Drag Force on a Vertical Axis Wind Turbine with Airfoil Pitch Control

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VAWT and HAWT

Vertical Axis Wind Turbine (VAWT)

Horizontal Axis Wind Turbine (HAWT)

VAWT vs. HAWT

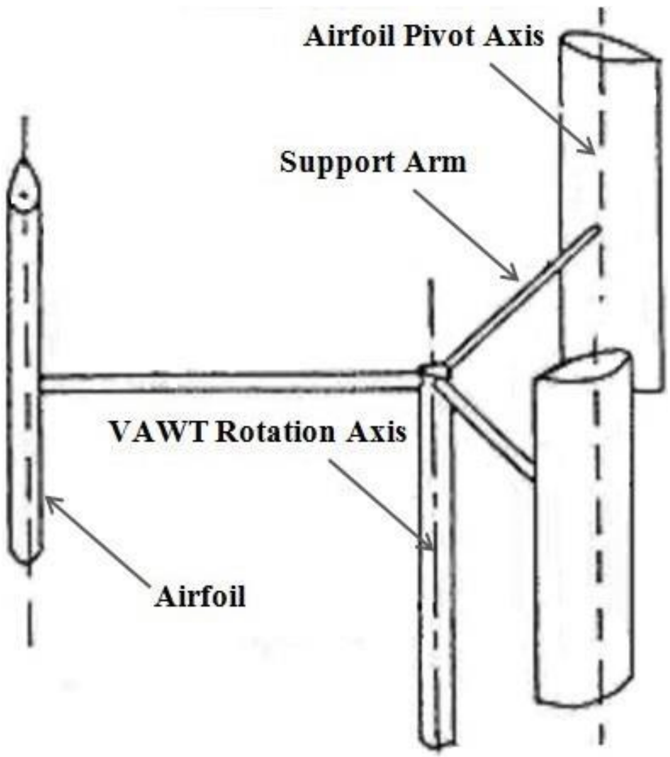
Advantages:

- *Easier to install and maintain*
- *No need to point into the wind*
- *Low risk for human and birds*
- *Can be install in urban area*
- *Easy to scale up and down*

Disadvantages:

- *Stall*
- *Low efficiency*
- *Aerodynamic stability*
- *Pulsatory torque*

VAWT with Pitch Control



Airfoils pivot around the vertical axes parallel to the central rotation axis

COMSOL Model

Low Speed Laminar Flow

Navier - Stokes Equations:

Conservation of mass:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \boldsymbol{u}) = 0$$

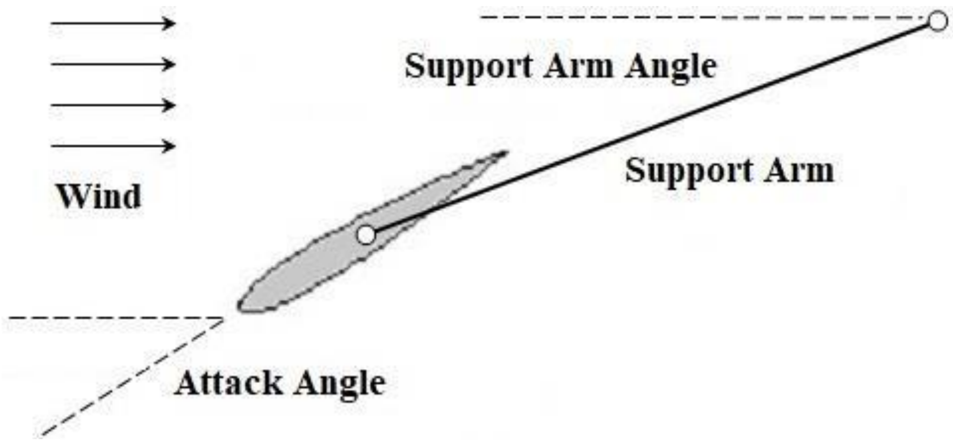
Conservation of momentum:

$$\rho \frac{\partial \boldsymbol{u}}{\partial t} + \rho(\boldsymbol{u} \cdot \nabla)\boldsymbol{u} = \nabla \cdot [-p\boldsymbol{I} + \tau] + \boldsymbol{F}$$

Conservation of energy in the form of temperature:

$$\rho \boldsymbol{C}_p \left(\frac{\partial T}{\partial t} + (\boldsymbol{u} \cdot \nabla)T \right)$$
$$= -(\nabla \cdot q) + \boldsymbol{\tau}{:}\, \boldsymbol{S} - \frac{T}{\rho} \frac{\partial \rho}{\partial T}\bigg|_p \left(\frac{\partial p}{\partial t} + (\boldsymbol{u} \cdot \nabla)p \right) + Q$$

Definitions of Concepts



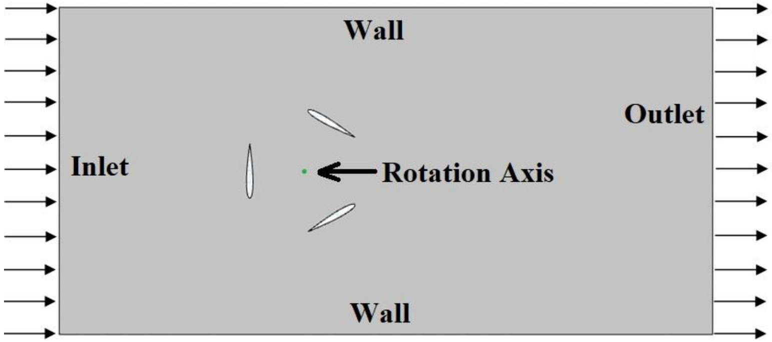
- ***Wind Attack Angle****: angle between wind and camber line of the airfoil*
- ***Support Arm Angle****: angle between wind and airfoil support arm*
- ***Drag on the VAWT****: force acting on the central rotation axis within the along the wind flow direction*
- ***Lift on the VAWT****: force acting on the central rotation axis perpendicular to the wind flow direction*

Drag and Lift Forces

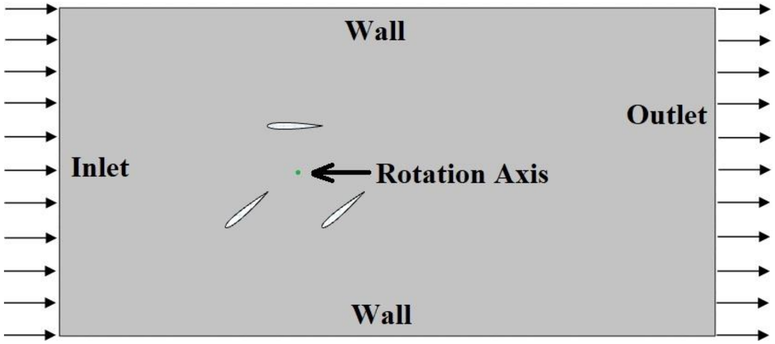
The lift and drag forces are obtained by integrating the total stress components ***spf.T_stressx*** *and* ***spf.T_****stressy along the air foil surfaces.*

The pressure and viscous force components are also calculated separately by integrating the pressure components ***p*spf.nxmesh*** *and* ***p*spf.nymesh*** *and viscous force components –****spf.K_stressx*** *and –****spf.K_stressy****.*

COMSOL CFD Model

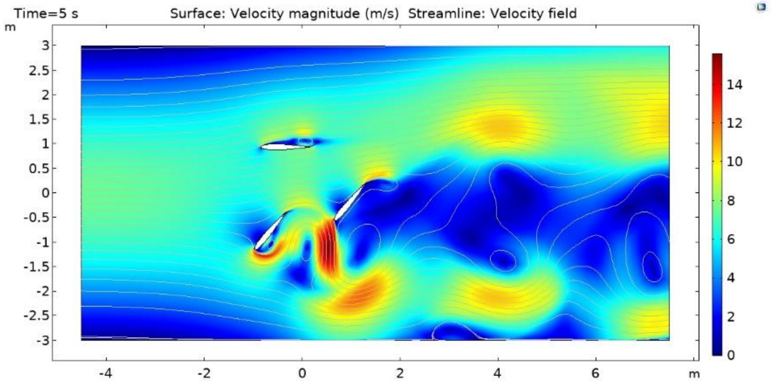


VAWT model with fixed airfoils

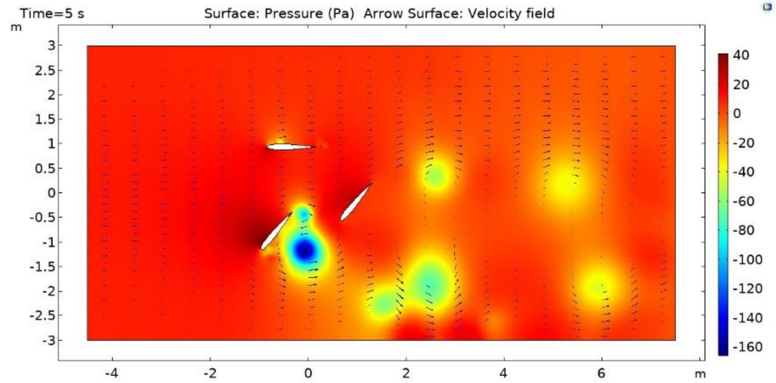


VAWT model with pitch controls

Sample Velocity & Pressure Fields

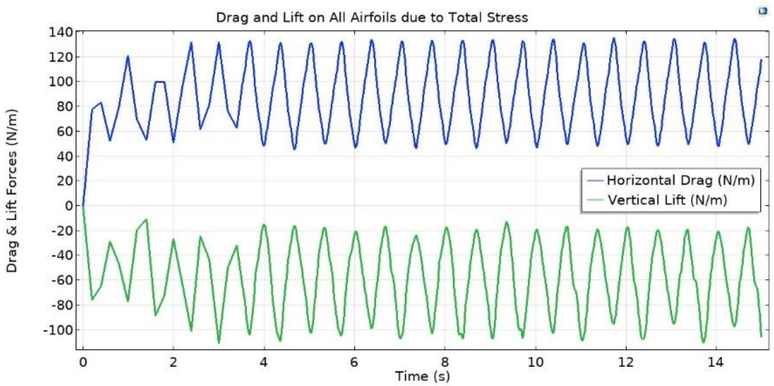


Velocity field for 50^0 support arm and wind attack angles

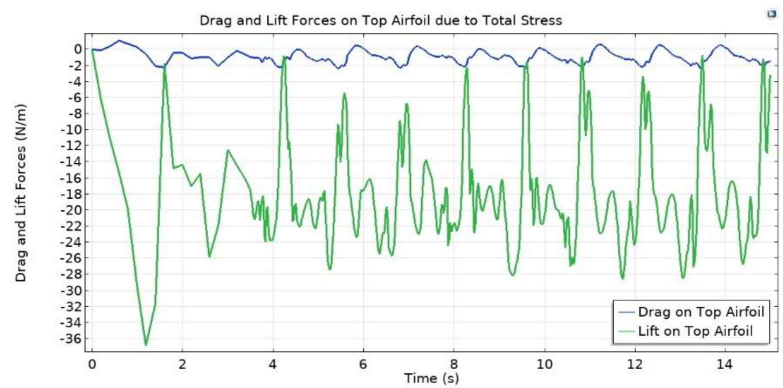


Pressure field for 50^0 support arm and wind attack angles

Sample Drag and Lift



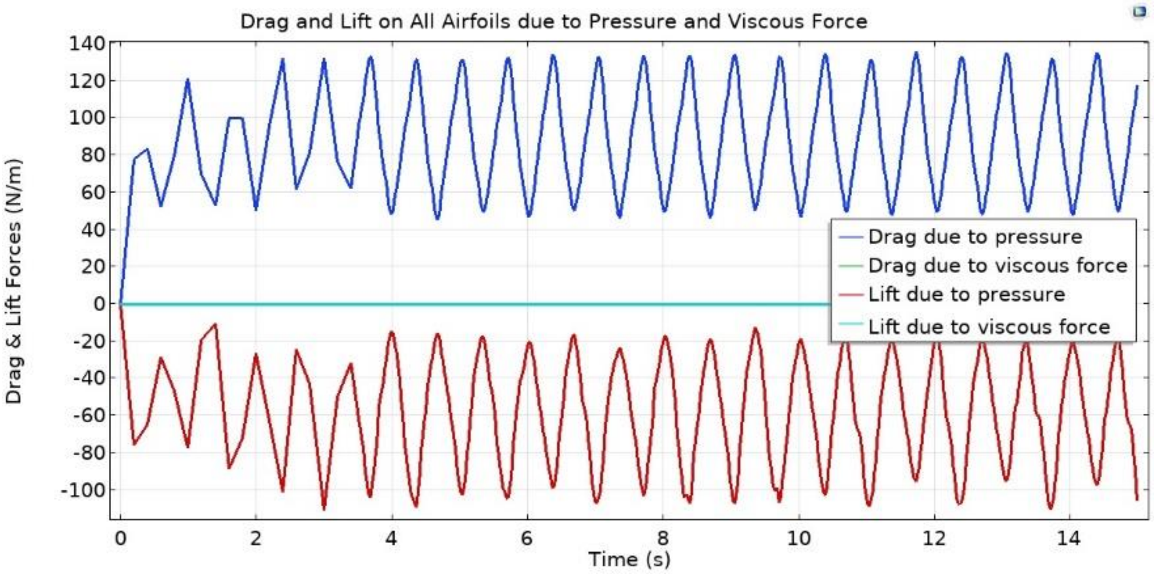
Drag and lift forces for 50^0 support arm and wind attack angles



Drag and lift forces for -70^0 support arm and 0^0 wind attack angles

- *Both drag and lift forces reach a steady pattern*
- *Drag force is positive indicating that it is acting along the wind flow direction*
- *Lift force is negative indicating that it is pushing the VAWT downward*
- *Drag force for 0^0 wind attack angle is zero with a none zero lift force*

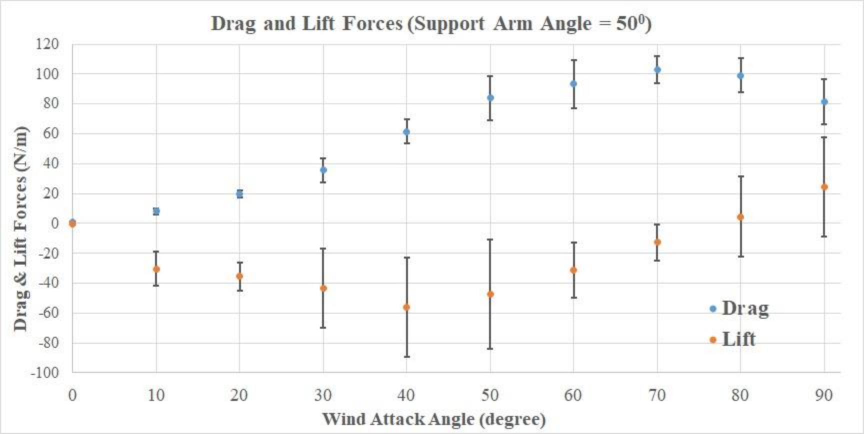
Pressure & Viscous Force Contribution



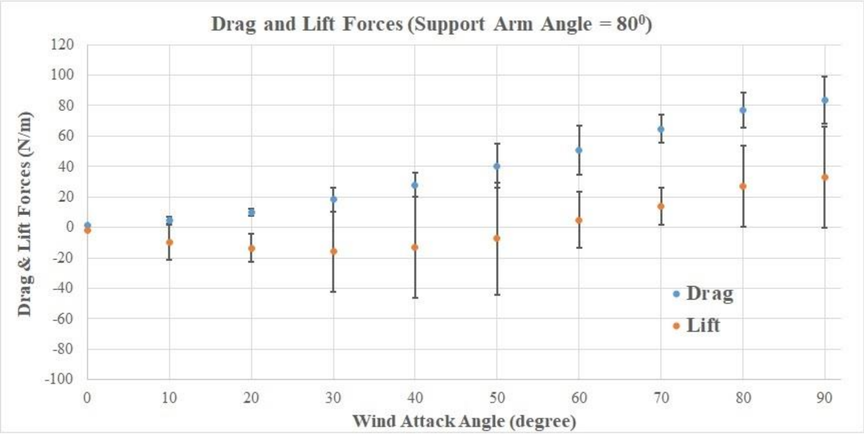
Drag and lift forces for 50^0 support arm and wind attack angles due to pressure and viscous force separately

- *Contribution of viscous force is so small that it can be neglected*

Effects of Wind Attack Angle



Effects of wind attack angle on drag and lift forces for 50^0 support arm angle



Effects of wind attack angle on drag and lift forces for 80^0 support arm angle

- *Lift force initially drops into negative ranges and then rise to positive value*
- *Drag force rises and then drops for small support arm angles (<70^0) and continuously increases for larger support arm angles (>80^0)*
- *Drag force is always positive*

Conclusions

- *Both drag and lift forces show dependency on support arm and wind attack angles*
- *Drag force is always positive indicating a persistent force acting on the main rotation axis along the wind flow direction*
- *Lift force changes from an initially negative value to a positive one as the wind attack angle increases for all given support arm angles*
- *Magnitudes of both drag and lift forces depends on the combinations of support arm and wind attack angles*

Future Work

- *This study is based on laminar flow for low wind speed. Simulation based on turbulent flow is necessary for high wind speed*
- *Since the simulation is 2-D based, the effects of airfoil edge need to be considered using 3-D models and simulations*

Questions?