College of Engineering

MIE 313: Final Project Report

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1. Introduction & Requirements

Mars-Or-Bust LLC is a company committed to colonizing Mars. This poses unique engineering challenges that require innovative designs that can maximize functionality while minimizing weight. Our team has been tasked by Mars-Or-Bust LLC to design a lightweight wrench handle and a compatible jaw for use in Martian operations. The wrench handle should be compatible with custom heads and/or jaws, while coming with one sample jaw.

Design Constraints:

- **Weight Limitation:** The total mass of the wrench, including the handle and detachable jaw, must not exceed 70 grams.
- **Screw and Head Size:** Our team is assigned a 3/8"-24 screw size with a 9/16" hex head. This defines the required geometry of the jaw.
- **Additional Functionality:** The wrench must serve at least one additional purpose beyond turning bolts. Our team decided to integrate a flathead screwdriver tip on one side of the wrench handle.
- **Modular Assembly:** The wrench handle and the head should come as separate parts that can be quickly assembled without the use of fasteners and/or adhesives. This would require us to either use snap fits or interference fits.
- **Wrench Handle Specifications:** The handle should:
    - Be 6 inches ± 0.25 inches in length.
    - Have one flat side and be able to rest stably on a surface.
    - Have all edges broken, either deburred or chamfered.
    - Provide the user with a secure grip
    - Be able to withstand reasonable loads expected during use
- **Jaw Specifications:** The jaw must be fixed in size with no adjustments. The jaw design can be either open or closed.

Manufacturing Constraints

- **Handle specifications:** The wrench handle must be machined from a provided aluminum bar stock with 6" × 1.5" × 0.25" dimensions.
- **Handle Machining**: The design should conform to the machining capabilities available at the MIE Innovation Shop. Machining should:
    - Consists of milling straight lines with no undercuts, facing, simple pockets and drilling.
    - Have all sharp edges "broken" and all burrs removed.
- **Jaw Fabrication:** The jaw must be fabricated using the FDM 3D printer in the machine shop using ABS plastic.

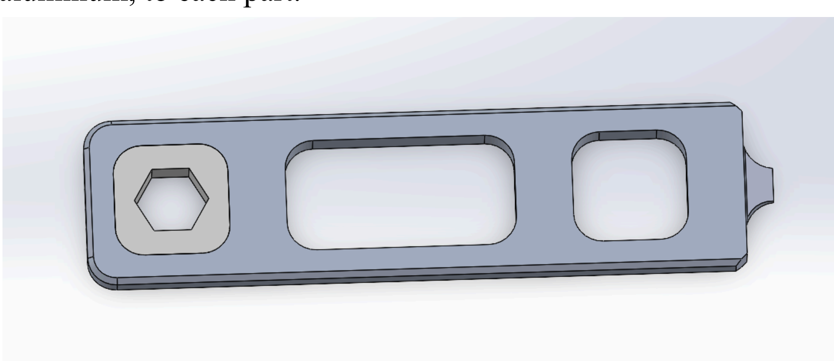
Since the wrench must be able to handle the target torque and resist deformation, our team decided that it must have a factor of safety of at least 2. Additionally, due to the restriction of "maximizing the use per gram", we planned on ensuring that the secondary function should be simple and useful and comply with the total weight constraints. It is also important to note that for our by-hand analysis, we assumed a SAE Grade 5 bolt.

2. Concept Generation

The following three concepts were developed as a part of the initial individual concept generation phase. The general goal was to create a lightweight, two-part assembly wrench design with a built-in additional feature that would not compromise the wrench's weight requirement of 70 grams.

Nolan

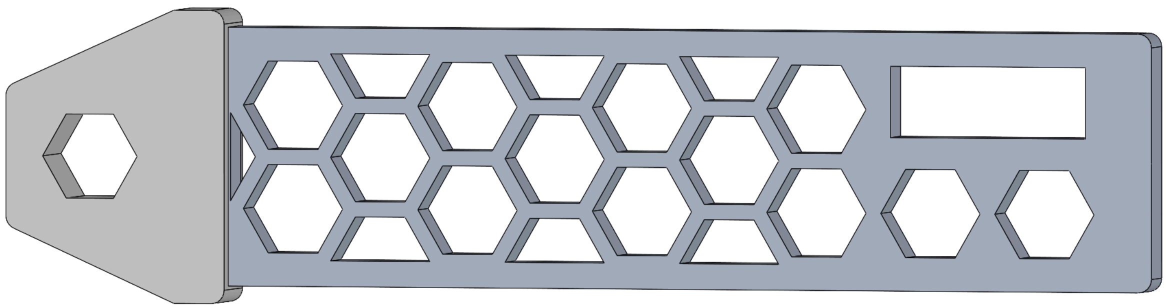
I wanted to design a wrench with maximum strength and ease of machinability in mind. I decided to go with a rectangular cross section and chose to keep the maximum cross of the aluminum bar, one and a half inches by a quarter inch. I figured this would give the handle the maximum strength and rigidity when applying a torque on a bolt. I opted to design 3 pockets in the handle to be milled out for weight reduction. I knew the strongest type of socket would be an enclosed head, and the aluminum handle would ideally surround it for even more strength. This is because 6061 aluminum has a much higher yield strength than ABS plastic. I chose to go with an interference fit for the socket to be pushed into the pocket milled out in the wrench design. I planned to heat up the ABS and seat it in the wrench handle to seal the fit and avoid any fracture. I made sure the pocket designed in the handle was rectangular so the ABS wouldn't round out in the aluminum pocket. I designed the pockets to be one-inch squares or 1x2 for the middle with half-inch fillets so that we would only need to use a half-inch end mill, and the dimensioning would be very simple. For an added feature of the wrench, I used a quarter of an inch off of the far side of the handle to design a small prybar/flathead screwdriver bit. I figured this quarter inch off of the six inches wouldn't affect the overall force on the handle too much. Pictures of the CAD of the jaw and handle are below. I made sure to add the materials, ABS and 6061 aluminum, to each part.



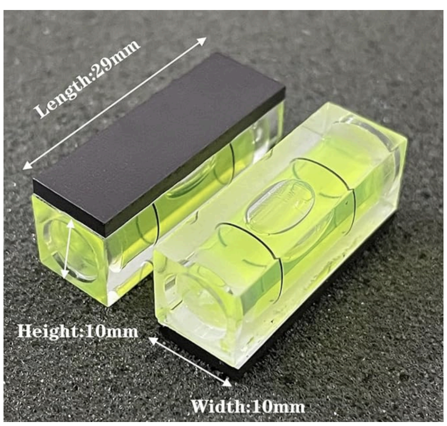
Fiorella

When thinking about the design of my wrench, I wanted to use a pattern that implements a high strength-to-weight ratio, like the honeycomb pattern. I did not take into account the capability of the mill machining and therefore this design was not optimal for machining.

I decided to design the wrench with a rectangular cross-sectional area because of the simplicity of fabrication, analysis



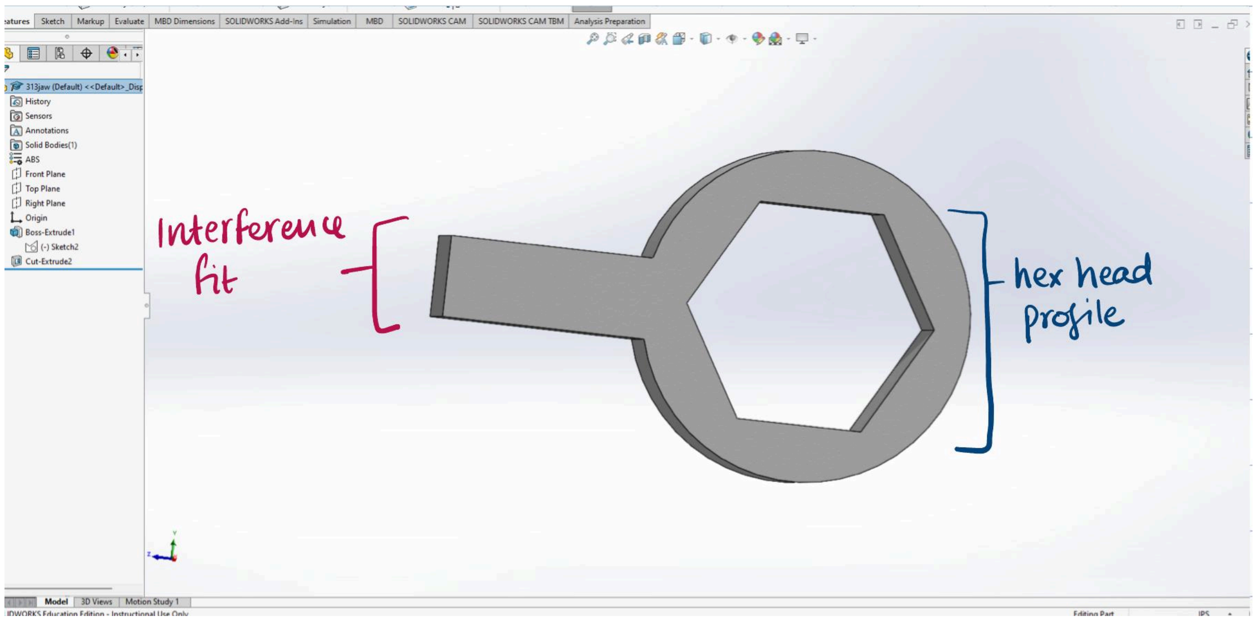
Inference fit:



Anoushka

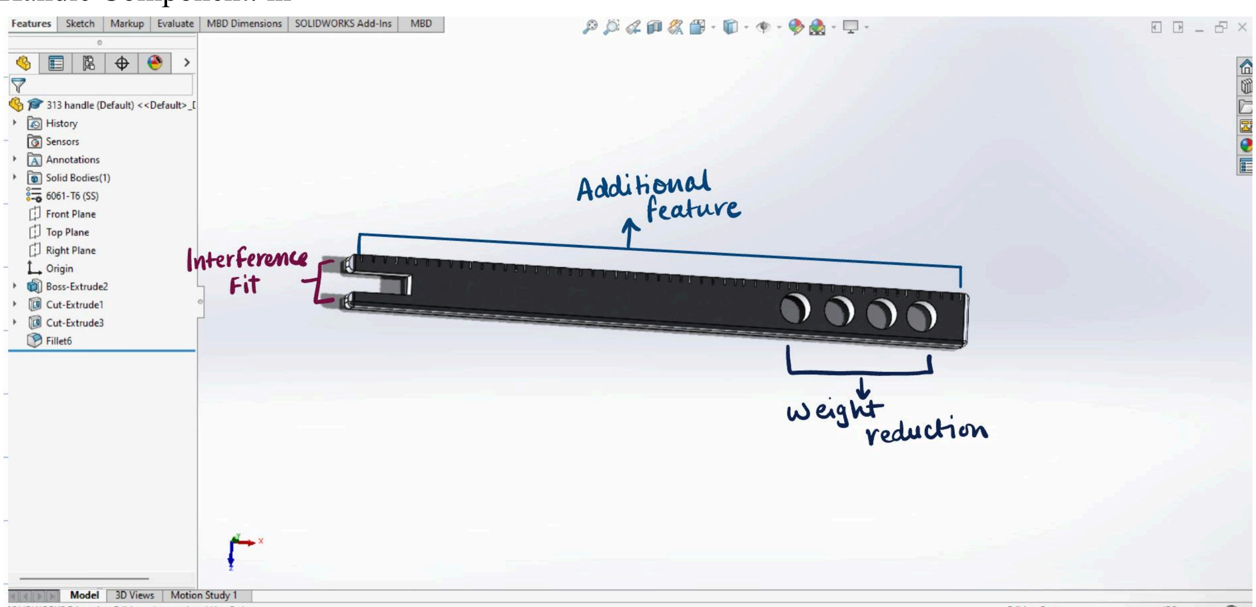
Pictured below are the CAD models of the wrench's ABS jaw and aluminum handle. Both of the components were designed to satisfy the weight, added functionality, durability and two-part assembly requirements.

Jaw Component:



A closed jaw geometry was chosen for the hex head profile based on comments made in class, it was recommended that open jaw configurations were likely to fail. The closed jaw allows for more even stress distribution and improved torque distribution (Budynas and Nisbett, 2020). The handle and jaw would be connected by a press-in interference fit. This would allow for quick assembly without adhesives and/or fasteners. A potential issue with this particular design choice would be that the repeated removal and insertion of the jaw component could degrade the ABS contact surface.

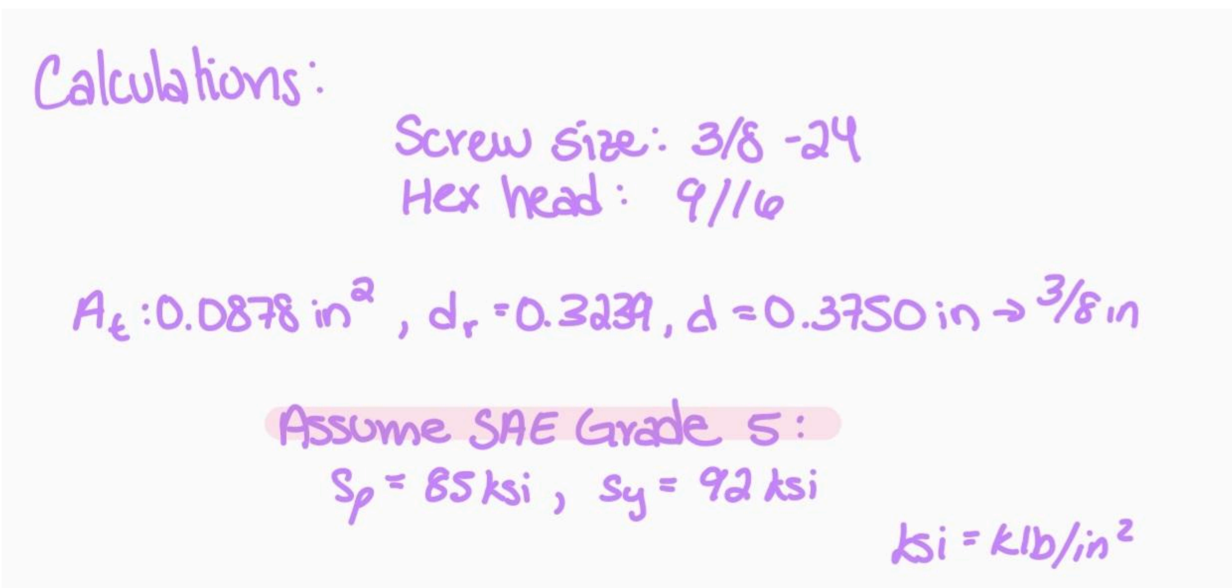
Handle Component: in



Pictured above is the aluminum handle of this wrench handle design. The three circular cutouts in the handle are designed to reduce the weight without compromising the structural strength of the handle. The calculations for this handle would be made by assuming the handle as a rectangular beam. The additional feature is a 6” ruler along the top edge of the handle with approximately 0.1”- 0.25” increments. Although this feature was designed with the weight constraint and usability in mind, ultimately it could have proven too impractical to file these increments into the aluminum handle. It is also important to note that, during initial calculations for this design, it was revealed that using the entirety of the allowable stock handle width of 1.5” would have caused this design to be over the weight limit. Therefore, this design has a reduced handle width of approximately 0.75”.

3. By-hand Analysis Set-up

A simplified by-hand calculation analysis was set up prior to the manufacturing of the prototype. This analysis focuses on concepts introduced in class. The hand calculations are pictured below, including all assumptions made and solving for the insertion force, torque, minimum cross-sectional area to allow the torque, and principal stresses.



Calculations:

Screw size: 3/8 -24
Hex head: 9/16

A_t : 0.0878 in^2 , d_r = 0.3239, d = 0.3750 in → 3/8 in

Assume SAE Grade 5:
S_p = 85 ksi , S_y = 92 ksi

ksi = klb/in^2

initial Force : $F_i = k_i A_t S_p = 0.9 \cdot 0.0878 in^2 \cdot 85 ksi$

$F_i = 6.7167$ kilo pounds ⇒ 6716.7 lbf

Insertion torque : $T = 0.2 \cdot F_i \cdot d_r$

$T = 0.2 \cdot 6716.7 lbf \cdot 0.3239 in$

$T = 435.10$ in-lbf $= 36.25$ lbf-ft

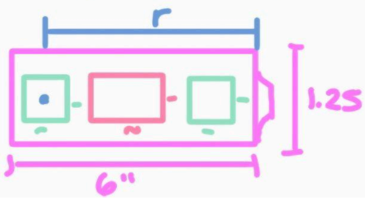
↳ Torque wrench must apply.

⇒ Calculations for wrench design used:

↳ $T = F \cdot r$ $\qquad r = L = 5.03\text{ in}$

$F = T/r$

⇒ $F = 435.10\text{ lbf-in} / 5.03\text{ in} = 86.5\text{ lbf}$



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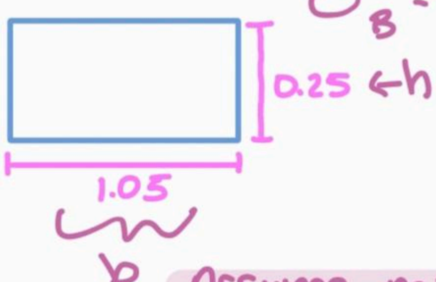
Bending stress: Assume cantilever beam

$M = F \times L \Rightarrow 86.5\text{ lbf} \cdot 6\text{ in} = 519.02\text{ lbf-in}$

$C = h/2 \Rightarrow 0.25\text{ in}/2 = 0.125\text{ in}$

$I = 1/12\, bh^3 = 1/12\,(1.5\text{ in})(0.25\text{ in}^3) = 0.001953\text{ in}^4$

$$\sigma_B = \frac{M \cdot C}{I} = \frac{519.02\text{ lbf-in} \cdot 0.125\text{ in}}{0.001953\text{ in}^4}$$



$\sigma_B = 33216.97\text{ lbf/in}^2$

$= 33216.97\text{ psi}$

Assume material is Aluminum 6061-T6

$\sigma_y = 40{,}000\text{ psi}$

→ Since $\sigma_B < \sigma_y$, the wrench will not yield with chosen dimensions.

Shear stress in jaw:

↳ Since we have a square ABS jaw piece $a = 1.05\text{in}$

$c = a/2 = 1.05/2 = 0.525\text{ in}$

$T = 435.10 \text{ lbf-in}$

Assume soild square cross section: $J = \frac{a^4}{6}$

$J = (0.525)^4/6 = 0.01266 \text{ in}^4$

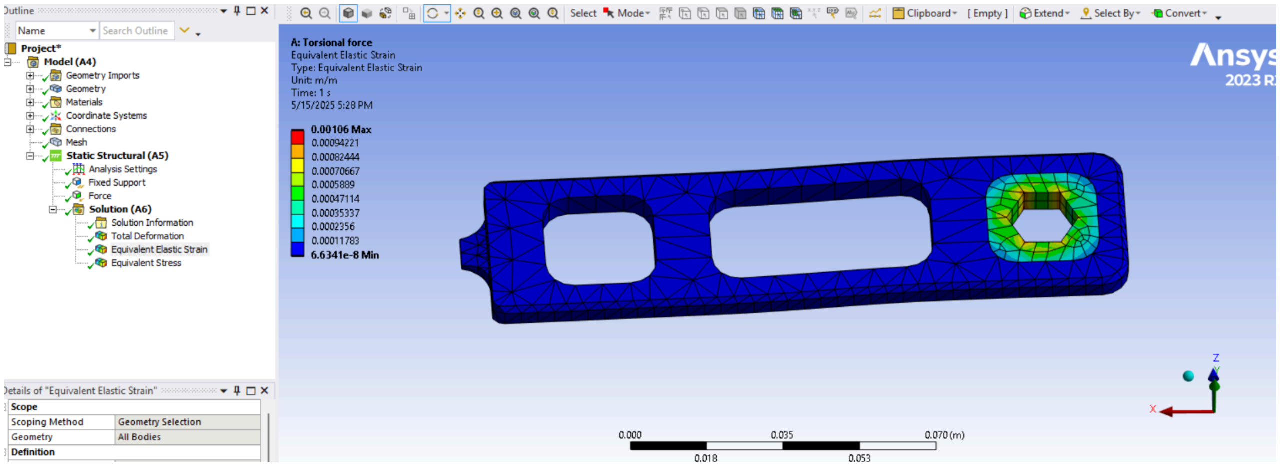
$$\tau_{max} = \frac{T \cdot c}{J} = \frac{435.10 \text{ lbf-in} \cdot 0.525\text{in}}{0.01266 \text{ in}^4} = 18{,}041.4 \text{ psi}$$

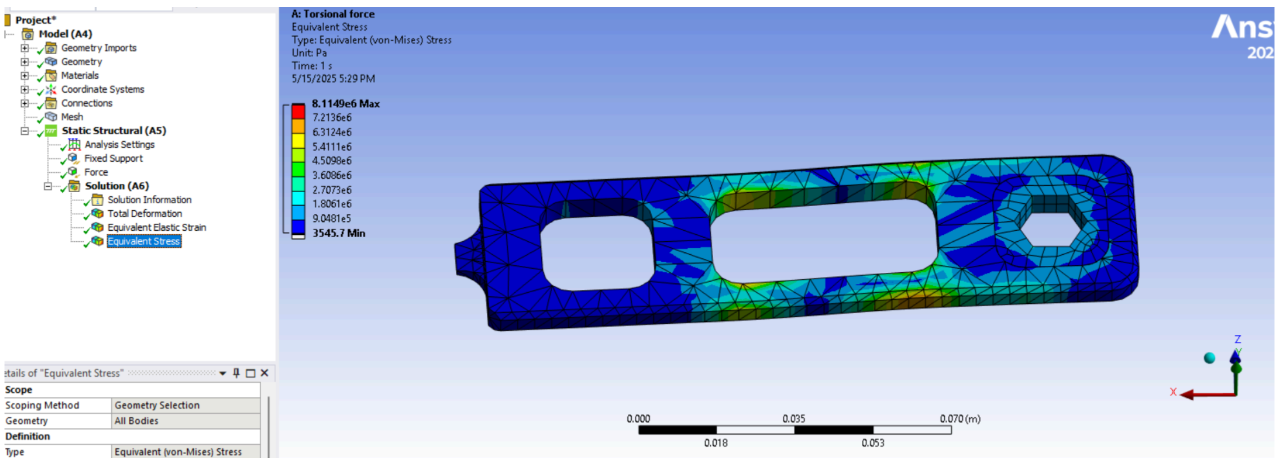
Since ABS' shear strength is 5,820 psi (from Mat lab), it is predicted to shear.

4. Finite Element Analysis Set-up

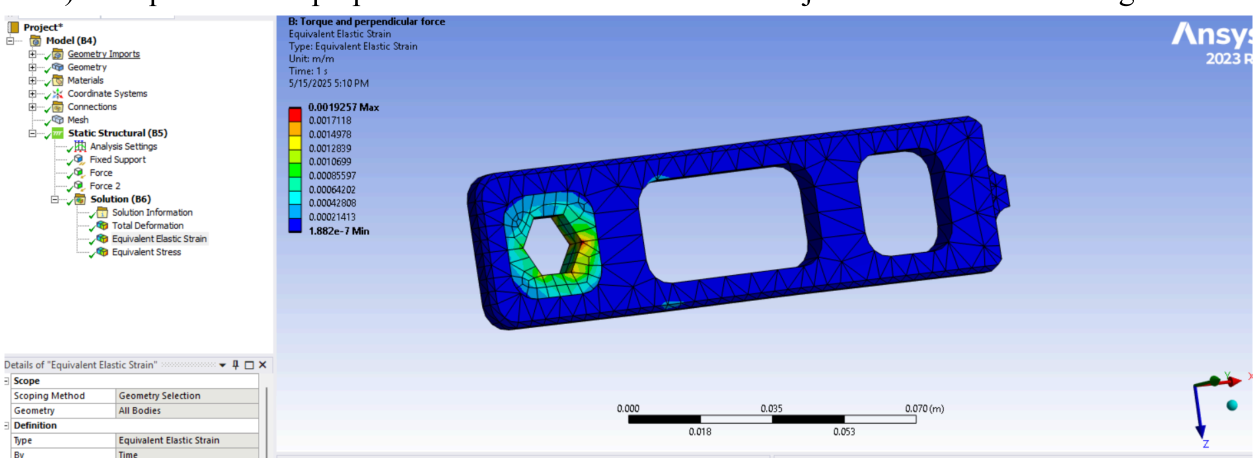
In order to conduct the finite element analysis on the handle, jaw, and combined handle and jaw, the jaw had to be redesigned in a way that it would not be an interference fit, as that would have caused problems with the meshing and contact surfaces in Ansys. For each of the three conditions, a static structural analysis system was used. The first step for each condition was to set the material for the handle and/or jaw. From the material section, 6061 Aluminum and ABS were chosen and set to the correct geometry. Then the connections between the handle and jaw were checked to be correct so that it would mesh properly. Next, the mesh was solved, and it was sure that everything was meshing properly. The fixed supports and forces were applied depending on the three analysis conditions given in the rubric. For the first two conditions, the walls of the jaw were fixed in a way that would contact the bolt head and apply a force to the side of the handle and the top of the handle (for the second condition). For the three-point bend test, an assembly in SolidWorks was created. The assembly included 3 hemisphere extrusions contacting the handle as they would in a real-world three-point bend test. It was ensured that those hemispheres were made out of structural steel to avoid deformation. The two supports were then fixed on either end, and a 25N load was applied to the top hemisphere. For each condition, the total deformation, equivalent elastic strain, and equivalent stress were added, and each model was solved to get the results of the finite element analysis. Figures are below:

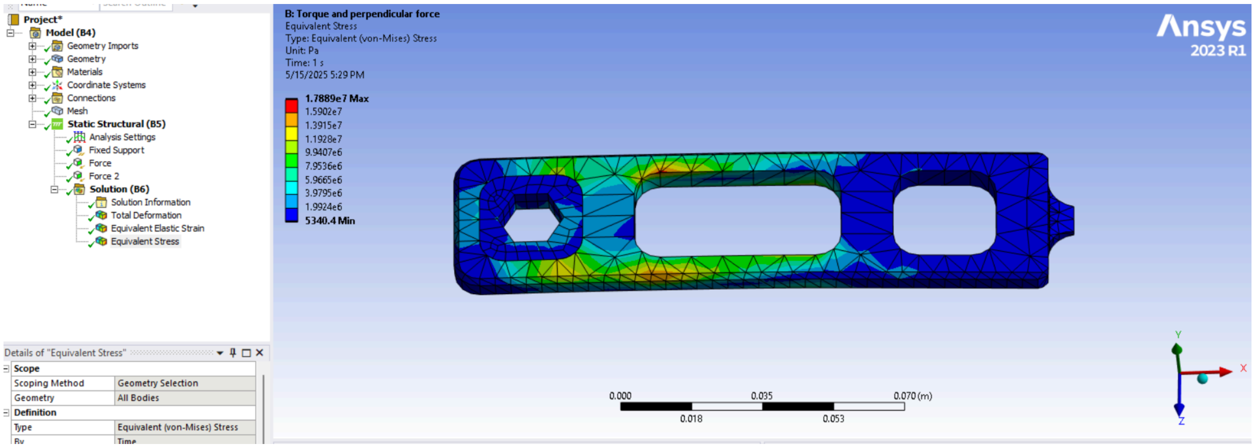
1) Torque on the handle and jaw from the bolt: stress and strain diagrams



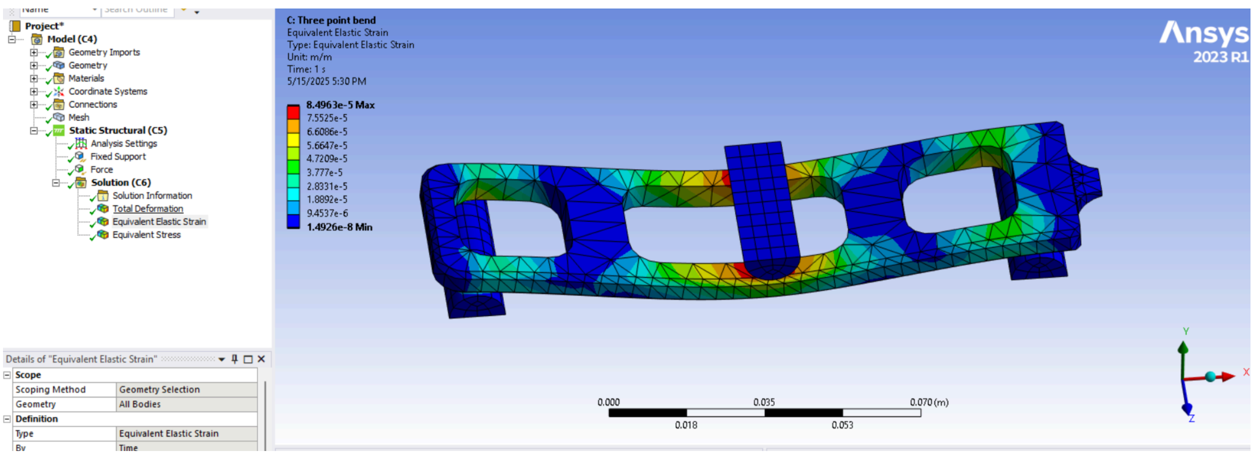


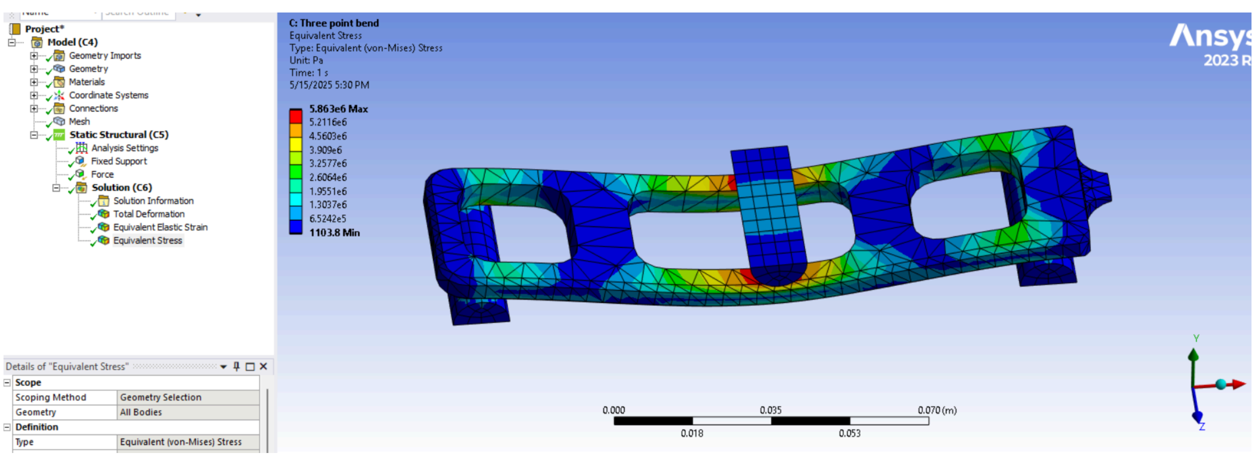
2) Torque and 25N perpendicular force on the handle and jaw: stress and strain diagrams

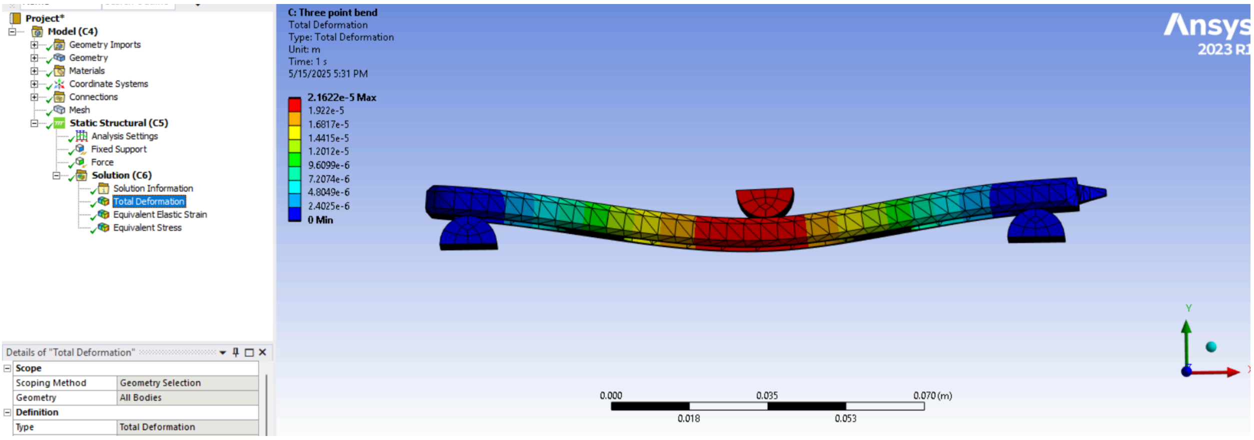




3) 3-point bend test on the handle of 25N: stress, strain, deformation diagrams

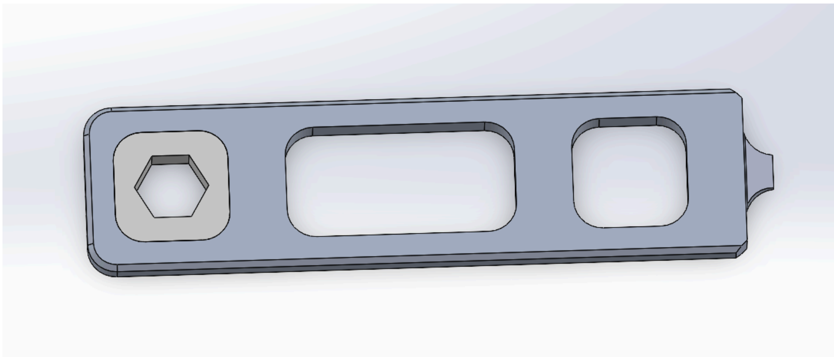






5. Design Process

We decided to go with Nolan's design as it was the simplest to manufacture and had clearance from Colby without the need for any design iterations. Critical values such as insertion force, torque, and bending stress were calculated by hand in order to initially gauge the strength of the design. These numbers were used in the Ansys analysis on the CAD to test the design with software. The calculated insertion force and insertion torque were 6,716.7 lbf and 36.25 lbf, respectively. The force calculated for the final design was 86.5 lbf. The minimum calculated cross-sectional area based on the computed force is 0.2625 inches squared, or 0.25 by 1.05 inches. Our handle was designed with a width of 1.25 inches, the maximum, which is larger than our calculated minimum, so the design should be able to withstand the forces. Matweb gives the ultimate yield strength for 6061 aluminum as 241MPa[2] and ABS plastic as 22.1MPa[3]. The max stress and strain for the analysis of the wrench when subject to an ideal torque from a bolt turning are 8.11 MPa and 0.001, respectively. The stress is showing up mostly in the middle of the handle and the strain is concentrated around the inner walls of the hex head of the socket. When subject to a 25N perpendicular load in addition, the max stress increases to 17.9 MPa and the strain increases to 0.0019. Again, the stress is concentrated on the middle of the handle slightly closer to the socket side, with this addition, perpendicular force, the stress also concentrates on the side of the wrench getting pushed down. Based on this analysis, we can assume that the first thing to fail will be the socket head as it is the weakest part of the wrench and has the strain concentrated on the inner walls of the bolt head contact surface. The aluminum handle can easily hold these forces as its UTS is over ten times higher than the max stress on the handle, 241 versus 17.9 MPa. On the other hand, the UTS of the jaw is very close to the max stress, 22.1 versus 17.9 MPa. This will lead us to believe that the jaw will fail far before the handle, but should be able to untorque the bolt head. Over time, with fatigue, the jaw will easily fail. The 3 point bend test showed a max stress of 5.9 MPa, max strain of 8.5E-5, and max deformation of 2.16E-5 meters. The final design is shown below in CAD, and a detailed drawing with dimensions is in the appendix. The added feature of the design is on the end opposite of the socket and is a flathead screwdriver bit/prybar.



Subsequent Manufacturing Process

After getting the design approval from Rick and Colby, we proceeded with the manufacturing of our prototype at the MIE Innovation Shop. The jaw component was fabricated using the Fused Deposition Modeling (FDM) ABS 3D Printer.

To manufacture the handle, we first used the variable-speed vertical band saw to cut the 6061 aluminum stock bar to our desired dimensions of 6” x 1.5”. We then used the track milling machine to create the three machined cutout features of the handle. The idea was to create a plunge cut in the centre of each slot and mill it to the drawing’s specifications. One cutout was machined for the jaw interference slot, while the other two were for weight reduction. To ensure precise edge detection, we used an edge finder. Then a ½” end mill was used for the desired slot creation. The additional feature of the flathead screw driver tip at the rear end of the handle was also produced using the track mill machine. For this, we had to carefully realign the milling machine’s XYZ components and relocate the rear edge using an edge finder.

During assembly, we initially encountered an issue with fitting the ABS jaw into its designated slot. We remachined and then manually filed the designated slot to try to overcome this problem. When this was not sufficient, we used a blowtorch to apply controlled heat to soften the ABS component. This was successful, and it ensured a snug interference fit between the designated slot and jaw components.

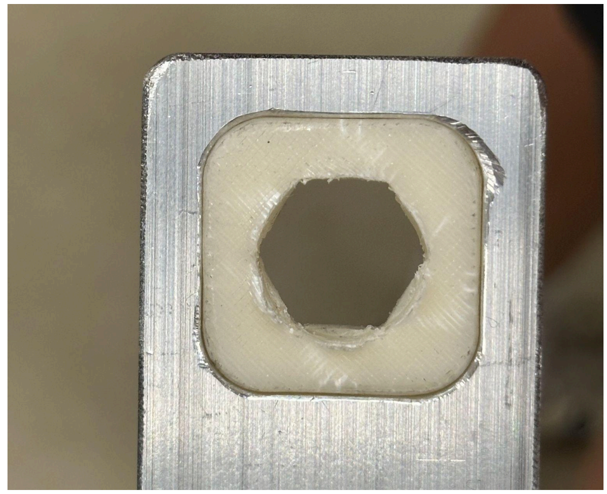
Finally, all handle edges were manually filed to remove burrs and sharp edges to ensure our prototype met with the requirement of “breaking all edges”. We also used the manual filing to further refine the flathead tip. Pictured below is our prototype after final assembly/before testing:

6. Test Results

The initial weight of the completely assembled wrench was 54.88 grams, which successfully met the weight constraint of remaining under 70 grams. As mentioned earlier, based on the by-hand calculations, the required torque to loosen the assigned fastener was calculated to be 36.2 lb-ft. After a thorough discussion with Mr. Joseph Condon at the testing lab, it was initially recommended that we begin testing at approximately 50% of the calculated torque value. This was recommended due to prior testing failures experienced by other groups when they applied the full calculated torque. Therefore, we initially planned to test the wrench at 18 lb-ft. However, after further discussion with Mr. Condon, the first two tests were conducted with a reduced torque of 10 lb-ft. These two tests ran without any major difficulties, and our wrench was able to effectively secure the bolt, apply the testing torque and successfully unbolt the fastener. There were no major visible or structural changes to the wrench.

Since the first two tests of 10 lb-ft ran successfully, we decided to increase the applied torque to 18 lb-ft to evaluate the performance of our wrench under higher loading. This test also ran successfully, the fastener was unbolted, and the wrench remained structurally intact. Following these three tests, the wrench weight remained unchanged, but some material deformation on the ABS jaw was observed after the third test. As pictured below, we observed scuffing on the plastic jaw, which was likely due to friction during insertion and increased torque application in the third test.

ABS Jaw before testing	**ABS Jaw after testing**

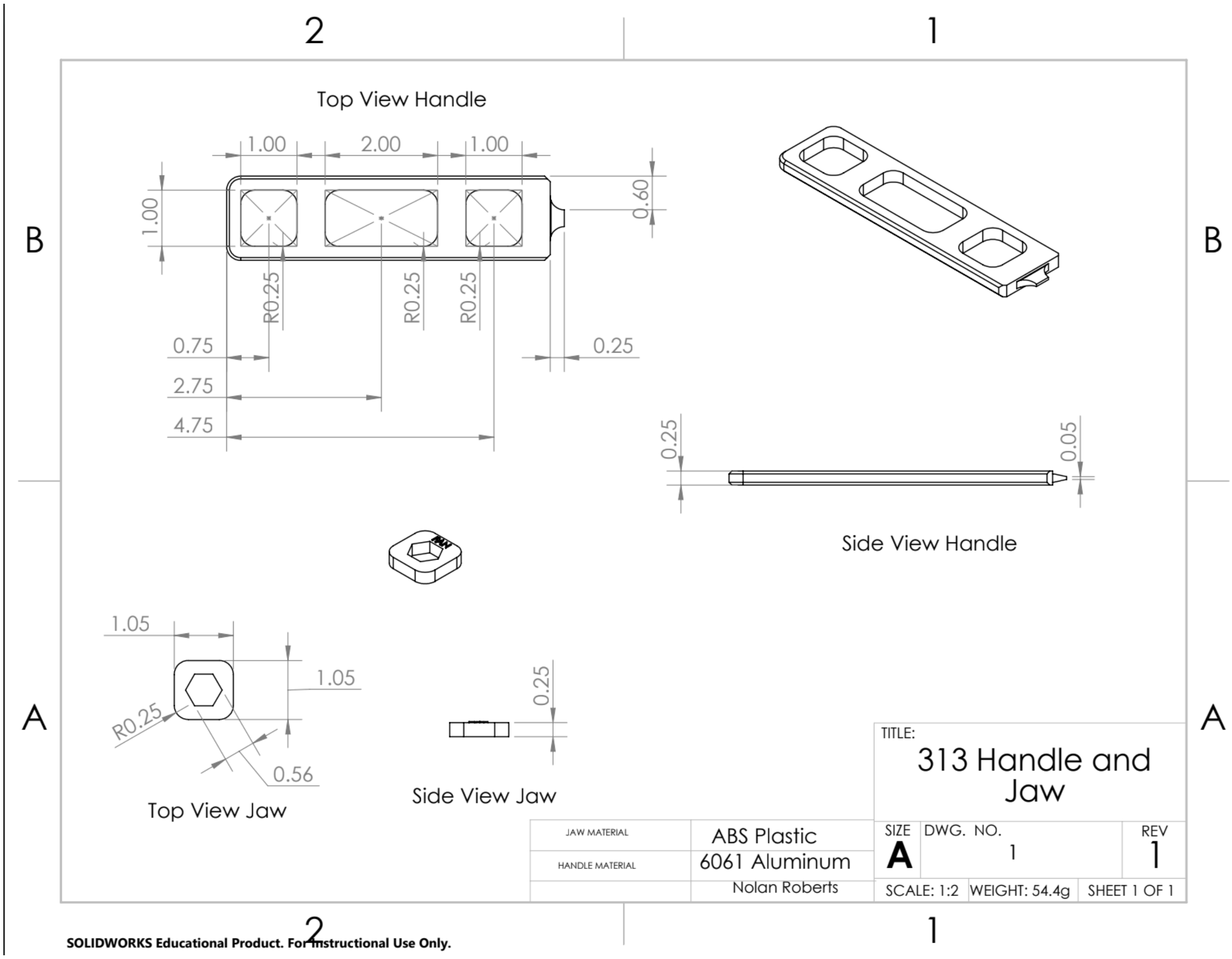
It is important to note that, during final assembly before testing, we encountered a minor challenge regarding our hex head profile. To ensure a snug interference fit between the jaw and handle, we had used a blowtorch to heat the ABS component and temporarily soften it for insertion into its designated slot on the handle. This heating caused thermal distortion to the jaw's hex head profile as it slightly enlarged the profile cavity from the intended 9/16" fit. To overcome this challenge, we performed additional filing of the cavity to restore the hex head profile to our desired size.

Another minor problem we encountered during testing was due to the flat design of our wrench. The testing configuration caused our design to rest entirely flush with the setup surface. Initially, it was slightly awkward to get a grip on the handle, but this was just a minor setback, and we were able to correctly position the wrench and run each trial without any further problems.

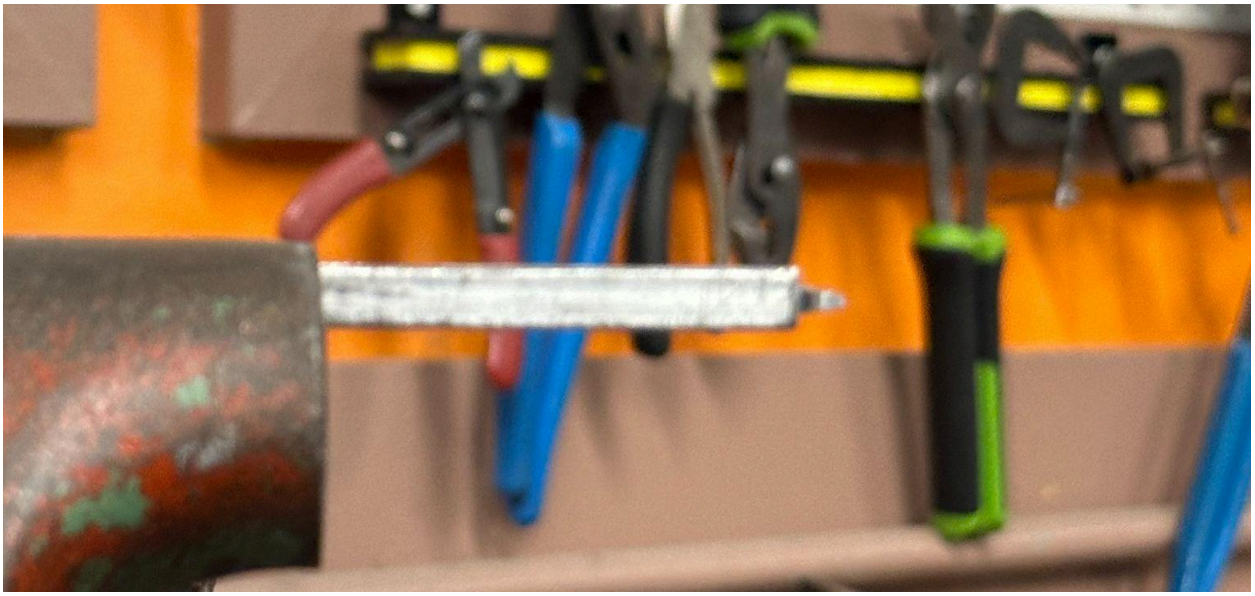
Overall, the wrench met the functional requirements of the project and performed reliably under the designated torques applied. This shows that the selected geometry, design and assembly were appropriate for its intended purpose.

7. Discussion and Conclusion

A. Appendix: Detailed Engineering Drawings of the final product



B. Appendix: Manufacturing Plan for the final product



Manual filing for broken edges and refining the flathead rear tip.

Refrences

[1] Budynas, R. G, and J. K. Nisbett. *Shigley's Mechanical Engineering Design*. 11th ed., pp. 444–447. McGraw-Hill Education, 2020.

[2] MatWeb, LLC. "Aluminum 6061-T6; 6061-T651." *MatWeb Material Property Data*, https://www.matweb.com/search/DataSheet.aspx?MatGUID=d5ea75577b1b49e8ad03caf007db5ba8. Accessed 16 May 2025.

[3] MatWeb, LLC. "ABS Resin." *MatWeb Material Property Data*, https://www.matweb.com/search/DataSheet.aspx?MatGUID=117ad852f5a945b3a4e7e35856c48568. Accessed 16 May 2025.