FINAL REPORT

Windmill Blade Competition System
Team Power House (TYL11)

Department of Electrical and Mechanical Engineering
The University of Texas at Tyler
MENG 4215 Senior Design Project

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Executive Summary

The objective of this project is to design and build a testing system for windmills built as part of elementary, middle, and high school competitions. The system allows competitors to install any windmill blades they design on a windmill mount and measures the power generated by their design under controlled wind conditions. In addition, the system allows the automation of the competition's registration, testing, and ranking processes. A team of undergraduate students developed this system as their senior year engineering design project. This applied research project is sponsored by the University of Texas at Tyler. The objectives of this final status report are to display the project's progress and design decisions, showcase how reviewers' feedback was implemented, and to outline the status of project completion.

This status report focuses on providing a progressive overview of the three main sections of the project: the mechanical design, electrical design, the software and controller design. For the mechanical design, all the parts have been ordered and received. On the device, the frame is completely assembled along with the tunnel and the fan has been installed. The hub and all other 3D printed components have been printed off and assembled. For the electrical design, the necessary circuits were designed and installed. The mapped-out wiring has been installed on the device along supporting switches. For the software and controller design, the parts have been assembled, and code has been finalized and installed onto the Raspberry Pi on the device. The code has been troubleshot and tested on the device.

Additionally, the current project timeline, completed milestones, and testing plans for the constructed design are provided to showcase the team's project completion status. The project will be fully assembled and operational and is ready for use in the Alief ISD wind competition. For the future, the device should be broken down and transported to the Houston Engineering Center and reassembled for the competition. In time, the team would like to see multiple successful competitions and more devices with the recommended updates built.

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1. Introduction and Background

The project originated at the Houston Engineering Center when the Alief Independent School District (ISD) partnered with The University of Texas at Tyler in Houston to design a science, technology, engineering, and mathematics (STEM) competition to generate interest in younger audiences regarding the future pursuit of STEM related career paths. The Houston Engineering Center (HEC) designed a windmill blade design competition tailored for elementary, middle, and high school students. The HEC, in conjunction with Alief ISD, established a competition registration system, staffed by volunteers, along with guidelines for creating windmill blades for the competition. HEC faculty and students developed a testing apparatus, shown in Figure 1, to measure the voltage generated by different teams' windmill blade designs. The original competition's guidelines are provided in Appendix A.



Figure 1. Alief ISD windmill blade testing apparatus.

The current testing apparatus was limited on measurable results and had to be maintained by several volunteers in addition to the staffed registration process. After the first competition was held, issues relating to error in the testing procedure and overall competition inefficiency were discovered that needed to be corrected for the future competitions. In order to mitigate these issues, The University of Texas at Tyler Department of Mechanical Engineering, through Dr. Andres Garcia, sponsored this Senior Design project to automate the current windmill competition, registration, and result display procedures. The goals of this project are to develop a system capable of reducing error and to streamline the competition's registration system, while working to generate young students' interest in STEM fields. Additionally, the sponsor desired to see the developed system marketed to other schools to further promote interest in STEM related education and fields. This document outlines the design of a viable and safe windmill competition registration, testing, and results display system that addresses the needs of the sponsor and future competition participants.

1.1. Similar Competitions

When determining the direction of the project, competitions systems were looked at to determine how other institutions handled similarly focused competitions. For each of the following competitions, system components such as the registration process, constraints on the windmill blades, and limits on the windmill testing device were examined when information was available.

1.1.1. KidWind Challenge

The KidWind Challenge is a competition system that is made available nationwide and has been conducted in accordance with the KidWind Challenge Rule Book, which is updated yearly. The Kid Wind Challenge's target audience is K-12 grade students from multiple schools and school districts. This competition utilizes a 48" x 48" testing chamber. Participating teams must provide their own windmill blades, turbines, and windmill mounts to test their designs. Each participating team's design is judged on the energy produced, overall turbine design, written design documentation, and Instant Wind Challenges, which are when participants are asked to apply their knowledge of wind energy to a task separate from the main challenge.

1.1.2. Tiger Windmill Contest

Tiger Windmill Contest, hosted by Cowley Community College, tests participants' windmill blade designs by determining which one can produce the highest average power in a 20 second time frame. The competition guidelines for this competition are a derivation of the KidWind Challenge guidelines. For windmill blade hubs, CD-ROMs are used as a base that the blades can be fastened to, and the windmill blade designs cannot exceed a 7.8" radius. The testing device utilizes a 2' box fan placed at a distance of 11.8" away from the windmill under test.

1.1.3. DOE Collegiate Wind Competition

The U.S. Department of Energy (DOE) Collegiate Wind Competition is a competition focused on college students as the target audience. The windmill designs must operate within a space of 17.7" x 17.7" x 17.7". This competition requires teams to provide their own generators in addition to their windmill blades. The testing apparatus used for this competition implements an emergency shut down; for use in the event something goes wrong during a test of the windmill blades. Multiple metrics were considered to rank the windmill designs, such as a dynamometer test, a rotor strength test, and a power generation test. Additionally, teams are required to present a digital poster related to their design and are also required to write a report about their design's performance. The report and poster are factored into the competition score when determining the team rankings for the competition.

1.1.4. Baugh Wind Energy Design Competition

The Baugh Wind Energy Competition is hosted by the college of engineering and computer science at Oklahoma Christian University. This competition's target audience is middle school and high school kids around ages 11-18. The competition utilized a Google Forms team

registration form for the teams to register for the competition. For creating windmill blades to test, participants are given design kits that include round 0.25" diameter dowels and a hub to construct the participants' designs on. The windmill testing apparatus supports only horizontal rotation axis windmill designs, with a test chamber opening that is 7" tall and 18" wide. In addition to the power generated, the teams are also judged on writing a report and creating a presentation of their windmill blade design.

2. Concept Statement

The following concept statement was developed to outline the scope of the windmill competition system project:

To design and build a testing system for windmills built as part of elementary, middle, and high school competitions. The system allows competitors to install any windmill blades they design on a windmill mount and measures the power generated by their design under controlled wind conditions. In addition, the system allows the automation of the competition's registration, testing, and ranking processes.

3. Requirements and Specifications

The specifications for the windmill competition setup were developed in conjunction with the project's sponsor contact and were subdivided into three categories: the main device (Table 1), windmill blade (Table 2), and electrical specifications (Table 3).

3.1. Main Specifications

Table 1. Windmill blade competition system main specifications.

Specification	Required or Optional	Value/Limit or Yes/No	Unit
Use similar dimensions to old device (4' x 4' x 10')	Required	Yes	N/A
Device can be broken down into multiple parts	Required	Yes	N/A
Utilize a blower fan with a commercially available diameter	Required	30	Inches
Support horizontal and vertical windmill axes	Required	Yes	N/A

Table 1. Continued.

Specification	Required or Optional	Value/Limit or Yes/No	Unit
Maintain a fixed distance between the blower fan and windmill	Required	Yes	N/A
Utilize a non-rectangular testing chamber	Required	Yes	N/A
Utilize a variable speed blower fan	Optional	Yes	N/A

3.2. Windmill Blade Specifications

Table 2. Windmill blade competition system windmill blade specifications.

Specification	Required or Optional	Value/Limit or Yes/No	Unit
Support different blade lengths	Required	12 (Maximum)	Inches
Support a varying number of windmill blades	Required	1-6	Blades
Standardize windmill blade-to-hub interface for the competition	Required	Yes	N/A

3.3. Electrical Specifications

Table 3. Windmill blade competition system electrical specifications.

Specification	Required or Optional	Value/Limit or Yes/No	Unit
Device is electrically powered	Required	120	Volts (AC)
Measure DC power with current and voltage sensors	Required	Yes	Watts

Table 3. Continued.

Specification	Required or Optional	Value/Limit or Yes/No	Unit
Include a safety blower fan shutoff	Required	Yes	N/A
Include a calibration procedure for any sensors	Required	Yes	N/A
Record team name, competition level, and school name	Required	Yes	N/A
Connect to external results display	Required	Yes	N/A

3.4. Additional Requirements

In addition to the listed specifications, a poster was created to present an overview of the project's focus and design, and this poster is provided in Appendix B. Additionally, new competition guidelines, a device assembly guide, and user manual were also requested by the sponsor. These documents can be found in Appendix C, Appendix D, and Appendix E, respectively. At the conclusion of the project, sponsor sign-off was required, so sign-off forms were compiled, shown in Appendix F, to receive verification that project requirements were met.

4. Constraints

Throughout the design process, multiple engineering and situational constraints were taken into consideration. Table 4 displays the four constraints that had the most impact on the project throughout its progression.

Table 4. Key project constraints.

Constraint	Value
Maximum Device Footprint	10' by 4'
Safety Level	Safe for children of all ages
Maximum Cost	$1000.00
Construction Deadline	April 2020
COVID-19 Shutdowns	Reduced project lab access

5. List of Relevant Standards

5.1. Mechanical Standards

The following standard developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) was selected for use in the testing of the project's wind generation systems.

- ASHRAE Standard 41.2-2018 [1]
  Standard Methods for Laboratory Airflow Measurement

5.2. Electrical Standards

The following set of standards developed by the Institute of Electrical and Electronics Engineers (IEEE) were selected for use in the development and operation of the project's electrical systems.

- IEEE 802.11-2016 [2]
  Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications
- IEEE 1100-2005 [3]
  Recommended Practice for Powering and Grounding Electronic Equipment

6. Final Design Details

6.1. Major Design Changes

The final design shown in Figure 2 and its specifications were signed off by the sponsor during the project design review. This final design implements the changes that were requested and recommended by the reviewers and the sponsor before the project could be fully approved. The suggested changes were the removal of the sliding windmill mount, a decrease in the length of the transparent testing chamber, the addition of a quick release and generator shaft lock for the windmill hub, the modification of the windmill blade hub for square dowel rods, and the removal of the second motor from the windmill mount assembly.

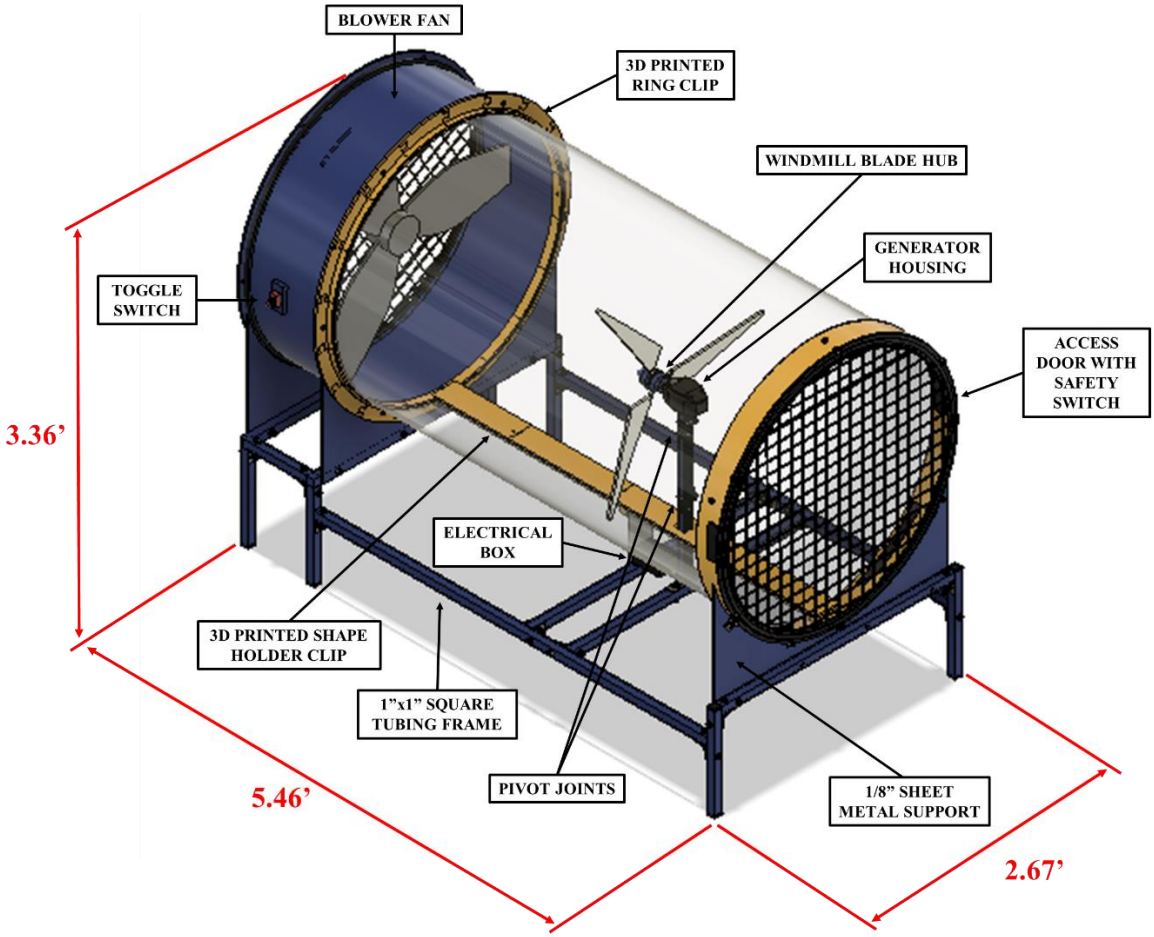


Figure 2. Final windmill blade testing device design.

Since the design review, additional changes have been made to the device to enhance the ease of assembly and device operation. The 3D printed ring clip was redesigned due to variability in the manufacture of the blower fan. The new design uses a wider rim around the circumference of the blower fan to support a wider variety of diameter variations in the blower fan. The electrical box, containing the microcontroller and other components of the DC circuit, has been moved from the side of the blower fan to the base of the windmill mount. This change reduced the wire lengths needed for the design in addition to improving design aesthetics. The windmill blade hub, shown

in Figure 3, was also redesigned to be easier to 3D print and provide a secure connection for the windmill blade dowels.



Figure 3. Windmill blade hub assembly.

6.2. Developed Design

The constructed design, shown in Figure 4, allows for windmill blades to be installed on the windmill mount, tested for power generation, and operated from an onboard user interface that is displayed on an external display with an HDMI connection. Additionally, the device includes a set of safety features to help protect the competition participants and the operators using the equipment. The access door comes equipped with a built-in safety switch, so the machine cannot operate when the door is open. Additionally, there is a manual kill switch on the side of the blower fan that can be used if all power needs to be cut off from the device.

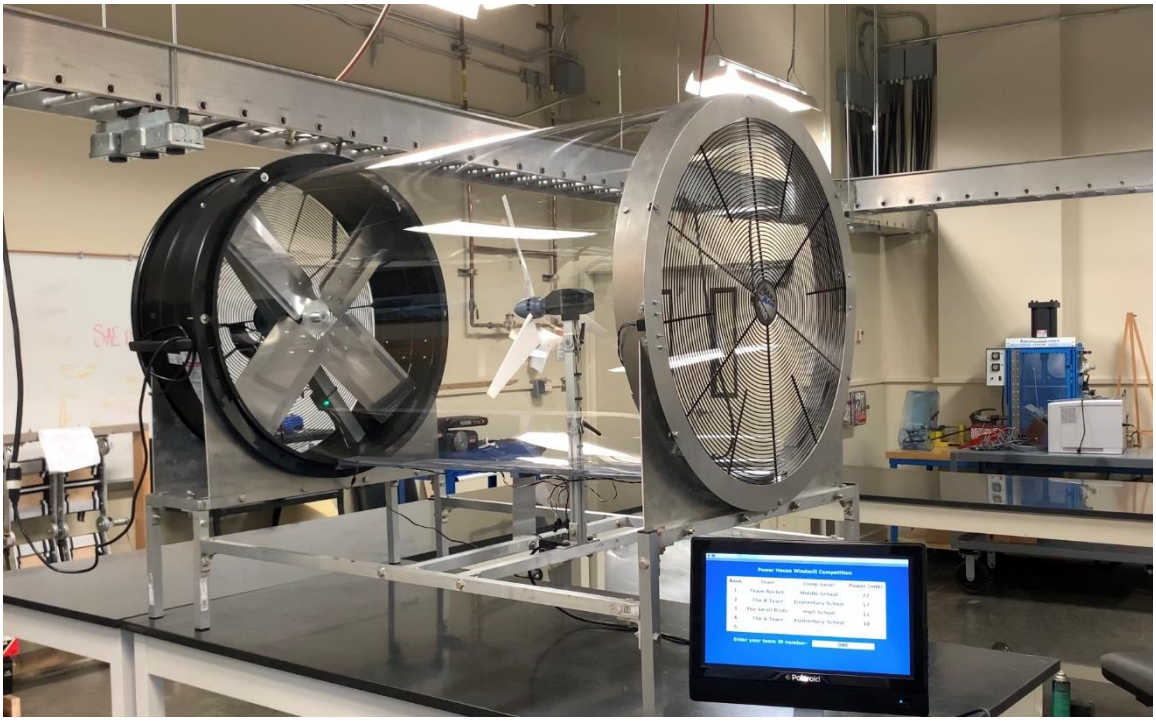


Figure 4. Constructed windmill testing device.

The frame materials consist of aluminum 1" x 1" square tubing, flat aluminum plates, and steel bolts. The aluminum square tubing is used to provide the support for the fan, access door, blade stand, and polycarbonate tube assemblies. Tig welding and bolt fasteners were used to join the square tubing together under the blower fan. The design features saddles made of flat plate

aluminum, which provide the fan with a stable base to sit upon the frame. 3/8" steel bolts were used to join the frame together. For more in depth information of the mechanical parts refer to Appendix G for mechanical drawings.

To control the device blower fan, implement the safety switches, and interface with the competition database, a Raspberry Pi centric control system was developed. To control the blower fan and measure the DC power generated, modifications to the blower fan were required as outlined in Appendix D, and shown in the circuit diagram of Figure H.1 in Appendix H. Additionally, to control the fan from the Raspberry Pi and measure DC power, the DC circuit shown in Figure H.2 of Appendix H was developed.

6.3. Competition Design Details

The registration system for the project utilizes Google Forms, a free survey creation tool linked to Google Drive cloud storage. The registration page, shown in Figure 5, allows registrants to enter their team name, school name, competition level (elementary, middle, or high school), and the number of windmill blades their design has.

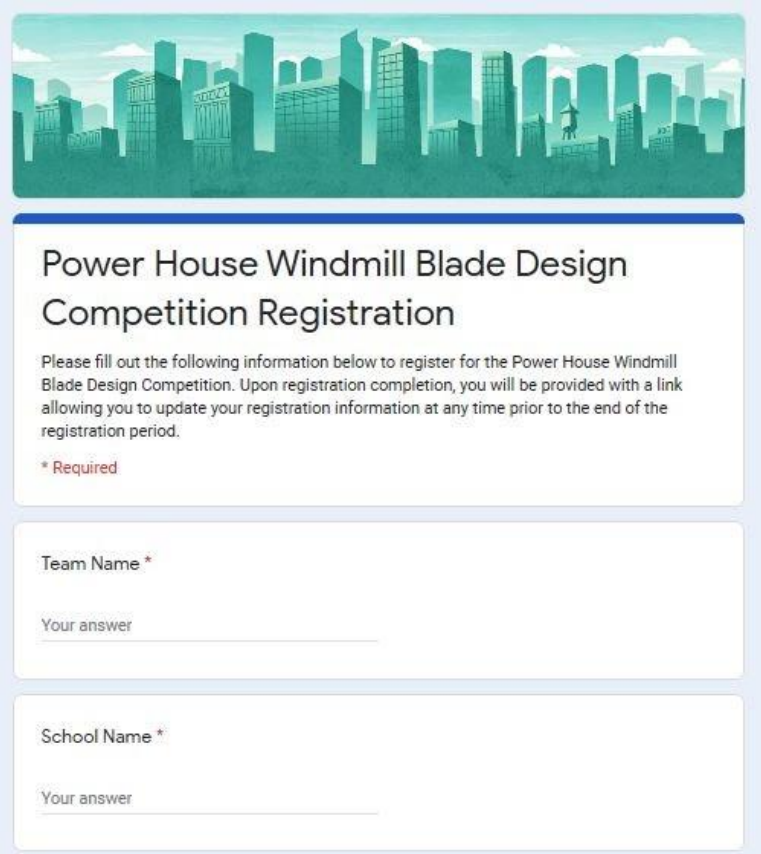


Figure 5. Competition registration form snippet.

Upon completion of the form, the registrant is provided with a link that will allow them to look up their team name to get their 5-digit registration number. The registration form is linked to a competition data spreadsheet on the Google Drive that the device interfaces with to display and

store results, and this spreadsheet uses a function that generates up to 1000 unique team ID numbers.

In order to conduct a windmill test, the participant will install their blades into the windmill hub and open the device access door. Once open, the windmill mount can be unlocked and lowered to facilitate the installation of the windmill hub, which twists and locks onto the generator shaft. Once the windmill mount is locked into the correct orientation, the access door must be closed. The participating team may then enter their 5-digit team identification number from the leaderboard page, shown in Figure 6, via a USB keyboard connected to the device's microcontroller.

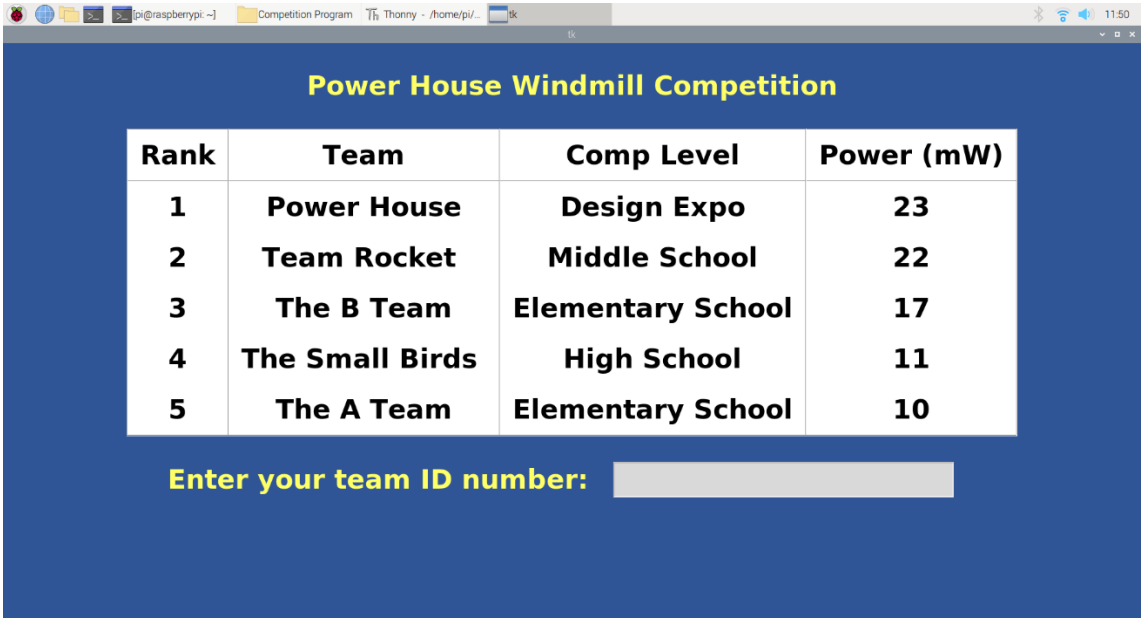


Figure 6. User interface leaderboard page.

If the door is closed, the fan will power on upon entry of a valid ID number, and the windmill test will operate for one minute. Once the test concludes, the team's power value and overall competition ranking will be displayed. Following this, the access door can be opened, and the team's windmill blades can be removed, and the next team can proceed.

7. System and Subsystem Black Box Diagrams

The inputs and outputs (I/O) to the entire windmill blade competition system were considered in the design process. The developed system's overall inputs and outputs are displayed in the black box diagram in Figure 7.

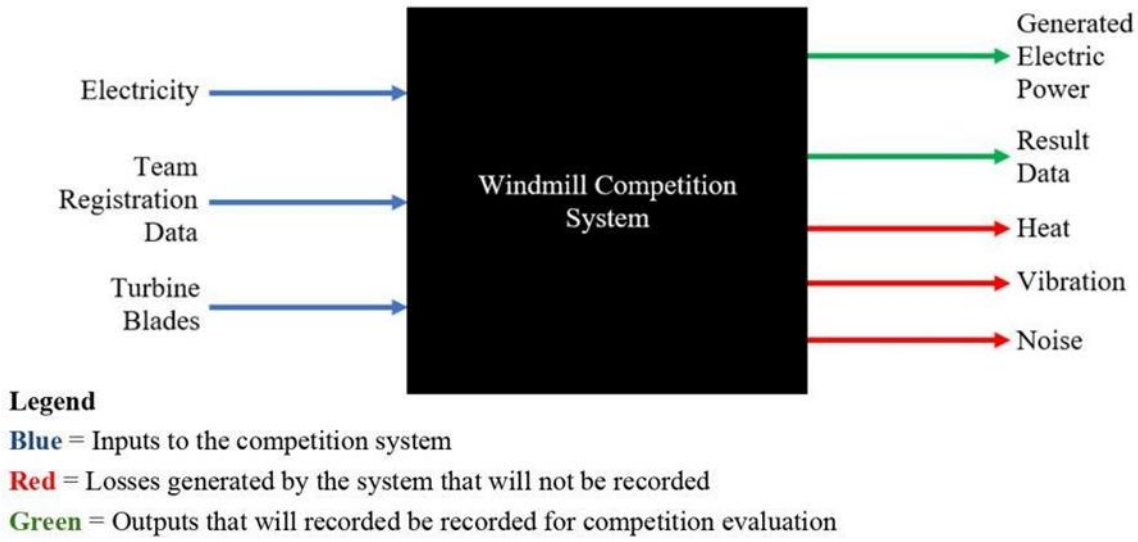


Figure 7. Windmill competition system black box diagram.

The electrical control and data acquisition subsystem within the windmill competition system is shown in Figure 8 with all relevant inputs and outputs displayed. Details of the AC blower fan control circuit (blue in Figure 8) and the power measurement circuit are covered further in the Electric Circuit Diagrams section.

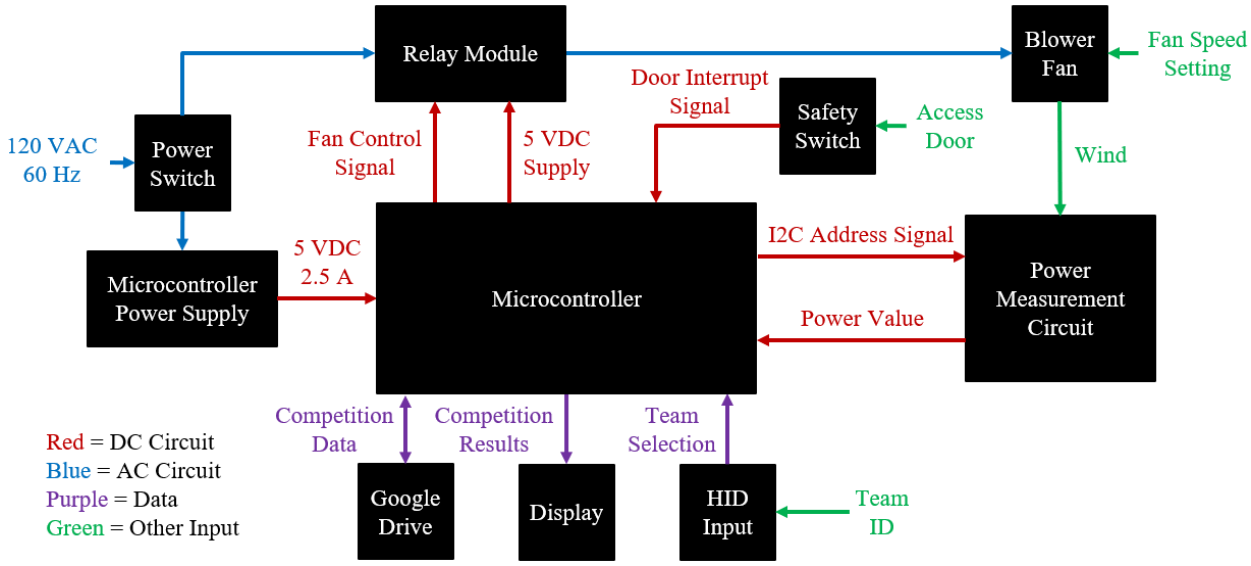


Figure 8. Electrical control and data acquisition subsystem black box diagram.

8. Design Calculations and Selection Reasoning

8.1. Mechanical Systems

This section includes a free body diagram to analyze critical points of the mechanism that holds the windmill blades. The windmill blade mount along with the windmill blades were analyzed with the force of the airflow. A blower fan, frame material, screws, and testing chamber material were selected based on the design calculations. The design calculations were also used to determine the maximum windmill blade mass, average air velocity at the point of impact of the windmill blades, maximum power generated by windmills under test, and power efficiency.

8.1.1. Windmill Mount Stand Force and Deflection Analyses

The analysis of the windmill mount stand with the windmill blades can be simplified by assuming the windmill mount stand acts as a cantilever beam fixed at one end. Figure 9 shows the free body diagram with the appropriate forces impacting the windmill mount stand during testing.

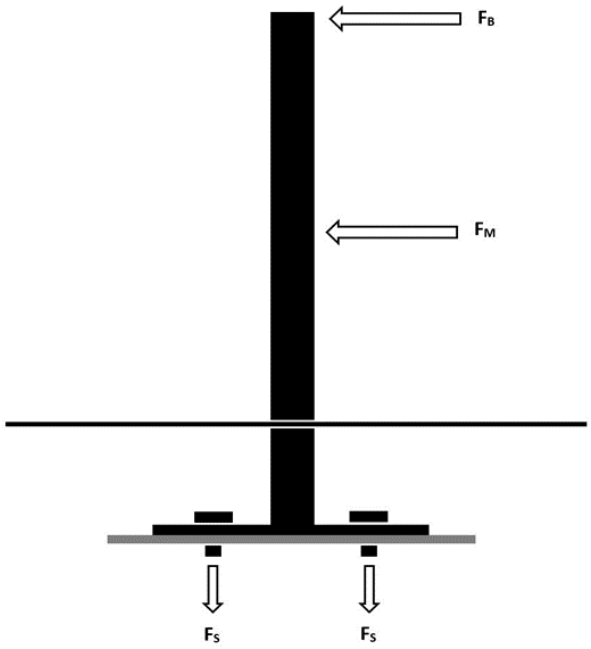


Figure 9. Simplified free body diagram of windmill mount stand.

One goal is to calculate the maximum force, moment, and deflection the windmill mount stand will encounter during testing to ensure the contact angle of the airflow on the windmill blades remains the same for each test and failure does not occur. The force of the air on the windmill mount stand and the windmill blades can be expressed by utilizing Equation (1I) in Appendix I. The surface area of the windmill blades under test will be different for each participating team's windmill test. To ensure the maximum force of the air on the windmill blades is considered, the blades' surface area will be assumed to be the maximum cross-sectional area of the testing chamber. The airflow forces exerted on the windmill mount stand and blades causes a moment to occur at the base of the windmill mount stand. The maximum moment about the base can be

calculated using Equation (5I) in Appendix I. The forces on the windmill mount stand also cause deflection of the windmill mount stand. The maximum deflection of the windmill mount stand is equal to the sum of the deflections caused by the force of the air exerted on the windmill blades and windmill mount stand. The maximum deflection can be represented by Equation (7I) in Appendix I. The maximum deflection of the windmill mount stand is calculated in Equation (9I) in Appendix I.

The calculations in Appendix I were used to verify finite element analyses (FEA) conducted on the windmill mount stand. The FEA in Appendix J Figure J.1. contains a stress analysis on the windmill mount stand while under maximum load. The FEA in Appendix J Figure J.2. contains a displacement analysis of the windmill mount stand while under maximum load. According to calculations and FEA, Table 5 displays the maximum force, deflection, and stress encountered by the windmill stand during testing.

Table 5. Maximum force, deflection, and stress encountered by the windmill stand.

Variable	**Value**
Maximum Force	≅4.08 lbf
Maximum Deflection	≅9.105e-5 in.
Maximum Stress	≅60 psi

The maximum force exerted renders a maximum stress and deflection on the windmill stand. The maximum stress occurs at the base of the windmill stand but remains well within safe levels. The maximum deflection occurs at the top of the stand but is negligible due to the value being so close to zero. The windmill stand will be able to withstand any stress or deflection caused by the force of the windmill blades and airflow.

8.1.2. Windmill Mount Stand Screw Safety Factor Analysis

According to Budynas and Nisbett, the Goodman failure criteria can be used to determine the fatigue factor of safety for the windmill mount stand screws for variable loading and a repeated loading situation [4]. Equation (1K), in Appendix K, can be used to determine the fatigue factor of safety for each screw encountering repeated loading. Equation (10K) in Appendix K shows that the factor of safety for each screw is 538.5. The selected screws for the windmill mount stand are sufficient for repeated and variable loading of the windmill blades.

8.1.3. Determination of Maximum Allowable Windmill Blade Mass

A moment is defined as the cross product of a radius vector and a force.

$$\boldsymbol{M} = r \times F \tag{1}$$

If there is a system of forces, a moment at a point can be described by the summation of the cross products of the radius vectors and forces.

$$\boldsymbol{M} = \sum(r \times F) \tag{2}$$

The centroid of the total assembly can be determined by taking into consideration the centroid locations and masses of each component. The moment of inertia about the bottom of the mount can be determined by taking the summation of the inertias of the windmill mount components and blades with respect to this point. This can be accomplished by finding the inertia of each component and utilizing the Parallel-Axis Theorem.

$$\boldsymbol{I_C} = I_m + m_m {r_m}^2 + I_{wb} + m_{wb} {r_{wb}}^2 \tag{3}$$

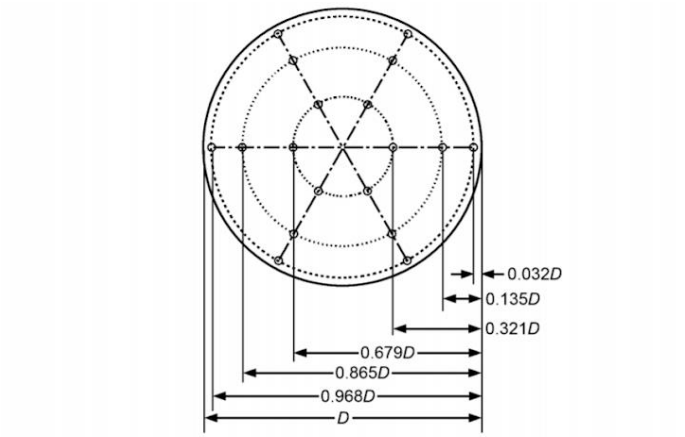
Once the mass moment has been determined, the radius of gyration can be found by taking the square root of the total mass moment of inertia about the bottom of the mount divided by the total mass of the assembly.

$$\boldsymbol{r_G} = \sqrt{\frac{I_C}{m_T}} \tag{4}$$

Finally, the maximum static moment applied to the bottom of the mount and the radius of gyration are known. Equation (1) can be used to determine the maximum force the blades can apply for the assembly to remain intact.

8.1.4. Average Air Velocity Affecting Windmill Blades

The blower fan comes with preset speed settings allowing for varying volumetric flow rates of air. The actual flow rate of the air is not known unless tested. The ASHRAE Standard 41.2-2018 [1] recommends taking samples of the velocity of air using the Log-Linear Rule for Circular Ducts. Figure 10 shows Log-Linear method in more detail.



No. of Measuring Points per Diameter	Position Relative to Inner Wall
6	0.032, 0.135, 0.321, 0.679, 0.865, 0.968
8	0.021, 0.117, 0.184, 0.345, 0.655, 0.816, 0.883, 0.979
10	0.019, 0.077, 0.153, 0.217, 0.361, 0.639, 0.783, 0.847, 0.923, 0981

Log-Linear Rule for Circular Ducts

Figure 10. Log-Linear Rule for Circular Ducts for determining average air velocity.

8.1.5. Determination of Maximum Power Generation

To ensure the generators do not saturate during testing, the theoretical maximum power generation must be determined. Power generated by the windmill blades under test is represented by P_{gen} in Equation (1L) in Appendix L.

8.1.6. 3D Printed Frame Component FEA

FEAs for the 3D printed frame components showcase the maximum displacement and stress that the printed frame could endure if overloaded with 10-pound forces to critical points in the structure during device operation. The resulting stress, shown in Figure J.3. in Appendix J, and displacement, shown in Figure J.4. in Appendix J, were within an acceptable range.

8.1.7. Material and Part Considerations

Tables 6, 7, and 8 display important material and part selections made during the design process.

Table 6. Windmill blade competition system support frame material considerations.

Material	Cost	Fatigue Strength (psi)	Brinell Hardness	Density (lb/in^3)
Hot rolled steel (6 ft)	$22.48	≅39000	≅126	≅0.284
Aluminum 6063-T5 (8 ft.)	**$20.98**	**≅10000**	**≅60**	**≅0.0975**

Table 6 displays the frame material considerations. Although steel is stronger and less susceptible to dents, it is heavier and costs more than aluminum. Aluminum is a lighter and less expensive alternative that will allow the design to be lighter and less expensive to manufacture.

Table 7. Windmill blade competition system testing chamber wall material considerations.

Material	Cost	Thickness (in)	Quantity Needed
Clear Acrylic Tube	$4,041.34	0.250	1
Clear Vinyl Sheet	$180.50	0.030	5
Clear Polycarbonate Sheet	**$95.26**	**0.030**	**1**
Clear Vinyl Foldable Sheet	$48.85	0.040	3 yards

Table 7 contains transparent materials considered for the wall of the testing chamber. The acrylic tube was first considered, but it was not feasible because of the price. Clear vinyl sheets were also considered to reduce the price of the material of the testing chamber. Although the sheets' cost was significantly less than the acrylic tube, the option of using this material for the testing chamber would include buying extra material to create the desired cylindrical shape of the testing chamber. The vinyl foldable sheet was considered as a very inexpensive option, but it also required extra material to create the desired shape of the testing chamber. Finally, a clear polycarbonate sheet was selected. The polycarbonate minimizes the need for extra material because it holds its shape very well which allows the design to have a virtually transparent testing chamber.

Table 8. Windmill blade competition system blower fan considerations.

Fan Option	Cost	Max CFM
Masterforce™ 30" Heavy Duty Drum Fan	$189.00	8800
MaxxAir™ 30" Heavy Duty Barrel Fan	**$209.97**	**5500**

Table 8 displays the blower fan considerations for the design. Both fans offer variable speeds of airflow and are 30 inches in diameter, but one offers a higher maximum CFM airflow. The blower fan that offers the lower maximum CFM airflow was selected because the system was created to test windmill blades designed by elementary school students to high school students. The selected blower fan offers enough airflow for windmill blade testing and will not subject the less efficient blades to larger airflow forces. The increased price is a result of sourcing the fan at a local business, thereby removing all shipping costs.

8.2. Electrical Systems

8.2.1. Selected Microcontroller

In determining the microcontroller for the data acquisition and control system for the windmill competition system, the microcontroller would need to be able to connect to the internet via Wi-Fi, read the output from digital sensors, and output data to an external results display. A Raspberry Pi 3B, shown with its key specifications in Appendix M, Figure M.1 and Table M.1, was provided by the sponsor for performing the data acquisition and storage operations of the windmill testing device, and it met all the requirements needed for the developed system without extensive amounts of additional circuitry.

One drawback to using the Raspberry Pi is that it does not include an onboard analog-to-digital converter. Without the addition of an analog-to-digital converter, any sensors that will need to interface with the Raspberry Pi need to do so digitally.

8.2.2. Selected Power Sensor

To measure the power generated by a windmill under test, a power sensor or combination of current and voltage sensors was needed. In this case, an INA219 current sensor breakout board, shown along with its key specifications in Appendix M, Figure M.2 and Table M.2, was selected for measuring generated power. This board was selected since it can measure both current and voltage, communicate with the Raspberry Pi via I^2C, and has prewritten Python libraries for sensor calibration and interfacing with the INA219 from the Raspberry Pi.

In addition to measuring current and voltage, the INA219 also includes an onboard multiplier that automatically calculates DC power from current (I) and voltage (V) using Equation (5) [7] and outputs this value to the I^2C bus in a digital format.

$$P_{DC} = IV\ (W) \tag{5}$$

In addition to offloading the power calculation from the Raspberry Pi, the digital power value output reduces the circuit complexity by removing the need to add an analog-to-digital converter between the INA219 and the Raspberry Pi.

8.2.3. Selected DC Motor

To generate power for a windmill under test, a Greartisan 12 V, 600 RPM motor was sourced for the design. This motor was selected due to its voltage rating being high enough to be able to drive a current across a small load resistance, as well as having a gear box on the shaft to help distribute the load of the windmill hub and blades away from the motor shaft.

A drawback of this motor is that it is a brushed design, requiring a brush noise reduction filter to made up of small, fast discharging capacitors to reduce the electrical noise provided to sensors in the circuit. The motor with its installed brush noise filter is shown in the "DC Motor Brush Noise Filter Assembly" section of Appendix D.

8.2.4. Selected Generator Load

Originally, the Adafruit DS3502 digital potentiometer breakout board, shown along with its key specifications in Appendix M, Figure M.3 and Table M.3, was selected since it allowed the load resistance to be controlled by an I^2C signal from the Raspberry Pi to reduce the likelihood of generator saturation.

During the testing of the sourced DC motor, it was determined that windmills under test would not approach the power generation needed to reach the motor's saturation point (see the Electrical Testing section for further details). This led to using a static 47 Ω 5 W resistor as the generator load to measure the power across. The static resistance was kept low to allow for higher values of current through the load current for a given generator voltage, since this would enhance the INA219's ability to read current values.

However, the increased current can lead to larger changes in the magnetic flux (Φ) within the generator. This change in magnetic flux will induce an electromotive force (ε) opposing the polarity of the electromotive force (emf) produced by the generator. This principle is described by Lenz's Law of Induction in Equation (6) [7].

$$\varepsilon = \frac{d\Phi}{dt}\ (V) \tag{6}$$

The resulting emf reduction will lead to a reduction in the armature current, thereby impeding the generator's shaft speed slightly.

8.2.5. Selected Diodes for Generator Rectifier

1N5818 diodes, from STMicroelectronics, were selected for use in a bridge rectifier of the power measurement circuit. This diode, shown along with its key specifications in Appendix M, Figure M.4 and Table M.4, is a Schottky diode, which was selected over a standard diode due to Schottky diodes' lower forward voltage drops. The lower forward voltage drop allows for more generated voltage to be dissipated in the load instead of in the diodes, thereby increasing the maximum measurable power across the load.

8.2.6. Power Measurement Circuit Simulation

The selected components and their properties were used to digitally set up and simulate the power measurement circuit. The power measurement circuit was simulated in Multisim (National Instruments), as shown in Appendix N, Figure N.1, to determine if the maximum expected generated current could damage the circuit components. For this simulation, the input voltage from the generator was assumed to be 20% higher than its maximum rating of 12 V (at 18 V). The -5% tolerance of the load resistor RL was applied to maximize the load current. The load current reached a maximum value of 325 mA. This value is well below the maximum current rating of 400 mA for the most sensitive components in the power measurement circuit. Using Equation (7) [7] with the maximum current value and the minimum RL value, the power dissipation across RL was calculated to be 4.72 W. This value was used to select a 5 W maximum power rating for RL.

$$P_{DC} = I^2R\ (W) \tag{7}$$

9. Electric Circuit Diagrams

9.1. AC Fan Wiring Circuit

The AC fan wiring circuit, shown in Appendix H, Figure H.1, was developed to allow for the device to utilize only one wall outlet connection to receive power. The wiring within the blower fan was modified to incorporate a power switch, the Raspberry Pi power supply, and a relay module for turning the fan on and off from the Raspberry Pi. Additionally, the circuit setup allows for the original fan speed switch at the back of the fan to switch between the two blower fan speeds prior to a windmill test, depending on a competition host's preference.

9.3. Power Measurement and Control Circuit

The power measurement and control circuit is shown in Appendix H, Figure H.2. For the power measurement portion, two IN5818 bridge rectifiers allow current flow from the windmill generators when their shafts rotate clockwise or counterclockwise. These rectifiers are hooked up to the input port of the INA219 sensor to read power across a 47 Ω load resistor. The INA219 relays the measurement values to the Raspberry Pi using the SDA and SCL lines for the I^2C communication protocol.

For the control portion of the circuit, the Raspberry Pi GPIO ports 4 and 17 are used. GPIO port 4 is used as an interrupt detection line while port 17 is used to signal the blower fan control relay to switch on and off, thereby turning the fan on and off.

9.4. Stepper Motor Control Circuit

Prior to receiving feedback from the design review, a stepper motor control circuit, shown in Appendix O, Figure O.8, was considered to move the windmill mount within the test chamber. A stationary windmill mount was requested by the sponsor and recommended by the reviewers during the design review, removing the need for this circuit in the final design.

10. Software Flowcharts

The following flowcharts describe the software operation for the competition registration, testing, and results display procedures.

10.1 Registration Procedure

The registration process uses cloud-based Google Forms to collect each teams' name, school name, competition level, and number of windmill blades. Google Forms is used because it can be accessed by any device with an internet connection, offloads the registration process from the Raspberry Pi, and automatically creates a Google Sheet containing the collected information. The flowchart shown in Figure 11 shows the logical flow of the registration procedure.

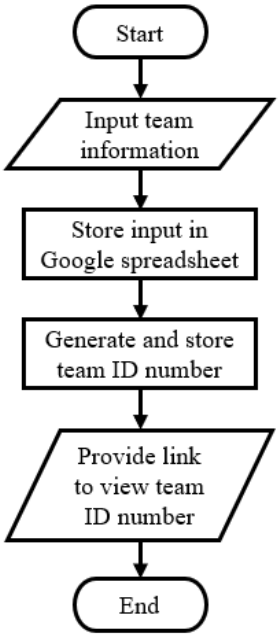


Figure 11. Logical flow of the competition registration procedure.

10.2 Standby and Results Display Procedure

The standby and results display procedure provides an interactive user interface and outputs the current leaderboards to an external display until a team ID number is provided as input to the device. Once an ID is provided, the windmill testing procedure is initiated. The flowchart shown in Figure 12 shows the logical flow of the standby and results display procedure. A program was developed to test the reading and writing of data to and from a Google spreadsheet, and its code is provided in Appendix P (36.1).

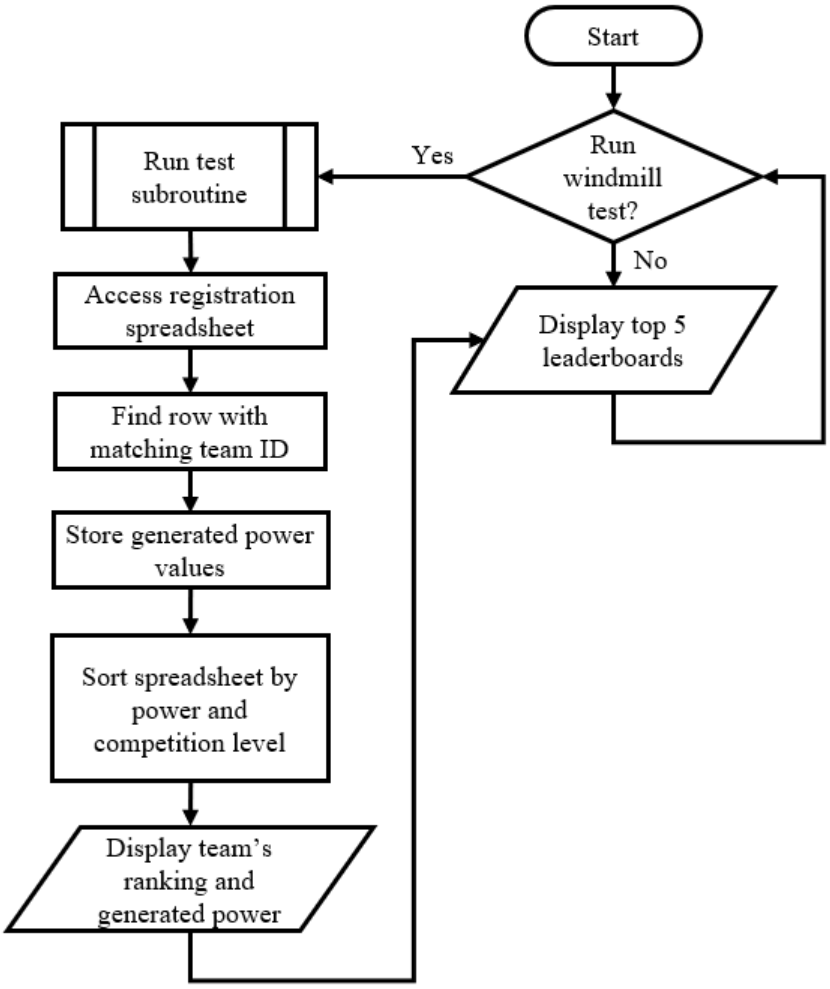


Figure 12. Logical flow of the standby and results display procedure.

10.3 Windmill Power Generation Test Subroutine

The windmill power generation test subroutine determines the power generated for a specific team ID. The test is interrupted at any time if the test chamber door is opened. The flowchart shown in Figure 13 shows the logical flow of the windmill power generation test subroutine. The test procedure runs for one minute. The code for this subroutine is embedded in the standby and results display program in Appendix P (36.1). The power averaging and access door interrupt functions are handled in separate Python classes that are accessed from within the subroutine, and their code is provided in Appendix P (36.4) and Appendix P (36.2), respectively.

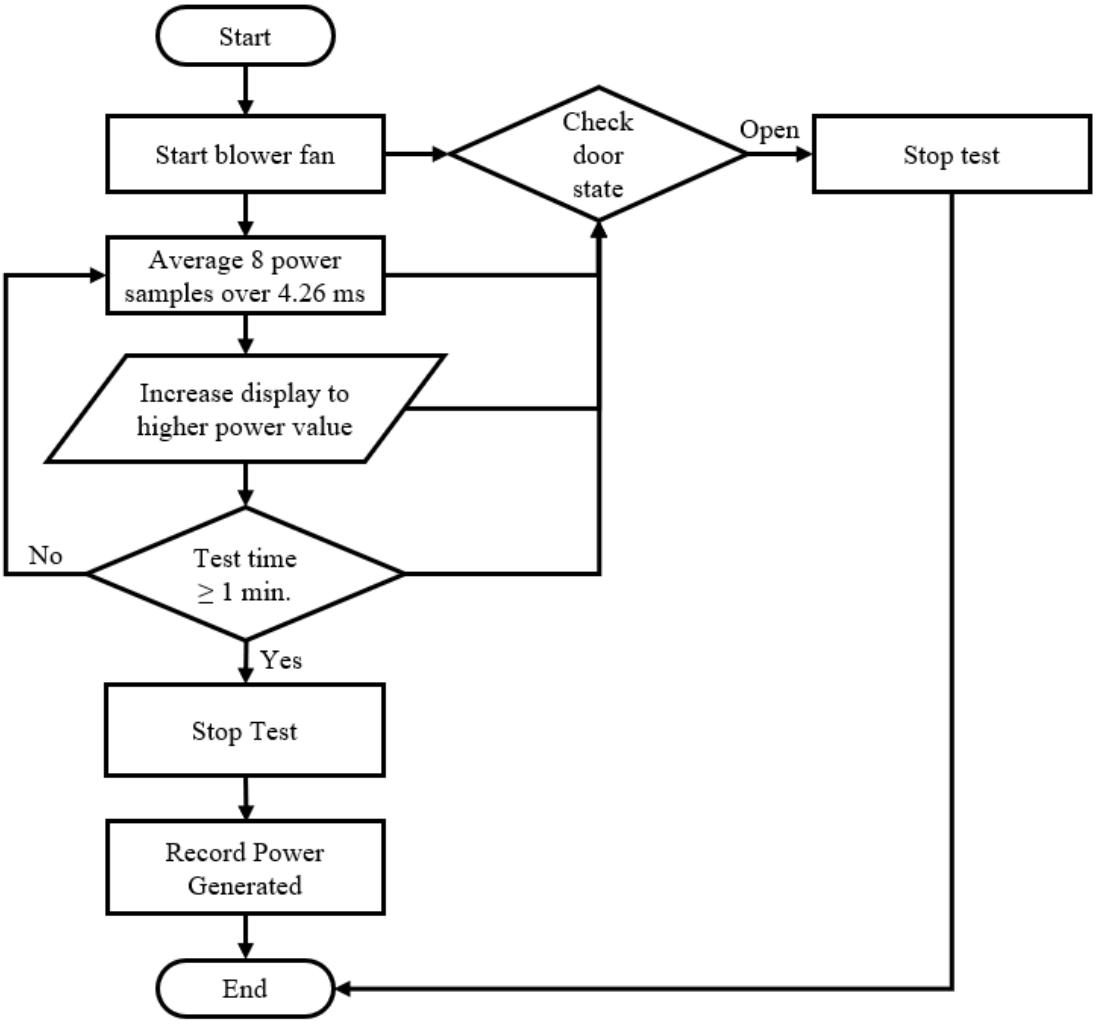


Figure 13. Logical flow of the windmill power generation test subroutine.

11. BOM and Detailed Budget

The project sponsor provided a budget of $1000.00 to complete the project. The proposed competition system mechanical and electrical components are shown along with their prices in Appendix Q, Tables Q.1 and Q.2, respectively. The total estimated project cost of $1050.45 slightly exceeded the allocated budget. However, multiple components were donated to the project, so only $508.02 was used from the allocated funds (excludes shipping and tax).

12. List of Risks Involved

Table 9 contains potential risks that were encountered as development of the windmill competition testing apparatus and competition system progressed.

Table 9. Mitigated project risks.

Risk	**Actions Performed to Reduce/Eliminate Risk**	**Potential Cost without Mitigation**
Structural integrity issues were present in the proposed 3D printed components.	The risk was mitigated by utilizing finite element analyses to verify the durability of the planned 3D printed components.	The team and device operator will constantly have to replace parts due to fractures in the 3D printed components.
Cost overruns were encountered due to product and shipping price increases, and unforeseen design issues.	The risk was mitigated by verifying the functionality of purchased parts on delivery and seeking suppliers with warranty periods for their products and services.	Seeking products without warranties and guarantees would have increased spending resulting in being substantially over budget.
Delays arose in the project schedule due to unforeseen design construction problems.	The risk was mitigated by consulting manufacturing experienced faculty to ensure the proposed manufacturing goals are feasible.	Without advice from design specialists, extra money and time would have been spent creating and building the device and system.
Some competition participants' windmill blades will not be designed well enough to sufficiently rotate the generator shaft during a windmill test, resulting in a reduced satisfaction level in the competition experience.	To mitigate this risk a few windmill blade designs of differing construction qualities were tested to determine what blade designs may not be able to rotate the generator shaft.	The users experience of using the device would be diminished. Through testing different blades operation suggestions have been made in the user manual.

Table 9. Continued.

Risk	Actions Performed to Reduce/Eliminate Risk	Potential Cost without Mitigation
Running out of time to complete the competition system	Each week we had at least three meetings to coordinate and constantly work on the project. Action items were given to team members to ensure deadlines were met.	Building the system would have never been accomplished. Even with the COVID pandemic, the team was able build a fully operational system.

13. Project Testing

13.1. Mechanical Testing

One of the goals of this project is to create a testing chamber to reliably and safely test the power generation capacity of windmill blades created by students. The device will undergo a longevity test, the wooden dowels will undergo stress and strain tests, and average air speed will be obtained using ASHRAE Standard 41.2-2018. Other concerns that may affect the device will be addressed also.

13.1.1. Longevity Test

The longevity test is to ensure the device will operate properly for many competitions to come. One way to ensure this is to mimic or replicate the life spans of the device's runtime. Each team's blades will be tested for about one minute and about 100 team will participate at each competition. The device will be tested to replicate a competition with 100 teams. There will be 3 types of blades created for testing that will represent blades that could be potentially made by elementary, intermediate and high school students. Mechanical and Electrical components will be analyzed after each set of blades are tested.
Unfortunately, due to the COVID-19 pandemic reducing access to the project lab, the test was not performed entirely. Individual tests were performed with a few different blade designs to ensure the electrical components were functioning properly, but the full competition simulation was not performed.

13.1.2. Stress and Strain Tests

The most common component in all the windmill designs will be the square dowel. The created windmill blades must fit into the hub's quarter inch square slots. Although the square dowel rods will not always be used as a part to the windmill blade design. However, the dowel rods are a common component of the windmill blades. They can be tested to create requirements for windmill blades constructed by the teams. Two types of square dowels will be tested: wooden square arts and crafts dowel, and a hard wood square dowel. Loads will be applied to wooden dowels to replicate worse case scenarios. Unfortunately, due to the COVID-19 pandemic the Stress and Strain test was not performed.

13.1.3. Air Speed Test

The average air speed, for each fan speed level, in the testing chamber will be used to provide a maximum power generation value to rate each team on an individual performance scale. This test was completed according to ASHRAE Standard 41.2-2018.
A hot wire anemometer, shown in Figure 14, was used to complete the test.



Figure 14. ALNOR CompuFlow Thermo-anemometer Model 8585

The wind chamber's ring was first marked with an Expo marker to indicate the position the anemometer would be placed when taking measurements. Figure 15 displays how each position was marked for testing. The testing chamber is 30 inches in diameter. According to ASHRAE Standard 41.2-2018, three measurements are required to be taken at each position. Measurements were approximately taken at 1 inch (inner position), 4 inches (middle position), and 9.5 inches (outer position) from the rim of the testing chamber for each position shown below. The data collected during the test is shown in Appendix R Table R.1.

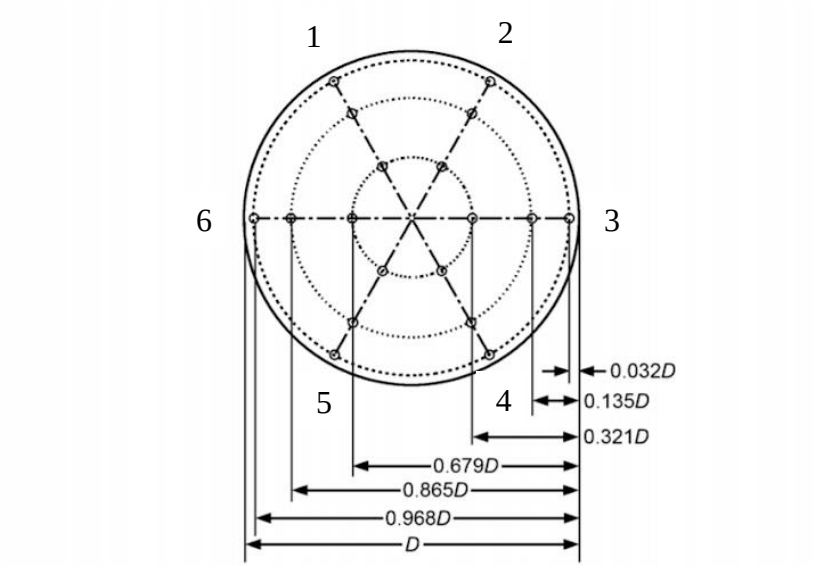


Figure 15. Testing Chamber's Testing Positions Illustration.

Table 10. Testing Chamber Air Velocity Results

Testing Chamber Air Velocity Results		
Fan Speed Setting:	**Low**	**High**
Average (ft/min)	981 - 1045	1105 - 1174
Average (ft/s)	16.3 - 17.4	18.4 - 19.6

The results, in Table 10, verify the maximum air velocity in the testing chamber, and give an average air velocity for each speed setting. Teams can be ranked not only against other teams, but also according to the power their blades generated from the airflow.

13.1.4. Other Mechanical Concerns

Vibrations is also another factor that is important to consider for the mechanical design. Windmill blades that are similar in weight and orientation should only be created by teams that are to be tested in the device. The blades should also be placed in the hub in a symmetric orientation to minimize vibrations, along with stress and strain on the components of the device.

13.2. Electrical Testing

13.2.1. Power Measurement Test

A prototype power measurement circuit, shown in Figure 16, was constructed to test its power measurement capabilities.

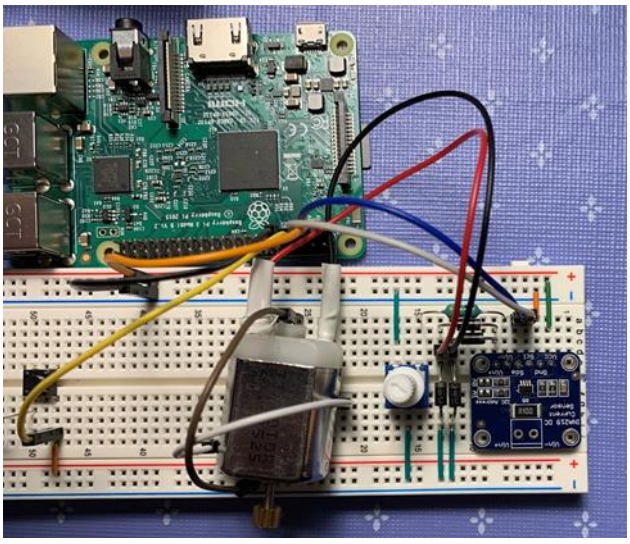


Figure 16. Power measurement circuit prototype. The motor shown in the circuit is to show where the generator leads are connected in the prototype.

With the load set to 47 Ω, as per the system design, a 1.2 V AA battery was placed across the terminals where the generator would be connected and the power value was recorded, alongside

voltage and current from a multi-meter. The power value of the multimeter was calculated using Equation (6). The results of this test are shown in Table 11.

Table 11. Power measurement test results.

Measurement Source	Current (A)	Voltage (V)	Power (mW)
INA219	---	---	11
Multi-Meter	0.0153	0.748	11.44

The similarity in measured power values showcased that the power measurement system can measure power accurately. The discrepancy in the micro-Watt range is a result of the resolution of the INA219 sensor.

13.2.2. Bidirectional Power Measurement Test

Since competition participants' designs may rotate either clockwise or counterclockwise, the device needed to be able to measure power for both directions. For blades of similar design but opposite rotation, the power measurement circuit detected around 10 mW of power from both designs. The system was able to measure the power generated from either rotation direction.

13.2.3. Generator Saturation Test

The selected motor was tested to see if it would saturate when used within the device at load. To simulate an excessive loading condition, the electric motor's shaft was connected to a drill motor and operated at 1400 RPM while connected to the power measurement circuit. The resulting voltage, current, and power generated was as shown in Table 12.

Table 12. Generator saturation test results.

Power Source	Current (A)	Voltage (V)	Power (mW)
12 VDC Greartisan 600 RPM Motor	0.325	13.893	4.515

The 1400 RPM value is not obtainable without an additional gear box on the motor shaft under the available wind conditions. Therefore, the selected motor will not reach its saturation limit during a windmill test. Additionally, the resulting current and power values were below the maximum values allowed for the circuit, so no damage to the circuit was incurred during the test.

13.2.4. Windmill Competition Length Test

With the device constructed, two different sets of blades were tested to determine the optimal length of a windmill power generation test. Both sets were 12" long, but one set of blades were a 3D printed model of real-world wind turbine blades, while the other set was small pieces of cloth stapled to square wooden dowels. These two blade types of varying quality were both put into the testing device on low speed for 2 minutes. Each blade design was tested twice, and the average times at which they reached full power potential are shown in Table 13.

Table 13. Windmill competition length test results.

Windmill Design Test	Average Time to Full Power (sec)	Average Power Generated (mW)
3D Printed Blades	18	27.5
Cloth-Wood Blades	50	10.5

From the two designs tested, it was determined that the test should run for 1 minute to allow time for certain blade designs to reach full power potential, while also maintaining competition throughput.

13.2.5. Google Drive Registration and Results Interface Test

For the teams to register for the competition and for the results to be linked to each team's registration, the interface between the Raspberry Pi and the Google Drive had to be tested. The registration form was filled out 25 times to generate 25 unique team ID's and registration entries on the Google Drive. Then, each team ID was passed to the program for a simulated windmill test (i.e. one with no blades installed, no blower fan running, and shortened to 25 seconds).

With the designs tested, it was determined that the test should run for 1 minute to allow time for certain blade designs to reach full power potential, while also maintaining competition throughput.

14. Testing and Verification of Acceptance Criteria

Acceptance criteria and related verification methods were developed for the specifications from Tables 1, 2, and 3, encompassing the main (Table S.1), windmill blade (Table S.2), and electrical (Table S.3) specifications in Appendix S. A final sign-off form for the sponsor to approve of the design deliverables and its testing methods is included in Appendix F.

15. Timelines and Milestones

The project timeline, shown in the Gantt charts of Figures 17 and 18, were used to keep track of the project progress. Due to COVID-19 lab closures, some of the deadlines laid out in Figure 18 were unable to be met as when originally planned. Key milestones for the project are shown in Table 14, with more details for the second semester. A detailed list of the project action items, and their responsible members is provided in Appendix T.

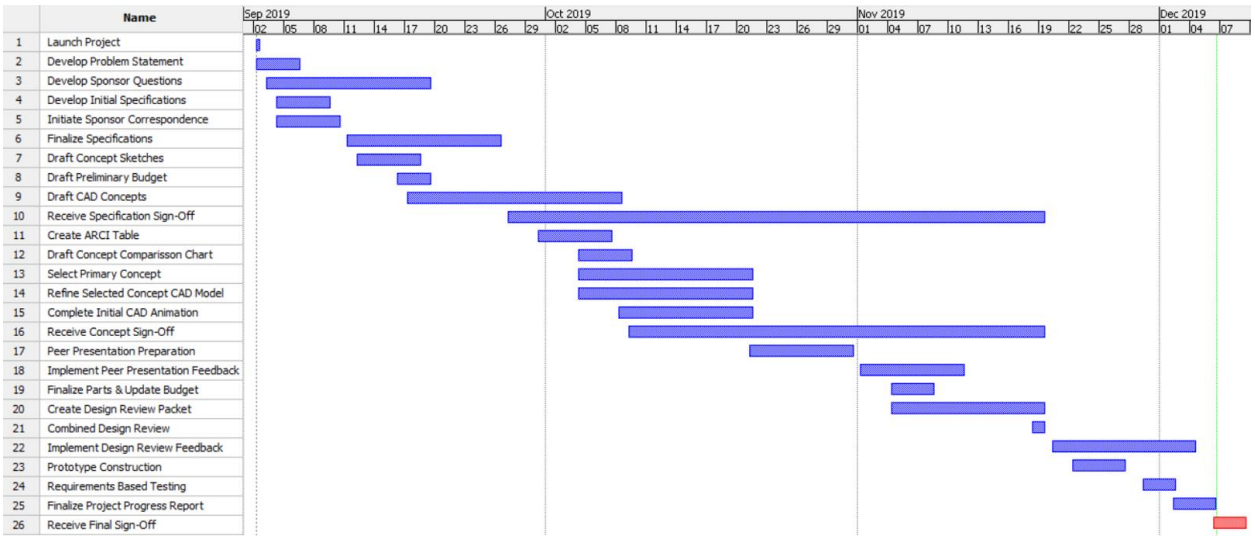


Figure 17. 1st semester project scheduling Gantt chart.

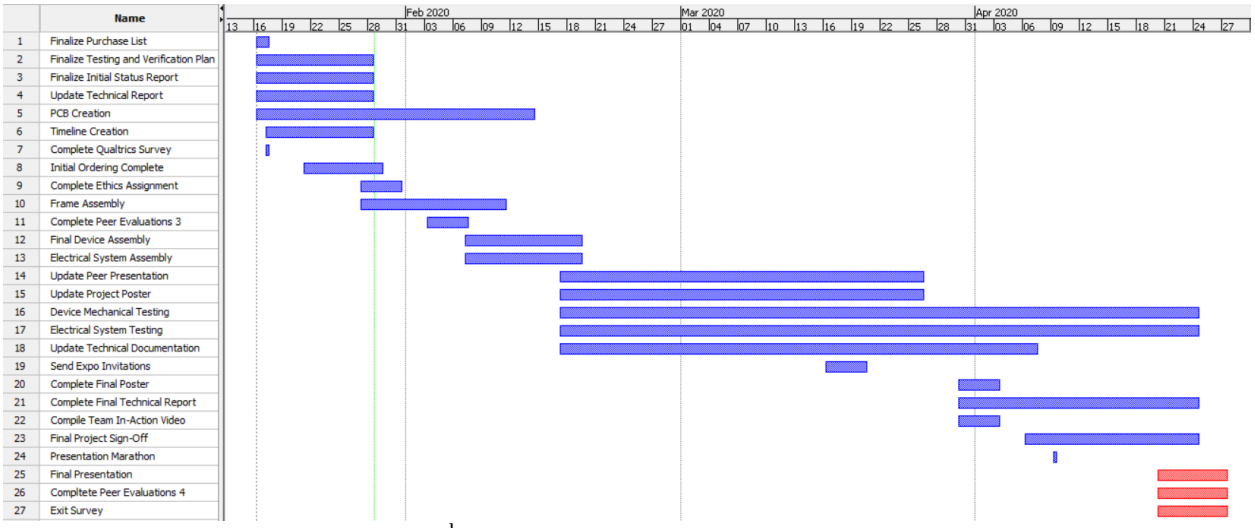


Figure 18. 2nd semester project scheduling Gantt chart.

Table 14. Key project milestones.

Milestone	**Expected Date**	**Completion Date**
Project Launch	Sept. 2, 2019	Sept. 2, 2019
Develop Problem Statement	Sept. 6, 2019	Sept. 6, 2019
Initial Sponsor Meeting	Sept. 16, 2019	Sept. 12, 2019
Finalize Specifications and Acceptance Criteria	Sept. 24, 2019	Sept. 26, 2019
Receive Sponsor Specification Sign-Off	Sept. 27, 2019	Nov. 19, 2019
Internal Concept Selection	Oct. 14, 2019	Oct. 21, 2019
Receive Sponsor Concept Sign-Off	Oct. 22, 2019	Nov. 19, 2019
Peer Presentation	Oct. 29, 2019	Oct. 31, 2019
Design Review	Nov. 18, 2019	Nov. 19, 2019
Start Initial Prototype	Nov. 22, 2019	Nov. 22, 2019
Finish Initial Prototype	Dec. 1, 2019	Nov. 27, 2019
Finish Initial Prototype Testing	Dec. 2, 2019	Dec. 1, 2019
Complete Qualtrics Survey	Jan. 17, 2020	Jan. 17, 2020
Finalize Purchase List	Jan. 17, 2020	Jan. 17, 2020
Finalize Initial Testing and Verification Plan	Jan. 24, 2020	Jan. 24, 2020

Table 14. Continued.

Milestone	**Expected Date**	**Completion Date**
Finalize Initial Status Report	Jan. 24, 2020	Jan. 28, 2020
Create Second Semester Timeline	Jan. 24, 2020	Jan. 24, 2020
Initial Ordering Complete	Jan. 27, 2020	Jan. 28, 2020
Complete Ethics Assignment	Jan. 30, 2020	Jan. 30, 2020
Finish PCB Design	Feb. 6, 2020	N/A
Frame Assembly	Feb. 7, 2020	Feb. 15, 2020
Complete Peer Evaluations 3	Feb. 7, 2020	Feb. 7, 2020
Final Device Assembly	Feb. 15, 2020	Mar. 23, 2020
Electrical System Assembly	Feb. 15, 2020	Mar. 19, 2020
Finish Initial Testing	Mar. 16, 2020	Mar. 24, 2020
Update Peer Presentation	Mar. 16, 2020	N/A
Update Project Poster	Mar. 16, 2020	Mar. 30, 2020
Send Expo Invitations	Mar. 20, 2020	N/A
Update Technical Documentation	Mar. 24, 2020	Apr. 23, 2020
Complete Final Poster	Apr. 3, 2020	Mar. 30, 2020

Table 14. Continued.

Milestone	Expected Date	Completion Date
Compile Team In-Action video	Apr. 3, 2020	Apr. 19, 2020
Device Mechanical Testing	Apr. 6, 2020	Apr. 9, 2020
Electrical System Testing	Apr. 6, 2020	Apr. 9, 2020
Presentation Marathon	Apr. 9, 2020	N/A
Final Project Sign-Off	Apr. 20, 2020	
Complete Final Technical Report	Apr. 24, 2020	Apr. 24, 2020
Final Presentation	Apr. 25, 2020	N/A
Complete Peer Evaluations 4	Apr. 25, 2020	Apr. 21, 2020
Complete Exit Surveys	Apr. 25, 2020	Apr. 23, 2020

16. ARCI Table

To clarify the roles and responsibilities of each member of the team, an ARCI table was constructed to outline these responsibilities as shown in Table 15. The key for the ARCI table is shown in Table 16.

Table 15. Power House task responsibility ARCI table.

WB Item No.	Work Item	Emmanuel Acuna	Davida Campbell	Joshua Stapp	Frederick Wehe	Spencer Wells
1	**Problem Statement**	**I**	**C**	**A**	**I**	**R**
1.1	Researching ideas	C	A	R	I	I
1.2	Creating concepts	A	C	C	R	I
1.3	Preparing Report	I	R	A	C	I
2	**System Design**	**A**	**R**	**I**	**C**	**I**
2.1	Sponsors ideas	I	I	A	R	I
2.2	Specifications	I	A	R	C	I
2.3	Black Box Diagram	I	I	A	C	R
2.4	Preparing Report	I	I	R	C	I

Table 15. Continued.

WB Item No.	Work Item	Emmanuel Acuna	Davida Campbell	Joshua Stapp	Frederick Wehe	Spencer Wells
3	**System Development**	**R**	**I**	**A**	**C**	**I**
3.1	Software	R	A	I	I	C
3.2	Hardware	C	I	R	A	I
3.3	3D Modeling	R	A	I	C	I
3.4	Preparing Report	A	I	R	C	I
4	**Prototyping**	I	I	R	C	A
4.1	Software	I	I	A	R	I
4.2	Hardware	I	I	A	R	I
4.3	Constructing and testing	A	I	R	I	I
4.4	Preparing Report	I	I	A	C	R

Table 16. Key for the ARCI table.

Letter	Role
A	Accountable
R	Responsible
C	Consulted
I	Informed

17. Discussion

Three major concepts were designed that met the requirements of the design proposal. Due to the sponsor wanting the device to generate STEM interest in elementary, middle school, and high school students, design aesthetics was considered an important factor. For the selected concept, this presented a challenge in terms of developing a device with curved test chamber walls with the given budget that would be durable enough to withstand repeated use. These concerns were addressed with the use of mechanical analyses. Through stress, force, and airflow calculations and FEA of critical components, the proposed device was shown to be structurally feasible. With simulations and prototypes of the device's power measurement circuitry, the method by which DC electric power was proposed to be measured was shown to be viable. Once all components were selected, the budgetary feasibility of the proposed design to stay close to the allocated budget was proven.

A feasible version of the design was showcased during a design review, where several changes were recommended by the reviewers and sponsor contact. These changes included the removal of a generator on the windmill mount, the removal of the sliding windmill mount and its supporting electronics, a reduction in the length of the device's testing chamber, and a redesign of the windmill hub to incorporate square holes and a generator shaft locking mechanism. The evaluation summary compiled by the reviewers is included in Appendix U. These changes were integrated into the current design to reduce system complexity and cost, while also increasing its feasibility. The removed and updated components are catalogued in Appendix O.

Minor updates occurred to the design during construction. The legs have been increased in length and the mounting has been slightly modified for sourcing convenience. The door saddle has been reduced to help with manufacture costs. These changes are all reflected in the Appendix D. The device was assembled by February 27 and testing began. The device is complete with data registry and safety features. The safety features include an emergency cut off switch on the fan, and a door sensor which stopped the device operation if opened during a test. The door switch will also prevent a test from starting if the door is left open. The device supports both orientations of windmill blades and has locks on the stand joints in order to reduce human error. The device can be easily disassembled into smaller components for transport and will fit through a standard doorway.

18. Recommendations

This section contains recommendations for future iterations of the device. Although the device follows all previous specifications and operates accordingly, these recommendations could help with the construction, operation, aesthetics, and lifespan of the device.

The current 4-part 3D printed shape-holder clip needs the interconnections to be redesigned. The connection rods on each of the four parts are currently frail and will break if they are mishandled. To remedy this in the current design, the 4-part assembly was held together with JB weld. To remedy this issue, the interface between each part of the shape-holder clip can be made wider and printed with an increased number of shells and increased infill. Additionally, the addition of

a groove along the bottom of the shape-holder clip would provide the device wiring harness space to be channeled to improve the aesthetics of the device.

Due to time constraints, the current door is designed using the removed fan grate from the front of the blower fan. Due to this not being the original plan for the door, the door frame flexes slightly under the additional weight of the steel fan grate. The door can be redesigned by cutting it from a piece of aluminum sheet to resolve this issue. Another option is to increase the thickness of the aluminum door frame ring.

On the software side, the leaderboards only update after each windmill test. If multiple devices are being used and one of them is not used for a certain period, the displayed leaderboards on that device will be out of date. This does not affect the integrity of the competition data and is only a cosmetic issue, but it may be confusing to competition participants looking at different device leaderboards until the device is used again to refresh the leaderboards. To remedy this, a polling procedure to poll the Google Drive database could be used to update the device leaderboards more frequently. However, the overhead needed to interface with the Google Drive will need to be considered.

Additionally, further testing is recommended regarding the repeated use of the competition system in order to check for software bugs that were not detected in the testing thus far. Since blower fan safety switch is a software interrupt for the Raspberry Pi, instead of being a direct connection to the fan's power supply, any software bug that causes the Raspberry Pi's execution to stall has the potential to leave the blower fan running after the access door is opened. During the testing conducted, this issue did not arise, and the main device power switch can be used as a kill switch in the event something goes wrong.

The final recommendation of the design is to update the way wiring is routed. Currently, a series of clips are epoxied to the bottom of the 3D printed shape holder clip to guide the wires. Replacing theses with a series of wiring conduits attached to the frame of the machine would protect the wiring better and improve the overall device aesthetics.

19. Conclusion

In conclusion, this report outlined the mechanical, electrical, and software design and feasibility of the proposed windmill blade competition system. Project specifications and constraints were used to narrow the design down to a final concept. Revisions were made to the selected concept to incorporate feedback from design reviewers and the sponsor contact. The mechanical, electrical, and software feasibility of the proposed design was showcased through calculations, structural analyses, circuit simulation, and program flowcharts when building the device. The bill of materials showcased the monetary feasibility of the project and reflects the final cost of the constructed device. The risk assessment, acceptance criteria, and testing plans lay out the considerations and criteria used to evaluate the completed design. The current project timeline and ARCI chart were provided to showcase the status of the project and the responsibilities of the project team members.

The device was constructed using the designs laid out during the design phase of the project. Following the construction of the device, testing was performed to ensure the device could meet the specifications and project requirements. Due to COVID-19, not all the tests originally planned were able to be conducted in their original scope. Through this report, the progress of the windmill blade competition system project was shown. The device has been constructed and is capable of being operated at the upcoming Alief ISD competition pending review of the project sponsor.

20. References

[1] ASHRAE. (2018). *ANSI/ASHRAE Standard 41.2-2018*. "Standard Methods for Laboratory Airflow Measurement." 2018, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

[2] IEEE. (2016). *IEEE Standard 802.11-2016*. "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications." Institute of Electrical and Electronics Engineers.

[3] IEEE. (2005). *IEEE Standard 1100-2005*. "Recommended Practice for Powering and Grounding Electronic Equipment." Institute of Electrical and Electronics Engineers.

[4] Budynas, R. G., Nisbett, J. K., & Shigley, J. E. (2011). *Shigley's Mechanical Engineering Design*. New York: McGraw-Hill.

[5] Raspberry Pi 3 Model B. (2016). Raspberry Pi Foundation. Retrieved from the Web 12/1/19, https://www.raspberrypi.org/products/raspberry-pi-3-model-b/

[6] INA219 Zerø-Drift, Bidirectional Current/Power Monitor With I^2C Interface. (2015). Texas Instruments. Retrieved from the Web 12/1/19, http://www.ti.com/lit/ds/symlink/ina219.pdf

[7] Cheng, D. K. (1989), "Field and Wave Electromagnetics." Addison-Wesley, P. 211, 308-310.

[8] DS3502 High-Voltage, NV, I2C POT. (2009). Maxim Integrated. Retrieved from the Web 12/1/2019, https://datasheets.maximintegrated.com/en/ds/DS3502.pdf

[9] 1N5818 Low drop power Schottky rectifier. (2011). STMicroelectronics. Retrieved from the Web 12/1/2019, https://www.st.com/resource/en/datasheet/1n5818.pdf

[10] Alief ISD Wind Turbine Blade Challenge Guidelines. (2018). Alief ISD/UT Tyler. Retrieved from the Web 9/12/19, https://www.google.com/url?client=internal-element-cse&cx=010606971384215444548:6qxeburxuvc&q=https://www.aliefisd.net/cms/lib/TX01917308/Centricity/Domain/148/091818%2520WIND%2520TURBINE%2520BLADE%2520CHALLENGE%2520directions.docx&sa=U&ved=2ahUKEwj3iNqv5qTmAhUHC6wKHTHaCDMQFjAAegQIABAC&usg=AOvVaw1Xmn_AdH5FOG4cuN9_Wrmx

[11] DRV8825 Stepper Motor Driver Carrier, High Current Retrieved from the Web 11/17/19, https://www.pololu.com/product/2133/specs

21. Appendix A: Previous Competition Guidelines

This appendix contains the rules and guidelines from the previous Alief ISD windmill blade design competition that the proposed testing apparatus will be used in [10].

WIND TURBINE BLADE CHALLENGE
ALIEF ISD / UT TYLER – HOUSTON TX

WHAT IS THE WIND TURBINE BLADE CHALLENGE?
The Wind Turbine Blade Challenge is a team effort of teachers, students, engineers, and volunteers, all working to make wind energy education and other renewable energy education accessible in classrooms around the world. The Wind Turbine Blade Challenge is executed across campuses at the ALIEF Independent School district. Our goal is to engage minds in exciting and challenging hands-on activities that teach basic science and engineering principles.

THE MAIN GOALS:
To get students excited about the promise and opportunities of renewable energy—specifically wind power—and its relationship to global climate change.
• To foster opportunities for students to build, test, explore, and understand wind energy technology at a manageable scale.
• To get students—particularly girls and underrepresented populations—excited about careers in STEM fields related to renewable energy.
• To build the capacity of teachers, coaches, and other educators to better understand wind energy technology and development, as well as its promise and limitations.
• To connect students to mentors and role models in the renewable energy industry.

WHO CAN PARTICIPATE?
Any Alief students excited about renewable energy's future
• Elementary Students.
• Middle School students.
• Intermediate School students
• High School students.

Any group of students in grades 4–12 is eligible to enter a team in any of the Wind Turbine Blade Challenge. Teams can have 3 – 5 members.

GENERAL RULES:
• There are three competition divisions: Elementary – Middle/Intermediate - High School
• Each team that registers must have its own turbine. You will not be allowed to modify another team's turbine and use it for testing. You cannot have one turbine shared between teams and simply change blades or other parts for each team.
• Your team's turbine blade must be able to fit inside the wind tunnel and must be able to operate within its 24" × 24" internal dimensions. It is highly recommended that you design your turbine to fit within these dimensions with plenty of room.

• There are no budgetary restrictions for your turbine design, but it is important to keep in mind that part of the judging process is the economical use of resources. Please use materials responsibly.

DESIGN AND MANUFACTURING RULES:
• You cannot use pre-manufactured wind turbine blades or airfoils/sheets.
• Your wind turbine blade will be tested in a tower/ test stand that will be provided.
• Metal, Plexiglas, and other dangerous blade materials are highly discouraged. Please be aware that turbines will be disqualified if they are deemed unsafe by the judges.
• 3D printed parts and components are allowed. While you do not have to use files you created yourself, you should bring documentation about the CAD files to the Challenge and be prepared to discuss the design and the 3D printing process. Judges will want to make sure you understand this technology if you decide to use it.
• In case of need on 3D Printed parts UT Tyler will provide full support.
• The turbine Blade can also be built with fabric, and resin (Provided in the Kit)
• Your turbine blade can either be built on a vertical or horizontal axis.

MATERIALS PROVIDED:
If you're registering a team for the Wind Turbine Blade Challenge, Alief will offers a number of materials to help you get started on your Wind Turbine Blade Challenge.
This initial kit will include:
#16 cork (2)
Skewers (8)
Transparency Sheet (4)
Toothpicks (100)
Spiral notebook
White glue
Scotch Tape
Push pin (20)
Directions

COMPETITION DAY:
To be eligible for the competition, all members of your team must be present on the competition day. Oct 19, 2018.

Exceptions include:
• Some of your team members are unable to attend because of a scheduling conflict with a school sanctioned trip. (A signed note from the teacher is required.)
• A team member cannot attend due to illness or family crisis. (A signed note from the teacher is required.)

COMPETITION WRITTEN DESIGN DOCUMENTATION:
Students must produce some type of documentation that reflects their design process and their knowledge of wind energy science. It is up to each team to determine how they want to document this part of their project.

We will consider the following:

- Short reports
- Engineer's notebook
- Video (four minutes maximum)
- PowerPoint
- Science fair poster board

Students must provide the means to play a video or run a slide show. We will not provide a computer or other device. Videos must be four (4) minutes or less.

22. Appendix B: Windmill Competition System Poster

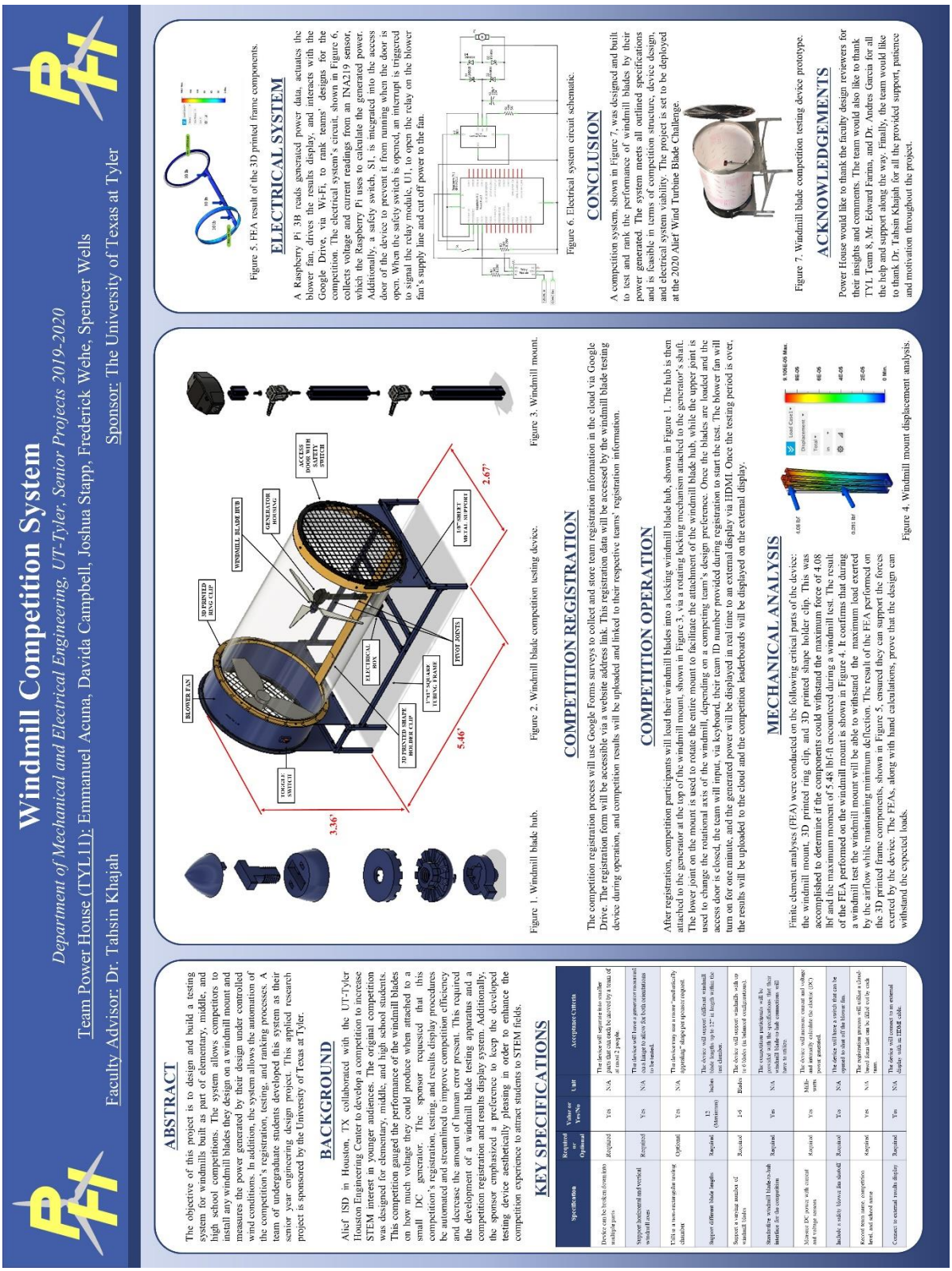


Figure B.1. Windmill Competition System project poster.

23. Appendix C: New Competition Guidelines

WIND TURBINE BLADE CHALLENGE
ALIEF ISD / UT TYLER – HOUSTON TX

WHAT IS THE WIND TURBINE BLADE CHALLENGE?

The Wind Turbine Blade Challenge is a team effort of teachers, students, engineers, and volunteers, all working to make wind energy education and other renewable energy education accessible in classrooms around the world. The Wind Turbine Blade Challenge is executed across campuses at the ALIEF Independent School district. Our goal is to engage minds in exciting and challenging hands-on activities that teach basic science and engineering principles.

THE MAIN GOALS:

To get students excited about the promise and opportunities of renewable energy—specifically wind power—and its relationship to global climate change.
• To foster opportunities for students to build, test, explore, and understand wind energy technology at a manageable scale.
• To get students—particularly girls and underrepresented populations—excited about careers in STEM fields related to renewable energy.
• To build the capacity of teachers, coaches, and other educators to better understand wind energy technology and development, as well as its promise and limitations.
• To connect students to mentors and role models in the renewable energy industry.

WHO CAN PARTICIPATE?

Any Alief students excited about the renewable energy future

• Elementary Students.
• Middle School students.
• Intermediate School students.
• High School students.

Any group of students in grades **4–12** is eligible to enter a team in any of the Wind Turbine Blade Challenge. Teams can have 3 - 5 members

GENERAL RULES:

• There are three competition divisions: Elementary – Middle/Intermediate - High School
• Each team that registers must have its own turbine. You will not be allowed to modify another team's turbine and use it for testing. You cannot have one turbine shared between teams and simply change blades or other parts for each team.
• Your team's turbine blade may have the maximum length of 12" to ensure that the blades fit within the 30" diameter.
• There are no budgetary restrictions for your turbine design, but it is important to keep in mind that part of the judging process is the economical use of resources. Please use materials responsibly.

REGISTRATION PROCESS:

Teams need an email account per team in order to register

- Enter the following information into the computer
    - Email address
    - School name
    - Level of education
    - Team name
- The team is given a 5-digit ID number, this number needs to be written down. This number is needed to run your test.

DESIGN AND MANUFACTURING RULES:

• You cannot use pre-manufactured wind turbine blades or airfoils/sheets.
• Your wind turbine blade will be tested in a stand that will be provided.
• Metal, plexiglass, and other dangerous blade materials are highly discouraged. Please be aware that turbines will be disqualified if they are deemed unsafe by the judges.
• 3D printed parts and components are allowed. While you do not have to use files you created yourself, you should bring documentation about the CAD files to the Challenge and be prepared to discuss the design and the 3D printing process. Judges will want to make sure you understand this technology if you decide to use it.
• In case of need on 3D Printed parts UT Tyler will provide full support.
• The turbine Blade can also be built with fabric, and resin (Provided in the Kit)
• Your turbine blade can either be built on a vertical or horizontal axis.
• The max amount of wind blades per team is 6.

MATERIAL PROVIDED :

If you are registering a team for the Wind Turbine Blade Challenge, Alief will offer a number of materials to help you get started on your Wind Turbine Blade Challenge.

This initial kit will include:

#16 cork (2)
Skewers (8)
Transparency Sheet (4)
Toothpicks (100)
Spiral notebook
White glue
Scotch Tape
Push pins (20)
Directions

COMPETITION DAY:

To be eligible for the competition, all members of your team must be present on the competition day.

COMPETITION DATE

Exceptions include:
• Some of your team members are unable to attend because of a scheduling conflict with a school sanctioned trip. (A signed note from the teacher is required.)
• A team member cannot attend due to illness or family crisis. (A signed note from the teacher is required.)

COMPETITION WRITTEN DESIGN DOCUMENTATION:

Students must produce some type of documentation that reflects their design process and their knowledge of wind energy science. It is up to each team to determine how they want to document this part of their project.

We will consider the following:
• Short reports
• Engineer's notebook
• Video (four minutes maximum)
• PowerPoint
• Science fair poster board

Students must provide the means to play a video or run a slide show. We will not provide a computer or other device. Videos must be four (4) minutes or less.

24. Appendix D: Windmill Testing Device Assembly Manual

WINDMILL TESTING DEVICE ASSEMBLY MANUAL

Windmill Blade Competition System
Team Power House (TYL11)

Department of Electrical and Mechanical Engineering
The University of Texas at Tyler
MENG 4215 Senior Design Project

Authored by Team Power House members:
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Sponsor: The University of Texas at Tyler

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Bill of Materials

The materials you need to complete this design are listed below.

Table 1. Mechanical component bill of materials for the windmill blade competition system.

Part No.	Item	Quantity	Cost	Source
1	Clear Polycarbonate Sheet	1	$95.26	Home Depot
2	Access Door Hinge	1	$3.28	Home Depot
3	Aluminum Square Tubing	4	$104.90	Lowe’s
4	Ring Clip	1	$20.00	3D Print
5	Locking Pivot Joints	2	$41.00	McMaster-Carr
6	47065T116 Windmill Stand	1	$7.79	McMaster-Carr
7	General Screws - 1/4" 20 Thread Phillips Round Head Screws (10 CT)	1	$7.75	McMaster-Carr
8	Hillman 200-Piece Steel Zinc-Plated Combo Fastener Kit - Hardware for Hinge(½”), Door(½”), and Plastic Ring (1”)	1	$4.78	Lowe’s
9	Everbilt Washer Pack - 1/4 in. x 1-1/4 in. Zinc-Plated Steel Fender Washer	4	$1.18	Home Depot
10	6061 Aluminum Angle - 2" Leg Length, 1/4" Wall Thk., 24" Length	1	$18.87	Amazon
11	Angle 6061-T6 Extruded Aluminum - 1" Leg Length, 1/8" Wall Thk., 5" Length	1	$1.55	Speedy Metal
12	3/8" 16 Thread 94895A031 Zinc Yellow-Chromate Plated Steel Hex Nut (100 CT)	1	$8.64	McMaster-Carr
13	1/8" 10-24 Thread Hollow-Lock Set Screw Black-Oxide Alloy Steel	1	$9.06	McMaster-Carr

Table 1. Continued.

Part No.	Item	Quantity	Cost	Source
14	3/8" 16 Thread 91257A630 High-Strength Grade 8 Steel Cap Screw (25 CT)	1	$8.14	McMaster-Carr
15	1/4" 20 Thread 91251A543 Black-Oxide Alloy Steel Socket Head Cap Screw (10 CT)	1	$6.59	McMaster-Carr
16	1/4" 20 Thread 91772A553 Pan Head Phillips Machine Screw (10 CT)	1	$5.24	McMaster-Carr
17	36" x 36" Aluminum Sheet, 1/8" thickness	1	$21.98	Home Depot
18	36" x 36" Aluminum Sheet, 1/24" thickness	1	$144	The Metal Store
19	Manufactured Aluminum Ring	1	$40.00	D&G Precision Fabrication
20	Fan Base Welds	1	$30.00	Lew’s Welding Service
21	Windmill Blade Hub (3 CT)	1	$5.00	3D Print
22	Door Hardware Mount	1	$0.75	3D Print
23	Windmill Mount Angle Stops	2	$0.25	3D Print
24	Generator Adapter	1	$0.25	3D Print
25	Vibration Pads	8	$4.00	3D Print

Table 2. Blower fan modification parts list.

Part No.	Item	Quantity	Cost	Source
BF1	MaxxAir PRO 30" Drum Fan	1	$209.97	Home Depot
BF2	Zip Ties (100 CT)	6	$7.99	Amazon
BF3	⅝" ID - ⅞" OD Rubber Grommet (10 CT)	1	$6.26	Amazon
BF4	⅛" Steel Washers (40 CT)	2	$2.28	Amazon
BF5	#4 Nylon Insert Lock Nuts (100 CT)	2	$7.89	Amazon
BF6	½" #4 Stainless Steel Screws (100 CT)	2	$6.74	Amazon
BF7	CanaKit 5 V - 2 .5 A Raspberry Pi 3 Power Supply	1	$9.95	Amazon
BF8	CHENBO 5V Relay Module (4 CT)	1	$8.99	Amazon
BF9	120 VAC Rocker Switches (5 CT)	1	$5.49	Amazon
BF10	18 AWG 600 V Stranded Wires (25')	1	$14.98	Amazon
BF11	22-14 AWG (Orange)Wire Nuts (100 CT)	2	$6.32	Amazon
BF12	Male-Female Spade Terminal Connectors (100 CT)	1 Male 6 Female	$9.99	Amazon
BF13	Relay Base Plate	1	$1.00	3D Print
BF14	Relay Housing	1	$1.00	3D Print
BF15	Pi Supply Prong Insulator	1	$0.50	3D Print

Table 3. Electrical component parts list.

Part No.	Item	Quantity	Cost	Source
EC1	Raspberry Pi 3B	1	$38.36	Amazon
EC2	CZH-LABS PCB Shield Board Kit (4 CT)	1	$14.99	Amazon
EC3	SanDisk 16 GB MicroSD Memory Card	1	$5.99	Amazon
EC4	HiLetgo INA219 DC Power Monitoring Sensor	1	$7.89	Amazon
EC5	1N5818 Schottky Diode	4	$1.64	Mouser
EC6	1 kΩ - ¼ W - 5% Resistor	2	$0.20	Mouser
EC7	47 Ω - 5 W - 5% Resistor	1	$0.80	Mouser
EC8	100 µF - 25 V Electrolytic Capacitors (10 CT)	1	$5.99	Amazon
EC9	0.1 µF - 50 V Ceramic Capacitors	3	$0.17	Mouser
EC10	125 VAC - 6 A Push Button Switches (10 CT)	1	$7.99	Amazon
EC11	Greartisan 12V DC - 600 RPM Motor	1	$13.99	Amazon
EC12	Assorted 20 AWG wires	1	$17.88	Amazon
EC13	QLOUNI JST SM Terminal Connector Kit	1	$12.99	Amazon
EC14	HDMI Cable	1	$6.99	Amazon
EC15	USB Touchpad Keyboard	1	$20.99	Amazon
EC16	DC Electrical Box	1	$2.00	3D printed

Table 3. Continued.

Part No.	Item	Quantity	Cost	Source
EC17	DC Electrical Box Lid	1	$1.00	3D printed
EC18	Safety Switch Housing	1	$0.50	3D printed
EC19	Wire Guide Clips	7	$0.50	3D Printed

Tool List

The tools need to manufacture this device are listed below.

- Saw
- Metal File
- Grinder
- Plasma Cutter (optional)
- Drill
- Threading Tap (¼-inch diameter 2-inch long)
- Flat Head Screwdriver
- Phillips Head Screwdriver
- Sockets: 9/16-inch, 3/8-inch, 5/16-inch
- 3D Printer (capacity to print 6" x 6" x 13") Suggested 3D Printer: Raise3D Pro2 Plus
- Tape measure
- 18-20 Gauge Wire Strippers
- Dupont Crimping Tool
- Trigger Clamps (optional)
- JB Weld
- Marker
- Drill Press (optional)
- Soldering Iron (Up to 750 degrees Fahrenheit)
- Lead-Free Solder

Approximate 3D Printing Time: **120 Hours**
Approximate Preparation Time: **6 hours**
Approximate Assembly Time: **240 minutes (4 hours)**

3D Printed Parts

Creating the custom 3D parts is the first step and possibly the longest step of creating this device. This is because of having access to only one 3D Printer to print all the parts. Printing the 3D parts will take approximately 110 hours with one 3D printer. It is suggested to use as many 3D printers as possible or a very large 3D printer to drastically decrease manufacturing time.

1. 3D print the Windmill Blade Hub. There should be 6 parts and should take about 11 hours to print.
2. Construct the Windmill Blade Hub by connecting all the printed parts together. Apply JB weld to the inside of the top of the cone and press it together. Following this, set the Hollow-Lock Set Screw in the hole on the side of the motor connect to allow it to lock onto the motor shaft.



Figure 1. Exploded View of Windmill Blade Hub.

3. 3D print the Generator Housing for the motor. There should be 2 parts and should take about 3 hours to print.
4. Construct the Generator housing, by connecting the printed parts together. The motor will be inserted into the housing at a later step.

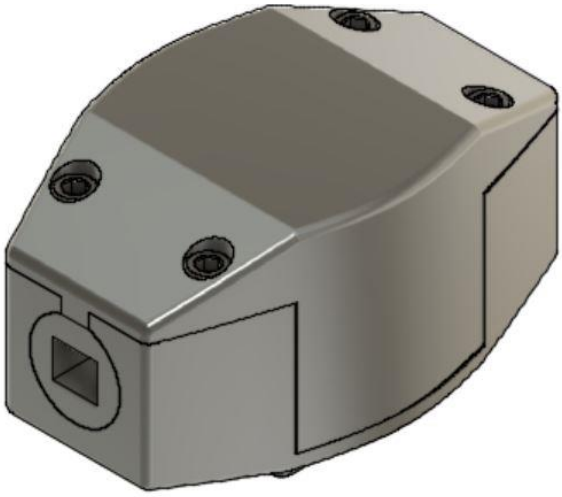


Figure 2. Assembled Generator Housing.

5. 3D print the Electrical Compartment. There should be 2 parts and should take about 2 hours to print.

6. 3D print the parts to make the testing chamber ring. There should be 18 parts and should take about 34 hours to print.
7. Construct the testing chamber ring, by connecting the 3D printed parts together. Apply JB weld to the joints in between each connecting piece. JB weld is optional but suggested if the device is going to be disassembled frequently. Refer to Figure 3 for reference.



Figure 3. Assembled testing chamber ring.

8. 3D print the tunnel base. There should be 4 parts and should take about 58 hours to print.

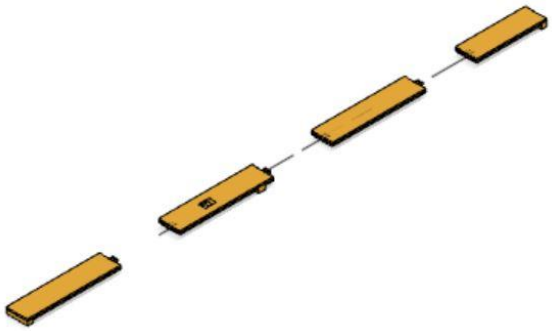


Figure 4. Exploded view of tunnel base.

9. Construct the 3D printed tunnel base. Apply JB weld to the joints in between each section. Refer to Figure 4.
10. Once the tunnel base is properly welded and has dried, flip it over and JB weld 5 wire guides on. Three will be on the long side of the square hole, and two on the other. On the short side, place one wire guide close to the square whole and one at the opposite end. On the long side, place one close to the square hole, one at the opposite end and one in the middle of the two previous wire guides.
11. 3D print 8 vibration pads, preferably out of TPU filament.

12. 3D print the relay baseplate and housing.
13. 3D print the prong insulator.
14. 3D print two windmill mount angle stops.
15. 3D print one door hardware mount.

Manufacturing Frame Components

This section contains information regarding the manufacturing steps to cut and drill the necessary frame and stand components of the windmill testing device, shown in Figure 5 and tabulated in Table 4. This section contains two parts Part I and Part II. Part I contains the cutting portion and Part II contains the drilling portion of manufacturing. Note the Metal Ring Component was manufactured by a local metal shop, details on dimensions and pricing will be provided below.

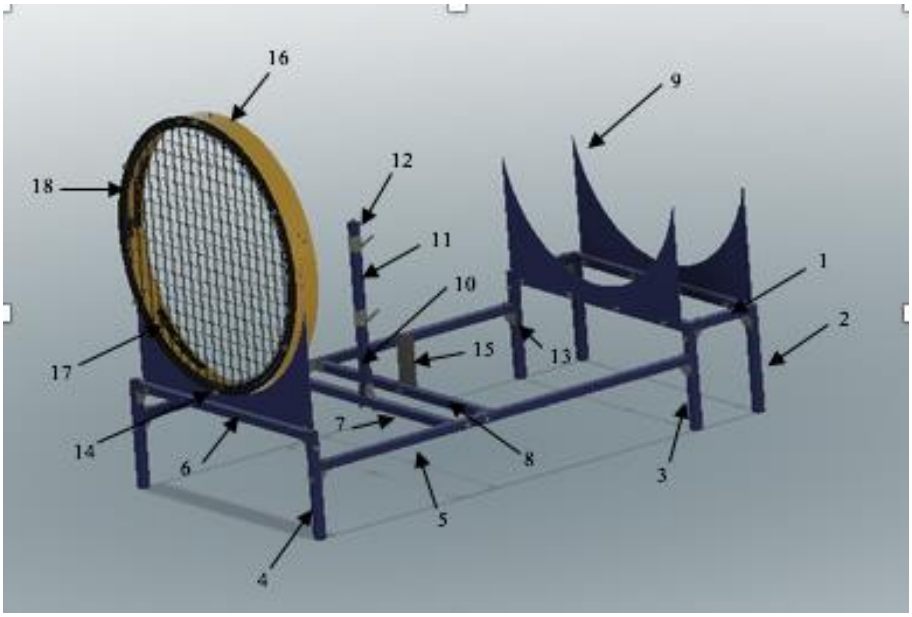


Figure 5. Frame Components Callout.

Table 4. Frame components.

Component	Quantity	Part Name
1	1	Welded Frame Base
2	2	Back Fan Leg
3	2	Front Fan Leg
4	2	Door Stand Leg
5	2	Horizontal Supports
6	1	Door Stand Support

Table 4. Continued.

Component	Quantity	Part Name
7	1	Crossmember-1
8	1	Crossmember-2
9	3	Blower Fan and Door Saddles
10	1	8-inch slotted section
11	1	6.5-inch slotted section
12	1	1.5-inch slotted section
13	16	2-inch angle brackets
14	4	1-inch angle brackets
15	1	3D Clip support
16	1	Door
17	5	Washers
18	1	Aluminum Ring

PART I: Cutting

Component 1
*This component requires welding

- Cut 2- 9.5-inch sections of aluminum square tubing
- Cut 2-32-inch sections of aluminum square tubing
- Make a 45 Degree cut at each end of the square tubing sections as shown in the Figures 6 and 7.

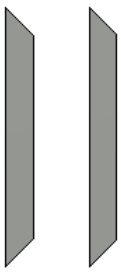


Figure 6. Short sections of tubing.



Figure 7. Long sections of tubing.

- Set the sections of aluminum square tubing as shown in Figure 8.



Figure 8. Welded blower fan base frame.

- Weld all four corners of the aluminum tubing sections to form the welded blower fan base frame.

Components 2, 3, and 4

- Cut four 11-inch sections of the aluminum square tubing to create 4 legs for the blower fan base frame. These sections will be used as components 2 and 3
- Cut two 12-inch sections of the aluminum square tubing to create 2 legs for the door stand base. These sections will be used as component 4

Component 5

- Cut two 50.5-inch sections of the aluminum square tubing to create the horizontal members of the frame.

Components 6, 7, and 8

- Cut three 30-inch sections of aluminum square tubing to create the cross members and door stand supports.

Component 9

- Cut 3 saddle supports using the dimensions provided in Figure 9. Recommended material is 0.125-inch-thick flat sheet of aluminum.

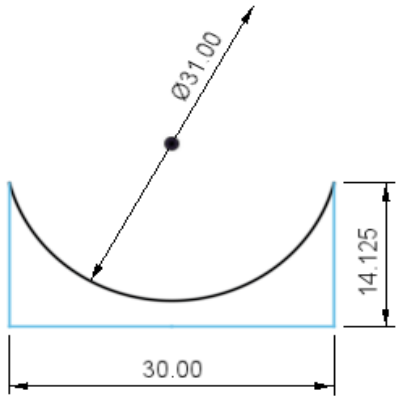


Figure 9. Perpendicular blower fan base component.

Components 10, 11, and 12

- Cut one 8-inch section of the T-slotted framing for the section of the windmill mount stand between the base frame and lower joint.

- Cut one 6-inch section of the T-slotted framing for the section of the windmill mount stand between the lower joint and the upper joint.

- Cut one 1-inch section of the T-slotted framing for the section of the windmill mount stand between the upper joint and generator housing.

Components 13,14

- Cut sixteen 1" in width sections of the 2" aluminum angle metal to create the L braces for the frame.
- Cut four 1' in width sections of the 1-inch aluminum angle metal to create the L braces for the door frame. Another option is to create 4 more 1' wide L braces from the 2" aluminum angle and trim them to one inch on each side of the angle.

Component 15

- Cut a 5-gage aluminum metal flat sheet into a 3-inch by 6.5-inch rectangular piece. Refer to the Figure 10.

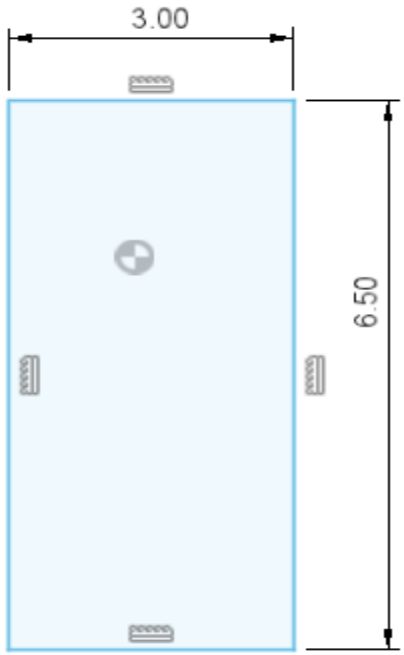


Figure 10. 3D clip support.

Component 16

- Cut a circular pattern on a 1/8-inch piece of flat aluminum using the dimensions provided in the figure. This piece will be used to make the door assembly.

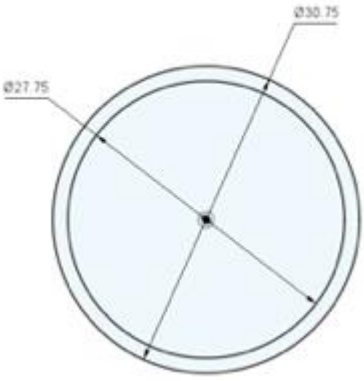


Figure 11. Circular pattern cut with dimensions.

Component 17

- Cut-5 rectangular two gage aluminum pieces. These pieces will hold up the polycarbonate sheet when assembling the tube. Refer to the Figure 11.



Figure 11. Rectangular two gage aluminum cut dimensions.

Component 18

- The metal ring in the device was outsourced from a local company. Refer to the figure to see the dimension used. The total cost of the ring was $40 which includes the material and labor cost.

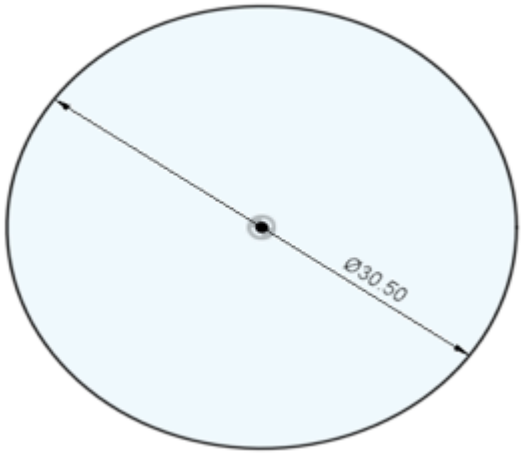


Figure 12. Metal ring with dimensions.

- Cut 4-½” along the width of the polycarbonate sheet. When complete, the modified polycarbonate sheet will be approximately 91-½" x 48".

PART II: Drilling Holes

Component 1

- Drill eight ⅜" diameters holes on the front and back face of the fan base. Drill four ⅜" diameter holes on the top face of the Fan base. Refer to the Figure 13.

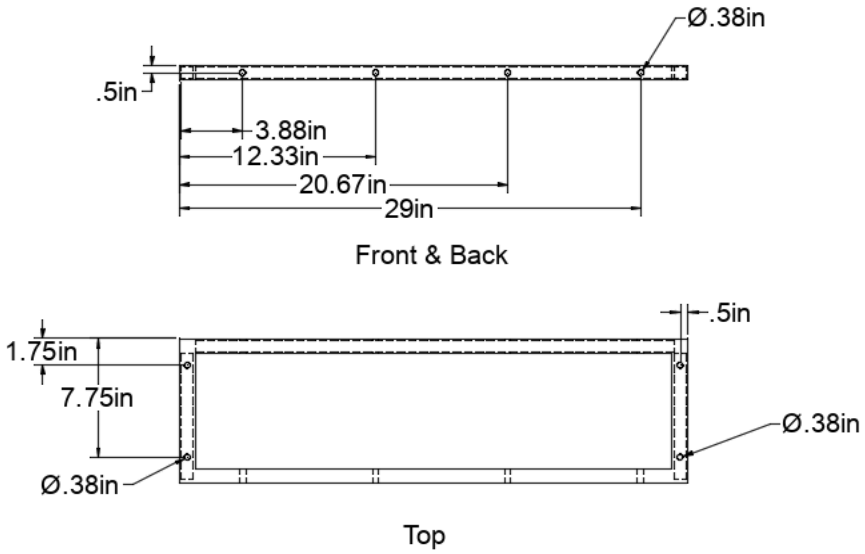


Figure 13. Fan base stand.

Component 2

- Drill a single ⅜-inch diameter hole for two sections of the 11” frame legs. Refer to the figure.

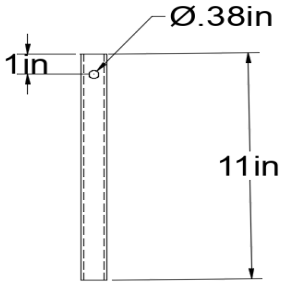


Figure 14. Drilled back legs.

Component 3

- Drill two ⅜" diameter holes for the remaining two sections of the 11" frame legs. Refer to Figure 15.

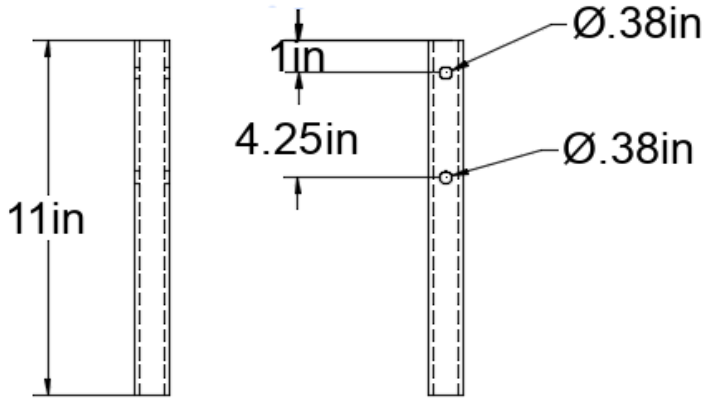


Figure 15. Drilled front legs.

Component 4

- Drill 2-⅜" diameters holes for the two 12" frame leg sections. Refer to Figure 16.

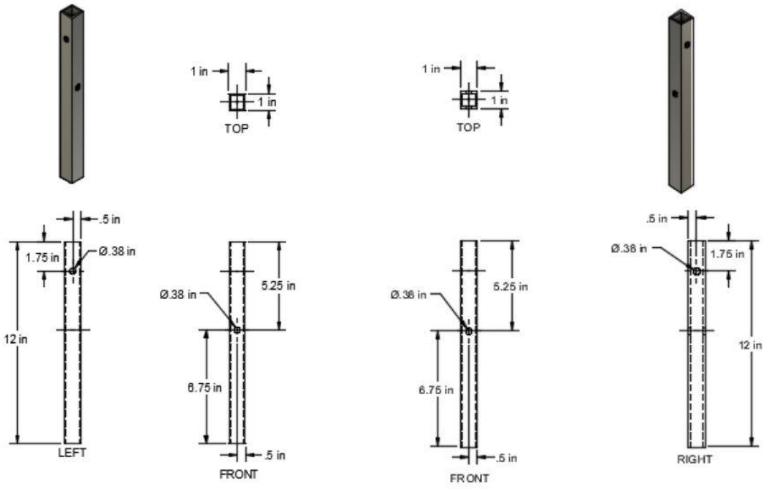


Figure 16. Drilled door stand legs.

Component 5

- Drill four ⅜" holes in the two Horizontal Frame sections. Refer to the Figure 17.

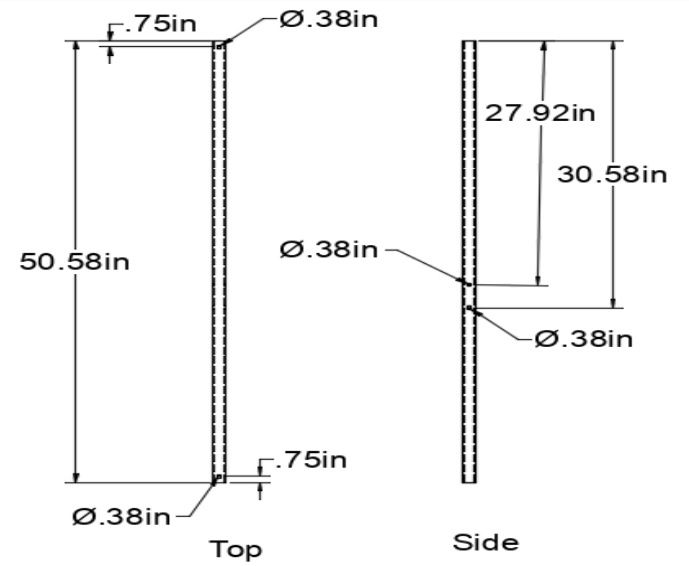


Figure 17. Drilled horizontal frame sections.

Component 6

- Drill six ⅜" diameter holes into the door stand frame section. Refer to the Figure 18.

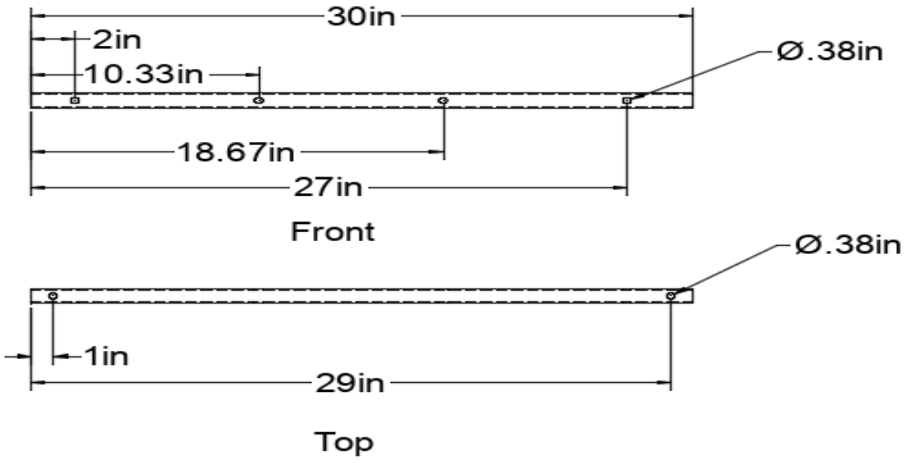


Figure 18. Drilled door stand frame section.

Component 7

- Drill four ⅜" diameter holes into the stand support crossmember section. Refer to the Figure 19.

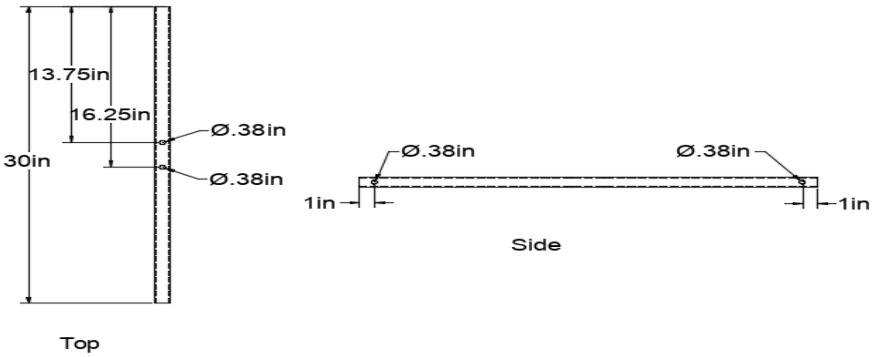


Figure 19. Drilled stand support crossmember.

Component 8

- Drill four ⅜-inch diameter holes into the tunnel support crossmember section. Refer to the Figure 20.

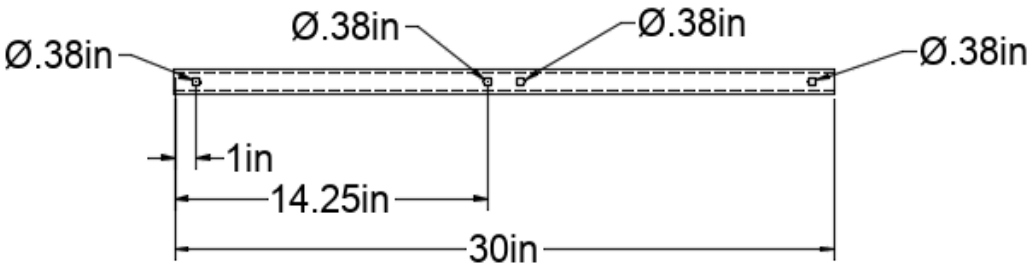


Figure 20. Drilled tunnel support crossmember.

Component 9

- Drill four ⅜" diameter holes approximately 0.5" from the bottom of the saddle. Drill four ¼" diameter holes at the top curved part of the saddle. This will be done for one of the three saddles. Refer to Figure 21.

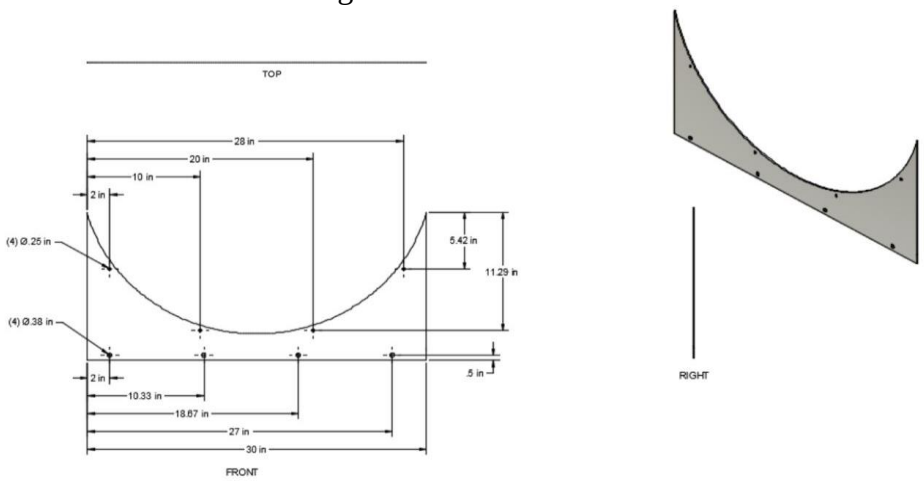


Figure 21. Drilled door frame saddle.

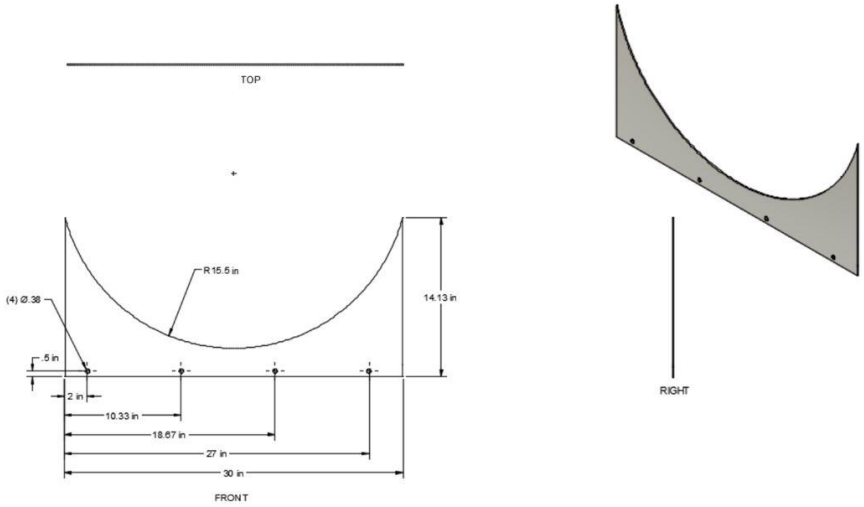


Figure 22. Drilled fan frame saddle.

Component 10

- Drill a 3/8-inch diameter hole into the 8-inch stand support section. Also, this section requires a ¼-inch diameter 2-inch long tap on the top side of the section. Refer to Figure 23.

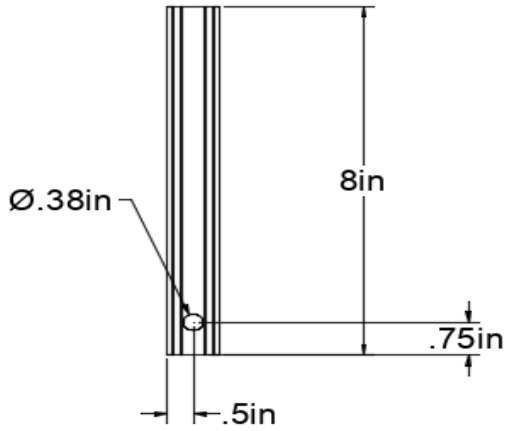


Figure 23. Drilled stand base support.

Component 11

- This section requires a ¼-inch diameter 2-inch long tap on the top and bottom side of the section.

Component 12

- This section requires a ¼-inch diameter 2-inch long tap on the top and bottom side of the section.

Component 13

- Drill two 3/8-inch diameter holes in the center of each L bracket at the 1-inch mark. Refer to Figure 24 (similar).

Component 14

- Drill two 3/8-inch diameter holes in the center of each L bracket at the ½-inch mark. Refer to the Figure 24.

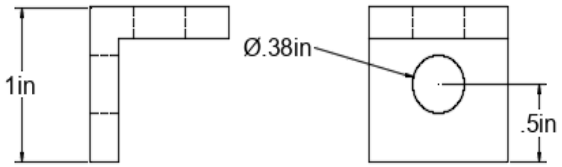


Figure 24. 1" L Bracket.

Component 15

- Drill two 3/8-inch holes in the component. Refer to Figure 25.

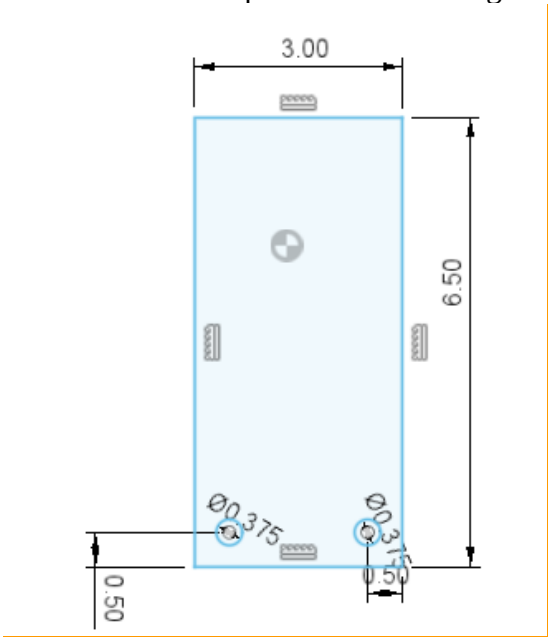


Figure 25. Component 15 drill pattern.

Component 16

- Drill six ¼-inch holes into the component. You must follow the hole pattern that the grate has. The holes are approximately 60 degrees apart. Refer to Figure 26.

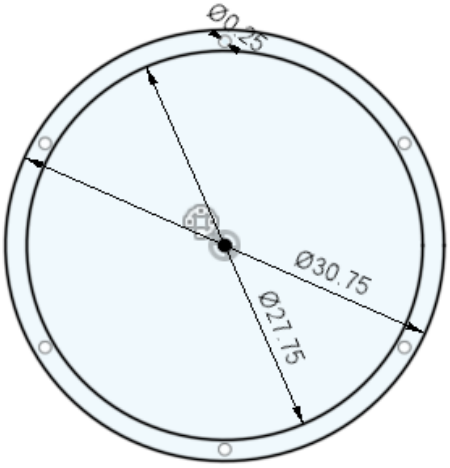


Figure 26 Component 16 drill pattern.

Component 17

- Drill a 1/4 -inch single hole in each component. Refer to Figure 27.

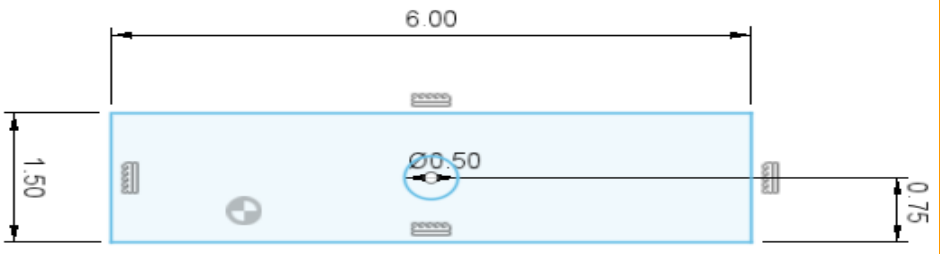


Figure 27. Component 17 drill pattern.

Component 18

- Drill four ⅜" diameter holes 0.312" away from the front edge of the ring at the bottom section of the metal ring. Refer to Figures 28 and 29.

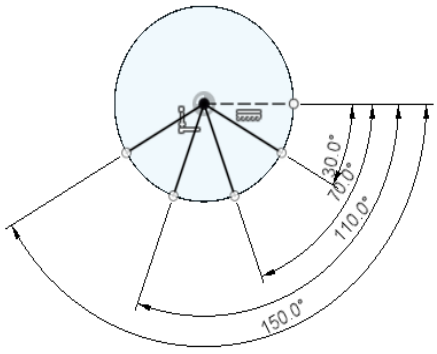


Figure 28. Angle at which ⅜" holes are drilled.

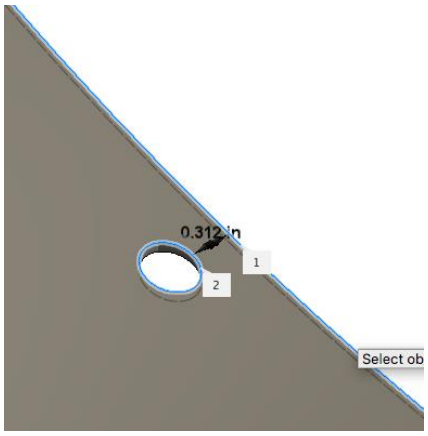


Figure 29. Distance from front face.

- Drill five ¼" diameter holes, 1-½" away front the front edge of the ring. Refer to Figures 30 and 31.

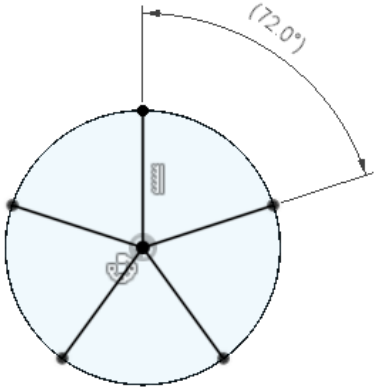


Figure 30. Angles at which ¼" holes are drilled.

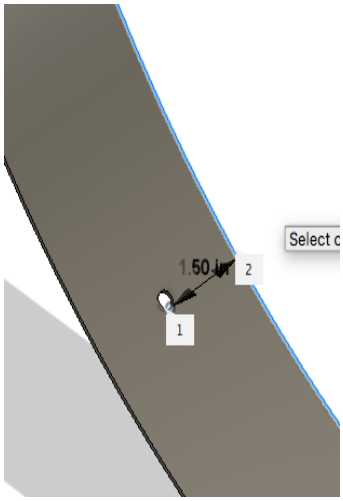


Figure 31. Distance from front face.

- Drill 2 -1/4" holes in the door ring. Attach the hinge temporarily to the door frame in order to make the marks on the door ring for drilling the hinge holes on the door ring. Attach the hinge to the door ring. Refer to Figure 32.

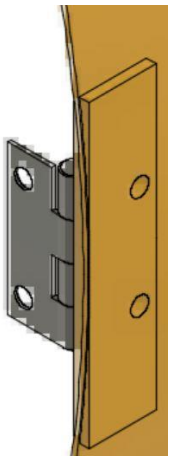


Figure 32. Door hinge mounting.

- Drill 6-1/4" holes in the door ring. Use the removed front grate existing holes to make the marks for drilling.
- Drill 4 -1/4" holes on the door frame opposite of the hinge. Use the door latches as a guide to mark the spacing between the holes. Refer to Figure 33.

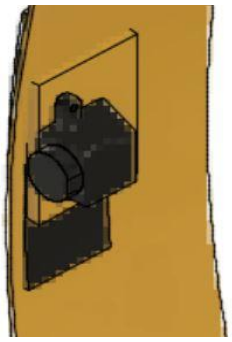


Figure 33. Door frame with clip mounting.

- Drill 4 - ¼" holes on the door ring. Insert the clips into the latches and put the door ring on the hinge. Swing the door shut and mark through the holes in the clips, this will serve as a guide where to drill the holes.

The last location for drilling is outlined in step 21 in the mechanical assembly section. Wait to drill these holes until all the mechanical steps previous are complete in order to ensure the holes drilled in the polycarbonate are aligned with the door frame holes.

Modifying the Blower Fan

Mechanical Changes



Figure 34. MaxxAir PRO 30” drum fan.

1. Remove the two wheels and stand from the MaxxAir PRO drum fan (Part No. BF1).
2. Remove the front grate from the MaxxAir PRO drum fan.
3. Drill 6- ¼" holes in the outer ring of the front side of the fan. Make sure the fan is oriented correctly before drilling the holes. Looking directly at the fan, the handle should be oriented at 180 degrees. For reference, use the 3D printed ring, shown in Figure 35, as a guide to make the marks for the holes.



Figure 35. 3D printed ring with bolt holes.

Modifying the Blower Fan Circuitry

1. 3D print the relay baseplate, relay housing, and prong insulator from the provided STL files.
2. Remove the protective grate from the back of the fan with a 5/16" socket wrench.
3. Unplug the 4 power connectors from the grate, cut the female connector off the neutral (white) wire of the motor, and strip 1/2" of the insulation from the wire.
4. Position the fan where the two metal support beams inside are vertical and the holes for the wheel and stand adapters are oriented at the bottom of the fan.

5. Cut a 0.775" by 0.475" hole for the power switch 2" above the fan's handle and 2" from the ridge around the back of the fan. For hole placement, refer to Figure 36.

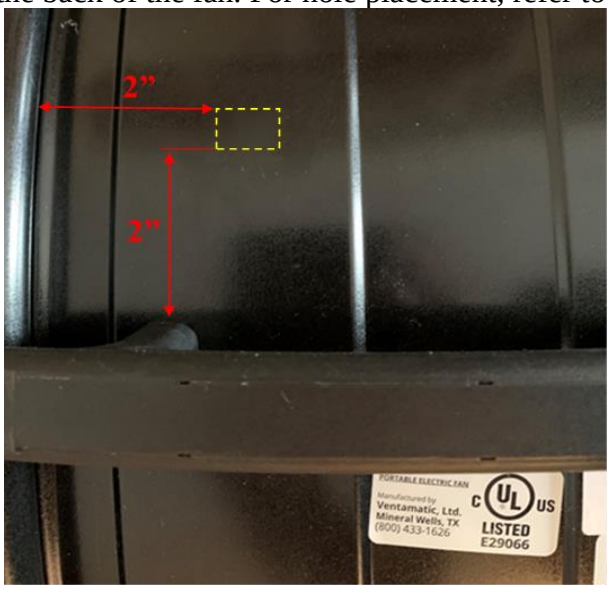


Figure 36. Power switch position diagram.

6. Put the power switch (Part No. BF9) into the hole with the open switch indicator (O) to the right.
7. Looking from the back of the fan, drill a 7/8" hole in the fan casing centered 1.5" away from the bottom of the right vertical support beam.
8. Insert a rubber grommet (Part No. BF3) into the hole drilled in step 7, refer to Figure 37.

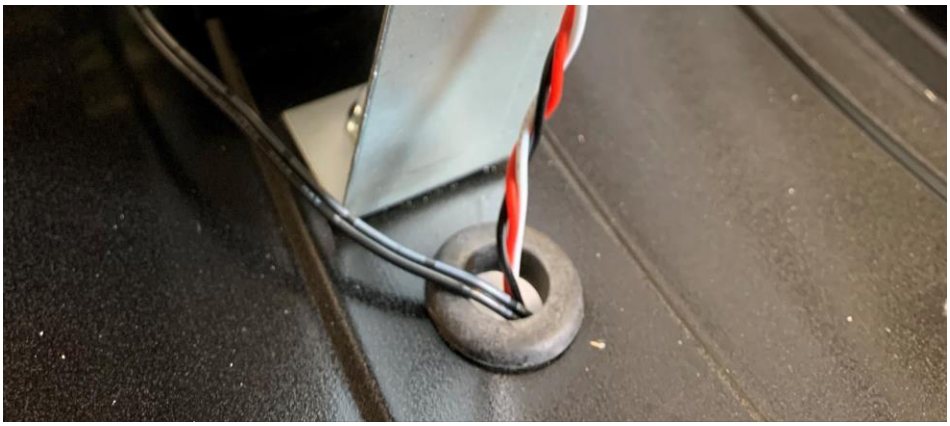


Figure 37. Blower fan wiring hole placement.

9. Looking from the back of the fan, drill a 3/16" hole centered in the middle of the right support beam 5" up from the bottom of the fan.
10. Drill another 3/16" hole 2.6" above the previous hole. Use the printed relay base plate (Part No. BF13), shown in Figure 38, as a hole guide if needed.

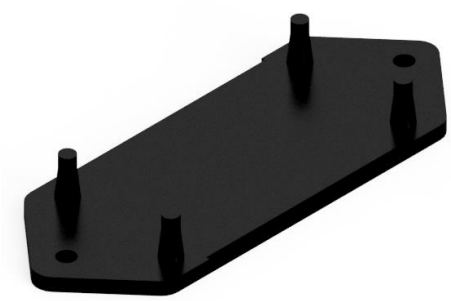


Figure 38. Relay base plate diagram.

11. Insert two 1/8" screws (Part No. BF6) into the relay baseplate, and then insert them into the holes drilled in the support beam from the right side of the beam.
12. Place a 1/8" washer (Part No. BF4) and a 1/8" lock nut (Part No. BF5) onto the back of each screw and tighten them down to secure the relay base plate within the fan.
13. Push the printed prong insulator (Part No. BF15), shown in Figure 39, onto the Raspberry Pi power supply (Part No. BF7) prongs until it sits flush against the Raspberry Pi power supply housing.

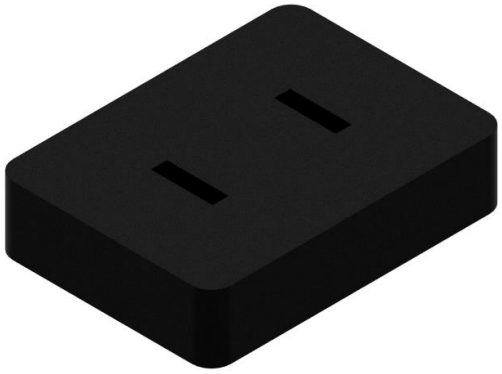


Figure 39. Prong insulator diagram.

14. Looking from the back of the fan, place the Raspberry Pi power supply at the bottom of the fan, between the two vertical support beams, with the prongs facing the back of the fan and its cable going towards the left support beam.
15. Make a mark on each side of the power supply, and drill 1/4" holes in the bottom of the fan housing at the two marked points. For reference, refer to Figure 40.

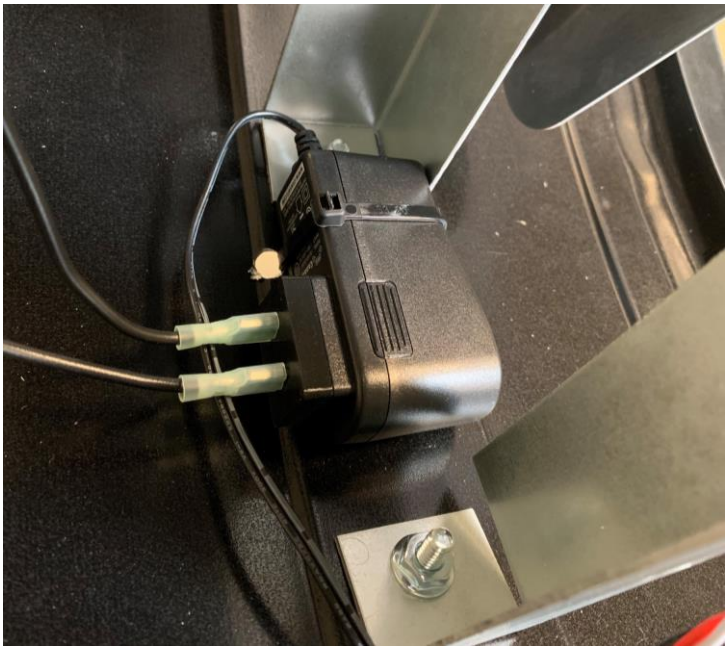


Figure 40. Raspberry Pi power supply placement.

16. Pass a zip tie (Part No. BF2) through the two holes drilled in step 15 and around the Raspberry Pi power supply to attach it to the fan housing.
17. Place the relay module (Part No. BF8) onto the pegs of the relay base plate within the fan.
18. Install the fan circuitry as shown in the wiring diagram in Appendix A. The wires needed will be as follows:

    - A 26.5" 18 AWG stranded black wire (Part No. BF10) with a male spade crimp connector (Part No. BF12) at one end and a female spade crimp connector at the other end. This wire will be mounted between the AC input and power switch.
    - A 26.5" 18 AWG stranded black wire with a female spade crimp connector at one end and 1/2" of bare wire at the other end. This wire will be mounted between the power switch and supply side wire nut (Part No. BF11).
    - A 9" 18 AWG stranded black wire with 1/2" of bare wire on one end and 3/16" of bare wire on the other end. This wire will be mounted between the supply side wire nut and the ON port of the relay module.
    - A 11.5" 18 AWG stranded black wire with 3/16" of bare wire on one end and a female spade crimp connector on the other end. This wire will be mounted between the COM terminal of the relay module and the center terminal of the fan speed switch on the fan grate.
    - A 15" 18 AWG stranded black wire with 1/2" of bare wire on one end and a female spade crimp connector on the other end. This wire will be mounted between the supply side wire nut and the left terminal of the Raspberry Pi power supply (relative to looking into the back of the fan).
    - A 15" 18 AWG stranded white wire with 1/2" of bare wire on one end and a female spade crimp connector on the other end. The wire will be mounted between the

neutral side wire nut and the right terminal of the Raspberry Pi power supply (relative to looking into the back of the fan).

- A 9" 18 AWG stranded white wire with 1/2" of bare wire on one end and a female crimp connector on the other end. This wire will be mounted between the neutral side wire nut and the AC supply neutral (white) wire on the back-fan grate.
- A 24" 20 AWG solid red wire (Part No. EC12) with 3/16" of bare wire on one end and a female JST SM connector pin (Part No. EC13) on the other end. This wire will be mounted between the DC+ terminal of the relay module and the DC+ line of the DC circuit wiring harness.
- A 24" 20 AWG solid black wire with 3/16" of bare wire on one end and a female JST SM connector pin on the other end. This wire will be mounted between the DC- terminal of the relay module and the DC- line of the DC circuit wiring harness.
- A 24" 20 AWG solid white wire with 3/16" of bare wire on one end and a female JST SM connector on the other end. This wire will be mounted between the IN terminal of the relay module and the IN line of the DC circuit wiring harness.
- Note: Twist the three 20 AWG wires together to hold them together and place a three-pin female JST SM connector housing on the ends with all the JST SM connector pins on them, and ensure the connection is secure.

19. Run the Raspberry Pi power supply cable and the three 20 AWG Raspberry Pi relay control lines through the hole with the rubber grommet in it.
20. Put the relay housing (Part No. BF14) onto the relay and its baseplate and tie it down to the vertical support beam with a zip tie, as shown in Figure 41.



Figure 41. Relay housing installation location.

21. With the fan speed switch mounted in the orientation of Figure 42, reconnect the 5 power lines to the back protective fan grate and reattach it to the fan, as shown in Appendix A. One of the power lines from the power switch will be connected to the supply wire coming from the power cable. See the leftmost black wire in Figure 43 for reference. The output wire from the COM terminal of the relay module will be connected to the center terminal of the fan switch. The black wire from the motor will be connected to the terminal of the switch behind the “LOW” text on the switch, and the red wire from the motor will be connected behind the “HI” text on the switch, as shown in Figure 42.



Figure 42. Fan speed switch orientation obverse (left) and reverse (right).

22. Use zip ties to secure loose wiring to the back-fan grate; specifically, for the two wires going to the power switch on the rim of the fan. For the best results, it is recommended that the wiring is tied down to one of the main supports of the fan grate as shown in Figure 43.



Figure 43. Zip tie placement on the fan grate.

Mechanical Assembly

1. Attach the welded blower fan support with the 2 exterior legs with drilled holes using the ⅜" steel cap screws, steel hex nuts, and L braces. Install the steel cap screws so the head of each screw is visible from one side. Refer to Figure 44.



Figure 44. Welded blower fan support with 2 exterior legs.

2. Attach the welded blower fan support with the 2 interior legs with drilled holes using the steel cap screws, steel hex nuts, and L braces to create the welded blower fan base. Install the steel cap screws so the head of each screw is visible from one side and the threaded portion of the screws installed on the exterior legs and interior legs are the closest to one another. Refer to Figure 45.



Figure 45. Welded blower fan base.

3. Attach the blower fan and access door connecting components, the windmill mount support, and the testing chamber support using the steel cap screws, steel hex nuts, and L braces to create the base connecting component. Install the steel cap screws so the head of each screw is visible from one side and the threaded portion of the screws are facing one another. Refer to Figure 46.

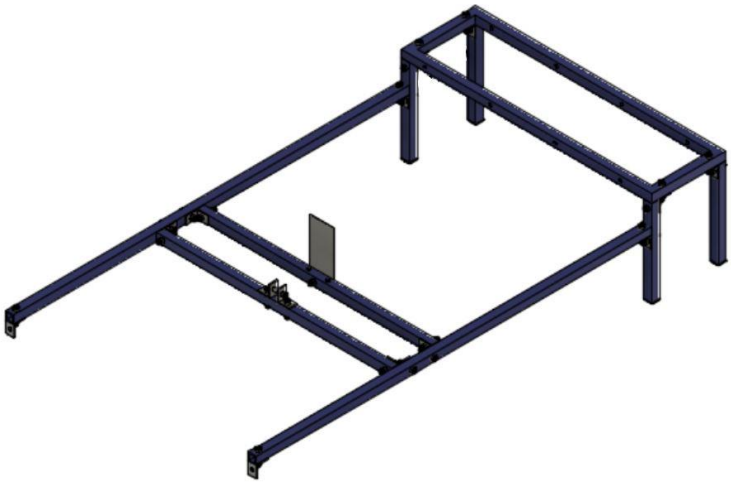


Figure 46. Base connecting component.

4. Attach the access door drilled cross member and the 2 access door legs using the steel cap screws and steel hex nuts to create the access door base. Install the steel cap screws so the head of each screw is visible from one side. Refer to Figure 47.



Figure 47. Access door base.

5. Attach the welded blower fan base, base connecting component, and access door base using the steel cap screws, steel hex nuts, and L braces to create the connected base. Install the steel cap screws so the heads of the screws are visible from each side view and the threaded portion of each screw along with the hex nut is not extruding from the device. Refer to Figure 48.

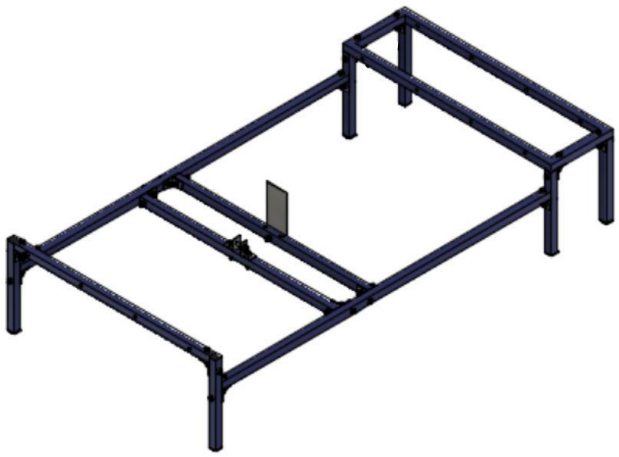


Figure 48. Connected base.

6. Attach the 3 identical saddles and the testing chamber support to the connected base using the steel cap screws, steel hex nuts, and L braces to create the base frame. Two saddles will be attached to the welded blower fan base and one will be attached to the access door base. Install the steel cap screws so the heads of the screws are visible from each side view and the threaded portion of each screw along with the hex nut is not extruding from the device. Refer to Figure 49.

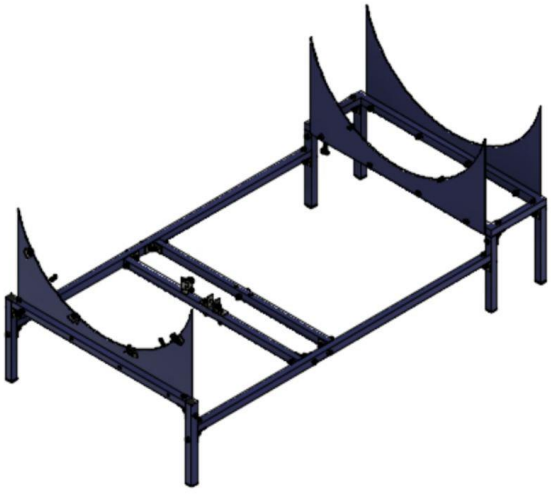


Figure 49. Base frame with saddles attached.

7. Attach the four 1” braces to the Door saddle with the steel capped screw and hex nut. make sure the nut is on the inside of the saddle.

8. Place the aluminum ring on the curve side of the ⅛” metal sheet support. Attach the aluminum ring to the access door base using the steel cap screws and steel hex nuts. Install the steel cap screws downwards through the ring and 1” L brace and secure with a bolt. Refer to Figure 50.



Figure 50. Base frame with aluminum ring.

9. Insert the polycarbonate sheet into the slots on each side of the 3D printed tunnel base.
10. Take the polycarbonate sheet and slide it into the gaps of the 3D printed ring. The 3D printed tunnel base will be connected to the base of the ring. This should create the circular chamber design as referred to in Figure 51.



Figure 51. Polycarbonate sheet attached to 3D printed parts.

11. Use the six long screws from the Hillman Screw kit and a washer to attach the tube assembly from the previous step to the side of the blower fan with no grate.

12. Using the frame clamps, clamp the polycarbonate to the inside of the ring. Mark five locations (3 distributed on the top of the ring, and one at the horizontal left and right) and drill through in order to put washers and hillman bolts and nuts to hold the tube firmly to the door frame.
13. Attach the door hinge to the inside of the door frame using the short screw and a bolt from the Hillman fastener kit with a washer.
14. Assemble the test chamber door by lining the holes drilled in the door ring with the front fan grate. Use short Hillman screws with nuts and a washer to secure the door ring to the grate.
15. Pick the door and line the hinge up with the drilled holes in the door ring. Attach the door ring to the hinge using Hillman screws with nuts and a washer.
16. Add feet protectors to the bottom of the legs to the device and to the top the legs on each side of the door saddle.

Windmill Mount Assembly

1. Assemble the windmill mount as shown in Figure 52.



Figure 52. Exploded view of the windmill mount.

2. Within each hinge, install a windmill mount angle stop as shown in Figure 53.

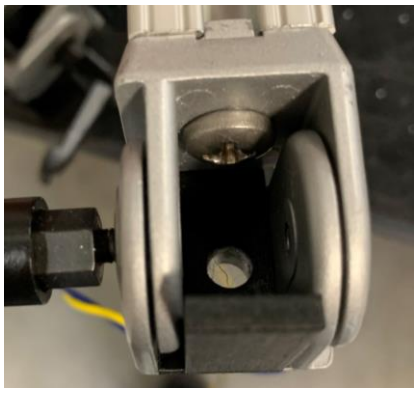


Figure 53. Windmill angle stop placement.

3. Slot the windmill mount through the hole in the bottom of the tube and connect the base of it to the frame with a steel head bolt and hex nut.

DC Motor Brush Noise Filter Assembly

Due to the presence of brushes within the DC motor, significant electrical noise can be introduced to the power measurement circuit when the motor is spinning at higher RPMs. To prevent this noise from affecting the device's measurement accuracy, the motor can be shielded using small capacitors to filter out the noise.

1. Solder a 0.1 µF ceramic capacitor (Part No. EC9) between the motor's metal casing and one of the terminals on the back of the DC motor (Part No. EC11).
2. Repeat this process for the other motor terminal, as shown in Figure 54.

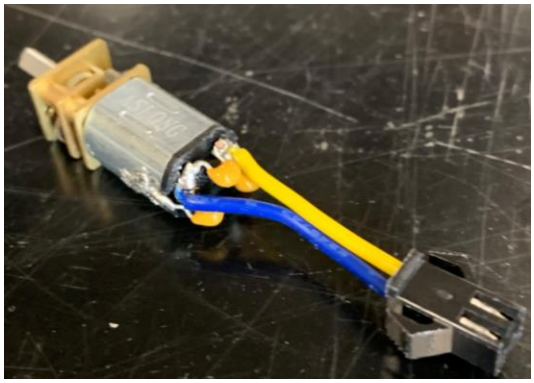


Figure 54. DC motor brush noise filter assembly.

3. Solder a 0.1 µF ceramic capacitor between both motor terminals. Refer to Figure 54 for the full brush noise filter assembly.
4. Cut two 2" pieces of 20 AWG wire and crimp female JST SM connector pins onto one end of each wire.
5. Solder a wire segment onto each motor lead, and make sure the JST SM connector pins are oriented the same way.
6. Slide a JST SM connector housing onto the two JST SM connector pins, and make sure the connection is secure.
7. Slide the motor into the generator adapter, as shown in Figure 55, and insert it into the windmill mount generator housing.

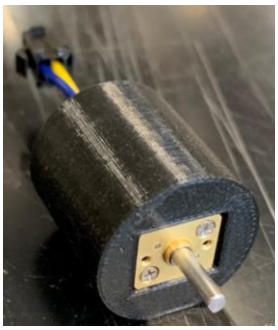


Figure 55. Motor placed within the generator adapter.

Wiring Harness Assembly

1. Cut 3.5' of blue and yellow 20 AWG wire and strip 1/4" of insulation off each end.
2. For each of the wires prepared in step 1, install a male JST SM connector pin on one end.
3. Insert the JST SM connector ends of the wires into a two-pin male JST SM connector housing, and ensure the connection is secure.
4. Twist the two wires together until there is around 2" of untwisted wire at the other end of the wires.
5. Route the untwisted ends of the wires up the back groove of the windmill stand into the generator housing.
6. Once the open ends of the wires are in the housing, install another two-pin male JST SM connector onto the set of wires, and ensure a good connection is made. Plug the wiring harness into the generator as shown in Figure 56.



Figure 56. Generator housing wiring installation.

7. Run the generator wiring down the back groove of the windmill mount and epoxy three wire guides to the mount to hold the wiring in place, as shown in Figure 57.

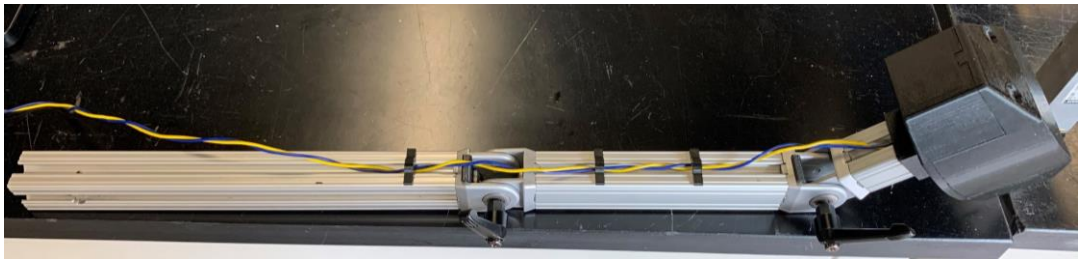


Figure 57. Generator wire guide installation.

8. Cut 4' of blue and black 20 AWG wire and strip 1/4" of insulation off each end.
9. For each of the wires prepared in step 8, install a male JST SM connector pin on one end.
10. Insert the JST SM connector ends of the wire into a two-pin male JST SM connector housing, and ensure the connection is secure.

11. Twist the two wires together until there is around 2" of untwisted wire at the other end of the wires.
12. Route this set of wires from the base of the windmill mount, underneath the 3D printed shape holder clip, and around the perimeter of the door frame on the opposite side of the hinge, as shown in Figure 58.



Figure 58. Door safety switch wire routing.

13. Epoxy two wire guide clips (Part No. EC19) to the bottom of the 3D printed shape holder clip and around the door switch wiring to hold the wiring in place.
14. Route the open ends of the wires through the safety switch housing (Part No. EC18) as shown in Figure 59.

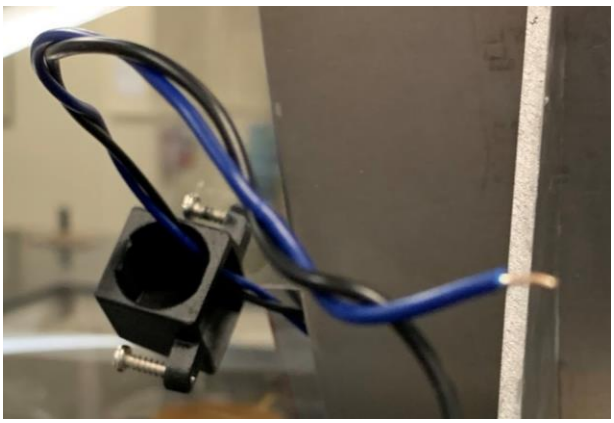


Figure 59. Routing of safety switch housing.

15. Solder the two open wires to the push button safety switch (Part No. EC10) terminals and insert the push button safety switch into the safety switch housing.

16. Using the two innermost screws from the door latches, attach the safety switch housing to the door frame as shown in Figure 60.

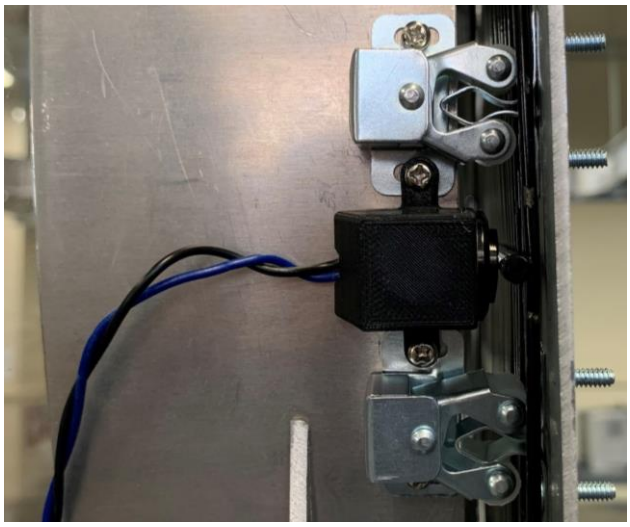


Figure 60. Door safety switch mounting configuration.

17. Check that continuity between the two wires is present when the door is closed. If this is not present adjust the switch position forward until the switch can be completely closed.
18. Cut 3' of red, white, and black 20 AWG wire and strip 1/4" of insulation off each end.
19. For each of the wires prepared in step 18, install a male JST SM connector pin on one end.
20. Insert the JST SM connector ends of the wire into a three-pin male JST SM connector housing, and ensure the connection is secure.
21. Twist the three wires together until there is around 2" of untwisted wire at the other end of the wires.
22. On the open ends of the three wires, install male JST SM connector pins.
23. Insert the JST SM connector pin ends of the wires into a three-pin male JST SM connector housing so that they will match their color-coded counterparts connected to the relay module in the blower fan, and ensure the connection is secure.
24. Route this set of wires from the base of the windmill mount to the edge of the front side of the blower fan under the 3D printed shape holder clip, and secure it in place by epoxying two wire guide clips to the bottom of the shape holder clip.

25. Plug the male connector on the wiring harness into the 3-wire connector installed during the blower fan circuitry modification, as shown in Figure 61.

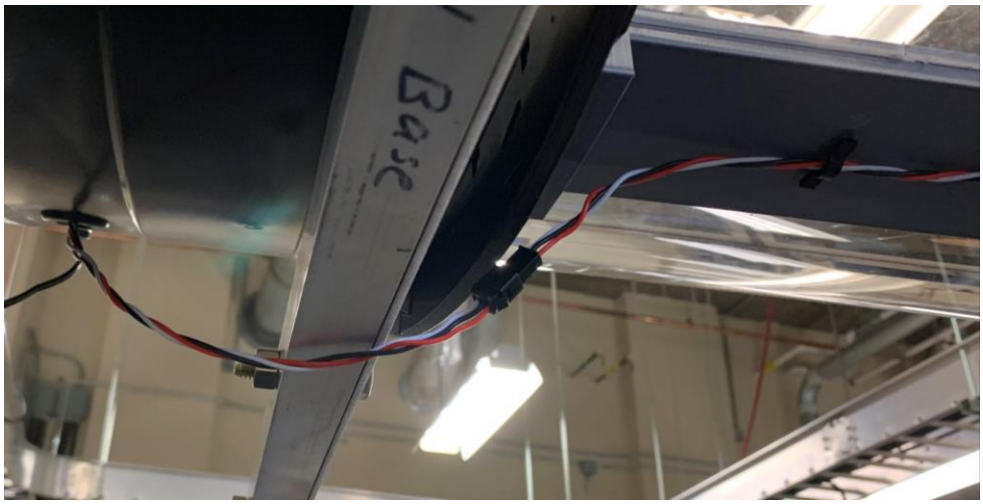


Figure 61. Blower fan relay control line connection.

Electronics Assembly

1. Download the Raspberry Pi Imager for the appropriate operating system from the following link:

   https://www.raspberrypi.org/downloads/

2. Image Raspbian onto a 16GB microSD card and insert it into the Raspberry Pi as shown in Figure 62.

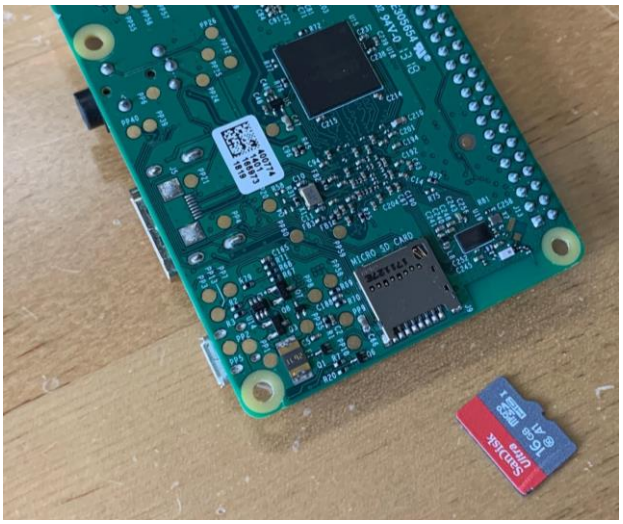


Figure 62. Installing the microSD card into the Raspberry Pi.

3. Solder the following components onto the Raspberry Pi control board as shown in Figure 63. For the exact layout, refer to the DC electrical schematic in Appendix B.

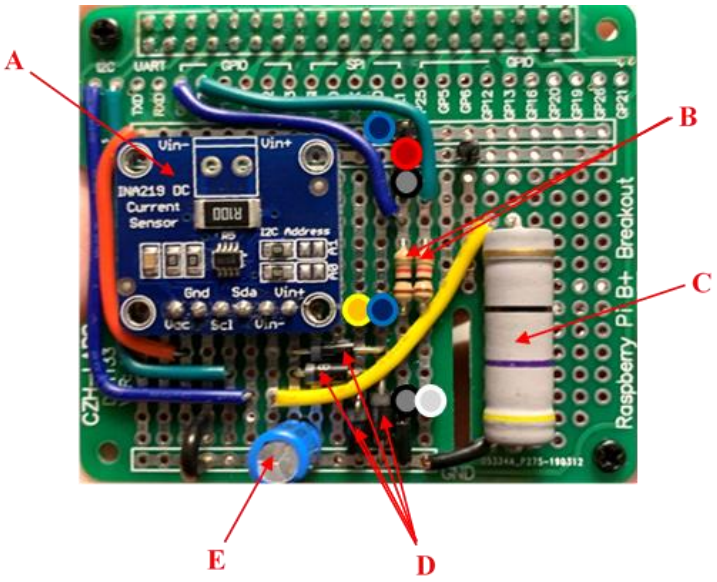


Figure 63. Raspberry Pi control board layout.

The components shown in Figure 63 are as follows:

A. INA219 DC Current Sensor (Part No. EC4)
B. 1 kΩ - ¼ W Resistors (2) (Part No. EC6)
C. 47 Ω - 5 W Resistor (Part No. EC7)
D. 1N5818 Schottky Diodes (4) (Part No. EC5)
E. 100 µF - 25 V Capacitor (Part No. EC8)

4. In Figure 63, there are six color coded circles corresponding to different solder points for the connections to the device wiring harness. Cut 3" red, yellow, blue, white, and black sections of 20 AWG wire corresponding to each of the six color coded circles in Figure 63.
5. Strip 1/8" of insulation from one end of each of the wires and solder them to the color-coded locations shown in Figure 63. The result will be similar to Figure 64.

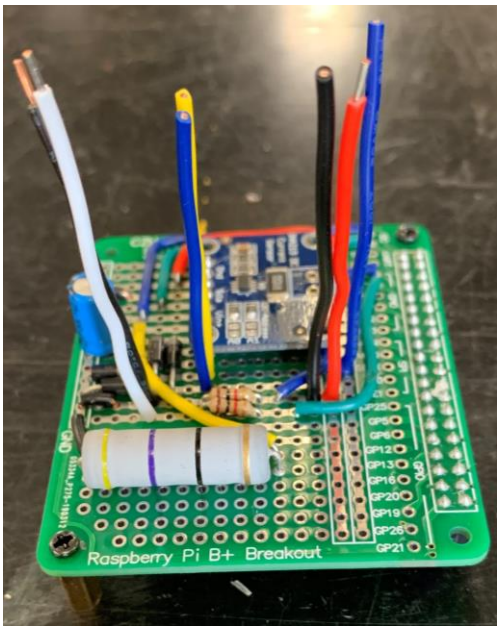


Figure 64. Wiring harness wire placement.

6. Strip 1/4" of insulation from the other ends of the wires and install female JST SM connector pins on them. Install a two-pin female connector onto the blue and yellow wires at the center of Figure 64. Install a two-pin female connector onto the blue and black wires at the right side of the board in Figure 65. Install a three-pin female connector onto the remaining three wires. For each connector ensure the wires will line up when connected to their similarly colored wiring harness wires.

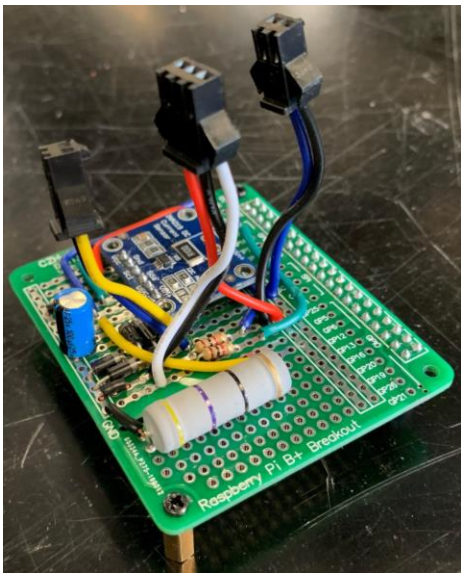


Figure 65. Wiring harness connector placement.

Electrical Box Assembly

1. Print out the electrical box (Part No. EC16) and its lid (Part No. EC17) from the provided files.
2. With the two electrical box mounting holes toward the back of the case, insert the Raspberry Pi (Part No. EC1) into the electrical box with the connectors lined up with their respective holes, as shown in Figure 66.



Figure 66. Raspberry Pi placement in the electrical box.

7. Insert screws into the top left and bottom right holes on the Raspberry Pi and tighten them to mount the board into the case.
8. Attach the mounting brackets (brass-colored supports in Figure 67) to the top right and bottom left holes on the control board.


Figure 67. Control board mounting bracket placement.

9. Install the control board onto the top of the Raspberry Pi in the electrical box as shown in Figure 68.

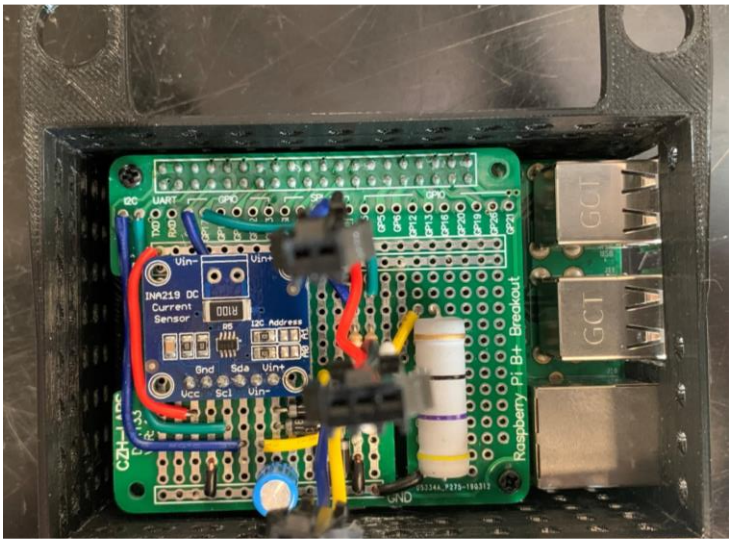


Figure 68. Control board placement in the electrical box.

10. Place the lid onto the electrical box and run the three wiring harness connectors through the holes in the top of the box as shown in Figure 69.

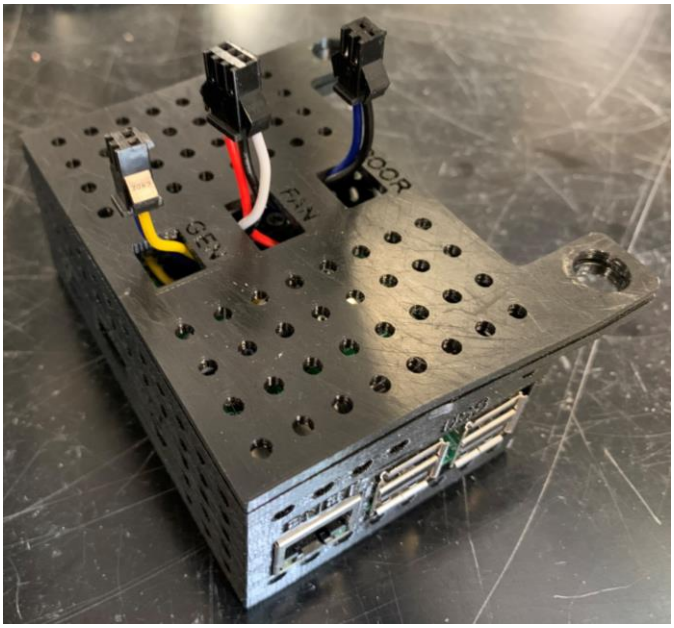


Figure 69. Wiring harness connector routing.

11. Remove the two bolts at the base of the windmill mount and run them through the two mounting holes at the back of the electrical box. Then, connect the color-coded wiring harness wires to their similarly colored counterparts on the electrical box as shown in Figure 70.

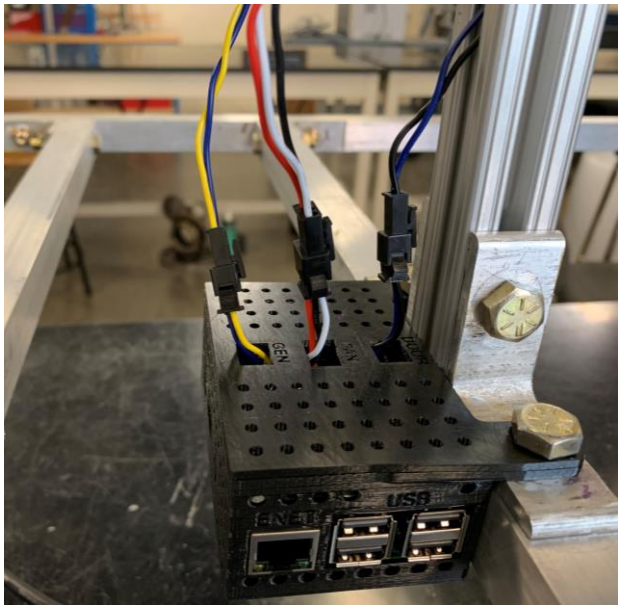


Figure 70. Electrical box installation and wiring connections.

12. Connect the Raspberry Pi power supply cable from the blower fan to the PWR port on the electrical box.

First-Time Software Setup

1. Connect a screen to the electrical box HDMI port and connect the USB touchpad keyboard to one of the USB ports on the electrical box.
2. Turn the device on by pressing the power switch on the side of the blower fan.
3. Once the Pi boots to the desktop, connect it to a Wi-Fi network by navigating to the Wi-Fi network icon at the top right of the desktop, as shown by the grey highlighting in Figure 71.

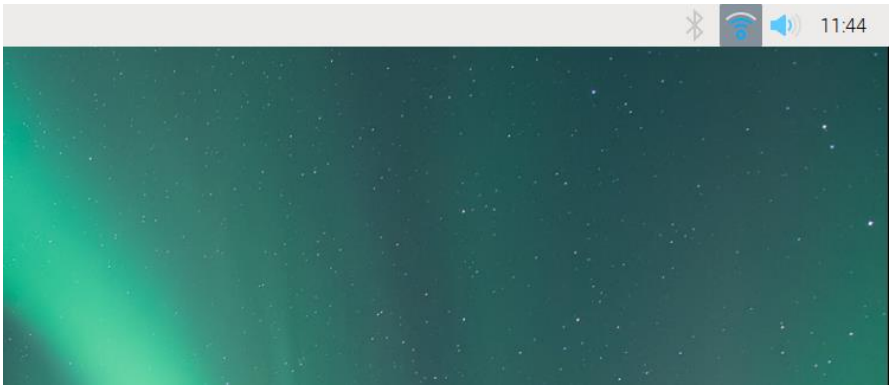


Figure 71. Wi-Fi settings location.

4. Navigate to the Raspberry Pi Configuration tab in the main menu at the top left of the desktop as shown in Figure 72.

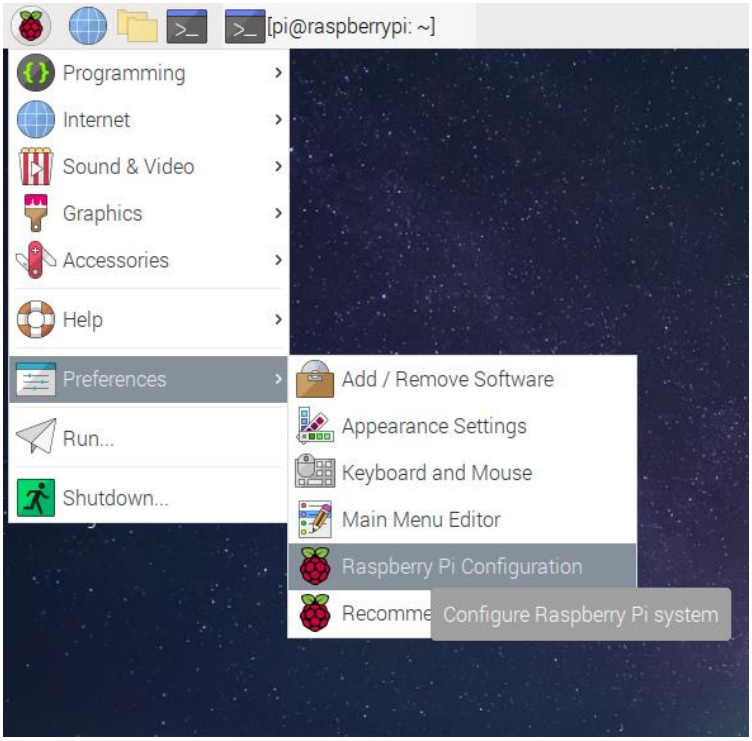


Figure 72. Raspberry Pi Configuration menu location.

5. From the Interfaces tab, select the "Enable" option for the I2C port as shown in Figure 73.

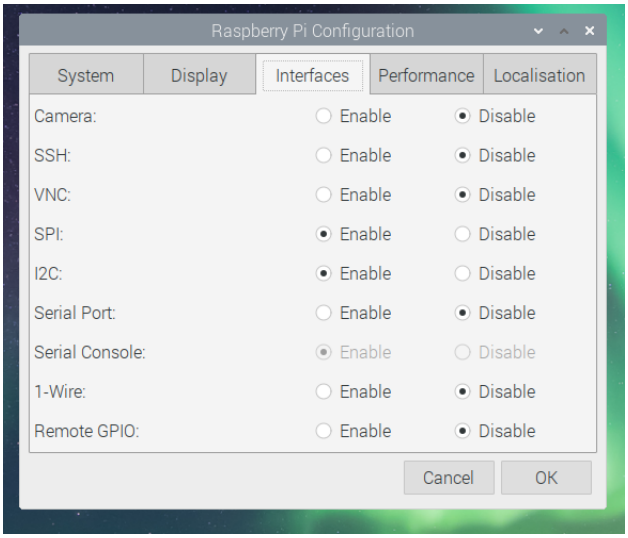


Figure 73. Required interface port menu settings.

6. If a prompt to reboot appears, reboot the Pi. If no prompt appears, reboot the Pi by selecting the "Shutdown…" option from the main menu.

7. Once the Pi has rebooted, open the Raspbian terminal, denoted by the icon shown in Figure 74, and enter the following commands:

   sudo apt-get update
   sudo apt full-upgrade

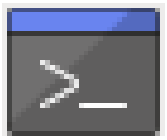


Figure 74. Terminal icon.

8. When prompted with, “Do you want to continue? [Y/n],” type the letter Y and press <Enter>. This will update the Pi’s software and may require a restart after it has finished updating.
9. In the terminal, enter the following command:

   sudo pip3 install --upgrade google-api-python-client google-auth-httplib2 google-auth-oauthlib adafruit-circuitpython-ina219

   This command installs the Python libraries for interfacing with the Google Drive and INA219 sensor.

10. Download the competition program files from the following link, and save them to the desktop:

    https://drive.google.com/drive/folders/1qhizWmsONQsSLnUP2zB6qDDoMn30_-2a?usp=sharing

Appendix A: AC Fan Wiring Schematic

The fan wiring schematic, shown in Figure A.1, shows the necessary connections described in the “Modifying the Blower Fan Circuitry” section needed to rewire the blower fan to be controlled by the Raspberry Pi.

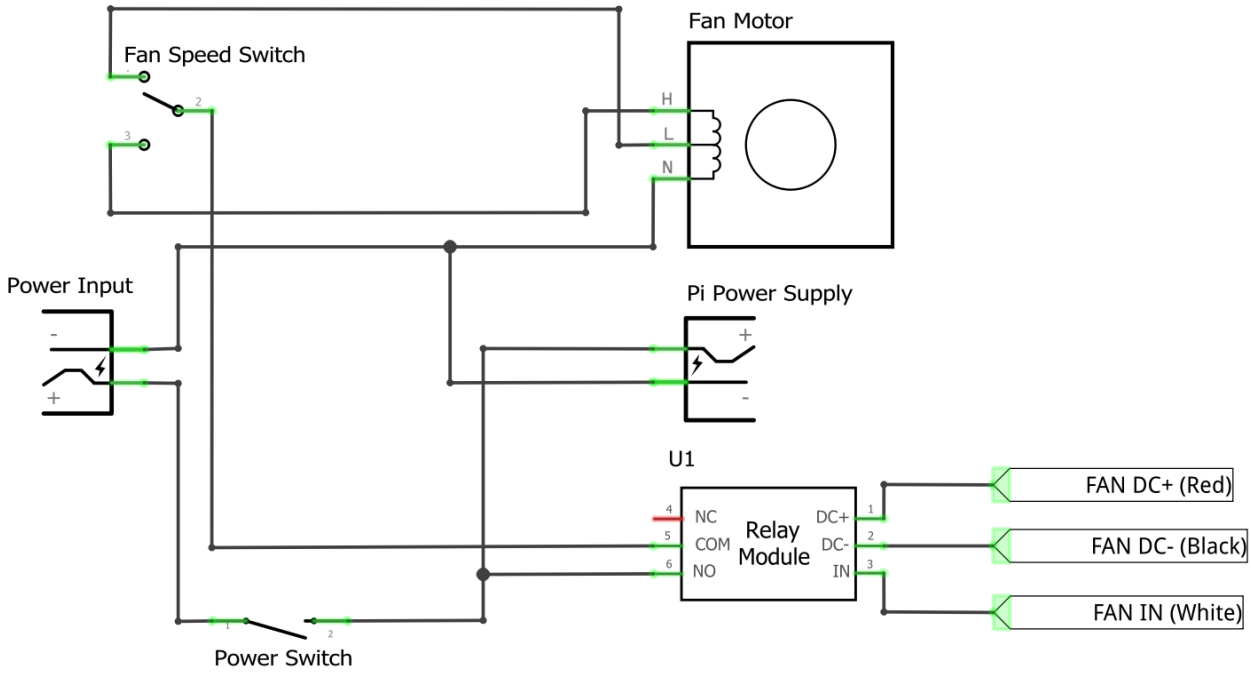


Figure A.1. Fan wiring schematic.

In Figure A.1, pin H on the fan motor refers to the black fan supply wire for the high-speed setting, and this wire should be plugged into the fan speed switch on the side labeled “LOW.” The L pin refers to the red fan supply wire for the low speed setting, and this wire should be plugged into the fan speed switch on the side labeled “HI.” The three-color coded FAN lines connect the AC circuit to the DC circuit shown in Appendix B. Additionally, a green ground wire (not shown) connects the ground of the power input to the fan grate.

Appendix B: DC Control Board Wiring Schematic

The control board schematic, shown in Figure B.1, shows the necessary connections described in the “Electronics Assembly” section needed to build the auxiliary control board for the Raspberry Pi.

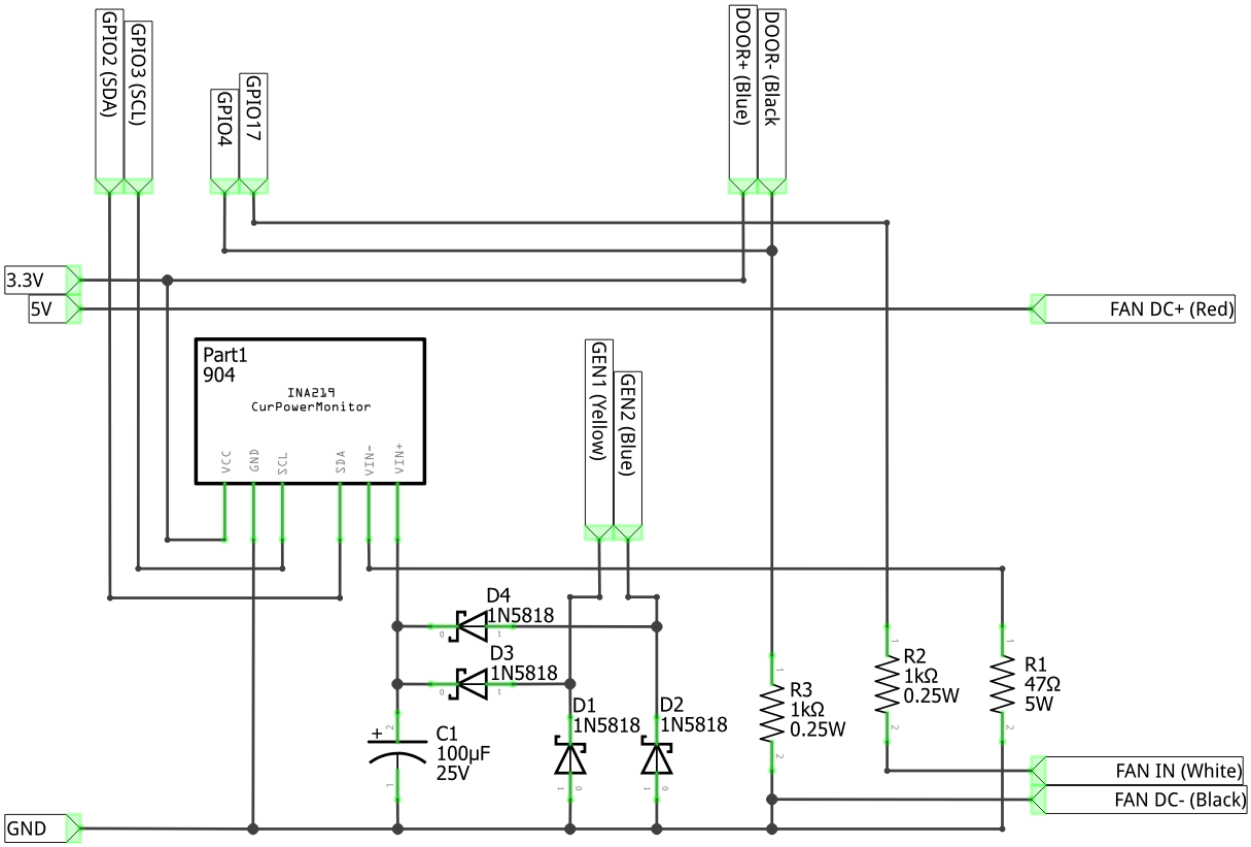


Figure B.1. Control board wiring schematic.

The color-coded wires in Figure B.1 correspond to the three wiring harness connector sets described in the “Wiring Harness Assembly” section.

25. Appendix E: Windmill Testing Device User Manual

WINDMILL TESTING DEVICE USER MANUAL

Windmill Blade Competition System
Team Power House (TYL11)

Department of Electrical and Mechanical Engineering
The University of Texas at Tyler
MENG 4215 Senior Design Project

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Sponsor: The University of Texas at Tyler

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Introduction

This manual is to explain and demonstrate certain aspects of the device. This manual will cover all mechanical and electrical parts in the functional device. It shows components on how to handle the device when it is turned on or off. Subjects include maintenance information, descriptions of main components and device features. There are also safety factors and repair information that are to show what happens when something goes wrong. The parts list is provided to help reference certain parts that are being tested or analyzed.

Features and Accessories

The device can be broken down into smaller parts, so it can be easier to transport the device from location to the next. The device is powered through a cord that is connected to the fan. A wall outlet supplies the power to the entire device, including the electrical interface. The main device is connected to an external TV display through Bluetooth. The tunnel is in a circular shape for aesthetic appeal to the audience instead of a rectangular box shape. The electrical box is placed under the tunnel next to the windmill blade stand, which makes the wiring easy and more accessible to connect the generator to the interface.

Descriptions of the Main Product Elements

The fan was store bought and it's a MaxxAir™ 30" heavy duty barrel fan. This fan was used to generate wind in the tunnel to test the windmill blades built by the competitors. The fan was 30" inches in diameter, which was the exact measurement used for the tunnel. The fan is built with four blades and has two speed settings. When the fan is attached to the tunnel, the inside is open to expose the blades of the fan, while the other is gated off with the switch on the outside. The dimensions for the fan were 14.25 in X 32.25 in X 33.75 in.

The mount that holds the constructed blades together when running the test is called the "blade mount adapter." This part was constructed using Autodesk Inventor. The part was then 3D printed using PLA plastic. The mount is supposed to attach the constructed windmill blades together to create the fan, and then attach to the generator that it will try and power during the test. The mount has 12 holes around the part to secure the wooden dowels on. The holes have a square shape to fit the wooden dowels. This is because the blades themselves could rotate out if they were attached to rounded dowels.

The pivot stand is the part that holds the generator at mount up in the center of the tunnel. This part was assembled into two basic parts: aluminum square tubing, and pivot joints. The aluminum square tubing for this part is different from the one used for the frame because it has

T-slots on all four sides. This reason for this is to help attach and hide the wiring to the device in a more efficient way. The stand is also made from two pivot joints that both have 90 degrees of limited rotation. One joint is to change the orientation for the blades, from vertical to horizontal. The other one is to rotate the stand closer to the door to reach and attach the blades on the mount.

The clear polycarbonate sheet was used to create the shape of the tunnel for the device. The material is clear, so that the audience can see the test happening in the device. The dimensions of the sheet were about 48 in X 96 in X 0.03125 in. This allowed the sheet to be flexible when bending it to a circular shape. The thickness was also just strong enough to withstand the shape and power of the fan when it is turned on. The sheet is attached to the frame of the fan itself and secured to a metal ring on the other side of the device.

The frame of the device is created to hold and assemble all the previous pieces mentioned. The frame was made from 1 in X 1 in aluminum square tubing. The tubing was bolted together with L-brackets to construct the frame. The reason for this is because aluminum is difficult and time consuming to weld together. Another reason for bolting the frame was for it to be easier to take apart and build together. When the fan is turned on, the frame can withstand the vibration that is created when running the test.

Some parts that are on the device had to be 3D printed. Parts such as the shape holder, testing chamber ring, and components on the mount had to be 3D printed. Doing this helped attached major parts to create the entire device. The 3D printed parts were constructed from the material called Polylactic acid (PLA). Using this material allowed the parts to withstand higher levels of force and vibration caused by other components of the device.

Setting Up the Registration System

Note: A Google account is required for the following steps.

From the following link, save a copy the Google Sheet templates titled, “Windmill Competition Data” and “Windmill Competition Registration Data” to the Google Drive:

https://drive.google.com/drive/folders/1vInI4ODYqQZejwXvvKoRLB0-sNTUsiuH?usp=sharing

Copying the competition data spreadsheet should also copy a Google Form that will be used for the registration system.

Open the copied competition data template spreadsheet on the Google drive and copy its Spreadsheet ID. This can be found by looking at its URL address as shown below:

https://docs.google.com/spreadsheets/d/[SPREADSHEET_ID]/edit...

This ID will be needed to set up the registration data spreadsheet and the Raspberry Pi to write data to Google Drive.

From within the registration data spreadsheet, in cell A1, modify the IMPORTRANGE function to use the competition data spreadsheet ID, as shown in Figure 1.

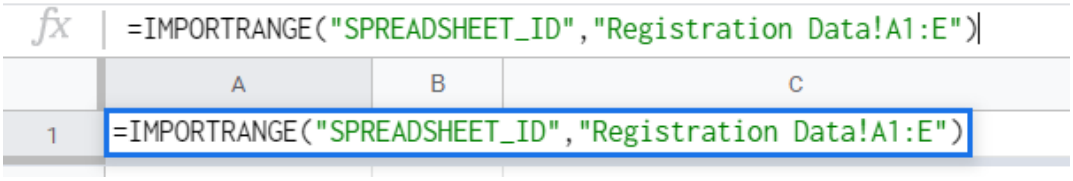


Figure 1. Modification of the IMPORTRANGE function.

In the top right of the registration spreadsheet page, click the green “Share” button and generate a shareable link set to “Anyone with the link can view,” and save this link.

Edit the competition registration form and access the Presentation tab of the form’s settings. Insert the registration data sheet’s shareable link into the confirmation message as shown in Figure 2.

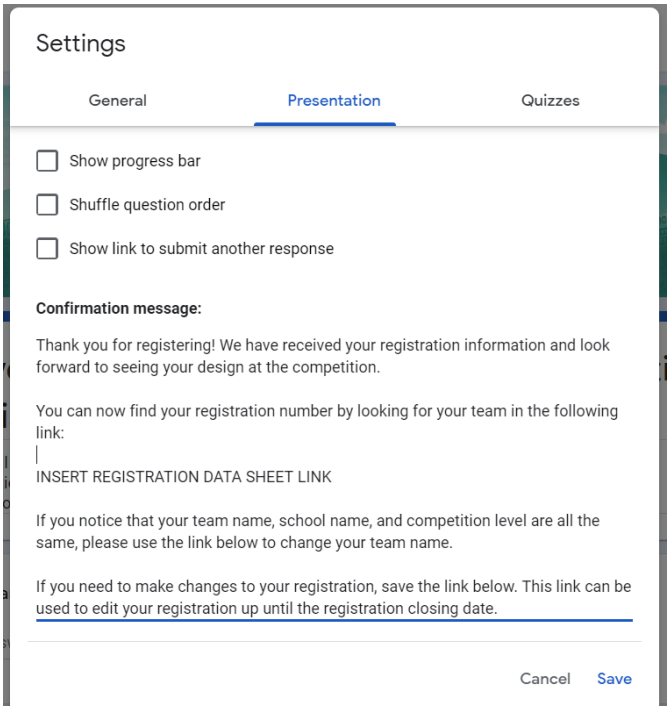


Figure 2. Registration confirmation message link edits.

When it is time to start receiving registration data for a competition, click the “Send” button at the top right of the Form editing screen to send the form to potential competition participants.

Important: Changes can only be made to the name and header of the form questions in the registration form. If changes are made to the existing registration form questions, the competition user interface program may not function properly.

Setting Up the Raspberry Pi

Connect the power cable to the port labeled PWR, connect the HDMI cable from the external display to the port labeled HDMI, connect the 3-pin connector coming from the fan to the FAN port on the electrical box, connect the 2-pin connector coming from the windmill mount to the GEN port on the electrical box, and connect the 2-pin connector coming from the door switch to the DOOR port on the electrical box.

After powering on the device with the switch on the side of the blower fan, navigate to the Wi-Fi settings in the top right of the Raspberry Pi desktop, shown in Figure 3, and connect to the desired network.

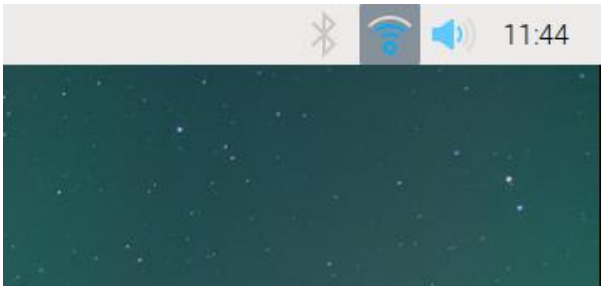


Figure 3. Wi-Fi settings location.

Depending on the institution or configuration of the desired Wi-Fi network, you may need to contact the system administrators for guidance on connecting to the desired network (i.e. passwords, clearance, etc.).

Modifying the Raspberry Pi Configuration and Credentials Files

On the Raspberry Pi desktop, there is a "config.txt" file for modifying how the competition program accesses the registration database and how the user interface looks. Within this file, there are the following modifiable fields:

- *competition_name* - This field contains the name of the competition that will be shown in the user interface. By default, this is set to "Power House Windmill Competition." Note: If the name is too long it may cause display issues.
- *spreadsheet_id* - This field contains the spreadsheet ID of the Google Sheet tied to the registration Form.
- *cred_path* - This field contains the file path to the Google Sheet access credentials file (credentials.json). By default, this is set to the Raspberry Pi desktop.
- *background_color* - This field sets the background color of the competition interface. It is a hexadecimal encoded number representing the color. By default, this is set to #2F5597 (Power House Blue) shown in Figure 4.
- *text_color* - This field sets the text color of the competition interface. It is a hexadecimal encoded number representing the color. By default, this is set to #FFFF66 (Power House Yellow) shown in Figure 4.

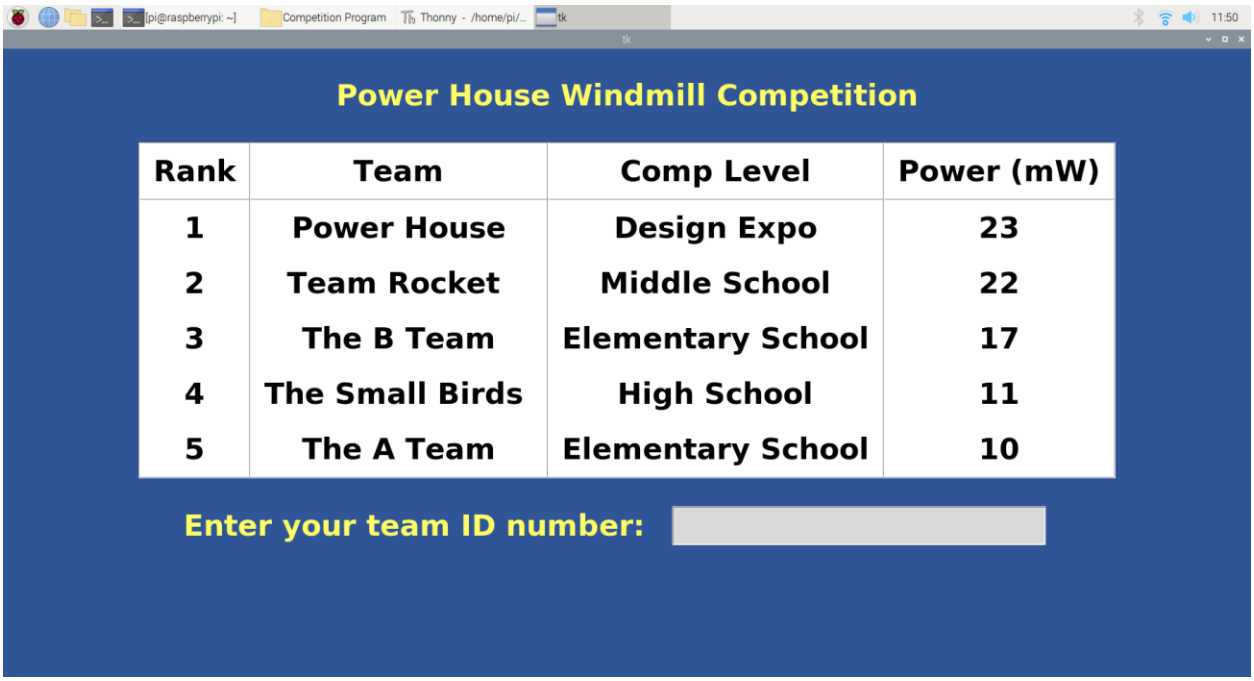


Figure 4. Competition user interface sample.

Copy the spreadsheet ID of the registration Form spreadsheet and put it into the *spreadsheet_id* field of the configuration file. If you plan on storing the credentials file somewhere other than the desktop, write the new path, in Unix format, to the *cred_path* field.

Important: The Raspberry Pi comes preloaded with a Google Sheets access "credentials.json" file that will request permission for the Power House Data Handler to make changes to Sheets on the account of the Google Drive being used. If you would rather use your own access credentials, follow step 1 from the following link to set up your own Google Sheets access credentials:

https://developers.google.com/sheets/api/quickstart/python

If you have decided to set up your own API account and generate your own credentials, save the credentials.json file to the path designated by the *cred_path* configuration file field and remove or rename the preloaded credentials file.

When the program is run for the first time, a web-prompt will show up asking for permission to modify Google Sheets on the Google Drive. Giving permission to the data handler will store the preferences for future runs of the competition, as long as the same Google sheet is used.

Product Operation Overview

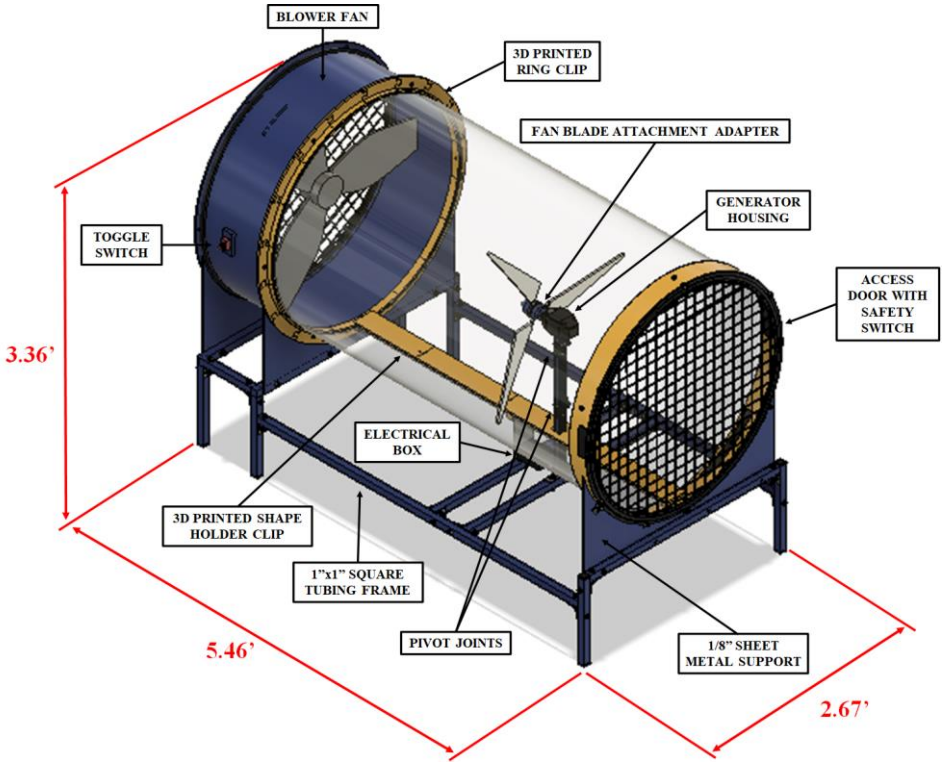


Figure 5. Windmill Blade Competition Testing Device

The list below is instructions to successfully perform a test of a team's windmill blades. For the best competition results, the instructions below should be followed by each team for every test cycle. Refer to Figure 5 as a tool to locate components of the device.

1. First, the device needs to be plugged into a wall socket to provide power to the device.
2. The competition host is to set the speed of the blower fan before the start of the competition. The blower fan has two speed settings. It is recommended to set the blower fan speed on the low setting.
3. Each team needs to register using the link provided by the competition host. The link will be sent to the team's designated email address. The teams will follow the instructions in the email and provide their team name, school name, competition level (elementary, middle, or high school), and number of windmill blades. Finally, the team will be given a unique ID number to input for the testing of their blades.
4. After registration, the team will load their blades into the device. The team representative or the collective team will open the access door and utilize the lower pivot joint to rotate a portion of the windmill mount 90 degrees. The generator housing will be closer to the user for easy blade loading.

5. Detach the windmill blade hub from the generator's shaft.
6. Once detached, remove the windmill blade hub from the testing chamber to begin loading the blades.
7. Unscrew the hub and evenly place the blades into the hub's slots.
8. Once the blades have been evenly placed in the hub's slots, the hub can be screwed back together, placed on the generator shaft, and locked into place.
9. Next, the stand can be moved back to a vertical stance by rotating the windmill mount 90 degrees about the lower joint away from the user.
10. Once the windmill mount is vertical, lock the pivot joint in place to secure the stand.
11. If the team's blades have a horizontal orientation skip to Step 12. If the team's blades have a vertical orientation, utilize the upper joint to rotate a portion of the windmill mount and generator housing 90 degrees toward the user. Then lock the upper pivot joint in place to secure the windmill mount.
12. Once the blades are loaded in either the horizontal or vertical position, the testing chamber's access door must be closed. Note: The windmill blade test will not be initiated until the access door is closed.
13. After the door is closed, a team member inputs the team's ID number into the user interface to begin the test.
14. After one minute has passed, and the fan is turned off, wait for the windmill blades to stop moving before opening the access door.
15. The blades can now be collected from the testing chamber. If you have horizontal blades utilize the lower pivot joint to bring the generator housing closer to detach the blades. If you have vertical blades, use the upper pivot joint first to bring the windmill mount to a complete vertical stance and then use the lower pivot joint to bring the generator housing closer.
16. If there is more testing to be completed for the competition, it is recommended for the previous team to leave the windmill mount in the horizontal stance for an easy transition between windmill tests.
17. The display connected to the device will display the ranking on the leaderboard. The table collecting data will update, and the team's ID number will correspond to the data received from the preceding test.

Operating the Competition Interface

Once the program has started, the UI will show the leaderboard screen shown in Figure 4. This screen shows the top 5 teams in terms of power generation and an entry box to enter team identification numbers. From this screen, pressing any key on the keyboard will enable the team ID entry box, which will allow the user to input their 5-digit team ID. Upon pressing <Enter>, if

the access door is closed and the team ID is present in the registration database. The power generation test will begin.

Once a test begins, the screen will switch to the power generation page shown in Figure 6, and this page will show the power generated by the windmill under-test, as well as a progress bar representation of the amount of time left for the test.

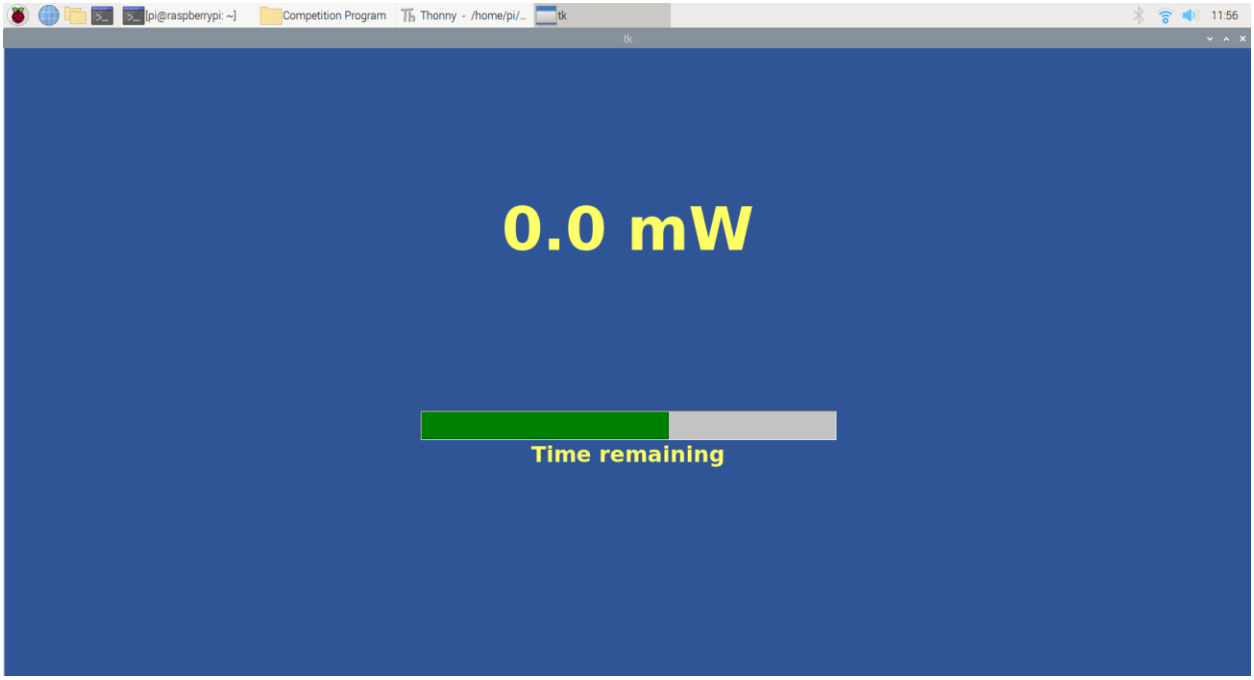


Figure 6. Competition UI power generation page.

Each windmill test will run for 1 minute. After the conclusion of the test, the team's final power and competition rank will be shown for 10 seconds, as shown in Figure 7, before returning to the leaderboard screen.

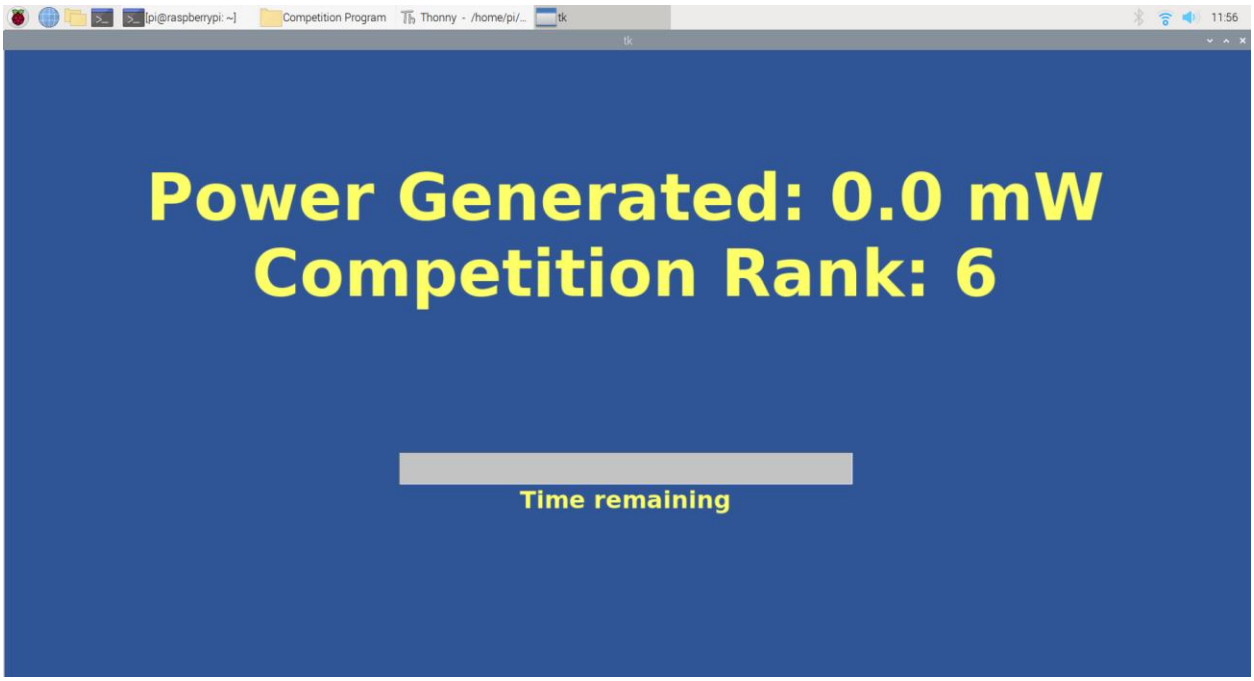


Figure 7. Team power generation and ranking display screen.

Note: The leaderboards only update during a transition between the power generation screen and the leaderboard screen due to the computational overhead required to interface with the registration database.

Important: If a power value fails to be written to the leaderboards database, re-running the power measurement test or manual power value entry may be required. To manually enter a power value, the owner of the competition data spreadsheet, or those given editing privileges, will have to access the first sheet (Registration Data) of the competition data spreadsheet and type in the measured power value.

Calibrating the Power Measurement Sensors

The user does not have to manually initiate the recalibration of the power measurement sensors on the device. Prior to each windmill test, the sensors are calibrated while the door is closed prior to the blower fan starting up.

Transporting the Device

1. Disconnect the wiring at the base of the windmill mount from the electrical box and remove the nut and bolt. Next remove the windmill mount by pulling it up though the inside of the testing chamber.

2. Disconnect the wiring running to the fan. Disconnect the 2 remaining plugs above the electrical box. Disconnect the plug at the end of the tube connecting to the fan. Unplug the power wire (black wire with circular plug) from the electrical box.
3. Remove the 4 bolts that connect the door frame to the door saddle, these are the four bolts inside the door at the bottom (you will need two people to complete this step). Have the second person hold the door frame, remove the 6 bolts that connect the end of the tub to the fan. Remove the tunnel and set it on the side without the door. Be careful not to apply pressure to the tube when loading it into a vehicle, this can cause fractures to form in the fan side ring.
4. Remove the bolts connecting the front two legs and the back two of four legs to the tubing that runs parallel with the tube.
5. The fan can be left in the saddle for transporting. If it is necessary, take note of the location of the handle of the fan, have someone on each side of the fan pull up on the fan to remove it from the saddle.
6. After the device has been transported, reverse the above steps in descending order (5,4,3, etc.) to reassemble the device in the desired location.

Safety Warnings

1. The blades should be secured onto the wooden dowels firmly to prevent them from detaching during the test.
2. Make sure that the blades are secure on the mount. This restricts the blades from falling out of the mount during a test.
3. The windmill blades should be with the limited length given, otherwise they can damage the tunnel and will not test properly.
4. The door should remain closed when running a test. If the door is opened during a test, the fan will shut off and the numbers will not be recorded. The device will not run a test if the door is open.
5. Teams should not interfere during the testing to fix their windmill blades, or other teams' windmill blade designs.
6. No weight should be applied to the polycarbonate tube, this can cause damage to the tunnel and could cause harm to the users.
7. If the program crashes, the blower fan may fail to shut off, since it is software controlled. If this happens, the power switch on the side of the blower fan will need to be used to cut off power to the entire device.

Maintenance Information

This section gives guidance and recommendations on how to properly take care of the device. Certain parts of the device should be preserved in a way, so that the device can be in proper shape whenever in use.

- *Aluminum Frame Maintenance*

The frame should be stored in a dry place until it is ready to be utilized for competition. This will ensure the aluminum frame does not corrode. If the aluminum becomes corroded, use a mild soap and sponge to clean the surface of the metal of any dust or dirt. Next use an aluminum metal polish to clean and shine the metal.

- *Polycarbonate Sheet Maintenance*

The polycarbonate sheet is UV resistant, but under extended exposure it will take sun damage over time and begin yellowing. It is recommended to limit the sheet's sun exposure.
In order to clean the polycarbonate sheet, use lukewarm water with mild soap and a soft cloth or sponge and gently wash with up and down motion. NEVER use ammonia-based products to clean the polycarbonate sheet, which includes Windex. Do not wipe dust or dirt off with hands or hard surfaces, this will imbed particles into the polycarbonate and leave scratches.

- *Generator Maintenance*

After extended use, brushes within the motor may fail, which will require that a replacement motor be installed. Refer to the assembly guide parts list to determine the motor type. A new motor will require the addition of three 0.1uF capacitors and the wiring leads (see the assembly guide "DC Motor Brush Noise Filter Assembly" section for more information).

- *Operating System and Competition Program Corruption*

If the operating system or device program becomes corrupted, re-flashing the system's microSD card will be required. To do so, remove the two bolts holding the electrical box to the bottom of the frame and open the electrical box. Then, remove the control board and the Raspberry Pi from the electrical box to access the microSD card. Reflash Raspbian to the SD card using the Raspberry Pi Imager for the appropriate operating system from the following link:

https://www.raspberrypi.org/downloads/

After re-flashing the microSD card, put the electronic box back together and hook it up to the rest of the machine. Then, reconfigure the device as outlined in the “First-Time Software Setup” section in the assembly manual.

Note: If there is a part that needs to be repaired, refer to the assembly guide on how to fix the part.

26. Appendix F: Project Sign-Off Form

The University of Texas at TYLER
COLLEGE OF ENGINEERING

Department of Mechanical Engineering
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Fax: +1.903.566.7148
Uttyler.edu/engineering

SENIOR DESIGN II – FINAL STATUS SHEET

TEAM: TYL 11 **Date: 4/24/2020**
Project final status: **COMPLETED: ___X___** **NOT COMPLETED: _____** **ESTIMATED % Completion ____ %**
Location on OneDrive where team project folder can be downloaded https://livepatriotsuttyler.sharepoint.com/sites/PowerHouseTYL11/Shared%20Documents/Forms/AllItems.aspx
PENDING ITEMS: N/A
OUTSTANDING ITEMS ORDERED (BUT NOT RECEIVED) N/A
OUTSTANDING ITEMS NOT ORDERED N/A
FINAL COMMENTS: The testing on the device was decreased due to the situation with COVID. More details on this is in the final report. The device operates as intended and is ready for the upcoming Alief ISD competition in November.
SIGNATURE: **1.- Name: Frederick Wehe** **Signature: _____** **2.- Name: Davida Campbell** **Signature: _____** **3.- Name: Joshua Stapp** **Signature: _____** **4.- Name: Spencer Well** **Signature: _____** **5.- Name: Emmanuel Acuna** **Signature: _____**

The University of Texas at TYLER
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Senior Design Project II
MENG 4216 / EENG 4315
Project Testing Instrumentation Setup for a Windmill Blade Design Competition Delivery and Acceptance

Senior design team Power House, from UT-Tyler College of Engineering, has worked with a sponsor: the University of Texas at Tyler to design, build, and deliver Testing Instrumentation Setup for a Windmill Blade Design Competition as part of the senior students' academic work during the academic year of 2019-2020. This document includes the sign-off list and the University of Texas at Tyler's final approval of the outcome of Testing Instrumentation Setup for a Windmill Blade Design Competition delivered by Power House, based on the previously set and mutually approved scope and specifications of the project. An authorized signature indicates this approval.

Table 1: Sponsor Sign OFF list for Deliverables of the Senior Project Testing Instrumentation Setup for a Windmill Blade Design Competition

Item No.	Description of Deliverable	Comments:	Sponsor Sign Off: Authorized Initials
Windmill Blade Testing Device	Blower Fan Housing and Blade Mount		
Aluminum Sheets	1/8" Aluminum Plate		
Aluminum Sheets	1/24" Aluminum Plate		
Blower Fan	5500 CFM Fan		
Polycarbonate Sheet	0.03" Sheet 96" x 48"		
Grated Access Door	Manufactured Device Door		
Electrical	Raspberry Pi Power Measurement Circuit		
Square Aluminum Tube	5' Max Lengths		

Plastic Frame Components	3D Printed	
Assorted Hardware	Assorted ANSI Screws and Bolts	
Electrical Box	3D Printed	
Power Measurement Program	Power Measurement Program	
GUI Program	GUI Control Program	
Production Model Documentation	Technical Documentation	
B.O.M.	Bill of Materials	
I.O.M.	Installation and Operations Manual	
Competition Guidelines	Windmill blade requirements for participating teams	
Electrical Schematic	Electrical Layout	
Testing	Testing of system	
Calibrating Electrical System	Generated power will be measured independently to verify the device's sensor calibration.	
Windmill Blade Variety Test	Multiple windmill blade designs of varying build quality will be tested to verify the device's ability to accommodate different designs.	Incomplete due to Coronavirus, but a few designs were tested.
Windmill Mount Stress Test	The windmill mount will be tested at full load for both horizontal and vertical windmill orientations.	Incomplete due to Coronavirus, but FEA was performed on windmill mount.

The following signatures indicate that The University of Texas at Tyler approves of the completion of this project and deliverables stated above which included all sponsor changes from original design and any consequent changes in the project, as mutually approved by all signing parties. Also indicated is the acknowledgement by The University of Texas at Tyler of reception of the final product of the project.

For UT-Tyler Mechanical Engineering: Dr. Tahsin Khajah	Date
For the University of Texas at Tyler: Dr. Andres Garcia *Houston Engineering Center Director*	Date
For the team Power House: Frederick R. Wehe *Team Leader*	Date

27. Appendix G: Mechanical Drawings

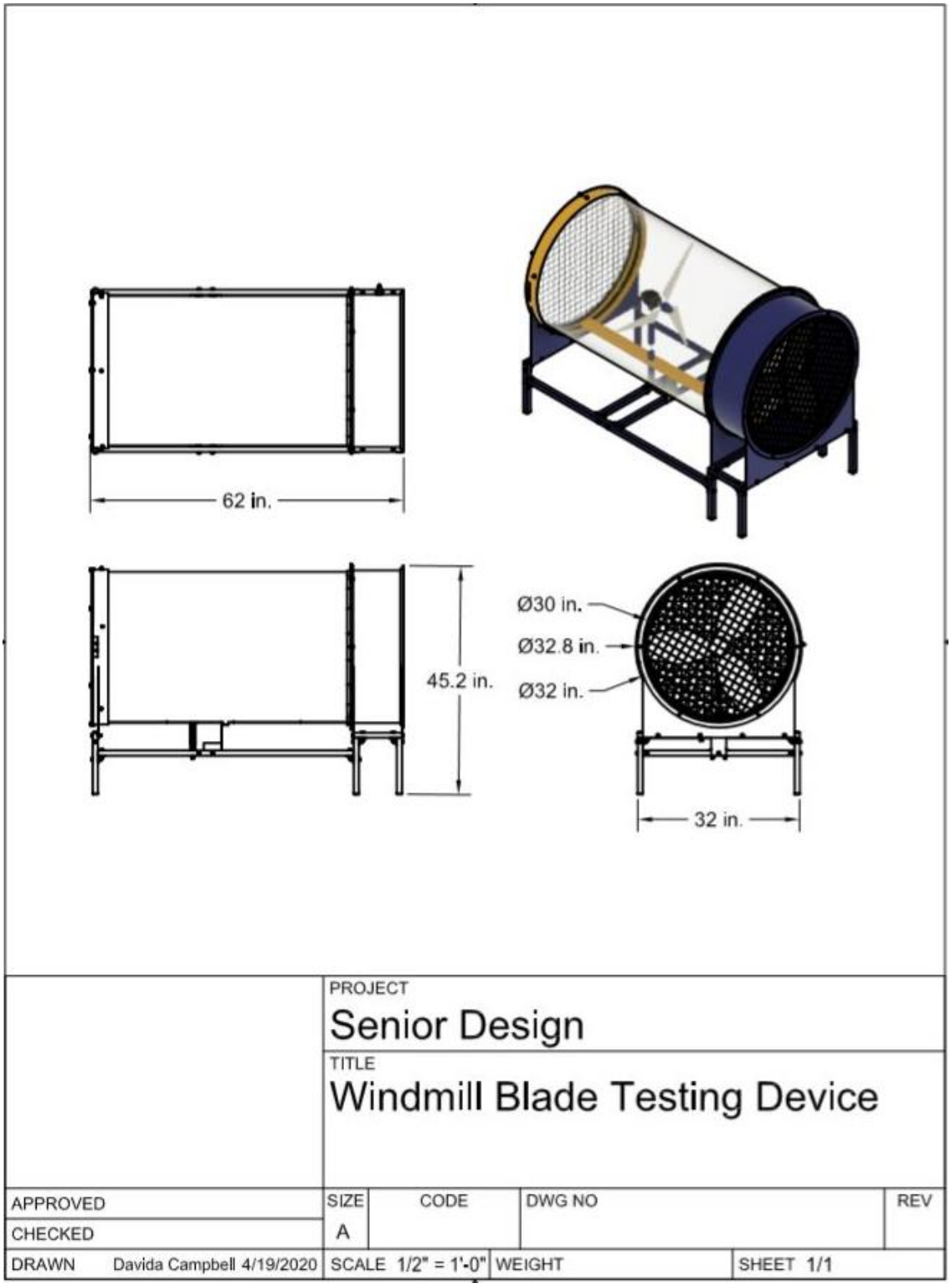
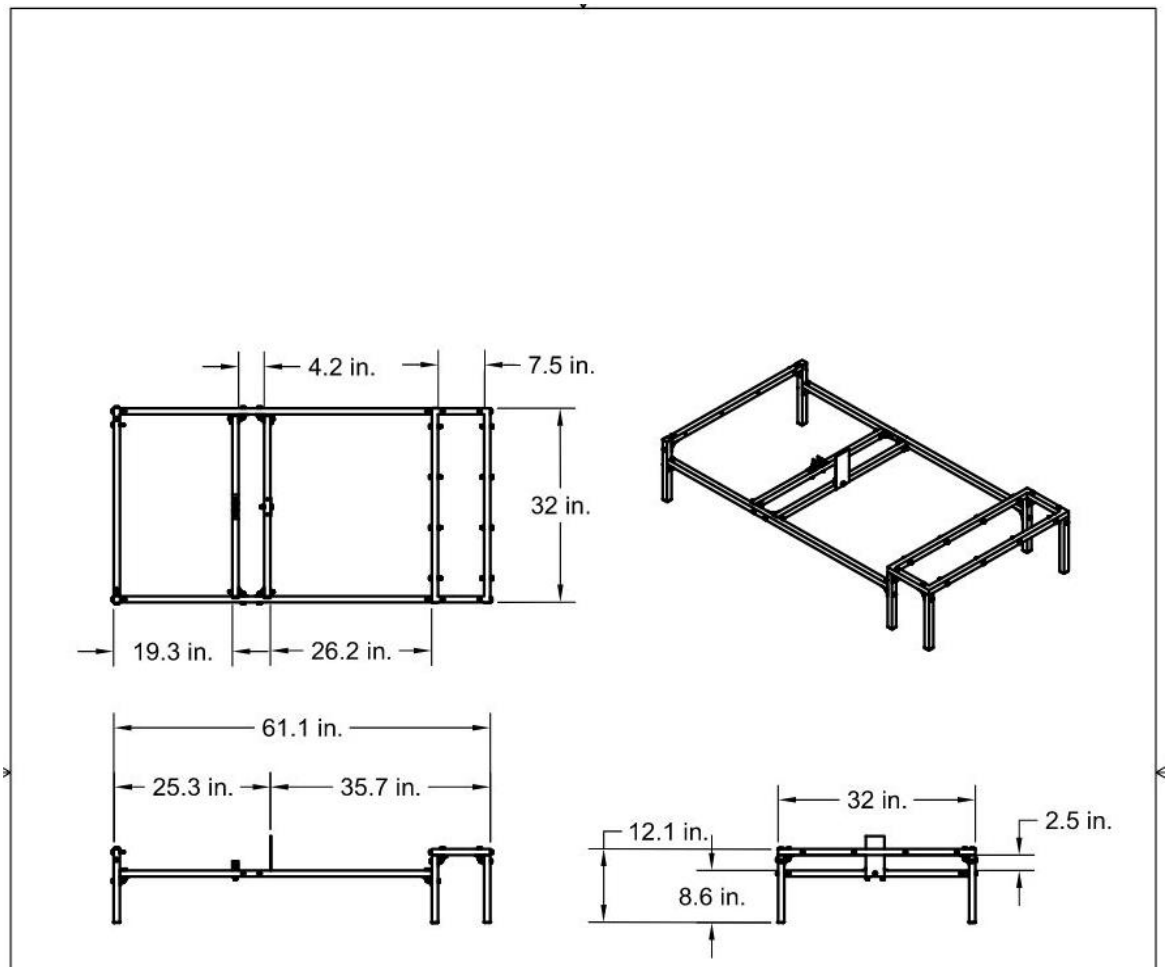


Figure G.1. Windmill blade testing device drawing.



	PROJECT Senior Design				
	TITLE Frame Assembly				
APPROVED	SIZE	CODE	DWG NO		REV
CHECKED	A				
DRAWN **Davida Campbell** 4/24/2020	SCALE **1/2" = 1'-0"**	WEIGHT		SHEET 1/1	

Figure G.2. Windmill blade testing device frame assembly.

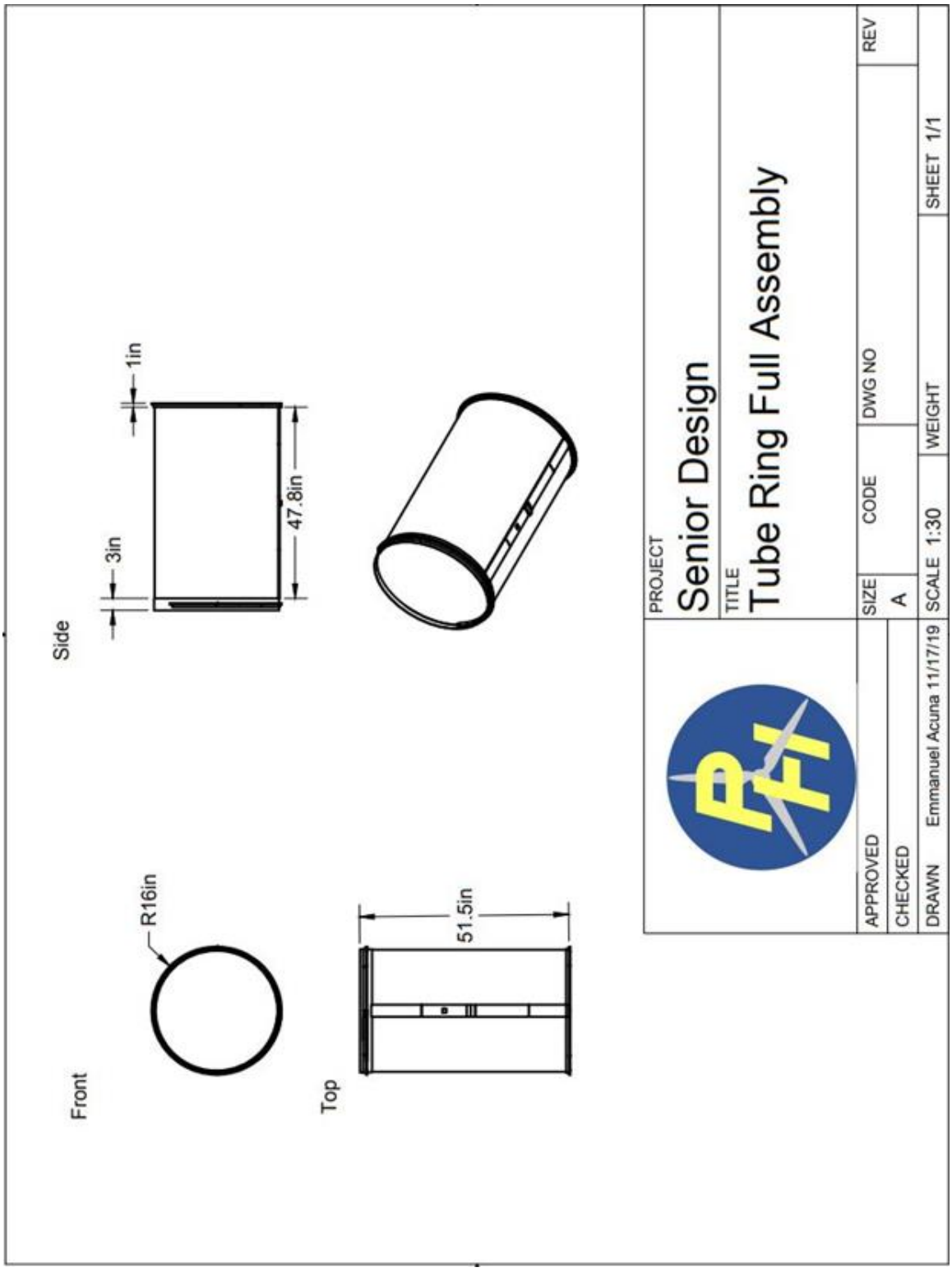


Figure G.3. Windmill blade testing device tube ring assembly.

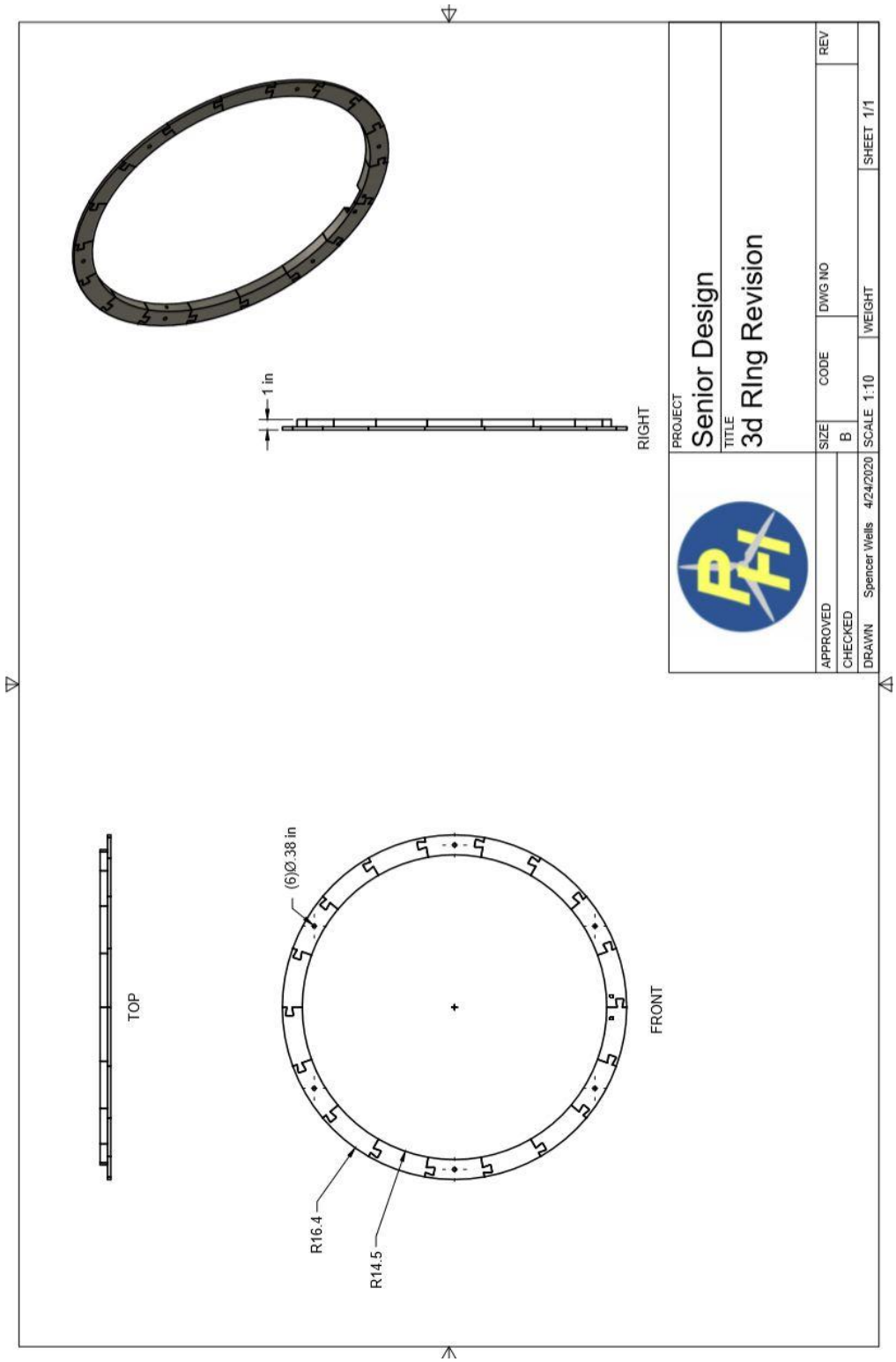


Figure G.4. Tube ring clip assembly.

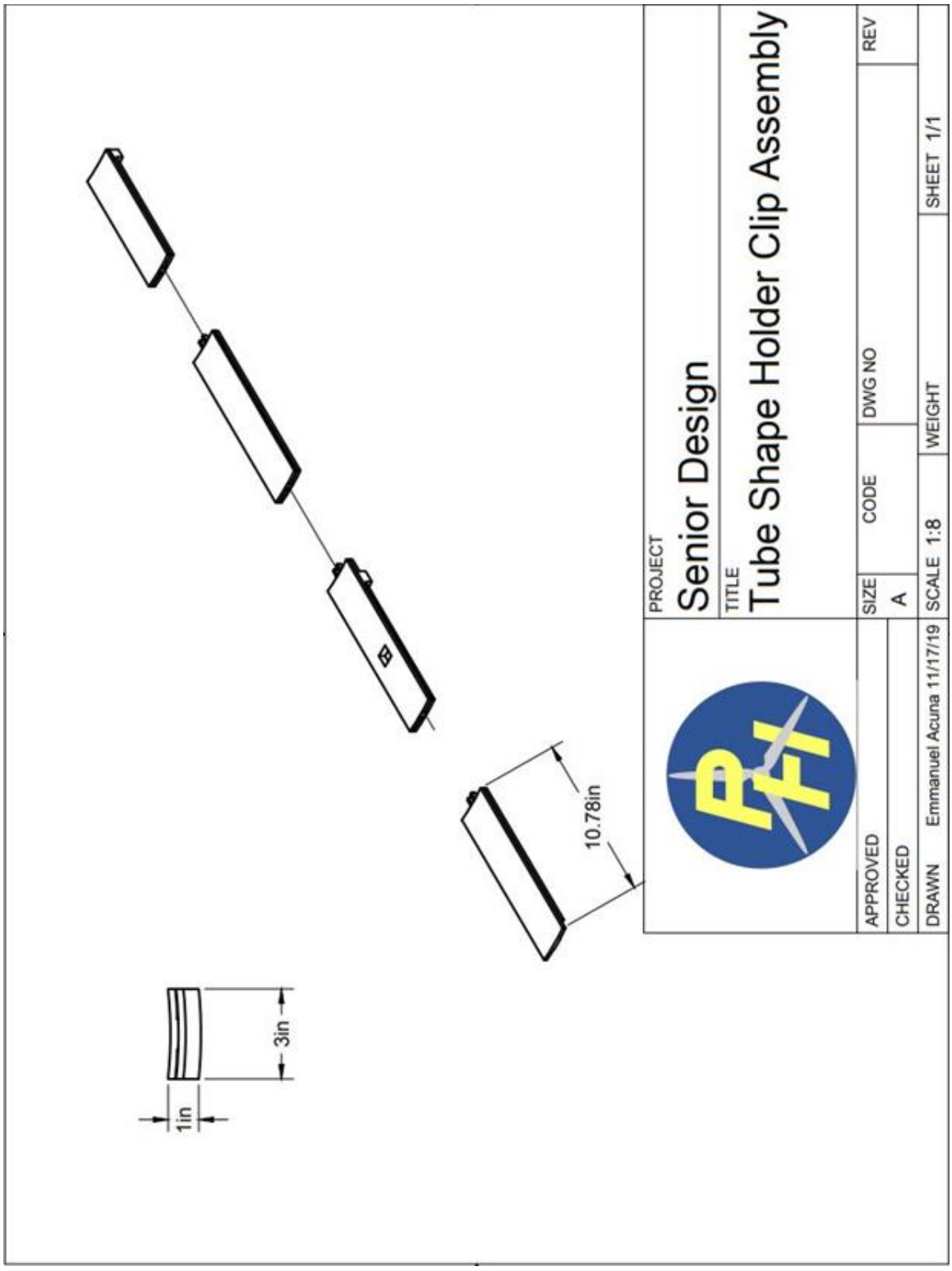


Figure G.5. Tube shape holder clip assembly.

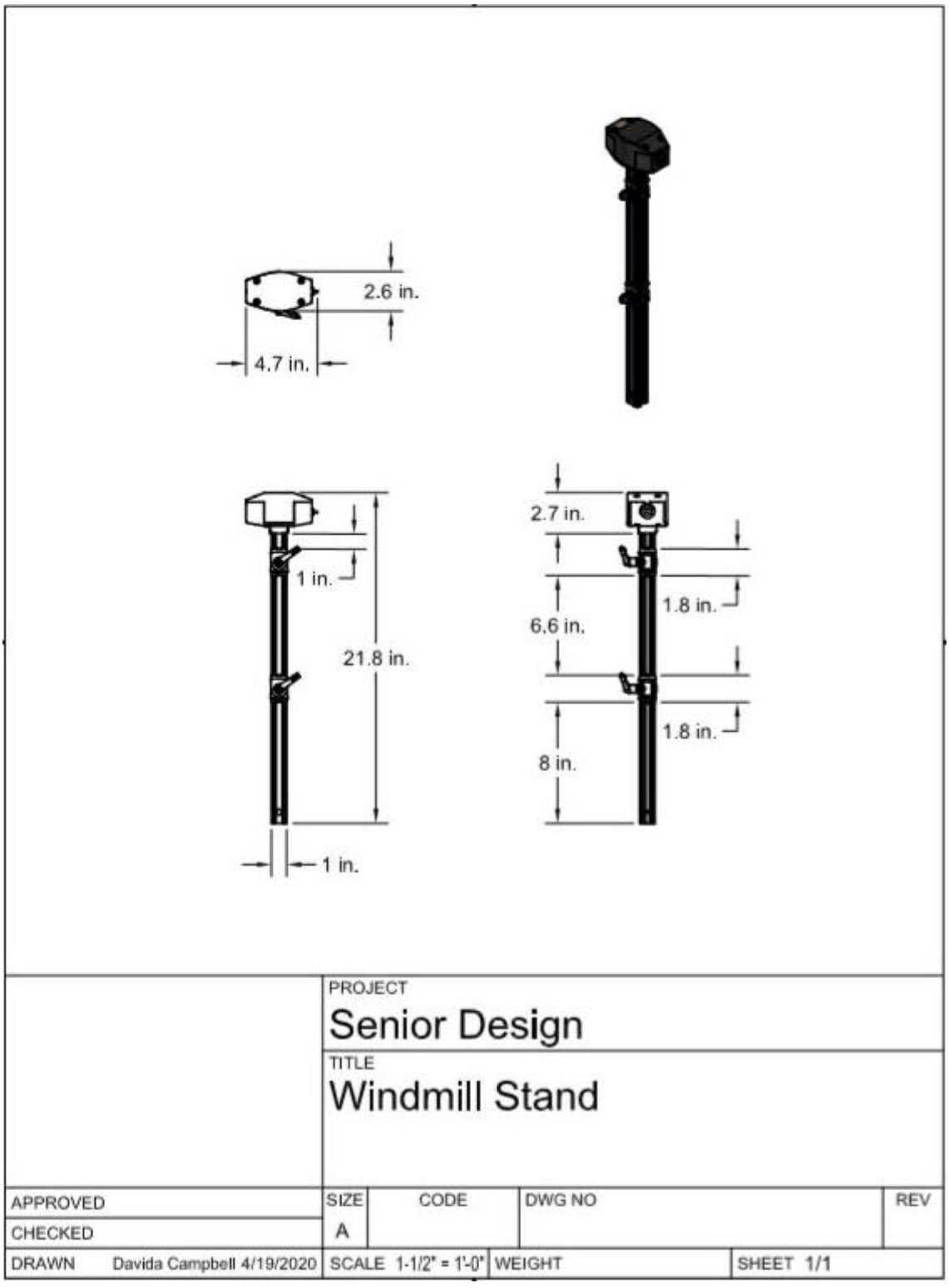


Figure G.6. Windmill stand drawing.

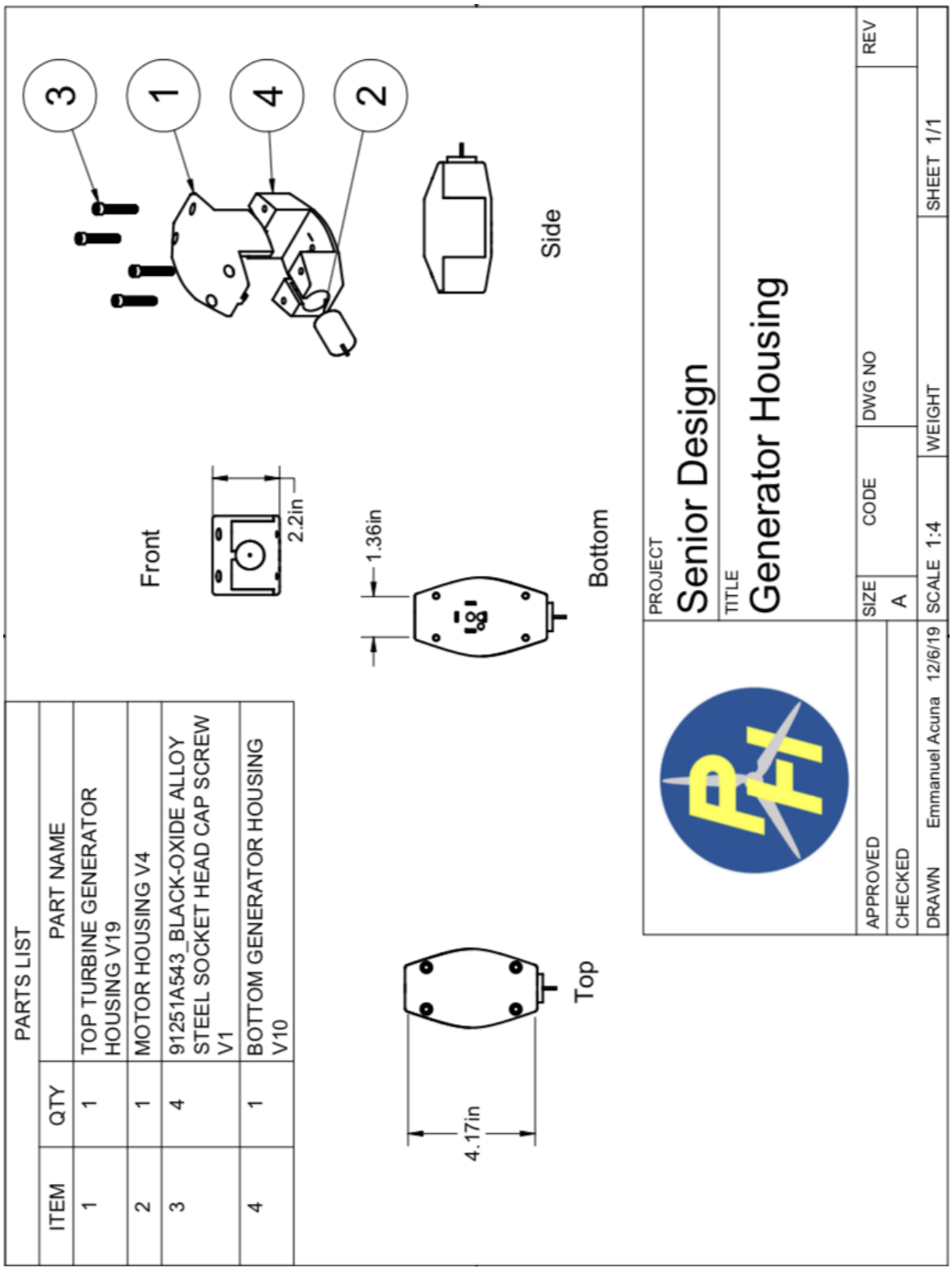


Figure 8.7. Generator housing assembly.

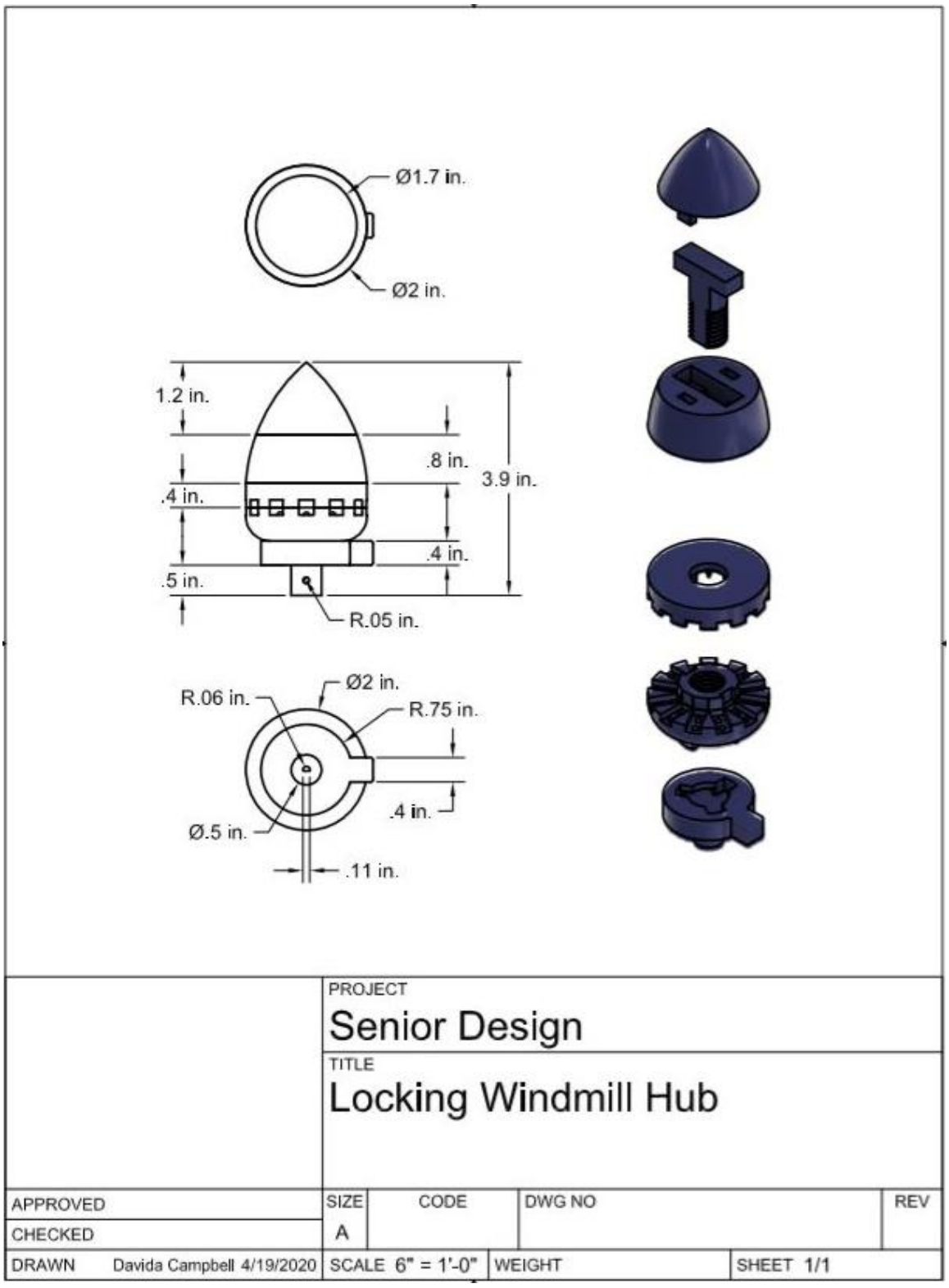


Figure G.8. Locking windmill hub drawing.

28. Appendix H: Circuit Diagrams

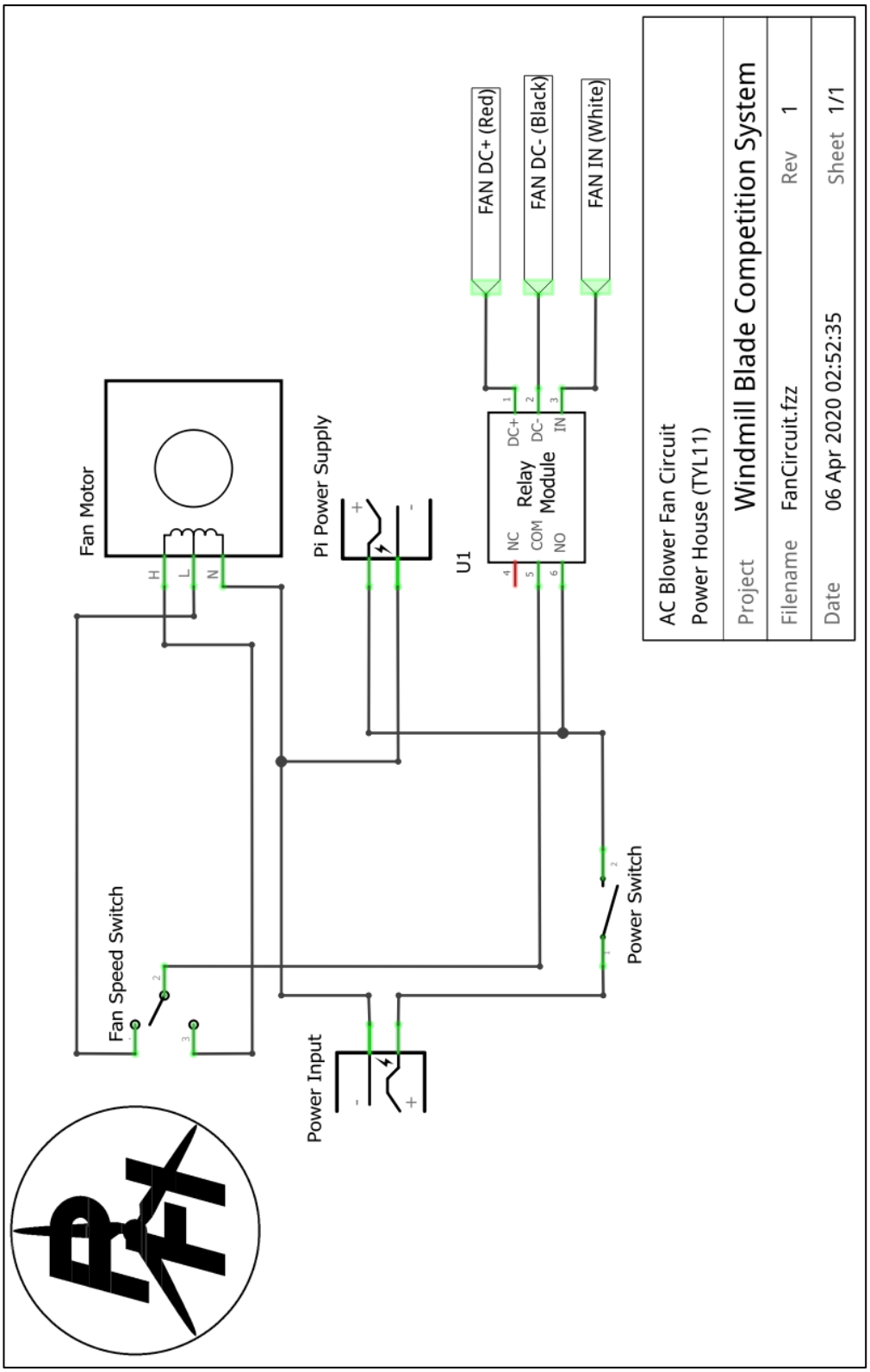


Figure H.1. AC fan wiring circuit.

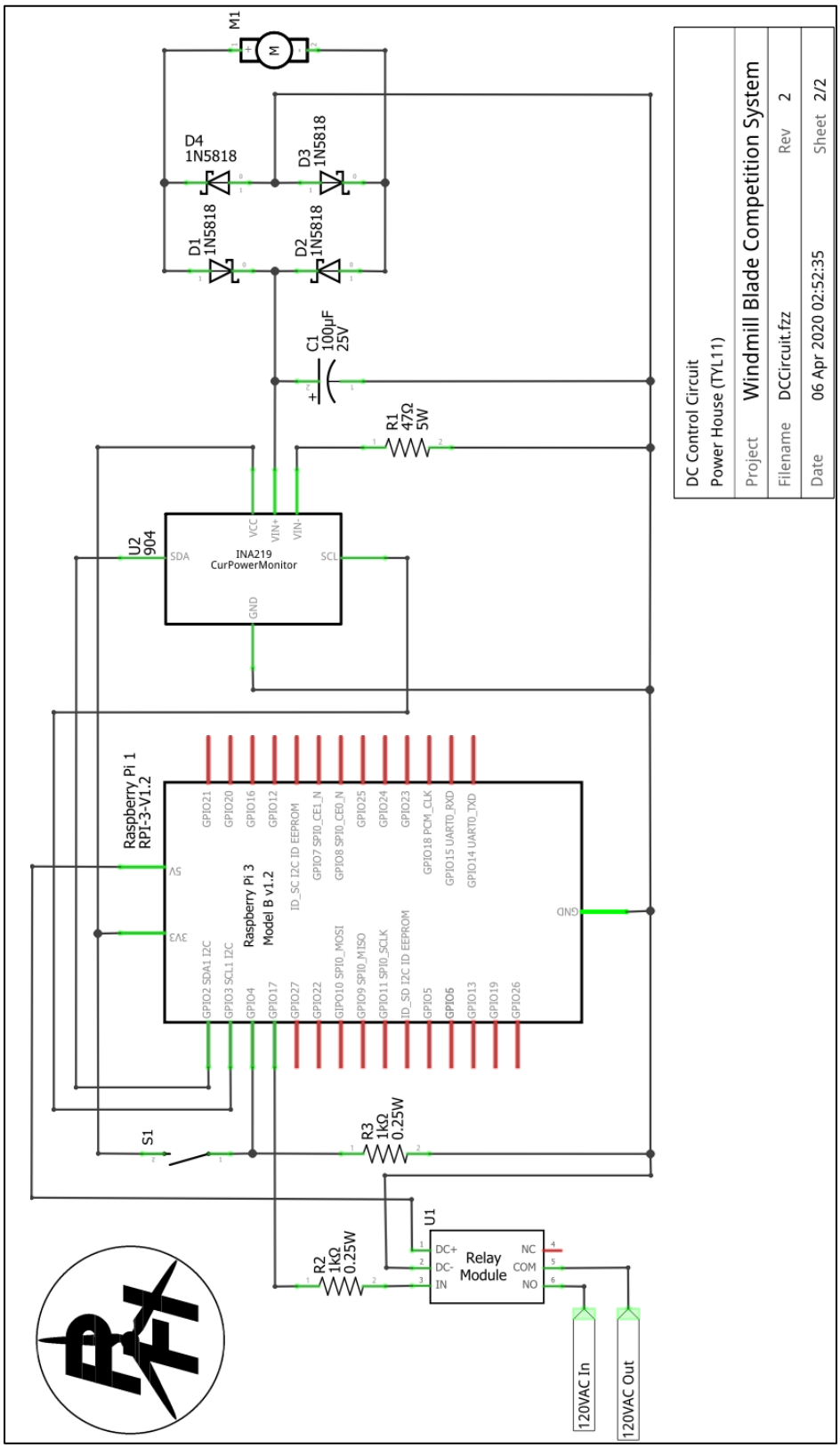


Figure H.2. Power measurement and control circuit.

29. Appendix I: Windmill Stand Force, Moment and Deflection Calculations

$$F = APC_d = A\rho v^2 \tag{1I}$$

The area the force is being exerted on is represented by *A*, the density of the air is represented by ρ and the velocity of the air is represented by *v* in Equation (1I). The assumed area the force of the air is exerted on is equal to the perpendicular contact area of the windmill mount stand and the windmill blades. The area of the windmill mount stand is 15.91 in^2 (0.11 ft^2). The assumed area of the windmill blades is 706.86 in^2 (4.91 ft^2). The density of the air can be assumed to be 0.0765 lb./ft^3, the average density of air at sea level.

$$F_{stand} = (0.11\ ft^2)(0.0765\ lbm/ft^3)(0.031\ slug/lbm)(18.7\ ft/s)^2 = 0.091\ lbf \tag{2I}$$

$$F_{blades} = (4.91\ ft^2)(0.0765\ lbm/ft^3)(0.031\ slug/lbm)(18.7\ ft/s)^2 = 4.08\ lbf \tag{3I}$$

$$F_{max} = 0.091\ lbf + 4.08\ lbf = 4.17\ lbf \tag{4I}$$

F_{stand} is the force exerted on the windmill mount stand by the airflow, F_{blades} is the maximum force exerted on the windmill blades and F_{max} is the maximum force of the airflow exerted on the windmill mount stand and windmill blades.

$$M_{base} = F_{stand}d_{stand} + F_{blades}d_{blades} \tag{5I}$$

$$M_{base} = (0.091\ lbf)(0.738\ ft) + (4.08\ lbf)(1.326\ ft) = 5.48\ ft - lbf \tag{6I}$$

The moment about the base of the stand is represented by M_{base}. The distance from the base of the stand to the force applied to the stand is expressed as the variable d_{stand}. The variable d_{blades} is represented as the distance between the base of the windmill mount stand and the force applied to the stand by the blades.

$$S_{max} = \frac{F_{stand}{d_{stand}}^3}{3EI}\left(1 + \frac{3b}{2d_{stand}}\right) + \frac{F_{blades}{d_{blades}}^3}{3EI} \tag{7I}$$

The deflection of the beam is represented by S_{max} in Equation (7I). The variables *E*, *I*, and *b* represent the modulus of elasticity of the windmill mount stand, moment of inertia of the windmill mount stand, and the distance from the force being exerted on the windmill mount stand to the bottom end of the windmill mount.

The modulus of elasticity for Aluminum 6063-T5 is 10,000 ksi (1.44×10^6 ksf). The moment of inertia of the windmill mount stand can be calculated by using Equation (8I).

$$I = \frac{a^3h}{12} + \frac{b^3}{12}(H - h) \tag{8I}$$

Figure I.1. illustrates the meanings of each variable in Equation (8I).

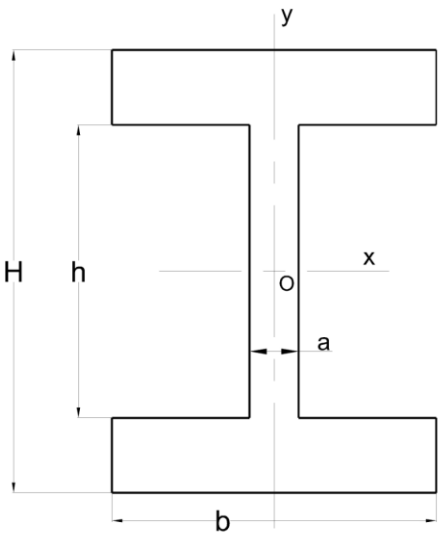


Figure I.1. Cross sectional area of cantilever beam with variable dimensions.

The moment of inertia for the simplified windmill mount stand is 3.454 in^4 (1.67×10^{-4} ft^4).

$$S_{max} = \frac{(0.091\ lbf)\ (0.738\ ft)^3}{3(1.44\times10^6 ksf)(1.67\times10^{-4} ft^4)}\left(1 + \frac{3(0.578ft)}{2(0.738ft)}\right) + \frac{(4.08lbf)(1.32ft)^3}{3(1.44\times10^6 ksf)(1.67\times10^{-4} ft^4)} \qquad (9I)$$

$$S_{max} = 1.32 \times 10^{-5}\ ft$$

30. Appendix J: FEAs of the Windmill Stand and 3D Printed Frame

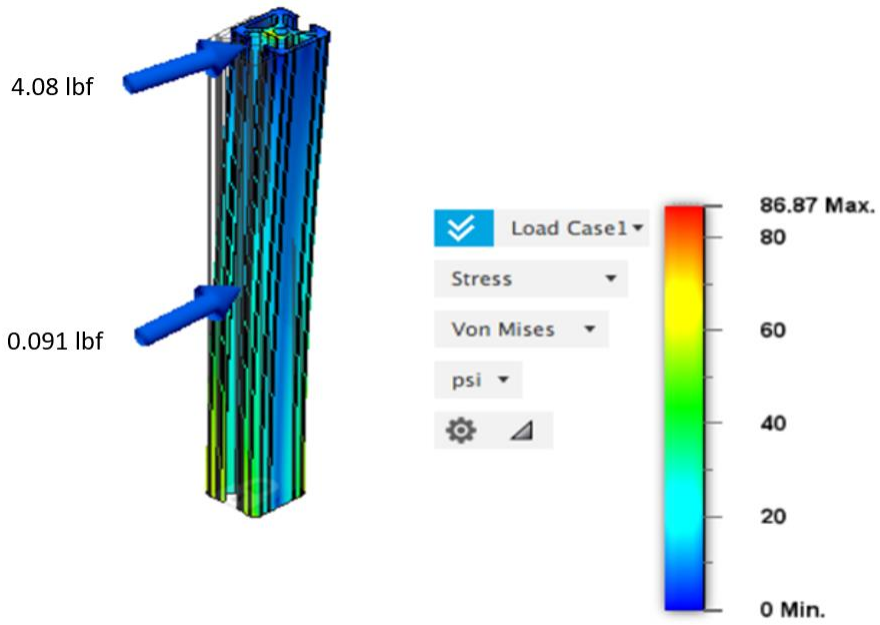


Figure J.1. Windmill mount stand stress analysis.

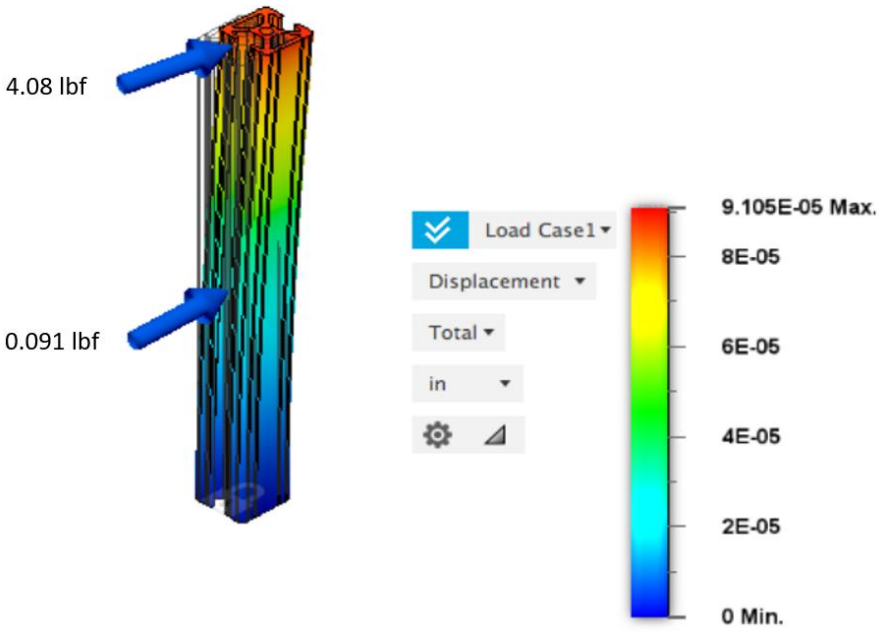


Figure J.2. Windmill mount stand displacement analysis.

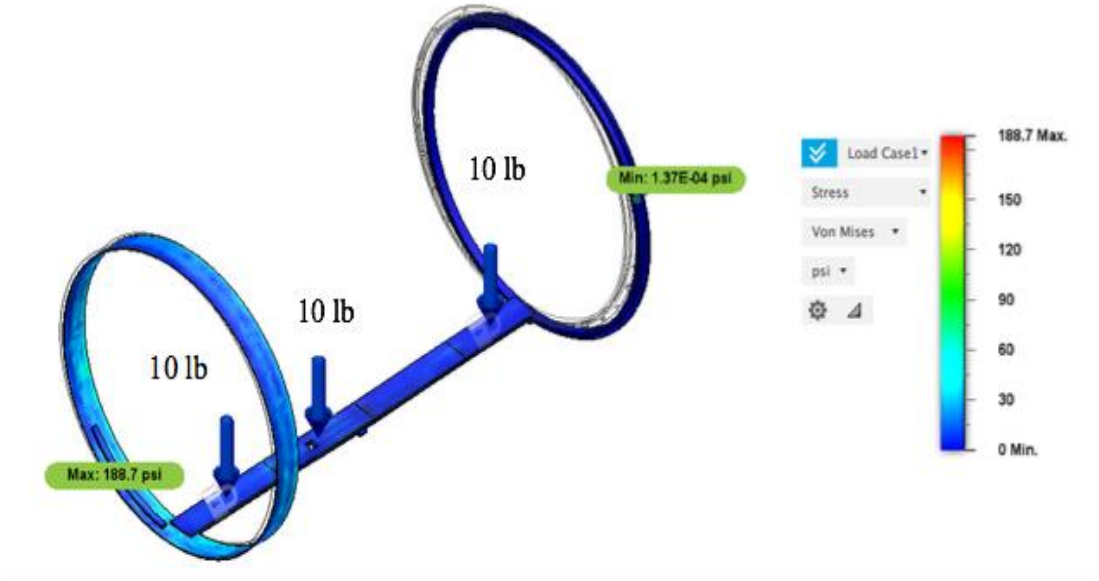


Figure J.3. 3D printed tube-ring assembly stress analysis.

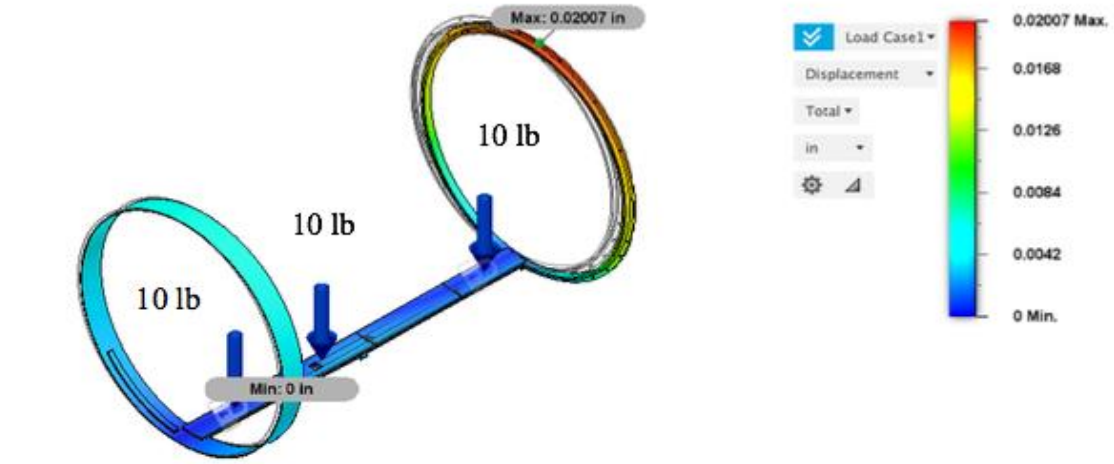


Figure J.4. 3D printed tube-ring assembly displacement analysis.

31. Appendix K: Windmill Stand Screw Factor of Safety Derivation

$$n_f = \frac{S_e\,(S_{ut} - \sigma_i)}{\sigma_a\,(S_{ut} + S_e)} \tag{1K}$$

The minimum tensile strength is represented by the variable S_{ut}. The variable S_e represents the endurance strength of a screw and can be calculated using Equation (2K).

$$S_e = k_a k_b k_c k_d k_e k_f S_e' \tag{2K}$$

In Equation (2K), the following factors are represented: the surface condition modification, size modification, load modification, temperature modification, reliability modification, and miscellaneous effects modification.

The surface condition modification factor, k_a, can be calculated using Equation (3K).

$$k_a = a S_{ut}^b \tag{3K}$$

In Equation (3K), a and b are equal to 2.70 kpsi and -0.265 respectively for a machined surface finish. The size modification factor, k_b, can be calculated using Equation (4K) for a screw with a diameter between 0.11 and 2 inches.

$$k_b = 0.879 d^{-0.107} \tag{4K}$$

The load modification factor, k_c, will be equal to 0.59 for torsional loading. The temperature modification factor, k_d, is about 1 for a screw during use.

The reliability factor, k_e, will assumed to 0.814 for a reliability percentage of 99%. The miscellaneous effects modification factor, k_f, accounts for the reduction in endurance of the screw. A negligible miscellaneous effect will be assumed and set to 1. The variable S_e' in Equation (2K) will be assumed to be 80,000 psi. The variable σ_a represents the amplitude component of the stress the screw encounters. Equation (5K) illustrates the calculation for the amplitude component of the stress on the screw.

$$\sigma_a = \left|\frac{\sigma_{max} - \sigma_{min}}{2}\right| \tag{5K}$$

The variable σ_i in Equation (5K) represents the initial preload stress experienced by the screw. The variables σ_{max} and σ_{min} represent maximum and minimum stresses applied to the screw. The maximum stress will be assumed to be F_{max} divided by the area of the screw, which is 0.049 in^2, and the minimum stress will be assumed to be zero. For the fatigue factor of safety for a repeat loading condition, the initial preload stress of one screw will be assumed to be zero. Equations (1K) and (2K) are used in Equations (6K) and (7K) to determine the factor of safety.

$$S_e = k_a k_b k_c k_d k_e k_f S_e' = 33.114\ ksi \tag{6H}$$

$$n_f = \frac{S_e\,(S_{ut} - \sigma_i)}{\sigma_a\,(S_{ut} + S_e)} = \frac{33.114\ ksi\ (80\ ksi - 0)}{42.55\ psi\ (80\ ksi + 33.114\ ksi)} = 550.4 \tag{7K}$$

Equation (8K) represents the fatigue factor of safety for a screw encountering variable loading.

$$n_f = \frac{1}{\frac{\sigma_a}{S_e} + \frac{\sigma_m}{S_{ut}}} \tag{8K}$$

The variable σ_m represents the midrange stress the screw encounters during operation and can be calculated using Equation (9K).

$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2} \tag{9K}$$

The fatigue factor of safety for the screws encountering variable loading of the windmill mount stand was calculated using Equation (8K) is shown with Equation (10K).

$$n_f = \frac{1}{\frac{\sigma_a}{S_e} + \frac{\sigma_m}{S_{ut}}} = \frac{1}{\frac{42.55\ psi}{32114\ psi} + \frac{42.55\ psi}{80000\ psi}} = 538.5 \tag{10H}$$

32. Appendix L: Maximum Power Generation Derivation

$$P_{gen} = \frac{1}{2}\rho A v^3 C_p \quad (1L)$$

Air density is represented by ρ, swept area of the wind turbine blades is represented by *A*, air velocity is represented by *v*, and the power coefficient of the turbine is represented by C_p in Equation (1L). Obtaining maximum theoretical power can be achieved by utilizing Equation (1L) and Betz' Limit. Betz's Limit states a maximum of 59.3% of the kinetic energy from wind can be captured by a wind turbine. Replacing the power coefficient with Betz's Limit yields Equation (2L).

$$P_{max} = \frac{1}{2}\rho A v^3 \beta \quad (2L)$$

The theoretical maximum power generation of a wind turbine is represented by P_{max} in Equation (2L). The average air density of the operational environment can be determined from air characteristics, and the velocity of the air can be determined by ASHRAE Standard 41.2-2018 [1]. Knowing the theoretical maximum power generation is a tool used for selecting the appropriate generators for the system.

The proposed testing chamber has an internal diameter of 30 inches (2.5 ft).

$$Area = A = \pi r^2 = 4.91\ ft^2 \quad (3L)$$

After implementing the Log-Linear Rule for finding the average velocity of air in the testing chamber, the maximum average air velocity in the chamber is found to be 18.70 ft/s.

$$Velocity = v = Q/A = (91.80\ ft^3/s)/(4.91\ ft^2) = 18.70\ ft/s \quad (4L)$$

This maximum average airflow velocity has been verified by a simulation of the airflow through the testing chamber, shown in Figure L.1.

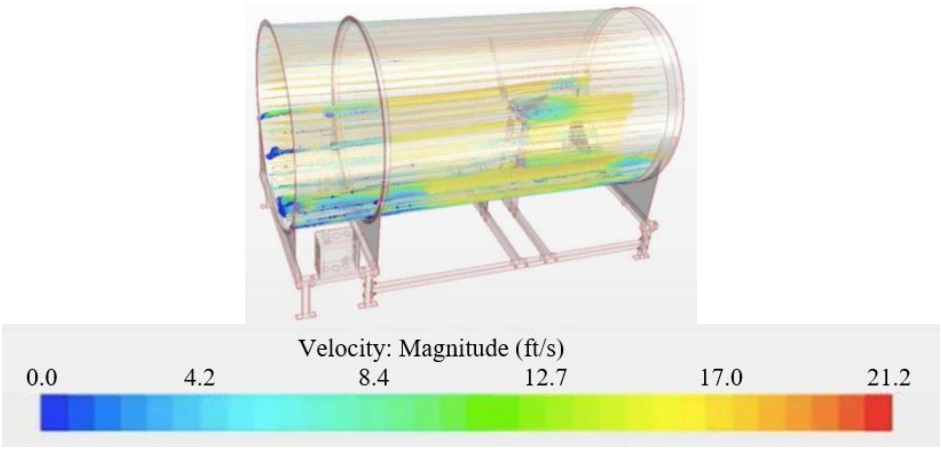


Figure L.1. Simulation of airflow through the testing chamber.

The air density can be determined by taking the dry bulb temperature, pressure, and humidity of the air into consideration. The density of the air is found to be 0.0765 lbm/ft^3. Finally, area, density, velocity, and Betz's Limit can be used in Equation (2L) to find the maximum theoretical power generation.

$$P_{max} = \frac{1}{2}(0.0765\ lbm/ft^3)(0.031\ slug/lbm)(4.91\ ft^2)(18.70\ ft/s)^3(0.593) \qquad (5L)$$

$$P_{max} = 22.58\ (ft\ lbf)/s$$

33. Appendix M: Electrical Components

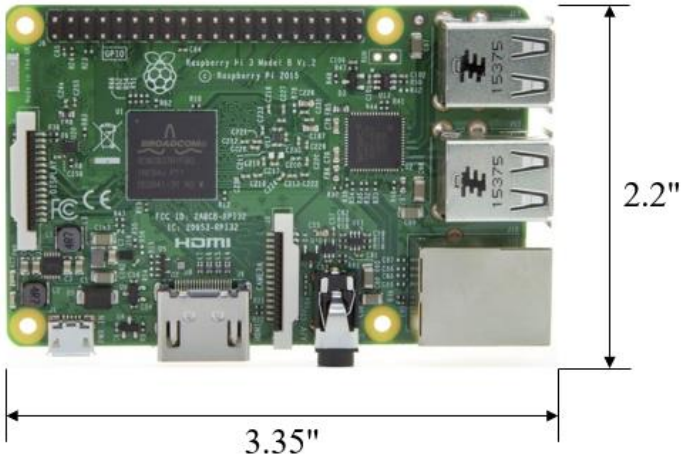


Figure M.1. Raspberry Pi 3B with dimensions.

Table M.1. Key specifications of the Raspberry Pi 3B [5].

Specification	**Value**
Input Voltage	5 V
Input Current	2.5 A
Supply Voltages	3.3 V and 5 V
Maximum 3.3 V Pin Current	50 mA
Processing Unit	Quad Core 1.2GHz Broadcom BCM2837 64bit CPU
RAM Size	1 GB
Number of I/O Pins	40 general purpose I/O (GPIO) pins
Communication Methods	BCM43438 wireless LAN, Bluetooth Low Energy, UART, I^2C

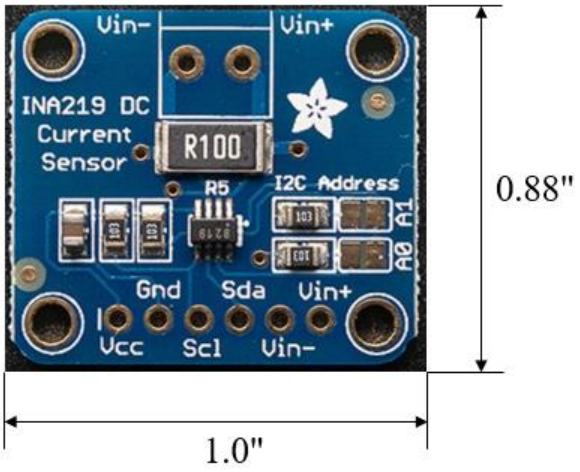


Figure M.2. Adafruit INA219 current sensor breakout board with dimensions.

Table M.2. Key specifications of the Adafruit INA219 breakout board [6].

Specification	**Value**
Supply Voltage	3-5.5V
Maximum Supply Current Draw	1 mA
Current Resolution	0.1 mA or 0.8 mA
Maximum Input Current	400 mA or 3.2 A
Maximum Measurement Error	±0.5 %
Communication Method	I^2C

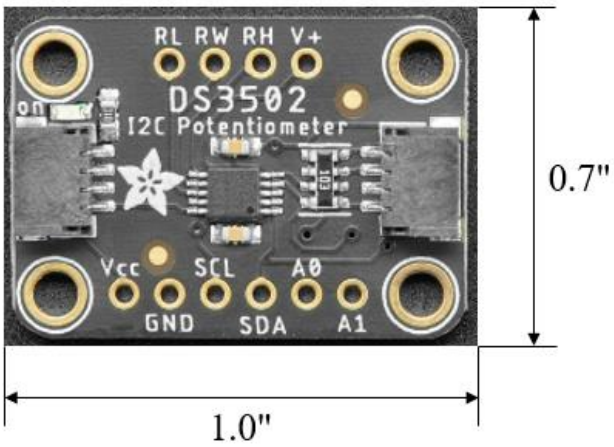


Figure M.3. Adafruit DS3502 digital potentiometer breakout board with dimensions.

Table M.3. Key specifications of the Adafruit DS3502 breakout board [8].

Specification	**Value**
Supply Voltage	2.5-5.5V
Maximum Supply Current Draw	3 mA
Resistance Range	0 to 10 kΩ
Step Size	78.125 Ω
Communication Method	I2C

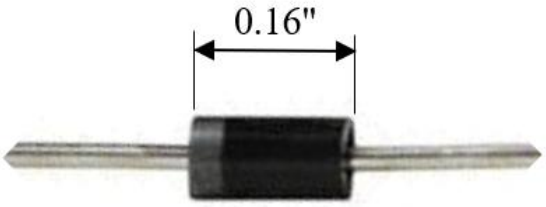


Figure M.4. STMicroelectronics 1N5818 Schottky diode.

Table M.4. Key specifications of the 1N5818 Schottky diode [9].

Specification	**Value**
Repetitive Peak Reverse Voltage	30 V
Average Forward Current	1 A
Forward Voltage Drop	0.5 V
Reverse Leakage Current	0.5 mA

34. Appendix N: Circuit Simulations

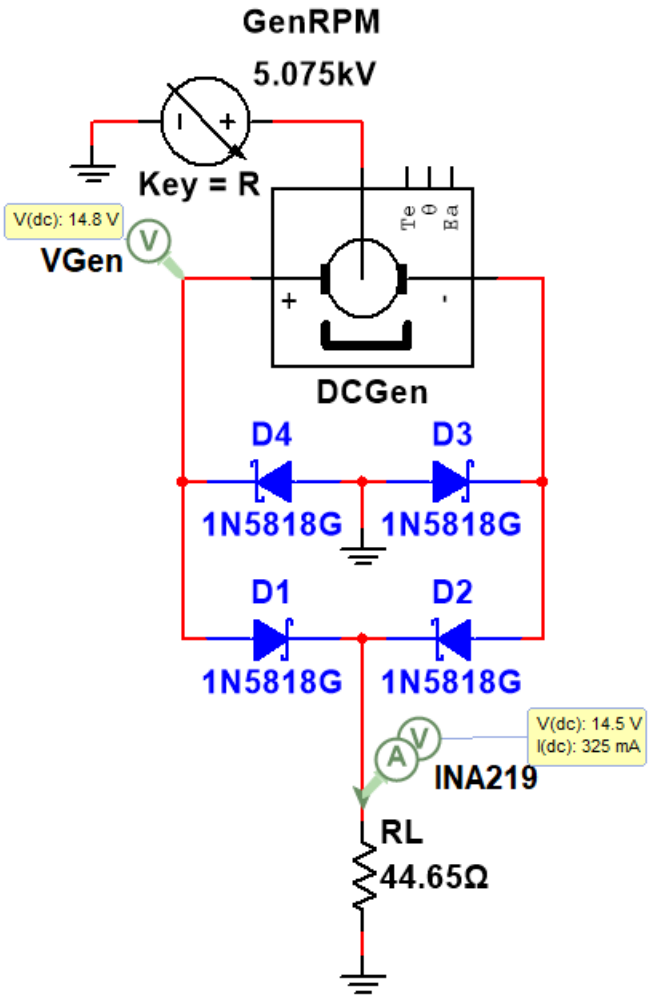


Figure N.1. Multisim simulation of the single generator power measurement circuit.

35. Appendix O: Removed and Updated Components

This appendix contains the components that were originally planned for use in the final design prior to the design review. After receiving feedback from the sponsor and reviewers in the design review, the following components were removed from the design and BOM.

35.1. Sliding Windmill Mounting Rail

The Igus mounting rail and slider, shown in Figure O.1, were selected to allow for the distance between the windmill mount and blower fan to be varied. This part will not be used in the final design due to reviewer feedback recommending the removal of the sliding windmill mount since the airspeed remains consistent in the testing chamber at different distances. The removal of this part reduced the projected cost by $118.89.

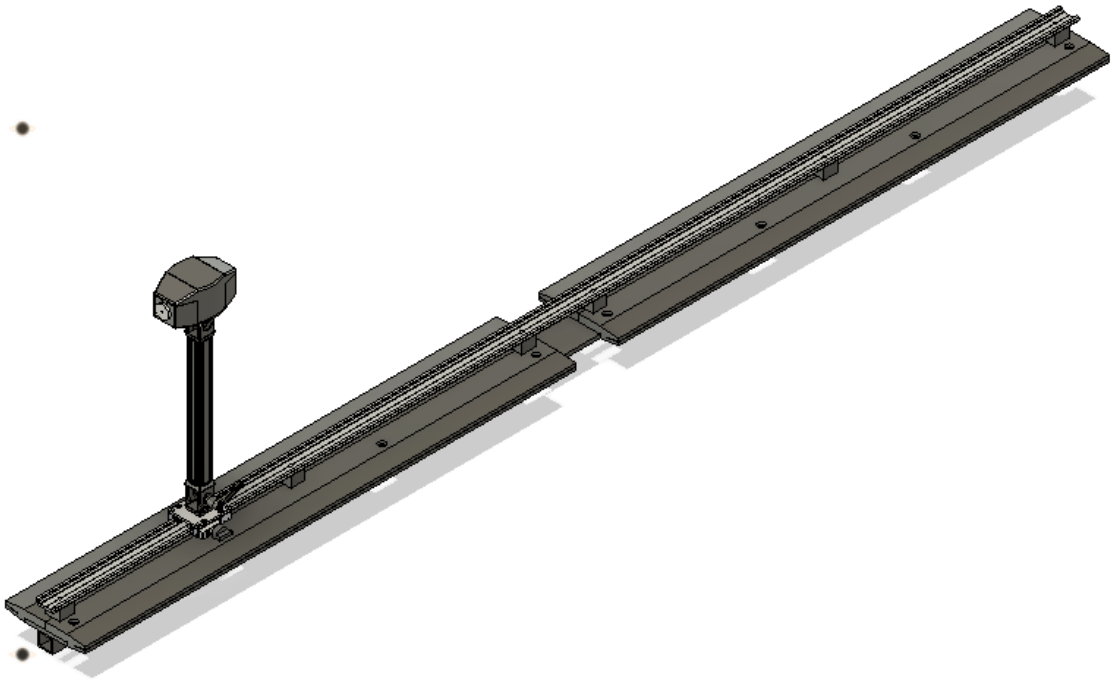


Figure O.1. Sliding windmill mounting rail.

35.2. Selected Stepper Motor Driver

The Pololu DRV8825 stepper motor driver breakout board was selected to allow for motorized distance control of the windmill mount. It is shown in Figure O.2 with its key specifications shown in Table O.1. This part will not be used in the final design due to the removal of the sliding windmill mount. The removal of this part reduced the projected cost by $11.85.

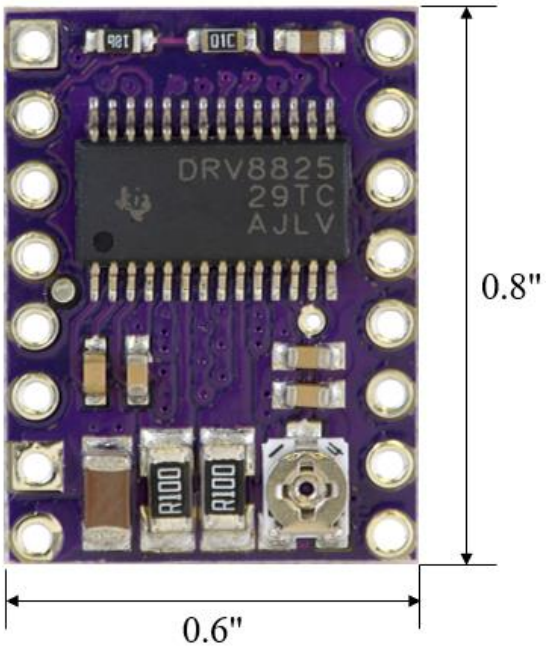


Figure O.2. Pololu DRV8825 stepper motor driver breakout board with dimensions.

Table O.1. Key specifications of the Pololu DRV8825 breakout board [11].

Specification	**Value**
Output Voltage Range	8.2-45 V
Continuous Driver Current	1.5 A
Maximum Driver Current	2.2 A
Logic Voltage Range	2.5-5.25V

35.3. Previous Windmill Hub Assembly

The windmill hub displayed in Figure O.3 was selected due to being a commercially available component that fit within the project specifications. During the design review, concerns about the feasibility of the mount were addressed and this part was removed and replaced.

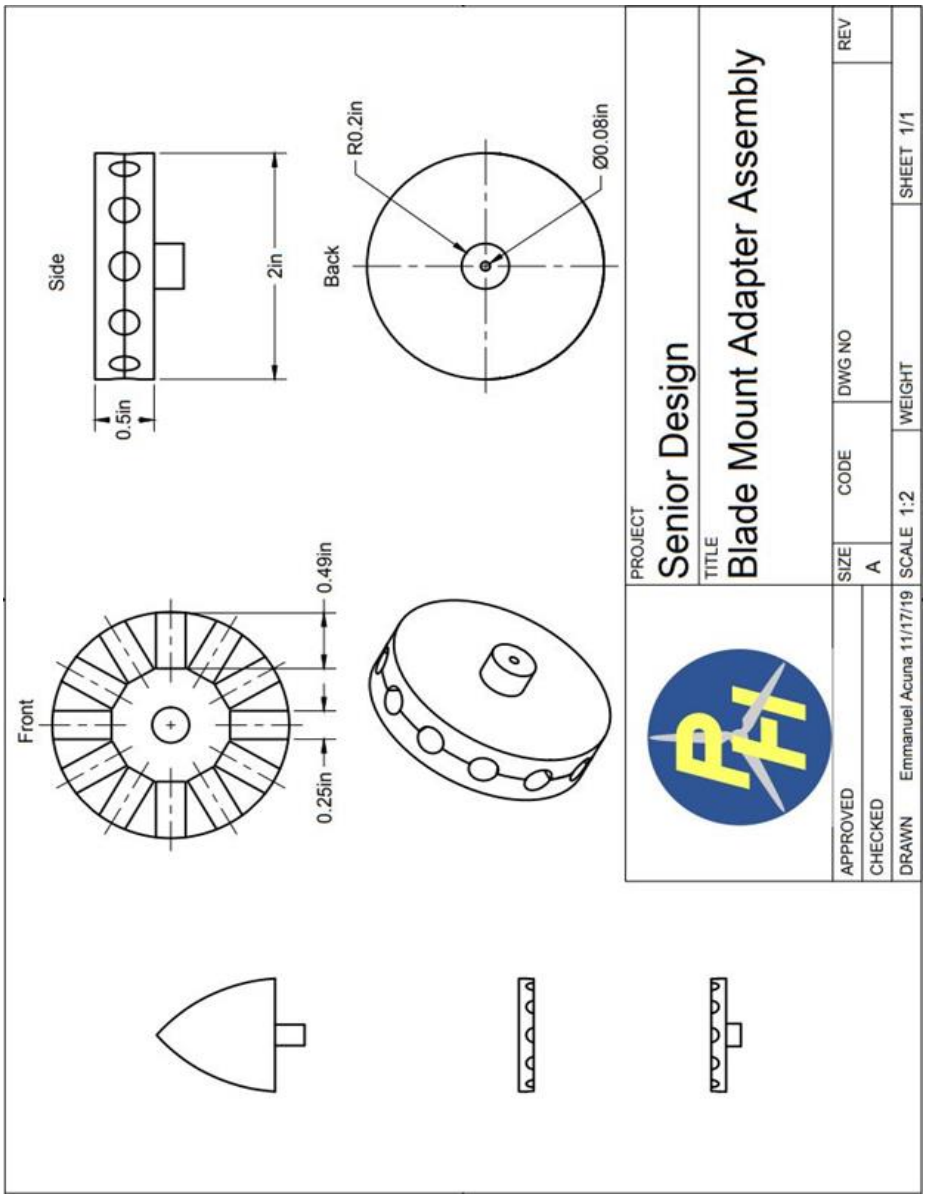


Figure O.3. Commercially available windmill hub.

35.4. Previous Windmill Mount Assembly

Figures O.4, O.5, and O.6 display the windmill mount assembly prior to the changes implemented from the design review.

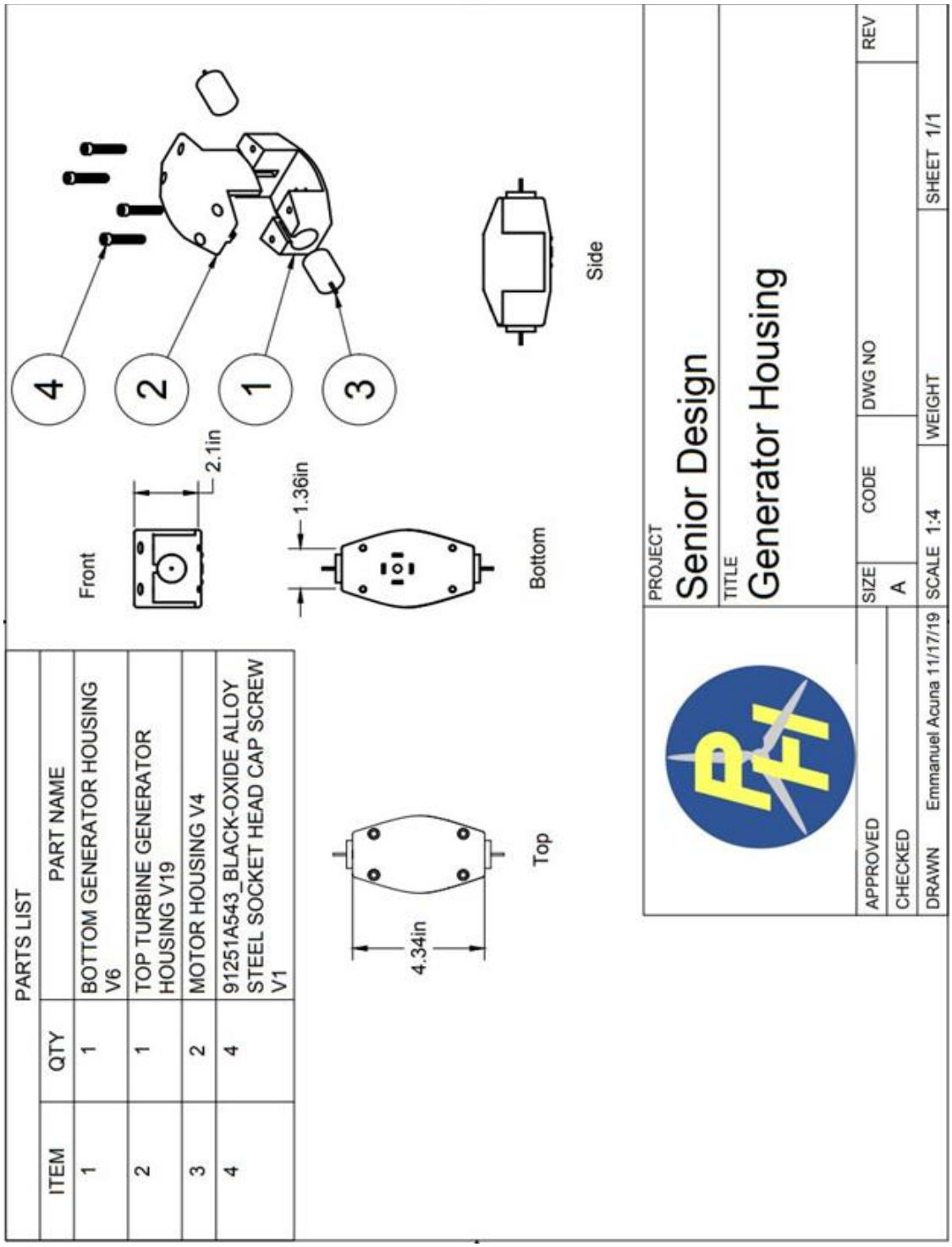


Figure O.4. Original generator housing for two generators.

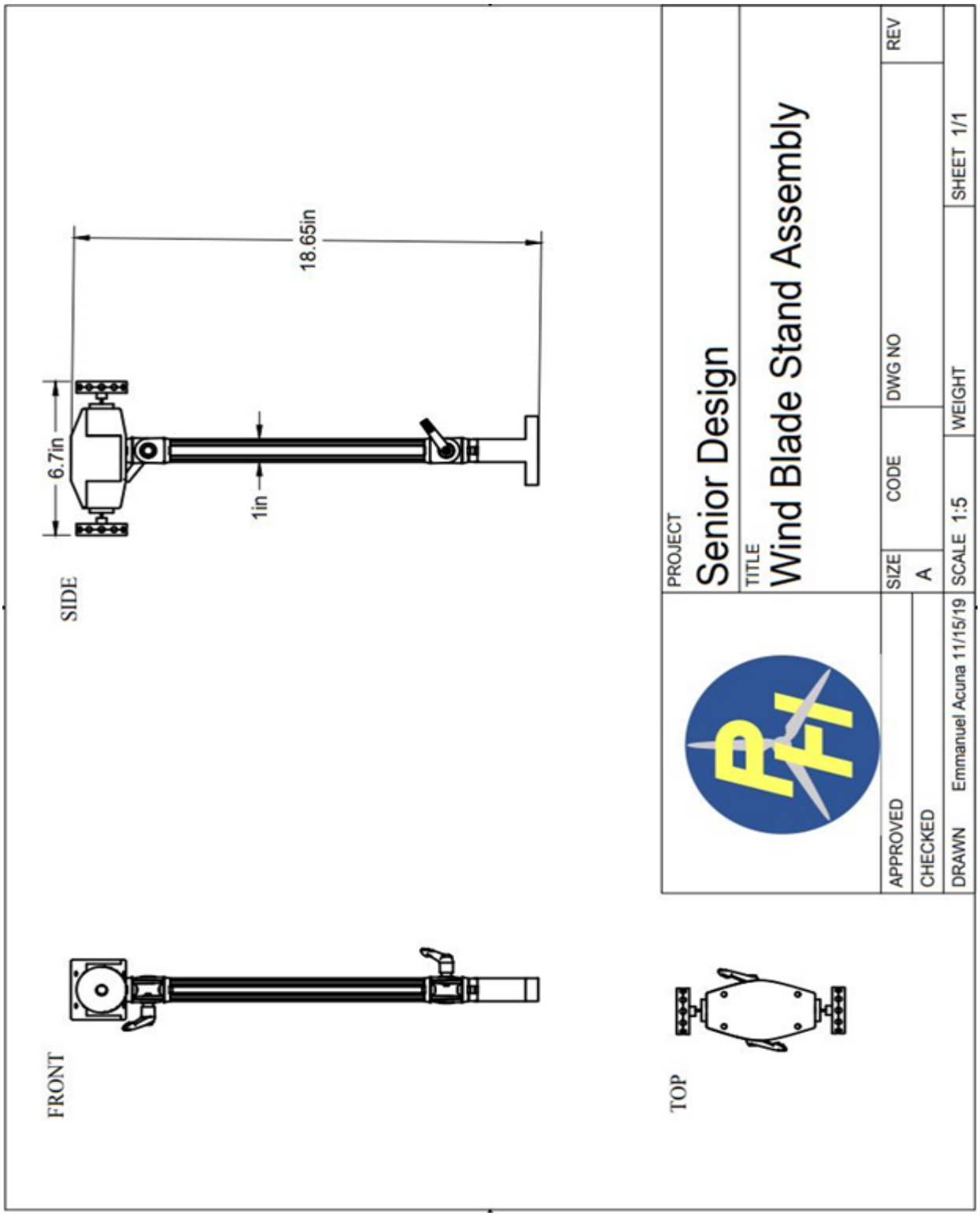


Figure O.5. Original windmill blade mount stand assembly with two generator mounts.

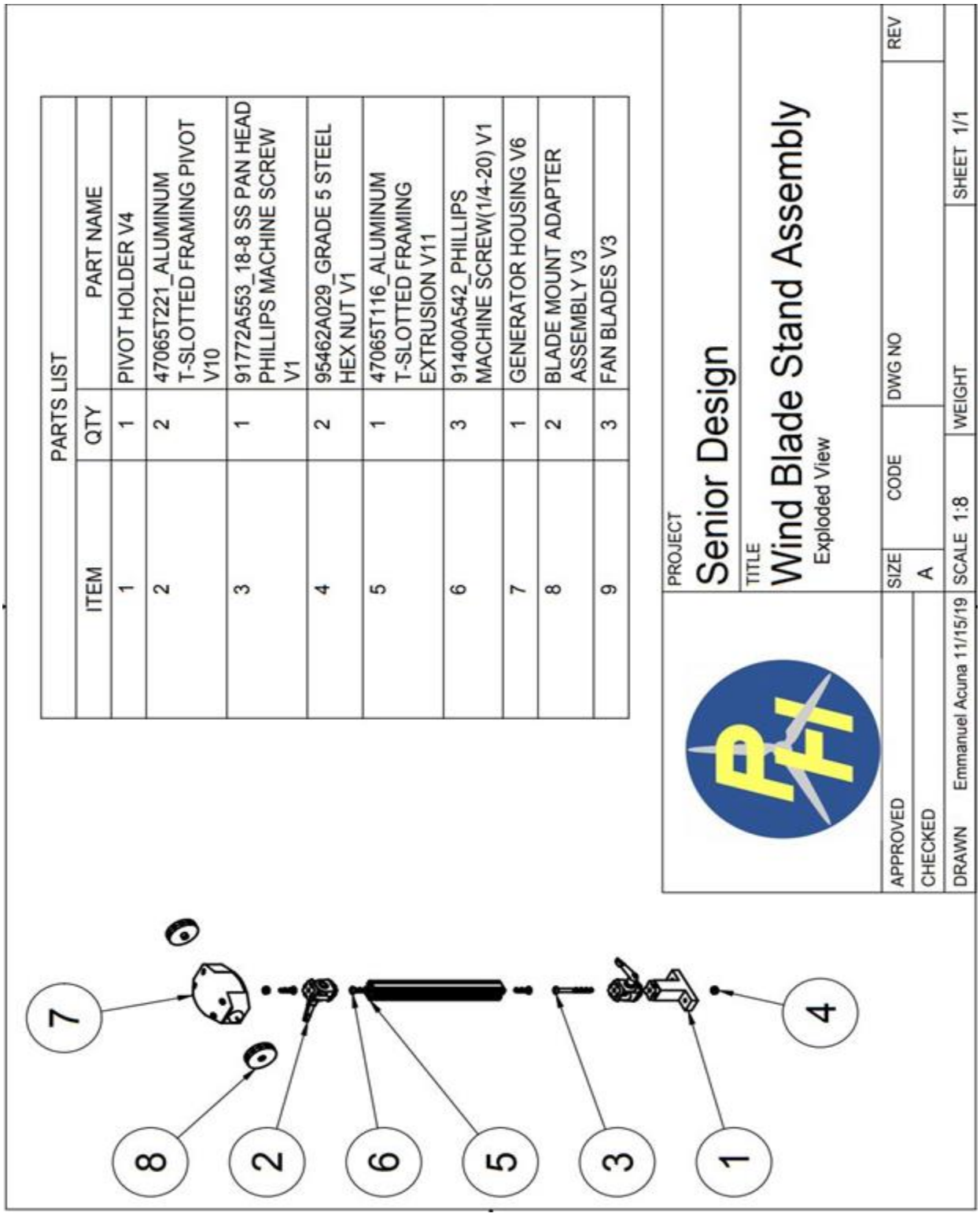


Figure O.6. Original windmill blade mount stand exploded view with two generator mounts.

35.5. Original Power Measurement Circuit

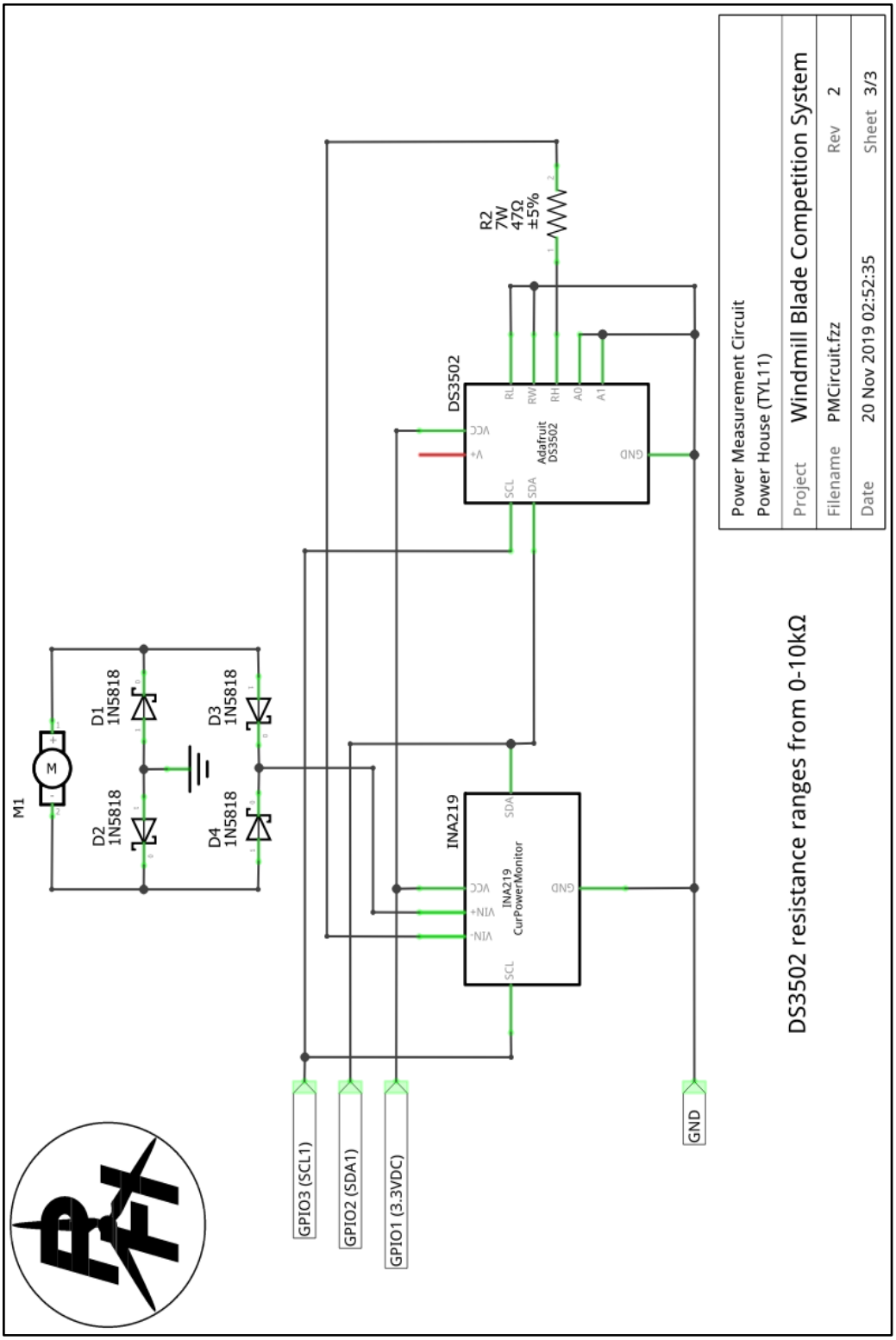


Figure O.7. Single generator power measurement circuit schematic Ver 1.

35.6. Stepper Motor Control Circuit

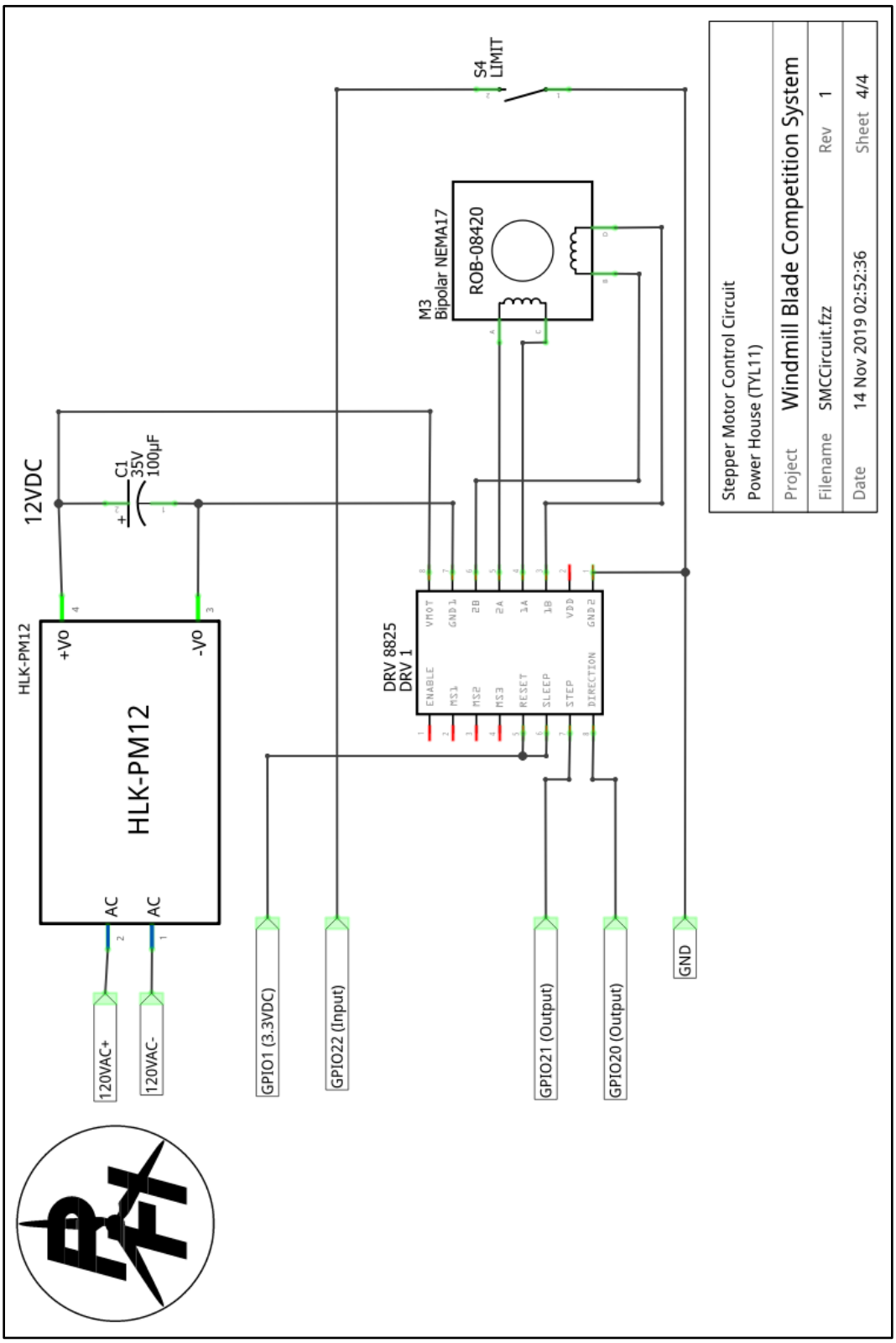


Figure O.8. Motorized windmill mount stepper motor control circuit schematic.

36. Appendix P: Program Code

36.1. Competition Interface Program

The following program is the main user interface and controller for the competition system.

```
# Power_House.py - Ver. 2
# Provides a simple interface between a Raspberry Pi and an INA219 sensor
# Written By: Joshua Stapp for Power House (TYL11)

# Import Statements
import tkinter as tk
from tkinter import ttk
from tkinter import font as tkfont
from datetime import datetime, timedelta
from fan_controller import FanController
from power_handler import PowerHandler
from sheet_handler import SheetHandler as sh
from googleapiclient.errors import HttpError

class SampleApp(tk.Tk):

    def __init__(self, *args, **kwargs):
        tk.Tk.__init__(self, *args, **kwargs)

        # Gets screen dimensions
        self.HGT = self.winfo_screenheight()
        self.WDT = self.winfo_screenwidth()

        # Stores config file data
        self.NAME = config_data[0]
        self.ID = config_data[1]
        self.PATH = config_data[2]
        self.BG = config_data[3]
        self.TXT = config_data[4]

        # Sets app to fullscreen mode
        self.geometry("%dx%d+0+0" % (self.WDT, self.HGT))

        # Initializes SheetHandler for the competition
        self.handler = sh(self.ID, self.PATH)

        # Initializes frame container for holding different UI frames
        container = tk.Frame(self)
        container.pack(side="top", fill="both", expand=True)
```

```
        container.grid_rowconfigure(0, weight=1)
        container.grid_columnconfigure(0, weight=1)

        # Creates frames for the UI
        self.frames = {}
        for F in (LeaderFrame, CompPage):
            page_name = F.__name__
            frame = F(parent=container, controller=self)
            self.frames[page_name] = frame

            # Places frames in same location; need to use show_frame() to make
            # a frame visible
            frame.grid(row=0, column=0, sticky="nsew")

        # Displays the Leaderboards Frame
        self.show_frame("LeaderFrame")
        self.regNum = 0

    # Shows the specified frame and deactivates the others
    def show_frame(self, page_name):
        frame = self.frames[page_name]

        # Starts competition if opening CompPage
        if page_name == "CompPage":
            frame.start_comp()

        # Updates leaderboards if openinig LeaderFrame
        elif page_name == "LeaderFrame":
            frame.lead.update_boards("Leaderboards")
            frame.select_frame()

        frame.tkraise()

# The Leaderboard Frame
class LeaderFrame(tk.Frame):
    def __init__(self, parent, controller):
        tk.Frame.__init__(self, parent, bg = self.controller.BG)

        # Sets font and widget sizing parameters based on screen size (experimental: may not work
on all screens)
        self.controller = controller
        self.font = tkfont.Font(family="Calibri", size=self.controller.HGT//30, weight="bold")
        err_font = tkfont.Font(family="Calibri", size=self.controller.HGT//40)
        xPad = self.controller.WDT//48
        yPad = self.controller.HGT//24
```

```
        # Sets window time for entering team IDs when the entry box is activated
        self.entry_reset_delay = 20000 # in ms

        # Sets title label
        label = tk.Label(self, text=self.controller.NAME, font=self.font, bg = self.controller.BG, fg
= self.controller.TXT)
        label.grid(row=0, column=0, columnspan=3,pady=yPad)
        self.grid_columnconfigure(0, weight=1)

        # Initializes Leaderboards object
        self.lead = Leaderboards(self,controller)
        self.lead.grid(row=1, column=0, columnspan=3,padx=xPad)

        # Sets entry box label
        label2 = tk.Label(self, text="Enter your team ID number:", bg =
self.controller.BG,fg=self.controller.TXT, font=self.font)
        label2.grid(row=2,column=0,sticky='E',pady=yPad)

        # Sets error display area
        self.err_var = tk.StringVar(self, "")
        self.err_label = tk.Label(self, textvariable=self.err_var, font=self.font, fg='red', bg =
self.controller.BG)
        self.err_label.grid(row=3,column=0,columnspan=3)

        # Sets entry box and its validation method
        vcmd = (self.register(self.is_valid_entry))
        self.entry = tk.Entry(self, width=self.controller.WDT//100,justify =
'center',state="disabled", validate='all', font=self.font,validatecommand=(vcmd,'%P'))
        self.entry.grid(row=2, column=1,sticky="W",padx=xPad,pady=yPad)
        self.grid_columnconfigure(1,weight=1)

    # Activates entry box upon LeaderFrame selection
    def select_frame(self):
        self.focus()
        self.bind("<Key>", self.activate_entry)
        self.entry.bind("<Return>", self.verify_registration)

    # Deactivates entry box upon LeaderFrame termination
    def deselect_frame(self):
        self.deactivate_entry()
        self.unbind("<Key>")
        self.entry.unbind("<Return>")

    # Activates entry box
    def activate_entry(self, event):
        if self.entry["state"] == "disabled":
```

```
        self.entry["state"] = "normal"
        self.entry.focus()
        self.after(self.entry_reset_delay, self.deactivate_entry)
# Deactivates entry box
def deactivate_entry(self):
    if self.entry["state"] != "disabled":
        self.focus()
        self.entry.delete(0, "end")
        self.entry["state"] = "disabled"

# Checks if entry is a five digit number
def is_valid_entry(self, P):
    if (len(P) <= 5 and str.isdigit(P)) or P == "":
        return True
    else:
        return False

# Verifies presence of registration number on Google Drive
def verify_registration(self, event):
    self.controller.regNum = event.widget.get()
    if self.controller.regNum != "":
        if len(self.controller.regNum) != 5:
            self.err_var.set('Invalid registration number provided')
            self.after(5000, self.clear_err_message)
        else:
            regStr = int(self.controller.regNum) // 100 + 1
            try:
                sheetNum = self.controller.handler.read_cells('B' + str(regStr))[0][0]
                if sheetNum == self.controller.regNum:
                    if fc.get_door_state() == 1:
                        self.deselect_frame()
                        self.after(1000,self.controller.show_frame("CompPage"))
                    else:
                        self.err_var.set('Please ensure the access door is closed and try again')
                        self.after(5000, self.clear_err_message)
                else:
                    self.err_var.set('Invalid registration number provided')
                    self.after(5000, self.clear_err_message)
            except HttpError:
                self.err_var.set('Unable to communicate with registraion database')
                self.after(5000, self.clear_err_message)

# Clears error message area
def clear_err_message(self):
    self.err_var.set("")
```

```
# Leaderboards Class
class Leaderboards(tk.Frame):
    # Initializes formatting of leaderboards
    def __init__(self, parent, controller):
        tk.Frame.__init__(self, parent, bg = 'white')
        self.controller = controller
        self.height = 8
        self.width = 8
        self.txtVar = []
        self.font = tkfont.Font(family="Calibri", size=self.controller.HGT//30, weight="bold")
        xPad = self.controller.WDT//100
        yPad = self.controller.HGT//75


        ttk.Separator(self,orient='horizontal').grid(row=0,column=0,sticky = 'EW',columnspan=8)
        ttk.Separator(self,orient='horizontal').grid(row=2,column=0,sticky = 'EW',columnspan=8)
        ttk.Separator(self,orient='horizontal').grid(row=self.height,column=0,sticky =
'EW',columnspan=8)

        tk.Label(self, textvariable=tk.StringVar(self,'Rank'), bg='white',font=self.font).grid(row=1,
column=1, padx=xPad, pady=yPad)
        tk.Label(self, textvariable=tk.StringVar(self,'Team'), bg='white',font=self.font).grid(row=1,
column=3, padx=xPad, pady=yPad)
        tk.Label(self, textvariable=tk.StringVar(self,'Comp Level'),
bg='white',font=self.font).grid(row=1, column=5, padx=xPad, pady=yPad)
        tk.Label(self, textvariable=tk.StringVar(self,'Power (mW)'),
bg='white',font=self.font).grid(row=1, column=7, padx=xPad, pady=yPad)

        # Sets vertical line separators in table
        for i in range(self.width+1):
            if (i % 2) == 0:
                ttk.Separator(self,orient='vertical').grid(row=0,column=i,sticky = 'NS',rowspan=8)

        # Initializes column names and leaderboard contents
        for i in range(3,self.height): #Rows
            for j in range(self.width): #Columns
                if j == 1:
                    tk.Label(self, text=str(i-2), font=self.font, bg='white').grid(row=i, column=j,
padx=xPad, pady=yPad)
                elif (j % 2) != 0:
                    txt = tk.StringVar(self,"---")
                    tk.Label(self, textvariable=txt, font=self.font, bg='white').grid(row=i, column=j,
padx=xPad, pady=yPad)
                    self.txtVar.append(txt)

    # Updates leaderboards from Google Drive
```

```
    def update_boards(self, board_name):
        try:
            teamData = self.controller.handler.read_cells('\'' + board_name + '\'!B3:F7');
        except HttpError:
            print('Invalid registration Number')

        for i in range(len(teamData)):
            adj = 0
            try:
                if teamData[i][4] != "":
                    for j in range(len(teamData[i])):
                        if (j % 2) == 0:
                            self.txtVar[i*3 + j - adj].set(teamData[i][j])
                        else:
                            adj += 1
            except IndexError:
                for j in range(3):
                    self.txtVar[i*3 + j].set("---")

# Competition Page class
class CompPage(tk.Frame):
    def __init__(self, parent, controller):
        tk.Frame.__init__(self, parent, bg = '#2F5597')
        self.controller = controller

        # Initialize CompPage Fields
        self.count = 0
        self.iter = 0
        self.pwrPrev = 0.00
        self.pwrCurr = 0.00
        self.pwrString = tk.StringVar()
        self.font = tkfont.Font(family="Calibri", size=self.controller.HGT//15, weight="bold")
        self.font2 = tkfont.Font(family="Calibri", size=self.controller.HGT//40, weight="bold")
        err_font = tkfont.Font(family="Calibri", size=self.controller.HGT//40)

        # Sets power display formatting
        label = tk.Label(self, textvariable=self.pwrString, bg =
self.controller.BG,fg=self.controller.TXT, font=self.font)
        label.grid(row=0,column=0, pady=self.controller.HGT//20, sticky = 'S')
        self.grid_columnconfigure(0, weight=1)
        self.grid_rowconfigure(0, weight = 1)

        # Sets time progressbar formatting
        s = ttk.Style()
        s.theme_use('default')
```

```
        s.configure("TProgressbar",thickness = self.controller.HGT//25, foreground = "green",
background = "green")
        self.progressbar=ttk.Progressbar(self, orient="horizontal", style =
"TProgressbar",length=self.controller.WDT/3, mode="determinate")
        self.progressbar.grid(row=1,column=0, sticky = 'S')
        self.grid_rowconfigure(1, weight = 1)

        # Sets progressbar label formatting
        label2 = tk.Label(self, text="Time remaining", bg =
self.controller.BG,fg=self.controller.TXT, font=self.font2)
        label2.grid(row = 2, column =0, sticky = 'N')
        self.grid_rowconfigure(2, weight = 1)
        self.progressbar["maximum"] = 1000

        # Sets error message area formatting
        self.err_var = tk.StringVar(self, "")
        self.err_label = tk.Label(self, textvariable=self.err_var, font=err_font, fg='red', bg =
self.controller.BG)
        self.err_label.grid(row=3,column=0, sticky = 'N')
        self.grid_rowconfigure(3, weight = 1)

    # Starts competition subroutine
    def start_comp(self):
        delay = 5000 # startup delay in ms
        self.progressbar["value"]=1000
        self.iter = 0
        self.pwrPrev = 0
        self.flag = 1
        self.pwrString.set("Initiating test ...")
        ph.calibrate()

        # Continues if door state is closed
        if fc.get_door_state() == 1:
            fc.start_fan()
        self.after(delay, self.read_power)

    # Reads power values
    def read_power(self):
        if self.iter == 0:
            self.pwrString.set("0.0 mW")
            self.iter =  1
            self.endTime = datetime.now() + timedelta(minutes=1)
        if fc.get_door_state() == 1:
            if datetime.now() < self.endTime:
                self.progstep = (self.endTime - datetime.now())/timedelta(minutes=1)
                self.progressbar["value"] = 1000*self.progstep
```

```
            self.count = 0
            self.pwrCurr = ph.read_power() * 1000
            self.diff = self.pwrCurr - self.pwrPrev
        else:
            self.flag = 0
            self.progressbar["value"] = 0
        self.after(1000, self.update_power)
    else:
        self.err_var.set('Error! Access door is open!\nClose the access door and restart the test.')
        self.after(5000, self.clear_err_message)

# Clears error message area
def clear_err_message(self):
    self.err_var.set("")
    self.after(5000, self.controller.show_frame('LeaderFrame'))

# Updates poweer display value
def update_power(self):
    if self.flag == 1:
        stepNum = 100
        if self.count < stepNum and self.diff > 0:
            self.pwrPrev = self.pwrPrev + self.diff/stepNum
            self.pwrString.set(("%.1f" % self.pwrPrev) + " mW")
            self.after(10, self.update_power)
            self.count += 1
        else:
            self.after(0,self.read_power)

    # Uploads competition data to the Google Drive
    else:
        fc.stop_fan()
        regStr = int(self.controller.regNum) // 100 + 1
        self.controller.handler.write_cells('G' + str(regStr), [[self.pwrPrev]])
        ranks = self.controller.handler.read_cells('\'Leaderboards\'!A3:A')
        rank = str(int(ranks.index([self.controller.regNum])) + 1)
        self.pwrString.set("Power Generated: " + ("%.1f" % self.pwrPrev) + " mW\nCompetition
Rank: " + rank)
        self.update()
        self.after(5000,self.return_frame())

# Returs to the LeaderFrame
def return_frame(self):
    self.after(5000, self.controller.show_frame('LeaderFrame'))

# Executes this if not being called by another script
if __name__ == "__main__":
```

```
# Initializes configuration data from the config.txt file
config_data = []
with open('/home/pi/Desktop/config.txt', 'r') as reader:
    for line in reader:
        config_data.append(line.split("=")[1].strip())

# Initializes fan controller
fc = FanController()

# Initializes power handler
ph = PowerHandler()

# Starts user interface program
app = SampleApp()
app.mainloop()
```

36.2. Fan Control Class

The following Python class is responsible for providing the access door interrupt and fan relay control signal

---

```
# fan_controller.py - Ver. 1
# Allows for a Raspberry Pi to control the fan control relay from a GPIO pin and
# creates an interrupt that turns off the relay if the device access door is opened
# Written By: Joshua Stapp for Power House (TYL11)

# Import Statements
import RPi.GPIO as GPIO

# FanController Class
class FanController():
    # Initializes FanController object
    def __init__(self):
        GPIO.setwarnings(False)
        GPIO.setmode(GPIO.BCM)

        # Sets access door interrupt on GPIO pin 4
        GPIO.setup(4, GPIO.IN, pull_up_down=GPIO.PUD_DOWN)

        # Sets GPIO pin 17 as the fan control line
        GPIO.setup(17, GPIO.OUT)

        # Initializes door and fan states
        GPIO.add_event_detect(4, GPIO.BOTH, self.door_isr)
        GPIO.setwarnings(True)
        self._fanstate = 0
        self._doorstate = GPIO.input(4)

    # Returns the current state of the fan (0 = off; 1 = on)
    def get_fan_state(self):
        return self._fanstate

    # Sends relay signal to start blower fan
    def start_fan(self):
        self._fanstate = 1
        GPIO.output(17, self._fanstate)

    # Sends relay signal to stop blower fan
    def stop_fan(self):
        self._fanstate = 0
        GPIO.output(17, self._fanstate)
```

```
# Returns the current state of the access door (0 = open; 1 = closed)
def get_door_state(self):
    self._doorstate = GPIO.input(4)
    return self._doorstate

# Shuts off blower fan if access door is opened
def door_isr(self, pin):
    if GPIO.input(pin):
        self._doorstate = 1
    else:
        self._doorstate = 0
        self.stop_fan()
```

36.3. Competition Data Handler Class

This program allows Python to interface with spreadsheets on the Google Drive.

```
# sheet_handler.py - Ver. 1
# Provides a simple interface to read and write Google Sheets data
# Written By: Joshua Stapp for Power House (TYL11)

### Setup Information ###
# 1. Complete step 1 from the following link to turn on the Sheets API:
#    https://developers.google.com/sheets/api/quickstart/python
#    Note: This step only needs to be completed once to obtain the credentails.json file
# 2. Run the following command from the terminal:
#    pip3 install --upgrade google-api-python-client google-auth-httplib2 google-auth-oauthlib
# 3. Find the spreadsheet ID for the Sheet you want to modify within its URL:
#    Example: https://docs.google.com/spreadsheets/d/SPREADSHEET_ID/...
# 4. Modify this file's main method to test the usage of the SheetHandler class

# Import Statements
import pickle
import os.path
from googleapiclient.discovery import build
from google_auth_oauthlib.flow import InstalledAppFlow
from google.auth.transport.requests import Request

class SheetHandler():
    # Contructor to initialize SheetHandler objects
    def __init__(self, spreadsheetID, tokenPath):
        self.spreadsheetID = spreadsheetID
        self.tokenPath = tokenPath

    # Defines spreadsheetID return value property
    @property
    def spreadsheetID(self):
        return self._spreadsheetID

    # Defines tokenPath return value property
    @property
    def tokenPath(self):
        return self._tokenPath

    # Defines spreadsheetID setter property
    @spreadsheetID.setter
    def spreadsheetID(self, spreadsheetID):
        # Raises exception if spreadsheetID is not a string
```

```
    if not isinstance(spreadsheetID, str):
        raise ValueError('spreadsheetID must of type str')
    self._spreadsheetID = spreadsheetID

# Defines tokenPath setter property
@tokenPath.setter
def tokenPath(self, tokenPath):
    # Raises exception if tokenPath is not a string
    if not isinstance(tokenPath, str):
        raise ValueError('tokenPath must of type str')
    self._tokenPath = tokenPath

    # Starts service with new tokenPath
    self._start_service()

# Purpose:  Return the values stored in the provided cell range
# Input:    Cell range string in the form of: 'SheetName!A1:B10'
# Output:   Array containing string cell values
def read_cells(self, cellRange):
    response = self._service.spreadsheets().values().get(spreadsheetId=self.spreadsheetID,
                                            range=cellRange).execute()
    return response.get('values', [])

# Purpose:  Write values to the provided cell range
# Input:    Cell range string in the form of: 'SheetName!A1:B10'
#           Array of cell values
# Output:   None
def write_cells(self, cellRange, cellValues):
    cellBody = {'values': cellValues}
    response = self._service.spreadsheets().values().update(spreadsheetId=self.spreadsheetID,
                                            range=cellRange,
                                            valueInputOption='RAW',
                                            body=cellBody).execute()

# Purpose:  Initiate Google Sheets API service
#           This method must be called if the token path is changed
# Input:    None
# Output:   None
def _start_service(self):
    scope = ['https://www.googleapis.com/auth/spreadsheets']
    creds = None

    # Loads credentials if they exist
    if os.path.exists(self.tokenPath + 'token.pickle'):
        with open(self.tokenPath + 'token.pickle', 'rb') as token:
            creds = pickle.load(token)
```

```
        # If there are no valid credentials available, lets the user log in
        if not creds or not creds.valid:
            if creds and creds.expired and creds.refresh_token:
                creds.refresh(Request())
            else:
                flow = InstalledAppFlow.from_client_secrets_file(
                    self.tokenPath + 'credentials.json', scope)
                creds = flow.run_local_server(port=0)

            # Saves the credentials for future use
            with open(self.tokenPath + 'token.pickle', 'wb') as token:
                pickle.dump(creds, token)

        # Initializes Google Sheets API service
        self._service = build('sheets', 'v4', credentials=creds)

# Example program showing usage of the SheetHandler class
def main():
    # The ID of the spreadsheet to be read from
    spreadsheetID = '1urFhrCpVdELdqRvWMocw1J7PZSwFVazyOLvV8soSi4w'

    # The path where the credentials.json file is stored
    tokenPath = '/home/pi/Desktop/Competition Program/'

    # Initializes Sheet handler object
    dh = SheetHandler(spreadsheetID, tokenPath);

    ### Read Spreadsheet Data ###
    # Reads data from the given range
    # If the range does not contain a SheetName, the data is read from the first sheet
    readVal = dh.read_cells('A2:E3')

    # The data read from teh spreadsheet is formatted as:
    # [[row1_val1, row1_val2, ...], [row2_val1, row2_val2, ...], ...]

    # Prints formatted spreadsheet data from read operation
    print('Spreadsheet Data')
    for row in readVal:
        print('%s, %s, %s, %s, %s' % (row[0], row[1], row[2], row[3], row[4]))

    ### Write Spreadsheet Data ###
    # Data to be written is formatted as:
    # [[row1_val1, row1_val2, ...], [row2_val1, row2_val2, ...], ...]
    storedVal = [[100], [120]]
```

```
    # Writes data to the given range
    # If the range does not contain a SheetName, the data is written to the first sheet
    dh.write_cells('G2:G3', storedVal)

    # Prints formatted spreadsheet data from write operation
    writeVal = dh.read_cells('G2:G3')
    print('\nWritten Data')
    for row in writeVal:
        print('%s' % row[0])

# Starts sample function to test SheetHandler class
if __name__ == '__main__':
    main()
```

36.4. Power Measurement Class

This program tests enables a Raspberry Pi to receive power readings from an INA219 breakout board, as well as calibrate the sensors.

```
# power_handler.py - Ver. 1
# Provides a simple interface between a Raspberry Pi and an INA219 sensor
# Written By: Joshua Stapp for Power House (TYL11)

# Import Statements
import board
from adafruit_ina219 import ADCResolution, BusVoltageRange, Gain, Mode, INA219

# PowerHandler class
class PowerHandler():
    def __init__(self):
        self.ina219 = INA219(board.I2C())
        self.calibrate()

    # Reads power value from INA219
    def read_power(self):
        return self.ina219.power

    # Calibrates INA219 sensor for the following parameters:
    # Maximum Voltage: 16 V
    # ADC Resolution: 12 bit over 8 samples
    def calibrate(self):
        self.ina219._current_lsb = 0.05
        self.ina219._cal_value = 8192
        self.ina219._power_lsb = 0.001
        self.ina219_raw_calibration = self.ina219._cal_value
        self.ina219.bus_voltage_range = BusVoltageRange.RANGE_16V
        self.ina219.gain = Gain.DIV_1_40MV
        self.ina219.bus_adc_resolution = ADCResolution.ADCRES_12BIT_8S
        self.ina219.shunt_adc_resolution = ADCResolution.ADCRES_12BIT_8S
        self.ina219.mode = Mode.SANDBVOLT_CONTINUOUS

# Main method
def main():
    # Creates new instance of PowerHandler class
    ph = PowerHandler()

    # Displays INA219 register fields
    print("Config register:")
    print("  bus_voltage_range:    0x%1X" % ph.ina219.bus_voltage_range)
    print("  gain:                 0x%1X" % ph.ina219.gain)
```

```
    print("  bus_adc_resolution:   0x%1X" % ph.ina219.bus_adc_resolution)
    print("  shunt_adc_resolution: 0x%1X" % ph.ina219.shunt_adc_resolution)
    print("  mode:                 0x%1X" % ph.ina219.mode)
    print("")

    print("Power:         {:.3f} W".format(ph.read_power()))
    print("")

# Starts sample function to test PowerHandler class
if __name__ == '__main__':
    main()
```

37. Appendix Q: Bill of Materials

Table Q.1. Mechanical component bill of materials for the windmill blade competition system.

Item	Quantity	Cost	Company
Clear Polycarbonate Sheet	1	$95.26	Home Depot
Access Door Hinge	1	$3.28	Home Depot
Aluminum Square Tubing	4	$104.90	Lowe’s
Ring Clip	1	$20.00	3D Print
Locking Pivot Joints	2	$41.00	McMaster-Carr
47065T116 Windmill Stand	1	$7.79	McMaster-Carr
General Screws - 1/4" 20 Thread Phillips Round Head Screws (10 CT)	1	$7.75	McMaster-Carr
Hillman 200-Piece Steel Zinc-Plated Combo Fastener Kit - Hardware for Hinge (½”), Door (½”), and Plastic Ring (1”)	1	$4.78	Lowe’s
Everbilt Washer Pack - 1/4 in. x 1-1/4 in. Zinc-Plated Steel Fender Washer	4	$1.18	Home Depot
6061 Aluminum Angle - 2" Leg Length, 1/4" Wall Thk., 24" Length	1	$18.87	Amazon
Angle 6061-T6 Extruded Aluminum - 1" Leg Length, 1/8" Wall Thk., 5" Length	1	$1.55	Speedy Metal
3/8" 16 Thread 94895A031 Zinc Yellow-Chromate Plated Steel Hex Nut (100 CT)	1	$8.64	McMaster-Carr
1/8" 10-24 Thread Hollow-Lock Set Screw Black-Oxide Alloy Steel	1	$9.06	McMaster-Carr
3/8" 16 Thread 91257A630 High-Strength Grade 8 Steel Cap Screw (25 CT)	1	$8.14	McMaster-Carr
1/4" 20 Thread 91251A543 Black-Oxide Alloy Steel Socket Head Cap Screw (10 CT)	1	$6.59	McMaster-Carr
1/4" 20 Thread 91772A553 Pan Head Phillips Machine Screw (10 CT)	1	$5.24	McMaster-Carr
36” x 36” Aluminum Sheet, 1/8“ thickness	1	$21.98	Home Depot

Table Q.1. Continued.

Item	Quantity	Cost	Company
36” x36” Aluminum Sheet, 1/24” thickness	1	$144	The Metal Store
Manufactured Aluminum Ring	1	$40.00	D&G Precision Fabrication
Fan base welds	1	$30.00	Lews Welding Service
Windmill Blade Hub (3 CT)	1	$5.00	3D Print
Door Hardware Mount	1	$0.75	3D Print
Windmill Mount Angle Stops	2	$0.25	3D Print
Generator Adapter	1	$0.25	3D Print
Vibration Pads	8	$4.00	3D Print
MaxxAir PRO 30" Drum Fan	1	$209.97	Home Depot
Zip Ties (100 CT)	6	$7.99	Amazon
⅝" ID - ⅞" OD Rubber Grommet (10 CT)	1	$6.26	Amazon
⅛" Steel Washers (40 CT)	2	$2.28	Amazon
#4 Nylon Insert Lock Nuts (100 CT)	2	$7.89	Amazon
½" #4 Stainless Steel Screws (100 CT)	2	$6.74	Amazon
CanaKit 5 V - 2 .5 A Raspberry Pi 3 Power Supply	1	$9.95	Amazon
CHENBO 5V Relay Module (4 CT)	1	$8.99	Amazon
120 VAC Rocker Switches (5 CT)	1	$5.49	Amazon
18 AWG 600 V Stranded Wires (25')	1	$14.98	Amazon
22-14 AWG (Orange)Wire Nuts (100 CT)	2	$6.32	Amazon

Table Q.1. Continued.

Item	Quantity	Cost	Company
Male-Female Spade Terminal Connectors (100 CT)	1 Male 6 Female	$9.99	Amazon
Relay Base Plate	1	$1.00	3D Print
Relay Housing	1	$1.00	3D Print
Pi Supply Prong Insulator	1	$0.50	3D Print

Table Q.2. Electrical component bill of materials for the windmill blade competition system.

Item	Quantity	Cost	Company
Raspberry Pi 3B	1	$38.36	Amazon
CZH-LABS PCB Shield Board Kit (4 CT)	1	$14.99	Amazon
SanDisk 16 GB MicroSD Memory Card	1	$5.99	Amazon
HiLetgo INA219 DC Power Monitoring Sensor	1	$7.89	Amazon
1N5818 Schottky Diode	4	$1.64	Mouser
1 kΩ - ¼ W - 5% Resistor	2	$0.20	Mouser
47 Ω - 5 W - 5% Resistor	1	$0.80	Mouser
100 µF - 25 V Electrolytic Capacitors (10 CT)	1	$5.99	Amazon
0.1 µF - 50 V Ceramic Capacitors	3	$0.17	Mouser
125 VAC - 6 A Push Button Switches (10 CT)	1	$7.99	Amazon
Greartisan 12V DC - 600 RPM Motor	1	$13.99	Amazon
Assorted 20 AWG wires	1	$17.88	Amazon
QLOUNI JST SM Terminal Connector Kit	1	$12.99	Amazon
HDMI Cable	1	$6.99	Amazon
USB Touchpad Keyboard	1	$20.99	Amazon

Table Q.2. Continued.

Item	Quantity	Cost	Company
DC Electrical Box	1	$2.00	3D printed
DC Electrical Box Lid	1	$1.00	3D printed
Safety Switch Housing	1	$0.50	3D printed
Wire Guide Clips	8	$0.50	3D Printed

Mechanical Component Cost: $889.61
Electrical Component Cost: $160.86

Total Estimated Cost: $1,050.47

38. Appendix R: Testing Results

38.1. Mechanical Testing Data

Table R.1. Testing chamber air velocity data.

Testing Chamber Air Velocity Data		
	Air Velocity (ft/min)	
Fan Speed Setting:	**Low**	**High**
Position 1		
inner	700	1010
middle	1130	1550
outer	1300	1330
Position 2		
inner	700	1015
middle	1200	1200
outer	1275	1360
Position 3		
inner	870	1055
middle	1155	1300
outer	1080	1000
Position 4		
inner	840	270
middle	1125	1400
outer	1215	1000
Position 5		
inner	725	945
middle	905	1100
outer	910	1080
Position 6		
inner	770	990
middle	1190	1430
outer	1150	1490

39. Appendix S: Specifications Acceptance Criteria

39.1. Main Specifications Acceptance Criteria

Table S.1. Windmill blade competition system main acceptance criteria and verification methods.

Specification	Acceptance Criteria	Verification Method	Outcomes
Use similar dimensions to old device (4' x 4' x 10')	The new device will take up (at most) the same floor space as the old setup at the competition venue.	The assembled device's overall length, width, and height will be measured with a measuring tape to ensure the dimensions meet the acceptance criteria.	The device fits within the 4' x 4' x 10' dimensions specified.
Device can be broken down into multiple parts	The device will separate into smaller parts that can each be moved by a team of at most 2 people.	Demonstrate that the device can be broken down into small multiple parts, that can be easily carried by at least 2 people	The device is movable by two when dismantled into sections.
Utilize a blower fan with a commercially available diameter	A blower fan will be sourced from a commercial supplier.	A commercially available diameter fan will be purchased and used in the device.	The selected fan is commercially available.
Support horizontal and vertical windmill axes	The device will have a generator mounted on a hinge to allow for both orientations to be tested.	Demonstrate that the windmill blades are mounted on the hub which is attached to a hinge that rotates 90 degrees to test both orientations on the device. The stability of the operation for both orientations will be observed under full load airspeed by testing with windmill blades that have maximum surface area for the inside of the device.	The device supports both horizontal and vertical windmill operations.

Table S.1. Continued.

Specification	Acceptance Criteria	Verification Method	Outcomes
Maintain a fixed distance between the blower fan and windmill	The device will maintain a fixed distance between the blower fan and windmill mount.	Perform physical tests to ensure that, under maximum load airspeed, the windmill blades with the maximum surface area remain at a fixed distance.	The distance between the blower fan and the windmill is at a fixed distance.
Utilize a non-rectangular testing chamber	The device may use a more 'aesthetically appealing' shape per sponsor request.	The device has been designed to have a cylindrical testing chamber per the sponsor's request. A video and photos of the assembled testing chamber will be sent to the sponsor for approval and feedback.	The sponsor approved of the cylindrical design of the test chamber.
Utilize a variable speed blower fan	The device may utilize a variable speed fan (that is commercially available), to test the windmill blades.	The variable speed setting of the fan will be tested to verify that the speed changes in a way that affects windmill blade performance. A comparison of the power measured for a set of test blades at different airspeed settings will be used to determine if the airspeed affects power generation.	The selected blower fan is rated for two speed settings, which can control the maximum power generation of windmill's under test.

39.2. Windmill Blade Specifications Acceptance Criteria

Table S.2. Windmill blade competition system windmill blade acceptance criteria and verification methods.

Specification	Acceptance Criteria	Verification Method	Outcomes
Support different blade lengths	The device will support different windmill blade lengths up to 12” in length within the test chamber.	Windmill blades of the maximum length of 12 inches will be created and tested by the device to ensure the windmill blades do not touch the interior of the testing chamber in both horizontal and vertical orientations. If additional restrictions on blade lengths and widths are needed, they will be included in the rules and regulations of the competition.	Different length blades, up to 12 inches, can operate without hinderance within the testing chamber.
Support a certain number of blades	The device will support windmills with up to 6 blades (in balanced configurations).	The hub design will be fully loaded with 6 blades and tested at full load airspeed to check for stable operation with the maximum number of supported blades.	The designed hub supports up to 6 blades in a balanced configuration.
Standardize windmill blade-to-hub interface for competition	The competition participants will be provided with the specifications that their windmill blade-to-hub connections will have to utilize.	The hub-to-blade interface method will be tested with ¼" square wooden dowels and 3D printed equivalents to ensure the standardized interface size will work for multiple materials.	Any designed blade within 12 inches built using a ¼" wide square blade connection stem fits with the standardized windmill blade-to-hub interface.

39.3. Electrical Specifications Acceptance Criteria

Table S.3. Windmill blade competition system electrical acceptance criteria and verification methods.

Specification	Acceptance Criteria	Verification Method	Expected Outcomes
Device is electrically powered	The device will be powered by a 120 V wall outlet.	The device will be plugged into a standard 120 V wall outlet and turned on and operated at full load to see if the device will operate correctly.	The device powers on and operates when supplied from a single 120V wall outlet.
Measure DC power with current and voltage sensors	The device will measure current and voltage and internally calculate the electric (DC) power generated.	Standard tests with several windmill blade designs, of varying quality, attached to the hub will be performed. The power measurement results will be verified by using a multimeter to measure the voltage in current separate from the device's electronic systems.	The device detects the produced DC power using the on-board sensors accurately.
Include a safety blower fan shutoff	The device will have a switch that can be opened to shut off the blower fan.	The device will be operated, and the safety switch will be opened to ensure that the blower fan shuts down correctly.	The device blower fan shuts off when the access door safety switch is opened.
Include a calibration procedure for any sensors	The device will have a sensor calibration procedure that can be activated by the user before data collection begins.	After calibration, the sensor values will be read without any wind being generated by the blower fan to ensure the sensors are reading a zero-power value correctly. The device will then be operated with a set of windmill blades inside, and the generated power value will be verified by an independent multimeter measurement.	The sensors auto-calibrate between windmill blade tests.

Table S.3. Continued.

Specification	Acceptance Criteria	Verification Method	Expected Outcomes
Record team name, competition level, and school name	The registration process will utilize a digital form that can be filled out by each team. This form will then be linked to a spreadsheet to tabulate the competition results per team.	Several basic registration forms will be filled out electronically. The cloud-based database for the registration information will then be checked to observe if all relevant information was correctly recorded.	The team name, competition level, and school name are correctly stored by the device.
Connect to external results display	The device will connect to an external display with an HDMI cable.	An external display will be connected to the device via HDMI cable and the device will be operated to confirm that the results are being shown on the display.	The system output is be visible on a display connected to the device via HDMI.

40. Appendix T: Project Action Items

This appendix contains a detailed breakdown of project action items, shown in Tables T.1 and T.2, from the start of the project up to the last team meeting with assigned member responsibilities.

Table T.1. Team Power House first semester project action items. The shaded rows indicate completed action items.

No	Item	Date assigned	Date expected	Date completed	Responsible person(s)	Status /Remarks
1	Finalize Week 2 PowerPoint	8/28/19	9/3/19	9/6/19	Joshua Stapp	Revised after 9/3/19
2	Submit Team Contract	9/3/19	9/4/19	9/9/19	Frederick Wehe	Delayed for typed format
3	Draft Sponsor Questions	9/3/19	9/5/19	9/9/19	Davida Campbell	Delayed for revision
4	Develop Concept Statement	9/4/19	9/6/19	9/6/19	Spencer Wells	
5	Develop Preliminary Specifications	9/4/19	9/9/19	9/9/19	Joshua Stapp	
6	Initiate Sponsor Correspondence	9/4/19	9/9/19	9/10/19	Davida Campbell	Delayed for question revision
7	Submit Sponsor Questions for Approval	9/9/19	9/9/19	9/9/19	Davida Campbell	
8	Finalize Week 3 PowerPoint	9/9/19	9/10/19	9/10/19	Joshua Stapp	
9	Refine Specifications	9/10/19	9/17/19	9/25/19	Joshua Stapp	
10	Generate Black Box Diagram	9/11/19	9/11/19	9/11/19	Frederick Wehe	
11	Submit Week 3 Deliverables	9/11/19	9/13/19	9/13/19	Joshua Stapp	
12	Finalize Specifications	9/11/19	9/23/19	9/26/19	Frederick Wehe	Delayed for revisions
13	Compile Initial Windmill Competition Research	9/12/19	9/16/19	9/16/19	Emmanuel Acuna	
14	Draft Concept Sketches	9/12/19	9/18/19	9/18/19	Davida Campbell Joshua Stapp	
15	Finalize Week 4 PowerPoint	9/16/19	9/17/19	9/17/19	Joshua Stapp	

Table T.1. Continued.

No	Item	Date assigned	Date expected	Date completed	Responsible person	Status /Remarks
16	Set Up Next Sponsor Meeting	9/16/19	9/18/19	9/18/19	Davida Campbell	Next meeting on 9/19/19
17	Draft Rough Budget	9/16/19	9/19/19	9/19/19	Emmanuel Acuna	
18	Draft First CAD Concept	9/17/19	9/20/19	9/20/19	Joshua Stapp	Rectangular Wind Tunnel
19	Submit Week 4 Deliverables	9/18/19	9/20/19	9/20/19	Joshua Stapp	
20	Send Sponsor Meeting Information to Advisor	9/18/19	9/19/19	9/19/19	Davida Campbell	
21	Recreate First CAD Concept	9/18/19	10/4/19	10/4/19	Spencer Wells	Rectangular Wind Tunnel
22	Compile Additional Project Research	9/23/19	9/27/19	9/27/19	Emmanuel Acuna	
23	Finalize Week 5 PowerPoint	9/23/19	9/24/19	9/24/19	Joshua Stapp	
24	Send New Questions to Sponsor	9/23/19	9/26/19	9/27/19	Davida Campbell	Delayed until next morning
25	Send Sponsor Finalized specs	9/24/19	9/27/19	9/27/19	Davida Campbell	
26	Source Potential Parts for design	9/24/19	9/30/19	9/30/19	Emmanuel Acuna	
27	Draft Second CAD Concept	9/25/19	10/4/19	10/8/19	Emmanuel Acuna	Cylindrical Wind Tunnel
28	Develop Specification Justifications	9/30/19	10/7/19	10/16/19	Davida Campbell Joshua Stapp	
29	Draft Project Gantt Chart	9/30/19	10/7/19	10/8/19	Frederick Wehe	Version 1
30	Create ARCI Table	9/30/19	10/7/19	10/14/19	Spencer Wells	
31	Finalize Week 6 PowerPoint	9/30/19	10/1/19	10/1/19	Joshua Stapp	
32	Submit Week 6 Deliverables	10/7/19	10/8/19	10/8/19	Joshua Stapp	
33	Finalize Week 7 PowerPoint	10/7/19	10/11/19	10/11/19	Joshua Stapp	

Table T.1. Continued.

No	Item	Date assigned	Date expected	Date completed	Responsible person	Status /Remarks
34	Contact Plastic Pipe Suppliers	10/8/19	10/11/19	10/11/19	Davida Campbell	
35	Add Mount Hinge to CAD	10/8/19	10/15/19	10/21/19	Emmanuel Acuna	
36	Complete CAD Animation	10/8/19	10/15/19	10/21/19	Emmanuel Acuna	
37	Contact Sponsor to Verify Concept Selection	10/9/19	10/18/19	11/19/19	Frederick Wehe Davida Campbell	Approved with Design Review
38	Justify Specifications with Calculations	10/9/19	10/15/19	10/15/19	Spencer Wells	
39	Finalize and Submit Week 8 Deliverables	10/15/19	10/18/19	10/18/19	Joshua Stapp	
40	Complete First Draft of Peer Presentation	10/15/19	10/21/19	10/22/19	Spencer Wells Frederick Wehe	
41	Complete Peer Presentation	10/22/19	10/28/19	10/28/19	Spencer Wells Frederick Wehe Joshua Stapp Davida Campbell	
42	Increase Thickness of CAD Model Center Support	10/22/19	10/23/19	10/23/19	Emmanuel Acuna	
43	Update Peer Presentation with Advisor Recommendations	10/29/19	10/31/19	10/31/19	Spencer Wells Frederick Wehe Joshua Stapp Davida Campbell	
44	Submit Week 10 Deliverables	10/29/19	11/1/19	11/1/19	Joshua Stapp	
45	Update CAD for Design Review	11/4/19	11/8/19	11/18/19	Emmanuel Acuna	
46	Update Budget	11/4/19	11/8/19	11/18/19	Emmanuel Acuna	
47	Submit Week 11 Deliverables	11/4/19	11/8/19	11/8/19	Joshua Stapp	

Table T.1. Continued.

No	Item	Date assigned	Date expected	Date completed	Responsible person	Status /Remarks
48	Build Detail Design PowerPoint	11/4/19	11/14/19	11/19/19	Spencer Wells Frederick Wehe	
49	Create Agenda/Handout for Design Review	11/4/19	11/13/19	11/18/19	Davida Campbell Joshua Stapp Frederick Wehe	
50	Electrical Schematics	11/4/19	11/11/19	11/12/19	Joshua Stapp Frederick Wehe	
51	Tunnel Calculations	11/4/19	11/11/19	11/18/19	Spencer Wells Davida Campbell	
52	Design Single-Motor Housing	11/19/19	12/3/19	12/3/19	Emmanuel Acuna	
53	Design Hub Locking and Disconnect Mechanism	11/19/19	12/3/19	12/6/19	Emmanuel Acuna	
54	Replace Frame Welding with Bolts	11/19/19	12/3/19	12/5/19	Emmanuel Acuna	
55	Design Schematics for One Motor	11/19/19	11/22/19	11/20/19	Joshua Stapp	
56	Update Flowchart to Include Dynamic Results Output	11/19/19	12/2/19	11/20/19	Joshua Stapp	
57	Bolt Stress Calculations	11/19/19	12/2/19	12/2/19	Emmanuel Acuna Davida Campbell	
58	Frame Stress Calculations	11/19/19	12/3/19	12/2/19	Emmanuel Acuna	
59	PLA Part Stress Calculations	11/19/19	12/2/19	12/7/19	Davida Campbell Spencer Wells	
60	Windmill Blade Mount Stress Calculations	11/19/19	12/6/19	12/6/19	Emmanuel Acuna Davida Campbell	
61	Project Summary	11/20/19	12/9/19	12/9/19	Davida Campbell Frederick Wehe Joshua Stapp	

Table T.1. Continued.

No	Item	Date assigned	Date expected	Date completed	Responsible person	Status /Remarks
62	Project Poster	11/20/19	12/6/19	12/9/19	Spencer Wells Joshua Stapp	
63	Prototype Construction	11/22/19	12/9/19	12/1/19	Joshua Stapp Frederick Wehe Davida Campbell	

Table T.2. Team Power House project second semester action items. The shaded rows indicate completed action items. The *Responsible person(s)* column indicates primary (1) and secondary (2) responsibility.

No	Item	Date assigned	Date expected	Date completed	Responsible person(s)	Status /Remarks
1	Control System Programming	12/2/19	2/21/20	4/17/20	Joshua Stapp (1) Frederick W. (2)	More time used to add error messages
2	Assign Team Members Tasks for New Semester	1/16/20	1/16/20	1/16/20	Frederick W. (1) Davida C. (2)	
3	Finalize Purchase List	1/16/20	1/17/20	1/17/20	Davida C. (1) Emmanuel A. (2)	
4	Test Power Measurement Prototype	1/16/20	3/16/20	2/12/20	Joshua Stapp (1) Frederick W. (2)	Basic Tests Complete
5	Complete Initial Status Report	1/16/20	1/24/20	1/24/20	Joshua Stapp (1) Frederick W. (2)	
6	Update Documentation	1/16/20	1/24/20	1/24/20	Spencer Wells (1) Joshua Stapp (2)	
7	Develop Testing and Verification Plan	1/16/20	1/24/20	1/24/20	Davida C. (1) Frederick W. (2)	
8	Create Initial Project Timeline	1/17/20	1/24/20	1/24/20	Spencer Wells (1) Frederick W. (2)	
9	3D Print New Hub Design	1/17/20	1/24/20	1/24/20	Emmanuel A. (1) Joshua Stapp (2)	
10	Record Weekly In-Action Video	1/22/20	1/24/20	1/24/20	Frederick W. (1) Emmanuel A. (2)	
11	Find Local Metal Fabrication Shop	1/23/20	2/3/20	2/12/20	Frederick W. (1) Emmanuel A. (2)	New vendor found
12	Submit Weekly Deliverables	1/23/20	1/27/20	1/27/20	Joshua Stapp (1) Emmanuel A. (2)	
13	Reformat Initial Status Report	1/26/20	1/28/20	1/28/20	Frederick W. (1) Joshua Stapp (2)	

Table T.2. Continued.

No	Item	Date assigned	Date expected	Date completed	Responsible person(s)	Status /Remarks
14	Ethics Assignment	1/27/20	1/30/20	1/30/20	All	
15	Redesign Blade Hub	1/30/20	1/31/20	2/21/20	Emmanuel A. (1) Joshua Stapp (2)	
16	Blade Hub Documentation	1/30/20	2/15/20	4/24/20	Emmanuel A. (1) Davida C. (2)	
17	Reserve Meeting Room	1/30/20	2/6/20	1/30/20	Joshua Stapp (1) Frederick W. (2)	
18	Pick Up Metal Tubing	1/30/20	1/31/20	1/31/20	Emmanuel A. (1) Spencer W. (2)	
19	Ask About Fab Lab Storage	1/30/20	1/31/20	1/31/20	Davida C. (1) Frederick W. (2)	Table space received
20	Check with Fab Lab for Manufacturing Access Door	1/30/20	2/3/20	1/31/20	Emmanuel A. (1) Davida C. (2)	Can cut door from aluminum sheet
21	Check with Fab Lab for Milling Aluminum Block	1/30/20	2/3/20	1/31/20	Emmanuel A. (1) Davida C. (2)	Not feasible
22	Mechanical Testing Research	1/30/20	2/10/20	3/13/20	Davida C. (1) Spencer W. (2)	
23	Writing Report Background	1/30/20	4/1/20	4/24/20	Spencer W. (1) Davida C. (2)	
24	Writing User Manual	1/30/20	4/1/20	4/24/20	Davida C. (1) Frederick W. (2)	
25	Writing Competition Guidelines	1/30/20	4/1/20	4/9/20	Spencer W. (1) Davida C. (2)	
26	Writing Maintenance Manual	1/30/20	4/1/20	4/24/20	Davida C. (1) Frederick W. (2)	
27	Writing Assembly Guide	1/30/20	4/1/20	4/24/20	Frederick W. (1) Emmanuel A. (2)	
28	Submit Weekly Deliverables	1/30/20	2/3/20	2/3/20	Joshua Stapp (1) Frederick W. (2)	
29	Finalize and Print Clip Ring	2/4/20	2/7/20	2/18/20	Emmanuel A. (1) Joshua Stapp (2)	
30	Finalize and Print Base	2/4/20	2/7/20	2/15/20	Emmanuel A. (1) Joshua Stapp (2)	
31	Design Access Door	2/6/20	2/7/20	3/2/20	Spencer Wells (1) Emmanuel A. (2)	Awaiting hole size revision

Table T.2. Continued.

No	Item	Date assigned	Date expected	Date completed	Responsible person(s)	Status /Remarks
32	Manufacture Saddles and Door	2/6/20	2/10/20	3/20/20	Emmanuel A. (1) Frederick W. (2)	
33	Update CAD Frame	2/6/20	3/27/20	4/24/20	Emmanuel A. (1) Spencer Wells (2)	
34	Submit Peer Evaluations	2/6/20	2/7/20	2/7/20	All	
35	Submit Weekly Deliverables	2/6/20	2/10/20	2/10/20	Joshua Stapp (1) Frederick W. (2)	
36	Purchase Dowels	2/6/20	2/10/20	2/8/20	Frederick W. (1) Davida C. (2)	
37	Square Dowel FEA	2/6/20	2/17/20	2/24/20	Spencer Wells (1) Davida C. (2)	
38	Follow Up with Metal Vendors	2/6/20	2/10/20	2/12/20	Davida C. (1) Frederick W. (2)	
39	Update Sponsor with Project Status	2/6/20	3/5/20	3/5/20	Davida C. (1) Frederick W. (2)	
40	Submit Weekly Deliverables	2/13/20	2/17/20	2/17/20	Joshua Stapp (1) Frederick W. (2)	
41	Finish Prototype Construction	2/13/20	2/21/20	3/23/20	Emmanuel A. (1) Frederick W. (2)	
42	Update Initial Status Report	2/20/20	2/24/20	3/4/20	Davida C. (1) Spencer W. (2)	
43	Implement Electrical Systems	2/20/20	2/21/20	3/20/20	Joshua Stapp (1) Frederick W. (2)	
44	Remanufacture Metal Ring	2/24/20	2/25/20	2/26/20	Davida C. (1) Frederick W. (2)	
45	Resubmit Peer Evaluations	2/24/20	2/25/20	2/25/20	All	
46	Submit Weekly Deliverables	2/27/20	3/2/20	3/2/20	Joshua Stapp (1) Frederick W. (2)	
47	Mechanical Testing	3/5/20	4/1/20	4/9/20	Davida C. (1) Spencer Wells (2)	
48	Electrical Testing	3/5/20	4/1/20	4/9/20	Joshua Stapp (1) Frederick W. (2)	
49	Contact Advisor	3/23/20	3/25/20	3/25/20	Davida C. (1) Frederick W. (2)	
50	Submit Weekly Deliverables	3/23/20	3/27/20	3/27/29	Joshua Stapp (1) Frederick W. (2)	
51	Finalize Poster	3/23/20	3/27/20	3/30/20	Davida C. (1) Joshua Stapp (2)	

Table T.2. Continued.

No	Item	Date assigned	Date expected	Date completed	Responsible person(s)	Status /Remarks
52	Finalize Door	3/24/20	3/26/20	3/26/20	Frederick W. (1) Emmanuel A. (2)	
53	Create Final Video	3/24/20	4/13/20	4/19/20	Frederick W. (1) Joshua Stapp (2)	
54	Take Project Photos	3/26/20	3/30/20	4/17/20	Frederick W. (1) Joshua Stapp (2)	

41. Appendix U: Final Design Review Grade Sheet

Senior Design Project

Design Review Evaluation Form

Please select the type of review:

1. ***Internal (No external Customer)***
2. ***External (Includes external Customer)***

Item	Information	Grade
Team #	TYL11	N/A
Team name	Power House	N/A
Project Title	Testing Instrumentation set up for an wind mill blade design competition	N/A
Project Type	External / Internal	N/A
Project Sponsor	University of Texas at Tyler	N/A
Date of Design Review	11/18/2019	N/A
Attendees	Dr. Barakat, Dr. Indic, Dr. Fumo, Dr. Gaercia, Dr. Khajah	N/A
Meeting Lead Student	Frederick Wehe	N/A
Minutes Takers	Spencer Wells, Joshua Stapp	N/A
Packet and Agenda distributed 48 hours ahead of meeting	Y / N	---- / 5
Quality and completeness of packet and handouts	H / M / L	---- / 10
Quality and completeness of Design details presented	H / M / L	---- / 10
Quality of team handling of the meeting and questions	H / M / L	---- / 10
Did the team achieve the goals of the design review?	Y / N / Partially	---- / 10
Advisor Evaluation		---- / 5
Result	1. Redo 2. Conditional approval to move forward 3. Unconditional approval to continue to next step	Total = 43.5 / 50

Comments / Conditions / Requirements for the team:

1. Mechanical design requires - clearly define the adapter holding the blades
2. Manipulation of data to obtain a consistent system should be done carefully
3. Reduce the number of generators to one, figure legends should be more descriptive.