

# See the Wind!

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# Lesson Zap! - See the Wind!



## Background

The goal of this exercise is to help students see the difference in the speed and smoothness of the wind at different altitudes above the earth. This is important for wind engineers as they seek to place their wind turbines in the fastest and smoothest winds possible. It is also a major reason that wind turbines are going higher in the sky, out in the plains and out in the ocean near the coast.



## Objectives:

Students will learn:

- Wind speed can vary with elevation over the earth's surface.
- Wind turbulence and shear are a concern for wind farms and wind turbine designers.
- What causes wind turbulence and shear and how to avoid putting turbines near these conditions.



## Suggested Level

Middle & High School



## Time Required

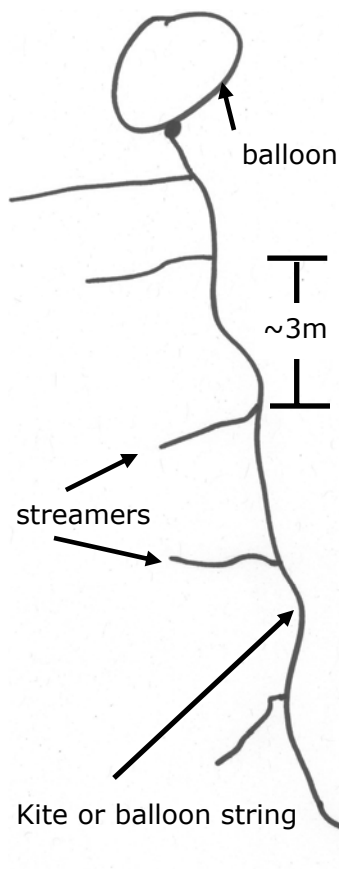
1 Class Period



## Materials Required

- Large Sturdy Kites or Large Helium Filled Balloons
- String
- Streamers – Yellow Caution Tape, Party Streamers
- Student Lab Sheet
- Optional - Wind Speed Meter (The Kestrel 1000 or InSpeed Hand-Held are nice meters to record wind velocity)

## Doing the Activity



### **Preparation**

Before class make sure it is a windy day.

The hardest part of this lesson is setting up the kites or the balloons. You can use either as the main goal is to get a string, with streamers attached to it, high into the sky.

In order to see the "smoothness" of the wind tie 1.5 meter sections of caution tape or streamers to the balloon or kite string. Because you are adding some weight to the kite or balloon you need to have a pretty good sized kite or helium balloon (or many balloons together) to hold everything up in the sky. Some teachers have had the students make the balloons or kites in previous lessons.

Cut at least 15 sections of "streamers" about 1.5 meters long. Attach the streamers at 3 meter intervals along the kite or balloon string. You can do this for 50-75 meters if you have that much string. The more you attach the higher the kite or balloon can go and still provide "data". But keep in mind the kite string will also get heavier.

Winding up all this string up with the streamers attached can be a pain. We recommend that you roll it around a medium sized box or bucket. This seems to keep things from getting tangled and you can then roll it back up when you are done. You can also do this and just lay out the string before class.

Wind speed meters are optional. The meters allow you to get an empirical reading on wind velocity and average. Then you can quantitatively compare wind speeds on the ground and at an elevation above the ground. If you are feeling brave you can try to attach a meter to the base of kite or balloon to get an empirical reading of the wind speeds at higher altitudes. The meters are pretty tough and will survive a crashes. You can also just head to the roof of your school or building and take some readings.

### **Class Time**

To get students thinking about why there are differences in the wind speed and direction you might start a conversation using a some of the questions below.

### **Possible Questions**

- Where was the windiest place you have ever been?
- Where you live is it windier in the winter or the summer?

- Is it windier on the top of a mountain or in the valley?
- Is it windier on a lake, ocean, field or in the city or forest?
- Have you ever seen a wind turbine or windmill?
- Are wind turbines usually low to the ground or high in the sky? Why?
- Why would people put wind turbines in fields or on ridges away from any buildings, trees and other obstacles?
- What areas are wind turbines typically located?
- Have you ever seen trees that look like they been “flagged” by the wind? Where did this occur?
- What happens to the wind when you go behind or on top of a building?

You will get a variety of answers some may be right on the money, others will not.. Let them stew on these ideas for a while and **do not tell them the “right” answers.** You want them to start thinking about how wind speed and direction are not the same as you rise in the atmosphere. But don’t tell them that, you want them to arrive there after some observations.

Pass out the attached data/observation sheet and briefly go over it with them. Tell the students that they need to be watching the streamers very closely as you raise the kite or balloon. This is important because once you get them outside they are probably not going to be totally attentive.

### Demonstration

Take the students outside.

You can layout the kite or balloons now or have them ready before the students arrive. Make sure the students bring their data/observation sheets.

An open field is a great place to do this experiment. It is also helpful if the field is bordered on one or two sides by some obstructions (trees, buildings) which will disrupt the smooth flow of the wind. This will help students “see” the lower wind speeds and turbulence caused by obstructions at lower elevations.

Run up the streamer kite or balloon. Once you get the kite up pretty high, tie it down and then ask the students to closely observe the streamers. (5-10 minutes)

### Recording wind speed

How do we record velocity in a car? Usually in MPH or KPH. Well wind scientists measure wind speed in MPH, but they more commonly use meters/second. To help students understand these numbers you might do a quick comparison.

1 MPH	~	.444 m/s
60 MPH	~	26 m/s
1 m/s	~	2.44 MPH

If you are doing further wind study it is a good idea for the students to be thinking about wind speeds in meters/second as this is a common unit for wind engineers and they will see these units on many charts

- Are the streamers all the doing the same thing (flapping & direction)?
- Compare the streamers that are down closer to the ground to the ones that are up near the balloon or kite?
- Are some flapping around more than others?
- Are some straighter out than others.
- Are they all going the same direction?

Have students make observations on their class sheet. To make it more formal tell the students that you will collect and grade this later.

After they have drawn some pictures and made observations collect the materials and gather the group together. For one final experiment ask the students to lie down on the ground as flat as they can. Can they feel the wind? Is it strong or weak? Why? If you can get a student up on a building or higher than the rest of the class to compare what it is like after lying on the ground.

Take them inside.

### **Optional Using the Wind Speed Meter**

If you have a wind speed meter take an average reading at ground level for a few minutes. Next you can try to attach the meter to the kite or balloon to get a reading in the sky. Make sure that you have reset the meter to record the wind speed and calculate. If you do not want to attach the meter to the balloon or kite try to find somewhere on a roof to set it for a few minutes so you can quantitatively compare wind velocity on the ground and at higher elevation. Keep in mind though that buildings can slow the wind down and create turbulence.

### **Discussion**

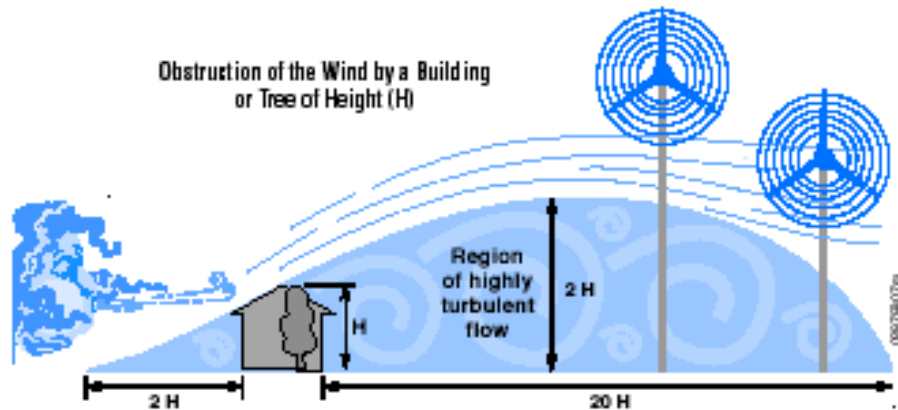
Once inside let them work on the worksheets in small groups for 5-10 minutes. Walk around the room probe them on their pictures and their answers to the questions.

Discuss the pictures they have drawn about the streamer kite/balloon.

- If the streamers move differently at different elevations on the kite string what does that mean?
- How could it be that the wind is stronger/smoothier/faster at different elevations? Shouldn't it be same? Why is this happening?

Let them try to figure this out for a while. You may get a wide variety of answer and ideas. Listen for any answers that talk about friction or interference of the wind with the ground.

## Why is turbulence occurring?



Notice the turbulence as the wind blows around structures and trees.

*Source: Small Wind Sourcebook, NREL*

The friction of the wind on the earth slows it down and can effect its direction. As we get away from the earth the effect of the friction reduces rapidly and the wind speeds up and gets smoother.

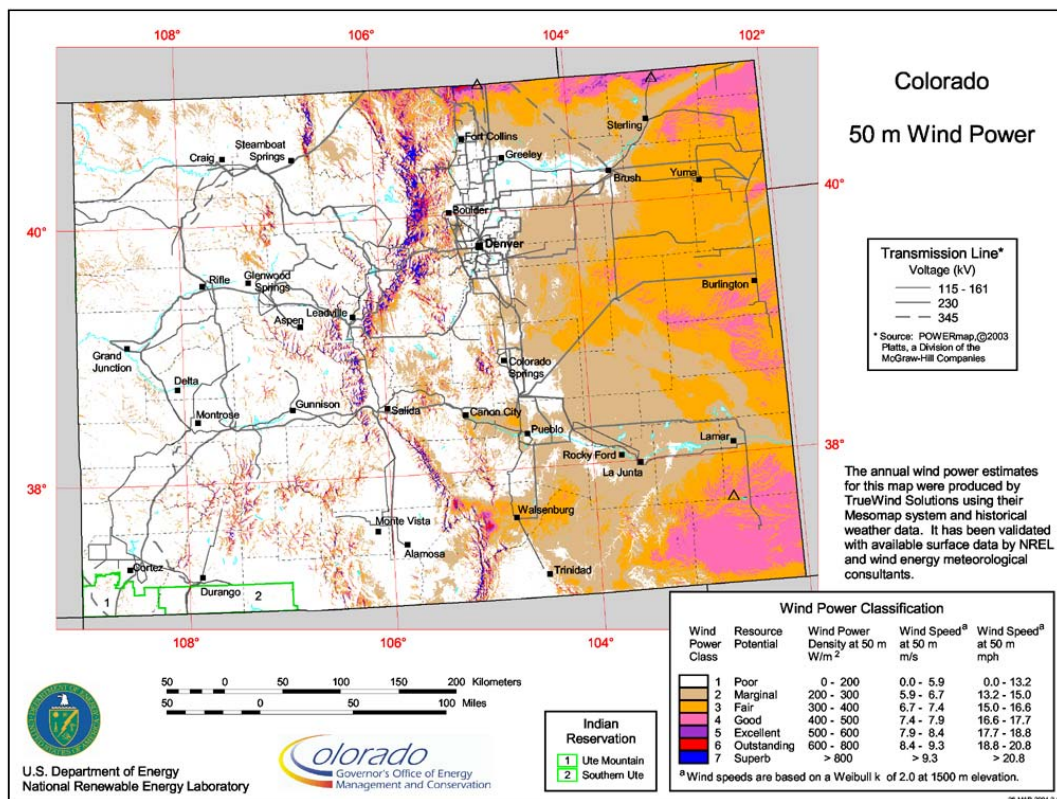
Trees and structures can cause a great deal of turbulence which will cause the streamers move in different directions as the wind swirls around the kite.

## Why is wind so important to Wind Turbines

Residential and larger commercial wind turbines must take turbulence and wind speed into account when they are designed and sited. Wind farmers want to put turbines in areas with the highest wind and lowest turbulence as this will produce the most power and not damage their turbines.

Small turbines (10kW-100kW) are typically 30-50m high. The newer commercial turbines (1MW-5MW) have hub heights at 60-100m and the blade tips going as high as 150 meters. If winds get faster and cleaner as you get higher then why don't they build 300m high turbines? Well putting tens of tons of generator on towers is expensive so they go as high as they can afford and makes sense. At some point going higher does not get you enough speed to make sense.

### Wind Speed Map of the State of Colorado at 50m



A cheaper way than building ever larger turbines is to site your wind turbines in the correct location making sure that you have very high average wind speeds and smooth air. Engineers also want to know what direction the wind is coming from most of the time so they can site the wind farms away from any obstructions which might cause turbulence. To make sure they have the right spot wind engineers work with meteorologists and collect data for many years. They can also use maps, like the one above, to quickly find possible sites.

One really windy place with few obstructions is the open ocean. Many new wind farms are currently being proposed just a few miles offshore (search for Cape Wind or Long Island Wind Project to see a few) as the winds are strong and very smooth because there are no obstructions. Winds are also very good at mountain ridges and passes. As you can imagine this is controversial as many people are not happy to see large wind turbines in these locations and right now a variety of debates are taking place about this issue.



## Additional Resources

**Additional resources for this lesson can be found on the KidWind website.**

<http://www.kidwind.org/materials/Lessons/seethewind/seewindmain.html>

### Wind Maps

**<http://www.awstruewind.com/inner/windmaps/UnitedStates.htm>**

AWS Truewind is a company that creates wind maps. Some of the maps they create are clickable so you can get wind data right over your school or house which is neat!

**[http://www.eere.energy.gov/windandhydro/windpoweringamerica/wind\\_maps.asp](http://www.eere.energy.gov/windandhydro/windpoweringamerica/wind_maps.asp)**

Windpowering America is a program by the Department of Energy to promote wind they have a very informative site that includes some wind maps.

### Wind Turbulence & Shear

**<http://www.windpower.org/en/tour/wres/shear.htm>**

**<http://www.windpower.org/en/tour/wres/turb.htm>**

Windpower.org is a Danish website with piles of wind energy information. It can get quite technical but is definitely thorough. They also have a kid section called Wind with Miller that is excellent.

**[http://www.rpc.com.au/reindex.html?http://www.rpc.com.au/products/windturbines/wind\\_faq.html](http://www.rpc.com.au/reindex.html?http://www.rpc.com.au/products/windturbines/wind_faq.html)**

This is a neat site that has a very easy to read section on why wind speed and shear are big issues when siting wind turbines. They also have some very nice pictures.

Gipe, Paul. **Wind Power: Renewable Energy for Home, Farm and Business.** Chelsea Green Publishing Company. January 2004.

A comprehensive wind energy book with lots of information on wind measurement and evaluation

Manwell, J.F. et al.. **Wind Energy Explained.** John Wiley & Sons. June 2002.

Very technical not for the novice and has a great deal of mathematics. This book may be useful to the very curious who want delve into the details of wind dynamics.

# Wind Speed, Shear & Turbulence in a Nutshell

Wind engineers care about wind speed because the power we can extract from the wind relies very heavily on velocity. The power in the wind is described by the following equation.

**$\rho$  = Density of the Air**  
 **$A$  = Area of Turbine Blades**  
 **$V$  = Wind Velocity**

$$P = 1/2 \rho A V^3$$

A doubling of wind speed leads to 8x the amount of power. This can be a huge difference and drives where developers site wind farms. Engineers are also concerned about wind shear and turbulence as this can cause a great deal of stress on their gearbox and bearings in their turbines.

## Characterizing Shear and Wind Speed

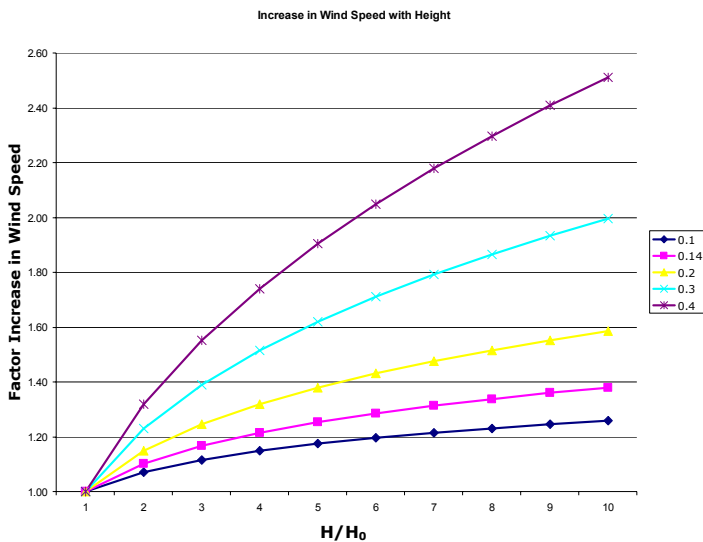
As you increase in altitude the wind speed typically increases due the reduction in friction between the moving air and the ground. There is a simple equation we can use to determine how much faster the wind is moving which is described below.

$V$  = Wind Speed at New Height  
 $V_o$  = Wind Speed at Original Height  
 $H$  = New Height  
 $H_o$  = Original Height  
 $\alpha$  = Wind Shear Exponent

$$V/V_o = (H/H_o)^\alpha$$

We can record wind velocity at a standard height quite easily using mounted anemometers. The wind shear exponent tells how rough the surface is that the wind is blowing over. A smooth surface like an ocean or ice might have a shear exponent of .07. A rough surface like suburbs or forests may have an value of .4. If we know that that wind is blowing over a flat surface like a the ocean at 3 m/s at 5 meters in height we can figure out how fast the wind is blowing at 50 meters. Solve for  $V$  and we find that wind velocity at 50 meters is around 3.5 m/s or around 16% faster.

$$V/3 = (50/5)^{.07}$$



This graph shows two things. As we increase in height (in this case the ratio of  $H/H_o$ ) our wind speed increases. It also shows that over rougher surfaces with a higher shear exponent this increase in speed can be dramatic. With a shear value of .4 (suburbs or woods) winds can be 2x faster at 7x the height. The problem is with a high shear factor that these winds may be quite turbulent.

## See the Wind!

Name \_\_\_\_\_

Average Wind Speed (*Optional - Using Kestrel 1000 or other wind speed meter*)

Ground \_\_\_\_\_ m/s

Above Ground (Kite/Building) \_\_\_\_\_ m/s

### Streamers on Kite or Balloon

Draw a picture of the kite or balloon with the streamers. The important thing to note is any differences in how the streamers are moving at different levels.

Compare the lower streamers with the higher streamers. How do they look different?

What streamers are flapping about widely? What streamers are straight and smooth?

Why would the streamers move differently?

Where do you think the highest wind speeds are located, near the ground or higher in the atmosphere? How can you prove this?

Where are the smoothest winds? How can you prove this?

What is friction? Describe an example.

How could friction affect the wind?

## See the Wind!

Name \_\_\_\_\_

Average Wind Speed (Optional - Using Kestrel 1000 or other wind speed meter)

Ground **This number should be smaller above ground data.**

Above Ground (Kite/Building) **This number should be higher the ground data.**

### Streamers on Kite or Balloon

Draw a picture of the kite or balloon with the streamers. The important thing to note is any differences in how the streamers are moving at different levels.



***It is important that students make very good observations as the answers to the lab questions require this. Prompt them to compare the streamers at all levels. Look at a flag if you have one near your test location. Don't give them the answer...but help them to look for important differences.***

Compare the lower streamers with the higher streamers. How do they look different?

***Lower streamers should be moving around more randomly and be a little more limp due to lower wind speeds and winds that are shifting directions and are more turbulent.***

What streamers are flapping about randomly? What streamers are straight and smooth?

***The streamers that are near the middle to the bottom may be moving wildly and the ones on top should be straight out like a flag on a windy day. Where this break point occurs will depend on the obstacles around you, how windy the day is and how rough the surface of the earth is near you.***

Why would the streamers move differently?

***They move differently because the wind speeds and direction are changing as we go up from the surface of the earth. We can "see" this as we observe the streamers.***

Where do you think the highest wind speeds are located, near the ground or higher in the atmosphere? How can you prove this?

***Higher in the atmosphere. The streamers were less limp and more taught on the string higher up.***

Where are the smoothest winds? How can you prove this?

***Up high in the atmosphere near the kite These streamers were moving in one direction and were not shifting all over. The streamers were also staying flatter and not flagging down.***

What is friction? Describe an example.

***Energy expended when two objects rub against one another.***

***Tires on the road, air on a moving body or car, swimmer in the water...you get the point.***

How could friction affect the wind?

***Friction can slows the wind down and create turbulence. How does friction affect your car or a student when they are running.***

***As we move higher in the atmosphere the wind has less friction with the surface of the earth so the effect of friction is reduced.***