



WeightLifter Wind Turbine

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WeightLifter PVC Wind Turbine Parts List

PVC Pipe & Fittings

- ◇ (6) 6" PVC pipe connectors
- ◇ (1) 24" PVC pipe tower
- ◇ (4) 90° pipe fittings
- ◇ (3) Ts pipe fittings (1 w/drilled hole)

Other Parts

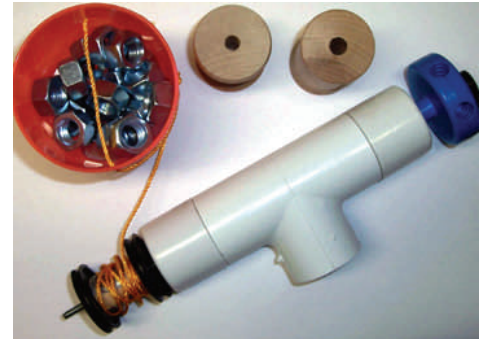
- ◇ (1) Weightlifter Nacelle w/ 12 Hole Hub
- ◇ (1) Package of Bolts (50)
- ◇ (1) Small Plastic Bucket and String
- ◇ (2) Various Sized Wooden Spools

Blade Materials

- ◇ (20) 1/4" diameter poplar dowels (m)
- ◇ (10) 18" sheets of balsa wood (n)
- ◇ (1) Protractor

Extended Kit Parts – Only in Extended Kit

- ◇ (1) Electrical Generator Nacelle
- ◇ (1) Simple Multimeter
- ◇ (1) 3" black three blade propeller
- ◇ (1) LED Bulb
- ◇ (1) Demonstration Motor w/Mini Prop



Tools & Materials

To build this turbine, you'll need at minimum wire strippers, duct tape, and glue.

Weightlifter Wind Turbine

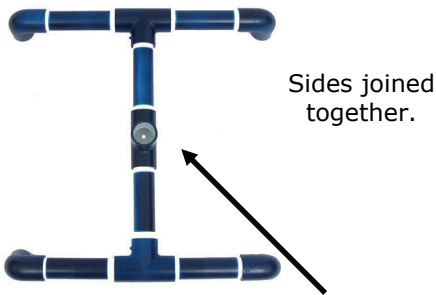
The WeightLifter PVC Turbine is designed to explore how well a wind turbine can move heavy objects. Before there were electrical generating wind turbines, windmills were used to grind grain, pump water and saw wood—today many windmills are still used to do these jobs. The wind machines often required the designers to create blades and drive trains that could move large stones, gears, or heavy water. These instructions will show how to build the WeightLifter as well as providing experiments and design tips for this device.



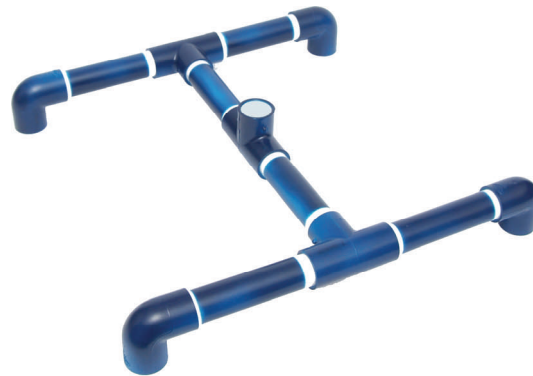
(2) Identical Base Sides

Building the PVC Tower Base

1. Using (4) 90° PVC fittings, (2) PVC tees and (4) 6" PVC pipe sections construct the two sides of the PVC turbine base.
2. Fit the parts together without using glue (PVC glue is really nasty stuff). To make them fit snugly you can tap them together with a hammer, or bang them on the floor once assembled.
3. Next you need to connect the two sides. If you have the *Electrical Generator Nacelle* use the PVC T with the hole to do this. You will need the hole to snake the wires from the DC motor out.



If you have the *Electrical Generator Nacelle* used the T with the hole here!



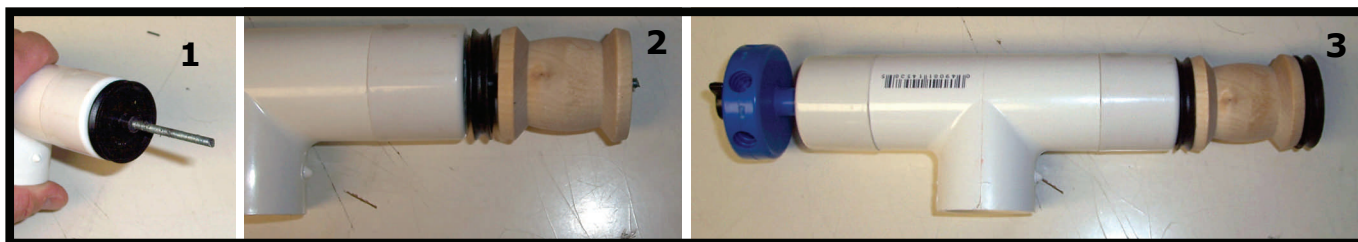
Attaching the Tower to the Base

1. Attach the nacelle (head) to the top of the tower.
2. Insert the bottom of the PVC tower into the T at the center of the turbine base.
3. It should look just like the wind turbine to the right!
4. Make sure the PVC pipe has seated well into the fittings by tapping together with a hammer, or by banging on the floor.
5. Make sure that you didn't use any glue! Because once you are done you can take it apart and then store it away for the next class or experiment.

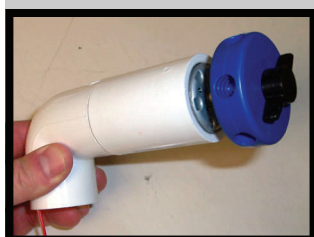


Attaching the Weight Bucket to the Tower

1. Tie or tape the string to the metal rod extending from the nacelle. **NOTE** — Do not glue the string to the rod, as this will prevent you from being able to alter the diameter of the rod for further experimentation. There is a small rubber stopper that you can put at the end of the threaded rod to prevent injuries.
2. We have included (2) wooden spools in this kit. As you change the diameter of the driveshaft you will affect how much weight you can lift and how long it takes to lift the weights.
3. You can also attach your string to a wooden spool that you install on the end of the weightlifter. To install a wooden spool use the diagrams below. If you are creative you can make even wider spools of coffee cans and bottles.
4. Sometimes the spool will spin separate from the driveshaft and the bucket will not move with the drivetrain. There are two ways to fix this — You can try to screw the plastic pulleys harder together to hold it in place. You could also try to secure the wooden spool to the steel rod by making the rod thicker with some duct tape or glue.



(Optional) Electrical Generator Nacelle



If you ordered the kit with the optional **electrical generator nacelle** you can turn your windmill into a wind turbine and generate a small amount of electricity. Replace the weightlifter head with the electrical generator nacelle. Be sure to snake the wires out the hole in the bottom. Experiments with this device are discussed on page 9.

IMPORTANT NOTE

It is very challenging to generate enough electricity with the Electrical Generator Nacelle to light a bulb. If you make some really excellent blades, or use your black propeller, and have a large box fan you might be able to light an LED that requires 1.75 volts.



Building & Attaching Blades

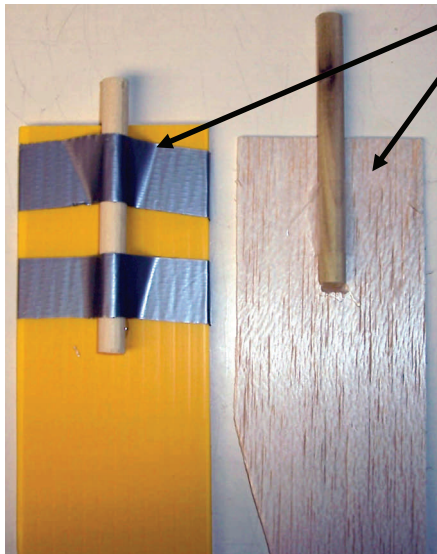


Caution!!

Never make blades out of metal or any sharp edged material because they could cause injury during testing. Blades tend to spin very fast (300-600 RPM) and can easily cut people if they have sharp edges.



1. To make blades, carve or cut different shapes and sizes out of a variety of materials (wood, cardboard, felt, fabric). Tape or hot glue them to the dowels. Students have made blades out of **styrofoam bowls, pie pans, and paper and plastic cups**. Anything you find around the house or classroom can be made into blades!



2. Before testing check that the blades are securely attached to the dowel. If not secured properly, they may detach or deform as you test your turbine in high winds. We recommend using a combination of tape and hot or regular glue.

3. Insert the dowels into holes on the crimping hub. It is important to tighten the hub when inserting the blades so that they do not come out at high speed.

4. When attaching the blades to the hub consider a few important questions:

- How close is the root of your blade to the hub? What do you think is optimal?
- Are your blades about the same size and weight? Blades that are not balanced will cause vibrations that can reduce the efficiency of your turbine..
- Are the blades equally distributed around the hub? If not you can also have a set up that is out of balance.
- Have you secured the hub after you inserted the blades? If not they can fly out at high speed!
- Want to know how fast your blades are spinning? Get a *Hangar 9 Micro Tachometer*.



Pie plate used to catch the wind.

As the crimping hub can be separated into two parts you can try different creative ways to attach "blades" to the hub. One of the best blades we ever saw was made from a pizza pie box!

Again, **DO NOT USE** sharp metal or very hard plastic to make blades, because blades can spin at very high speeds (500RPM) and could cause injury.



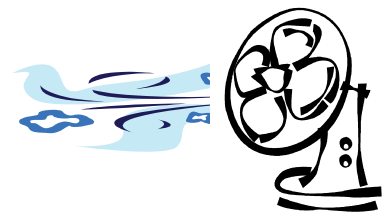
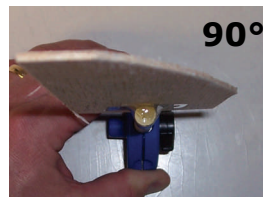
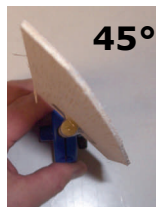
Some Blade Building Tips

KidWind model wind turbines are designed for use in science classes, or as a hobby or science fair project. Their purpose is to give students an affordable way to perform various blade design experiments quickly. **Efficient blades are a key part of generating power from a wind turbine. Sloppy or poorly-made blades will never make enough energy to do anything. It takes time and thought to make good blades!**

An important concept to keep in mind when making turbine blades is drag. Ask yourself, **"Are my blades creating too much DRAG?"**. Your blades are probably catching the wind and helping to spin the hub and motor drive shaft, but consider the ways that their shape or design might be slowing the blades down as well. If they are adding **DRAG** to your system it will slow down and in most cases low RPM means less power output.

Some tips on improving blades:

- **SHORTEN THE BLADES** - Wind turbines with longer blades do make more power. While this is also true on our small turbines it is often difficult for students (and teachers) to make large, long blades that don't add lots of drag and inefficiency. See what happens when you shorten them a few centimeters.
- **CHANGE THE PITCH** - Students commonly set the angle of the blades to around 45° the first time they try to use the turbine. Try making the blades flatter towards the fan ($0^\circ - 5^\circ$). Pitch dramatically affects power output, so play with it a bit and see what happens. Finding a way to **TWIST** the blades (0° near the tips and around $10^\circ - 20^\circ$ near the root) can really improve performance.



- **USE FEWER BLADES** - To reduce drag try using 2, 3 or 4 blades.
- **USE LIGHTER MATERIAL** - To reduce the weight of the blades use less material or lighter material.
- **SMOOTH SURFACES** - Smooth blade surfaces create less drag. Try removing excess tape or smoothing rough edges to reduce drag.
- **FIND MORE WIND** - Make sure you are using a decently sized box or room fan with a diameter of at least 14"-18".
- **BLADES VS. FAN** - Are your blades bigger than your fan? If the tips of your blades are wider than the fan you're using, then they're not catching any wind—they are just adding drag!
- **BLADE SHAPE** - Are the tips of your blade thin and narrow or wide and heavy? The tips travel much faster than the root and can travel faster if they are light and small, which means that if you have wide or heavy tips you may be adding lots of drag.



SAFETY & BLADE TESTING AREA



- **It is important to wear safety goggles when constructing and testing blades.**
- **NEVER make blades using metal or any sharp edged material as these could cause injury while spinning fast during testing.**

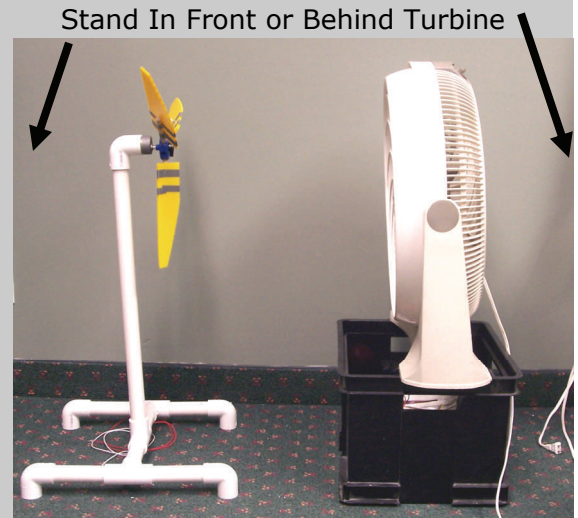
SETUP FOR TESTING

Safely set up your testing area like the picture below. It is important to clear this area of debris and materials.

Make sure the center of the fan matches up with the center of the wind turbine. You may need to raise your fan with some books or a container.

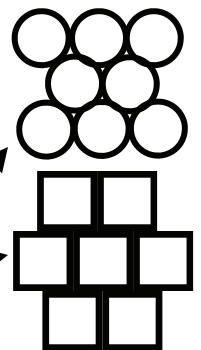
Some things to note about fan wind that reduces the efficiency. Fans create;

- *Highly Turbulent & Rotational Wind*— Blades may spin better one direction than another
- *Highly Variable Wind Speed* - Wind speed is about 10-13 MPH on high for a \$20 circular fan. Wind speeds near the middle will be much different than the edges.
- *Limited Diameter*— Blades bigger than fan will not “catch” more wind—they will just add drag and slow down your blades.



How to Clean Up Wind?

Want some more “professional wind”? You can try to build a simple wind tunnel. Lots of plans can be found online (search term: classroom wind tunnel) and at <http://www.KidWind.org>. One simple way to make more laminar—smooth, straightened—flow is to build a honeycomb in front of your fan using milk cartons, 2” PVC pipe or some other material.



Going Outside?

While you can use your wind turbine outside, you must make sure that you face it into the into wind. This is because most of our wind turbines are not designed to YAW (or rotate) to face the wind. If the wind shifts, and the turbine cannot rotate, winds will hit the blades from the sides causing stress and inefficiency.

For a wind turbine that can yaw check out the Kidwind Yawing PVC turbine on our website (<http://www.kidwind.org>)!



What can you do with your turbine?

Factors that Affect Power Output

How much power is your wind turbine producing? The weightlifter turbine uses simple machines (pulleys, wheels) to transform the energy in the wind to lift heavy objects. There are two factors that determine how much power your turbine is producing: (1) How much weight it can lift, and (2) How fast the weight is lifted. Look at the next page to learn more about power in the wind and how to get the most out of your turbine. Once you have read through the materials, start experimenting! What factors can you change to increase the power output of your turbine?

Here are a few ideas for starters.

- *Wind Speed*
- *Blades*
- *Diameter of driveshaft, adding gears, etc.*

Wind speed is an easy one. Take your turbine and place it in front of a fan at three different distances. How does the power output change? Why does it change? Make a graph and discuss. Think about this in relation to the Power in the Wind equation.

Blade Design

An entertaining group of experiments involves blade design. The blades on modern turbines "capture" the wind and use it to rotate the shaft of a generator. The spinning shaft of the generator spins magnets near wires and generates electricity. The WeightLifter turbine does not produce electricity, but works in much the same way to convert wind into power. How well you design and orient your blades can greatly impact how much power your turbine produces.

The ideal blade setup for the weightlifter turbine may be different than the ideal blade setup for an electricity producing turbine. When producing electricity, the goal is to make the rotor spin as fast as possible to spin the generator faster. When lifting weights, however, your blades need to provide lots of torque (muscle) not just speed. It can really pay off to experiment with your blades until you find a setup that provides lots of torque and speed.

Experiments with blades can be simple or very complicated, it depends on how deep you want to explore. Some variables you can test with blades include:

- *Blade Length*
- *Blade Shape*
- *Blade Number*
- *Blade Materials*
- *Blade Pitch*
- *Blade Weight*

If you are doing this for a science fair or project you should focus on just one these variables at a time as your results can get confusing quite quickly.

Experimental Ideas

How many bolts can your model lift?

Using your preliminary blade setup and design, how many bolts does your turbine lift? Can you fill the bucket and still lift it? The most efficient turbine will lift a lot of weight with a low wind speed. Try moving your turbine away from the fan or leaving the fan on a low setting. How much weight can you lift now?

Experiment with the number of blades:

For this experiment it is important to keep the pitch of the blades constant.

How many blades did you use? What happens if you only use two blades? Next try three, six blades, even one!! Is there a relationship between the number of blades and the lifting capacity of the turbine? Will six blades lift twice as much weight as three blades? Is there some point where adding blades makes the wind turbine less efficient?

When testing the number of blades, one strategy is to keep the weight constant while altering the blade number. Then measure the time it takes to lift the weight to determine which blade setup gives you the most power. The faster it lifts the weights the more power you are generating.

What blade number gives you the most power? Why?

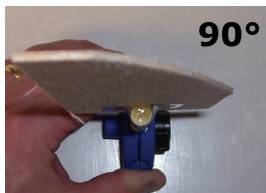
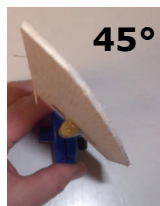
Experiment with the blade pitch:

For this experiment it is important to keep the number of blades constant.

When the blades are flat against the wind (0°), the air will push the blades in the same direction as the wind. This results in a minimum transfer of energy from the moving air. Likewise, when the blades are 90° , or perpendicular, to the wind, there is no push at all from the moving air since there is very little exposed surface. Half way between these two extremes, at 45° , some of the force pushes the arm sideways while some force pushes it backwards. Therefore, in principle, an angle of 45° should provide for the maximum push from the wind...is this true?

Experiment with different blade angles. Again, it might be a good strategy to keep the weight a constant and only adjust your angle. Measure the time it takes to lift the weight as you change your blade pitch.

What blade pitch gives you the most power? Why?



Experiment with driveshaft diameter:

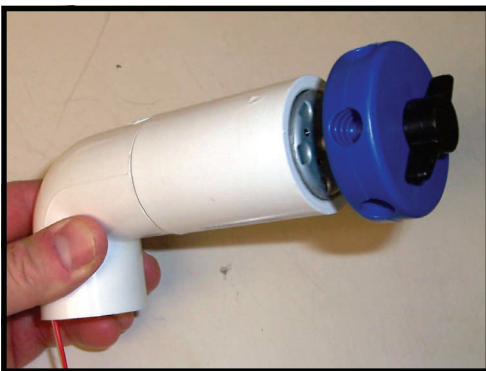
When you change the diameter of the shaft where your string is connected, the mechanical energy required to lift the same amount of weight will change. Keeping the weight and blade setup constant, insert one of the wooden spools onto the shaft and re-attach your weight bucket to the larger diameter. Can you lift the same amount of weight? Does the weight get lifted faster? Why? Does it take more or less power to lift the same amount of weight with a larger diameter? Why?



Comparing Blades—Electricity Generation vs. Moving Weights

This Experiment Requires the Electrical Generating Nacelle

If you have the optional **Electrical Generating Nacelle** in your kit you can make some comparisons concerning the optimal blades for two very different turbines.



Take your best blade set up from your weightlifting device and attach them to the hub on your electrical generating device. Record your voltage output using the multimeter— For information on using a multimeter with your turbine see page 15.

By manipulating the # of blades, pitch of the blades see if you can increase the voltage output. Are the optimal blades for the weightlifter optimal for the electrical turbine? Why?

The two pictures below show windmills designed to do two very different things. One is designed to pump water one is designed to generate electricity. Do you have an idea which one is which?



Power in the Wind – A Simple Look

If a large truck or a 250lb linebacker was moving toward you at a high rate of speed, you would move out of the way, right?

Why do you move? You move because in your mind you know that this moving object has a great deal of ENERGY as a result of its **mass** and its **motion**. And you do not want to be on the receiving end of that energy.

Just as those large moving objects have energy, so does the wind. Wind is the movement of air from one place on earth to another. That's the motion part.

What is air though? Air is a mixture of gas molecules. It turns out that if you get lots of them (and I mean lots of them) together in a gang and they start moving pretty fast, they can definitely give you — a sailboat or a windmill — a serious push. Just think about hurricanes, tornadoes, or a very windy day!

Why aren't we scared of light winds while we stay inside during a hurricane or wind storm? The velocity of those gangs of gas molecules have a dramatic impact on whether or not we will be able to stay standing on our feet. In fact, in just a 20 mph gust you can feel those gas molecules pushing you around.

Humans have been taking advantage of the energy in the wind for ages. Sailboats, ancient windmills and their newer cousins the electrical wind turbines, have all captured the energy in the wind with varying degrees of effectiveness. They all use a device such as a sail, blade or fabric to "catch" the wind. Sailboats use wind energy to propel them through the water. Windmills use this energy to turn a rod or shaft.

A simple equation for the **Power in the Wind** is described below. This equation describes a the power found in a column of wind of a specific size moving at a particular velocity.

P = Power in the Wind (watts)
 ρ = Density of the Air (kg/m³)
r = Radius of your swept area (m²)
V = Wind Velocity (m/s)
 Π = pi 3.14

$$P = 1/2 \rho \Pi r^2 V^3$$

From this formula you can see that the size of your turbine and the velocity of the wind are very strong drivers when it comes to power production. If we increase the velocity of the wind or the area of our blades we increase power output. The density of the air has some impact as well. Cold air is more dense than warm air so you can produce more energy in colder climates (as long as the air is not too thin!).

The weightlifter turbine illustrates the principle of power in the wind not by electrical output, but by lifting weights using mechanical energy. It is important to note that the power your turbine produces is defined by both the amount of weight lifted as well as the speed that this weight is lifted. Power is a *rate* of energy transfer. This means that your actual power produced by the weightlifter wind turbine is the amount of mechanical energy produced divided by the time taken for this energy transfer.

How much wind power is coming from a regular house fan?

V = 5 m/s (meters/sec)
 ρ = 1.0 kg/m³ (kilograms/cubic meter)
r = .2 meters
A = .125 m² (Area of Circle = Πr^2)

$$\text{Power in the Wind} = \frac{1}{2} \rho A V^3$$

$$\begin{aligned} \text{Power} &= (.5)(1.0)(.125)(5)^3 \\ &= 7.85 \text{ Watts} \end{aligned}$$

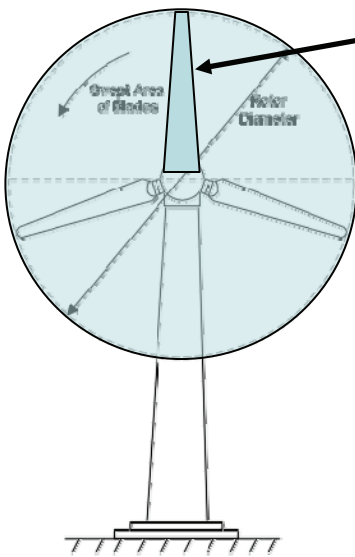
There are 7.85 watts of wind power coming out typical house fan on high. Can our little turbines capture all of this power? Do some research on the **BETZ LIMIT** to find out.

ADVANCED EXPERIMENT #1 - COMPARING SOLIDITY

For turbines of the same size (blade diameter) the power we can get out of our wind device is related to how fast the blades spin and how hard they spin — or the rotational force. The simple equation below shows the relationship between these two forces. The most powerful turbine (if we were comparing devices of similar size) is one that has high rotational speed with lots of torque...but this can be difficult to achieve in practice.

Power Output = Torque x Rotational Speed

Solidity is the ratio of the blade area to total swept area of the turbine.



If we know the area of one blade we can easily determine the surface area of all of our blades together.

To determine the swept area use the formula below to calculate the Area of Circle. (r = radius of the blade swept area)

$$\text{TOTAL SWEEPED AREA} = \pi r^2$$

Now we can calculate SOLIDITY.

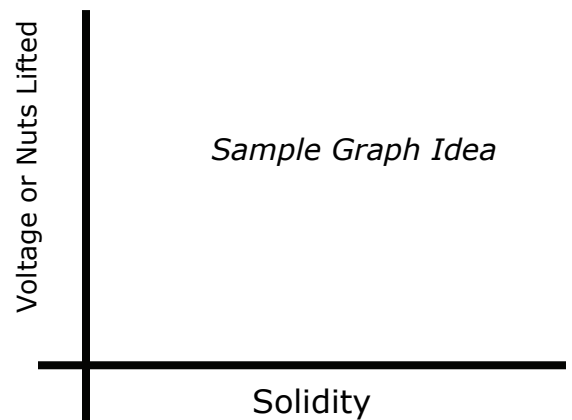
$$\text{SOLIDITY} = \frac{\text{AREA of BLADES}}{\text{TOTAL SWEEPED AREA}}$$

A device with a **Solidity** of 1 would have the entire swept area filled with a solid disc. This would probably not work very well as blades must let some air past so they can spin.

Using this equation you can now determine the solidity of the blades on your turbine and relate that to power output (nuts lifted or watts generated). If you have an electric generating nacelle you can compare the optimal solidity for the WeightLifting turbine and the electrical generating wind turbine and compare the similarities and differences in blade configurations.

Some questions to think about:

- Do the optimal blades for weight lifting and electricity generation have the same or different solidity values?
- What spins faster high or low solidity turbines?
- What solidity value has the most turning force?
- Did I hold my other variables constant as I did these experiments? (wind speed, pitch, length)



Advanced Experiment #2—Determining Horsepower

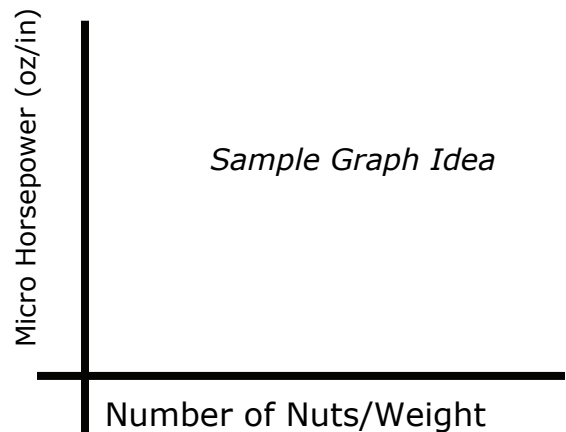
The power created by the weightlifter wind turbine can be measured in horsepower. However, because the horsepower (measured in ft/lbs) produced by these turbines is so small, it is more sensible to measure this power in micro-horsepower (MHP), measured in ounce/inches. The following formula is derived to compute micro-horsepower:

$$\text{MHP} = \frac{\text{Wt (ounces)} \times \text{Ht (inches)} / .1056}{t \text{ (sec)}}$$

Figuring out the micro-horsepower of your turbine is a quantitative method of analyzing its performance. The higher your horsepower, the better your turbine is performing.

If you wish to analyze your data in an even more advanced way, calculate MHP for your turbine using 5 or more different weights, ranging from a few nuts to many.

You should be able to see from the resulting data at which weight your turbine produces the most horsepower. You can also represent this data graphically, which will help you and others visualize at which weight your turbine performs best. Keep in mind that it is important to keep your other variables constant (length, pitch, number) while you compare numbers the amount of weight you can lift



Some information for this section is adapted from Windmills— Future Scientists and Engineers of America Curriculum Document—<http://www.FSEA.org>

Want to Know How Much Electricity Your Turbine Could Produce?

We can convert between Horsepower to Watts with a few simple calculations.

First we need to convert from MHP to HP

$$\text{Horsepower} = \text{MHP} \times 1/1000$$

Next we convert Horsepower to Watts.

$$\text{Watts} = \text{Horsepower} \times 746$$

Keep in mind it takes about 40-100 watts to light your average incandescent light bulb. How many mini turbines would it take to light a bulb at your house?

PVC Wind Turbine FAQ

Why won't the rotor spin when I put my turbine in front of the fan?

Check the orientation of the blades. Are your blades oriented in the same direction? Are they flat? Are they hitting the tower? Look at some pictures of old and new windmills to get some ideas about how to orient your blades.

Why does the turbine slow down when I attach it to a load (pump, bulb, motor)?

Loading the generator forces it to do work. This makes it harder to push electrons through the circuit. The more load you add the harder it is for the generator to turn and the more torque you must generate from the blades. The only way to do this is to make bigger blades or relocate your wind turbine to a place with higher wind speeds.

Why are the readings on my multimeter all over the place?

Your readings may be fluctuating because the wind coming out of your fan is fluctuating. This can also be caused by blades that don't spin smoothly or change shape as they spin. Additionally, if your blades are not balanced, evenly distributed, or are producing unequal amounts of drag your readings will be irregular.

Why are the readings on the multimeter NEGATIVE?

The meter is reading the polarity of the wires. As your turbine spins in one direction one wire will be the positive lead the other negative will be the negative lead. If you spin your turbine the other direction the polarity of the wires will be reversed. For LEDs and Fuel Cells hooking up the correct polarity matters—on other items the polarity is not critical.

What are the best blades?

That is for you to figure out! Lots of testing and playing will get you closer to your answer.

Is a fan a good wind source to test with?

Well, it is the best we've got, unless you have a wind tunnel handy! The wind that comes out of a fan has a great deal of rotation and turbulence. It isn't very smooth. While it will still make your turbine spin it is not exactly like the wind outside. To see this turbulence, hold a short piece of thread in front of a fan and move it from the center out. It should head out straight all the time...does it?

Can I take my turbine outside? Can I leave it there?

You can certainly take, use and test your wind turbine outside. But unless you have a yawing turbine it will not track the wind and may not perform optimally. To make it work well you will have to continually face it into the wind. It is not a good idea to leave your turbine outside for too long. It is designed for basic lab tests and not to endure the rigors of the outdoor environment!

Based on the Power in the Wind equation it seems that longer blades should make more power. On my turbine this is not true!! WHY??

The blades on your turbine may be bigger than the diameter of the fan. If that is the case, the extra part is only adding drag so your blades will slow down. Additionally, if you design large blades poorly they will have lots of drag near the tips and slow down. This will negate any positive effect of the added length. Also, short blades spin faster than long ones, so if you are just recording voltage they will seem better. Try short blades with a load in series and see if they have enough torque to spin. In many cases they do not!

How to use the Multimeter

To accurately measure power production you should use a multimeter. Small DC motors like the one you're using do not produce much power when spun slowly. As a result, the electrical output will be limited and even a great set of blades in high winds might only be able to light an LED. If you are interested in lighting bulbs and creating more electricity you may want to check out the *Geared PVC Turbine* at the KidWind Website (<http://www.kidwind.org>).

Power (Watts) = Voltage (V) x Current (A) <-- Watch Your Units

Make sure you are recording volts and amps (not milli or microvolts unless you want to!)

If your readings are higher than 1 – 2 watts you have done something wrong!

Voltage



1. Attach the wires from the generator to the multimeter. Color does not matter!!
2. To check the voltage select DC Volt (V) and set the whole number to 20 volts.

3. Place your turbine out in the wind or in front of a fan and let it run.

It is normal for the readings to

fluctuate. Power output is often unsteady because the wind is inconstant or your blades are not balanced.

Set to 20 DC Volts



4. A set of very well designed blades may make around 1 –2 volts. Typical blades will be in the 0.5 - 0.8 volt range.
5. When measuring voltage you are calculating how fast the DC generator is spinning. The faster it spins the higher the voltage. Since there is no load on the generator it has very little resistance and can spin very fast. If you look closely when you attach a load (bulb, pump or small motor) the RPM may drop as will your voltage.

Amperage

1. To get a more accurate picture of the power output of your turbine measure amperage as well. To accurately measure the amperage you must hook up your multimeter differently.
2. Place a load (a resistive object - small LED bulb, resistor, pump etc.) in series with the meter so that the generator is "loaded" and has to do work.
3. A set of very well designed blades will produce around 0.1 amps (100 milliamps) with this motor. Typical blades will make .02-.05 amps (20 – 50 milliamps). This will vary based on your resistive load.
4. When measuring amperage you are gauging how many electrons are being pushed through the wire by the turbine. This relates to how much torque your blades are generating.

DON'T FORGET TO TURN OFF THE METER WHEN YOU ARE DONE OR THE BATTERY WILL DIE!!

