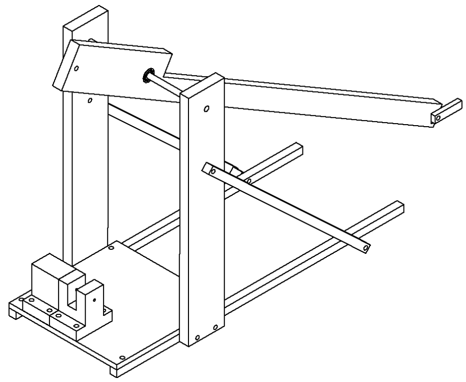
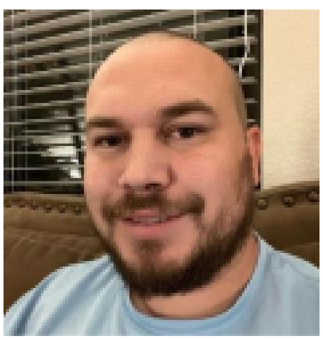
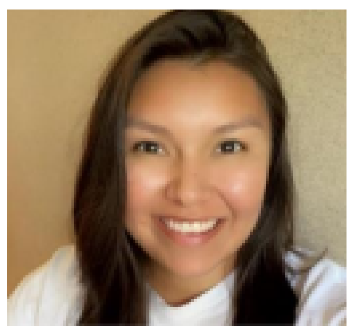
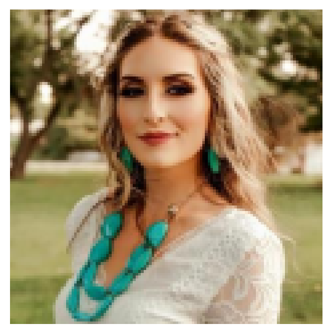
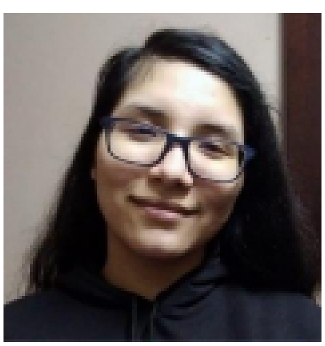
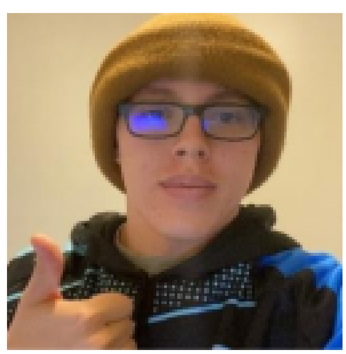
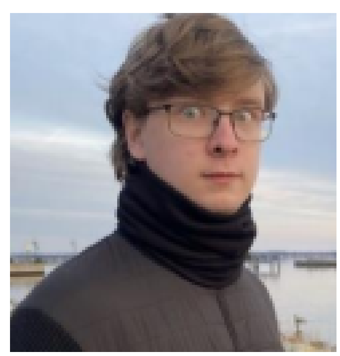
# TEAM YEET

*Project Write Up*

ME – 260L

12/11/2022



**Members of the team:** (Left to right)

Michael Gurule, Precious Frank, Brittany Lundstrum, Alexandra Vasquez, Aiden Romero, Gleb Dziu

# Table of Contents

# Background

The twelfth-century Old French word trebuchet means “siege engine,” from a trebuchet, to “overturn or overthrow.” This trajectory system, shown in Fig. 1, was used as early as 400 B.C.E. in Asia and remained popular as a siege device well into the Middle Ages in Europe. The trebuchet is much more efficient than a traditional catapult in transferring the potential energy of its counterweight into the kinetic energy of its projectile. Making use of centrifugal force, the trebuchet was used to launch heavy projectiles in the hopes of bringing down fortress walls. This siege weapon remained relevant until the advent of gunpowder.

*Figure 1. General Model of a Trebuchet*

From previous grade school science fair experiments to current trending medieval films and tv series, our inspiration eventually became a unanimous decision and the ‘YEET Machine’ was created. After numerous team collaborations and a few upgrades in design we were able to come up with a great concept for our team project.

# Theory

A trebuchet transfers stored potential energy(PE) from a counterweight into a projectile on the other end of a fixed lever, which is usually secured closer to the counterweight. Trebuchets are much more efficient than a standard catapult mainly for the fact that it makes use of a "double lever." The sling, which is attached to the end of the lever arm, acts as a secondary lever itself. Mathematically, this means that the angular velocities of both the main lever arm and the sling compound together to produce a higher launch velocity for the projectile. It was this concept that kept the trebuchet relevant for many centuries.

### Lever Arm Optimization

The optimal ratio for a trebuchet lever arm is 4:1 and this must be achieved while keeping the center of gravity of the lever arm as close to the weight side as possible. Creating this out of a 24" piece of aluminum left us with the approximate dimensions of 19":5" with the throwing arm being half the width of the counterweight arm. Using a virtual trebuchet simulator as a reference, and assuming a launch angle of 45 degrees, it was determined that a trebuchet with these dimensions can throw a projectile the required distance of 10ft while requiring a 5lb weight. This simulation is pictured below.

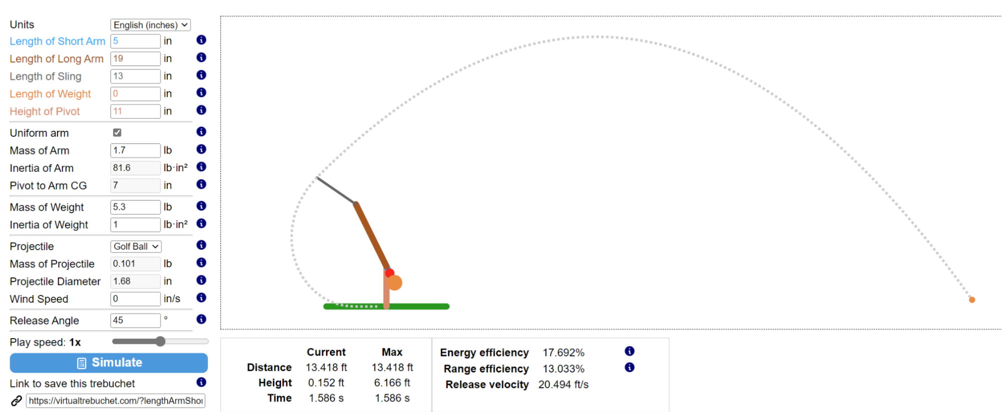



*Figure 2. Simulation of Trebuchet*

**Launch Velocity**

The launch velocity required for a trebuchet to throw an item the required 14 ft(accounting for adjustability and the item being thrown from behind the assembly) can be determined through the equation for horizontal range which is $d = \frac{sin(2\theta)v^2}{g}$ where d is the distance in meters, $\theta$ is the launch angle, v is the launch velocity in $\frac{m}{s}$ and g is gravity($9.8\frac{m}{s^2}$). Plugging in our numbers and solving for the launch velocity needed to throw this projectile 4.3m(14ft.) we find that we will need a launch velocity of 6.46$\frac{m}{s}$.

# Engineering Drawings

## Assembly Drawings

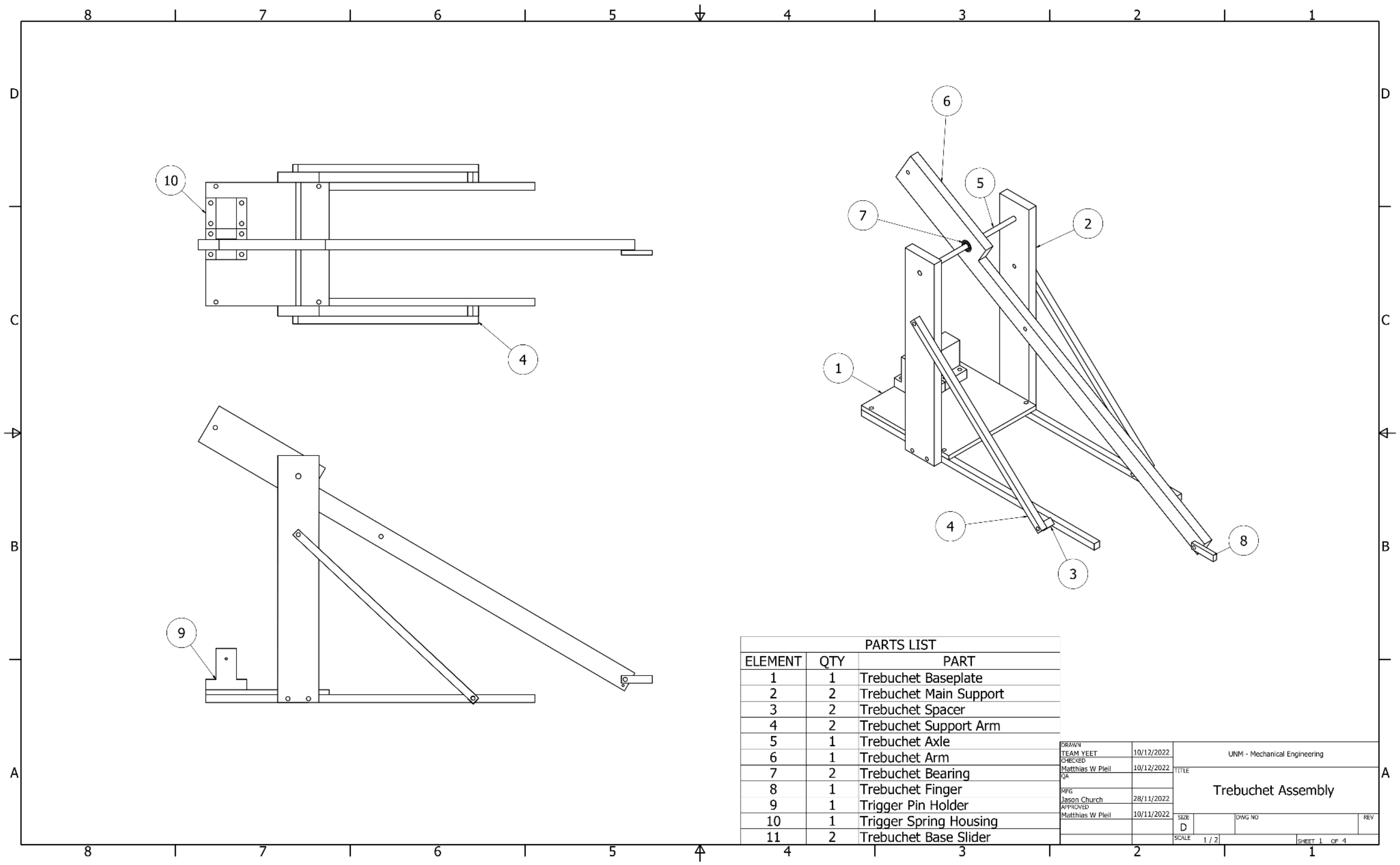
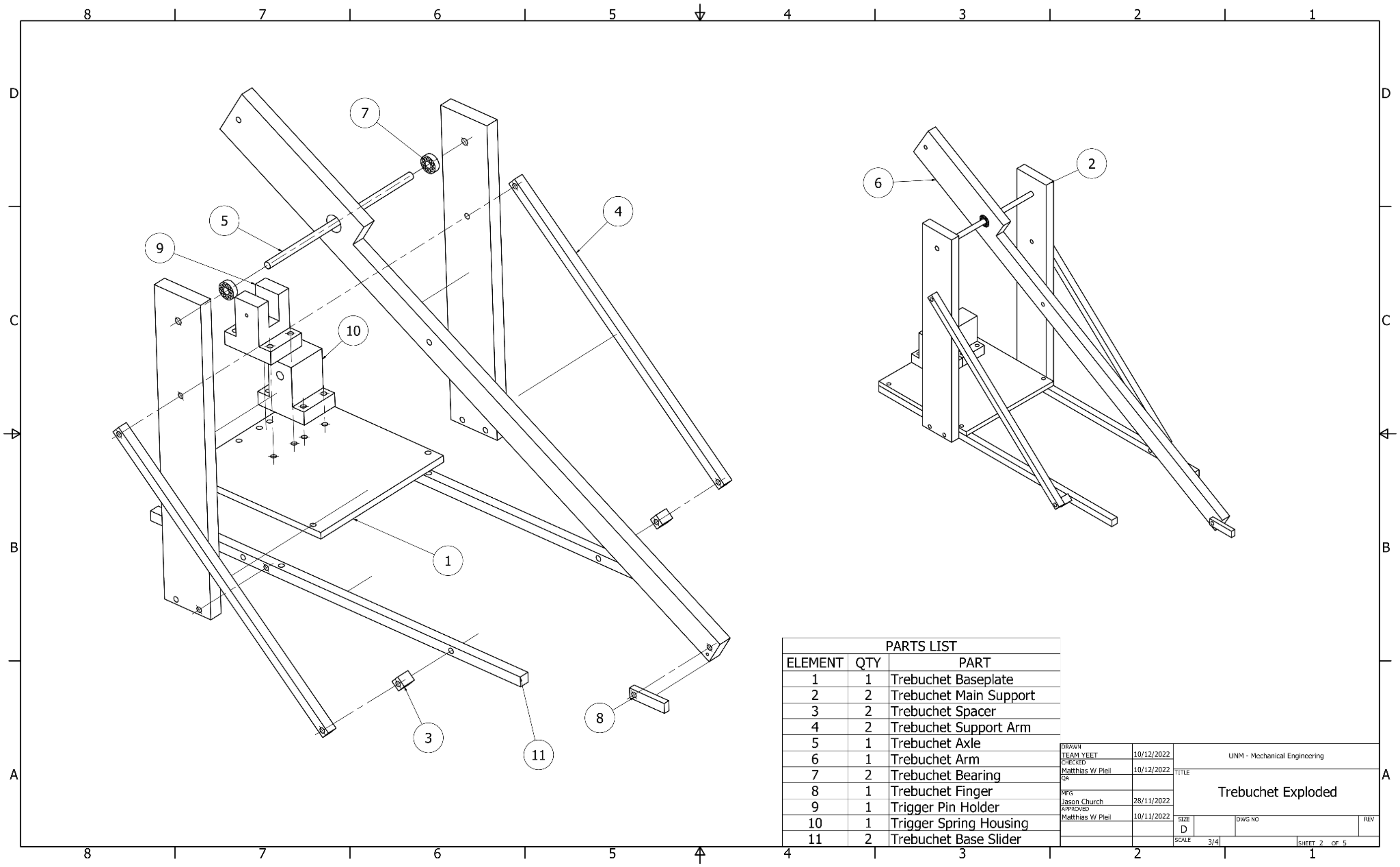



*Figure 3. Trebuchet Assembly Drawing*




| PARTS LIST | | |
|---|---|---|
| ELEMENT | QTY | PART |
| 1 | 1 | Trebuchet Baseplate |
| 2 | 2 | Trebuchet Main Support |
| 3 | 2 | Trebuchet Spacer |
| 4 | 2 | Trebuchet Support Arm |
| 5 | 1 | Trebuchet Axle |
| 6 | 1 | Trebuchet Arm |
| 7 | 2 | Trebuchet Bearing |
| 8 | 1 | Trebuchet Finger |
| 9 | 1 | Trigger Pin Holder |
| 10 | 1 | Trigger Spring Housing |
| 11 | 2 | Trebuchet Base Slider |

*Figure 4. Trebuchet Assembly Exploded View*

## Detail Parts Drawings

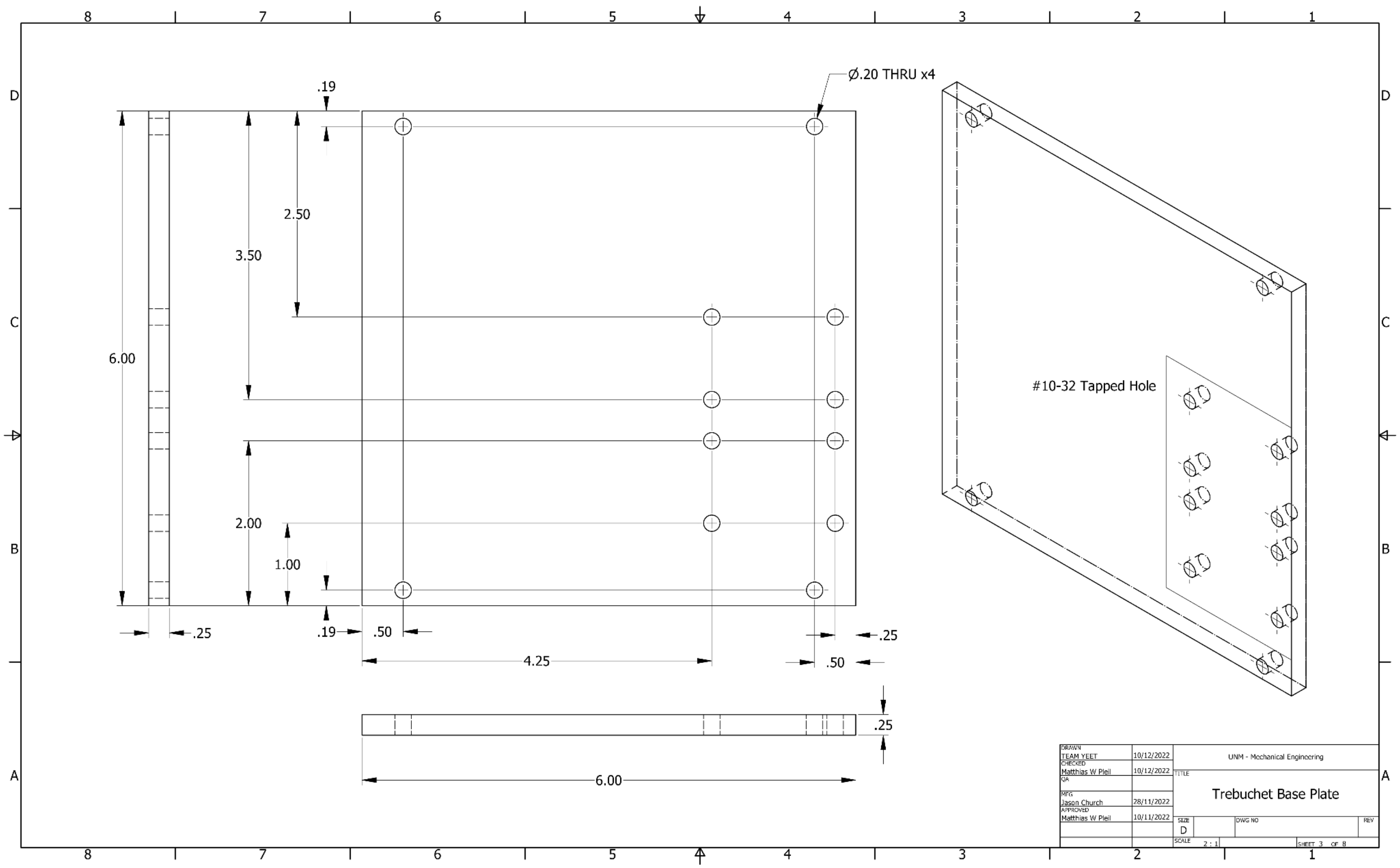



*Figure 5. Trebuchet Base Plate Drawing*

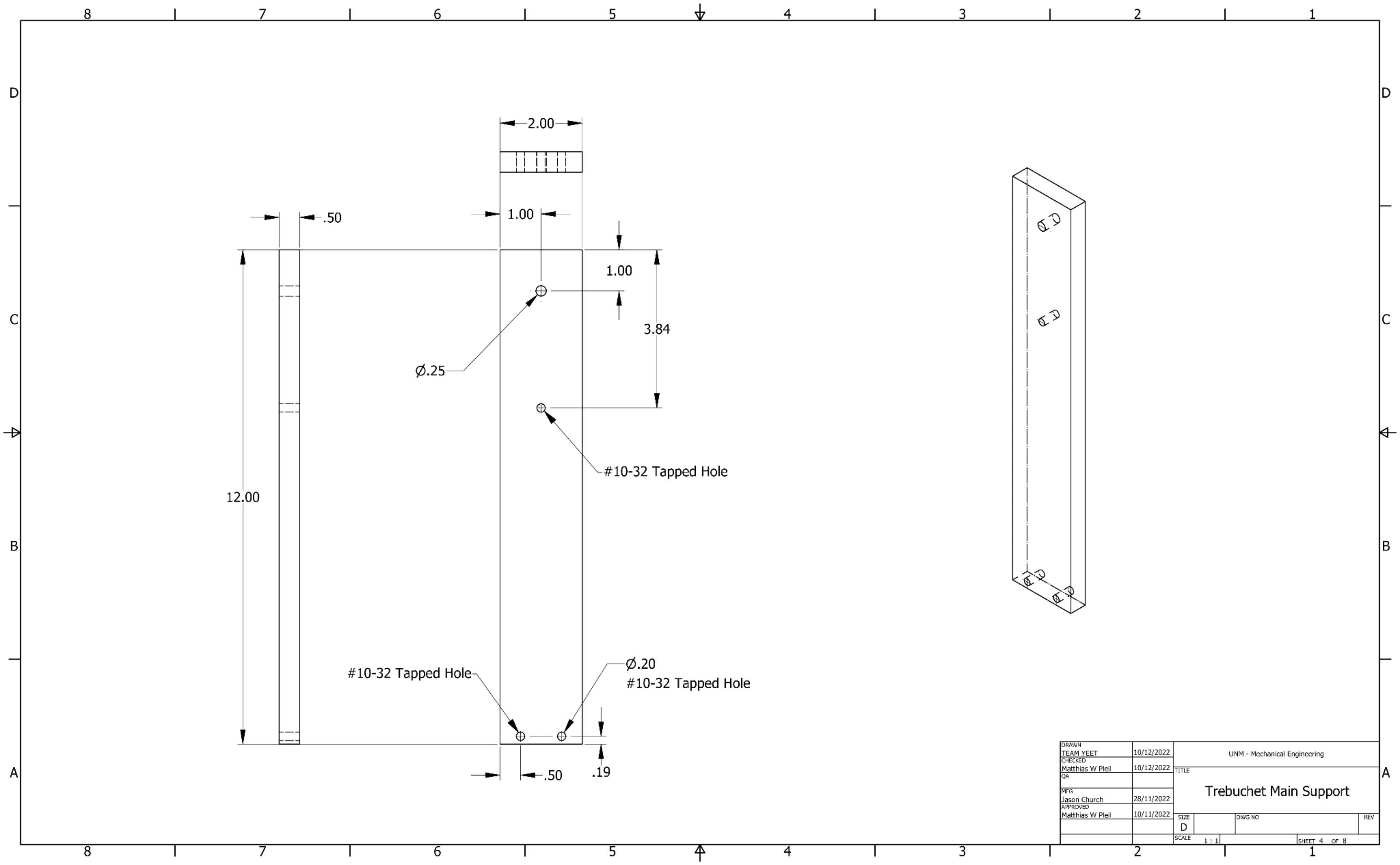



*Figure 6. Trebuchet Main Support Drawing*

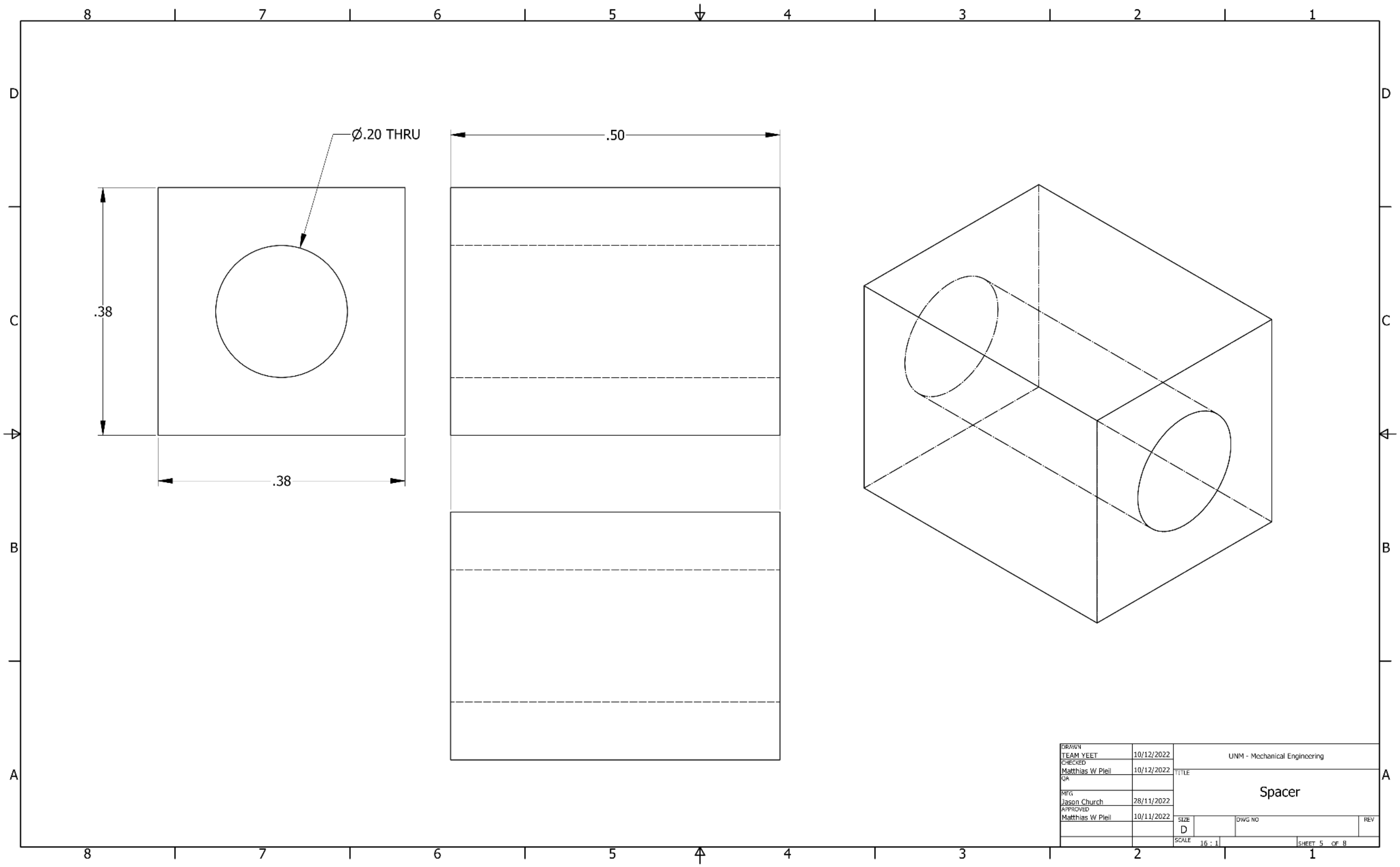



*Figure 7. Trebuchet Spacer Drawing*

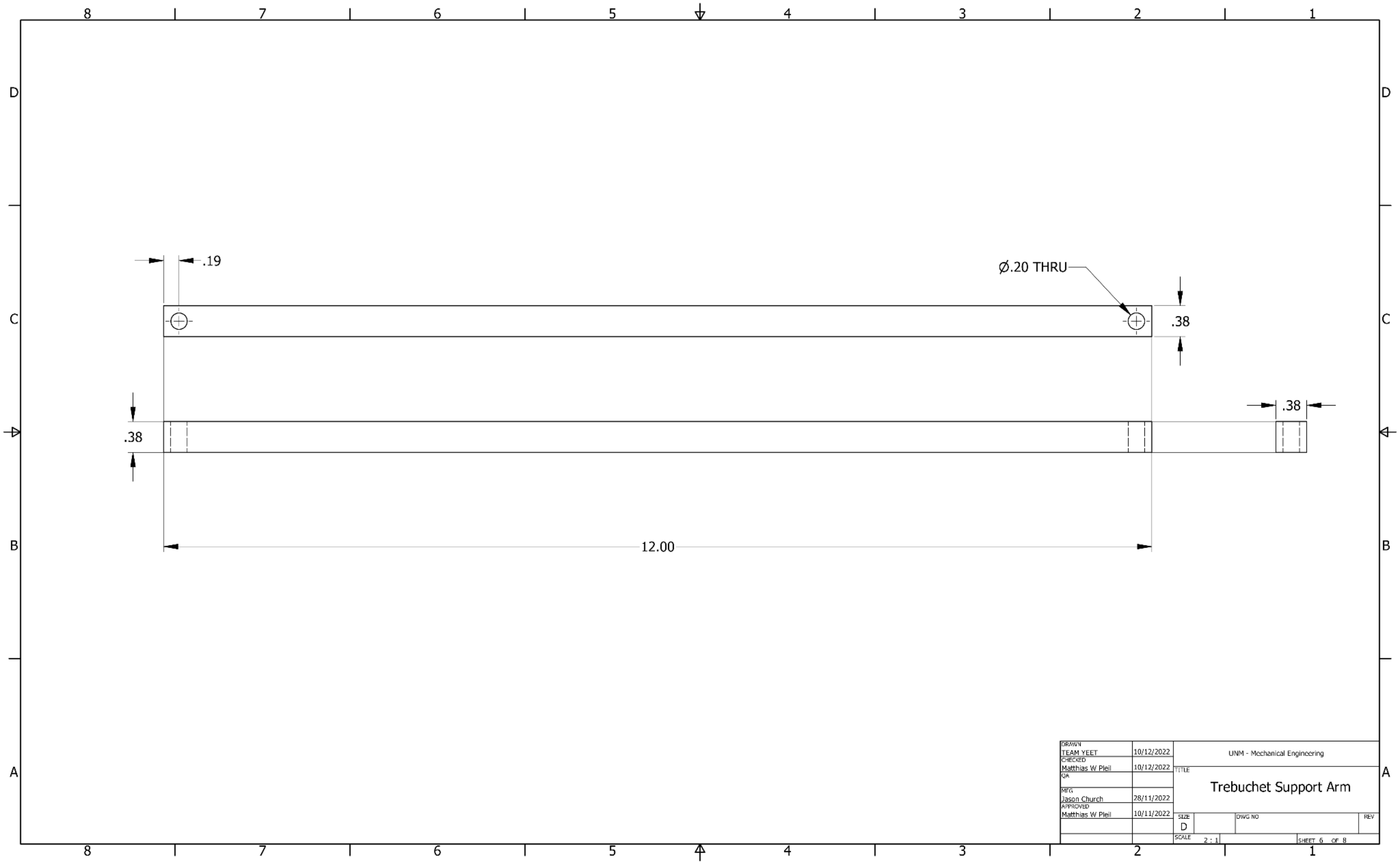



*Figure 8. Trebuchet Support Arm Drawing*

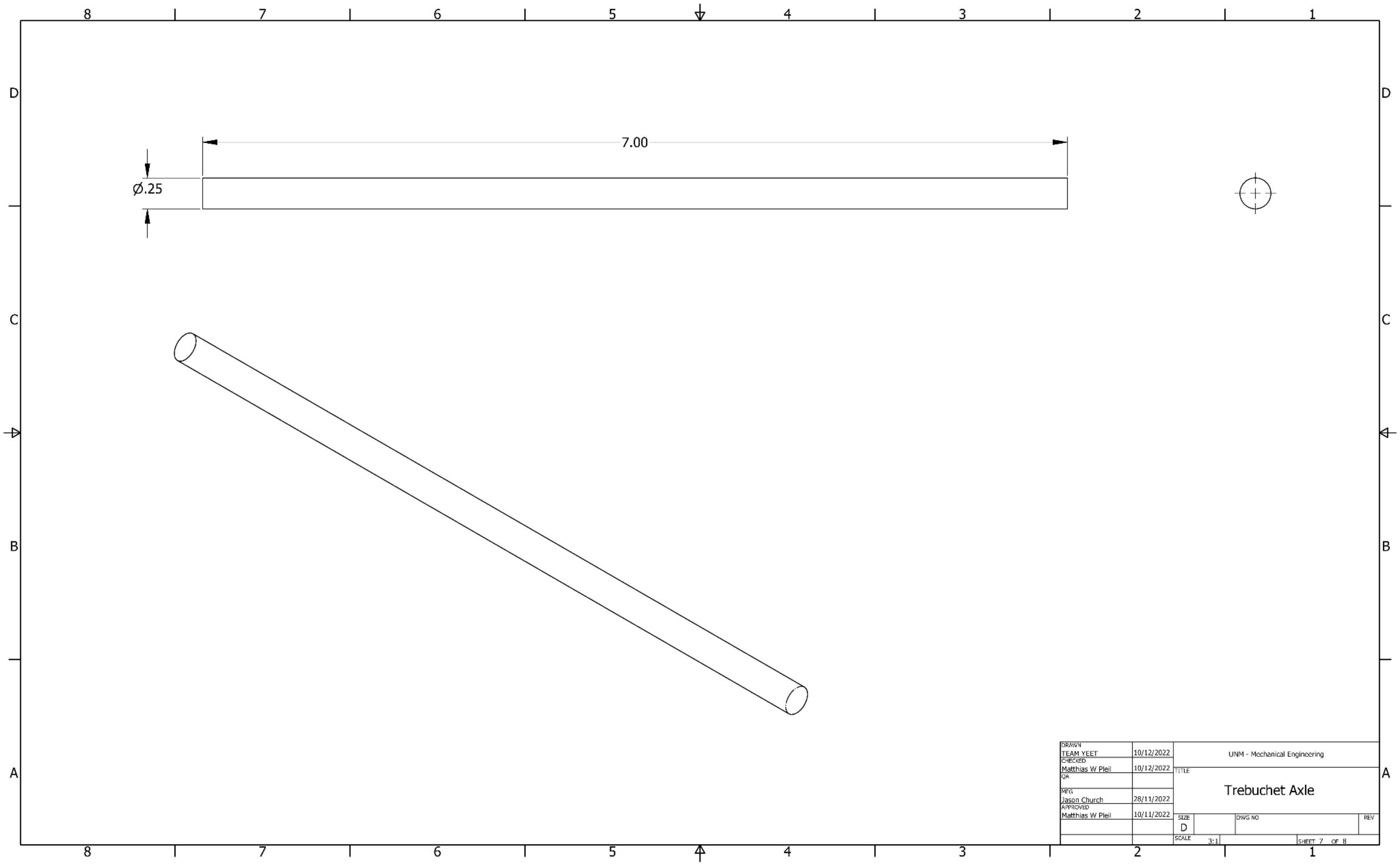



*Figure 9. Trebuchet Axle Drawing*

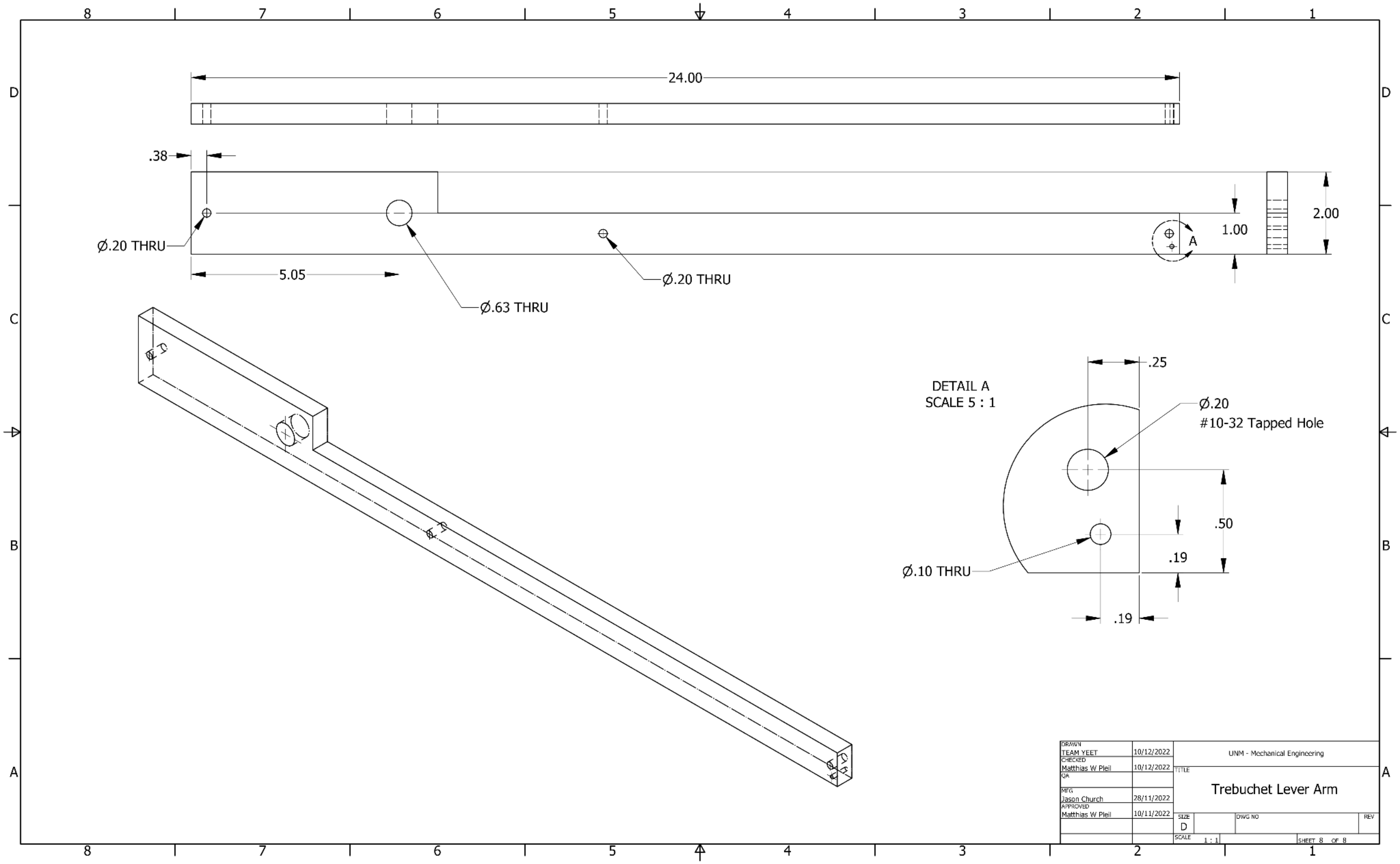



*Figure 10. Trebuchet Lever Arm Drawing*

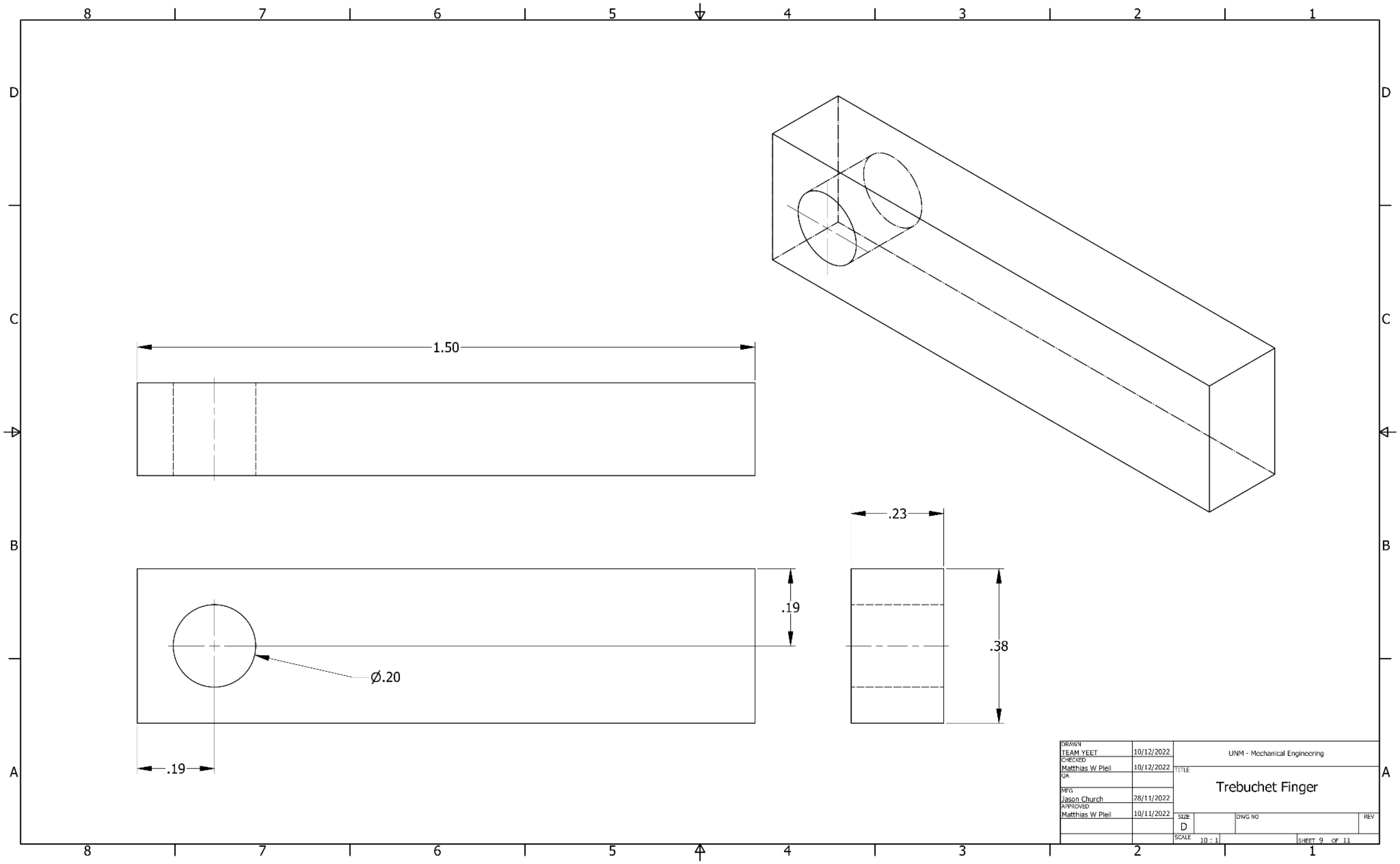



*Figure 11. Trebuchet Finger Drawing*

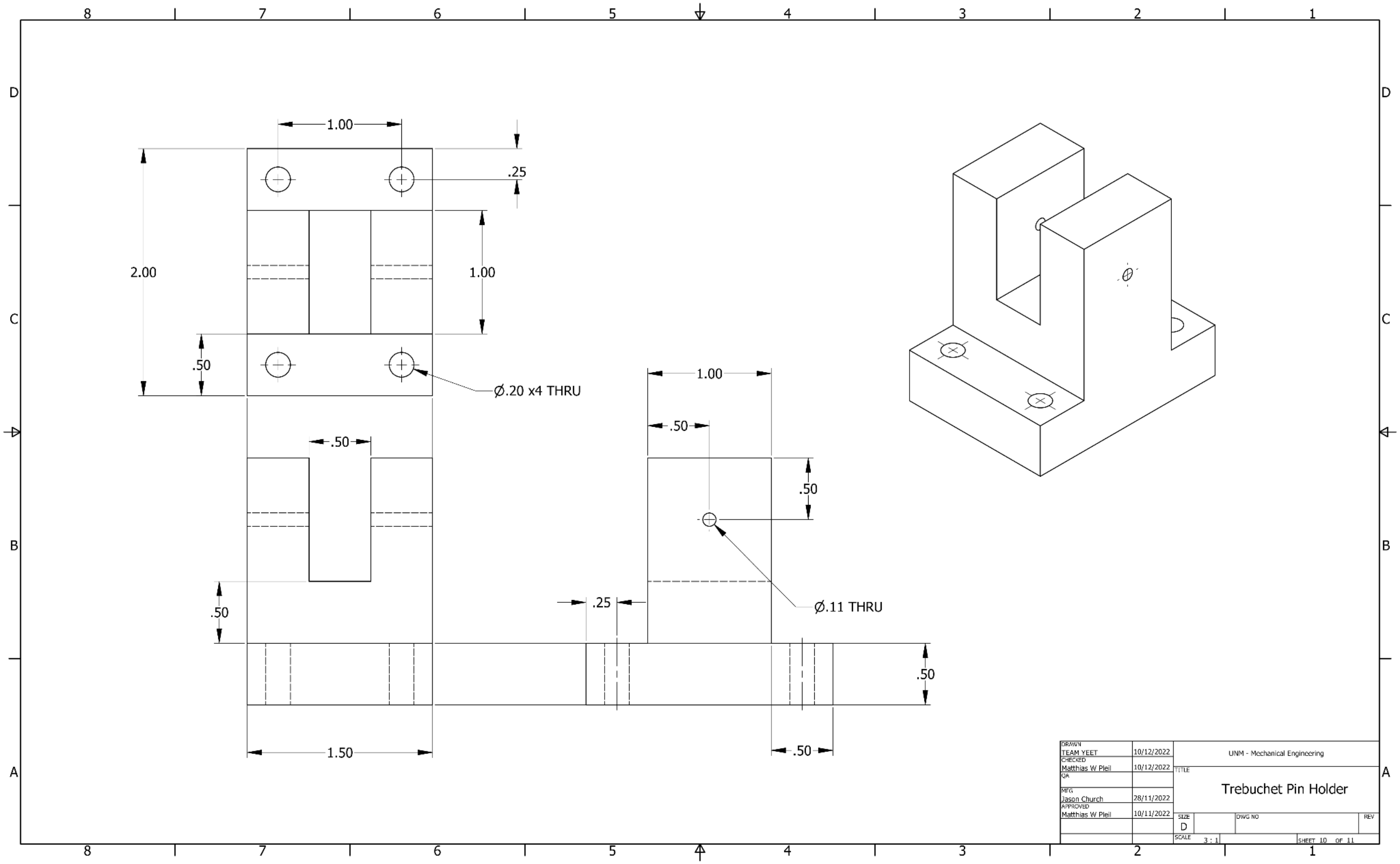



*Figure 12. Trebuchet Pin Holder Drawing*

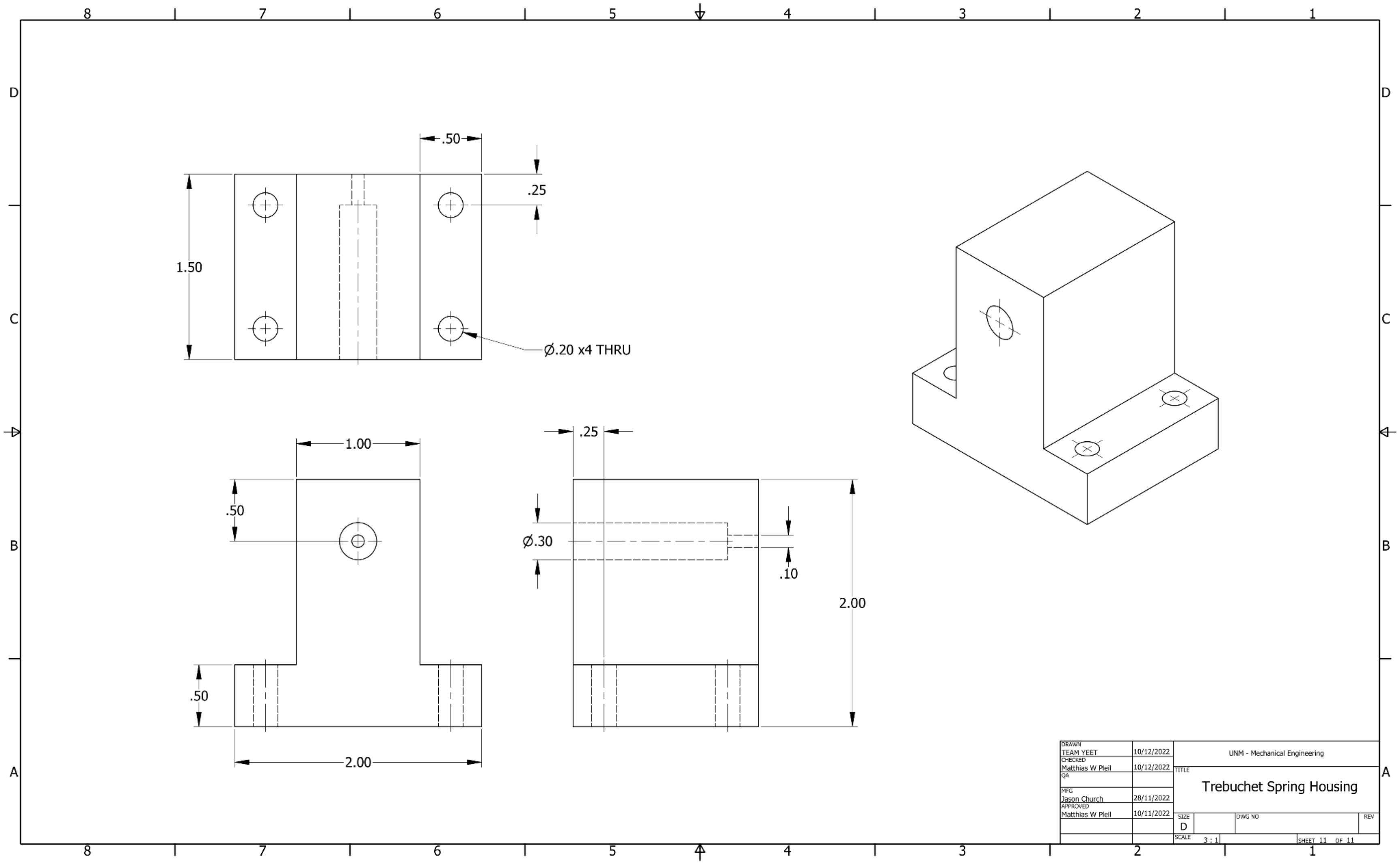



*Figure 13. Trebuchet Spring Housing Drawing*

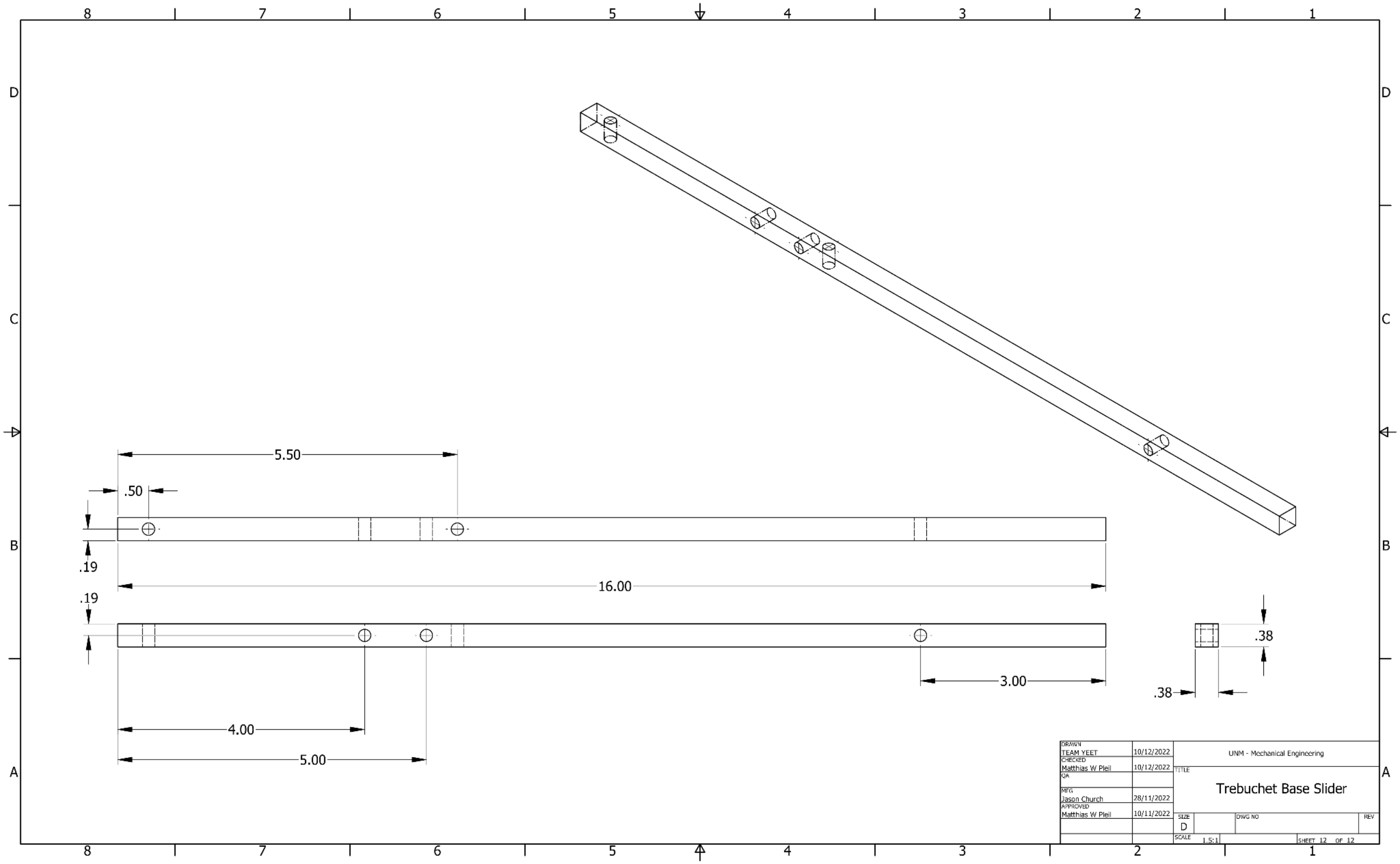



*Figure 14. Trebuchet Base Slider Drawing*

# Standard Parts List

For this launch system, we have the following parts:

- Lever Arm: The main part for the trebuchet, the one that takes care of launching the projectile as it is attached to it.
- Main frame: The base in where the trebuchet will stand.
- Supports: Brings stability to the trebuchet and support for the launch.
- Actuator System: Is responsible for moving and activating the lever arm for the throw.

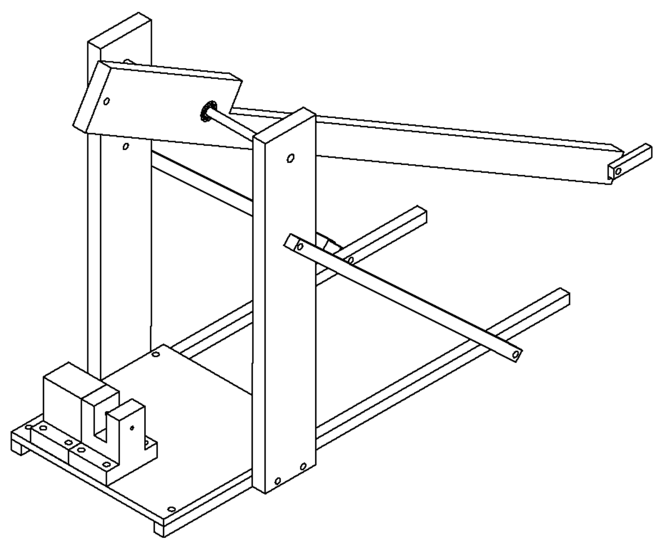


*Figure 15. Trebuchet Final Design*

# Machining Process

The Machining Process used in (Figure 17) is a milling machine with a 6-inch vice to hold the base plate. A #7 size drill was used for the four outer holes of the base plate. In (Figure 17.) the 8 holes in the red shaded region were drilled with a #22 drill size and tapped with a 10-36.

*Figure 16. Brittany Machining Base Plate*

*Figure 17. Machining holes on Base Plate*

*Figure 18. Base Plate 98% done* *Figure 19. Trigger Spring Housing*

As a final result, we have in Figure 20, the assembled and painted trebuchet after the machining of every part.

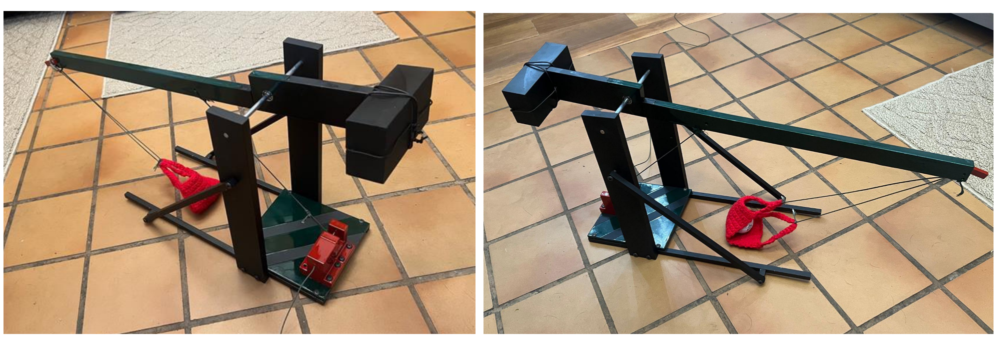


*Figure 20. Assembled Trebuchet*

# Experiment Data

The standard deviation(SD) at our chosen angle of 50 degrees was calculated to be 2.6in. Meaning that the projectile lands 2.6in north or south from the center on average.

*Table 1. Experimental data at various launch angles and distances*

| Launch Angle (◦) | Average Distance | Launch distance 1-10 measured from sling | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 45 | 13'6" | 13'7" | 13'3" | 13'9" | 13'4" | 13'8" | 13'6" | 13'2" | 13'7" | 13'2" | 13'10" |
| 50 | 13'0" | 12'10" | 13'3" | 13'0" | 12'11" | 13'5" | 12'9" | 12'11" | 13'0" | 13'1" | 13'3" |
| 55 | 12'5" | 12'3" | 12'2" | 12'8" | 12'6" | 13'0" | 12'4" | 12'7" | 12'3" | 12'4" | 12'6" |

**Regulating Distance**

Regulating counterweight height was found to be a significant contributor to regulating launch distance. When the counterweight was found to be slightly lower or higher than desired, the projectile would launch shorter or further respectively. Counterweight height is controlled by the length of string between the middle of our lever arm and our trigger mechanism. Once this was fixed we found more consistent distances during testing. While tuning the device to the optimal trajectory we found that the angle of our aiming finger successfully gave us control of the release angle of our projectile. Adjusting the aiming finger in the positive direction toward the target lowers the launch angle resulting in a lower elevation while the negative direction toward the sling will increase the launch angle resulting in higher elevation. Optimal launch angle for max distance is 45 degrees. It was found that a launch angle of approximately 50 degrees is optimal for this challenge using this device.

## Fine Tuning

Below is an illustration of a grouping of 10 shots that were taken from 13ft during testing (Figure 21). Sling placement prior to engaging the device was an important factor in precision operation. When the sling is tight there is less energy lost during launch and this results in a slightly longer distance covered by the projectile. Conversely, if the sling has slack in the line during launch it seems to dampen the trebuchet and will result in a shorter launch. It was also found that if the sling is not centered correctly the resulting launch will be off target to the left or right.

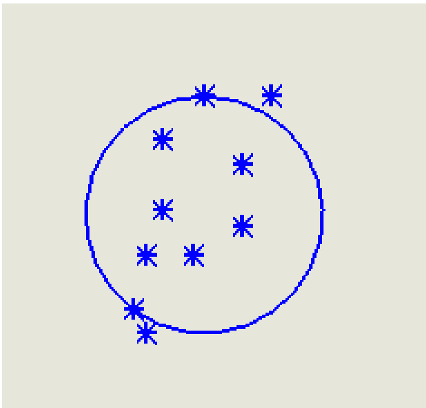


*Figure 21. Schematic of the 10 Shots*

**Confirming Launch Velocity**

The theoretical launch velocity needed to sling a projectile 4.3m(14ft) at 45 degrees was calculated as $6.46\frac{m}{s}$. In order to estimate our launch velocity experimentally, it was necessary to calculate and sum all the angular velocities at play (W1 and W2 in Figure 22) and then multiply this value by the distance from the axis of rotation during launch. This will provide a velocity of the projectile. To find the angular velocities, a video was taken of the device in action and the time it took for both the lever arm and the sling to travel 1.57 radians, 90 degrees, was recorded. The angular velocities W1 and W2 were calculated to be approximately equal as they both occurred over a time period of 0.4s. Because they are equal we can now find the estimated launch velocity from the formula $2\omega r = v$. Solved with our estimated values we get $2 \times 3.93\frac{rad}{s} \times 0.84m = 6.6\frac{m}{s}$. This estimated value is close enough to the theoretical value to be considered accurate. A difference in launch angle, estimated values and measuring equipment limitations are more than likely the culprit for these differences in values.

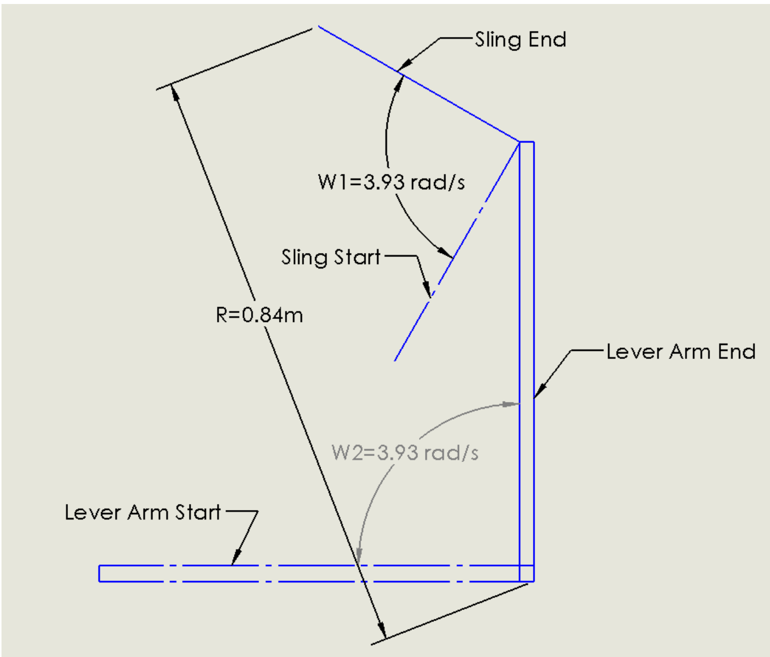



*Figure 22. Schematic of the Launch Velocity*

**Efficiency**

When judging the efficiency of our device we can use the Law of Conservation of Energy to solve for the ideal launch velocity of a trebuchet with a 5lb weight. This formula is $MgH = \frac{1}{2}mv^2 + mgh$ where M is the mass of our counterweight, g is gravity, H is the height of counterweight prior to launch, m is the mass of the projectile, v is the launch velocity of the projectile, and h is the height of the projectile. Each of these equations are the equations for Potential Energy of the counterweight, Kinetic Energy and potential energy of the golf ball at launch, respectively. Plugging in our values of M=5lb, H=0.13m, g=$9.8\frac{m}{s^2}$, m=1.01lb, and h=0.84m we have a theoretical launch velocity of $10\frac{m}{s}$ . Comparing this to our calculated value of 6.6$\frac{m}{s}$ we can conclude that our design has an approximate 66% efficient launch velocity compared to an ideal model. Factors that will factor into this loss will be design, environmental factors and loss due to dampening forces in materials.

# Modifications and Lessons Learned

At the beginning of our project, our team made the decision to build a trebuchet. Some of the reasons that we came to this decision are because there are many historical designs available for us to learn from. It also worked well with the materials that we were provided.

We had at first discussed having the launch arm fold to create a faster launch speed, but we decided that that would overcomplicate things. We added a base plate to hold the two supports and the trigger mechanism. This was done to add overall stability to our design, and it worked better with the materials provided.

Something we did not consider revising until it was too late was the weight we used. We attached it to the lever arm by drilling a hole and attaching it with wire to attach the weight, instead of machining it to attach. The reason that we did not create a system to attach a weight is we wanted it to be versatile enough that we could substitute other weights and we did not want to be limited to a specific weight.

During the time we built the trebuchet we had to be mindful of the limitations of the equipment that we used and the limitations that the machines had. For example, we had some minor issues machining small parts because of the vibrations causing damage to the more fragile parts.

In the testing phase, we learned it was important to ensure that the sling that held the projectile was in the same place as the previous launch to be precise.

Making a trebuchet as a team helped us improve our communication and learn how important it is among engineers. Each part must fit together to make a well-functioning machine and it is each engineer's responsibility to clearly communicate their vision to each other.

# Hours Logged

Every team member has reported that every part of the project they have made was done with the utmost care and attention to detail presented on the blueprints. The above statement is supported by the fact that the trebuchet itself came together nicely without a hiccup. Every team member was a nice addition to the team, keeping team spirit and completing their parts before the due dates.

*Table 2. Time Log for each member of the team*

| | Designing time | Part Machined | Date machined | Hours per day |
|---|---|---|---|---|
| Michael Gurule: | 10 hours in early november | Lever arm | Nov 17th | 4 |
| | 3, 45 minute meetings | | Nov 22nd | 4 |
| | | Aiming finger | Nov 28th | 1 |
| | | Axle | Nov 28th | 1 |
| Precious Frank: | 3, 45 minute meetings | Two base rails | Dec 5th | 4 |
| | | | Dec 6th | 2 |
| Brittany Lundstrum: | 3, 45 minute meetings +1h device assignment | Base Plate | Dec 7th | 4.5 |
| Alexandra Vasquez: | 3, 45 minute meetings | Side supports and spacers | Nov 23rd | 2 |
| | Exploded View Drawing | | Dec 10th | 2 |
| Aiden Romero: | 3, 45 minute meetings | Trigger housing | Dec 7th | 4 |

| | | | | |
|---|---|---|---|---|
| | | Trigger | Dec 8th | 2 |
| Gleb Dziuba: | 3, 45 minute meetings | Two base plates | Dec 6th | 4 |

Finally, we have the total amount of hours that every team member spent on this project during the semester.

*Table 3. Time Log in total*

| | **Total hours** | | **Total hours** |
|---|---|---|---|
| **Michael Gurule:** | 22.5 | **Alexandra Vasquez:** | 6.5 |
| **Precious Frank:** | 8.5 | **Aiden Romero:** | 8.5 |
| **Brittany Lundstrum:** | 8 | **Gleb Dziuba:** | 6.5 |

# Citations and References

Finio, Ben. “Build a Mini Trebuchet.” Scientific American, Scientific American, 19 May 2016, www.scientificamerican.com/article/build-a-mini-trebuchet/

V., Satya. “Trebuchets!!!” TREBUCHETS!!!, http://pleasehelpmewithphysics.blogspot.com/2012/05/trebuchets.html

Trebuchet Mechanics - Weber State University. https://faculty.weber.edu/kharward/MET1000/trebmath35.pdf

“The Trebuchet.” USC Viterbi School of Engineering, 11 Nov. 2017, https://illumin.usc.edu/the-trebuchet/

Virtual Trebuchet: A Web Based Trebuchet Simulator, https://virtualtrebuchet.com/?lengthArmShort=5&lengthArmLong=19&lengthSling=13&lengthWeight=0&heightOfPivot=11&massArm=1.7&inertiaArm=81.6&pivotToArmCG=7&massWeight=5&inertiaWeight=1&massProjectile=0.101&projectileDiameter=1.68&windSpeed=0&releaseAngle=50&units=englishi&projectile=golfBall&uniformArm=true&distance=3.444110817945612

Trebuchet Time, http://tuhsphysics.ttsd.k12.or.us/Research/IB08/ConnBrabJohn/Connbrajoh.htm#:~:text=According%20to%20Bob%20Kibble%20of%20Physics%20Review%20%282005%29%2C,weight%20and%20range%20of%20the%20projectiles%20and%20gravity