20S-PHYSICS 4AL-12 Final project report

CHARLES XIAN ZHANG, CLAIRE CHUNG, RYAN ROSSMANGO, Neil Vaishampayan, Brendan M Rossmango

TOTAL POINTS

44 / 50

QUESTION 1

1 Names, Title, Abstract **5 / 5**

✓ **- 0 pts** Correct

QUESTION 2

2 Introduction **5 / 6**

✓ **+ 0 pts** Correct

+ 5 Point adjustment

QUESTION 3

3 Methods **11 / 12**

✓ **+ 0 pts** Correct

+ 11 Point adjustment

QUESTION 4

4 Results **16 / 20**

✓ **+ 0 pts** Correct

+ 16 Point adjustment

QUESTION 5

5 Conclusions **5 / 5**

+ 0 pts Correct

+ 5 Point adjustment

QUESTION 6

6 References **2 / 2**

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Observing the Effects of Friction on Household Objects and Objects in Freefall

Claire Chung, Brendan Rossmango, Ryan Rossmango, Neil Vaishampayan, Charles Zhang
Physics 4AL, Lab 12, Group 2
June 14, 2020

Abstract

This project experimentally computed the coefficients of friction of various household objects, and analyzed the effect of air friction and the rotation on objects in freefall. Across any friction, we intend to observe motion that is discernibly different from motion calculated from idealized theory. Additionally, in regards to the Magnus effect, which causes rotating objects to experience a force perpendicular to the prior motion, we hypothesized that vertical freefall velocity would be proportional to horizontal acceleration and that horizontal velocity would be proportional to upward Magnus acceleration. We also aimed to show that, unlike non-rotating objects, rotating objects would move horizontally and consequently stay in the air longer.

For our coefficient of friction experiments of sliding objects, we selected a flat surface of a known length, and ran multiple trials of five different objects moving down this surface. The same process was repeated with three different objects that exhibited rotational motion. In order to experiment on drag forces and the Magnus effect, three different balls were dropped from a rooftop, one trial with spin, and one trial without. Videos of these trials were recorded and analyzed using Tracker to extrapolate the necessary raw data, and then run through a Python script to derive our final values.

In all of these experiments, we do observe deviations from the idealized calculations of physical phenomena which deem friction negligible. However, we did not find any strong linear correlation between the drag force acceleration and vertical velocity for statically dropped objects. We also did not find any strong linear correlation between vertical velocity and horizontal acceleration or horizontal velocity and upwards acceleration for spinned objects.

Introduction

In the ideal model of physics, theoretical motion ignores friction, and thus typical physics calculations cannot represent the real world. However, by measuring the effects of friction on objects, one can obtain a more correct representation of friction on motion, both linear motion on flat and inclined planes and freefall motion through the air. Trials using various household objects were held for the linear motion on the surface planes and trials using sports balls were held for the freefall motion.

The trials involving various household objects on surfaces, both flat and inclined planes, were held to find experimental values of coefficients of friction for different materials like wood or cardboard, whereas the freefall trials were used to find the effects of air friction and drag force on objects in freefall. Videos were taken of these trials to then be analyzed on Tracker, where we collected position and time data for the first set of trials and both horizontal and vertical position and time data for the freefall trials.

For the surface trials, through the use of kinematic equations, this positional data was then translated into velocity and acceleration for each of the trials. Then, we found the coefficients of friction using Newton's second law of motion and the relationship between friction and normal force. For the freefall trials, to measure the effect of friction and the drag force, we used the horizontal position data to understand the Magnus effect. Objects were dropped vertically in one set of freefall trials and then these same objects were spun rapidly in another set of trials. The Magnus effect is a force perpendicular to the motion of a spinning object through the air. As the object spins through the air, it spins and pushes back against the air, which produces a deflection of the path in a perpendicular direction, so the object then begins to move horizontally in addition to vertically after it is dropped straight down. Then, because the object moves horizontally, the Magnus effect also stays in effect; a drag force is created as the object spins and pushes against the air again, resulting in the object staying

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In all of these experiments, we do observe deviations from the idealized calculations of physical phenomena which deem friction negligible. However, we did not find any strong linear correlation between the drag force acceleration and vertical velocity for statically dropped objects. We also did not find any strong linear correlation between vertical velocity and horizontal acceleration or horizontal velocity and upwards acceleration for spinned objects.

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Since the true values of the coefficients of friction of materials we analyzed were unavailable, we hypothesized to find coefficients of friction that made sense in the context of commonly known coefficients of friction - that the values were not extremely large or small, and that rougher materials had higher coefficients of friction than did smoother objects (since these materials have a larger frictional force to overcome). For the freefall trials, we hypothesized that the objects that were simply dropped would stay in the air for a smaller amount of time than objects that were spun rapidly due to the Magnus effect.

Method

In order to study the effects of static friction and kinetic friction on objects, we set up variations of the same trial. We used a uniform plank of wood as the surface in order to ensure as much consistency in our results as possible. From there, five different objects were slid across the surface, and three objects were rolled across it. Three trials of each object were recorded to negate the effects of potential outliers. This process was then repeated with the plank angled downwards so that the objects' downward acceleration was only affected by gravity. Each of these trials were recorded and imported into the Tracker software to translate into positional data, which could then be exported and used to extrapolate acceleration data.

To study the effects of drag and the Magnus Effect, we dropped multiple sports balls (baseball, tennis ball, wiffle ball) off of a roof. To isolate the impact of the Magnus Effect, two trials were done for each object; one with spin, where each ball was spun rapidly in a vertical line, and one where the ball was simply dropped straight down. All trials were tracked with Tracker, from which the acceleration data was exported and used to generate the necessary data.

All of the data analysis was done in Python. We used Python scripts to automatically create graphs relating the sliding data to a kinematics model ignoring friction, and then calculated the coefficient of friction from the best fit acceleration of the graphs. For the ball drop trials, we designed another script to plot the acceleration of the ball against its perpendicular velocity.

Fig 1a: Flat-Ground Setup

Fig 1b: Angled Setup

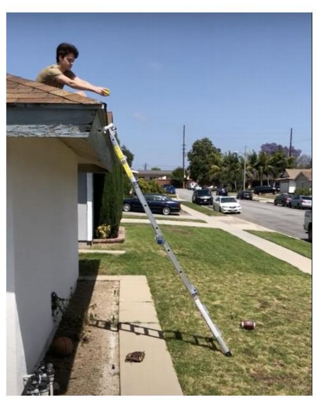

Fig 2: Ball Drop Setup

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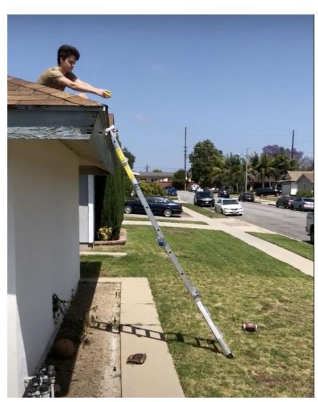

Fig 2: Ball Drop Setup

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Results

Sliding Graphs

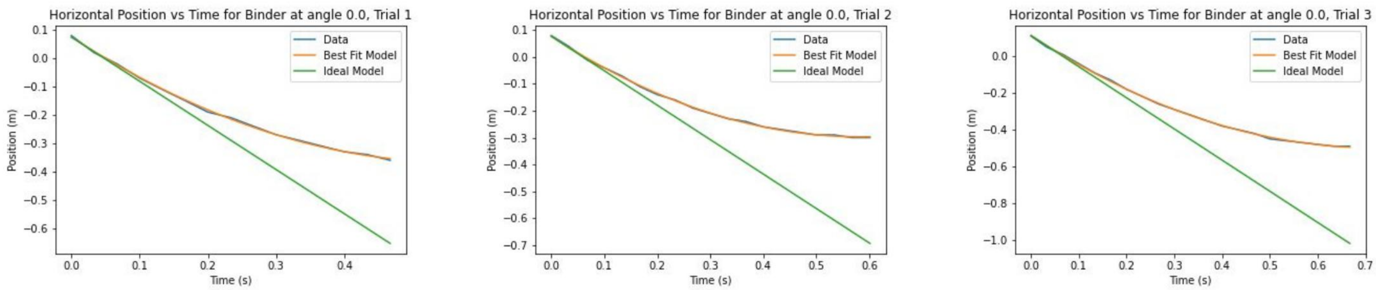

Fig 3a : Position graphs of all Flat Trials for Binder

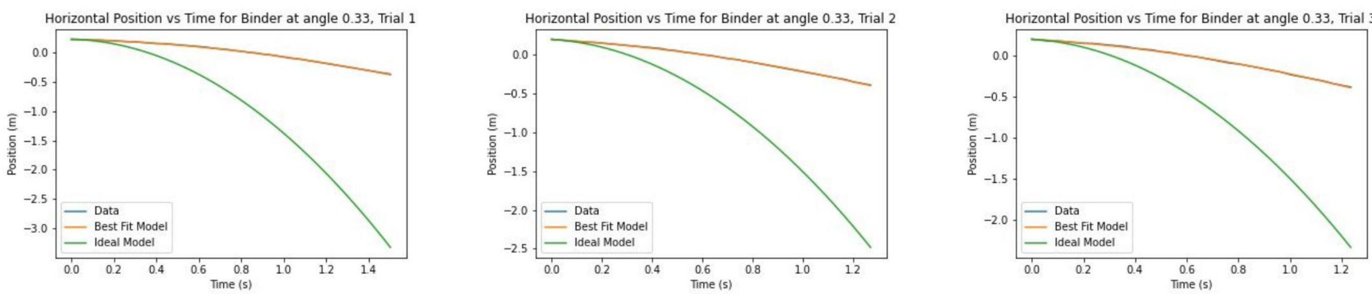

Fig 3b : Position graphs of all Sloped Trials for Binder

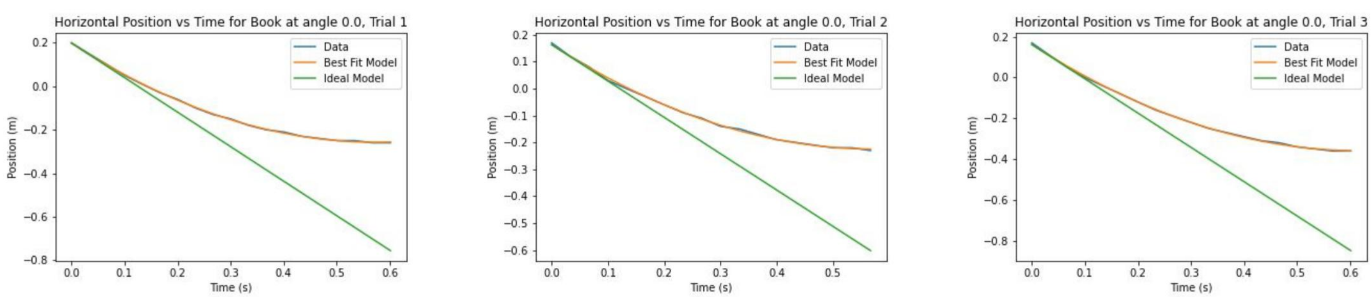

Fig 4a : Position graphs of all Flat Trials for Book

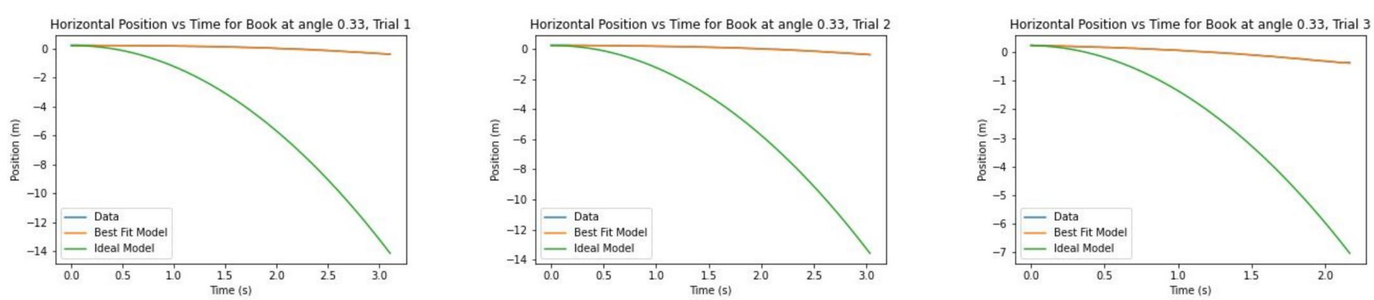

Fig 4b: Position graphs of all Sloped Trials for Book

Fig 5a: Position graphs of all Flat Trials for Box

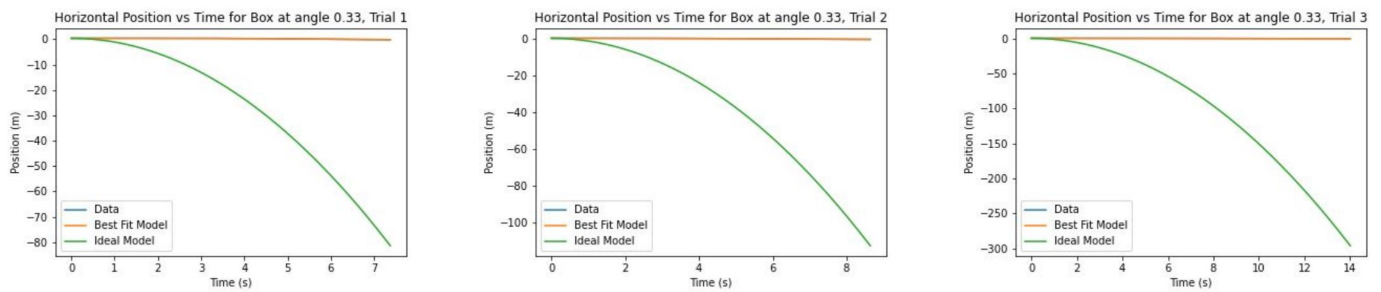

Fig 5b: Position graphs of all Sloped Trials for Box

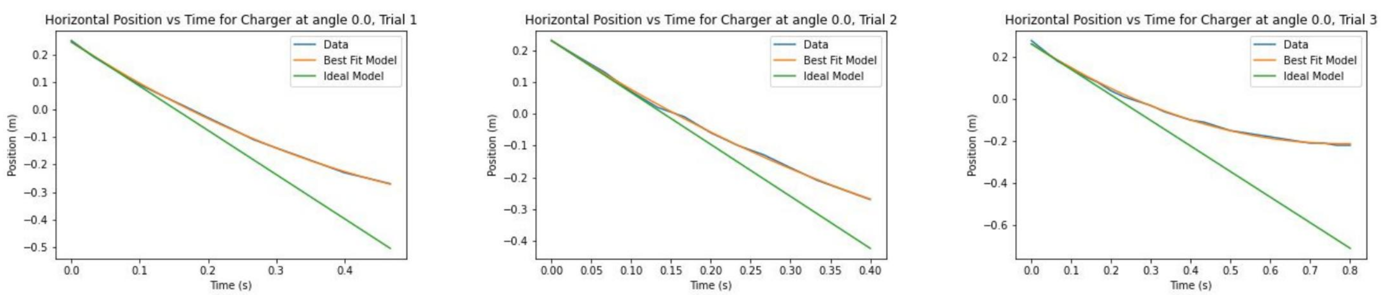

Fig 6a: Position graphs of all Flat Trials for Charger

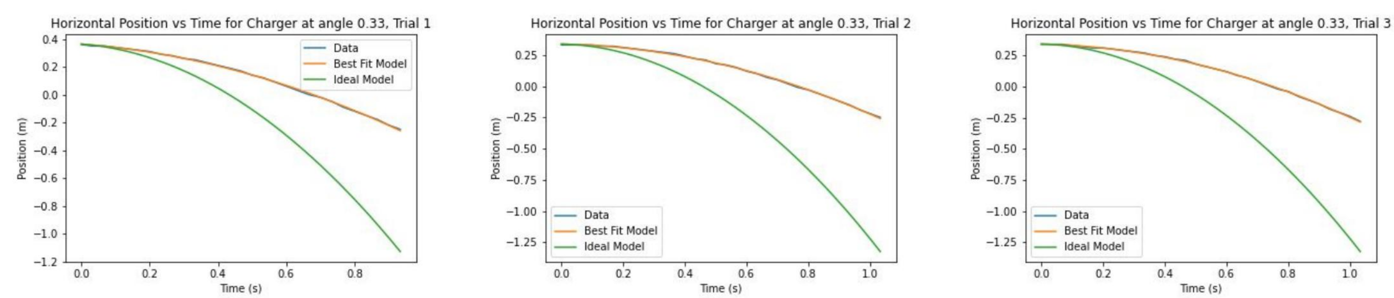

Fig 6b: Position graphs of all Sloped Trials for Charger

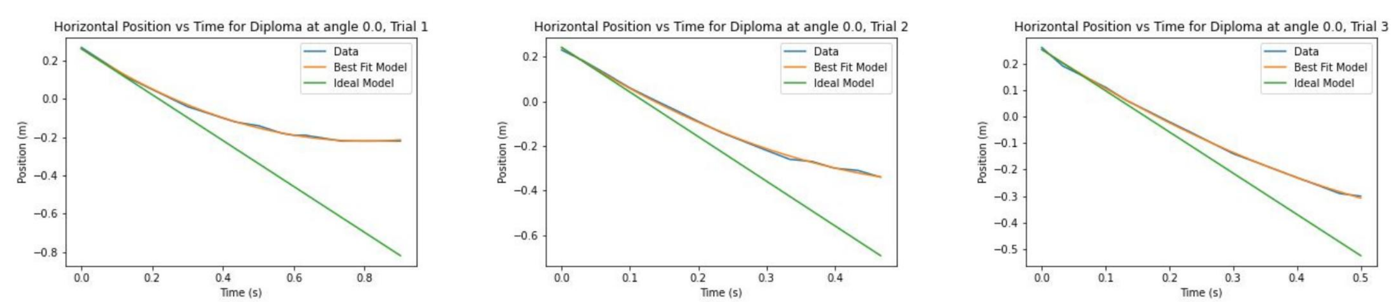

Fig 7a: Position graphs of all Flat Trials for Diploma

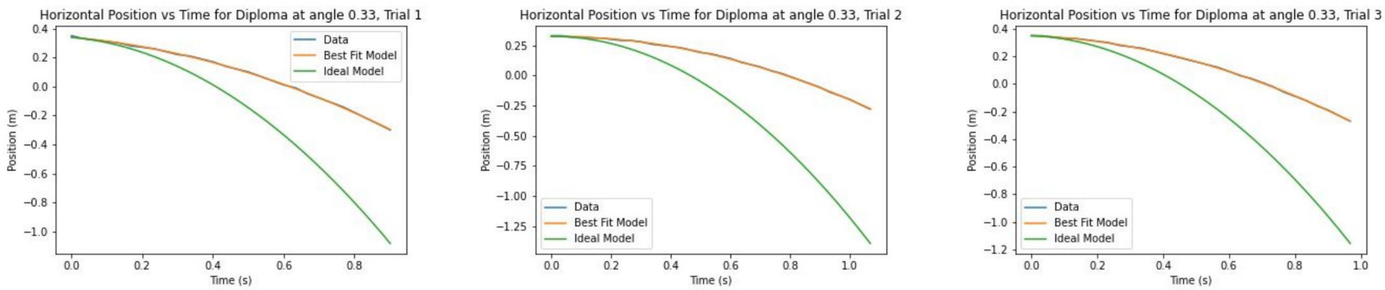

Fig 7b: Position graphs of all Sloped Trials for Diploma

Rolling Graphs

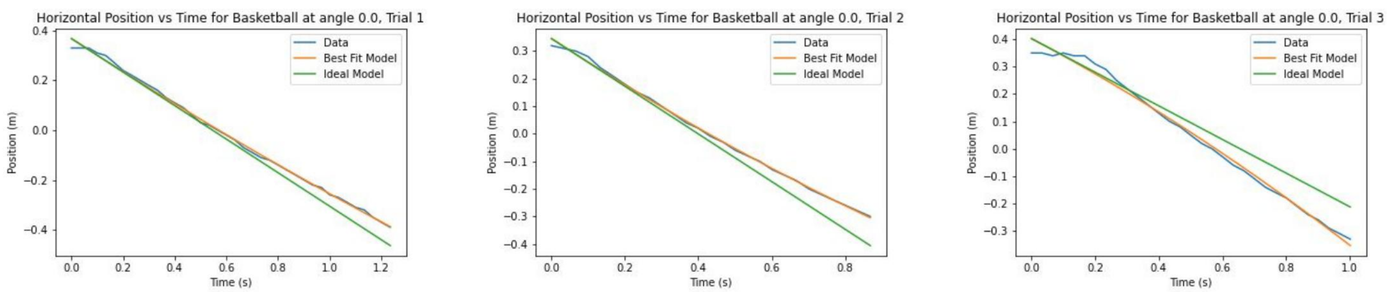

Fig 8a: Position graphs of all Flat Trials for Basketball

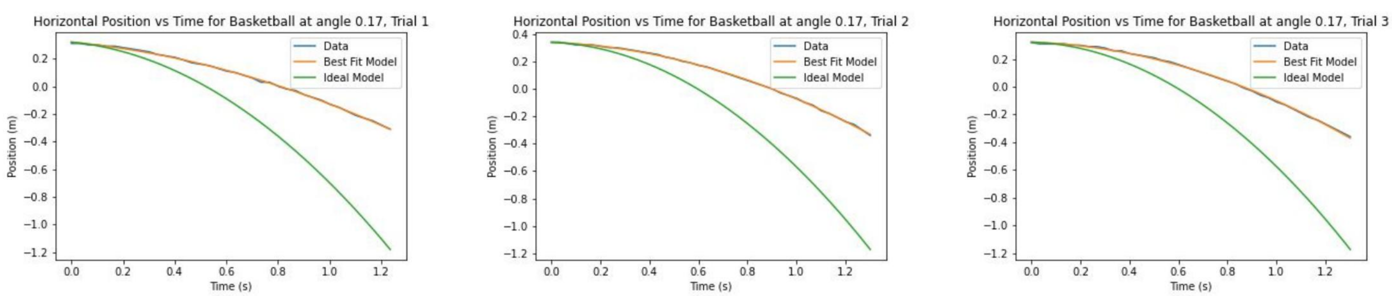

Fig 8b: Position graphs of all Sloped Trials for Basketball

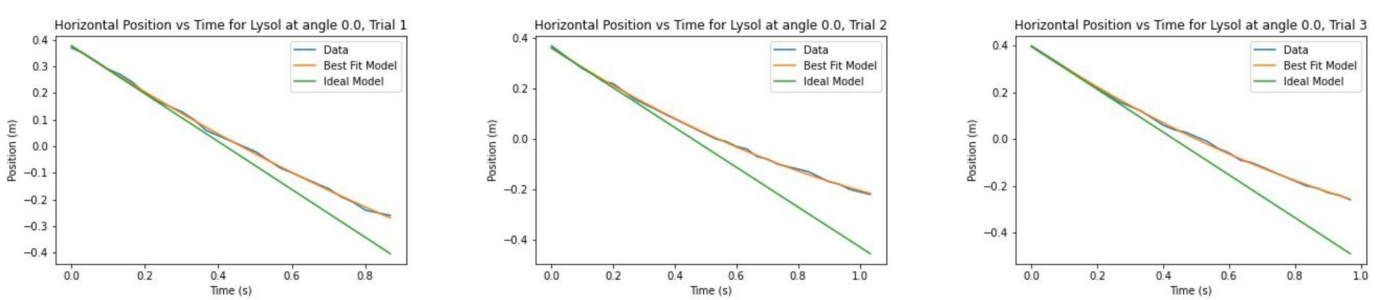

Fig 9a: Position graphs of all Flat Trials for Lysol Container

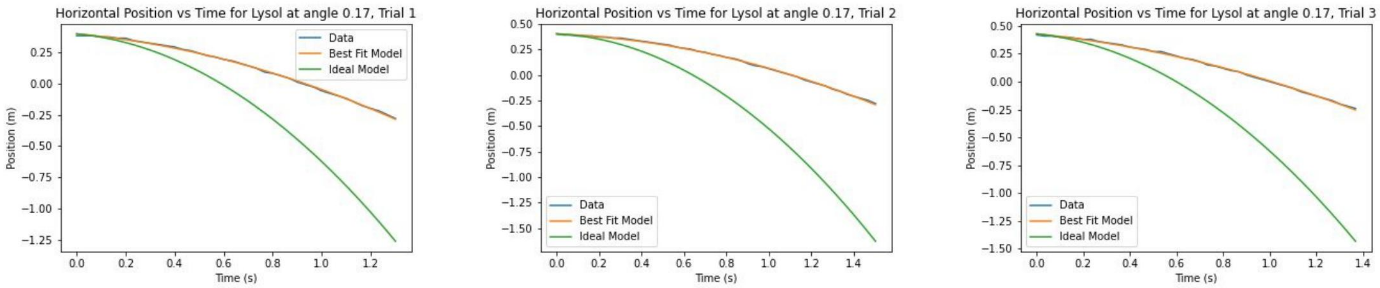

Fig 9b: Position graphs of all Sloped Trials for Lysol Container

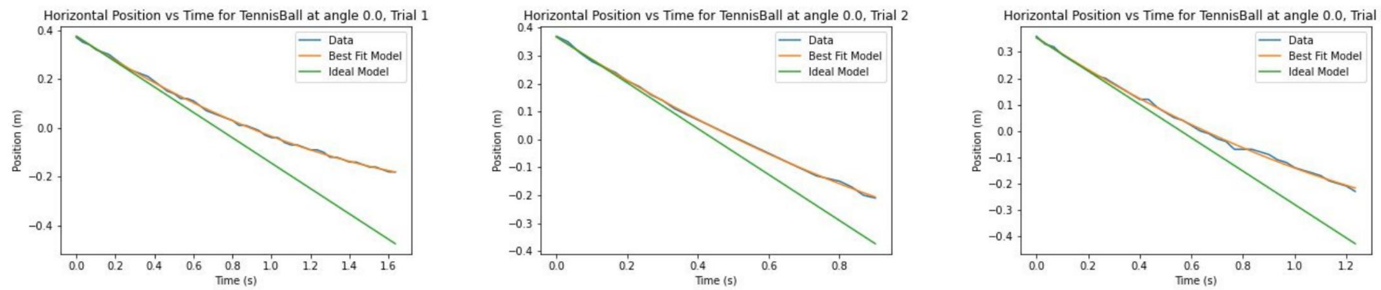

Fig 10a: Position graphs of all Flat Trials for Tennis Ball

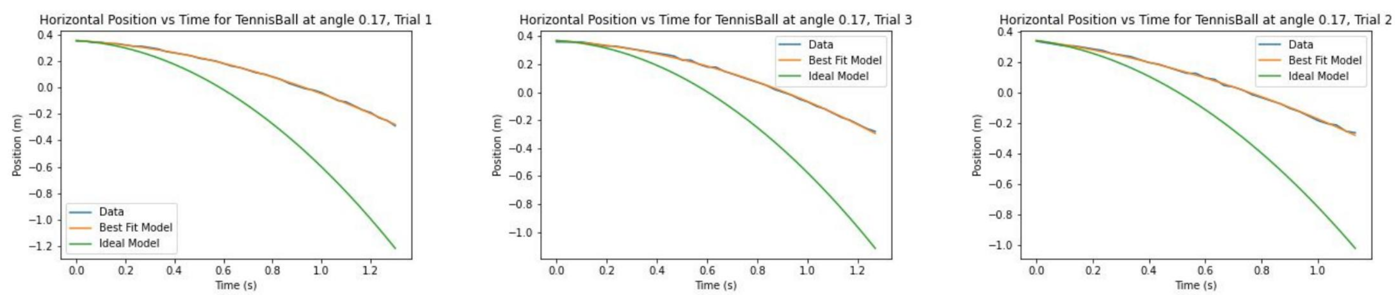

Fig 10b: Position graphs of all Sloped Trials for Tennis Ball

Freefall Graphs

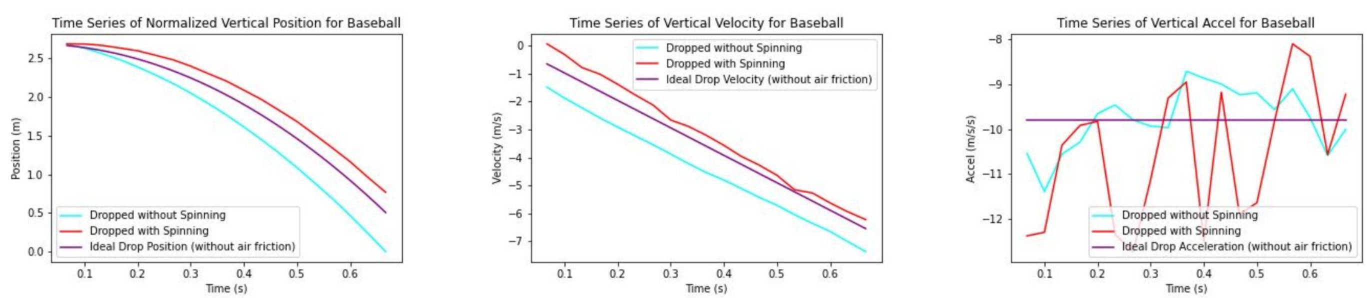

Fig 11: Position, Velocity, and Acceleration Time Series for dropped Baseball

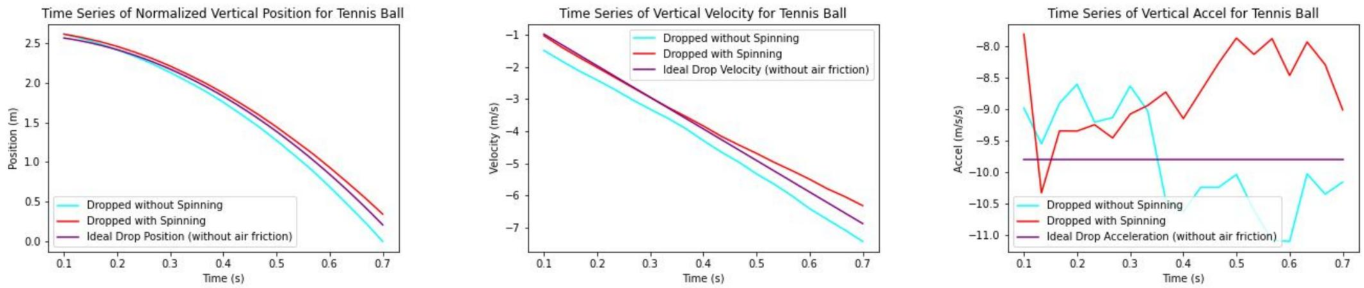

Fig 12: Position, Velocity, and Acceleration Time Series for dropped Tennis Ball

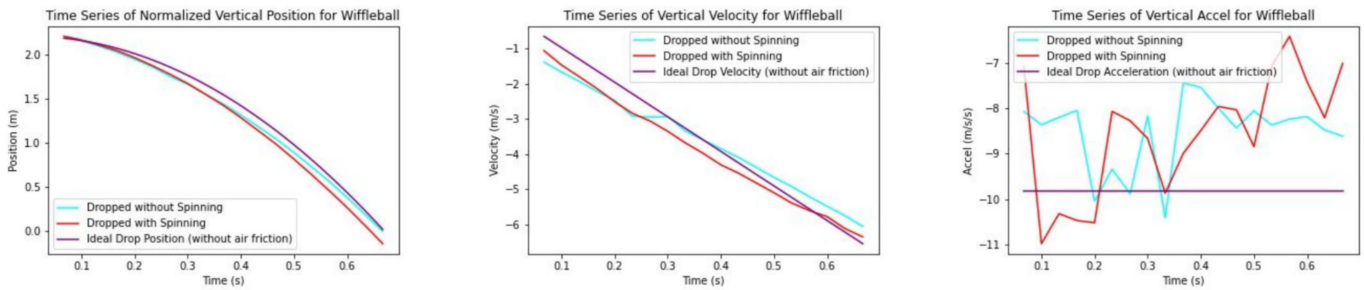

Fig 13: Position, Velocity, and Acceleration Time Series for dropped Wiffleball

Air Friction Results

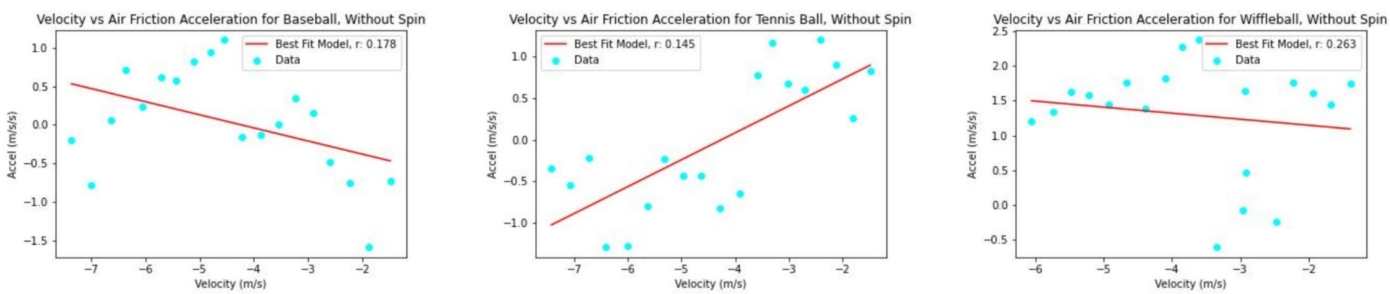

Fig 14: Drag Acceleration due to Air Friction for all Dropped Objects

Magnus Effect Results

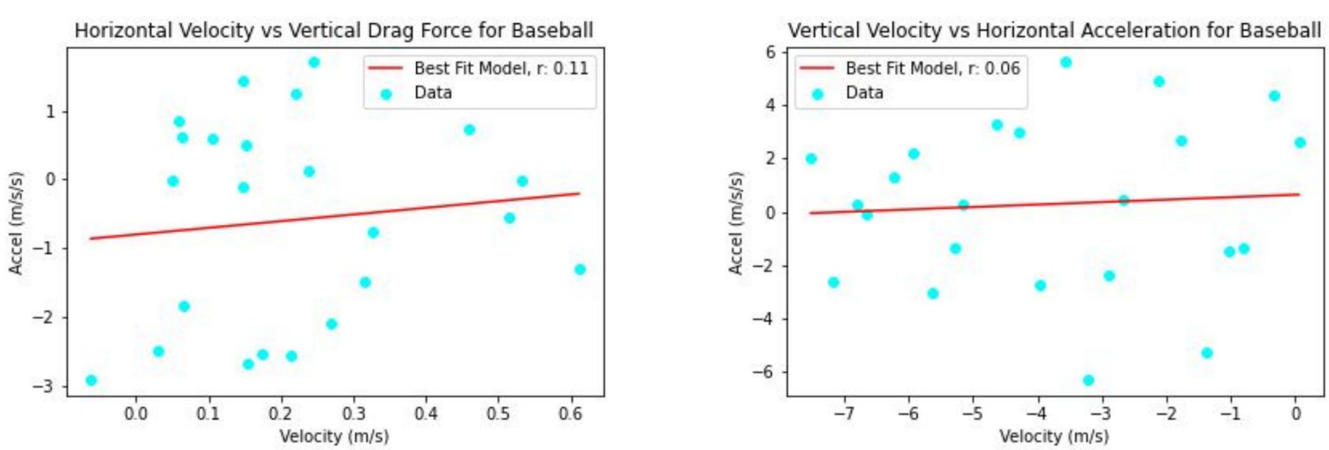

Fig 15: Magnus Force Acceleration due to Perpendicular Velocity of spinning Baseball

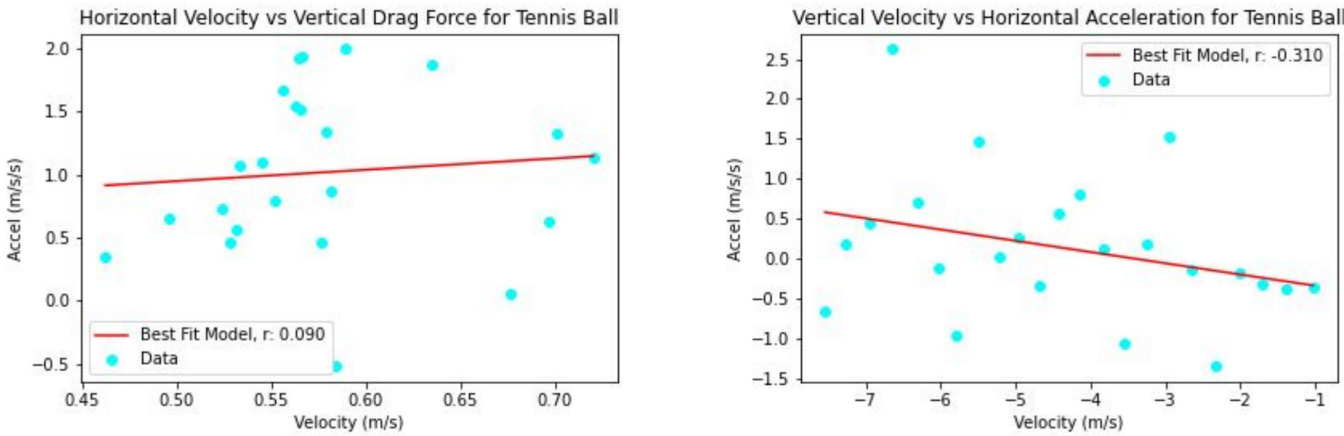

Fig 16: Magnus Force Acceleration due to Perpendicular Velocity of spinning Tennis Ball

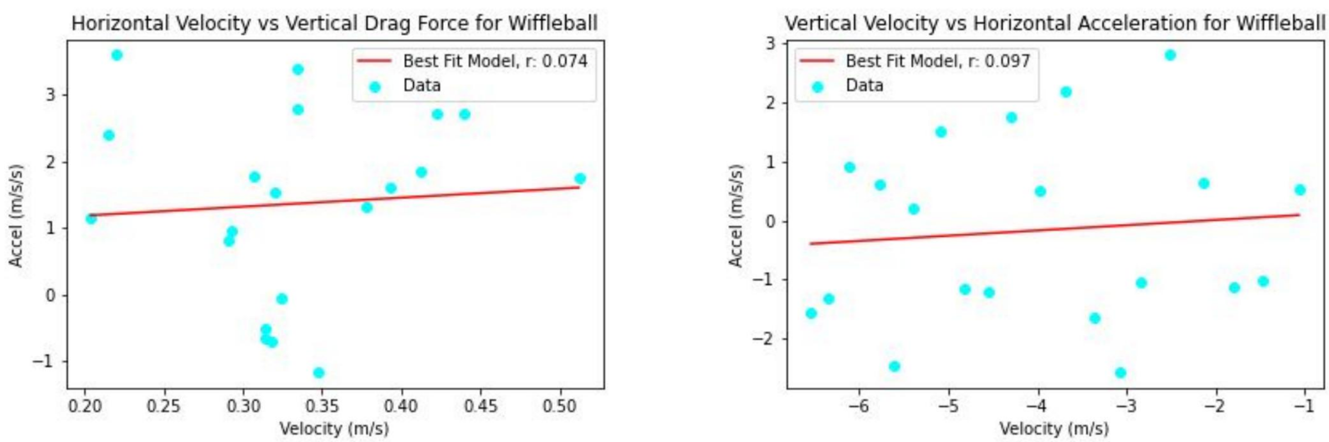

Fig 17: Magnus Force Acceleration due to Perpendicular Velocity of spinning Wiffleball

Object	**Coefficient (Flat)**	**Coefficient (Angled)**
Binder	0.248 ± 0.023	0.394 ± 0.003
Book	0.266 ± 0.019	0.364 ± 0.002
Box	0.283 ± 0.012	0.347 ± 0.001
Charger	0.191 ± 0.025	0.463 ± 0.003
Diploma	0.220 ± 0.079	0.469 ± 0.003
Basketball	0.022 ± 0.008	0.245 ± 0.009
Lysol Container	0.044 ± 0.006	0.227 ± 0.005
Tennis Ball	0.031 ± 0.008	0.238 ± 0.006

Table 1: Mean Coefficients of Friction for all Trials

Object	Coefficient of Friction
Wood	0.4 (McKenzie, 1968)
Cardboard	0.3 (*Container Handbook*, 2020)
Tennis Ball	0.25 (Brody, 1995)

Table 2: Theoretical Coefficients of Friction for Reference Objects

Conclusion

A rather trivial endeavor in itself, finding the coefficients of friction of random household objects enabled us to see that, even in objects whose coefficients of friction were of order of magnitude 10^{-2}, the actual position plots differed from the theoretical motion. This result was expected of course, but in looking at the graphs, the degree of difference was rather high. For many of the trials, at the final position, the theoretical description differed from the actual motion by at most 0.8 to 1.2 meters. The objects traversed down the slopes at a much slower rate than what was theoretically predicted. For these angled slopes, the predicted motion was far too parabolic, whereas for the flat surfaces, frictional forces of course served to sap the object's kinetic energy and bring it to a halt. More research could be done on other objects and slopes to improve the experiment, but the current findings suffice in telling us that friction should not so easily be neglected.

In the latter half of our research, some undesired results came to be. Regarding the freefall experiments, differences between the theoretical and actual motion were found, but in the wrong direction. The baseball and tennis ball fell to the ground much faster than what was theoretically derived. Of course, a drag force should slow down the object's freefall, and the balls should have reached the ground at a later time. For some reason, we saw that the speed of these objects was larger than what was derived. One might wonder how we could have gotten the position derivations to be below the actual motion, or one could just concede to the idea that, at least for freefall, including friction in computations is not necessary. With regards to the physics, it would be difficult to find a way to speed up the fall of the dropped objects. The wiffle ball's motion was closest to being above the theoretical prediction, and this notion is likely due to the ball's structure, as it is much more susceptible to wind and drag force. We also expected to find a linear relationship between vertical velocity and upward acceleration, because the drag force is simply some constant multiplied by velocity. However, these relationships were not found, and the correlations were very low.

As for the Magnus effect, it was observed that the baseball and tennis ball stayed in the air for a longer duration than the same balls that were just dropped. The wiffle ball, however, was an aforementioned anomaly, again due to its structure. Strong correlations between the perpendicular components of motion (horizontal acceleration vs. vertical velocity, horizontal velocity vs. vertical acceleration) were, similarly to the previous experiment, were not found. The Magnus effect should have acted on the rotating ball and accelerated the object horizontally, by definition of the Magnus effect. As the ball would then move horizontally, vertical, upwards acceleration should have been seen. However, the scatter plots of these relationships looked very random and told us nothing. We suspect that the height of the drop, which was about 3 meters, was too small for any noticeable horizontal motion to be seen. Although it is true that the above description of motion, in which the rotating ball gains a horizontal acceleration, which then leads to an upwards vertical acceleration, should have been seen, perhaps the actual hypotheses could have been thought out more. Maybe a linear relationship does not in fact exist between vertical velocity and horizontal acceleration, but perhaps a relationship between vertical and horizontal velocity does. Rotational velocity and horizontal acceleration could have also been examined, which we would expect to be characterized by an upwards sloping line, as rotational velocity stays at its initial value and the ball begins to accelerate in the horizontal trajectory. With these findings, we do not

4 Results 16 / 20

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To rectify these undesired findings and improve our experiment, a higher drop could have helped to allow the ball to experience its full range of motion. We could have also tried to rotate the ball with a faster rotational velocity. Moreover, data on other balls, such as footballs and basketballs, could have been acquired. Perhaps the Magnus effect could have affected a larger ball more noticeably. Lastly, we could find a more reliable data collection process to pursue and use a more consistent tool instead of Tracker in future experiments. We could have spray painted the balls pink or black so that Tracker would not fail to follow the object properly. A different roof could have been used to drop from, perhaps a flat one with a white background underneath, so that the balls could be more reliably dropped in freefall and spun.

References

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Seattle University. "Physics." Thermodynamics - Physics Demos - Physics - College of Science and Engineering - Seattle University, www.seattleu.edu/scieng/physics/physics-demos/thermodynamics/magnus-effect/.

Sutter, Thomas, Personal Correspondence, 2020.

5 Conclusions **5 / 5**

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\+ **5** **Point adjustment**

reject the Magnus effect, but we should seek to find improvements with data collection and with the predicted relationships.

To rectify these undesired findings and improve our experiment, a higher drop could have helped to allow the ball to experience its full range of motion. We could have also tried to rotate the ball with a faster rotational velocity. Moreover, data on other balls, such as footballs and basketballs, could have been acquired. Perhaps the Magnus effect could have affected a larger ball more noticeably. Lastly, we could find a more reliable data collection process to pursue and use a more consistent tool instead of Tracker in future experiments. We could have spray painted the balls pink or black so that Tracker would not fail to follow the object properly. A different roof could have been used to drop from, perhaps a flat one with a white background underneath, so that the balls could be more reliably dropped in freefall and spun.

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✓ - 0 pts Correct