3. PROBLEM № 8: WIND CAR

SOLUTION OF BRAZIL

Problem № 8: WINDCAR

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The problem

Construct a car which is propelled solely by wind energy. The car should be able to drive straight into the wind. Determine the efficiency of your car.

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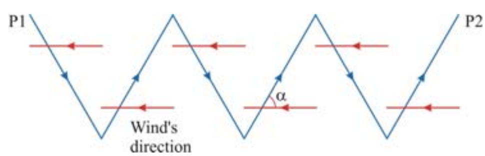
1. Objective: In this problem we are supposed to construct a car, which can be able to drive straight into the wind. The car has to be propelled just by wind energy, which means that we can not use others energy sources to move the car. The problem also asks us to determine the car's efficiency. In this part of the resolution (calculating efficiency) we have to establish the car's performance.
The experimental section of this problem is extremely necessary (indispensable). We have to construct a prototype that respect the problem's limitation, in order to make the necessary measurements to explain the car functionality and to determine its efficiency.

2. Theoretical Background: In this part of the resolution we will focus on each variable that could interfere with the final result, such as studies about momentum transmission as well studies about different kind of speed: scalar speed and angular speed. We will also exemplify possible models and the energy loss in each one, as well how to calculate efficiency.
At the beginning, we thought in three kinds of cars that could drive straight into the wind:

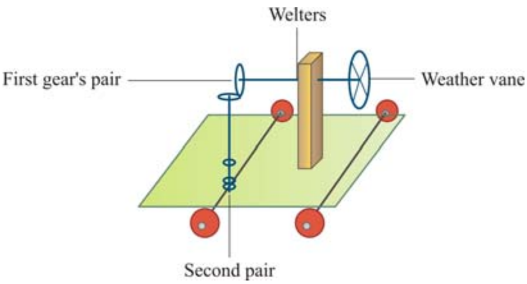
1- A sail's car (moved by sail): In this car we would utilize the force of the wind (blowing directly in the sail) to make the car walk. But as the car has to walk straight into the wind, this car would not respect the problem's limitation because it would have to drive in a zigzag trajectory to use the wind buoyancy.

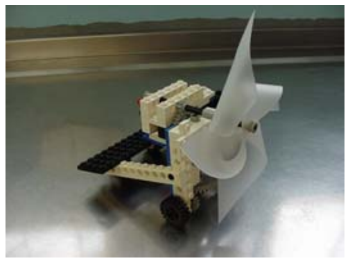


2- An electric car: The principle of the electric car is to transform the kinetic energy into electric energy (using a dynamo moved by a weather vane). Then, it would transform, with an electric engine, this electric energy into mechanical energy that would make the car walk.

- Loss in this car: air viscous force in the weather vane as well a considerable loss in the energy transformations (mechanic-electric-mechanic): energy dissipation.

3- A mechanic car: Using a weather vane (twirled by the wind) and pairs of gears, we would make the mechanic car move by energy transmission.
Loss in this car: friction in the axes (energy dissipation), gears heating (another example of energy dissipation) and tendency to slide in the wind direction (as the wind is blowing against the car (opposite to the problem's direction).
Considering this three models, and the energy loss of each one, we chose the third one (mechanic car) to develop the prototype. Below, a initial idea of the mechanic car

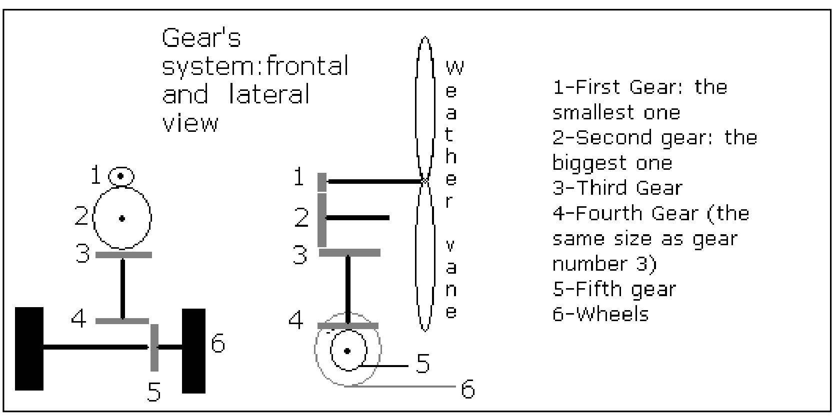




2.1 Mechanic car: Our mechanic car consists in a base (with four wheels) that support all the car structure, the gear's structure and its welters

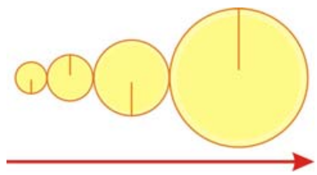
The car inner working is simple: basically the wind will twirl the weather vane, which, by gear's transmission, will roll a pair of wheels, making the car move. The transmission of momentum (wind blowing and twirling the weather vane) will be made by gears and axes.

Below, a drawing of the prototype (graphic project) and its photo:

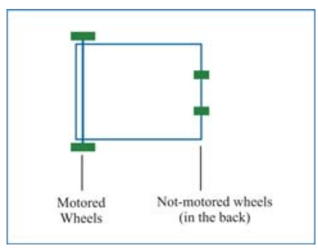


Important things for considering:

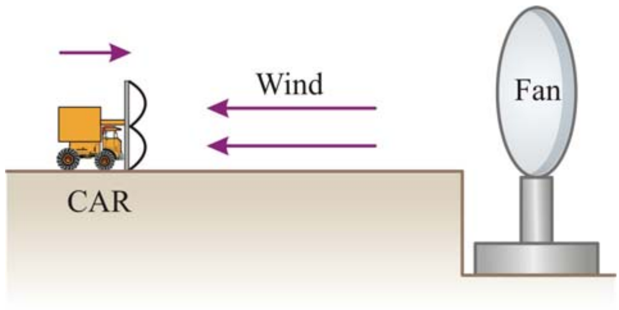
- <u>Frontal Area:</u> It is important to have the smallest frontal area (not considering the weather vane area). Air resistance force depends on the frontal area of the car. Smaller frontal area have smaller resistance (wind buoyancy), which is capable to reduces the car final speed and, consequently, the car efficiency.
- <u>The weather vane size</u>: The total torque on the weather vane determines the driving speed of the car. A bigger vane will have a larger torque on it, and, consequently, the car will drive faster into the wind. However, a larger weather vane has more contact surface area, thus it will have more resistance force, which tends to push back the car. So, we need to find a optimum size that delivers a maximum torque and a minimum resistance force.
- <u>The heating process in the gear's tooth</u>: Since we are working with gears to transmit momentum, we need to consider the heating process in the gear's tooth. The gear is heated by friction on its teeth. This) heating process can not be put aside because to twirl another gear, one gear has to hit its teeth in the other gear teeth. This process one form of energy dissipation and represents a reduction in the final performance.
- <u>Gear's position:</u> For a better performance, we have to put the smaller gear in the same axis of the weather vane and then, we need to increase the gear's size, until the wheels axis. (When we have the gears in the same axis, the gears can have the same size, because there are no force raise in the same axis). In this way we "give" a bigger torque to the wheel (responsible for moving the car).



- <u>Car's weight</u>: The car can not be too heavy, because the friction force increases directly proportional to the weight, given by the equation: $\vec{F}_{at} = \vec{N}.\mu$; where $\vec{N}$ is the compression (Normal) force between the surface and the car, which is also the weight force reaction pair; μ is the static friction coefficient between the wheel material and the surface material. With a heavier car, we will have a bigger Normal force, thus more attrition. However, the car weight is limited by the fact that too little friction increases the chance of wheels skidding (not a good "interaction" between the plan and the wheels).
- <u>Wheels:</u> There are four wheels in our mechanic car: Two are moved, indirectly, by the wind (motored wheels) and two wheels (not motored) have the function of equilibrating the car (this wheels are located at the back of the car). Below we show a drawing of the wheel's arrangement.

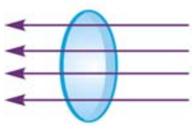


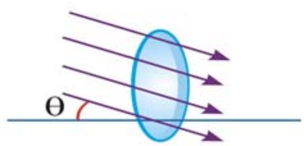
- Wind Source: In our experiment, we will use a fan as the wind source. Our fan has three different powers: it means that there are three possibilities of wind power (three different wind escape intensities). For a more complete resolution, we will utilize all powers to calculate the efficiency.
- Wind direction: The efficiency depends on the direction that the wind blows at the car frontal area. For a better performance, we used a step to put the fan, so we had a better wind utilization (picture)



If we had used the wind in a transversal form (forming an angle (θ) with the horizontal), the air flux would change, as we show in the pictures below (because just the horizontal speed component will be utilized).

$$\text{flux} = V_n \,.\, \text{Area} \tag{1}$$



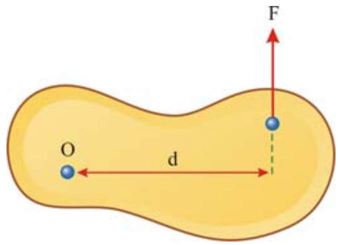


$$F = |\vec{V}|.A \qquad F = (\vec{V}.\vec{n}).A \qquad (2)(3)$$

In our case we will just utilize the equation 2 because in our setup the wind will always be perpendicular to the weather vane area.

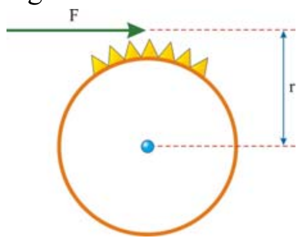
2.2 Force Momentum (torque): In mechanics, generally, we work with particles. But in our experimental setup it is necessary to work with objects (spatial corpus) and not just particles. Considering objects which do not deform itself when an external force is applied, we define momentum (*M*), or torque of a force $\vec{F}$ (acting in this body in relation to a axis which pass in *O*), by the relation below (where *d* is the distance between the *O* and the perpendicular projection of the force):

$$M = F \cdot d \qquad (4)$$



In our case, we will use momentum as one form to calculate the efficiency and also to relate the transmission among the gears and the weather vane. In the gear, momentum will be calculated by the force applied in the gear's tooth (extremity of the gear) times *r*, which will represent the gear's radium.

$$M = F \cdot r \qquad (5)$$

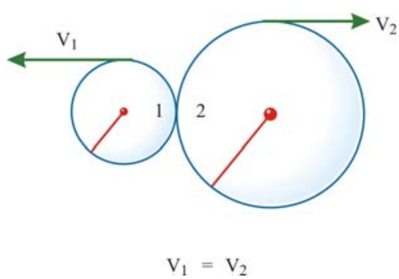


2.1.1 – Gears: In this car, the gear will be used to transmit linear and angular momentum. The gears also will help us in: (1) Changing the rotation direction, (2) Increasing or decreasing the rotation speed, (3) Changing the rotation axis and (4) synchronizing the rotation direction.

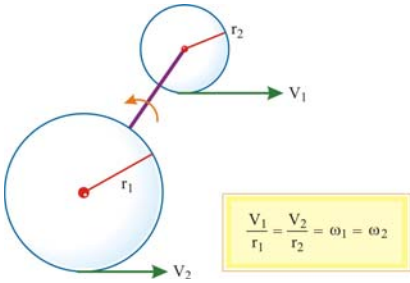
Gear's size: The relation between two gears in touch determines the rotation speed of each one. A reduction of the relative radium between to gears reduces the angular speed of the bigger gear (It happens because all the points in the extremity of the both gear have the same speed).

- Gears that are contact have the same scalar speed. Scalar speed is a speed defined by the equation below, where C is the length of the circle (perimeter), *r* is the radius (in our problem we just consider the radius as the maximum possible radius) and *T* is the period of gear revolution:

$$\vec{v} = \frac{\Delta S}{\Delta T} = \frac{C}{T} = \frac{2 \cdot \pi \cdot r}{T} \qquad (6)$$



- Gears that are in the same axis have the same angular speed. Angular speed is a speed defined by the equation below, where 2π is the angle's variation (in our case, a complete lap), *r* is the radius (in our problem we just consider the radius as the maximum possible radius) and T is the time that the gear takes to complete one revolution. Two gears in the same axis have the same angular speed and their scalar speed is proportional to theirs radius.



$$\omega = \frac{\Delta\theta}{\Delta T} = \frac{2 \cdot \pi}{T}$$

2.2 Efficiency:

Classically, in general problems, we calculate efficiency as the ratio between the effective energy used to our purpose and the total energy available. Ratio equal to 1, means the system has a 100% performance.

Firstly, we thought about efficiency like being the result of the division below:

$$\eta = \frac{\overline{V}_{car}}{\overline{V}_{wind}} \tag{9}$$

But, in the wind car problem, more specifically in our experiments, this division is ambiguous. The wind speed is measured in our reference frame? Or in the car's frame? Clearly the energy available will be different. Thus we must state if we are referring to wind relative speed or to the wind absolute speed.

Therefore, let's deduce the efficiency model.

- Speed and Kinetic energy: The kinetic energy modules are related to the speed modules. The kinetic energy also depends on the body mass and it is defined by the equation below (where m is the body mass and V is its speed):

$$K = \frac{m \cdot V^2}{2} \tag{10}$$

- The done work by the car: Physically speaking, the car does not do work. The work is done by the forces which propels the car. But, we will deal with the phrase that the work is done by the car to make things easier.

The work done by the car is defined by the kinetic energy theorem, which says that the work is the difference between the final kinetic energy and the initial kinetic energy:

$$W = \Delta K = \frac{m \cdot V_F^{\ 2}}{2} - \frac{m \cdot V_I^{\ 2}}{2} \tag{11}$$

We can obtain the work modules because we have the average speed of the car (assuming that the car has a constant acceleration). With the average speed (and with constant acceleration) we can find the final speed, using the equation below (where $\overline{V}$ is the average speed and V_F is the final speed):

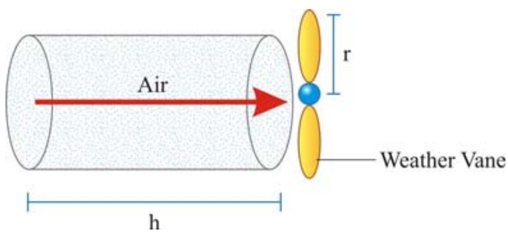
$$V_F = 2 \cdot \overline{V} \ . \tag{12}$$

Using this result and the fact that the car starts from rest, we conclude that the total car's kinetic energy is:

$$W = \frac{m \cdot \left(2 \cdot \overline{V}\right)^2}{2} = \frac{m \cdot 4 \cdot \overline{V}^{\,2}}{2} = 2 \cdot m \cdot \overline{V}^{\,2} \tag{13}$$

- The done work by the wind: Physically saying, wind does not do work, the work is done by the resistive force applied by the wind. But, we will deal with the phrase that the work is done by the wind to make things easier.

Considering a frontal air cylinder, (in front of the weather vane), like in the picture, with a fixed volume (V) and a the average wind speed ($\overline{V}$), we can say:



a) The cylinder volume is the relation between mass and density (air density):

$$\rho = \frac{m}{V} \Rightarrow V = \frac{m}{\rho} \tag{14}$$

b) The cylinder volume is the same as the cylinder height multiplied by the cylinder's base (the weather vane area). So,

$$V = A \cdot h \text{ and } V = \frac{m}{\rho} \quad (15) \qquad A \cdot h = \frac{m}{\rho} \Rightarrow m = A \cdot h \cdot \rho \quad (16)$$

$$A = \pi \cdot r^2 \quad (17) \qquad m = h \cdot \pi \cdot r^2 \cdot \rho \quad (18)$$

$$h = \frac{m}{\pi \cdot r^2 \cdot \rho} \quad (19)$$

where h is the cylinder height (length), r is the weather vane radius and ρ the air density.

c) The air cylinder speed is calculated by:

$$\overline{V} = \frac{h}{\Delta T} \quad \text{So,} \quad \overline{V} \cdot \Delta T = h \quad (20)$$

Comparing equation (19 and 20) we can conclude that:

$$\overline{V} \cdot \Delta T = \frac{m}{\pi \cdot r^2 \cdot \rho} \quad (21)$$

$$m = \overline{V} \cdot \Delta T \cdot \pi \cdot r^2 \cdot \rho \quad (22)$$

Using the kinetic equation (10) we substitute the mass (22) and discover that:

$$K = \frac{m \cdot \overline{V}^2}{2} \Rightarrow K = \frac{\Delta T \cdot \pi \cdot r^2 \cdot \rho \cdot \overline{V}^3}{2} \quad (23)$$

As we know the kinetic energy (work), the efficiency (performance) is defined as the division of the car work (13) by the wind work (23):

$$\eta = \frac{W_{car}}{W_{wind}} = \frac{2 \cdot (\overline{V}_{car})^2 \cdot m_{car}}{\frac{\Delta T \cdot \pi \cdot r^2 \cdot \rho \cdot (\overline{V}_{wind})^3}{2}} = \frac{4 \cdot (\overline{V}_{car})^2 \cdot m_{car}}{\Delta T \cdot \pi \cdot r^2 \cdot \rho \cdot \overline{V}_{wind}^{\,3}} \quad (24)$$

Where:

$\overline{V}_{car}$	is the average car speed
$\overline{V}_{wind}$	is the average Wind speed
m_{car}	is the car mass
r	is the weather vane radius
ρ	is the average air density
ΔT	is the total time that the car took to cross over the fixed distance (in our case, 05, meters)

Efficiency → $$\eta = \frac{4 \cdot (\overline{V}_{car})^2 \cdot m_{car}}{\Delta T \cdot \pi \cdot r^2 \cdot \rho \cdot (\overline{V}_{wind})^3} \quad (25)$$

3. Experimental Setups:

1. Prototype: characteristics

Measuring:
2. Wind speeds (three different intensities wind sources)
3. Car speeds (three different intensities)
4. Car efficiency (performance

Additional Information:
5. Acceleration

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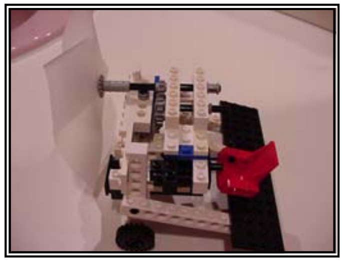
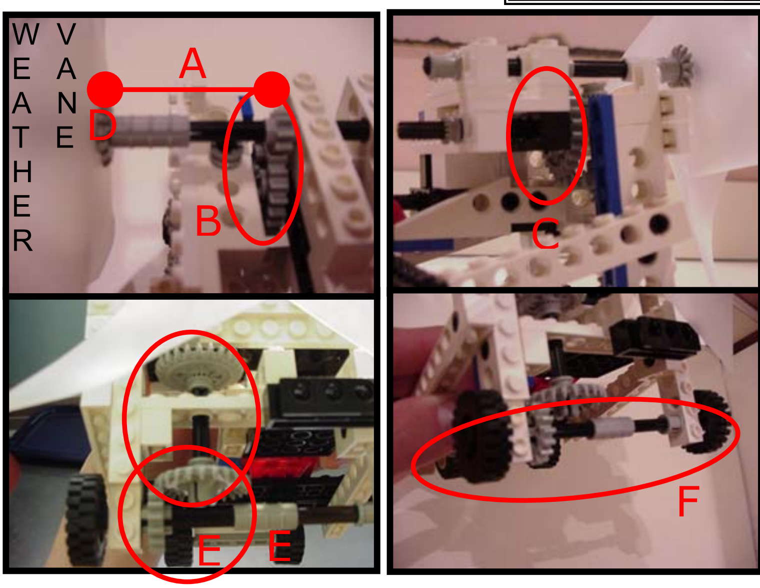
1. Prototype: characteristics

Our car has five gears, four wheels (two pairs) and one weather vane. Below, we show photos of the car and also a photo of each pair of gears (in the same axis and in contact also). It was made with pieces of LEGO™ and with a plastic weather vane.





A- First pair: gear and weather vane (same axis: equal angular speed)
B- Second pair of gear (equal scalar speed)
C- Third pair of gear (equal scalar speed)
D- Fourth pair of gear (same axis: equal angular speed)
E- Fifth pair of gear (equal scalar speed)
F- Sixth pair: gear and wheel axis (same axis: equal angular speed)

Gear's Characteristics:

Sizes: with a help of a measure instrument we measure the gears and wheels diameter and then, dividing per two, we found the average radius:

	Diameter (cm)	Radius (cm)
Weather Vane	15,49 ± 0,05	7,745 ± 0,025
First gear (the smallest)	0,96 ± 0,05	0,480 ± 0,025
Second gears (the biggest)	2,57 ± 0,05	1,285 ± 0,025
Third gear	2,56 ± 0,05	1,280 ± 0,025
Fourth gear	2,56 ± 0,05	1,280 ± 0,025
Fifth gear	1,77 ± 0,05	0,885 ± 0,025
Motored wheels	2,44 ± 0,05	1,220 ± 0,025
Not-motored wheels	2,10 ± 0,05	1,050 ± 0,025

Car Mass: It is important to know the car mass because we need it for knowing the kinetic energy (that involves speed and mass)

Car mass	0,150 kg

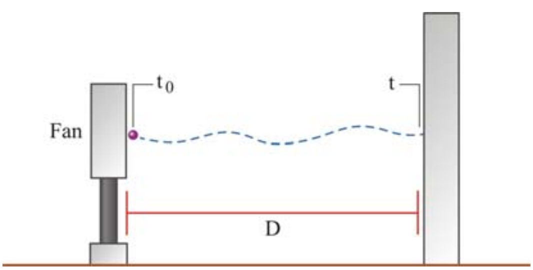
Measuring:

2. Wind speeds (three different intensities of the same wind sources)

Wind Speed: For calculating the car efficiency, it is necessary to know the wind speed. There are a lot of methods to measure the wind speed: one method, homemade, consists in throwing small polystyrene balls in front of the fan and the, measuring the average time that the balls take to reach a fixed distance.

For measuring it, we had to do an experiment. The results for 2 meter runs are shown in the next topics, in all wind intensities. We then calculated the average time over all runs and the average wind speed for all three different wind intensities (fan's power).

First, a draw of the wind speed calculation experience:



$$\overline{V}_{wind} = \frac{\Delta S}{\Delta T} = \frac{D}{t - t_0} \qquad (26)$$

➢ Wind speed in the fan's third power: The time that the particle (polystyrene ball) took to cross over two meters applying the "wind third" power (the fastest/strongest one). We measured the time in 20 runs and average over them:

T(s)

0,39	0,40	0,44	0,42	0,44	0,47	0,36	0,35	0,39	0,32
0,39	0,48	0,44	0,39	0,45	0,35	0,47	0,47	0,28	0,49

$$\overline{M} = \frac{\sum t_n}{n}$$

Thus:

$$\boxed{\overline{M} = 0{,}4095 = 0{,}41s}$$

Wind speed: → (equation 26) $\overline{V} = \frac{2{,}0m}{T_{medium}}$ $\overline{V} = \frac{2{,}0m}{0{,}41s}$

- Average wind speed (in the third power): $\boxed{\overline{V}_3 \cong 4{,}9m/s}$

➢ Wind speed in the fan's second power: The time that the particle (polystyrene ball) took to cross over two meters applying the "wind second" power (middle one). We measured the time in 20 runs and average over them:

T(s)

0,57	0,56	0,55	0,53	0,59	0,53	0,46	0,51	0,51	0,49
0,53	0,59	0,52	0,52	0,51	0,48	0,51	0,54	0,53	0,56

$$\overline{M} = \frac{\sum t_n}{n}$$

Thus,

$$\boxed{\overline{M} = 0{,}5295 = 0{,}53s}$$

Wind speed: (equation 26) $\overline{V} = \frac{2{,}0m}{T_{medium}}$ $\overline{V} = \frac{2{,}0m}{0{,}53s}$

- Average wind speed (in the second power): $\boxed{\overline{V}_3 \cong 3{,}8m/s}$

- Wind speed in the fan's first power: The time that the particle (polystyrene ball) took to cross over two meters applying the "wind first" power (the smallest one). We measured the time in 20 runs and average over them:

T(s)

0,57	0,66	0,64	0,61	0,55	0,62	0,65	0,69	0,72	0,54
0,74	0,70	0,66	0,62	0,59	0,59	0,64	0,68	0,71	0,59

$$\overline{M} = \frac{\sum t_n}{n}$$

In our case:

$$\boxed{\overline{M} = 0{,}6385 = 0{,}64s}$$

Wind speed: (equation 26) $\overline{V} = \frac{2{,}0m}{T_{medium}}$ $\quad \overline{V} = \frac{2{,}0m}{0{,}64s}$

- Average wind speed (in the third power): $\boxed{\overline{V}_3 \cong 3{,}1m/s}$

3. Car speeds (three different intensities)

For measuring the car speed, important for calculating the car efficiency, we fixed a distance (in our case 0,5 meter) and then, divided for the average time that car spent to cross over this distance.

In the tables below, we show the times that the car took, in each fan's power, to cross 0,5 meters. After this, we did, for each fan's power, the calculus of the average time, to express correctly the car speed.

- Car speed in the fan's first power:

In the first fan power (wind intensity), we obtained these values:

T(s)

2,00	2,18	1,95	1,92	1,97	1,84	2,12	2,06	1,99	2,18
2,08	2,20	1,87	2,03	2,09	2,11	2,16	2,14	1,96	1,87
2,06	2,09	2,23	2,00	1,90	2,29	2,04	2,28	2,12	2,24
2,25	2,15	2,20	2,23	2,08	2,17	2,17	1,95	2,00	2,18

$$\overline{M} = \frac{t_1 + \ldots + t_n}{n}$$

In our case:

$$\overline{M} = \frac{t_1 + ... + t_{40}}{40} = \frac{2{,}00 + ... + 2{,}18}{40} = \frac{83{,}35}{40} = 2{,}0837 \approx 2{,}1\,s$$

<u>Car speed</u>: $\rightarrow \overline{V} = \frac{0{,}5m}{T_{medium}} \rightarrow \overline{V} = \frac{0{,}5m}{2{,}1s}$

- Final car speed (in the first power): $V_1 \cong 0{,}24 m/s$

➢ <u>Car speed in the fan's second power</u>:
In the second fan power we obtained these values:

T(s)

1,78	1,67	1,59	1,75	1,59	1,69	1,94	1,52	1,65	1,75
1,56	1,60	1,72	1,62	2,00	1,71	1,51	1,44	1,81	1,94
1,50	1,55	1,70	1,65	1,57	1,53	1,48	1,78	1,47	1,59
1,72	1,47	1,66	1,54	1,51	1,61	2,00	1,68	1,72	1,79

$$\overline{M} = \frac{t_1 + ... + t_n}{n}$$

In our case:

$$\overline{M} = \frac{t_1 + ... + t_{40}}{40} = \frac{1{,}78 + ... + 1{,}79}{40} = \frac{66{,}36}{40} = 1{,}659 = 1{,}7s$$

<u>Car speed</u>: $\rightarrow \overline{V} = \frac{0{,}5m}{T_{medium}} \rightarrow \overline{V} = \frac{0{,}5m}{1{,}7s}$

- Final car speed (in the second power): $V_1 \cong 0{,}30 m/s$

➢ <u>Car speed in the fan's third power</u>:
In the third fan power, we obtained these values:

T(s)

1,47	1,44	1,46	1,65	1,53	1,50	1,63	1,53	1,36	1,38
1,33	1,46	1,50	1,46	1,43	1,44	1,44	1,53	1,53	1,49
1,50	1,39	1,53	1,42	1,43	1,56	1,47	1,50	1,43	1,34
1,51	1,40	1,50	1,43	1,39	1,38	1,53	1,37	1,69	1,42

$$\overline{M} = \frac{t_1 + ... + t_n}{n}$$

In our case:

$$\overline{M} = \frac{t_1 + ... + t_{40}}{40} = \frac{1{,}47 + ... + 1{,}42}{40} = \frac{58{,}75}{40} = 1{,}4687 = 1{,}5s$$

Car speed: → $\overline{V} = \frac{0{,}5m}{T_{medium}}$ → $\overline{V} = \frac{0{,}5m}{1{,}5s}$

- Final car speed (in the third power): $V_3 \cong 0{,}33m/s$

4. Car efficiency:

To determine the car efficiency we use equation (25). We will just substitute, in the three cases (different wind intensity) the average car speed, as also the average wind speed, the air density, the weather vane radius and the time variation (ΔT) and the car mass.

Efficiency Equation:

$$\eta = \frac{4 \cdot (\overline{V}_{car})^2 \cdot m_{car}}{\Delta T \cdot \pi \cdot r^2 \cdot \rho \cdot (\overline{V}_{wind})^3}$$

Information that we need to use:

DATA	VALUE (International Units System)
Wind speed in fan's first power	3,1 m/s
Wind speed in fan's second power	3,8 m/s
Wind speed in fan's third power	4,9 m/s
Car speed in fan's first power	0,24 m/s
Car speed in fan's second power	0,30 m/s
Car speed in fan's third power	0,33 m/s
Average time that the car took to cross over 0,5 meter in the fan's first power	2,1 s
Average time that the car took to cross over 0,5 meter in the fan's second power	1,7 s
Average time that the car took to cross over 0,5 meter in the fan's third power	1,5 s
Car mass	0,150 kg
Weather Vane radius	0.07745 m
Air density	1,21 kg/m^3

Substituting the wind average speed the car average speed the air density, the weather vane radius, the car mass and the time that the car took to cross over 0,5 meter into equation (25), we calculate an efficiency of

- First Power: Second Power: Third Power:

$\eta = 2,4\%$ $\eta = 2,5\%$ $\eta = 1,6\%$

Presenting the car efficiency:

	Efficiency (%)	**Error (%)**
First Fan's Power	2,40	±0,04
Second Fan's Power	2,50	±0,02
Third Fan's Power	1,60	±0,06

3. Car acceleration in the three different wind intensities

We suppose that the car has a constant acceleration. In reality this is not the case, as when the car comes closer to the fan the torque on the weather vane can increase, and, consequently, the final car speed increases also. However, the wind speed does not vary considerably along five meters. Thus, supposing the torque and acceleration constant is a good approximation.

To measure the car acceleration we need to consider as if it is constant. We determined the car acceleration in the three fan's power using the equation below

$$V_F^{\ 2} = V_0^{\ 2} + 2 \cdot a \cdot \Delta S \qquad (27)$$

Substituting V_F of the car according to equation (12), ΔS equal to 0,5 (meter), we find that the acceleration is:

$$a = 4 \cdot \overline{V}_{car}^{\ 2} \qquad (28)$$

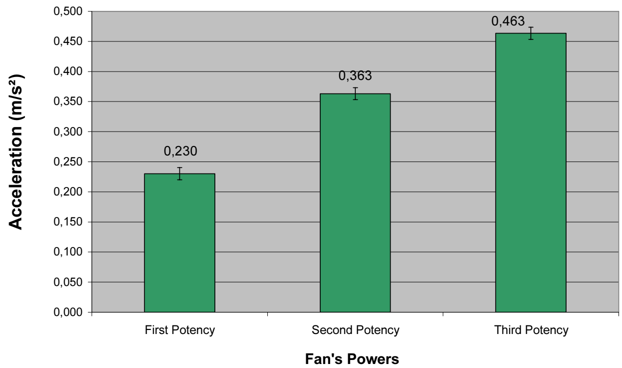
Information we will need to calculate the acceleration:

Average Car speed in fan's first power	0,24 m/s
Average Car speed in fan's second power	0,30 m/s
Average Car speed in fan's third power	0,33 m/s

Substituting the average car speed and placing them in the equation (28): we have, in this fan's power, an acceleration of:

- First Power: Second Power: Third Power:

$a = 0,23 m/s^2$ $a = 0,36 m/s^2$ $a = 0,44 m/s^2$



3.1 Materials:

In our prototype, we used pieces of LEGO™ and a square plastic to make the weather vane, and as the wind source, we used a domestic fan. For doing the measure and calculating efficiency, we use a ruler, chronometers, a measure tape, stickers and polystyrene small balls.

3.2 Possible errors sources:

We did a lot of approximation, like considering the wind speed, as well the car acceleration, constant. There is also friction between the wheels and its welters that could perturb the car.

-Optimization for a next experiment: Maybe if we could work with ideal condition the experimental analyzes as well the mathematical and physical deductions, would be more precise.

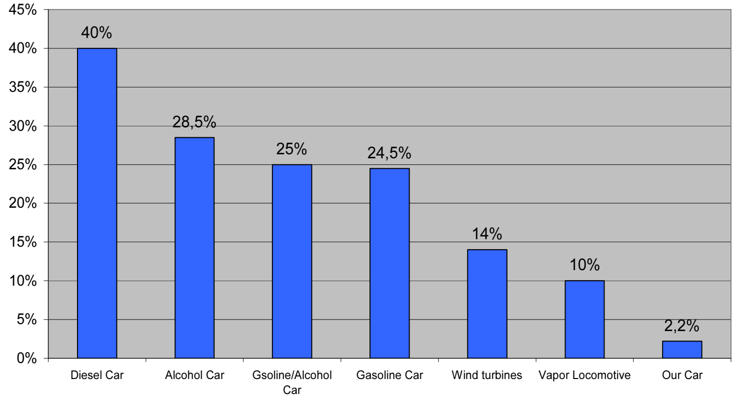
Importance:

- Future energy lapse
- Recent researches about new clean energy
- Environment preservation (pollution)

4. Conclusion:

In this problem, we develop a prototype and also calculated the efficiency of the prototype for different wind intensities (we discover that in the middle power the car has a better performance). The car's efficiency is high if we compare with other systems that also have wind as theirs energy sources.

Gasoline cars have an efficiency of around 25%, diesel cars have efficiency of around 40% (the highest one) and alcohol cars have efficiency of around 28%. Thermo Machines (e.g. vapor locomotive) have efficiency of 10%. Wind turbines (for energy) have an efficiency of 17%. Therefore, our car (average efficiency of 2,2%) is good if we compare it with others professionals models. Below, a graphs of others systems efficiency.



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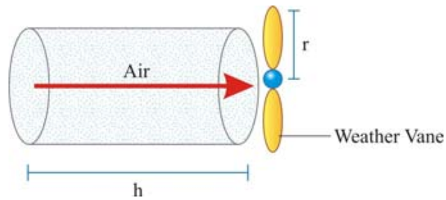
Deduction of efficiency model

- Speed and Kinetic energy: $K = \frac{m \cdot V^2}{2}$
-
- The done work by the car:
-
- $W = \Delta K = \frac{m \cdot V_F^{\ 2}}{2} - \frac{m \cdot V_I^{\ 2}}{2}$ $\qquad V_F = 2 \cdot \overline{V}$

$$W = \frac{m \cdot \left(2 \cdot \overline{V}\right)^2}{2} = \frac{m \cdot 4 \cdot \overline{V}^{\,2}}{2} = 2 \cdot m \cdot \overline{V}^{\,2}$$

- The done work by the wind:



a) $\rho = \frac{m}{V} \Rightarrow V = \frac{m}{\rho}$

b) $V = A \cdot h$ and $V = \frac{m}{\rho}$

$A \cdot h = \frac{m}{\rho} \Rightarrow m = A \cdot h \cdot \rho$ → $A = \pi \cdot r^2$ → $m = h \cdot \pi \cdot r^2 \cdot \rho$ →

$$h = \frac{m}{\pi \cdot r^2 \cdot \rho}$$

c) $\overline{V} = \frac{h}{\Delta T}$ So, $\overline{V} \cdot \Delta T = h$

d) $\overline{V} \cdot \Delta T = \frac{m}{\pi \cdot r^2 \cdot \rho}$ → $m = \overline{V} \cdot \Delta T \cdot \pi \cdot r^2 \cdot \rho$

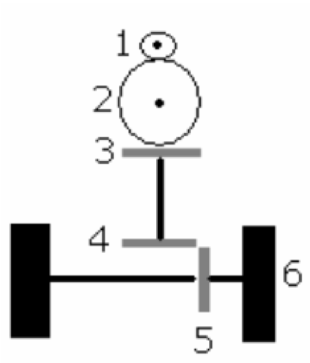
e) $K = \frac{m \cdot \overline{V}^{\,2}}{2} \Rightarrow K = \frac{\Delta T \cdot \pi \cdot r^2 \cdot \rho \cdot \overline{V}^{\,3}}{2}$

f) $\eta = \frac{W_{car}}{W_{wind}} = \frac{2 \cdot (\overline{V}_{car})^2 \cdot m_{car}}{\frac{\Delta T \cdot \pi \cdot r^2 \cdot \rho \cdot (\overline{V}_{wind})^3}{2}}$ → $\eta = \frac{4 \cdot (\overline{V}_{car})^2 \cdot m_{car}}{\Delta T \cdot \pi \cdot r^2 \cdot \rho \cdot (\overline{V}_{wind})^3}$

Wheels, Gears and Weather Vane Revolution
- Model -

We will make a model capable to predict how many revolutions does a gear (or also the weather vane) make with ***n*** revolutions of the wheel. After, we also can

substitute the real values to see the interdependence of the number of revolutions. Our first referential will be the "motored" wheel (number 6, in the drawing).
The number of each gear can be identified in the drawing below:



Gear NUMBER 5: As it is in the same axis than the wheel, we have:

$$n_5 = n_{wheels}$$

Gear NUMBER 4: As it is in contact with gear number 5, we have:

$$n_4 = n_5 \cdot \frac{r_5}{r_4} \rightarrow n_4 = n_{Wheels} \cdot \frac{r_5}{r_4}$$

Gear NUMBER 3: As it is in the same axis of gear number 4, we have:

$$n_3 = n_4 \rightarrow n_3 = n_{Wheels} \cdot \frac{r_5}{r_4}$$

Gear NUMBER 2: As it is contact with gear number 3 and $r_3 = r_4$, we have:

$$n_2 = n_3 \cdot \frac{r_3}{r_2} \rightarrow n_2 = n_{Wheels} \cdot \frac{r_5}{r_4} \cdot \frac{r_3}{r_2} \rightarrow n_2 = n_{Wheels} \cdot \frac{r_5}{r_2}$$

Gear NUMBER 1: As it is in contact with gear number 2, we have:

$$n_1 = n_2 \cdot \frac{r_2}{r_1} \rightarrow n_1 = n_{Wheels} \cdot \frac{r_5}{r_2} \cdot \frac{r_2}{r_1} \rightarrow n_1 = n_{Wheels} \cdot \frac{r_5}{r_1}$$

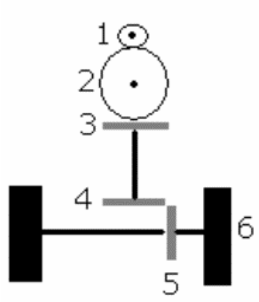
Weather Vane: As it is in the same axis of gear number 1, we have:

$$n_{Vane} = n_{Wheels} \cdot \frac{r_5}{r_1}$$

Wheels, Gears and Weather Vane Revolution
- Results -

We will substitute the radius of each gear in this part of the resolution to see how many revolution does each gear (or also the weather vane) make with one complete revolution of the "motored" wheel (number 6, in the drawing).
The number of each gear can be identified in the drawing below:

For each wheel complete revolution...



Gear NUMBER 5: makes: $n = 1$ revolution

Gear NUMBER 4: makes: $n \approx 0{,}7$ revolution

Gear NUMBER 3: makes: $n \approx 0{,}7$ revolution

Gear NUMBER 2: makes: $n \approx 0{,}7$ revolution

Gear NUMBER 1: makes: $n \approx 1{,}8$ revolutions

Weather Vane: makes: $n \approx 1{,}8$ revolutions

Scalar Speed

As we know the relation between angular speed of the weather vane and the wheel, and we also know the radius of both, we will now calculate the scalar speed (of the extremity of the wheel and of the extremity of the weather vane, respectively)

→ According to the relation of angular speed and scalar speed, we find that the scalar speed of the wheel and the weather vane is, in each fan's power:

$$V = \frac{2 \cdot \pi \cdot r}{T}$$

Scalar speed

Wheels

	Radius (m)	Time (T)	Scalar Speed (m/s) (Error: 0,05m/s)
First Power	0,024	2,1 s	0,023 π
Second Power	0,024	1,7 s	0,028 π
Third Power	0,024	1,5 s	0,032 π

Weather Vane

	Radius (m)	Time (T)	Scalar Speed (m/s) (Error: 0,03m/s)
First Power	0,077	2,1 s	0,067 π
Second Power	0,077	1,7 s	0,091 π
Third Power	0,077	1,5 s	0,10 π

Angular Speed

As we know the relation between the number of revolutions in the Wheel and in the weather vane, we will calculate now the angular speed.

For this part, we need to know how many times does the length of the wheel fit the fixed 0,5 meter distance:

$$x = \frac{0,5}{C} = \frac{0,5}{d \cdot \pi} = \frac{0,5}{0,021 \cdot \pi} \approx 7,6$$

7,6 means the number of revolution that the wheel makes in that distance. It is, approximately, 15π Rad. Using the *models for revolution*, we find that the weather vane, make, in the same space:

13,7 revolutions (approximately, 27π Rad)

→ According to the formula of angular speed, we find that the angular speed of the wheel and the weather vane is, in each fan's power:

$$\omega = \frac{\Delta\theta}{T}$$

Angular Speed:

<u>Wheels</u>

	Angle's variation (Δθ) (Error: ± 0,6 π Rad)	Time (T)	Angular Speed (Rad/s) (Error: ± 0,3 π Rad)
First Power	15π Rad	2,1 s	7,14 π
Second Power	15π Rad	1,7 s	8,82 π
Third Power	15π Rad	1,5 s	10,00 π

<u>Weather Vane</u>

	Angle's variation (Δθ) (Error: ± 0,4 π Rad)	Time (T)	Angular Speed (Rad/s) (Error: ± 0,5 π Rad)
First Power	27π Rad	2,1 s	12,86 π
Second Power	27π Rad	1,7 s	15,88 π
Third Power	27π Rad	1,5 s	18,00 π

Statistic treatment

Average: $\bar{x} = \frac{1}{N} \sum x_i$

Error: $\sigma = \sqrt{\frac{1}{N-1} \sum (\bar{x} - x_i)^2}$

Error of the average: $\sigma_M = \frac{\sigma}{\sqrt{N}}$