Final Report

MIE 313

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12/16/2024

Introduction

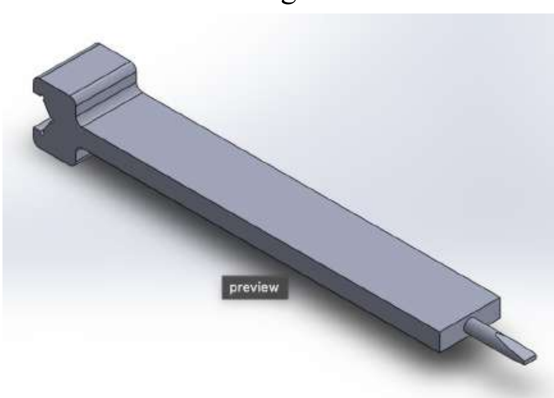
The goal of this project was to design a lightweight wrench suitable for ultralight biking gear, emphasizing minimizing weight and functionality. The wrench needed to withstand a three-point bending test of 50 N, be made from 1.5”x⅜”x10” stock Aluminum 6061-T6 from manual machining with no undercuts or sharp edges, no shorter than 6” long, and under 35.4 grams. It was also required to loosen a 3/8-16 bolt with an applied torque of 160 in-lbs, giving our team a basis of the initial design of the wrench.

One requirement we made was to guarantee the structural integrity of the wrench, while minimizing weight. In order to account for that requirement, we introduced an aggressive factor of safety of 1.5 to account for the stresses we may fail to consider. This would help the wrench to resist yielding without carrying non-functional weight. Furthermore, we added an extra functionality to the wrench, fulfilling the requirement to provide a multi-use capability. This functionality was achieved through additive manufacturing of capsules made from ABS material with 100% infill. These capsules were designed to hold items such as small screws and allen wrenches.

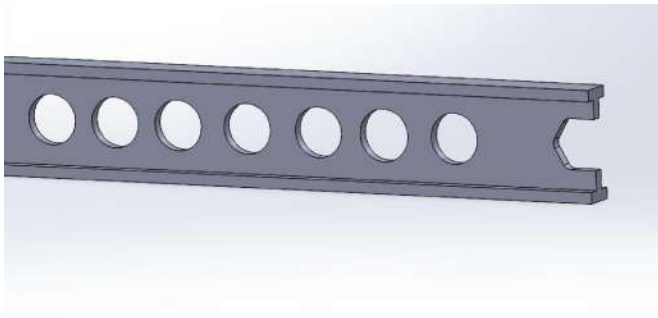
Our group was restricted to only manual machining, which constrained the design and manufacturing approach. These constraints required solutions to balance functionality and manufacturability with the project's requirements.

Concept Generation

For the initial designs, two of ours utilized an I-Beam design with the head at the end of the I-Beam and the other two designs followed a traditional wrench in functionality and looks.

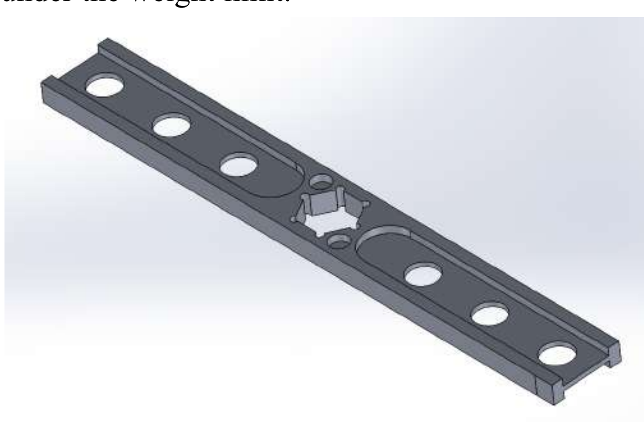


Aman Patel Initial Design: My initial decision came from just an ordinary wrench. The idea would be a thin handle with a build up in material going towards the actual head of the wrench to apply the load necessary to loosen the bolt. The second functionality would have been to apply a hex nut hole where the flathead would be, so that you can change the wrench to adapt to whatever situation you would want. So it could change to an allen, a flathead, or even a phillips head. This was later adapted into the a 3D-printed functionality to the final product.



Liam Wasser Initial Design: The I beam design allows for a large force to be applied to the end of the wrench while also saving lots of weight. I beams have been utilized for high compressive loads within the construction industry and by taking inspiration from that I assumed it would hold up the best for the least amount of weight. The holes further the weight saving by taking out material that is not directly subjected to a load. While the material is still thick further iterations could test how much material we could take out

Max Somers Initial Design: This design features a traditional wrench head with a continuous cross section with a flat head at the end. It has a simple functionality, but lacks in terms of manufacturability. Our team would not be able to make the majority of the features in this wrench, which is the reason it was scrapped. The design weighed around 17 grams, making it far under the weight limit.



Tiernan O'Kane Initial Design: The I beam allows for a high moment of inertia to cross sectional area ratio which is favorable for our weight requirements. The bending moment for I beams is normally the limiting factor compared to transverse shear stress which is the reason for the speed holes machined down the centerline of the wrench. The hex head in the middle is designed to require less machining operation by having holes at the corners of the hex so as to not require edge cleanup, which sharp corners would require. The partial holes machined close to the hex were my added functionality, gluing neodymium magnets into those slots so that the wrench could be magnetically held to the bike frame rather than requiring a separate compartment.

FEA Set-up: - Max Somers

- Entered material data with Aluminum 6061-T6 under Isotropic Elasticity with Young's Modulus 69 GPa and 0.33 for Poisson's. Used default Structural Steel as a basis for the bolt. ABS was modeled with 170 MPa for Young's Modulus and 0.4 for Poisson's.
- Imported SolidWorks geometry into ANSYS Static Structural. Design was a basic I-Beam with slots to meet weight conditions, with the bolt slot in the center of the wrench to reduce bending.
- Set a frictional contact between the bolt and slot of the wrench using a coefficient of 0.3 as a rough estimation.
- Meshed with a body sizing constraint from 0.005 m to 0.003 m using brick elements.

6061 Alloy

Structural	
Isotropic Elasticity	
Derive from	Young's Modulus and Poisson's Ratio
Young's Modulus	6.89e+10 Pa
Poisson's Ratio	0.33
Bulk Modulus	6.7549e+10 Pa
Shear Modulus	2.5902e+10 Pa

ABS

Structural	
Isotropic Elasticity	
Derive from	Young's Modulus and Poisson's Ratio
Young's Modulus	1.7e+09 Pa
Poisson's Ratio	0.4
Bulk Modulus	2.8333e+09 Pa
Shear Modulus	6.0714e+08 Pa

Perpendicular Torque Test (Pressure Based)

- Applied pressure of 588.352 MPa to 1"x3/8" faces at the end of the wrench.
- Calculated this pressure by:
    - $Torque = 160\ in - lb,\ Centroid\ of\ Area\ of\ Contact\ 1/2"\ inwards$

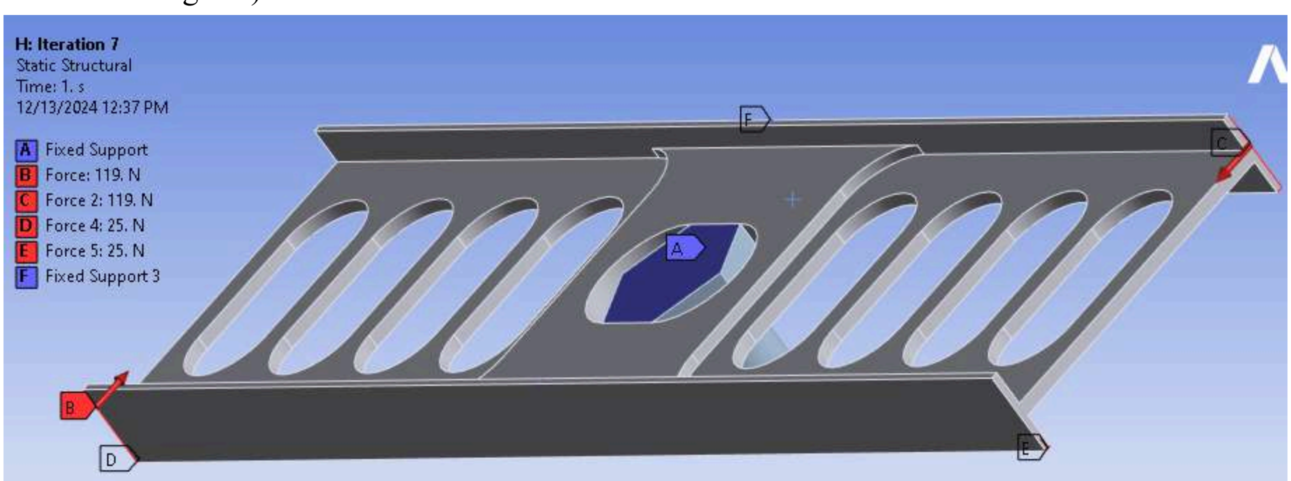
- $Area\ of\ contact\ =\ 1"x3/8"\ =\ 3/8\ in^2,\ Total\ length\ =\ 6"$
- $Total\ Force\ =\ (160\ in - lb/2\ contacts)/(2.5"\ away\ from\ center)\ =\ 32lbs$
- $Pressure\ =\ F/A\ =\ 32\ lbs/0.375\ in^2\ =\ 85.33\ psi\ =\ 588.352\ MPa$
- Fixed the top face of the bolt.

Perpendicular Torque Test (Force Based)
- Applied a force of 119 N to each edge at the end of the wrench.
- Calculated force through:
  - $160\ in - lb\ =\ F\ x\ 3"$
  - $F\ =\ 53.3\ lbf$ ➡ $P\ =\ F/2$ ➡ $P\ =\ 26.6\ lbf \approx 119\ N$
- Fixed top face of the bolt.

Ideal Torque Test
- Applied a moment of 18.1 Nm at the center face of the wrench.
- $160\ in - lb\ =\ 18.1\ Nm$
- Fixed top face of the bolt.

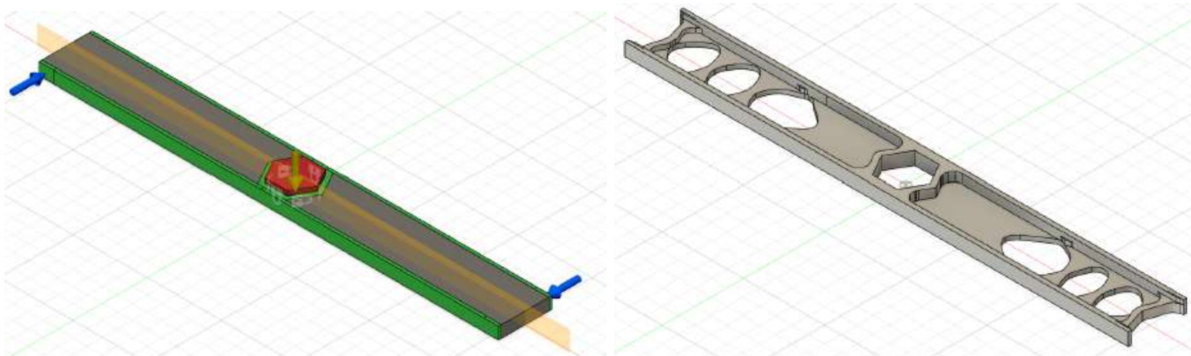
Three Point Bend Test
- Used a split line in SolidWorks to create an edge to concentrate a force of 50 N.
- Fixed both ends of the I-Beam and suppressed the bolt and capsules.

Torque for Bolt Turning and Perpendicular Torque Test
- Combined loads from the Three Point Bend Test and Perpendicular Torque Test
- Fixed the top face of the bolt and the center of the wrench
- Applied 119N on axis at both ends (accounts for the perpendicular torques) and 25 N off axis at both ends (accounts for the incidental torques by using the reaction forces of the bending test)

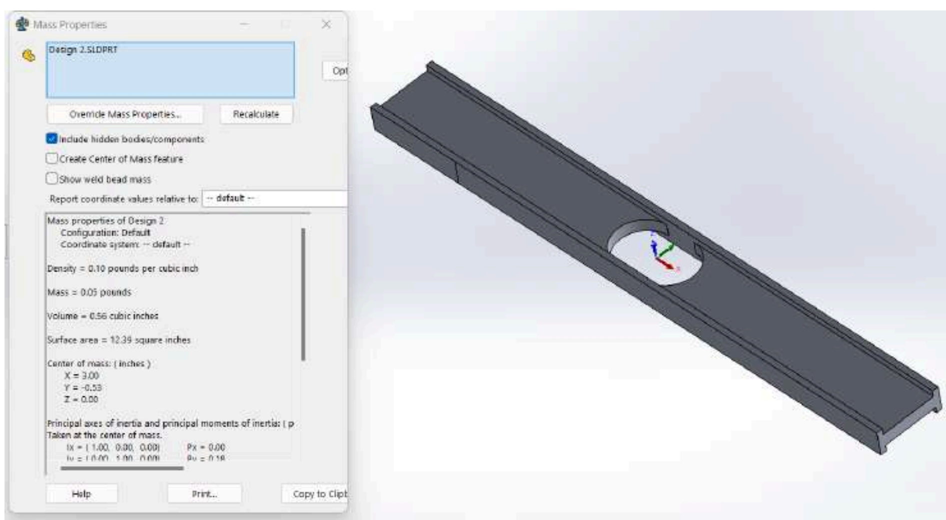


Torque for Bolt Turning and Perpendicular Torque Test Set-up

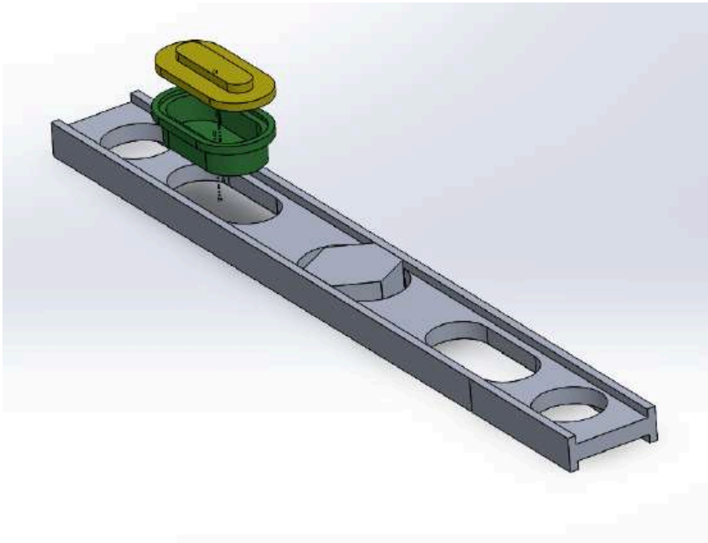
Design Iteration



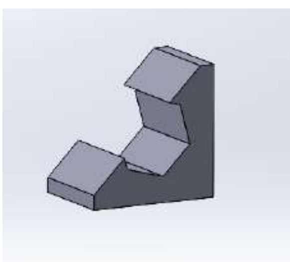
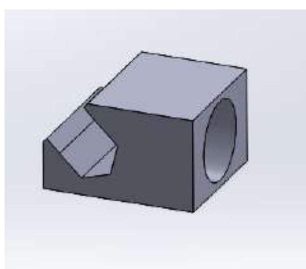
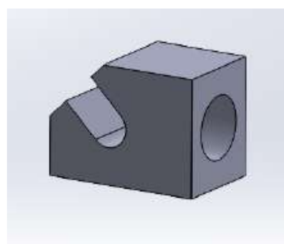
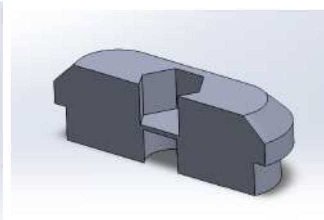
Fusion 360 generative design: Above is the setup and results of a generative design simulation run using Autodesk Fusion 360. Generative design attempts to meet all the design requirements, in this case, our loading conditions, using the least material possible. In this simulation the constraints were our two load cases, combined with the manufacturing requirement of only using two-axis milling. This simulation gave us an idea of how optimized we could theoretically make our design.



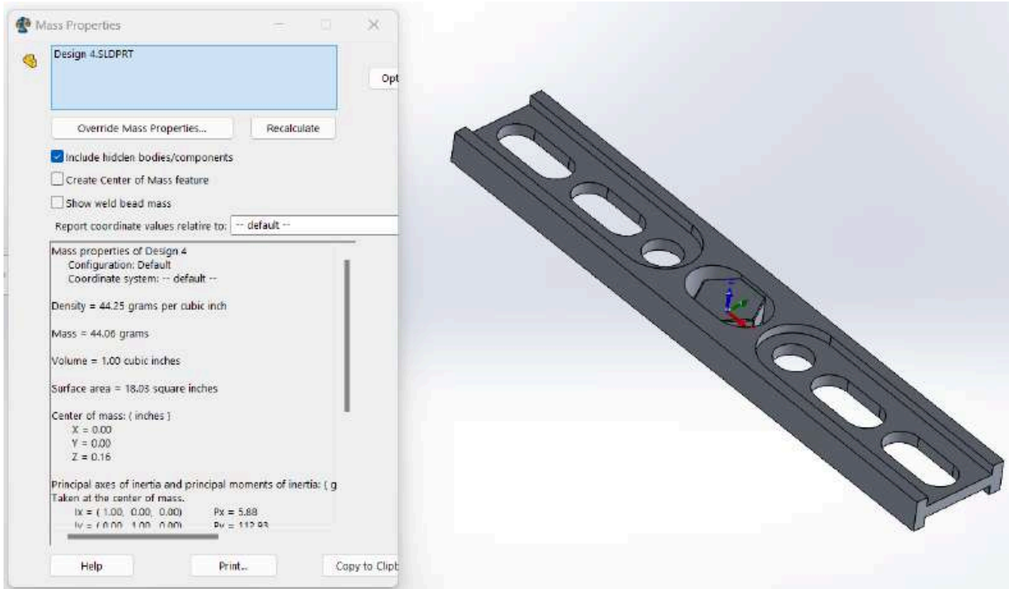
V1: This design focused on making the design easily manufacturable, while keeping the bolt hole in the middle of the wrench because our by hand analysis showed that that would reduce bending stresses by half. This design is manufactured using only three slots, allowing for a simple manufacturing process.



V2: This design iteration focused on the added functionality for the wrench, adding a capsule that would fit into the slots cut in the body of the wrench. The capsule would allow for holding of spare parts, such as small nuts and bolts.

Added Functionality Design: This design iteration focused on developing multiple added functionalities, testing them and selecting the best of the designs. The first three photos above are design iterations of a clip that would fit into the inner corner of the I beam of our wrench, allowing an allen wrench to be clipped into the slot. The first design attempted to use pressure to hold the allen wrench in place with the second two using a small magnet to hold the allen wrench. The last photo is a sectional view of an insert that fits into the slot on our wrench. The insert allows you to insert hex-sized drill inserts into the wrench, effectively turning the wrench into a multitool.



V3: This design focused on making the design more user-friendly, extending the wrench length to eight inches, up from six. This would allow the user to more easily apply the required torque to the bolt by increasing their available mechanical advantage. This design did come out overweight and we ultimately decided to prioritize low weight over ease of use.

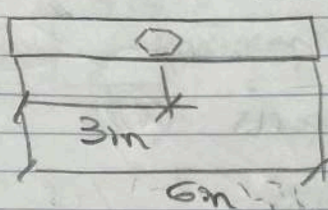
By Hand Analysis Setup - Tiernan O’Kane

Below is documentation showing our by-hand analysis. Our by hand analysis confirmed that our choice to put the bolt in the middle of the handle would cut the bending stress in half for the wrench cross-section. Additionally we showed that the cross-section of our design was reasonable by reducing the I-Beam dimensions down to a single variable and using the parallel axis theorem to solve for the moment of inertia. We could then use this generalized moment of inertia to calculate the optimal general dimension (shown as a) for the cross-section for the I-Beam. We additionally did calculations for the transverse shear using this generalized cross-section simplified to a single dimension.

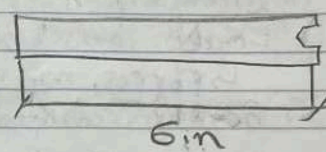
By-Hand Analysis

(Group 4) 3/8-16 Bolt w/ 160 in-lb torque

Designs



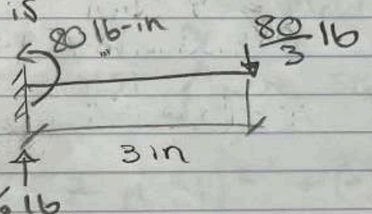
or



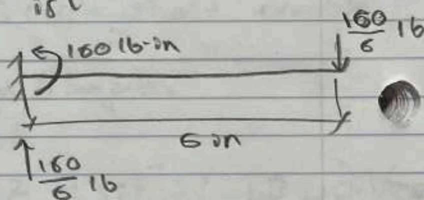
118.0762

Torque in this case is

2X



Torque in this case is



FOS of 1.5

AL-6061-T6: 276 MPa

276 MPa / 1.5 FOS = 184 MPa

$\sigma = \frac{My}{I}$

$184\ MPa = \frac{80\ lb\text{-}in \cdot y}{I}$ → 9.04 N·m

$\frac{I}{y} = \frac{9.04\ Nm}{184\ MPa}$

FOS of 1.5

AL-6061-T6: 276 MPa

276 MPa / 1.5 FOS = 184 MPa

$\sigma = \frac{My}{I}$

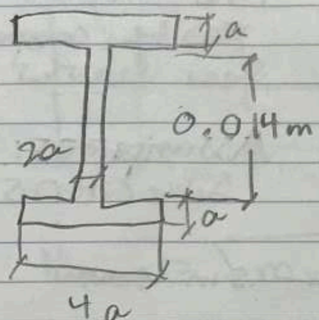
$184\ MPa = \frac{y \cdot 160\ lb\cdot in}{I}$

$\frac{I}{y} = \frac{18.05\ Nm}{184\ MPa}$

$\frac{I}{y}$ is twice for the second design

Cross-section Design

↳ Weight constraint: ≤ 0.0782 lb



$$\sigma = \frac{My}{I}$$

$\sigma = (276 \cdot 10^6) / 1.5$ FOS

$M = 80$ lb-in
$= 9$ N·m

$y = (0.014\,m/2) + (a)$

$$I = 2\left(\frac{4a(a^3)}{12}\right) + \left(\frac{2a(0.014)^3}{12}\right) + (4a \cdot a) \cdot \left(\left(\frac{0.014}{2}\right) + \frac{a}{2}\right)^2$$

MPa

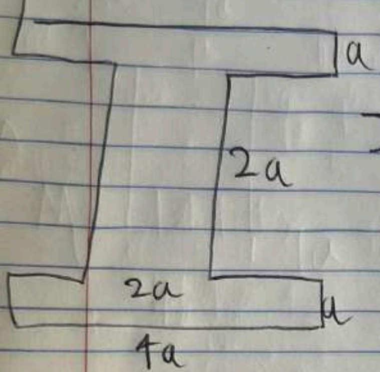
$$\frac{(276 \cdot 10^6)}{1.5} = \frac{(9\,N \cdot m)\left(\left(0.014/2\right) + a\right)}{\left(2\left(\frac{4a(a^3)}{12}\right)\right) + \left(\frac{2a(0.014)^3}{12}\right) + (4a \cdot a) \cdot \left(\left(\frac{0.014}{2}\right) + \frac{a}{2}\right)^2}$$

276×10^6 $\quad I_1 = \frac{1}{12}$

$\sigma = 276\ MPa$ $\quad FOS = 1.5$

$M = q$

$Y = 2a$



$\sigma = \frac{My}{I}$

$2a^3 \cdot 2a$
$4a^2 \cdot 2a$
$8a^3 \cdot 2a$
$16a^4$

$I = I_{cc} + \Sigma A p^2$

$I = \frac{2a \cdot (2a)^3}{12} + \frac{2 \cdot 4a \cdot a^3}{12} + \cancel{2}$

$\frac{16a^4}{12} + \frac{8a^4}{12} + \left(a + \frac{a}{2}\right)^2$

$2a^4 + (2 \cdot a \cdot 4a) \cdot (\cancel{2a})^2$

$4a^2 \cdot 2 \cdot 2$

$8a^2 \cdot 4a^2$

$2\ \cancel{12a}$

$\frac{276 \times 10^6}{1.5} = \frac{2a \cdot q}{\cancel{32a^4}\ 2a^4 + (2 \cdot a\, 4a) \cdot \left(a + \frac{a}{2}\right)\ 32a^4} = 34a^4$

$a = 0.0016q\ m$

$\left[= 0.06 \text{ inches} \right]$

By hand Analysis

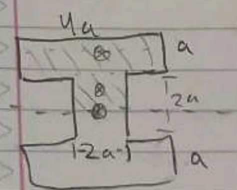
Bolt: 3/8-16

FOS = 1.5 AL-6061-T6: 276 MPa (YS) = 40030.415613 psi

$$\tau = \frac{VQ}{IB}$$

T = 160 in lb = 18.077573 Nm

$$I = \frac{2a(2a)^3}{12} + 2\frac{(4a)(a)^3}{12} + 2\left((a\cdot 4a)\left(a+\frac{a}{2}\right)^2\right)$$



$$I = \frac{16a^4}{12} + \frac{8a^4}{12} + 2\left[4a^2\left[a^2 + a^2 + \frac{a^2}{4}\right]\right]$$

$$\frac{16a^4}{12} + \frac{8a^4}{12} + 8a^2\left[\frac{9a^2}{4}\right]$$

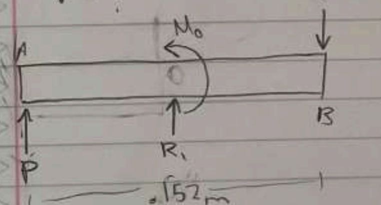
$$Q = \Sigma\bar{y}A = (a)(2a\cdot a) + \left(a+\frac{a}{2}\right)(4a\cdot a) \qquad \frac{16a^4}{12} + \frac{8a^4}{12} + \frac{72a^4}{4}$$

$$= 2a^3 + 4a^3 + 2a^3 = 8a^3 \qquad \frac{240a^4}{12} = 20a^4 = I$$

$Q = 8a^3$

B = 2a (max transverse shear @ NA)

V = ?



$M_0 \approx 18$ Nm

$\Sigma M_A \leq 0$

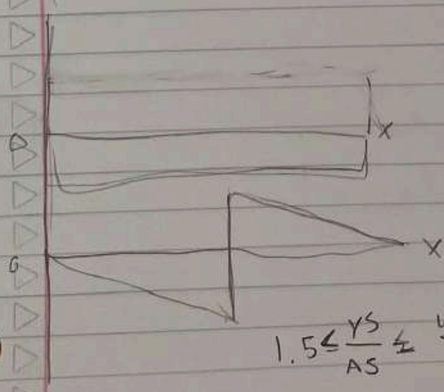
$M_0 \leq P(6)$

$P \geq \frac{M_0}{6} = \frac{18\ Nm}{.152\ m} = 118.93\ N = 26.73\ lbf$

$\Sigma F_y = 0$

$P + R_1 = P$

$R_1 = 0$



$$\tau = \frac{(26.73)(8a^3)}{(20a^4)(2a)} = \frac{5.347}{a^2}\ psi$$

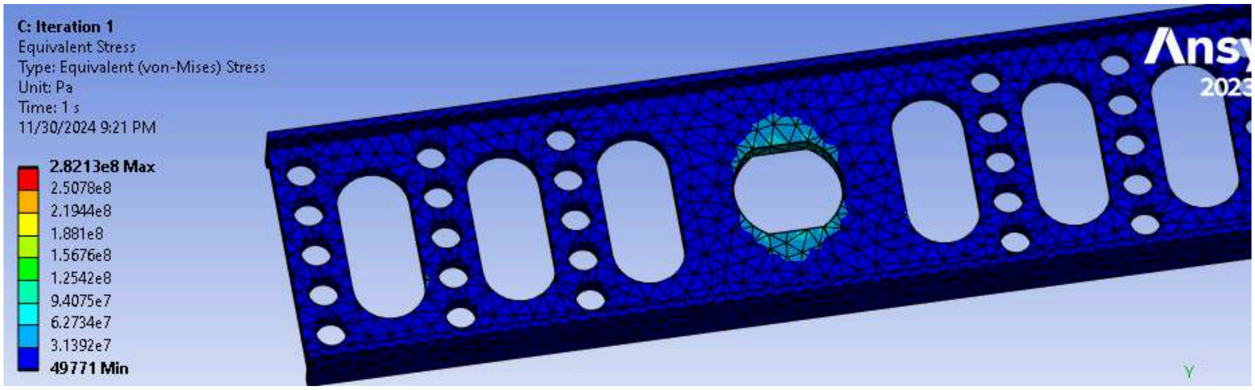
$$1.5 \leq \frac{YS}{AS} \leq \frac{40030a^2}{5.347}$$

$$a^2 \geq \frac{1.5(5.347)}{40030} = .0002$$

$\boxed{a \geq .0447\ in.}$

Design Iteration Continued / FEA Results:

V4:

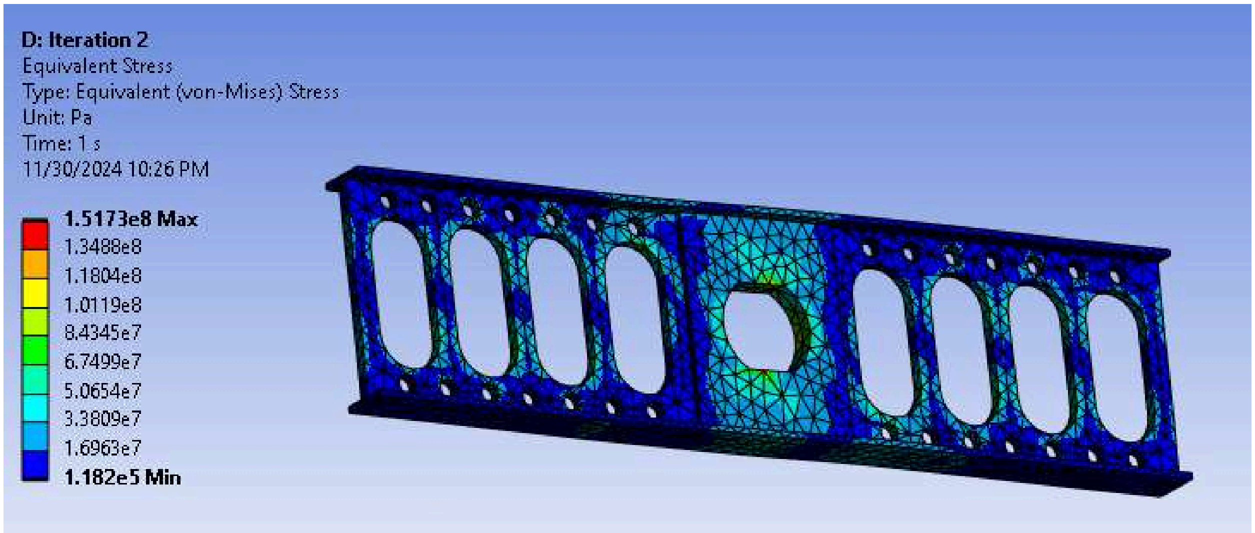


Equivalent stress (Von-Mises) in pascals (Perpendicular Torque Test Pressure Based)

$$FS = \frac{\sigma\_failure}{\sigma\_allowed} = \frac{\sigma\_failure}{\sigma\_actual}$$

Lost designs, similar to the dimensions from our by-hand analysis, failed in their initial simulations. Based on those results, we made a design that utilized the aluminums stock's dimensions. To reduce stress, our team knew that the moment of inertia was inversely related to both bending and transverse shear stresses. Utilizing the rectangular formula for moment of inertia, $I = bh^3/12$, we can see that h^3 is a dominant term in comparison to b, so orienting the 1.5" dimension of the stock to be the height would benefit our team the most. Through this concept, our team generated a design that has a factor of safety of 0.97 using Aluminum 6061-T6's failure criterion of 276 MPa yield strength. Our goal factor of safety is 1.5, and 0.97 guarantees it to yield. This test alone tells us another iteration is needed. Its raw weight is 31.55 grams. Further improvement could consist of increasing the thickness in the center to reduce transverse shear stress and reducing the thickness towards the ends of the wrench to lower weight.

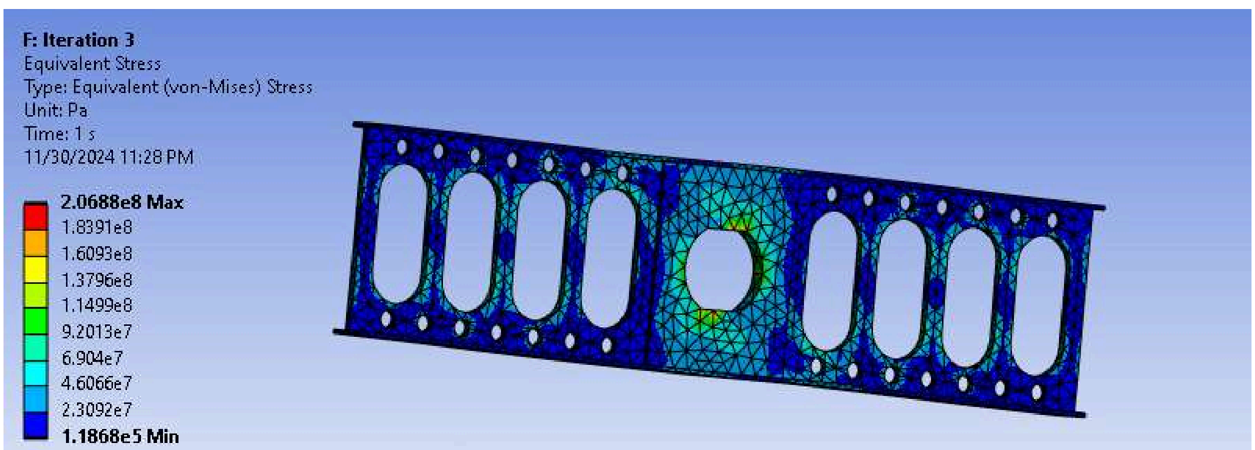
V5:



Equivalent stress (Von-Mises) in pascals (Perpendicular Torque Test Pressure Based)

This design had a factor of safety of 1.82 and a raw weight of 29.96 grams. This design should be able to withstand the torque, but further weight reduction can be done. With the intention of filling all the capsule slots, the raw weight needs to be at least 25.8 grams.

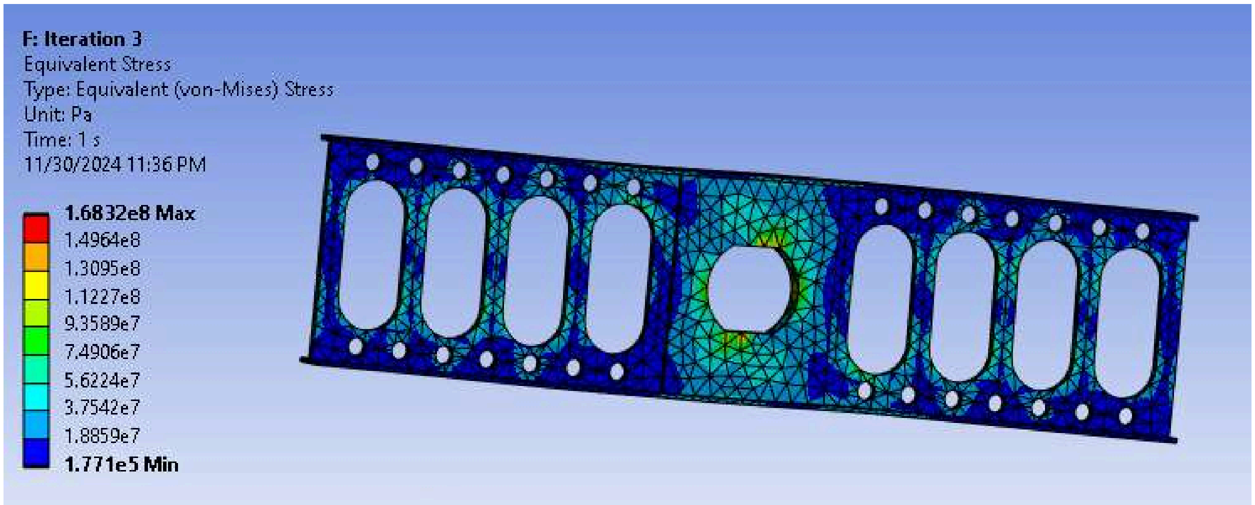
V6:



Equivalent stress (Von-Mises) in pascals (Perpendicular Torque Test Pressure Based)

In this design, the cross section was reduced to a web thickness of 0.06” and flange thickness of 0.03” at the ends. The center web thickness was decreased from 0.175” to 0.125”. It had a factor of safety of 1.34 and raw weight of 22.51 grams. The next iteration will need to increase thickness at the center.

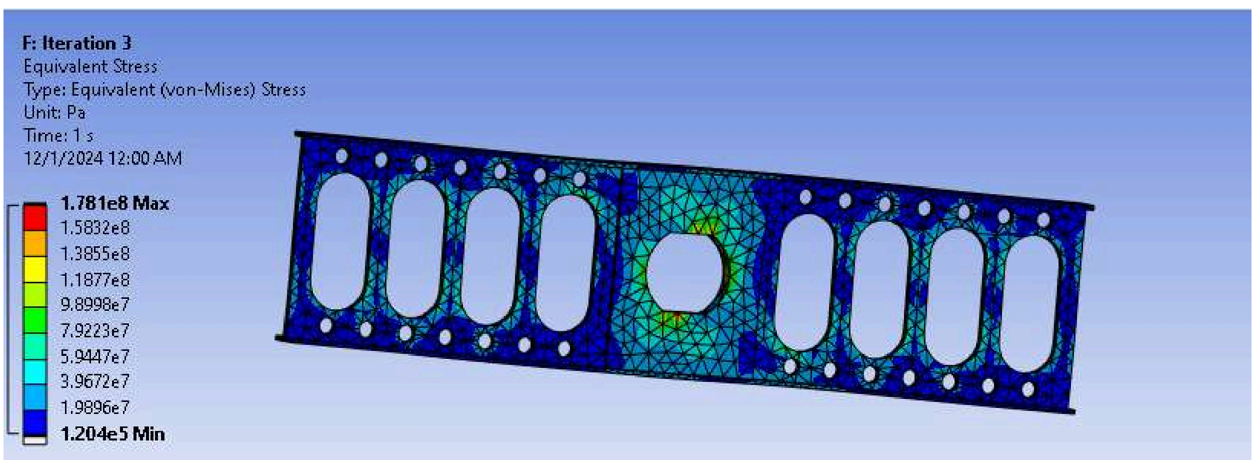
V7:



Equivalent stress (Von-Mises) in pascals (Perpendicular Torque Test Pressure Based)

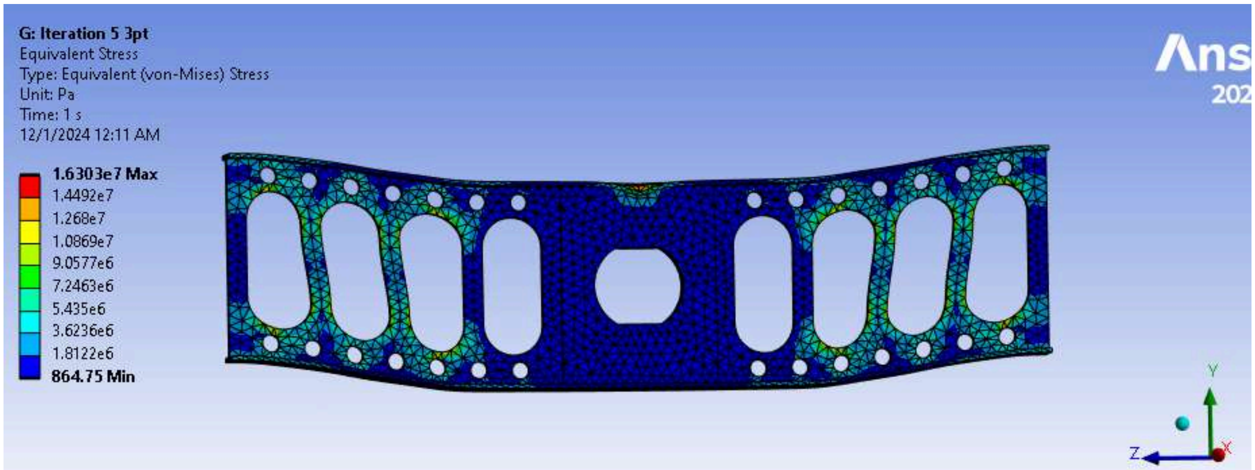
After readjusting the center web thickness from 0.125" to 0.15", the factor of safety jumped up to 1.61. If about 0.1" is removed from the center, we should be closer to our chosen factor of safety.

V8:



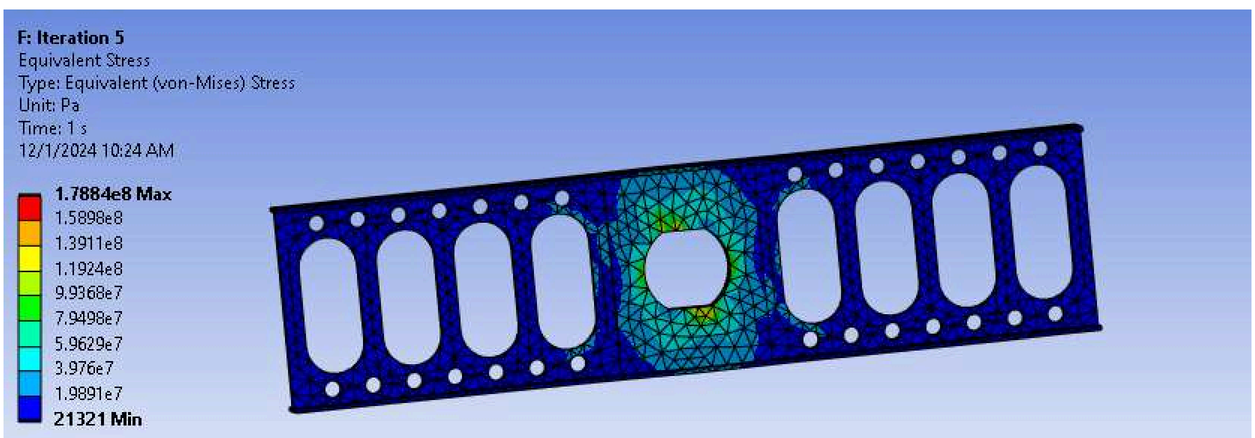
Equivalent stress (Von-Mises) in pascals (Perpendicular Torque Test Pressure Based)

Current center web thickness is 0.14" with a weight of 23.38 grams and a factor of safety of 1.54, which is 2.66% within the proposed factor of safety. We then mistakenly simulated the three point bend test in the wrong direction, which is seen below.

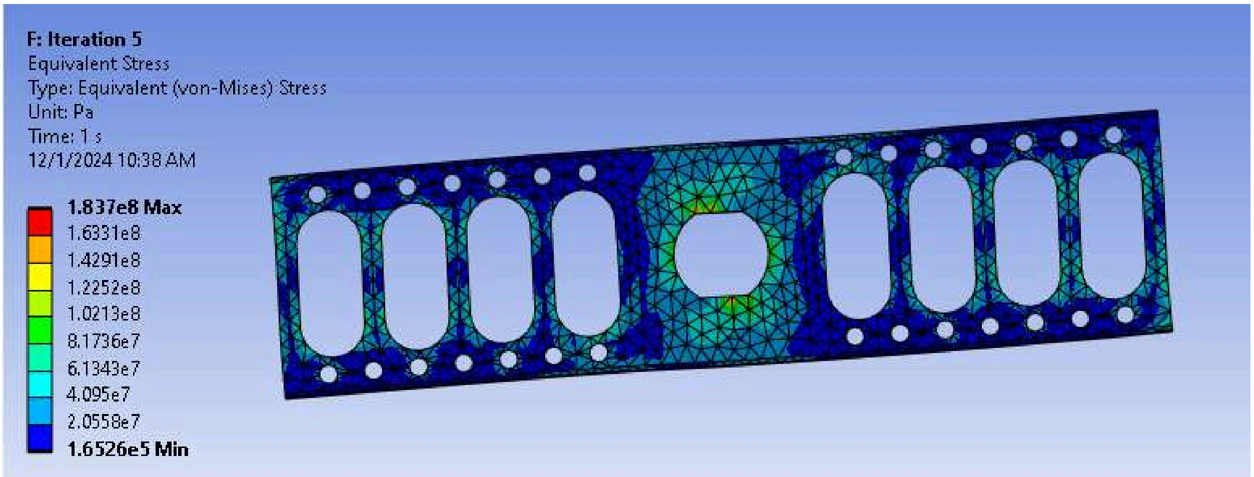


Equivalent stress (Von-Mises) in pascals (Three Point Bend Test)

The bending test has a maximum Von-Mises stress of 16.3 MPa, which gives a factor of safety of 16.93. It is important to note that multiple bending simulations were run, but due to improper set-up and communication from our team, we have decided to leave them out. Below are the Ideal Torque Test and the Force Based Perpendicular Torque Test.



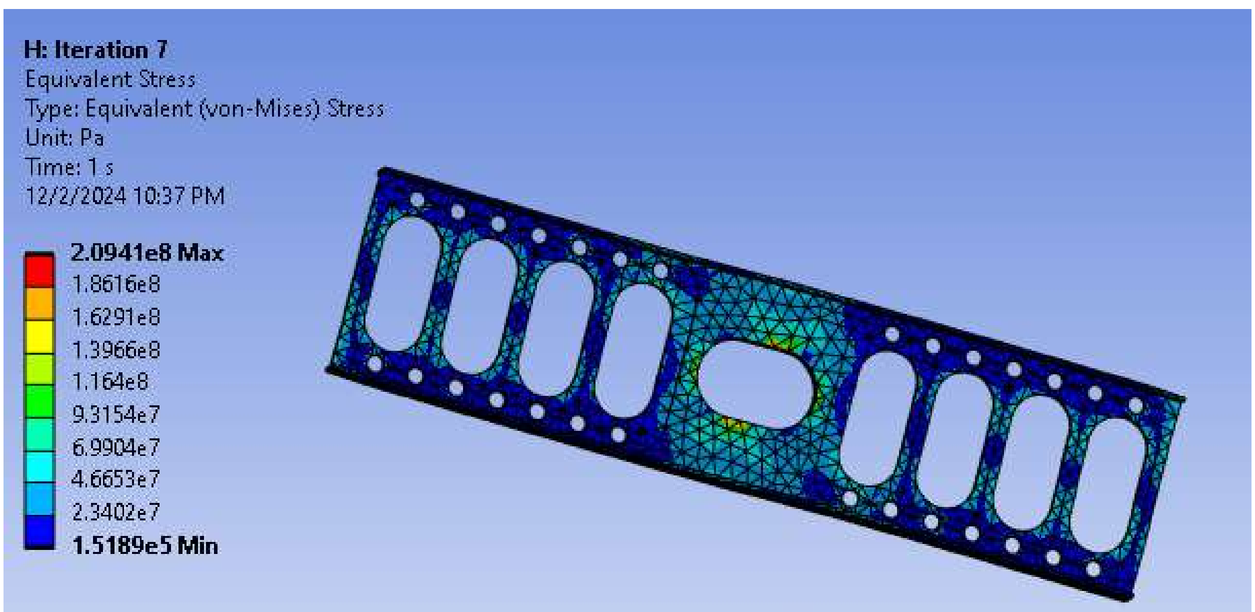
Equivalent stress (Von-Mises) in pascals (Ideal Torque Test)



Equivalent stress (Von-Mises) in pascals (Perpendicular Torque Test Force Based)

After the analysis of different ways to simulate the torque test, we can see that the factor of safety is around 1.50 (Force Based Perpendicular Test) and 1.54 (Ideal Torque Test) when it comes to the functional test.

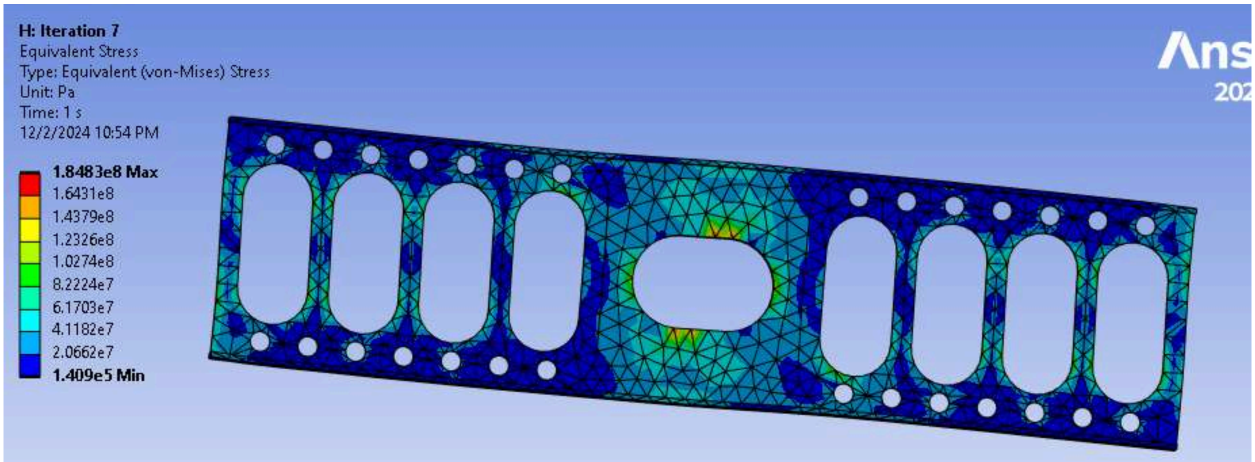
V9 (Post-Manufacturing Check):



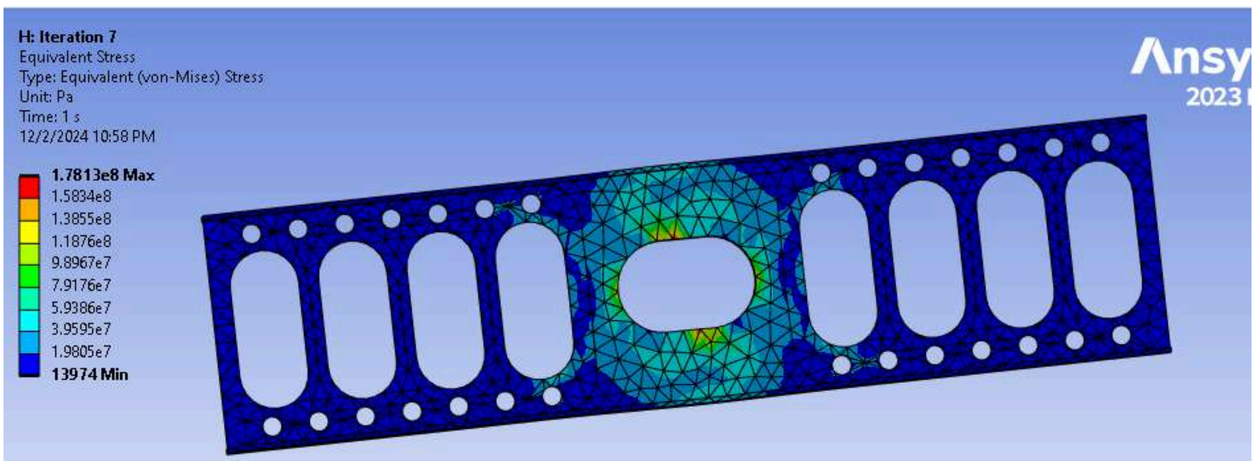
Equivalent stress (Von-Mises) in pascals (Perpendicular Torque Test Force Based)

After meeting with Rick and Colby, we decided to add ¼" fillets where the raised web portion meets the unraised portion. This was to accommodate our constraints in machining as sharp corners as before were non manufacturable. The force based perpendicular torque test showed a factor of safety of 1.32. This means another iteration is needed.

V10:

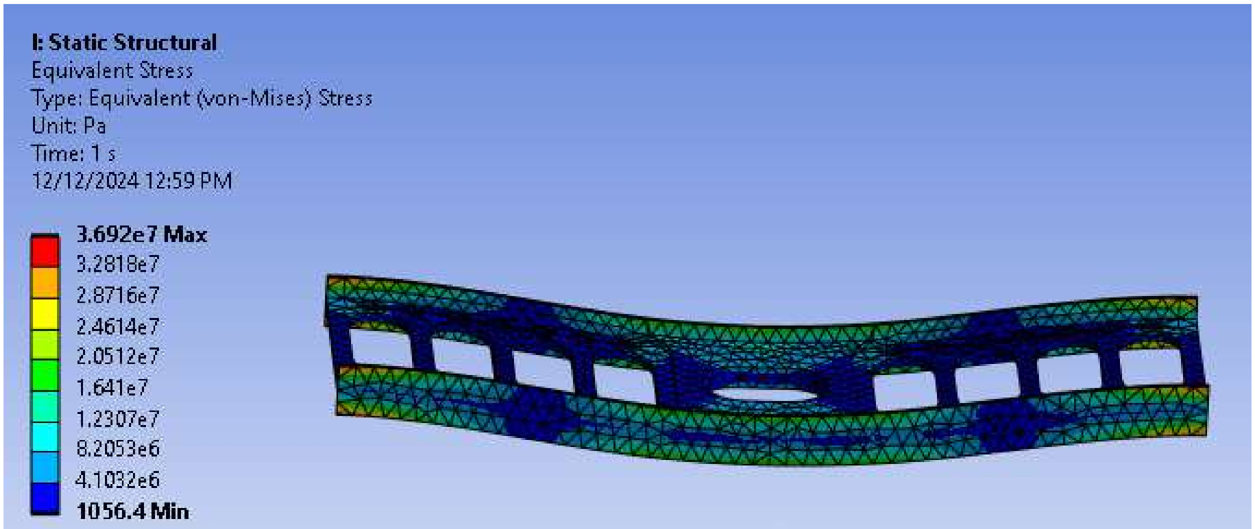


Equivalent stress (Von-Mises) in pascals (Perpendicular Torque Test Force Based)

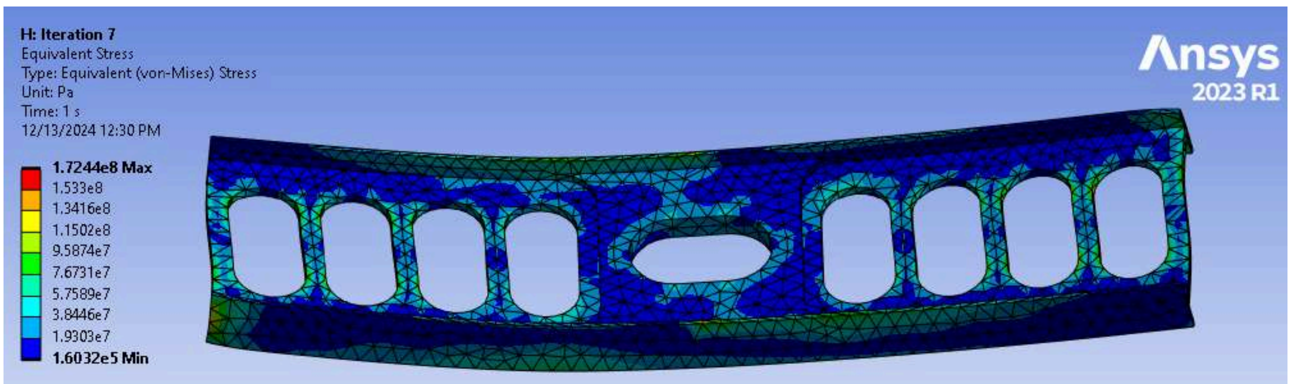


Equivalent stress (Von-Mises) in pascals (Ideal Torque Test)

After increasing the thickness and the width at the center, the perpendicular torque force based test showed a factor of safety of 1.49 and the ideal torque test showed a factor of 1.54. According to SolidWorks' mass properties, the final wrench design should be 24.41 grams. A proper bending simulation is provided below, with a shown factor of safety of 7.46. Based on that test, a simulation for a torque for bolt turning and a perpendicular torque was run to help simulate incidental torques. It was shown to have a factor of safety of 1.6. This is above the factor of safety we intended, but to stay conservative, we held our basis on the previous two tests.

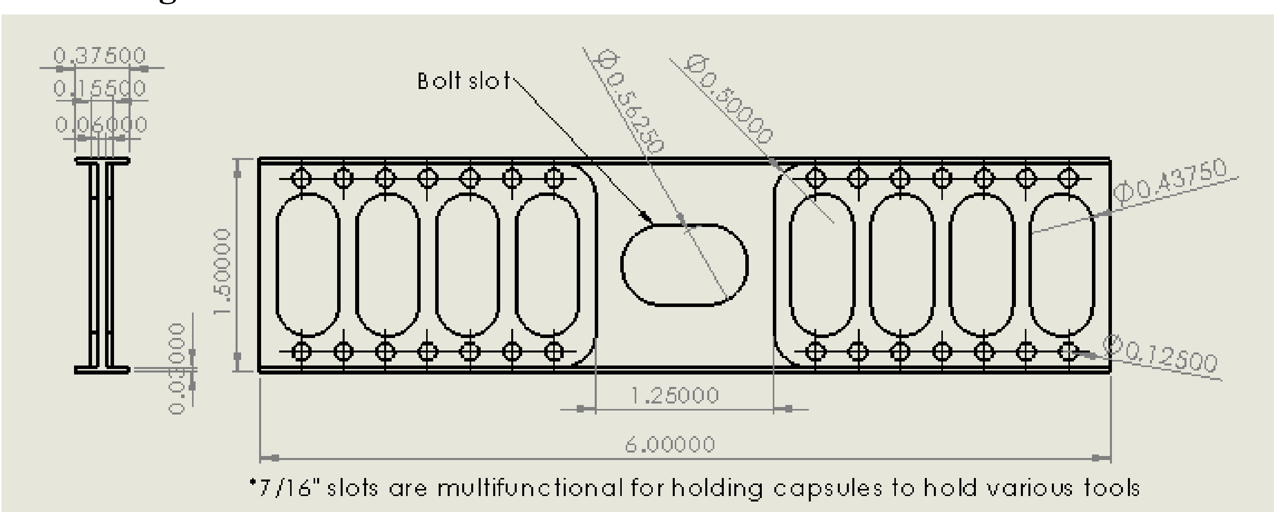


Equivalent stress (Von-Mises) in pascals (Corrected Three Point Bend Test)



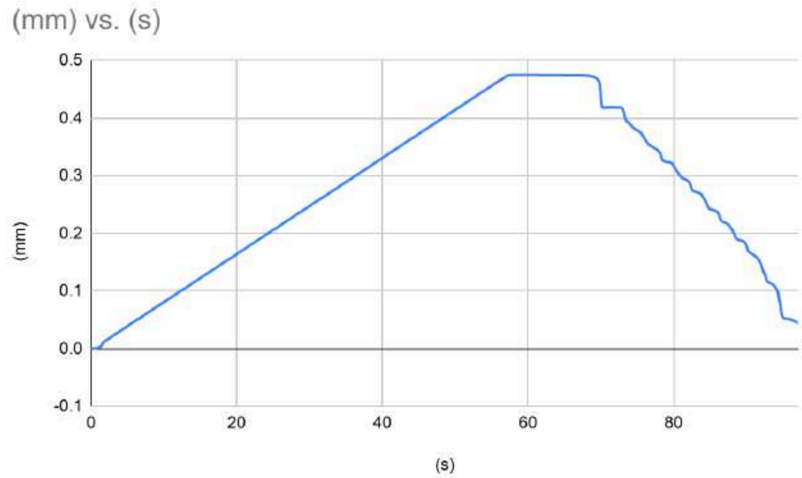
Equivalent stress (Von-Mises) in pascals (Torque For Bolt Turning and a Perpendicular Torque)

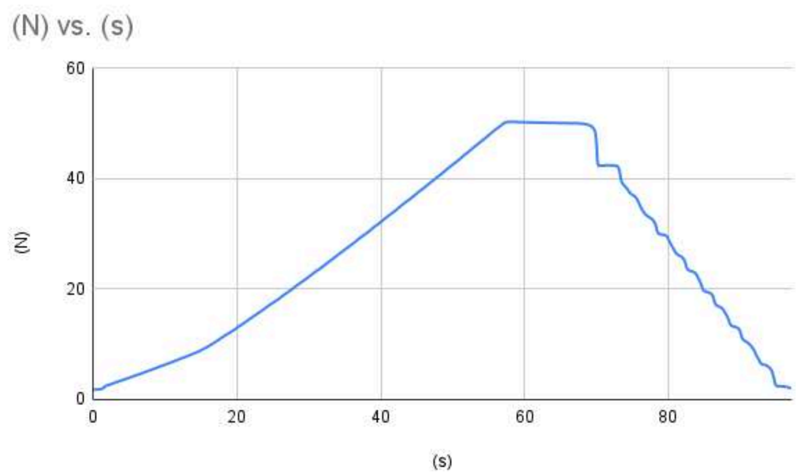
Final Design:



Final Test Results - Liam Wasser

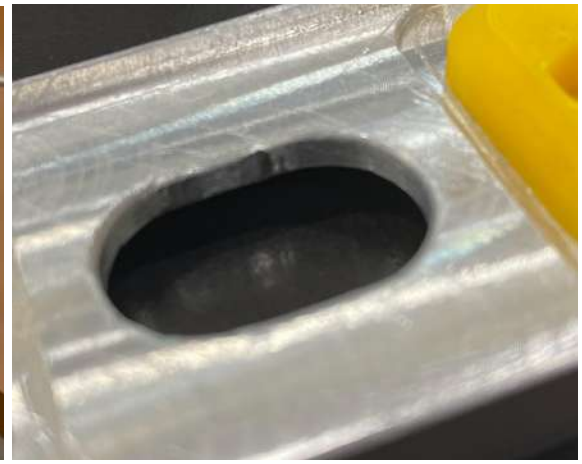
Our wrench came in at a staggering 29.3 grams with the additional capsules and it could go down to 22-23 grams without them equipped. This is well under the desired weight of 35.4 grams.
During the three point stiffness bend test, a force of 50 newtons was slowly loaded on the off axis direction with supports on either end. At a force of 50 newtons, the wrench peaked with a maximum displacement of 0.47 millimeters which was .07 millimeters more than what our analysis FEA calculated the deformation to be. The force was then gradually reduced until there was no more pressure on the wrench. The requirement of this test was to make sure it would not bend and deform plastically. Our wrench deformed elastically and it went back to its pre-loaded shape after the force was relieved.





While the force was being loaded up to 50 Newtons, the middle of the wrench displaced linearly within the elastic region of the material allowing it to return to its natural shape.

To test the functionality of the wrench, a ⅜ inch bolt was torqued down to 160 in-lbs on a plate of metal. The wrench was then used to loosen and ultimately remove the bolt from the plate. While the testing set up was not optimal for our style of wrench, we were successful in this test with slight damage to the bolt slot.



Functional Test Set-up *Deformation in the Bolt Slot*

Conclusion - Aman Patel

This project incorporated design, manufacturing, and testing of a lightweight wrench to meet both weight and requirements for ultralight biking. The final design successfully proved several goals and has shown us opportunities for further improvements.

The first major crucial point was the selection of the I-Beam design for the wrench handle. The I-Beam design was chosen due to its high moment of inertia, which increases the strength while reducing material use when developing the wrench. Through iterative design processes, we changed the cross-sectional area by increasing the beam width, by using the h^3 relationship in the moment of inertia formula. This allowed us to use vertical slots, replacing the initial horizontal slot design, but also enhanced the structural integrity and resistance to transverse shear stress for the wrench

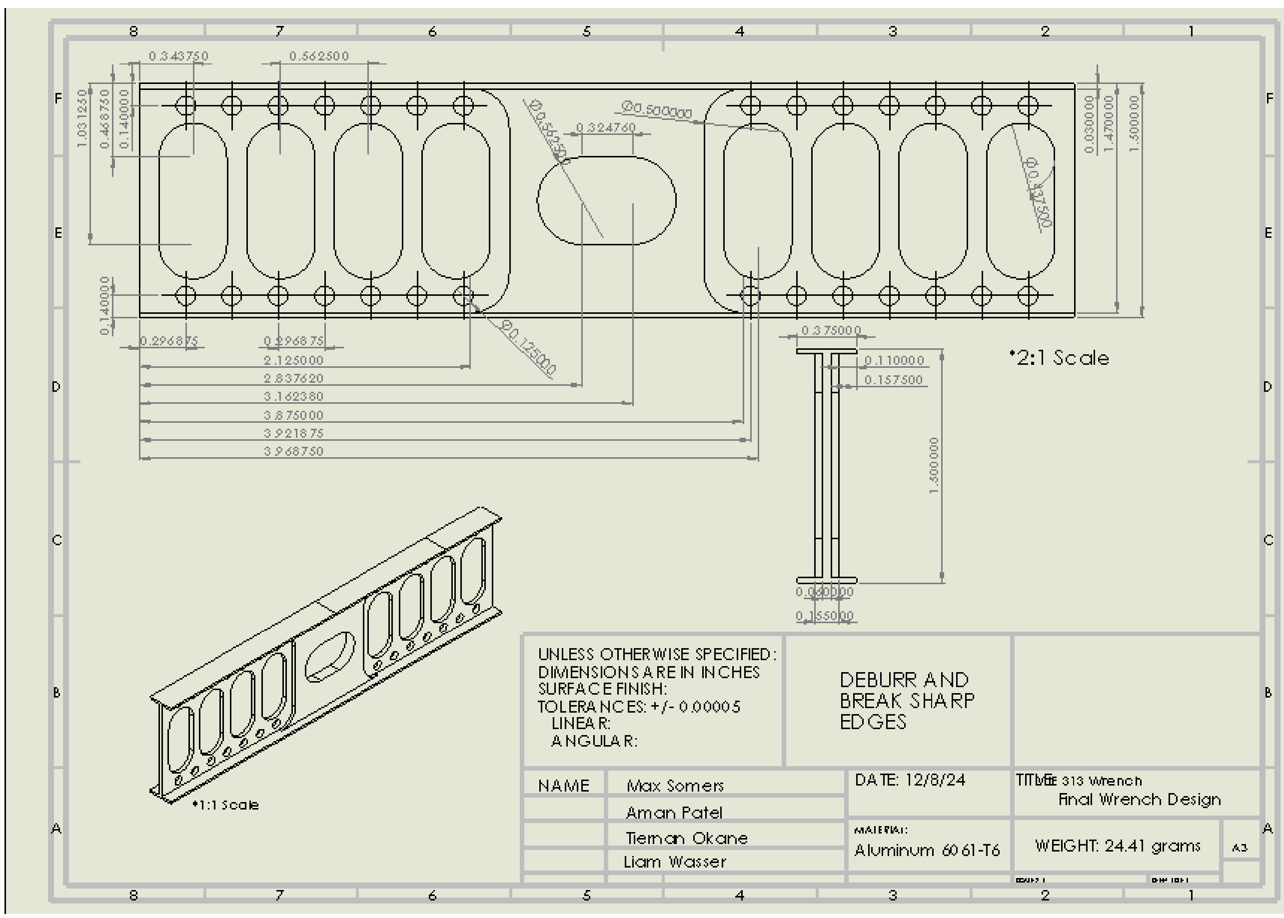
Another important part of the wrench was the inclusion of 3D-printed slots as an additional feature. Originally, the idea was to use them as capsule slots for carrying small parts for the bike. We decided to add another functionality by adding allen hex nut slots. This feature allows users to fix other bike components other than the bolt. This attachment can be turned into bits like flatheads or Phillips head bits, increasing the wrench's utility.

The testing phase was also important for the wrench's mechanical performance. During the three-point bending test, the wrench showed great durability, with minimal deformation and a displacement of only 0.47 mm under a 50 N load. In bolt testing, the wrench loosen a bolt torqued to 160 in-lbs. However, unscrewing the bolt required some effort, which made it apparent to the team that there was room for improvement for a more ease of use product

While the project met the goals required, there are still some areas for improvement the team have discussed. One area of improvement would be increasing the overall length of the wrench. This can help the user get more leverage to apply more torque, making it easier to help unscrew the bolt. Another iteration would be increasing the thickness around the center bolt hole. This is because there was slight deformation of the wrench in the center during the bolt test. By applying more material and overall thickness to the wrench, this would help reduce the stresses applied in the center areas. Lastly, refiguring the printer settings for the slots can help us get a more precise fit and improve the attachment purpose for the slots. Additionally, to ensure the slots stay in place, an adhesive like JB-Welding can help the slots remain in place, helping the functionality of the wrench and the parts inside of it stay in one place.

In conclusion, the project was an overall success in showing the functionality of the wrench. Looking towards the future, using the suggestions mentioned would further optimize the wrench for better performance and user experience.

Appendix: Detailed Drawing:



Appendix: Manufacturing Plan

Basic Setup

1. Cut the stock down to 1.5” x 0.375” x 6.125” - **Liam**
2. Face ends to 6” using the edge finder. Remember to zero at contact points and then 0.1” inward. End with the origin to top left corner of stock - **Liam**
3. Using 1/2” end mill, make a slot from (0, -0.28,0) and face 0.125” at a time until (0, -1.22, -0.1100) - **Liam**
4. With the same end mill, make a slot from (0, -0.28, -0.1100) and face until (2.1250, -1.22, -0.1575). Be aware of cutting direction. - **Aman**
5. Now do the other side, start from (6, -0.28, -0.1100) and face until (3.875, -1.22, -0.1575) - **Tiernan**
6. Flip the piece and repeat steps 4 and 5 - **Max and Aman**

Making the Bolt Slot - Tiernan

7. Using a 9/16” end mill, make the bolt slot by starting at (3, -0.75, -0.375) and end at (3.16238, -0.75, -0.375). Then go to (2.83762, -0.75, -0.375)

Capsule Slots - Max

8. With the 7/16” end mill, make the capsule slots. Start at (0.34375, -0.46875, -0.375) and end at (0.34375, -1.03125, -0.375). The center of each slot is 0.5625” away from the next.
9. Second capsule slot: start (0.90625, -0.46875, -0.375) and end at (0.90625, -1.03125, -0.375)
10. Third slot: start (1.46875, -0.46875, -0.375) and end at (1.46875, -1.03125, -0.375)
11. Fourth slot: start (2.03125, -0.46875, -0.375) and end at (2.03125, -1.03125, -0.375)
12. Now the fifth slot is on the other side. start (3.96875, -0.46875, -0.375) and end at (3.96875, -1.03125, -0.375)
13. Sixth slot: start (4.53125, -0.46875, -0.375) and end at (4.53125, -1.03125, -0.375)
14. Seventh slot: start (5.09374, -0.46875, -0.375) and end at (5.09374, -1.03125, -0.375)
15. Last slot: start (5.65625, -0.46875, -0.375) and end at (5.65625, -1.03125, -0.375)
16. Weigh the piece here to see if it is under 25.8g and if extra holes are necessary. (35.4 - (1.2 x 8))=25.8

Our team decided against doing the holes as our part was already under the weight limit and it would have been a tedious process that could sacrifice the strength of the part. The general process of what would’ve been the holes is below.

⅛” Holes

17. Setup with a ⅛” end mill. Each hole is 0.296875” apart
18. Drill holes at these locations: (0.296875, -0.1400), (0.59375, -0.1400), (0.890625, -0.1400), (1.1875, -0.1400), (1.484375, -0.1400), (1.78125, -0.1400), (2.078125, -0.1400)

19. Now these: (0.296875, -1.3600), (0.59375, -1.3600), (0.890625, -1.3600), (1.1875, -1.3600), (1.484375, -1.3600), (1.78125, -1.3600), (2.078125, -1.3600)
20. Now these: (3.921875, -1.3600), (4.21875, -1.3600), (4.515625, -1.3600), (4.8125, -1.3600), (5.109375, -1.3600), (5.40625, -1.3600), (5.703125, -1.3600)
21. Lastly: Now these: (3.921875, -0.1400), (4.21875, -0.1400), (4.515625, -0.1400), (4.8125, -0.1400), (5.109375, -0.1400), (5.40625, -0.1400), (5.703125, -0.1400)