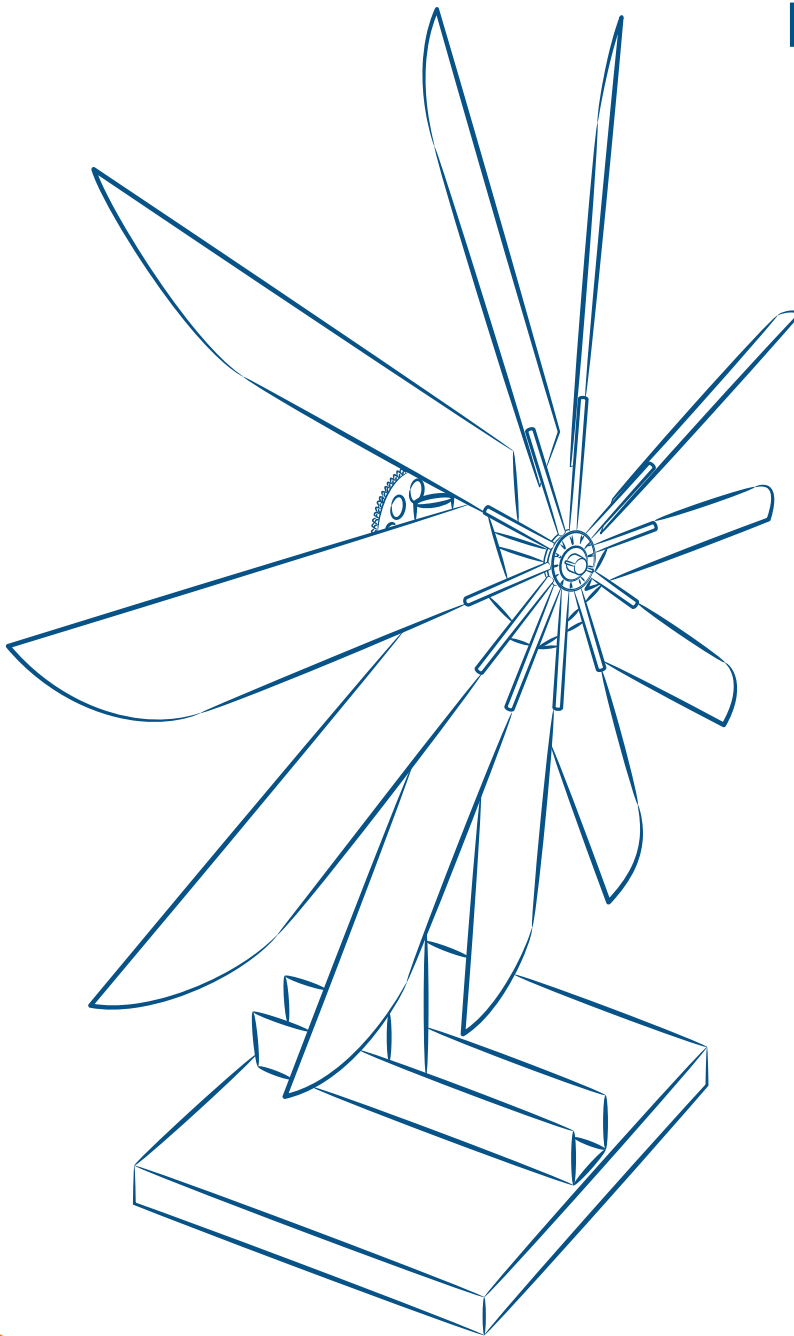




Advanced Blade Design



instructions

About KidWind

The KidWind Project is a team of teachers, students, engineers, and practitioners exploring the science behind wind energy in classrooms around the US. Our goal is to introduce as many people as possible to the elegance of renewable energy through hands-on science activities which are challenging, engaging, and teach basic science principles.

While improving science education is our main goal, we also aim to help schools become important resources for both students and the general public, to learn about and see renewable energy in action.

Thanks to . . .

We would like to thank the Wright Center for Science Education at Tufts University for giving us the time and space to develop this idea into a useful project for thousands of teachers.

We would also like to thank Trudy Forsyth at the National Wind Technology Center and Richard Michaud at the Boston Office of the Department of Energy for having the vision and foresight to help establish the KidWind Project in 2004. Lastly, we would like to thank all the teachers for their keen insight and feedback on making our kits and materials first rate!

Wind for All

At KidWind, we strongly believe that K–12 education is an important foundation for promoting a more robust understanding of the opportunities and challenges that emerging clean energy technologies present.

The Wind for All program seeks to support teachers and students all over the globe who do not have the financial capacity to access our training programs and equipment. We believe that all teachers and students—regardless of where they live or what school they attend—must be part of the clean energy future.

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Our plastic components are made from recycled resins.

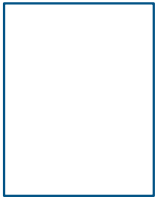


We source domestically whenever possible, and assemble and pack our kits in St. Paul, MN.

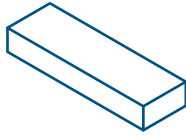


Proceeds from your purchase help us train and supply teachers.

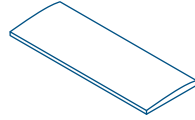
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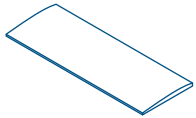
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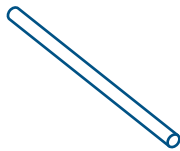
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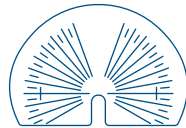
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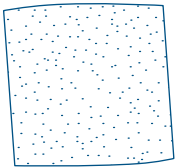
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Advanced Blade Design Pack Parts List

15 Chip board sheets, 8.5" x 11"

4 Balsa wood blocks, 1/2" x 3" x 12"

6 Airfoil balsa wood blades, 1/4" x 3" x 12"

6 Airfoil balsa wood blades, 3/16" x 3" x 12"

25 1/4" Dowels

1 Blade Pitch Protractor

4 Sandpaper sheets

Other Useful Materials (not included)

Model turbine that can interchange blades

Multimeter or voltage/current meter

Box fan

Ruler/straight edge

Craft knife (use caution!)

Cardboard poster tubes (to make twisted blades)

Hot glue



Introduction

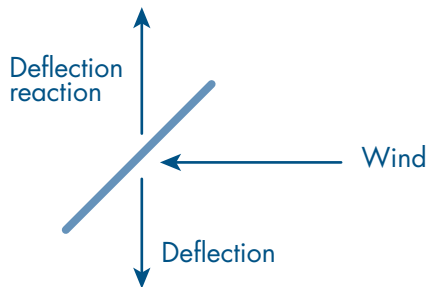
Blade design and engineering is one of the more complicated and important aspects of current wind turbine technology. Engineers strive to design blades that extract as much energy from the wind as possible in a variety of wind speeds, while remaining durable, quiet and affordable. This engineering process requires a great deal of scientific experimentation, modeling, and testing.

With some simple materials and a bit of creativity, you can experiment with advanced concepts in wind turbine blade design, including airfoil shapes and twisted-pitch blades. You may want to try building three-dimensional blades that will outperform the standard flat turbine blades used on most KidWind turbine kits. This guide will help you understand the science and aerodynamics behind real wind turbine blades and how they are designed.

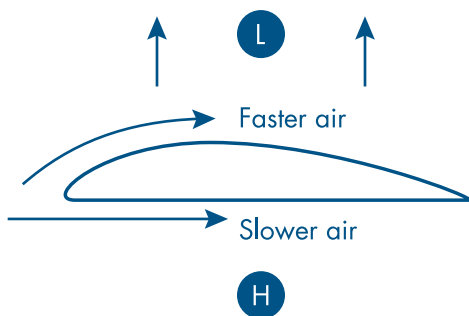
Why Do Wind Turbine Blades Move in the Wind?

There are two important reasons why wind turbine blades are able to spin in the wind: Newton's Third Law and the Bernoulli Effect.

1. Newton's Third Law states that for every action, there is an equal and opposite reaction. In the case of a wind turbine blade, the action of the wind pushing air against the blade causes the reaction of the blade being deflected, or pushed. If the blade has no pitch (or angle), the blade will simply be pushed backwards (downwind). But since wind turbine blades are set at an angle, the wind is deflected at an opposite angle, pushing the blades away from the deflected wind. This phenomenon can be viewed on a simple, flat blade set at an angle. If you push the blade with your finger from the direction of the oncoming wind, the blade will deflect away from your finger.



2. The Bernoulli Effect tells us that faster moving air has lower pressure. Wind turbine blades are shaped so that the air molecules moving around the blade travel faster on the downwind side of the blade than those moving across the upwind side of the blade. This shape, known as an airfoil, is like an uneven teardrop. The downwind side of the blade has a large curve, while the upwind side is relatively flat. Since the air is moving faster on the curved, downwind side of the blade, there is less pressure on this side of the blade. This difference in pressure on the opposite sides of the blade causes the blade to be "lifted" towards the curve of the airfoil.



Airfoil shape (blade cross section)

You can do a small, simple experiment to demonstrate the Bernoulli Effect. Take two small pieces of paper and fold them slightly in the middle. Hold the two pieces of paper in your hands so that the outside creases of the

folds are facing each other. Then blow air in between the two pieces of paper. When you blow air between the papers, would you expect them to push apart or pull together? Were you surprised?

When you blow air between the papers, the speed of the air is higher between the two pieces of paper than outside the papers. Bernoulli's Principle tells us that this higher velocity will lead to a lower pressure between the papers. That is why the papers are sucked in towards each other!

Understanding Wind

Wind turbine blades must be optimized to efficiently convert oncoming winds into mechanical energy to rotate the main driveshaft. But when designing turbine blades, the real wind is only one part of a larger equation—good blades must also account for the apparent wind that is experienced as the blade passes through the air.

Imagine riding your bike on a day with a fresh breeze at your side. As you begin to ride and pick up speed, you feel this wind from the side, but also wind pushing back at you from the direction you are moving. When you stop riding, there is just the wind from the side again. This wind that is "created" as you are moving is known as headwind. The headwind, combined with the real wind, is known as apparent wind. A wind turbine blade experiences apparent wind as it passes through the air. This apparent wind is from a different direction than the "real" wind that has caused the blade to begin moving. Since the tips of large turbine blades may be moving through the air at speeds up to 322 km/h (200 mph), this apparent wind can be very significant!

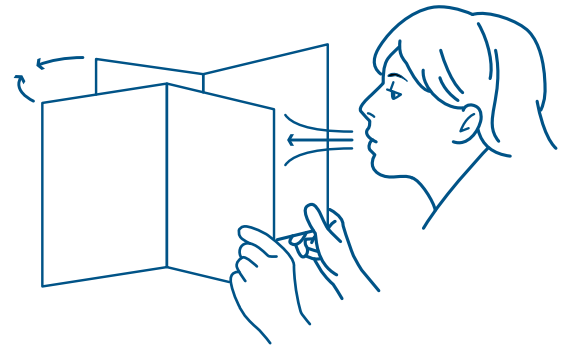
Drag, Lift, and Torque

The efficiency of a wind turbine blade depends on the drag, lift, and torque produced by the blade. These factors are affected by the size and shape of the blades, the number of blades, and the blade pitch.

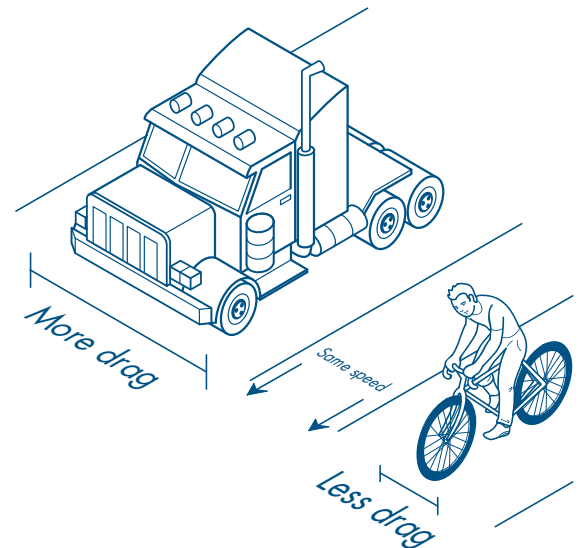
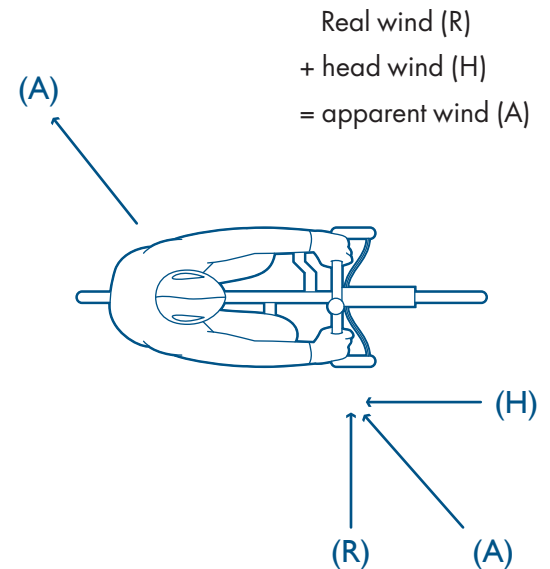
What is Drag?

Drag, or air resistance, is a force that is working against the blades, causing them to slow down. Drag is always important when an object moves rapidly through the air or water. Airplanes, race cars, rockets, submarines, and wind turbine blades are all designed to have as little drag as possible.

Imagine riding your bike down a big hill. To go faster, you might tuck your body to expose as little of it to the apparent wind as possible. This is a trick to reduce drag. Now imagine you have a big parachute strapped to your back when you ride down the hill. The parachute increases the drag significantly and this drag force slows you down. But you would sure be happy to have all that extra drag if you were jumping out of a plane!



You can demonstrate the Bernoulli Effect using two pieces of paper.





Drag increases with the area facing the wind—a large truck has a lot more drag than a motorcyclist moving at the same speed. Wind turbine blades have to be streamlined so they can efficiently pass through the air. Changing the angle of the blades will change the area facing the apparent wind. This is why blade pitch angles of 10-20 degrees tend to have much less drag than greater angles.

Drag also increases with wind speed. The faster an object moves through the air, the more drag force it experiences. This is especially important for wind turbine blades, since the blade tips are moving through the air much faster than the base of the blade. The shape and angle of wind turbine blades changes along the length of the blade to reduce drag at the blade tips.

What is Lift?

Lift is the aerodynamic force that allows airplanes and helicopters to fly. The same force applies to the blades of wind turbines as they rotate through the air. Lift opposes the force of drag, helping a turbine blade pass efficiently through air molecules. The main goal of a well-designed wind turbine blade is to generate as much lift as possible while minimizing drag.

The amount of lift a blade or wing can generate is determined by several factors—the shape of the blade, the speed of the air passing around the blade, and the angle of the blade relative to the apparent wind.

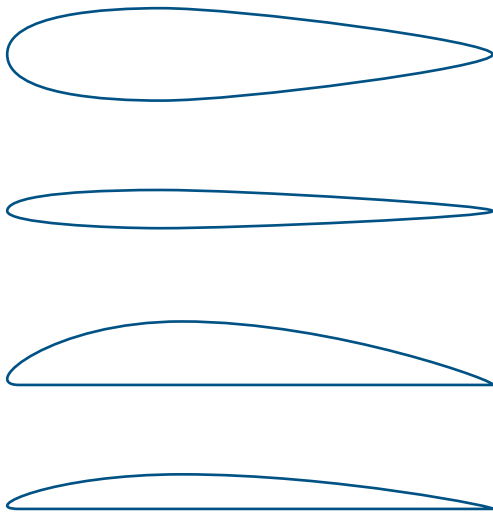
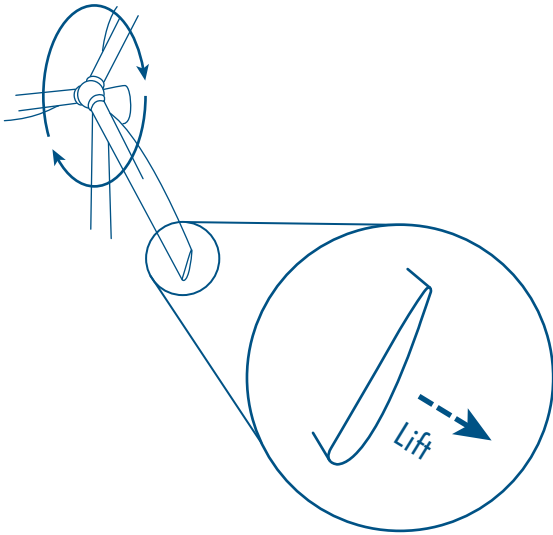
Shape

The airfoil shape of the blade helps to generate lift by taking advantage of the Bernoulli Effect described above. Wind turbine blade designers have experimented with many different airfoil shapes over the years in an effort to find the perfect shape that will perform well in a range of wind speeds. Even minor changes in this blade shape can dramatically affect the power output and noise produced by a wind turbine. To get some ideas of different airfoils used in airplane wings and wind turbine blades, research the United States National Advisory Committee for Aeronautics (NACA). This group was responsible for designing a wide range of airfoils in the 1940's.

The airfoil profile (shape) of a turbine blade will actually change down the length of the blade, generally getting flatter and narrower toward the tips of the blades. This is to optimize the lift and minimize drag.

Speed

Remember that the speed of the air passing around the blade is a combination of the real wind and the headwind as the blade moves. The faster the blade is moving, the more drag/headwind it experiences, but the lift force will also increase as the blades move faster.



Airfoil shapes

The tips of wind turbine blades travel much further with each rotation of the blades, and therefore move through the air much faster than the roots of the blades. Since they are traveling the furthest distance with each rotation (distance/time = speed), the tips of turbine blades experience more headwind. The roots, or base, of the blades do not experience as much headwind since they are passing through the air much more slowly.

The faster the air molecules are passing over a blade or wing, the more lift can be generated. So the tips of real turbine blades generate much more lift than the roots. Some large wind turbines have blade tip speeds over 322 km/h (200 mph)!

Angle

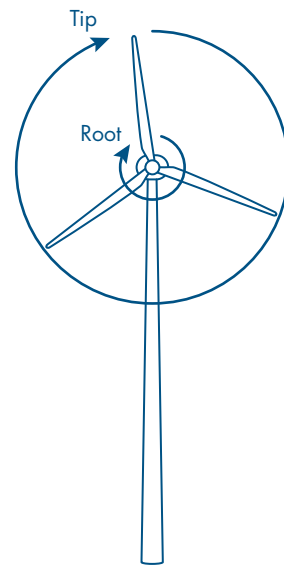
The angle of the blades also greatly impacts how much lift is generated. On large wind turbines, the blade angle is constantly adjusted to give the blades the optimal angle into the apparent wind. The angle of the blade relative to the plane of rotation is known as the pitch angle. The angle of the blade relative to the apparent wind is called the angle of attack. The angle of attack is very important, but also complicated since it will change as the real wind speed changes and the speed of the blade (headwind) changes. On most airfoil blades shapes, an angle of attack of 10-15 degrees creates the most lift with the least drag.

Real wind turbine blades typically have a twisted pitch—meaning the blade angle is steeper at the root of the blade and flatter further away from the hub. Once again this is due to the fact that the tips move so much faster through the air. By twisting the pitch, the blades are able to take advantage of a more ideal angle of attack down the length of each blade. The tips of a real turbine blade may have close to a 0 degree pitch angle, but this section of the blade generates a great deal of lift.

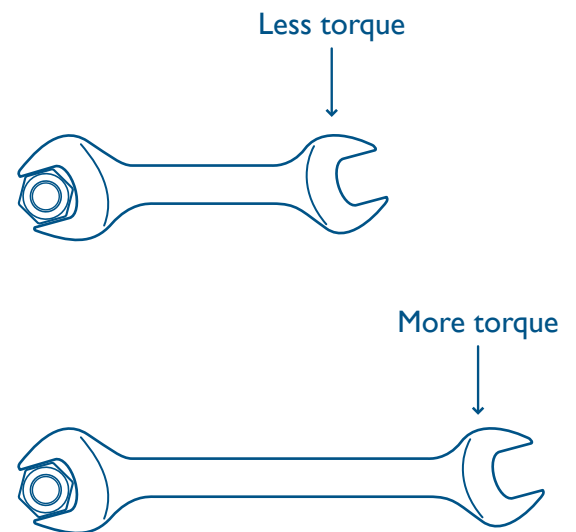
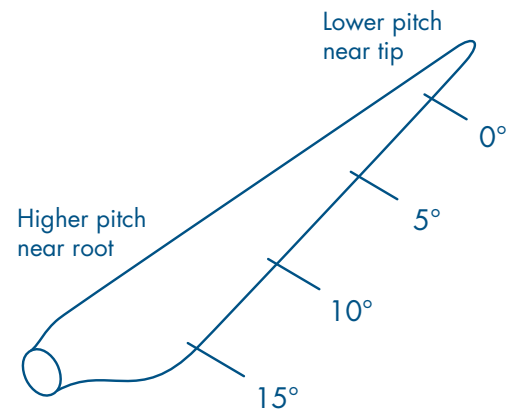
What is Torque?

Torque is a force that turns or rotates something. When you use a wrench on a bolt or twist a screw loose with a screwdriver, you are generating torque. Torque is a lot like leverage. If you are trying to turn a wrench, sometimes you need a lot of leverage to loosen a tight bolt. Wind turbine blades are like big levers—but instead of your muscle turning them they use the force of the wind!

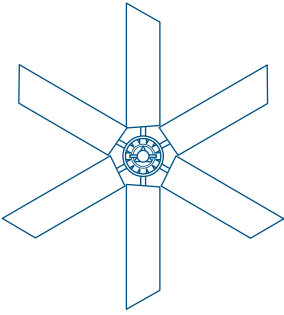
Torque is equal to the force multiplied by distance. This means that the longer your blades are, the more torque you can generate. For example, imagine someone trying to wrench loose a tight bolt. Pushing with all their might, they can exert 100 pounds of force. If their wrench was 1 foot long, they would be exerting 100 foot-pounds of torque. If they applied the same force to a 2 foot long wrench, they would then be exerting 200 foot-pounds of torque on the bolt. This additional leverage makes it much easier to loosen the bolt!



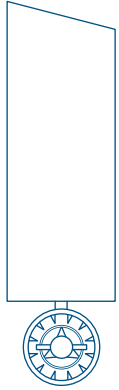
Blade speed is faster at the tip.



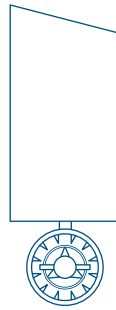
More torque



Less torque



More drag



Less drag

On a real wind turbine, the long blades give the turbine a lot of leverage to provide power to the generator. Utility scale wind turbines often have large gearboxes that increase the RPM of the rotor by 80 or 100 times. This big gear reduction demands a lot of leverage from the blades. Think about riding your bicycle—when you shift into a higher gear it may be harder to pedal. A higher gear ratio demands more torque.

Various load devices you try to power with your wind turbine may require more torque as well. A simple illustration of this is to use your model turbine to power a small LED light bulb and a small incandescent light bulb (Christmas tree light bulbs work well). The LED bulb does not require much torque, so small turbine blades will generally work. The incandescent bulb, on the other hand, requires a lot more amperage to light up so more torque is needed from the blades. Very small blades may not work under a load like an incandescent bulb or a small water pump.

Increasing the torque generated by your blades also often increases the drag they experience as they rotate. For example, longer blades will generate more torque and more drag. Increasing the blade pitch will generally increase the torque and increase the drag. Increasing the number of blades will generally give you more torque and more drag. For this reason, it is important to design your blades to match your load application. If you are using a windmill to lift a bucket of weights, a slowly spinning rotor that generates LOTS of torque will be best. A turbine with a large gear ratio will also need a lot of torque. But if you using a direct drive turbine to light a string of LED bulbs wired in series, you will need a rotor that spins very rapidly with very little drag.

Experimentation

Real wind turbine blades are optimized to generate a lot of torque and lift with very little drag. This is not an easy task! Wind turbine blade engineers have degrees in aeronautical engineering and expensive computer software at their fingertips. But by understanding the relationship between torque, drag, and lift, you can design some great blades with simple materials.

Wind Turbine Blade Variables to Explore:

- Blade shape
- Blade size
- Number of blades
- Angle (pitch) of blades
- Blade material
- Airfoil shapes
- Twisted pitch blades

Designing Curved/Twisted Pitch Blades

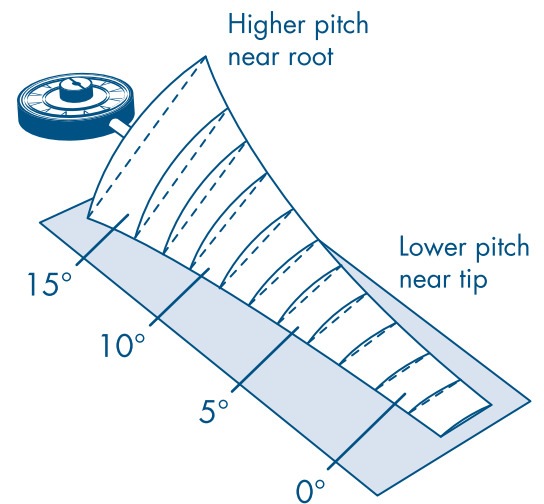
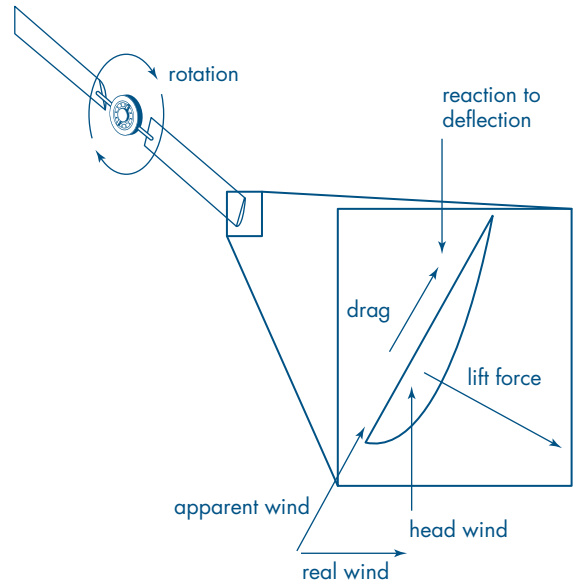
Many modern wind turbine blades have a twisted pitch. At the root of the blade (near the hub), the pitch may be close to 20 degrees from the plane of rotation. The pitch will flatten down the length of the blade so the tips are close to 0 degrees. This is a great way to reduce the drag experienced by your blades, while also maintaining the length needed to generate more torque.

You can design twisted pitch blades with the chipboard in this kit. Remember that you want more pitch near the hub, and almost no pitch at the tips. To make the blades:

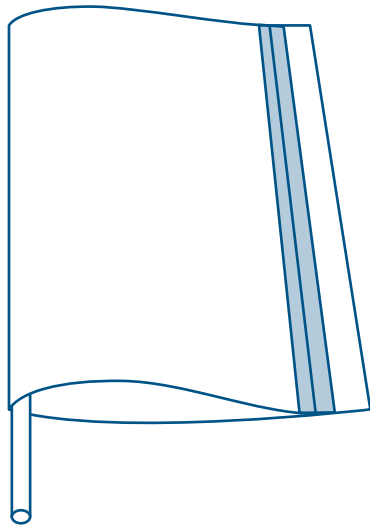
1. Soak chipboard in sink or hold under running water until it is thoroughly wetted, usually no more than one minute.
2. Let excess water drip off over sink. Hold the chipboard to a tube, pipe, or any cylindrical object in order to curl it into a curved shape. You can use rubber bands or masking tape to hold it in place.
3. Air-drying your blade will take about a day; if you like, you can speed the process up by using a hair dryer. When the chipboard is dry, remove it from the cylindrical mold, and admire your handiwork!

Designing Airfoil Blades

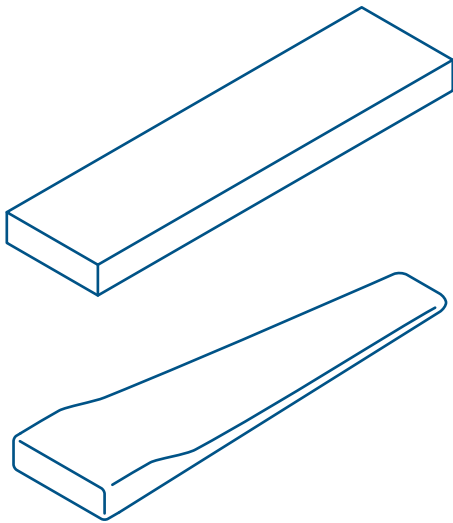
Well-designed airfoil blades will greatly reduce the drag experienced by your blades, while also generating more lift! Remember that the airfoil shape is like an asymmetrical tear-drop. One side is relatively flat, and the other side has a tapered curve.



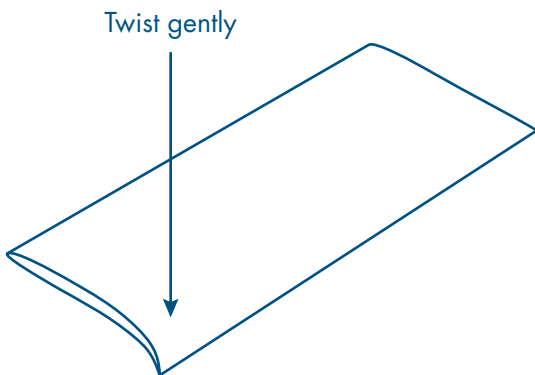
Design your own twisted pitch blades by bending either cardboard or corrugated plastic into a twisted shape.



Shape a piece of chipboard into an airfoil blade.



Sand a balsa wood block into an airfoil blade.



Soak the airfoil balsa, then twist and let dry.

On a turbine blade, the curved side faces downwind. The real wind will hit the turbine blade on the flatter side. This way, as the turbine starts to rotate, lift is generated on the backside of the blade which “pulls” the blade efficiently through the air.

Making your own airfoil blades can be very interesting and challenging. Try a few different designs and you will find that they perform much more efficiently than a flat blade. Here are a few ideas to get you started in designing airfoil blades:

- Shape a piece of chipboard. Fold the chipboard in half widthwise and tape the top half 3/4” from the end of the bottom half. Using hot glue, attach one 1/4” dowel inside the folded chipboard on the crease. This is just one way you could shape your chipboard!
- Carve a balsa wood block into airfoil shaped blades using the included sandpaper. You could also use a file or a handsaw.

You can use the airfoil-shaped balsa wood pieces in this kit in many different ways:

- Use the blades as they are—just attach a dowel!
- Attach the flat sides of two blades together with glue or double-sided tape. Does the thicker blade perform better or worse than a thinner blade?
- File or sand the leading edge to be rounded, and the trailing edge to be sharp. Does this improve blade performance?
- Make a tapered airfoil by cutting the balsa so the tip is narrower than the base.
- You can soak and reshape the balsa to create pitch. Soak the balsa in water for at least an hour, preferably overnight. Remove the balsa and let the excess water drip off. Create the pitch by either gently curving the balsa wood around a cylinder or simply twisting it. Let it dry for one to two days.

Helpful Links and Resources:

<http://www.scoraigwind.com/wpNotes/bladeDesign.pdf>

<http://www.scoraigwind.com/download/windrotord.pdf>

<http://www.otherpower.com/bladecarving.shtml>

<http://www.otherpower.com/blades.html>

http://www.otherpower.com/otherpower_wind_tips.html#blades

http://www.windstuffnow.com/main/blade_design_help.htm



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