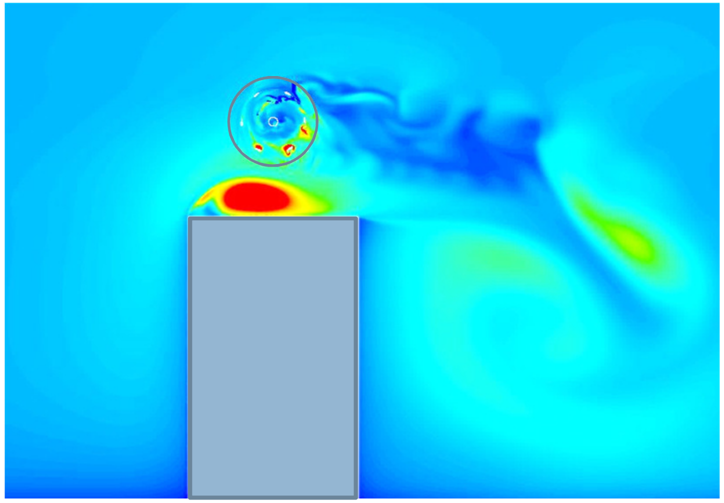
The effect of the upstream wind conditions on the performance of a vertical axis wind turbine (VAWT)



Dr. Ava Shahrokhi
Prof. Lin Ma
Prof. Derek Ingham
Prof. Mohamed Pourkashanian
Mr. Ioannis Bouras

Content

Characteristics of a VAWT

Advantages

- ✓ Omni directional
- ✓ Heavy mechanisms can be located at ground level
- ✓ Less visually intrusive
- ✓ Generally quieter than HAWTs
- ✓ Suitable for urban and rural regions

Disadvantages

- × Lower efficiencies
- × Not typically self-starting
- × Torque variation can instigate vibration problems

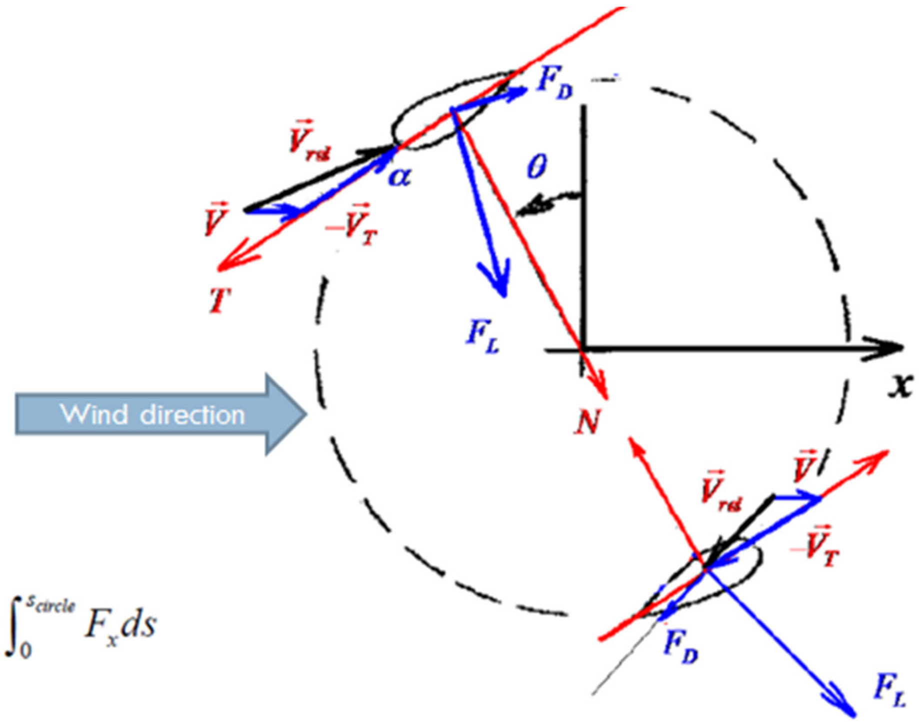
Aerodynamic principal of a Darrieus VAWT

Tip speed ratio $\lambda = \frac{V_T}{V_\infty}$

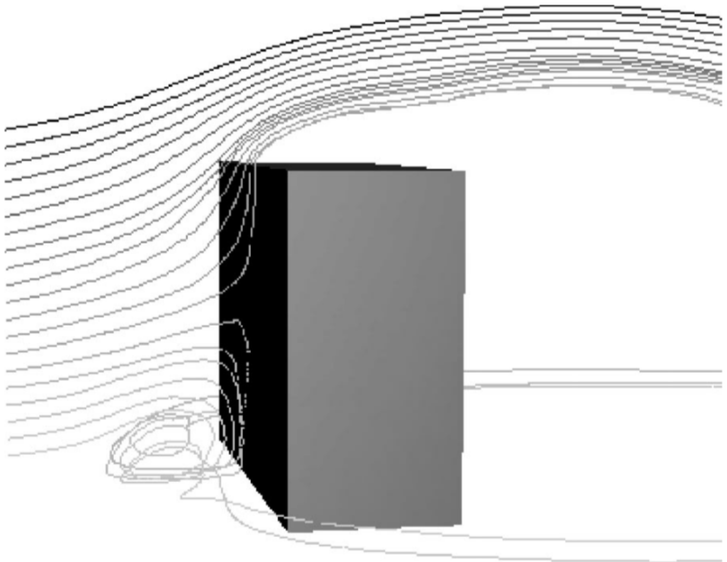
Average tangential force $\overline{F}_T = B\frac{1}{2\pi}\int_0^{2\pi} F_T d\theta$

Power coefficient $C_P = \frac{\overline{F}_T R\omega}{\frac{1}{2}\rho A V_\infty^3}$

Thrust coefficient $C_{thurst} = \frac{\overline{F}_x}{\frac{1}{2}\rho A V_\infty^2}$ $\overline{F}_x = \frac{B}{S_{circle}}\int_0^{S_{circle}} F_x ds$



VAWTs in the Urban Environment



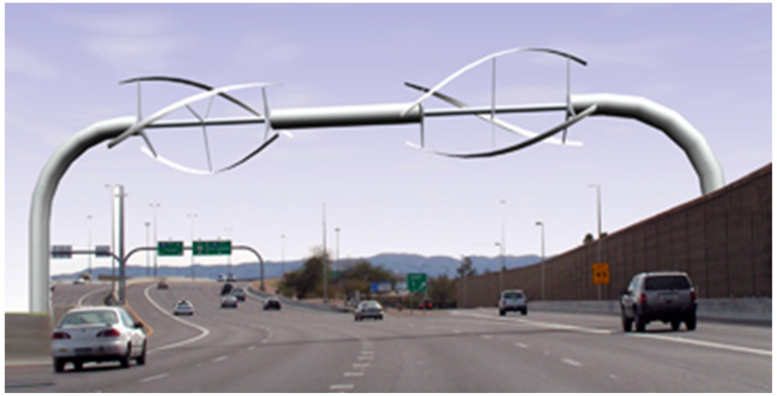
Aims and Objectives

The majority of the VAWT simulations include solely the turbine, whereas in practice inflow conditions are influenced by the surrounding environment.

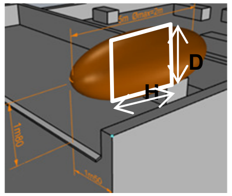
The current presentation aims to:

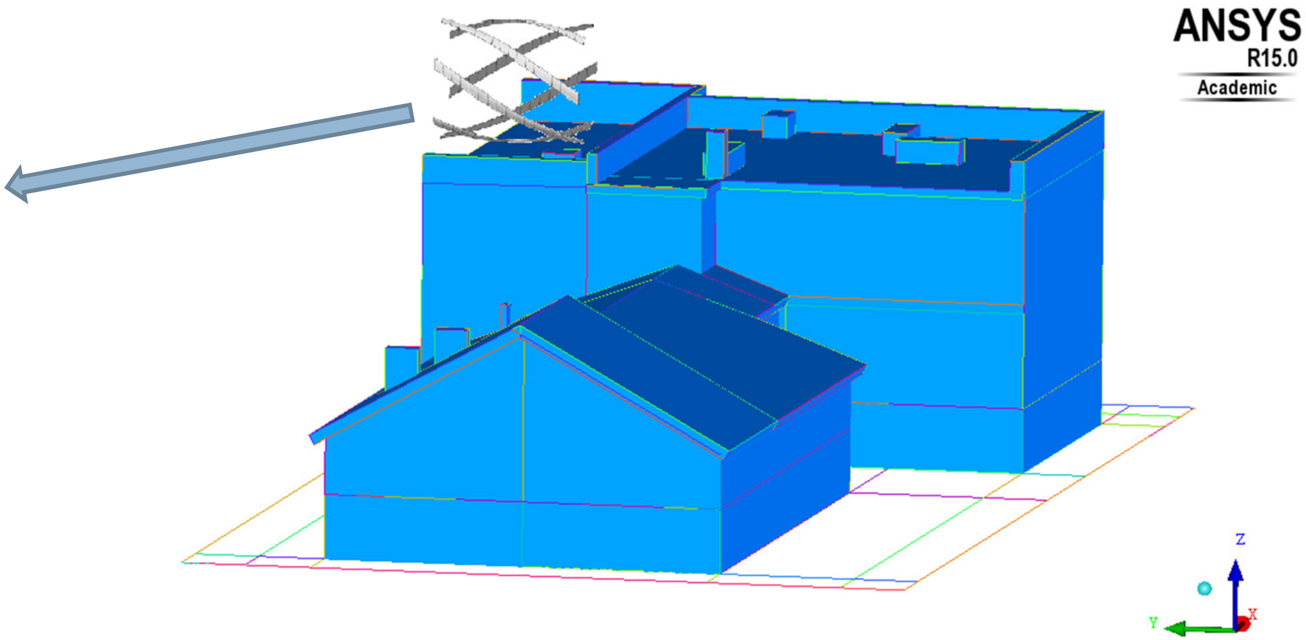
- Investigate the effect of the presence of a building where the turbine is installed.
- Examine the effects of the ground roughness.

All of the simulations are performed using Computational Fluid Dynamics.



Problem Specifications



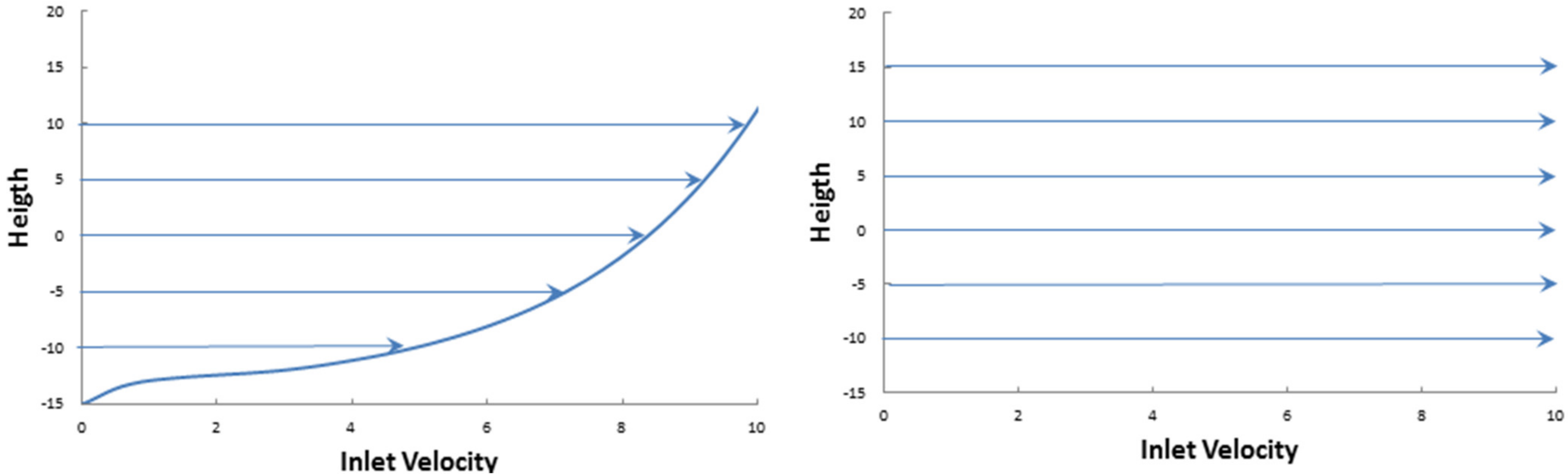


Turbine Specifications	
Airfoil profile	DU 06-W-200
Number of blades	6
Radius	1m
Swept Area	4 m^2

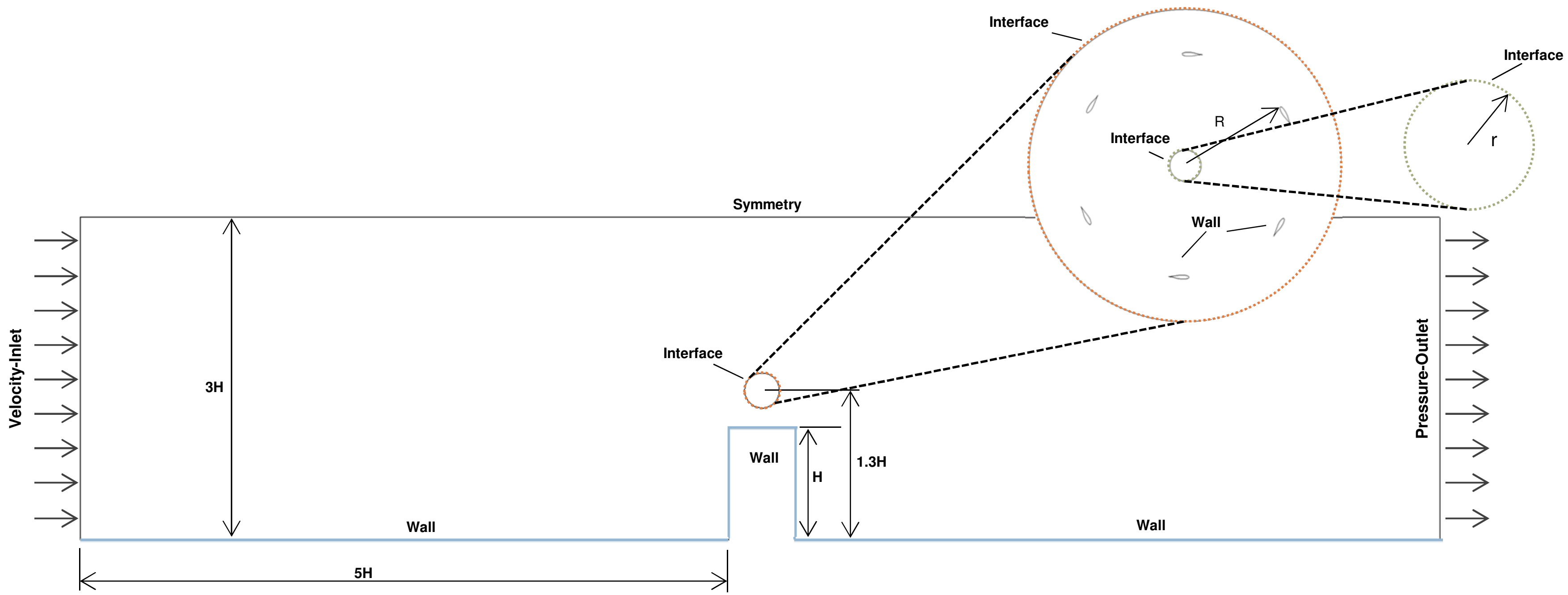
Operational Conditions	
Wind velocity	10 m/s
Tip Speed Ratio	1.99
Rotational Velocity	19.9 rad/s

Effect of the roughness

The effect of the roughness in the form of the inlet velocity profile:
Two different cases are considered.



Computational Domain and Boundary Conditions

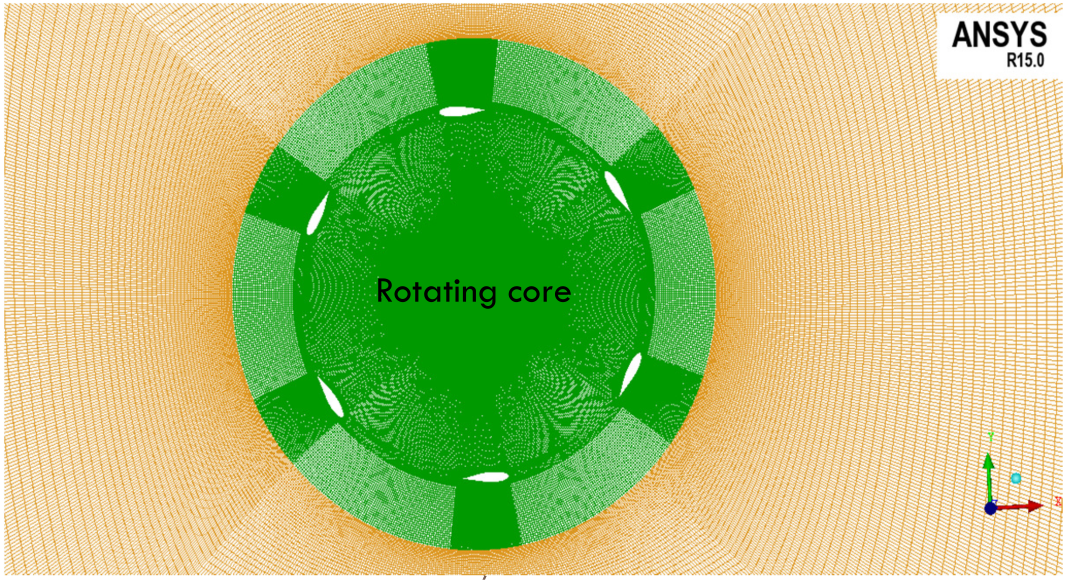


Part	Boundary Condition
Inlet	Velocity-inlet
Outlet	Pressure-outlet
Upper	Symmetry
Rotational Disk	Interface

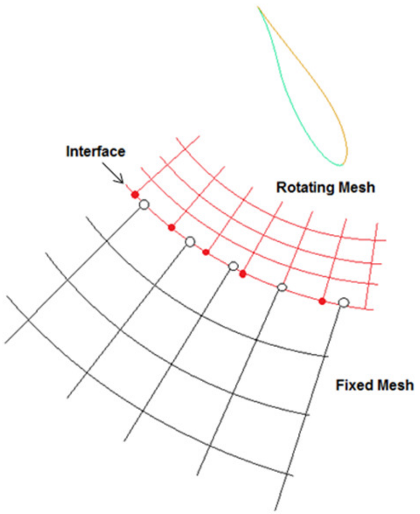
CFD Model

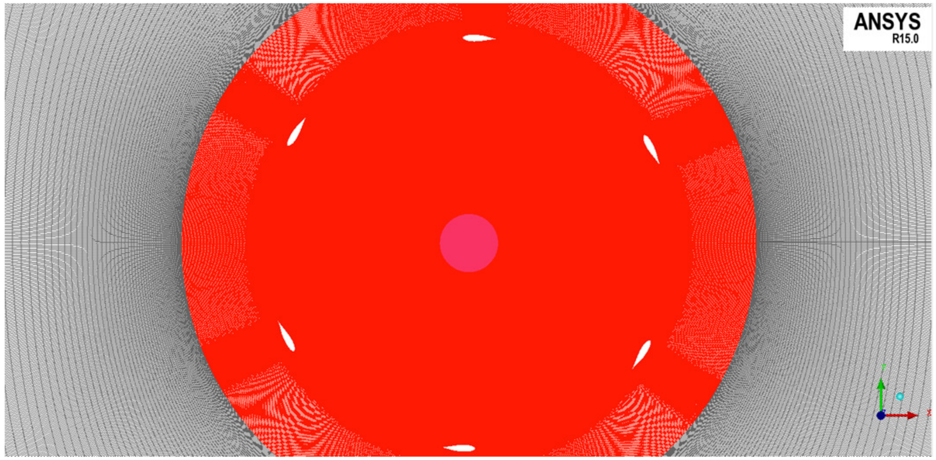
Unsteady simulation for VAWT:

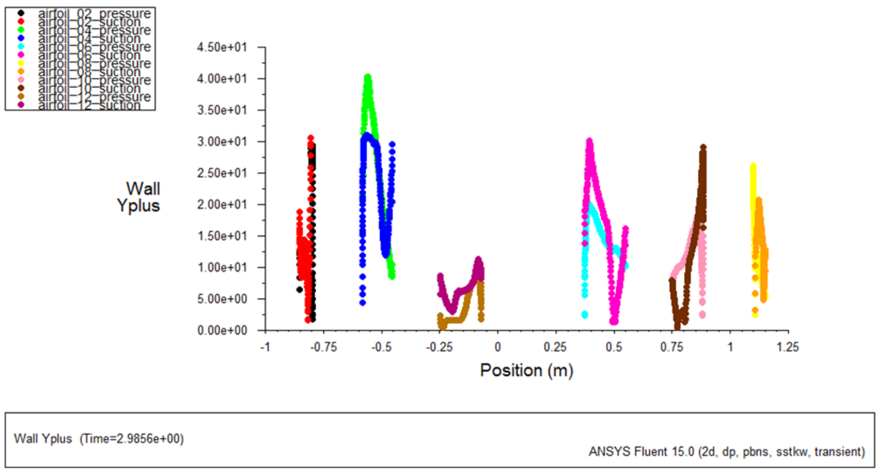
Mesh: Hybrid (V2: 1M), Moving frame for rotating core
Turbulence model: k-omega/SST
Turbulent intensity (%): 20
Turbulence length scale (m): 7

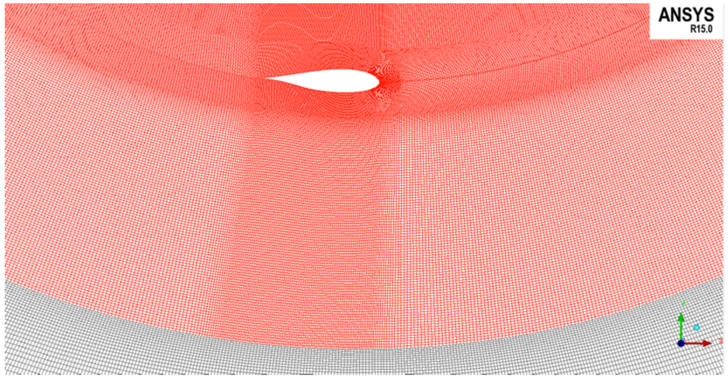


Meshing


Interface
Rotating Mesh
Fixed Mesh


ANSYS
R15.0


airfoil_02_pressure
airfoil_02_suction
airfoil_04_pressure
airfoil_04_suction
airfoil_06_pressure
airfoil_06_suction
airfoil_08_pressure
airfoil_08_suction
airfoil_10_pressure
airfoil_10_suction
airfoil_12_pressure
airfoil_12_suction
Wall Yplus
4.50e+01
4.00e+01
3.50e+01
3.00e+01
2.50e+01
2.00e+01
1.50e+01
1.00e+01
5.00e+00
0.00e+00
-1
-0.75
-0.5
-0.25
0
0.25
0.5
0.75
1
1.25
Position (m)
Wall Yplus (Time=2.9856e+00)
ANSYS Fluent 15.0 (2d, dp, pbns, sstkw, transient)

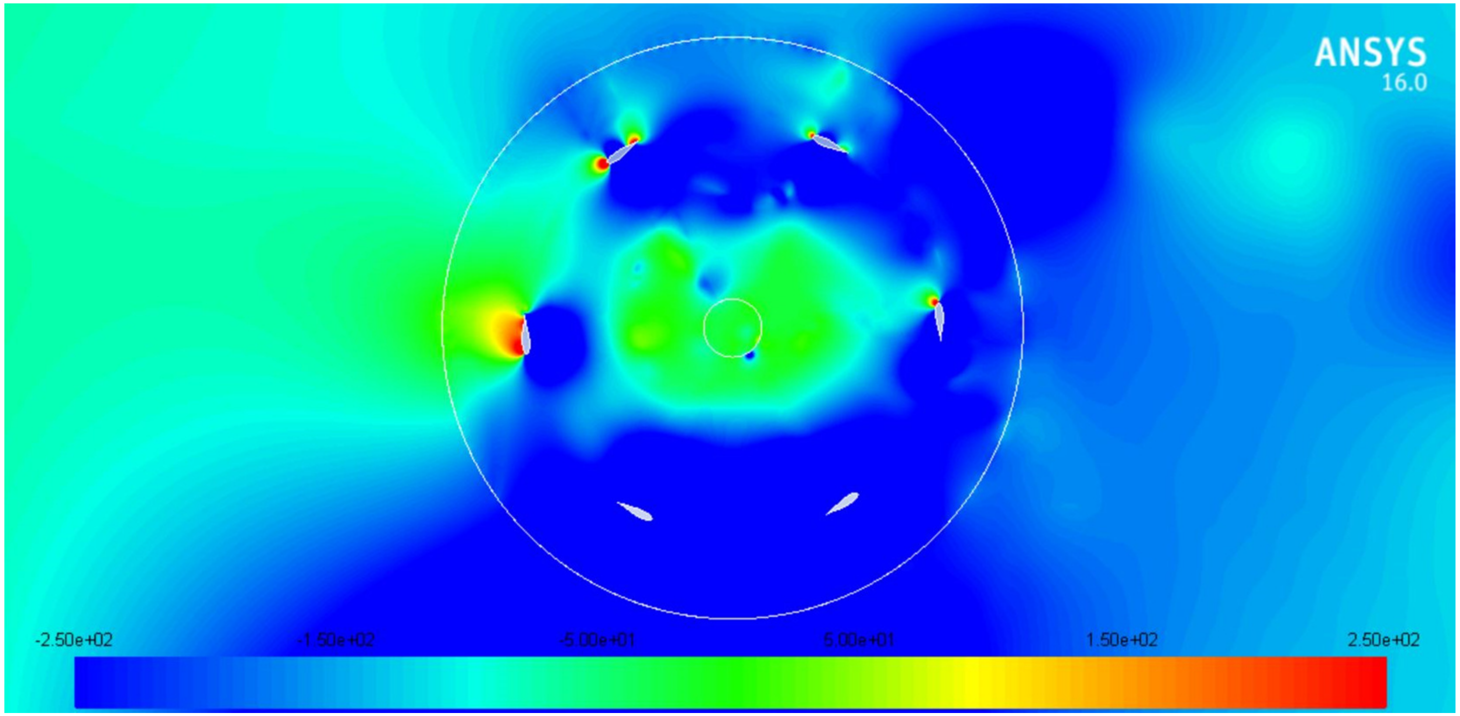

ANSYS
R15.0

Case Study

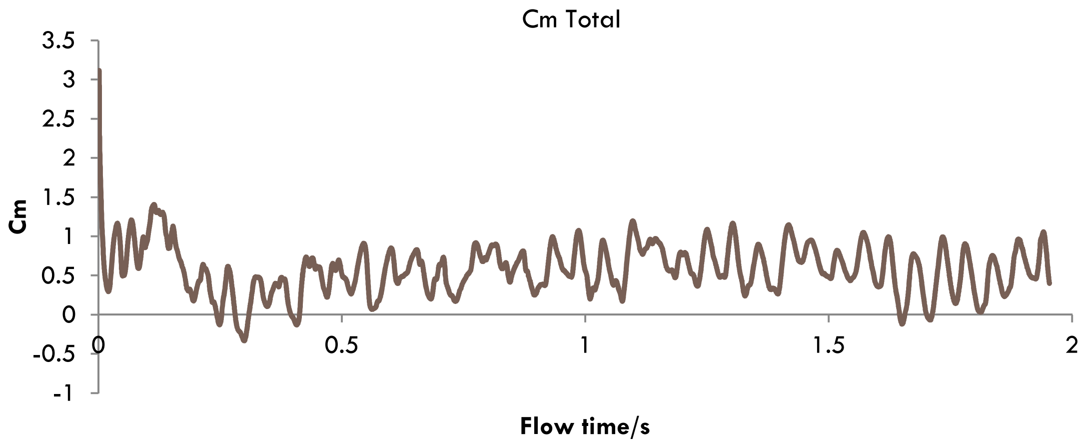
The simulation is performed for three cases:

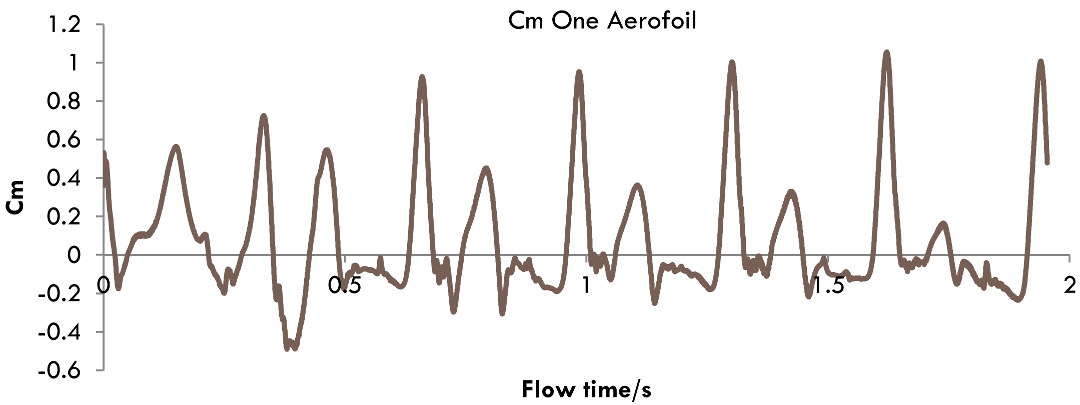
1. VAWT without the building considering a uniform velocity at inlet, Case(1)
2. VAWT with simplified building considering a uniform velocity at inlet, Case(2)
3. VAWT with simplified building considering a velocity profile at inlet, Case(3)

Interface Analysis

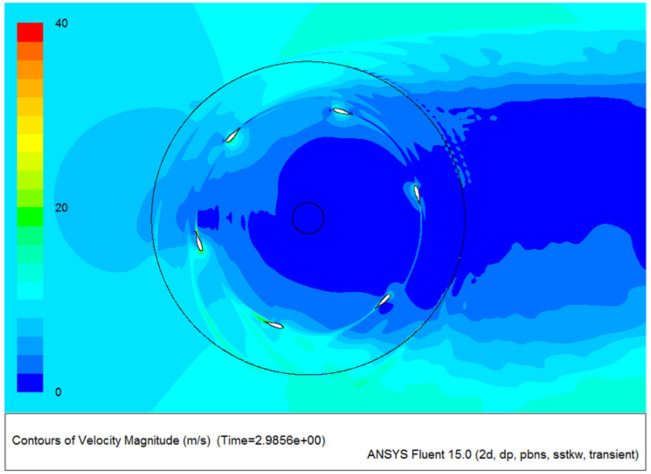


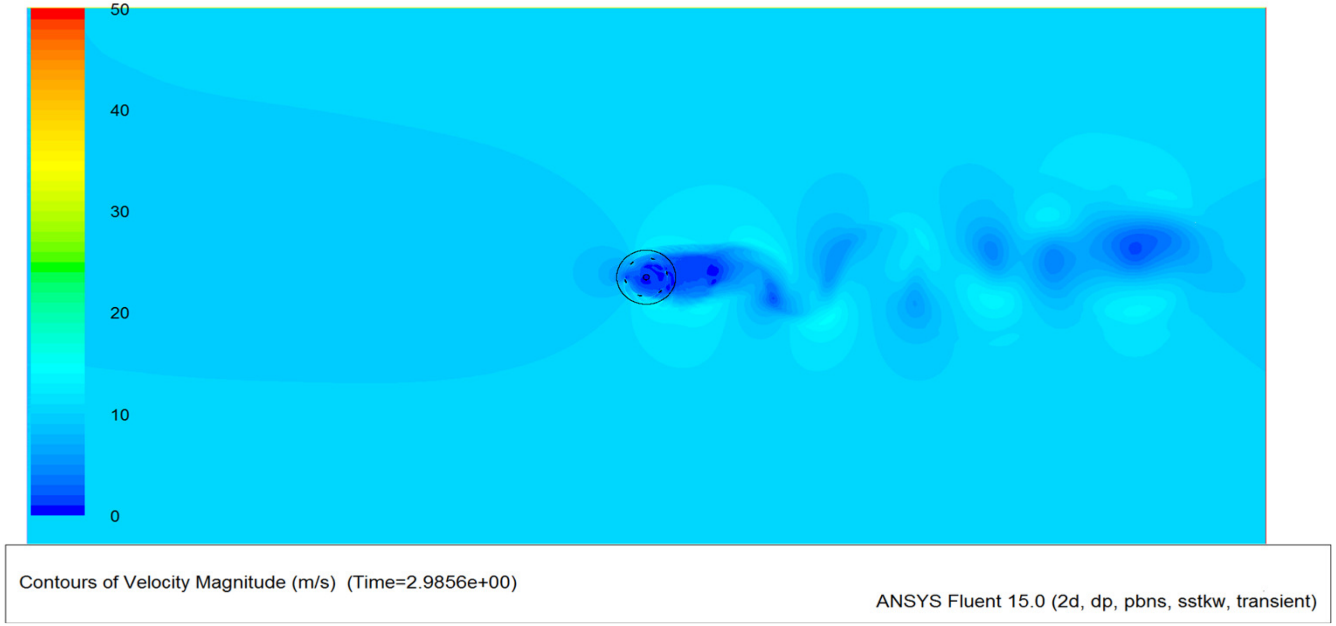
Convergence Analysis



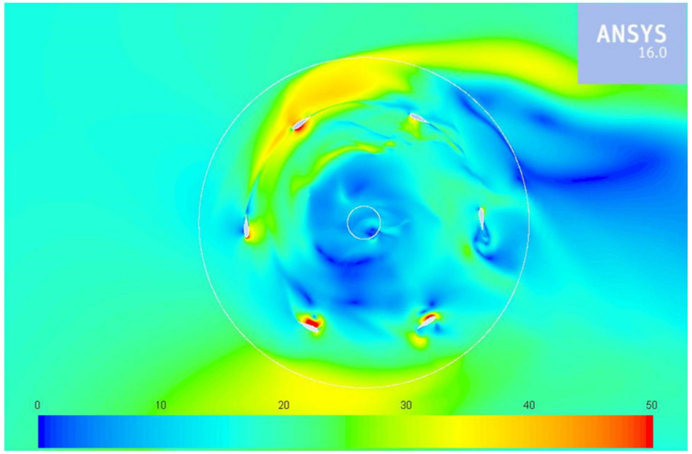


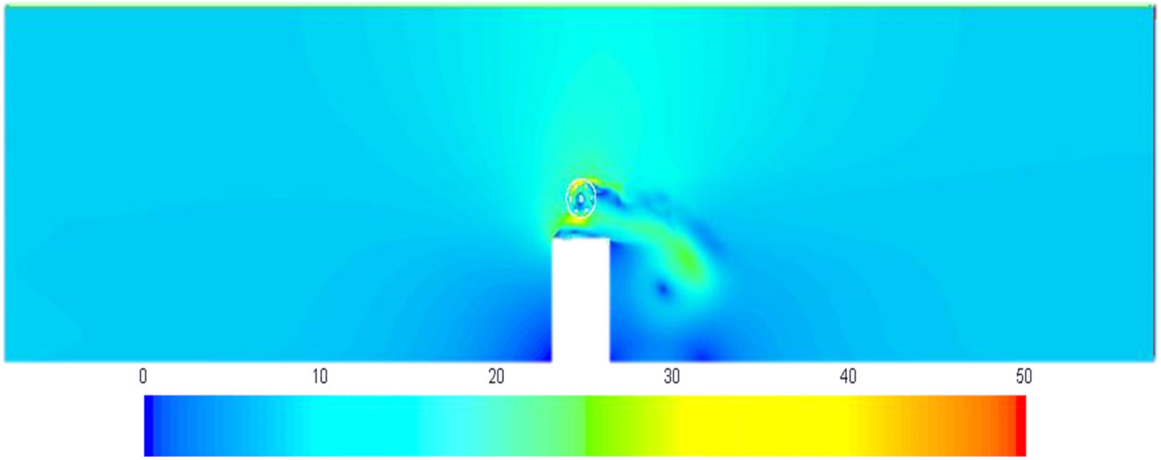
Flow Visualisation: VAWT without the Presence of the Building (Case1)



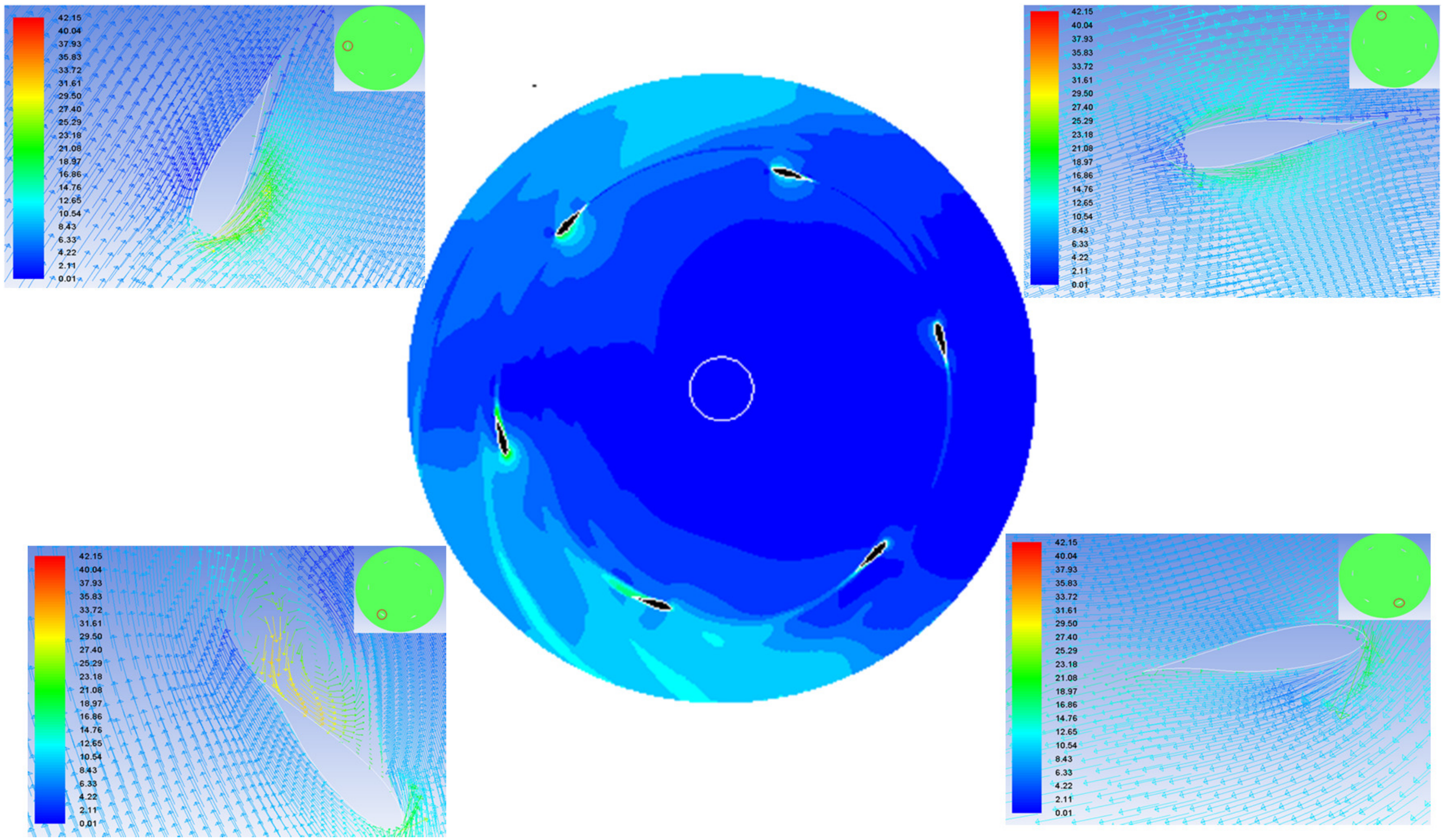


Flow Visualisation: VAWT with the Presence of the Building (Case 2)

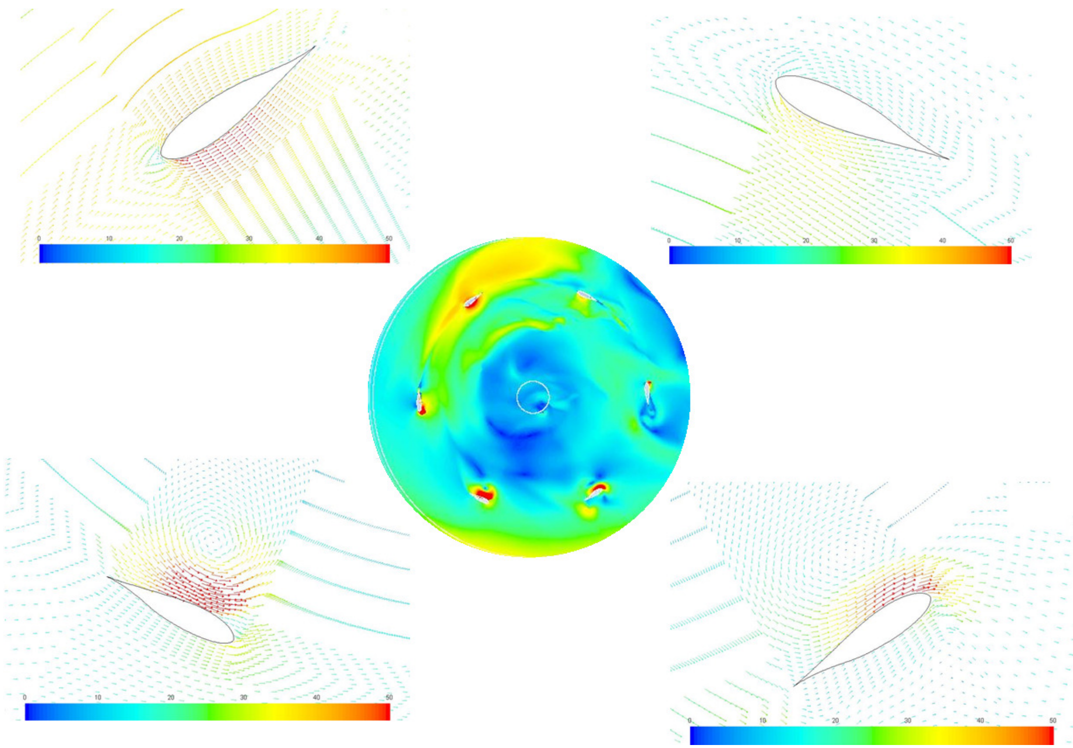




Velocity Vectors, with Building, Case(1)



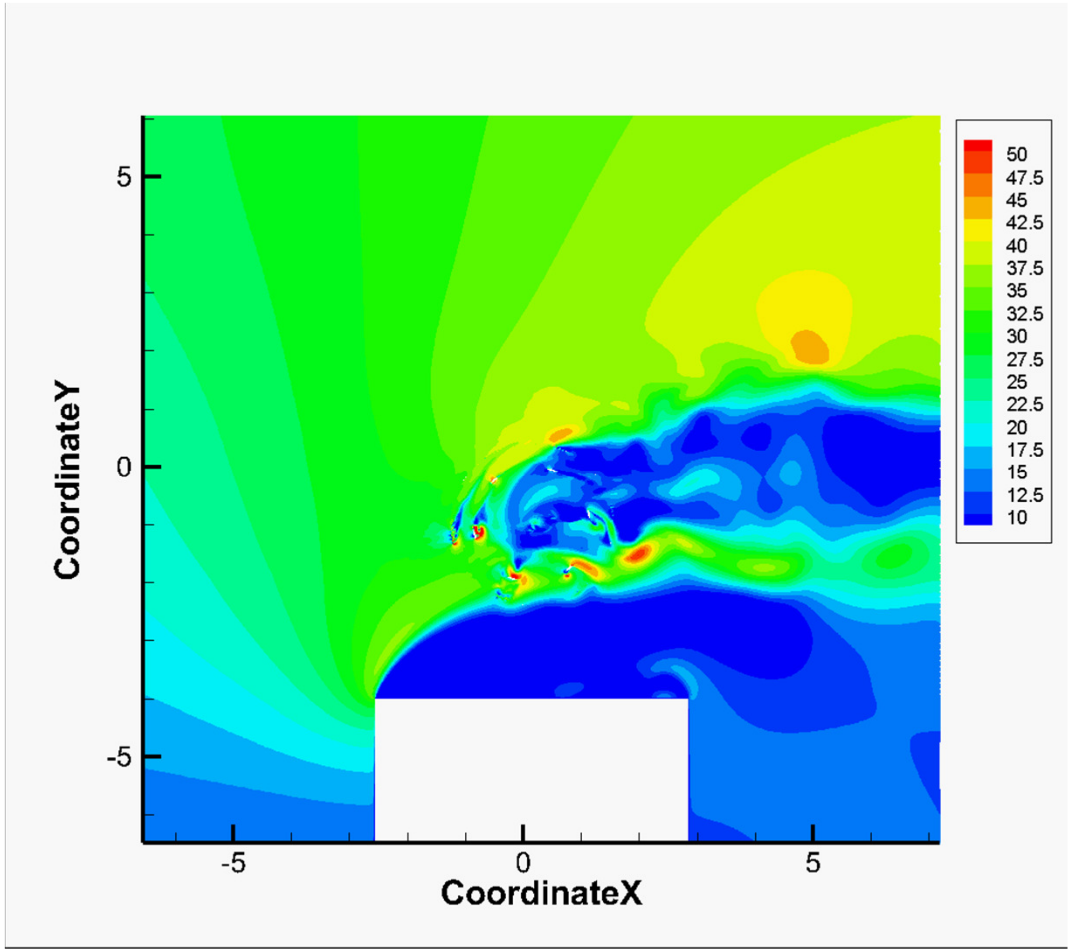
Velocity Vectors, with Building, Case(2)



Performance Analysis

Case	Inlet type	Average velocity at inlet (ms^{-1})	$\overline{C_m}$	Torque (Nm)	Power (kW)
Without Building (case 1)	Uniform velocity	10.0	0.20	49.0	0.975
With building (case 2)	Uniform velocity	10.0	0.495	121.3	2.41
With building (case 3)	Velocity profile	7.69	0.63	115.9	2.31

Flow Animation



Limitations of results

- This was a 2D simulation, in reality turbine power will be substantially lower than the 2D prediction. As the blade tip losses are not considered in a 2D simulation. Blade tip losses also reduce the power of the turbine.
- Computational resources limited the accuracy of the data obtained.

Conclusion

- 3 different Cases of a VAWT have been studied using 2D CFD
- The effects of skewed flow induced by the building lead to a region of increased velocity above the building.
- Power achieved by a VAWT can be significantly increased if located on a building in comparison to a free stream.
- The power was slightly decreased when ground roughness was considered.

Acknowledgements

- This study has been a part of a European project “New innovative solutions, components and tools for the integration of wind energy in urban and peri-urban areas” (acronym SWIP, project no. 608554).

Thank you for your Attention!