

Wind Energy

Concepts to consider:

Type of windmill

A vertical axis is mainly used for torque, and a horizontal is used for speed.

Tower Design

Towers are important in the construction of the windmill because not only do they have to support the windmill, but they must also be subject to their own weight and the drag of the wind and torque from the blades.

Height of windmill axis

The optimal position is at the center of the axis of the box fan. This ensures the windmill “captures” the most amount of wind and in the optimal direction (parallel).

Number of windmill blades

A significant factor determining the efficiency of windmills is the number of blades: more blades capture more energy. However, there is a trade off with weight and initial inertia to smmpitart the windmill. In addition, there is a law of diminishing returns (not getting any additional benefit) for adding more blades.

Angles or orientation of windmill blades

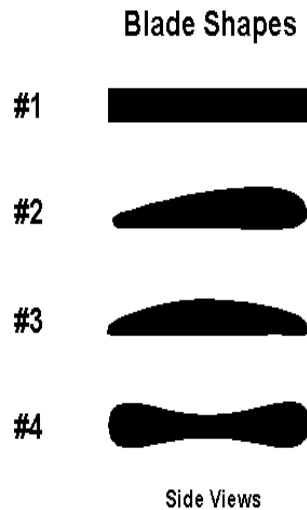
The angle or orientation of the blades is one factor in optimizing the efficiency of the windmill in “capturing” the wind

Shape of Blades

If an optimum blade shape is discovered, then the overall productivity of a windmill can be increased. Possible blade shapes are as follows:

1. Flat, unmodified blade surface;
2. Wing shape, with one leading edge rounded with the other edge tapered to a thin line;
3. Both edges tapered to a thin line; and
4. Both edges rounded like the leading edge of a conventional airplane wing.

Drawings are provided below for sample blade shapes:



Size of windmill blades

Larger blades have a greater swept area and thus catch more wind with each revolution. Because of this, they may also have more torque.

Ratio of turning mechanisms to axis

The ratio of the turning mechanism (pulley) to the axle of the windmill is the *mechanical advantage* from the applied force. You must balance the initial resistance to start with the advantage of multiplication of force.

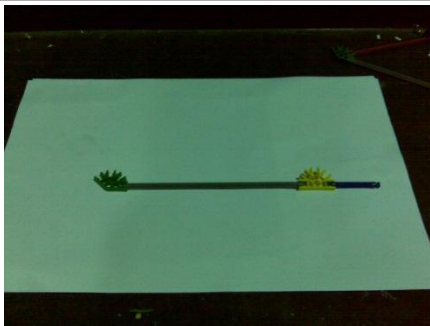
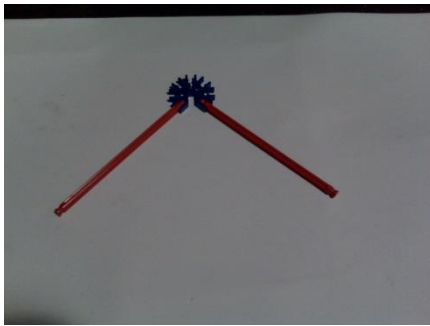
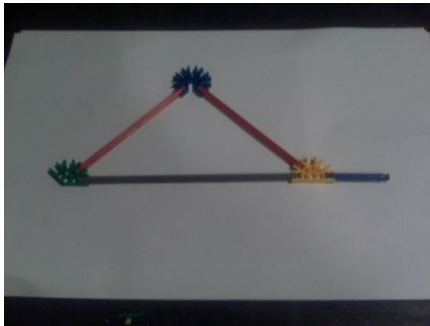
- Bicyclists use low gear up hill
 - Pedals turn more for fewer wheel turns.
 - Large mechanical advantage
 - Gear & Axle or Axle & wheel almost same size
- For speed use high gear
 - Many wheel turns per pedal
 - Small mechanical advantage
 - Gear much smaller than axle which is much smaller than wheel.
- Best of both worlds
 - Gear shift maximizes both
 - Large pedal turns small axle turns larger wheel

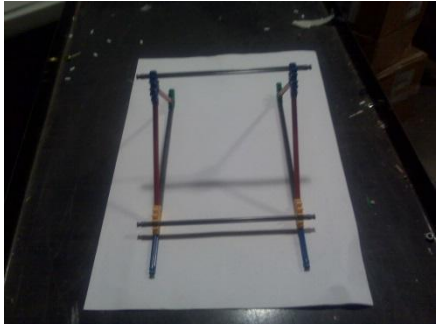
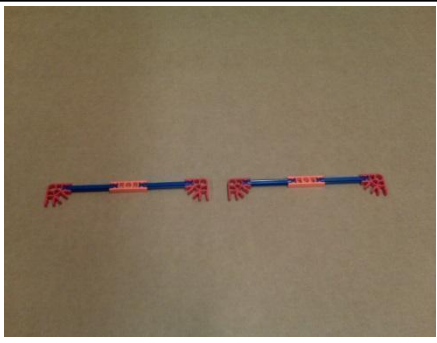
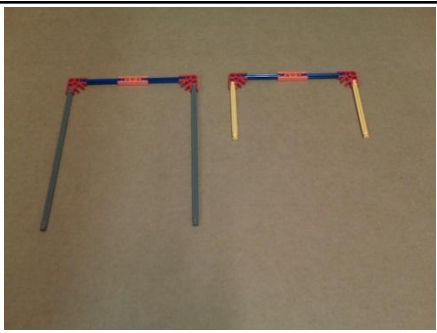
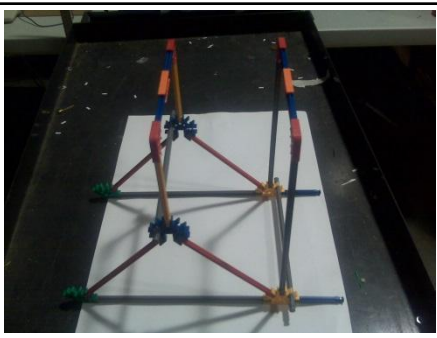
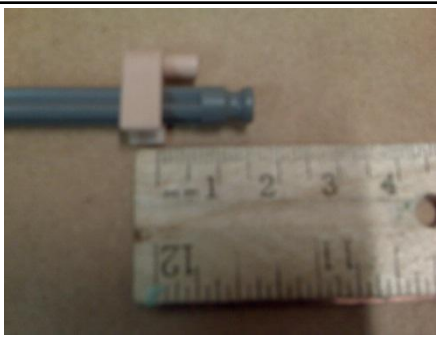
Activity 1 – Build the Windmill Structure

Materials (per group):

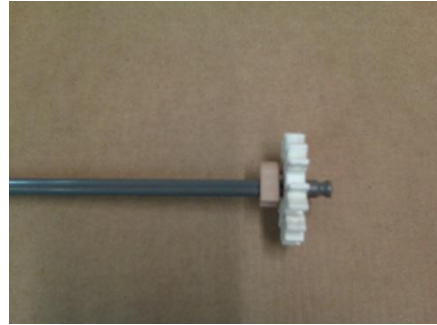
• 1 white connector • 2 yellow connectors • 2 blue connectors • 2 green connectors • 4 red connectors • 2 orange connectors	• 2 gray connectors • 1 beige connector • 4 red or green rods • 8 yellow rods • 6 blue rods • 7 gray rods
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Directions:

1. Insert a blue rod into one side of a yellow connector. 2. Insert a gray rod into the other side of the yellow connector. 3. Insert the other end of the gray rod into the side of a green connector 4. This is a base 5. Repeat steps 1 to 3 to create a second a second base	
6. Insert a red rod into a slot right next to the opening on the blue connector 7. Insert a second red rod into the other slot right next to opening 8. This is your angled support 9. Repeat steps 6 & 7 to create a second angled support	
10. Connect an angled support to a base by inserting the red rods to the green and yellow connectors as shown in the picture to create a “foot” 11. Repeat for the other angled support and base to create another “foot”	

12. Stand each foot so blue connectors face up 13. Connect the two “feet” by inserting a gray rod into the slots <u>behind</u> the top slots of each of the blue connectors 14. Insert another gray rod into the open front slot of the yellow connectors of both “feet” (immediately above the horizontal slot) 15. This is the windmill base	
16. Insert a blue rod into each end of an orange connector 17. Insert other end of each blue rod to the outside end of a red connector 18. Repeat with identical components to create another “bridge”	
19. Insert gray rods into the bottoms of the red connectors to form the front bridge 20. Insert yellow rods into the bottoms of the other connector to form the back bridge	
21. Attach front bridge to the front of the windmill base by inserting the gray rods into the top slots of the yellow connectors 22. Attach back bridge to the rear of the windmill base by inserting yellow rods into the top slots of the blue connectors	
23. Attach tan connector (pointing outward) 1.5cm from the edge of a gray rod)	

24. Insert the same end through the center of a white connector



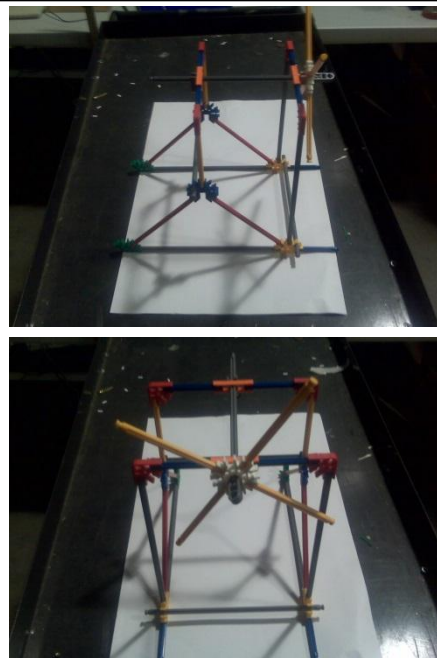
25. Attach the gray connector to the end of the gray rod extending out of the white connector



26. Insert the yellow rods into the white connector 90° apart.
27. This is the blade mechanism



28. Insert the free end of gray rod of blade mechanism through the hole in the orange connector front bridge and through the hole in the orange connector back bridge
29. Snap the second gray connector to the gray rod of the blade mechanism to keep it from sliding back too far and causing the blades to strike the structure



Activity 2 – Create the Blades and Lifting Object

Materials (per group):

- 4 yellow rods
- 8 – 3x5 index cards
- 3oz cup
- Pencil

Shared materials:

- Masking tape
- String
- Balsa Wood

Directions:

1. Remove the 4 yellow rods of the blade mechanism
2. Using the 4 removed yellow rods and 4 additional yellow rods for a total of 8 blades, tape a 3x5 card to each of the yellow rods. The bottom edge of the card should line up with the end of the grooves in the rod.



3. Tape a piece of balsa wood to the back to give each blade extra support (width of card)



4. Cut a string 1.25 meter long
5. Under the rim of a 3oz cup, punch two holes across from each other, using a pencil
6. Insert string through the holes and tie so that the cup is suspended from the string



7. Place the windmill on the table, on the edge of the table, with the back end hanging over the edge and the string perpendicular to the floor.
8. With the cup resting on the floor, tape the other end string to the back end of the gray rod of the blade mechanism.

Activity 3 – Optimal Blade Design

Materials:

- Stopwatch (per group)
- Scissors (per group)
- Protractor (per group)
- Hex nuts (shared)
- 3x5 index cards (shared)

Directions:

1. Using Table 3a below, determine **the maximum weight of hex-nuts that can be lifted by the number of blades specified in the table**. The number of blades that carry the most number of hex-nuts will be the optimal number of blades.
2. Using the specified number of blades for each test, place blades at a 45° angle from the plane of the white connector holding them.
3. Record your data in Table 3a from each test
4. At the end of each experiment, calculate the ratio of hex-nuts to time (i.e. 8 hex-nuts in 4 seconds would yield a ratio of 8/4 which would equal to 2)

Notes:

- If the blades change orientation due to the force of the fan, add a small amount of tape to the yellow rod to form a more snug fit into the slot of the connector
- The paper cup weighs approximately 1.8g and each hex nut weighs approximately 3.1g

Table 3a - How many blades lift the most weight?

Number of Blades	Maximum number of hex-nuts lifted	Time (s)	Ratio: Hex-nuts/time
2	15	34.98	0.43
4	30	39.12	0.75
8	36	54.60	0.65

5. We will assume that the optimal number of blades will remain the same regardless of the orientation of the blades and will use it for the next test. Using the Table 3b below, determine the **best orientation angle** of the optimal number of blades determined from above. 45° was the angle used for Table 3a, so transfer the data for the optimal number of blades used (2, 4, or 8) to the table below for 45°.

Optimal Number of blades: 4 (2, 4, or 8)

Table 3b – What blade orientation will lift the most weight?

Angle of blade orientation (°)	Maximum number of hex-nuts lifted	Time (s)	Ratio: Hex-nuts/time
30°	20	42.87	0.46

45°	30	39.65	0.75
60°	30	89.12	0.33

6. We will assume that the optimal number and orientation of blades will remain regardless of the shape of the blades and will use them for the next test. Using the Table 3c below, determine the **best shape** for the blades of the blade shapes shown below from the optimal number of blades and the optimal angle of the blades determined above. Create new blades for chosen blade shapes (see *Shape of Blades* on page 2 for description and *Activity 2* for instructions); be sure to keep the length the same as the 3x5 card. We have used the rectangle (#1) in the prior two tests, so record your data for it in Table 3c.

Optimal Number of blades: 4 (2, 4, or 8)

Optimal angle of blades: 45 (30°, 45°, or 60°)

Blade Shapes

#1 

#2 

#3 

#4 

Side Views

Table 3c – What blade shape will lift the most weight?
Choose two shapes from #2 through #4 above

Blade Shape	Maximum number of hex-nuts lifted	Time (s)	Ratio: Hex-nuts/time
#1	15	20.16	0.75
#2	15	19.54	0.76
#3	15	31.98	0.46

7. We will assume that the optimal number, orientation of blades and blade shape will remain regardless of the size of the blades and will use them for the next test. Using the table below, determine the **best size** of the blades from the optimal number of blades, the optimal angle of blades, and the optimal blade shape from the above tests. Scale the

widths and the lengths equally. 100% is the value you've used thus far, so record the data in Table 3d.

Optimal Number of blades: 4 (2, 4, or 8)

Optimal angle of blades: 45 (30°, 45°, or 60°)

Optimal blade shape #: 2 (#1, #2, #3, or #4)

Table 3d – What blade size will lift the most weight?

Blade size	Maximum number of hex-nuts lifted	Time (s)	Ratio: Hex-nuts/time
50%	18	30	0.6
100%	34	38	0.89
200%	40	70	0.57

Questions for Analysis:

In each test, we have made assumptions that the results of the prior tests would hold true in the subsequent tests.

1. Do you think our assumptions are valid?

They are not completely valid. For the testing it is very useful, but there are too many variables to check. For example, 45 degrees worked very well with 4 blades and rectangular shape of the blade, but other shape of the blade and number of blades might work better with other angles. So, it is better to use simulation

2. How could you prove or disprove them?

Instead of changing one category at a time, we can test each one this will give us better results. Also, for this one we will have to use new paper for each blade type, size, angle, and quantity

3. In the raising a mass part of the competition, the best score is based on a ratio of the mass lifted over time. So, a winning score will maximize weight and minimize time. In activity 3, we experimented to maximize weight (although we did measure time). Consider that a smaller weight at a faster time could maximize the ratio. What type of experiment could you do to test this theory?

We would have to run trials with different amounts of hex-nuts, for example 10, 20, 30, 36, then record each time and calculate the ratio. This would give the exact answer for whether the smaller weight or more weight is better.

Activity 4 – Gear Ratio

Materials:

- 1 beige connector
- 1 small wheel

Directions:

1. Determine if changing the gear ratio will affect the efficiency of the windmill
2. Remove string from the back end of the gray rod of blade mechanism
3. Where string was attached, use the beige connector to attach small wheel
4. Attach string in groove of small wheel
5. Repeat *Activity 3: Optimal Blade Design* with changed gear ratio
6. Record data in tables below

Table 4a – Optimize the number of blades

Number of Blades	Maximum number of hex-nuts lifted	Time (s)	Ratio: Hex-nuts/time
2	14	38.8	0.36
4	25	41.86	0.59
8	28	61.42	0.46

Optimal Number of blades: 4 (2, 4, or 8)

Table 4b – Optimize blade orientation

Angle of blade orientation (°)	Maximum number of hex-nuts lifted	Time (s)	Ratio: Hex-nuts/time
30°	5	21.8	0.18
45°	25	41.86	0.59
60°	10	29.54	0.24

Optimal Number of blades: 4 (2, 4, or 8)

Optimal angle of blades: 45 (30°, 45°, or 60°)

Table 4c – Optimize blade shape
(See Activity 3.6 for blade shapes)

Blade Shape	Maximum number of hex-nuts lifted	Time (s)	Ratio: Hex-nuts/time
#1	25	41.86	0.59
#2	20	38.32	0.53
#3	8	28.34	0.28

Optimal Number of blades: 4 (2, 4, or 8)

Optimal angle of blades: 45 (30°, 45°, or 60°)

Optimal blade shape #: 1 (#1, #2, #3, or #4)

Table 4d – Optimize blade size

Blade size	Maximum number of hex-nuts lifted	Time (s)	Ratio: Hex-nuts/time
50%	12	29.69	0.40
100%	25	41.86	0.59
200%	30	71.24	0.42

Optimal Number of blades: 4 (2, 4, or 8)

Optimal angle of blades: 45 (30°, 45°, or 60°)

Optimal blade shape #: 1 (#1, #2, #3, or #4)

Optimal blade size #: 100 (50%, 100%, or 200%)

Questions for Analysis:

- What conclusions can you draw from using or not using a gear?
Adding gear did not improve the ratios; they are pretty much the same.
- Considering the mechanical advantage may result in a better ratio and thus a better score.
How could you test this theory?
We could test the windmill using different wheel sizes, but keeping everything else the same.