

Development of a Wind Monitoring System and Grain Grinder

for WPI's Kite Power System

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Abstract

The goal of this project was two-fold: 1) to develop a wind monitoring system to be used during field testing of the WPI kite power system, and 2) to develop a grain grinder accessory for the same system for use in a developing nation such as Namibia. Kite power is emerging as an economically sound alternative energy source as the kites used can operate at higher altitudes than wind turbines. At higher altitudes, wind speed is higher, and hence, a greater amount of power is available. The WPI kite power system operates via a large wind boarding kite, which pulls the end of a long rocking arm. This in turn spins a generator which produces electricity. The developed wind monitoring system consists of a carbon fiber pyramid shaped frame mounted to the underside of a weather balloon with a wind measuring anemometer hung from the frame. Steps taken in the design process include deciding on a deployment system (i.e. how to place the anemometer at the desired altitude), conceptualizing and building a stable frame to mount the anemometer to, constructing a rotating platform and hinge assembly to keep the anemometer vertical and facing normal to the wind, developing MATLAB code to accept the signal transmitted from the anemometer wirelessly, and building the wireless transmitter for the anemometer.

The grain grinder accessory serves to broaden the functionality of the kite power system. The system was already designed to harness energy, but now also creates rotational motion to grind grain. A pulley system was developed to scale down system shaft speeds to an appropriate rotational velocity for the grain grinder which is mounted to the side of the kite power system frame.

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1. Introduction

1.1 Access to Reliable Electricity

1.1.1 In Developing Nations

It is reported that 1.6 billion people live without electricity.⁷ This indicates that over a quarter of the earth's population must rely on alternative fuel sources such as biomass and kerosene when it comes to simple necessities such as heating water and cooking food. This is an issue that needs to be addressed by those socially and financially able. In reality, it is the social responsibility of the advantageous to make an effort to improve the lives of those in need as best they can.

The World Energy Council estimated that in 2004, nearly 1.6 billion people lacked access to electricity.³ This implies that nearly a quarter of the world's population relies on materials like wood, dung, and charcoal as their main fuel supply. Kerosene has become a common cooking fuel in many African nations. This has led to the poisoning of thousands of South African children. This is primarily due to incorrect storage of the substance.⁴ Kerosene may smell rather inviting to a small child, and ingestion quickly leads to problems with the respiratory and central nervous systems. De Wet et al. states that preventing these cases would be far more cost effective for the county than treating the cases of poisoning. Explosions are also a dire problem troubling nations desperate for more reliable and safe energy sources. According to a national survey conducted in South Africa, over 46,517 paraffin related fires occurred in the year 2000. It's estimated that nearly 2,500 to 3,500 burn deaths occur each year in South Africa.²

It is clear that any amount of electricity made available to developing regions would greatly increase their productivity and standard of living. Amenities like being able to refrigerate food to easily and effectively heating water will become available for those who have not had access to these technologies before. People who live in the more remote, rural areas of regions are generally those hit worst by this hardship. Due to the distance between some rural towns and the local main power grids, governing bodies of the country often deem it far too expensive to extend power lines far enough to accommodate these people.

1.1.2 Alternative Energy Solutions

A way to help alleviate some of the adversity involved in living in a developing nation is through alternative energy solutions. Wind power is becoming widely considered as one of the more attractive and simple to harvest energy sources available. Unfortunately, it is not especially reliable. Without a method to store power, areas relying primarily on wind energy would suffer frequent blackouts.

Currently the most widely used method for harnessing wind energy is by use of a windmill. Wind energy has been tapped for centuries in the forms of windmills and wind pumps, and is a very attractive method for approaching this problem.

One of the first obstacles encountered in this particular situation, is that most modern day wind turbines are prohibitively expensive for the areas that need them the most. Even smaller scale turbines designed specifically to supply rural off-grid areas with power tend to not produce enough power to make their purchase worthwhile. Issues that arise include the fact that these turbines need very tall towers, as high as around 42.5 meters (139 ft).¹ Some people have expressed disapproval for these steel towers now dominating their horizon in locations such as Northumberland, England⁶ and Larnaca, Greece.⁸ Taking all of these factors into account damages the argument for wide-scale wind turbine placement.

1.1.3 Wind Power

The challenge that arises is to conceptualize a system that will harness the power of the wind, remain low enough cost for use in developing nations, and still avoid as many of the problems detailed above. One of the most promising ideas is the utilization of large kites. One main advantage is that a kite produces its own lift, and will remain aloft under very low wind speeds. Conversely, a wind turbine requires up to 15 mph of wind before it begins generating a substantial amount of power. The power required to initially start the turbine, and the power needed to stop the blades when wind speed approaches the upper limit that the mill can handle must also be considered.⁵ More importantly, under the same wind conditions, a kite will generate much more power, as it can harvest wind energy at a much higher altitude. With higher altitudes come higher wind speeds, and so in turn, more energy is produced. This changes how we may have previously viewed certain areas where harnessing wind energy was considered undesirable, or where the construction of a wind energy mill would be cost prohibitive.

This problem has been considered by several project groups at WPI over the past few years, with Professor D. Olinger advising student's efforts. Since 2006, teams have been working on various aspects of this problem, with a group completing their senior engineering project by developing a one kilowatt scale prototype of a kite power system. Groups have dedicated much time to furthering the efforts put forth by the first team.

In 2006-2007, the problem of developing a kite power system was addressed by students, and the team working on the project succeeded in creating a conceptual design of a 1kW scale demonstrator of the kite power system.¹⁰



Figure 1.1 - WPI Kite Power System

Work continued on the project in 2007-2008 by a group as their Major Qualifying Project, required by all students for graduation from WPI. This group focused on improving the functionality of the existing kite power system by redesigning key components, as well as adding their own innovations. Particularly notable was an attempt at controlling the unwanted lateral motion of the kite. Only vertical, lifting motion from the kite can produce power for the system, as any side to side motion is undesirable because it can potentially damage the system via a kite crash. While this mechanism was not completely successful, it did reduce useless motion, and hence served as a starting point for future groups to control the flight path of the kite more effectively. Another significant problem addressed by the team was the sideways force produced on the arm, which was beginning to weaken the original pivot structure. The large moments created on the long aluminum arm were beginning to tear bolts loose on the pivot. The need for a stronger design was incorporated by effectively eliminating the yaw created by these moments, considerably improving the structural integrity of the system. Most notable of all of the group's achievements was the actual generation of usable power by the team for short periods of time.¹¹

The full scale demonstrator, shown in Figure 1.1 above, included a fully functioning battery bank and electrical system, capable of translating the kite's motion into power by using a rotating rocking arm. Successful field tests of this demonstrator were able to show that the system's design could be used to produce power, and that the wooden frame it was mounted in was capable of supporting the loads created by the kite's motion. These factors conclusively show that kite power is a feasible approach to addressing growing alternative energy demand.¹²

While power had been produced previously by moving the rocking arm by hand in the lab, this team succeeded in harnessing wind power with the kite, and translating it into an electrical output. This achievement further cements the feasibility of this idea. One responsibility of the 2008 IQP team was to develop an electrical system for the WPI Kite Power project. The system was to store electricity in the batteries, charge the batteries, and output AC electricity. The DC generator used the rotating shaft to fully charge the batteries, while the inverter converted the DC to AC electricity. The system was flexible, and allowed many devices to be powered, such as light bulbs, radios and cell phones.¹⁵

1.2 Basic Outline of Project

The IQP project had two main goals that we strove to accomplish. The first goal of our IQP was to aid the MQP group in measuring wind speed. This involved figuring how to accurately measure wind speed at the altitude at which the kite flies, and how to relay and display the information at the ground. If the wind speed is high enough to generate a reasonable amount of power, then the main system will be used to harness energy.

The second goal is an extension of the Kite Power MQP, in which an attachment powered by the system will be created. The objective was to create a grain grinder accessory to be added to the main kite power system that could be used in developing nations. Specifically, the system will be used to see if the wind speed at the altitude of the kite is sufficient for adequate power production. If the wind speed is insufficient for harnessing a reasonable amount of electrical power, then the best choice would be to use the grain grinder accessory. By connecting the existing mechanical architecture of the kite system via pulley to a grain grinder, the system can be easily adapted to serve two purposes with minimal alterations.

1.3 Other Kite Systems

1.3.1 Wind Lift

In today's society, it's important to be able to use renewable energy sources as gasoline may be depleted before we know it. Harnessing wind power use kite energy is the focus of a number of different companies. We will look into various companies in order to learn more about using kite energy.

There are several kite systems being utilized today in various applications. One company by the name of WindLift²³, focuses on a kite engine that will do a variety of tasks. The implementation is simple, with a kite attached to a pump or generator. The wind energy is harvested and can be used for a variety of needs. These range from generating power, charging batteries, pumping water or even compressing air. The idea is for the first engines developed to be used in remote areas, and to assist with irrigation and providing a water supply. The company hopes that the system will then be automated, which would allow the mechanism to provide power to various treatment facilities and plants.

The advantage of using this system is that the kite energy is less expensive compared to the other wind alternatives and fossil fuels. Since there is no tower or blades necessary, this drastically reduces the cost of the entire system. It could also be used for marine applications, or used in areas where hurricanes are likely, as the system can be easily moved.

The details of this mechanism are still being worked out by WindLift, Inc. Currently, the power output can be measured from the engine through two 8-KW generators and a variable load bank. Next summer the kite engines will be tested at Kitty Hawk in North Carolina, where it will be compared to ideal models. Once the system has been tested and redesigned, operations will be set up in Durham and Salvo, North Carolina. The goal is to provide kite engines of various powers within 18-24 months.



Figure 1.2 – WindLift, LLC. System

1.3.2 Kite Gen

Another company known as KiteGen²⁴ has been effectively harnessing the wind power from kites to produce electricity. Kites are tethered to a large circular structure on the ground that revolves. These kites go up to heights of 800 m to 1000 m. The unique part about this system is that the movements of the kites are electronically controlled by advanced sensors and software.

KiteGen can easily be compared to wind turbines in terms of efficiency. One of these plants with a circular path of 800 m in diameter produces the same quantity as 150 of the latest, more efficient wind turbines. In order to keep the possible power yield at its highest, wind turbines require a large amount of space. The KiteGen plant only uses about 5 Km² as its required area to generate the highest power yield.



Figure 1.3 - KiteGen's System

1.3.3 Delft University

At the Delft University in the Netherlands, research has been developing with obtaining power from flying kites at high altitudes.¹² The kites are attached to generators, and a 10 square meter kite can generate up to 10 kW of power. The project is known as “Laddermill” and can provide electricity to 10 homes. Scientists hope to expand the project to support 100,000 homes. This would use multiple kites and ideally produce 100 MW of power.

The kite is able to generate power by pulling on a string attached to generators on the ground. When the maximum height is reached, the kite is reeled back and the process is repeated. Scientists at the university have figured out that flying kites in a figure eight pattern maximizes the power. Also when the kite is reeled in, it is angled in such a way so that it acts like a glider. This reduces the power needed to reel the kite in, and therefore increases the power produced.

1.3.4 Highest Wind LCC

There is a company based in New Hampshire known as Highest Wind LLC¹³ that is developing a glider system to harness wind energy. Their tethered energy gliders will fly at altitudes between 500 and 1200 feet. The system will be automated, and the gliders controlled to rise and then fall a few hundred feet, to produce 20 kW of power at a time. These systems are planned for use in various locations such as farms, golf courses, schools, or even entire villages. In one year the usage will 90,000 kW hours, and the system reaches its breakeven point in approximately seven years.

1.4 Project Objectives

Our main project objectives for our IQP have been mentioned previously. The following is a bulleted list of our main project goals.

- Develop a mobile, wind monitoring system to be used during field testing of the WPI Kite Power system.
- Develop a wireless system to transmit wind speed at the kite height to a laptop on the ground
- Develop a grain grinder accessory for the MQP Kite Power System

2. Wind Monitoring System

One goal of our project is to develop a mobile, wind monitoring system to be used during field testing of the WPI kite power system. We will discuss the various design areas as follows. We will begin with a discussion of the anemometer we chose, and lead to the structure which supports the anemometer. From there the lifting options (kite and balloon) will be explored. The topic of communication, including the data logging with MATLAB and the FM transmitter will be discussed at length. Next, the design of the structure that supports the anemometer including the use of potential flow equations will be discussed. Testing of the various components of the anemometer system will then be summarized.

2.1 Anemometer

One goal of our project is to develop a mobile, wind monitoring system to be used during field testing of the WPI kite power system. The first problem we addressed was how to accurately measure the wind speed. We began with researching different wind monitoring systems and anemometers of various types. After putting together a comprehensive list of anemometers, we narrowed it down to our top three choices. From there we performed a value analysis to choose the best option for our particular needs. In Figure 2.1 below, the system can be seen.

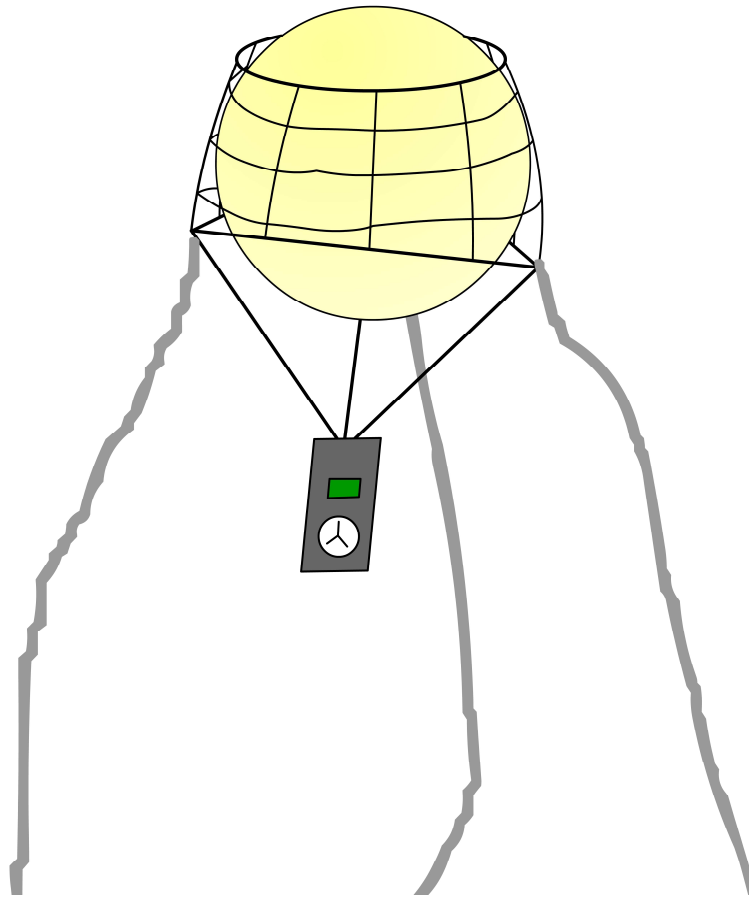


Figure 2.1 - Wind Monitoring System

2.1.1 Types of Anemometers

There were three main types of anemometers that we considered, the cup, hot wire and turbine anemometers. The cup system is a method that has been used for over a century, and has been improved for many years. This is a basic design that involves a cup mounted on each horizontal arm; usually three to four arms are used. As the air flows past the cups, the arms rotate at a rate proportional to the wind speed. An example of this type of turbine can be seen below in Figure 2.2.



Figure 2.2 - Example of a cup anemometer

One of the disadvantages of using this system is that it may suffer orientation issues when measuring high wind speeds. If the orientation of the cups and arms are not normal to the wind speed, measurements could differ. It was also discovered that each cup produced a maximum torque when it was at 45 degrees to the wind flow. By using this type of anemometer, we would most definitely run into severe orientation and mounting issues.

The other type of anemometer we researched was the hot wire anemometer. The basic idea of this type is to heat up a fine wire to a specific temperature. As the air flows past wire, it cools the wire down. The electrical resistance of the wire depends on its temperature, so there is a distinct relationship between the air flow velocity and the resistance of the wire. The air flow velocity can be calculated from the resistance measured.

There are a few advantages and disadvantages to using this particular anemometer design. An advantage is that as long as the wire is normal to the wind direction, it will accurately measure the velocity. The disadvantages are that many models are expensive, which is not suitable for our project. Hot wire anemometers are also very fragile, so it is not suitable for our project. The concept of a hot wire anemometer can be seen in Figure 2.3 below.

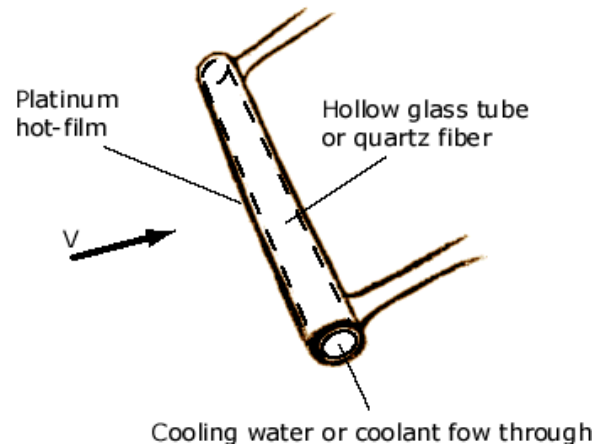


Figure 2.3 - Hot wire concept

The third type of anemometer we researched was based on a micro turbine. This involves a mere turbine that rotates as air passes through it. The wind velocity can be measured relative to the speed of the turbine. These models are usually cheaper to purchase, and are more lightweight. As we were searching for models we noticed they were more readily available compared to the other two models. A disadvantage as with the other models of anemometers is the problem of orientation. If the turbine is not facing the direction of the wind, the velocity reading will be inaccurate.

There were also some combination systems looked into. These combined the hot wire and turbine anemometer designs. The prices on these were very high, and we didn't see an advantage to having both systems as part of our project.

2.1.2 Top Three Anemometers Chosen

We narrowed down our list to our top three choices. Our first choice was the Sper Scientific 840003. The advantages were that it had a real time RS232 output, which was one of our top requirements. It was also a reasonable price, at \$134, and a reasonable weight at approximately 0.38 lbs. The disadvantages were that no actual data logging was done and it has an auto power off after 20 minutes.

The next of our top choices of anemometer was the Extech CFM Vane Anemometer Data Logger. The advantage of this model was that it had an RS-232 PC serial interface. It also had a high wind velocity range, of up to 100 mph. It has a somewhat high weight at 0.77 lbs. Another disadvantage was that this model is somewhat expensive, at about \$320. Another disadvantage is that the turbine is not directly part of the meter, which would make it more difficult to mount to whatever lift system we choose to implement.

Our last choice of anemometer is the Air Velocity Meter, Vane and Hotwire - TPI® 575C1. The advantage is course that there are two types of anemometers used, which would be good for our project to see which type was more accurate. It was also a relatively low weight. Another advantage is that it had an RS232 output. The main disadvantage was that it was expensive, at \$225. It also had an auto power off after 10 minutes.

2.1.3 Value Analysis

After deciding on these three, we performed a value analysis to come up with our top choice. We decided on categories with which to rate each anemometer. These included the type of anemometer, cost, weight, size, power supply, accuracy, wind speed range, data logging/output. Each of these categories was given a weight factor to show relative importance. For example, weight, wind speed range and data logging/output were all weighted at 0.8, while the rest of the areas were rated at 0.6. This means that we considered weight, wind speed range, and data logging/output to be the most important areas to consider when completing the value analysis.

For each of the anemometers, a number from 1 to 5 was assigned in each category depending on how well the anemometer fit the category. The scale was from 1 to 5, with 1 being the lowest on the scale. For example, if an anemometer chosen was very heavy, a 1 would be assigned to the weight category, as a heavy anemometer is not ideal for our project. The ratings for each of the categories were added together for the three anemometers first without scaling. A weighted total was then calculated based on if the category received a 0.8 or a 0.6 in importance. Therefore the anemometer with the highest weighted total would be the best suited for our project. The complete value analysis can be seen below in the table.

Scale: 1 - lowest, 5 - highest											
Weighting: 1,0.8,0.6,0.4											
Name	Type	Cost	Weight	Size	Power supply	Accuracy	Wind Speed Range	Data Logging/ Output	Total	Weighted Total	d
Weighting		0.6	0.6	0.8	0.6	0.6	0.6	0.8	0.8		
Anemometer - Sper Scientific 840003	4	5	4	4	4	4	4	5	34	23	23
Extech [®] CFM Vane Anemometer Data Logger	4	2	3	4	4	4	5	5	31	21.2	21.2
Air Velocity Meter, Vane and Hotwire - TPI [®] 575C1	5	3	4	4	5	5	3	5	34	22.8	22.8

Table 2.1 – Anemometer Value Analysis

From this value analysis it can be seen that the Sper Scientific 840003 received the highest weighted total. These weighted totals are very close to each other. This means that perhaps we should have been more careful in our assigning of the ratings and most definitely scaling factors. Though the Sper Scientific didn't "win" by much, we were confident in our choice.

There were many reasons we decided not to choose the Extech CFM Vane Anemometer Data Logger. Though it had a high wind speed range and RS-232 serial interface, the factor that made a big difference was the cost and weight. It was too expensive for our project and the weight would have made a large difference in our lift system.

Our group didn't choose the combination vane and hotwire anemometer for several reasons. According to our value analysis, having both types of anemometers to work with would have been ideal, but rethinking this having two types may not be the best option. It may have added extra work for one of the types that may not be used. It was also slightly on the expensive side, and unfortunately the wind range wasn't as high as we ideally wanted it to be.

2.1.4 Final Anemometer Choice

We decided on the Sper Scientific 840003 for reasons not solely based on the outcome of the value analysis. It was the lowest cost out of the three choices, at a price of \$134. Its weight was also the second of the three, at 0.38 lbs. Most importantly, the wind speed accuracy was reasonable with a maximum of 67 mph, and it has a real time RS-232 output. The anemometer can be seen in Figure 2.4 below.



Figure 2.4 - Sper Scientific 8400003 Anemometer

2.1.5 Anemometer Assembly

The three tethers and inverted pyramid shape of the frame will reduce random motion of the balloon due to wind gusts and turbulence, but this motion cannot be completely eliminated. Also, the angle of the frame relative to the ground will change with wind speed, and can only be compensated by adjusting the lengths of the tethers manually. The mechanism attaching the anemometer to the balloon must compensate for both of these effects. This can be seen in Figure 2.6.

To keep the anemometer facing into the wind, it must be able to spin while on the frame. Proper alignment with the wind can be achieved using a small fin off of the back of the anemometer.

The fin must be large enough to create sufficient force for proper alignment, but not too large to affect the air flow through the anemometer.

To adjust the vertical angle of the anemometer, the device was attached to the hard drive bearing via a hinge. A sturdy spring was used to dampen oscillations caused by abrupt wind changes. We decided on using a small bearing from a computer hard drive as an axis of rotation, as these bearings are light-weight, readily available, and have an extremely small coefficient of friction. The bearing allows the anemometer to always face the wind direction. The hinge accounts for the change in wind speed, which will change the drag on balloon, the tether angle, and the balloon height as a result.



Figure 2.5 - Hard Drive Bearings

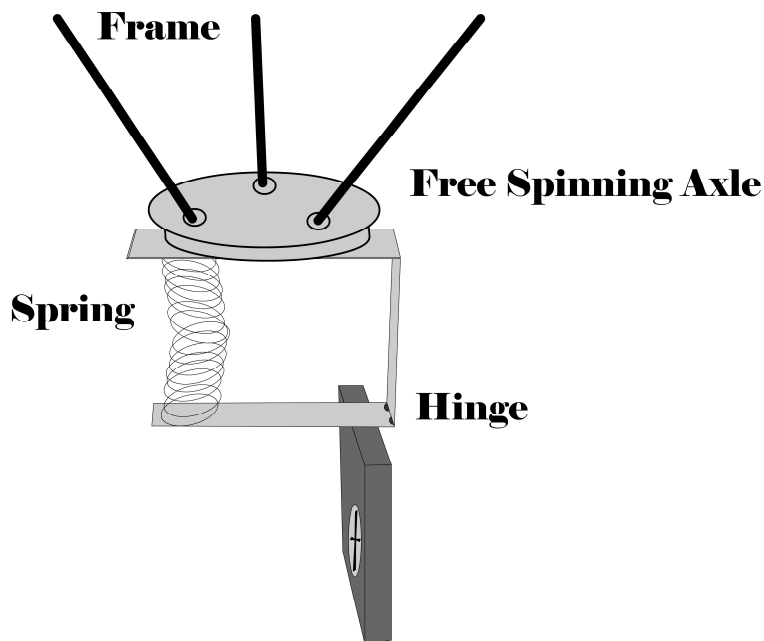


Figure 2.6 - Anemometer attachment Assembly

2.2 Lifting Options

The other major part of our methodology was to find a method to lift an anemometer up to the height of the kite to measure the wind speed. This could be done a number of different ways. One of the ways this could be achieved would be to use a second kite to attach the anemometer. This could then be flown at the specific height of the main kite power system. Another idea would be use a pole with an anemometer at the top. The last idea would be to use a balloon, where the anemometer could hang from a structure attached to the balloon.

These three options were analyzed, with advantage and disadvantages developed for each of the systems. Various types of kites and balloons were researched. Our group decided to purchase a kite and a balloon to field test both and see which one was more suitable.

2.2.1 Lifting Advantages and Disadvantages

One of our three main ideas was to use a second kite to attach the anemometer, and fly it at the specific height. An advantage of this system is that it's likely to be cheaper than the other options. Also, it will probably generate enough lift for most anemometers and can easily attain the height of the main kite power system.

There are a number of disadvantages to using a second kite. It will have to be manually controlled. Winds can be unpredictable, and a kite's flight path is relatively chaotic. This can severely hinder many wind measuring systems. It's likely to crash because of fluctuation in wind speed or initial attempts to get the kite off the ground.

Another option was to use a long telescoping pole to attach the anemometer to at the top of. There are a few advantages to this type of design. It will probably hold up a greater weight depending on the material and structural integrity of the pole. Also depending on the design it could be compact and mobile.

Unfortunately the disadvantages outweigh the pros of this type of design. Getting enough of a specific material to reach a height of 100 feet is costly. It would also be difficult to reach a height of 100 feet and remain very stable. The chance of the pole falling down would cause a great amount damage, probably more than if the other systems failed. Local zoning requirements also have to be taken into consideration, as tall structures over a certain height may not be allowed.

The last option was to use a weather balloon to which the anemometer would be attached to by a frame. There are many advantages to using a large balloon; first of all it is a mobile system that can be used at different field test sites. A balloon will allow for more control and stability. Also, a balloon will

most likely be able to attain the desired height regardless of wind conditions. The lift generated by the balloon can also be tailored to specifically what is required for our system.

There are a number of disadvantages with using a balloon to lift the anemometer. It may be more expensive than the kite system. If multiple tethers are not utilized, the accuracy will suffer greatly with shifting winds. With a single tether, the balloon will also rotate and have random motions, which will interfere with wind measurements. Durability of the balloon is also in question for extended use.

2.2.2 Kite Options

Our group researched a number of different types of kites. After compiling information about them, we picked our top choice of kite and looked into specific models. After comparing a few different models we purchased a kite.

The first type of kite that we looked at was the fighter kite, which can be seen in Figure 2.7 below. This is a highly unstable kite that would require constant attention. This would interfere with making measurements, and this type of kite tends to run on the more expensive side. This type of kite was quickly ruled out.



Figure 2.7 - Example of a fighter kite¹⁷

Next a foil was researched. These are very large kites, as can be seen in Figure 2.8 below. This is a very stable kite design, but unfortunately may destabilize in strong cross winds. These kites do produce a large amount of lift, and have a large power to size ratio.



Figure 2.8 - Example of a foil kite¹⁸

The next type of kite looked into was the box kite. This is a readily available and usually quite cheap. This is a kite often used and is very stable. This type also generates more lift than many other kite designs.



Figure 2.9 - Example of a box kite¹⁹

The last type of kite looked into was the kytoon. The kytoon is a combination of a balloon and a kite. The advantage of having a combination is that it would stay aloft without a great amount of wind.

Unfortunately the “balloon” aspect of the kytoon will make the overall system more susceptible to changing winds, which would disturb measurements.



Figure 2.10 - Example of a kytoon²⁰

2.2.3 Pole Options

Using a pole to hold the anemometer was briefly considered. We thought of using materials such as aluminum, stainless steel, or a combination of both. Aluminum would be the cheapest option, but also may not be a strong enough material. Stainless steel is much more expensive than aluminum, but would be strong and resist harsh conditions well. With a combination or manufactured material, it would be the most expensive option, but may not be available in telescoping options.

The long telescoping pole option was ruled out for several reasons. First, it would most likely be a very expensive option, as the pole would have to be at least 100 feet tall. It’s not feasible to make a pole out of any type of strong metal as it would be heavy and unstable at such high heights. Most importantly, because of local zoning requirements, a tall pole may not be allowed as it would interfere with sight.

2.2.4 Balloon Options

Our group researched possible balloons that could be used to lift an anemometer at to a minimum of at least 100 feet high. We researched weather monitoring balloons, as these types of large balloons can be implemented at very high altitudes.

The first weather balloon we chose was from NovaLynx Corporation, which is involved with Weather Monitoring Instruments and Systems. They provide large sounding balloons, which are generally used to carry various types of payload such as radar targets. We chose the 400-8237 model, which costs \$30. This balloon had a nominal weight of 300 grams with a 5 ft inflated diameter. The

payload of this balloon is 630 grams, which is approximately 1.389 lbs. The anemometer chosen is 0.381 lbs, which leaves about 1 lb for tether lines and a support frame.

Our second choice was a weather balloon from Kaymont Meteorological Balloons. The model we chose was the KCI1200, at a cost of \$65. This balloon has a weight of 1200 grams with a diameter of about 6 feet. The payload is 1050 grams, which is about 2.314 lbs.

We decided to purchase the KCI1200 balloon from Kaymont. Even though it's more expensive, the payload is much bigger, and will allow us more freedom with the structure to attach the anemometer to.

2.3 Communication

One of the most important parts of the project is how to transmit the wind velocity data from the anemometer to a laptop on the ground, in order to measure the wind speed over time.

2.3.1 Wireless Adapter

We researched a number of different products for a wireless adapter. One of our options was the Universal Wireless RS232 to USB Transceiver. The others were the HPS-120 Wireless Serial Port - Wireless RS232 Adapter and the Cordless Serial Adapter. These choices varied in price and adaptability.

The anemometer is documented as having an RS-232 output, so we first decided to use the Serial Adapter with Bluetooth Wireless Technology from IOGEAR. This would allow us to connect an RS-232 output to a computer with Bluetooth interface. In reality, the output is a 3.5mm audio jack, for which an expensive adapter cable can be purchased.

2.3.2 Data Logging using MATLAB

Once in the air, the anemometer will sample wind speed at the target height. From there the anemometer data must be recorded. There are two ways for the data to be recorded, the first being to have a small data recording device in the air, which could be read after the anemometer is taken down, the second being to have a transmitter send the signal to a recording device on the ground. Having the recording device on the ground has the advantage that, in the event of a catastrophic lift system failure, the data would still be accessible even if the airborne electronics suffered damage. Another distinct advantage of using a transmitter is that a laptop can be used as the recording device, enabling the data to be displayed in real time.

Since the output is essentially an audio signal, we decided that a simple radio transmitter would be ideal, as it they are cheap and compact, and any portable radio with a headphone jack can be used to receive the signal.

The readily available options for small FM transmitters are primarily from the MP3 market. They are intended to send an audio signal from an MP3 player to a car radio. The best range listed for any of these devices is 30 ft, and tend to require a 3 – 5 volt voltage source, as this is available straight from an MP3 player. A device that can run off a 9 volt battery would be ideal, as it could share the 9v battery with the anemometer, eliminating excess weight. There are “open source” schematics readily available for 9v FM transmitters, with ranges up to a few hundred feet, comprised of a dozen or so basic components. Building the transmitter from scratch offers the advantage of being cheap and easily customizable. Any device we could purchase would most likely have additional features that could add unnecessary weight, such as LCD screens, bulky enclosures, etc. Building from scratch won't produce an optimally small transmitter, but it will be lightweight and will not have any unnecessary components.

The manufacturer of the anemometer offers software that automatically records data from the device. Unfortunately, the software is not included with the anemometer, and is fairly expensive. Also, there is extremely little documentation as to how this software works, and what features it offers, making it difficult to determine if the software would perform as desired before purchasing it. Fortunately, the output of the anemometer is simply an audio signal, which can be easily recorded on a laptop, and can also be read, in real time, by MATLAB. Importing the signal into MATLAB allows for customizable data logging. The only drawback to this method was that, initially, it wasn't clear whether the digital signal from the anemometer could be interpreted, since the documentation was so vague. Eventually, the signal was deciphered and read wind speed and temperature data from the device. From there, MATLAB was able to graph the data in real time.

In the field, the MQP team will be monitoring the power generated by the kite system, while wind speed is simultaneously being monitored. Both the MQP teams and our sets of data will need to be synced, so as to determine the efficiency of the kite power system. Since both teams will be recording data on separate computers, the most thorough way to line up the data is to sync the clocks on the computers, and include a time reading with every collected data point. Afterwards, both sets of data can be brought together and easily aligned.

2.3.3 FM Transmitter

The adapter cable available for the anemometer is long and bulky, so rather than use the adapter to convert the 3.5mm to RS-232, and then transmit via the RS-232 Bluetooth device, a better option would be to build a simple FM transmitter. After researching online, a reasonably simple circuit was found. Components were purchased from the ECE shop and the circuit was bread boarded. Initially,

a signal was picked up from the transmitter on an FM radio. After observing that the circuit functioned correctly, the components were soldered onto a perf board.

Significant problems were encountered while testing the circuit on the PCB. The transmitter's carrier frequency wasn't in the proper FM radio range, as it was too low. We added and changed a number of capacitors and inductors, with no improvement. Adjusting the variable capacitor should have drastically changed the frequency, but showed little effect.

Because of time constraints, we decided to order a kit for a similar circuit online. This kit contains the printed circuit board for the transmitter, which allows for a more compact unit, in turn reducing stray capacitance. After assembling the transmitter, the device's carrier frequency range was measured, and was found to be within the FM radio frequency range. Audio signals were then successfully received from the device.

A small radio was purchased to receive the data from the anemometer. An additional telescopic antenna for the transmitter was also purchased, as the antenna included in the kit was simply a long wire. In Figure 2.8 below, the FM transmitter can be seen, and Figure 2.9 shows the anemometer system.



Figure 2.11 - FM transmitter

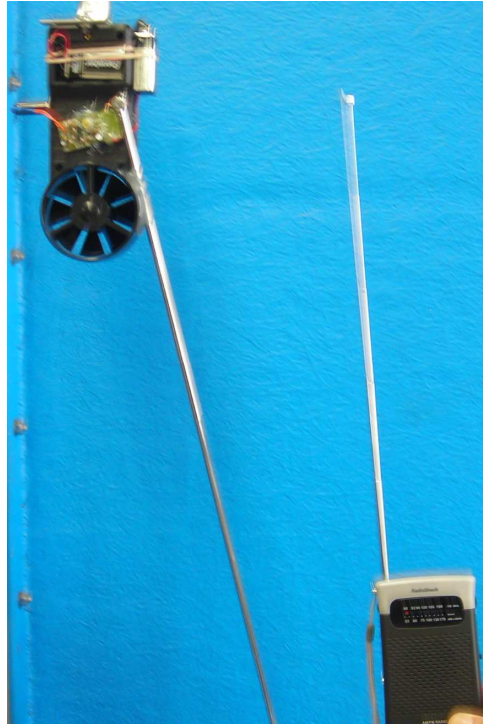


Figure 2.12 - Anemometer

2.4 MATLAB Code Description

2.4.1 Top Level Code Description

The anemometer produces a signal every three seconds. This signal is comprised of 180 bits of data. The speed at which these bits are sent (baud rate) can be set on the anemometer to either 1200 or 2400 bits/second. Analysis of the signals at both baud rates showed that the faster baud rate produces a cleaner signal from the receiver, and the code is set by default to check for the 2400 bits/second signal.

When run, the user is prompted to enter a sample length (in seconds). The program will keep sampling data for this length of time. Since the signal is sent every three seconds, sampling is broken into 3 second segments. Each segment is analyzed individually, and the binary values are converted into the proper value for wind velocity. After each sample, the new measured value is printed to the MATLAB command screen, and a time plot of the velocity measurements is updated. In Figure 2.10 below, anemometer data with a direct connection to the computer can be seen.

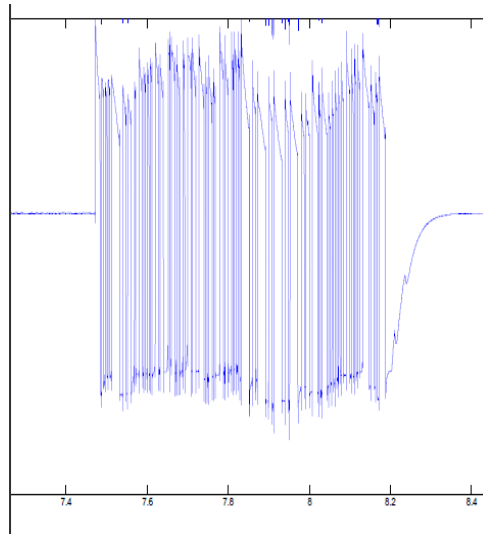


Figure 2.13 - Anemometer signal with Direct Connection to Computer

Figure 2.11 shows the anemometer signal received from the transmitter. The bottom waveform is the raw data recorded by MATLAB. The middle waveform shows the data after undergoing a low pass filter. The tick marks on the middle waveform show where the algorithm reads individual bits. The top waveform shows the filtered data being averaged over each bit individually.

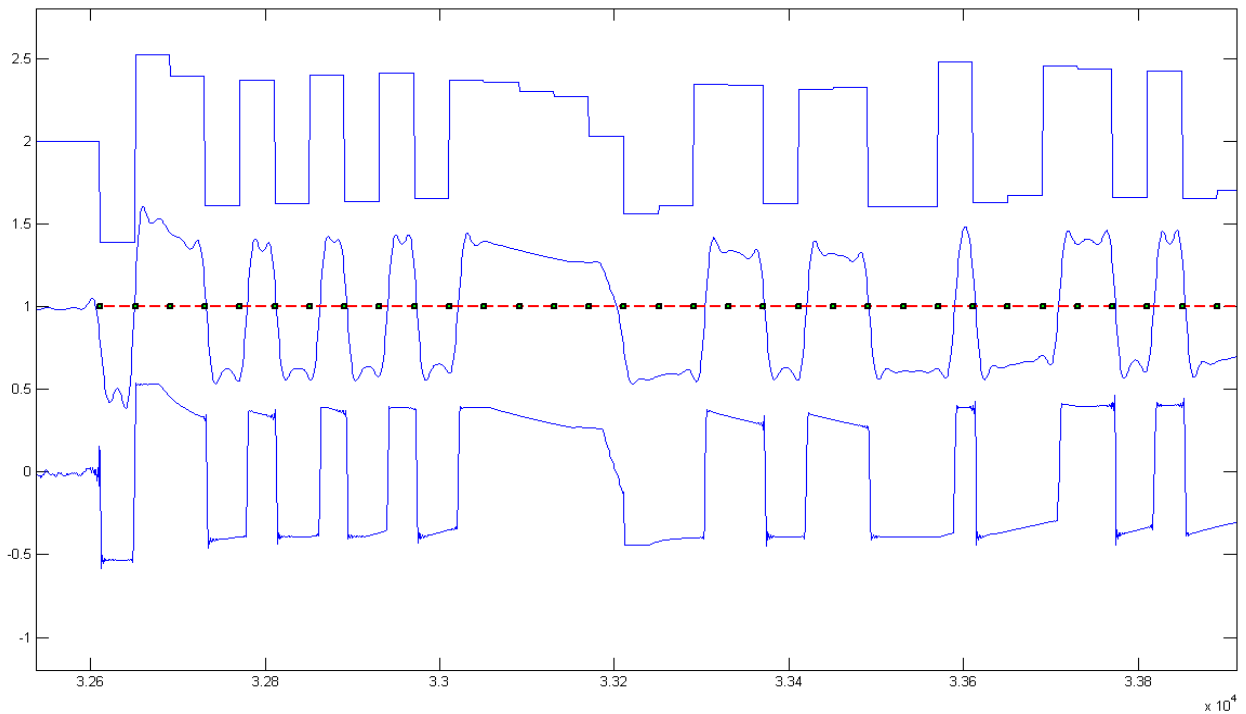


Figure 2.14 - Anemometer signal through transmitter

2.4.2 Algorithm

The code follows the following algorithm:

- 1) Initialize audio inputs
- 2) Set baud rate and related variables
- 3) Prompt user for sample duration
- 4) Initialize low pass Butterworth filter
- 5) Start main counter
- 6) Loop until counter value exceeds sample duration length
 - i. Sample for three seconds
 - ii. Apply filter to sampled data (removes high frequency noise)
 - iii. Locate start of signal, ignoring invalid spikes in the data
 - iv. For each bit, take average value of signal
 - v. Convert averaged values to binary 1 or 0. The signal will be inverted, so if the data average is greater than 0, the binary value will be zero, and vice versa.
 - vi. Check formatting bits for accuracy. Disregard data if formatting is bad, otherwise:
 - a. Convert binary values to actual velocity measurements
 - b. Set time stamp for velocity measurement
 - c. Update velocity versus time plot
- 7) End

2.5 Anemometer Support Structure

In order to attach the anemometer to the weather balloon, a structure had to be built. We brainstormed ideas and decided upon an inverted pyramid frame. The balloon would sit at the top of the inverted pyramid and the anemometer assembly would attach to the bottom tip of the structure. This would allow the balloon to “sit” in the frame.

Dowels that were 4 feet long were first used to create a frame. A notch was created and the end of each of the dowels, so they could have a firm, grooved connection. The connections were glued, and the pieces themselves zip tied together for a preliminary frame. The frame was then tied to the kite lines off of the balloon.

In order to make a more stable frame, we decided to purchase 1/8” diameter carbon fiber rods to replace the wooden dowels. Using six of the 4 ft. long rods, we constructed a tetrahedron, or an

inverted pyramid. Carbon fiber was chosen because of its properties. Wood dowels break easily when a stress is applied in a certain direction, but carbon fiber can be both flexible and strong.

2.5.1 Flow Equations

A design constraint was imposed upon the system by the choice to use a balloon to lift our anemometer. Treating the weather balloon as a perfect sphere, it must be considered what happens to airflow around a sphere. When a stream of air approaches a sphere, it accelerates around it. This fact indicates the anemometer must be placed a particular distance below the sphere to assure that it is the free-stream velocity that is actually being measured. To establish this distance, fluid dynamics potential flow theory must be applied to the system.

Potential flow describes the velocity field of a system as the gradient of the velocity potential. Potential flow theory assumes incompressible (low speed) friction loss flow around the balloon. One of the tools potential flow can provide is known as the stream function. Constant values of ψ produce what are known as streamlines. Streamlines can display graphically how the flow over an object is going to act. Figure 1 displays streamlines traveling over a face of a sphere.

Stream Function

$$a = 36 \text{ in} = 3 \text{ ft}$$

Balloon Radius

$$\psi = -\frac{1}{2}U_{\infty}r^2\sin^2\theta + \frac{\lambda}{r}\sin^2\theta \quad \theta = -\frac{\pi}{2}$$

(1) Rotational Velocity

$$V_r = U_{\infty} \cos\theta \left(1 - \frac{a^2}{r^3} \right)$$

(2) Location of maximum velocity around sphere

$$V_{\theta} = -\frac{1}{2}U_{\infty}\sin\theta \left(2 + \frac{a^3}{r^3} \right)$$

(3) Tangential Velocity

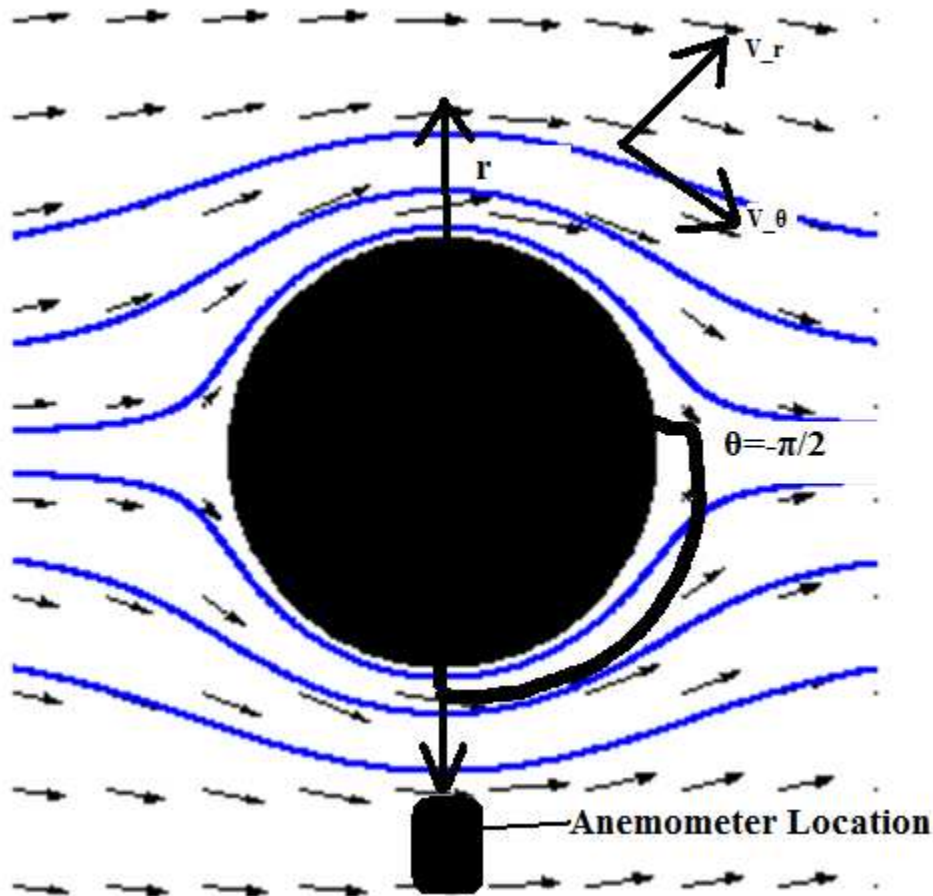


Figure 2.15 - Flow Over a Sphere

It is required that V_θ be as close to U_∞ as possible.

$$\text{For } V_\theta = 1.01U_\infty$$

$$V_\theta = -\frac{1}{2}U_\infty \sin\theta \left(2 + \frac{a^3}{r^3} \right)$$

$$(4) \text{ Let } \frac{V_\theta}{U_\infty} = C$$

$$-2C = \sin\left(\frac{\pi}{2}\right) \left(2 + \frac{a^3}{r^3} \right)$$

$$2C = 2 + \frac{a^3}{r^3}$$

$$r^3 = \frac{a^3}{2(C-1)}$$

$$r = \sqrt[3]{\frac{a^3}{2(C-1)}}$$

$$r = \sqrt[3]{\frac{3^3}{2(1.01-1)}}$$

(5) $r = 11.0521 \text{ ft}$

(6) For $V_\theta = 1.02U_*$

$$r = \sqrt[3]{\frac{a^3}{2(C-1)}}$$

$$r = \sqrt[3]{\frac{3^3}{2(1.02-1)}}$$

(7) $r = 8.772 \text{ ft}$

(8) For $V_\theta = 1.03$

$$r = \sqrt[3]{\frac{a^3}{2(C-1)}}$$

$$r = \sqrt[3]{\frac{3^3}{2(1.03-1)}}$$

(9) $r = 7.663 \text{ ft}$

(10) For $V_\theta = 1.05U_*$

$$r = \sqrt[3]{\frac{a^3}{2(C-1)}}$$

$$r = \sqrt[3]{\frac{3^3}{2(1.05-1)}}$$

(11) $r = 6.436 \text{ ft}$

From these calculations it was concluded that the anemometer must be placed at least 6.4 ft from the balloon center to keep normal velocities within 5% of wind velocity. The pyramid shaped anemometer support structure (Fig 2.1) was designed accordingly.

3. Testing of Wind Monitoring System

3.1 Testing of box kite

During mid-November of 2008, the IQP team tested the traditional box kite that had been purchased from Premier Kites & Designs at a field site in Westborough, MA. A mock anemometer was made out of wood to mimic the weight of the actual anemometer. After a number of attempts, the kite was unable to successfully lift the mock anemometer at the desired height. The decision was then made to focus on the use of a weather balloon to lift the anemometer.

3.2 Lab Testing of Balloon

The balloon was tested a number of times during the November and December of 2008. For the first testing, we filled it with helium and attached a rope to test the lift in the lab. We attached small weights as well as the anemometer in order to figure out the actual payload of the balloon. We calculated the extra payload to be about a pound. We also did not have the balloon inflated to the maximum, which limited the amount of weight that could be lifted.

We built a net around the balloon before taking it out to the field to see how it would perform in strong winds. This net would be used to attach the triangular frame to the balloon. We had planned to purchase a soccer net to drape around the balloon, but these nets proved to be too small and expensive. We researched nets and purchased a large mosquito net to drape over the balloon. Thin kite line was used to create a net around the balloon, which was taped to the surface. We thought that with a net it would be easier to attach tethers and gain more control of the balloon.

3.3 Field Testing of Balloon

We realized our net wasn't very effective after bringing it to the field in Westborough. We tested the balloon with a different number of tethers. For the tethers we used thin kite line attached to the neck of the balloon either by tying it, or with zip ties. With one tether, the balloon moved around a great deal, and could not be easily controlled. Two tethers were then used. This offered greater control, but was still relatively unstable.

Three tethers (our ideal option) were next attached to the balloon. One tether was attached to the ground, with the other two controlled by members of our IQP team. We spaced ourselves equally in

an equilateral triangle when trying to control the balloon. We discovered that actually forming an isosceles triangle worked better, with one tether acting as the leading tether (in this case the one attached to the ground).

During our second round of testing, we attached the carbon fiber inverted pyramid to the balloon. The mosquito net was also hung on the balloon and attached to the frame. After bringing the balloon out to the field and attaching three tethers, we realized that the net did not help much. Pictures of testing can be seen below:



Figure 3.1 - Testing Balloon I



Figure 3.2 - Testing Balloon II



Figure 3.3 - Testing Balloon III

After the performance of the balloon was observed, it became apparent that the net material was too flimsy, and the shape of the net was not well adapted for fastening the balloon in place. However, the solid ring built into the top of the net proved to be valuable in preventing the net from slipping. This ring was reused, with six tethers running from the ring to the three corners and three sides of the frame. This reduced the overall weight of the system.

For the third round of testing, the balloon was taken out to an open field with the complete anemometer assembly attached. The balloon was sent up to a height of approximately 100 feet. The stability of the system was greater than expected at moderate wind speeds. Wind velocity data was then successfully transmitted and received while the balloon was at the target height. Some erroneous data was detected, but this represented a small fraction of the total data received. The overall complexity of the receiver setup had been reduced greatly over numerous revisions of the MATLAB code, and the total time spent adjusting the wireless system was minimal.

Despite a small number of false data readings, the wind measurement system functioned as intended at its target height at moderate wind speeds.



Figure 3.4 - Testing balloon IV



Figure 3.5 - Testing balloon V

3.4 FM Transmitter Testing

Wirelessly interfacing the anemometer and computer presented many challenges. Initially, the transmitter was simply plugged into the anemometer, and transmitted via a long wire acting as an antenna. Since the transmitter was not solidly fixed in position, any movement could generate noise on the signal. The loose wires would periodically act as antennae, picking up additional noise. The movement of the wire antenna also affected the signal.

These problems were resolved by permanently fixing the transmitter to the anemometer, reducing loose wire lengths, and replacing the wire antenna with a fixed, solid, extendable antenna.

Initially, the transmitter was intended to share a 9V battery with the anemometer. When both connected to the same battery, it was discovered that the anemometer causes periodic voltage fluctuations at the battery terminals, approximately two times per second. These fluctuations inadvertently propagated through the transmitter, and were received along with the actual anemometer signal as noise. Attempts to filter this noise via MATLAB failed. For this reason, the transmitter and anemometer must both have separate batteries.

Another source of noise was discovered in the placement of the transmitter battery. If the transmitter battery is located too close to the anemometer battery, the previously discussed fluctuations still propagated through the system. To fix this, the transmitter battery was moved to the top of the anemometer, where the hinge is attached. The movement of the metal hinge was also found to cause noise in the system, and the battery was consequently moved to side of the anemometer, where it is free from interference.

The most elusive source of signal distortion was caused by the baud rate of the anemometer. After much experimentation, it was discovered that some element of the wireless system rejects DC signals, i.e. a constant signal value will eventually be sampled as a value of zero. For some segments of the signal, the anemometer outputs the same binary value many consecutive times. This effectively appears as a DC signal, and the sampled signal reduces to zero prematurely, resulting in erroneous velocity measurements. Increasing the baud rate on the anemometer effectively reduces the time a segment of the signal will remain one value, eliminating the problem. From there, the MATLAB code was easily adapted to read the faster the baud rate.

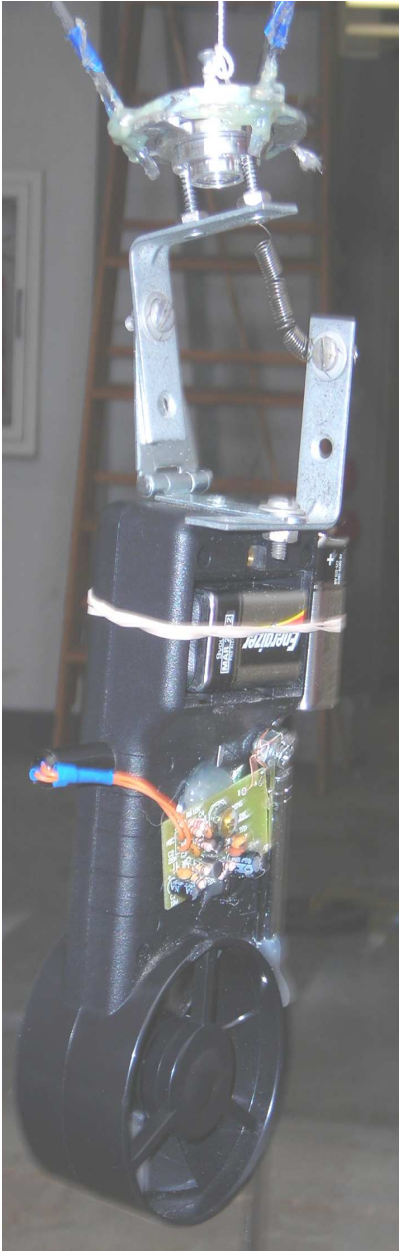


Figure 3.6 - Close up of the anemometer assembly

4. Grain Grinder Accessory

4.1 Development of Kite Power Accessories

As stated above, a goal for our project is to develop an accessory that can be powered by the kite power system for use in a developing nation. Initial ideas resulted in accessories such as a grain grinder or a water pump. The system would be made modular, in which it could be “retrofitted” for each purpose. This means that smaller systems could be easily added and

interchanged to the main kite system, depending on what was purpose people most needed. Our main focus would be to develop these accessories to be used in a developing nation such as in Namibia, Africa, where a WPI project center is located.

4.1.1 Economy of Namibia

As stated previously, the IQP and MQP projects will hopefully be utilized in Namibia. The country is located in the southwest area of Africa. An important thing to first consider is that Namibia is one of the richer countries in Africa. But the income for many adults is only about 120 Euro per month, and most have a much smaller income. The unemployment rate is high, as 40% of the population that can actually work are unemployed.¹⁴

The economy of Namibia is comprised of mining, agriculture and fishing among other industries. In order for a modular system to be most beneficial to those in Namibia, it is reasonable to focus on the needs of these three areas. Approximately one third of the Gross Domestic Product is owed to mining. The majority of the minerals mined are diamonds, where half the export of mining products comes from. Uranium, gold, copper and marble also contribute to the mining products.

Agriculture is another vital portion of Namibia's economy. Unfortunately this area only contributes a very small part to the GDP, but because of poor wages, greater than half of all jobs are found in agriculture. There are a large number of farms owned by white farmers that export the meat of cattle and sheep to South Africa, while others produce ostrich meat. Subsistence farming is also common in specific areas, and in this case millet and maize are produced.

Lastly, fishing is the other major area that contributes a significant amount to the economy of Namibia. Most of what is caught is exported to Spain and Japan. Approximately 20 years ago, the country set up a 200 sea-mile zone where strictly Namibian companies can fish. This is a growing industry, which currently employs more than 15,000 people.

4.1.2 Current Wind Energy in Namibia

The current ways in which energy is harvested in Namibia were explored. It is one of the sunniest countries, in which one would assume that solar power is used. Unfortunately solar power is underutilized in this country. Obtaining energy from wind has a good potential, especially in areas near the coast. Some systems have been combined with diesel generators, to create what are known as "hybrid" energy systems.

A wind map was examined, to see which regions of the country have high wind speeds. As would be expected, these areas were along the coast of Namibia. Namibia also has one of the higher wind speeds when compared to the rest of southern Africa. The annual average wind speed for all of

Namibia is 6 to 7 m/s which amounts to 13-16 mph. The central part of Namibia only yields between 4 and 9 mph, while at the coast it gets usually between 9 and 13 mph. The wind map can be seen below, and the scale is in mph.²²

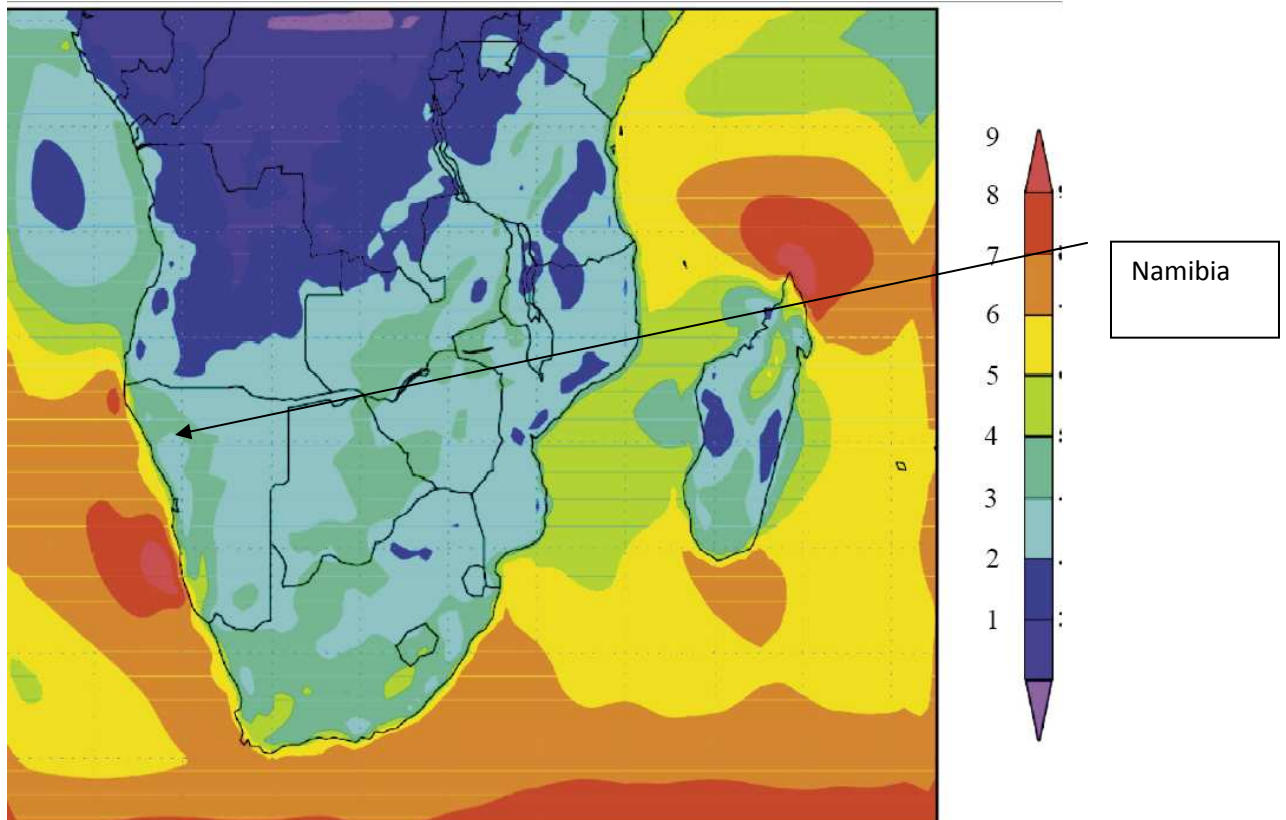


Figure 4.1 - Wind map of Southern Africa⁶

Two areas of Namibia with wind potential are Lüderitz and Walvis Bay area. These two cities are on the coast of Namibia, and because of their location on the coast, the wind speed is greater. Close to Walvis Bay a large wind turbine, WindWorld 220 kW unit was installed. Wind energy studies have been carried out at these two locations, which aims to assess the feasibility of wind farm projects. Other alternatives such as importing electricity from South Africa were also explored.¹⁴

Fortunately, wind energy is currently being harvested in Namibia. One way is using wind water pumps. These are mechanisms in which wind turns rotor blades, which in turn turns a gear box. The movement causes a piston to lift up in the borehole cylinder through rods. Water is then transferred through pipes. Wind water pumps are a common way of obtaining wind energy, with approximately 30,000 in the country. Namibia actually has the second highest number in all of Africa. As mentioned before, systems such as these are combined with diesel engines, to form a hybrid. This is done so during

months with little wind speed. The only downside is that the wind pumps generally need a good deal of maintenance.²²

Another method of using wind for energy is through wind chargers, which generate electricity for homes. The advantage is that these can be used at relatively low wind speeds of 4 m/s. The blades rotate based on the wind which turn a generator, and the electricity is then stored in batteries. These mechanisms are light-weight, and can be used in conjunction with Solar Home Systems. These once again require some maintenance, but can produce a great amount of power, between 400 W and 6kW.

Wind turbines are also used, and are similar to wind chargers, but produce a much larger amount of power. They can produce between 100kW and 4.5 MW of power. The first one in Namibia was installed in 2005 at Walvis Bay. This particular wind turbine can provide enough power to 50 to 100 homes over a span of a month.¹⁴

4.1.3 Meeting with Professor Looft

The IQP group met with Professor Fred Looft, the head of the ECE department at WPI in order to gain perspective of what Namibia is actually like. He was the faculty advisor for the group of students that completed their IQP at the Namibia project center last year, and we believed it would be beneficial to talk to him about the country. The need for light and electricity were discussed, especially in the “improvised settlements” that many Namibian residents live in. A vital use of electricity would be for the safety of the women. He next put us in touch with Jodi Lowell, who works at the Desert Research Foundation of Namibia, DRFN.

4.1.4 Interactions with DRFN

Research was conducted about DRFN, as well as about Namibia before contacting Jodi Lowell. DRFN is a non-governmental organization in Namibia that focuses on sustainability in various areas. Its main divisions are the land, water and energy sectors. Previously, the grid systems in Namibia were very large-scale and also quite centralized. Now it is shifting to a smaller scale, as it is unable to increase access for residents to electricity and also make sure that there is a stable supply of electricity.

The DRFN organization does work in a variety of areas. First it provides a professional service in the area of sustainability. They also provide opportunities for students and graduates to conduct research for the organization. An eventual goal of the kite power work at WPI, is for students to collaborate with the DRFN and to establish a kite power system in Namibia.¹¹

4.1.5 Contact with Jodi Lowell at DRFN

We were able to contact Jodi Lowell by e-mail at DRFN to discuss our project and gain her perspective. The following is a portion of the e-mail from her:

I think this is an awesome project! I think some of the most useful applications of this system in Namibia would be charging cell phones, powering radios, and indoor and outdoor lighting. That's what I can see this being used for the most. Some of these may require the system being hooked up to a car battery to get enough voltage and this would also allow the unused energy to be stored instead of wasted. If there's a way to hook it up to a car cigarette charger adapter that would be beneficial because that will open the door to a lot more applications (like hair clippers). One of the things I cannot see this power being used for is replacing the cooking over a fire (it's a taste thing).

For reference, the project I did in Namibia used a solar panel to charge a car battery and then that funneled down to multiple car cigarette lighter outlets. The entrepreneur we worked with then used these outlets to charge his neighbor's cell phones for a minimal cost (thus, introducing a business to supplement his income).

The feedback from Jodi Lowell at the DRFN was very useful. The earlier MQP and IQP teams at WPI have previously created a kite power demonstrator and electrical system. It could be used to power cell phones in Namibia. Therefore we will develop a different module, and a grain grinder attachment was decided upon. However the existing electrical system can easily be adapted to charge cell phones.¹⁵

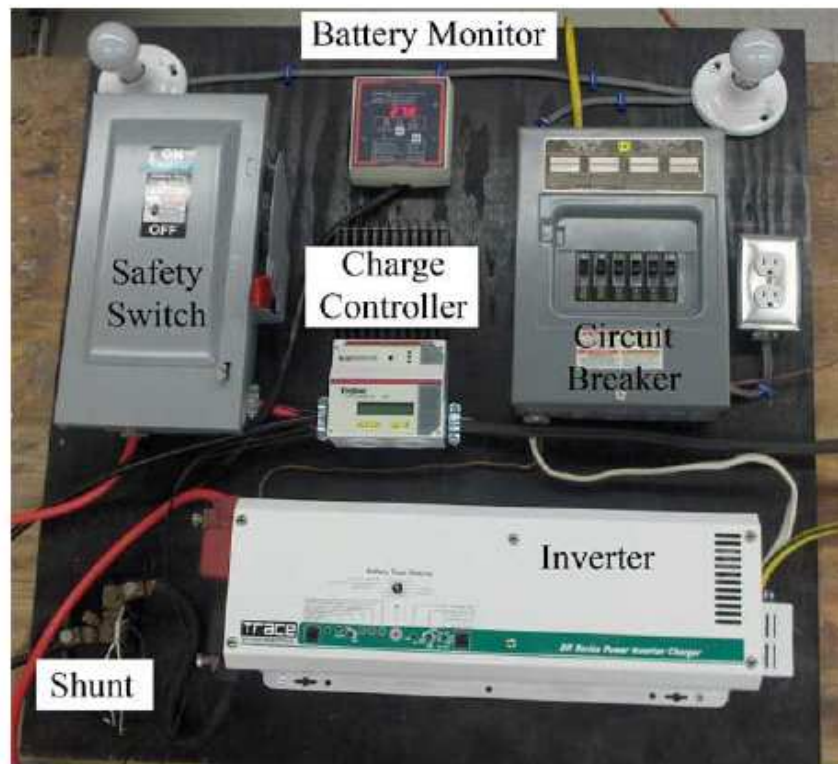


Figure 4.2 - WPI Kite Electrical System

Creating an automated grain grinder system is important because of the work involved with a human powered grain grinder. A human powered grain grinder has a couple of disadvantages. First the amount of grain grinded is less with a human grinding it, as a person can easily get tired when grinding grain, reducing production. Having a grain grinder powered by the kite system would be much more efficient for the long run.

4.2 Grain Grinder Decision and Attachment

The second objective of the IQP project is to make a modular attachment to the kite power system that can be used in developing nations. Our objective was to use the kite power system to power a grain grinder to be used in locations such as Namibia.

At Rowan University, students have been building an aluminum grain crusher that attaches to a bicycle.²⁵ The back wheel turns a pulley that moves plates in the crusher to grind the food. The device has worked on split peas, barley, lentils and corn. Rowan University has created a human powered grain grinder. It can be seen below in Figure 4. 3.



Figure 4.3 - Human powered grain grinder⁹

We researched a number of different common grain grinders²⁸ and decided on the Country Living Grain Mill. The site we looked at had useful information about a variety of grain grinders. Each of them differed in price, size, if they were hand or electric powered, etc. We chose the Country Living Grain Mill for a number of reasons. Though it was a bit more on the expensive side, it had a very simple design and seemed very stable. Compared to the others, it had extensive information about the

mill on their website. A picture of the grain grinder can be seen in Figure 4.4 below.



Figure 4.4 - The Country Living Grain Mill⁵

The simplest way to power the grain grinder was to create a pulley system. A belt was attached to the crank wheel of the grain grinder to another pulley. This second pulley is on the shaft of the kite power system. This shaft rotates at about 250 rpm, but the grain grinder is rate for use at 50 rpm to a max of 75 rpm. Therefore a gear reduction of approximately 4:1 would be sufficient. The diameter of the crank wheel is 1 foot, so the secondary pulley purchased had a diameter of 3 inches. (12 inches/3 inches = 4:1 ratio needed). A diagram of the system can be seen below in Figure 4.5. Figures 4.6 and 4.7 show diagrams of the grain grinder attachment.

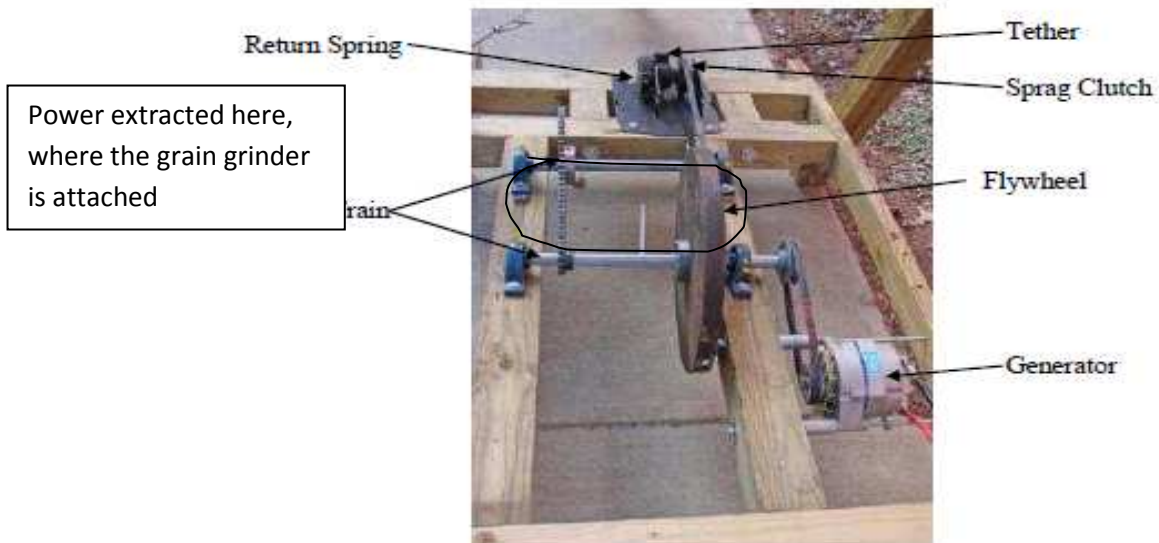


Figure 4.5 - Power Conversion System of WPI Kite Power System¹¹

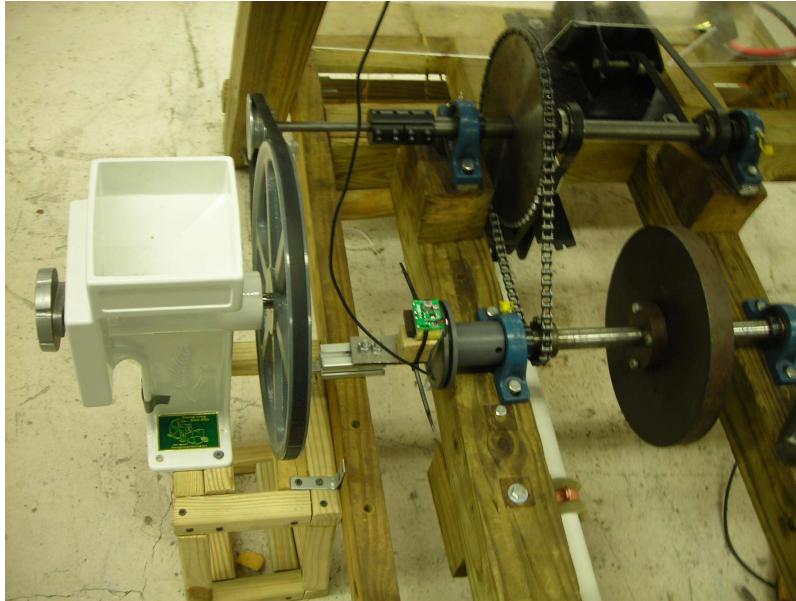


Figure 4.6 - Grain Grinder attachment



Figure 4.7 - Another view of the grain grinder

The three inch diameter pulley had to be attached to the shaft of the kite power system. Since the shaft is 1" in diameter, and was too short to be extended, a longer steel shaft was purchased. We

met with the mechanical lead of the MQP team to replace the shaft. The shaft to the pulley is only ½” in diameter, so a coupling was used to attach the 1” shaft to the ½” shaft of the pulley.

After the grain grinder was attached as seen above, the main tether that connects to the rocking arm was pulled manually, successfully turning the grain grinder shaft. The system was able to effectively grind coffee beans into a coarse powder.

5. Conclusions and Future Work

Overall, doing this IQP project was an enjoyable experience for us. We learned a great deal about harnessing wind energy from kites and gliders. For instance we learned about various companies that are involved with kite power, such as KiteGen and WindLift. From the MQP team we also gathered knowledge about their project and future work.

Another area we were able to delve into was the situation in developing countries. We began by researching DRFN, and contacting Professor Fred Looft and Jodi Lowell. They were able to provide us with valuable information about what the people of Namibia need. This also led into our second objective for the project, with using the main Kite Power MQP system to grind grain.

Our project encompassed a variety of areas of expertise. There was Electrical and Computer Engineering work involved with the anemometer and interfacing it with MATLAB in order to display wind speed in real time. Building the FM transmitter also involved some electrical knowledge. A large amount of Mechanical Engineering knowledge was also required, as our project involved building a proper frame and mount for the anemometer. Mechanical and design knowledge was also needed when constructing the grain grinder frame.

Design concepts were thoroughly used in the project. We had to perform value analyses, such as deciding upon which anemometer to use. We also had to draw out proper designs for the anemometer support structure, attachment to the balloon and net, etc. We had to purchase many parts, from the anemometer to materials for mounting the anemometer. The IQP group successfully achieved the goals that were set at the beginning of the year for the project. We were able to send the balloon up in the air

with the frame and anemometer fully attached, and could transmit and display the wind speed over time. As for the grain grinder, we attached it to the existing kite power system and were able to grind coffee beans.

We hope that future work will be able to continue for next year, and that the MQP team will be able to successfully utilize our project without difficulty. The entire lift system can be made more stable, and different materials could be experimented with for the frame. The method of attaching the anemometer to the frame could also be improved upon. One aspect that was looked into but not implemented, was the idea of fins attached to the anemometer to make sure it would be facing the wind direction. Further testing can lead to refinement of data acquisition, making the wireless system more user friendly, and preventing measurement errors.

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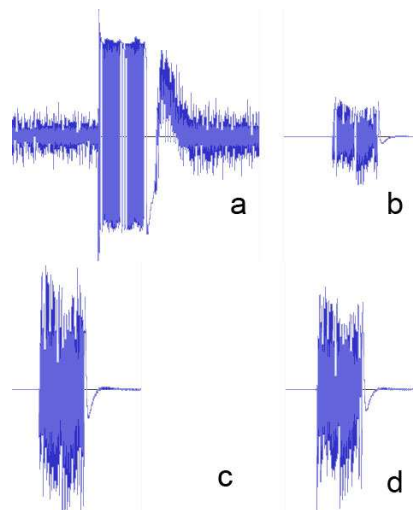
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6. Appendices

6.1 FM Transmitter Setup

- 1) Power on FM radio (leave the transmitter unplugged)
- 2) Tune radio to a frequency not already in use, so the transmitter doesn't conflict with existing radio signals.
- 3) Power on anemometer and transmitter.
- 4) Configure anemometer units and baud rate settings. The anemometer will remember these settings, but if the battery get unplugged, these settings must be reset.
 - a. While device is off, press "average" and "power" at the same time.
 - b. Release power button first
 - c. "ft/min" or "M/s" will be displayed. Release "average" button. If "M/s" is displayed, press "average" to switch to "ft/min".
 - d. If "ft/min" is displayed, press "max/min" to save the setting, and then "hold" to continue.
 - e. The baud rate can now be selected. Press "average" to select 2400 bits/second, or "hold" to select 1200. 1200 is the default for the anemometer, but the MATLAB program calls for 2400.
 - f. Press "max/min" to save the settings, and then "hold" to continue.
 - g. Automatic Shut Off disable
 - h. With the unit turned off, simultaneously press the "power" and "hold" buttons.
 - i. Release the "power" button.
 - j. When "n" displays, release the "hold" button. The meter will remain on until the "power" button is pressed again.

- 5) Extend antenna transmitter antenna fully.
- 6) Tune transmitter until the anemometer signal can be heard on the radio. It should be mostly silent, with a beeping noise occurring every 3 seconds.
- 7) Plug radio into laptop's audio input with the stereo 1/8" to 1/8" cable.
- 8) Open computer audio settings, specifically the recording settings. Select microphone (as opposed to line in) and make sure microphone boost (under advanced options) is not selected. Open audio recording program to set levels. Windows Sound Recorder is ok, Audacity or similar program is better.
- 9) Start recording in selected program and observe the sound levels. The signal should be visible above the noise. Adjust receiver AND computer volume levels until background noise is as reduced as possible, and the signal is as large as possible. Lowering the receiver volume too much can cause distortion in itself, so its ok to leave some noise on the signal as long as the signal is visibly larger than the noise. Also, the signal should not be so large that it clips.



a) Too much noise

b) Signal too small

c) Signal close to clipping

d) Optimal signal amplitude and signal/noise ratio

The file "transmitter_adjust_example.mp3" is an audio recording of the anemometer signal through the FM transmitter, into the computer. Initially, the signal can be heard through a large amount of background noise. As the sample progresses, the volume on the FM receiver is being lowered, and the noise reduces while the signal remains at approximately the same level. At the end of the audio clip, the signal can be heard on its own with no noise.

6.2 Reading Raw Anemometer Data

Every three seconds, the anemometer puts out a signal. This signal is comprised of 180 bits. In the physical signal, this is a high voltage or low voltage, which corresponds to a Boolean 1 or 0.

The signal as a whole consists of 18 characters, each being 10 bits long, hence 180 bits. The first bit for each character should ALWAYS be a 0, and the last bit should ALWAYS be a 1. These bits are called start and stop bits, and are a convenient way to check the validity of a signal, though they have no actual meaning as far as the data is concerned. The data that MATLAB collects will be a long string of all 180 bits, but if formatted as shown on the next page, the start and stop bits line up correctly. Between the start and stop bits is an ASCII representation of the character. These are read BACKWARDS. This may seem counterintuitive, but it's fairly standard protocol. Analyzing the first line gives (next page):

0001010101

Disregard the start bit (0) and the stop bit (1):

00101010

Reverse this number:

01010100

This is the BINARY representation of the character. Most ASCII tables will list Hex numbers (base 16), as this is more compact than binary, but it is very easy to convert between hex and binary. See Table 1 on the next page.

Break this number into two 4 bit binary numbers,

0101 and 0100

Convert each to a hex number individually using Table 1.

5 and 4

Now, look up the hex number 54 in an Ascii Table (note: Make sure not to look at 54 under the decimal column of the table.) 54 in an Ascii table corresponds to a capital T, for "Temperature." This indicates that the following characters are a temperature measurement.

0 0 0 1 0 1 0 1 0 1 = T
0 0 0 0 0 1 1 0 0 1 = 0
0 0 1 1 0 1 1 0 0 1 = 6
0 1 1 0 0 1 1 0 0 1 = 3
0 0 1 1 1 0 1 0 0 1 = .
0 0 0 0 1 1 1 0 0 1 = 8
0 0 1 1 0 0 0 1 0 1 = F
0 0 1 0 1 1 1 0 0 1 = :
0 0 1 1 0 1 0 1 0 1 = V
0 0 0 0 0 1 1 0 0 1 = 0
0 0 0 0 0 1 1 0 0 1 = 0
0 0 0 0 0 1 1 0 0 1 = 0
0 0 1 1 0 0 0 1 0 1 = F
0 0 0 1 0 1 0 1 0 1 = T
0 1 0 1 1 0 0 1 0 1 = M
0 1 0 1 1 0 0 0 0 1 = cR
0 0 1 0 1 0 0 0 0 1 = New Line

Data from anemometer, arranged as one character (10 bits) per line

Decimal	Binary	Hex
0	0000	0
1	0001	1
2	0010	2
3	0011	3
4	0100	4
5	0101	5
6	0110	6
7	0111	7
8	1000	8
9	1001	9
10	1010	A
11	1011	B
12	1100	C
13	1101	D
14	1110	E
15	1111	F

Table 6.1 – Decimal, Binary and Hexadecimal Conversions

Dec	Hx	Oct	Char	Dec	Hx	Oct	Html	Chr	Dec	Hx	Oct	Html	Chr	Dec	Hx	Oct	Html	Chr
0	0	000	NUL (null)	32	20	040	 	Space	64	40	100	@	@	96	60	140	`	`
1	1	001	SOH (start of heading)	33	21	041	!	!	65	41	101	A	A	97	61	141	a	a
2	2	002	STX (start of text)	34	22	042	"	"	66	42	102	B	B	98	62	142	b	b
3	3	003	ETX (end of text)	35	23	043	#	#	67	43	103	C	C	99	63	143	c	c
4	4	004	EOT (end of transmission)	36	24	044	$	\$	68	44	104	D	D	100	64	144	d	d
5	5	005	ENQ (enquiry)	37	25	045	%	%	69	45	105	E	E	101	65	145	e	e
6	6	006	ACK (acknowledge)	38	26	046	&	&	70	46	106	F	F	102	66	146	f	f
7	7	007	BEL (bell)	39	27	047	'	'	71	47	107	G	G	103	67	147	g	g
8	8	010	BS (backspace)	40	28	050	((72	48	110	H	H	104	68	150	h	h
9	9	011	TAB (horizontal tab)	41	29	051))	73	49	111	I	I	105	69	151	i	i
10	A	012	LF (NL line feed, new line)	42	2A	052	*	*	74	4A	112	J	J	106	6A	152	j	j
11	B	013	VT (vertical tab)	43	2B	053	+	+	75	4B	113	K	K	107	6B	153	k	k
12	C	014	FF (NP form feed, new page)	44	2C	054	,	,	76	4C	114	L	L	108	6C	154	l	l
13	D	015	CR (carriage return)	45	2D	055	-	-	77	4D	115	M	M	109	6D	155	m	m
14	E	016	SO (shift out)	46	2E	056	.	.	78	4E	116	N	N	110	6E	156	n	n
15	F	017	SI (shift in)	47	2F	057	/	/	79	4F	117	O	O	111	6F	157	o	o
16	10	020	DLE (data link escape)	48	30	060	0	0	80	50	120	P	P	112	70	160	p	p
17	11	021	DC1 (device control 1)	49	31	061	1	1	81	51	121	Q	Q	113	71	161	q	q
18	12	022	DC2 (device control 2)	50	32	062	2	2	82	52	122	R	R	114	72	162	r	r
19	13	023	DC3 (device control 3)	51	33	063	3	3	83	53	123	S	S	115	73	163	s	s
20	14	024	DC4 (device control 4)	52	34	064	4	4	84	54	124	T	T	116	74	164	t	t
21	15	025	NAK (negative acknowledge)	53	35	065	5	5	85	55	125	U	U	117	75	165	u	u
22	16	026	SYN (synchronous idle)	54	36	066	6	6	86	56	126	V	V	118	76	166	v	v
23	17	027	ETB (end of trans. block)	55	37	067	7	7	87	57	127	W	W	119	77	167	w	w
24	18	030	CAN (cancel)	56	38	070	8	8	88	58	130	X	X	120	78	170	x	x
25	19	031	EM (end of medium)	57	39	071	9	9	89	59	131	Y	Y	121	79	171	y	y
26	1A	032	SUB (substitute)	58	3A	072	:	:	90	5A	132	Z	Z	122	7A	172	z	z
27	1B	033	ESC (escape)	59	3B	073	;	;	91	5B	133	[[123	7B	173	{	{
28	1C	034	FS (file separator)	60	3C	074	<	<	92	5C	134	\	\	124	7C	174	|	
29	1D	035	GS (group separator)	61	3D	075	=	=	93	5D	135]]	125	7D	175	}	}
30	1E	036	RS (record separator)	62	3E	076	>	>	94	5E	136	^	^	126	7E	176	~	~
31	1F	037	US (unit separator)	63	3F	077	?	?	95	5F	137	_	_	127	7F	177		DEL

Source: www.LookupTables.com

Table 6.2 - Ascii Table and Description

6.3 MATLAB Code

```
function[] = annie()

%%initialize audio inputs
AI = analoginput('winsound');
addchannel(AI, 1:2);
Fs = 48000;
set(AI, 'SampleRate', Fs)
duration = 3.4;
set(AI, 'SamplesPerTrigger', duration*Fs);

baudrate = 2400;%%anemometer baud rate, in bits/seconds
samperbit = Fs/baudrate; %% # computer samples corresponding to one bit from anemometer
sampleforsecs = input('sample length?:'); %%prompts user for duration of sample (in seconds)

nsamples = 1;
shift_num = -1;

fnorm = 2400/(Fs/2); %%Lowpass Butterworth filter cutoff. Set to anemometer baudrate
[b,a] = butter(10,fnorm,'low'); %%setup filter
lhplot(1:(duration*Fs)) = 0; %%initialize, make all zeros

tic %%starts counter
while(toc<sampleforsecs)%%runs until sample duration reached
start(AI); %%start sampling
data = getdata(AI); %%return sampling results to data
long = duration*Fs; %%total # samples
breaker = 1; %%stores the sample # at which the signal begins
smoothdata = filtfilt(b,a,data(:,1)); %%data filtered and stored in smoothdata

%%If the antenna gets bumped, signal spikes can occur.
```

%%This segment of code determines where the signal starts,
%%but is designed to ignore signal spikes.

```
spike = 1;
for i = 1:1:long %%run through all samples
    if (abs(smoothdata(i)) >= .6) %%indicates signal activity
        if(breaker == 1) %%only set if it hasn't been set yet
            breaker = i;
        end
    end
end

if((breaker ~= 1) && (spike == 1))%%if breaker set, make sure it's on the signal
    %%and not on a spike
    for i = (breaker+5*sampsperbit):(breaker + 10*sampsperbit) %%checks spaces 5->10 bits away
        if (abs(smoothdata(i)) >= .6)
            spike = 0; %%if more signal detected afterwards, then the signal is detected, not a spike
        else
            breaker = 1; %%no signal detected, just a spike
        end
    end
end
end
end
```

%%

%%
%%AVERAGING ALGORITHM

```
for i=1:1:breaker
    lhplot(i) = 0; %%all values prior to signal are 0
end

for i = breaker:1: (breaker + (Fs/8000)*1200)
    lhplot(i) = data(i,1); %%initially set lhplot to data for signal range
end
```

```

for i = (breaker + (Fs/8000)*1200):1:long
    lhplot(i) = 0; %%all values after signal are 0
end

%%for loop averages value of filtered signal over range of sample
for i = 0:1:180
    hold_value = 0;
    for j = 1:1:sampsperbit
        hold_value = hold_value + smoothdata(breaker + i*sampsperbit + j);
    end
    hold_value = hold_value/sampsperbit;
    lhplot((breaker + i*sampsperbit):(breaker + i*sampsperbit+sampsperbit)) = hold_value;
end

bins = 0;
for n = 1:1:180
    bins(n) = (1 - (lhplot(breaker + n*sampsperbit-sampsperbit)>0)); %%stores binary values, 1->180
end

%%Tf is temperature in degrees fahrenheit (not used, but useful for
%%debugging)
%%Vftm is wind velocity in feet/minute
Tf(nsamples) = 100*(8*bins(15) + 4*bins(14) + 2*bins(13)+ bins(12)) + 10*(8*bins(25) + 4*bins(24) +
2*bins(23)+ bins(22)) + (8*bins(35) + 4*bins(34) + 2*bins(33)+ bins(32)) + (8*bins(55) + 4*bins(54) +
2*bins(53)+ bins(52))/10;
Vftm(nsamples) = 1000*(8*bins(95) + 4*bins(94) + 2*bins(93)+ bins(92)) + 100*(8*bins(105) +
4*bins(104) + 2*bins(103)+ bins(102)) + 10*(8*bins(115) + 4*bins(114) + 2*bins(113)+ bins(112)) +
(8*bins(125) + 4*bins(124) + 2*bins(123)+ bins(122))
timee(nsamples) = toc; %%time stamps for each data value
nsamples = nsamples + 1; %%increment nsamples
plot(timee,Vftm) %%plot wind velocity vs time

```

end

%%bins(1:180) are binary values of data.

%%Leave commented out unless debugging

%%See "reading raw anemometer data" description

% bins(1:10)

% bins(11:20)

% bins(21:30)

% bins(31:40)

% bins(41:50)

% bins(51:60)

% bins(61:70)

% bins(71:80)

% bins(81:90)

% bins(91:100)

% bins(101:110)

% bins(111:120)

% bins(121:130)

% bins(131:140)

% bins(141:150)

% bins(151:160)

% bins(161:170)

% bins(171:180)

%%markers and marky are for debugging. When plotted, they appear ON the

%%signal itself and show where samples are being made.

%markers = (breaker+90*sampsperbit):sampsperbit:(breaker+150*sampsperbit);

% markers = (breaker):sampsperbit:(breaker+180*sampsperbit);

% marky(1:length(markers)) = 0;

```
plot(smoothdata)
hold on
plot(markers,marky,'--rs','LineWidth',2,'MarkerEdgeColor','k','MarkerFaceColor','g','MarkerSize',3);
lhplot = lhplot +2; %%moves values up by 2 so they can compared agains smoothdata when graphed
plot(lhplot)
```