Objective
To design and build a laboratory scale wind-turbine and evaluate its performance.

Apparatus
Each team is provided with a wind turbine kit consisting of a PVC pipe tower frame, geared drive shaft, generator, crimping hub, dowels, and blade materials. The assembled wind turbine will be placed in front of a 30-inch, ¼ HP pedestal fan at a prescribed distance. The leads of the wind turbine will be connected to a variable load (resistor), and you will measure its output power as a function of load using an ammeter and voltmeter.

http://www.kidwind.org/pdfiles/gearedinstv2.pdf

A critical aspect is that each team will design its own blades. You can select your own
- blade material (cardboard, plastic, balsa wood, etc.)
- number of blades (two, three or six)
- blade shape, radius, and width
- blade pitch
**Theory**

A wind turbine converts kinetic energy of the wind to mechanical energy using a rotating shaft carrying a set of blades, and subsequently to electrical energy using a generator.

Let us use the following terminology:

- $V_1$: incoming velocity of the wind (m/s)
- $V_2$: exit velocity of the wind in the wake (m/s)
- $R$: radius of the rotor blade (m)
- $\rho$: density of the air (kg/m$^3$)

With reference to the above figure, let $V_1$ be the wind velocity far upstream of the turbine, and $V_2$ be the velocity in the wake far downstream of it. The incoming streamtube must expand in area as shown in the figure because $V_2$ is less than $V_1$ (principle of mass conservation). The incoming wind velocity $V_1$ is not under our control, but we can feather the blades and adjust rotor rpm to control the wake velocity $V_2$. It turns out that power is maximized when $V_2 = V_1/3$, giving

$$\text{Maximum Power} = \frac{16}{27} \left( \frac{1}{2} \pi R^2 \rho V_1^3 \right)$$

Equation 1
The quantity in square brackets in Equation 1 is the total wind power intercepted by the rotor. However only $\frac{16}{27}$ (or 59%) of this power can be actually extracted due to the fundamental limits imposed by nature. This factor is called the Betz coefficient. In practice, the extracted power is even smaller than 59% due to friction and other non-ideal processes.

**Note:** The power extracted varies as the *cube* of wind speed, and as the *square* of the rotor radius. It is therefore no surprise that locating the wind turbine in a windy area is of crucial importance, and also, that modern rotor blades are very long indeed (up to 60 m radius).

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The axial loading applied by the wind on the rotor blades is transmitted to the hub. Therefore, the rotor blades must be robust enough to withstand the bending loads due to this thrust force, as well as the rotor shaft bearings. The axial thrust at maximum power is:

$$\text{Thrust}_{\text{Max Power}} = \frac{8}{9} \left[ \frac{\pi R^2 \rho V_1^2}{2} \right]$$  \hspace{1cm} \text{Equation 2}

The thrust scales as the *square* of the wind speed, and the rotor radius.

**Procedure:**
1. Design and fabricate your rotor blades by selecting an appropriate material. The number of blades and their shape, length and width are parameters you can experiment with. **You must do this first step before coming to the lab.**
2. Mount the blades onto dowels using tape or glue.
3. Assemble the rotor tower using the given PVC pipe sections.
4. Mount the blades to the frame using the crimping hub. Set the blade pitch to an angle of your choice.
5. Face the assembled wind turbine into the wind provided by the pedestal fan. The center of the turbine must line up with the center of the fan.
6. Connect the leads of the turbine to an electrical load (10 turn, 100 Ohms potentiometer).
7. Vary the load from 100 Ohms to 0 Ohm in steps, while measuring the current ($I$) and voltage ($V$) at each step. You must prepare a table with appropriate headings for data entry before coming to the lab.
8. The product of $V$ and $I$ is power ($P$) measured in watts (W).  $P = VI$
9. Measure the blade rpm by counting the time in seconds ($T$) for $N$ revolutions using a stopwatch.  $\text{RPM} = \frac{N}{T} \times 60$
10. Also note down the wind speed $V_1$. 

![Wind Turbine Diagram](image-url)
Analysis
1. Enter your data into an Excel spreadsheet.
2. Plot $V$ as a function of $I$.
3. Plot $P$ as a function of $I$.
4. Plots should have a title, and the axes must be correctly labeled with the units. Provide detailed discussion on the nature of both curves. What is the trend of the curve? Why does it behave in that manner?
5. What is the maximum power extracted by your turbine?
6. What is the efficiency ($\eta$) of your turbine?

$$\eta = \frac{\text{Output Power}}{\text{Input Power}} = \frac{P_{\text{MAX}}}{\frac{\pi R^2 \rho V_1^3}{2}}$$

Comment on your efficiency. Is it acceptable? How could you improve $\eta$?
7. What is the tip speed of the blade? What is the advance ratio?

Error Analysis
1. What sources contribute to error in the measured output power?
2. How much confidence do you have in your measured output power? (I.e., is your power measurement accurate to 1%? 10%? 50%?)