Ping-Pong Ball Launcher

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***Abstract* – This paper describes the design, construction, and testing of a small trebuchet used to launch a water filled ping-pong ball. The trebuchet is composed of few, simple elements. The most crucial part is the main arm, where a small change in size made a big difference. The best dimensions were chosen after a multitude of simulations to produce the longest launch distance. The final testing did not confirmed the simulations as they lacked some variables.**

Keywords: Trebuchet; Ping-Pong Ball Launcher, Laser-cutter;

I. INTRODUCTION

This report describes the design, construction, and testing of a ping-pong ball launcher. The launcher met its goal of launching a water-filled ping-pong ball 5 meters and was completed on time. During the design process analysis of all major components was performed as well as a simulation to predict the launch distance. The final design (see Fig. 1) under-performed due to a flawed simulation but yet the trebuchet met its functional requirements.

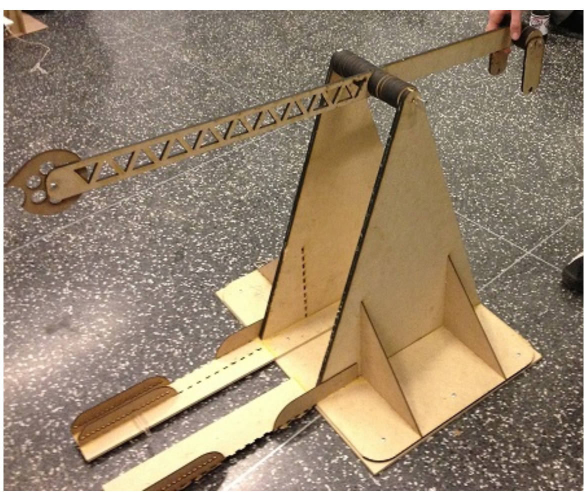

Fig. 1. Final design.

II. DESIGN

The initial concept was to build a simple catapult. With the help of a MatLab script the design was optimized to launch the furthest distance. By creating a loop that compared different pivot point locations the launch distance was calculated for each configuration (see Fig. 2). Unfortunately, the script did not take the mass of the arm into the calculations and the design wouldn't launch as expected. This is why, a different calculator was used for the second and final design. An online Java applet [1] was utilized to determine the best parameters for the final trebuchet. With this estimation almost all variables were taken into account, starting with the mass and inertia of the arm, all the way to the projectile air resistance. The dimensions obtained from the online simulator (see Fig. 3) were used in the final design and predicted a launch distance of 13.3 meters.

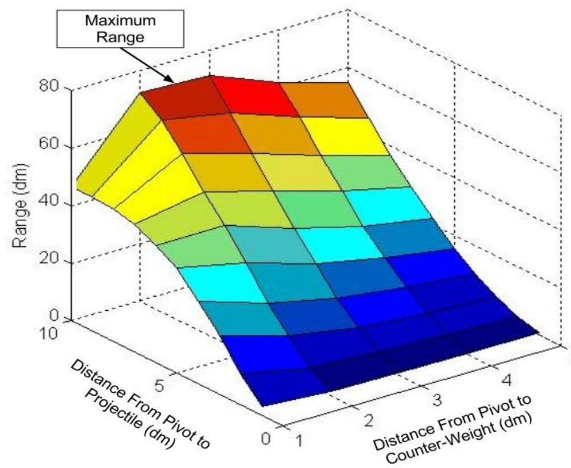

Fig. 2. Predicted launch distance for catapult with different pivot point locations.

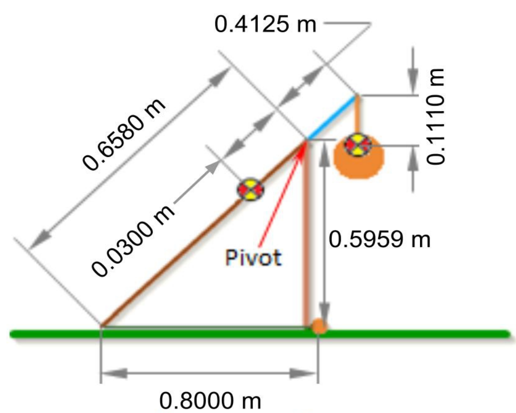

Fig. 3. Parameters obtained from online simulation.

The final design was modeled in AutoDesk Inventor (see Fig. 4). To confirm that the design would work as expected a dynamic simulation was performed using the same software.

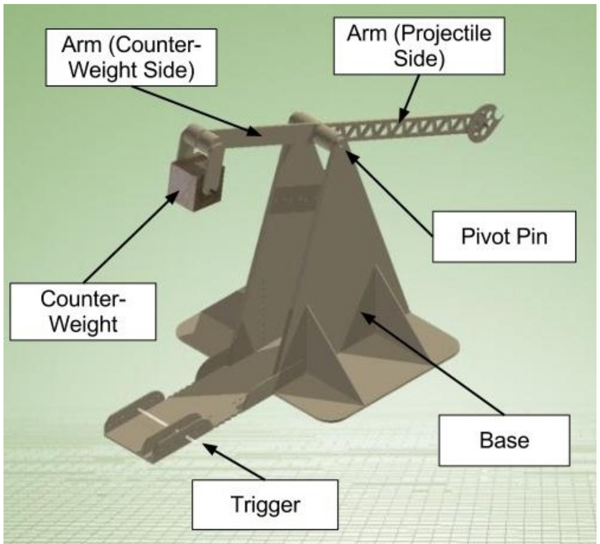

Fig. 4. Final design modeled in AutoDesk Inventor

III. TRIGGER DESIGN

It is not as hard to construct a proper trigger when dealing with a small machines such as this one, but once higher forces are taken into account a proper trigger is a must [2]. The trigger used in the final design (see Fig. 5) was a simple pin trigger that consisted of acrylic rod and three ⅛ inch thick MDF plates. Extra holes were added in order to provide more adjustability once the assembly was completed. This proved to be an adequate solution for the trebuchet. Further analysis of the forces acting on the trigger pin is detailed in the next section.

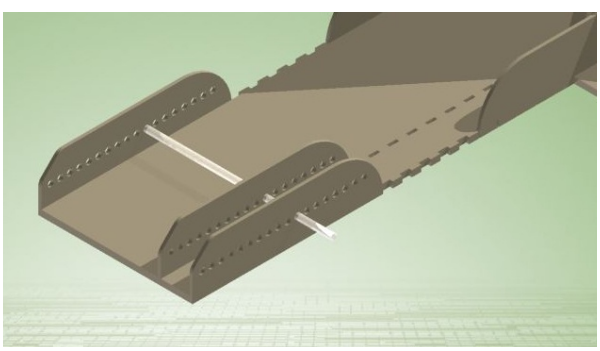

Fig. 5 Adjustable pin trigger.

IV. COMPONENT ANALYSIS

Two of the main components were analyzed in depth to confirm adequate strength. The force acting on the trigger mechanism was also calculated in order to determine the force needed to pull the pin out.

A. Finite Element Analysis of Arm (Counter-Weight Side)

One of the particular areas of concern was the counter-weight side of the arm. Finite element analysis (FEA) was performed in AutoDesk Inventor in order to confirm that the arm would withstand the loads from the counter-weight. The reactions in bending and tension were studied. In both modes the component was subjected to a 20N force, more than twice of which will be experienced during operation. In bending (see Fig. 6) the lowest safety factor was 1.04, this meant that the component was close to failing but it would still hold.

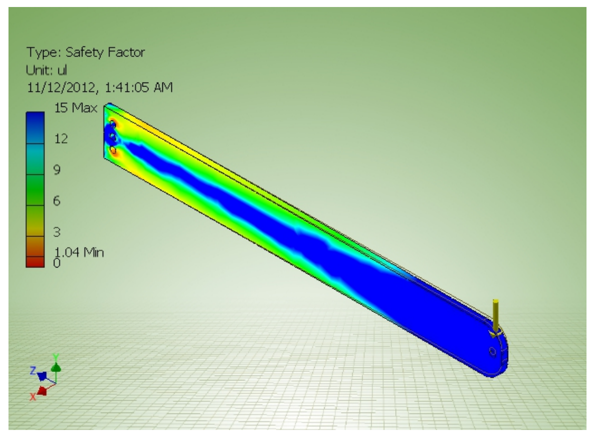

Fig. 6. Safety factor in bending, 1.04ul minimum.

The results in tension (see Fig. 7) were much more satisfactory. The minimum safety factor in this type of loading was 15ul. This meant that a force 15 times greater would have to be applied in order to break this part of the arm.

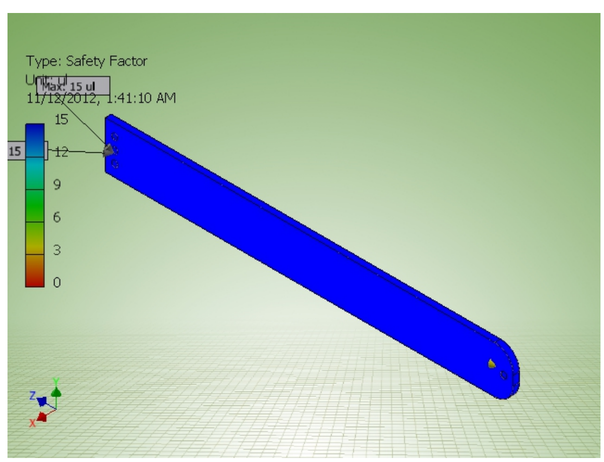

Fig. 7. Safety factor in tension, 15ul minimum.

B. Analysis of Pivot Pin

Another component that was analyzed was the pivot pin. Initially the main concern was that it could shear so the force required to shear it was calculated (see Fig. 8). Material data was obtained online [3], due to the lack of such specifications from the manufacturer, giving some margin of error, but the required force to shear the pin was much greater than any working load the pin would experience. Equation one [4] was used to determine the shear force (the force required to shear the pin).

$$Shear\ Force = \frac{Area \times Shear\ Strength}{2} \quad \textbf{(1)}$$

Where area is the cross-sectional area of the pin and shear strength refers to the strength of the material, in this case acrylic. The calculations proved that the pin would not shear since the force required (982.6 N) for it to fail is almost 10 times greater than the loads it will experience.

$$\frac{(3.16\times10^{-5}\,m^2)(62052815\,Pa)}{2} = 982.6\,N$$

Fig. 8. Shear force required to break pivot pin calculations.

C. Pin Trigger Analysis

In order to determine if the trigger would perform as expected the force required to pull out the pin was calculated. First to obtain the force acting on the trigger pin due to the counter-weight a sum of moments was used (2) [5] (see Fig. 9). The calculated force (see Fig 10). turned out to be 6.15N.

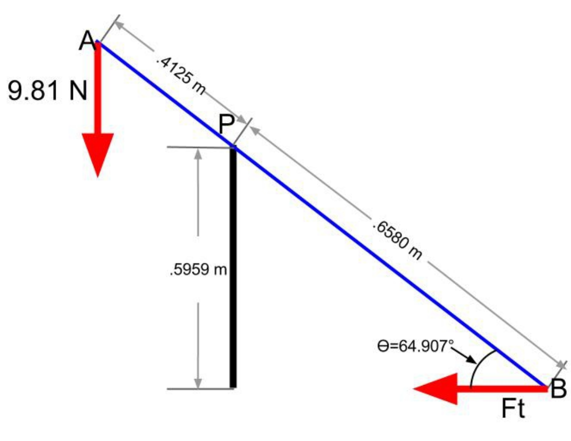

Fig. 9. Reference diagram for force acting on trigger calculations.

$$\sum M_p = [r_{PA} \times -9.81\text{N}\,\hat{j}] + [r_{PB} \times F_t\,\hat{i}] =$$
$$= 0\,\hat{k}\,N\cdot m \quad \textbf{(2)}$$
$$[r_{PA} \times -9.81\text{N}\,\hat{j}] = -[r_{PB} \times F_t\,\hat{i}]$$
$$[r_{PA} \times -9.81\text{N}\,\hat{j}] = -r_{PB} F_t \sin(90-\theta)$$
$$F_t = 6.15\text{N}$$

Fig. 10. Force acting on trigger calculations.

To calculate the force required to pull the trigger pin out. Another sum of moments and forces was taken (see Fig. 11). The resulting equation (3) shows a simple relationship between the force needed to pull the pin out and the force acting on the trigger. The resulting force is equal to 6.15N which is the equivalent of picking up a 0.62kg weight, something that no one should have a problem with.

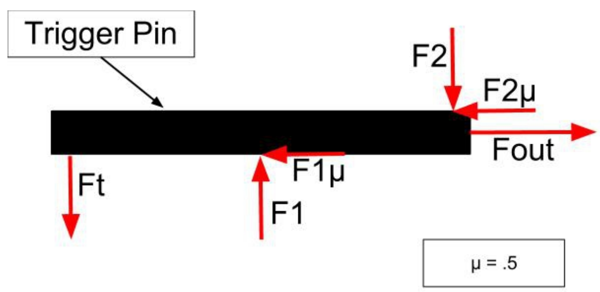

Fig. 11. Reference diagram for pull out force calculations.

$$F_{out} = F_{\mu 1} + F_{\mu 2} \quad \textbf{(3)}$$
$$F_2 = F_1\ b/c \sum F\ , \quad F_2 = F_t b/c \sum M$$
$$F_{out} = 6.15(.5) + 6.15(.5) = 6.15\text{N}$$

Fig. 12. Trigger pin pull out force calculations

V. TESTING

A. Initial Testing

During the initial testing performed by the group a major problem was discovered. The tolerance between the counter-weight and the supporting plates was so tight that the counter-weight would hit the sides of the base. After a couple trials to verify the problem the base was cut in half and a piece of MDF was inserted in-between to resolve the problem. Next the launch angle was adjusted by turning the angle of the hook at the end of the arm. This quick fix jeopardized the pivot pin though. Since the distance between supporting side plates of the base was greater than planned, the spacers in-between the arm and the supports were too small. This resulted in a broken pin during further trial launches since the pin was put in bending rather than pure double shear which it was designed for.

B. Final Testing

Extra spacers were cut and added to the existing ones to place the replacement pin in pure shear. After further refining the launch angle the maximum launch distance that the projectile traveled was 6 meters. This was repeated 3 constitutive times within 5 minutes proving the trebuchet's redundancy.

VI. CONCLUSIUON

The design under-performed when compared to the predicted results. Both of the simulations did not account for friction which was a big factor that reduced launch distance. Also the launch hook could have been improved by making it a straight plate rather than a circular hook, that produced unreliable results. The trebuchet met all functional requirements and exceeded the required launch distance. Fortunately the issues that came into play during initial testing were resolved quickly proving the designs simplicity and adaptability. If the project were to be repeated tolerances should be taken into account to perform less modifications once the prototype is ready to be tested.

VII. REFERENCES

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