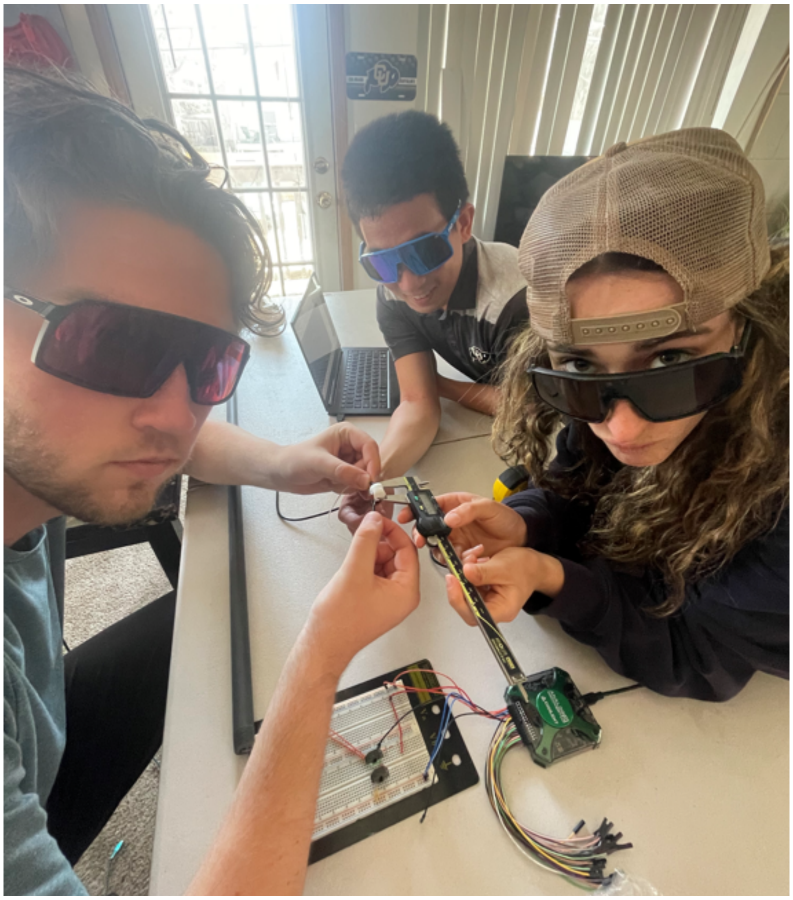
Pneumatic Solenoid Triggered “Marshmallow” Cannon

Section No: 103, Group No: 4



515-118

610-666

332-804

MCEN 3047: Data Analysis and Experimental Methods

Date: 05/04/2022

ABSTRACT

The purpose of this experiment was to design an experiment, integrate and calibrate a sensor, write custom software and run an appropriate analysis of our data around a phenomenon that interests us as a group. Additionally, this experiment was used as a test on how we use our skills that we have developed throughout the course of MCEN 3047 in regards to DAQ and sensor selection as well as LabView knowledge. We chose to conduct our experiment around the physics involved with pneumatic air cannons and solenoids so that we could create a cannon that we could perform an analysis on to determine optimal pressure and barrel length that yield the maximum escape velocity. Throughout this experiment and analysis, we were able to take a mathematical model and our own data and analyze it to determine these variables.

I. INTRODUCTION AND BACKGROUND

A. Motivation and Interest

Our interest for this project stemmed from our fascination and entertainment from seeing hotdogs shot across bleachers of people via high powered pneumatic cannons at baseball games. As we delved deeper into our interest, we narrowed down our experiment focus as pneumatic cannons in general and how they function. With the task of designing an experiment that integrates a calibrated sensor, custom software and data analysis, we chose to question how the length of a pneumatic cannon barrel influences the initial velocity of a ‘marshmallow’ across various pressures.

For our experiment we chose to use a phototransistor reflective object sensor, a Honeywell 140 PC series pressure sensor, a NI USB-6008 DAQ and LabView to collect and analyze our data. Additionally we used PVC pipes and adapters, wires, a breadboard, resistors, a PVC clipper, a solenoid valve, 9V battery, Teflon and a small projectile composed of a hot glue filled piece of PVC to emulate a marshmallow. We aimed for our experiment to show us the ideal barrel length and pressure combination so that we could determine our ‘ideal’ barrel length for our projectile

B. Pneumatic Air Cannon

Pneumatic air cannons are devices used to launch projectiles using compressed air. The cannon consists of a large pressure chamber that holds compressed air for launching the projectile. A valve is used to control the pressurized air in the pressure chamber. Then a long barrel is connected to the valve that guides the projectile in the desired direction. Air cannons are typically used in stadiums to launch merchandise like t-shirts as they are soft yet travel far. Air cannons can also shoot loose projectiles such as paint and confetti. The equation used for the velocity of the projectile out of the air cannon is,

$$V = \sqrt{2\left(\frac{P^{*}A}{m}\right)L}, \tag{1}$$

Where P is the gauge pressure of the pressure chamber, A is the inner cross sectional area of the barrel, m is the mass of the projectile, and L is the length of the barrel.

C. Honeywell 140 PC Series Pressure Sensor

Pressure of the air cannon’s pressure chamber was measured using a Honeywell 140 PC series pressure sensor [2]. This pressure sensor is able to measure the gauge pressure of the pressure chamber which subtracts the ambient atmospheric air pressure from the absolute pressure in the pressure chamber. This sensor works by using a piezoresistive strain gauge to convert the pressure from the measured air to a strain. The voltage from this strain gauge is then used to calculate pressure. This sensor in particular can measure ranges from 0 psi to 100 psi. However, the maximum pressure measured in this experiment did not exceed 30 psi. Other pressure sensors with more appropriate ranges were not available which led to the decision of using this particular sensor.

D. QRB1114 Phototransistor Reflective Object Sensor

The sensor used to calculate the exit velocity of the projectile is called a phototransistor reflective object sensor [3]. The sensor consists of an infrared emitter and an infrared photo transistor. The emitter is powered to 1.5 volts along with the phototransistor. When infrared light is reflected off of an object, the phototransistor increases its resistance and can be visualized in an oscilloscope as a drop in the voltage out of the phototransistor. Two of these sensors will be used to measure the exit velocity by tracking the presence of the object at two different times and distances. The equation used below is used to calculate the velocity of an object.

$$V = \frac{D}{\Delta t}, \tag{2}$$

Where D is the distance between the two sensors and Δt is the change in time between the detection of the object.

E. Solenoid Valves

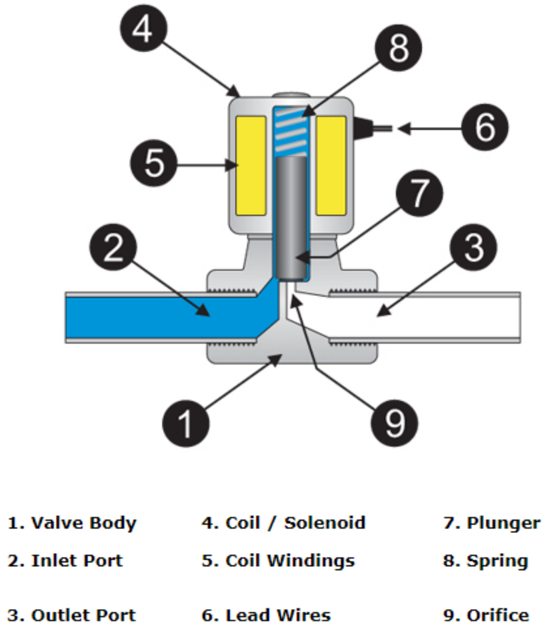


Figure 1. Diagram of the inside of a Solenoid valve

Solenoid valves are commonly used for irrigation systems to remotely control the flow of irrigation water. The valve is normally closed and can be open by applying a voltage to the solenoid coil pack which opens the flow stream through the valve. In our lab we needed to remove the human error of how fast we can open valves. To create an accurate and repeatable burst of pressure to the projectile, we decided on a solenoid valve over a ball valve. The solenoid can be repeatedly opened using a push button rather than a slower ball valve. We decided to use the Irritrol 2400T solenoid valve because it was easy to source, readily serviceable, and has ample documentation. The valve is rated to a maximum of 120psi which is lower than needed for safety purposes. The valve is also "leak proof" whis was necessary to ensure the chamber would hold accurate pressures before firing. The valve came with threaded ports which was also necessary for the threaded barrel. The valve requires 24V to activate the solenoid, however with lower pressures, we were able to quickly and safely open the valve with a 9V battery and momentary switch.

II. PROCEDURES

A. Part 1: Pneumatic Air Cannon Construction

Before beginning to prep our experimental set up to gather data, we needed to build our pneumatic solenoid air cannon out of the parts specified in appendix A. First, we constructed our pressure chamber using two pieces of threaded PVC tubing (part B), a threaded PVC end cap (part F), a threaded PVC coupler (part D), tubeless tire valve (schrader valve) (part G) and our Honeywell 140 PC Series Pressure Sensor. Beginning with our end cap, we proceeded to drill a .625 inch hole in the top where we press fit our schrader valve so that we could fill the chamber with pressured air. Then taking one of the pieces of PVC threaded tubing (Part A) we drilled a .125 inch hold and proceeded to insert our Honeywell 140 PC Series Pressure Sensor. We attempted to make our sensor as press fit as possible and just for safe measures, used hot glue to adhere the outside of the sensor. To complete our pre assembly we then wrapped each threaded end of our PVC tubing (part B) in 10 layers of Teflon to ensure that they had a tight seal.

With our pre assembly complete for our pressure chamber, we then started to construct the full pressure chamber as seen in figure 2. Then, we moved onto connecting our chamber to the backend of the solenoid valve using the threaded male end of our PVC (part B) and the female end of the solenoid.

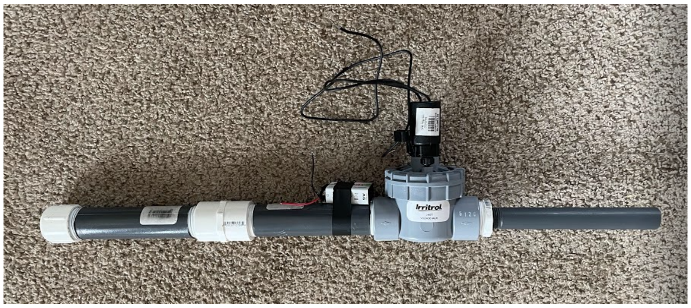


Figure 2. Full pneumatic air cannon setup fully assembled

For our barrel, we chose another threaded piece of PVC (part E) to connect the male end to our other exciting female end of the solenoid as seen in figure 2. This piece was not wrapped in Teflon so that we could easily remove the barrel to adjust length during data collection.

B. Part 2: Making Our Projectile

To make the marshmallow analog projectile, we cut ½" of the PEX-A pipe (part A), then placed the short cylinder on its end on top of a heat proof mat and filled the center cavity with low temp hot glue. After we waited for the glue to dry, we used a strip of sand paper (part M), and sanded the sharp edges of the cylinder on both ends to more resemble the marshmallow.

C. Part 3: Setting up Pressure Sensor Circuit

For this experiment we used the National Instruments USB-6008 DAQ which helped us construct a method of data collection via making a circuit with our pressure sensor.

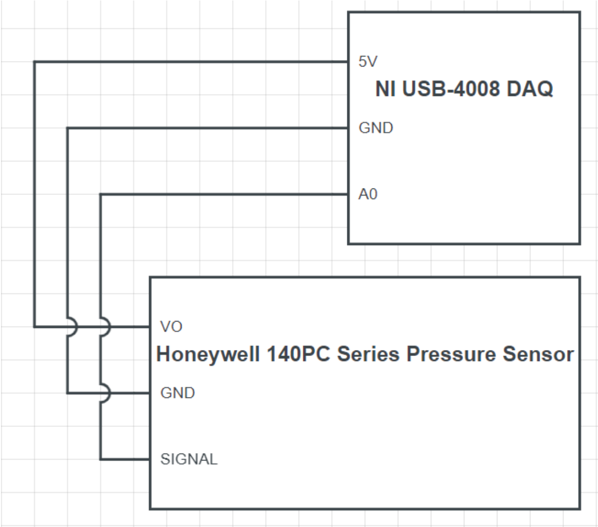


Figure 3. Schematic of our pressure sensor and DAQ setup

As seen in figure 3, we connected our Vo of our pressure sensor to 5V from the DAQ, both of our ground pins together and the signal pin from the pressure sensor to the A0 port of our DAQ.

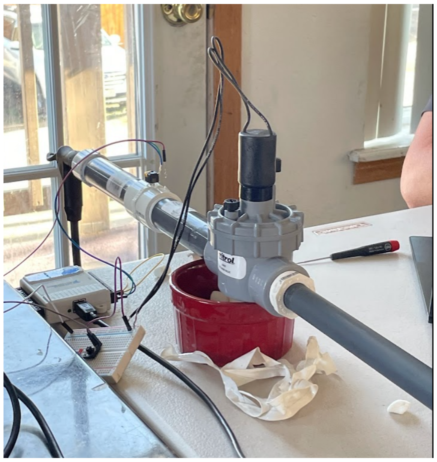


Figure 4. Pressure sensor setup

D. Part 4: Setting Up Phototransistor Object Sensor Circuit

Assemble the phototransistor circuit on a breadboard using the following figure.

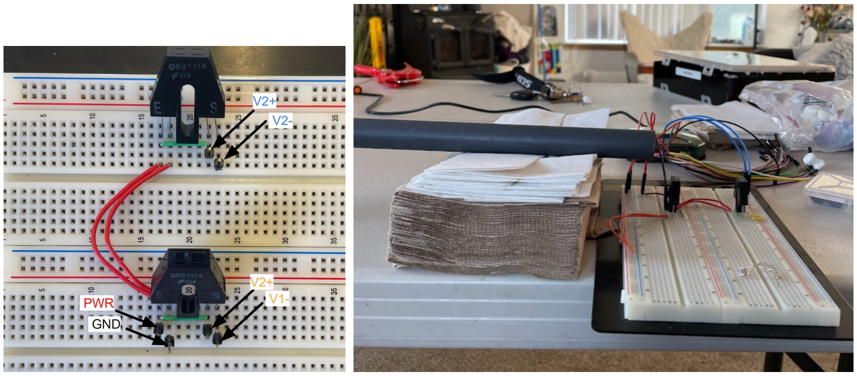


Figure 5 & 6. (Left) Phototransistor sensor circuit and (Right) experimental setup.

The circuit is powered to 1.5 volts and monitored using an oscilloscope at the indicated pins. 2 channels are required to monitor the two sensors. The circuit was powered and monitored using an AD2 with the accommodating software Waveforms. Samples were taken at 8kHz. Δt is calculated by using the X-cursors to measure the time between the minimum voltage of each sensor.

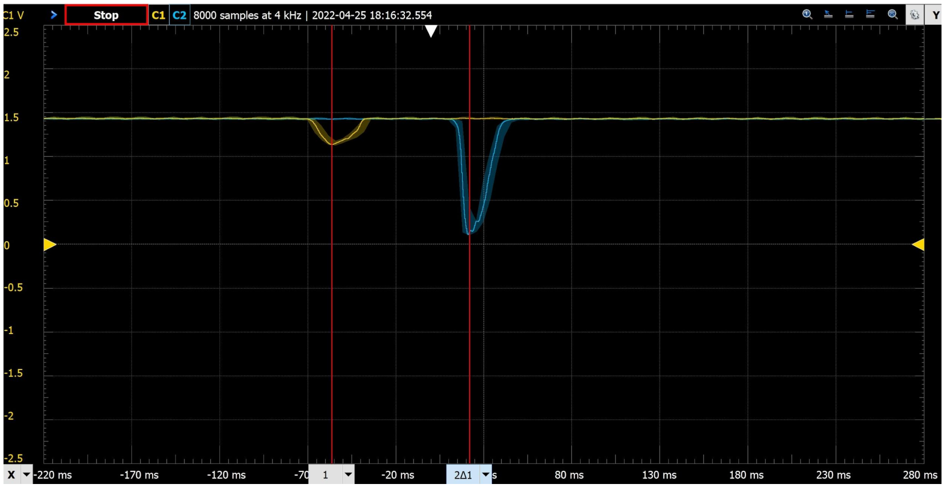


Figure 7. Oscilloscope reading voltage of sensors. Red lines are the X-cursors measuring Δt.

E. Part 5: Build the VI

With the pressure sensor, photoresistive reflective object sensors and DAQ properly set up, we then connected the DAQ to the USB port on the monitor and opened up LawView. We then proceeded to create a Blank VI and added a DAQ assistant to the block diagram with the analog pressure input reading from the pressure sensor via channel A0 of the USB-4006 DAQ. The acquisition mode was also adjusted to read N samples, the number of samples to 2, and the sampling frequency to 1 Hz. Finally, we changed the Timeout to be 2.01 seconds under the Advanced Timing Tab.

With our VI set up, we proceeded to make a calibration curve where we measured the pressure from 0 to 50 psi with 10 psi increments recording the voltage as we went.

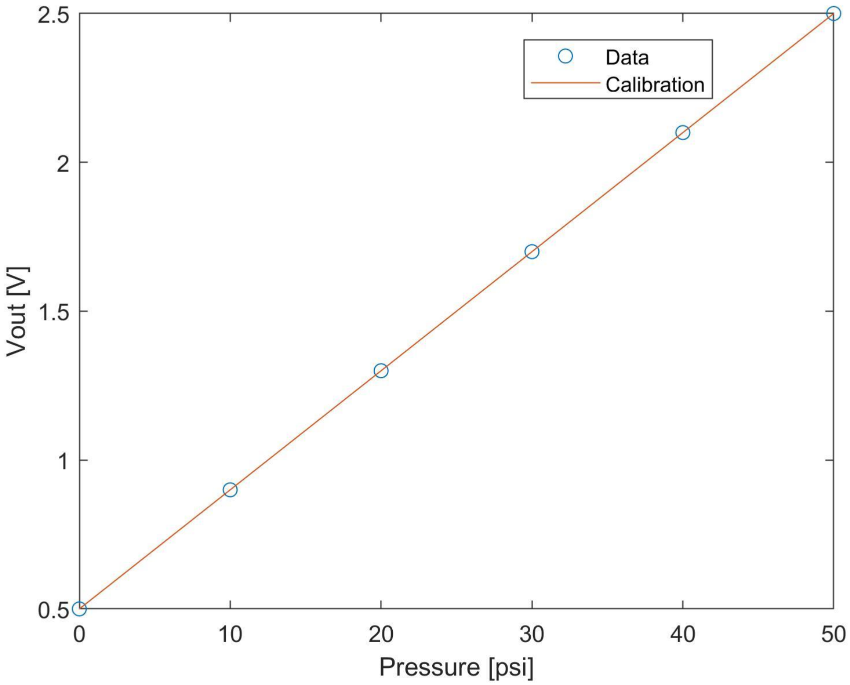


Figure 8: Calibration curve for pressure sensor.

With our base calibrations made, we then added a Waveform Graph with a cursor and the y axis limits set to be 0 to 2 V to the Front Panel to display the Pressure of the chamber as a function of time. With our LabView Front Panel and VI set up, we ran the VI and recorded the voltages indicated on the plot.

F. Part 6: Experimental Setup

To prepare our experimental setup, we began by measuring our initial length of the barrel at 24 inches and then recording that to the second decimal place in our table. Then we set our pneumatic cannon and photoresistive reflective object sensor circuit on a level surface, which in our case was a lab table. Then using towels and supports (stacked plates), we leveled the barrel making sure that the pressure sensor's DAQ system was not being obscured by its placement away from the exit of the barrel. Furthermore, we placed the exit of the barrel right before the first photoresistive reflective object sensor which made sure that the barrel was as close as possible above the sensors without having our projectile hit them during its launch. This was essential so that the IR light could be read as accurately as possible and thereby produce cleaner timestamp readings.

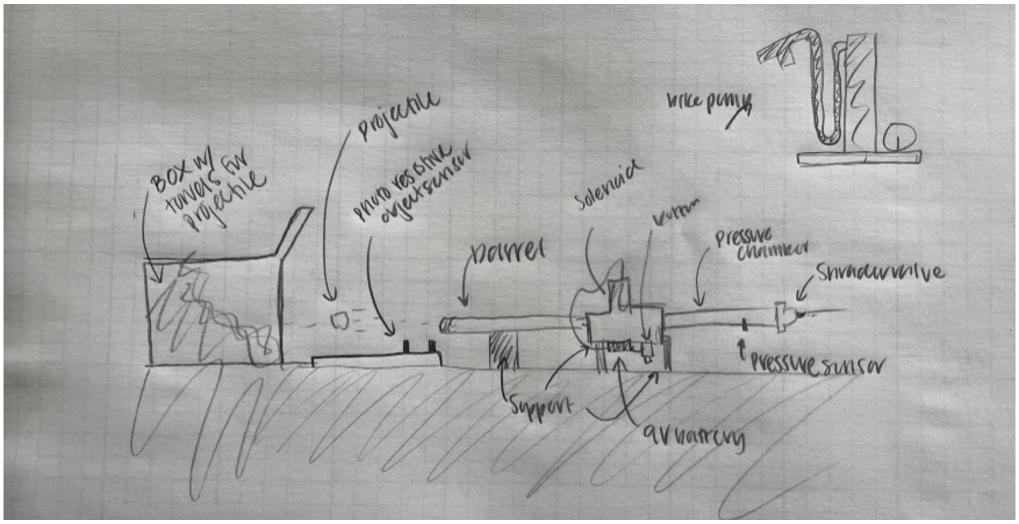


Figure 9. Drawing of our setup for the duration of our lab

With both our sensor circuits (pressure and object) set up in place with our stationary cannon, we set up a cardboard box packed with towels behind the object sensor circuit so that the slug could be caught and slowed down inside of the box. For further details, see figure 9.

G. Part 7 : Data Collection

Once our experiment was completely set up, we began to acquire our data. To conduct the first measurement, we removed our barrel via unscrewing the threaded end, and then took our slug and placed it in the back end of the barrel where it was closest to the threaded end that would be then screwed back into the solenoid. At the same time, we took a bike pump and pumped up the chamber to our first pressure interval which was at 10psi; this was estimated and measured via the gauge on the bike pump itself. With our chamber loaded to our respective pressure, we ran the VI and recorded the voltage value for the indicated pressure in our table. With the chamber loaded and the barrel and projectile prepped for 'firing', we then made sure everything was level and that the end of the barrel was placed close enough to the object sensors. With our system check finished, we began to run the other VI for the object sensor and then pressed the button which powers the solenoid so that the slug was fired. Once the projectile was shot, we then recorded the Δt (measured from part D) and added it to our spreadsheet for velocity calculation using equation 2.

To acquire the rest of our data for this experiment, we took two more shots at 24 inch barrel length and 10 psi. We then measured the pressure at two other intervals (20 and 30 psi) giving our first data set at 24 inches in barrel length three interval pressures (10, 20 and 30 psi). This process of three pressure intervals at 10, 20 and 30 psi was repeated and recorded in our table as stated above at 18, 12 and 6 inches.

H. Part 8: Tidy Up

To clean up our 'lab station', we made sure to disconnect our cables and power off all the equipment. We then broke down the cannon, cardboard box and circuits and put them back in their respective places.

III. RESULTS AND ANALYSIS

A. Data results `

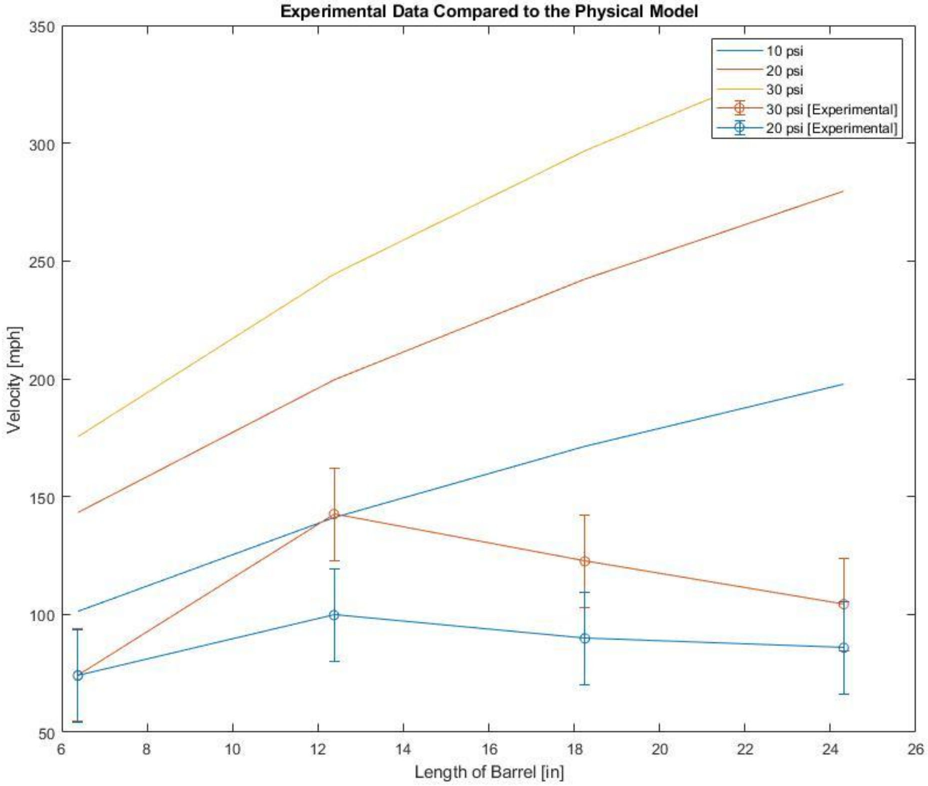


Figure 8. Experimental data collected during the experiment compared to the physical mathematical model.

After testing our data showed that at 10 psi the projectile did not leave the barrel and thereby we could not record a speed using our sensor. At 20 psi the projectile had a velocity of 73.99, 99.68, 89.82, and 85.85 mph at barrel lengths of 6, 12, 18, and 24 inches respectively. At 30 psi the projectile exited with velocity of 74.19, 142.6, 122.5, and 104.3 mph at barrel lengths of 6, 12, 18, and 24 inches respectively.

The error in our experiment was estimated by using the average standard deviation of velocity over five trials of the four barrel lengths and two pressures that had a velocity reading. We found this error to be ±19.63 mph.

Comparing the experimental data to the model, our results show that the average velocities of the experimental data are lower than the physical model. The model does show that the change in velocity over the barrel length will decrease, however unlike our experimental data, the model does not have a local maximum velocity. Our data shows that at 12 inches of barrel length the given pressure above 10 psi will have the highest exit velocity. As the barrel length increases past 12 inches in our experimental data, the velocity decreases. We believe this is due to the friction between the marshmallow and the barrel; as the length increases the marshmallow has more time to experience acceleration loss due to friction in the barrel, causing a lower exit velocity. The model does not account for the friction in the barrel nor the volume of the pressure chamber. While performing the experiment we made note that if the barrel volume became so large as to equal the volume of the barrel and the pressure chamber, the force from the atmosphere would slow the marshmallow such that a vacuum would be created in the pressure chamber and prevent the marshmallow from leaving the barrel. However, we did not measure the pressure in the chamber during firing so we cannot confirm that this affected the 10 psi trials.

B. Things we found along the way

Throughout the experiment, issues that caused inconsistent results introduced more uncertainty leading to minor changes in procedure. First, marshmallows were inconsistent in size and introduced a confounding friction variable that caused initial results to be inconclusive. This issue was addressed by using a more consistent projectile made of PEX tubing and hot glue. This projectile led to more consistent results for analysis. Second, the pressure sensor pins were broken and had to be connected to DAQ wires by hand. To accommodate this issue, DAQ frequency was increased and to avoid connection issues when measuring pressure. Last, the solenoid used in initial experiments failed and needed to be replaced. After these issues were resolved, the experiment was conducted again resulting in the current results.

IV. CONCLUSION

Through analysis of our data, we determined our mathematical model does not match our data; however our data still provides an optimal barrel length of 12 inches at 20 and 30 psi with speeds of 99.69 mph and 142.6 mph respectively. Additionally, we found that at 10 psi the projectile did not leave the barrel at all lengths. Furthermore, our model we chose had a slug with a 12x larger mass and 10x larger pressure [4]. Therefore we reject our mathematical model and conclude that we need more data points, and a model that acknowledges the variations of barrel length, friction and a projectile with smaller mass across lower pressures.

V. REFERENCES

[1]. *Solenoid Valve Basics*. Solenoid valve basics. (n.d.). Retrieved May 4, 2022, from http://www.solenoid-valve-info.com/solenoid-valve-basics.html

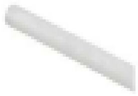
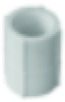
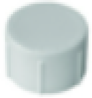
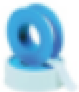
[2]. *Interactive catalog replaces catalog pages - datasheet.octopart.com*. octopart.com. (n.d.). Retrieved May 4, 2022, from https://datasheet.octopart.com/142PC15A-Honeywell-datasheet-5318696.pdf

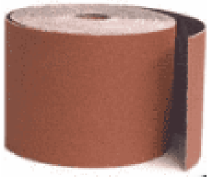
[3]. *QRB1113/QRB1114 phototransistor reflective object sensor*. digikey.com. (n.d.). Retrieved May 4, 2022, from https://media.digikey.com/pdf/Data%20Sheets/Fairchild%20PDFs/QRB1113_14.pdf

[4]. Rohrbach, Z. J. (n.d.). *Modeling the exit velocity of a compressed air cannon - wabash college*. persweb.wabash.edu. Retrieved May 4, 2022, from http://persweb.wabash.edu/facstaff/madsenm/publications/AJP_80_24_rohrbach_air_cannon.pdf

VI. APPENDIX

A. Pneumatic Solenoid Cannon Part List

Part Number	Part Name	Description	Quantity	Image
A	Flair-It SAFEPEX Pro 16050 PEX-A Straight Stick Pipe, 3/8 in, Red, 5 ft L	Used for marshmallow replacement	1	
B	B & K ProLine 403-480 Pipe Nipple, 1/2 in MIP, 48 in L, Gray	Main barrel one threaded end attached to solenoid valve (see part number C)	1	
C	VALVE - SPRNK "2400T" JARTOP STR	Solenoid Valve used for firing (See background for info)	1	
D	GENOVA 300 Series 30128 Pipe Coupler, 1 in FIP, White	Coupler for pressure chamber	1	
E	B & K ProLine 405-060 Pipe Nipple, 1 in MIP, 6 in L, Gray	Pressure chamber pieces	2	
F	GENOVA 300 Series 30168 Pipe Cap, 1 in FIP, White	Pressure chamber end cap	1	
G	Slime 2080-A Tubeless Tire Valve, Rubber, For TR413 Tires,	Shcrder valves for the pressure chamber. Able to be pressurized with bike pump	1	
H	HARVEY 017072B-500 Thread Seal Tape, PTFE, Blue/White	Teflon tape used for airtight seal	1	

I	GENOVA 300 Series 34315 Pipe Reducing Bushing, 1 in	Reducer for connection from solenoid valve to barrel	1	
J	DeWALT DW1177 Drill Bit Set, HSS, Black Oxide, 20-Piece	⅛” drill bit used for drilling hole in the chamber for the pressure sensor nozzle. Larger ⅝” drill was used for end cap schrader valve fit	1	
K	SUREBONDER Mini Size GM-160 Hot Glue Gun, 5/16 in Dia Glue	Used to fill in the marshmallow analogue	1	
L	SUREBONDER Mini Size DT-25 Hot Glue Stick, Clear, 25 Pack	Hot glue sticks (See part K)	1	
M	Sand Paper (From Launch Point ITLL)	Makes the PEX pipe look like a marshmallow	1	

B. FinalProject_FinalData.m

```
Data Analysis Group 4 Final Project
clc
clear
close all
Import Data
[length, pressure, time] = readvars('FinalData.xlsx');
velSensDist = 0.04798; %[m]
Apply Calc to find velocity
time = time/1000; %Time was recorded in ms and the equation we
 will use is in s
velocity = (velSensDist./time) * 2.23694;
pressure = (pressure*25)-2.5; %Calibration Curve for [V->Psi]
Plot Three Pressure Plots that show the length
vs velocity
```

```
press1_x = [length(1) length(4) length(7) length(10)];
press1_y = [velocity(1) velocity(4) velocity(7) velocity(10)];
press2_x = [length(2) length(5) length(8) length(11)];
press2_y = [velocity(2) velocity(5) velocity(8) velocity(11)];
press3_x = [length(3) length(6) length(9) length(12)];
press3_y = [velocity(3) velocity(6) velocity(9) velocity(12)];
subplot(2,2,1);
scatter(press1_x, press1_y, 'filled')
hold on
title("Velocity as Barrel Length Increases at 10 psi");
xlabel("Length of Barrel [in]");
ylabel("Velocity [mph]");
1
% trendline
trend = polyfit(press1_x, press1_y, 1);
px = [min(press1_x) max(press1_x)];
py = polyval(trend, px);
axis([10 26 30 70]);
box on
subplot(2,2,2);
scatter(press2_x, press2_y, 'filled')
title("Velocity as Barrel Length Increases at 20 psi");
xlabel("Length of Barrel [in]");
ylabel("Velocity [mph]");
% trendline
hold on
box on
trend = polyfit(press2_x, press2_y, 1);
px = [min(press2_x) max(press2_x)];
py = polyval(trend, px);
plot(px, py, 'LineWidth', 0.5);
subplot(2,2,3);
scatter(press3_x, press3_y, 'filled')
title("Velocity as Barrel Length Increases at 30 psi");
xlabel("Length of Barrel [in]");
ylabel("Velocity [mph]");
box on
% trendline
hold on
trend = polyfit(press3_x, press3_y, 1);
px = [min(press3_x) max(press3_x)];
py = polyval(trend, px);
plot(px, py, 'LineWidth', 0.5);
subplot(2,2,4);
scatter3(length, pressure, velocity, 'filled');
title("Velocity in Relation to Pressure and Barrel length");
xlabel("Length of Barrel [in]");
ylabel("Pressure [psi]");
zlabel("Velocity [mph]");
box on
```

```
hold off
figure
err(1:4) = 1.021043e-03;
2
%std from prelim results including marshmello fit
stdPre = 19.63;
err(1:4) = stdPre;
errorbar(press2_x, press2_y, err, '-o');
%plot(press2_x, press2_y, '-o');
hold on
%plot(press3_x, press3_y, '-o');
errorbar(press3_x, press3_y, err, '-o');
legend("20 psi [Experimental]", "30 psi [Experimental]");
xlabel("Length of Barrel [in]");
ylabel("Velocity [mph]");
title("Experimental Results of Length vs Velocity Over Various
 Pressures");
hold off
%close all
3
Using our model
% v = sqrt(((P*A)/m) * L);
P = (10 * 6.89476)*1000; %Chamber Pressure [Pa]
d = 0.540 * 0.0254; % Diameter of barrel [m]
A = pi*(d/2)^2; %Cross section os barrel [m^2]
m = 1.61 / 1000; %Mass of projectile [kg]
%L = 6 * 0.0254; %Length of barrel [m]
vel = @(L) (((P*A)/m) * L * 2).^(1/2);
figure
plot((length), (vel(length * 0.0254)) * 2.23694); %Returns
 velocity in mph
hold on
xlabel("Length of Barrel [in]")
ylabel("Velocity [mph]")
hold on
P = 20 * 6.89476*1000; %Chamber Pressure [kPa]
vel = @(L) (((P*A)/m) * L * 2).^(1/2);
plot((length), (vel(length * 0.0254)) * 2.23694); %Returns
 velocity in mph
4
P = 30 * 6.89476*1000; %Chamber Pressure [kPa]
vel = @(L) (((P*A)/m) * L * 2).^(1/2);
plot((length), (vel(length * 0.0254)) * 2.23694); %Returns
 velocity in mph
legend("10 psi", "20 psi", "30 psi");
title("Experimental Data Compared to the Physical Model");
% the
Puncert = 0.1; %[V]
Luncert = 0.0625; %[in]
Tuncert = 0.001; %[s]
```

```
sensorDist(1:12) = 0.04798; %[m]
sensorUncert = 0.0005; %[m]
M = [pressure length time sensorDist'];
Sn = [Puncert Luncert Tuncert sensorUncert];
n = 4;
sum = 0;
for i = 1:n
 %long
 Mp = M;
 Mm = M;
 Mp(i) = M(i) + Sn(i);
 Mm(i) = M(i) - Sn(i);
 Beta1 = errfun(Mp);
 Beta2 = errfun(Mm);
 sum = sum + (((Beta1 - Beta2))/2)^2;
end
fprintf("The uncertainity in velocity is +- %d mph\n", sum);
% Uncertainty
function [beta] = errfun(BETA0)
pressure = BETA0(1);
length = BETA0(2);
time = BETA0(3);
velSensDist = BETA0(4); %[m]
time = time/1000; %Time was recorded in ms
 and the equation we will use is in s
velocity = (velSensDist./time) * 2.23694;
pressure = (pressure*25)-2.5; %Calibration Curve for [V-
>Psi]
%velocity return
beta = velocity;
end
5
The uncertainity in velocity is +- 1.901729e-03 mph
Published with MATLAB® R2020a
6
```