SuperGen Assembly
Cranfield University.
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Incident and Wake Turbulence and Interactions with Horizontal Axis Rotors.

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Acknowledgements: Rafael Palacios-Nieto, David Hankin (BMT FM).
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Imperial College London

Summary:

- **HAWT**s typically 3 bladed, upwind rotor machines, diameter up to ~150m, tip speed ~ 80+ms^{-1}.

  [HATT prototypes typically 2 bladed, up- & down-stream rotors, diam. ~ 30m, tip speed O(10ms^{-1}).]

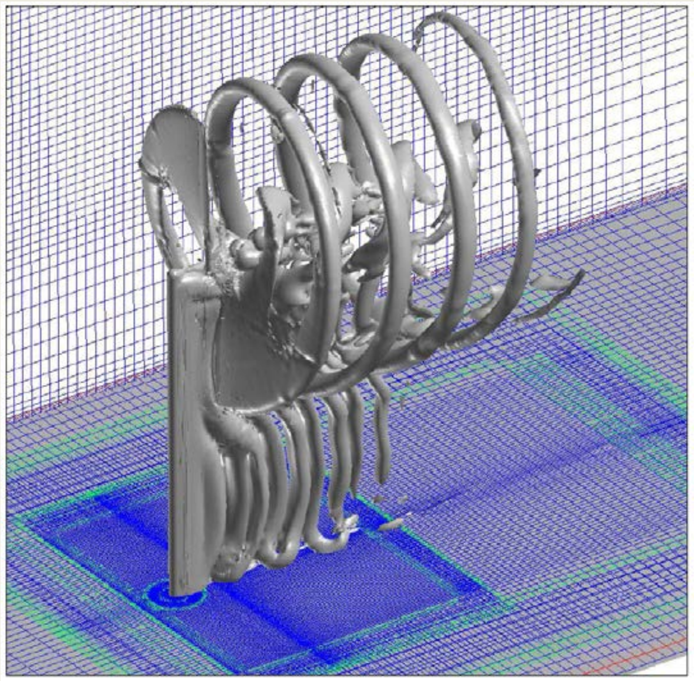
- Rotor blades are subject to **Random** loads due to incident **Turbulence** in the **ABL** or in **wakes** of other upstream turbines when deployed in farm arrays.
- As part of SuperGen (MAXFARM) Imperial College is investigating aerodynamic control to reduce unsteady blade loading.
- This presentation will deal with some issues of the turbulence impacting the rotor blades.

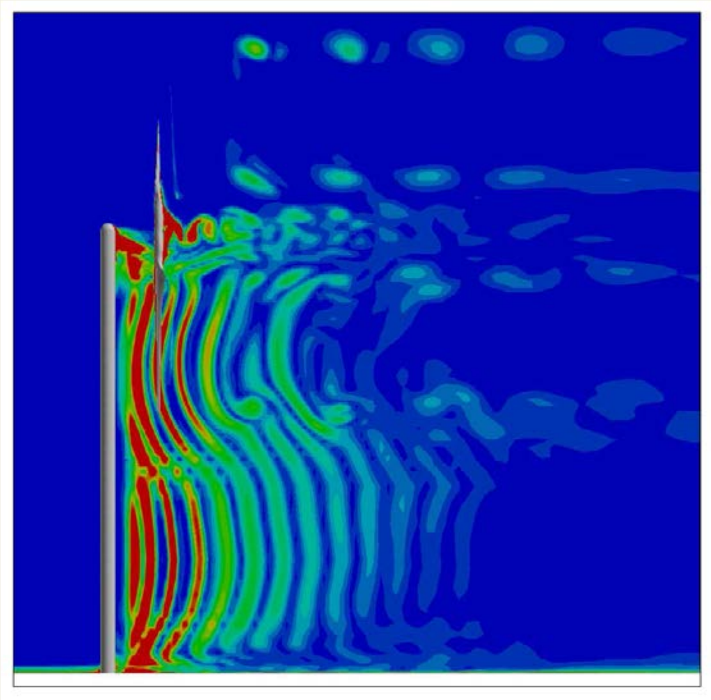
Rotor Wakes.

Wind-Farm (Horns Rev, offshore) Denmark)

Flow Field Computation

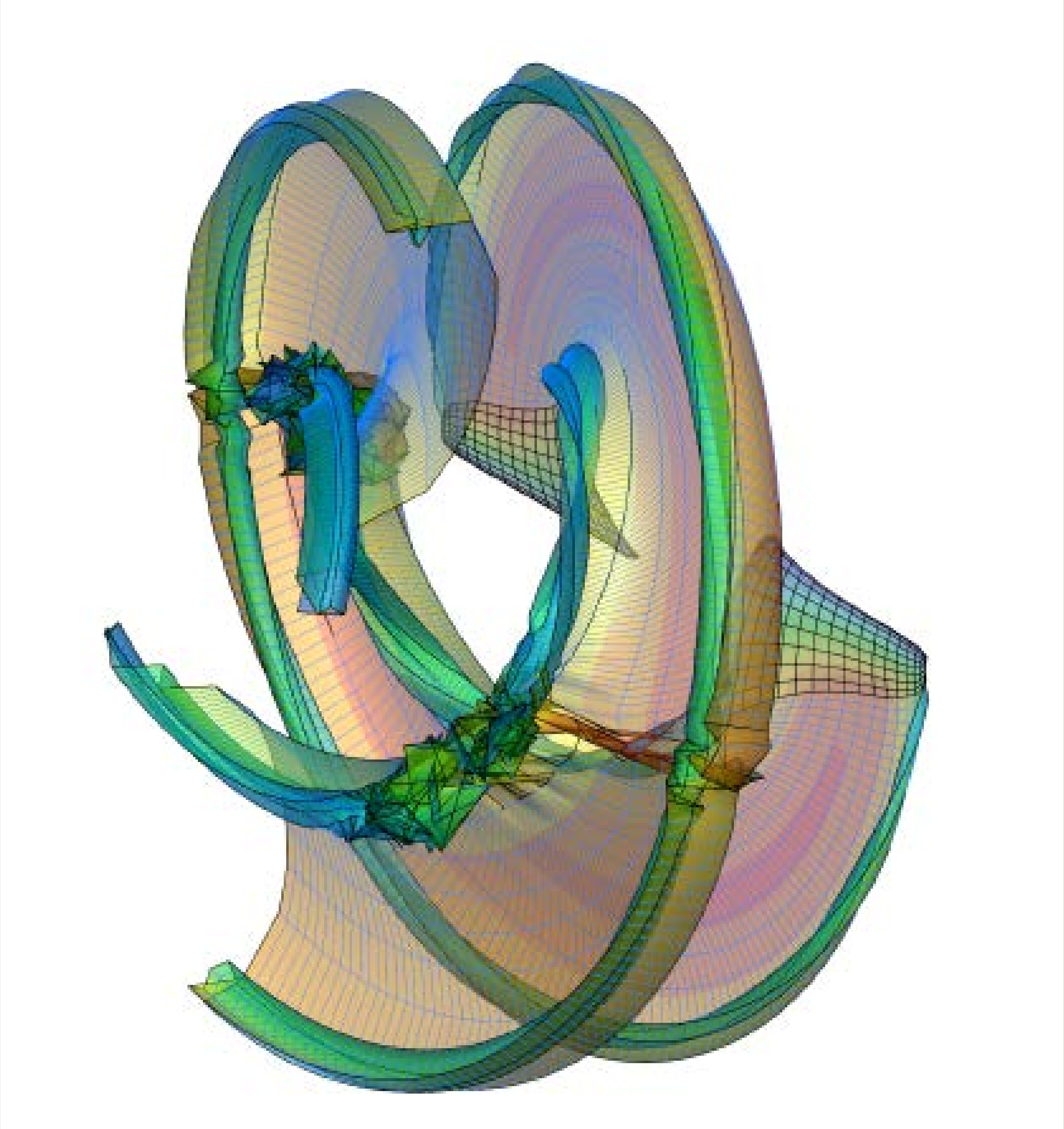
- URANS computation of the flow around a (downwind) HAWT. [Acknowledgement F. Zahle (Risoe Lab.)]
- Iso-contours of absolute vorticity shown.
- Tip and root vortices preserved well downstream of turbine when incident flow is uniform.



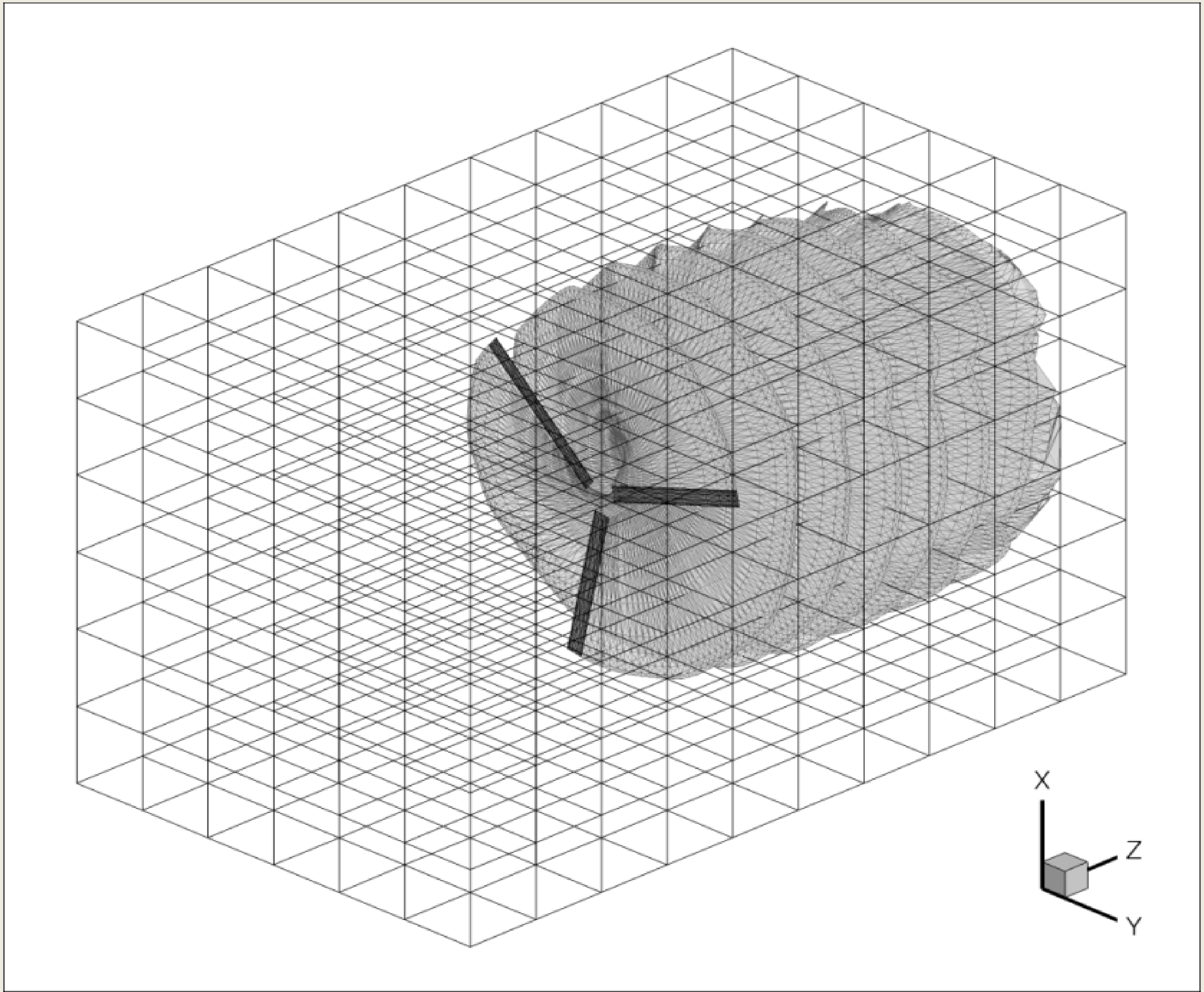


Aeroelastic Rotor Flow Simulation

[Free Wake Panel Method – unsteady vortex lattice method (UVLM), FEA Beam element dynamics, Twin-bladed rotor].



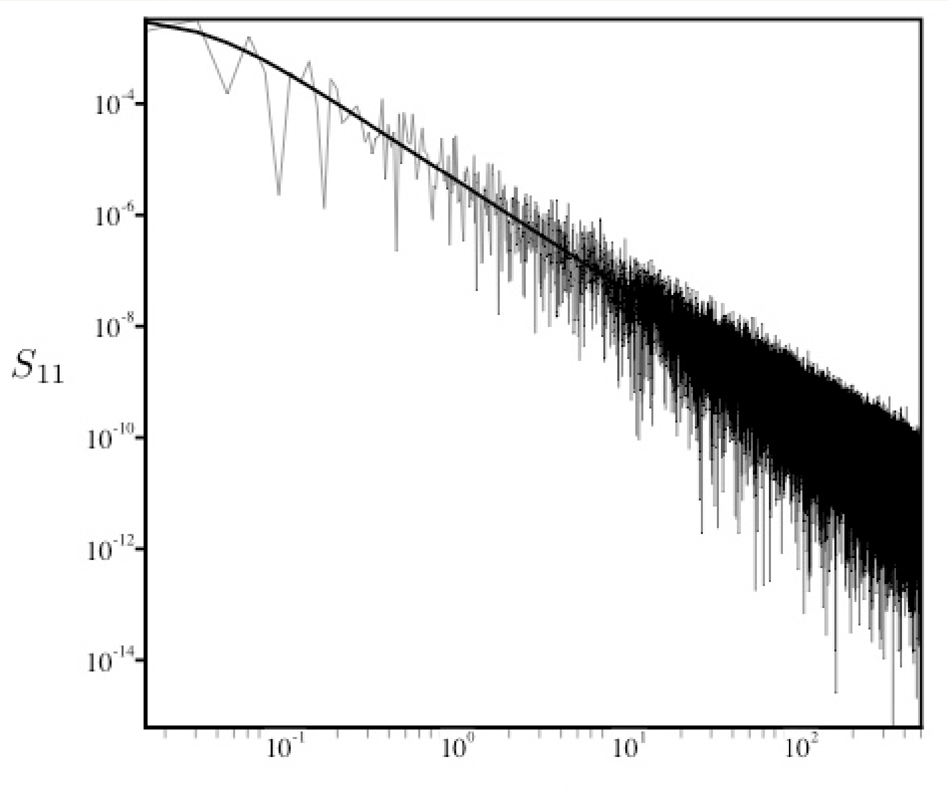
Mesh for convected turbulence field

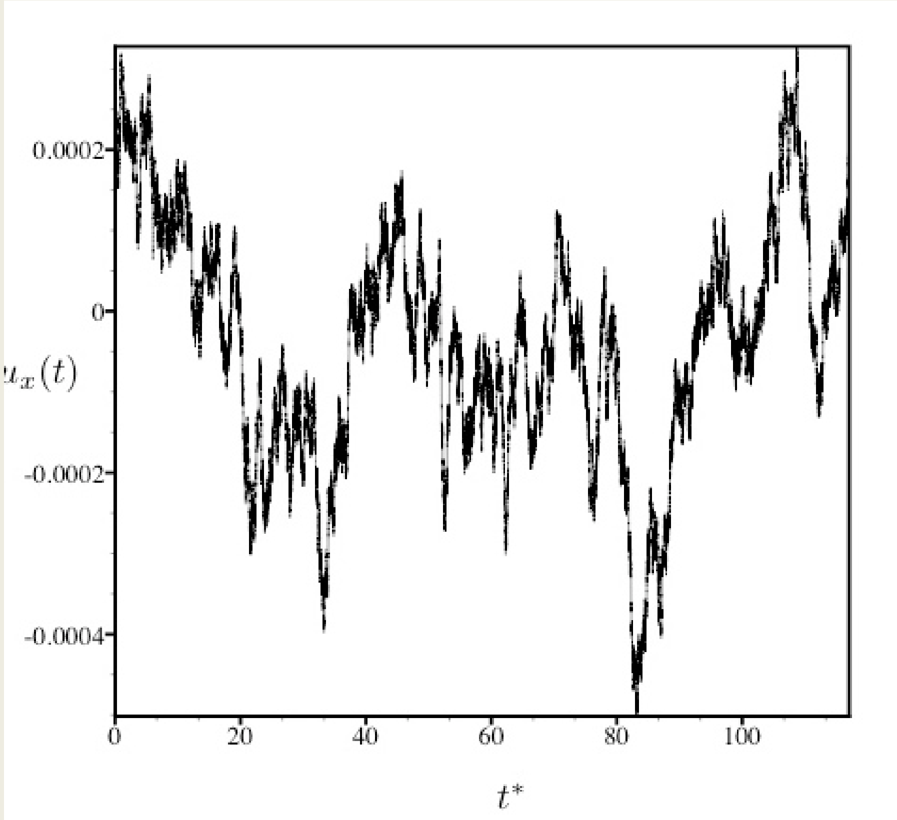


INCIDENT TURBULENCE (ABL)

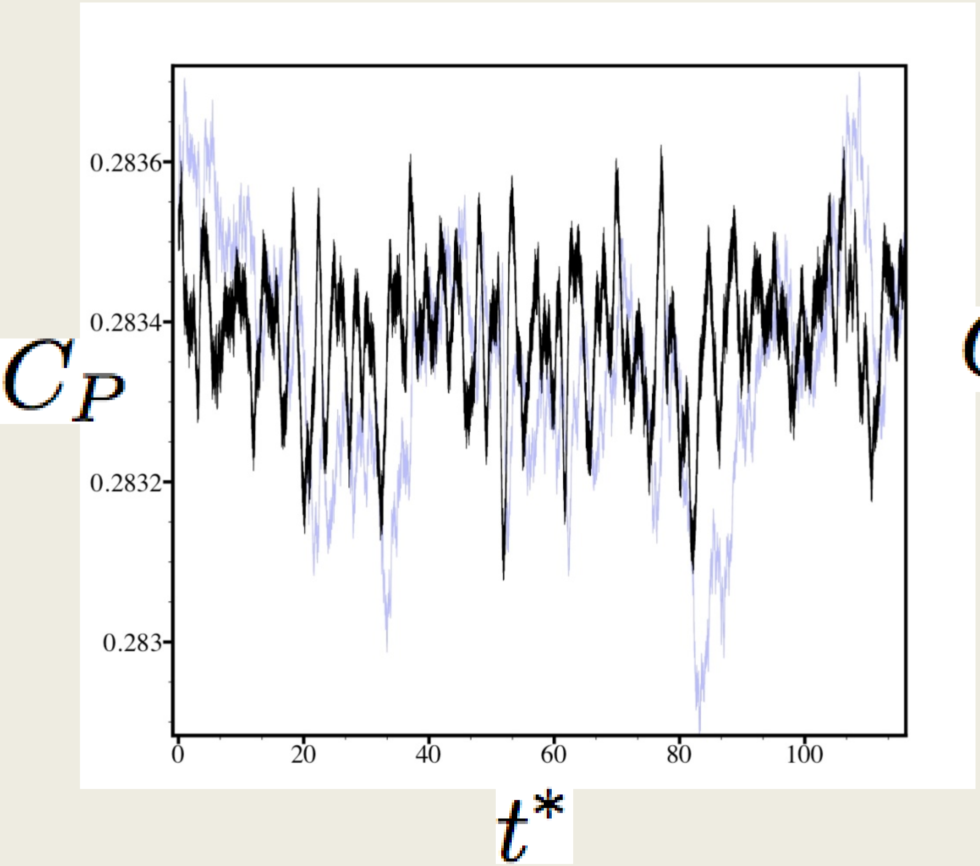
Simulated Streamwise Velocity Component assuming von-Karman spectrum and Gaussian probability.

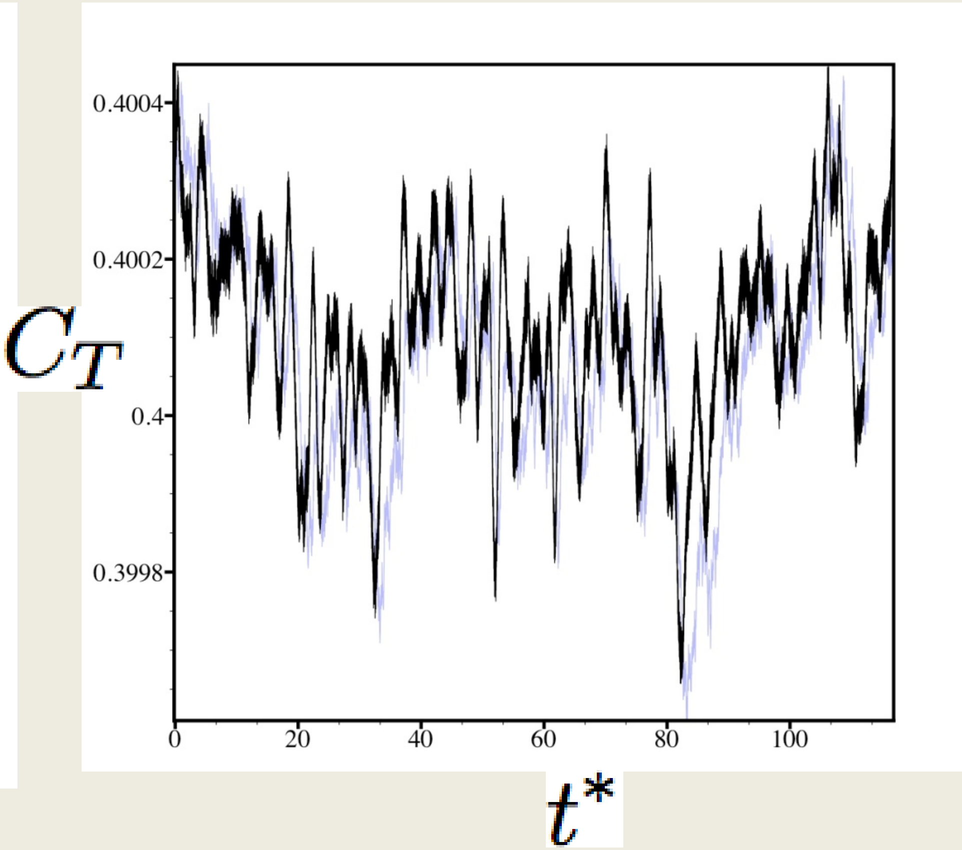
Von Karman spectrum **u velocity component**





Power and Thrust Coefficient Response

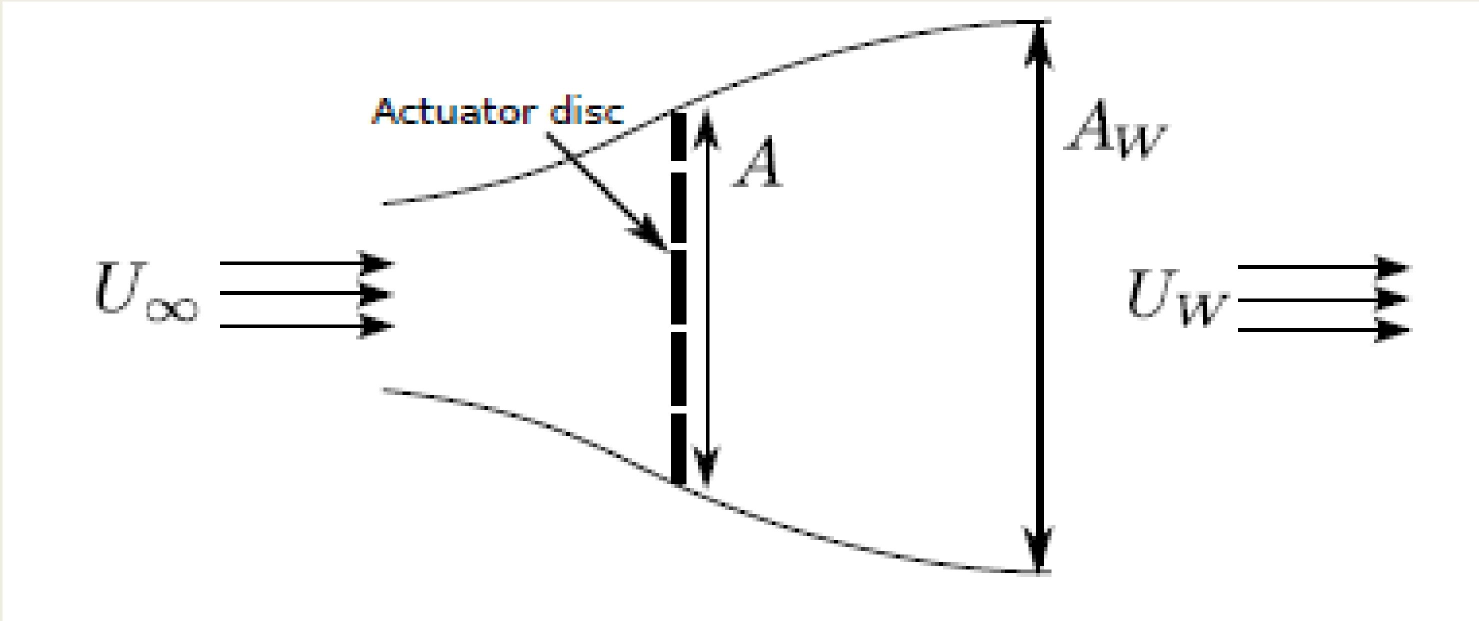




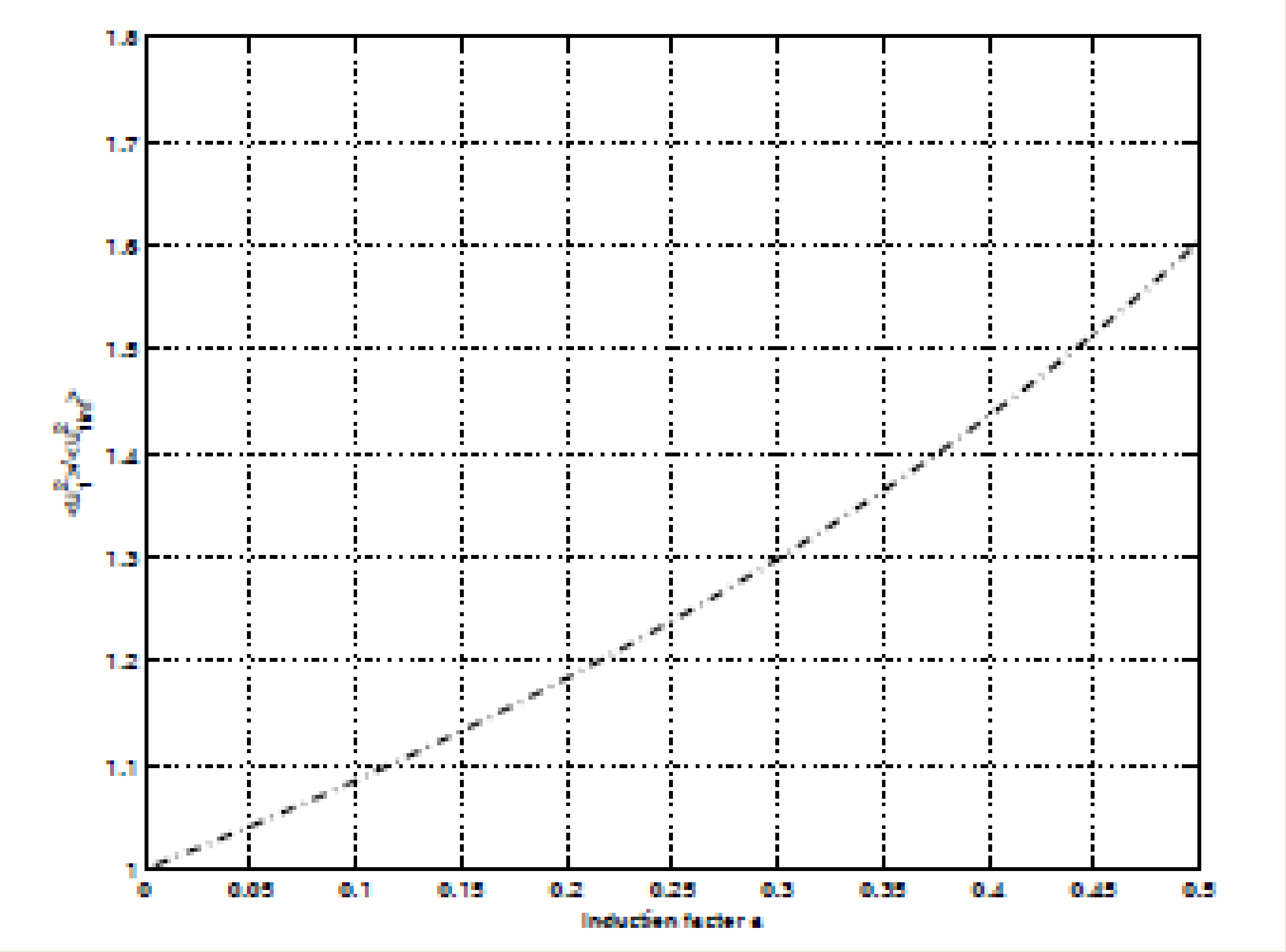
$\Lambda = 5$

INCIDENT TURBULENCE DISTORTION

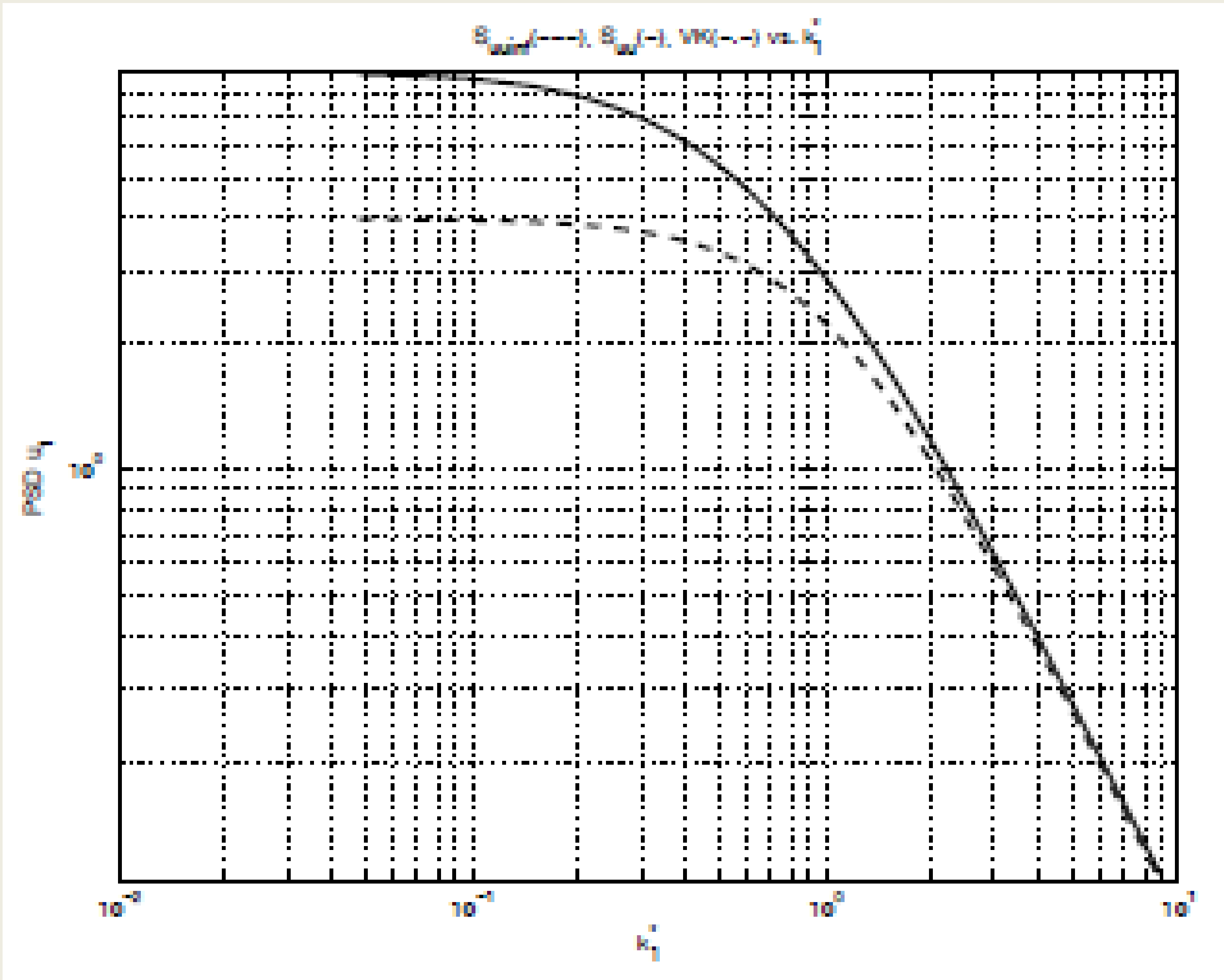
Schematic of Actuator Disc Mean Flow



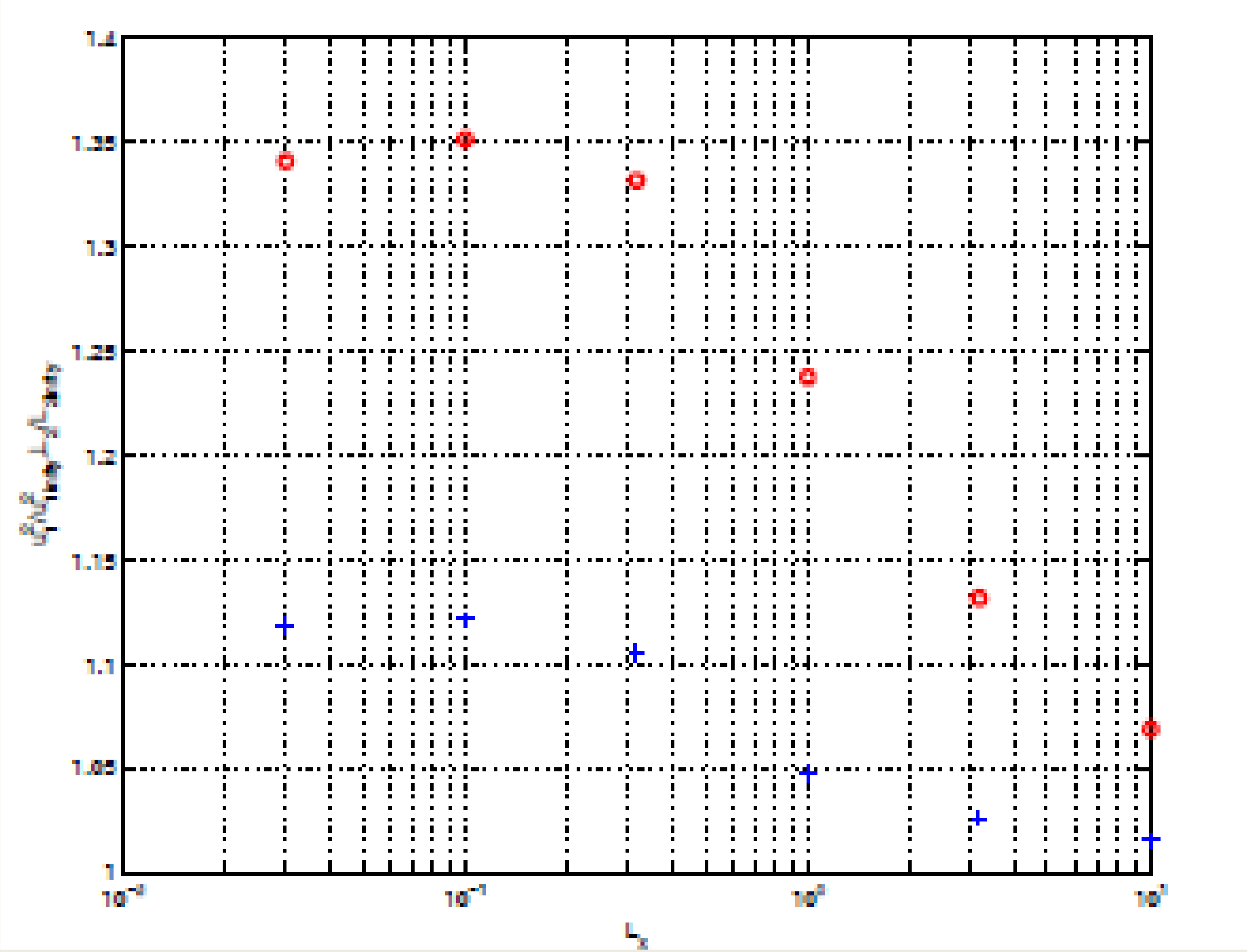
(Homogeneous) distortion of small length-scale turbulence $\overline{u^2}/\overline{u_\infty{}^2}$, (Batchelor & Proudman, Farr & Hancock)



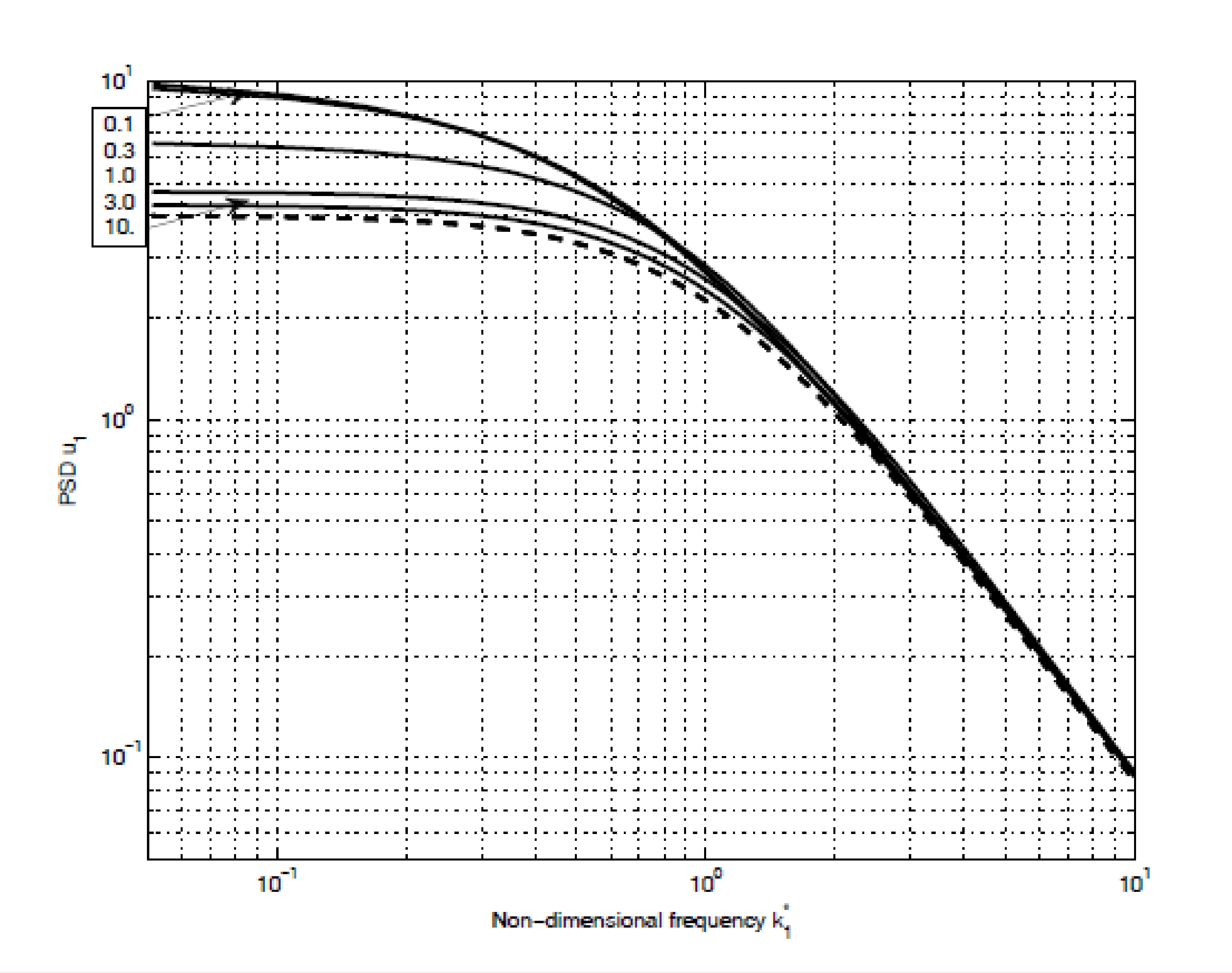
Spectrum S_{uu} of distorted small length-scale turbulence, ---- undistorted (von Karman spectrum).



Mean square intensity and transverse length-scale of distorted turbulence $\overline{u^2}/\overline{u_0{}^2}$, $L_2/L_{2,0}$



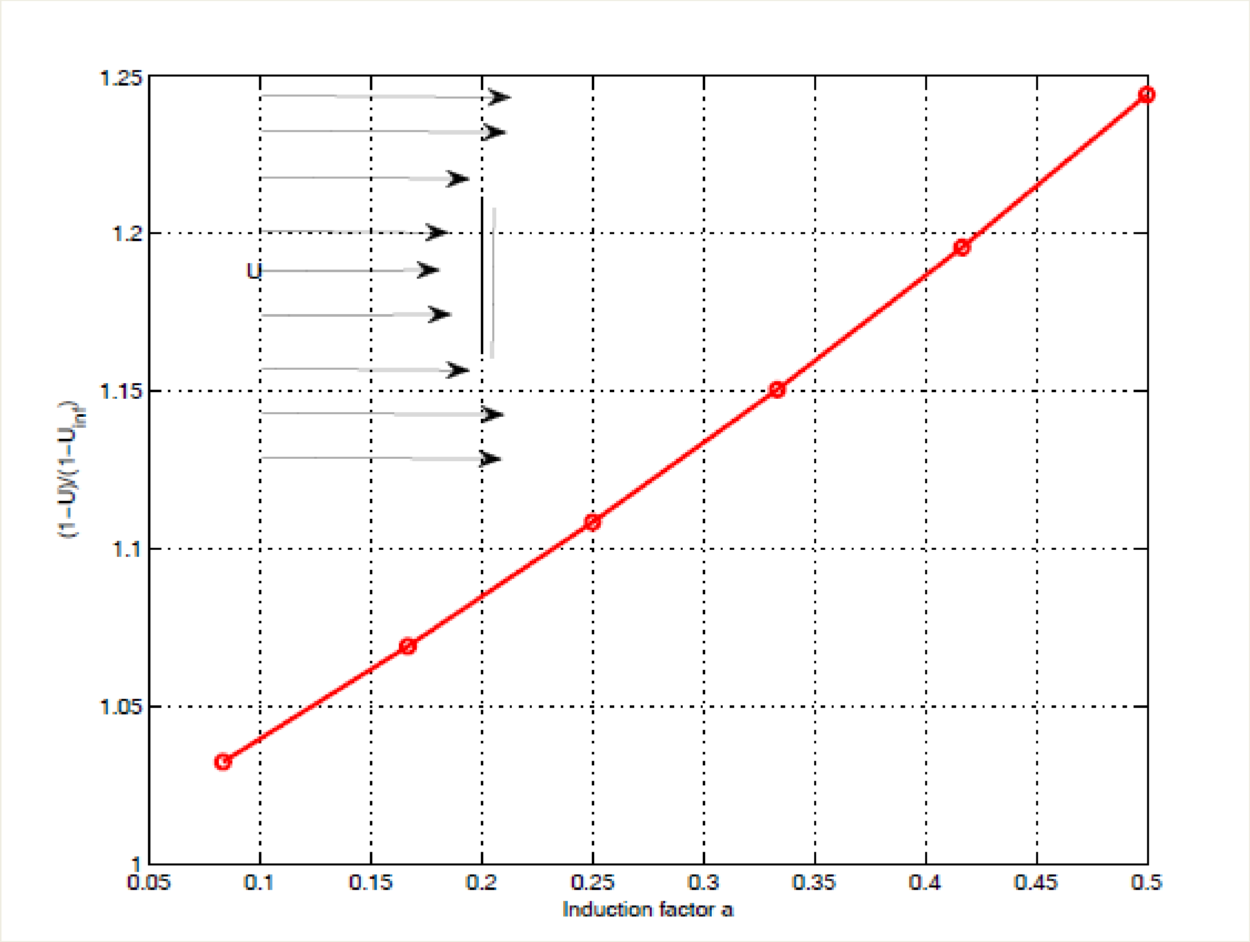
Distortion of Turbulence into a HAWT Rotor (axis)



Incident Wakes from Upwind Rotors

Mean flow and turbulence

Distortion of mean flow profile of rotor wake.

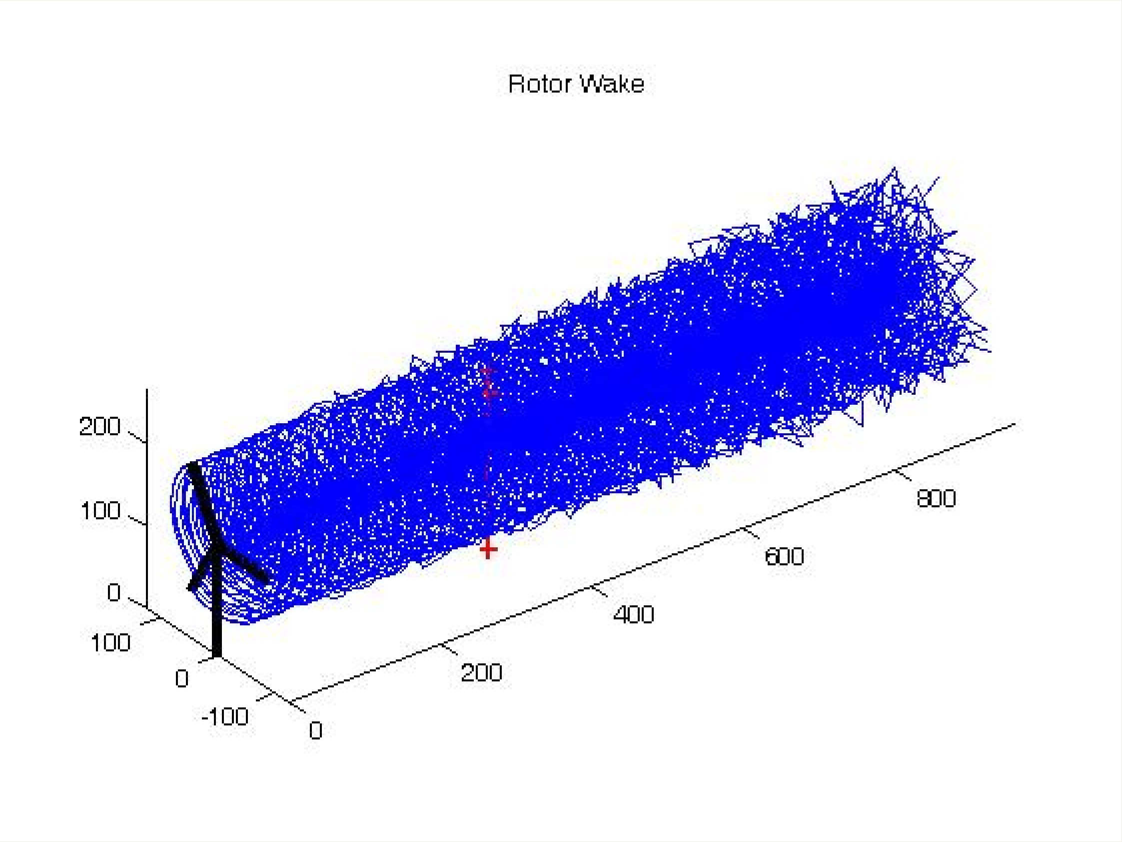


Mean ΔU on axis at rotor / ΔU_∞

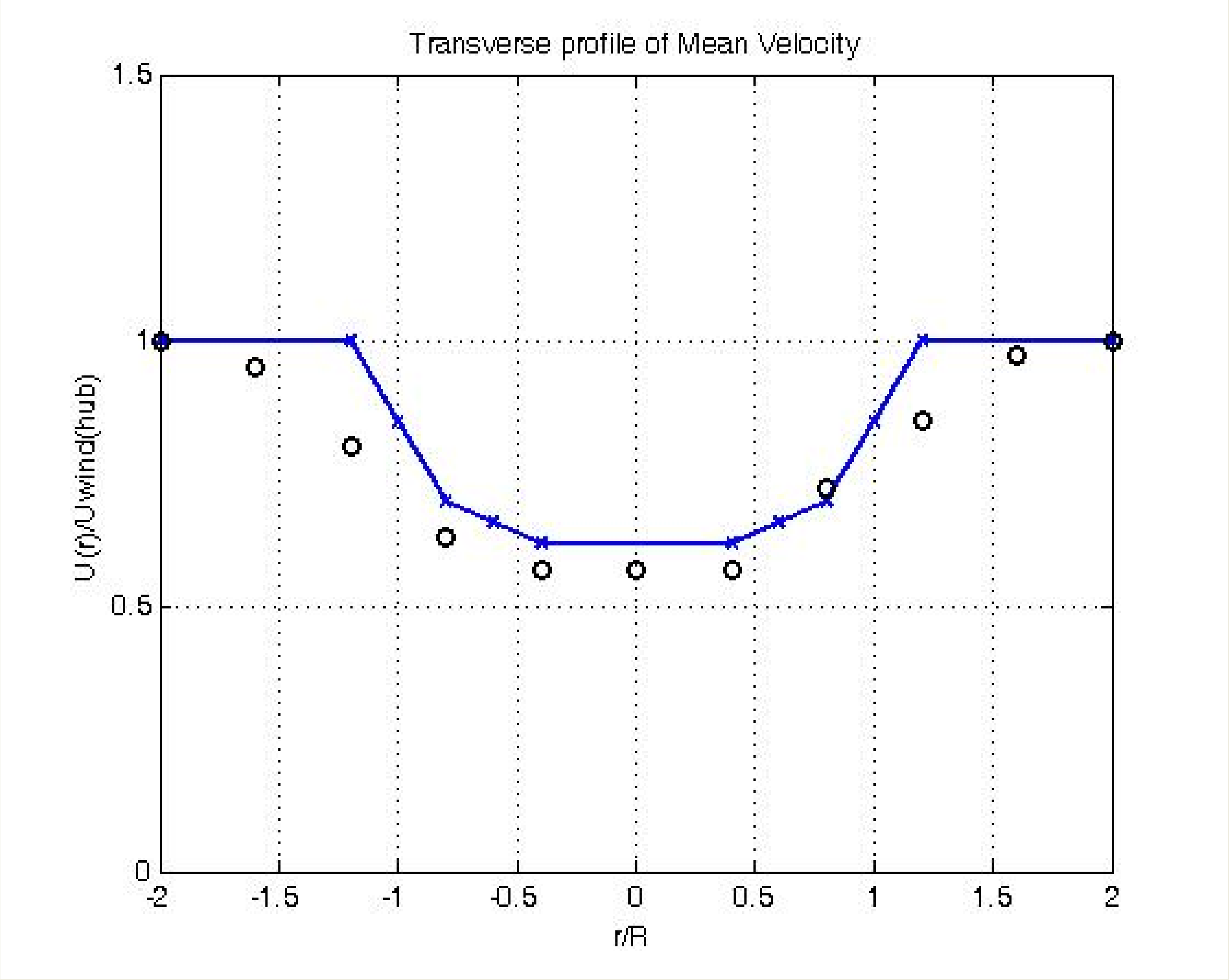
Velocity defect $\Delta U_\infty = 0.25U_\infty$

Turbulence and Wake Interactions (Wind Tunnel Expt.)

Wake of a three bladed rotor in uniform incident flow (UVLM free vortex wake)



Mean wake velocity profile U(y), versus experiment of Hancock & Pascheke (o)

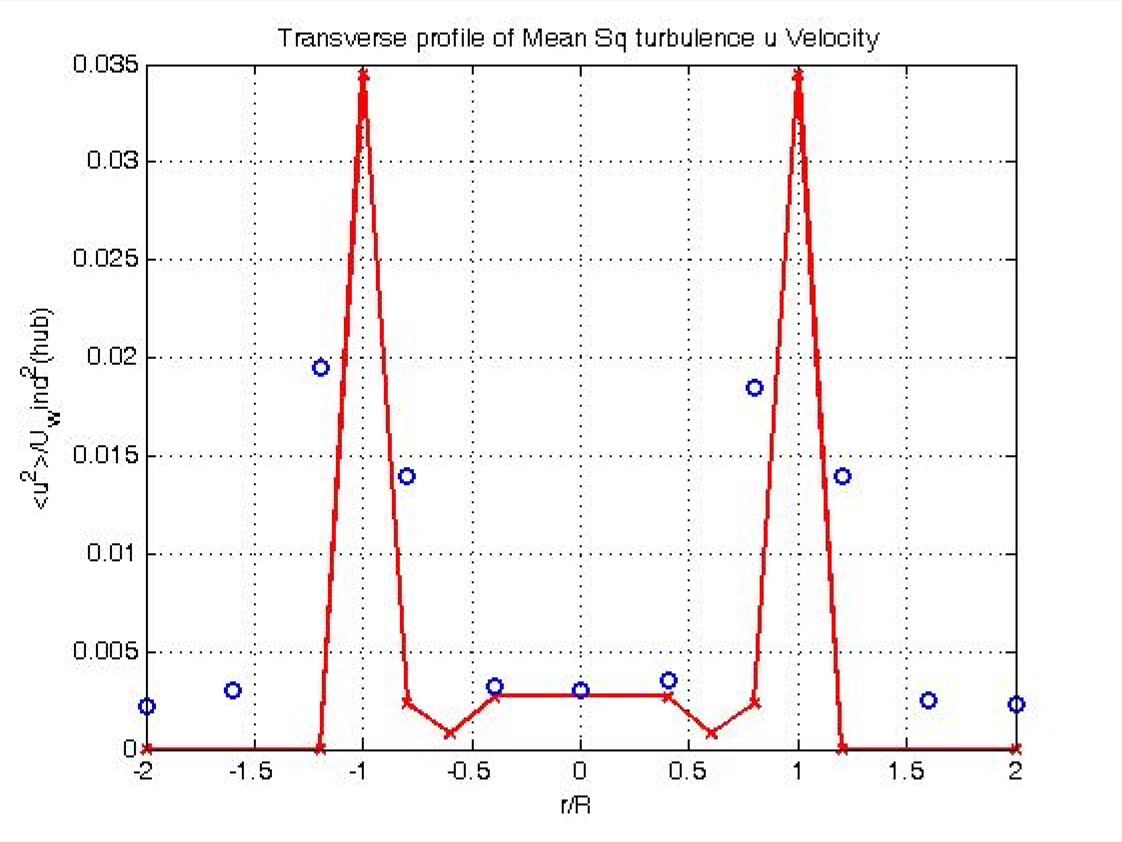


Actuator disc or line representation of rotors for RANS computations of turbulence in wind farms.

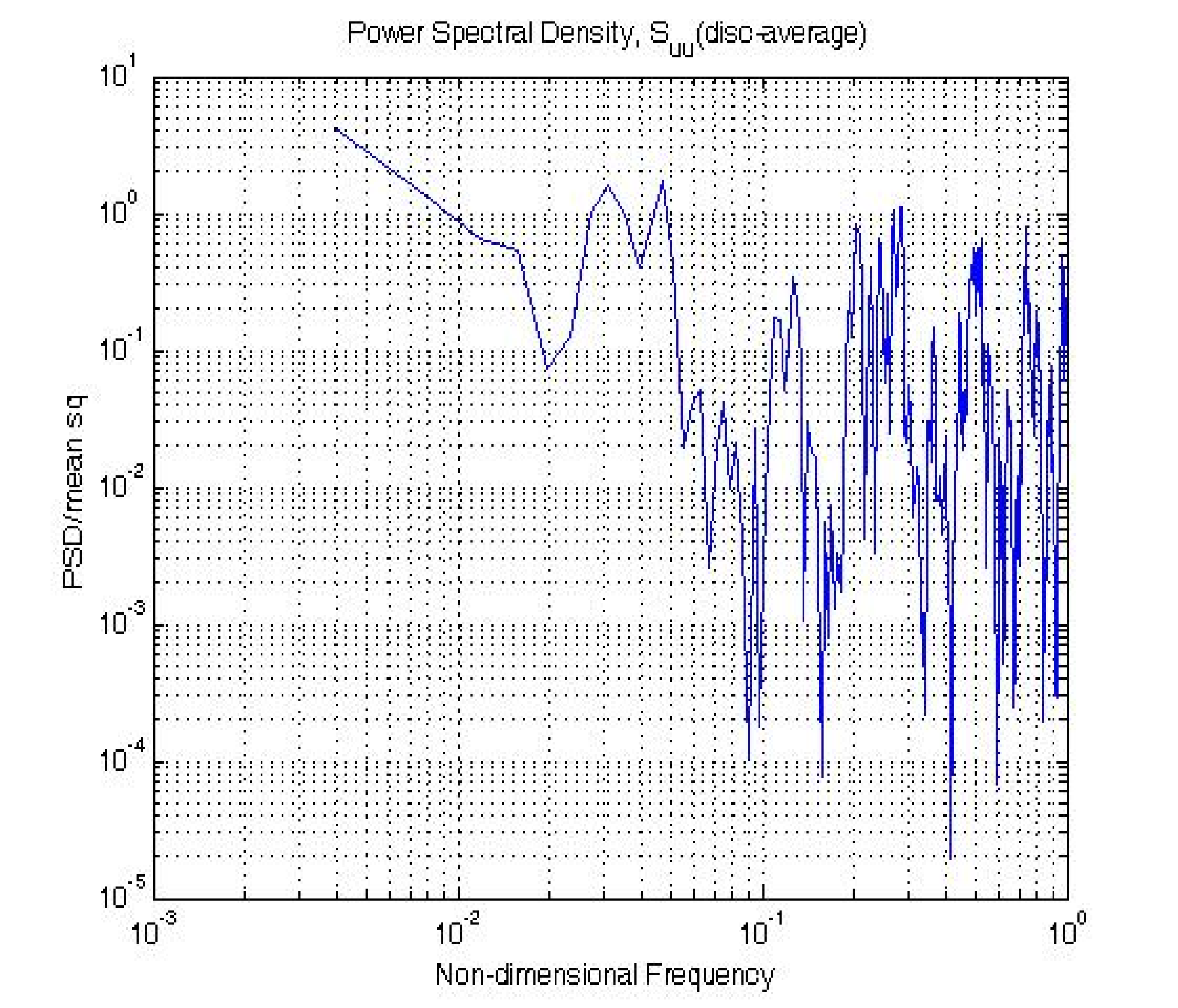
- Sinks of mean flow momentum.
- Sources of turbulence KE. (κ)
- Length-scale of rotor wake turbulence (ε)

Alternatively LES simulations (eg: Porte-Agel et al.)

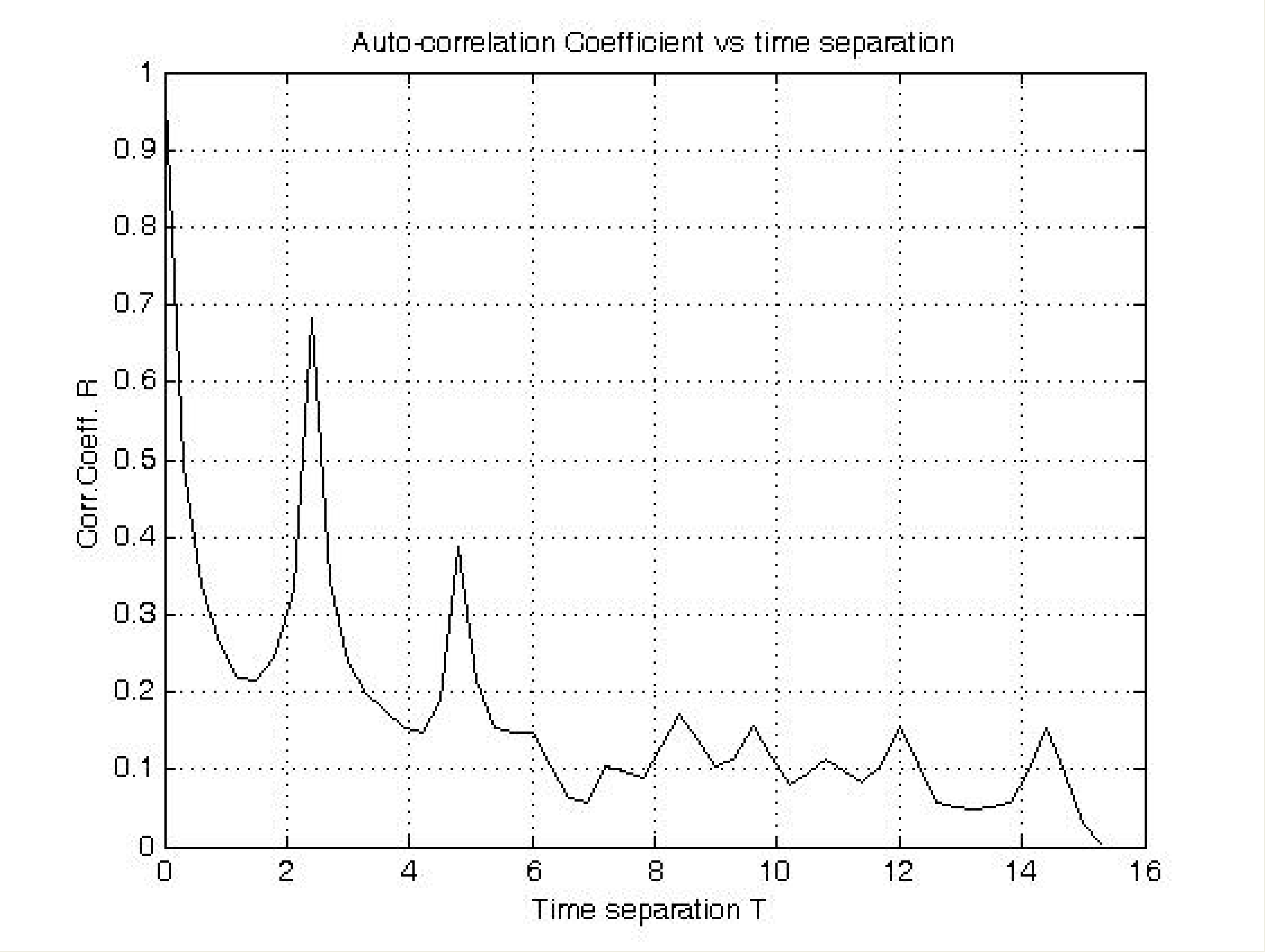
Transverse profiles of $\overline{u^2}/U^2$, o Hancock & Pascheke



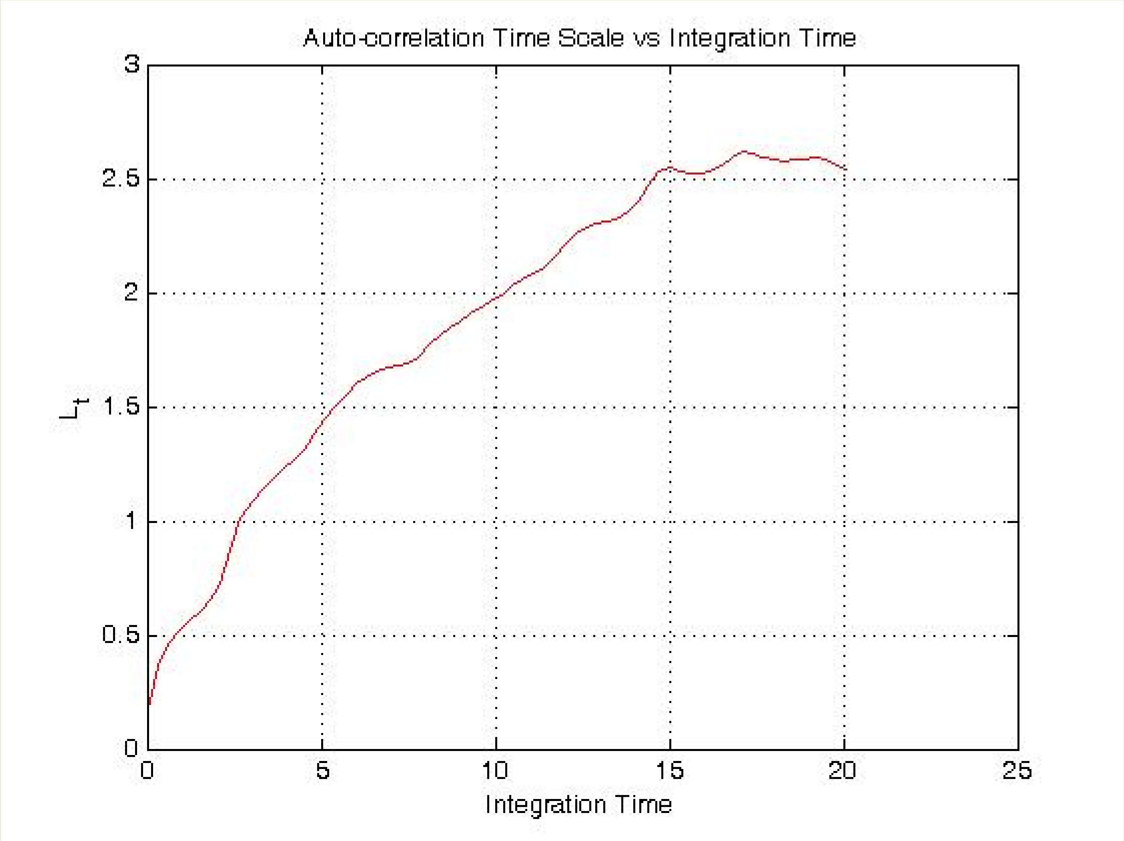
Spectrum of turbulence in rotor wake 1D downstream of rotor.



Autocorrelation coefficient versus time separation in wake 1D downstream of rotor.



Autocorrelation time-scale L_T in wake of rotor 1D downstream



Turbulence intensity $\overline{u^2}/{U_{wind}}^2$ versus rotor thrust coefficient C_T

Sampling of turbulent velocities induced in (UVLM) rotor wake indicates a quadratic correlation between $\overline{u^2}/{U_\infty}^2$ and C_T

Turbulence Energy, Length scale and dissipation in rotor wake

Approximating $\kappa = \frac{1}{2}\overline{q^2}$ by $\overline{u^2}$

$$L_\varepsilon \approx L_x \sim \frac{(1-a)D}{N_B \Lambda}$$

Therefore dissipation

$$\varepsilon = \kappa^{3/2} / L_\varepsilon \sim \frac{N_B \Lambda\, {C_T}^3 {U_{wind}}^3}{(1-a)D}$$

- Conclusions

Distortion of turbulence only significant if length scale of turbulence < rotor diameter.

Some distortion (< 15%) of mean wake profiles may be expected.

Some empirical correlations for turbulence KE. (κ) and length-scale (dissipation ε) have been estimated for a rotor wake.