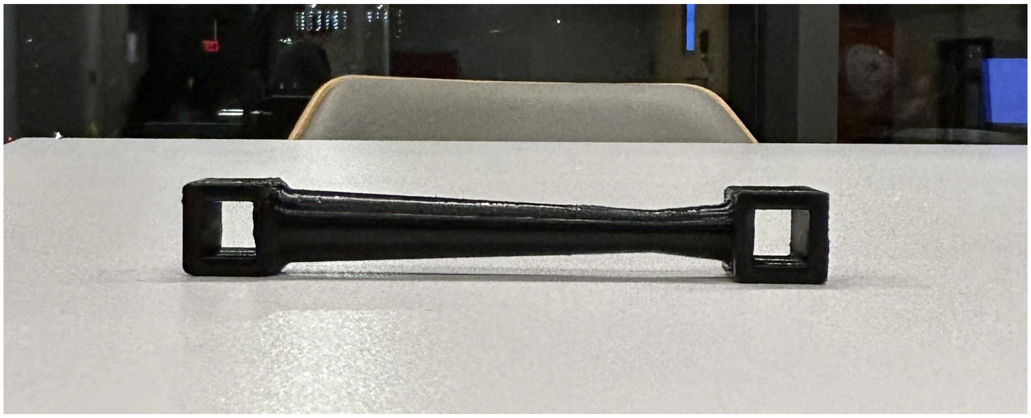
Building Blocks



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Problem Statement

In order to tackle a potential safety hazard, our group was tasked with developing a bicycle crank to minimize the risk of lower-limb injuries during rapid braking maneuvers. Our primary concern stemmed from when forces exceeding 12 Newtons of force were applied on the pedal. Thus, our main design objective was to design a bicycle crank that approaches a factor of safety of 1.0 at the critical 12N deceleration force. Other objectives we were tasked with were to minimize the crank's overall mass in consideration of cost efficiency, as well as making sure that all failures occurred at least one centimeter away from the interface components due to safety concerns.

In proceeding to create our first design, we first needed to calculate the acting force on the pedal and how it would translate over to the bicycle crank. To achieve an accurate simulation of what was happening, we created an assembly within CAD that mimicked the situation at hand. Using two rods and a basic crank, we fixed the crank on the rods and applied the required force at one end of a rod. After applying the correct fixtures + loads and running the study, we came to the consensus that ideally, we wanted the center of our crank to snap at 39.2 Newtons. Furthermore, we were able to deduce that the large majority of the applied stress was bending stress.

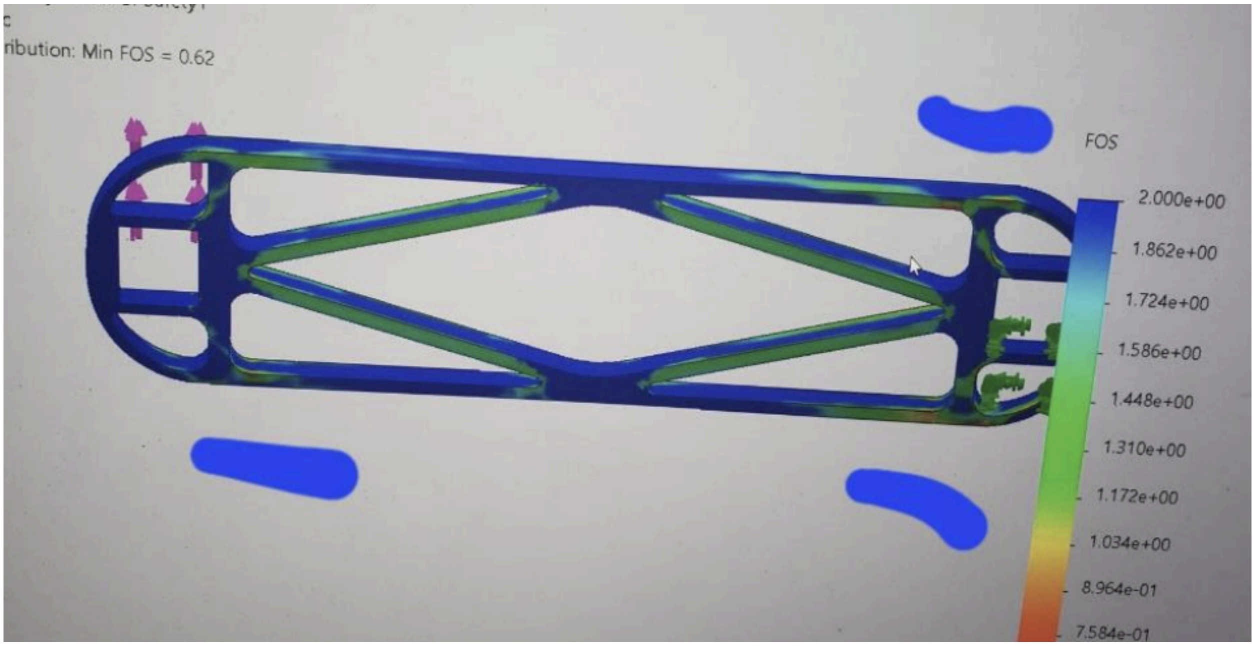
Prototyping Round 1

Design Approach:

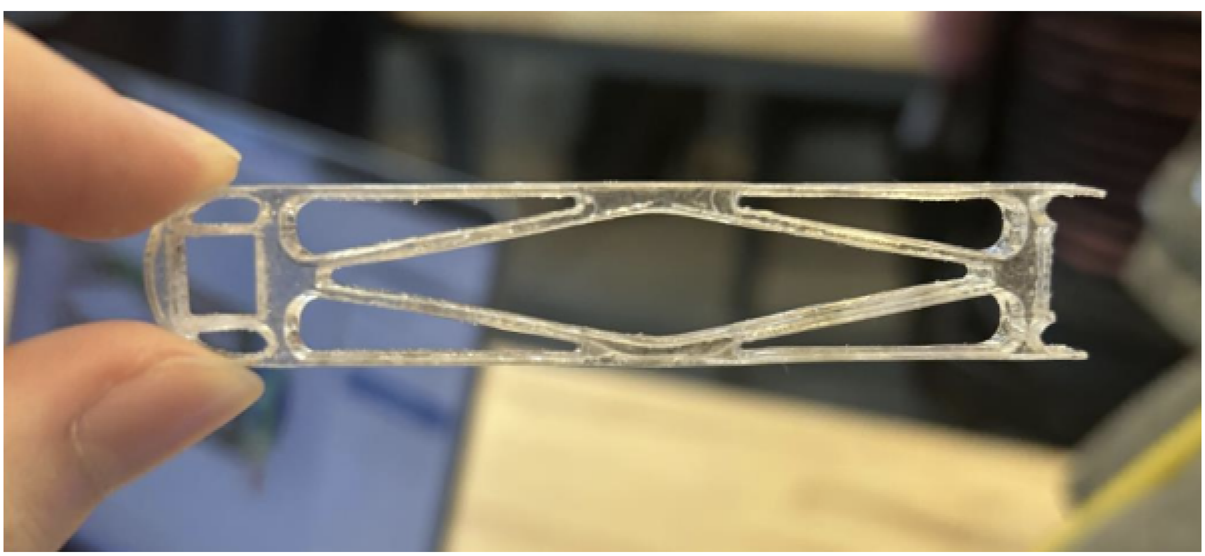
Our first Idea was to elaborate and optimize our crank from a simple rectangular prism. Our first step to creating our design was proceeding with a weight optimized approach. With this in consideration, our second step was making sure that this design would snap at the center. Additionally, for visual aesthetic and ease of hand calculations (if needed), we wanted to make a symmetrical design. With all of these components in mind, we decided to carve pieces out of our prism to tackle the weight issue, but made sure to leave in support beams that would not only aid our design's goal of snapping at the center, but providing maximal bending resistance with minimal material. Once this was achieved, we shaved off material wherever possible without risking failure. Eventually, we were satisfied with our final design which featured a symmetrical rectangular shape with rounded edges, hollowed interiors, and multiple support beams.

FEA Analysis:

For our first part we relied on FEA analysis to optimize our design.



Testing Results and Insights:



The first round of testing did not proceed as we expected. One of the largest issues we encountered was our failure to account for the epoxy affecting our ease of fit into the testing rig. This led to cracks and and damages to our prototype in effort to shove the rods through the holes, influencing its failure at the holes.

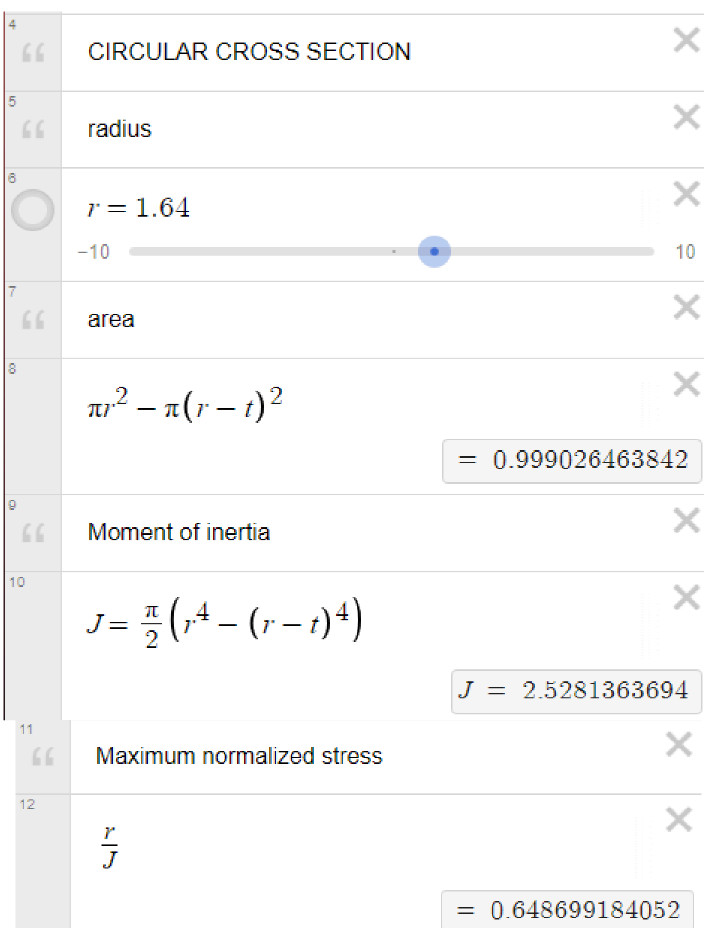
Prototyping Round 2

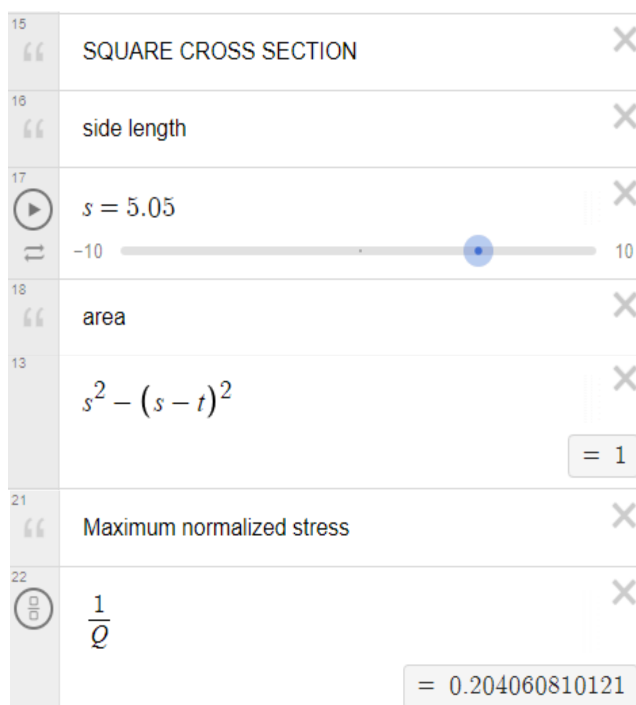
Design Approach:

Our second approach involved a different approach to resisting bending stress. Rather than a rectangular cross section, we decided on a circular cross section to minimize the torsional stress our crank would experience. To satisfy this, we went with a cylinder with carved out sockets for the rods. Since it would be impossible to laser cut a cylindrical model using the provided acrylic sheets, we used PLA to 3D print this prototype.

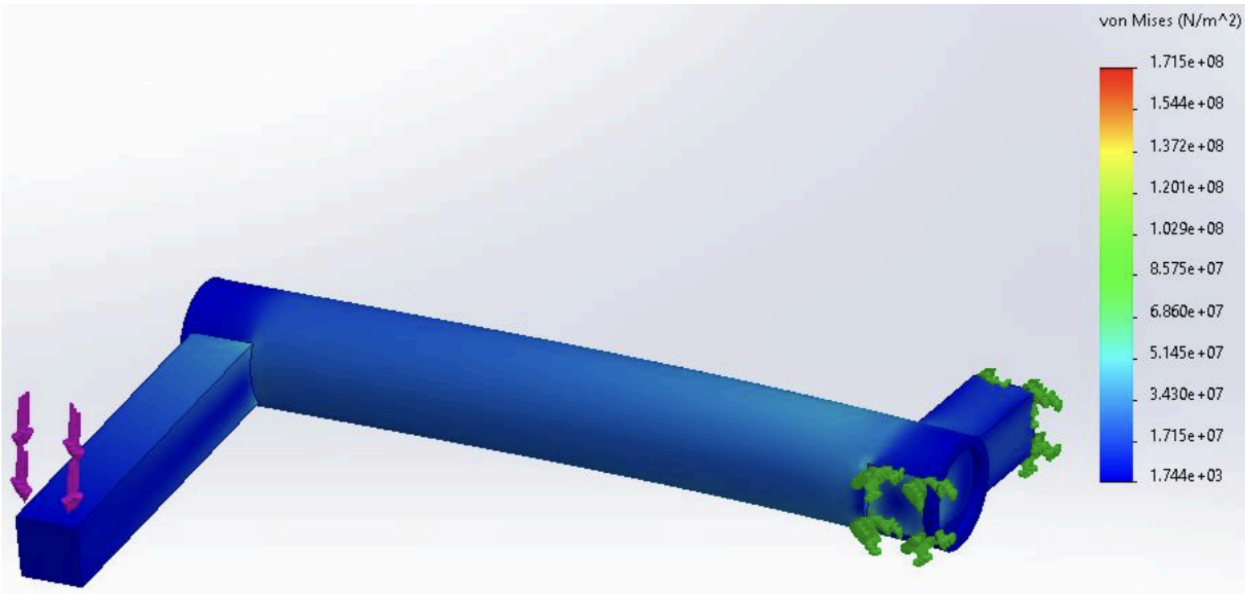
Hand and FEA Analysis:

To optimize our second prototype, we looked at different shapes of a beam to find which one would work best. We compared a hollow circular cross section and a hollow square, to find which one would resist torsion the best.





We prioritized minimizing torsion as it is the dominating stress when combined with bending stress under brittle/ductile failure, which allowed us to minimize the material we used. We then did FEA analysis to get an idea of how our new part would look under load.



Testing Results and Insights:

The second round of testing did not go as expected. Due to the printing pattern of the 3D printer, this prototype had weakened areas near the insertion points for the rods, which is ultimately where it failed, after application of a 6 pound weight. However, it did succeed in that it performed much better than our first prototype. If not for the premature failure at the unexpected point, we speculate that it would've far exceeded 6 pounds, which caused us to re-evaluate our dimensions and design shape, outside of just the insertion points.

Final Prototyping Round

Design Approach:

For the final round, we updated our design and opted for a dog-bone shaped structure. With this change, we figured we could maximize the factor of safety at the application of the weights and influence the breakage point by narrowing down towards a singular point.

However, in our practice trials we learned that the condition of the printer had a non-negligible effect on the prototype’s factor of safety. When testing models, there was a considerable difference in each design's strength depending on their manufacturing speed. We noticed that the models printed alone seemed to collapse when subjected to a larger load, while the models that were printed in batches(i.e. two being made simultaneously) collapsed a lighter load.

This is likely an occurrence of thermal expansion and bond strength. The faster a printer is able to lay down material, the larger the effective material placed is. If you bound more plastic on top of the material before it has a chance to cool to room temperature, it will have a larger diameter and then be pulled into that configuration by the hot layer above. This likely locks the larger diameter in and increases the strength from inertia related stresses. Additionally if the printer is able to lay down another layer while the layer below is still at its glass transition temp, such that the bottom is still moldable, the top layer will sink into the one below. This increases each layer's bond to each other by increasing their contacting surface area.

To have a repeatable breakage at a Force near 9 lbs, the design was printed vertically and in batches of two. This vertical manufacturing created a fault line perpendicular to the length of the part that allowed for a failure that appeared brittle but was from a ductile material. Batches of two removed the inconsistency from printing speed and normalized the parts.

Hand and FEA Analysis:

In this model, producing useful FEA analysis proved to be very difficult. Explicit manufacturing defects and modifications arose much more commonly with 3d printing, and modeling the extrusion lines, layers, and other small geometry changes that resulted from 3d printing appeared to be a laborious task. Instead, knowing that we had simplified our design to one with overly reinforced side pieces and a tapered pipe, we instead performed hand analysis on these revisions. To estimate the yield strength, we tested an oversized prototype until failure. Then by performing hand calculations for max ductile stress, we ended with an estimated 30.39mm outer diameter with 1mm wall thickness. The wall thickness was derived from limitations of the 3d printer. The calculations are below:

8 Stress due to bending (MPa)

9 $$t = \frac{\frac{Nx(a+d)}{\frac{\pi}{4}(a+d)^4 - \frac{\pi}{4}a^4}}{10^6}$$

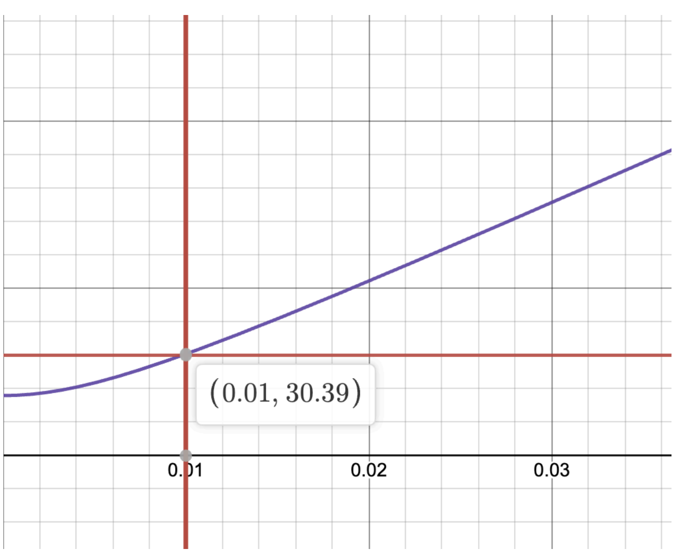
10 $l = .0701$ (slider −10 to 10)

11 $l_1 = \frac{l}{2}$ → $l_1 = 0.03505$

12 $N = 40$ (slider −10 to 40)

13 Ductile Yield (MPa)

14 $$\sqrt{\frac{D^2}{4} + t^2}$$



1 Stress due to torsion (MPa)

2 $$D = T \cdot \frac{\frac{a}{J}}{10^6}$$ → $D = 35.9084533511$

3 $$J = \frac{\pi}{2}\left((a+d)^4 - a^4\right)$$ → $J = 9.6249759526 \times 10^{-11}$

4 $d = .001$ (slider −10 to 10)

5 $a = .00195$ (slider −10 to 10)

6 $a + d$ → $= 0.00295$

7 $T = 40 \cdot .04431$ → $T = 1.7724$

Our final diameter was 29.5, which was slightly smaller than calculations. We tested .5mm steps on diameters until we were able to reach a consistent breakage at 9 lbs. This likely resulted from inconsistencies when measuring loads and manufacturing inconsistencies.

Testing Results and Insights:

In the final round of testing, our design experienced brittle failure at just barely over 8lbs of force, which is what we were looking for and hoped to expect. Ideally, our prototype would have snapped right at 9 pounds, but this margin of error can be attributed to inconsistencies in printer manufacturing, storage wear, and day of testing. To achieve this design, over 54 variations were made and tested. Overall, we were satisfied with our design's performance.