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Vertical Wind Energy Engineering

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DESIGN AND EVALUATION OF TWISTED SAVONIUS WIND TURBINE

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1 PROBLEM DEFINITION

The goal of this project is to design and test a vertical axis wind turbine that will meet the following objectives:

1. The design will be novel and untested
2. The design will be self-starting
3. Design can be tested under harsh environmental conditions to assess longer-term reliability

2 SCOPE

This project will focus on the initial design and assessment of a new vertical axis wind turbine design. It will not compare efficiency to horizontal axis wind turbine, nor will it assess the feasibility of a full-scale model. This project will essentially be a demonstration of the proof of concept for the selected design. See Appendix A for initial design proposal.

3 BACKGROUND

3.1 Wind Energy and Wind Power

The conversion of wind energy into other useful forms of energy such as electricity is known as wind power. Large scale wind farms are typically connected to the local electric power transmission network with smaller turbines being used to provide electricity to isolated locations.

Wind energy is an ample and renewable source of green energy. The widespread distribution of suitable wind patterns and the declining cost of wind energy production make wind energy a viable alternative. The main drawbacks to wind generated power are the inconsistent power production caused by variable wind conditions and the low electrical conversion efficiency. Combating these conditions requires increased capital investment in energy storage solutions.

Wind energy is favoured as an alternative to fossil fuels as it is plentiful, renewable, widely distributed, and produces lower greenhouse gas emissions. Although the construction of wind farms is not universally welcomed due to the negative visual impact and the effect on wildlife, it remains one of the largest forms of green energy used in the world today.

3.2 Vertical Axis Wind Turbines (VAWT)

A wind turbine is a rotating machine that converts the kinetic energy of wind into mechanical energy which, in turn, can be converted into electricity. The main rotor shaft of vertical axis wind turbines are arranged vertically giving them the key advantage of not having to be aligned with the wind. This type of arrangement is highly advantageous on sites where the wind direction is highly variable as VAWTs can utilize wind from varying directions. The generator and gearbox of a VAWT can be placed near or at ground level, eliminating the need to be supported by a tower. This also makes them more accessible for maintenance.

Major concerns of VAWTs are the low power conversion efficiency, a pulsating torque created by some models and drag forces experienced as the blades rotate into the wind. This pulsating torque has a negative effect on wildlife and as such, efforts are being made to eliminate the pulsating torque and to develop more wildlife-friendly designs.

3.3 The Twisted Savonius

Darrieus turbines have relatively good efficiency but produce large torque ripple and cyclic stress on the tower contributing to poor reliability. The blades of a Darrieus turbine can be canted into a helix. This allows the wind to pull each blade around on both the windward and leeward sides of the turbine. As this feature spreads the torque evenly over the entire revolution, it prevents destructive pulsations. Savonius turbines have the advantage of being self starting and are considered more reliable; however they are low efficiency power turbines.

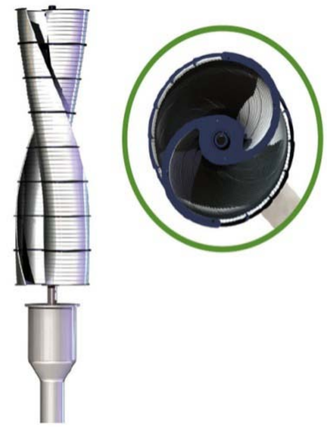


Figure 1 - Twisted Savonius

The Twisted Savonius as shown in Figure 1 combines the advantages of the savonius turbine with the twisted design of the helical darrieus. The blades, used for converting the power of the wind into torque on a rotating shaft, are uniquely designed to catch the wind from all directions, while the skewed leading edges reduce resistance to rotation.

4 DESIGN

The twisted savonius wind turbine design is based on complex fluid-structure interaction. It is in this regard that a computational fluid dynamic (CFD) analysis was undertaken in order to model and simulate the fluid interaction with varying design parameters.

4.1 Concept Selection

In the harsh climate of Newfoundland and Labrador, collecting wind energy has proven to be troublesome. Despite the fact that Newfoundland and Labrador has an ample supply of wind energy, the high wind speeds, icing conditions and harsh marine environment reduce the reliability of wind energy production. In general, all wind turbines used in the province

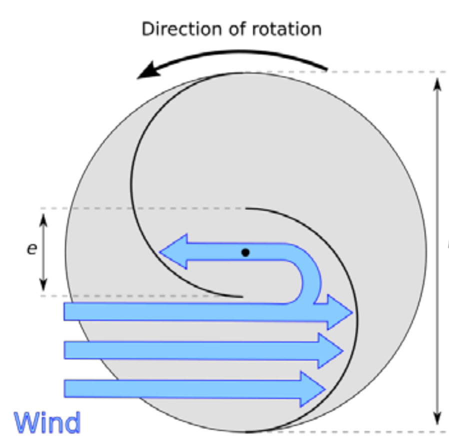


Figure 2 - Typical Savonius Wind Turbine Cross-Section

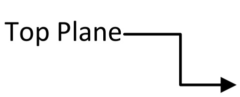
are horizontal axis wind turbines. The ongoing operations and maintenance costs make wind energy production, on a small scale, economically infeasible. To combat these reliability issues, there was a need to perform preliminary design and testing on a VAWT to assess energy production efficiency. Future testing of the turbine should focus on short and long-term reliability of the prototype.

A basic design was selected that had not previously been tested. The selected design exhibited a closed center chamber while most savonius wind turbines are open in the center to allow air to move between the two twisted chambers on each side of the turbine axis as can be seen in Figure 2. As will be shown later, the theoretical analysis of this turbine showed that the 360° angle of twist would provide the largest static torque. This also makes this design different from traditional twisted savonius wind turbines where a 180° angle of twist is standard.

4.2 Modelling

The twisted savonius wind turbine design is based on complex fluid-structure interaction. It is in this regard that a computational fluid dynamic (CFD) analysis was undertaken in order to model and simulate the fluid interaction with varying design parameters.

Through modelling varying savonius blade designs within Solidworks 2008, the optimal prototype concept was developed. The concept has been designed based on changing the angle of twist (Figure 3) and blade shape (Figure 4).



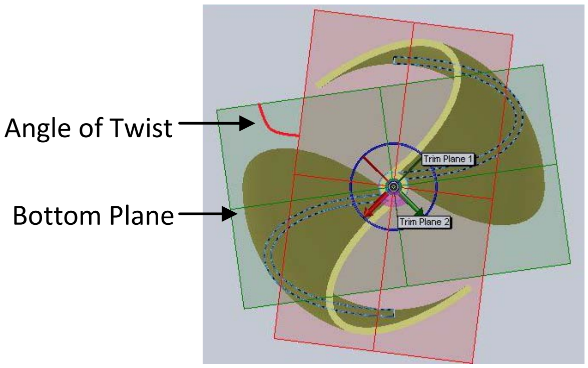


Figure 3 - Angle of Twist

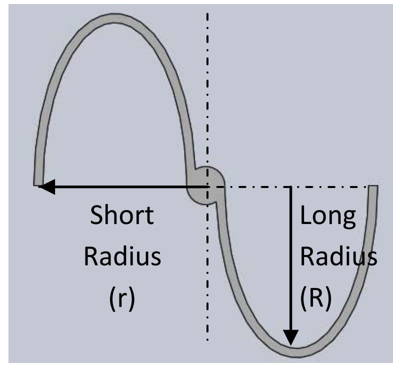


Figure 4 - Blade Radius

4.2.1 Limitations

The importance of foil size is an obvious consideration in developing the prototype. However, the foil size is limited by the working area of the rapid prototype machine and the wind tunnel.

Another limitation which was of great concern was the CFD software being used, FloWorks. FloWorks is limited to measuring static torque analysis on the varying foil designs. This restricted any comparisons to how the varying designs would perform under dynamic conditions in which the foil would be rotating at various speeds under varying torques. In the end, the decision was made to select the foil which showed greatest promise based on the calculated static torque from CFD analysis.

4.3 Computational Fluid Dynamics (CFD)

4.3.1 CFD Parameters

CFD analysis was utilized with the SolidWorks 2008 FloWorks software package. The following parameters were held constant for all prototype design variations:

Fluid:	Air
X direction velocity:	15m/s
Y and Z direction velocity:	0m/s

4.3.2 CFD Results

CFD analysis of variations of both angle of twist and long and short radius yielded the following results:

4.3.2.1 Circular Foil Design

Varying the angle of twist and measuring the torque generated on a static foil yielded the results shown in Table 1. Torque versus angle of twist is plotted in Figure 5.

Circle Radius	Angle of Twist (°)	Torque (N-m)			
		Value	Max	Avg	Min
47.8	45	-0.1595	-0.15987	-0.1591	-0.15631
47.8	90	-0.23381	-0.23397	-0.23224	-0.22986
47.8	180	-0.37821	-0.37821	-0.37535	-0.37123
47.8	270	-0.45554	-0.45562	-0.4435	-0.42907
47.8	315	-0.3479	-0.34802	-0.34576	-0.34209
47.8	360	-0.4708	-0.47348	-0.4716	-0.47006
47.8	405	-0.30022	-0.30242	-0.30144	-0.30022
47.8	540	-0.3131	-0.31657	-0.314	-0.3131
47.8	720	-0.2379	-0.23908	-0.23834	-0.23759

Table 1 - Summary of Torque by Changing Angle of Twist

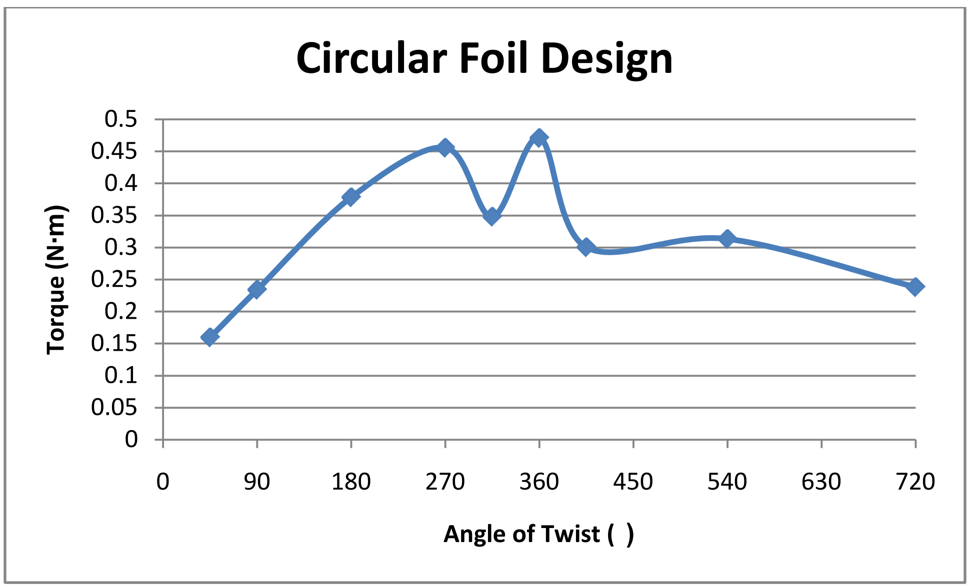


Figure 5 – Torque vs. Angle of Twist

From this analysis it is clear that maximum torque is achieved at a twist angle of 360°. This was an interesting result considering standard twisted savonius turbines use only a 180° twist.

4.3.2.2 Elliptical Foil Design

Holding angle of twist constant at 360°, based on results of Circular Foil CFD, and varying the long radius resulted in the static torque measurements shown in Table 2. Torque versus long radius is plotted in Figure 6.

Long Radius (mm)	**Short Radius (mm)**	**Angle of Twist (deg)**	**Torque (N-m)**			
			value	max	avg	min
20	47.8	360	-0.27497	-0.27632	-0.27545	-0.27485
40	47.8	360	-0.40699	-0.40931	-0.40733	-0.4058
80	47.8	360	-0.41232	-0.4168	-0.41354	-0.41199
60	47.8	360	-0.49076	-0.49076	-0.48759	-0.48541
100	47.8	360	-0.51999	-0.5219	-0.518	-0.515
108.3	47.8	360	-0.56037	-0.56549	-0.56242	-0.55956
160	47.8	360	-0.55805	-0.56369	-0.56176	-0.55805

Table 2 – Summary of Torque by Changing Elliptical Major Axis

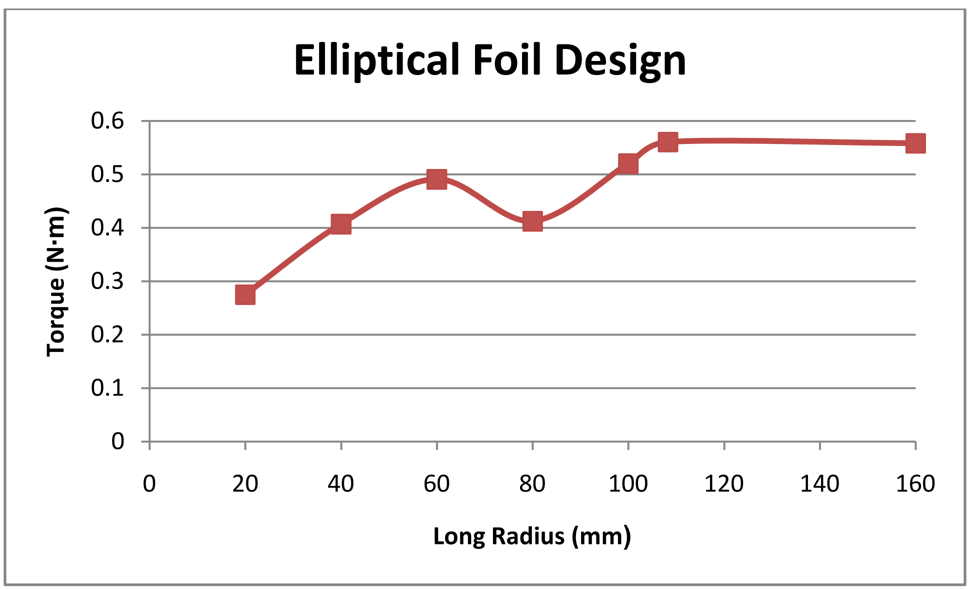


Figure 6 – Torque vs. Elliptical Major Axis

From this analysis it is clear that maximum torque is achieved at a long radius of 108.3 mm.

To verify that a twist angle of 360° is optimum for various elliptical designs, the twist angle was also varied at various long radii (refer to Table 3).

Long Radius (mm)	Short Radius (mm)	Angle of Twist (°)	Torque (N-m)			
			Value	Max	Avg	Min
80	47.8	90	-0.04497	-0.07151	-0.04697	-0.03456
80	47.8	180	-0.29442	-0.30212	-0.29507	-0.28883
80	47.8	360	-0.41232	-0.4168	-0.41354	-0.41199
80	47.8	405	-0.20715	-0.21397	-0.20818	-0.20599
108.3	47.8	0	0.425486	0.395606	0.417385	0.451704
108.3	47.8	45	0.3183	0.304751	0.335832	0.35658
108.3	47.8	90	0.208451	0.163101	0.198852	0.232821
108.3	47.8	180	-0.21527	-0.21826	-0.21599	-0.21457
108.3	47.8	270	-0.42199	-0.42884	-0.42261	-0.42068
108.3	47.8	360	-0.56037	-0.56549	-0.56242	-0.55956
108.3	47.8	450	-0.42772	-0.42781	-0.42342	-0.4182

Table 3 – Summary of Torque by Changing Angle of Twist and Elliptical Major Axis

The results of Table 3 indicate that a twist angle of 360° results in the greatest static torque generated by the foil.

4.3.2.3 Summary of Results

The following conclusions can be drawn based on the CFD analysis conducted:

- A 360° angle of twist results in the greatest static torque for both circular and elliptical foil designs.
- A long radius of 108.3mm at a twist angle of 360°, results in a larger static torque than that generated for a circular design at a 360° twist angle (0.56037 N·m and 0.4708 N·m respectively).

The final design drawings are shown in Appendix B.

5 Prototype Fabrication

The design and construction of the twisted savonius foil was focused solely on turbine performance. This allows for improved analysis of the turbine performance without introducing unknown variables such as generator efficiency or line losses. Sizing of the blade was constrained by the maximum dimensions of the rapid prototype machine and the wind tunnel. The rapid prototype machine can create an object having maximum dimensions of 10” by 10”, as such the width of the blade was restricted to 9 inches. Vertical turbines commonly have a 3 to 1 height to width ratio suggesting a 27 inch height for the foil. With consideration given to installation and clearance within the wind tunnel, the proposed 9 x 27 inch foil was deemed acceptable. To create this design using the rapid prototyping machine, the foil was sectioned into pieces of a manageable height for construction and assembled to create a single unit. In such a way the foil can be constructed for approximately $6300 (The quotation is available in Appendix C).

5.1 Rapid Prototyping

Construction of the prototype blade was completed using the Fused Deposition Modeling (FDM) rapid prototyping machine available at Memorial University. The rapid prototyper uses FDM to turn computer-aided design (CAD) geometry into solid physical objects. PC-ABS thermoplastic material is heated such that it is extruded in a semi-liquid state. Figure7, Figure 8, and Figure 9 show the FDM model tray, injection head and PC-ABS material. The successive layers fuse together and solidify to build an accurate, three-dimensional model of the blade design.

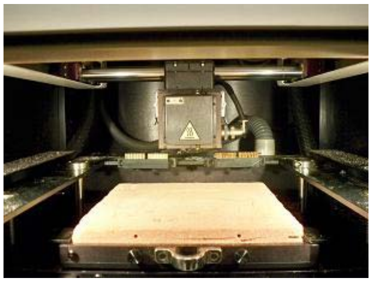


Figure 7- Model Tray

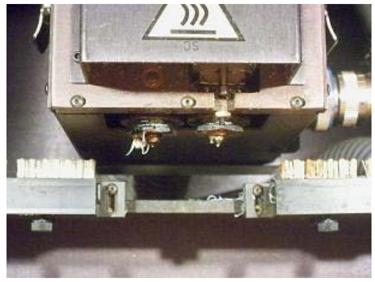


Figure 8 - Injection Head

Figure 9 - PC-ABS Material

The Figures below show various stages of blade construction.

Figure 10 - Completed Section Showing Support Material

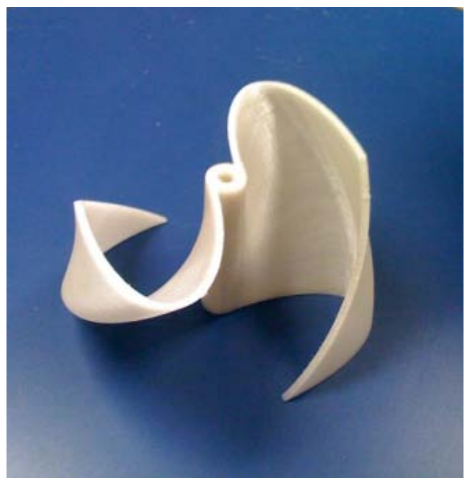


Figure 11 - Completed Blade Section

Figure 12 - Assembled Sections (4 of 6, 270°)

5.2 Challenges and Limitations

Fabrication introduced a number of challenges, creating minor setbacks and deviation from the original design plan. Each challenge and corresponding solution are presented below.

5.2.1 Prototype Size Constraints

Limitations in nozzle movement prevented achieving maximum cross-section.

Upon entering the proposed CAD model for the first section into the rapid prototyping machine, it was discovered that, while the design model dimension were inside the build restraints of the machine, the full cross sectional area could not be realized due to limitations in movement of the nozzle head. As such, the model was reduced to 95% of the initially proposed dimensions, reducing the size of the completed foil to 217mm (8.55") in diameter and 651mm (25.65") in height.

Damage to nozzle heads due to overheating of material in the semi-liquid state.

Within the original design plan the blade was sectioned into three segments of 217mm (8.55") in diameter and 217mm (8.55")in height as to remain within the build limitations of the prototyper, (shown in figure 13). It was found that the long run time (approx. 75 hours) required to create each section would cause the machine to overheat, damaging the nozzles, making the machine inoperable. The blade was further sectioned into 6 equal segments, 108mm (4.25") in height to reduce runtime (21 hours) and prevent overheating.

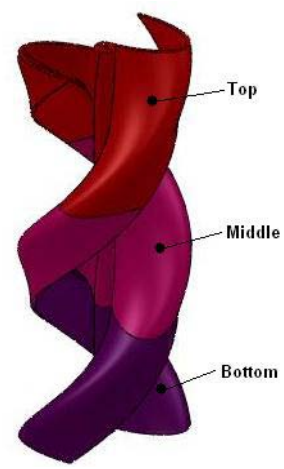


Figure 13 - Sectioned Foil Design

5.2.2 Assemblage

Shrinkage of the material during cooling from the semi-liquid state.

Shrinkage of the ABS material during cooling caused the thin material at the outer tip of each section to deviate from the specified height, creating discontinuities in the foil surface when assembled. Commercial body filler was applied to each joint and shaped to match the surround contour of the foil as to prevent disruption of the air flow. This can be seen as the blue material shown in Figure 12.

Rotational unbalance within the foil due to body filler and flexibility of shaft.

The original design plan implemented a two segment aluminum shaft that was passed through the exterior wall of the wind tunnel and inserted into either end of the foil. This shaft was found to be too flexible and was inadequate in maintaining a smooth rotation at high speeds. In addition, the use of body filler during the assembly phase created an unavoidable rotational imbalance due to the excess mass along the edge of the foil. To combat these issues, a continuous shaft composed of more rigid material (carbon steel) was inserted through the foil and attached to the top and bottom of the wind tunnel.

5.3 Prototype Setup and Testing

5.3.1 Setup

The blade section will be tested using Memorial University's wind tunnel. The wind tunnel is a horizontal open-circuit facility with a rectangular 20.0 x 0.93 x 1.04 meter test section. The turbine will be installed centered both horizontally and vertically within the wind tunnel with both ends of the shaft extending through the bottom and top of the tunnel. The shaft shall have low resistance bearings connected at both ends to a support base.

5.3.2 Testing Setup

With the blade section installed vertically within the wind tunnel, testing instrumentation must be calibrated and installed. The following components were installed for testing and data acquisition during operation:

- Friction Brake Dynamometer (Includes Friction Brake and Load Cell)
- Digital Tachometer
- Anemometer

5.3.2.1 Friction Brake Dynamometer

The frictional dynamometer brake is used to measure the power generated by the rotating turbine. It consists of an adjustable clamp around the fly wheel to induce friction and the force required to keep the clamp from revolving with the shaft is measured using a load cell.

The friction brake is supported on a rotating support table. The bottom section of the table is fixed to the wind tunnel while the top section of the table is free to rotate.

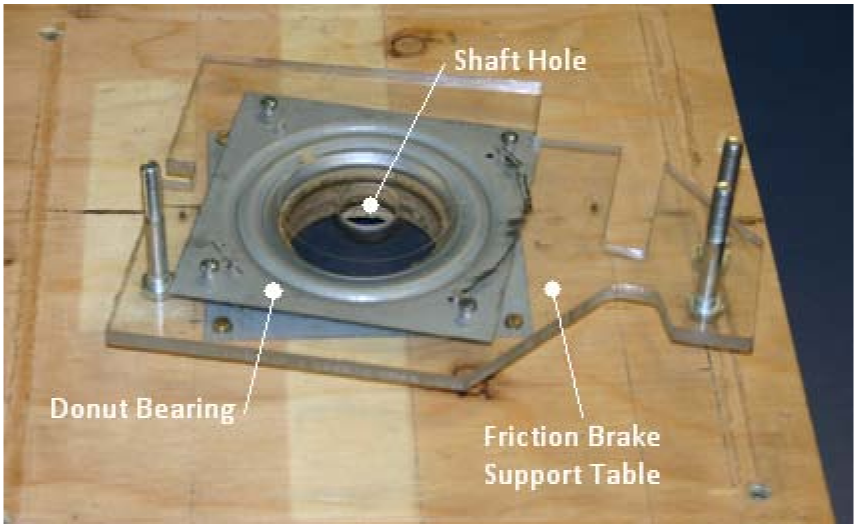


Figure 14 - Friction Brake Support Table

A LFS 270 Miniature S-Beam Load Cell with a load range capacity from 0-1lb was an intergrated part of the Friction Brake Dynamometer. It was used to capture the load applied to the friction brake by the rotating flywheel. Friction was adjusted throughout the test program using the friction adjustor.

Calibration of the load

Load	
N	Volts
0	0.0488
1.962	0.0684
2.943	0.0781
4.905	0.0967

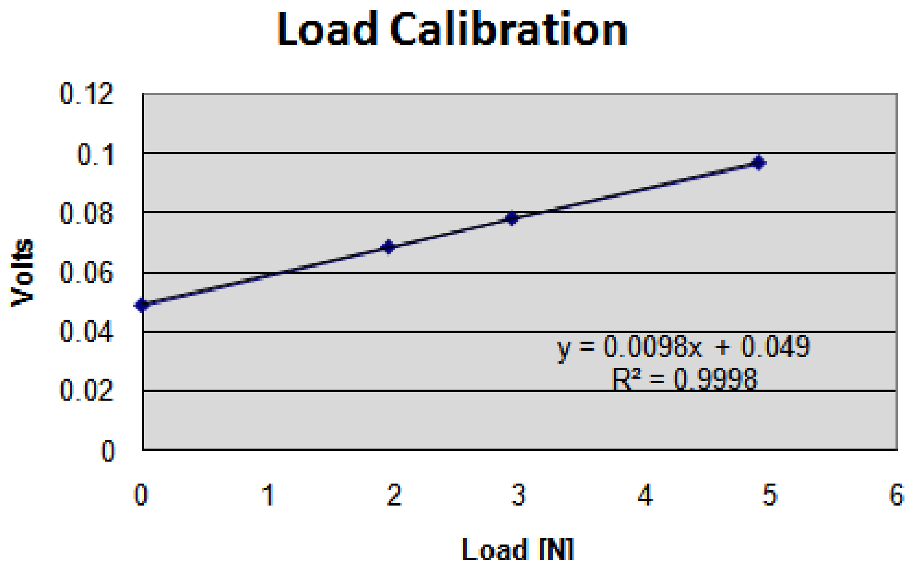


Figure 15 - Volt - Load Conversion

Figure 16 - Friction Brake Dynamometer

5.3.2.2 Digital Tachometer

The digital tachometer was used to measure the rotation speed of a shaft while the turbine was rotating in revolutions per minute (RPM). This was a manual process and was done during all phases of testing and recorded for analysis (See Appendix D for Tachometer specifications).

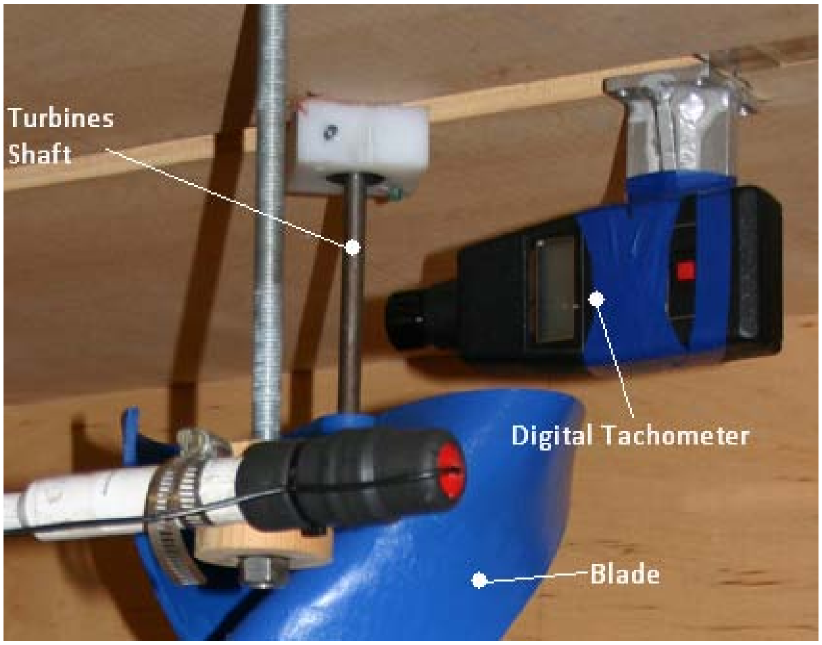


Figure 17 - Digital Tachometer

5.3.2.3 Anemometer

The fixed anemometer is used to measure and record the wind speed in the wind tunnel adjacent to the turbine during testing. The fixed wind anemometer was calibrated using a handheld anemometer and varying the wind tunnel flow. As the wind flowed past the anemometer, the wind speed was acquired using the handheld anemometer and used as the input value for calibration. The table on the following page shows the calibration data and plots.

Wind Speed	
m/s	Volts
0	-0.0091
1.19	0.0765
3.07	0.2223
5.18	0.3826
7.3	0.5371
8.81	0.6601
9.71	0.7381
10.68	0.8162

Table 4 - Wind Speed Calibration Data

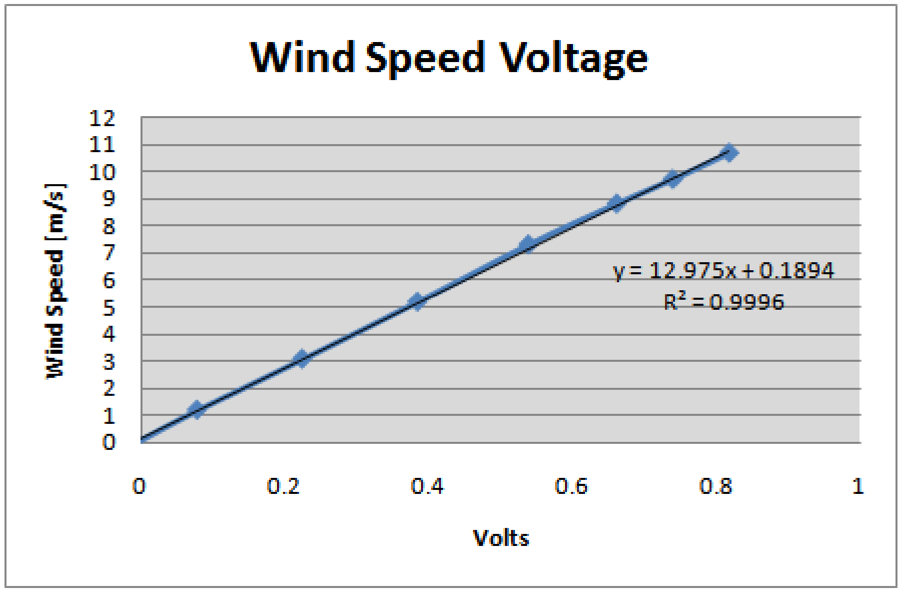


Figure 18 - Volts - Wind Speed Conversion

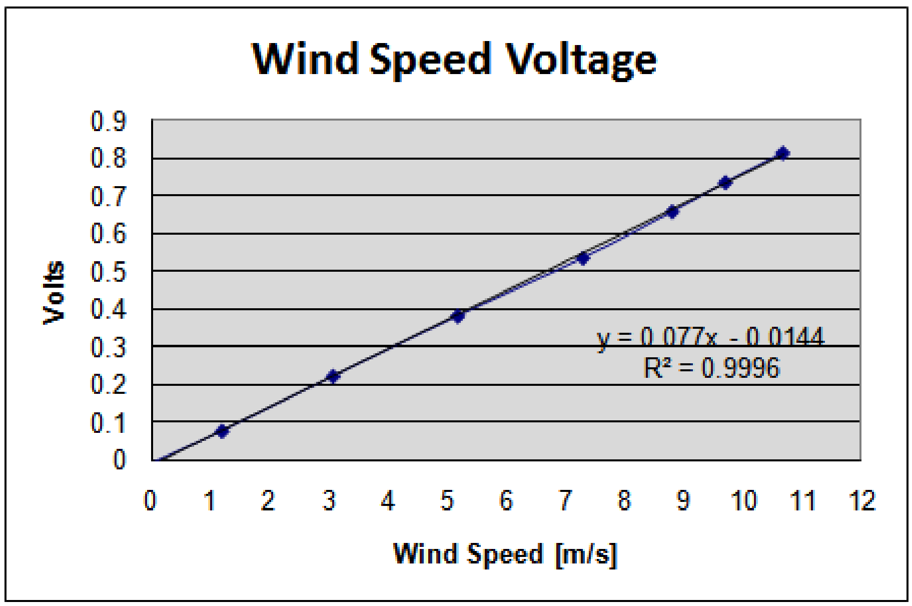


Figure 19 - Wind Speed - Volts Conversion

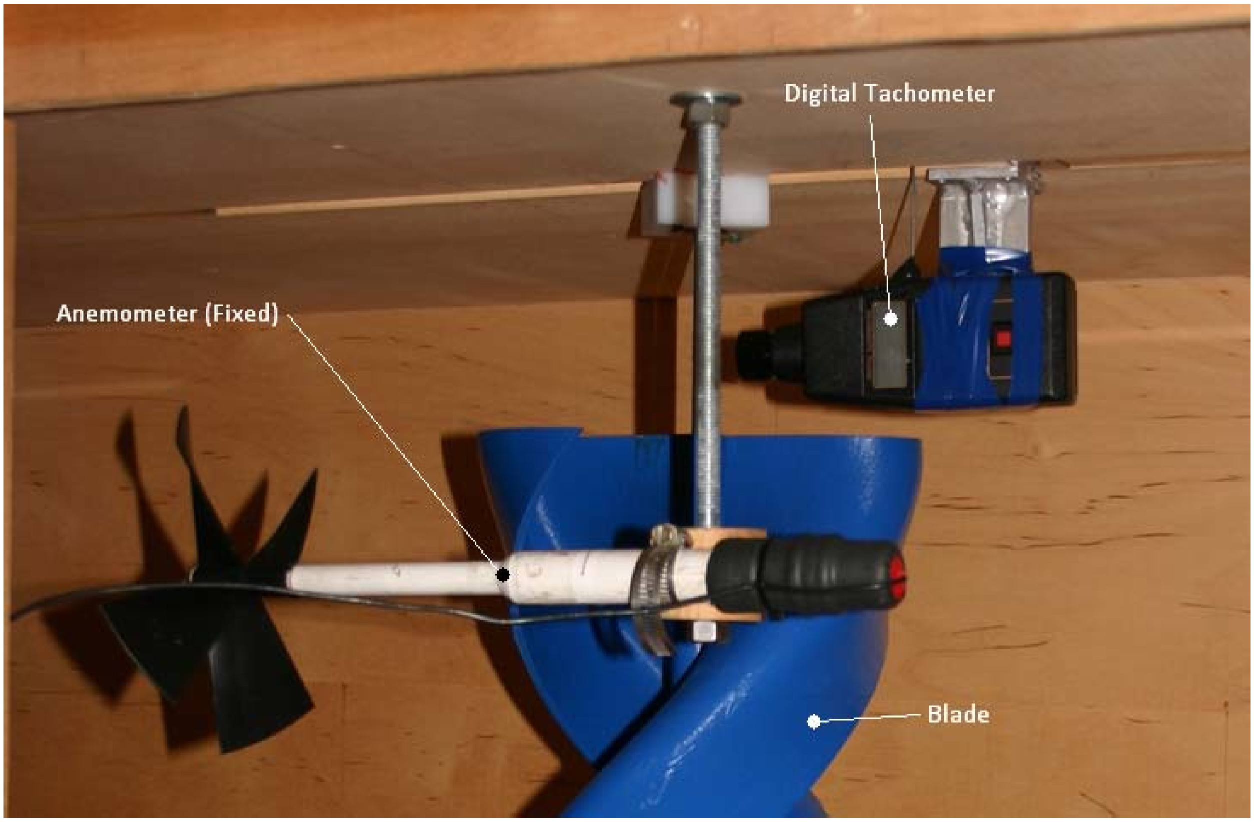


Figure 20 - Anemometer Installation

5.3.3 Testing

Upon final installation of the blade and instrumentation in the wind tunnel, the blade was exposed to wind speeds from 5 m/s to 10.5 m/s. Data was acquired at approximately 30 to 35 points throughout the testing phase to generate data that could be later analysed. The testing data involved acquiring load data from the friction brake dynamometer load cell, wind speeds from the anemometer and manual measurement of the rotational speed of the turbine shaft.

The testing matrix for the wind turbine tests were as follows:

Helical Savonius Wind Turbine Test Matrix				
Test Number	Wind Tunnel [km/h]	[m/s]	Torque Setting	Test Condition
S5-T1	18	5.0	1	Static
S5-T2	18	5.0	2	Dynamic
S5-T3	18	5.0	3	Dynamic
S5-T4	18	5.0	4	Dynamic
S5-T5	18	5.0	5	Dynamic
S5-T6	18	5.0	6	Dynamic
S6-T1	21.6	6.0	1	Static
S6-T2	21.6	6.0	2	Dynamic
S6-T3	21.6	6.0	3	Dynamic
S6-T4	21.6	6.0	4	Dynamic
S6-T5	21.6	6.0	5	Dynamic
S6-T6	21.6	6.0	6	Dynamic
S7-T1	25.2	7.0	1	Static
S7-T2	25.2	7.0	2	Dynamic
S7-T3	25.2	7.0	3	Dynamic
S7-T4	25.2	7.0	4	Dynamic
S7-T5	25.2	7.0	5	Dynamic
S7-T6	25.2	7.0	6	Dynamic

Helical Savonius Wind Turbine Test Matrix				
Test Number	Wind Tunnel [km/h]	[m/s]	Torque Setting	Test Condition
S8-T1	28.8	8.0	1	Static
S8-T2	28.8	8.0	2	Dynamic
S8-T3	28.8	8.0	3	Dynamic
S8-T4	28.8	8.0	4	Dynamic
S8-T5	28.8	8.0	5	Dynamic
S8-T6	28.8	8.0	6	Dynamic
S9-T1	32.4	9.0	1	Static
S9-T2	32.4	9.0	2	Dynamic
S9-T3	32.4	9.0	3	Dynamic
S9-T4	32.4	9.0	4	Dynamic
S9-T5	32.4	9.0	5	Dynamic
S9-T6	32.4	9.0	6	Dynamic
S10-T1	36	10.0	1	Static
S10-T2	36	10.0	2	Dynamic
S10-T3	36	10.0	3	Dynamic
S10-T4	36	10.0	4	Dynamic
S10-T5	36	10.0	5	Dynamic
S10-T6	36	10.0	6	Dynamic

Figure 21 - Testing Matrix

Static tests were conducted with the frictional brake fully set, while the dynamic tests were conducted by reducing the friction of the brake on the flywheel.

The following picture shows the completed installation of the blade and all testing components:

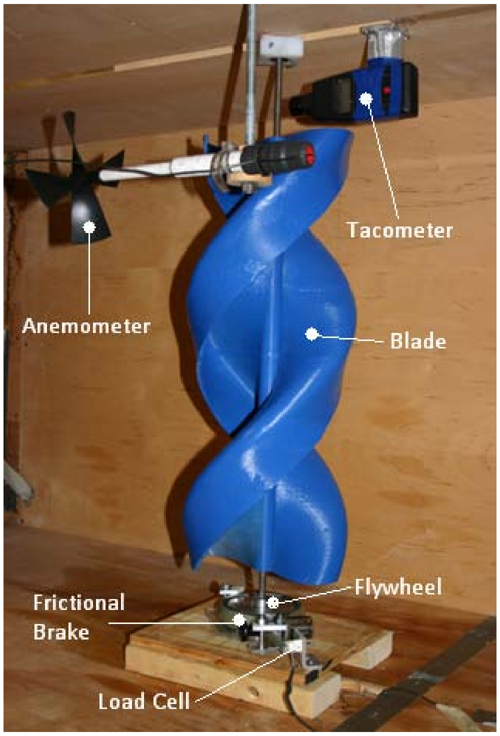


Figure 22 - Turbine Test Setup

5.3.4 Testing Results

Analysis of all tests where preformed using excel. The primary data was grouped and averaged over different times ranging from 20 seconds to 1 minute. This allowed for delays in the response of the turbine due to the difference in inertia between itself and the anemometer. Figure 23 below shows the data acquired for load and wind speed of a single test at approximately 5 m/s. The graph shows a moving average of wind speed and loads. This type of graph best shows the data acquired from the test by moderating the effect of outliers and data variability.

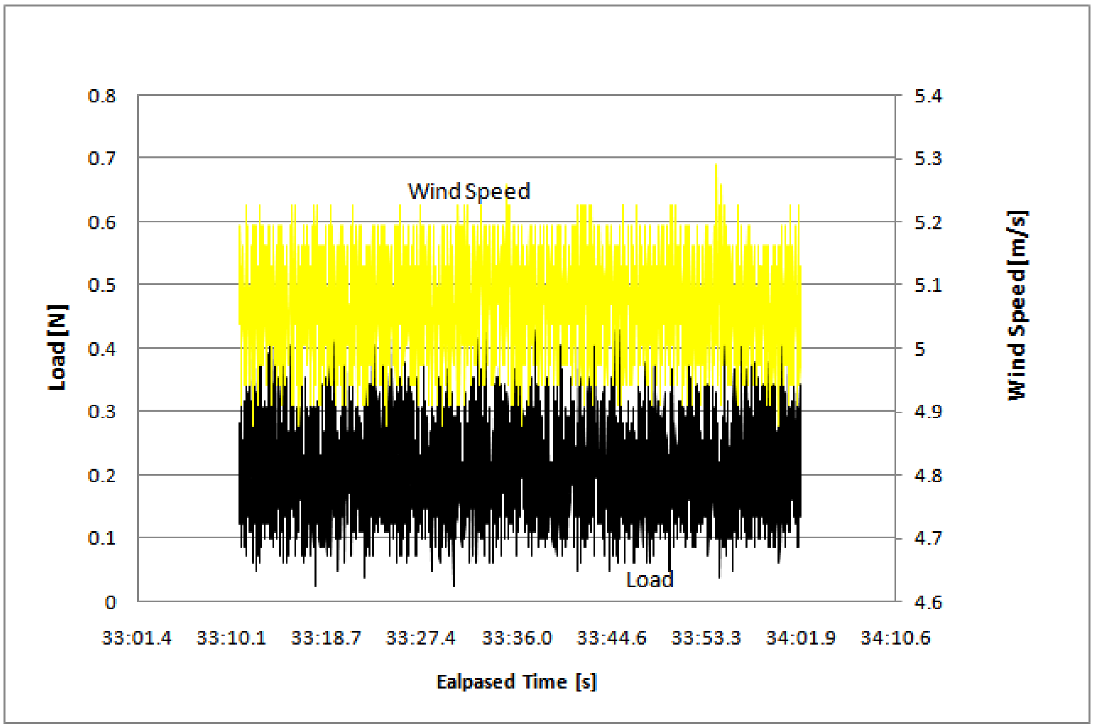


Figure 23 - Running Plot of Average Wind Speed and Load

The Tip Speed Ratio (TSR) is of vital importance in the design of any wind turbine. If the blades of the wind turbine turn too slowly, most of the wind will pass unused up the slope of the blades. Alternatively, if the blades turn too quickly, the blurring blades will appear like a solid wall to the wind. Therefore, wind turbines are designed with optimal tip speed ratios to extract as much power out of the wind as possible. Typical TSR graphs are plotted against the power coefficient (Cp) of the turbine and a good design looks like Figure 24 as seen below. Please note that this graphic represents the a horizontal axis wind turbine where the tangential velocity of the tip of the turbine blade can exceed the wind speed by up to 9 times.

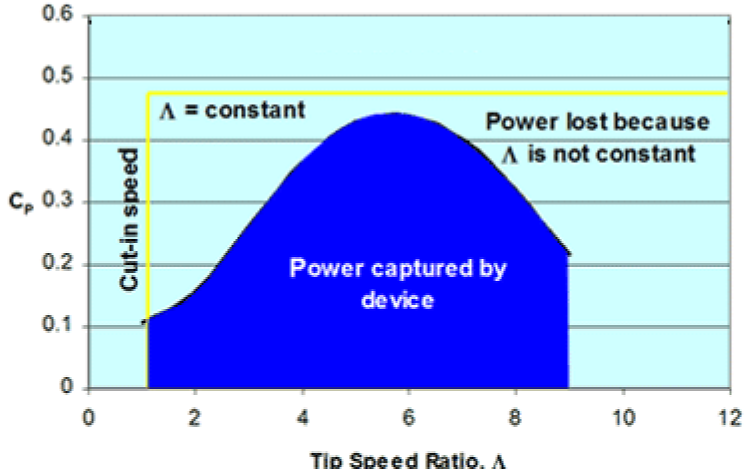


Figure 24 - Typical TSR vs. Cp

The data collected and analyzed from testing the Twisted Savonius blade design are shown within the table below:

Wind Speed [m/s]	cp	Tip Speed Ratio	Power [Watts]
5.1	0.143	0.682	1.962
5.1	0.136	0.746	1.875
5.1	0.120	0.835	1.649
5.1	0.104	0.893	1.426
5.0	0.066	0.993	0.907
5.0	0.048	1.013	0.666
6.0	0.103	0.254	1.983
6.0	0.103	0.338	1.988
5.9	0.106	0.490	2.033
5.9	0.100	0.610	1.915
5.8	0.088	0.922	1.681
7.2	0.007	0.340	0.230
7.1	0.033	0.605	1.023
7.1	0.046	0.736	1.406
7.0	0.049	0.971	1.504
7.0	0.036	1.022	1.118
7.8	0.028	0.525	1.144
7.8	0.040	0.687	1.631
7.7	0.029	0.881	1.157
7.7	0.011	1.047	0.463
9.1	0.097	0.288	6.174
9.0	0.081	0.463	5.207
9.0	0.087	0.543	5.557
9.0	0.052	0.625	3.329
8.9	0.045	0.839	2.864
8.9	0.035	0.776	2.244
10.6	0.124	0.298	12.309
10.5	0.115	0.369	11.390
10.5	0.085	0.601	8.487
10.5	0.082	0.683	8.157
10.4	0.066	0.951	6.558

Table 5 - Processed Testing Data

The data within the table above has been graphed for easier interpretation and visualization.

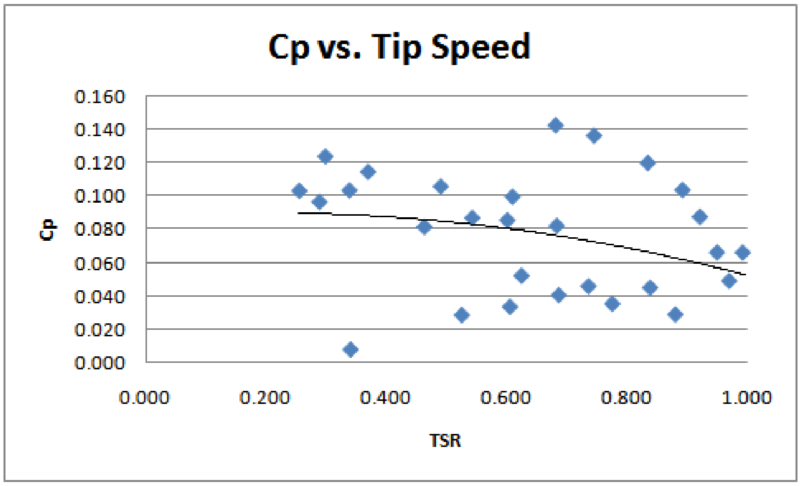


Figure 25- Cp vs Tip Speed

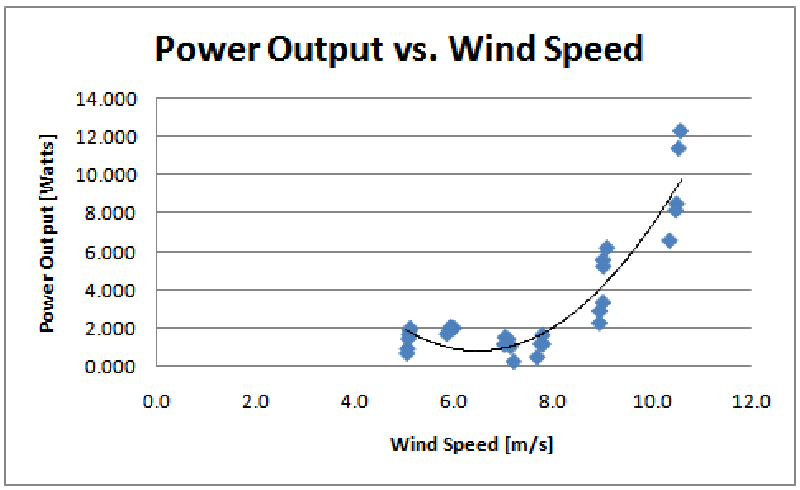


Figure 26 - Power Output vs. Wind Speed

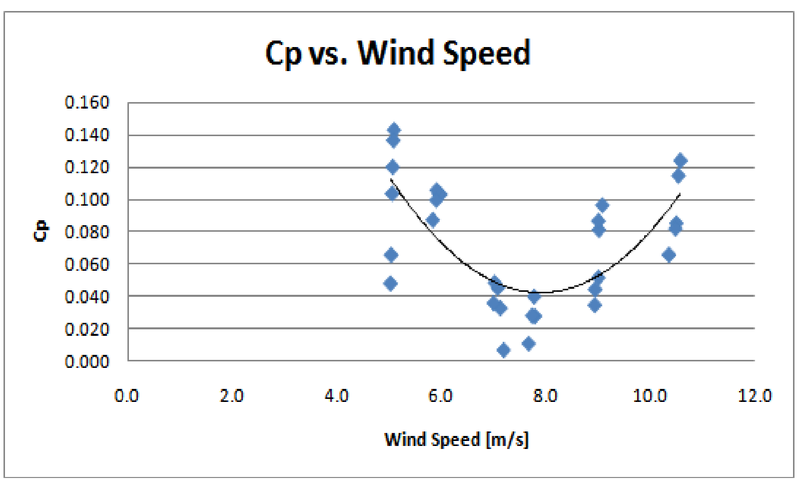


Figure 27 - Cp vs. Wind Speed

The results indicate that as the wind speed increases, the Cp follows a concave profile reaching a maximum concave point at approximately 8 m/s. This is contrary to what was predicted from the CFD Analysis. The Cp results range from a .4% to 15%, which range span was larger than expected.

Figure 24 shoes a typical Cp vs. Tip Speed Ratio profile for a good design where the maximum efficiceny occurs at the peak of the line and the total power output by the turbine is represented by the area under the curve. The test data indicates a slight convex profile but does not accurately mimic the general curve shape as seen in Figure 24.

Power outputs ranged from 0.23 watts (at 7 m/s) to 12.3 watts (at 10.6 m/s). The maximum power output for this design is relatively good based on the size of the tested model.

The blade design enabled a self-start under no load at a wind speed as low as 1.2 m/s. The starting wind speed may, in fact, be lower but this could not be measured as the minimum wind speed available in the testing facility was only 1.2m/s.

5.3.5 Testing Installation Limitations

The method of installation of the blade section and instrumentation components likely affected the accuracy of the test results. The loads acquired during testing are as large as 2.6N (0.58 Lbs), which is approximately half of what was predicted through the CFD Analysis of 5N (1.1 Lbs). Considering that these loads are lower than expected, the following are areas of concern which likely affected the test results:

Friction Plate Support Table

The friction from the friction brake support table would more significantly affect low wind speed tests. At these low speeds, the friction between the brake and the support table would have a larger impact on the measure load.

Friction Brake / Flywheel Interaction

A slight pulse vibration was imposed on the friction brake by the rotating flywheel at all speeds. This pulse vibration imposed undesired loads to the load cell. Post processing of the raw data was unsuccessful in filtering out the pulse loads.

The friction applied by the friction brake was in a coarse manner. The adjustment of this brake never allowed low rotational tests normally below 200 RPM. Releasing the brake from the static test was difficult to control where it was not possible to determine the break-free load for the turbine.

Blade Balance

The completed blade was fabricated from 6 sections where each section slightly varied in shape, size and weight. Joining all 6 sections together to form the completed blade required epoxy and automotive body filler. The addition of the epoxy and body filler, plus variations in each section, caused a slight unbalance in the blade. Therefore, during rotations, this unbalance caused the blade to vibrate, amplifying the pulse effects of the friction brake – flywheel interaction described above.

Data Acquisition System (DAQ)

The physical hardware of the DAQ system limited the data acquisition sampling rate. The maximum sampling rate of the DAQ was 50Hz while the desired sampling rate was 250 to 500Hz. Such a high sampling rate was necessary to utilize the selected LED tachometer. This method of measuring the rotational speed of the turbine was forgone and a handheld digital tachometer was used.

6 CONCLUSION

The results of this analysis met all established performance goals. A new variation of the standard twisted savonius wind turbine was analyzed, designed and tested under various wind conditions. The turbine also proved to be self-starting under low wind speeds. The data from testing showed more than desired variation but allowed for some general conclusions and provided insight into areas for future improvement. The maximum measured power output from the blade was just over 12W and the maximum blade efficiency was approximately 15%. When the tip speed ratio was plotted against the coefficient of performance, the data was irregular but a polynomial curve did show a general trend that resembled the expected curve. Additional testing would be required to make a definitive conclusion. However, the general curvature supports the general engineering theory behind VAWTs.

7 FUTURE CONSIDERATIONS

Due to the large variations in testing data, additional testing is required. This testing should focus on the following key areas to improve testing results:

1. **Data Acquisition System** – Increase the sampling frequency of the DAQ to allow for a more accurate reading of the rotational speed of the shaft. Increasing the sample rate will permit the use of a LED sensor that can count the number of rotations made by the turbine.
2. **Braking Mechanism** – The friction brake presented problems in pulse loading. It should be determined if the use of an eddy current is feasible. Alternatively, a friction brake more suited to the current testing methods can be acquired and used.

Additional considerations to validate or invalidate this particular design include:

1. **Install a small generator** – Connect the turbine to a small generator to determine the power output of the entire system. This particular study focused on the blade performance but the full concept should include the total system efficiency.
2. **Reliability Testing** – Testing of the turbine should be conducted under various weather conditions to determine the reliability of the turbine. This turbine should be subjected fully developed and turbulent winds under icing and snowing conditions. The components should also undergo longer term reliability testing when subjected to Newfoundland’s environment.

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9 APPENDIX A: INITIAL DESING PROJECT PROPOSAL

4

MEMORIAL UNIVERSITY

Sustainable Design And Enterprise

Mechanical Engineering 8936
Engineering Project Proposals For Winter 2009

Team Members (print name/student #):

1. Jeremy Wiseman / 200336428
2. Ian Duffett / 009723628
3. Jeff Perry / 200211837
4. Blaine Stockwood / 009224597

NB: Authorization is required for anything other than 3-4 students.

Project Supervisor:

I have read this project proposal and agree to act as a technical project supervisor for this student design team during the Winter 2009 academic semester.

TARIQ IQBAL

(Print Name)

Signature

Project Title:

Reliability and Performance Evaluation of Vertical Axes Wind Turbines for use in Newfoundland

Project Description:

Investigation into the predicted performance of vertical axes wind turbines under variable wind and environmental conditions. Examine mechanical stability and reliability under unfavorable weather and prolonged exposure to a harsh costal environment. Evaluate potential installation in coastal communities in Newfoundland.

Project Methodology (i.e. how will you solve this problem):

- Research climate conditions and evironmental exetremes experienced along the coast of Newfoundland.
- Research design and performance of vertical axes turbines and potential performance under predicted conditions
- Fabrication & Testing of scaled prototype under various wind tunnel conditions. Apply regiours testing regime mimicing environmental conditions.
- Provide final performance evaluation and conclusions on applicability of design for Newfoundland.

MEMORIAL UNIVERSITY

Sustainable Design And Enterprise

Project Requirements/Specifications (i.e. what is a successful solution) :

- Scalable power output from prototype testing under variable wind conditions
- Mechanical stability and reliability during unfavorable weather (testing) and simulated prolonged exposure to a harsh coastal climate.

Project Deliverables (i.e. reports, presentations, virtual prototypes, functioning prototype, etc.) :

- Early Concept Design Report w/ predicted plan forward
- Development and Flow Study on C.G. model
- Fabricated (scalable) prototype
- Testing Analysis for prototype exposure to various wind and mimiced environmental conditions.
- Final Design Report / Presentation detailing performance evaluation, predicted mechanical reliability and applicability of design for installation in Newfoundland.

Please attach a timeline for the various stages/tasks of the project in Gantt Chart format including major project milestones.

Signatures:

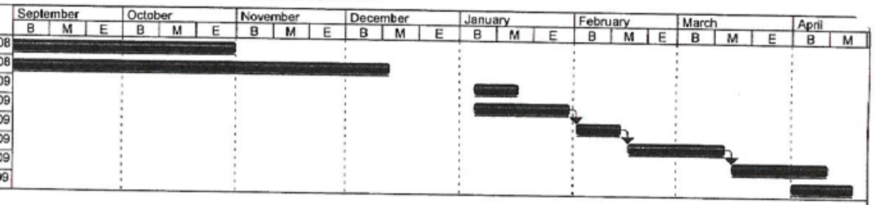
The above statements accurately reflect the nature and scope of the project we intend to pursue in for our Term 8 design course.

1. [signature]
2. B. Stenmel [signature]
3. [signature]
4. [signature]

Date: 31/07/08

Reliability Investigation into Use of Vertical Adis Wind Turbine in Newfoundland Climate

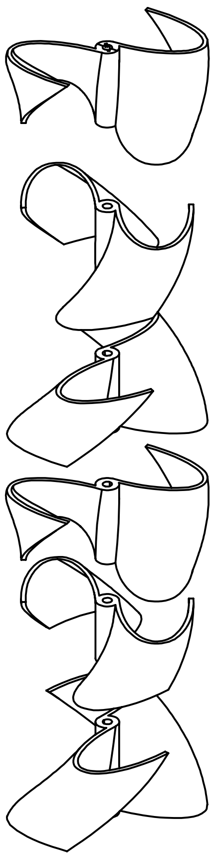
ID	Task Name	Duration	Start
1	Research Newfoundland Environmental Conditions	45 days?	Mon 01/09/08
2	Research Design and use of Vertical Axis Turbine	75 days?	Mon 01/09/08
3	Develop Conceptual Design Report w/ Pridicted Plan Forwar	10 days?	Mon 05/01/09
4	Development of Computer Generated Turbine Model	20 days?	Mon 05/01/09
5	Flow Study on Computer Generated Model	10 days?	Mon 02/02/09
6	Fabrication of Scaled Prototype	20 days?	Mon 16/02/09
7	Testing Analysis of Prototype under Variable Conditions	20 days?	Mon 16/03/09
8	Final Analysis and Design Report	13 days?	Wed 01/04/09



Project: Project Schedule
Date: Wed 30/07/08

Task | Split | Progress | Milestone | Summary | Project Summary | External Tasks | External Milestone | Deadline

10 APPENDIX B: TURBINE DESIGN ENGINEERING DRAWINGS



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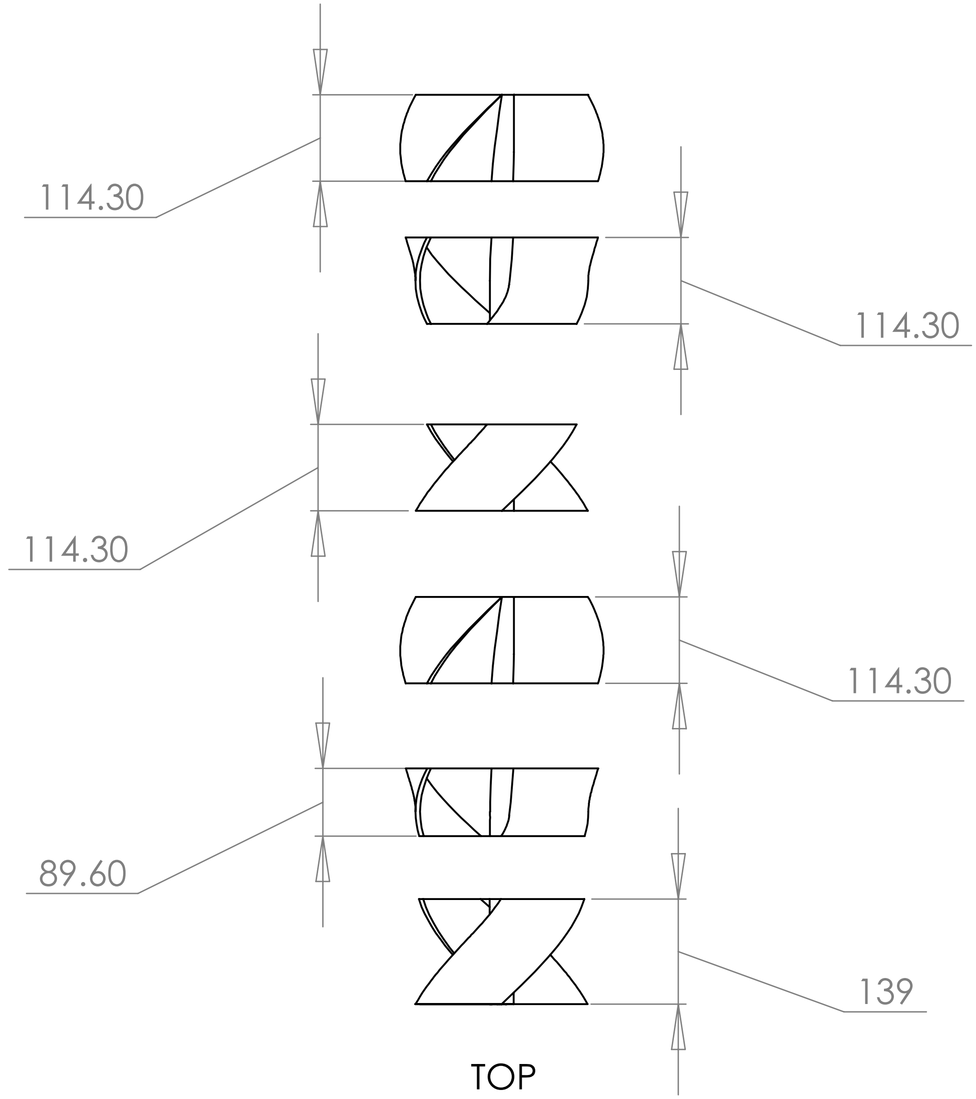


TOP

	NAME	DATE
DRAWN	JW	04/05/2009
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN mm

MATERIAL
PC-ABS Thermoplastic

DO NOT SCALE DRAWING

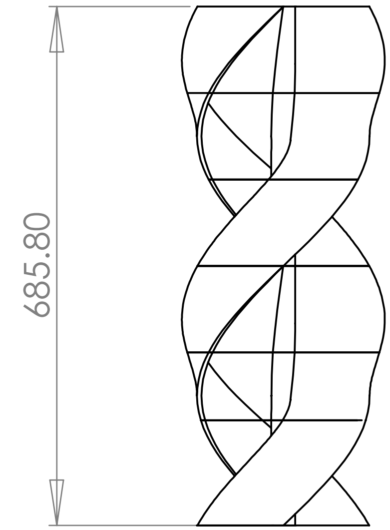
TITLE:

Turbine Foil Exploded View

SIZE A | DWG. NO. VWEE - 01-01 | REV 0

SCALE: 1:10 WEIGHT:

5 4 3 2 1



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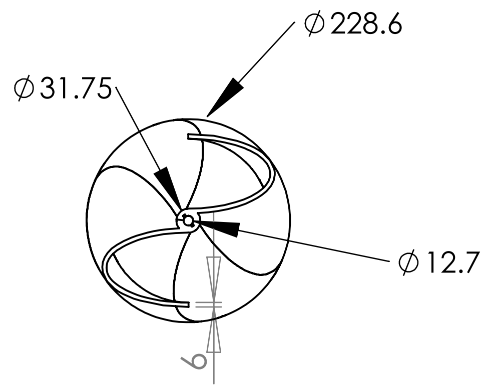

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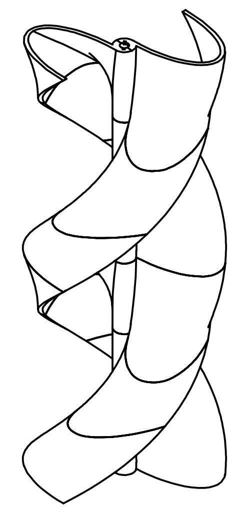


ISOMETRIC

PROPRIETARY AND CONFIDENTIAL

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN mm

MATERIAL
PC-ABS Thermoplastic

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	JW	04/05/2009
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

Turbine Foil
Detailed Dimensional View

SIZE	DWG. NO.	REV
A	VWEE - 01-02	0

SCALE: 1:10 WEIGHT:

5 4 3 2 1

11 APPENDIX C: RAPID PROTOTYPE QUOTATION

QUICKPARTS

ISO 9001:2000 Certified

301 Perimeter Center North
Suite 600
Atlanta, GA 30346

Phone: [illegible]
Fax: [illegible]
www.quickparts.com

Formal Quotation

Quote ID: 404896_v3 **April 1, 2009**

Customer Information

Company Name:	Memorial University	**Email Address:**	j.perry@mun.ca
Company Contact:	Jeff Perry	**Phone:**	(709) 765-4149

Quote Information

Process	Part Name	Quantity
FDM	360deg - 108.3mm - middle(bottom).STL	6

Family Build Total:
$6356

Additional Information

Payment Terms	Estimated Delivery	Finish	Material	Shipping
Net 30 days	Standard	Standard	Rigid ABS - White	Not Included
By placing an order of parts listed on this formal quotation, customer agrees to abide by Quickparts' Terms and Conditions of Sale				

Notes:

Quickparts Contact:

Low-Volume Sales Managers	Tooling and Production Sales Managers	Project Managers
Robert A Bellingrath	Kyle M Adams	Alisa S Kelly Adam C Ragsdale

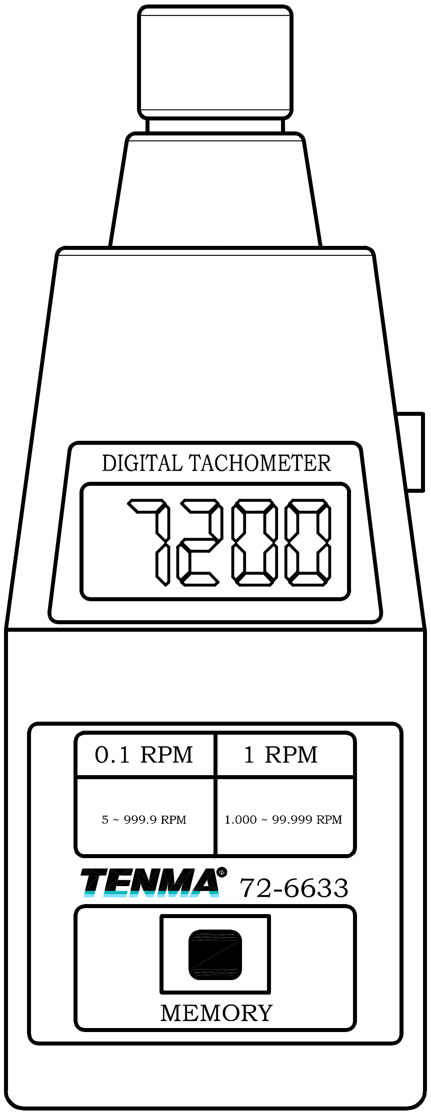
AUTHORIZATION TO PROCEED	
By signing this Authorization to Proceed, Memorial University hereby authorizes Quickparts to begin the work specified herein, subject to Quickparts' Terms and Conditions of Sale and shall pay Quickparts for all work specified in this Formal Quotation. Jeff Perry will provide a purchase order or credit card information within two business days.	
____ PO Number ______________________ ____ CC Number ______________________ CC Exp Date ______/______ CC Security ID __________	Name On Card ______________________ Signed ______________________ Date ___/___/___

Your Single Source For Custom Parts.

Page 1 of 2

12 APPENDIX D: DIGITAL TACHOMETER SPECIFICATION

REVISIONS								
DOC. NO. SPC-F005 * Effective: 12/21/98 * DCP No: 680								
DCP #	REV	DESCRIPTION	DRAWN	DATE	CHECKD	DATE	APPRVD	DATE
430	A	RELEASED	HYO	11/17/00	JC	11/21/00	DJC	11/21/00



Features:
1. Large 5 digit LCD display with function annunciator
2. One second response time at distances from 2" to 6"
3. Stores Last/Min./Max. readings
4. Includes 23" reflective tape, carrying case and owner's manual
5. One year limited warranty
6. Requries four 1.5V "AA" batteries not included

CE

SPECIFICATIONS

Range	5 to 99,999 RPM
Resolution	0.5 ~999.9 RPM: 0.1 RPM Over 1,000 RPM: 1 RPM
Accuracy	±(0.05% + 1 digit)
Sampling Time	1 Sec. (over 60 RPM)
Range Selection	Automatic
Detecting Distance	50~150mm (2~6 inches) *Typical Max. 300mm (12") depending upon ambient light*
Time Base	Quartz Cyrstal, 4.194 MHz
Size	190 x 72 x 37mm (7.5 x 2.8 x 1.5 inch)
Weight	235g (.52lb) Including batteries
Operating Temp.	0~50°C (32°F~122°F)
Memory	Last, Maximum, & Minimum Values

DISCLAIMER: ALL STATEMENTS AND TECHNICAL INFORMATION CONTAINED HEREIN ARE BASED UPON INFORMATION AND/OR TESTS WE BELIEVE TO BE ACCURATE AND RELIABLE. SINCE CONDITIONS OF USE ARE BEYOND OUR CONTROL, THE USER SHALL DETERMINE THE SUITABILITY OF THE PRODUCT FOR THE INTENDED USE AND ASSUME ALL RISK AND LIABILITY WHATSOEVER IN CONNECTION THEREWITH.

TENMA®

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE FOR REFERENCE PURPOSES ONLY.

DRAWN BY:	DATE:
HISHAM ODISH	11/17/00
CHECKED BY:	DATE:
JOHN COLE	11/21/00
APPROVED BY:	DATE:
DANIEL CAREY	11/21/00

DRAWING TITLE: Digital Photo Tachometer

SIZE	DWG. NO.	ELECTRONIC FILE	REV
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SCALE: NTS	U.O.M.: INCHES [mm]	SHEET: 1 OF 1	

SPC-F005.DWG