# Trebuchet Technical Report

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***Abstract*—This report details the design process used to construct a trebuchet. The trebuchet was made of 1/8 in. medium density fiberboard, had a main pivot arm axle made of 1/4 in. diameter acrylic rod, and was triggered by a servo. A MatLab simulation used varying dimensions of the trebuchet in order to maximize the launch window while minimizing the reaction force on the main pivot arm axle. The analysis showed that the main pivot arm axle did not fail or deform too much. The drawings of the trebuchet were made using AutoDesk Inventor and the parts of the trebuchet were laser cut. The parts were assembled using wood glue and the pin on the main arm was adjusted to release a 27g rubber ball at 45 degrees. The launch distance was only about 9m, which was less than the desired distance of 12m.**

## I. Introduction

A trebuchet was constructed and this report details the design process. The trebuchet had to meet the following functional requirements: launches a 27g rubber ball, 1/4 in. acrylic rod used as the main arm axle, assembled using wood screws or glue, uses a servo controlled by an Arduino board as the trigger mechanism, and uses only a 4 lb weight as the counterweight. The final trebuchet is shown in Figure 1. This paper will explain each step taken in the design process of the trebuchet, from choosing the dimensions to experimental validation.

## II. Concept Generation and Evaluation

### A. Finding the Design Parameters

MatLab code was used to find the launch window, the amount of time that the trebuchet can release the ball in order for it to go over 12m, and the reaction force on the acrylic rod. Code was run changing the dimensions of the trebuchet, shown in Figure 2 [1]. The lengths of the counterweight arm were iterations of .11m to .35m, and the sling arm were iterations of .46m to .7m. The length of the counterweight pivot was always the pivot height, which was half a meter, minus .05m more than the length of the counterweight arm, to ensure the weight did not hit the base of the trebuchet, and the length of the rope attaching the ball to the arm was equal to the length of the sling arm.

The plots shown in Figures 3 and 4 show the launch window and reaction force, respectively, for the differing values of the counterweight arm and sling arm length.

## III. Analysis

### A. Analyzing Forces on Axle and Servo

To find a reaction force that would not result in too much deflection, or even failure in the acrylic rod, the deflection of

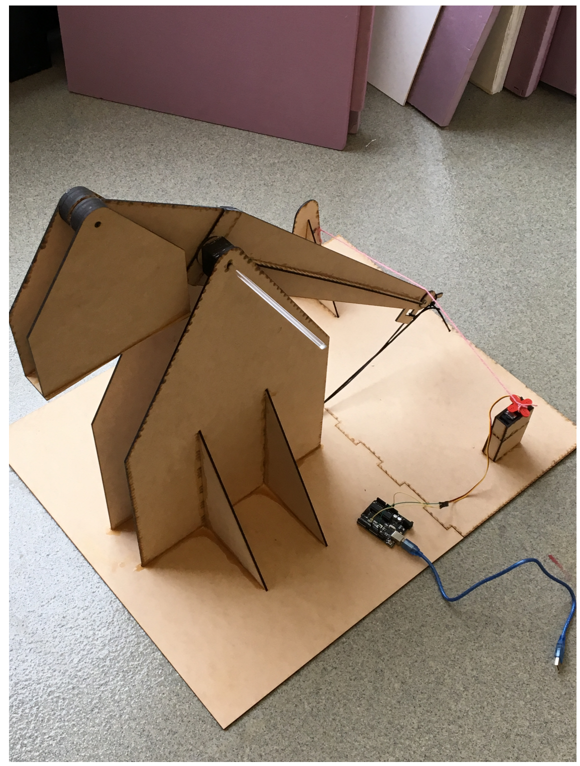


Fig. 1. Final Trebuchet

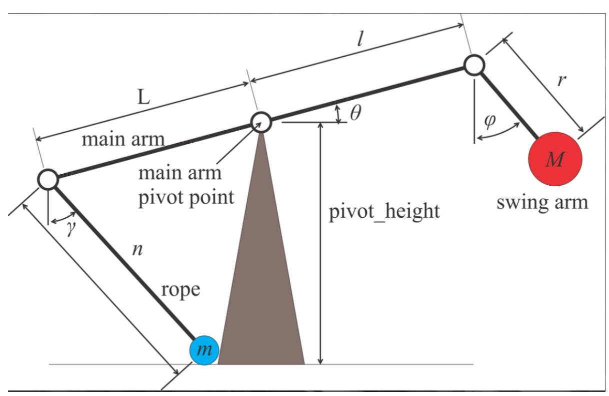



Fig. 2. The Trebuchet Dimensions

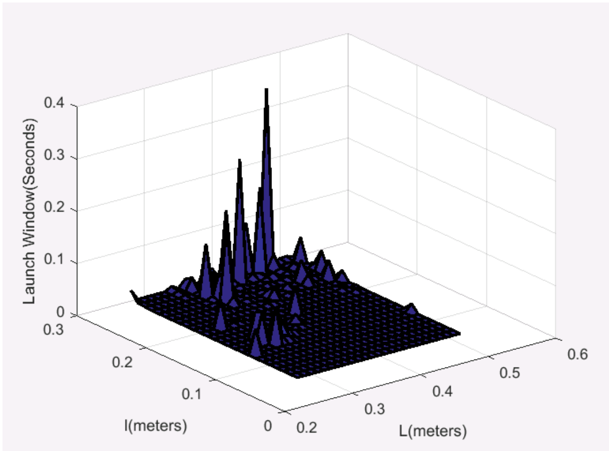



Fig. 3. Plot of Launch Window as the Counterweight and Sling Arm Lengths Differ.

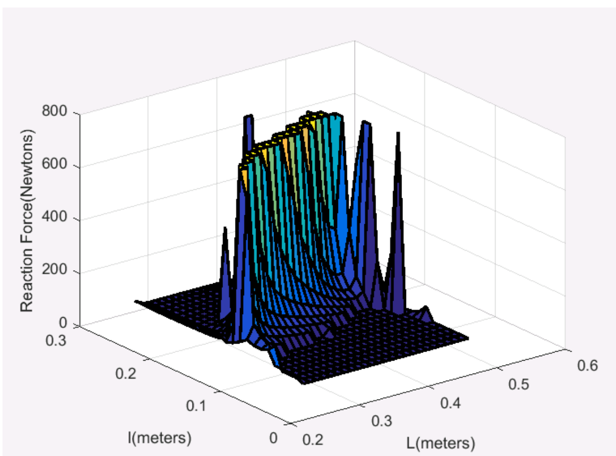



Fig. 4. Plot of Reaction Force as the Counterweight and Sling Arm Lengths Differ.

the rod as a function of the rod length was plotted. The length of the rod for my design was approximately 9mm so knowing the tensile strength of acrylic is 69MPa, the rod would not break due to any reaction force under around 700N using the following stress equation,

$$\sigma = Mc/I \tag{1}$$

where $M$ is the positive bending moment, $c$ is the radius of the acrylic rod, and $I$ is the second moment of area.

To ensure the rod did not deflect more than 0.635mm, a tenth of the diameter of it, the reaction force for the design had to be under 150N, using equation

$$\delta = Fl^3/48EI \tag{2}$$

where $F$ is the force on the rod, $l$ is the displacement of the force from the end of the rod, $I$ is the same from above, and $E$ is the modulus of elasticity of acrylic, which is generally around 3GPa. The maximum reaction force for my design was only 80N so its deflection was only about .33mm.

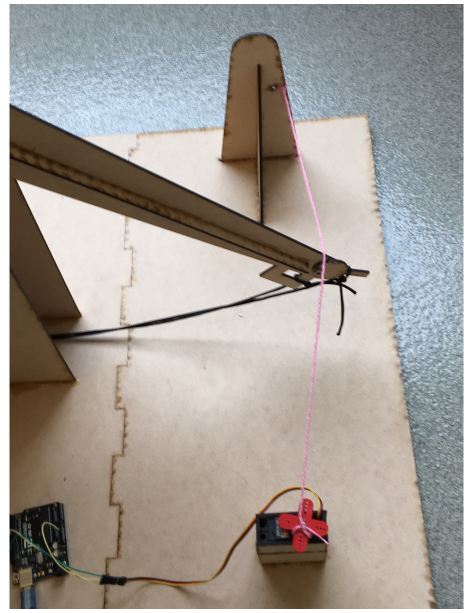


Fig. 5. Trigger Mechanism

The static servo torque also had to be accounted for in the trigger mechanism. I designed a mechanism such that the trigger mechanism of the trebuchet did not have a moment arm, as displayed in Figure 5, and therefore the servos static torque can be disregarded. I wanted to maximize the launch window while staying under the acceptable reaction force and one of the set of lengths for the sling and counterweight arm that went along with that was 60cm and 20cm, respectively. These two lengths were used for my design which implies that the length of the rope attaching the ball to the main arm was 60cm and the length of the counterweight pivot was 25cm.

## IV. Experimental Results

### A. Testing the Trebuchet

The parts of the trebuchet were modeled in Autodesk Inventor and they were fabricated into 1/8 in. medium density fiberboard. The trebuchet was assembled and trials launches were performed, adjusting the pin in order to get the optimal release angle of 45 degrees. The trebuchet launched a 27 gram rubber ball around 9m with only a four pound weight used as the counterweight.

## V. Discussion

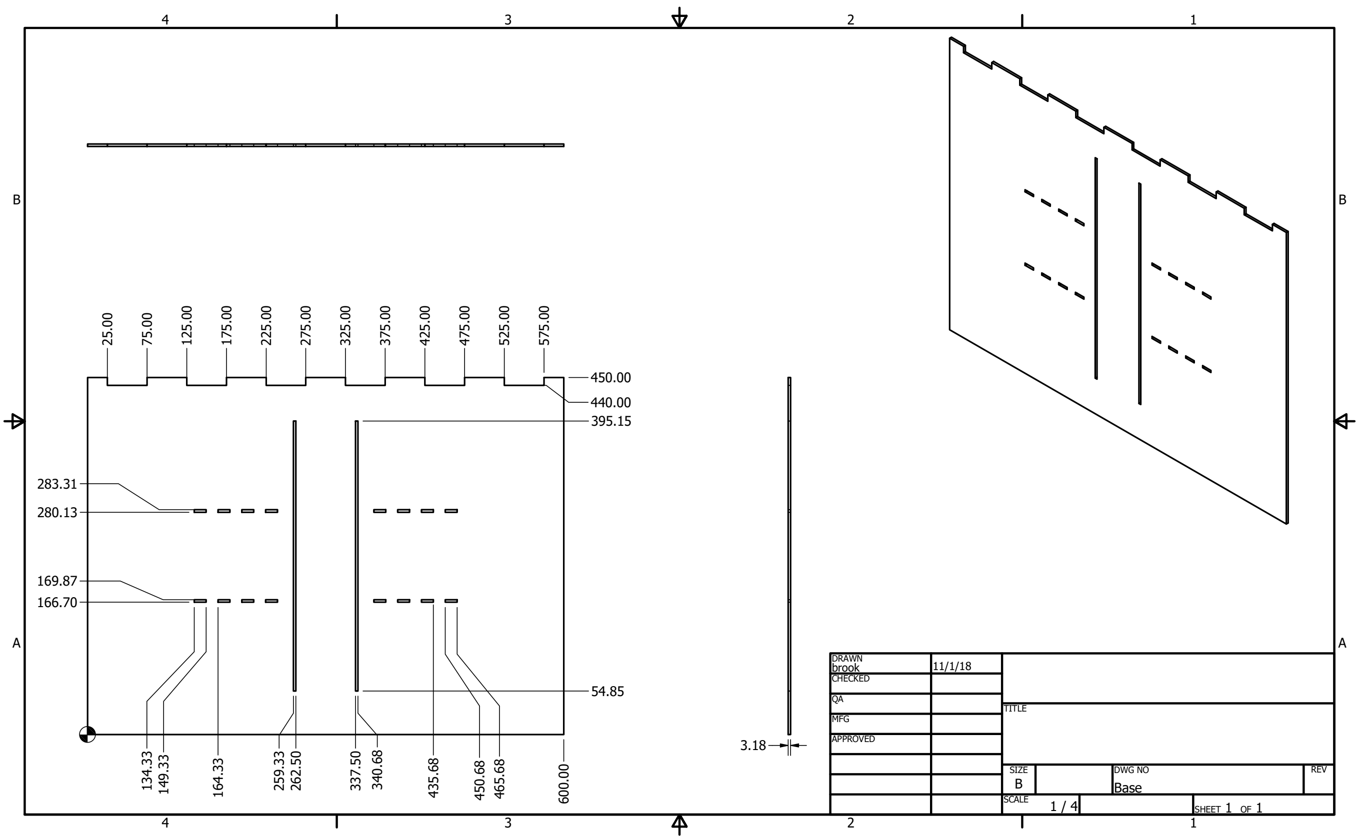
### A. Analysis of Final Product

While the trebuchet did launch the rubber ball around 9 meters, there could have been some changes made to increase that distance. The length of the main arm pivot axle was only about one centimeter so with the bending of it was relatively small, about $10^{-6}$ meters, there was very little energy lost due to the axle. One major difference from what was originally planned for the design was that the rope attaching the ball to the main arm could not be .6 meters and instead it was only about .4 meters. This was due to the sling being wider than the distance between the support ends for the main arm.

This means that if the sling did extend out to .6 meters, as the trebuchet launched the sling would get stuck against the support ends which would interfere with the way the ball released from the sling. Everything else went as planned from the design to the testing phase.

## VI. Conclusion

The construction of this trebuchet better acquainted me with the design process and optimizing design elements. My trebuchet fit all the functional requirements and launched a 27g rubber ball around 9m. This report was written in $\LaTeX$.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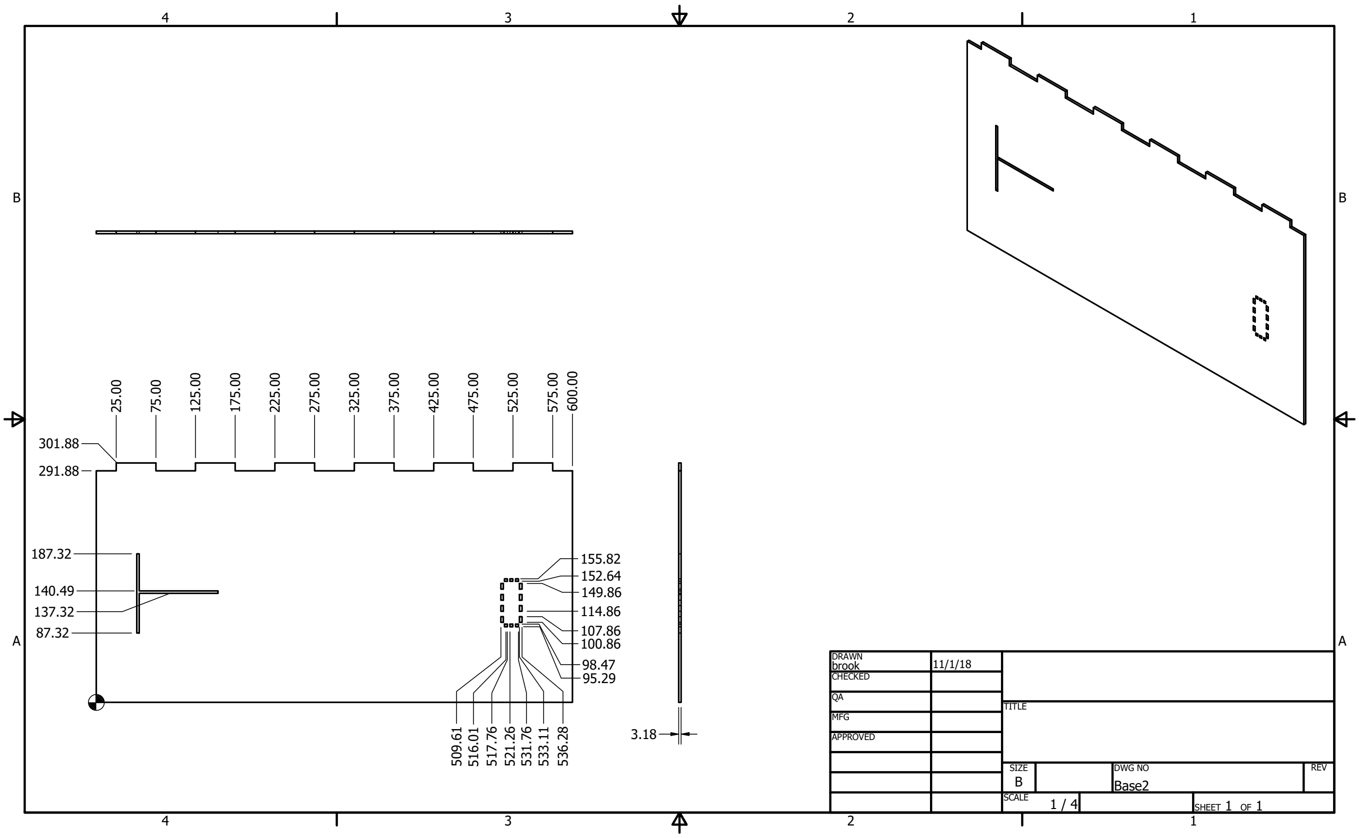

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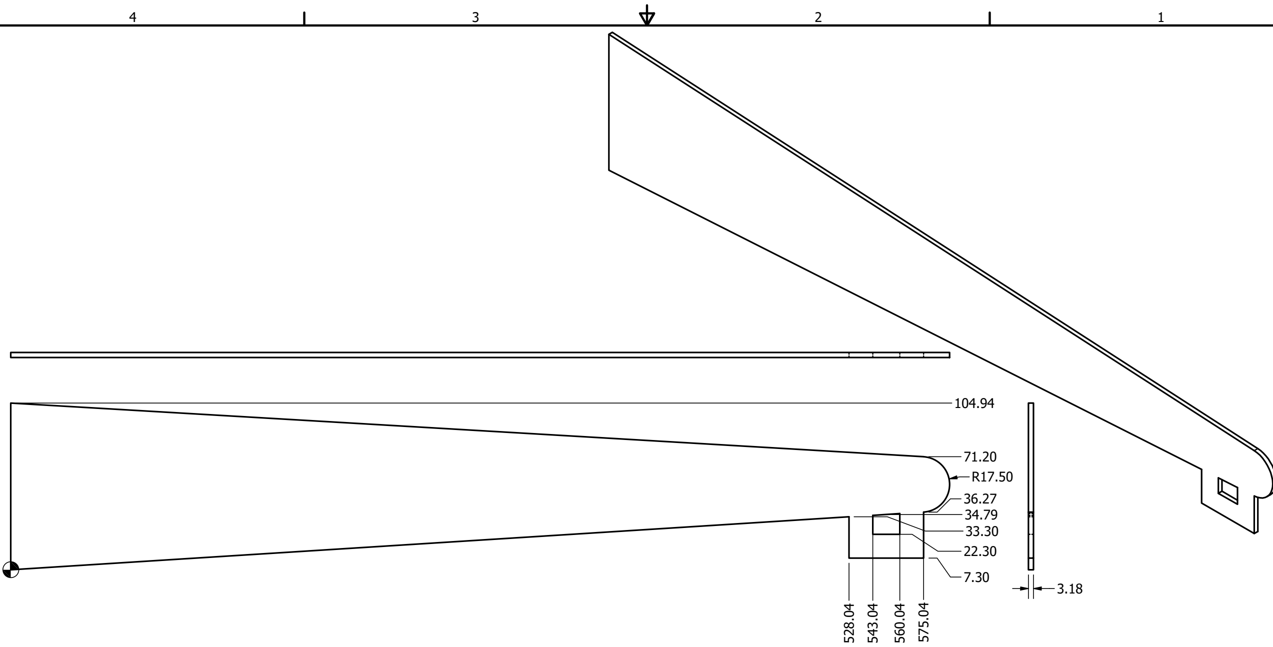


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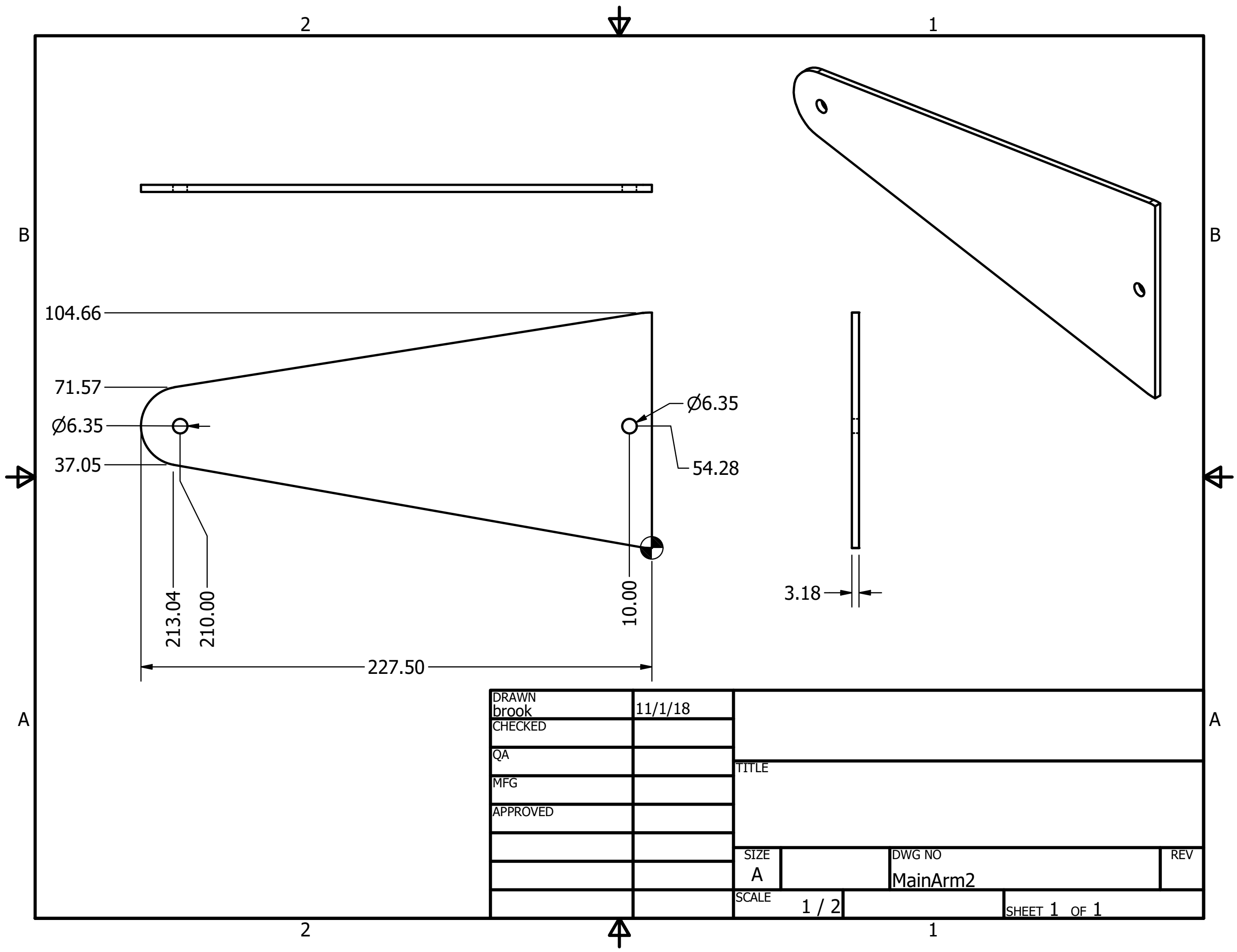
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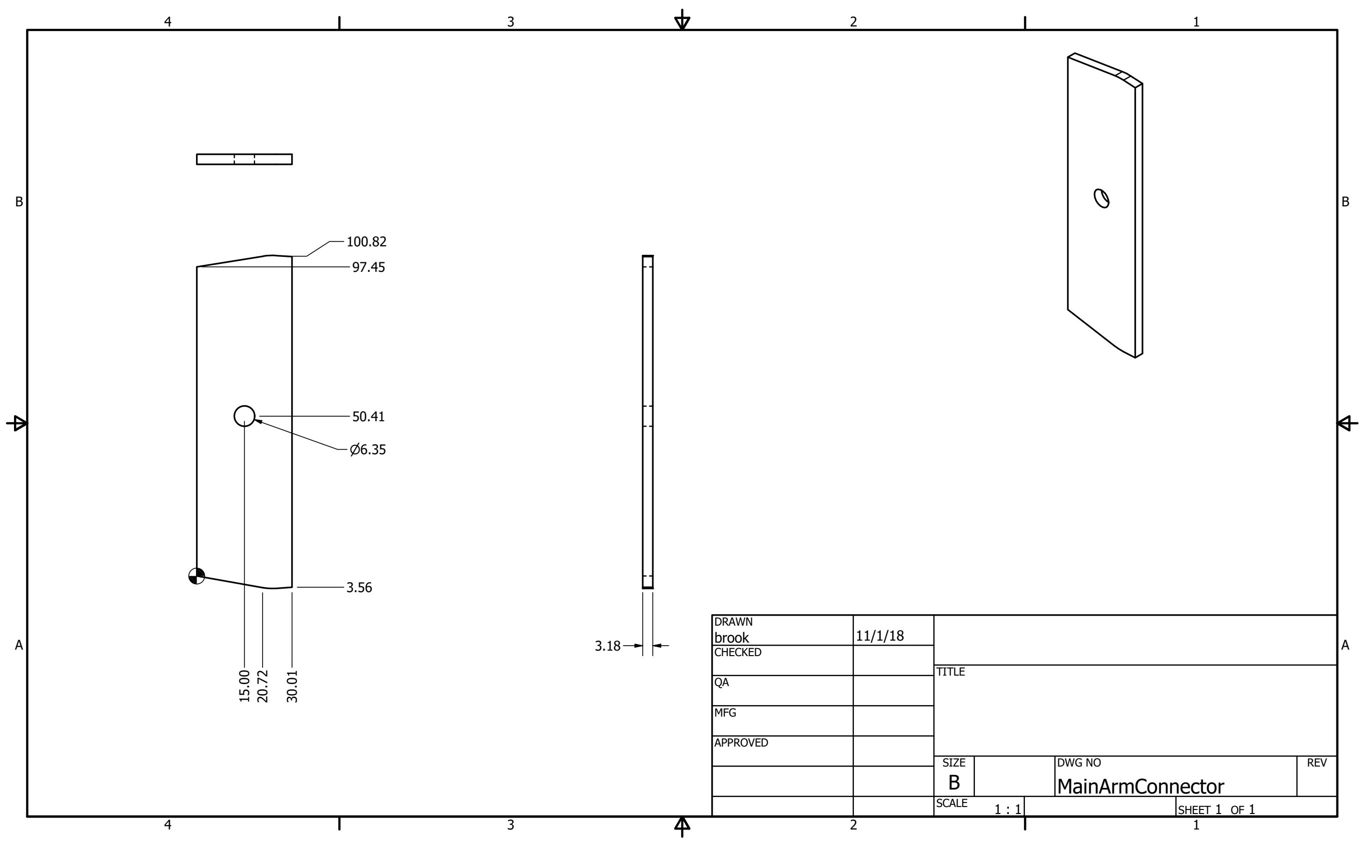
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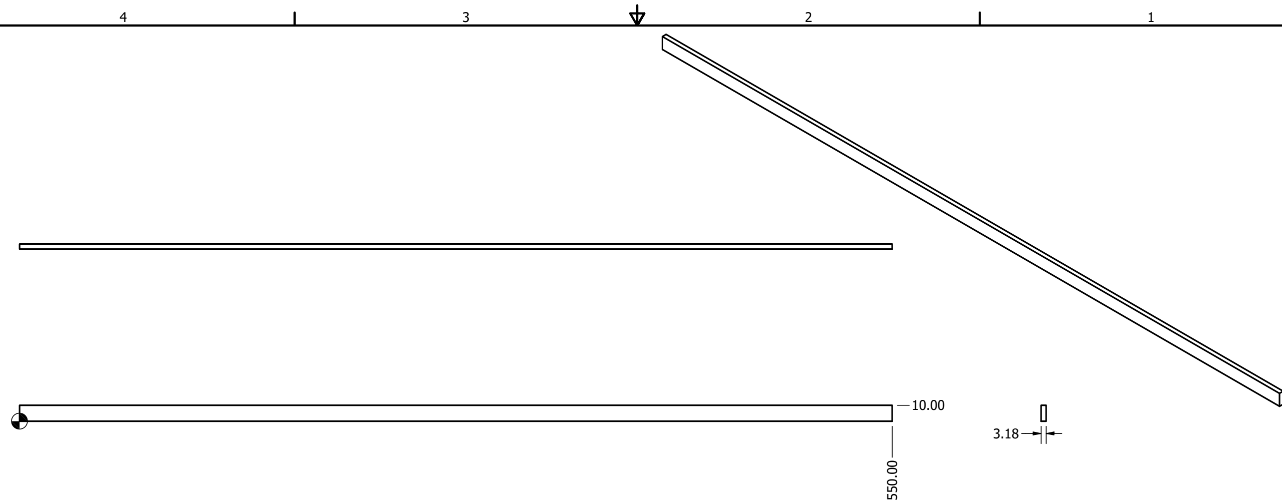


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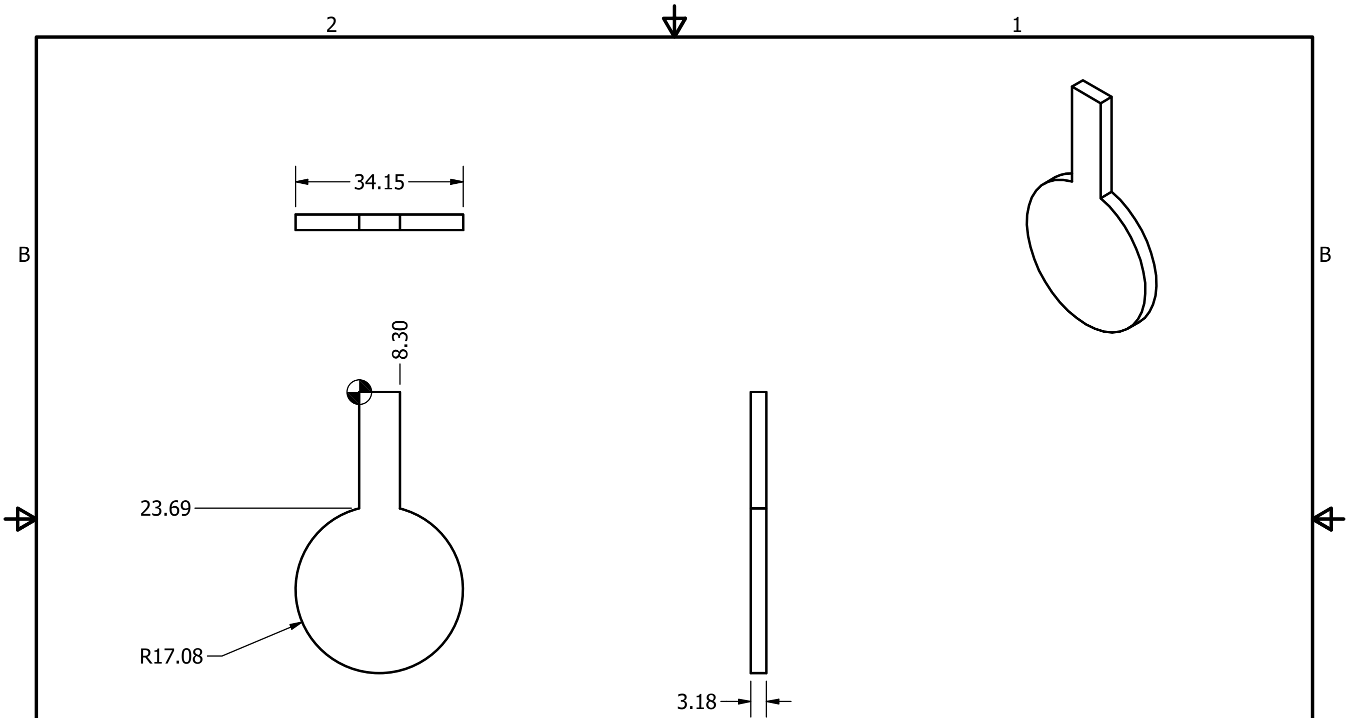


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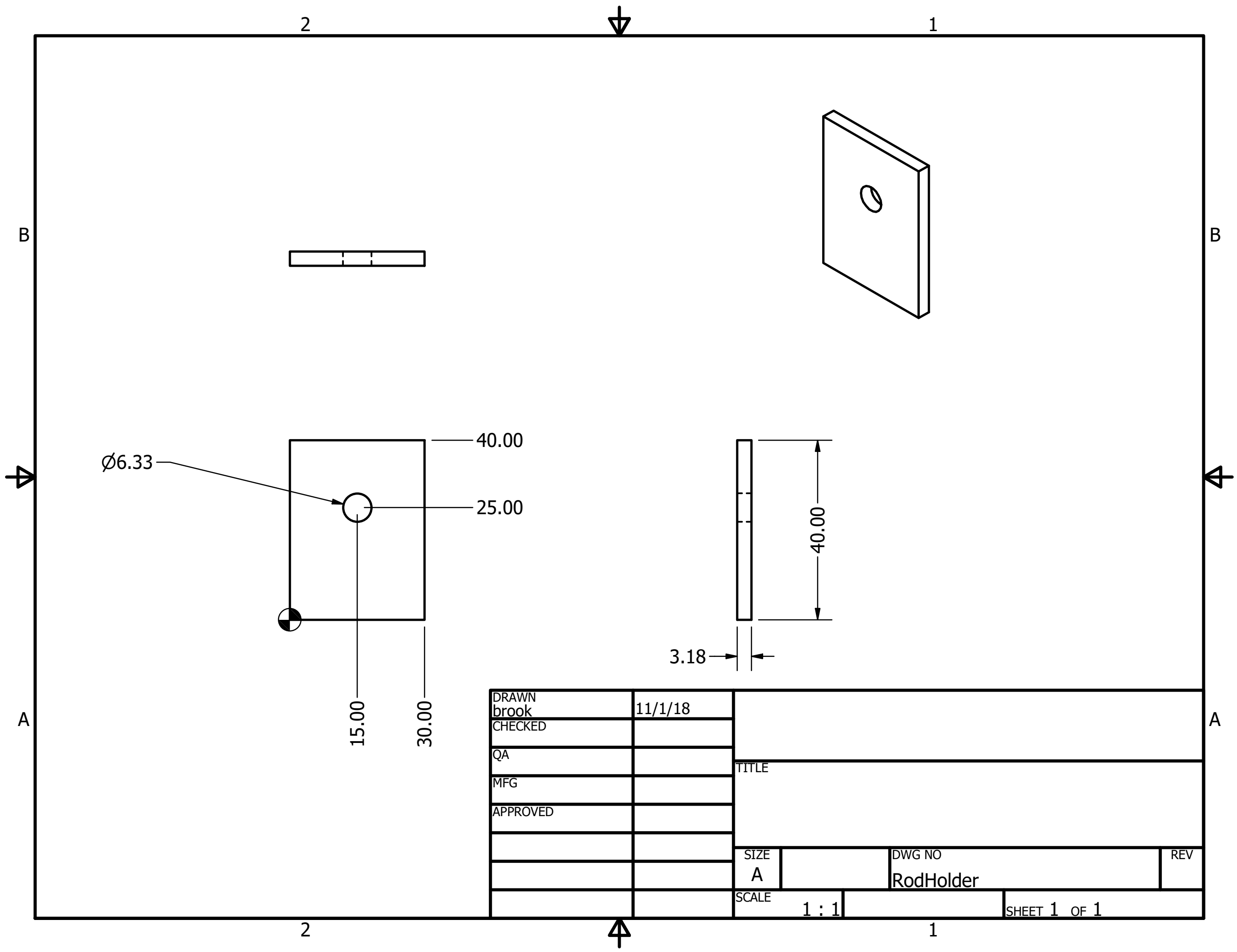

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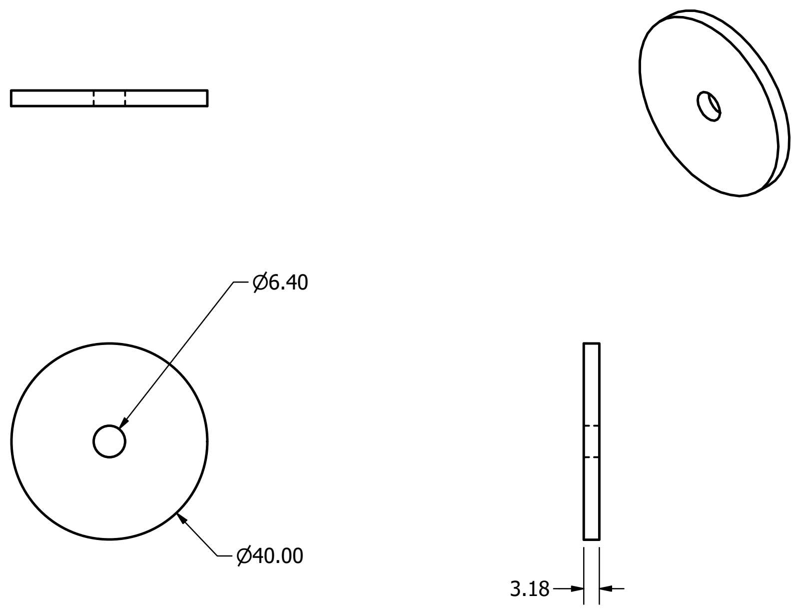


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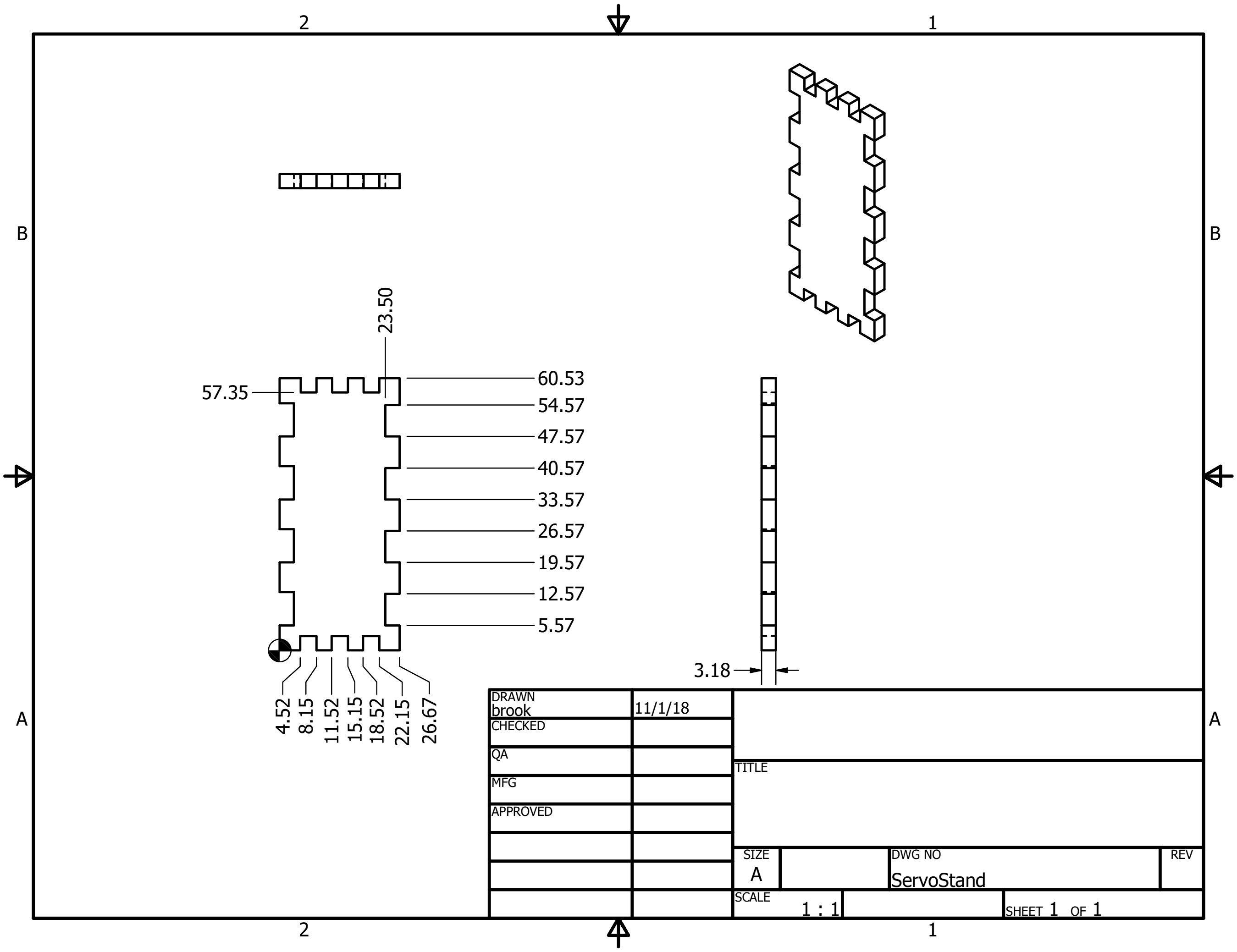

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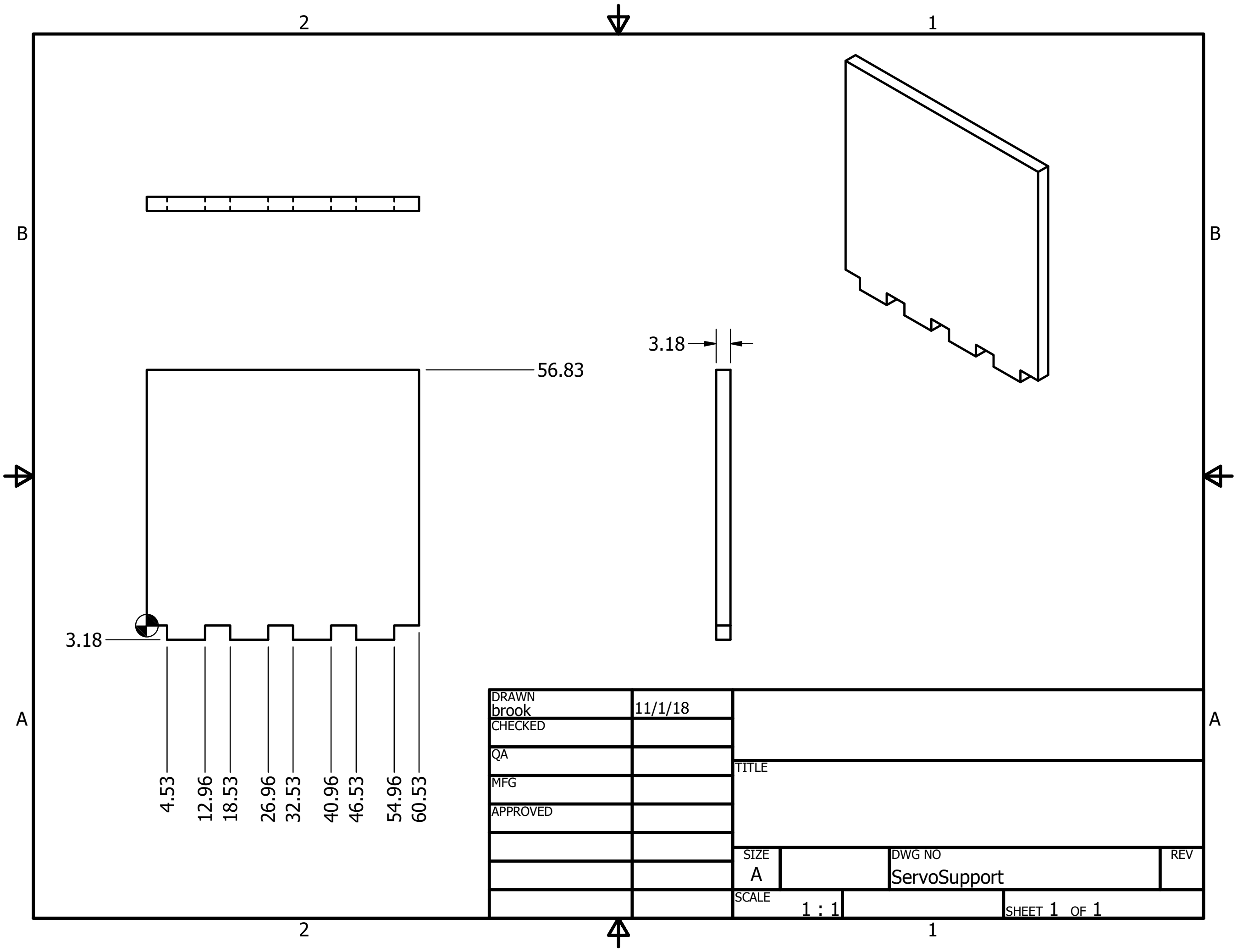

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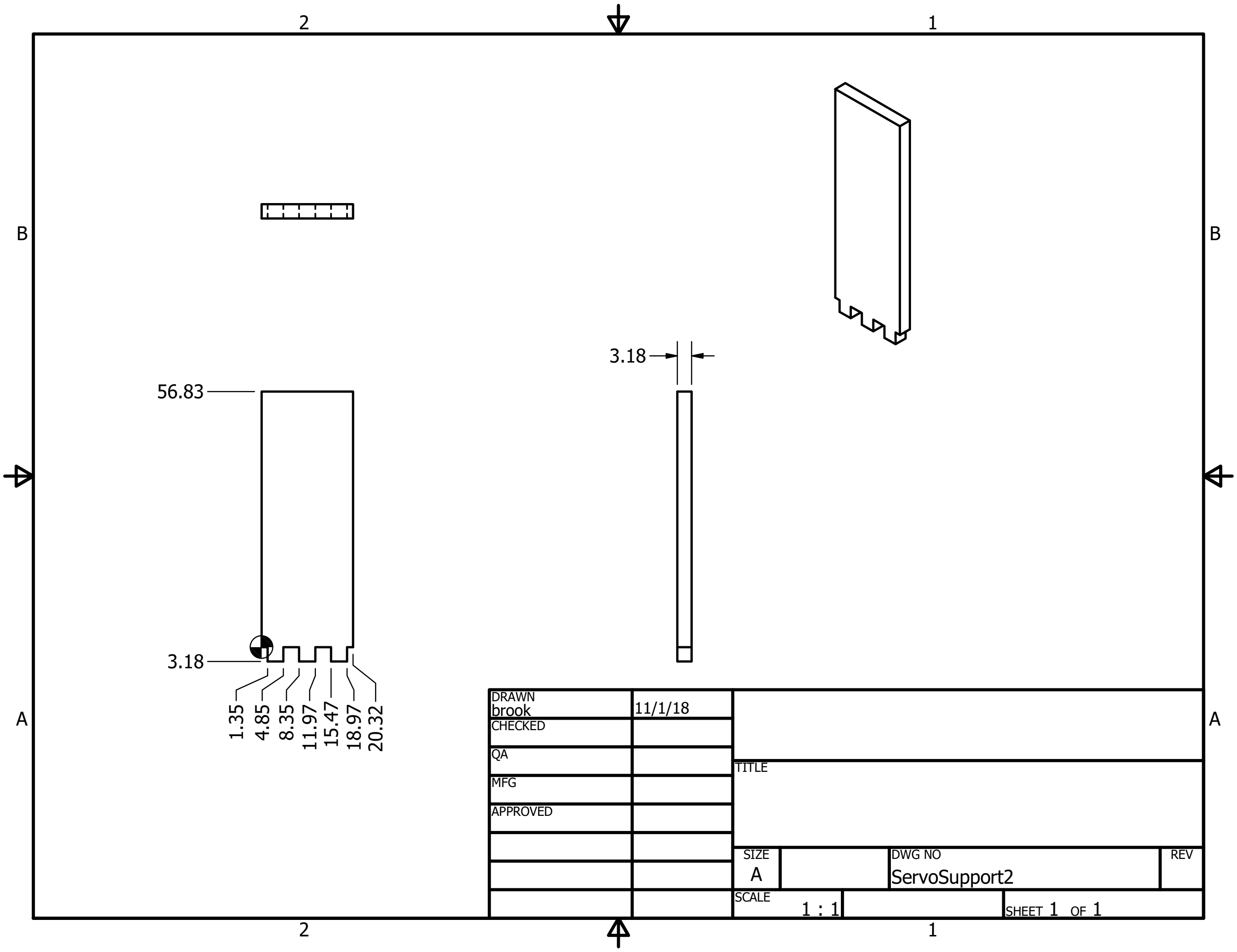

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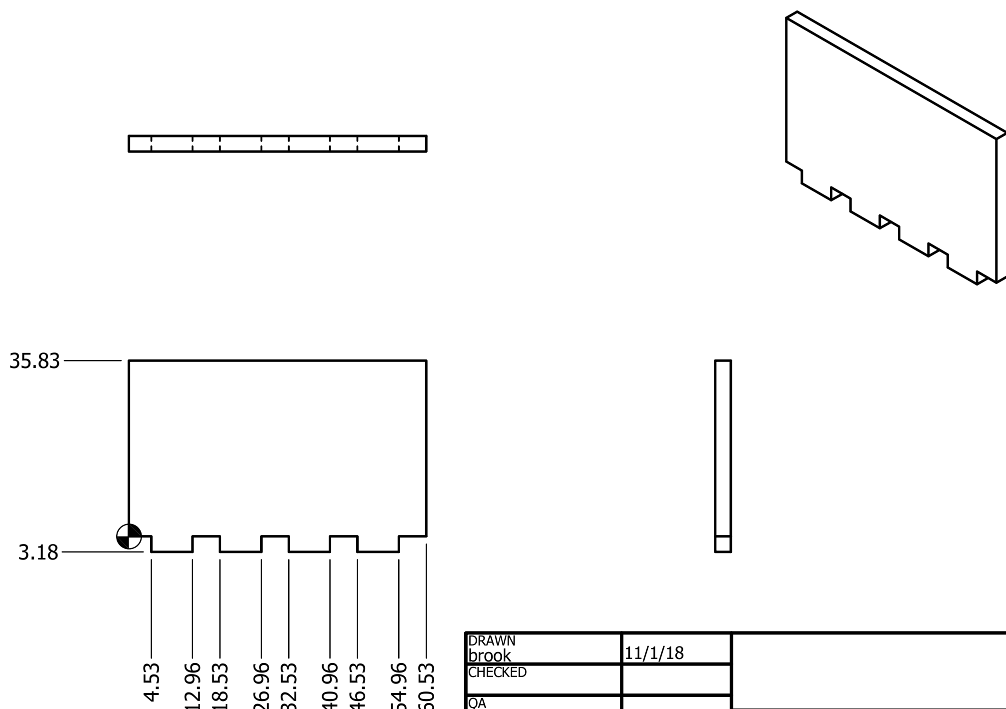


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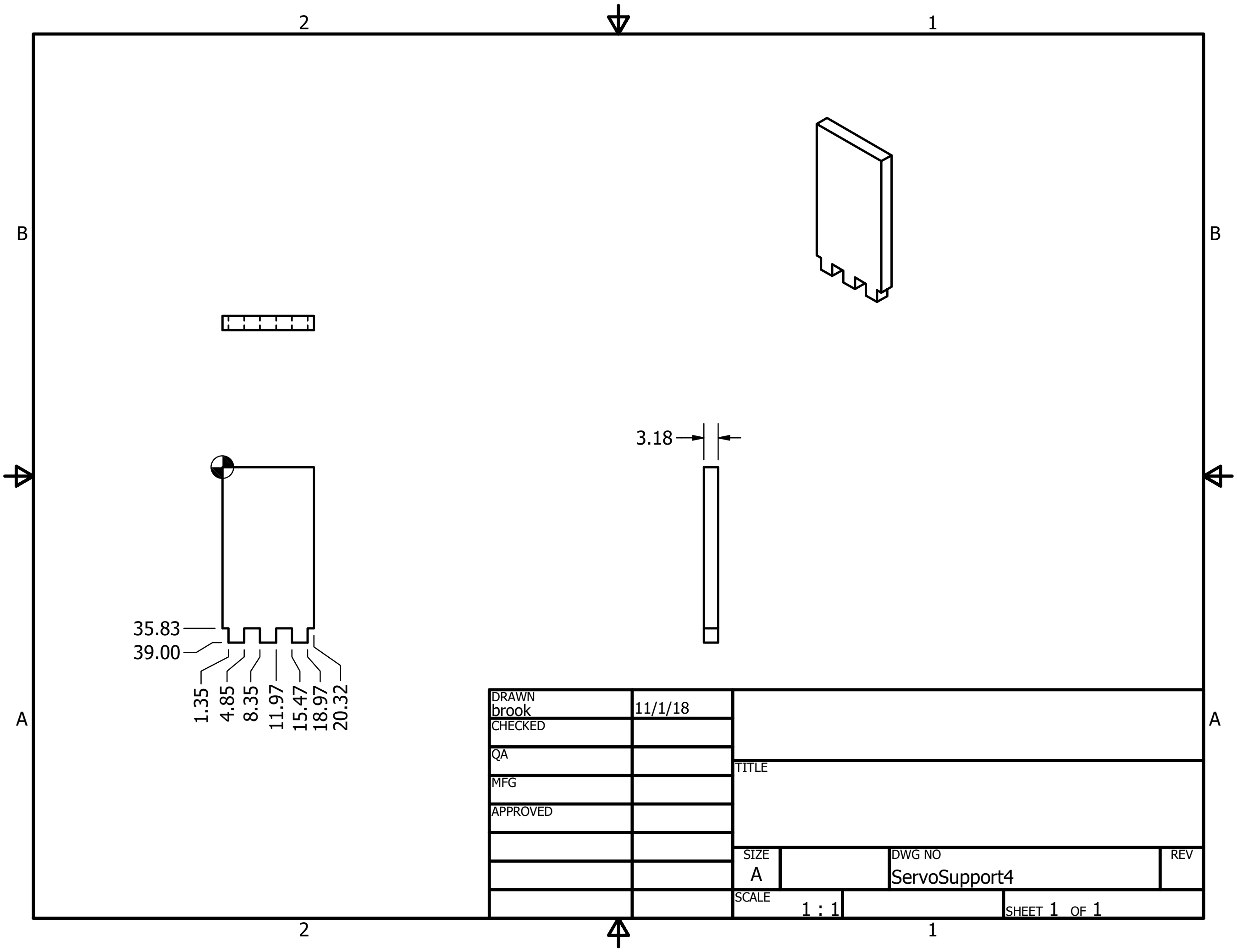
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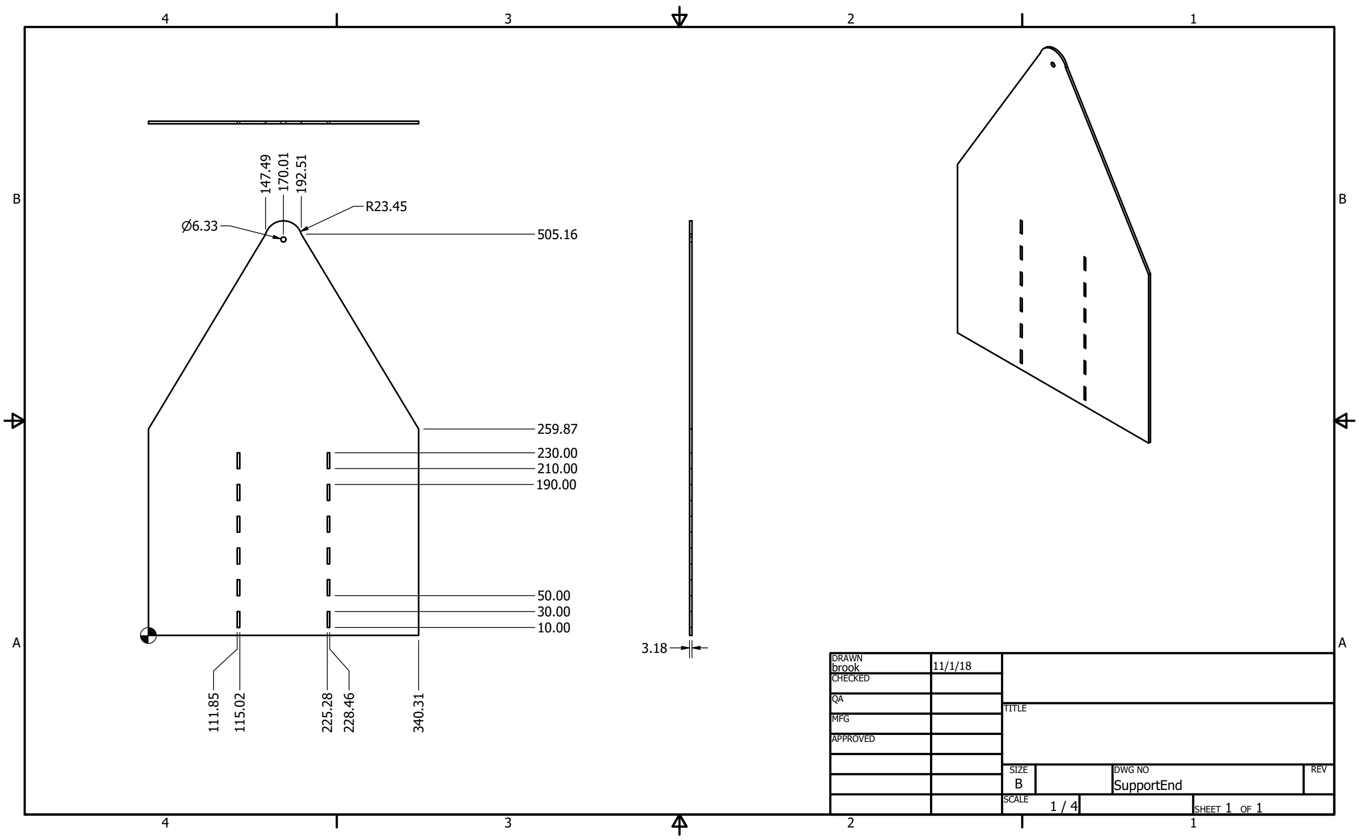

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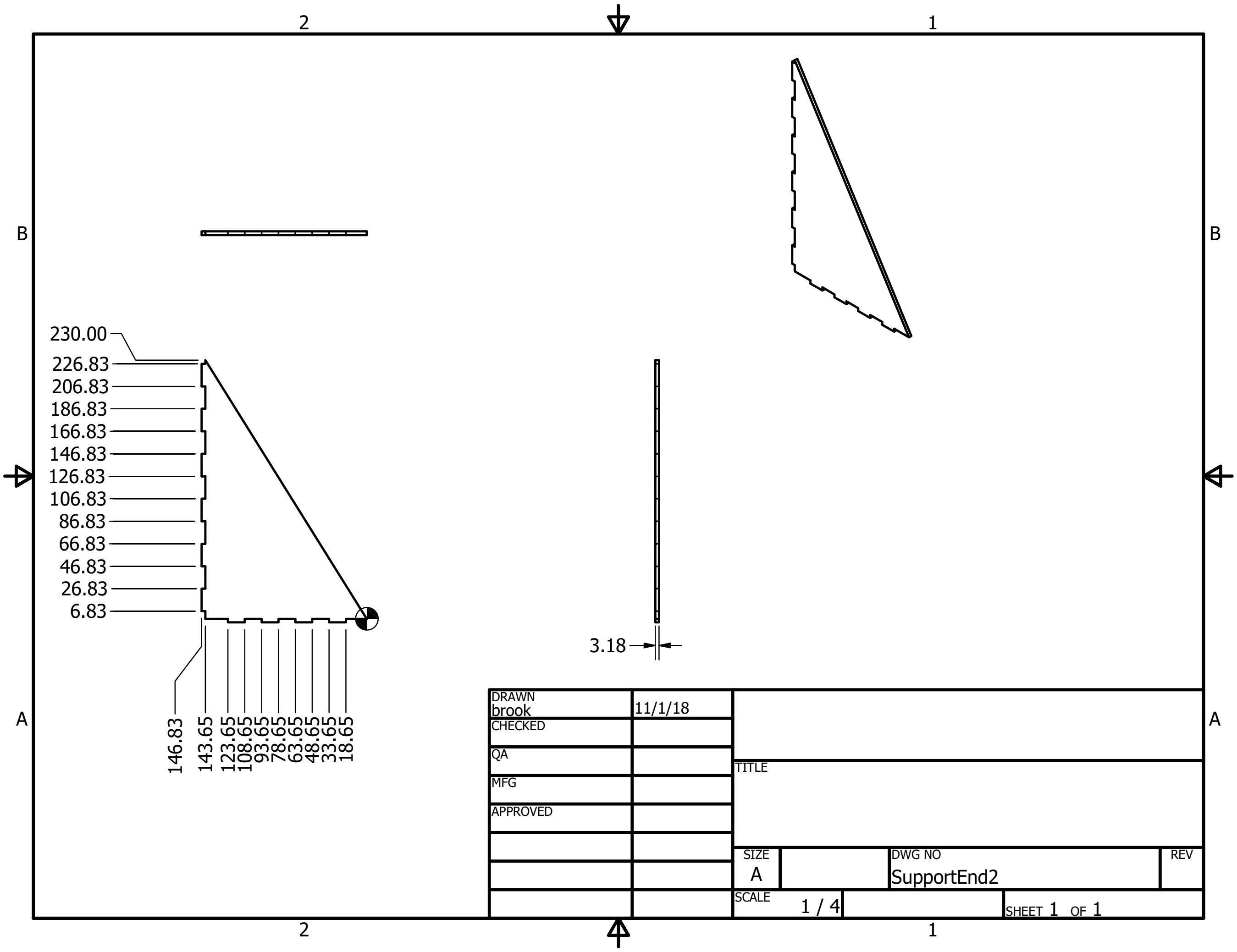
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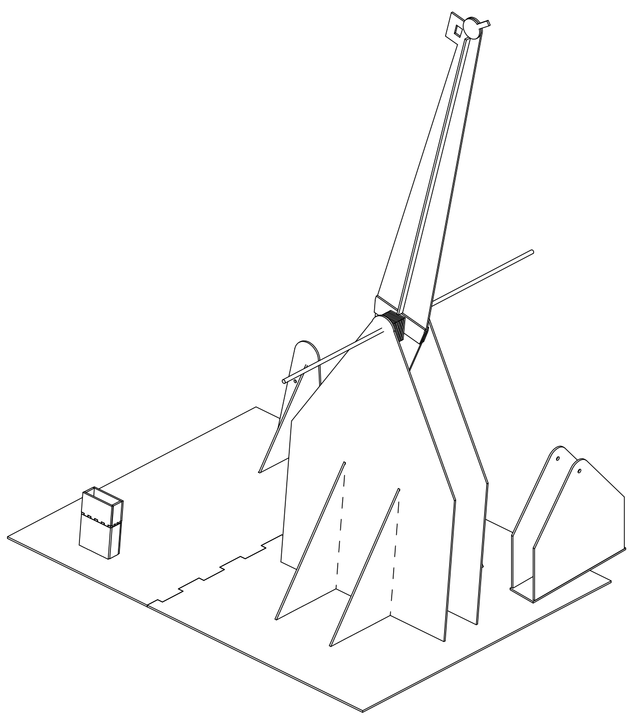

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| 7 | 1 | TriggerSupport1 |
| 8 | 1 | TriggerSupport2 |
| 9 | 1 | ServoStand |
| 10 | 2 | ServoSupport |
| 11 | 2 | ServoSupport2 |
| 12 | 2 | ServoSupport3 |
| 13 | 2 | ServoSupport4 |
| 14 | 19 | RodHolder |
| 15 | 1 | AcrylicRod |
| 16 | 1 | MainArm |
| 17 | 1 | MainArm2 |
| 18 | 2 | MainArmConnector |
| 19 | 2 | MainArmSupport |
| 20 | 1 | Pin |
| 21 | 19 | RodHolder1 |

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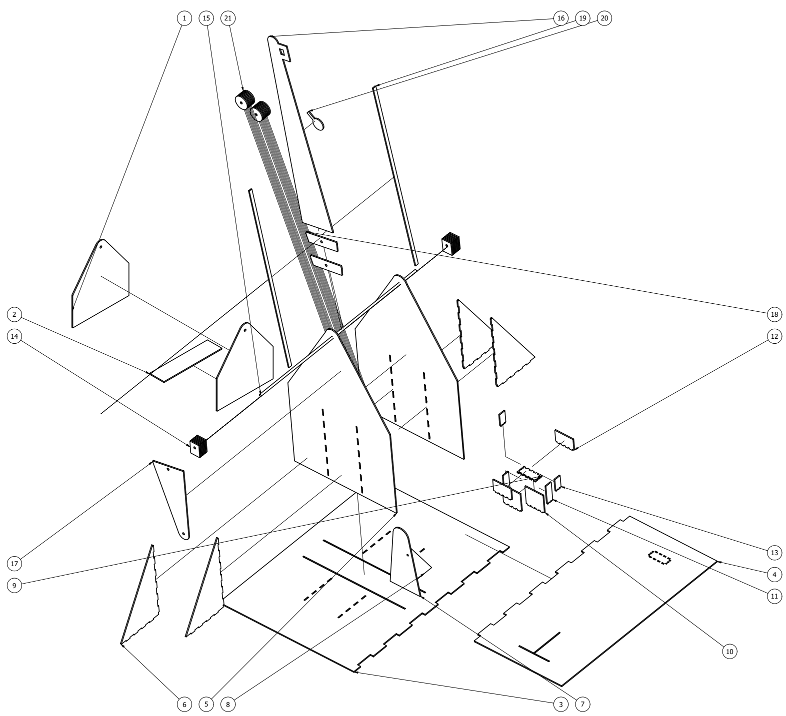


| PARTS LIST | | |
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| 6 | 4 | SupportEnd2 |
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| 8 | 1 | TriggerSupport2 |
| 9 | 1 | ServoStand |
| 10 | 2 | ServoSupport |
| 11 | 2 | ServoSupport2 |
| 12 | 2 | ServoSupport3 |
| 13 | 2 | ServoSupport4 |
| 14 | 19 | RodHolder |
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| 16 | 1 | MainArm |
| 17 | 1 | MainArm2 |
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| 19 | 2 | MainArmSupport |
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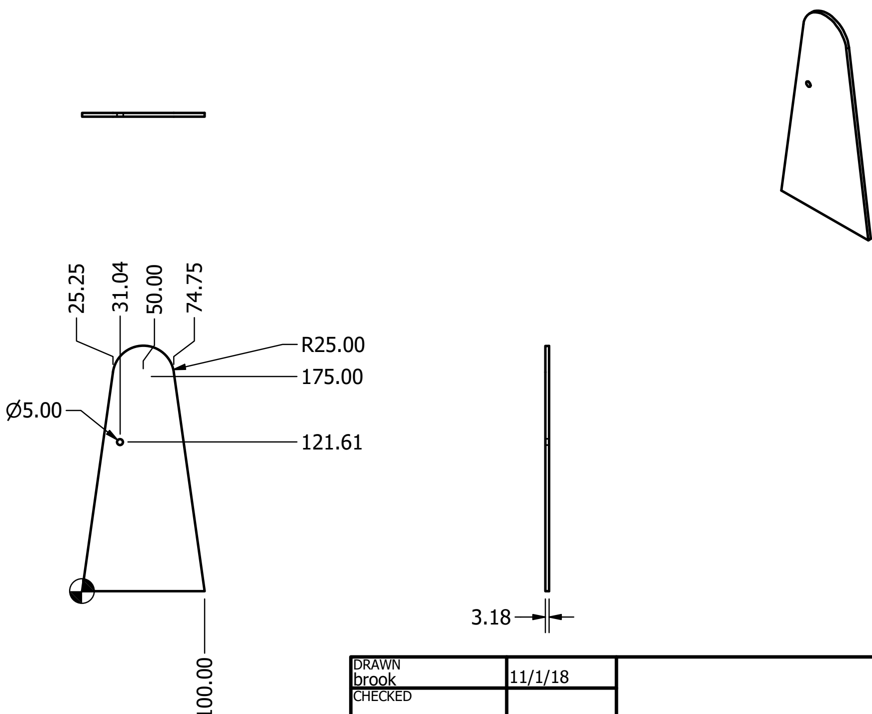


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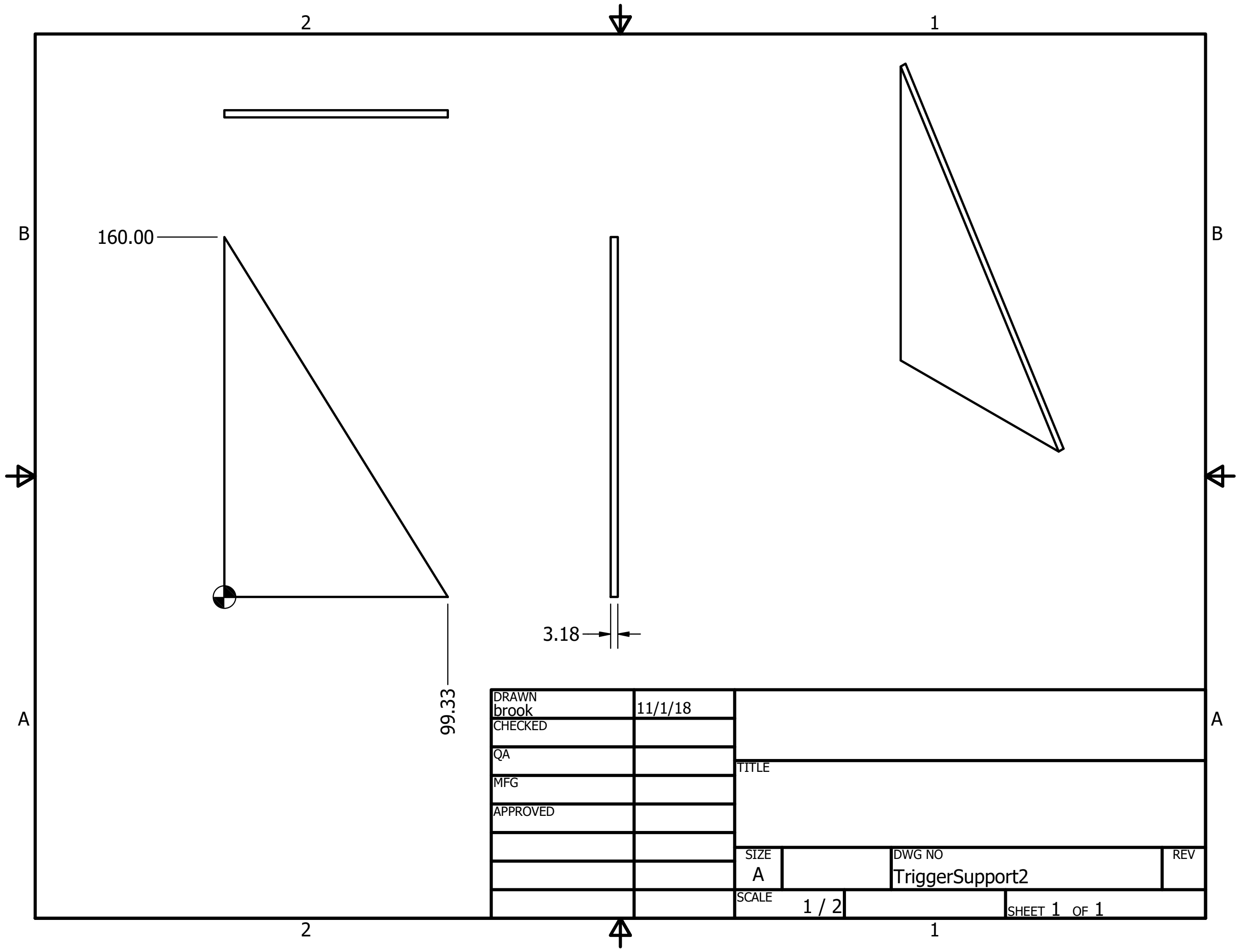
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# REFERENCES

[1] Matthew Spenko *Trebuchet Part 1* 2016: Illinois Institute of Technology Mechanical Design.