Name: ______________________________

Computer **6**

Blade Design: Pitch

Do you know that the air you breathe is actually made up of atoms? When you are running down the street or moving fast on a bike, have you felt wind blowing on your face? What you are feeling is atoms hitting your skin!

When blades move through the air, they also run into the atoms that make up air. The atoms cause resistance, just like the resistor in a circuit reduces the flow of electrons in a circuit. The resistance a blade feels when it moves through air is called *drag*.

Blade design engineers try to reduce the amount of drag experienced by blades while maximizing power output. One of the ways they do this is by changing the pitch or angle of a blade. In this experiment, you will explore the relationship between blade pitch and wind turbine output.

OBJECTIVES

- Measure power output of a wind turbine with a Vernier Energy Sensor.
- Investigate how blade pitch affects power output.
- Determine optimal blade pitch for maximum power output.

MATERIALS

computer
Vernier data-collection interface
Logger Lite software
Vernier Energy Sensor
Vernier Resistor Board
KidWind MINI Wind Turbine
KidWind Wind Turbine Hub
Blade Pitch Protractor
2 wire leads with clips
safety goggles
multi-speed box fan
centimeter ruler
2 premade blades **or** materials to make 2 blades:
    scissors
    hot glue
    wooden dowels
    blade material

VOCABULARY

Vocabulary term	Explanation
drag	Drag is the force caused by blades hitting air as the blades move. It is also called wind resistance. Drag causes the blades to slow down.
hypothesis	an idea that can be tested through experimentation
pitch	the angle of a blade
variable	any factor that can be controlled, changed, or measured in an experiment

PRE-LAB ACTIVITY

In this experiment, you will test blades with the following blade pitches

70° 55° 40° 25° 10°

1. Write a hypothesis about which blade pitch will produce the greatest power output.

   Hypothesis

   I believe the blade with a pitch of __________ degrees will produce the greatest power output because

   ____

   ____

   ____

2. What variable will you change in this experiment?

   ____

   ____

3. List at least three variables that you will keep the same during the experiment.

   ____

   ____

   ____

PROCEDURE

1. Get two blades from your teacher or make two blades for your turbine.
   a. If you are making blades, cut out two blades that are 12 cm long. They should be rectangular in shape.
   b. Attach the blades to wooden dowels with hot glue.

Figure 1

2. Assemble the blades and Wind Turbine Hub.
   a. Loosen the knob on the hub a little bit (see Figure 1). Do not loosen the knob too much or the hub will come apart.
   b. Gently create a space between the front and back pieces of the hub, as shown in Figure 2. The space should be just big enough for you to insert the dowel of one of the blades.
   c. Insert the other blade in a hole on the opposite side of the hub.
   d. Tighten the knob on the hub. The blades will be held in place by the hub.

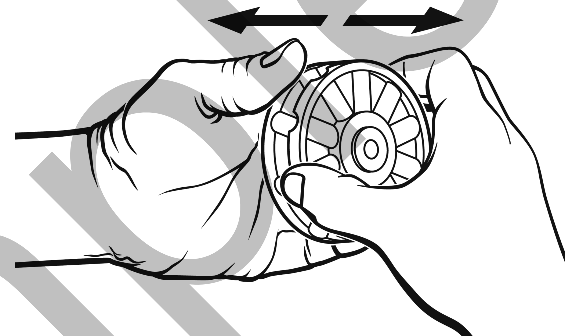


Figure 2

3. Connect the Wind Turbine Hub to the wind turbine.
   a. If the Red Blade Set is connected to the turbine, ask your teacher to remove it.
   b. Gently press the hub on to the turbine motor pin.

4. Adjust blade pitch using the Blade Pitch Protractor.
   a. To adjust a blade, rotate the Wind Turbine Hub so that the blade is positioned vertically at the 12 o'clock position.
   b. Slightly loosen the knob of the Wind Turbine Hub.
   c. Slip the protractor around the dowel from the front side of the hub.
   d. Turn the wooden dowel until the base of the blade is aligned with –70°.

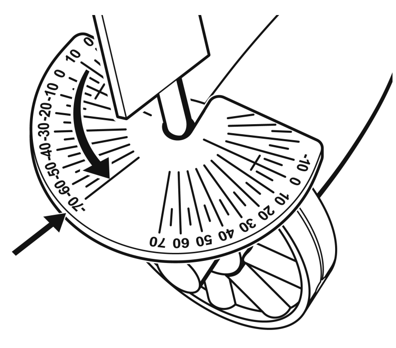


Figure 3

   e. Rotate the Wind Turbine Hub clockwise until the next blade reaches the 12 o'clock position.

f. Slip the protractor around the dowel and turn the blade until the pitch is –70°.

g. When you have adjusted the pitch on your blades, tighten the knob of the Wind Turbine Hub.

h. Give the blade set a gentle push with your finger to make sure it spins freely without hitting anything. If the blades hit the tower, adjust them until everything spins freely.

5. Set up the data-collection equipment.
   a. Connect the Vernier Energy Sensor Current and Voltage connectors to the interface.
   b. Start Logger Lite.
   c. Click the Open button, .
   d. Open the folder “Investigating Wind Energy.”
   e. Open the file “06 Blade Pitch.”

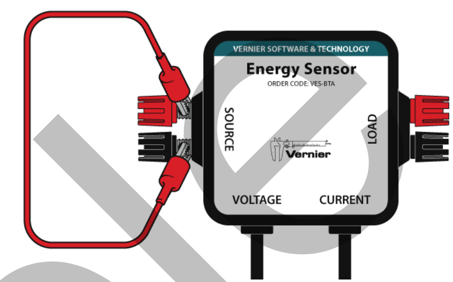


Figure 4

6. Zero the Energy Sensor.
   a. Connect the Energy Sensor Source terminals to each other with a wire lead, as shown in Figure 4.
   b. Click the Zero button, Zero, on the toolbar. Both sensors are selected.
   c. Click OK. The readings for both current and voltage should be close to zero.

7. Connect the wind turbine to the Energy Sensor Source terminals.
   a. Disconnect the wire lead that is connecting the Source terminals.
   b. Connect the red wire from the turbine to the red Source terminal.
   c. Connect the black wire from the turbine to the black Source terminal.

8. Use two wire leads to connect the Resistor Board to the Energy Sensor Load terminals.
   a. Clip one lead to the black Load terminal and then to the hole on the left side of the 39 ohm resistor (see Figure 5).
   b. Use the other lead to connect the red Load terminal to the hole on the right side of the 39 ohm resistor. **Note:** The color of the leads does not matter when connecting the Resistor Board.

9. Position the fan so the center of the fan is in line with the center of the hub of the turbine. The fan should be 15 cm from the turbine. The distance needs to be the same each time you collect data.

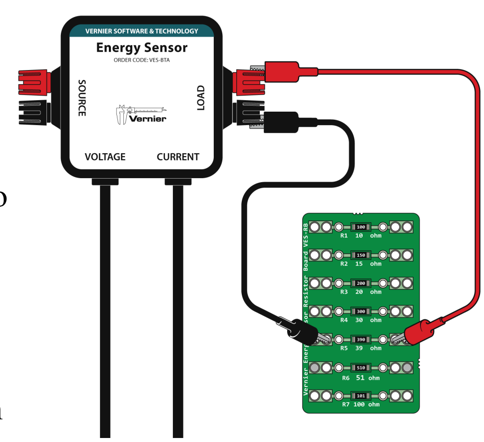


Figure 5

10. Put on safety goggles and turn on the fan to the highest speed setting. **CAUTION:** Do not stand in the plane of rotation of the wind turbine rotor.

11. Collect data.
    a. After the fan has been on for at least 30 seconds, you are ready to collect data. This ensures that the wind turbine is spinning at a constant speed. Click ▶ Collect to start data collection. Data collection will stop after 30 seconds.
    b. When data collection finishes, turn off the fan.

12. Determine the mean power output (mW).
    a. Click somewhere on the power *vs.* time graph to make it active.
    b. Click the Statistics button, , on the toolbar.
    c. Record the mean power value in the data table.

Pitch (°)	Mean power (mW)
–70	
–55	
–40	
–25	
–10	

13. Use the Step 4 procedure to set the blades to a pitch of –55°.

14. Collect data.
    a. Reposition the fan and turbine so that they are in the same positions as before. Measure to make sure they are 15 cm apart.
    b. Turn on the fan to the highest speed setting.
    c. After the fan has been on for at least 30 seconds, click ▶ Collect to start data collection. Data collection will stop after 30 seconds.
    d. When data collection finishes, turn off the fan.

15. Record the mean power value in the data table.

16. Set the blades to a pitch of –40° and repeat Steps 14–15.

17. Set the blades to a pitch of –25° and repeat Steps 14–15.

18. Set the blades to a pitch of –10° and repeat Steps 14–15.

DATA ANALYSIS

1. Use the data in the data table to create a bar graph of power *vs*. pitch.
    - Graph the blade pitch data on the x-axis (horizontal).
    - Graph the power data on the y-axis (vertical).
    - Label the x-axis and the y-axis of your graph.
    - Add a title to your graph.

2. Was your hypothesis correct? ______________________________
3. Which pitch produced the greatest power output? ______________________________

4. Why do you think this pitch produced the greatest power output?

____

____

____

5. Which pitch produced the smallest power output? ____________________________

6. Why do you think this pitch produced the smallest power output?

____

____

____

7. In your own words, explain what drag means.

____

____

____

8. Describe the relationship between blade pitch, drag, and power output.

____

____

____

Blade Design: Pitch

In this experiment, students are introduced to the design variable known as pitch or angle and discover how blade pitch is related to the power output of a wind turbine. Students begin by testing blades with a 70° pitch. They then test additional pitches in an effort to determine the optimal pitch.

Content vocabulary is critical for student understanding. Vocabulary strategies that actively engage students in their learning are highly recommended. For example, have students hold their arms horizontally out away from their bodies and then rotate them to resemble changes in blade pitch. They can also experience drag by facing a fan that is on and then turning 90° to the fan.

Note: The student pages with complete instructions for data collection using LabQuest App and Logger Lite (computers) can be found on the CD that accompanies this book. See *Appendix A* for more information.

If you are using Logger Lite, the auto-ID files necessary for this experiment can be found in Logger Lite 1.8, or newer. If you are using LabQuest App, you must use LabQuest App version 2.3.1, or newer. If you are using an older version, please update to the most recent version. Updates can be found at www.vernier.com/downloads

ESTIMATED TIME

We estimate that set up, exploration, and clean up can be completed in one 60–75 minute class period.

RELATED SKILLS

Equipment and Data-Collection Skills

- Connect the data-collection interface, Energy Sensor, Resistor Board, and MINI Wind Turbine
- Zero the Energy Sensor
- Use Logger Lite software or LabQuest App to collect data
- Use the Statistics tool to determine mean power

Math Skills

- Measure distance in centimeters (cm)
- Read, write, and compare decimals and whole numbers
- Collect and record data in a table
- Measure angles with a protractor
- Construct and plot data on a bar graph

NEXT GENERATION SCIENCE STANDARDS (NGSS)

Disciplinary Core Ideas	Crosscutting Concepts	Science and Engineering Practices
PS3.A Definitions of Energy (4-PS3) PS3.B Conservation of Energy and Energy Transfer (4-PS3) ETS1.A: Defining and Delimiting Engineering Problems (3-5-ETS1) ETS1.B: Developing Possible Solutions (3-5-ETS1) ETS1.C: Optimizing the Design Solution (3-5-ETS1)	Patterns Cause and Effect Scale, proportion, and quantity Systems and system models Energy and matter: Flows, cycles, and conservation	Asking questions and defining problems Developing and using models Planning and carrying out investigations Analyzing and interpreting data Using mathematics and computational thinking Constructing explanations and designing solutions

EQUIPMENT TIPS

1. Set up a safe testing area.
   - Clear the area of debris and materials.
   - Instruct students to not stand in the plane of rotation of the turbine blades. Also tell them that they should not touch the turbine blades while they are spinning. Blades can move very fast and can hurt if they hit someone.
   - Emphasize to students that they should not stick their fingers in the cage of the fan as the fan blades can cause injury, too.
   - If the wind turbine is moved by the wind during data collection, students can tape the base of the wind turbine to the tabletop.
2. **Important:** Provide safety goggles for your students. Students should wear safety goggles any time they are working with a turbine that is spinning.
3. Making blades.
   - For this experiment, we recommend using rectangular blades. This will help students learn that it is the pitch of the blade that makes the turbine spin clockwise or counterclockwise, not the shape of the blade.
   - Blades that are approximately 12 cm long (excluding the dowel) work well with a box fan.
   - We recommend attaching the dowels to the blades using hot glue because it dries quickly, provides a secure attachment, and is easy to find. You can use other types of glues as long as they securely attach the blades to the dowels. Add time to your lesson plan if blades will be made using a type of glue that dries more slowly than hot glue.
   - Tape can also be used to attach the blades and dowels. However, be aware that this is not an ideal technique. We have found that tape does not connect the blade and dowels

securely enough to keep blade pitch constant. This can affect the results of the experiment.

4. Use caution when removing the Red Blade Set from the wind turbine. Prying off the Red Blade Set can be difficult, especially for students. Remove the Red Blade Sets before giving the turbines to the students.

5. Setting up fans.
   - Align the center of the fan with the center of the hub of the wind turbine. You may find it useful to place the fan on a box or stand to bring it level with the turbine hub. The fan should be about 15 cm from the turbine. If these guidelines do not work for your equipment, experiment to figure out what will work well for your classroom setup.
   - Larger box fans may need some backing support, such as a large book, so that they do not tip over.
   - Remind students to frequently check the positions of the fan and the wind turbine throughout the experiment. If the turbine is in a different relative position to the fan, it may experience a different wind speed. Consider placing pieces of tape on the table at the bases of the fan and turbine to help students position the equipment more easily.

6. The student procedure directs students to construct blades and assemble the hub and wind turbine. If time permits, having students assemble the turbines is a good introductory engineering construction activity. On the other hand, you may want to preassemble the blades and turbines in order to allow students to focus on data collection and analysis.

7. The Energy Sensor needs to be zeroed each time the software is restarted, a new file is opened, or you choose New from the File menu. The student version of this experiment includes the procedure for zeroing the Energy Sensor.

   When you zero the Energy Sensor, you are setting the "zero" state for the sensor and the software. If you have ever tared a scale, you have, in effect, zeroed the scale.

TEACHING TIPS

1. Students need to have some familiarity with decimal number concepts prior to engaging in this experiment. You may wish to incorporate the experiments in this book into your lesson plans later in the school year, after students have developed foundational decimal place and value concepts.

2. This experiment also works well as an inquiry-based investigation. Remove the Procedure from the student version of the experiment and have student plan and carry out their own investigation.

3. Demonstrate how to connect the MINI Wind Turbine, Vernier Energy Sensor, and Resistor Board, especially if this is the first time students are using the equipment.

4. It may be helpful to project a computer running Logger Lite data-collection software to demonstrate how to use the software, sensors, and interface for data collection. If you are using LabQuest App for data collection, the LabQuest Viewer software can be used to project a LabQuest screen.

5. Demonstration of how to use the blade protractor is essential. A document camera and projector set up would be helpful. At the time of publication, a video clip of how to use the blade pitch protractor is available at http://vimeo.com/23227643

6. Check in with each group before they start data collection to ensure that the Energy Sensor is zeroed and that they are connected to the 39 ohm resistor.

ANSWERS TO PRE-LAB ACTIVITY

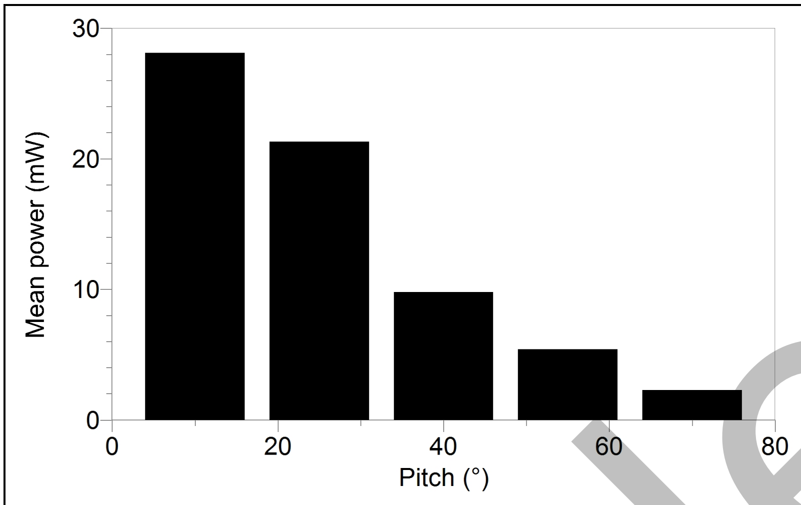
1. Answer will vary.

2. Blade pitch is the variable that will be changed.

3. Answer will vary. Possible answers include fan speed, blade shape, and distance between fan and turbine.

SAMPLE RESULTS

Pitch (°)	Mean power (mW)
–70	2.3
–55	5.4
–40	9.8
–25	21.3
–10	28.1



ANSWERS TO ANALYSIS QUESTIONS

1. Graph should correspond to the student's data in the data table.
2. Answer will depend on student's prediction.
3. Answer will vary depending on blade construction and pitch accuracy. Generally, a 10–20° blade pitch will produce the greatest mean power value.
4. Possible student response: The –10° pitch had the greatest power value because it produced more spin and very little drag.
5. Answer will vary depending on blade construction and pitch accuracy. A –70° blade pitch will generally produce the smallest mean power value.
6. Possible student response: The –70° pitch had the smallest power value because it produced less spin and a lot of drag.
7. Student should explain the concept of drag in his or her own words.
8. Answer will depend on student's understanding of the concepts in this experiment.