MiniWind Lab Kit

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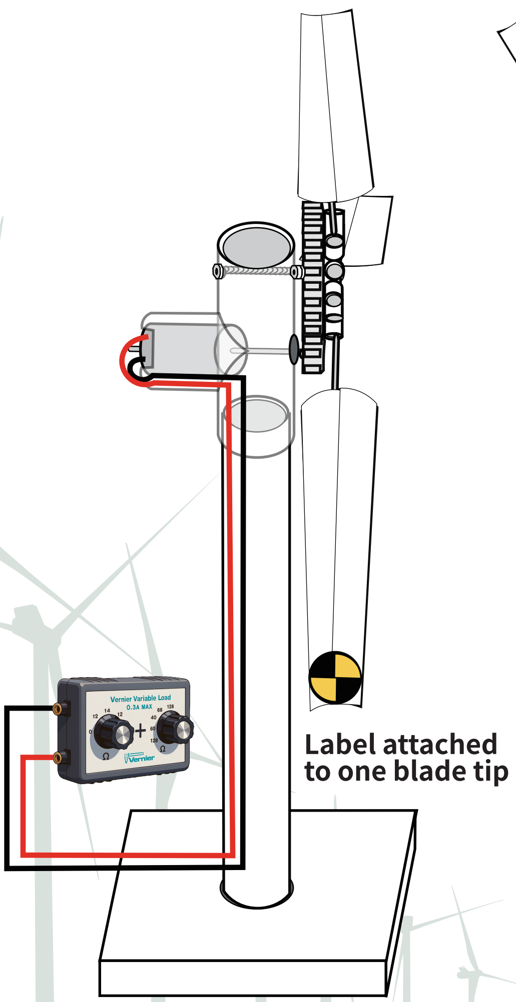
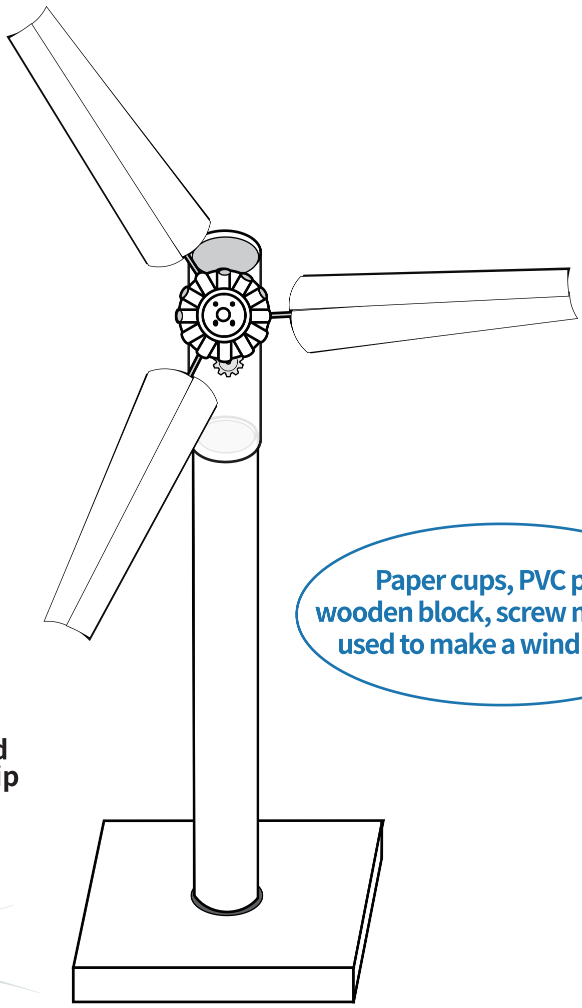
Asia-Pacific Energy & Science Education Association

- Introduction to the MiniWind Lab Kit:

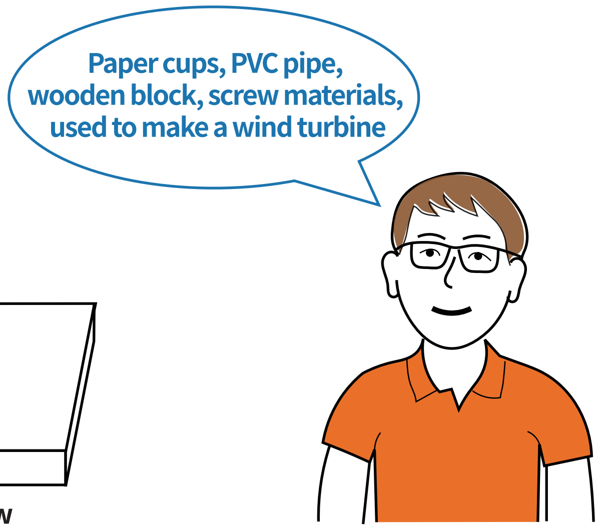
The MiniWind Lab Course covers STEM, which stands for Science, Technology, Engineering, and Mathematics. Using paper cups as blades, designing the blades involves applying mathematical geometry. Screws serve as the rotor shaft, PVC plastic pipes as the tower, and wooden blocks as the base, which fall under technological skills. Additionally, the generator and variable resistor incorporate knowledge of physical electricity. Plastic gears paired with a hub supporting up to 12 blades allow for engineering optimization by adjusting the pitch angle and resistance value. Finally, through teamwork, students learn how to design blades, adjust pitch angles, and resistance values to maximize the electrical power output of the wind turbine. Through hands-on activities, a wind energy competition, and presentations, students validate the completion of their wind turbine project.



side view

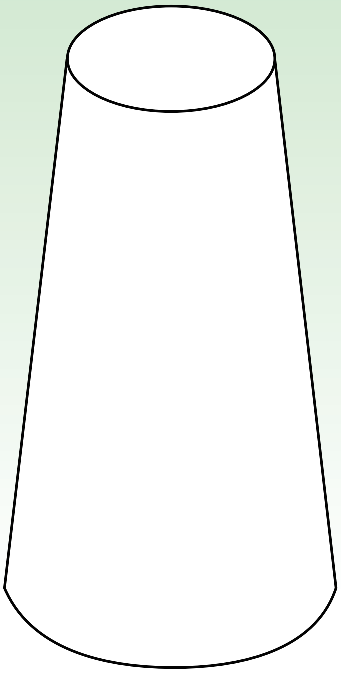


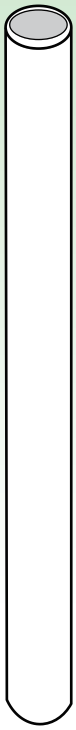
front view



- Materials and Tools:

Materials kit


500cc paper cups ×3


PVC plastic pipe

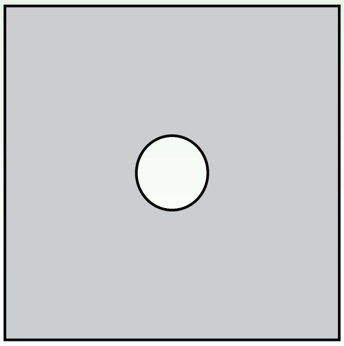

Short bamboo skewers ×4

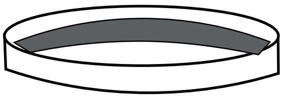

Plastic plugs ×4

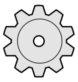

M3 long screw

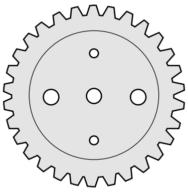

Small screws ×2

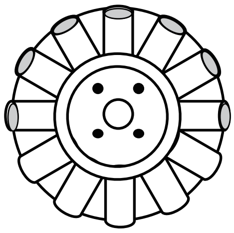

M3 nuts ×3

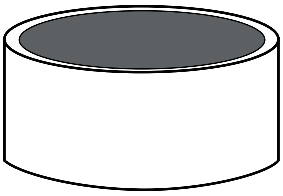

Wooden base

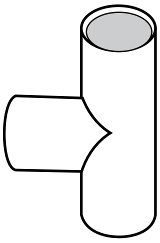

Double-sided tape or Foam tape

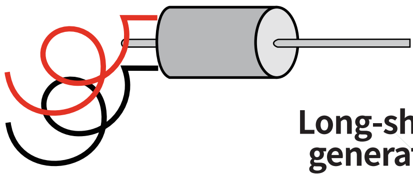

10-tooth plastic gear


30-tooth plastic gear


12-hole plastic hub


Wide transparent tape or Kapton tape

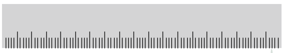

T-shaped PVC plastic pipe


Long-shaft generator

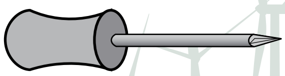
Self-prepared tools (to be purchased separately)

VERNIER VARIABLE LOAD (Order code:VES-VL)

GO DIRECT ENERGY SENSOR (Order code:GDX-NRG)

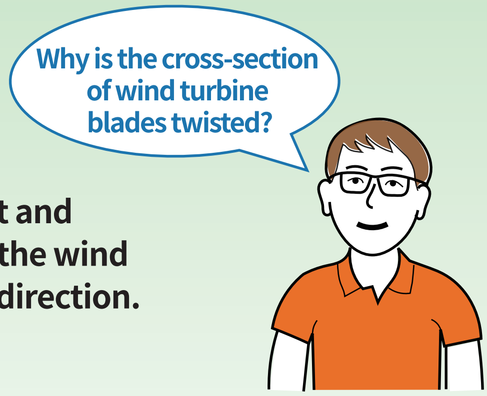

Ruler


Scissors

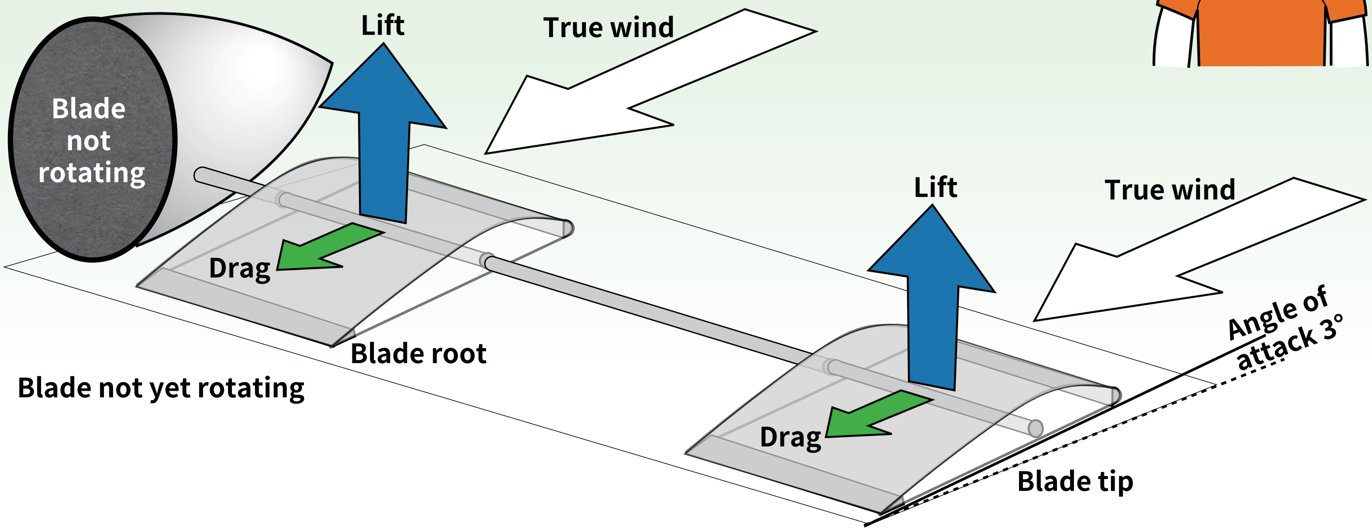

Screwdriver


Utility knife

- Why do the blades of a wind turbine have different angles at the root and the tip?

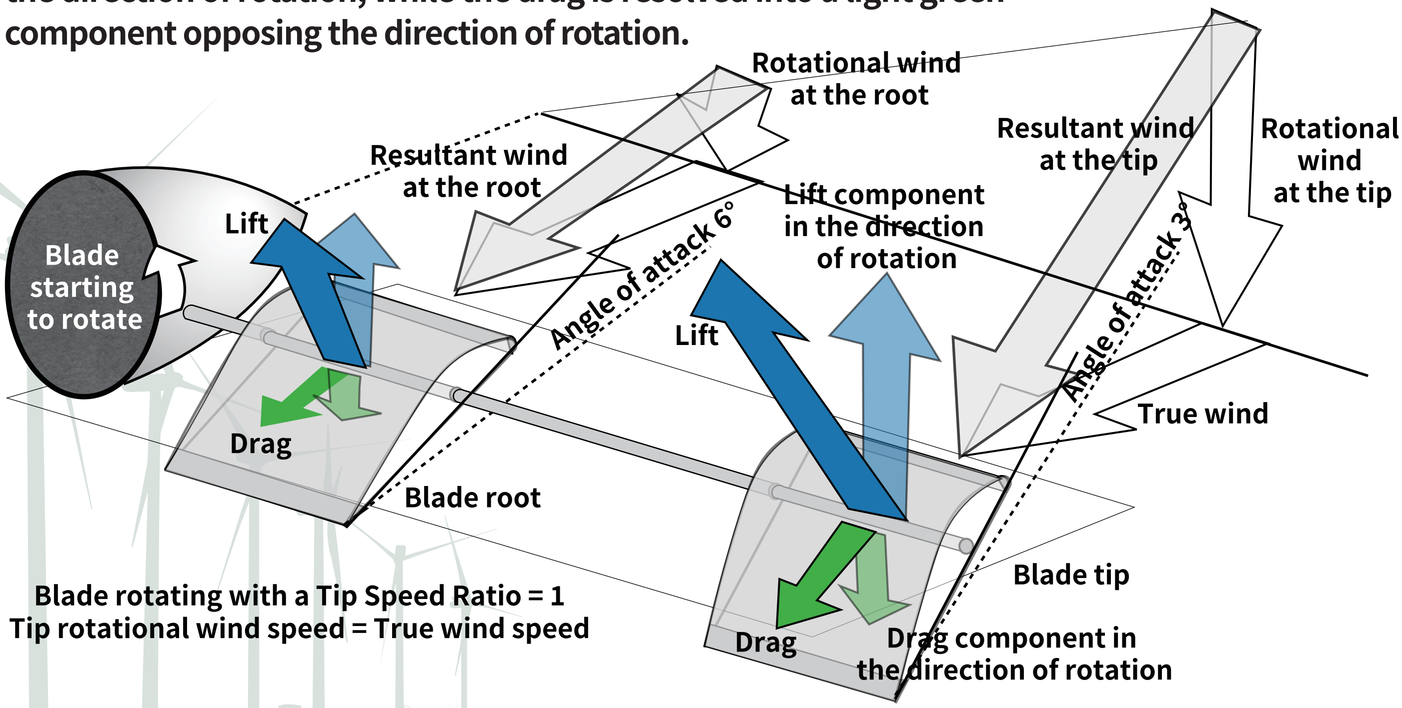


Assume the blade is not rotating. The blade, like an airplane wing, generates lift and is about to start rotating! At this point, both the blade root and tip are only affected by the "true wind." The angle of the blades at the inner root and outer tip is the same. The blue lift force is perpendicular to the wind direction, while the green drag force is parallel to the wind direction.



The blade begins to rotate. The blade is now affected by two types of wind: one is the true wind, and the other is the wind generated by rotation. The rotational wind speed at the outer blade tip is greater than at the inner blade root. Currently, at the blade tip, the rotational wind speed equals the true wind speed, which is referred to as a Tip Speed Ratio = 1. The blade is ultimately affected by a "resultant wind," which is the combination of these two perpendicular wind speeds.

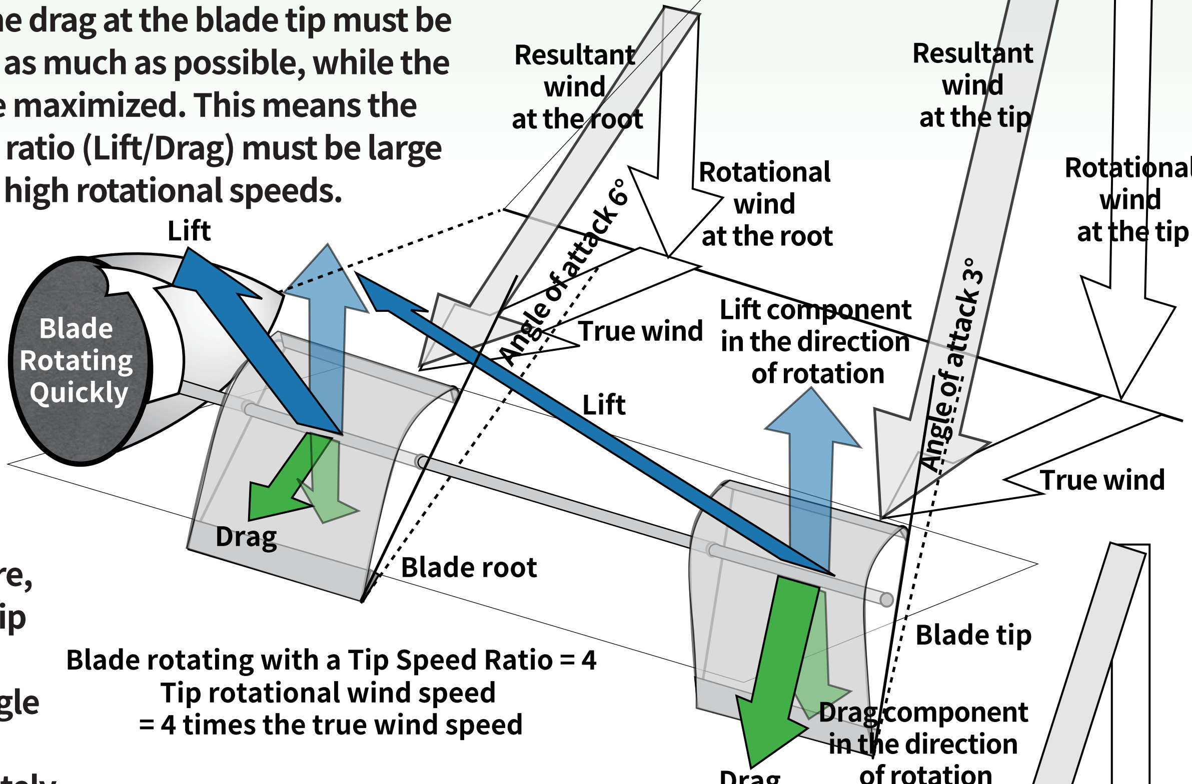
At this point, the blue lift force is perpendicular to the resultant wind, and the green drag force is parallel to the resultant wind. Then, the lift is resolved into a light blue component in the direction of rotation, while the drag is resolved into a light green component opposing the direction of rotation.



The blades are rotating faster. If the rotational wind speed at the blade tip is four times the true wind speed, this is referred to as a Tip Speed Ratio = 4. The blade is ultimately affected by a "resultant wind," which is the combination of these two perpendicular wind speeds. At this point, the speed of the "resultant wind" is much faster than the true wind speed.

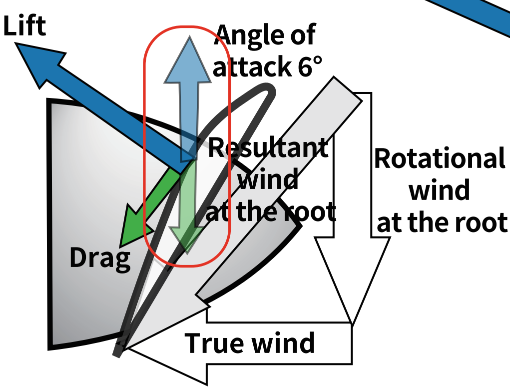
The magnitude of lift and drag is proportional to the square of the wind speed. Therefore, the lift and drag generated by the blade at the tip increase significantly! Although the lift increases greatly, the lift direction is perpendicular to the resultant wind, so the light blue lift component in the direction of rotation is not very large. Conversely, the light green drag component opposing the direction of rotation increases significantly.

If the light blue lift component in the direction of rotation is not greater than the light green drag component opposing the direction of rotation, the blade cannot maintain continued rotation. To achieve a rotational wind speed several times greater than the true wind speed, or even a Tip Speed Ratio as high as six or more, the drag at the blade tip must be minimized as much as possible, while the lift must be maximized. This means the lift-to-drag ratio (Lift/Drag) must be large to achieve high rotational speeds.

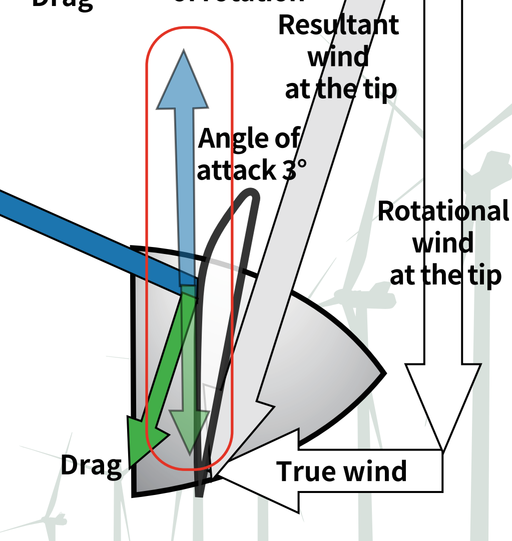


Blade rotating with a Tip Speed Ratio = 4
Tip rotational wind speed
= 4 times the true wind speed

Therefore, the blade tip requires a smaller angle of attack, approximately 3°, to minimize drag generation. At the blade root, the ratio of the lift component in the direction of rotation is larger, so the angle of attack at the root can be increased to about 6°.

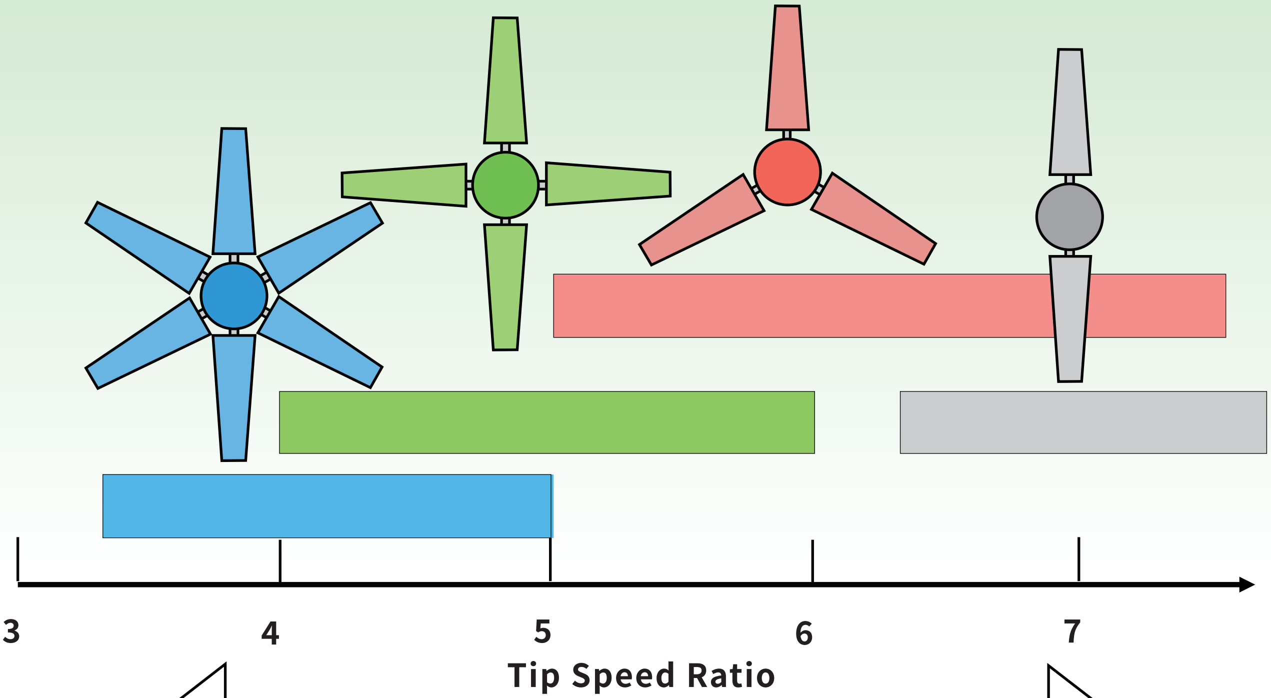


Lift and drag components at the blade root in the direction of rotation (red box)



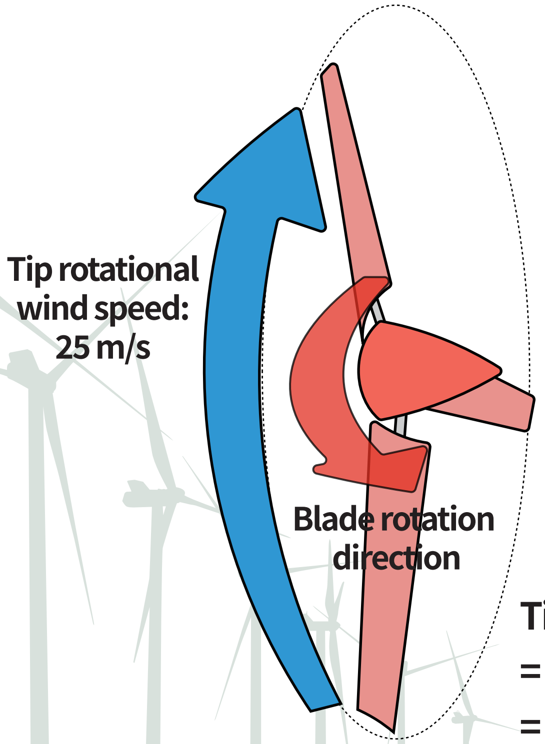
Lift and drag components at the blade tip in the direction of rotation (red box)

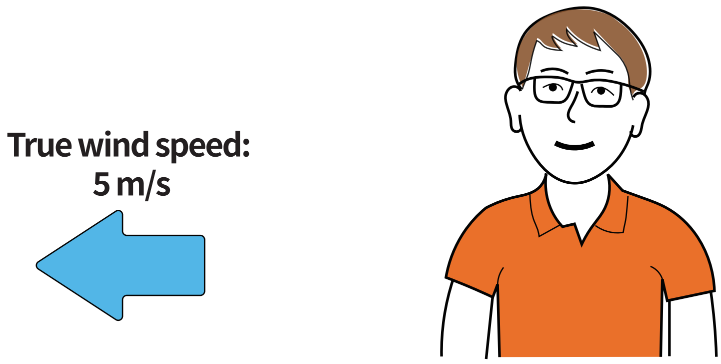
- Step 1: Determine the Number of Blades. Should you choose a low-speed, high-torque or high-speed , low-torque rotor design?



More blades result in greater drag, leading to low speed and high torque.

Fewer blades result in less drag, leading to high speed and low torque.





Tip Speed Ratio (TSR)

= (Tip wind speed 25 m/s) / (True wind speed 5 m/s)

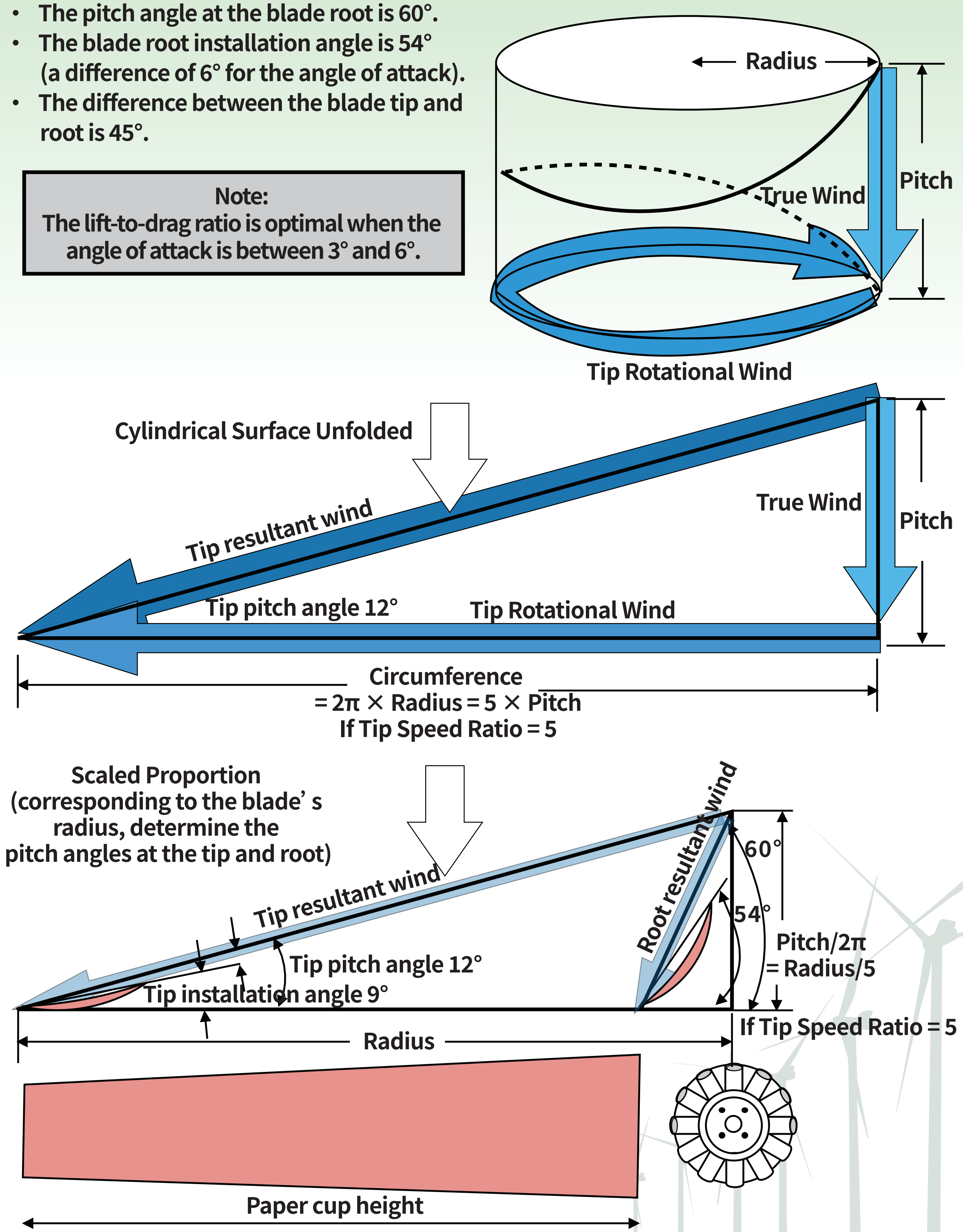
= 5

- Step 2: Determine the Pitch Angle

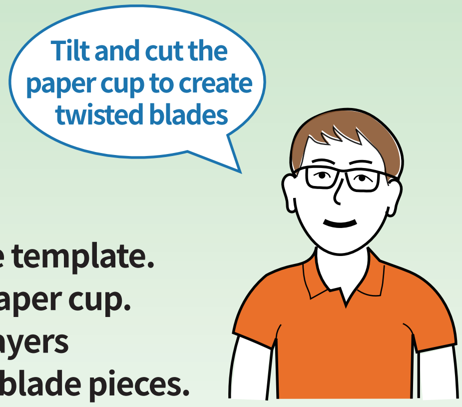
For example, with a set Tip Speed Ratio of 5:

- From calculations, the pitch angle at the blade tip is approximately 12°.
- The blade tip installation angle is 9° (a difference of 3° for the angle of attack).
- The pitch angle at the blade root is 60°.
- The blade root installation angle is 54° (a difference of 6° for the angle of attack).
- The difference between the blade tip and root is 45°.

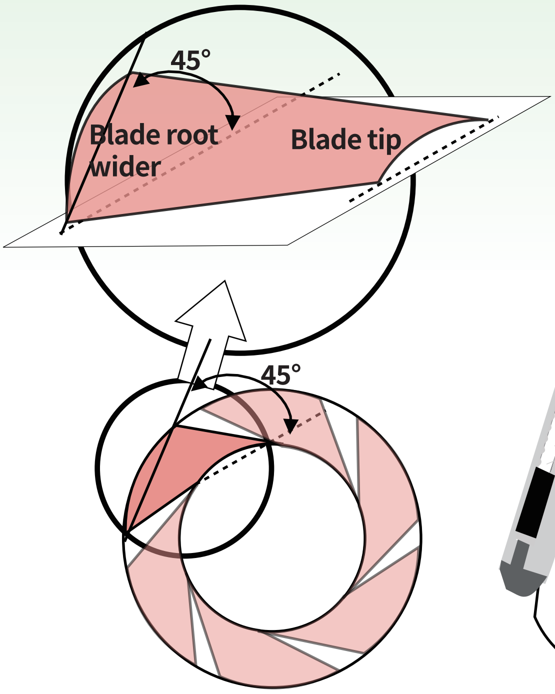
> Note:
> The lift-to-drag ratio is optimal when the angle of attack is between 3° and 6°.



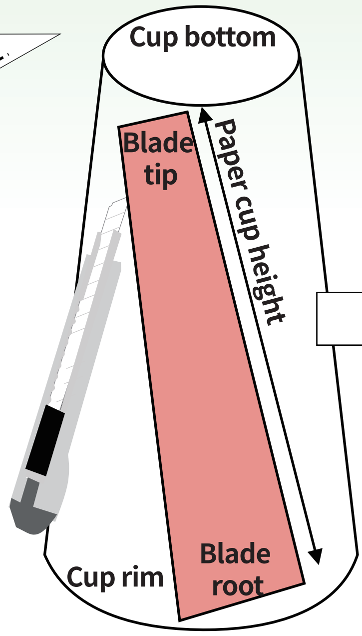
- Step 3: Cut Out the Paper Cup Blades



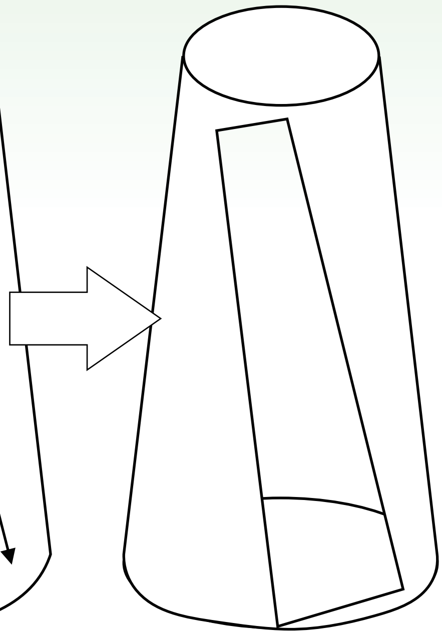
- From Step 2, the blade tip installation angle is 9°, and the blade root installation angle is 54°, with a difference of approximately 45°.
- The bottom of the paper cup serves as the blade tip, while the cup rim serves as the blade root, which is wider.
- Use a utility knife to cut open a paper cup to create a blade template. Use this template to trace the blade shape onto another paper cup.
- To create a three-blade turbine, each blade requires two layers (top and bottom), so you need to trace the outlines for six blade pieces.



When viewed from the cup bottom toward the rim, the red color represents the blade.

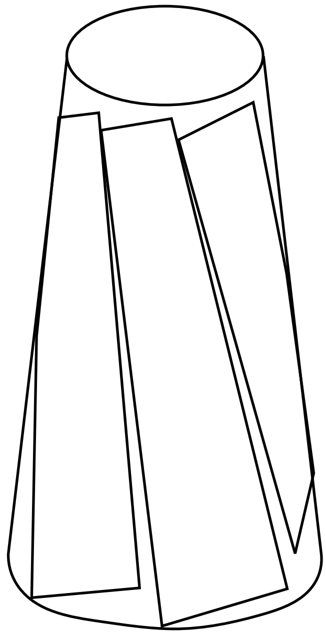


Use a utility knife to cut open and create the blade template.

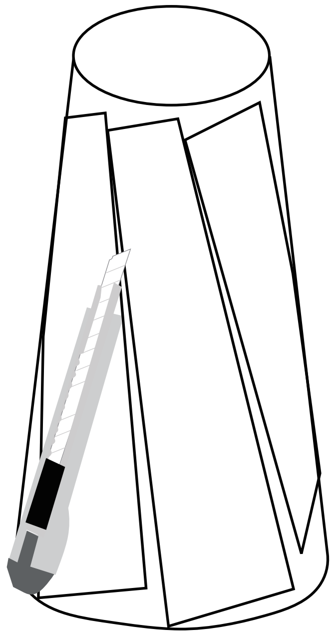


Complete the blade template.

Place the blade template on a paper cup and trace the outlines for 6 blade pieces with a pen.

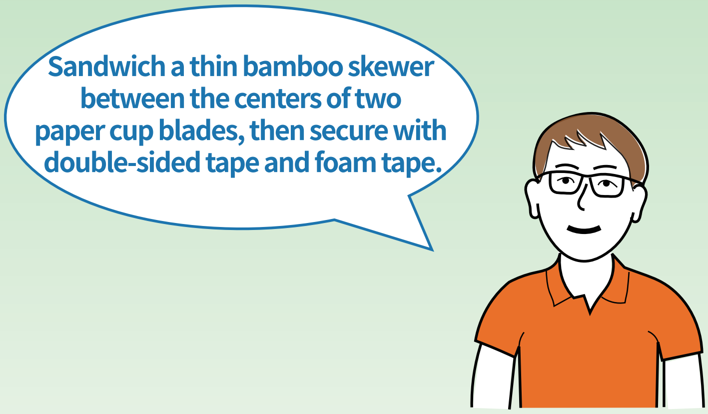


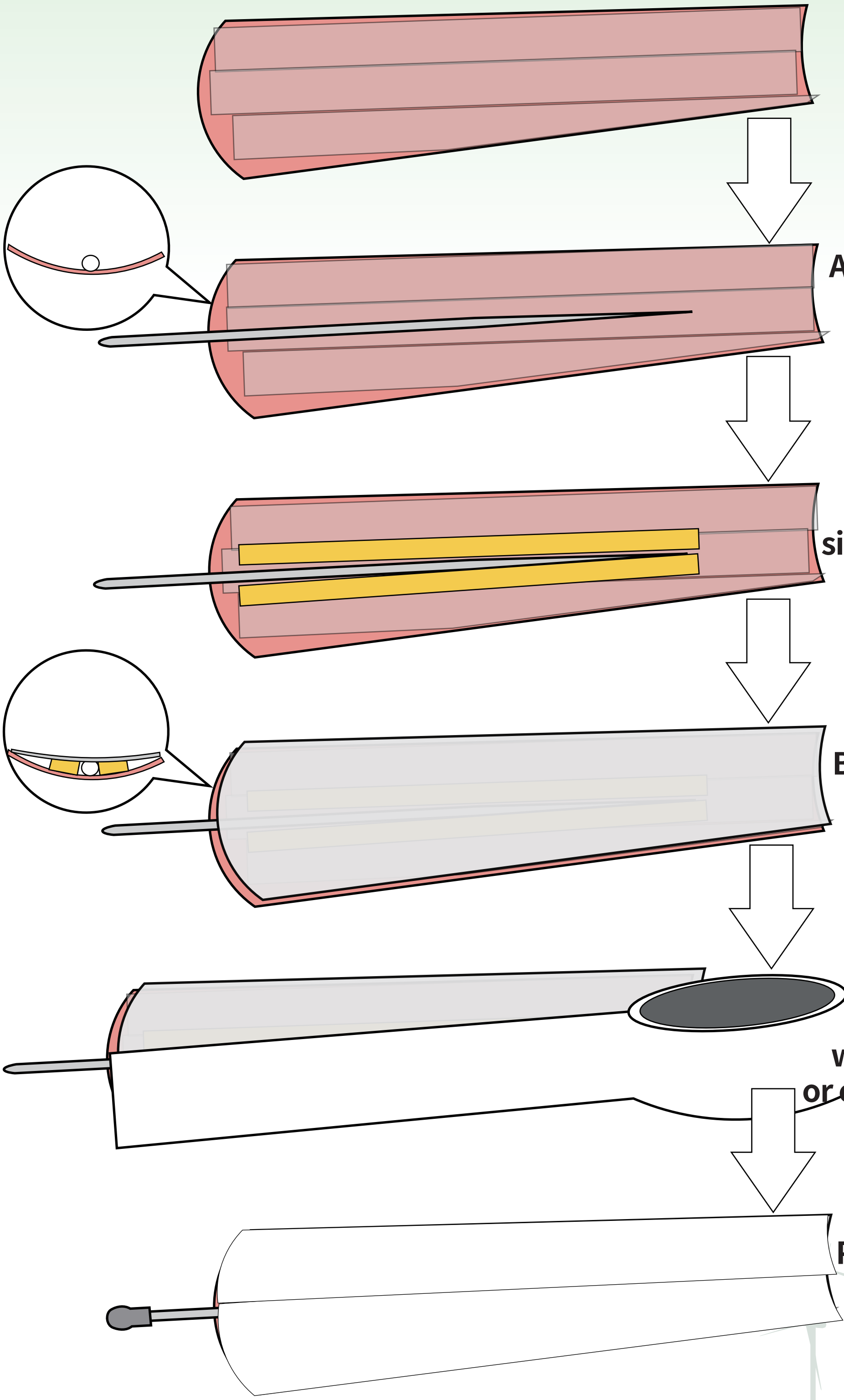
Remove the blade template.



Cut out each blade individually.

- 步驟四：組裝葉片





Apply double-sided tape fully to the concave surface of the blade.

Attach the bamboo skewer to the concave surface of the blade.

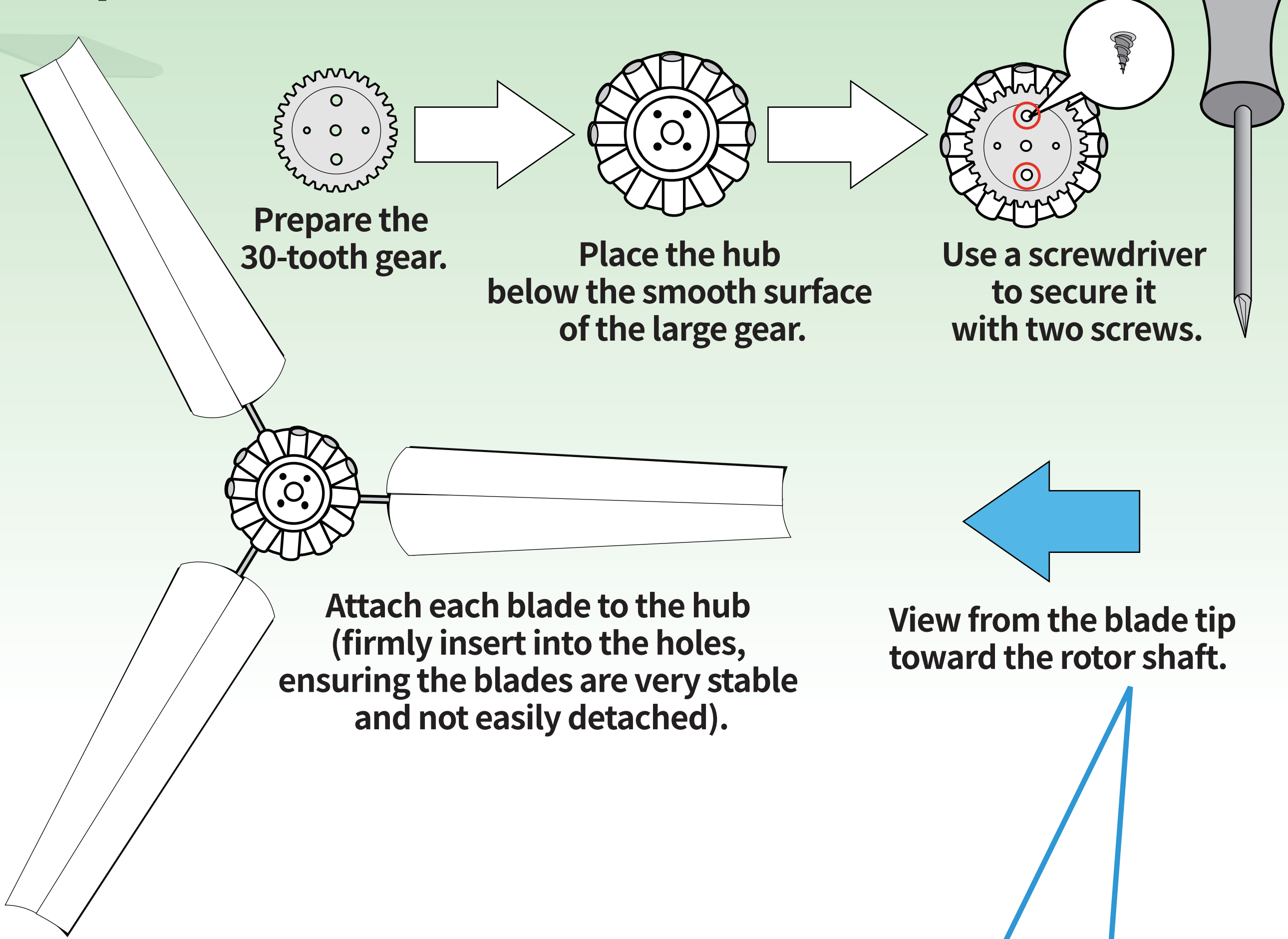
Apply foam tape to both sides of the bamboo skewer.

Bond the two blade pieces together.

Wrap the bonded blades with wide transparent tape or cutting sheet to secure them.

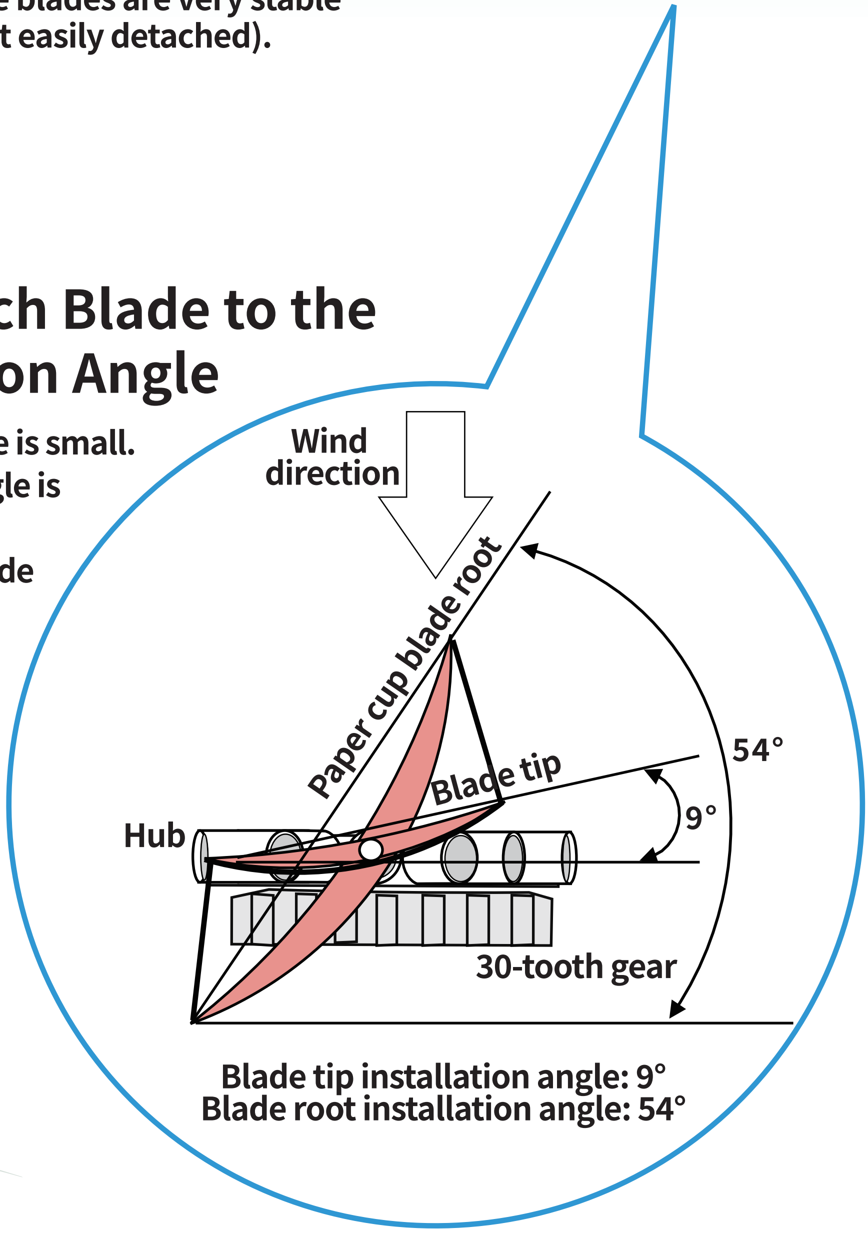
Place a plastic sleeve over the bamboo skewer.

- Step 5: Assemble the Blades onto the Hub

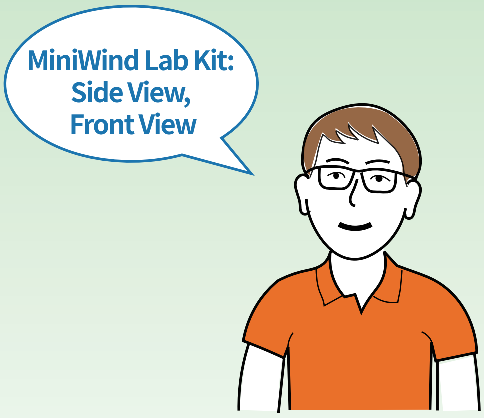


- Step 6: Adjust Each Blade to the Correct Installation Angle

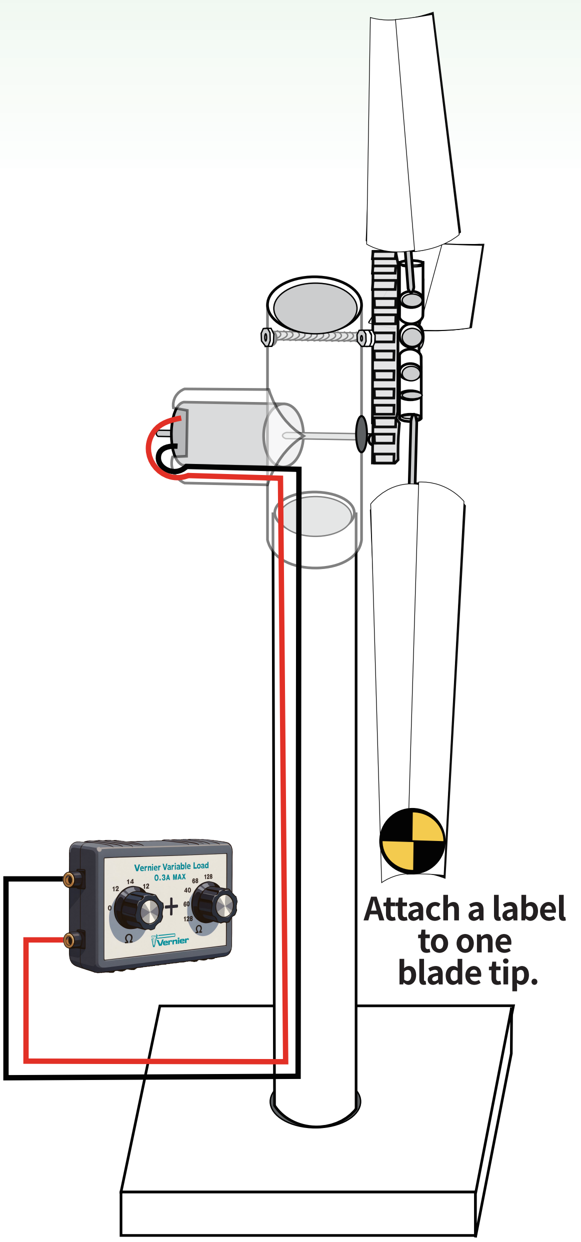
- The blade tip installation angle is small.
- The blade root installation angle is large.
- The concave surface of the blade faces the wind.



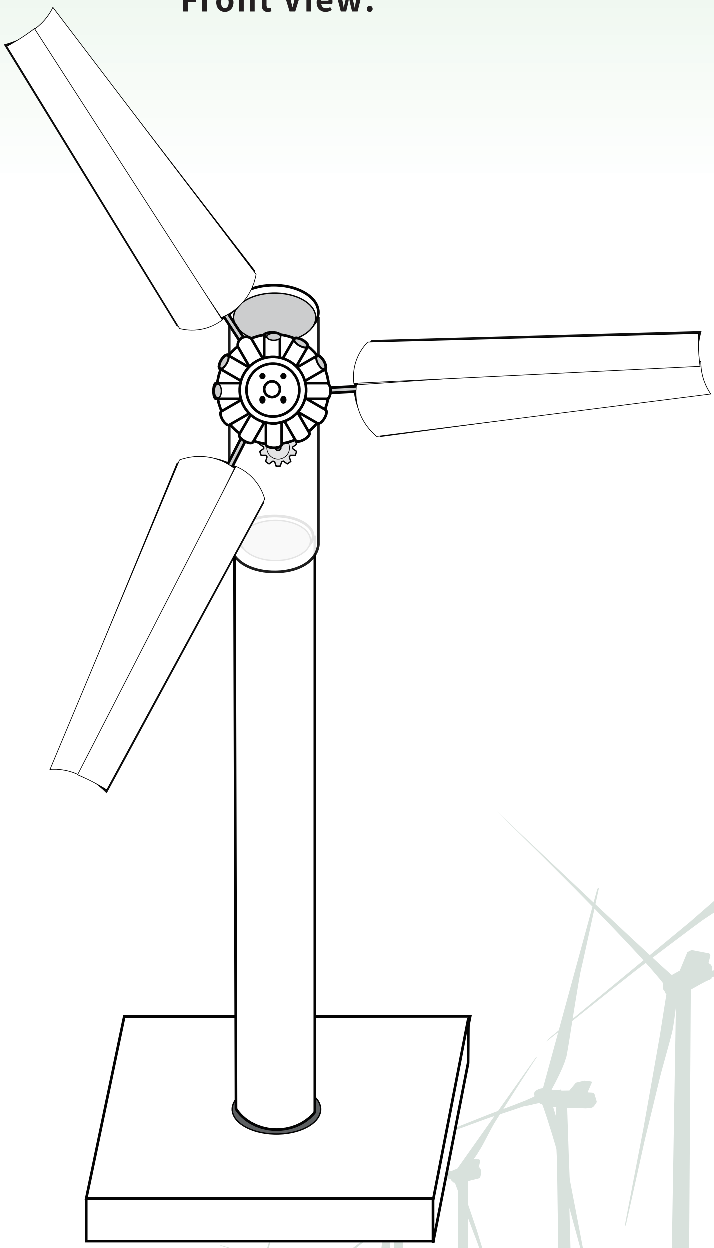
- Step 7: Assemble the Generator, Tower, Base, Rotor, and Gears



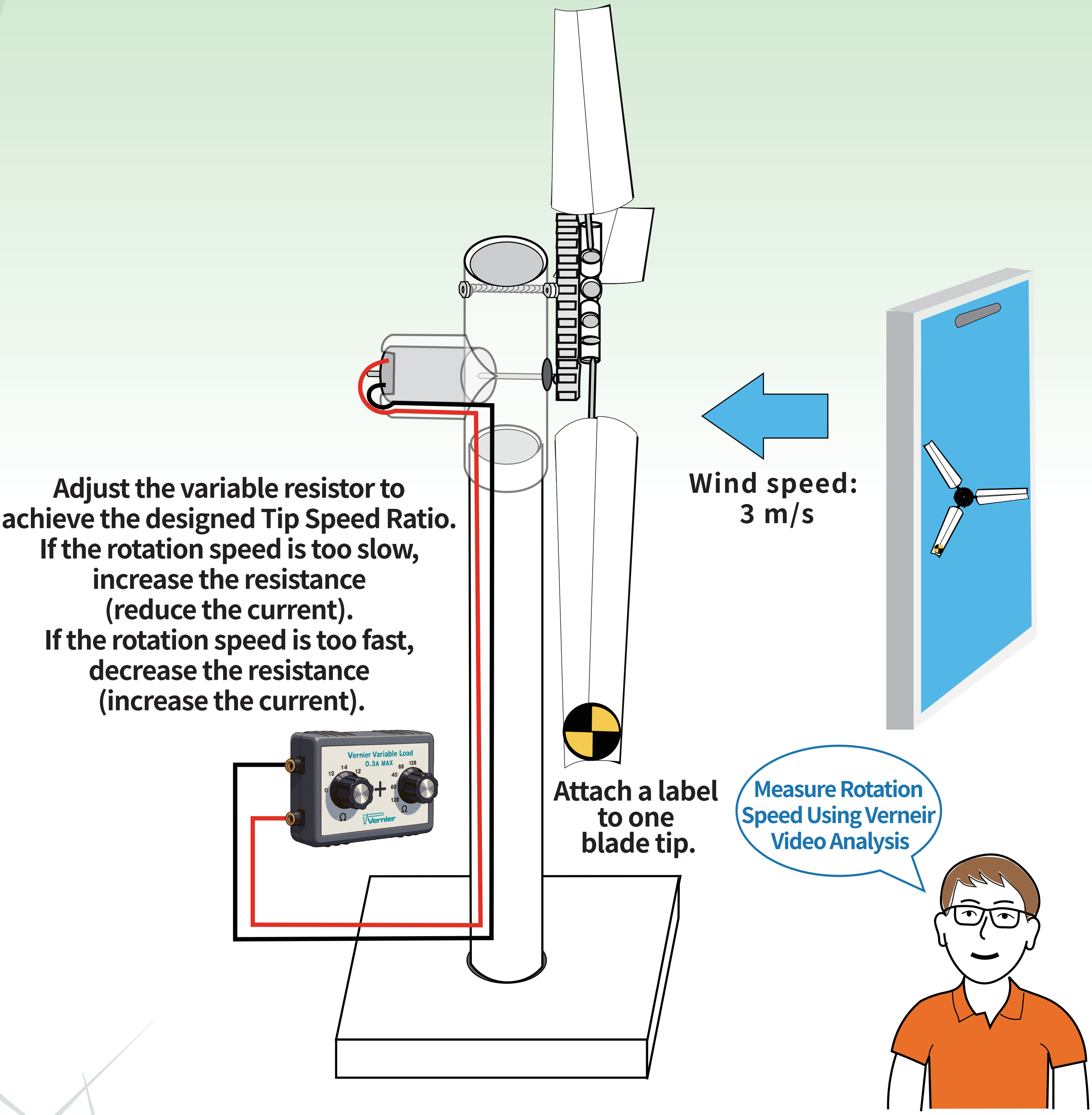
Side View: Adjust the variable resistor to achieve the designed Tip Speed Ratio.
If the rotation speed is too slow, increase the resistance (reduce the current).
If the rotation speed is too fast, decrease the resistance (increase the current).



Front View:



- Step 8: Measure Whether the Generator Rotor Meets the Original Tip Speed Ratio Setting



Use slow-motion video to measure the time it takes for the marked blade to complete one full rotation.With a wind speed of 3 m/s and a Tip Speed Ratio of 5, the blade tip rotational speed is 15 m/s.

If the blade radius is 15 cm, use the formula $v = \frac{2\pi R}{T}$

$$15\text{m/s} = \frac{(2\pi(0.15m))}{T}$$

Using π = 3.14, the period for one rotation, T, is calculated as 0.0628 seconds. This corresponds to a frequency of approximately 16 rotations per second.

- Step 9: Measure the Electrical Power of the Paper Cup Wind Turbine, Adjust Pitch Angle and Resistance