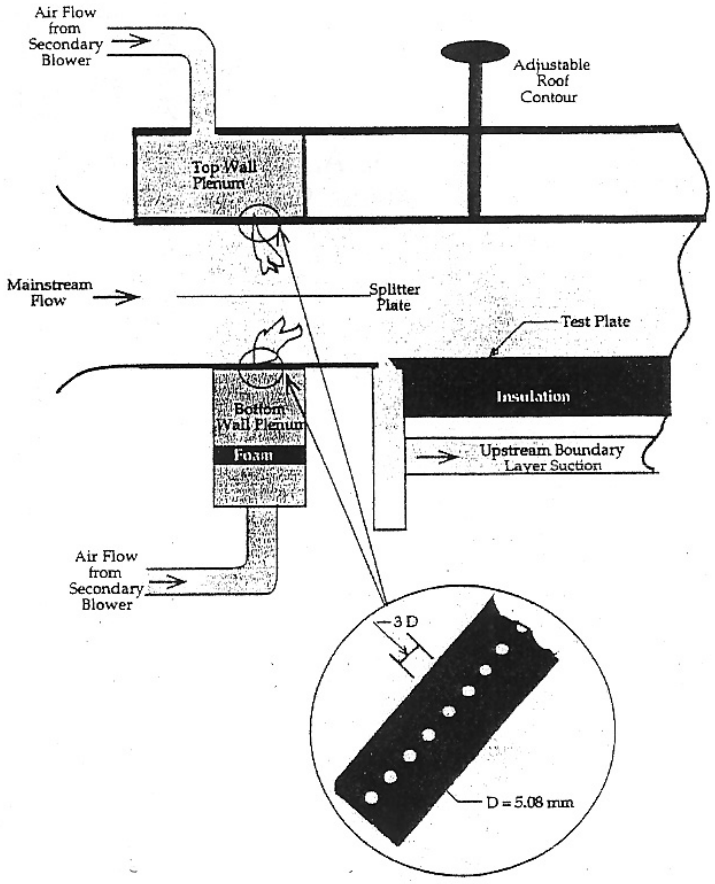
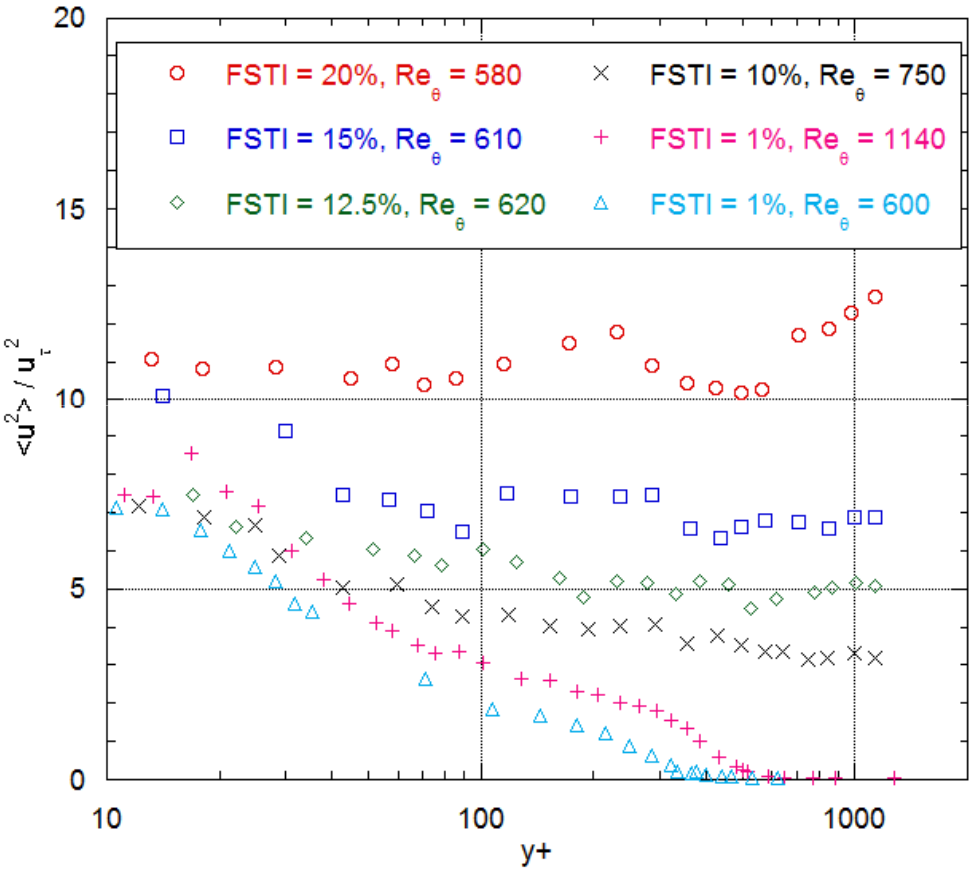


Fig. 1 Schematic of the wind tunnel test section and the turbulence generator

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)

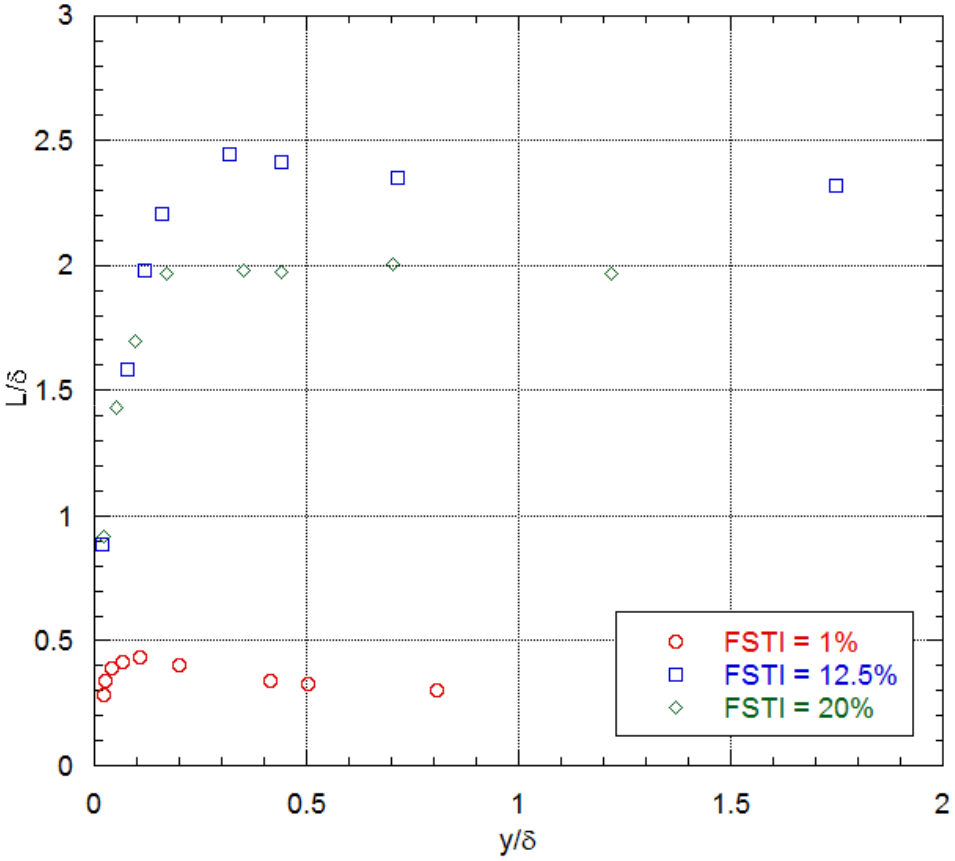
- Found collapse in near-wall $\langle u^2 \rangle / u_\tau^2$ values for intensities less than 12.5%



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)

- 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.

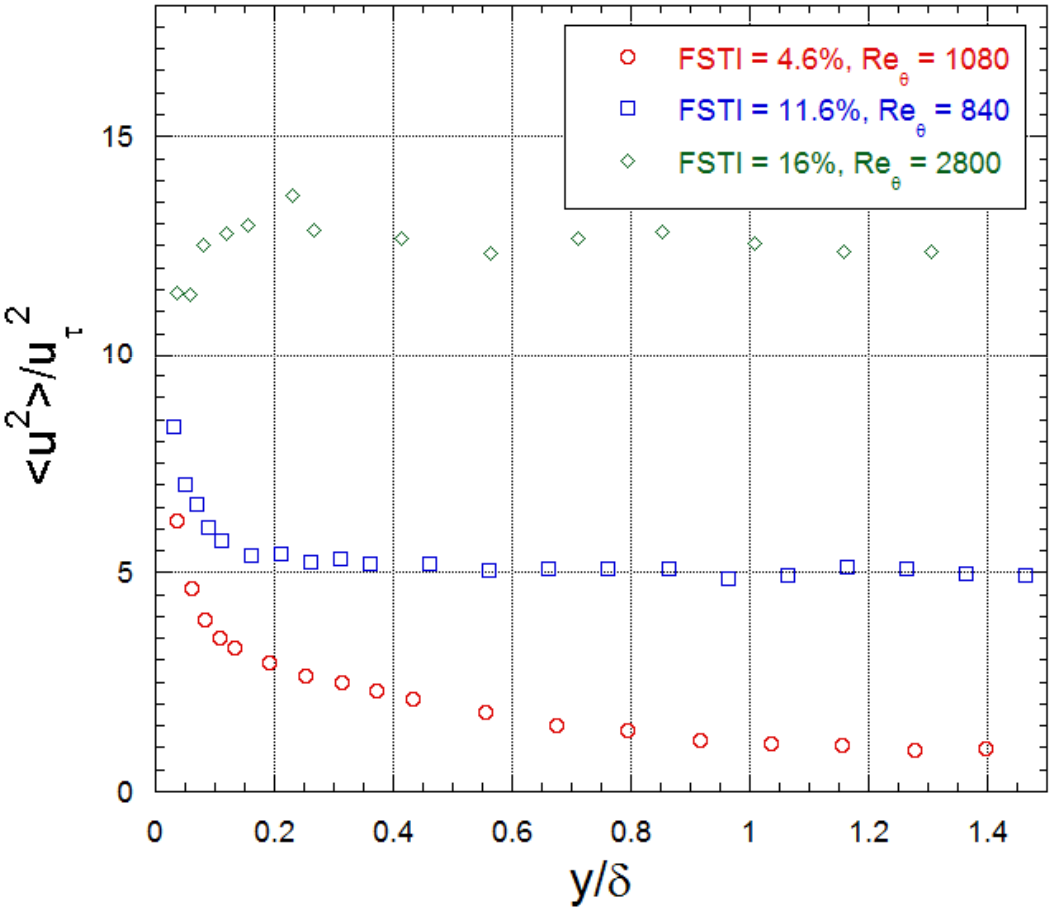
Results

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

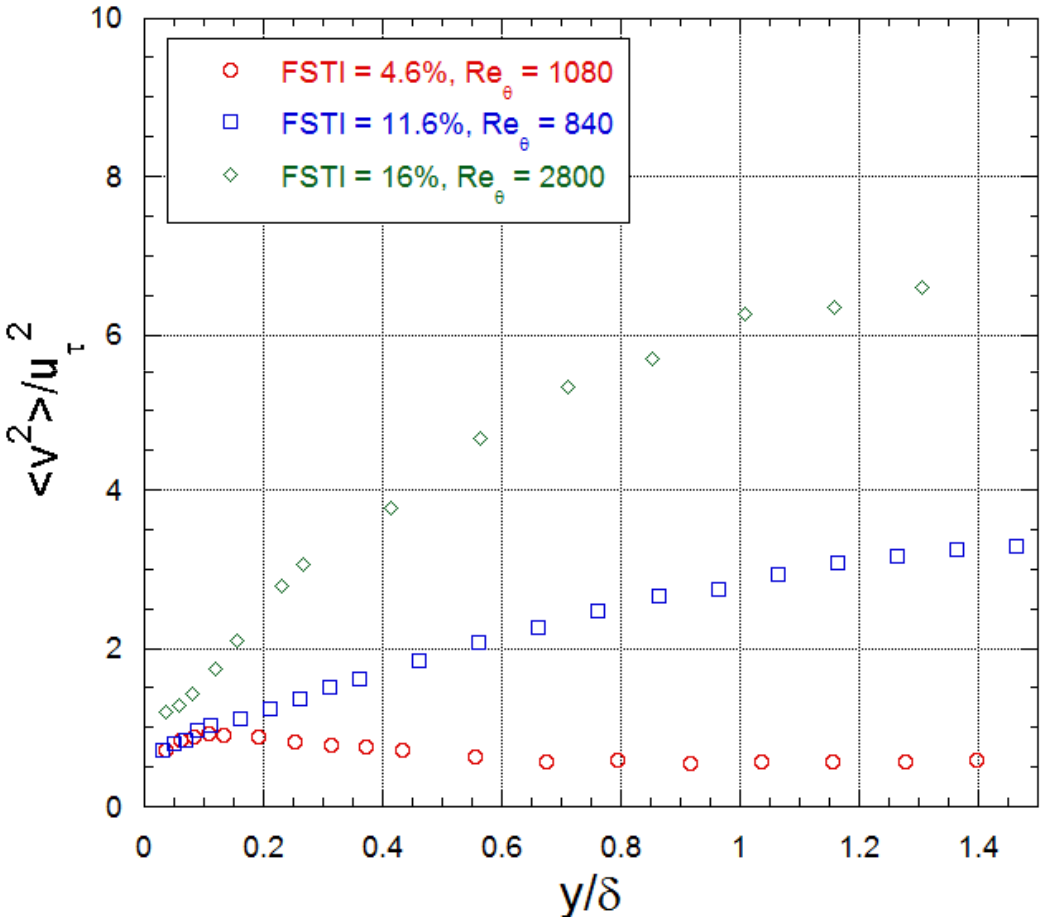
Normal Stresses - $\langle u^2 \rangle$

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



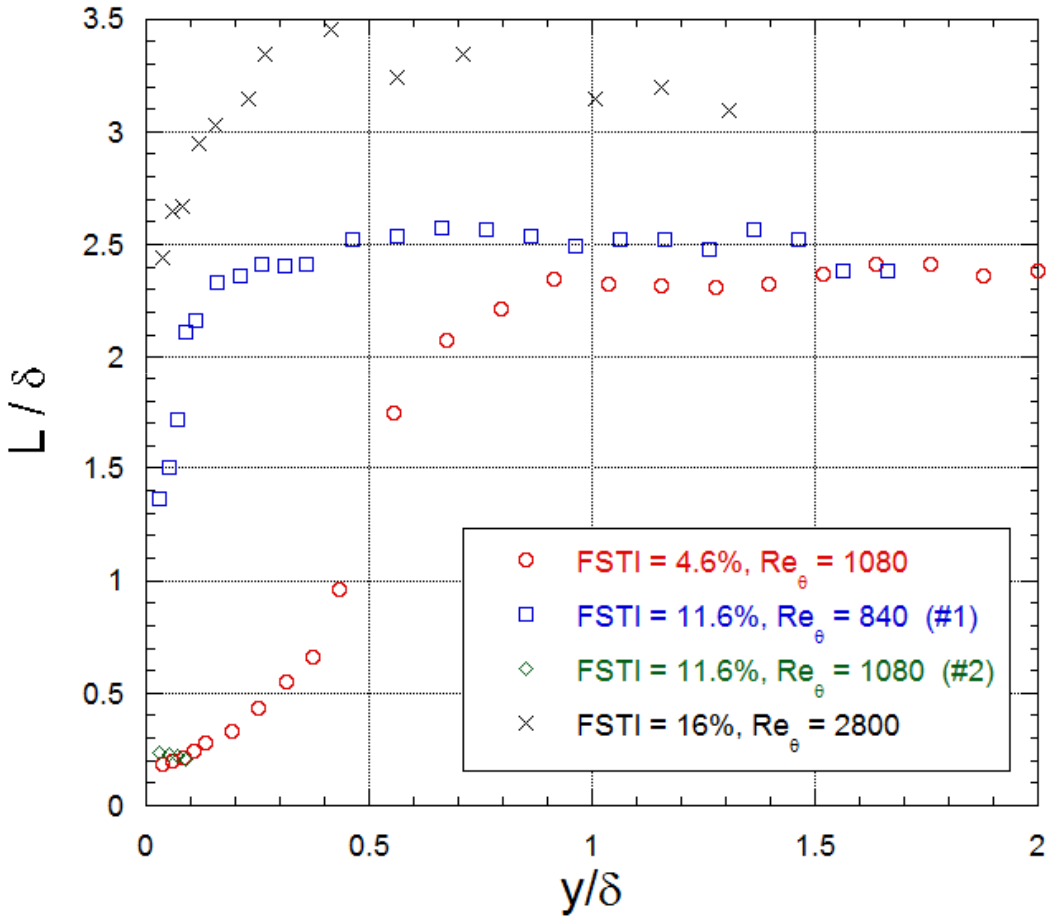
Normal Stresses - $\langle v^2 \rangle$

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



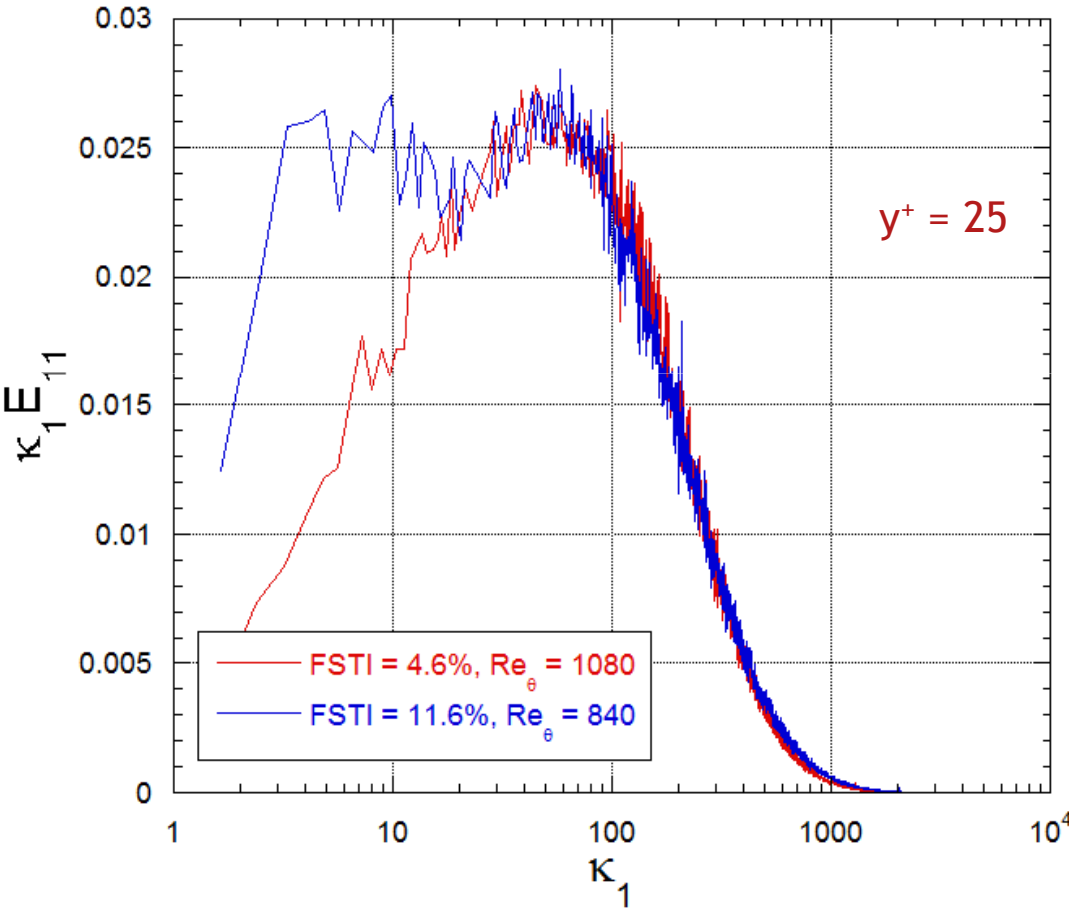
Lengthscales

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



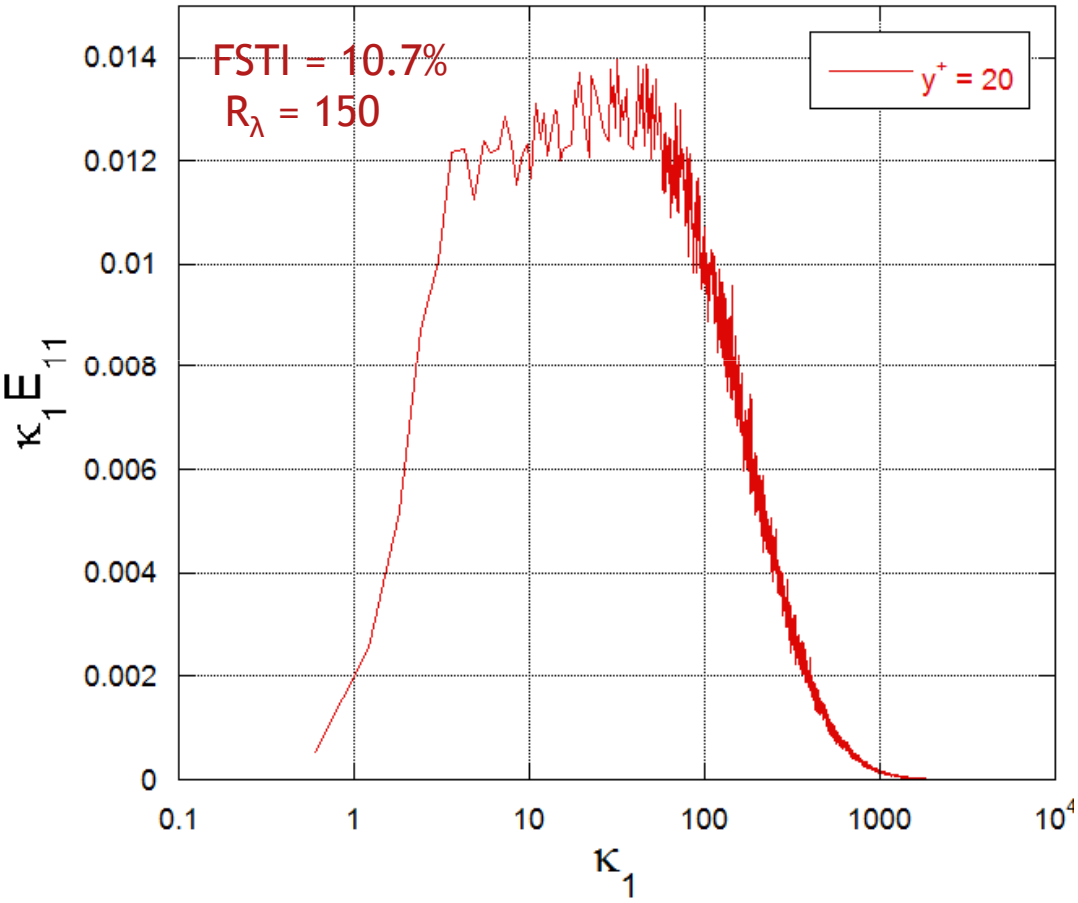
Lengthscales

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



Evolution of Spectra

- Second peak decreases further from the wall



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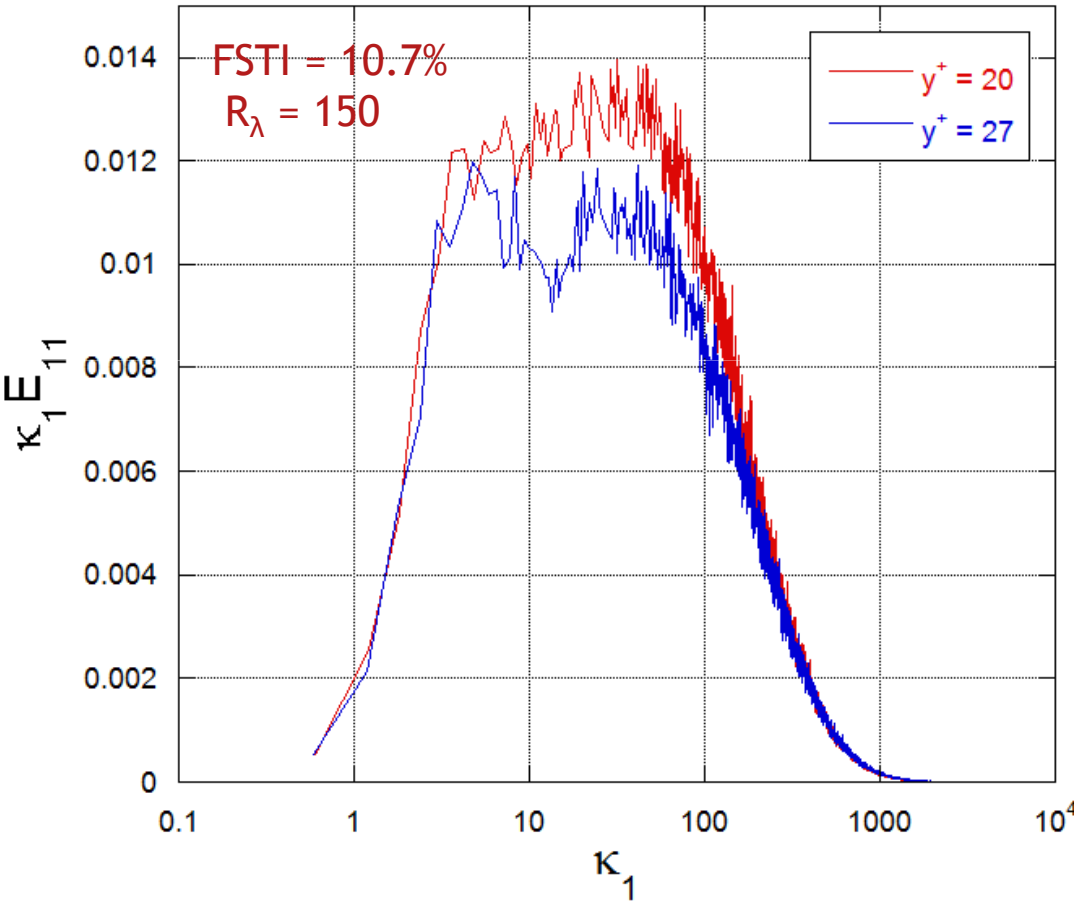
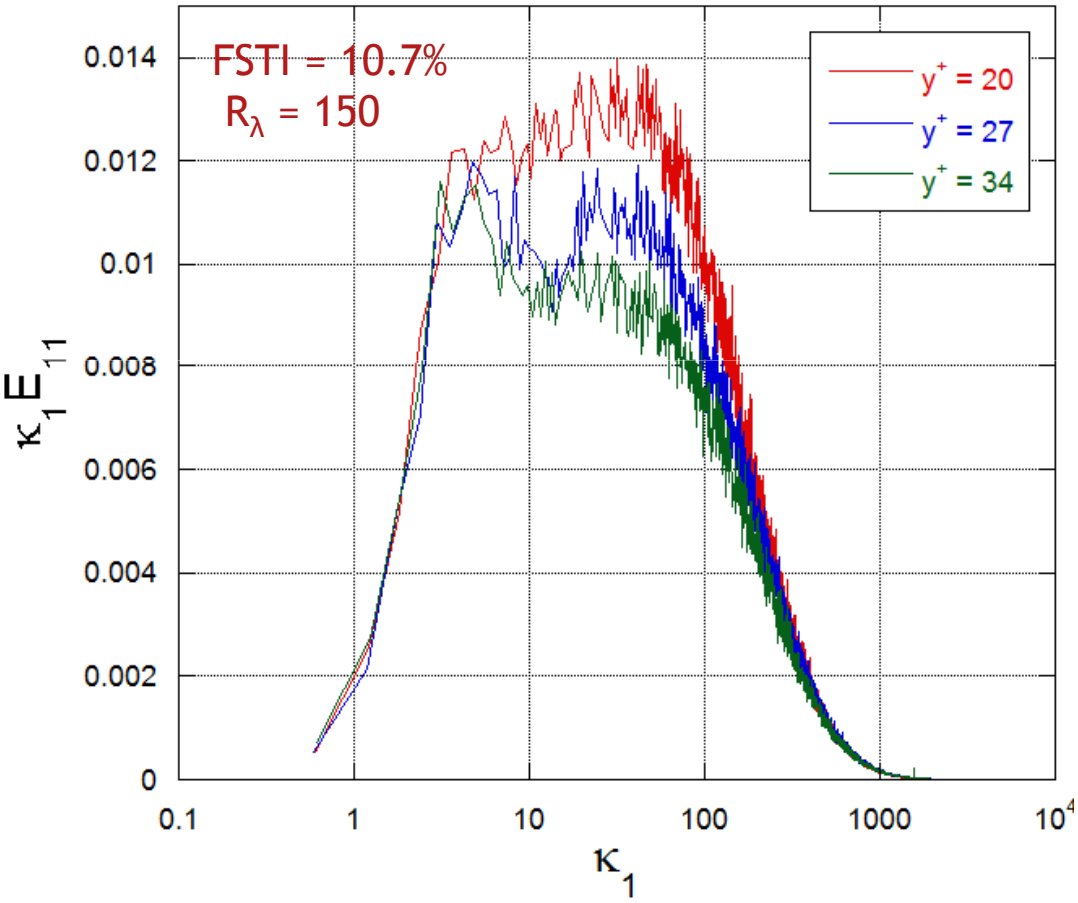


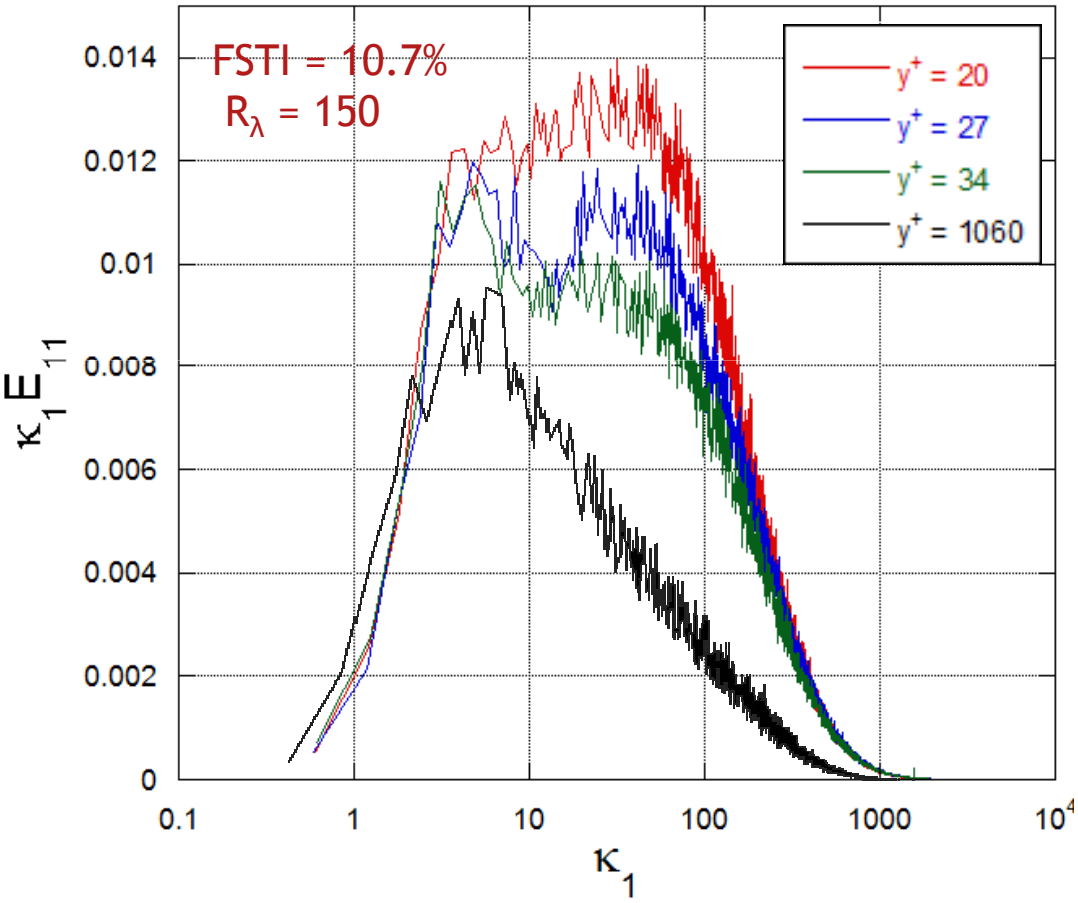
Evolution of Spectra

- Second peak decreases further from the wall



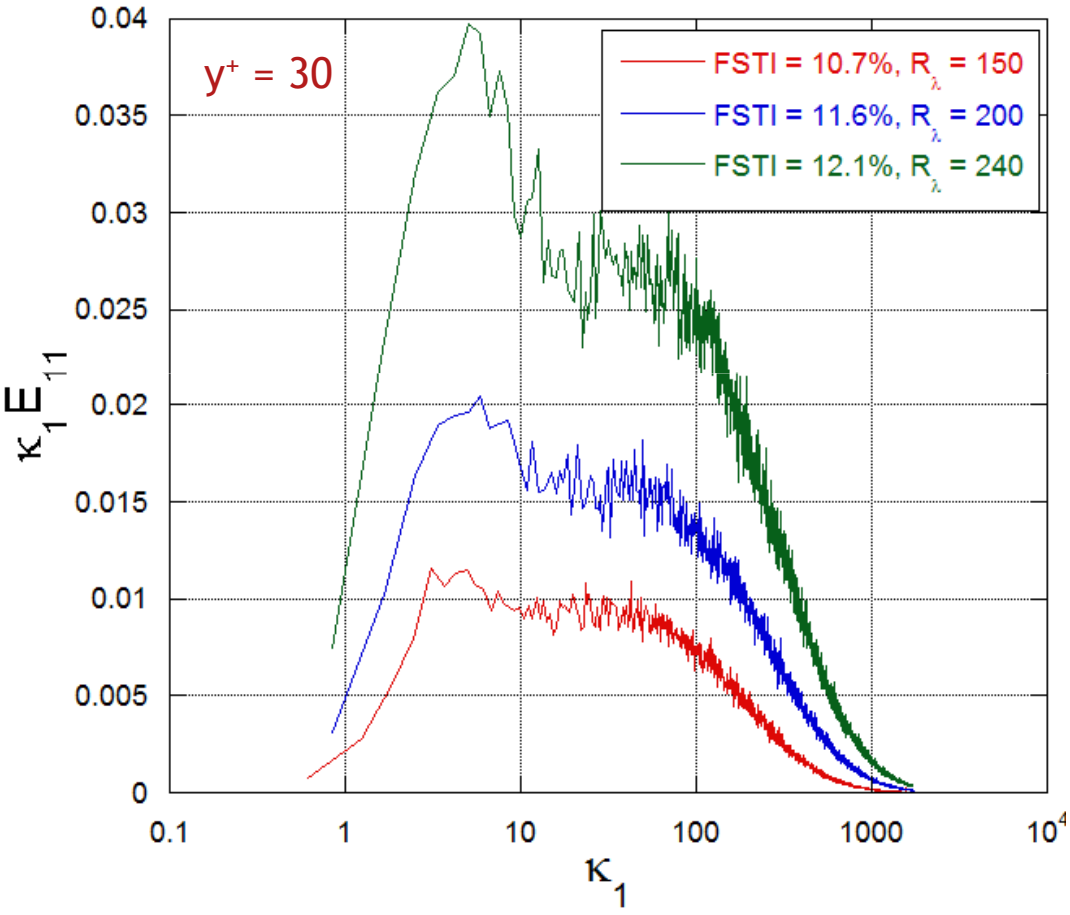
Evolution of Spectra

- Second peak decreases further from the wall



Evolution of Spectra

- 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

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