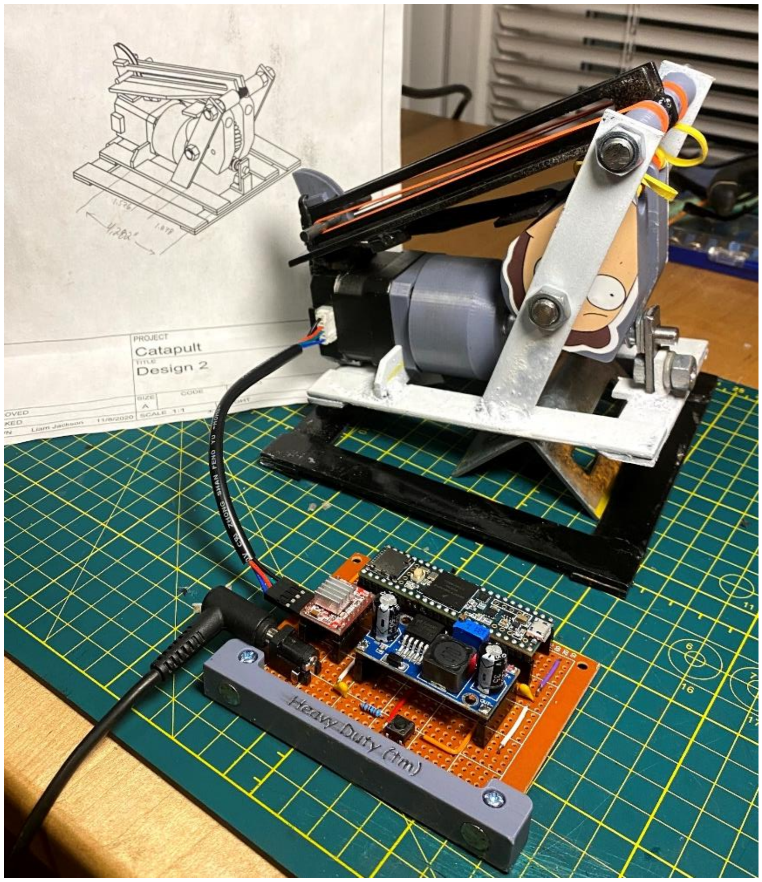
Introduction

Welcome, what you see here is the Heavy Duty™.



I am an avid DIYer and tinkerer. Fortunately (or unfortunately) my room is filled with scrap material from other projects and tools I have acquired through years as a professional handyman. I tried to remain conservative in the design process, knowing what I have for tooling and the environment available for fabrication (the dark alley behind my apartment). We are very proud of our creation.

Through several over-caffeinated conversations, Zach and I landed on a couple key design parameters we tried to achieve. We wanted a way to develop as much tension as possible within the 6” cube. Having a history in archery, I suggested a cam system to torsion rubber bands. We liked it, so we rolled with it. I wanted an excuse to practice welding, so we also decided on steel as the main component for the frame. I had several lengths of 0.75” angle and flat stock, 0.375” all thread, and various nuts, bolts, and washers from old projects, so the design utilized those for its structure. A dinner fork was additionally used, see below. We also had on-hand electrical components from old projects, of primary interest a NEMA 17 stepper motor with a driver. To produce the tension we wanted, we needed a torque-y motor that we could control via an Arduino. We had several ‘duinos in our arsenal but settled on the Teensy to adhere to the size limitations.

Design

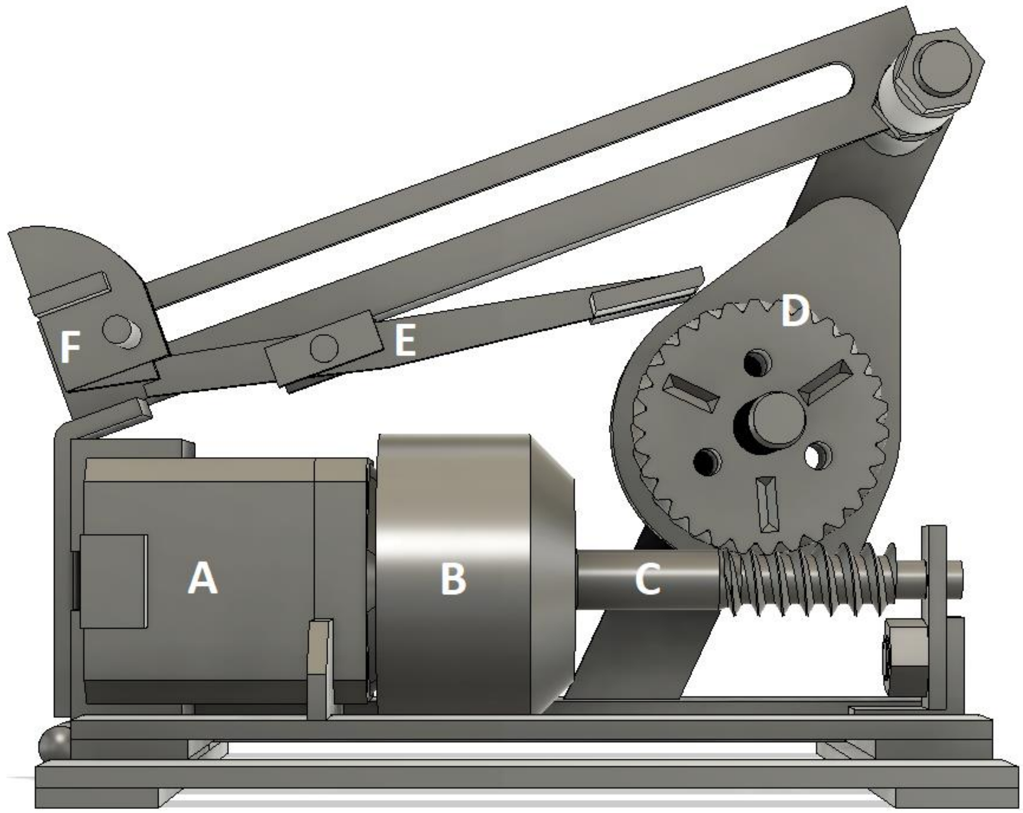


Figure 1. Right Cross Section. Visibility-occluding frame, hardware, and right cam hidden.

I began developing a CAD model. By testing the holding torque of the motor, we found that we needed to multiply the torque to achieve necessary power to drive the system. The solution was an inline planetary torque converter (B, above) I designed and fit to the front face of the stepper. The ring gear is driven by 4 planets, their carrier being fixed to the motor which drives the sun gear. The gear box has a 4:1 ratio, meaning 4 revolutions of the motor (A) shaft causes 1 revolution of the ring gear. [Note: due to radius variations between the motor shaft and the eventually described worm (C), the final ratio is not exactly 4:1.]

The modeling process began with forming a rough frame within the spatial constraints. Then I designed the motor/torque converter assembly (A,B). The ring of the gearbox assembly (B) encases a slightly modified lag bolt (C), creating a worm drive. Then, a custom helical gear fixed to 2 symmetric cams (D) was modeled. Designing a helical gear with teeth that meshed with the lag threads was the most challenging portion of this process. Then the cams were designed to have 2 lobes, the larger providing leverage for the tension to be produced and the smaller lobe, hidden by the worm drive above, actuating the trigger (E) at maximal tension. The trigger was then designed to fit the frame and slotted track which the quarter carrier (F) rides on.

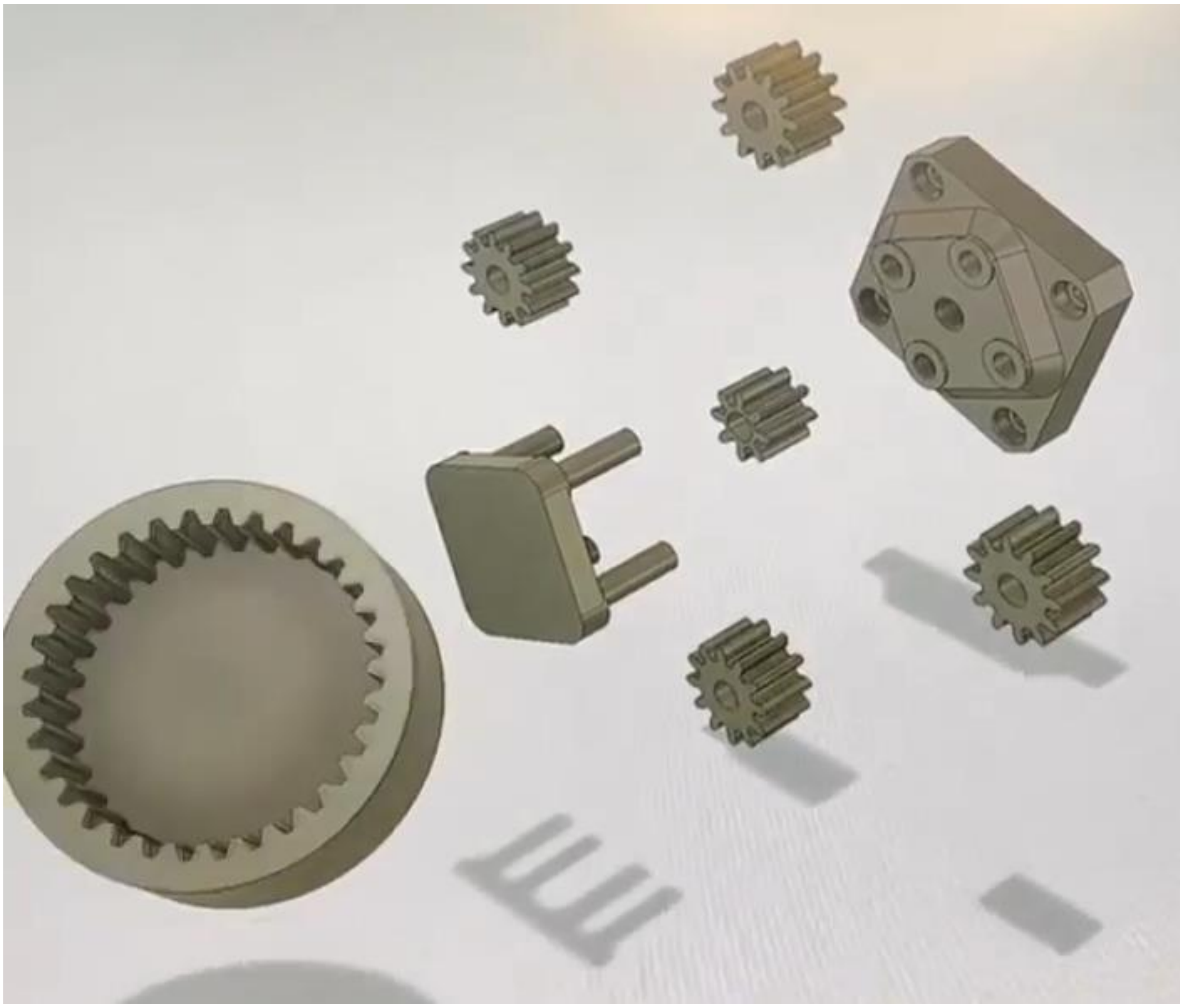


Figure 2. Exploded view of (B) in Fig.1.

Fabrication

The torque converter, helical gear/cams, and quarter carrier were 3D printed on an Ender 3. From the CAD design, I was able to create engineering drawings for each component to be made from steel. Planar cutting processes were easy to achieve with an angle grinder and cutoff wheel. Holes were dimensioned and located with calipers and created with a drill, standard twist bits, and WD40 as coolant. Using dimensions from the drawings, I then welded the frame components. (This was my second welding project—*a grinder and paint make me the welder I ain't.)*

The modified lag screw was machined using an inverted drill held in a vise, spinning a socket that held the workpiece. The tip of the lag screw was held in position with the same bracket used in the final layout, secured in a second vise. The "poor man's lathe" was powered and the material removed with a file. This took hours, mostly because my drill battery only lasts about 15 minutes on a full charge.

Zach oversaw the circuitry and programming. We used a solderable breadboard and components on-hand to layout a circuit that controlled the stepper. To control the stepper, we used a Teensy 3.6 to operate the A4988 driver. The power for the motor is supplied by a laptop charger via a barrel jack. The voltage is stepped down with an LM2596 buck converter tuned to 5V to safely power the Teensy. A button wired to one of the digital pins on the Arduino allows us to control the program.

The program makes use of the AccelStepper library. The Arduino can act in one of three ways: it can move the stepper to the final position, move the stepper to the initial position, or stop the stepper. The button toggles between these modes (move to final > stop > move to initial > stop > move to final ... etc).

All components were soldered to the board and connected via a combination of solder traces and jumper wires.

To add a little bit of flair, we even put on a couple stickers hosting some characters from a TV show we watch and added a couple coats of paint. The white paint is actually Plasti Dip, a sprayable rubber coating. We like to think it reduces some vibrations in the motor mounts.

Performance

We initially intended to use 3/8" surgical tubing I have from a slingshot repair I made but found the motor couldn't produce enough torque to drive the system. Instead, we opted to use 4 conventional rubber bands.

After the initial culmination of materials, we found the carrier mechanism to be too unstable in the cocked position. It tended to tilt forward while under the tension of the bands. I exhausted my supply of scrap steel at this point, so we hacked apart our least favorite dinner fork for this purpose.

It very rarely occurs that a design works on the first try. After fabricating the structural components and soldering the circuit, we had our first real test of the whole shebang. And it worked flawlessly. If I had a nickel for every time that happened, I would have one nickel.

Our best shot:

~45deg pitch angle, 2 rubber bands, standard US Quarter, catapult positioned on the ground – 45ft

Final Thoughts

We did our best to design a unique catapult and used only the things we found in our apartment. Though conventional, the materials had to be modified with janky methods and with glorified Fisher-Price tools, many hand-me-downs and Harbor Freight products. Most of the parts were made in the dark, the only light being a headlamp. Given the circumstance, we are especially proud to note the largest deviation from the specified measurements was 50 thousandths of an inch.

-Thank you for your consideration! Made by Liam Jackson (MS, BME '21) and Zach Beever (MS, ECE '21)

Appendix

Additional Photos Follow:

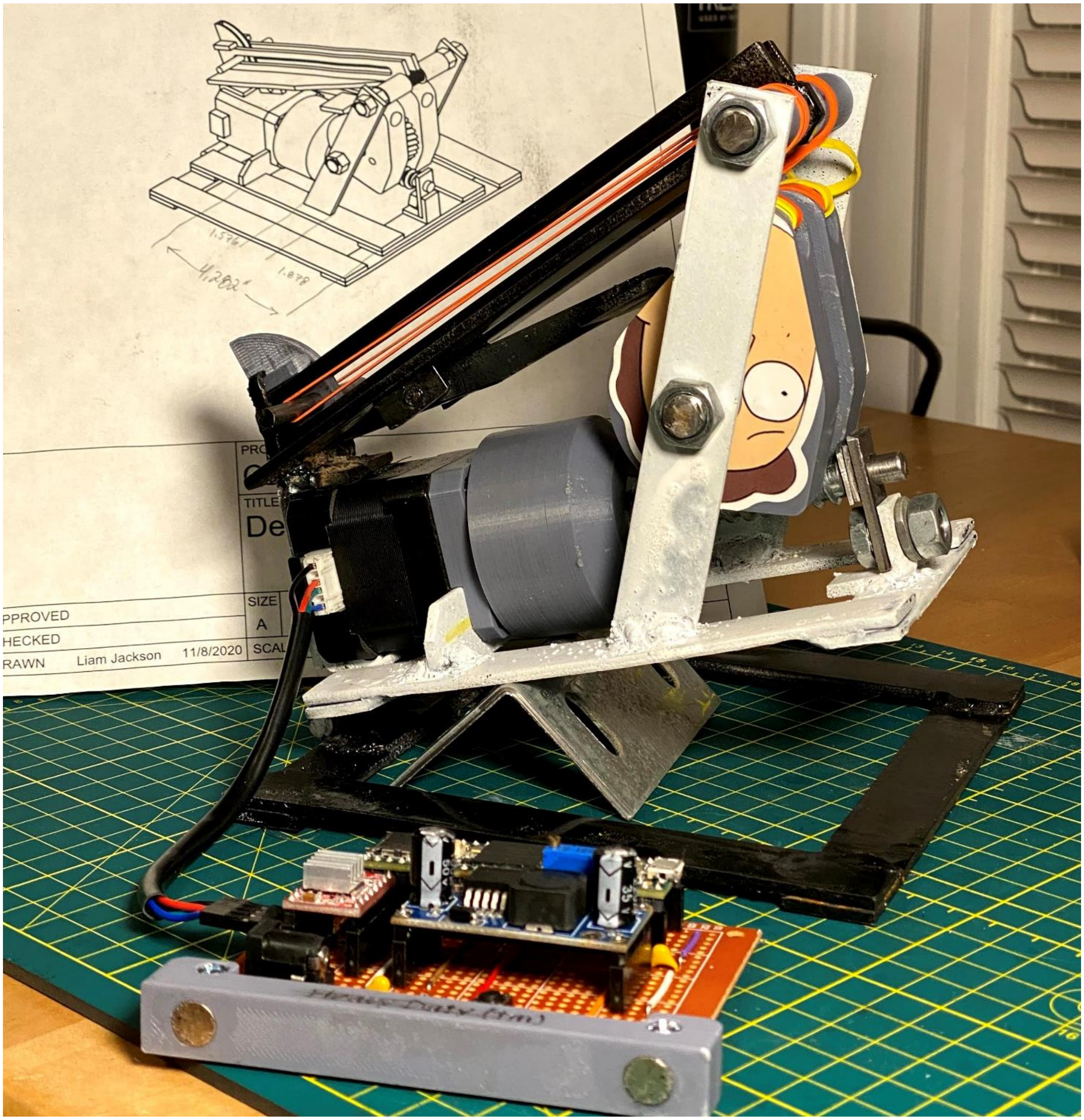


Figure 3. The magnets in the base of the PCB holder allow easy removal/rearrangement of the circuitry. The black piece holding down the quarter carrier, top left, is the piece made from a fork.

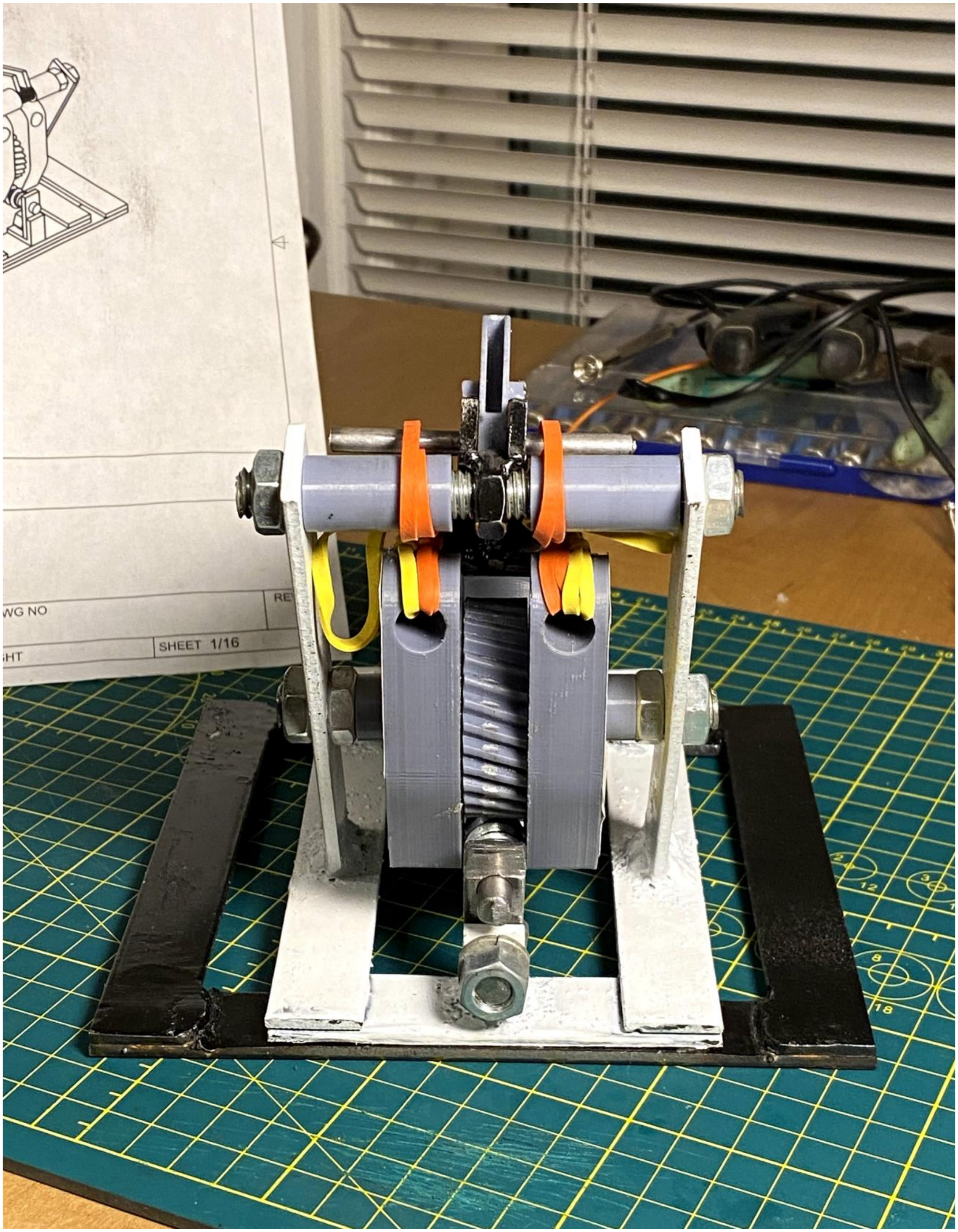


Figure 4. Power of the catapult can be modulated by increasing/decreasing number of rubber bands applied to the carrier bar.

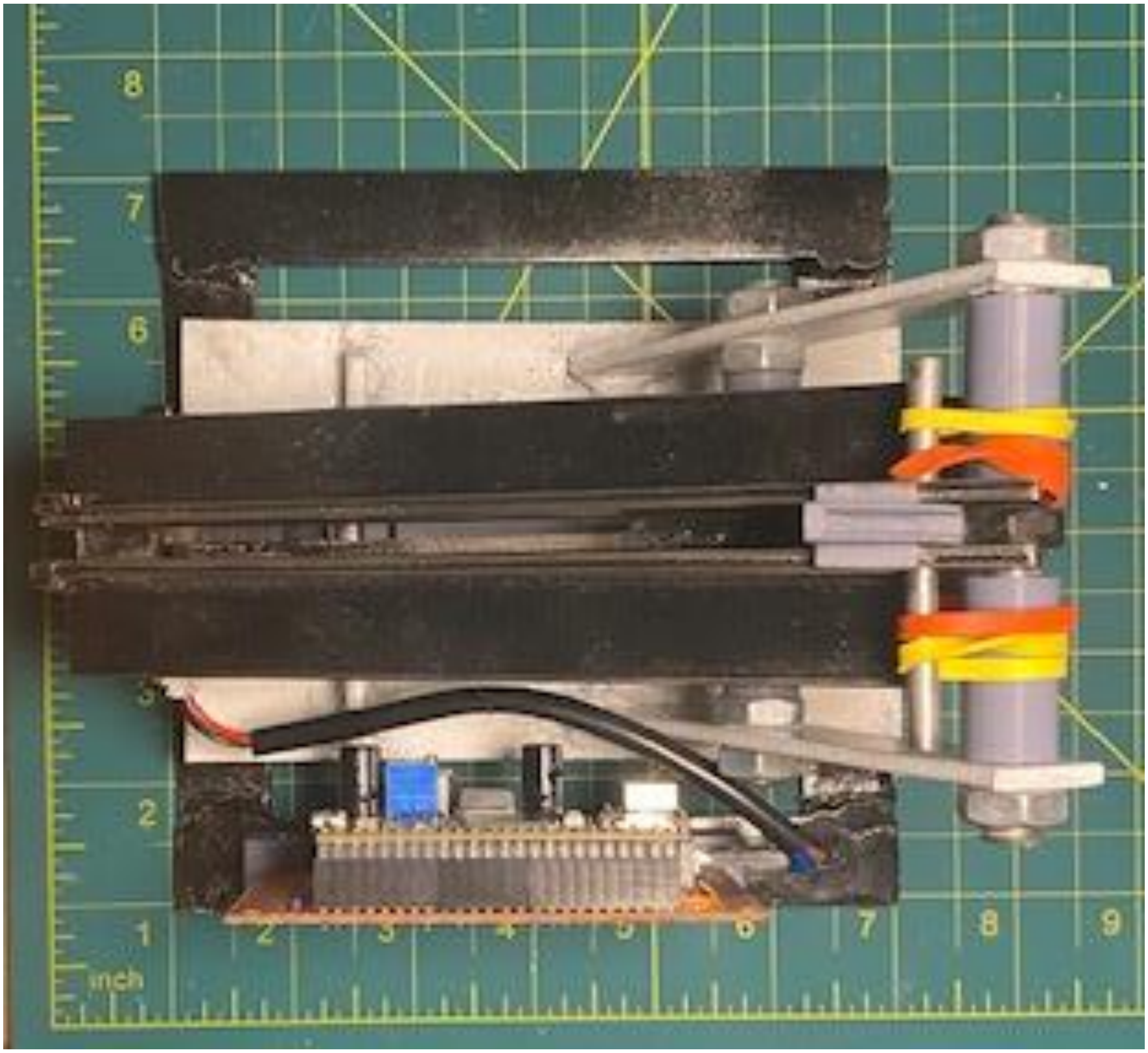


Figure 5. Overhead dimensions. Note the perspective of the camera makes the catapult appear to fall outside the 6" square, however that is a product of the camera's focal length. The footprint falls exactly on the 6"x6" box. Also note the orientation of the PCB, with componentry flipped from the previous images. The base is magnetized so it is easy to rearrange depending on the circumstance (photos vs. functioning).

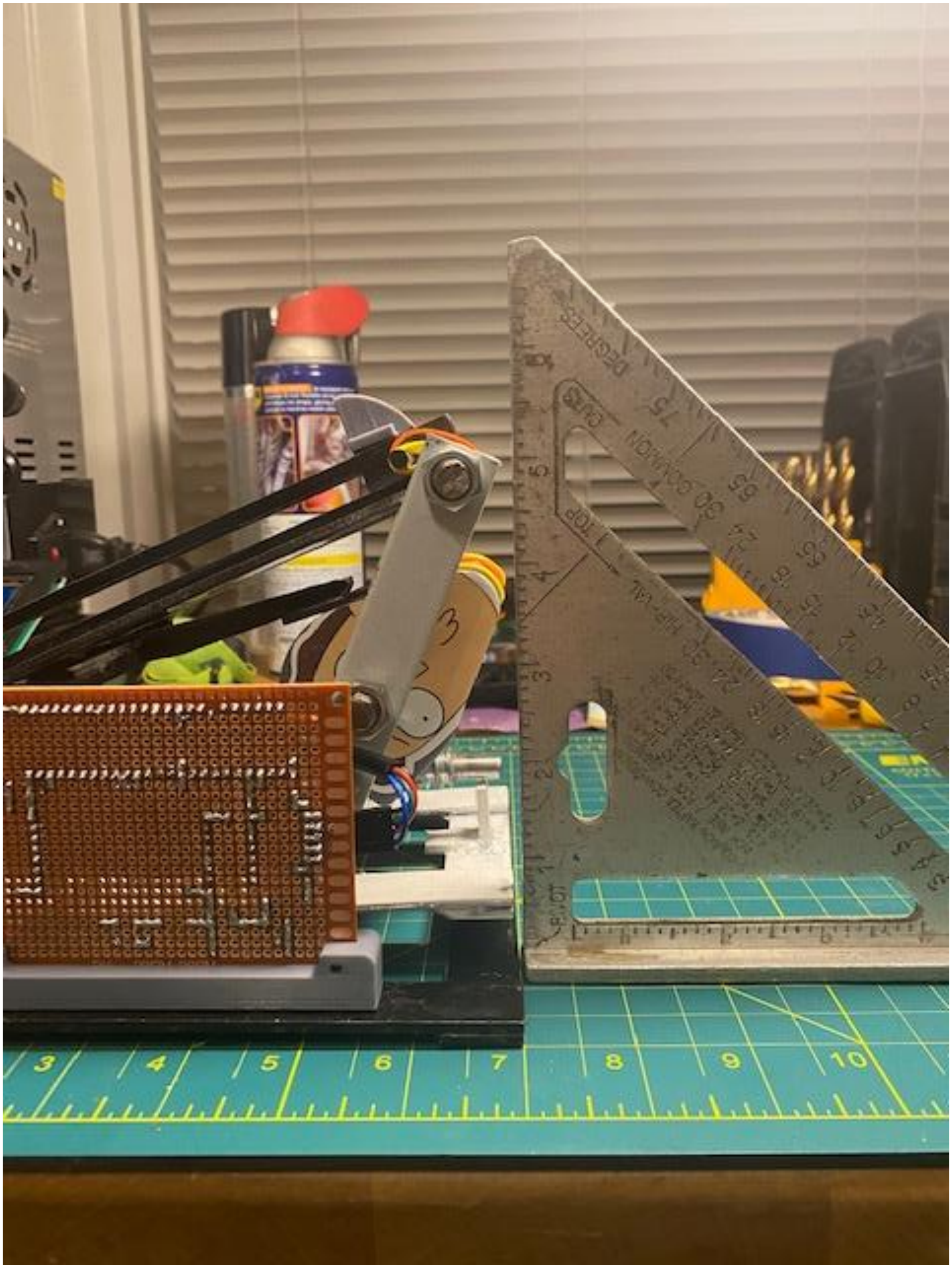


Figure 6. The highest point on the machine lies below the 6" line on the square at the right.

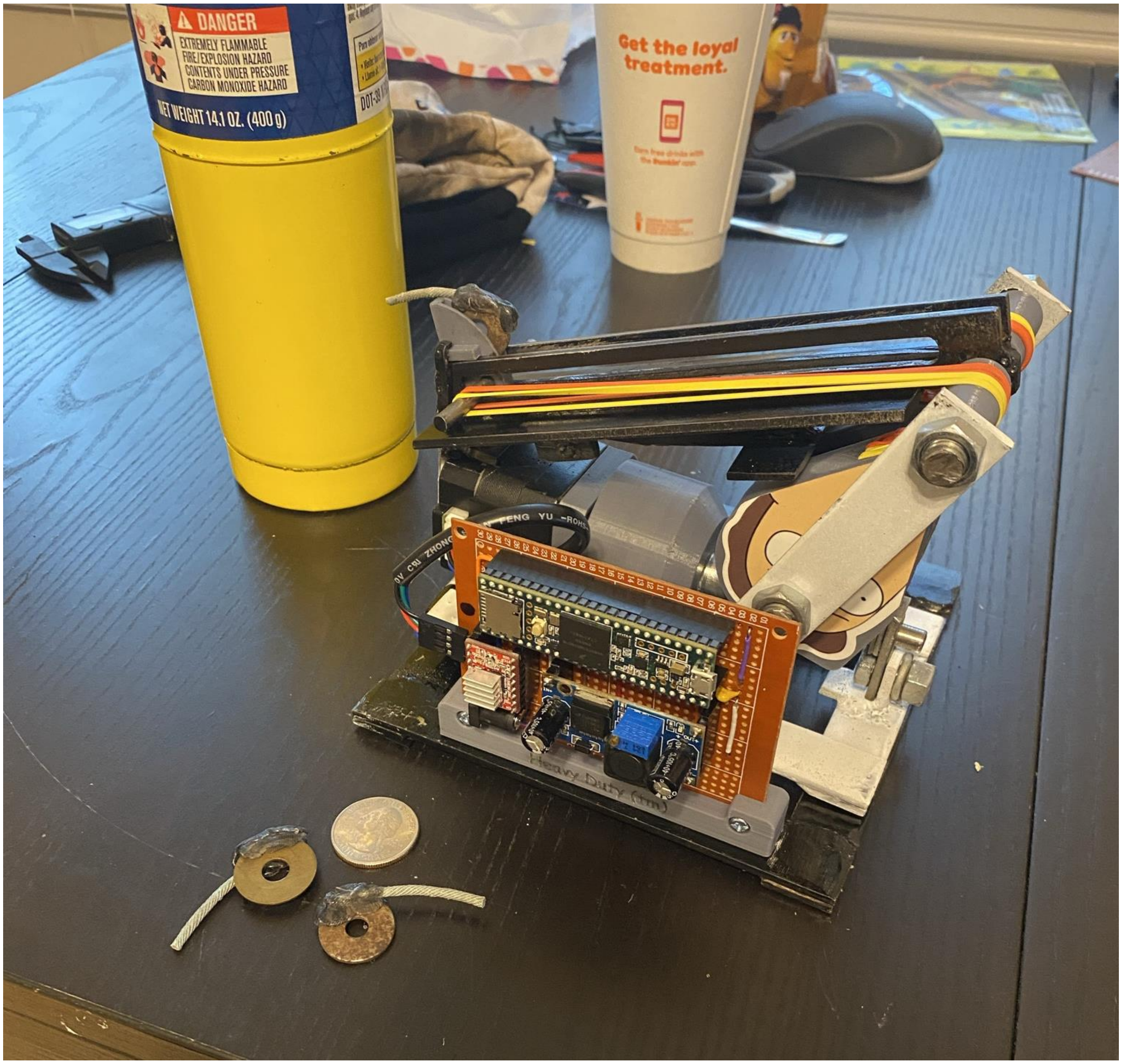
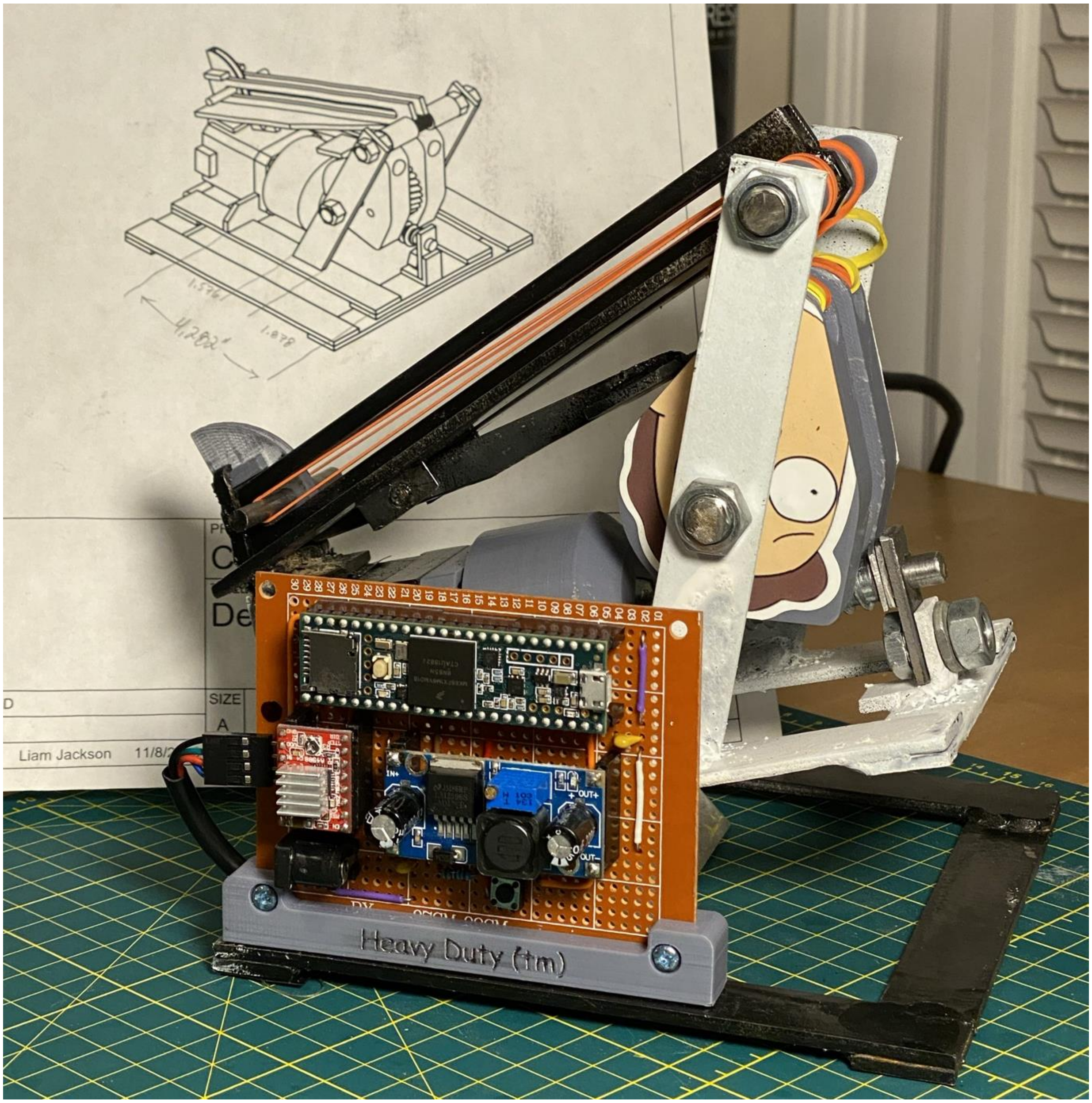
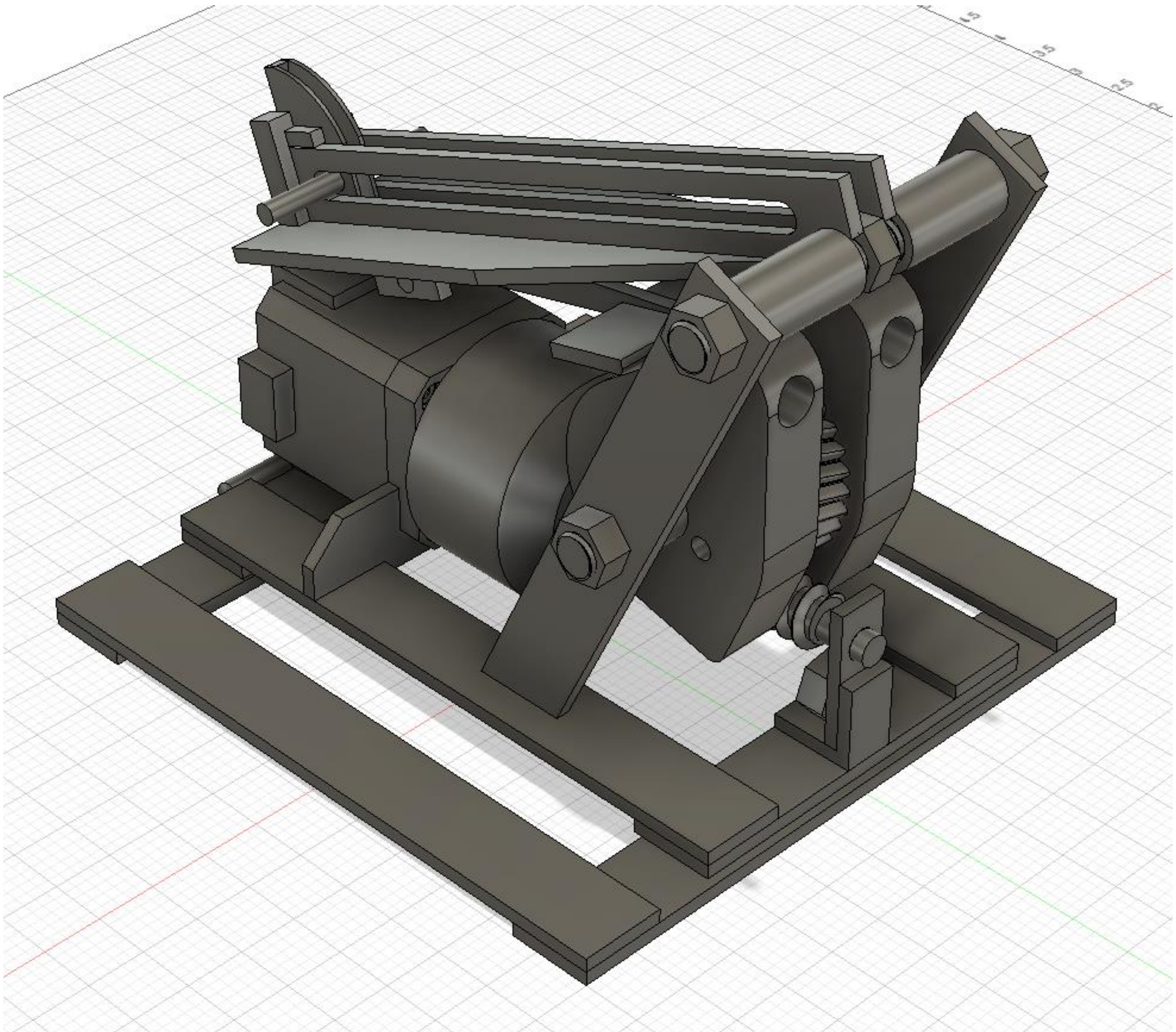
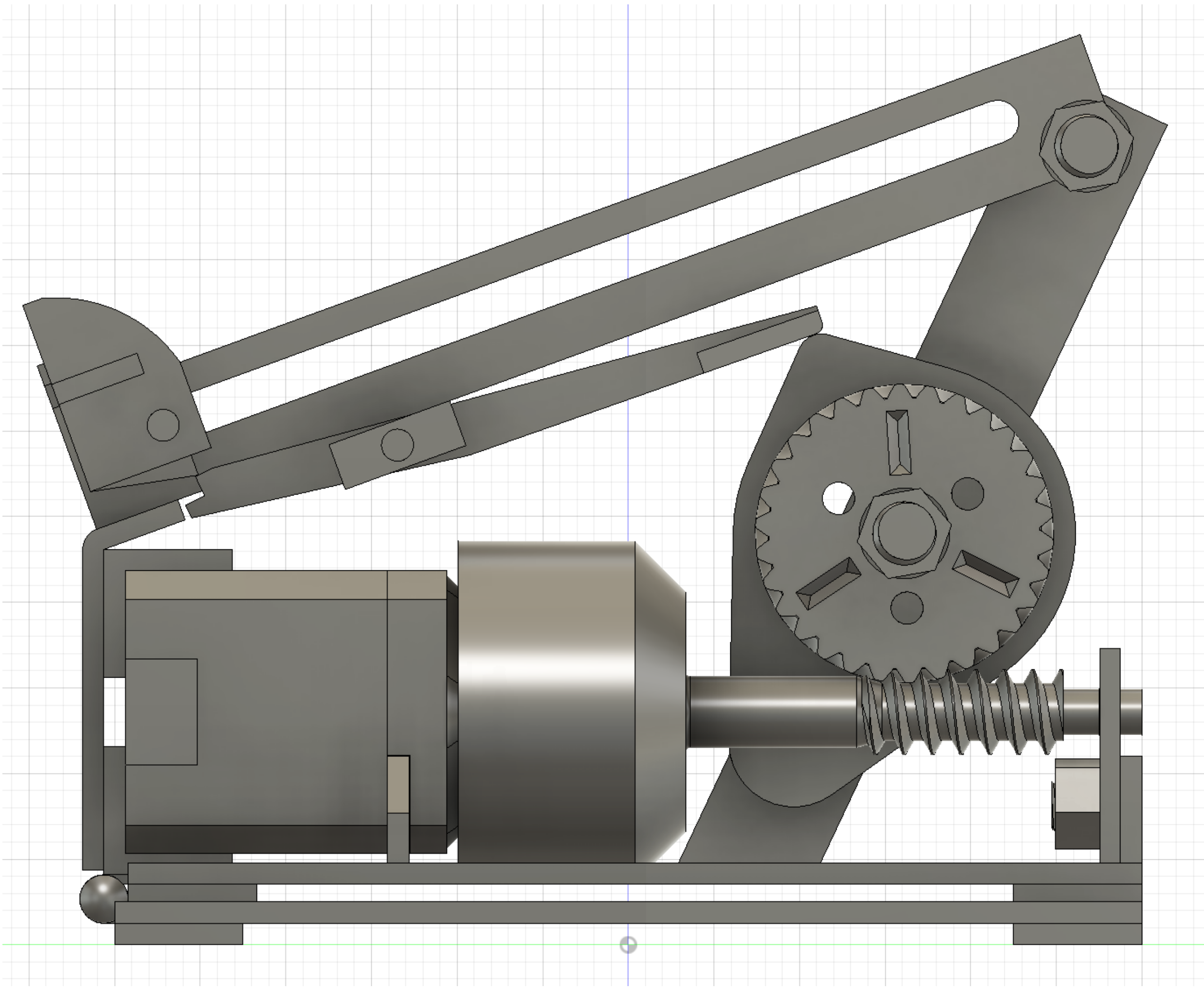


Figure 7. "Tracer rounds" made from old washers the approximate size of the quarter with fuse hot glued to the surface. Fuse left over from my pyrotechnics/model rocketry phase.



Liam Jackson
Heavy Duty (tm)





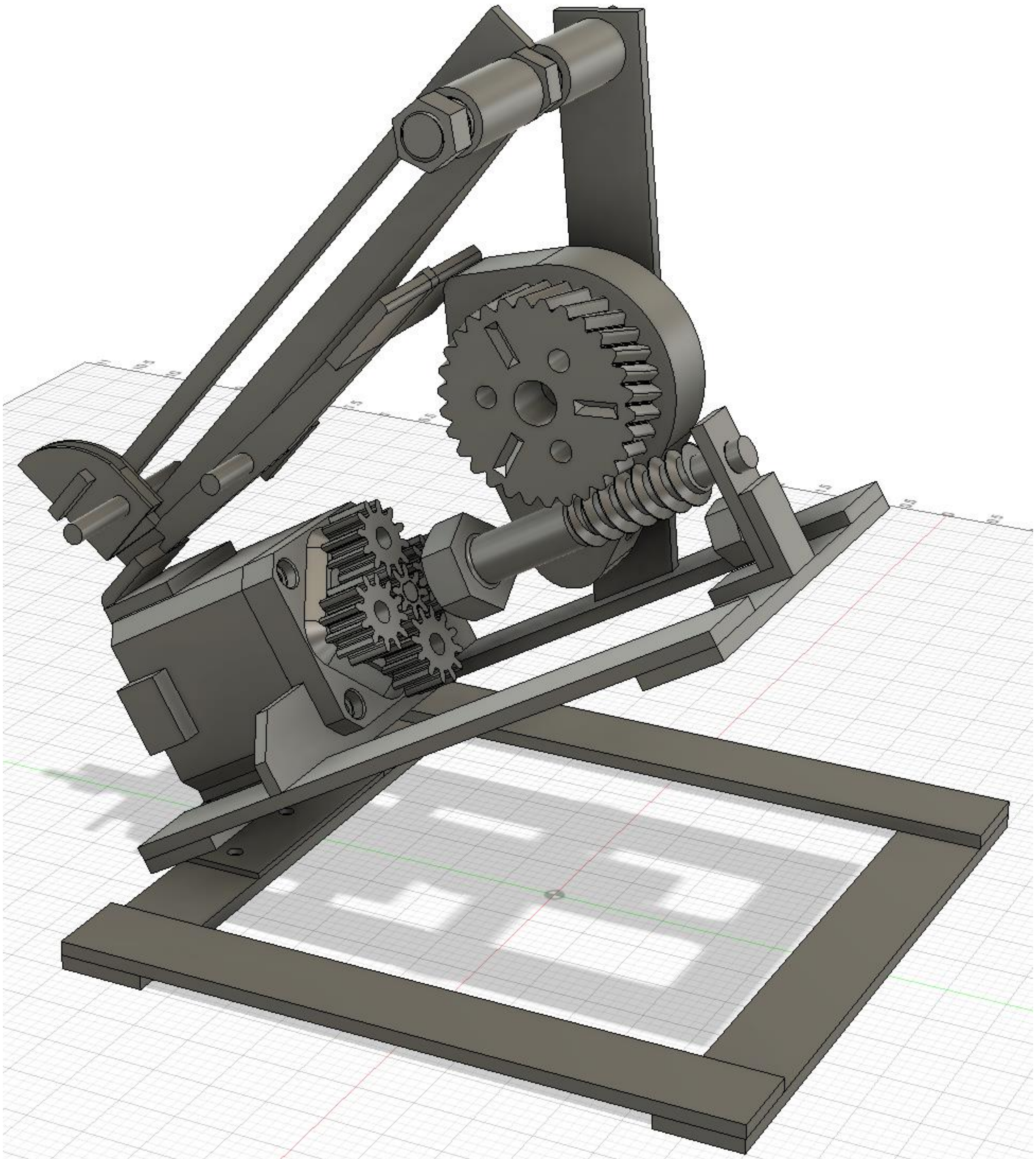


Figure 8. Some components are removed to show the inner workings of the torque multiplier

Bill of Materials:

5ft ¾”x 1/8” Flat Bar stock

2ft ¾”x 1/8” Angle stock

1 Uggo Dinner Fork

1ft 3/8” all-thread

6” 5/16” rod

2.5” Tee Hinge

4 M3 machine screws

2.5”x1/2” Lag Screw

Assorted Nuts, Washers, Lock (Split) Washers

eSun Gray PLA+

E71T-GS Flux Core Welding Wire

90sec Instant Set Epoxy

White Plasti-Dip

Gloss Black Rustoleum HD Enamel

Blue Loctite

Teensy 3.6

A4988 Stepper Motor Driver

19V Laptop PSU

Barrel Jack

Perf board

LM2596 DC-DC Buck converter

Discrete components (Resistors, Capacitors, Switch)

Solder

Rubber Bands

Neodymium magnets

CA Glue