Cylinder Race

Jillian Mangum

Table of Contents:

Introduction
Method/Procedure
Materials
Diagram
Results/Analysis
Conclusion/Evaluation
Bibliography
Related Links

Introduction:

Since the creation of the first cars in the late 1800s, there has always been racing, the first recorded official motoring competition being on July 22, 1894, from Paris to Rouen. (Paolozzi) The construction of gasoline automobiles sparked a brand new interest in racing and encouraged inventors to push the limits of cars when it came to time trials, distance trials, and speed trials, continuously improving the automobile industry.

My whole life, my family has always been into cars and racing, and as a result of that, I was a toy car enthusiast as a child. This inspired me to involve track and time trials in my IA so I could incorporate some of my favorite aspects of cars, the racing, speed, and time trials.

Friction is the force responsible for the movement of objects from a car to in my case a cylinder. Friction is a resistive force that occurs when objects are in contact with each other, and it prevents slipping or sliding of objects. Friction is what allows the track to function, as it is responsible for the rolling motion of an object, in this case a cylinder.

I will be looking at the cylinder as it rolls down a track and timing it, then comparing my results in accordance with the height that will change each trial. The time will hopefully decrease as the height increases. This should happen because increasing the height will change the angle at which the track is, and the angle increase will make the track steeper. The more steep the angle is, the more parallel force is acting on the track. Seeing as the gravity is parallel to the plane at which the cylinder is rolling, the faster the cylinder will accelerate. As it accelerates faster, the shorter time it will take to reach the bottom of the track. The cylinder did prove to encounter some slipping issues when the track was raised too high because the steepness of the hill caused less contact between the track and the cylinder and less friction. The friction is responsible for the speed and movement of the cylinder and so maintaining the friction throughout the experiment was crucial.

The purpose of this investigation is to determine the relationship between height and time as a cylinder rolls down a track, specifically trying to see how friction affects both of these variables. The controlled variable is the length of the track, the length will stay the same each time while only the height is changing. The person timing and the person starting the roll of the cylinder will also remain the same in order to maintain consistency between the takes of data. The height is the independent variable in the experiment and the time is the dependent variable as the time it takes to roll down the ramp depends on the height of the ramp. My hypothesis is that gravity will pull the cylinder down the track. Friction will make it roll, but it will slow down the cylinder as it goes down the track. The time it takes for the cylinder should depend only on the length of the track, the height of the end of the track and gravity according to the equation $t = \frac{2l}{\sqrt{gh}}$, which is derived below.

To verify this information I will be timing the cylinder as it rolls down the track while executing this experiment at different heights (meaning that the track will be positioned at different slopes). The height, meaning the height at the end of the track however, could not reach too high or too low because of some of the external factors that would affect the data. Too high of a height would cause the cylinder to slip too much instead of rotate, while too low of a height would not give the cylinder enough momentum to make it down the track and get accurate time. Using the wood cylinder would also hopefully allow some consistency in my trials, as any other object could have imperfections that would affect the data. The data should linearize and prove that there is a linear relationship between the height and time using rotational mechanic equations and friction equations.

Method/Procedure:

I faced some challenges in gathering data, however I was able to get my variations for each for my set using some creative problem solving. In order to gather my data I had to figure out how to manipulate the height of the track in order to obtain the different times, this is why I decided to include the use of books to raise the height of the track, and obtain my different variations. Once I had the heights, I would take the cylinder and put it at the top of the track, there would then be a lever and a stopper, that when pulled would release the cylinder and allow it to roll down the track.

The height was the independent variable in this experiment, and it was changed using the stack of books. I would continue adding a book at a time to raise the height gradually, avoiding making it too high to avoid the slipping of the cylinder. The time was the dependent variable since it changed in accordance with the height. This time was measured using a stopwatch on my phone to time the cylinder starting at the release of the lever, until it reached a designated stopping point at the end of the track. The controlled variable was the length of the track and there was nothing I needed to do in order to keep it the same length as it did not change with the height. It was able to stay constant because its length was preset and could not change because it was a solid object and had no opportunities to lengthen or shorten.

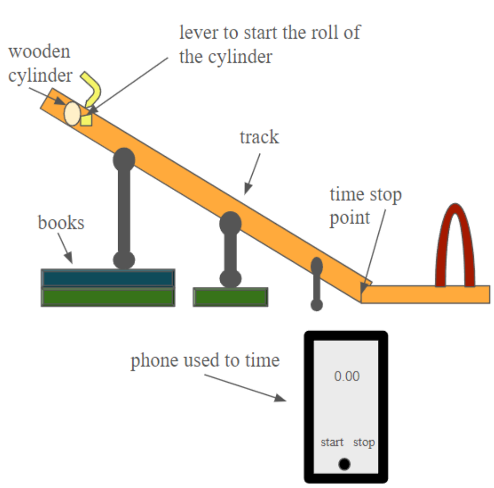
The data was gathered in sets of 7 data points over variation with ten different variations. I decided to have ten different variations of increasing heights, as it was very difficult to get heights that differed enough to show a change on a graph between the times. It was decided to get 7 data points to make up for fewer variations. The amount of trials would also give me a more accurate average for the time and would make it more exact. There were also no ethics or safety concerns during the course of gathering my sets of data.

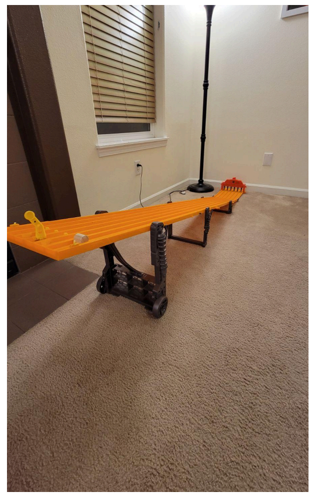
Materials:

- Books
- Track

- Wooden Cylinder
- Timer (used from a phone)
- Measuring tape (to measure height and length)

The Diagram showing the track, cylinder, and phone used for timing purposes as well as a photo of the setup.





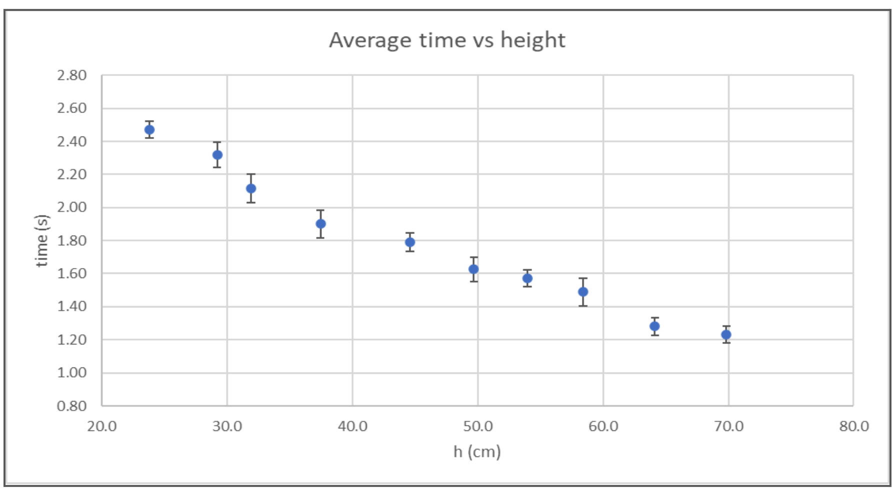
Results/Analysis:

The raw data tables includes ten different trials, with the different trials all being represented with the height given in centimeters, and the given time in seconds. The times stay relatively consistent throughout each of the trials, as the ranges of the time stay within an average of about 0.16 seconds of each other.

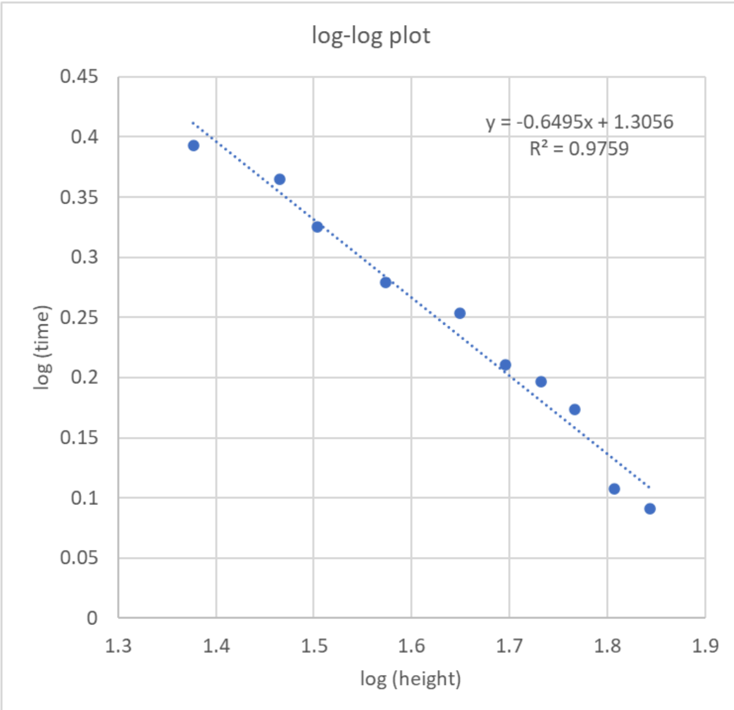
Trial 1		**Trial 2**		**Trial 3**		**Trial 4**		**Trial 5**	
height (cm)	time (s)	height (cm)	time (s)	height (cm)	time (s)	height (cm)	time (s)	height (cm)	time (s)
23.8	2.45	29.2	2.31	31.9	2.19	37.5	1.79	44.6	1.79
	2.53		2.25		2.13		1.93		1.86
	2.47		2.26		2.19		1.80		1.79
	2.47		2.38		2.00		2.00		1.86
	2.54		2.45		2.11		1.99		1.79
	2.39		2.25		2.00		1.86		1.72
	2.45		2.33		2.19		1.93		1.73

Trial 6		**Trial 7**		**Trial 8**		**Trial 9**		**Trial 10**	
height (cm)	time (s)	height (cm)	time (s)	height (cm)	time (s)	height (cm)	time (s)	height (cm)	time (s)
49.7	1.53	54	1.53	58.4	1.40	64.1	1.30	69.9	1.20
	1.60		1.59		1.46		1.21		1.27
	1.67		1.66		1.46		1.21		1.21
	1.66		1.60		1.66		1.33		1.28
	1.73		1.59		1.46		1.28		1.27
	1.53		1.52		1.46		1.29		1.14
	1.66		1.52		1.53		1.34		1.26

The graph below shows the average time against the average height with error bars. The averages were found by taking each of the data sets, adding them together, and then dividing by the number of points in each trial. The error bar data was calculated using the standard deviation, and they demonstrate the errors in the time. The graph follows a downward trend and stays fairly linear, however there are some points that don't quite follow the trend in the expected way due to outliers in the time.

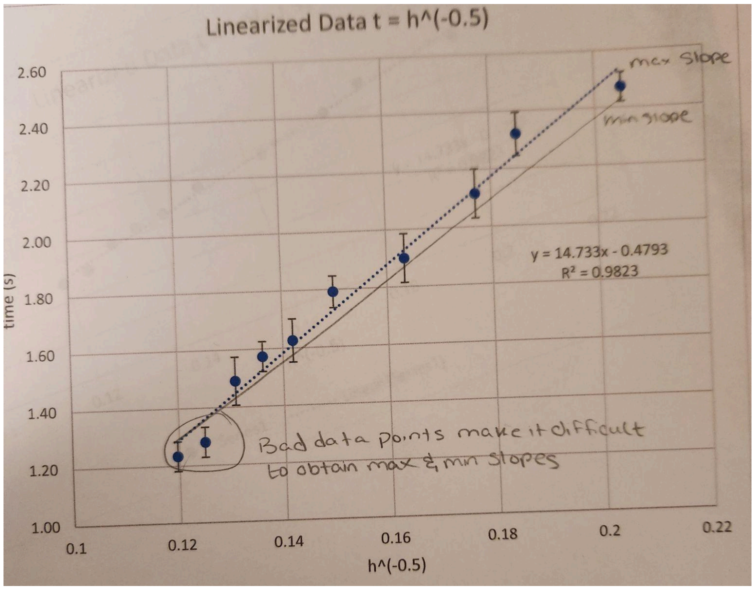


The log-log plot below shows the log of the time against the log of the height. This graph shows whether or not the data was linear. The result of the log-log plot tells us that the data of the original graph was not linear, because the logs result in a linear line instead. The slope of the log-log plot line shows the power of the relationship between the dependent and independent variables. The equations for the relationship between time and height tell us that the power should be negative 0.5, while the slope of the line from my data was 0.65.



With the linearized data graph below, the equation shows the linearized trend line's slope of 14.7 (s per cm^-0.5), which ended up being somewhat close to the expected slope of 12.4. THis expected slope comes from the derived the equation $t = \frac{2l}{\sqrt{gh}}$. Reasons for deviations from the expected slope are discussed below, but briefly, this higher slope than expected indicates that I had more friction than was accounted for in my equations.

There was an issue with the linearization of this graph though because the trend line also ended up being the steepest, or maximum slope line through the error bars. This is due in part to the last two data points being affected by the lack of friction with the increasing height. This is where the cylinder encountered slipping problems, causing the last two heights on the graph to not follow the previous trend.



Overall the data collected did not end up fitting quite as expected. Outside errors affected the data too much and as a result the slopes of the graphs for each set of data did not align with the slopes calculated by the equation used to try and prove the relationship between the height and time, however despite there not being an established relationship, there was still a correlation.

Conclusion/Evaluation:

[**DataFile**]

Using the equation $t = \frac{2l}{\sqrt{gh}}$ the investigation attempted to identify the relationship between height and time. In order to obtain this equation, I needed to use a few different formulas. These equations included those for, torque, force, work and energy, and motion. I used the net torque to find the force of friction. I used the sum of the forces to find the acceleration. I used the equations of motion to find the velocity. Finally I substituted each of these into a conservation of energy equation that also accounted for the work done by by friction. When I put it all together and solved for how long it should take a cylinder to roll down the ramp I got the final equation of $t = \frac{2l}{\sqrt{gh}}$.

Torque Equations:

$$\sum \tau = I\alpha$$

$$f \cdot r = I\alpha$$

$$\alpha = \frac{a}{r}$$

$$f = \frac{I \cdot a}{r^2}$$

Force Equations:

$$\sum F = mg\sin\theta - f = ma$$

$$mg\sin\theta - \frac{I \cdot a}{r^2} = ma$$

$$a = \frac{mg\sin\theta}{m + \frac{I}{r^2}}$$

$$\sin\theta = \frac{h}{l}, I_{cyl} = \frac{1}{2}mr^2$$

$$a = \frac{2gh}{3l}$$

Work and Energy Equations:

$$mgh = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2 - W_{friction}$$

$$I = \frac{1}{2}mr^2$$

$$mgh = \frac{3}{4}mv^2 - f \cdot l$$

$$gh = \frac{3}{4}a^2t^2 - \frac{1}{2}al$$

Equations of Motion:

$$v = v_0 + at$$

$$v^2 = a^2t^2$$

The fit of the resulting gave a slope that was close to the calculated value, however the trend lines show that it wasn't exactly aligning with the expected results. The errors affecting the data would cause for inaccuracies in the results, mostly due to outliers that did not match the rest of the data, and experimental errors. My hypothesis was that gravity will pull the cylinder down the track in a predictable fashion that was calculated above. Friction will make it roll, but it will also slow down the cylinder as it goes down the track. This hypothesis ended up being proven correct, but the data did not accurately portray this to the extent at which it is true.

There were a few different sources of error that would have affected the accuracy of the data, some being human errors, some being the fault of the track. The timing itself could've been off as a result of a slow reaction time, such as the button not being stopped or started at the moment of the start of the roll and at the end of the roll. Another non-human source of error could have been the track itself. The track is not perfectly smooth, there are some small bumps in places so the cylinder might not follow the exact same path every time and would have varying amounts of friction each run. There could have also been some instability in the books causing slight movements in the track that would have affected time. Another error could be the cylinder bumping the sides of the track adding unwanted friction to the cylinder, this is most likely the largest source of error.

In order to avoid some of these issues to minimize the errors, a sturdier track would be needed. The track could be based in the ground as well to avoid any possible movement of the track that could occur during the roll. Making a wide enough lane to minimize any added friction from contact with the sides would also increase the time accuracy. A much longer track would reduce time errors because the times measured were very short for being solely measured by a stopwatch, thus a longer time could minimize this error. Also not having to stack books to adjust the height of the track and having a more easily adjusted height would be beneficial for a person taking measurements.

Further research ideas could include changing the mass and size of the cylinder and analyzing if the correlations between the time and heights are still consistent with the equations I found. It is worth noting that in the equations, the mass cancels out and so there should be no dependence there. Also, the radius of the cylinder also cancels out, so again changing for different sizes or masses of the cylinder should have no impact. Additional experiments could be done to prove that this is true. One could also investigate racing different cylinders of the same mass and size at the same time and in a perfect world they would presumably have the same time to reach the bottom, but in actuality, this most likely would not happen. Investigating why this could happen would allow one to see how uncontrollable errors affect results in data.

Bibliography:

Khan Academy. "What Is Friction?" *Khan Academy*, Khan Academy, 2016, www.khanacademy.org/science/physics/forces-newtons-laws/inclined-planes-friction/a/what-is-friction.

Panvini, R.S. “CLASS NOTES.” *Vanderbilt.edu*, Vanderbilt, 15 Sept. 2002, www.vanderbilt.edu/AnS/physics/panvini/p110a/f02/supp8.html. Accessed 17 Jan. 2024.

Paolozzi, Remi. “The Cradle of Motorsport.” *Forix.autosport.com*, 28 May 2003, forix.autosport.com/8w/bdb.html. Accessed 17 Jan. 2024.

Related Links:

https://www.techtarget.com/whatis/definition/kinetic-energy
- This article discusses the differences in the types of energy and how they are conserved and the relationships between movement and energy.

https://www.livescience.com/37161-what-is-friction.html
- This article talks about how friction works and how friction applies in everyday situations.

https://asmedigitalcollection.asme.org/mechanismsrobotics/article/16/1/015001/1160109/Embedded-Linear-Motion-Developable-Mechanisms-on
- This article talks specifically about cylindrical motion and how it is different from other types of motion in association with different objects.

https://www.physicsclassroom.com/class/1DKin/Lesson-1/Acceleration
- This article talks about acceleration and how to find it, and how it applies.

https://www.physicsclassroom.com/class/vectors/Lesson-3/Inclined-Planes
- This article talks about inclined planes and how gravity and forces affect objects moving down inclined planes.