**Force and Acceleration on the Air Track**

Terence Henriod

TA: Marshall Liddle

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**Abstract**

A weighted glider on an air track was pulled by a string that was ran through a pulley and weighted such that the force of gravity accelerated the system in order to verify theory Newton’s second law, that force applied is equal to mass multiplied by acceleration. This was done by varying the masses of the two weight bearing components of a glider/weight cradle system, and measuring how quickly the glider moved across a reference distance.

The results of this experiment only weakly supported the theory of this lab. While the results did demonstrate the expected relationships between the variables of Newton’s second law (a linear relationship between acceleration and force, an inverse relationship between acceleration and mass), the measured accelerations and expected ones were rather discordant, with percent differences ranging from 52.1-85.1% emerging. In the first portion, accelerations ranging from 0.030-0.864 m/s2 were measured, while theoretically values from 0.200-1.803 m/s2 were expected. In the second portion, accelerations ranging from 0.037-0.055 m/s2 were measured, while theoretically values from 0.166-1.209 m/s2 were expected. I would propose that there was a factor that was neglected that was responsible for this discrepancy: friction between the glider and the air track and between the string and the pulley, which were assumed to be negligible.

**Theory**

The experiment allowed the testing of Newton’s second law using both varied forces and masses. In the first portion of the experiment, the force acting on the system was varied, but the mass was not; in the second portion, the force was not varied, but the mass of the system was. This illustrated the relationships the variables within the equation F = m \* a have with one another.

Again, Newton’s law states that applied force is equal to mass multiplied by acceleration. This can be rearranged to show that acceleration is equal to the force applied divided by the mass of the system. Also displayed is the derived formula for acceleration as it applies to the system used in our experiment.

[ unit: meters per squared second (m/s2) ]

For the purposes of finding the measured acceleration of the glider, some kinematic equations were utilized so that a measured value of the acceleration of system could be found to compare to the theoretical one. Also shown is the equation derived for acceleration that utilizes the measured times collected in the experiment. The change in time for the glider’s movement was measured by totaling the time it took the glider to cross the distance between breaking the photogate beams and the mid-point of the times the glider spent breaking the photogate beam.

[ units: velocity: meters per second (m/s), acceleration: meters per second squared (m/s2) ]

Finally, once again, experimental values will be compared to accepted or expected values with a percent difference approach.

[unit: percent]

*Procedure*

The experiment was performed using an air track, two photogates, data collection software, an air track glider, a string, a pulley attached to the air track, a weight hanger, and an assortment of small, metric weights. The system was set up by placing the glider on the track and attaching the string to the glider and the weight hanger. The glider was placed on the air track, with the string running parallel to the track, then through the pulley, such that the weight hanger was hung over the pulley so that the string then ran perpendicular to the ground, allowing the full force of gravity to act on the weight hanger. The photogates were placed over the track a set distance apart, in this case 0.500 m. The photogates were plugged into an interface device to allow the data collection software to collect time data.

In both portions of the experiment, the glider was pulled back behind the first photogate, with the weight hanger raised and ready to drop. The glider was released, data collection was started, and the weight hanger was allowed to drop, pulling the glider fully through both photogates so that complete time data could be collected. The times that were collected were as follows: t1 was the duration of time that the glider broke the first photogate’s beam, t2 was the duration that the glider broke the second gate’s beam, and t3 was the time that passed between the end of t1 and the beginning of t2. Five trials were conducted in the first portion of the experiment and four trial were conducted in the second.

In the first portion of the experiment, the mass of the system was kept constant. This was done by starting with 50 grams added to the glider, and no mass added to the weight hanger. In subsequent trials, weight was moved 10 grams at a time from the glider to the hanger (thus altering the force applied to the system), and then data was collected.

In the second portion of the experiment, the mass of the glider was varied and the weight of the hanger was kept the same (thus keeping the force applied to the system constant). In the first trial 40 grams was added to the glider, and for each subsequent trial 20 grams were added.

Figure 1: The experiment apparatus.

**Data**

|  |  |  |  |
| --- | --- | --- | --- |
| Length L of the Glider (m) | Distance D Between Photogates (m) | Mass of Unloaded Glider (g) | Mass of Unloded Cradle (g) |
| 0.126 | 0.500 | 189.8 | 5.0 |

Table 1: Preliminary data used for computations.

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Trial | Glider Mass (g) | Cradle Mass (g) | t1 (s) | t2 (s) | t3 (s) | V1 [L/t1] (m/s) | V2 [L/t2] (m/s) | a (m/s^2) | Force (N) | Theoretical Acceleration (m/s^2) | % Difference |
| 1 | 239.8 | 5.0 | 0.7142 | 0.4754 | 2.3717 | 0.176 | 0.265 | 0.030 | 0.049 | 0.200 | 85.1 |
| 2 | 229.8 | 15.0 | 0.3054 | 0.1983 | 1.0036 | 0.413 | 0.635 | 0.177 | 0.147 | 0.601 | 70.5 |
| 3 | 219.8 | 25.0 | 0.2274 | 0.1472 | 0.7463 | 0.554 | 0.856 | 0.323 | 0.245 | 1.002 | 67.7 |
| 4 | 209.8 | 35.0 | 0.1640 | 0.1048 | 0.5363 | 0.768 | 1.202 | 0.647 | 0.343 | 1.403 | 53.9 |
| 5 | 199.8 | 45.0 | 0.1429 | 0.0909 | 0.4666 | 0.882 | 1.386 | 0.864 | 0.441 | 1.803 | 52.1 |

Table 2: The results of the first portion of the experiment, including the theoretical results and the percent differences.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Trial | Mass of Weighted Glider (g) | Total Mass [mass of glider + mass of cradle] (g) | t1 (s) | t2 (s) | t3 (s) | V1 [L/t1] (m/s) | V2 [L/t2] (m/s) | a (m/s^2) | Theoretical Acceleration (m/s^2) | % Difference |
| 1 | 229.8 | 234.8 | 0.5541 | 0.3577 | 1.8210 | 0.227 | 0.352 | 0.055 | 0.209 | 73.8 |
| 2 | 249.8 | 254.8 | 0.5948 | 0.3834 | 1.9512 | 0.212 | 0.329 | 0.048 | 0.193 | 75.1 |
| 3 | 269.8 | 274.8 | 0.6304 | 0.4079 | 2.0718 | 0.200 | 0.309 | 0.042 | 0.178 | 76.4 |
| 4 | 289.8 | 294.8 | 0.6638 | 0.4315 | 2.1861 | 0.190 | 0.292 | 0.037 | 0.166 | 77.5 |

Table 3: The results of the second portion of the experiment, including the theoretical results and percent differences.

**Computations**

Computations were performed through the use of Microsoft Excel. Sample calculations are as follows:

Velocity needed to be calculated (for computing the acceleration later) using the length of the glider (the distance traveled) and the time a photogate was blocked (the time change as the glider was displaced). This example is for the first V1 calculation from t1 in trial 1 of the first portion of the experiment:

The actual acceleration was calculating the initial and final measured velocities and the three time periods (t3 and the second half of t1 and first half of t2). This particular case comes from the first trial of the first portion of the experiment:

The theoretical acceleration was found using the calculated force applied to the system (the numerator of the following equation) and the total mass of the system (the denominator), as seen in the first trial of the first portion of the experiment:

Finally, percent difference was computed, in this example using the measured and theoretical accelerations from trial 5 of the first portion of the experiment:

*Uncertainty*

Four devices were used to collect measurements in this experiment:

The ruler built into the air track. This ruler was used to measure the distance between photogates and the length of the glider. The ruler measured to a precision of 0.001 meters, which was used in data collection. There was little reason to believe this device was inaccurate, and I would argue that use of this device contributed only moderately to the overall uncertainty of the measurements. Because the ruler was built into the track, it was difficult to assess the distance between the photogates because they were somewhat removed from the track. When measuring the length of the glider, the ruler was likely accurate to 0.001 m, but when measuring the distance between the gates was only precise to 0.005 m (likely the main contribution to the overall uncertainty of measurements.

The scale. A scale that was precise to 0.1 grams was used to weigh the weight hanger and the glider. This preceision was used in all data collection. I believe that the scale was accurate to 0.1 grams, and have little reason to believe otherwise, as this was a quality scale, despite its limited precision. This would likely contribute very little to the measurement uncertainty, considering that the weights (masses) used for calculations were, for the most part, on a magnitude at least 10 times greater than the minimal precision of the scale, thus any propagation of uncertainty error would likely be attenuated.

The masses added to the glider and hanger. The assorted weights were labeled with a precision of 5 or 10 grams, depending on which particular weight was selected, however I assumed that these weights utilized a precision of 0.1 g for data collection. I did this because I had little reason to believe that the labels were printed with the full extent of precision used in manufacturing them. I did not weigh the masses with the scale to identify how accurate the labels on the weights were, which I should have done to properly assess the measurement uncertainty in using these weights. Despite the limited precision in the labeling, I would assert that the labels were accurate to 0.2 grams. This is because the weights appear to be uniformly manufactured, no marked differences could be observe between one weight and another of the same type. There likely was some variation in the weights due to damage from the abuse of years of use in lab classes and slight discontinuities in the material used to manufacture the weights. Again, these weights likely did not contribute significantly to the overall uncertainty of measurements in this lab.

The photogates and accompanying software. The times were measured to a precision of 0.0001 s. This level of precision was used when recording data. However, I doubt the accuracy of these measurements to this precision, and would assert that they were only accurate to the 0.001 s. This is because despite the precision of the photogates, the measurements did not seem to be very consistent and because there were many factors that might interfere with the photogate’s measurements, such as the hypersensitivity of the photogates allowing the string to break the photogate beam, or the photogates being lightly displaced because they were not secured and could be easily bumped. Any increase in the time measured by the photogates, which I do suspect happened, would lead to lower findings for velocity and acceleration, which would help to explain the disparity between my results and expected values. However, the photogates are a favorable alternative to other methods, such as hand timing, so this uncertainty is certainly tolerable. I assert that the uncertainty of the photogate measurements did contribute moderately to the overall uncertainty of measurements.

**Results**

The results of interest are displayed in Table 4, all other numerical results can be found in Tables 1-3, and Figures 2 and 3. Figures 2 and 3 illustrate the expected and observed relationships between the components of Newton’s second law.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Portion of Experiment | Trial | Measured Acceleration (m/s/s) | Theoretical (Expected) Acceleration (m/s/s) | % Difference |
| (1) Constant Mass | 1 | 0.030 | 0.200 | 85.1 |
| 2 | 0.177 | 0.601 | 70.5 |
| 3 | 0.323 | 1.002 | 67.7 |
| 4 | 0.647 | 1.403 | 53.9 |
| 5 | 0.864 | 1.803 | 52.1 |
| (2) Constant Force | 1 | 0.055 | 0.209 | 73.8 |
| 2 | 0.048 | 0.193 | 75.1 |
| 3 | 0.042 | 0.178 | 76.4 |
| 4 | 0.037 | 0.166 | 77.5 |

Table 4: A summary of experiment results.

Figure 2: Acceleration vs Force Applied. Trend lines have been applied to highlight the linear relationship between force and acceleration.

Figure 3: Acceleration vs. Mass. Power trend lines have been applied to help highlight the inverse relationship between acceleration and mass.

To reiterate: the results of this experiment only weakly supported the theory of this lab. While the results did demonstrate the expected relationships between the variables of Newton’s second law (a linear relationship between acceleration and force, an inverse relationship between acceleration and mass), the measured accelerations and expected ones were rather discordant, with percent differences ranging from 52.1-85.1% emerging. In the first portion, accelerations ranging from 0.030-0.864 m/s2 were measured, while theoretically values from 0.200-1.803 m/s2 were expected. In the second portion, accelerations ranging from 0.037-0.055 m/s2 were measured, while theoretically values from 0.166-1.209 m/s2 were expected. I would propose that there was a factor that was neglected that was responsible for this discrepancy: friction between the glider and the air track and between the string and the pulley, which were assumed to be negligible. Measurement uncertainty likely only moderately, at most, contributed to the discrepancy between observations and expectations.

*Questions*

Questions were taken from the “Calculations” section of the lab instructions, only questions not answered previously in data tables are addressed here:

4. Refer to Figure 2. The graph is theoretically linear when mass is kept constant, the relationship between applied force and acceleration does appear to be linear, this notion is supported by the experimental data.

5. Refer to Figure 3. The graph is not linear. The relationship between acceleration and mass is in fact inverse. This is difficult to tell from the graph, but it is known to be true analytically.

*Discussion*

This experiment tested Newton’s second law using a glider on an air track that was pulled by a weight hung on a string. The weight on the hanger was varied to vary the force applied to the system in one portion of the experiment, and the mass of the entire system was varied in another. Through these method’s, Newton’s second law was tested.

The results weakly support the concepts of Newton’s law, likely, in part, due to measurement uncertainty, but I would posit that there was another factor that was not considered in the experiment, and the best candidate for this I would assume would be friction within the system that was assumed to be negligible, both between glider and track and between string and pulley. Of these I suspect the pulley to be the prime candidate in foiling the acceleration of the system. The measured accelerations fell well below the predicted accelerations, with discrepancy ranging from 52.1-85.1%. These results were far too discordant to be due to measurement uncertainty, I assert, because of the relatively high level of precision that was utilized in data collection.

Experimental error likely resulted from both the aforementioned friction, the hypersensitivity of the photogates that was discussed in the Uncertainty section, and an imperfect release of the glider by the experimenter. It is doubtful that error due to the photogates can be reduced, but glider release error could be reduced by using a simple machine to release the glider, rather than a human hand, and friction error could be reduced by ensuring that a better air supply for the track is used and that a well-functioning pulley is used.