Testing the Accuracy Amongst Air Tracks and the Capstone Software Through Conservation of Energy and Friction

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1 Abstract

The purpose of this project was to determine the accuracies of the results gained from using air tracks and the Capstone software on the lab computers at Christopher Newport University. Not every piece of equipment in a lab will operate the same. In performing the experiment that is detailed throughout this final report, I was able to see how much of a difference there is between air tracks. Throughout this project many different types of data were gathered. The majority of the data presented is quantitative, but there are other forms such as notes that are qualitative. The results produced from this project consist of raw data, data from code, statistical data based on computed data, notes from when performing the experiment and presented data.

The project performed consisted of two major experiments. These experiments were named Experiment 1 and Experiment 2. In Experiment 1, values such as gravitational potential energy, kinetic energy, and coefficient of friction were calculated. In Experiment 2, values such as spring potential energy, kinetic energy, total weight, and force were calculated. Another component that was necessary in completing this project was a computational component. This component contained multiple files of Python Code. PyCharm Community was used in order to complete all of the Python code. By using Python, I was able to find all of the energies, total weight, force and many other values. PyCharm was another excellent way to store important data. Other forms of important data were statistical data. These statistical data included mean, median, mode, root mean square, standard deviation and other values.

Lastly, as a result data that was found throughout the project was displayed in the following final report. The data was transfered from PyCharm Community

and placed into charts or graphs for better observance. Graphs that were made during the experimental portion of the project are also included.

2 Introduction

As mentioned above, my project was designed in order to test the accuracy of the air tracks used during a physics lab along with the equipment and software. I used three different air tracks, three different computers and three different blowers. The techniques I chose were to find the conservation of energy and the coefficient of friction. I was able to compute the values for spring potential energy, kinetic energy, and gravitational potential energy. I chose to find the coefficient of friction between all three air tracks to see if they were truly frictionless. When performing Experiment 1 I was able to find the coefficient of friction. Experiment 1 was Gravitational Potential Energy vs. Kinetic Energy. Experiment 2 was Spring Potential Energy vs. Kinetic.

3 Theory

3.1 Mathematical Modeling

The following are equations that were used in my computational portion of my project.

3.1.1 Gravitational Potential Energy

$$U_g = mgh \tag{9}$$

Using the height(floor to the top of the pulley), acceleration due to gravity and the mass of the hanging mass, I was be able to calculate the gravitational potential energy.

3.1.2 Spring Potential Energy

$$U_s = \frac{1}{2}k(\Delta x)^2 \tag{10}$$

This first equation was used to calculate the energy stored in a compressed spring.

$$F = -k\Delta x$$

(11)

By multiplying the spring constant with the compression value I was able to find the force in Experiment 2. In order to find the spring constant I needed to plot force vs. compression. The output was a straight line. The slope of this line determined what the spring constant was for each air track.

3.1.3 Kinetic Energy

$$K = \frac{1}{2}mv^2 \tag{12}$$

To solve for kinetic energy I added the mass of the air track cart and hanging mass together. The total mass was then multiplied by the squared velocity value and 0.5.

3.1.4 Total Weight

Total weight was computed by multiplying total mass and acceleration due to gravity.

3.1.5 Coefficient of Friction

$$f = m * g - m * a - M * a \tag{13}$$

m was the hanging mass, M was the mass of the cart and flag, g was acceleration due to gravity, and a was the acceleration of the cart.

3.2 Data and Error Analysis

3.2.1 Analyzing Data

In order to analyze my data, I collected measurements and put the values (mass, height, etc.) into the corresponding equations that I have listed in Mathematical Modeling. Values such as velocity and acceleration were gathered through the Capstone software.

3.2.2 Comparing to Theory

As for comparing my findings to theory, I used the data and calculations I collected while performing the experiments and compared them with other data that I have found during the computational portion of my project.

3.2.3 Uncertainties

The uncertainties I looked for were for the raw data values (velocity and acceleration). I also found the uncertainty values for all of the data that was calculated through Python coding. These other uncertainty values were gravitational potential energy, spring potential energy, kinetic energy, total weight, force, and coefficient of friction. These uncertainties values were found by inputting all data mentioned into a website called Calculator Soup. Once the data was computed I used the standard deviation that was presented to me as the uncertainty values. All found uncertainty values will be displayed in the data section of this final report.

4 Methods

4.1 Procedures

4.1.1 Experimental

Experiment 1:
In Experiment 1, I was looking for both Gravitational Potential Energy and Kinetic Energy. In order to do so I needed to have a pulley system with hanging masses attached to the air track cart. The hanging masses used were 0.00193 kg, 0.01179 kg, 0.01668 kg, and 0.01959 kg.The air track cart was held at the end closest to the lab computer and then released just before it hit the rubber barrier at the opposite end. I initially planned to have a different pulley set and hanging masses with each air track. I changed it to the same set because I realized in my initial method planning I did not have enough dependent variables. By keeping the same pulley set I was able to see more clearly if there was a consistency throughout all three air tracks. During this experiment I used four different masses for each air track. I kept with the 15 trials per mass per air track, making a total of 180 trials. Since I took data for both velocity and acceleration during this portion of my project I ended up getting 360 data points. This was not the only data that I took though. In the beginning I did one air track a completely different way before deciding I did not want to go about that method. Essentially I was only using about half of the air track and was not getting the final velocities and final accelerations that I wanted. I compared the values I received with values I got in the lab prior to this project. I did not throw out these data points I took, instead I chose to include them in a test section of my Python code. I also took other test data points on the other two air tracks. These test data points included changes in how much of the air track I used and different amounts of air pressure used. In the testing, I

chose to remain consistent in testing the distance for this portion. The reason I changed the air pressure was because I was curious in how different amounts of air pressure would affect my project. When changing the air pressure, I stayed within the range of medium to high.

Experiment 2: Experiment 2 consisted of the spring and rod attached to the end of the air track. Unlike Experiment 1, I chose to find the initial velocity during this portion of my project. I launched the air track farthest from the lab computer. Right after it was launched I recorded the initial velocity. I found the initial velocities for two different distances that the spring was compressed to. Both of these distances were 0.02 meters and 0.025 meters. I performed 15 trials for both distances for three different air tracks. I was also able to gather test trials. These trials were performed on my first day in the lab. I originally planned to launch the cart and wait for it to bounce off of the barrier closest to where I was sitting. This ended up giving me the final velocity. Because I wanted to find the initial velocity, I redid all fifteen trials and kept the previous ones as test trials.
When finding the compression I stacked a series of slotted weights on top of the spring. The spring was placed over a rod with a piece of the air track attached to it as a base. As each series of weights were placed on the mass I measured the compression. In order to find the spring constant I plotted the values for force and compression in the Capstone software. The slope for each graph that was produced for each air track was the determined spring constant.

**Each air track was placed on its own table.

4.1.2 Computational

The computational portion of my project is comprised of Python code. For my Python code I have multiple Python files. Those files are:
Data Comparison (Exp. 1)
Data Comparison (Exp. 2)
Data Comparison (Test- Exp.1)
Data Comparison (Test- Exp.2)
Experiment 1
Experiment 2
Percent Differences(Exp 1)
Percent Differences(Exp. 2)
Percent Differences (Test- Exp. 1)
Test Comparison (Spring)
Test Runs- Experiment 1
Test-Runs Experiment 2
Test Comparison (Exp. 1)
Test Comparison (Exp. 2)

Python files such as Experiment 1 and Experiment 2 contain the calculations I needed to find outlined in my final design report and proposal. In Experiment 1 I wrote for loops to find values for gravitational potential energies, kinetic energies, coefficients of friction, velocities, accelerations, and all of the averages that go along with those values. For all three tracks I wrote for loops. Each hanging mass I used (four different hanging masses) had their own set of for loops. In Experiment 2 I also wrote for loops for the values of spring potential energies, kinetic energies, Force, total weights, and all of the averages that go along with those values. In Experiment 2 I also used three air tracks in my project. Each air track had two different distances of which I compressed the spring to. Each of those spring distances had their own set of for loops.

4.2 Utilized tools

The tools I utilized throughout my project were:
Pasco Air Track (3)
Motion Sensor II (used 1 but had 3 on hand)
Pasco Capstone Software for all three lab computers
Flag for the cart (1)
Lab computer
My personal laptop
Spring, rod, washer, and slotted weights (Experiment 1)[Used 3 different springs and 3 different rods]
Pulley system(Experiment 2)[1]
Ruler(1)
Scale(2)

Bubble level to make sure the track was leveled correctly.

PyCharm for all of my Python Code

5 Data

For data please see attachment at the end of this final report.

5.1 Experiment 1

When taking a look at my data comparison Python file for Experiment 1, 99 percent of the time I either had "None" or "Unknown" listed as an outlier. I can conclude that based on this and looking at the numbers in the lab as I performed each air track for this portion of the lab that I did not have any noticeable differences. That my values for velocity and acceleration were as expected.

Now taking a look at the percent differences for Experiment 1, I can see that there tends to be a noticeable difference in the numbers. When comparing the percent differences for Experiment 1 Air Track 1 vs Air Track 2, I get through my calculations: velocity at 10.05802707930368 percent and acceleration at 200.0 percent for the hanging mass of 0.00193 kg. My percentages for velocity and acceleration for Air Track 2 vs. Air Track 3 are pretty close to the percentages for Air Track 1 vs. Air Track 2. For velocity it was 9.505334626576126 percent and for acceleration it was 200.0 percent. These two values were also for the hanging mass of 0.00193 kg. When taking a look at the percent differences for velocity and acceleration for hanging mass 0.00193 kg for Air Track 1 vs. Air Track 3 there were significant differences. The percentages I found for those two values are 0.5540166204986309 percent and 0 percent respectively. From studying the remaining hanging masses, just like with the hanging mass of 0.00193, there seems to be the trend were one set of percent differences will match another set but not all sets will match one another. For example, one hanging mass for Air Track 1 vs. Air Track 2 will be close to the same hanging mass for Air Track 2 vs Air Track 3, but it will not be close to the same hanging mass for Air Track 1 vs. Air Track 3. Looking at the charts made for all three percent differences (Air Track 1 vs. Air Track 2, Air Track 2 vs. Air Track 3, and Air Track 1 vs. Air Track 3), it is clear that the raw data and calculated data was not as similar as when I was comparing it in the lab. The only data that was as similar as possible to one another were the percent differences for hanging mass 0.01179 kg for Air Track 2 vs. Air Track 3 and Air Track 1 vs Air Track 3.

When taking a look at the coefficients of friction across all three air tracks and four hanging masses, it is visible that friction may have affected the results of my project.

5.2 Experiment 2

After studying the percent differences for Experiment 2 it is clear that the values are a lot different than one another. I was primarily looking for closeness in percent differences for the raw data. The percent differences for the raw data show that the data was not as close as I initially believed it to be. As for studying the percent differences across all three sets of percent differences there does seem to be closeness in the computed data percent differences. For all three sets the percent difference for weight was 0.0 percent. For Air Track 2 vs. Air Track 3 and Air Track 1 vs. Air Track 3 there is not much of a difference in the percent differences for spring potential energy. Those percent differences respectively are 9.15555820258964 percent and 9.18908279753314 percent. The next closest values in percent differences occurred for force for Air Track 1 vs. Air Track 2 and Air Track 1 vs. Air Track 3. Those percent differences respectively are -5.07751218771613 percent and -5.99711225277861 percent. As previously mentioned the rest of the data did not resemble any closeness to one another and for the most part the data was all over the place. Just like in Experiment 1, there seemed to be two sets of air tracks in Experiment 2 that showed similarities with one another but not with the third set of air tracks.

5.2.1 Test Data

Because test data was not taken for all air tracks for both experiments all of the data such as raw data and calculated data will be provided for in the data section of this final report. The main discussion and conclusions for the data I found or came up with will consist of data from Experiment 1 and Experiment 2.

6 Discussion and Conclusions

6.1 Discussion

6.1.1 Experiment 1

Upon comparing my results in the lab I did not see any notable differences in the velocities or accelerations in Experiment 1. This was due partly to me using the same pulley set for all three air tracks. I did go back every so often when completing the experimental portion of my project for a couple of reasons. One of the reasons was to make sure the Motion Sensor II was aligned accurately with the air track and that the air track itself was leveled as much as possible. The other reason being that I chose to keep the same pulley set for all three air tracks and that I initially believed that because of this my results should be as close as possible to one another.

6.1.2 Experiment 2

Just like with Experiment 1, as I was performing Experiment 2 I would look at the data between each trial and each air track. While in the lab the velocities for the spring between each air track seemed to have similar values to one another. Although as talked about in the data section, there are differences between the values I gathered.

6.2 Conclusions

There are a few changes I could make if I were to do this project over again. While using the pulley system the string kept falling off. Having a pulley that is designed better would have stream lined the project by a lot. A pulley with a deeper groove or some kind of barrier on top that could keep the string from falling off the top of the pulley would help a lot. If the cart traveled too far on the air track the hanging weights would hit the ground and fall apart. Due to this the cart needed to be stopped at a specific distance just before the weights hit the ground. It would be beneficial to have a set of hanging masses that would stick together or lock together so they would not fall apart or come off easily. After completing a few trials I noticed the Motion Sensor II coming unaligned. This was not as big of a problem that would have required me to start over on my trials for a specific spring or hanging mass on one of the air tracks. One way to improve in this area could be a better type of sensor or to have it clamped to the table. The wooden flag I used had to be fixed every so often. Unless positioned perpendicularly on the air track, it would affect my data. Another type of flag could also be useful in completing this project again. Lastly, if I were to complete this project over again I would maybe add one or two more air tracks. By adding more, I would be able to have a broader picture of how similar the air tracks are.

In reference to the negative coefficients of friction, I believe it could have been one of two things or a combination. Keeping in mind how the Motion Sensor II will measure either positive or negative depending on the direction of the car: so with this being said, I believe it was either human error in calculating the exact impact of the cart to whereas the cart may have hit the bumper and bounced back slightly. Therefore causing a negative reading. The other possible outcome, would be a computer lag from the time I hit stop to the actual time it measured on the cart and the measuring device. Because my goal was to time it right before impact.

When completing both Experiment 1 and Experiment 2, along with their trials, I was lucky to have the help of my parents. Without my parents help I would not have been able to complete the experimental portion at the rate and efficiency that I was able to. A trigger release for the track with an accurate timing mechanism would enhance the accuracy of all experiments. Or one must be very cautious not to incorporate human error by simply releasing the track with the finger tip.
*overall the experimental portion of the project took about a 5 day span to complete. The total number of hours spent working on the experimental portion is about 31.5 man hours.
Amount of time spent on out of lab work was 44 hours.

7 Appendices

All code, tools and facilities were of primary importance in order to complete my project.

For notes made throughout the experimental portion of my project please see the attachments made to this final report titled as "Capstone Notes".

8 Bibliography

Three sources were used in order to help me complete my project. The third source listed could only be found in web-link format.

PHYS 201L Lab 5: Air Track III: Conservation of Energy
Tipler, P., Mosca, G., Physics for Scientists and Engineers Sixth Edition, W.H. Freeman,(2007)
https://web.pa.msu.edu/courses/2015spring/PHY251/Lab$_0$4.*pdf*