Rotational Mechanics

Next Generation Science Standards

NGSS Science and Engineering Practices:

- ☐ 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
- ☐ Engaging in argument from evidence
- ☑ Obtaining, evaluating, and communicating information

NGSS Cross-cutting Concepts:

- ☐ Patterns
- ☐ Cause and effect
- ☑ Scale, proportion, and quantity
- ☐ Systems and system models
- ☐ Energy and matter
- ☑ Structure and function
- ☐ Stability and change

NGSS Disciplinary Core Ideas:

- ☑ PS2.A: Forces and Motion

Initial Prep Time

Approx. 5 min. per apparatus

Lesson Time

1 – 2 class periods, depending on experiments completed

Assembly Requirements

- Small Phillips-head screwdriver
- Small hex wrench

Materials (for each lab group):

- Horizon Wind Energy Education Kit
- Electric fan
- Metric ruler
- Stopwatch
- Horizon Renewable Energy Monitor or multimeter (optional)

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Lab Setup

- You should complete the Post and Support Base Assembly (described in section IV of the Assembly Guide) before students start their experiments.
- You may find it useful to test out different blade configurations before your students arrive to see which ones work best with the speed of your particular fans. In general, lower wind speeds will require more blades at a lower angle of attack, while faster speeds will require fewer blades at a higher angle of attack.
- Lab includes small parts that can go missing easily. Set up a resource area for each lab table or for the entire class to minimize lost pieces.

Safety

- With a powerful fan in front of them, the turbine blades can move very quickly. Students should keep their hands and faces at a safe distance and wear safety goggles at all times.

Notes on the Wind Energy Kit:

- A small, handheld fan won't be powerful enough to turn the turbine blades. Be sure to use a large, desktop fan.
- A fan with multiple settings is ideal and will allow your students to conduct more experiments about how the turbines operate at different wind speeds. If you don't have a fan with multiple speeds, you can simulate different wind speeds by adjusting the distance between the fan and the turbine, but turbulence will cause some variation in your data.
- When attaching the blade assembly to the nacelle, students should be sure to push it in until it clicks, otherwise it may fall off when spinning. There will be a gap between the blade assembly and nacelle, but it should be less than ¼ inch.

Common Problems

- The turbine spins best when the center of the turbine is lined up with the center of the fan.
- Students might choose configurations of turbine blades that don't spin very well. If their fan is lined up correctly and they can't get their turbine to turn, have them try other blade configurations.

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Goals

- Assemble a wind turbine
- Measure the parameters of its motion
- Make calculations based on data

Background

Linear motion, in one dimension and in a straight line, is relatively easy to understand. People, vehicles, billiard balls, elevators, and countless other examples travel in linear directions all the time, so it's simple to apply the concepts of linear motion to everyday life. But when things move in a circle, things get a little more complicated.

A rotating object is constantly accelerating, even if it's moving at the same speed all the time. Yes, that really is as strange as it sounds. The reason is that velocity is a vector quantity: it has a magnitude (like 5 m/s or 50 mph) and a direction. A rotating object is constantly changing the direction it's moving (imagine the always-changing view from a carousel) so that means its velocity is always changing, and any change in velocity is defined in physics as an acceleration.

For this reason, it's easier to talk about an object's angular velocity (abbreviated with the Greek letter omega: ω) which is a measurement of the angle the object goes through in a certain amount of time. It's easy to imagine an object completing one revolution every second, for example.

The angular velocity is closely related to what's known as the object's period: the time it takes to complete one rotation. The period is abbreviated T in physics, so we get this equation:

$$\omega = \frac{2\pi}{T}$$

Where 2π is the number of radians in a complete circle. We can also calculate the velocity of the object traveling in the circle just by knowing how large the radius (r) of the circle is:

$$v = \frac{2\pi r}{T}$$

So objects farther out on a circle, even if they are rotating at the same rate as objects closer to the center, are traveling faster. If a bunch of people hold hands and try to move in a circle, the people near the center will hardly have to move at all while those on the end might have trouble running fast enough to keep up.

In this activity, we will use a wind turbine to explore rotational motion and make adjustments to it to try and maximize its angular velocity.

Procedure

1. Look at the three different types of blades available (labeled A, B, and C). How are they similar? How are they different? Discuss with your group which type of blade you think would work best with your turbine and record your observations below.
2. Select the type and number of blades you want to test. Why do you want to test this type of blade first? Do you think it will be better or worse than the other types?
3. Check that the blades are in the same position using the three notches near the white bases of the blades.

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Rotate the individual blades if needed to get all the blades into the same position. Would your turbine still work if the blades were in different positions?

4. Insert the blades into the Rotor Base and put the Blade Holder and the Blade Assembly Lock, then attach the Blade Unit to the metal shaft of the turbine. Can your blades be positioned backwards? How do you know if there's a "right way" for a blade to be positioned?
5. Connect the base of the turbine to the LED lights using the black and red wires. Why do you think the lights need two wires to work?
6. Turn on the fan and position it in front of the turbine. It will work best if you keep the fan close to the turbine and line up the center of the fan with the center of the turbine. Why would changing the position of the fan affect the wind hitting the turbine?
7. Record your observations in the Data Table below: Did the lights turn on? Were they dim or bright?
8. Discuss what you observed with your group and discuss what you want to change: the number of blades, the angle of the blades, the type of blades, or some combination of those.
9. Repeat steps 1-8 with as many changes as you can think of.

Observations

Data Table:

Blade Type (A, B, C):	Number of Blades:	Blade Angle (6°, 28°, 56°):	Observations:

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Experimentation

1. Based on your data from the previous experiment, keep the angles of the blades the same and try different numbers of different types of blades to see which works best. Record your observations below:

Number of Each Type of Blade:	Observations:

What combination worked best?

2. If you used a combination of different types of blades, try changing the arrangement of the blades (A, B, A, B or A, A, B, B, for example) to try and get the rotor to turn faster. If your rotor spun fastest with only one type of blade, you can skip this experiment.

Blade Order:	Observations:
1	
2	
3	
4	

What arrangement worked best?

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3. To measure the revolutions per minute of your fastest configuration, you'll need a stopwatch and some masking tape. Put a piece of masking tape around one of your blades. Have one group member operate the stopwatch and another stand next to the turbine to count the revolutions. (It's easier to count if you stand next to the turbine and count the times the taped blade comes over the top.) Have the timekeeper say "Go!" once the turbine is turning and count the number of times the taped blade completes a revolution. Stop counting at exactly 15 seconds. You can then multiply your count by 4 to get the total revolutions per minute. Record your data below. If your turbine spins too fast to measure in this way, use the Horizon Renewable Energy Monitor as described in the next section.

Trial:	Rev. Count (for 15 seconds):	RPM (4 x Count):
1		
2		
3		
4		

What arrangement worked best?

Average RPM:

1. Convert your average RPM to the period of rotation (T):

Avg. RPM:________ / 60 = __________Revolutions/second

1/(Rev per second) = ____________ Seconds/revolution = T

2. Calculate the angular velocity (ω):

ω = 2π/T = 2π/_________ = _____________

3. Calculate the velocity (v) of the outermost edge of the fan.

Radius (measure from center of fan rotor to outer edge) = __________ cm

v = ωr = ________ x __________ = ______________

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Measurement

For this section, you will need a multimeter or the Horizon Renewable Energy Monitor. For an introduction to using a multimeter, click here.

1. Skip questions 1-4 if you've already completed the RPM experiment from above. Press the Select button on the Renewable Energy Monitor until you see Watts, Joules, and RPM displayed. Record your RPM below:

The Horizon Renewable Energy Monitor can't detect RPM below 200.
RPM: _______________

2. Use this RPM measurement to calculate the velocity of the outermost edge of the fan. First, convert your average RPM to the period of rotation (T):

Avg. RPM:________ / 60 = ___________Revolutions/second

1/(Rev per second) = _____________ Seconds/revolution = T

3. Calculate the angular velocity (ω):

$\omega = 2\pi/T = 2\pi/$__________ = ______________

4. Calculate the velocity (v) of the outermost edge of the fan.

Radius (measure from center of fan rotor to outer edge) = ___________ cm

$v = \omega r$ = ________ x ___________ = _______________cm/sec * 100 = __________ m/s

5. How fast would the outer edge of your turbine blades be moving if it had the same RPM but it was a full-sized wind turbine generator, with a radius of 40m?

Students should use the $v = \omega r$ equation, with the same value for ω but 40m for r. They don't need to convert cm/s to m/s.

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6. The speed of sound is 343.2 meters per second. Could a full-sized wind turbine move at the speed you calculated without breaking the sound barrier?

The speed they calculated will be in excess of the speed of sound if they measured more than 80 RPM. If that's the case, then no, a full-sized turbine could not move at that speed.

Analysis

1. Make a scientific claim about what you observed while running your wind turbine.

Claim should reference the turbine's capabilities.
Example: "The turbine can't spin at more than 250 rpm with this fan."

2. What evidence do you have to back up your scientific claim?

Evidence should cite data in Observations and/or Experimentation sections.
Example: "Our fastest measurement was 244 rpm with the three A blades at 56° and no other configuration came close to that speed."

3. What reasoning did you use to support your claim?

Reasoning can draw from Background section and/or other materials used in class.
Example: "Since we tried every possible arrangement of the blades, the only way it could spin faster would be if the blades were redesigned or if the turbine was changed in a different way."

4. Design an experiment that would test whether its easier for a turbine to turn with added weight on the farthest edges of its blades or near the center of its rotor.

There are many possible answers, but students should describe how they would attach weights, how they would measure the turbines spins, and have clear control and experimental groups in their description.

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Conclusions

1. A full-sized wind turbine has blades that are 40m in radius. If the outer edges travel close to the speed of sound (343.2 m/s), they could tear themselves apart under the stress. What would be the maximum RPM you would recommend for a full-sized wind turbine so that it wouldn't be in danger of breaking?

Use the velocity equation:

$$v = \frac{2\pi r}{T} \qquad 343.2 = \frac{2\pi 40}{T} \qquad T = \frac{80\pi}{343.2} \qquad T \approx 0.732$$

$$\frac{Rev}{sec} = {}^{1}/_{T} \approx 1.366 \qquad RPM = \frac{Rev}{sec} * 60 \approx 81.93$$

So in order to avoid getting close to the speed of sound, large turbines shouldn't spin at more than 60-70 RPM, about one revolution per second.

2. Which turbine blade shape worked best, according to your experiments? Do you think this would be true for full-sized turbines as well?

Students will answer according to their data, which will differ depending on the speed of the fan they used. As for whether the same shape would work for full-sized turbines, students could answer "Yes" or "No" provided they were able to back up their assertion with evidence.

3. Would your turbine would work as well in faster and slower wind speeds? Explain:

Answers should cite their experimental data, though students can also answer "I don't know" if they can describe an experiment that would allow them to test their turbines in different wind speeds.