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To: Dr. Oman

From: 20F14 Turbine

Date: February 12, 2021

Re: Hardware Review 1

Introduction

This memo will be detailing the hardware that is used in the turbine and all of the various iterations that some components went through. The main components that will be focused on are the: base of the turbine, the tower, coupling points, nacelle, braking system, yawing system, shaft, rotor assembly, hub, and the blades. The memo details all the parts and progress the team has made with prototyping either through physical models or digital designs.

Current State of System

1 Digital Design

At this point in time, the digital prototype is complete and all relevant parts have been modeled. Because the group utilizes a 3D printer to fabricate many of the parts in the assembly, the in depth display of each of these models is valuable when trying to understand the overall manufactured product. Figure 1 shows the full assembly. This section, as well as the following section, is separated into four categories entitled rotor, shaft, nacelle, and tower. For a clearer representation on any of the components seen in Figure 1, please refer to the relevant subsections.

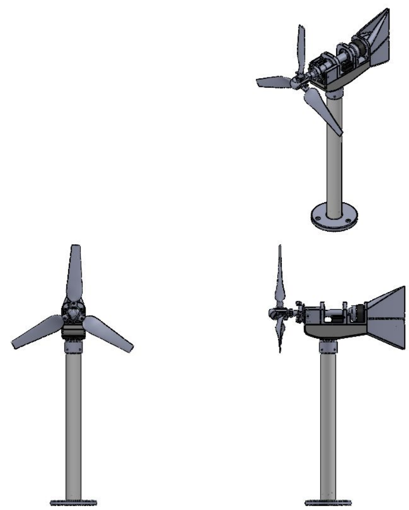

Figure 1: Full Digital Assembly

1.1 Rotor

Figure 2 is the rotor assembly of the turbine. This part features three designed CAD models and one outsourced part. The goal of the rotor is to fit within a 45x45 cm plane, while maximizing that amount of space consumed by the blade profile rather than the centralized hub to avoid upstream back pressure. However, the current blade design and the requirements set by the competition results in a maximum angular velocity of 7000 rpm, which must be considered with areas of stress concentrations, such as the connections at the hub.

Figure 2: Digital Rotor Assembly

1.1.1 Hub

The hub has seen many iterations that have converged on the model below. The hub is intended to be 3D printed with draft cuts that will allow for bolts to thread into the plastic. A slight relief is present on the faces to allow for the insertion of the mounted bearing that allows the pitching system to operate.

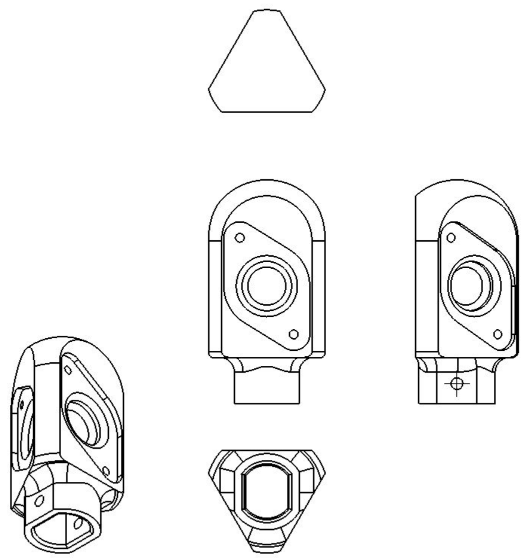

Figure 3: Hub

1.1.1.2 Mounted Bearings

The mounted bearings have proved vital to the key design point of the group's turbine, being the pitching system. These mounts allow for the blades to be easily rotated with minimal frictional forces that would prevent said movement.

Figure 4: Mounted Bearings

1.1.2 Blade

The blades have gone through several iterations, the one displayed below being the 5th and current design. We designed the blades using the well documented Blade Element Momentum Theory. This process uses a momentum balance on a rotating annular stream tube as well as force and torque evaluations at various sections of the blade based on lift and drag coefficients.

From there we get equations that can be solved iteratively using MATLAB. Figure 5 features a length just short of 200 mm utilizing NACA2412, NACA1412, and NACA0012 airfoil profiles.

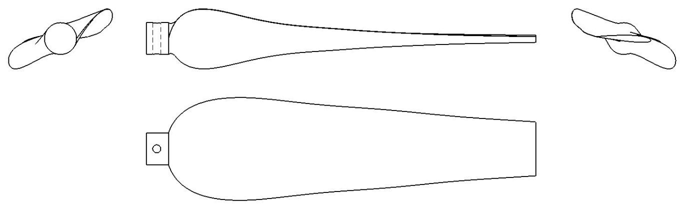

Figure 5: BEM Blade Design

1.1.3 Coupler

The rotor coupler can be seen in Figure 6. This figure is representative of the 5th iteration of the coupler. This part allows the blade to connect to the mounted bearing shown in Figure 4. This part was originally part of the hub, which changed once the group decided to outsource the mounted bearings. The group foresees the combining of this part with the blade seen in Figure 5 to reduce stress concentrations throughout the model.

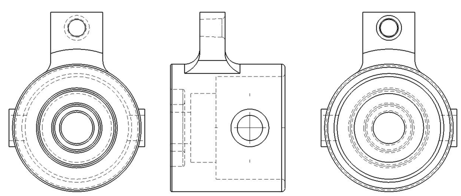

Figure 6: Rotor Coupler

1.2 Shaft

The shaft features three components. The swash shaft allows for the movement of the driven swash plate seen in Figure 13 and the section break allows for the placement of a fly wheel on the generator shaft, as seen in Figure 21.

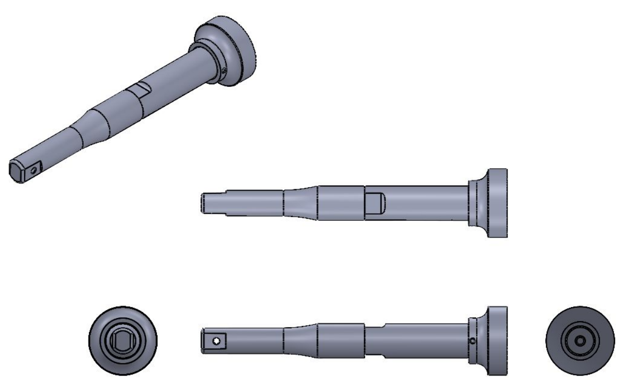

Figure 7: Shaft Assembly

1.2.1 Swash Shaft

The swash shaft is the first piece of the two piece shaft and is to the fore. This piece of the shaft will have a diameter drop from the main 25 mm diameter which will allow for clearance of the pitching mechanism. This piece of the shaft will also be holding the hub design at the far end of the shaft.

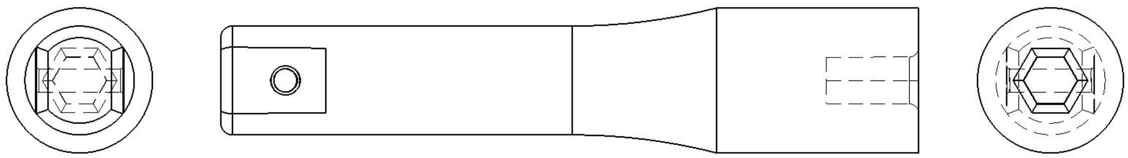

Figure 8: Swash Shaft

1.2.2 Generator Shaft

The generator shaft is the second piece of the two piece shaft. The aft end of the shaft is connected to the generator. The generator will have a coupler that will connect to the generator and the other end will connect to the shaft allowing for a stable connection to the rest of the system. On the separation there is a portion for a floating disk to sit on the shaft.

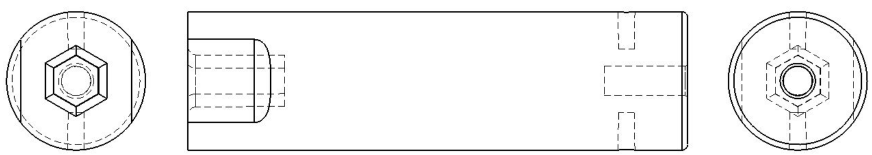

Figure 9: Generator Shaft

1.2.3 Generator Coupler

The coupler allows the group to allow the generator selection to remain fluid in the overall turbine design. This has been and will continue to be important as the team interfaces with the electrical team. The current iteration is intended to mesh with the MAD 5012, as seen in Figure 23. Some changes the group foresees with this part is the inclusion of clearances for bolts that can thread into the generator and solidify the connection.

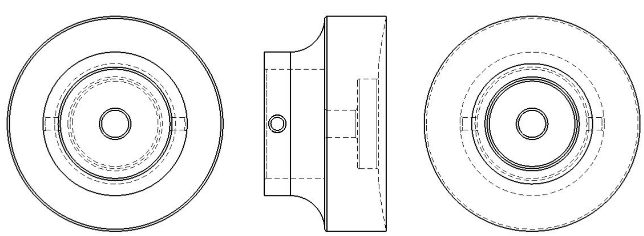

Figure 10: Generator Coupler

1.3 Nacelle

The Nacelle as seen in Figure 11 is responsible for the space management of the physical and electrical aspects of the turbine. This ranges from properly supporting the shaft via a drive train to coordinating the wiring required to export and import power to and from the electrical components.

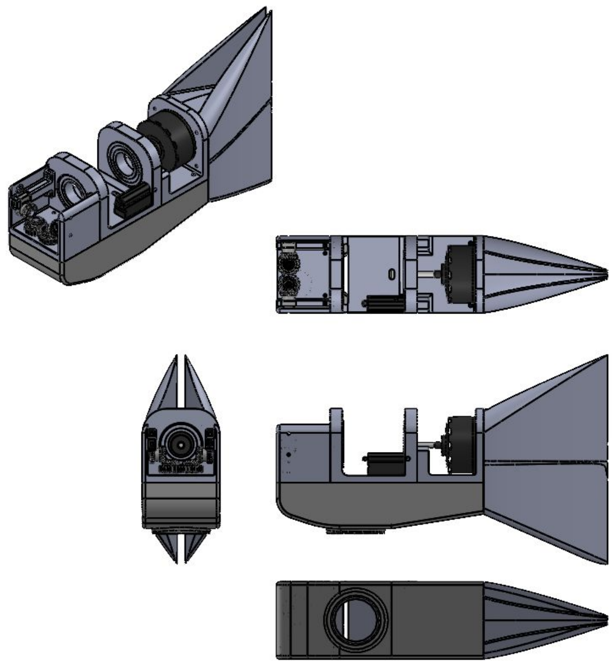

Figure 11: Nacelle Assembly

1.3.1 Pitch

The pitching system was the largest design decision made by the group. The inclusion of the following mechanisms allows for the pitching of the blades, making the concerns of start up torque less prevalent. However, the inclusion of the system adds complexity to the overall plan.

1.3.1.1 Driving

The driving mechanism for pitching the blades was decided upon via various team meetings. At first the team was considering using a crank and slider mechanism. This design was later thrown out due to concerns with moments being generated on the driven pitching mechanism as seen in Figure 13. These moments could seize up the overall mechanism and or create uneven loading. The concerns listed above lead us to the design seen in Figure 12. The current design uses a gear train assembly that creates even loading on the driven mechanism, fits within the constraints of the nacelle dimensions and also provides the necessary linear displacement to provide start up, rated, and stall angles of attack for the blades. The design includes a combination of spur gears, miter gears, and rack gears. All miter gears shown have 20 teeth, a module of 0.8, pitch diameter of 16 mm and a face width of 3.5 mm. The two spur gears attached to the nacelle bracket floor and stepper motor include 20 teeth, a module of 1, pitch diameter of 20 mm and a face width of 6 mm. The two rack gears attached to the nacelle bracket walls include 30 teeth, a module of 0.5 and a face width of 5.38 mm. Each gear has a 20 degree pressure angle and is made from PLA.

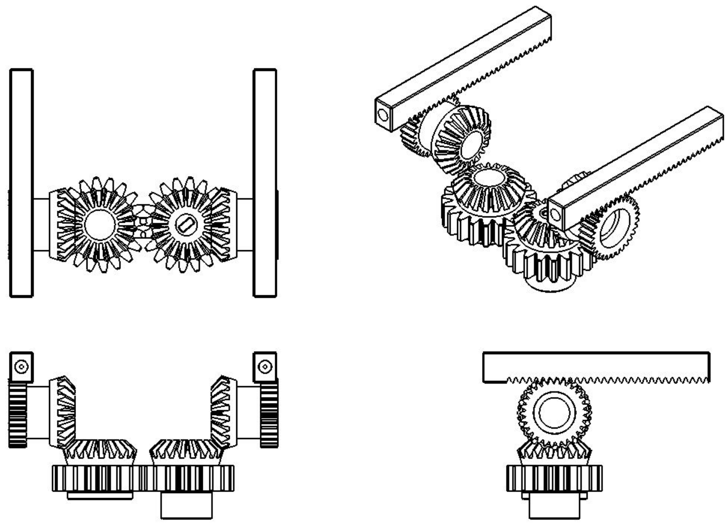

Figure 12: Driving Pitching Mechanism

1.3.1.2 Driven

The group experienced a lot of difficulty with the part displayed in Figure 13 because the original idea was to outsource the part. There were very few purchasable parts that fit the required specifications. Eventually, the group forwent the use of a swash plate and utilized parts designed in SolidWorks. Although the part no longer functions as a swash plate, the name stuck.

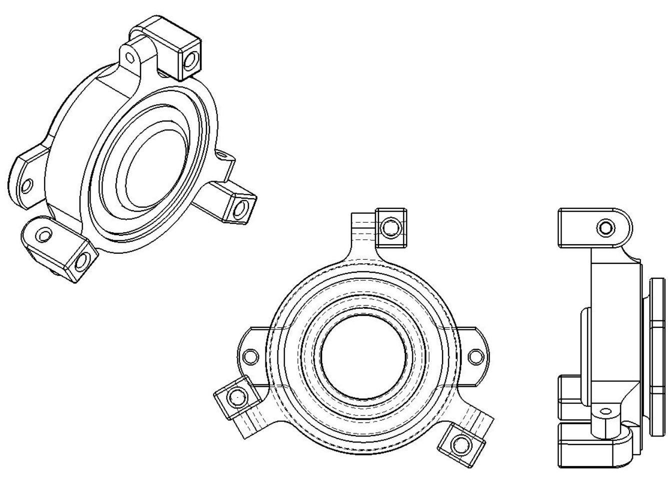

Figure 13: Driven Pitching Mechanism

1.3.1.2.1 Heim Joints

Heim joints are utilized to connect the appendages coming off of Figure 6 to the inserts seen in Figure 13. The heim joints allow for an extra degree of freedom which enables the blades to rotate sufficiently for pitching purposes.

Figure 14: Heim Joints

1.3.2 Brackets

The brackets serve as the foundation for the nacelle. The brackets were originally a single part, but have been split in three in hopes of easing the consequences of failed prints. It is very possible that the three sub-brackets will be redesigned into a single piece for the final product.

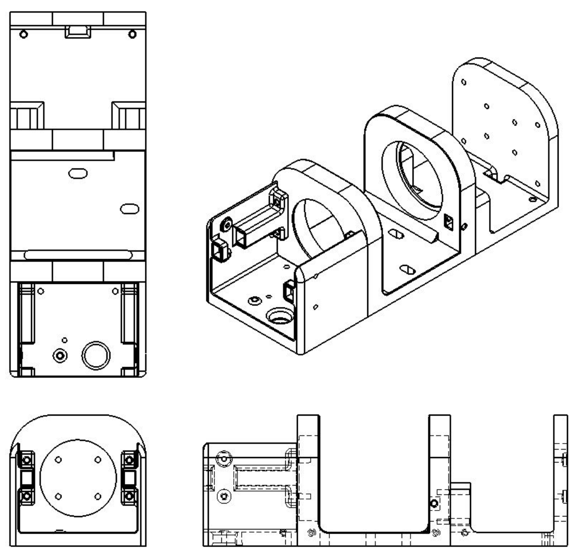

Figure 15: Swash, Drive, and Generator Brackets

1.3.2.1 Swash Bracket

The swash bracket takes into consideration many things, such as clearance for the stepper motor and gearing which is to be used in the pitching system, bearing surfaces, guidance systems for the rack gears, and the connection methodologies between the electrical housing and drive bracket.

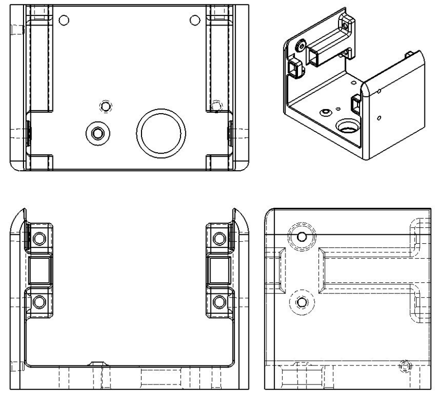

Figure 16: Swash Bracket

1.3.2.1.1 Stepper Motor

The current step motor comes as an add on to the arduino instructional kit. Preliminary tests have shown that the holding torque is sufficient for static operation, but further testing will illustrate whether a more specialized stepper motor will be required in the final iteration of the turbine.

Figure 17: Stepper Motor

1.3.2.2 Drive Bracket

The drive bracket also has many considerations required to operate sufficiently. The first and foremost is supporting the shaft. From there this bracket is also responsible for locking down the linear actuator, hall sensor tachometer, and brake disk.

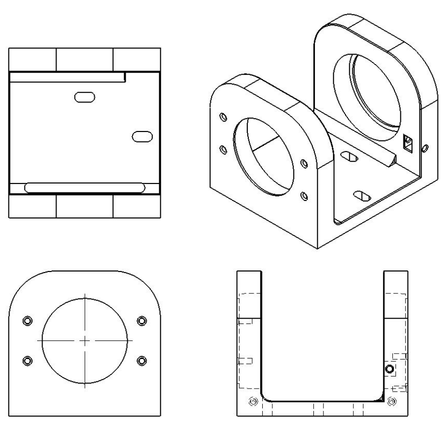

Figure 18: Drive Bracket

1.3.2.2.1 Linear Actuator

The linear actuator will be placed within the drive bracket shown above. This device will act as the main breaking unit for the turbine by applying a rubber brake pad to the central flywheel shown below. The team has decided to go with an actuator containing a gearing ratio of 100:1, this will provide the largest breaking force to the final design ensuring that the turbine will come to a complete stop within the time frame required by the department of energy.

Figure 19: Actuonix Linear Actuator

1.3.2.2.2 Hall Sensor

The magnetic Hall sensor is shown below. The effect of this sensor is to read the magnetic field coming off of the shaft and read by an Arduino microcontroller. Once in the Arduino microcontroller system, there will be a code that transforms the information given to the Arduino into a usable RPM reading.

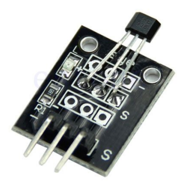

Figure 20: Hall Sensor Tachometer

1.3.2.2.3 Brake Disk

The main function of the braking system will aid the pitching system in slowing the overall turbine to a complete stop. This system will be being designed by using a bracket system to hold the overall Linear actuator as well as the brake pads. This flywheel is being manufactured out of 1018 Steel as seen in Figure 21.

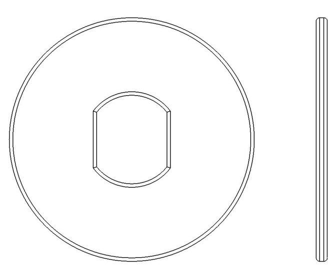

Figure 21: Brake Disk

1.3.2.3 Generator Bracket

The generator bracket, in comparison to the other brackets, has much less responsibility when it comes to the functionality of the control system. Strictly speaking, the generator brackets job is to allow connection to the drive bracket, electrical housing, and yawing fin. These three connections along with supporting the generator are the summation of this part's responsibilities.

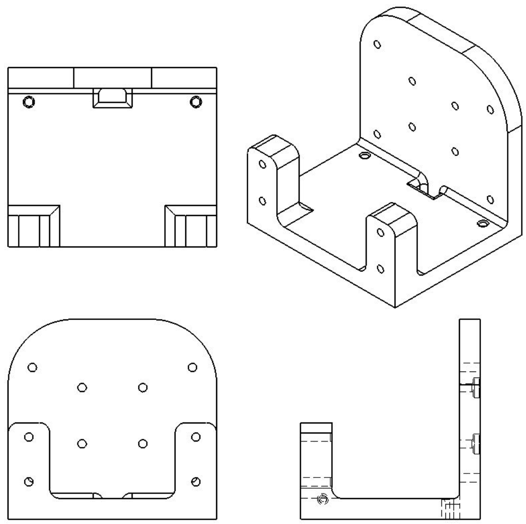

Figure 22: Generator Bracket

1.3.2.3.1 Generator

This system will be responsible for creating a power output to the point of common coupling. The team have been looking at different three phase brushless motors and examining the different cogging torques that will slow, and cause a difficult cut in speed. The motor will be outsourced due to the shortness of time in the planning and creation stages. Figure 23 below shows the MAD5012 motor that the team has been looking into, this motor has a KV rating of 160 and the team believes that this rating will lead to the best overall performance of the turbine.

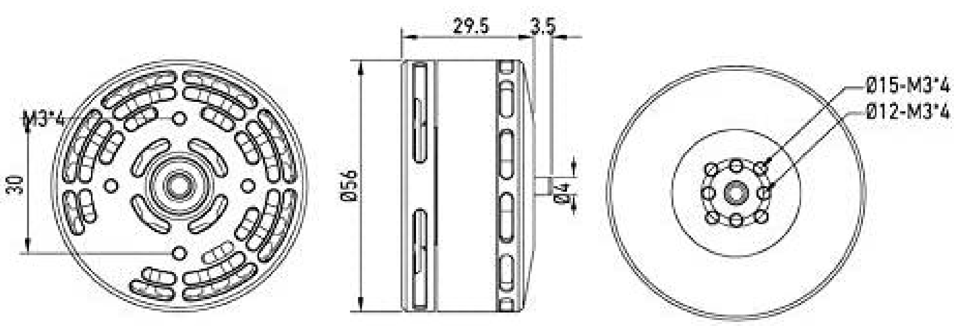

Figure 23: MAD 5012 Motor

1.3.4 Fin

The yawing fin shown in Figure 24 is the 8th iteration of fin design. This component was designed with the intent to maximize airflow and yawing torque with the necessity to keep the blades of the turbine facing upwind using only passive force from the windstream. The two primary criteria to maximize airflow was minimizing both streamline disconnects, reducing vortices, and to create low frontal area to reduce upstream pressure. The fin was designed to allow for minimal streamline disconnections by changing the angle of attack to account for our highest speed of operation as well as implementing modified airfoils for each component. Lowering the frontal area was accomplished by matching the mating surface of the fin with the entire back face of the nacelle, while only bolting to the upper section to allow for full functionality of the hinges. This task was met with resistance as we evaluated the maximum length requirements of the competition; opting us into a dual vertical fin design.

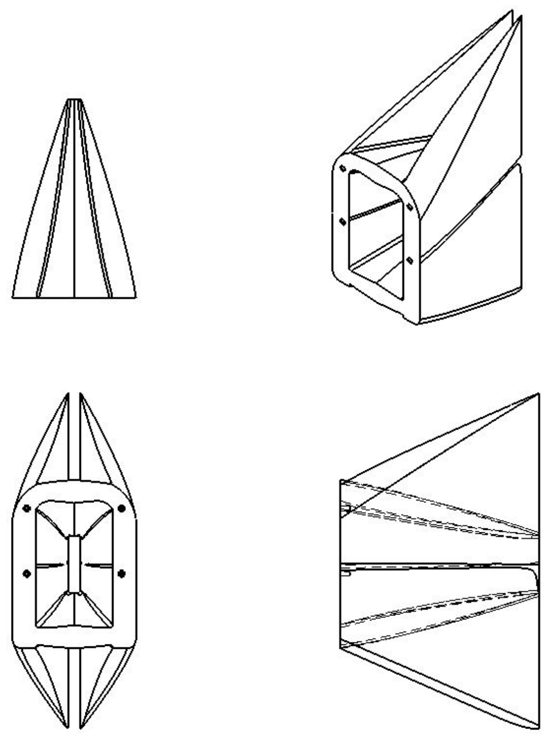

Figure 24: Yawing Fin

1.3.5 Electrical Housing

This is the secondary layer within the solidworks design that the bracket assembly sits on. This system will house the necessary electronics in the nacelle such as breadboards for the capacitance circuit, the stepper motor, and the wire management for the linear actuator and generator. The electrical housing will also incorporate a hinge system to allow for easy access to electrical components.

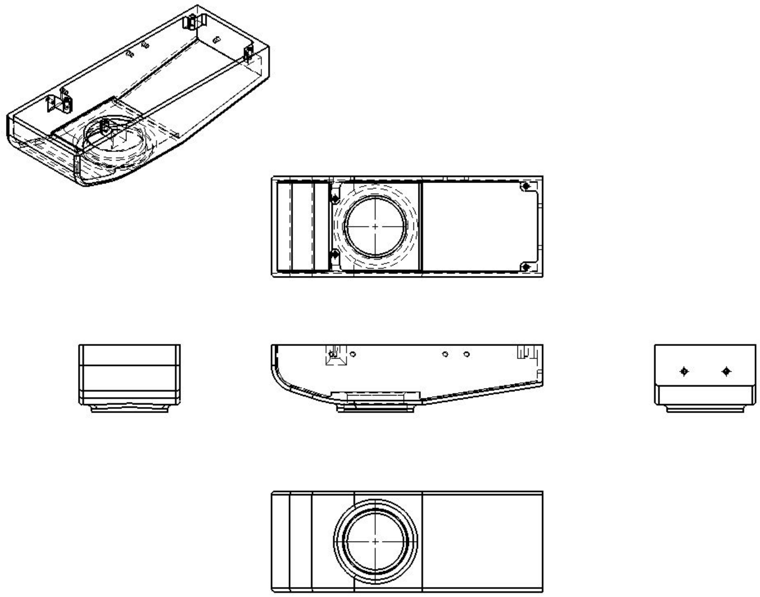

Figure 25: Electrical Housing

1.4 Tower

The tower assembly is shown in Figure 26. The main tower is simply a PVC tube and has not been given an individual figure. The tower's biggest design considerations are at the connections of the baseplate and nacelle, where large amounts of torque will be concentrated.The group most definitely foresees several of the parts in this assembly needing to be machined.

Figure 26: Tower Assembly

1.4.1 Nacelle Coupler

This is the part that links the tower and electrical housing together. It currently has a single bearing press fit into the tower, but due to high forces we are planning on adding an extra bearing to distribute the force more evenly. This will be manufactured at the machine shop to assure that the extra forces between the nacelle and tower won't cause the part to fail.

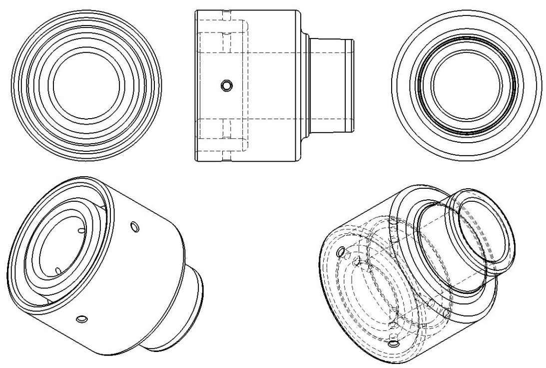

Figure 27: Nacelle Coupler

1.4.2 Base Plate

The base plate, as seen in Figure 28, has very simplistic features. There are 3 M10 bolt holes placed around the edge of the plate to allow for connection to the competition's mounting frame. From there, three M3 bolt holes can be seen in the center that are used to connect to the base plate coupler, as seen in Figure 29. The group would like to allow for a deeper indent to hug the PVC tower, but competition rules allow for a base plate no thicker than 16.1 mm, greatly limiting the group's design.

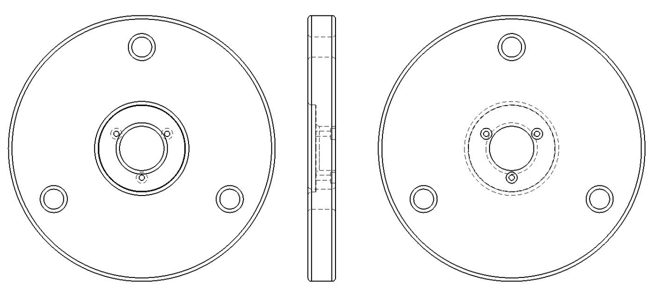

Figure 28: Base Plate

1.4.3 Base Plate Coupler

The base plate coupler will connect the PVC tower to the PLA baseplate and is placed within the tower itself. There are six bolt threads, three to connect to the base plate and another three to lock in the position of the PVC tower. The group would like to utilize machined parts in the final iteration of this coupler.

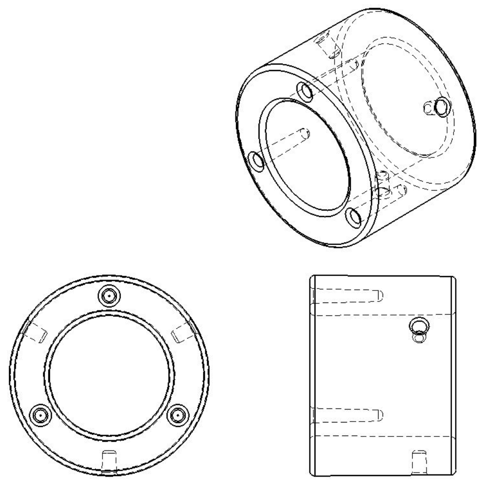

Figure 29: Base Plate Coupler

2 Physical Prototype

Figure 30 is a disassembly of the existing turbines, including printed parts, outsourced parts, electrical components, and even fasteners. Furthermore, Figure 31 is an assembled version. It is of note that this is not a full prototype, as it is missing the electrical housing and yawing fin, in other words, the brackets are sitting atop the tower with no real mechanism to hold it in place. Since a majority of the last section covered the design decisions for each part, this section will discuss the iterations the team has gone through up until this point to arrive at the current designs shown above.

Figure 30: Disassembly of Prototype (1/26/2021)


Figure 31: Refashioned Prototype (01/31/2021)

2.1 Rotor

Figure 32 is the current iteration of the rotor prototype. This prototype has been attached to the dynamometer and rotated at 1700 rpm. Although no parts were damaged, one of the screws connecting the mounted bearing to the hub had significantly loosened itself.


Figure 32: Current Iteration of Rotor Assembly (02/09/2021)

2.1.1 Hub

The hub for the turbine has gone through a variety of iterations. Figure 33 shows the first six iterations of the hub (does not include the most recent 7th iteration currently shown in Figure 30, 31, and 32). The evolution from theoretical to practical can be seen throughout. On the 4th iteration, the group included a mechanism to allow for bearing rotation. In the 5th iteration, it can be seen that the group chose to outsource mounted bearings for optimum rotation and include a cap. In the 6th iteration, dimension optimization can be seen and is very similar to the current model seen in Figure 32.

Figure 33: Hub Progression (02/01/2021)

2.1.2 Blades

Figure 34 represents the blade iterations (oldest to the right, newest to the left) and although very similar to the 4th iteration, the 5th and current iteration is not included (can be seen in Figures 30, 31, and 32). The biggest difference between the first and second iteration is the transition from school to personal printers. From there, the third iteration features the proper use of splines within SolidWorks. The final iteration of the blade in the figure incorporates more realistic dimensions that adhere to the competition's guidelines.

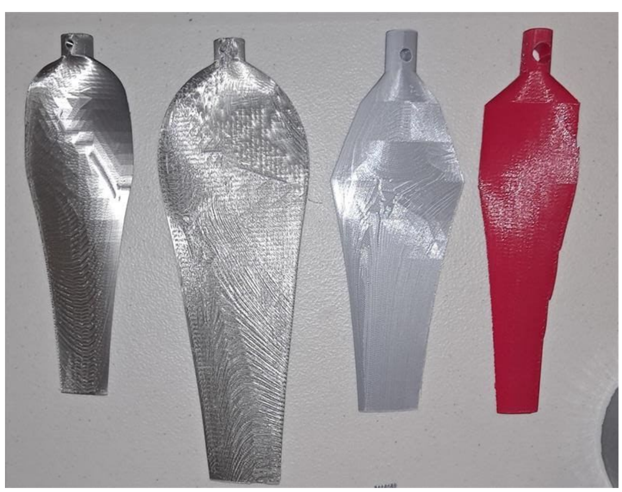

Figure 34: Blade Progression (02/01/2021)

2.1.3 Coupler

Figure 35 shows the three latest iterations (3th-5th) of the rotor coupler, with the current member to the far left. The first two iterations are seen in Figure 34 attached to their respective hubs. The process once again has revolved around CAD experience, attainment of outsourced parts, and consideration of stress concentrations. The group is almost certain that this part will need to be adjusted for machining purposes or become a part of the blade itself.

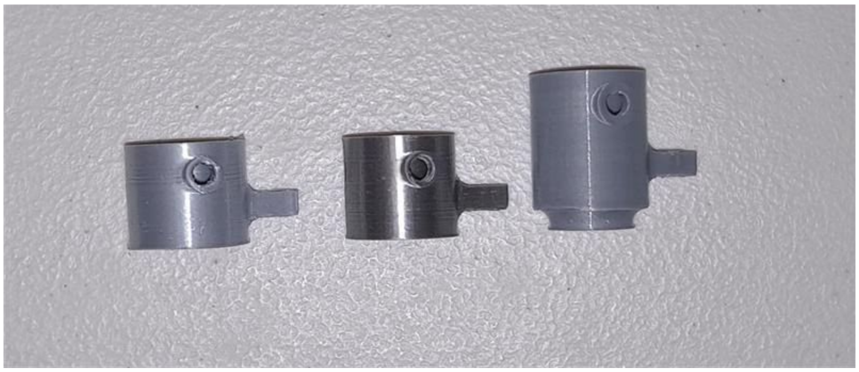

Figure 35: Rotor Coupler Progression (02/01/2021)

2.2 Shaft

Unlike the components of the rotor, the current swash and generator shaft are still on their first iterations. Both can be seen in Figure 36. This part was not tested at the same RPM as the rotor was, but a supplemental shaft of the same material and same diameter of the fore cross section of the swash shaft (the smallest cross section within the shaft) proved sufficient to withstand the forces reached. However, the supplemental shaft was a single piece, so the stress concentrations that form at the connection point have not yet been experimentally investigated.

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Figure 36: Current Shaft Assembly

2.2.3 Generator Coupler

This is the part that connects the shaft of the turbine to the generator. Making the part instead of buying a connection to the motor saved the team both time and money. The option to create the part allowed for more freedom of design both in regard to the shaft and where the generator would be mounted on the nacelle bracket.

Figure 37: Generator Coupler

2.3.1 Pitch

The driven pitch system is seen below in Figure 38. The newer iteration is on the left with the heim joints attached. This part was originally going to be outsourced, but the group came to the conclusion that designing a part would not only reduce redundancy in the design, but also prove quite cost effective. The biggest changes between the first and second iteration of the driven mechanism is the length of the appendages and the reduction from a full circular profile of the stationary member to simple appendages.

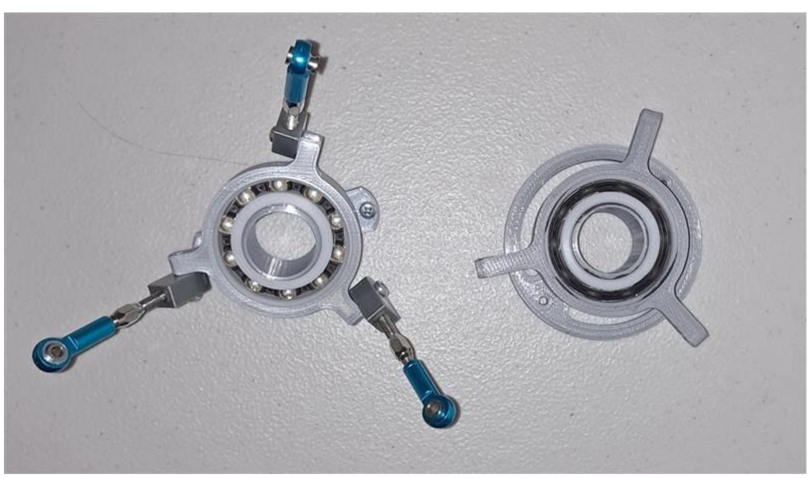

Figure 38: Pitching mechanism

2.3.2.1 Swash Bracket

Figure 39 represents not only the swash bracket, but also features the driving pitching mechanism. The gears were printed so that bearings can be fit within the bottom with enough clearance for a bolt to pin them to the bracket. The bracket has slight extrudes at locations where the gears are placed to allow the bearings to spin with minimal frictional resistance. The gears were printed at 100% infill, and the bracket was printed at 75% infill. The group anticipates changes with the swash bracket, at which time a full 100% infill will be used.

Figure 39: Swash plate bracket

2.3.2.2 Drive Bracket

The drive bracket shown in Figure 40 has reliefs to fit 2 bearings, which are also present in the figure. This part was only printed with an infill of 35%, as the group once again is anticipating changes before a 100% infill final product can be reached. So far, this part has exhibited no issues, but this is expected to change once the inclusion of the hall sensor tachometer has been considered.

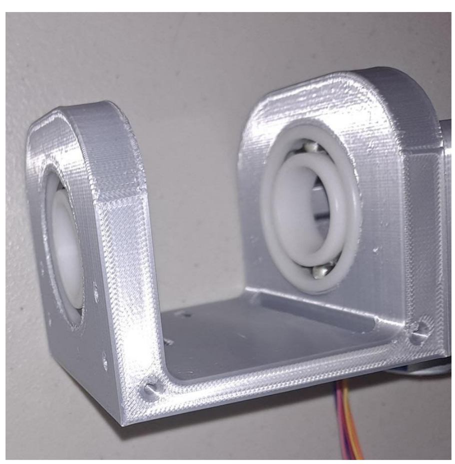

Figure 40: Drive bracket

2.3.2.3 Generator Bracket

The generator bracket also utilized a 35% infill. Although still functional, the group would like to elongate the part slightly upon redesign to add additional clearance for the coupler. A more apparent problem is the incorrect dimensioning of the bolt holes on the back of the bracket meant to suspend the generator, which proved slightly too close together upon completion of the print.

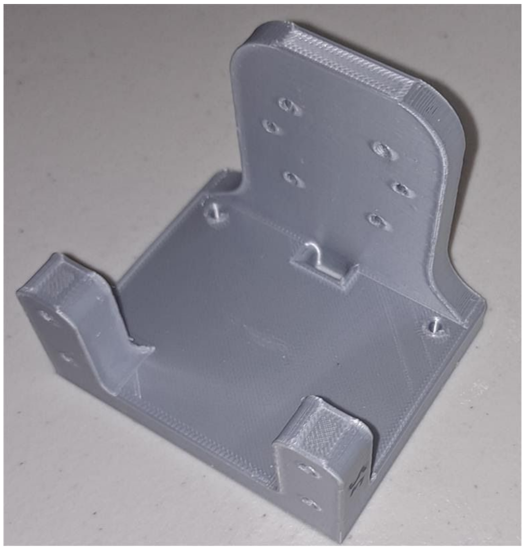

Figure 41: Generator bracket

2.4.1 Nacelle Coupler

Figure 42 shows the coupler, the connection point between the top of the tower and the electrical housing. The current design is 3D printed with a single bearing, but due to some concerns with the forces acting at the connection point it has been decided that this part will be machined after a slight redesign.

Figure 42: Nacelle Coupler

2.4.2 Baseplate

Figure 43 represents the 2nd print of the base plate. The difference between the first and second plate is very minimal. The group realized the bolts on the back of the plate need to sit flush in order for the entire plate not to wobble. This was a very clear example of why it is important to prototype early.

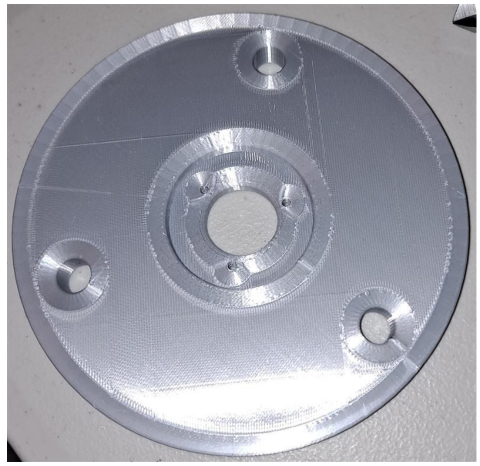

Figure 43: Base plate

2.4.3 Base Plate Coupler

The group will be machining the base plate coupler. Although the team has previously printed two different iterations, both have broken under conditions similar to maximum operating forces.

3 Control Systems

The main functions of the turbine will be controlled through various input variables and henceforth other output variables. One of the main output variables of concern is voltage. The voltage will come off the turbine and go through a series of resistors that end in an Arduino Mega (Figure 44) that will output the voltage and display it on an LCD screen (Figure 45). Current will also be read off the turbine and into the Arduino. There will also be an IR LED and photodiode board (Figure 46) that will reflect light off of reflective tape and receive an RPM count off the turbine, also being displayed on the LCD screen. However, there will be an updated LCD display (Figure 47) that will show all the readings at the same time. Then through the Arduino there will be separate lines of code that will do calculations to operate the linear actuator (Figure 19) that will be the braking system of the turbine. Through more lines of code within the Arduino IDE program, the pitching system of the turbine will be managed and this will be done physically through a stepper motor (Figure 17). In the PCP box there will be a temperature sensor (Figure 48) that will read the ambient temperature in the box and if it is too hot the Arduino will turn on a fan (Figure 49) to cool down the box to prevent the melting of electrical components.

Figure 44: Arduino Mega

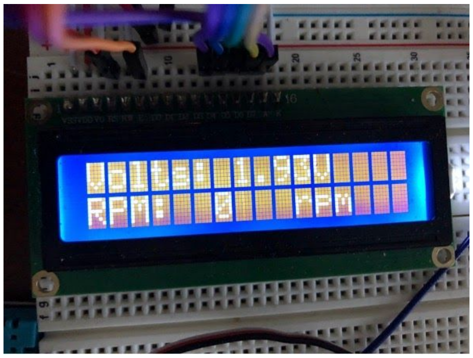

Figure 45: LCD Display

Figure 46: LED and Photodiode Board

Figure 47: Large LCD Display

Figure 48: DHT 11 Temperature Sensor

Figure 49: PC Fan

3.1 Point of Common Coupling Connection (PCC)

The PCC is the team's main source of power, monitoring, and testing the final design of the turbine. This part will be made of multiple different components. The main housing of the box will be a waterproof box that will have a piece of plexiglass across the top so that the team will be able to see the internal components. Some of the large internal components will include an 1100 W power supply, two computer fans, multiple circuit boards, and an internal arduino. These different components will be connected by multiple different wiring, and the entire box will be powered by the internal arduino.

The team will also be utilizing a smaller set up for the motor testing. The figure below shows the smaller testing setup for the motor. This setup will be used for finding the overall max speed in

RPM that the motor of choice will be operating at. The team will also be using this set up for the testing of the generator shaft and the entirety of the shaft.

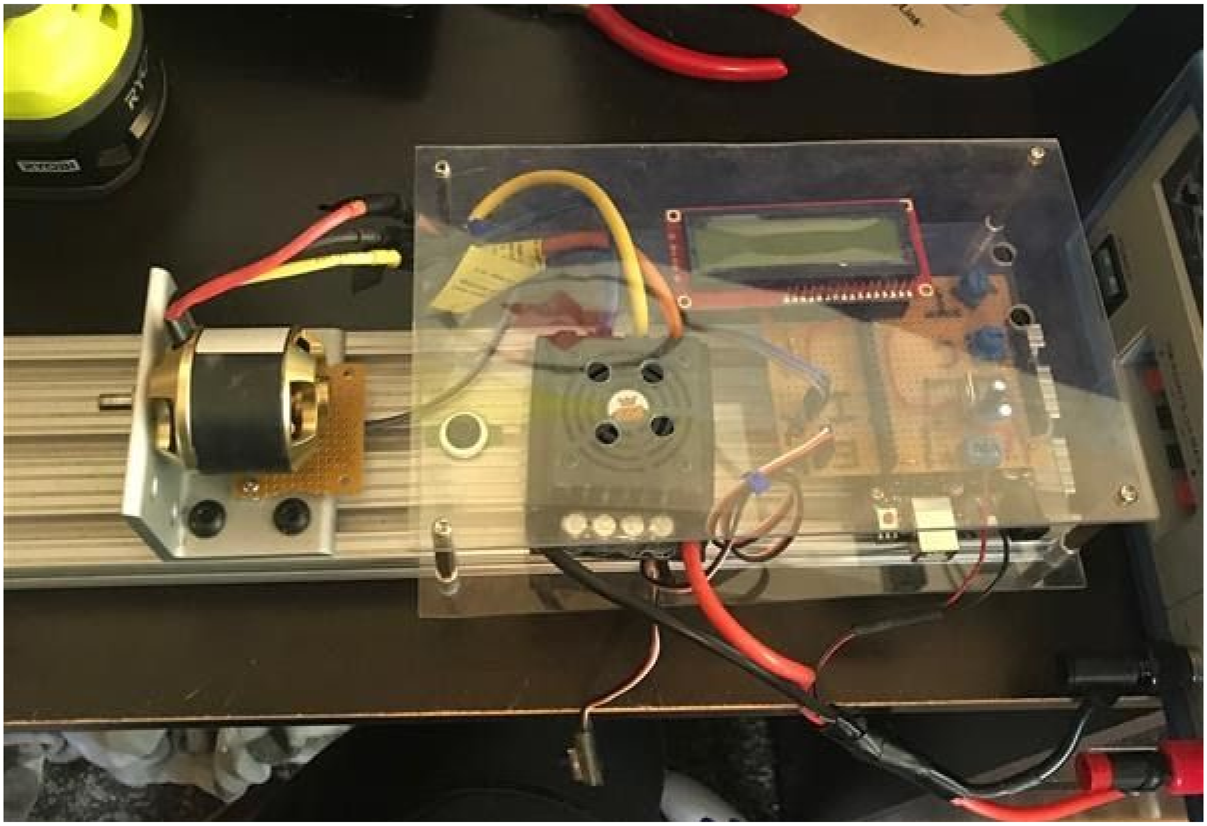

Figure 50: Motor testing setup