

Operation/Assembly Manual

2021 Collegiate Wind Competition

Northern Arizona University



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Special thanks to,

David Willy, David Trevas, and Sarah Oman.

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Overview

Competition Parameters

Table 1 lists the design and engineering requirements needed to compete in the 2021 collegiate wind competition. These requirements are found in the competition rules and where used as the design points, constraints, and requirements for our micro wind turbine.

Table 1: Competition Parameters

Design Requirements
Design and analyze to withstand continuous winds up to 22 m/s
Rotor and non-rotor turbine parts must be within a size of 45x45x45 cm cube
15 cm diameter cylinder centered on the mounting flange containing non-turbine parts
Full assembly must be confined to 61 cm by 122 cm dimensions
Maximum thickness of the base plate is 16.1 millimeters
Turbine base must withstand a torque of 50 Newton-meters
Yaw rate of 180 degrees/second
Engineering Requirements
Cut-in wind speed of 2.5 m/s (meters per second) to 5 m/s to achieve a positive current average over a 5 second interval
+/- 10% maximum average power
Control rate power at 11 m/s
Brake system activates when the emergency stop button is pushed, disconnected from PCC (point of common coupling), or when winds reach above 22 m/s
Design can function for 5 minutes at speeds from 6 m/s to 13 m/s

Bill of Materials

Table 2: Summarized Bill of Materials

	Part ID	Item Name	Qty.
Major Components	1	Mechanical Bracket	1
	2	Electrical Housing	1
	3	Upper Fin	1
	4	Lower Fin	1
	5	Tower	1
	6	Blade	3
	7	Linear Pitch Bearing	1
	8	Shaft	1
	9	Motor	1
	10	Hub	1
	11	Cover	1
Minor Components	12	Mounted Bearing	3
	13	Heim Joint	3
	14	Heim Coupler	3
	15	Wall Gear	2
	16	Floor Gear	1
	17	Stepper Gear	1
	18	Rack Gear	2
	19	Stepper Motor	1
	20	Stepper Driver	1
	21	Circuit Board	1
	22	Shaft Coupler	1
	23	Hall Sensor	1
	24	Linear Actuator	1
	25	Brake Disk	1
	26	Brake Pad	1
	27	Slip Ring	1
	28	Retaining Ring	1

	29	25x47x12 mm Bearing	2
	30	7x14x5 mm Bearing	2
	31	45x58x7 mm Bearing	2
Electrical Components	32	3' 18 Gauge Wire	12
	33	Rectifier	1
	34	Boost Converter	1
	35	MCU	1
	36	Test Load	1

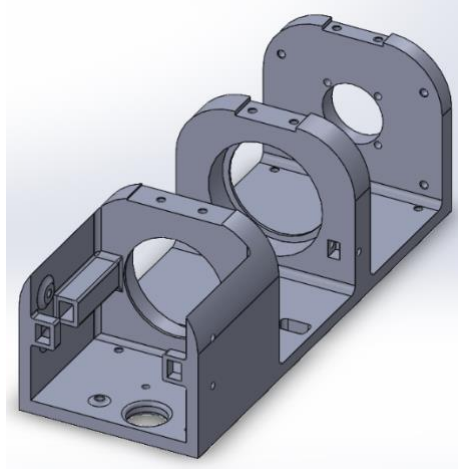


Figure 1: Mechanical Bracket (MB)

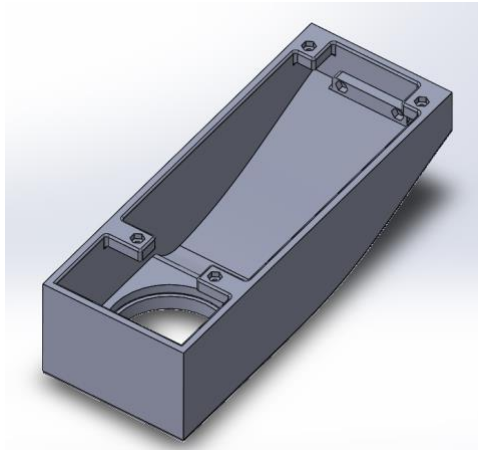


Figure 2: Electrical Housing (EH)

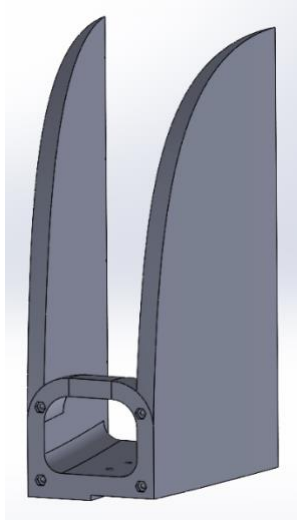


Figure 3: Upper Fin

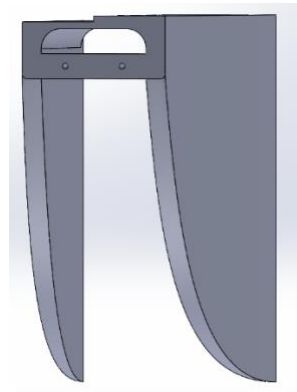


Figure 4: Lower Fin

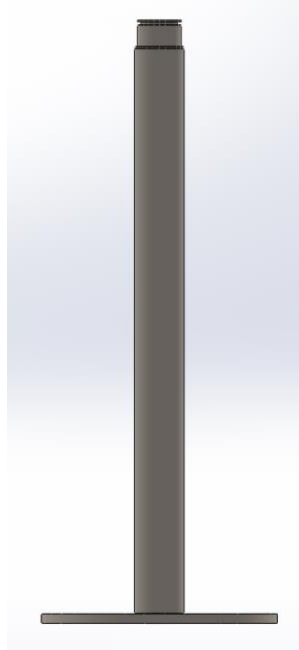


Figure 5: Tower

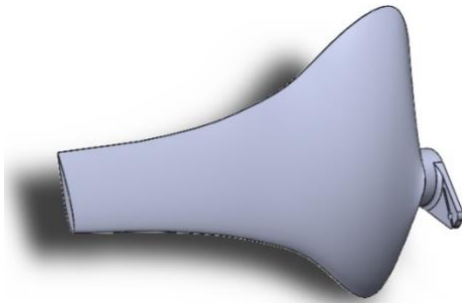


Figure 6: Blade

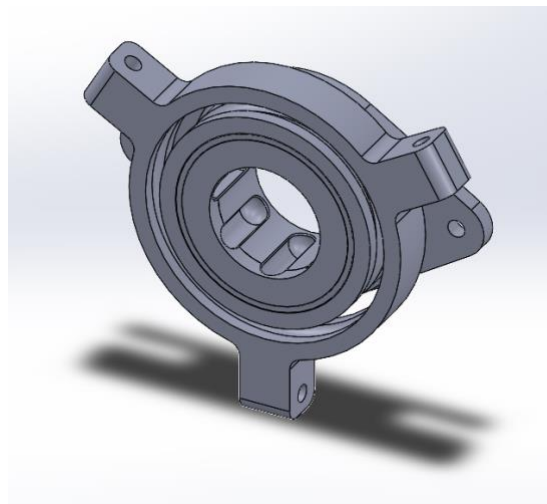


Figure 7: Linear Pitch Bearing

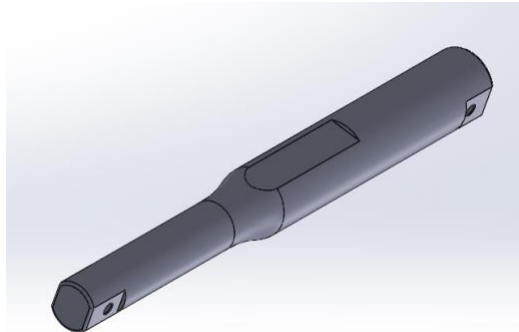


Figure 8: Shaft

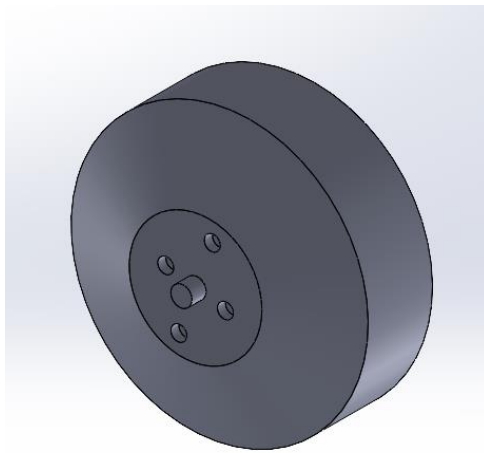


Figure 9: Motor

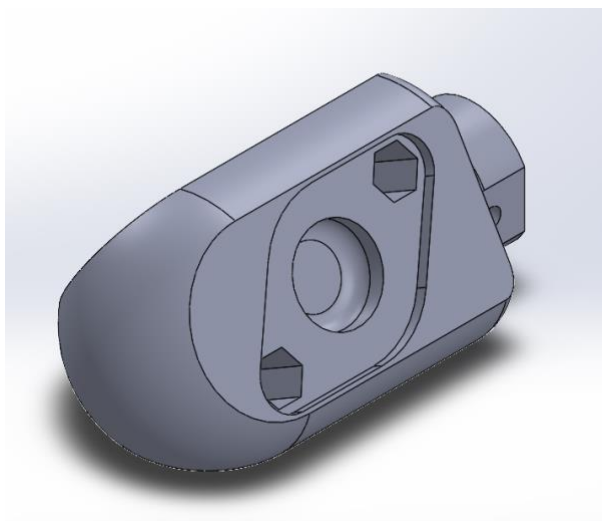


Figure 10: Hub

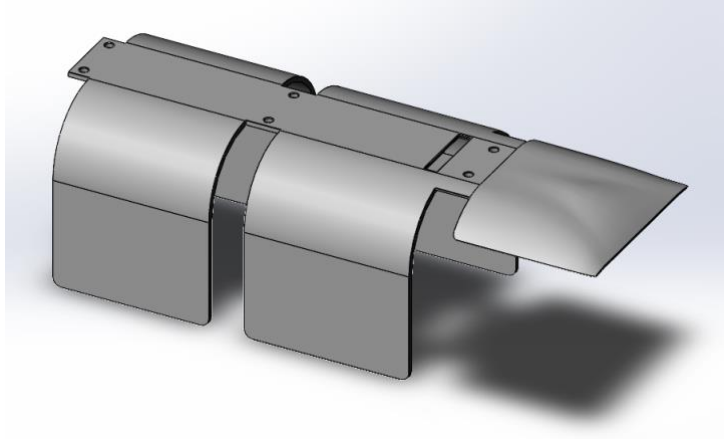


Figure 11: Cover

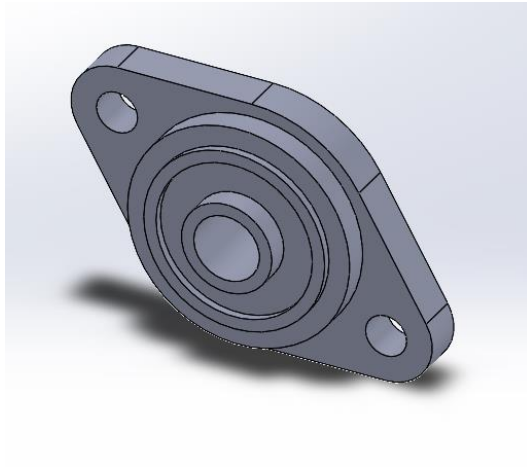


Figure 12: Mounted Bearing

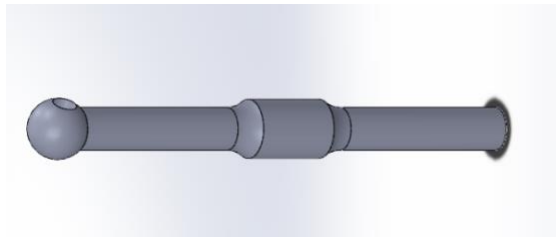


Figure 13: Heim Joint

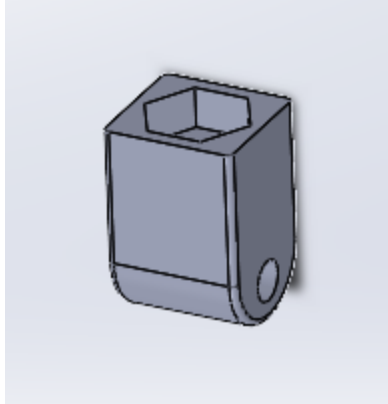


Figure 14: Heim Coupler

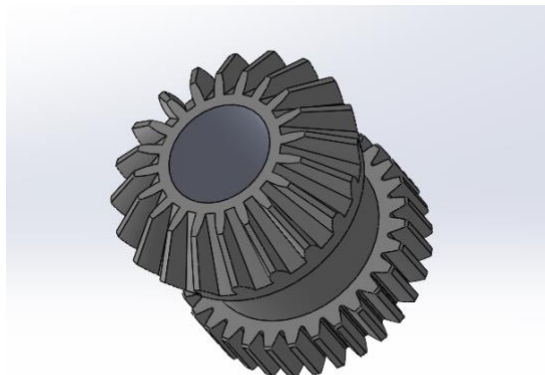


Figure 15: Wall Gear

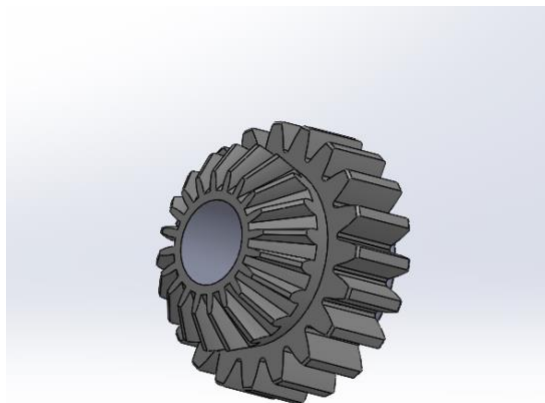


Figure 16: Floor Gear

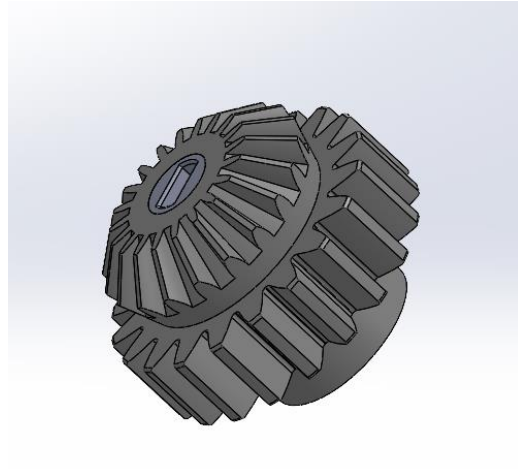


Figure 17: Stepper Gear

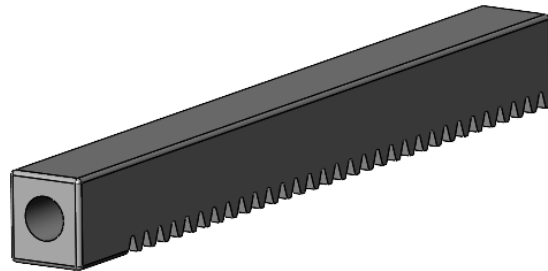


Figure 18: Rack Gear

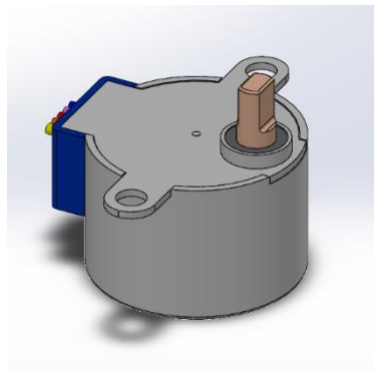


Figure 19: Stepper Motor



Figure 20: Stepper Driver

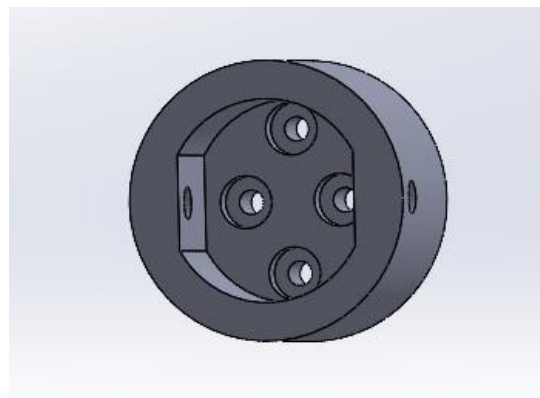


Figure 22: Shaft Coupler

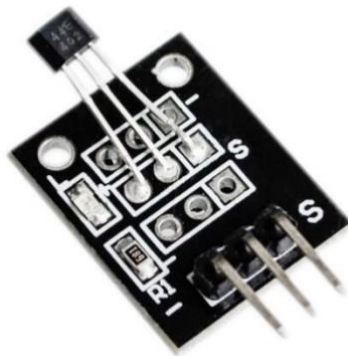


Figure 23: Hall Sensor



Figure 24: Linear Actuator

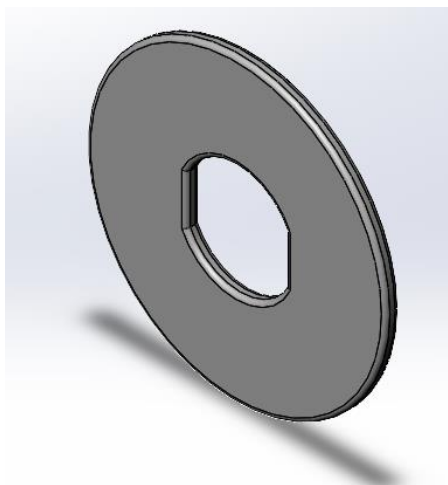


Figure 25: Brake Disk

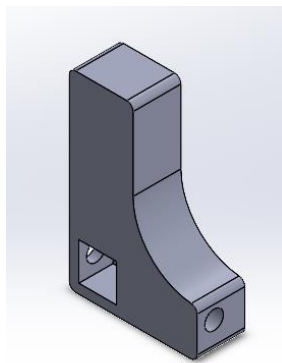


Figure 26: Brake Pad

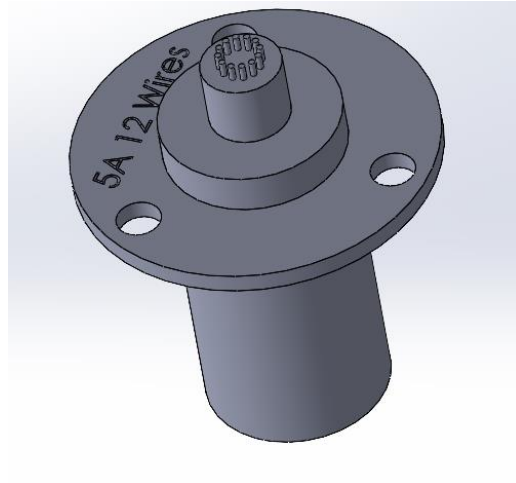


Figure 27: Slip Ring

Construction

Production

Printing

3D printing was the main source of manufacturing for our micro wind turbine. Table 3 lists the parts that were 3D printed in house in accordance with the CAD model

Table 3: 3D printed parts

3D Printed Parts		
Part ID	Part Name	Qty.
1	Mechanical Bracket	1
2	Electrical Housing	1
3	Upper Fin	1
4	Lower Fin	1
6	Blade	3
14	Wall Gear	2
15	Floor Gear	1
16	Stepper Gear	1
17	Rack Gear	2
21	Shaft Coupler	1

The 3D printer used for manufacturing the parts was the ender V3. All parts were printed with 100% infill using PLA plus.

Machining

Parts that could not be 3D printed due to high stresses acting on them and or friction i.e. heat acting on them were machined. The main parts that were machined were an aluminum shaft to hold under the high RPM rating of the turbine. The same idea was applied to the brake disc. The disc was instead made of steel. The shaft was turned down in a lathe then once the proper outer diameters were established a file was taken to certain areas of the shaft to make a proper holding spot for the hub assembly and the rotor assembly. The disc was made by using a drill press then using precision welds a slot is created so that it may sit on the shaft while still floating along the axis of the shaft. The tower for the turbine was made of 6061 Aluminum. One side of the aluminum pipe was lathed down so that a bearing can fit over the tower and a retaining ring. The base plat for the tower was machined out of the same type of aluminum with a center hole and three different bolt holes allowing for future connections. Once the first part of the tower was machined down it was then welded to the base plate.

Table 4: Machined Parts

Machined Parts		
Part ID	Part Name	Qty.
5	Tower	1
8	Shaft	1
25	Brake Disk	1

Purchasing

Parts that would take the team too long to design and or did not require customization were outsourced.

Table 5 list these parts.

Table 5: Outsourced Parts

Outsourced Parts		
Part ID	Part Name	Qty.
9	Motor	1
12	Mounted Bearing	1
13	Heim Joint	3
19	Stepper Motor	1
20	Stepper Driver	1
21	Circuit Board	1
23	Hall Sensor	1
24	Linear Actuator	1
27	Slip Ring	1
28	Retaining Ring	1
29	25x47x12 mm bearing	2
30	7x14x5 mm bearing	2
31	45x58x7 mm bearing	2
32	3' 18 Gauge Wire	12
33	Rectifier	1
34	Boost Converter	1
35	MCU	1
36	Test Load	1

Assembly

Exploded View

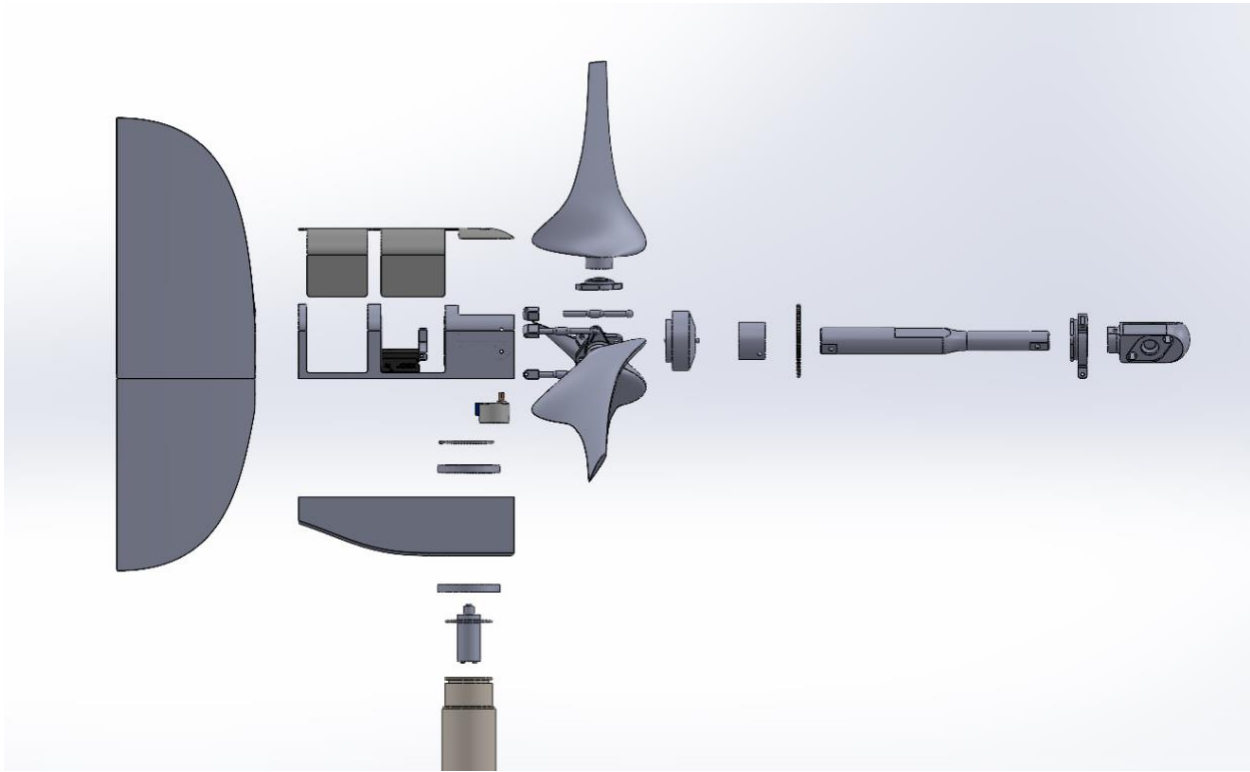


Figure 28: Exploded View of Turbine

Assembly Process

Step 1: Driving Pitch

The necessary components for the assembly of the pitching system are the mechanical bracket (MB), stepper motor, stepper gear, floor gear, wall gears, and 7x14x5 mm guide bearings. Begin by attaching the stepper motor to the bottom of the MB. Place the stepper gear atop the shaft and push down until the gear is firmly situated. The floor gear and wall gears can respectively be placed atop their mounts and fastened. A 90° Philips head is recommended for this process. Lastly, add the guide bearings at the top of the MB. Use lock nuts to firmly secure all protruding bolts. This process is depicted throughout the illustrations in Figure 29.

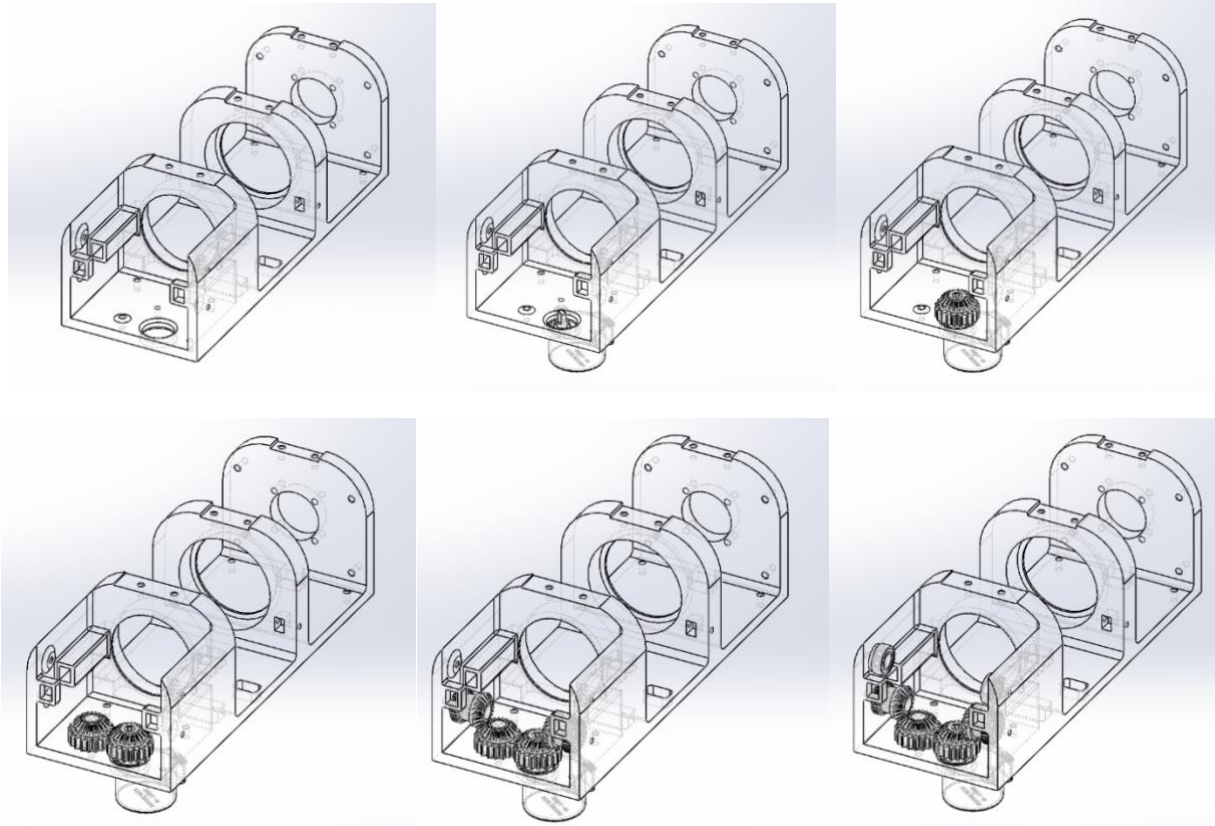


Figure 29: Step 1 Visualization

Step 2: Upper Nacelle

To complete this second process, the 25x47x12 mm bearings, shaft, brake disc and pad, shaft coupler, generator, hall sensor, and linear actuator are required. First, insert the support bearings in the housings and place the hall sensor in the center of the MB and secure it. Then, the shaft is lead through the back of the MB until the tip of the shaft is about to enter the second bearing housing. The brake disc is inserted around the shaft. Push the shaft forward until the shaft's key and second bearing housing are pinching the brake disc. The generator and coupler can now be inserted. Secure the coupler and shaft with an M4 bolt. Then mount the generator through the back of the MB. Finally, after the brake pad has been bolted to the linear actuator, the actuator can be inserted into the cut out on the right of the MB. Figure 30 depicts the actions required to complete this step.

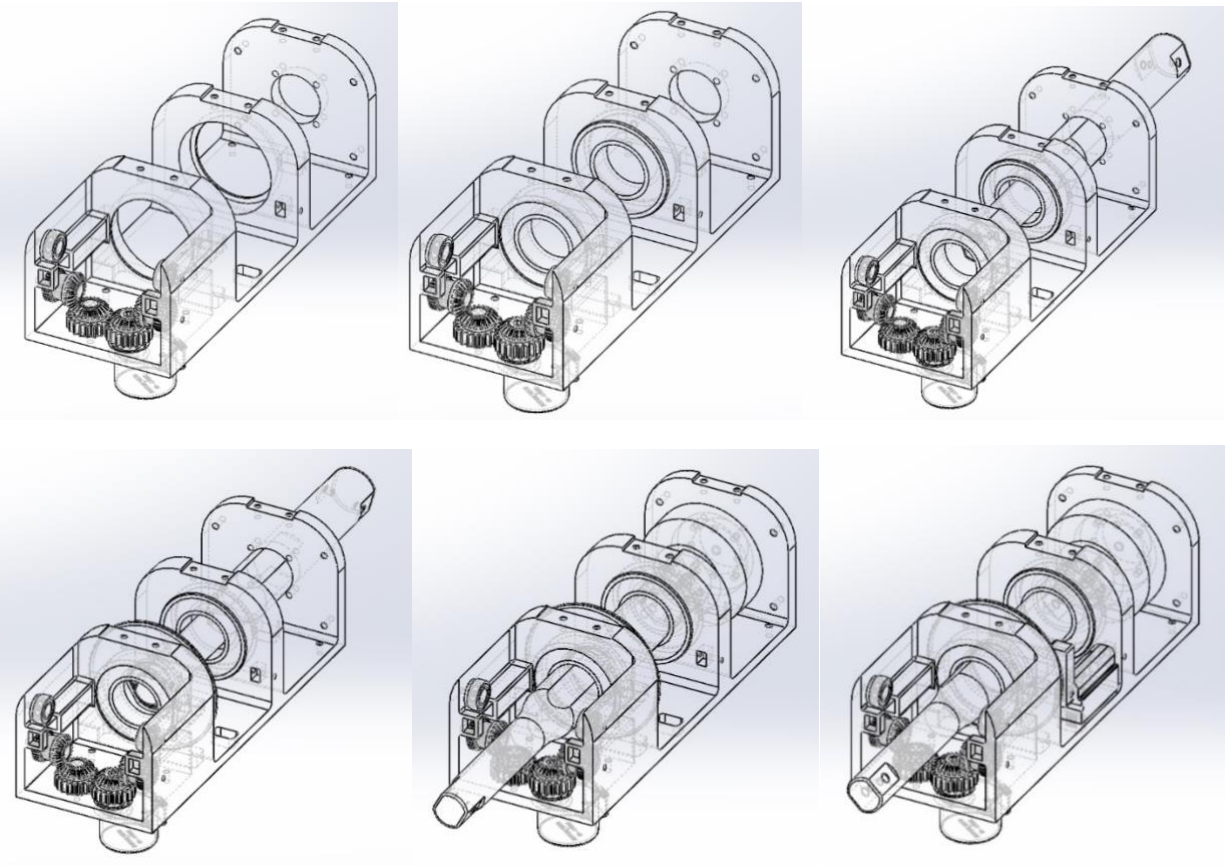
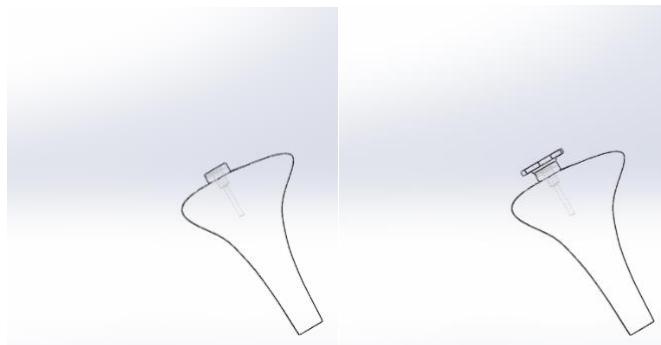


Figure 30: Step 2 Visualization

Step 3: Rotor

In this process, the hub, blades, mounted bearings, linear pitch bearing, rack gears, and three heim joints with their couplers will serve as the needed components. First place the lip of the mounted bearings within the clearing at the blade root. Connect the blade and mounted bearing using an M6 bolt. Then bolt down each mounted blade in the hub using M4 bolts. The first half of step three is seen in Figure 31.



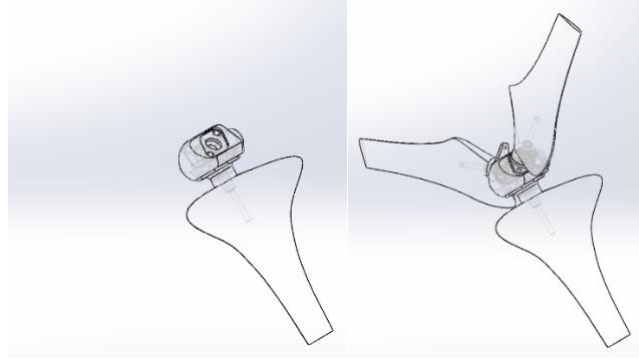


Figure 31: Step 3 Visualization: Rotor

Moving to the linear pitch bearing, secure the rack gears to the stationary portion of the bearing. From there, attach the three heim couplers to the rotating portion of the swash assembly. The heim joints can now be screwed into said couplers. This three-stage process is seen in Figure 32. Lastly, attach the heim joints to the extensions at the bottom of the blades. Results are displayed in Figure 33.

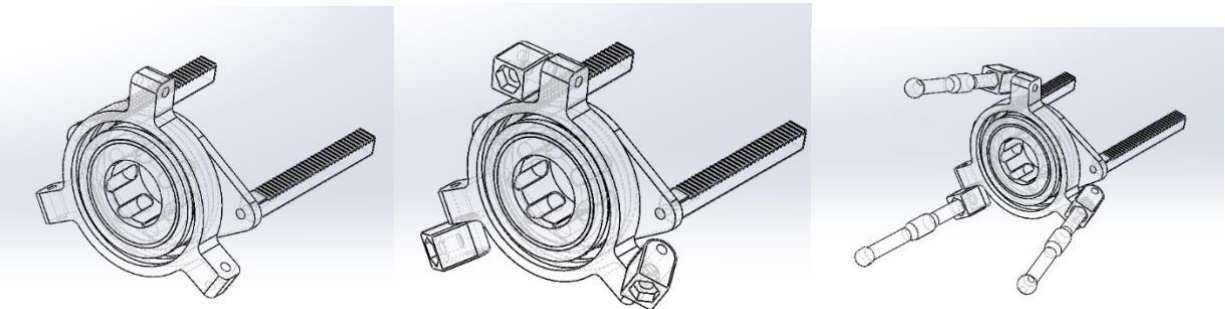


Figure 32: Step 3 Visualization: Driven Pitch

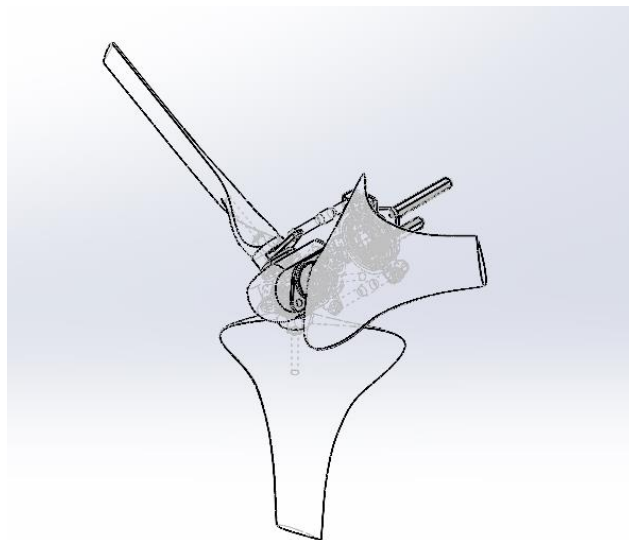


Figure 33: Step 3 Visualization

Step 4: Lower Nacelle/Tower

For this process, the aluminum tower, the 45x58x7 mm bearings, the electrical housing (EH), brass retaining ring, slip ring, stepper motor driver, and circuit board will be utilized. First, place the slip ring atop the tower. Then, insert one of the bearings around the tower, followed directly by the EH, the second bearing, and then the brass retaining ring. The electronic setup will need to be completed prior to complete assembly. The turbine needs eight control wires for the stepper motor, linear actuator, generator, and hall sensor, as well as power out and in for the generator and operation of components. Considering all components can operate at 6 V, only a single feedback is required, totally 11 wires. The physical illustration of this step can be seen in Figure 34. Table 5 shows the color coordinating the relevant wiring. Figure 34 shows the assembly process in six stages: 1. A clear aluminum tower with a slip ring at the top. 2. The tower with one bearing installed. 3. The tower with the electrical housing (EH) installed. 4. The tower with the second bearing installed. 5. The tower with the brass retaining ring installed. 6. The tower with the electrical housing (EH) and bearings installed, and the stepper motor driver and circuit board mounted on top.

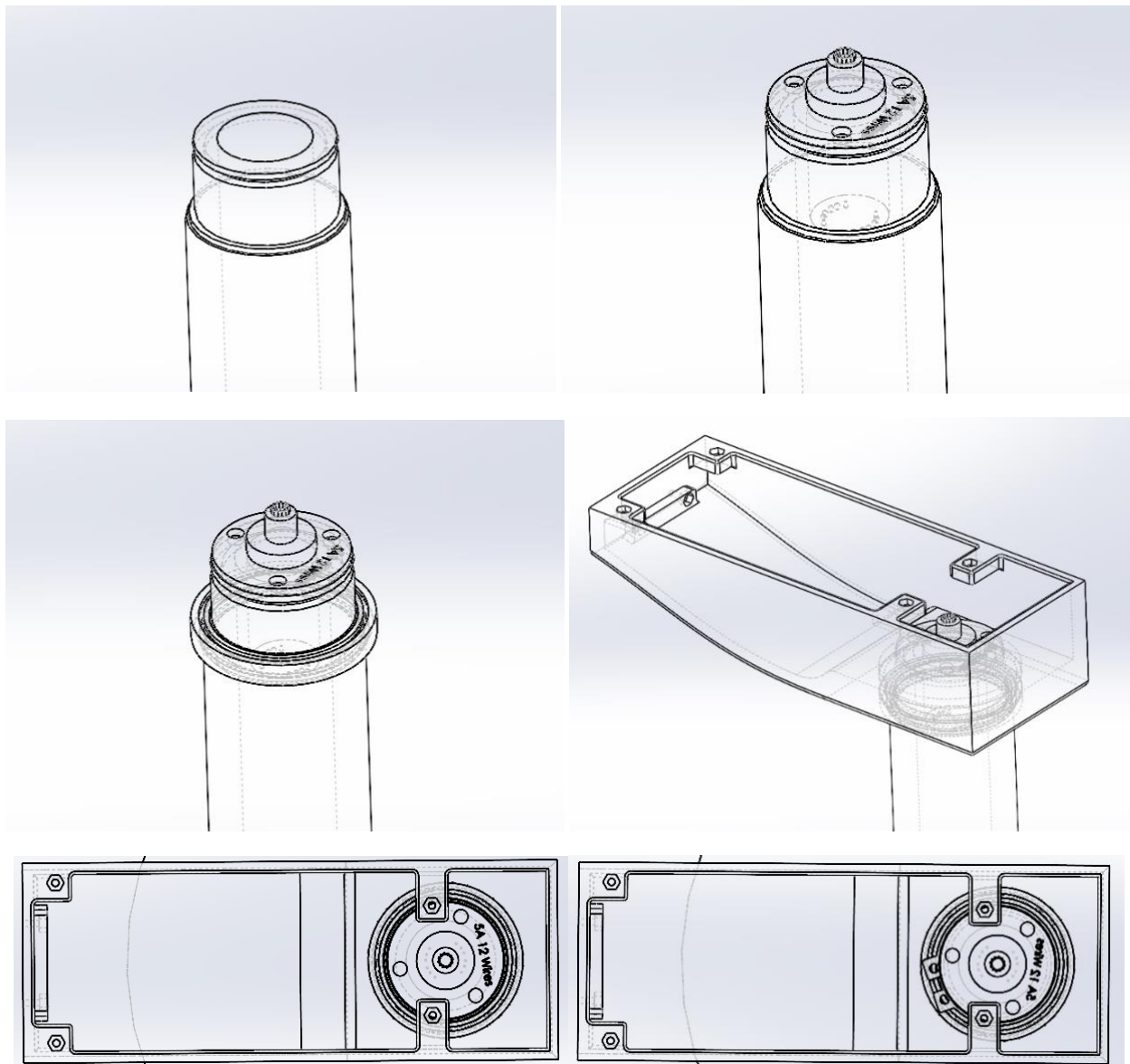


Figure 34: Step 4 Visualization

Table 6: Wiring Color Coordination

Nacelle Side	Load Side	Function
Yellow	Yellow	Stepper Motor Control
Brown	Green (Taped)	Stepper Motor Control
Orange	Yellow (Taped)	Stepper Motor Control
Green	Green	Stepper Motor Control
Black	Black	Ground
Purple	Blue	3 Phase
Red	Red	6V Feedback
Pink	Yellow (Taped II)	~Extra
Grey	White (Taped)	Hall Sensor Control
White	White	Linear Actuator Control
Dark Blue	Blue	3 Phase
Light Blue	Blue	3 Phase

Step 5: Electrical Systems

The electrical subassemblies consist of four critical components. These are the rectifier, boost converter, microcontroller, and load. The electrical team utilized a 6-diode full bridge rectifier which is used to convert the AC power from the generator to the DC power required by the rest of the circuit. The DC/DC boost converter is used to increase the voltage out of the rectifier. Finally, the DC electrical load uses either a current control or a voltage control mode. The team can limit the current in this way to assure that the circuit is not overloaded and interfaces smoothly with the slip ring through twelve 18-gauge wires. Although this step is vital to the operation of the turbine, this subsystem was designed and developed by the electrical CWC 2021 team. For further information on the physical depiction and instructions, please refer to the appropriate documentation.

Step 6: Subassembly Connections

The subassemblies prepared up until this point will now be combined to form the turbine. The fin assembly has not been included previously, but it is simply connected by four M4 bolts. The subassemblies needed for this step is the EH assembly, MB assembly, rotor assembly, fin, and cover. Begin by securing the shaft into the hub with an M4 bolt. While doing this, the rack gears will enter their housing. The guide bearings may need to be adjusted. From there, bolt down the MB to the EH. A magnetic screwdriver should be used to access the front connections. Lastly, bolt the fin to the back of the MB and secure the cover to the top of the MB. Finally, confirm all connections from the nacelle to the electrical systems. Figure 35 is the completed turbine assembly.

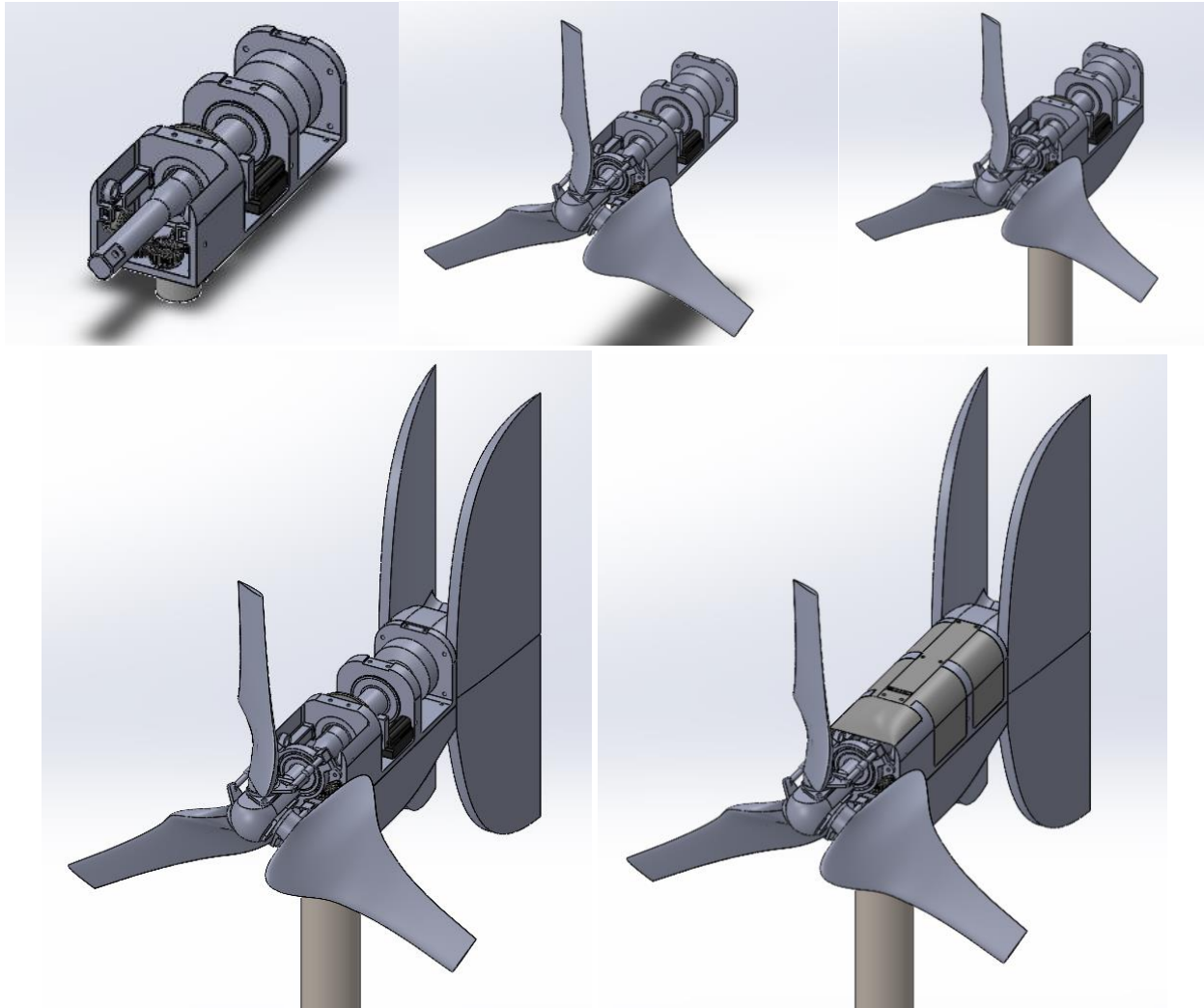


Figure 35: Step 6 Visualization

Operation

Safety Instructions

Read entire document before attempting operation. This device has been designed with a factor of safety of at least 2 for all parts in regular operating conditions. The designers nor providers are liable for injury or damage via negligence of users regarding operation nor improper inspection of all parts. Please visit Maintenance and Troubleshooting sections to address any concerns with parts BEFORE operation.

Pre-Op Testing

Before operating the turbine proper inspection of the following areas is critical for user safety.

- Blade to hub connection

When checking the blade to hub connection make sure the blades are completely tightened down the mounted bearings with no wobble

- Nacelle to tower connection

Inspection of the nacelle to tower connection included making sure the turbine yaws smoothly as well as ensuring the bearing and retaining ring are placed properly

- Gear alignment

Ensure gears are meshing correctly

- Brake pad and disk fitment

Ensure that brake pad is tightened down with no wobble and make sure the brake disk slides smoothly

- Emergency stop button

Ensure emergency stop button works is plugged into correct location

- Control system

Make sure the MCU is receiving power and in proper location

Start

For startup conditions the team will be taking voltage readings from an Arduino Mega. Through the voltage read in values the pitching system will be activated. Voltage can be directly related to the RPM values of the turbine. The turbine may produce up to 60 volts however the power off the turbine will go through a voltage drop so that it may be recorded through the Arduino. This will allow the proper sets of code to be executed. If the voltage reading is between the values of 0 and 1 then the turbine will go into the startup angle this will be considered an angle of attack of zero. This angle will be determined by the number of steps the stepper motor will take. The code for the voltage read in and the change of the stepper motor can be seen in the figure below. This portion is also controlled by the Arduino code. Through the voltage readings, the pitching system will be activated. Voltage can be directly related to the RPM of the turbine.

```
//Stepper motor control
if (NewVoltage < 1.00) {
  digitalWrite(RedPin, LOW);
  one();
  if (POS == 1) {}
  if (POS == 2) {
    steppermotor.step(-STEP);
    POS = 1 ;
  }
  if (POS == 3)
    steppermotor.step(-STEP * 2);
  POS = 1;
```

Figure 36: Startup Conditions for the Turbine

Ideal

When pitching into the ideal conditions the voltage will be read again and if the voltage has a read in of greater than 1 and less than 4.9 then the pitching will be at an operational angle of attack. The large range of values is supposed to generate the most power and therefore has the largest range. The code below shows how the ideal operation will take place. The Arduino code will know what position the turbine is in and will adjust from the previous position to the ideal position. In this operation the turbine will slowly pitch the blades into this angle of attack. While the Arduino is operating the turbine it will also be recording the data the turbine is outputting.

```

if (NewVoltage > 1.00 && NewVoltage < 4.90) {
  digitalWrite(RedPin, LOW);
  two();
  if (POS == 2) {}
  if (POS == 1) {
    steppermotor.step(STEP);
    POS = 2 ;
  }
  if (POS == 3)
    steppermotor.step(-STEP);
  POS = 2;
}

```

Figure 37: Operating Conditions for the Turbine

Stop

The final angle of attack for the turbine will be a stop or a stall condition. This will also be read off of the Arduino code. This condition will come into effect when the turbine is outputting a voltage greater than 4.95 volts after the voltage drop. The code that will putting this condition into effect can be seen below. This will restore the turbine to an angle of attack of zero.

```

if (NewVoltage > 4.95) {
  digitalWrite(RedPin, HIGH);
  three();
  if (POS == 3) {}
  if (POS == 2) {
    steppermotor.step(STEP);
    POS = 3 ;
  }
  if (POS == 1) {
    steppermotor.step(STEP * 2);
    POS = 3;
  }
}
}

```

Figure 38: Stall Conditions for the Turbine

Emergency Stop

In the case of an emergency the turbine can be stopped by pressing the 'emergency stop' button located in the PCC box. Pressing this will halt all power being collected by the turbine and will brake the blades and keep them in stalled position until 'Start' is re-initiated.

In the case of an emergency, the power and operation to the turbine can be shut off by pressing the emergency stop button located in the PCC box. This will halt the power being stored from the turbine and keep the blades at a stall position until start is initiated.

Maintenance

Bearings

Per: 20 hours of indoor runtime

7 hours of outdoor runtime

Bearings should be regularly checked for excessive resistance. This may occur often during prolonged operation as they are exposed directly to the airflow, and particulate matter in the air such as dust may cause increased rate of seizure. To revitalize the bearings, for efficient operation of the turbine, adhere to the following steps.

1. Remove bearing from turbine completely. (Review assembly process for tips)
2. Use air compressor or soft brush to remove particulate matter.
 - a. Rotate bearing throughout process until seizure ceases.
3. Apply dry lubricant between the races in small amounts.
 - a. Rotate bearing throughout process until no irregularity in movement.
4. Reinstall. (Review assembly process for tips)

Brake

Hey bud

Per: 10 high speed/sliding brake cycles

80 low speed/immediate brake cycles

Brake pads should be inspected before every run for safety and durability. Brake pads may deform due to prolonged use, excessive heat, drying, or improper connection. Inspect the appearance of the brake pads for any irregularities. If edges are curled, reglue, and press the brake closed until resealed. If the pads have sharp edges (angle less than 90 degrees), they need to be trimmed and rounded to avoid chatter (angle should be larger than 110 degrees to prolong use). If pads have bubbles or slick marks, allow brake disk to cool for 10 minutes, then replace both brake pads. If brake pad on either side of disk has deteriorated to less than 1/8th inch thickness, replace both brake pads. Always replace brake pads as a pair to avoid warping brake disk. To replace brake pads, adhere to the following steps.

1. Remove brake boot from actuator. (Review assembly process for tips)
2. Slide brake disk up the shaft; out of the way.

Following steps for each pad.

3. Carefully press razor on one corner between rubber and plastic.
4. Cut along short edge, with half inch of penetration.
5. Using pliers, peel rubber back from plastic along the longest edge.
6. Using sand paper, roughen surface to reapply glue.
7. Apply thin layer of glue to surface of plastic and to new brake pad.

8. Hand press new pads onto surfaces.
9. Reconnect brake boot to actuator. (Review assembly process for tips)
10. Activate brake continuously until glue dries.

Troubleshooting

Plastic Fracture

If any of the following parts develop fractures, STOP OPERATION IMMEDIATELY and assess for hairline fractures across part. Chips will need to be sanded down past the occurrence of any hard edges. If hairline fractures are discovered across the part, replace the part.

When looking at the blades and hub prints, it is important to make sure that all parts are treated correctly. When placing the blades and hub, it is important to make sure you do not over tighten the bolts, this will cause the prints to break and potentially shatter.

One of the other main components that will be subject to failure will be the Fin assembly. This failure will be caused due to excessive thrashing in wind testing. It is important to make sure the mounting bolts are secured but not over torqued causing excess pressure on the parts.

All of the parts that are 3D printed will require the total part to be replaced, and this is due to the importance of the parts as well as the fragility of the 3D plastic being damaged.

Code Unresponsive

When not getting readouts from both the Point of Common coupling and Arduino digital readout, first check the wiring connections to all points with both the Arduino components, as well as the Point of common coupling. These will be your main sources of error.

If the problem is still unresolved, take off the nacelle and check the overall connections within the slip ring. Follow the wiring diagram to make sure all components are correctly clamped to each part. If all components are correctly clamped, using a voltmeter, run the motor at a smaller voltage and check all the wires to ensure all wires are intact and not melted.

Pitching Mechanism Binding

When moving the overall blade angles to the various stages and there is no movement within the pitching system. First you want to check the stepper motor to ensure it is disconnected and not locked in place. If the motor is disconnected and the pitching mechanism is still unresponsive, move the rotor as well as the shaft to ensure that they are free and not stuck within the bearings.

If the issue is still unresolved, disconnect the heim joints and inspect for overall damage. If any damage is examined, these parts will need to be replaced to ensure the overall continuity of the system.

Improper AOA (Angle Of Attack)

When adjusting the overall pitching mechanism and the blades do not adjust into the correct position. First you want to check the driving mechanism and make sure the overall alignment is in the correct order.

Without the mechanism being in the correct position, the blades will be in the incorrect position and breaks the data collection as well as the overall pitching mechanism.

If the problem still continues. The next step is to look at the overall heim joints, it is important to make sure that they are all equal lengths, otherwise the blades will be in overall different positions therefore throwing off the overall wind direction of the turbine and creating new airfoils and potentially harming the overall turbine design.