Physics - ARCHERY

Research Question: How Does Projectile and Bow's String Angle Affect an Arrow's Flight

Word Count: 3458

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1. Introduction:

Archery has been used by humans throughout our existence. The earliest evidence of archery dates back around 20,000 BC and it is possible that it dates back even further. It was at first designed to be used while hunting, and later gained importance in combats and wars.[1] Archery consists of bow and arrow. A bow is a curved piece of wood which is connected by a string from its both ends and arrow is a straight piece of thin stick which has a sharp tip and a cross-like feathers or small wings at its end. From their definition, it is easy to understand that creating a simple bow and an arrow does not take much engineering and humans were able to invent it easily in the earlier times.

Bow is used to launch the arrow by pulling the string and using the tension to our advantage. Arrow has little weight and a small frontal surface area; therefore, it can move a great distance without losing much momentum. Although the idea of shooting an arrow is easy, it takes a professional to shoot an arrow with much accuracy and precision.

Today, archery lost its importance in combat and war with the discovery of gun powder and invention of firearms. Bow and arrow are used mostly in sports or in hunting situations as it is still more silent than firearms and does not scare away animals. There have been many different types of bows and arrows throughout history. Physics lie in the hearth of these changes as it was used to find a bow or arrow which is better or more suitable for different situations.

[1] https://www.worldarchery.sport/sport/history#:~:text=The%20history%20of%20the%20bow,bows%20and%20arrows%20even%20earlier.

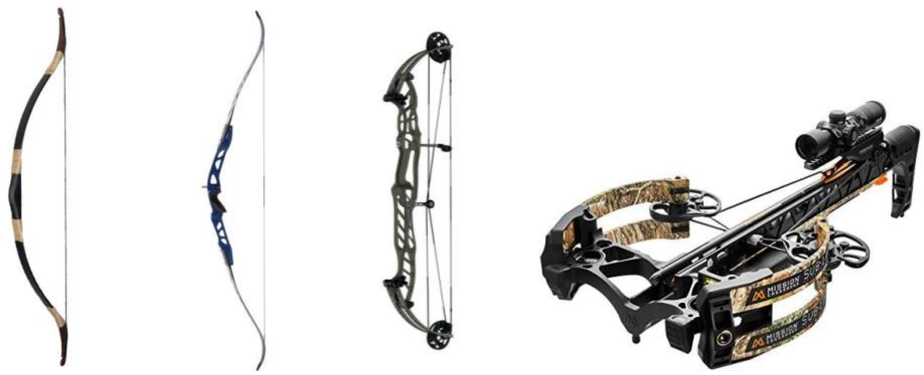


Figure 1, 2, 3 and 4: Traditional Bow, Modern Bow, Compound Bow and Crossbow in order.

It is important to investigate how different arrow techniques are used in different ways in life. It is one of the key points in humankind's understanding of mechanics, and archery plays an important role in projectile motion. An arrow can be launched in different forces and angles depending on the purpose. Also, time, distance and the way an arrow lands are important and should be investigated for those purposes.

This project aims to investigate the displacement of an arrow can move with the way it has been shot. There are two independent variables with which the questions below will be answered.

1. How does the displacement of the arrow change when the arrow's projectile angle changes?
2. How does the displacement of the arrow change when the string's angle change

To answer these questions, an experiment will be conducted using bow and arrow. The bow used in this experiment is not a professional bow, however it is still powerful. Also, for safety reasons, an arrow with suction cup tip is going to be used. The data obtained from this experiment will later be used to determine an optimal way of shooting the arrow for different purposes and understand the relationship between independent variable and displacement better. The results will later be discussed.

Overall, this project aims to put into use what we have learned in our high-level physics course projectile motion lesson. The results derived from this study will be graphed and analyzed and provide insight into one of the primary examples of projectile motion. The findings can be used to improve the aerodynamics of projectiles and how to send them more accurately and precisely.

2. Background Information

2.1 Projectile Motion

First of all, a projectile is any object which is thrown/send into space upon which the only acting force on the object is gravity. Projectile motion occurs when a projectile is thrown near the earth's surface and moves along a curved path under constant acceleration. This acceleration is the result of gravity therefore it is towards the center of the earth, assuming that the projectile stays near the earth's surface. This motion is called projectile motion.

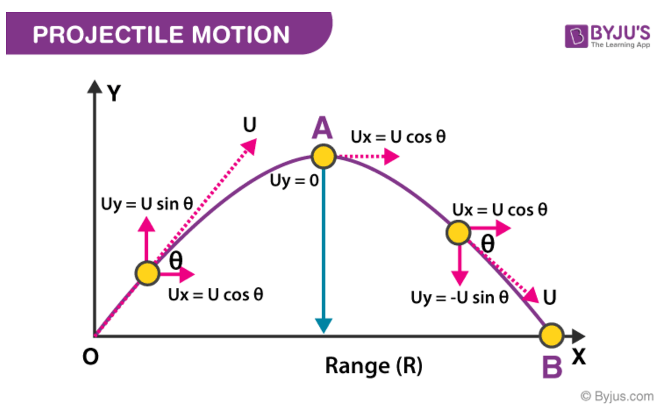


Figure 5: Projectile Motion[2]

[2] https://byjus.com/physics/projectile-motion/

$$\mathcal{V} = \mathcal{U} - gt$$

$$S = \mathcal{U}t - \frac{1}{2}gt^2$$

$$\mathcal{V}^2 = \mathcal{U}^2 - 2gS$$

$\mathcal{U}$ = Initial Velocity g = Gravitational Acceleration

$\mathcal{V}$ = Final Velocity S = Displacement t = Time

The total time a projectile flies depends on the vertical velocity / force component of it. For that reason, we can find the total time of flight as:

An arrow will be exposed to drag force. Drag is the aerodynamic force which opposes an object's motion through the air. If the solid body, in this case arrow, is not in contact with the object and there is no motion between the object and the fluid, then there is no drag.[3] There are mainly three types of drag:

i) Skin friction between the fluid and the object. As it is an interaction between the object and the fluid, the magnitude of the skin friction mainly depends on the properties of the object and the fluid. For the gas, the magnitude depends on the viscosity of the air, which is expressed as Reynolds number.

ii) Form drag is the type of drag that depends on the shape of the object. As air flows around the object, the local velocity and pressure are changed. Form drag depends directly on the

[3] "*What is Drag?*" NASA, T.Benson

frontal area of the object that is perpendicular to the air's flow direction and the size of the object's body

iii) There is also ram and wave drag. However, it is mostly related to aircrafts and does not have a major impact for this experiment.

Form drag is the one which is related closely to this experiment out of these three types of drag. The drag force equation is:

$$F_D = \frac{1}{2} \times C_d \rho \mathcal{V}^2 A$$

$$F_D \rightarrow (Drag\ Force), C_d \rightarrow (Drag\ Coefficient), \mathcal{V} \rightarrow Velocity, A \rightarrow Area$$

The arrowhead of the arrows used in this experiment are suction cup tips, so it can be assumed that they have a shape and drag coefficient similar to the object below:

Figure 6: Drag coefficient of a prism with the given flow direction[4]*, Figure 7: The Arrowhead*

The suction cup tip's surface area is:

$$(2.5 \times 10^{-2})^{2} \times \pi = 19.6 \times 10^{-4} m^2$$

The Arrow's highest initial velocity was determined to be 36.3 m/s. Also, pure and dry air has a density of 1.293$kg\ m^{-3}$ at a pressure of 101.325kPa and a temperature of 273K[5]. The

[4] https://www.grc.nasa.gov/www/k-12/rocket/shaped.html
[5] https://www.earthdata.nasa.gov/topics/atmosphere/atmospheric-pressure/air-mass-density#:~:text=Pure%2C%20dry%20air%20has%20a,of%20at%20least%2050%20km.

environment which the experiment was conducted in has a similar temperature and pressure. With that information we can find the drag force as below:

$$F_D = \frac{1}{2} \times C_d \rho \mathcal{V}^2 A = \frac{1}{2} \times 1.14 \times 1.293 \times 36.3^2 \times 19.6 \times 10^{-4} = 1.90N$$

Bows should be able to launch an arrow to a great extent in order to fulfill its function in combat, hunting etc. A study which has been conducted at Harvard University shows that the force constant of the bow is about $500N/m$. Considering that a regular bow is drawn about 50 to 70 centimeters depending on the person, drag force has little impact on the overall motion of the arrow. Therefore, in this experiment, it is assumed that the drag force is negligible.

This assumption enables the use of equation of motion for this experiment. If a projectile is thrown from ground level and there is no change in the ground level, total vertical displacement of the projectile will be zero. Also, the time an object takes to reach maximum altitude and the time to fall back from the maximum altitude to ground will be equal if the drag force is negligible. For that reason, in *Figure 5,* the time it takes to move from O to A and A to B is the same. However, an arrow is thrown from an initial height which is different than the ground level as a person has a height, so this information is not suitable for this experiment. Considering that the vertical component of the initial velocity is $\mathcal{U}_y = \mathcal{U} \sin\theta$ and the fact the acceleration for this projectile is g (Gravitational Acceleration), the time an arrow takes to reach maximum altitude is given by:

$$Reaching\ Maximum\ altitude\ (t) = \frac{\mathcal{U} \sin\theta}{g}$$

The arrow is thrown from an initial height of 150cm. The projectile angles (θ) for this experiment are $0°, 15°, 30°$ and $45°$. Also, the string's angles (σ) at drawn positions are $75°$, $70°$ and $65°$. A bow's string is inelastic, and the elastic potential energy comes from the bow itself. Before starting the experiment, the velocities of the arrows which are going to be shot with drawn positions $35°, 40°, 45°$ are measured. Depending on the bow angle ($75°, 65°$ $60°$), they are 26.2, 32.1 and 36.3 m/s respectively. Higher string angle values mean that the bow is drawn less. Taking these values into consideration, the values which should be found in the experiments are:

(Meters are rounded in respect to 1dp, seconds are rounded in respect to 3sf.)

For Projectile Angle (θ) = 0°, the horizontal displacement of the arrow is;

$$S_y = \mathcal{U}_y t + \frac{1}{2} g t^2 \qquad 1.5 = 0t + \frac{1}{2} 9.81 t^2$$

$$t = 0.553s$$

$$S_{x1} = \mathcal{U}_{x1} t = 36.3 \times 0.553 = 20.1m$$

$$S_{x2} = \mathcal{U}_{x2} t = 32.1 \times 0.553 = 17.8m$$

$$S_{x3} = \mathcal{U}_{x3} t = 26.2 \times 0.553 = 14.5m$$

For Projectile Angle (θ) = 15°, the horizontal displacement of the arrow is;

$\sigma = 65° \rightarrow$

$$\mathcal{V}_{y1} = \mathcal{U}_1 \sin 15 - gt \qquad 0 = 36.3 \sin 15 - 9.81t \qquad t = 0.958$$

$$S_{y1} = \frac{1}{2} g t^2 = \frac{1}{2} \times 9.81 \times 0.958^2 \qquad S_{y1} = 4.5m$$

$$S_{total1} = 4.5 + 1.5 = 6.0m \qquad 6.0 = \frac{1}{2} 9.81 t^2 \quad t = 1.22s \quad \therefore t_{total} = 2.18s$$

$$S_{x1} = \mathcal{U}_{x1}t = 36.3\cos 15 \times 2.18 = 76.5m$$

$\sigma = 70° \rightarrow$

$$t = \frac{\mathcal{U}\sin\theta}{g} = \frac{32.1\sin 15}{9.81} = 0.846$$

$$S_{y2} = \frac{1}{2}gt^2 = \frac{1}{2} \times 9.81 \times 0.846^2 \qquad S_{y2} = 3.5m$$

$$S_{total2} = 3.52 + 1.5 = 5.0m \qquad 5.0 = \frac{1}{2}9.81t^2 \qquad t = 1.01s \quad \therefore t_{total} = 1.86s$$

$$S_{x2} = \mathcal{U}_{x2}t = 32.1\cos 15 \times 1.86 = 57.6m$$

$\sigma = 75° \rightarrow$

$$t = \frac{\mathcal{U}\sin\theta}{g} = \frac{26.2\sin 15}{9.81} = 0.691$$

$$S_{y3} = \frac{1}{2}gt^2 = \frac{1}{2} \times 9.81 \times 0.691^2 \qquad S_{y3} = 2.3m$$

$$S_{total3} = 2.3 + 1.5 = 3.8m \qquad 3.8 = \frac{1}{2}9.81t^2 \qquad t = 0.880s \quad \therefore t_{total} = 1.57s$$

$$S_{x3} = \mathcal{U}_{x3}t = 26.2\cos 15 \times 1.57 = 39.8m$$

For Projectile Angle (θ) = 30°, the horizontal displacement of the arrow is;

$\sigma = 65° \rightarrow$

$$t = \frac{\mathcal{U}\sin\theta}{g} = \frac{36.3\sin 30}{9.81} = 1.85$$

$$S_{y1} = \frac{1}{2}gt^2 = \frac{1}{2} \times 9.81 \times 1.85^2 \qquad S_{y1} = 16.8m$$

$$S_{total1} = 16.8 + 1.5 = 18.3m \qquad 18.3 = \frac{1}{2}9.81t^2 \qquad t = 1.93s \quad \therefore t_{total} = 3.78s$$

$$S_{x1} = \mathcal{U}_{x1}t = 36.3\cos 30 \times 3.78 = 118.9m$$

$\sigma = 70° \rightarrow$

$$t = \frac{\mathcal{U}\sin\theta}{g} = \frac{32.1\sin 30}{9.81} = 1.64$$

$$S_{y2} = \frac{1}{2}gt^2 = \frac{1}{2} \times 9.81 \times 1.64^2 \qquad S_{y2} = 13.1m$$

$$S_{total2} = 13.1 + 1.5 = 14.6m \qquad 14.6 = \frac{1}{2}9.81t^2 \qquad t = 1.73s \quad \therefore t_{total} = 3.36s$$

$$S_{x2} = \mathcal{U}_{x2}t = 32.1\cos 30 \times 3.36 = 93.4m$$

$\sigma = 75° \rightarrow$

$$t = \frac{\mathcal{U}\sin\theta}{g} = \frac{26.2\sin 30}{9.81} = 1.34$$

$$S_{y3} = \frac{1}{2}gt^2 = \frac{1}{2} \times 9.81 \times 1.34^2 \qquad S_{y3} = 8.8m$$

$$S_{total2} = 8.8 + 1.5 = 10.3m \qquad 10.3 = \frac{1}{2}9.81t^2 \qquad t = 1.45s \quad \therefore t_{total} = 2.78s$$

$$S_{x3} = \mathcal{U}_{x3}t = 26.2\cos 30 \times 2.78 = 63.1m$$

For Projectile Angle (θ) = 45°, the horizontal displacement of the arrow is;

$\sigma = 65° \rightarrow$

$$t = \frac{\mathcal{U}\sin\theta}{g} = \frac{36.3\sin 45}{9.81} = 2.62$$

$$S_{y1} = \frac{1}{2}gt^2 = \frac{1}{2}\times 9.81\times 2.62^2 \qquad S_{y1} = 33.6m$$

$$S_{total1} = 33.6 + 1.5 = 35.1m \qquad 35.1 = \frac{1}{2}9.81t^2 \qquad t = 2.67s \quad \therefore t_{total} = 5.29s$$

$$S_{x1} = \mathcal{U}_{x1}t = 36.3\cos 45 \times 5.29 = 135.8m$$

$\sigma = 70° \rightarrow$

$$t = \frac{\mathcal{U}\sin\theta}{g} = \frac{32.1\sin 45}{9.81} = 2.31$$

$$S_{y2} = \frac{1}{2}gt^2 = \frac{1}{2}\times 9.81\times 2.31^2 \qquad S_{y2} = 26.3m$$

$$S_{total2} = 26.3 + 1.5 = 27.8m \qquad 27.8 = \frac{1}{2}9.81t^2 \qquad t = 2.37s \quad \therefore t_{total} = 4.69s$$

$$S_{x2} = \mathcal{U}_{x2}t = 32.1\cos 45 \times 4.69 = 106.5m$$

$\sigma = 75° \rightarrow$

$$t = \frac{\mathcal{U}\sin\theta}{g} = \frac{26.2\sin 45}{9.81} = 1.89$$

$$S_{y3} = \frac{1}{2}gt^2 = \frac{1}{2} \times 9.81 \times 1.89^2 \qquad S_{y3} = 17.5m$$

$$S_{total3} = 17.5 + 1.5 = 19.0m \qquad 19.0 = \frac{1}{2}9.81t^2 \qquad t = 1.97s \quad \therefore t_{total} = 3.86s$$

$$S_{x3} = \mathcal{U}_{x3}t = 26.2\cos 45 \times 3.86 = 71.5m$$

Therefore, the expected values for the horizontal displacement are:

Chart 1: Expected values of m with respect to θ and σ

Horizontal Displacement (m) (3sf)	$\sigma = 65°$	$\sigma = 70°$	$\sigma = 75°$
θ = 0°	20.1	17.8	14.5
θ = 15°	76.5	57.6	39.8
θ = 30°	118.9	93.4	63.1
θ = 45°	135.8	106.5	71.5

When projectile angle increases from 0° to 45°, horizontal displacement also increases. As the angle increases further form 45°, the total flight time increases. However, horizontal velocity, ($\mathcal{U}\cos\theta$) decreases as cosine value starts to decrease even further and horizontal displacement decreases.

3. Hypothesis:

The horizontal displacement of the arrow increases as projectile angle increases from 0° to 45°. As bow's string angle increases, the string will be pulled less, therefore the total force acting on the arrow decreases and the horizontal displacement also decreases.

4. Materials:

- Tape measure ($\pm 0.05cm$)
- Protractor ($\pm 0.5°$)
- 20xRock
- 10×Rope (1.0m $\pm 0.05cm$)
- Bow
- Arrow
- Photogate Sensor
- Tripod
- Camera

5. Variables:

Independent Variable:	Projectile angle (θ)
	Bow String Angle (σ)
Dependent Variable:	Horizontal Displacement (m)
	Time (s)

Controlled Variable	**How It is Controlled**	**Why It is Controlled**
Temperature	By making the experiment at the same place which has a constant temperature at all times	Drag force was assumed to be negligible, however, if the temperature changes, air density will also change and result in an additional uncertainty
Air Pressure	By making the experiment at the same place which has a constant pressure at all times	Drag force was assumed to be negligible in this experiment. However, change in air pressure will affect the air density, which will result in an uncertainty
Bow	By using the same bow	Different bows can have different elastic potentials and alter with arrow's velocity
Arrow	By using the same arrow	Different arrows will fly differently and change the effect of drag force. This will alter with the reliability of the experiment
Archer (Person who shoots the arrow)	By not changing the person and doing the experiment when they are not tired	Archery is a sport, and the technique a person uses can change how well an arrow flies. Therefore, the person who shoots the arrow will remain the same and not tired in order to maximize accuracy
Gravitational Acceleration	By making the experiment at the same place (no change in altitude)	Gravitational acceleration changes as the altitude increases or decreases. However, small changes in height of the arrow is insignificant for the reliability of the experiment

6. Assumptions:

- It is assumed that the gravitational acceleration does not change while conducting the experiment. As an object moves further away from the earth's center, gravitational force that acts on it decreases. However, very small differences like the ones we see in this experiment does not result in a significant change. For that reason, this assumption is made.
- Drag force acting on the arrow is negligible. Drag force is considerably smaller than the force that the bow applies. The arrow used in this experiment has a very small frontal surface area. Also, a normal arrow's frontal surface area is considerably smaller than the arrow used in this experiment. For these reasons, it is reasonable to assume that the drag force is negligible.
- Again, related to drag force, the air is assumed to be static. As my body moves during the experiment, or additional air flows occur, the air will be dynamic. When air is not static, it can affect the data gathered from this experiment. However, arrow has a very small surface area and cannot easily be affected by air flows. As it is unlikely to conduct this experiment in a place which has a static air, it is assumed that it does not alter with the result.
- It is assumed that the bow and the arrow does not deform during the experiment. If they do, the initial speed of the arrow can change, as well as the drag force acting on the arrow.

7. Procedure:

1. Measuring the initial velocity of the arrow with the help of photogate sensor and protractor for each bow string angle (in this case, 36.3 / 32.1 / 26.2 $m/s \pm 0.1 m/s$)
2. Fixing ropes to the ground with rocks by intervals of 1 meter in order to place markers.
3. By using the data on *Chart 1,* planning the shooting point. The expected horizontal displacement differs by more than 100 meters. Therefore, it is better to change the shooting

point rather than taping hundreds of ropes. Using the tape measure, I marked every 5 meters by a small tape and kept on going back until I was 140 meters away from the furthest mark.

4. Placing the tripod and the camera pointing towards the markers. These arrows will most likely bounce off the initial landing site, so it is better to use a camera and pinpoint the exact landing spot to minimize any uncertainties. With the help of this, it is clearly visible whether the arrow landed on the first half of the one meter or the second half. (Markers had an interval of 1 meter.) So, the uncertainty will be $\pm 0.25m$ rather than $\pm 0.5m$.
5. Shooting the arrow with the given projectile angles and bow string angles.
6. Gathering the data from the video and writing a chart.
7. Discussing the reliability of the experiment and the relationship between the independent and dependent variables.

Figure 8: Shooting the Arrow

Figure 9 and 10: The Flight and The Landing of The Arrow

8. Raw Data:

First, the projectile angle θ = 0° was tested. The results obtained were close to what was projected.

Chart 2: First Results with Projectile angle θ = 0°

Bow String Angle °	First Trial ($\pm 0.25m$)	Second Trial ($\pm 0.25m$)	Third Trial ($\pm 0.25m$)
$\sigma = 65°$	19.5	20.0	19.5
$\sigma = 70°$	17.5	17.5	17.0
$\sigma = 75°$	14.5	14.0	14.0

Secondly, the projectile angle θ = 15° was tested. These results were also close to what was expected, however, not as close as θ = 0°.

Chart 3: Third Results with Projectile angle θ = 15°

Bow String Angle °	First Trial ($\pm 0.25m$)	Second Trial ($\pm 0.25m$)	Third Trial ($\pm 0.25m$)
$\sigma\ = 65°$	75.5	76.0	75.0
$\sigma\ = 70°$	57.5	56.0	56.5
$\sigma\ = 75°$	40.0	39.5	39.5

Thirdly, the projectile angle θ = $30°$ was tested. It was observed that as the projectile angle increases, the data obtained from the experiment becomes gradually smaller than the expected value.

Chart 4: Third Results with Projectile angle θ = 30°

Bow String Angle °	First Trial ($\pm 0.25m$)	Second Trial ($\pm 0.25m$)	Third Trial ($\pm 0.25m$)
$\sigma\ = 65°$	118.0	118.5	117.5
$\sigma\ = 70°$	93.0	92.0	92.0
$\sigma\ = 75°$	62.0	62.0	62.0

Lastly, the projectile angle θ = $45°$ was tested. The biggest difference to the expected value was observed with this projectile angle. However, if the differences were considered as a percentage to the horizontal displacement, overall effect of drag force does not alter with the experiment and gives an accurate relation between projectile and bow angles.

Chart 5: Last Results with Projectile angle θ = 45°

Bow String Angle °	First Trial ($\pm 0.25m$)	Second Trial ($\pm 0.25m$)	Third Trial ($\pm 0.25m$)
$\sigma = 65°$	133.0	132.5	132.5
$\sigma = 70°$	104.5	104.0	104.5
$\sigma = 75°$	70.5	70.0	69.5

9. Processed Data:

Average values obtained from the experiment is given below:

Chart 6: Average Horizontal Displacement Obtained from the Experiment

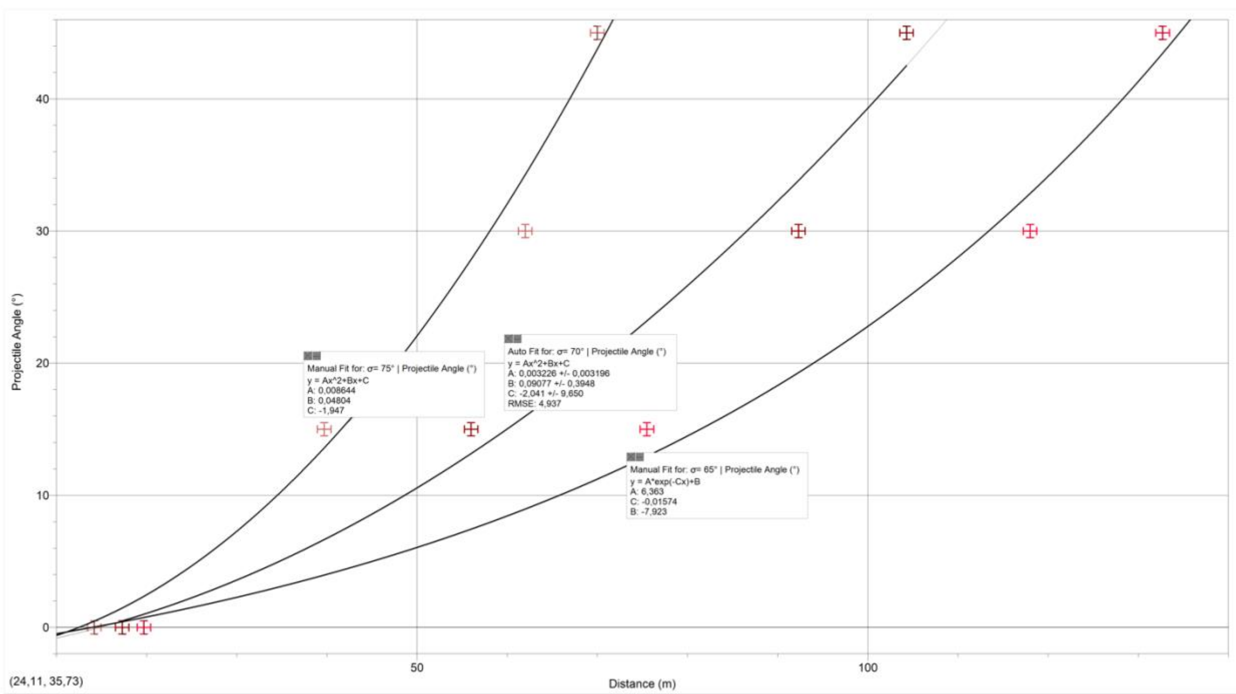
Horizontal Displacement ($\pm \mathbf{0.75m}$) (3sf)	$\boldsymbol{\sigma = 65°}$	$\boldsymbol{\sigma = 70°}$	$\boldsymbol{\sigma = 75°}$
θ = 0°	19.7	17.3	14.2
θ = 15°	75.5	56.0	39.7
θ = 30°	118.0	92.3	62.0
θ = 45°	132.7	104.3	70.0

Considering the expected results in *Chart 2*, the uncertainty is fairly low, and it also proves that drag force acting on the arrow is negligible.

Chart 6: Comparison of Expected and Experimental Data

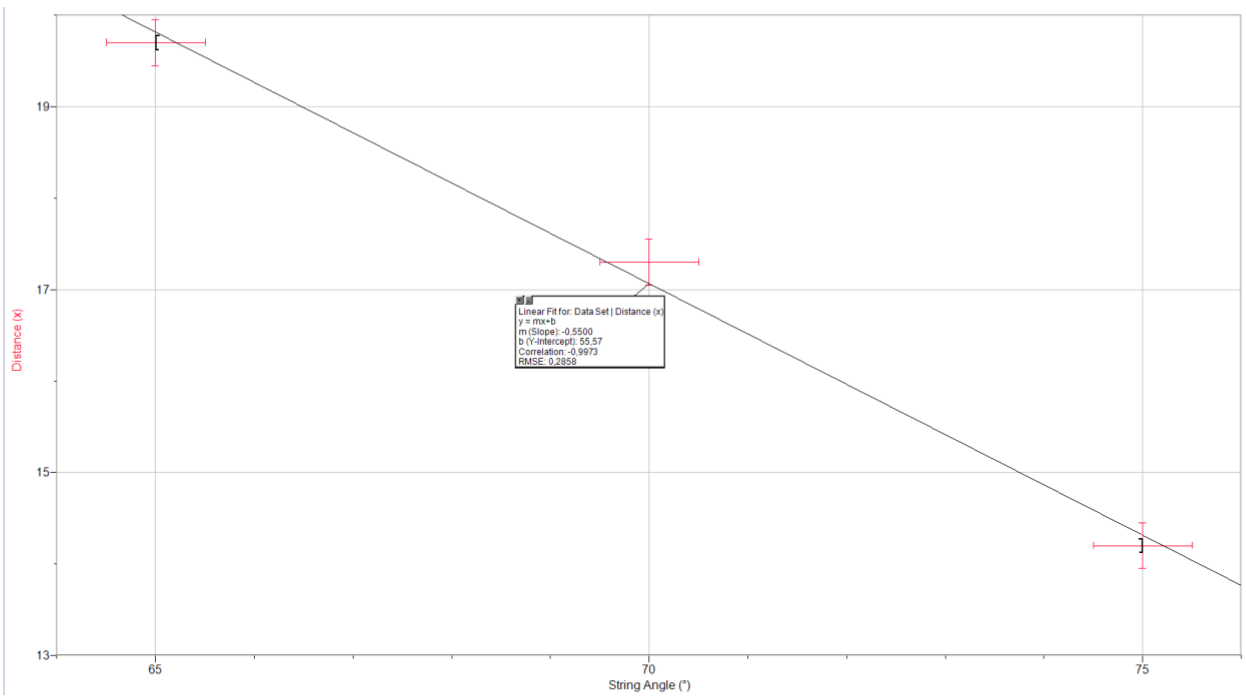
Experiment / Expected ($\pm 0.75m$) (3sf)	$\sigma = 65°$	$\sigma = 70°$	$\sigma = 75°$
$\theta = 0°$	19.7 / 20.1	17.3 / 17.8	14.2 / 14.5
$\theta = 15°$	75.5 / 76.5	56.0 / 57.6	39.7 / 39.8
$\theta = 30°$	118.0 / 118.9	92.3 / 93.4	62.0 / 63.1
$\theta = 45°$	132.7 / 135.8	104.3 / 106.5	70.0 / 71.5

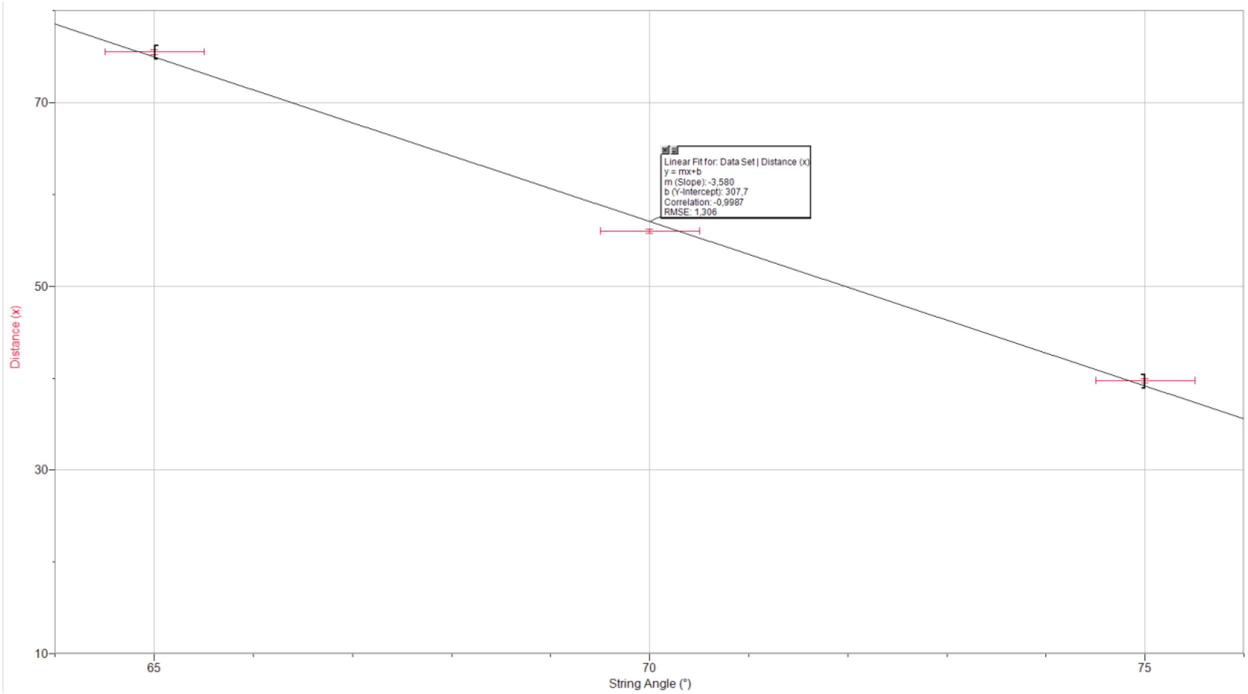
Graph 1: Processed Data Graph (Projectile Angle / Horizontal Displacement)

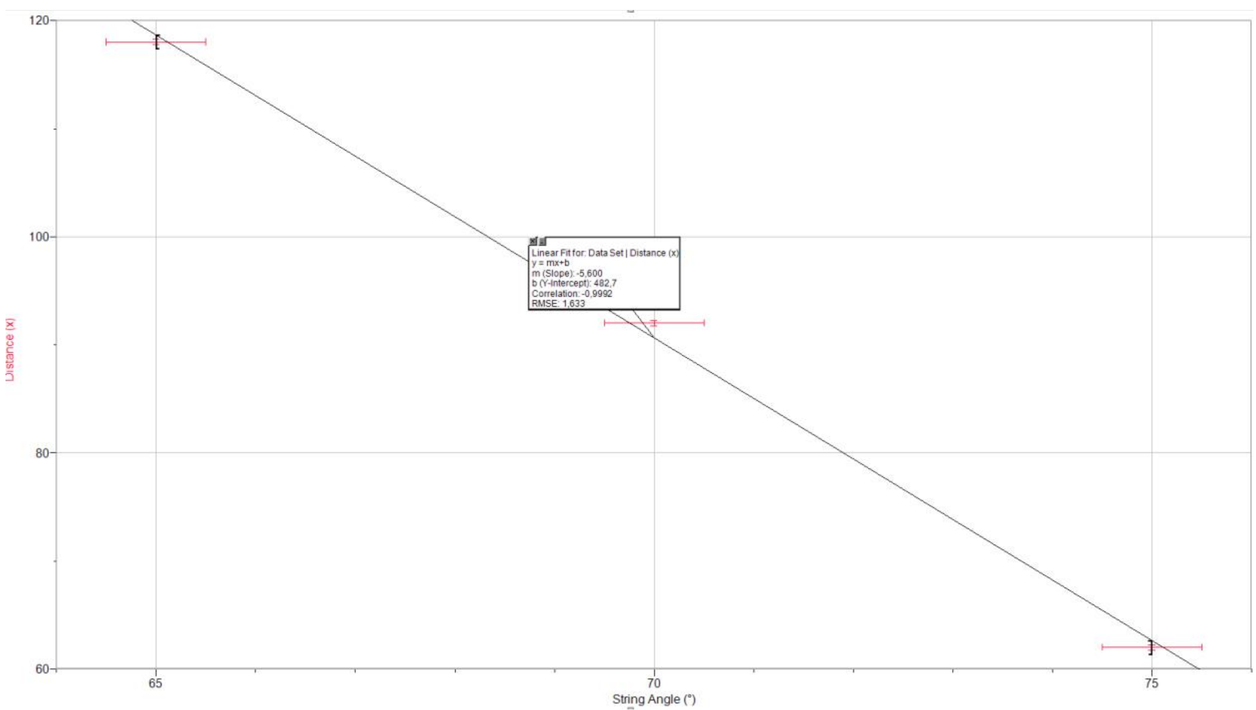


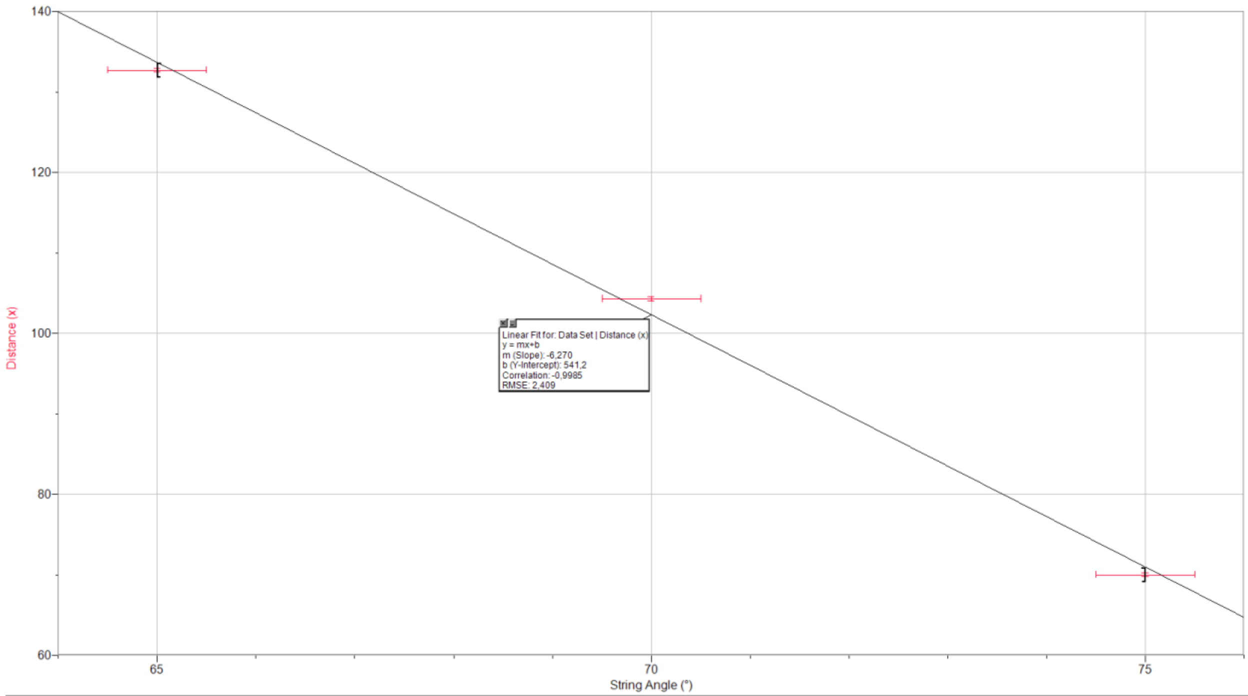
Logger Pro was used to find best fit lines. However, after many tries, Logger Pro was unable to come up with a best fit line. The best general equations were either quadratic or natural exponential. Even though there is not a clear best fit line, it is evident that increase in horizontal displacement decreases as projectile angle is increased.

Graph 2, 3, 4 and 5: Processed Data Graphs for θ = 0°, 15°, 30°, 45° respectively (σ/m)




Linear Fit for: Data Set | Distance (x)
y = mx+b
m (Slope): -3,580
b (Y-Intercept): 307,7
Correlation: -0,9987
RMSE: 1,306
Distance (x)
String Angle (°)


Linear Fit for: Data Set | Distance (x)
y = mx+b
m (Slope): -5,600
b (Y-Intercept): 482,7
Correlation: -0,9992
RMSE: 1,633
Distance (x)
String Angle (°)



Linear best fit lines were found for the graphs above (*2, 3, 4 and 5*) Both questions which were mentioned in introduction have been answered and the hypothesis was confirmed. The horizontal displacement of the arrow increased as projectile angle was increased from 0° to 45°. As bow's string angle increased, the horizontal displacement decreased.

10. Conclusion:

Today, archery is a sport and archers mostly do not perform shots which have a projectile angle as high as the ones which were tested in this experiment. This experiment's purpose was to get an overall idea about the physics behind archery. Throughout history, archery was used as a means of hunting and combat. Therefore, the distance between someone's target was important and knowing how to successfully aim that target was crucial for their survival. For example, using a high projectile angle value in a war would mean reaching the enemy from further away. Even though the angle with which arrow hits the ground was the topic of this experiment, I have observed that the impact angle increased as the projectile angle was increased. This also shows us that an archer would prefer high projectile angles in order to avoid enemy's' shield.

Experiment is successful as the raw data obtained from it is similar to what was expected. The reliability of this experiment was checked with the help of projectile motion equations. Hypothesis has also been confirmed: as projectile angle increased from $0°$ to $45°$, the horizontal displacement of the arrow also increased. Also, as the string angle increased, the horizontal displacement decreased. The results can be improved if drag force is taken into account. However, as the experiment also suggested, drag force did not have much impact on the overall conclusion that this experiment reached. A linear relationship was found between string angles and distance. From the linear equations, we can also calculate how one degree of change in bow string angle can affect the distance an arrow flies for each projectile angles. Overall, the experiment was a success as the hypothesis was confirmed and the data obtained was similar to what was expected.

11. Evaluation:

There are weaknesses of this experiment just like any other experiment has. The only great obstacle for this experiment is the drag force as it decreases the horizontal displacement. Although it was assumed to be negligible and the calculations were made with this assumption, the data was not significantly different from the expected values and there appears to be little random error and some systematic error caused by the assumption made about the drag force. With the help of a drag coefficient which is more precise than the one given in this experiment, drag coefficient can also be considered in the calculations. Air was assumed to be static throughout the experiment. The experiment was conducted when there was no evident wind or sudden decrease in pressure or temperature, therefore the environment was suitable for a good measurement. It is highly unlikely someone can conduct this experiment in an environment where the air is constantly static, so it is a fairly normal limitation of this project. Other than finding a lab which stabilizes air (if there is one), there are no improvements for this weakness as air will always be in a normal environment in which it is dynamic. Lastly, the uncertainty of the theoretical horizontal distance that the arrow flies was not given in this experiment. This is because the values were just to have an idea about how an arrow acts and how accurate the experiment is depending on the theoretical flight data. There comes a very small weakness with the lack of uncertainty regarding this data, but it should not be considered significant at all. The uncertainty of the experiment is given, and it is the one that counts the most.

There are strengths of this experiment too. The method of the experiment would be one of them. If an arrow was shot poorly, the trial was repeated to get the best result possible. Also, the experiment has been double-checked with projectile motion equations. Measurements can be inconsistent as shooting an arrow is not easy and a person can have different results each trial. Every shot must be perpendicular to the markers (ropes) in order to have an accurate measurement. The accuracy and reliability of this exploration/project heavily lie on how the experiment was conducted, so the method was carefully planned. Although the experiment may look easy to conduct, there are many challenging factors as the experiment environment cannot be as controlled as some other may be. This project and the experiment were successful in answering the research question regardless of the difficulties faced.

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