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Blade assembly design and optimization for the 2025 Science Olympiad division C wind power event

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Abstract
A wind power device converts the wind's kinetic energy to electricity. Wind power has been a frequent event at the Science Olympiad for the last 15 years (2009, 2010, 2011, 2016, 2017, 2024 and 2025). The objective of the event is to inspire middle and high school students to explore green energy and physics. However, few documents or research articles provide technical guidance for students on making an efficient blade assembly while complying with the event rules. Thus, all the teams are challenged to make their own devices at the most fundamental level. This paper discusses basic steps, including blade shape design, 3D printing, and experiments to construct a high-performance assembly for the 2025 Science Olympiad Wind Power Event, Division C (9-12 grades). In this study, it was found that, in compliance with the construction rules, (1) a tip speed ratio of 4.2 be used for blade shape design, (2) the two-blade assembly device be adopted, and (3) during testing, the blade assembly be positioned about 10 cm off the 20" box fan's center to achieve the maximum voltage output.

Keywords
Wind energy, Wind power, Blade design, 3D printing, Tip Speed Ratio, Wind turbine, Angle Of Attack, Lift to Drag Ratio, Science Olympiad

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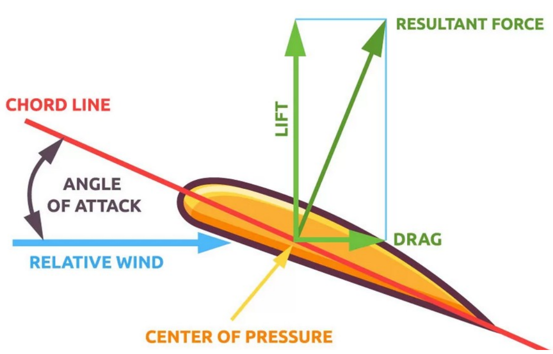
Introduction

Basics of wind turbine blade aerodynamics

A wind power device (or wind turbine) aims to convert the wind's kinetic energy to electrical energy. Wind is the largest source of renewable electricity generation in the U.S. It provided approximately 12% of the total utility-scale electricity in 2023 (1). For the modern designs of wind turbines, the horizontal axis wind turbine (HAWT) is the most popular design due to its higher efficiency than the vertical axis wind turbine (VAWT). HAWT is driven by the lift force, which is caused by the pressure difference between the front and back of the blade (Figure 1).

The angle of attack (AOA) is the angle between the relative wind direction and the blade airfoil chord line (Figure 1). The ratio of lift to drag, also known as the lift-to-drag ratio (L/D), is crucial in determining the efficiency of a wind turbine. Ideally, the blade design should maximize lift while minimizing drag to achieve the most efficient conversion of wind energy into rotational energy (2). One widely used method to determine the optimal AOA is to find the AOA when the lift-to-drag ratio is the largest. For example, Burton (3) found that the AOA was 7º for a blade design when the lift-to-drag ratio was the maximum.



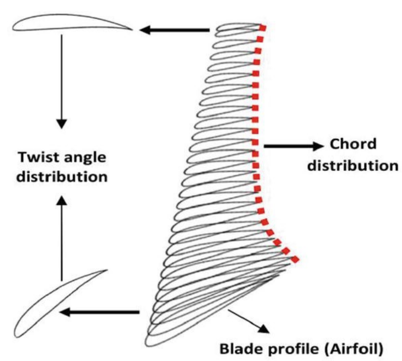


Figure 1. (Left) Aerodynamics of the wind turbine blade (source: mwi-inc.com/blog-post/what-is-an-airfoil-and-whats-its-purpose/)

Figure 2. (Right) Wind turbine blade twist (source: www.intechopen.com/chapters/81347)

As the blade rotates, the blade speed increases along the radius of the blade (i.e., the tip travels faster than the root). Consequently, the blade must have an appropriate twist from root to tip to maintain approximately the same optimum AOAs along the length of the blade (Figure 2). An optimal wind turbine blade design should have an appropriate blade twist from the hub to the tip to achieve optimal AOAs along the airfoil's spanwise direction.

Rules of the wind power event in the 2025 Science Olympiad division C

Wind power is one of the events in the 2025 Science Olympiad division C competition (9-12 grades). The event has two parts: the written part and the device testing part. Each part accounts for 50% of the final score.

Each team supplies a pre-constructed blade assembly device for the device testing part. The device is essentially a HAWT, as described earlier. The construction parameters for the 2025 event are summarized below, as shown in Figure 3 (4).

The blade assembly device consists of any type and number of blades. The central disc must either be a mini (8.0 cm in diameter) or a standard (12.0 cm in diameter) commercially-made CD, DVD, or Blu-Ray disc. Modifying the disc is not allowed (except affixing the blades via tape, glue, etc.). When mounted, no part of the blade assembly may have a radial distance from the center of the axis of rotation of more than 10.0 cm. The blade assembly must be made of only nonmetallic, nonmagnetic substance(s).

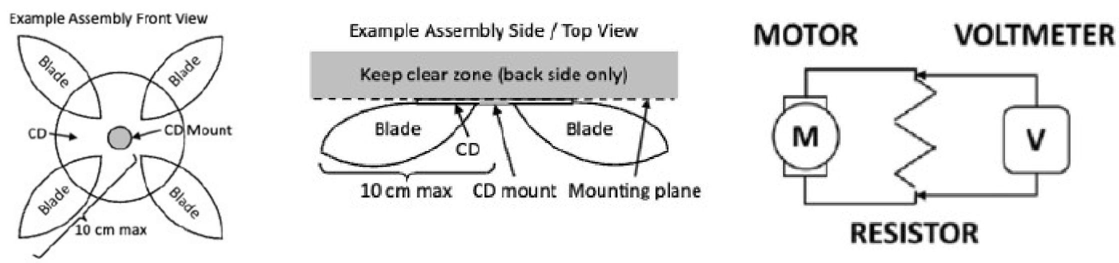


Figure 3. Illustration of the blade assembly and its testing circuit defined by the 2025 Science Olympiad div. C Wind Power (4)

During device testing, key aspects governing the test facility and rules are as follows (4). A 20” multi-speed box fan(s) is to be used as the wind source(s). A support stand(s) can be used that allows for vertical and horizontal adjustments. A motor/generator(s) is mounted to the support stand(s), with the axis of rotation approximately parallel to the axis of the fan. Load resistor(s) must be between 5 and 25 ohms (1/4 watts or greater), wired in parallel with the motor/generator, and which must have the same value for all teams. After initial set-up, the blade assembly must be tested once with the fan at a low wind speed and once at a high wind speed. Teams can start and stop the blade assembly rotation and reposition the support stand during the set-up period. After the set-up period, with the fan on and the blade assembly rotating, the students inform the event supervisor to begin a 30-second measurement period. The team must not touch, modify, influence, or reposition the blade assembly or support stand during the measurement period.

The Wind power event has made frequent appearances in the Science Olympiad competition in the last 15 years (2009, 2010, 2011, 2016, 2017, 2024, and 2025). The blade assembly construction rules change each year, mainly by changing the dimensional requirements. So far, few or no documents or research articles have been identified that provide technical guidance for middle and high school students for constructing an efficient wind power device. As a result, most teams have insufficient prior experience to rely on for creating such a device. However, the emergence of affordable 3D printers makes it possible for students to design, manufacture, test, and optimize their devices independently. The current investigation designed and optimized such a blade assembly device using a wind turbine design program, CAD software, a 3D printer, and a data acquisition system.

Materials

A 20'' Lasko brand box fan from a generic outlet store was used as a source of the wind. A generic multimeter was used to measure voltage and resistance. A generic anemometer was used to measure wind speed. A generic tachometer was used to measure rotational speed or RPM. A 10 Ω resistor was used to form the circuit as required by the event rules (Figure 3). A Data acquisition system box (DataQ DI-2108) was used to receive voltages across the resistor and to send the data to a generic laptop via USB. The data collection frequency was 10 Hz or 10 data points per second. An 8 cm diameter CD/DVD was used as the central disc for the blade assembly. The blade assembly was attached to a min-generator through a CD spindle hub. All the other parts for the device were manufactured using a personally owned Flashforge 5M Pro 3D printer (Flashforge, Hangzhou, Zhejiang, China).

Methods

Blade design

Under a public license, the blade airfoil shapes were designed and optimized through Qblade® Community Edition (https://qblade.org). Qblade® is an advanced multi-physics software. It is designed to facilitate the comprehensive aero- servo- hydro- elastic development, prototyping, simulation, and certification of wind turbines. It employs a highly optimized and thoroughly validated Lifting Line Free Vortex Wake Method for its aerodynamic calculations (5).

The blade model was completed in Solidworks® (https://solidworks.com student version) by attaching the blade airfoil generated in Qblade® to the blade root model. The construction of the blade assembly is described in later sections as are the main design factors for the blade device.

Benchmark wind speed

The 20" Lasko® box fan is a widely available box fan in the market. In the event, it was most likely that the same type of box fan or a similar one would be used. Measurements determined that the 20" box fan used in the current study generated ~4.9 m/s wind speeds at the high setting and ~3.5 m/s at the low setting. The wind speed of their average (eq1) was then used as a benchmark for the blade design calculations. $V_{benchmark} = \frac{V_{high} + V_{low}}{2} = 4.2\left[\frac{m}{s}\right]$ (eq1)

RPM (Revolutions Per Minute) and TSR (Tip Speed Ratio)

The main challenge of the blade design in this study was that the device's actual RPM was unknown during the design process. RPM is needed to calculate relative wind speed (Figure 1) so that the blade shape can be designed to ensure the appropriate AOA along the radius direction. RPM is also associated with the TSR (the ratio of blade tip speed to wind speed). The TSR is the most important parameter in the blade's design. The power coefficient of a wind turbine varies with the TSR and is only a maximum for a unique TSR (3). For the current blade assembly under investigation, TSR was calculated as $TSR=\frac{RPM\cdot 2\pi/60\cdot R}{V_{benchmark}}$ (eq2), where R=0.1 m as required by the rules (Figure 3), and $V_{benchmark}$=4.2 m/s as aforementioned. A parametric study was performed at 15 different RPMs and their corresponding TSRs, as shown in Table 1. Those TSRs were then used as the blade design parameters in Qblade®.

In summary, 15 blade shape design parameters were calculated with 15 different TSRs used in Qblade®, and all these blade assembly devices were manufactured to determine the design with the best performance.

Table 1. RPM and TSR for the blade assembly design at a wind speed of 4.2 m/s.

Design #	RPM	TSR
1	1000	2.5
2	1100	2.7
3	1200	3.0
4	1300	3.2
5	1400	3.5
6	1500	3.7
7	1600	4.0
8	1700	4.2
9	1800	4.5
10	1900	4.7
11	2000	5.0
12	2100	5.2
13	2200	5.5
14	2300	5.7
15	2400	6.0

Blade airfoil profile and its aerodynamic characteristics

The blade profile (NACA airfoil code: 5409) used in Qblade® was generated from the National Advisory Committee for Aeronautics (NACA) airfoil database. The chord length was 2.5 cm, and the thickness was 0.225 cm, as shown in Figure 4.

The NACA 5409 is one of the cambered airfoils which have curved chord lines, which allows them to produce lift at a zero angle of attack. Generally, cambered airfoils have higher maximum lift/drag ratios than symmetrical airfoils for positive angles of attack (3).

The Reynolds number needed to be determined to perform the airfoil aerodynamic characteristics analysis. The Reynolds number expresses the ratio of inertial forces to viscous forces (6). The performance characteristics of an airfoil, such as the lift coefficient C_l, drag coefficient C_d, and lift-to-drag ratio C_l/C_d, change significantly at different Reynolds numbers (7). At a higher Reynolds number, all of the airfoils exhibited better performance, which included a higher lift coefficient, a lower drag coefficient, and a larger lift-to-drag ratio at any given angle of attack (7).

For the flow conditions under consideration, the Reynolds number was calculated as,

$$\Re = \frac{V \cdot l}{v} = \frac{4.2\left[\frac{m}{s}\right] \cdot 0.025[m]}{1.5 \times 10^{-5}\left[\frac{m^2}{s}\right]} = 7000 \quad \text{(eq3)}$$

where V is the wind speed, l is the chord length, and v is the kinematic viscosity of air at room temperature. The Reynolds number under consideration for the current study was significantly lower than the typical Reynolds numbers for commercial wind turbines, which are typically in the order of millions. The reason for such a low Reynolds number was largely because of the small size of the device in compliance with the construction rules of the competition.

The current study evaluated the aerodynamic characteristics of a series of NACA wind blade airfoils, i.e., NACA 44xx and 54xx, in Qblade®. As expected, airfoils demonstrate better lift-to-drag ratios as the airfoil thickness decreases (8), but they can also result in a 3D printing problem of maintaining smooth surfaces. As a consequence, the NACA 5409 airfoil (2.5 cm chord length and 0.225 cm thickness) was ultimately chosen for the current wind power device.

At Re=7,000, the aerodynamic characteristics of the NACA 5409 airfoil were calculated in Qblade® and are shown in Figure 4.

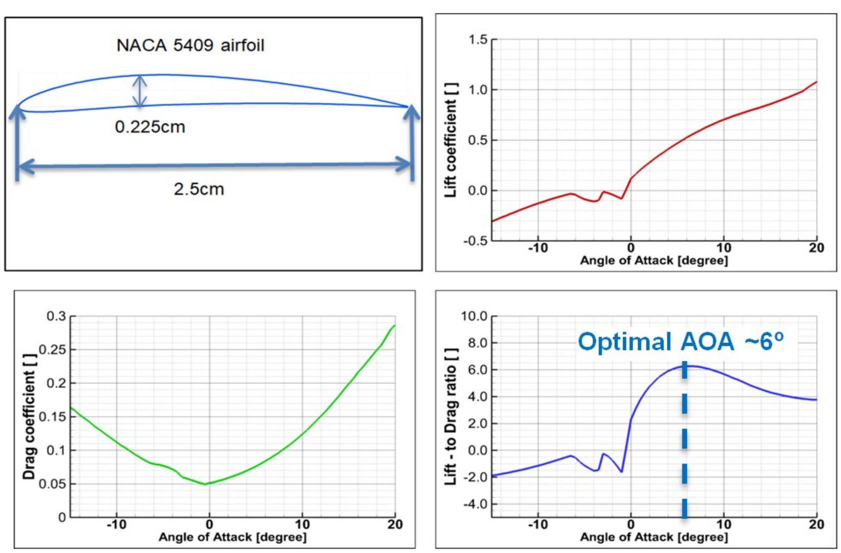


Figure 4. NACA 5409 airfoil and its characteristics calculated by Qblade® at Re=7,000

Figure 4 shows the coefficient of lift (C_l), coefficient of drag (C_d), and lift-to-drag ratio (L/D) as a function of angle of attack (AOA), as calculated by Qblade®. It shows that the optimal AOA is ~ 6°.

Blade hub and height

The blade hub radius was 4 cm. 8 cm diameter CD/DVDs were used in all assemblies because the event rules (4) stated that "The central disc must be either a mini (8.0 cm in diameter) or a standard (12.0 cm in diameter)" and "no part of the blade assembly may have a radial distance from the center of the axis of rotation of more than 10.0 cm."

As the following calculations show, when the blade tip radius was 10 cm, the 8 cm diameter mini CD/DVD was calculated to have a 31% larger blade swept area than when using the 12 cm diameter CD/DVD (84π vs. 64π cm^2). $A_{mini_{CD}} = \pi(10^2 - 4^2) = 84\pi\,[cm^2]$ (eq 4) and $A_{standard_{CD}} = \pi(10^2 - 6^2) = 64\pi\,[cm^2]$ (eq 5). Eq.6 calculates the total energy available through a wind turbine as $Pt = 0.5 \cdot \rho \cdot A \cdot V^3$ (eq 6), where ρ (rho) is the air density, A is the circular area the wind turbine blades sweep, and V is the wind speed. As a result, the wind energy available when using a mini CD is 31% higher than that when using a standard CD. When using a min CD, the maximum height the blade can have is 6 cm.

Number of blades

The number and configuration of the blades are very important because they affect the speed and efficiency of the turbine (9). While a greater number of blades on a wind turbine generates more torque, it also slows the rotation speed due to the increased drag caused by the resistance to wind flow (9-11). Experiments show that by using more blades on the wind turbine, it is easier to rotate at lower wind speeds, but it also causes a lower performance and higher torque (12).

Thus, wind turbines used to generate electricity do not require much torque, and consequently a smaller number of blades is preferred (9). Any number of blades greater than three would create greater wind resistance, slowing the generation of electricity and thus becoming less efficient than a typical three-bladed turbine (13). The decision to design three-bladed turbines for most commercial wind turbines was a compromise (9, 13). Two-blade turbines have also gained significant interest from industry for their high efficiency and low cost (14, 15). For this particular wind turbine application for the Science Olympiad competition, the two-blade device was considered to be the best choice because of the objective to generate the highest voltage. In an effort to verify this, experiments were performed to investigate the effect of the number of blades on the voltage generated.

Blade shape optimization in Qblade®

Using the aforementioned blade geometry and inputting different TSRs, the blade twists were automatically calculated in Qblade® using the Schmitz method (16) for each design in Table 1. Figure 5 shows the resulting blade twist profiles for two selected designs.

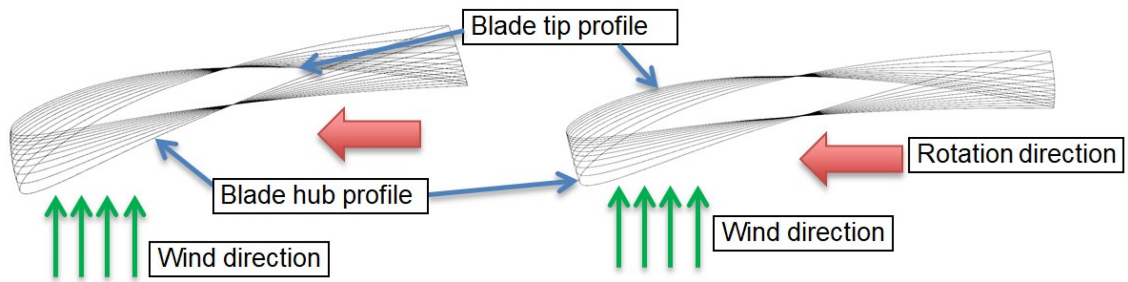


Figure 5. Blade twists calculated by Qblade©-CE (left: Design 3; right: Design 8 in Table 1)

A final blade height was set at 5.9 cm to ensure that the device passed the dimensional specifications. This resulted in a blade tip radius of 9.9 cm; slightly less than the maximum 10 cm radius required by the event. The blade airfoil geometry generated in Qblade® was imported into Solidworks® and merged with the blade root to form the final blade model (Figure 6).

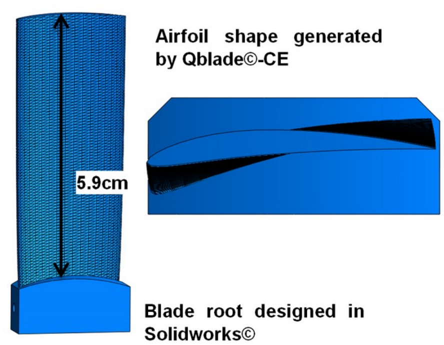


Figure 6. Blade CAD model

All the blades were left-handed hence that they rotated counterclockwise. The reason for selecting the left-handed blades rotating counterclockwise is discussed later. In summary, fifteen blade design cases (Table 1) were considered by assuming different TSRs. Using Qblade®, these were used to generate different blade models with optimum root-to-tip twists. The final blade design recommended for the competition was then based on the device performances; as determined by the maximum voltage generated at the low and high speeds.

Construction of the blade assembly

The blade assembly was constructed in compliance with the aforementioned event rules. In particular, structural integrity under centrifugal force needed to be assured during testing, especially since the rotating speed could be greater than 2,000 RPM. Blades were mounted in the blade holder attachment using 1.75 mm plastic pins (cut from the 3D printer filament). The blade holder attachment was glued on the CD face. In this manner, different blades could be easily removed and replaced within the holder attachment. This assembling design effort made parts exchangeable and hence saved 3D printing work. Figure 7 shows the blade assembly CAD model (three-blade device) and the 3D printed parts assembled.

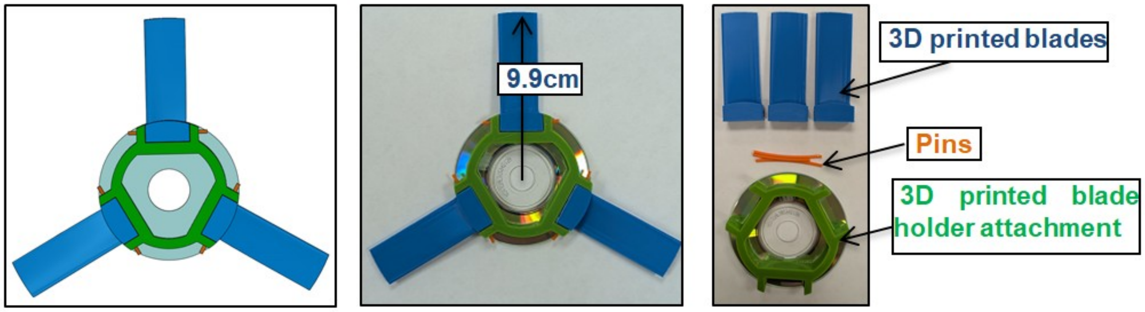


Figure 7. Blade assembly (from left to right: CAD assembly model, actual blade assembly, 3D printed parts)

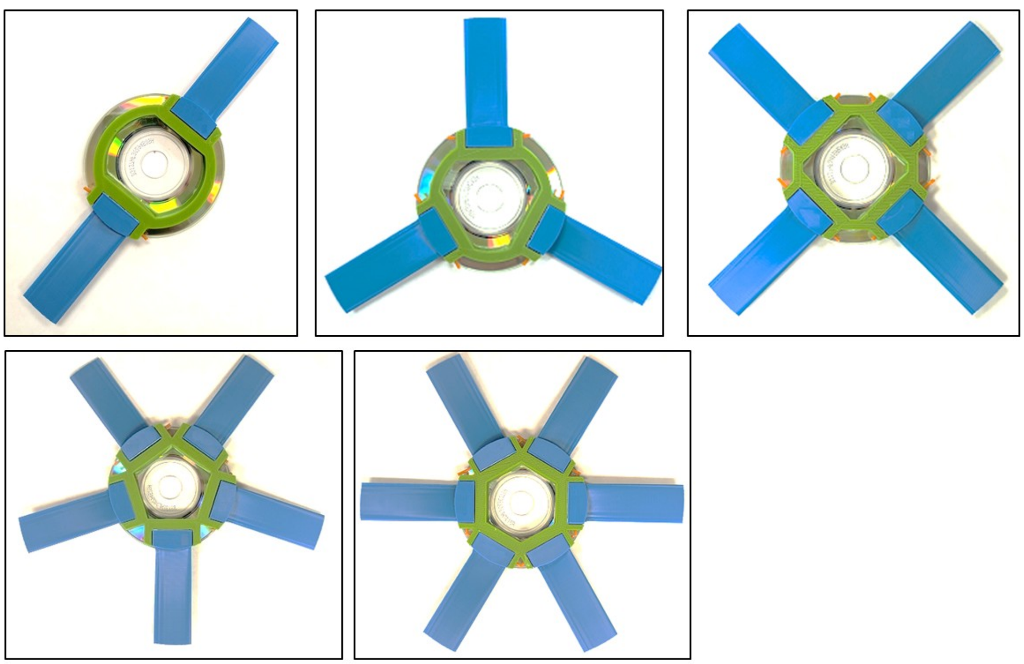


Figure 8. Blade assemblies with different numbers of blades

Five different blade holder attachments for varying numbers of blades (2x, 3x, 4x, 5x, and 6x) were designed and manufactured using a 3D printer (Figure 8) to study the effect of the different number of blades on the device performance. A total number of ~60 parts (blades and holder attachments) were manufactured throughout this study.

Testing Facility

Figures 9 and 10 show the testing facility and the methodological flowchart.

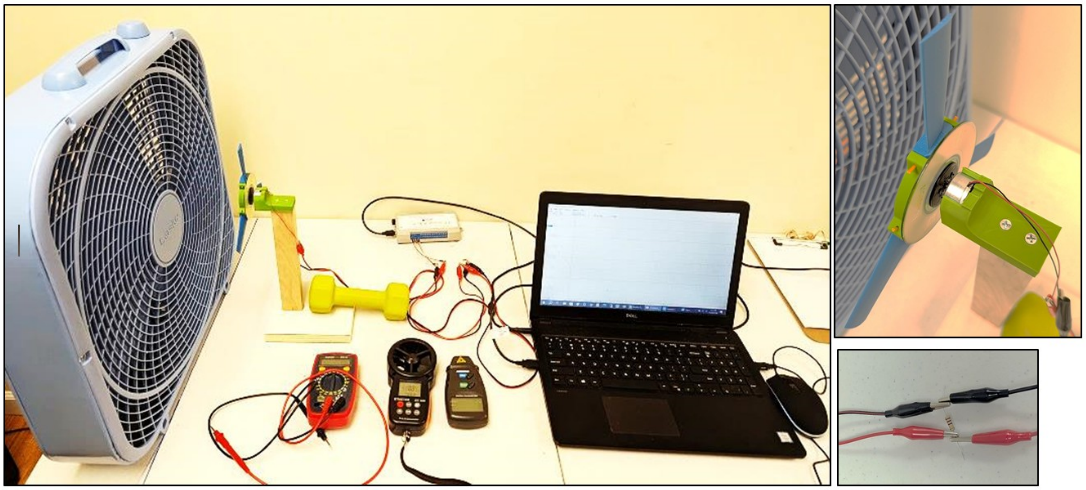


Figure 9. The testing set up

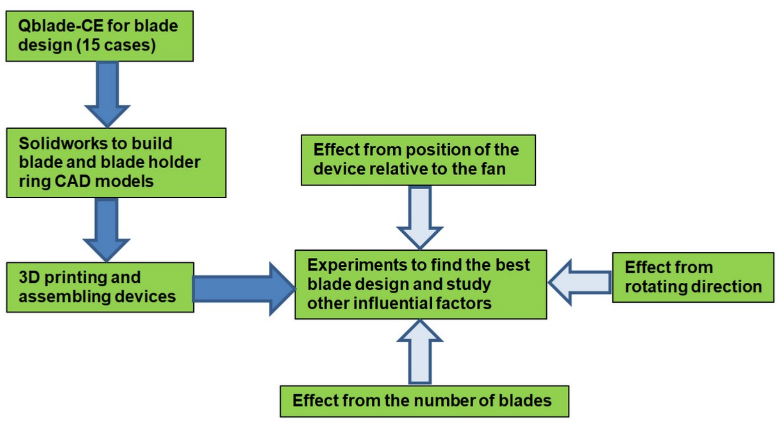


Figure 10. Methodology flowchart

Results and Discussion

Blade design evaluation

Two-blade and three-blade assemblies for all fifteen designs (Table 1) were manufactured and tested at both high and low wind speeds. The data acquisition system recorded the one-minute voltages at 10 Hz after the blade assembly reached its highest voltage (despite some fluctuation). Each experiment's minimum, maximum, and mean voltage values were obtained and compared. Figure 11 shows the voltages for the fifteen designs (Table 1) measured at high-speed and low-speed wind at one minute after start. The data bar indicates the maximum and minimum values measured for that test.

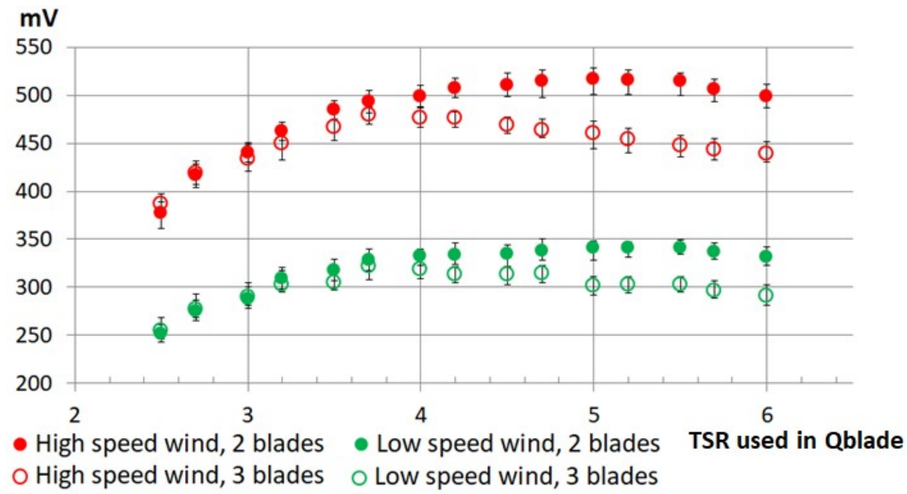


Figure 11. Measured voltages for 15 designs (high-speed vs. low-speed wind; 2 blades vs. 3 blades). The two-blade devices perform better than the three-blade devices except in Design 1 and Design 2.

Figure 12 shows the total voltages for the fifteen designs (Table 1) by adding voltages measured at the high-speed and the low-speed wind together.

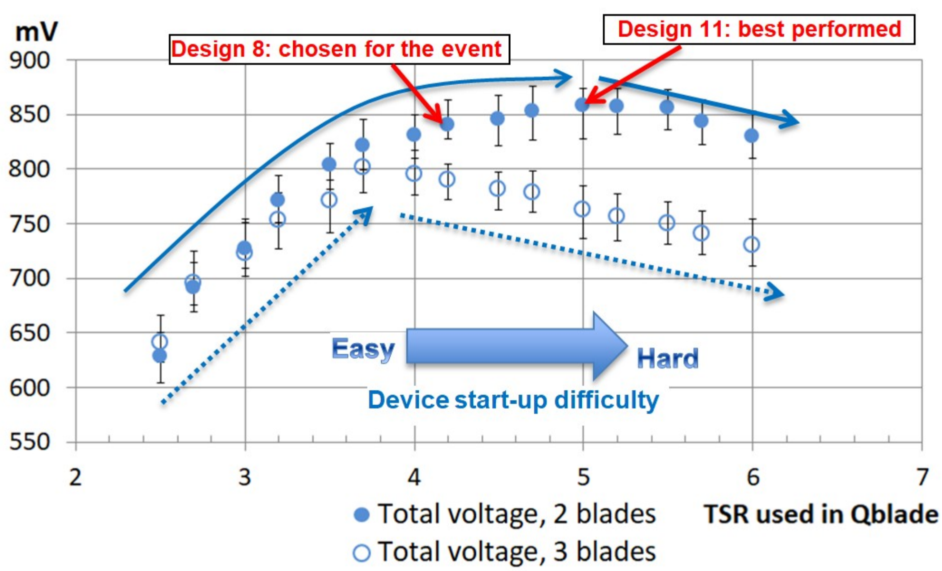


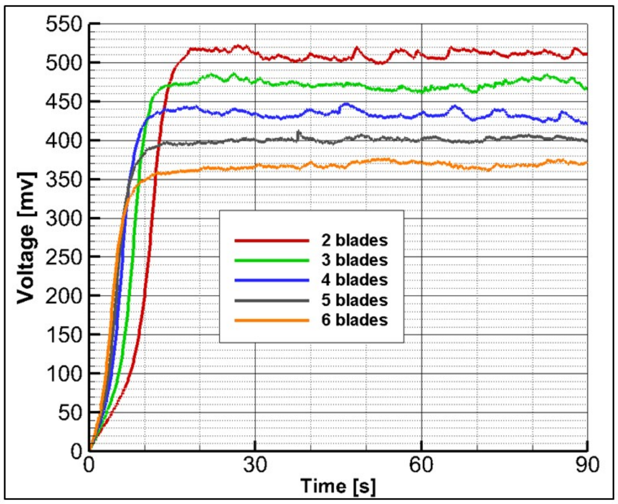
Figure 12. Measured total voltages (voltage from the high-speed wind + voltage from the low-speed wind) for the 15 designs (2 blades vs. 3 blades). Design 11 (TSR=5.0) of the two-blade device performed the best in generating the highest overall voltage. Design 8 was ultimately selected for the balance on achieving a high voltage and the assurance that the device could start successfully at the low-speed wind

It also should be noted that the "TSR used in Qblade" in Figures 11 and 12 refer to TSR numbers listed in Table 1 when using Qblade® to design the blade. It can be seen from the figures that the high-speed wind generated significantly higher voltages than the low-speed wind. This is not unexpected. According to eq.6 the available wind energy increases in proportion to the third power of the wind speed. For the same wind speed, the two-blade devices performed better than the three-blade devices except in designs 1 and 2, where the TSR used in the design was the smallest. For the two-blade devices, as the TSR increased, the voltage increased, reached a peak when TSR was 5.0 (Design 11), and then decreased slowly at both high-speed and low-speed wind (Figure 11). Similarly, for the three-blade devices tested at both the high-speed wind and low-speed wind, as the TSR increased, the voltage increased, reached the peak when TSR was 3.7 (Design 6), and then decreased slowly (Figure 11). Figure 12 indicates that Design 11 (TSR=5.0) of the two-blade device performed the best in generating the highest overall voltage. However, the challenge of the device start-up in the low-speed wind was noted as a practical consideration. This difficulty with the device during start-up gradually worsened from Design 1 to Design 15, especially for the two-blade devices in the low-speed wind regime. This was understood as a consequence of the later cases being designed using higher TSRs, which corresponded to higher RPMs (Table 1). Thus, when the RPM was low at the beginning of the experiments, it became harder for them to start. Designs 8-11 resulted in similar voltages, but Design 8 (TSR=4.2) was much easier to start up than Design 11. Design 8 of the two-blade device could start up by itself or with a slight push at the low-speed wind. At the low-speed wind, for Designs 9 and later, the two-blade device could only start up with a hard push or by first turning on the high-speed wind to gain sufficient RPM and then switching to the low-speed wind. The tachometer registered an RPM of ~ 2050 for the two-blade assembly of Design 8 at the high-speed wind.

As a result, Design 8 (designed using TSR=4.2) of the two-blade device was ultimately chosen for the 2025 Science Olympiad wind power division C event. The decision was balanced on achieving a high voltage and the assurance that the device could start successfully at the low-speed wind during the event.

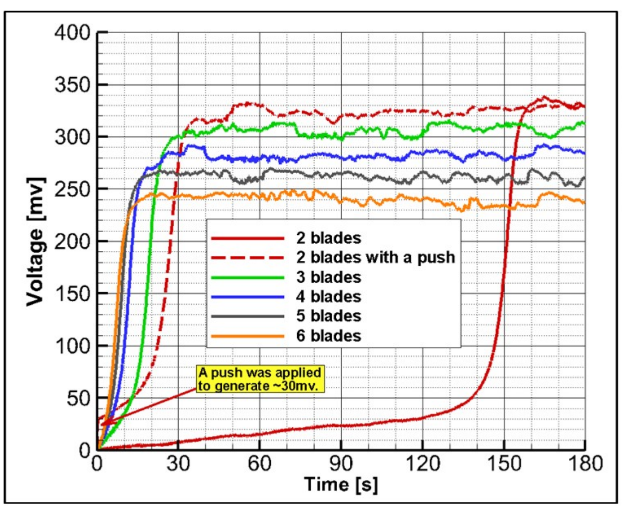
The effect of the number of blades

Experiments were performed to investigate the effect of changing the number of blades. The Design 8 blades were used for all the assemblies with different combinations of blades. Blade assemblies with 2, 3, 4, 5, and 6 blades (Figure 8) were eventually tested. The voltage data was collected from the time when the device started rotating to the time when the device reached its maximum RPM. Figures 13 (high-speed wind) and 14 (low-speed wind) show the voltages as a function of time for all the blade assemblies. For both the high-speed wind and the low-speed wind velocities, the greater the number of blades, the lower the peak voltage and the RPM of the device and the shorter the time taken to reach peak voltage (despite some fluctuation). For the high-speed wind (Figure 13), all the blade assemblies reached the peak voltage in less than 20 seconds. For the low-speed wind (Figure 14), all the blade assemblies except the two-blade device reached peak voltages in ~ 30 seconds. Without a push, the two-blade device reacted slowly to the low-speed wind. It took ~ 160 seconds to reach the peak voltage. It was determined that a push on the device could assist significantly in starting rotation. Such a push is allowed by the rules. As Figure 14 shows, a small push that generated only about 30 mV could significantly accelerate the start-up of the two-blade device.



Blade #	Peak voltage [mv]	Est. peak RPM
2	520	2050
3	486	1920
4	447	1760
5	412	1630
6	376	1480

Figure 13. Voltage vs. Time when the blade assemblies (with different numbers of blades) start under the high-speed wind. The greater the number of blades, the lower the peak voltage of the device. All the blade assemblies reached the peak voltage rapidly



Blade #	Peak voltage [mv]	Est. peak RPM
2	338	1330
3	316	1250
4	293	1150
5	270	1070
6	250	980

Figure 14. Voltage vs. Time when the blade assemblies (with different numbers of blades) start under the low-speed wind. All the blade assemblies except the two-blade device reached peak voltages in ~ 30 seconds. A small push could significantly accelerate the start-up of the two-blade device.

The above observations were consistent with the previous investigations (9-12) for the effect of number of blades on the voltage generated and on the torque (ease of starting). In summary, for the wind power event of the Science Olympiad competition, the two-blade device was adopted because it generated the greatest voltage.

The effect of rotating direction and position of the assembly relative to the fan

A mechanical device generates the fan wind with certain aerodynamic patterns. Based on the author's experience, all the box fans in the market rotate clockwise if viewed from the front. It was considered whether the rotating direction (counterclockwise vs. clockwise of the blades if viewed from the front, as shown in Figure 15) could affect the device's performance. Using the same Design 8 blades, a left-handed two-blade assembly (rotating counterclockwise) and a right-handed two-blade assembly (rotating clockwise) were compared for their performance.

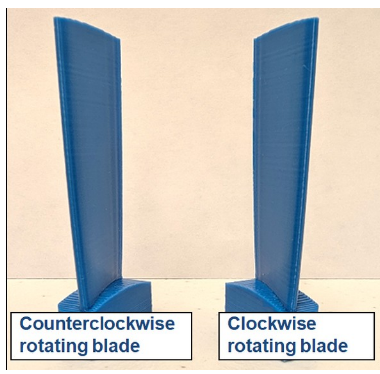


Figure 15. Counterclockwise vs. clockwise rotating blades

It was further considered how the positioning of the blade assembly relative to the fan could also affect the device's performance. The commonly used position was that the blade assembly's center aligned with the fan's center. Other possible positions were tested at 1 cm intervals, where the center of the blade assembly was pointing away from the center of the fan, being offset by a certain distance up to 20 cm (Figure 16).

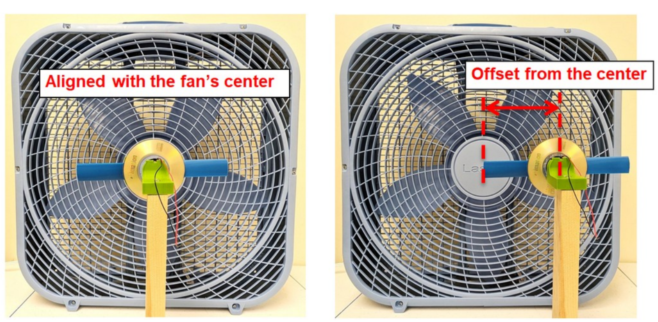


Figure 16. Blade assembly position: center alignment vs. off-center alignment to the fan

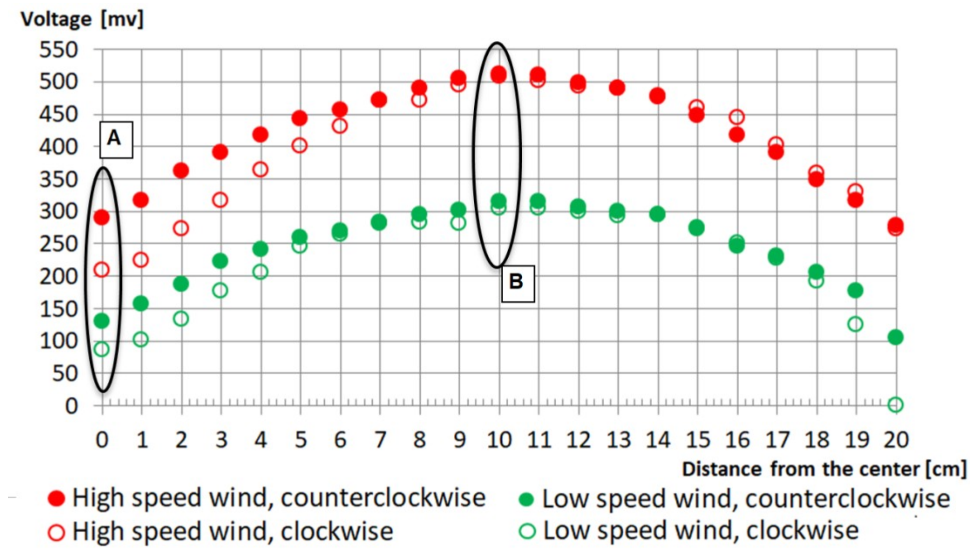


Figure 17. Effect from the position alignment and rotating direction on the blade assembly performance (two-blade device was used)

Figure 17 shows the experimental results (average voltages from 60 s measurements) in comparing the performances between counterclockwise rotating blades and clockwise rotating blades at different positions using the two-blade devices (Design 8 blade design).

When the device was aligned to the center of the fan rotating clockwise, the counterclockwise rotating blade assembly generated significantly higher voltage than the clockwise rotating blade assembly for both wind speeds (Region A in Figure 17). For both the counterclockwise rotating and clockwise rotating blade assemblies, as the device was positioned away from the center of the box fan, the voltage increased gradually, reaching the peak when there is was a 10 cm offset from the center of the fan (Region B in Figure 17), and subsequently decreasing as the blade assembly was positioned further away from the box fan. In general, the counterclockwise rotating blade assembly performed better than the clockwise rotating blade assembly especially when the blade assemblies were aligned to the center of the fan. At the position of a 10 cm offset from the center, both counterclockwise rotating and clockwise rotating blade assemblies reached similar peak voltages (Region B in Figure 17).

It can be speculated that for the relatively small size of this blade assembly (9.9 cm in radius), if the device faces the center of the fan, the blade assembly receives much less wind because the fan hub has a radius of ~7.7cm. Therefore, the effective area where the blade assembly receives wind is only the area between the 7.7cm and 9.9cm radii. On the other hand, when the blade assembly is 10 cm off the center of the fan, it generates much higher voltages because it receives more wind. When the blade assembly is aligned to the center of the fan, the wind generated by the clockwise rotating fan blades favors the counterclockwise rotating blade assembly. This may be due to the wind flow characteristics of the fan. If the wind were to be a pure parallel airflow, there would not be any performance difference between the counterclockwise rotating and the clockwise rotating blade assemblies.

All the previous experiments (Figures 11-14) were performed using the counterclockwise rotating blade assemblies, which were positioned ~10 cm off the center of the fan to achieve the best performance (greatest voltage) possible.

One potential design improvement is to have adjustable blades. This is so that participants can change the blade angle positions when switching from one wind speed to another to achieve the best possible performance for both wind speeds. However, participants should pay attention to the construction and testing rules to make sure such an adjustment is allowed as the rules vary each year. Such a mechanism for blade position adjustment also needs more 3D printed parts and involves more sophisticated assembly designs.

Conclusion

Calculations, design and experiments were performed to maximize the performance of a blade assembly device for the wind power event of the 2025 Science Olympiad Div. C competition (9-12 grades). From these studies, it was concluded that the blade airfoil shape optimized for TSR=5.0 (Design 11) performed the best when using two blades for the device (Figure 12). However, considering the difficulty of device start-up at the low-speed wind, the two-blade device with the airfoil shape optimized for TSR=4.2 (Design 8) was used for the event competition. It presented an optimized decision to achieve the high voltage and ensure the device could start successfully at the low-speed wind setting during the event. A greater number of blades decreased the voltage generated by the device. On the other hand, the greater the number of blades, the shorter the time required for the device to reach its peak voltage, i.e., faster start-up time. When testing the blade assembly, the blade assembly was positioned ~10 cm off the center of the fan (Figures 16 and 17) to maximize the wind power output. A moderate push was applied (acceptable under the rules) to help the device start rotating. When the device was positioned ~10 cm off the center of the fan, the rotating direction had a negligible effect on the device's performance. When the device was placed at the center of the fan, the counterclockwise rotating device generated a significantly higher voltage than the clockwise rotating device. If the blade assembly is large enough (for instance, as permitted in Division C in 2024 with a maximum radius of 14 cm and limited to using standard CD/DVDs), aligning the blade assembly with the center of the fan may generate the maximum voltage compared to the other positions. In such a case, a counterclockwise rotating device must be selected to achieve the maximum voltage.

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