ME127 | Spring 2022 | Project 2

Hook'd

a portable hook for all of your on the go storage needs

Team 😎😵‍💫 | Alyssa Charley, Britney Ky, Omar Ramos Escoto

Project Description

Timeline: 2 Weeks

Objective

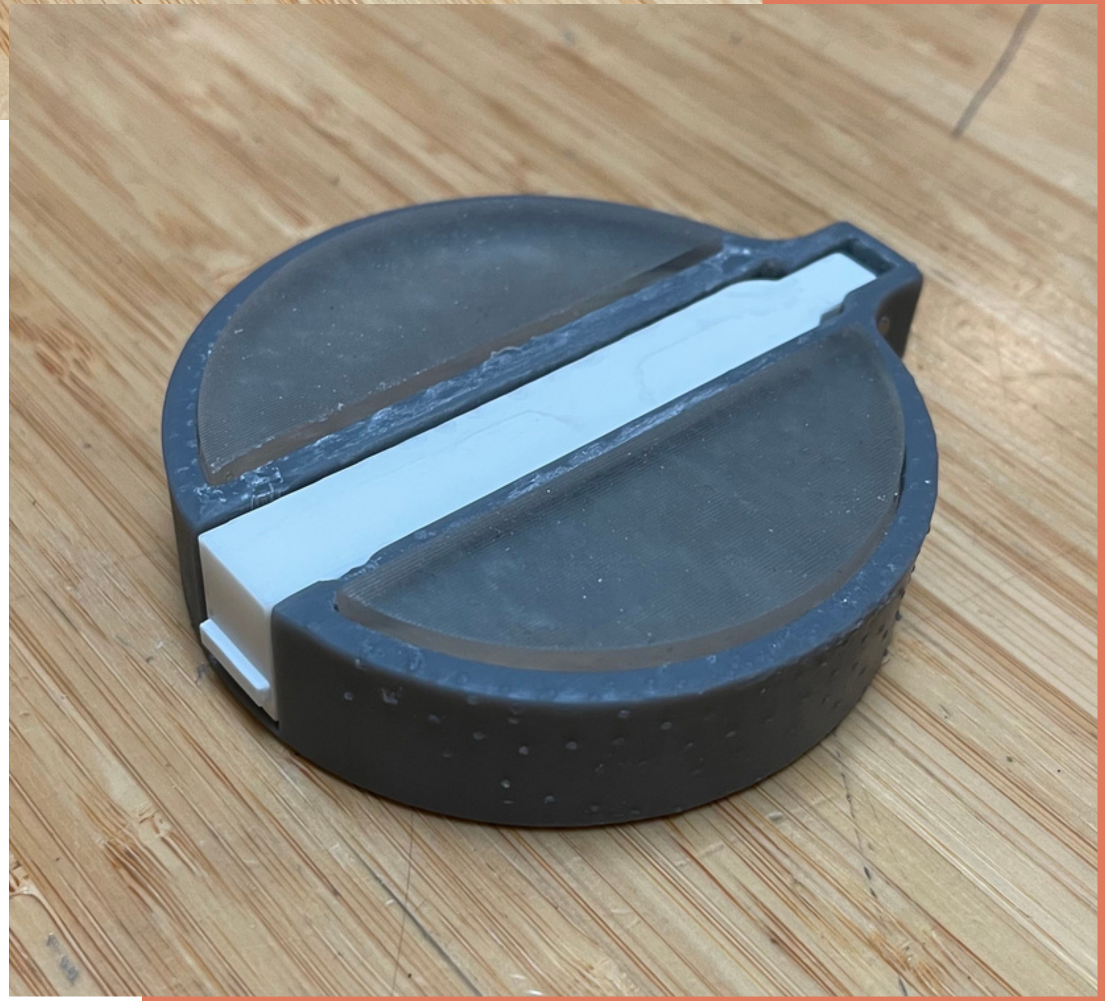
Design an assembly of 3D printed parts that performs a mechanical function. Projects must leverage the unique properties of at least two different materials.

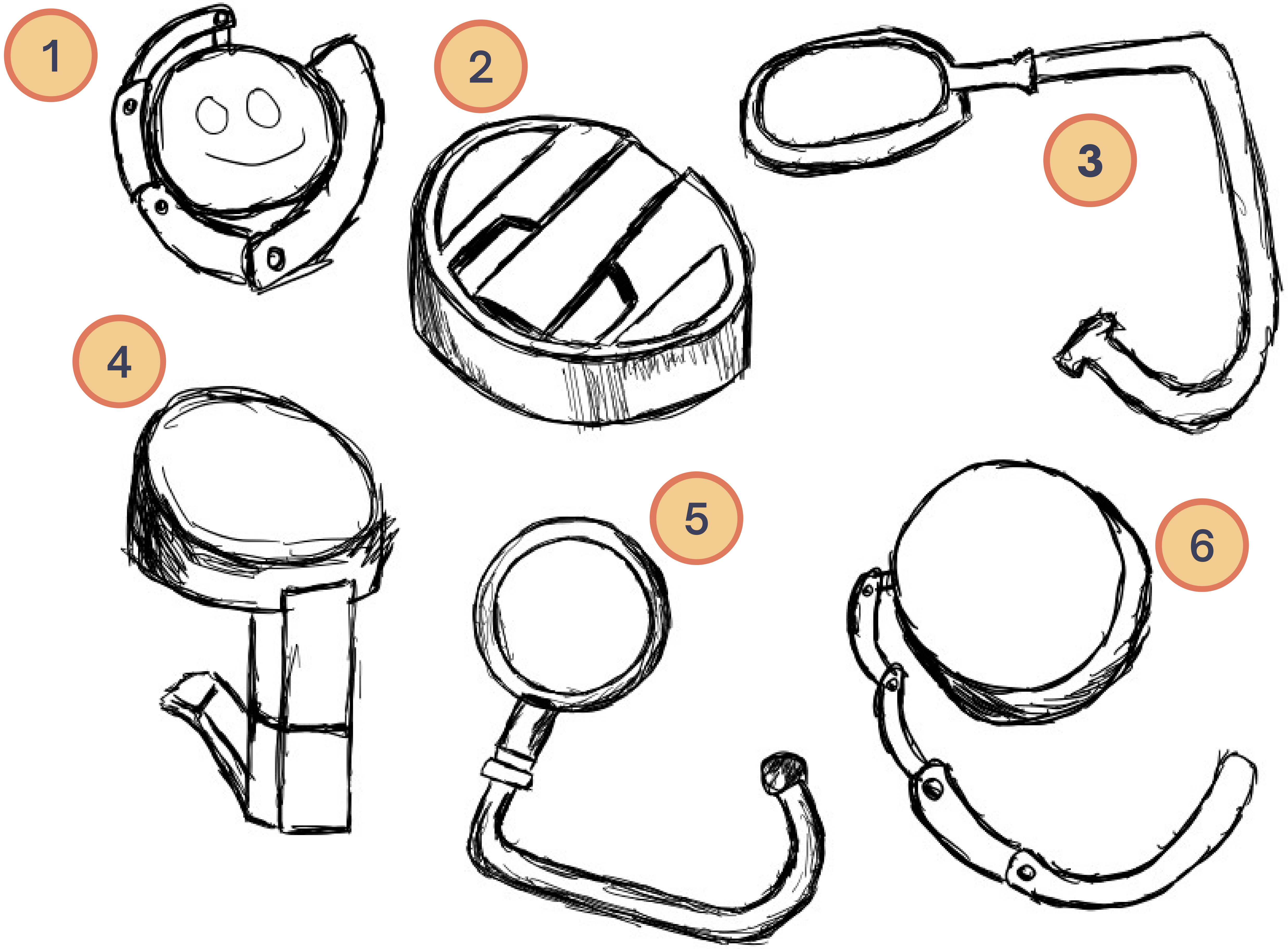
User & Use Cases

We designed a portable hanging hook. Users would be able to unfold the hook and hang masks, bags, or keys off of any flat surface with overhang. The hook would refold at pin joints and remain closed via magnets, all set in place with press fits. This would be a convenient accessory for all to use.

Goal

In order to measure our performance, we set a quantifiable design goal of ensuring the hook would support 20 pounds without failing. We also wanted to use new equipment and processes; no one in the group had utilized Form 3 machines before.





Brainstorming

We explored the different shapes and configurations that the part can take, as well as how to best incorporate the hook to alleviate stress while using linkages with pins.

This helped to drive our design forward to a more optimal, easy-to-analyze design that would leverage our materials and the additive manufacturing process.

We wanted to minimize the number of joints while still allowing for the arm to fold and be portable, so we settled on an iteration close to **design #4** for further refinement. This is simple for analysis and suitable for printing.

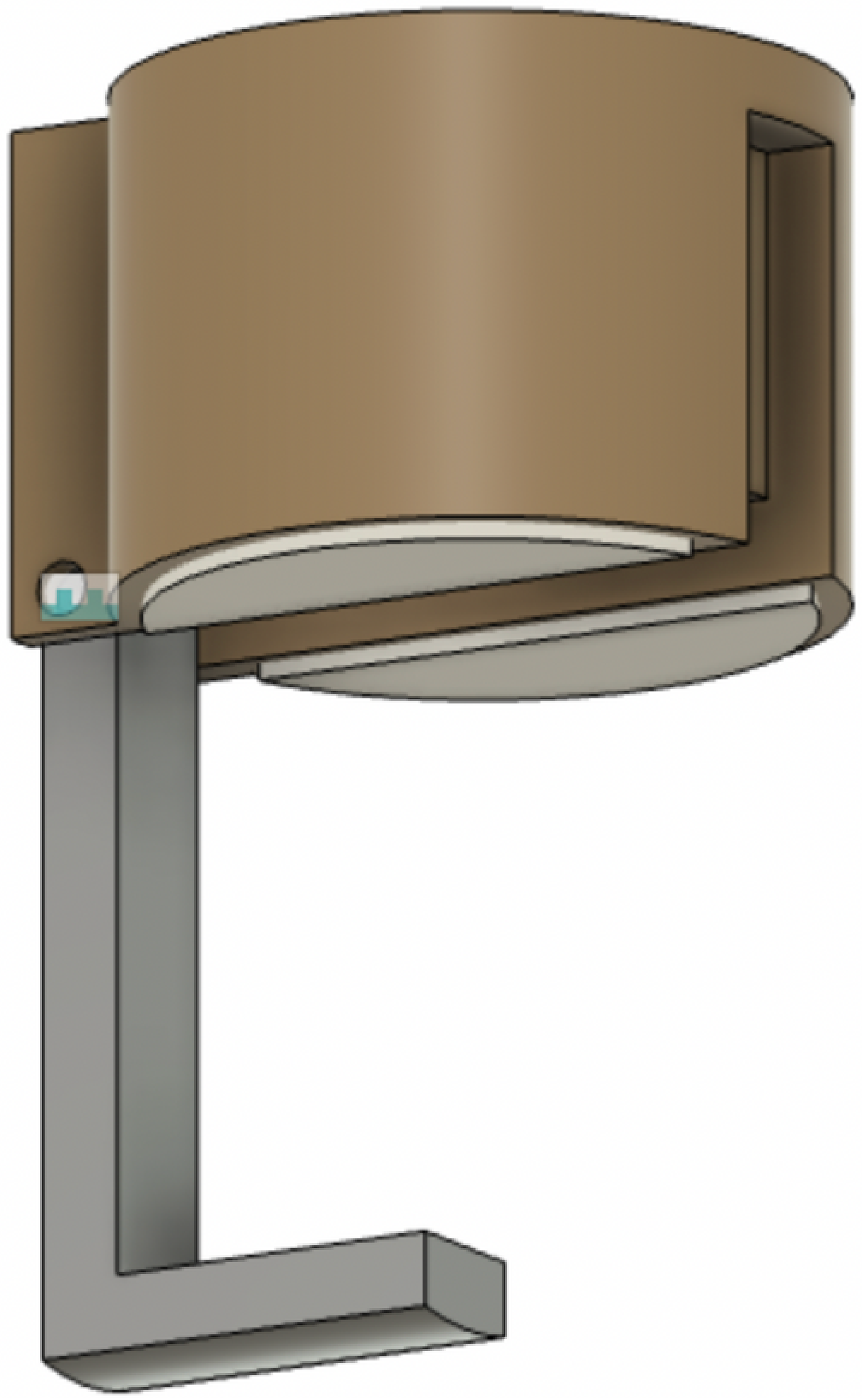
Iteration & Prototyping

Simplified Model - PLA

To get a sense of how our component would behave when loaded, we first printed a simplified model that did not fold out of PLA.

This provided a fast and cost-effective way to validate our free body diagram and pinpoint areas of stress to stay alert to and choose our materials to accomplish this

From this prototype, we see that the bottom member holding the bag experiences the most stress and bending. So for our free-body diagrams and inverse analysis, this is the member we will pay most attention to.



One press fit pin such that the arm can pivot into the cylindrical body

Arm would stay closed via either magnets or a snap fit

First Iteration

Material Analysis

RIGID 10K

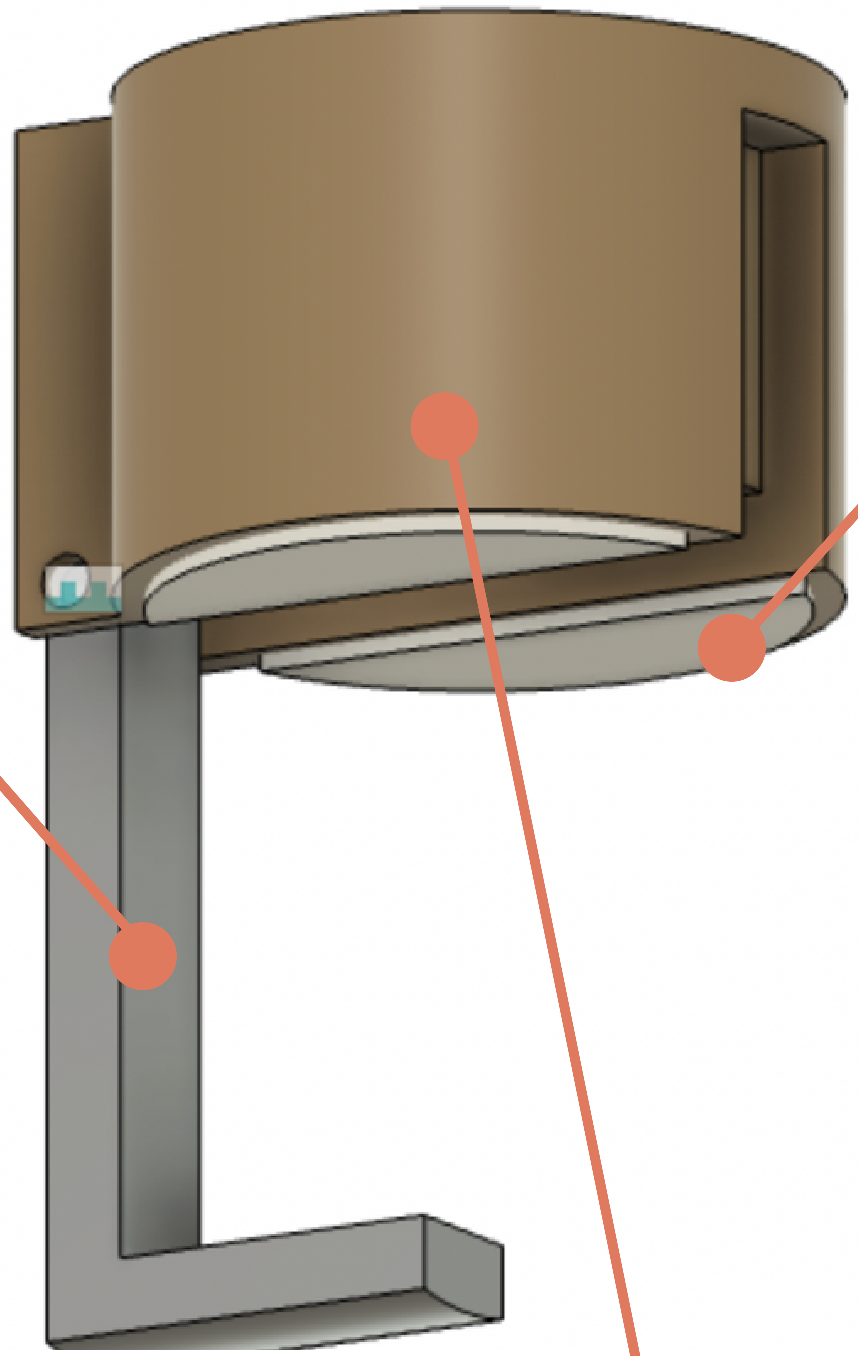
COLUMN ONE

High Strength & Stiffness

We wanted the strongest material to support load without failing

Little Deformation

We also wanted it to deform as little as possible so forces would remain in line as according to our FBDs.



FLEXIBLE 80A

COLUMN TWO

High Friction

Prevents the hook from slipping on the surface of the table , especially if accidentally bumped

Soft Material

Prevents the hard body from scratching the table material while being stiff enough to maintain shape

Though we did not proceed with this design, the material properties and use cases were the same in our final design

STANDARD GRAY

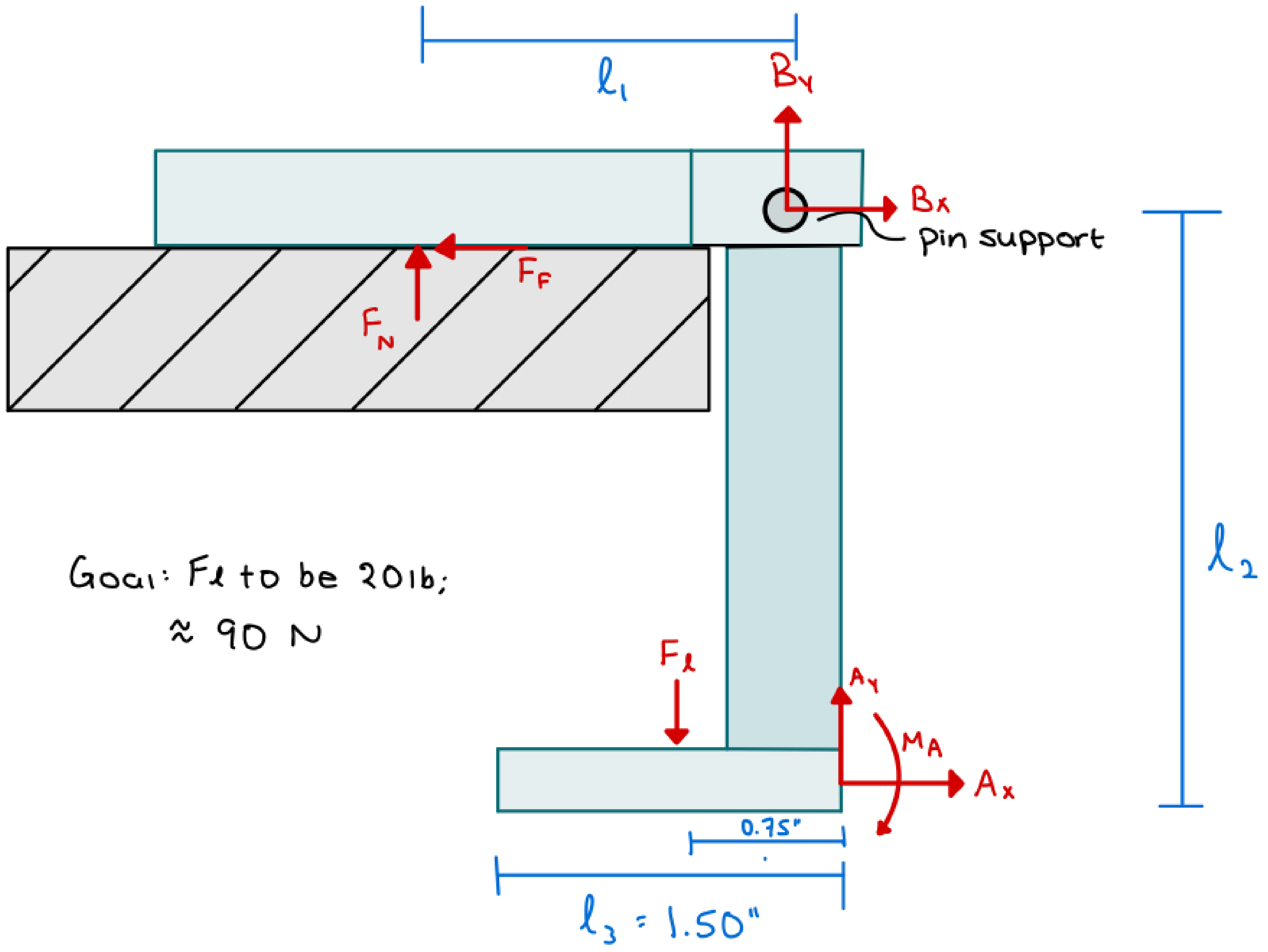
Low Cost

The cylindrical body required the largest volume of resin and was not a critical load bearing feature, so we chose in an inexpensive resin.

Aesthetics

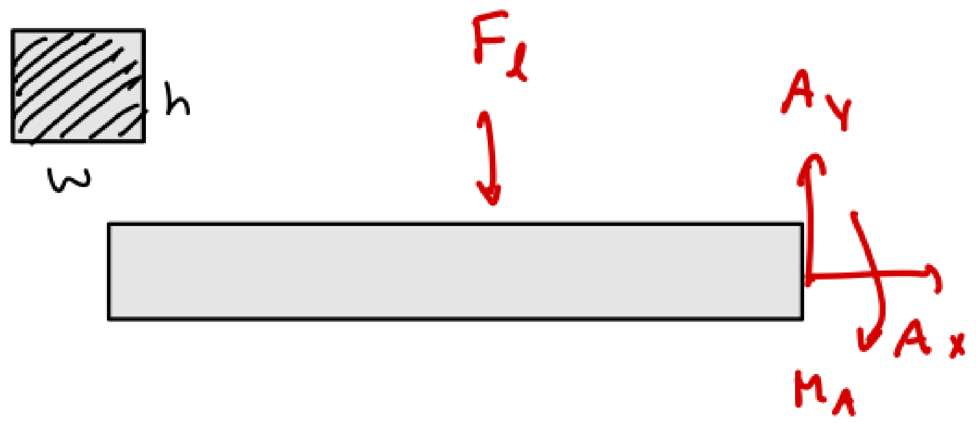
Great opaque finish in a pleasing color complementary to white Rigid 10k

Free-Body Diagrams



A free body diagram allowed us to see the forces in play with the part and to see which components would require the most focus. As we saw from our prototype, the bottom member experiencing the load will be more prone to stress, so we will focus our analysis for that component.

SIMPLIFY BODIES



$$I = \frac{bh^3}{12}$$

$$\sigma = \frac{M \cdot y}{I} \rightarrow \sigma_{max} = \frac{6 \cdot F \cdot l}{wh^2}$$

$$FoS = \frac{S_y}{\sigma_{max}}$$

We used these equations to relate the stress to our chosen Factor of Safety and yield stress of our given material to maximize efficiency.

Inverse Stress Analysis

From our preliminary prototype, we determined that the greatest stress concentrations would be felt along the member holding the bag since it experiences the greatest moment that could result in failure from bending stress.

Setting the Factor of Safety to 2 and using the tabulated yield stress of Rigid 10K, we were able to see how thick our part needed to be in order to accomplish our goal of it withstanding 20 lbs (~90 N).

This analytical solution served as our guideline on how to dimension our CAD design.

$$w \cdot h^2 = \frac{6 \cdot F \cdot l}{\sigma_{max}} = \frac{6 \cdot F \cdot l \cdot FoS}{S_y}$$

Will set FoS = 2; yield strength for Rigid 10K is $S_y \approx 84$ MPa (Formlabs Data sheet)

$$w \cdot h^2 = \frac{6 \cdot (90\ N) \cdot (0.0381\ m)}{(84 \times 10^6\ N/m^2)} \cdot 2$$

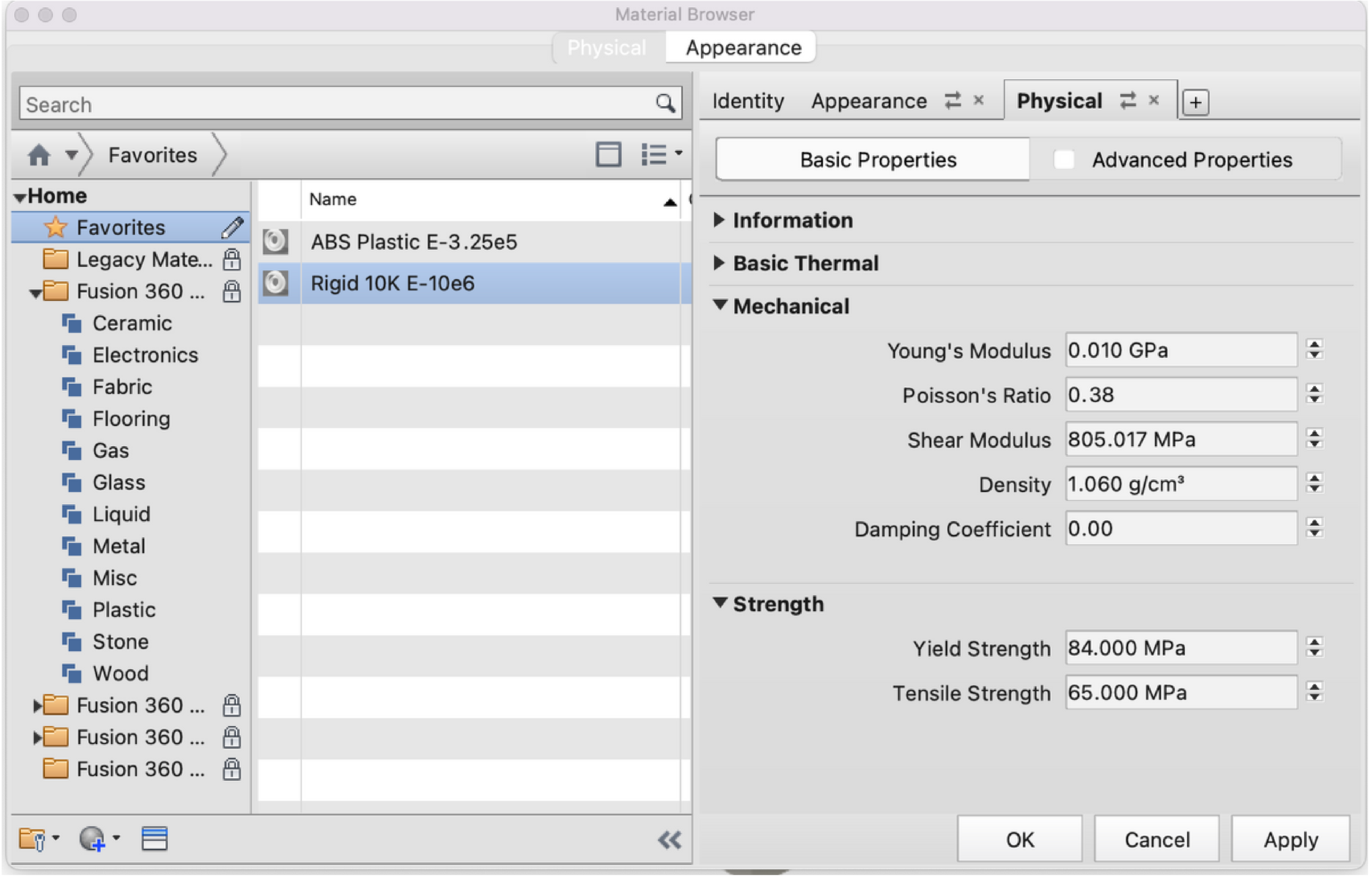
$$w \cdot h^2 = 4.89857e^{-7}\ m^3$$

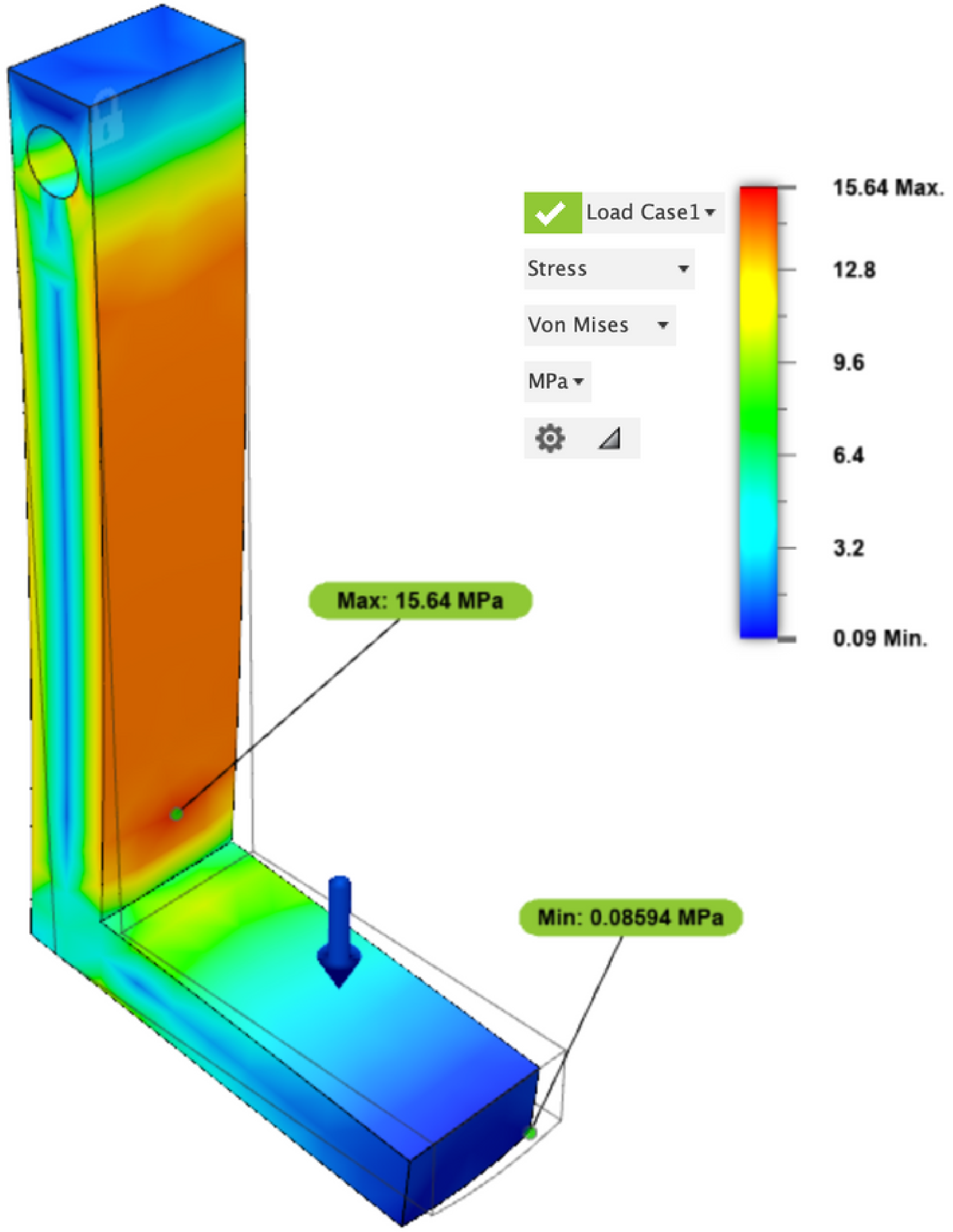
$$w \cdot h^2 = 489.857\ mm^3$$

Trying what we had in our prototype → w = 0.25" or w = 6.35 mm

w = 6.35 mm
h = 8.78 mm

Simulation



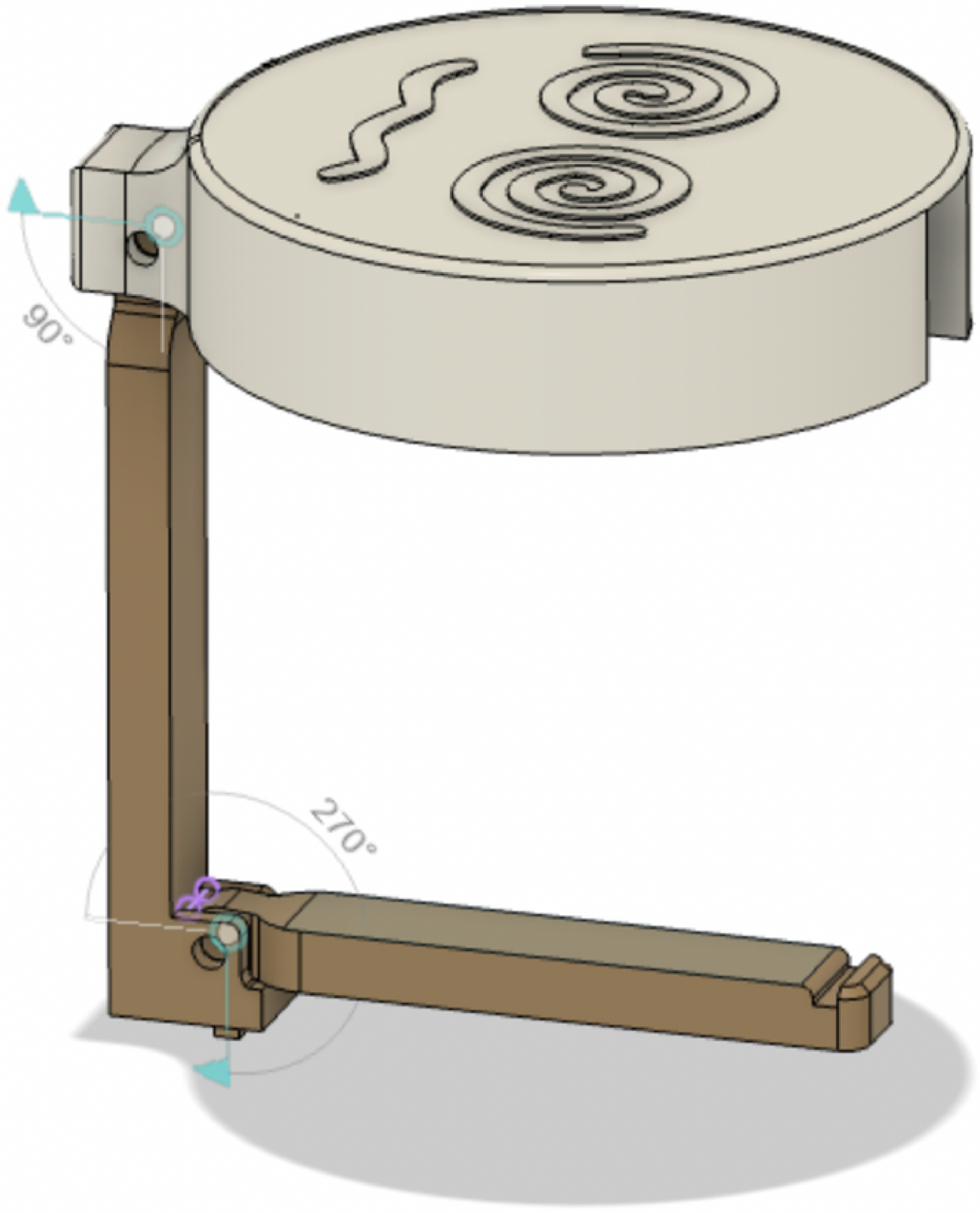


The capabilities of Fusion360 allowed us to have more accurate results by matching the material's mechanical and physical properties to the resin of our choice. Therefore, running this through the simulation gave us a better understanding of our part.

Conducted a static stress FEA analysis with a fixed constraint at the pin location and 90 N load applied to the top face of the component on a Von Mises scale.

Though the first design required fewer moving parts, since the geometry of the arms was reliant on the geometry of the cylinder, the cylinder protrudes too excessively to be used comfortably. Moreover, it would be costly to print.

Though another pin joint was added, this design is qualitatively similar such that the same material analysis, FBDs, simulations, and calculations from iteration one were still applicable.

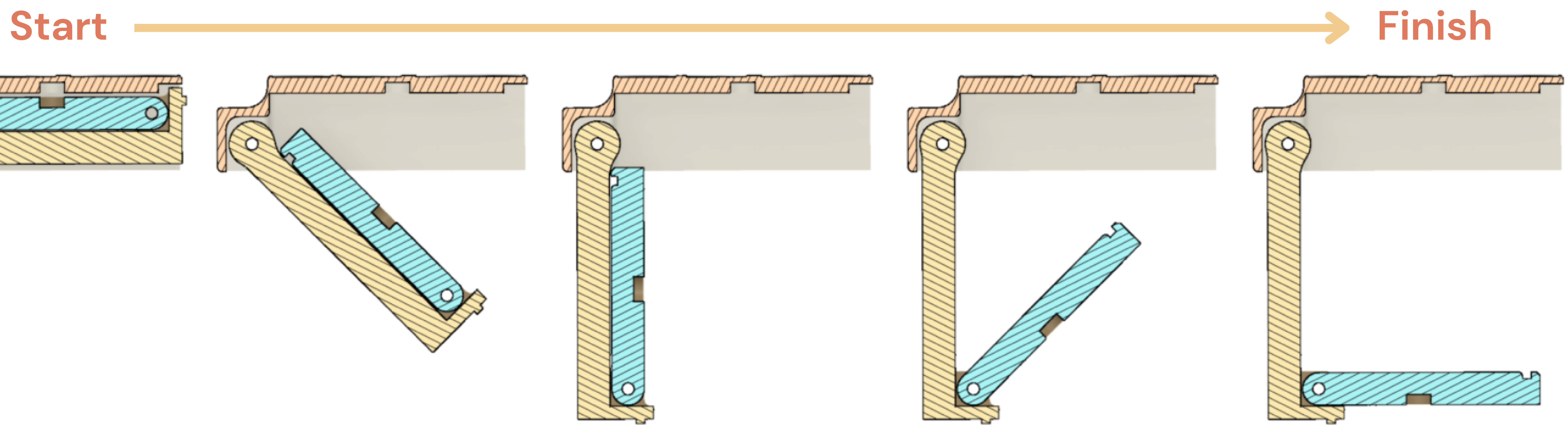


From our brainstorming and analysis, we chose to proceed with this design due to the part using less material for the cylinder head, lower price, as well as easy manufacturability with only two pins.

In a nod to our team name, we designed it to look like an emoji.

Final Design

Design Interaction



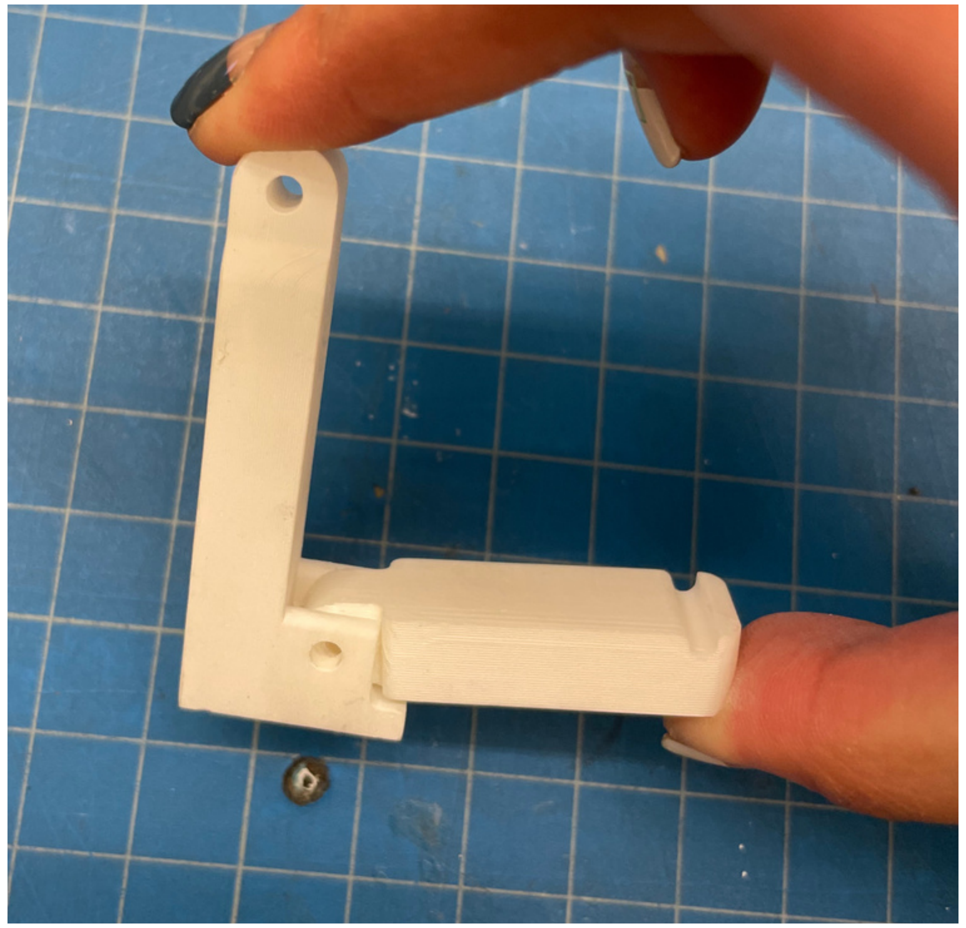
Members are fully unlinked when they rotate 90 degrees, with the first member perpendicular to the cylinder head and the second member parallel. We also had to consider the clearance required to disengage and re-engage the members relative to achieve a snug fit for a compact design.

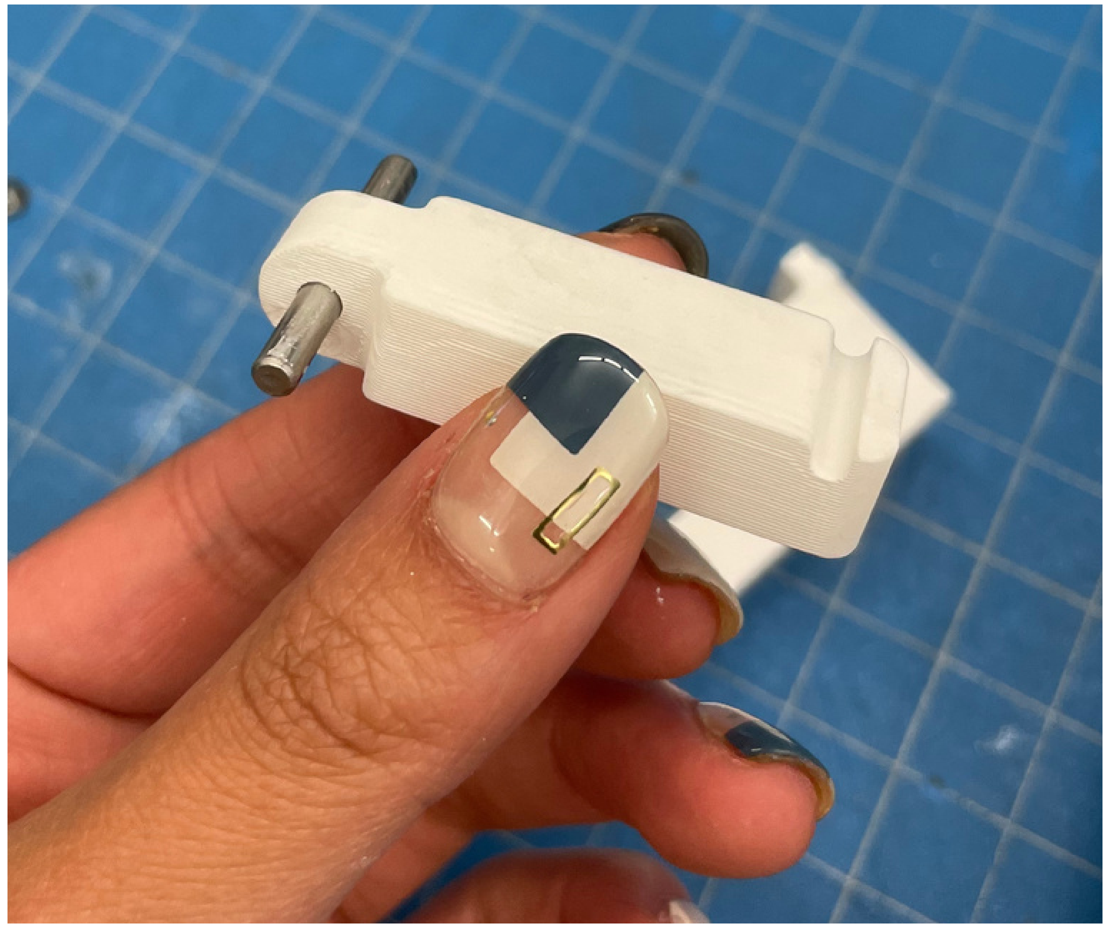
Interfacing: Arm linkages will pivot on pins, where one side is a press fit. Magnets, also held via press fit, will lock the arms in place when not in use

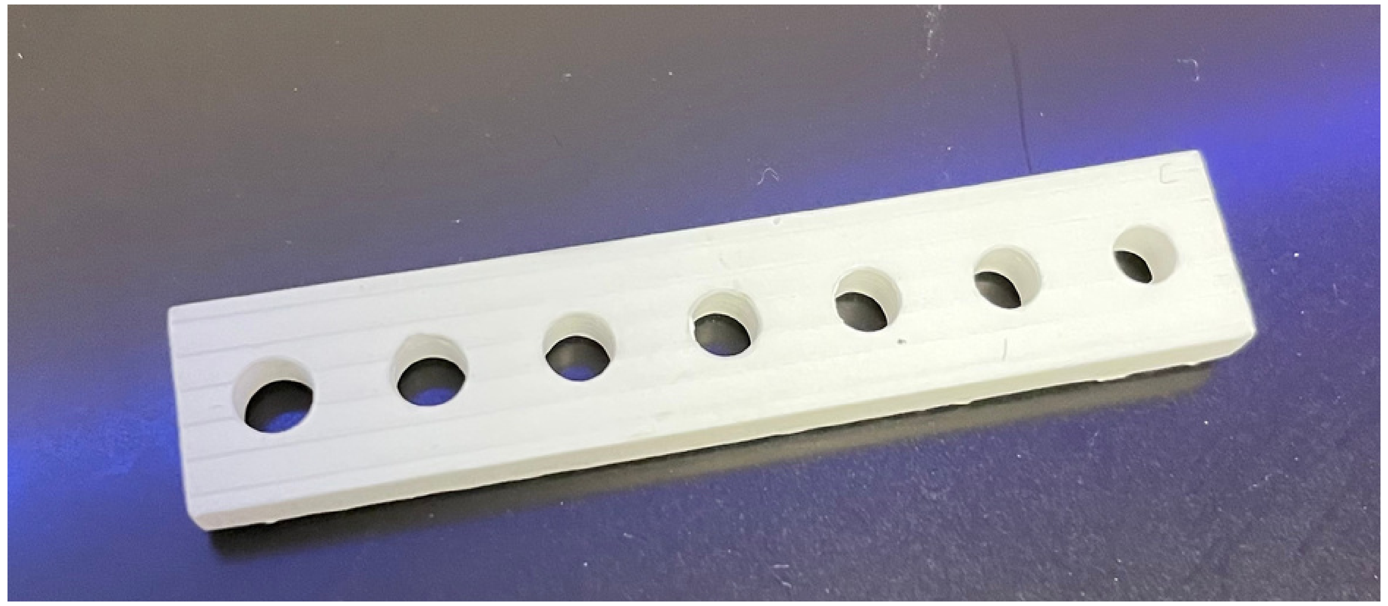
Iteration & Prototyping

Rigid 10k Tolerancing

We first focused on printing the arms as it was the critical load-bearing part. Its dimensions would then define all others.





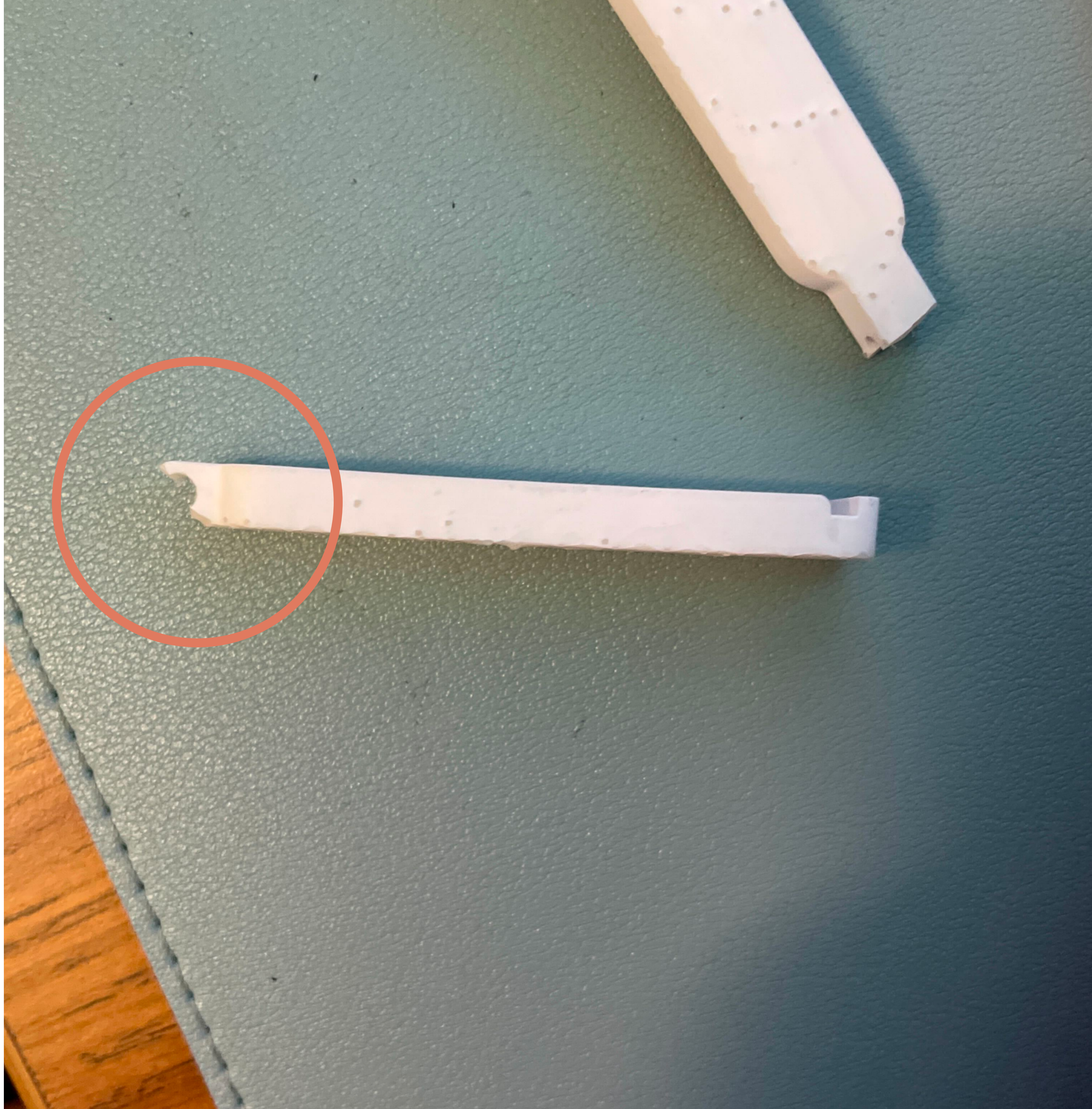


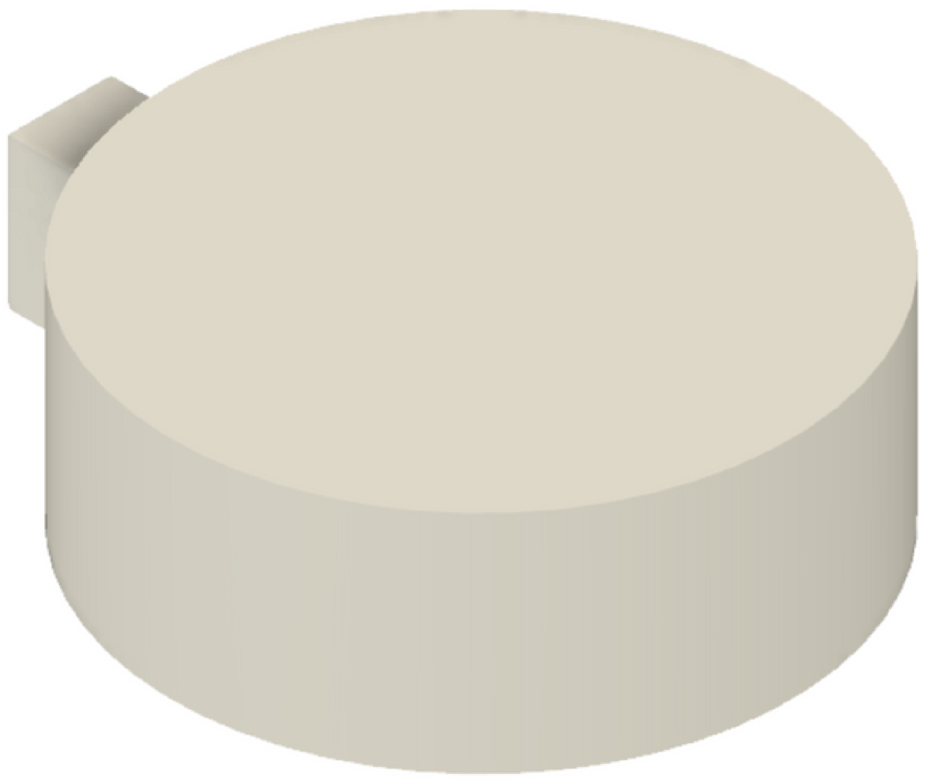
Though hole sizes for press-fitting pins were well dimensioned after a tolerance check, we needed to modify the geometry to provide users with more hanging space and modify features that prevented the arm from rotating.

After making those tolerance adjustments, we then loaded our printed part with approximately 10 pounds. Unfortunately, the part broke around the pins.

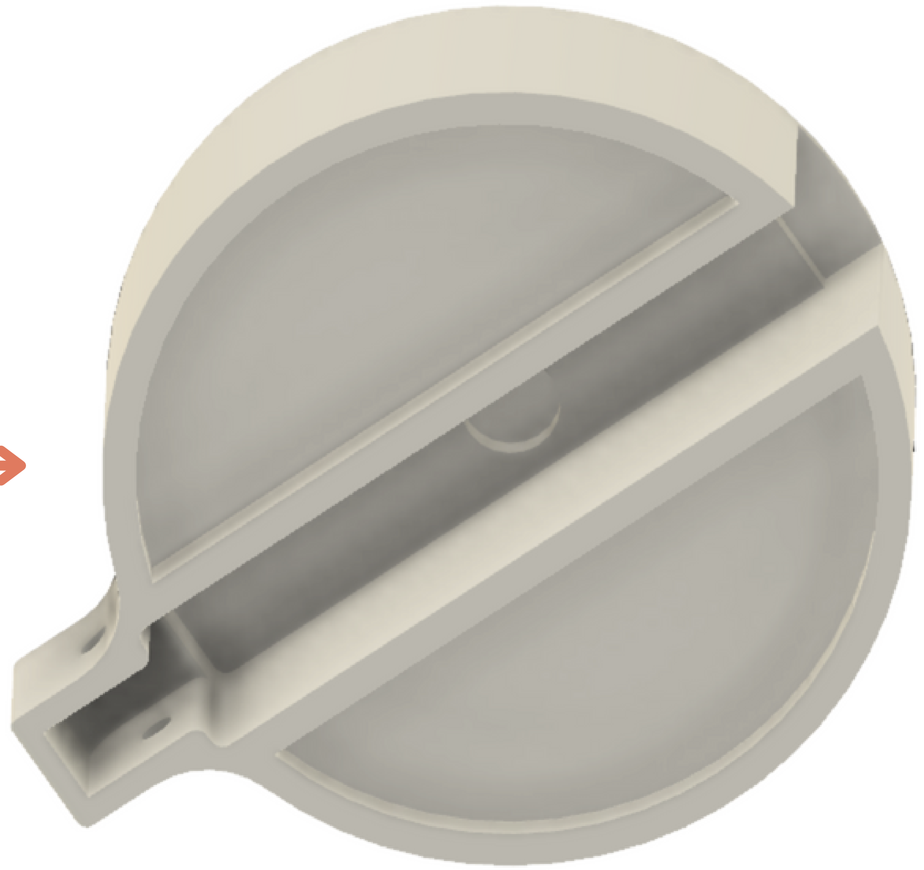
We hypothesized that our FEA simulation oversimplified our pin constraints, making them appear stronger than they were.

We increased material around the pins and re-ran the simulations for our final iteration.

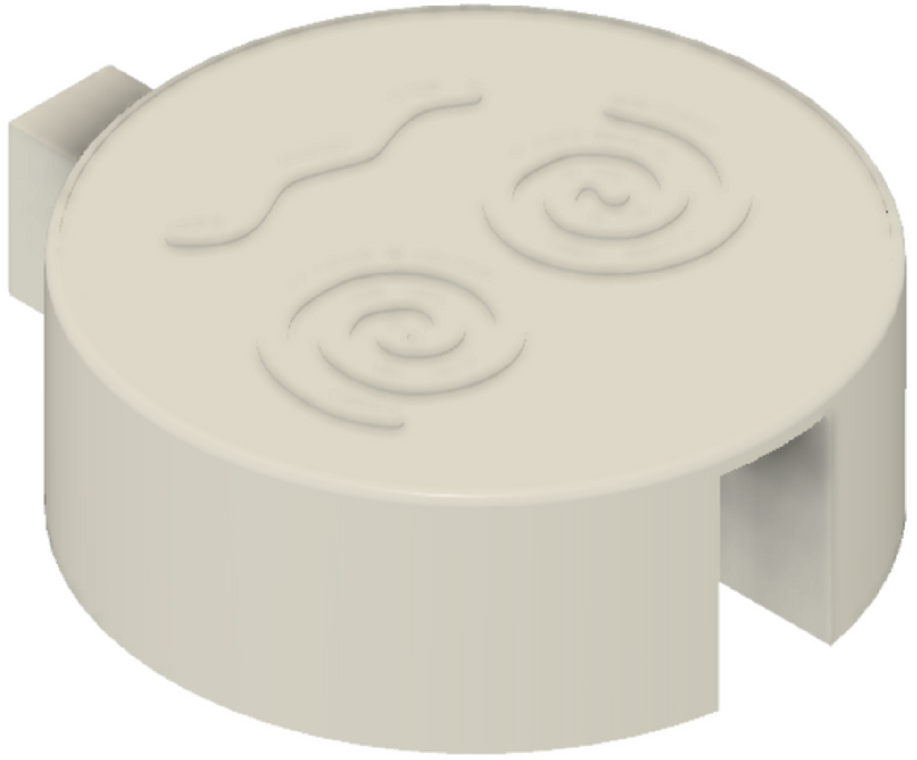




Started with a simple cylindrical body with extrusion for the pin to interface and connect the members, defining parameter to modify the thickness if needed.

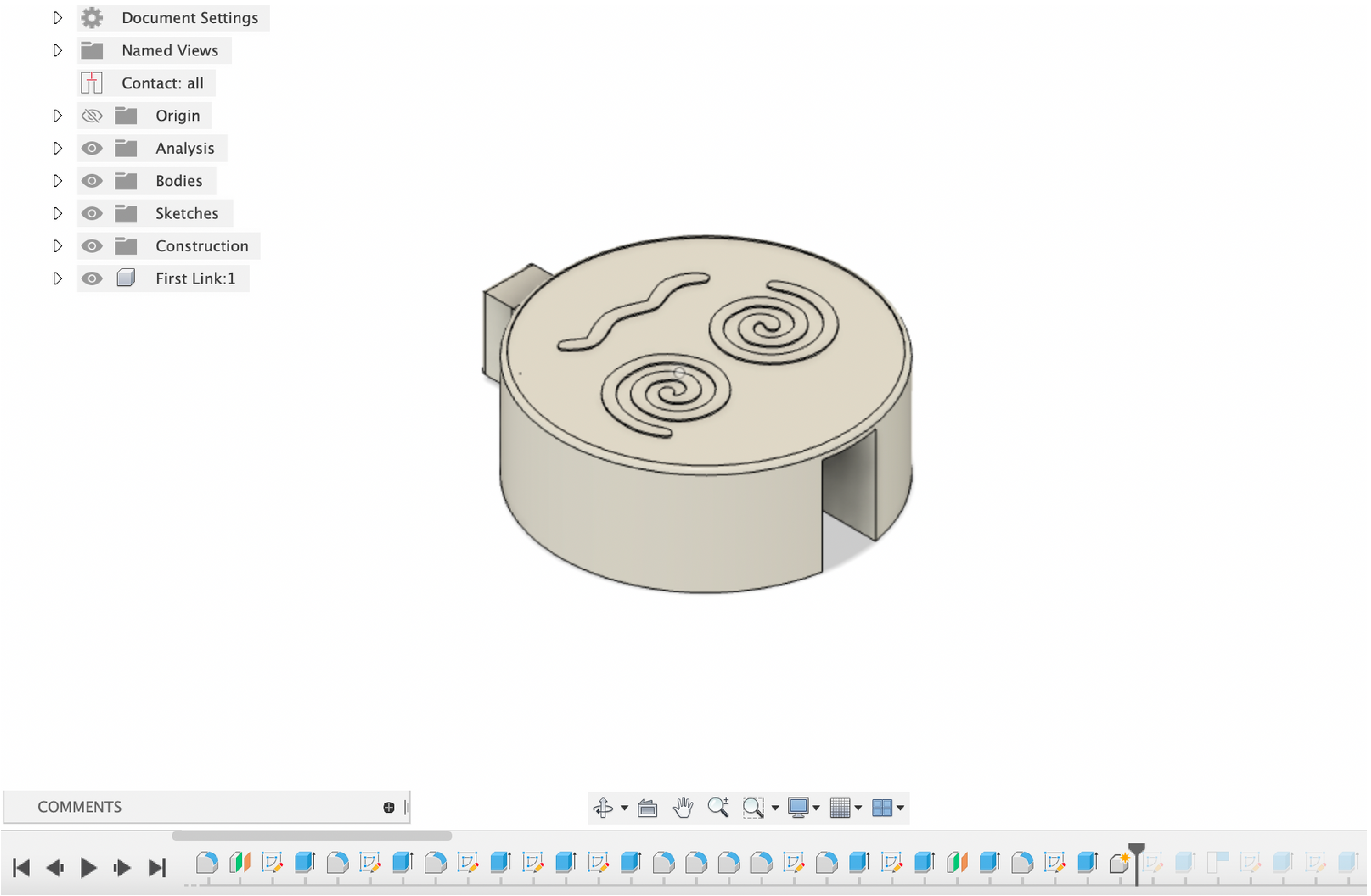


Extruded and made shells under the cylinder for the members to fold into and snap into place. The hole in the middle is an iteration to use magnets for the members to stay in place.

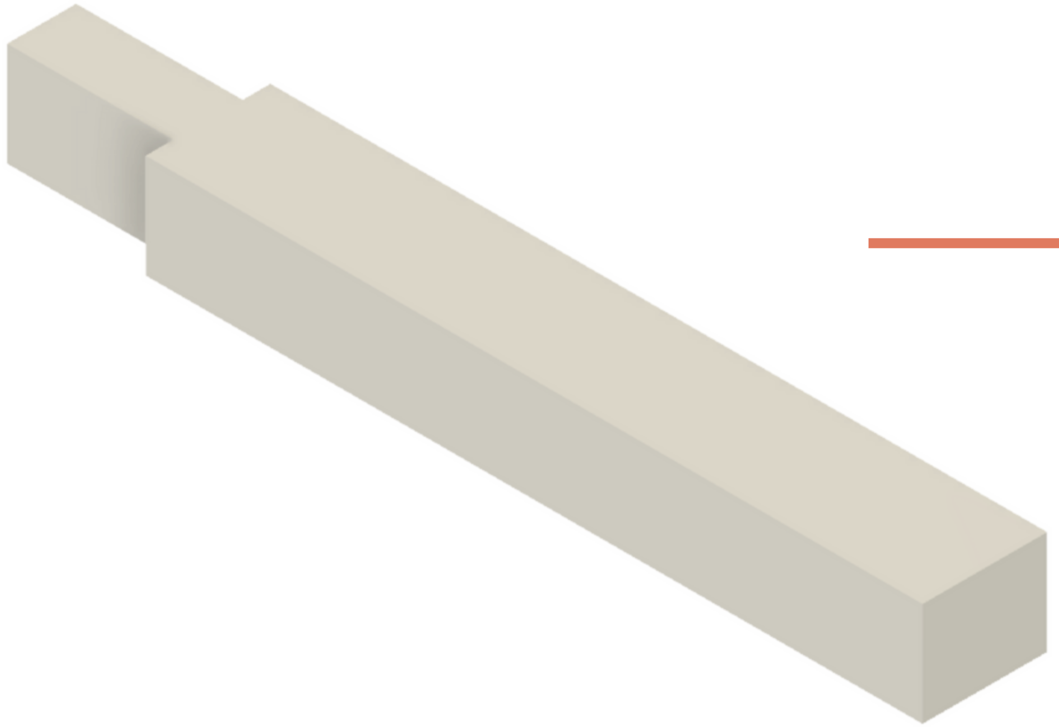


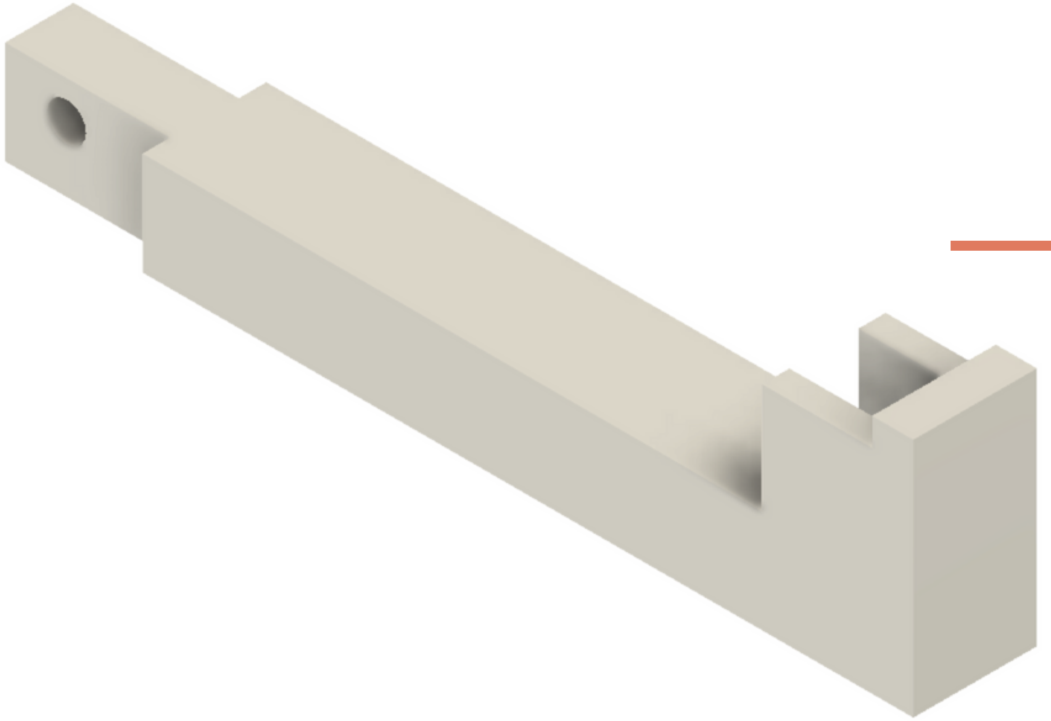
Emoji was added to the top of the cylinder head for visual aesthetic and design quality,

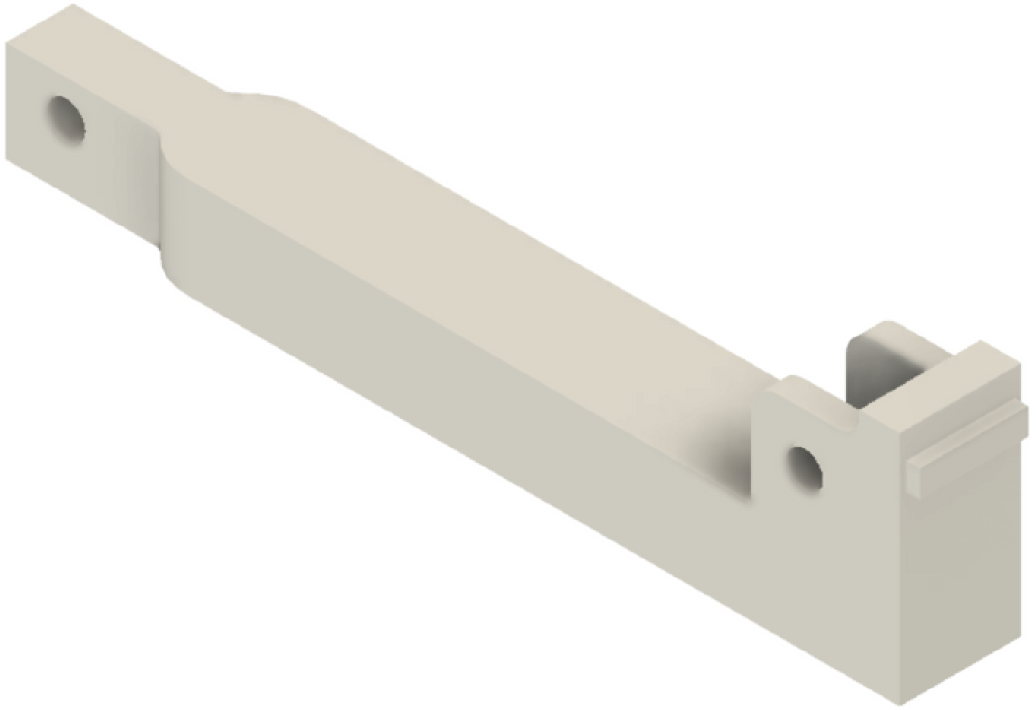
CAD - Cylinder



CAD - Cylinder Fusion File



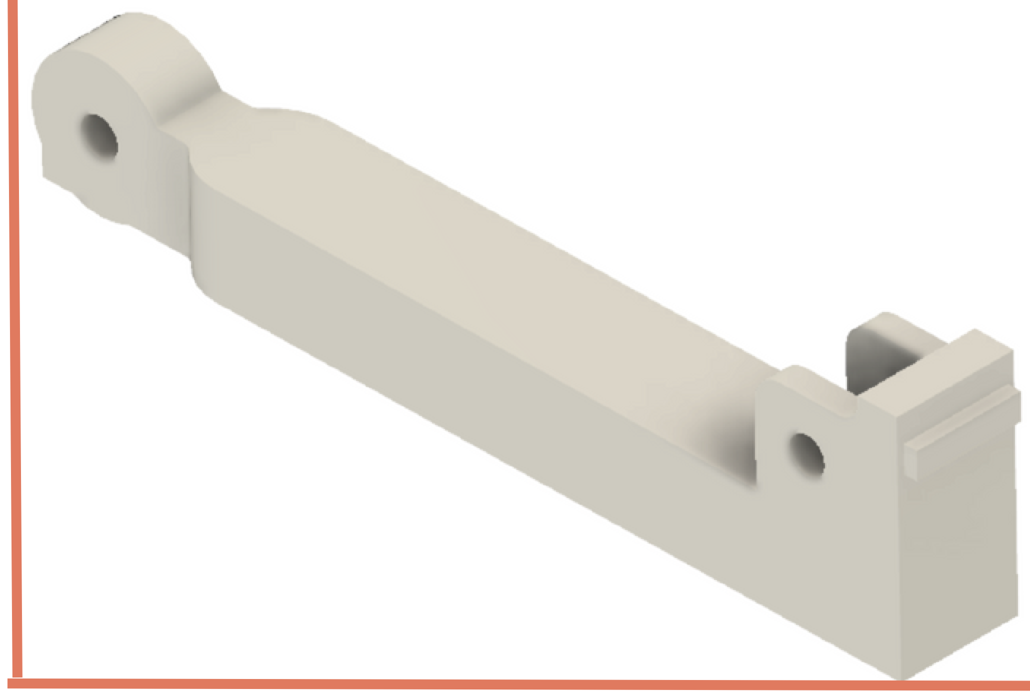


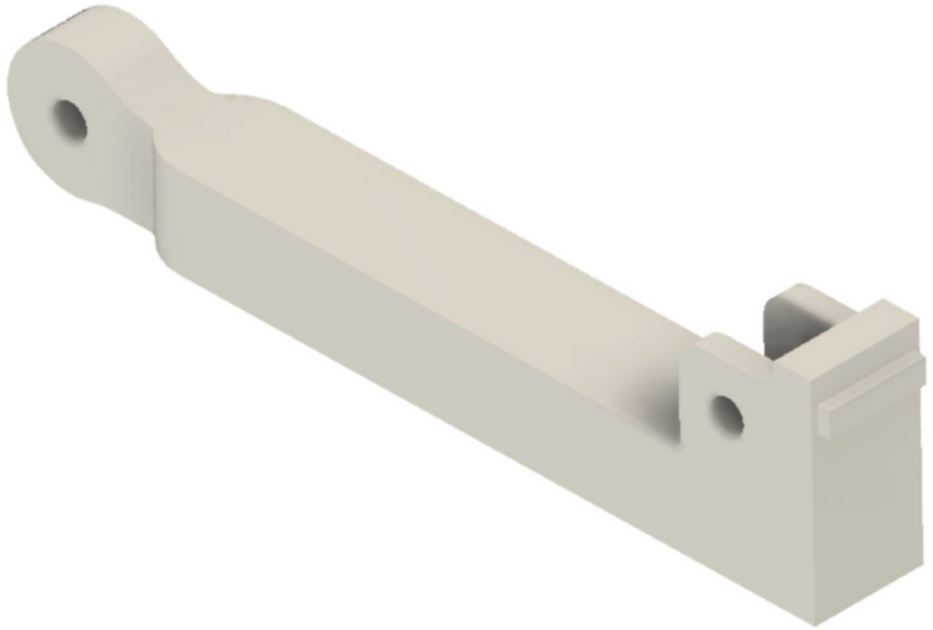


Started with simple cross-section for easy modification

Created holes for pins with correct tolerances found

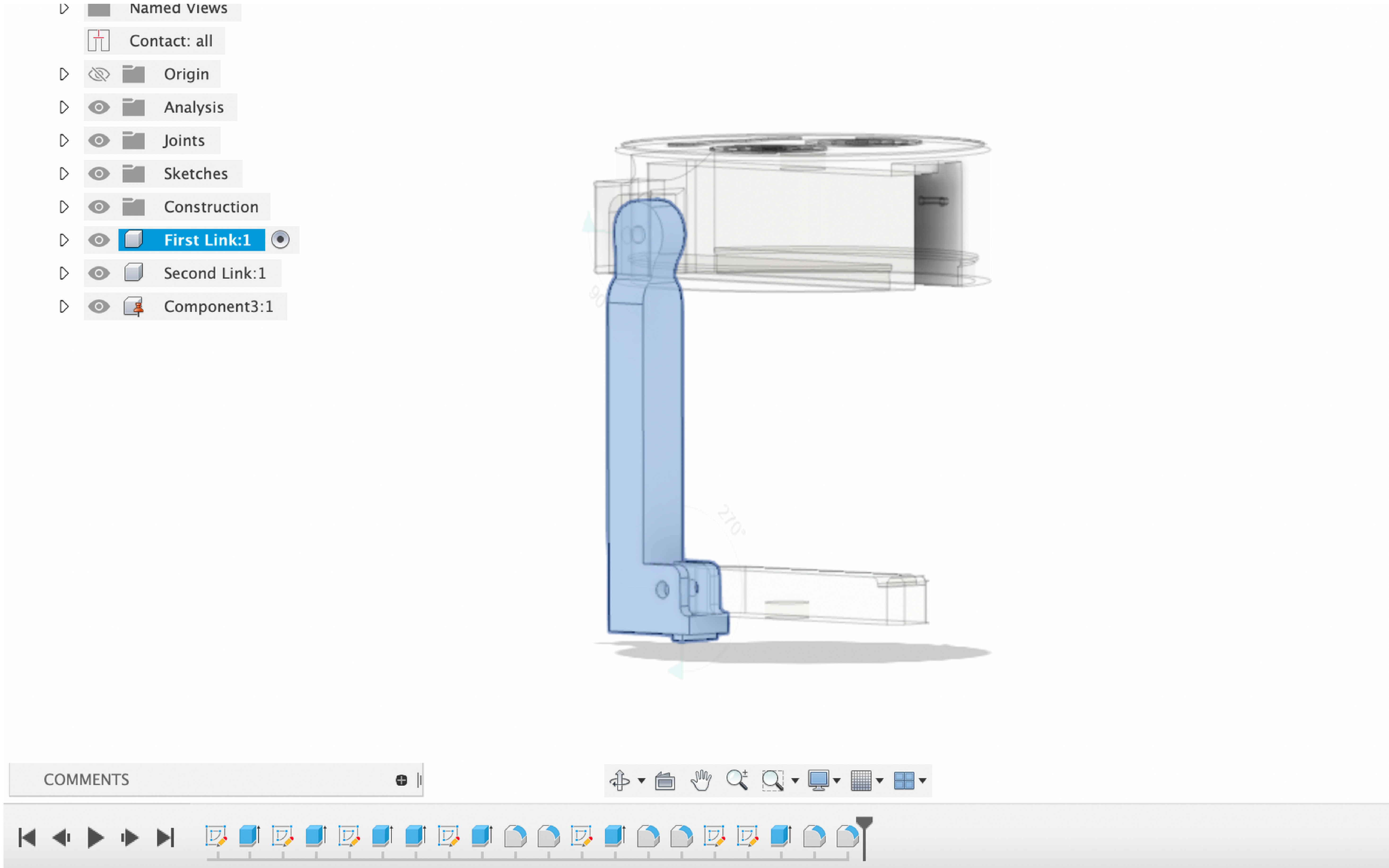
Added fillets and smaller details for optimal design.



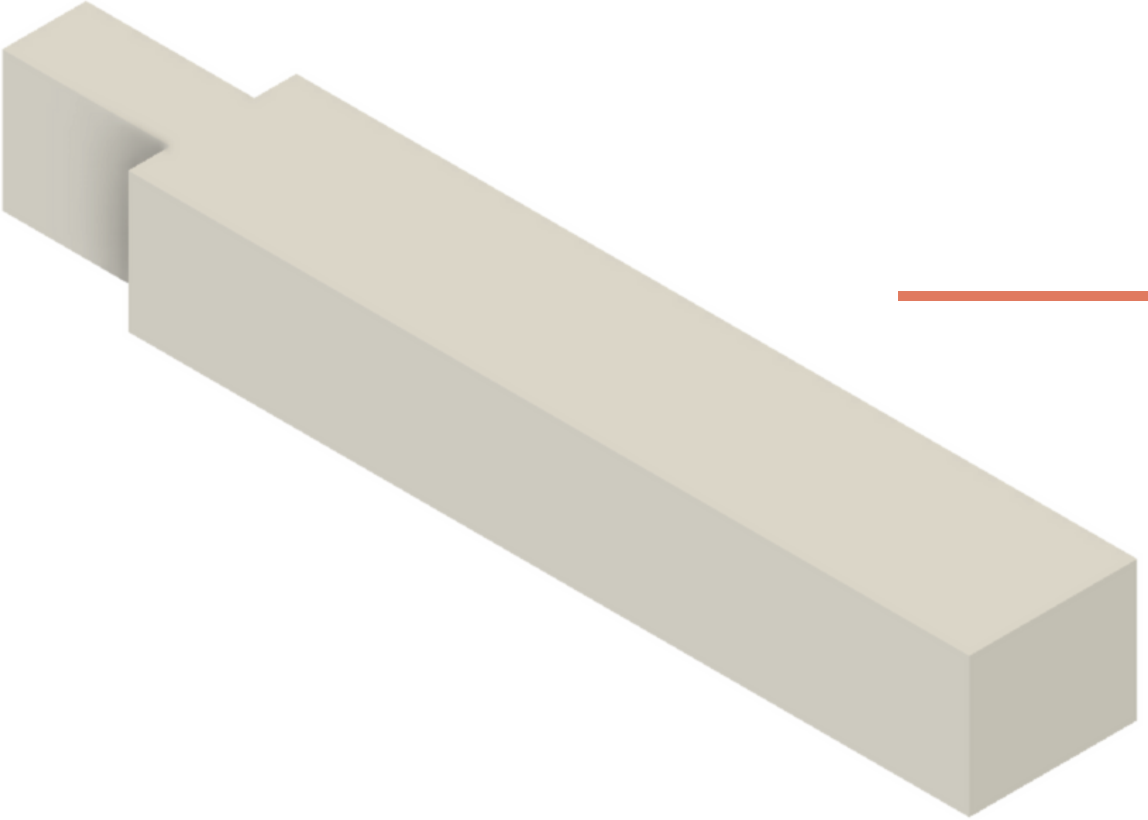


Based on our failed first print and using simulation, the head where the pin rests was iterated until we had the optimized shape.

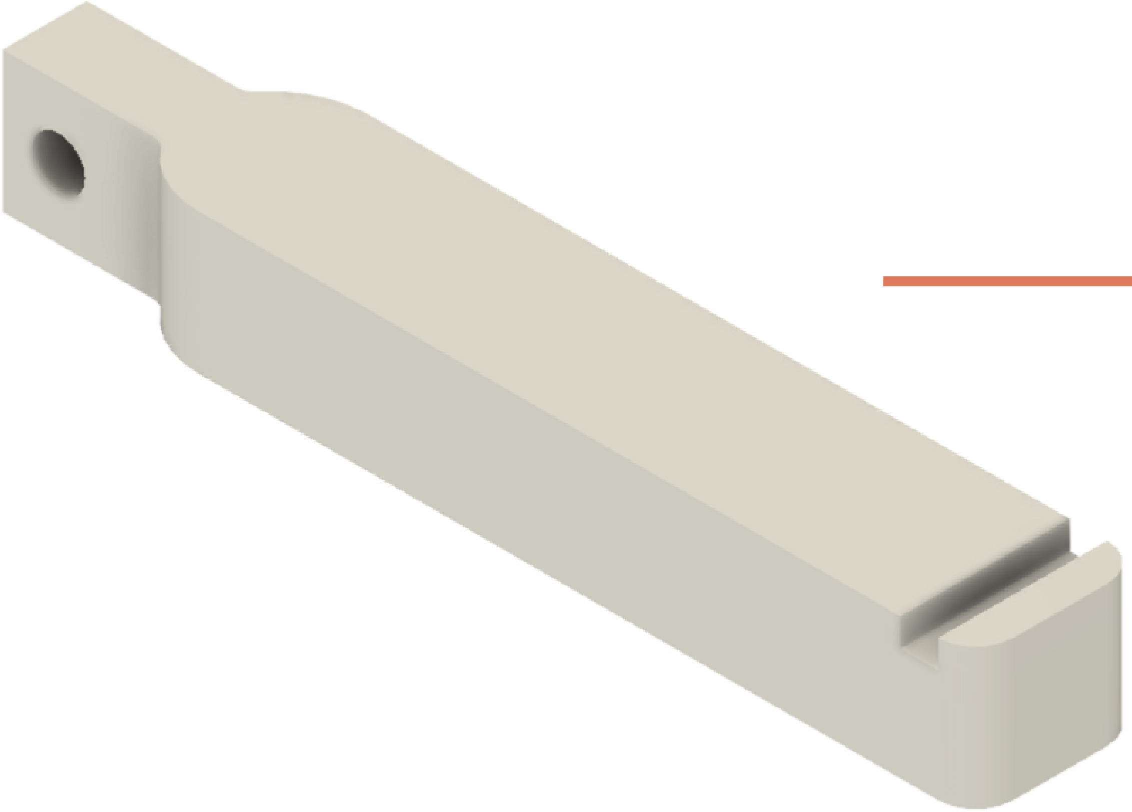
CAD - First Pin



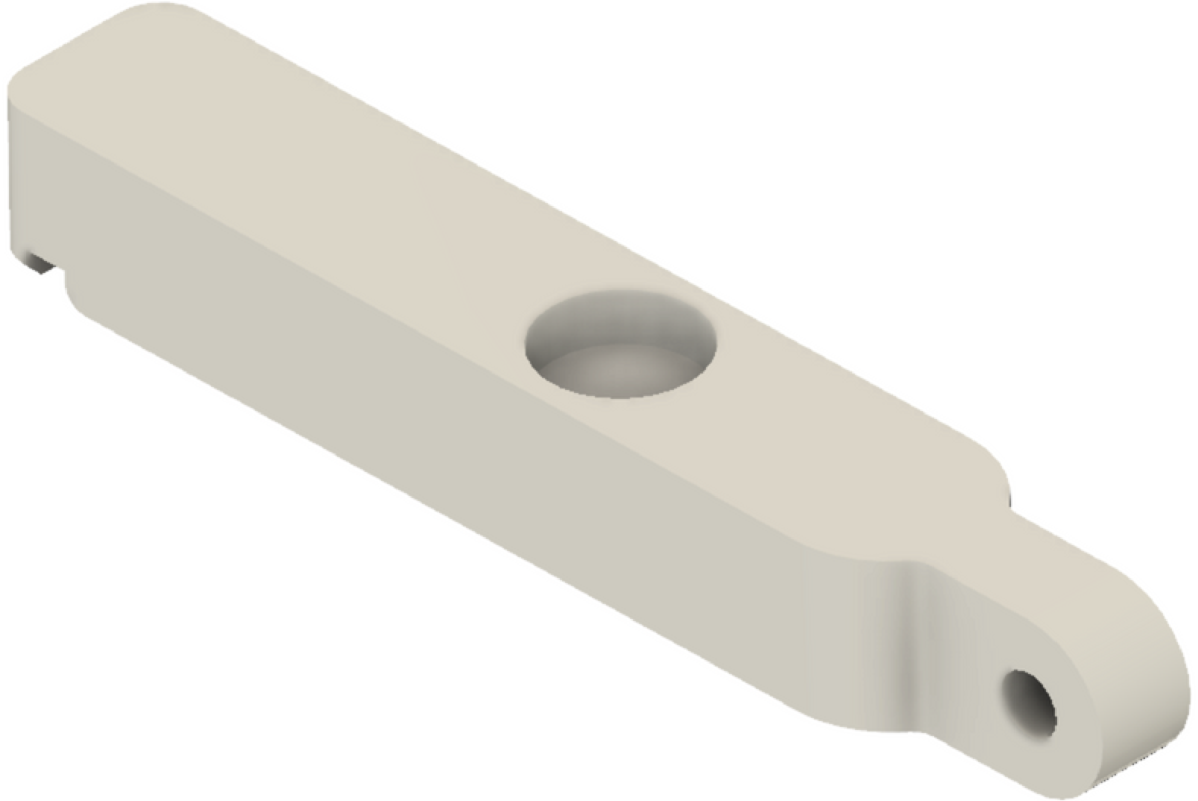
CAD - First Pin Fusion File



Started with a simple cross-section, and used a different length to hold the load (bag) comfortably for the user.

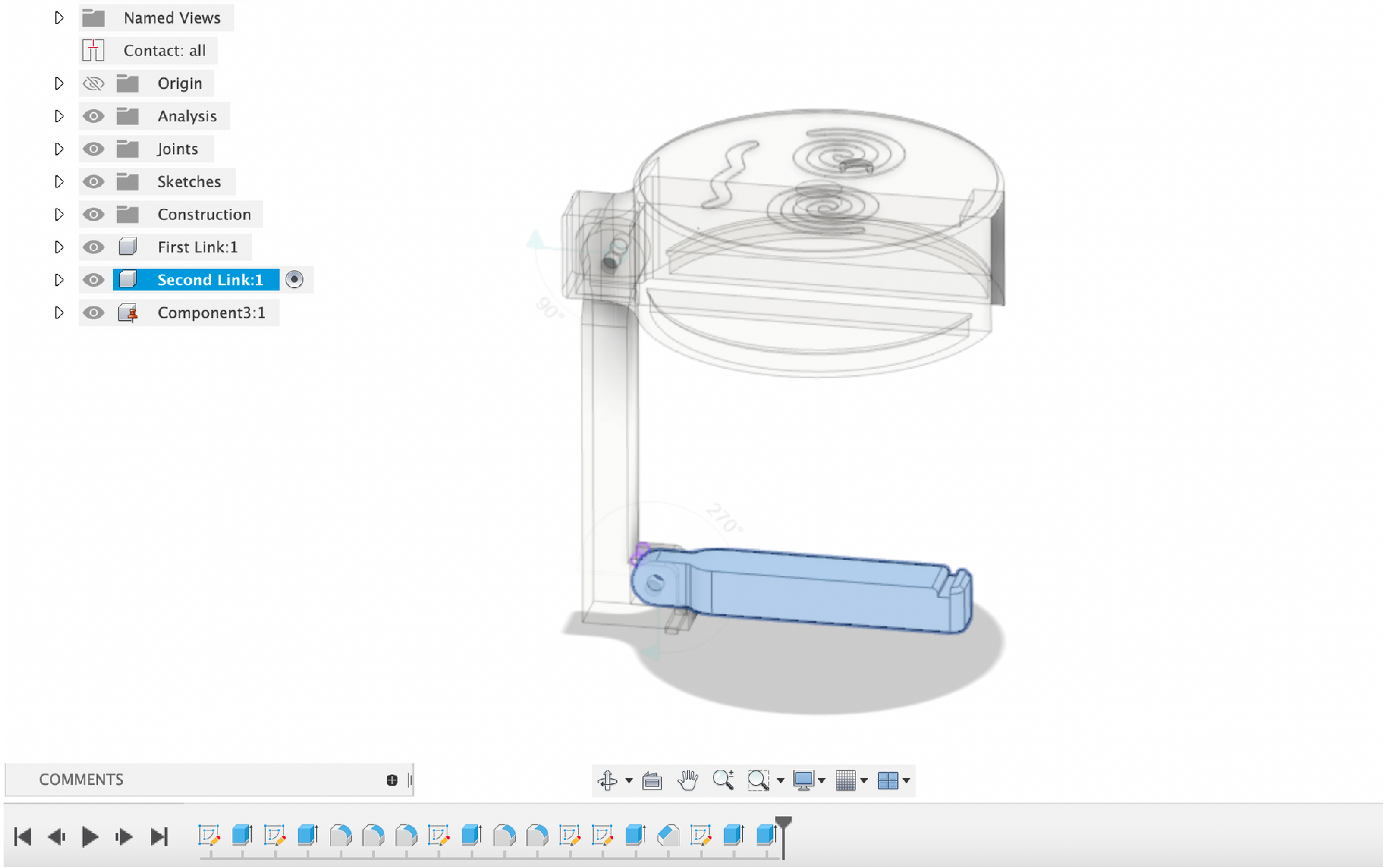


Added the hole with the same tolerance we found for the pin, as well as adding fillets to reduce stress concentration

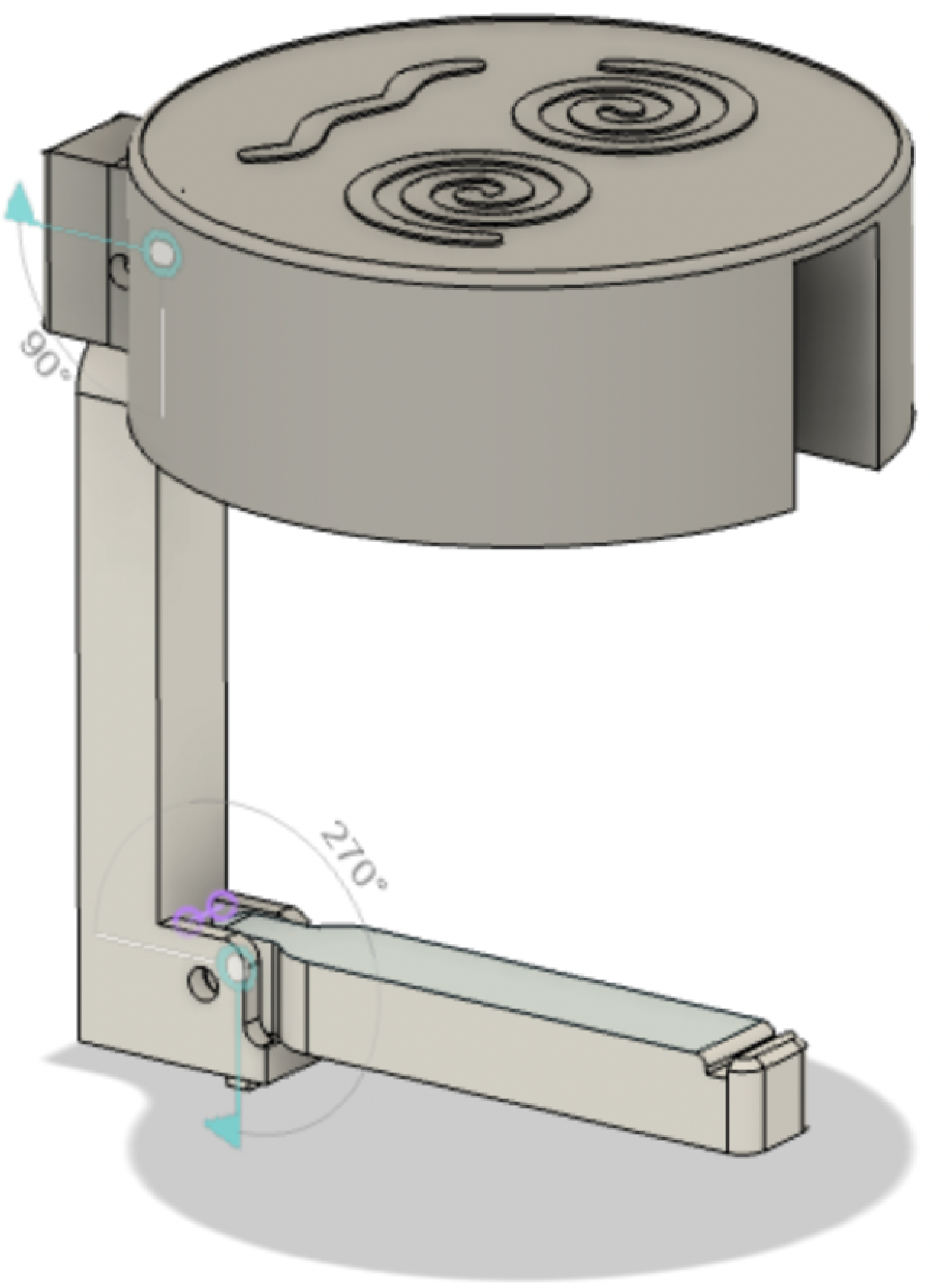


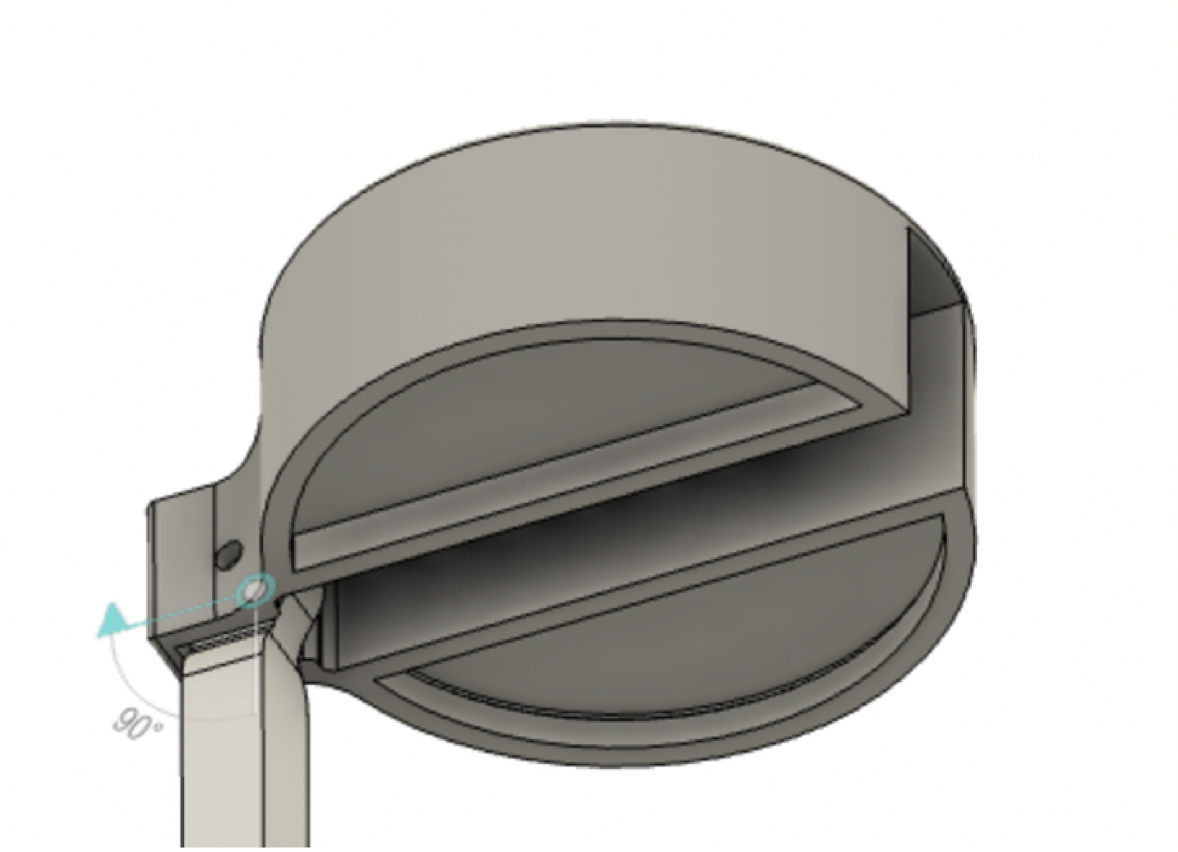
Added a hole for the magnet to press-fit into, based on our design for the member to hold inside the cylinder head.

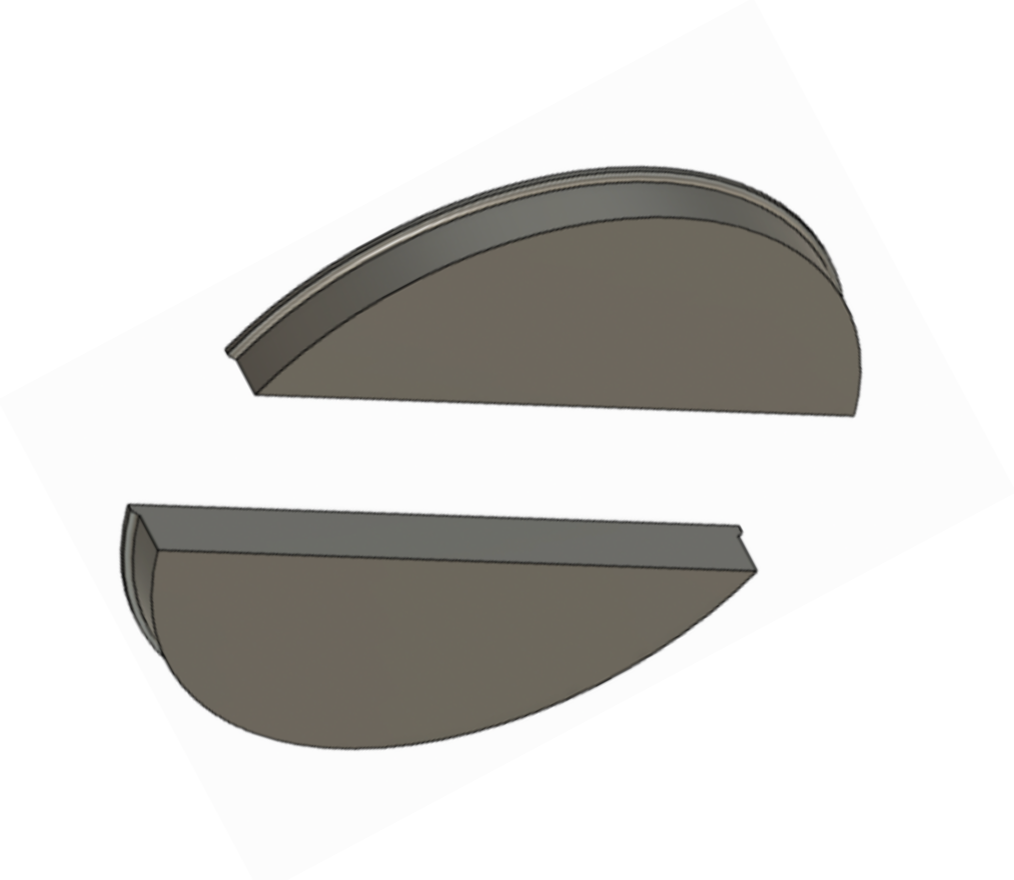
CAD - Second Pin



CAD - Second Pin Fusion File







Interfacing:
Since Flexible 80A has high friction and forces do not act in directions that would dislodge them, we chose to create a small groove around the circumference which would allow them to interlock into the matching groove at the underside of the body. The pins will connect the members allowing rotation.

CAD - Assembly

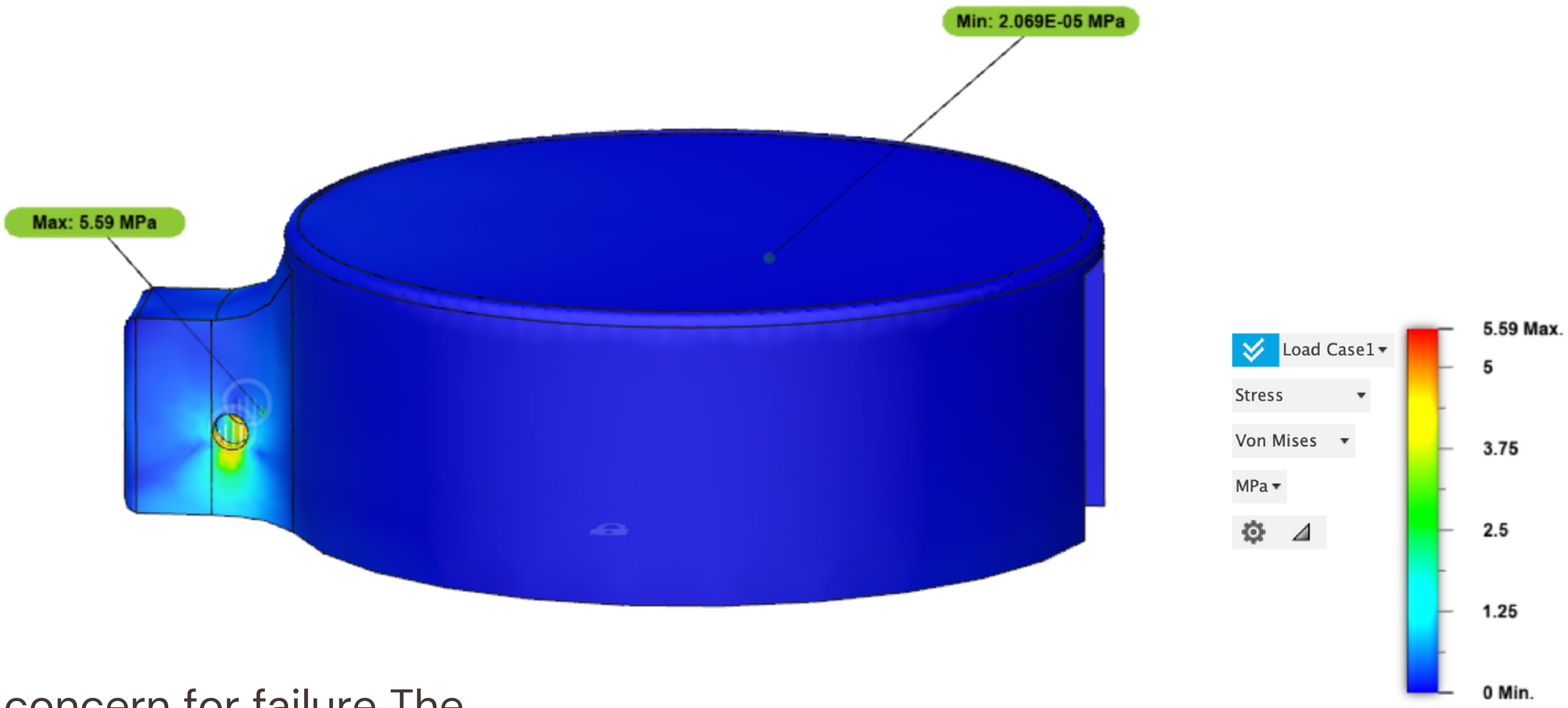
FOS: ~11-15

Constraints:

- Pin connection
- Fixed bottom face

Loads:

- Bearing load from pin



This component is not a large concern for failure The greatest stress concentration is around the pin; this geometry can be modified easily to alleviate stress, but given the high FOS, it was not our biggest priority.

Stress Analysis - Cylinder

FOS: ~2.5-3 (lowest)

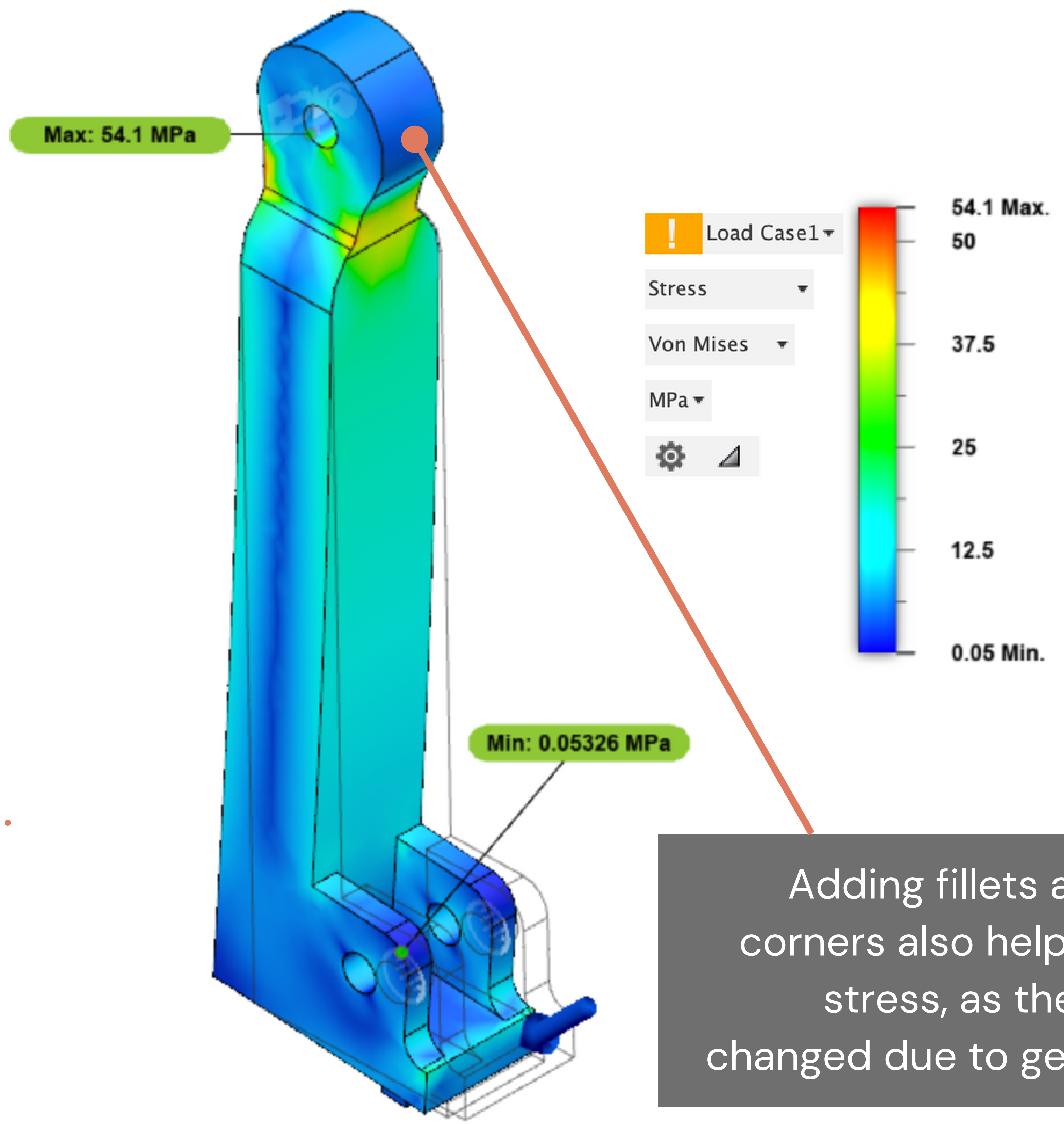
Constraints:

- Pin Connections

Loads:

- Contact force from the horizontal member on edge of the support
- Bearing load from pin

Primary area of concern: geometry around the pin, this member is the most likely to fail. Thickening the area around the pin helps to minimize the stress and ensure the member is robust enough to handle the load.



Adding fillets and avoiding sharp corners also helped to alleviate the stress, as the length cannot be changed due to geometry constraint

Stress Analysis - First Pin

FOS: ~12-15

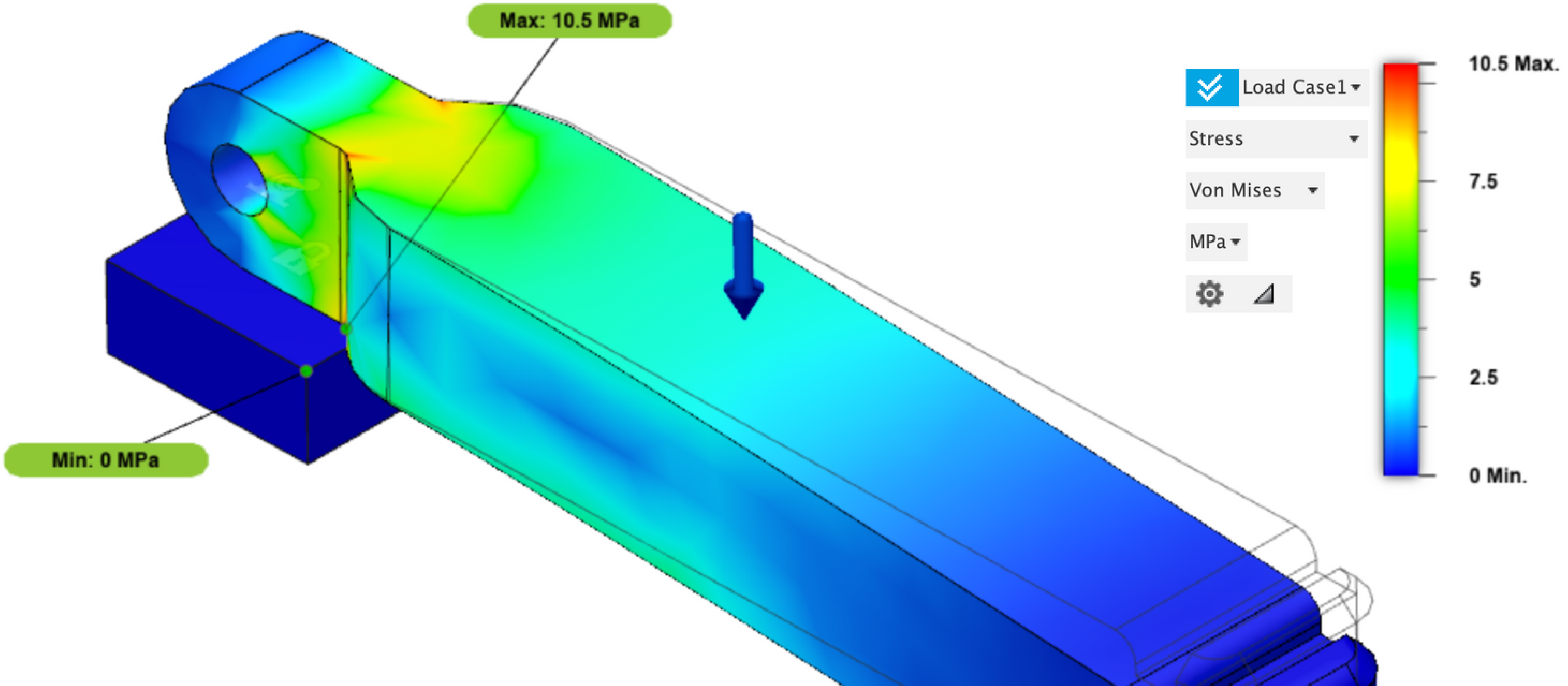
Constraints:

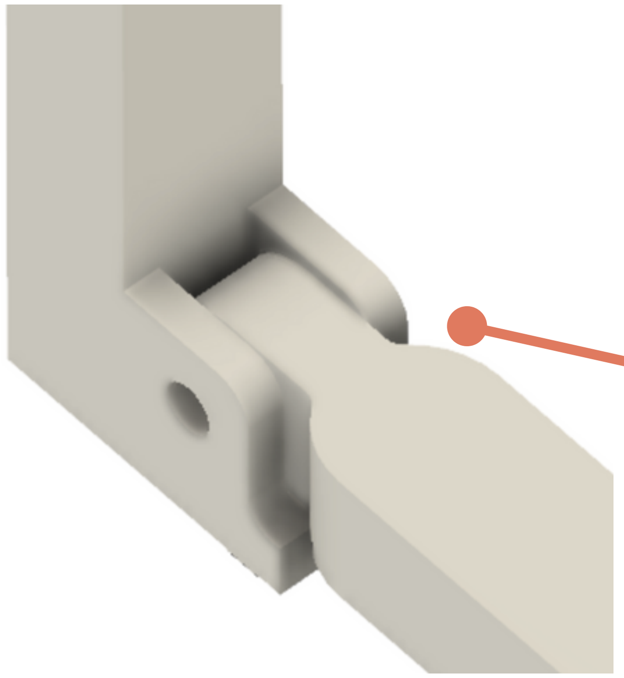
- Pin Connections
- Simplified contact with the vertical component

Loads:

- Applied force

This component is not as large a concern for failure as the first member. Adding fillets can help to minimize the stress. However, due to our pin design, we will not modify the geometry due to the interface constraints we need for the pins.



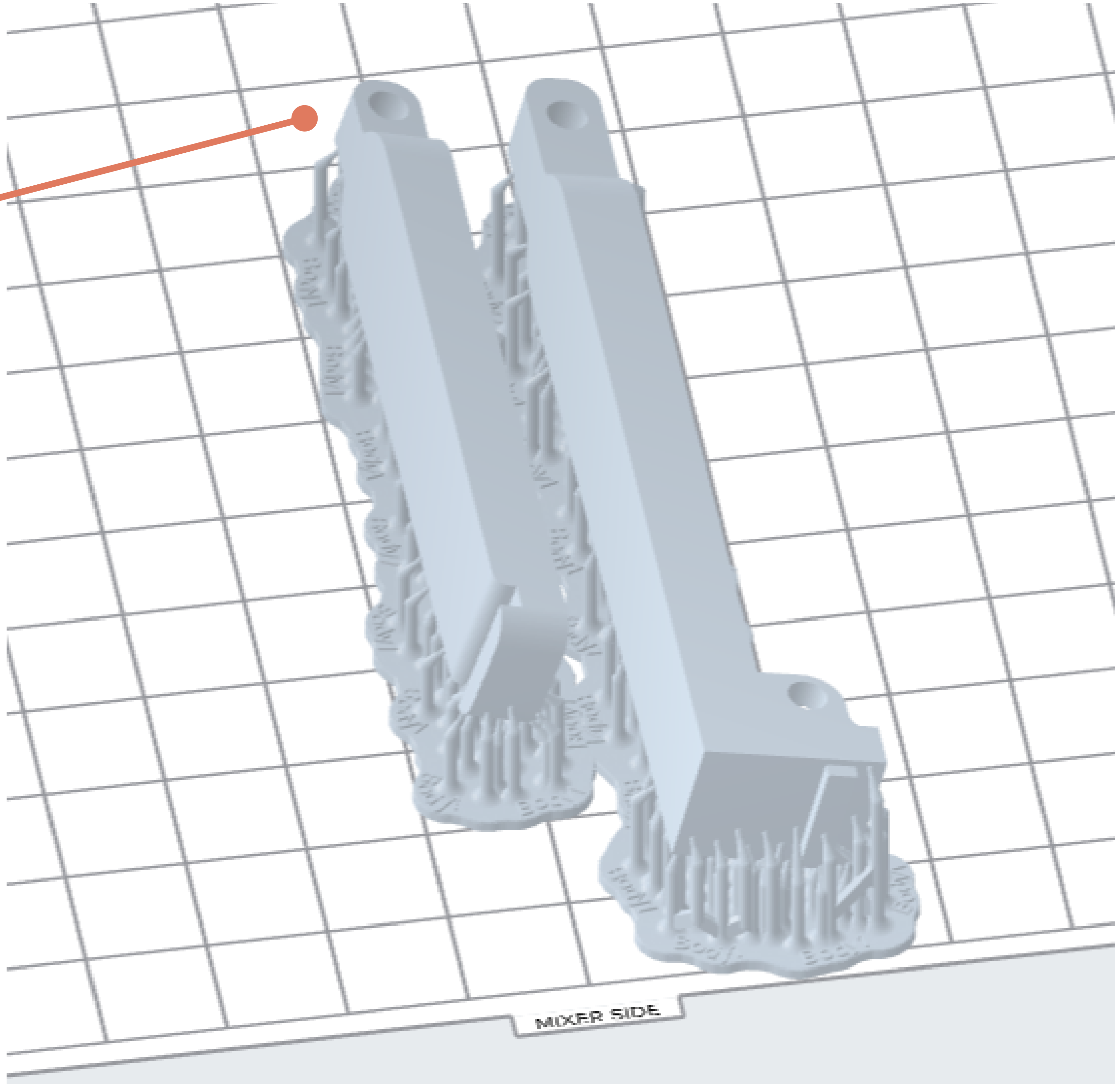


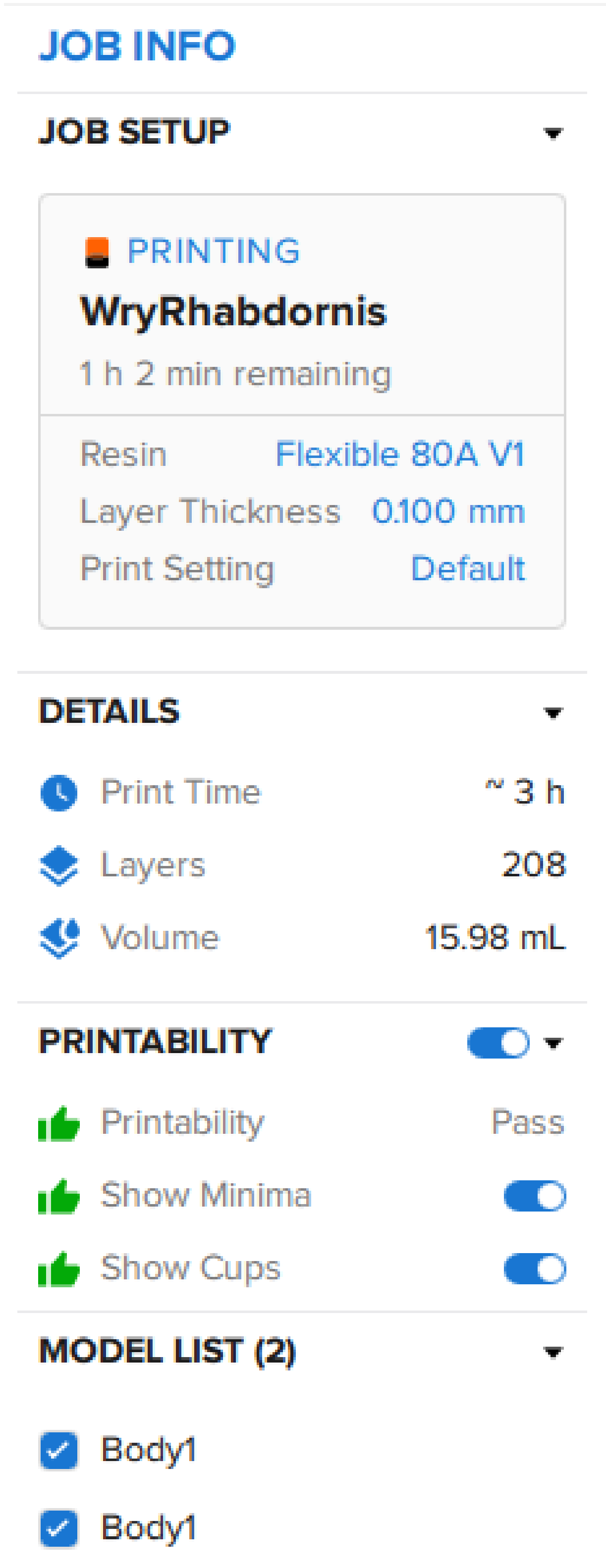
Changing the geomtery too much can affect our pin interface

Stress Analysis - Second Pin

Parts are oriented to preserve the integrity of the holes and pin tolerances for the part.

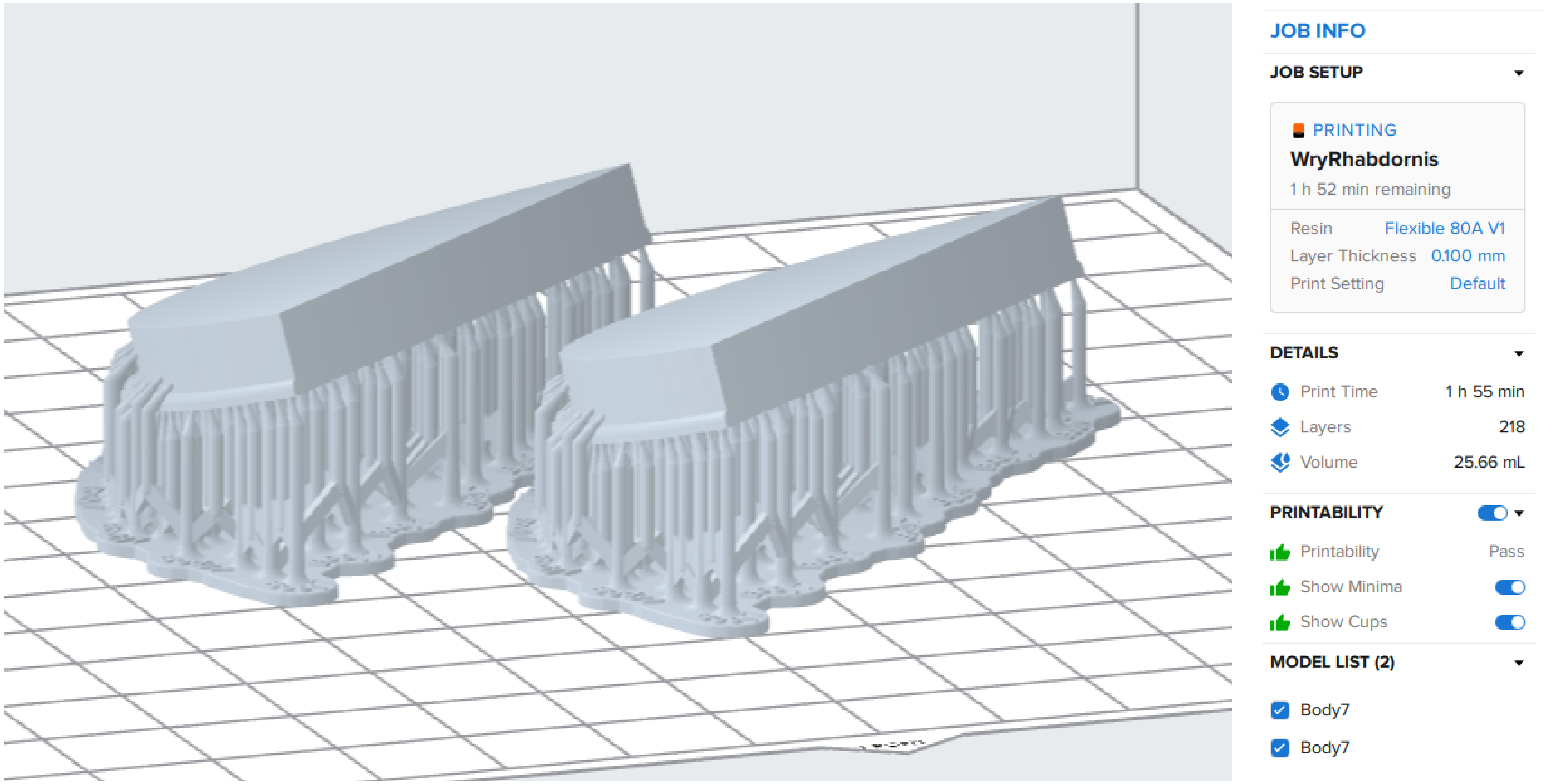
For this part and all of our prints with FormLabs, we oriented the part to print at an angle for manufacturability. We also did not consider layer adhesion and smoothness, due to SLA being more consistent than FDM.





Preform

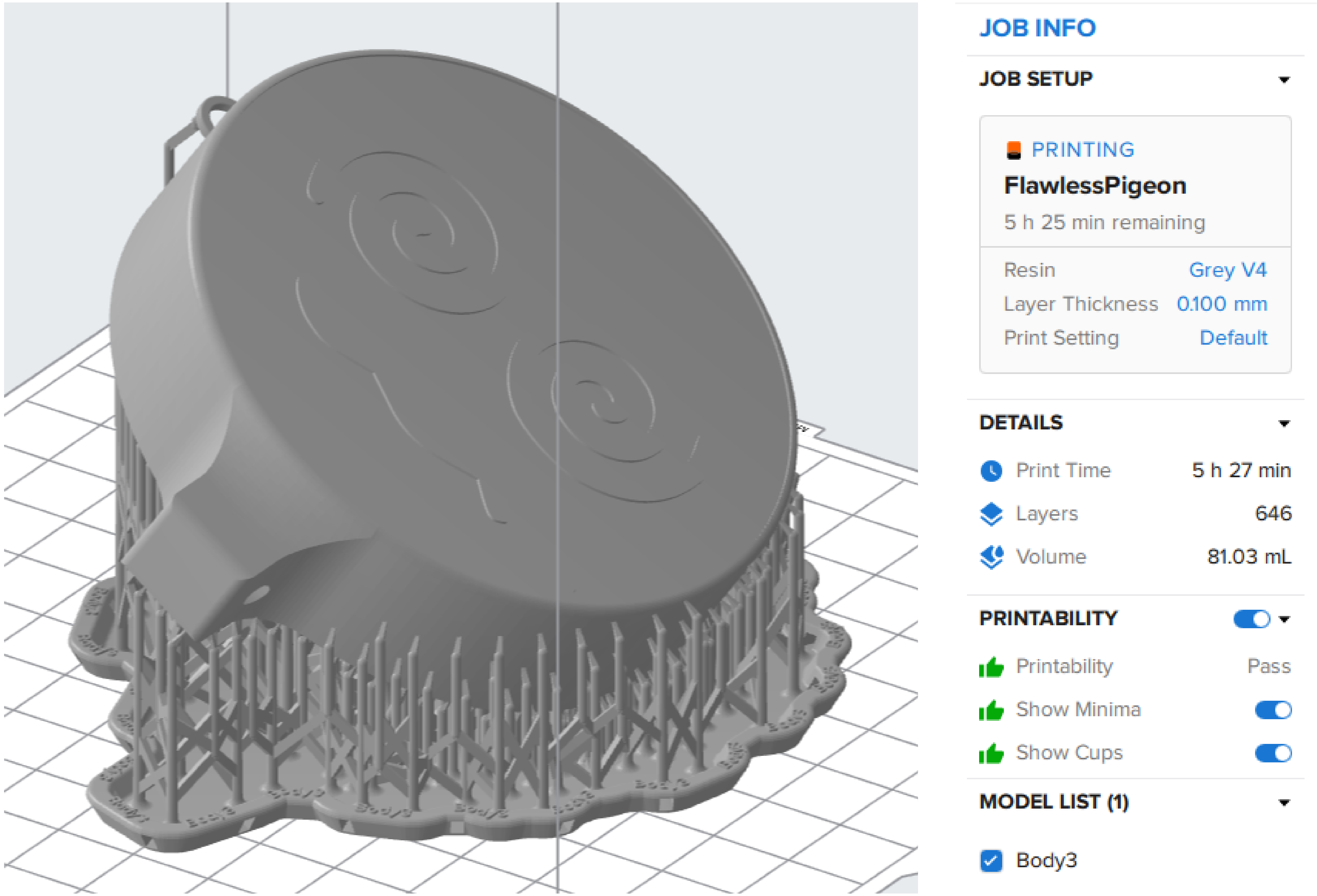
Parts are oriented such that the supports are on the surface that will be hidden inside the cylindrical cavity when assembled, maintaining a clean visual aesthetic.



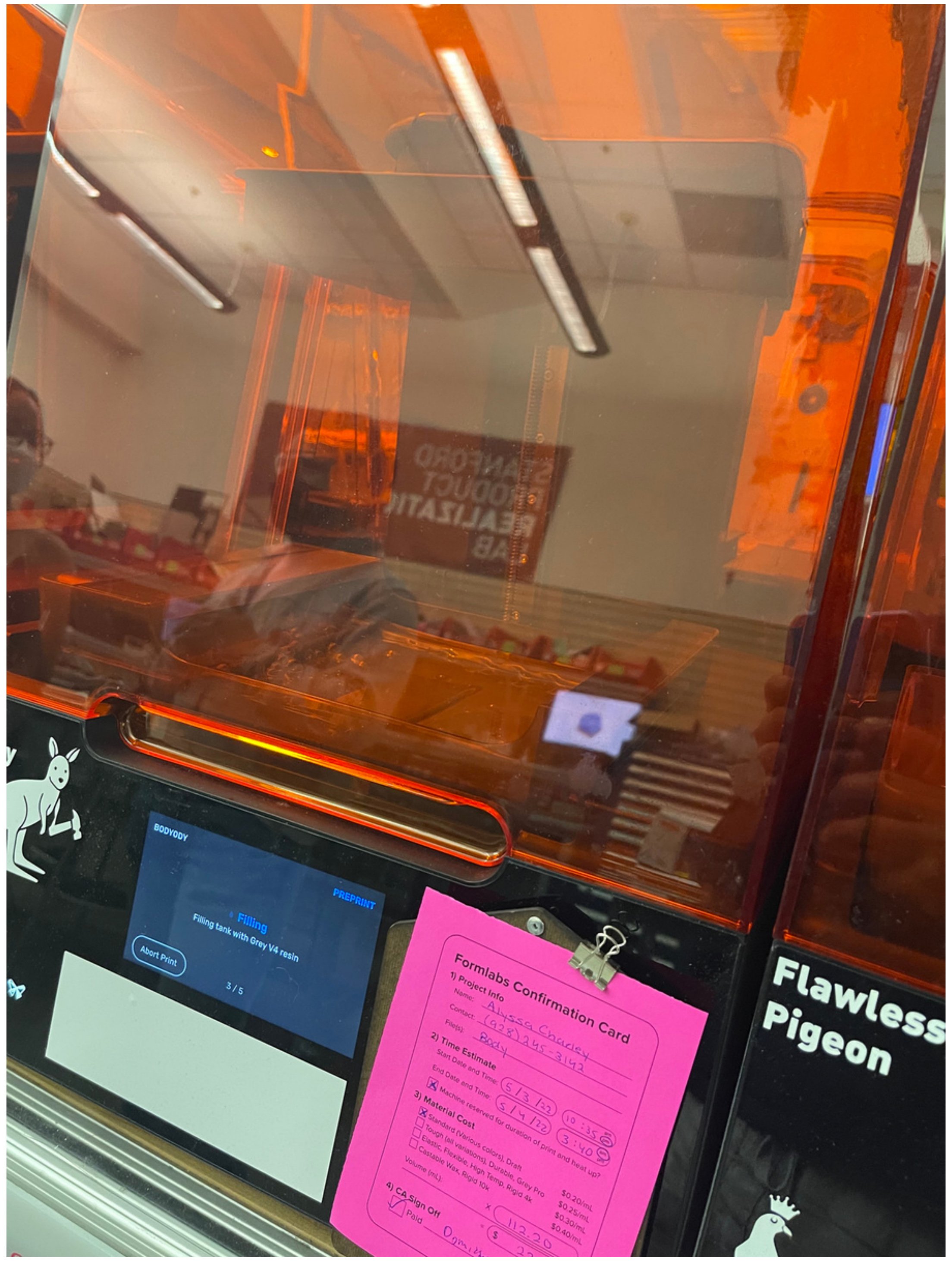
Preform

Part is oriented such that the supports will not touch the outer surface and ruin the visual detail.

There are small shells under the cylindrical component, but their depth is not enough to be considered for *cupping* or *hollow* parts, so we did not worry about creating drain or vent holes.



Preform



Used FormLabs printer for our selected thermoset resin materials.

Once printing was finished, we assembled the components with the selected pins.

We tested our part until failure, and found it to at least 20 lbs!

Realization

Budget & Key Takeaways

Total Cost **~$70**

- Final Part $35
- Prototype $35

Time **23 Hours**

- Brainstorming .... 2 hours
- CAD .... 12 hours
- Print Process .... 8 hours
- Post Processing .... 1 hours

Be only as indecisive as your timeline allows

With such a broad prompt, we spent too much time waiting for the ~perfect~ idea to spark, which forced us to work harder to catch up as the deadline approached.

Version control and coordination is important

Though Fusion allows team file sharing, only one person can edit at the same time, so we made multiple files rather than one with multiple components. We fell short in communicating versions and files, leading to some incorrect prints and confusion.

Working with different materials and printers

Each material prints differently and has different tolerances even with the same printer.

Leverage software features as you iterate

We should have run simulations to inform our geometries much sooner and defining parameters makes changing designs much more simple

Results & Future Considerations

Results

Overall, much of our intended design was achieved. We were able to dimension our parts such that press fits were achieved and the parts aligned to fold up and close properly.

Though we were able to meet our goal and load 20 pounds without it yielding, the arms did undergo slight plastic deformation.

More robust mathematical analysis

With additional time we could run more accurate simulations and complete more test prints to make our component more compact and accurate to our loading scenario

Aesthetics

We had a lot of fun ideating different creative designs and shapes that the cylinder could have instead, such as designs to reduce mass or make it more aesthetically pleasing.

Reflections

Alyssa

Since learning about the different materials available for additive manufacturing, I was particularly excited about this project to leverage the different mechanical properties. Especially when performing the analytical stress analysis and numerical on Fusion, I valued learning how to incorporate this into the mechanical design, and scoping this aspect can make the design process easier.

I gained more insight from collaborating with my team. We all learned together how to use FormLabs resin and maximize its manufacturing capabilities.

Britney

Prior to making this, I had only ever 3D printed with PLA on my personal Ender3 printer. It was interesting to work with the Form 3's and learn about the materials and features of the different resins.

I also learned a lot about interfacing materials and simulations, which I had little experience with before. It was so helpful to see how these quick analyses helped inform design decisions with little time or effort, especially at these touch points.

Overall, I gained so many more skills to incorporate into future projects!

Omar

Like my teammates, I was very excited to use a different 3D printing process, and I am very glad we made that choice as I now feel very comfortable with using the Form 3's.

Interfacing with stock components also reminded me about the importance of tolerance testing. We made tolerance test prints multiple times along the process and ultimately got great fits for all of our pins.

But most importantly, I gained a lot of experience with very open-ended prompts and the value of being decisive earlier in the process while still being open to design changes.

Hook'd