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PERFORMANCE OPTIMIZATION OF A ROOF TOP TRANSVERSE AXIS WIND TURBINE

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MECHANICAL ENGINEERING

UNIVERSITI TEKNOLOGI PETRONAS

JANUARY 2020

CERTIFICATION OF APPROVAL

PERFORMANCE OPTIMIZATION OF A ROOF TOP TRANSVERSE AXIS WIND TURBINE

by

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22729

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Approved by,

____

(Mr. Mohd Syaifuddin B Mohd)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

JANUARY 2020

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is mine except as stated in the references and acknowledgements, and that the original work contained herein was not undertaken or performed by unspecified sources or individuals.

AIDIL

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(AHMAD AIDIL AIZAT BIN BAHARUDDIN)

ABSTRACT

A novel design of roof top transverse axis wind turbine had been proposed for application along the coastlines of east coast of Peninsular Malaysia. Preliminary experimental results indicated that this particular design could potentially operate in the low speed wind condition with wind direction varying as much as 60 degrees from the prevailing wind main direction. However, the wind turbine rotation speed varies according to the angle of prevailing wind. Hence, this paper will cover the process on performance optimization of a roof top transverse axis wind turbine through design enhancement. The performance optimization through design enhancement focuses on modeling a component called ‘End Cap’, analysis and study of several designs of ‘End Cap’ that will optimize the transverse axis wind turbine mounted on a rooftop performance. The impact of wind flow pattern on “End Cap” designs will be observed and studied through the aid Computational Fluid Dynamics simulation of CAE program which help in the selection of best design. In this project, the author design and examine the effect of ‘End Cap’ on the transverse axis wind turbine based on relevant parameters and determine which design for ‘End Cap’ will maintain or reduce the variation speed of wind turbine regardless of the angle of prevailing wind within the effective range. The design constructed are studied and discussed for further improvements.

ACKNOWLEDGEMENT

First, I would like to forward my thank to Mr. Mohd Syaifuddin B Mohd, my supervisor for both Final Year Project 1 (FYP 1) and Final Year Project 2 (FYP 2), which I am grateful for the excellent insights about the project's scope, for his diligent ongoing assistance and wise guidance throughout this project, apart from the comprehensive understanding that I have acquired through his guidance.

Next, I would also like to convey my gratefulness towards my parent for their comprehension and support for me. Their careful advice on the whole aspect of life as a student that allows me to be focused with my studies and tasks. Their guidance and encouragement has availed me to go through this study period prosperously and gave me some thoughts on how to overcome difficulties.

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CHAPTER 1: INTRODUCTION

One of the suppliers of global energy demand is renewable energy sources (RES). Wind, solar, hydropower, tidal, and geothermal energy are one of the sources provide renewable energy sources. Wind energy is one of the sustainable and non-polluting sources of energy [1].

The usage of wind power has become increasingly important, attractive and cost-effective. When wind energy systems advantages became widely known, system developers began to try their incorporation. With modern turbines and energy conversion systems, the extraction of power from wind is a proven global industry [2].

Wind turbine is required to harness wind energy for extraction purposes and convert it to electrical energy. The wind turbine system (WTS) started with a few tens of kilowatts of power in the 1980s. These days, only up to 6-8 MW of multi-megawatt wind turbines are commonly installed. Wind turbines are commonly used in distribution networks and more and more wind power stations are directly connected to the transmission networks, functioning as power plants. Wind power is growing larger than any other renewable energy (RES) and is becoming a major player in the global energy supply process as shown in the figure below [3].

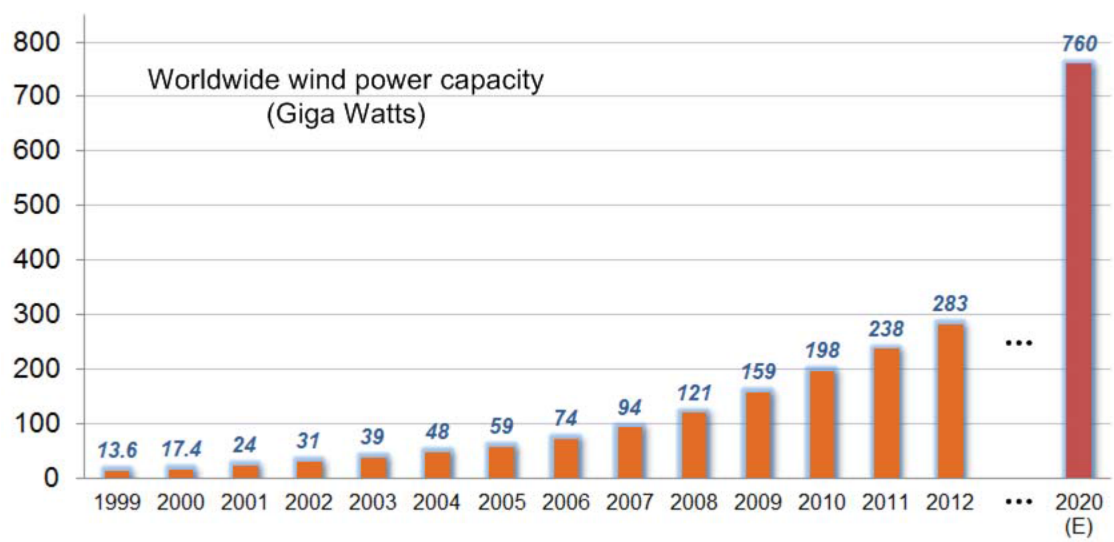


Figure 1.1 Global cumulative installed wind power capacity from 1999 to 2020

1.1 PROBLEM STATEMENT

The novel design of roof top transverse axis wind turbine which had been proposed having issue in maintaining the rotation speed of wind turbine during different angle of prevailing wind at constant wind speed. The novel design needs to be improved by enhancing the novel design with the focus in addressing this issue. Therefore, to optimize the performance of the roof top transverse axis wind turbine, design enhancement on the novel design is imperative.

1.2 OBJECTIVES

This research objectives are:

- To study the effect of different design of 'End Cap' on the wind flow pattern and on the performance of transverse axis wind turbine.
- To improve performance of the transverse axis wind turbine design utilizing optimized "End Cap" design.

1.3 SCOPE OF STUDY

The study focuses on performance optimization of roof top transverse axis wind turbine through design enhancement. Modelling and Computational Fluid Dynamics simulation through computer aided engineering (CAE) software are used in order to study and analyze the "End Cap" design effect on wind flow pattern.

CHAPTER 2: LITERATURE REVIEW

2.1 Roof Top Transverse Axis Wind Turbine

A novel design for the roof top axis wind turbine that has been established has issues in maintaining the wind turbine rotation speed in varying angle of prevailing wind at constant speed within the effective range. The effective range are between 0^{θ} - 60^{θ} with the 0^{θ} is the center of the effective range. This issue has impacted the overall roof top axis wind turbine performance. The roof top axis wind turbine is only able to perform at its optimum capacity at a specific angle while the performance drop occur at any other angle within the effective range [4].

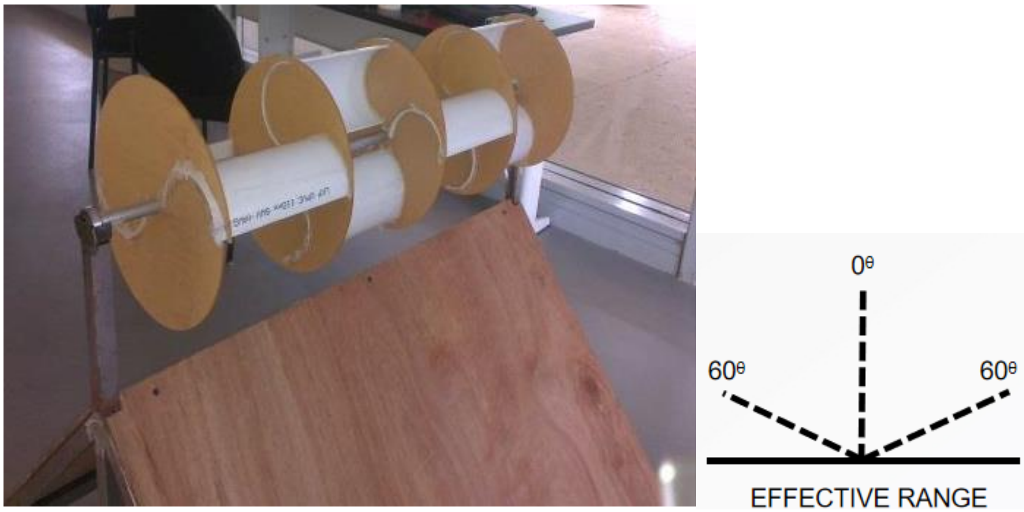


Figure 2.1 Example of Roof Top Transverse Axis Wind Turbine and Effective Range

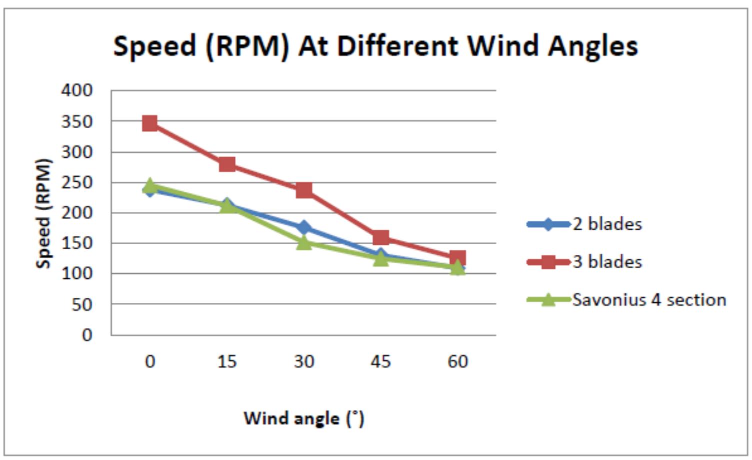


Figure 2.2 Speed (RPM) At Different Wind Angle

Hence, with the goal of optimizing the roof top axis wind turbine performance, the present study will focus on design enhancement of the existing design. The enhance design will focus on redirecting the flow of prevailing wind into the effective range of the roof top axis wind turbine. Research and study are conducted on design enhancement to optimize the performance of roof top axis wind turbine.

2.2 Design Enhancement Parameters

2.2.1 Roof Effect

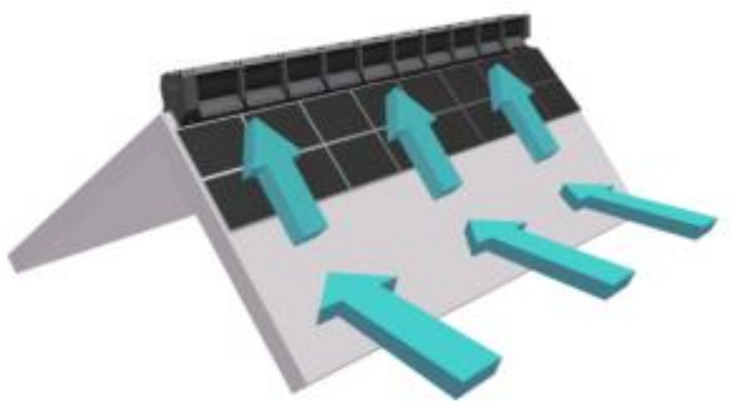


Figure 2.3 Roof Effect

Roof effect occurs when the wind impacts the pitched roof's flat surface and deflects the airflow upwards as it travels up the roof to the top like the wind currents over an aircraft wing. When this occurs, the wind speed is boosted to almost twice the velocity at the peak velocity. This situation is equivalent to increasing air velocity over a wing, which, according to Bernoulli's equation reduces the air pressure above the wing and thus provides lift to the wing. The wind turbine at the top of the roof captures the velocity as it passes over the roof top. This in turn increases the turbine speed to almost double what it would be away from the roof. In essence, this condition almost doubles the wind generator's effectiveness. The roof effect factor is known as the actual roof wind speed divided by the undisturbed air wind speed [5][6].

2.2.2 Wind Turbine Blade

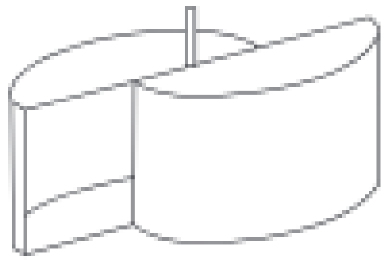


Figure 2.4 Savonius type wind turbine blade

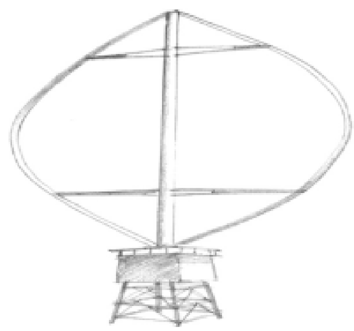


Figure 2.5 Darrieus type wind turbine blade

Wind turbine blade has a range of design in which multiple blades of design of wind turbines have been the subject of numerous research such as Savonius type and Darrieus type. The theory of Savonius type is based on the principle developed by Flettner, which is created by cutting a cylinder along the central plane into two halves and then moving sideways along the cutting plane to two semi-cylindrical surfaces, that the cross-section resembled the letter ' S'. For Darrieus type, is originally invented by Darrieus. This form has two or three curve blades with a constant chord length airfoil cross-section connected to a shaft. A combination of Savonius type and Darrieus type wind turbine blade has many advantages over individual Savonius type and Darrieus type wind turbine blade such as higher efficiency than Savonius type and high starting torque than Darrieus type [7].

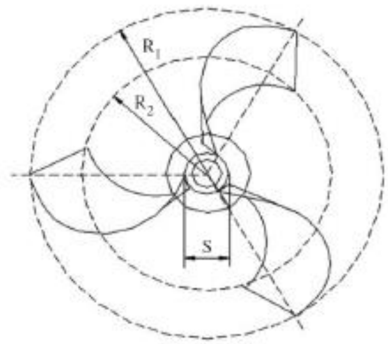


Figure 2.6 Combination of Savonius type and Darrieus type wind turbine blade

In addition, performance analysis comparing twisted blade and conventional semi-circular blade in terms of starting characteristics, static torque and rotational speed shows that the twisted blade has smooth riding, higher efficiency and self-starting capability compared to conventional semi-circular blade [8].

2.2.3 End Plate

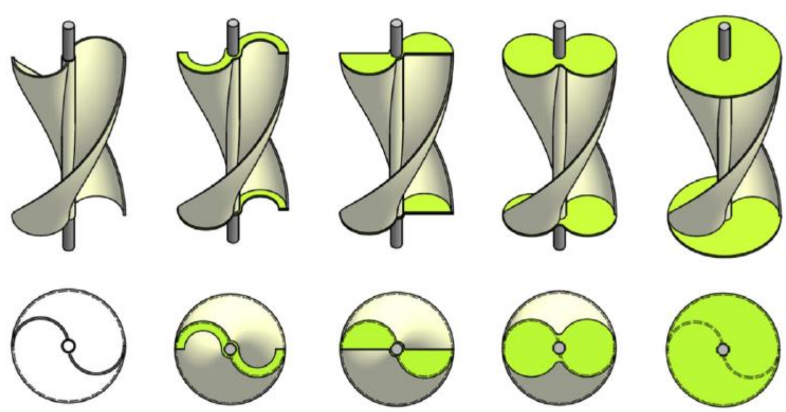


Figure 2.7 Sample of End Plate Design

The use of end plate is the easiest way to improve the wind turbine's aerodynamic efficiency by playing the role of preventing spill-over flow at the end of the bucket, thereby increases the momentum transfer from the air stream. The circular end plate is the best choice to maximize power and the Savonius wind turbine torque coefficient [9].

2.2.4 Wind Data

Wind data in table below are obtained from "Assessment of Wind Energy Potential Mapping For Peninsular Malaysia" are used as reference parameter for simulation in order to further increase the reliability of this simulation by using real life data such as the wind speed of each specified location[10]. The data from the table below will be extracted to be used in the sinulation.

Table 2.1 Wind Data

	MOST PROBABLE WIND DIRECTION			MEAN WIND SPEED	
LOCATION	1ST	2ND	RESULTANT VECTOR	2008	2009
BATU EMBUN	0.00	315.00	349.00	0.91	0.90
BAYAN LEPAS	0.00	22.50	342.00	2.66	2.65
BUTTERWORTH	90.00	67.50	33.00	2.84	2.88
CAMERON HIGHLANDS	67.50	270.00	351.00	2.57	2.63
CHUPING	0.00	22.50	1.00	1.52	1.46
IPOH	22.50	45.00	42.00	2.25	2.24
KLIA SEPANG	0.00	157.50	20.00	2.39	2.04
KOTA BHARU	90.00	0.00	128.00	3.09	2.82
KUALA KRAI	0.00	135.00	191.00	1.30	1.20
KUALA TERENGGANU	180.00	202.50	147.00	2.63	2.64
KUANTAN	0.00	337.50	359.00	2.16	2.12
MALACCA	45.00	0.00	25.00	2.71	2.99
MERSING	247.50	0.00	270.00	4.06	4.01
SENAI	0.00	337.50	348.00	2.13	2.24
SITIAWAN	0.00	90.00	18.00	1.64	1.59

CHAPTER 3: METHODOLOGY

This project was carried out with the goal of improving the performance of a roof top transverse axis wind turbine through design enhancement. Design enhancement was executed with the aid of computer aided engineering (CAE) software. This section will explain the function of computer aided engineering (CAE) software used for design enhancement as well the details to conduct the simulation. All the data obtained will be recorded. The results obtained were then to be discussed.

3.1 Modelling (Computer Aided Engineering (CAE) Software)

Process and research regarding to design and modelling of the “End Cap” and turbine model was carried out with the aid of computer aided engineering (CAE) software. Through CAE software, the design for “End Cap” and turbine model with “End Cap” will be constructed. The “End Cap” design will focus on redirecting wind flow into the effective range of the roof top transverse axis wind turbine.

3.1.1 End Cap Design

The modelling process of End Cap design are conducted with the aid of CAE software. The detailed dimension of the End Cap designs is located at the appendix of this report. The first end cap design was based on the design of aero foil which were redefined into circular shape. Aero foil design was known due to its aerodynamics shape which were designed to increase the velocity of the airflow above its surface. Hence, this design aim to increase the wind flow speed which acts on its surface before the wind flow pass through the turbine blade.

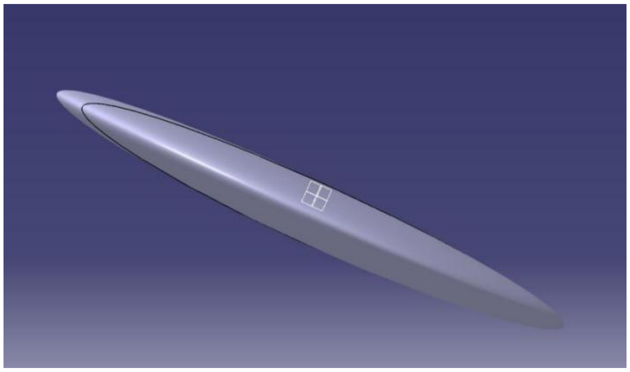


Figure 3.1 End Cap Design 1

The second end cap design was based on concave shape which were redefined into circular shape. Concave shape design has the ability to redirect flow into its focal point in which this situation is similar on how concave mirror redirect light into its focal point. Hence, this design aim to redirect the wind flow into the focal point at the center region of the end cap in which the turbine blade are located.

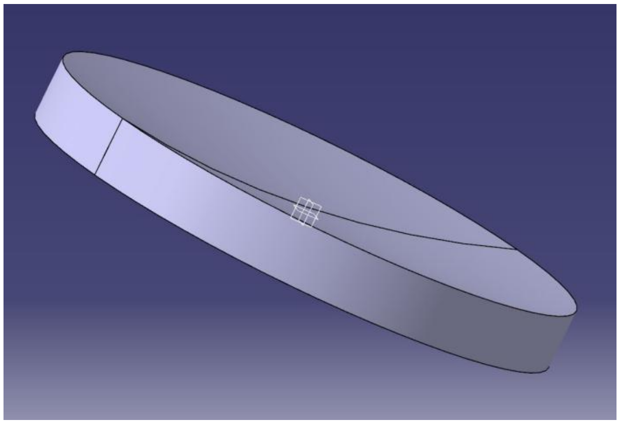


Figure 3.2 End Cap Design 2

The third end cap design was based on the combination of both first and second end cap design. This design combines the benefits of both design into a single design. The design outer circle is based on the first design while the inner circle is based on the second design. The outer circle design will help to increase the wind flow speed while the inner circle will help to redirect the flow towards the turbine blade. Hence, this design aim to increase the wind flow speed and then redirect the flow into the focal point of end cap in which the turbine blade is located.

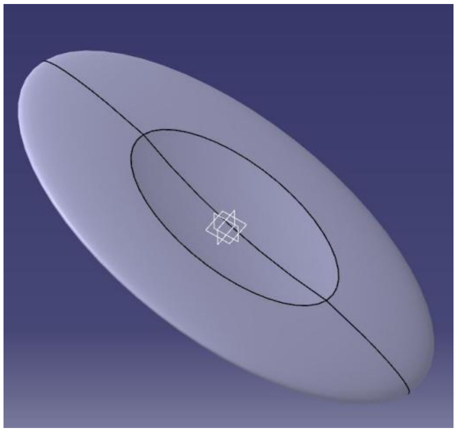


Figure 3.3 End Cap Design 3

3.1.2 House Model

The modelling process of the house model are conducted with the aid of CAE software. The reference dimension of the house model is obtained from CIDB Malaysia and Standard Malaysia such as the dimension for the house length, width, height, wall thickness, roof overhang, roof angle and roof thickness [11,12]. The detailed dimension of the house model are located at the appendix of this report. Below table shows the house model dimension from reference and the ratio dimension for modelling.

Table 3.1 House Model Dimension

DETAIL	DIMENSION	
	Ratio 1:1	Ratio 1:4
LENGTH	13.6m	3400mm
WIDTH	8.5m	2125mm
HEIGHT	3.2m	800mm
WALL THICKNESS	0.15m	37.5mm
ROOF OVERHANG	0.6m	150mm
ROOF ANGLE	35◦ to 45◦	35◦ to 45◦
ROOF THICKNESS	0.04m	10mm

3.1.3 Turbine Blade

The modelling process of the turbine blade are conducted with the aid of CAE software. The detailed dimension of the turbine are located at the appendix of this report. The turbine blade for this project consist of three blade which is the optimum number of turbine blade[4]. Below table and figure shows the position allocation of the turbine blade.

Table 3.2 Turbine Blade Position and Angle Allocation

Position	Angle Blade 1	Angle Blade 2	Angle Blade 3
1	0◦	120◦	240◦
2	40◦	160◦	280◦
3	80◦	200◦	320◦

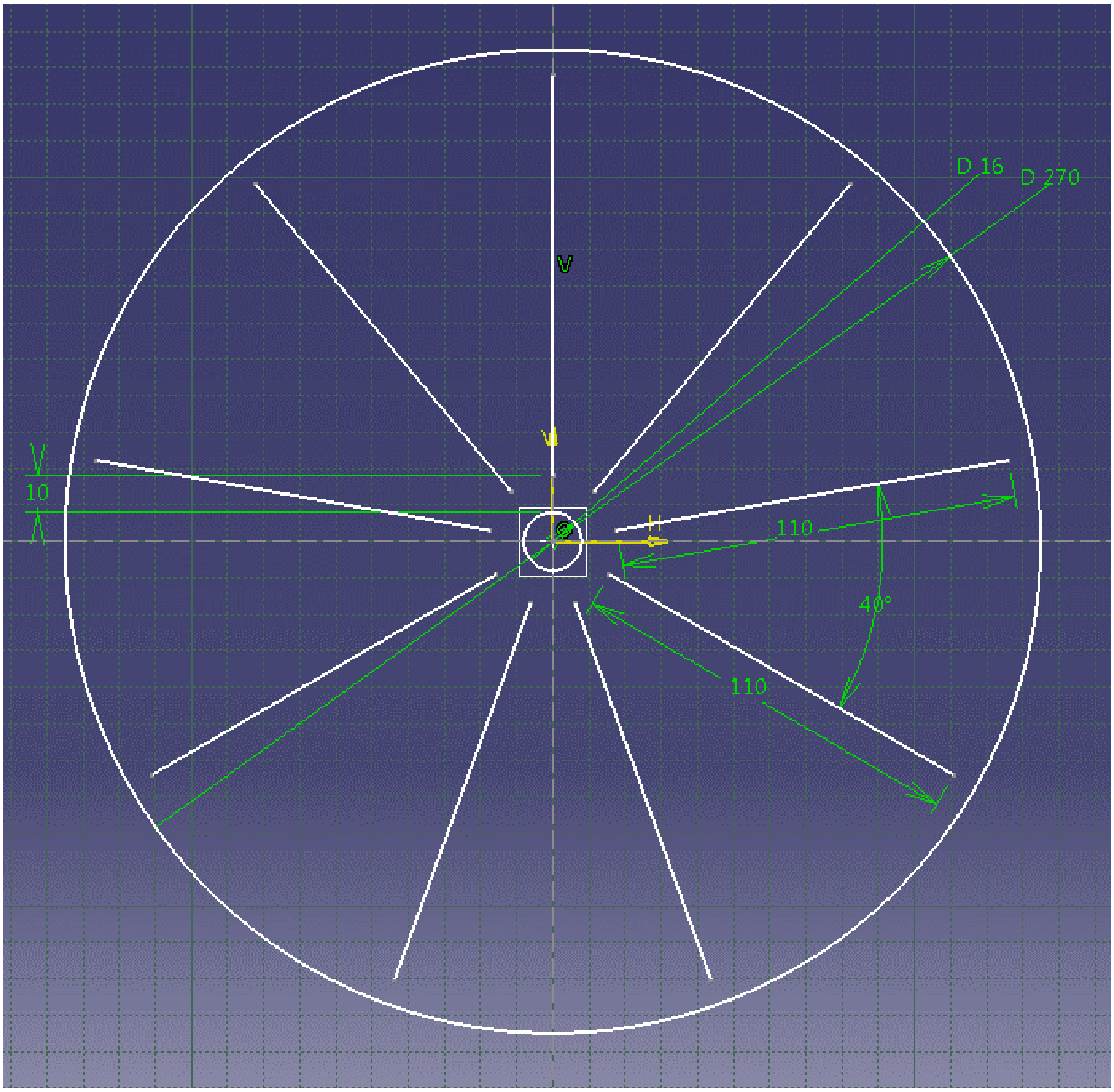


Figure 3.4 Turbine Blade Position Allocation

3.2 Computational Fluid Dynamics (CFD) Simulation

The model of end cap designs which have been constructed with the help of CAE software were exported for computational fluid dynamics (CFD) simulation. These simulations were done to observe the wind flow effect on the model of end cap designs. The boundary condition for these simulations mainly focus on the wind flow speed which were set during the initial setup of simulation which define in Data Gathering section. The result of the computational fluid dynamics (CFD) simulation will portrayed through Flow Path Line and Flow Simulation.

3.2.1 Data Gathering

Based on data from "Assessment of Wind Energy Potential Mapping For Peninsular Malaysia", the data for the wind speed are recorded at 10 meter above ground while the simulation model will be at around 3 meter above ground. Hence, it is necessary to calculate the wind speed at 3 meter above ground by using the formula below:

$$v \approx v_{ref} \cdot \frac{\ln\left(\frac{z}{z_0}\right)}{\ln\left(\frac{z_{ref}}{z_0}\right)}$$

where:

- V = velocity to be calculated at height z
- Z = height above ground level for velocity v
- V_{ref} = known velocity at height z_{ref}
- Z_{ref} = reference height where v_{ref} is known
- Z_0 = roughness length in the current wind direction

By using the formula above, the wind speed at 3 meter above ground can be calculated. Then the average wind speed between 2008 and 2009 are tabulated. From this average wind speed, the minimum, maximum and average wind speed are identified to be used in turbine model simulation as shown by table below.

Table 3.3 Wind Speed Data for Turbine Model Simulation

	MEAN WIND SPEED		MEAN WIND SPEED AT 3M (10M)		
LOCATION	2008	2009	2008	2009	Average
BATU EMBUN	0.91	0.90	0.57	0.56	0.565
BAYAN LEPAS	2.66	2.65	1.67	1.67	1.67
BUTTERWORTH	2.84	2.88	1.78	1.80	1.79
CAMERON HIGHLANDS	2.57	2.63	1.61	1.65	1.63
CHUPING	1.52	1.46	0.95	0.91	0.93
IPOH	2.25	2.24	1.41	1.40	1.405
KLIA SEPANG	2.39	2.04	1.50	1.28	1.39
KOTA BHARU	3.09	2.82	1.93	1.77	1.85
KUALA KRAI	1.30	1.20	0.81	0.75	0.78
KUALA TERENGGANU	2.63	2.64	1.65	1.65	1.65
KUANTAN	2.16	2.12	1.35	1.33	1.34
MALACCA	2.71	2.99	1.70	1.87	1.785
MERSING	4.06	4.01	2.54	2.51	2.525
SENAI	2.13	2.24	1.33	1.40	1.365
SITIAWAN	1.64	1.59	1.03	1.00	1.015
	Minimum Wind Speed				0.565
	Average Wind Speed				1.446
	Maximum Wind Speed				2.525

3.2.2 End Cap

3.2.2.1 Flow Path Line

Flow Path Line of computational fluid dynamics (CFD) simulation results are showing the wind flow pattern and its speed when interact with the model of end cap designs as shown below:-

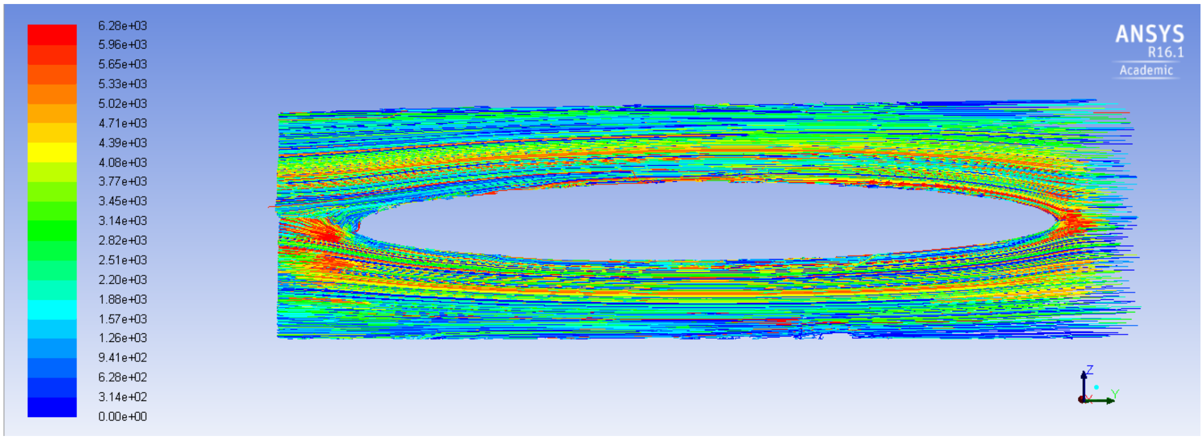


Figure 3.5 Flow Path Line For Design 1 Cross Section

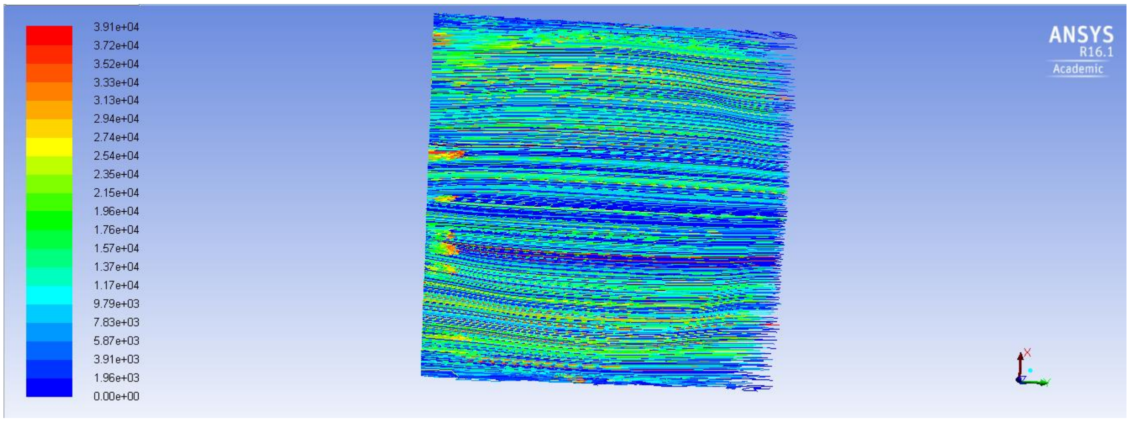


Figure 3.6 Flow Path Line For Design 1 Full Section

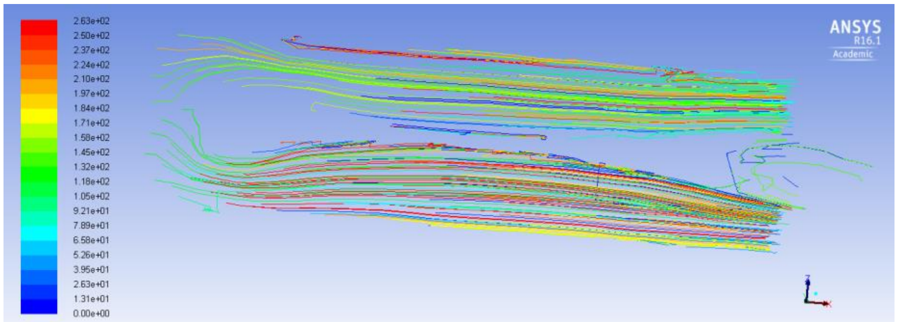


Figure 3.7 Flow Path Line For Design 2 Cross Section

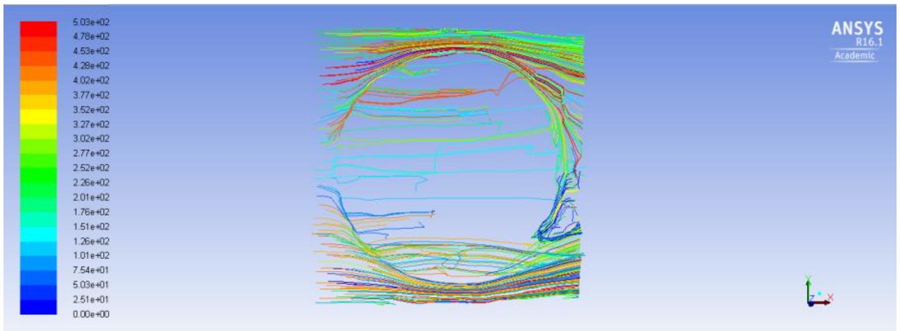


Figure 3.8 Flow Path Line For Design 2 Full Section

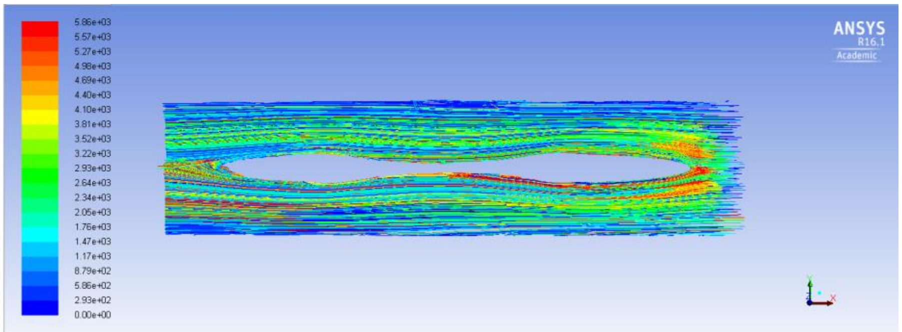


Figure 3.9 Flow Path Line For Design 3 Cross Section

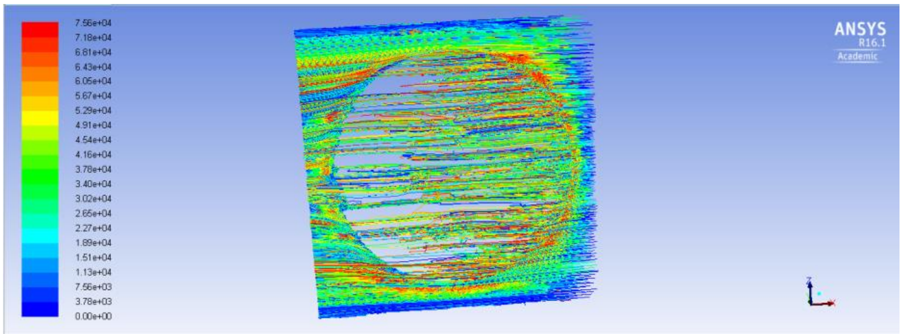


Figure 3.10 Flow Path Line For Design 3 Full Section

3.2.2.2 Flow Simulation

Flow Simulation of computational fluid dynamics (CFD) simulation results are showing the wind flow contour and its speed when interact with the model of end cap designs as shown below:-

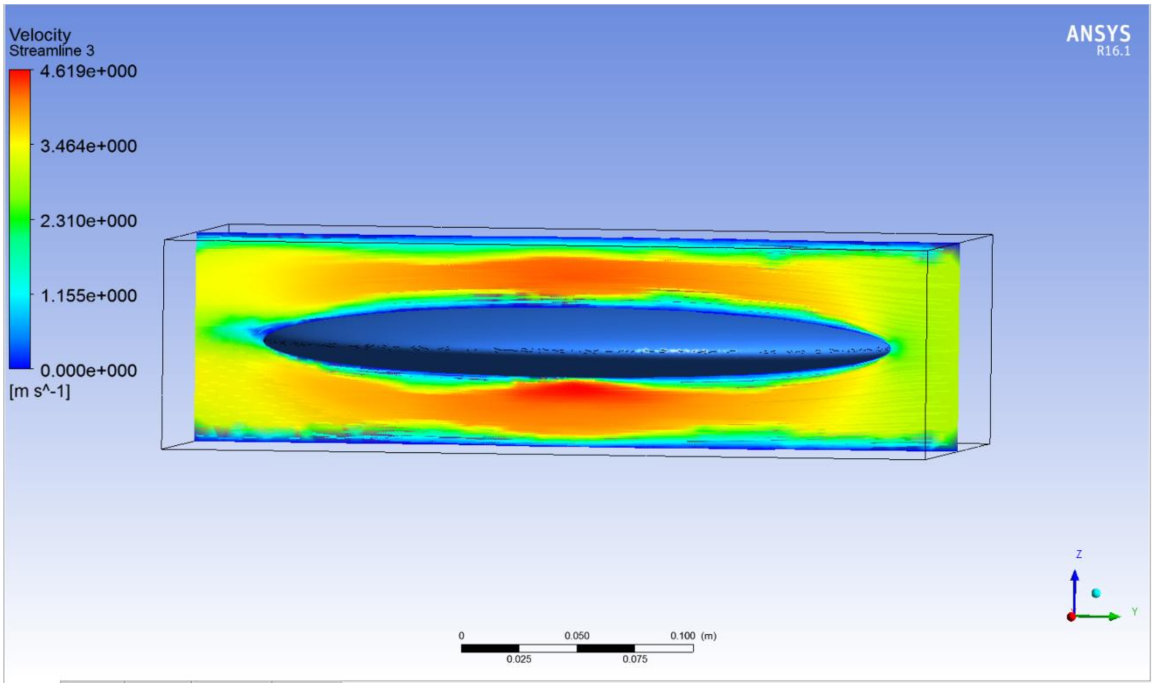


Figure 3.11 Flow Simulation For Design 1 Cross Section

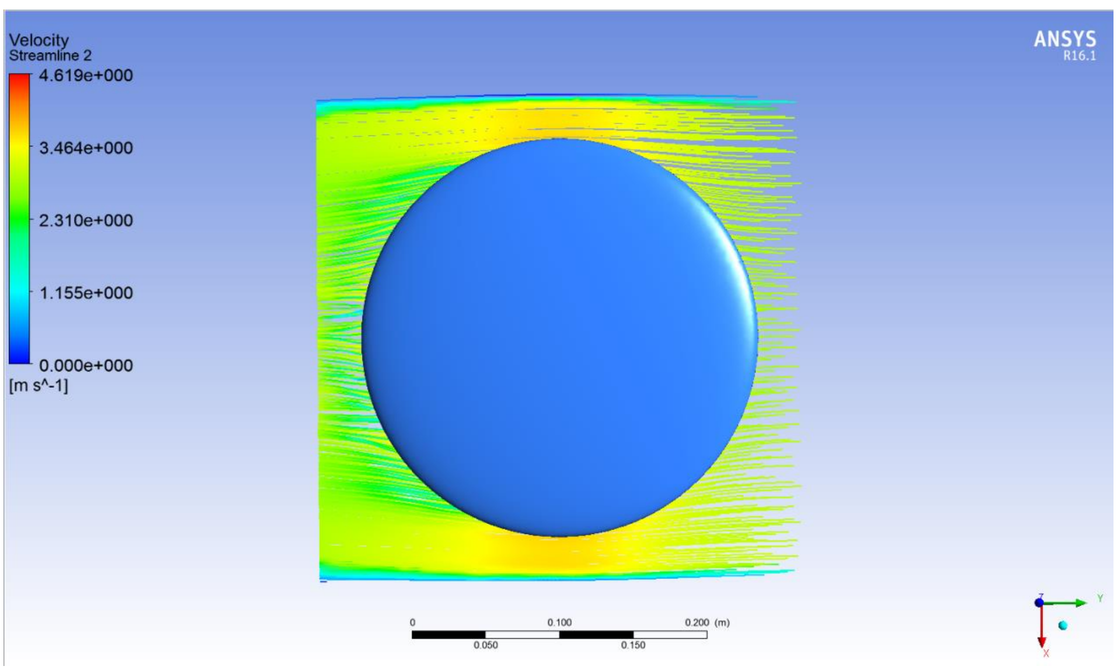


Figure 3.12 Flow Simulation For Design 1 Full Section

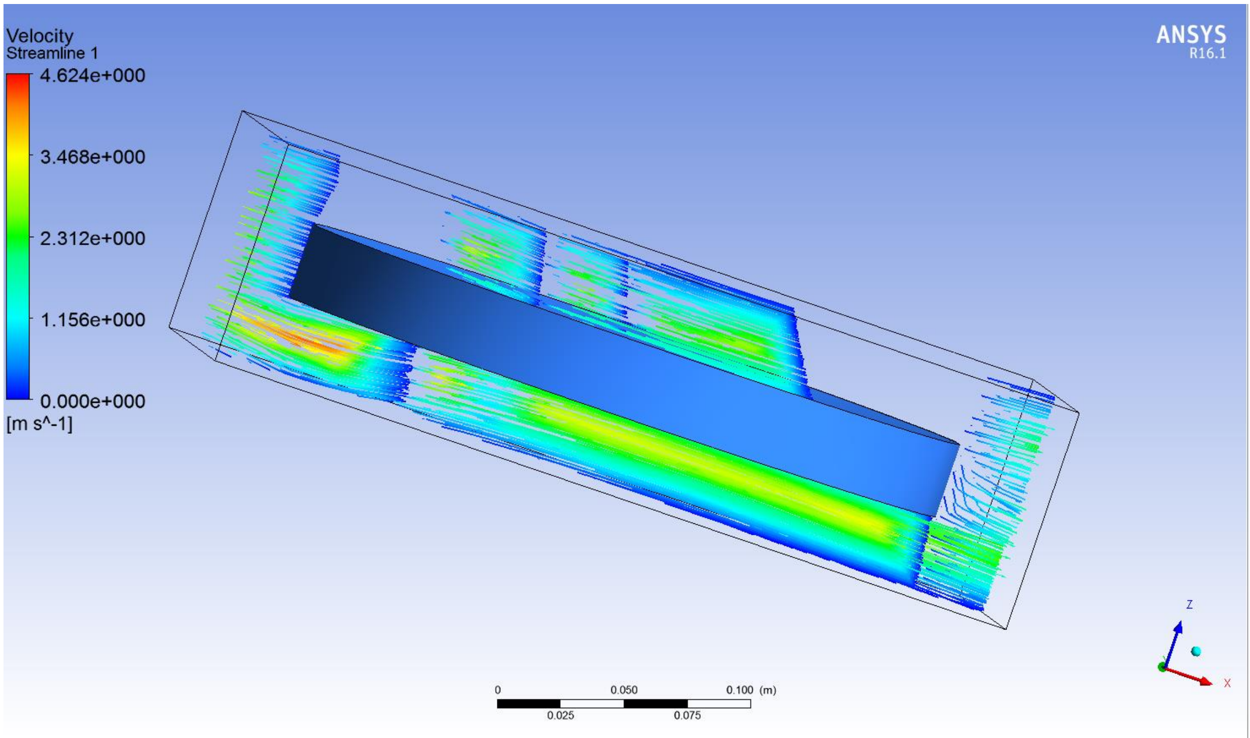


Figure 3.13 Flow Simulation For Design 2 Cross Section

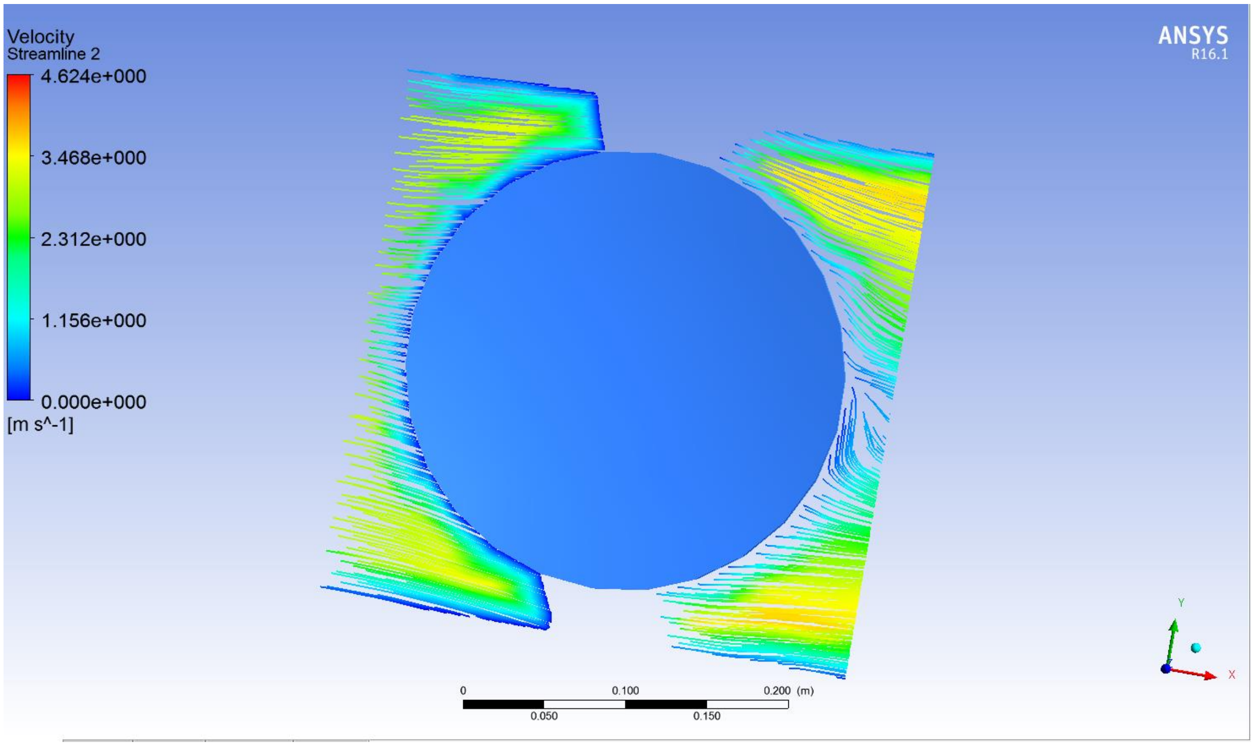


Figure 3.14 Flow Simulation For Design 2 Full Section

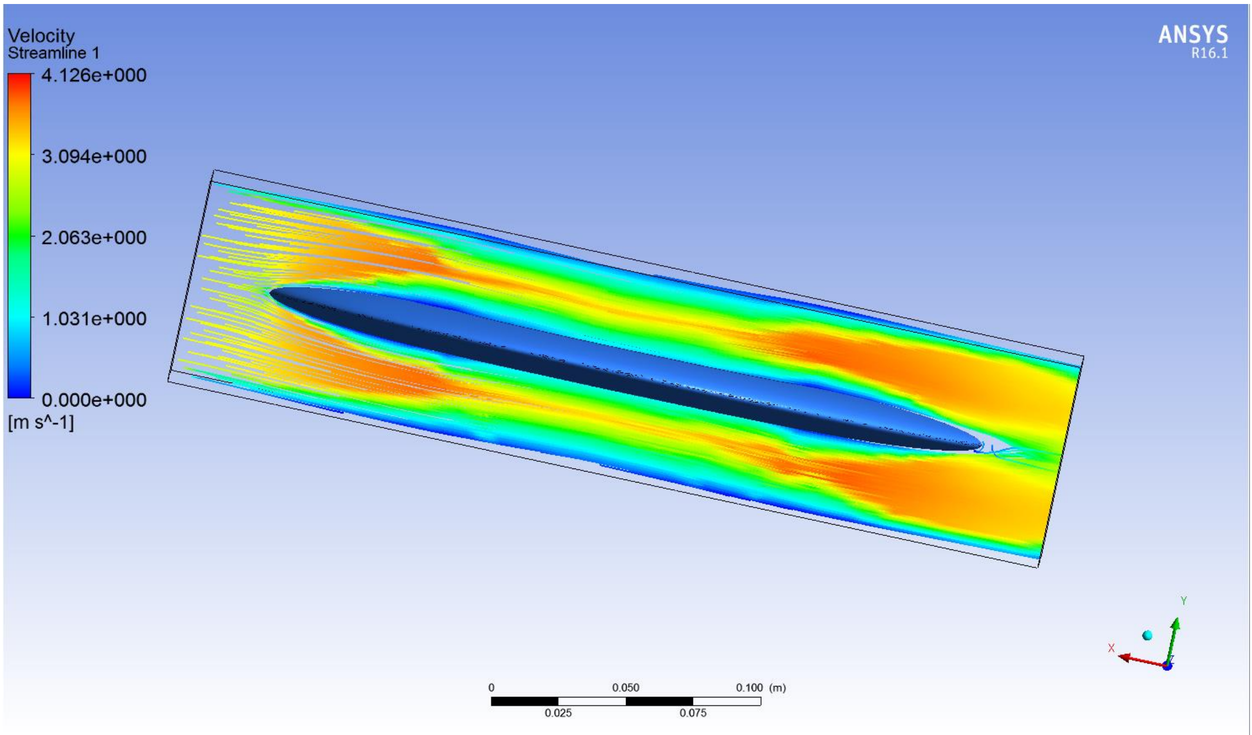


Figure 3.15 Flow Simulation For Design 3 Cross Section

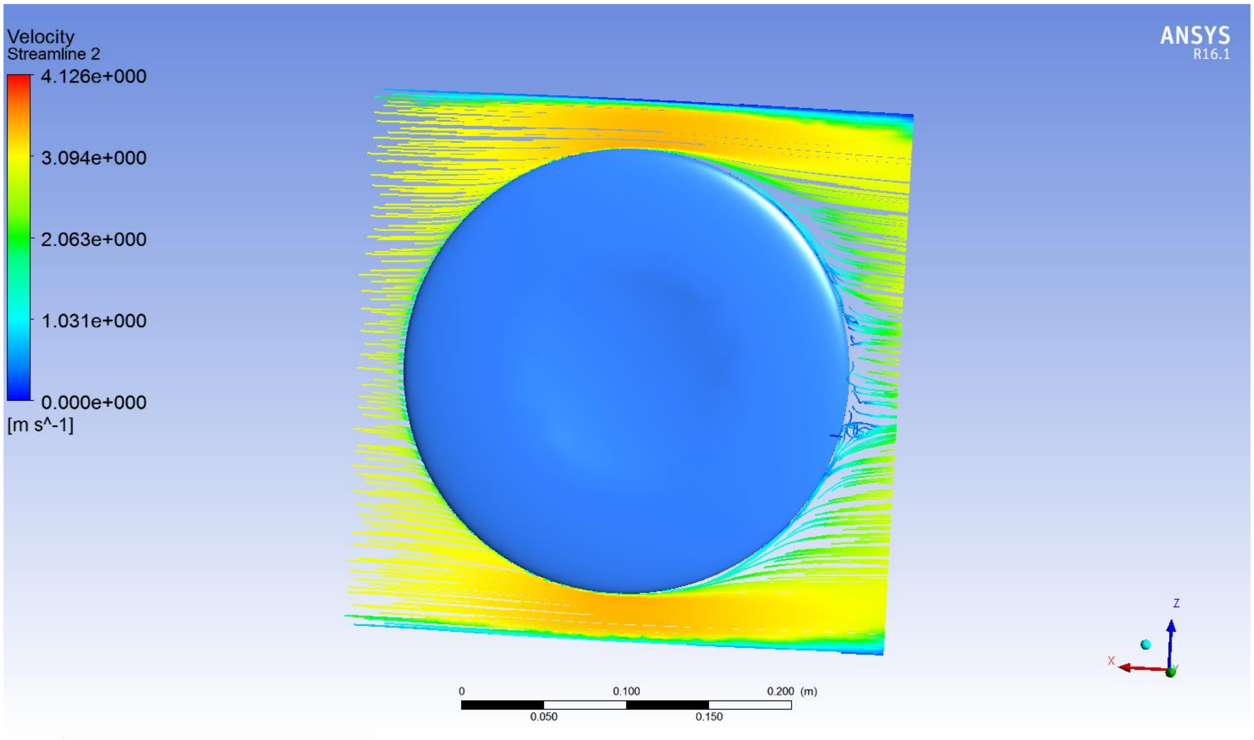


Figure 3.16 Flow Simulation For Design 3 Full Section

Based on the flow path line and flow simulation of End Cap design, Design 1 and 3 clearly depict their capability to increase the wind speed that flow over them compare to Design 2. Hence, for turbine model simulation, the Design 1 and Design 2 End Cap will be chosen to undergo simulation to identify the optimum design.

3.2.3 Turbine Model

Two model were created for turbine model simulation each for Design 1 and Design 2. For this simulation, the initial boundary condition will be made up of the minimum, maximum and average wind speed obtain at data gathering section which will made up for the total of 6 simulation, 3 for each design. The simulation model enclosure is 3 meters from each axis except for -Z axis which set to zero to act as ground. The enclosure set to 3 meter is to reduce blockage effect. The results of the simulations are shown at result and discussion session.

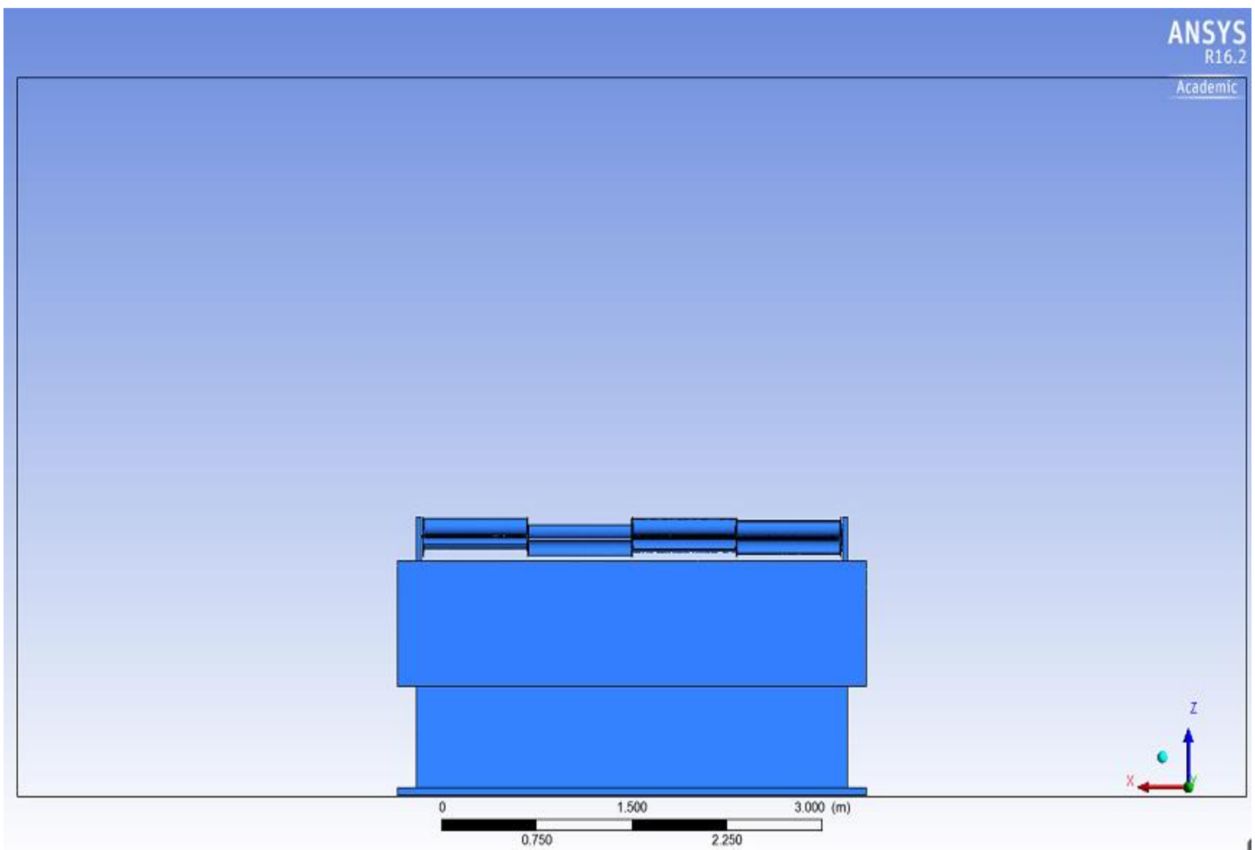
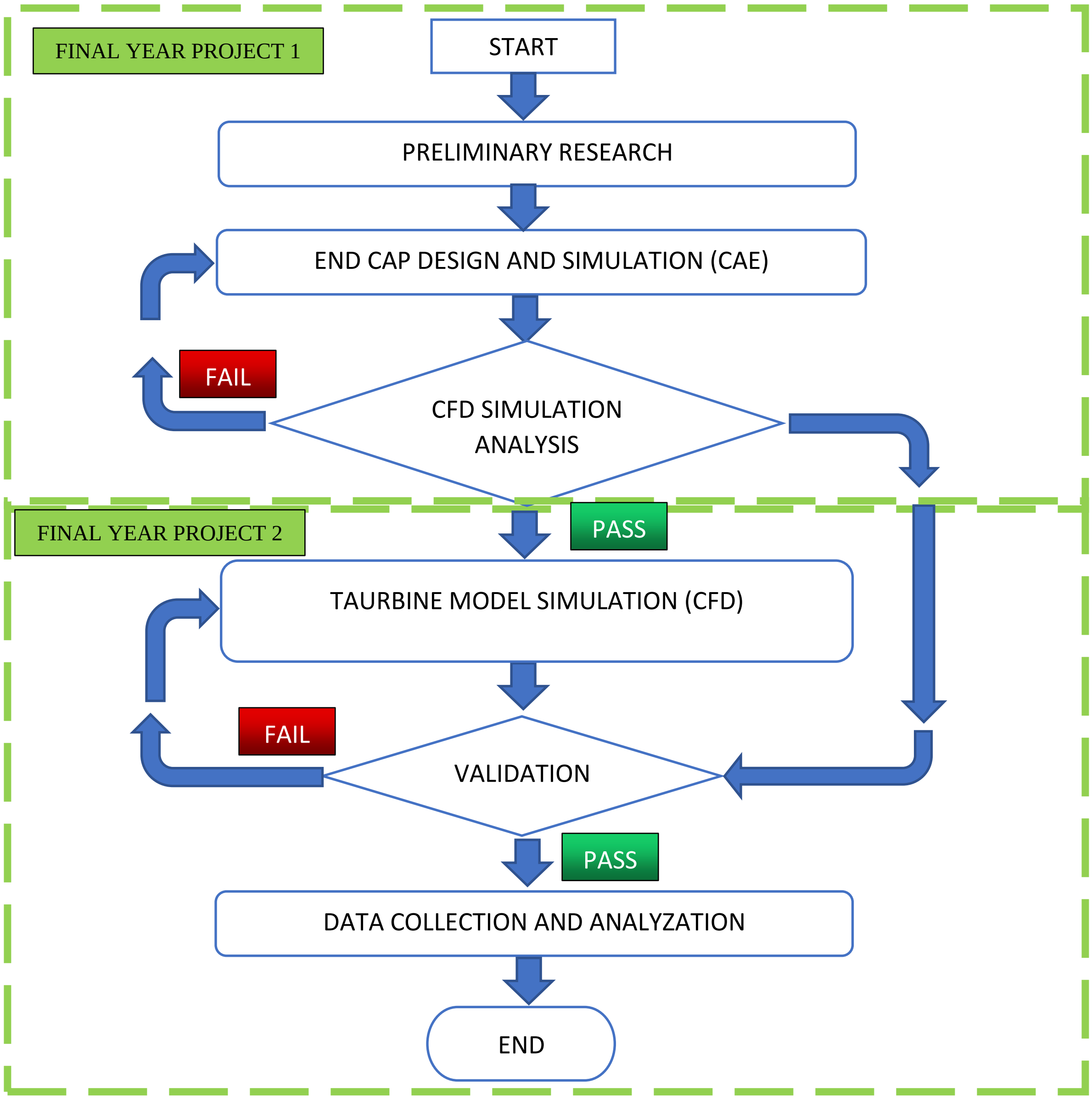


Figure 3.17 Turbine Model Simulation

3.5 Project Process Flowchart



3.6 Gantt Chart

3.6.1 PHASE 1: PROJECT PREPARATION (FINAL YEAR PROJECT 1)

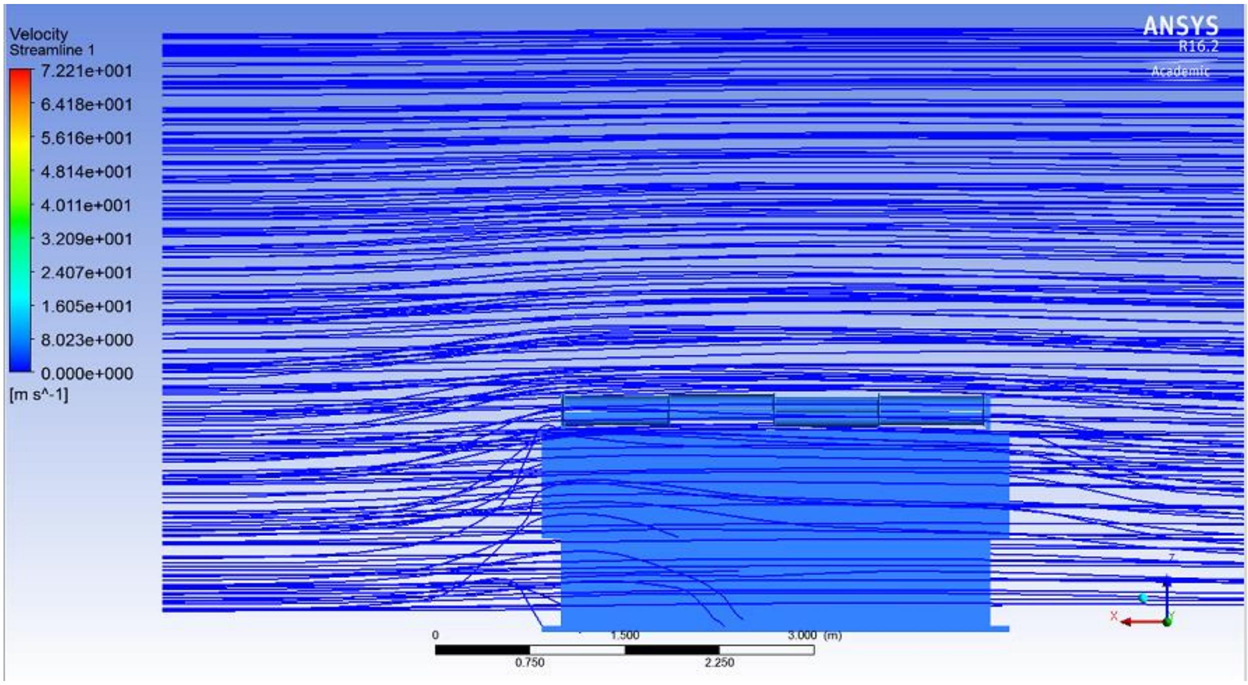
TITLE: PERFORMANCE OPTIMIZATION OF A ROOF TOP TRANSVERSE AXIS WIND TURBINE														
PROJECT ACTIVITY	WEEK													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
PHASE 1: PROJECT PREPARATION (FINAL YEAR PROJECT 1)														
PROJECT TOPIC SELECTION	■													
PROJECT OBJECTIVE AND SCOPE		■												
PRELIMINARY RESEARCH			■	■	■	■	■	■	■	■	■	■	■	■
PROGRESS ASSESSMENT 1						■	■	■						
END CAP DESIGN MODELLING									■	■	■	■	■	■
CFD SIMULATION									■	■	■	■	■	■
PROPOSAL DEFENSE										■	■			
PROGRESS ASSESSMENT 2												■	■	
INTERIM REPORT														■

<u>3.6.2 PHASE 2: PROJECT PREPARATION (FINAL YEAR PROJECT 2)</u>

TITLE: PERFORMANCE OPTIMIZATION OF A ROOF TOP TRANSVERSE AXIS WIND TURBINE														
PROJECT ACTIVITY	WEEK													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
PHASE 2: PROJECT EXECUTION (FINAL YEAR PROJECT 2)														
HOUSE MODEL CONSTRUCTION														
TURBINE MODEL SIMULATION														
DATA COLLECTION AND ANALYZATION														
MODIFICATION AND IMPROVEMENT														
PROGRESS ASSESSMENT 1														
DRAFT DISSERTATION														
PROJECT OUTCOME PRESENTATION														
PROGRESS ASSESSEMENT 2														
PROJECT DISSERTATION														

CHAPTER 4: RESULT AND DISCUSSION

4.1 Minimum Wind Speed (0.565 m/s)



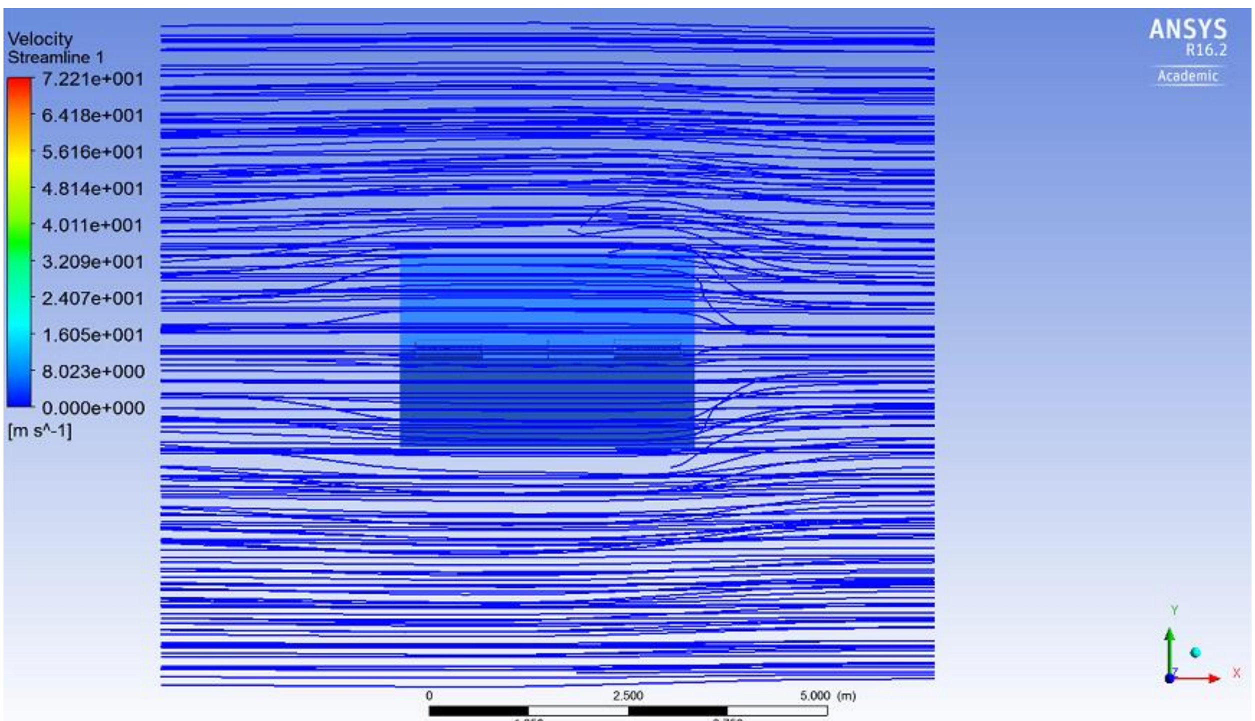


Figure 4.1 Minimum Wind Speed Model 1

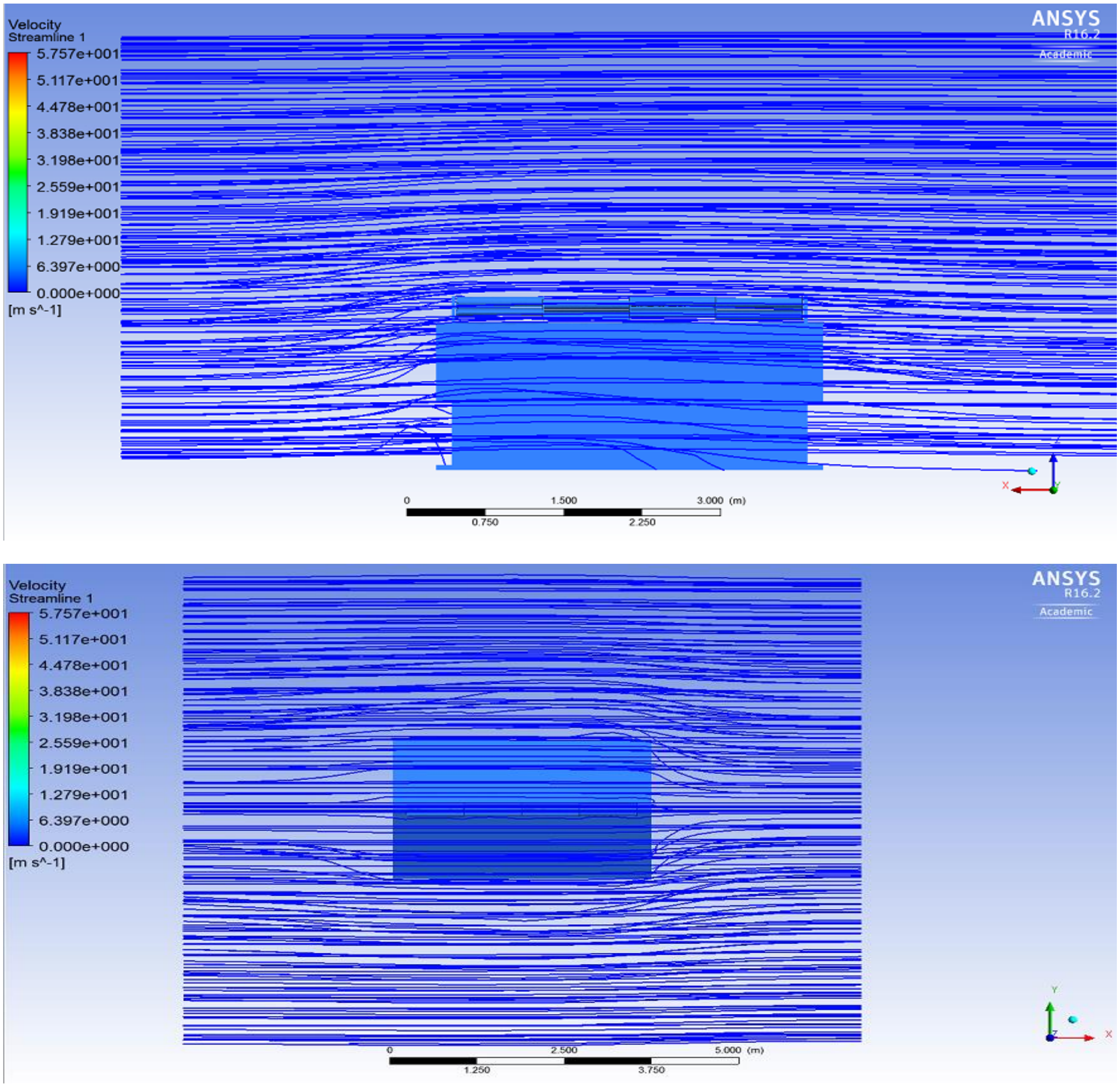


Figure 4.2 Minimum Wind Speed Model 3

As shown in Figure 4.1 and Figure 4.2, the wind speed with initial speed of 0.565 m/s are increasing when flowing over the turbine model due to the roof effect. For both model, simulations were conducted by using the same initial wind speed and house model dimension with the difference of end cap design. The wind flow is set to comes at 90-degree angle which is perpendicular to the wind turbine so that the effect of end cap could be observed. From this simulation, we could observe that different end cap design will cause the wind speed to be differ accordingly. Hence, for minimum wind speed, the end cap Design 1 are preferable than Design 3.

4.2 Maximum Wind Speed (2.525 m/s)

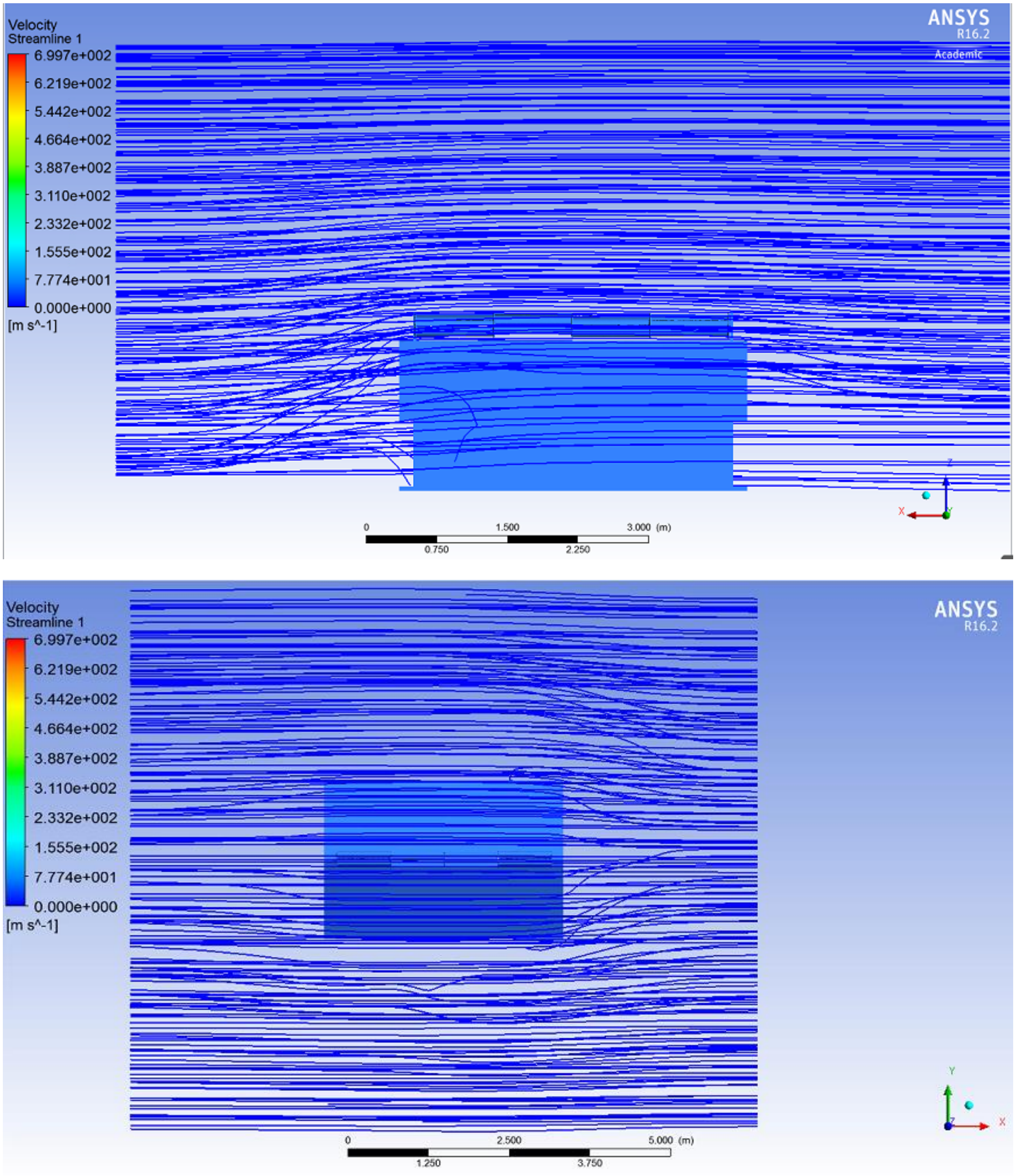


Figure 4.3 Maximum Wind Speed Model 1

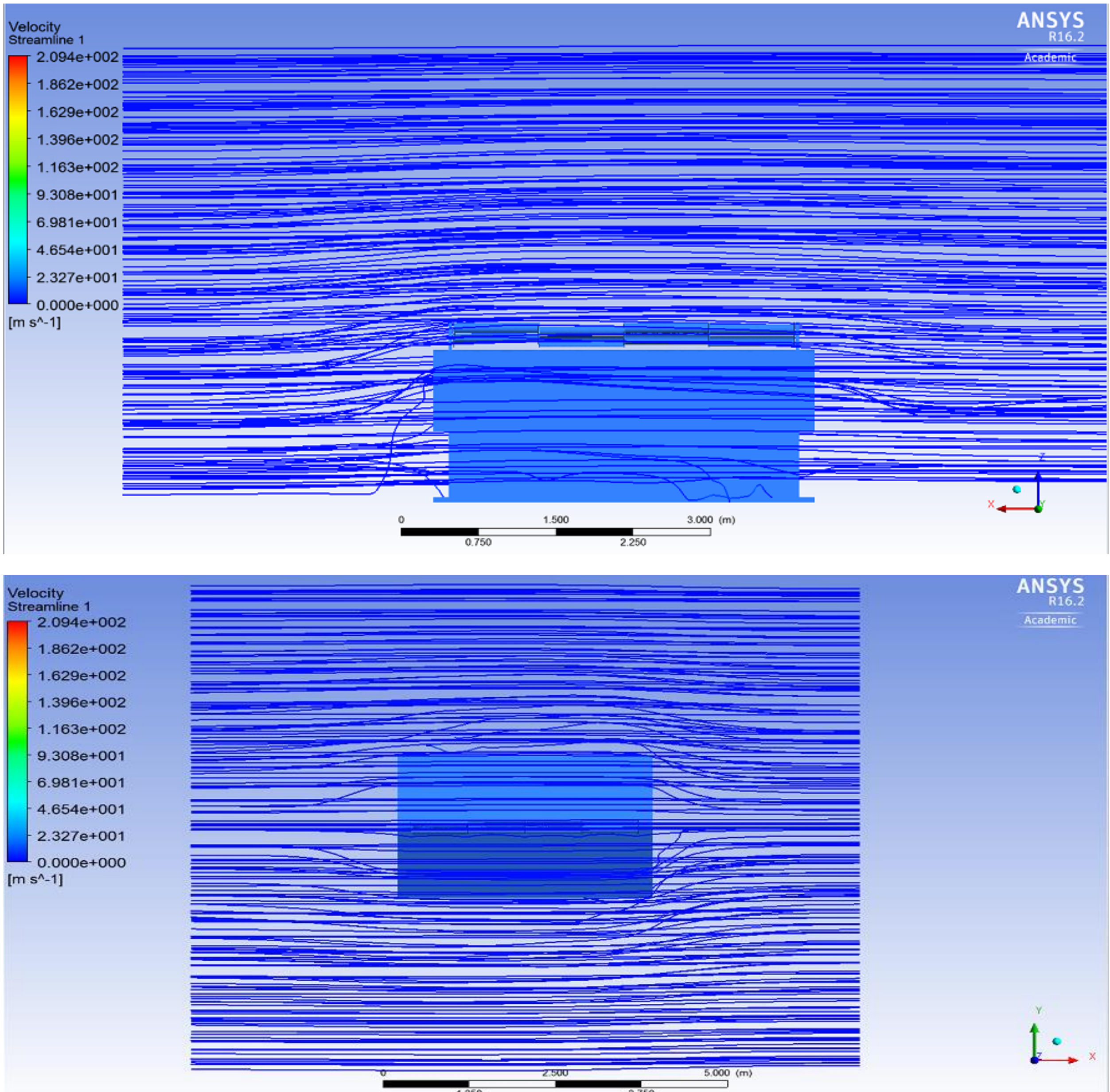


Figure 4.4 Maximum Wind Speed Model 3

As shown in Figure 4.3 and Figure 4.4, wind speed with an initial velocity of 2.525 m/s increases due to the roof effect when flowing over the turbine model. Simulation was performed for both models using the same initial wind speed and house model dimension with difference end cap design. The wind flow is set to comes at 90-degree angle which is perpendicular to the wind turbine so that the effect of end cap could be observed. We may note from this simulation that different design of end cap would cause the wind velocity to differ accordingly. Therefore, for this simulation, the end cap Design 1 is better for maximum wind speed than Design 3.

4.3 Average Wind Speed (1.446 m/s)

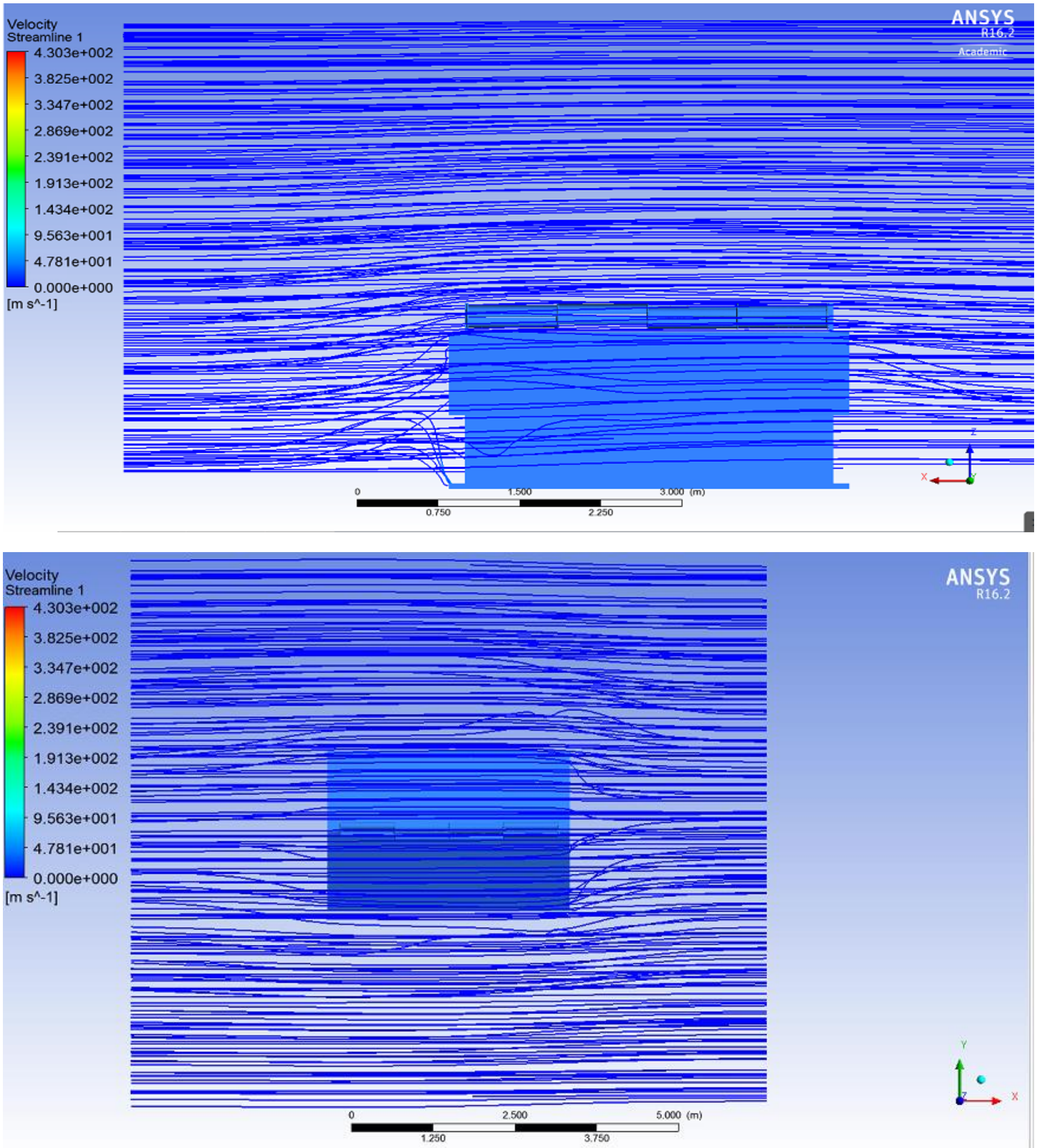


Figure 4.5 Average Wind Speed Model 1

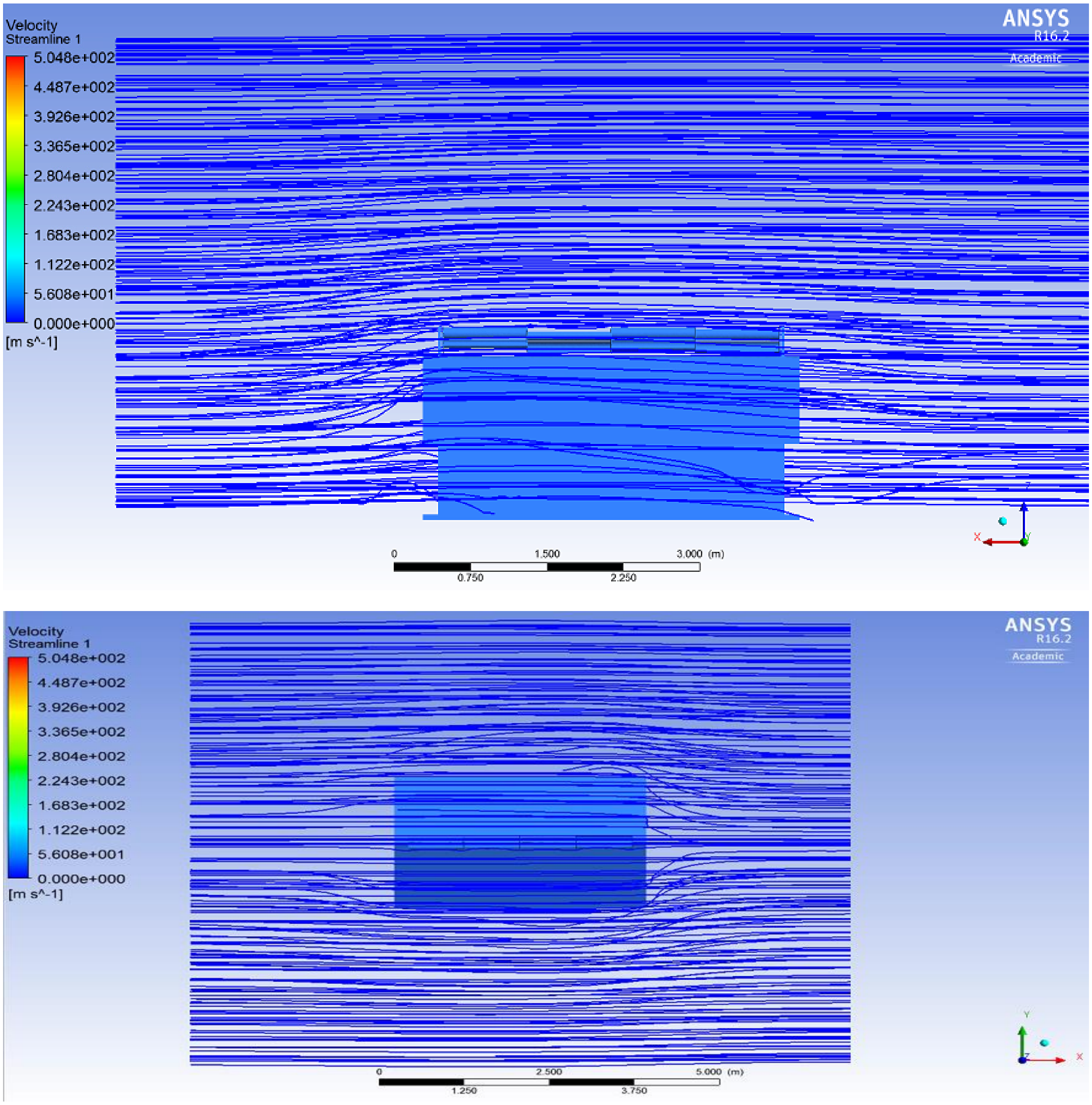


Figure 4.6 Average Wind Speed Model 3

As shown in Figure 4.5 and Figure 4.6, the wind speed with an initial speed of 1.446 m/s is rising due to the roof effect while flowing over the turbine model. Simulations for models was performed using the same initial wind speed and house model dimension with the difference in the design of the end cap. The wind flow is set to comes at 90-degree angle which is perpendicular to the wind turbine so that the effect of end cap could be observed. From this simulation, we can note that different design of the end caps will cause the wind speed to differ accordingly. So, for this simulation, the end cap Design 3 is the preferable design for average wind speed than Design 1.

CONCLUSION AND RECOMMENDATION

Based on the result of computational fluid dynamics (CFD) simulation for End Cap design, both design 1 and 3 shows promising effect. Both designs Flow Path Line which are showing the wind flow pattern and its speed when interact with the model of end cap designs are within this project's desired outcome which is to increase the wind speed that flow over it. Moreover, both designs Flow Simulation are also showing the wind flow contour and its speed when interact with the model of end cap designs according to this project's desired outcome. Hence, for Turbine Model simulation, Design 1 and Design 3 will be used along with the house model for simulation.

Based on the result of computational fluid dynamics (CFD) simulation for Turbine Model, Design 1 overpass Design 3 in every wind speed condition. For the minimum and maximum wind speed condition, Design 1 are more capable to increase the wind speed compare to Design 3. While for the average wind speed condition, Design 3 are more capable to increase the wind speed compare to Design 1. However, at average wind speed condition, the difference in wind speed of both design are paltry compare to the difference in wind speed at both minimum and maximum wind speed condition. Hence, the end cap Design 1 is more relevant to be used in every wind speed condition of this project compare to Design 3.

For recommendation, future improvement could be done on the simulation by using moving mesh instead of static mesh. This would enable the simulation to record the rotation per minute (rpm) of the turbine model. This type of simulation will be able to clearly depict the improvement causes by the end cap design towards the performance of wind turbine.

REFERENCES

[1] N. L. Panwar, S. C. Kaushik, S. Kothari, "Role of renewable energy sources in environmental protection: A review," in *Renewable and Sustainable Energy Reviews*, vol.15, no. 3, pp. 1513-1524, April 2011.

[2] M.K.Deshmukh, S.S.Deshmukh, "Renewable and Sustainable Energy Reviews," *European Journal of Electrical Engineering*, vol. 19, no. 5-6, pp. 367-374, 2017.

[3] F. Blaabjerg and K. Ma, "Future on Power Electronics for Wind Turbine Systems," in *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 1, no. 3, pp. 139-152, Sept. 2013.

[4] R. A. Deraman, "A Study on Blade Performance of Transverse Axis Wind Turbine Mounted on a Rooftop," B.S. Dissertation, Bachelor of Engineering (Hons), Mechanical Engineering Department, Universiti Teknologi Petronas, Perak, Malaysia, Sept 2013.

[5] G Kane - US Patent App. 12/456,400, 2010 - Google Patents

[6] R. E. Paggi - US Patent 8,545,298, 2013 - Google Patents

[7] R. Gupta, A. Biswas, K. K. Sharma, “Comparative study of a three-bucket Savonius rotor with a combined three-bucket Savonius–three-bladed Darrieus rotor,” in *Renewable Energy*, vol. 33, no. 9, pp. 1974-1981, Sept 2008.

[8] U. K. Saha, M. J. Rajkumar, “On the performance analysis of Savonius rotor with twisted blades,” in *Renewable Energy*, vol. 31, no. 11, pp. 1776-1788, Sept 2006.

[9] K. S. Jeon, J.I. Jeong, J. Pan, K. Ryu, “Effects of end plates with various shapes and sizes on helical Savonius wind turbines,” in *Renewable Energy*, vol. 79, pp. 167-176, July 2015.

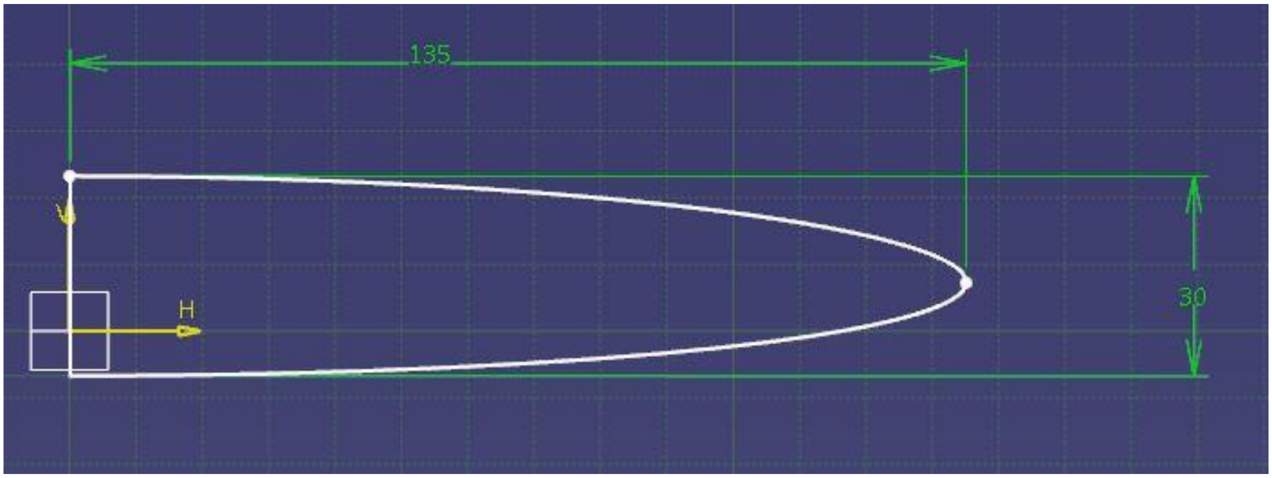
[10] M. R. ISLAM, "Assessment of Wind Energy Potential Mapping For Peninsular Malaysia," M.Eng.Sc. Dissertation, Master of Engineering Science, Faculty of Engineering, University of Malaya, Kuala Lumpur, Malaysia, 2011.

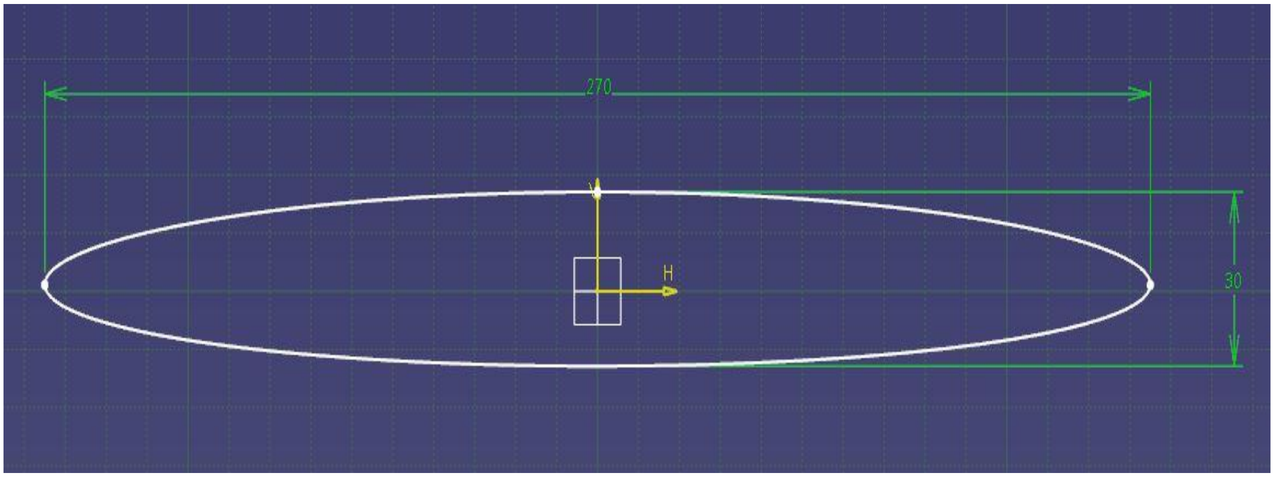
[11] CIDB Malaysia, “RBM Building System Design Standard and Specification,” in *RBM Building System*, 2010.

[12] Standard Malaysia, “CIS 18: 2018,” in *Standard Industri Pembinaan (Construction Insdustry Standard)*, 2018.

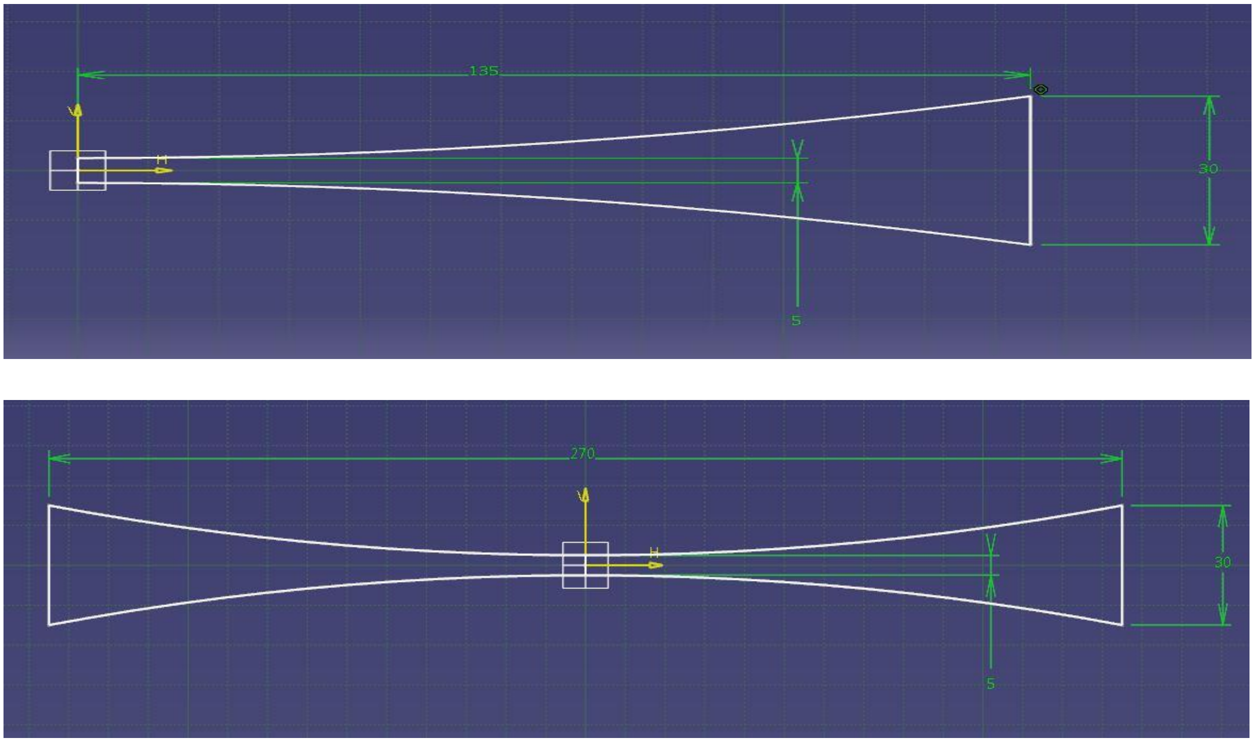
APPENDIX

End Cap Design Dimension

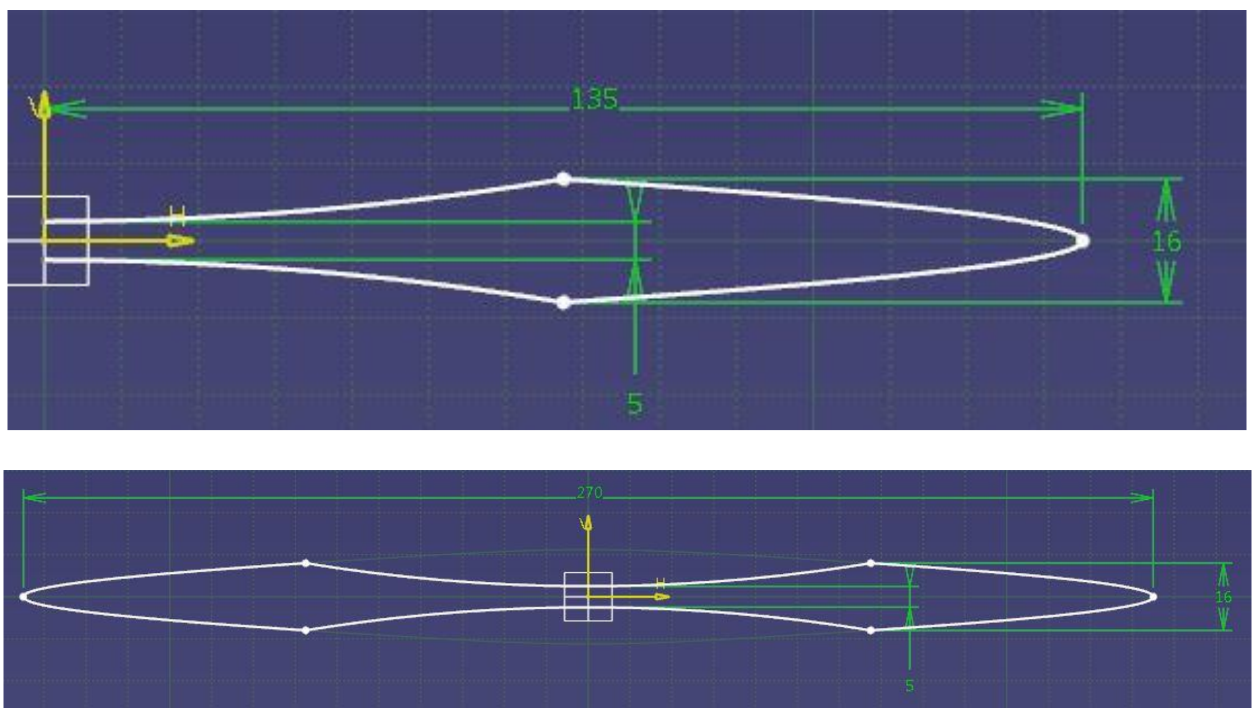




End Cap Design 1

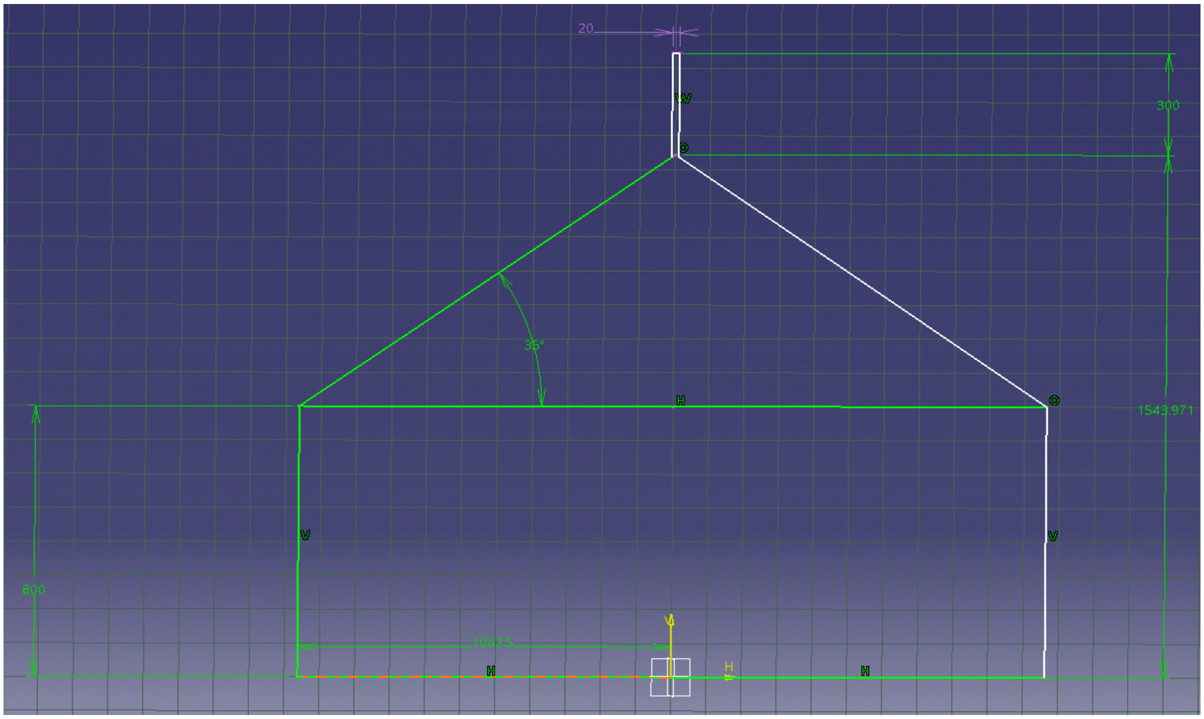


End Cap Design 2

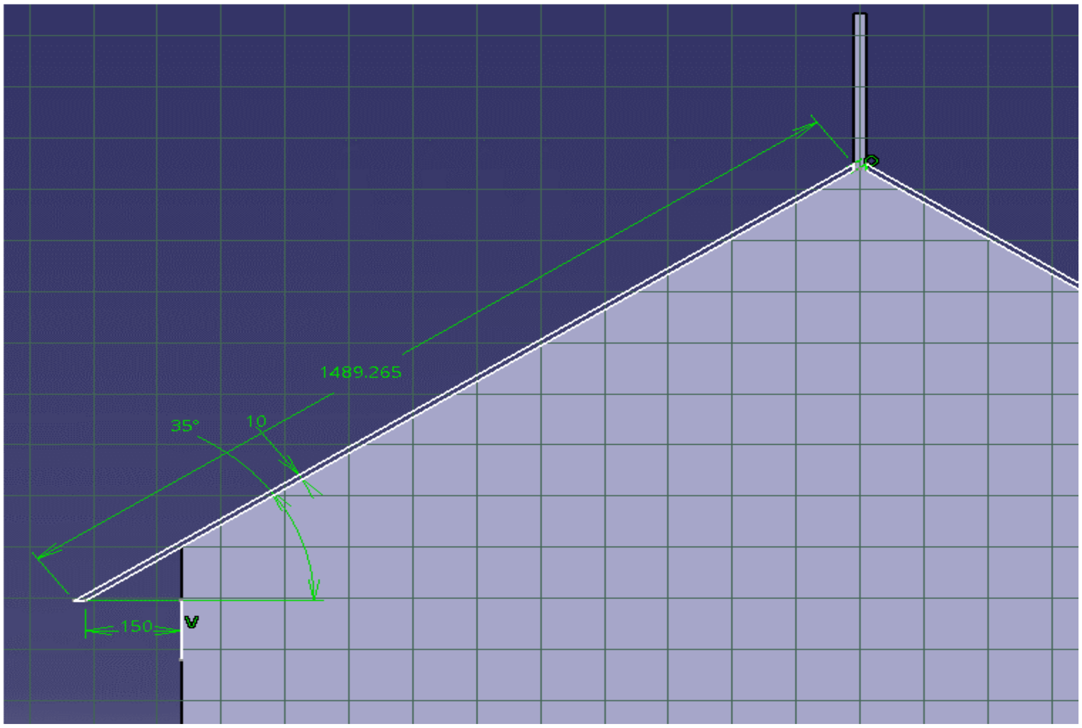


End Cap Design 3

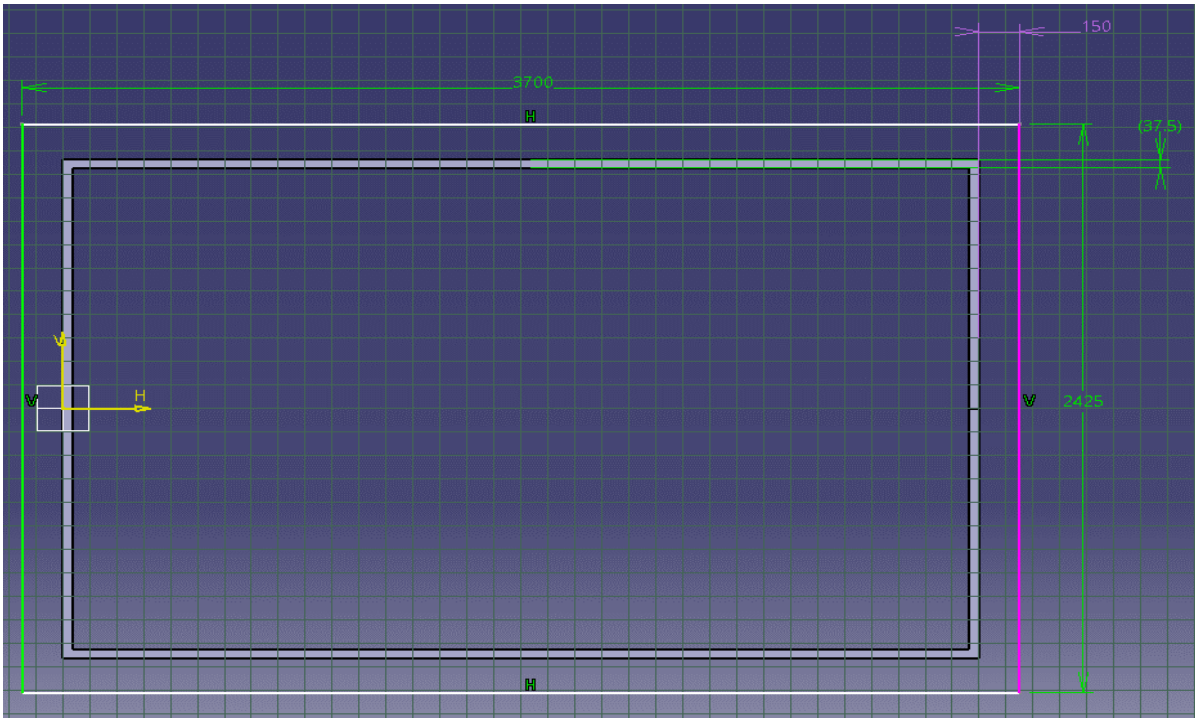
House Model Dimension



House Dimension Width & Height

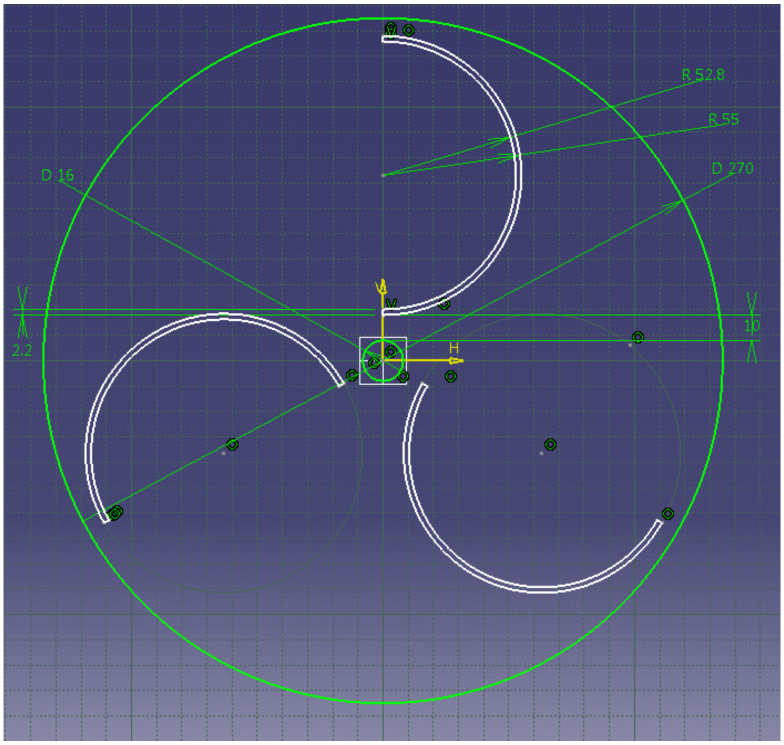


House Dimension Roof Angle, Thickness & Overhang

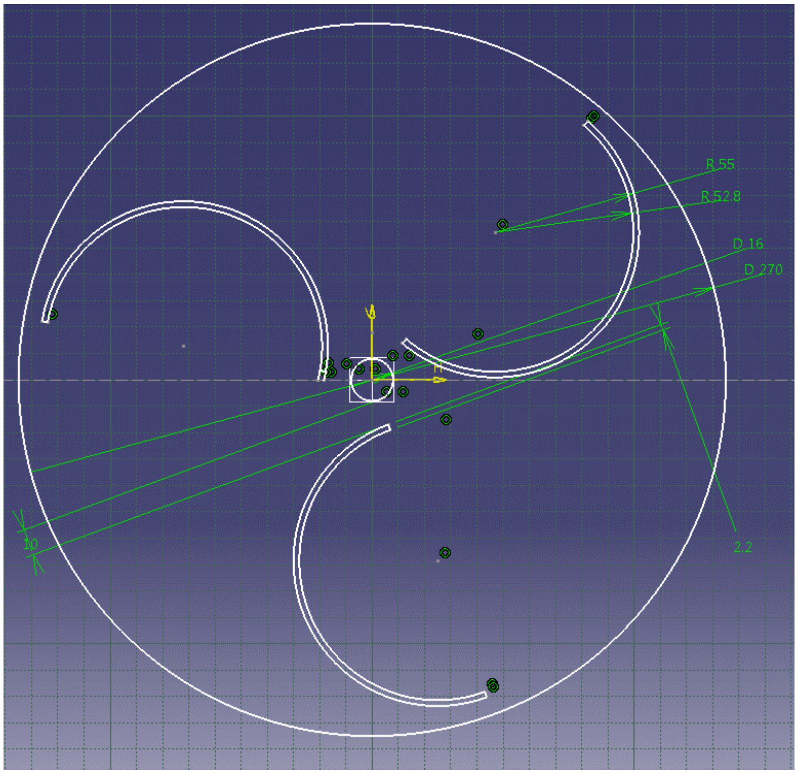


House Dimension Length and Wall Thickness

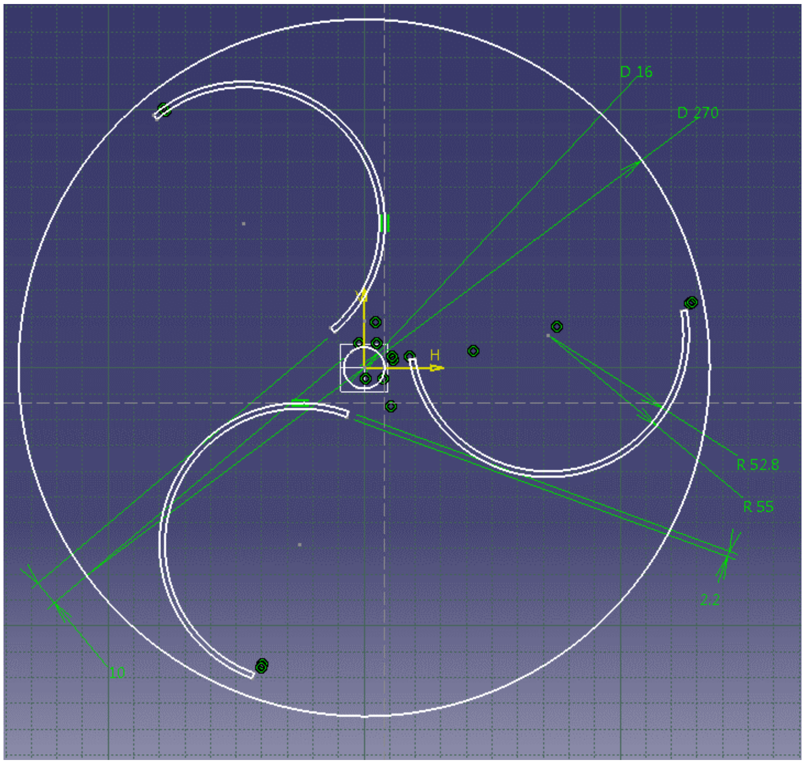
Turbine Blade Position and Dimension



Position 1 Dimension

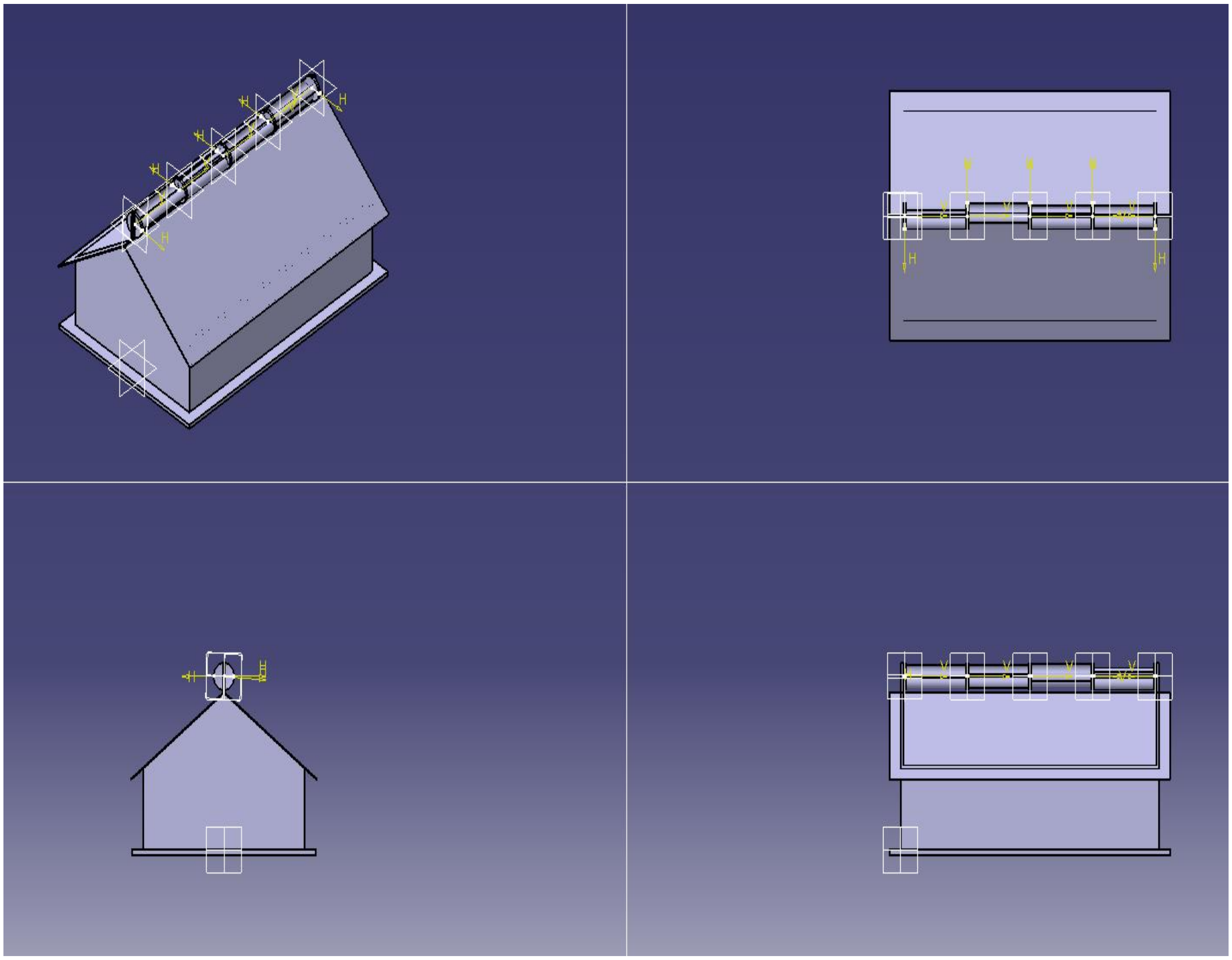


Position 2 Dimension



Position 3 Dimension

House Model with Turbine



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PERFORMANCE OPTIMIZATION OF A ROOF TOP TRANSVERSE AXIS WIND TURBINE

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MECHANICAL ENGINEERING
UNIVERSITI TEKNOLOGI PETRONAS
JANUARY 2020