Increasing the Efficiency of a Trebuchet

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Abstract

This laboratory experiment was conducted as a part of a high school physics course during the unit on projectile motion in two dimensions. To begin the lab we fixed the trebuchets that had been built by the previous year's classes and got them in working condition again. We then test fired the machines using 5 different counterweights to establish a baseline of performance data. Once that was established, we then modified the trebuchet in an effort to improve its performance. Our trebuchet was changed by drilling holes in the firing arm on the sling side of the fulcrum in order to decrease its mass. After making these changes we then re-tested the machine using the same counterweights as before the modifications. We determined that the machine improved in efficiency by a considerable amount.

Introduction

A trebuchet is a medieval weapon of war that has its origins in the 12th century. It was used by both Christian and Muslim kingdoms to hurl projectiles of up to 350 pounds at enemy fortifications. The trebuchet is essentially a machine that consists of a lever arm and a sling, and is powered by the force of gravity. The firing arm of the trebuchet consists of a force arm where the counterweight is added to provide force, and a load arm where the sling is attached to hurl the projectile. The sling itself acts as a second lever arm increasing the speed of the projectile. Last year's physics classes crated these trebuchets and tried to determine if the mass of an unknown counterweight could be determined by comparing the distance it hurled a projectile to other counterweights where the masses were known. Our class was attempting to learn if there were ways we could modify the trebuchets to increase their ability to hurl objects. This was a fun and interesting project because it got us out of the classroom actually building and testing real machines and doing science instead of simply learning about science. We modified our trebuchet by drilling holes into the load arm of the trebuchet and decreasing its mass, thus hoping that, according to Newton's Second Law, we could increase the acceleration experienced by the projectile and cause it to fly further.

Hypothesis

If we decrease the mass of the mass of the load arm by drilling holes into it then the trebuchet will hurl objects farther using the same counterweights.

Materials

- Trebuchet
- Racquet Balls (projectile)
- Metric Measuring Tape (at least 50m)
- 5 Counterweights w/ masses of 1.0, 1.5, 2.0 2.5, 3.0kg
- Various tools necessary for modifications

Procedure

This laboratory experiment was done by taking several days to repair last year's trebuchets and experimenting with the best way to arrange the projectile, sling, and release pin. We then tested the trebuchet using 5 different counterweights using and established baseline data for its performance. Each counterweight was fired three times with the distance fired recorded each time. An average was then calculated for each counterweight. We then made the modifications to the throwing arm of the machine. Our modification was to use a ¾ inch spade drill bit to drill holes in the load arm of the machine and lower its mass. We fired the machine again using this modified arm to see if the distance traveled by the projectiles was further.

Before modification

1. Load the projectile into the sling of the trebuchet and add the 1.0 kg counterweight to the force arm of the machine.
2. Pull the release pin and record how far the projectile traveled using the metric tape measure. Record this data.
3. Repeat two more times for the 1.0 kg counterweight recording the data each time.
4. Calculate the average distance the projectile fired.
5. Graph your results.

Modification of throwing arm

1. Obtain the mass of the throwing arm by using a scale.
2. Using a ¾" spade drill bit drill holes in the load arm side of the throwing arm leaving approximately ½" between the holes.
3. Obtain the mass of the throwing arm by using a scale.

After modification

1. 1. Load the projectile into the sling of the trebuchet and add the 1.0 kg counterweight to the force arm of the machine.
2. Pull the release pin and record how far the projectile traveled using the metric tape measure. Record this data.
3. Repeat two more times for the 1.0 kg counterweight recording the data each time.
4. Calculate the average distance the projectile fired.
5. Graph your results.

Results

The testing and retesting of the trebuchet showed that our modifications had a significant impact on the performance of the machine. As can be seen in both Table 1 and 2, the average distance of each launch increased. Also, while both graph 1 and 2 showed the same upward trend in the average distance, Graph 2 had a steeper increase in the slope of the line. While the data did show positive growth, there were difficulties in attaining it. The trebuchet itself required constant fine tuning of the release pin at the end of the load arm to ensure that the projectile launched at the optimum 45 degree angle. The ceiling of the testing are also posed some problems. While the ceiling of the gymnasium and commons are of our school are quite high there were times when the projectile made contact with the ceiling which forced us to invalidate the result. Despite these challenges, our data were very reliable and informative.

Table 1: Launch distances before modification

	Distance Traveled (m)			
Counterweight Mass (Kg)	Trial 1	Trial 2	Trial 3	Average
1.0	.8	1.2	.9	0.9666
1.5	2.5	2.3	2.1	2.3
2.0	6.0	5.5	5.4	5.6666
2.5	7.0	7.6	6.8	7.1333
3.0	8.5	9.9	9.5	9.3

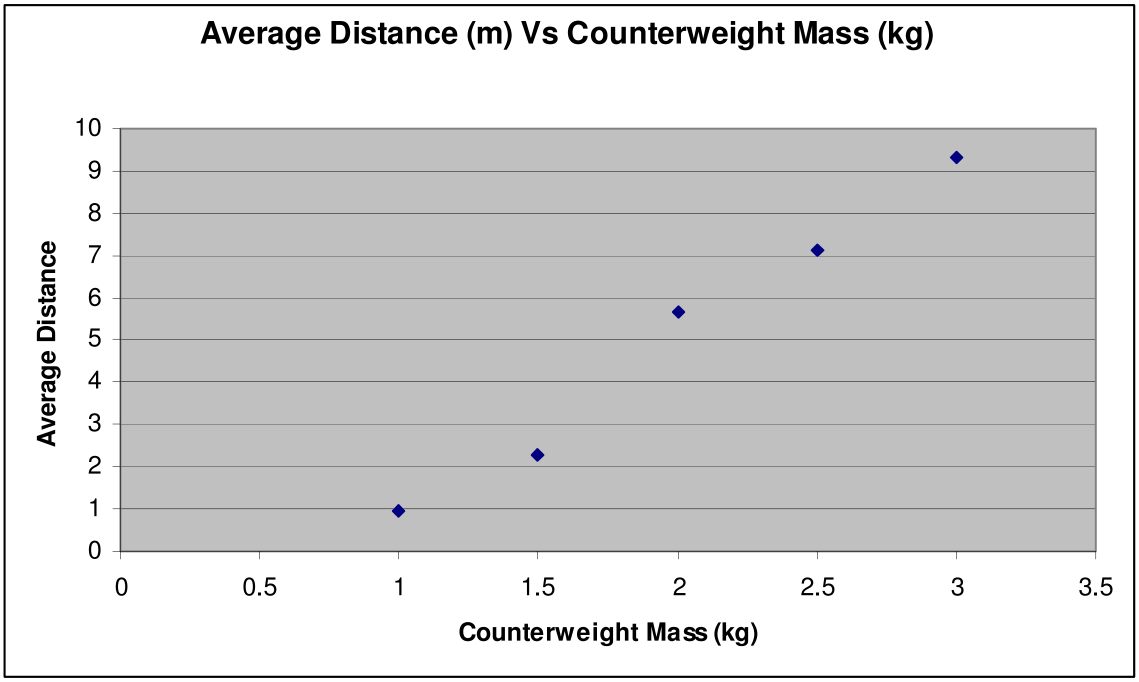
Table 2: Launch distance after modification

	Distance Traveled (m)			
Counterweight Mass (Kg)	Trial 1	Trial 2	Trial 3	Average
1.0	1.5	1.7	1.6	1.6
1.5	2.3	2.9	2.7	2.633
2.0	4.5	5.0	4.8	4.766
2.5	8.5	8.8	8.5	8.6
3.0	11.1	10.8	10.9	10.933

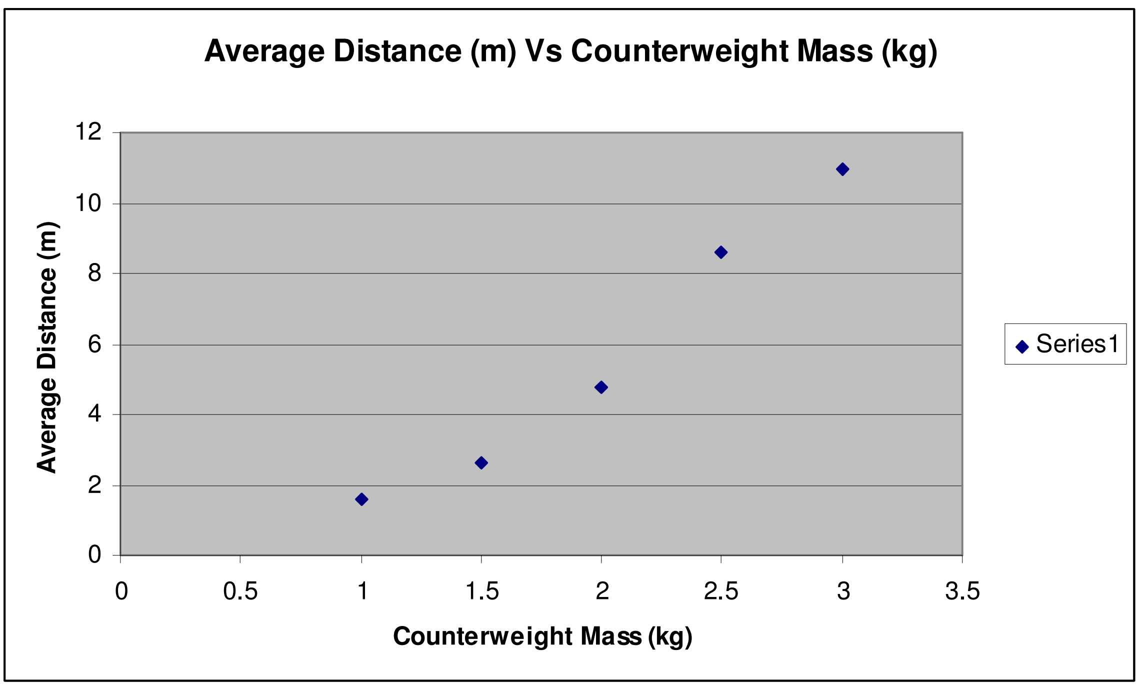
Table 3: Change in throwing arm mass

	Before Modification	After Modification
Throwing Arm Mass (Kg)	1.53	1.06

Graph 1: Efficiency of trebuchet before modifications



Graph 2: Efficiency of trebuchet after modification.



Conclusion

The data from my experiment did support my hypothesis that by reducing the mass of the load arm we would increase the average distance traveled by the projectile. If one looks at Table 1 and 2, it can be seen that the average distance traveled while using the 3.0 kg counterweight was 9.3 meters, while the same counterweight hurled the projectile 10.93 meters after the modifications. A similar increase in average distance traveled can be observed at every counterweight mass. Further, the slope of the trend line in graph 2 is steeper than the trend line of Graph 1, showing that the rate of change was greater in addition to the overall increase in average distance. I believe these results can best be explained by using Newton's Second Law. In Newton's Second Law (NSL) f is equal to the product of mass multiplied by the acceleration. By using the same counterweights the force created by gravity remains the same for both machines. But by decreasing the mass of the firing arm we increased the acceleration experienced by the load arm of the machine and the projectile. While this experiment was fun and successful, there were definite improvements that could have been made. First the number of trials could be increased from three to ten. These additional trials would make the data more reliable as the occasional errant launch did happen. Also, the counterweights could have greater interval between them in mass. Currently the counterweights increase by a half a kilogram each time, by changing this to a full kilogram we would see greater distinction between the launches and therefore more clear data. In summation, this was an interesting and challenging lab that showed us that physics is a subject that exists outside the classroom.