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Sandia National Laboratories

COMPARISON OF FIELD MEASUREMENTS AND LARGE EDDY SIMULATIONS OF THE SCALED WIND FARM TECHNOLOGY (SWIFT) SITE

PRESENTED BY

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AJKFLUIDS2019-5493
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Overview and Goals

Overview:

Introduction
- SWiFT

Computational Approach

Results
- Validation
- Simulations of yaw effects

Conclusions & Further Work

Goals:

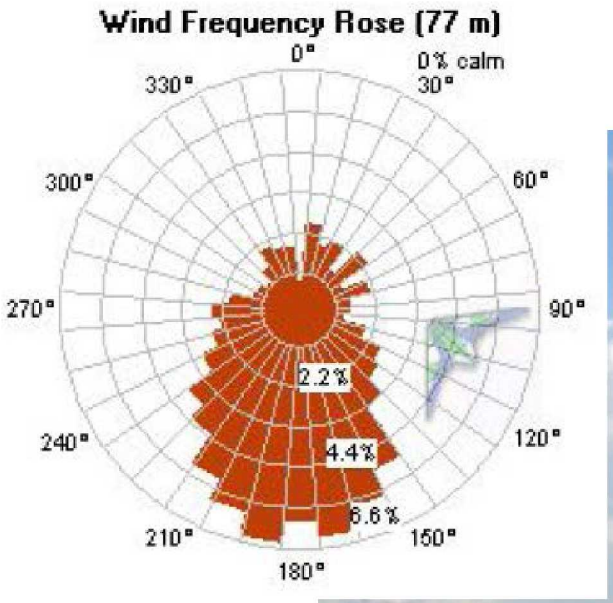
Describe SWiFT facility

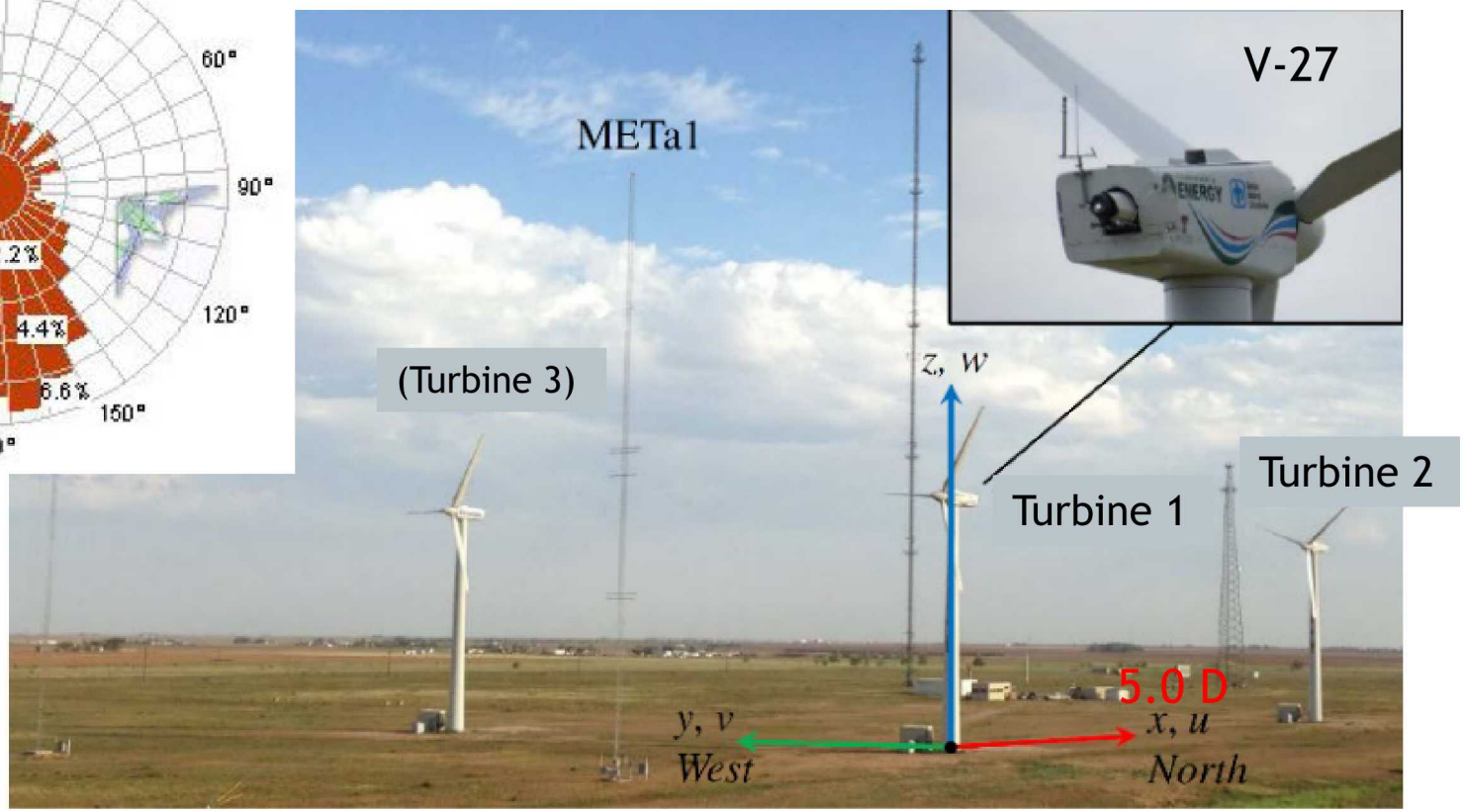
Validate Nalu-Wind + OpenFAST

Proof of concept that simulations can show effects of turbine yaw.

SWiFT: Scaled Wind Farm Technology

Texas Tech University's National Wind Institute Research Center in Lubbock, Texas





Instrumentation

Meteorological Evaluation Towers (MET)

- 2.5 D in front of 1st turbine
- 60 meter tall – 6 heights
- 3D sonic anemometers and thermometers

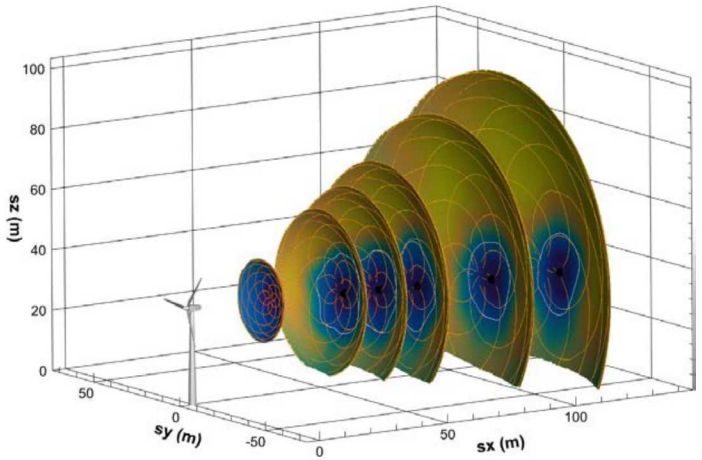
SpinnerLidar for Wake Measurements

- Technical University of Denmark (DTU)

Vestas V-27 Turbines

- Rotor diameter = 27 m
- Hub height = 32.1 m
- Strain gages: root-bending & tower
- Rotor azimuth and yaw angle measurements
- Nacelle accelerometer measurements

Lidar Planes



Nalu-Wind + OpenFAST

Nalu-Wind: Atmospheric Boundary Layer

- Large Eddy Simulation
- One-equation, constant coefficient, turbulent kinetic energy model

OpenFAST: Turbine Actuator Line Model

- https://nwtc.nrel.gov/OpenFAST – Jason Jonkman, et al.
- Flow-structure interaction, turbine controls
- Rotor power, thrust, and blade flap root bending moments

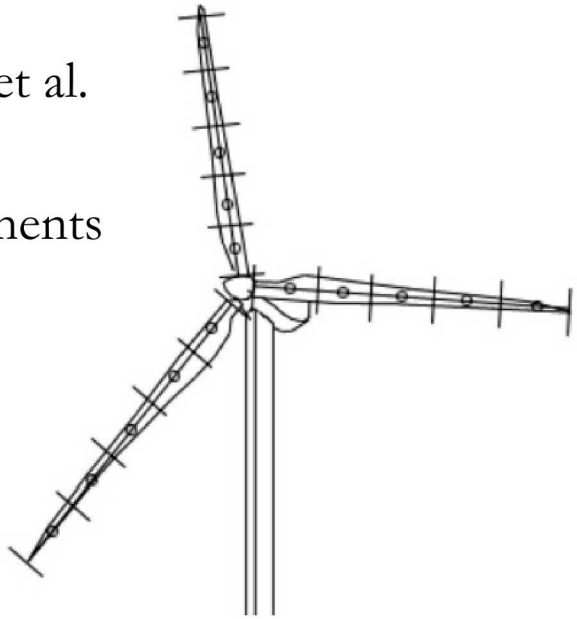


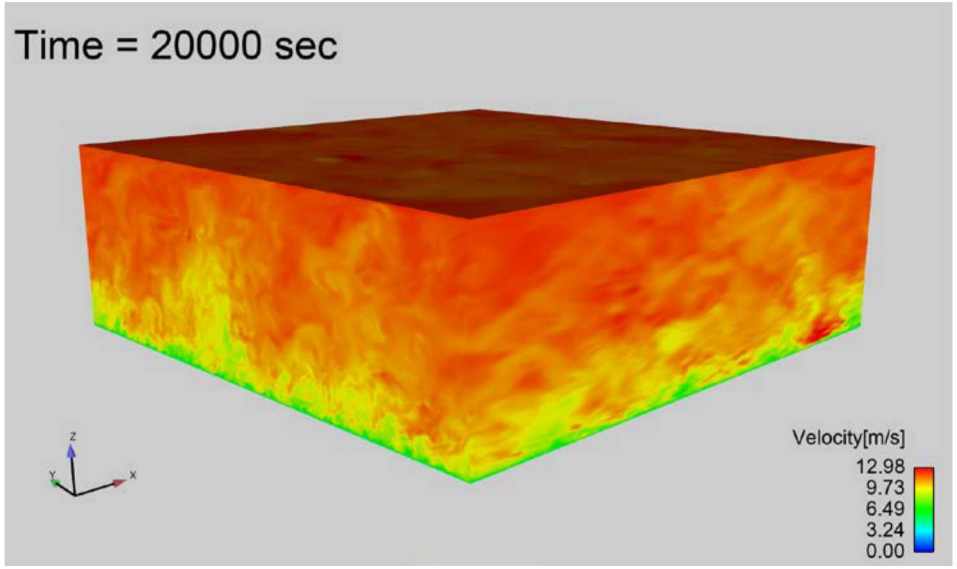
Image: Yu, Zheng, Ma

Nalu-Wind + OpenFAST Workflow

1. Precursor
- **3km x 3km x 1km**
- **10 m resolution mesh**
- **Periodic BC**
- **20,000 sec for well established flow**
- **Neutral Boundary Layer (306 K=91° F)**
- **Wind 8.3 m/s at hub height (h=32.1m) aligned with 2 turbines**

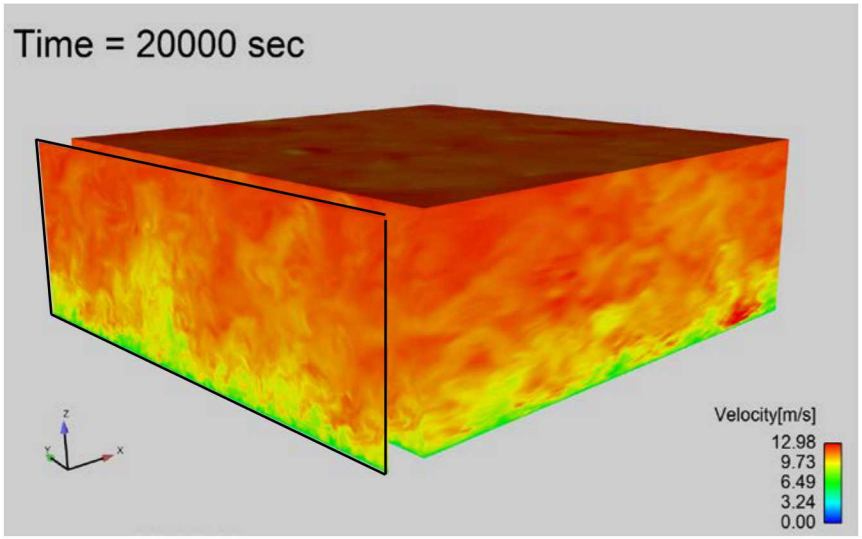
2. Precursor + I/O plane
- 10 min

3. Turbines Running for 10 min
- Refinement around turbine area
- IC of Precursor at 20,000 sec
- I/O plane as inflow

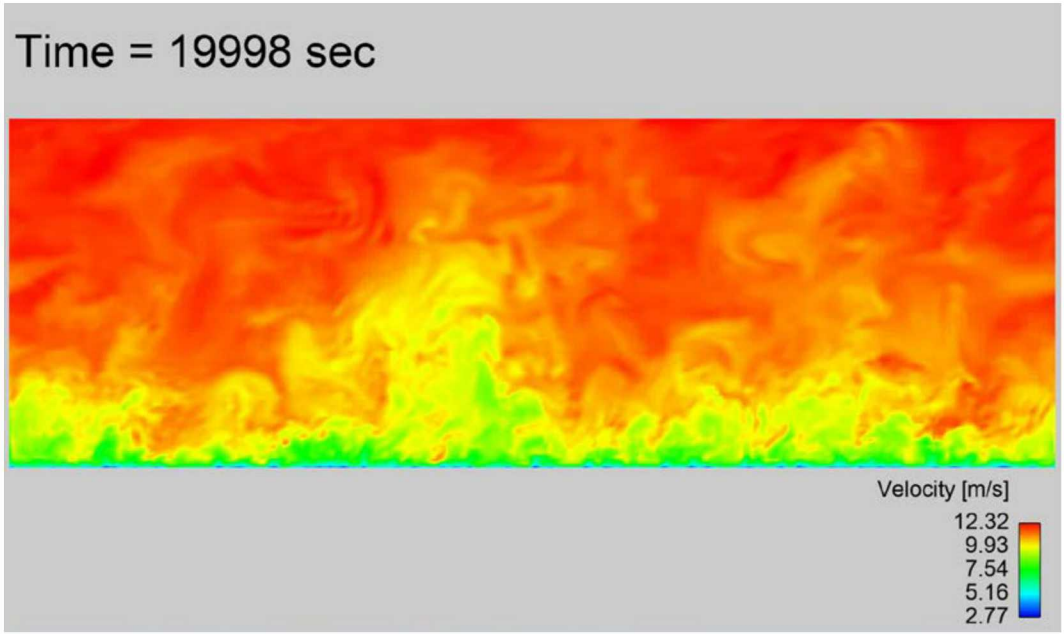


Nalu-Wind + OpenFAST Workflow

1. Precursor
   - 3km x 3km x 1km
   - 10 m resolution mesh
   - Periodic BC
   - 20,000 sec for well established flow



2. Precursor + I/O plane
   - **10 min additional**
   - **Same as #3, but without turbines**
   - **Copy inflow to a plane**



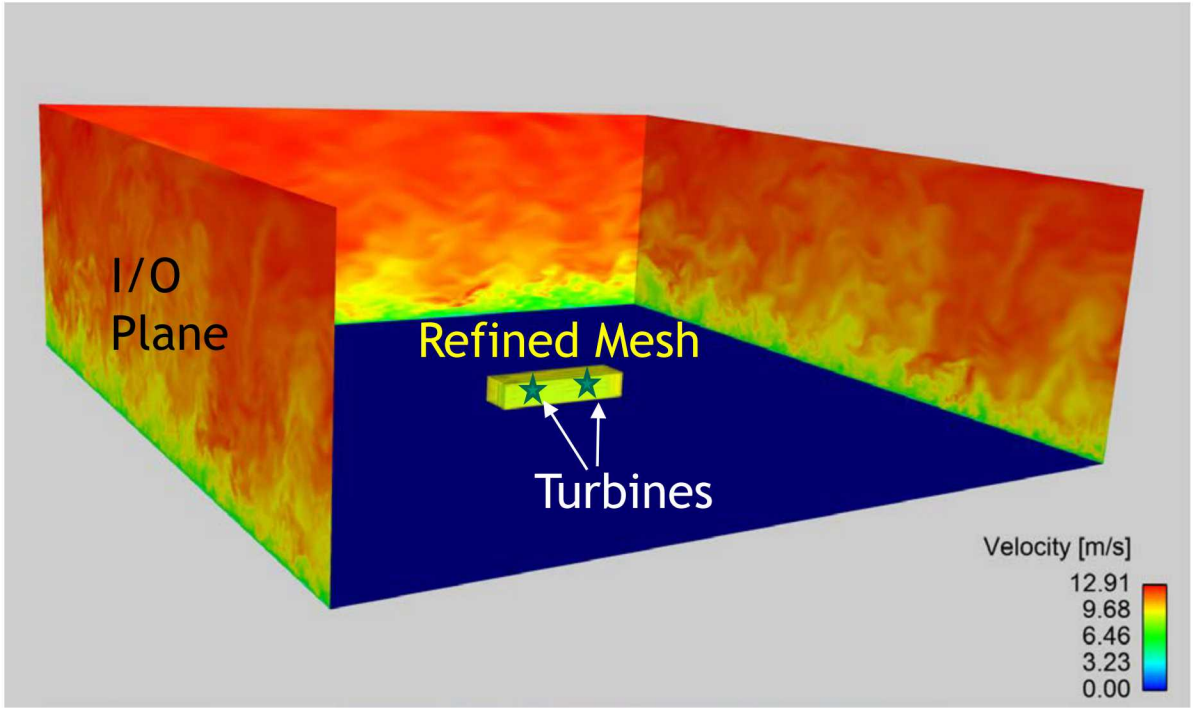
3. Turbines Running for 10 min
   - Refinement around turbine area
   - IC of Precursor at 20,000 sec
   - I/O plane as inflow

Nalu-Wind + OpenFAST Workflow

1. Precursor
   - 3km x 3km x 1km
   - 10 m resolution mesh
   - Periodic BC
   - 20,000 sec for well established flow

2. Precursor + I/O plane
   - 10 min

3. Turbines Running for 10 min
   - **Refinement around turbine area**
   - **IC of Precursor at 20,000 sec**
   - **I/O plane as inflow until 20,600 sec**

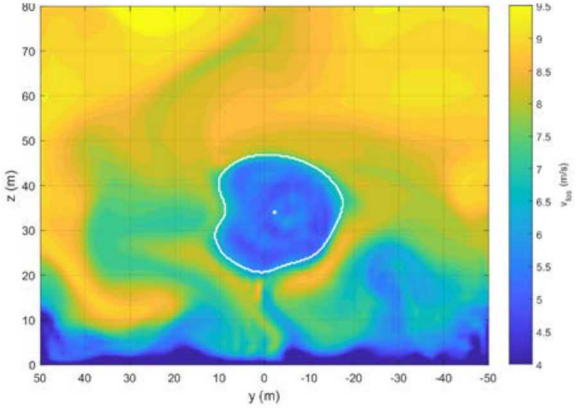


Grid Resolution Study

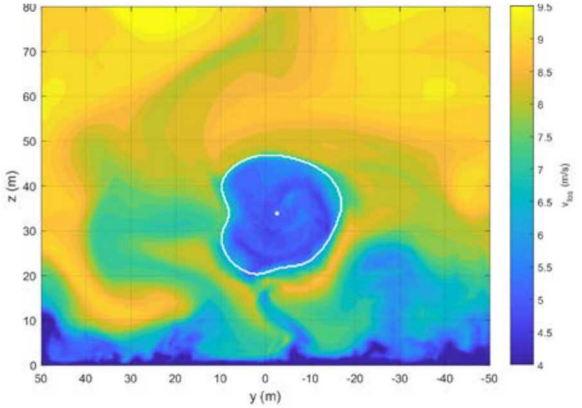
Resolution	# Elements	Finest Δx
Coarse	11.7 M	1.25 m
Medium	22.5 M	0.625 m
Fine	37.5 M	0.3125

U-velocity 5 D Downwind

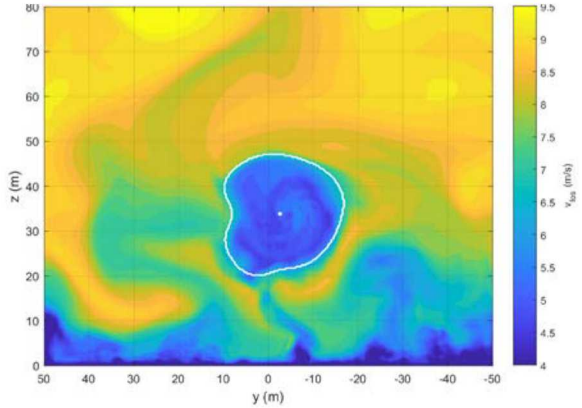
Coarse



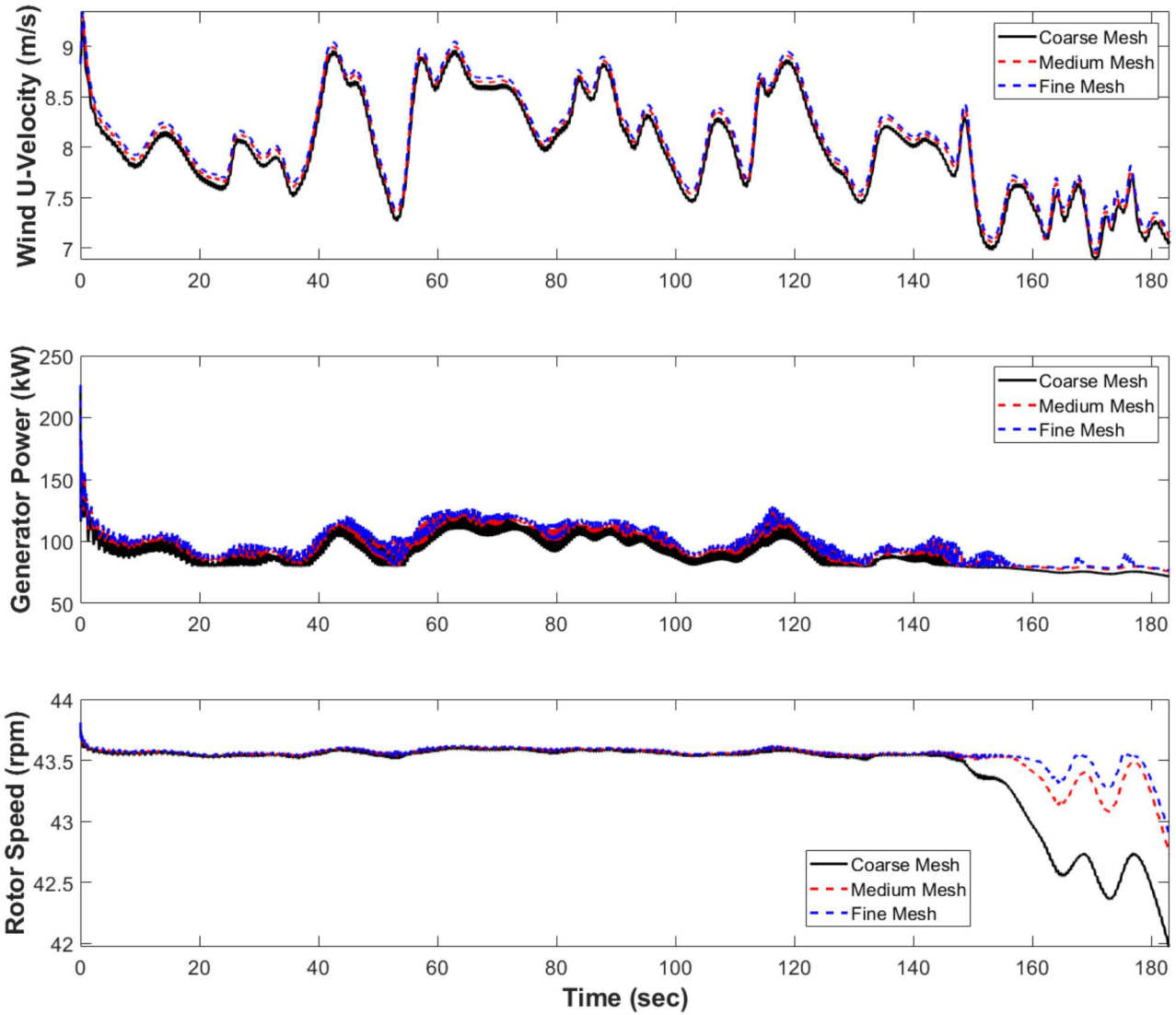
Medium



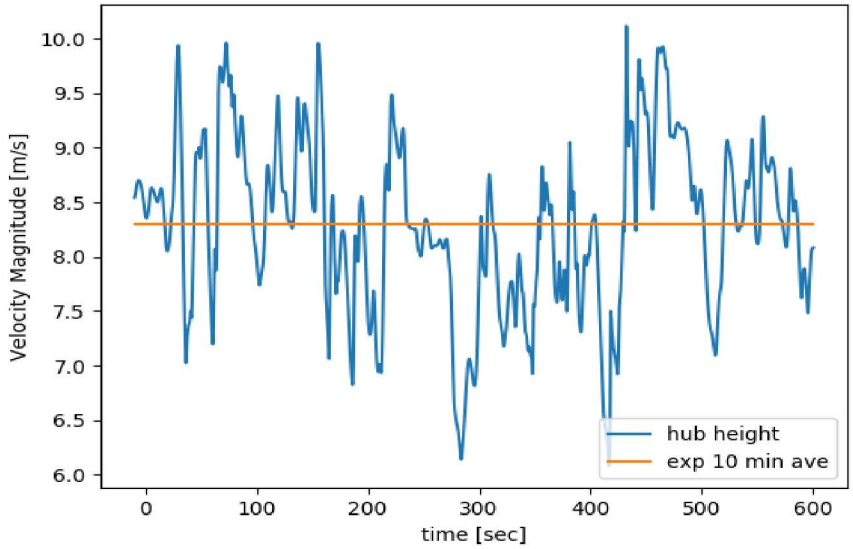
Fine

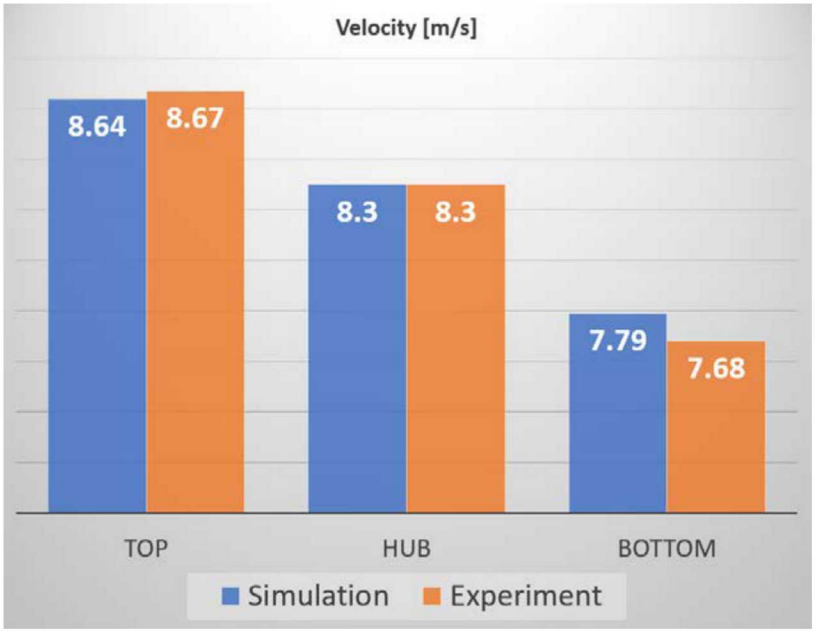


Grid Resolution Study



Average Velocity Comparison – Precursor Data

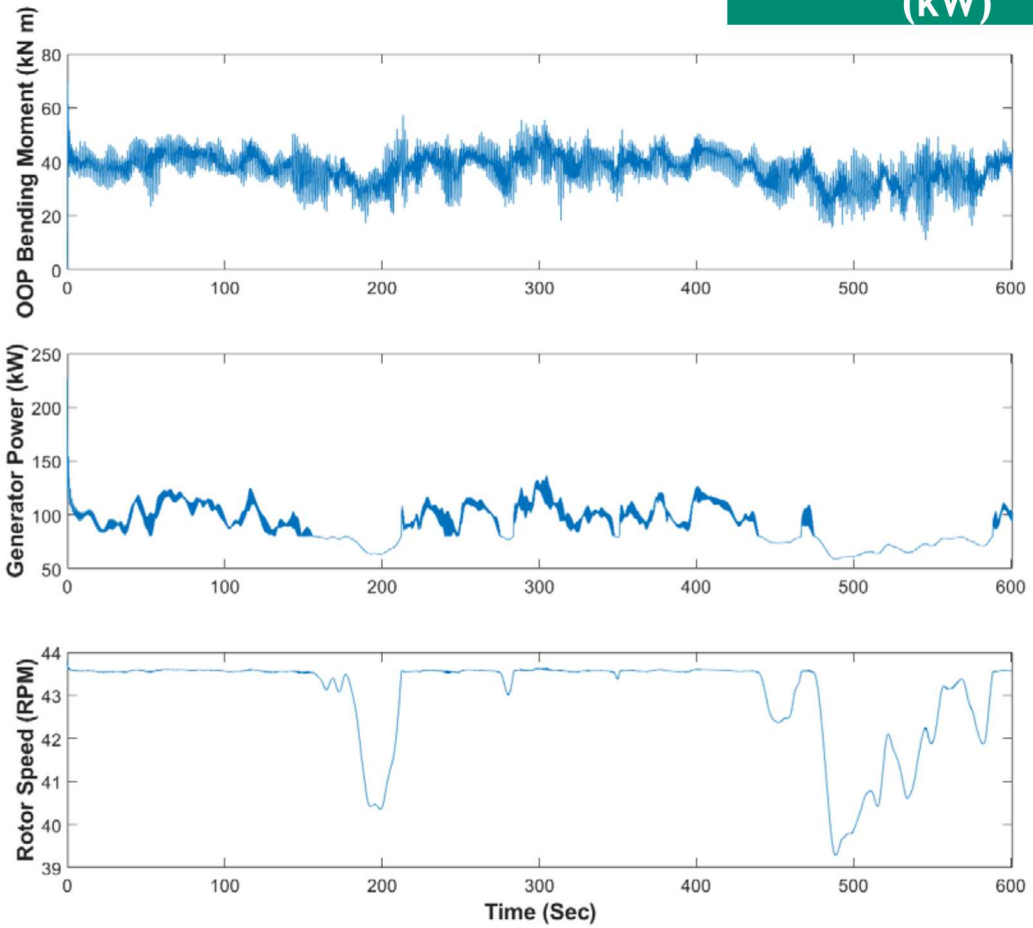




	Simulation	Experiment
Top of rotor, 45.6 m (m/s)	8.64 +/- 0.70	8.67 +/- 0.85
Hub height, 32.1m (m/s)	8.30 +/- 0.78	8.30 +/- 0.79
Bottom of rotor, 18.6 m (m/s)	7.79 +/- 0.93	7.68 +/- 0.96
Turbulent intensity at hub height	0.094	0.095

Turbine Results

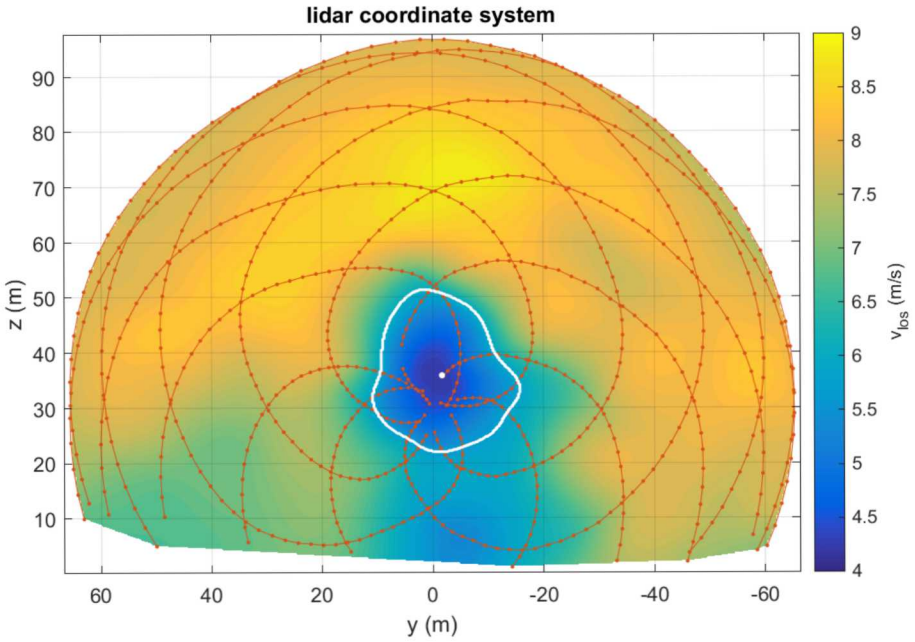
	Simulation	Experiment
Out-Of-Plane Blade Bending (kN m)	37.0 ± 6.0	37.1 ± 6.2
Rel. Flapwise Damage Equivalent Momentum (sim./exp.)	1.06	1.00
Generator Power (kW)	88.4 ± 17.3	81.2 ± 19.3



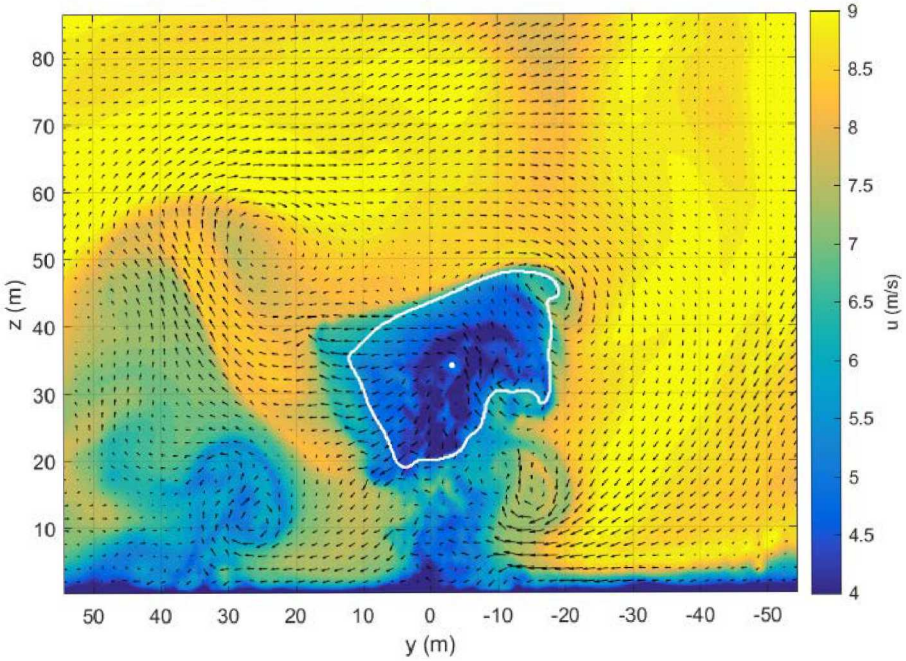
Error in power is from generator and gearbox efficiency (which has been updated)

Wake Results: Instantaneous

Experiment - SpinnerLidar

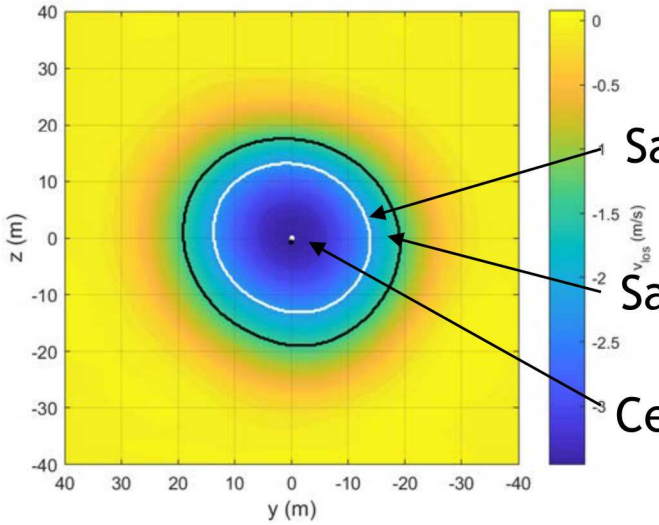


Nalu-Wind



Wake Results: 10 min Average

Experiment - SpinnerLidar

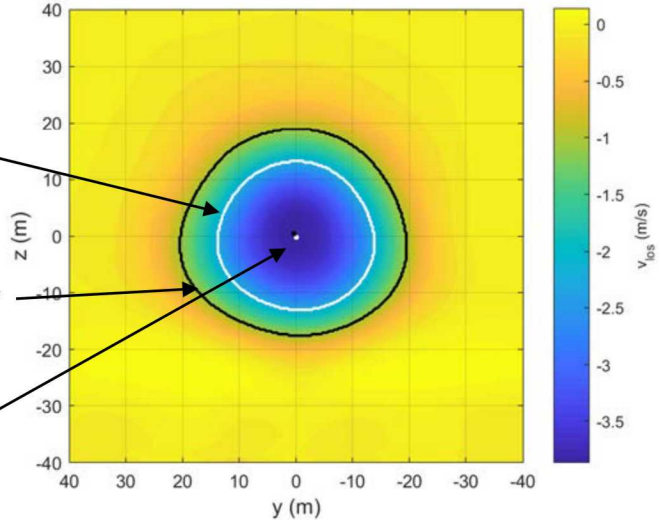


Same area as rotor

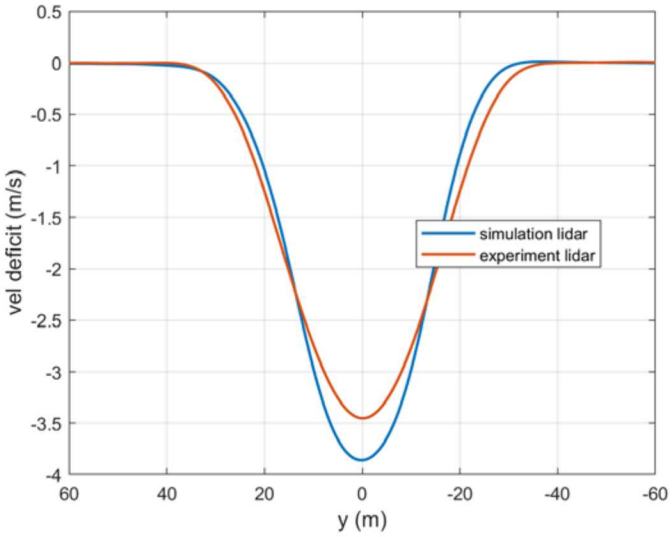
Same thrust as rotor

Centroid of velocity

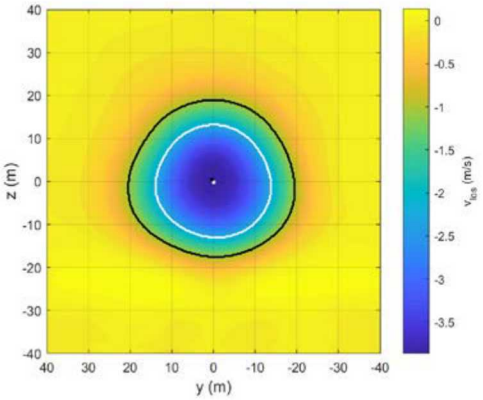
Nalu-Wind

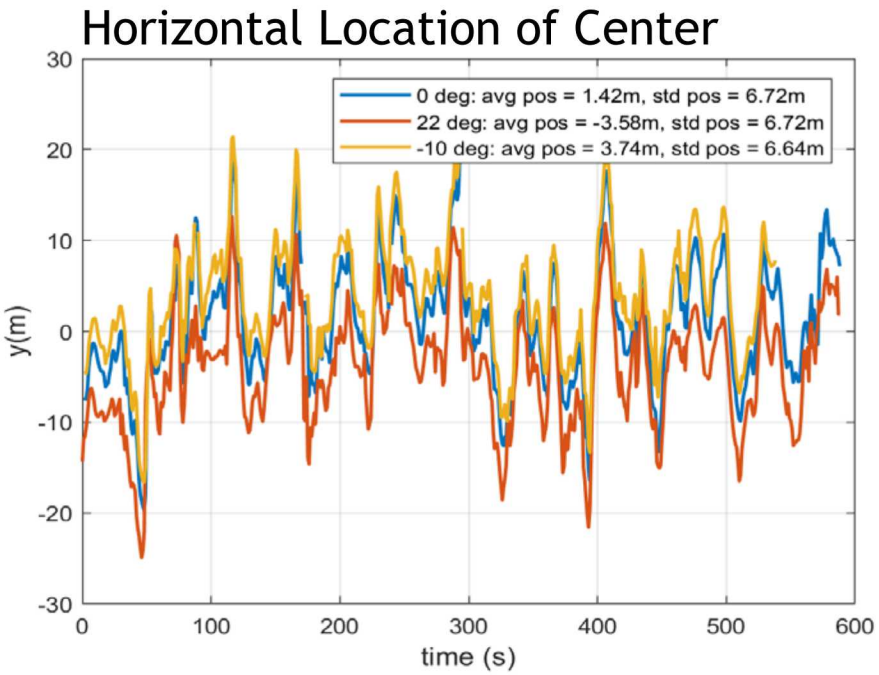


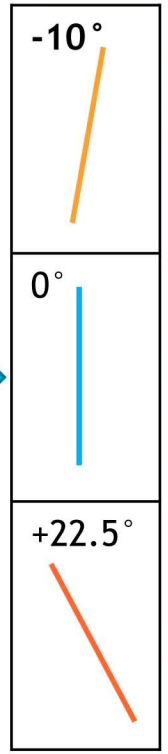
Velocity Deficit



Simulated Yaw Angles

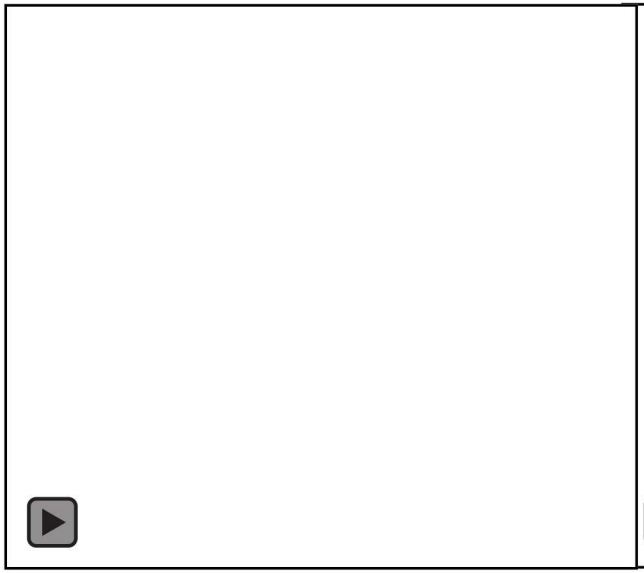




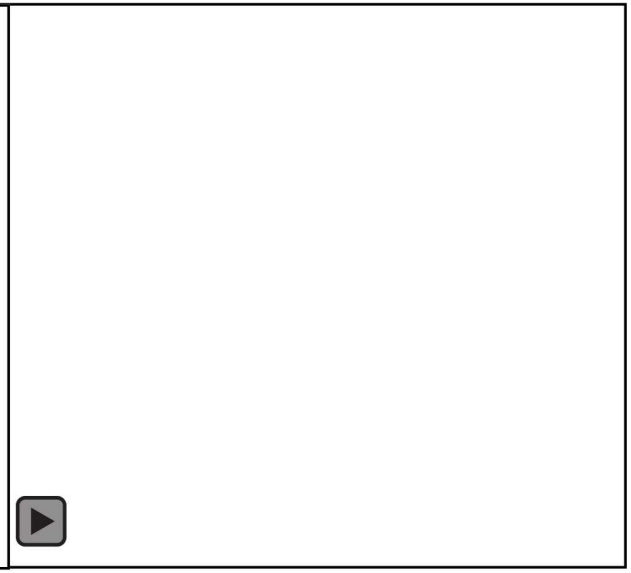


	Turbine #1		
Yaw of #1 (deg)	Generated Power (kW)	Δ Power (kW)	Total Power (kW)
-10	87.46	-4.91	-
0	92.37	-	-
+22.5	67.83	-24.54	-
	Turbine #2		
-10	47.90	+0.68	135.36
0	47.22	-	139.59
+22.5	48.80	+1.58	116.63

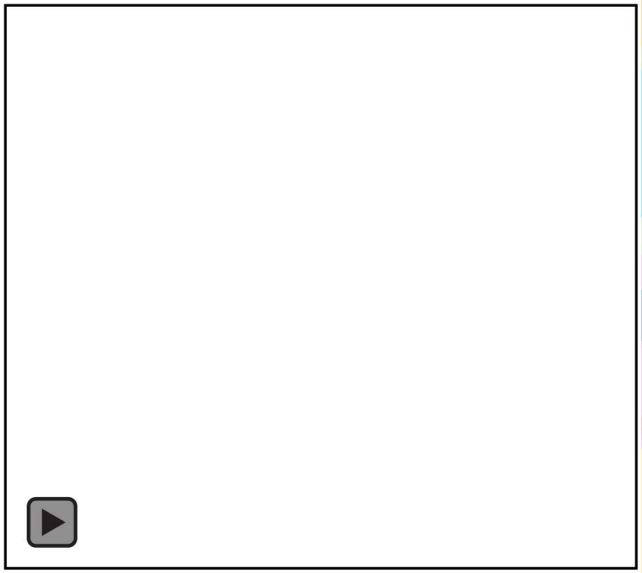
Simulated Yaw Angles



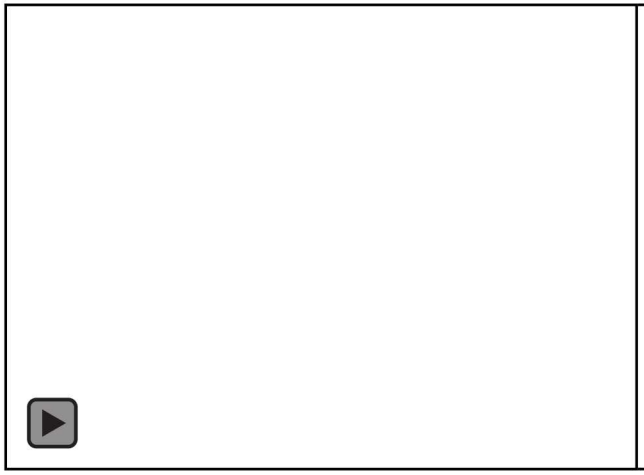
-10°

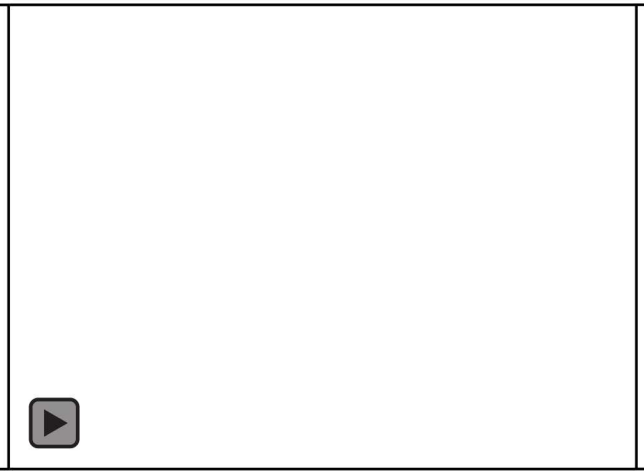


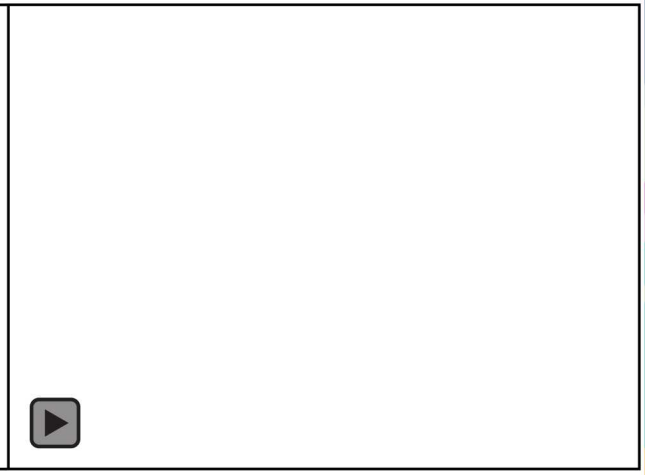
0°



+22.5°







Conclusions & Future Work

Nalu-Wind matches experimental data.

- Precursor velocity plane measurements
- OpenFast turbine power and loads
- Wake deficits

Yawing the upwind turbine can increase the power of the second turbine.

- Might lead to total power loss (with just two turbines – multiple rows might show increase)

Yawing study will build into a Multi-Level-Multi-Fidelity UQ study.

Stable & Unstable atmospheric conditions will also be validated.

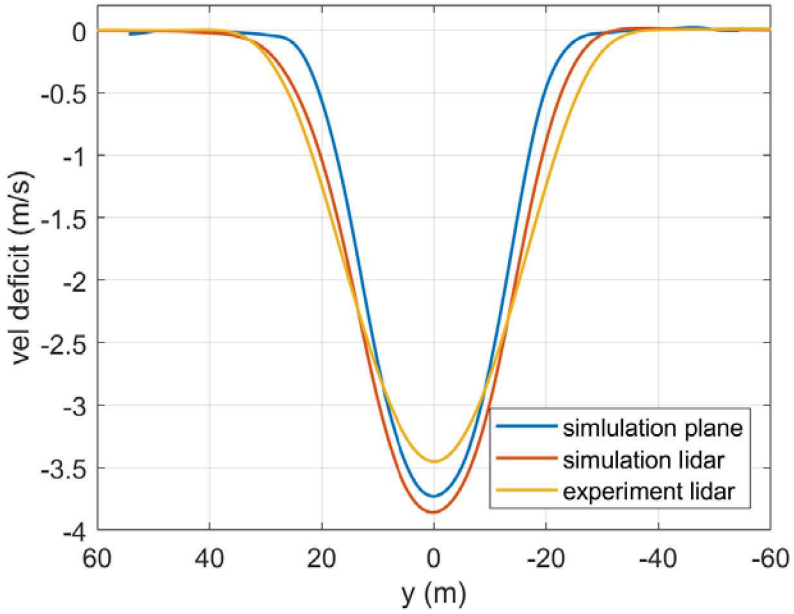
Thank you!

https://energy.sandia.gov/energy/renewable-energy/wind-power/wind_plant_opt/

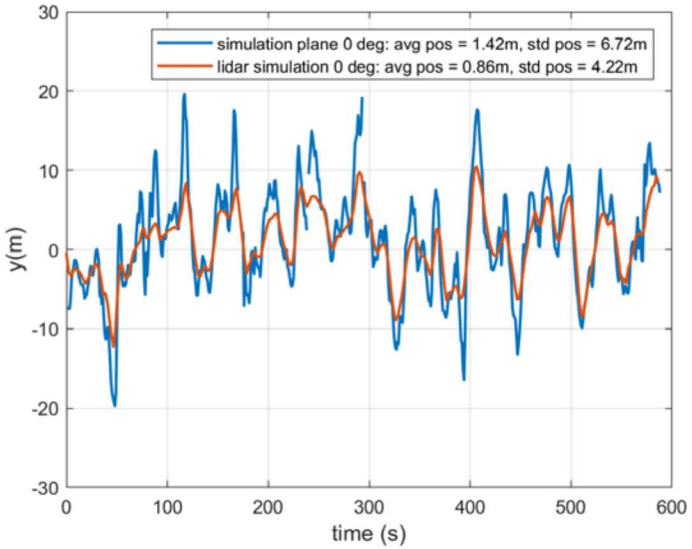
Funding from DOE – Wind Energy Technology Office

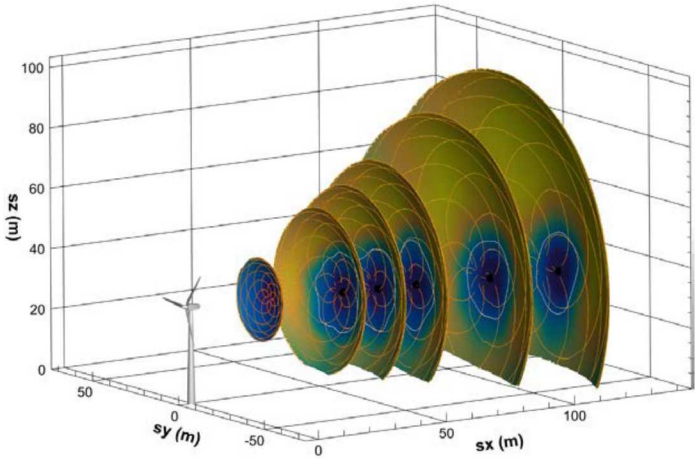
Wake Results: Plane vs Synthetic lidar

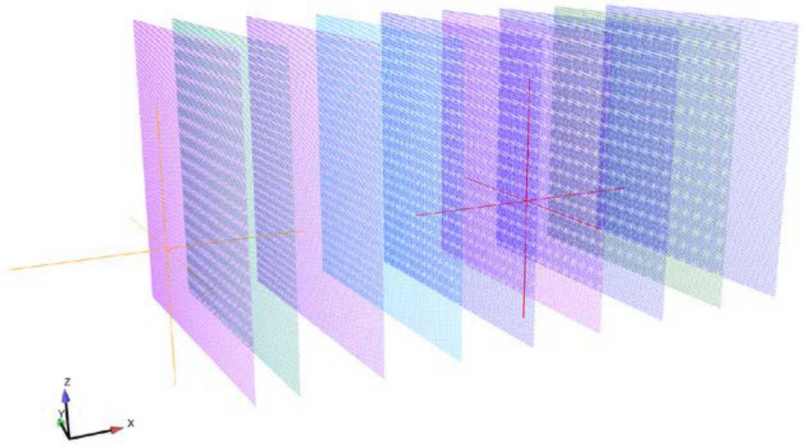
Velocity Deficit



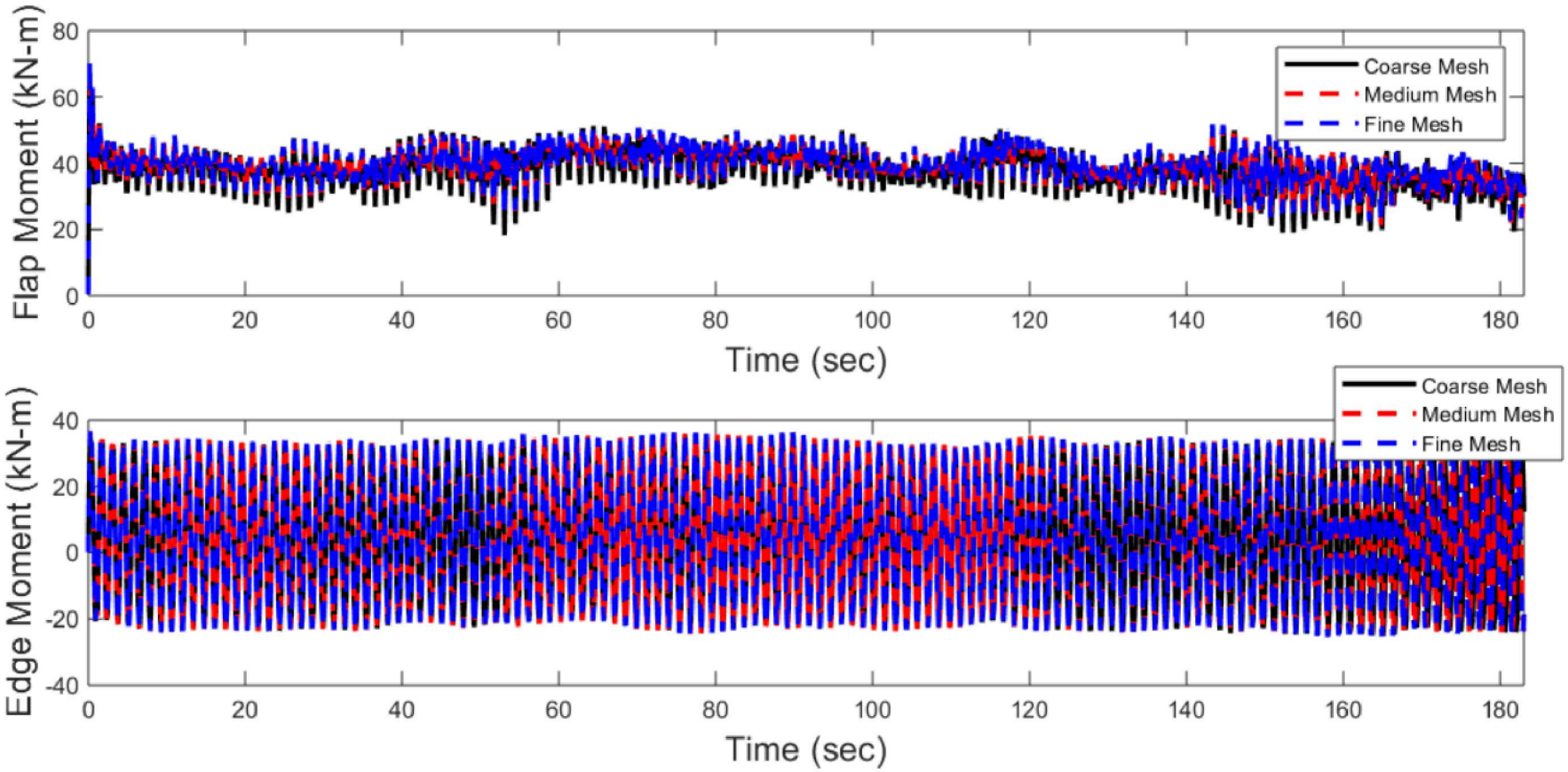
Horizontal Location of Center







Grid Resolution Study Results



Grid Resolution Study