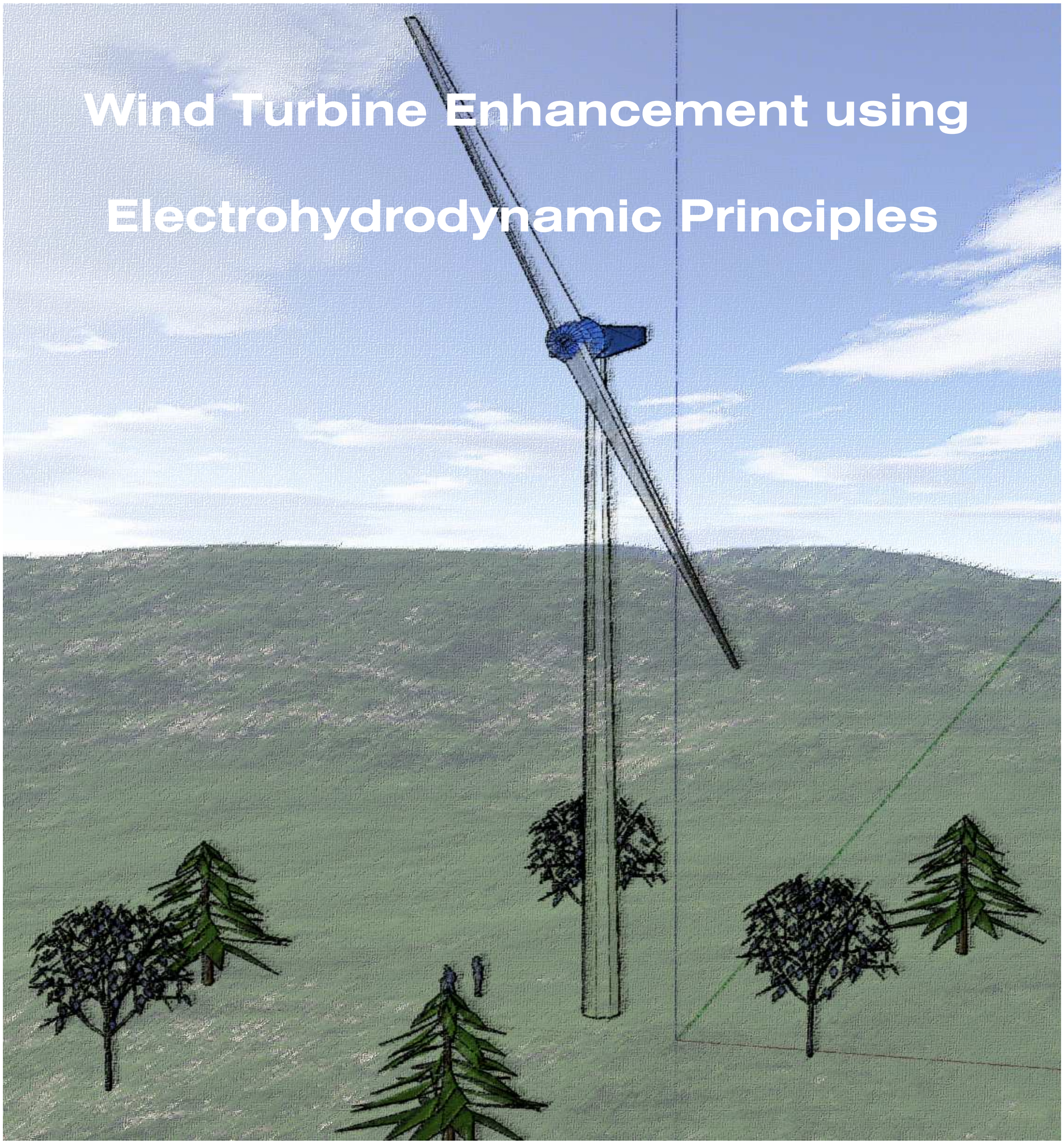


Arthur J Petron

Table of Contents

Wind Turbine Enhancement using Electrohydrodynamic Principles

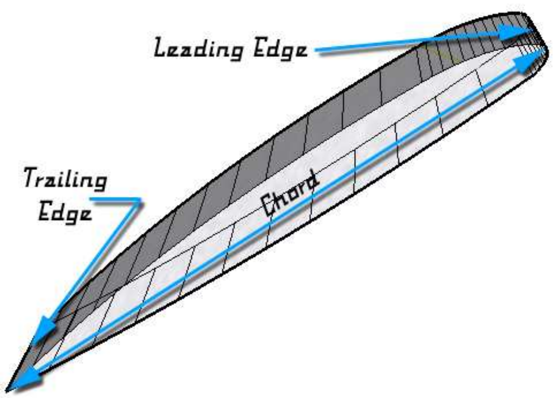
Introduction

While there are those who deem no need for alarm about the exhaustion of our natural resources because they say that the resources will not run out for another few hundred years, they make a contradictive point in their truthfulness; they admit that our natural resources will run out. When they do, how will the world gather energy? A simple question, the world will rely on the renewable resources available, because when the day the last mineable piece of coal is lifted from the earth and burnt for electricity does come, the winds will continue to blow, the rivers will continue to flow, and the tidal forces of the ocean will continue to ebb to and fro.

We have already made somewhat substantial use of these renewable resources, but the problem which this experiment addresses does not necessarily lie in our lack of use of the resources which are readily available, but in our inefficiency in harnessing the power adequately. If the implementation of an electrohydrodynamic device on a wind turbine generates a positive numerical difference between the amount of electrical energy consumed by the device and the mechanical gain created, then this experiment will be a success.

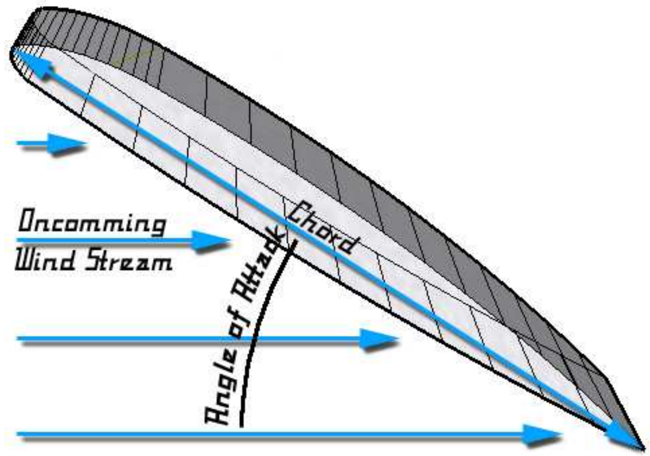
The first hydroelectric power plants were waterwheels which allowed 90% of the energy now harnessed to go to waste down the stream. The first solar cells were only capable of capturing a percentage of the energy which they can currently capture. The first wind turbines appeared as clumsy lighthouses with blades attached to the manually controlled, gargantuan nacelle as if to mimic an image described in Don Quixote.

Today's wind turbines are much more efficient than those of the past, and because they are made with materials hundreds of times as structurally strong, much larger (Hills 12). This combined with an extensive understanding of aerofoil aerodynamics and computer modeled airflow calculations makes them able to produce more power than ever before, but is simply making a wind turbine larger the answer? Putting many wind turbines together also is commonly used to get more energy out of a windy setting, but only so many turbines can fit in a given area because of the law of conservation of matter, and the fact that the turbines take energy from the air as they generate electricity, leaving it with less kinetic energy.



A more efficient way to gather wind could be employed, but what? The aerodynamics of the turbine could be examined in order to allow them to catch more of the winds energy. An aerofoil, sometimes referred to as an airfoil, most simply consists of a curved control surface designed to react with oncoming parallel airstreams in order to produce lift. The front of an aerofoil is called the leading edge and rear is called the trailing edge. A straight line that connects the two is defined as the chord.

An aerofoil can be angled into the wind many different ways in order to produce lift. The angle between the chord line and the relative wind direction is called the angle of attack. Another angle, the angle of incidence, is the angle between the chord line and the longitudinal axis of the wind turbine. These two angles are as critical as the shape of the aerofoil in that they determine the effectiveness of the blades. At different wind velocities the angle of attack should change in order to reflect the change in conditions (Manor 1).



Contrary to popular belief, the majority of the lift in an aerofoil is *not* created by what is called Bernoulli's effect, which states that the shape of the aerofoil causes differences in pressure due to the change in velocities between the upper and lower chambers of the aerofoil, and this in turn causes lift. While this does affect the performance of an aerofoil, it is not the main factor. The main factor, in fact, is the angle of attack of the aerofoil. According to Newton's third law of motion (action – reaction), the deflection of the air caused by the collision between the molecules that make up the air and the surface of the aerofoil cause a deflection, the vertical component of which causes lift (Wortman 6). Drag is the unfortunate horizontal consequence of the action of producing lift. The higher the angle of attack, the larger the angle of deflection of air molecules; this means that a high angle of attack will produce a high amount of lift, but drag will be increased also.

There are two types of drag on an aerofoil. There is the drag caused by the horizontal component the angle at which incoming air is deflected and there is the friction between the aerofoil and the air molecules as they strike each other. The viscosity of the air plays a large role in the amount of the latter type of friction; the higher the viscosity, the higher the friction (Auhl N.p.). Factors that contribute to the amount of viscosity air possesses include: temperature, humidity, chemical make-up, and pressure.

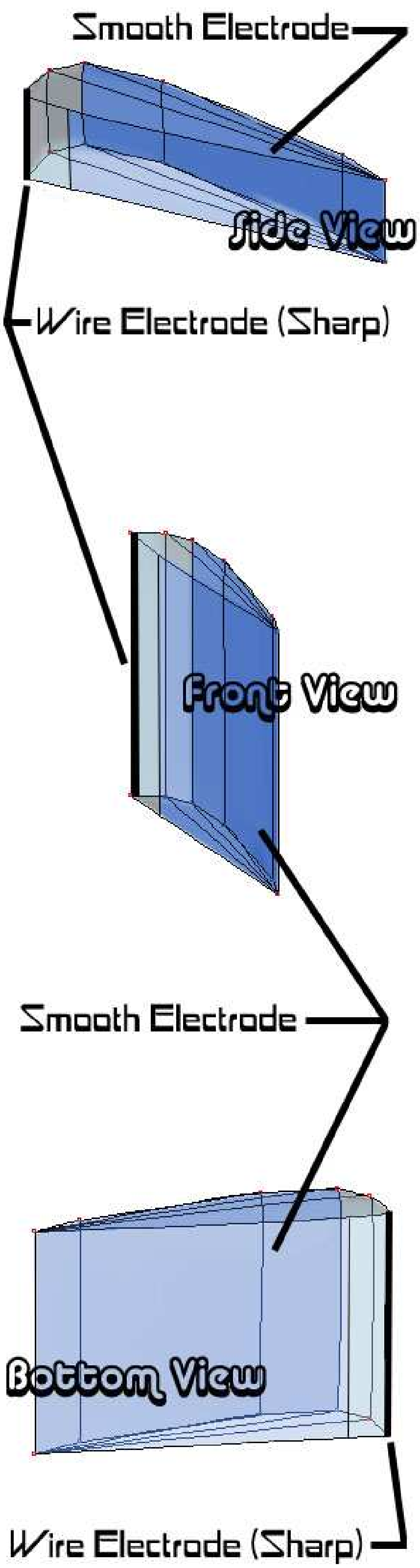
The blades on a wind turbine create frictional drag when the air that powers them slams into the blades just as the wings of an airplane do. If this drag could be reduced, the blades would incur less drag as they slip through the air, wasting less energy creating eddy currents, and vibrational disturbances (noise).

The use of electrohydrodynamic principles in the form of a device attached to the blades of a wind turbine could create the “lubricating” effect needed to allow them to slip through the air more smoothly. The word electrohydrodynamic seems menacingly complex, but when broken down, it is relatively simple. Electro is a Latin prefix that means electricity. Hydro is a Greek prefix that means fluid or water. Finally, dynamic is an adjective relating to energy and motion. Put all the pieces together, and electrohydrodynamic means a motion of a liquid from electricity. The fluid in question is implied to be the air. The motion is caused when the electrical potential energy supplied to the device is converted in to kinetic mechanical energy in the form of moving air. This moving air is also affected by the ionization caused by the way the electricity must be supplied to device in order for it to work: 24,000 volts with a current of $2.12*10^{-4}$ amps.

The end effect is a reduction of the drag force and an increase of the pushing force of the object with the device installed on it -- the blades in this case. Previous year's work has allowed for the deduction that a 7.69% effect on dynamic pressure, as measured with a pitot-static probe is possible using the device under static conditions. The change in dynamic pressure relates to an air velocities, this velocities depending on the atmospheric conditions at the time with the equation $\Delta p_d = \sqrt{\frac{2(p_d - p_a)}{\rho}}$.

A wonderfully useful effect it would be if the energy used to supply such a device was available in limitless supply. Unfortunately, this is not the case, as the energy is electrical energy, and any energy has to come from some source; it cannot simply be created. Yet there is still a possibility that the electrohydrodynamic device will create a greater gain in energy than is lost powering it.

This does not seem possible at first thought; it seems to defy certain laws of energy, namely the law of conservation of energy, but this project does not violate this law (Ilyes N.p.). The electrohydrodynamic device simply enhances the power of the wind generating energy for the wind turbine, making the energy gained a result of more efficient harnessing of the wind's energy. Compare the electrohydrodynamic apparatus to a car rolling down a hill with a spring loaded break system that holds the breaks on slightly. A simple pull of a lever can release the breaks, but this pull requires energy; yet, if this energy is expended, the car will end up with much more energy than it would have had with the breaks engaged even if the energy required to hold the breaks off were taken into account. With this in mind, the device should be able to accomplish the feat of enabling the blades to produce more power than is required to power the device. The exact amount of over-production will depend on the power created by the blades. The device requires 5.088 Watts of power in order to function properly. The turbine will have to be producing at least 5.088 Watts in order for the effect to generate enough power to overcome the power used by the device.



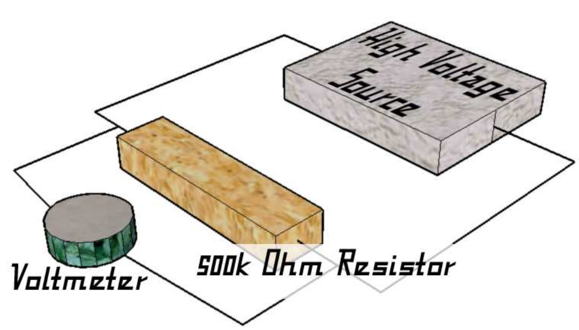
The function of an electrohydrodynamic device is as simple as its name. The device works off of the principle that sharp electrodes release an abundance of electrons much easier than smooth electrodes. This is because the electrons in the atoms of sharp electrodes have a fewer number of neighbors to which to give their extra electrons. In smooth electrodes, each atom is surrounded by other atoms and thus any extra electrons simply travel on to the next atom. When a high potential (high voltage) is connected across the electrodes, the electrons tend to diffuse off of the sharp electrode (platinum wire) into the air, ionizing it. This ionization progresses outward until a path for the electrons can be found to the smooth electrode about an inch away from the wire. The invisible lines of charged particles are sometimes referred to as feelers or seekers. When a path is found, the electrons flow in huge numbers over the newly created bridge in order to complete the circuit that has just been formed. This would create a spark, but in the case of the apparatus, the distance between the electrodes is too large for a spark to occur, but ionization of the air still occurs.

Just as the north side of a magnet is attracted to its opposite pole, negatively charged atoms attract to any area of higher potential, the larger the potential difference, the larger the attraction. The distance between the electrodes requires a large potential in order for an adequate attraction between them to occur. This is why thousands of volts are needed for the device to work.

When the electrons travel from a wire to a larger smooth electrode, they take the molecules that make up air with them through electrical attraction, sometimes splitting them in the process to form other molecules. The result of this is an airflow which can be physically felt emanating from the back edge of the blade. The air also has a pungent odor to it which can sometimes be smelled during thunderstorms and electrical short circuits. This is the smell of the molecule ozone, which forms during the ionization process (Moreland, N.p.).

High voltage is very dangerous and should be used with very high caution. The current before a spark occurs is very low and relatively harmless, but when arcing occurs between two points, the current flowing between those two points can easily melt metal and kill people. Please do not attempt to reproduce this experiment unless you have proper supervision from someone with a background in electronics and electricity or have the background in electricity needed for this experiment yourself.

High voltage, besides being dangerous, is much more difficult to measure



quantitatively. The high potential of the electricity trends to destroy integrated circuits if it is not connected properly and readings must be taken inductively rather than deductively. In other words, to find the current of the electricity, one cannot simply connect an ammeter in series with the circuit in question and expect not to destroy their ammeter. There are, however, ways around this. Ohm's law states that V = IR, or voltage is equal to current times resistance. Using this law, the current of the high voltage circuit can be found using a known resistance and a measured voltage drop over the resistor in parallel with the high voltage circuit.

Methods and Materials

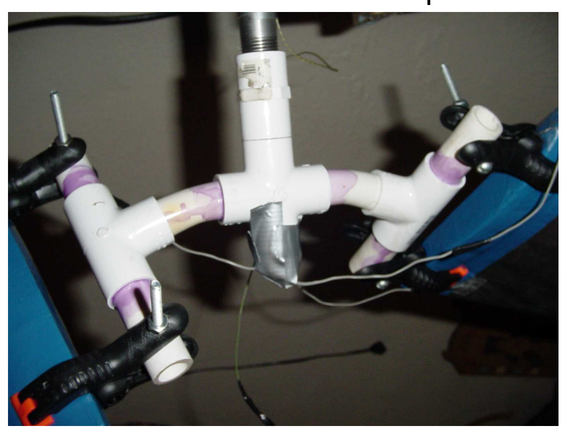
This project required the engineering and construction of all experimental apparatuses except for the DC motor and the 25 volt AC/DC power supply. Engineering methods not found in this report may be found in previous year's material.

Construction

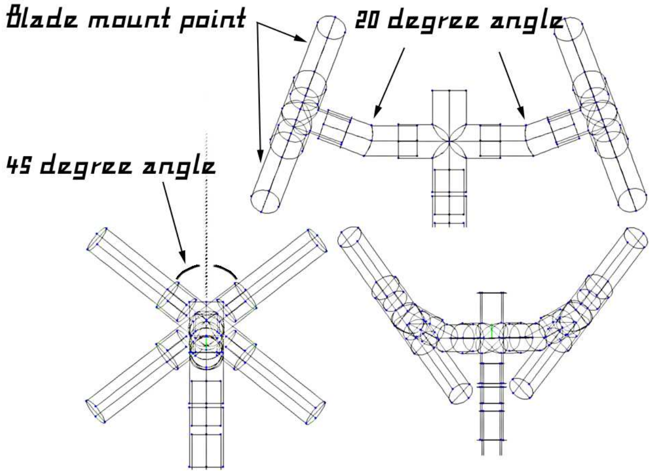
The blades of the turbine were constructed from Styrofoam wings of a large glider which was purchased at a hobby shop. Two gliders had to be purchased because of the needed orientation of the blades on the turbine. A blade was needed from the same side on each model. The blades were covered with Solarcoat, a low-temperature plastic covering for use with model airplanes.

After the blades were completely covered, aluminum foil was attached to the blades by using the Solarcoat to cover the edges and hold it to the blade. This method of attaching the foil, which served as the smooth electrode, allowed for a very smooth transition from blade to electrode that may not have been possible with glue or tape. Also, by covering all of the edges of the foil, there was no hazard of an edge catching and tearing the foil off. Platinum wire with a diameter of 0.002 inches (0.046 mm) was attached to the leading edge of the blades with clear tape.

The blades were mounted to the shaft through a system of PVC and small spring loaded clamps. The clamps simply clamped onto the blades at the same location on each blade and holes were drilled into the handles of the clamps to allow for one 10-32 bolt to be passed through each clamp and fastened with a nut. These bolts held the clamps to a 2" long piece of 0.5" diameter PVC pipe which was attached to a "T" connector for each blade. These "T" connectors were



attached to a 4" long piece of 0.5" piece of PCV which was bent at a 20º angle. The ends of these 4" pieces connected to a "┼" connector. The base of the "┼" piece was attached to a threaded connector which tightened onto the 0.75" steel shaft. All PVC connections were permanently fastened with PVC cement except the connections between the "T" connector piece and the 4" long 0.5" PVC that was bent at a 20º angle.

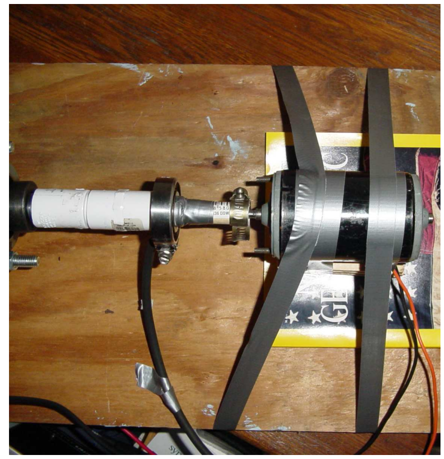


The shaft of the turbine was turned to a diameter of 0.8125” (13/16”) and held in place by two flange bearings on either end of the nacelle with set collars for fastening purposes. Each end of the shaft was threaded and this allowed the threaded PVC connector pieces to screw directly onto the shaft forming a tight, secure fit without the need for glue.

The nacelle consisted of 6” PCV pieces. A rounded end cap formed one

end of and a clean-out plug formed the other, making the inside of the nacelle accessible by unscrewing the plug. The two pieces were connected with a joining piece and 6” PVC piping. The square piece on the end cap was faced off on a lathe and the entire surface, including any lettering on the surface of the cap was turned flat. The rounded front of the PVC cap was turned flat to a radius of 2”, allowing the flange mount bearing to mount to its surface. The wall thickness of the cap after it was turned remained over 0.125”, thus a hole with 0.06125” clearance for the shaft was turned through the center of the cap. Loosening the set screws on the fastening collars of the bearings allowed the shaft to slide completely out of the nacelle. The bearings were attached to the nacelle with 4 0.75” bolts complete with washers and lock-washers. Two bolts were used for each bearing.

At the end of the shaft, another PVC connector was screwed on and this connector was attached to a joining piece with PVC cement. One inch of a 2” long 0.5” piece of PVC was turned to 20mm in order for a bearing to fit over it. A small hole was drilled where the polyvinyl chloride was turned to 20mm in order for a high voltage wire to make contact with the underside of the bearing and create a press fit connection. The unturned portion of the pipe was glued into the end of the joiner. Inserted into the inside of the turned PVC pipe was a dowel rod with a diameter of 0.610”. A 0.1875” hole was drilled into the exposed end of the dowel rod for the shaft of a small DC motor. This shaft was tightened into place with an adjustable stainless steel strap (hose clamp). The high voltage wire connects to the bearing previously mentioned in this paragraph, and another separate wire was also connected to the outside of the bearing with an adjustable stainless steel strap.



A high voltage wire ran from the underside of the strapped bearing through the steel pipe to the front of the turbine, where it emerged from the “┼” connector and attached to 24-gauge wire which in turn attached to the platinum wire. The smooth electrodes are grounded by attaching 24-gauge wire to the electrodes and then attaching those wires to the steel pipe. A ground wire brushes the pipe just before the first bearing, grounding the pipe and two main bearings. These wires follow a curved path to the pipe, arching over the high voltage wires in order to prevent arcing.

The entire assembly was taped to a 12” x 40” x 0.5” piece of plywood with Duct tape with the blades protruding off the edge. This provided a stable work platform that could be moved without disturbing the layout of the components of the turbine.

Experimentation

A retro-fitted computer monitor was used to provide the high voltage potential needed to run the experiment. A 25V power AC/DC power supply was attached to the motor at the end of the shaft. A photogate and plastic trigger were attached to the shaft between the blades and the first bearing. As the turbine spun, it would trigger the photogate, showing the time one revolution took to complete to three significant digits, allowing RPM calculations to be done.

The photogate was attached to a ULI2 PC interface which integrated with *LoggerPro* software created by Vernier Software & Technology of Beaverton, Oregon. The *LoggerPro* software was configured to calculate the angular velocity of the turbine in rounds per minute as the data was electronically collected. The voltage on the power supply was turned to 25.1 volts and the *LoggerPro* software set to the “Collect” mode. The number readings taken for each test was thirty one, and an RPM value calculated from each reading was graphed in “Graphical Analysis,” another software product of Vernier. This test was completed five times to ensure a reproducible mean. Similar readings were taken with the voltage settings at 23.8 volts and 22.4 volts, all with the power to the blades off. The voltage was returned to 25.1 volts and the same test was done except with the power to the blades on. The thirty-one values were averaged for each of the five graphs and graphed together. The mean of these values was use as the final value.

Data

Table 1: Angular Velocity vs Time Power Off 25.1V			
Test	Time (min)	Delta T (s)	Rounds per Minute
1	0		
2	0.031	1.886	31.812
3	0.066	2.066	29.041
4	0.099	1.991	29.041
5	0.134	2.075	28.92
6	0.169	2.135	28.106
7	0.203	2.044	29.351
8	0.239	2.162	27.753
9	0.274	2.065	29.053
10	0.308	2.083	28.800
11	0.344	2.139	28.052
12	0.378	2.056	29.181
13	0.417	2.289	26.214
14	0.452	2.154	27.852
15	0.487	2.094	28.653
16	0.523	2.120	28.303
17	0.557	2.072	28.952
18	0.596	2.308	25.996
19	0.631	2.123	28.263
20	0.667	2.147	27.950
21	0.702	2.135	28.099
22	0.737	2.083	28.808
23	0.778	2.425	24.742
24	0.814	2.187	27.436
25	0.851	2.194	27.35
26	0.888	2.236	26.828
27	0.922	2.070	28.989
28	0.961	2.300	26.090
29	0.997	2.182	27.492
30	1.034	2.246	26.717
31	1.072	2.254	26.622

Table 2: Angular Velocity vs Time Power Off 23.8V			
Test	Time (min)	Delta T (s)	Angular Velocity (RPM)
1	0		
2	0.034	2.035	29.479
3	0.068	2.069	29.003
4	0.103	2.105	28.501
5	0.140	2.174	27.603
6	0.177	2.260	26.554
7	0.212	2.053	29.229
8	0.247	2.143	28.000
9	0.285	2.251	26.654
10	0.322	2.233	26.868
11	0.361	2.334	25.704
12	0.395	2.049	29.286
13	0.432	2.187	27.432
14	0.468	2.191	27.382
15	0.504	2.173	27.617
16	0.544	2.372	25.298
17	0.580	2.163	27.739
18	0.618	2.275	26.374
19	0.656	2.266	26.482
20	0.697	2.465	24.337
21	0.739	2.541	23.608
22	0.775	2.184	27.474
23	0.813	2.253	26.636
24	0.850	2.234	26.861
25	0.890	2.404	24.956
26	0.930	2.394	25.064
27	0.966	2.149	27.920
28	1.003	2.196	27.323
29	1.038	2.141	28.031
30	1.078	2.414	24.853
31	1.12	2.486	24.137

Table 3: Angular Velocity vs Time Power Off 22.4V			
Test	Time (min)	Delta T (s)	Angular Velocity (RPM)
1	0		
2	0.037	2.205	27.211
3	0.078	2.450	24.494
4	0.116	2.310	25.971
5	0.153	2.244	26.738
6	0.196	2.559	23.448
7	0.233	2.229	26.921
8	0.276	2.567	23.378
9	0.315	2.334	25.708
10	0.354	2.314	25.928
11	0.398	2.672	22.458
12	0.437	2.310	25.979
13	0.482	2.713	22.119
14	0.522	2.427	24.723
15	0.562	2.382	25.193
16	0.608	2.783	21.560
17	0.649	2.468	24.312
18	0.693	2.635	22.769
19	0.735	2.477	24.223
20	0.775	2.432	24.673
21	0.820	2.675	22.432
22	0.860	2.421	24.785
23	0.907	2.843	21.103
24	0.956	2.907	20.64
25	0.999	2.567	23.371
26	1.043	2.650	22.640
27	1.085	2.540	23.625
28	1.131	2.726	22.012
29	1.175	2.667	22.493
30	1.220	2.696	22.257
31	1.264	2.654	22.606

Table 4: Angular Velocity vs Time Power On 25.1V			
Test	Time (min)	Delta T (s)	Angular Velocity (RPM)
1	0		
2	1.955	1.955	30.686
3	3.793	1.838	32.645
4	5.656	1.863	32.204
5	7.505	1.849	32.451
6	9.442	1.937	30.978
7	11.428	1.986	30.211
8	13.366	1.938	30.964
9	15.292	1.926	31.158
10	17.153	1.862	32.227
11	19.149	1.996	30.063
12	21.101	1.952	30.745
13	23.032	1.931	31.072
14	25.014	1.983	30.264
15	26.915	1.900	31.574
16	28.896	1.981	30.286
17	30.849	1.954	30.710
18	32.801	1.952	30.740
19	34.809	2.008	29.884
20	36.760	1.951	30.747
21	38.852	2.091	28.689
22	40.856	2.004	29.937
23	42.752	1.896	31.649
24	44.760	2.008	29.878
25	46.694	1.934	31.024
26	48.792	2.098	28.605
27	50.869	2.078	28.879
28	52.905	2.036	29.470
29	55.007	2.102	28.547
30	56.931	1.924	31.177
31	59.107	2.176	27.576

Table 5: Power Used vs Theoretical Power Gained		
Power Used	Power Gained	Angular Velocity
Watts	Watts	RPM
5.088	5.979	28.2
5.088	4.98	25.6
5.088	1.254	23.9

Data Treatment

In order to find total power gained by the operation of the electrohydrodynamic device, the three voltage readings at the applied voltages to the motor were multiplied by their matching current requirements, which was recorded from a digital output on the power supply, and the resulting power readings were graphed against the average RPM values calculated from the 155 (31 x 5) readings taken at each voltage. This graph related angular speed and power required, thus a regression analysis on the graph produced an equation for interpolating any angular speed value with any power input. The angular speed value of the HV (high voltage) on readings was interpolated into the equation resulting from the regression analysis and the power required by the corresponding HV off RPM readings was subtracted from this value. The resulting number was the power that must be supplied to the motor in order to run at the angular speed at which the blades of the turbine rotated.

The power used by the device was found by adding a one mega-ohm (MΩ) resistor in series with the HV circuit and measuring the voltage drop with a regular voltage meter in parallel with the resistor. Using the equation $I = E / R$, a rearrangement of Ohm's law, the current drawn from the 24,000 volt power supply can be calculated, and multiplied by 24,000 volts. The result is the power consumed by the device in Watts.

The data from this experiment created numerous different graphs, many of which are derived from other graphs which in some cases have been derived from yet another graph. The logical progression can easily become confusing. Please use the flowchart and table below to help with interpreting the analysis of the data.

Averages at Each Experimental Configuration			
Angular Velocity	**25.1 Volts (RPM)**	**23.8 Volts (RPM)**	**22.4 Volts (RPM)**
High Voltage Off	28.2	25.6	23.9
High Voltage On	30.7	27.4	24.5

<u>Deduction of Differences in Power output</u>

Equation used from Figure 9.

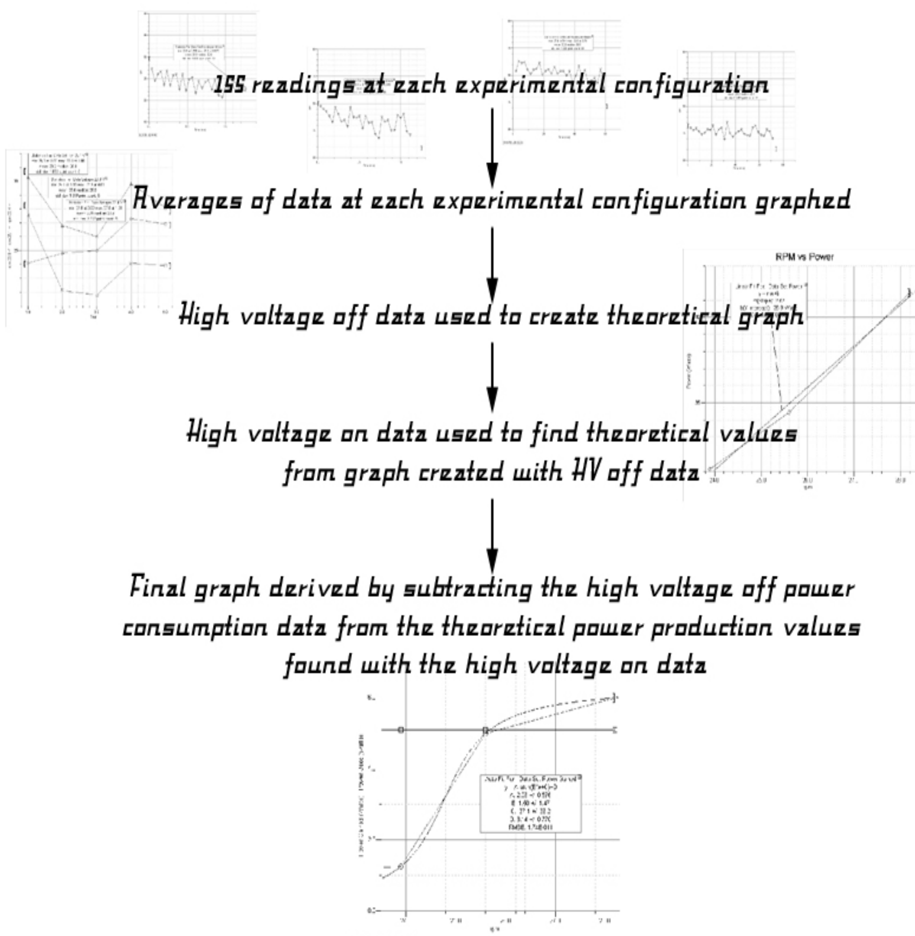
$$y = 2.42x - 26.9 \text{ Watts}$$

HV on values substituted into equation to find theoretical gain.

$$y = 2.42 \text{ Watts/RPM}(30.7 \text{ RPM}) - 26.7 \text{ Watts} = 47.394 \text{ Watts}$$

Original Power requirements taken from power off reading at same voltage

$$47.394 \text{ Watts} - 41.415 \text{ Watts (HV off V reading times I)} = 5.979 \text{ Watts}$$



Discussion

The following figures (1 – 3) show the angular velocity readings gathered from the turbine at 25.1 volts, 23.8 volts, and 22.4 volts with the power to the electrohydrodynamic device off. The mean in the statistical box is the value that is used in later graphs comparing all 5 readings taken at each voltage and power setting. *See data book for other graphs of this test.*

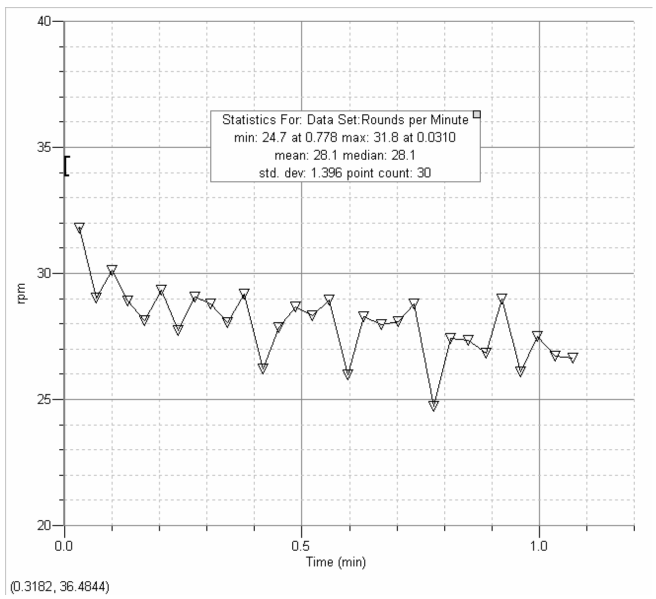


Figure 1: Power off angular velocity readings at 25.1V (RPM vs. time)

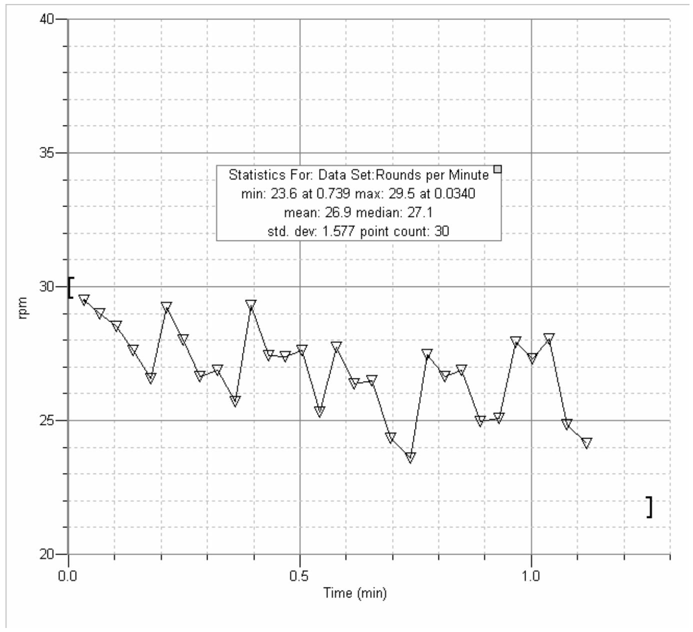


Figure 2: Power off angular velocity readings at 23.8V (RPM vs. time)

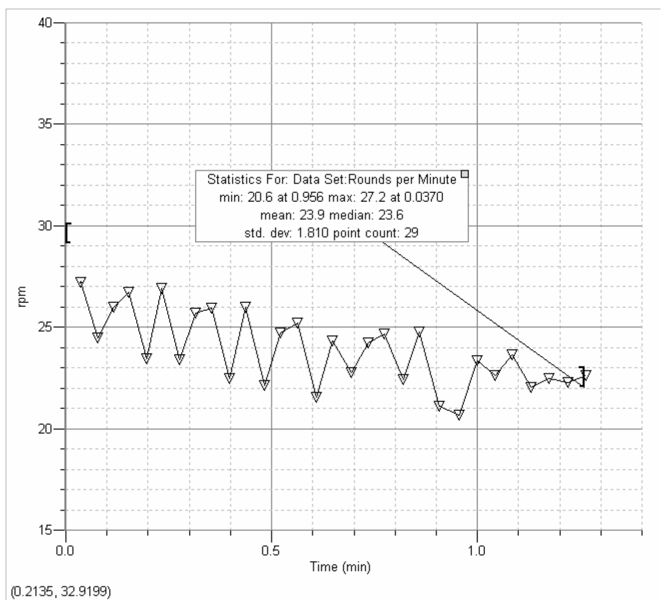
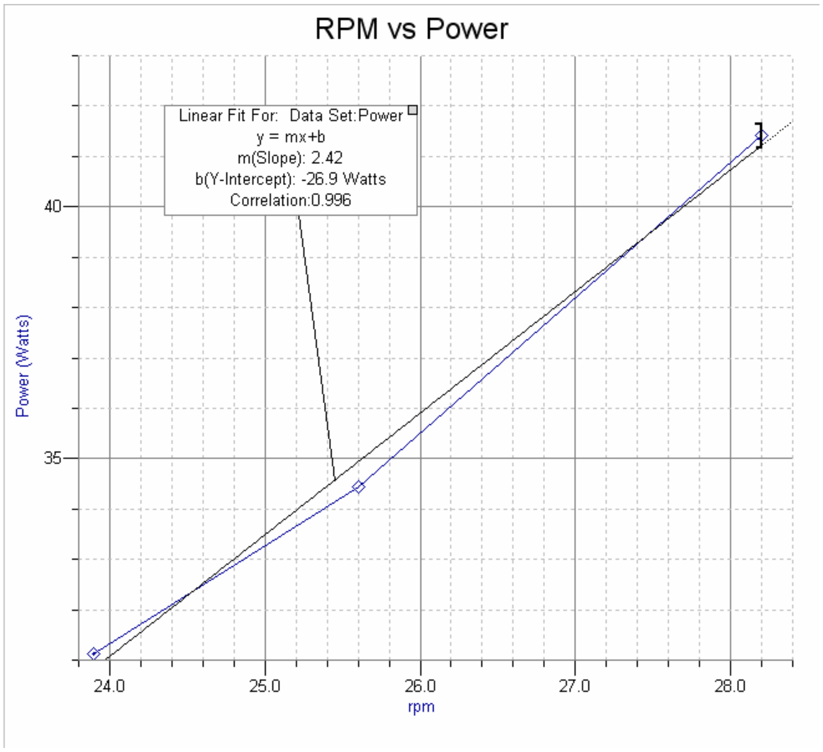


Figure 3: Power off angular velocity readings at 22.4V (RPM vs. time)

As the flowchart above states, the 155 readings that make up the five

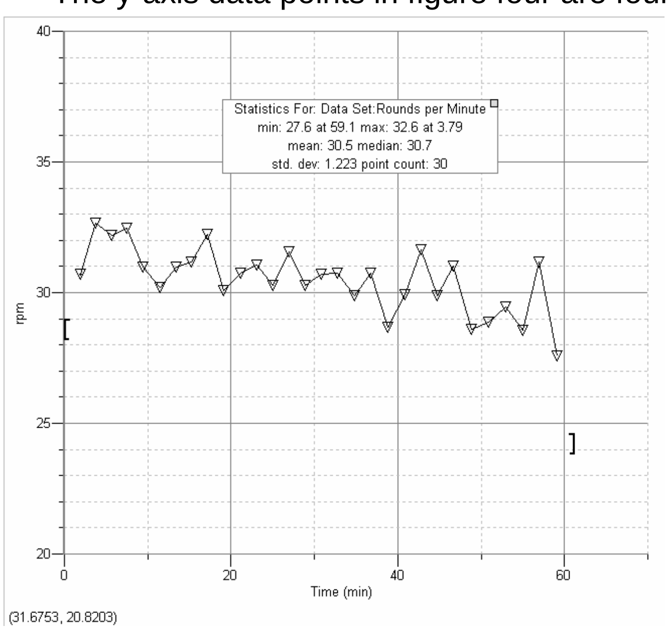


graphs, each like those above, are used to make a graph that determines the amount of electrical energy required for the turbine to spin at x RPM.

Figure 4: Angular velocity vs. Power for three different voltages

This graph can then be used in conjunction with the high voltage data (figures 5 – 7), which contain the data that pinpoints the angular velocity of the turbine at each of the three voltages with the high voltage on to determine the power that would be needed to spin the turbine at the same speed had the electrohydrodynamic device not existed on the blades.

The y-axis data points in figure four are found by multiplying the voltage by



the corresponding amperage recorded from the digital readout on the AC/DC power supply during experimentation. The voltage and amperage data are both accurate to three significant digits.

Figure 5: Power on angular velocity readings at 25.1V (RPM vs. time)

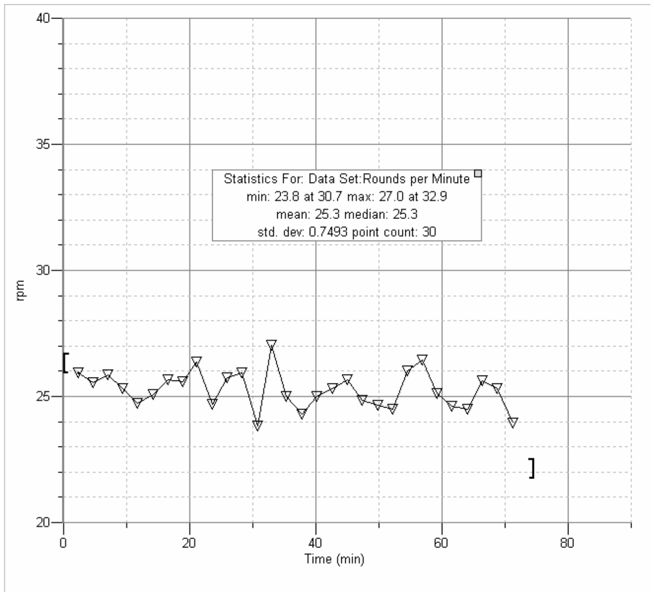


Figure 6: Power on angular velocity readings at 22.4V (RPM vs. time)

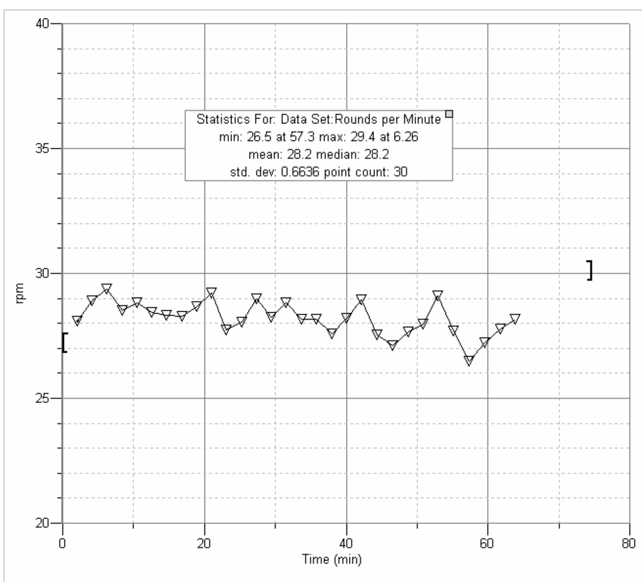
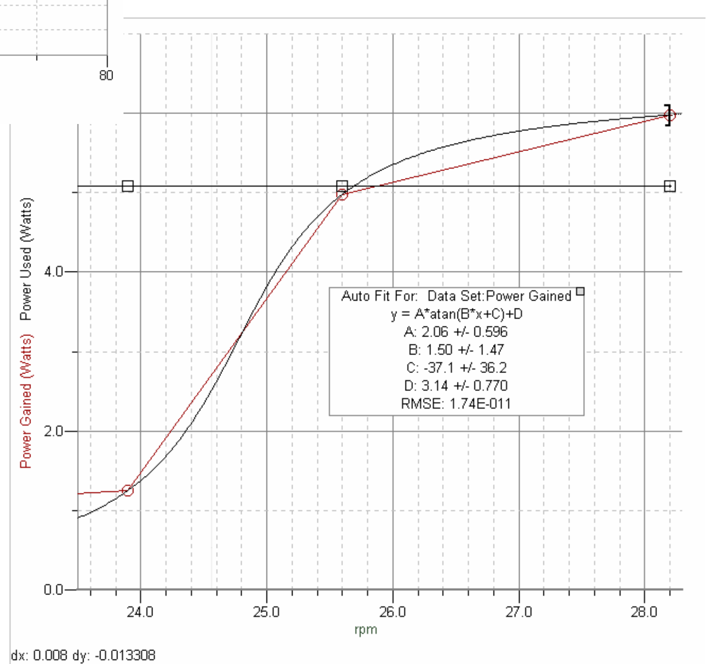


Figure 7: Power on angular velocity readings at 23.8V (RPM vs. time)



Using the theoretical power requirements derived by using figure 4 with the high voltage on data, the points on the curved line of figure 8 are found by subtracting the y-values of figure 4 (the HV off total power consumption data) from the these theoretical values. The result has a unit in Watts and represents the theoretical power gain of the implementation of an electrohydrodynamic device on a wind turbine.

Figure 8: Power Consumed vs. Theoretical Gain

The results of this experiment show that the electrohydrodynamic device produces more power than it uses by allowing the turbine to capture the winds energy with more efficiency. The motor used could only achieve rotation speeds of about 37 RPM. Perhaps if the blades spun at a faster rate (simulating the production of more power in turbine mode) the gap would become larger than it currently is.

The results tend to show a relationship that is not linear as originally predicted. The relationship appears to be an equation of the form $y = A(\tan^{-1}(Bx + C)) + D$. Using this equation, it can be seen that the energy that could be gained from the implementation of this device on a wind turbine will level out at a certain point, making an increase of angular velocity not worth the very small energy gained. This is actually not a hindrance, because wind turbines have a set speed at which they can produce the most energy. The device could simply be calibrated for this speed, which is specific point of maximum power generation that is specific to each turbine on which the electrohydrodynamic device is installed.

It is easy to see that the turbine used in this experiment was not driven by wind power. This *was* the intention of the experiment, but the large bearings required to hold the shaft of the turbine produced a tremendous mechanical friction that made rotation of the blades in the wind impossible. A motor to spin the blades therefore simulates the action of the blades being spun by wind. This can be accomplished because a motor, while being powered, spins, and when spun by some non-electromagnetic torque, produces power. The downside to using this method is that the values used in the results of this experiment are more theoretical in nature than they would be had if the motor were not used.

Construction of the apparatus was rather difficult, and it was the bulk of the project. The nacelle in the experiments performed serves no purpose, but had the bearings had less mechanical drag, and allowed the shaft to turn freely, the nacelle would have served to protect testing equipment and hold the turbine in place as it turned to face the wind above a local football stadium press box. Also, getting the high voltage from a static position to a continuously rotating shaft is interesting considering the fact that the high voltage being used can arc almost an inch.

The slant of the blades is important when looking at the turbine under working conditions. When in the wind, the blades will encounter more resistance with the wind facing it than facing away from it. This will make the entire nacelle turn to face away from the wind, thus placing the blades in the correct position or produce power. A pivot was with a weight bearing bearing that was designed to support the nacelle as it turned in the wind.

Secondary experiments with new bearings are currently in process, but the results currently only reinforce the previous conclusions. The newly rebuilt turbine rotates using the wind's energy alone, without the help of a motor. The tests that have already been completed have been at low angular velocities (below 12 RPM) in order only to prove the viability of the new apparatus, and the data was not recorded because it served no purpose. The early results are only useful in showing that angular velocities at this low of an angular velocity produce very low gains as is expected. Again, results have not been reported with these tests because they do not bring any new evidence to the results, and the new experimental method has not been completely refined.

While already very promising, further experimentation into this application is necessary in order to show its full usefulness. This will include completely re-designing the turbine's physical make-up. The systems which allow motion will be refined in order to produce the least amount of resistance possible. If resistance is kept to a minimum the electrohydrodynamic device alone can cause the blades to spin in still air!

In short term, something as simple as a power supply with a maximum voltage of 50 volts DC could produce more positive results. The results would not be a large amount more than they are, however, because of the way the gain and power generation in this system are interrelated. The point at which maximum gain and ideal angular velocity are achieved will be specific to each wind turbine equipped with this device. This point does exist, and will need to be found in order for this device to be put into service.

In further experimentation the motor driving the blades will be removed and wind provided either by a fan or the environment will power the turbine. The bearings used now will be discarded, new free-moving bearings will be found at the cost of redesigning the shaft to fit smaller bearings. Speed and ease of movement are key to allowing the turbine to function as it would in real life.

Analysis of Error

While using a motor does not make the results unreliable, it does introduce some error into the experiment. When powered by wind, the air will be moving past the blades much faster than in still air conditions with a motor driving the shaft. The faster moving air seems like it will actually increase the effect of the device, from the current results of the experiment. This is because the faster the blades spin the more air they spin through over time, which is essentially the same effect as increasing the wind speed past the blades.

The largest source of error in the project is the bearings which do not allow the shaft to spin freely. Unfortunately, no other bearings with less resistance for a shaft the same size as the one used in the experiment were available. Had the bearings been better, the entire methods and materials section would have changed substantially, allowing for more accurate measurement of data in real life conditions.

The power input to the motor gives the power that would be produced had the blades of the turbine been spinning at the same speed. This assumes the mechanical loss for the motor is the same for both power generation and power consumption, which is a reasonable assumption to make considering the mechanical operation of the motor.

The motor seemed to vary its speed slightly as its temperature increased with use over time. As the motor heated up, the rounds per minute would decrease. This decrease can be seen on some of the graphs showing RPM readings over time. To account for this, the motor was allowed to cool before each reading, or each successive reading would become slower and slower.

Conclusion

The electrical power required to power the electrohydrodynamic device was 5.088 Watts. A positive numerical difference between the amount of electrical energy consumed by the device and the mechanical gain created was observed. A linear relationship between power consumed and power gained was not observed; instead, the equation $PowerGained = A(\tan^{-1}(B(v_{RPM}) + C)) + D$ describes the relationship between power gained and angular velocity. The theoretical power production at 25.7 RPM was determined to be 35.1 Watts. This marks the point at which the power consumed by the electrohydrodynamic device and the power gain created by it are equal. The hypothetical value of 33.9 Watts at 25.2 RPM was 3.42% higher than anticipated.

Works Cited

Auhl, Richard. Pennsylvania State University Aerospace Engineering Laboratory. Personal Interview. 18 January. 2001.

Benson, Tom. “Aerodynamics General Information.” Aerodynamics General Information. Available: http://www.grc.nasa.gov/WWW/K-12/airplane/bga.html. 22 April. 2003. 30 April. 2002.

Brown, Thomas. “Electrohydrodynamics” and “Electrophoretic Thruster.” Available: http://www.soteria.com/brown/docs/ehydro/hydro.pdf. http://homepage.ntlworld.com/ufophysics/ephoretic.htm. 22 September. 2002.

Gipe, Paul. Wind Power for Home and Business. Chelsea Green Publishing, 1993.

Hills, Richard L. Power From Wind. Cambridge, MA: Cambridge University Press, 1994.

Illyes, Mark. Physics Teacher. Personal Interview. 22 April. 2002.

Koehler, Kenneth R. “Coulomb Force.” Coulomb Force. Available: http://www.rwc.uc.edu/koehler/biophys/4a.html. 22 September. 2002.

Manor, Joseph. “Pilot's Web The Aviator's Journal - Lift and Drag.” Airfoils. Available: http://www.pilotsweb.com/principle/lift.htm. 1 May. 2003. 17 January. 2003.

Moreland, Robert. Chemistry Teacher. Personal Interview. 2 May 2002.

Odell, Kathleen. “NWTC Advanced Wind Turbines.” Advanced Wind Turbines. Available: http://www.nrel.gov/wind/about_aerodynamics.html. 4 August. 2002.

Serway, Raymond A. and Faughn, Jerry S. College Physics, Fifth Edition. Harcourt Brace College Publishers. USA. 1999.

Seyed-Yagoobi, J. and Bryan, J. E. "Electrohydrodynamic Pumping Enhances…" Available: http://www.nasatech.com/Briefs/Dec00/MSC22847.html. 22 September. 2003.

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