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Experiment 1: Uniform Acceleration Report

Experiment Overview

In this experiment, we created an accelerometer by putting a glider on top of an air track, and attached a weight to the glider and let the weight drop, pulling the glider along the track. The air track was used to reduce friction. We attached masses of 4g, 5g, 9g, 20g, and 35g to the glider and calculated its velocity over time, presented below. We expect the acceleration to increase with mass, but the rate of acceleration should be constant in each run.

Data and Graphs

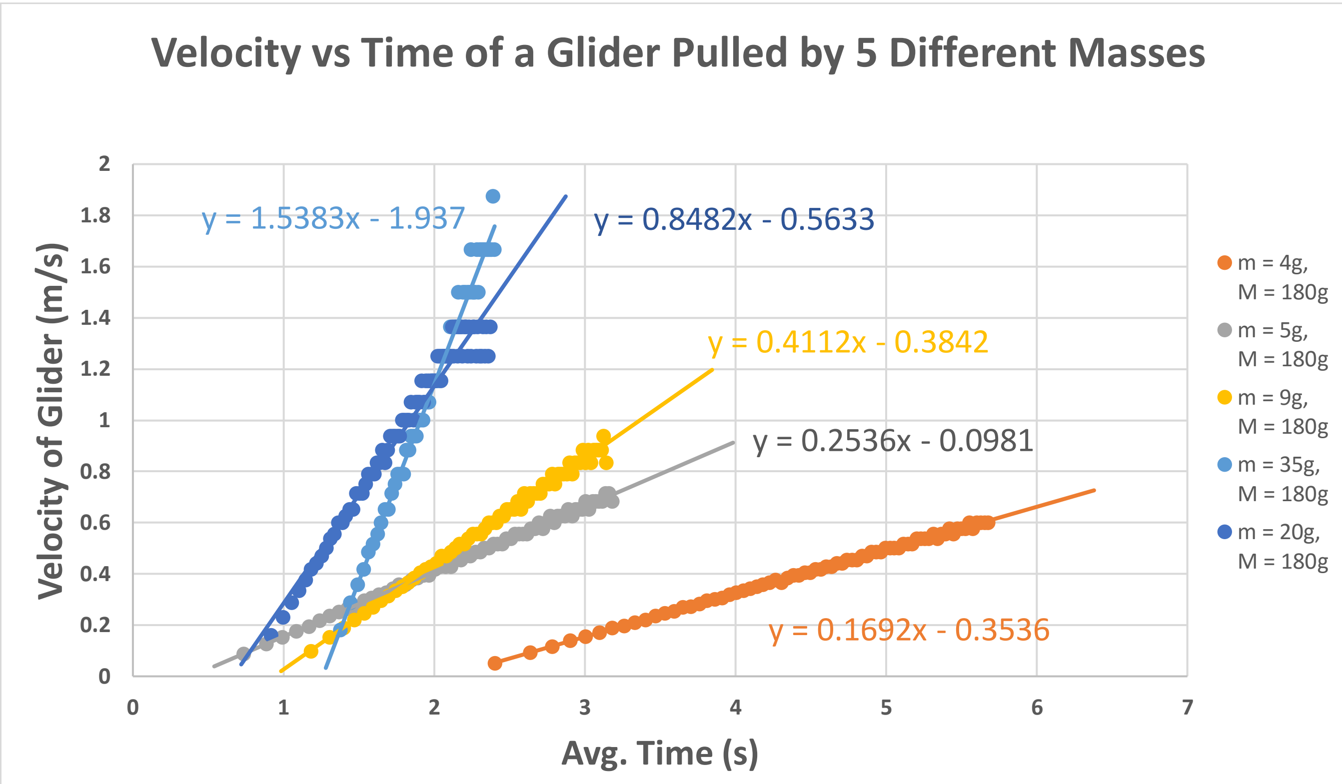


Figure 1: The figure above graphs the relationship between velocity and time of a weight attached to a horizontal glider, with 5 different masses attached to the weight.
At m = 4g, M = 180g, $v = (0.169 \pm 0.001)\ t - (0.354 \pm 0.003)$ in m/s
At m = 5g, M = 180g, $v = (0.254 \pm 0.002)\ t - (0.098 \pm 0.004)$ in m/s
At m = 9g, M = 180g, $v = (0.411 \pm 0.004)\ t - (0.384 \pm 0.009)$ in m/s
At m = 20g, M = 180g, $v = (0.84 \pm 0.02)\ t - (0.56 \pm 0.03)$ in m/s
At m = 35g, M = 180g, $v = (1.54 \pm 0.02)\ t - (1.94 \pm 0.04)$ in m/s

Data Table

Trial	Hanging Mass m_{best} (g)	Glider Mass M_{best} (g)	Fit Acceleration a_{fit} (m/s^2)	Predicted Acceleration a_{best} (m/s^2)
1	4.0	180.0	0.169 ± 0.001	$.21 \pm 0.03$
2	5.0	180.0	0.254 ± 0.002	$.27 \pm 0.03$
3	9.0	180.0	0.411 ± 0.004	$.46 \pm 0.03$
4	20.0	180.0	0.84 ± 0.02	$.98 \pm 0.02$
5	35.0	180.0	1.54 ± 0.02	1.60 ± 0.02

Derivation of Acceleration Equation (Equation 1.1)
We apply Newton's second law to the system, where the sum of forces is equal to the total mass of the system times the acceleration of the system.

$$\sum\vec{F} = m_{system}\vec{a}$$

The only notable force is gravity acting on the small mass. The total mass of the system is (M + m), where M is the mass of glider and m is mass of weight, and so by substitution, we get:

$$m\vec{g} = (M + m)\vec{a}$$

By dividing by (M + m) to isolate acceleration, we get

$$\vec{a} = \frac{mg}{M+m}, \text{ in terms of } (\text{m}/s^2)$$

which is equivalent to equation 1.1.

Derivation of Propagation of Uncertainties
We apply the propagation of uncertainties formula,

$$\delta f = \left. \sqrt{\left(\frac{\partial f}{\partial x}\delta x\right)^2 + \ldots + \left(\frac{\partial f}{\partial z}\delta z\right)^2}\,\right|_{x_{best},\ldots z_{best}}$$

to the formula we just previously derived, the acceleration of the system, to find it's uncertainty range.

$$\vec{a} = \frac{mg}{M + m}$$

We use m and M as our two variables of differentiation.

$$\delta a = \sqrt{\left(\frac{\partial a}{\partial M}\delta M\right)^2 + \left(\frac{\partial a}{\partial m}\delta m\right)^2}$$

Find the derivatives with respect to M and m,

$$\frac{\partial a}{\partial M} = \frac{-mg}{(m + M)^2} \qquad \frac{\partial a}{\partial m} = \frac{gM}{(m + M)^2}$$

And substitute in the uncertainties equation.

$$\delta a = \sqrt{\left(\frac{-mg}{(m + M)^2}\right)^2 * \delta M^2 + \left(\frac{gM}{(m + M)^2}\right)^2 * \delta m^2}$$

$$\delta a = \sqrt{\frac{g^2}{(m + M)^4}}\sqrt{m^2 * \delta M^2 + M^2 * \delta m^2}$$

$$\delta a = \frac{g}{(m + M)^2} * \sqrt{m^2 * \delta M^2 + M^2 * \delta m^2}$$

For measurements, the uncertainty is half the smallest unit of measurement, which for our scale is grams. Thus, $\boldsymbol{\delta M}$ and $\boldsymbol{\delta m}$ are both equal to 0.5g. We convert 0.5g to kilograms.

$$\delta a = \frac{g}{(m + M)^2} * \sqrt{m^2 * 0.0005^2 + M^2 * 0.0005^2}$$

$$\boldsymbol{\delta a} = \frac{\left(\mathbf{5} * \mathbf{10^{-4}}\right)\boldsymbol{g}}{(\boldsymbol{m}+\boldsymbol{M})^{\mathbf{2}}} * \sqrt{\boldsymbol{m}^{\mathbf{2}} + \boldsymbol{M}^{\mathbf{2}}}$$

Since in our experiment, M is not varied and is always 180g, we can set M = 180g in our uncertainty equation. We cannot do this if we had varied the mass of glider. All masses in the final equation have units of kilograms, since the acceleration equation is derived from the force, and weight is measured in part by kilograms.

$$\boldsymbol{\delta a} = \frac{(\mathbf{5}*\mathbf{10^{-4}})\boldsymbol{g}}{(\boldsymbol{m}+\mathbf{0.180})^{\mathbf{2}}} * \sqrt{\boldsymbol{m}^{\mathbf{2}} + \mathbf{0.180^{2}}} \text{ , in terms of } (\mathrm{m}/s^2)$$

We find the uncertainty ranges for our predictions up above by plugging in the mass of the falling weight m into the uncertainty equation we found.

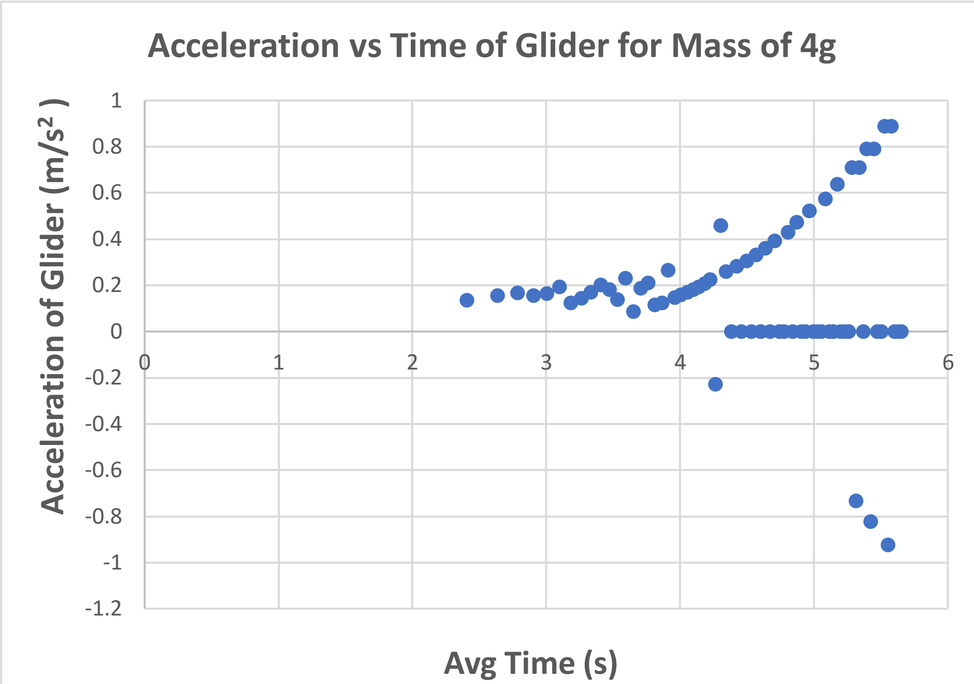
<u>Conclusion</u>

Overall, my data supports the conclusion that a greater mass causes greater acceleration on the glider. We also show that the acceleration by a constant force(gravity) is constant and uniform. However, where my data and my predictions differ is by how much acceleration. The percentage for error for the 4g mass is 19.5%, for the 5g mass is 5%, for the 9g mass is 10.7%, for the 20g mass is 14.3%, and lastly for the 35g mass is 4.0%(using the best accelerations for both predicted and actual). Every mass's real acceleration turned out to be less than their predicted values. Some of the masses, such as 5g and 35g came close, but were still less. Therefore, we can assume there is some external factor causing friction to slow the acceleration, which our predicted model does not take into account.

Some of these potential sources come from the fact that it is impossible to entirely remove friction from the system; this is only possible in a vacuum, and unfortunately UCLA cannot afford the enormous expense to shoot the entire 4AL class into space. Sources of friction include the string rubbing on the pulley as the weight drops, friction due to the spin of the pulley, and friction due to air resistance (even though the track removes friction due to sliding, it does not remove friction due to air entirely, however slight that friction is). Additionally, the glider may not have been positioned correctly onto a flat surface, and a slight upward rise in the track would certainly cause the glider to accelerate slower. All these sources of error contribute to the difference between the predicted and actual values of acceleration.

One way to improve the accuracy of the accelerometer is to ensure that the table is truly level and the glider, eliminating that source of error. You could include a bubble or spirit level to indicate whether or not the track is level, and if it is not level adjust the legs of the track until the level indicates the track is level.

Extra Credit



This data has a lot of noise, and does not have a slope of zero that a constant acceleration normally should have. However, the average acceleration of this graph is (0.16 ± 0.31 m/s^2) (uncertainty calculated on Excel with STDEV.S), which is relatively close to the calculated acceleration (0.169 ± 0.001 m/s^2) we found by taking the slope of the velocity vs time graph.

We see a lot of noise in this graph because factors such as friction on the pulley wheel and air friction, as well as inconsistent air pumping from the air track, may have caused the glider's acceleration to slow or speed up. These factors are unpredictable and hard to prevent, although they do not affect the final acceleration calculation by too much. However, the twice differentiated acceleration had a percent error of 23.8% compared to the predicted acceleration, which is worse than the velocity vs time graph acceleration, which is 19.5%. We can therefore assume that this graph is more affected by little differences caused by external factors mentioned previously.

Because obtaining acceleration from the velocity vs time graph resulted in a more accurate acceleration and is much more readable to humans, it is a better way to obtain the acceleration than by differentiating position twice by time.

Nuclear Fusion Reactors with ITER

ITER, or the International Thermonuclear Experimental Reactor, is the world's largest nuclear fusion reactor experiment being built in Cadarache, France[1]. Construction of the reactor formally began in 2008, and is expected to be finished in 2018, when scientists can finally begin to experiment with large scale magnetic confinement plasma fusion[1]. The goal of the project is to produce nuclear reactors that are stable enough to operate for long periods of time and produce a net gain of energy[2].

How does nuclear fusion produce energy? Two hydrogen atoms strike each other at extremely high speeds, creating a new atom, usually helium, and ejects a neutron. The process can be visualized with the equation ${}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{2}He + {}^{1}_{0}n +$ energy. The energy on the right side of the equation comes from a bit of mass that is converted to energy in the process. The energy converted is calculated according to $E = mc^2$, and this energy is what scientists hope to capture in nuclear fusion.

The Sun achieves nuclear fusion through its own immense mass, compressing hydrogen together at its core so tightly that hydrogen atoms fuse[3]. However, our Sun is only able to fuse hydrogen because it is so massive, so scientists on Earth must find a way to force hydrogen together in a different way. At ITER, the hot plasma will instead be held together by a magnetic confinement field[3]. Charged electrons and protons break apart from one another during fusion and become bound to a magnetic field because of their charge[3]. This allows scientists to direct the flow of the plasma and keep it contained. The magnetic field is looped in a torus, directing the flow of plasma in a circle and preventing loss of plasma particles[3]. Nuclear fusion happens inside this circular magnetic field[3].

Scientists at ITER will use a device called the Tomahawk, charged magnetic coils wrapped around in a donut-like fashion, to contain nuclear fusion reactions[3]. The temperatures inside the Tomahawk can reach above 150 million °C (almost 10 times as hot as the core of the sun)[3]. This heat is both beneficial and not: we capture some of that heat as energy, yet such large temperatures can cause large fluxes and turbulence in the reactor, which could breach the reactor and cause nuclear fusion to fail[3].

One current limitation of viable nuclear fusion is the walls. Fusion is held in place in the tomahawk by magnetic force, but some parts of the magnetic field intersect and cross the wall, which brings the hot plasma in contact with the wall.[4] Because this plasma travelled along the magnetic field line, it is concentrated and so that part of the wall experiences much greater heat per square area than most parts of the wall. The average heat of the wall, or average wall-load, is 0.15 MW/m^2 [4]. However, plasma along the magnetic field lines, called peak loads, can be as hot as 20 MW/m^2 [4]. For reference, the safe limit of high heat is at 10MW/m^2, half the heat released by peak loads.[4] Peak loads damage the wall by scraping off the inner layer and weakening its foundations. If the wall were to break, the fusion reaction would halt.

Even without peak loads, erosion of the wall due to heat happens naturally, which can cause pieces of the wall to fall into the reacting plasma as well[4]. Such impurities dilute the fuel of the reaction and lowers the output of energy fusion can provide[4]. Scientists must create a wall that can withstand both the high heat of the peak loads and prevent contamination of the plasma during reaction[4]. Scientists are currently experimenting with materials such as Beryllium, Tungsten, and Graphite[4].

Scientists plan to test ITER with normal hydrogen for the first 10 years, before moving onto deuterium and tritium, the heavier isotopes of hydrogen[2]. These heavier isotopes produce much more energy when fused[2]. A key objective of ITER is to sustain fusion for at least 8 minutes, to prove magnetic confinement can sustain fusion for a long period of time[4]. If stability is achieved, nuclear fusion can provide large amounts of energy at almost no environmental cost, all at the expense of hydrogen molecules in water.

Word Count: 698

References

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