Development of Computational Fluid Dynamic model of a Vertical Axis Wind Turbine using the ALM approach

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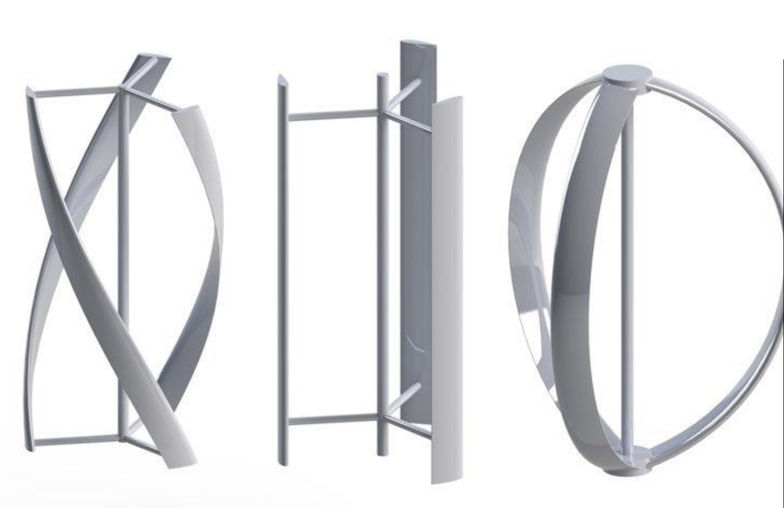
Introduction

Vertical Axis Wind Turbines (VAWTs) have recently gained continuously increasing attention due to their unique yet understated advantages over the more popular Horizontal Axis Wind Turbines (HAWTs) such as:

- VAWTs are capable to operate in a wide range of environmental condition.
- VAWTs are less sensitive to the wind direction due to the design and do not require complex yaw control.
- Most of the heavy power generation mechanisms and gearbox are placed directly on the ground hence, are easy to maintain.
- Most VAWTs are simplistic in terms of construction and transportation.

Wind farms consist of a large number of such turbines which create complex interactions between each VAWT and the wakes of the VAWTs upstream. Understanding this interaction is crucial for us to increase the productivity of energy through such farms. Moreover, recent research has peeked interest in adding VAWTs to existing HAWT wind farms to boost their power generation.

Computational Fluid Dynamic Models of a VAWT can simulate the complex interactions between the VAWT and wakes from upstream VAWTs as well as blade forces experienced by the turbines. This process is a lot more economical as well as time efficient.



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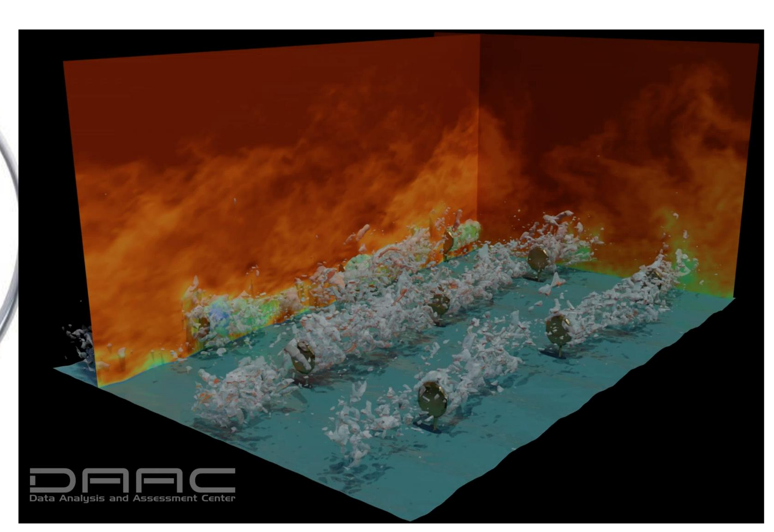
Types of VAWTs



Sample result of an LES model for wind farm with HAWT

Objectives

- The primary objective of this SURF research project is to simulate the wake dynamics of a Vertical Axis Wind Turbine using Computational Fluid Dynamics (CFD)
- Actuator Line Method was selected to develop a CFD model of the turbines
- Implement the ALM model into a large-eddy simulation (LES) flow solver developed by Dr. Yang's group.

Method of Computation

Large Eddy Simulation (LES) is used to solve a filtered Navier – Stokes equation to model the turbulent flow. Key features of Dr. Yang's LES solver include:

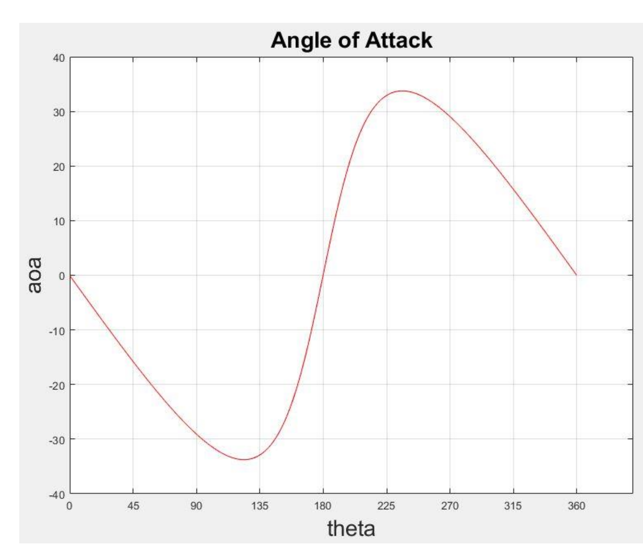
- Terrain following moving grid
- A coupled high-order wave simulator for offshore conditions
- Advanced Lagrange-averaged scale-dependent dynamic model for subgrid-scale turbulent effects

$$\nabla \cdot \tilde{\mathbf{u}} = 0, \qquad \frac{\partial \tilde{\mathbf{u}}}{\partial t} + \tilde{\mathbf{u}} \cdot \nabla \tilde{\mathbf{u}} = -\frac{1}{\rho} \nabla \tilde{p} + \nabla \cdot \left(\nu_t \tilde{\mathbf{S}} \right) + \frac{\mathbf{f}_t}{\rho}$$

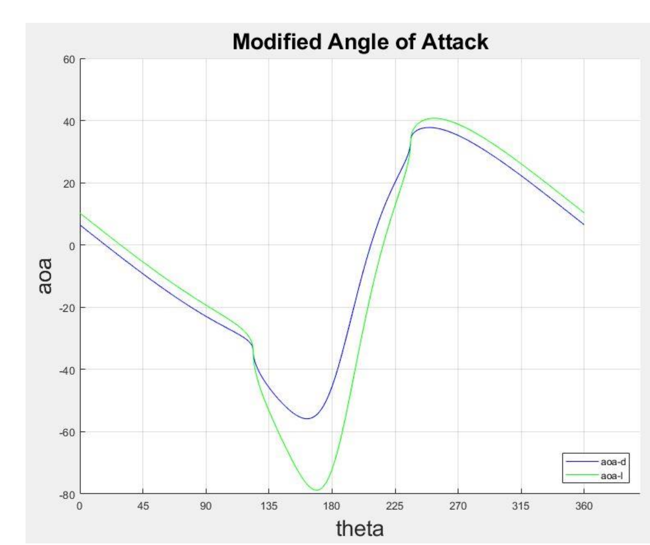
Relevant Navier – Stokes equation

Results

The Angle of Attack for each blade, as it traverses through the Windstream, was calculated and can be seen below. This was then used to get modified angle of attack produced as a result of dynamic stall.

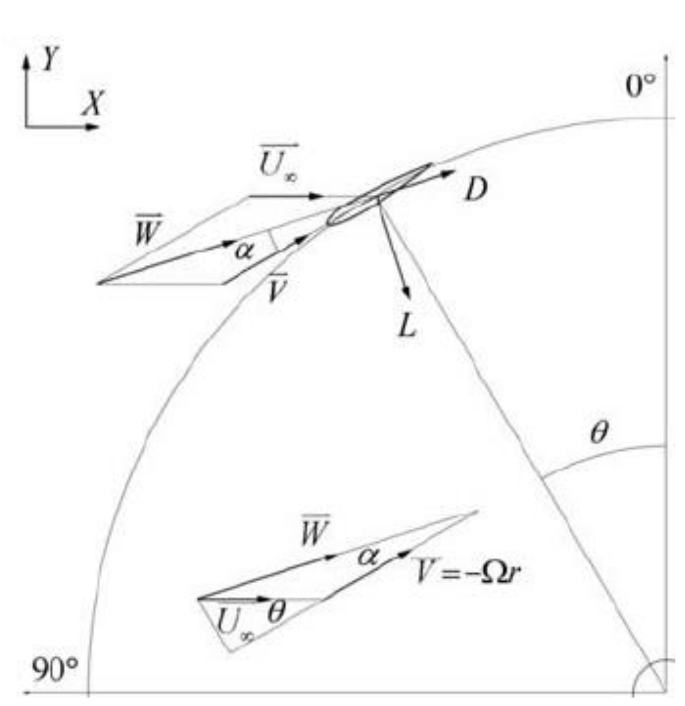


Angle of Attack vs the Angle traversed

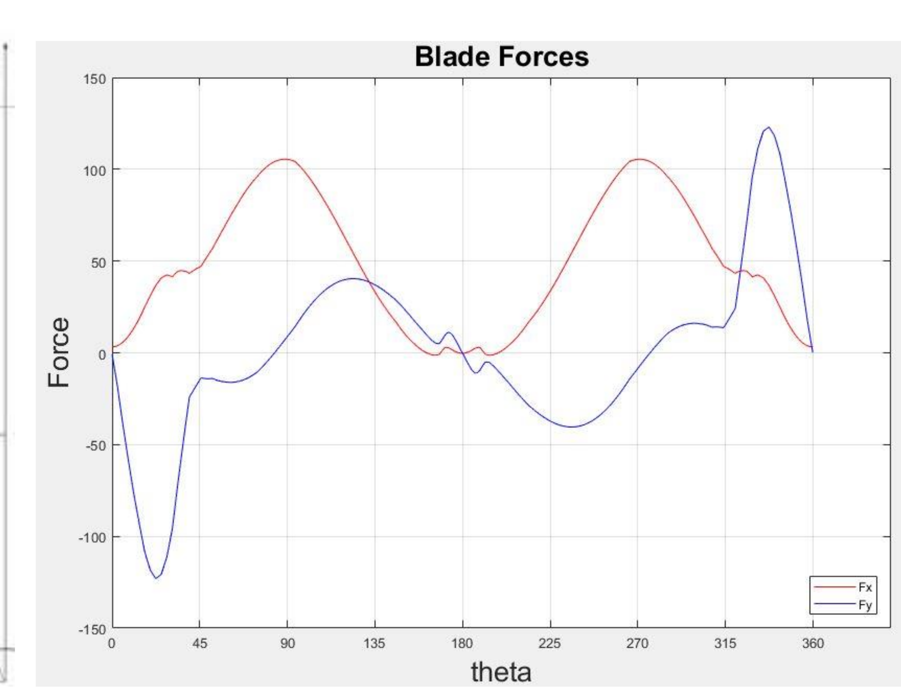


Modified Angle of Attack vs the Angle traversed

The angle of attack was then used to compute Lift and Drag forces. These forces were then manipulated to evaluate horizontal and vertical components. These components are required as input for the LES Solver.



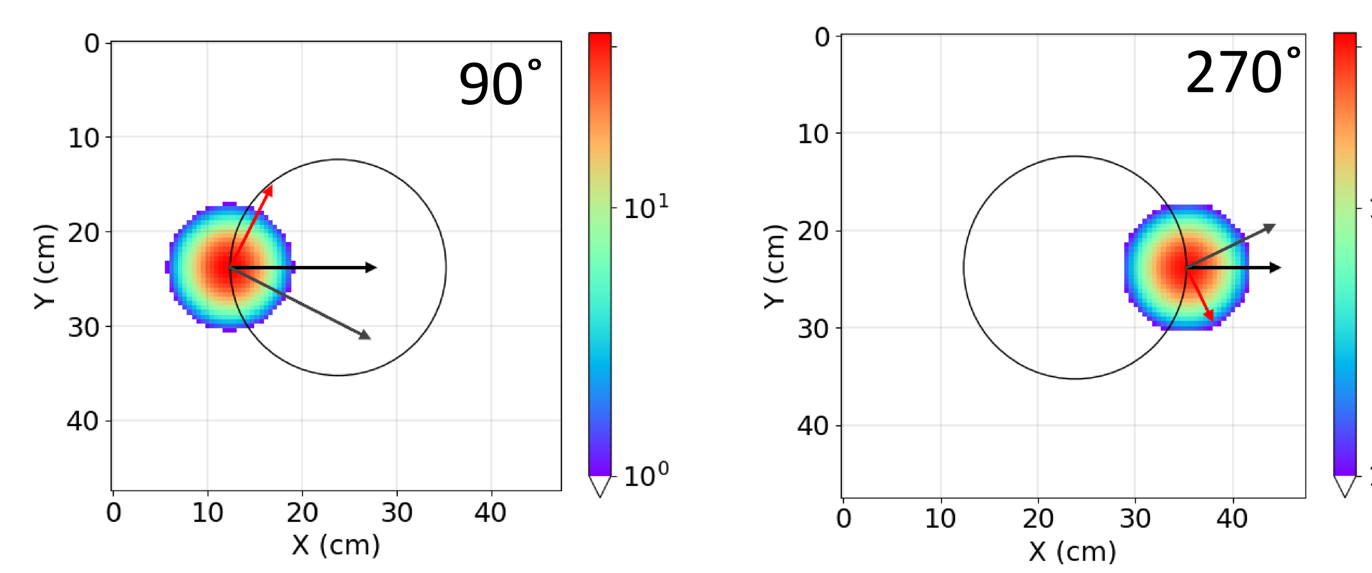
Orientation of Lift and Drag forces



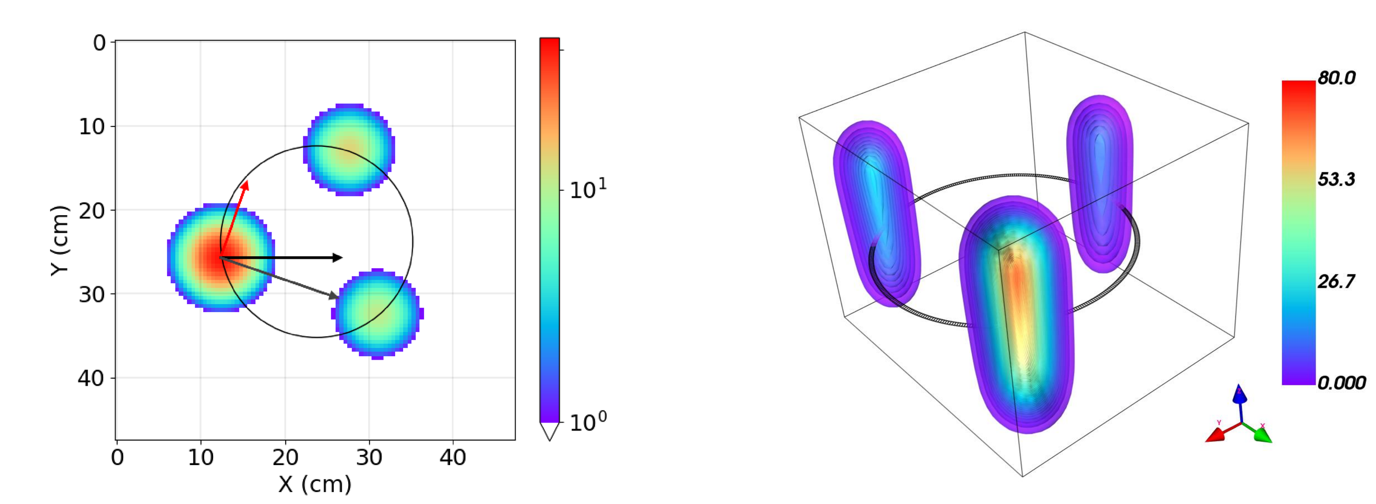
Horizontal and Vertical components of blade force

ALM Method

ALM model was developed which computes the total force using a blade-element model and distributed the force to LES grids using a Gaussian function.



Gaussian Distribution of the forces



2D and 3D Gaussian Distribution of 3 blades

Future Work

Next step involves implementing this ALM model into the LES flow solver to evaluate wakes of the turbine. This will need more information as well as validation from the wind tunnel. Wind tunnel can be used to experiment a small prototype model of the turbine in similar environmental conditions. This will lead to the development of a complete model of a VAWT which can evaluate wakes for multiples VAWTs in a wind farm.

References

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