

TAM 212: Ping-Pong Ball Launcher

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Introduction

The key learning experience to take away from this project was to understand how to apply the concepts we learned in class to a real world problem. The main idea of this project was to run experiments in order to find the drag coefficient of a ping pong ball, that would eventually help us in building a ping pong ball launcher. The main purpose of the ping pong ball launcher was to hit a desired target, given a horizontal and vertical distance. Using the concepts that we learned throughout the semester we needed to create a launcher taking into account the drag force and the force of gravity.

This project report outlines our understanding of the flight of the ping pong ball, and the equations and experiment we used to derive the drag coefficient. The report will also talk about the mechanism used in designing the launcher and the method used to build the actual launcher. Ultimately, our goal is to successfully hit a desired target by using calculations derived from theories learned from class.

Theory

For the purposes of conducting the experiment successfully, we needed to make assumptions. We started off by assuming that the density of the air was $1.2041 \frac{kg}{m^3}$ and that the dynamic viscosity of the air was $18.13 \times 10^{-6} \frac{kg}{ms}$ for the purposes of our calculations. We also assumed that there was no velocity of air in the room that we conducted the experiments in. The values of the viscosity and the density of air would vary based on the humidity and temperature of the air at that time, which would change the values of calculations by a small amount. While calculating the drag force and taking it into account, we assumed that the drag force only acted in the y-direction. This may have not been true but helped making calculations easier. When using the mass of the ping pong ball, we assumed that the ball perfectly spherical, which may not have been true, but the symmetric imperfections of the ball would allow this to be a viable assumption. Another assumption we made is that the ball fell down in a straight path and that the air velocity did not affect the

trajectory. We also assumed that the initial velocity of the ball was zero on dropping it. There may have been an initial velocity imparted on it while dropping it.

Equations Used:

$$a. \quad V_f^2 = V_i^2 + 2aD$$

$$i. \quad V_f = \text{Final Velocity}$$

$$ii. \quad V_i = \text{Initial Velocity}$$

$$iii. \quad a = \text{Acceleration of the ball}$$

$$b. \quad D = V_i^2 + \frac{1}{2}at^2$$

$$i. \quad D = \text{Drop Height}$$

$$ii. \quad t = \text{time of flight}$$

$$c. \quad \Sigma F = F_d - mg = ma \Rightarrow F_d = ma + mg$$

$$i. \quad F_d = \text{Drag Force}$$

$$ii. \quad m = \text{Mass of ping pong ball}$$

$$iii. \quad g = \text{acceleration due to gravity}$$

$$d. \quad F_d = -cV^2\hat{v}$$

$$i. \quad c = \text{Drag coefficient}$$

$$ii. \quad V = \text{Velocity}$$

$$iii. \quad \hat{v} = \text{Unit vector of velocity}$$

$$e. \quad C_d = \frac{8F_d}{\pi\rho D^2V^2}$$

$$f. \quad c = \frac{\pi\rho D^2}{16}$$

$$g. \quad F_d = -cV^2 \cdot \hat{v}$$

$$h. \quad \text{Reynolds Number} = \frac{\rho v l}{\mu}$$

$$i. \quad \rho = \text{Density of Air} = 1.2041 \frac{\text{kg}}{\text{m}^3}$$

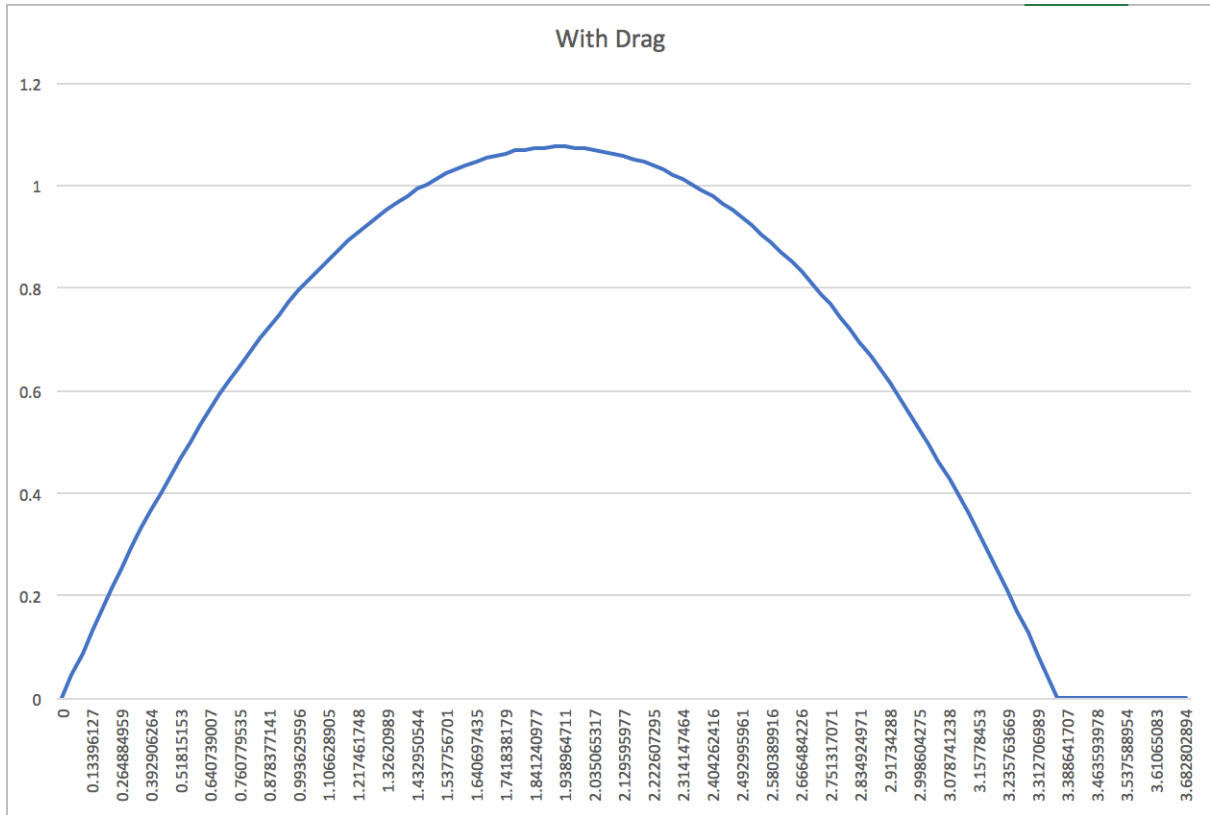
$$ii. \quad v = \text{Velocity of the ball} = 4.932 \frac{\text{m}}{\text{s}}$$

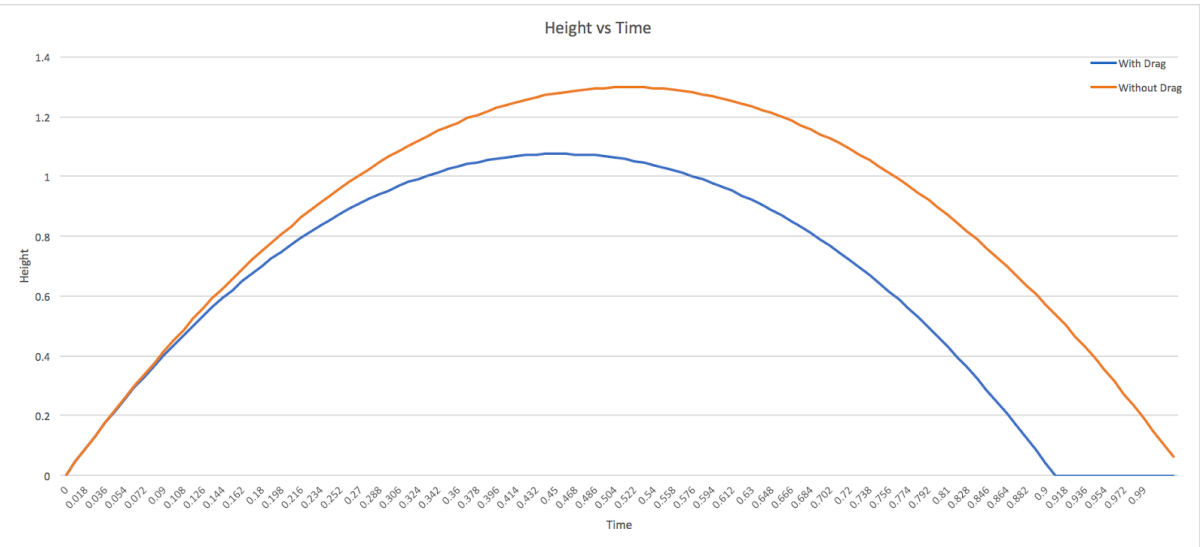
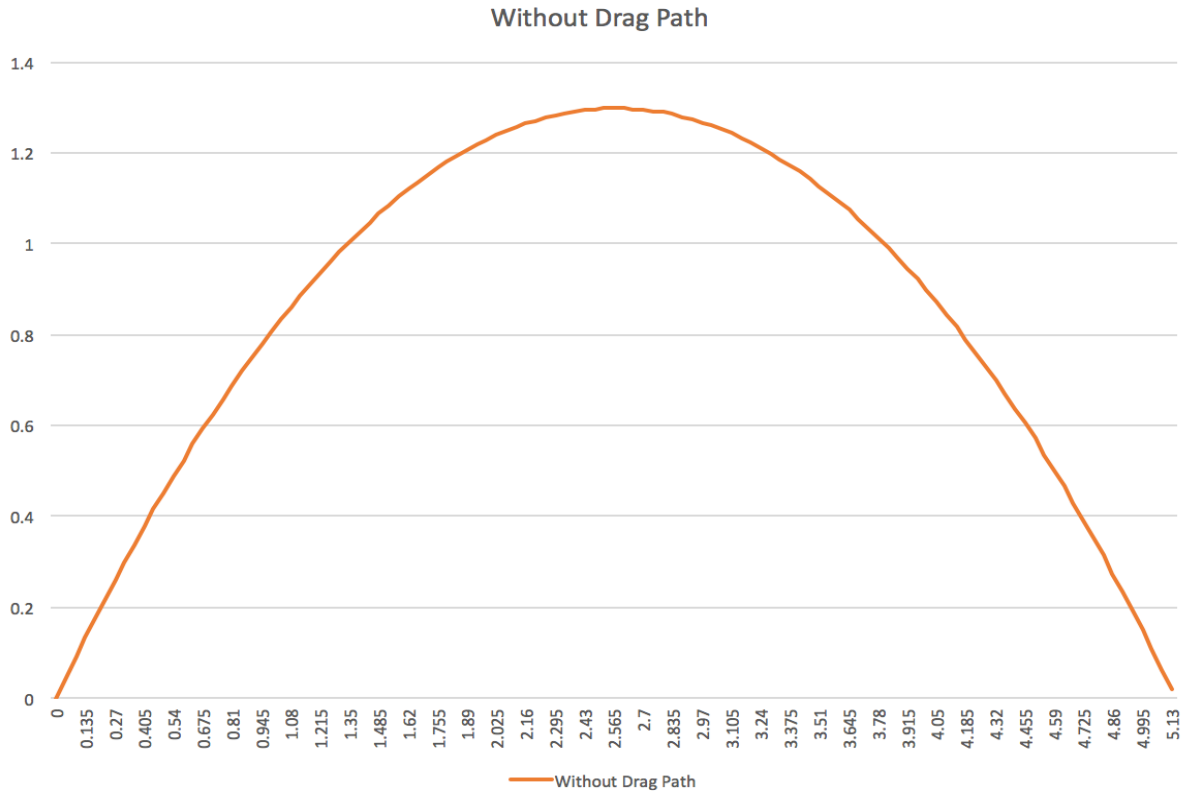
$$iii. \quad l = \text{Diameter of the ball} = 0.04 \text{ m}$$

$$iv. \quad \mu = \text{Dynamic Viscosity of Air} = 18.13 \times 10^{-6} \frac{\text{kg}}{\text{ms}}$$

Combining equations (e), (f), and (g) gave us the following two equations for C_d :

$$C_d = \frac{Fd}{2cV^2} \quad \text{or} \quad C_d = \frac{8c}{\pi\rho D^2}$$





Experimental Design and Results

Procedure:

- a. For this experiment, we performed 50 trials at a measured height of 2.155 m. The following is an example of one trial, and will be repeated exactly the same for the rest of the trials and distances.
- b. The meter stick will be placed vertically since the ball will be dropped vertically. Set the meter stick and the camera in front of it (make sure that the camera is far back enough to catch the fall of the ball from the beginning).
- c. Drop the ball from the top of the meter stick while recording and taking time. Stop the time right before the ball hits the floor.
- d. Record the following variables:
 $V_i = \text{initial velocity}$, $d = \text{distance}$, $a = \text{acceleration due to gravity}$, $m = \text{mass of ball}$
- e. Solve for the following variables using the equations from section 3:
 $V_f = \text{final velocity}$, $t = \text{time}$, $F_d = \text{drag force}$, $c = \text{drag parameter}$
- f. Record the following values on a data sheet.
- g. Repeat steps (b) through (f) the desired amount of times for each distance using the meter stick.
- h. After all trials have been done, average the drag parameters to obtain a final estimated value for c.

Using our experimental data, we obtained average values for final velocity (V_f) and acceleration (a) of the ball from 50 trials. The ball of diameter $d = 40\text{mm}$ and mass $m = 0.0021\text{ kg}$ was dropped from a height 2.155m . The kinematics equations described above were used to derive values for c and Cd , with the appropriate constants also listed above. Using the program Microsoft Excel, we were able to find c and Cd by setting equations for c and Cd in the cells and simply inputting the final velocity. If a program is not available, you can calculate the final velocity from kinematics equation (a), and find the drag force using equation (c.i.). The experimental c value can be derived by setting equation (c.i.) to equation (d), further allowing the calculation of Cd by using the experimental value of c in equation (e). We used statistics to remove the outliers included taking the interquartile range to find the upper and lower bound for the times.

This resulted in $Q1=0.42\text{ sec}$, $Q3=0.4875\text{ sec}$, $IQR=0.0675\text{ sec}$ ($Q3-Q1$), Upper Bound= 0.58875 sec ($Q3+[1.5*IQR]$), and Lower Bound = 0.31875 sec ($Q1-[1.5*IQR]$). Removing the outliers for time gave us an average time of 0.4504 sec , average final velocity of $4.932361305\frac{m}{s}$, average acceleration of $5.644591194\frac{m}{s^2}$, average drag force of

0.008780572582 N, and a drag parameter of 0.0003609217656. Compared to the theoretical drag parameter of 0.000384 resulted in a percent error of 6%.

Using our experimental c value of 0.00036092175, $m = 0.0021$ kg, $V_f = 4.932361$ and $F_d = 0.0087805725$, we obtain $Cd = 0.500073$. This is a great close approximation to the theoretical value of a sphere, which is $\frac{1}{2}$. We found the standard deviation of c to be 0.0002987413107 and the standard deviation of C_d to be 0.3834061484.

In order to calculate a representative Reynolds number, we used the listed equation (h). The constants we used are listed under equation (h) as (h.i., h.ii, h.iii, h.iv). Using these values, we obtained the following:

$$\text{Reynolds Number} = \frac{\rho v l}{\mu} = 13102.3$$

The density and viscosity of air is assumed at room temperature. From our calculations the Reynolds number is consistent with our assumptions. This makes sense because a turbulent flow is more than 4000 and our values goes consistent with that! Turbulent flow indicates that the speed of the ball undergoes continuous change in magnitude and direction since the air is flowing around it, therefore the ball moves in a certain direction with resistance faced from the air.

Discussion of Results

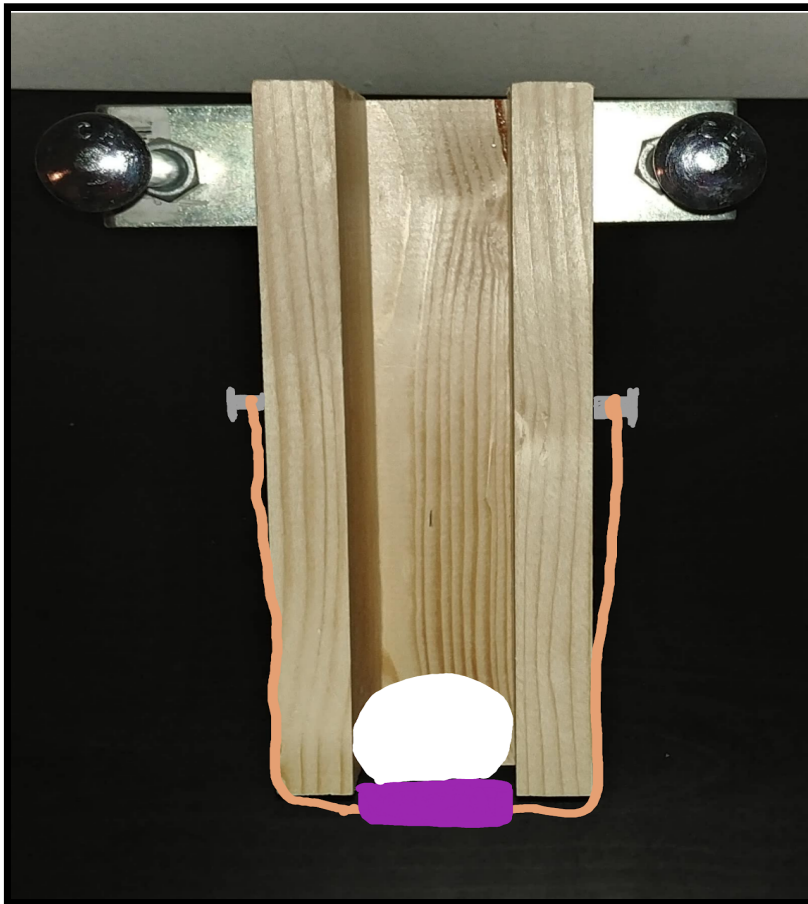
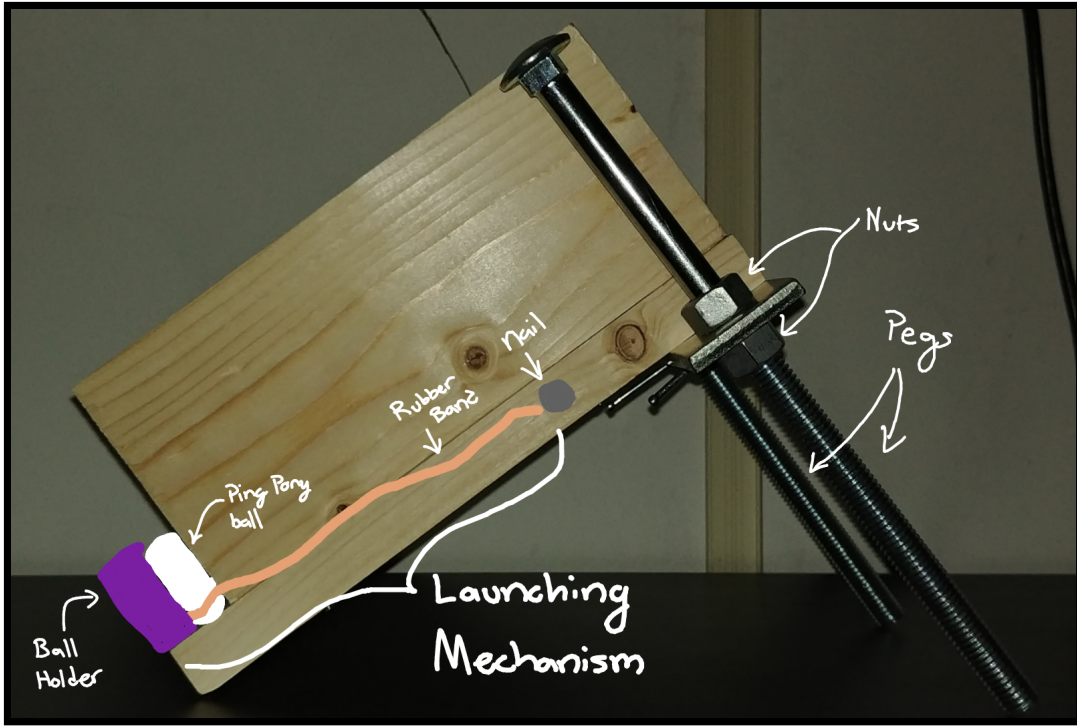
We successfully obtained an average acceleration of $5.644 \frac{m}{s^2}$ and an average drag force of 0.00878 N. Using these two values, we calculated an experimental drag parameter (c) value of 0.0003619. When compared to the theoretical drag parameter .0003783, there is a 6% error. This is an acceptable difference between our experimental and theoretical parameter. Using our experimental value, we calculated the experimental drag coefficient to be .500073. This gives us a less than 1% error when compared to the theoretical drag coefficient of a sphere which is .5. A possible main source of error could be the inaccurate measurements of the time it took for the ball to fall the distance of 2.155 meters. This would affect our calculations of the acceleration of the ball, introducing error into our calculated

drag force and thus affecting our drag parameter and drag coefficient. To reduce the chance of error, a recording software could be used to obtain a more accurate time measurement by slowing down the footage of the ball dropping.

Launching Mechanism

The ping-pong ball launcher design we might go with is fairly simple. It consists of a holder for the ball, rubber bands attached to two nails to apply force, pegs to adjust the angle of launch, and rails to steady the ball during launch. The angle will be adjusted by tightening and loosening the nuts on the pegs. We tested how much force is given by the rubber band when pulled back to a certain distance so then all we have to do is adjust the location and angle of the launcher to hit our target. The materials we used are two 10 inch long/0.5 inch diameter metal bolts, four 0.5 inch diameter nuts, a metal electrical wire organizer, two rubber bands, eight nails, a bottle cap, two 1x4x8 inch wood boards for the rails, and one 1x4x9 inch board for the base.

The launcher works by adjusting the pegs to the desired angle and then placing the ping pong ball in the bottle cap so it's secured. The bottle cap is then drawn back by the correct distance to achieve the correct amount of force. Once the cap is released the ball should travel up the base, through the rails, and towards the target. The pictures on the next page, respectively, are the side and top views.



Conclusion

In order to create the ping pong ball launcher we first needed to determine the drag coefficient that would then help us in calculating the angle to launch the ball. We started off by calculating the theoretical value for the drag parameter and then performed an experiment to determine our experimental value for the drag parameter. The experimental value for our drag coefficient was 6% away from the theoretical value that we calculated. The values of the drag coefficient then enabled us to determine the kinematic equations that enabled us to create a ping pong ball launcher.

It is necessary to account for air resistance as the drag coefficient affects the trajectories of the ball. The graphs illustrate that the drag coefficient reduces the distance that the ball travels by about 24% which is a huge margin of error if it is not accounted for. Therefore we had to take this into account in order to build a launcher that will accurately hit the target.