COLLEGIATE
WIND COMPETITION
. EPARTMENT OF ENERGY

U.S. Department of Energy Collegiate Wind Competition 2015

RULES AND REQUIREMENTS

Last Updated: 11/30/14

Note to Teams Regarding Rules

The organizers welcome the opportunity to develop competitions that challenge the intellect and ingenuity of the nation's aspiring wind energy industry contributors. This document seeks to create fair contest rules for determining appropriate measurable outcomes.

In the spirit of this creative educational venture, the organizers reserve the right to change contest criteria, rules, and measurable outcomes as needed and within reason whenever improved approaches become apparent.

In the same spirit, the organizers encourage the teams to bring to our attention rules that are unclear, misguided, or in need of improvement. The organizers will seriously consider suggestions that are aimed at improving the competition, its rules, and its measurable outcomes.

The organizers will make carefully considered changes to the rules and measurable outcomes if it is feasible within our constraints and will improve the competition in regards to fairness and precision.

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Section I: Background

The objective of the U.S. Department of Energy Collegiate Wind Competition is to prepare students from multiple disciplines to enter the wind energy workforce. Currently, the wind industry needs more qualified people to fill key jobs such as scientists, educators, design and research engineers, technical workers, and project managers. Wind-specific advanced degrees are not required for many of these jobs, but hiring managers' value wind industry experience. The Collegiate Wind Competition is also aligned with the central goals of the U.S. Department of Energy (DOE), which are to catalyze the timely, material, and efficient transformation of the nation's energy system; secure the United States' leadership in clean energy technologies; and maintain a vibrant domestic effort in science and engineering as a cornerstone of economic prosperity.

Section II: Rules

2-1 Safety and Conduct during Competition Event

Each team is responsible for the safety of its operations. Each team member shall work in a safe manner at all times during the Collegiate Wind Competition 2015 in accordance with the requirements identified in this document and in the subcontract agreement.

Teams must follow OSHA rules for safety equipment based on expected activities (see National Renewable Energy Laboratory [NREL] contract with your university, Appendix B Clause 8: Worker Safety and Health Requirements, for more information). Organizers may issue a stop work order at any time during the project if a hazardous condition is identified.

All team members shall wear appropriate personal protective equipment (PPE) when working on, testing, and operating turbines. Teams are expected to bring the following appropriate PPE for use during wind tunnel testing and other potentially hazardous activities at the competition event:

- Safety glasses
- Hard hats and steel-toe boots if expecting to use heavier loads
- Electrical PPE if electrical voltage demands it
- Hearing protection for use in areas in close proximity to the wind tunnels during tunnel operation.

Each team is responsible for the transport of its wind turbine and all necessary tools and equipment and shall be responsible for any damage to or loss of such items. Shipping information will be provided before the April 2015 competition date.

2-2 Competition Components, Requirements, and Scoring Overview

The Collegiate Wind Competition 2015 emphasizes analytical modeling and validation along with electronics and control skills to build on last year's challenge to develop a lightweight, transportable wind turbine to charge small electronic devices. The event will consist of two technical contests, the Design Report contest and the Turbine Performance Testing contest.

The Design Report contest focuses on the team's efforts to conceive, design, and analytically demonstrate buildability of an operable wind turbine and represents 400 points out of 1,000 total possible points. The Turbine Performance Testing contest focuses on the performance of the turbine built by the team and represents 600 points out of 1,000 total possible points. The contests are summarized in the table below.

Contest	Weight	Points
Design Report	40%	400
Turbine Performance Testing	60%	600
	TOTAL	1,000

Judges will score design reports prior to the event. To complement the two contests, teams will present their concepts and unique design considerations to the other teams, the organizing committee, and invited members of the National Wind Technology Center (NWTC) and the wind industry. A 10-minute interactive question-and-answer session will follow this presentation. This is an opportunity for the teams to share their successes with other teams and wind energy professionals. The technical presentation will not be scored.

2-2.1 Competition Event Schedule (subject to change)

Wednesday, April 29, 2015

8:30 a.m.—3 p.m.	OPTIONAL—Arrival, Tunnel Safety Session, Site Tour, Tunnel Practice (NWTC)	
3 p.m.—4 p.m.	Welcome Session Rules and Logistics (NWTC)	
4 p.m.—8 p.m.	Travel to Colorado School of Mines in Golden for Tours and Welcome Reception	

Thursday, April 30, 2015

8 a.m.— 8:45 a.m.	Continental Breakfast	
8:45 a.m.—9 a.m.	Announcements	
9 a.m.—12 p.m.	Turbine Performance Testing (NWTC High Bay)	Technical Presentation (NWTC Conference Room)
12 p.m.—1 p.m.	Lunch (NWTC)	
1 p.m.—5 p.m.	Turbine Performance Testing (NWTC High Bay)	Technical Presentation (NWTC Conference Room)
5 p.m.—7 p.m.	No-Host Dinner in Boulder or Broomfield	

Friday, May 01, 2015

8 a.m.—8:45 a.m.	Continental Breakfast	
8:45 a.m.—9 a.m.	Announcements	
9 a.m.—12 p.m.	Turbine Performance Testing (NWTC High Bay)	Technical Presentation (NWTC Conference Room)
12 p.m.—1 p.m.	Lunch (NWTC)	
1 p.m.—2:30 p.m.	Contest Results and Awards (NWTC)	

Turbine performance testing activities
Technical presentation activities
General activities with all participants

A detailed, team-specific schedule will be provided to teams before the event..

2-2.2 Judge Requirements

A three-person panel of judges is responsible for scoring team performance. The panel of electrical and mechanical engineers will evaluate performance from a variety of angles.

Judges will not:

- Have financial, familial, or other conflicts of interest with team members or participating institutions
- Advise teams, although they can provide clarification on the judging process
- Discuss team performance with other teams or their advisors.

Judges will use the scoring rubrics included in this document to evaluate team performance for each contest.

At the conclusion of the competition, teams will receive copies of the final score sheets with judge annotations. Judges will provide a short narrative from their deliberation or notes from their individual reviews.

2-2.3 Design Report and Scoring

The Design Report contest is intended to review the process by which each team developed its turbine from concept to finished product from the engineering perspective (not cost or marketing) to ensure a durable, robust turbine that will meet safety and performance requirements. The design report should include, but not be limited to, the following components:

- Basic static performance analysis (e.g., C_P Lambda Report): annual energy production over a range of operational parameters applicable to each team's turbine design
- Electrical analysis: generator model, power electronics (e.g., Canonical model), load model
- Control model analysis?: operational modes (control states diagram, description of primary operational modes).

Teams must submit the design report by 11:59 p.m. Mountain Daylight Time on **April 13, 2014.** The report must adhere to the following specifications:

- 15 pages maximum, including all diagrams, specifications, cover sheet, etc.
- 8.5 x 11 single-sided pages
- 1-inch margins
- 11-pt Calibri type, double-spaced
- Numbered captions for figures and tables.

The design report will be evaluated based on the following criteria:

Design Overview: Conveys the team's design objective and how components of the design support this objective.
(15% of design report contest or 60/1,000 points of overall score)

Modeling and Testing: Describes initial modeling objectives, design refinements based on modeling results, laboratory and/or field testing procedures, and design refinements based on testing results.
(35% of design report contest or 140/1,000 points of overall score)

Engineering Diagrams: Presents diagrams suitable for an engineering review with the baseline dimensions and properties of the turbine and its subsystems, including control algorithms and software. Construction drawings or full software code listings, etc. are not expected but are allowed.
(25% of design report contest or 100/1,000 points of overall score)

Engineering Specifications: Provides specifications suitable for an engineering review, the baseline and operating properties of the turbine and its subsystems, including loading requirements, operational limits, control algorithms, and software.
(25% of design report contest or 100/1,000 points of overall score)

Judge's Score Sheet: Design Report Contest

Team/University Name: ___________________________________

Judge's Name: ____

Design Report Criteria		
Description	**Possible Points**	**Score**
Design Overview: Conveys key components of the actual design in terms suitable for executive management and the general public.	60	
Modeling and Testing: Describes initial modeling objectives, design refinements based on modeling results, laboratory and/or field testing procedures, design refinements based on testing results.	140	
Engineering Diagrams: Diagrams suitable for an engineering review with the baseline dimensions and properties of the turbine and its subsystems, including control algorithms and software.	100	
Engineering Specifications: Provides specifications suitable for an engineering review, the baseline and operating properties of the turbine and its subsystems, including loading requirements, operational limits, control algorithms, and software.	100	
Subtotal (up to 400 possible points)		

2-2.4 Turbine Design Basis

The turbine must be designed within the following specifications, with the intent that it will be tested inside the Collegiate Wind Competition wind tunnel. (See Appendix for wind tunnel specifications.)

- The maximum design wind speed for the wind tunnel is 14 m/s. The turbine must be designed to withstand continuous winds of 14 m/s.
- The minimum turbine output is 10 W continuous for at least one wind speed from 5 to 14 m/s. If the turbine does not meet this criterion, the score for the performance portion of the test will be zero.
- Maximum rotor dimensions and rotor placement:
  - The rotor dimensions cannot exceed the following measurements:
    - 45 cm length
    - 45 cm width
    - 45 cm height
  - The center of the rotor must be within 2.54 cm of the centerline of the wind tunnel.
  - If these specifications are not met, the turbine will not be allowed to compete.
- The wind turbine system must be mountable on the test stand at the specified location within the wind tunnel (refer to Appendix for tunnel specifications and mounting flange specifications). All turbines must fit through the turbine door in one assembly with no additional assembly occurring inside the tunnel other than attachment to the base flange. Any non-rotor auxiliary turbine parts must fit within 45 cm of the vertical center line of the mounting flange. The area for non-rotor auxiliary turbine parts is a cylinder with a 45-cm radius around the vertical centerline of the mounting flange. Other electronic components could also technically be outside the tunnel.
- The turbine base plate should be constructed of material no thicker than ½" to fit the base flange, and to fit over three ¼-inch diameter studs where it will be secured to the base flange with nuts. Refer to wind tunnel appendix for the bolt pattern on this flange. Teams are free to apply their engineering judgment to their own base plate design, keeping in mind that turbine bases **must** be designed with adequate tolerances such that they can be attached safely to the base flange in the wind tunnel.
- The teams must provide a length of wire sufficient to exit the tunnel at the turbine base plus 1 additional foot to the point of common coupling (PCC) where they will meet the Competition-provided connectors. This wire will be terminated with Anderson Powerpole connectors, PP15-45 (a red and a black for positive and negative). Teams can provide their own Powerpole connectors if desired, or the testing judges will provide housings, pins, and a crimp tool at the Competition to make this connection. Judges will provide pins for all three Powerpole sizes (15A, 30A, and 45A), which are specified to handle wire gauges from 10AWG through 20AWG. Teams can choose the wire size they want to provide in this range. All three pin sizes fit into the same housing (PP15-45) as stated above.
- Energy storage elements, such as capacitors and/or inductors, can be used but NOT for the purpose of bulk energy storage. They must register zero state of charge at the

beginning of the test. No batteries of any type will be permitted. The electrical load provided by the Competition testing team does not have a blocking diode and may be drawn upon to provide power to the test turbine or its electronics. Verification of zero energy at the start of the test will be accomplished by the use of a multimeter to measure 0 zero voltage at all required points.

- Turbines must be capable of shutting down on command as well as when electrically disconnected.
    - The judges will initiate electrical shutdown by disconnecting the Anderson Powerpole connector.
    - Manual shutdown will be triggered by a Competition-provided, normally closed switch and will be located outside the tunnel. The teams must provide two wires of approximately 20AWG exiting the tunnel at the base flange to reach this switch. The judges will connect these wires to the switch prior to tunnel operation. Judges will initiate manual shutdown by depressing the button and opening the circuit.

2-2.5 Turbine Performance Testing Methodology and Scoring

The Turbine Performance Testing contest consists of a number of individual turbine tests. This section describes the requirements of the contests in which the turbine is expected to perform, the parameters of the testing conditions, and details on the scoring algorithms.

This portion of the contest provides teams with opportunities to demonstrate the performance aspects of their turbines in objective contests that will delineate to what extent teams have succeeded in developing a durable and safe high-performance wind turbine, as performance will ultimately be a major component of its ability to compete successfully in the marketplace.

The turbines will be tested in a wind tunnel provided by the organizers. The teams are expected to design, develop, construct, and test their wind turbine systems that will be able to complete all testing requirements safely and reliably at the Competition in April 2015.

Testing Procedure

Teams will follow a prescribed schedule for testing in the wind tunnel. Only one team's turbine will be tested at a time. Each team will have 30 minutes of tunnel time, 25 minutes to install the turbine and complete all testing and 5 minutes for turbine removal. Team members will not be allowed to touch their turbines or controls during the test. Turbine failure is defined as anything out of the ordinary such as cracking, breaking, pieces falling off, smoking, sparking, or failure to produce electrical current. If a team cannot complete its testing during the allocated 30-minute period, the team may request a "re-test" for a subsequent 30-minute period later during the Competition. The re-test will be a full retest, and all scores from the first test will be replaced. If there are unforeseen delays caused by the organizers (e.g., wind tunnel issue, power outage, etc.), the time consumed in rectifying the problem will not be included as part of the team's allowable minutes.

(i). *Power Curve Performance Task*

(30% of Turbine Performance Testing Contest or 180/1,000 points of overall Score)

Objective:

- The measurements taken during the Power Curve Performance Task will test the team's power curve for each 1 m/s interval from 5 to 14 m/s.

Procedure:

- Teams are required to attach their turbines to the fixed base apparatus (e.g., boltable flange) provided by the Competition (see Appendix for details of the attachment specifications).
- Load will be constant, regulated 5V power sink provided by the Competition organizers
- Each turbine will be tested at wind speeds with 1 m/s intervals between 5 and 14 m/s inclusive for a maximum duration of 60 seconds or less with the stated intent of obtaining a "stable power reading" defined as "stable in RPM and stable in power per multimeter readings" during the test period. As power output may fluctuate, for purposes of this test, the allowable power outputs to be included in the maximum average power (per electronic testing devices) during any 5-second interval will be defined to be +/-10% of the maximum average power.

Cut-In Wind Speed Task

(20% of Turbine Performance Testing Contest or 120/1,000 points of overall score)

Objective:

- Cut-in wind speed is one of the turbine characteristics that can differentiate it from other turbines as being better suited to lower-wind-speed regimes. Lower wind speed is generally deemed more desirable in the small turbine market.

Procedure:

- Each turbine will be measured to determine the wind speed at which it begins to produce power (aka "cut-in" wind speed). For purposes of the Competition, the definition of "producing power" is achieving a positive current (A) while operating at 5V (average over a 5-second interval must be positive).

Control at Maximum Power Task

(20% of Turbine Performance Testing contest or 120/1,000 points of overall score)

Objective:

- The "rated power" or "maximum rated power" is often the label that consumers associate with a turbine. The rated power is the turbine power output at a particular wind speed (determined by the manufacturer). It is a defining characteristic of any turbine. The rated power is sometimes included in the turbine name. An accurate and realistic maximum power rating is an important component of turbine differentiation.
- This task is intended to determine the actual rated power of each turbine. Readings of pressure and temperature will be made available to the teams throughout the competition for the purpose of calculating air density to be used in the maximum rated power calculation for the Control at Maximum Power task. Once the turbine is installed in the tunnel, the team shall submit a maximum power rating that will

show the expected power output precise to 1% of the predicted value or better, in the interval from 5 to 14 m/s.

Procedure:

- Turbines that control rated power to within 10% of target as defined by the team will earn full points (120 points). There will be a 10-point reduction in score for each 10% of power production variance. The team receives one score based on its maximum power output at any wind speed in the wind regime being tested.

Durability Task

(15% of Turbine Performance Testing contest or 90/1,000 points of overall score)

Objective:

- Turbines are expected to perform over the long term, subject to a wide variety of weather conditions. Being able to produce power effectively and to do so over the turbine's useful life are desirable turbine design qualities.

Procedure:

- For durability, each turbine will be subjected to the same proscribed wind speed time-series over a 5-minute test period to verify that it can operate in a wide range of operating conditions.

Safety Task

(15% of Turbine Performance Testing contest or 90/1,000 points of overall score)

Objective:

- Turbine safety is of utmost importance to turbine designers and manufacturers. To be certified, turbines must be able to safely shut down rapidly and with fail-safe back-up shutdown capability. Turbines must be capable of shutting down when disconnected from the grid as well as manually upon command as described in the turbine basis section of this document.

Procedure:

- The turbine will be required to safely shut down at the end of the power curve performance task and also at the end of the 5-minute durability test period. One of each shutdown type will be tested.

Turbine Performance Testing Scoring Rubric

The scoring categories of this contest with general descriptors include:

Power Curve Performance Task

***(30% of Turbine Performance Testing contest or 180/1,000 points of** overall score)*

The wind turbine will be tested for 5 seconds at 1 m/s interval wind speeds from 5 to 14 m/s. A power output reading will be taken at each 1 m/s wind speed interval. A $C_{p(electrical)}$ will be calculated from the power output and the rotor-swept area. A weighted average will be calculated according to the table below. That average will be multiplied by 300 for a total score in this task. For example, an average C_p(e) of 0.4 will result in 120 points.

C_p(e) Weighting for Power Curve Performance Task

Wind Speed (m/s)	%C_p(e)
5	15%
6	15%
7	15%
8	15%
9	10%
10	10%
11	5%
12	5%
13	5%
14	5%
Subtotal	**100%**

Note: If a particular test point cannot be reached by the wind tunnel for any competitor, all teams will receive full points for that test point.

Cut-In Wind Speed Task

(20% of Turbine Performance Testing contest or 120/1,000 points of overall score)

A team will earn 24 points if the turbine is able to cut in and produce power between 4.5 and 5.0 m/s. Producing power is defined as achieving a positive current (A) while operating at 5 V averaged over 5 seconds. An additional 24 points will be earned for each incrementally lower 0.5 m/s wind speed bin the turbine can cut in at up to the maximum number of points for this task. The team receives one score based on its cut-in wind speed.

- % of Turbine Performance Testing contest scoring = 20% on a 100% scale within Turbine Performance Testing contest

Scoring Sample for Cut-In Wind Speed Task

Cut-In Wind Speed (m/s)	Score (Points)
4.7	24
4.3	48
3.4	72
2.8	96
2.3	120

Control at Maximum Power Task

***(20% of Turbine Performance Testing contest or 120/1,000 points of** overall score)*

Turbines that control rated power to within 10% of the target as defined by the team will earn full points (120 points). Judges will reduce a score by 24 points for each 10% of power production variance. The team receives one score based on its maximum power output at any wind speed in the wind regime being tested.

Scoring Sample for Maximum Power Control Task (note: assumes predicted rated power is 100W)

Measured Power (W)	Score (Points)
93	120
84	96
73	72
and so on	
107	120
115	96
121	72
and so on	

Durability and Safety Tasks

***(30% of Turbine Performance Testing contest or 180/1,000 points of** overall score)*

Durability Scoring: This portion of the Turbine Performance Testing contest is scored on a pass/fail basis. The turbine must produce power during the entire 5-minute test to earn 90 points. If the turbine is able to produce power without fault above the cut-in speed and below the cut-out speed for the full 5 minutes, the team will receive 90 points (out of a possible 90). If the turbine experiences any faults or is not able to produce power above the cut-in speed and below the cut-out speed for the full 5 minutes, then the team will receive 0 points. This includes faults detected by observation during operation that don't cause a detected fault or a loss of ability to produce power such as high vibration, cracks, loss of parts or pieces of parts, or other problems detectable by visual observation.

- % of Turbine Performance Testing contest scoring = 15% on a 100% scale within Turbine Performance Testing contest.
- # of points for this task= 90 of 1,000 points for overall competition

Scoring Sample for Durability Task

Time Producing Power (Min)	Score (Points)
5.0	90
4.5	0
3.2	0

*Safety Scoring***:** Teams must be able to safely shut their turbines down on command within 10 seconds for any wind speed up to 17 m/s. For purposes of this task, "shut down" is defined as dropping below 10% of the rated turbine rotor rotational speed as specified by the team, or the maximum RPM achieved during the prior testing, whichever is greater.

- % of Turbine Performance Testing contest scoring = 15% on a 100% scale within Turbine Performance Testing contest
- # of points for this contest = 90 of 1,000 points for overall competition. Each of the two shut-downs will be worth 45 points.

Scoring Sample for Safety Test

	Turbine Result	Score (Points)
Teams score points in one result category, not both	Mechanical shut-down in 5 sec to 5% of rated RPM, Electrical shut-down in 7 sec to 9% of rated RPM	90
	Mechanical shut-down in 8 sec to 9% of rated RPM, electrical shut-down in 12 sec	45
	Mechanical shut-down to 13% of rated RPM, electrical shut-down in 9 sec to 8% of rated RPM	45
	Mechanical shut-down in 13 sec, electrical shut-down to 12% of rated RPM	0

For each individual turbine, the shut-down process will be initiated once “on command” and separately by electrical disconnect. The turbine must be capable of re-starting between tests. Teams may choose to address these shut-down scenarios with one or two systems or mechanisms.

Judge’s Score Sheet: Turbine Performance Testing Contest

Collegiate Team Name: ______________________________________

Judge’s Name: ____

Turbine Performance Testing Criteria		
Description	**Possible Points**	**Score**
Power Curve Performance Task	180	
Cut-In Wind Speed Task	120	
Control at Maximum Power Task	120	
Durability	90	
Safety Tasks	90	
Subtotal (up to 600 possible points)		

Section III: Instructions for Submitting Competition Documents

The required file-naming convention for the design report is as follows:

[TEAM ABBREVIATION]_DESIGNREPORT_[SUBMISSION DATE (YYYY-MM-DD)].[EXTENSION]

See Table 1 for a list of team names. For any other documents to be shared with the Competition team, teams should replace "DESIGNREPORT" in the file name above with the name of the deliverable.

Table 1: Team and Deliverable Abbreviations

Team Name	TEAM ABBREVIATION
Boise State University	BSU
California Maritime Academy	CAL_MARITIME
Colorado School of Mines	MINES
James Madison University	JMU
Kansas State University	KSU
Northern Arizona University	NAU
Pennsylvania State University	PSU
University of Alaska Fairbanks	UAF
University of Kansas	KU
University of Massachusetts Lowell	UMASS_LOWELL

Appendix A Wind Tunnel Specifications

A-1. Wind Tunnel Specifications

The basic wind tunnel configuration is shown below. The wind tunnel has inlet and outlet components that extend beyond the test chamber as shown. The tunnel has a “draw down” configuration; i.e., air is “sucked through” the box—entering at the left, exiting at the right—with the draw down induced by the fan on the rear of the tunnel. A honeycomb flow straightener located at the wind tunnel inlet reduces turbulence in the inlet and test section. There are two debris filters, one at each side of the fan section. The screen is composed of wire mesh to prevent turbine pieces from getting sucked into the fan unit or fingers from reaching the fan blades from the outside.

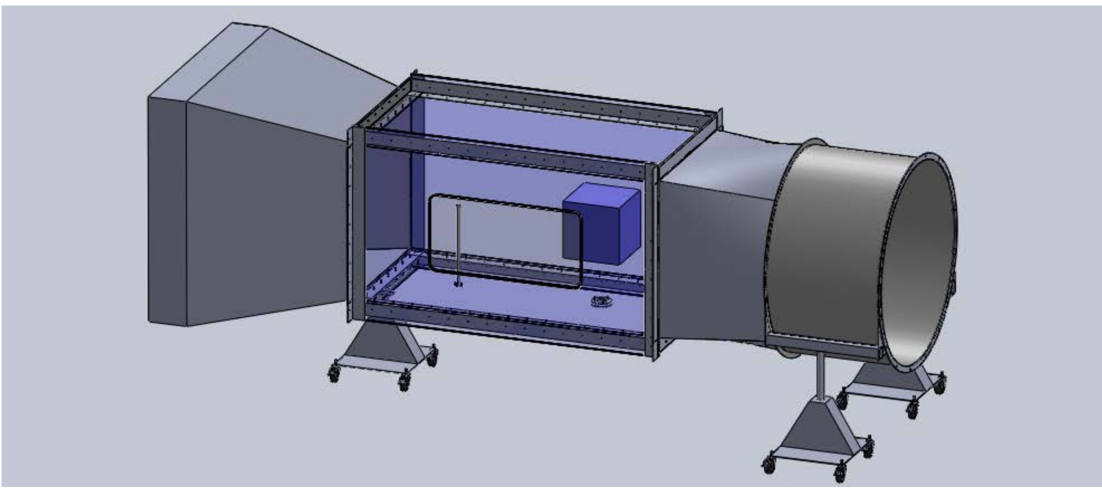


Figure 1. Wind tunnel

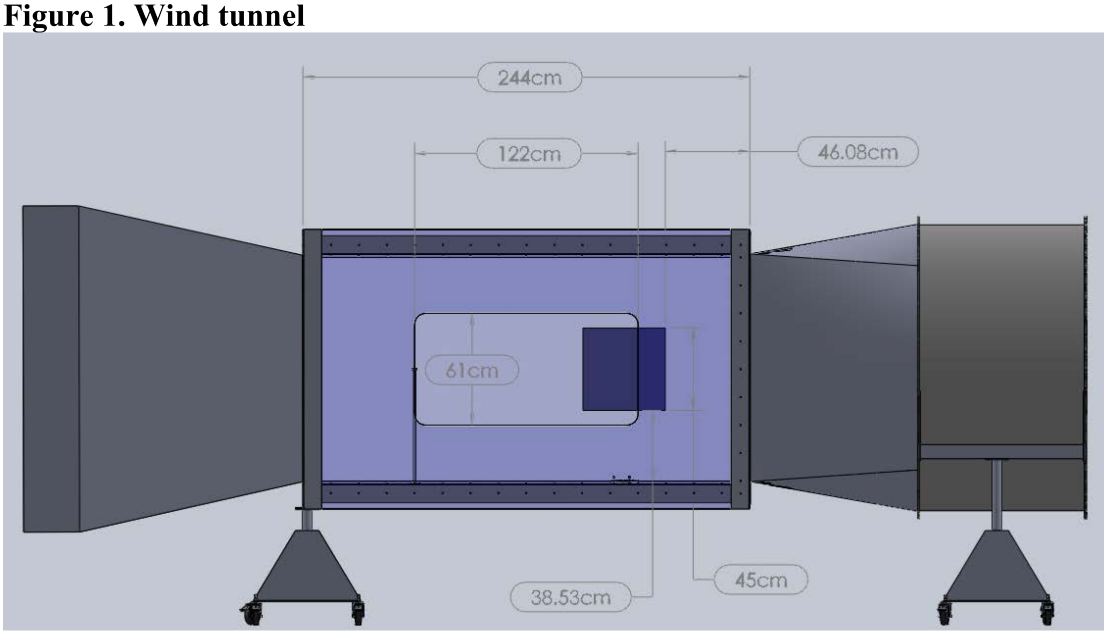
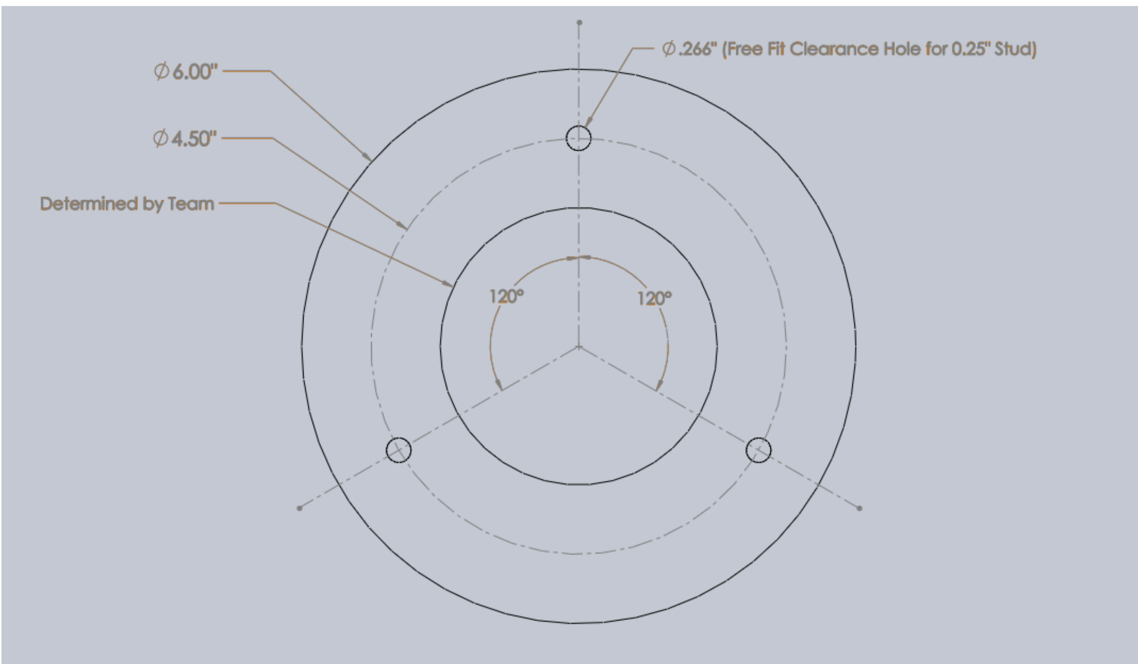


Figure 2. Wind tunnel dimensions

The tunnel is designed for the rotor to fit within a 45 cm x 45 cm x 45 cm “cube” at a specified location within the wind tunnel and be centered at the tunnel centerline. The door is 61 cm by 122 cm. An “attachment stand” will be located at the bottom of the cube (see figure below). The base flange in the tunnel is constructed as a 6-inch diameter, ¼-inch thick aluminum plate with three ¼-inch diameter studs. Turbine bases are attached to this flange with ¼-inch, -20 nuts. The base flange in the wind tunnel includes a 3-inch diameter opening in the center to allow for routing electrical connections out of the wind tunnel. The base flange specification provided was intended to universally allow for a secure and properly aligned attachment. The base flange will be mounted to the floor of the wind tunnel with each team's base plate mounted on top. So, the bottom plane of the team's base plate will be 1/4” above the floor of the wind tunnel. The attachment stand will be fixed in its position within the wind tunnel, and teams are not allowed to change the location or type of the attachment stand. The drawing below shows a top view of the turbine base plate with the top of the drawing oriented toward the tunnel inlet. Air will flow from the area depicted at the top of the drawing to the bottom, parallel to the reference line from the top hole/stud to the center of the plate.



A-2. Collegiate Wind Competition Power Sink

At the competition, Anderson Powerpole connectors (PP15-45, a red and a black for positive and negative) on the test equipment serve as the PCC to connect the turbines to the test equipment.

The power sink will be a 5V power supply with load resistors attached. The power supply will have remote sense leads that will connect to the PCC to ensure that the voltage is sensed and regulated at that point. Line resistance between the turbine and the PCC will affect the turbines, but that is a direct result of wire size, which is a team-selected design variable.

In essence, the test turbines will have to inject current into a constant, regulated 5V sink, much like on-grid turbines have to inject current into the constant, regulated voltage (but AC instead of DC) of the power grid.