Design, Rapid Prototyping, and Testing of the Darrieus Wind Turbine

by

Nik Mohd Faizal Bin Nik Abd Ghani

Dissertation report in partial fulfillment of
the requirements for the
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(Mechanical Engineering)

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
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Approved by,

____
(Dr. Azmi Abdul Wahab)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

JANUARY 2009

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

NIK MOHD FAIZAL BIN NIK ABD GHANI

Abstract

This report contains design, rapid prototyping and testing of the Darrieus wind turbine. The Darrieus wind turbine rotates in the same sense regardless of the direction of the air stream. In order to maximize its efficiency, several variations of this turbine design will be required for testing and evaluation. One of the objectives of this project is to test parameters that will affect the performance of the Darrieus wind turbine. Two parameters that will evaluated for evaluation is number of blades of the turbine and diameter of the turbine. Also for each turbine, the minimum wind speed required to start the rotation and the speed it can rotate with varying wind speed will be determined. Three prototypes are created for testing purposes. Results showed that the increase the diameter of the turbine will reduce the rotation of the turbine. In addition higher number of blades will increase the rotation of the wind turbine.

ACKNOWLEDGEMENT

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLE

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Prototyping is a complex and expensive process. Before a prototype can be created, several processes must take into consideration. In order to reduce cost and skip some of the processes, rapid prototyping technique can be use. Rapid prototyping is very useful when finalizing the geometry of a design, and this process can reduce the time and cost associated with finding the correct geometry of the final design.

This project will focus on the design, rapid prototyping and testing the Darrieus wind turbine. The Darrieus wind turbine can spin at many times the speed of the wind hitting. This type of turbines is not self-starting. Therefore a small powered motor is required to start off the rotation, and then when it has enough speed the wind passing across, the rotor starts to generate torque and the rotor is driven around by the wind.

Wind blowing across the blade generates lift on turbine. The advantages of the Darrieus turbine are the simplicity and low cost, Omni-directionality with respect to wind direction, and the vertical axis of rotation preclude the necessity for a gear box or a generator mounted adjacent to the turbine.

This wind turbine received little or no attention. The energy awareness of this decade and the projected shortages of energy have stimulated a revived interest in wind energy along with the Darrieus wind turbine.

1.2 PROBLEM STATEMENT

In designing several processes are required before a prototype can be created. Rapid prototyping machine can usually create any shape required. It also reduces the cost for prototyping. The Darrieus wind turbine is a complex shape and is a suitable subject for testing. Initial geometry and configuration of the turbine can be studied by producing prototyped using the rapid prototyping process.

1.3 OBJECTIVES

The objectives of study are as follows:

1. To study the existing types and design the Darrieus wind turbine.
2. To design the configuration of the blade of the Darrieus wind turbine
3. To fabricate the Darrieus wind turbine using rapid prototyping technique.
4. To test the Darrieus wind turbine prototype in the wind tunnel.
5. To analyse the data from the prototype.

1.4 SCOPE OF STUDY

In this project, the performance of the Darrieus wind turbine will be evaluated by the rotational speed of the turbine. The parameters that will be tested are:

1. Diameter of the wind turbine
2. Number of blades of the Darrieus wind turbine

CHAPTER 2

LITERATURE REVIEW

2.1 Darrieus wind turbine

2.1.1 The inventor of Darrieus wind turbine

Georges Jeans Mary Darrieus (1888-1979), is a French engineer who designed the first modern vertical axis wind turbine (patented 1931) [1]. Darrieus rotor is made of slender, curved, airfoil-section blades attached at the top and bottom of a rotating vertical tube (see Figure 2-1).

Figure 2-1 Darrieus wind turbine [1]

The Darrieus rotor is a vertical axis type of wind turbine (VAWT). It is powered by the lift forces generated from a set of airfoil blades so it can reach blade speed much higher than the blowing wind speed. It can have two to four blades, which form bows from the top of the tower to the machinery that is sited at ground level. The blades are symmetrical and very thin. The form directs the centrifugal forces to the point where they are connected to the central axis, so that the bending moments are minimized. In most material the tensile strength is stronger than the bending strength. A Darrieus turbine does not need much material relative to the power produce [2].

Compared to the more common horizontal axis turbine, the Darrieus turbine design has several attractive features. First, the blade operates at very high tension, so a relatively light, inexpensive blade is sufficient. Second, by locating the power train, generator, and controls near ground level, they are easier to construct and maintain (refer to Figure 2-2). However, a disadvantage of the Darrieus turbine is that it is not typically self-starting, requiring an induction motor connected to the local power network to initiate operation [3].

The major components of the Darrieus wind turbine are rotor blades, which will capture wind's energy and convert it to rotational energy of shaft. Shaft will transfer the rotational energy and generate torque to the generator. Guy wire is used to hold the tower steady (see Figure 2-2).

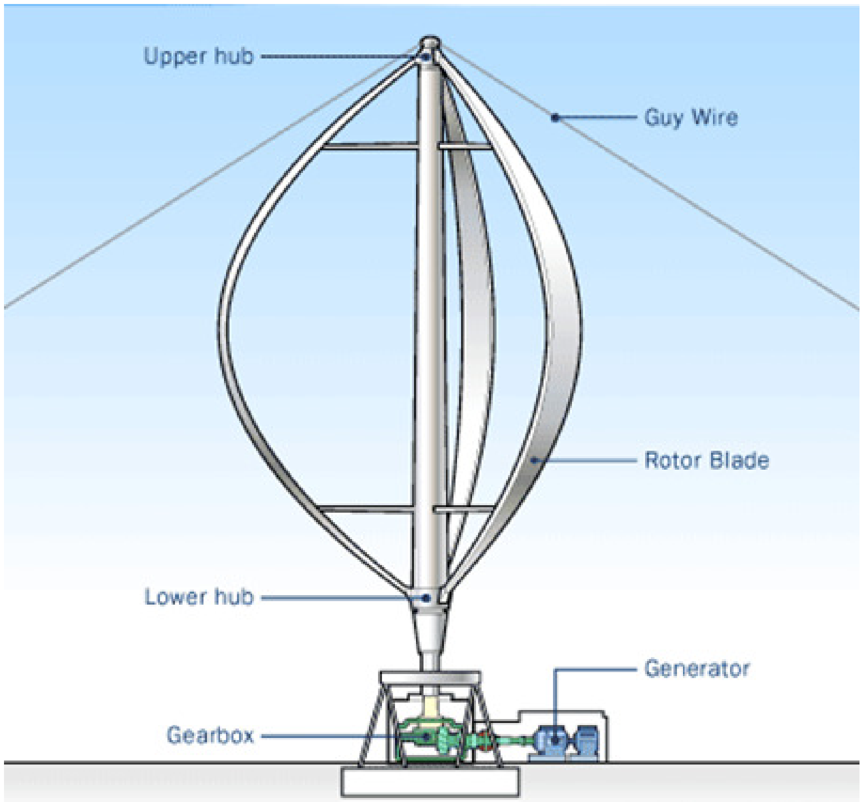

Figure 2-2 Component of Darrieus wind turbine [2]

The measurement of height and the diameter of the Darrieus wind turbine shown below (see Figure 2-3)

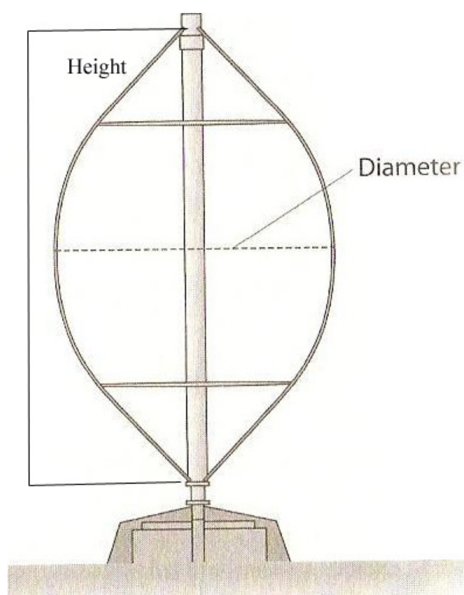

Figure 2-3 Dimension of the Darrieus wind turbine [2]

The blades of a Darrieus turbine can be canted into a helix, example three blades and a helical twist of 60 degrees. Since the wind pulls each blade around on both the windward and leeward sides of the turbine, this feature spreads the torque evenly over the entire revolution, thus preventing destructive pulsations. The skewed leading edges reduce resistance to rotation; by providing a second turbine above the first, with oppositely directed helices, the axial wind-forces cancel, thereby minimizing wear on the shaft bearings. Another advantage is that the blades generate torque well from upward-slanting airflow, such as occurs above roofs and cliffs.

The shape cross section and details are shown in Figure 2-4, Figure 2-5 and Table 2-1.

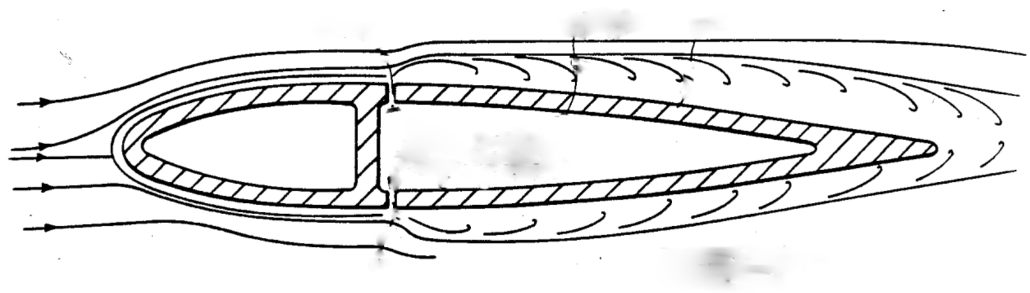

Figure 2-4 Blade cross sections [5]

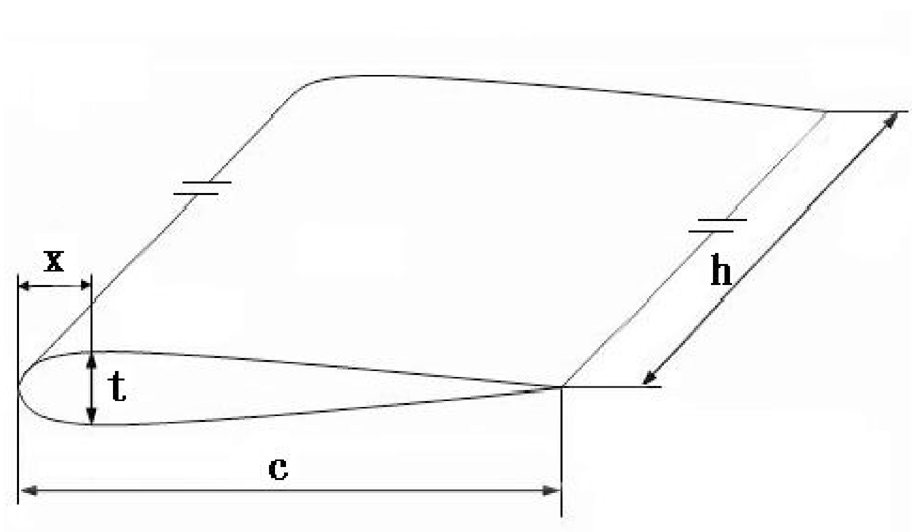

Figure 2-5 Blade notations [7]

Table 2-1 Blade notations and description [7]

Notation	Description
c	Blade Chord
t	Maximum thickness
x	Position of maximum thickness

2.1.2 Working principle of Darrieus wind turbine

The working principles for Darrieus wind turbine (see Figure 2-6), assume that the retarded wind in front of the rotor still remains straight. When the blades are moving much faster compare to the original undisturbed wind speed i.e. ratio of blade speed to freestream wind speed, tip speed ratio (TSR), TSR> 3, the picture above shows the velocity vector of the airfoil blades at different angular position. With such a high TSR, the airfoils will be 'cutting through' the wind with small angle of attack.

The resulting lift force always assists the rotor rotation while the drag force always opposes the rotation. As the lift zeroing at the left side (0 degree) and right side (180 degree) where the symmetrical airfoil moves paralleled to wind, the torque changes to negative around these position. At the near front (90 degree) and far back (270 degree) position, the lift component is much higher than the drag component, so positive torque is produced. The total torque per revolution will be positive with a good set of airfoils so the rotor will accelerate at the right direction [1].

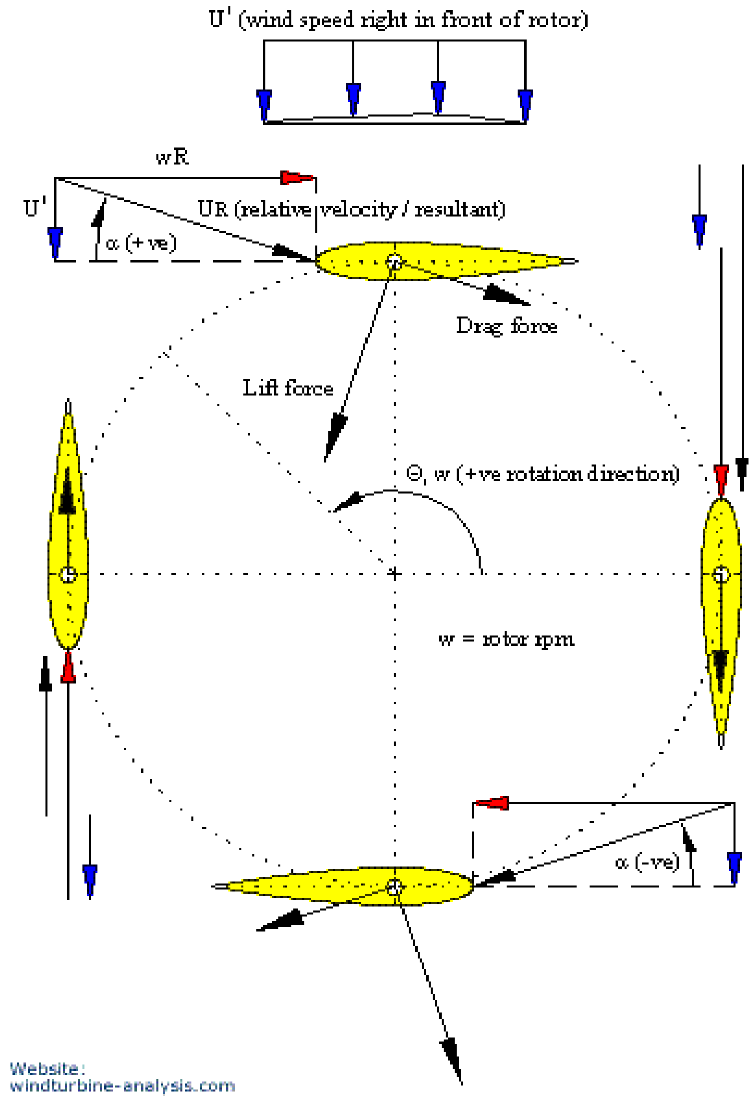

Figure 2-6 Working principle of Darrieus wind turbine [1]

During startup, the starting torque depends on the angular position of rotor with respect to the wind direction, so the rotor might rotate at the right direction straight away or wobble slightly before starting. Normally, the rotor will need some form of assistance to reach higher rotational speed before it begins to rotate by itself as the Darrieus rotor has very low torque at low TSR which can be easily worsened (till negative) by friction in the system [1].

2.2 Rapid prototyping concept

Rapid prototyping technique is used to create a prototype. Rapid prototyping is the automatic construction of physical objects using solid freeform fabrication. Rapid Prototyping can be defined as a group of techniques used to quickly fabricate a scale model of a part or assembly using three-dimensional computer aided design (CAD) data. The first techniques for rapid prototyping became available in the late 1980s and were used to produce models and prototype parts [4].

The primary advantages of additive fabrication are:

- its ability to create almost any shape or geometric feature
- To increase effective communication
- To decrease development time
- To decrease costly mistakes
- To minimize sustaining engineering changes
- To extend product lifetime by adding necessary features and eliminating redundant features early in the design.

Rapid prototyping takes virtual designs from computer aided design or animation modeling software, transforms them into thin, virtual, horizontal cross-sections and then creates each cross-section in physical space, one after the next until the model is finished. With additive fabrication, the machine reads in data from a CAD drawing and lays down successive layers of liquid, powder, or sheet material, and in this way builds up the model from a series of cross sections. These layers, which correspond to the virtual cross section from the CAD model, are joined together or fused automatically to create the final shape.

Rapid Prototyping has also been referred to as solid free-form manufacturing; computer automated manufacturing, and layered manufacturing. Rapid prototyping has obvious use as a vehicle for visualization. In addition, Rapid prototyping models can be used for testing, such as when an airfoil shape is put into a wind tunnel. Rapid prototyping models can be used to create male models for tooling, such as silicone rubber molds and investment casts. In some cases, the Rapid prototyping part can be the final part, but typically the Rapid prototyping material is not strong or accurate enough. When the Rapid prototyping material is suitable, highly convoluted shapes (including parts nested within parts) can be produced because of the nature of rapid prototyping.

Rapid Prototyping decreases development time by allowing corrections to a product to be made early in the process. By giving engineering, manufacturing, marketing, and purchasing a look at the product early in the design process, mistakes can be corrected and changes can be made while they are still inexpensive. The trends in manufacturing industries continue to emphasize the following:

- Increasing number of variants of products.
- Increasing product complexity.
- Decreasing product lifetime before obsolescence.
- Decreasing delivery time.

The basic methodology for rapid prototyping techniques can be summarized as follows:

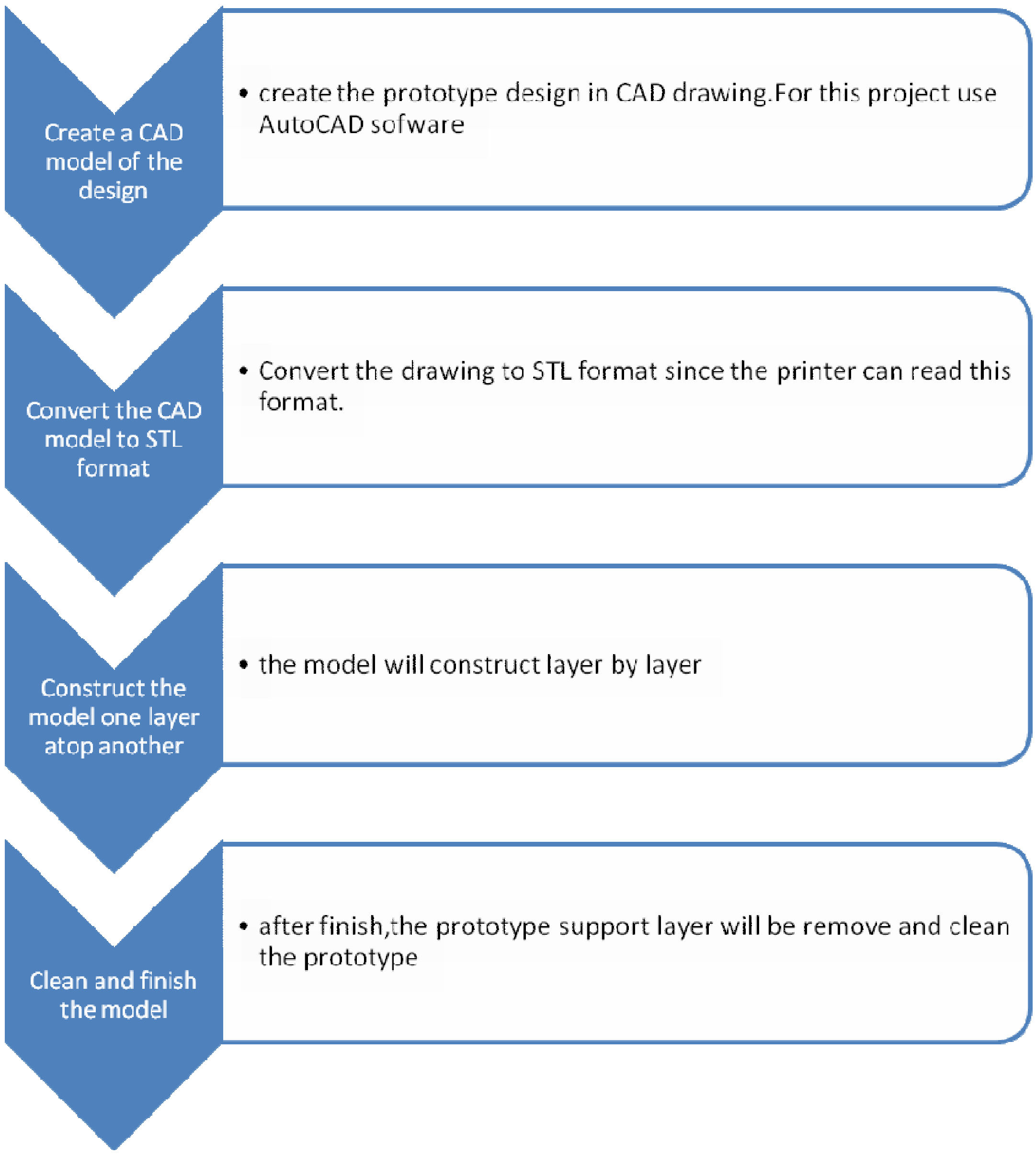

Figure 2-7 Rapid prototyping technique methodology

CHAPTER 3

METHODOLOGY

3 Process flow of the project

This chapter discussed the procedures involved in completing the project for the whole semester. There were procedures to be followed in order to carry out and implement the project. This was to ensure that the project can be accomplished within the given timeframe. The Gantt chart for two semesters was included in appendices. Process flows of the project are shown below (see Figure 3-1)

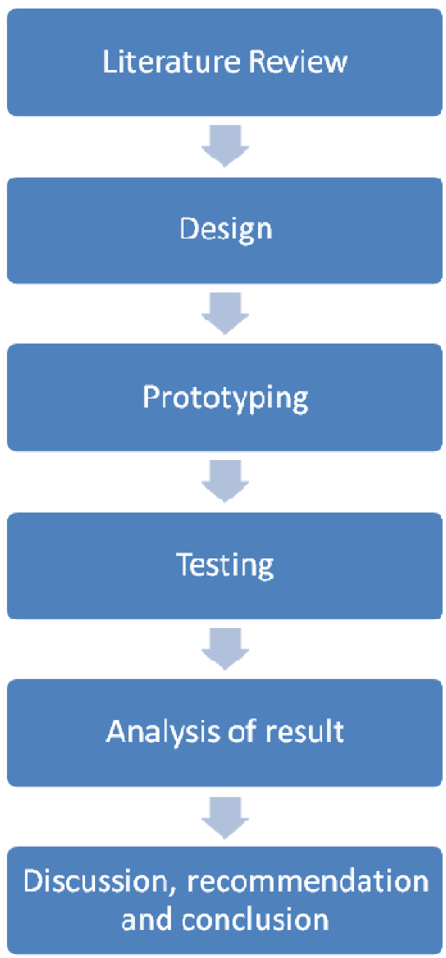

Figure 3-1 Process flow of the project

3.1 Literature Review

Literature review related the Darrieus wind turbine was taking place in this stage. Literature review for the design and review the evaluation for performance of the Darrieus turbine are from several sources such as from books, internet and research paper. In this stage, software and equipments needed to use in this project was also familiarized.

3.2 Design the prototype

AutoCAD software was used for design the prototype. The design dimension is based on the capabilities of the rapid prototype machine and wind tunnel testing area. The maximum dimension of the prototype that can be created is 200mm (L) X 250mm (W) X 200mm (H). The design that was used for testing is a scaled down model of the 2-blade 17m diameter Darrieus wind turbine used in Sandia National Laboratories, USA. The blade section of the turbine used a 0.54m chord. For evaluation process, several variations of the turbine was compared make such as the diameter and the height of the turbine.

There are three prototypes designed for testing purposes:

1. Darrieus wind turbine 95mm, 2 blade (refer Figure 3-2)

2. Darrieus wind turbine 155mm, 2 blade

3. Darrieus wind turbine 95mm, 3 blade

Drawings for each turbine are available in the appendix.

Figure 3-2 Darrieus wind turbine 95 mm, 2 blades

3.3 Create the prototype

After identifying the various designs for fabricate, the designs were selected for prototyping purposes. The designs were fabricated using rapid prototyping technique. The process used multi jet modeling. The models of a suitable scale and specification were used to evaluate the performance of the turbine.

The model of the rapid prototyping machine is Thermojet 3D printer (Figure 3-3). Each drawing was converted to STL format since the printer only can read this format. The converting was using the AutoCAD software since it has built-in software that will convert the previous DWG format to STL format.

The material used to create the prototype was Thermo Jet 88 (TJ88). Known as a wax co-polymer, it is essentially a modified wax with a melting point around 70^{o}C.These material was solid thermopolymer material. It contains hydrocarbons, amides and esters. TJ88 is harder but more brittle. These materials come in 3 colors -

neutral (cream), grey or black. High cleanliness is required to ensure the fine jets are not blocked. These products were not considered to be hazardous.

The data for thermojet 88:

Handling procedures	:	No special precautions are required.
Storage procedures	:	Store sealed in the original container. Keep separate from incompatible materials.
Storage temperature	:	< 38 °C / 100 °F

The CAD software will divide the model to the thin layer. Rapid prototyping is combining process, combining layers of wax to create a solid object. Printer would create the model layer by layer until completion. Rapid prototyping additive nature allows it to create objects with complicated internal features.

Figure 3-3 Thermojet 3D printer

Thermojet 3D printer capability:

- Dimension: 200mm (L) X 250 (W) X 200mm (H)
- Material use to create the prototype: Thermo Jet 88 (TJ88)

3.4 Test the prototype

A series of testing on the prototype was performed in the wind tunnel. Tools and equipment to be used were identified and familiarized prior to the laboratory tests to avoid malfunctioning of the system. Suitable equipments were used in the tests in order to get accurate results. The testing evaluated the speed of the turbine.

The testing would verify the hypothesis that is the performance of the turbine is based on number of blade and the diameter of the turbine. The testing would also verify the requirement wind speed for starting the turbine.

Every prototype would be tested at the same air speed and the corresponding rotational speed is recorded. Plots of turbine rotational speed as a function of wind speed would be produced.

To evaluate the effect of the diameter to the performance of the Darrieus wind turbine, the following turbine would be evaluated:

1. Darrieus wind turbine 95mm, 2 blade;
2. Darrieus wind turbine 155mm, 2 blade.

To evaluate the effect of the number of blades to the performance of the Darrieus wind turbine, these turbines would be tested:

1. Darrieus wind turbine 95mm, 2 blade;
2. Darrieus wind turbine 95mm, 3 blade.

The capability of wind tunnel used as follows:

- Testing area: 300mm (L) X 1500mm (W) X 300mm (H)
- Wind speed: max 50m/s

3.5 Analysis of Results

Results obtained from the laboratory tests would be analyzed and interpreted in order to see the performance of the wind turbine. The data required from the experiment were the minimum speed for turbine to start to rotate and the speed of the turbine with varying wind speed. The result of all testing were compiled and the overall conclusion will be produced based on the data obtained from laboratory test.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Design of the Darrieus wind turbine

The base design for the Darrieus wind turbine prototype was the 17m diameter prototype at Sandia laboratories.The scaled down model of the Sandia laboratories wind turbine were chosen since it has been built and tested.

Several considerations were taken before the prototypes were produced. The capabilities of the rapid prototyping machine and wind tunnel were taken into consideration. Based on these requirements, the model was scaled down for prototyping process. The maximum dimension that can be use for prototyping process and testing is **200mm (L) X 200mm (W) X 200mm (H)**.

The blade and rotor were joined together since separate parts created problems during prototyping and testing. The rotor will attach to ball and roller bearings (see Figure 4-1). The rotor diameters were made slightly smaller than the diameter of the ball bearing. Silicone adhesive was used to fill the gap between the rotor and the ball bearing.

Figure 4-1 Attachment of rotor to the ball and roller bearing

A base was required before the prototype can be tested in the wind tunnel. The base was used to hold the shaft of the turbine. The 28mm ball bearings were placed at the top and bottom of the shaft. Two ball bearings were use to support the turbine to rotate smoothly and prevent the shaft from breaking due to the vibration that occur during the rotation.

Figure 4-2 Base of the turbine

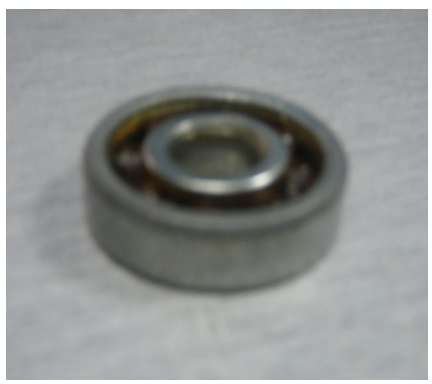

Figure 4-3 28mm ball bearing

Figure 4-4 Assembled of the turbine

The dimensions for the prototype are given in Table 4-1

Table 4-1 Dimension data for prototype

	Actual model (meter)	Scale down model (mm)
Height	36	190
Diameter	17	95

In addition to the scaled down prototype (see Figure 4-5), two other prototypes were fabricated with the same 190mm height. These prototypes were as follow:

1. Darrieus wind turbine 155mm, 2 blade
2. Darrieus wind turbine 95mm, 3 blade

Figure 4-5 Darrieus wind turbine 95 mm, 2 blades

The blade of the Darrieus wind turbine

The blade section of the turbine used was scaled down from the 0.54m chord model of the 2-blade 17m diameter Darrieus wind turbine used in Sandia National Laboratories, USA.

The dimensions of the blade use in his project:

Table 4-2 Dimension of the blade

	Actual model(m)	Scaled down(mm)
Blade Chord	0.54	10.4
Maximum thickness	0.15	3
Position of maximum thickness	0.19	3.4

Refer to appendix for the blade cross section drawing.

4.2 The performance of the wind turbine

4.2.1 Minimum speed for turbine start up

From the experiment, the turbine would not rotate unless forced. In order to conduct the experiment, the rotor would be forced to rotate while the wind tunnel is running. The rotor was nudged with a long stick with the wind tunnel running.

4.2.2 Effect of turbine diameter

The following data (Table 4-3) was obtained to study the effect of diameter on turbine rotational speed.

Table 4-3 Experiment data of the diameter parameter

Wind speed(m/s)	Rotational speed(rpm)	
	diameter 95mm	diameter 155mm
5	15	12
10	20	16
15	22	17
20	22	20

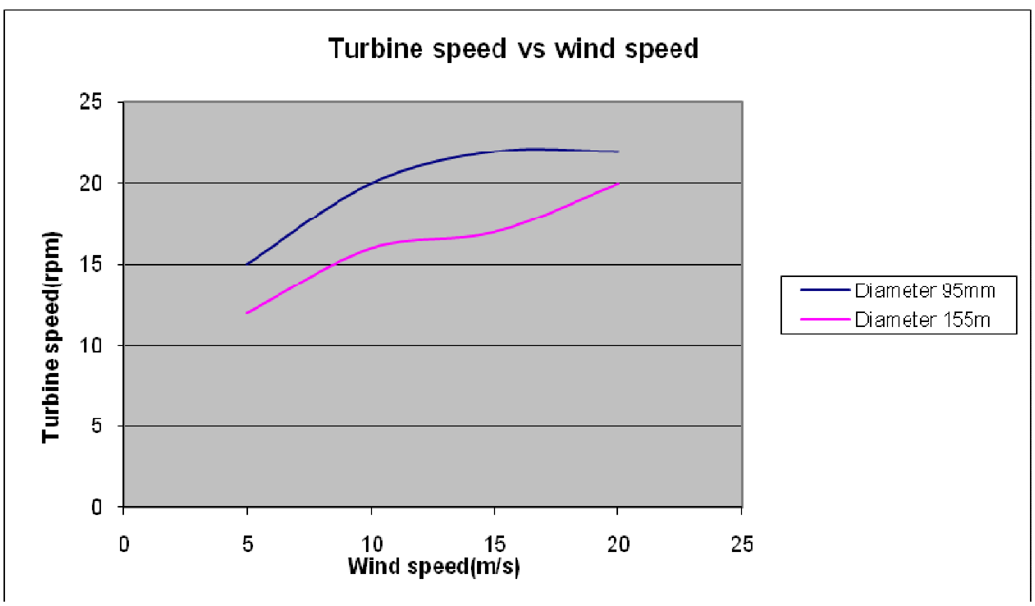

Figure 4-5 Graph of diameter turbine speed vs wind speed for two different turbines

From the Figure 4-5 above, the increase in turbine diameter decreased the rotational speed of the turbine. The drag force generate from the larger blades appeared to slow the turbine

4.2.3 Effect of number of blades

The following data (Table 4-4) was obtained to study the effect of numbers of blades on turbine rotational speed. This data is shown graphically in Figure 4-6.

Table 4-4 Experiment data of the number of blade parameter

Wind speed(m/s)	Rotational speed(rpm)	
	2 blades	3 blades
5	15	17
10	20	22
15	22	25
20	22	25

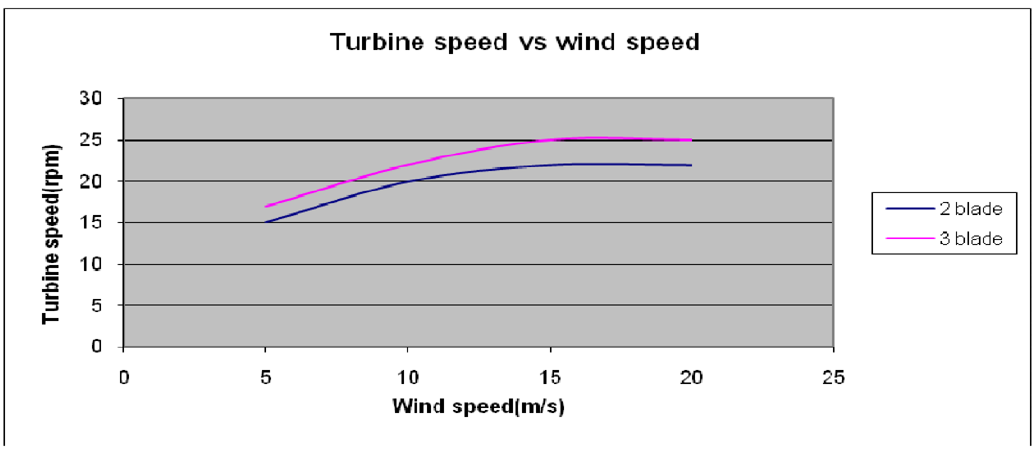

Figure 4-6 Graph of turbine speed vs wind speed for different number of blades

From Figure 4-6 above, the additional number of blade increased the rotational speed of the wind turbine. The increase in contact area of the blade with the air stream resulted in higher rotational speed. For 3-blade turbine, the angle cover for each blade is minimal compare with 2 blades. With small angle cover, the drag force generated from the blade would push the shaft faster and resulted in higher revolution compared with 2-blade turbine at the same wind speed.

CHAPTER 5

CONCLUSION AND RECOMENDATION

In conclusion, the objectives of these projects were achieved. The objectives of the study were as follow:

1. To study the existing types and design the Darrieus wind turbine.
2. To design the configuration of the blade of the Darrieus wind turbine
3. To fabricate the Darrieus wind turbine using rapid prototyping technique.
4. To test the Darrieus wind turbine prototype in the wind tunnel.
5. To analyse the data from the prototype.

Experiment work of this project was done successfully. Three designs of the Darrieus wind turbine were created for testing purposed. The prototypes were created using the rapid prototyping technique and it was tested in the wind tunnel. The results showed that the additional number of blade will increase rotational speed of the turbine and furthermore, the increase in diameter of the turbine will reduce the rotational speed of the wind turbine

Based on the research, the Darrieus wind turbine has several advantages which are listed below:

1. They need no tail or yaw mechanism to orient them into the wind and the power generated can be easily transmitted via the vertical shaft.
2. Maintenance and construction the power train, generator, and controls near the ground level are easier since there would be no need to place the major components at higher locations.
3. Darrieus wind turbine was Omni-directional with respect wind direction.

Capabilities of the rapid prototyping techniques can be summarized as follows:

1. This technique can virtually create any shape that need to be prototyped.
2. Design should consider the waste parts that were not used. The waste portion should be minimized in order to reduce cost.
3. The minimum thickness the rapid prototyping machine can print is 0.7mm but at this thickness, the prototype will be brittle.

Some recommendations for future work are as follows:

1. To model and built additional configurations of the Darrieus wind turbine for further testing.
2. To manufacture actual prototypes using suitable materials to test the actual capabilities of the Darrieus wind turbine.

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APPENDICES

Table 1: Gantt chart semester 1

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10		11	12	13	14
1	Selection of Project Topic	■										Mid-semester break				
2	Preliminary Research Work		■	■	■											
3	Submission of Preliminary Report				●											
4	Project Research Work (design)					■	■	■	■	■	■					
5	Submission of Progress Report								●							
6	Seminar								●							
7	Project Research work continues(fabricate)												■	■	■	■
8	Submission of Interim Report Final Draft														●	
9	Oral Presentation															●

● milestone

■ Process

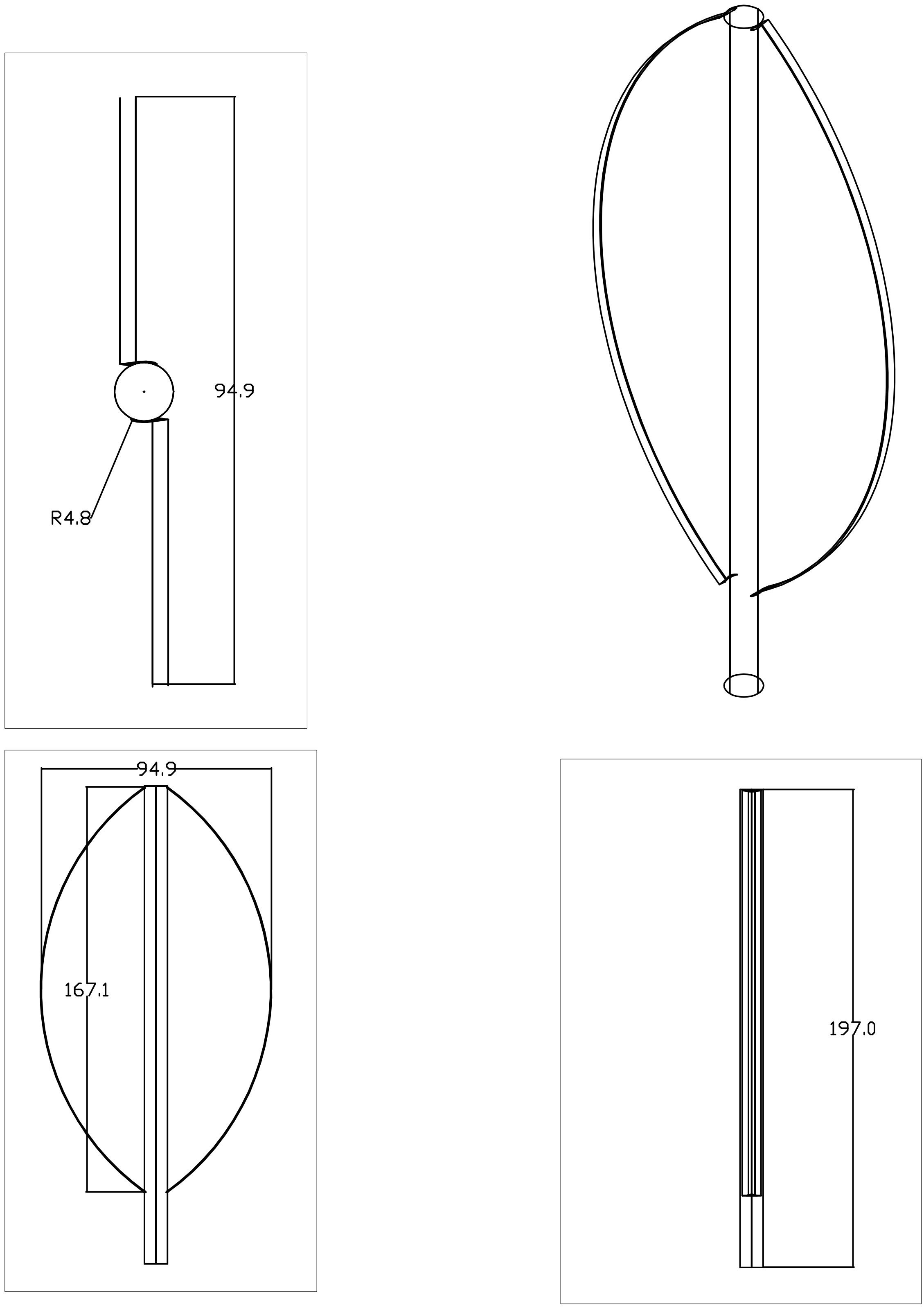
Table 2: Gantt chart semester 2

No.	Detail/ Week	1	2	3	4	5	6	7	8	9		10	11	12	13	14
1	Fabricate the Prototype	■	■	■	■						Mid-semester break					
2	Submission of Progress Report 1				●											
3	Testing the Prototype				■	■	■	■	■	■		■				
4	Submission of Progress Report 2								●							
5	Seminar									●						
6	Analyze the result/report writing									■		■	■	■	■	
7	Poster Exhibition											●				
8	Submission of Dissertation														●	
9	Oral presentation															●

● milestone

■ Process

RevNo	Revision note	Date	Signature	Checked



Itemref	Quantity	Title/Name, designation, material, dimension etc	Article No./Reference

Designed by	Checked by	Approved by - date	File name	Date	Scale
NIK	AAW	10/03/09	95mm,2 blade	06/01/09	N.T.S

NIK

DARRIEUS WIND TURBINE 95mm

DIMENSION IN MM

Edition	Sheet
0	30

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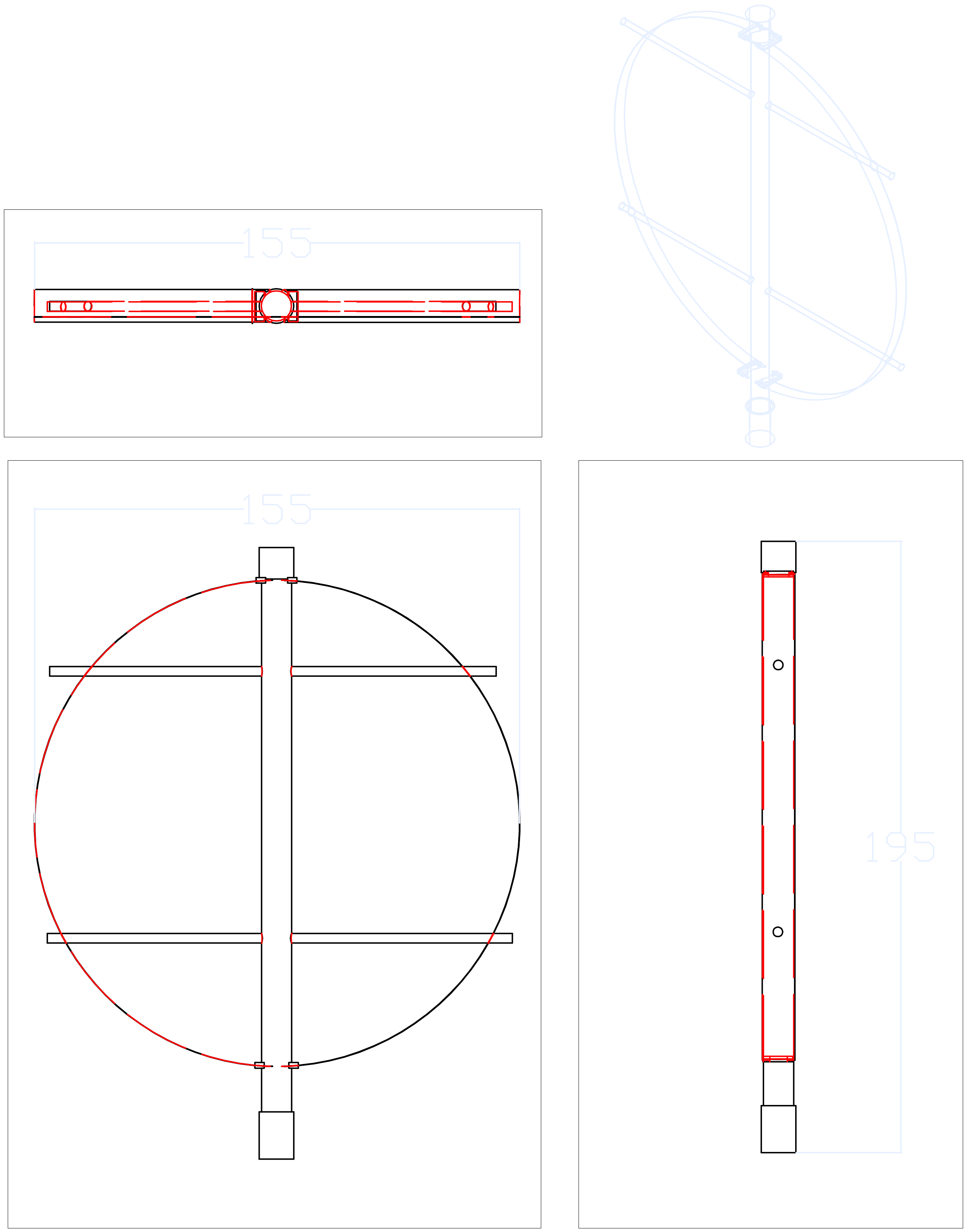


Itemref	Quantity	Title/Name, designation, material, dimension etc	Article No./Reference

Designed by	Checked by	Approved by - date	File name	Date	Scale
NIK	AAW	10/03/09		06/03/09	N.T.S

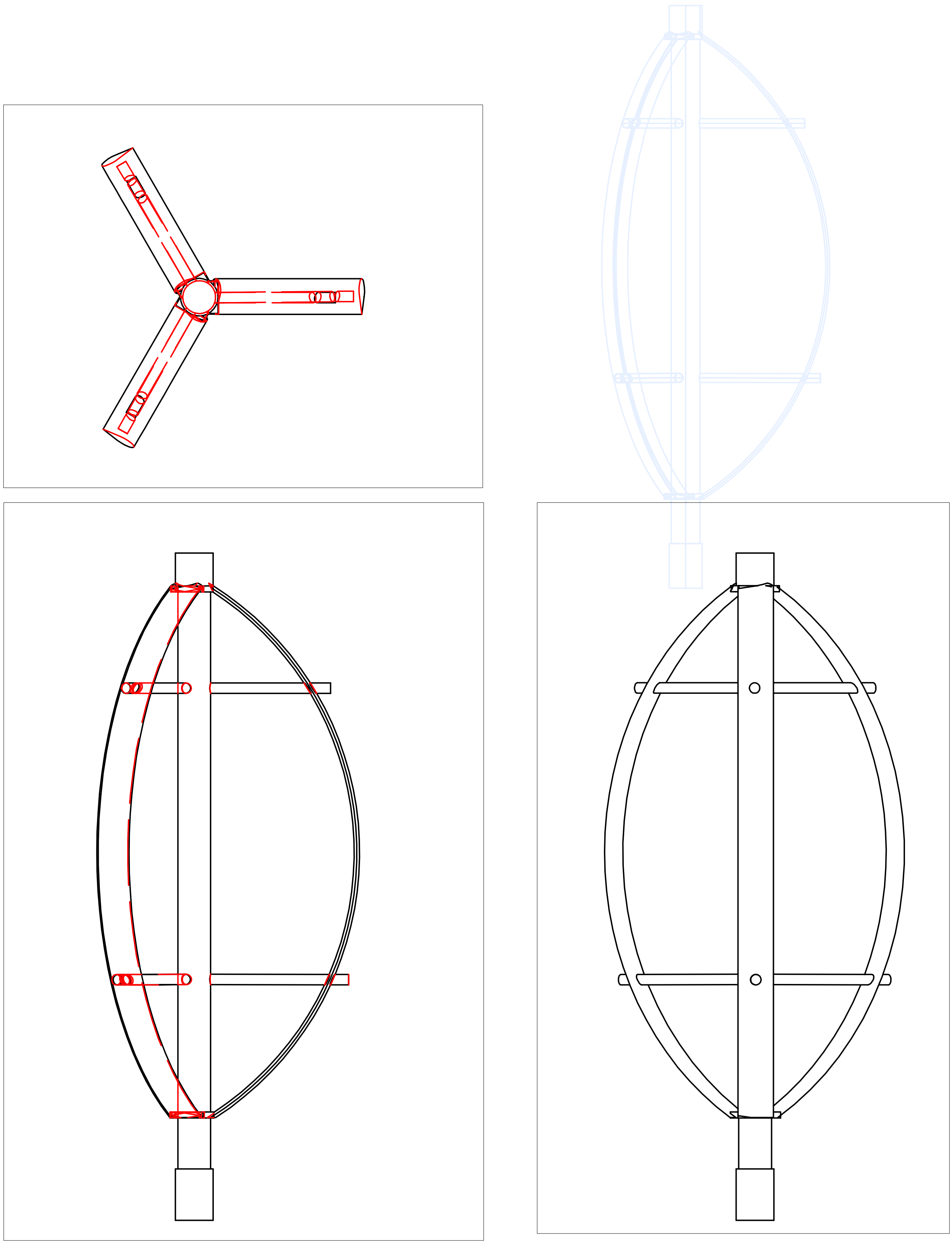
NIK

DARRIEUS WIND TURBINE 155mm

DIMENSION IN MM

Edition	Sheet
2	31

RevNo	Revision note	Date	Signature	Checked



Itemref	Quantity	Title/Name, designation, material, dimension etc	Article No./Reference

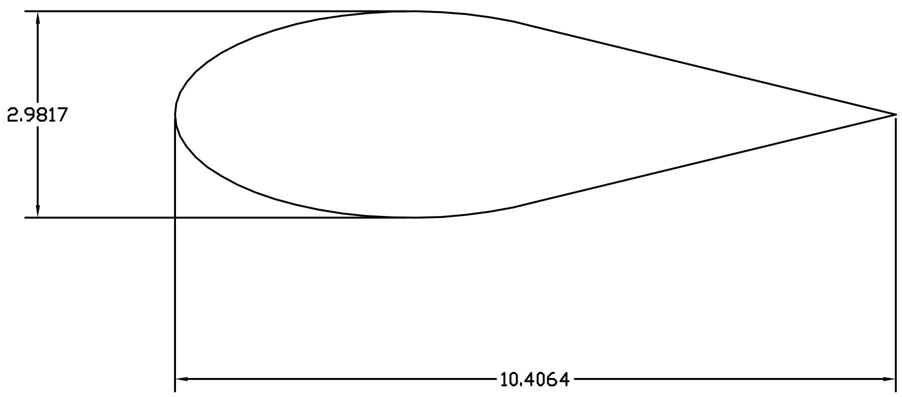
Designed by	Checked by	Approved by - date	File name	Date	Scale
NIK	AAW	10/03/09		06/01/09	N.T.S

NIK

DARRIEUS WIND TURBINE 95MM

	Edition	Sheet
DIMENSION IN MM	3	32

RevNo	Revision note	Date	Signature	Checked



Itemref	Quantity	Title/Name, designation, material, dimension etc	Article No./Reference

Designed by	Checked by	Approved by - date	File name	Date	Scale
NIK	AAW	10/03/09	THE BLADE CROSS SECTION	03/06/09	N.T.S

NIK

BLADE CROSS SECTION

Edition	Sheet
1	33