EXPERIMENT MANUAL

WIND POWER

THAMES & KOSMOS

WARNING — Science Education Set. This set contains chemicals and/or parts that may be harmful if misused. Read cautions on individual containers and in manual carefully. Not to be used by children except under adult supervision.

Dear Parents and Supervising Adults,

This experiment kit will familiarize your child with the topic of environmentally-friendly energy production. The instruction manual and the materials in the kit will show how to use wind energy to produce electricity.

But first, it is natural to be concerned about safety. Specifically tell your child to read all instructions and safety warnings, and to keep them on hand for reference.

The experiments additionally require a 1.2-volt R6-type rechargeable battery (AA), NiCd or NiMH, able to supply 700-1,200 mAh, which cannot be included in the kit due to its limited shelf life. Please be sure to dispose of used batteries in an environmentally responsible way.

We wish you lots of fun and success with your experiments!

Warning!

For the exclusive use of children at least 8 years of age. Instructions for parents or other supervising adults are included and must be followed. Save the packaging, as it contains important information.

Caution!

Parts of this experiment kit have pointed or sharp corners or edges. Do not injure yourself!

- While experimenting, avoid short-circuiting the battery. It could explode!
- Never recharge non-rechargeable batteries. They could explode!
- Only charge rechargeable batteries under the supervision of an adult.
- Do not perform any experiments using power from an electrical outlet.
- Never insert wires or components into electrical outlets.
- Household voltage (120 volts) can be deadly.

Environmental protection notices

At the end of their life span, all electrical and electronic components of this product must be delivered to a collection point for the recycling of electronic appliances, rather than simply being disposed of in the household trash. This is indicated by the symbol on the product, in the instructions for use, or on the packaging.

The materials are recyclable as indicated by their designation. Through re-use, recycling of materials, or other forms of recycling of used equipment, you are making an important contribution to the protection of our environment. Please ask your local authorities about the relevant disposal facilities.

1st Edition, Franckh-Kosmos Verlags-GmbH & Co. KG, Stuttgart, Germany / 2006
0704083 I-I AN 050706

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Photos: adpic Photography Agency, Forschungsinstitut für Kraftfahrtwesen und Fahrzeugbau [Research Institute for Vehicle Engineering and Construction] FKFS Stuttgart, M. Berrer
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Printed in Taiwan / Imprimé en Taiwan

wind power

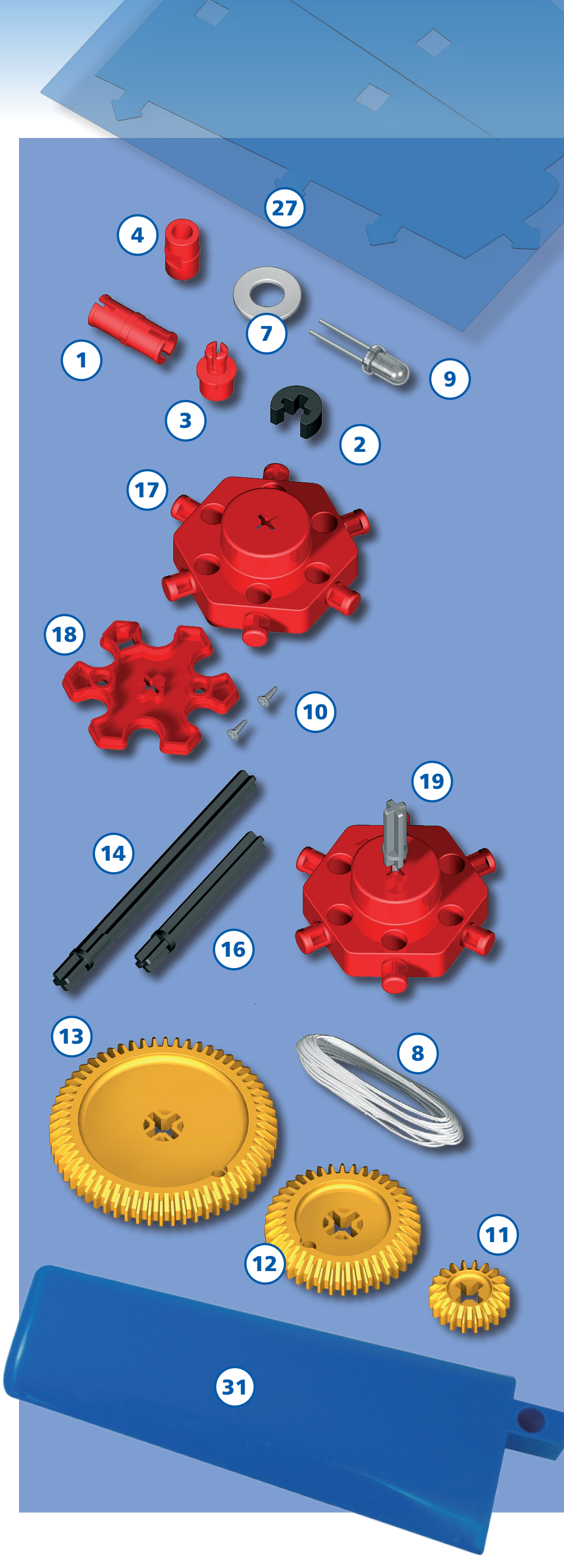
Experiment Manual

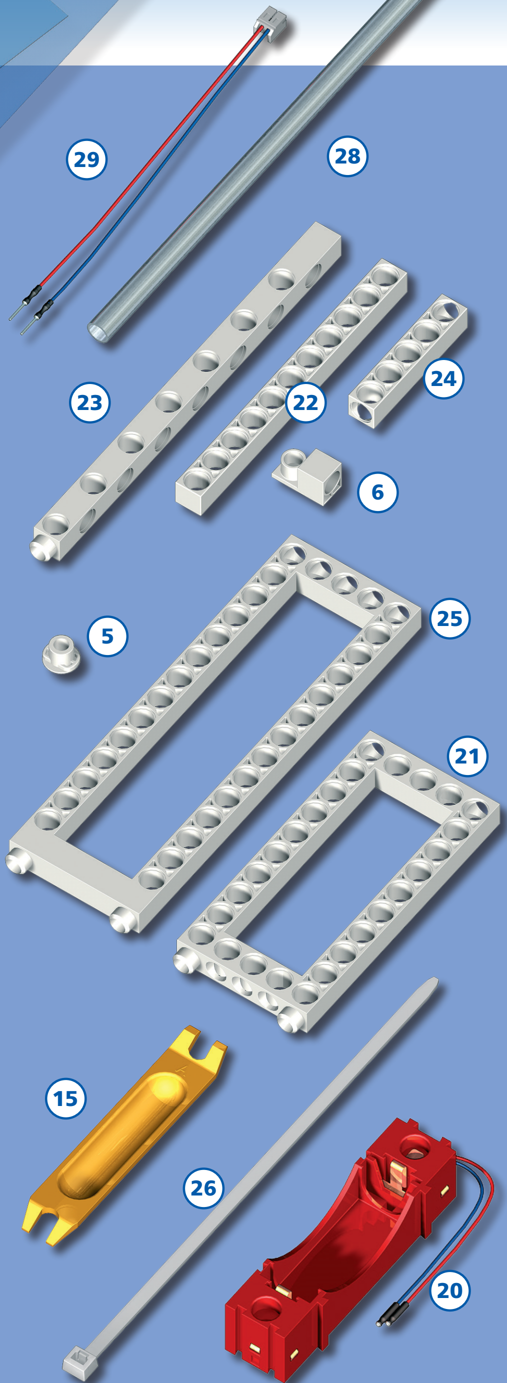
Thames & Kosmos, LLC, Providence, Rhode Island, USA
Franckh-Kosmos Verlags-GmbH & Co. KG, Stuttgart, Germany

Kit Components

No.	Description	Quantity	Part No.
1	Joint pin	1	702524
2	Axle lock	4	702813
3	Shaft plug	4	702525
4	Anchor pin	20	702527
5	Button pin	24	704062
6	Perpendicular connector	6	704064
7	Washer	6	702816
8	Cotton string	1	702812
9	Light-emitting diode (LED)	1	704072
10	Screw	4	704084
11	Small gear wheel	5	702504
12	Medium gear wheel	3	702505
13	Large gear wheel	1	702506
14	Long axle	3	703518
15	Part separator tool	1	702590
16	Medium axle	2	703518
17	Universal adapter housing	2	704066
18	Universal adapter lid	2	704071
19	Pre-assembled generator	1	704068
20	Battery mount	1	704073
21	Small frame	4	703232
22	Short eleven-hole rod	2	703233
23	Long seven-hole rod	6	703235
24	Extra short five-hole rod	3	704163
25	Large frame	2	703239
26	Cable tie	3	704081
27	Wind turbine blade set	1	704065
28	Aluminum tube	1	704080
29	Connector cable	1	704103
30	Experiment manual	1	704083E
31	Hard plastic turbine blades	6	704THA

We reserve the right to make technical changes.





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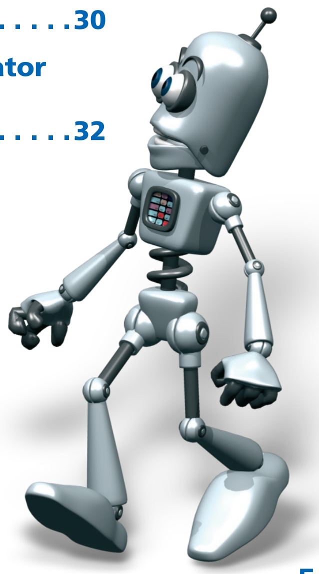
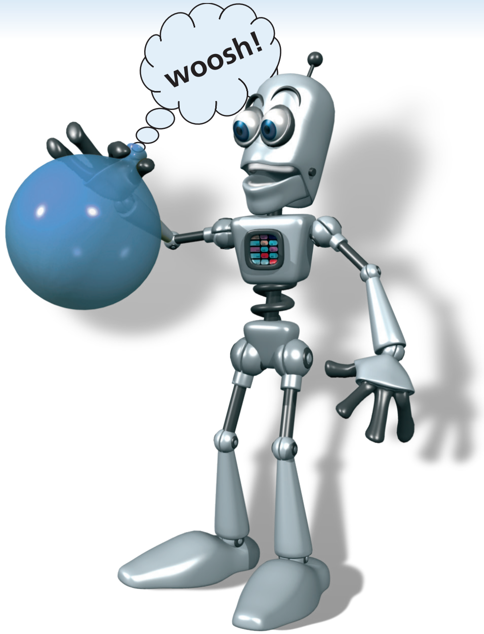


The Air Never Rests

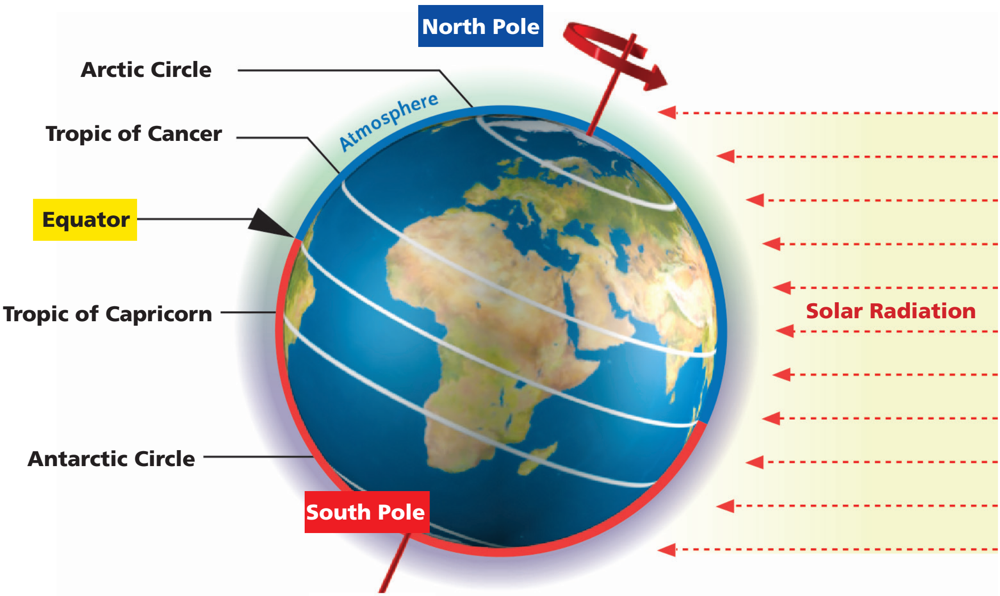
Air in motion

Inflate a balloon and pinch the opening shut. Now touch its surface. Why is it so tight? The air stretched it and became compressed in the process. The air is under pressure and wants to escape. If you let go of the balloon's opening, the air comes hissing out. In other words: You're creating wind. It comes into existence because the pressure in the balloon is greater than that of the surroundings. Wind is nothing but air that gets put into motion in order to balance out unequal pressures.



Solar radiation at the equator and at the poles

The Earth is surrounded by an envelope of air called the atmosphere. It is heated most powerfully where the sun's rays strike it most directly from above — namely, at the latitudes near the equator. All objects expand when they are heated. If they can't expand, they come under pressure. That's how it is with the body of air around the Earth. Where the sun shines strongest — always around the equator — the air pressure is the highest. Near the poles, the pressure is lower. Air that is under pressure always tries to go where the pressure is lower, or toward the poles. You would think the air masses near the



equator should actually move in a straight line to the poles. Instead, they rotate, meaning that they equalize the pressure differences in larger and smaller swirls. These pressure regions are called “high” or “low.”

Compass rose with wind directions

N = North	S = South	W = West	E = East

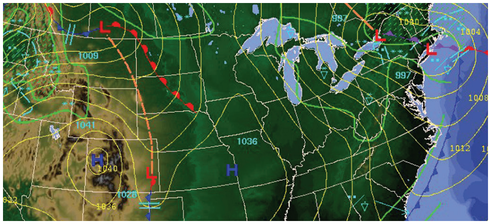
NW = Northwest
NE = Northeast
NNW = North-northwest
NNE = North-northeast
WNW = West-northwest
ENE = East-northeast

SW = Southwest
SE = Southeast
SSW = South-southeast
SSE = South-southeast
WSW = West-southwest
ESE = East-southeast

The wind strength scale

bft	m/s	km/h	Designation	Description
0	0 - 0.2	0 - 0.8	Calm	Smoke rises straight up
1	0.3 - 1.5	0.9 - 5.5	Light air	Smoke indicates wind, flag does not
2	1.6 - 3.3	5.6 - 12.1	Light breeze	Flag moves
3	3.4 - 5.4	12.2 - 19.6	Gentle breeze	Small twigs move
4	5.5 - 7.9	19.7 - 28.5	Moderate breeze	Wind move twigs and thin branches
5	8 - 10.7	28.6 - 38.8	Fresh breeze	Small bushes sway
6	10.8 - 13.8	38.9 - 49.8	Strong breeze	Strong branches move
7	13.9 - 17.1	49.9 - 61.7	Near gale	Entire trees move
8	17.2 - 20.7	61.8 – 74.6	Gale	Wind breaks twigs off of trees
9	20.8 - 24.4	74.7 – 88.0	Severe gale	Minor damage to houses
10	24.5 - 28.4	88.1 – 102.4	Storm	Weak trees fall
11	28.5 - 32.6	102.5 – 117.0	Violent storm	General storm damage
12-17	> 32.6	> 117	Hurricane	Heaviest destruction

Renewable Energy



High and low

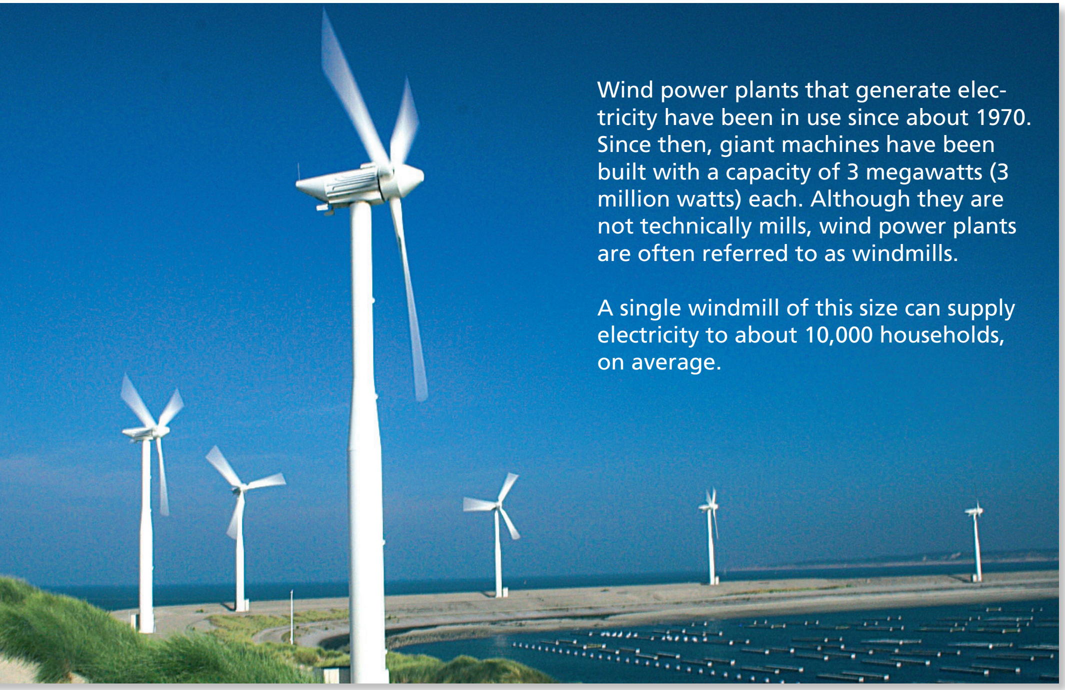
In addition to global air pressure equalization above the Earth, there are also geographical differences in pressure. They come about due to differences in the degree to which air is heated or cooled at different times of day.

The landscape also plays an important role. Over deserts and ripe grain fields, the air heats up more than over oceans and mountains. The movements of air caused by this can deviate a great deal from the general wind directions of the highs and lows. For example, air movement is stronger on coasts and in mountains than over the rest of the land. But the sun is always involved. Wind energy is transformed solar energy.

Endless renewable energy

The atmosphere of our planet is getting warmer and warmer. This leads to more and more frequent extremes in weather: torrential rainfalls with flooding, tornadoes, and forest fires. The main culprit is carbon dioxide spewed out by automobile engines, power plants, and factories. It is created in the combustion of fossil fuels (petroleum, coal, natural gas). But their supplies will be used up in a few decades. For this reason, we increasingly have to tap renewable energies: the heat of the sun, sunlight, biomass, heat from the Earth, and energy from ocean waves and tides. Hydropower plants also supply renewable energy. And of course the wind. It is natural, inexhaustible, and environmentally friendly, and it never runs out. Wind power plants are being built around the world, and in March 2008 their total power capacity reached 100,000 megawatts.

Windmills of Yesterday and Today



Wind power plants that generate electricity have been in use since about 1970. Since then, giant machines have been built with a capacity of 3 megawatts (3 million watts) each. Although they are not technically mills, wind power plants are often referred to as windmills.

A single windmill of this size can supply electricity to about 10,000 households, on average.

Wind farm with modern, three-blade windmills

Sail windmills on Majorca

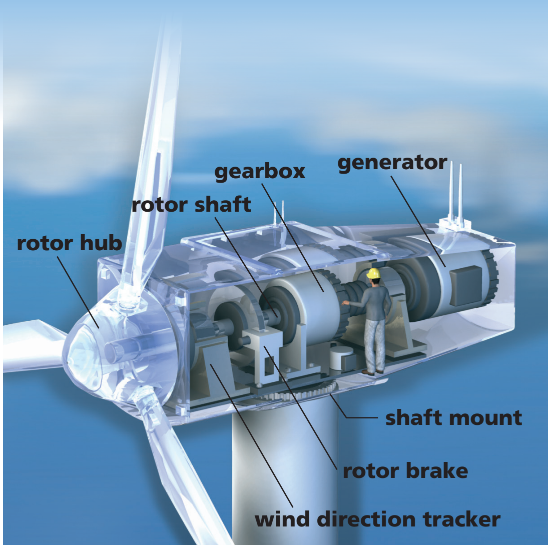
For many centuries, wind power has been used to perform work. Sailing ships crossed the oceans and sail vehicles transported loads on roads. Windmills were used to grind grains and pump water.

Traditional Dutch four-blade windmill

Your Windmill

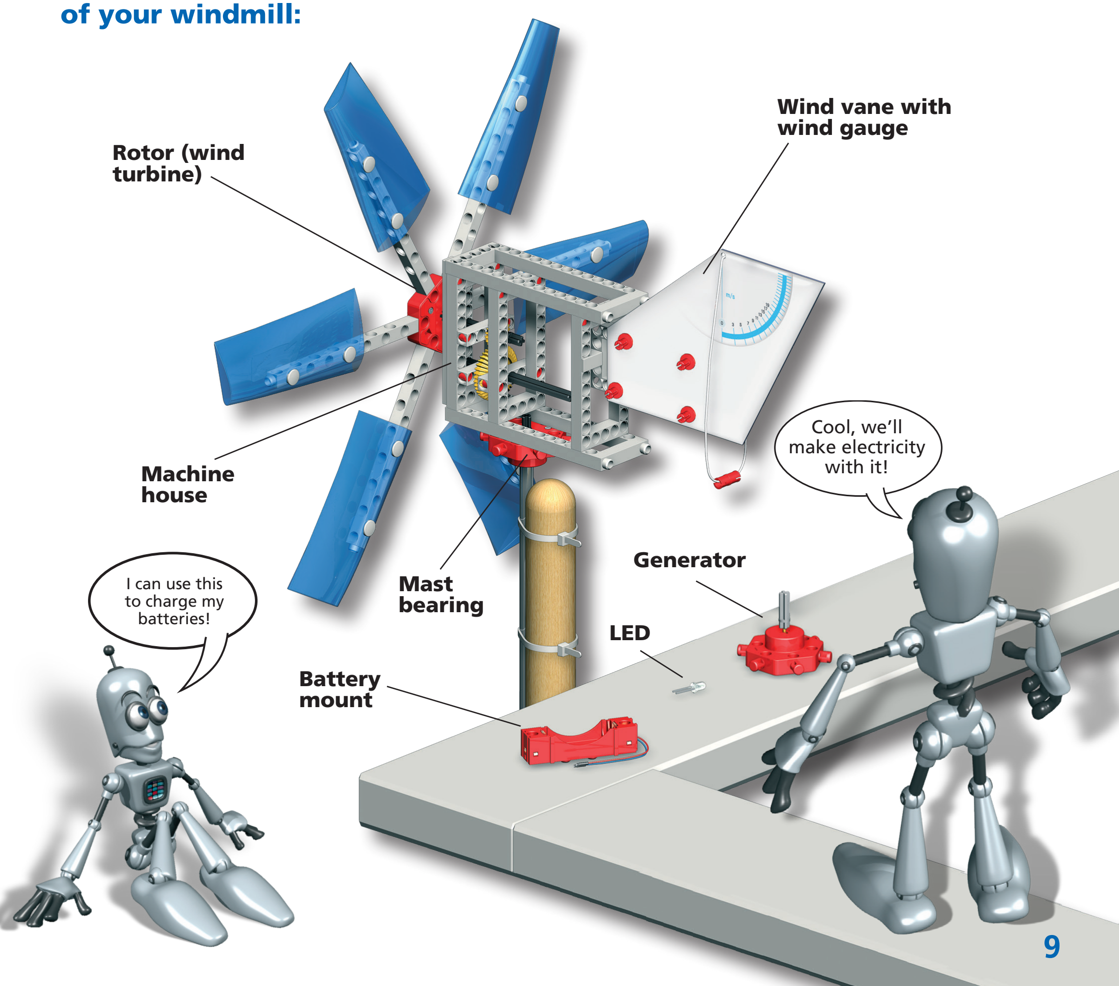
What energy does the wind hold?

In order to get a feel for the wind's energy, we will have to assemble the first stage of our wind power plant. First, let's take a look at its component parts. Just like a big windmill, your windmill has a rotor, a machine house, and a so-called tower (or mast). You can mount the rotor with 2, 3, or 6 blades, and you can install an electricity generator or crane system in the machine house. You can complete the model with a wind vane and wind measurement scale, a battery mount, and an LED.



The inside of the machine house of a modern wind power turbine.

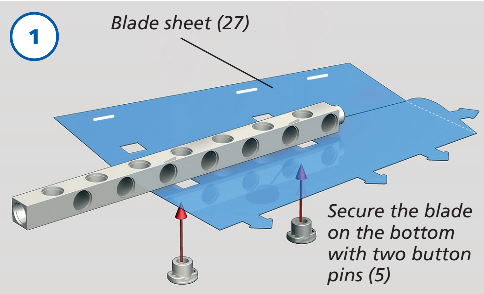
The main components of your windmill:

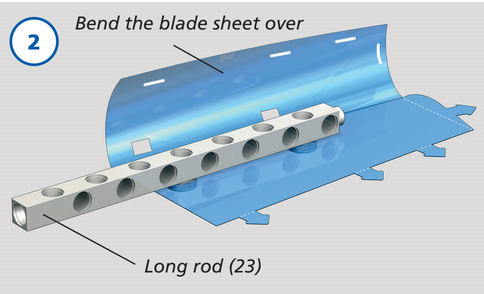


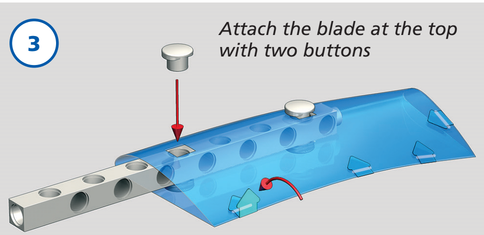
Let’s Build the Wind Power Plant

Assembling the soft plastic blades

You will need the set of blade pieces (27), the long rods with holes (23), and four buttons pins (5) per blade. Fold the blade sheet around the long rods and secure them with the four button pins as shown. When you do this, pay careful attention to the precise position of the blade sheet and the button pins on the rod. Then insert the arrow-shaped tabs into the slits. When you bend the sheet over the rod, you will end up with a typical curved aerodynamic wing profile. The blades can be disassembled by removing the button pins (see page 11, top).

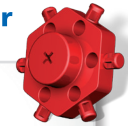


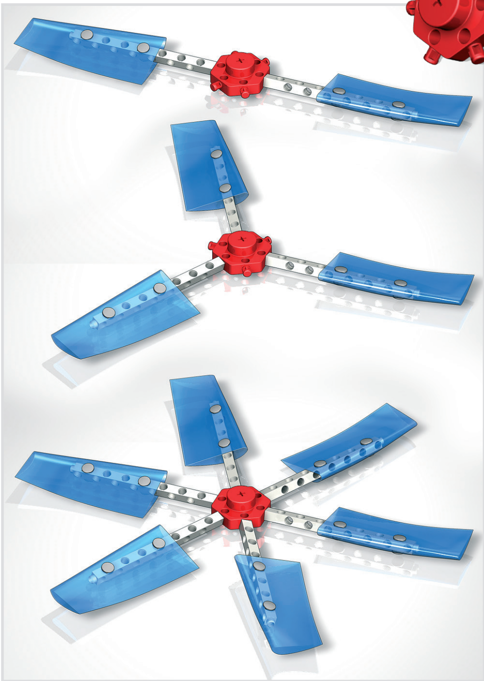




Bend the four arrow-shaped tabs and insert them into the slits. If necessary, secure with tape.

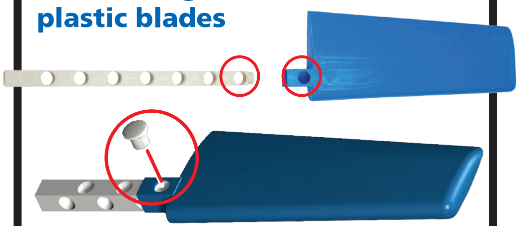
Rotor with universal adapter





The rotor can consist of two, three, or six blades. In the center, the universal adapter functions as the hub, and the blades are inserted into it. There are three universal adapters in the kit. They serve as hub, generator housing, and mast bearing.

Assembling the hard plastic blades

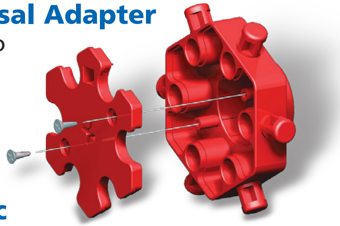


Instead of the soft plastic blades, you can use the hard plastic blades. These are easier to assemble, but they are a little heavier, so you need a stronger wind. Experiment with both types of blades!

Components and Mounting

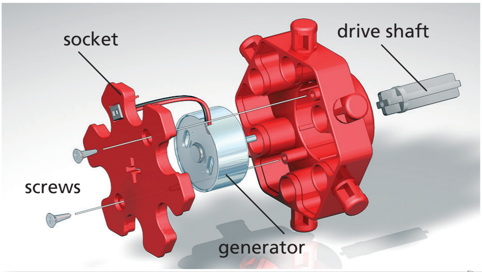
The Universal Adapter

consists of two sections (17 & 18) held together with two screws.

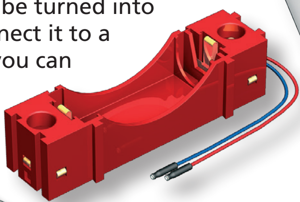


The Electric Generator

in your kit is already assembled. You can use the generator (19) to light up the LED, for example, or to charge a 1.2-volt rechargeable battery. Use the battery mount (20) for that.

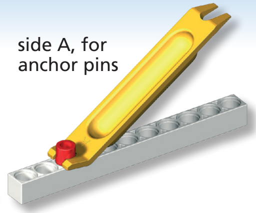


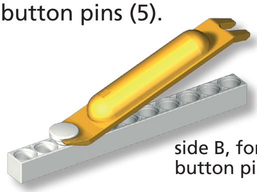
The generator can be turned into a motor if you connect it to a battery. This way, you can convert the rotor into a table fan, for example.



The Part Separator Tool

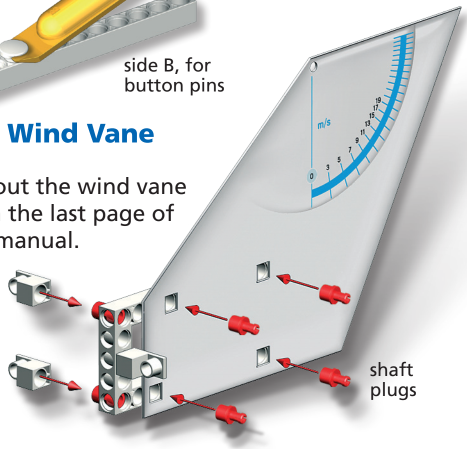
Tool (15) is used to lift out anchor pins (4) and button pins (5).



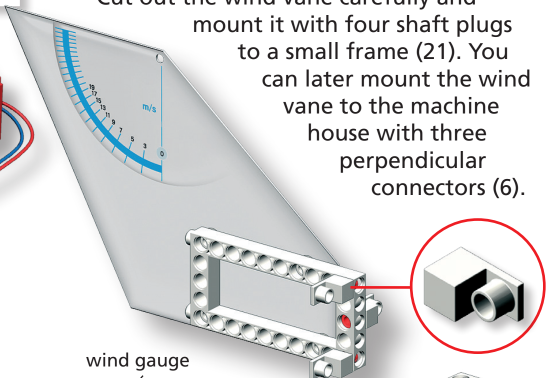


The Wind Vane

Cut out the wind vane from the last page of this manual.

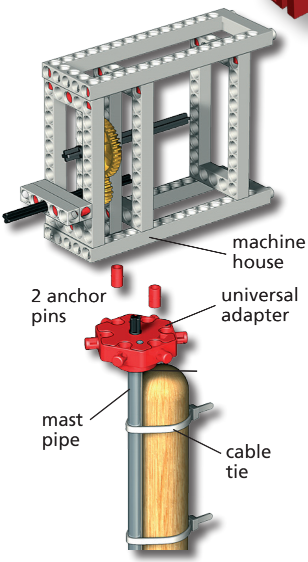


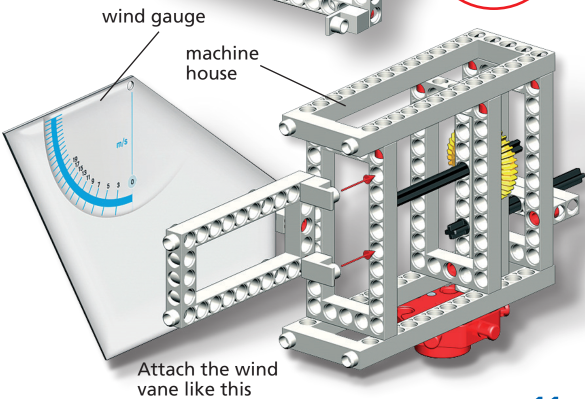
Cut out the wind vane carefully and mount it with four shaft plugs to a small frame (21). You can later mount the wind vane to the machine house with three perpendicular connectors (6).



The mast bearing

This is how the machine house is secured with two anchor pins. You can attach it to a broomstick, secured to a balcony railing for example, with the two cable ties.





The First Power Test

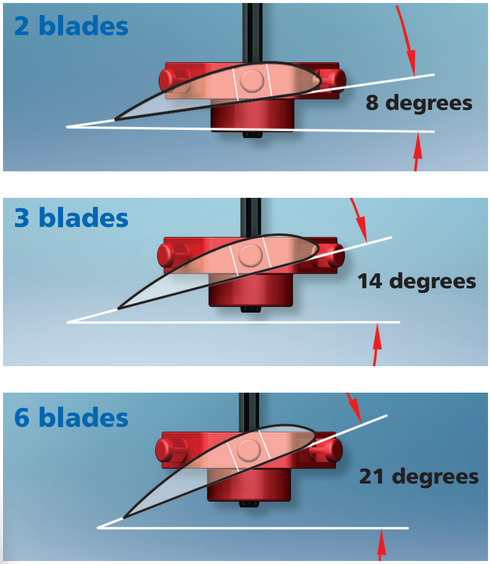
01 *Experiment*

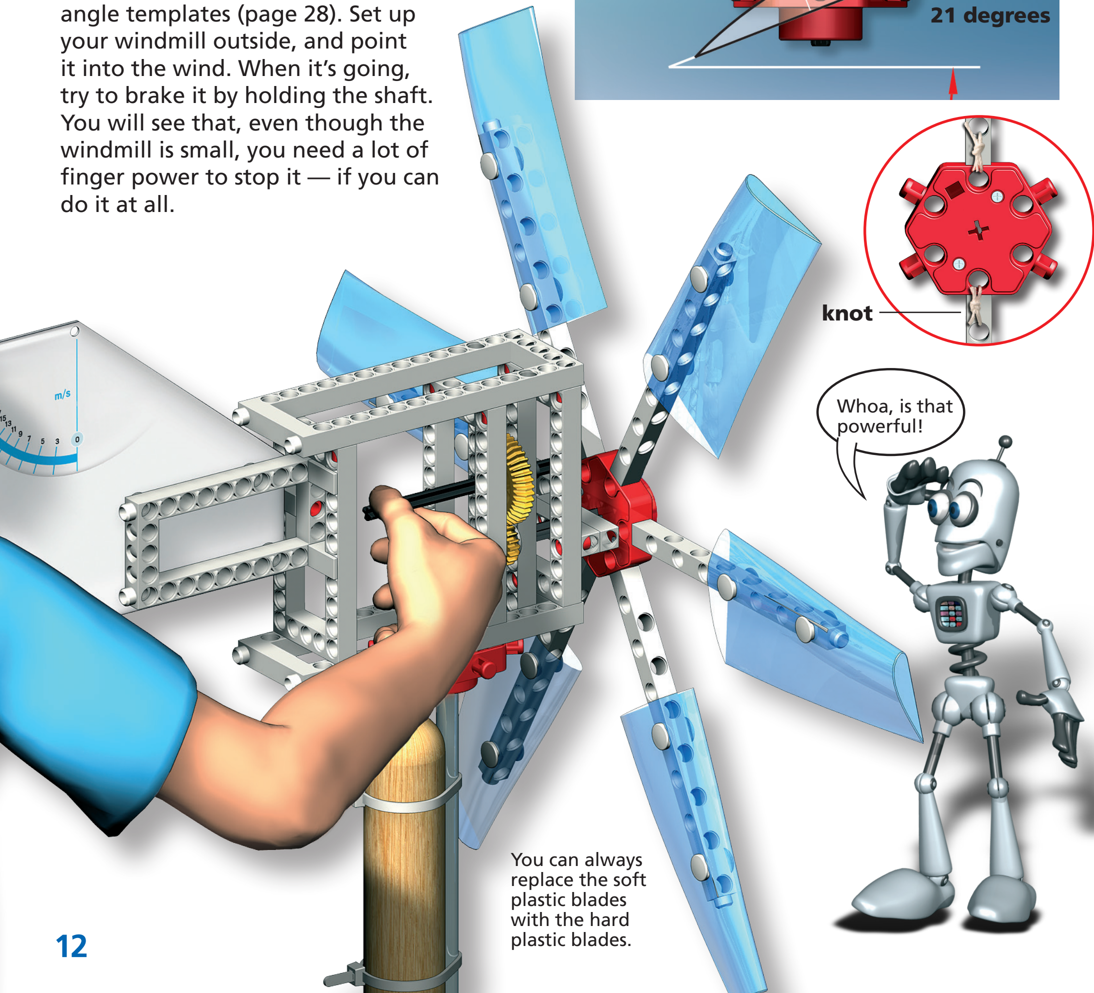
Feeling wind energy with your fingers

First, assemble the machine house as shown on the next page. Attach the 6-blade rotor and the wind vane. You can also secure the blades to the hub with the string, as shown in the inset detail diagram.

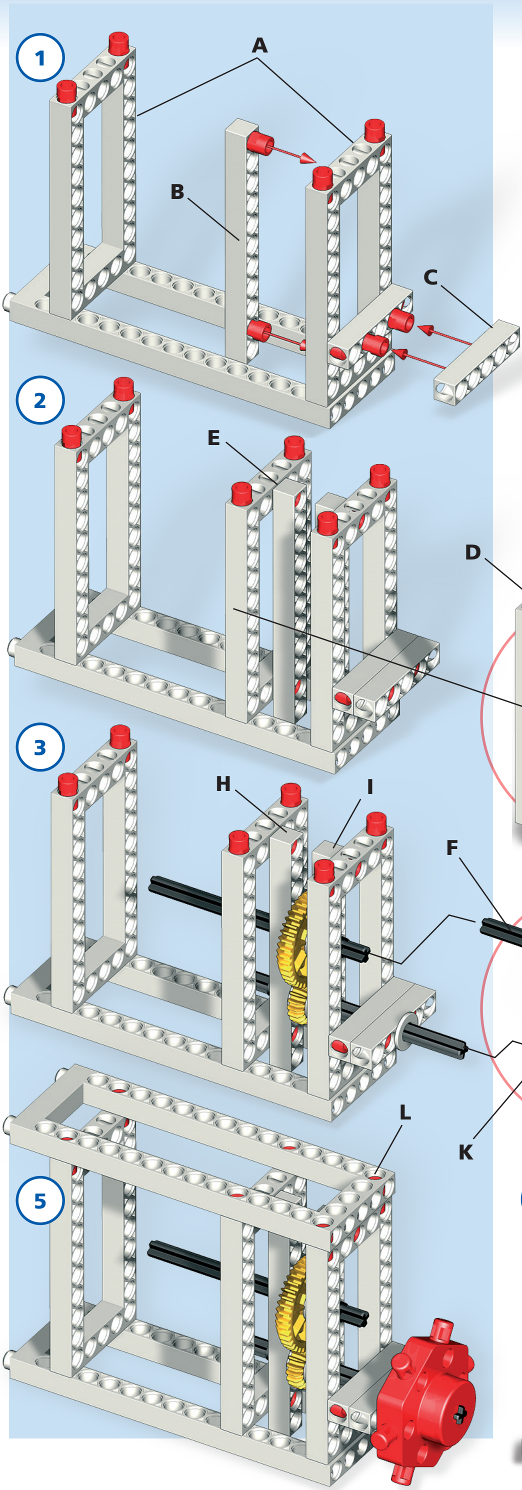
Always set the adjustment angle of the blades in accordance with the number of blades being used. To do this, use the angle templates (page 28). Set up your windmill outside, and point it into the wind. When it's going, try to brake it by holding the shaft. You will see that, even though the windmill is small, you need a lot of finger power to stop it — if you can do it at all.

The adjustment angles





You can always replace the soft plastic blades with the hard plastic blades.

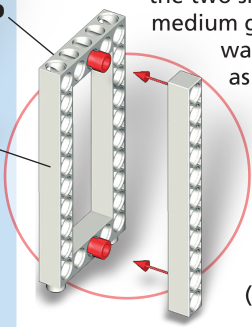


First, attach two small frames to a large frame (A). On top of these, insert the four red anchor pins.

(B) The short rod is attached to the middle of the small frame at the front with two anchor pins.

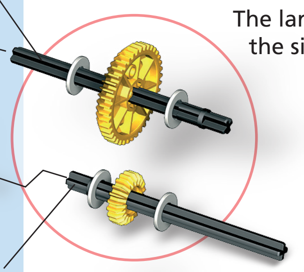
Two five-hole rods (C) are attached to the front small frame with two anchor pins, as shown in Figure 1 and 2.

(D) Now prepare another small frame by mounting a short rod on it, in the middle. Attach it to the large frame as indicated by (E).

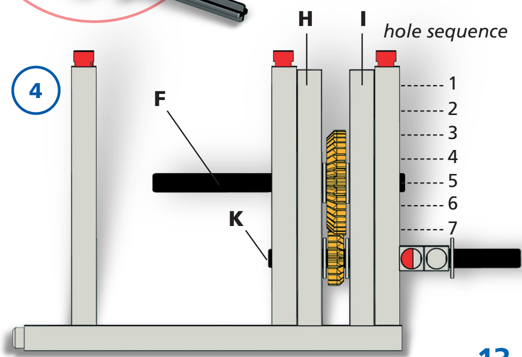


Insert a long shaft (F) from the front through the two short rods (I) and (H). The medium gear wheel and the two washers go between them, as shown in Figure 4.

Insert the second long shaft (K) from behind through the two rods (H) and (I). One small gear wheel and two washers go between rods (H) and (I).



The large frame (L) goes on the six anchor pins on top.

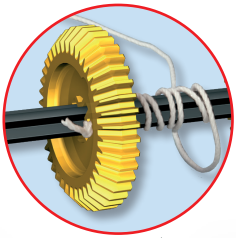


02 *Experiment*

The Windmill Lifts a Weight

Materials: 1.5 meter string and a plastic bottle

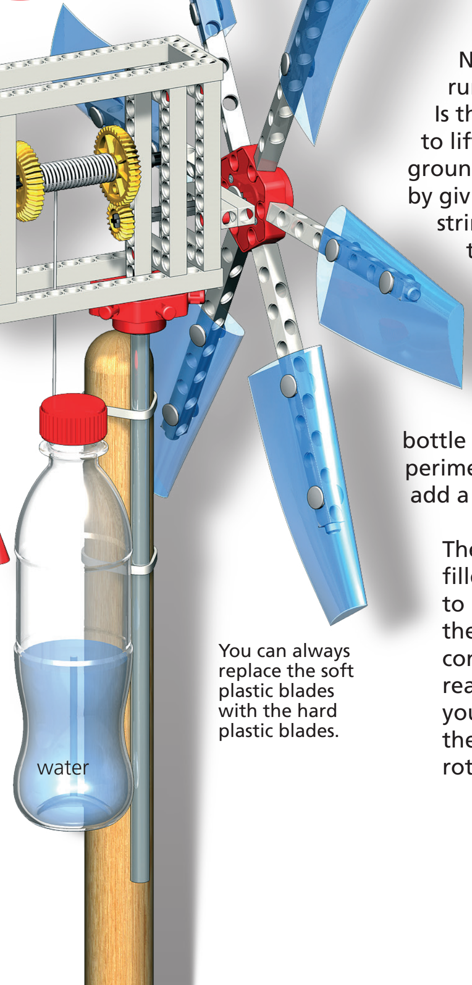
Attach the string like this

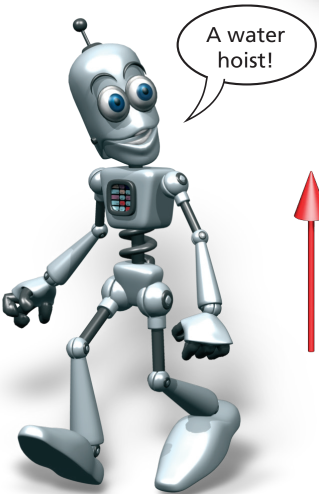


Now you can put your windmill to work. You can make it lift a bottle off the ground by converting it into a crane. Follow the instructions on the next page.

Tie the string to the rotor shaft. Block the rotor from turning by sticking a long shaft through a hole in the front frame. Now attach the windmill to the balcony railing or a fence post with the mast pipe. You can also simply hold your windmill in your hand. First fill the bottle halfway with water. Unwind enough string for it to reach the ground and tie it to the bottle.

Now let the rotor run free and observe: Is there enough wind to lift the bottle off the ground? If not, help it start by giving it a lift until the string winds around the spool a little and then let it go. If the windmill still doesn't have enough power, pour a little water out of the bottle and repeat the experiment. If it goes too fast, add a little water again.





You can always replace the soft plastic blades with the hard plastic blades.

The bottle should be filled just enough for it to lift up slowly given the prevailing wind conditions. Once it reaches the top, turn your power plant out of the wind and block the rotor again.

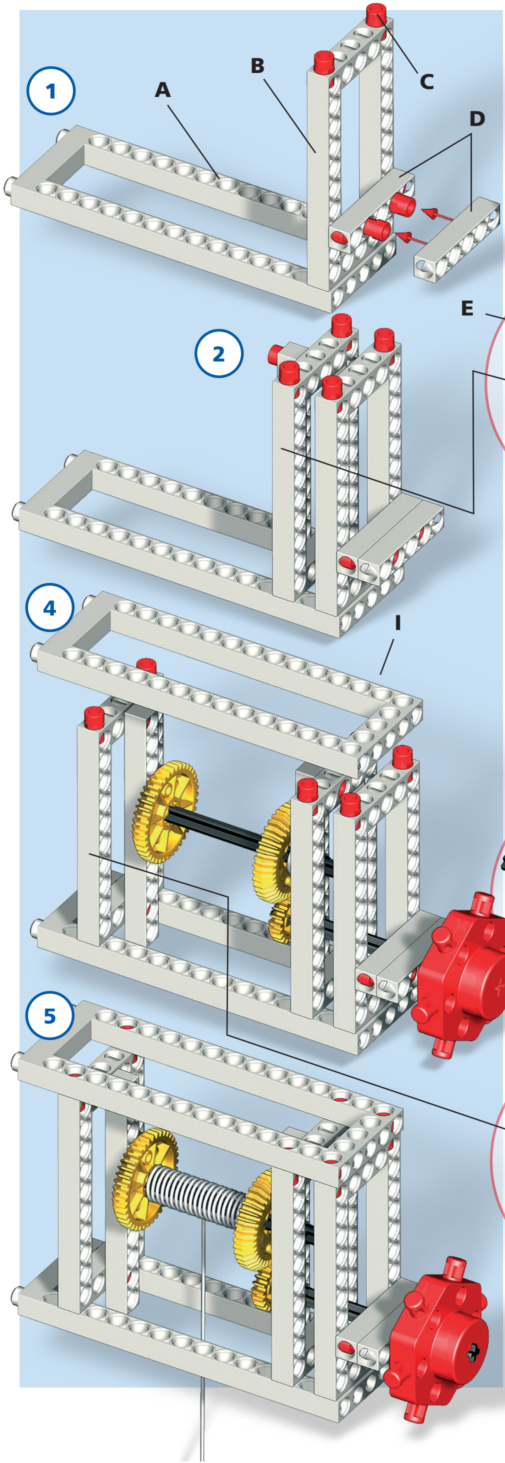
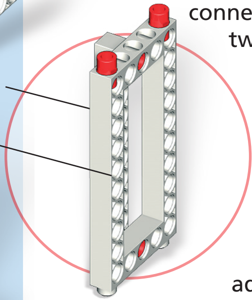


Figure 1: On a large frame (A), attach a small frame (B) at the front and two anchor pins (C) on top of the small frame.

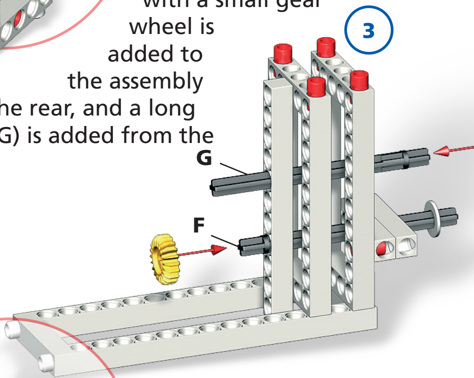
Affix two five-hole rods (D) to the front of the small frame with four anchor pins.

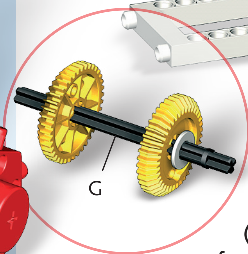
(E) Prepare a small frame with a short rod connected in the middle with two anchor pins. And two more anchor pins on top.



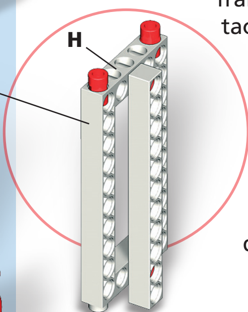
Position this assembly as shown in Figure 2.

Figure 3: A long shaft (F) with a small gear wheel is added to the assembly from the rear, and a long shaft (G) is added from the front.





A washer and then two medium gear wheels are added to the long shaft from the rear.



(H) Now place a small frame with a short rod attached (two anchor pins between the parts and two on top) onto the rear of the large base frame.

Now add the large frame (I) on top and the propeller hub, and you're done!

The Wind Performs Work

Work is force times distance — Let's measure the work done by your windmill

It's possible to measure the work that your power plant accomplishes. But first let's take a look at what physicists mean by work. A physicist would say: **Work is force along a certain distance.**

Work = Force x Distance

And what does a physicist mean by force? Force can accelerate a body, or more precisely a mass. That is, force can make mass go faster:

Force = Mass x Acceleration

Speed is indicated in miles per hour (mph) or kilometers per hour (km/h), and in physics it's common to use meters per second (m/s). An increase in speed per second, or **acceleration**, is written **m/s** or **m/s²**.

What is force? What is mass?

The unit of measure for force is the **new-ton**.

One newton (N) is the force required to accelerate a **mass** of one kilogram by 1 m/s². Mass is the characteristic of an object to be heavy and inert, and it stays the same for that object on any heavenly body. The weight of an object is due to the action of gravity on the object's mass.

On Earth, this is the earth's **gravitational pull**. It amounts to 9.81 newtons. So an object with a mass of 1 kilogram has a force of weight of 1 kg x 9.81 = 9.81 newtons.

On the moon, with a gravity six times smaller than that of Earth, the force of weight of the same object would be just 1.63 N. (That's why you can jump six times as far on the moon!)

The unit of measure for work is the **newton meter** or **joule**, or **watt-second** or **kilo-watt-hour.** So if a force of 1 newton moves an object with a mass of 1 kg by 1 meter, 1 joule's worth of work is performed.

What makes work different from energy?

Energy means the ability to perform work, and energy itself is stored work.

There are various forms of energy

The water that is stored high up in a reservoir, the electrochemical energy in a battery, or the centrifugal energy in a carrousel are all forms of energy. The energy contained in a moving object like the wind is called **kinetic energy**, which literally means movement energy. Energy is measured in joules as well. In the next experiments, we will start measuring work and power.

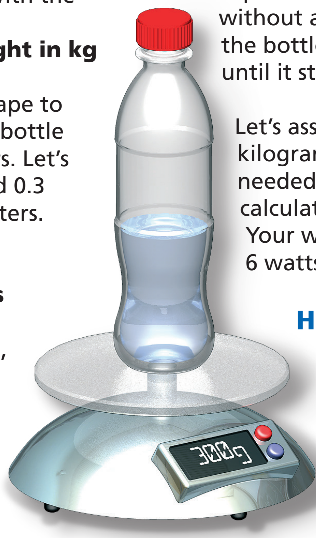
03 *Experiment*

All bottled up

Let's measure work

Materials: kitchen or letter scale, yardstick or measuring tape

Repeat the last experiment and then use a letter or kitchen scale to weigh the bottle including its contents, in kilograms. If your scale only measures weight in pounds, convert pounds to kilograms with the following formula:
weight in lbs x 0.454 = weight in kg



Use a yardstick or measuring tape to measure the distance that the bottle was lifted. Measure it in meters. Let's assume that the windmill lifted 0.3 kilograms a distance of 1.2 meters.

Then you calculate:
0.3 x 9.81 x 1.2 = 3.53 joules

Our wind crane is really strong, isn't it? A much smaller wind crane would be able to do the same work, although you'd have to install a smaller transmission. Then it would just need more time. But you would still say that your windmill accomplishes more, because it lifts the bottle faster. The equation for the **power** of a machine does factor in time, which would be joules per second to a physicist or engineer.

The unit of measurement for power is the watt (W) = J/s, or the kilowatt (kW) = kJ/s.

$$\text{Power} = \frac{\text{Work}}{\text{Time}}$$

04 *Experiment*

Lifting bottles with the stopwatch

Let's measure power

Materials: a watch with a second hand, or a stopwatch

Start by placing the bottle on a chair and measure the distance from the lip of the bottle to the spot where it hits the shaft. Keep some spare string for a few test runs without a load. Measure the lift time of the bottle from the moment it takes off until it stops at the shaft.

Let's assume that the windmill lifted 1.5 kilograms a distance of 1.2 meters and needed 3 seconds to do it. Then you calculate: 1.5 x 9.81 x 1.2 = 5.9 watts. Your windmill has this power of around 6 watts even with a light wind.

How much power does the wind have?

The power of your power plant depends on the wind speed. The faster the wind blows against the rotor, the more power it produces. The air is a body too. One cubic meter (a cube with sides one meter in length) weighs 1.22 kilograms. However, since it is a flowing body rather than a solid one, it imparts its force fluidly rather than all at once to an object that stands in its way. When the object moves aside, some of the wind's kinetic energy is transferred to it. The rotor blades are this kind of object. They move aside by rotating away from the wind. In the process, they convert the wind energy into mechanical energy.

The Wind Formula

If you want to calculate this, you will need to know three variables:

1. The density of the air. In physics, density has the symbol "ρ." (It indicates the mass of a gas in kilograms per cubic meter; in the case of air, this is 1.22.)

2. The prevailing wind velocity (v) in meters per second (m/s).

3. The cross-sectional area (A), in m^2, for which the wind power is to be calculated.

The power formula for wind:

$$N = 0.5 \times \rho \times A \times v^3$$

ρ is the Greek letter rho, for density. N is power. A is cross-sectional area. v^3 means that the velocity is multiplied by itself three times.

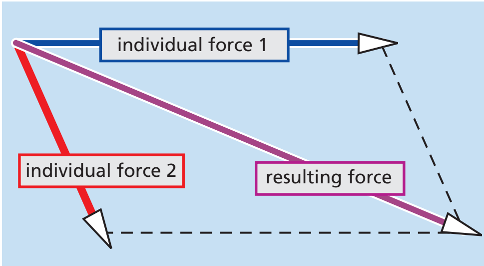
Let's assume that the wind acts on a windmill that has a blade surface of 1 m^2 with a density of $\rho = 1.22$ and a velocity of 10 m/s, or 36 km/h ($v^3 = 10 \times 10 \times 10 = 1{,}000$), in which case it would yield a power at the rotor of 0.5 x 1.22 x 1 x 1,000 = 610 watts.

How does the windmill blade take energy away from the wind?

Now we come to the actual secret of a windmill: Namely, how it manages to absorb kinetic energy from the wind and turn it into rotational movement. We will reveal the secret in an experiment.

Adding up forces and breaking them down

You can add up forces of various sizes and directions by representing them as arrows. The length of the arrow indicates the magnitude of the force, and its direction indicates the force's line of action. Two individual forces yield a third resulting force. If they act on a common point, you can add them up with a force parallelogram. For each force, you draw a parallel line through the arrow point of the other force. The point where the parallel lines intersect is the point where the resulting force ends.



You can add up forces with a force parallelogram

Conversely, you can break down one known force into two individual forces whose direction you know but whose magnitude you want to determine. We will do that in order to determine the forces in Experiment 5.

05 *Experiment*

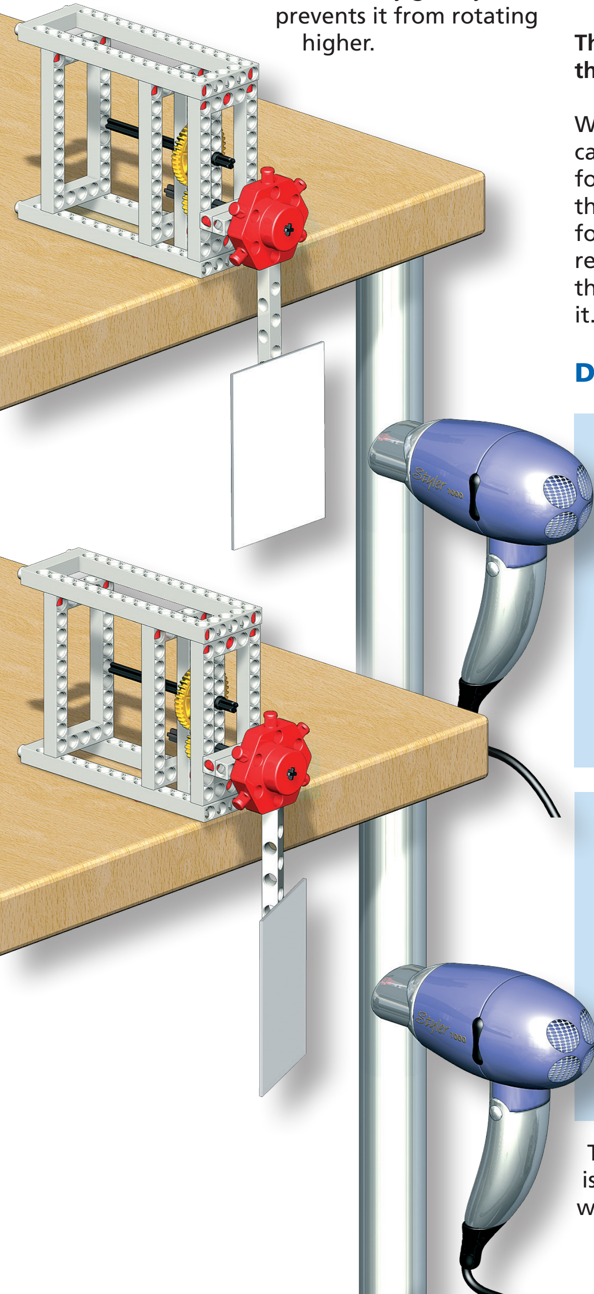
The wind on the inclined plane

Materials: hair dryer, postcard, tape

Remove all the blades from the rotor, stick one single long rod onto the hub, and attach half a postcard to the rod with tape so that it is flat (at a right angle) relative to the hair dryer wind. That's your test blade. Set the assembly at the edge of a table. Now blow air against the blade (not too strongly) from the front. It hardly moves.

A Wind Experiment: Forces on a Flat Surface

When you assembled the rotor (page 10), you were careful to mount the blade rods at an angle in the rotor hub. Again, twist the rod so the blade is at an angle to the wind, and blow. You will see that the test blade turns to the side. Only gravity prevents it from rotating higher.

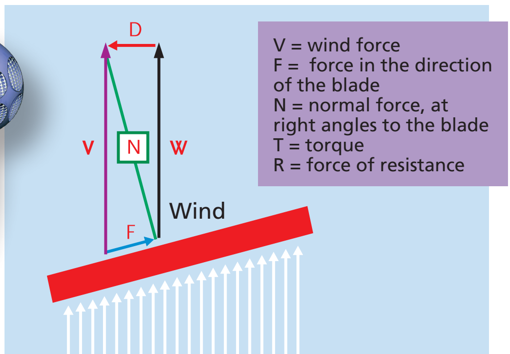


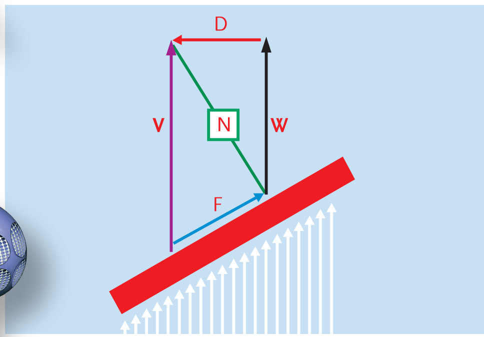
Now set the cardboard blade at more of an angle and you can see that it gets deflected farther. From a physics perspective, the post-card is an inclined plane. It can only convert the wind power V into sideways movement when it is mounted at an angle.

This angled position of a wing is known as the angle of attack.

With a force triangle, the force of the wind can be decomposed into the two individual forces N (the normal force perpendicular to the plane) and F (at an angle). The normal force can be broken down into the force of resistance R and the torque T, which moves the blade to the side (gives it lift) and turns it.

Distribution of forces at the blade



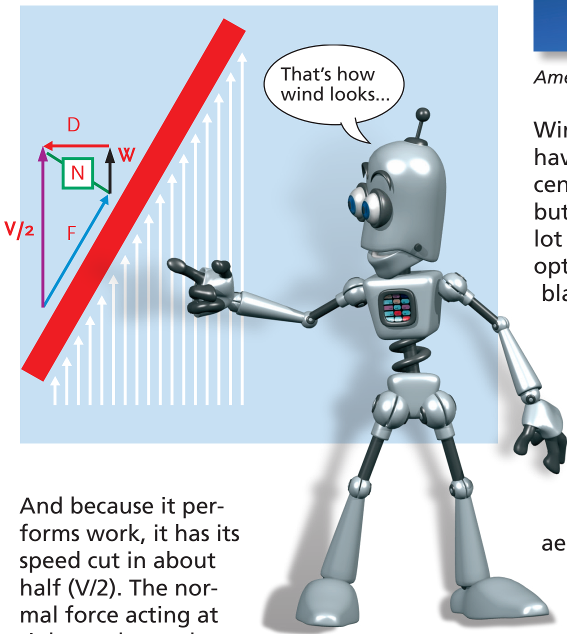


The greater the angle at which the plane is set, the stronger the torque T is, and the weaker the resistance.

Apparent Wind

The last experiment showed how forces are distributed in the resting position and with a very slow sideways movement of a surface. Now let's imagine a windmill with several such angled blade surfaces and that is turning. Then, it is not just the normal wind (the true wind) that is involved, but also the wind produced by the blades themselves. The two combine into a new direction. The wind that actually flows around the blades comes at a much steeper angle from the front.

We call it by the same term used in sailing, namely **apparent wind**. It's like this:



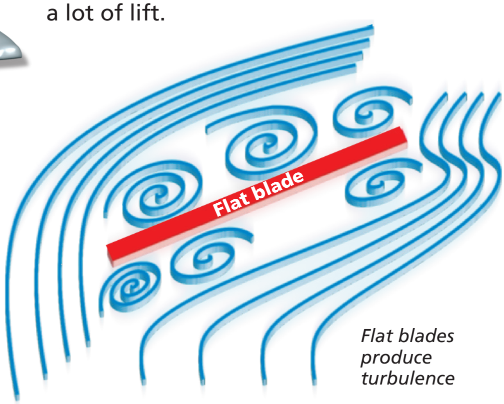
And because it performs work, it has its speed cut in about half (V/2). The normal force acting at right angles to the blade is also known as lift. It is divided into two partial forces, R and T. You can see that not all the lift of the blade aids in rotation, and the blade's resistance is greatly reduced by the steep oncoming flow. That is precisely the goal of a windmill builder: low resistance with high lift.

There were and still are windmills constructed with an entire wreath of flat blades like this. A classic example is the American-style windmill used mostly for pumping water.

American-style windmill

Windmills on the Spanish island of Majorca have been pumping water to the fields for centuries. They rotate slowly and patiently, but they are simple to build and produce a lot of force. Unfortunately, they do not make optimal use of the wind, because their flat blades cause too much turbulence.

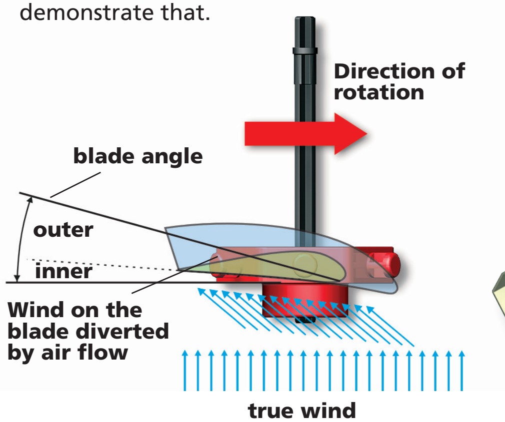
Turbulence wastes energy because it produces resistance. Electricity-producing windmills have to turn quickly and powerfully without much loss from turbulence. Their generators require a high number of rotations per minute. That works best with aerodynamically-shaped blades that produce a lot of lift.



Flat blades produce turbulence

Turbulence and resistance

What does it mean to be aerodynamically designed? It means that a body has a shape that offers the least resistance to the wind. Rounded, tapering surfaces produce less turbulence than sharp edges. An experiment will demonstrate that.



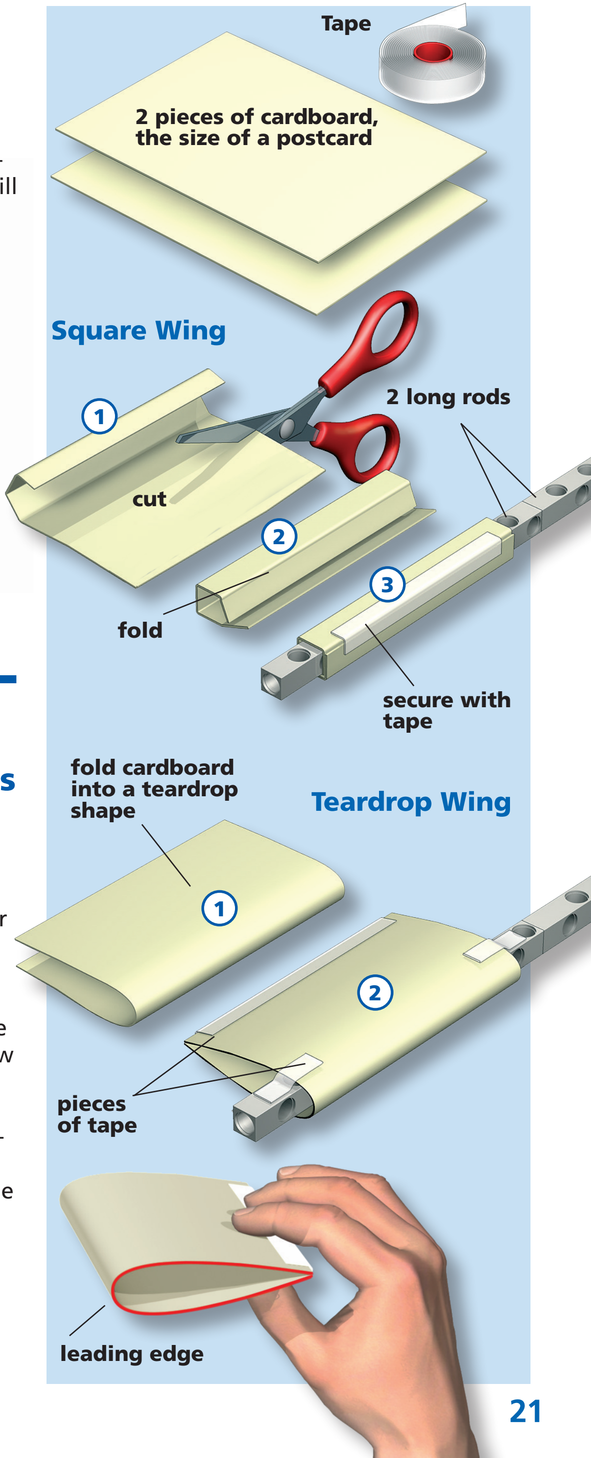
06 *Experiment*

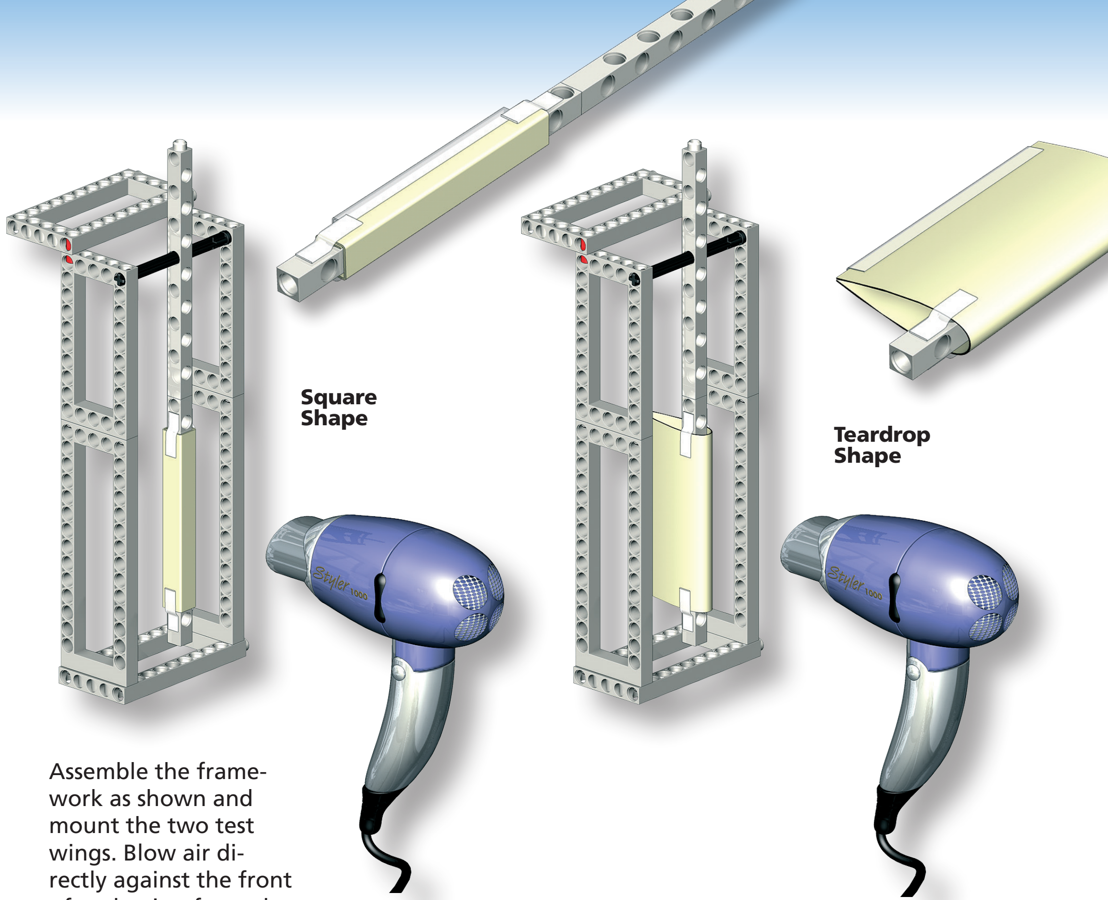
Comparing resistance shapes

Materials: four long rods (23), four small frames (21), two large frames (25), one long shaft (14), two pieces of thin cardboard the shape and size of a postcard, tape, hair dryer

Take one cardboard piece and fold it very tightly lengthwise around a long rod, to create a four-cornered tube. Be sure that the tube has sharp corners. Tape it together. Now connect another long rod to the first.

Fold the second cardboard piece into a pear- or teardrop-shaped tube with a round leading edge. Be careful not to crease it! Examine the illustrations closely.



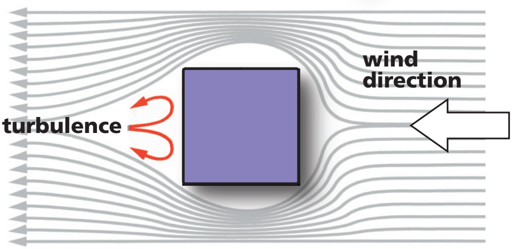


Assemble the framework as shown and mount the two test wings. Blow air directly against the front of each wing from about 30 cm away, alternating back and forth between the two, and watch how they move.

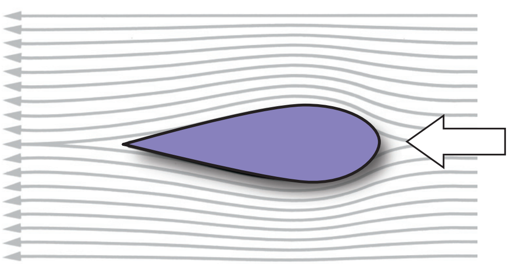
The square wing clearly gets pushed farther back, even though it has the same cross-sectional surface area relative to the wind as the teardrop-shaped wing and the wind flows over a considerably larger surface. Of all shapes, the streamlined teardrop offers the least resistance to the wind. The lines of airflow around the object hug tightly to its surface. With the four-cornered shape, the air particles are slowed down in turbulence.

The flow of air particles around a body of resistance is represented with streamlines. In order the extract as much energy as possible from the wind, a long teardrop shape is always better than an angular board.

Streamlines



Development of turbulence on a square wing



Little resistance on a teardrop-shaped wing

07 ***Experiment***

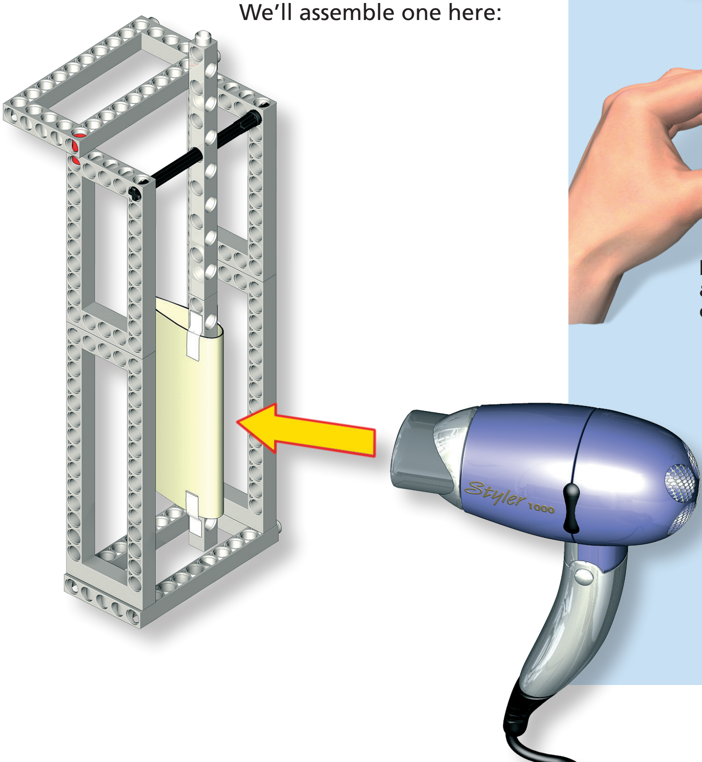
Intermediate wing with teardrop shape

First, blow air on the nose of the wing with the teardrop shape. The resistance makes it move back.

Now move the hair dryer slowly to the side, so the air stream hits the front of the wing at an angle. What happens? The rod with the wing doesn't just return to its resting position, it moves forward a little.

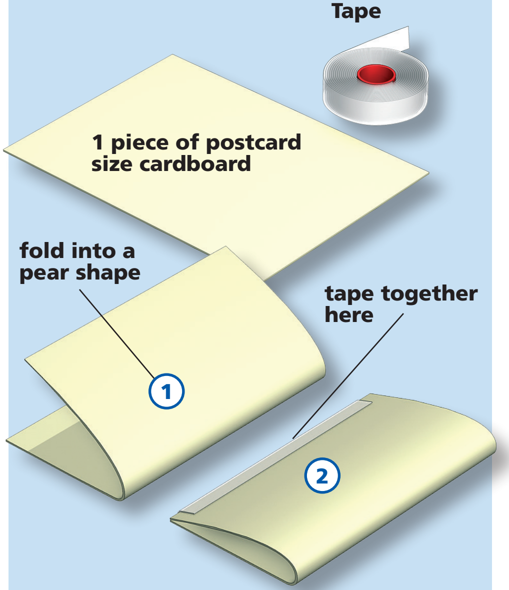
That's how much smaller the resistance has become and how much greater the lift! What you see here also happens when the windmill turns. You have copied the direction of flow of the apparent wind.

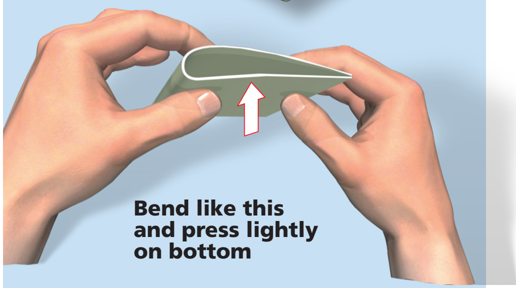
But it gets even better with a shape that birds and airplanes use to fly. We'll assemble one here:



Aerodynamic wing with lift

Materials: a very flexible postcard or a piece of heavy drawing paper, tape.



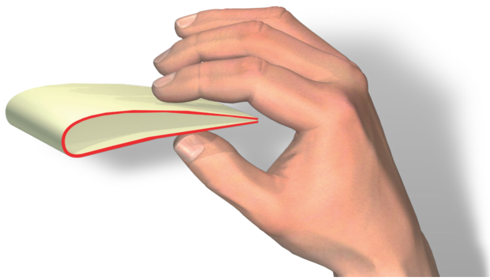


Fold the cardboard into a pear-shaped tube and tape the two short edges together.

Hold the tube firmly at the seam and press upward as shown in the illustration.

Caution: Bend the sheet downward a little! When you let go, you will end up with a teardrop-shaped wing flattened on the bottom — a wing that provides lift.

Now let's test the lift of our aerodynamic wing. This is how it should look.



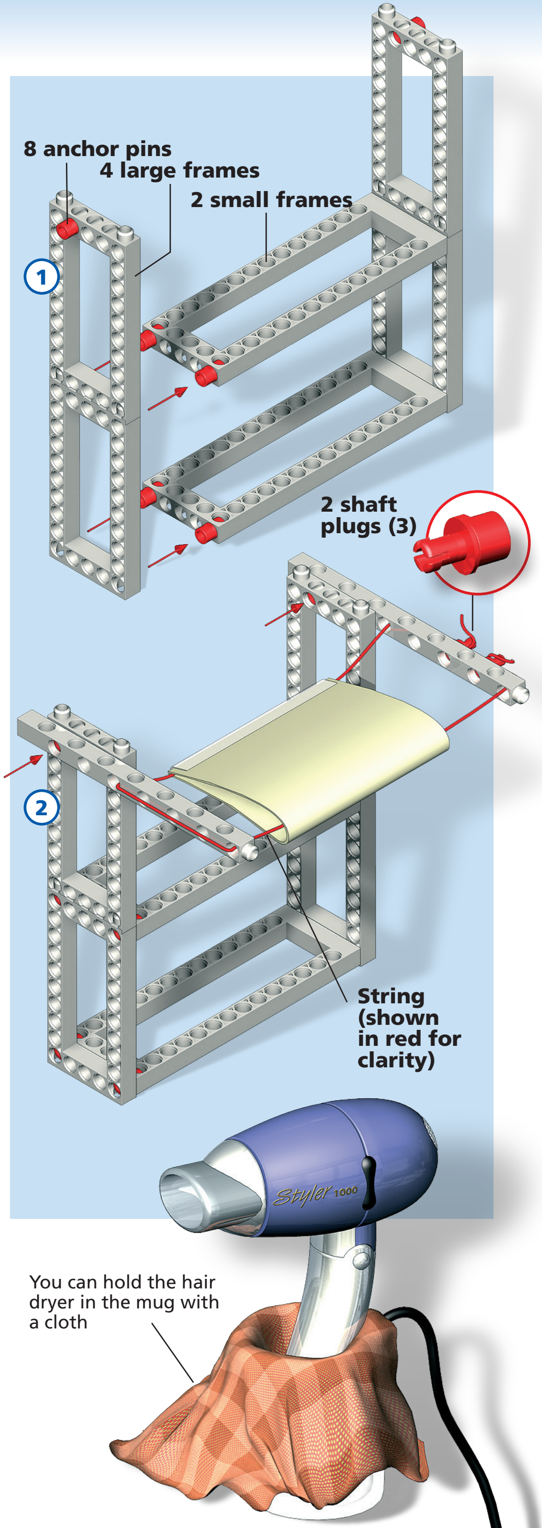
08 *Experiment*

Putting the aerodynamic wing to the test

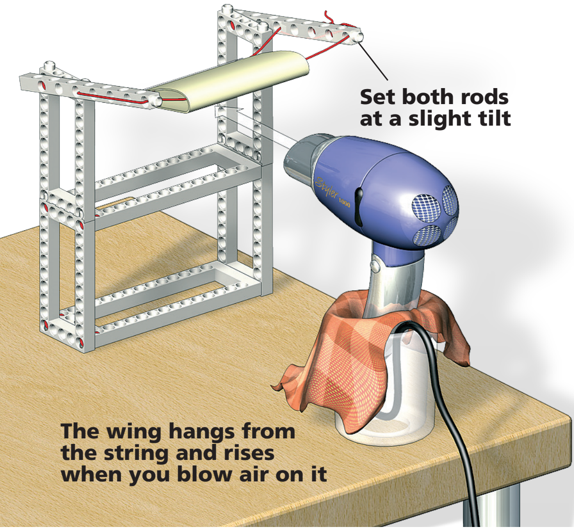
Materials: kit parts as shown, hair dryer, knitting yarn, paper glue

First we'll build a new experimental assembly as shown in Figures 1 and 2.

Then position the hair dryer in such a way that you can keep both hands free. You could set its handle in a mug or some other container stuffed with cloth. The outside ends of the two long rods should be at the height of the hair dryer's air stream when they are in their horizontal starting position. Then draw a string through both rods and the wing, so that the wing is supported at both the front and the rear. Let the string sag a little and clamp it in the rods with two shaft plugs. Tip the two rods up a little, so the air stream meets the test wing a little under the leading edge. Turn on the hair dryer — the wing will rise. That is what lift does. You can look at the front suspension string to see how

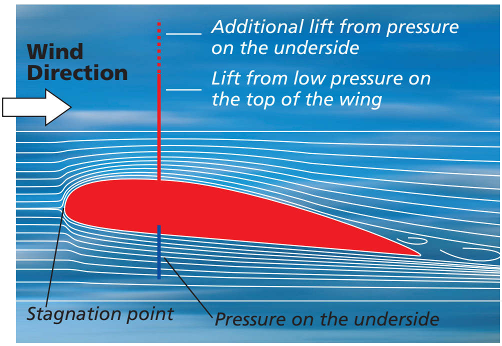


You can hold the hair dryer in the mug with a cloth resistance and lift are distributed. Resistance drags it backward, while lift pulls it up. See how things change when you try different wing angles.



This is how we test the aerodynamic wing

Suction and compression — lift on the aerodynamic wing



Aerodynamic wing with angle of attack

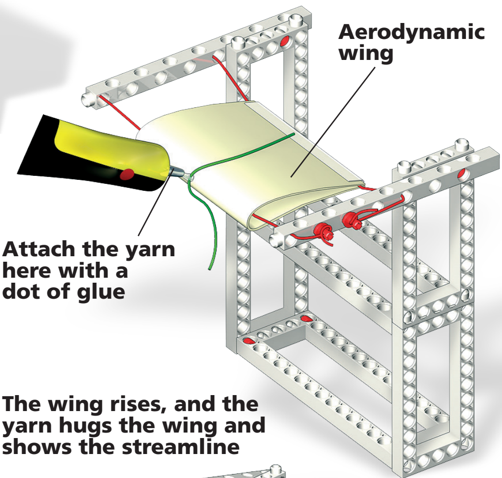
09 ***Experiment***

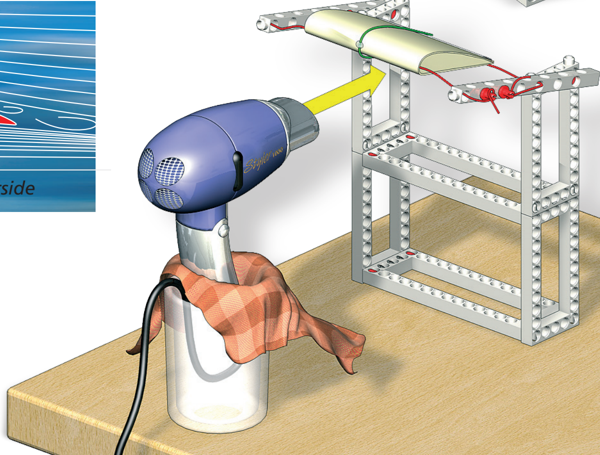
Streamline on the aerodynamic wing

What happens on the aerodynamic wing designed for lift?

Materials: assembly from previous experiment, a piece of fine yarn, all-purpose glue

Stick a fine piece of yarn onto the nose of the aerodynamic wing with a small drop of glue, so it reaches completely around the top and bottom. Start the hair dryer and observe: The yarn hugs the wing tightly, fluttering a little bit at the rear only.

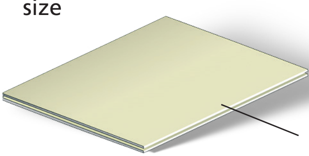




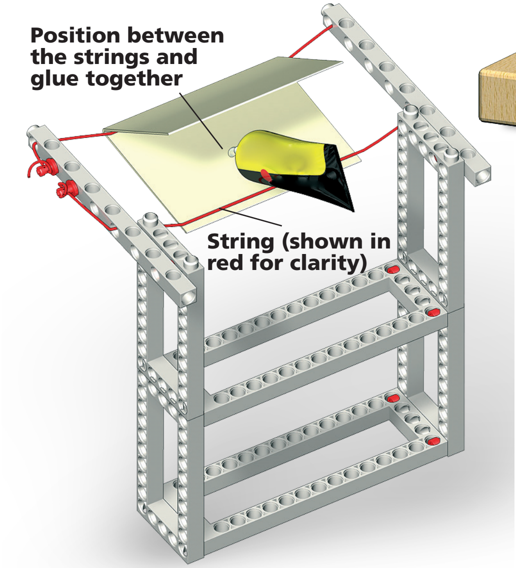
10 *Experiment*

Streamline on a panel

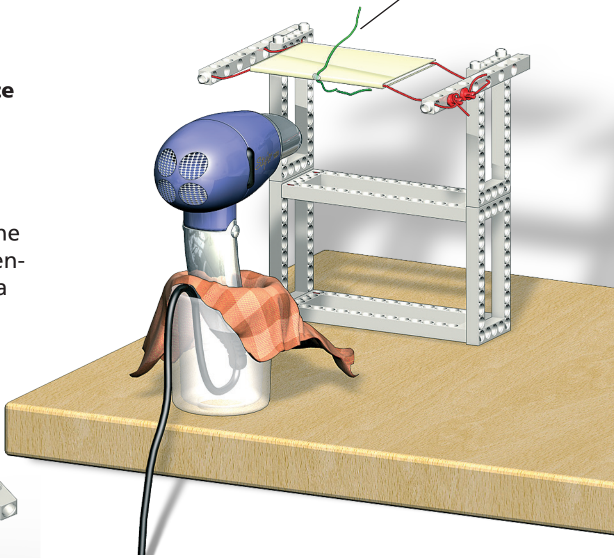
Materials: a piece of cardboard the size of a postcard or heavy drawing paper the same size



Fold the new piece of cardboard in the middle with a sharp edge, apply glue to the inner surfaces, guide it over the two suspension strings, and glue it together to form a flat panel.



Take the aerodynamic wing from the framework and loosely mount the strings again. Be sure that all the strings sag slightly. As in Experiment 10, attach a piece of yarn to the front edge and adjust the rods so that the panel is hit by the wind at an angle from the front and below. Let the wind blow and watch: It's not only the panel that flaps in the wind. The yarn flutters uneasily, pulling away and is not stretched smoothly over the upper side. On the underside, it hangs a little more smoothly, but still keeps its distance — because of a thin layer of turbulence.



So with the panel, turbulence determines what happens.

Let's take a closer look at the aerodynamic wing shape: Similar to the teardrop shape, the air stream is low in turbulence and tight against the surface. The air stream coming at and angle from the lower front pushes against its underside, producing pressure. The air particles on the upper side have to cover a greater distance due to the arch shape, if they want to keep up with those on the underside and the rest of the air. They can only do that if they hurry. The faster stream on the upper side creates a low pressure region.

And it creates an upward suction on the wing. So the wind gets pressure on its underside and suction from the top, and that makes it rise. On the rear half of the upper side, the air stream pulls away due to the high speed and becomes turbulent (as shown by the fluttering yarn). The higher the speed and the steeper the wing angle, the earlier the yarn will tear away. The point of departure should ideally lie as far to the rear as possible.

Rotor blades are rotating, twisted wings

Blades of a modern windmill

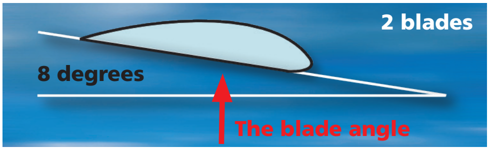
The wind blade of a windmill is a rotating aerodynamic wing. Because it produces more lift than the flat teardrop shape in Experiment 7, it also produces more power. The main difference between it and a normal airplane wing lies in its mounting: That is, its blades are turned inward. Why?

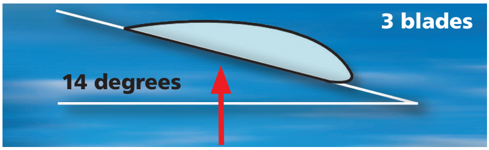
The inner edge of the blade traces a smaller circle as it rotates than the tip of the blade. Its speed as it travels around is therefore less than that of the tip. In order to keep the turbulence as low as possible along the entire length of the blade, the blade angle is reduced from the inside to the outside. This gives rise to the twist in the blade. All kinds of propellers have twisted blades. By the way, a windmill can absorb at most 60% of the wind energy, while the rest of the energy (at least 40%) has to remain with the wind in order for it to flow away from the blade again. That is why there has to be enough space between the blades.

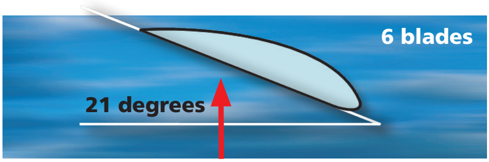
Coefficients of lift and resistance

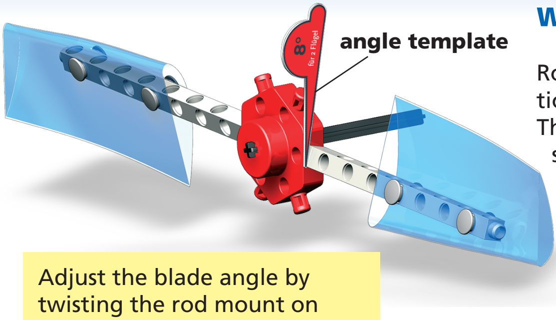
Thick or thin, slow or fast? Not all wing shapes have the same characteristics. Wings with strongly arched contours have a lot of lift but also a lot of resistance, and the air stream flows over them slowly. Slender, slightly arched ones produce less lift, but also less resistance. They make up for the smaller amount of lift with higher speed. Fat wings need a larger blade angle, thin ones less of an angle. Fast fighter jets often have razor-sharp wings, while transport planes, which have to carry large cargos through the air, have wings that look like hunchbacks.

The blade angle









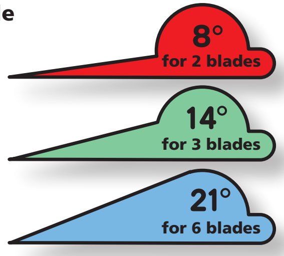
Adjust the blade angle by twisting the rod mount on the hub. The angle template cutouts will help.

What determines rotation speed?

Rotation speed indicates the number of rotations or revolutions per second or minute. The following facts determine the rotation speed:

- The wind speed
- The size of the windmill
- The number of blades
- The shape of the blades
- The required power

The three angle templates



Each wing or propeller shape is determined by a specific lift ratio, or the so-called **coefficient of lift** (C_L). It has a **drag coefficient** (C_d) as well. The coefficients of different wing shapes have been determined in special wind tunnels. So have the drag coefficients of various automobile bodies and other vehicles.

Airplane model in wind tunnel

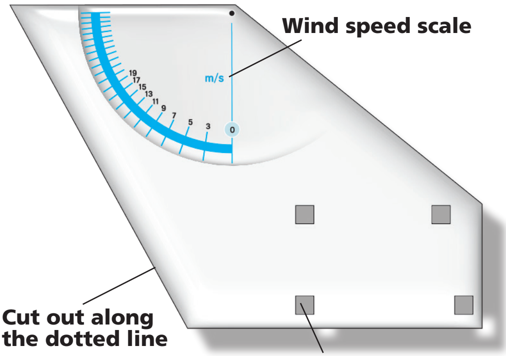
Your rotor blades are fairly arched and intended for a low-speed model. But what's slow and what's fast?

For our experiments, we will have to be able to determine the wind speed. To do that, we will assemble a wind gauge.

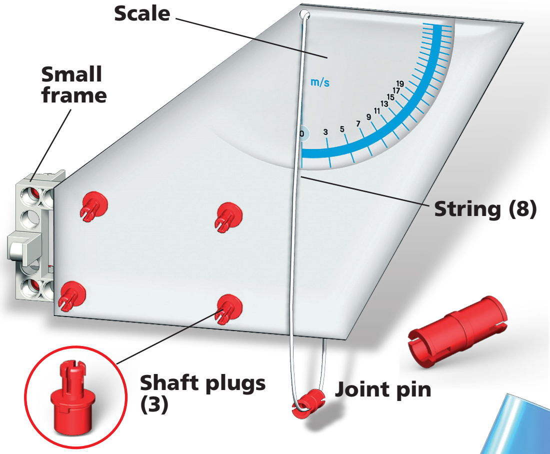
11 *Experiment*

Materials: wind speed scale (cutout), 40 cm of string (8), joint pin (1)

Cut the wind vane with the wind speed scale out of the cut-out sheet at the end of this experiment manual. Guide the string through the hole, and pull it through the joint pin as well. Tie its ends together so that the joint



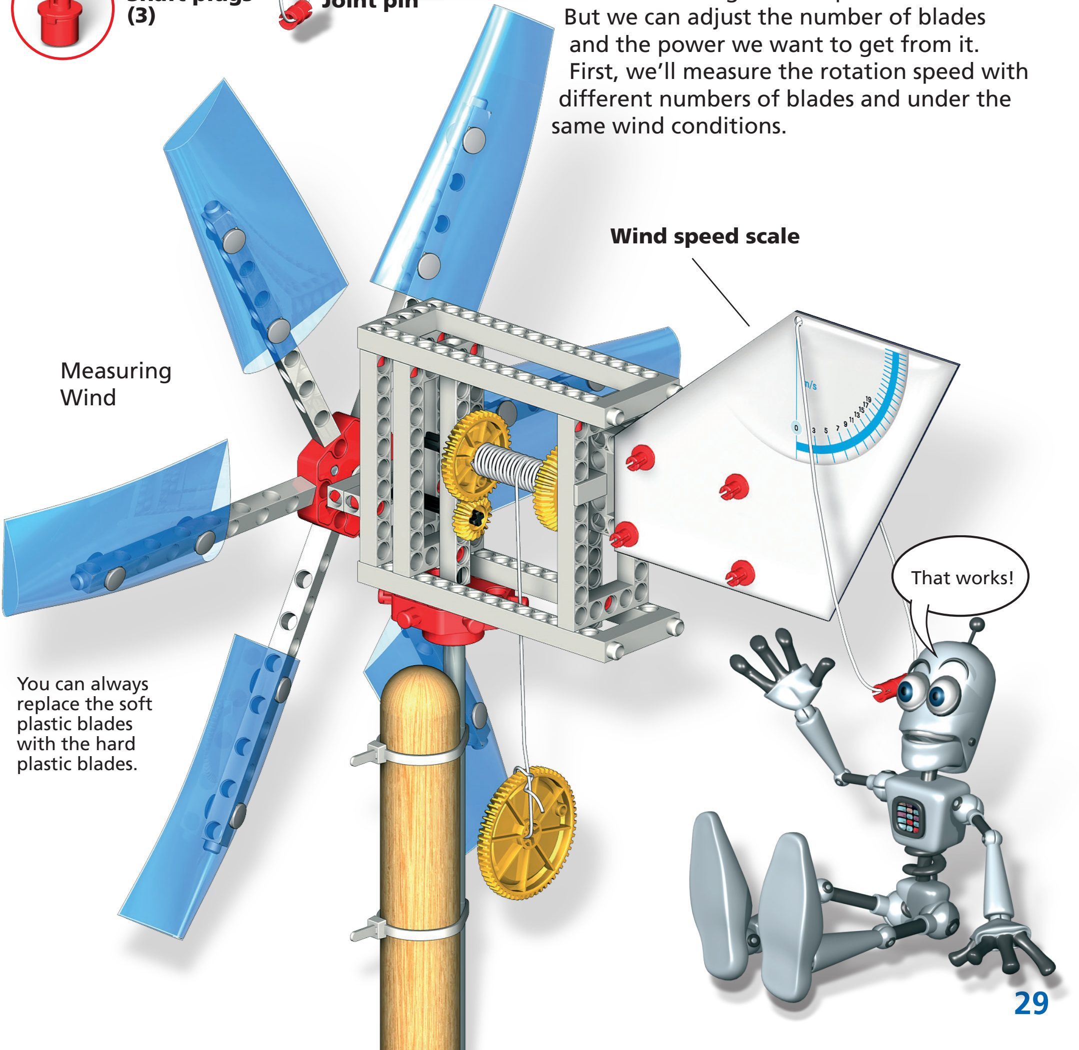
Windy Measurements



pin hangs 3 cm below the bottom edge of the vane. Hide the knot inside the pin and center it.

The string is the pointer. When there is no wind, it is on zero. It travels up the scale depending on the strength of the wind. It indicates speed in meters/second. (A bicycle goes about 4 m/s on average.) The wind gauge isn't one hundred percent accurate, but you can use it to compare measurement results under the same wind conditions.

We cannot change the diameter of our rotor, nor can we change the shape of its blades. But we can adjust the number of blades and the power we want to get from it. First, we'll measure the rotation speed with different numbers of blades and under the same wind conditions.



How Fast Is Your Windmill Spinning?

12-14 *Experiments*

Measuring rotation speed

Materials: basic setup as shown. In addition, 1 medium (12) and 1 large (13) gear wheel, 1.5 m string, watch with second hand, and measuring tape

For these experiments, select a day and — if possible — a location with steady, not-too-light wind. First measure the rotation speed of the 6-blade windmill. Check the blade angle (cf. page 12, blade angle illustration). Attach the wind gauge.

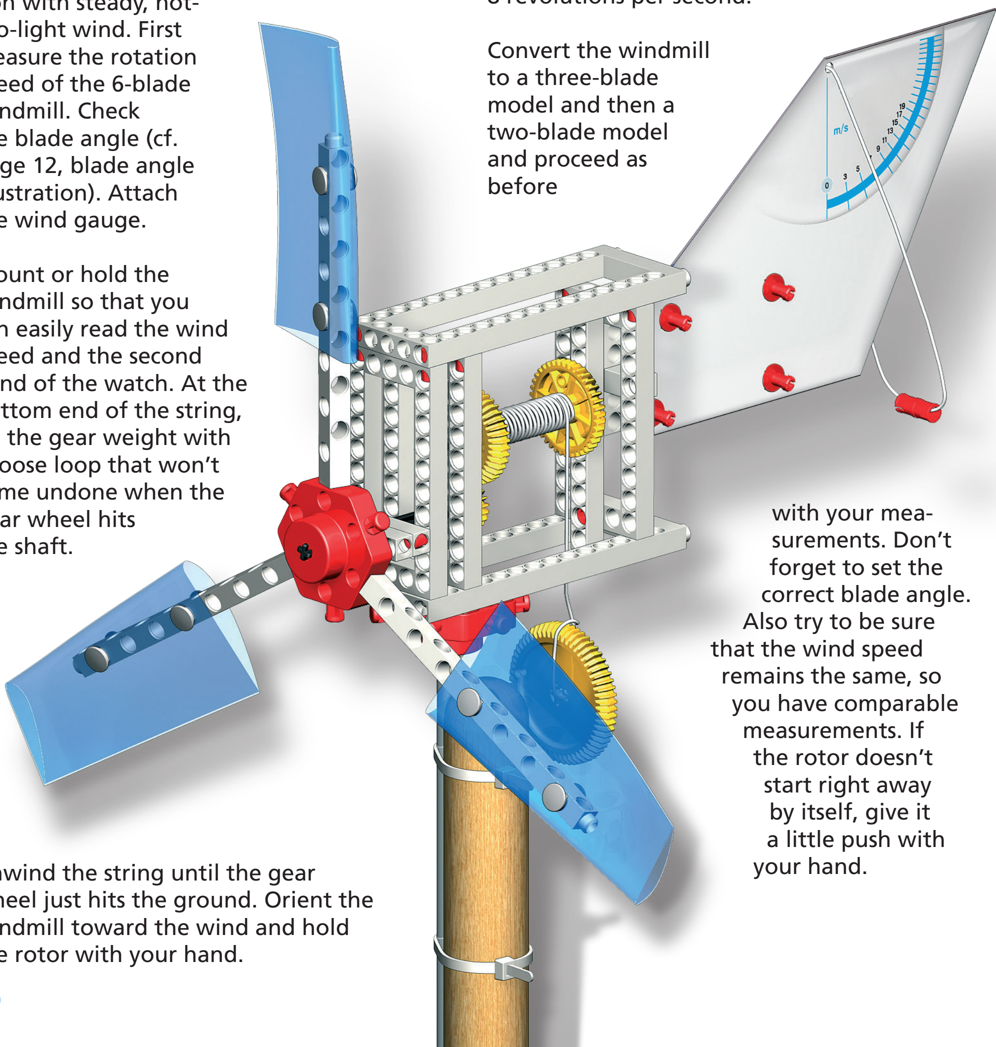
Mount or hold the windmill so that you can easily read the wind speed and the second hand of the watch. At the bottom end of the string, tie the gear weight with a loose loop that won't come undone when the gear wheel hits the shaft.

Unwind the string until the gear wheel just hits the ground. Orient the windmill toward the wind and hold the rotor with your hand.

Look at the wind gauge and note what it reads. Watch the second hand and let the windmill go. Measure the time until the moment when the gear wheel reaches the shaft. Note how many seconds have passed and the number of times the string has wound around the shaft. Because of the gear transmission ratio (1:3), you have to multiply it by three. Once you have divided the number of windings by the number of seconds, you have the rotation speed.

Example: 40 windings in 5 seconds corresponds to a rotation speed of 40:5 = 8 revolutions per second.

Convert the windmill to a three-blade model and then a two-blade model and proceed as before with your measurements. Don't forget to set the correct blade angle. Also try to be sure that the wind speed remains the same, so you have comparable measurements. If the rotor doesn't start right away by itself, give it a little push with your hand.



You will notice that the two-blade and the three-blade models have a harder time getting started. That's because they present a smaller inclined plane to the wind as a contact surface than the six-blade model. But once they get started, they turn much faster. Therefore: The fewer blades a windmill has, the faster it turns. Why is that?

Windmills with up to four blades are called high-speed, while if they have more, they are called low-speed. There are windmills with up to 50 blades.

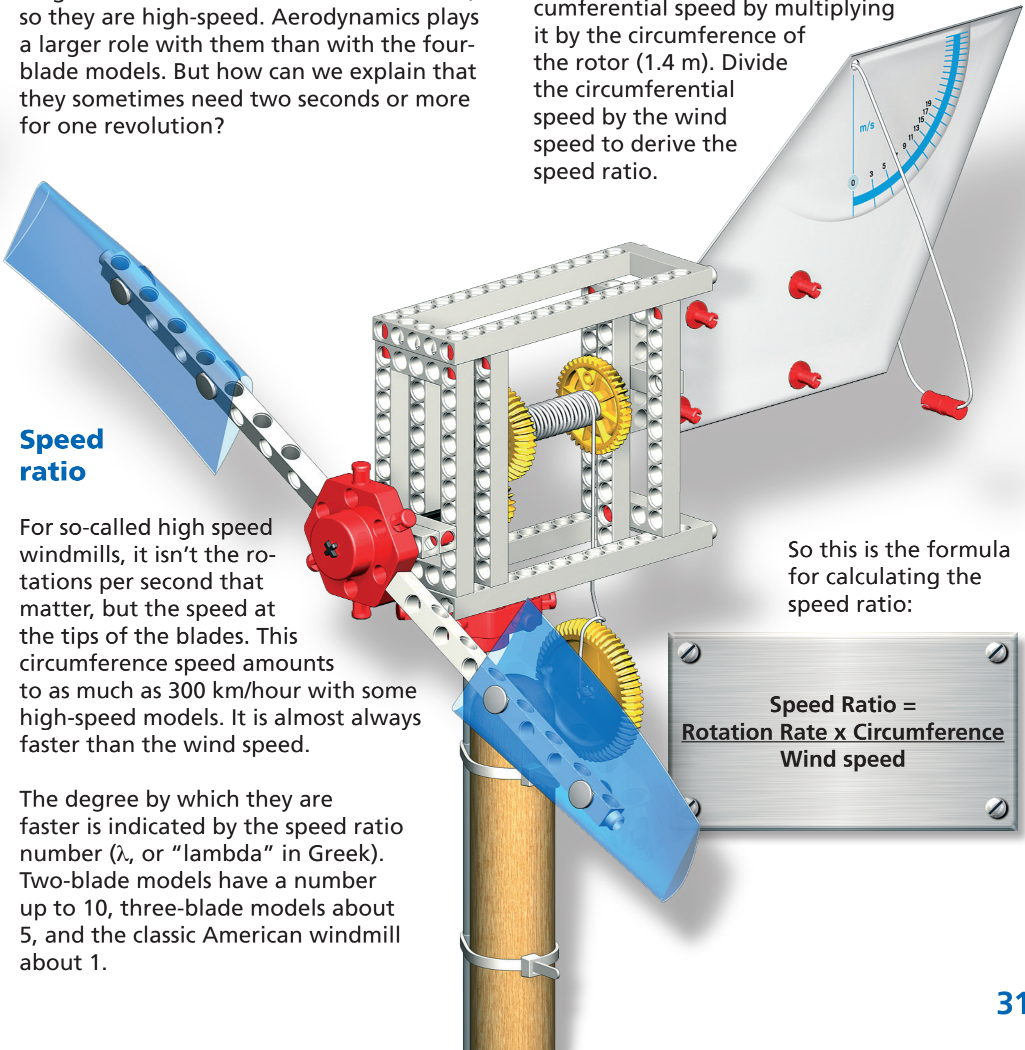
Large modern windmills have three blades, so they are high-speed. Aerodynamics plays a larger role with them than with the four-blade models. But how can we explain that they sometimes need two seconds or more for one revolution?

15-17 *Experiments*

Let's measure the speed ratio

Choose a day with light, steady wind and measure the revolution rate as in Experiments 12-14 under the most consistent wind speed conditions possible. First fit the rotor with two blades, then three, and finally six.

From the revolution rate, calculate the circumferential speed by multiplying it by the circumference of the rotor (1.4 m). Divide the circumferential speed by the wind speed to derive the speed ratio.



Speed ratio

For so-called high speed windmills, it isn't the rotations per second that matter, but the speed at the tips of the blades. This circumference speed amounts to as much as 300 km/hour with some high-speed models. It is almost always faster than the wind speed.

The degree by which they are faster is indicated by the speed ratio number (λ, or "lambda" in Greek). Two-blade models have a number up to 10, three-blade models about 5, and the classic American windmill about 1.

So this is the formula for calculating the speed ratio:

$$\text{Speed Ratio} = \frac{\text{Rotation Rate} \times \text{Circumference}}{\text{Wind speed}}$$

Wind Generator Assembly Instructions

Now, after having learned the theory and performed the experiments, you can assemble your own wind power plant with machine house, gear transmission, and generator.

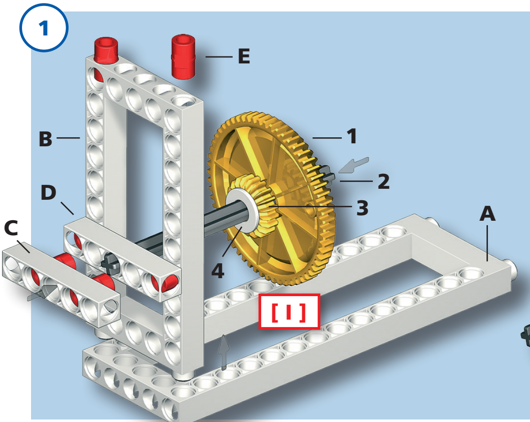


Figure 1
First mount a small frame (B) on a large frame (A), and insert two red anchor pins (E) in the small frame, following the illustration carefully. Now mount two five-hole rods (C, D) as shown using four anchor pins. Slide a large gear wheel (1), a small gear wheel (3), and a washer (4) onto a long axle (2), paying attention to the orientation of the gears. Insert the shaft assembly [I] into the two five-hole rods from the back as shown.

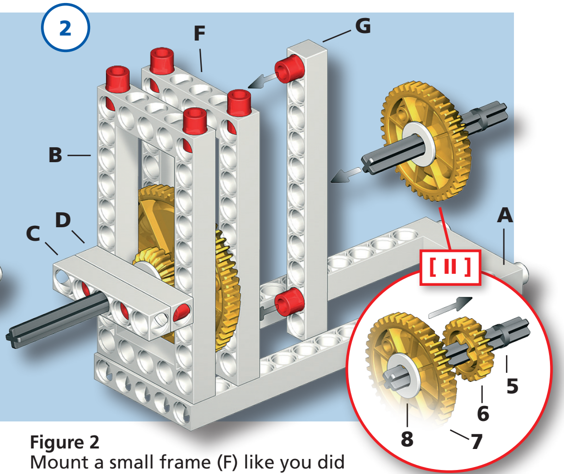


Figure 2
Mount a small frame (F) like you did for frame (B). Now mount a short rod (G) to the middle of frame (F) with two anchor pins. Slide a small gear wheel (6), a medium gear wheel (7), and a washer (8) onto a medium axle (5), paying attention to the orientation of the gears. Important! The gear wheels (6) and (7) should not be pushed all the way together. Leave a small space between them. From the back, insert shaft assembly [II] through the rod (G) at the sixth hole from the bottom.

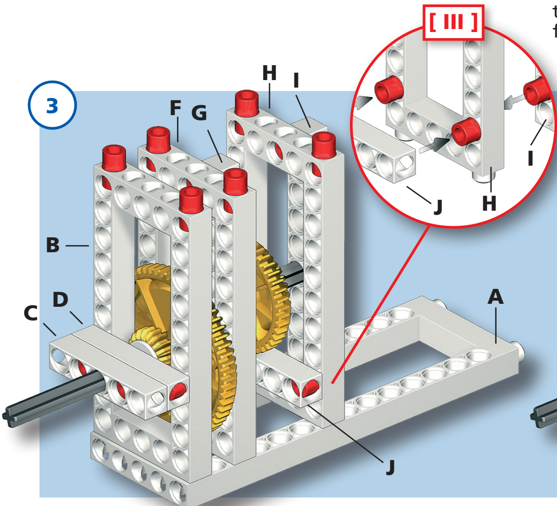


Figure 3
Attach a five-hole rod (J) to a small frame (H) one hole from the bottom with two anchor pins, as shown in [III]. Mount the small frame (H) as you did (B) and (F), and attach another short rod (I) to the middle of it with two anchor pins. Check to make sure it works; all of the gears should turn easily, but they do not yet mesh together.

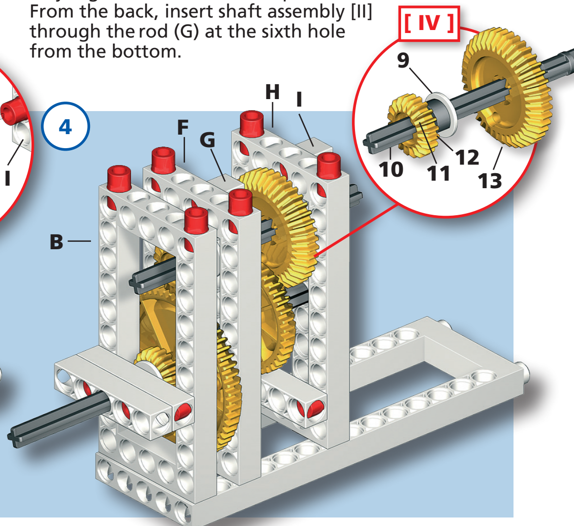


Figure 4
Now you will add shaft assembly [IV]: you have to assemble it inside the framework, so don't assemble it all at once as shown in inset [IV]. First slide a long axle (10) through the third hole from the top of rod (I). Place a medium gear wheel (13) onto the axle. Then continue to push the axle (10) through the hole in rod (G). Now put a washer (9), an axle lock (12), and a small gear wheel (11) onto the axle (10) and continue to push the axle until it cannot go any farther.

Important! This is a challenging building project! You should practice with the other models in this kit first. If you are having trouble, visit our technical support web page at www.thamesandkosmos.com.

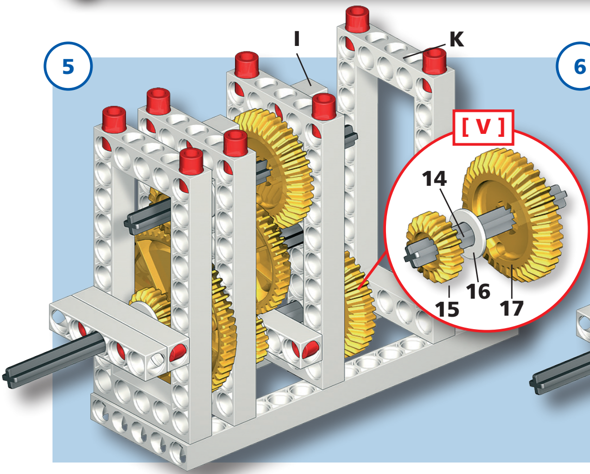


Figure 5
Now you will add shaft assembly [V], and again you have to assemble it inside the framework, so don't assemble it all at once as shown in inset [V]. First slide a medium axle (14) into the third hole from the bottom of rod (I) and through the middle hole in rod (J). Then put a washer (16) and a small gear wheel (15) onto the end of axle (14). Finally, put a medium gear wheel (17) onto the short end of axle (14).
Now attach small frame (K), with two anchor pins at the top, to the large frame (A).

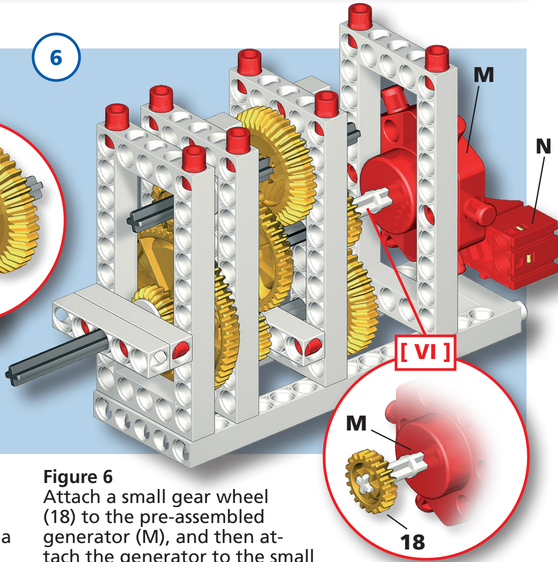


Figure 6
Attach a small gear wheel (18) to the pre-assembled generator (M), and then attach the generator to the small frame (K) at the fifth holes from the bottom. Attach it so that the little white socket is at the top on its back side. Attach the battery holder (N) to the generator.
Test it out: Do all of the gears spin together when you turn axle (2)? If not, try adjusting the parts. Refer to Figure 6b to see how all the gears should mesh.

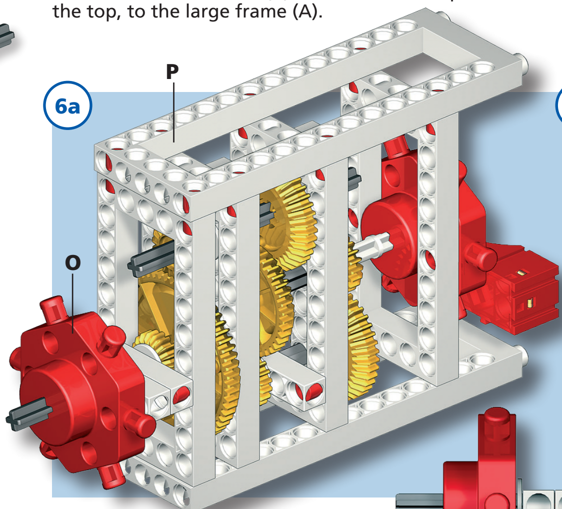
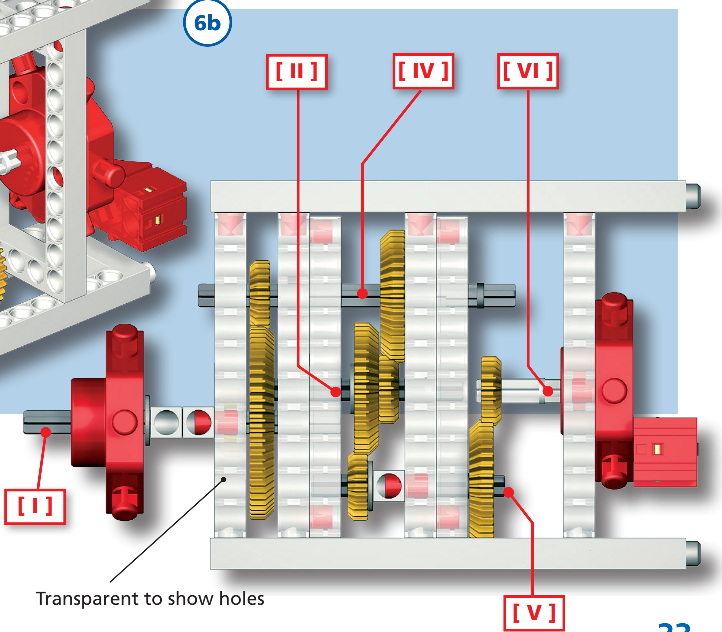


Figure 6a
Attach one of the assembled universal adapters (O) to the front of long axle (2) in the shaft assembly [I]. Attach large frame (P) to the top of the assembly.

Figure 6b
Refer to this side-view figure if you have any questions about the final placement of the parts.



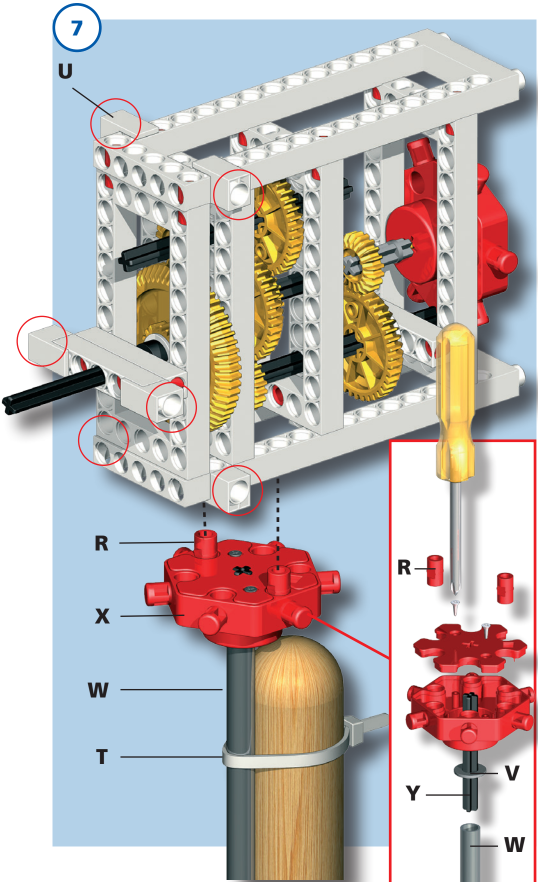
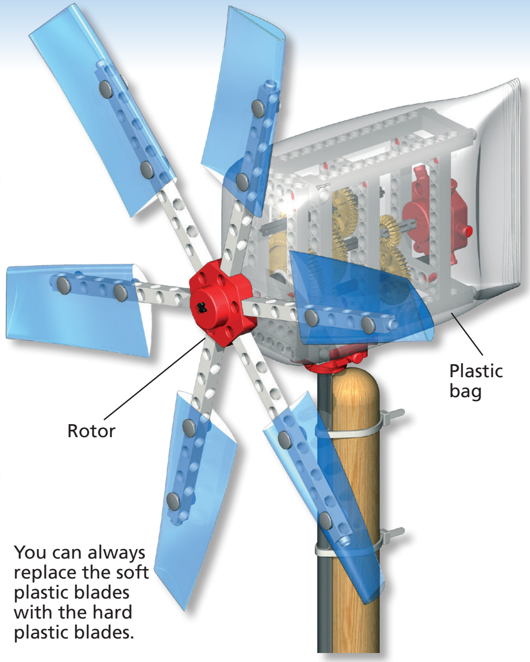


Figure 7
Mount six perpendicular connectors (U) to the bottom and top large frames and to the five-hole rod at the front. The mast bearing consists of a universal adapter (X) installed with a long axle (Y), a washer (V), the aluminum pipe (W), and two anchor pins (R). It is attached to the frame from the rear with the two anchor pins (R). To protect your wind power plant from dampness and dust, you can cover the machine house with a plastic bag such as a freezer bag.

Insert the rotor onto the long shaft from the front. You can secure the aluminum pipe to a post or railing, for example, with the cable tie (T). You can also attach the aluminum pipe to a tripod, if you have one.

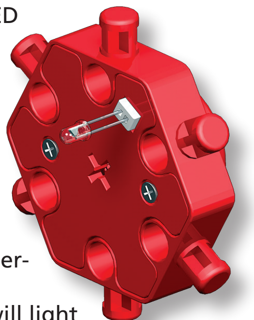


You can always replace the soft plastic blades with the hard plastic blades.

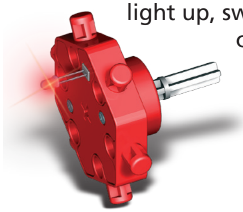
18 *Experiment*

The windmill produces light

Just like the big windmills, our small one can also generate electricity and, for example, light up an LED (9). Let's try it now:



Insert the LED by its two wire leads into the connection socket on the generator (19) (universal adapter with integrated generator). Wait for a moderate wind and let the windmill go. The LED will light up. If the LED doesn't light up, switch the orientation of the LED by turning it around in the socket. The LED only works in one direction.



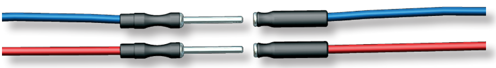
19 *Experiment*

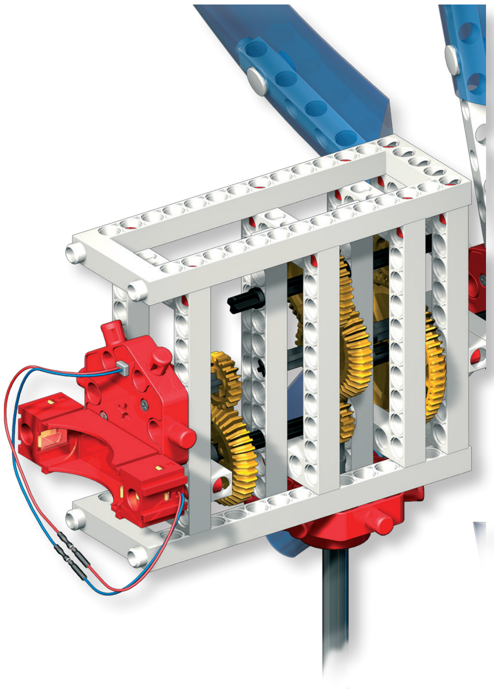
Let's charge a rechargeable battery

You can charge an R6-size (AA) rechargeable battery, NiCd or NiMH type, of 1.2 volts and a 750-1200 mAh capacity.

We are going to store electricity by charging the battery. Install the battery mount (20). Insert the connection cable (29) into the generator in place of the LED, and at the other end insert the little plugs into the sockets of the battery mount wires.

Pay attention to the cable colors when connecting them! **RED** to **RED** and **BLUE** to **BLUE**.





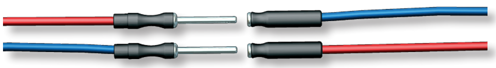
Safety notes:
- Pay attention to the safety warnings on the rechargeable battery.
- Do not force open the battery.
- Do not throw the battery into the fire.
- Pay attention to the correct polarity.
- Pay attention to the charging times.
- Do not short-circuit rechargeable batteries — they could explode!

Tip: Do not operate the wind generator in the rain, because it might short-circuit.

20 *Experiment*

The windmill becomes a fan

In the last experiment, the generator produced electricity. If, on the other hand, it receives an electric current, it becomes an electric motor capable of turning something. This will transform your windmill into a fan! For this experiment, you will have to switch the cable plugs. So now, connect **RED** to **BLUE** and **BLUE** to **RED**.



Insert an already-charged battery and the rotor will spin and create wind.

Safety notes:
Be careful not to let the windmill get blown by the wind in this setup, or to rotate it forcefully with your hand. That would result in the battery getting charged with the wrong polarity, which might damage it.

Tip: To discharge the battery, let the fan run until it doesn't turn anymore.

Tip: Only recharge uncharged batteries, or they might lose their charge capacity.

Test Your Knowledge of Wind Energy

1) Where does the wind get its energy?

A. From the Earth
B. From the tides determined by the moon
C. From the sun

2) Why is it risky to burn fossil fuels?

A. The carbon dioxide it creates is partially responsible for global warming
B. It robs the atmosphere of oxygen

3) How much does a cubic meter of air weigh (a cube having edges one meter in length)?

A. 1.2 grams
B. 1.2 kilograms
C. 120 kilograms

4) How do you specify the tilted position of the rotor blades of a windmill?

A. With the angle of attack or blade angle
B. With the blade slope
C. With the position of the rotor relative to the wind

5) In what direction does lift act on the rotor blades?

A. At right angles to the curved upper side and upward
B. Forward at a slant
C. Straight ahead

6) What is the main thing an engineer wants to achieve with the shape of a rotor blade?

A. To make the rotor turn quickly
B. To make it turn quietly
C. To achieve little resistance with a lot of lift

7) What causes the lift with aerodynamically designed windmill blades?

A. The suction on the upper side and pressure on the underside, and the tilted angle of the blade
B. The rotation of the rotor
C. The air turbulence caused by the rotor

8) What does speed ratio indicate?

A. Revolutions per second
B. Circumferential speed divided by wind speed
C. Number of rotor blades

9) How many households (3-4 people) can a modern windmill installed in a windy area supply with electrical energy?

A. About 100 households
B. About 1,000 households
C. About 10,000 households

10) There are many kinds of windmills. Which are best for producing electricity?

A. Aerodynamic fast-speed ones
B. Majorca-type windmills
C. Dutch windmills

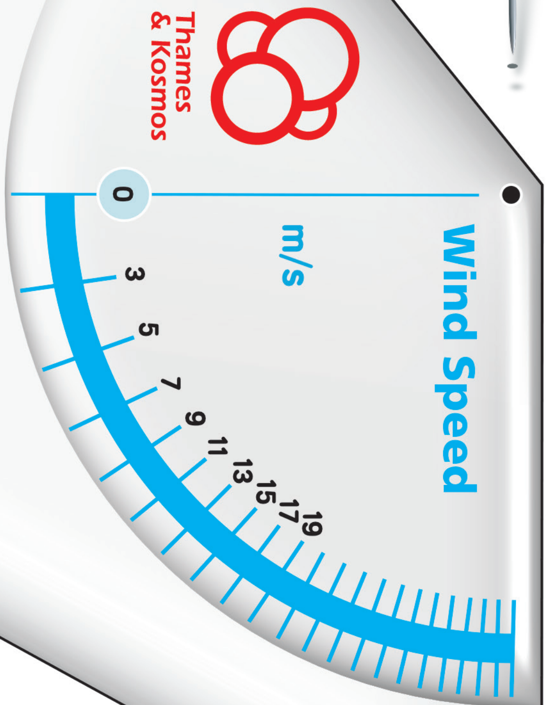
Answers

1. C (page 6)
2. A (page 7)
3. B (page 17)
4. A (page 19)
5. A (page 25)
6. C (page 28)
7. A (page 25)
8. A (page 31)
9. C (page 8)
10. A (page 8)

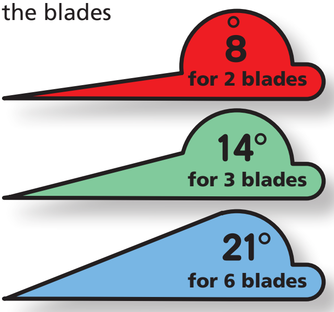
Wind vane with wind gauge

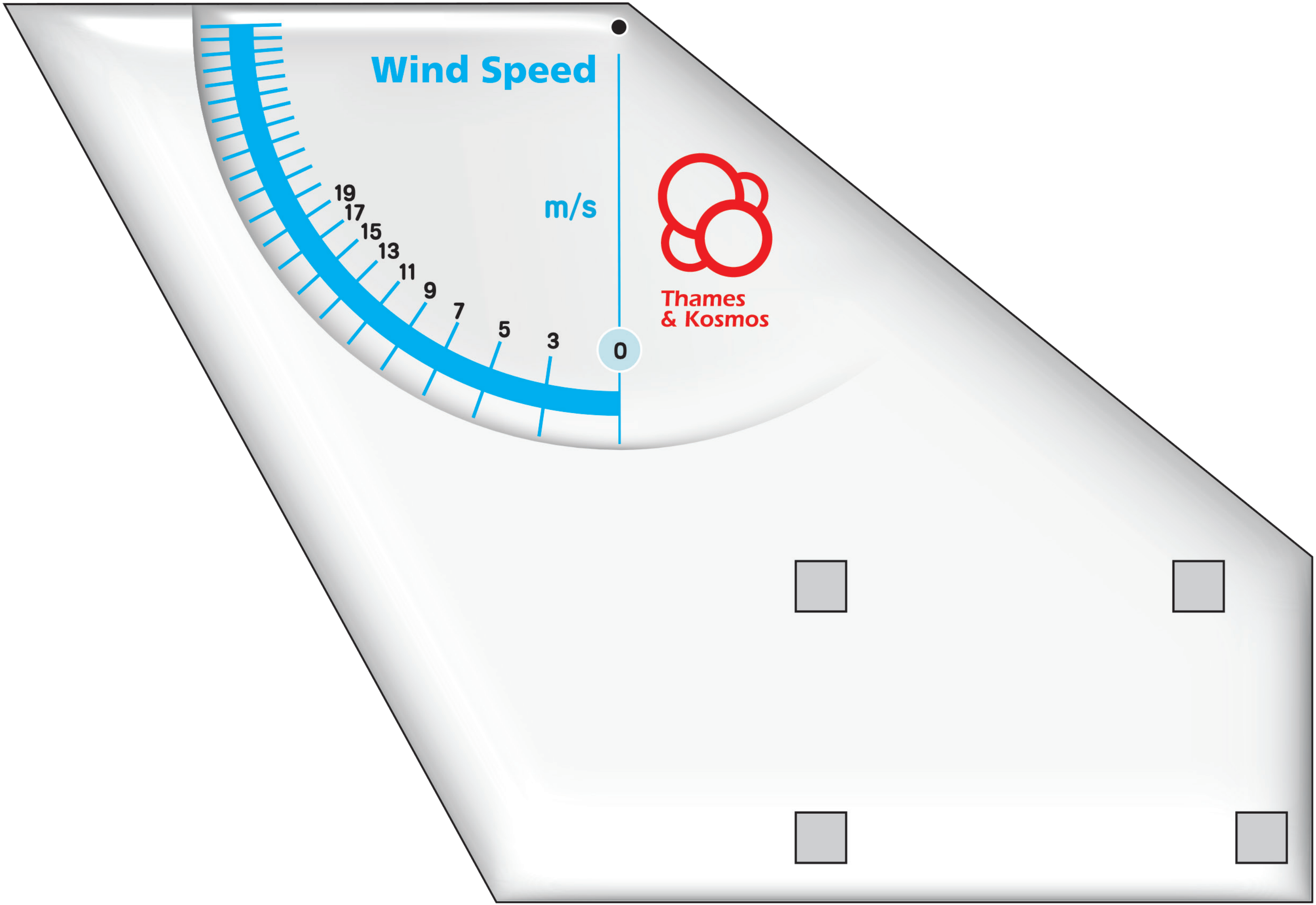
The wind vane and the angle templates must be cut out precisely along the black outlines. It is best to cut out the four square holes with a sharp knife. Be careful with the tools. Have an adult help you.

Make a hole in the black dot with a needle.



Angle templates
to adjust the angle of the blades




Wind Speed
m/s
0
3
5
7
9
11
13
15
17
19
Thames
& Kosmos