The Angry Bird Trebuchet

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AP Physics C: Mechanics

October 23, 2023

History of the Trebuchet

The first accounts, origins, and inspirations of the trebuchet can be dated back to China around the 3rd - 5th century B.C.. Over the centuries the inventions of the trebuchet had spread across all throughout Eurasia and to the Mediterranean. The siege engine was well popularized for military conquests during the 7th to 13th centuries spreading across North Africa, the Middle East, and Eurasia. Due to the influence of the siege engines, scholars during the Middle Ages were able to advance theoretical mechanics. Around the 13th century, a mathematician named Jordanus de Nemor conceptualized the idea of positional gravity which is greater than labored force, hence the idea of the trebuchet was formed. Most trebuchets were formed out of wood and iron and required hundreds of strong men to carry them to their destination. As warfare began to modernize, the development of gunpowder around the 15th century began to overshadow the use of the trebuchet. In modern society, the trebuchet is now mainly used to show concepts of physics to students.

Design

To begin with, we were dealt with the option to choose between a trebuchet or a catapult. One of the main objectives of this project was to try to get either the trebuchet or catapult to launch a projectile as far as possible. Our team chose to create a trebuchet because we felt that we could use gravity and leverage to our advantage and go a further distance. We believed that if we added a substantial amount of counterweight while using a durable material, we could spin the arm to launch the projectile at a greater distance. If we used a catapult, we would've been relying on tension or torsion, rather than using gravity to our advantage.

Our trebuchet design was based on a similar design to Figure 1.

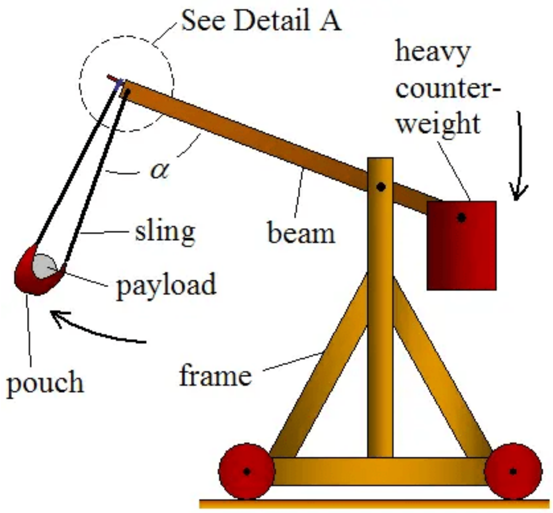


Figure 1: Trebuchet Design [4]

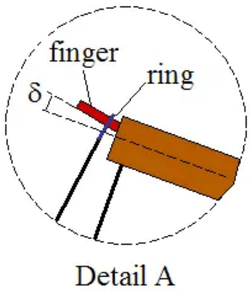


Figure 2: Detail A [4]

Theme and Construction Materials

For the theme of our trebuchet, we decided to do Angry Birds. The main reason why we decided to do Angry Birds is because in the game you are launching a limited amount of birds to eliminate all the pigs. At the same time, you can also destroy the varying structures surrounding the pigs to eliminate them. Trebuchets were used in siege fighting and since Angry Birds is similar to siege fighting, we thought it would be interesting to base our trebuchet on a game everybody knows while keeping the function the same.

While deciding what materials to use to construct our trebuchet, we want to use materials that we know will be durable enough to carry a substantial amount of weight. We decided that using metal and welding the base would be the best idea

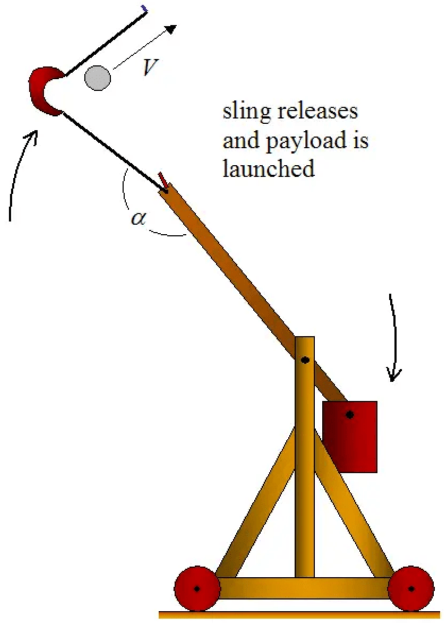


Figure 3: Trebuchet Launch [4]

to get a durable base. For our arm, we used wood and tied the weights to the bottom of our arm.

Our final design did not differ much from our first design. The only thing that did change was the mechanism to cock the trebuchet. Originally, we were going to use a latch lock mechanism. The latch would be attached to our trebuchet arm, the lock would be attached to the trebuchet base, and a string was going to be attached to the latch. The string would be used as a way to launch our trebuchet since the latch would not be attached to the base anymore. However, due to the angle and length of our trebuchet arm, we quickly realized that the latch lock mechanism wasn't feasible.

Instead of doing a latch lock mechanism, we cut a piece of steel pipe and welded chains to both sides. We drilled a hole in the top of our arm so that when it is cocked, we could put the steel pipe in the hole so that it doesn't sling back. In order for the steel pipe to stay in place, we welded 2 loops of chain that we could slide the pipe through. When we were ready to launch, all we had to do was quickly remove the pipe so that it could launch.

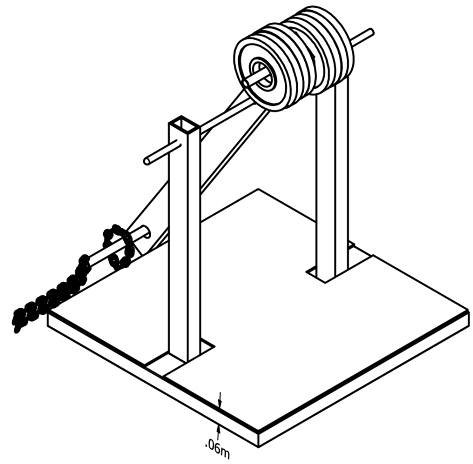


Figure 4: Final Design

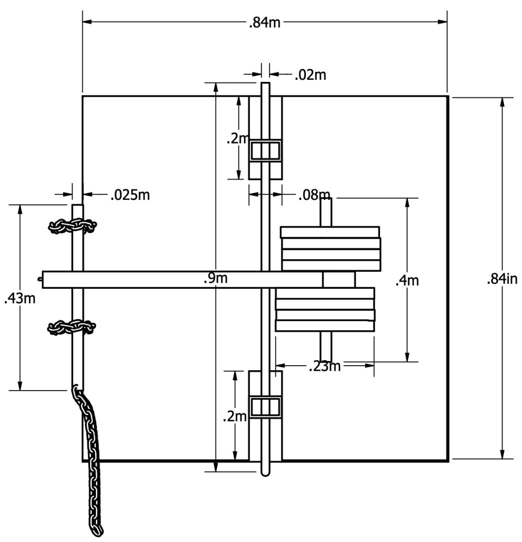


Figure 5: Final Design

Data Analysis and Results

Although our trebuchet did not successfully launch the bean bag on test day, we did test it the night before and gathered the data. The data collected is listed below.

Horizontal Distance: $x = 17.1\ m$
Hangtime: $t = 2.89\ s$
Time to reach Maximum Height: $t = 1.45\ s$
Horizontal Velocity: $v_x = 5.92\ m/s^2$
Maximum Height: $y_{max} = 10.23\ m$
Initial Vertical Velocity: $v_{y0} = 14.16\ m/s^2$
Initial Velocity: $v_0 = 15.35\ m/s^2$
Final Velocity: $v = 13.35\ m/s^2$
Launch Angle: $\theta = 67.31°$

Calculations

Calculating Horizontal Velocity
Horizontal velocity is given by

$$v_x = \frac{d}{t}$$

where d represents displacement and t represents the total flight time or hangtime. Using this equation, we can calculate our horizontal velocity.

$$v_x = \frac{17.1m}{2.89s} = 5.92m/s^2$$

Calculating Maximum Height
Our maximum height can be calculated by using the kinematic equation

$$y_{max} = y_0 + v_{y0}t - \frac{1}{2}gt^2$$

where y_0 represents our initial position, v_{y0} represents our initial vertical velocity, t represents half of our hangtime, and g represents gravity. Using this equation we can calculate our maximum height achieved.

$$y_{max} = 0 + 0\left(\frac{2.89s}{2}\right) - \frac{1}{2}(-9.8m/s^2)\left(\frac{2.89s}{2}\right)^2 = 10.23m$$

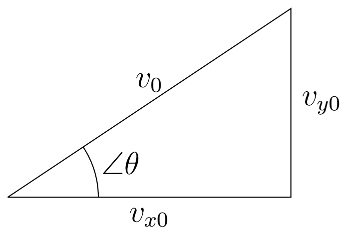
Calculating Initial Vertical Velocity
Our initial vertical velocity can be calculated by the kinematic equation

$$v_{y0} = v_y + gt$$

where v_y represents our vertical velocity, g represents gravity (in positive value), and t represents half of our hangtime. Using this equation we can calculate our initial vertical velocity.

$$v_{y0} = 0 + (-9.8m/s^2)\left(\frac{2.89s}{2}\right) = 14.16m/s$$

Calculating Initial Velocity and Launch Angle



By the Pythagorean Theorem, we can use it to calculate our initial velocity.

$$a^2 + b^2 = c^2 \Rightarrow (v_{x0})^2 + (v_{y0})^2 = (v_0)^2$$

$$v_0 = \sqrt{(v_{x0})^2 + (v_{y0})^2}$$

$$v_0 = \sqrt{(5.92m/s)^2 + (14.16m/s)^2} = 15.35m/s$$

To calculate our launch angle, we can use inverse tan.

$$\theta = \tan^{-1}\left(\frac{v_{y0}}{v_{x0}}\right) = \tan^{-1}\left(\frac{14.16m/s}{5.92m/s}\right) = 67.31°$$

Discussion

Although we believed our trebuchet was going to fire on test day, it did not. One of the biggest reasons is we all tried to make adjustments in order to get the projectile to get farther. We were making adjustments all the way up to the day we were supposed to launch. There could've been many possibilities that caused our trebuchet to not launch, and we believe that the biggest one is all the adjustments made before test day.

When we were first assigned the project, we all felt like it was going to be impossible to try to get our projectile to launch. However, after we started researching different methods to building trebuchets and playing with trebuchet simulators, we all felt much more comfortable as the project progressed.

One of the things our group would do differently is how we assigned tasks. Although it was efficient and productive, we could've managed time a bit better to not deal with unnecessary stress. Another thing we would do differently is not try to focus too much on getting it really far, but rather actually getting it to launch. As we saw on test day, it did not launch. Building the trebuchet helped us understand different concepts of motion, especially how to get projectiles to be launched.

References

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[4] https://www.real-world-physics-problems.com/trebuchet-physics.html.