DESIGN AND CONSTRUCTION OF VERTICAL TURBINE FOR WIND POWER FARMING

By

ROHAIDA IDAYU NAWI

DISSERTATION

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
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Universiti Teknologi Petronas
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved:

Dr. Saeed Ul-Hasan Naqvi
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

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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.

Rohaida Idayu Nawi

ABSTRACT

Renewable energy is the term used to describe energy that comes from sources whose supplies are regenerative and virtually in exhaustible. Among these sources are sunshine, wind, water, vegetation and the heat of the earth. A project involving renewable energy, specifying in wind energy system has been entitled. The scope of this project may cover understanding the theory of wind energy resources and the working principles of wind turbines, applies the theory into practical and study the variety of wind turbines available, investigate and make a design comparison for the best power output; efficiency. The aim is to come out with a design which practical, high efficiency and low dependency on air flow. Based on these criteria, Tesla Turbine has been chosen. During this project several methods have been carried out in completing the task; consists by doing literature review and calculations. The final outcome combine typical Tesla Turbine with another part that functioning as to maximize the air flow before entering the turbine. This element may know as the wind-catchment area which applies the theory of temperature difference. The sun will heat up the air inside the catchment area, and the difference will result in high pressure air. This hot air will generate the Tesla Turbine; which is the main part of the project.

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CHAPTER 1
INTRODUCTION

This project is dealing with renewable energy system that uses wind power as the source. However the scope has been narrowed down to study only the vertical-axis machine. After being through a lot of discussion and considering many alternatives, the design has been divided into two related parts. Pondering on a few important factors like, practicality, efficiency and realism; the first part is the design and construction of Tesla turbine and second is the testing. This project has continued for two semesters; giving an opportunity to develop a design with better performance. Based on the literature survey and experimental results, enhanced performance has been attempted.

1.1 Background of Study

Renewable energy includes all sources of energy that are captured from on-going natural processes, such as solar power, water flow in streams (hydro power), biomass, bio-diesel, geothermal heat flow and wind power.

In the Asian-Pacific region, Southeast Asia is, as a whole, an energy surplus region with a variety of energy resources. This region is pioneering the application of, and trade in, renewable energy equipment. Partly because countries such as, Indonesia, Philippines, Thailand and Malaysia have been at the forefront of some of the region's effort to develop both the technology and the markets for the products under review, also their potential as producers, users and traders.

Renewable energy resources may be used directly, or used to create other more convenient forms of energy. Examples of indirect use which require energy harvesting are electricity generation through wind turbines. A wind turbine or wind generator is a device for converting wind power to mechanical rotation with a low velocity turbine designed for compressible fluids (air).

Like almost all other forms of renewable energy sources, wind energy also comes from the Sun. About 1 to 3 percent of the energy from the Sun is converted into wind energy. Most of this wind energy is at high altitudes where continuous wind speeds of over 44.48 m/s (100 mph) are common. Eventually, the wind energy is converted through friction into diffuse heat all through the earth's surface and atmosphere [10].

In the process of wind generation, sunlight heats different parts of the earth surface differently. Land is heated more quickly during the day (and cools faster during the night) than the sea, and areas near the equator are heated more than areas near the poles. The heated surface heats the air above it, which rises to about 10 km (6 miles) altitude (the top of the troposphere) and then spreads out to cooler areas where it falls. This convection system is what drives the earth's winds. The change of seasons, the spin of the earth, and the friction of wind over mountainous areas are some of the many factors which complicate the flow of wind over the surface.

At present, the use of wind turbines in Malaysia is negligible. The potential of wind systems for rural areas could be viable option for mechanical energy applications such as water pumping and to produce low power electricity in rural areas on the east coast of West Malaysia and in some areas of Sabah and Sarawak. Typical demands and applications for wind energy systems in Southeast Asia per unit are presented in Table 1 and Table 2 [1].

Table 1 Typical Energy Demands per Unit

Application	*Use*	*Average daily energy demand (kWh/day)*
Water Pumping	Village water supply	3
Refrigeration	Food Storage, drug and vaccine preservation	0.3 - 1
Lighting	Homes	0.1 – 0.5
	Institutions	0.2 - 1
Communications	Educational, TV, rural	0.1 – 0.4

	telephones, radio transmitters	

Table 2 Typical Applications of Wind Turbines

Typical rated power in 12m/s	*Typical use*
50W	Battery charging for lighting and communications in remote locations
1kW	Multi-battery charging and communications
10kW	Heating and multi-electrical uses, probably with some battery storage
50kW	Stand-alone electricity generation for communities (small villages)
100kW	Grid connection, export and sale of output to grid company

The wind currents from the Indian Ocean and the Pacific Ocean are affected by the surrounding land mass. Consequently, high wind velocities in West Malaysia are rare. The general wind direction through the land mass is in a northeast or southwest direction. The air streams and prevailing surface winds create a pattern of four seasons per year: the north-east monsoon (November-March) and the south-west monsoon (June-October), which are separated by two intermonsoon dry spells. The winds are stronger and more regular during the traditional dry periods (Table 3) [1].

Table 3 Annual Wind Speed and Wind Power in West Malaysia

Name of station	*Altitude (m)*	*Annual mean wind speed (m/s)*	*No. of years observation*	*Annual mean wind power (W/m^2)*
Penang	2.8	1.66	16	1.90
Malacca	8.5	1.61	16	2.21

A.Setar	3.9	1.05	16	0.50
Sitiawan	7.0	1.44	16	1.14
Mersing	43.7	3.14	16	15.09
Kuantan	15.3	1.84	16	2.76
K.Terengganu	35.1	2.64	16	7.53
K.Bharu	4.6	1.63	16	2.00
Ipoh	39.0	1.80	16	2.13
C.Highlands	1471.6	1.58	16	1.65
P.Jaya	45.7	1.07	14	0.48
Subang	16.5	1.05	16	0.46
J.Bahru	37.8	1.44	16	1.48
Kluang	88.1	2.08	12	5.21
Temerloh	39.1	0.52	7	0.06
Chuping	21.7	0.99	6	0.88

Wind data was collected at five stations (Mersing, Kuala Terengganu, Alor Setar, Petaling Jaya and Malacca) in Malaysia from 1982 to 1991. The results indicate that the station at Mersing has the greatest potential with a mean power density of 85.61 W/m^2 at 10 meters above sea level. In the month of January, the mean power density increases to 119.7 W/m^2 due to the monsoon season. However, the wind direction for Mersing is not consistent, especially during November through March. In addition, the wind direction is much more stable and consistent during the middle of the year. Consistent wind directions can be found at the other stations, Kuala Terengganu being the best of four. Most of the wind data stations are at airports or near the coast, where land and sea breezes can influence the wind regime [1].

Wind turbines can be separated into two general types based on the axis about which the turbine rotates, which are, horizontal-axis and vertical-axis. Horizontal axis windmills have the main rotor shaft and generator at the top of a tower, and must be pointed into the wind by some means. While, Vertical axis windmills have the main rotor shaft running vertically. The main advantages of this arrangement are the location of the generator and/or transmission at the bottom, on or near the ground, and the lack of a pointing mechanism. But, in this project, focus on another type of wind turbine, which definitely applies different working principle from types mentioned before, is Tesla Turbine.

The Tesla Turbine is a bladeless turbine design patented by Nikola Tesla in 1913. It is referred to as a bladeless turbine because it utilizes the boundary layer effect and not by a fluid impacting the blades in a conventional turbine. The Tesla Turbine is also known as the Prandtl layer turbine (after Ludwig Prandtl), boundary layer turbine, cohesion-type turbine, and bladeless turbine [11].

A Tesla Turbine consists of a set of smooth disks, with nozzles applying a moving air to the edge of the disk. The air will drag on the disk by means of viscosity and the adhesion of the surface layer of the air. As the air slows, it adds energy to the disks; it spirals in to the center exhaust. Since the rotor has no projections, the rotor is very sturdy [12].

1.2 Problem Statement

Renewable energy sources are fundamentally different from fossil fuel or nuclear power plants because of their widespread occurrence and abundance - the Sun will 'power' these 'power plants' (meaning sunlight, the wind, flowing water, etc.) for the next four billion years.

Historically, low fossil fuel prices, especially for natural gas, have made growth difficult for renewable fuels. The deregulation and restructuring of the electric power industry could have a major impact on renewable energy consumption. Demands for cheaper power in the short term would likely decrease demand for renewable energy, while preferences for renewable included in some versions of proposed electricity restructuring legislation would breathe new life into this industry.

It is hard to imagine an energy source more kind to the environment than wind power; it produces no air or water pollution, involves no toxic or hazardous substances (other than those commonly found in large machines), and poses no threat to public safety. And yet a serious obstacle facing the wind industry is public opposition reflecting concern over the visibility and noise of wind turbines, and their impacts on wilderness areas.

Yet, there is resistance to the establishment of wind farms owing initially to perceptions they are noisy and contribute to 'visual pollution'.

There are few other weaknesses that are aimed to overcome in this project. They are:

- *Dependency on the air flow.* The wind turbine should boast certain velocity to start working, as what happens within Horizontal axis wind turbine. Unlike HAWT, Vertical axis wind turbine is not self starting; the torque fluctuates with each revolution as the blades move into and away from the wind; and speed regulation in high wind can be difficult. However, basically if the acceleration is higher, more energy is produced.
- *Betz Law.* According to the Betz Law, any wind turbine can only convert less than 16/27 (or 59%) of the kinetic energy in the wind to mechanical energy. Compared both types of wind turbine, HAWT are more common and highly developed than VAWT, and this includes the fact which HAWT have better performance with higher efficiency.
- *Potential in Southeast Asia.* In Southeast Asia, wind energy systems have been utilized for water pumping for decades. Yet, with a wind regime less than 5 m/s (most of the time), wind energy projects have not been successful.

Based on these resistances, theory, mathematical modeling and principle learned throughout this project will be applied to overcome the limitation, and come out with a better design. The target is to come out with a design which has higher efficiency compared with others and practical to be applied in 'not-really-windy-country', such as in Southeast Asia region. For quite a long time, wind energy known to be involved in water pumping, with the new idea proposed later, the application shall be widen, for household, communications or maybe commercial use.

1.3 Objective and Scope of Study

The objectives of this project are:

- To appreciate the differences between a variety of wind turbine.
- To understand the underlying principles of wind turbines (mechanics and aerodynamics).

- To relate the performance of the systems with the theorem of Betz limit.
- To understand the meaning of the key parameters related to the operation of a wind turbine.
- Carry out simple calculation from the key parameters.

The objectives of the design itself are to come out with a model that fulfills these requirements, which are:

- Practical.
- Highly efficient.
- Less dependent on air flow rate.

Scope of study will cover following areas.

- Understanding the theory of wind energy resources and the working principles of wind turbines.
- Apply the theory into practical via model making.
- Study the variety of wind turbines available, investigate and make a design comparison for the best power output; efficiency.
- Recommend new design or techniques and apply if possible.

CHAPTER 2

LITERATURE REVIEW AND THEORY

Wind power has been used for several hundred years. It was originally used via large sail-blade windmills with slow-moving blades. These large mills usually either pumped water or powered small mills. Newer windmills featured smaller, faster-turning, more compact units with more blades. These were mostly used for pumping water from wells. Recent years have seen the rapid development of wind generation farms by mainstream power companies, using a new generation of large, high wind turbines with two or three immense and relatively slow-moving blades.

2.1 Wind Extraction

The power in the wind can be extracted by acting on a moving wing (or rotor), which converts some of that power into torque on the rotor. The amount of power transferred depends on the wind speed, the swept area, and the density of the air.

The mass flow of air that travels through the swept area of a wind turbine varies with the wind speed and air density. The kinetic energy of a given mass varies with the square of its velocity. Because the mass flow increases with the wind speed, the wind energy available to a wind turbine increases as the cube of the wind speed.

2.2 Betz Law

A German physicist, Albert Betz, determined in 1919 that a wind turbine can extract at most 59% of the energy that would otherwise flow through the turbine's cross section. The Betz limit applies regardless of the design of the turbine. More recent work by Gorlov shows a limit of about 30% for propeller-type turbines. Actual efficiencies range from 10% to 20% for propeller-type turbines, and are as high as 35% for three-dimensional vertical-axis turbines like Darrieus or Gorlov Turbines [2].

Betz prove that a wind turbine would not extract more than 59% of this available power. Instead of looking at how much torque/power can a rotor produce, Betz looks at how fast the wind can lose its energy to wind turbine [3]. Due to the fact that the wind turbine retards wind far before it reaches the rotor, the flow rate of the wind across the wind turbine will be lowered if the turbine retards the wind too much in order to extract maximum energy. In another word, the turbine can extract off all the energy in the wind but at a slow rate. To optimize the rate of energy extraction, the energy extraction must not be too high so that a good flow rate can be achieved.

2.3 Power of the Wind: Cube of Wind Speed

The wind speed is extremely important for the amount of energy a wind turbine can convert to electricity. The energy content of the wind varies with the cube (the third power) of the average wind speed [3]. In wind turbine case, the energy from braking the wind being used, and if the wind speed is double, it will result as twice as many slices of wind moving through the rotor every second, and each of those slices contains four times as much energy.

The power of the wind passing perpendicularly through a circular area is:

$$P = \frac{1}{2}\rho v^3 A$$

Where P = the power of the wind (Watt)

ρ = the density of dry air = 1.225 measured in kg/m^3 (kilograms per cubic meter, at average atmospheric pressure at sea level at 15° C)

v = the velocity of the wind (meters per second)

A= the swept area (meter square)

2.4 Practical Power Extractable from the Wind

2.4.1 Axial thrust (pressure)

The action of the wind onto the rotating propeller creates a pressure force acting along the shaft, called the thrust, which can be shown to have the value

$$\text{Axial thrust} = \frac{1}{2}\rho A V_1^2\left[1-\left(\frac{V_2}{V_1}\right)^2\right]$$

Where ρ = the density of dry air = 1.225 measured in kg/m^3 (kilograms per cubic meter, at average atmospheric pressure at sea level at 15° C)

A = the swept area (meter square)

V_1 = the velocity of the wind (metes per second)

V_2 = the velocity of the wind acts onto the rotating propeller (meters per second)

The axial thrust acts to try and topple the turbine but is countered by the foundation of the structure.

2.4.2 Solidity factor

The solidity factor is defined as the total blade area of the rotor divided by the swept area normal to the wind. Turbines with high solidity usually suffer from a large degree of aerodynamic interference between the blades which results in low values of both tip speed ratio and power coefficient.

Wind turbines of high solidity usually operate at low rotational speeds but have high starting torques. They are used for direct mechanical applications such as water pumping but are not suitable for driving electric generators. For the purpose of electricity generation it is usual to use low solidity machines.

2.4.3 Shaft torque and power

Most wind energy systems are used to generate electricity. The wind turbine is usually coupled to the electric generator directly, as in Figure 1, or via a gearbox to step-up the generator shaft speed, as in Figure 2 [4]. For this reason the generator is invariably mounted at the top of the supporting tower, along with the turbine and gearbox. Electric cables run down the tower to connect the generator to its electrical load (e.g. lighting, electric motors, battery charges) on the ground below. The wind as a power source is attractive because it does not impose an extra heat burden on the environment like the heat work systems involving fossil or nuclear fuels. The torque, speed and power of a rotating shaft are related by the relationship

$$P = \tau\omega$$

If the power is in watts, then torque τ is in newton-metres (Nm) and the angular speed of rotation ω is in radians per second. in Figure 1 and Figure 2 it follows that

$$\tau_t = \frac{P_{ex}}{\omega_t}$$

and

$$\tau_g = \frac{P_g}{\omega_g}$$

Where τ_l = torque for the load (newton meters)

τ_g = torque for the generator (newton meters)

P_{ex} = power extracted from the wind (watts)

P_g = power from the generator (watts)

ω_l = angular speed of rotation for the load (radians per second)

ω_g = angular speed of rotation for the generator (radius per second)

P_w and P_c from Figure 1 and Figure 2 means power from the wind and power between the generator and load.

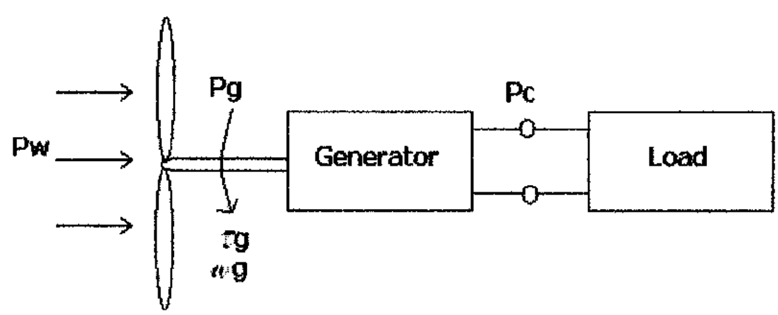

Figure 1 Relation of power, torque and angular speed of rotation between generator and load

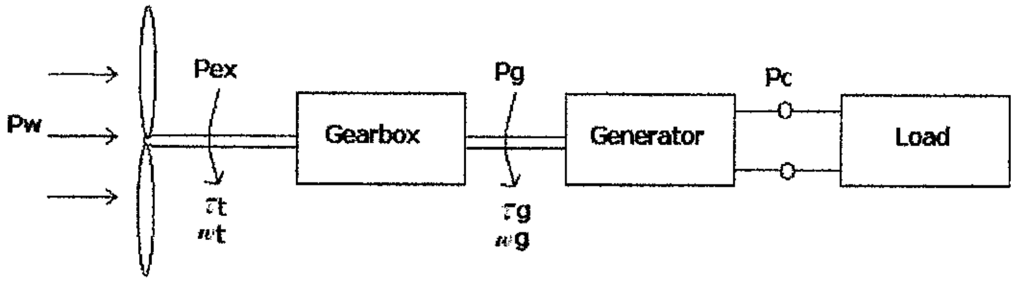

Figure 2 Relation of power, torque and angular speed of rotation between gearbox, generator and load

Considerable torsional stress is imposed on the shaft due to the rotational forces on the turbine propeller. For a solid, cylindrical shaft at any arbitrary radius *r*, Figure 3 is given by

$$f_s = \frac{\tau_r}{J} N/m^2$$

Where f_s = torsional shear stress

τ_r = torque (Nm)

J = area moment of inertia (m^4)

For a solid cylindrical shaft of radius r_0, J is given by

$$J = \frac{\pi r_0^4}{2} m^4$$

Combining the equation of f_s and J gives an expression for the shear stress at the surface of a solid-cylindrical shaft of radius.

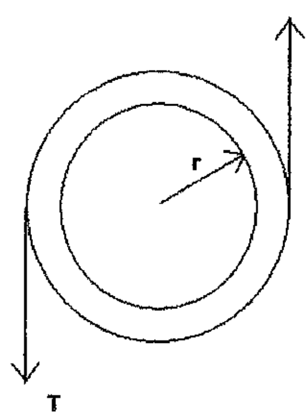

Figure 3 Cylindrical shaft

2.5 Reynolds Number

The Reynolds number is the most important dimensionless number in fluid dynamics. Where two similar objects in perhaps different fluids with possibly different flow rates have similar fluid flow around them, they are said to be dynamically similar. Typically it is given as:

$$\mathrm{Re} = \frac{\rho v_s L}{\mu}$$

or

$$\mathrm{Re} = \frac{v_s L}{v}$$

Where v_s = mean fluid velocity

L = characteristic length (equal to diameter $2r$ if a cross-section is circular)

μ = (absolute) dynamic fluid viscosity

ν = kinematic fluid viscosity: $\nu = \mu / \rho$

ρ = fluid density

The Reynolds number is the ratio of inertial forces ($v_s\rho$) to viscous forces (μ/L) and is used for determining whether a flow will be laminar or turbulent. In Tesla Turbine, Laminar flow is important. However, small amount of Turbulent flow can be accepted [11]. Laminar flow occurs at low Reynolds numbers, where viscous forces are dominant, and is characterized by smooth, constant fluid motion, while turbulent flow, on the other hand, occurs at high Reynolds numbers and is dominated by inertial forces, producing random eddies, vortices and other flow fluctuations.

The transition between laminar and turbulent flow is often indicated by a critical Reynolds number (*Re*), which depends on the exact flow configuration and must be determined experimentally. Within a certain range around this point there is a region of gradual transition where the flow is neither fully laminar nor fully turbulent, and predictions of fluid behavior can be difficult.

2.5.1 Turbulent flow

Turbulent flow is a flow regime characterized by low momentum diffusion, high momentum convection, and rapid variation of pressure and velocity in space and time. Flow that is not turbulent is called laminar flow. The Reynolds number characterizes whether flow conditions lead to laminar or turbulent flow.

In turbulent flow, unsteady vortices appear on many scales and interact with each other. Drag due to boundary layer skin friction increases. The structure and location of boundary layer separation often changes, sometimes resulting in a reduction of overall drag. Because laminar-turbulent transition is governed by Reynolds number, the same transition occurs if the size of the object is gradually increased, or the viscosity of the fluid is decreased, or if the density of the fluid is increased [8].

2.5.2 Laminar flow

Laminar flow is when a fluid flows in parallel layers, with no disruption between the layers. In fluid dynamics, laminar flow is a flow regime characterized by high momentum diffusion, low momentum convection, and pressure and velocity independence from time. It is the opposite of turbulent flow.

The process of a laminar boundary layer becoming turbulent is known as boundary layer transition. The point at which the boundary layer changes from laminar to turbulent is called the transition point. Where the boundary layer becomes turbulent, drag due to skin friction is relatively high. As speed increases, the transition point tends to move forward. As the angle of attack increases, the transition point also tends to move forward [8].

2.6 Tesla Turbine

Tesla Turbine is an efficient self-starting prime mover which may be operated as a steam or mixed fluid turbine, without changes in construction and is on this account very convenient. Minor departures from the original shape have been attempted to improve efficiency. It will be found highly profitable to the owners of the steam plants to use Tesla Turbine with some modification of their old installation. However, the best economic results in getting power from steam by the Tesla Turbine will be obtained in plants especially adapted for the purpose [12].

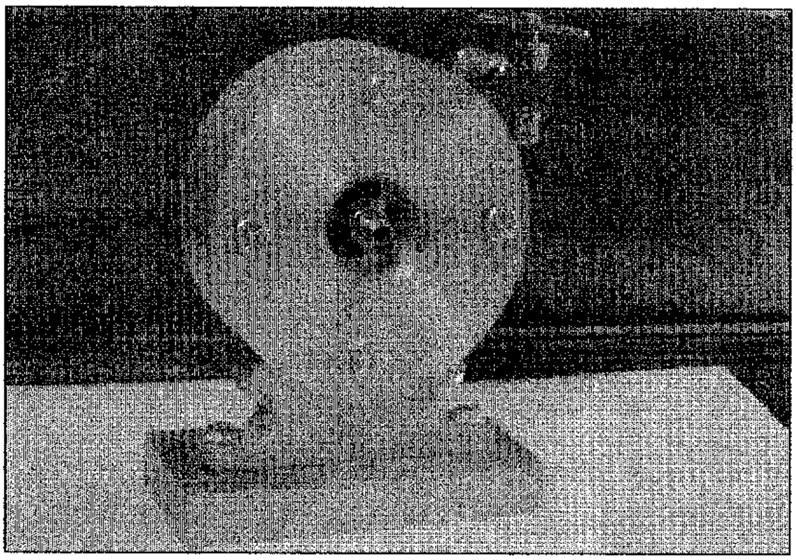

Figure 4 The Tesla Turbine

2.6.1 The design

This construction permits free expansion and contraction of each plate individually under the varying influence of heat and centrifugal force and possesses a number of other advantages which are of considerable practical unimportance. A larger active plate area and consequently more power are obtained for a given width, this improves efficiency. Warping is virtually eliminated and smaller side clearances may be used which result in diminished leakage and friction losses. The rotor is better adapted for dynamic balancing and through rubbing friction resists disturbing influences thereby ensuring quieter running. For this reason and also because the discs are not rigidly joined is safer against damage which might otherwise be caused by vibration or excessive speed [11].

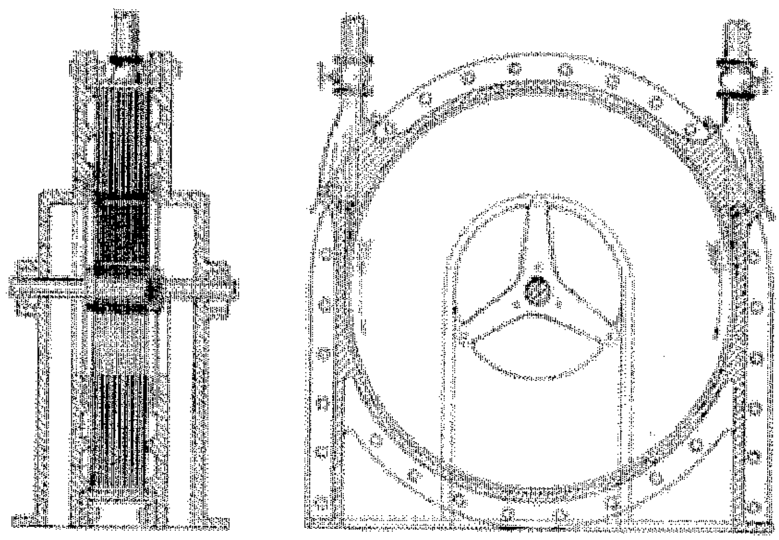

Figure 5 Tesla Turbine design

The boundary layer is the layer of fluid in the immediate vicinity of a bounding surface. In the atmosphere the boundary layer is the air layer near the ground affected by diurnal heat, moisture or momentum transfer to or from the surface. The Boundary layer effect occurs at the field region in which all changes occur in the flow pattern. The boundary layer distorts surrounding nonviscous flow. It is a phenomenon of viscous forces.

$$F = \frac{\eta v A}{l}$$

Where η = viscosity of the fluid

v = velocity of the fluid

A = area of the disks

l = separation between the disks

The boundary layer is particularly important in aerodynamics because it is responsible for a considerable amount of drag. In high-performance designs, much attention is paid to controlling the behavior of the boundary layer to minimize drag. Two effects need to be considered. First, the boundary layer adds to the effective thickness of the body, hence increasing the pressure drag. Second, the shear forces at the surface of the wing create skin friction drag [11].

A Tesla Turbine differs from a conventional turbine only in mechanism used to transfer energy to the blades. Various analyses show that the flow rate between the disks must be kept relatively low to maintain efficiency. This translates to needing to grow the number of disks as the flow rate increases. In addition, the disks need to be as thin as possible at the edges so as not to introduce turbulence as the fluid leaves the disks.

2.6.2 Efficiency

In Tesla's time, the efficiency of conventional turbines was low because the aerodynamic theory to proper blade design at all did not exist and the engineering materials of the time put severe limitations on operating speeds and temperatures. The efficiency of a conventional turbine is related to the difference in temperature between the intake and the exhaust. This requires that the materials used to construct it be able to withstand very high temperatures for reasonable efficiency.

Tesla's design sidestepped the key drawbacks of the bladed turbine, but does suffer from other problems such as shear losses and flow restrictions. Tesla Turbine's advantages lie in the relatively low flow rate and small applications. Maximum efficiency comes in this system when the inter-disk spacing approximates the thickness of the boundary layer, and since boundary layer thickness is dependent on viscosity and pressure, the claim that a single design can be used efficiently for a variety of fuels and fluids is incorrect [11].

Interestingly, the efficiency of the Tesla Turbine goes down with increased load. (Under light load, the spiral taken by the fluid moving from the intake to the exhaust is a tight spiral, undergoing many rotations. Under load, the number of rotations drops and the spiral becomes progressively shorter. This increases the shear losses and reduces the efficiency).

A claim of 95% rotor efficiency (as opposed to overall device efficiency) for this design was published in 1991 by Professor Warren Rice [11]. Rice conducted a bulk-parameter analysis of model laminar flow in multiple disk turbines. This analysis ignored inlet and outlet losses. Tesla claimed 98% overall efficiency and Rice attempted to re-create Tesla's experiments. Rice did not perform his tests on a pump built strictly in line with the Tesla's patented design.

Rice's experimental system was a single stage version of the Tesla Turbine. It also used air as the working fluid. Its system was not a Tesla multiple staged turbine nor did it possess Tesla's nozzle design. It's test turbines, as published in his papers, produced an overall measured efficiency of 36% to 41% (modern multiple stage bladed turbines typically reach 60% - 70% efficiency).He suggests a maximum fluid power efficiency of approximately 65% for boundary layer turbines may be likely.

2.7 Local Winds

For a weather observer, local controls of air movement may present more problems. Diurnal tendencies are superimposed upon both the large and the small scale patterns of wind velocity. These are particularly noticeable in the case of local winds. Under normal conditions, wind velocities tend to be least about dawn when there is little vertical thermal mixing and the lower air is less affected by the velocity of the air loft. Conversely, velocities of some local winds are greatest around 13:00 to 14:00 hours, when the air is most subject to terrestrial heating and vertical motion, thereby enabling coupling to the upper-air movement. Air always moves more freely away from the surface, because it is not subject to the retarding effects of friction and obstruction [6].

Air motion is described by its horizontal and vertical components: the latter is much smaller than the horizontal velocities. Horizontal motions compensate for vertical imbalances between gravitational acceleration and vertical pressure gradient. The horizontal pressure gradient, the earth's rotational effect (Coriolis force), and the curvature of the isobars (centripetal acceleration) determine horizontal wind velocity. All three factors are accounted for in the gradient wind equation, but this can be approximated in large-scale followed by the geostrophic wind relationship. Below 1500m, the wind speed and direction are affected by surface friction [5].

Local winds occur as a result of diurnally varying thermal differences setting up local pressure gradients (mountain-valley winds and land-sea breezes) or due to the effect of a topographic barrier on airflow crossing it. In most locations there is a characteristic pattern of wind velocity over the year. Although there may be significant variations of wind on a daily (sometimes hourly) basis, with regard to both magnitude and direction, the annual features are fairly consistent. The wind speed increases greatly at higher heights. Wind speeds are defined in terms of the Beaufort Scale [5].

Table 4 Beaufort Scale of Wind Velocities

Description of Wind	***Observation***	***Speed, m/s***
Calm	Smoke rises vertically.	0-0.4
Light air	Smoke drifts slowly.	0.4-1.3
Light breeze	Wind felt on the face. Leaves rustle.	1.8-3.1
Gentle breeze	Leaves and small twigs in constant motion. Flags or streamers extend.	3.6-5.4
Moderate breeze	Raises dust. Small branches move.	5.8-8.0
Fresh breeze	Small trees begin to sway.	8.5-10.7
Strong breeze	Large branches in motion. Umbrellas difficult to hold.	11.1-13.8
Moderate gale	Whole trees in motion.	14.3-17.0
Fresh gale	Breaks twigs off trees. Difficult to walk.	17.4-20.6
Strong gale	Slight structural damage to roofs and signs possible.	21.0-24.1
Full gale	Trees uprooted. Considerable structural damage occurs.	24.6-28.2
Storm	Widespread damage.	28.6-32.2

Wind regime in Malaysia generally is weak and always changing in direction periodically. There are four seasons to be considered, which are South-west monsoon, North-east monsoon and two monsoon transformation seasons that are shorter. South-west monsoon happened during second-half of the month of May/ early June until the end of September. In general, the wind flows from south-west and very weak, usually below 7.7 m/s. North-east monsoon begins early November and ends in March. The wind flows from east or north-east with speed 5.1 m/s – 10.3 m/s. States in east of West Malaysia is highly affected, the speed which sometimes can be up to 15.4 m/s.

During monsoon transformation seasons, wind is usually weak and the direction is always changing. From April to November, in which, hurricane always formed in west pacific and move towards west through Philippines, south-west wind in Sabah coastline and Sarawak become stronger at 10.3 m/s and above.

As a country surrounded by the sea, the effect of land-sea breezes on the wind regime is great especially during hot day. Land-sea breeze with the speed of 5.1 m/s – 15.4 m/s usually happens in the afternoon, and can reach to 10.3 m/s or more in rural area. During the night, the process change, where weaker land-sea breeze can be experienced along the beach area. Maximum wind speed with the average data collected so far is 3.1 m/s. Mersing, Johor and Kuching, Sarawak have been stated with the highest wind flows of 41.7 m/s on 15th September 1992 [13].

2.8 Turbine Installation

As a general rule, wind turbines are practical where the average wind speed is greater than 5.5 m/s [10]. When wind turbines are located in broad flat areas (e.g. over water), large-scale wind maps may be useful. For smaller installations in hilly areas, the precise location of the wind turbine can greatly affect its productivity.

Large installations will often install anemometers for a year or two before installing turbines, to get a more precise local map of the winds. For smaller installations where such data collection is too expensive, the normal way of prospecting for wind-power sites is to look for trees or vegetation that is permanently "cast" or deformed by the prevailing winds. Another way is to use a wind-speed survey map or historical data from a nearby meteorological station, although this is less reliable.

The wind blows faster at higher altitudes because of the drag of the ground and the viscosity of the air. The variation in velocity, called wind shear is most dramatic near the ground. Typically, the variation follows the 1/7th power law, which predicts that wind velocity rises proportionally to the seventh root of altitude. Doubling the altitude of a turbine increases the expected velocity by 10% and the expected power by 34%. In typical land-based installations, a tower lifting the bottom of the turbine 30 meters will pay for itself by placing the turbine in faster air [10].

2.8.1 Roughness

High above ground level, at a height of about 1 kilometer, the wind is hardly influenced by the surface of the earth at all. In the lower layers of the atmosphere, however, wind speeds are affected by the friction against the surface of the earth. In the wind industry one distinguishes between the roughness of the terrain, the influence from obstacles, and the influence from the terrain contours, which is also called the orography of the area.

In general, the more pronounced the roughness of the earth's surface, the more the wind will be slowed down. Forests and large cities obviously slow the wind down considerably, while concrete runways in airports will only slow the wind down a little. Water surfaces are even smoother than concrete runways, and will have even less influence on the wind, while long grass and shrubs and bushes will slow the wind down considerably.

In the wind industry, people usually refer to roughness classes or roughness lengths, when they evaluate wind conditions in a landscape. A high roughness class of 3 to 4 refers to landscapes with many trees and buildings, while a sea surface is in roughness class 0. Concrete runways in airports are in roughness class 0.5. The same applies to the flat, open landscape to the left which has been grazed by sheep. The proper definition of roughness classes and roughness lengths may be found in the Reference Manual in **Appendix A** [4]. The term roughness length is really the distance above ground level where the wind speed theoretically should be zero.

2.8.2 Wind shear formula

The fact that the wind profile is twisted towards a lower speed as it moves closer to ground level is usually called wind shear. Wind shear may also be important when designing wind turbines. The wind speed at a certain height above the ground level is:

$$v = \frac{v_{ref} \ln(\frac{z}{z_0})}{\ln(\frac{z_{ref}}{z_0})}$$

Where v = wind speed at height z above ground level.

v_{ref} = reference speed, i.e. a wind speed we already know at height z_{ref}.

ln(...) is the natural logarithm function.

z = height above ground level for the desired velocity, v.

z_0 = roughness length in the current wind direction.

(Roughness lengths may be found in the **Appendix A**)

z_{ref} = reference height, i.e. the height where we know the exact wind speed v_{ref}.

2.9 Pros and Cons of Wind-Generated Electrical Power

Some advantages and disadvantages of the use of wind power are summarized in table below, for convenience of references. There is no clear-cut and explicit overriding feature which dominates the issue, above all others. Moreover, the weight that one might care to give to particular items in a table may be subject to national and international political considerations, which tend to change [9].

All financial features of the use of wind energy for electricity generation have to be considered in comparison with other options, in particular the price of oil. Comparative costing is published from time to time but there is no on going agreement as to the findings. This is to be expected because the perspective is influenced by personal as well as business and political considerations.

Table 5 Advantages and Disadvantages of Wind Powered Electricity Generation

Advantages	*Disadvantages*
• Prime fuel is free.	• Risk of bladed failure (total destruction of the installation).
• Infinitely renewable.	• Suitable small generators not readily available.
• Non-polluting.	• Unsuitable for urban areas.
• In UK the seasonal variation matches electricity demand.	• Cost of storage battery or mains converter system.

• Big generators can be located on remote sites.	• Acoustic noise of gearbox and rotor blades.
• Saves conventional fuels.	• Height construction costs of the supporting tower and access roads.
• Saves the building of (otherwise necessary) conventional generation.	• Electromagnetic interference if metal rotor used.
• Diversity in the methods of electricity generation.	• Lack of an objective assessment.

2.10 Wind Energy Conversion Design

During designing stage, there was several type of wind-catchment area that was taken into consideration. However, after considering the resistance and the desire objective to be achieved, 'sun-heater' would be a perfect match. The theory of difference in temperature is the vital rule, so that a wind flow can maintain at 5m/s. The electrical power generated at the end is no longer depends on the inconsistent daily wind regime. Figure below, make the theory clearer.

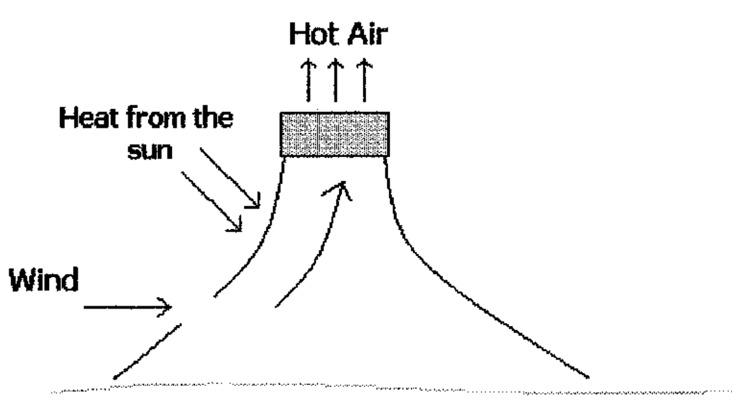

Figure 6 Sun-heater

The difference in temperature of the wind outside the catchment area with the inside, resulting in high pressure air. This condition will produce much better wind flow, swifter than the outside wind.

The second part is the Tesla Turbine attached at the top of the chimney. The chimney being design as a cone, to enhanced the speed of the air before entering the turbine.

CHAPTER 3

METHODOLOGY AND PROJECT WORK

A systematic approach has been adapted to find the information and sources. Below are the components of methodology being used to study the systems of wind turbine for the project work.

Starting from first week until second week of the semester, a title selection process has been done. When the title had been allocated, a literature survey on the topic was made. In this case, it is about the renewable energy specifying on the wind energy systems. After all the information was gathered, work on mathematical model was started. Parallel with mathematical modeling, designing step ware also carried out.

In the second semester of this project, the calculations and design was finalized. After the completion of entire designing task, the next step was to perform card-board modeling. Then a prototype model to be built.

Throughout the research project, several methods were carried out to complete the task. The project planning is attached in the **Appendix B** and **Appendix C** for both semesters.

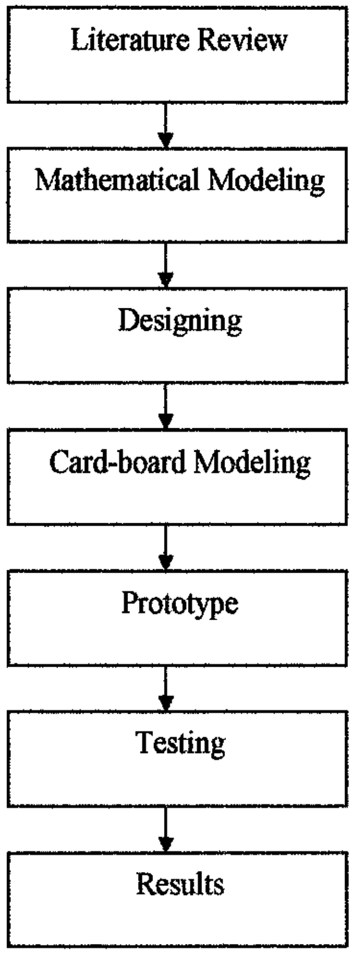

Figure 7 Process flowchart

3.1 Literature Review

Literature review contributes the most part in the project. References of the theory, principles and calculations of the Tesla Turbine were obtained from the books, journals and web pages. Besides general information on the existing wind turbines, their efficiency and performance were compared and analyzed. By doing this, current technology was probed, some of which are implemented in the project. This as the platform for solving the problems related to the of wind turbine.

3.2 Mathematical Modeling

Actually, a lot of literature review has been done especially to find the appropriate equations to calculate the needed parameters. Besides, some derivation of formulae also has been done in order to obtain the required parameters. Finally, a systematic approach has been a big help to obtain the final specific electrical power to be produced by the Tesla Turbine. Some of the required parameters are:

- Determine the torque, τ
- Determine the angular velocity, ω
- Determine the system's efficiency, η

In order to arrive at a more reliable and accurate formulation, it is necessary to consider the fluid property of the air and hence the density prior to the ready kinetic energy formulation. For this purpose, it is necessary to start the derivations through the following basic physical steps.

First of all, the total force F on the turbine area A due to a wind blow for time duration, T with wind speed, V must be considered. The basic definition of force in physics is given by Newton's second law as

$$F = m \ dV / dt$$

substitution of $m = \rho AVT$ into this last expression gives

$$F = \rho ATV \ \ dV / dt$$

On the other hand, the energy (or work) is defined physically as the product of force and distance, say small distance, dL, as

$$dE = F \ dL = \rho a TV \ \ dVdL / dt$$

where the ratio, dL/dt is equal to the physical definition of velocity, and hence, this expression becomes succinctly

$$dE = \rho ATV^2 \ dV$$

Finally, the total energy can be obtained after the integration of both sides according to

$$E = (1/3)\rho ATV^3$$

or $E_w = E/(AT)$, the wind intensity is given by

$$E_w = (1/3)\rho V^3$$

3.3 Designing

The design has been divided into two parts. The first part is solar chimney. And the second part is the Tesla Turbine. Both elements are dependant on each other.

The overall design for the Tesla Turbine is the standard layout. The disks and spacers are held together by the two end plates. The end plates are wider versions of the spacers. The inside diameter of these end plates has to fit on the shaft running through them. The air inlet will taped on the chamber. The technical drawing for construction of Tesla Turbine is attached in **Appendix D**.

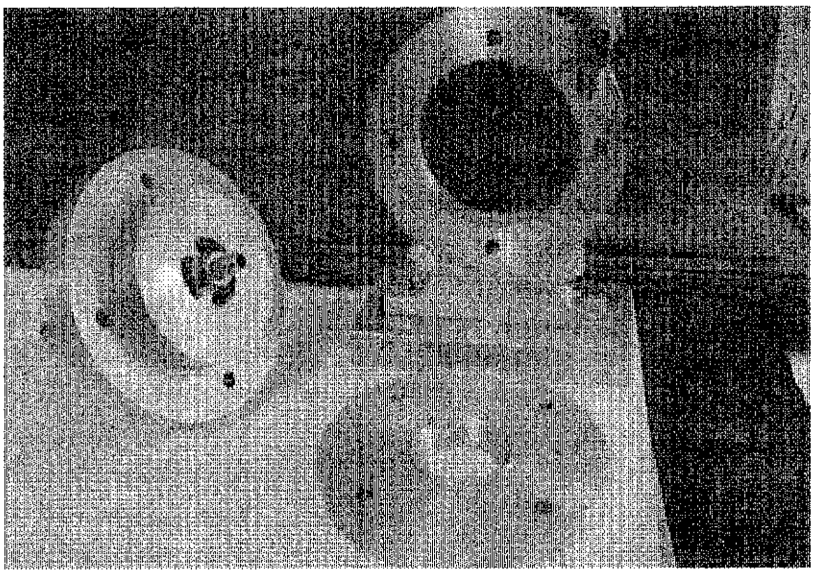

Figure 8 The assembly of Tesla Turbine

3.4 Card-board Modeling

A small-scale model has been made to get the right parameters before coming up with the prototype. The model is made up of material, such as cardboard, transparent plastic card and wooden rod.

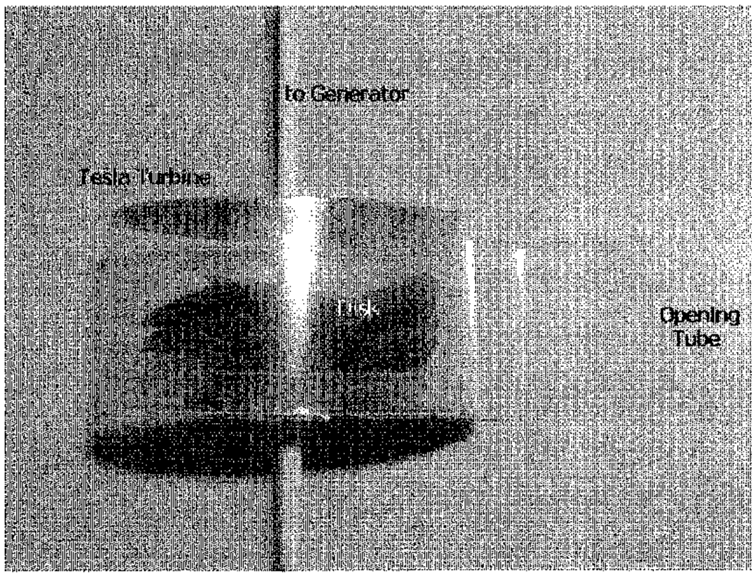

Figure 9 Tesla Turbine card-board model

3.5 Prototype

At first, steel sheet with 0.5 mm thickness been used for the disks and spacers. These steel sheet been machined down to get eleven disks with 70 mm in diameter and ten spacers. But the outcome did not what as expected. The surface of the disks is uneven and jagged. That is why CDs were being used, because of their large and smooth surface area.

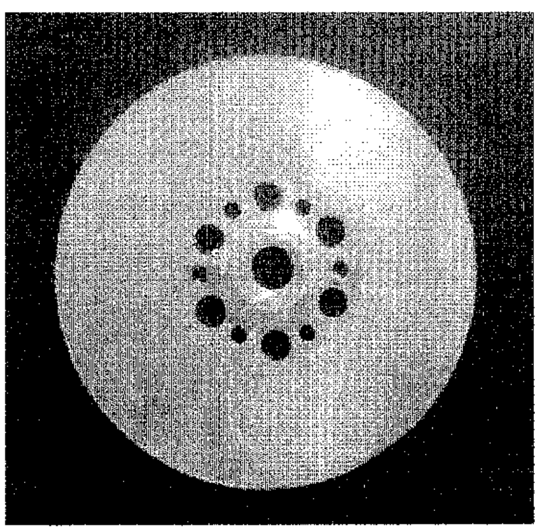

Figure 10 Metal steel disk

Besides having the center hole for shaft and washers for spacers, the CDs been drilled to get 12 holes, for the purpose of air ventilation. Those holes are in two sizes, 10 mm and 4 mm in diameter.

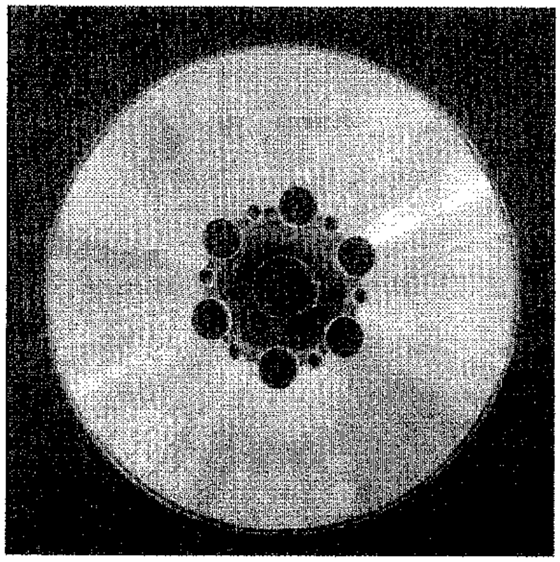

Figure 11 Disk made from CD

The spacers used between the disks have thickness of 2.0 mm. This increased the distance and lead to laminar flow.

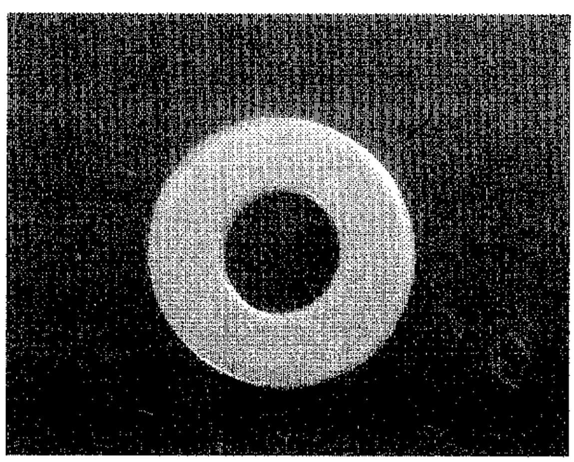

Figure 12 Spacer

With the turbine disks and spacers complete, a shaft was turned from aluminium solid block. Aluminium has been chosen because it easier to machine compared to metal steel that has been used before. The outcome is smoother, put side by side with the shaft made from metal steel. The inside diameter of both the disks and spacers is 15 mm which made the diameter of the shaft 14 mm. The whole length is 120 mm, fit with the width of the chamber. Two set of screws been made from aluminium block to hold the disks and spacers in place.

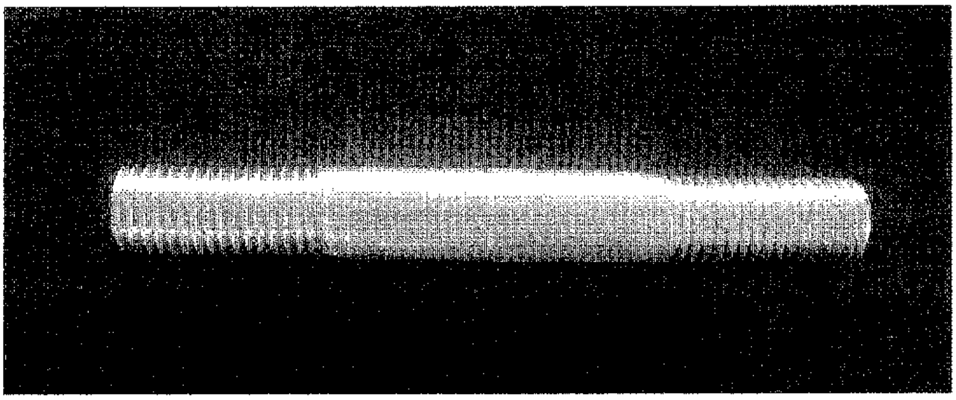

Figure 13 Shaft

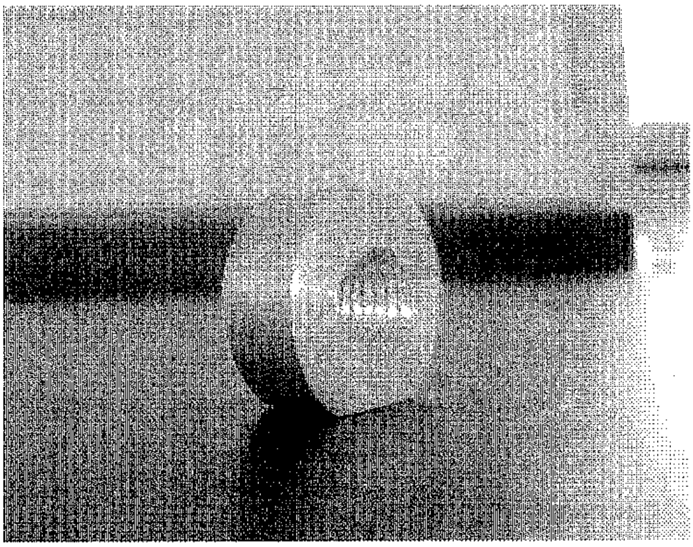

Figure 14 Screw

There are eleven disks and ten spacers held together by the two screws. The CDs are hard to keep clean so gloves are essential when assembling the rotor. There should be a fair amount of pressure between the disks and screw, or the disks will rotate about the shaft instead of with it.

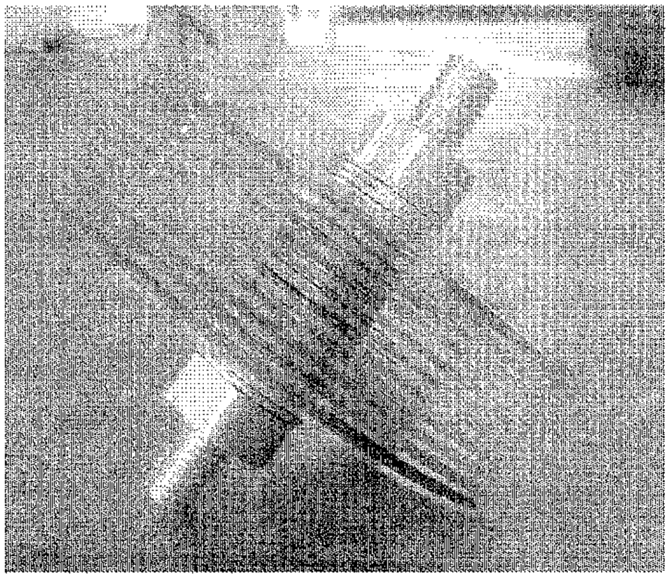

Figure 15 Rotor assembly

The main chamber is a wood block machined down to 180 mm x 180 mm x 92 mm. The square block was drilled, filed and then bored out to get the hole. The final cutout is 5.0 mm larger than the disks. The air inlet is taped for a 20 mm pipe thread and all other holes are taped for 14 mm socket head cap screws. The side panels are 3.0 mm thick prospect and have 14 mm holes for alignment to the main chamber.

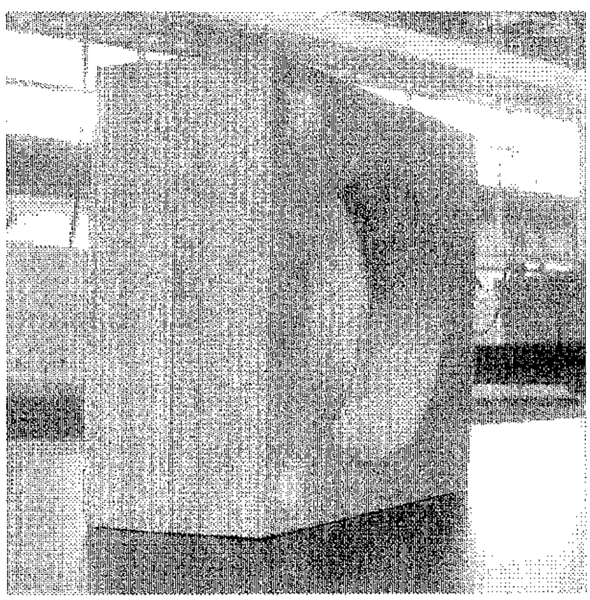

Figure 16 Main chamber

3.5.1 Tool required

Tools and materials listed bellows are for the construction of Tesla Turbine. They are:

- CDs (120 mm diameter)
- Aluminium solid (304 mm length, 19 mm diameter)
- Wood block (228.6 mm x 50.8 mm)
- Bearing
- Drilling machine
- Medium duty lathe machine
- 10" Horizontal band saw
- Saw
- Files

3.6 Testing

The best operating air pressure to test run the turbine was from 105 down to 80 PSI, which was determined by trial and error. Then by using the above air pressure limits, the first series of tests was to determine the optimum spacing for the rotor disks. Spacers with three different thicknesses will be tested.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Results

Manual calculation being performed as a guide. This is to ensure the error before starting doing the modeling can be minimized. The manual calculation is based on average atmospheric pressure at sea level at 15°C. All the parameters and relevant data were taken from different information resources. The final design is discussed below.

4.1.1 Steps of calculation

As what mentioned before, wind turbines are practical where the average wind speed is greater than 5.5 m/s. Hence, the required minimum average of flow rate must maintain more than 5.5 m/s. As in this project, experiment will be conducted with smaller amount. The desired output power is calculate to be 10 kW.

1. The volume flow rate of air is use as input for Tesla Turbine.
2. The input wind power at Tesla Turbine is P_{in} = *pressure x flow rate.*
3. The power output of Tesla Turbine is P_{out} = *torque x angular velocity.*
4. The maximum power of electric generator, coupled to turbine is

$$P_E = \frac{V_{out}^{\ 2}}{\max imum\_load}$$

$$Overall\_Efficiency = \frac{P_1}{P_E} = \frac{\rho v_1^{\ 3} A_1 x \max imum\_load}{V_{out}^{\ 2}}$$

4.1.2 Tesla Turbine: The design

Tesla Turbine is constructed where all the disks and spacers are fitted on and keyed to a shaft at the ends and equipped with end plates. This construction permits free expansion and contraction of each disk individually under the varying influence of centrifugal force and possesses a number of other advantages which are of considerable practical moment. A larger active disk area and consequently more power are obtained for a given width, this improving efficiency. The rotor assembly is better adapted for dynamic balancing and through rubbing friction resists disturbing influences thereby ensuring quieter running. For this reason and also because the disks are not rigidly joined it is safer against damage which might otherwise be caused by vibration or excessive speed.

Tesla Turbine's advantages lie in the relatively low flow rate and small applications. Maximum efficiency comes in this system when the inter-disk spacing approximates the thickness of the boundary layer, and since boundary layer thickness is dependent on viscosity and pressure. Figure 7 shows the whole design.

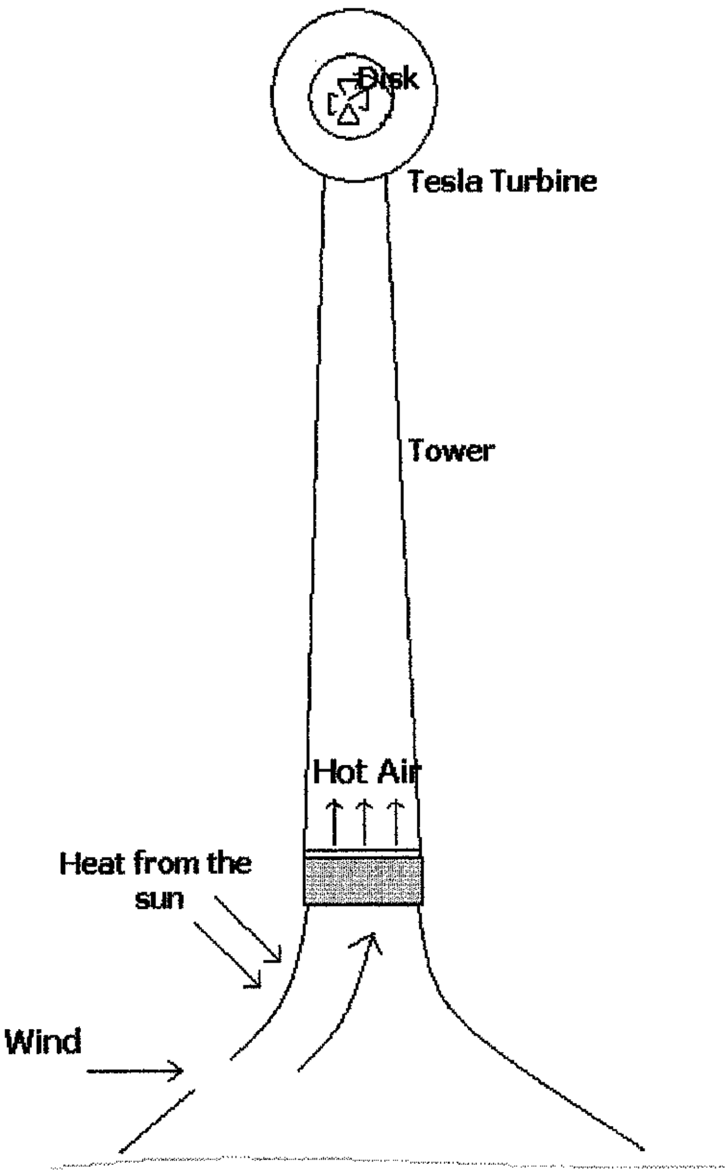

Figure 17 The vertical-axis wind turbine

4.1.3 Modeling

The card-board model has been run by blowing air into the turbine. To see whether the cardboard disks are spinning the motion of rotor shaft was observed. However, the speed of rotation was not as desired. The cause maybe was the material used, which was cardboard which is considered too thick for the disk. It may also the due to the way the disks were folded, as shown in Figure 8. In the real Tesla Turbine, the disks holes on them, so that the incoming air can move the disk independently, as shown in Figure 9.

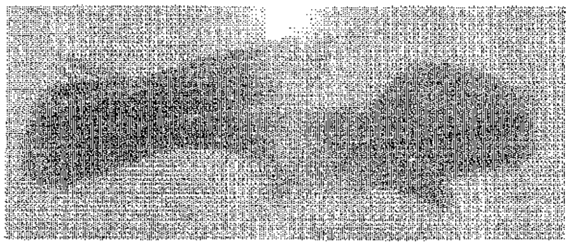

Figure 18 The card-board disks

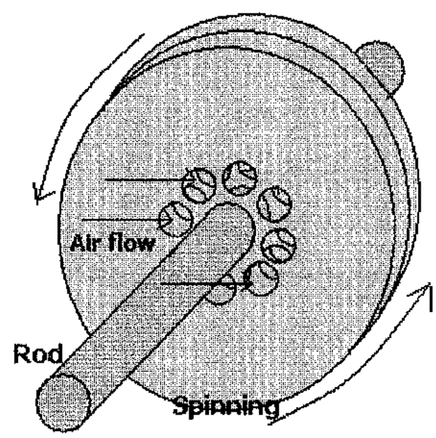

Figure 19 The illustration of the disks

The warm air enters through the air entrance tube and goes directly into the turbine. The flowing air spins the disks and generates the torque. The transforming process of mechanical energy to electrical energy takes place in the generator. The faster the speed of rotation of the disks, greater the power is produced. That is why the solar tower has smaller diameter at the top, which enhance air speed.

4.1.4 Construction of Tesla Turbine

The overall design is a standard layout. For rotor assembly, there are eleven disks held together by the two end plates. The inside diameter of the end plates has to fit on the shaft. But they can not be neither too tall nor too wide, as they will block the ventilation holes in the disks.

The greatest efficiency is achieved when the disks rotate at the speed of the air, but maximum torque is realized when the disks rotate at just over 50% of the air speed.

Other factors that affect efficiency and power are the same as those affecting aircraft or any aerodynamically sensitive object: surface finish, geometry, etc.

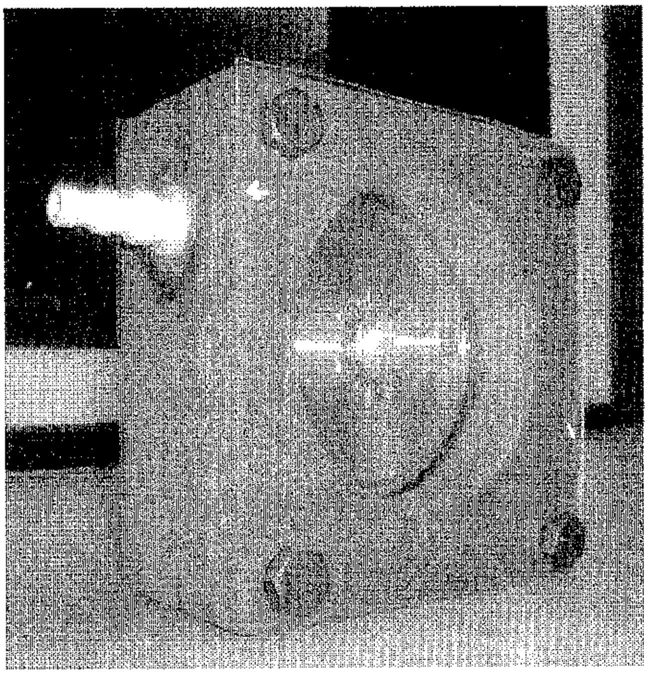

Figure 20 Prototype of Tesla Turbine

4.2 Discussion

To estimate the global potential for wind energy it is necessary to know the mean wind speed over the earth's surface. This has been measured and the results are published in the form of wind atlases for countries and regions, even for the earth as a whole. Although these atlases often depend on interpolation of wind data obtained from dispersed measuring stations, they can give a useful estimate of the available wind resource for initial planning purposes.

In the practical application of mechanical power based on the use of air as the vehicle energy, Tesla Turbine has been demonstrated that, in order to attain the highest economy, the changes in velocity and direction of movement of the air should be as gradual as possible.

The purpose by adding up the wind-catchment area for wind flow is to maximize the velocity of the air entering the part.

The device accomplished this by harnessing the internal forces opposing molecular separation and the shock of the fluid against the asperities of the solid substance. (Asperities are surface deformities, which even the smoothest disk will have.) The pump disks in the turbine are keyed to a single shaft.

The patent states that to reduce clogging, a solid disk or disks (each in its own casing) can be used. Also, the pump can be staged for increased pressure, using the output of one disk as the input to the next, in series on one shaft. With rotational force applied to the shaft, rotating the keyed disks, the air rotates as well and moves towards the outer edge of the disks.

According to Tesla's own patent, the torque is directly proportional to the square of the velocity of the fluid relatively to the runner and to the effective area of the disks and, inversely, the distance separating them. The best way to begin figuring horsepower and torque is through experimental process.

Tesla recorded approximately 110 hp for his 254 mm (247.65 mm disk diameter) turbine using 25 disks at 175 pounds of steam pressure. Theoretical calculations for boundary layer disks show an exponential increase of torque over horsepower. In other words, as the horsepower doubles the torque quadruples.

Gas adhesion to the disk surfaces to be as great as possible- which means the disks, must be as highly polished as possible. Imperfections in the disk surface because vortices in the gas flow, resulting in lose of adhesion and lower energy transfer efficiencies. Since larger gaps allow turbulent regions to operate, the energy transfer mechanism shifts from adhesion to turbulent parasitic drag. However if the spacing between the disks become too small, an aperture closing effect causes the high velocity gas to go around the disk pack rather than through it.

The fluid might complete one or more revolutions, or less than a revolution, before reaching the outer edges of the disks, depending on the viscosity of the air, the speed of rotation, the width between the disks, and other factors.

In general, the spacing of the disks should be such that the entire mass of the air, before leaving the runner (the disks), is accelerated to a nearly uniform velocity, not much below the periphery of the disks under normal working conditions and almost equal to it when the outlet is closed and the particles move in concentric circles.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

As a conclusion, most of the objectives mentioned before have been achieved, which is to design a practical and highly efficient vertical turbine that less dependent on air flow rate for wind power farming. However the construction part can be improved by build few more Tesla Turbine with different parameter to observe the outcome. By trial and error, hopefully the best Tesla Turbine with higher efficiency can be manufacture.

The main problem encountered during this project is difficulty to get materials for the construction of Tesla Turbine. Since the construction is based on trial and error method, the need of enough reserve of CDs and aluminium solid is very necessary. Hence several prototypes can be made to observe the changes. Solid results can be conclude. .

The Tesla Turbine does not use friction in the conventional sense; it precisely avoids it, and uses adhesion and viscosity instead. It utilizes the boundary layer effects on the disk blades. This is an important point of this invention.

In short, so far most of the objectives listed before have been achieved. However, seems the construction of the prototype is still in progress, I hoping that the results is as what I expected. Which are when the speed of air flow is increased, the torque will also increase. Other way to maximize the torque is by decreasing the spacing between each disk and increase the number of disk used.

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APPENDICES

APPENDIX A

WIND ENERGY REFERENCE MANUAL: WIND ENERGY CONCEPTS

Unit Abbreviations

m = metre = 3.28 ft.

s = second

h = hour

N = Newton

W = Watt

HP = horsepower

10^{-12} = p pico = 1/1000,000,000,000

10^{-9} = n nano = 1/1000,000,000

10^{-6} = µ micro = 1/1000,000

10^{-3} = m milli = 1/1000

10^{3} = k kilo = 1,000 = thousands

10^{6} = M mega = 1,000,000 = millions

10^{9} = G giga = 1,000,000.000

10^{12} = T tera = 1,000,000,000,000

10^{15} = P peta = 1,000,000,000,000,000

J = Joule

cal = calorie

toe = tonnes of oil equivalent

Hz= Hertz (cycles per second

Wind Speeds

1 m/s = 3.6 km/h = 2.237 mph = 1.944 knots

1 knot = 1 nautical mile per hour = 0.5144 m/s = 1.852 km/h = 1.125 mph

Wind Speed Scale

Wind Speed at 10 m height m/s	knots	Beaufort Scale (outdated)	Wind
0.0-0.4	0.0-0.9	0	Calm
0.4-1.8	0.9-3.5	1	Light
1.8-3.6	3.5-7.0	2	
3.6-5.8	7-11	3	
5.8-8.5	11-17	4	Moderate
8.5-11	17-22	5	Fresh
11-14	22-28	6	Strong
14-17	28-34	7	
17-21	34-41	8	Gale
21-25	41-48	9	
25-29	48-56	10	Strong Gale
29-34	56-65	11	
>34	>65	12	Hurricane

Roughness Classes and Roughness Lengths

The roughness class is defined in the **European Wind Atlas** on the basis of the roughness length in metres z_0, i.e. the height above ground level where the wind speed is theoretically zero. ln is the natural logarithm function.

if (length <= 0.03)

class = 1.699823015 + ln(length)/ln(150)

if (length > 0.03)

class = 3.912489289 + ln(length)/ln(3.3333333)

Roughness Classes and Roughness Length Table

Roughness Class	Roughness Length m	Energy Index (per cent)	Landscape Type
0	0.0002	100	Water surface
0.5	0.0024	73	Completely open terrain with a smooth surface, e.g.concrete runways

			in airports, mowed grass, etc.
1	0.03	52	Open agricultural area without fences and hedgerows and very scattered buildings. Only softly rounded hills
1.5	0.055	45	Agricultural land with some houses and 8 metre tall sheltering hedgerows with a distance of approx. 1250 metres
2	0.1	39	Agricultural land with some houses and 8 metre tall sheltering hedgerows with a distance of approx. 500 metres
2.5	0.2	31	Agricultural land with many houses, shrubs and plants, or 8 metre tall sheltering hedgerows with a distance of approx. 250 metres
3	0.4	24	Villages, small towns, agricultural land with many or tall sheltering hedgerows, forests and very rough and uneven terrain
3.5	0.8	18	Larger cities with tall buildings
4	1.6	13	Very large cities with tall buildings and skycrapers

Definitions according to the **European Wind Atlas, WAsP.** For practical examples, see the Guided Tour section on **Wind Speed Calculation.**

Density of Air at Standard Atmospheric Pressure

Temperature °Celsius	Temperature ° Farenheit	Density, i.e. mass of dry air kg/m^3	Max. water content kg/m^3
-25	-13	1,423	
-20	-4	1,395	
-15	5	1,368	
-10	14	1,342	
-5	23	1,317	
0	32	1,292	0,005
5	41	1,269	0,007
10	50	1,247	0,009
15	59	1,225 *)	0,013
20	68	1,204	0,017
25	77	1,184	0,023
30	86	1,165	0,030
35	95	1,146	0,039

40	104	1,127	0,051

*) The density of dry air at standard atmospheric pressure at sea level at 15° C is used as a standard in the wind industry.

Viscosity of Atmospheric Air

Temperature ° Celsius	μ	20	1.80 E -5	1.50 E -5
50	1.95 E -5	1.79 E -5		

Note: E -5 means exponential notation, i.e. the number should be multiplied by 0.00001

Power of the Wind **)

m/s	W/m^2	m/s	W/m^2	m/s	W/m^2
0	0	8	313.6	16	2508.8
1	0.6	9	446.5	17	3009.2
2	4.9	10	612.5	18	3572.1
3	16.5	11	815.2	19	4201.1
4	39.2	12	1058.4	20	4900.0
5	76.2	13	1345.7	21	5672.4
6	132.3	14	1680.7	22	6521.9
7	210.1	15	2067.2	23	7452.3

**) For air density of 1.225 kg/m^3, corresponding to dry air at standard atmospheric pressure at sea level at 15° C.

The formula for the power per m^2 in Watts = 0.5 * 1.225 * v^3, where v is the wind speed in m/s.

Warning:

Although the power of the wind at a wind speed of e.g. 7 m/s is 210 W/m^2, you should note, that the average power of the wind at a site with an average wind speed of 7 m/s typically is about twice as large. To understand this, you should read the pages in the Guided Tour beginning with the Weibull Dustribution and ending with the Power Density Function.

Standard Wind Class Definitions (Used in the U.S.)

Class	30 m height	50 m height

	Wind speed m/s	Wind power W/m^2	Wind speed m/s	Wind power W/m^2
1	0-5.1	0-160	0-5.6	0-200
2	5.1-5.9	160-240	5.6-6.4	200-300
3	5.9-6.5	240-320	6.4-7.0	300-400
4	6.5-7.0	320-400	7.0-7.5	400-500
5	7.0-7.4	400-480	7.5-8.0	500-600
6	7.4-8.2	480-640	8.0-8.8	600-800
7	8.2-11.0	640-1600	8.8-11.9	800-2000

APPENDIX B

PROJECT PLANNING FOR THE FIRST SEMESTER

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic	■	■												
	-Propose Topic														
	-Topic assigned to students														
2	Preliminary Research Work		■	■											
	-Introduction														
	-Objective														
	-List of references/literature														
	-Project planning														
3	Submission of Preliminary Report			●											
4	Project Work				■	■	■	■							
	-Reference/Literature														
	-Practical/Laboratory Work														
5	Submission of Progress Report							●							
6	Project work continue								■	■	■	■			
	-Practical/Laboratory Work														
7	Submission of Interim Report Final Draft											●			
8	Oral Presentation												●		
9	Submission of Interim Report													●	

● Suggested milestone

■ Process

APPENDIX C

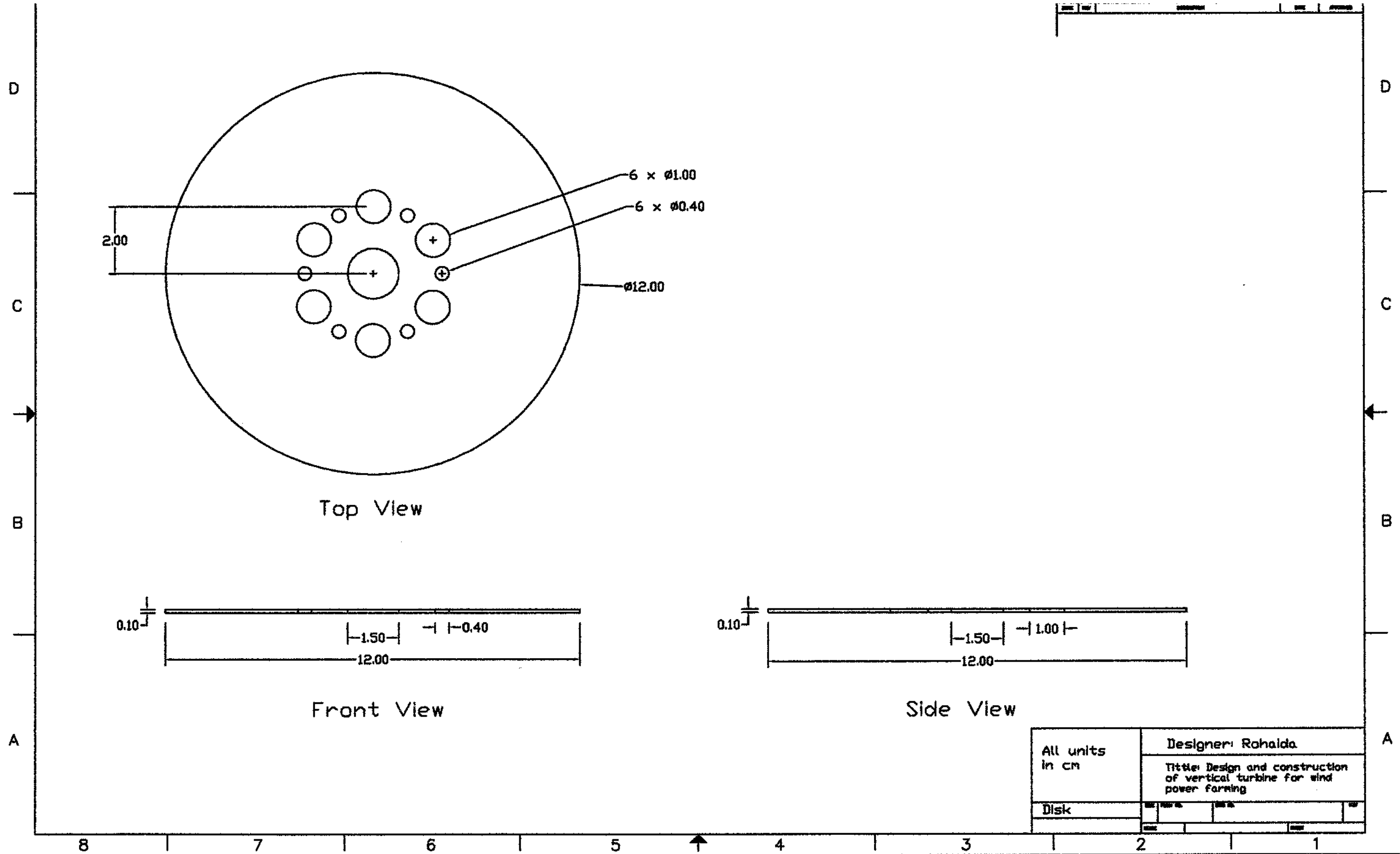
PROJECT PLANNING FOR THE SECOND SEMESTER

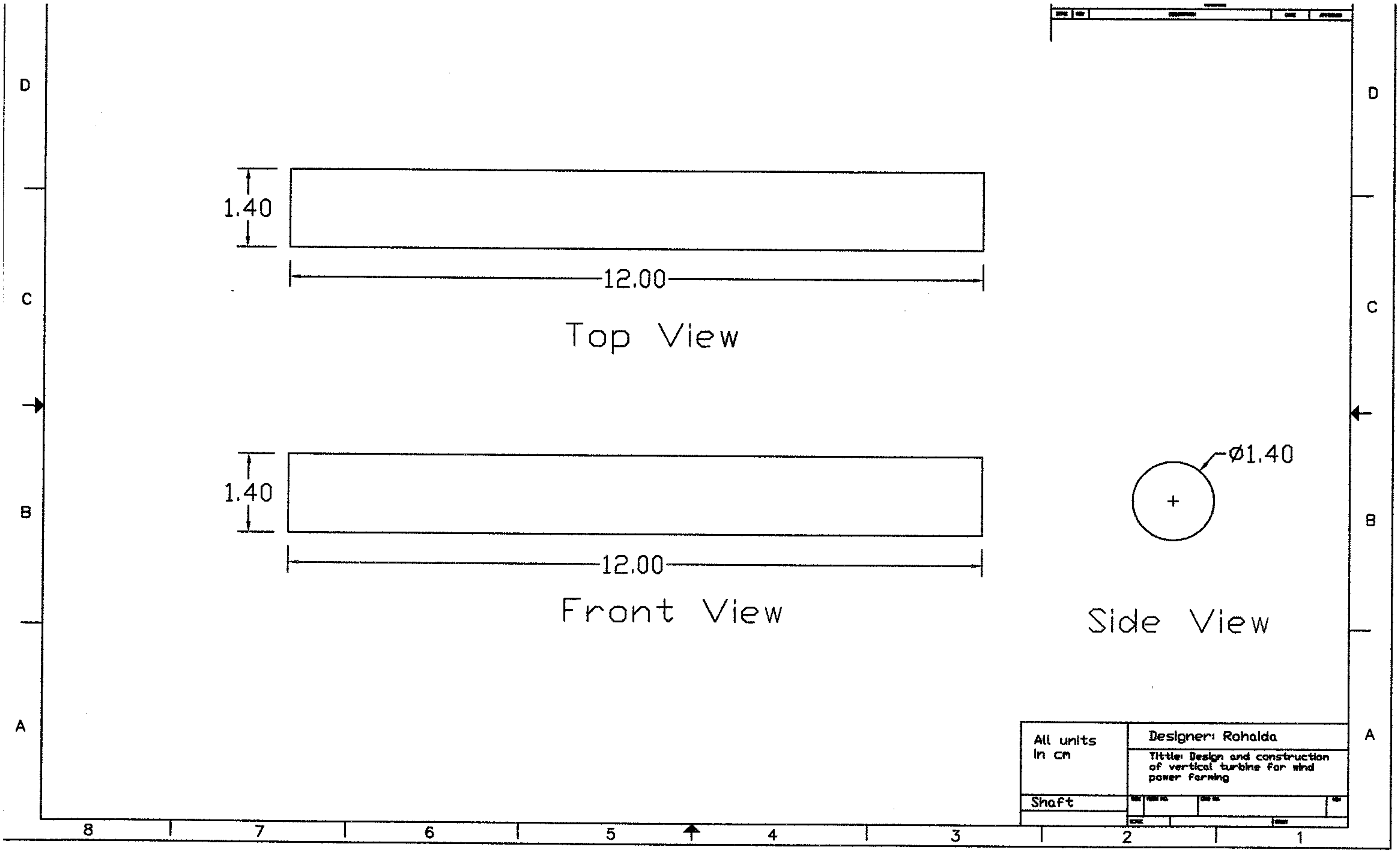
).	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Project Work Continue		■	■											
	-Literature Review														
2	Submission of Progress Report 1		●												
3	Project Work Continue				■	■	■	■	■						
	-Designing														
	-Mathematical modeling														
	-Design modeling														
4	Submission of Progress Report 2							●							
5	Project work continue								■	■	■	■	■		
	-Design modeling														
	-Prototype construction														
6	Submission of Dissertation Final Draft										●				
7	Oral Presentation											●			
8	Submission of Project Dissertation												●		

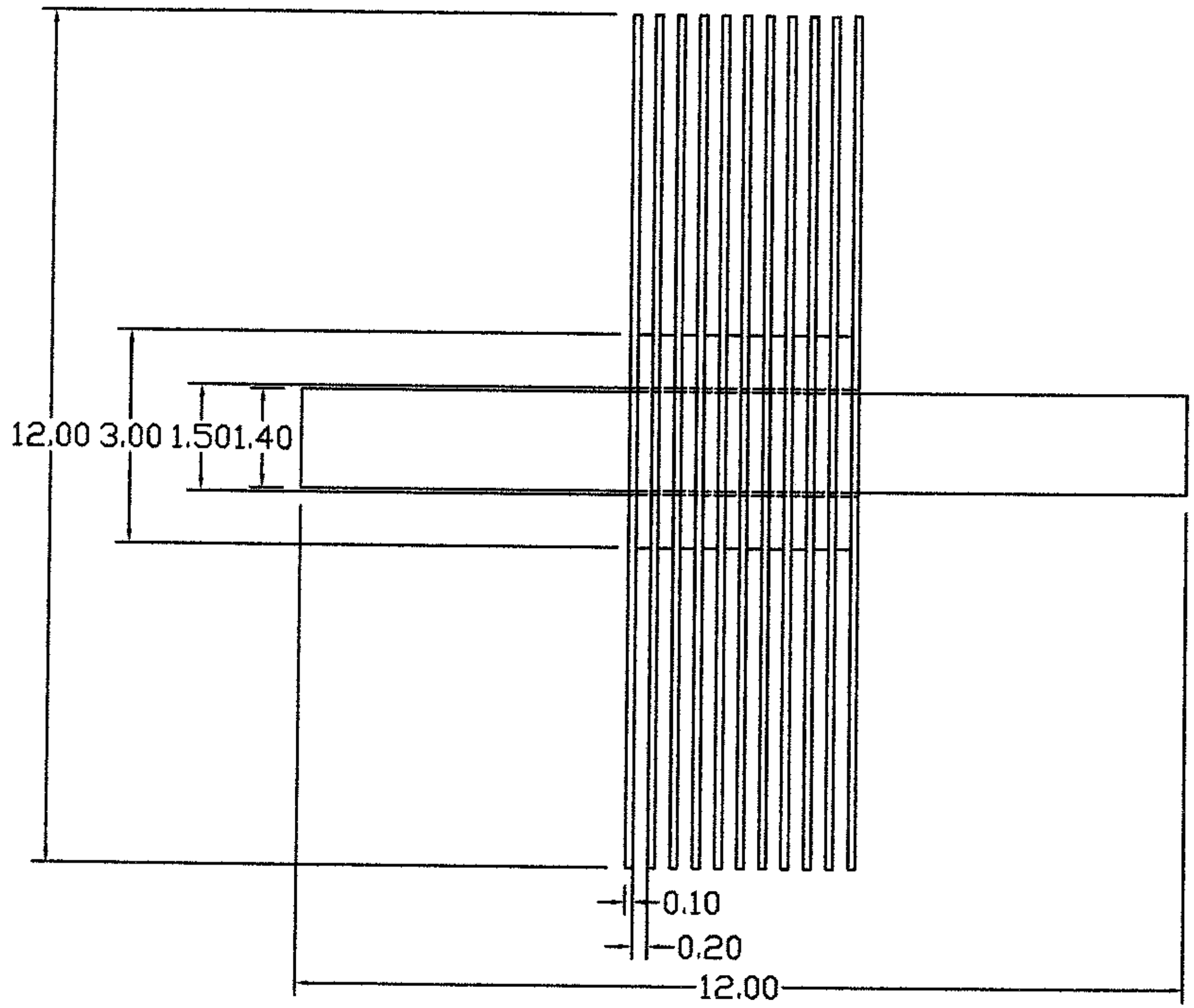
● Suggested milestone

■ Process

APPENDIX D
TECHNICAL DRAWING

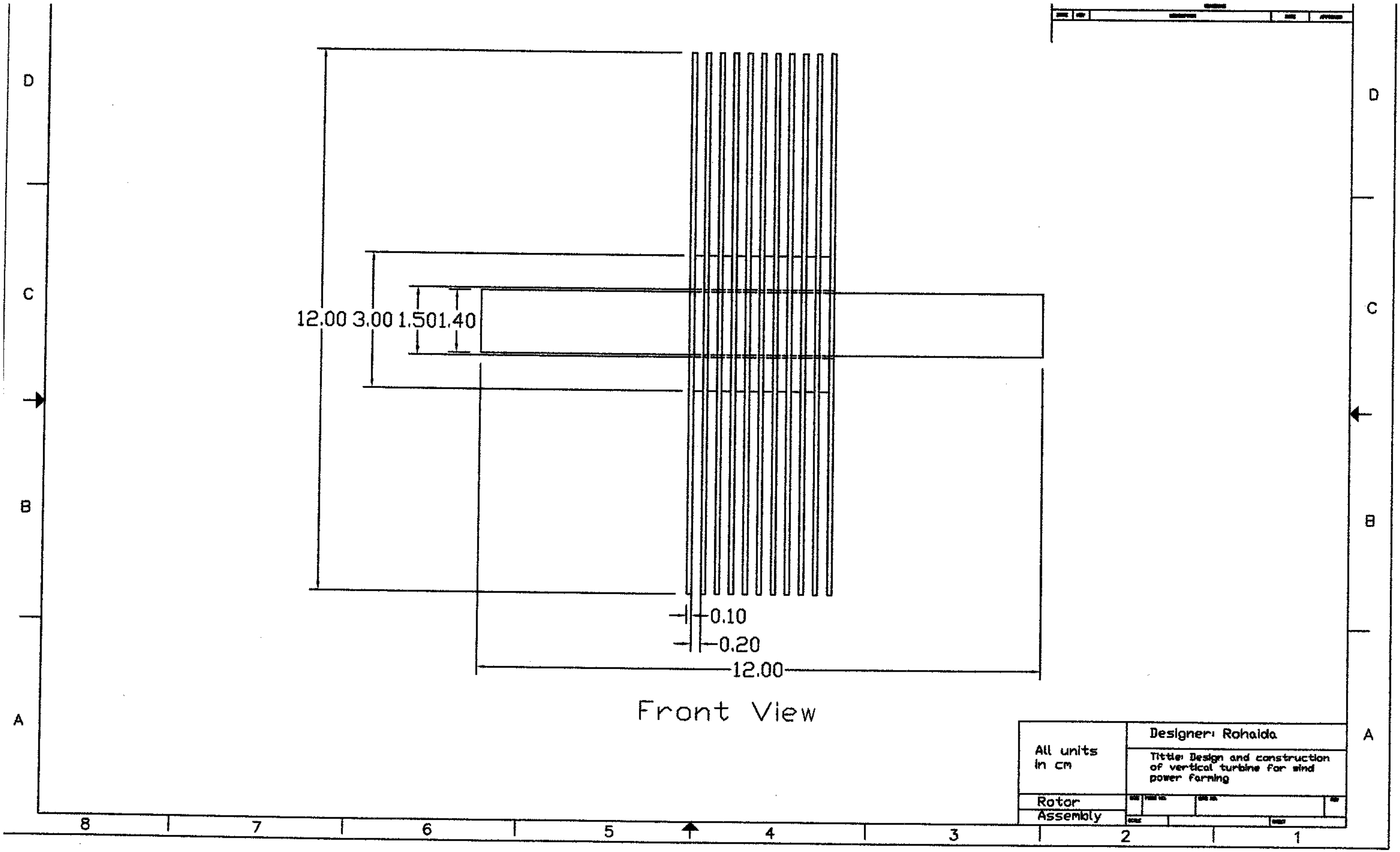

6 × ø1.00
6 × ø0.40
ø12.00
2.00
Top View
0.10
1.50
0.40
12.00
Front View
0.10
1.50
1.00
12.00
Side View
All units in cm
Designer: Rohaida
Tittle: Design and construction of vertical turbine for wind power farming
Disk
D
C
B
A
8
7
6
5
4
3
2
1

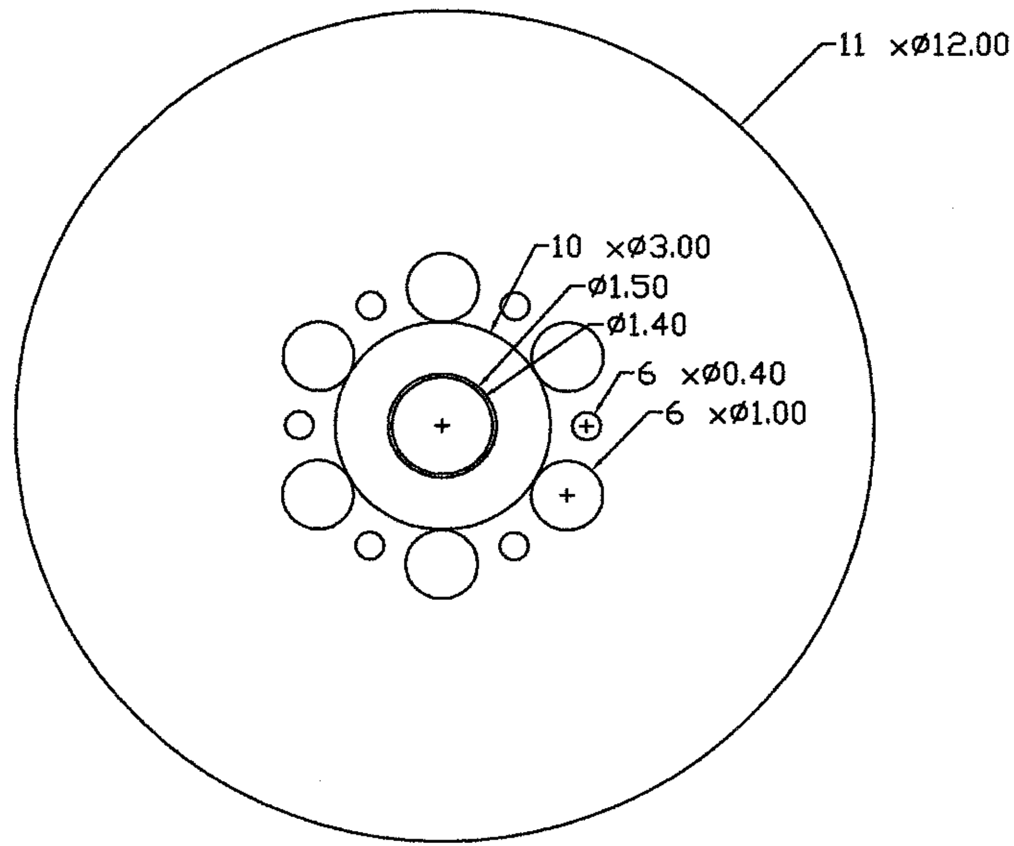

1.40
12.00
Top View
1.40
12.00
Front View
Ø1.40
Side View
All units
In cm
Designer: Rohalda
Tittle: Design and construction of vertical turbine for wind power farming
Shaft



Top View

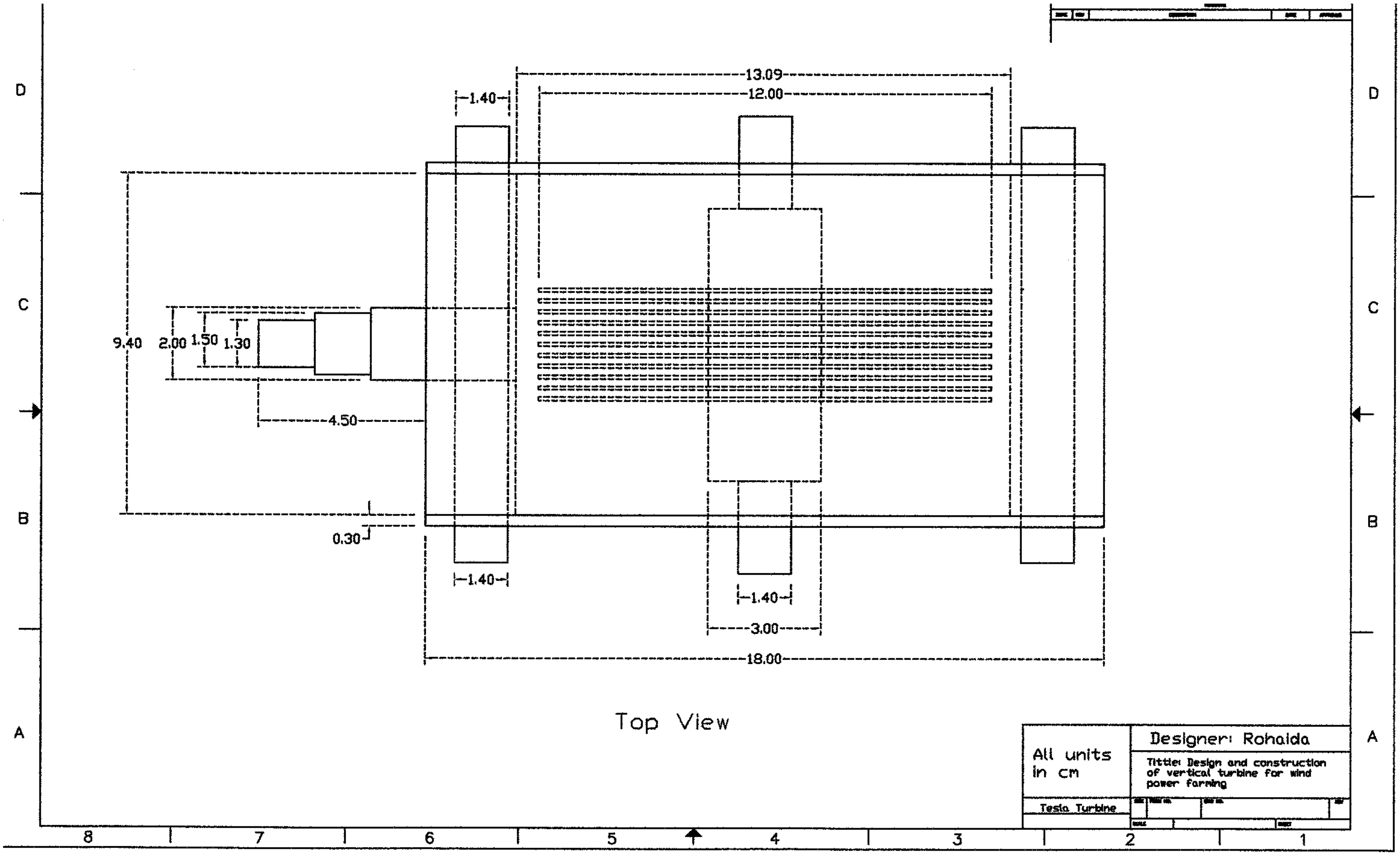
All units in cm	Designer: Rohaida
	Tittle: Design and construction of vertical turbine for wind power farming
Rotor Assembly	

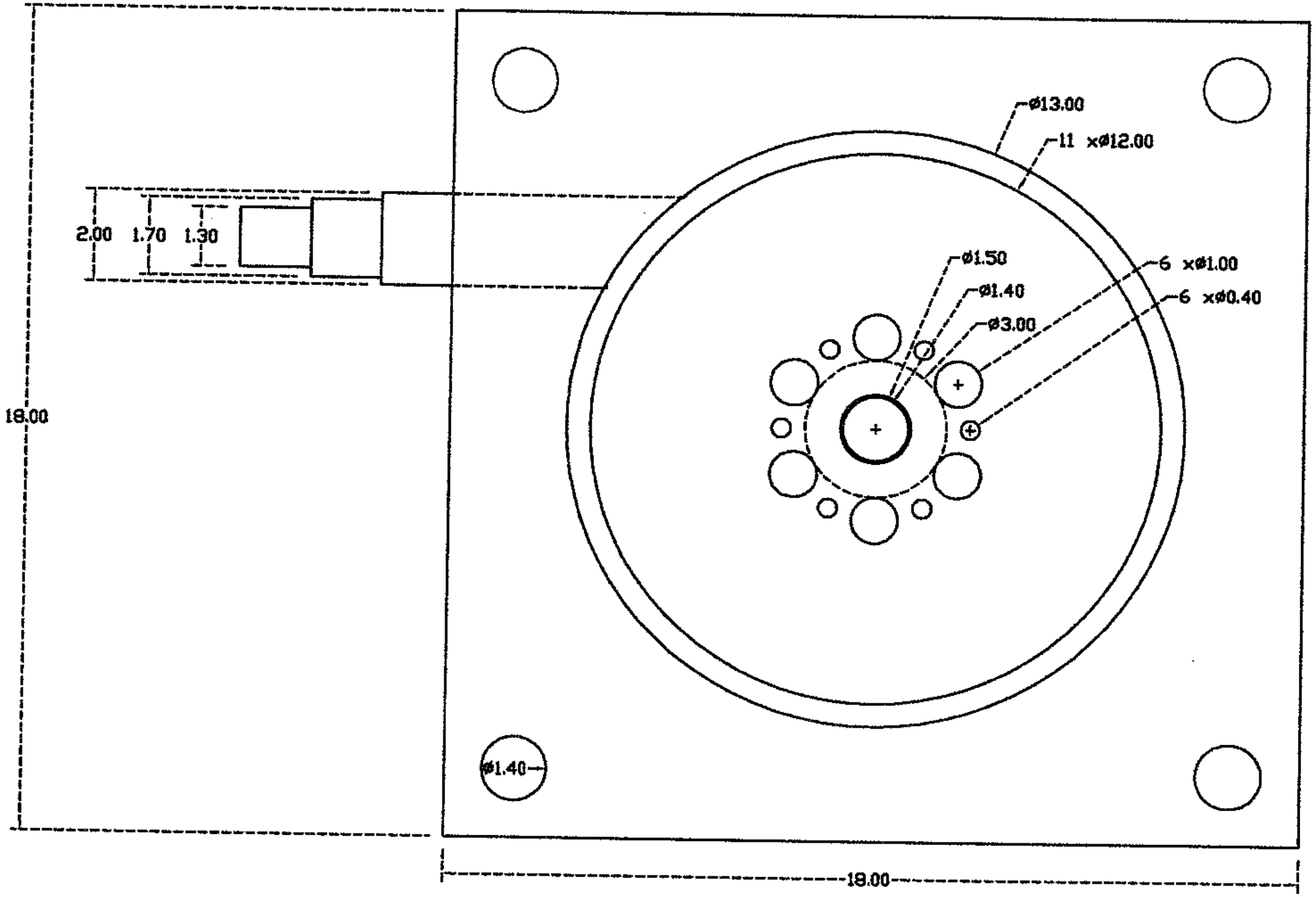

12.00
3.00
1.50
1.40
0.10
0.20
12.00
Front View
Designer: Rohaida
All units in cm
Tittle: Design and construction of vertical turbine for wind power forming
Rotor
Assembly
D
C
B
A
8
7
6
5
4
3
2
1



Side View

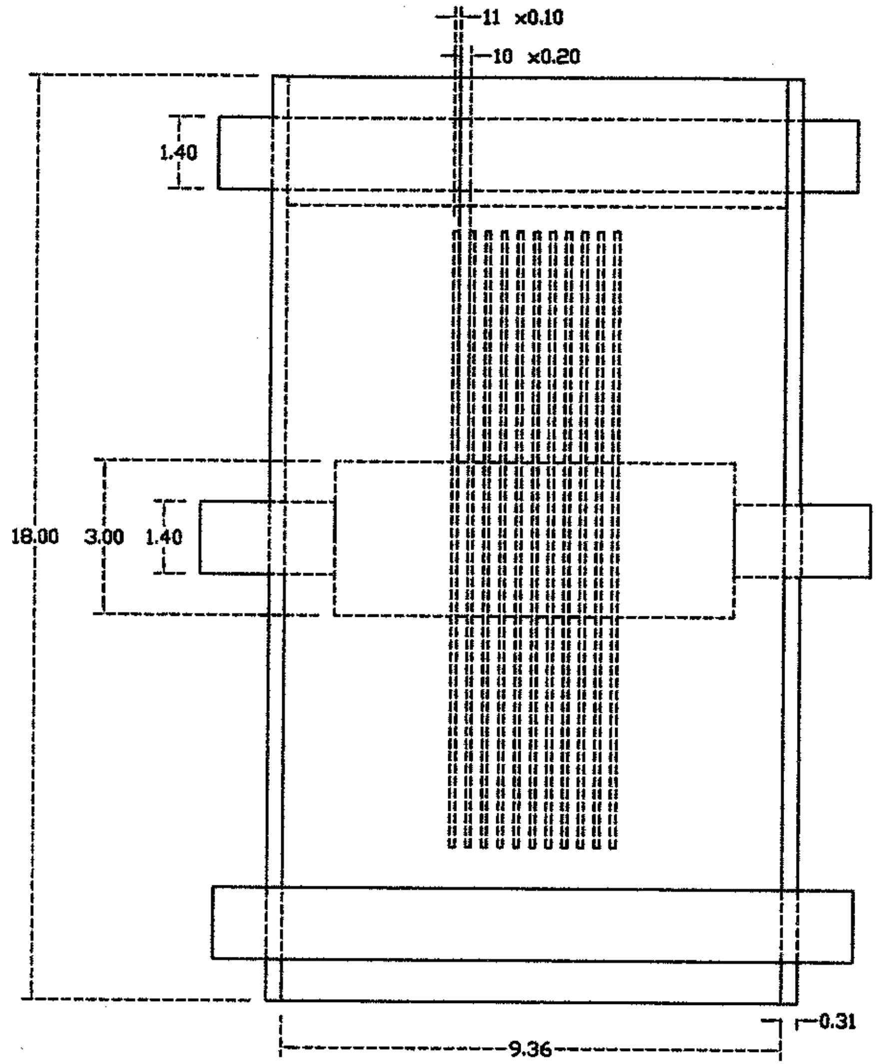
All units in cm	Designer: Rohalda
	Tittle: Design and construction of vertical turbine for wind power farming
Rotor Assembly	


13.09
12.00
1.40
1.40
1.40
3.00
18.00
9.40
2.00
1.50
1.30
4.50
0.30
Top View
All units in cm
Testa Turbine
Designer: Rohaida
Tittle: Design and construction of vertical turbine for wind power farming



Front View

All units in cm	Designer: Rohaida
	Tittle: Design and construction of vertical turbine for wind power farming
Tesla Turbine	



Side View

All units in cm	Designer: Rohaida
	Tittle: Design and construction of vertical turbine for wind power farming
Tesla Turbine	