Wind Energy Research Center

School of Energy Resources

ENGINEERING APPLIED SCIENCE

UNIVERSITY OF WYOMING

Effects of Varying Temporal and Spatial Scale Turbulent Inflow on Wind Turbine Performance

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Outline

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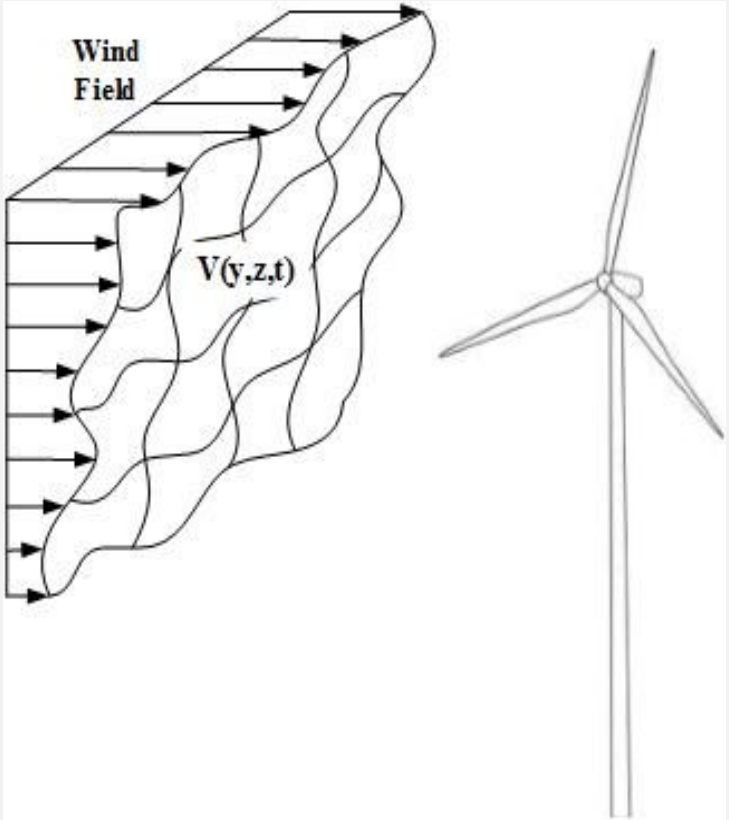
- **Wind simulation**
  - Large Eddy Simulation
- **Wind turbine performance**
  - Aero-elastic code FAST
  - Results
- **Conclusions**



Motivation and Objective

- **Atmosphere contains a wide range of turbulent scales**
  - Wind turbines interact with these turbulent scales
    - **Wind turbine size is increasing > surface layer**
  - Turbulence production varies with the atmospheric conditions
- **Do turbulent scales (spatial and temporal) affect the wind turbine performance?**

Objective: *To study the effect of turbulent scales on wind turbine performance*

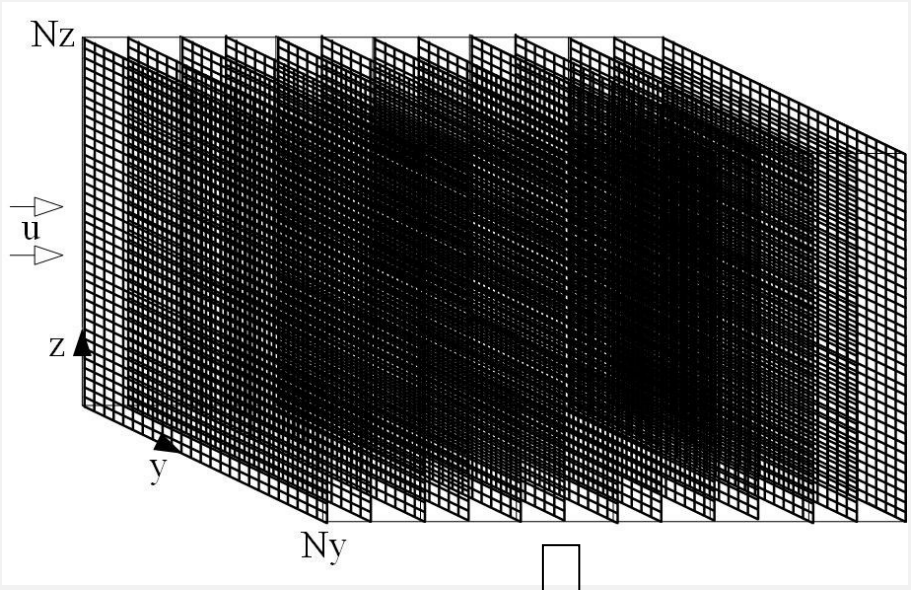
Approach: *Compare the turbine response to the spatially and temporally varying resolution wind inflows*

Large Eddy Simulation

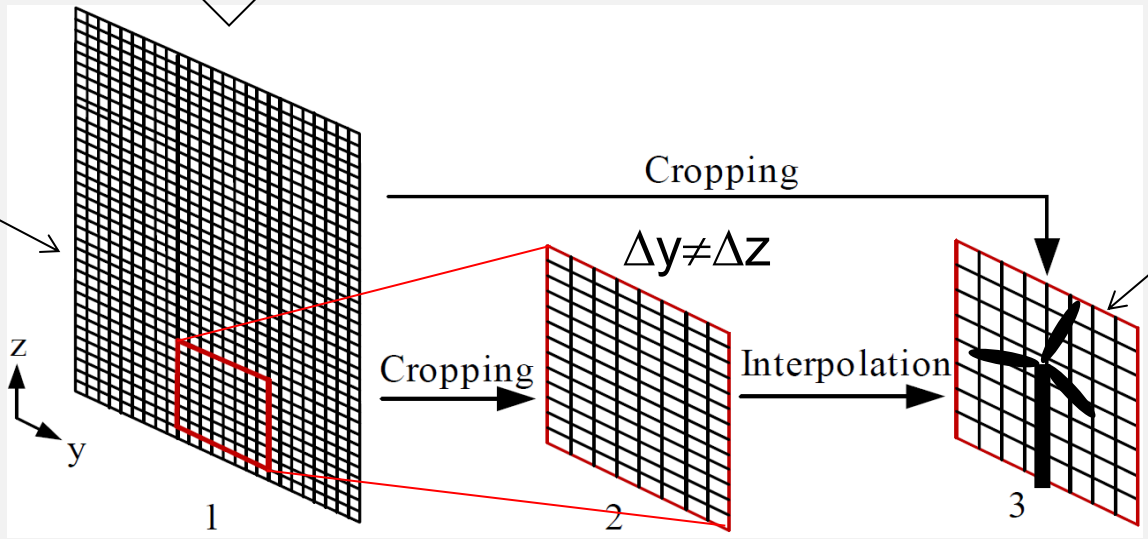
(Neutral Atmospheric Boundary Layer)

Framework used	SOFWA from NREL
Boundary condition	• Periodic BC in stream and span-wise directions • Stress free at top and wall function approach at bottom
Compt. Domain	3 km $\times$ 1.5 km $\times$ 1 km ($x \times y \times z$)
Grid spacing	• 10 m along y and z direction • 15 m —————— • 20 m ——————
Time-step size	0.1 s
# time steps used	18,000

Wind Inflow Preparation



Original Inflow plane
$(N_y \times N_z)$



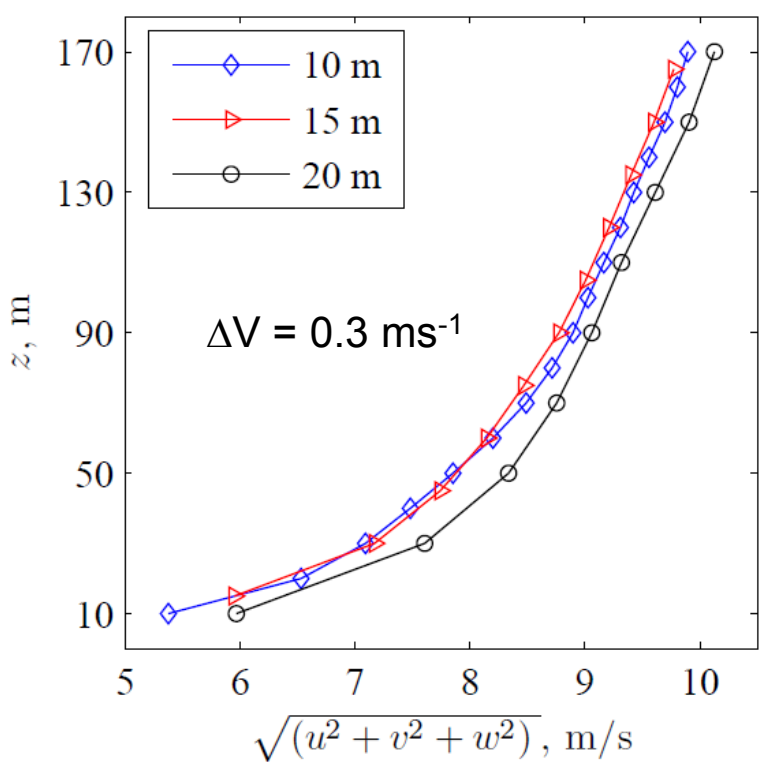
Cropped Inflow plane
$(n \times n)$

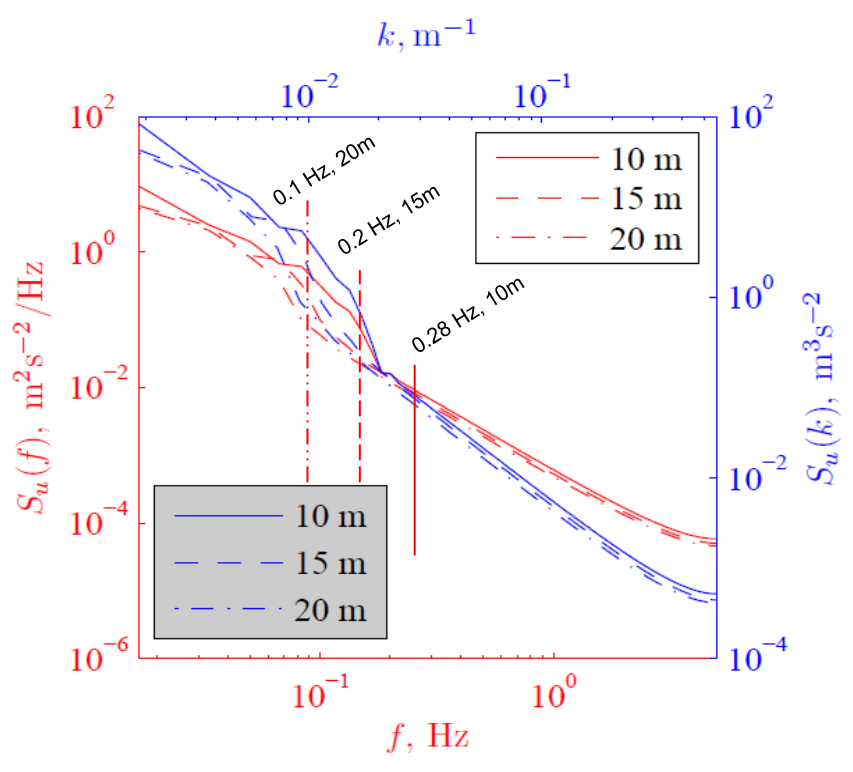
Δy=Δz
Square grid

Spatial Resolution Effect

$\Delta y = \Delta z$ = 10 m, 15m, and 20 m
Δt = 0.1 s

Result: Mean Wind Profile and u_{hub} Spectra

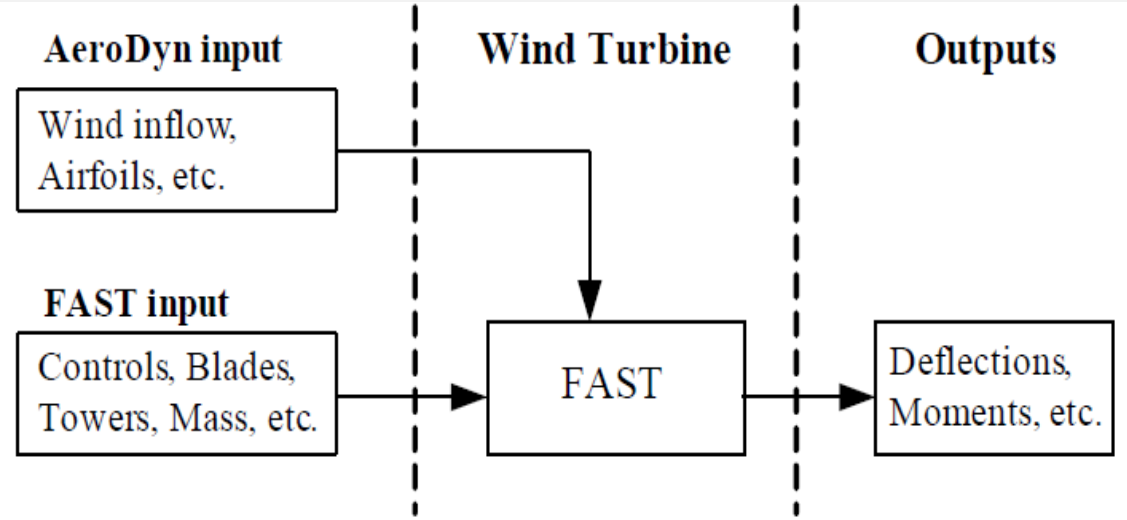




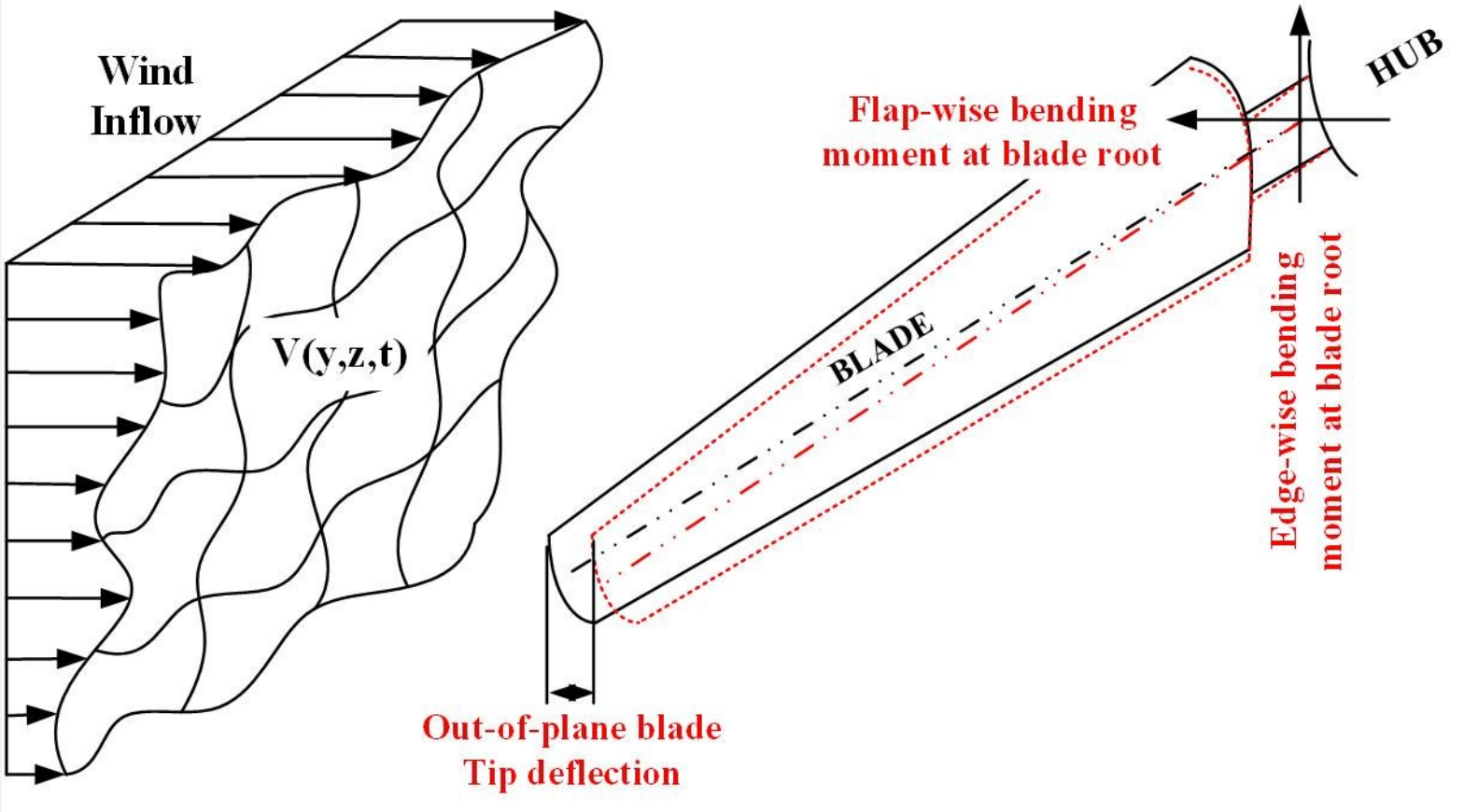
FAST

(Fatigue, aerodynamics, structures, and Turbulence)

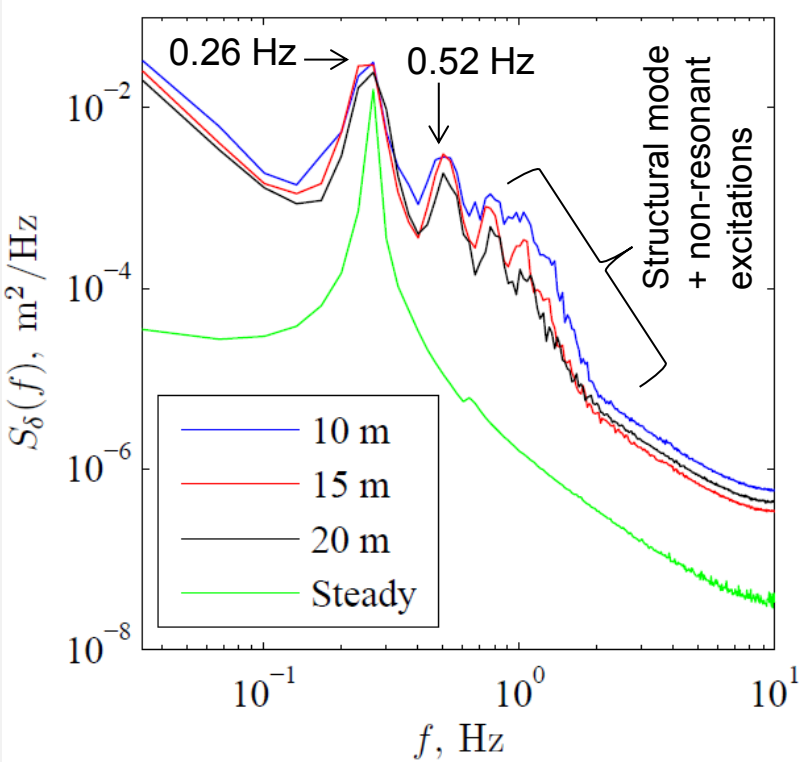
- **Aero-elastic code**
- **Input - loads, geometry and material properties of wind turbine**
  - AeroDyn → aerodynamics loading using wind inflow
- **FAST solves equation of motion**
- **Output – Turbine responses**
- **Turbine:**
  - 1.5 MW, Dia. 70 m
  - 5.0 MW, Dia. 126 m
  - Onshore
  - Active pitch control
  - Time step 0.005 s

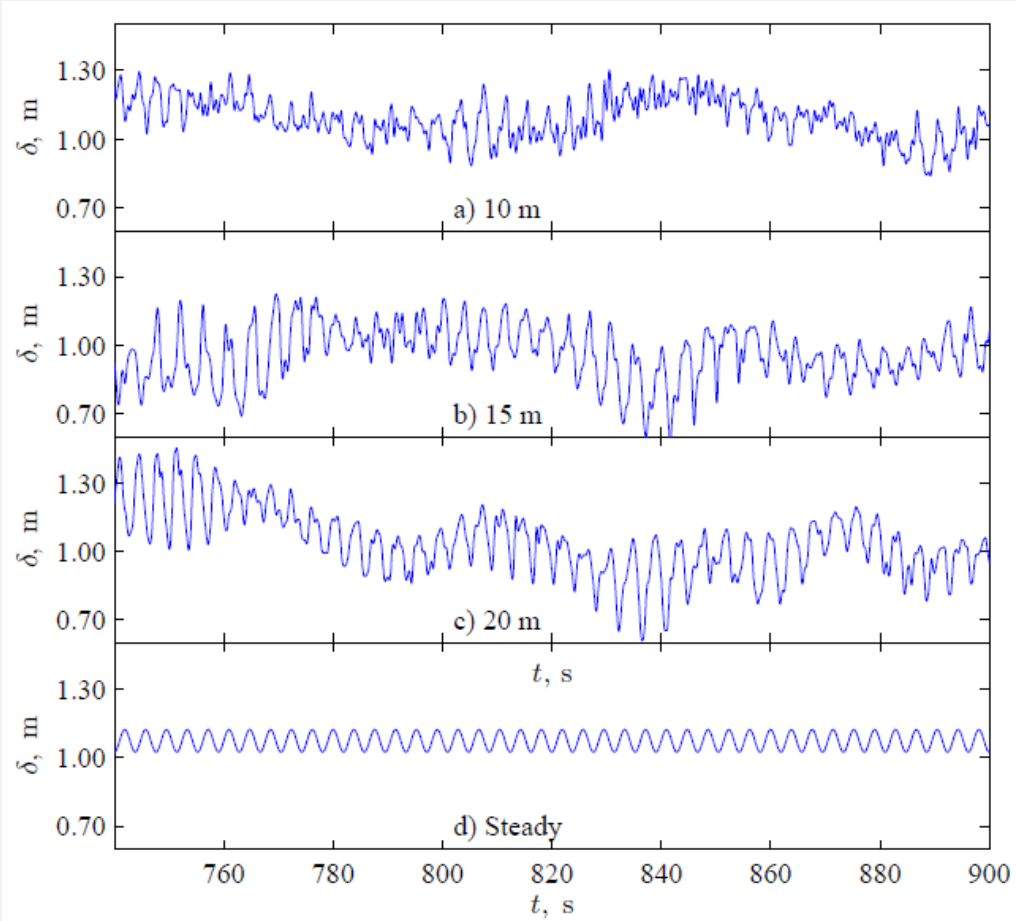


Turbine Outputs



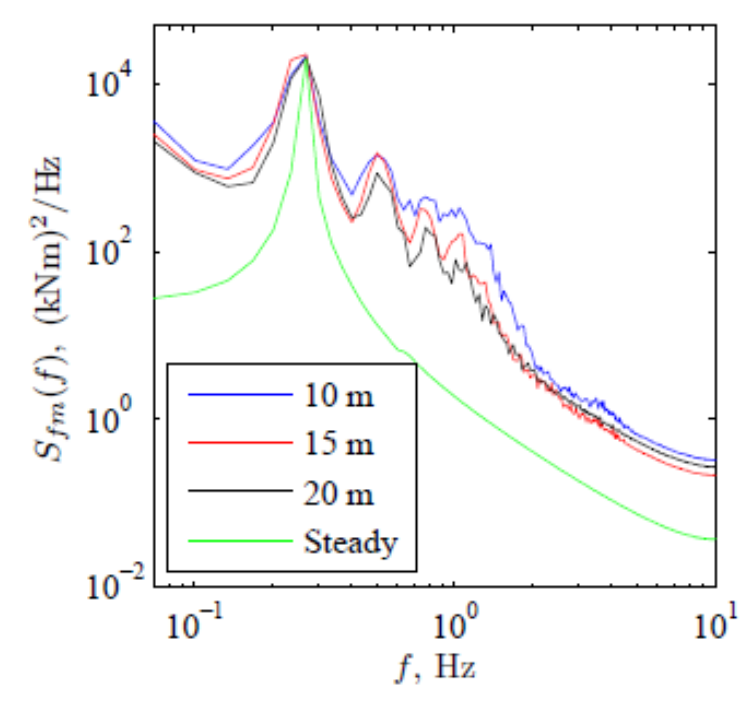
Result: Out-of-plane Blade Tip Deflection (1.5 MW Turbine)



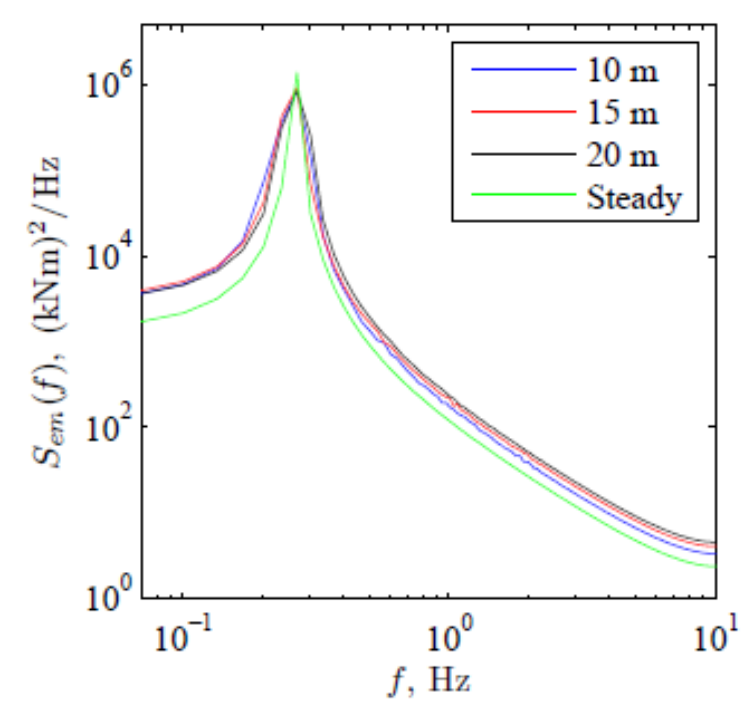


Result: Flap-wise and Edge-wise Bending Moments (1.5 MW Turbine)

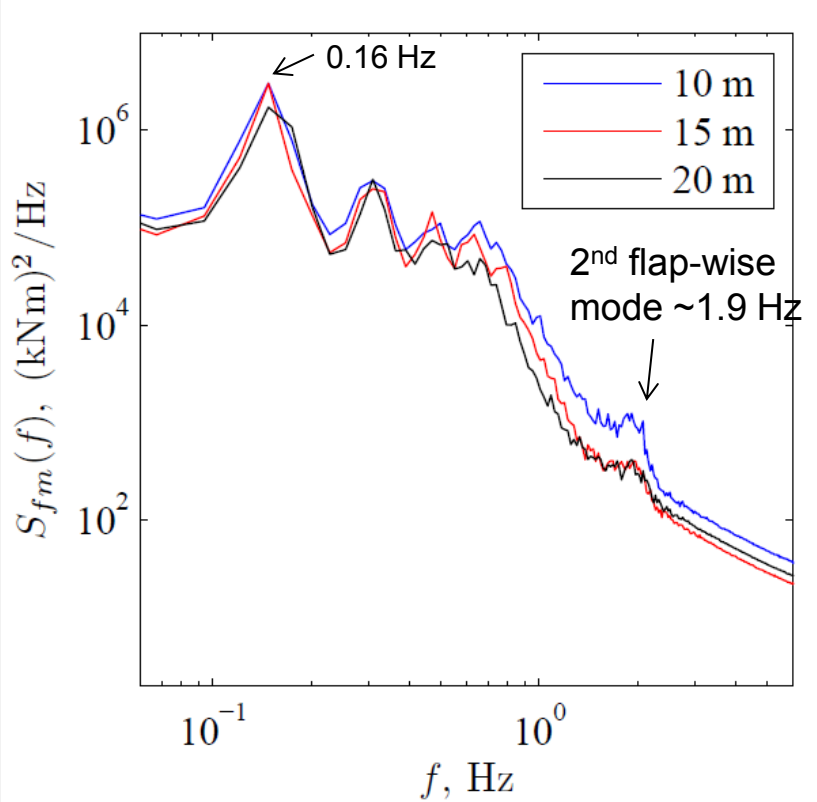
Flap-wise Moment

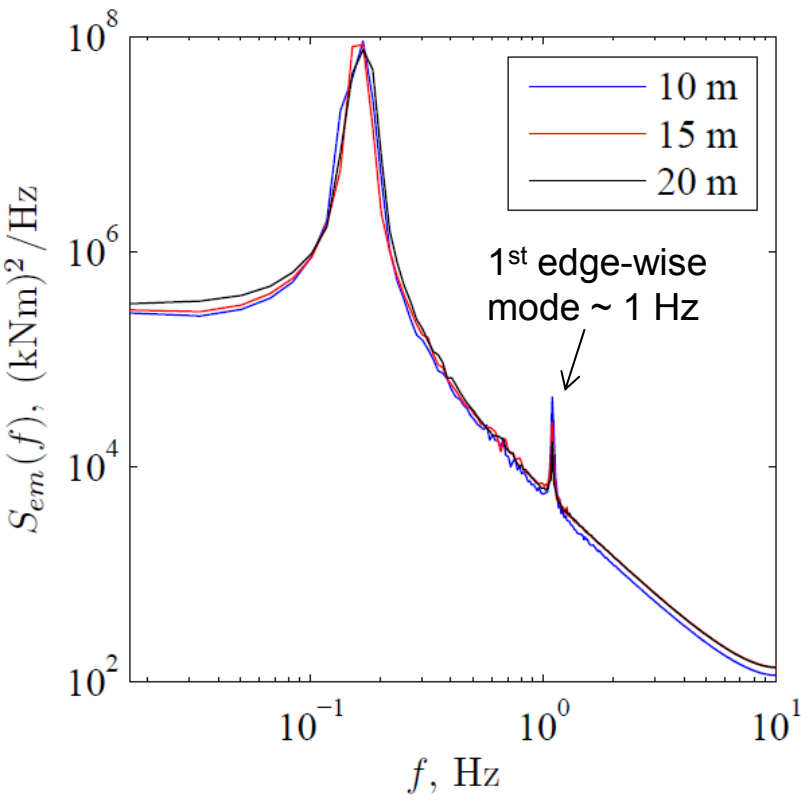


Edge-wise Moment



Result: Flap-wise and Edge-wise Bending Moments (5 MW)





Result: Turbulence Effect

LES Turbulent wind

=

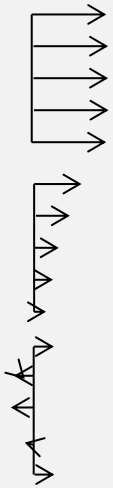
Uniform (**U**)

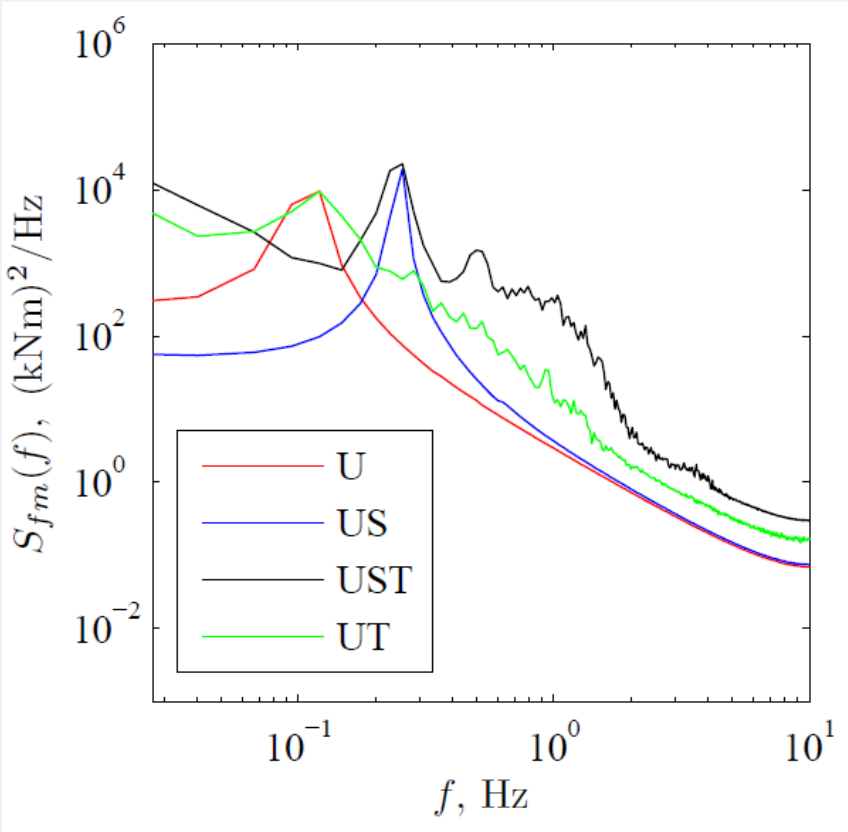
+

Shear (**S**)

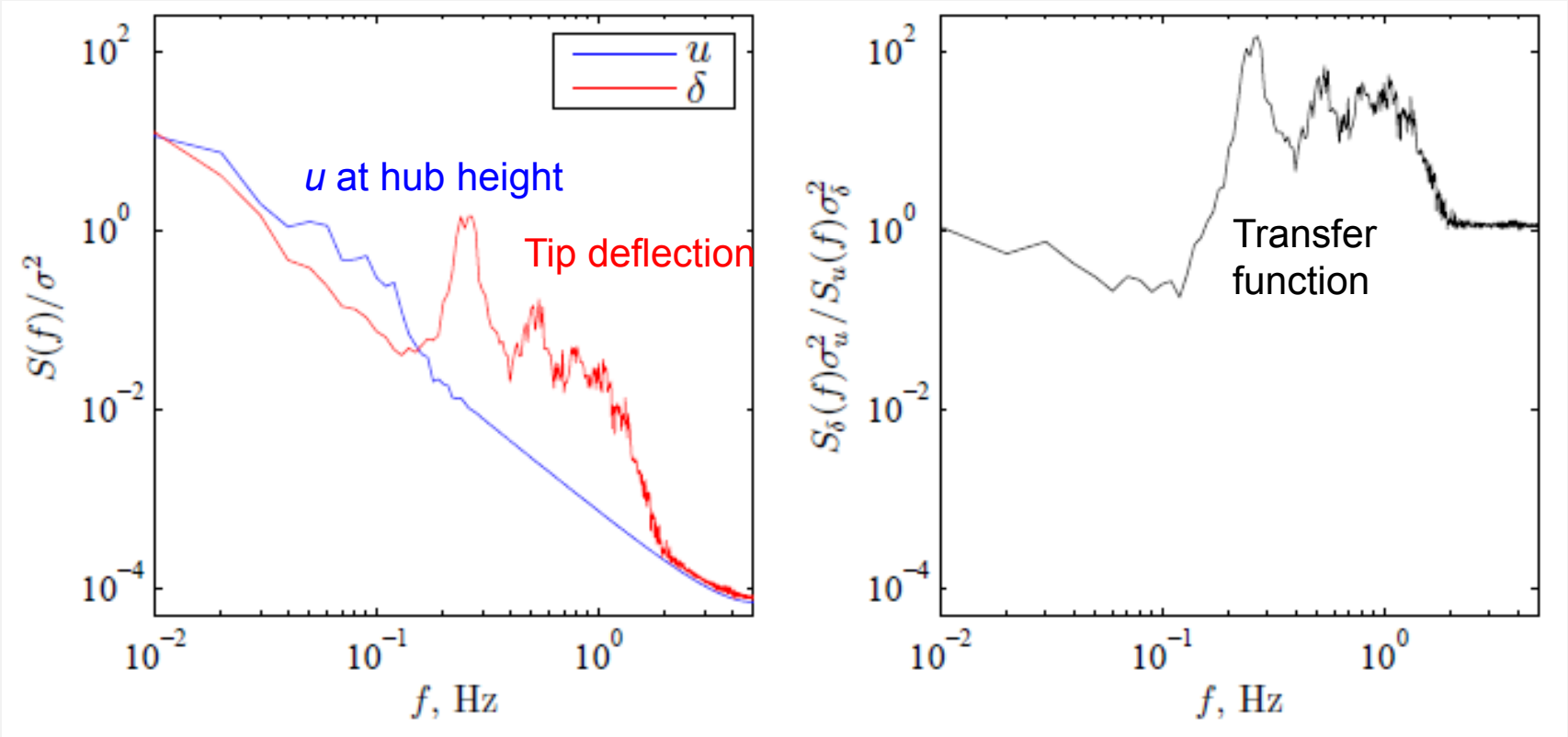
+

Turbulence (**T**)



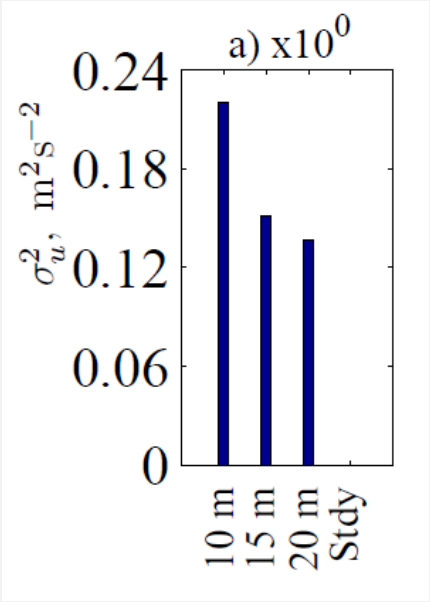


Result: Output (turbine response) to Input (wind inflow)

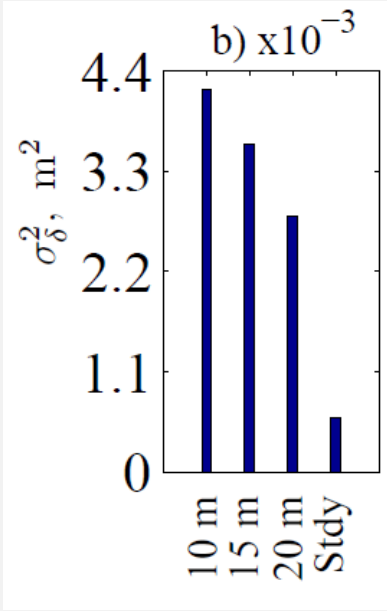


Result: Variance

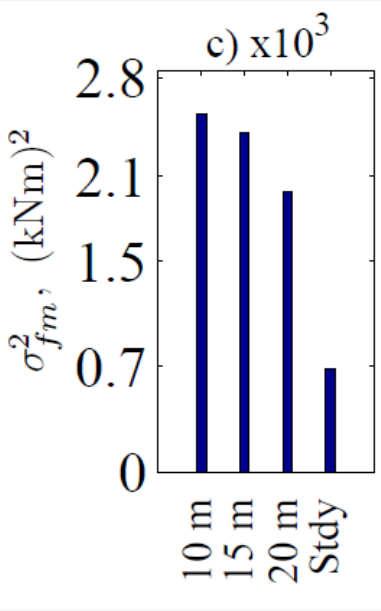
u_{hub}



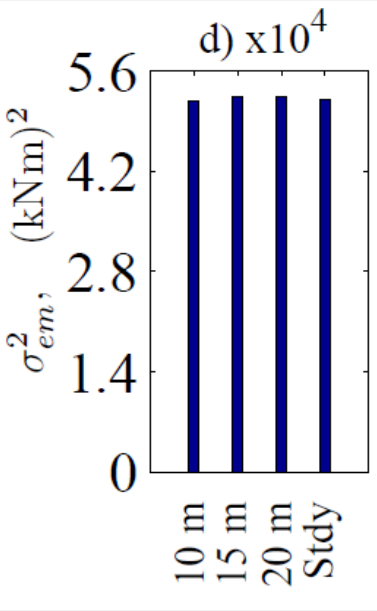
Deflection

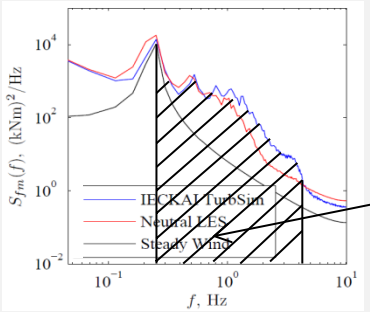


Flap-wise Mom.



Edge-wise Mom.



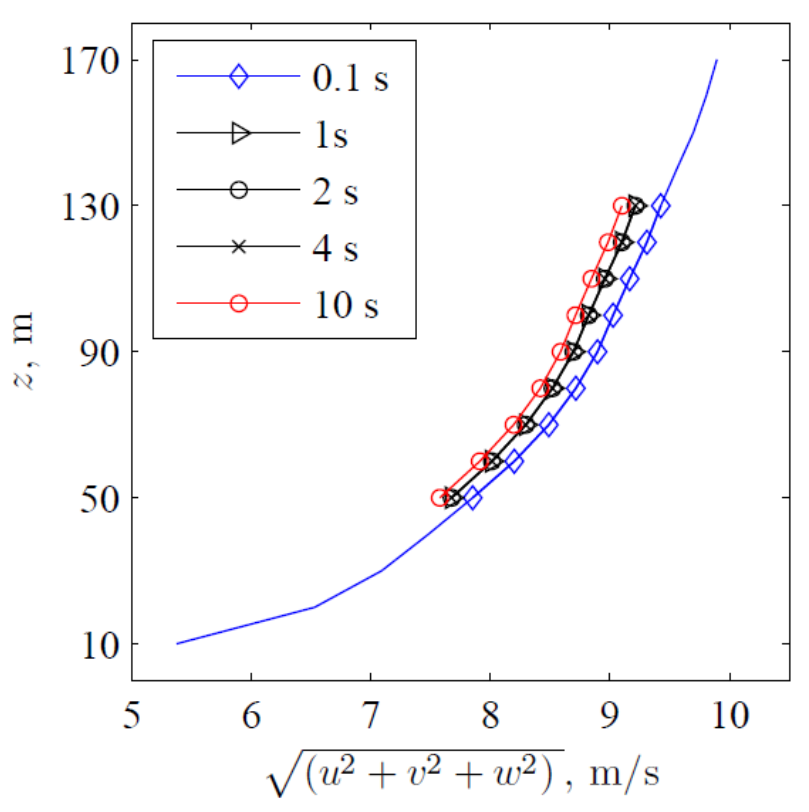


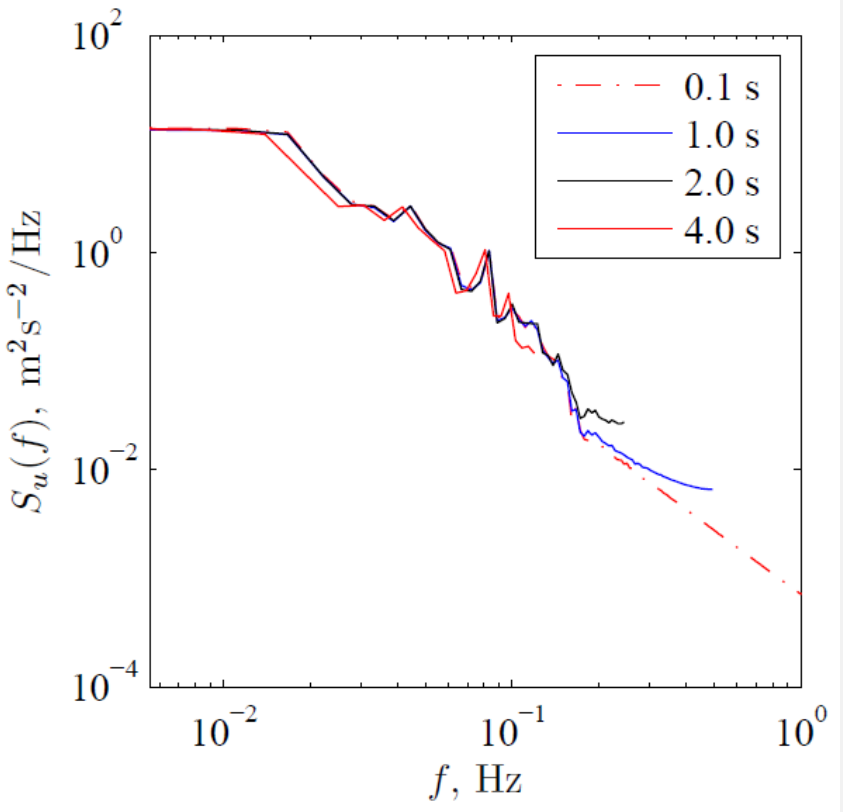
Variance = σ^2

Temporal Resolution Effect

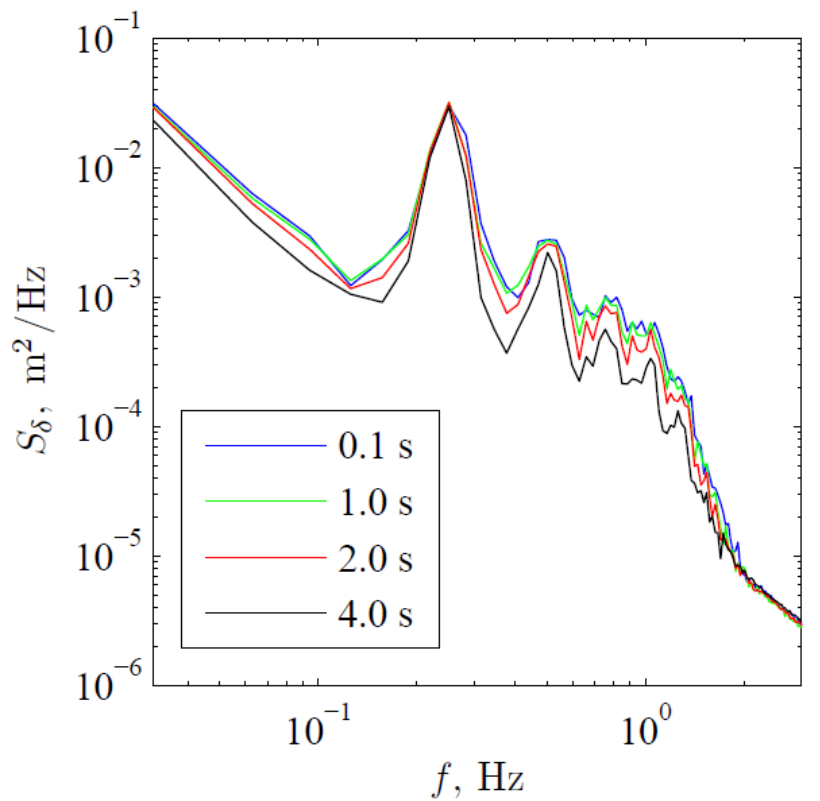
$\Delta y = \Delta z = 10$ m
$\Delta t = 0.1$ s, 2 s, 4 s, 10 s

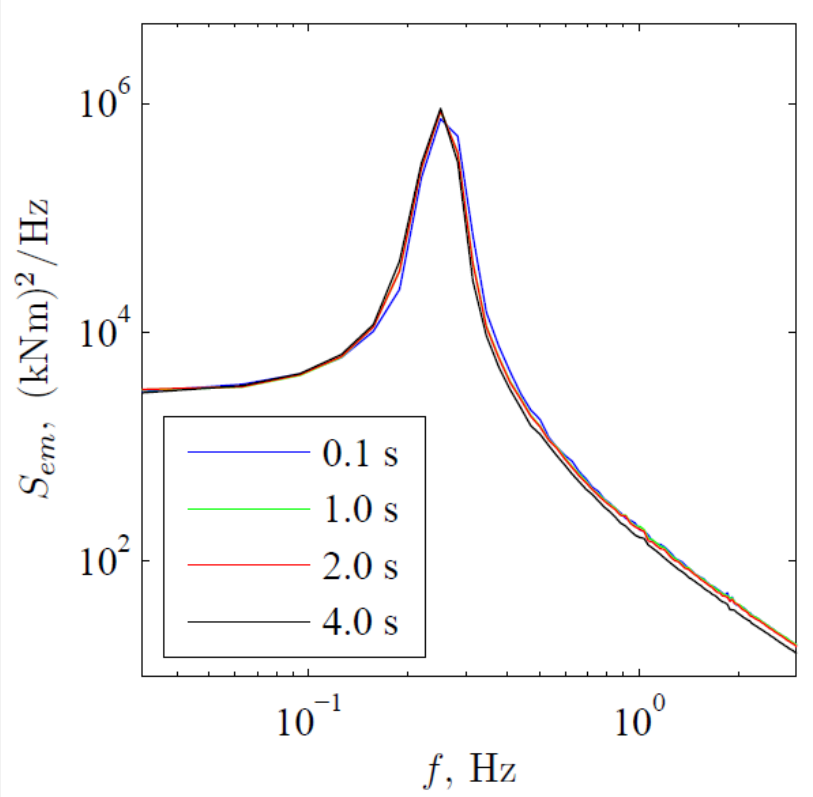
Result: Mean Wind Profile and u_{hub} Spectra





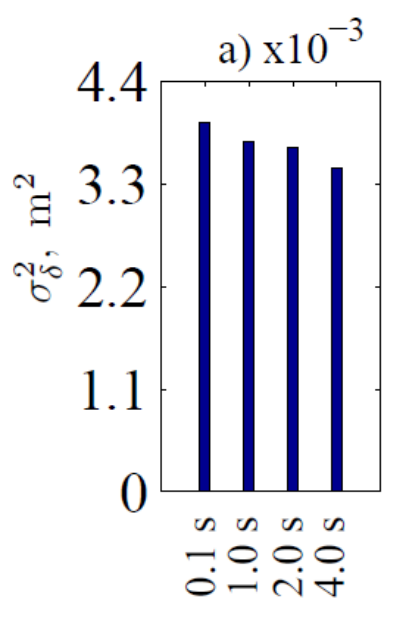
Result: Flap-wise and Edge-wise Bending Moment (1.5 MW Turbine)



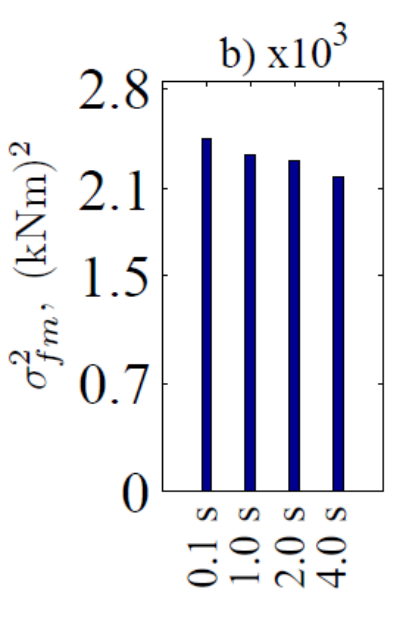


Result: Variance

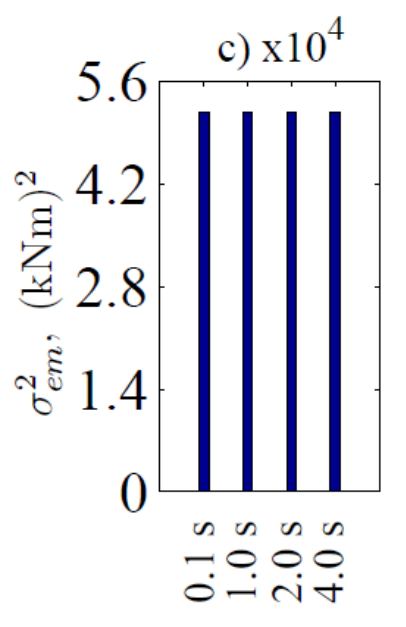
Deflection



Flap-wise Mom



Edge-wise Mom



Conclusions

- **Wind turbine responds dynamically to higher frequency turbulent structures**
  - The presence of turbulence and shear amplifies the turbine response in the higher frequency region
  - Spatial resolution showed more sensitivity to the wind turbine response than the temporal resolution

- **Highly resolved wind inflow is important to wind turbine simulation**
  - Provides better design and performance of wind turbine
    - **Fatigue loading and stress**

Acknowledgements

- **Gift support**
  - BP Alternative Energy North America, Inc.
- **LES data**
  - Harish Gopalan (Post Doc.), University of Wyoming