Comparison of Actuator Line Model and a Filtered Lifting Line Correction Implemented in Nalu-Wind Large Eddy Simulations of the Atmospheric Boundary Layer

Sandia National Laboratories

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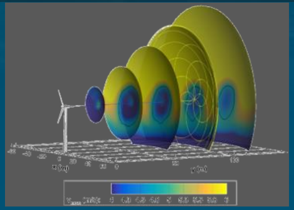

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Actuator Line Model (ALM)

- ALM – Force points along moving blade line

$$\vec{F} = \vec{L} + \vec{D}$$

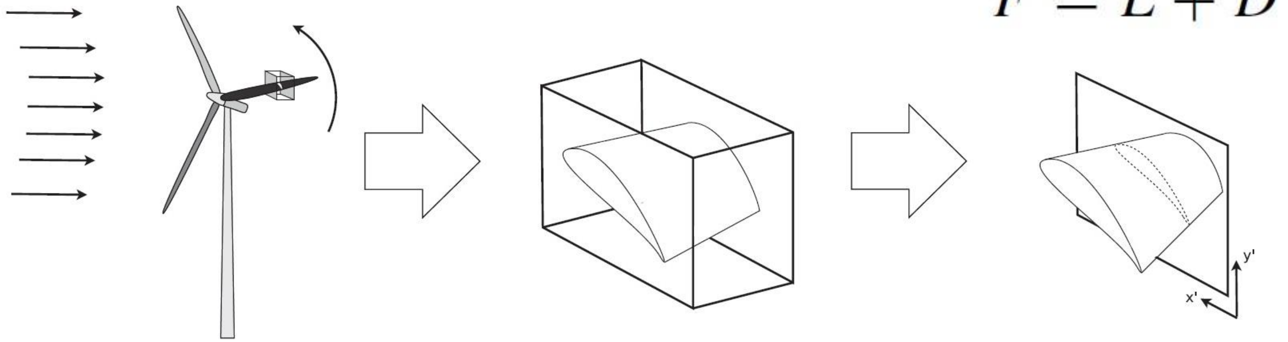
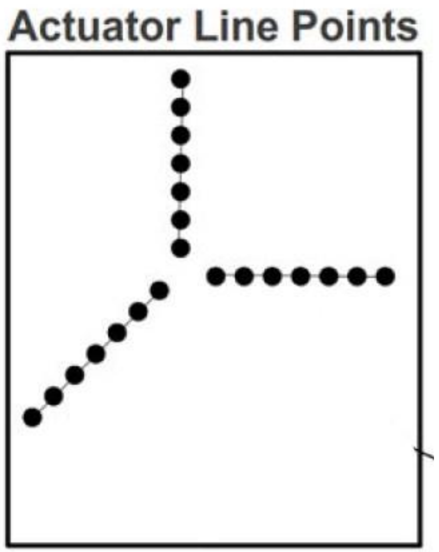
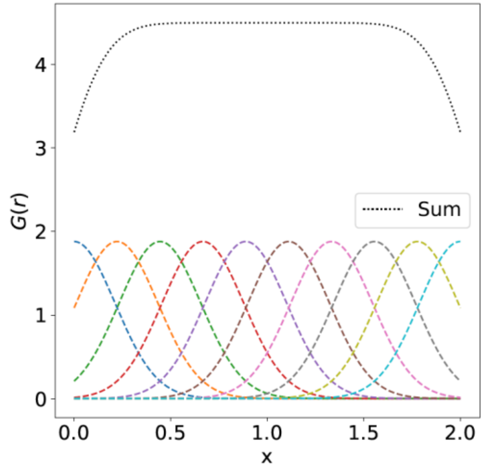


Figure 2. A two-dimensional section of the blade with the respective airfoil shape at that location.



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

ϵ -Smoothing length scale for the Gaussian kernel

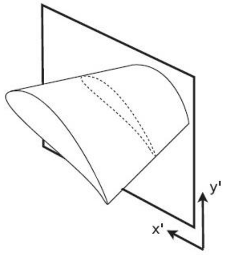


Sorensen & Shen, 2002

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

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 ϵ and ϵ^{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

- $\epsilon/[(\Delta x\_fine] \geq 5$ (for grid independence) (Martínez-Tossas et al., 2015)
- $\epsilon/c \leq \sim 0.25$ (for optimal accuracy of blade loading) (Martínez-Tossas et al., 2017)
- $\epsilon/D\_rotor \leq 0.035$ (for power production) (Churchfield et al. 2017)
- $\epsilon/\Delta x \geq 1$ (to resolve the Gaussian kernel)

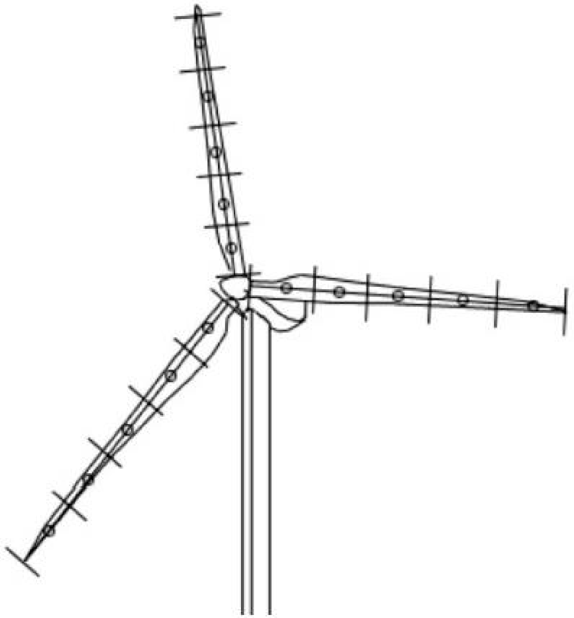
Parameter Space:

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

- Number of ALM points along the blade: 100, 200, 300

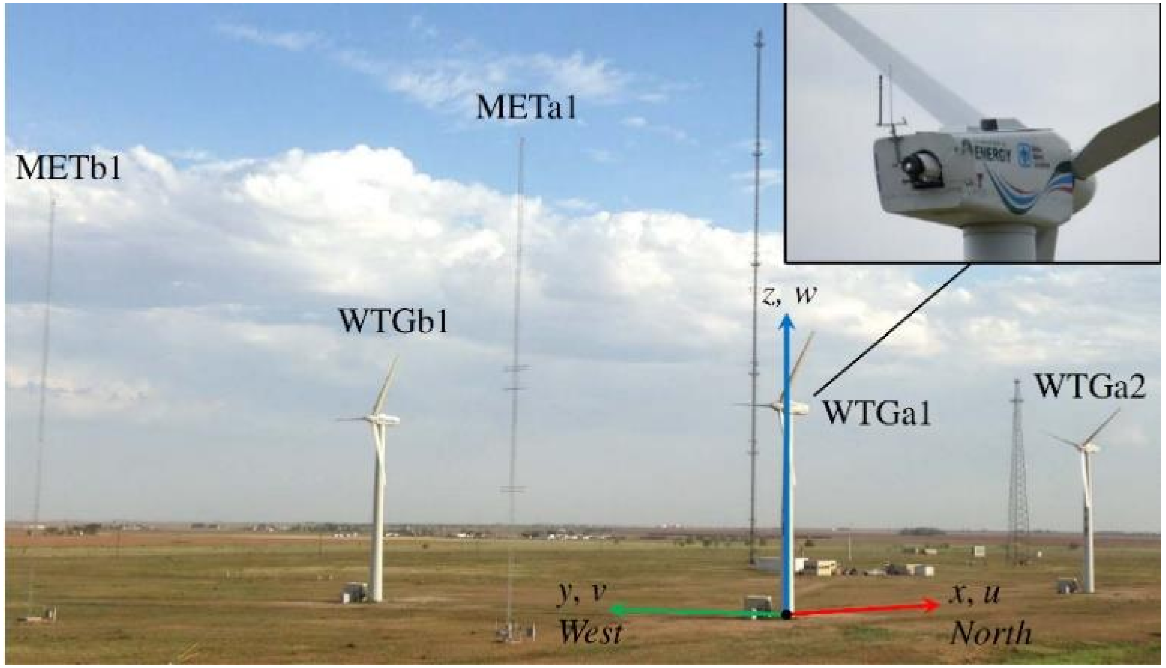
Nalu-Wind + OpenFAST

- Nalu-Wind: Part of the ExaWind code suite
  - Large Eddy Simulation of Atmospheric Boundary Layer
  - 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, and blade flap root bending moments



SWiFT – Simulation Setup

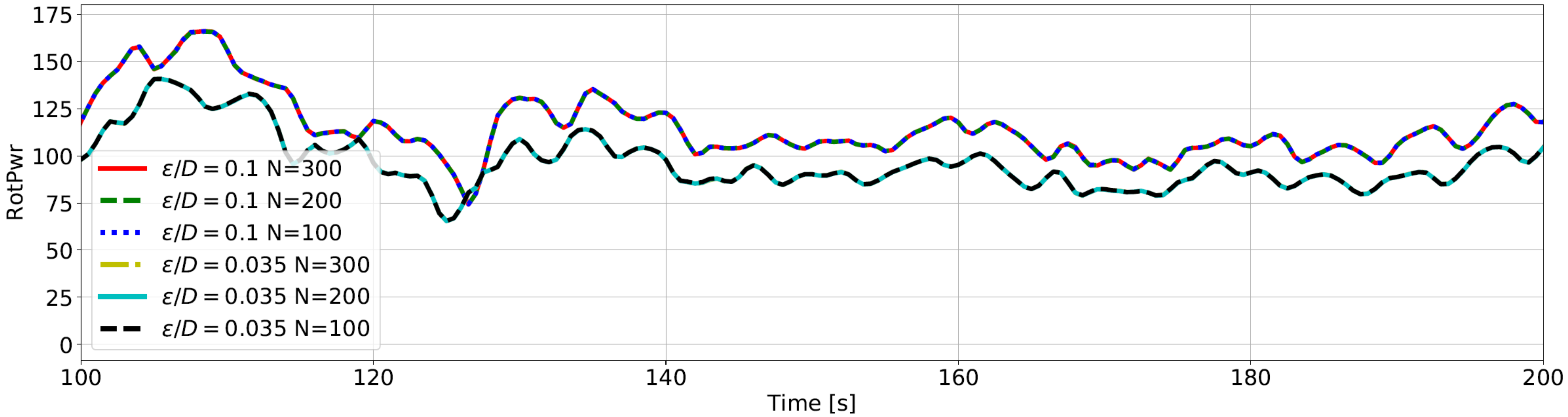
- SWiFT: Scaled Wind Farm Technology Center - Texas Tech University's National Wind Institute Research Center in Lubbock, Texas
- Single V-27 Rotor Turbine
- Neutral Atmospheric Boundary Layer*
  - Wind Speed Average for 10 min window 8.7 m/s at hub-height (32m)
  - TSR = 6.8



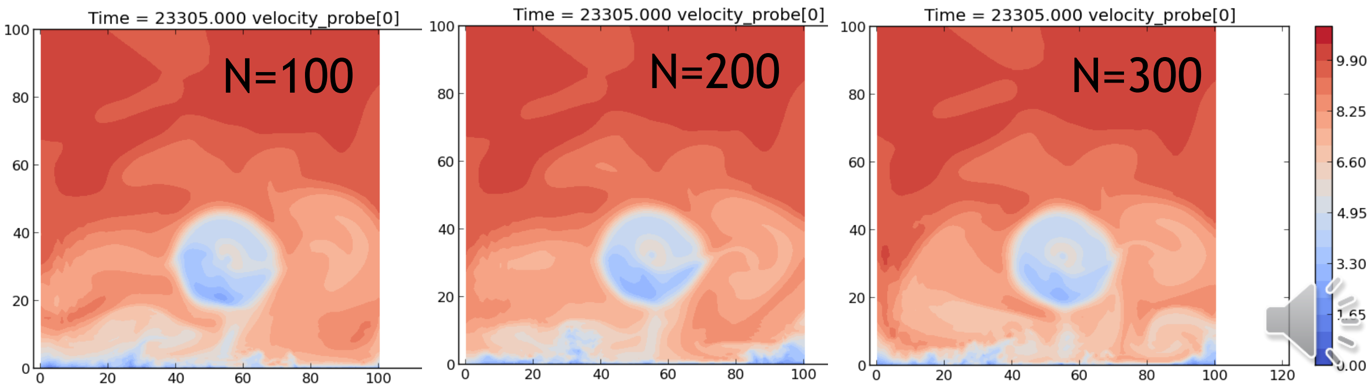
***High-Fidelity Wind Farm Simulation Methodology with Experimental Validation**
Alan Hsieh, et al. In Review

ALM – Number of Points Along the Blade

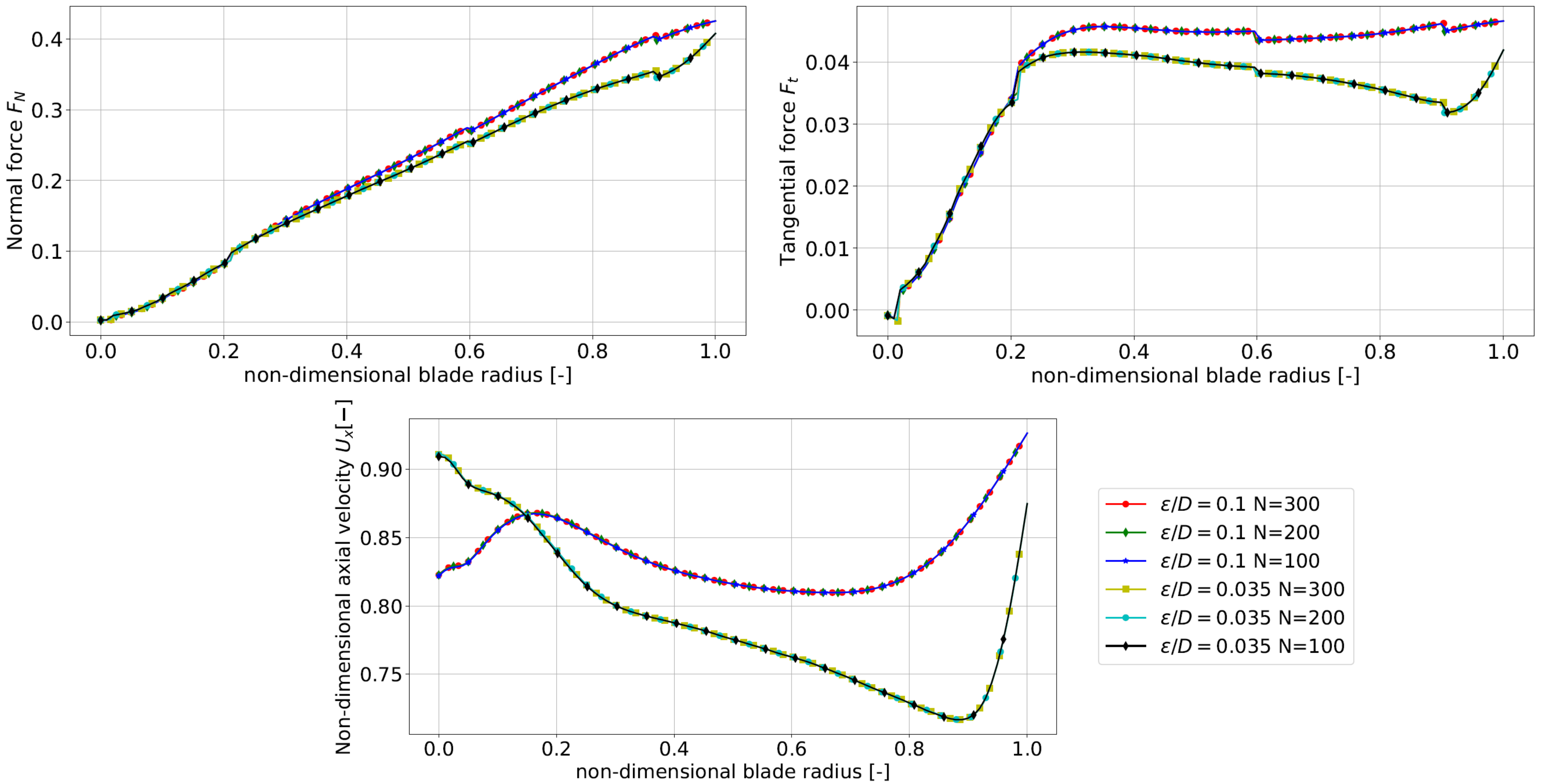
- Effect of changing number of points (N=100, 200, 300) is negligible
- Higher epsilon gives an artificially higher power



0.5 D Down Steam
Medium Mesh, ϵ/D=0.1

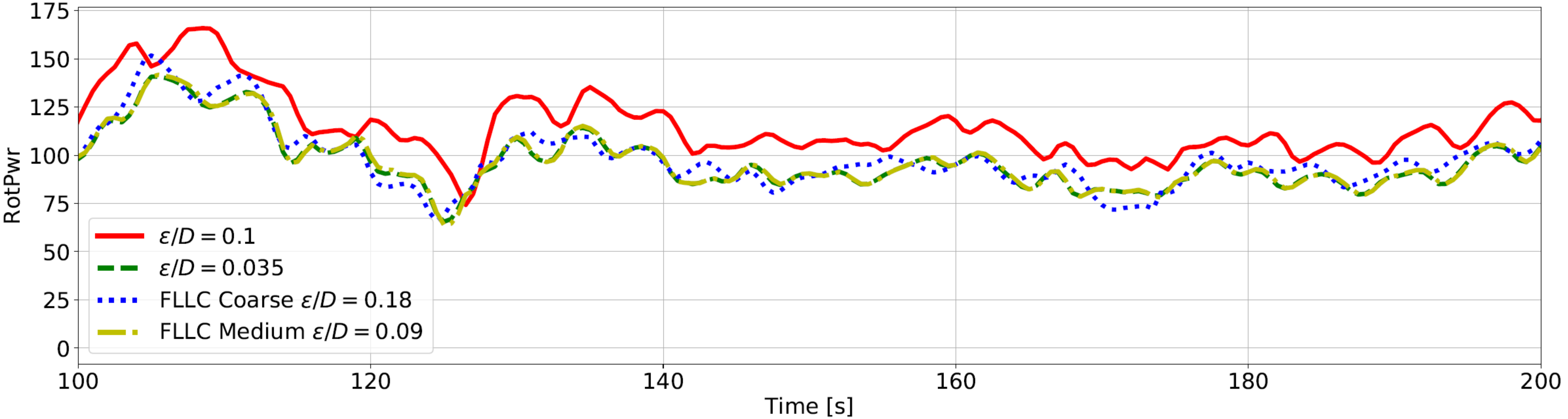


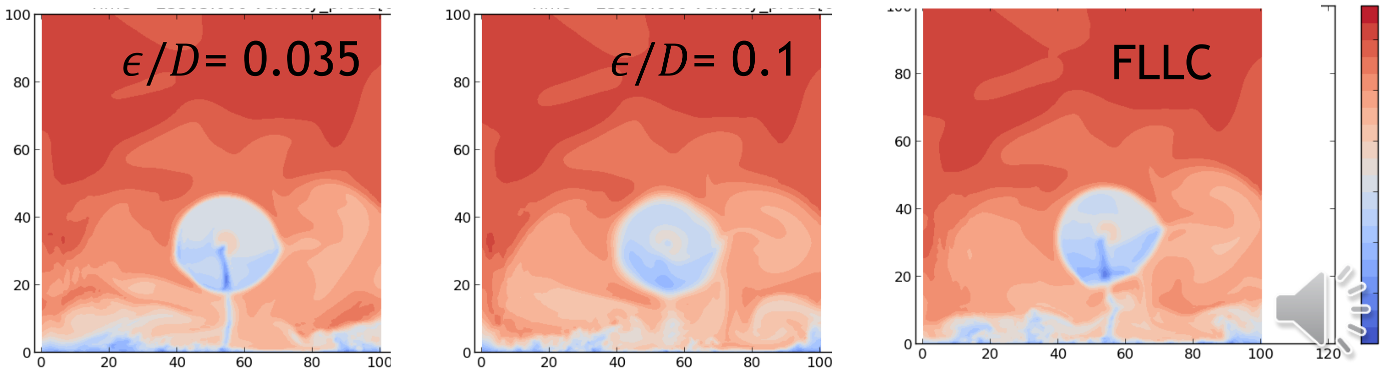
ALM – Number of Points Along the Blade



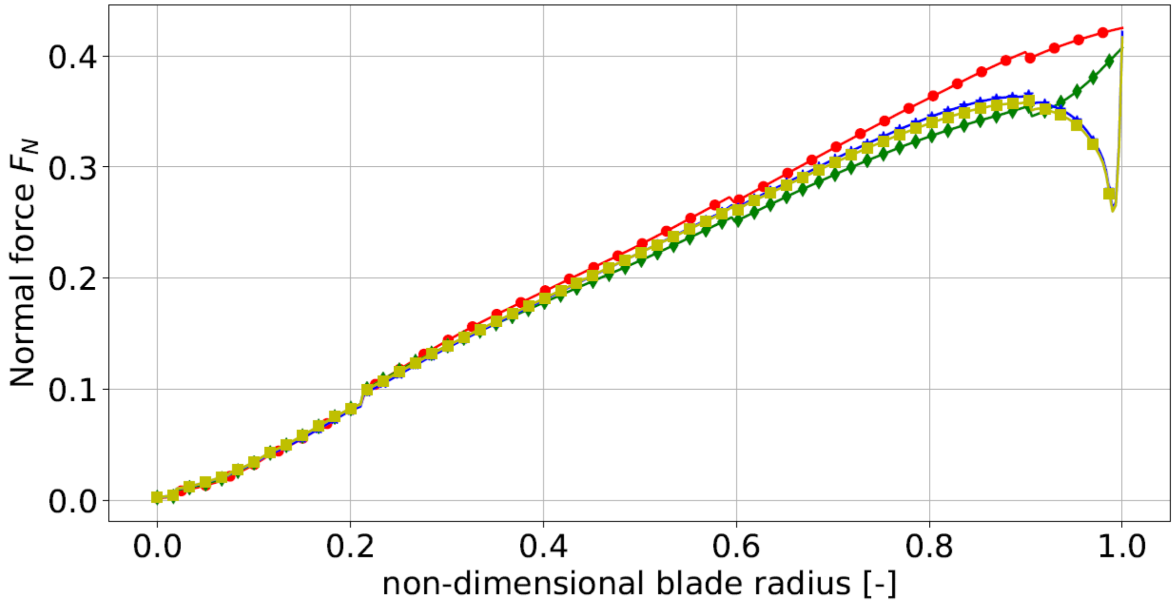
FLLC Results – Power

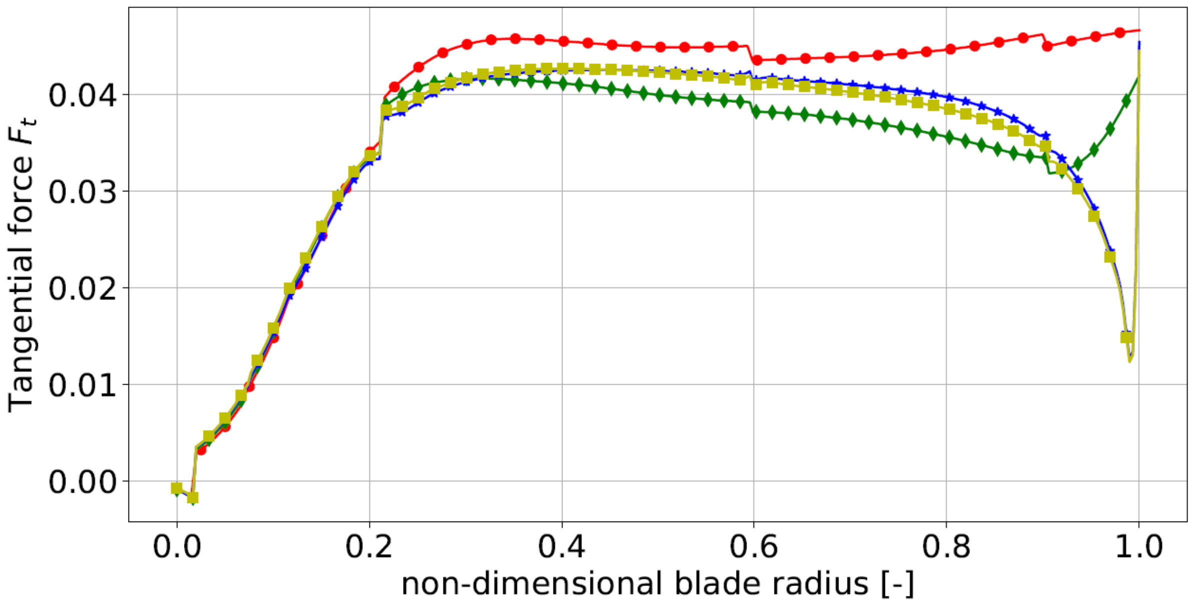
- Power from FLLC medium mesh matches ϵ/D = 0.035
- Power from FLLC coarse mesh is close, but still off – still need resolved mesh



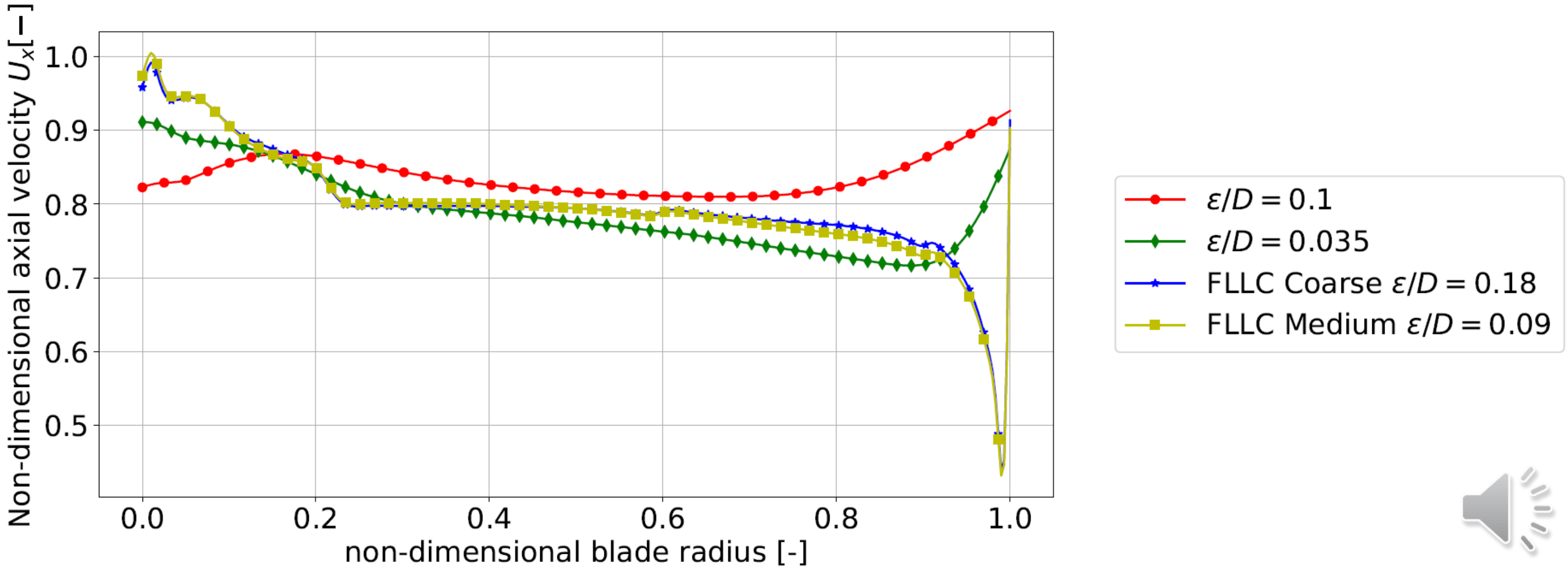


FLLC Results – Forces and Axial Velocity along the blade

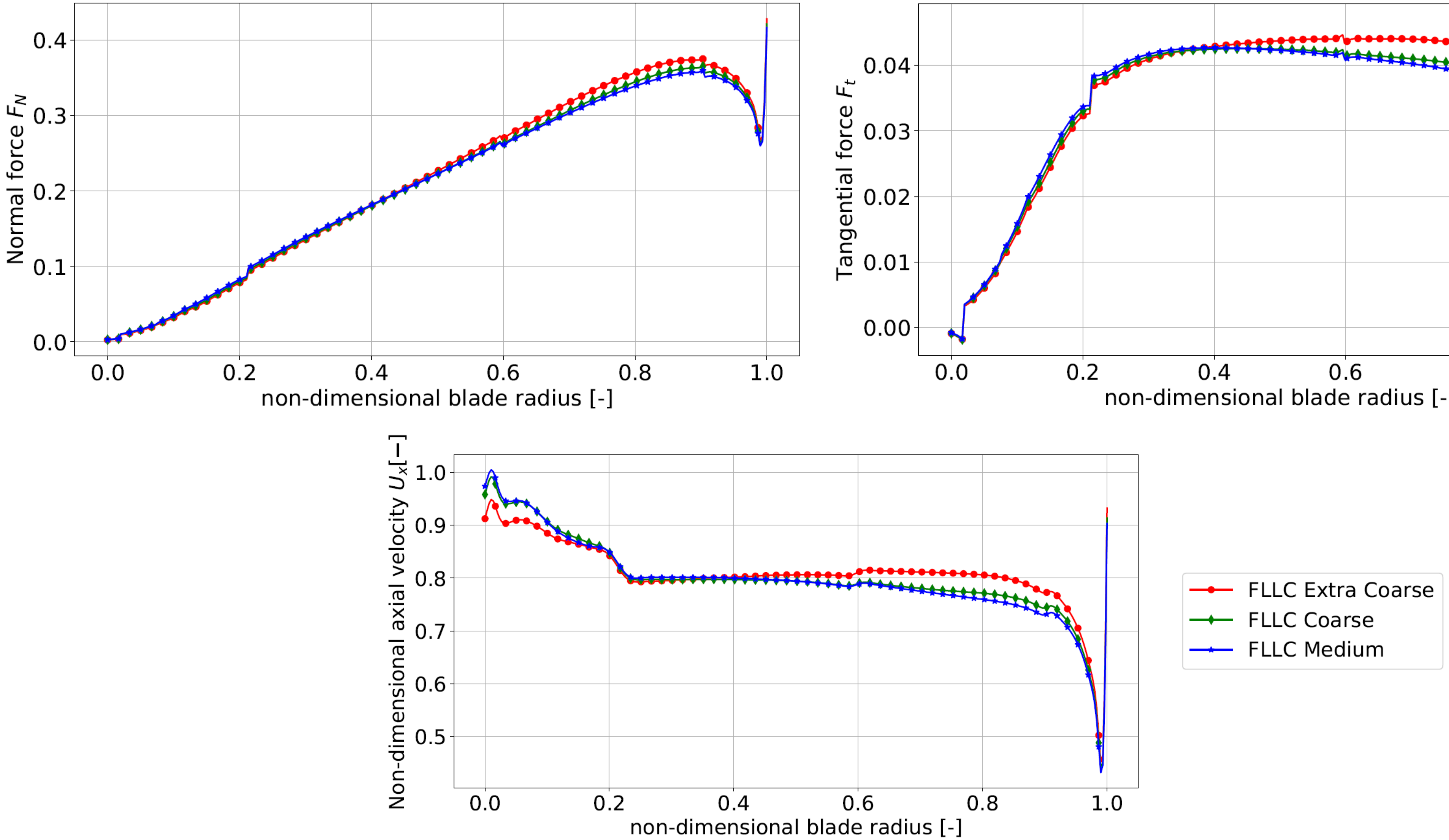




- FLLC captures tip loss
- FLLC blade loading for coarse & medium meshes match, even though power did not



FLLC Results – Grid Dependence

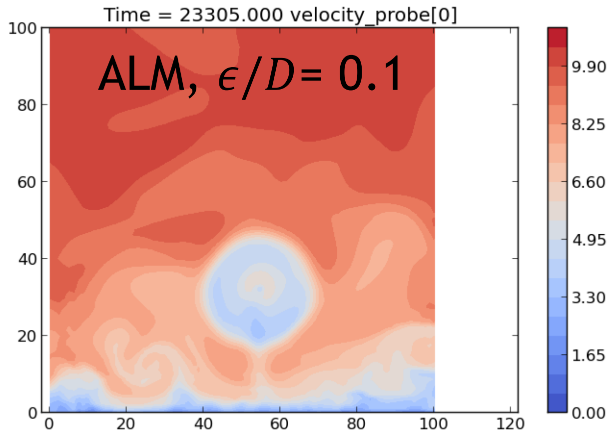


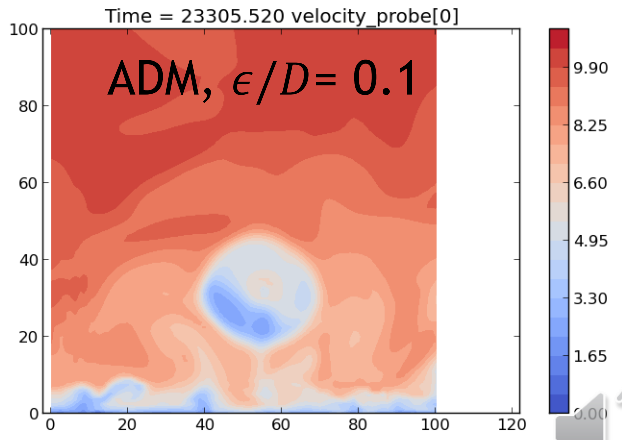
Conclusions

- Power from FLLC 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 collapse (including tip loss) with FLLC.
- Changing N from 100 to 300 has negligible effect
- Wake QoIs will still be driven by mesh size and epsilon, FLLC will correct turbine QoIs
- Timing for FLLC is same order of magnitude
- First time the FLLC has been run with turbulent flow. Has the same benefits previously demonstrated with uniform inflow

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





Extra Slides

Epsilon Effect on Tip Resolution

- Increasing epsilon causes a reduction in resolution of the loading near the tip

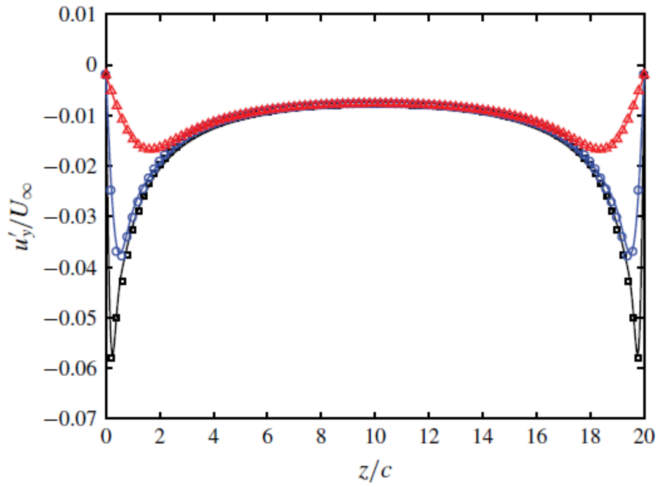


FIGURE 4. (Colour online) Comparisons of the full numerical solution of filtered lifting line theory (lines) (3.21) applied to a constant chord, c, blade of constant lift coefficient, $c_{Lb} = 1$ and finite length $L/c = 20$, with discrete superposition (4.9) of the fitted solution to the canonical filtered lifting line solution (symbols). U_∞ is constant. Black line and squares: $\varepsilon = 0.25$, blue line and circles: $\varepsilon = 0.5$. Red line and triangles: $\varepsilon = 1.5$.

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