MECH2210-1-R-2020F

Dynamics

(Section 1 & 2)

Final Report

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Executive Summary:

The trebuchet is a counterweight weapon and the modern variation is called a floating arm trebuchet. This design of the trebuchet is significantly different from the traditional trebuchet. The design of this trebuchet is composed of the counterweight, base, the projectile, the sling and a rotating arm attached to the frame using a pin joint. The counterweight is placed on a slot in the middle of the trebuchet and is allowed to be dropped vertically downwards, during the drop the potential energy stored in the counterweights is converted to kinetic energy which pulls on the arm and thus launches the sling in the air. Wood is a primary material that has been used to build a trebuchet. The friction between the contacting surfaces is minimized by adding wheels in order to convert the sliding friction to rolling because it is a well known physics fact that rolling friction is less than sliding friction thus more energy is used to launch the sling. The AutoCAD drawing gives the visual representation of the trebuchet along with dimensions. It also shows that the dimensional constraints of the frame, counterweights and the projectile are followed. The trebuchet uses a unique function to release the projectile from the sling and this mechanism is explained in the description provided from the model. The release mechanism is an important aspect of the trebuchet as it decides the angle of release and the initial velocity of the projectile. The initial angle of release needs to be 40-45 degrees to get the longest range possible. The calculation for release velocity is conducted and based on the energy conservation that shows the results 89% efficiency with the release velocity of 31.73 m/s^2. Illustrations have been provided to show the values derived on the working model 2D. The formulas for calculations are referred to from the concept of projectile motion as the trebuchet is one of the applications of projectile motion. The further Rmax calculation shows the maximum range covered by the projectile and the efficiency of the trebuchet that defines the energy loss. After launching the projectile, the trebuchet moves backwards by a fraction of centimeters this is because of Newton's third law of motion which states that every action has an equal and opposite reaction, so when the projectile is launched there is a force acting backwards that pushes the frame back by a few centimeters. The point of impact of the projectile is around the 102m mark but we have the line of fire set at 0.8m in order to avoid the frame to go beyond it . The working 2D model is also given in the report for reference alongside the graph. The graph gives us the information about the projectile's vertical and horizontal height. Overall, the trebuchet helped to understand the basic foundation of projectile motion and the working of it. It also taught us how a small change in a value can bring a huge change in the output. This project also helped us to learn and work as a team that helped us to improve our working culture as a team. The references have been given in the report for further detailed information on the topic. Additional information is also provided in the uncommon words and topics for better understanding at the end of the document in the appendix columns.

Introduction:

Floating Arm Trebuchet is a counterweight based trebuchet which is placed on the top of the drop channel that falls under the influence of gravity which converts potential energy into kinetic energy. The counterweight drops through the channel only after the trigger is released. In the medieval period, it was used as a counterweight siege weapon to break walls of the castle or to bombard a very large surface area. A floating arm trebuchet is a more efficient type of trebuchet. It is 30-40percent more productive than that of a fixed trebuchet. The very primary floating arm trebuchet was constructed which had an arm resting off-centre on an axle with floating hinged counterweight at the short end of the arm. In order to re-use the device again, the counterweight has to be put back to the original place of the trebuchet. Additionally, having two arms with different lengths provide mechanical advantage to the system.

When the counterweight is dropped through the channel with the release of the trigger, the wheel of the axle attached to it moves accordingly which induces torque on each arm to move in the opposite direction that will release the projectile that is kept in the sling. Also, the motion of the payload or the lump through the levers is a projectile motion. This motion in the graph looks like a curve, to be exact, a parabola. To provide high resistance to the impact that is created while the counterweight drops on the ground, beams are attached to the axle. Similarly, friction can be reduced during the dropping down of the counterweight to the glide strike by using silicone grease or a thin film of plastic on the drop channel. One of the points to be noted is that reducing the drop distance of the wheel axle to the glide track would reduce the outcome range of the trebuchet but would also reduce the overall damage to the trebuchet. A picture of the floating arm trebuchet is shown below.

Figure.I. Floating Arm Trebuchet

loating arm Trebuchet can be distinguished from the ordinary trebuchet by observing its arm because its arm has no fixed pivot; that is, it “floats” during a launch. The counterweight is constrained by a track to fall dead vertical, and the entire throwing arm, running on wheels set in a horizontal track, shifts to accommodate the counterweight. This linear drop of the counterweight is more efficient in transferring potential energy to kinetic energy than the pendulum counterweight motion of a traditional trebuchet. Likewise, in a floating arm trebuchet, the torque in the sling can be increased also by using more wheels. For example, using two wheels to convert sliding friction from one wheel to rolling friction on the others to have a more efficient sling. A simple floating arm trebuchet will have the following parts-

1. Counterweight
2. Track
3. Sling
4. Projectile /Pouch
5. Floating Arms/Lever

We know that Potential energy = mgh
Where, m= mass of the body, g=acceleration of the gravity, and h=height from the ground level.
If m and g are constant. The potential energy that is converted to kinetic energy is only dependent on height. Thus, the higher the counterweight is placed, or as bigger the trebuchet is, the maximum is the range of the distance the projectile will travel. However, having more height will also create more impact on the arm on the glide track and will cause eventual damage and may need maintenance to the system. Thus, a proper calculation should be thoroughly done. Besides, a Floating arm trebuchet is very difficult to build than the regular trebuchet. But, an ideal floating arm trebuchet performs always better than the fixed trebuchet.

Detailed CAD drawing:

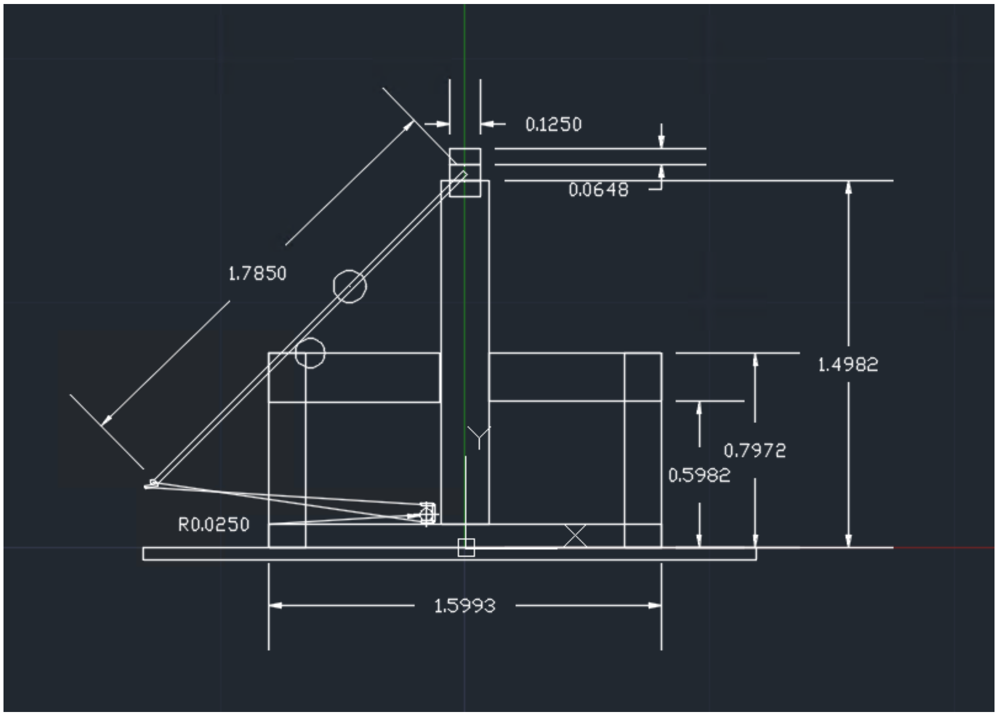

Figure.II. AutoCad drawing

Construction details:

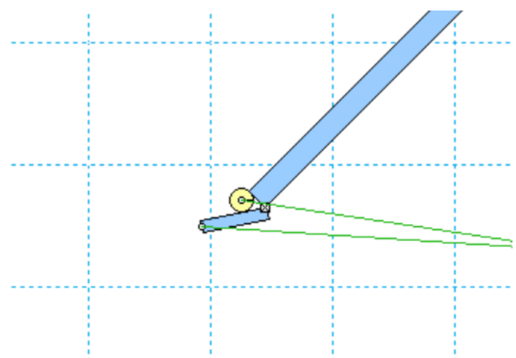

Figure.III. Release Mechanism

For the design we chose to build a floating arm trebuchet to avoid a fixed axis rotation. As per the constraints the trebuchet is made entirely of wood. The arm (long diagonal wood piece) is very thin to keep the trebuchet within the weight limit of 2.5 kg as we are using the maximum counterweight allowed. The throwing arm/ the beam would be connected to the counterweight through a pin joint. The other end of the arm is connected to a small wooden slide which holds another sphere with a completely elastic rope attached to it, this forms our release mechanism. When the counterweights drop along the slot, the arm swings, at some point the sphere on the small slide rolls off and thus allows the projectile to be released from the sling. There are two wheels on the trebuchet, one attached to the arm and another on the frame on which the first wheel rolls, This is done to convert every possible sliding friction to rolling friction. The arm is 1.81 m tall placed at an angle of 45 degrees for optimal range and the wooden frame is 1.498m tall. The individual legs would be 0.797m tall and the width of the whole trebuchet would be 1.6m. With all these parts the total weight of the trebuchet comes to be 1.61 Kg.

Calculations for the efficiency of release velocity:

The trebuchet is a simple sliding arm trebuchet. Our aim was to utilise all the resources and constraints given to us to the best of their abilities. The counterweights have the maximum possible weight to maximise the range. Therefore, the counterweight is 1.08 kg (3*0.360) . The length of the beam is 1.84m even though the total height of the frame does not exceed 1.5 m. The total mass of the trebuchet is 1.617kg. The density of wood was set at 0.5kg/m^3. The static and kinetic friction were utilised as defined at 0.30 and 0.24 respectively. The acceleration due to gravity was set at 9.807m/s^2. The mass of the projectile is 25g and the radius is 2.5cm. The flight time of the projectile is 5.8 s and the angle of release of the sling is 43.79 degrees and the release velocity is 29.01m/s. Also, the line of fire of the trebuchet is 0.8m. So this distance will have to be subtracted from the final distance.
In a perfect scenario, all of the potential energy of the counterweight gets converted to kinetic energy of the projectile as the counterweight falls down. Friction between the counterweight and the ropes is neglected as the counterweights are free falling.

$$m_1gh=\frac{1}{2}mv^2$$

Here m is the weight of the counterweights and the potential energy is being converted to kinetic energy of the projectile.

$$(1.08)(9.807)(1.5) = (0.5)(0.025)v^2$$
$$1270.98 = v^2$$
$$\text{Therefore } v = 35.65 \text{ m/s.}$$

So, the efficiency for velocity is, *31.73/35.65* *100
= **89.004%**.

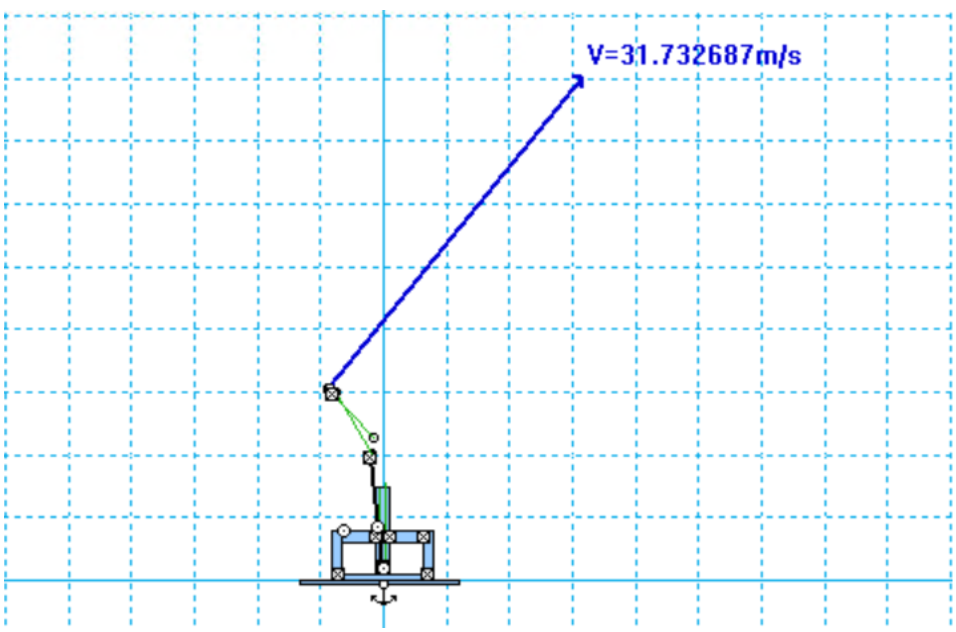

Figure. IV. Release Velocity

Calculation for Rmax and the efficiency of the range:

To increase the efficiency to the maximum possible range, we added wheels to the sides of the throwing arm, to convert the sliding friction caused by the arm on the frame to rolling friction because of the fact that the rolling friction is significantly less than sliding friction and hence less energy is wasted.

The range of our trebuchet was calculated using the formula:

$$Rmax = 2v^2 \frac{Sin\boldsymbol{\alpha}Cos\boldsymbol{\alpha}}{g}$$

Here $\boldsymbol{\alpha}$ = angle of release(43.79)
v= velocity of release(31.73)
g = acceleration due to gravity(9.807)

$$Rmax = 2(31.73)^{\wedge 2} \frac{Sin(43.79)Cos(43.79)}{9.807}$$

$$= \frac{2(1006.79)}{9.807} \text{Sin(43.79)Cos(43.79)}$$

= 205.65 (0.692*0.721)
= 205.65 (0.499)
= **102.80m**

But the line of fire for the trebuchet is 0.8m.
Therefore, the actual maximum range is (102.80- 0.8)m = 102 m.
We found out through the working model 2D analysis that the range of our trebuchet is 101.20m.(102-0.8).

So, the efficiency of our trebuchet is = $\frac{101.20}{102}*100$

= **99.21%**

We find out that given the circumstances of the experiment, our trebuchet is 99.21 percent efficient. The high efficiency can be attributed to wheels on the side of the throwing arm as well as the free fall motion of the counterweights that the floating arm trebuchet provides.
We also recognize that the trebuchet gets pushed back a bit when the trebuchet is fired as it is not bolted/ glued to the ground at all.

About the model:

We built the selected design on working model 2D and with a few tiny changes, we were able to get optimum results, i.e. release velocity of 31.73m/s and the distance travelled to be 102m.

This model is called the floating arm trebuchet. It works on the principle of conservation of energy. The weight is stored at a height so that it has high potential energy and zero kinetic energy. When released, the weight falls vertically downwards due to gravity through a slot, the weights are attached to a rod which has a supporting wheel on it. When the weights fall below a certain height, the wheel touches and rolls over the supporting frame, to smoothly transfer all the kinetic energy to the payload that is attached to a sling that is connected to the rod. The transfer of tremendous kinetic energy results is a high release velocity and when released at an optimum angle, the payload covers a huge length of ground.

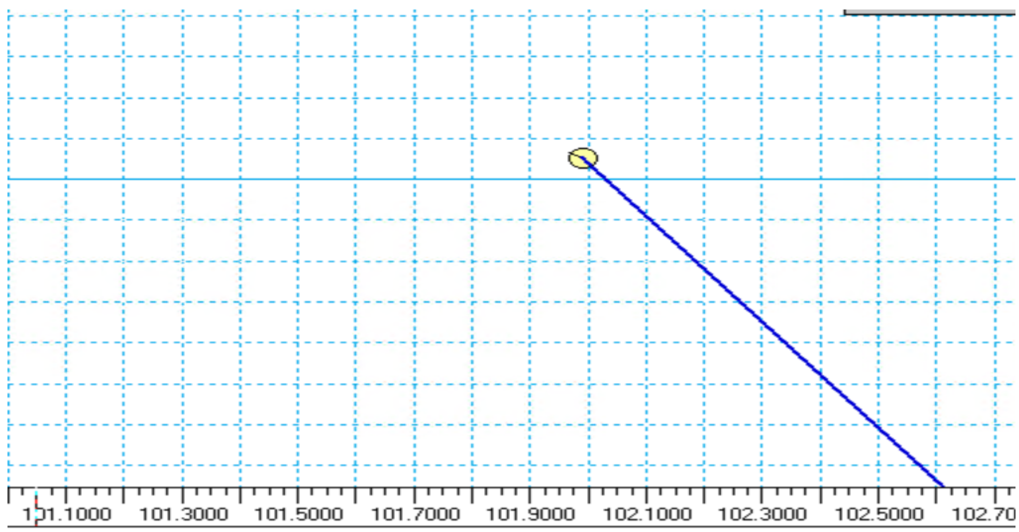

Figure.V. Point of impact

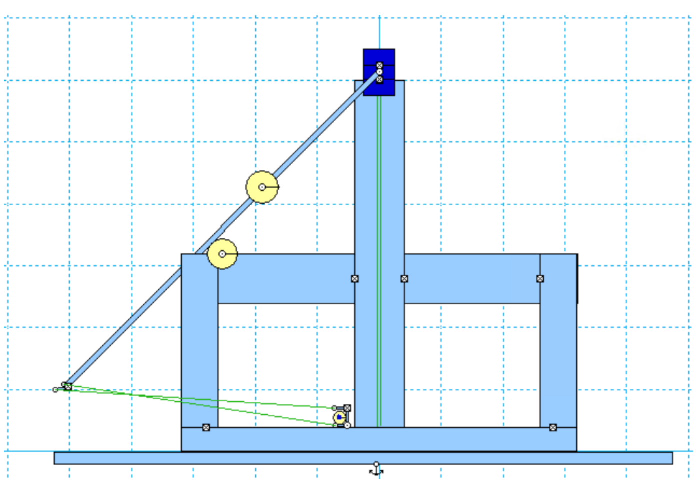

Figure.VI. Working model 2D construction

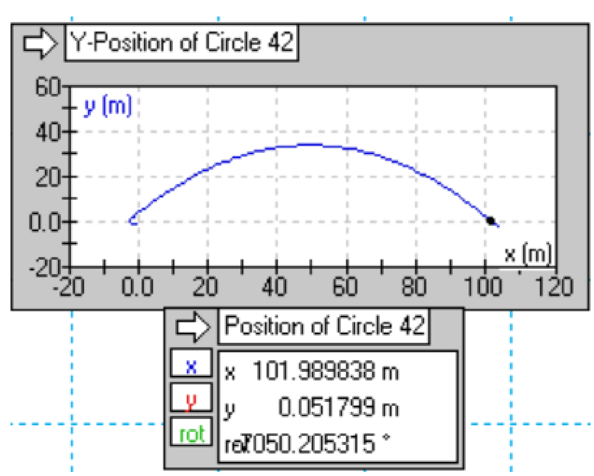

Figure. VII. Graph of the Projectile

Conclusion:

The project on constructing a trebuchet has given us an opportunity to use and understand various aspects of physics such as Newton's 2^{nd} law and law of conservation of energy. This project allowed us to visualize how these laws are applied in real life solutions.Furthermore, the learning outcome of this project mainly focused on learning various design processes like AutoCad and Working Model 2D. In the very beginning, we learnt about the basic structure and ideology of a simple trebuchet. While doing so, we gained enough knowledge about the history and the primary purpose of this device. After that, we came with the preliminary sketches and discussed the best possible design of the trebuchet by staying under the constraints of the project.The chosen design was then recreated in the AutoCAD and virtual testing was done by members through Working Model 2D to learn the working of the trebuchet. While doing so, various trials were done and were preceded with improvements such as arranging the dimensions, adding or subtracting wheels, fixing the wheel of the axles, choosing perfectly rigid material for construction, and using material with smooth surfaces to reduce friction. After the selection of material and finalizing the design, the release mechanism was postulated. Subsequently, analysis on how changes on the variables are affecting the motion, the calculations for release velocity and range covered by the projectile was carried to precisely anticipate the projectile motion of the body. Ultimately, we constructed the floating-arm trebuchet that gave us the best results. This model so far changed the potential energy of the counterweight to the kinetic energy to the maximum possible value. Further as we proceeded, we also found some limitation of trebuchet such as the counterweight cannot be increased after a certain point as the stand was incapable of handling the weight as well as the balance started to fall apart and in the real world scenario the result could be different as the environment started to play its role such as wind which could decrease and change the direction of the projectile. In order to provide more rigidity to the design, we came to know the importance of the beam. Thus, with every step we took, we came across problems related to that particular scenario; however with proper analysis and research, we overcame the difficulty and designed the trebuchet that travels the distance of 102m.

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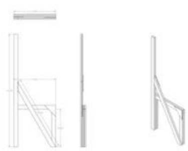
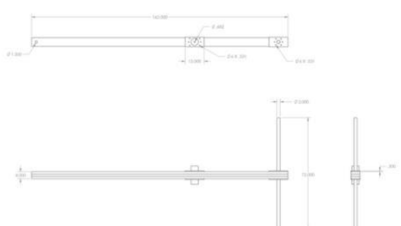
Appendices:

Community Harvest Project: Floating Arm Trebuchet

In the summer of 2019 my supervisor at Waters Corporation approached me to ask if I wanted to join a fundraiser that my coworkers did each year for Community Harvest Project. They would build a trebuchet to launch pumpkins at a harvest festival in early November, and this year they had the idea to field not only their 20’ normal trebuchet, but a second floating arm trebuchet. I had heard of a trebuchet before, but wasn’t really sure what I was getting into. He gave me the height and weight limits rules, showed me a youtube video, and left the design to me.





Quarter frame assembly drawing

Research and initial design idea:

A trebuchet is a weapon of destruction that was predominantly employed in the middle ages to smash enemy walls and to destroy any type of defense from a distance. This weapon was majorly used because it attacked from a distance keeping the army safe from the enemy archers.

To begin this project the team did an individual study on this subject and made notes on the resources gathered. The team also made a simple trebuchet design to clearly understand how each component works. For this project, the task is to maximize the range of the trebuchet. Primarily the range depends on the height of the trebuchet and the weight attached, but since we are already given a fixed number on these components, we had to put a bit more research into the topic. The first thing we focused on was the angle of release, since this is an example of projectile motion we considered 45° to be the optimum angle for maximum range. But, since the arm is raised above the ground when it releases the projectile, the optimum angle is unlikely to be 45˚. There is also the shape of the projectile to consider, as well as its mass and the effects of spin and air resistance which will mean the optimum angle is less likely to be 45˚. To figure this out, we simulated the given trebuchet set up on a few simulators and figured the optimum angle to be between 20˚ and 30˚. We also want to make sure that 100% of the potential energy from the movement of the weights is transferred to the projectile in the form of kinetic energy thus making the projectile velocity, range, and efficiency larger. With our research done into few constructed models, we want to aim for an efficiency of about 60%. To do this, we need to figure out the best way to attach the weights and also the best possible length of the sling, and the arms. This has just been the first step into the research, within the coming few weeks we expect to get more precise with the numbers and customizations needed to get the best possible range.

supposed to have been used. The entire argument for the existence of hybrid trebuchets rests on accounts of increasingly more effective siege weapons. Peter Purton suggests that this was simply because the machines became larger. The earliest depiction of a hybrid trebuchet is dated to 1462, when trebuchets had already become obsolete due to cannons.[33]

Counterweight trebuchet [edit]

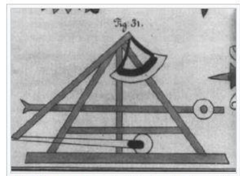
The counterweight trebuchet has been described as the "most powerful weapon of the Middle Ages."[33]

The earliest known depiction of a counterweight trebuchet, by Mardi ibn Ali al-Tarsusi, c. 1187

The earliest known description and illustration of a counterweight trebuchet comes from a commentary on the conquests of Saladin by Mardi ibn Ali al-Tarsusi in 1187.[34][35] However cases for the existence of both European and Muslim counterweight trebuchets prior to 1187 have been made. In 1090, Khalaf ibn Mula'ib threw out a man from the citadel in Salamiya with a machine and in the early 12th century, Muslim siege engines were able to breach crusader fortifications. David Nicolle argues that these events could have only been possible with the use of counterweight trebuchets.[36]

Paul E. Chevedden argues that counterweight trebuchets appeared prior to 1187 in Europe based on what might have been counterweight trebuchets in earlier sources. The 12th-century Byzantine historian Niketas Choniates may have been referring to a counterweight trebuchet when he described one equipped with a windlass, which is only useful to counterweight machines, at the siege of Zevgminon in 1165.[37] At the Siege of Nicaea in 1097 the Byzantine emperor Alexios I Komnenos reportedly invented new pieces of heavy artillery which deviated from the conventional design and made a deep impression on everyone.[38] Possible references to counterweight trebuchets also appear for the second siege of Tyre in 1124, where the crusaders reportedly made use of "great trebuchets".[39] Chevedden argues that given the references to new and better trebuchets that by the 1120–30s, the counterweight trebuchet was being used in a variety of places by different peoples such as the crusader states, the Normans of Sicily and the Seljuks.[40]

The earliest solid reference to counterweight trebuchets in European sources dates to the siege of Castelnuovo Bocca d'Adda in 1199. They were used in Germany from around 1205, in England at least by 1217, and in Iberia shortly after 1218. By the 1230s the counterweight trebuchet was a common item in siege warfare.[41]



Muslim counterweight trebuchet, 1285

Counterweight trebuchets do not appear with certainty in Chinese historical records until about 1268 when the Mongols laid siege to Fancheng and Xiangyang. After failing to take the twin cities of Fancheng and Xiangyang for several years, collectively known as the Siege of Fancheng and Xiangyang, the Mongol army brought in two Persian engineers to build hinged counterweight trebuchets. Known as the Huihui trebuchet (回回砲, where "huihui" is a loose slang referring to any Muslims), or Xiangyang trebuchet (襄陽砲) because they were first encountered in that battle. Ismail and Al-aud-Din travelled to South China from Iraq and built trebuchets for the siege.[42] Chinese and Muslim engineers operated artillery and siege engines for the Mongol armies.[43] By 1283, counterweight trebuchets were also used in Southeast Asia by the Chams against the Yuan dynasty.[44]

> The design of the Muslim trebuchets came originally from the Muslim countries, and they were more powerful than ordinary trebuchets. In the case of the largest ones, the wooden framework stood above a hole in the ground. The projectiles were several feet in diameter, and when they fell to the earth they

Preliminary Sketches:

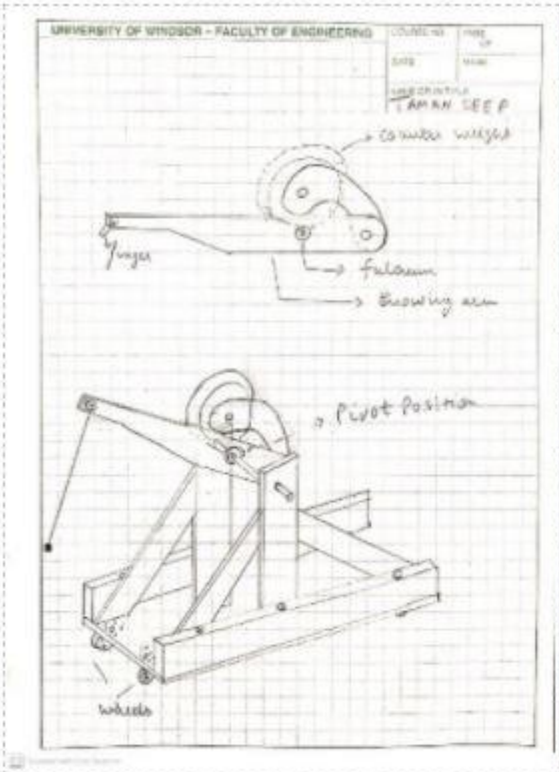


Fig. IV. Taman's Design

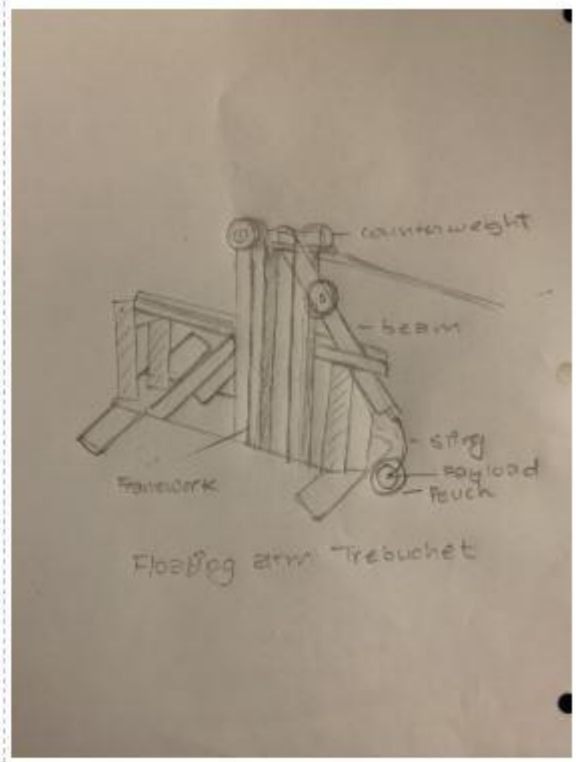


Fig. V. Riwash's Design

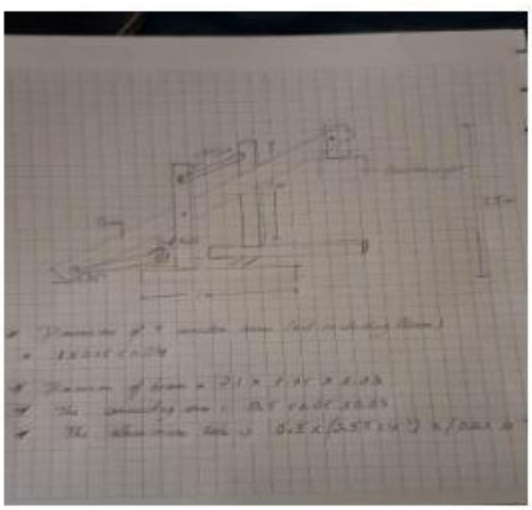


Fig. VI. Milind's Design

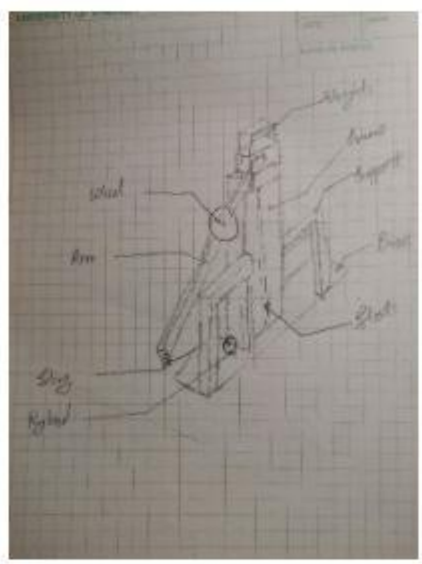


Fig. VII. Hardik's Design

Academic Honesty Statement:

We, Team Neoteric, vow that
1. We completed the assessment item in accordance with any direction provided by the instructor(s). (Typically found on the cover sheet of any test, project, or examination.)
2. That we had no assistance from any other individual(s) during the tutorial, test, project, or examination on any topics relevant to the assessment item.
3. That we did not have any communications of any type with other individuals on the topics of the tutorial, test, project, or examination during the period of assessment.