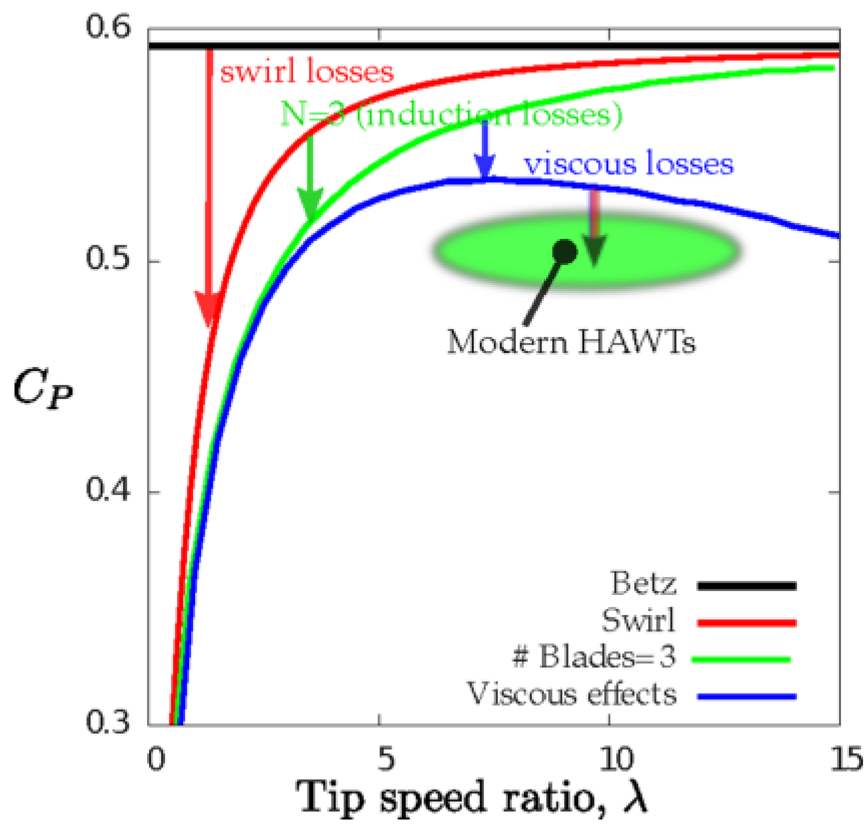
Iowa State University
College of Engineering

A Numerical Investigation of Dual Rotor Wind Turbines

Aaron Rosenberg
Department of Aerospace Engineering
Mentor: Dr. Anupam Sharma

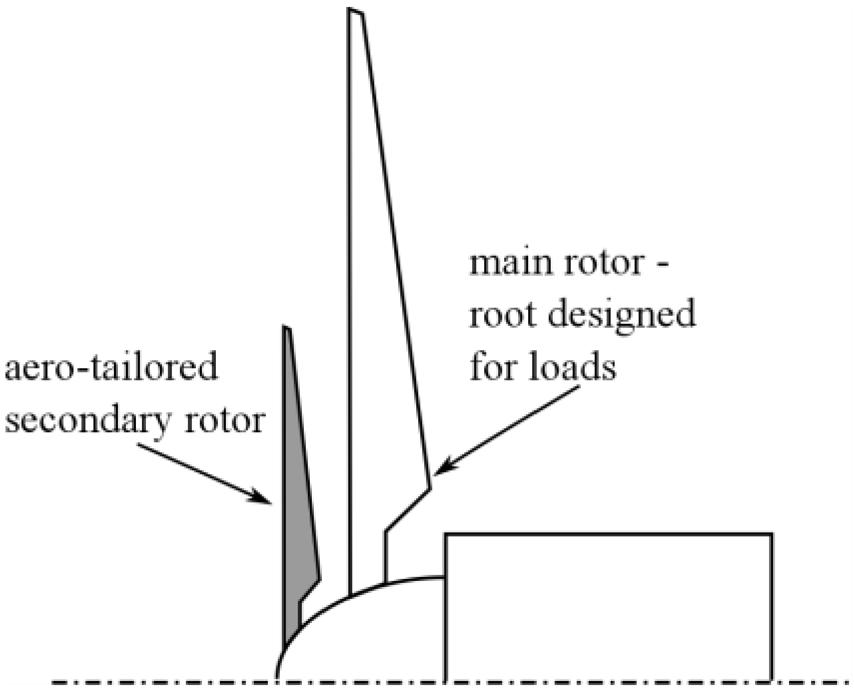
Motivation

- Betz limit: $C_P = 0.593$
  - Modern HAWTs operate well below this
- Root loss (≈5%)
  - Poor root performance
  - Designed for structural integrity
- Wake loss (≈8−40%)
  - Not operating in isolation
- 1% Increase in C_P could save as much $1.31 Billion annually



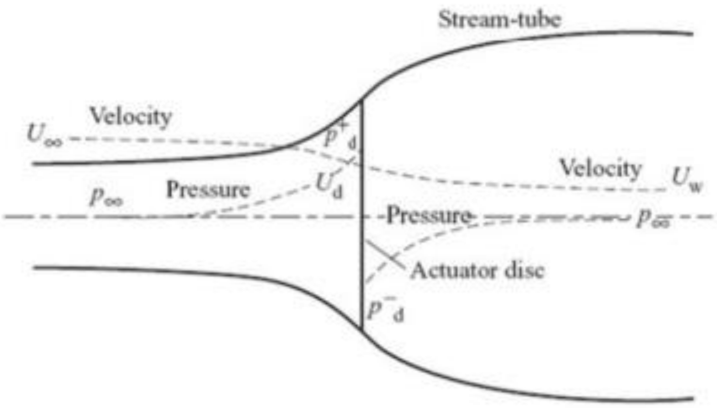
Concept and Design

- Dual Rotor Wind Turbine (DRWT)
  - Rotate independently
- Reduce root loss
- Reduce wake loss
  - Enhance mixing
  - Like turbulent atmosphere
- Secondary rotor inversely designed using BEM



Theoretical Power Extraction

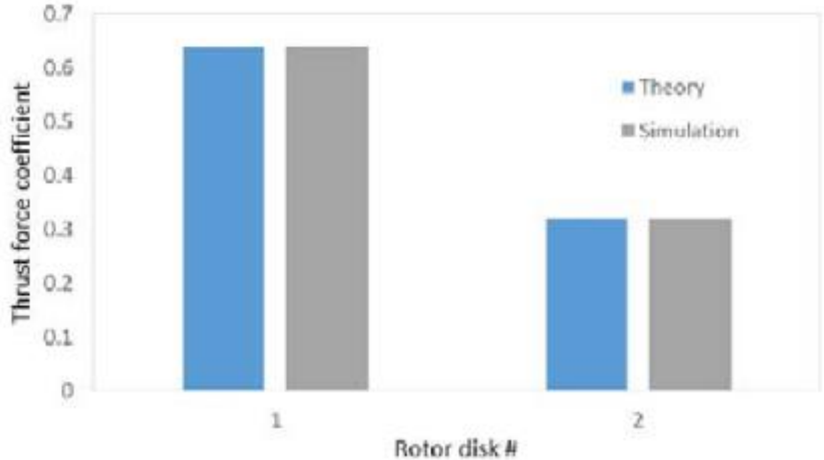
- *Newman* 1985
- 1-D Momentum Theory
  - 1 Disk: $C_{P_{\max}} = 0.593$
    - Betz Limit
  - 2 Disks: $C_{P_{\max}} = 0.640$
  - 4 Disks: $C_{P_{\max}} = 0.658$
- Diminishing Returns



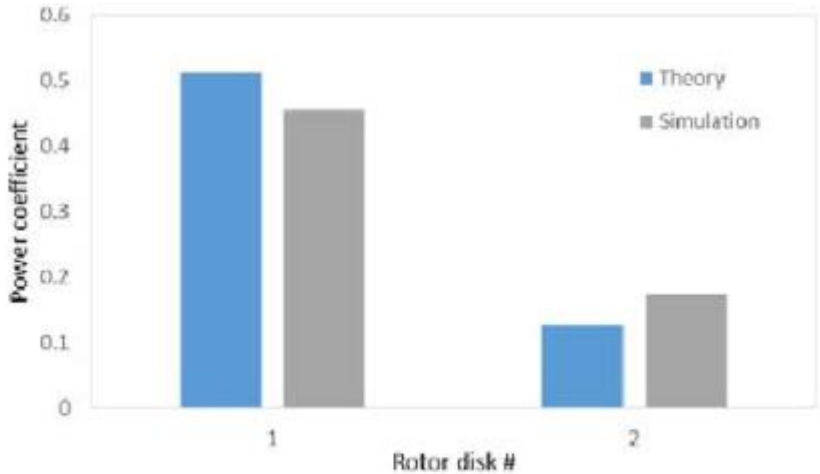
RANS Validation

- *Selvaraj,* Master's Thesis
- Reynold's Averaged Navier-Stokes
- Equal Sized Rotors
- Uniformly loaded
- Spacing = $0.5R_{blade}$

RANS Validation: Two Rotors

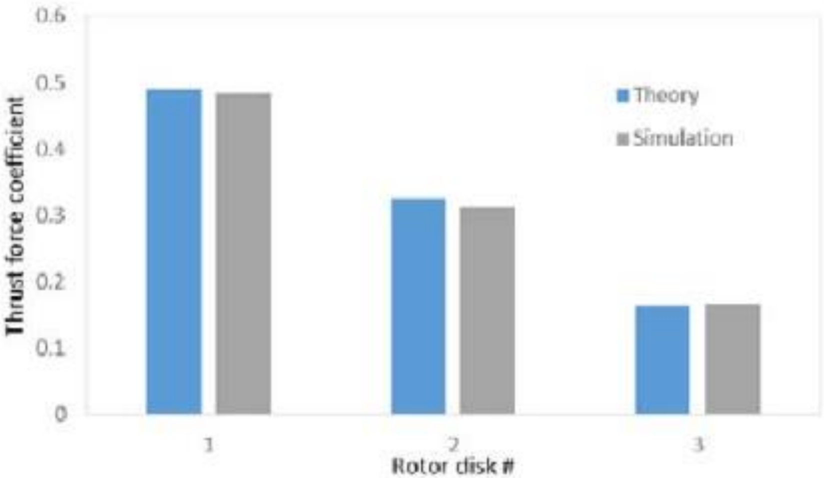


(a) C_T

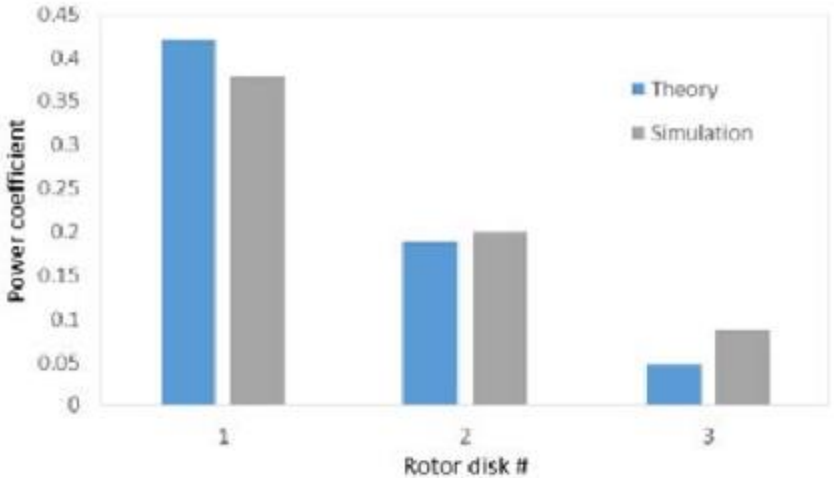


(b) C_P

RANS Validation: Three Rotors

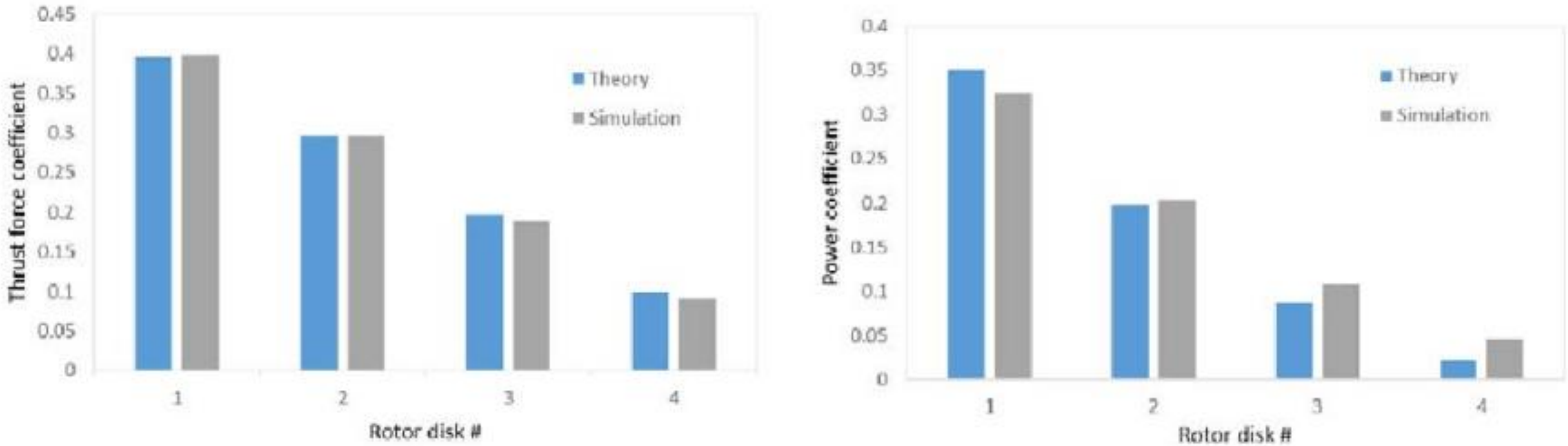


(a) C_T



(b) C_P

RANS Validation: Four Rotors

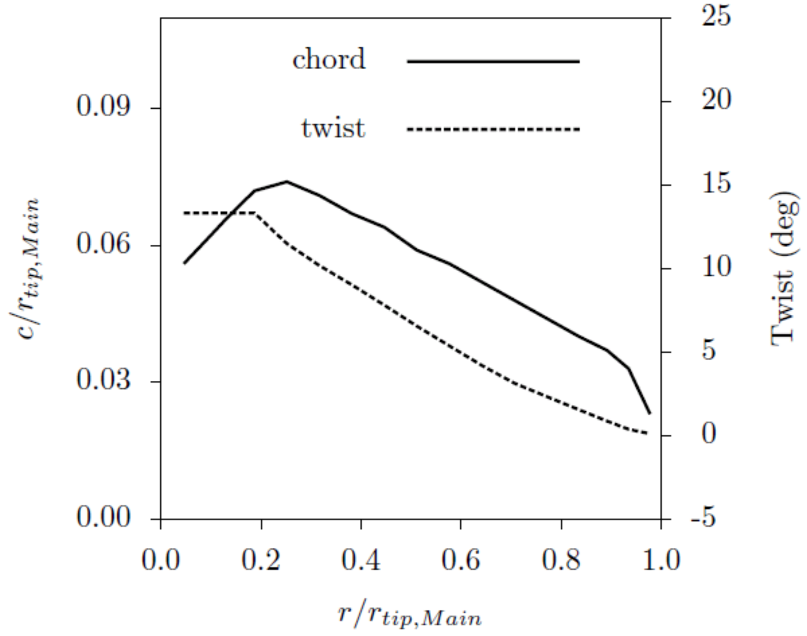


(a) C_T (b) C_P

DUAL ROTOR DESIGN

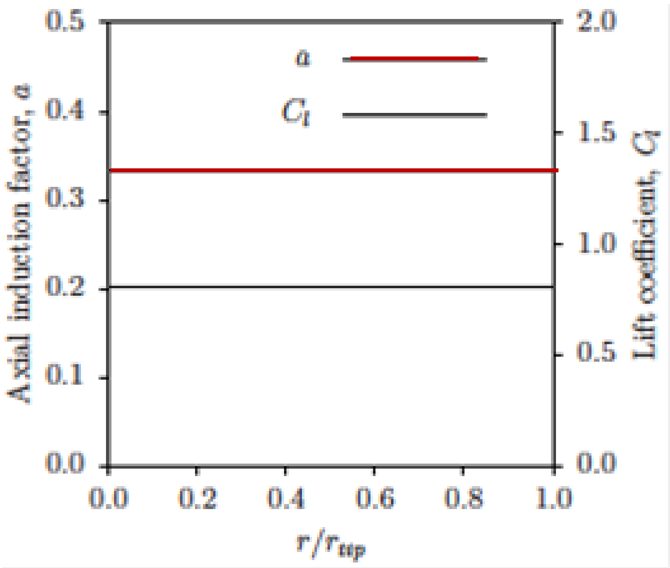
Primary Rotor Design – NREL 5 MW

- Not optimal
  - Transportation
  - Manufacturability
- Root designed to withstand loads
  - Aerodynamically inefficient
  - Negative torque

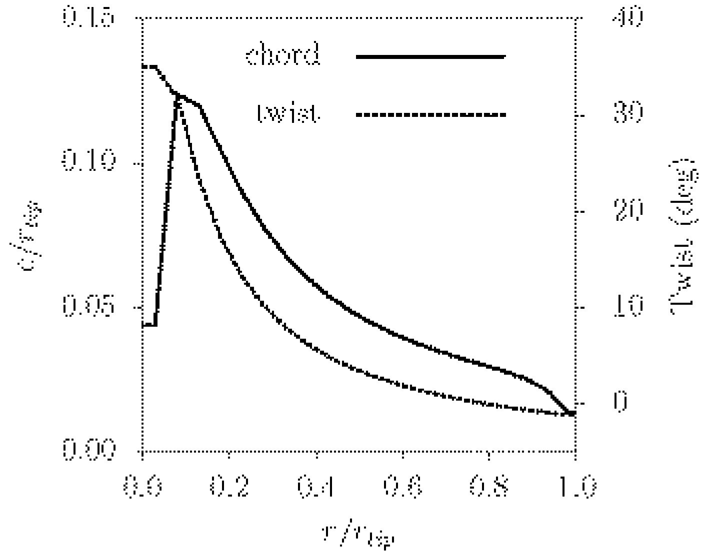


Secondary Rotor Design

Input: DU 96 Airfoil (Betz Optimum Rotor)



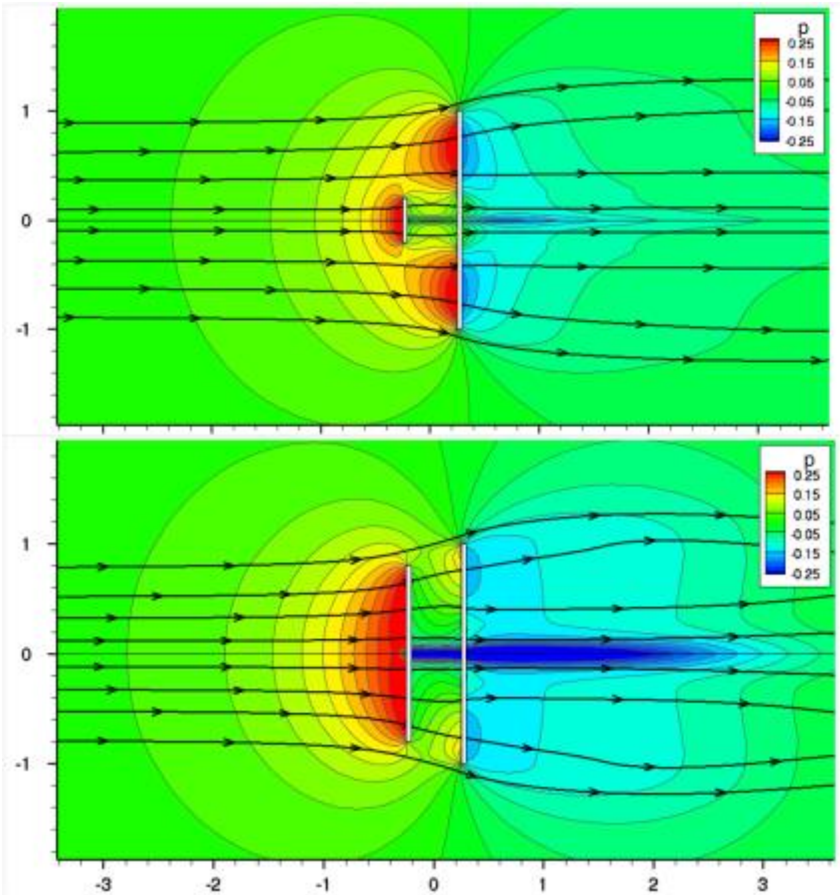
Output (Nearly Optimal)

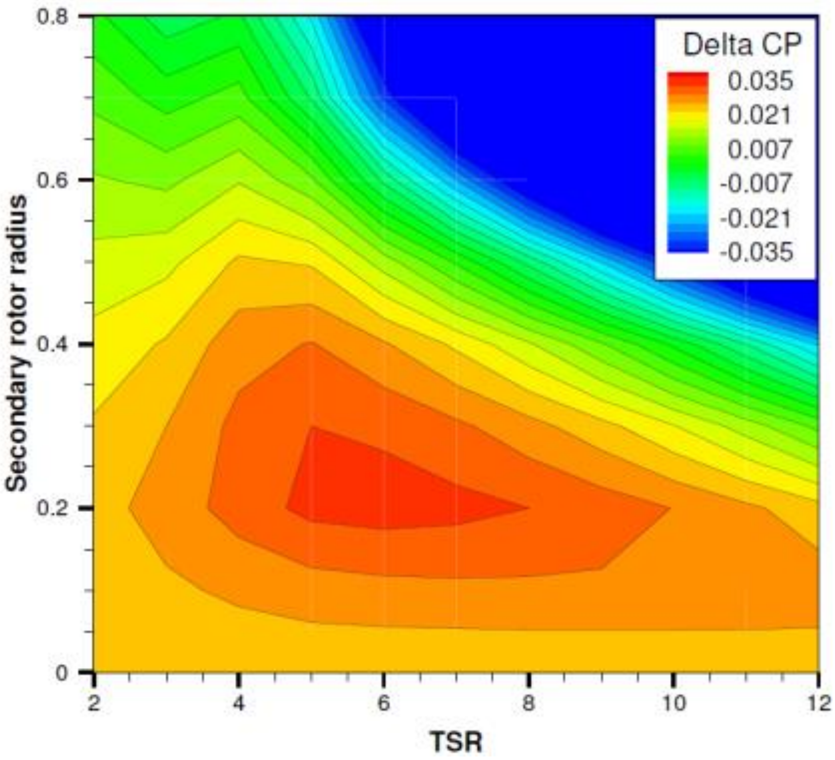


Optimization Study (RANS)

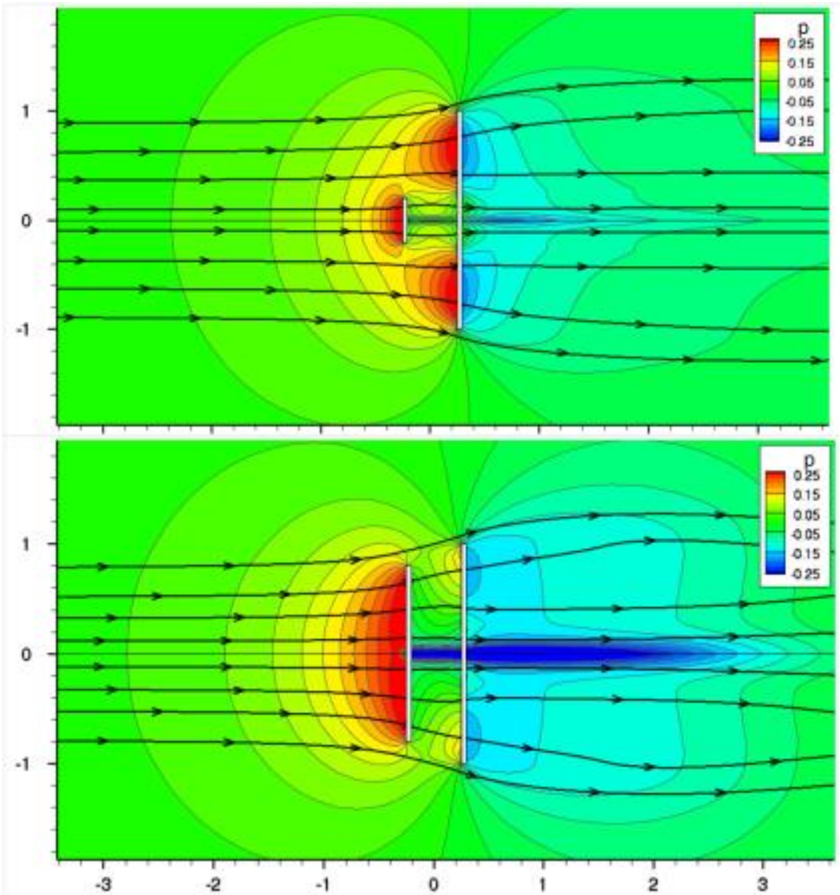
- Find optimal configuration
- Parametric study 1: Rotor Size
  - Vary secondary rotor size, tip speed ratio
  - Constant axial spacing ($\Delta x = 0.5R_{main}$)
- Parametric study 2: Axial Spacing
  - Vary secondary spacing, tip speed ratio
  - Constant rotor size $R_{secondary} = 0.3R_{main}$

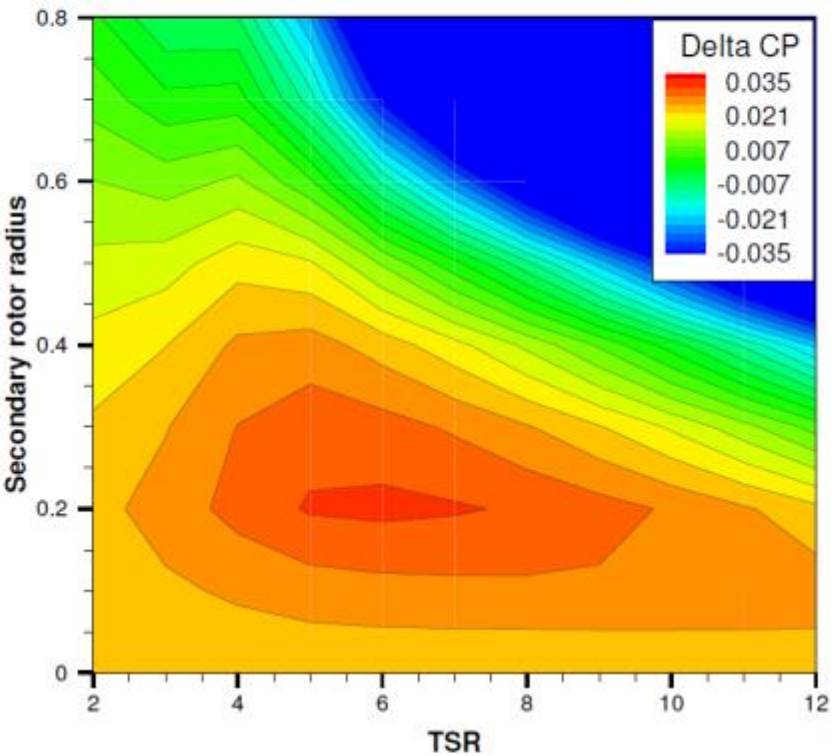
Rotor Size (Counter-Rotating)



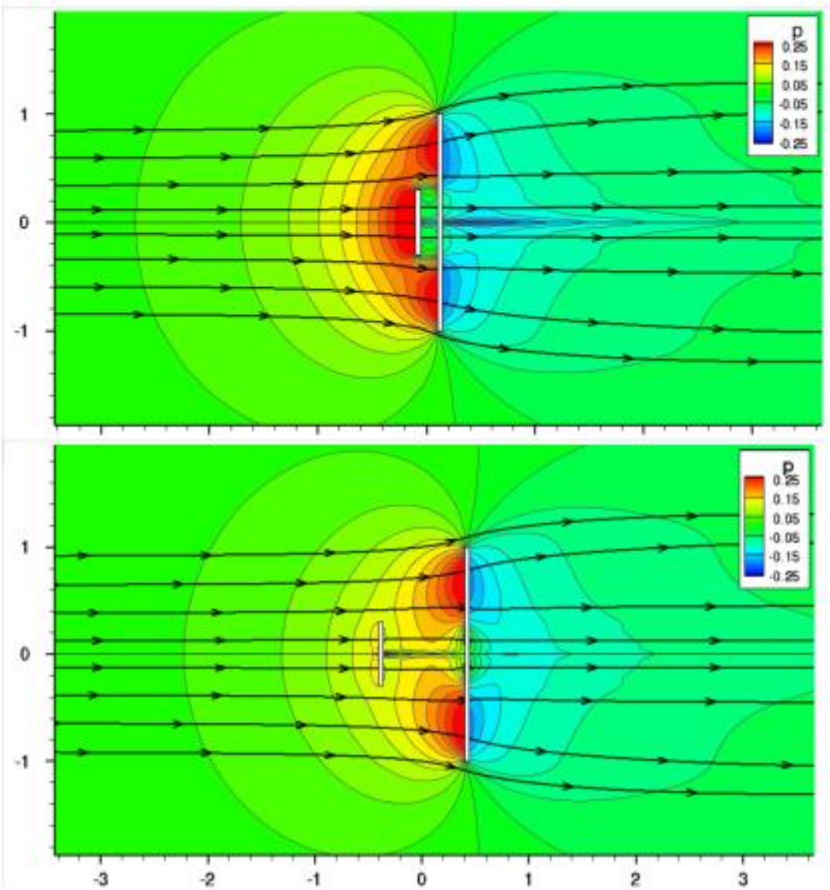


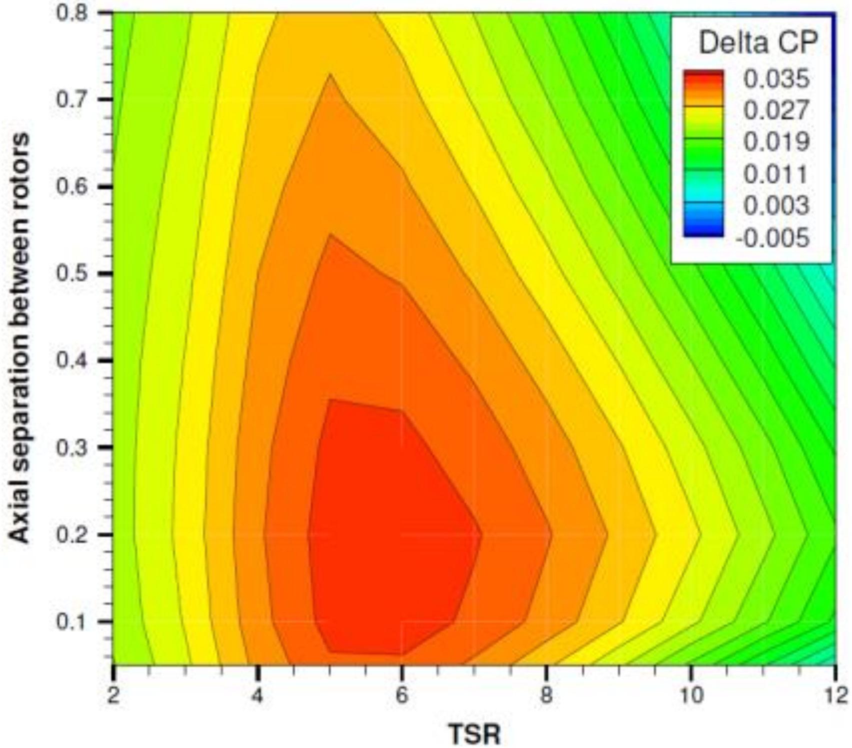
Rotor Size (Co-Rotating)



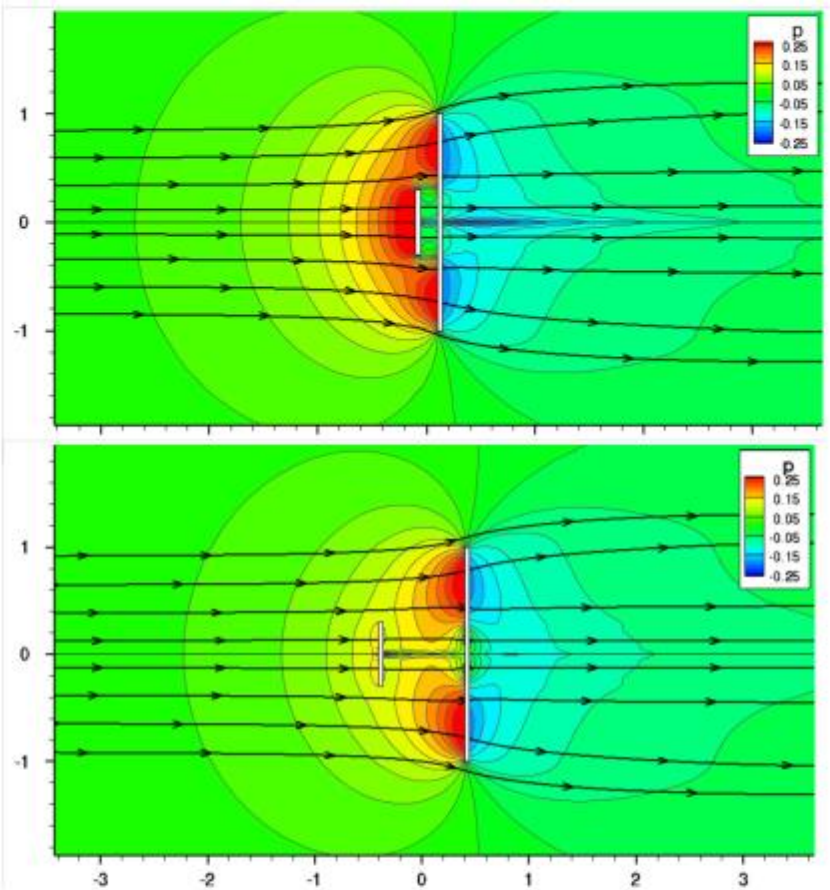


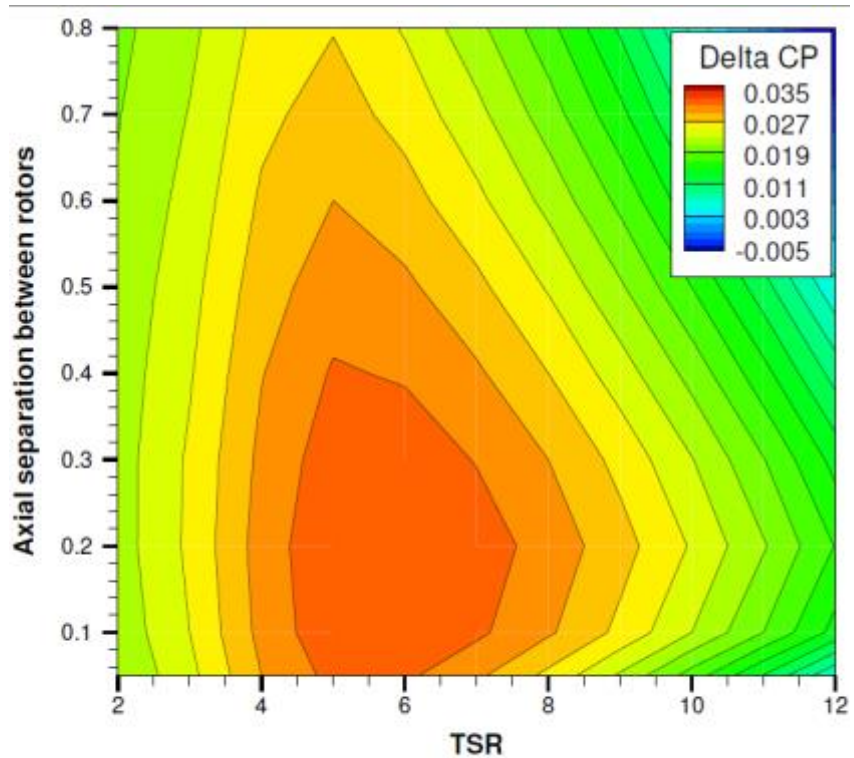
Rotor Spacing (Counter-Rotating)





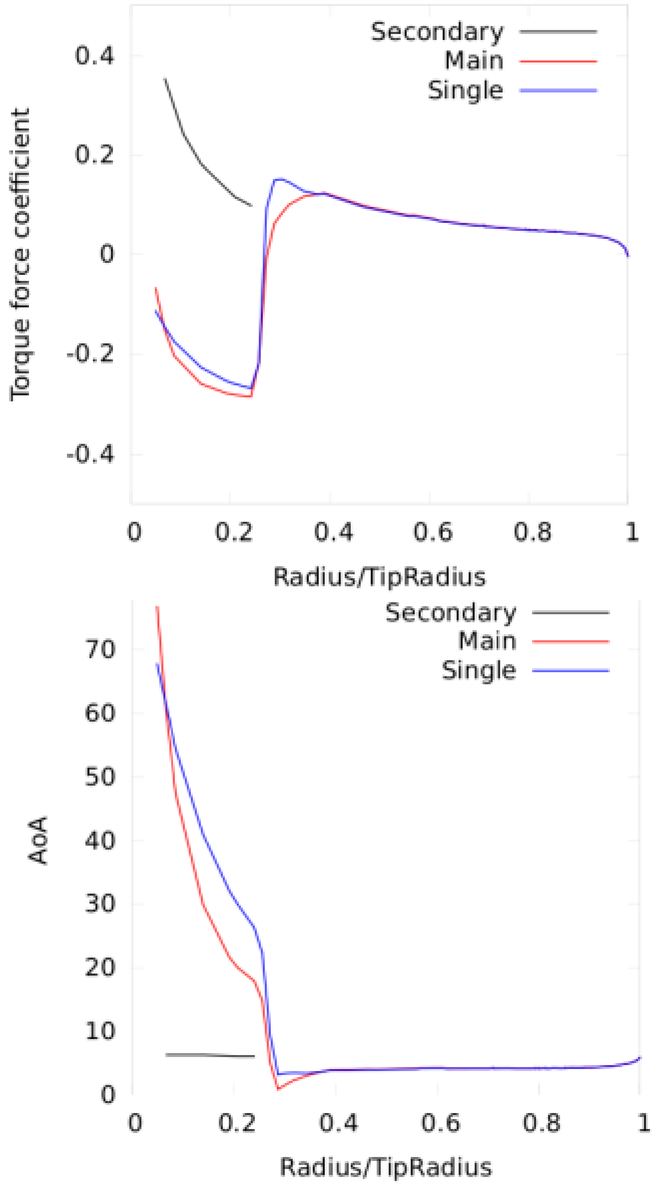
Rotor Spacing (Co-Rotating)





Optimization Study

- Optimal Spacing
  - $\Delta x \approx 0.2R_{main}$
- Optimal Size
  - $R_{secondary} \approx 0.3R_{main}$
- Torque captured by secondary rotor near root
  - Constant angle of attack
  - **7% Increase in Cp**



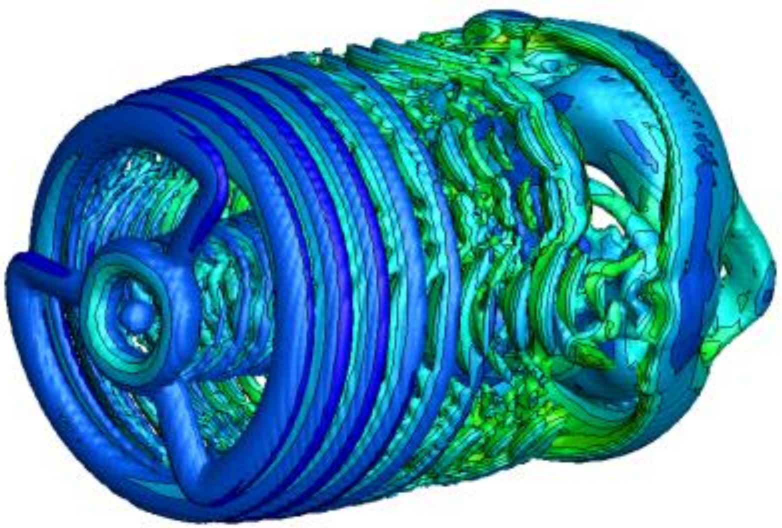
LARGE EDDY SIMULATIONS

Large Eddy Simulations

- SOWFA
- Stampede Super Computer
  - Texas Advanced Computing Center
  - 7^{th} Most Powerful Supercomputer in the world
- Computationally expensive simulations

LES DRWT Simulations

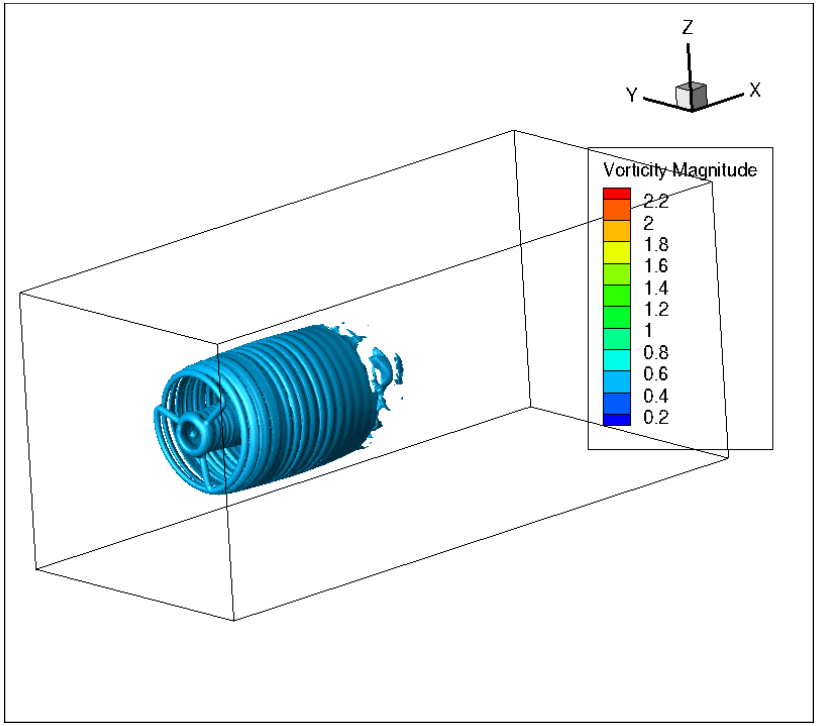
- Motivation
  - Visualize wake evolution
  - Analyze wake mixing
  - Unsteady features
- RANS optimized configuration
  - Co-rotating
- Compare with SRWT
- SOWFA
  - LES + Actuator Line

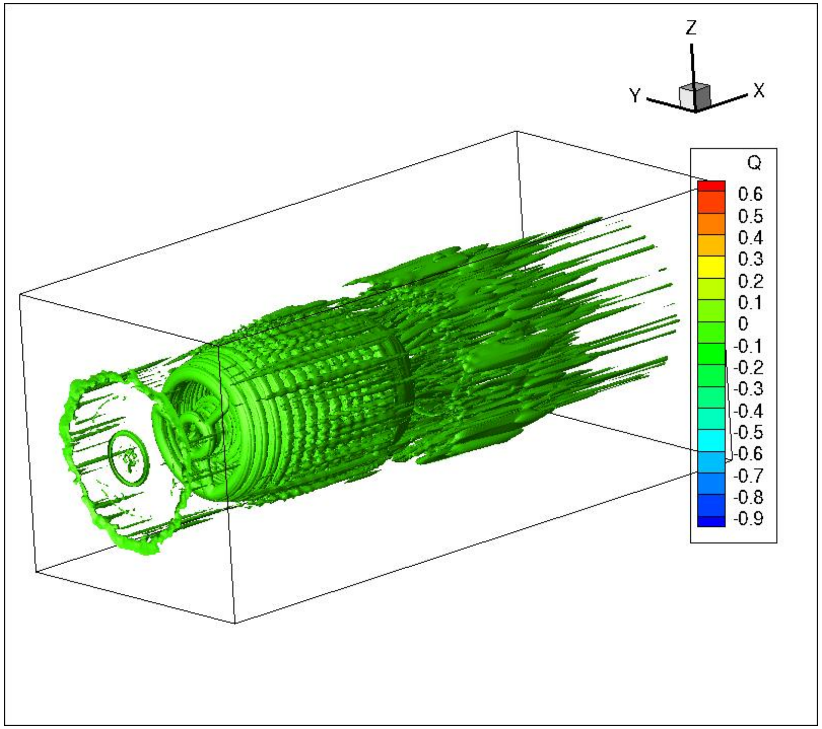


LES DRWT Simulations

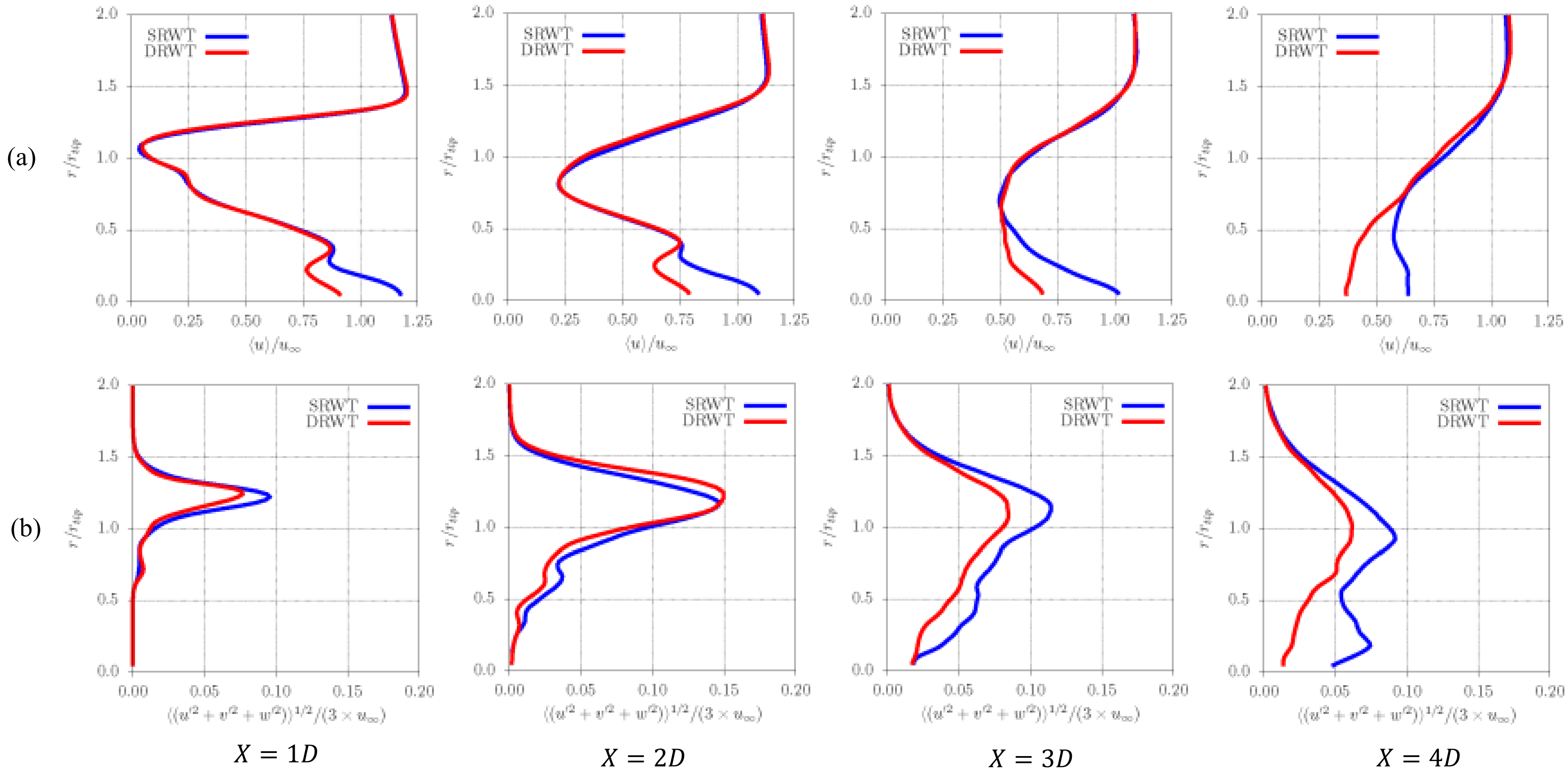
- 170 Seconds
  - Averaged from 150 to 170 seconds
  - Quasi-steady state
- $U_\infty = 8 \text{ m}/s$
- Periodic Boundary Conditions
  - Infinite array of turbines
- Nacelle and tower are not considered

LES DRWT Simulations





LES DRWT Results: Wake Evolution



Radial wake (a) and turbulence (b) variation comparisons between a single-rotor (SRWT) and a dual-rotor (DRWT) turbine at four downstream distances.

LES DRWT Conclusions

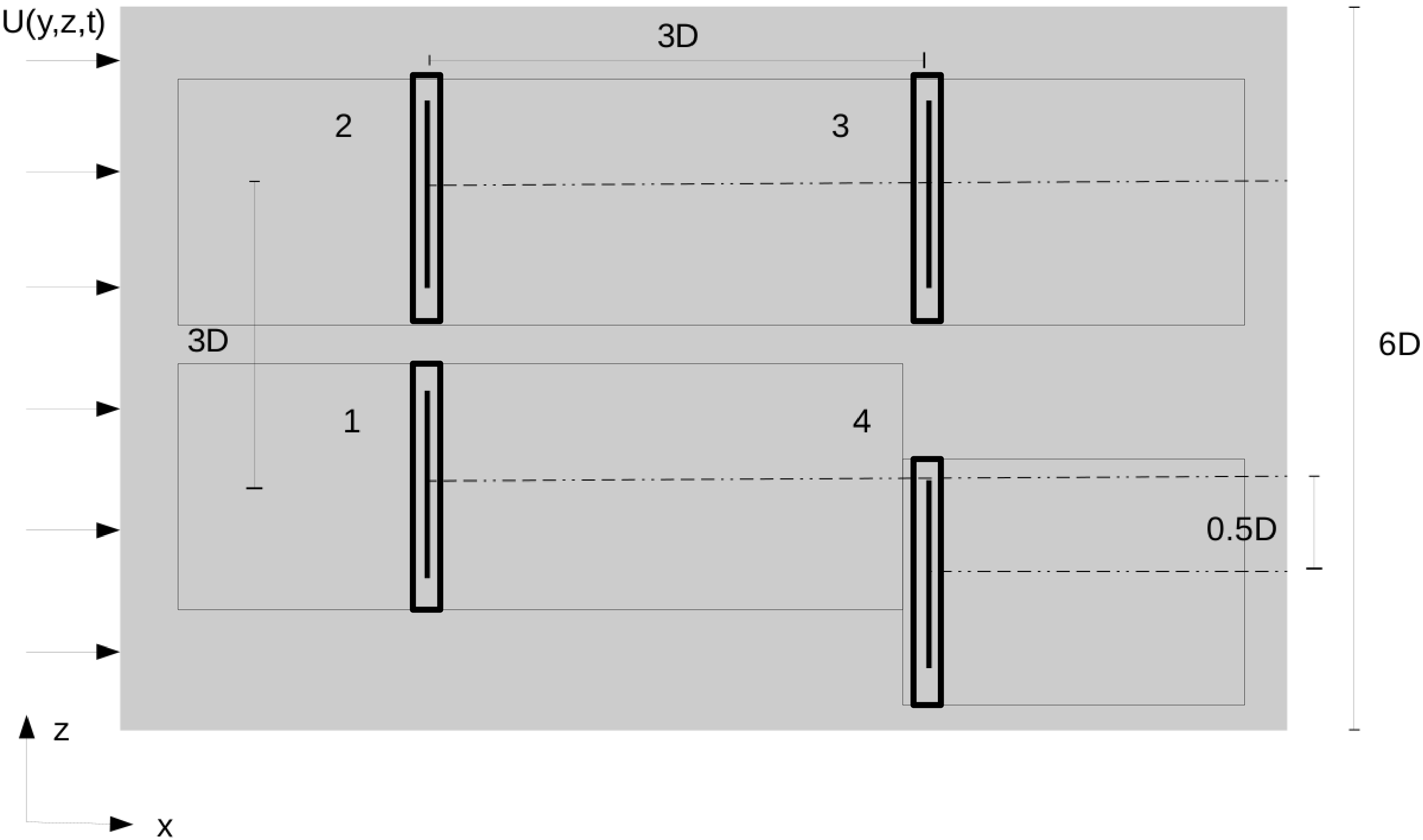
- Preliminary Results
  - Mixing is **NOT** enhanced
  - C_P increases by 6% (RANS: 7%)
    - Efficient extraction of energy in root region
- Future Research
  - Add turbines
  - Longer simulations
  - Different rotor configurations
  - Atmospheric Boundary Layer

FUTURE WORK

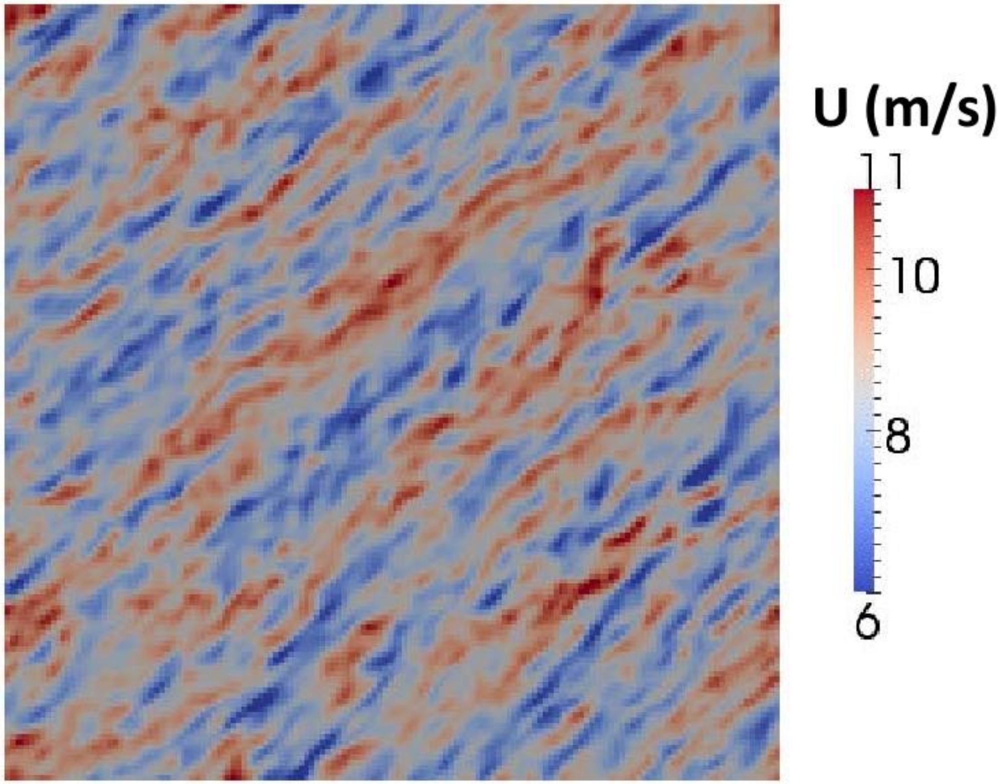
Wind Farm Simulation

- Investigate turbines in full/partial wake
- With and without turbulent ABL
  - PrecursorABL (SOWFA)
  - Does atmospheric turbulence show increased mixing?
- DRWT
  - Enhance mixing?
  - More energy capture?

Wind Farm Layout

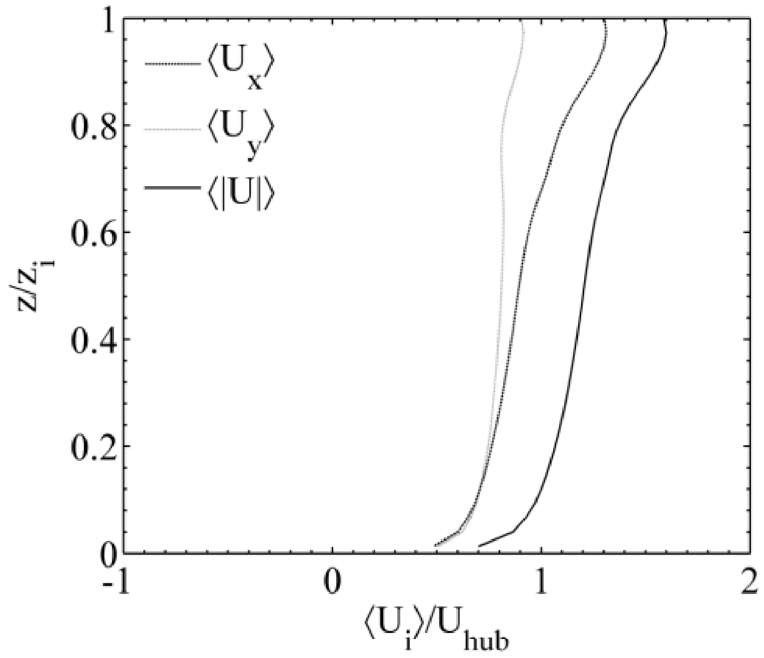


PrecursorABL

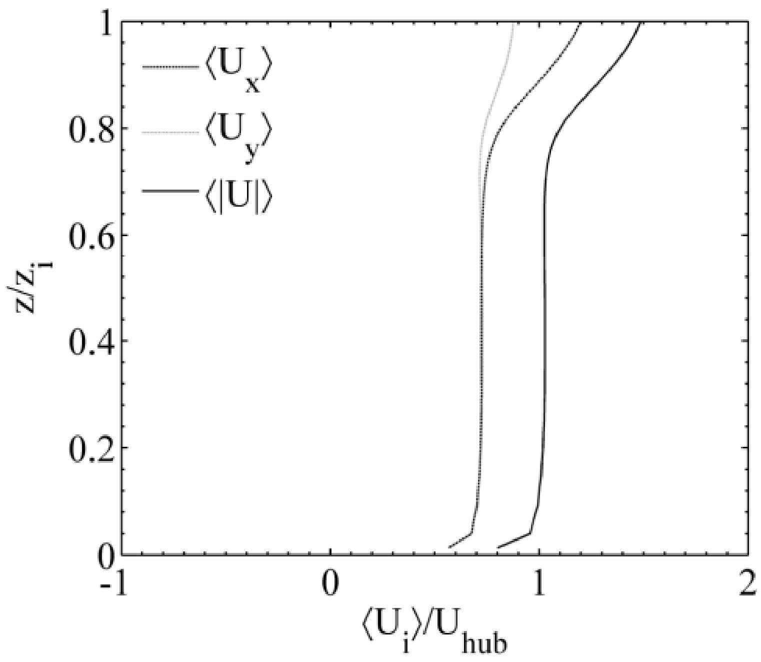


From NREL

PrecursorABL



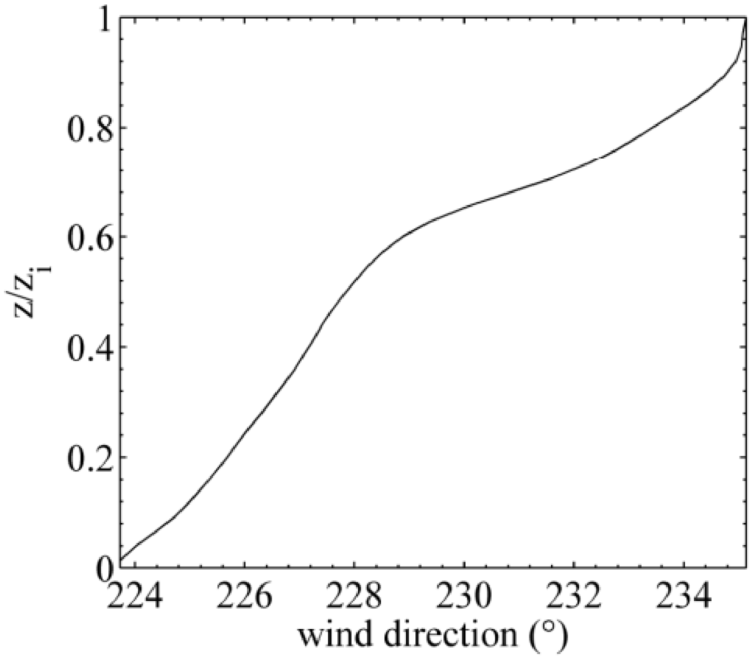
neutral



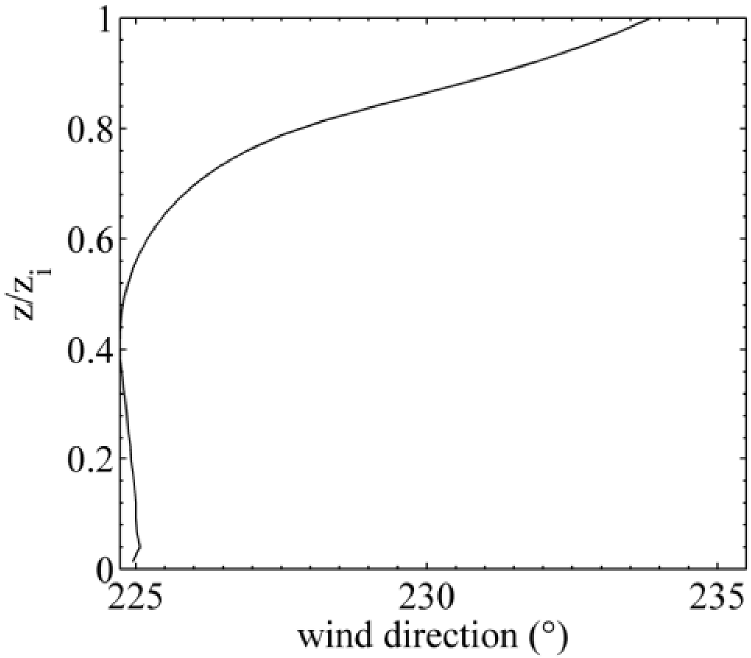
unstable

From NREL

PrecursorABL



neutral



unstable

From NREL

Acknowledgments

- Mentors: Dr. Anupam Sharma
- Suganthi Selvaraj
- Bharat Agrawal

QUESTIONS?