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# Vertical Axis Wind Turbine Design and Analysis

A Major Qualifying Project

submitted to the Faculty

of

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in partial fulfillment of the requirements for the

Degree of Bachelor of Science

By


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## Abstract

Wind power, as a sustainable "green" technology, is becoming a larger component of electrical power generation. Research into various configurations of wind turbines has led to the desire to explore the potential benefits of a vertical-axis wind turbine, or VAWT. The product development process for a low-cost, roof-mounted wind turbine for residential installations requires the design and analysis of a model turbine and a funneling enclosure, as well as determining how the behavior of the model is expected to change once a full-scale prototype is developed. An operational overview of the entire power generation system is also explored, outlining how the electrical power is transferred from the turbine to the consumer.

## Executive Summary

Wind turbines are becoming a larger focus for electrical power generation, so the potential for the development of a vertical-axis wind turbine is being evaluated. Vertical-axis turbines have the potential to be more easily produced and installed, leading to a higher rate of adoption among homeowners. Thus, a main goal of this and subsequent projects is to improve the efficiency of the turbine wherever possible in order to increase the overall appeal of wind power.

The first series of tests in the wind tunnel in Higgins Laboratories at Worcester Polytechnic Institute tested for the number of blades and their angle of orientation with respect to the oncoming wind. A subsequent test involved testing these conditions with the addition of an enclosure, designed to improve the airflow within the turbine system.

During testing, the conditions inside the wind tunnel caused the data gathered for a turbine inside an enclosure to be less than optimal, due to vibrations in the system resulting in the turbine striking the walls of the enclosure. As such, a stabilizer that would attach the turbine to the top of the wind tunnel to reduce vibrations was developed. Procedures for additional testing conditions were developed, such as including the effect of torque on the turbine and the torque produced by the turbine, as well as designing a means of attaching a funneling mechanism to the interior of the wind tunnel.

The turbine itself is just one part of the entire electrical generation system. Additional components were researched, including the generator and charging system, to present a sample system overview of how the turbine would fit into the larger picture, and how easily a wind turbine would be able to fit into the existing framework of a home.

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## Capstone Design Statement

The current stage of development of the vertical axis wind turbine featured two main design components: the design of a funneling apparatus for future testing, and a system design for the entire turbine assembly. The funneling apparatus involved devising a way to place a modular shield in front of the wind turbine inside of the wind tunnel, in order to test the effect of variations in air flow on the turbine. Design constraints on the funneling apparatus included not being able to drill through the walls of the wind tunnel for support, being able to easily add and remove the funnel, and keeping material costs low. The system design for the turbine assembly consisted of sourcing components that would be used in conjunction with the turbine to provide supplemental electric power to a residential household.

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# 1 Background

The concept of harnessing wind as an energy source dates back to as far as 1000 B.C. (Dodge). The first application of harnessing wind power was the sailboat, which is still one of the most common forms of using wind as a source of energy. Sailboat designs have seen some changes over time, but the same fundamental concept remains. The first windmills were created for the tasks of grinding grains and pumping water (Dodge 1). These machines were used in parts of Europe and Central America. It is believed that around 500 A.D. that the first vertical-axis windmills were created in Persia. However, there is no real record of these inventions, so their designs and operation can only be determined through verbal accounts (Dodge 2). Early vertical axis windmills were also found in China around the same time period. Like the Persians, the Chinese also used these windmills for pumping water and grinding grains (Clean Green Energy). Horizontal axis windmills were first seen in Western Europe, and came much later than the vertical axis windmill. This new style of windmill was made most popular through the design of the water wheel. Transporting and installing horizontal structures was much easier than moving the more bulky vertical axis mills (Clean Green Energy), but moving any of these structures was difficult in this time period, due to the lack of reliable heavy transportation methods. Therefore they were often built in their "final resting positions". As time went on, the technology behind windmills continued to advance in addition to various inventions increasing their ability to be produced. A more modern, tower-mill design was created first by the Dutch in 1390, however, this design may have existed earlier being used in the Mediterranean Sea (Clean Green Energy). By the early 1900s, wind turbines began to be used for power generation as the turbines were hooked up to electrical generators. However, by the 1950s the use of wind turbines for producing electrical power began to fall out of favor, as fossil fuels and nuclear power generation were focused on as the (then) cheaper option. In 1973, oil prices spiked by a large margin, and wind power began to see a resurgence as the public slowly began to realize that oil was a limited commodity. Over the next few decades, this fact combined with the pollution emitted by fossil fuel plants has led wind power to become a widely-researched potential for energy generation (Mathew).

Figure 1-1 - Early European windmill

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Figure 1-2 - Modern wind farm

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Harnessing energy from wind continues to be a growing field of study and practice. At the current time, “other than hydropower, wind power is the most mature and most important of the renewable sources of power” (Leithead 957). The United States has just begun to see the advantages of large wind turbines and turbine farms. Several countries in the European Union have seen a large increase in turbines, which have led to substantial increases in electricity generation. The possibility of further increasing production depends on a few things, “the available wind resource, technical development and most importantly public acceptance” (Leithead 957). The last item may be the most important part to further advances in energy production, because so many people are opposed to the technology for a variety of reasons. When a wind farm is first proposed, there are generally concerns over its impact on the local environment. This impact can consist of “the noise, the effect on birds and the visual intrusion in the landscape” (Leithead 968). All of these issues can be a reason for concern, but the impact can be minimized with the proper planning. Overall, renewable sources of energy, like wind turbines, represent an important part of future sustainability. Moving away from the reliance on oil in this country is important for future generations.

In order to understand how wind turbines produce electricity, a general knowledge of how power is generated from sources other than wind is beneficial. Most power plants operate using similar principles. Mechanical energy is used to spin a shaft, which in turn rotates an electrical generator. The methods used to collect the mechanical energy can vary widely, but all are based on the concept of using a fluid to spin a turbine. Hydroelectric plants use water; windmills use wind, while fossil fuel and nuclear plants use steam. The fluid flows into a turbine, a disk-shaped mechanical device that is caused to rotate when the fluid pushes against it, usually by the fluid hitting against “blades” that convert the momentum of the fluid into rotational energy of the turbine. The turbine is connected to a shaft, which in turn is connected to a generator. The kinetic energy of the moving fluid is collected by the turbine in the form of rotational energy, and is ultimately converted to electric energy (Rubin).

Figure 1-3 - Conventional steam turbine

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The steam that powers “conventional” power plants is produced by heating a volume of water. The most common method of heating the water is by burning a fossil fuel: petroleum, natural gas, or coal. In the case of a nuclear reactor, the heat produced by a series of controlled nuclear reactions is used to heat the water. One concern with plants that use steam is the waste produced by the heating process, in the form of “fly ash” and other byproducts. Before society was largely concerned with pollutants, these waste materials were discharged into streams and into the atmosphere. While government regulations now exist to regulate the discharge of these pollutants, their effect on the environment is still of large concern. Nuclear plants have their own waste problem, as the radioactive waste produced by the nuclear reaction cannot be further reacted with, and takes a long time to decay (in the range of tens of thousands of years) as well as potentially producing harmful radiation (Rubin).

As the purpose of a wind turbine is to generate electricity, it is important to have some knowledge of how electromechanical generators function. Motor action is the conversion of electrical energy to mechanical energy, while generator action is the conversion of mechanical energy to electrical energy. Thus, systems that produce motor action are called motors, and systems that produce generator action are called generators. More simply, any system consisting of an electrical system, a mechanical system, and a coupling device can be referred to as an electromechanical energy converter. Motors and generators use the exact same principles in their construction and design. Electrical devices called inductors produce a magnetic field when current passes through them. Conversely, an inductor will produce current in the presence of a moving magnetic field. By positioning magnetic materials on the rotating shaft rotating around stationary inductors, an alternating current can be generated. In an ideal system, the electrical energy produced can be calculated from the mechanical energy exerted using Equation 1.

$$vi = T\omega \qquad \text{(Equation 1)}$$

In the above equation, $v$ represents the voltage produced, $i$ represents the current, $T$ is the torque, and $\omega$ is the angular velocity (Sarma). Real systems will deviate from this formula from losses due to friction, heat energy produced from the electricity, among other causes. Many companies develop generators for use with wind turbines, specifically designed to have a low starting torque and to be able to withstand large forces acting on the shaft of the generator (Ginlong Technologies).

Wind turbines require a number of mechanical systems to provide power to the generator. These mechanical systems are housed in a nacelle, designed to protect the components from exposure to the elements. The blades collect energy from the wind, spinning the rotor. The rotor is attached to a shaft, termed the "low-speed shaft". This shaft is connected to a gearbox, which rotates a second shaft, termed the "high-speed shaft". This second shaft is what is connected directly to the generator. The high-speed shaft rotates at a higher rate in order to spin the generator as fast as possible, leading to higher electrical output. To avoid damaging the generator, a brake is applied to the low-speed shaft in high wind conditions, limiting the speed of the rotor to a fixed value (Ragheb

13). The electricity generated from the turbine is connected either to a battery or the power grid, depending on the intended use of the turbine. In either case, specialized circuitry is required when transmitting the electricity. For a battery, a charging circuit is required to avoid overcharging and potentially damaging the battery (Davis). For distribution on the power grid, circuitry to avoid disrupting the power grid is required (Ragheb 36).

Wind energy can provide tremendous savings to individual households. Assuming an average household of three people uses 6000 kWh of energy per year (Silverman), the savings provided by using different sizes of generators can be determined. Due to the natural fluctuations in the speed and intensity of wind, the "capacity factor", or the actual output of a wind turbine over time as compared to its theoretical maximum, is about 15%. Thus, a generator rated for 1 kW of power output (yielding a theoretical maximum of 8760 kWh per year) will produce approximately 1314 kWh per year (National Wind Watch). If the cost of electricity is 13.727 cents per kWh (National Grid), a 1 kW generator could lower the overall cost of electricity for an average household from $823.62 per year to $643.25. A 2 kW generator would reduce the cost to $462.87, and a 4 kW generator would reduce the cost to $102.13. A 5 kW generator would produce an energy surplus. These costs assume that all energy that is produced is either used or stored in batteries. As wind is unpredictable, even a household with a 5 kW generator should be hooked up to the energy grid to provide energy in times of lower than normal wind speeds (National Wind Watch).

There are two general types of wind turbines: vertical axis wind turbines and horizontal axis wind turbines. They both have their advantages and disadvantages and choosing which style to implement depends upon their size, application and location.

Horizontal axis wind turbines currently dominate the majority of the wind industry. Horizontal axis means that the rotating axis of the wind turbine is horizontal, or parallel with the ground. For large wind farms or industrial customers, horizontal axis wind turbines are the dominant type of turbine.

However, in smaller or residential wind applications, vertical axis turbines have a place. The advantage of the horizontal axis is that it is simply able to produce much more electricity from a given amount of wind. A disadvantage of horizontal axis turbines is that they are generally heavier and do not produce much power in turbulent winds. Therefore their location plays a big part in how successful the turbine will be and the amount of energy it will produce.

Figure 1-4 - Horizontal axis wind turbine

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A horizontal axis wind turbine, or HAWT can have any number of blades, ranging from one (balanced with a counterweight) to upwards of twelve, with most commercial turbines using three blades (Mathew). The number of blades can be represented by the solidity of the turbine, or the ratio between the areas covered by the blades in relation to the swept area of the rotor, or the area the blades cross. In theory, two turbines with the same rotor swept area experiencing the same wind velocity will have the same power output. In real life, drag experienced by the blades as they spin will reduce the power output for a higher numbers of blades. In some instances, the drag can be useful, as the starting torque of the turbine increases with the solidity. Water pumping mechanisms require a high starting torque, for example (Mathew).

HAWT can be further categorized as upwind or downwind. In upwind turbines, the turbine is upwind of the tower: the wind passes through the rotor before it hits the tower. This mode requires a mechanism to be able to control the yaw of the tower such that it may face the direction of the wind. With downwind turbines, the wind passes the tower before reaching the rotor. This mode doesn't necessarily need a yaw mechanism, but the "shadow" of the tower may cause uneven loading on the rotor (Mathew).

Vertical axis wind turbines, or VAWT, operate differently, in that the rotational axis of the turbine stands vertical or perpendicular to the ground. As mentioned previously, vertical axis turbines are primarily used in smaller or residential installations. Vertical axis turbines are powered by wind coming from all 360 degrees. In some cases, vertical axis turbines can be powered when the wind blows from top to bottom. Because of their versatility, vertical axis wind turbines are thought to be ideal for installations where wind conditions are not consistent. If there are certain public ordinances or restrictions on how high a turbine can be placed, vertical axis installments provide a good alternative. Therefore, if the turbine cannot be placed high enough to benefit from steady wind, vertical axis turbines should be used.

Figure 1-5 - Vertical axis wind turbine

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VAWT are visually distinctive as compared to HAWT, and can bear little resemblance to the common perception of a wind turbine. Various shapes of rotor designs have been proposed or implemented, but the common trait is a number of vertical blades attached to a central shaft. VAWT need no yaw control mechanism, experience relatively high efficiency and have higher rotational speeds compared to HAWT (Wortman). The generator and gearbox of the system can be located at ground level rather than elevated in the air as in a HAWT, leading to a higher ease of installation and contributes to their economic feasibility. However, VAWT often may not be able to start moving on their own without an additional mechanism (Mathew), and tend to stall in gusts. Additionally, their tendency to be installed in lower operating heights results in lower wind speed conditions (Wortman).

Smaller wind turbines used in residential or small commercial installations are beginning to gain popularity. These systems vary in design, but their size makes them desirable for residential applications. The average American home would require a small wind turbine with a 5 kW generating capacity to meet all or most of its electricity needs (Dougherty). This makes them appropriate for individual homes and businesses or, when grouped together, to act as a wind farm.

Increased environmental concerns and regulations on greenhouse gases have brought alternative energy sources to the table. Both federal and state incentives for renewable energy generation have created a promising environment for landowners wishing to invest in wind energy. Before embarking on such a project, landowners should research and review all applicable local, state, and federal laws and regulations thoroughly. Small turbines can be designed as standalone systems or grid-connected. Grid connected systems require collaboration with the local utility provider in order to be able to connect to the grid. Overall, several factors must be examined when considering an investment in a small wind system: wind availability, zoning restrictions, generation capacity needed, site selection, and utility interconnection. These five factors are the most important to consider for any wind project, especially small-scale or residential applications.

# 2 Methodology

A series of model wind turbines were manufactured for testing in order to determine the ideal conditions for their eventual use in a large-scale prototype. The effects of adding either an enclosure or a funnel to the system are two additional design considerations that were to be tested. Once these variables were tested, an analysis of how the behavior of the turbine would change when scaled up would occur. A suitable location for deployment of the prototype turbine would be determined.

## 2.1 Wind Turbine Data Collection

Testing various wind turbine designs requires a facility with access to a wind tunnel. Collecting data from the wind tunnel in Higgins Laboratories was an important part in the design process and the evaluation of various designs. The wind tunnel provides data which can be displayed in a spreadsheet, which easily allows for graphs to be created. The revolutions per minute of the turbine are tracked at the varying wind speed inside the tunnel. A shaft is set in place inside the enclosure to hold each turbine design in place, while the wind speed is increased until the test is completed. The rotation of the wind tunnel's fan is increased from 1 Hz to 17 Hz, in increments of 1 Hz. The tunnel is left at each speed increment for 30 seconds before increasing its speed, resulting in a total testing time of 8.5 minutes. Before any testing could be conducted, a general knowledge of operating the wind tunnel was needed. With the help of lab instructors, knowledge of the operating process was gained. The data collection process was also explained with the help of instructors and computer software. From here, various tests needed to be conducted for the multiple turbines, which range from four to eight blades. Also, various placements of shrouds around the turbine must be tested. After the data for all the tests is gathered, the team can begin to make conclusions about which shroud design and number of blades presents produces the best result. Once all the data has been analyzed for the numerous turbines, shroud locations, and effective output an optimal design could be developed.

Figure 2-1 - Constructed wind turbines awaiting use

In order to design a suitable turbine, the data gathered from the lab had to be analyzed to identify their strengths and weaknesses. Certain factors such as: number of blades, alignment of shrouds, and the angle which they would be placed must be considered. With data from the wind tunnel, and the graphs for RPM vs. wind speed, an optimal design can be made. After the design is created, a scale-up factor can be determined for larger structures.

### 2.1.1 Operation of Wind Tunnel

The low-speed closed-return wind tunnel at Worcester Polytechnic Institute was chosen as a suitable testing platform due to its size and proximity. The controls for the tunnel consist of a numerical indication of the rotation speed of the fan blades in the tunnel, as well as stop/start controls. When the turbine is placed inside the tunnel, the shaft is connected to a device that records the rotations per minute of the shaft. Using this information, it is possible to determine the speed of the turbine at different wind speeds.

Figure 2-2 - Wind tunnel in Higgins Laboratories at Worcester Polytechnic Institute

#### 2.1.2 Testing Variables

Testing the wind turbine involved determining the ideal conditions for the maximum rotation and torque to be applied on the turbine at any given wind speed, such that the maximum possible useful energy was extracted from the wind. The variables to be considered were the number and angle of blades on each turbine, whether the addition of an enclosure would increase the speed of the turbine, and whether the addition of a funnel would increase the speed of the turbine.

## 2.2 Wind Turbine Data Analysis

After collecting data in the wind tunnel, the data was analyzed in order to design for an enclosure which would ultimately funnel incoming wind. The data can also be utilized to perform a scale up for a larger turbine. Specifically, a one to two kilowatt turbine would be the ideal size. The turbine would function on a commercial or residential property rooftop. Also, data from anemometers located around the Worcester Polytechnic Institute campus would provide knowledge of the typical wind speeds seen here. Depending upon the size and dimensions of the final turbine design, it may or may not be functional for this setting.

### 2.2.1 Scaling Factor

In order to plan for a larger turbine with the same functions as the current model, a scale up factor must be determined in order to accurately design for a larger model. When important measurements are kept in proportion like this, the model is said to be a scale version of the original. When a scale copy of an object or machine is created, the original and the copy have the same proportions. A scaling factor is used to describe how much an object has been scaled up or down. The scale factor is defined as the number you multiply the original dimensions by to get the dimensions on the model. From this, the following two equations can be used.

$$(\text{Original Measurement}) \times (\text{Scaling Factor}) = \text{Model Measurement} \qquad (\text{Equation 2})$$

$$\frac{(\text{Model Measurement})}{(\text{Original Measurement})} = \text{Scaling Factor} \qquad (\text{Equation 3})$$

In summary, scale factors express the degree of enlargement or reduction of a specific object. A scale factor of less than 1 reduces the size of an object. A scale factor greater than 1 increases its size.

A vector has magnitude and direction and, usually, a point of origin. A two dimensional vector can sometimes be represented on an x y graph as a line from the origin to the coordinates (x,y). If someone is talking about scaling a vector, they're referring to scaling the magnitude. For any scale factor k, the vector (x,y) has the same direction as the vector (kx, ky) but the magnitude has been "scaled" by the factor k.

## 2.3 Funnel

It is hypothesized that funneling a larger volume of air into the wind turbine will increase the speed the turbine spins, demonstrated in Figure 2-3. In order to be able to test this hypothesis, an assembly to hold the funneling mechanism in place inside the wind turbine needed to be constructed. Because no modifications were able to be made to the walls of the wind tunnel, a means for the funneling mechanism to be held in place in front of the wind turbine needed to be designed. The design for holding the funnel in place was a large box with beveled edges, designed to fit snugly inside the wind tunnel. The box would attach to the existing ports in the sides of the tunnel, as well as having a pole extending through the top of the tunnel to be attached on the outside. Exact measurements of the wind tunnel were taken, and a mock-up of the box was drafted in AutoCAD 2012, detailed in Section 3.4.

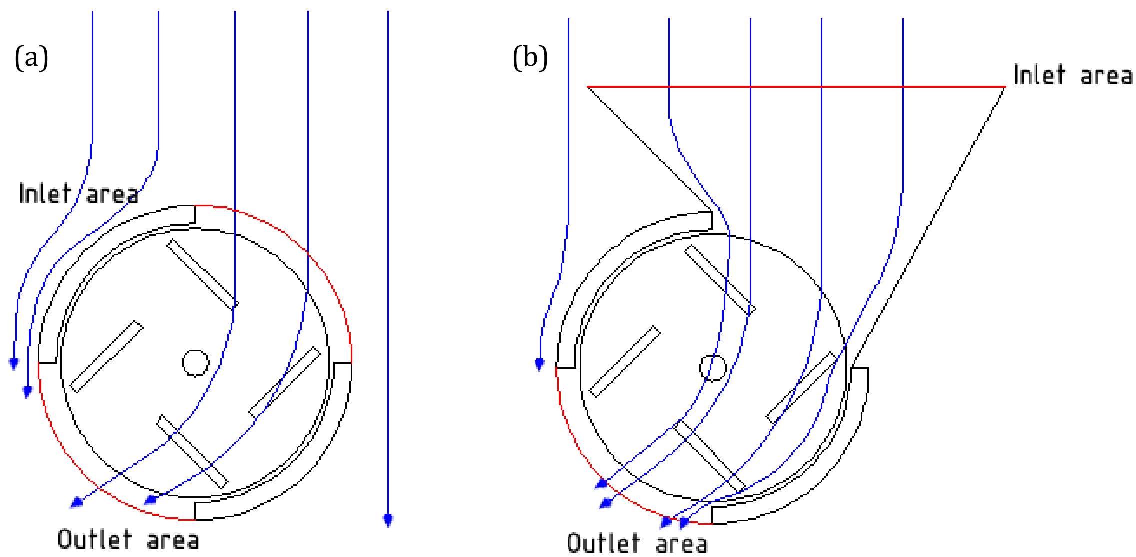



Figure 2-3 – Volume of air travelling through a turbine (a) without a funnel; (b) with a funnel

In addition to a funnel, the assembly should be able to house a deflection blade and a vectoring vane to test whether an enclosure is a necessary component. The enclosure is desired in the end product due to wildlife concerns, but as an engineering study the question should be answered. The deflection blade is designed to redirect wind away from exerting force on the turbine opposite the direction of rotation, as shown in Figure 2-4(a). The vectoring vane acts as a "funnel" by redirecting additional airflow into the turbine, as shown in Figure 2-4(b).

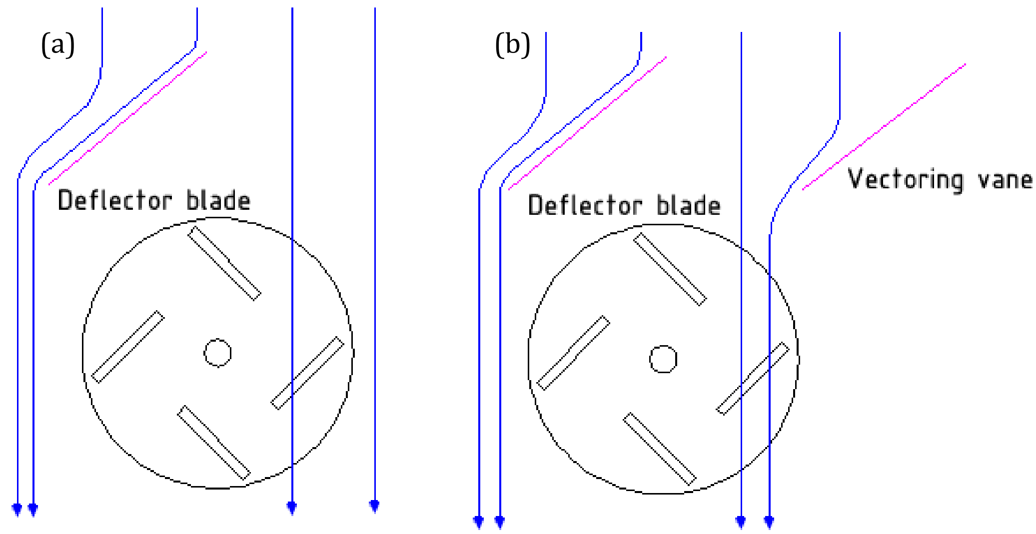



Figure 2-4 - Turbine with (a) deflector blade; (b) deflector blade and vectoring vane

## 2.4 Enclosure

One feature that has been suggested for the turbine is the inclusion of an enclosure to surround the turbine while in operation. The two main benefits of this feature are the prevention of wildlife from accidentally interfering with the operation of the turbine, and improving the airflow around the turbine, potentially leading to an increased power output due to faster rotation.

### 2.4.1 Enclosure Manufacturing

Three different enclosures were manufactured, as pictured in Figure 2-5(b). Each enclosure was cut from a tube of plastic, with the inner diameter appropriately sized to fit the turbine inside the enclosures. Two circular pieces of plastic were cut to provide a stable platform for the enclosure to rest on, and the entire assembly was glued to fit. Two similar pieces of plastic were cut to serve as a lid, and were held to the assembly with rubber bands. Four threaded holes were drilled in the base of the enclosure, in which four threaded rods were installed. Each of these assembled enclosures were to be then tested with each turbine, in order to determine the effect of the shape of airflow on the speed of the turbine.

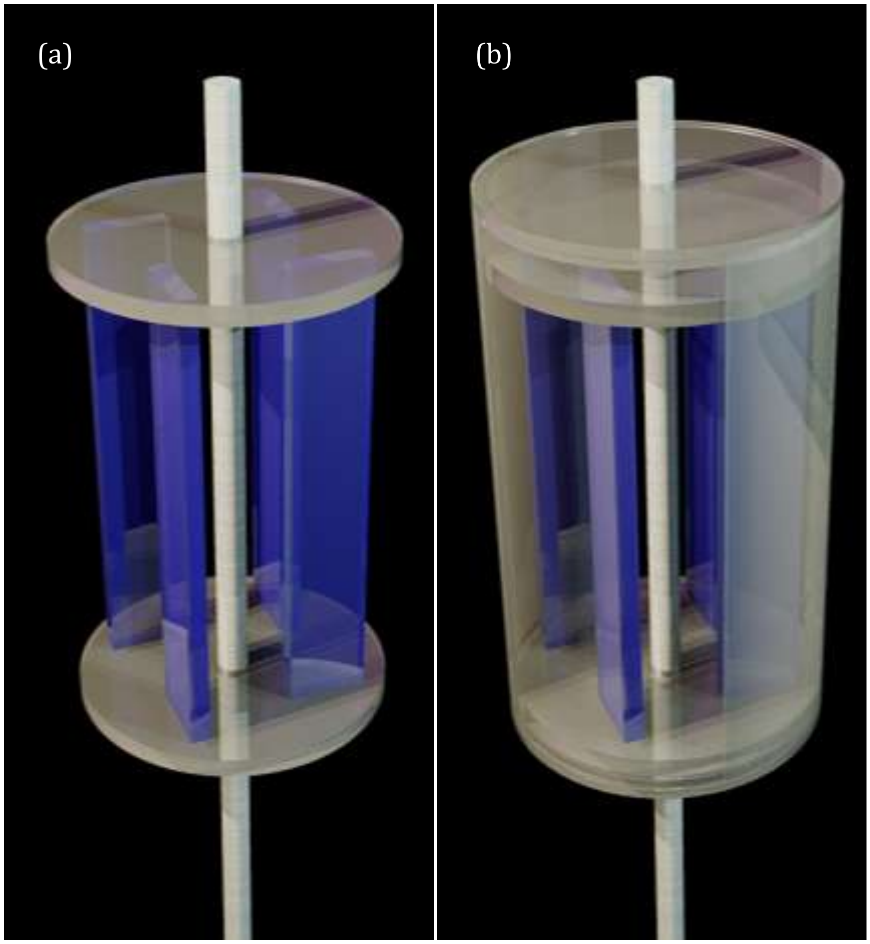



Figure 2-5 - (a) Turbine; (b) Turbine in enclosure

# 3 Results and Analysis

The key to the naming of each turbine in Figure 3-1 and Figure 3-2 was as follows: the number of blades was represented by the first term (B4 for four blades), the angle of pitch into the wind was represented by the second term (B4-45 had four blades at 45 degrees), and if the turbine was enclosed it was represented by the third term (B4-45-E1 used the first enclosure design). If E is not referenced, the turbine was tested open to the wind.

## 3.1 Original Testing Conditions

On July 13 and 26, 2011, the wind turbines were each tested inside the wind tunnel.

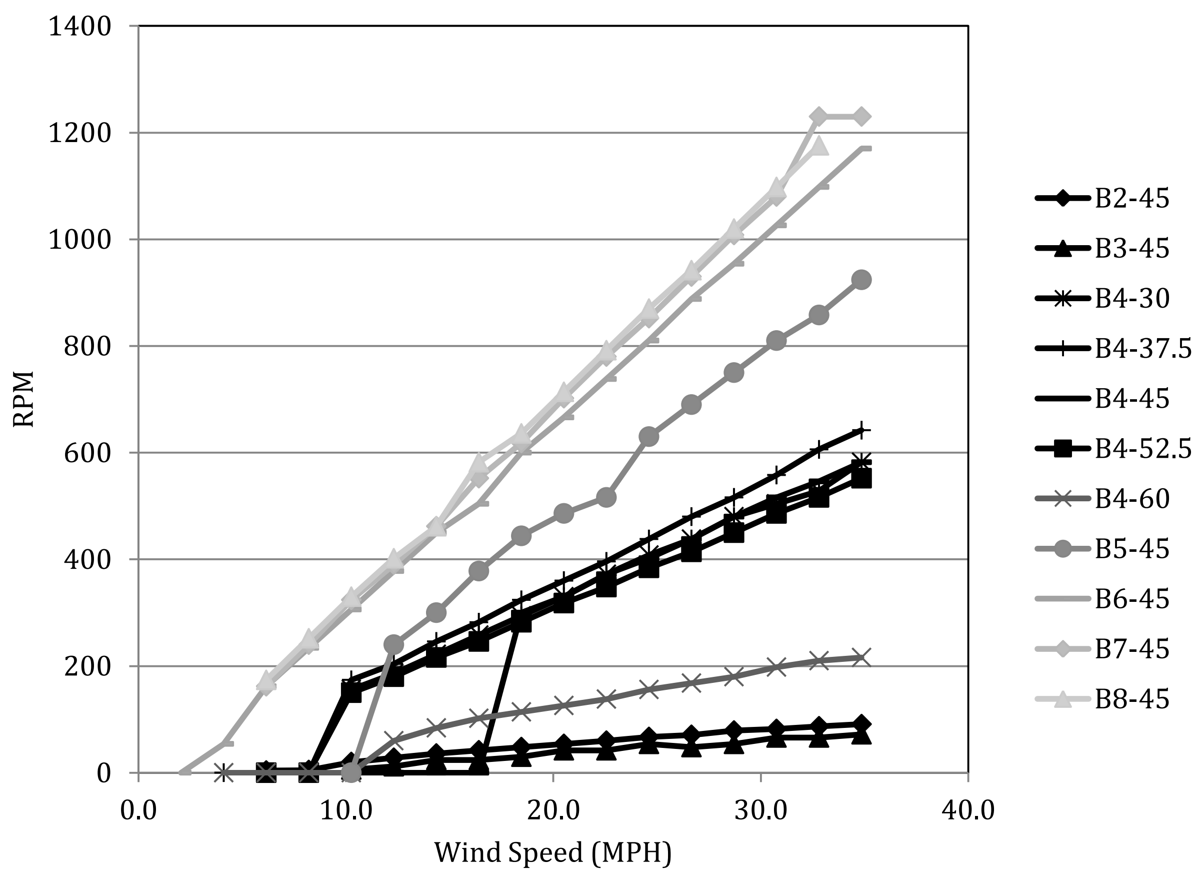



Figure 3-1 - Graphical display of RPM of turbine at various wind speeds

This data shows the rotational speed of the turbines as a function of wind speed, without taking into account the effect of an applied torque (such as the effect that would be had if a generator were to be attached to the shaft). The data suggests that there is a relationship between the number of blades on a turbine and the maximum possible rotational energy extracted from the wind. It can also be determined that a blade pitch of 45 degrees is efficient.

## 3.2 Original Testing Conditions, With Enclosure

On July 13, 26, and 28, 2011, the turbines were tested inside of an enclosure, to determine the effect of restricting and redirecting the airflow inside the turbine.

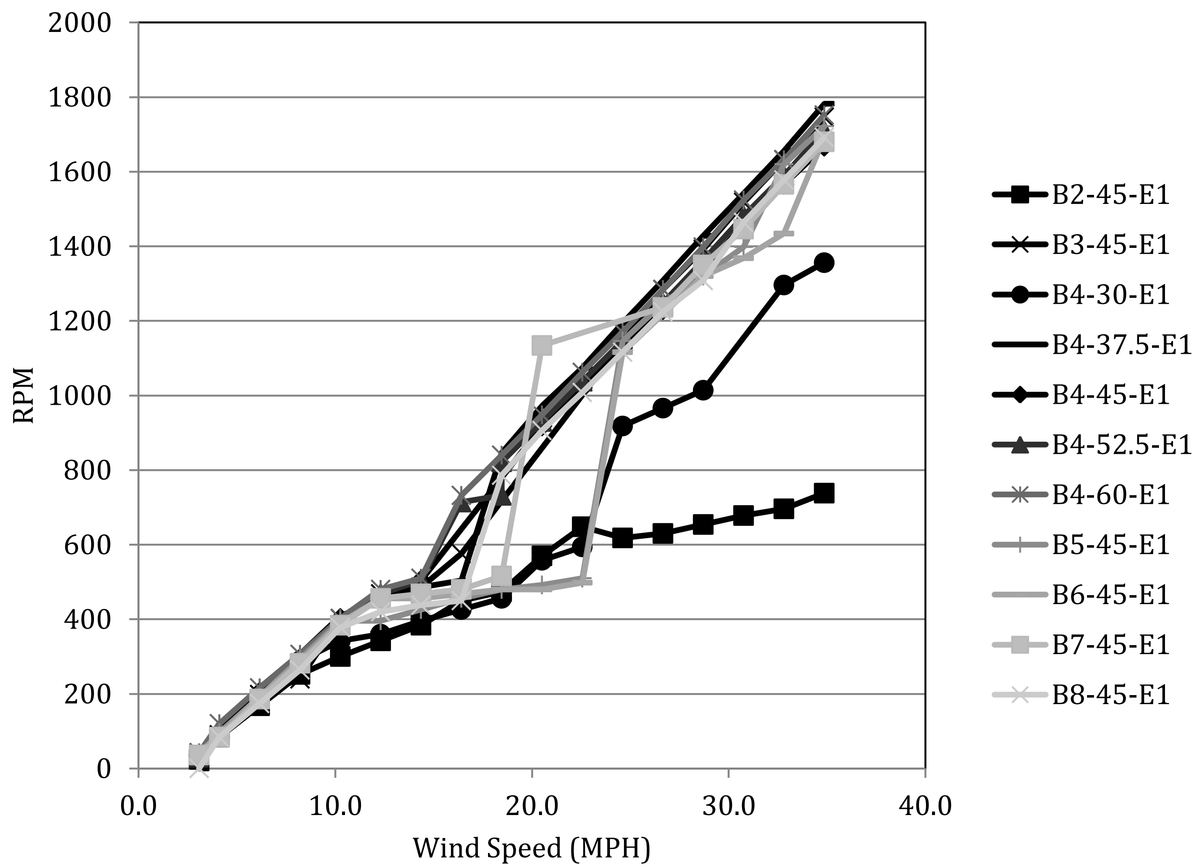



Figure 3-2 - Graphical display of RPM of turbine in enclosure at various wind speeds

As the wind speed increased, the turbine began to vibrate slightly. As the enclosure was designed with a very precise tolerance around its edges, the vibration caused the turbine to collide with its enclosure. These collisions reduced the speed of the turbine somewhat, until the wind speed was increased to an amount sufficient to overcome the vibrations.

The data points during these collisions must be discarded, and new tests run with a means of preventing the turbine from colliding with the enclosure. The shape of the curve of the graphs indicates that it may be possible to extrapolate the shape of the graph for the missing areas, but for thoroughness the tests will be re-run.

## 3.3 First Test with Stabilizer

On September 21, 2011, to rectify the issue of vibrations causing the turbine to collide with the enclosure, the tests were re-run using a stabilizer device to fix the top end of the turbine against the top wall of the wind tunnel. During these tests, the wind turbine did not spin at any wind speed, and no data was collected.

The stabilizer device, due to a manufacturing oversight, applied too much frictional force on the turbine, causing it to remain stationary. The stabilizer should have allowed the turbine to rotate freely, using an internal mechanism reducing frictional losses from ball bearings.

As no data was able to be collected, the testing was stopped until a replacement stabilizer and matching turbine shaft could be manufactured.

## 3.4 Wind Tunnel Testing Platform Design

The purpose of the wind tunnel testing platform is to be able to study the effects of an alteration of air flow through the wind turbine. The tunnel in Higgins Laboratories at Worcester Polytechnic Institute is unable to be modified; therefore a means of attaching various funneling mechanisms inside the tunnel is required. Each figure in this section is enlarged for detail in Appendix C: CAD Drawings.

The proposed solution involved building a structure that would fit on the inside of the wind tunnel. As the tunnel itself is square (see Figure 2-2), a box with dimensions matching the interior of the tunnel could be constructed, allowing various wind adjustment mechanisms to be attached to the box, avoiding the problem of being unable to attach structures directly to the tunnel. The box would be manufactured from four pieces of 3' by 2' acrylic, with each edge beveled at 45 degrees, as shown in Figure 3-3.

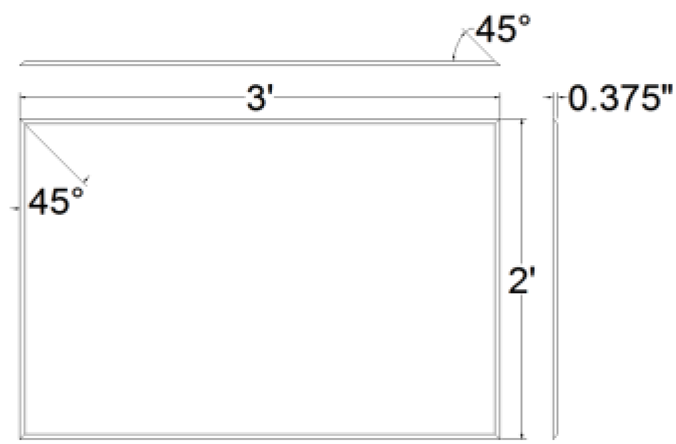



Figure 3-3 - Uncut wall of wind tunnel testing platform

Beveling the edges along the horizontal axis allow the pieces to fit together inside the tunnel, attaching to together with glue. The edges along the vertical axis are beveled to avoid disturbing the wind flow through the tunnel.

To keep the box from shifting out of place under wind loading, a support structure is screwed into the side of the box, as pictured in Figure 3-4. The support is circular, matching the diameter of an existing hole along the side of the wind tunnel.

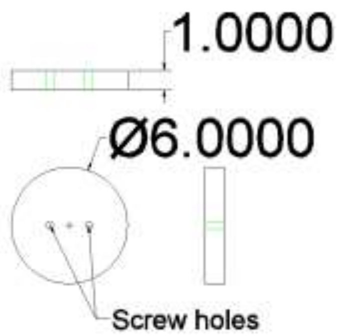



Figure 3-4 – Wind tunnel testing platform support

The support is screwed into place rather than glued to allow the box to be installed and removed from the tunnel without attaching it permanently into the tunnel.

Once the hollow box has been assembled with the support in place, it should appear as depicted in Figure 3-5. Holes in the top and bottom of the box are cut to allow the turbine shaft to be placed inside the box.

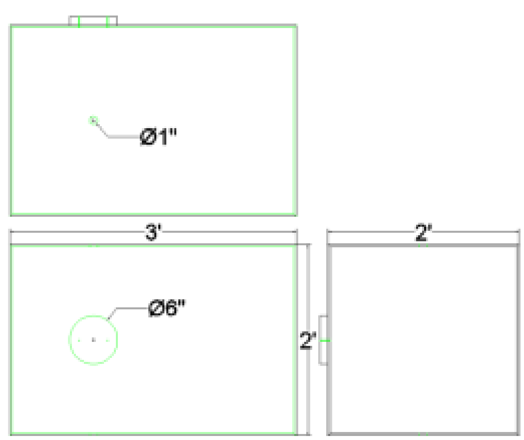



Figure 3-5 - Wind tunnel testing platform, assembled and uncut

Figure 3-5 shows how the box would look without adding any funneling mechanisms. Figure 3-6 shows the first funneling mechanism, the deflector.

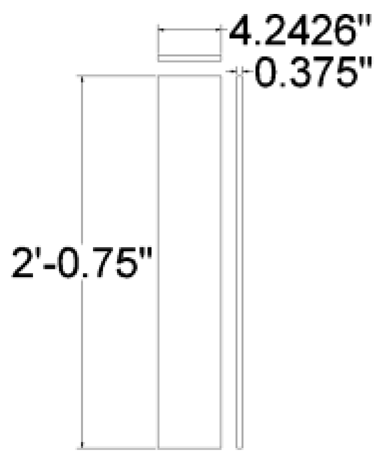



Figure 3-6 - Deflector blade for testing platform

The deflector blade is designed to prevent wind from exerting forces on the turbine opposite from the direction of rotation, as described in Section 2.3. The deflector would be positioned as in Figure 3-7.

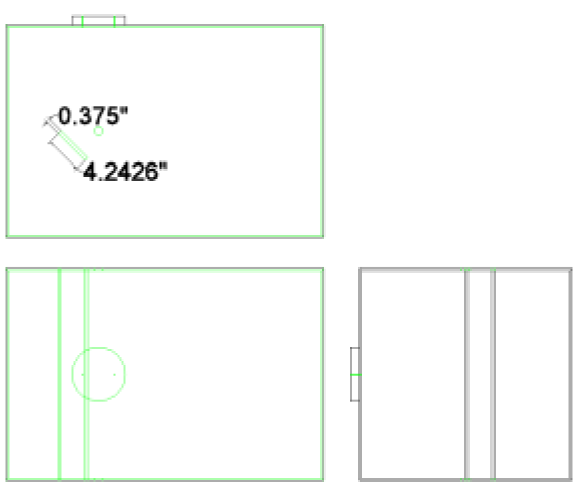



Figure 3-7 - Testing platform with deflector blade installed

The vectoring vane, described in Section 2.3, should be able to have its angle adjusted, to allow for an additional testing variable (testing what the ideal angle for a funnel would be). As such, the vane has a small protrusion at the top that will slide freely in a matching groove cut into the top of the box. The vane will rotate using a round peg fit into a small hole in the bottom of the box. Figure 3-8 shows the vane, including the peg and the protrusion.

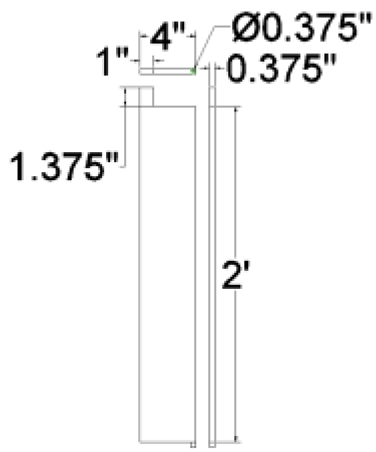



Figure 3-8 - Vectoring vane for testing platform

Figure 3-9 shows the box with both the deflector and the vane installed. On the top view the groove allowing for the movement of the vane is visible. The dimensions of where the various cuts for the deflector and vane should be located is seen in Figure 3-10.

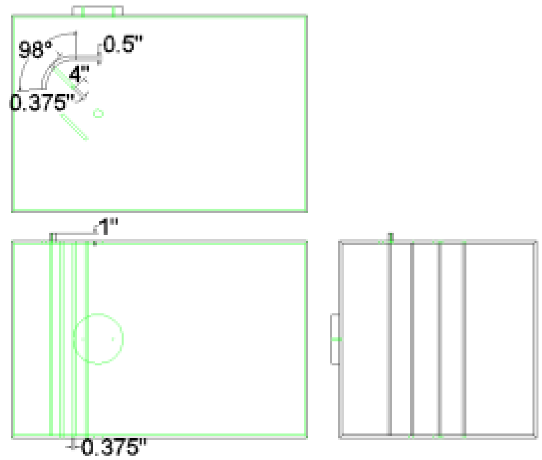



Figure 3-9 - Testing platform with deflector and vectoring vane installed

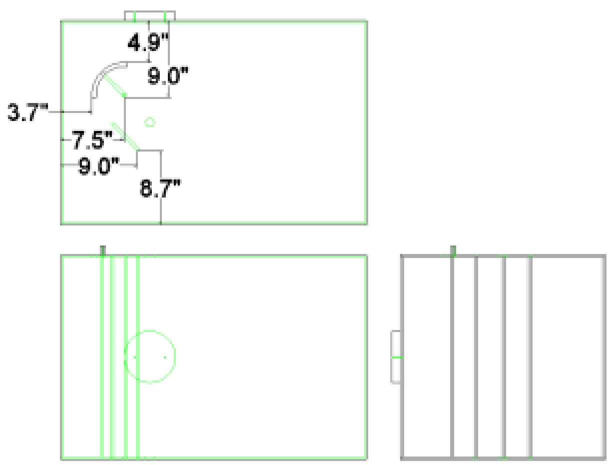



Figure 3-10 - Testing platform with deflector and vectoring vane installed, cut locations

The deflector and vectoring vane are designed to be used without an enclosure on a turbine. The funnel, used to test how an increased flow rate through the turbine will affect the power output of the system, is shown in its individual components in Figure 3-11, and assembled in the box in Figure 3-12.

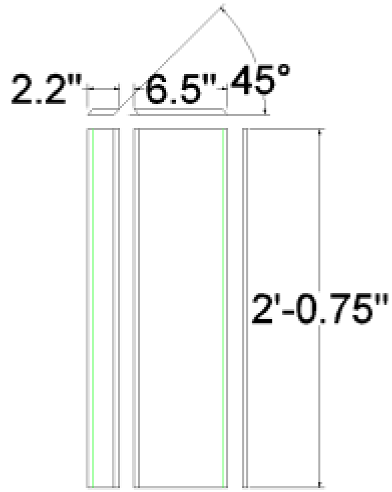



Figure 3-11 – Funnel segments for testing platform

The funnel is attached in two segments, each beveled at 45 degrees on either end. The beveling is to avoid disturbing the airflow around the funnel.

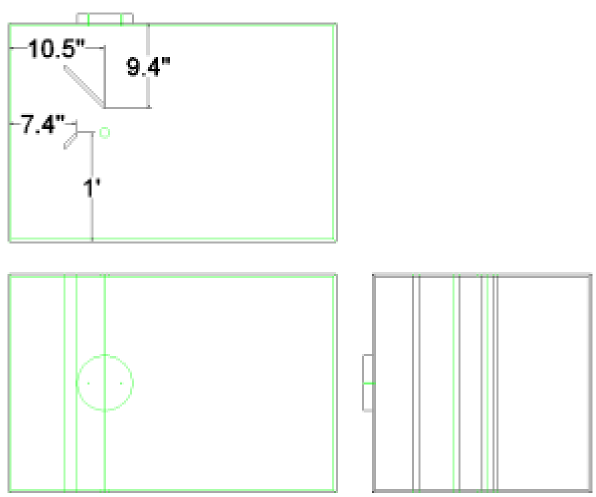



Figure 3-12 - Testing platform with funnel installed

# 4 Conclusions and Recommendations

One conclusion that can be drawn from these experiments involves the starting rotation speed, which is the point where the forces acting on the turbine are enough to overcome the static friction acting on the turbine. It can be assumed that as the number of blades increases, the starting rotation speed will decrease. Likewise, it is assumed that the addition of the enclosure will lower the starting rotation speed. The point at which each turbine began to spin is recorded in Table 4-1.

Table 4-1 - Starting speed of the turbines with and without enclosure

| | Starting Speed (MPH) |
|---|---|
| B2-45 | 6.2 |
| B2-45-E1 | 3.1 |
| B3-45 | 10.3 |
| B3-45-E1 | 3.1 |
| B4-30 | 10.3 |
| B4-30-E1 | 3.1 |
| B4-37.5 | 10.3 |
| B4-37.5-E1 | 4.1 |
| B4-45 | 12.3 |
| B4-45-E1 | 3.1 |
| B4-52.5 | 10.3 |
| B4-52.5-E1 | 3.1 |
| B4-60 | 12.3 |
| B4-60-E1 | 3.1 |
| B5-45 | 12.3 |
| B5-45-E1 | 3.1 |
| B6-45 | 4.1 |
| B6-45-E1 | 3.1 |
| B7-45 | 6.2 |
| B7-45-E1 | 3.1 |
| B8-45 | 6.2 |
| B8-45-E1 | 4.1 |

To test each assumption, the corresponding data points were plotted. Figure 4-1 shows the starting speed vs. the number of blades in each turbine.

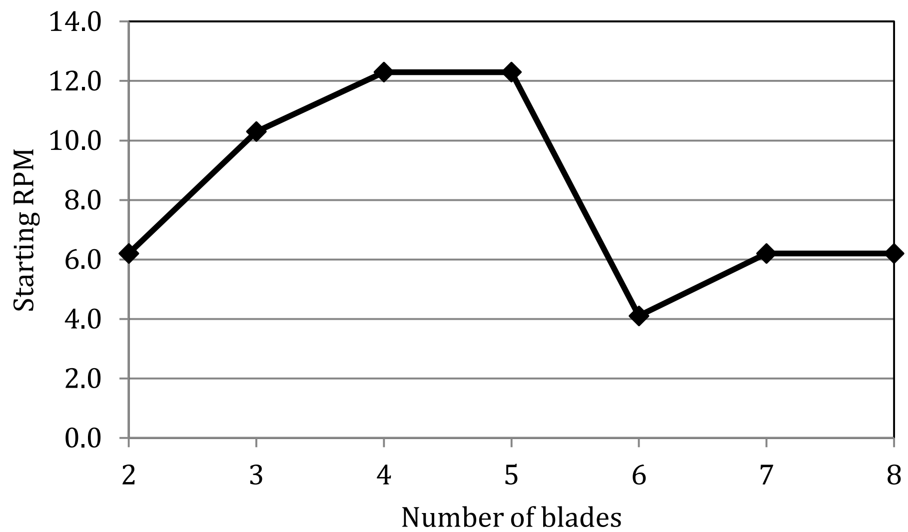



Figure 4-1 - Starting speed of turbines vs. number of blades

The data in Figure 4-1 exhibits a general downwards trend. Due to the measurements of the wind speed inside the turbine being taken from the readout from the wind tunnel (which does not have a particularly fine gradation), there is the possibility of error in these measurements. Therefore, it is assumed that the theory holds true, but more testing is required to confirm.

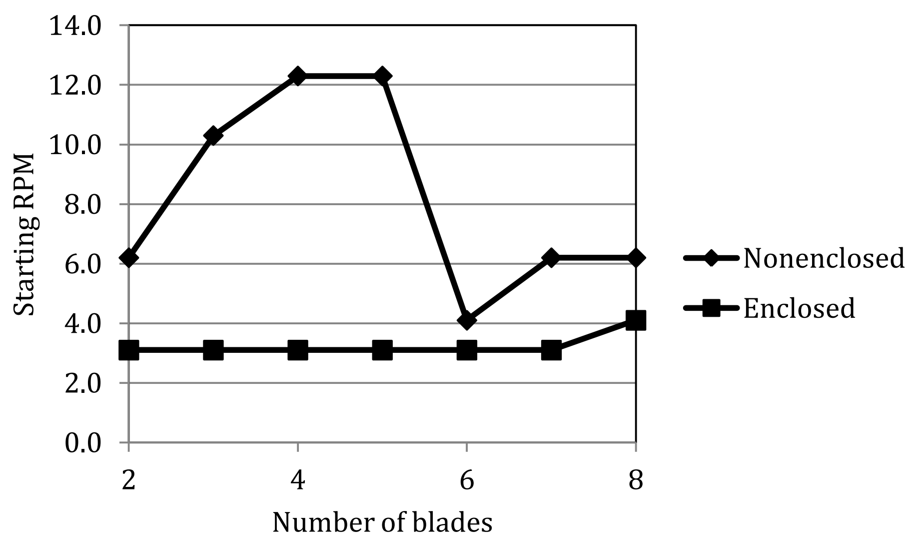



Figure 4-2 - Starting speed for enclosed and nonenclosed turbines

Figure 4-2 shows the starting speed of the turbines vs. the number of blades, considering the difference between the nonenclosed turbines and the enclosed turbines. As predicted, enclosing the turbines (thus increasing the effective wind speed through the turbine) has the effect of lowering the starting speed of the turbines.

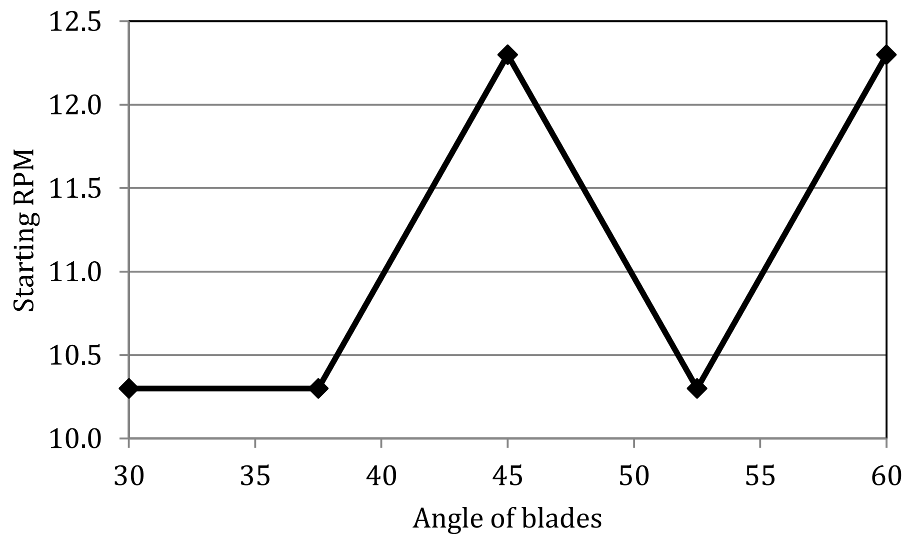



Figure 4-3 - Starting speed of turbines vs. angle of blades

In Figure 4-3, the starting speeds of the turbines were plotted vs. the angle of the blades for each of the turbines with four blades, to see if any conclusions could be drawn. The graph exhibits no clear trends, and thus no conclusions can be drawn from this data.

## 4.1 Alternative Testing Options

To further explore the potential of the vertical axis wind turbine, more testing should be performed. With the use of a device to apply torque and to measure various applied torques, data can be gathered for the torque produced by the captured wind energy at various wind speeds, as well as how the RPM of the turbine will change at various applied torques. Testing the turbine with applied torque simulates the addition of various mechanical systems acting on the turbine, while testing the torque generated by the turbine will determine whether the turbine will be sufficient to drive these mechanical systems.

#### 4.1.1 Turbine Shaft Stabilizer

During testing, it was found that a means of preventing the turbine from vibrating was required (See Section 3.2). For this purpose, a long cylinder, able to be supported by a hole in the top of the wind tunnel, is attached to the shaft of the turbine. The shaft is able to freely rotate inside the cylinder, by means of a series of ball bearings. Each test that had been previously been run should be completed again using the stabilizer, so that accurate data may be collected.

#### 4.1.2 Enclosures

Once the manufacturing of the remaining enclosures has been completed, testing should continue on each turbine using each of these enclosures, to determine the optimal pathway for airflow through the turbines.

### 4.2 Future Applications

Wind energy can be gathered in almost any setting, location, or area of the country. Some locations present stronger wind speeds or higher average wind speeds. Also, some public locations could present the opportunity to collect energy where wind speeds are high. For example, tunnels can experience high wind speeds from the traffic traveling through them. Whether it is a tunnel designed for vehicle traffic or train/subway traffic, the wind force created by the high speeds of the traffic could create a great opportunity. The idea is to mount small turbines on the walls of the tunnel to collect the wind energy created by passing cars. The high rates of speed which vehicles and trains travel causes the movement of air. It is believed that the closer one gets to the passing object, the higher the wind speeds. Of course, the turbines must be mounted a safe distance away from passing traffic, so they are not hit or damaged. The desired turbine would be one which would operate the best under variable wind speeds, because the traffic may not always be present, or they could be traveling at much slower rates of speed due to delays or accidents inside the tunnel.

Currently, the only technology which uses wind power generated by passing trains is still in the conceptual stage (Ridden). The T-box is a device which is mounted between the rails which acts as a vent, collecting the wind produced by a moving train. This technology is still unproven and has many areas of concern, which need to be addressed before the box could be mass produced. This is currently the only technology which gathers wind from passing trains and uses it to produce electricity.

## 4.3 Proposed System Overview

The wind turbine assembly will feature a number of different components in addition to the blade assembly being tested. This section will provide an overview of the other main components.

### 4.3.1 Generator

The GL-PMG-1000 generator is rated to produce 1000 watts of electrical energy when it is rotating at 450 RPM. From testing, the turbine model rotates at 450 RPM at wind speeds from 10 to 15 MPH. The generator requires 31.5 Nm of torque to be able to spin at 450 RPM, and requires 0.5 Nm of starting torque (Ginlong Technologies). The specifications for the generator are detailed in Appendix B.

When the turbine exceeds the maximum rated RPM of the generator, a braking system would need to be installed to prevent damage to the generator.

### 4.3.2 Charging System

In most residential applications, the wind turbine will be supplementing electricity from the power grid. Therefore it is necessary to employ a system designed to properly interface power from the turbine with the power from the grid in a safe and efficient manner. The main components in this system are the power inverter, the charge controller, and the battery bank.

#### *4.3.2.1 Battery Bank*

The battery bank is a number of batteries, wired to provide the required voltage and amperage. For ease of maintenance, absorbent glass mat batteries (sealed to avoid the accidental discharge of battery fluids) are the most commonly used (Homepower Magazine).

#### *4.3.2.2 Charge Controller*

When the turbine is producing electricity, the charge controller directs the flow of electricity to where it may be best used at the current moment. The simplest decision the charge controller makes is whether to feed electricity into the batteries, or to feed it directly into the household power supply via the inverter. If the turbine has been producing an abundance of power and the batteries are full, excess power may not be able to be used by the household power demand. In this case, the excess power can be sold back into the power grid, providing a decreased payment for the homeowner's next electric utilities bill (Outback Power Technologies).

#### *4.3.2.3 Power Inverter*

Electric power that has been stored in batteries is not immediately available in the form required for residential household usage, as batteries provide DC electricity with a wide variability of voltage and current, while household electronics require very specific values of AC electricity (120 V and 15 A in North America). Power inverters take electricity as distributed from the charge controller (either from the batteries or from the turbine) and allow it to be used alongside electricity from the mains (and in the case of a power outage, in place of it).

It is possible to use a device that combines the functionality of a power inverter with the functionality of a charge controller, aiding in maintenance and installation. One such device is the Radian GS8048 by Outback Power Technologies, as detailed in Appendix B.

## 4.4 Anemometer Data Collection

To better gain an understanding of local wind conditions, a series of wind anemometers should be installed on various rooftops around the Worcester Polytechnic Institute campus. The data provided by these anemometers will determine whether certain locations on the campus are suitable as a location for large-scale prototyping of the turbines.

## 4.5 Scale-Up and Prototyping

Once testing has been completed, a larger model should be constructed. This larger model should be able to fit inside of the Higgins Labs wind tunnel, allowing the scale-up factor to be tested and to see if any additional technical considerations need to be addressed before a full-scale prototype is developed. Once the prototypes have been manufactured, they should be deployed in the suitable wind sites found in Section 4.4.

# 5 References


Clean Green Energy. Early History of Wind Energy. 6 September 2011 <http://cleangreenenergyzone.com/early-history-of-wind-energy/>.

Creative Commons. "Attribution 3.0 Unported." Creative Commons. 8 December 2011 <http://creativecommons.org/licenses/by/3.0/legalcode>.

—. "Attribution-ShareAlike 3.0 Unported." Creative Commons. 8 December 2011 <http://creativecommons.org/licenses/by-sa/3.0/legalcode>.

Davis, Michael. How I Built an Electricity Producing Wind Turbine. 6 October 2011 <http://www.mdpub.com/Wind_Turbine/>.

Dodge, Darrell M. Early History Through 1875. 6 September 2011 <http://www.telosnet.com/wind/early.html>.

Dougherty, Thomas J. Small Wind Turbines, Large Benefits. 2 November 2011 <http://www.rothgerber.com/showarticle.aspx?Show=1375>.

Ginlong Technologies. Wind Turbine Permanent Magnet Generator Introduction. 3 October 2011 <http://www.ginlong.com/wind-turbine-permanent-magnet-generator-introduction.htm>.

Homepower Magazine. Wind Power Basics. 7 December 2011 <http://homepower.com/basics/wind/>.

Leithead, W.E. "Wind Energy." Philospohical Transactions: Mathematical, Physical and Engineering Sciences 365.1853 (2007): 957-970.

Mathew, Sathyajith. Wind Energy: Fundamentals, Resource Analysis and Economics. Berlin, Germany: Springer-Verlag, 2006.

National Grid. Regular Residential (R-1) Rates. 16 October 2011 <https://www.nationalgridus.com/masselectric/home/rates/4_res.asp>.

National Wind Watch. FAQ -- Output. 23 October 2011 <http://www.wind-watch.org/faq-output.php>.

Outback Power Technologies. Radian Series Inverter. 7 December 2011 <http://www.outbackpower.com/products/sinewave_inverter/radian/>.

Ragheb, Magdi. Wind Power Systems. 6 October 2011 <https://netfiles.uiuc.edu/mragheb/www/NPRE%20475%20Wind%20Power%20Systems/>.

Ridden, Paul. "T-box concept to capture wind energy from trains." 30 March 2011. Gizmag. 16 November 2011 <http://www.gizmag.com/tbox-concept-would-capture-wind-energy-from-speeding-trains/18272/>.

Rubin, Edward S. Introduction to Engineering and the Environment. New York, NY: McGraw-Hill, 2001.

Sarma, Mulukutla S. Introduction to Electrical Engineering. New York, NY: Oxford University Press, USA, 2000.

Silverman, Dennis. Southern California Household Energy Savings. October 2007. 23 October 2011 <http://www.physics.uci.edu/~silverma/actions/HouseholdEnergy.html>.

Wortman, Andrze J. Introduction to Wind Turbine Engineering. Woburn, MA: Butterworth Publishers, 1983.

## Appendix A: Raw Data for Wind Turbine Tests

The following tables detail the raw data collected during testing of the vertical axis wind turbine assemblies.

### A.1 Two Blades, 45 Degrees

The following data was collected on July 13, 2011 at 1:45PM in the Higgins Laboratories wind tunnel at Worcester Polytechnic Institute. The wind turbine was tested in the enclosure on July 13, 2011 at 12:29PM.

Table A-1 - Raw data for wind turbine with two blades at 45 degrees

| B2-45 | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM |
| 6.0 | 12.3 | 0 | 5.0 | 10.3 | 24 | 4.0 | 8.2 | 12 | 4.0 | 8.2 | 6 | 7.0 | 14.4 | 36 | 9.0 | 18.5 | 48 | 11.0 | 22.6 | 66 | 14.0 | 28.7 | 78 |
| 6.0 | 12.3 | 6 | 4.0 | 8.2 | 18 | 4.0 | 8.2 | 12 | 4.0 | 8.2 | 0 | 7.0 | 14.4 | 36 | 9.0 | 18.5 | 54 | 11.0 | 22.6 | 60 | 14.0 | 28.7 | 84 |
| 6.0 | 12.3 | 18 | 4.0 | 8.2 | 18 | 4.0 | 8.2 | 18 | 4.0 | 8.2 | 6 | 7.0 | 14.4 | 36 | 9.0 | 18.5 | 48 | 11.0 | 22.6 | 60 | 14.0 | 28.7 | 78 |
| 6.0 | 12.3 | 24 | 4.0 | 8.2 | 18 | 4.0 | 8.2 | 12 | 4.0 | 8.2 | 6 | 7.0 | 14.4 | 36 | 9.0 | 18.5 | 48 | 11.0 | 22.6 | 60 | 14.0 | 28.7 | 78 |
| 6.0 | 12.3 | 30 | 4.0 | 8.2 | 12 | 4.0 | 8.2 | 18 | 5.0 | 10.3 | 6 | 7.0 | 14.4 | 36 | 9.0 | 18.5 | 54 | 11.0 | 22.6 | 60 | 15.0 | 30.8 | 78 |
| 6.0 | 12.3 | 24 | 4.0 | 8.2 | 18 | 4.0 | 8.2 | 12 | 5.0 | 10.3 | 6 | 7.0 | 14.4 | 36 | 9.0 | 18.5 | 48 | 11.0 | 22.6 | 60 | 15.0 | 30.8 | 84 |
| 6.0 | 12.3 | 30 | 4.0 | 8.2 | 12 | 3.0 | 6.2 | 12 | 5.0 | 10.3 | 12 | 7.0 | 14.4 | 36 | 9.0 | 18.5 | 48 | 11.0 | 22.6 | 66 | 15.0 | 30.8 | 84 |
| 6.0 | 12.3 | 30 | 4.0 | 8.2 | 18 | 3.0 | 6.2 | 12 | 5.0 | 10.3 | 24 | 7.0 | 14.4 | 36 | 9.0 | 18.5 | 48 | 11.0 | 22.6 | 60 | 15.0 | 30.8 | 78 |
| 6.0 | 12.3 | 30 | 4.0 | 8.2 | 12 | 3.0 | 6.2 | 12 | 5.0 | 10.3 | 18 | 7.0 | 14.4 | 36 | 10.0 | 20.5 | 54 | 11.0 | 22.6 | 60 | 15.0 | 30.8 | 84 |
| 6.0 | 12.3 | 24 | 4.0 | 8.2 | 12 | 3.0 | 6.2 | 6 | 5.0 | 10.3 | 18 | 8.0 | 16.4 | 36 | 10.0 | 20.5 | 54 | 11.0 | 22.6 | 60 | 16.0 | 32.8 | 84 |
| 6.0 | 12.3 | 30 | 4.0 | 8.2 | 12 | 3.0 | 6.2 | 6 | 5.0 | 10.3 | 24 | 8.0 | 16.4 | 42 | 10.0 | 20.5 | 54 | 12.0 | 24.6 | 66 | 16.0 | 32.8 | 84 |
| 5.0 | 10.3 | 24 | 4.0 | 8.2 | 18 | 3.0 | 6.2 | 6 | 5.0 | 10.3 | 24 | 8.0 | 16.4 | 42 | 10.0 | 20.5 | 54 | 12.0 | 24.6 | 66 | 16.0 | 32.8 | 90 |
| 5.0 | 10.3 | 24 | 4.0 | 8.2 | 12 | 3.0 | 6.2 | 0 | 5.0 | 10.3 | 18 | 8.0 | 16.4 | 42 | 10.0 | 20.5 | 60 | 12.0 | 24.6 | 66 | 16.0 | 32.8 | 84 |
| 5.0 | 10.3 | 24 | 4.0 | 8.2 | 12 | 3.0 | 6.2 | 6 | 5.0 | 10.3 | 24 | 8.0 | 16.4 | 42 | 10.0 | 20.5 | 54 | 12.0 | 24.6 | 66 | 16.0 | 32.8 | 90 |
| 5.0 | 10.3 | 18 | 4.0 | 8.2 | 12 | 3.0 | 6.2 | 0 | 6.0 | 12.3 | 24 | 8.0 | 16.4 | 42 | 10.0 | 20.5 | 54 | 12.0 | 24.6 | 66 | 16.0 | 32.8 | 90 |
| 5.0 | 10.3 | 24 | 4.0 | 8.2 | 18 | 3.0 | 6.2 | 6 | 6.0 | 12.3 | 24 | 8.0 | 16.4 | 42 | 10.0 | 20.5 | 54 | 12.0 | 24.6 | 72 | 16.0 | 32.8 | 90 |
| 5.0 | 10.3 | 18 | 4.0 | 8.2 | 12 | 3.0 | 6.2 | 0 | 6.0 | 12.3 | 30 | 8.0 | 16.4 | 42 | 10.0 | 20.5 | 60 | 12.0 | 24.6 | 66 | 17.0 | 34.9 | 84 |
| 5.0 | 10.3 | 24 | 4.0 | 8.2 | 18 | 3.0 | 6.2 | 6 | 6.0 | 12.3 | 30 | 8.0 | 16.4 | 48 | 10.0 | 20.5 | 54 | 12.0 | 24.6 | 66 | 17.0 | 34.9 | 96 |
| 5.0 | 10.3 | 24 | 4.0 | 8.2 | 12 | 3.0 | 6.2 | 0 | 6.0 | 12.3 | 30 | 8.0 | 16.4 | 42 | 10.0 | 20.5 | 54 | 13.0 | 26.7 | 66 | 17.0 | 34.9 | 90 |
| 5.0 | 10.3 | 18 | 4.0 | 8.2 | 12 | 3.0 | 6.2 | 6 | 6.0 | 12.3 | 30 | 8.0 | 16.4 | 42 | 10.0 | 20.5 | 60 | 13.0 | 26.7 | 72 | 17.0 | 34.9 | 96 |
| 5.0 | 10.3 | 24 | 4.0 | 8.2 | 18 | 3.0 | 6.2 | 0 | 6.0 | 12.3 | 30 | 8.0 | 16.4 | 42 | 10.0 | 20.5 | 54 | 13.0 | 26.7 | 72 | 17.0 | 34.9 | 90 |
| 5.0 | 10.3 | 18 | 4.0 | 8.2 | 12 | 3.0 | 6.2 | 6 | 6.0 | 12.3 | 24 | 8.0 | 16.4 | 42 | 11.0 | 22.6 | 54 | 13.0 | 26.7 | 72 | 17.0 | 34.9 | 90 |
| 5.0 | 10.3 | 24 | 4.0 | 8.2 | 12 | 3.0 | 6.2 | 0 | 6.0 | 12.3 | 30 | 8.0 | 16.4 | 48 | 11.0 | 22.6 | 60 | 13.0 | 26.7 | 72 | | | |
| 5.0 | 10.3 | 18 | 4.0 | 8.2 | 12 | 4.0 | 8.2 | 6 | 6.0 | 12.3 | 30 | 8.0 | 16.4 | 42 | 11.0 | 22.6 | 54 | 13.0 | 26.7 | 72 | | | |
| 5.0 | 10.3 | 24 | 4.0 | 8.2 | 18 | 4.0 | 8.2 | 6 | 6.0 | 12.3 | 30 | 8.0 | 16.4 | 42 | 11.0 | 22.6 | 54 | 13.0 | 26.7 | 72 | | | |
| 5.0 | 10.3 | 24 | 4.0 | 8.2 | 12 | 4.0 | 8.2 | 6 | 6.0 | 12.3 | 24 | 8.0 | 16.4 | 42 | 11.0 | 22.6 | 60 | 14.0 | 28.7 | 78 | | | |
| 5.0 | 10.3 | 18 | 4.0 | 8.2 | 18 | 4.0 | 8.2 | 0 | 6.0 | 12.3 | 30 | 8.0 | 16.4 | 42 | 11.0 | 22.6 | 54 | 14.0 | 28.7 | 78 | | | |
| 5.0 | 10.3 | 24 | 4.0 | 8.2 | 12 | 4.0 | 8.2 | 6 | 7.0 | 14.4 | 30 | 9.0 | 18.5 | 42 | 11.0 | 22.6 | 60 | 14.0 | 28.7 | 78 | | | |

Table A-2 - Raw data for wind turbine with two blades at 45 degrees in enclosure

| B2-45-E1 | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM |
| 1.5 | 3.1 | 0 | 2.0 | 4.1 | 78 | 6.0 | 12.3 | 354 | 9.0 | 18.5 | 456 | 12.0 | 24.6 | 654 | 14.0 | 28.7 | 654 |
| 1.5 | 3.1 | 0 | 2.0 | 4.1 | 84 | 6.0 | 12.3 | 366 | 9.0 | 18.5 | 474 | 12.0 | 24.6 | 654 | 14.0 | 28.7 | 654 |
| 1.5 | 3.1 | 0 | 2.0 | 4.1 | 84 | 6.0 | 12.3 | 360 | 9.0 | 18.5 | 474 | 12.0 | 24.6 | 648 | 14.0 | 28.7 | 660 |
| 1.5 | 3.1 | 6 | 3.0 | 6.2 | 96 | 6.0 | 12.3 | 354 | 9.0 | 18.5 | 480 | 12.0 | 24.6 | 636 | 14.0 | 28.7 | 648 |
| 1.5 | 3.1 | 6 | 3.0 | 6.2 | 108 | 6.0 | 12.3 | 348 | 9.0 | 18.5 | 474 | 12.0 | 24.6 | 630 | 14.0 | 28.7 | 654 |
| 1.5 | 3.1 | 18 | 3.0 | 6.2 | 126 | 6.0 | 12.3 | 348 | 9.0 | 18.5 | 474 | 12.0 | 24.6 | 642 | 14.0 | 28.7 | 660 |
| 1.5 | 3.1 | 12 | 3.0 | 6.2 | 138 | 6.0 | 12.3 | 342 | 9.0 | 18.5 | 468 | 12.0 | 24.6 | 636 | 14.0 | 28.7 | 654 |
| 1.5 | 3.1 | 18 | 3.0 | 6.2 | 144 | 6.0 | 12.3 | 342 | 9.0 | 18.5 | 456 | 12.0 | 24.6 | 636 | 14.0 | 28.7 | 654 |
| 1.5 | 3.1 | 24 | 3.0 | 6.2 | 156 | 6.0 | 12.3 | 342 | 9.0 | 18.5 | 462 | 12.0 | 24.6 | 630 | 15.0 | 30.8 | 690 |
| 1.5 | 3.1 | 24 | 3.0 | 6.2 | 162 | 6.0 | 12.3 | 342 | 10.0 | 20.5 | 462 | 12.0 | 24.6 | 624 | 15.0 | 30.8 | 690 |
| 2.0 | 4.1 | 24 | 3.0 | 6.2 | 168 | 6.0 | 12.3 | 336 | 10.0 | 20.5 | 504 | 12.0 | 24.6 | 624 | 15.0 | 30.8 | 684 |
| 2.0 | 4.1 | 30 | 3.0 | 6.2 | 168 | 6.0 | 12.3 | 348 | 10.0 | 20.5 | 564 | 12.0 | 24.6 | 630 | 15.0 | 30.8 | 684 |
| 2.0 | 4.1 | 30 | 3.0 | 6.2 | 174 | 7.0 | 14.4 | 372 | 10.0 | 20.5 | 576 | 12.0 | 24.6 | 624 | 15.0 | 30.8 | 678 |
| 2.0 | 4.1 | 36 | 4.0 | 8.2 | 180 | 7.0 | 14.4 | 378 | 10.0 | 20.5 | 582 | 12.0 | 24.6 | 618 | 15.0 | 30.8 | 678 |
| 2.0 | 4.1 | 30 | 4.0 | 8.2 | 192 | 7.0 | 14.4 | 390 | 10.0 | 20.5 | 576 | 12.0 | 24.6 | 630 | 16.0 | 32.8 | 708 |
| 2.0 | 4.1 | 36 | 4.0 | 8.2 | 210 | 7.0 | 14.4 | 390 | 10.0 | 20.5 | 570 | 12.0 | 24.6 | 624 | 16.0 | 32.8 | 726 |
| 2.0 | 4.1 | 42 | 4.0 | 8.2 | 228 | 7.0 | 14.4 | 390 | 11.0 | 22.6 | 594 | 12.0 | 24.6 | 618 | 16.0 | 32.8 | 720 |
| 2.0 | 4.1 | 36 | 4.0 | 8.2 | 234 | 7.0 | 14.4 | 390 | 11.0 | 22.6 | 642 | 12.0 | 24.6 | 618 | 16.0 | 32.8 | 714 |
| 2.0 | 4.1 | 42 | 4.0 | 8.2 | 252 | 7.0 | 14.4 | 384 | 11.0 | 22.6 | 642 | 12.0 | 24.6 | 612 | 16.0 | 32.8 | 702 |
| 2.0 | 4.1 | 42 | 4.0 | 8.2 | 246 | 7.0 | 14.4 | 384 | 11.0 | 22.6 | 642 | 12.0 | 24.6 | 612 | 16.0 | 32.8 | 696 |
| 2.0 | 4.1 | 42 | 4.0 | 8.2 | 252 | 7.0 | 14.4 | 384 | 11.0 | 22.6 | 648 | 13.0 | 26.7 | 624 | 16.0 | 32.8 | 690 |
| 2.0 | 4.1 | 42 | 5.0 | 10.3 | 264 | 8.0 | 16.4 | 384 | 11.0 | 22.6 | 648 | 13.0 | 26.7 | 636 | 16.0 | 32.8 | 684 |
| 2.0 | 4.1 | 54 | 5.0 | 10.3 | 276 | 8.0 | 16.4 | 414 | 11.0 | 22.6 | 642 | 13.0 | 26.7 | 642 | 16.0 | 32.8 | 696 |
| 2.0 | 4.1 | 60 | 5.0 | 10.3 | 288 | 8.0 | 16.4 | 432 | 11.0 | 22.6 | 648 | 13.0 | 26.7 | 636 | 17.0 | 34.9 | 726 |
| 2.0 | 4.1 | 60 | 5.0 | 10.3 | 288 | 8.0 | 16.4 | 444 | 11.0 | 22.6 | 642 | 13.0 | 26.7 | 636 | 17.0 | 34.9 | 720 |
| 2.0 | 4.1 | 66 | 5.0 | 10.3 | 300 | 8.0 | 16.4 | 450 | 11.0 | 22.6 | 648 | 13.0 | 26.7 | 630 | 17.0 | 34.9 | 732 |
| 2.0 | 4.1 | 72 | 5.0 | 10.3 | 300 | 8.0 | 16.4 | 456 | 12.0 | 24.6 | 666 | 13.0 | 26.7 | 624 | 17.0 | 34.9 | 726 |
| 2.0 | 4.1 | 72 | 5.0 | 10.3 | 300 | 8.0 | 16.4 | 450 | 12.0 | 24.6 | 672 | 13.0 | 26.7 | 630 | 17.0 | 34.9 | 726 |
| 2.0 | 4.1 | 78 | 6.0 | 12.3 | 306 | 8.0 | 16.4 | 450 | 12.0 | 24.6 | 660 | 13.0 | 26.7 | 654 | 17.0 | 34.9 | 726 |
| 2.0 | 4.1 | 84 | 6.0 | 12.3 | 336 | 8.0 | 16.4 | 450 | 12.0 | 24.6 | 666 | 13.0 | 26.7 | 660 | 17.0 | 34.9 | 738 |

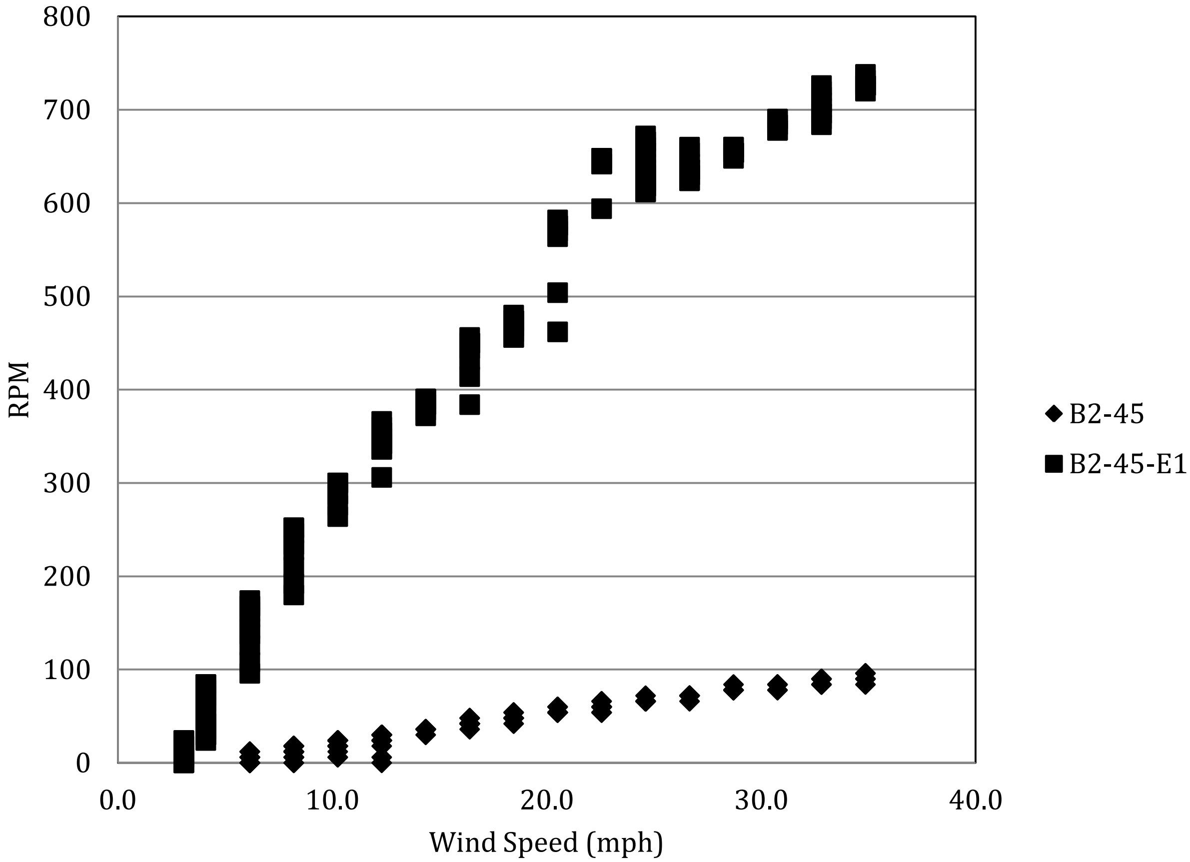



Figure A-1 - RPM of turbine with two blades at 45 degrees at various wind speeds

## A.2 Three Blades, 45 Degrees

The following data was collected on July 13, 2011 at 2:08PM in the Higgins Laboratories wind tunnel at Worcester Polytechnic Institute. The wind turbine was tested in the enclosure on July 13, 2011 at 12:08PM.

Table A-3 - Raw data for wind turbine with three blades at 45 degrees

| B3-45 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Hz | MPH | RPM | | Hz | MPH | RPM | | Hz | MPH | RPM |
| 5.0 | 10.3 | 0 | | 9.0 | 18.5 | 36 | | 14.0 | 28.7 | 60 |
| 5.0 | 10.3 | 0 | | 9.0 | 18.5 | 36 | | 14.0 | 28.7 | 54 |
| 5.0 | 10.3 | 0 | | 9.0 | 18.5 | 36 | | 15.0 | 30.8 | 66 |
| 5.0 | 10.3 | 0 | | 9.0 | 18.5 | 36 | | 15.0 | 30.8 | 60 |
| 5.0 | 10.3 | 0 | | 9.0 | 18.5 | 36 | | 15.0 | 30.8 | 60 |
| 5.0 | 10.3 | 6 | | 9.0 | 18.5 | 36 | | 15.0 | 30.8 | 66 |
| 5.0 | 10.3 | 6 | | 9.0 | 18.5 | 30 | | 15.0 | 30.8 | 66 |
| 5.0 | 10.3 | 6 | | 10.0 | 20.5 | 42 | | 15.0 | 30.8 | 66 |
| 5.0 | 10.3 | 6 | | 10.0 | 20.5 | 42 | | 16.0 | 32.8 | 60 |
| 5.0 | 10.3 | 12 | | 10.0 | 20.5 | 36 | | 16.0 | 32.8 | 66 |
| 6.0 | 12.3 | 6 | | 10.0 | 20.5 | 42 | | 16.0 | 32.8 | 72 |
| 6.0 | 12.3 | 6 | | 10.0 | 20.5 | 42 | | 16.0 | 32.8 | 66 |
| 6.0 | 12.3 | 12 | | 11.0 | 22.6 | 42 | | 16.0 | 32.8 | 66 |
| 6.0 | 12.3 | 6 | | 11.0 | 22.6 | 42 | | 16.0 | 32.8 | 66 |
| 6.0 | 12.3 | 12 | | 11.0 | 22.6 | 42 | | 17.0 | 34.9 | 66 |
| 7.0 | 14.4 | 6 | | 11.0 | 22.6 | 48 | | 17.0 | 34.9 | 66 |
| 7.0 | 14.4 | 6 | | 11.0 | 22.6 | 42 | | 17.0 | 34.9 | 78 |
| 7.0 | 14.4 | 24 | | 11.0 | 22.6 | 42 | | 17.0 | 34.9 | 72 |
| 7.0 | 14.4 | 24 | | 12.0 | 24.6 | 48 | | 17.0 | 34.9 | 72 |
| 7.0 | 14.4 | 24 | | 12.0 | 24.6 | 48 | | 17.0 | 34.9 | 72 |
| 7.0 | 14.4 | 24 | | 12.0 | 24.6 | 54 | | 17.0 | 34.9 | 72 |
| 7.0 | 14.4 | 24 | | 12.0 | 24.6 | 48 | | | | |
| 7.0 | 14.4 | 24 | | 12.0 | 24.6 | 54 | | | | |
| 7.0 | 14.4 | 24 | | 13.0 | 26.7 | 54 | | | | |
| 7.0 | 14.4 | 24 | | 13.0 | 26.7 | 54 | | | | |
| 8.0 | 16.4 | 24 | | 13.0 | 26.7 | 54 | | | | |
| 8.0 | 16.4 | 30 | | 13.0 | 26.7 | 48 | | | | |
| 8.0 | 16.4 | 30 | | 14.0 | 28.7 | 60 | | | | |
| 8.0 | 16.4 | 30 | | 14.0 | 28.7 | 54 | | | | |
| 8.0 | 16.4 | 24 | | 14.0 | 28.7 | 60 | | | | |

Table A-4 - Raw data for wind turbine with three blades at 45 degrees in enclosure

| B3-45-E1 | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** |
| 1.5 | 3.1 | 0 | 3.0 | 6.2 | 144 | 5.0 | 10.3 | 402 | 7.0 | 14.4 | 480 | 14.0 | 28.7 | 1392 |
| 1.5 | 3.1 | 0 | 3.0 | 6.2 | 150 | 6.0 | 12.3 | 420 | 7.0 | 14.4 | 486 | 15.0 | 30.8 | 1404 |
| 1.5 | 3.1 | 0 | 3.0 | 6.2 | 168 | 6.0 | 12.3 | 438 | 7.0 | 14.4 | 486 | 15.0 | 30.8 | 1464 |
| 1.5 | 3.1 | 0 | 3.0 | 6.2 | 174 | 6.0 | 12.3 | 456 | 7.0 | 14.4 | 486 | 15.0 | 30.8 | 1488 |
| 1.5 | 3.1 | 0 | 3.0 | 6.2 | 180 | 6.0 | 12.3 | 462 | 8.0 | 16.4 | 486 | 15.0 | 30.8 | 1500 |
| 1.5 | 3.1 | 0 | 3.0 | 6.2 | 186 | 6.0 | 12.3 | 468 | 8.0 | 16.4 | 504 | 15.0 | 30.8 | 1512 |
| 1.5 | 3.1 | 0 | 3.0 | 6.2 | 186 | 6.0 | 12.3 | 474 | 8.0 | 16.4 | 504 | 15.0 | 30.8 | 1512 |
| 1.5 | 3.1 | 0 | 3.0 | 6.2 | 198 | 6.0 | 12.3 | 468 | 8.0 | 16.4 | 510 | 15.0 | 30.8 | 1512 |
| 1.5 | 3.1 | 0 | 4.0 | 8.2 | 192 | 6.0 | 12.3 | 468 | 8.0 | 16.4 | 504 | 15.0 | 30.8 | 1518 |
| 1.5 | 3.1 | 0 | 4.0 | 8.2 | 216 | 6.0 | 12.3 | 474 | 8.0 | 16.4 | 504 | 15.0 | 30.8 | 1518 |
| 1.5 | 3.1 | 0 | 4.0 | 8.2 | 240 | 6.0 | 12.3 | 468 | 8.0 | 16.4 | 534 | 16.0 | 32.8 | 1566 |
| 1.5 | 3.1 | 12 | 5.0 | 10.3 | 252 | 7.0 | 14.4 | 480 | 8.0 | 16.4 | 576 | 16.0 | 32.8 | 1602 |
| 1.5 | 3.1 | 12 | 5.0 | 10.3 | 264 | 7.0 | 14.4 | 498 | 13.0 | 26.7 | 834 | 16.0 | 32.8 | 1620 |
| 1.5 | 3.1 | 18 | 5.0 | 10.3 | 270 | 7.0 | 14.4 | 492 | 13.0 | 26.7 | 1032 | 16.0 | 32.8 | 1626 |
| 1.5 | 3.1 | 18 | 5.0 | 10.3 | 282 | 7.0 | 14.4 | 492 | 13.0 | 26.7 | 1140 | 16.0 | 32.8 | 1632 |
| 1.5 | 3.1 | 30 | 5.0 | 10.3 | 282 | 7.0 | 14.4 | 492 | 13.0 | 26.7 | 1200 | 16.0 | 32.8 | 1632 |
| 1.5 | 3.1 | 30 | 5.0 | 10.3 | 288 | 7.0 | 14.4 | 486 | 13.0 | 26.7 | 1242 | 16.0 | 32.8 | 1632 |
| 1.5 | 3.1 | 30 | 5.0 | 10.3 | 300 | 7.0 | 14.4 | 492 | 13.0 | 26.7 | 1266 | 17.0 | 34.9 | 1638 |
| 1.5 | 3.1 | 36 | 5.0 | 10.3 | 312 | 7.0 | 14.4 | 486 | 13.0 | 26.7 | 1272 | 17.0 | 34.9 | 1680 |
| 1.5 | 3.1 | 42 | 5.0 | 10.3 | 342 | 7.0 | 14.4 | 486 | 13.0 | 26.7 | 1278 | 17.0 | 34.9 | 1716 |
| 2.0 | 4.1 | 42 | 5.0 | 10.3 | 360 | 7.0 | 14.4 | 492 | 13.0 | 26.7 | 1284 | 17.0 | 34.9 | 1734 |
| 2.0 | 4.1 | 54 | 5.0 | 10.3 | 366 | 7.0 | 14.4 | 486 | 13.0 | 26.7 | 1278 | 17.0 | 34.9 | 1746 |
| 2.0 | 4.1 | 60 | 5.0 | 10.3 | 378 | 7.0 | 14.4 | 486 | 13.0 | 26.7 | 1284 | 17.0 | 34.9 | 1740 |
| 2.0 | 4.1 | 66 | 5.0 | 10.3 | 390 | 7.0 | 14.4 | 486 | 14.0 | 28.7 | 1308 | 17.0 | 34.9 | 1746 |
| 2.0 | 4.1 | 78 | 5.0 | 10.3 | 390 | 7.0 | 14.4 | 486 | 14.0 | 28.7 | 1356 | 17.0 | 34.9 | 1746 |
| 2.0 | 4.1 | 78 | 5.0 | 10.3 | 390 | 7.0 | 14.4 | 486 | 14.0 | 28.7 | 1380 | 17.0 | 34.9 | 1746 |
| 2.0 | 4.1 | 84 | 5.0 | 10.3 | 396 | 7.0 | 14.4 | 486 | 14.0 | 28.7 | 1380 | 17.0 | 34.9 | 1746 |
| 2.0 | 4.1 | 90 | 5.0 | 10.3 | 402 | 7.0 | 14.4 | 486 | 14.0 | 28.7 | 1392 | | | |
| 3.0 | 6.2 | 102 | 5.0 | 10.3 | 402 | 7.0 | 14.4 | 486 | 14.0 | 28.7 | 1392 | | | |
| 3.0 | 6.2 | 120 | 5.0 | 10.3 | 402 | 7.0 | 14.4 | 486 | 14.0 | 28.7 | 1392 | | | |

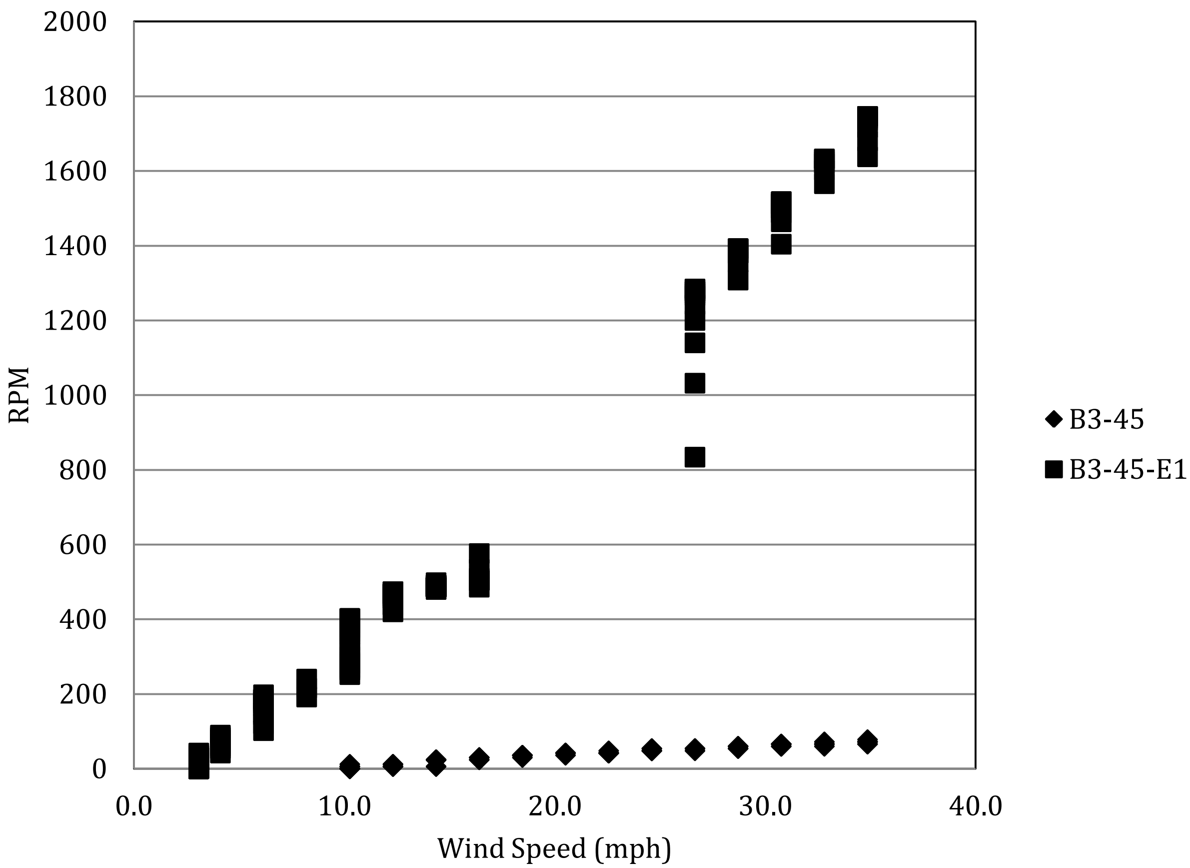



Figure A-2 -RPM of turbine with three blades at 45 degrees at various wind speeds

## A.3 Four Blades, 30 Degrees

The following data was collected on July 13, 2011 at 3:49PM in the Higgins Laboratories wind tunnel at Worcester Polytechnic Institute. The wind turbine was tested in the enclosure on July 26, 2011 at 12:59PM.

Table A-5 - Raw data for wind turbine with four blades at 30 degrees

| B4-30 | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** |
| 3.0 | 6.2 | 0 | 6.0 | 12.3 | 156 | 9.0 | 18.5 | 300 | 13.0 | 26.7 | 438 | 17.0 | 34.9 | 582 |
| 3.0 | 6.2 | 0 | 6.0 | 12.3 | 180 | 9.0 | 18.5 | 294 | 14.0 | 28.7 | 444 | 17.0 | 34.9 | 582 |
| 3.0 | 6.2 | 0 | 6.0 | 12.3 | 180 | 10.0 | 20.5 | 294 | 14.0 | 28.7 | 462 | 17.0 | 34.9 | 582 |
| 3.0 | 6.2 | 0 | 6.0 | 12.3 | 192 | 10.0 | 20.5 | 318 | 14.0 | 28.7 | 474 | 17.0 | 34.9 | 576 |
| 3.0 | 6.2 | 0 | 6.0 | 12.3 | 186 | 10.0 | 20.5 | 330 | 14.0 | 28.7 | 480 | 17.0 | 34.9 | 582 |
| 3.0 | 6.2 | 0 | 6.0 | 12.3 | 192 | 10.0 | 20.5 | 330 | 14.0 | 28.7 | 468 | | | |
| 3.0 | 6.2 | 0 | 6.0 | 12.3 | 186 | 10.0 | 20.5 | 336 | 14.0 | 28.7 | 480 | | | |
| 3.0 | 6.2 | 0 | 7.0 | 14.4 | 192 | 10.0 | 20.5 | 330 | 14.0 | 28.7 | 474 | | | |
| 4.0 | 8.2 | 0 | 7.0 | 14.4 | 192 | 10.0 | 20.5 | 336 | 14.0 | 28.7 | 474 | | | |
| 4.0 | 8.2 | 0 | 7.0 | 14.4 | 204 | 10.0 | 20.5 | 330 | 14.0 | 28.7 | 480 | | | |
| 4.0 | 8.2 | 0 | 7.0 | 14.4 | 222 | 11.0 | 22.6 | 330 | 15.0 | 30.8 | 474 | | | |
| 4.0 | 8.2 | 0 | 7.0 | 14.4 | 222 | 11.0 | 22.6 | 354 | 15.0 | 30.8 | 504 | | | |
| 4.0 | 8.2 | 0 | 7.0 | 14.4 | 228 | 11.0 | 22.6 | 372 | 15.0 | 30.8 | 510 | | | |
| 4.0 | 8.2 | 0 | 7.0 | 14.4 | 228 | 11.0 | 22.6 | 366 | 15.0 | 30.8 | 504 | | | |
| 4.0 | 8.2 | 0 | 7.0 | 14.4 | 222 | 11.0 | 22.6 | 372 | 15.0 | 30.8 | 510 | | | |
| 4.0 | 8.2 | 0 | 8.0 | 16.4 | 228 | 11.0 | 22.6 | 372 | 15.0 | 30.8 | 510 | | | |
| 5.0 | 10.3 | 0 | 8.0 | 16.4 | 234 | 11.0 | 22.6 | 366 | 15.0 | 30.8 | 504 | | | |
| 5.0 | 10.3 | 0 | 8.0 | 16.4 | 252 | 11.0 | 22.6 | 372 | 16.0 | 32.8 | 510 | | | |
| 5.0 | 10.3 | 0 | 8.0 | 16.4 | 264 | 12.0 | 24.6 | 366 | 16.0 | 32.8 | 522 | | | |
| 5.0 | 10.3 | 6 | 8.0 | 16.4 | 258 | 12.0 | 24.6 | 396 | 16.0 | 32.8 | 534 | | | |
| 5.0 | 10.3 | 36 | 8.0 | 16.4 | 258 | 12.0 | 24.6 | 402 | 16.0 | 32.8 | 528 | | | |
| 5.0 | 10.3 | 66 | 8.0 | 16.4 | 264 | 12.0 | 24.6 | 408 | 16.0 | 32.8 | 534 | | | |
| 5.0 | 10.3 | 102 | 8.0 | 16.4 | 264 | 12.0 | 24.6 | 402 | 16.0 | 32.8 | 528 | | | |
| 5.0 | 10.3 | 120 | 8.0 | 16.4 | 258 | 12.0 | 24.6 | 408 | 17.0 | 34.9 | 534 | | | |
| 5.0 | 10.3 | 138 | 9.0 | 18.5 | 264 | 13.0 | 26.7 | 408 | 17.0 | 34.9 | 558 | | | |
| 5.0 | 10.3 | 144 | 9.0 | 18.5 | 270 | 13.0 | 26.7 | 414 | 17.0 | 34.9 | 582 | | | |
| 5.0 | 10.3 | 144 | 9.0 | 18.5 | 288 | 13.0 | 26.7 | 438 | 17.0 | 34.9 | 582 | | | |
| 5.0 | 10.3 | 156 | 9.0 | 18.5 | 300 | 13.0 | 26.7 | 444 | 17.0 | 34.9 | 576 | | | |
| 5.0 | 10.3 | 150 | 9.0 | 18.5 | 294 | 13.0 | 26.7 | 438 | 17.0 | 34.9 | 576 | | | |
| 5.0 | 10.3 | 156 | 9.0 | 18.5 | 300 | 13.0 | 26.7 | 444 | 17.0 | 34.9 | 582 | | | |

Table A-6 - Raw data for wind turbine with four blades at 30 degrees in enclosure

| B4-30-E1 | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM |
| 1.5 | 3.1 | 0 | 3.0 | 6.2 | 96 | 5.0 | 10.3 | 318 | 8.0 | 16.4 | 426 | 12.0 | 24.6 | 924 | 16.0 | 32.8 | 1266 |
| 1.5 | 3.1 | 0 | 3.0 | 6.2 | 120 | 5.0 | 10.3 | 330 | 8.0 | 16.4 | 426 | 12.0 | 24.6 | 924 | 16.0 | 32.8 | 1290 |
| 1.5 | 3.1 | 0 | 3.0 | 6.2 | 126 | 5.0 | 10.3 | 336 | 9.0 | 18.5 | 444 | 12.0 | 24.6 | 918 | 16.0 | 32.8 | 1296 |
| 1.5 | 3.1 | 6 | 3.0 | 6.2 | 144 | 5.0 | 10.3 | 336 | 9.0 | 18.5 | 456 | 12.0 | 24.6 | 918 | 17.0 | 34.9 | 1302 |
| 1.5 | 3.1 | 6 | 3.0 | 6.2 | 156 | 5.0 | 10.3 | 336 | 9.0 | 18.5 | 462 | 13.0 | 26.7 | 936 | 17.0 | 34.9 | 1302 |
| 1.5 | 3.1 | 6 | 3.0 | 6.2 | 162 | 5.0 | 10.3 | 342 | 9.0 | 18.5 | 456 | 13.0 | 26.7 | 966 | 17.0 | 34.9 | 1314 |
| 1.5 | 3.1 | 12 | 3.0 | 6.2 | 168 | 6.0 | 12.3 | 336 | 9.0 | 18.5 | 462 | 13.0 | 26.7 | 966 | 17.0 | 34.9 | 1314 |
| 1.5 | 3.1 | 12 | 3.0 | 6.2 | 174 | 6.0 | 12.3 | 354 | 9.0 | 18.5 | 456 | 13.0 | 26.7 | 972 | 17.0 | 34.9 | 1320 |
| 1.5 | 3.1 | 18 | 3.0 | 6.2 | 180 | 6.0 | 12.3 | 366 | 10.0 | 20.5 | 480 | 13.0 | 26.7 | 966 | 17.0 | 34.9 | 1326 |
| 1.5 | 3.1 | 18 | 3.0 | 6.2 | 180 | 6.0 | 12.3 | 366 | 10.0 | 20.5 | 552 | 13.0 | 26.7 | 966 | 17.0 | 34.9 | 1338 |
| 1.5 | 3.1 | 18 | 3.0 | 6.2 | 186 | 6.0 | 12.3 | 366 | 10.0 | 20.5 | 564 | 13.0 | 26.7 | 966 | 17.0 | 34.9 | 1356 |
| 1.5 | 3.1 | 24 | 3.0 | 6.2 | 186 | 6.0 | 12.3 | 366 | 10.0 | 20.5 | 564 | 13.0 | 26.7 | 960 | | | |
| 1.5 | 3.1 | 24 | 3.0 | 6.2 | 186 | 6.0 | 12.3 | 360 | 10.0 | 20.5 | 564 | 13.0 | 26.7 | 966 | | | |
| 1.5 | 3.1 | 30 | 3.0 | 6.2 | 192 | 6.0 | 12.3 | 366 | 10.0 | 20.5 | 558 | 14.0 | 28.7 | 990 | | | |
| 1.5 | 3.1 | 24 | 4.0 | 8.2 | 192 | 6.0 | 12.3 | 360 | 10.0 | 20.5 | 564 | 14.0 | 28.7 | 1014 | | | |
| 1.5 | 3.1 | 30 | 4.0 | 8.2 | 192 | 7.0 | 14.4 | 384 | 10.0 | 20.5 | 558 | 14.0 | 28.7 | 1026 | | | |
| 1.5 | 3.1 | 36 | 4.0 | 8.2 | 210 | 7.0 | 14.4 | 396 | 10.0 | 20.5 | 558 | 14.0 | 28.7 | 1020 | | | |
| 2.0 | 4.1 | 30 | 4.0 | 8.2 | 228 | 7.0 | 14.4 | 402 | 11.0 | 22.6 | 576 | 14.0 | 28.7 | 1014 | | | |
| 2.0 | 4.1 | 42 | 4.0 | 8.2 | 240 | 7.0 | 14.4 | 396 | 11.0 | 22.6 | 594 | 14.0 | 28.7 | 1014 | | | |
| 2.0 | 4.1 | 42 | 4.0 | 8.2 | 252 | 7.0 | 14.4 | 396 | 11.0 | 22.6 | 600 | 15.0 | 30.8 | 1062 | | | |
| 2.0 | 4.1 | 54 | 4.0 | 8.2 | 264 | 7.0 | 14.4 | 396 | 11.0 | 22.6 | 600 | 15.0 | 30.8 | 1200 | | | |
| 2.0 | 4.1 | 54 | 4.0 | 8.2 | 270 | 7.0 | 14.4 | 396 | 11.0 | 22.6 | 594 | 15.0 | 30.8 | 1248 | | | |
| 2.0 | 4.1 | 60 | 4.0 | 8.2 | 270 | 8.0 | 16.4 | 402 | 11.0 | 22.6 | 600 | 15.0 | 30.8 | 1254 | | | |
| 2.0 | 4.1 | 66 | 4.0 | 8.2 | 282 | 8.0 | 16.4 | 426 | 11.0 | 22.6 | 594 | 15.0 | 30.8 | 1266 | | | |
| 2.0 | 4.1 | 72 | 4.0 | 8.2 | 282 | 8.0 | 16.4 | 426 | 12.0 | 24.6 | 606 | 15.0 | 30.8 | 1272 | | | |
| 2.0 | 4.1 | 78 | 4.0 | 8.2 | 288 | 8.0 | 16.4 | 432 | 12.0 | 24.6 | 648 | 15.0 | 30.8 | 1278 | | | |
| 2.0 | 4.1 | 78 | 4.0 | 8.2 | 288 | 8.0 | 16.4 | 432 | 12.0 | 24.6 | 666 | 15.0 | 30.8 | 1278 | | | |
| 2.0 | 4.1 | 78 | 4.0 | 8.2 | 288 | 8.0 | 16.4 | 426 | 12.0 | 24.6 | 768 | 15.0 | 30.8 | 1278 | | | |
| 2.0 | 4.1 | 84 | 5.0 | 10.3 | 288 | 8.0 | 16.4 | 426 | 12.0 | 24.6 | 882 | 15.0 | 30.8 | 1260 | | | |
| 3.0 | 6.2 | 90 | 5.0 | 10.3 | 306 | 8.0 | 16.4 | 432 | 12.0 | 24.6 | 918 | 16.0 | 32.8 | 1242 | | | |

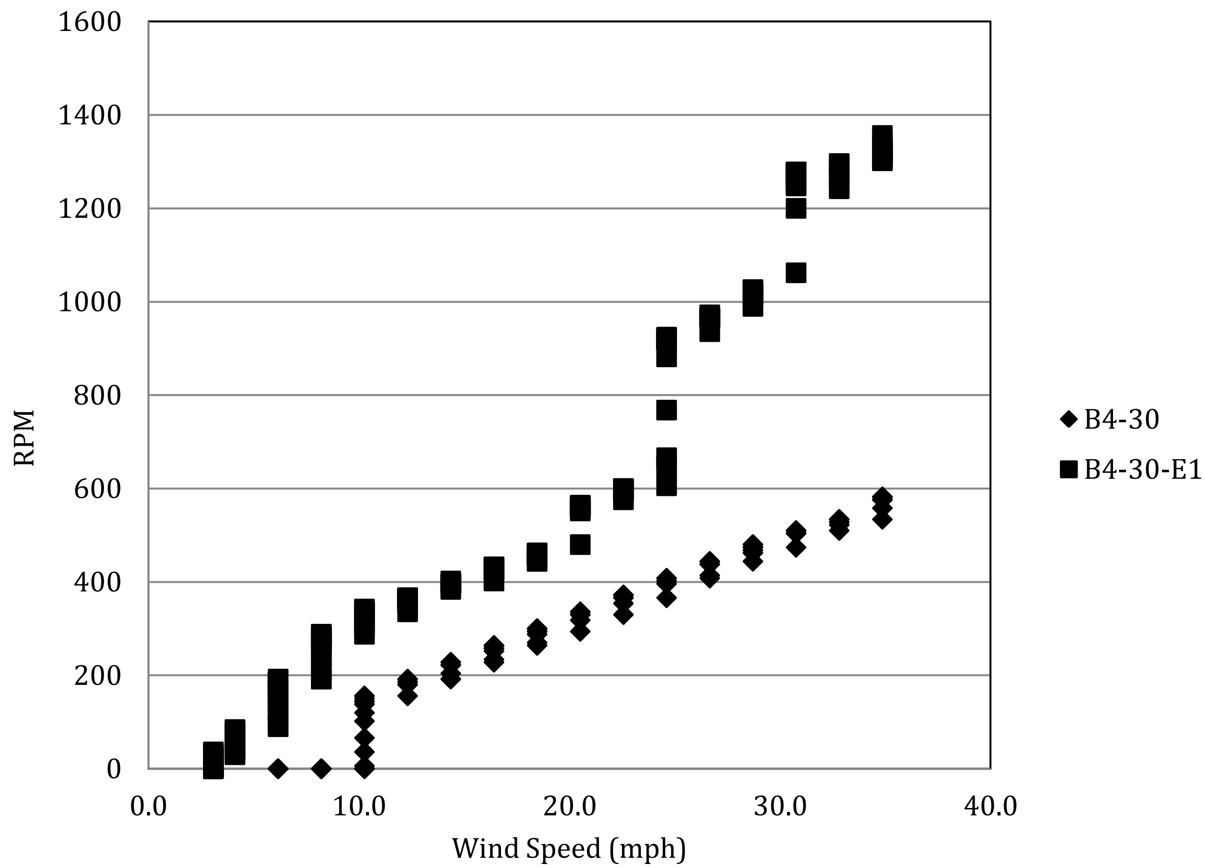



Figure A-3 - RPM of turbine with four blades at 30 degrees at various wind speeds

## A.4 Four Blades, 37.5 Degrees

The following data was collected on July 26, 2011 at 10:51AM in the Higgins Laboratories wind tunnel at Worcester Polytechnic Institute. The wind turbine was tested in the enclosure on July 28, 2011 at 10:26AM.

Table A-7 - Raw data for wind turbine with four blades at 37.5 degrees

| B4-37.5 | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM |
| 2.0 | 4.1 | 0 | 5.0 | 10.3 | 12 | 8.0 | 16.4 | 258 | 11.0 | 22.6 | 402 | 14.0 | 28.7 | 516 | 16.0 | 32.8 | 600 |
| 2.0 | 4.1 | 0 | 5.0 | 10.3 | 12 | 8.0 | 16.4 | 270 | 11.0 | 22.6 | 396 | 15.0 | 30.8 | 534 | 16.0 | 32.8 | 600 |
| 2.0 | 4.1 | 0 | 5.0 | 10.3 | 6 | 8.0 | 16.4 | 282 | 11.0 | 22.6 | 402 | 15.0 | 30.8 | 564 | 16.0 | 32.8 | 600 |
| 2.0 | 4.1 | 0 | 5.0 | 10.3 | 42 | 8.0 | 16.4 | 282 | 11.0 | 22.6 | 402 | 15.0 | 30.8 | 558 | 16.0 | 32.8 | 594 |
| 2.0 | 4.1 | 0 | 5.0 | 10.3 | 96 | 8.0 | 16.4 | 282 | 11.0 | 22.6 | 396 | 15.0 | 30.8 | 558 | 16.0 | 32.8 | 606 |
| 2.0 | 4.1 | 0 | 5.0 | 10.3 | 126 | 8.0 | 16.4 | 282 | 12.0 | 24.6 | 408 | 15.0 | 30.8 | 558 | 17.0 | 34.9 | 600 |
| 2.0 | 4.1 | 0 | 5.0 | 10.3 | 150 | 9.0 | 18.5 | 282 | 12.0 | 24.6 | 432 | 15.0 | 30.8 | 558 | 17.0 | 34.9 | 636 |
| 3.0 | 6.2 | 0 | 5.0 | 10.3 | 156 | 9.0 | 18.5 | 288 | 12.0 | 24.6 | 438 | 15.0 | 30.8 | 558 | 17.0 | 34.9 | 642 |
| 3.0 | 6.2 | 0 | 5.0 | 10.3 | 162 | 9.0 | 18.5 | 318 | 12.0 | 24.6 | 438 | 15.0 | 30.8 | 558 | 17.0 | 34.9 | 642 |
| 3.0 | 6.2 | 0 | 5.0 | 10.3 | 162 | 9.0 | 18.5 | 318 | 12.0 | 24.6 | 444 | 15.0 | 30.8 | 558 | 17.0 | 34.9 | 642 |
| 3.0 | 6.2 | 0 | 5.0 | 10.3 | 162 | 9.0 | 18.5 | 324 | 12.0 | 24.6 | 438 | 15.0 | 30.8 | 558 | 17.0 | 34.9 | 642 |
| 3.0 | 6.2 | 0 | 5.0 | 10.3 | 162 | 9.0 | 18.5 | 324 | 12.0 | 24.6 | 444 | 15.0 | 30.8 | 558 | 17.0 | 34.9 | 642 |
| 3.0 | 6.2 | 0 | 5.0 | 10.3 | 174 | 9.0 | 18.5 | 324 | 12.0 | 24.6 | 438 | 16.0 | 32.8 | 558 | 17.0 | 34.9 | 636 |
| 4.0 | 8.2 | 0 | 6.0 | 12.3 | 192 | 9.0 | 18.5 | 324 | 13.0 | 26.7 | 468 | 16.0 | 32.8 | 594 | 17.0 | 34.9 | 642 |
| 4.0 | 8.2 | 0 | 6.0 | 12.3 | 198 | 9.0 | 18.5 | 318 | 13.0 | 26.7 | 474 | 16.0 | 32.8 | 606 | | | |
| 4.0 | 8.2 | 0 | 6.0 | 12.3 | 198 | 9.0 | 18.5 | 324 | 13.0 | 26.7 | 480 | 16.0 | 32.8 | 600 | | | |
| 4.0 | 8.2 | 0 | 6.0 | 12.3 | 204 | 10.0 | 20.5 | 324 | 13.0 | 26.7 | 480 | 16.0 | 32.8 | 600 | | | |
| 4.0 | 8.2 | 0 | 6.0 | 12.3 | 204 | 10.0 | 20.5 | 330 | 13.0 | 26.7 | 486 | 16.0 | 32.8 | 594 | | | |
| 4.0 | 8.2 | 0 | 6.0 | 12.3 | 198 | 10.0 | 20.5 | 348 | 13.0 | 26.7 | 480 | 16.0 | 32.8 | 600 | | | |
| 4.0 | 8.2 | 0 | 6.0 | 12.3 | 204 | 10.0 | 20.5 | 360 | 13.0 | 26.7 | 480 | 16.0 | 32.8 | 600 | | | |
| 4.0 | 8.2 | 6 | 6.0 | 12.3 | 204 | 10.0 | 20.5 | 360 | 13.0 | 26.7 | 474 | 16.0 | 32.8 | 600 | | | |
| 4.0 | 8.2 | 0 | 6.0 | 12.3 | 204 | 10.0 | 20.5 | 360 | 13.0 | 26.7 | 480 | 16.0 | 32.8 | 600 | | | |
| 4.0 | 8.2 | 0 | 7.0 | 14.4 | 198 | 10.0 | 20.5 | 360 | 14.0 | 28.7 | 492 | 16.0 | 32.8 | 600 | | | |
| 4.0 | 8.2 | 0 | 7.0 | 14.4 | 210 | 10.0 | 20.5 | 360 | 14.0 | 28.7 | 516 | 16.0 | 32.8 | 594 | | | |
| 4.0 | 8.2 | 0 | 7.0 | 14.4 | 222 | 10.0 | 20.5 | 360 | 14.0 | 28.7 | 516 | 16.0 | 32.8 | 594 | | | |
| 4.0 | 8.2 | 0 | 7.0 | 14.4 | 234 | 10.0 | 20.5 | 360 | 14.0 | 28.7 | 516 | 16.0 | 32.8 | 600 | | | |
| 5.0 | 10.3 | 0 | 7.0 | 14.4 | 240 | 10.0 | 20.5 | 360 | 14.0 | 28.7 | 510 | 16.0 | 32.8 | 600 | | | |
| 5.0 | 10.3 | 6 | 7.0 | 14.4 | 240 | 11.0 | 22.6 | 360 | 14.0 | 28.7 | 516 | 16.0 | 32.8 | 594 | | | |
| 5.0 | 10.3 | 12 | 7.0 | 14.4 | 246 | 11.0 | 22.6 | 384 | 14.0 | 28.7 | 516 | 16.0 | 32.8 | 600 | | | |
| 5.0 | 10.3 | 12 | 8.0 | 16.4 | 240 | 11.0 | 22.6 | 396 | 14.0 | 28.7 | 516 | 16.0 | 32.8 | 600 | | | |

Table A-8 - Raw data for wind turbine with four blades at 37.5 degrees in enclosure

| B4-37.5-E1 | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM |
| 1.5 | 3.1 | 0 | 2.0 | 4.1 | 102 | 3.0 | 6.2 | 210 | 3.0 | 6.2 | 216 | 5.0 | 10.3 | 408 | 6.0 | 12.3 | 462 | 9.0 | 18.5 | 810 | 12.0 | 24.6 | 1170 |
| 1.5 | 3.1 | 0 | 2.0 | 4.1 | 102 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 216 | 5.0 | 10.3 | 402 | 6.0 | 12.3 | 462 | 9.0 | 18.5 | 822 | 12.0 | 24.6 | 1176 |
| 1.5 | 3.1 | 0 | 2.0 | 4.1 | 102 | 3.0 | 6.2 | 204 | 4.0 | 8.2 | 240 | 5.0 | 10.3 | 408 | 6.0 | 12.3 | 462 | 9.0 | 18.5 | 834 | 12.0 | 24.6 | 1182 |
| 1.5 | 3.1 | 0 | 2.0 | 4.1 | 108 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 246 | 5.0 | 10.3 | 414 | 6.0 | 12.3 | 456 | 9.0 | 18.5 | 840 | 12.0 | 24.6 | 1188 |
| 1.5 | 3.1 | 0 | 2.0 | 4.1 | 102 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 264 | 5.0 | 10.3 | 408 | 6.0 | 12.3 | 462 | 9.0 | 18.5 | 846 | 12.0 | 24.6 | 1188 |
| 1.5 | 3.1 | 0 | 2.0 | 4.1 | 108 | 3.0 | 6.2 | 216 | 4.0 | 8.2 | 270 | 5.0 | 10.3 | 408 | 6.0 | 12.3 | 456 | 9.0 | 18.5 | 852 | 12.0 | 24.6 | 1194 |
| 1.5 | 3.1 | 0 | 2.0 | 4.1 | 108 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 282 | 5.0 | 10.3 | 408 | 6.0 | 12.3 | 462 | 9.0 | 18.5 | 846 | 12.0 | 24.6 | 1188 |
| 1.5 | 3.1 | 0 | 2.0 | 4.1 | 108 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 282 | 5.0 | 10.3 | 408 | 6.0 | 12.3 | 462 | 10.0 | 20.5 | 852 | 12.0 | 24.6 | 1194 |
| 1.5 | 3.1 | 0 | 2.0 | 4.1 | 102 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 288 | 5.0 | 10.3 | 414 | 6.0 | 12.3 | 456 | 10.0 | 20.5 | 882 | 12.0 | 24.6 | 1194 |
| 2.0 | 4.1 | 0 | 2.0 | 4.1 | 114 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 294 | 5.0 | 10.3 | 408 | 6.0 | 12.3 | 456 | 10.0 | 20.5 | 912 | 12.0 | 24.6 | 1194 |
| 2.0 | 4.1 | 0 | 3.0 | 6.2 | 108 | 3.0 | 6.2 | 216 | 4.0 | 8.2 | 294 | 5.0 | 10.3 | 414 | 6.0 | 12.3 | 462 | 10.0 | 20.5 | 936 | 13.0 | 26.7 | 1194 |
| 2.0 | 4.1 | 6 | 3.0 | 6.2 | 120 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 300 | 5.0 | 10.3 | 408 | 6.0 | 12.3 | 456 | 10.0 | 20.5 | 948 | 13.0 | 26.7 | 1224 |
| 2.0 | 4.1 | 18 | 3.0 | 6.2 | 138 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 300 | 5.0 | 10.3 | 408 | 7.0 | 14.4 | 468 | 10.0 | 20.5 | 954 | 13.0 | 26.7 | 1266 |
| 2.0 | 4.1 | 36 | 3.0 | 6.2 | 150 | 3.0 | 6.2 | 216 | 4.0 | 8.2 | 306 | 5.0 | 10.3 | 414 | 7.0 | 14.4 | 480 | 10.0 | 20.5 | 960 | 13.0 | 26.7 | 1284 |
| 2.0 | 4.1 | 36 | 3.0 | 6.2 | 156 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 306 | 5.0 | 10.3 | 408 | 7.0 | 14.4 | 486 | 10.0 | 20.5 | 966 | 13.0 | 26.7 | 1290 |
| 2.0 | 4.1 | 48 | 3.0 | 6.2 | 168 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 306 | 5.0 | 10.3 | 408 | 7.0 | 14.4 | 486 | 10.0 | 20.5 | 966 | 13.0 | 26.7 | 1302 |
| 2.0 | 4.1 | 60 | 3.0 | 6.2 | 174 | 3.0 | 6.2 | 216 | 4.0 | 8.2 | 306 | 6.0 | 12.3 | 414 | 7.0 | 14.4 | 492 | 10.0 | 20.5 | 972 | 13.0 | 26.7 | 1296 |
| 2.0 | 4.1 | 60 | 3.0 | 6.2 | 186 | 3.0 | 6.2 | 210 | 5.0 | 10.3 | 318 | 6.0 | 12.3 | 426 | 7.0 | 14.4 | 486 | 10.0 | 20.5 | 966 | 13.0 | 26.7 | 1308 |
| 2.0 | 4.1 | 72 | 3.0 | 6.2 | 180 | 3.0 | 6.2 | 210 | 5.0 | 10.3 | 342 | 6.0 | 12.3 | 444 | 7.0 | 14.4 | 486 | 10.0 | 20.5 | 972 | 13.0 | 26.7 | 1308 |
| 2.0 | 4.1 | 72 | 3.0 | 6.2 | 192 | 3.0 | 6.2 | 216 | 5.0 | 10.3 | 354 | 6.0 | 12.3 | 462 | 8.0 | 16.4 | 486 | 11.0 | 22.6 | 990 | 13.0 | 26.7 | 1302 |
| 2.0 | 4.1 | 78 | 3.0 | 6.2 | 192 | 3.0 | 6.2 | 210 | 5.0 | 10.3 | 372 | 6.0 | 12.3 | 456 | 8.0 | 16.4 | 504 | 11.0 | 22.6 | 1020 | 13.0 | 26.7 | 1308 |
| 2.0 | 4.1 | 84 | 3.0 | 6.2 | 198 | 3.0 | 6.2 | 216 | 5.0 | 10.3 | 378 | 6.0 | 12.3 | 462 | 8.0 | 16.4 | 510 | 11.0 | 22.6 | 1050 | 13.0 | 26.7 | 1308 |
| 2.0 | 4.1 | 90 | 3.0 | 6.2 | 198 | 3.0 | 6.2 | 210 | 5.0 | 10.3 | 384 | 6.0 | 12.3 | 456 | 8.0 | 16.4 | 504 | 11.0 | 22.6 | 1062 | 13.0 | 26.7 | 1308 |
| 2.0 | 4.1 | 90 | 3.0 | 6.2 | 198 | 3.0 | 6.2 | 216 | 5.0 | 10.3 | 390 | 6.0 | 12.3 | 462 | 8.0 | 16.4 | 498 | 11.0 | 22.6 | 1068 | 13.0 | 26.7 | 1308 |
| 2.0 | 4.1 | 90 | 3.0 | 6.2 | 204 | 3.0 | 6.2 | 210 | 5.0 | 10.3 | 396 | 6.0 | 12.3 | 462 | 8.0 | 16.4 | 504 | 11.0 | 22.6 | 1074 | 13.0 | 26.7 | 1302 |
| 2.0 | 4.1 | 90 | 3.0 | 6.2 | 204 | 3.0 | 6.2 | 216 | 5.0 | 10.3 | 396 | 6.0 | 12.3 | 462 | 9.0 | 18.5 | 528 | 11.0 | 22.6 | 1080 | 13.0 | 26.7 | 1308 |
| 2.0 | 4.1 | 96 | 3.0 | 6.2 | 204 | 3.0 | 6.2 | 210 | 5.0 | 10.3 | 402 | 6.0 | 12.3 | 462 | 9.0 | 18.5 | 618 | 11.0 | 22.6 | 1074 | 13.0 | 26.7 | 1308 |
| 2.0 | 4.1 | 102 | 3.0 | 6.2 | 204 | 3.0 | 6.2 | 210 | 5.0 | 10.3 | 408 | 6.0 | 12.3 | 456 | 9.0 | 18.5 | 702 | 12.0 | 24.6 | 1080 | 13.0 | 26.7 | 1308 |
| 2.0 | 4.1 | 96 | 3.0 | 6.2 | 204 | 3.0 | 6.2 | 216 | 5.0 | 10.3 | 402 | 6.0 | 12.3 | 462 | 9.0 | 18.5 | 750 | 12.0 | 24.6 | 1110 | 13.0 | 26.7 | 1302 |
| 2.0 | 4.1 | 102 | 3.0 | 6.2 | 210 | 3.0 | 6.2 | 210 | 5.0 | 10.3 | 408 | 6.0 | 12.3 | 462 | 9.0 | 18.5 | 786 | 12.0 | 24.6 | 1140 | 13.0 | 26.7 | 1308 |

Table A-9 - Raw data for wind turbine with four blades at 37.5 degrees in enclosure, continued

| B4-37.5-E1 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM |
| 14.0 | 28.7 | 1344 | 14.0 | 28.7 | 1410 | 15.0 | 30.8 | 1542 | 17.0 | 34.9 | 1776 |
| 14.0 | 28.7 | 1380 | 14.0 | 28.7 | 1422 | 15.0 | 30.8 | 1542 | 17.0 | 34.9 | 1782 |
| 14.0 | 28.7 | 1398 | 14.0 | 28.7 | 1416 | 15.0 | 30.8 | 1542 | 17.0 | 34.9 | 1776 |
| 14.0 | 28.7 | 1398 | 14.0 | 28.7 | 1416 | 15.0 | 30.8 | 1542 | 17.0 | 34.9 | 1782 |
| 14.0 | 28.7 | 1410 | 14.0 | 28.7 | 1428 | 15.0 | 30.8 | 1542 | 17.0 | 34.9 | 1776 |
| 14.0 | 28.7 | 1410 | 15.0 | 30.8 | 1464 | 16.0 | 32.8 | 1548 | 17.0 | 34.9 | 1782 |
| 14.0 | 28.7 | 1410 | 15.0 | 30.8 | 1506 | 16.0 | 32.8 | 1596 | 17.0 | 34.9 | 1782 |
| 14.0 | 28.7 | 1410 | 15.0 | 30.8 | 1518 | 16.0 | 32.8 | 1626 | 17.0 | 34.9 | 1782 |
| 14.0 | 28.7 | 1404 | 15.0 | 30.8 | 1530 | 16.0 | 32.8 | 1644 | 17.0 | 34.9 | 1776 |
| 14.0 | 28.7 | 1410 | 15.0 | 30.8 | 1536 | 16.0 | 32.8 | 1650 | 17.0 | 34.9 | 1782 |
| 14.0 | 28.7 | 1410 | 15.0 | 30.8 | 1536 | 16.0 | 32.8 | 1650 | 17.0 | 34.9 | 1776 |
| 14.0 | 28.7 | 1404 | 15.0 | 30.8 | 1542 | 16.0 | 32.8 | 1662 | 17.0 | 34.9 | 1782 |
| 14.0 | 28.7 | 1410 | 15.0 | 30.8 | 1536 | 16.0 | 32.8 | 1656 | 17.0 | 34.9 | 1776 |
| 14.0 | 28.7 | 1404 | 15.0 | 30.8 | 1542 | 16.0 | 32.8 | 1656 | 17.0 | 34.9 | 1782 |
| 14.0 | 28.7 | 1410 | 15.0 | 30.8 | 1542 | 16.0 | 32.8 | 1656 | 17.0 | 34.9 | 1776 |
| 14.0 | 28.7 | 1404 | 15.0 | 30.8 | 1536 | 16.0 | 32.8 | 1656 | 17.0 | 34.9 | 1782 |
| 14.0 | 28.7 | 1404 | 15.0 | 30.8 | 1542 | 16.0 | 32.8 | 1656 | | | |
| 14.0 | 28.7 | 1404 | 15.0 | 30.8 | 1542 | 16.0 | 32.8 | 1656 | | | |
| 14.0 | 28.7 | 1410 | 15.0 | 30.8 | 1542 | 16.0 | 32.8 | 1662 | | | |
| 14.0 | 28.7 | 1404 | 15.0 | 30.8 | 1542 | 16.0 | 32.8 | 1656 | | | |
| 14.0 | 28.7 | 1404 | 15.0 | 30.8 | 1542 | 16.0 | 32.8 | 1656 | | | |
| 14.0 | 28.7 | 1404 | 15.0 | 30.8 | 1542 | 16.0 | 32.8 | 1656 | | | |
| 14.0 | 28.7 | 1404 | 15.0 | 30.8 | 1536 | 17.0 | 34.9 | 1662 | | | |
| 14.0 | 28.7 | 1404 | 15.0 | 30.8 | 1542 | 17.0 | 34.9 | 1710 | | | |
| 14.0 | 28.7 | 1398 | 15.0 | 30.8 | 1542 | 17.0 | 34.9 | 1740 | | | |
| 14.0 | 28.7 | 1404 | 15.0 | 30.8 | 1542 | 17.0 | 34.9 | 1758 | | | |
| 14.0 | 28.7 | 1398 | 15.0 | 30.8 | 1542 | 17.0 | 34.9 | 1770 | | | |
| 14.0 | 28.7 | 1404 | 15.0 | 30.8 | 1542 | 17.0 | 34.9 | 1770 | | | |
| 14.0 | 28.7 | 1398 | 15.0 | 30.8 | 1542 | 17.0 | 34.9 | 1782 | | | |
| 14.0 | 28.7 | 1398 | 15.0 | 30.8 | 1542 | 17.0 | 34.9 | 1776 | | | |

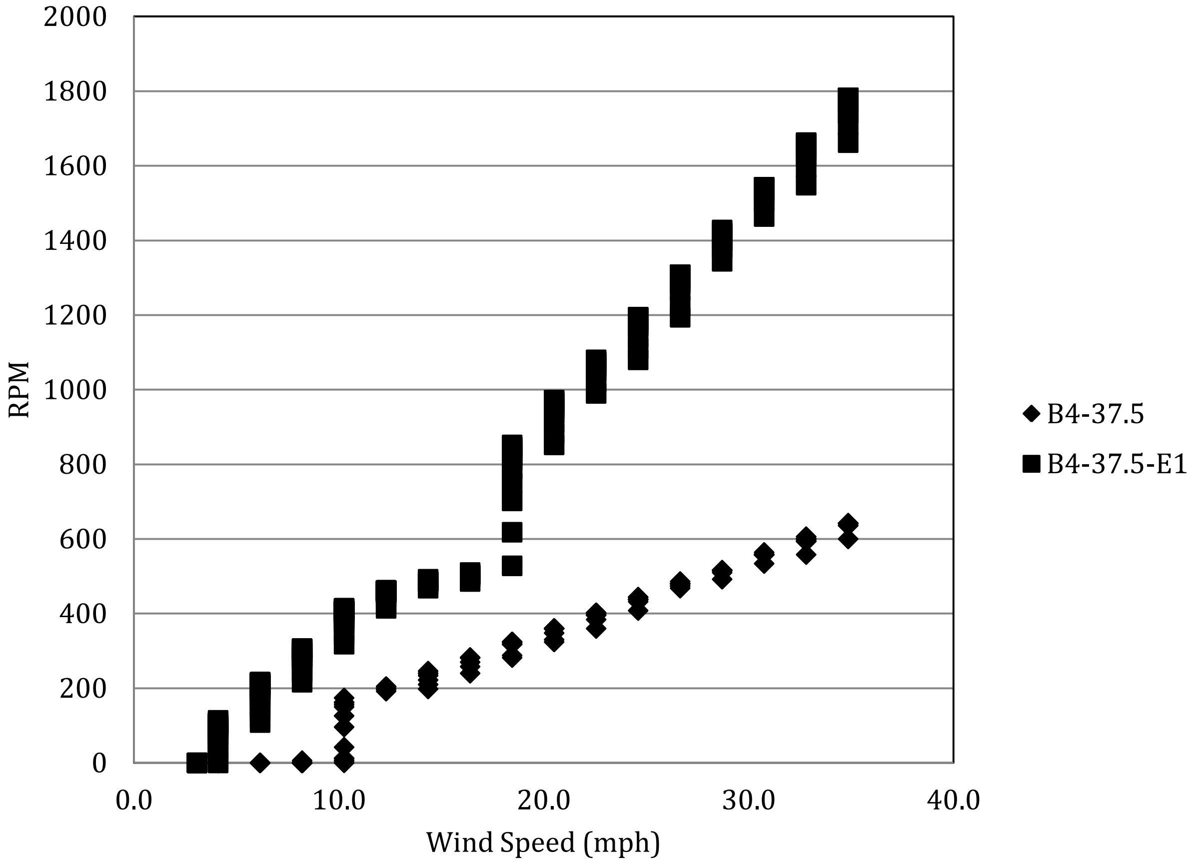



Figure A-4 - RPM of turbine with four blades at 37.5 degrees at various wind speeds

## A.5 Four Blades, 45 Degrees

The following data was collected on July 13, 2011 at 2:20PM in the Higgins Laboratories wind tunnel at Worcester Polytechnic Institute. The wind turbine was tested in the enclosure on July 13, 2011 at 11:48AM.

Table A-10 - Raw data for wind turbine with four blades at 45 degrees

| B4-45 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** |
| 5.0 | 10.3 | 0 | 9.0 | 18.5 | 300 | 12.0 | 24.6 | 408 | 16.0 | 32.8 | 546 |
| 5.0 | 10.3 | 0 | 9.0 | 18.5 | 300 | 12.0 | 24.6 | 402 | 16.0 | 32.8 | 546 |
| 5.0 | 10.3 | 0 | 9.0 | 18.5 | 294 | 12.0 | 24.6 | 402 | 16.0 | 32.8 | 546 |
| 5.0 | 10.3 | 0 | 9.0 | 18.5 | 294 | 12.0 | 24.6 | 402 | 17.0 | 34.9 | 570 |
| 5.0 | 10.3 | 6 | 9.0 | 18.5 | 300 | 12.0 | 24.6 | 408 | 17.0 | 34.9 | 582 |
| 5.0 | 10.3 | 0 | 10.0 | 20.5 | 300 | 12.0 | 24.6 | 408 | 17.0 | 34.9 | 582 |
| 5.0 | 10.3 | 0 | 10.0 | 20.5 | 318 | 12.0 | 24.6 | 408 | 17.0 | 34.9 | 588 |
| 5.0 | 10.3 | 0 | 10.0 | 20.5 | 330 | 12.0 | 24.6 | 402 | 17.0 | 34.9 | 588 |
| 5.0 | 10.3 | 0 | 10.0 | 20.5 | 336 | 13.0 | 26.7 | 420 | 17.0 | 34.9 | 582 |
| 6.0 | 12.3 | 12 | 10.0 | 20.5 | 330 | 13.0 | 26.7 | 444 | 17.0 | 34.9 | 582 |
| 6.0 | 12.3 | 6 | 10.0 | 20.5 | 336 | 13.0 | 26.7 | 438 | | | |
| 6.0 | 12.3 | 12 | 10.0 | 20.5 | 330 | 13.0 | 26.7 | 438 | | | |
| 6.0 | 12.3 | 12 | 10.0 | 20.5 | 330 | 13.0 | 26.7 | 444 | | | |
| 6.0 | 12.3 | 0 | 10.0 | 20.5 | 336 | 13.0 | 26.7 | 438 | | | |
| 7.0 | 14.4 | 6 | 10.0 | 20.5 | 330 | 14.0 | 28.7 | 462 | | | |
| 7.0 | 14.4 | 12 | 11.0 | 22.6 | 342 | 14.0 | 28.7 | 474 | | | |
| 7.0 | 14.4 | 12 | 11.0 | 22.6 | 366 | 14.0 | 28.7 | 480 | | | |
| 7.0 | 14.4 | 6 | 11.0 | 22.6 | 366 | 14.0 | 28.7 | 474 | | | |
| 7.0 | 14.4 | 0 | 11.0 | 22.6 | 366 | 14.0 | 28.7 | 480 | | | |
| 8.0 | 16.4 | 12 | 11.0 | 22.6 | 366 | 14.0 | 28.7 | 480 | | | |
| 8.0 | 16.4 | 6 | 11.0 | 22.6 | 372 | 14.0 | 28.7 | 480 | | | |
| 8.0 | 16.4 | 0 | 11.0 | 22.6 | 366 | 15.0 | 30.8 | 504 | | | |
| 8.0 | 16.4 | 0 | 11.0 | 22.6 | 372 | 15.0 | 30.8 | 510 | | | |
| 8.0 | 16.4 | 0 | 12.0 | 24.6 | 396 | 15.0 | 30.8 | 516 | | | |
| 9.0 | 18.5 | 0 | 12.0 | 24.6 | 402 | 15.0 | 30.8 | 510 | | | |
| 9.0 | 18.5 | 0 | 12.0 | 24.6 | 408 | 15.0 | 30.8 | 516 | | | |
| 9.0 | 18.5 | 6 | 12.0 | 24.6 | 402 | 16.0 | 32.8 | 516 | | | |
| 9.0 | 18.5 | 78 | 12.0 | 24.6 | 402 | 16.0 | 32.8 | 540 | | | |
| 9.0 | 18.5 | 246 | 12.0 | 24.6 | 408 | 16.0 | 32.8 | 552 | | | |
| 9.0 | 18.5 | 294 | 12.0 | 24.6 | 402 | 16.0 | 32.8 | 552 | | | |

Table A-11 - Raw data for wind turbine with four blades at 45 degrees in enclosure

| B4-45-E1 | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM |
| 1.5 | 3.1 | 0 | 3 | 6.2 | 156 | 5 | 10.3 | 360 | 10 | 20.5 | 618 | 12 | 24.6 | 1128 | 16 | 32.8 | 1548 |
| 1.5 | 3.1 | 0 | 3 | 6.2 | 174 | 5 | 10.3 | 372 | 10 | 20.5 | 738 | 13 | 26.7 | 1140 | 16 | 32.8 | 1548 |
| 1.5 | 3.1 | 0 | 3 | 6.2 | 174 | 5 | 10.3 | 378 | 10 | 20.5 | 810 | 13 | 26.7 | 1176 | 16 | 32.8 | 1560 |
| 1.5 | 3.1 | 0 | 3 | 6.2 | 180 | 5 | 10.3 | 384 | 10 | 20.5 | 852 | 13 | 26.7 | 1206 | 16 | 32.8 | 1554 |
| 1.5 | 3.1 | 6 | 3 | 6.2 | 186 | 5 | 10.3 | 390 | 10 | 20.5 | 876 | 13 | 26.7 | 1218 | 16 | 32.8 | 1560 |
| 1.5 | 3.1 | 6 | 3 | 6.2 | 192 | 5 | 10.3 | 390 | 10 | 20.5 | 894 | 13 | 26.7 | 1224 | 16 | 32.8 | 1554 |
| 1.5 | 3.1 | 12 | 3 | 6.2 | 192 | 5 | 10.3 | 396 | 10 | 20.5 | 906 | 13 | 26.7 | 1230 | 16 | 32.8 | 1560 |
| 1.5 | 3.1 | 18 | 3 | 6.2 | 192 | 5 | 10.3 | 396 | 10 | 20.5 | 906 | 13 | 26.7 | 1230 | 16 | 32.8 | 1560 |
| 1.5 | 3.1 | 18 | 3 | 6.2 | 198 | 5 | 10.3 | 396 | 10 | 20.5 | 918 | 13 | 26.7 | 1236 | 16 | 32.8 | 1560 |
| 1.5 | 3.1 | 24 | 3 | 6.2 | 198 | 5 | 10.3 | 402 | 10 | 20.5 | 912 | 13 | 26.7 | 1230 | 16 | 32.8 | 1554 |
| 1.5 | 3.1 | 30 | 3 | 6.2 | 204 | 6 | 12.3 | 402 | 10 | 20.5 | 918 | 14 | 28.7 | 1254 | 16 | 32.8 | 1560 |
| 1.5 | 3.1 | 30 | 3 | 6.2 | 204 | 6 | 12.3 | 432 | 11 | 22.6 | 924 | 14 | 28.7 | 1296 | 16 | 32.8 | 1560 |
| 1.5 | 3.1 | 30 | 3 | 6.2 | 204 | 6 | 12.3 | 444 | 11 | 22.6 | 960 | 14 | 28.7 | 1320 | 16 | 32.8 | 1560 |
| 1.5 | 3.1 | 36 | 3 | 6.2 | 204 | 6 | 12.3 | 450 | 11 | 22.6 | 990 | 14 | 28.7 | 1332 | 16 | 32.8 | 1560 |
| 2 | 4.1 | 42 | 3 | 6.2 | 204 | 6 | 12.3 | 456 | 11 | 22.6 | 1002 | 14 | 28.7 | 1332 | 16 | 32.8 | 1554 |
| 2 | 4.1 | 42 | 3 | 6.2 | 204 | 6 | 12.3 | 456 | 11 | 22.6 | 1014 | 14 | 28.7 | 1332 | 16 | 32.8 | 1560 |
| 2 | 4.1 | 48 | 4 | 8.2 | 216 | 6 | 12.3 | 450 | 11 | 22.6 | 1014 | 14 | 28.7 | 1338 | 16 | 32.8 | 1566 |
| 2 | 4.1 | 54 | 4 | 8.2 | 228 | 6 | 12.3 | 456 | 11 | 22.6 | 1020 | 14 | 28.7 | 1338 | 17 | 34.9 | 1590 |
| 2 | 4.1 | 66 | 4 | 8.2 | 246 | 6 | 12.3 | 456 | 11 | 22.6 | 1020 | 15 | 30.8 | 1338 | 17 | 34.9 | 1638 |
| 2 | 4.1 | 72 | 4 | 8.2 | 258 | 7 | 14.4 | 456 | 11 | 22.6 | 1020 | 15 | 30.8 | 1368 | 17 | 34.9 | 1656 |
| 2 | 4.1 | 78 | 4 | 8.2 | 270 | 7 | 14.4 | 474 | 12 | 24.6 | 1026 | 15 | 30.8 | 1410 | 17 | 34.9 | 1662 |
| 2 | 4.1 | 78 | 4 | 8.2 | 282 | 7 | 14.4 | 498 | 12 | 24.6 | 1068 | 15 | 30.8 | 1428 | 17 | 34.9 | 1662 |
| 2 | 4.1 | 84 | 4 | 8.2 | 282 | 7 | 14.4 | 504 | 12 | 24.6 | 1098 | 15 | 30.8 | 1446 | 17 | 34.9 | 1668 |
| 2 | 4.1 | 90 | 4 | 8.2 | 282 | 7 | 14.4 | 510 | 12 | 24.6 | 1110 | 15 | 30.8 | 1452 | 17 | 34.9 | 1668 |
| 2 | 4.1 | 90 | 4 | 8.2 | 294 | 7 | 14.4 | 498 | 12 | 24.6 | 1116 | 15 | 30.8 | 1452 | 17 | 34.9 | 1668 |
| 2 | 4.1 | 96 | 4 | 8.2 | 294 | 7 | 14.4 | 504 | 12 | 24.6 | 1128 | 15 | 30.8 | 1458 | 17 | 34.9 | 1668 |
| 3 | 6.2 | 96 | 4 | 8.2 | 294 | 7 | 14.4 | 504 | 12 | 24.6 | 1122 | 15 | 30.8 | 1452 | 17 | 34.9 | 1668 |
| 3 | 6.2 | 120 | 5 | 10.3 | 306 | 10 | 20.5 | 504 | 12 | 24.6 | 1128 | 15 | 30.8 | 1458 | 17 | 34.9 | 1668 |
| 3 | 6.2 | 138 | 5 | 10.3 | 324 | 10 | 20.5 | 504 | 12 | 24.6 | 1128 | 16 | 32.8 | 1494 | | | |
| 3 | 6.2 | 150 | 5 | 10.3 | 348 | 10 | 20.5 | 528 | 12 | 24.6 | 1128 | 16 | 32.8 | 1530 | | | |

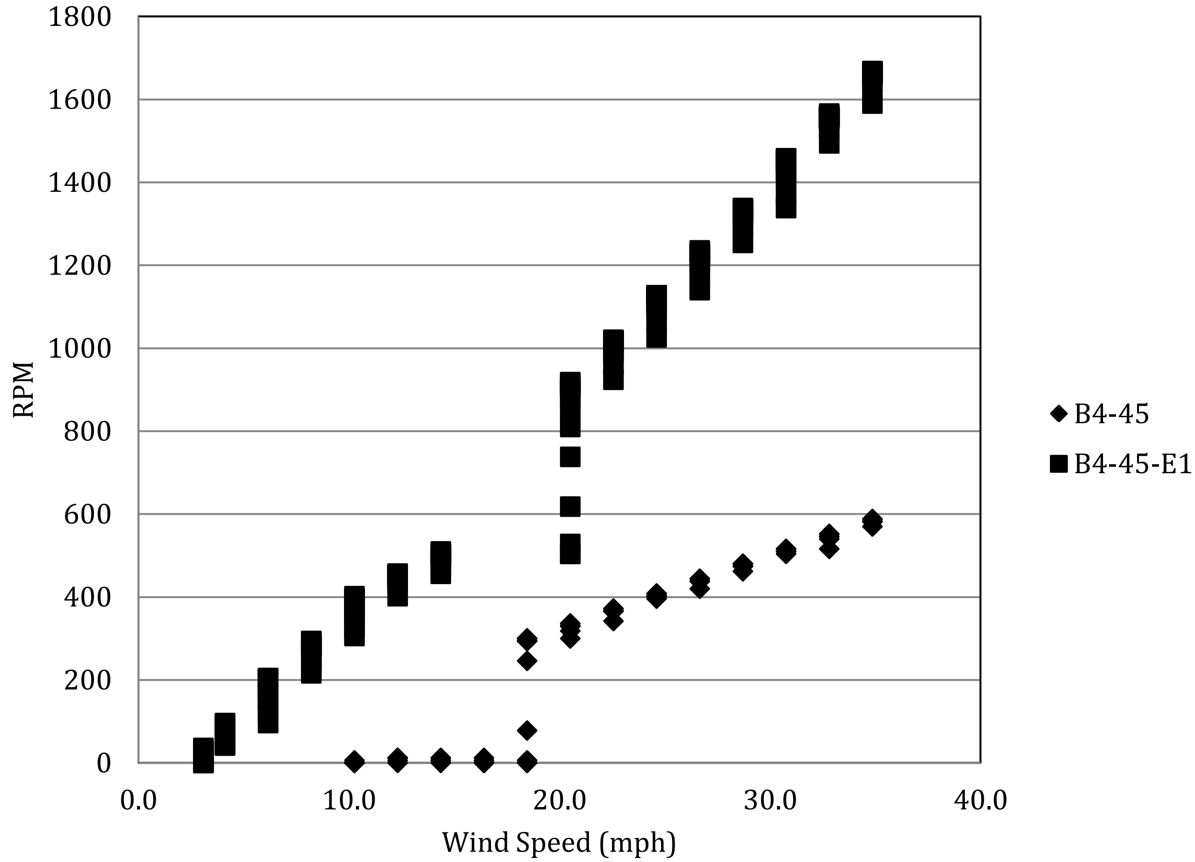



Figure A-5- RPM of turbine with four blades at 45 degrees at various wind speeds

### A.6 Four Blades, 52.5 Degrees

The following data was collected on July 26, 2011 at 11:11AM in the Higgins Laboratories wind tunnel at Worcester Polytechnic Institute. The wind turbine was tested in the enclosure on July 28, 2011 at 11:01AM.

Table A-12 - Raw data for wind turbine with four blades at 52.5 degrees

| B4-52.5 | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM |
| 3.0 | 6.2 | 0 | 4.0 | 8.2 | 0 | 5.0 | 10.3 | 144 | 8.0 | 16.4 | 246 | 10.0 | 20.5 | 312 | 12.0 | 24.6 | 384 | 15.0 | 30.8 | 480 |
| 3.0 | 6.2 | 0 | 4.0 | 8.2 | 0 | 5.0 | 10.3 | 144 | 8.0 | 16.4 | 246 | 10.0 | 20.5 | 318 | 12.0 | 24.6 | 384 | 15.0 | 30.8 | 480 |
| 3.0 | 6.2 | 0 | 5.0 | 10.3 | 0 | 5.0 | 10.3 | 150 | 8.0 | 16.4 | 246 | 10.0 | 20.5 | 312 | 12.0 | 24.6 | 378 | 15.0 | 30.8 | 486 |
| 3.0 | 6.2 | 0 | 5.0 | 10.3 | 0 | 6.0 | 12.3 | 144 | 8.0 | 16.4 | 246 | 10.0 | 20.5 | 318 | 12.0 | 24.6 | 384 | 16.0 | 32.8 | 498 |
| 3.0 | 6.2 | 0 | 5.0 | 10.3 | 0 | 6.0 | 12.3 | 150 | 8.0 | 16.4 | 252 | 10.0 | 20.5 | 312 | 12.0 | 24.6 | 378 | 16.0 | 32.8 | 516 |
| 3.0 | 6.2 | 0 | 5.0 | 10.3 | 0 | 6.0 | 12.3 | 174 | 8.0 | 16.4 | 246 | 10.0 | 20.5 | 318 | 12.0 | 24.6 | 384 | 16.0 | 32.8 | 510 |
| 3.0 | 6.2 | 0 | 5.0 | 10.3 | 0 | 6.0 | 12.3 | 180 | 8.0 | 16.4 | 246 | 10.0 | 20.5 | 312 | 12.0 | 24.6 | 378 | 16.0 | 32.8 | 516 |
| 3.0 | 6.2 | 0 | 5.0 | 10.3 | 0 | 6.0 | 12.3 | 180 | 8.0 | 16.4 | 246 | 10.0 | 20.5 | 318 | 12.0 | 24.6 | 384 | 16.0 | 32.8 | 516 |
| 4.0 | 8.2 | 0 | 5.0 | 10.3 | 0 | 6.0 | 12.3 | 180 | 8.0 | 16.4 | 252 | 11.0 | 22.6 | 342 | 13.0 | 26.7 | 384 | 17.0 | 34.9 | 522 |
| 4.0 | 8.2 | 0 | 5.0 | 10.3 | 0 | 6.0 | 12.3 | 180 | 8.0 | 16.4 | 246 | 11.0 | 22.6 | 348 | 13.0 | 26.7 | 414 | 17.0 | 34.9 | 546 |
| 4.0 | 8.2 | 0 | 5.0 | 10.3 | 18 | 6.0 | 12.3 | 180 | 8.0 | 16.4 | 246 | 11.0 | 22.6 | 354 | 13.0 | 26.7 | 414 | 17.0 | 34.9 | 552 |
| 4.0 | 8.2 | 0 | 5.0 | 10.3 | 60 | 6.0 | 12.3 | 180 | 9.0 | 18.5 | 264 | 11.0 | 22.6 | 348 | 13.0 | 26.7 | 414 | 17.0 | 34.9 | 546 |
| 4.0 | 8.2 | 0 | 5.0 | 10.3 | 108 | 6.0 | 12.3 | 180 | 9.0 | 18.5 | 276 | 11.0 | 22.6 | 348 | 13.0 | 26.7 | 414 | 17.0 | 34.9 | 546 |
| 4.0 | 8.2 | 0 | 5.0 | 10.3 | 126 | 6.0 | 12.3 | 180 | 9.0 | 18.5 | 282 | 11.0 | 22.6 | 348 | 13.0 | 26.7 | 414 | 17.0 | 34.9 | 546 |
| 4.0 | 8.2 | 0 | 5.0 | 10.3 | 138 | 6.0 | 12.3 | 174 | 9.0 | 18.5 | 282 | 11.0 | 22.6 | 348 | 13.0 | 26.7 | 414 | 17.0 | 34.9 | 552 |
| 4.0 | 8.2 | 0 | 5.0 | 10.3 | 144 | 6.0 | 12.3 | 180 | 9.0 | 18.5 | 282 | 11.0 | 22.6 | 348 | 13.0 | 26.7 | 414 | 17.0 | 34.9 | 546 |
| 4.0 | 8.2 | 0 | 5.0 | 10.3 | 150 | 6.0 | 12.3 | 180 | 9.0 | 18.5 | 282 | 11.0 | 22.6 | 354 | 13.0 | 26.7 | 420 | 17.0 | 34.9 | 552 |
| 4.0 | 8.2 | 0 | 5.0 | 10.3 | 144 | 6.0 | 12.3 | 180 | 9.0 | 18.5 | 282 | 11.0 | 22.6 | 348 | 13.0 | 26.7 | 414 | | | |
| 4.0 | 8.2 | 0 | 5.0 | 10.3 | 144 | 7.0 | 14.4 | 204 | 9.0 | 18.5 | 282 | 11.0 | 22.6 | 348 | 13.0 | 26.7 | 414 | | | |
| 4.0 | 8.2 | 0 | 5.0 | 10.3 | 144 | 7.0 | 14.4 | 210 | 9.0 | 18.5 | 282 | 11.0 | 22.6 | 348 | 14.0 | 28.7 | 432 | | | |
| 4.0 | 8.2 | 0 | 5.0 | 10.3 | 150 | 7.0 | 14.4 | 216 | 9.0 | 18.5 | 282 | 11.0 | 22.6 | 354 | 14.0 | 28.7 | 450 | | | |
| 4.0 | 8.2 | 0 | 5.0 | 10.3 | 144 | 7.0 | 14.4 | 210 | 9.0 | 18.5 | 282 | 11.0 | 22.6 | 348 | 14.0 | 28.7 | 450 | | | |
| 4.0 | 8.2 | 0 | 5.0 | 10.3 | 144 | 7.0 | 14.4 | 216 | 9.0 | 18.5 | 282 | 11.0 | 22.6 | 348 | 14.0 | 28.7 | 450 | | | |
| 4.0 | 8.2 | 0 | 5.0 | 10.3 | 150 | 7.0 | 14.4 | 216 | 10.0 | 20.5 | 294 | 12.0 | 24.6 | 378 | 14.0 | 28.7 | 450 | | | |
| 4.0 | 8.2 | 0 | 5.0 | 10.3 | 144 | 7.0 | 14.4 | 210 | 10.0 | 20.5 | 318 | 12.0 | 24.6 | 384 | 14.0 | 28.7 | 450 | | | |
| 4.0 | 8.2 | 0 | 5.0 | 10.3 | 144 | 7.0 | 14.4 | 216 | 10.0 | 20.5 | 312 | 12.0 | 24.6 | 384 | 14.0 | 28.7 | 444 | | | |
| 4.0 | 8.2 | 0 | 5.0 | 10.3 | 150 | 7.0 | 14.4 | 216 | 10.0 | 20.5 | 318 | 12.0 | 24.6 | 384 | 14.0 | 28.7 | 450 | | | |
| 4.0 | 8.2 | 0 | 5.0 | 10.3 | 144 | 7.0 | 14.4 | 210 | 10.0 | 20.5 | 318 | 12.0 | 24.6 | 384 | 15.0 | 30.8 | 480 | | | |
| 4.0 | 8.2 | 0 | 5.0 | 10.3 | 144 | 7.0 | 14.4 | 216 | 10.0 | 20.5 | 312 | 12.0 | 24.6 | 384 | 15.0 | 30.8 | 480 | | | |
| 4.0 | 8.2 | 0 | 5.0 | 10.3 | 150 | 8.0 | 16.4 | 234 | 10.0 | 20.5 | 318 | 12.0 | 24.6 | 378 | 15.0 | 30.8 | 486 | | | |

Table A-13 - Raw data for wind turbine with four blades at 52.5 degrees in enclosure

| B4-52.5-E1 | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM |
| 1.5 | 3.1 | 0 | 3.0 | 6.2 | 156 | 5.0 | 10.3 | 384 | 8.0 | 16.4 | 684 | 9.0 | 18.5 | 822 | 12.0 | 24.6 | 1134 | 15.0 | 30.8 | 1380 | 16.0 | 32.8 | 1548 |
| 1.5 | 3.1 | 0 | 3.0 | 6.2 | 162 | 5.0 | 10.3 | 390 | 8.0 | 16.4 | 690 | 10.0 | 20.5 | 828 | 12.0 | 24.6 | 1140 | 15.0 | 30.8 | 1416 | 16.0 | 32.8 | 1560 |
| 1.5 | 3.1 | 0 | 3.0 | 6.2 | 174 | 6.0 | 12.3 | 402 | 8.0 | 16.4 | 702 | 10.0 | 20.5 | 858 | 12.0 | 24.6 | 1146 | 15.0 | 30.8 | 1440 | 16.0 | 32.8 | 1578 |
| 1.5 | 3.1 | 6 | 3.0 | 6.2 | 174 | 6.0 | 12.3 | 426 | 8.0 | 16.4 | 702 | 10.0 | 20.5 | 876 | 12.0 | 24.6 | 1146 | 15.0 | 30.8 | 1458 | 16.0 | 32.8 | 1578 |
| 1.5 | 3.1 | 6 | 3.0 | 6.2 | 186 | 6.0 | 12.3 | 432 | 8.0 | 16.4 | 708 | 10.0 | 20.5 | 894 | 12.0 | 24.6 | 1140 | 15.0 | 30.8 | 1464 | 16.0 | 32.8 | 1584 |
| 1.5 | 3.1 | 18 | 3.0 | 6.2 | 180 | 6.0 | 12.3 | 450 | 8.0 | 16.4 | 714 | 10.0 | 20.5 | 906 | 12.0 | 24.6 | 1146 | 15.0 | 30.8 | 1470 | 16.0 | 32.8 | 1590 |
| 1.5 | 3.1 | 12 | 3.0 | 6.2 | 192 | 6.0 | 12.3 | 456 | 8.0 | 16.4 | 708 | 10.0 | 20.5 | 912 | 13.0 | 26.7 | 1164 | 15.0 | 30.8 | 1476 | 16.0 | 32.8 | 1590 |
| 1.5 | 3.1 | 24 | 4.0 | 8.2 | 192 | 6.0 | 12.3 | 456 | 8.0 | 16.4 | 714 | 10.0 | 20.5 | 924 | 13.0 | 26.7 | 1200 | 15.0 | 30.8 | 1482 | 16.0 | 32.8 | 1590 |
| 1.5 | 3.1 | 24 | 4.0 | 8.2 | 210 | 6.0 | 12.3 | 462 | 8.0 | 16.4 | 714 | 10.0 | 20.5 | 924 | 13.0 | 26.7 | 1218 | 15.0 | 30.8 | 1476 | 16.0 | 32.8 | 1590 |
| 1.5 | 3.1 | 24 | 4.0 | 8.2 | 228 | 6.0 | 12.3 | 468 | 9.0 | 18.5 | 732 | 10.0 | 20.5 | 924 | 13.0 | 26.7 | 1230 | 15.0 | 30.8 | 1482 | 16.0 | 32.8 | 1590 |
| 1.5 | 3.1 | 36 | 4.0 | 8.2 | 240 | 6.0 | 12.3 | 462 | 9.0 | 18.5 | 756 | 10.0 | 20.5 | 930 | 13.0 | 26.7 | 1236 | 15.0 | 30.8 | 1482 | 16.0 | 32.8 | 1590 |
| 1.5 | 3.1 | 30 | 4.0 | 8.2 | 252 | 6.0 | 12.3 | 468 | 9.0 | 18.5 | 774 | 10.0 | 20.5 | 930 | 13.0 | 26.7 | 1248 | 15.0 | 30.8 | 1482 | 16.0 | 32.8 | 1608 |
| 2.0 | 4.1 | 36 | 4.0 | 8.2 | 264 | 6.0 | 12.3 | 462 | 9.0 | 18.5 | 792 | 11.0 | 22.6 | 942 | 13.0 | 26.7 | 1248 | 15.0 | 30.8 | 1476 | 17.0 | 34.9 | 1656 |
| 2.0 | 4.1 | 36 | 4.0 | 8.2 | 264 | 6.0 | 12.3 | 468 | 9.0 | 18.5 | 798 | 11.0 | 22.6 | 972 | 13.0 | 26.7 | 1248 | 15.0 | 30.8 | 1482 | 17.0 | 34.9 | 1680 |
| 2.0 | 4.1 | 48 | 4.0 | 8.2 | 276 | 7.0 | 14.4 | 474 | 9.0 | 18.5 | 810 | 11.0 | 22.6 | 996 | 13.0 | 26.7 | 1254 | 15.0 | 30.8 | 1482 | 17.0 | 34.9 | 1692 |
| 2.0 | 4.1 | 54 | 4.0 | 8.2 | 282 | 7.0 | 14.4 | 492 | 9.0 | 18.5 | 810 | 11.0 | 22.6 | 1008 | 13.0 | 26.7 | 1248 | 15.0 | 30.8 | 1482 | 17.0 | 34.9 | 1704 |
| 2.0 | 4.1 | 60 | 4.0 | 8.2 | 282 | 7.0 | 14.4 | 498 | 9.0 | 18.5 | 816 | 11.0 | 22.6 | 1020 | 13.0 | 26.7 | 1254 | 15.0 | 30.8 | 1476 | 17.0 | 34.9 | 1704 |
| 2.0 | 4.1 | 66 | 4.0 | 8.2 | 288 | 7.0 | 14.4 | 498 | 9.0 | 18.5 | 816 | 11.0 | 22.6 | 1026 | 14.0 | 28.7 | 1266 | 15.0 | 30.8 | 1482 | 17.0 | 34.9 | 1704 |
| 2.0 | 4.1 | 72 | 4.0 | 8.2 | 288 | 7.0 | 14.4 | 498 | 9.0 | 18.5 | 816 | 11.0 | 22.6 | 1032 | 14.0 | 28.7 | 1308 | 15.0 | 30.8 | 1482 | 17.0 | 34.9 | 1704 |
| 2.0 | 4.1 | 78 | 4.0 | 8.2 | 294 | 7.0 | 14.4 | 498 | 9.0 | 18.5 | 816 | 11.0 | 22.6 | 1032 | 14.0 | 28.7 | 1326 | 15.0 | 30.8 | 1482 | 17.0 | 34.9 | 1704 |
| 2.0 | 4.1 | 84 | 5.0 | 10.3 | 300 | 7.0 | 14.4 | 498 | 9.0 | 18.5 | 822 | 11.0 | 22.6 | 1032 | 14.0 | 28.7 | 1332 | 15.0 | 30.8 | 1476 | 17.0 | 34.9 | 1704 |
| 2.0 | 4.1 | 84 | 5.0 | 10.3 | 324 | 7.0 | 14.4 | 504 | 9.0 | 18.5 | 822 | 11.0 | 22.6 | 1038 | 14.0 | 28.7 | 1350 | 15.0 | 30.8 | 1482 | 17.0 | 34.9 | 1710 |
| 2.0 | 4.1 | 90 | 5.0 | 10.3 | 336 | 7.0 | 14.4 | 498 | 9.0 | 18.5 | 816 | 11.0 | 22.6 | 1038 | 14.0 | 28.7 | 1350 | 15.0 | 30.8 | 1482 | 17.0 | 34.9 | 1710 |
| 2.0 | 4.1 | 90 | 5.0 | 10.3 | 348 | 7.0 | 14.4 | 504 | 9.0 | 18.5 | 822 | 11.0 | 22.6 | 1032 | 14.0 | 28.7 | 1356 | 15.0 | 30.8 | 1482 | 17.0 | 34.9 | 1704 |
| 2.0 | 4.1 | 90 | 5.0 | 10.3 | 366 | 8.0 | 16.4 | 504 | 9.0 | 18.5 | 816 | 11.0 | 22.6 | 1038 | 14.0 | 28.7 | 1362 | 15.0 | 30.8 | 1482 | 17.0 | 34.9 | 1710 |
| 2.0 | 4.1 | 96 | 5.0 | 10.3 | 366 | 8.0 | 16.4 | 540 | 9.0 | 18.5 | 822 | 12.0 | 24.6 | 1062 | 14.0 | 28.7 | 1356 | 15.0 | 30.8 | 1482 | | | |
| 3.0 | 6.2 | 102 | 5.0 | 10.3 | 372 | 8.0 | 16.4 | 582 | 9.0 | 18.5 | 816 | 12.0 | 24.6 | 1086 | 14.0 | 28.7 | 1362 | 15.0 | 30.8 | 1476 | | | |
| 3.0 | 6.2 | 120 | 5.0 | 10.3 | 384 | 8.0 | 16.4 | 624 | 9.0 | 18.5 | 822 | 12.0 | 24.6 | 1110 | 14.0 | 28.7 | 1362 | 15.0 | 30.8 | 1482 | | | |
| 3.0 | 6.2 | 138 | 5.0 | 10.3 | 378 | 8.0 | 16.4 | 654 | 9.0 | 18.5 | 822 | 12.0 | 24.6 | 1122 | 14.0 | 28.7 | 1362 | 16.0 | 32.8 | 1476 | | | |
| 3.0 | 6.2 | 150 | 5.0 | 10.3 | 390 | 8.0 | 16.4 | 666 | 9.0 | 18.5 | 816 | 12.0 | 24.6 | 1134 | 14.0 | 28.7 | 1362 | 16.0 | 32.8 | 1512 | | | |

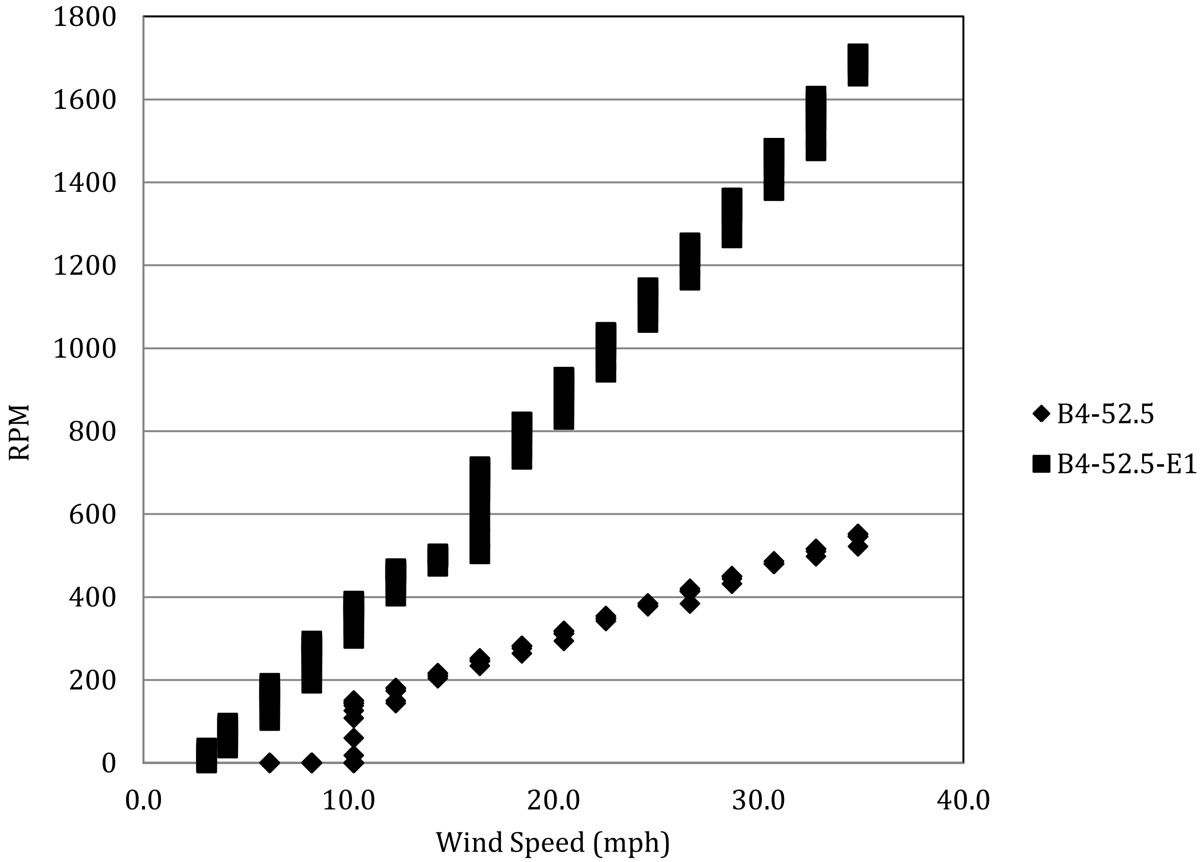



Figure A-6 - RPM of turibne with four blades at 52.5 degrees at various wind speeds

## A.7 Four Blades, 60 Degrees

The following data was collected on July 26, 2011 at 11:46AM in the Higgins Laboratories wind tunnel at Worcester Polytechnic Institute. The wind turbine was tested in the enclosure on July 28, 2011 at 11:24AM.

Table A-14 - Raw data for wind turbine with four blades at 60 degrees

| B4-60 | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM |
| 2.0 | 4.1 | 0 | 3.0 | 6.2 | 0 | 5.0 | 10.3 | 0 | 7.0 | 14.4 | 84 | 10.0 | 20.5 | 126 | 13.0 | 26.7 | 162 | 17.0 | 34.9 | 216 |
| 2.0 | 4.1 | 0 | 3.0 | 6.2 | 0 | 5.0 | 10.3 | 0 | 7.0 | 14.4 | 84 | 10.0 | 20.5 | 126 | 13.0 | 26.7 | 168 | 17.0 | 34.9 | 216 |
| 2.0 | 4.1 | 0 | 3.0 | 6.2 | 0 | 5.0 | 10.3 | 0 | 7.0 | 14.4 | 84 | 10.0 | 20.5 | 126 | 14.0 | 28.7 | 168 | 17.0 | 34.9 | 216 |
| 2.0 | 4.1 | 0 | 3.0 | 6.2 | 0 | 5.0 | 10.3 | 0 | 7.0 | 14.4 | 84 | 10.0 | 20.5 | 132 | 14.0 | 28.7 | 180 | 17.0 | 34.9 | 222 |
| 2.0 | 4.1 | 0 | 3.0 | 6.2 | 0 | 5.0 | 10.3 | 0 | 7.0 | 14.4 | 84 | 10.0 | 20.5 | 120 | 14.0 | 28.7 | 174 | 17.0 | 34.9 | 222 |
| 2.0 | 4.1 | 0 | 4.0 | 8.2 | 0 | 5.0 | 10.3 | 0 | 7.0 | 14.4 | 78 | 10.0 | 20.5 | 132 | 14.0 | 28.7 | 180 | 17.0 | 34.9 | 210 |
| 2.0 | 4.1 | 0 | 4.0 | 8.2 | 0 | 5.0 | 10.3 | 0 | 7.0 | 14.4 | 84 | 10.0 | 20.5 | 126 | 14.0 | 28.7 | 180 | 17.0 | 34.9 | 222 |
| 2.0 | 4.1 | 0 | 4.0 | 8.2 | 0 | 5.0 | 10.3 | 0 | 7.0 | 14.4 | 84 | 10.0 | 20.5 | 126 | 14.0 | 28.7 | 180 | 17.0 | 34.9 | 216 |
| 2.0 | 4.1 | 0 | 4.0 | 8.2 | 0 | 5.0 | 10.3 | 0 | 7.0 | 14.4 | 84 | 10.0 | 20.5 | 126 | 14.0 | 28.7 | 180 | 17.0 | 34.9 | 216 |
| 2.0 | 4.1 | 0 | 4.0 | 8.2 | 0 | 5.0 | 10.3 | 0 | 8.0 | 16.4 | 90 | 11.0 | 22.6 | 126 | 14.0 | 28.7 | 180 | 17.0 | 34.9 | 216 |
| 2.0 | 4.1 | 0 | 4.0 | 8.2 | 0 | 5.0 | 10.3 | 0 | 8.0 | 16.4 | 96 | 11.0 | 22.6 | 138 | 14.0 | 28.7 | 180 | 17.0 | 34.9 | 216 |
| 2.0 | 4.1 | 0 | 4.0 | 8.2 | 0 | 5.0 | 10.3 | 0 | 8.0 | 16.4 | 96 | 11.0 | 22.6 | 138 | 14.0 | 28.7 | 174 | 17.0 | 34.9 | 216 |
| 2.0 | 4.1 | 0 | 4.0 | 8.2 | 0 | 6.0 | 12.3 | 0 | 8.0 | 16.4 | 96 | 11.0 | 22.6 | 138 | 15.0 | 30.8 | 186 | | | |
| 2.0 | 4.1 | 0 | 4.0 | 8.2 | 0 | 6.0 | 12.3 | 0 | 8.0 | 16.4 | 96 | 11.0 | 22.6 | 138 | 15.0 | 30.8 | 198 | | | |
| 2.0 | 4.1 | 0 | 4.0 | 8.2 | 0 | 6.0 | 12.3 | 12 | 8.0 | 16.4 | 96 | 11.0 | 22.6 | 138 | 15.0 | 30.8 | 198 | | | |
| 2.0 | 4.1 | 0 | 4.0 | 8.2 | 0 | 6.0 | 12.3 | 18 | 8.0 | 16.4 | 96 | 11.0 | 22.6 | 138 | 15.0 | 30.8 | 198 | | | |
| 2.0 | 4.1 | 0 | 4.0 | 8.2 | 0 | 6.0 | 12.3 | 48 | 8.0 | 16.4 | 96 | 11.0 | 22.6 | 138 | 15.0 | 30.8 | 192 | | | |
| 3.0 | 6.2 | 0 | 4.0 | 8.2 | 0 | 6.0 | 12.3 | 54 | 8.0 | 16.4 | 102 | 12.0 | 24.6 | 150 | 15.0 | 30.8 | 192 | | | |
| 3.0 | 6.2 | 0 | 4.0 | 8.2 | 0 | 6.0 | 12.3 | 54 | 8.0 | 16.4 | 90 | 12.0 | 24.6 | 156 | 15.0 | 30.8 | 192 | | | |
| 3.0 | 6.2 | 0 | 4.0 | 8.2 | 0 | 6.0 | 12.3 | 60 | 8.0 | 16.4 | 96 | 12.0 | 24.6 | 156 | 15.0 | 30.8 | 198 | | | |
| 3.0 | 6.2 | 0 | 4.0 | 8.2 | 0 | 6.0 | 12.3 | 60 | 8.0 | 16.4 | 102 | 12.0 | 24.6 | 150 | 16.0 | 32.8 | 198 | | | |
| 3.0 | 6.2 | 0 | 4.0 | 8.2 | 0 | 6.0 | 12.3 | 54 | 9.0 | 18.5 | 102 | 12.0 | 24.6 | 156 | 16.0 | 32.8 | 210 | | | |
| 3.0 | 6.2 | 0 | 4.0 | 8.2 | 0 | 6.0 | 12.3 | 54 | 9.0 | 18.5 | 114 | 12.0 | 24.6 | 156 | 16.0 | 32.8 | 204 | | | |
| 3.0 | 6.2 | 0 | 4.0 | 8.2 | 0 | 6.0 | 12.3 | 60 | 9.0 | 18.5 | 114 | 12.0 | 24.6 | 150 | 16.0 | 32.8 | 204 | | | |
| 3.0 | 6.2 | 0 | 4.0 | 8.2 | 0 | 6.0 | 12.3 | 54 | 9.0 | 18.5 | 114 | 12.0 | 24.6 | 156 | 16.0 | 32.8 | 204 | | | |
| 3.0 | 6.2 | 0 | 5.0 | 10.3 | 0 | 6.0 | 12.3 | 60 | 9.0 | 18.5 | 108 | 13.0 | 26.7 | 168 | 16.0 | 32.8 | 210 | | | |
| 3.0 | 6.2 | 0 | 5.0 | 10.3 | 0 | 6.0 | 12.3 | 60 | 9.0 | 18.5 | 114 | 13.0 | 26.7 | 168 | 16.0 | 32.8 | 198 | | | |
| 3.0 | 6.2 | 0 | 5.0 | 10.3 | 0 | 7.0 | 14.4 | 66 | 9.0 | 18.5 | 114 | 13.0 | 26.7 | 162 | 16.0 | 32.8 | 204 | | | |
| 3.0 | 6.2 | 0 | 5.0 | 10.3 | 0 | 7.0 | 14.4 | 72 | 9.0 | 18.5 | 114 | 13.0 | 26.7 | 168 | 16.0 | 32.8 | 210 | | | |
| 3.0 | 6.2 | 0 | 5.0 | 10.3 | 0 | 7.0 | 14.4 | 84 | 10.0 | 20.5 | 114 | 13.0 | 26.7 | 168 | 16.0 | 32.8 | 210 | | | |

Table A-15 - Raw data for wind turbine with four blades at 60 degrees in enclosure

| B4-60-E1 | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM |
| 1.5 | 3.1 | 0 | 2.0 | 4.1 | 96 | 3.0 | 6.2 | 198 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 306 | 5.0 | 10.3 | 402 | 5.0 | 10.3 | 408 | 6.0 | 12.3 | 486 |
| 1.5 | 3.1 | 0 | 2.0 | 4.1 | 96 | 3.0 | 6.2 | 198 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 306 | 5.0 | 10.3 | 402 | 5.0 | 10.3 | 402 | 6.0 | 12.3 | 480 |
| 1.5 | 3.1 | 0 | 2.0 | 4.1 | 102 | 3.0 | 6.2 | 204 | 3.0 | 6.2 | 216 | 4.0 | 8.2 | 306 | 5.0 | 10.3 | 408 | 5.0 | 10.3 | 408 | 6.0 | 12.3 | 480 |
| 1.5 | 3.1 | 0 | 2.0 | 4.1 | 96 | 3.0 | 6.2 | 204 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 306 | 5.0 | 10.3 | 402 | 5.0 | 10.3 | 402 | 6.0 | 12.3 | 486 |
| 1.5 | 3.1 | 6 | 2.0 | 4.1 | 102 | 3.0 | 6.2 | 204 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 312 | 5.0 | 10.3 | 402 | 5.0 | 10.3 | 408 | 6.0 | 12.3 | 480 |
| 1.5 | 3.1 | 6 | 2.0 | 4.1 | 102 | 3.0 | 6.2 | 204 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 306 | 5.0 | 10.3 | 408 | 5.0 | 10.3 | 402 | 6.0 | 12.3 | 480 |
| 1.5 | 3.1 | 12 | 2.0 | 4.1 | 102 | 3.0 | 6.2 | 210 | 3.0 | 6.2 | 210 | 5.0 | 10.3 | 306 | 5.0 | 10.3 | 402 | 5.0 | 10.3 | 408 | 6.0 | 12.3 | 486 |
| 1.5 | 3.1 | 18 | 2.0 | 4.1 | 108 | 3.0 | 6.2 | 204 | 3.0 | 6.2 | 216 | 5.0 | 10.3 | 330 | 5.0 | 10.3 | 402 | 5.0 | 10.3 | 402 | 6.0 | 12.3 | 480 |
| 1.5 | 3.1 | 18 | 2.0 | 4.1 | 102 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 210 | 5.0 | 10.3 | 348 | 5.0 | 10.3 | 402 | 5.0 | 10.3 | 402 | 6.0 | 12.3 | 486 |
| 1.5 | 3.1 | 24 | 2.0 | 4.1 | 102 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 228 | 5.0 | 10.3 | 360 | 5.0 | 10.3 | 408 | 5.0 | 10.3 | 408 | 6.0 | 12.3 | 480 |
| 1.5 | 3.1 | 24 | 2.0 | 4.1 | 108 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 240 | 5.0 | 10.3 | 366 | 5.0 | 10.3 | 402 | 5.0 | 10.3 | 402 | 6.0 | 12.3 | 486 |
| 1.5 | 3.1 | 30 | 2.0 | 4.1 | 108 | 3.0 | 6.2 | 204 | 4.0 | 8.2 | 258 | 5.0 | 10.3 | 378 | 5.0 | 10.3 | 402 | 5.0 | 10.3 | 408 | 6.0 | 12.3 | 480 |
| 1.5 | 3.1 | 30 | 2.0 | 4.1 | 108 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 264 | 5.0 | 10.3 | 390 | 5.0 | 10.3 | 408 | 5.0 | 10.3 | 402 | 6.0 | 12.3 | 486 |
| 1.5 | 3.1 | 36 | 2.0 | 4.1 | 102 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 276 | 5.0 | 10.3 | 384 | 5.0 | 10.3 | 402 | 6.0 | 12.3 | 408 | 6.0 | 12.3 | 480 |
| 1.5 | 3.1 | 36 | 2.0 | 4.1 | 108 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 282 | 5.0 | 10.3 | 396 | 5.0 | 10.3 | 402 | 6.0 | 12.3 | 420 | 6.0 | 12.3 | 486 |
| 1.5 | 3.1 | 42 | 2.0 | 4.1 | 108 | 3.0 | 6.2 | 216 | 4.0 | 8.2 | 282 | 5.0 | 10.3 | 396 | 5.0 | 10.3 | 408 | 6.0 | 12.3 | 438 | 6.0 | 12.3 | 480 |
| 1.5 | 3.1 | 36 | 2.0 | 4.1 | 108 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 294 | 5.0 | 10.3 | 396 | 5.0 | 10.3 | 402 | 6.0 | 12.3 | 456 | 6.0 | 12.3 | 480 |
| 1.5 | 3.1 | 48 | 2.0 | 4.1 | 108 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 294 | 5.0 | 10.3 | 402 | 5.0 | 10.3 | 402 | 6.0 | 12.3 | 462 | 7.0 | 14.4 | 492 |
| 1.5 | 3.1 | 42 | 2.0 | 4.1 | 114 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 294 | 5.0 | 10.3 | 402 | 5.0 | 10.3 | 408 | 6.0 | 12.3 | 474 | 7.0 | 14.4 | 504 |
| 2.0 | 4.1 | 48 | 2.0 | 4.1 | 120 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 300 | 5.0 | 10.3 | 402 | 5.0 | 10.3 | 402 | 6.0 | 12.3 | 474 | 7.0 | 14.4 | 504 |
| 2.0 | 4.1 | 54 | 3.0 | 6.2 | 144 | 3.0 | 6.2 | 216 | 4.0 | 8.2 | 300 | 5.0 | 10.3 | 402 | 5.0 | 10.3 | 402 | 6.0 | 12.3 | 474 | 7.0 | 14.4 | 510 |
| 2.0 | 4.1 | 66 | 3.0 | 6.2 | 150 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 306 | 5.0 | 10.3 | 402 | 5.0 | 10.3 | 408 | 6.0 | 12.3 | 480 | 7.0 | 14.4 | 504 |
| 2.0 | 4.1 | 72 | 3.0 | 6.2 | 156 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 300 | 5.0 | 10.3 | 402 | 5.0 | 10.3 | 402 | 6.0 | 12.3 | 480 | 7.0 | 14.4 | 510 |
| 2.0 | 4.1 | 72 | 3.0 | 6.2 | 174 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 306 | 5.0 | 10.3 | 402 | 5.0 | 10.3 | 402 | 6.0 | 12.3 | 480 | 7.0 | 14.4 | 504 |
| 2.0 | 4.1 | 78 | 3.0 | 6.2 | 174 | 3.0 | 6.2 | 216 | 4.0 | 8.2 | 306 | 5.0 | 10.3 | 408 | 5.0 | 10.3 | 408 | 6.0 | 12.3 | 480 | 7.0 | 14.4 | 510 |
| 2.0 | 4.1 | 84 | 3.0 | 6.2 | 180 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 306 | 5.0 | 10.3 | 402 | 5.0 | 10.3 | 402 | 6.0 | 12.3 | 480 | 7.0 | 14.4 | 510 |
| 2.0 | 4.1 | 84 | 3.0 | 6.2 | 186 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 306 | 5.0 | 10.3 | 402 | 5.0 | 10.3 | 402 | 6.0 | 12.3 | 480 | 7.0 | 14.4 | 504 |
| 2.0 | 4.1 | 90 | 3.0 | 6.2 | 192 | 3.0 | 6.2 | 216 | 4.0 | 8.2 | 306 | 5.0 | 10.3 | 402 | 5.0 | 10.3 | 408 | 6.0 | 12.3 | 486 | 7.0 | 14.4 | 510 |
| 2.0 | 4.1 | 96 | 3.0 | 6.2 | 192 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 306 | 5.0 | 10.3 | 408 | 5.0 | 10.3 | 402 | 6.0 | 12.3 | 480 | 7.0 | 14.4 | 510 |
| 2.0 | 4.1 | 90 | 3.0 | 6.2 | 198 | 3.0 | 6.2 | 210 | 4.0 | 8.2 | 312 | 5.0 | 10.3 | 402 | 5.0 | 10.3 | 402 | 6.0 | 12.3 | 480 | 7.0 | 14.4 | 510 |

Table A-16 - Raw data for wind turbine with four blades at 60 degrees in enclosure, continued

| B4-60-E1 | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** |
| 7.0 | 14.4 | 510 | 8.0 | 16.4 | 636 | 8.0 | 16.4 | 732 | 9.0 | 18.5 | 840 | 11.0 | 22.6 | 1050 | 12.0 | 24.6 | 1170 | 13.0 | 26.7 | 1284 |
| 7.0 | 14.4 | 504 | 8.0 | 16.4 | 666 | 8.0 | 16.4 | 732 | 9.0 | 18.5 | 840 | 11.0 | 22.6 | 1056 | 12.0 | 24.6 | 1170 | 13.0 | 26.7 | 1290 |
| 7.0 | 14.4 | 510 | 8.0 | 16.4 | 684 | 9.0 | 18.5 | 732 | 9.0 | 18.5 | 840 | 11.0 | 22.6 | 1056 | 12.0 | 24.6 | 1170 | 13.0 | 26.7 | 1284 |
| 7.0 | 14.4 | 510 | 8.0 | 16.4 | 702 | 9.0 | 18.5 | 762 | 10.0 | 20.5 | 840 | 11.0 | 22.6 | 1056 | 12.0 | 24.6 | 1170 | 13.0 | 26.7 | 1284 |
| 7.0 | 14.4 | 510 | 8.0 | 16.4 | 708 | 9.0 | 18.5 | 780 | 10.0 | 20.5 | 864 | 11.0 | 22.6 | 1062 | 13.0 | 26.7 | 1170 | 13.0 | 26.7 | 1284 |
| 7.0 | 14.4 | 510 | 8.0 | 16.4 | 714 | 9.0 | 18.5 | 798 | 10.0 | 20.5 | 894 | 11.0 | 22.6 | 1062 | 13.0 | 26.7 | 1200 | 13.0 | 26.7 | 1290 |
| 7.0 | 14.4 | 510 | 8.0 | 16.4 | 720 | 9.0 | 18.5 | 816 | 10.0 | 20.5 | 906 | 11.0 | 22.6 | 1062 | 13.0 | 26.7 | 1230 | 13.0 | 26.7 | 1284 |
| 7.0 | 14.4 | 510 | 8.0 | 16.4 | 720 | 9.0 | 18.5 | 816 | 10.0 | 20.5 | 924 | 11.0 | 22.6 | 1062 | 13.0 | 26.7 | 1248 | 14.0 | 28.7 | 1296 |
| 7.0 | 14.4 | 510 | 8.0 | 16.4 | 726 | 9.0 | 18.5 | 822 | 10.0 | 20.5 | 930 | 11.0 | 22.6 | 1062 | 13.0 | 26.7 | 1260 | 14.0 | 28.7 | 1326 |
| 7.0 | 14.4 | 510 | 8.0 | 16.4 | 726 | 9.0 | 18.5 | 828 | 10.0 | 20.5 | 936 | 12.0 | 24.6 | 1086 | 13.0 | 26.7 | 1272 | 14.0 | 28.7 | 1356 |
| 7.0 | 14.4 | 510 | 8.0 | 16.4 | 732 | 9.0 | 18.5 | 828 | 10.0 | 20.5 | 942 | 12.0 | 24.6 | 1116 | 13.0 | 26.7 | 1272 | 14.0 | 28.7 | 1368 |
| 7.0 | 14.4 | 510 | 8.0 | 16.4 | 732 | 9.0 | 18.5 | 834 | 10.0 | 20.5 | 948 | 12.0 | 24.6 | 1140 | 13.0 | 26.7 | 1278 | 14.0 | 28.7 | 1380 |
| 7.0 | 14.4 | 510 | 8.0 | 16.4 | 726 | 9.0 | 18.5 | 834 | 10.0 | 20.5 | 948 | 12.0 | 24.6 | 1146 | 13.0 | 26.7 | 1278 | 14.0 | 28.7 | 1386 |
| 7.0 | 14.4 | 510 | 8.0 | 16.4 | 732 | 9.0 | 18.5 | 834 | 10.0 | 20.5 | 948 | 12.0 | 24.6 | 1158 | 13.0 | 26.7 | 1284 | 14.0 | 28.7 | 1386 |
| 7.0 | 14.4 | 510 | 8.0 | 16.4 | 732 | 9.0 | 18.5 | 834 | 10.0 | 20.5 | 948 | 12.0 | 24.6 | 1164 | 13.0 | 26.7 | 1278 | 14.0 | 28.7 | 1392 |
| 7.0 | 14.4 | 510 | 8.0 | 16.4 | 732 | 9.0 | 18.5 | 834 | 10.0 | 20.5 | 954 | 12.0 | 24.6 | 1164 | 13.0 | 26.7 | 1290 | 14.0 | 28.7 | 1392 |
| 7.0 | 14.4 | 510 | 8.0 | 16.4 | 732 | 9.0 | 18.5 | 840 | 10.0 | 20.5 | 948 | 12.0 | 24.6 | 1170 | 13.0 | 26.7 | 1278 | 14.0 | 28.7 | 1398 |
| 7.0 | 14.4 | 510 | 8.0 | 16.4 | 732 | 9.0 | 18.5 | 834 | 10.0 | 20.5 | 954 | 12.0 | 24.6 | 1170 | 13.0 | 26.7 | 1284 | 14.0 | 28.7 | 1398 |
| 7.0 | 14.4 | 516 | 8.0 | 16.4 | 732 | 9.0 | 18.5 | 840 | 10.0 | 20.5 | 948 | 12.0 | 24.6 | 1170 | 13.0 | 26.7 | 1284 | 14.0 | 28.7 | 1392 |
| 7.0 | 14.4 | 510 | 8.0 | 16.4 | 732 | 9.0 | 18.5 | 834 | 10.0 | 20.5 | 948 | 12.0 | 24.6 | 1170 | 13.0 | 26.7 | 1284 | 14.0 | 28.7 | 1398 |
| 7.0 | 14.4 | 510 | 8.0 | 16.4 | 732 | 9.0 | 18.5 | 840 | 10.0 | 20.5 | 954 | 12.0 | 24.6 | 1170 | 13.0 | 26.7 | 1284 | 14.0 | 28.7 | 1398 |
| 7.0 | 14.4 | 510 | 8.0 | 16.4 | 732 | 9.0 | 18.5 | 834 | 10.0 | 20.5 | 948 | 12.0 | 24.6 | 1170 | 13.0 | 26.7 | 1290 | 14.0 | 28.7 | 1392 |
| 7.0 | 14.4 | 510 | 8.0 | 16.4 | 732 | 9.0 | 18.5 | 840 | 10.0 | 20.5 | 948 | 12.0 | 24.6 | 1176 | 13.0 | 26.7 | 1284 | 14.0 | 28.7 | 1392 |
| 7.0 | 14.4 | 516 | 8.0 | 16.4 | 732 | 9.0 | 18.5 | 840 | 10.0 | 20.5 | 954 | 12.0 | 24.6 | 1170 | 13.0 | 26.7 | 1284 | 14.0 | 28.7 | 1398 |
| 7.0 | 14.4 | 510 | 8.0 | 16.4 | 732 | 9.0 | 18.5 | 840 | 11.0 | 22.6 | 960 | 12.0 | 24.6 | 1170 | 13.0 | 26.7 | 1284 | 14.0 | 28.7 | 1398 |
| 7.0 | 14.4 | 510 | 8.0 | 16.4 | 732 | 9.0 | 18.5 | 834 | 11.0 | 22.6 | 984 | 12.0 | 24.6 | 1170 | 13.0 | 26.7 | 1284 | 14.0 | 28.7 | 1398 |
| 7.0 | 14.4 | 510 | 8.0 | 16.4 | 732 | 9.0 | 18.5 | 840 | 11.0 | 22.6 | 1008 | 12.0 | 24.6 | 1170 | 13.0 | 26.7 | 1290 | 14.0 | 28.7 | 1398 |
| 8.0 | 16.4 | 516 | 8.0 | 16.4 | 732 | 9.0 | 18.5 | 840 | 11.0 | 22.6 | 1032 | 12.0 | 24.6 | 1170 | 13.0 | 26.7 | 1284 | 15.0 | 30.8 | 1398 |
| 8.0 | 16.4 | 540 | 8.0 | 16.4 | 726 | 9.0 | 18.5 | 840 | 11.0 | 22.6 | 1032 | 12.0 | 24.6 | 1170 | 13.0 | 26.7 | 1284 | 15.0 | 30.8 | 1434 |
| 8.0 | 16.4 | 600 | 8.0 | 16.4 | 732 | 9.0 | 18.5 | 840 | 11.0 | 22.6 | 1050 | 12.0 | 24.6 | 1170 | 13.0 | 26.7 | 1284 | 15.0 | 30.8 | 1470 |

Table A-17 - Raw data for wind turbine with four blades at 60 degrees in enclosure, continued

| B4-60-E1 | | | | | | |
|---|---|---|---|---|---|---|
| Hz | MPH | RPM | | Hz | MPH | RPM |
| 15.0 | 30.8 | 1488 | | 16.0 | 32.8 | 1698 |
| 15.0 | 30.8 | 1506 | | 17.0 | 34.9 | 1710 |
| 15.0 | 30.8 | 1506 | | 17.0 | 34.9 | 1734 |
| 15.0 | 30.8 | 1512 | | 17.0 | 34.9 | 1740 |
| 15.0 | 30.8 | 1524 | | 17.0 | 34.9 | 1746 |
| 15.0 | 30.8 | 1518 | | 17.0 | 34.9 | 1752 |
| 15.0 | 30.8 | 1518 | | 17.0 | 34.9 | 1752 |
| 15.0 | 30.8 | 1524 | | 17.0 | 34.9 | 1752 |
| 15.0 | 30.8 | 1524 | | 17.0 | 34.9 | 1752 |
| 15.0 | 30.8 | 1524 | | 17.0 | 34.9 | 1752 |
| 15.0 | 30.8 | 1524 | | 17.0 | 34.9 | 1758 |
| 15.0 | 30.8 | 1524 | | 17.0 | 34.9 | 1758 |
| 15.0 | 30.8 | 1524 | | 17.0 | 34.9 | 1752 |
| 15.0 | 30.8 | 1518 | | | | |
| 15.0 | 30.8 | 1524 | | | | |
| 16.0 | 32.8 | 1530 | | | | |
| 16.0 | 32.8 | 1554 | | | | |
| 16.0 | 32.8 | 1590 | | | | |
| 16.0 | 32.8 | 1608 | | | | |
| 16.0 | 32.8 | 1614 | | | | |
| 16.0 | 32.8 | 1626 | | | | |
| 16.0 | 32.8 | 1626 | | | | |
| 16.0 | 32.8 | 1632 | | | | |
| 16.0 | 32.8 | 1632 | | | | |
| 16.0 | 32.8 | 1632 | | | | |
| 16.0 | 32.8 | 1632 | | | | |
| 16.0 | 32.8 | 1638 | | | | |
| 16.0 | 32.8 | 1632 | | | | |
| 16.0 | 32.8 | 1638 | | | | |
| 16.0 | 32.8 | 1656 | | | | |

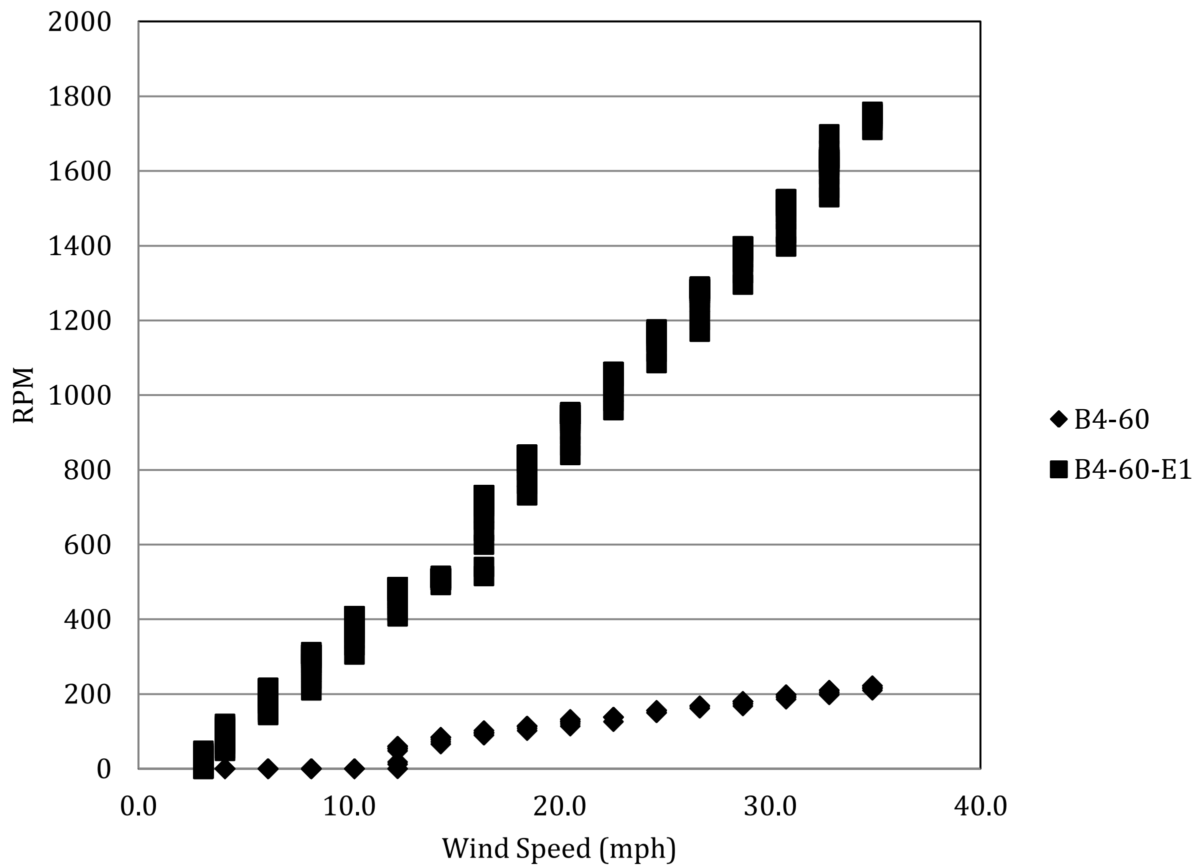



Figure A-7 - RPM of turbine with four blades at 60 degrees at various wind speeds

## A.8 Five Blades, 45 Degrees

The following data was collected on July 13, 2011 at 2:31PM in the Higgins Laboratories wind tunnel at Worcester Polytechnic Institute. The wind turbine was tested in the enclosure on July 13, 2011 at 9:19AM.

Table A-18 - Raw data for wind turbine with five blades at 45 degrees

| B5-45 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** |
| 5.0 | 10.3 | 0 | 8.0 | 16.4 | 366 | 12.0 | 24.6 | 624 | 17.0 | 34.9 | 918 |
| 5.0 | 10.3 | 0 | 8.0 | 16.4 | 372 | 12.0 | 24.6 | 630 | 17.0 | 34.9 | 924 |
| 5.0 | 10.3 | 0 | 8.0 | 16.4 | 378 | 13.0 | 26.7 | 636 | 17.0 | 34.9 | 924 |
| 5.0 | 10.3 | 0 | 9.0 | 18.5 | 390 | 13.0 | 26.7 | 666 | 17.0 | 34.9 | 924 |
| 5.0 | 10.3 | 0 | 9.0 | 18.5 | 408 | 13.0 | 26.7 | 684 | | | |
| 5.0 | 10.3 | 0 | 9.0 | 18.5 | 420 | 13.0 | 26.7 | 690 | | | |
| 5.0 | 10.3 | 0 | 9.0 | 18.5 | 426 | 13.0 | 26.7 | 690 | | | |
| 6.0 | 12.3 | 0 | 9.0 | 18.5 | 438 | 13.0 | 26.7 | 690 | | | |
| 6.0 | 12.3 | 0 | 9.0 | 18.5 | 444 | 13.0 | 26.7 | 690 | | | |
| 6.0 | 12.3 | 60 | 9.0 | 18.5 | 444 | 13.0 | 26.7 | 690 | | | |
| 6.0 | 12.3 | 144 | 9.0 | 18.5 | 444 | 14.0 | 28.7 | 720 | | | |
| 6.0 | 12.3 | 204 | 10.0 | 20.5 | 450 | 14.0 | 28.7 | 744 | | | |
| 6.0 | 12.3 | 228 | 10.0 | 20.5 | 468 | 14.0 | 28.7 | 750 | | | |
| 6.0 | 12.3 | 234 | 10.0 | 20.5 | 480 | 14.0 | 28.7 | 744 | | | |
| 6.0 | 12.3 | 240 | 10.0 | 20.5 | 480 | 14.0 | 28.7 | 750 | | | |
| 6.0 | 12.3 | 240 | 10.0 | 20.5 | 486 | 15.0 | 30.8 | 750 | | | |
| 6.0 | 12.3 | 240 | 10.0 | 20.5 | 486 | 15.0 | 30.8 | 792 | | | |
| 7.0 | 14.4 | 246 | 10.0 | 20.5 | 486 | 15.0 | 30.8 | 804 | | | |
| 7.0 | 14.4 | 264 | 11.0 | 22.6 | 492 | 15.0 | 30.8 | 810 | | | |
| 7.0 | 14.4 | 282 | 11.0 | 22.6 | 510 | 15.0 | 30.8 | 798 | | | |
| 7.0 | 14.4 | 288 | 11.0 | 22.6 | 510 | 15.0 | 30.8 | 810 | | | |
| 7.0 | 14.4 | 294 | 11.0 | 22.6 | 516 | 16.0 | 32.8 | 804 | | | |
| 7.0 | 14.4 | 300 | 11.0 | 22.6 | 516 | 16.0 | 32.8 | 852 | | | |
| 7.0 | 14.4 | 300 | 11.0 | 22.6 | 516 | 16.0 | 32.8 | 864 | | | |
| 7.0 | 14.4 | 300 | 12.0 | 24.6 | 516 | 16.0 | 32.8 | 864 | | | |
| 8.0 | 16.4 | 306 | 12.0 | 24.6 | 534 | 16.0 | 32.8 | 864 | | | |
| 8.0 | 16.4 | 324 | 12.0 | 24.6 | 582 | 16.0 | 32.8 | 864 | | | |
| 8.0 | 16.4 | 336 | 12.0 | 24.6 | 618 | 16.0 | 32.8 | 858 | | | |
| 8.0 | 16.4 | 348 | 12.0 | 24.6 | 624 | 17.0 | 34.9 | 870 | | | |
| 8.0 | 16.4 | 354 | 12.0 | 24.6 | 630 | 17.0 | 34.9 | 918 | | | |

Table A-19 - Raw data for wind turbine with five blades at 45 degrees in enclosure

| B5-45-E1 | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM |
| 5.0 | 10.3 | 0 | 2.0 | 4.1 | 222 | 2.0 | 4.1 | 114 | 2.0 | 4.1 | 60 | 4.0 | 8.2 | 198 | 5.0 | 10.3 | 396 | 7.0 | 14.4 | 408 | 8.0 | 16.4 | 450 |
| 5.0 | 10.3 | 0 | 2.0 | 4.1 | 216 | 2.0 | 4.1 | 114 | 2.0 | 4.1 | 66 | 4.0 | 8.2 | 210 | 6.0 | 12.3 | 396 | 7.0 | 14.4 | 426 | 8.0 | 16.4 | 450 |
| 5.0 | 10.3 | 36 | 2.0 | 4.1 | 210 | 2.0 | 4.1 | 114 | 2.0 | 4.1 | 66 | 4.0 | 8.2 | 228 | 6.0 | 12.3 | 402 | 7.0 | 14.4 | 438 | 8.0 | 16.4 | 450 |
| 5.0 | 10.3 | 120 | 2.0 | 4.1 | 204 | 1.0 | 2.1 | 108 | 2.0 | 4.1 | 72 | 4.0 | 8.2 | 240 | 6.0 | 12.3 | 402 | 7.0 | 14.4 | 432 | 8.0 | 16.4 | 450 |
| 5.0 | 10.3 | 192 | 2.0 | 4.1 | 192 | 1.0 | 2.1 | 102 | 2.0 | 4.1 | 78 | 4.0 | 8.2 | 252 | 6.0 | 12.3 | 396 | 7.0 | 14.4 | 432 | 8.0 | 16.4 | 450 |
| 5.0 | 10.3 | 246 | 2.0 | 4.1 | 186 | 1.0 | 2.1 | 102 | 2.0 | 4.1 | 78 | 4.0 | 8.2 | 258 | 6.0 | 12.3 | 396 | 7.0 | 14.4 | 432 | 8.0 | 16.4 | 456 |
| 5.0 | 10.3 | 282 | 2.0 | 4.1 | 180 | 1.0 | 2.1 | 96 | 2.0 | 4.1 | 84 | 4.0 | 8.2 | 270 | 6.0 | 12.3 | 390 | 7.0 | 14.4 | 432 | 9.0 | 18.5 | 468 |
| 5.0 | 10.3 | 312 | 2.0 | 4.1 | 174 | 1.0 | 2.1 | 90 | 2.0 | 4.1 | 84 | 4.0 | 8.2 | 270 | 6.0 | 12.3 | 396 | 7.0 | 14.4 | 426 | 9.0 | 18.5 | 480 |
| 4.0 | 8.2 | 324 | 2.0 | 4.1 | 168 | 1.0 | 2.1 | 90 | 2.0 | 4.1 | 84 | 4.0 | 8.2 | 276 | 6.0 | 12.3 | 396 | 7.0 | 14.4 | 432 | 9.0 | 18.5 | 474 |
| 4.0 | 8.2 | 330 | 2.0 | 4.1 | 162 | 1.0 | 2.1 | 84 | 2.0 | 4.1 | 90 | 4.0 | 8.2 | 282 | 6.0 | 12.3 | 390 | 7.0 | 14.4 | 432 | 9.0 | 18.5 | 480 |
| 4.0 | 8.2 | 318 | 2.0 | 4.1 | 162 | 1.0 | 2.1 | 78 | 2.0 | 4.1 | 90 | 4.0 | 8.2 | 282 | 6.0 | 12.3 | 396 | 7.0 | 14.4 | 432 | 9.0 | 18.5 | 474 |
| 4.0 | 8.2 | 318 | 2.0 | 4.1 | 150 | 1.0 | 2.1 | 78 | 2.0 | 4.1 | 96 | 4.0 | 8.2 | 288 | 6.0 | 12.3 | 396 | 7.0 | 14.4 | 426 | 9.0 | 18.5 | 474 |
| 4.0 | 8.2 | 312 | 2.0 | 4.1 | 150 | 1.5 | 3.1 | 0 | 2.0 | 4.1 | 90 | 4.0 | 8.2 | 294 | 6.0 | 12.3 | 396 | 7.0 | 14.4 | 432 | 9.0 | 18.5 | 480 |
| 4.0 | 8.2 | 312 | 2.0 | 4.1 | 150 | 1.5 | 3.1 | 0 | 2.0 | 4.1 | 96 | 4.0 | 8.2 | 288 | 6.0 | 12.3 | 390 | 7.0 | 14.4 | 426 | 9.0 | 18.5 | 474 |
| 4.0 | 8.2 | 312 | 2.0 | 4.1 | 144 | 1.5 | 3.1 | 0 | 2.0 | 4.1 | 96 | 4.0 | 8.2 | 294 | 6.0 | 12.3 | 396 | 7.0 | 14.4 | 426 | 9.0 | 18.5 | 480 |
| 4.0 | 8.2 | 306 | 2.0 | 4.1 | 138 | 1.5 | 3.1 | 6 | 3.0 | 6.2 | 102 | 5.0 | 10.3 | 300 | 6.0 | 12.3 | 396 | 8.0 | 16.4 | 432 | 9.0 | 18.5 | 474 |
| 3.0 | 6.2 | 306 | 2.0 | 4.1 | 132 | 1.5 | 3.1 | 12 | 3.0 | 6.2 | 108 | 5.0 | 10.3 | 306 | 6.0 | 12.3 | 396 | 8.0 | 16.4 | 450 | 9.0 | 18.5 | 480 |
| 3.0 | 6.2 | 294 | 2.0 | 4.1 | 138 | 1.5 | 3.1 | 12 | 3.0 | 6.2 | 126 | 5.0 | 10.3 | 330 | 6.0 | 12.3 | 396 | 8.0 | 16.4 | 456 | 9.0 | 18.5 | 474 |
| 3.0 | 6.2 | 294 | 2.0 | 4.1 | 126 | 1.5 | 3.1 | 18 | 3.0 | 6.2 | 138 | 5.0 | 10.3 | 348 | 6.0 | 12.3 | 396 | 8.0 | 16.4 | 450 | 9.0 | 18.5 | 480 |
| 3.0 | 6.2 | 276 | 2.0 | 4.1 | 132 | 1.5 | 3.1 | 24 | 3.0 | 6.2 | 150 | 5.0 | 10.3 | 354 | 6.0 | 12.3 | 396 | 8.0 | 16.4 | 450 | 9.0 | 18.5 | 474 |
| 3.0 | 6.2 | 270 | 2.0 | 4.1 | 126 | 1.5 | 3.1 | 24 | 3.0 | 6.2 | 156 | 5.0 | 10.3 | 366 | 6.0 | 12.3 | 396 | 8.0 | 16.4 | 450 | 9.0 | 18.5 | 480 |
| 3.0 | 6.2 | 264 | 2.0 | 4.1 | 120 | 1.5 | 3.1 | 24 | 3.0 | 6.2 | 168 | 5.0 | 10.3 | 372 | 6.0 | 12.3 | 396 | 8.0 | 16.4 | 450 | 9.0 | 18.5 | 474 |
| 3.0 | 6.2 | 258 | 2.0 | 4.1 | 126 | 1.5 | 3.1 | 30 | 3.0 | 6.2 | 168 | 5.0 | 10.3 | 378 | 6.0 | 12.3 | 396 | 8.0 | 16.4 | 450 | 9.0 | 18.5 | 474 |
| 3.0 | 6.2 | 252 | 2.0 | 4.1 | 120 | 1.5 | 3.1 | 36 | 3.0 | 6.2 | 174 | 5.0 | 10.3 | 378 | 6.0 | 12.3 | 396 | 8.0 | 16.4 | 450 | 9.0 | 18.5 | 480 |
| 3.0 | 6.2 | 246 | 2.0 | 4.1 | 120 | 1.5 | 3.1 | 36 | 3.0 | 6.2 | 180 | 5.0 | 10.3 | 384 | 6.0 | 12.3 | 396 | 8.0 | 16.4 | 450 | 9.0 | 18.5 | 474 |
| 3.0 | 6.2 | 240 | 2.0 | 4.1 | 114 | 1.5 | 3.1 | 36 | 3.0 | 6.2 | 180 | 5.0 | 10.3 | 390 | 6.0 | 12.3 | 396 | 8.0 | 16.4 | 450 | 9.0 | 18.5 | 474 |
| 3.0 | 6.2 | 234 | 2.0 | 4.1 | 120 | 1.5 | 3.1 | 42 | 3.0 | 6.2 | 186 | 5.0 | 10.3 | 390 | 6.0 | 12.3 | 396 | 8.0 | 16.4 | 450 | 9.0 | 18.5 | 480 |
| 3.0 | 6.2 | 234 | 2.0 | 4.1 | 114 | 1.5 | 3.1 | 36 | 3.0 | 6.2 | 192 | 5.0 | 10.3 | 390 | 6.0 | 12.3 | 396 | 8.0 | 16.4 | 450 | 9.0 | 18.5 | 480 |
| 3.0 | 6.2 | 234 | 2.0 | 4.1 | 114 | 2.0 | 4.1 | 48 | 3.0 | 6.2 | 186 | 5.0 | 10.3 | 390 | 6.0 | 12.3 | 396 | 8.0 | 16.4 | 450 | 10.0 | 20.5 | 504 |
| 3.0 | 6.2 | 222 | 2.0 | 4.1 | 114 | 2.0 | 4.1 | 48 | 3.0 | 6.2 | 192 | 5.0 | 10.3 | 390 | 7.0 | 14.4 | 396 | 8.0 | 16.4 | 450 | 10.0 | 20.5 | 504 |

Table A-20 - Raw data for wind turbine with five blades at 45 degrees in enclosure, continued

| B5-45-E1 | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM |
| 10.0 | 20.5 | 504 | 11.0 | 22.6 | 516 | 13.0 | 26.7 | 1254 | 14.0 | 28.7 | 1326 | 14.0 | 28.7 | 1326 | 14.0 | 28.7 | 1320 | 15.0 | 30.8 | 1392 | 17.0 | 34.9 | 1722 |
| 10.0 | 20.5 | 504 | 11.0 | 22.6 | 516 | 13.0 | 26.7 | 1248 | 14.0 | 28.7 | 1326 | 14.0 | 28.7 | 1326 | 14.0 | 28.7 | 1320 | 15.0 | 30.8 | 1398 | | | |
| 10.0 | 20.5 | 504 | 11.0 | 22.6 | 510 | 13.0 | 26.7 | 1248 | 14.0 | 28.7 | 1326 | 14.0 | 28.7 | 1326 | 14.0 | 28.7 | 1320 | 15.0 | 30.8 | 1392 | | | |
| 10.0 | 20.5 | 504 | 11.0 | 22.6 | 516 | 14.0 | 28.7 | 1254 | 14.0 | 28.7 | 1326 | 14.0 | 28.7 | 1332 | 14.0 | 28.7 | 1314 | 15.0 | 30.8 | 1398 | | | |
| 10.0 | 20.5 | 498 | 11.0 | 22.6 | 510 | 14.0 | 28.7 | 1284 | 14.0 | 28.7 | 1320 | 14.0 | 28.7 | 1326 | 14.0 | 28.7 | 1314 | 16.0 | 32.8 | 1434 | | | |
| 10.0 | 20.5 | 498 | 12.0 | 24.6 | 522 | 14.0 | 28.7 | 1308 | 14.0 | 28.7 | 1320 | 14.0 | 28.7 | 1332 | 14.0 | 28.7 | 1320 | 16.0 | 32.8 | 1452 | | | |
| 10.0 | 20.5 | 498 | 12.0 | 24.6 | 678 | 14.0 | 28.7 | 1314 | 14.0 | 28.7 | 1320 | 14.0 | 28.7 | 1320 | 14.0 | 28.7 | 1314 | 16.0 | 32.8 | 1470 | | | |
| 10.0 | 20.5 | 498 | 12.0 | 24.6 | 858 | 14.0 | 28.7 | 1314 | 14.0 | 28.7 | 1326 | 14.0 | 28.7 | 1326 | 14.0 | 28.7 | 1320 | 16.0 | 32.8 | 1494 | | | |
| 10.0 | 20.5 | 492 | 12.0 | 24.6 | 972 | 14.0 | 28.7 | 1320 | 14.0 | 28.7 | 1320 | 14.0 | 28.7 | 1320 | 15.0 | 30.8 | 1314 | 16.0 | 32.8 | 1542 | | | |
| 10.0 | 20.5 | 498 | 12.0 | 24.6 | 1032 | 14.0 | 28.7 | 1314 | 14.0 | 28.7 | 1326 | 14.0 | 28.7 | 1320 | 15.0 | 30.8 | 1338 | 16.0 | 32.8 | 1572 | | | |
| 10.0 | 20.5 | 492 | 12.0 | 24.6 | 1074 | 14.0 | 28.7 | 1320 | 14.0 | 28.7 | 1326 | 14.0 | 28.7 | 1326 | 15.0 | 30.8 | 1368 | 16.0 | 32.8 | 1584 | | | |
| 10.0 | 20.5 | 492 | 12.0 | 24.6 | 1104 | 14.0 | 28.7 | 1320 | 14.0 | 28.7 | 1326 | 14.0 | 28.7 | 1326 | 15.0 | 30.8 | 1374 | 16.0 | 32.8 | 1602 | | | |
| 10.0 | 20.5 | 498 | 12.0 | 24.6 | 1116 | 14.0 | 28.7 | 1314 | 14.0 | 28.7 | 1320 | 14.0 | 28.7 | 1320 | 15.0 | 30.8 | 1386 | 16.0 | 32.8 | 1602 | | | |
| 10.0 | 20.5 | 492 | 12.0 | 24.6 | 1128 | 14.0 | 28.7 | 1320 | 14.0 | 28.7 | 1326 | 14.0 | 28.7 | 1326 | 15.0 | 30.8 | 1392 | 16.0 | 32.8 | 1608 | | | |
| 10.0 | 20.5 | 492 | 12.0 | 24.6 | 1128 | 14.0 | 28.7 | 1320 | 14.0 | 28.7 | 1320 | 14.0 | 28.7 | 1320 | 15.0 | 30.8 | 1392 | 16.0 | 32.8 | 1608 | | | |
| 10.0 | 20.5 | 492 | 12.0 | 24.6 | 1140 | 14.0 | 28.7 | 1320 | 14.0 | 28.7 | 1320 | 14.0 | 28.7 | 1320 | 15.0 | 30.8 | 1392 | 16.0 | 32.8 | 1614 | | | |
| 10.0 | 20.5 | 492 | 12.0 | 24.6 | 1140 | 14.0 | 28.7 | 1320 | 14.0 | 28.7 | 1320 | 14.0 | 28.7 | 1326 | 15.0 | 30.8 | 1386 | 16.0 | 32.8 | 1614 | | | |
| 10.0 | 20.5 | 498 | 12.0 | 24.6 | 1140 | 14.0 | 28.7 | 1320 | 14.0 | 28.7 | 1320 | 14.0 | 28.7 | 1320 | 15.0 | 30.8 | 1392 | 16.0 | 32.8 | 1614 | | | |
| 10.0 | 20.5 | 492 | 12.0 | 24.6 | 1140 | 14.0 | 28.7 | 1320 | 14.0 | 28.7 | 1326 | 14.0 | 28.7 | 1314 | 15.0 | 30.8 | 1386 | 16.0 | 32.8 | 1620 | | | |
| 10.0 | 20.5 | 492 | 12.0 | 24.6 | 1146 | 14.0 | 28.7 | 1326 | 14.0 | 28.7 | 1326 | 14.0 | 28.7 | 1320 | 15.0 | 30.8 | 1392 | 16.0 | 32.8 | 1614 | | | |
| 10.0 | 20.5 | 492 | 13.0 | 26.7 | 1152 | 14.0 | 28.7 | 1320 | 14.0 | 28.7 | 1320 | 14.0 | 28.7 | 1320 | 15.0 | 30.8 | 1392 | 16.0 | 32.8 | 1620 | | | |
| 10.0 | 20.5 | 492 | 13.0 | 26.7 | 1188 | 14.0 | 28.7 | 1332 | 14.0 | 28.7 | 1320 | 14.0 | 28.7 | 1320 | 15.0 | 30.8 | 1392 | 16.0 | 32.8 | 1620 | | | |
| 11.0 | 22.6 | 504 | 13.0 | 26.7 | 1212 | 14.0 | 28.7 | 1320 | 14.0 | 28.7 | 1326 | 14.0 | 28.7 | 1320 | 15.0 | 30.8 | 1392 | 17.0 | 34.9 | 1662 | | | |
| 11.0 | 22.6 | 516 | 13.0 | 26.7 | 1230 | 14.0 | 28.7 | 1326 | 14.0 | 28.7 | 1320 | 14.0 | 28.7 | 1314 | 15.0 | 30.8 | 1392 | 17.0 | 34.9 | 1692 | | | |
| 11.0 | 22.6 | 522 | 13.0 | 26.7 | 1236 | 14.0 | 28.7 | 1320 | 14.0 | 28.7 | 1326 | 14.0 | 28.7 | 1320 | 15.0 | 30.8 | 1392 | 17.0 | 34.9 | 1704 | | | |
| 11.0 | 22.6 | 516 | 13.0 | 26.7 | 1242 | 14.0 | 28.7 | 1320 | 14.0 | 28.7 | 1320 | 14.0 | 28.7 | 1314 | 15.0 | 30.8 | 1386 | 17.0 | 34.9 | 1710 | | | |
| 11.0 | 22.6 | 522 | 13.0 | 26.7 | 1242 | 14.0 | 28.7 | 1326 | 14.0 | 28.7 | 1326 | 14.0 | 28.7 | 1320 | 15.0 | 30.8 | 1392 | 17.0 | 34.9 | 1722 | | | |
| 11.0 | 22.6 | 516 | 13.0 | 26.7 | 1248 | 14.0 | 28.7 | 1326 | 14.0 | 28.7 | 1326 | 14.0 | 28.7 | 1320 | 15.0 | 30.8 | 1392 | 17.0 | 34.9 | 1728 | | | |
| 11.0 | 22.6 | 516 | 13.0 | 26.7 | 1248 | 14.0 | 28.7 | 1326 | 14.0 | 28.7 | 1326 | 14.0 | 28.7 | 1326 | 15.0 | 30.8 | 1398 | 17.0 | 34.9 | 1728 | | | |
| 11.0 | 22.6 | 516 | 13.0 | 26.7 | 1248 | 14.0 | 28.7 | 1326 | 14.0 | 28.7 | 1326 | 14.0 | 28.7 | 1326 | 15.0 | 30.8 | 1392 | 17.0 | 34.9 | 1728 | | | |

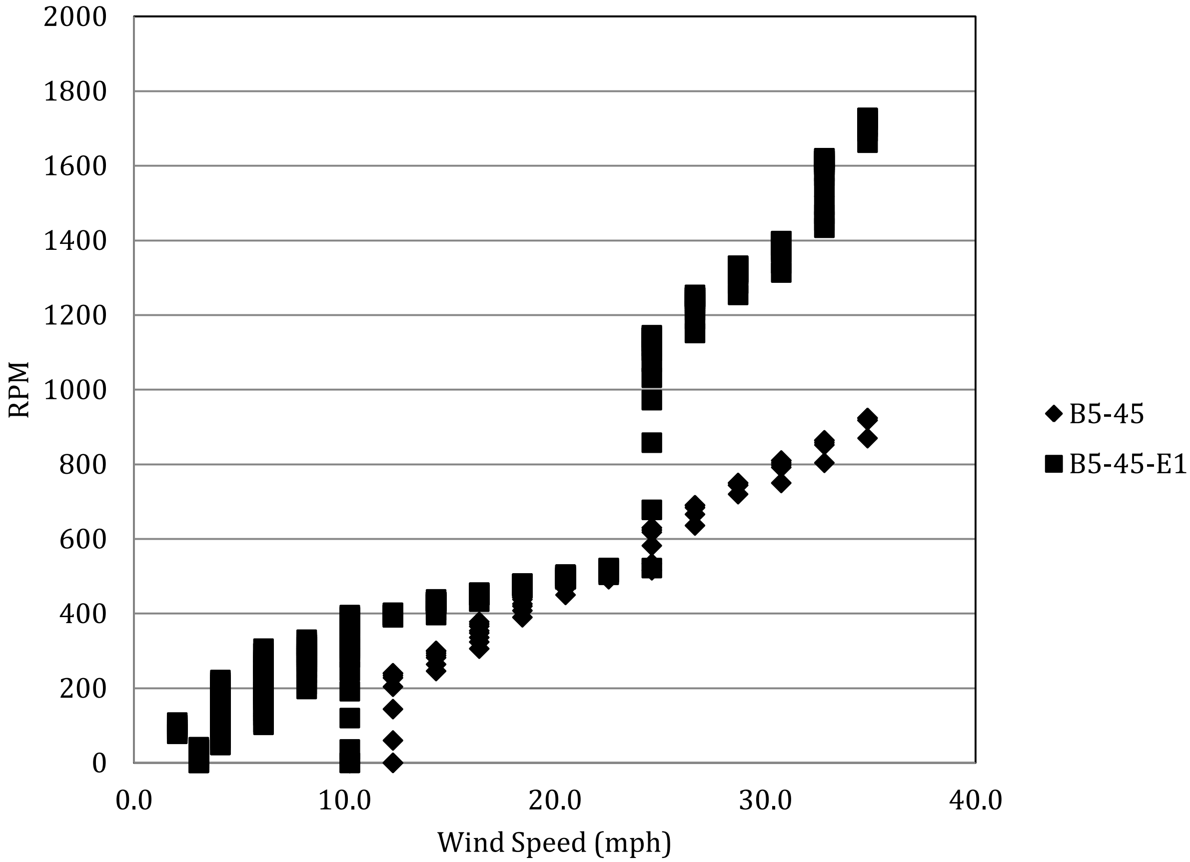



Figure A-8 - RPM of turbine with five blades at 45 degrees at various wind speeds

## A.9 Six Blades, 45 Degrees

The following data was collected on July 13, 2011 at 2:42PM in the Higgins Laboratories wind tunnel at Worcester Polytechnic Institute. The wind turbine was tested in the enclosure on July 13, 2011 at 10:35AM.

Table A-21 - Raw data for wind turbine with six blades at 45 degrees

| B6-45 | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM |
| 5.0 | 10.3 | 0 | 2.0 | 4.1 | 114 | 1.0 | 2.1 | 24 | 2.0 | 4.1 | 30 | 5.0 | 10.3 | 270 | 9.0 | 18.5 | 600 | 13.0 | 26.7 | 882 | 17.0 | 34.9 | 1176 |
| 5.0 | 10.3 | 0 | 2.0 | 4.1 | 108 | 1.0 | 2.1 | 24 | 2.0 | 4.1 | 24 | 5.0 | 10.3 | 288 | 9.0 | 18.5 | 600 | 14.0 | 28.7 | 936 | 17.0 | 34.9 | 1164 |
| 5.0 | 10.3 | 0 | 2.0 | 4.1 | 102 | 1.0 | 2.1 | 18 | 2.0 | 4.1 | 30 | 5.0 | 10.3 | 300 | 10.0 | 20.5 | 600 | 14.0 | 28.7 | 954 | 17.0 | 34.9 | 1176 |
| 5.0 | 10.3 | 0 | 2.0 | 4.1 | 96 | 1.0 | 2.1 | 24 | 2.0 | 4.1 | 30 | 5.0 | 10.3 | 306 | 10.0 | 20.5 | 648 | 14.0 | 28.7 | 954 | 17.0 | 34.9 | 1170 |
| 5.0 | 10.3 | 18 | 2.0 | 4.1 | 96 | 1.0 | 2.1 | 18 | 2.0 | 4.1 | 42 | 5.0 | 10.3 | 312 | 10.0 | 20.5 | 666 | 14.0 | 28.7 | 960 | 17.0 | 34.9 | 1170 |
| 5.0 | 10.3 | 96 | 2.0 | 4.1 | 96 | 1.0 | 2.1 | 18 | 2.0 | 4.1 | 42 | 5.0 | 10.3 | 306 | 10.0 | 20.5 | 666 | 14.0 | 28.7 | 954 | 17.0 | 34.9 | 1170 |
| 5.0 | 10.3 | 168 | 2.0 | 4.1 | 90 | 1.0 | 2.1 | 12 | 2.0 | 4.1 | 54 | 5.0 | 10.3 | 306 | 10.0 | 20.5 | 672 | 14.0 | 28.7 | 954 | 17.0 | 34.9 | 1170 |
| 4.0 | 8.2 | 210 | 2.0 | 4.1 | 90 | 1.0 | 2.1 | 18 | 2.0 | 4.1 | 54 | 6.0 | 12.3 | 312 | 10.0 | 20.5 | 666 | 15.0 | 30.8 | 1014 | | | |
| 4.0 | 8.2 | 222 | 2.0 | 4.1 | 90 | 1.0 | 2.1 | 12 | 3.0 | 6.2 | 54 | 6.0 | 12.3 | 354 | 10.0 | 20.5 | 666 | 15.0 | 30.8 | 1026 | | | |
| 4.0 | 8.2 | 234 | 2.0 | 4.1 | 90 | 1.0 | 2.1 | 12 | 3.0 | 6.2 | 72 | 6.0 | 12.3 | 366 | 11.0 | 22.6 | 702 | 15.0 | 30.8 | 1026 | | | |
| 4.0 | 8.2 | 228 | 2.0 | 4.1 | 90 | 1.0 | 2.1 | 6 | 3.0 | 6.2 | 90 | 6.0 | 12.3 | 378 | 11.0 | 22.6 | 738 | 15.0 | 30.8 | 1026 | | | |
| 4.0 | 8.2 | 234 | 2.0 | 4.1 | 90 | 1.0 | 2.1 | 12 | 3.0 | 6.2 | 102 | 6.0 | 12.3 | 378 | 11.0 | 22.6 | 738 | 15.0 | 30.8 | 1026 | | | |
| 4.0 | 8.2 | 234 | 2.0 | 4.1 | 90 | 1.0 | 2.1 | 6 | 3.0 | 6.2 | 114 | 6.0 | 12.3 | 378 | 11.0 | 22.6 | 738 | 15.0 | 30.8 | 1026 | | | |
| 4.0 | 8.2 | 234 | 1.0 | 2.1 | 84 | 1.0 | 2.1 | 6 | 3.0 | 6.2 | 132 | 6.0 | 12.3 | 378 | 11.0 | 22.6 | 738 | 15.0 | 30.8 | 1020 | | | |
| 4.0 | 8.2 | 234 | 1.0 | 2.1 | 90 | 1.0 | 2.1 | 6 | 3.0 | 6.2 | 138 | 7.0 | 14.4 | 390 | 11.0 | 22.6 | 738 | 15.0 | 30.8 | 1032 | | | |
| 4.0 | 8.2 | 234 | 1.0 | 2.1 | 84 | 1.0 | 2.1 | 0 | 3.0 | 6.2 | 144 | 7.0 | 14.4 | 432 | 11.0 | 22.6 | 738 | 15.0 | 30.8 | 1026 | | | |
| 4.0 | 8.2 | 234 | 1.0 | 2.1 | 72 | 1.0 | 2.1 | 6 | 3.0 | 6.2 | 156 | 7.0 | 14.4 | 438 | 12.0 | 24.6 | 756 | 15.0 | 30.8 | 1026 | | | |
| 3.0 | 6.2 | 234 | 1.0 | 2.1 | 72 | 1.0 | 2.1 | 0 | 3.0 | 6.2 | 150 | 7.0 | 14.4 | 450 | 12.0 | 24.6 | 804 | 16.0 | 32.8 | 1056 | | | |
| 3.0 | 6.2 | 204 | 1.0 | 2.1 | 60 | 1.0 | 2.1 | 0 | 3.0 | 6.2 | 162 | 7.0 | 14.4 | 444 | 12.0 | 24.6 | 810 | 16.0 | 32.8 | 1092 | | | |
| 3.0 | 6.2 | 192 | 1.0 | 2.1 | 60 | 2.0 | 4.1 | 48 | 3.0 | 6.2 | 162 | 7.0 | 14.4 | 450 | 12.0 | 24.6 | 810 | 16.0 | 32.8 | 1098 | | | |
| 3.0 | 6.2 | 180 | 1.0 | 2.1 | 54 | 2.0 | 4.1 | 48 | 4.0 | 8.2 | 192 | 8.0 | 16.4 | 474 | 12.0 | 24.6 | 816 | 16.0 | 32.8 | 1104 | | | |
| 3.0 | 6.2 | 174 | 1.0 | 2.1 | 48 | 2.0 | 4.1 | 48 | 4.0 | 8.2 | 210 | 8.0 | 16.4 | 498 | 12.0 | 24.6 | 810 | 16.0 | 32.8 | 1098 | | | |
| 3.0 | 6.2 | 168 | 1.0 | 2.1 | 48 | 2.0 | 4.1 | 42 | 4.0 | 8.2 | 222 | 8.0 | 16.4 | 498 | 12.0 | 24.6 | 810 | 16.0 | 32.8 | 1098 | | | |
| 3.0 | 6.2 | 168 | 1.0 | 2.1 | 42 | 2.0 | 4.1 | 48 | 4.0 | 8.2 | 228 | 8.0 | 16.4 | 504 | 13.0 | 26.7 | 834 | 16.0 | 32.8 | 1098 | | | |
| 3.0 | 6.2 | 162 | 1.0 | 2.1 | 42 | 2.0 | 4.1 | 42 | 4.0 | 8.2 | 234 | 8.0 | 16.4 | 498 | 13.0 | 26.7 | 876 | 16.0 | 32.8 | 1098 | | | |
| 3.0 | 6.2 | 162 | 1.0 | 2.1 | 36 | 2.0 | 4.1 | 42 | 4.0 | 8.2 | 234 | 8.0 | 16.4 | 504 | 13.0 | 26.7 | 882 | 16.0 | 32.8 | 1098 | | | |
| 2.0 | 4.1 | 156 | 1.0 | 2.1 | 36 | 2.0 | 4.1 | 36 | 4.0 | 8.2 | 234 | 9.0 | 18.5 | 546 | 13.0 | 26.7 | 882 | 17.0 | 34.9 | 1146 | | | |
| 2.0 | 4.1 | 138 | 1.0 | 2.1 | 30 | 2.0 | 4.1 | 36 | 4.0 | 8.2 | 234 | 9.0 | 18.5 | 588 | 13.0 | 26.7 | 888 | 17.0 | 34.9 | 1170 | | | |
| 2.0 | 4.1 | 126 | 1.0 | 2.1 | 30 | 2.0 | 4.1 | 30 | 4.0 | 8.2 | 234 | 9.0 | 18.5 | 594 | 13.0 | 26.7 | 882 | 17.0 | 34.9 | 1170 | | | |
| 2.0 | 4.1 | 120 | 1.0 | 2.1 | 30 | 2.0 | 4.1 | 30 | 4.0 | 8.2 | 234 | 9.0 | 18.5 | 600 | 13.0 | 26.7 | 888 | 17.0 | 34.9 | 1170 | | | |

Table A-22 - Raw data for wind turbine with six blades at 45 degrees in enclosure

| B6-45-E1 | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** |
| 1.5 | 3.1 | 36 | 3.0 | 6.2 | 180 | 5.0 | 10.3 | 378 | 6.0 | 12.3 | 456 | 9.0 | 18.5 | 480 | 11.0 | 22.6 | 492 | 13.0 | 26.7 | 1218 | 16.0 | 32.8 | 1434 |
| 1.5 | 3.1 | 30 | 3.0 | 6.2 | 186 | 5.0 | 10.3 | 384 | 7.0 | 14.4 | 462 | 10.0 | 20.5 | 498 | 11.0 | 22.6 | 498 | 13.0 | 26.7 | 1218 | 16.0 | 32.8 | 1434 |
| 1.5 | 3.1 | 42 | 3.0 | 6.2 | 186 | 5.0 | 10.3 | 384 | 7.0 | 14.4 | 474 | 10.0 | 20.5 | 486 | 12.0 | 24.6 | 504 | 13.0 | 26.7 | 1224 | 16.0 | 32.8 | 1428 |
| 1.5 | 3.1 | 36 | 3.0 | 6.2 | 192 | 5.0 | 10.3 | 384 | 7.0 | 14.4 | 474 | 10.0 | 20.5 | 486 | 12.0 | 24.6 | 558 | 13.0 | 26.7 | 1218 | 16.0 | 32.8 | 1434 |
| 1.5 | 3.1 | 42 | 3.0 | 6.2 | 186 | 5.0 | 10.3 | 390 | 7.0 | 14.4 | 468 | 10.0 | 20.5 | 480 | 12.0 | 24.6 | 762 | 13.0 | 26.7 | 1218 | 16.0 | 32.8 | 1434 |
| 1.5 | 3.1 | 42 | 3.0 | 6.2 | 192 | 5.0 | 10.3 | 384 | 7.0 | 14.4 | 468 | 10.0 | 20.5 | 480 | 12.0 | 24.6 | 906 | 14.0 | 28.7 | 1242 | 16.0 | 32.8 | 1434 |
| 2.0 | 4.1 | 42 | 4.0 | 8.2 | 198 | 5.0 | 10.3 | 384 | 7.0 | 14.4 | 462 | 10.0 | 20.5 | 486 | 12.0 | 24.6 | 990 | 14.0 | 28.7 | 1272 | 17.0 | 34.9 | 1464 |
| 2.0 | 4.1 | 54 | 4.0 | 8.2 | 210 | 5.0 | 10.3 | 390 | 7.0 | 14.4 | 462 | 10.0 | 20.5 | 480 | 12.0 | 24.6 | 1032 | 14.0 | 28.7 | 1296 | 17.0 | 34.9 | 1500 |
| 2.0 | 4.1 | 54 | 4.0 | 8.2 | 228 | 5.0 | 10.3 | 384 | 7.0 | 14.4 | 462 | 10.0 | 20.5 | 480 | 12.0 | 24.6 | 1068 | 14.0 | 28.7 | 1308 | 17.0 | 34.9 | 1554 |
| 2.0 | 4.1 | 66 | 4.0 | 8.2 | 240 | 5.0 | 10.3 | 390 | 7.0 | 14.4 | 456 | 11.0 | 22.6 | 510 | 12.0 | 24.6 | 1080 | 14.0 | 28.7 | 1314 | 17.0 | 34.9 | 1614 |
| 2.0 | 4.1 | 66 | 4.0 | 8.2 | 246 | 5.0 | 10.3 | 384 | 7.0 | 14.4 | 462 | 11.0 | 22.6 | 504 | 12.0 | 24.6 | 1092 | 14.0 | 28.7 | 1314 | 17.0 | 34.9 | 1644 |
| 2.0 | 4.1 | 66 | 4.0 | 8.2 | 258 | 5.0 | 10.3 | 390 | 7.0 | 14.4 | 456 | 11.0 | 22.6 | 504 | 12.0 | 24.6 | 1104 | 14.0 | 28.7 | 1320 | 17.0 | 34.9 | 1662 |
| 2.0 | 4.1 | 78 | 4.0 | 8.2 | 264 | 5.0 | 10.3 | 384 | 7.0 | 14.4 | 456 | 11.0 | 22.6 | 504 | 12.0 | 24.6 | 1104 | 14.0 | 28.7 | 1320 | 17.0 | 34.9 | 1668 |
| 2.0 | 4.1 | 72 | 4.0 | 8.2 | 270 | 5.0 | 10.3 | 390 | 8.0 | 16.4 | 462 | 11.0 | 22.6 | 504 | 12.0 | 24.6 | 1110 | 14.0 | 28.7 | 1320 | 17.0 | 34.9 | 1680 |
| 2.0 | 4.1 | 84 | 4.0 | 8.2 | 270 | 5.0 | 10.3 | 390 | 8.0 | 16.4 | 474 | 11.0 | 22.6 | 498 | 12.0 | 24.6 | 1110 | 14.0 | 28.7 | 1320 | 17.0 | 34.9 | 1686 |
| 2.0 | 4.1 | 78 | 4.0 | 8.2 | 282 | 5.0 | 10.3 | 384 | 8.0 | 16.4 | 474 | 11.0 | 22.6 | 498 | 12.0 | 24.6 | 1110 | 15.0 | 30.8 | 1326 | 17.0 | 34.9 | 1692 |
| 2.0 | 4.1 | 84 | 4.0 | 8.2 | 276 | 5.0 | 10.3 | 390 | 8.0 | 16.4 | 474 | 11.0 | 22.6 | 504 | 12.0 | 24.6 | 1116 | 15.0 | 30.8 | 1350 | 17.0 | 34.9 | 1686 |
| 2.0 | 4.1 | 84 | 4.0 | 8.2 | 282 | 5.0 | 10.3 | 390 | 8.0 | 16.4 | 474 | 11.0 | 22.6 | 498 | 12.0 | 24.6 | 1116 | 15.0 | 30.8 | 1368 | 17.0 | 34.9 | 1692 |
| 2.0 | 4.1 | 90 | 4.0 | 8.2 | 288 | 5.0 | 10.3 | 384 | 8.0 | 16.4 | 468 | 11.0 | 22.6 | 498 | 12.0 | 24.6 | 1116 | 15.0 | 30.8 | 1374 | 17.0 | 34.9 | 1686 |
| 3.0 | 6.2 | 102 | 5.0 | 10.3 | 294 | 5.0 | 10.3 | 390 | 8.0 | 16.4 | 474 | 11.0 | 22.6 | 498 | 13.0 | 26.7 | 1128 | 15.0 | 30.8 | 1368 | 17.0 | 34.9 | 1692 |
| 3.0 | 6.2 | 114 | 5.0 | 10.3 | 318 | 6.0 | 12.3 | 396 | 8.0 | 16.4 | 474 | 11.0 | 22.6 | 498 | 13.0 | 26.7 | 1164 | 15.0 | 30.8 | 1374 | 17.0 | 34.9 | 1692 |
| 3.0 | 6.2 | 126 | 5.0 | 10.3 | 330 | 6.0 | 12.3 | 414 | 8.0 | 16.4 | 468 | 11.0 | 22.6 | 498 | 13.0 | 26.7 | 1188 | 15.0 | 30.8 | 1368 | | | |
| 3.0 | 6.2 | 132 | 5.0 | 10.3 | 348 | 6.0 | 12.3 | 432 | 9.0 | 18.5 | 486 | 11.0 | 22.6 | 498 | 13.0 | 26.7 | 1194 | 15.0 | 30.8 | 1368 | | | |
| 3.0 | 6.2 | 150 | 5.0 | 10.3 | 354 | 6.0 | 12.3 | 444 | 9.0 | 18.5 | 480 | 11.0 | 22.6 | 498 | 13.0 | 26.7 | 1206 | 15.0 | 30.8 | 1368 | | | |
| 3.0 | 6.2 | 156 | 5.0 | 10.3 | 360 | 6.0 | 12.3 | 456 | 9.0 | 18.5 | 486 | 11.0 | 22.6 | 498 | 13.0 | 26.7 | 1212 | 15.0 | 30.8 | 1368 | | | |
| 3.0 | 6.2 | 156 | 5.0 | 10.3 | 372 | 6.0 | 12.3 | 456 | 9.0 | 18.5 | 480 | 11.0 | 22.6 | 498 | 13.0 | 26.7 | 1212 | 15.0 | 30.8 | 1368 | | | |
| 3.0 | 6.2 | 168 | 5.0 | 10.3 | 372 | 6.0 | 12.3 | 456 | 9.0 | 18.5 | 486 | 11.0 | 22.6 | 498 | 13.0 | 26.7 | 1218 | 15.0 | 30.8 | 1368 | | | |
| 3.0 | 6.2 | 174 | 5.0 | 10.3 | 372 | 6.0 | 12.3 | 456 | 9.0 | 18.5 | 480 | 11.0 | 22.6 | 492 | 13.0 | 26.7 | 1218 | 16.0 | 32.8 | 1386 | | | |
| 3.0 | 6.2 | 174 | 5.0 | 10.3 | 378 | 6.0 | 12.3 | 456 | 9.0 | 18.5 | 486 | 11.0 | 22.6 | 498 | 13.0 | 26.7 | 1218 | 16.0 | 32.8 | 1416 | | | |
| 3.0 | 6.2 | 180 | 5.0 | 10.3 | 384 | 6.0 | 12.3 | 456 | 9.0 | 18.5 | 480 | 11.0 | 22.6 | 498 | 13.0 | 26.7 | 1224 | 16.0 | 32.8 | 1428 | | | |

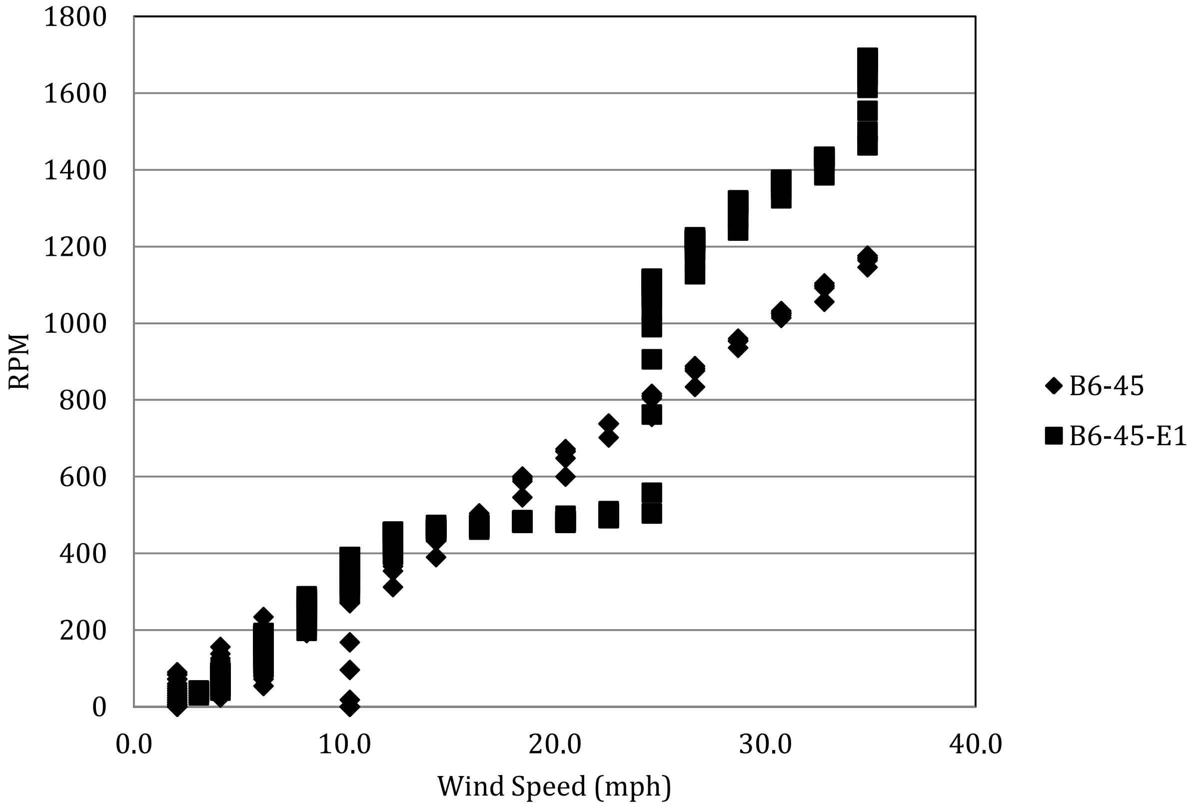



Figure A-9 - RPM of turbine with six blades at 45 degrees at various wind speeds

## A.10 Seven Blades, 45 Degrees

The following data was collected on July 13, 2011 at 3:06PM in the Higgins Laboratories wind tunnel at Worcester Polytechnic Institute. The wind turbine was tested in the enclosure on July 13, 2011 at 11:02AM.

Table A-23 - Raw data for wind turbine with seven blades at 45 degrees

| B7-45 | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM |
| 3.0 | 6.2 | 0 | 4.0 | 8.2 | 240 | 7.0 | 14.4 | 462 | 9.0 | 18.5 | 618 | 12.0 | 24.6 | 858 | 14.0 | 28.7 | 1008 | 17.0 | 34.9 | 1236 |
| 3.0 | 6.2 | 0 | 5.0 | 10.3 | 252 | 7.0 | 14.4 | 462 | 10.0 | 20.5 | 684 | 12.0 | 24.6 | 852 | 14.0 | 28.7 | 1002 | 17.0 | 34.9 | 1230 |
| 3.0 | 6.2 | 0 | 5.0 | 10.3 | 270 | 7.0 | 14.4 | 456 | 10.0 | 20.5 | 696 | 12.0 | 24.6 | 852 | 14.0 | 28.7 | 1008 | 17.0 | 34.9 | 1236 |
| 3.0 | 6.2 | 6 | 5.0 | 10.3 | 300 | 7.0 | 14.4 | 462 | 10.0 | 20.5 | 702 | 12.0 | 24.6 | 858 | 15.0 | 30.8 | 1062 | 17.0 | 34.9 | 1236 |
| 3.0 | 6.2 | 18 | 5.0 | 10.3 | 312 | 8.0 | 16.4 | 486 | 10.0 | 20.5 | 702 | 12.0 | 24.6 | 852 | 15.0 | 30.8 | 1080 | 17.0 | 34.9 | 1230 |
| 3.0 | 6.2 | 36 | 5.0 | 10.3 | 318 | 8.0 | 16.4 | 534 | 10.0 | 20.5 | 696 | 12.0 | 24.6 | 852 | 15.0 | 30.8 | 1080 | | | |
| 3.0 | 6.2 | 66 | 5.0 | 10.3 | 318 | 8.0 | 16.4 | 546 | 10.0 | 20.5 | 702 | 12.0 | 24.6 | 852 | 15.0 | 30.8 | 1080 | | | |
| 3.0 | 6.2 | 84 | 5.0 | 10.3 | 318 | 8.0 | 16.4 | 552 | 10.0 | 20.5 | 702 | 12.0 | 24.6 | 852 | 15.0 | 30.8 | 1080 | | | |
| 3.0 | 6.2 | 108 | 5.0 | 10.3 | 324 | 8.0 | 16.4 | 546 | 10.0 | 20.5 | 696 | 12.0 | 24.6 | 858 | 15.0 | 30.8 | 1080 | | | |
| 3.0 | 6.2 | 132 | 5.0 | 10.3 | 318 | 8.0 | 16.4 | 552 | 10.0 | 20.5 | 702 | 12.0 | 24.6 | 852 | 15.0 | 30.8 | 1080 | | | |
| 3.0 | 6.2 | 138 | 5.0 | 10.3 | 324 | 8.0 | 16.4 | 552 | 10.0 | 20.5 | 702 | 13.0 | 26.7 | 894 | 15.0 | 30.8 | 1080 | | | |
| 3.0 | 6.2 | 156 | 6.0 | 12.3 | 318 | 8.0 | 16.4 | 552 | 10.0 | 20.5 | 702 | 13.0 | 26.7 | 924 | 15.0 | 30.8 | 1080 | | | |
| 3.0 | 6.2 | 156 | 6.0 | 12.3 | 342 | 8.0 | 16.4 | 552 | 10.0 | 20.5 | 696 | 13.0 | 26.7 | 924 | 15.0 | 30.8 | 1080 | | | |
| 3.0 | 6.2 | 156 | 6.0 | 12.3 | 372 | 8.0 | 16.4 | 552 | 10.0 | 20.5 | 702 | 13.0 | 26.7 | 930 | 16.0 | 32.8 | 1134 | | | |
| 3.0 | 6.2 | 168 | 6.0 | 12.3 | 384 | 8.0 | 16.4 | 546 | 11.0 | 22.6 | 714 | 13.0 | 26.7 | 930 | 16.0 | 32.8 | 1152 | | | |
| 3.0 | 6.2 | 162 | 6.0 | 12.3 | 396 | 8.0 | 16.4 | 552 | 11.0 | 22.6 | 762 | 13.0 | 26.7 | 930 | 16.0 | 32.8 | 1158 | | | |
| 3.0 | 6.2 | 168 | 6.0 | 12.3 | 390 | 9.0 | 18.5 | 582 | 11.0 | 22.6 | 780 | 13.0 | 26.7 | 930 | 16.0 | 32.8 | 1152 | | | |
| 3.0 | 6.2 | 168 | 6.0 | 12.3 | 396 | 9.0 | 18.5 | 618 | 11.0 | 22.6 | 774 | 13.0 | 26.7 | 930 | 16.0 | 32.8 | 1158 | | | |
| 3.0 | 6.2 | 162 | 6.0 | 12.3 | 396 | 9.0 | 18.5 | 624 | 11.0 | 22.6 | 780 | 13.0 | 26.7 | 936 | 16.0 | 32.8 | 1158 | | | |
| 4.0 | 8.2 | 168 | 6.0 | 12.3 | 396 | 9.0 | 18.5 | 630 | 11.0 | 22.6 | 774 | 13.0 | 26.7 | 930 | 16.0 | 32.8 | 1158 | | | |
| 4.0 | 8.2 | 186 | 6.0 | 12.3 | 396 | 9.0 | 18.5 | 630 | 11.0 | 22.6 | 774 | 13.0 | 26.7 | 930 | 16.0 | 32.8 | 1158 | | | |
| 4.0 | 8.2 | 204 | 6.0 | 12.3 | 396 | 9.0 | 18.5 | 630 | 11.0 | 22.6 | 780 | 13.0 | 26.7 | 924 | 16.0 | 32.8 | 1158 | | | |
| 4.0 | 8.2 | 222 | 6.0 | 12.3 | 390 | 9.0 | 18.5 | 630 | 11.0 | 22.6 | 774 | 13.0 | 26.7 | 930 | 16.0 | 32.8 | 1152 | | | |
| 4.0 | 8.2 | 234 | 7.0 | 14.4 | 414 | 9.0 | 18.5 | 630 | 11.0 | 22.6 | 780 | 13.0 | 26.7 | 930 | 16.0 | 32.8 | 1158 | | | |
| 4.0 | 8.2 | 234 | 7.0 | 14.4 | 450 | 9.0 | 18.5 | 624 | 11.0 | 22.6 | 774 | 14.0 | 28.7 | 966 | 16.0 | 32.8 | 1152 | | | |
| 4.0 | 8.2 | 246 | 7.0 | 14.4 | 456 | 9.0 | 18.5 | 630 | 11.0 | 22.6 | 780 | 14.0 | 28.7 | 1002 | 16.0 | 32.8 | 1176 | | | |
| 4.0 | 8.2 | 240 | 7.0 | 14.4 | 462 | 9.0 | 18.5 | 630 | 12.0 | 24.6 | 816 | 14.0 | 28.7 | 1002 | 16.0 | 32.8 | 1224 | | | |
| 4.0 | 8.2 | 246 | 7.0 | 14.4 | 462 | 9.0 | 18.5 | 630 | 12.0 | 24.6 | 852 | 14.0 | 28.7 | 1008 | 16.0 | 32.8 | 1230 | | | |
| 4.0 | 8.2 | 246 | 7.0 | 14.4 | 456 | 9.0 | 18.5 | 624 | 12.0 | 24.6 | 852 | 14.0 | 28.7 | 1008 | 17.0 | 34.9 | 1230 | | | |
| 4.0 | 8.2 | 246 | 7.0 | 14.4 | 462 | 9.0 | 18.5 | 630 | 12.0 | 24.6 | 852 | 14.0 | 28.7 | 1002 | 17.0 | 34.9 | 1236 | | | |

Table A-24 - Raw data for wind turbine with seven blades at 45 degrees in enclosure

| B7-45-E1 | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** |
| 1.5 | 3.1 | 0 | 3.0 | 6.2 | 96 | 5.0 | 10.3 | 300 | 7.0 | 14.4 | 462 | 9.0 | 18.5 | 492 | 13.0 | 26.7 | 1224 | 15.0 | 30.8 | 1452 |
| 1.5 | 3.1 | 0 | 3.0 | 6.2 | 114 | 5.0 | 10.3 | 324 | 7.0 | 14.4 | 468 | 9.0 | 18.5 | 498 | 13.0 | 26.7 | 1230 | 15.0 | 30.8 | 1446 |
| 1.5 | 3.1 | 0 | 3.0 | 6.2 | 126 | 5.0 | 10.3 | 336 | 7.0 | 14.4 | 462 | 9.0 | 18.5 | 498 | 13.0 | 26.7 | 1224 | 15.0 | 30.8 | 1452 |
| 1.5 | 3.1 | 6 | 3.0 | 6.2 | 132 | 5.0 | 10.3 | 348 | 7.0 | 14.4 | 468 | 9.0 | 18.5 | 504 | 13.0 | 26.7 | 1236 | 15.0 | 30.8 | 1452 |
| 1.5 | 3.1 | 12 | 3.0 | 6.2 | 144 | 5.0 | 10.3 | 360 | 7.0 | 14.4 | 462 | 9.0 | 18.5 | 504 | 13.0 | 26.7 | 1230 | 15.0 | 30.8 | 1446 |
| 1.5 | 3.1 | 12 | 3.0 | 6.2 | 150 | 5.0 | 10.3 | 360 | 7.0 | 14.4 | 468 | 9.0 | 18.5 | 504 | 13.0 | 26.7 | 1236 | 16.0 | 32.8 | 1458 |
| 1.5 | 3.1 | 18 | 3.0 | 6.2 | 156 | 5.0 | 10.3 | 372 | 7.0 | 14.4 | 462 | 9.0 | 18.5 | 504 | 13.0 | 26.7 | 1236 | 16.0 | 32.8 | 1488 |
| 1.5 | 3.1 | 18 | 3.0 | 6.2 | 162 | 5.0 | 10.3 | 372 | 7.0 | 14.4 | 468 | 9.0 | 18.5 | 504 | 13.0 | 26.7 | 1236 | 16.0 | 32.8 | 1524 |
| 1.5 | 3.1 | 18 | 3.0 | 6.2 | 168 | 5.0 | 10.3 | 378 | 7.0 | 14.4 | 462 | 9.0 | 18.5 | 504 | 13.0 | 26.7 | 1230 | 16.0 | 32.8 | 1536 |
| 1.5 | 3.1 | 30 | 3.0 | 6.2 | 174 | 5.0 | 10.3 | 378 | 7.0 | 14.4 | 468 | 9.0 | 18.5 | 504 | 13.0 | 26.7 | 1236 | 16.0 | 32.8 | 1548 |
| 1.5 | 3.1 | 24 | 3.0 | 6.2 | 174 | 5.0 | 10.3 | 378 | 7.0 | 14.4 | 462 | 9.0 | 18.5 | 504 | 14.0 | 28.7 | 1242 | 16.0 | 32.8 | 1560 |
| 1.5 | 3.1 | 30 | 3.0 | 6.2 | 180 | 5.0 | 10.3 | 384 | 7.0 | 14.4 | 462 | 9.0 | 18.5 | 498 | 14.0 | 28.7 | 1278 | 16.0 | 32.8 | 1572 |
| 1.5 | 3.1 | 30 | 3.0 | 6.2 | 180 | 5.0 | 10.3 | 384 | 7.0 | 14.4 | 468 | 9.0 | 18.5 | 504 | 14.0 | 28.7 | 1302 | 16.0 | 32.8 | 1566 |
| 1.5 | 3.1 | 36 | 3.0 | 6.2 | 186 | 6.0 | 12.3 | 384 | 7.0 | 14.4 | 462 | 9.0 | 18.5 | 498 | 14.0 | 28.7 | 1314 | 17.0 | 34.9 | 1572 |
| 1.5 | 3.1 | 36 | 3.0 | 6.2 | 186 | 6.0 | 12.3 | 408 | 7.0 | 14.4 | 468 | 9.0 | 18.5 | 516 | 14.0 | 28.7 | 1326 | 17.0 | 34.9 | 1596 |
| 1.5 | 3.1 | 36 | 4.0 | 8.2 | 192 | 6.0 | 12.3 | 420 | 8.0 | 16.4 | 462 | 10.0 | 20.5 | 522 | 14.0 | 28.7 | 1332 | 17.0 | 34.9 | 1626 |
| 1.5 | 3.1 | 36 | 4.0 | 8.2 | 186 | 6.0 | 12.3 | 438 | 8.0 | 16.4 | 474 | 10.0 | 20.5 | 522 | 14.0 | 28.7 | 1338 | 17.0 | 34.9 | 1650 |
| 2.0 | 4.1 | 48 | 4.0 | 8.2 | 192 | 6.0 | 12.3 | 444 | 8.0 | 16.4 | 480 | 10.0 | 20.5 | 522 | 14.0 | 28.7 | 1338 | 17.0 | 34.9 | 1656 |
| 2.0 | 4.1 | 48 | 4.0 | 8.2 | 210 | 6.0 | 12.3 | 450 | 8.0 | 16.4 | 474 | 10.0 | 20.5 | 522 | 14.0 | 28.7 | 1344 | 17.0 | 34.9 | 1668 |
| 2.0 | 4.1 | 60 | 4.0 | 8.2 | 222 | 6.0 | 12.3 | 450 | 8.0 | 16.4 | 480 | 10.0 | 20.5 | 516 | 14.0 | 28.7 | 1338 | 17.0 | 34.9 | 1674 |
| 2.0 | 4.1 | 60 | 4.0 | 8.2 | 234 | 6.0 | 12.3 | 456 | 8.0 | 16.4 | 480 | 10.0 | 20.5 | 522 | 14.0 | 28.7 | 1344 | 17.0 | 34.9 | 1674 |
| 2.0 | 4.1 | 66 | 4.0 | 8.2 | 246 | 6.0 | 12.3 | 450 | 8.0 | 16.4 | 480 | 10.0 | 20.5 | 546 | 14.0 | 28.7 | 1344 | 17.0 | 34.9 | 1674 |
| 2.0 | 4.1 | 72 | 4.0 | 8.2 | 252 | 6.0 | 12.3 | 456 | 8.0 | 16.4 | 474 | 10.0 | 20.5 | 756 | 14.0 | 28.7 | 1344 | 17.0 | 34.9 | 1680 |
| 2.0 | 4.1 | 72 | 4.0 | 8.2 | 264 | 6.0 | 12.3 | 456 | 8.0 | 16.4 | 480 | 10.0 | 20.5 | 954 | 14.0 | 28.7 | 1350 | 17.0 | 34.9 | 1680 |
| 2.0 | 4.1 | 72 | 4.0 | 8.2 | 264 | 7.0 | 14.4 | 462 | 8.0 | 16.4 | 480 | 10.0 | 20.5 | 1068 | 15.0 | 30.8 | 1374 | 17.0 | 34.9 | 1680 |
| 2.0 | 4.1 | 78 | 4.0 | 8.2 | 276 | 7.0 | 14.4 | 468 | 8.0 | 16.4 | 474 | 10.0 | 20.5 | 1134 | 15.0 | 30.8 | 1404 | 17.0 | 34.9 | 1680 |
| 2.0 | 4.1 | 84 | 4.0 | 8.2 | 276 | 7.0 | 14.4 | 468 | 8.0 | 16.4 | 480 | 13.0 | 26.7 | 1170 | 15.0 | 30.8 | 1422 | | | |
| 2.0 | 4.1 | 78 | 4.0 | 8.2 | 276 | 7.0 | 14.4 | 468 | 8.0 | 16.4 | 474 | 13.0 | 26.7 | 1194 | 15.0 | 30.8 | 1434 | | | |
| 2.0 | 4.1 | 84 | 4.0 | 8.2 | 282 | 7.0 | 14.4 | 462 | 8.0 | 16.4 | 480 | 13.0 | 26.7 | 1212 | 15.0 | 30.8 | 1440 | | | |
| 3.0 | 6.2 | 90 | 5.0 | 10.3 | 288 | 7.0 | 14.4 | 468 | 9.0 | 18.5 | 486 | 13.0 | 26.7 | 1212 | 15.0 | 30.8 | 1440 | | | |

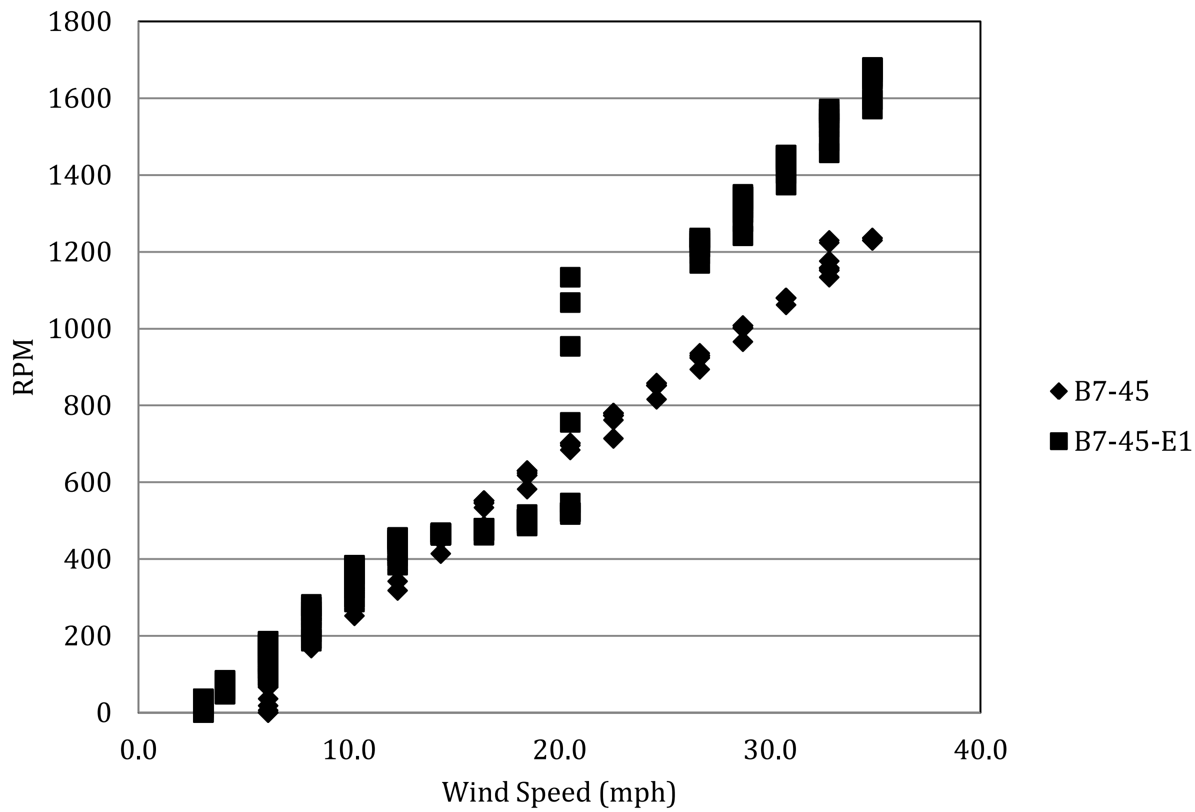



Figure A-10 - RPM of turbine with seven blades at 45 degrees at various wind speeds

## A.11 Eight Blades, 45 Degrees

The following data was collected on July 13, 2011 at 3:29PM in the Higgins Laboratories wind tunnel at Worcester Polytechnic Institute. The wind turbine was tested in the enclosure on July 13, 2011 at 11:25PM.

Table A-25 - Raw data for wind turbine with eight blades at 45 degrees

| B8-45 | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** | **Hz** | **MPH** | **RPM** |
| 3.0 | 6.2 | 0 | 4.0 | 8.2 | 252 | 7.0 | 14.4 | 462 | 10.0 | 20.5 | 714 | 12.0 | 24.6 | 864 | 16.0 | 32.8 | 1164 |
| 3.0 | 6.2 | 0 | 4.0 | 8.2 | 252 | 7.0 | 14.4 | 462 | 10.0 | 20.5 | 714 | 12.0 | 24.6 | 864 | 16.0 | 32.8 | 1170 |
| 3.0 | 6.2 | 0 | 4.0 | 8.2 | 246 | 7.0 | 14.4 | 468 | 10.0 | 20.5 | 714 | 12.0 | 24.6 | 858 | 16.0 | 32.8 | 1170 |
| 3.0 | 6.2 | 0 | 4.0 | 8.2 | 252 | 7.0 | 14.4 | 462 | 10.0 | 20.5 | 720 | 12.0 | 24.6 | 870 | 16.0 | 32.8 | 1176 |
| 3.0 | 6.2 | 6 | 5.0 | 10.3 | 258 | 7.0 | 14.4 | 462 | 10.0 | 20.5 | 714 | 13.0 | 26.7 | 918 | 16.0 | 32.8 | 1170 |
| 3.0 | 6.2 | 30 | 5.0 | 10.3 | 276 | 7.0 | 14.4 | 468 | 10.0 | 20.5 | 714 | 13.0 | 26.7 | 942 | 16.0 | 32.8 | 1170 |
| 3.0 | 6.2 | 48 | 5.0 | 10.3 | 306 | 7.0 | 14.4 | 462 | 10.0 | 20.5 | 720 | 13.0 | 26.7 | 936 | 16.0 | 32.8 | 1170 |
| 3.0 | 6.2 | 72 | 5.0 | 10.3 | 312 | 8.0 | 16.4 | 486 | 10.0 | 20.5 | 714 | 13.0 | 26.7 | 942 | 16.0 | 32.8 | 1176 |
| 3.0 | 6.2 | 102 | 5.0 | 10.3 | 324 | 8.0 | 16.4 | 534 | 11.0 | 22.6 | 750 | 13.0 | 26.7 | 936 | 17.0 | 34.9 | 1206 |
| 3.0 | 6.2 | 114 | 5.0 | 10.3 | 330 | 8.0 | 16.4 | 552 | 11.0 | 22.6 | 792 | 13.0 | 26.7 | 942 | 17.0 | 34.9 | 1242 |
| 3.0 | 6.2 | 138 | 5.0 | 10.3 | 324 | 8.0 | 16.4 | 558 | 11.0 | 22.6 | 792 | 13.0 | 26.7 | 942 | 17.0 | 34.9 | 1248 |
| 3.0 | 6.2 | 144 | 5.0 | 10.3 | 330 | 8.0 | 16.4 | 558 | 11.0 | 22.6 | 792 | 13.0 | 26.7 | 942 | 17.0 | 34.9 | 1248 |
| 3.0 | 6.2 | 156 | 5.0 | 10.3 | 324 | 8.0 | 16.4 | 564 | 11.0 | 22.6 | 792 | 14.0 | 28.7 | 1002 | 17.0 | 34.9 | 1248 |
| 3.0 | 6.2 | 162 | 5.0 | 10.3 | 330 | 8.0 | 16.4 | 558 | 11.0 | 22.6 | 792 | 14.0 | 28.7 | 1008 | 17.0 | 34.9 | 1248 |
| 3.0 | 6.2 | 162 | 5.0 | 10.3 | 324 | 8.0 | 16.4 | 564 | 11.0 | 22.6 | 786 | 14.0 | 28.7 | 1020 | 17.0 | 34.9 | 1254 |
| 3.0 | 6.2 | 168 | 5.0 | 10.3 | 330 | 8.0 | 16.4 | 558 | 11.0 | 22.6 | 786 | 14.0 | 28.7 | 1020 | | | |
| 3.0 | 6.2 | 168 | 6.0 | 12.3 | 336 | 8.0 | 16.4 | 558 | 11.0 | 22.6 | 786 | 14.0 | 28.7 | 1014 | | | |
| 3.0 | 6.2 | 174 | 6.0 | 12.3 | 372 | 8.0 | 16.4 | 582 | 11.0 | 22.6 | 786 | 14.0 | 28.7 | 1020 | | | |
| 3.0 | 6.2 | 168 | 6.0 | 12.3 | 390 | 9.0 | 18.5 | 618 | 11.0 | 22.6 | 786 | 14.0 | 28.7 | 1014 | | | |
| 3.0 | 6.2 | 174 | 6.0 | 12.3 | 396 | 9.0 | 18.5 | 636 | 11.0 | 22.6 | 792 | 14.0 | 28.7 | 1020 | | | |
| 3.0 | 6.2 | 174 | 6.0 | 12.3 | 402 | 9.0 | 18.5 | 636 | 12.0 | 24.6 | 846 | 14.0 | 28.7 | 1020 | | | |
| 4.0 | 8.2 | 192 | 6.0 | 12.3 | 396 | 9.0 | 18.5 | 636 | 12.0 | 24.6 | 858 | 15.0 | 30.8 | 1062 | | | |
| 4.0 | 8.2 | 216 | 6.0 | 12.3 | 402 | 9.0 | 18.5 | 636 | 12.0 | 24.6 | 870 | 15.0 | 30.8 | 1092 | | | |
| 4.0 | 8.2 | 228 | 6.0 | 12.3 | 402 | 9.0 | 18.5 | 642 | 12.0 | 24.6 | 864 | 15.0 | 30.8 | 1098 | | | |
| 4.0 | 8.2 | 240 | 6.0 | 12.3 | 402 | 9.0 | 18.5 | 636 | 12.0 | 24.6 | 864 | 15.0 | 30.8 | 1098 | | | |
| 4.0 | 8.2 | 246 | 6.0 | 12.3 | 402 | 9.0 | 18.5 | 642 | 12.0 | 24.6 | 858 | 15.0 | 30.8 | 1092 | | | |
| 4.0 | 8.2 | 246 | 6.0 | 12.3 | 402 | 9.0 | 18.5 | 636 | 12.0 | 24.6 | 864 | 15.0 | 30.8 | 1098 | | | |
| 4.0 | 8.2 | 246 | 7.0 | 14.4 | 414 | 10.0 | 20.5 | 672 | 12.0 | 24.6 | 864 | 15.0 | 30.8 | 1092 | | | |
| 4.0 | 8.2 | 252 | 7.0 | 14.4 | 444 | 10.0 | 20.5 | 708 | 12.0 | 24.6 | 864 | 15.0 | 30.8 | 1098 | | | |
| 4.0 | 8.2 | 252 | 7.0 | 14.4 | 462 | 10.0 | 20.5 | 714 | 12.0 | 24.6 | 864 | 16.0 | 32.8 | 1110 | | | |

Table A-26 - Raw data for wind turbine with eight blades at 45 degrees in enclosure

| B8-45-E1 | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM | Hz | MPH | RPM |
| 1.5 | 3.1 | 0 | 3.0 | 6.2 | 78 | 5.0 | 10.3 | 372 | 9.0 | 18.5 | 486 | 11.0 | 22.6 | 984 | 14.0 | 28.7 | 1296 | 17.0 | 34.9 | 1596 |
| 1.5 | 3.1 | 0 | 3.0 | 6.2 | 90 | 5.0 | 10.3 | 372 | 9.0 | 18.5 | 564 | 11.0 | 22.6 | 990 | 14.0 | 28.7 | 1302 | 17.0 | 34.9 | 1626 |
| 1.5 | 3.1 | 0 | 3.0 | 6.2 | 102 | 5.0 | 10.3 | 372 | 9.0 | 18.5 | 636 | 11.0 | 22.6 | 1002 | 14.0 | 28.7 | 1314 | 17.0 | 34.9 | 1650 |
| 1.5 | 3.1 | 0 | 3.0 | 6.2 | 114 | 5.0 | 10.3 | 378 | 9.0 | 18.5 | 684 | 11.0 | 22.6 | 1002 | 14.0 | 28.7 | 1314 | 17.0 | 34.9 | 1668 |
| 1.5 | 3.1 | 0 | 3.0 | 6.2 | 126 | 6.0 | 12.3 | 384 | 9.0 | 18.5 | 714 | 11.0 | 22.6 | 1002 | 14.0 | 28.7 | 1314 | 17.0 | 34.9 | 1680 |
| 1.5 | 3.1 | 0 | 3.0 | 6.2 | 132 | 6.0 | 12.3 | 408 | 9.0 | 18.5 | 744 | 11.0 | 22.6 | 1008 | 14.0 | 28.7 | 1308 | 17.0 | 34.9 | 1686 |
| 1.5 | 3.1 | 0 | 3.0 | 6.2 | 144 | 6.0 | 12.3 | 420 | 9.0 | 18.5 | 756 | 12.0 | 24.6 | 1014 | 14.0 | 28.7 | 1308 | 17.0 | 34.9 | 1692 |
| 1.5 | 3.1 | 0 | 3.0 | 6.2 | 150 | 6.0 | 12.3 | 432 | 9.0 | 18.5 | 762 | 12.0 | 24.6 | 1038 | 15.0 | 30.8 | 1314 | 17.0 | 34.9 | 1698 |
| 1.5 | 3.1 | 0 | 3.0 | 6.2 | 150 | 6.0 | 12.3 | 420 | 9.0 | 18.5 | 774 | 12.0 | 24.6 | 1062 | 15.0 | 30.8 | 1362 | 17.0 | 34.9 | 1692 |
| 1.5 | 3.1 | 0 | 3.0 | 6.2 | 162 | 6.0 | 12.3 | 426 | 9.0 | 18.5 | 780 | 12.0 | 24.6 | 1080 | 15.0 | 30.8 | 1392 | | | |
| 2.0 | 4.1 | 0 | 3.0 | 6.2 | 162 | 6.0 | 12.3 | 420 | 9.0 | 18.5 | 786 | 12.0 | 24.6 | 1092 | 15.0 | 30.8 | 1410 | | | |
| 2.0 | 4.1 | 0 | 3.0 | 6.2 | 168 | 6.0 | 12.3 | 426 | 9.0 | 18.5 | 786 | 12.0 | 24.6 | 1098 | 15.0 | 30.8 | 1434 | | | |
| 2.0 | 4.1 | 6 | 3.0 | 6.2 | 174 | 6.0 | 12.3 | 420 | 9.0 | 18.5 | 786 | 12.0 | 24.6 | 1104 | 15.0 | 30.8 | 1440 | | | |
| 2.0 | 4.1 | 12 | 4.0 | 8.2 | 186 | 6.0 | 12.3 | 420 | 10.0 | 20.5 | 810 | 12.0 | 24.6 | 1110 | 15.0 | 30.8 | 1446 | | | |
| 2.0 | 4.1 | 24 | 4.0 | 8.2 | 198 | 7.0 | 14.4 | 432 | 10.0 | 20.5 | 834 | 12.0 | 24.6 | 1104 | 15.0 | 30.8 | 1452 | | | |
| 2.0 | 4.1 | 30 | 4.0 | 8.2 | 216 | 7.0 | 14.4 | 432 | 10.0 | 20.5 | 852 | 12.0 | 24.6 | 1116 | 15.0 | 30.8 | 1458 | | | |
| 2.0 | 4.1 | 36 | 4.0 | 8.2 | 228 | 7.0 | 14.4 | 438 | 10.0 | 20.5 | 870 | 13.0 | 26.7 | 1122 | 15.0 | 30.8 | 1458 | | | |
| 2.0 | 4.1 | 42 | 4.0 | 8.2 | 240 | 7.0 | 14.4 | 432 | 10.0 | 20.5 | 882 | 13.0 | 26.7 | 1158 | 15.0 | 30.8 | 1464 | | | |
| 2.0 | 4.1 | 54 | 4.0 | 8.2 | 246 | 7.0 | 14.4 | 438 | 10.0 | 20.5 | 888 | 13.0 | 26.7 | 1176 | 15.0 | 30.8 | 1458 | | | |
| 2.0 | 4.1 | 54 | 4.0 | 8.2 | 258 | 7.0 | 14.4 | 438 | 10.0 | 20.5 | 894 | 13.0 | 26.7 | 1194 | 15.0 | 30.8 | 1464 | | | |
| 2.0 | 4.1 | 54 | 4.0 | 8.2 | 264 | 7.0 | 14.4 | 432 | 10.0 | 20.5 | 894 | 13.0 | 26.7 | 1206 | 16.0 | 32.8 | 1482 | | | |
| 2.0 | 4.1 | 66 | 5.0 | 10.3 | 264 | 7.0 | 14.4 | 438 | 10.0 | 20.5 | 900 | 13.0 | 26.7 | 1206 | 16.0 | 32.8 | 1518 | | | |
| 2.0 | 4.1 | 60 | 5.0 | 10.3 | 288 | 8.0 | 16.4 | 444 | 10.0 | 20.5 | 900 | 13.0 | 26.7 | 1212 | 16.0 | 32.8 | 1536 | | | |
| 2.0 | 4.1 | 72 | 5.0 | 10.3 | 312 | 8.0 | 16.4 | 450 | 10.0 | 20.5 | 906 | 13.0 | 26.7 | 1218 | 16.0 | 32.8 | 1554 | | | |
| 2.0 | 4.1 | 66 | 5.0 | 10.3 | 324 | 8.0 | 16.4 | 444 | 10.0 | 20.5 | 900 | 13.0 | 26.7 | 1218 | 16.0 | 32.8 | 1560 | | | |
| 2.0 | 4.1 | 78 | 5.0 | 10.3 | 336 | 8.0 | 16.4 | 450 | 10.0 | 20.5 | 906 | 13.0 | 26.7 | 1218 | 16.0 | 32.8 | 1566 | | | |
| 2.0 | 4.1 | 72 | 5.0 | 10.3 | 348 | 8.0 | 16.4 | 450 | 11.0 | 22.6 | 906 | 13.0 | 26.7 | 1224 | 16.0 | 32.8 | 1566 | | | |
| 2.0 | 4.1 | 78 | 5.0 | 10.3 | 354 | 8.0 | 16.4 | 444 | 11.0 | 22.6 | 936 | 14.0 | 28.7 | 1218 | 16.0 | 32.8 | 1578 | | | |
| 2.0 | 4.1 | 78 | 5.0 | 10.3 | 360 | 8.0 | 16.4 | 450 | 11.0 | 22.6 | 954 | 14.0 | 28.7 | 1248 | 16.0 | 32.8 | 1572 | | | |
| 2.0 | 4.1 | 84 | 5.0 | 10.3 | 360 | 9.0 | 18.5 | 450 | 11.0 | 22.6 | 978 | 14.0 | 28.7 | 1272 | 16.0 | 32.8 | 1578 | | | |

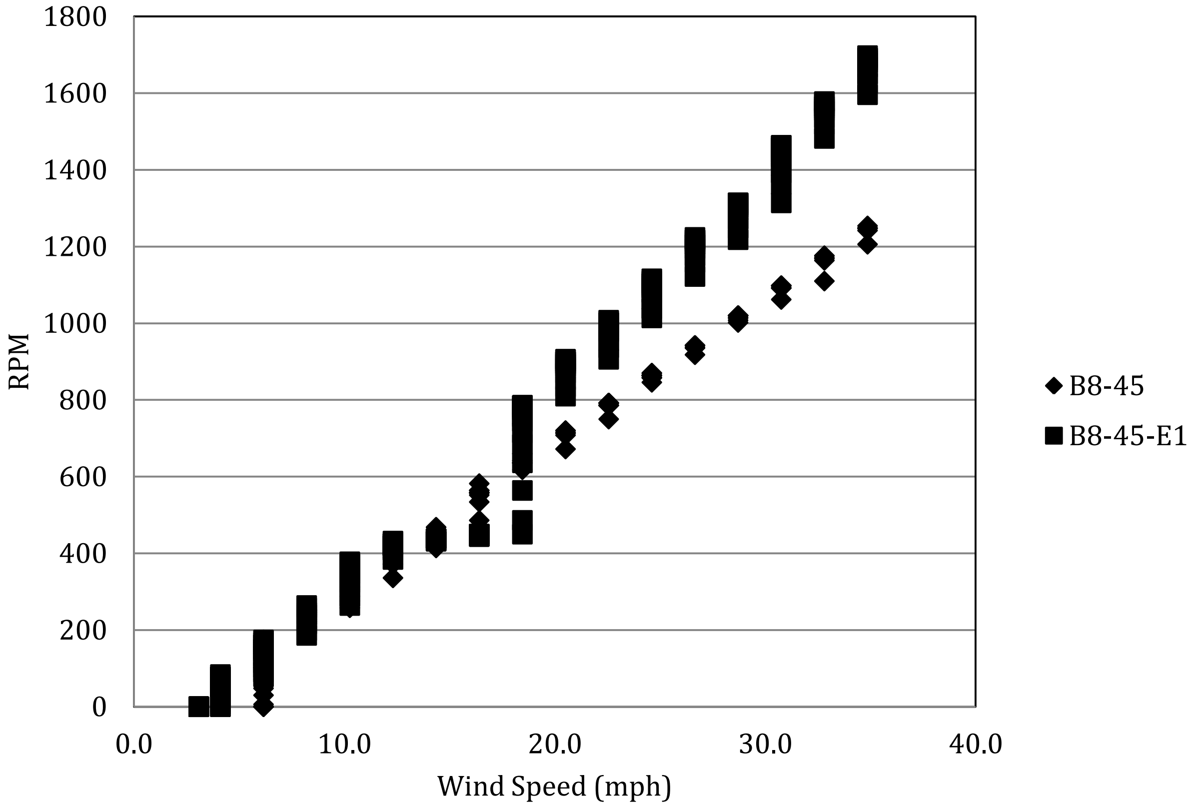
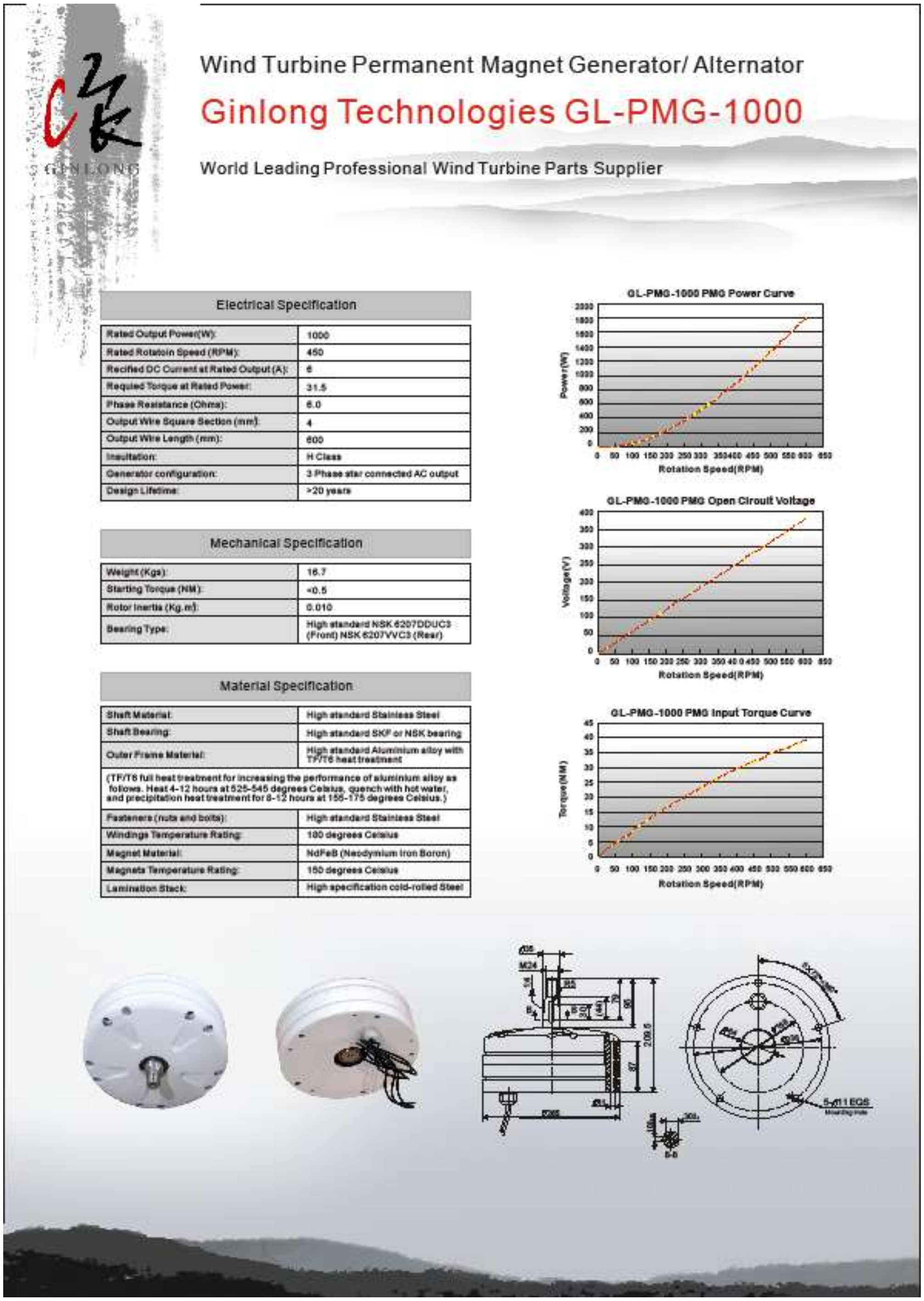



Figure A-11 - RPM of turbine with eight blades at 45 degrees at various wind speeds

## Appendix B: Specification Sheets

### B.1 Ginlong Technologies GL-PMG-1000



Wind Turbine Permanent Magnet Generator/ Alternator

Ginlong Technologies GL-PMG-1000

World Leading Professional Wind Turbine Parts Supplier

Electrical Specification

| | |
|---|---|
| Rated Output Power(W): | 1000 |
| Rated Rotatoin Speed (RPM): | 450 |
| Recified DC Current at Rated Output (A): | 6 |
| Requied Torque at Rated Power: | 31.5 |
| Phase Resistance (Ohms): | 6.0 |
| Output Wire Square Section (mm): | 4 |
| Output Wire Length (mm): | 600 |
| Insultation: | H Class |
| Generator configuration: | 3 Phase star connected AC output |
| Design Lifetime: | >20 years |

Mechanical Specification

| | |
|---|---|
| Weight (Kgs): | 16.7 |
| Starting Torque (NM): | <0.5 |
| Rotor Inertia (Kg.m): | 0.010 |
| Bearing Type: | High standard NSK 6207DDUC3 (Front) NSK 6207VVC3 (Rear) |

Material Specification

| | |
|---|---|
| Shaft Material: | High standard Stainless Steel |
| Shaft Bearing: | High standard SKF or NSK bearing |
| Outer Frame Material: | High standard Aluminium alloy with TF/T6 heat treatment |
| (TF/T6 full heat treatment for increasing the performance of aluminium alloy as follows. Heat 4-12 hours at 525-545 degrees Celsius, quench with hot water, and precipitation heat treatment for 8-12 hours at 155-175 degrees Celsius.) | |
| Fasteners (nuts and bolts): | High standard Stainless Steel |
| Windings Temperature Rating: | 180 degrees Celsius |
| Magnet Material: | NdFeB (Neodymium Iron Boron) |
| Magnets Temperature Rating: | 150 degrees Celsius |
| Lamination Stack: | High specification cold-rolled Steel |



Figure B-1 - Specification sheet for the Ginlong Technologies GL-PMG-1000

## B.2 Ginlong Technologies GL-PMG-1800

Wind Turbine Permanent Magnet Generator/ Alternator

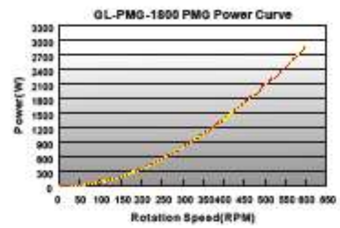
Ginlong Technologies GL-PMG-1800

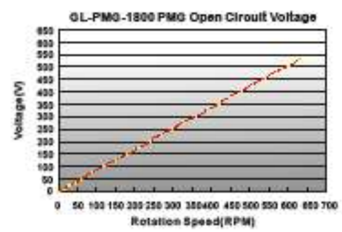
World Leading Professional Wind Turbine Parts Supplier

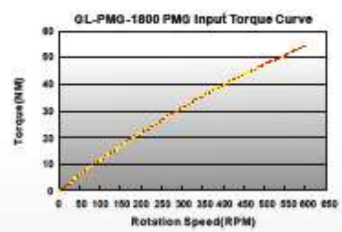
| Electrical Specification | |
|---|---|
| Rated Output Power(W): | 1800 |
| Rated Rotatoin Speed (RPM): | 480 |
| Recified DC Current at Rated Output (A): | 6 |
| Requied Torque at Rated Power: | 44.5 |
| Phase Resistance (Ohms): | 5.0 |
| Output Wire Square Section (mm): | 4 |
| Output Wire Length (mm): | 600 |
| Insultation: | H Class |
| Generator configuration: | 3 Phase star connected AC output |
| Design Lifetime: | >20 years |

| Mechanical Specification | |
|---|---|
| Weight (Kgs): | 19.5 |
| Starting Torque (NM): | <0.9 |
| Rotor Inertia (Kg.m²): | 0.013 |
| Bearing Type: | High standard NSK 6207DDUC3 (Front) NSK 6207VVC3 (Rear) |

| Material Specification | |
|---|---|
| Shaft Material: | High standard Stainless Steel |
| Shaft Bearing: | High standard SKF or NSK bearing |
| Outer Frame Material: | High standard Aluminium alloy with TF/T6 heat treatment |
| (TF/T6 full heat treatment for increasing the performance of aluminium alloy as follows. Heat 4-12 hours at 525-545 degrees Celsius, quench with hot water, and precipitation heat treatment for 8-12 hours at 155-175 degrees Celsius.) | |
| Fasteners (nuts and bolts): | High standard Stainless Steel |
| Windings Temperature Rating: | 180 degrees Celsius |
| Magnet Material: | NdFeB (Neodymium Iron Boron) |
| Magnets Temperature Rating: | 150 degrees Celsius |
| Lamination Stack: | High specification cold-rolled Steel |



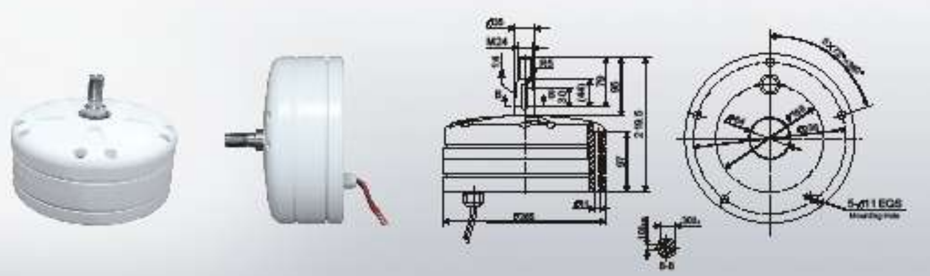



Figure B-2 - Specification sheet for the Ginlong Technologies GL-PMG-1800

## B.3 Outback Power Technologies Radian Series GS8048

**Specifications for Model GS8048**

**Electrical Specifications**

| | | |
|---|---|---|
| Nominal DC Input Voltage | | 48 Vdc |
| Continuous Output Power at 25°C | | 8000 VA |
| AC Output Voltage / Frequency | | 120/240 Vac / 60 Hz |
| Continuous AC Output Current at 25°C | | 33.3 Aac at 240 Vac |
| Idle Consumption - Invert mode, no load | | 30 W |
| CEC Weighted Efficiency | | 90% |
| Total Harmonic Distortion | Maximum total harmonic | <5% |
| | Maximum single voltage harmonic | <2% |
| Output Voltage Regulation | | ± 2% |
| Maximum Output Current | 1 ms peak | 100 Aac at 240 Vac, 200 Aac at 120 Vac |
| | 100 ms RMS | 70.7 Aac at 240 Vac |
| Overload Capability | 100 ms surge | 16.97 kVA |
| | 5 second | 12 kVa |
| | 30 minute | 9 kVa |
| AC Input Voltage Range (Adjustable) | | (L1 or L2) 70 to 140 Vac |
| AC Input Frequency Range | | 54 – 66 Hz |
| Grid-Interactive Voltage Range (IEEE) | | (L1 or L2) 108 to 132 Vac |
| Grid-Interactive Frequency Range (IEEE) | | (L1 or L2) 59.3 to 60.5 Hz |
| Maximum AC Input Current | | 50 Aac at 240 Vac |
| Continuous Battery Charge Output | | 115 Adc |
| Temperature Range | Operating | 0°C to 50°C (power derated above 25°C) |
| | Storage | -40°C to 60°C |
| DC Input Voltage Range | | 40 to 64 Vdc |

**Mechanical Specifications**

| | | |
|---|---|---|
| Dimensions (H x W x D) | Unit | 28 x 16 x 8.7" (71.1 x 40.6 x 22.2 cm) |
| | Shipping | 14.5 x 34.5 x 21" (36.8 x 87.6 x 53.3 cm) |
| Weight | Unit | 125 lbs (56.8 kg) |
| | Shipping | 140 lbs (63.6 kg) |
| Accessory Ports | | Remote Temperature Sensor and MATE3/HUB Communications |
| Non-volatile Memory | | Yes |
| Field Upgradable Firmware | | Yes |
| Chassis Type | | Vented |
| Certifications | | ETL Listed to UL1741 |
| | | CSA C22.2 No. 107.1 |

OutBack POWER

Main Office:
5917 195th St. NE #7
Arlington, WA 98223 USA
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www.outbackpower.com

Available From:

980-0028-01-00 Rev C

Figure B-3 - Specification sheet for the Outback Power Technologies GS8048

## B.4 Outback Power Technologies MATE3

**MATE3 Specifications**

| | |
|---|---|
| Display | 4.0 x 1.2" full graphical display |
| Quick System Access | 5 system operation hot keys, 1 user programmable hot key |
| Status Indicators | Nine LED Status Indicators |
| Navigational Controls | 5 navigational keys |
| Setpoint Adjustment | Touch sensitive scroll wheel |
| Communication Protocol | Proprietary OutBack Communications Protocol |
| Interconnection Cabling | Standard CAT 5 network cable with RJ45 modular jack - 6' (2 m) included |
| PC Computer Interface | Ethernet |
| Microprocessor | 80 MHz 32 bit processor |
| Setpoint and Data Memory | 8Mb RAM/ 64Mb of flash RAM |
| Clock/ Calendar | On-board real time clock with battery backup |
| Environmental Rating | Indoor Type 1 (IP 30) |
| Maximum Cable Length | 300' (100 m) |

*Specifications subject to change without notice

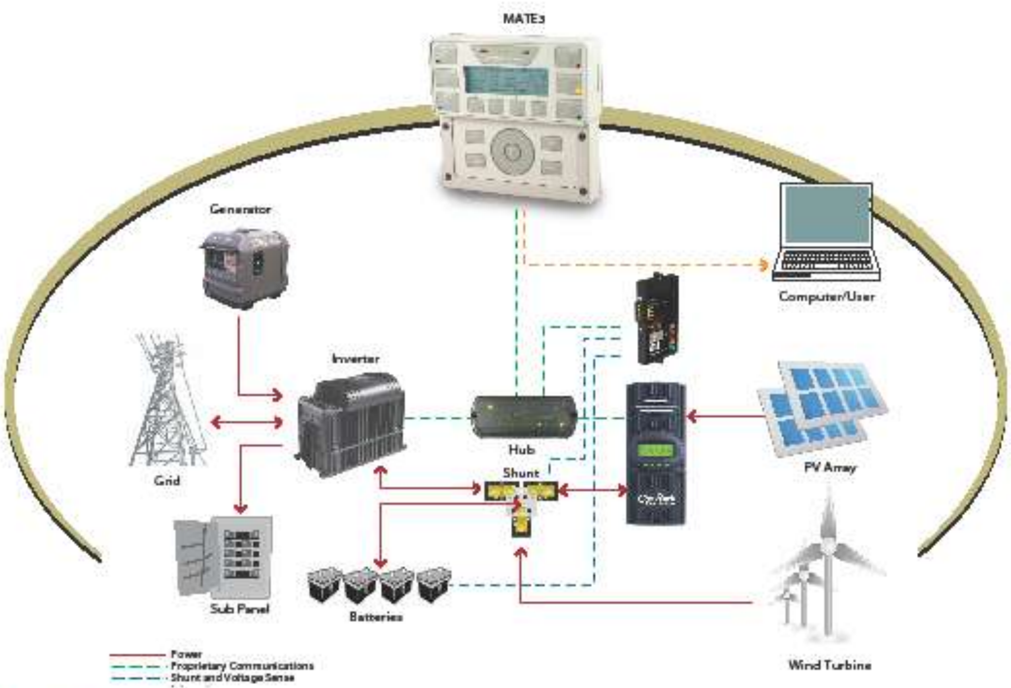


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Figure B-4 - Specification sheet for the Outback Power Technologies MATE3

## Appendix C: CAD Drawings

These figures, referenced in the main text, are included in this section at a larger scale for improved readability.

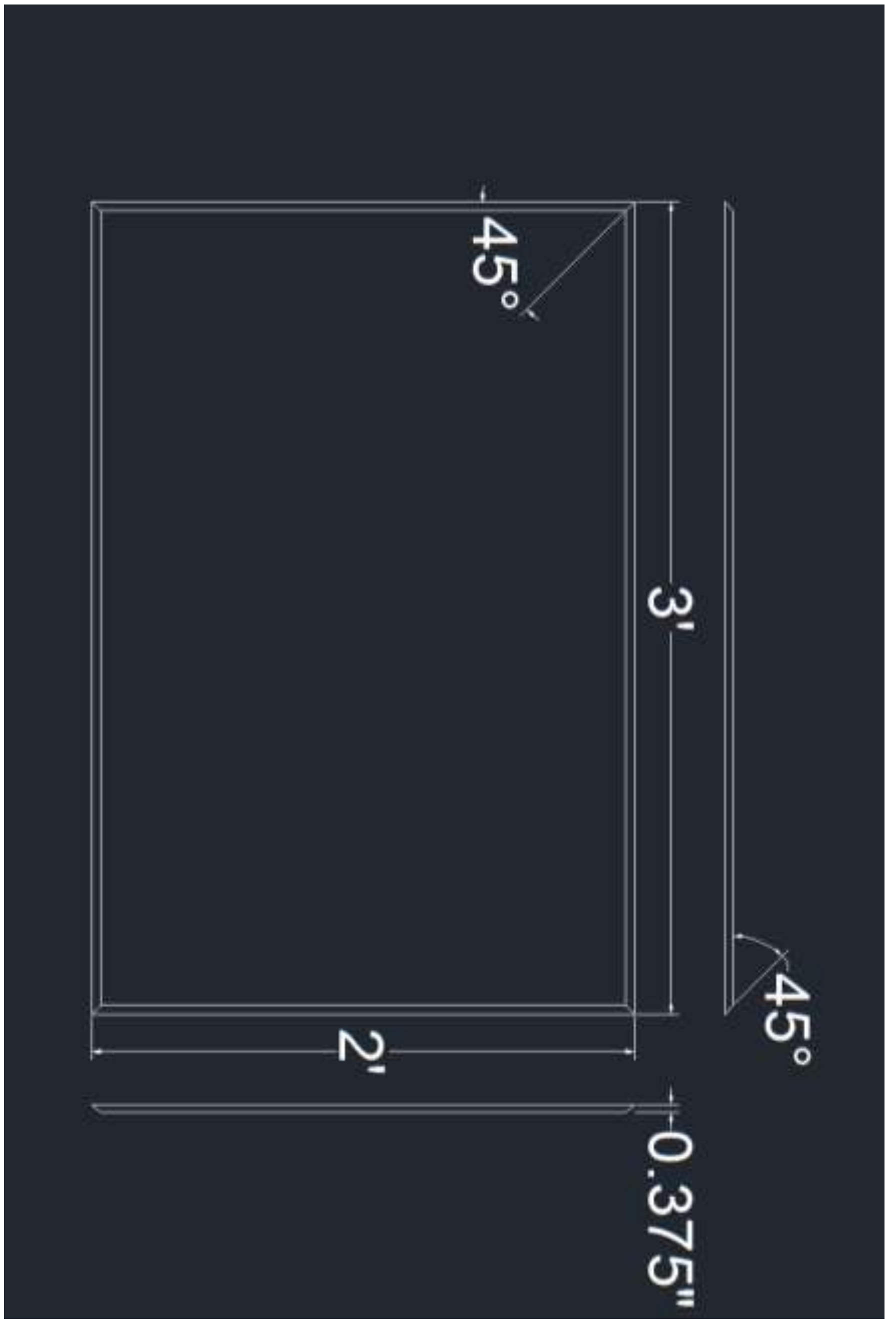


Figure C-1 - Uncut wall of testing platform
(Enlarged version of Figure 3-3)

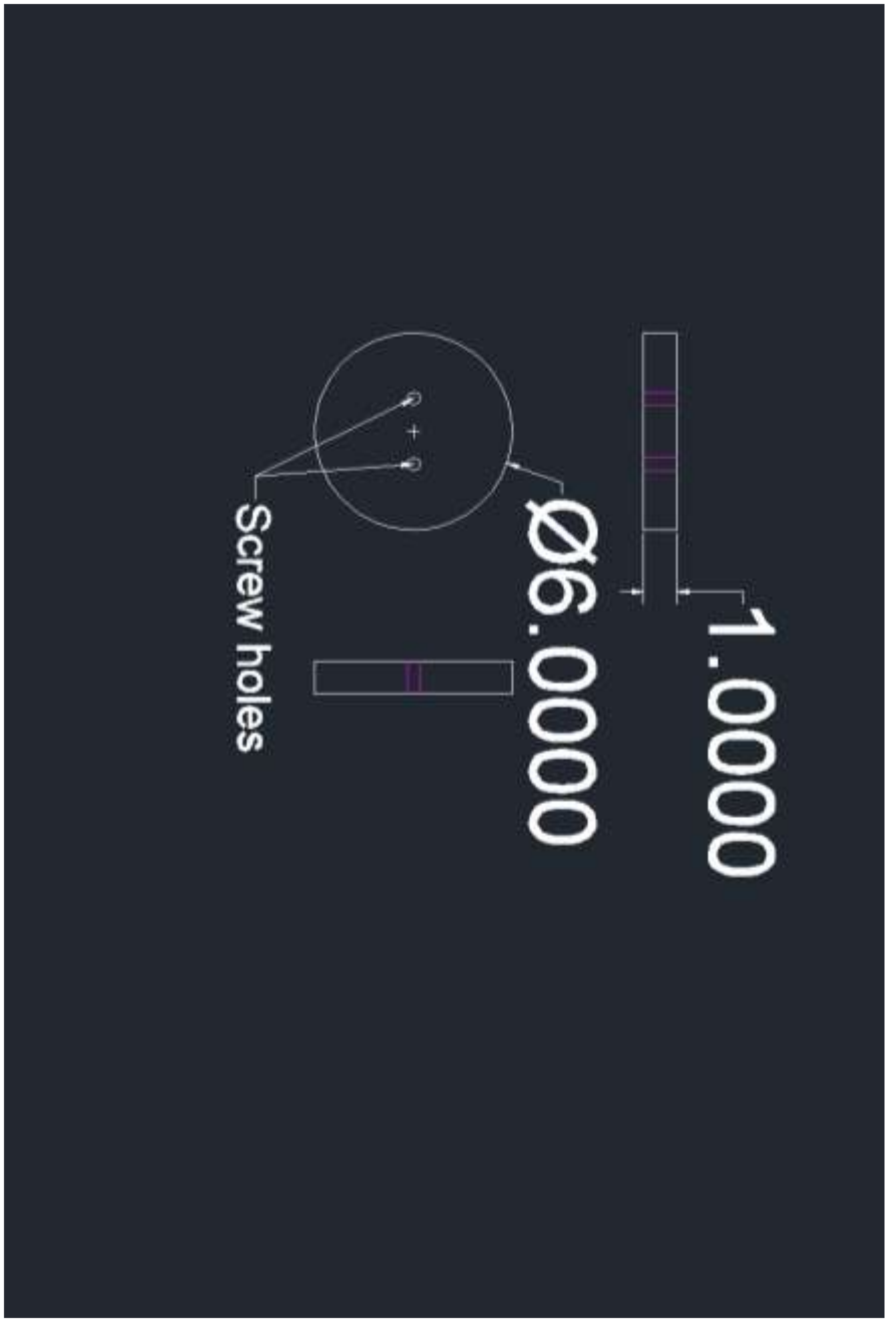


Figure C-2 - Wind tunnel testing platform support
(Enlarged version of Figure 3-4)

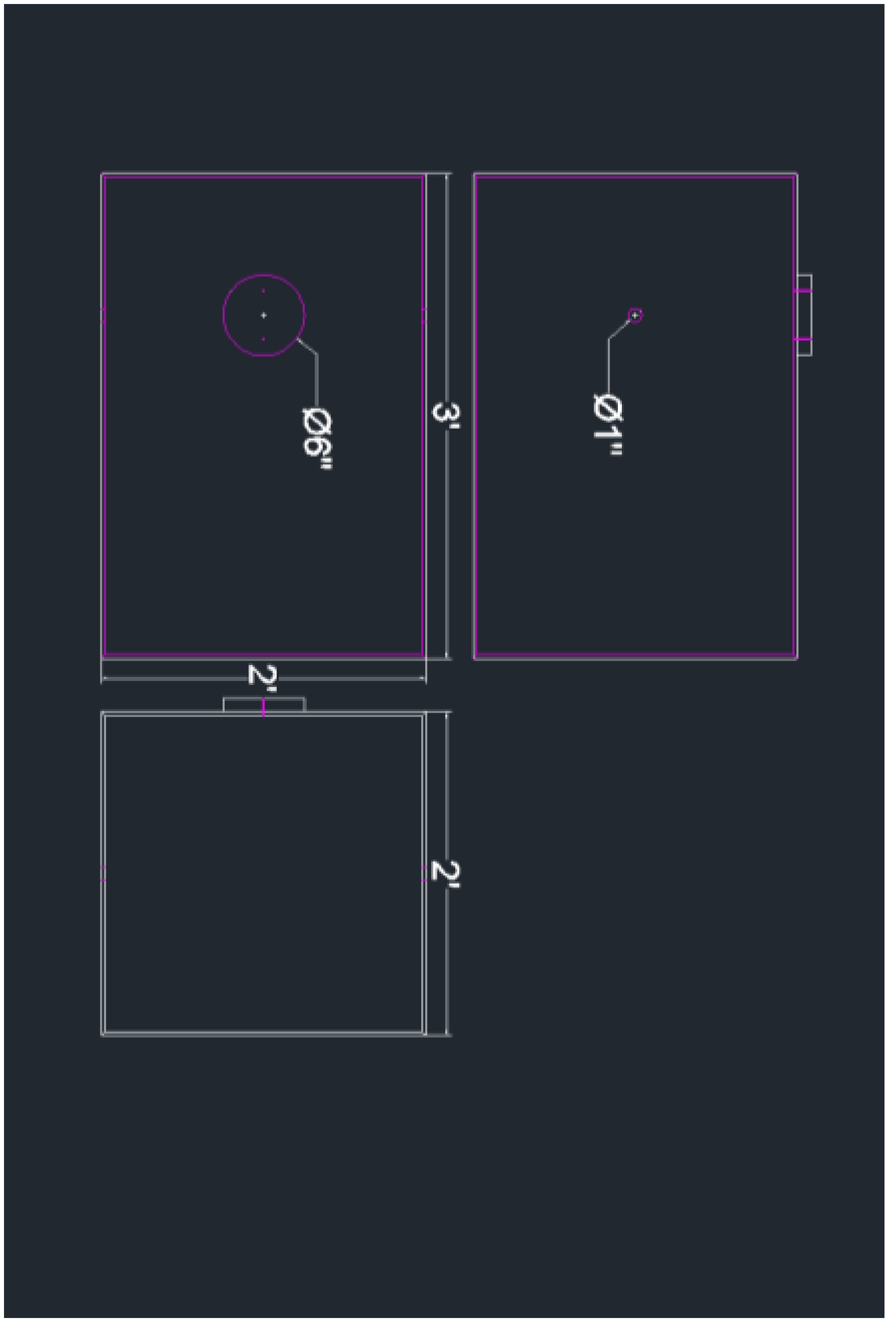


Figure C-3 - Wind tunnel testing platform, uncut
(Enlarged version of Figure 3-5)

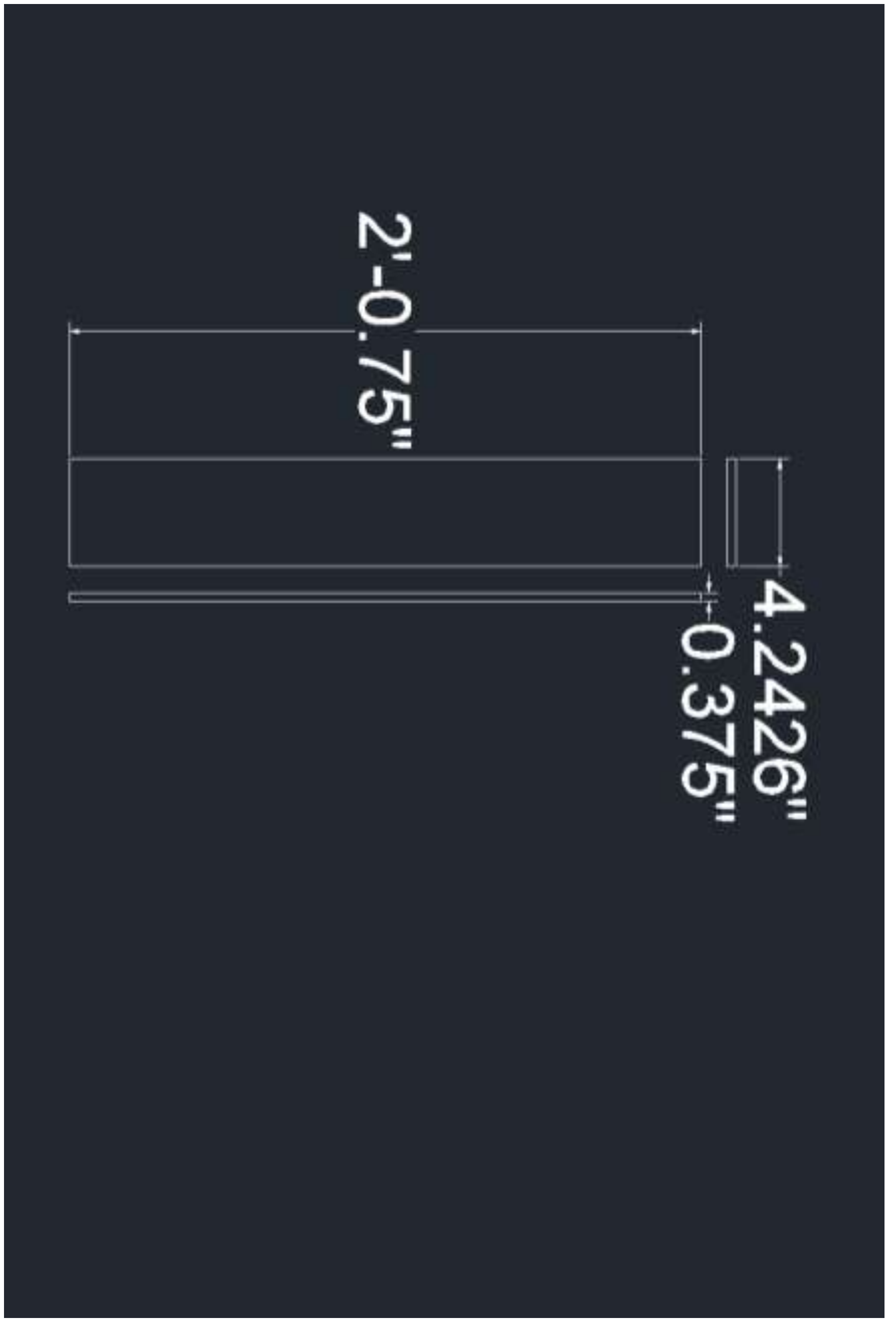


Figure C-4 - Deflector for testing platform
(Enlarged version of Figure 3-6)

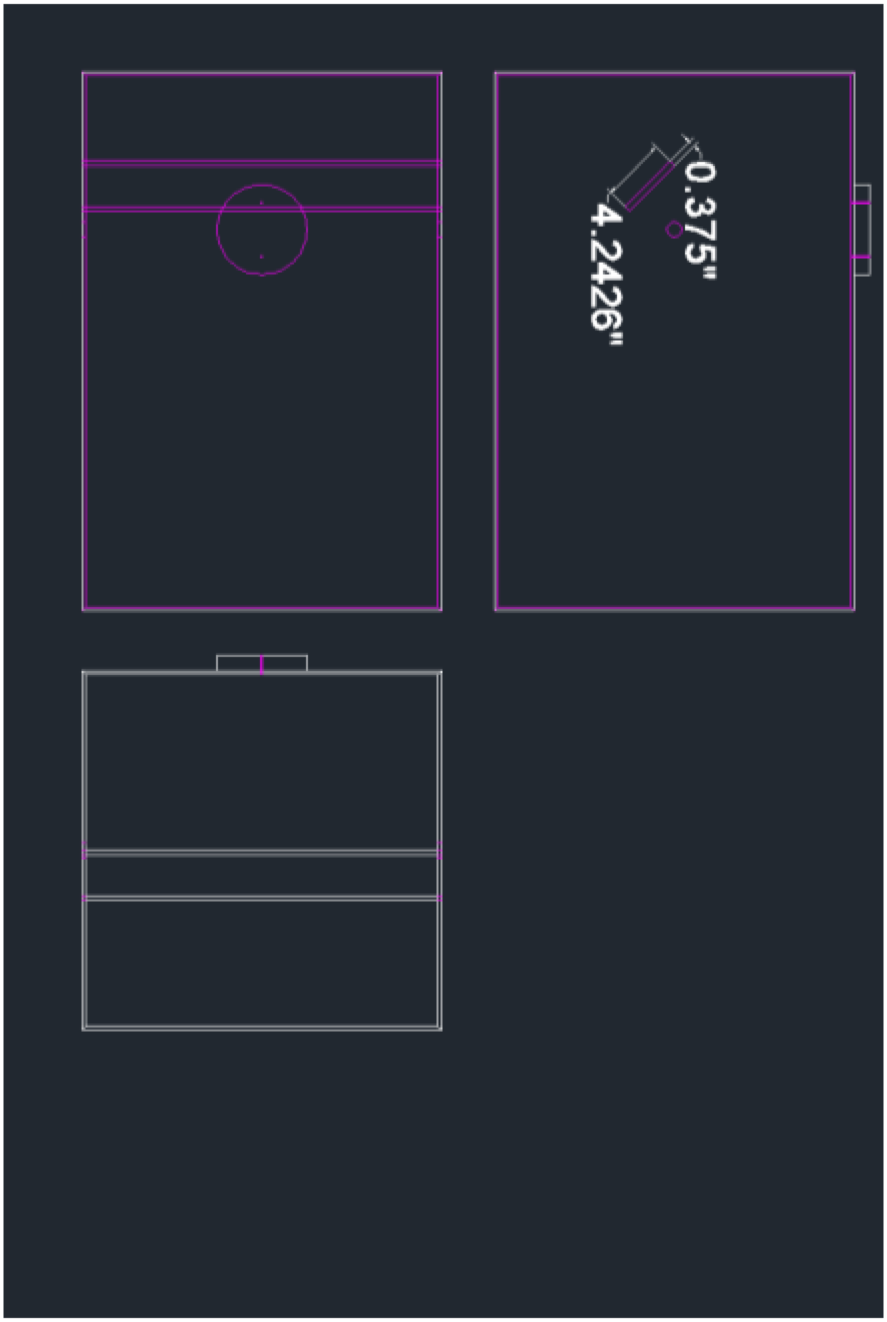


Figure C-5 - Testing platform with deflector installed
(Enlarged version of Figure 3-7)

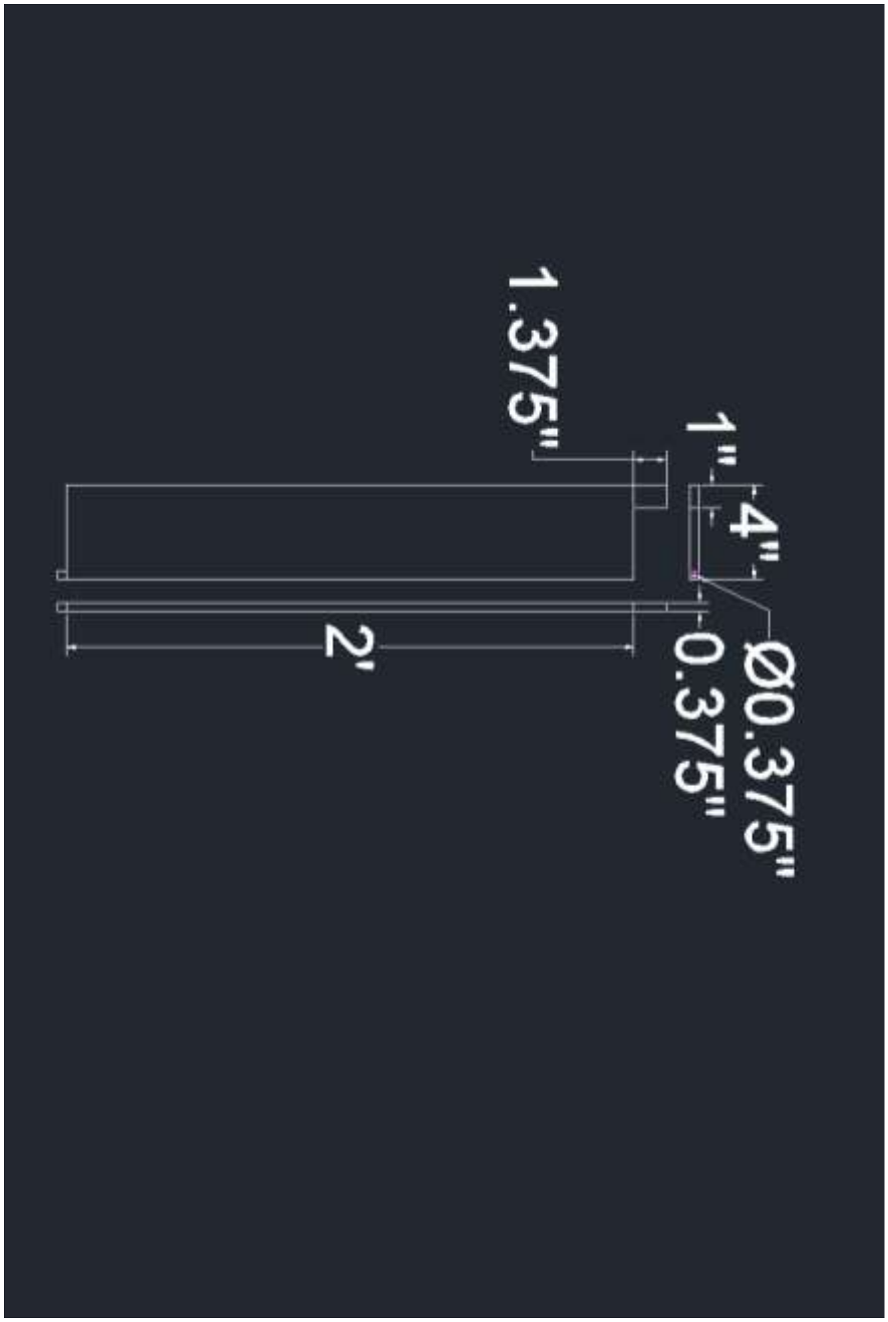


Figure C-6 - Vectoring vane for testing platform
(Enlarged version of Figure 3-8)

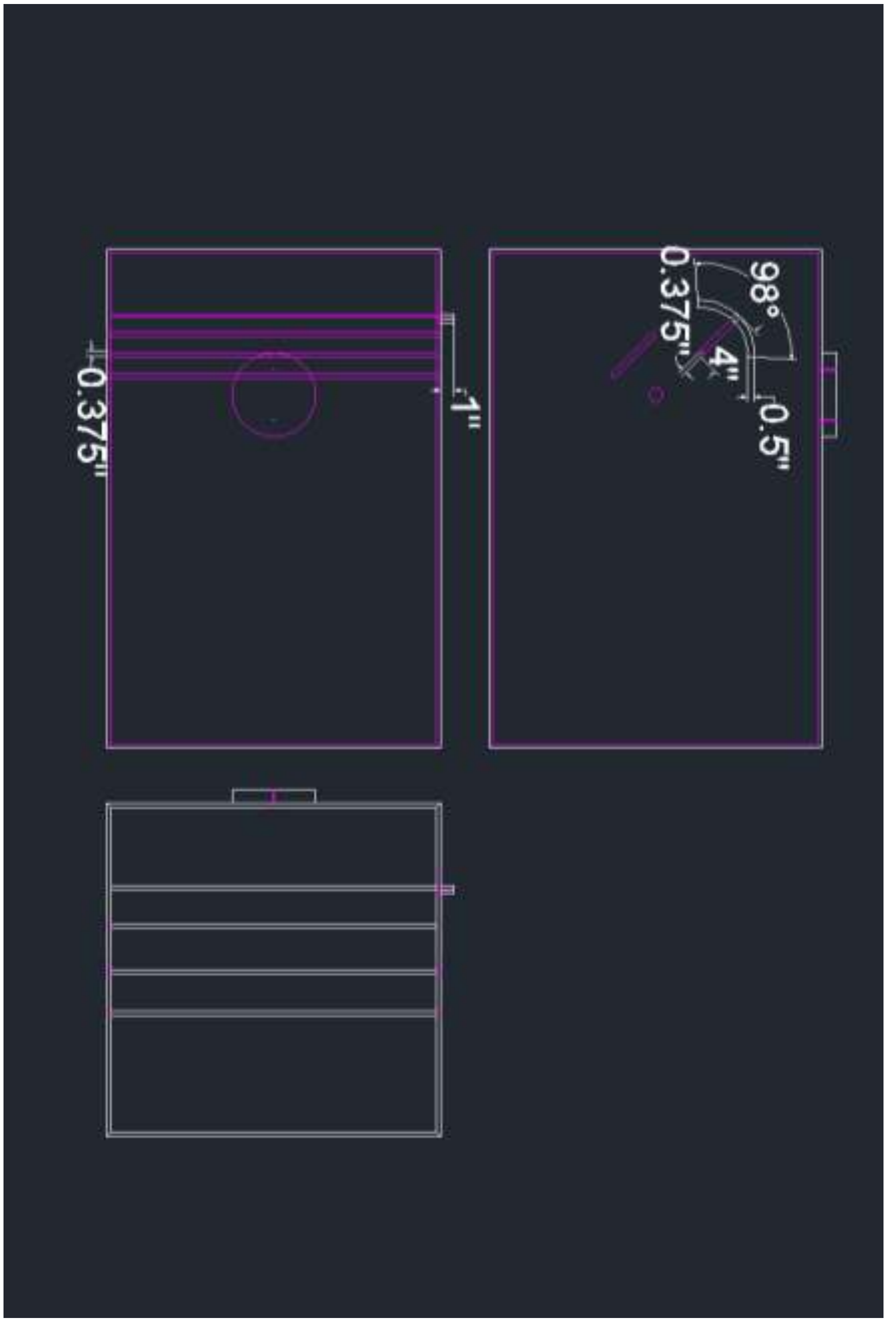


Figure C-7 - Testing platform with deflector and vectoring vane installed
(Enlarged version of Figure 3-9)

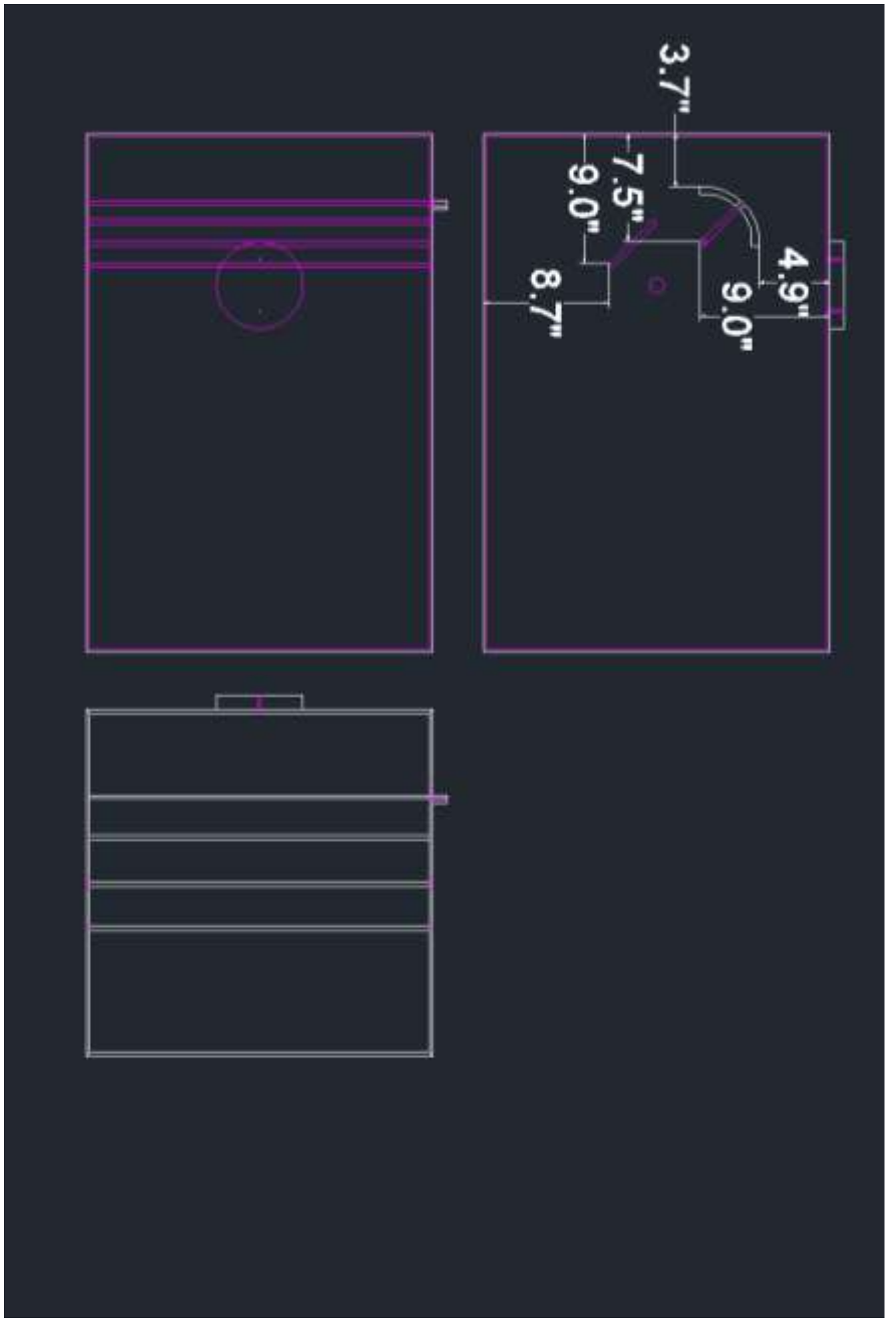


Figure C-8 - Testing platform with deflector and vectoring vane installed, cut measurements
(Enlarged version of Figure 3-10)

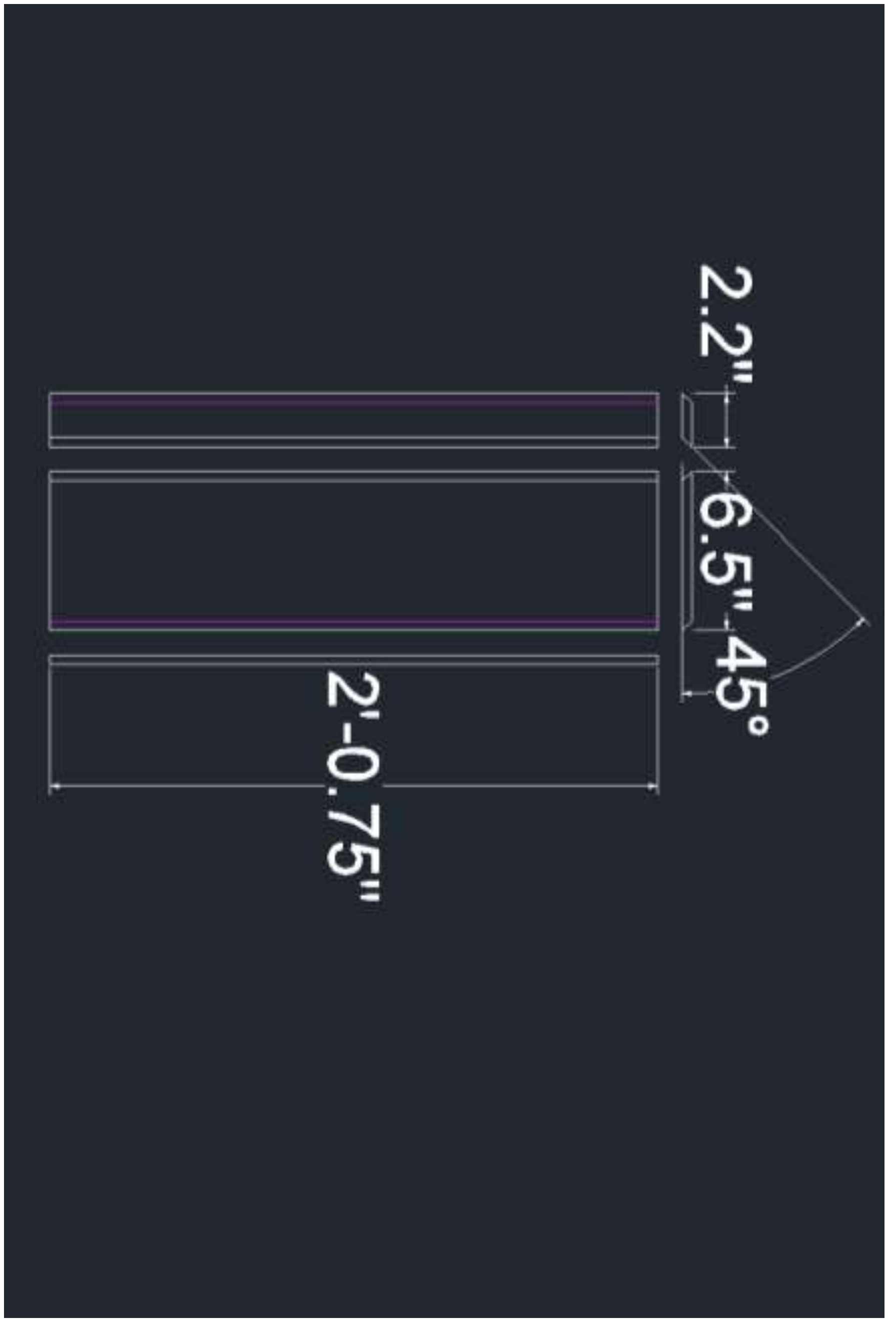


Figure C-9 - Funnel segments for testing platform
(Enlarged version of Figure 3-11)

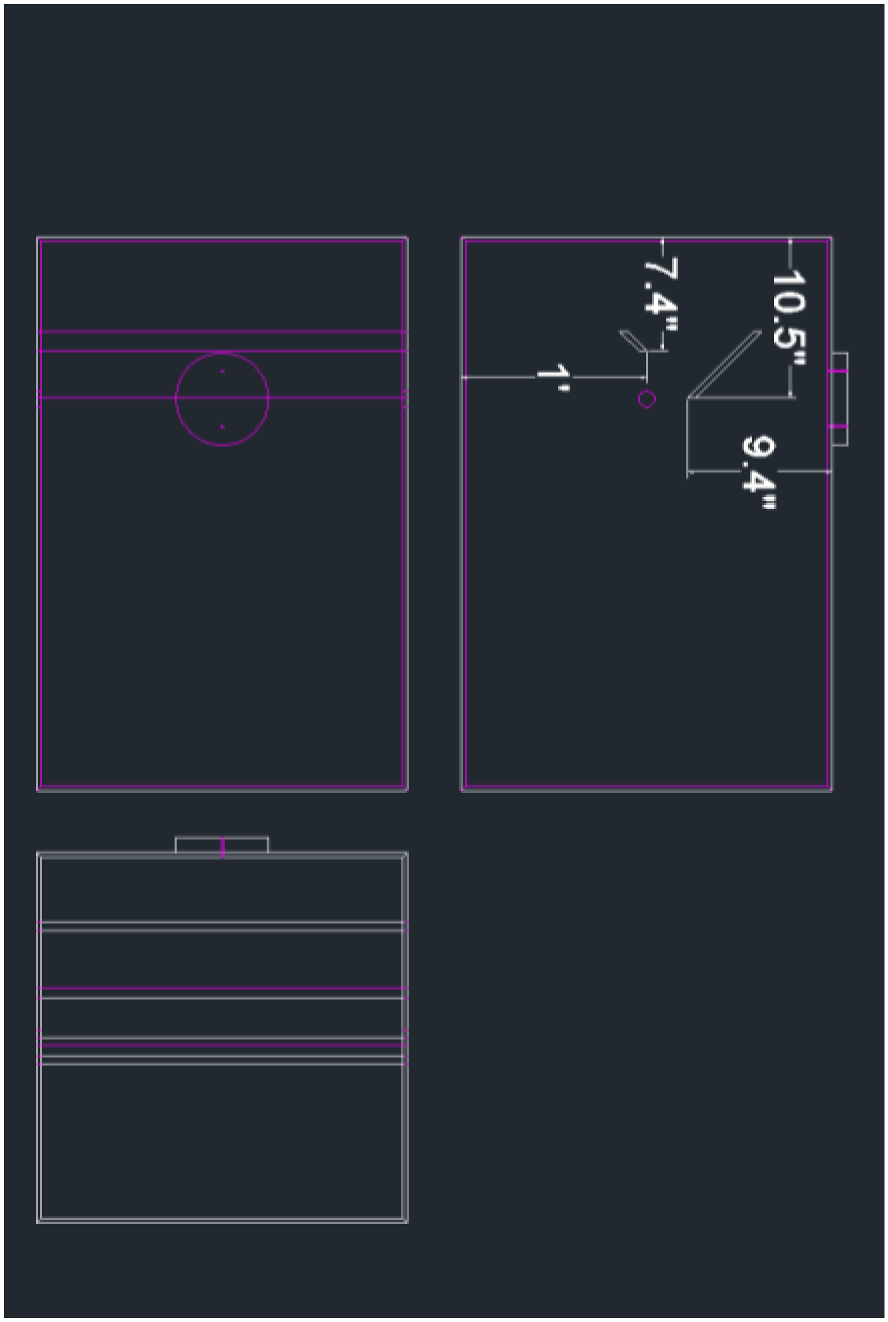


Figure C-10 - Testing platform with funnel installed
(Enlarged version of Figure 3-12)