Catapult Report

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"Devil's Bow"

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Introduction

The purpose of this project was to increase comprehension of motion in two dimensions by applying previously studied concepts in a practical setting. The objective was to construct a durable, accurate, and efficient catapult, capable of launching a tennis ball to meet two requirements—an accurate distance of precisely 7 meters and a complete maximum distance. Additionally, data for three distinct launch angles and three varying release velocities was collected and analysed to provide additional detail and insight on the assignment.

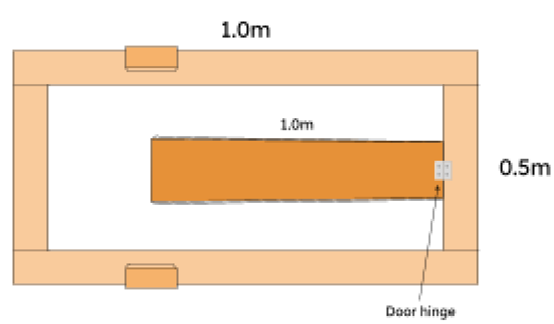
Method and Materials

Method

- **Pre-Build Planning and Preparation:**
    - Initiated with internet research and decided on the development of a modified ballista / slingshot mechanism.
    - Composed preliminary plans and sketches.
    - Finalized optimal dimensions based on knowledge of projectile motion and Pythagorean theorem
    - Purchased materials, however, the acquired supplies proved to be insufficient.

- **First Build Day** - many obstacles.
    - Attempted to utilize wood glue with failure due to weak bond strength.
    - Lacked experience with the use of a drill, resulting in cracked holes in a few vital pieces of wood.
    - Revision and change of mind led to many adjustments in the placement of screws and wood.
    - Discovered that the handsaw lacked efficiency.
        1. Cut out two 1.0m and two 0.3m pieces of wood.
    - Constructed roughly half of the rectangular base.
        1. Attached the two 1.0m pieces of wood with the two 0.3m pieces of wood in a rectangular shape using 3 inch screws.

- **Second Build Day** - obtained an electric saw and purchased extra wood.
    - Rest of the wood pieces were cut to precise dimensions through the use of the electric saw (shown in diagram).
    - Decided to use screw brackets to attach certain wood pieces together after the difficulties with the wood glue.

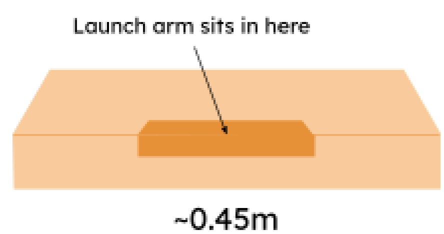


TOP VIEW

- Completed the construction of the rectangular base.
    i. Attached 1.0m launch arm to the back width of the base using a door hinge.
    ii. Made sure all pieces were attached firmly with metal brackets and extra wood glue in crevices for optimal structural integrity.

- **Third Build Day:**
    - Purchased more materials.
    - Attached 1.0m vertical arms
        i. Used angled 90° screw brackets and 2-inch screws.
        ii. Arms were placed on the outer edge of the 1.0m base lengths and at 0.7m from the end of the base
    - Attached a 0.5m horizontal wood piece at the top of the two vertical arms using 2-inch screws to secure them firmly in place.

- **Fourth Build Day -** Pegs added
    - Cut up 3 pairs of small wooden pegs (2"x4"x2") to attach to the interior of each of the vertical arms.
        i. These acted as the supports for the horizontal arm, where the adjustable launch arm would lean on.
        ii. 3 pairs of pegs for 3 adjustable launch angles.
    - Attached the pegs using small 90° screw brackets and 1-inch screws.
    - Fastened velcro strips on top of each peg.
    - Cut a plank of wood to fit tightly between the two vertical arms (~0.45m).
        i. Attached corresponding velcro strips to the bottom of the plank.
        ii. Using a chisel and hammer, a slit was carved into the front, for the launch arm to rest inside.
        iii. This would act as the horizontal arm that sits on top of the pegs as a support for the adjustable launch arm.



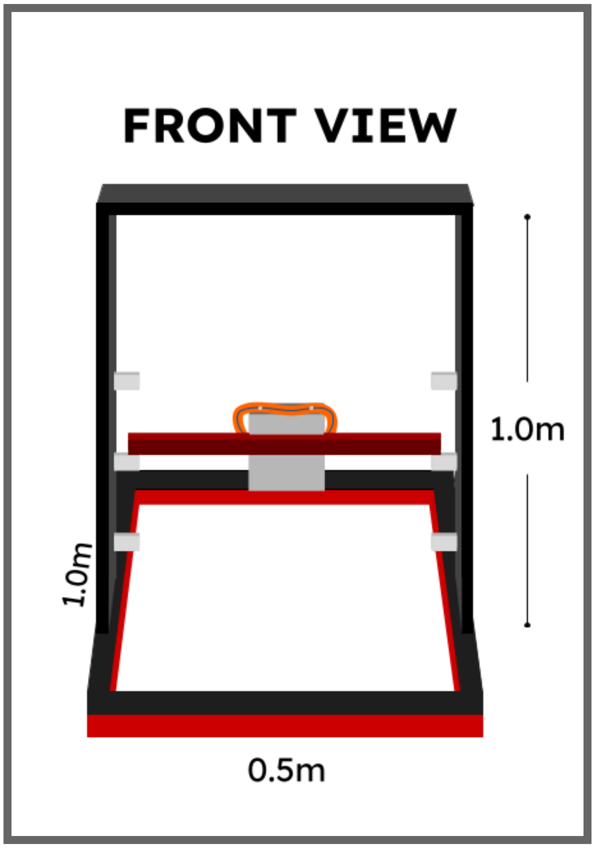
- **Fifth Build Day -** Elastic apparatus added.
    - We had purchased 3 different bungee cords and 2 resistance bands, and attached them one at a time to the launch arm in different ways to determine the best strategy and best band to use.
        i. Decided on the orange PTP resistance band.
        ii. Secured it onto the launch arm by drilling two holes into the front of the band, and screwing in 2 hook screws to fasten it to the front of the launch arm.
        iii. Launch strategy decided; ball is placed inside the naturally-occuring pouch of the resistance band, band is pulled back to maximum stretch and then released.

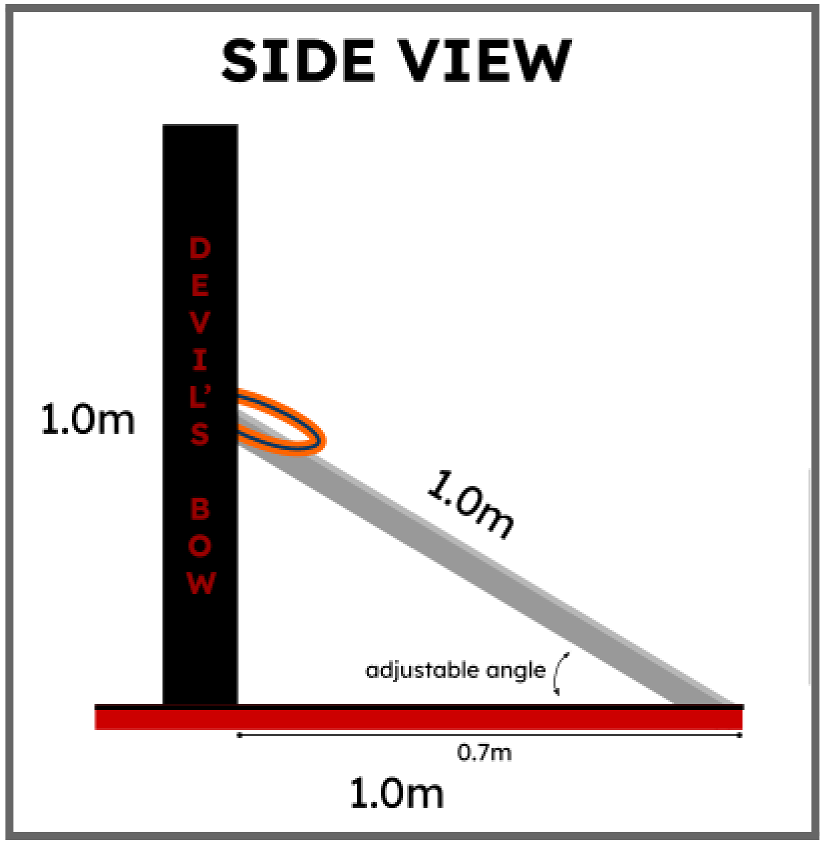
- **Final Build Day** - All test launches were conducted and data collected, followed by painting with spray paint and wood paint.
    - Started painting.
        i. Rained a little while painting.
        ii. Initially wanted had a black with blue accent theme, however, shortage of required colour resulted in alternate plans.
        iii. Started experimenting with different colours and decided on grey for the pegs and arm, red around the border, and black for everything else.
        iv. Added red details to compliment the Halloween theme.
    - Measured and recorded the data.
        i. Salt bag was placed at the base to keep the catapult sturdy.
        ii. Conducted in slight rain and at night on level ground.
        iii. As the measuring tape was not long enough to measure a full launch, objects were placed at each full interval as place holders.
        iv. Tennis ball was placed in the resistance band pouch and pulled back to an extent and released.
        v. The ball's movement from release until its first bounce was timed and recorded.
        vi. The distance from the edge of the catapult to the first bounce was measured and recorded.
        vii. The experiment was reset and the last three steps were repeated for three different launch velocities (pulling back to different stretch distances) and three different launch angles.

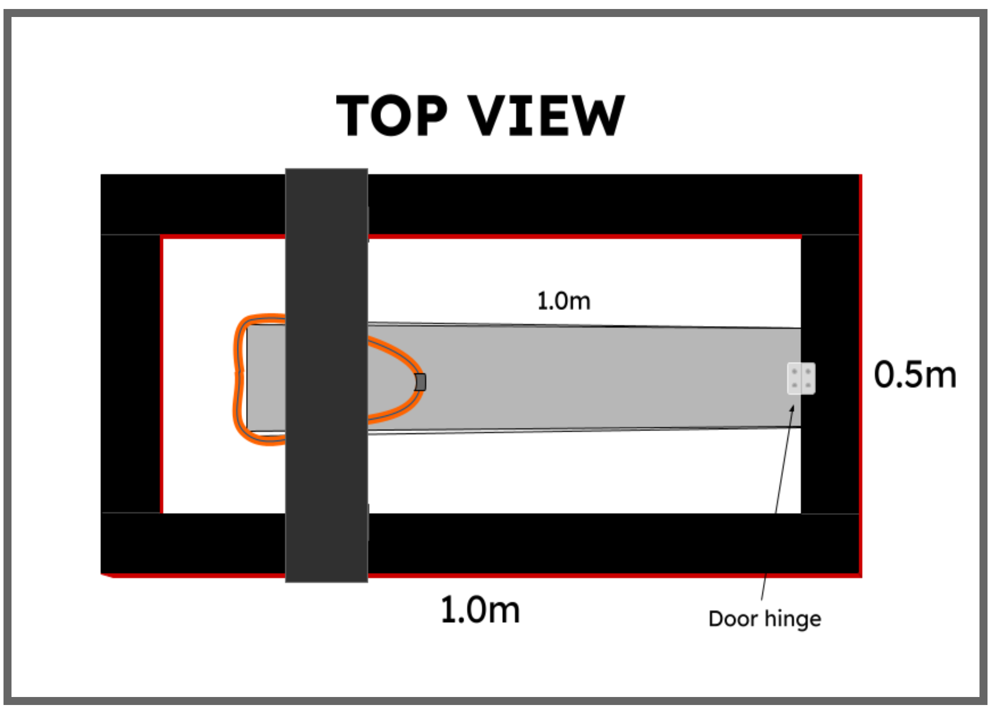
Materials

- ➢ **3x** (2”x4”x8’) wood planks
- ➢ 1cm x 18cm x 1.0m wood launch arm
- ➢ **8x** 90° flat screw brackets
- ➢ Straight brackets
- ➢ **4x** “L” shaped screw brackets
- ➢ Door hinge
- ➢ 2 metal hook screws
- ➢ 2-inch, 1-inch, and 3-inch screws
- ➢ Velcro strips
- ➢ Wood glue
- ➢ PTP Microband X Heavy Resistance Band
- ➢ Salt bag
- ➢ Red and black paint
- ➢ Painter’s tape

Diagrams


FRONT VIEW
1.0m
1.0m
0.5m


SIDE VIEW
DEVIL'S BOW
1.0m
1.0m
adjustable angle
0.7m
1.0m


TOP VIEW
1.0m
0.5m
1.0m
Door hinge

Observations

Table 1: Constant velocity for three different launch angles

Launch Angle	Range (m)	Avg. Range (m)	Flight time (s)	Avg. Flight time (s)
Highest (45°)	20.1m	19.9m	1.97s	1.97s
	20.4m		2.08s	
	19.2m		1.63s	
	19.5m		1.88s	
	29.4m		2.31s	
Medium (34°)	23.8m	22.4m	1.90s	1.77s
	22.6m		1.82s	
	21.6m		1.65s	
	23.1m		1.88s	
	21.0m		1.60s	
Lowest (22°)	18.6m	17.4m	1.38s	1.30s
	17.1m		1.32s	
	16.8m		1.15s	
	17.4m		1.54s	
	17.1m		1.13s	

Table 2: Constant launch angle (34°) for three different release velocities

Launch Velocity	Range (m)	Avg. Range (m)	Flight time (s)	Avg. Flight time (s)
Highest Velocity	23.8m	22.4m	1.90s	1.77s
	22.6m		1.82s	
	21.6m		1.65s	
	23.1m		1.88s	
	21.0m		1.60s	
Medium Velocity	15.8m	17.0m	1.66s	1.79s
	17.7m		1.80s	
	18.6m		1.95s	
	16.2m		1.75s	
	16.5m		1.79s	
Lowest Velocity	10.1m	9.9m	1.30s	1.26s
	9.8m		1.07s	
	10.4m		1.25s	
	9.8m		1.36s	
	9.4m		1.33s	

Table 3: Maximum distance trials

Highest Velocity + 34° Launch Angle	Range (m)	Avg. Range (m)	Flight time (s)	Avg. Flight time (s)
	23.8m	22.4m	1.90s	1.77s
	22.6m		1.82s	
	21.6m		1.65s	
	23.1m		1.88s	
	21.0m		1.60s	

Analysis

Calculations

Table 1: 3 different launch angles

Launch Angle:	**Highest** (range: 19.9m time: 1.97s)	**Medium** (range: 22.4m time: 1.77s)	**Lowest** (range: 17.4m time: 1.30s)
Horizontal Velocity	10.1 m/s [F]	12.7 m/s [F]	13.4 m/s [F]
Initial Vertical Velocity	9.15 m/s [U]	8.12 m/s [U]	5.60 m/s [U]
Initial Release Velocity	13.6 m/s [F42°U]	15.0 m/s [F33°U]	14.5 m/s [F23°]
Highest point of trajectory	5.27m	4.35m	2.60m
Time to highest point	0.933s	0.827s	0.572s
Velocity of ball **on impact**	14.3 m/s [F45°D]	15.7 m/s [F36°D]	15.2 m/s [F28°D]

Table 2: 3 different launch velocities, same angle (experimentally 34°)

Launch Velocity:	**Highest** (range: 22.4m time: 1.77s)	**Medium** (range: 17.0m time: 1.79s)	**Lowest** (range: 9.9m time: 1.26s)
Horizontal Velocity	12.7 m/s [F]	9.50 m/s [F]	7.9 m/s [F]
Initial Vertical Velocity	8.12 m/s [U]	8.21 m/s [U]	5.4 m/s [U]
Initial Release Velocity	15.0 m/s [F33°U]	12.6 m/s [F41°U]	9.5 m/s [F34°U]
Highest point of trajectory	4.35m	4.44m	2.5m
Time to highest point	0.827s	0.838s	0.55s
Velocity of ball on impact	15.7 m/s [F36°D]	13.3 m/s [F44°D]	11 m/s [F42°D]

Discussion

Experimental vs Theoretical

The experimental results include the flight time and range of each launch, as well as the measured values for the three launch angles. The theoretical values were determined through the various calculations, and we found the initial horizontal and vertical velocity, launch velocity, highest point + time to highest point, and velocity of the ball on impact for 6 different cases. There were several differences between the experimental and theoretical results for this lab.

For example, the three launches with different release velocities and the same **measured** launch angle of 34° had been calculated to each have different theoretical launch angles, ranging from 33° to 41°. Additionally, a low velocity launch had a higher max height point than a higher velocity launch from the same launch angle, which does not support the rules of projectile motion. These inconsistencies were due to the several sources of error listed below.

By looking at the calculations, we can make the conclusion that the ball will land in roughly the same direction as it was launched. The angle of launch and and the angle of landing seem to vary by a little bit, but that could be due to sources of error mentioned below. Also by looking at the calculations, we can conclude that the best velocity to launch the ball for maximum distance would be the 15m/s.

We probably could have achieved greater numbers in our calculation but there was Aoa ways the reluctant fear of crossing the elastic region which would deform the bands shape and make it less effective. Therefore we tried not to pull the band back further than the 15m/s launch. Dw

Comparatively, the three launches with different launch angles should have had the same velocity for each trial because the ball was pulled back to the same point on the arm each time. However, through calculations it was found that the theoretical velocities ranged from 14.3 m/s to 15.7 m/s. During initial research it was predicted that the launch angle of 45° would provide results with the maximum distance and that hypothesis was proven wrong. It was discovered that the middle angle of 33° with the velocity of 15m/s actually had the furthest distance. However, the highest angle did result in the highest of trajectory and flight time.

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Sources of Error

The surface of the wood used for the arm is not uniform. The wood itself and the coat of paint may be to blame for this. As a result, the resistance band and ball experience various levels of friction as they move through the surface of the wood, which affects how the launch turns out. This could have decreased the launch velocity and/or caused inconsistencies in the data collected. Wood may not have been the most ideal material to use for a smooth launch. It was originally planned to have the ball launch off a layer of aluminum foil that had some type of lubricant on it to reduce the amount of friction, however due to time constraints the feature was not included in the final product.

Unfortunately, we had unexpected rainy weather on the day of the testing, making the ball damp. As a result, the ball's launch acceleration and velocity decreased and its mass increased. As mass is a key component of momentum, this also reduced the ball's momentum. On a different day, we attempted to conduct trails, but the same issues persisted due to the puddles left over from the prior day.

The trials were conducted in November, a month with a lot of unpredictable wind. This had a significant impact on the observations since it had an impact on a variety of variables, including velocity. When the wind was working in the catapult's favour, the initial horizontal velocity was enhanced, which in turn increased the horizontal displacement. When the catapult was pointed away from the wind, it had the reverse effect, reducing the horizontal displacement by working against the horizontal velocity. The effects of wind and air resistance faced by the ball while in motion could have altered our experimental results. Theoretically, the ball would have a trajectory of a perfect parabola, as assumed by our calculations, but due to the external factors (ie. wind resistance) this was not the case. These factors are not accounted for when finding theoretical results, and therefore ensued altered results. Multiple trials were conducted and data was averaged in order to combat these errors.

Human error and reaction time may have caused some of our data to be inaccurate. It is impossible to accurately pinpoint exactly when the ball was released or first bounced, as well as where exactly it bounced. Some estimation had to be made for the position of the first bounce, and due to the trials being done in the evening the human eye was an inaccurate judge of the ball's position.