Validation of an Actuator-Line Tower Model for Upwind and Downwind Turbine Configurations

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Why model the tower?

Tower presence modifies:

- Blade loads
  - Up/down-wind configurations
- Rotor Wake
  - Meandering
  - Vortex break-down

Importance:

- Capture unsteady blade loads
- Future of downstream turbines
- Better farm power prediction

Existing Tower Implementations

Fully resolved

- Body fitted mesh required
- Very computationally expensive

Immersed Boundary Method

- Smaller mesh (Santoni)

Drag actuators with oscillating lift

- Match to Strouhal shedding (Sarlak)

Drag actuator points

- Single or multiple lines (Churchfield, Wang)

C_p Based Actuator Tower Model

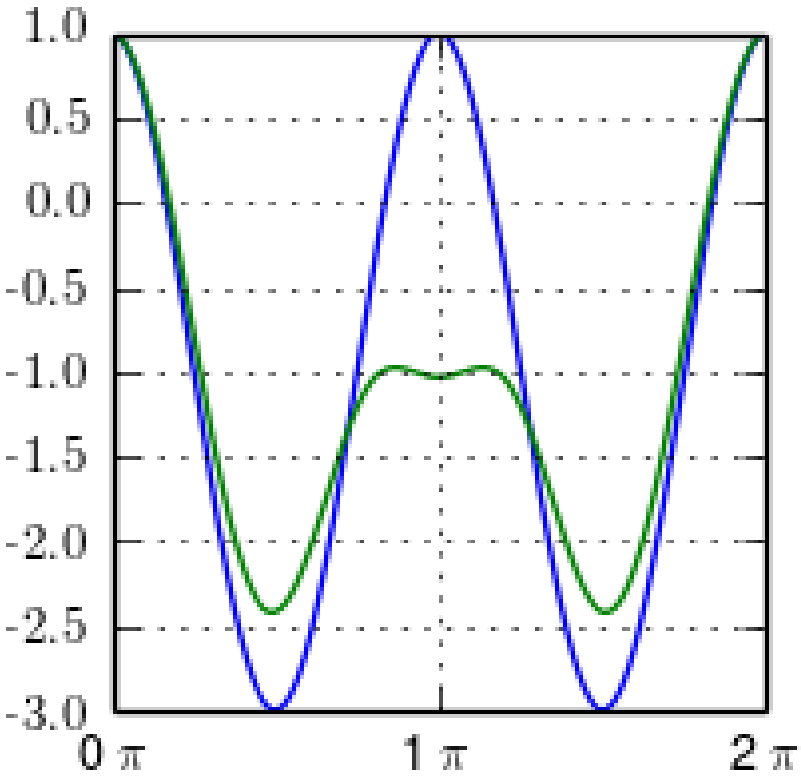
Typical Drag Tower Model:

- Distribute force using Gaussian spreading

C_p based Tower Model:

- Distribute force in θ using C_p distribution
- Force distribution in r and z unchanged
- Smaller mesh requirement than resolved, IBM
- Able to reuse blade code for implementation

Churchfield & Wang approach:



Potential Flow Distribution
Modeled Distribution

C_p Based Actuator Tower Model - 2

C_p **distribution** from smooth, subcritical cylinder:

$$g_{potential}(\theta) = 1 - 4\sin^2\theta \tag{1}$$

$$g_{correction}(\theta) = 1 - 3\exp^{-\left(\frac{\theta-\pi}{\frac{\pi}{4}}\right)^2} - \exp^{-\left(\frac{\theta}{\frac{\pi}{2}}\right)^2} - \exp^{-\left(\frac{\theta-2\pi}{\frac{\pi}{2}}\right)^2} \tag{2}$$

$$g(\theta) = \frac{g_{potential} + g_{correction}}{c} \tag{3}$$

Set c such that total drag is 1:

$$\int_0^{2\pi} g(\theta)\cos\theta d\theta = 1 \tag{4}$$

Drag found from actuator point velocity and look-up table.

Methods & Tools

Numerical Solver:

- OpenFOAM
- SOWFA
- pisoFoamTurbine.ALMAdvanced
- In-house modifications

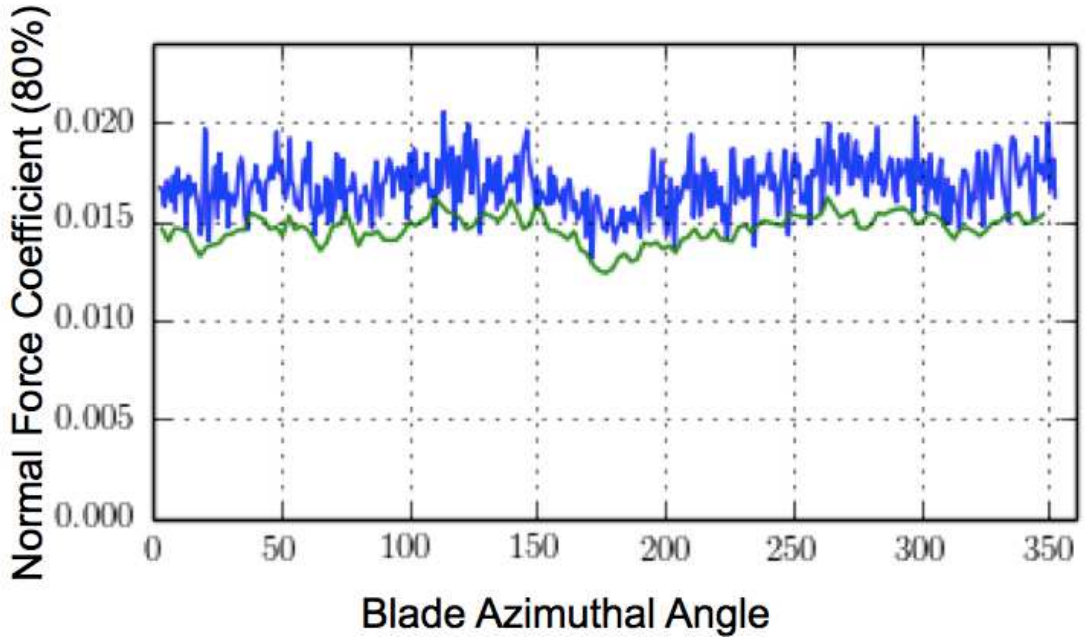
Validation:

UAE Phase VI experiment

- Seq S: Upwind
- Seq B: Downwind
- Seq 3: Tower wake

Upwind Rotor

Normal force on the 7 $\frac{m}{s}$ upwind case at $\frac{r}{R} = 0.8$:



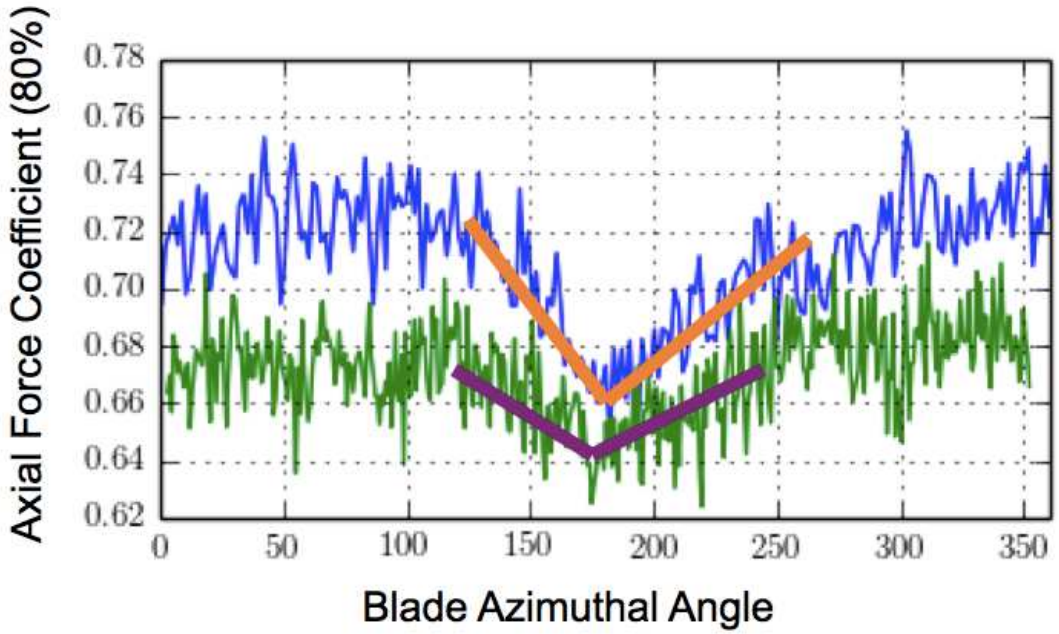
NREL UAE VI
SImulation

Reasonable Comparison:

- Predicts mean value well
- Follows the shape well

Downwind Rotor

Axial force on the 7 $\frac{m}{s}$ downwind case at $\frac{r}{R} = 0.8$:



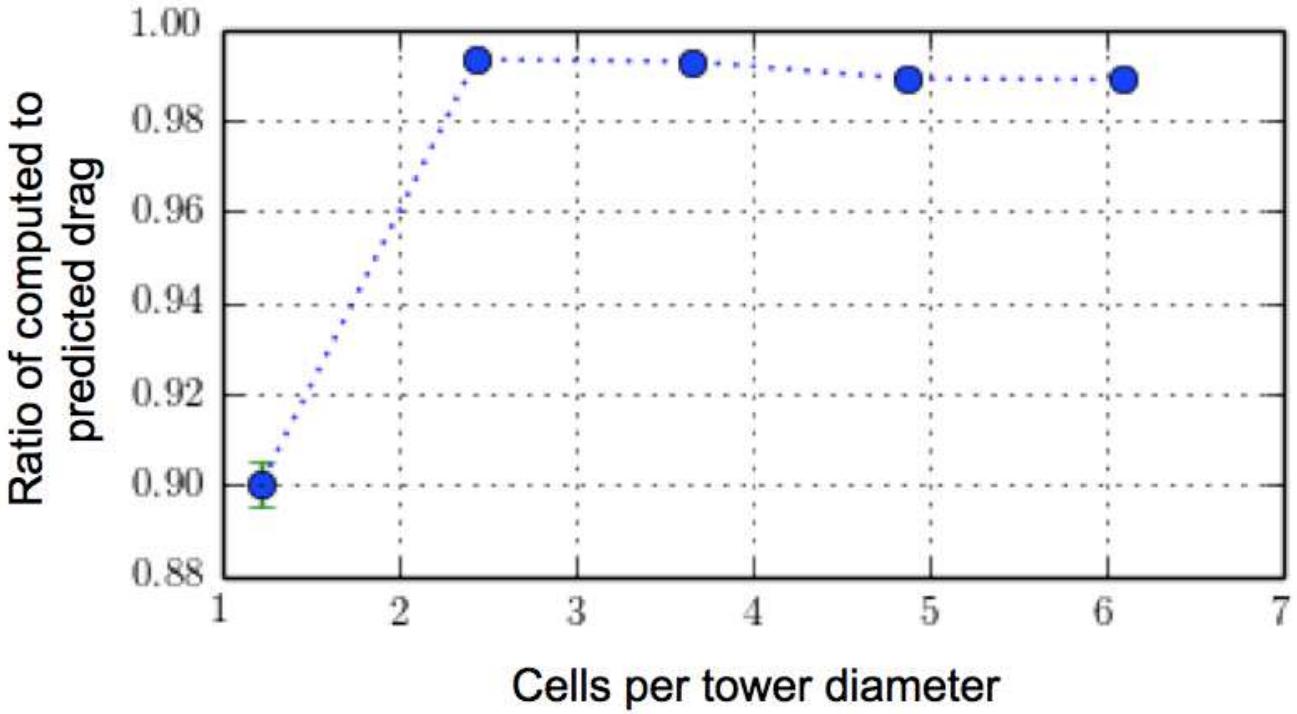
NREL UAE VI
SImulation

Not as Reasonable Comparison:

- Mean value not predicted as well
- Shape not predicted well

Where are the differences coming from?

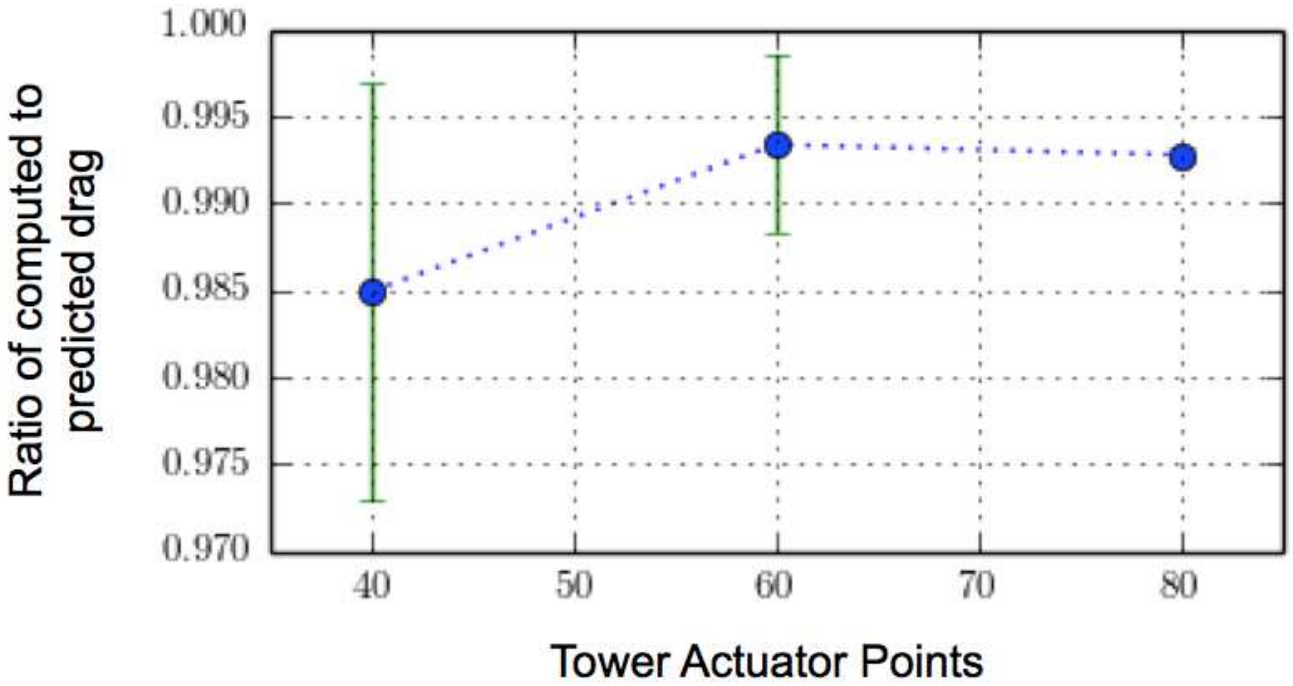
Tower-only mesh resolution study



Requirement: 3+ cells needed

- At 4+ in wind turbine cases
- Smaller than requirement for IBM

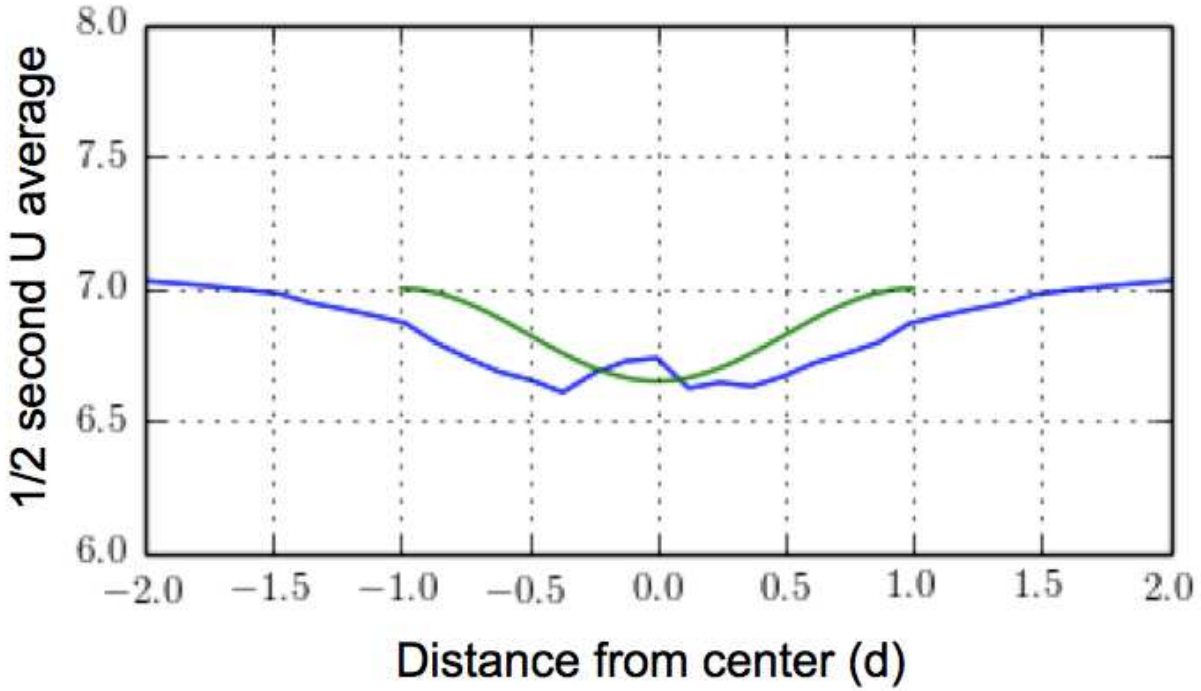
Number of tower actuator points study



Requirement: 60+ actuator points needed

- Good convergence of mean at 60
- Convergence of variance requires more points

Tower Wake



NREL UAE VI
SImulation

Momentum deficit can be used to calculate drag:

- Different drag value
- Different peak momentum deficit
- Simulation matches input file

UAE Phase VI @ 7 m/s isn't fully subcritical?

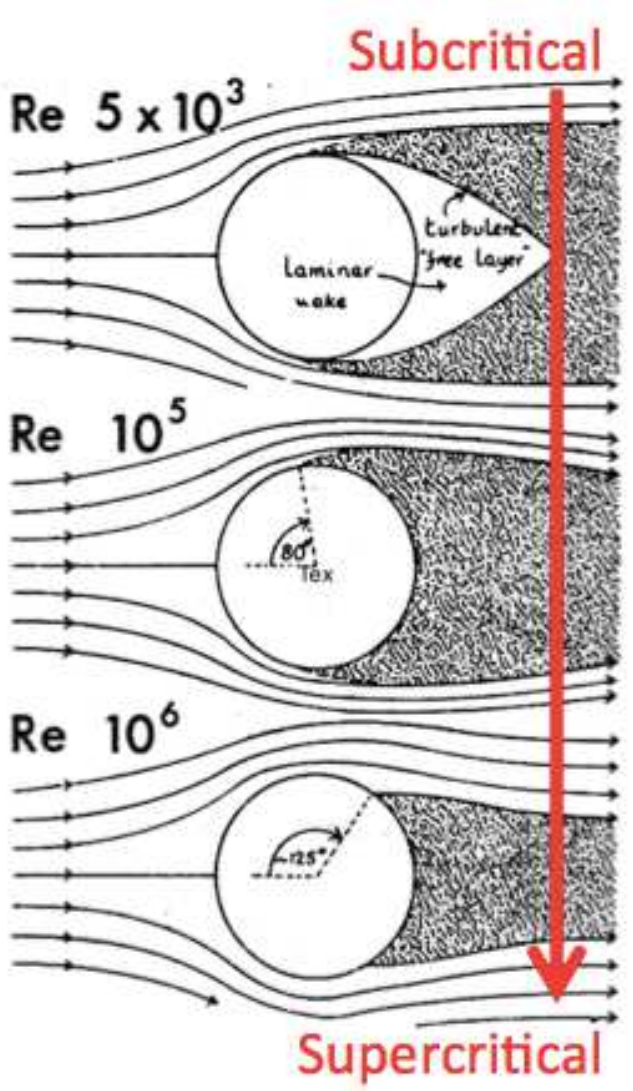
Ongoing Work

Extend C_p model:

- Add supercritical C_p
- Add $C_d = \text{fxn}(U, r)$

as required by:

- UAE Phase VI
- Utility scale turbines



Middleton and Southard (1984)

Fin

Thank you for your attention.

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Questions?

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