Will the addition of a *shield* increase the efficiency of a Vertical Axis Wind Turbine (VAWT)?

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Abstract

A very common conflict that vertical axis wind turbines encounter is that when the wind blows toward the turbine, one set of turbine blades produces a torque in one direction (i.e clockwise), but the other set of blades produces a torque, ideally with a smaller magnitude, in the opposite direction (i.e counter-clockwise). This indifference results in a smaller overall magnitude in one direction due one set of blades creating an opposing torque. Figure 1 shows a top view of a generic VAWT and the forces that act on it.

This research proposes the idea of a *shield/shroud* that would cover the side containing the set of blades that would create the smaller, yet opposing torque. The shield would ideally deflect the wind from coming in contact with these blades and would prevent the opposing torque. This proposition should theoretically increase the revolutions of the turbine blades, resulting in a higher electrical production and an increase in efficiency from the turbine.

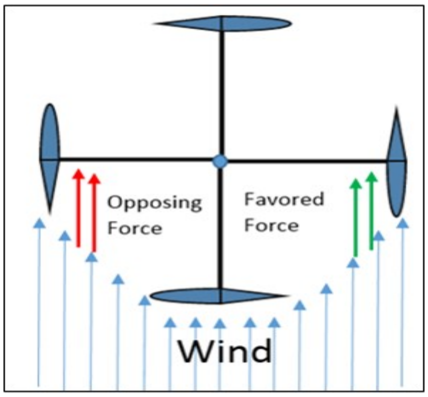


Figure 1: This image represents a top view of a VAWT and the forces that act on the turbine from the wind.

Figure 2: This is an example photo of a Vertical Axis Wind Turbine (VAWT).

1. Background

Wind Turbines have been around for quite some time and have increased in popularity over the past decade. With a push for alternative energy sources, wind power has become one of the readily available options of these renewable energy sources.

A wind turbine is a complex machine used to harvest wind and convert its power into electricity through various concepts of Mechanics and Fluid Dynamics. Wind Turbines can rotate on one of two axes: a vertical axis (VAWT) or a horizontal axis (HAWT).

The abbreviations for these types are "HAWT" for a horizontal axis wind turbine and "VAWT" for a vertical axis wind turbine, respectively. For the purpose of this research, the least common type of wind turbine, shown in Figure 2, was studied: a vertical axis wind turbine (VAWT).

2. Methodology

The proposed research was planned to be carried out in four main phases: 1) Use theoretical Physics to understand the function of a VAWT and the conflict revolving it; 2) produce Computer Aided Designs (CAD) of the various parts and assemblies of the prototype that would be built; 3) fabricate a prototype of the wind turbine and the proposed *shroud*; and, 4) test the prototype to collect raw data through experimental methods.

2.1 Theoretical Physics

The original motive behind this project grew from a final project from a Mechanics course in theoretical Physics. During the completion of this course project, an issue arose in the topic of study that had seemed to be overlooked or unnoticed. It was curiosity that had sparked the motivation to initiate such study.

In an attempt to investigate further into the conflict revolving the area of research, theoretical analysis became a significant aspect of this project. At first, the analysis seemed to be best carried out using concepts of rotational dynamics, such as torque, angular velocity, angular acceleration, rotational inertia, etc. With parameters of a preliminary model of a prototype, calculations were carried out using these concepts. Problems were developed based on these parameters. However, what was seen was surprising; even with simplification, the problems always seemed to *work out* where the sum of the torques produced on one side would eventually balance out with the torques produced by the blades of the other side; due to symmetry. These results would later become the motive for various bends and angle choices used in the blade designs. Equation 1 below shows the equation used for torque.

$$\tau = I\alpha, \tag{1}$$

where τ is torque, I is the moment of inertia of the turbine with respect to the axis of rotation, and α is angular acceleration.

Inconclusive results using Mechanics led theoretical analysis into Fluid Dynamics [1]. Using this branch of Physics, air now had to be considered a fluid. With more advanced Mathematics involved (vector calculus), the problems related to the turbine were simplified. For example, calculations were done finding the *flow* (velocity $\vec{v}$ of air) against two connected planes at an angle β from each other. For a steady flow in the absence of the local spinning motion (vorticity), this velocity is the gradient of a scalar function called the velocity potential ϕ. The components of the velocity in the polar coordinates r and θ are thus:

$$v_r = \frac{\partial \phi}{\partial r}, \quad v_\theta = \frac{\partial \phi}{r \partial \theta}. \tag{2}$$

For an incompressible fluid, the velocity potential satisfies the Laplace equation:

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial \phi}{\partial r}\right) + \frac{\partial^2 \phi}{r^2 \partial \theta^2} = 0. \tag{3}$$

The solutions of the Laplace equation are important in many fields of science, including fluid mechanics, electromagnetism, thermodynamics, and astronomy. The theory of these solutions is a standard part of mathematical physics and could be used in the analysis of the motion of the turbine.

2.2 Computer Aided Designs

The computer aided designs (CAD) for the prototype were created using Autodesk Inventor© and Solidworks© and completed before any fabrication work was done. However, as fabrication took place, many changes in the production arose which led to changes to the initial designs of various parts of the prototype. For example, in the initial designs, a car alternator was going to be used to produce the electrical potential (voltage) and current from the turbine's rotation. However, after a bit of research on car alternators themselves, it became evident that a car alternator was not a suitable option for generating power for a wind turbine. The reasons to why this option was not suitable will be discussed later in this document under the Hurdles section.

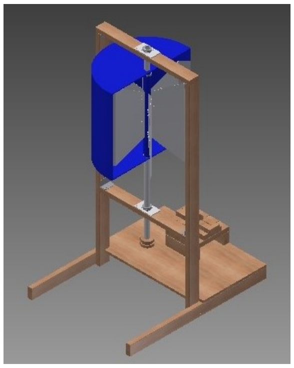


Figure 3: A screen capture of the final assembly of the VAWT with the proposed *shroud*.

However, this obstacle led to a change in the choice of part to produce the electricity which in turn led to changes in the design and assembly of the turbine. Figure 3 below shows a 3-D model of the final assembly of the turbine and shield using Autodesk Inventor ©.

2.3 Fabrication

The fabrication of the prototype itself was separated into five main sections:

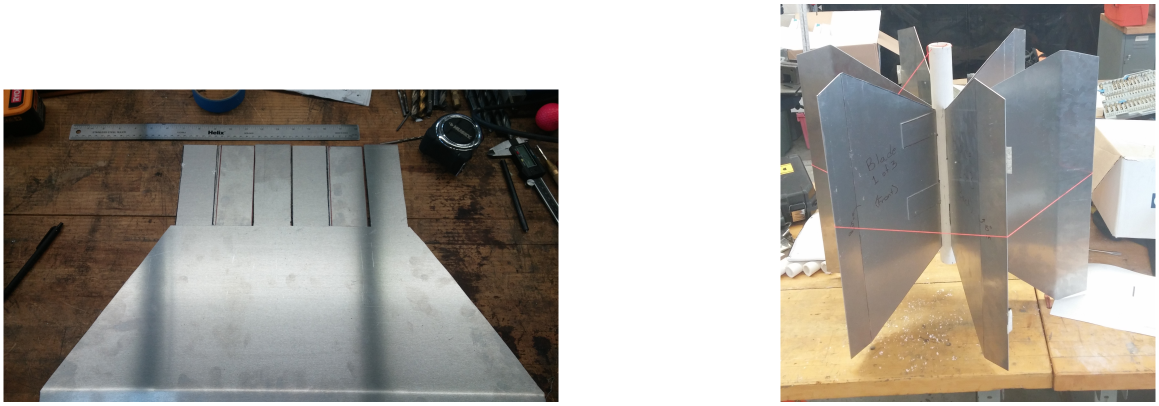
1. Surrounding stand
2. Aluminum blades
3. Aluminum post & Bearing mounts
4. Alternator/Generator
5. Shield

The proposed turbine was tested on the wind tunnel located in room 116 of Buckman Hall at the University of New Haven. The wind tunnel contains an outlet that is 24 inches in diameter and where the top of the outlet is 60 inches high off the ground. Therefore, the dimensions of wind tunnel's outlet left design constraints for the turbine that would be fabricated. The dimensions of turbine blades had to match the diameter of the tunnel's outlet, as well as its height with respect to the ground. With efforts of trying to satisfy constraints, there also raised the question of trying to keep the turbine *stable* and upright.

2.3.1 Surrounding Stand

With this next objective to satisfy, a stand of some sort was required. With that said, a simple stand was fabricated that would house and hold the turbine to keep it from falling over or moving out of place. This stand was built using standard construction pine lumber measuring 2 inches by 4 inches and a 0.5 inch thick piece of plywood. Figure 4 shows a picture of the stand that was built for the turbine.

Figure 4: Image showing the fabricated support stand using construction lumber (pine). This stand would be used to hold the VAWT.



(a)

(b)

Figure 5: **(a)** Pictured are 3 sets of 6 blades; each set containing 2 blades. The location of the two tabs on each blade distinguishes each set from one another. **(b)** Assembly of the post prototype housing the six Aluminum blades.

2.3.2 Aluminum Blades

As mention in the previous section, the turbine was constrained to the dimensions of the wind tunnel that would be later used to test the finished prototype. The tunnel's outlet had strict dimensions that could not be altered. As a result, the design of the blades experienced constraints as well.

Before any physical parameters could have been determined, there was a question of what type of blade or *wing* to use to produce the rotation. There has been a great deal of previous research on blade designs that would increase revolutions and efficiency in the past. However, for this research, the main focus was to analyze the effect that a *shield* would produce on the overall efficiency. This was going to be conducted experimentally, through physical testing of a prototype, and theoretically through concepts of Mechanics (and Fluid Dynamics later on) in Physics. For this reason, it was best to choose a flat blade design, with small alterations, to encourage simpler calculations when performing theoretical analysis.

The blade that would be used would be cut from an 18 inch by 24 inch aluminum sheet of 0.0625 inch thick Al-6061. The section of the blade that would actually encounter the wind generated by the tunnel measured to be 12 inches wide by 24 inches long. The other 6 inches would be utilized to create an inter-locking tab system to add stability to the turbine and prevent as much vibration as possible. Each blade would have 2 tabs that would be used to drive through the slots on the post and bolt onto the opposite blade. The turbine has a total of 6 blades, 3 sets of 2 blades each. The reason for 3 sets of blades was due to the location of the tabs on the blade. An image is included above (Figure 5a) to help visualize this tab system and the difference between sets.

2.3.3 Aluminum Post & Bearing Mounts

With the blades now fabricated, a post was needed to house the blades and keep them from sliding out. This was done through a series of slots that the tabs of the blades would fit through, spread at a congruent angle from each other, onto an aluminum post. This unit angle worked out to be 60 degrees from each blade (360/6 = 60). Because this post required higher precision, a small prototype for just the post was created first out of PVC (PolyVinyl Chloride) piping before making the actual post out of Aluminum.

The post prototype was first measured out using dimensions from a mechanical drawing of the post. Then, the marked prototype was drilled using a milling machine in the machine shop of Buckman Hall. With the post prototype complete, it was then tested by inserting the Aluminum blades and observing the stability of the overall assembly. Factors that were paid close attention to included gap between the blades and the post and vibration of the blades. One factor that did need improvement was the gap between the post and the blades. The gap that the prototype possessed was slightly too large and resulted in more vibration. However, this small factor was improved by simply using a smaller end mill on the milling machine to drill the slots in the post. Figure 5b shows an image of the post prototype.

With small factors taken care of, the same measurements used for the post prototype were transferred onto the aluminum post and the slots were drilled using the smaller end mill. The blades were then inserted into the aluminum post where the same observations were taken. With slightly smaller slots, the blades now fit much tighter eliminating the majority of the vibration that existed on the prototype.

A small issue dealing with friction of the initial bearing system lead to the use of a more suitable construction which incorporated thrust bearings. The use of thrust bearings required a mount/bracket to hold the thrust bearing assembly and prevent it from sliding or vibrating. The bearing mount that was built for the turbine prototype was made using a $1/4$ inch thick piece of aluminum. A square, measuring the diameter of the thrust washer on each side, was drilled into the aluminum plate deep enough to hold the bearing assembly in place. This plate was then screwed into the 2 by 4 inch wood supports on the turbine stand. An image of the fabricated bearing mounts is included below (Figure 6).

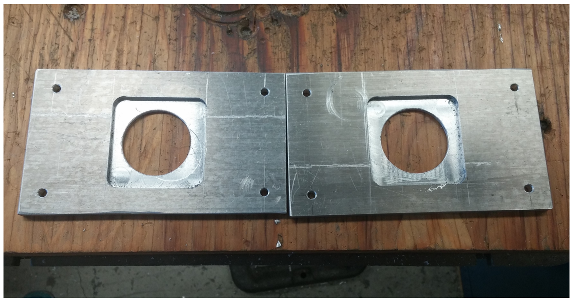


Figure 6: Completed mounts used to hold the thrust bearings in place.

2.3.4 Alternator/Generator

Initially, the project was proposed to incorporate a generator that would use the rotational motion of the turbine to produce electricity. A car alternator initially seemed like a reliable and readily available option for electric production for a wind turbine. However, after a bit of research on the function and makeup of car alternators, in was concluded that a car alternator wasn't such a great option for what it was going to be used for. A more detailed description of this will be included in the Hurdles section of this paper. With car alternators being ruled out of the picture, other options were beginning to be explored. After speaking with Mark Morton from the Electrical Engineering department here at UNH, a DC permanent magnet alternator was salvaged to be used for the project.

With a new alternator chosen, there had to be some means of keeping the motor itself stable and rigid. With some leftover, scrap 2 inch by 4 inch pieces of wood, a quick design was made on Autodesk Inventor©. Using the mechanical drawings of the mount that was modelling, the motor mount was fabricated. The design consisted of a system in which the motor could be moved left and right, as well as toward and away from the turbine. The motive behind this feature was for ease of creating tension in the belt that would be used to connect the pulley on the turbine to the motor. This would prevent the need to re-position the entire mount when re-tensioning the belt.

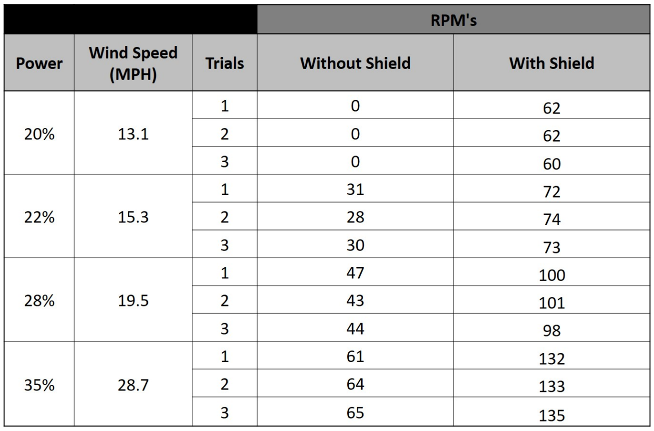
2.3.5 Shield/Shroud

Because experiments like these have never been done before, there weren't any sources to gather ideas from. However, it was decided to simply create a shroud shaped much like a semi-circular cylinder that would encompass half of the wind turbine. The shield was fabricated by cutting a 0.5 inch thick piece of plywood into two semi-circles, each with a radius of 14.5 inches. These two semi-circles were then joined together through a series of wood balusters of 3/8 inches thick using screws. In addition, a small support was made to prevent the top and bottom semi-circular pieces from separating from the balusters. This support included two holes that would run a threaded rod with 4 nuts and washers to keep the shield's height fixed. Finally, the entire shield was covered in a waxed poster board material. Figure 7 shows two images of the shield that was fabricated.

2.4 Testing and Results

Like mentioned before, experimental testing of the prototype was done using the wind tunnel located in room 116 in Buckman Hall at the University of New Haven. The wind tunnel contained a circular outlet where flow of air was produced by turbine blades within the wind tunnel. In addition, the tunnel had a Data Acquisition (DAQ) system where the user could limit the power of the inner turbine (on a percentage scale). The DAQ also displayed a relative wind speed in multiple units using integrated sensors. However, even though the DAQ system gave a reading of the wind speed, a digital anemometer was used to determine the speed of the air exiting the outlet of the tunnel. The reading from the anemometer was used instead of the reading from the DAQ since the DAQ collected data of the wind speed from another compartment within the wind tunnel.

To test the efficiency of the turbine with the addition of the shield, the revolutions of the turbine were measured and recorded with and without the shroud on the turbine. This was done by placing a piece of reflective tape on the post of the turbine and using a digital revolution counter to count the amount of revolutions per minute (RPM) that the turbine achieved. Due to issues with the brushed DC motor and resistance in the v-belt, the turbine was simply tested for the amount of revolutions. Further discussion of this issue is seen in the Hurdles section. This test was run for different wind speeds and varying percentages of power of the wind tunnel. The chart below outlines the results that were achieved with and without the shroud (Figure 8).



			RPM's	
Power	**Wind Speed (MPH)**	**Trials**	**Without Shield**	**With Shield**
20%	13.1	1	0	62
		2	0	62
		3	0	60
22%	15.3	1	31	72
		2	28	74
		3	30	73
28%	19.5	1	47	100
		2	43	101
		3	44	98
35%	28.7	1	61	132
		2	64	133
		3	65	135

Figure 8: This chart shows raw data collected by measuring the RPM that the turbine achieved at different wind speeds.

3. Hurdles

Throughout the course of the project, there were a few areas where changes were made, mostly due to learning more about the type of changes as they arose. This section will go into depth about a few of the hurdles that were overcome and what they entailed.

(a)

(b)

Figure 7: (a) Top section of the shield. Two pieces of 1 by 3 inch lumber were added as braces for stability. These braces act as the anchors for the threaded rods you see in the next picture. (b) Shield assembled onto the turbine. The threaded rods connect the top and bottom sections of the shield using nuts. These nuts are adjusted to achieve a fixed height for the shield.

3.1 Bearing System

The initial proposed bearing system consisted of a block of wood with a hole smaller than 0.5 inches in diameter spinning on a 0.5 inch diameter aluminum rod, shaved to a point. When the post prototype was tested, the prototype was also mounted onto this bearing system to test for any issues. It came to be that when the tunnel began to create wind, the turbine had a hard time overcoming the friction to initiate rotation, due to the bearing.

This issue led to the use of actual thrust bearings. Because the load that the bearing would experience was parallel to the turbine shaft, thrust bearings had to be used instead of roller bearings. The difference between the two types is that thrust bearings are designed to handle an axial load but not a radial load, where standard roller bearings can handle a radial load (perpendicular to the axis of rotation) but not an axial load. The use of a roller bearing would lead to a malfunction in the bearing's operation and most likely damage to the bearing's seal.

3.2 Alternator

The original idea for measuring efficiency was to compare readings of voltage and current from the alternator with and without the shield. At the time, the most logical choice of an alternator was one from an automobile. However, after a bit of investigation into the use of automobile alternators for wind power generation, it was discovered that a car alternator was not such a great option for such application.

Car alternators have integrated regulators which switch the current being supplied to the battery on and off. In addition, a car alternator is designed in such a way where the alternator shaft needs to spin at a certain number of revolutions per minute to generate a current. This number is usually around 700 to 800 rpm, which is the typically RPM value of a cold automobile engine. Also, car alternators perform in a way where there is always a load from the battery. Due to factors like these, a car alternator was found to be a bad choice for an alternator on a wind turbine.

Through the same research on car alternators, it was found that permanent magnet alternators were the best type of alternators for an application such as a wind turbine. After coming to this conclusion, Mark Morton from the Electrical Engineering department at the University of New Haven was consulted for help on finding such an alternator. As a result, there was a spare DC permanent magnet alternator that was donated for the project. A mount was fabricated to hold the motor and a pulley was used to connect a v-belt from the motor to the turbine.

However, even after using this alternator, the torque required to begin the rotation of the turbine was too large to test at low wind speeds. In order to overcome this resistance, the turbine needed to be tested at higher winds (55-70 mph) in order to see rotation. It was decided that the results produced by testing at such wind speeds were going to be unrealistic since such wind speeds are rarely achieved. As a result, the method of testing was resorted to measuring RPM of the turbine without an alternator. With still an issue about an alternator, there are future plans being pursued to fabricate an permanent magnet alternator that would connect directly to the end of the post of the turbine that would not entail this same resistance since belts and pulleys are not going to be used.

4. Future Plans

Below are some of the future plans put in place to be completed soon, for this project is still ongoing.

4.1 Alternator Build

Like previously mentioned, there are current plans being carried out to fabricate a permanent magnet alternator that would directly connect to the end of the shaft of the turbine. The alternator would be built to contain a stator and a magnetic rotor or *magneto*. The stator would contain 9 coils of magnetic wire, each wound into a circular shape with a certain number of turns (to be determined). These coils will be encased in an epoxy resin. This epoxy resin will harden and become the shell of the stator. The magnetic rotor, or *magneto*, will contain 12 N42 Neodymium magnets measuring 1 inch in diameter and $3/8$ of an inch thick. These magnets will be placed on an aluminum plate in a circular pattern with a few millimeters of gap between each magnet.

4.2 Further Theoretical Exploration

At first, the theoretical aspect of this project seemed much easier than it worked out to be. At first, an attempt to make sense of the turbine's function was done through concepts of Mechanics, such as torque, angular velocity and acceleration, etc. However, it came to be that when analysis was done using these concepts, there was always symmetry between torques of both sides of the turbine. This led the calculations to another applicable area: Fluid Dynamics. Using this area of physics, *air* was considered a fluid. Due to the very complex calculations in this area, simple problems were analyzed such as the flow of a *fluid* against two planes at a certain angle.

Such calculations take a great amount of time and understanding of more advanced Mathematics. As the understanding of more advanced areas increase, this analysis can be pursed much more easily. Computer simulation is also a possible tool of analysis being considered for this future theoretical exploration.

References

[1] L. D. Landau and E. M. Lifshitz, *Fluid Mechanics* (Pergamon, 1987).

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Mr. Mark Morton

Antonio Di Vita is a sophomore at the University of New Haven studying Mechanical Engineering with a minor in Physics.

Antonio's interests in areas such as Vertical Axis Wind Turbines has increased his creativity and curiosity about many aspects in life.

Antonio continues to grow his knowledge in his field by taken as many opportunities as he can. He feels that a lack of motivation and devotion toward a student's area of interest does not make a good student.