Intro Project Tension Spring Catapult

ABSTRACT

Professor Ramos had two goals in mind when tasking the class with this project, one was to build a catapult capable of launching a golf ball a distance of 10 feet constantly, and the other was to learn and gain experience with the engineering design process. While the first goal of this project was a failure and ended up being almost an average of 50% off the total range our team intended to achieve. The second goal was a huge success. Throughout this project, our team experienced the engineering design process in a way that would not have been possible without going through each stage of the design. The training our team has gained through this project will allow our team to be successful in our future endeavors; in this way our project was successful.

I. INTRODUCTION AND BACKGROUND

The goal of this project was to immerse the class in the engineering design process; by having our team construct a catapult capable of hitting a target 10 feet away. Professor Ramos, our client, has requested this catapult to prepare our team for the future in not only our engineering studies but also in real-world applications. The engineering design process is one that engineers use for every project in the future, hence the sooner our team is exposed and becomes comfortable with the process the better.

II. OVERVIEW

Our design process started with sketches of our desired design. We then put our design into a CAD Onshape model where we constructed our model to scale in a 3D model space. Once we were comfortable and confident in our design, we consulted ITLL engineer Viri Varela. The consultation was brief but informative[Figure 6]. The main concerns that Ms. Varela addressed to us were to make sure the barrel was adjustable and that the pull-back mechanism included a unique trigger mechanism to minimize errors in accuracy. We assured Ms. Varela that our design was fully adjustable and that the final design will include a trigger mechanism. She then signed and approved our design to allow us to start the manufacturing process. To begin this process, the most important parts of the build had to be sourced. The PVC tube and the spring are the two most vital components that needed to be initially sourced. It was easier to build around the PVC pipe rather than find a piece of pipe to fit the build. With the spring being our main force to launch our golf ball, finding a spring that didn't take too much force to pull back but also had enough strength to launch the ball was a top priority. Our next priorities were sourcing some of the build components such as the acrylic for the arches, dowel, wood, and the hardware for the rest of the catapult. Starting assembly was the next task. First up was preparing the base. At first, our design had a single 2x4 base which our team soon realized was not enough and quickly added 2 more layers, the first layer had two notches cut out on the front and back for the rear supports and the front arches. From there the two layers below were nailed to the current layer. Our team then drilled through the PVC pipe to allow the bolt to pass through and to be affixed to both of the legs in the rear.[Figure 5] Our team used the laser cutter in the ITLL to cut two acrylic arches and a logo for the front of the catapult. The arches had a groove cut in the middle of them allowing for a bolt to pass through and allowing the barrel to vary in range from 0 to 36 degrees. Our team ended up using two bolts in the arches one on top and one below the barrel reducing movement in the barrel when caulking the firing action. For a trigger, a hole was drilled in the top of the PVC pipe then put a screw through it barely holding back the dowel. To release the trigger the user could push up the bottom of the exposed dowel releasing the plunger from the screw allowing it to force the ball out of the barrel.

The catapult consisted of 3 main materials; PVC, Douglas Fir lumber, and acrylic. The base of the catapult was fastened by box nails(2) in the center of the original base. The secondary base has (2) 74-inch x 2-inch x 1.5-inch wood pieces side by side with a third piece of the same dimensions, fastened above by (2) more box nails. The PVC tube has a diameter of 2 inches with a length of 9 inches. A 1⁄2 inch mounting hole was drilled in the PVC tube ¾ inch in from the aft end of the pipe and 0.35 inches up. The aft mount bolt is connected to the original base by (2) particle board mounts measuring 4.5 x 1.5 inches. The particle board mounts are fastened to the original base by (2) self-tapping raised head screws. To control the angle of the catapult launch, acrylic was used to produce (2) arches with a free range of adjustment up to 36 degrees. These two pieces were cut on the Epilog Legend 36 EXT laser cutter. These arches were then attached to the front of the base using (2) self-tapping screws located; 2.75 inches from the front of the original base and 0.75 inches up.[Figure 1]

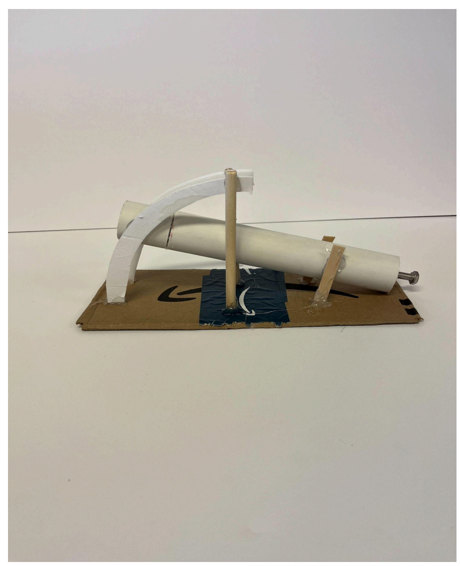

Figure 2: Final Design Figure 3: Prototype Design

Choosing a spring was the most important part of the catapult design. Three different springs were tested, all with varying spring constants. The pullback mechanism in our prototype design [Figure 3] is one that we kept and improved on for our final design [Figure 2]. We then started our search for a spring(s) capable of meeting our needs of launching the golf ball ten feet. Ultimately the spring that worked best for our design had a spring constant of 5.638 in-lbs. The spring constant was calculated by using the mass of the golf ball, the mass of the plunger, and the change in length of the spring. Acceleration due to gravity was taken in feet per second squared. Once our model was in working order testing would begin. Ten feet was the distance required for the catapult to launch so this phase of testing was based on that. At first, the range of the golf ball was sporadic and missed more shots than made. Our team left it how it was and it was working well, then a piece that was made out of particle board which is less rigid than needed to affect the golf ball in the desired way. Since it wore out and broke in the barrel of our catapult, our team replaced it with a different material and it worked again but not like it did before the piece broke. With the new piece in the catapult, out of ten shots, only 3 would make it to ten feet. Our team concluded that our dowel rod didn't have anything guiding it to project it forward so it would go in the path of least resistance. This accounted for the sporadic shooting. Our design team built an end cap that would guide the dowel down the PVC pipe. This adhered to the end of the PVC then the dowel rod would be inserted into that. This small correction improved the accuracy of the catapult. On demonstration day the guide inserted into the back of the PVC became disengaged, not allowing our dowel to move through the end of its range.

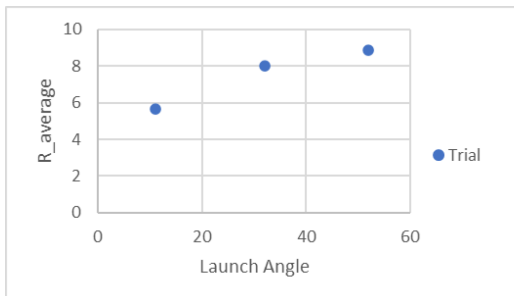

Figure 4: Initial Testing Results

Our team compared our actual results to our targeted results and calculated accuracy and overall accuracy for our testing. The targeted results were to get ten shots to hit a target at a distance of ten feet. These shots had to clear an 8-inch wall at approximately a distance of nine feet from the catapult. If the golf ball contacted the wall it was counted as a distance of nine feet. Our team counted all misfires after launching commenced and measured the distance using a tape measure that uses decimal feet instead of inches so every 10 increments is a foot instead of every 12. The average, standard deviation, and overall accuracy were all calculated using the standard formulas. During our initial testing, our team used the overall accuracy of our catapult to figure out which angle to set the catapult at although the calculations indicated it was going to be around 35 degrees due to our calculations thorough testing and because of human error, the results were getting more consistent at 36 degrees[Figure 4][Figure 7]. Our team continued the same analysis process for the final data as well.

	Launch Angle(Deg)	
	36	
Trial	Range	Accuracy
1	10.20	98
2	6.40	64
3	6.50	65
4	7.00	70
5	8.50	85
6	7.30	73
7	7.50	75
8	0.00	0
9	0.00	0
10	0.00	0
Average	5.34	
STD	3.65	
Overall Accuracy		53

Table 1. Measurements of the distance of projectile traveled as a function of a launch angle

Our results did not meet our expectations, with a percent error of 46.6%. Our catapult had an average range of 5.34 feet[Table 1], out of the total ten shots but of the seven shots our catapult could complete our average was 7.63 feet. While this still falls short of the 10-foot goal. These results show that our catapult still needs some modifications to ensure its consistency before any scaling up can be done. Our main issue with this design as previously stated is that the plug used to guide our plunger down the center of the catapult became dislodged during the first launch. The first launch achieved the anticipated results, but every shot after that was off, this is due to the center plug moving up the plunger causing more friction, messing up the balance, and limiting the range of motion of the plunger. Eventually, the guide plug moved far enough up the plunger that on our 7th shot, it completely detached the platform that the golf ball was resting on inside of the PVC tube. This made our catapult unable to finish the final 3 shots and was the main cause of our accuracy of 53. The free-floating guide plug caused anomalies with the range, if it were to have stayed in place our accuracy and average would increase Before our team could proceed further with our design, a new method for securing the center plug in the PVC tube or developing a new method for centering the plunger in the PVC tube would need to be developed. Either of these options would allow our catapult to achieve the goal distance similar to what it did on the first shot and would allow our team to continue further if our team wanted to with the design.

III. CONCLUSION

The goal set by Professor Ramos for our team was to immerse ourselves in the engineering design process. That process sets a foundation for our team to use for future engineering projects. When our group was first briefed on the project, our team set specific project objectives in mind which were to make sure the catapult was unique, effective, and followed all of the rules set in place by Professor Ramos. Our design goal was to make sure that the catapult was adjustable for any angle, involved a unique trigger mechanism, and that it was not unwieldy.

The main findings of our analysis on the delivery day were that our catapult design had significant flaws in our shooting mechanism that became more pronounced the more the catapult launched. This included the plate on the dowel that pushes the golf ball out of the PVC barrel. The screw that was placed at the top of the barrel would wear down the launching platform the more our catapult fired and would need frequent readjustments with a screwdriver. These big flaws were the cause of our catapult's shortcomings. Our catapult was excellent for the first shot but as our materials degraded, so did its performance.

For future work and advice for incoming design groups working on a catapult, the main takeaway is testing. Groups should do a significant amount of testing of varied materials, mechanisms, and designs that should be considered for improvements and the ultimate goal of consistency. To have consistency, research, and testing should be at the forefront of a group's project goals. Finding the best materials for your needs and the best and most efficient mechanisms for the catapult would lead to better results.

IV. APPENDIX

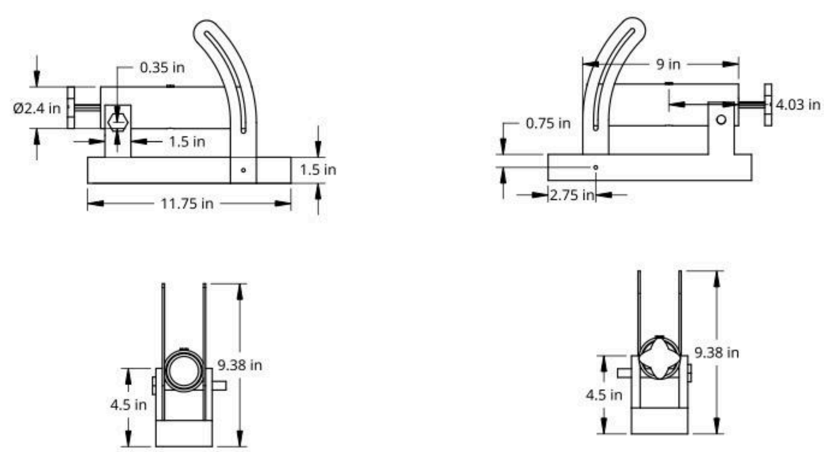

Figure 1. Drawing of catapult assembly and original base.

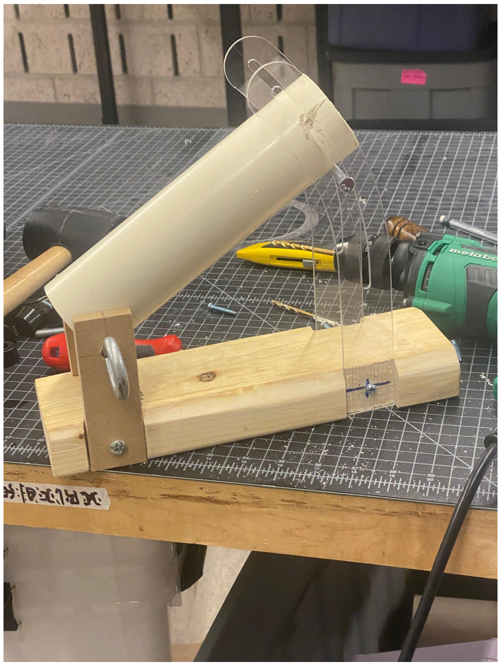

Figure 5: Design Buildup

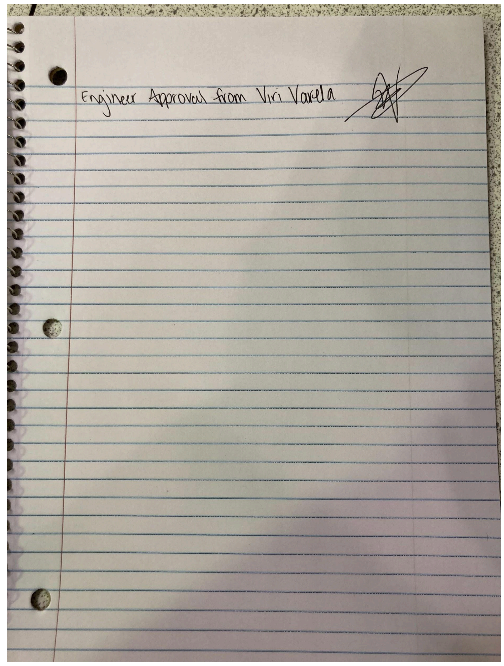

Figure 6: Engineer Approval

Trial	Range(ft)	Launch Velocity (ft/s^2)
1	7.2	30.22
2	8.3	32.45
3	7.8	31.46
4	8.1	32.06
5	4.8	24.68
6	8.5	32.84
7	9	33.79
8	8.7	33.22
9	8.8	33.41
10	8.9	33.6

Figure 7: Test day data to find velocity of projectile(Launch angle 36 degrees)

For all equations it was assumed that the air resistance was zero.
The velocity was calculated using the following equation:

$$v = \sqrt{(R * g)/(2 * cos(\theta) * sin(\theta))}$$

Where:
R =10 feet

g= 32.2ft/s^2
θ= 36

After finding the initial velocities of each trial of 36 degrees, we can then find the horizontal range from the following equation:

$$R = (v)^2 sin(2(\theta))/g$$

Where:
v is the initial velocity of the projectile= 35.79ft/s^2
θ is the launch angle measured above the horizontal =36
g is the gravitational constant =32.2 ft/s^2

Formula used to find needed spring constant

$$k = (((m_b/g) + (m_p/g)) \cdot (v^2/s^2)) \cdot 12$$

Where:
m_b is the mass of the golf ball =0.101lbs
m_p is the mass of the piston/dowel =0.088lbs
s is the change in the length of the spring from equilibrium = 4 in
g is the acceleration due to gravity in feet and seconds =32.2ft/s^2
12 is the unit conversion

V. REFERENCES

Ramos, Katherine. "GEEN 1400." University of Colorado Boulder, 17 Jan. 2023, Boulder, CO