Nate Christianson

Mrs. Yocum

Science 7

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Trials of a Trebuchet

Question

Which combination of projectile and counterweight will fire the highest and farthest?

Hypothesis

I believe that a combination of the heaviest counterweight (CW) and the lightest projectile will fire the farthest.

Materials

Trebuchet:

- Forty feet of PVC 40 pipe
- Four 90° Elbows
- Two 4-way intersection elbows
- Four T-Elbows
- Eight 45° Elbows
- One ¾″ wide, 12″ long bolt
- Four ¾″ fender washers
- Four 5/16″ Cut Washers
- Eight ¾″ hex nuts

- One package of nylon cord
- PVC cement
- PVC edge cleaner
- Two 1″ long eye bolts
- Two 2″ long eye bolts
- One Pin
- One old bicycle inner tube, cut into diamond-shaped pieces

Counterweight:

- Two ¾″ Bolts
- Wood
- Assorted bricks, patio pavers, and other construction debris lying around the house

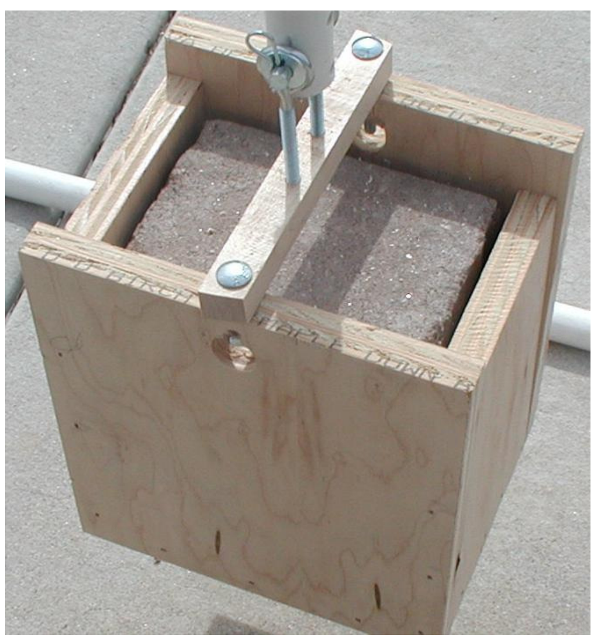

Fig. 1. Casing and Counterweight for Trebuchet

Projectiles:

- Golf balls-1.75 oz
- Small plastic practice golf balls-0.2oz
- Tennis balls-2.25 oz

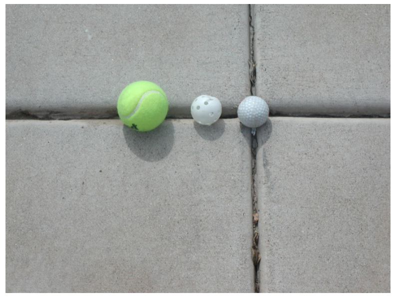

Fig. 2. Projectiles

Procedure

1. Build your trebuchet.
2. Haul the siege weapon to the street in front of your house.
3. Place signs in strategic locations to alert passing drivers to potential danger.
4. Advise neighbors and bystanders to move out of the way.
5. Pull the trebuchet’s arm down and slide the pin through the eye bolts and washer.
6. Pull the sling back as far as it can go and load a projectile.
7. STAND CLEAR! Pull the rip cord and watch with pride as your projectile flies into space.

8. Measure an approximate distance and record your results.

9. Repeat steps five through eight. Acquire three good measurements with each increment of counterweight (bricks) using the tennis ball, golf ball, and practice golf ball.

Fig. 3. The finished trebuchet

Results

Attempts

# of Bricks	1	2	3	4	5	6	7	8	9	10	11	12	Average	Failure Rate
1	FA	FA	FA	FA	FA	FA	FA	FA	FA	FA	FA	FA	0.0	100%
2	FA	40	FA	FA	40	FA	FA	FA	FA	25	FA	20	31.3	33%
3	FA	55	55	FA	FA	FA	45	45					50.0	50%
4	60	FA	50	60									56.7	75%

FA= Failed Attempts

Fig. 4. Golf Ball Raw Data

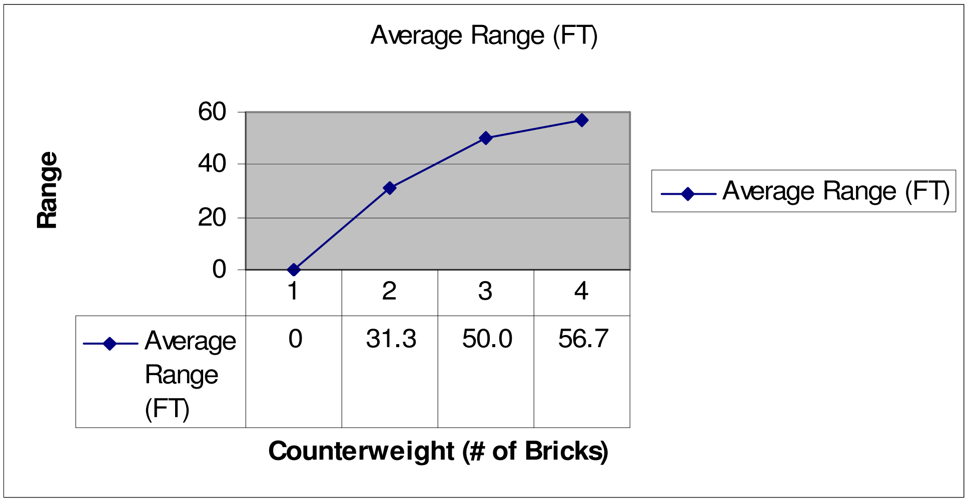

Fig. 5. Average Range for Golf Ball

	Attempt				
# of Bricks	1	2	3	4	Average
4	50	50	55		51.7

Fig. 6. Tennis Ball Raw Data

I discovered that the distance a projectile can fly is in direct proportion to the amount of weight placed in the counterweight casing. In other words, the heavier the counterweight, the farther the projectile flies. This is true regardless of the weight of the projectile, up to a certain point. For example, you can't really shoot a cinderblock and expect it to fire a long distance, regardless of the amount of weight you put in the counterweight casing.

Additionally, I learned some interesting things about the projectiles themselves. The plastic practice golf balls, which are basically miniature whiffle balls, didn't go as far as a solid golf ball because of the holes. The plastic balls didn't work as well because air flew through the holes instead of around the ball. This created additional drag, which decreased the ball's speed through the air. With a solid golf ball, there was no design flaw to hold the ball back, so it flew further. The tennis ball has the same structure as the solid golf ball, so it, too, flew farther than the plastic ball. Its increased size and weight, however, decreased its range. The average range of the tennis ball was 51.7 ft versus 56.7 ft for the golf ball. To adjust for this increased size and weight, I found that if I increased the amount of weight in the counterweight casing, I could get better range out of a larger projectile. Eventually, however, when I added too much weight to the counterweight, I found that the counterweight just got too heavy to move. The result was that the arm pivoted and swayed, but never got enough swing to fire the projectile. Usually the projectile just stayed in its harness or flopped out onto the ground.

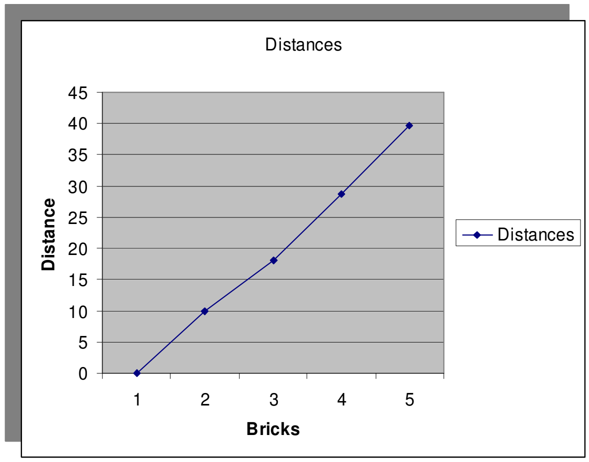

Fig. 7. Distance in Proportion to Counterweight

Conclusion

Through extensive research and a lot of trial and error, I have successfully created a working trebuchet.

My research told me that what makes a trebuchet work is gravity. I decided that the best way to make gravity work for me was to build the device so that the arm was on a single pivot. Through research, I learned that the best trebuchets had an arm that was divided into unequal lengths – a short end and a long end. The massive counterweight went onto the short end and the sling and the projectile went onto the long end. The reason for this, I learned, was to keep the counterweight from hitting the ground. So you have to measure carefully to make sure that when the weight swings freely, the arm does not touch the ground and get in the way of firing. It took me a couple of tries to figure out what the secret was to success here. Eventually I discovered that on my trebuchet, the side that held the weight needed to be exactly 12 inches, with the arm's total length reaching to 49 inches.

Newton's First Law states that, "every object in uniform motion tends to stand in that motion unless an external force is applied to it." In this case when you are firing the trebuchet the ball starts off motionless, until the counterweight is dropped. Then the arm pulls the ball by applying an external force, therefore slinging the ball.

Newton's Second Law states that force equals mass times acceleration. When the counterweight drops the force of gravity is being applied to the short arm which pulls up on the long arm. This occurs because the force of gravity is smaller on the longer arm because the mass of the projectile is smaller.

Newton's Third Law is responsible for releasing the projectile. "For every action there is an equal and opposite reaction." This means that when the short arm is moving at a certain speed, the long arm should be going faster and the sling should be going at the same speed, which creates an equal and opposite reaction to the arm's falling. This is what makes a conventional trebuchet work.

Unfortunately, I discovered that a conventional trebuchet's firing mechanism for holding the projectile didn’t work very well – at least with the materials I had available. The conventional firing arm on a trebuchet also represented a great danger to my head. My first design was downright dangerous to the person who was firing it. There were a few times where I barely escaped concussion because the arm flew forward so quickly that I didn’t have time to get out of the way. This led me to conclude that the trebuchet was dangerous, although my family and neighbors concluded it was quite amusing to watch me dive out of the way.

So I found a way to get rid of the danger by modifying the trebuchet so it uses a few design ideas from a catapult. My dad and I talked over some different designs, and I learned that the idea we decided on was actually part of an ancient Roman catapult design called an Onager. My trebuchet’s projectiles are still fired from a sling and both ends still swing freely. The difference is that I changed the firing mechanism so that I could stand back at a safe distance, pull a rope, and watch the projectile sail into space.

Through many sessions of testing, I discovered that there are many variables that can change the way that the trebuchet fires. I used a mathematical equation to help me make an educated guess about range. This equation was R=

Mcw ÷ Mp • H • ER, which in English means "range equals the mass of the counterweight divided by the mass of the projectile times the vertical distance the counterweight travels times the efficiency ratio (percent)."

This equation eventually found its way to a graph that is labeled as Figure 7 above. My conclusion is there is an increase in the range that the projectile will fire that is in direct proportion to however many bricks or weight you add. As I mentioned above, however, this is not always true. The range will stay the same for a while as you increase the weight, but eventually the range will decrease as the weight increases. This is because the trebuchet simply exhausts its ability to fire when the weight is too much. This is due to my trebuchet's design and the materials used, and it is not necessarily a flaw. It just reached the limits of its ability.

Additionally, I concluded that the trebuchet's single firing mechanism could jeopardize the entire firing sequence if it was used incorrectly. If there is no projectile, then the thing will not fire anything at all and it's a complete waste of time. The chart below in Figure 8 shows the Success/Failure Ratio.

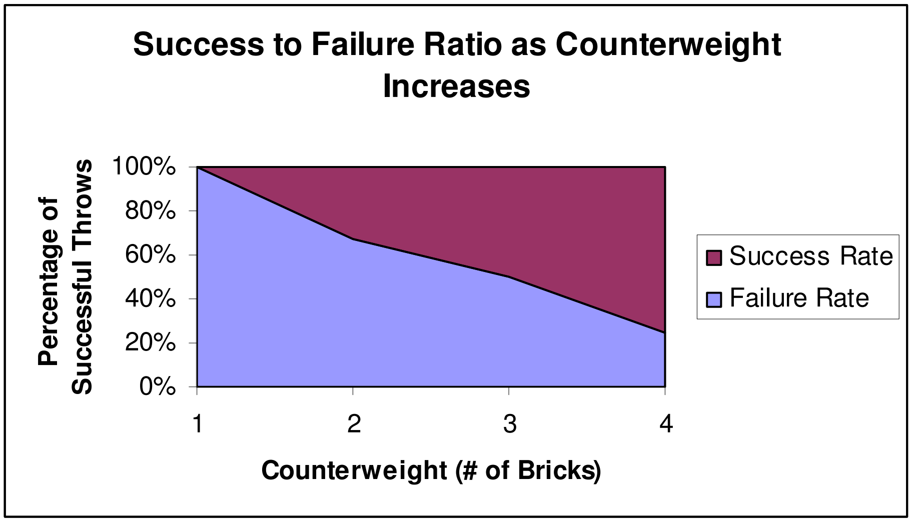

Fig. 8. Success/Failure Ratio

Some of my results proved to be failures because they either didn't reach the minimal range, they threw backwards, or the ball stayed in the sling and didn't go anywhere. Throughout the entire experiment process, I found that my original hypothesis was correct -- that the combination of a lighter ball and heavier counterweight will fire the farthest.

There are several ways I can take advantage of what I've learned. First of all, I now understand the science behind projectiles and the way they fire. This will be useful in water balloon fights and in fact, I plan that my next experiment with the trebuchet will involve water, latex, and my little brother.

On a more serious note, I can see that this sort of knowledge would be useful in any career or project that involves kinetic energy. Where I see myself using this knowledge right now is with sports. A baseball player could really benefit from an understanding of kinetic energy and projectiles, especially if he's a pitcher. A golfer could improve his swing if he understood the physics behind it.

In addition to all the scientific things I learned, I learned that trebuchets were very dangerous to employ. I think you can say that the soldiers who fire these massive siege weapons were very brave. There are so many things that could have gone wrong when firing a trebuchet and any one of them could have killed or significantly wounded a person. When I use this knowledge in the future, I will know what to look out for and how it works.

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