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Fig. 1: Rollercoaster in Tibidabo amusement park. Image's source: El periodico.

HOW DOES FRICTION AFFECT THE ENERGY'S CONSERVATION IN A ROLLERCOASTER?

ABSTRACT

Taking into consideration the law of conservation of energy, the central question to be examined in this paper is to what extent does a rollercoaster follow this law and how does friction affect the amount of mechanic energy of a rollercoaster wagon.

THEORETICAL BACKGROUND

Rollercoasters are mainly based on the law of conservation of energy because of the absence of a drive motor. Nevertheless, the amount of mechanical energy decreases along the ride, which is known as energy loss. That means that part of the energy is transformed into other kinds of energy such as heat or mechanical work. This is due to the resistance to the movement caused by friction.

ENERGY CONSERVATION LAW

The mechanical energy of an object is defined by the sum of its kinetic energy and its potential energy. The energy conservation law establishes that the amount of mechanical energy of an object is kept constant.

(1)

$$E_{m_0} = E_{m_f}$$

$$\frac{1}{2}m{v_0}^2 + mgh_0 = \frac{1}{2}m{v_f}^2 + mgh_f$$

Which leads us to the non-intuitive conclusion that the mass does not affect the final velocity.

(2)

$$\frac{1}{2}{v_0}^2 + gh_0 = \frac{1}{2}{v_f}^2 + gh_f$$

We prooved this experimentally by asking some volunteers to step on a scale and ride the rollercoaster. As showed in **(3)**, the mass did not affect the movement of the wagon since the times for the rides did not vary.

(3)

Number of people	People's mass	Total wagon's mass	Time increase in seconds (Δt)
2 people	108,1kg	4022kg	1min 30s - 36s = 54s
4 people	238,1kg	4152kg	1min 31s - 37s = 54s
6 people	356,8kg	4271kg	1min 30s - 36s = 54s
8 people	527,1kg	4441kg	1min 27s - 34s = 53s

ENERGY "LOSS"

From **(2)** we can deduce the velocity at a certain point and then compare it to the data recorded experimentally. We used an accelerometer (SensorLog) as well as a high-definition camera situated away from the rollercoaster. In order to analyse the data, the physics program Tracker was used.

We focussed our calculations on the first and biggest slope of the ride.

Height of the slope	18 m
Initial velocity of the wagon	3 m/s *

* The initial velocity was obtain through video analysis.

(4)

$$\frac{1}{2} \cdot 3\,m/s^2 + 9.8\frac{m}{s^2} \cdot 18\,m = \frac{1}{2}{v_f}^2 + 9{,}8\frac{m}{s^2} \cdot 0\,m$$

$$v_f = +\sqrt{2 \cdot \left[\frac{1}{2} \cdot (3\,m/s)^2 + \frac{9.8\,m}{s^2} \cdot 18\,m\right]} = 19\,m/s$$

However, according to the analysis of the data recorded with SensorLog using Excel, the velocity was 14 m/s. Therefore, some mechanical energy that was supposed to be kinetic became another form of energy.

EFFECT OF FRICTION

The friction with the rails might be responsible for part of this energy loss. If it is true, we would measure an increase in temperature. However, attaching a sensor to the rails or the wheels of the wagon is really hard. Instead, we have decided to use an infrared thermometer. According to it there was an increase of 5°C, but everything points that this value is in fact far bigger, since we only could reach the wheels after being braked.

The air also resists the movement of the wagon which is commonly known as drag force. The drag force is defined as follows:

(5)

$$F_D = 0.5 \cdot C \cdot A \cdot \rho \cdot v^2$$

$F_D = drag\ force$
$A = cross - sectional\ area\ perpendicular\ to\ the\ flow$
$C = drag\ coefficient$
$\rho = fluid's\ density$
$v = velocity\ of\ the\ body$

Nevertheless, if the velocity is rather low and the flow's regime is laminar, therfore drag force is proportional to the velocity instead of the quadratic of velocity. It is recommended to recognise if the flow is turbulent or laminar to apply the best equation. In a laminar regime the air flows in parallel layers but in a turbulent flow eddies and cross currents appear. We have decided to carry out two experiments related to the friction of air.

Experiment A

We started by investigating the type of air friction which affected the wagon. We used a visual method which consisted of the following: three flexible tapes were attached to the back of the rollercoaster wagon. They were 0.5 m to facilitate the observation.

As shown in *Fig. 2*, the flexible tapes move randomly. That means that the drag force which affects the rollercoaster's wagon is not linear resistivity but quadratic resistivity as established in the equation **(5)**.

Fig. 2: Movement of flexible tapes

Experiment B

According to **(5)** the drag force is affected by the area facing the flow. We wanted to prove it experimentally by increasing the surface offering resistance to the air flow. We did it by adding a 1m^2 kite to the last wagon of the rollercoaster. We held the kite to the roller coaster using a dozen of flanges and we recorded the data and compared it with the data recorded without the kite. The result was a 3 seconds increase in the length of the ride.

Fig. 3: Kite attached to the last wagon of the Rollercoaster.

CONCLUSION

We had managed to conduct all the experiments that we had planned, but we had to face unexpected difficulties. For example, the values that we obtained for the temperature increments are useless because they are not reliable. We did not have access to the wagon before the brake and we are not sure if we pointed the gun directly at the wheel.
Moreover, we also had trouble with data analysis. It is hard to relate the data obtained with SensorLog with the images of the high-definition camera. For this reason few numbers can appear in this paper because of their inaccuracy.
However, we learned a lot from these experiments, e.g. the difficulties of obtaining valid data and the role of friction on a rollercoaster.

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