GREEN GENERATION

Rachel Dee **Kimberly Heagerty** **Ellen Meyer** **Joseph Vaccarella** **Kelton Williams**

ABSTRACT

There is a deficit of green energy sources available on campus for student use. Wind power can be harnessed and used to spin a generator, through which a battery can be charged and used to power students' phones.

PROBLEM DEFINITION

Sustainable green energy generation has been agreed upon by many as the most important combatant to global warming. There are wide-scale green energy options available, like solar panel farms or nuclear power plants, but green energy is relatively inaccessible to the average college student. The current average college student will likely face the impact of global warming, and therefore has stake in the development of green energy generation. The available options, though, are wide-scale and far removed. A student is unable to directly plug their phone directly into a green energy source. Energy needs to be generated in a novel, environmentally sustainable manner on campus. Once this option is made available to students, easily accessible green energy will become directly available to them.

REQUIREMENTS, SPECIFICATIONS, DELIVERABLES

Deliverables

The University of Rochester River Campus provides a myriad of opportunities for harnessing ambient, renewable energy. This is especially true for small scale energy generation. Since there are many sources of energy, the deliverables for this project were designed to be vague. The deliverables are as follows:

1. A working prototype that generates energy using ambient energy on campus.
2. Theory of operation manual.
3. Technical report, compiling test data and the process that went into designing and creating the prototype.

This set of deliverables outlines the bare minimum that should be expected of the project. They are intended to be guidelines for the group as ideas are identified and further developed. These deliverables are broken down into smaller, more specific focus areas, which can be seen in the Work Breakdown Structure (WBS) in the Appendix.

The timeframe for developing and creating the deliverables is available in the Critical Path Management (CPM) sheet and flowchart, which can be seen in the Appendix. These documents outline the specific tasks and events which must occur for the deliverables to be finished.

Requirements

Requirements further define the deliverables of a project. Unlike specifications, they are not testable but can be observed and can be defined using other reference materials. The requirements for this project are as follows:

1. Must translate easily available form of energy on campus to usable energy for charging batteries;
2. Must include at least one USB-Standard A port;
3. Must be safe to standards dictated by the University;
4. Must be able to charge a standard phone battery;
5. Can be used to charge an intermediate battery;
6. All exposed blades or surfaces must not have sharp edges;
7. There will be no exposed wires;
8. Under normal operation, a user cannot access pinch points;
9. When in operation, the supporting structure cannot be relocated; and
10. Cannot obstruct normal University operations.

These requirements are meant to define safety standards as well as ensure that a typical phone will be able to connect to the prototype and be charged by the generator. They were determined using research on industry standards for electronics and general safety standards.

Specifications

A product or prototypes specifications must be testable, numerically defined goals, which the project must achieve. The specifications for this project are defined as follows:

1. Requires no more than 2 people to install;
2. Individual components may weigh no more than 70lbf;
3. Power output must provide a minimum of 0.5 Amps of current while in operation;

4. When in operation, power output must be at least 4.5 Volts;
5. Power output must be no more than 5 Watts; and
6. When the generator is running at nominal speed, at least 2-Watt hours will be generated over the course of 4 hours.

These specifications are mainly tied to ensuring safety for installation as well as specifying the outputs needed to charge a typical cellphone battery. If the voltage, amperage, or wattage values are not within a tolerable range, then a cell battery would not charge and could even be irreparably damaged. Typical phone batteries are 2000-3000mWh and cannot tolerate a voltage greater than 5V. Supplying a 5-Watt charging output results in a 2-to-3-hour charge time which is typical for most phones. The reasoning behind the creation of specification 6. was to ensure that a typical phone could receive a substantial amount of charge from the working generator.

CONCEPTS

With there being a variety of energy sources available on campus, the source to be used had to be selected. To decide on the source to be harnessed, a Pugh Decision Matrix was created, with wind power, waterpower, and human powered as the options. The initial designs for each energy source were a wind turbine, a water wheel spun with rainwater collected on campus, and an interactive spinning wheel, respectively. These choices were scored on the availability of the resource, the manufacturability of the potential design, and how enjoyable the end design may be for a college student. The Pugh Decision Matrix used to determine the optimal energy source can be seen in the Appendix.

Based on the results of the Pugh Matrix, the optimal energy source was determined to be wind. Once this was determined, the location of the design had to be selected. Wind measurements were taken at various high-traffic areas on campus including between Rush Rhees and Morey Hall, between Bausch & Lomb Hall and Dewey Hall, at the tunnel exit outside Hoyt Hall, between Wegmans Hall and Taylor Hall, and outside Carlson Library. Measurements were taken using an anemometer on multiple days. These measurements and their corresponding locations on a map can be seen in the Appendix.

In combination with the wind measurements, the observed foot traffic led to the conclusion that the optimal location for a wind turbine would be between Wegmans Hall and Taylor Hall. This location is central to entering the Engineering Quad and has a graveled area with picnic tables. Initial wind measurements for this location averaged at 1.92 m/s, with a maximum wind speed of 4.7 m/s.

While the optimal location for the system was being determined, the wind turbine design was being selected. After some initial research, three potential designs were developed, and small prototypes were created for additional testing. The three types of turbines were the Helical, Savonius and Darrius-Helical hybrid designs. These designs were then tested in the wind tunnel. They were evaluated on the maximum RPM they could spin at as well as other factors such as vibration, minimum wind starting speed and the amount of noise created by spinning. The Darrius-Helical design was quickly eliminated due to its high minimum start speed. The Helical and Savonius both had similar characteristics except for the fact that the Savonius design is much easier to machine. Thus, the Savonius turbine was selected for the final design.

MECHANICAL ANALYSIS

Multiple mechanical analyses were completed in support of this project.

A basic beam model was analyzed to determine deflection of the axle and axle housing. The axle housing, made of PVC, had an assumed Young's Modulus of 500 kpsi. Later, testing was done and it was determined that the axle housing has a Young's Modulus of 467.9 kpsi (see Appendix I) The axle, made of 1566 carbon steel, has an assumed Young's Modulus of 20000 kpsi. The load from the wind was first determined by calculating the pressure from the wind. Assuming a speed (v) of 5 m/s (determined by 4.8 m/s being the max wind speed that was observed at the location of the table over the course of several weeks) and an air density (p) of 1.293 kg/m^3, the pressure (P) was calculated using equation 1.

$$P = 0.5 \cdot p \cdot v^2 \qquad \text{(eq. 1)}$$

With a pressure of 0.009376707 psi, this was multiplied by the projected area of the turbine and a coefficient of drag. The projected area was based on a turbine with a width of 24 in and a height of 32 in. The coefficient of drag used was 2.30, which is the coefficient for a concave semicircle piece like that of the wind turbine. Although the turbine has two stages with one rotated 90° and therefore will always have one semicircle piece-oriented opposite to the other, 2.30 was still used as the coefficient of drag because it would represent a worst-case scenario. The resulting wind load was determined to be 4.14lbf.

Next, both the axle and the axle housing were modeled as beams, with forces being applied at to the axle at the location of the middle of the turbine, the location of the bearing, and the location of the connection to the generator. For the axle housing, the forces were applied at the location of the bearing, the location of the tabletop, and the location of the table's leg support structure. The corresponding diagrams are shown in Appendix H.

After establishing the problem set up, the magnitude of each applied force was solved for in terms of the known force of the wind loading, and the positions of each point of force application. These calculations are also shown in Appendix H.

To find the deflection at the desired locations, the formula for deflection at the end of a beam with simple supports and an overhang load from Shigley's Mechanical Engineering Design was used:

$$y = \frac{Fa^2}{3EI}(l + a) \%\% \qquad \text{(eq. 2)}$$

where l is the distance between supports and a is the distance between the load and the support.

In the end, this analysis found that the axle housing would deform 0.816 inches at the site of the bearing, and the axle would deform 0.088 inches at the site of the middle of the turbine. These values were small enough that they were determined allowable for this design.

Tolerancing played a role in fitting the plastic bearings onto the axle. When the bearings and axle were purchased, the inner diameter of the bearings and the diameter of the axle were noted as being the same; ¾". This would allow for the bearings to be press-fit onto the axle, making the axle and inner portion of the bearings spin together. Though when the parts arrived and assembled, there was slop between the bearings and the axle; so much so that the axle and bearing interior did not spin together. The tolerance of the parts was not considered when the parts were ordered, resulting in an incorrect fit. This was fixed by adding material between the bearings and the axle, which made the assembly spin as one piece, as initially intended.

Fatigue was the main concern for the torque transfer plate that is attached to the wind turbine, since it will repeatedly experience a varying load. This was analyzed using the stress-life method. Based on availability of materials, aluminum was selected to be used for this piece. Aluminum has an ultimate strength (S_{UT}) of around 45 kpsi.

$$Se' = \{0.5 \cdot Sut\ for\ Sut\ \leq 200\ kpsi\}$$
$$Se' = \{100\ for\ Sut\ > 200\ kpsi\} \qquad \text{(eq. 3)}$$

Using equation 2, the endurance limit (S_e‘) is initially estimated to be 22.5 kpsi. This value is then modified using equation 3,

$$Se = Se' \cdot ka \cdot kb \cdot kc \cdot kd \cdot ke \cdot kf \qquad \text{(eq. 4)}$$

where k_a, k_b, k_c, k_d, k_e, and k_f are the modification factors for surface condition, size, load, temperature, reliability, and miscellaneous effects, respectively. For this application, all modification factors are equivalent to 1 except for k_a and k_c. The former was determined using equation 4 and the latter was determined to be equal to 0.85, which corresponds to axial loads.

$$ka = a \cdot Sut^b \qquad \text{(eq. 5)}$$

Considering the machined finish of the material, factor *a* was set equal to 2.70, and *b* was set equal to –0.265. This resulted in the surface condition modification factor being equal to 0.985.

When applying these values to equation 3, the resulting endurance limit is S_e = 18.84 kpsi.

Fastener torque was determined for the fasteners attaching the torque transfer plate to the turbine.

The bearings in the axle housing were analyzed to determine lifetime. Using the following equation:

$$F_R = F_D\left(\frac{L_D n_D 60}{L_R n_R 60}\right)^{1/a} \qquad \text{(eq. 6)}$$

$$\#\ of\ Revolutions\ Rating = \left(\frac{L_D n_D 60}{\left(\frac{F_R}{F_D}\right)^a}\right) \qquad \text{(eq. 7)}$$

Here, a = 3 because ball bearings are being used. Most data regarding bearings pertains to metal bearings, so some liberties must be considered throughout this analysis. Most bearings are rated for 10^6 revolutions, but this isn’t necessarily true for plastic bearings. If the desired RPM is taken as 95 RPM (the optimal RPM for the generator). If the system is designed to run for atleast 1 year, and the system is assumed to be spinning optimally atleast 40% of the time, the bearings would have a total desired lifetime of 3456 hours. If the desired loading on the system is assumed to be approximately 20 lbf, and the Dynamic Radial Load Rating is 75 lbf, then the system would be rated for 3.73 x 10^5 revolutions, which is about a 1/10 of the typical rating a metal bearing.

One situation where a computer analysis was used was in a vibrational model of the system. The turbine axle system was modeled in NX with the axle as a beam that was fixed at one end with a concentrated mass to represent the wind turbine at the other end. Although the entire system is a little more complex than this simplification, this model still gave a general idea of how the system would respond vibrationally. Since the turbine and the axle will be rotating during operation, it was important to estimate what the natural frequency of the turbine axle system is, so that it can be ensured that the rotational frequency of the system does not equal the natural frequency of the system, as this would result in harmful resonance.

The details of this analysis can be found in the Appendix as a one-pager. The most important result is that the first mode has a natural frequency of 4.27 Hz. Although it is not yet known what the rotational frequency of the turbine will be during operation, estimates can be made based on the testing done in the wind tunnel. For the lowest tested airspeed in the wind tunnel of 9.7 m/s, the test turbine had a rotational speed of 400 rpm, which is equal to 6.67 rotations per second. Also, the test wind turbine is about 5 times smaller than the actual turbine, which means that we can expect the rotational speed of the actual turbine to be around at least 5 times smaller, or about 1.33 rotations per second. This is also not factoring in the fact that the expected wind speeds that the actual turbine will face are about one half of the speed tested in the wind tunnel, which means that the expected rotational speed of the actual turbine would be even slower. All in all, the vibrational analysis, when compared to the data from the wind tunnel, allows for confidence that vibrations will not be an issue with the chosen design of the turbine.

Overall, material properties were an important factor in material selection. One area where this had to be considered carefully was in the material properties of the PVC pipe that made up the axle housing. Since this pipe is long, it could have been subjected to significant deflection, and therefore the Young’s Modulus of the PVC was an important quantity to know. Although an estimate of the modulus was found on the supplier’s website, this value needed to be determined more precisely. To do so, the deflection of the PVC pipe when a load was applied at different spots was measured, and then the data was fit to a curve using MATLAB to determine Young's Modulus. It was found that the Young's Modulus was 467900 psi. See the data plot in Appendix I.

MANUFACTURING

The Table Turbine system consists of the following manufactured components:

Wind Turbine

The wind turbine was manufactured out of acrylic sheets. These sheets are secured together with epoxy. Vertical components are made from 1/16 sheet, while the horizontal components are made from 1/8 sheet. Necessary designs were cut out of the stock material using the laser cutter on campus. The flat Polycarbonate sheets were then thermoformed into more rounded parts. Polycarbonate was chosen as the material of choice as it's lightweight, strong, and impact resistant.

Turbine-Axle Adapter

A small aluminum plate that slides onto the machined slot on the axle. This component allows the turbine to transfer torque from the turbine to the axle. Only one adapter was created as trying to align two of these adapters may have over-constrained the system. Aluminum was selected for its high rigidity, and low weight.

Axle

The axle is stock from McMaster-Carr, other than a small slot cut into it on one of its ends using a mill. Carbon-Steel was chosen for its rigidity.

Axle Housing

The axle housing was made from PVC pipe. A plastic bearing was pressed into its end in order to allow for the axle to pass through and spin freely.

Table Insert

The table insert was 3D printed and coated with an acrylic protective coating.

Axle-Generator Adapter

The turbine-axle adapter was created using a spare aluminum cylinder. This piece was put on the lathe, brought to size, and then diameter. One side is a press fit, while the other side was made to receive the threads. A special M16-1.5 tap was ordered in order to match the threads to the generator. Aluminum was chosen for its ease of manufacturability and its relatively high tensile strength and rigidity.

Electronics Housing

The electronics housing was built from readily available plywood. Pieces were cut to size using a table saw and assembled using screws. This housing was then painted, and then covered in a layer of sealant in order to reduce any risk of water seeping in. Wood was chosen for its ease of manufacturability, abundance, and because it's easy to paint.

The cost estimation for manufacturing the system can be seen in Table 1, and the development time can be seen in Table 2.

If the production of this system would be scaled from a quantity of 1 to 1000, a variety of changes would need to be made. Firstly, the electronics box would be changed from a wood box to a plastic-molded box. It would be easier to manufacture, and its dimensions would be more consistent. Additionally, the system would be waterproof without needing additional coatings of paint and sealants. Secondly, the generator would be sourced from a reliable manufacturer instead of from Professor Muir. This would standardize each product, ensure consistency with the electronics, and could be chosen to optimize the starting torque of the system. Another important change that would have to be made is the size of the axle and axle housing. The standard picnic table umbrella hole was slightly too small for the PVC for the axle housing, and it needed to be filed down in order for the product to be installed. For a large-scale production of the Turbine Table, the axle housing tube should be made ¼ smaller in diameter to fit better in the table. Finally, the turbine creation process would be heavily optimized. Instead of bending each panel by hand, a mold of a half circle would be used instead. This would ensure consistency and increase the rate of production greatly.

TEST PLAN AND RESULTS

Each specification had to be tested in order to determine if the system passed said specification or not. The results of the tests are tabulated in the Appendix.

The first specification, must be able to be assembled by 2 persons, was to be tested by challenging 2 persons to assemble the system. The system passed this test, as 2 people were able to successfully assemble the system.

The second specification dictated that the system must not weigh more than 70 pounds. This was tested by weighing the individual components to ensure that the system did not exceed this value. Upon testing this specification, the system passed.

The next specification, power output must provide a minimum of 0.5 Amps of current while in operation, was to be tested by measuring output current with a multimeter. The system passed the test and was able to provide at least 0.5 Amps of current while in operation.

While in operation, the system had to have a power output of at least 4.5 V and at most 5 V (specifications four and five, respectively). This was to be tested by connecting a multimeter to the system and measuring output voltage. The system passed this test and fulfilled the specifications.

The final specification was more difficult to verify, as "nominal speed" is not a set value. Since the team was set on using the generator provided by Professor Muir, a band of RPM values were gathered from testing the generator, and the turbine was then designed to spin at such speeds. This will then be verified once the assembly is completed.

INTELLECTUAL PROPERTY

When first determining patentability, the system must be determined to be new or novel. When conducting a quick Google search ("Wind turbine that charges phone"), it can be seen that systems of the sort exist. Based on this quick search, it can be determined that this likely is not a patentable system.

The subject matter must be useful. It is clear that the proposed system has a purpose and is therefore useful.

The system also must be non-obvious. In other words, there must not be similar patents that have been granted protection. When determining non-obviousness, it is helpful to understand what a patent is claiming. For the proposed system, the patent would contain claims such as the following:

1. A system comprising:
    a. A vertical axis wind turbine connected to an axle;
    b. A generator attached to the axle; and
    c. A battery pack connected to the generator.
2. The system of claim 1, wherein multiple vertical axis wind turbines are connected to said axle;
3. The system of claims 1 and 2, further comprising a table with a hole on the flat surface through which the axle may pass;
4. The systems of claims 1, 2, and 3, further comprising an attachment which slides over said axle and through which USB ports may be housed.

For this system to be non-obvious and therefore patentable, the above claims must not violate the claims in any other patent. Upon conducting a prior art search, there are many patents for wind turbines that could impinge on the patentability of the system. One that seems particularly impeding is US10024302B2, "Vertical axis wind turbine," currently assigned to Vortexis Energy Solutions Inc. The system described in the patent is similar to the wind turbine used in the proposed turbine table design, as it is a vertical axis turbine coupled to a generator. This is quite like the proposed turbine table design and likely would impinge on the patentability of the system.

SOCIETAL AND ENVIRONMENTAL IMPLICATIONS

The Green Generation project has the potential to greatly improve the use of green energy at the University of Rochester and beyond. There are few drawbacks regarding public health, safety, and welfare, but there are numerous benefits in terms of sustainability and global impact.

The Table Turbine has limited impact on public health, safety, and welfare. The system encourages people to get outside rather than staying in to charge their electronics. It is also free for the public to use, which makes a charged phone more accessible to those who either cannot afford a portable charger or for those who need to charge their phone in a pinch. This project has large global implications because it harnesses wind energy on a small scale and encourages its use with the general public. To combat the use of fossil fuels, energy sources such as wind can be a great replacement or supplement to nonrenewable energy.

By installing the system on campus, it reaffirms the University of Rochester's commitment to sustainability and environmentally sustainable sources of electricity. The Table Turbine will signal to students that wind energy is a viable alternative to nonrenewable energy sources and can be implemented in both large and small-scale applications. The system will be mounted at an ADA accessible picnic table as a source of electricity and as an art installation. It will encourage students to sit outside and interact with one another while using the charging station.

As in any project, there are benefits and drawbacks. The benefits clearly include the sustainable manner of electricity generation. The accessibility of sustainably generated electricity is the most desirable aspect of this project, as it is rooted in the reason the system was designed. But this comes with drawbacks; it may not be as efficient or abundant other sources of alternative energy sources available on campus, and its usage is limited to charging personal devices.

The materials used in this project include acrylic sheets for the wind turbine, aluminum for the turbine-axle adapter, carbon-steel for the axle, PVC for the axle-housing, 3D printed ABS for the table insert, aluminum for the axle-generator adapter, and plywood for the electronics housing.

From an environmental standpoint, acrylic and PVC are the least environmentally friendly products from this list. Acrylic production emits gases such as carbon dioxide and monoxide which is harmful to the environment. It is not biodegradable, but can be recycled and if done so properly, can greatly decrease environmental pollution. PVC emits pollutants during manufacturing and cannot be recycled. Acrylic and PVC should be used in moderation, which is why the remainder of the parts are manufactured with other materials. The best way to improve this project for the future in terms of environmental concerns would be to manufacture the turbine out of a material other than acrylic. Metals such as aluminum and carbon steel are environmentally friendly materials due to their ability to be recycled without needing to downcycle or reduce the quality of product. By recycling the product, large amounts of energy can be saved. Plywood, used for the electronics housing, is environmentally friendly due to it being a renewable resource along with the ease of manufacture. In general, this project takes several hours of machining to construct the necessary parts required but relies on human assembly and installation. The energy consumed during manufacturing will be offset by the use of this product over time in charging cell phones using renewable energy.

RECOMMENDATIONS FOR FUTURE WORK

The timeframe of this project was limited to the length of one semester. Had there been more time, there are multiple changes that would have been made.

Further research would be conducted to determine the behavior of various wind turbine designs in varying wind speeds. Research was conducted in the wind tunnel with the design intended to be used in the final system, though ideally, more time would be allotted to conduct tests on various wind turbine designs.

Additional improvements to increase the electricity efficiency of the system would be to use a 12V DC-DC generator rather than the provided generator. The one provided is not particularly efficient in converting mechanical energy to electricity. However, as one of the guiding principles of the project is sustainability, the loss in efficiency was worth the tradeoff, as the motor was able to be upcycled.

TABLES

TABLE 1
System Cost Estimate

TABLE 2
Development Time Estimate

Member	Hours	Cost (USD)
Rachel Dee	75	$7500
Kimberly Heagerty	144.5	$14450
Ellen Meyer	84.5	$8450
Joseph Vaccarella	81	$8100
Kelton Williams	98	$9800
Total	483	$48300

ACKNOWLEDGMENTS

The completion of this project would not have been possible without the guidance, assistance, and mentorship of Christopher Muir, Robert Nowak, Chris Pratt, Jim Alkins, and Kaleb Chitaphong.

REFERENCES

R. G. Budynas and J. K. Nisbett, "Shigley’s Mechanical Engineering Design, 9th edition," McGraw-Hill, Jan 2011.

APPENDIX

A. Work Breakdown Structure

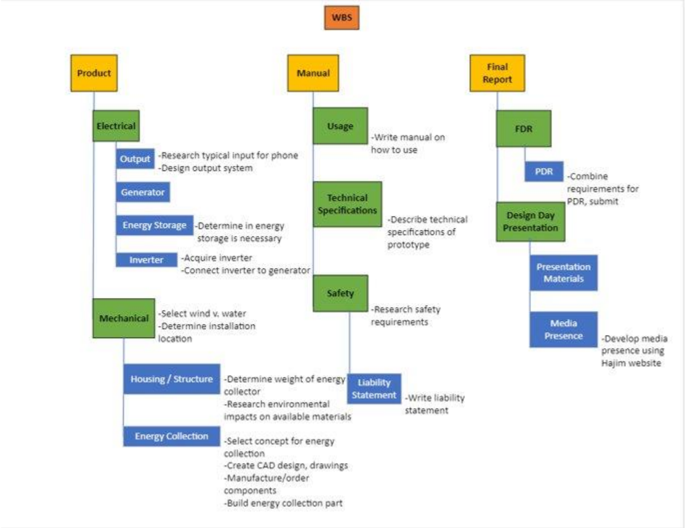


Figure 1. *Work Breakdown Structure with supporting activities*

B. Critical Path Management

Item	Cost (USD)
Rachel Dee manufacturing	$1200
Kimberly Heagerty manufacturing	$100
Ellen Meyer manufacturing	$1400
Joseph Vaccarella manufacturing	$2000
Kelton Williams manufacturing	$1400
Voltage Rectifier	$18.35
Anker 26800mAh Powerbank, 3 USB Ports	$69.99
USB 2.0 Extension Cable 6.5Ft	$13.32
DC-DC Converter 48V Step-Down to 5V 2A Buck Converter	$11.20
Plastic Bearings	$20.77
Shaft (no key), 8ft long, 3/4" diameter	$115.25
Flexible shaft coupling hub 1 5/8 OD for 3/4 shaft	$117.46
Durometer 98A Spider for 1-5/8" OD and 41 mm OD Vibrate-Damping Precision Flexible Shaft Coupling	$29.14
PVC with OD 1 21/32 10ft	$26.00
Chemical-Resistant PVC Rod, 2" Diameter, 1 ft	$13.13
Clear Scratch- and UV-Resistant Acrylic Sheet 24" x 24" x 1/16"	$78.60
Clear Scratch- and UV-Resistant Acrylic Sheet 24" x 24" x 1/8"	$70.26
10 pcs, 608-2RS Ball Bearings	$8.99
2PCS 8mmX350mm Linear Motion Rod	$11.99
10 PCS/Pack 8mm Shaft Lock Collar	$8.89
Total	

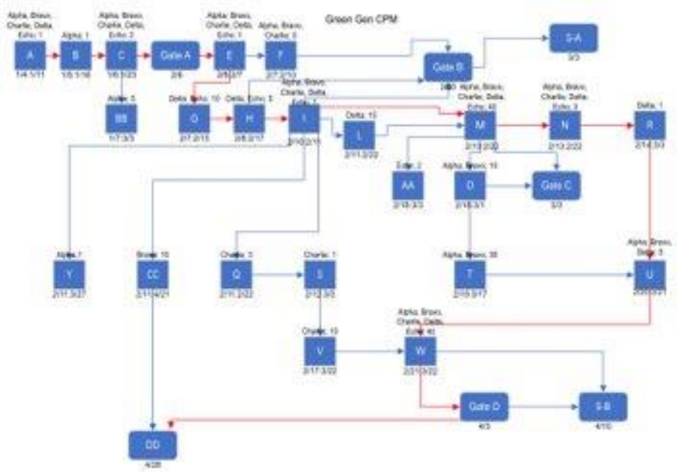
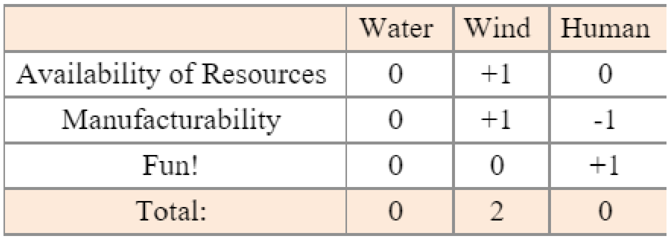


Figure 2. *Critical Path Management*

Critical Path Method (CPM) Chart										
Number	Gate	Activity	Due Date	Category	Duration (hrs)	Predecessor(s)			Approved?	Flow Chart Designator
						#1	#2	#3		
1		Start the project	1/11/2023	Activity	1				Y	A
2		Sponsor Contact	1/16/2023	Activity	1	1			Y	B
3		Problem Definition	1/23/2023	Activity	2	2			Y	C
4	A	R&S/Schedule/Background	2/6/2023	Event	N/A	3			Y	
5		Generate 3 Concepts	2/6/2023	Activity	1	4			Y	E
6		First Principle Analysis	2/10/2023	Activity	5	5			Y	F
7		Create Prototypes	2/13/2023	Activity	10	5			Y	G
8		Test Prototypes	2/17/2023	Activity	5	7			Y	H
9		Decide on Final Concept	2/17/2023	Activity	1	8			Y	I
10	B	Concept Generation (>3)/Selection/PDR	2/20/2023	Event	N/A	9	8	5	Y	
11	S-A	Sponsor Validation Proof of Concept/Deliverables/PDR	3/3/2023	Event	N/A	10			Y	
12		Select preliminary mechanical components	2/22/2023	Activity	15	9			Y	L
13		Design overall system in CAD	3/1/2023	Activity	40	12	9		Y	M
14		Select final mechanical components	3/2/2023	Activity	3	13			Y	N
15		Create drawings and manufacturing plan	3/2/2023	Activity	10	13			Y	O
16	C	Frankenstein Model/Initial Drawing Package/MFG Plan	3/3/2023	Event	N/A	15	13		Y	
17		Select electrical components	2/22/2023	Activity	3	9			Y	Q
18		Purchase mechanical components	3/3/2023	Activity	1	14			Y	R
19		Purchase electrical components	3/3/2023	Activity	1	17			Y	S
Spring Break (3/4 - 3/12)										
20		Manufacture additional components	3/20/2023	Activity	30	15			Y	T
21		Assemble mechanical subsystem	3/22/2023	Activity	5	20	18		Y	U
22		Wire electrical components together	3/23/2023	Activity	10	19			Y	V
23		Build/Make it work	3/27/2023	Activity	40	22	21		Y	W
24	D	Testing/Validation/FDR	4/3/2023	Event	N/A	23			Y	
25		Create / purchase an energy storage system	3/27/2023	Activity	7	9			Y	Y
26	S-B	Sponsor Validation Satisfied with Build/Test/FDR	4/10/2023	Event	N/A	24	23		Y	
27		Approval from UR administration to deploy	3/3/2023	Activity	2	13			Y	AA
28		Develop media presence	3/3/2023	Activity	5	3			Y	BB
29		Develop Design Day presentation materials	4/21/2023	Activity	10	9			Y	CC
30		Design Day Presentation	4/28/2023	Activity	4	29	24		Y	DD

Figure 3. *Critical Path Management respective activities*

C. Pugh Matrix for Energy Sources



	Water	Wind	Human
Availability of Resources	0	+1	0
Manufacturability	0	+1	-1
Fun!	0	0	+1
Total:	0	2	0

Figure 4. *Pugh Matrix used to determine optimal energy source*

D. On-Campus Wind Measurements

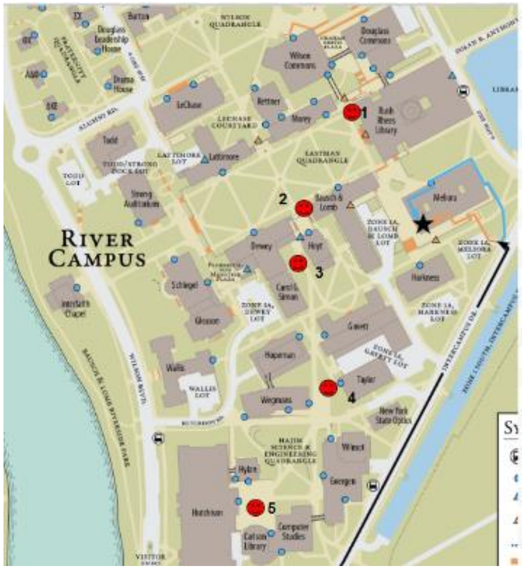
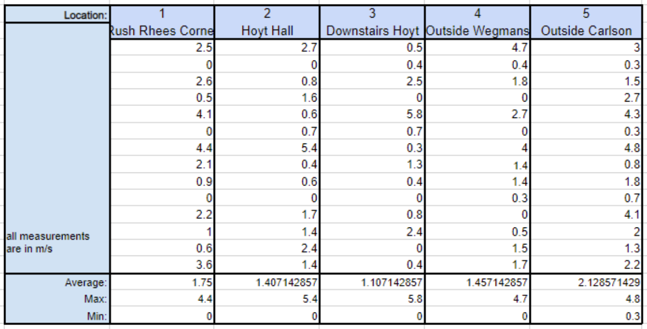


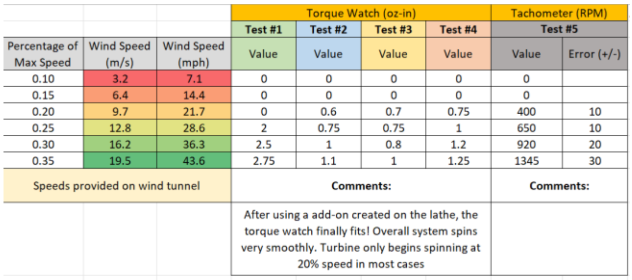
Figure 5. *Map of campus with red smiley faces where wind measurements were recorded*



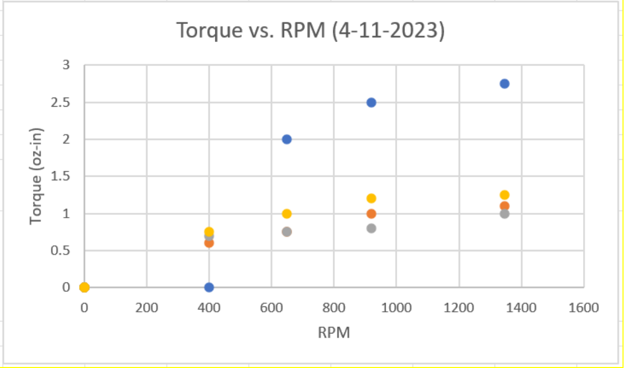
Location:	1 Rush Rhees Corne	2 Hoyt Hall	3 Downstairs Hoyt	4 Outside Wegmans	5 Outside Carlson
all measurements are in m/s	2.5	2.7	0.5	4.7	3
	0	0	0.4	0.4	0.3
	2.6	0.8	2.5	1.8	1.5
	0.5	1.6	0	0	2.7
	4.1	0.6	5.8	2.7	4.3
	0	0.7	0.7	0	0.3
	4.4	5.4	0.3	4	4.8
	2.1	0.4	1.3	1.4	0.8
	0.9	0.6	0.4	1.4	1.8
	0	0	0	0.3	0.7
	2.2	1.7	0.8	0	4.1
	1	1.4	2.4	0.5	2
	0.6	2.4	0	1.5	1.3
	3.6	1.4	0.4	1.7	2.2
Average:	1.75	1.407142857	1.107142857	1.457142857	2.128571429
Max:	4.4	5.4	5.8	4.7	4.8
Min:	0	0	0	0	0.3

Figure 6. *Wind measurements and their recorded location*

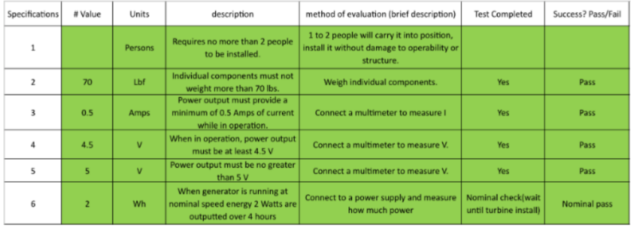
E. Wind Tunnel Data



			Torque Watch (oz-in)				Tachometer (RPM)	
			Test #1	Test #2	Test #3	Test #4	Test #5	
Percentage of Max Speed	Wind Speed (m/s)	Wind Speed (mph)	Value	Value	Value	Value	Value	Error (+/-)
0.10	3.2	7.1	0	0	0	0	0	
0.15	6.4	14.4	0	0	0	0	0	
0.20	9.7	21.7	0	0.6	0.7	0.75	400	10
0.25	12.8	28.6	2	0.75	0.75	1	650	10
0.30	16.2	36.3	2.5	1	0.8	1.2	920	20
0.35	19.5	43.6	2.75	1.1	1	1.25	1345	30
Speeds provided on wind tunnel			Comments:				Comments:	
			After using a add-on created on the lathe, the torque watch finally fits! Overall system spins very smoothly. Turbine only begins spinning at 20% speed in most cases					



F. Specification Testing



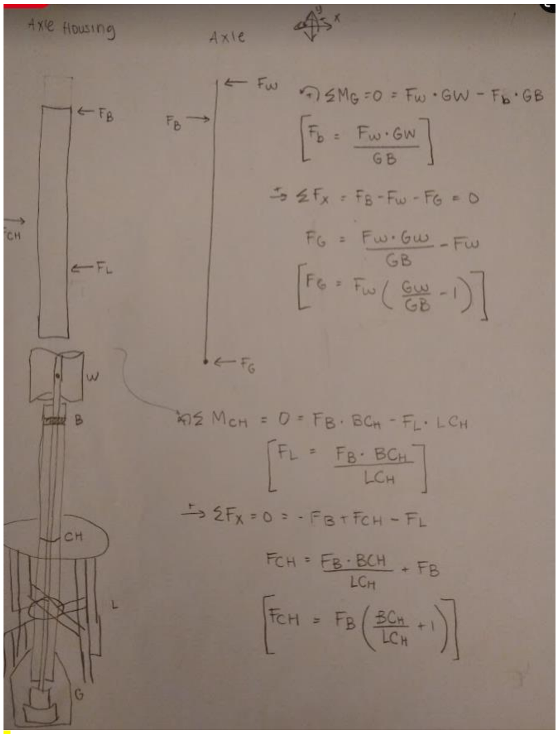
Specifications	# Value	Units	description	method of evaluation (brief description)	Test Completed	Success? Pass/Fail
1		Persons	Requires no more than 2 people to be installed.	1 to 2 people will carry it into position, install it without damage to operability or structure.		
2	70	Lbf	Individual components must not weight more than 70 lbs.	Weigh individual components.	Yes	Pass
3	0.5	Amps	Power output must provide a minimum of 0.5 Amps of current while in operation.	Connect a multimeter to measure I	Yes	Pass
4	4.5	V	When in operation, power output must be at least 4.5 V	Connect a multimeter to measure V.	Yes	Pass
5	5	V	Power output must be no greater than 5 V	Connect a multimeter to measure V.	Yes	Pass
6	2	Wh	When generator is running at nominal speed energy 2 Watts are outputted over 4 hours	Connect to a power supply and measure how much power	Nominal check(wait until turbine install)	Nominal pass

Figure 7. *Project specifications and testing*

G. Assembly Drawing

a. [and BOM]

H. Vibration Analysis Results



$$\Sigma M_G = 0 = F_W \cdot GW - F_b \cdot GB$$

$$\left[F_b = \frac{F_W \cdot GW}{GB} \right]$$

$$\Sigma F_x = F_B - F_W - F_G = 0$$

$$F_G = \frac{F_W \cdot GW}{GB} - F_W$$

$$\left[F_G = F_W \left(\frac{GW}{GB} - 1 \right) \right]$$

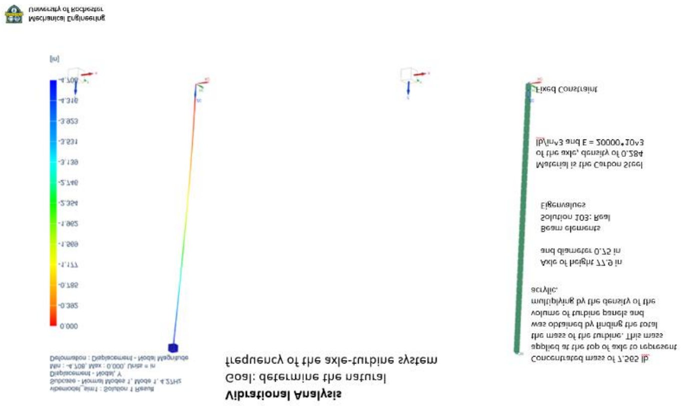
$$\Sigma M_{CH} = 0 = F_B \cdot BC_H - F_L \cdot LC_H$$

$$\left[F_L = \frac{F_B \cdot BC_H}{LC_H} \right]$$

$$\Sigma F_x = 0 = -F_B + F_{CH} - F_L$$

$$F_{CH} = \frac{F_B \cdot BCH}{LC_H} + F_B$$

$$\left[F_{CH} = F_B \left(\frac{BC_H}{LC_H} + 1 \right) \right]$$



Mechanical Engineering
University of Rochester

Vibrational Analysis

Goal: determine the natural frequency of the axle-turbine system

Concentrated mass of 7.565 lb applied at the top of axle to represent the mass of the turbine. This mass was obtained by finding the total volume of turbine panels and multiplying by the density of the acrylic.

Axle of height 77.9 in and diameter 0.75 in

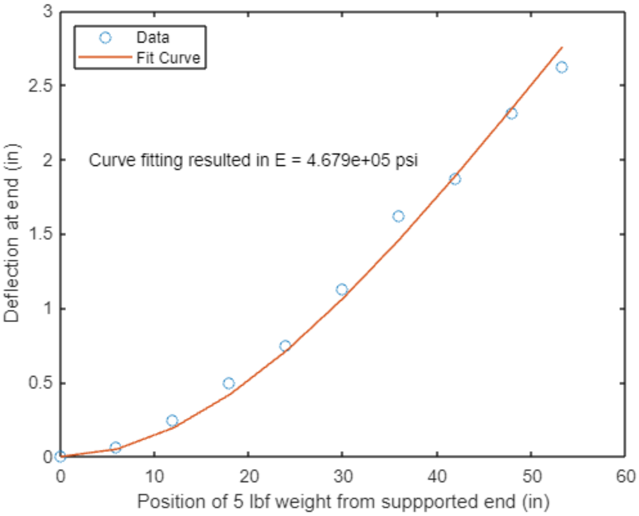
Beam elements
Solution 103: Real
Eigenvalues

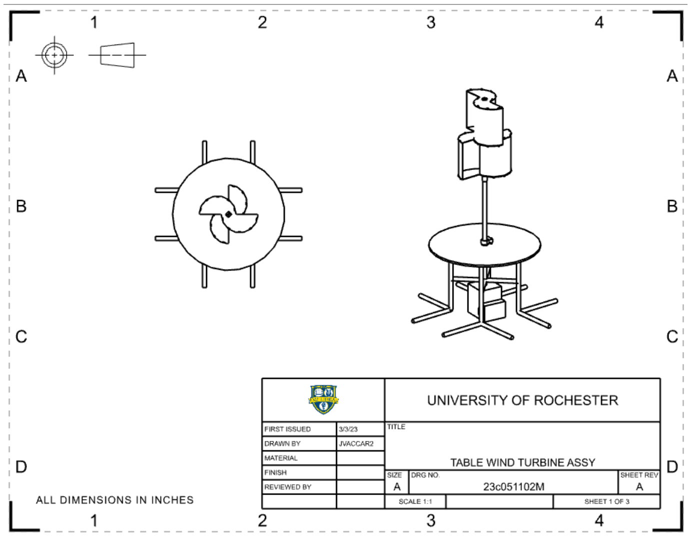
Material is the Carbon Steel of the axle, density of 0.284 lb/in^3 and E = 20000*10^3

Fixed Constraint

vibemodel_sim1 : Solution 1 Result
Subcase - Normal Modes 1, Mode 1, 4.27Hz
Displacement - Nodal, Y
Min : -4.708, Max : 0.000, Units = in
Deformation : Displacement - Nodal Magnitude

I. PVC Young's Modulus Testing



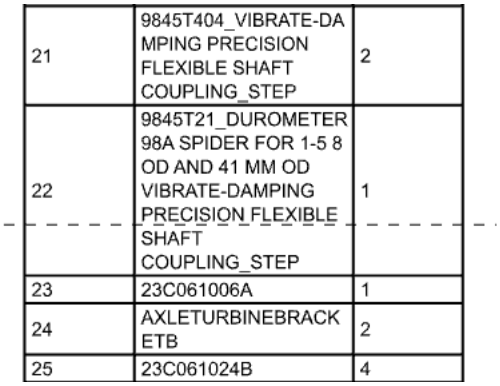


UNIVERSITY OF ROCHESTER

FIRST ISSUED: 3/3/23
DRAWN BY: JVACCAR2
MATERIAL:
FINISH:
REVIEWED BY:

TITLE: TABLE WIND TURBINE ASSY
SIZE: A
DRG NO.: 23c051102M
SHEET REV: A
SCALE 1:1
SHEET 1 OF 3

1	23C033004B	1
2	23C033007A	1
3	23C033005D	1
4	23C033008A	1
5	23C033009A	1
6	23C024008A	3
7	23C024009A	1
8	48925K14_STANDARD-WALL UNTHREADED RIGID PVC PIPE FOR WATER_STEP	1
9	6455K86_PLASTIC BALL BEARING_STEP	1
10	6061K317_LINEAR MOTION SHAFT_STEP	1
11	23C051103A	1
12	23C033010A	2
13	23C033013A	1
14	23C024004B	1
15	23C024006A	2
16	23C024005A	1
17	23C024007B	1
18	23C065001	1
19	23C065002B	1
20	23C065003B	1
21	9845T404_VIBRATE-DAMPING PRECISION FLEXIBLE SHAFT COUPLING_STEP	2



21	9845T404_VIBRATE-DAMPING PRECISION FLEXIBLE SHAFT COUPLING_STEP	2
22	9845T21_DUROMETER 98A SPIDER FOR 1-5 8 OD AND 41 MM OD VIBRATE-DAMPING PRECISION FLEXIBLE SHAFT COUPLING_STEP	1
23	23C061006A	1
24	AXLETURBINEBRACKETB	2
25	23C061024B	4

ADDITIONAL FILES

The attached files include the following:

- A circuit diagram for the electronic components, including a description and bill of materials (TeamGreenGenComponentCircuitDiagrams.pptx)
- An operational manual (TeamGreenGenTheoryOfOperation.docx)
- A detailed drawing package (TeamGreenGenDrawingPackage.pdf)

The above files are located in a Kenesto folder titled *TeamGreenGenProjectMaterials.*