NORTHERN ARIZONA UNIVERSITY
Mechanical Engineering

19F06
CWC Turbine Team

To: Dr. David Trevas

From: Lucas Duncan, Ethan Malteverne, Daniel Massaglia, Marina McCue, Matt Mennell, Sean Veden

Date: February 14, 2020

Subject: ERs and Tps Revamp Memo

1 Introduction

Throughout the progression of this project, the Collegiate Wind Competition (CWC) turbine team has adhered to a set of customer and engineering requirements provided by the Department of Energy (DOE) and David Willy. Because the rules of the competition have been stated so clearly by the DOE, requirements have not changed. Testing procedures 1 and 2 have stayed the same but the procedure for the rotor strength test has seen some improvements. The original test was to be using a pad in case of catastrophic failure, but the newest procedure features a protective wooden box as well as a quarter inch of polycarbonate clear plastic. This box is to enclose the blades failure from causing damage to surroundings and the clear plastic provides a sight window. The fourth testing procedure described later in this document has not had the opportunity to be met yet due to its association with a later stage in the project but is expected to be performed.

2 Customer Requirements (CRs)

Customer requirements are mandatory product functions that the final product must abide by in order to be a successful design. Shown below, in Table 1, is a list of customer requirements and their weighted importance that the final system will accept. No matter what the team does, staying within budget is one of the major requirements a project must meet. Capstone class requirement demand that it is accompanied by durability, reliability, and the safety of operation. The design is considered a failure if the system is not safe to operate, so it is imperative that it is reliable and durable.

Table 1 - Customer Requirements

	Costumer Requirements	Weight
1	Cost within budget	10
2	Durable and Robust design	8
3	Reliable design	7
4	Safe to operate	10
5	Competition size / electrical connection restrictions	9
6	Product consistent power without exceeding 48V	10
7	Portable	6
8	Single Tail Yaw system	5
9	Improved 2019 CWC Braking design	8
10	Low Cog Generator	8

Requirements 5-7 in Table 1 above are given by the CWC Rule packet and are important if the team is to compete at the competition. In order to fit into the wind tunnel at competition, turbine volume restrictions are shown below in Figure 1. Requirements 8-10 were given to the team by David Willy, the project advisor, who has several years of experience advising this project. While the 2018 turbine team used a dual tail yaw, the 2019 team’s single tail yaw system saw great success. Because of this, the 2020 turbine team will also create a single tail yaw system. Another thing that the 2019 model excelled in was the brake design, using a single disk pressing against a brake pad with an electronic actuator. This design will also be considered when designing the new system due to the request of David Willy.

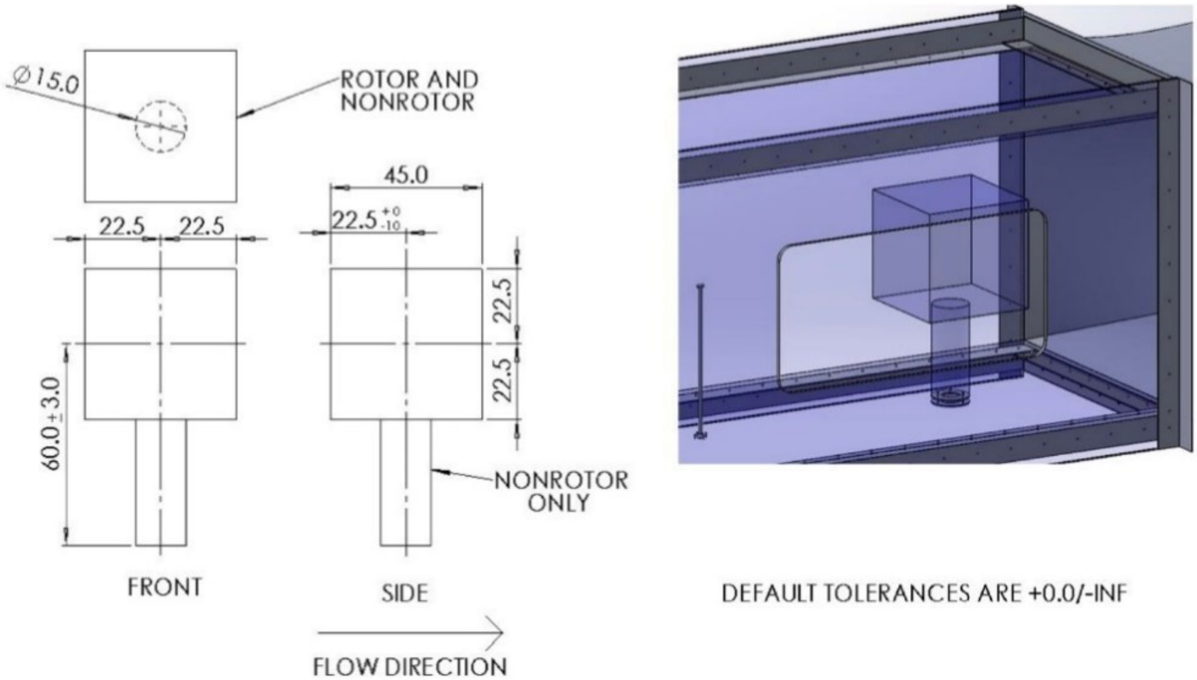

Figure 1 – Allowable turbine volume

Figure 1 uses dimensions in cm and shows how the volume of the turbine will be measured. These volume dimensions symbolize how big the turbine can be for it to fit through the entry door fully assembled as one piece. Since there is no building allowed in the wind tunnel and no other tools can be used on the turbine other than for tightening the base plate seen in Figure 2, the whole system should have its components secured properly.

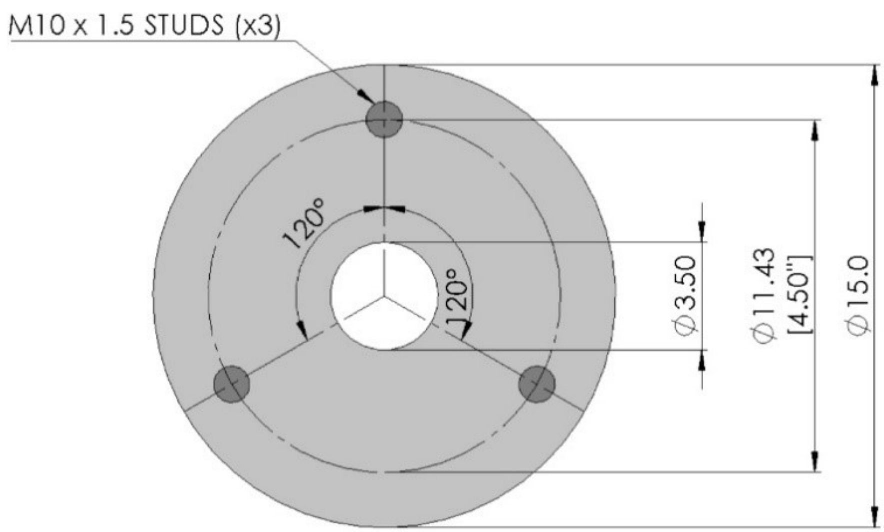

Figure 2 – Base flange dimensions for attachment to tunnel (cm)

Each turbine in the competition will be fastened in the wind tunnel with three M10 x 1.5inch studs as seen in Figure 2. The hole in the center of the plate will be used to allow wires to be fed to the Point of Common Coupling (PCC) where specific connectors will be used which are shown in Figure 4. Not included in the picture, the plate also has a maximum thickness of 16.1 mm to allow for the already mounted studs to be functional. The system that this plate is mounted to also spins the tower in order to test yaw function by simulating a change in direction of the wind.

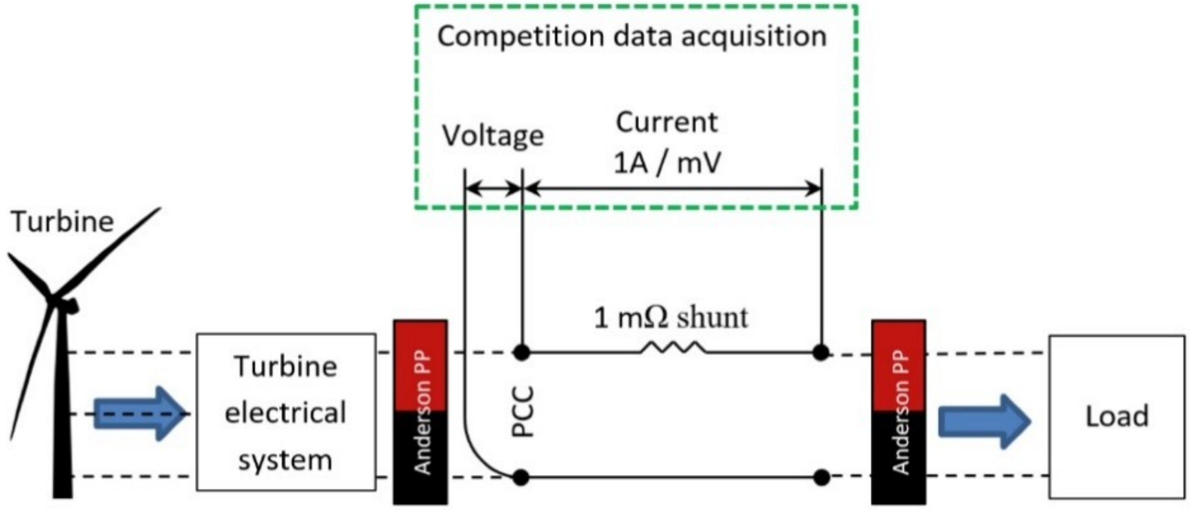

Figure 3 – Load, Turbine, Storage and Point of Common Coupling Arrangement

The PCC has two sides; a turbine side and a load side shown in Figure 3. Both sides of the PCC will be using PP15-45 connectors so using the wrong connectors on the turbine would cause the system to not be monitored. A noticeable feature of this diagram is the 1 mΩ shunt resistor which each school will provide within their design. The point of this resistor is to prevent the competition data acquisition system from being overloaded with current. Reviewing previous NAU turbine designs, this resistor has been known to fail so designing for that occasion is something the team will consider.

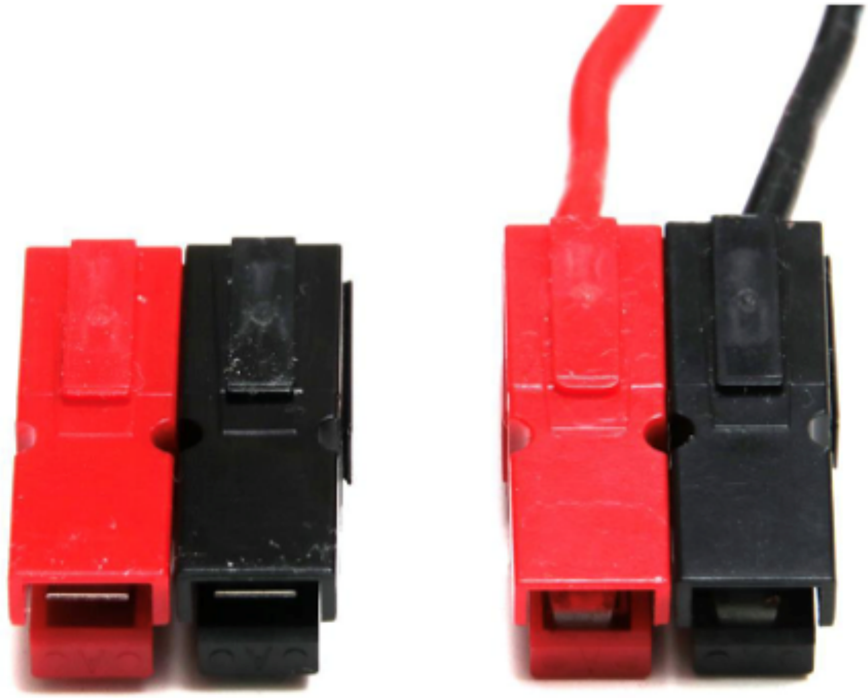

Figure 4 – Proper Anderson Powerpole polarity to match tunnel wiring

Figure 4 shows the Anderson Powerpole connectors that will be used to connect the turbine to the data acquisition system. Teams are expected to use these connectors with either a 15, 30, or 45A specification seeing as the actual connector size is the same. The output amperage will be specified by the team which will dictate which one will be used.

3 Engineering Requirements (ERs)

With customer requirements in mind, the team will use engineering techniques to meet them. Making sure to have a reliable design, numerous tests will be conducted to ensure that a failure point is known so that improvements can be made. Doing as many calculations and sub system level testing will ensure that the final assembly will have as little flaws as possible. Customer requirements will be met by having an organized design within the nacelle, making sure components with specified measurements in the rule packet are within parameters, using a low cogging torque generator that allows for voltage to be converted easily to allow for power restrictions, and finally having aerodynamics that promote functionality as well as simplicity.

Within the nacelle, the main body of the turbine, a drive shaft will be connected from the hub in the front all the way to the yaw system. Both the generator and the brake system will be mounted along the shaft within the nacelle. Keeping a simple but effective drive line will keep the construction easy and allow for the team to replace any components that fail quickly. A new aspect of the design this year, in comparison to previous ones, is having all electrical engineering team components located outside of the wind tunnel rather than inside the nacelle. In the 2019 design, the nacelle did not have a cover, leaving the motherboard and other electrical components exposed in order to allow the components to be air cooled. The team plans to have an aerodynamic nacelle cover that lets air flow into the nacelle then out of the cover into the yaw, allowing for the generator and brake to stay cool even with the cover. To keep electrical components out of the tunnel cool, a fan system in the control box where they are located will be considered.

Table 2 – CWC 2020 Rules and Regulations

CWC 2020 Rules and Requirements	
Volume of Turbine	45x45x45 cm ± .1 cm
Tip of Blades attached to Turbine Hub	60 cm ±.3 cm
Generator Produce Power	5V < P < 48V
Team Power Goal	42 < P > 46V ±1V

The cogging torque of the generator is the measure of how much torque is required to start spinning the generator. Having a low cogging torque will let the drive shaft spin with more ease. This is important because the easier it is to spin the shaft of the generator, the lower the cut-in wind speed. The cut-in wind speed is the speed at which the thrust forces from the blades can overcome the static force of the shaft and allow rotation to start. The higher the cogging torque of the generator, the more resistance to start up the turbine has. In order to attain this in a generator, the offset of pole pairs to magnets must be low, meaning it is beneficial to have as little poles directly spaced to magnets as possible. The team will accomplish this requirement by finding generators that have a small magnet area and the ability to produce sufficient power.

Keeping the aerodynamics of the blade design, nacelle, and yaw all symbiotic with each other is another necessary design requirement. To prevent from having three well working systems that don't work well in relation to each other, they will be designed to flow right into the next. The hub of the blades has always just been a mounting point, but the team will attempt to have that be where the flow begins. The hub will have a cone shape like current full-scale turbines but will also feature three air channels that will feed directly into the blades. Behind the blades, the nacelle will feature air scoops in order to pull air from the tunnel into the system. The air will then escape towards the rear of the nacelle pointing directly at the yaw system making the ambient air not the only air hitting the system. While these additional forces could be negligible, it will direct the air passing through the nacelle to cool the brake and generator

.

3.1 ER #1: Blades Factor of Safety

3.1.1 ER #1: Blades Factor of Safety Target = 2.5

The team wants to ensure that the blades will not shatter during the competition causing damage to the CWC wind tunnel.

3.1.2 ER #1: Blades Factor of Safety Tolerance = 2.5 ± 0.5

The team wants to ensure a factor of safety of at least 2.

3.2 ER #2: Blades Allowable RPM

3.2.1 ER #2: Blades Allowable RPM =7000

One of the worst things that could happen at the competition in the wind tunnel is have the blades shear from too high of an RPM. Shattering in bits and pieces while knowing the backup blades probably have the same exact material properties, broken blades could end the team's competition early.

3.2.2 ER #2: Blades Allowable RPM - 7000 ± 200

This set expectation of 7000RPM lets the generator max out between 5500-6000RPM and not worry about the integrity of the blade system. Even with the maximum wind speed induced at the competition, only the lowest end of the range has the possibility of being met.

3.3 ER #3: Total Cost Under $1,500

3.3.1 ER #3: Total Cost Under $1,500 - Target = $1,250

The client was able to increase the overall budget to $1,500 from the $1,000 that was set last semester. The team believes the cost should not exceed $1,250 based on the current Bill of Materials.

3.3.2 ER #3: Total Cost Under $1,500 - Tolerance = +/- $250

The maximum cost for this project is now set at $1,500, but the team is set to design towards only using $1,250 to allow a contingency of $250.

4 Testing Procedures (TPs)

To have a reliable and working final design the team should be able to run accurate tests on various components apart of the full assembly. This section will discuss the various ways that system components such as the generator, brake design, tower, and electrical systems will be tested in a safe and reliable manor. Creating testing procedures that allow the team to ensure the engineering and customer requirements are met is important.

4.1 Testing Procedure 1: Dynamometer

As a deliverable to the DOE for the competition, the team is tasked to use a dynamometer and show characteristics for the turbine generator. With a dynamometer, multiple generators can be tested and compared for ideal traits for the turbine design. While controlling the throttle of the driving motor being powered by a constant power source, voltage and current can be measured with an Arduino and used to find the cut in wind speed that is required to start making power. The dynamometer testing will accomplish the engineering requirements of cut-in wind speed, low resistance drive shaft, and a 48V maximum output. Using a dynamometer built by the NAU Energy Club, the CWC Turbine team can test any generator and determine if it is the ideal generator for the final design.

4.1.1 Testing Procedure 1: Objective

To begin testing a generator on the dynamometer, the generator must be mounted onto a plate to ensure the shaft is concentric with the shaft of the driving motor shaft. Seen in Figure 8 is the main driving motor connected to the generator with a coupler that allows the male shaft from the generator to the male driving motor shaft. This allows the driving motor to start to spin the generator simulating the rotational energy that would normally be supplied by the blades. Using an infrared tachometer and a dual channel DC load power supply, the voltage, current, and revolutions per minute can be found to be plotted against each other to find the optimal power and rpm for the generator being tested.

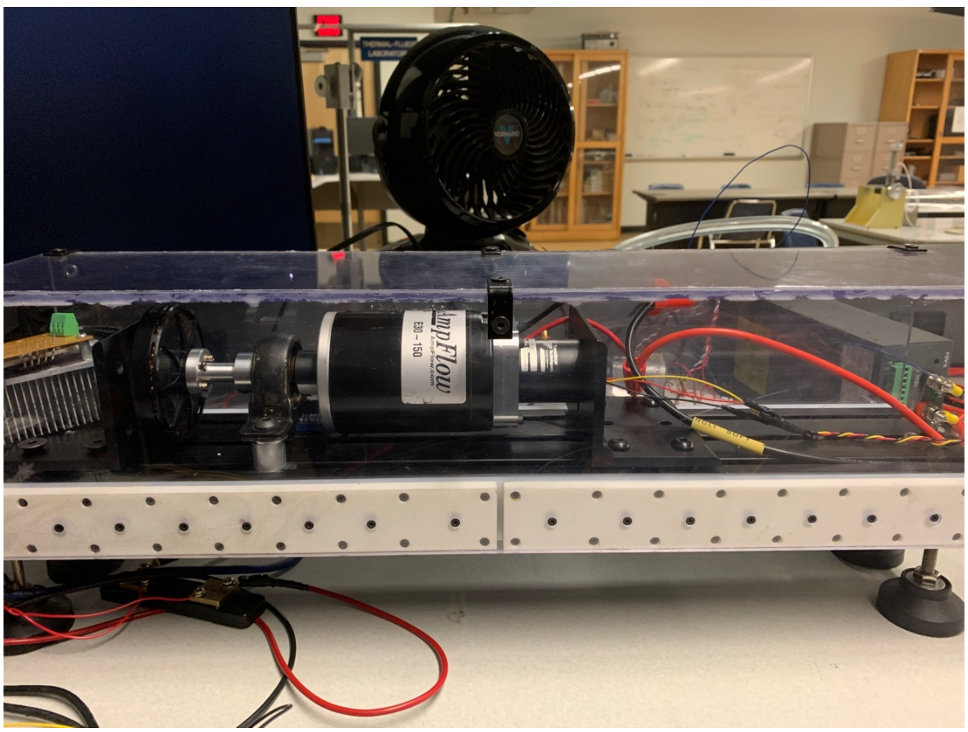

Figure 8 – Dynameter

The torque transducer can also be seen in figure 8 connected to the right of the generator which once calibrated, will give information about the torque needed to spin the generator. Also seen in Figure 8, to the left of the generator, the 3-phase AC to DC rectifier, which takes the output voltage and current from the generator and feeds it to the load and shunt resistor.

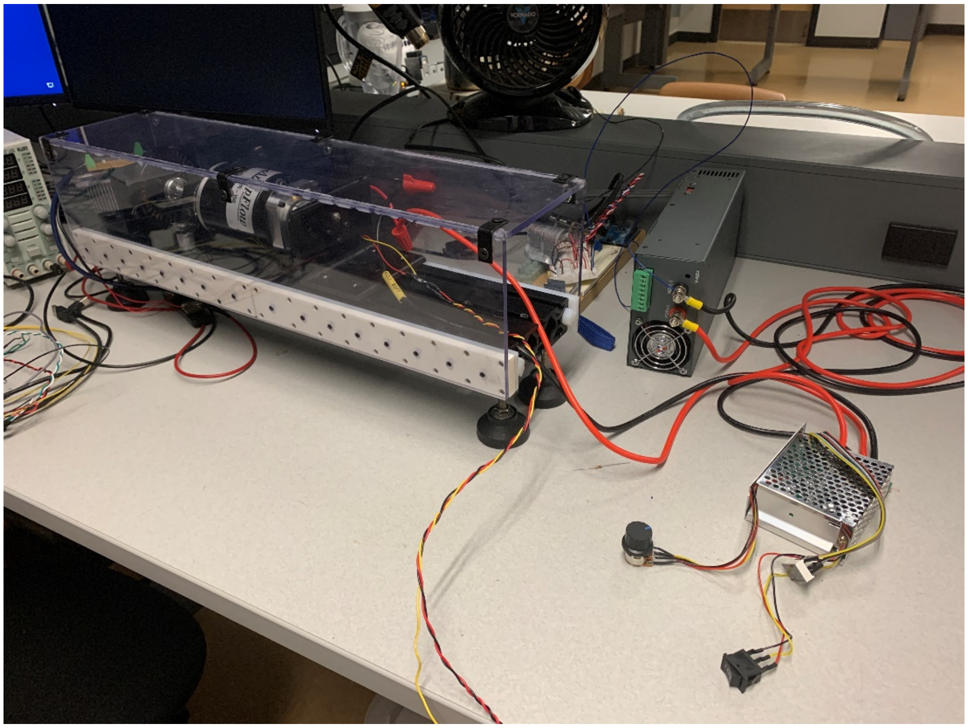

Figure 9 – Dynameter Side View

Figure 9 shows both the main power source as well as the throttle control module. To start testing, one member of the team twists the analog throttle in equal increments such as every 10%. Once the generator is spinning, the generator's unloaded voltage can be found to verify the rated generator voltage from the factory. After that, a load can be applied using a second power source to the generator. Knowing the revolutions per minute, associated voltage and current at a set throttle percentage, power curves can be plotted and compared at different voltages.

4.1.2 Testing Procedure 1: Resources Required

For testing, two people are needed but having three is recommended so that one person can control the throttle and use the tachometer, the second person controls the variating load to try and control the voltage and current being supplied, and the third person has an excel document open to record the values that person two reads. The resources required to complete this test include a constant power source, a throttle control module with percentage display, a driving generator, AC to DC rectifier, and finally a second power source with voltage and current display. All these components need to be mounted on metal brackets to ensure that the shaft from the generator and the driving generator are concentric since the RPMs could reach up to 6000.

4.1.3 Testing Procedure 1: Schedule

Due to the dynamometer deliverable required by the DOE, initial dynamometer testing needs to be done mid-November forcing the team to conduct dynamometer testing early in the project. This tool allows the team to select and test any generator as the team acquires it.

4.2 Testing Procedure 2: QBlade

A QBlade [26] analysis will be completed to ensure airfoil selection and blade geometry (Figure 10) is optimized for the competition conditions. These conditions, as previously stated, are for the rotor to begin rotation between 2.5 to 5 meters per second and the turbine to produce consistent and stable power between 5 to 11 meters per second. QBlade is an open source wind turbine calculation software that allows for rapid design of custom airfoils and computes their performance.

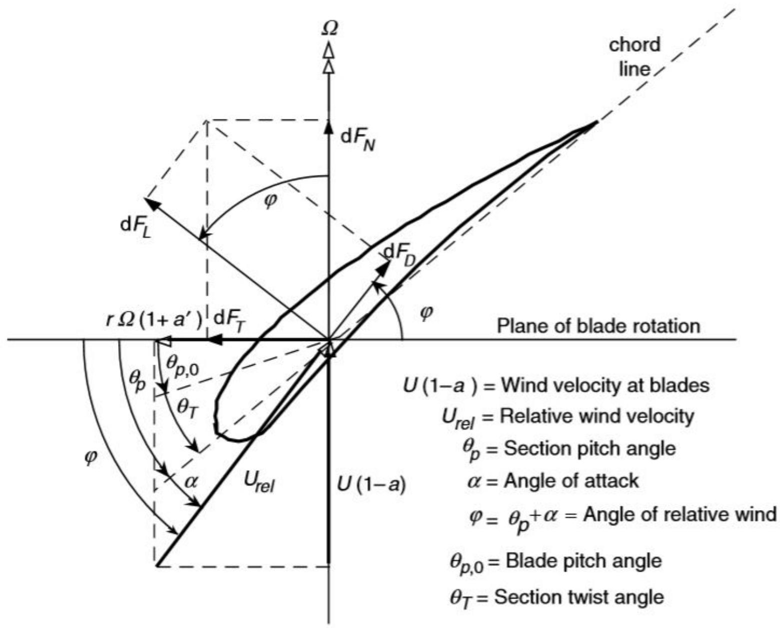

Figure 10 – Wind Turbine Blade Geometry [3]

4.2.1 Testing Procedure 2: Objective

This testing procedure is an iterative process. First, blade parameters such as tip speed ratio, chord length, angle of attack, angle of relative wind, pitch angle, twist angle, and section pitch angle are calculated in MATLAB assuming ideal rotor conditions. This information is then inputted into QBlade along with airfoil selections, and power performance versus tip speed ratio and the coefficient of lift over drag versus angle of attack is generated. The tip speed ratio where coefficient of power is at a maximum and the angle of attack where coefficient of lift over drag is a maximum is then put back into the MATLAB code. Then new chord lengths, angle of relative wind, pitch angle, twist angle, and section pitch angle are recalculated and put into QBlade again. This process is continued until a wind power performance curve is optimized. This ensures that the final blade design will begin rotation at the required cut-in wind speed and produce optimal power.

4.2.2 Testing Procedure 2: Resources Required

The resources required for this testing procedure is only the software QBlade and consulting the project advisor, David Willy, when questions arise. As mentioned, QBlade is a free software and can be downloaded from their website and any computer can run it.

4.2.3 Testing Procedure 2: Schedule

The QBlade testing procedure has been an on-going process and was started at the beginning of the first semester. All other components of the final turbine design are dependent on the completed blade design, making this the first procedure started and necessary to complete as soon as possible. The testing is estimated to be finished at the end of November 2019.

4.3 Testing Procedure 3: Runaway Test

A runaway test will be done to ensure that the rotor does not runaway, meaning that the blades do not rotate too fast and shear off the rotor. One of the tests at the competition is to subject the turbine to wind speeds up to 25 meters per second and the braking systems is required to stop the rotor and then let rotation begin again when the wind speeds drop back down.

4.3.1 Testing Procedure 3: Objective

The objective of this test is to make sure that the electrical system will automatically apply the brake until rpm drops back down to the optimal rotational speed. Brake and electrical systems will be tested along with the welds on the tower and baseplate. Another objective for this test is to make sure that the blades don't shear as well.

4.3.2 Testing Procedure 3: Resources Required

The resources required to complete this test include the team building an enclosure for the rotor assembly with a working speedometer. Mounting brackets to accept the baseplate and a window to run electrical wiring (but preferably a sunroof) are also needed. Other resources needed include mounting hardware and possibly a pad to prevent any damage to the car in the result of the blades shearing.

4.3.3 Testing Procedure 3: Schedule

The primary scheduling conflict for this test is with the weather. To get accurate results, a calm and clear day is needed so that any additional wind energy isn't absorbed. In addition to this requirement, a stable prototype must also be constructed to test similar materials and size constraints.

4.4 Testing Procedure 4: SolidWorks Flow Simulation

A SolidWorks flow simulation will be conducted to guarantee that the yaw of the turbine performs as expected. A yaw orientation system is needed for a vertical axis wind turbine to keep the rotor shaft properly aligned with the wind. There are two different types of yaw systems: active and passive. Active yaws use sensors and gears to manually position the turbine into the direction of the wind and passive yaws self-align. Commonly turbines have active yaw systems, but the team decided to use a passive yaw system as it is easier to implement into the design, requires less components, and is affective for small scale wind turbines [4]. One of the competition tests is to rotate the turbine at a rate of 180 degrees per second and the wind turbine is expected to stay oriented in the direction of the wind. The SolidWorks flow simulation is a computational fluid dynamics solution that enables fluid simulation of a 3D model.

4.4.1 Testing Procedure 4: Objective

The team's final turbine design will be inputted into SolidWorks and a fluid simulation will be completed. This test is to analyze how the surface area of the yaw responds to change in wind direction.

4.4.2 Testing Procedure 4: Resources Required

The only resources required to complete this deliverable are the SolidWorks software, which the team has access to through a license provided by the university, and a computer capable of running the software.

4.4.3 Testing Procedure 4: Schedule

The yaw will be one of the last components designed and completed because it depends on all other components finished first. The size of generator selected, braking system, etc., affects the size of the nacelle, which affects the aerodynamics of the turbine, in turn affecting the design of the yaw. This test will be done sometime late in the second semester, estimated to be started around February 2020 and finished in the same month.