WindWise Education

Wind Energy Activities for Students

LESSON 6: WHAT ARE WIND SHEAR AND TURBULENCE?

WindWise Education Curriculum

ISBN 978-1-4951-4354-0

WHAT ARE WIND SHEAR AND TURBULENCE?

LESSON 6

KEY CONCEPT

This activity helps students understand the concepts of wind turbulence and wind shear—or the smoothness and speed of the wind at different altitudes above the ground.

TIME REQUIRED

1–2 class periods

GRADES

6–8
9–12

SUBJECTS

Mathematics
Earth Science

KidWind PROJECT®

www.KidWind.org

BACKGROUND

The speed and smoothness of the wind in a given area is an important factor for wind farm developers in deciding where to place wind turbines. Gusty, turbulent winds can cause turbine components to wear out faster, reducing the lifespan of the turbine and increasing the maintenance costs. It makes the most sense to place turbines in locations with smooth, straight wind flow.

Wind shear refers to a change in wind speed or direction at different heights above the ground. Imagine that at ground level the wind is blowing 4 meters/second. At 80 meters in the air, which is the hub height of a typical utility scale turbine, the wind speed may be 12 meters/second. This change in wind speed is called wind shear.

Wind engineers and developers want to site turbines in areas with smooth, fast, and predictable wind patterns. To do this, they must have a good understanding of wind shear and turbulence.

OBJECTIVES

At the end of the lesson, students will:

- understand and be able to explain the concept of wind shear
- understand and be able to explain the concept of wind turbulence
- know how wind shear and turbulence affect wind turbine performance
- understand how trees, buildings, and other obstacles contribute to turbulence

METHOD

Students use a kite or large helium balloon with streamers attached at intervals along the string to visualize the effect of wind shear and turbulence. After measuring the height of the kite in the air, they estimate how high above the ground a turbine would have to be in order to be clear of turbulent winds.

MATERIALS

- ❑ A large sturdy, single-line kite. (A large helium balloon will also work.)
- ❑ Streamers, caution tape, or field marking tape
- ❑ Measuring tape
- ❑ Protractor
- ❑ Medium-sized bucket or box
- ❑ Student reading passages and student worksheets*
- ❑ Wind speed meter (recommended)

*included with this activity

Additional Resources for every lesson can be found at http://learn.kidwind.org/windwise/. Resources include presentations, videos, extension activities, and other materials.

By watching the streamers attached to the string of the kite students will be able to see the wind and make observations about how it is moving.

GETTING READY

- Cut 20 sections of "streamers," approximately 1 meter long each.
- Tell students to read the passage about wind shear and turbulence before class.
- Distribute the data collection worksheet for students to review before going outside for the experiment.
- Try to do this on a windy day; you will need enough wind to fly the kite.
- Find a good place to fly the kite during class time.

ACTIVITY

Step 1: Beginning questions for students

- Where was the windiest place you have ever been?
- Is it windier on top of a mountain or in the valley?
- What does the wind feel like on a windy day in a city?
- What does the wind feel like on a windy day in a field?
- What does the wind feel like on a windy day at the ocean or a large lake?
- Why are wind turbines placed so high in the sky?
- Have you ever experienced "turbulence" on an airplane?

Step 2: Prepare the kite

The streamers should already be cut out. Attach the streamers at 3 meter intervals along the kite string. Students can do this for 60 meters—or more if there is enough kite string. The more streamers students attach, the higher the kite can go, and the more data they can collect. The kite string will also get heavier with each streamer added.

With the streamers attached, winding the string back up can be a challenge. It is much easier if students wind the string around a bucket or medium sized box. This will prevent tangling of string and streamers.

Step 3: Go outside and launch the kite

An open field is a great place to do this experiment. It is also helpful if the field is bordered by some obstructions which will disrupt the smooth flow of the wind. This will help students "see" the lower wind speeds and turbulence caused by trees, buildings, and other objects.

If you have a wind speed meter, ask students to take an average reading at ground level for a few minutes. Make sure this wind speed is recorded on students' worksheets. If you are feeling risky you can try to attach your wind speed meter to the kite. Reset the meter before launching—so that you can get a reading of average wind speed and peak wind speed.

Launch the kite with streamers attached. Once the kite is high in the air and flying steadily, tie it down and ask the students to observe the streamers. The effect will be especially dramatic if you have some objects obstructing the wind at low altitudes upwind from where you are flying the kite.

Step 4: Make observations and record data
Ask students to make a few general observations about the streamers and the kite.

- Was it hard to launch the kite? Did it seem to "take off" after it got to a certain height?
- Are all the streamers doing the same thing, or do they look very different?
- Compare the streamers that are close to the ground to those that are very high in the sky.

Tell students to record some observations and fill in data on their worksheet.

Step 5: Calculate the height of the kite (Grade 9–12 math)
Knowing the length of the string let out and the angle of the kite string relative to flat ground, students can calculate the kite's height off the ground using a simple trigonometry formula. The kite string is like the hypotenuse of a right triangle (c)—and students are trying to calculate the length of the side of the triangle opposite from the kite string handle (a).

Students can figure out how many meters of string were let out based on the number of streamers flying. Remember that the streamers were attached at 3 meter intervals. Tell students to multiply the number of streamers by 3 to determine how much string is out. This value is the hypotenuse of the right triangle formed by the kite (c).

Next, tell students to use a protractor to measure the angle of the kite string relative to flat ground (A).

Now students can use the formula: sin A = opposite (a)/hypotenuse (c)

Therefore opposite (a) = hypotenuse (c) × sin A

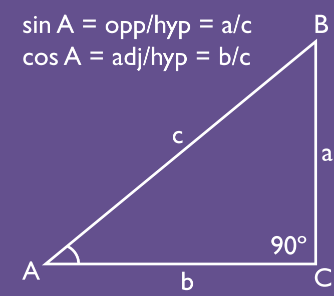
For example: If you let out 20 streamers, this is 60 meters of string. So the hypotenuse (c) is 60 meters. The angle of your kite string (A) is 68 degrees.

Sin (68) = 0.927

0.927 × 60 meters = 55.63 meters

Step 6: Estimate the height required to avoid turbulence (Grade 9–12 math)
Ask students to select the lowest streamer that they determine is not experiencing a high degree of turbulence. This streamer should be flying relatively straight—without flapping around dramatically. Students can use the same process used above to calculate the height of this streamer.

This time, the hypotenuse will be a different number—which can be calculated by counting the number of streamers down the kite string from the selected streamer. Once again, multiply the number of streamers by 3 to calculate the length of string (in meters) before the selected streamer.



Using simple trigonometry students can calculate the height of the kite.

A = student

B = kite

C = directly below the kite

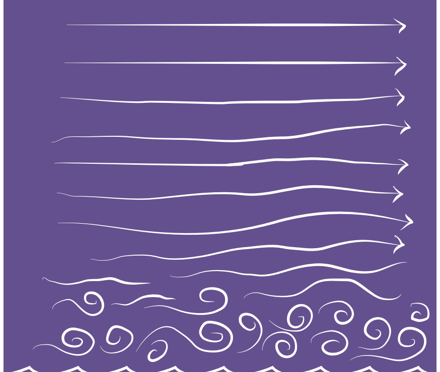
a = height of kite above ground

b = distance from student to directly below kite

c = how much string you have let out

Wind turbulence over obstacles

Wind turbulence over a flat surface



Once students have done their calculations, follow up with these questions:

- How high in the sky does a wind turbine have to be before it does not encounter a great deal of turbulence?
- What do you think would happen as the wind turbine goes even higher off the ground?
- What tools could scientists and engineers use to conduct a more detailed study of wind turbulence and wind shear?
- What do you think would happen to a wind turbine in very turbulent winds?

Step 7: Follow up

Return to the classroom and ask students to finish incomplete sections on their worksheets. Follow up the activity with a discussion about wind shear and turbulence.

- What happened to the streamers as they got higher and higher off the ground?
- Why would the wind be smoother at higher elevations?
- Why would the wind be faster at higher elevations?
- Considering the effect of turbulence, what locations around town might be best for a wind turbine?
- Do you think putting a wind turbine on a rooftop would be a good idea?
- Would a wind farm located a few miles offshore experience as much turbulence as a wind farm on land? Why or why not?
- How does friction affect the wind?
- Knowing that winds get stronger and smoother higher in the atmosphere, why are manufacturers not building turbines that are 300 meters tall?

EXTENSION

- This lesson can go much further if you have actual wind speed data. Using an anemometer like the Inspeed Hand Held meter or WindWare Data Collector can give you some great wind speed data. Many schools have Davis or Weatherbug weather stations that may keep track of average wind speeds. If you have a hand-held anemometer, students can walk around the school searching for locations with the best wind speed and least turbulence. This is known as "micro-siting."
- Tell students to research "wind shear coefficient." This is a value that will help you extrapolate the wind speeds at different elevations if you only know the wind speed at one elevation. Different locations will have a different wind shear coefficient, depending on topography and surface roughness.

VOCABULARY

ground drag – The friction that occurs between the surface of the Earth and the moving air molecules (wind) that flow over it. Ground drag reduces the velocity of the wind.

surface roughness – A measurement of the smoothness of the surface the wind is blowing over. High surface roughness (urban areas, forested hills, etc.) leads to increased ground drag, greater turbulence, and a more dramatic wind shear. Low surface roughness (smooth prairie or sea) has very little turbulence and less shear.

wind shear – A change in wind speed or direction at different heights above the Earth

wind shear coefficient – A value used to calculate the variation in wind speed with respect to height.

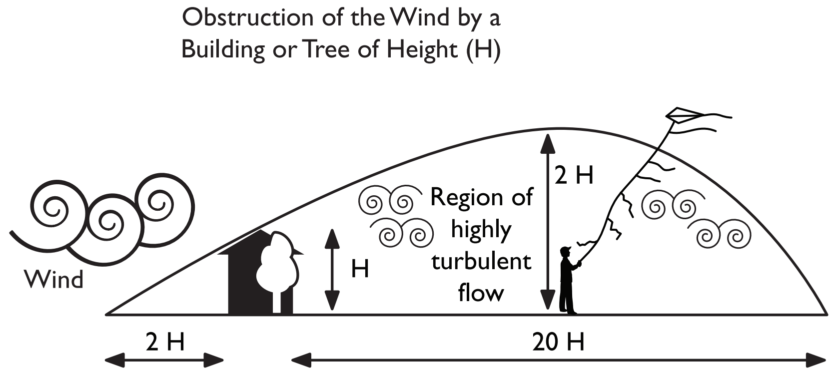
wind site assessment (siting) – The process of analyzing local wind resource and obstacles to determine the best location to place a wind turbine.

wind turbulence – Wind passing over or around obstacles will tumble, swirl, slow, and change direction. This turbulent wind is not good for a wind turbine.

RELATED ACTIVITIES

- Lesson 5: Where Is It Windy?
- Wind Data Appendix
- Lesson 17: Where Do You Put a Wind Farm?

READING PASSAGE



You may have noticed that wind turbines are typically installed on very tall towers. Have you ever thought about why these towers have to be so tall? What do you think happens to the wind speed as you go higher and higher off the ground?

It turns out that winds get much stronger as you go higher above the Earth. The main reason for this is known as "ground drag." Ground drag is the friction that occurs between the surface of the Earth and the moving air molecules (wind) that flow over it. Ground drag reduces the velocity of the wind, thereby reducing the kinetic energy available in that wind. This is particularly important for wind power, since the output of a wind turbine is proportional to the cube of the wind speed. That means that doubling the wind speed can give you eight times the kinetic energy available in the wind!

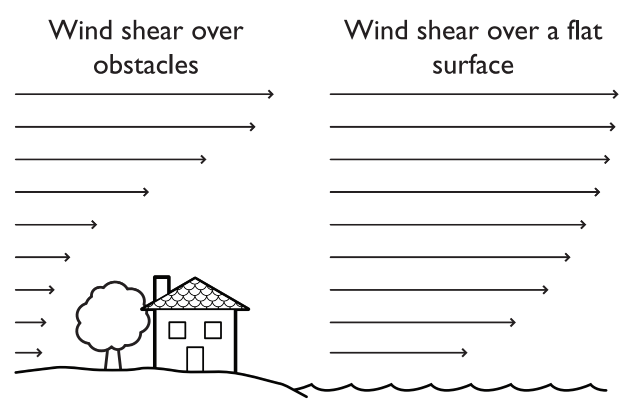
This difference in wind speed at different elevations above Earth is known as wind shear. Wind shear is a very important concept for wind turbine developers and installers to understand—since a small difference in wind speed can make a huge difference in power output.

Landscapes with buildings and trees create much more ground drag than open fields or oceans—which is why some of the best wind resources in the United States are in the Great Plains regions and offshore areas like the Atlantic Ocean, the Gulf Coast, and the Great Lakes.

Trees, buildings, and other obstacles also cause a lot of turbulence in the wind. This means that the wind tumbles and swirls around rather than flowing smoothly. Turbulence is particularly bad for wind turbines, because it slows the wind down (reducing kinetic energy in the wind) and also causes a great deal of wear and tear on the turbine. A wind turbine placed in a turbulent wind area would require more maintenance and would have a shorter life span.

Some inventors and designers are experimenting with "airborne wind turbines." These giant kite-like wind machines are able to float hundreds of meters above ground level, capturing the strong, smooth winds higher in the atmosphere. They are tethered to the Earth with a cable that also transmits the electricity produced. Though the concept is not yet fully proven, the theory of raising a wind generator higher in the sky while using fewer materials is very promising.

Since wind is the "fuel" for a wind generator, it makes sense to place a turbine where it will receive the most fuel. As wind power guru Mick Sagrillo has been known to say, "Putting a wind turbine on too short of a tower is like putting a solar panel in the shade!" When installing a wind turbine, whether it is a small residential machine or a large industrial turbine, it is very important to build towers tall enough to avoid turbulence and reach high wind speeds.



KITE TURBULENCE ACTIVITY: OBSERVATION WORKSHEET

Rank each kite streamer on a 1–5 scale

1	Most turbulent	Streamer moves around wildly and changes direction frequently.
2	More turbulent	Streamer moves back and forth and waves around considerably.
3	Somewhat Turbulent	Streamer waves around but does not move back and forth much.
4	Less Turbulent	Streamer waves a little but always points in the same direction.
5	Not Turbulent	Streamer is almost always straight out with very little waving.

STREAMER NUMBER	DISTANCE FROM KITE (METERS)	TURBULENCE RANKING (1–5)	DRAWING OF STREAMER
1	3 meters		
2	6 meters		
3	9 meters		
4	12 meters		
5	15 meters		
6	18 meters		
7	21 meters		
8	24 meters		
9	27 meters		
10	30 meters		
11	33 meters		

STREAMER NUMBER	DISTANCE FROM KITE (METERS)	TURBULENCE RANKING (1–5)	DRAWING OF STREAMER
12	36 meters		
13	39 meters		
14	42 meters		
15	45 meters		
16	48 meters		
17	51 meters		
18	54 meters		
19	57 meters		
20	60 meters		
21	63 meters		
22	66 meters		
23	69 meters		
24	72 meters		
25	75 meters		

ON GRADING THE WIND SHEAR AND TURBULENCE ACTIVITY

While worksheet answers will vary to some extent, students should observe a general trend towards the wind getting less turbulent as the streamers get higher off the ground. Streamers that are higher above ground clutter and obstructions will get into the more smooth, laminar winds that are less turbulent. These winds are also generally faster.