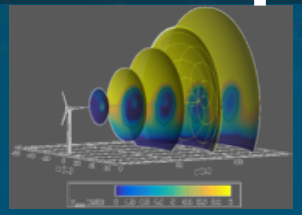
SAND2021-15447C

Validation of Actuator Line and Actuator Disk Models with Filtered Lifting Line Corrections Implemented in Nalu-Wind Large Eddy Simulations of the Atmospheric Boundary Layer

Sandia National Laboratories

Funding provided by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Wind Energy Technologies Office.



PRESENTED BY

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*NREL

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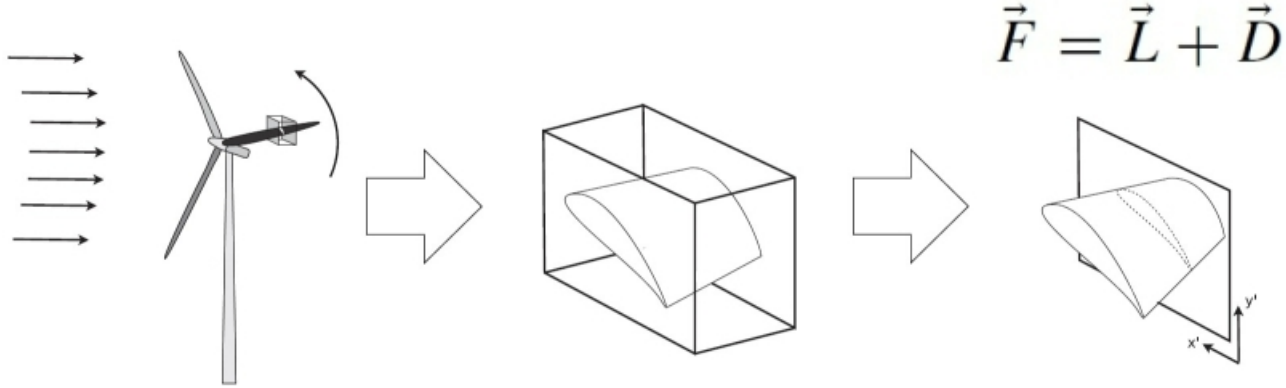
SAND2021-6267 C

Actuator Line Model (ALM)

- ALM – Force points along moving blade line



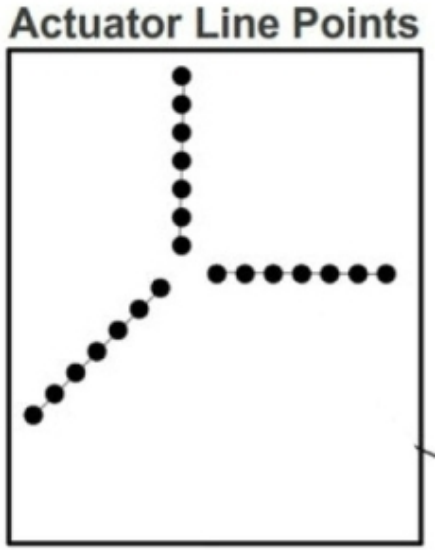
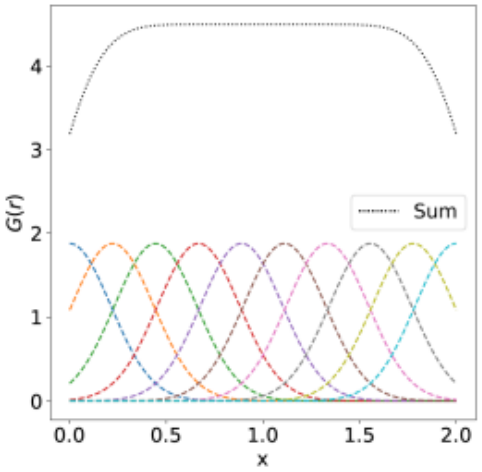


Figure 2. A two-dimensional section of the blade with the respective airfoil shape at that location.

$$\vec{\mathbf{f}}_{turb} = \frac{\vec{F}}{\epsilon^3 \pi^{3/2}} exp[-(r/\epsilon)^2]$$

ϵ -Smoothing length scale for the Gaussian kernel



Sakievich, 2021

Sorensen & Shen, 2002

Large eddy simulations of the flow past wind turbines: actuator line and disk modeling, 2015
Luis A. Martínez-Tossas, Matthew J. Churchfield, and Stefano Leonardi

Actuator Disk Model (ADM)

- ADM – Force points in a stationary disk

$$\vec{\mathbf{f}}_{turb} = \frac{\vec{F}}{\epsilon^3 \pi^{3/2}} exp[-(r/\epsilon)^2]$$

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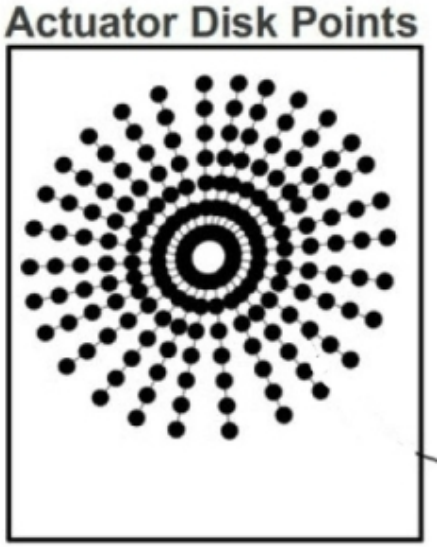
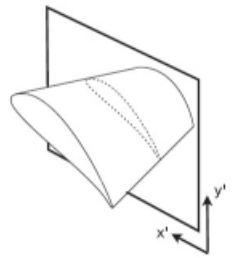


Large eddy simulations of the flow past wind turbines: actuator line and disk modeling
Luis A. Martínez-Tossas, Matthew J. Churchfield, and Stefano Leonardi

Filtered Lifting Line Correction (FLLC)

- Corrects for non-optimal epsilon
- Adds the induced velocity that can't be resolved from the mesh
- Higher accuracy with larger mesh size
- This is first time with turbulent flow



Compute forces from velocity using aerodynamic model

Extract lift distribution along the blade from the forces

From lift distribution, compute an induced velocity twice, with and ^{opt} - get correction

$$\Delta u_y = u_y(z_i; \epsilon^{opt}) - u_y(z_i; \epsilon^{LES})$$

Apply original ALM steps, up to velocity interpolation from fluid domain

Apply correction to the velocity, compute forces with corrected velocity

$$\widehat{\boldsymbol{u}}(\boldsymbol{x}_i) = \widetilde{\boldsymbol{u}}(\boldsymbol{x}_i) + \Delta u_y^n(z_i)\boldsymbol{j}.$$

Filtered lifting line theory and application to the actuator line model, 2019
Luis A. Martínez-Tossas and Charles Meneveau

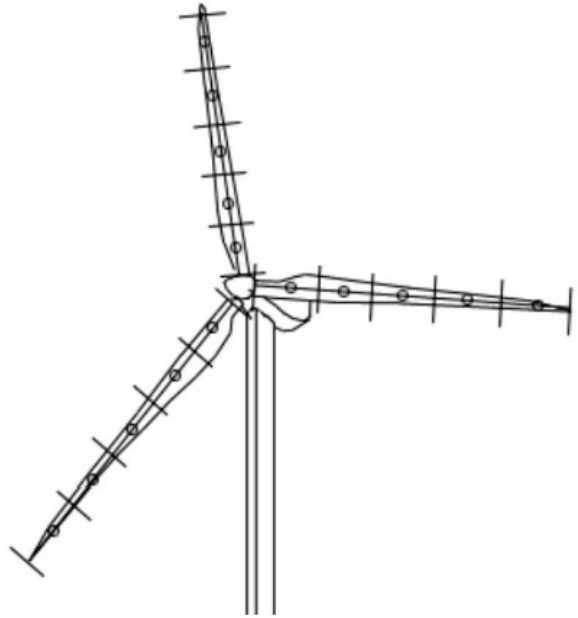
Best Practices for Epsilon Values

- ϵ/c ≤ ~0.25 (for optimal accuracy of blade loading) (Martínez-Tossas et al., 2017)
- ϵ/D_rotor ≤0.035 (for power production) (Churchfield et al. 2017)
- $\epsilon/\Delta x$ ≥1(to resolve the Gaussian kernel)

Parameter Space:	Mesh Spacing-Δx				
	Extra Coarse	Coarse	Medium	Fine	
	2.5	1.25	0.625	0.3125	
ϵ/D =0.1	1.08	2.16	4.32	8.64	$\epsilon/\Delta x$
ϵ/D =0.035	0.378	0.756	1.512	3.024	
FLLC	2	2	2	2	

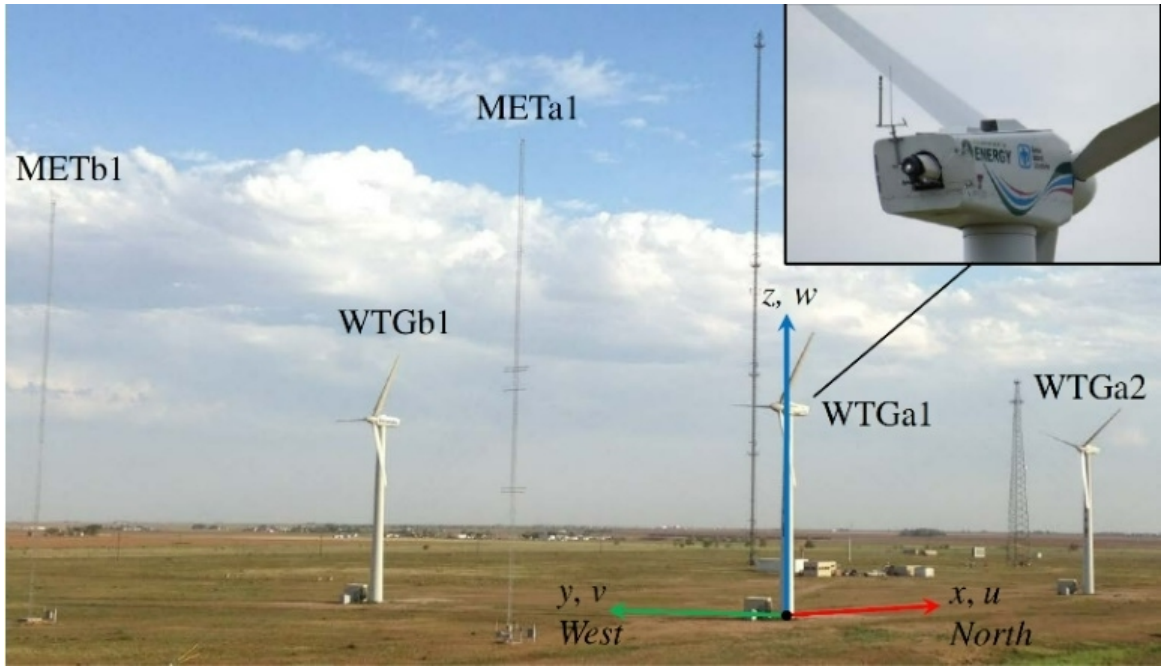
Nalu-Wind + OpenFAST

- Nalu-Wind: Part of the ExaWind code suite
  - Large Eddy Simulation of Atmospheric Boundary L
  - One-equation, constant coefficient, turbulent kinetic energy model
  - Actuator Line Model or Actuator Disk Model of turbine
- OpenFAST: Turbine Load Model
  - https://nwtc.nrel.gov/OpenFAST – Jason Jonkman, et al.
  - Flow-structure interaction, turbine controls
  - Rotor power, thrust, blade flap root bending moments, and blac



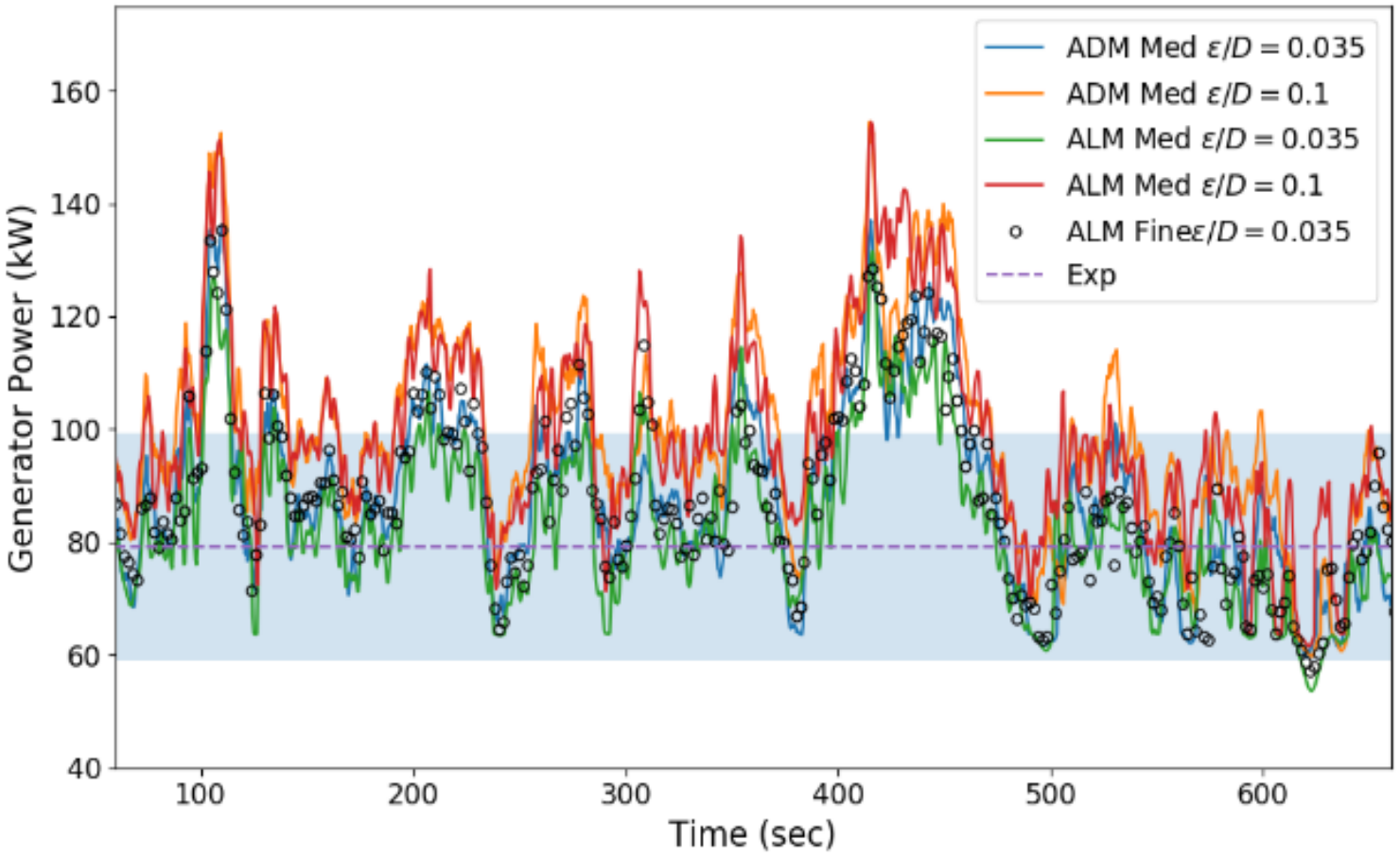
SWiFT – Simulation Setup

- SWiFT: Scaled Wind Farm Technology Center - Texas Tech University's National Wind Institute Research Center in Lubbock, Texas
- Single V-27 Rotor Turbine
- Neutral Atmospheric Boundary Layer*
  - Wind Speed Average for 10 min window 8.7 m/s at hub-height (32m)
  - TSR = 6.8



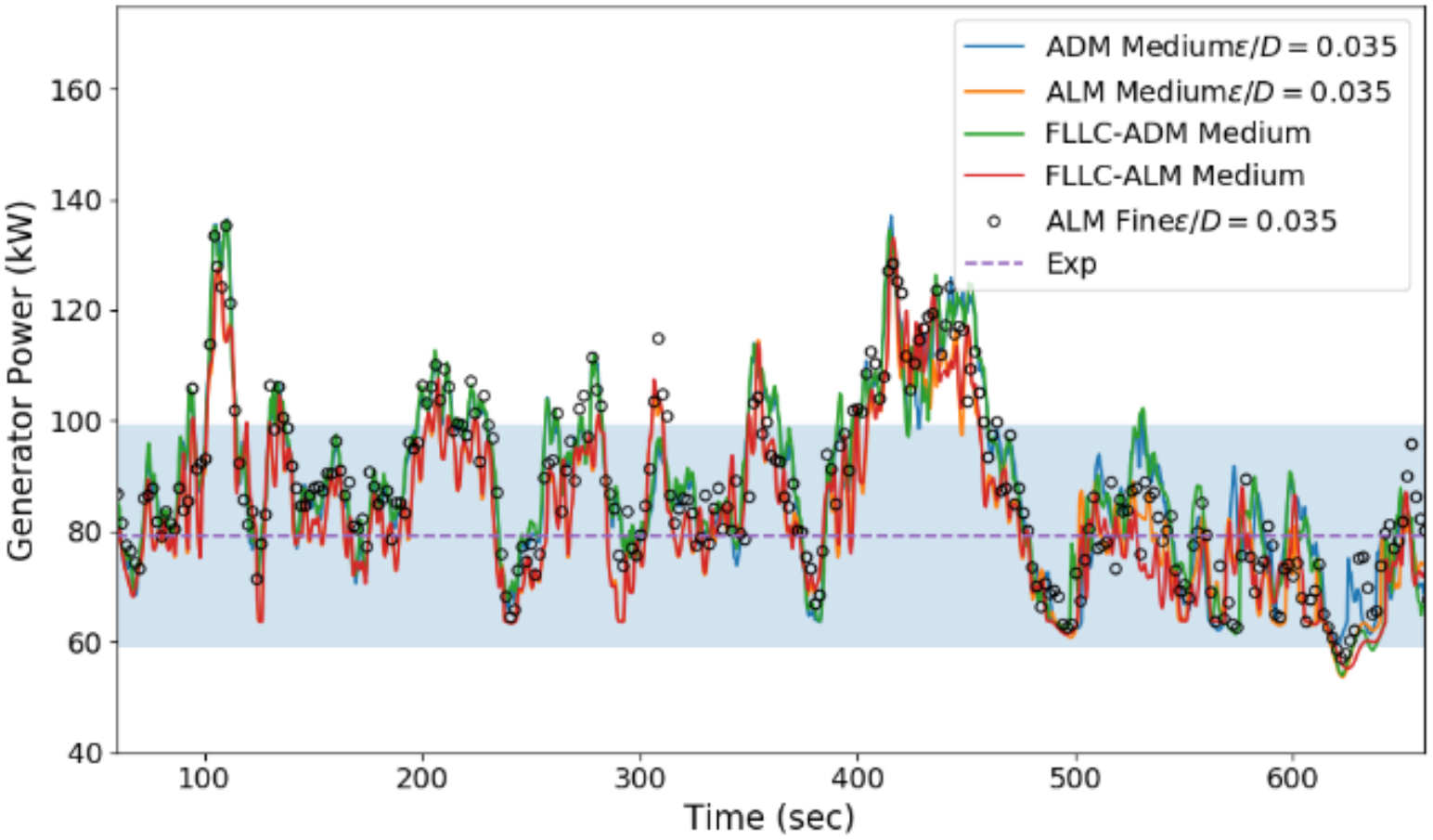
***High-Fidelity Wind Farm Simulation Methodology with Experimental Validation**
Alan Hsieh, et al. 2021

ADM & ALM for two ϵ/D values

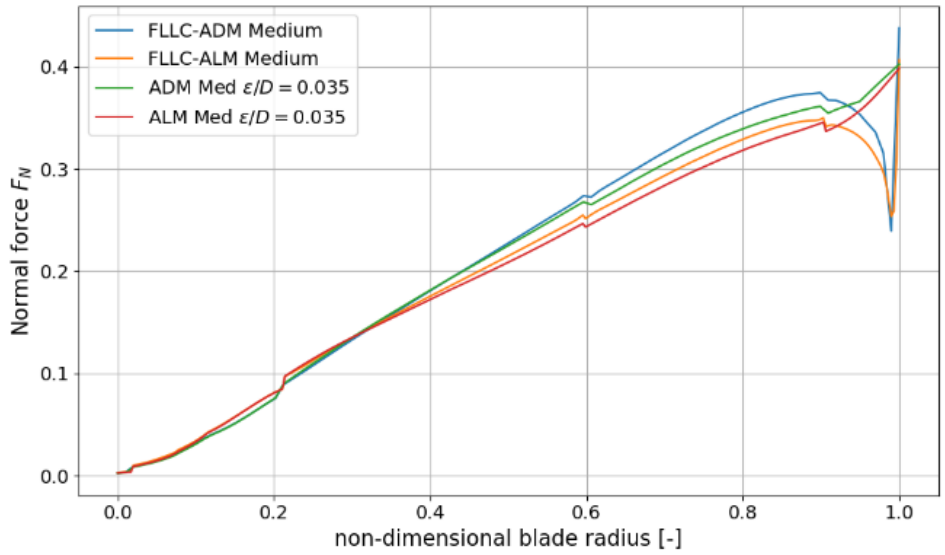


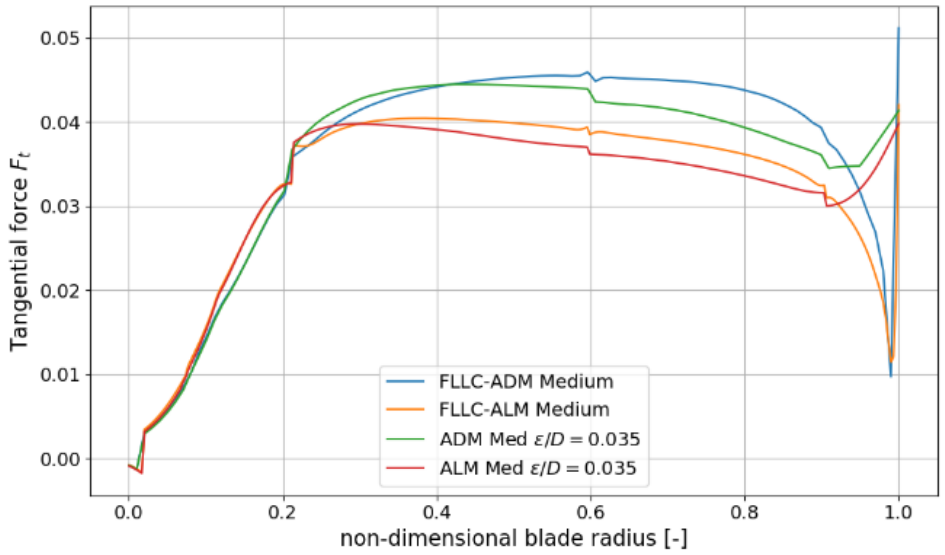
ALM/ADM/FLLC – Power

- Power from FLLC medium mesh matches $\epsilon/D = 0.035$

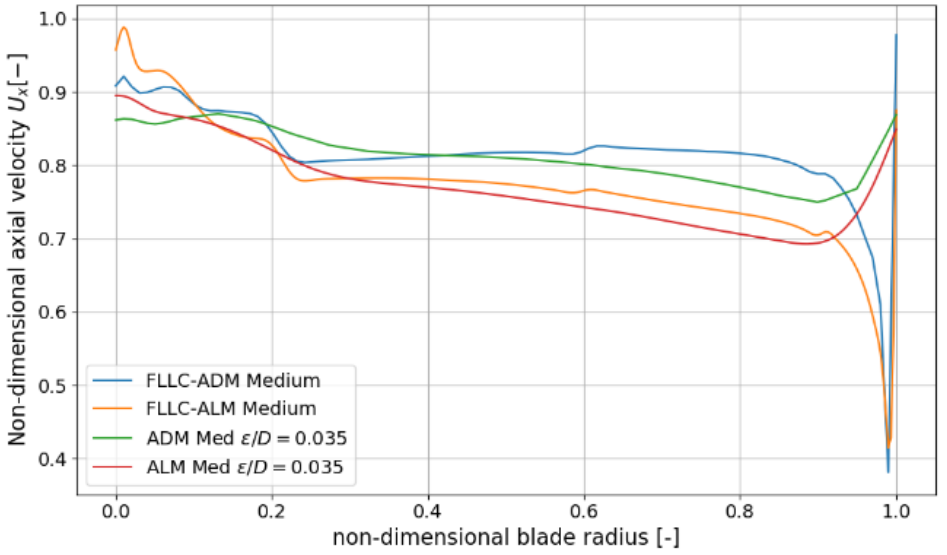


ALM/ADM/FLLC– Forces and Axial Velocity along the blade

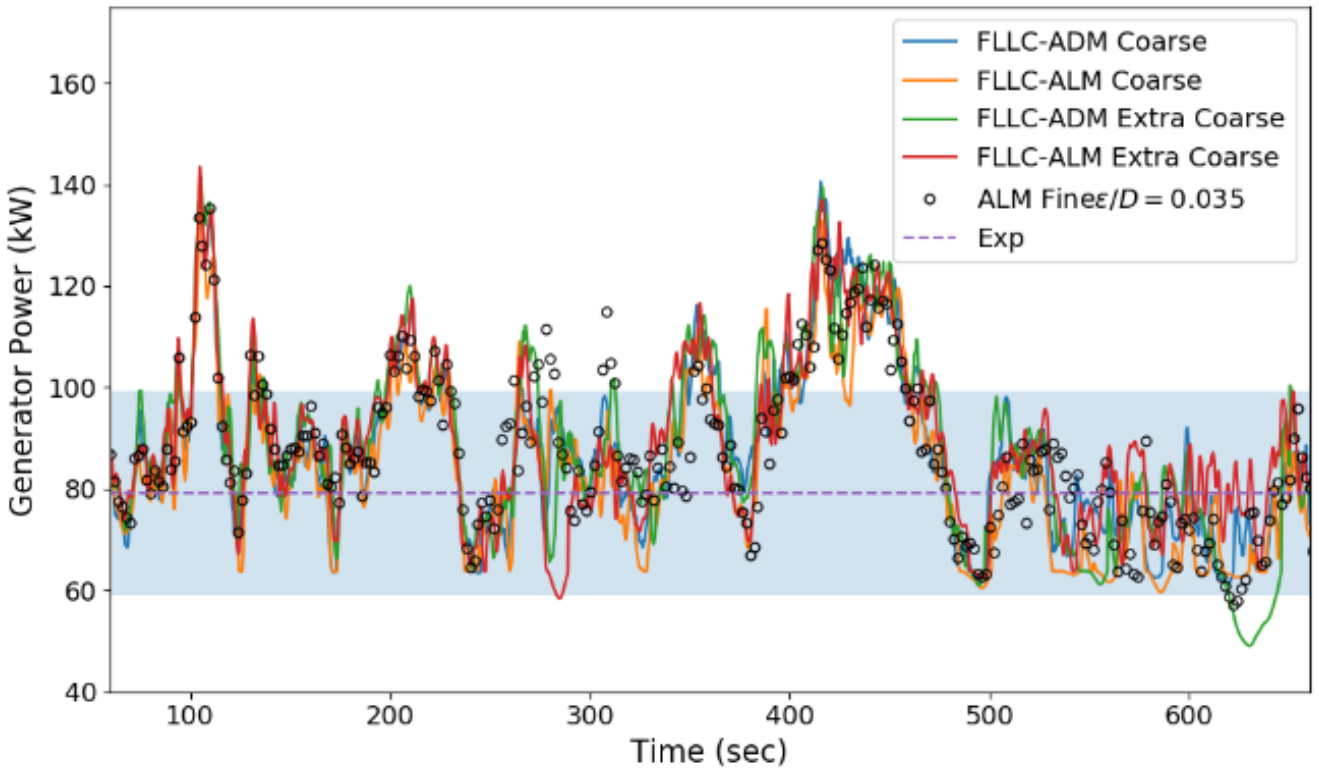


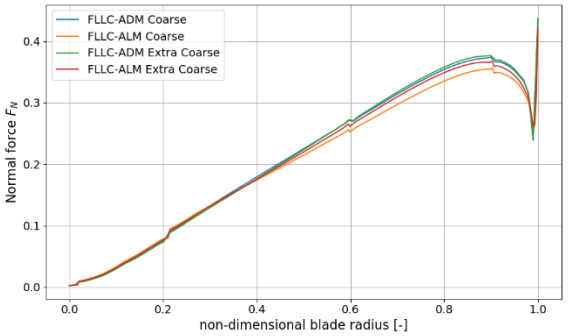


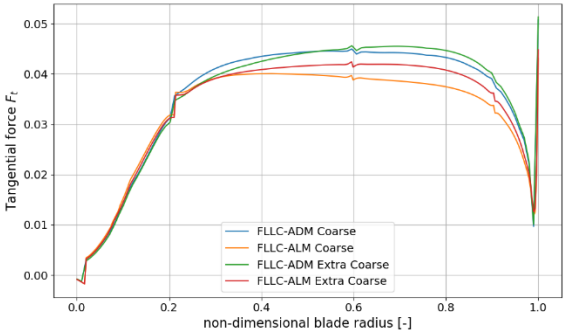
- FLLC captures tip loss
- FLLC blade loading for coarse & medium meshes match, even though power did not

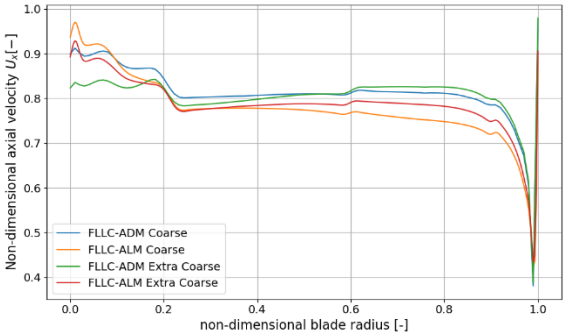


FLLC Coarse & Extra Coarse Meshes

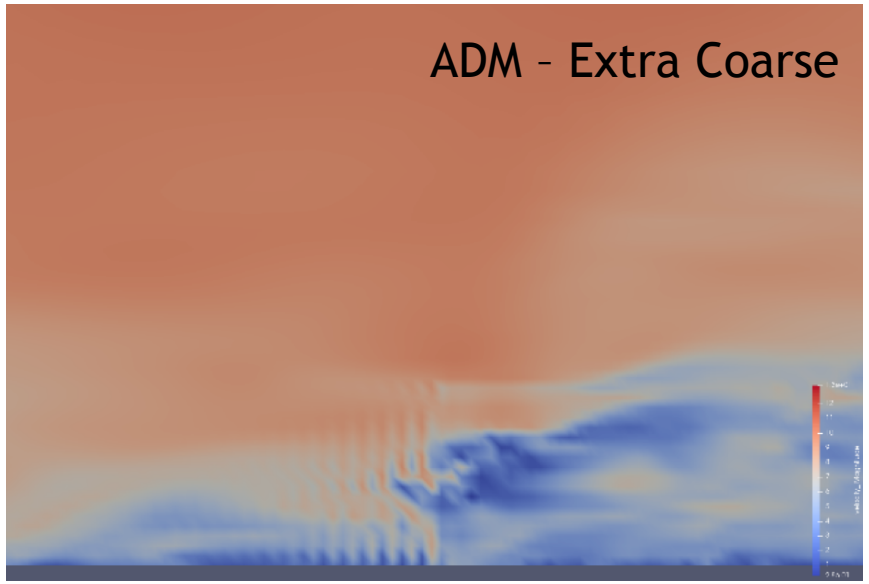


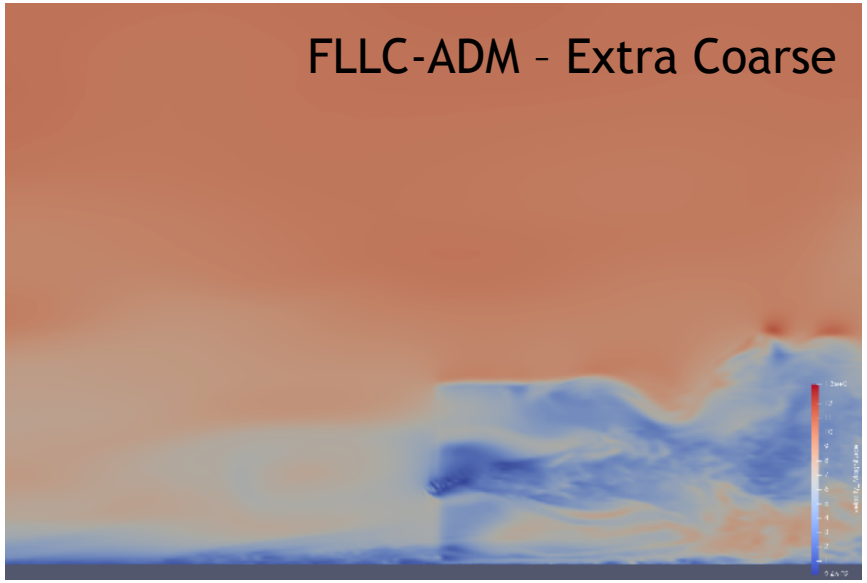


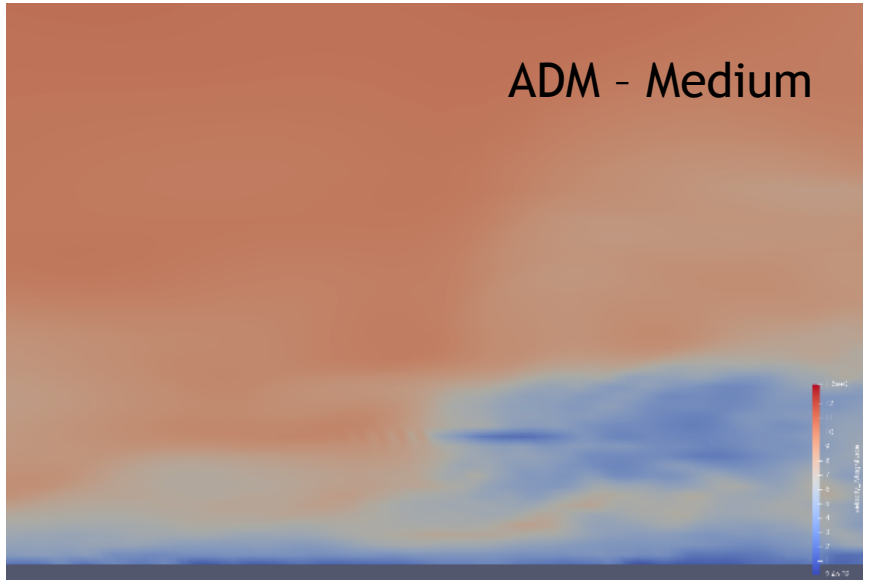


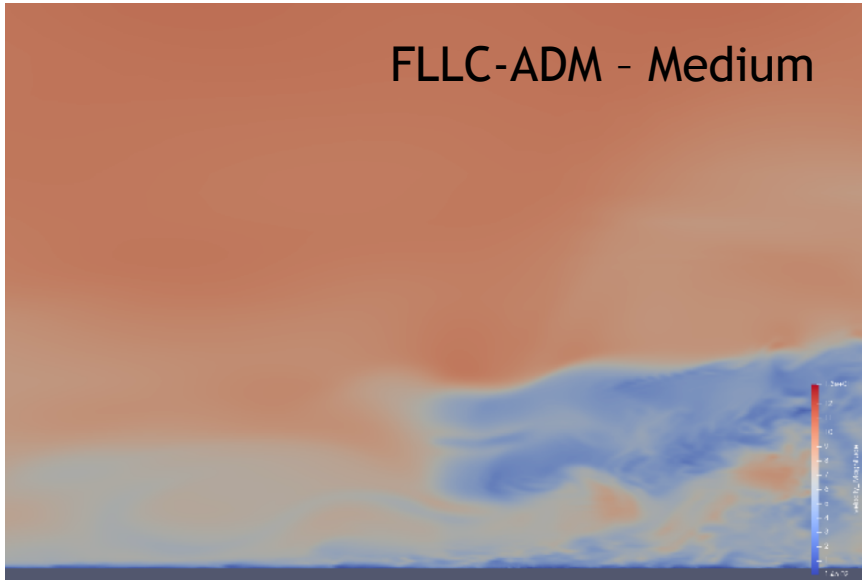


Runge Phenomenon









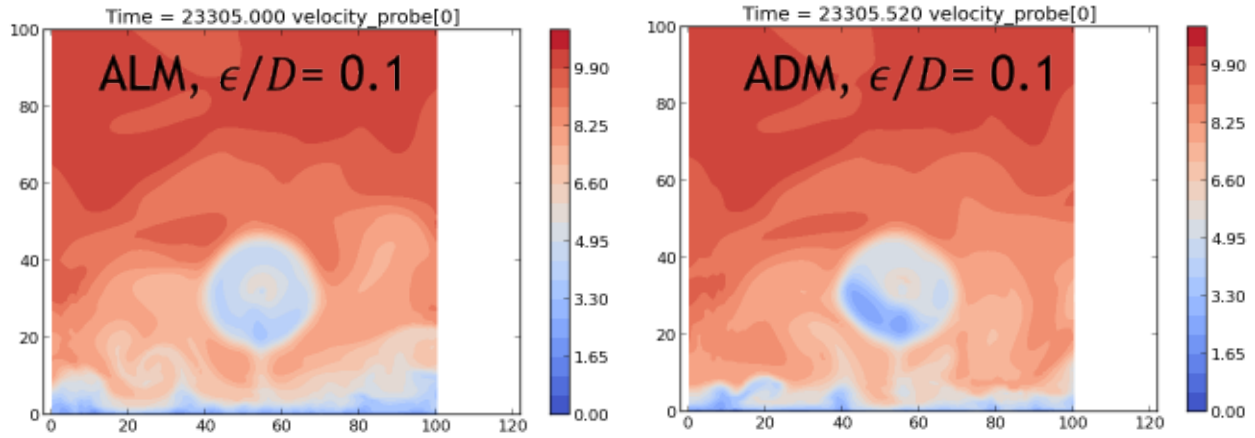
Conclusions

- First time the FLLC –ADM has been run with turbulent flow. Has the same benefits previously demonstrated with uniform inflow and FLLC-ALM
- Power from FLLC-ALM and FLLC-ADM matches the epsilon that is optimal for power (ϵ/D_rotor ≤0.035). Even though shape of blade loading curves are different.
- Time Averaged blade loading profiles from different grid resolutions all converge (including tip loss) with FLLC.
- FLLC seems to alleviate Runge phenomenon in coarse meshes.
- FLLC allows for shorter simulation time because coarser grids can be used with the same power output.
- Further study is needed to see if wake QoIs will be affected by using FLLC

Extra Slides

Going Forward

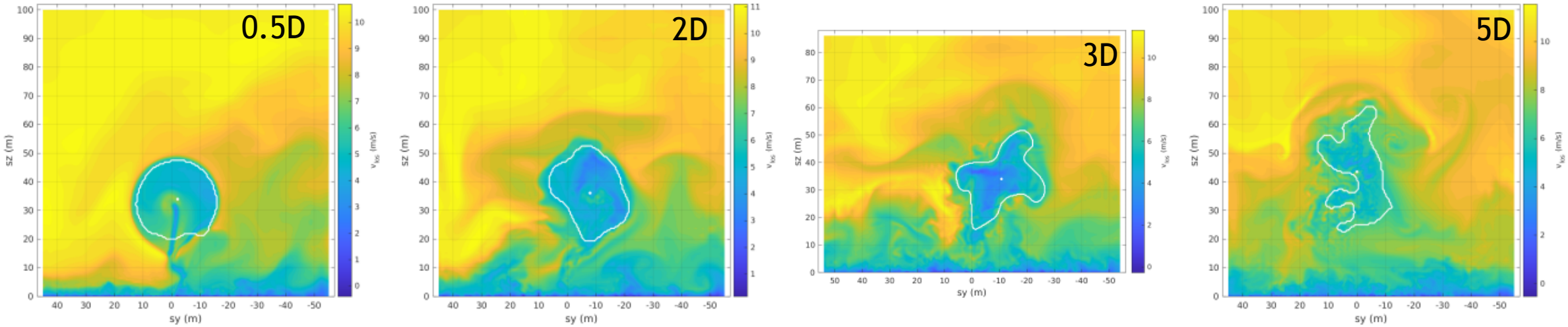
- ~~Validate power generation with field data~~
- ~~Analyze wake variations with epsilon and FLLC and validate with field data~~
- How low can N go?
- Investigate timing of FLLC
- ~~Actuator Disk Model~~
- Multiple turbine interaction



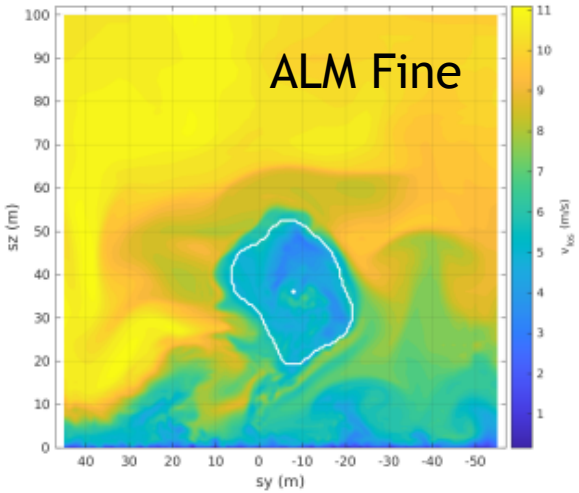
Timing

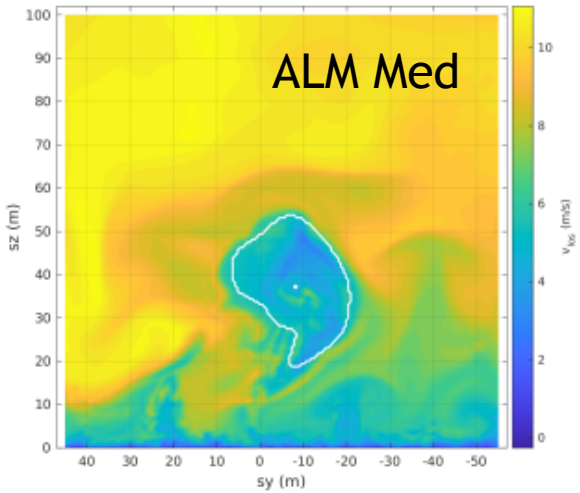
Case	Δt (sec)	Wall Clock Time for ten steps (sec)	Calculated Wall Clock Time for 1 min of simulation time (sec)
ALM Med Mesh	0.02	141.771	42,531
ADM Med Mesh	0.07	175.705	15,060
FLLC-ALM Med Mesh	0.02	138.293	41,488
FLLC-ADM Med Mesh	0.07	364.278	31,224
FLLC-ALM Coarse Mesh	0.04	140.722	21,108
FLLC-ADM Coarse Mesh	0.14	219.173	9,393
FLLC-ALM Extra Coarse Mesh	0.08	126.816	9,511
FLLC-ADM Extra Coarse Mesh	0.25	143.184	3,436

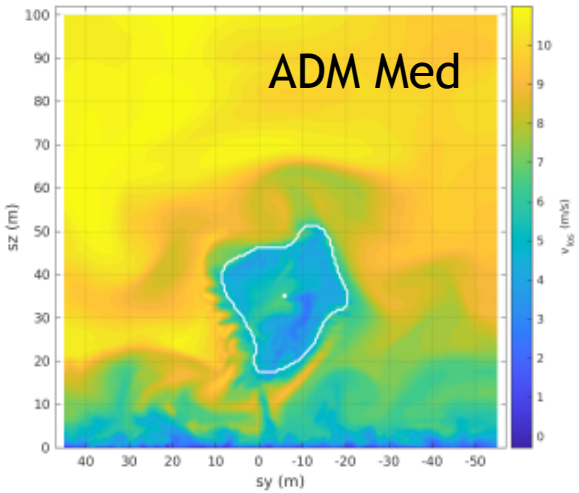
Fine ALM e/D 0.035

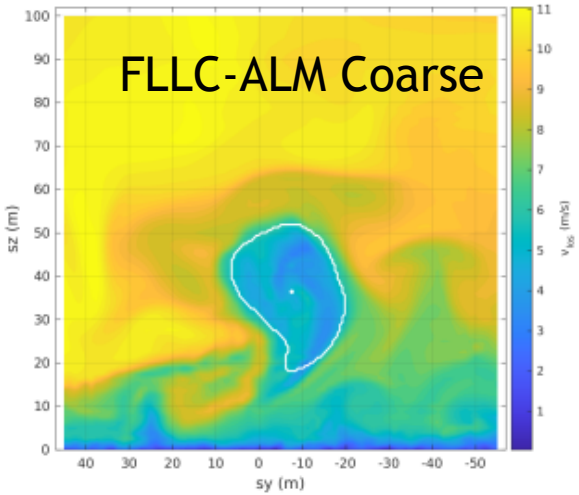


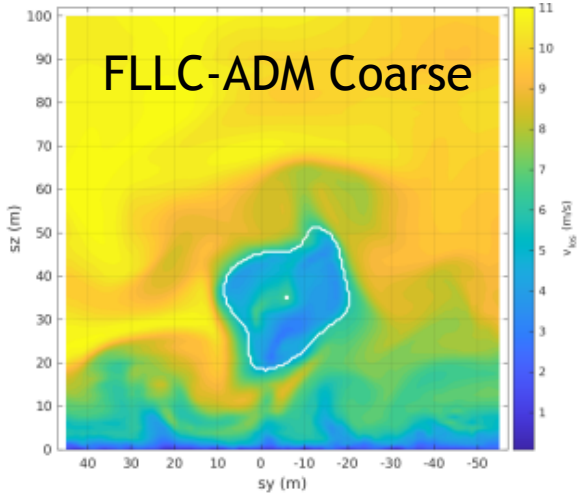
2D – Case Comparisons

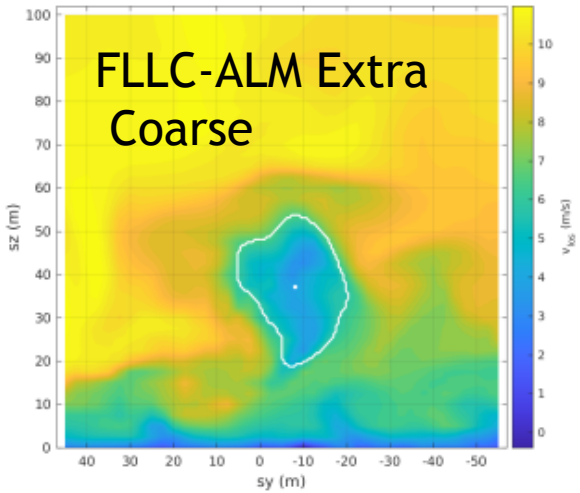


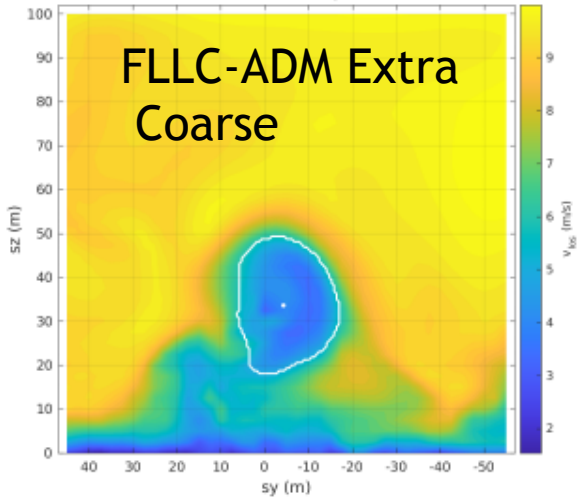


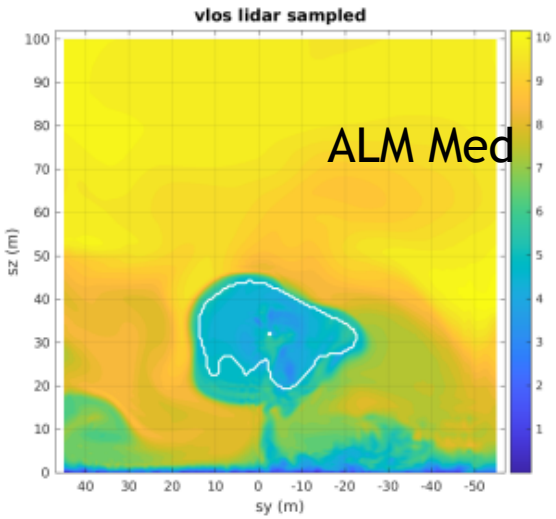












Case	Wake Position Standard Deviation	Velocity Deficit	Thrust
ALM Fine Mesh	[1.5, 32.6] [4.8, 2.5]	-2.33	0.99
ALM Med Mesh	[-1.3, 33.0] [3.3, 1.9]	-1.76	0.76
ADM Med Mesh	[-1.4, 33.0] [3.5, 2.1]	-1.79	0.82
FLLC-ALM Coarse Mesh	[-1.4, 33.1] [3.3, 2.0]	-1.80	0.77
FLLC-ADM Coarse Mesh	[-1.5, 33.0] [3.4, 2.0]	-1.87	0.77
FLLC-ALM Extra Coarse Mesh	[-1.4, 33.0] [3.2, 2.0]	-2.27	0.80
FLLC-ADM Extra Coarse Mesh	[-1.3, 32.9] [3.5, 2.0]	-2.35	0.75