Large Eddy Simulations and Low-Order Models of Tethered Coaxial Turbines

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Background

Tethered coaxial, counter-rotating turbines offer the advantage of operating in zero-net torque mode to avoid tether twisting and entanglements. The optimization of single- and multiple coaxial devices for power generation requires insights into wake behavior and advances in low-order wake modeling.

Project Objectives

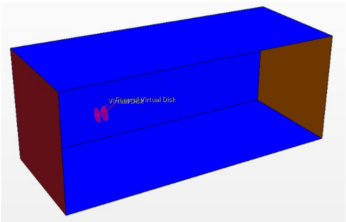
- To use Large Eddy Simulations to develop insights into the evolution of the wake from a tethered turbine across a range of operating conditions and inlet turbulence
- Develop a low-order model for power extraction and wake growth, for the above described conditions.

Challenges

- The counter-rotating operation of the rotor tandem in a coaxial turbine creates complex flow conditions in the wake, such as swirl, enhanced levels of turbulence etc.
- Tethered turbines will be deployed in OCT farms, therefore modeling tools must be capable of accurately describing wake interaction between individual units at reasonable computational cost

Our Approach

- We propose to characterize the wake of a fully-modelled coaxial turbine using a low-order model for an ***Equivalent Single Rotor (ESR)***



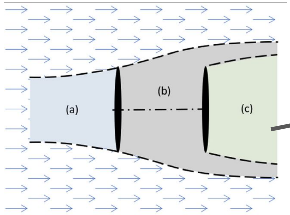
LES Parameters

D = 0.2 m
Length = 20D
Height = 8D
Width = 8D
U_{mean} = 1 m/s

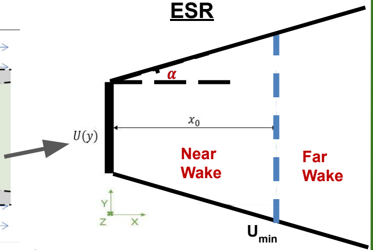
Distance Between Disks = 0.5D

An ESR is defined as an equivalent single rotor, defined by its induction factor, that extracts the same relative power from the mean flow as a dual-rotor coaxial turbine, while injecting the same amount of turbulence into the wake

Coaxial turbine [1]



ESR



Induction factor for ESR is found by requiring:

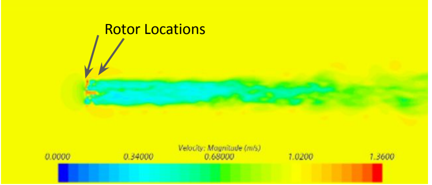
$$C_{P,ESR} = C_{P,W} + C_{P,L}$$

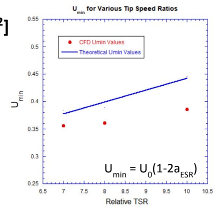
$$4a_{ESR}(1-a_{ESR})^2 = 4[(1-a_W)^2 + (1-a_L)^2(a_L-2a_W)^2]$$

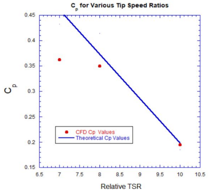
Solve for a_{ESR}

Validation

- ESR approach is validated from comparing the wake structure from LES of a coaxial turbine with results from simulation of a single rotor, but operating with an induction factor of the corresponding ESR, a_{ESR}



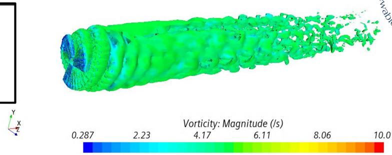


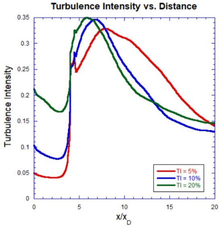


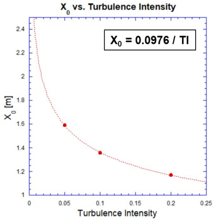
Peak turbulence

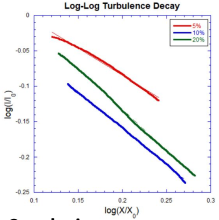
$$\sqrt{I_0^2 + I_m^2}$$

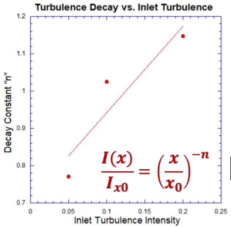
The vorticity generated in the wake varies with inlet and machine turbulence











Linear fit: n = 2.3218*TI + 0.70966

Turbulence Effects

- A coaxial turbine exposed to a higher inlet turbulence produces a higher maximum turbulence intensity (TI), leading to faster wake recovery
- This peak occurs sooner for higher inlet TI
- Our LES show turbulent decay rate also increases linearly with inlet TI
- Breakdown of vortex structures earlier for higher turbulence

Conclusions

- The LES results for coaxial turbines at varying inlet turbulence levels provide insight into the wake behavior resulting from the interaction between blades. We have developed a wake model based on an Equivalent Single Rotor, and validated model predictions (power prediction, wake growth rates) with results from Large Eddy Simulations.
- ESR model can be extended to capture wake interactions between multiple turbines in an OCT farm.

Acknowledgements

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References:

[1] R. Metoyer et al., Ocean Engineering, 215, 107877 (2020).