International Baccalaureate

PHYSICS

HIGH LEVEL

Extended Essay

Relationship between the maximum height reached by the vertical projection of the sponge ring called ”the note”, and the weight and the speed of the motors.

Word count: 3926

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1. INTRODUCTION

1.1 Rationale

Since my early years in secondary school, I have actively participated in numerous robotics competitions. These have shaped my view over science, especially physics, and its applications in real-world problem-solving. Witnessing how complex formulas can accurately model physical interactions in real-life situations and the guiding results they gave, I decided to conduct this research on the subject that I am passionate about. Understanding the principles behind these calculations is essential for designing efficient and innovative engineering solutions.

This year, the concept of the competition we will participate in is launching a ring shaped sponge into a hoop with a vertical projection(1). What makes this topic interesting is the behaviours of the ring within the dynamic interactions between the components of our system that we will manufacture. Before the manufacturing process, we need to ensure that the mechanism will work properly to optimize the design, ensuring precision and efficiency. So, throughout this research, while my knowledge and practice on the physics concepts deepen, I will also gain insight into the theoretical calculations and real-life performance of our design.

1.2 Overview of the Research

This research studies the behaviors of a sponge ring named “the note” during its projection in a vertical axis. The vertical projection is done by a system called “the Shooter” which was designed and manufactured by myself. It is controlled using a computer and a joystick connected to it. Experimentally, the speed of the shooter and the mass of the object will be changed, and theoretically spring constant of the note and height approximations will be done to investigate the relationship and draw conclusions.

1.3 Background Information

1.3.1 Projectile Motion

Any unpowered object moving through the air will follow a trajectory affected by the strength of the gravitational field and, if significant, air resistance. Such objects are often called projectiles(2). When a projectile is launched, its motion can be analyzed by separating into horizontal and vertical components.

Diagram 1: Components of the Projectile(3)

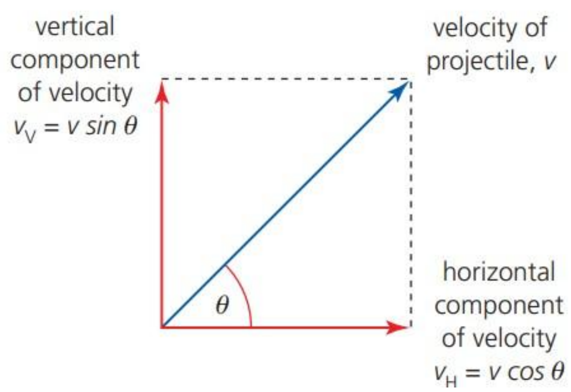


Diagram 2: Separation of the components(4)

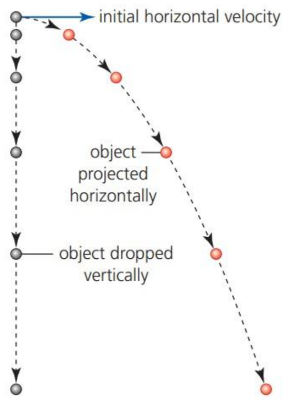


Diagram 1 illustrates the components of the projectile with an angle θ. Horizontal velocity is found by the formula $v_H = v\,cos(\theta)$. this research focuses on vertical projection, meaning the object is launched perpendicular to the surface ($\theta = 90°$). Since, $cos(90°) = 0$ we obtain $v_H = 0$. This confirms that we will only consider the vertical speed of the projection and as $sin(90°) = 1$, $v_V = v$.

The other formulas of the projectile motion are shown by **Table 1**.

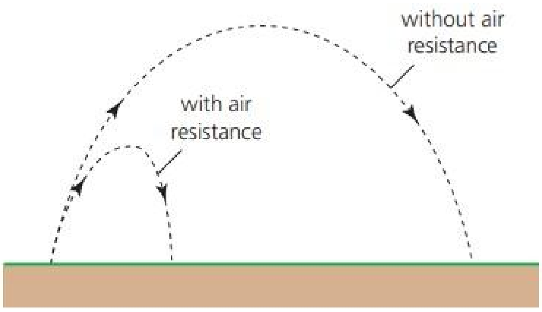
Table 1: Formulas of the projectile motion(5)

Formula	**Definitions**
$v = u + at$	v = final velocity u = initial velocity a = acceleration t = time s = displacement
$v^2 = u^2 + 2as$	
$s = ut + \frac{1}{2}at^2$	
$s = \frac{v+u}{2}t$	

<u>1.3.2 Fluid Resistance</u>

Fluid resistance is a force caused by collisions between the moving object and fluid molecules(6). This force opposes the motion creating a resistance that slows down the object. In this research, fluid resistance is called the air resistance as the object moves through the air.

Diagram 3: Effect of the air resistance on the motion of the object(7)



As **Diagram 3** indicates, air resistance influences both the horizontal and vertical components of motion by reducing the object's velocity in both directions. The formula of the force exerted by the air resistance under slow speeds is(8);

$$F_a = kv$$

Where;

- F_a = air resistance force (N)
- k = drag coefficient
- v = velocity of the object (ms^{-1})

This equation shows that air resistance is directly proportional to the object's velocity. Its potential effects, such as a decrease in maximum height, will be discussed in the evaluation of results.

1.3.3 Law of Conservation of the energy

We can neither create nor destroy energy. Therefore, total (mechanical) energy of the system is always equal to the sum of all energy storage methods on the object(9). The storages of energies considered in this research are kinetic energy(E_K), gravitational potential energy(E_P), and spring potential energy(E_S).

- Kinetic energy is the form of energy that an object or a particle has by reason of its motion. If work, which transfers energy, is done on an object by applying a net force, the object speeds up and thereby gains kinetic energy. The amount of kinetic energy depends on both the mass(m) of the object and its velocity (v)(10). Formula of the kinetic energy is(11):

$$E_K = \frac{1}{2}mv^2$$

- Potential energy is the stored energy that depends upon the relative position of various parts of a system. A spring has more potential energy when it is compressed or stretched. A steel ball has more potential energy raised above the ground than it has after falling to Earth(12). The formulas of the potential energies dependent during this research is(13):

$$E_P = mgh$$

Where;

- m = mass of the object
- g = acceleration of the freefall of the earth
- h = height of the object

$$E_S = \frac{1}{2}kx^2$$

Where;

- k = constant of the spring
- x = displacement of compression or extension of the spring from the equilibrium position

Diagram 4: Gravitational Potential Energy(14)

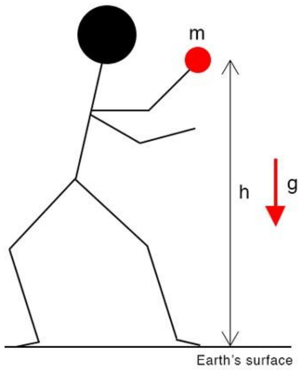
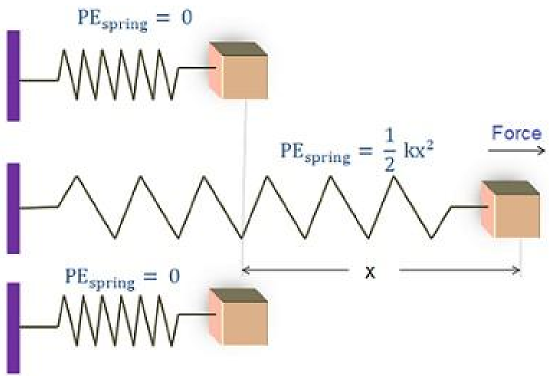


Diagram 5: Elastic Potential Energy(15)



Therefore, mechanical energy of the system is equal to:

$$E_M = E_K + E_P + E_S$$

1.4 Research Question

How does the maximum height reached by the vertical projection of the sponge ring called ”the note”, theoretically and experimentally affected related to the weight manipulated by the metal lab weights (100g, 200g, 300g, 400g, 500g, 600g, 700g, 800g) at 1138.0 RPM and the speed (567.6, 649.9, 732.2, 814.5, 891.1, 1055.7, 1138.0, 1214.7)(rotation per minute, RPM) of the motors located in the mechanism called “the shooter” adjusted using the computer software.

1.5 Hypothesis

As the motor speed increases, the maximum height reached by the note will also increase due to the rising kinetic energy and therefore the mechanical energy. This is because of the conservation of energy discussed in the previous sections. Conversely, as the mass of the note increases, the maximum height of the note will decrease. This is connected to the lower initial velocity of the note, related to the concept of the projectile motion discussed.

2. METHODOLOGY

2.1 Variables

Table 2: Experimental Variables and Measurement Methods

Experimental Variable	Name of the Variable	Method of Measurement
Independent Variable	Motor Speed	Adjusting the parameters in the code via the computer software.
	Mass of the Note	By attaching lab weights to the note.
Dependent Variable	Maximum Height Reached by the Note	**Experimentally:** By the rulers fixed to the wall.
		Theoretically: Using the calculation methods.
Controlled Variable	Dimensions of the note	The same note was used during the experiment.
	Placement of the Note Inside the Shooter	Before each shot, the position of the note was checked properly using a ruler.
	Compression of the note	The distance between the wheels located in the shooter remains constant.
	Shooter Mechanism and Alignment	The shooter was positioned between two tables of equal height during the experiment.
	Motor Type and Specifications	Identical brushless DC motors (same torque, RPM, output power) were used across trials.
	Friction Between the Shooter and the Note	The same wheels remained in contact with the note during the experiment.

Continuation Table 2: Experimental Variables and Measurement Methods

Uncontrolled Variable	Ambient conditions	The wind, temperature and pressure of the room cannot be controlled and can cause errors.
	Abrasion of the note	Repeated launches deformate the outer surface of the note which causes variations in performance.
	Measurement Uncertainties	Inconsistencies in height measurements, due to human error or ruler misalignment, could cause deviations in experimental results.

2.2 Materials

Table 3: List of the materials used in experiment

Material	Purpose	Spesifications	Amount
Plexiglass	Plate used as the structural base of the shooter mechanism covering the top and bottom, and providing a surface for component assembly.	Length: 26 cm Width: 43 cm Height: 0.5 cm	2
Polyurethane Wheels	Rotated by the motors and allows the note to be projected.	Diameter: 10 cm Height: 3	4
Shafts	Transmit rotational motion from the motors to the wheels.	Diameter: 1.3 cm Length: 10 cm	4
Bearings	Reduce friction and allow smooth rotation of the shafts.	6800	6
Pulley	The part that allows the belts to be turned.	30 teeth 3M	4
Belts	Stretched between the pulleys to synchronize the rotation of the upper and lower wheels.	36 cm 3M	2
Battery	Supplies the electrical power required for the system to operate.	Voltage: 12 V Capacity: 18 AH	1
Power Distribution Hub	Distributes electricity from the battery to various other components.	-	1
Motor	Drives the motion of the entire system.	Type: Brushless Speed: 5676 RPM Power: 380 W	2
Motor Controller	Regulates and controls the activation of motors in response to commands.	60 Amper	2
Cable	Provide electrical connections between components.	Diameter: 12 awg Length: 8 m	1

Continuation of Table 3: List of the materials used in experiment

Roborio	The main element that runs the code and controls the mechanism.	-	1
Radio	Enables wireless communication with the computer.	-	1
Fuse	The element that allows the system to be turned on and off, cuts off the electricity in case of any short circuit.	Max. Current: 120 Amper	1
Computer	Used for programming the mechanism and sending commands to control its motion.	-	1
Joystick	Allows the operator to manually control the mechanism.	-	1
Sponge Ring "the Note"	The component launched by the shooter.	Outer Diameter: 36 cm Inner Diameter: 25 cm Height: 5 cm Mass: 235.3 cm	1
Lab Weights	Used to adjust the mass of the note..	Mass: 100g each	8
Rulers	Measurement tools that allow the height of the vertical shot to be measured.	Length: 100 cm Uncertainty: ±0.05	2
Camera	The element that allows the height of the vertical shot to be recorded.	-	1
Screwdriver	Used for assembling and securing mechanical components.	-	1
Plier	The tool that is used to prepare connections, usually in the electrical circuit of the mechanism.	-	1
Hand Drill	The tool that allows the necessary holes to be opened on the components.	-	1
Screws	To fix the motors and two plexiglass together.	-	20
Duct Tape	Used to attach the rulers to the wall.	-	1

Figure 1: The Note

2.3 Experimental Design and Methodology

2.3.1 The Shooter`s Mechanical Setup

Figure 2: 3D Drawings of the Shooter(16)

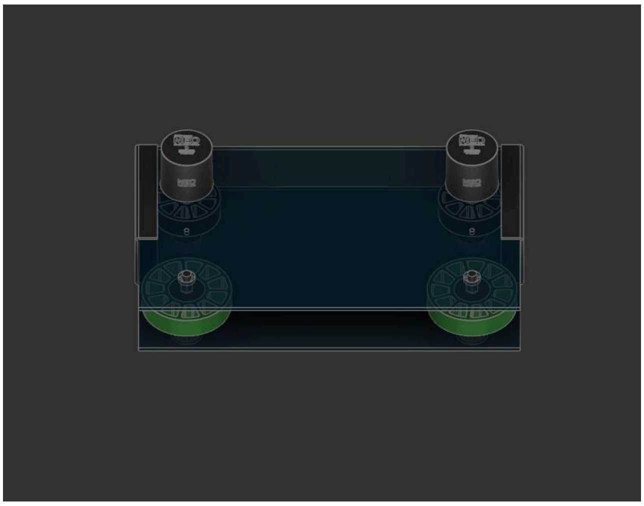
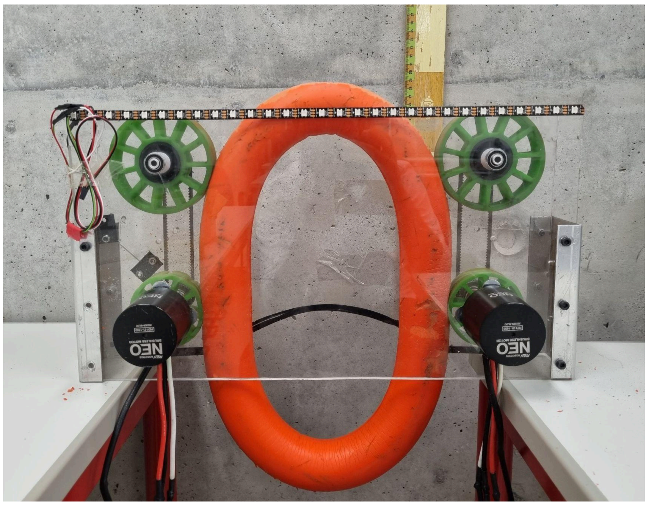


Figure 3: Photo of the Shooter



- ➢ Cut two rectangular plexiglass pieces to the dimensions of 26×43cm and prepare them for the assembly by drilling the necessary holes using the hand drill.
- ➢ Slide the wheels onto the shafts until they fit perfectly to their designated positions.
- ➢ Insert the bearings into the pre-drilled holes on one of the rectangle pieces of the plexiglass and place the shafts inside the bearings to ensure smooth rotation.
- ➢ Secure the motors onto the second plexiglass piece.
- ➢ Stack the two plexiglass pieces on top of each other using the shafts as spacers to create a sandwich-like structure and fix it with the screws.
- ➢ Attach the pulleys to the sections of the shafts extending outside the assembled frame.
- ➢ Position the belts between the pulleys with appropriate tension.
- ➢ Position the shooter perpendicularly between two tables of equal height providing enough space to slide the note in it.

2.3.2 The Shooter`s Electrical Setup

Diagram 6: Electrical Diagram of the Shooter(17)

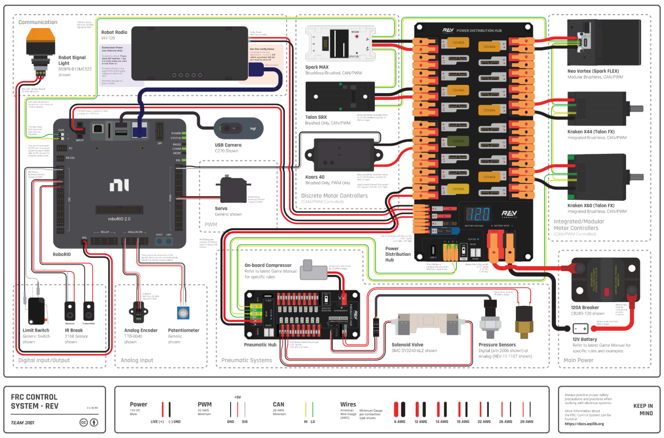
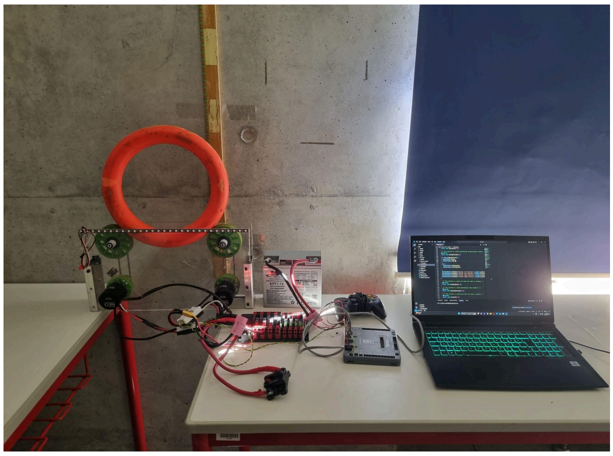


Figure 4: Photo of the Electrical Setup



- ➢ Connect the motor controllers to the cables of the motors placed on the plexiglass carefully indicating the positive and negative terminals.
- ➢ Connect the motor controllers to the power distribution board as shown in Diagram 6.
- ➢ Connect the roborio and the radio to the 12V 5A port of the power distribution board to provide the power.
- ➢ Attach the red and black power cables to the designated battery port on the power distribution board.
- ➢ Integrate the switch into the red cable line and securely plug in the battery.
- ➢ To prevent possible damage to electronics, double-check every connection to ensure proper wiring.
- ➢ Once all connections are verified, close the switch to activate the system.
- ➢ Connect a computer to the radio to transmit the code to the mechanism.
- ➢ Plug in the controller to finalize the setup and prepare for testing.

2.3.3 Methodology of the Data Collection

Figure 5: Rules fixed to the wall

Figure 6: Lab Weights

- ➢ Fix the rulers end-to-end to the wall using duct tape.
- ➢ Place the shooter 30 cm away from the wall to prevent any possible contact with the wall or rulers during the vertical projection.
- ➢ Place the camera at a proper height and distance from the wall to ensure minimum distortion of the data caused by the angle variations and record every projection.
- ➢ Insert the note inside the shooter without any weight adjustment.
- ➢ Using the controller, activate the shooter at velocity 567.6 RPM. Repeat this trial for 5 times to minimize random error.
- ➢ Repeat the same process for seven additional velocity values ensuring that the mass of the note remains constant throughout these trials.
- ➢ After this, adjust the weight without changing the speed (1138.0 RPM) starting from 100g and increase incrementally by 100g for a total of eight different masses.
- ➢ For each weight adjustment, repeat the same process as in the velocity trials.
- ➢ After the trials, observe every height using the camera record by pausing the video where the note stops to rise.

2.4 Justifications

The method used in this experiment ensures that data collection is precise and accurate. The shooter is designed to ensure that the vertical projection remains stable and repeatable and minimizes systematic errors caused by variations in launch conditions. The use of plexiglass provides clear sight into the mechanism for the observer to see the location of the note and detect any potential mechanical issues that could affect performance. The powertrain enables the continuous power transfer to the system which provides the same conditions for every trial during the projection. Furthermore, cables were selected appropriately to handle the ampere and voltage load of the system. All of this provides the perfect circumstances for an accurate experiment.

The systematic increase of motor speed (from 567.6 RPM to 1214.7 RPM) and mass (from 100g to 800g), helps in obtaining an accurate height measurement for each trial. This approach establishes the formation of an investigatable relationship between each variable.

2.5 Risk Assessment and Ethical Considerations

This research involves potential risks to both the environment and human health. Environmental risks are based on the waste generated, including plexiglass residues left after cutting and drilling processes, tape pieces left, and plastic and metal parts that are formed during the preparation of the electrical setup. All waste was carefully collected and disposed of in appropriate recycling bins to minimize environmental impact.

Human health risks are injuries that may occur during drilling and cutting operations, and electrical leaks that may occur during the experiment. To prevent these, personal protective equipment such as gloves and glasses were used throughout the experiment, clothing appropriate for the laboratory environment was worn, and laboratory rules were followed.

3. DATA COLLECTION AND RESULT ANALYSIS

3.1 Raw Data Tables

Table 4: Raw data of independent variable velocity

Velocity (RPM)	**Trial 1 (cm) (±0.05)**	**Trial 2 (cm) (±0.05)**	**Trial 3 (cm) (±0.05)**	**Trial 4 (cm) (±0.05)**	**Trail 5 (cm) (±0.05)**
567.6	47.30	60.00	55.50	52.50	43.10
649.9	60.00	63.60	64.30	59.80	61.70
732.2	75.50	79.70	78.00	74.20	78.10
814.5	93.80	91.60	91.00	96.00	97.00
891.1	113.00	108.30	110.50	112.90	111.50
973.5	128.00	126.00	132.20	134.90	131.00
1055.7	154.00	153.00	155.40	149.00	150.30
1138.0	170.30	179.30	177.50	170.00	178.30

Table 5: Raw data of independent mass

Additional Mass (g)	**Trial 1 (cm) (±0.05)**	**Trial 2 (cm) (±0.05)**	**Trial 3 (cm) (±0.05)**	**Trial 4 (cm) (±0.05)**	**Trail 5 (cm) (±0.05)**
100	176.30	172.00	173.00	178.00	175.90
200	171.80	175.00	173.70	178.80	173.40
300	169.90	174.10	175.50	179.70	171.20
400	168.00	169.80	166.20	179.20	177.70
500	172.00	172.60	168.00	165.90	173.40
600	172.00	162.60	168.00	165.90	173.40
700	165.50	167.40	169.80	171.20	167.00
800	164.00	169.90	169.00	166.30	168.80

3.2 Processed Data

In this section, theoretical values of the experiment will be calculated to make comparison with the results of the real-life experiment. With this process we will be able to evaluate the precision and accuracy between theoretical calculation and real-world situation.

3.2.1 Calculations

3.2.1.1 Average Calculation of the Raw Data

The average of 5 trials for every RPM and mass value must be calculated to convert them to a one most proper value. The average formula used for this is:

$$Average = \frac{Trial\ 1 + Trial\ 2 + Trial\ 3 + Trial\ 4 + Trial\ 5}{5}$$

Sample calculation of average maximum height for 567.6 RPM

From the formula, average maximum height becomes;

$$Average = \frac{47.30 + 60.00 + 55.50 + 52.50 + 43.10}{5} = 51.68 \pm 0.05\ cm$$

This was repeated for all other speed and mass values.

3.2.1.2 The Spring Potential

As the note is a ring shaped object that can be compressed and return to the old state, this comparison creates a springlike motion. The shooter vertically launches the note by the wheels and wheels compress it to increase the friction for full transfer of the speed. However, when the contact between the wheels and the note is cut off, this compression adds an additional velocity to the note. Therefore, to find this velocity, we need to find the spring potential energy using the formula:

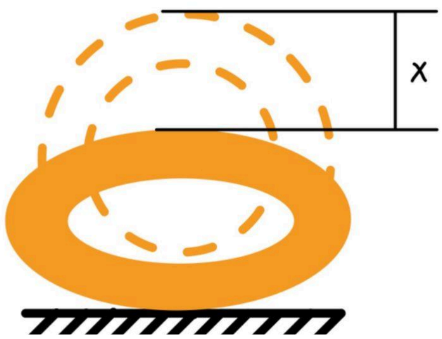
$$E_S = \frac{1}{2}kx^2$$

To use this formula, we need the value of k which is the spring constant of the note. To calculate this, constant the value of x and something equal to the energy of the spring must be known. x value is the compression of the note, so it can be measured using a ruler. In addition, from the law of conservation of energy, we know that the initial energy of the system is equal to the final energy of the system. If the note was compressed and released vertically, it will reach a height where the velocity is zero which will enable us to calculate the potential energy. As the velocity of the note at that point is zero, there is no other energy storages, therefore;

$$E_P = E_S$$

$$mgh = \frac{1}{2}kx^2$$

Diagram 7: Compression of the note(18)



Calculation of the spring constant

The compression (x) shown by **Diagram 7** is 11cm. The height(h) when the velocity of the note was zero was measured as 5cm by a ruler. Mass(m) of the note was specified as 235.3g by the producer and the freefall acceleration(g) of the Earth is $9.81ms^{-1}$. Before applying these values to the formula, they must be converted to SI units. Therefore:

- $x = \frac{11}{100} = 0.11m$
- $h = \frac{5}{100} = 0.05m$

- $m = \frac{235.3}{1000} = 0.2353kg$

Using these values, the formula becomes:

$$0.2353 \times 9.81 \times 0.05 = \frac{1}{2} \times k \times (0.11)^2$$

$$k = \frac{0.2353 \times 9.81 \times 0.05}{\frac{1}{2} \times (0.11)^2} \simeq 19.08\ N/m$$

3.2.1.3 Calculating the Theoretical Height related to the Speed

Sample calculation of the theoretical maximum height for 567.6 RPM

To calculate the theoretical maximum height of the note, this formula will be used:

$$v^2 = u^2 + 2as$$

Where;

- v = final speed of the note
- u = initial speed of the note
- a = g = acceleration of the freefall
- s = displacement from the start, which in this case the maximum height reached by the note

Some of the values above are known, Table 6 shows those values and their explanations.

Table 6: Values and explanations of the known variables

Name	**Value**	**Unit**	**Explanation**
v	0	ms^{-1}	As the maximum height reached by the note is the turning point of the projection, the velocity and kinetic energy is zero, when height and the potential energy is maximum.
g	9.81	ms^{-1}	According to the literature, acceleration of the freefall is assumed to be equal everywhere on Earth, and this is the value used by the IB.

The value of initial velocity(u) depends on two things in this mechanism, the velocity of the wheels and the spring potential energy of the note. From the conservation of energy, the total energy given to the note will be converted directly to kinetic energy over the note. Therefore, this formula can be used to calculate the initial kinetic energy of the note:

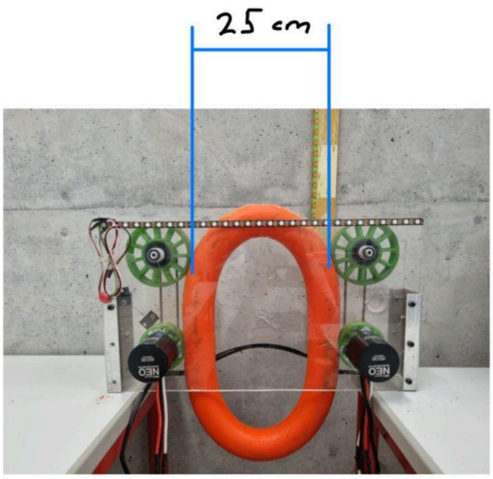
$$E_{K\,initial} = E_S + E_{K\,wheel}$$

The formula for E_S is:

$$E_S = \frac{1}{2}kx^2$$

The value of the spring constant(k) is calculated in the previous section and equal to 19.08 N/m. x is the displacement from the equilibrium position of the note and it depends on the compression between the wheels. **Figure 7** shows the compression of the note.

Figure 7: Compression of the note



As the equilibrium diameter of the note is 36cm, the displacement from the equilibrium is;

$$x = 36.0 - 25.0 = 11.0cm$$

$$= \frac{11}{100} = 0.110m$$

Using this values, the spring potential energy of the note becomes;

$$E_S = \frac{1}{2} \times 19.08 \times 0.110^2 \simeq 0.115\,J$$

As the rotation per minute of the wheels located in the shooter changed, the energy transferred to the note changed relatively. To calculate this, the RPM value of the motors, therefore wheels, must be converted to velocity. For this, rotation per minute will be converted to rotation per second and then will be multiplied with the perimeter of the wheels.

$$567.6\ RPM = \frac{567.6}{60} = 9.460\ rotation\ per\ second$$

The diameter of the wheels are 10.0cm. Therefore;

$$radius\ (r)\ of\ the\ wheel = \frac{10.0}{2} = 5.00\ cm$$

Using the perimeter of circle formula;

$$perimeter = 2\Pi r = 2 \times \Pi \times 5.00 \simeq 31.4\ cm$$

$$= \frac{31.4}{100} = 0.314\ m$$

From this, the velocity of the wheels are;

$$9.460 \times 0.314 \simeq 2.97\ ms^{-1}$$

So, the kinetic energy supplied from the shooter calculated from the formula;

$$E_{K\ wheel} = \frac{1}{2}mv^2$$

$$= \frac{1}{2} \times 0.2353 \times 2.97^2 \simeq 1.04\ J$$

The initial kinetic energy (sum of the kinetic energy from the shooter and the spring potential energy) of the note is;

$$E_{K\ initial} = 0.115 + 1.04 = 1.155\ J$$

The initial velocity of the note can be calculated from there;

$$\frac{1}{2} \times 0.2353 \times (v_{initial})^2 = 1.155\ J$$

$$(v_{initial})^2 = \frac{1.155}{\frac{1}{2} \times 0.2353}$$

$$v_{initial} = \sqrt{\frac{1.155}{\frac{1}{2} \times 0.2353}} \simeq 3.133 ms^{-1}$$

With this calculation, all of the values needed to calculate the theoretical maximum height have been determined. So, using the formula, the theoretical maximum height is;

$$v^2 = u^2 + 2as$$

$$0 = 3.133^2 + 2 \times 9.81 \times s$$

$$s = \frac{3.133^2}{2 \times 9.81} \simeq 0.500m$$

$$= 0.500 \times 100 = 50.0cm$$

3.2.1.4 Calculating the Theoretical Height related to the Mass

Sample calculation of the theoretical maximum height for 100g at 1138.0 RPM

For these calculations, speed was the same and the mass of the note was manipulated.

The spring potential energy is not related to the mass therefore the value of it is the same.

$$E_S = \frac{1}{2}kx^2$$

$$E_S = \frac{1}{2} \times 19.08 \times 0.110^2 \simeq 0.115J$$

The rotation per second at the 1138.0 RPM is calculated as;

$$1138.0\,RPM = \frac{1138.0}{60} = 18.97\,rotation\ per\ second$$

The velocity of the wheel at 1138.0 RPM is;

$$18.97 \times 0.314 \simeq 5.96ms^{-1}$$

The original mass of the note was 235.3g, therefore the manipulated mass of the note converted to kilogram is;

$$235.3 + 100 = 335.3g$$

$$\frac{335.3}{1000} = 0.3353kg$$

Using these values, the kinetic energy given by the wheels to the note become;

$$E_{K\,wheel} = \frac{1}{2} \times 0.3353 \times 5.96^2 \simeq 5.96J$$

The initial kinetic energy of the note is;

$$E_{K\ initial} = 0.115 + 5.96 = 6.075\, J$$

So the initial velocity is;

$$\frac{1}{2} \times 0.3353 \times (v_{initial})^2 = 6.075\, J$$

$$(v_{initial})^2 = \frac{6.075}{\frac{1}{2}\times 0.3353}$$

$$v_{initial} = \sqrt{\frac{6.075}{\frac{1}{2}\times 0.3353}} \simeq 6.020 ms^{-1}$$

Using the formula, the theoretical maximum height at 100g increase is;

$$v^2 = u^2 + 2as$$

$$0 = 6.020^2 + 2 \times 9.81 \times s$$

$$s = \frac{6.020^2}{2\times 9.81} \simeq 1.85m$$

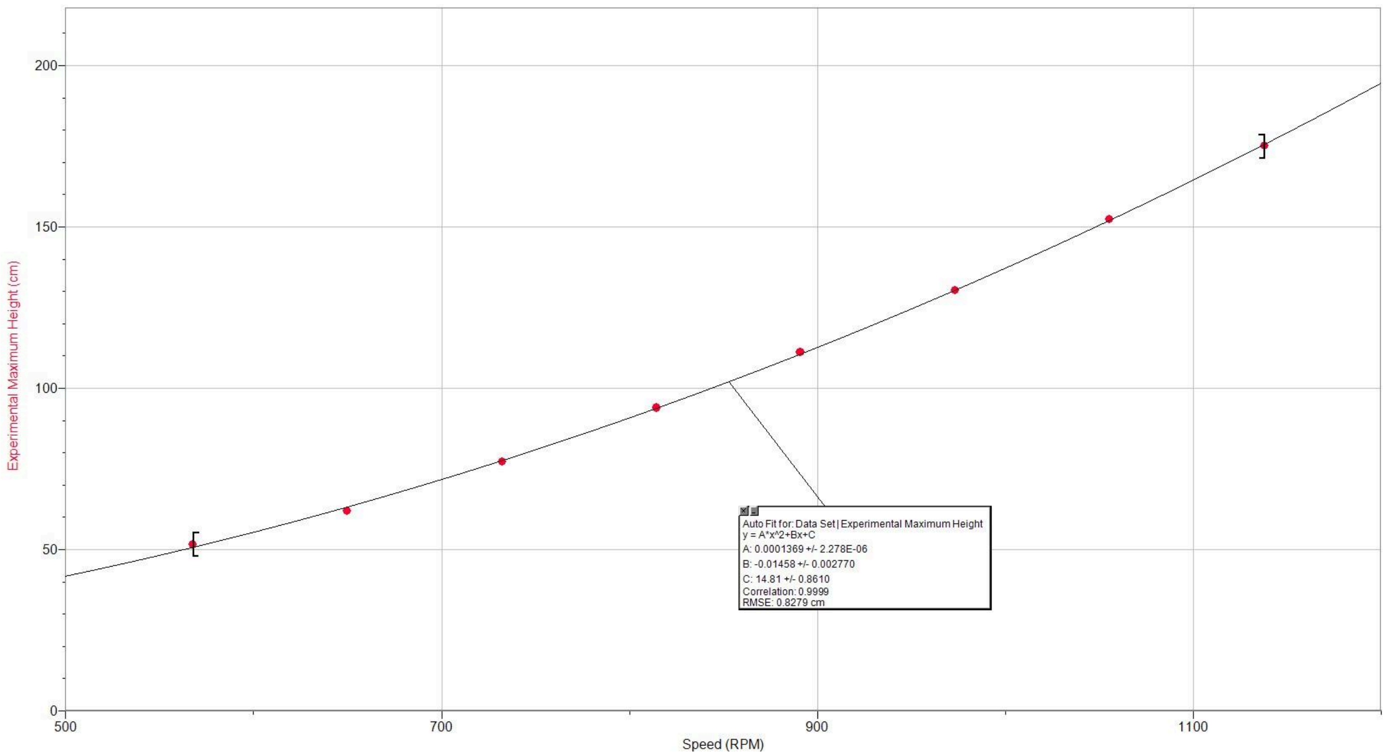
$$= 1.85 \times 100 = 185cm$$

3.2.2 Processed Data Tables

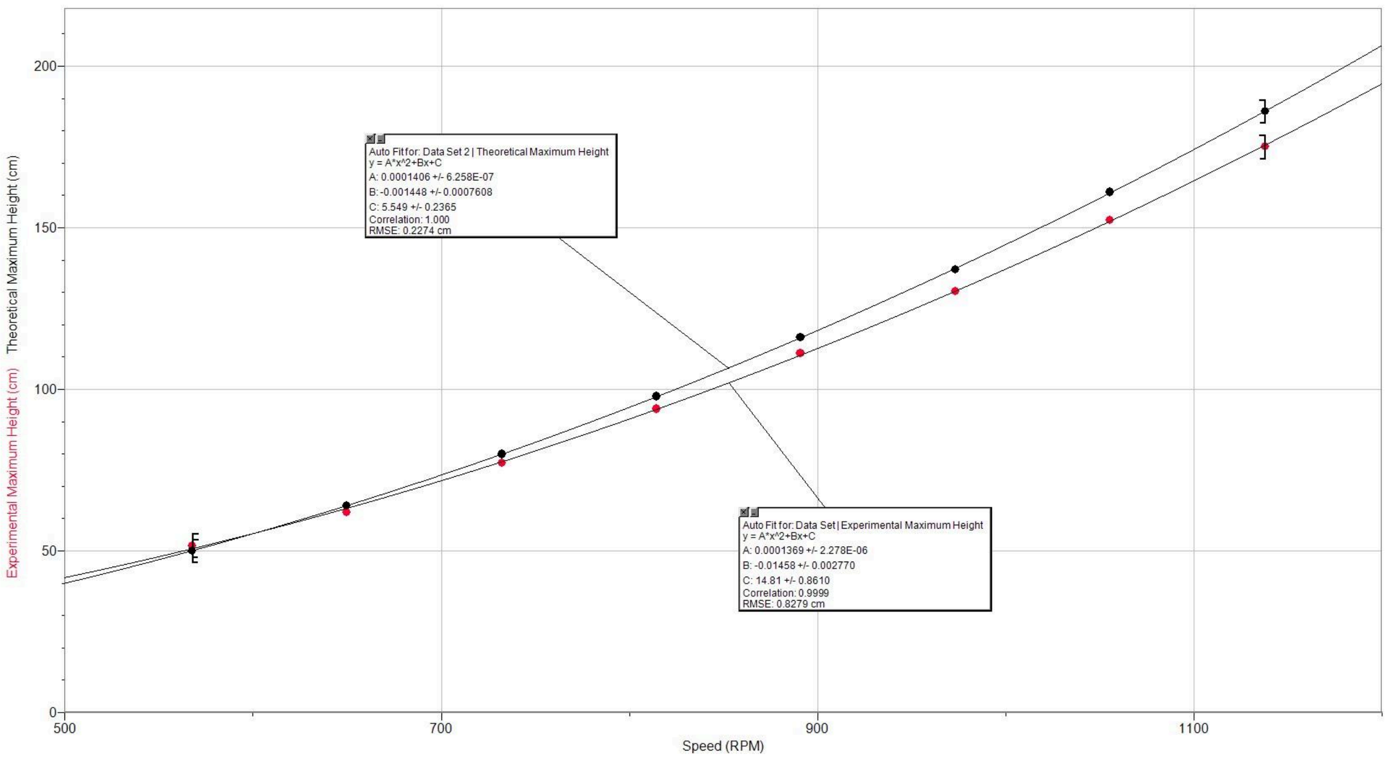
Table 7: Experimental and Theoretical maximum height of different RPMs

RPM	**Experimental Maximum Height (cm) (±0.05)**	**Theoretical Maximum Height (cm)**
567.6	51.6	50.0
649.9	61.9	64.0
732.2	77.1	79.9
814.5	93.9	97.8
891.1	111.2	116.0
973.5	130.4	137.0
1055.7	152.3	161.0
1138.0	175.1	186.0

Graph 1: Experimental value of the maximum height depending on the speed



Graph 2: Experimental and theoretical value of the maximum height depending on the speed

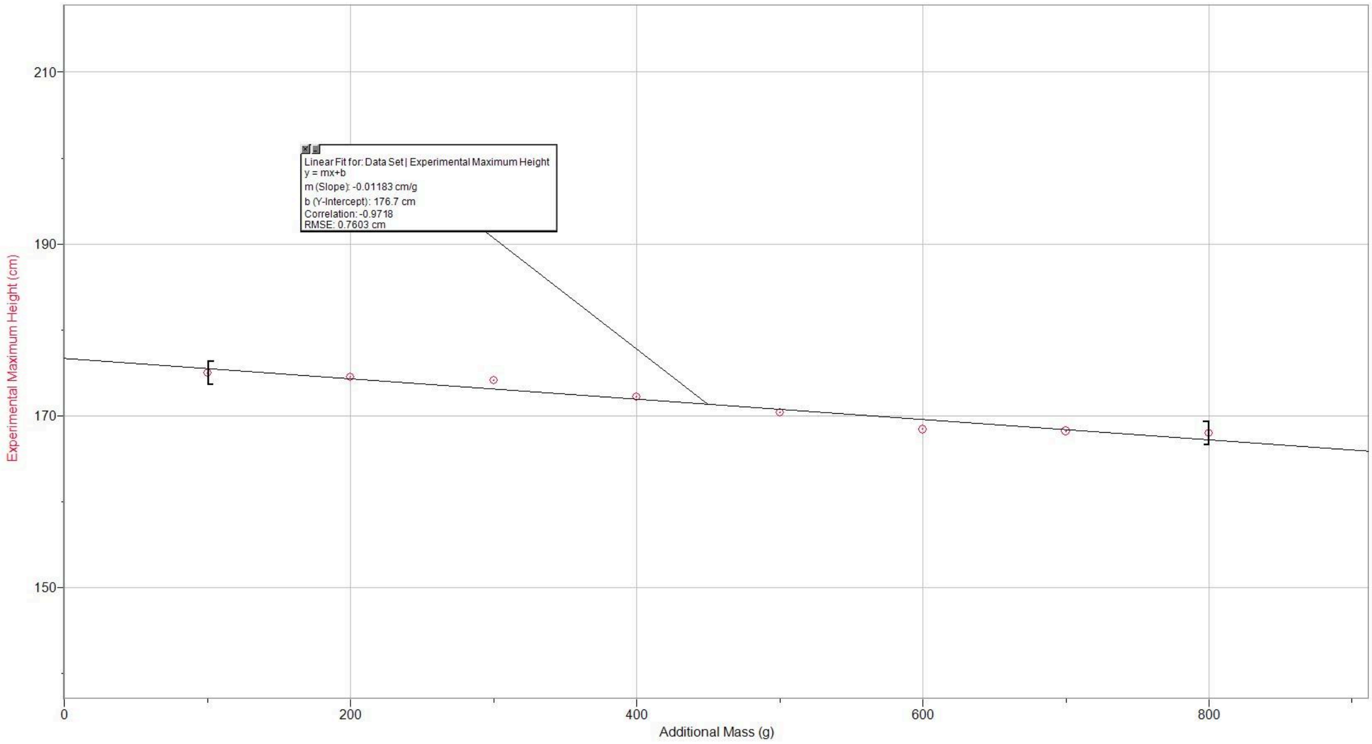


To examine the effect of shooter speed on the maximum height reached by the note, both experimental and theoretical values were determined. **Table 7** and **Graph 2** provide a comparative analysis of these values in relation to the shooter's RPM. This approach is taken due to the principle that variations in speed directly influence the energy transfer. **Table 7** and **Graph 1** proves that as the speed of the wheels increases, the maximum height reached by the note increases relatively. Also, the strong correlation (0.999 for experimental and 1.000 for theoretical) and incremental trend of the best-fit line supports the conclusion that the maximum height reached by the note is proportional to the square of the wheel speed.

Table 8: Experimental and Theoretical maximum height of different masses at 1138.0 RPM

Additional Mass(g)	**Experimental Maximum Height (cm) (±0.05)**	**Theoretical Maximum Height (cm)**
100	175.0	185.0
200	174.5	184.0
300	174.1	183.0
400	172.2	183.0
500	170.4	183.0
600	168.4	182.0
700	168.2	182.0
800	168.0	182.0

Graph 3: Graph of experimental maximum height depending on the additional mass



Graph 4: Graph of experimental and theoretical maximum height depending on the additional mass

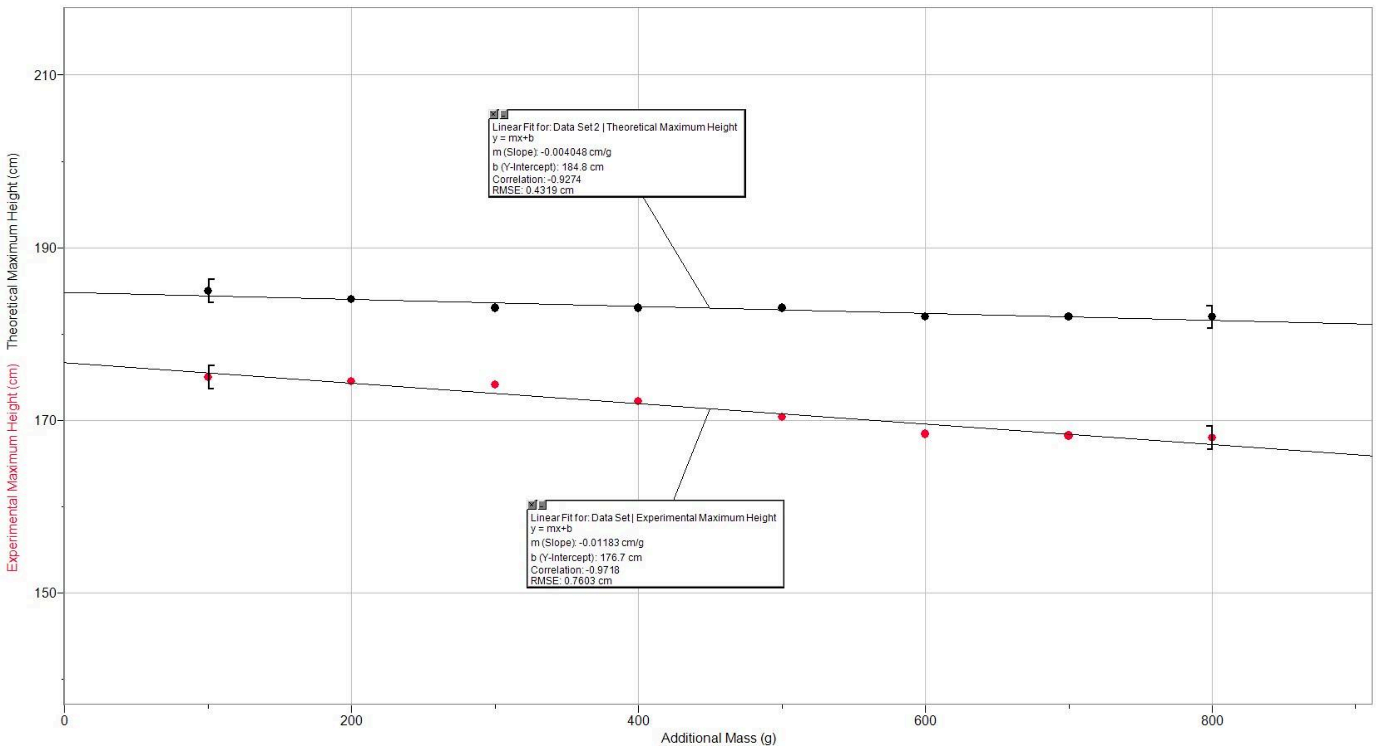
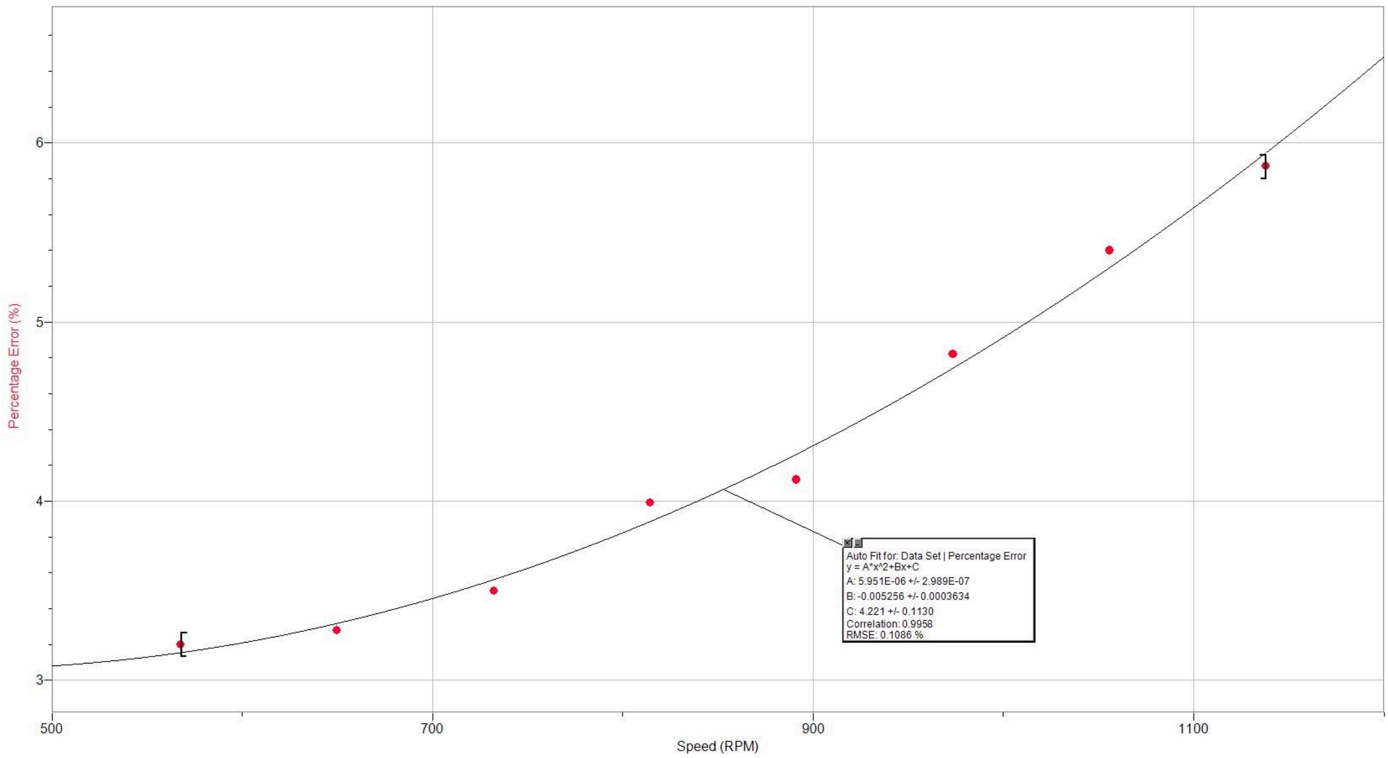


Table 8 and **Graph 4** present a comparison between the experimental and theoretical values of the height related to the mass, showing another effective variable on the maximum height. Unlike RPM, the effect of mass is relatively smaller, resulting in a linear decrease in maximum height. This trend is confirmed by the linear best-fit lines in **Graph 3** and **Graph 4** with strong correlation values of 0.927 and 0.972. These results prove that as the mass of the note increases, the maximum height reached by the note decreases.

Table 9: Difference between results of different RPMs

RPM	**Experimental Maximum Height (cm) (±0.05)**	**Theoretical Maximum Height (cm)**	**Percentage Difference (%)**
567.6	51.6	50.0	3.20
649.9	61.9	64.0	3.28
732.2	77.1	79.9	3.50
814.5	93.9	97.8	3.99
891.1	111.2	116.0	4.12
973.5	130.4	137.0	4.82
1055.7	152.3	161.0	5.40
1138.0	175.1	186.0	5.87

Graph 5: Graph of percentage difference between values depending on RPM



Percentage difference between theoretical and experimental values was found to better investigate the effects of the external factors not considered in theoretical calculations. **Graph 5** illustrates, while the RPM value increases, the percentage error increases with a parabolic trend shown by the line of best fit. This indicates that as the speed increases, external factors have a greater impact on the maximum height reached. In this case, the most effective external factor that is not accounted for in theoretical calculations is air resistance. Parabolic relationship can be explained by the air resistance formula:

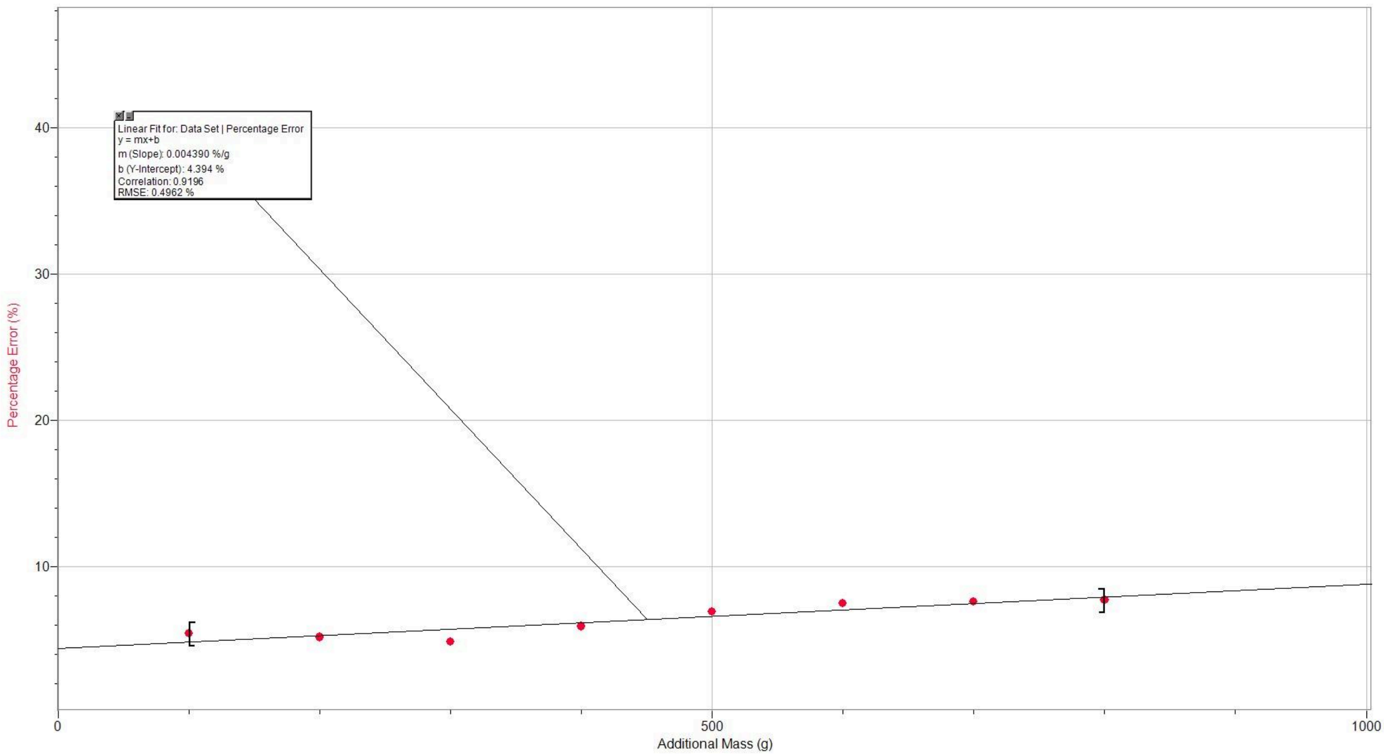
$$F_{air} = kv$$

According to this equation, as velocity increases, the opposing force due to air resistance also increases proportionally and the velocity will decrease faster. This behaviour is observed in **Graph 5** as RPM increases.

Table 10: Error between results of different masses at 1138.0 RPM

Additional Mass(g)	Average Maximum Height (cm) (±0.05)	Theoretical Maximum Height (cm)	Percentage Difference (%)
100	175.0	185.0	5.41
200	174.5	184.0	5.16
300	174.1	183.0	4.86
400	172.2	183.0	5.90
500	170.4	183.0	6.89
600	168.4	182.0	7.47
700	168.2	182.0	7.58
800	168.0	182.0	7.69

Graph 6: Graph of percentage difference between values depending on mass



As the mass values change linearly, according to the energy formulas, percentage error differences are also expected to be in a linear trend. **Graph 6** confirms this expectation as the line of best fit is linear, demonstrating a strong correlation value of 0.920. This result suggests that mass has a more predictable effect on the maximum height reached by the note.

4. CONCLUSION AND EVALUATION

4.1 Conclusion

The results of this experiment indicate a strong relationship between speed of the motors, mass and the maximum height reached by the note as expected. As hypothesis indicated, an increase in motor speed led to a higher maximum height, while an increase in mass resulted in a lower maximum height. The results under the influence of the independent variable RPM support the hypothesis with the maximum height increasing from 51.6cm at the lowest RPM (567.6) to 175.1cm at the highest RPM (1138.0). This increment follows a parabolic trend consistent with theoretical expectations. Also, the hypothesis again proved regarding mass at 1138.0 RPM as the maximum height measured at 100g was 175.0cm, decreasing to 168.0cm at 800g,

The differences between theoretical and experimental results were primarily attributed to the effects of air resistance. In experimental trials, air resistance was an important factor, however, in theoretical calculations air resistance was neglected. Since air resistance exerts a force opposite to the motion, it performs negative work, reducing the kinetic energy available for upward motion. This causes the note to reach a lower maximum height than predicted by theoretical calculations.

To sum up, the general hypothesis was confirmed through both experimental and theoretical results. However, a discrepancy was observed between these results. This is caused by external factors, especially by the air resistance. Additional factors such as wind, temperature, and atmospheric pressure may have also contributed to variations in results. Beyond validating the hypothesis, The research provides an overview to the performance of the shooter which will be used in the competitions this year, and enables us to gain insight into real-life applications of physics.

4.2 Evaluation

4.2.1 Strength of the Research

- ➢ The experimental setup is designed to establish precise and consistent conditions during the experiment for accurate data collection. Also, it is easier to intervene in case of any problem on the mechanism during the experiment.
- ➢ Performing 5 trials for each value of RPM and mass improved reliability by reducing the chance of random error, which can affect results significantly.
- ➢ Controlled variables increase the stability of the system and provide precise and accurate data collection through the research.
- ➢ Use of uncertainty in experimental values further strengthened the experiment by being aware of potential measurement errors.

4.2.2 Limitations of the Research

- ➢ The most important limitation of the research is the air resistance. Since air resistance is neglected during the theoretical calculations, it affects the accuracy when compared with the real world situation.

- The acceptance of acceleration of the freefall as $9.81ms^{-1}$ introduced potential inaccuracies during the theoretical calculations.
- The camera setup can cause slight measurement errors. Although the camera was placed carefully, some angle differences could contribute to measurement inaccuracies.
- Even though the fixing process was done carefully, any warpage that may have occurred in the meters fixed to the wall may have caused minor errors in the results.
- Use of significant figures may have caused minor changes in the calculation results.
- The difference between the experimental and theoretical results may be due to the momentary excessive increase in the load on the motor when contact is established between the shooter and the note. This may lead to decrease in motor speed and cause the note being thrown at a speed lower than the desired speed.
- As a result of the contact that may have been established between the note and the plexiglass during the vertical projection, a friction force may have been created and affected the initial speed of the note.

4.2.3 Possible Improvements

- To reduce instantaneous load effects, a motor with higher torque and power values can be used.
- By repeating the experiment at more RPM and weight values, the behavior of the note during vertical projection can be better examined.
- In addition to the vertical projection, the angled projection may have been tried to examine the behavior of the note in more detail.
- When recording the results, a wider angle camera can be used to minimize any changes in angle.

5. BIBLIOGRAPHY

(1) FIRST, “FIRST Robotics Competition Game & Season”, 2024, retrieved from https://www.firstinspires.org/

(2) Allum, John “Physics Study and Revision Guide”, 2017, retrieved from https://ebooks.papacambridge.com/viewer/ib/group-4-sciencesphysics-hodder-physics-study-and-revision-guide-john-allum-hodder-2017-pdf

(3) Allum, John “Physics Study and Revision Guide”, page 16, 2017, retrieved from https://ebooks.papacambridge.com/viewer/ib/group-4-sciencesphysics-hodder-physics-study-and-revision-guide-john-allum-hodder-2017-pdf

(4) Allum, John “Physics Study and Revision Guide”, page 17, 2017, retrieved from https://ebooks.papacambridge.com/viewer/ib/group-4-sciencesphysics-hodder-physics-study-and-revision-guide-john-allum-hodder-2017-pdf

(5) IB, “Physics data booklet”, 2025

(6) Khan Academy, “Air and Fluid Resistance”, retrieved from https://www.khanacademy.org/computing/computer-programming/programming-natural-simulations/programming-forces/a/air-and-fluid-resistance

(7) Allum, John “Physics Study and Revision Guide”, page 17, 2017, retrieved from https://ebooks.papacambridge.com/viewer/ib/group-4-sciencesphysics-hodder-physics-study-and-revision-guide-john-allum-hodder-2017-pdf

(8) IB, “Physics data booklet”, 2025

(9) Bağcı, Fulya “Conversation of Energy”, Ankara Universitesi, 2015, retrived from https://acikders.ankara.edu.tr/

(10) Encyclopaedia Britannica, “kinetic energy”, 2025, retrieved from https://www.britannica.com/science/kinetic-energy

(11) IB, “Physics data booklet”, 2025

(12) Encyclopaedia Britannica, “potential energy”, 2025, retrieved from https://www.britannica.com/science/potential-energy

(13) IB, “Physics data booklet”, 2025

(14) Science Facts, “Gravitational Potential Energy”, 2024, retrieved from https://www.sciencefacts.net/gravitational-potential-energy.html

(15) Physics and Radio-electronics, “Elastic Potential Energy”, 2015, retrieved from https://www.physics-and-radio-electronics.com/physics/energy/potential-energy/elastic-energy.html

(16) TNT Robotics, Fusion 360, 2024, retrieved from https://www.autodesk.com/tr/products/fusion-360/

(17) First Robotics Competition, “Introduction to FRC Robot Wiring”, 2025, retrieved from https://docs.wpilib.org/tr/stable/docs/zero-to-robot/step-1/intro-to-frc-robot-wiring.html

(18) Goodnotes, 2025, retrieved from https://www.goodnotes.com/