The Decepticons

Project Final Report

Manufacturing Processes

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Executive Summary

Problem Statement

The objective of the project was to design, fabricate, and evaluate a sheet metal steel bracket capable of securely holding standard 12-oz, 16-oz, and 24-oz aluminum cans while adhering to manufacturability, cost, and performance requirements. The design is intended to serve users with mobility limitations but specifically allows customers who utilize crutches and wheelchairs to have the ability to keep beverages within easy reach. With this intended audience in mind, driving factors of the design included an emphasis on the upper support to the bracket to firmly hold various can sizes in place, especially because crutches create a lot of movement as the user oscillates their position. In addition, most crutches on the market can adjust the handles to meet different arm lengths, and screws are positioned 1 inch apart, which inherently meets project design requirements. The screw holes are also aligned vertically, justifying the design choice of placing the holes on the bracket vertically. Another driving factor of the design was the ease of manufacturability because when it makes the bracket cheaper and when the bracket is cheaper to produce, there is a reduced price that consumers would have to pay. Based on the alternative solutions analysis, bracket 1 (Table A.2.2.2) provided the most optimal balance between affordability, usability, and material efficiency. However, its manufacturability was still an issue in terms of interference of the sheet metal when finger bending but was addressed in the future iteration of the design by breaking the bracket into two parts and spot welding.

Beta Bracket

Figure 1: Unloaded Bracket

Figure 2: Bracket with 12oz Can

Figure 3: Bracket with 16oz Can

Figure 4: Bracket with 24oz Can

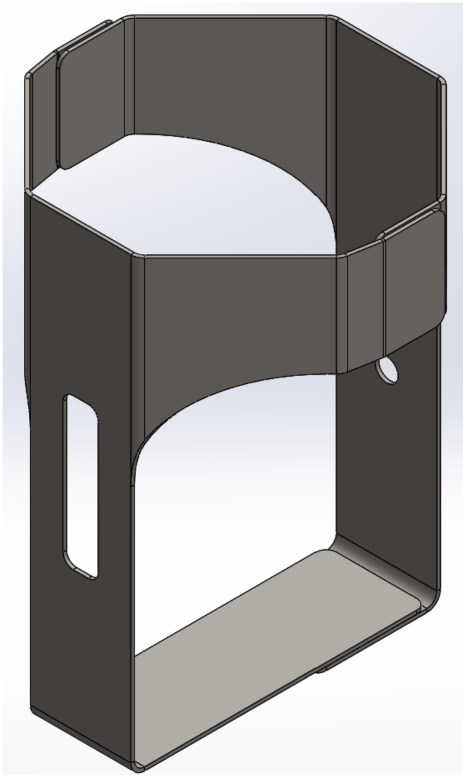

Figure 5: Beta Bracket Cad Model Iso

Figure 6: Beta Bracket with All resin Components

Final Cost

Total Machining cost	$1.488
Total Material Cost	$7.031
Total Labor Cost	$16.67
Total Finishing (Coating) Cost	$0.315
Total Bracket Cost	$25.50

Table 1. Total Cost Breakdown (Calculations in A.6.1: Final Cost Calculations)

Target Sales Price

The manufacturing cost of the wheelchair cup holder bracket is $25.40 per unit. A target retail price of approximately $40 is appropriate based on current market competition. One competitor offers a steel wheelchair-mounted bracket priced at $44.99 [1], while another sells a plastic alternative for $40.00 [2]. By pricing our product at $40, we can offer a higher-quality bracket at a competitive price, undercut the steel competitor, and remain competitive with plastic alternatives while maintaining a ~50% profit margin.

Alpha and Beta Prototype Fabrication and Performance

Evolution of the Bracket

The bracket underwent various stages to get to its final iteration. First, the team use Cardstock to validate the geometry of the bracket, ensuring cans were able to fit, and enough clearance existed when bending. During this stage, the brackets side support was raised so that the can would be less likely to fall out. Additionally, there was an issue during the finger bending, with two ninety-degree bends too close to each other to allow enough clearance. These issues led to the Alpha design, which raised the support arms and split the main bracket into two. This made it actually possible to bend the sheet metal as it no longer interfered with itself. The raised arms also provided ample support for the cans, and we were able to successfully build this prototype. This meant the bracket needed an additional 2 spot welds. However, these were not huge financial investments. Finally, for the final Beta prototype, our team optimized the bottom connection and used the minimum amount of material needed to hold the cans at a factor of safety of 2. This reduced the total amount of material, as well as reducing the number of spot welds by 1.

Time Study

Front Step	Time spent (s) (ignoring setup time)
1	20s
2	20s
3	25s
4	25s
5	30s
6	30s
7	30s
Front Total	3min
Back Step	Time spent (s) (ignoring setup time)
1	30s
2	30s
3	30s
4	30s
5	30s
Back Total	2min 30s
Overall Total	5min 30s

Table 2: Time Study

Group Member	Cutting	Finishing/Cleaning	Bending	Welding	Total
Del	28s	17min	10min	10min	37min 28s
Connor	28s	15min	14min	6min	35min 28s
William	28s	15min	13min	8min	36min 28s
Averages	28s	15min 40s	12min 20s	8min	36min 28s

Table 3: Team #44's Submitted Time Study from Checkpoint 6

As clearly seen when comparing the tables, there is a vast difference in the time study completed by The Decepticons and Team #44. There are a few factors that influenced the difference including knowledge and efficiency with dross removal tools and Team #44's inclusion of setup time. As shown within the table, finishing the sheet metal with a hammer and chisel took the contracted group the most time when, in theory, that process should be the quickest aside from plasma cutting. The group member in The Decepticons responsible for the surface conditioning is highly acquainted with the tools and was able to create the chamber extremely quickly. However, to ease manufacturing, especially when scaling the bracket to a higher scale, there must be a shift to a more efficient surface conditioning tool, which will be further discussed in the following section. The other difference in the time studies was the Decepticons' choice to ignore setup time. This decision was intentionally made because with a increased production rate of 200 brackets for example, all the machines would only need to be fully set up when first starting the manufacturing process, then it's just rinse and repeat. Ultimately, Team #44's time study should be used as a benchmark time for the first bracket being produced because it includes all the steps accounting setup, while The Decepticons time study should be used as a reference for when the process is fully running at maximum efficiency.

Comments from the DFMA Feedback

External manufacturing team #44 gave well-constructed feedback and highlighted a few design changes for the design for manufacturing and assembly (DFMA). The first bit of feedback they gave was that the use of a hammer and chi sel for dross removal slowed the cleaning of the bracket. Specifically, from their time study, 15-17 minutes of the overall process was used to remove the dross which dominated the total fabrication time. In recommending the use of a surface conditioning tool, there would be a dramatic reduction in the time for that step as well as improving the surface finish. Next, it was observed that the small notches used to indicate bend lines were difficult to see, and the roughness produced by the plasma cutter obscured fine details. To mitigate this problem, increasing the size of the bend-location notches in the DXF file was recommended, so the person producing the bracket knows the exact location to finger bend. It was also noted that the bracket was difficult to mount to the walls because the surface across from the holes blocked clean access to the screws. To solve this issue, it was recommended to cut out a small portion directly across from the screw holes to allow a screwdriver to easily access the screws. Finally, the contracted team highlighted a few updates that needed to be made to the work instructions. While the high level of detail in the plasma cutting sections and usefulness of the welding photos were praised, they noted that the photos did not always match the current revision of the bracket. In specific, the older version shown required two bottom welds, whereas the updated version only required one. To increase clarity within the instructions,

Design Update Implementation from DFMA Feedback

Recommendations for design updates were previously discussed in a general sense, but this section will discuss the specific changes made to the model that would be implemented if the bracket is brought to full scale production. Starting with the slot on the opposite side of the screw holes to allow the user to more easily mount the bracket, a 0.5in by 1.5in slot was added to the front bracket. Adding the slot does change the structural support of the bracket, thus an updated structural analysis conducted (more details in A.3) to validate the new geometry would not deform under a load. In addition, the size of the small indents that mark the bend locations increased from a diameter of 0.01in to 0.02in with the main goal easing manufacturing. Specifically, as mentioned with the dross created from the plasma cutter, it was hard for the contracted team to identify the exact locations to bend, however increasing the size of the indents should define the intending bend line with better accuracy. Ultimately, these changes will allow the people responsible for manufacturing the bracket a better understanding of how to make the bracket as well as usability for the user.

Polymer Bracket Overview

Overview of Each Polymer Component and Functionality

Arael's Resin Component

This polymer component is a resin-printed Decepticon piece, with a crutch on each side. This then mounts onto the bracket to provide a smoother and safer user contact surface, as shown in Figures 7 below. The component is designed to attach directly to the existing metal geometry without requiring fasteners or permanent modification to the bracket.

The polymer component does not affect the structural integrity of the bracket since it is not a primary load-bearing element. However, it does improve ergonomics and safety by eliminating sharp metal edges and providing a more comfortable surface for user interaction. Additionally, the use of a resin polymer component improves the marketability of the bracket by giving it a more finished and consumer-ready appearance compared to an all-metal design.

One Elegoo Saturn 4 Ultra 16K build plate can fit 3 of this polymer components in a single print. A single component requires 30.882 mL of resin, has a mass of 33.971 g, and costs approximately $0.85 to produce. The total print time for one component is approximately 1 hour and 33 minutes. This print orientation minimizes support contact on functional surfaces while maintaining dimensional accuracy.

When transitioning from resin printing to injection molding, several design changes would be required. Draft angles would need to be added to vertical surfaces, and wall thicknesses would need to be made more uniform to prevent sink marks. Additionally, the design would need to include a clear gate location for the injection molded shot to ensure proper material flow and consistent part quality.

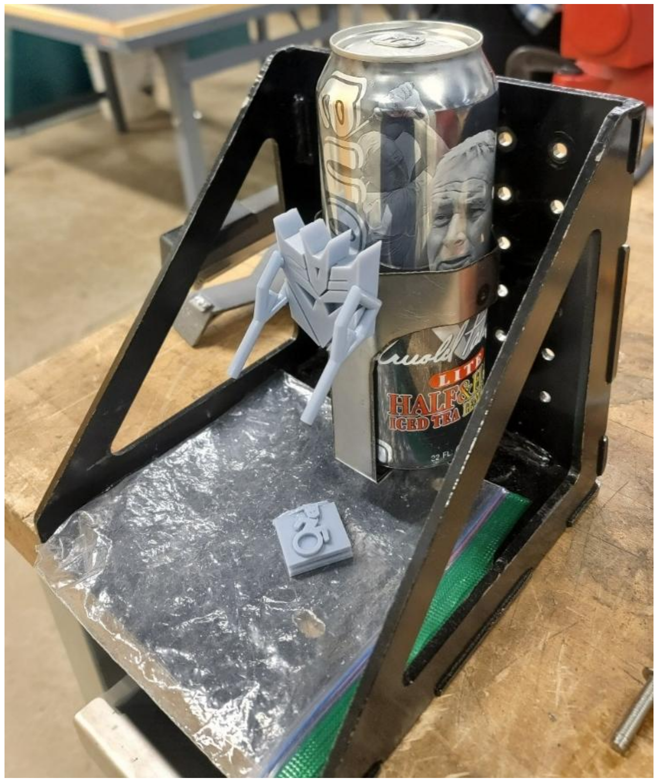

Figure 7: Loaded Bracket with Arael's Resin Component

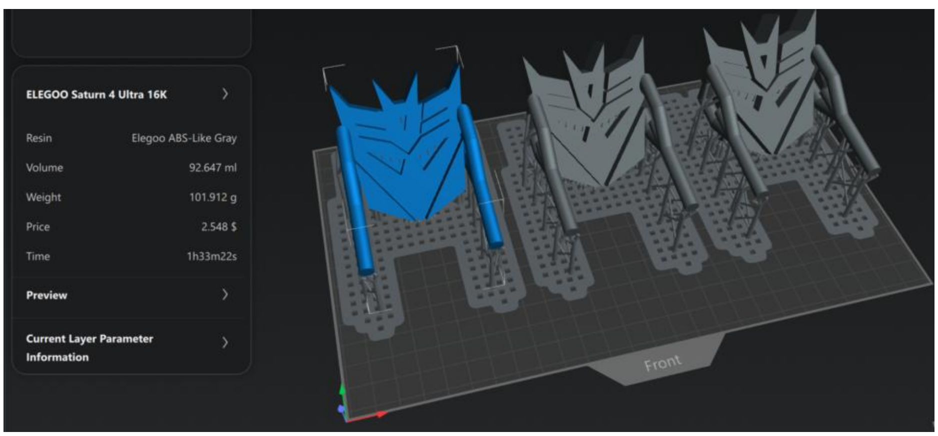

Figure 8: Max number (3) of Arael's Resin Components on Build Plate

Jordan's Resin Component:

This polymer component is a symbol of a wheelchair with a Decepticon head for easy brand recognition. The component just easily slides onto the side of the bracket as shown in Figure 9 below.

The polymer component does not affect the structural integrity or ergonomics of the bracket, but it does improve the marketability of the bracket since it adds brand recognition.

One Elegoo Saturn 4 Ultra 16K build plate can fit 33 of my polymer components as seen in Figure 10. The 33 cost $4.914 because of the 196.542 grams required. It also only takes around

57 minutes to make them, which is 1.73 minutes per part, which is extremely quick for VPP printing.

When transitioning from resin printing to injection molding, the tolerancing could be tighter to fit on the bracket securely. A modification would be locating an area to have the injection molded shot inserted into.

Figure 9: Loaded Bracket with Jordan’s Resin Component

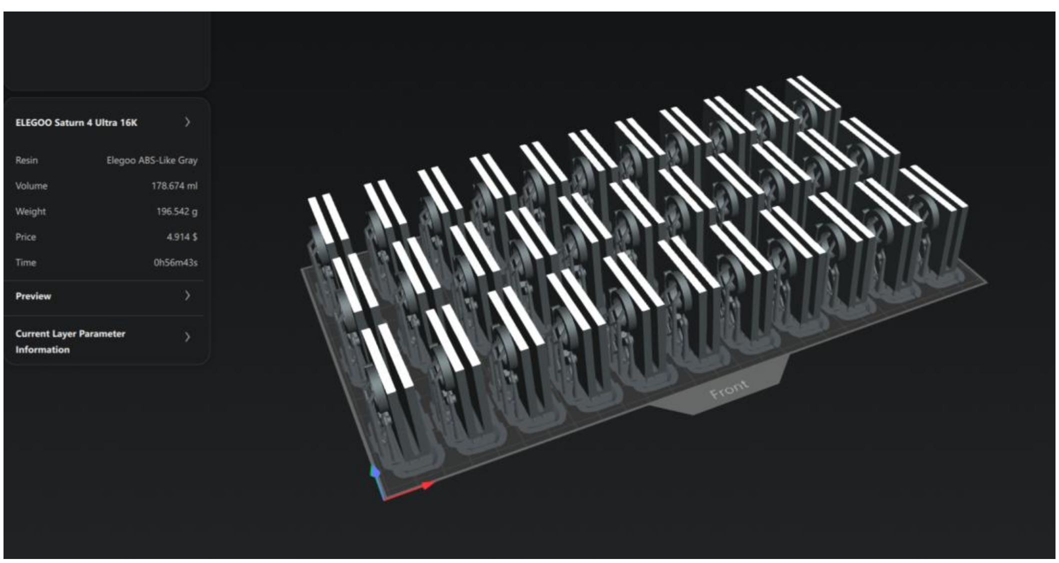

Figure 10: Max number (33) of Jordan’s Resin Components on Build Plate

Daven's Resin Component

The resin printed polymer component serves as a platform to provide extra support to the bottom of the various can sizes. This is achieved with a circular design that includes a design with The Decepticons logo and an extruded text naming the team and school. On the bottom of the design, there are two equally spaced clips to securely attach to the bottom of the metal bracket. The diameter of the polymer component is 0.2 inches less than the distance from each of the side walls to minimize horizonal movement of the part.

While the structural integrity of the bracket is not affected by the addition of the polymer component, it does add value in terms of ergonomics and marketability. Because the design adds a flat surface to the bottom of the bracket, there is more contact area and the ability for the can to fall out of either side of the base of the bracket is eliminated.

Based on the use of the ELEGOO Saturn 4 Ultra 16k and the size of its bed, 7 of the polymer components can be printed on one bed. At a volume of resin used being 149.25mL, the overall cost of a full bed comes out to $4.10 with a print time of just over 2 hours. The orientation and addition of a raft were chosen to maximize the number of parts on the bed while still having enough surface area to maintain adhesion.

The main advantages of switching from resin printing to injection molding are the significant decrease in time to produce on part as the ability to choose the specific material. Because number of layers printed is directly proportional to the time it takes to finish a print, the chosen orientation will take longer to finish, but output more finished polymer components. In addition, resin itself creates more brittle parts, which is an issue in terms of the clip on the underside of the component because it must slightly bend to attach to the bracket. The main con would also be the geometry of the clips being difficult to produce with standard die designs. In addition, there is a high upfront cost for the production of the die, so switching to injection molding should only be considered if there's a higher volume of brackets being made.

Figure 11: Loaded bracket with Polymer Component

Figure 12: Unloaded Bracket with Polymer Component

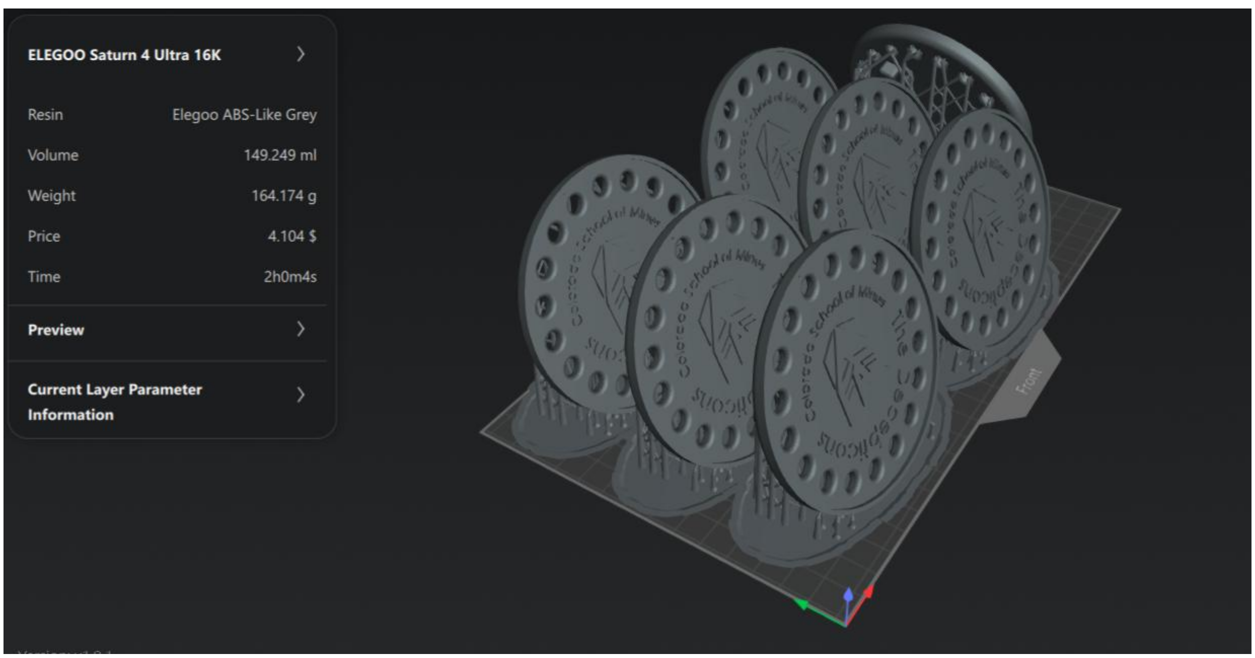

Figure 13: Max number (7) of Daven’s Resin Components on Build Plate

Reflection

Low Volume Production

Going from a singular prototype to a low-volume production run of 200 brackets, the design choices, fabrication sequence, and resource allocation need to be reevaluated to ensure consistent quality and efficiency to produce the required brackets within the confines of 3 months. Because the beta prototype validates geometry and strength, we will shift focus to reduce manual labor, standardize the bend operations, and optimize the welding process to minimize the cost per bracket produced.

For the next iteration of the design, we are planning to optimize the amount of material used for spot welds. In the bottom section of the bracket specifically, we currently have both brackets completely overlapping to create a double layer of metal. While this does add reinforcement to the part of our design under the most load, due to A36 steel's high yield strength, we believe we can save material by decreasing this area. We may still need to use two spot welds, but this decrease should help lower costs and mildly offset the cost of using two spot welds. A similar process can be performed on the overlap at the top of the bracket; however, the effects of this will be much more minimal.

Based on the time study conducted, the manual finishing and bending dominate the total fabrication process, however with the switch from hammer and chisel to the Hercules Surface Conditioning Tool, the cleaning should only take 5 minutes instead of 15-17 minutes. Setup time for each machine is incurred only once at the start of production rather than for every part, thus can be ignored. Overall, the total hand-on fabrication per bracket is about 17-20 minutes. For a production of 200 brackets, that equates to 57-67 hours of total labor. With the time constraint of 3 months or about 12 weeks, 5-6 hours of fabrication would be required per week, making this production extremely possible with little machinery. Specifically, the required equipment for such a small production would require one CNC Plasma Cutter, one Manual Finger Break, and one Spot Welder to complete the process.

High Volume Production

Scaling the bracket to a high-volume production run of 200,000 units would require a fundamental shift in both the design and the manufacturing approach. While the current fabrication process is effective for prototyping and low-volume production, the time study and costing analysis clearly show that manual operations dominate the total production time and cost. At this scale, efficiency, repeatability, and labor reduction become the primary drivers of design decisions.

One of the most significant changes would be to move away from flexible, low-cost fabrication methods toward processes better suited for repetition and consistency. Operations that were acceptable at low volume, such as extensive manual surface conditioning, manual bending, and operator-dependent welding, would become major bottlenecks when multiplied across hundreds of thousands of parts. The DFMA feedback highlighted surface finishing and bend identification as key inefficiencies, and these issues would be amplified at high volume. As a result, the design would be simplified to reduce the total number of forming operations and eliminate features that require post-processing.

Based on structural analysis, the bracket has excess strength beyond what is required for its functional loading. This margin could be leveraged to reduce material overlap, decrease the number of bends, and simplify joint geometry. These changes would not compromise structural performance but would significantly improve manufacturability and consistency. In high-volume production, small reductions in material usage and operation will translate to large cost savings across the full run.

Assembly methods would also be revised to minimize part handling and alignment steps. Rather than relying on manual joining, the design would favor repeatable joining strategies that ensure consistent quality with minimal operator input. This approach reduces variability while improving throughput and overall product reliability.

For the polymer components, additive manufacturing would no longer be viable at this scale. While resin printing was effective for prototyping and low-volume customization, high-volume production would require a transition to a more scalable manufacturing method like injection molding. This would drive additional design updates, such as more uniform wall thickness and simplified geometry, to ensure consistent quality and reduce per-part cost.

Overall, the transition to high-volume production would shift the focus from flexibility and ease of iteration to manufacturability, automation compatibility, and cost efficiency. The insights gained from the time study, DFMA feedback, and structural analysis directly inform these changes. By simplifying geometry, reducing manual labor, and standardizing processes, the bracket design becomes well-suited for mass production while maintaining the functionality and performance validated during prototyping.

Appendix:

A.1: Initial Designs

A.1.1: Arael's Initial Design

I believe that this bracket design optimizes a few key categories. First, the amount of material is very low compared to other brackets. Since the can is held in place from the side arms, the bottom and back supports can be minimal. This means that per piece this bracket could save as much as $1.30 on materials cost. Not only that, but compared to other brackets, this design minimizes the amount of plasma cutting. This is a very expensive process ($120 / hour), so this could potentially save the company 100's of dollars in fabrication. However, due to the nature of the design, there will be a longer bend time as both arms must be bent to their appropriate angles. The part of the design where the arms meet should also be welded together to properly support the can. Structurally the steel at the bottom should be strong enough to support even 2 pounds of force on it, with the arms helping to support that bottom piece. This bracket also provides a much nicer aesthetic than alternatives, creating a fun octagonal look that is a better design.

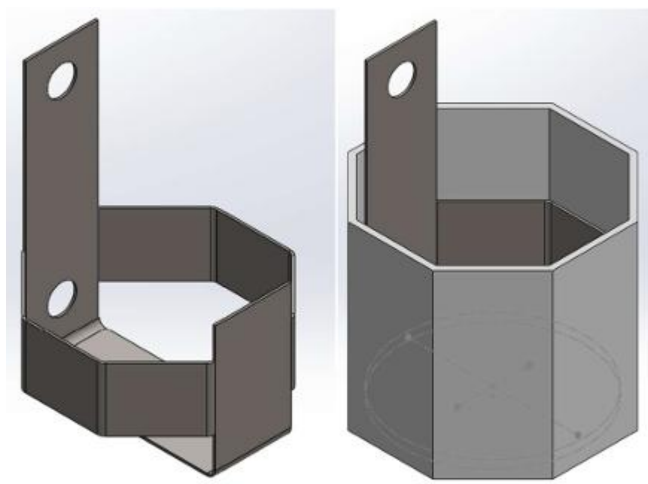

Figure A.1.1: Total Surface Area: 18.63 in^2. Total Weight: .19 lbs.

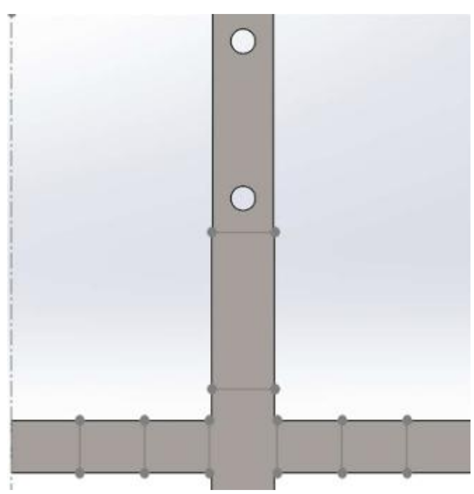

Figure A.1.2: Unbent Bracket

A.1.2: Jordan's Initial Design

This design would be very simple to manufacture, which would decrease costs. There would only need to be two bends after cutting the outline and the top hole of the holder, which would be extremely easy to manufacture and hard to mess up. Additionally, the bracket is minimalist which appeals to a certain demographic. It only uses 22.95 in^2 of area out of the 50 in^2 available. There is no welding which is unfortunate to our experience but decreasing cost and ease of manufacturing even more. Although the steel is thin, simulations have shown that there should not be much strain when even the heaviest can (~2lb) is placed on it.

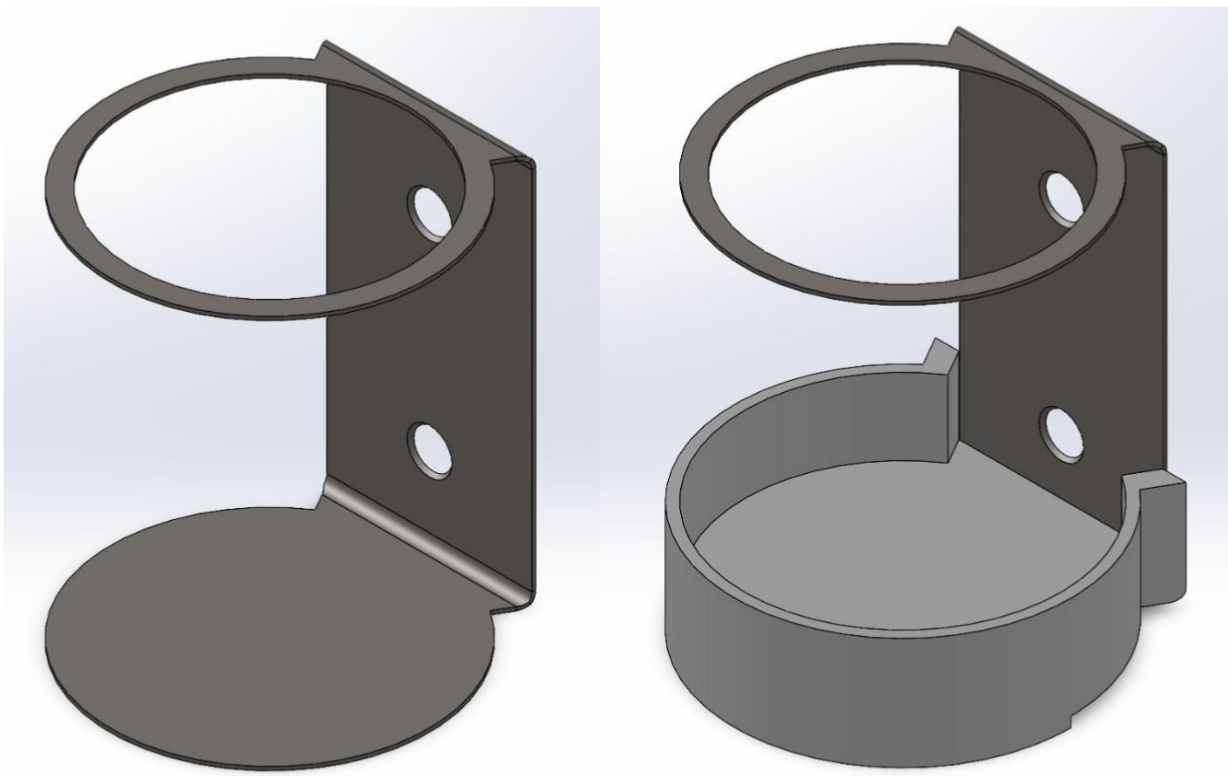

Figure A.1.2.1: One side surface area: 22.95 in^2. Total surface area is 46.79 in^2.

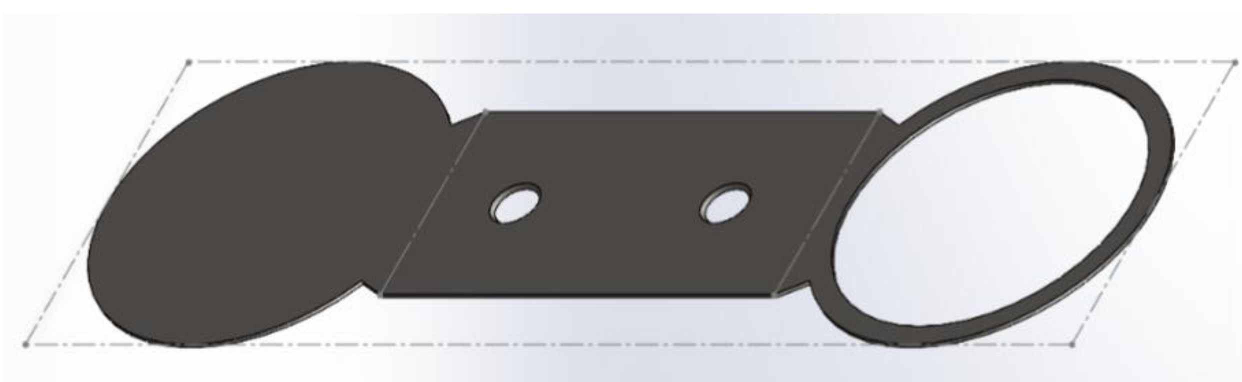

Figure A.1.2.2: Unbent Bracket

A.1.3: Daven's Initial Design

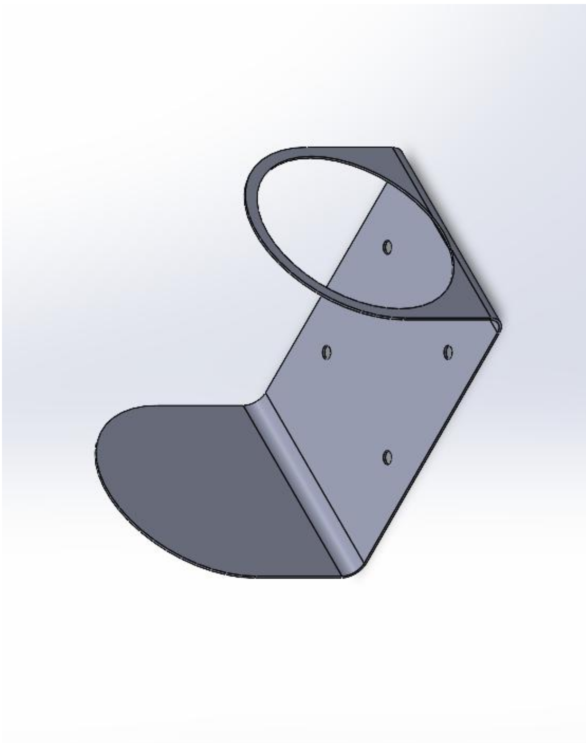

Figure A.1.3.1: One Side Surface Area: 34.36in^2

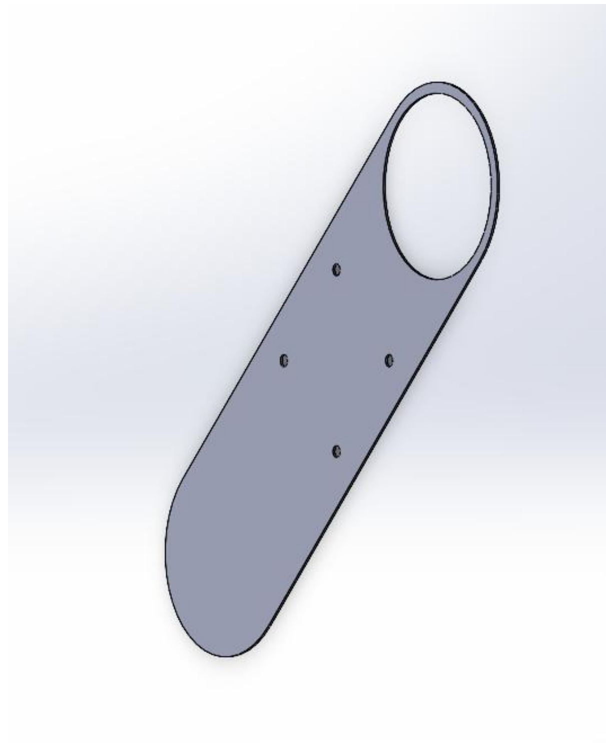

Figure A.1.3.2: Unbent Bracket Design Mass: 0.04lb

For this design, ease of manufacturing was most important. Specifically, a design was chosen that was the same on each side, specifically the two semi circles on each side with the one major cut out for the insertion of each can. With having the same design on each side, there are no unique shapes that needed to be cut, making the production of a lot of the holders easier. In addition, with the tolerances of can size in mind (12 ounce is 2.6in, 18 ounces at 2.6in, and 24 ounce at 2.87). Thus, the inner diameter was chosen at 2.9 inches in diameter so there is enough clearance.

A.2: Down Selection, ASA, and Market Analysis

A.2.1: Design Iterations

Figure A.2.1.1:
Weight: 0.28 lb.
Area: 27.16 in^2

Figure A.2.1.2:
Weight: 0.30 lb.
Area: 22.95 in^2

Figure A.2.1.3:
Weight: 0.28 lb.
Area: 27.72 in^2

	Bracket 1: Arael	**Bracket 2: Jordan**	**Bracket 3: Daven**
Pros	Way more interesting product	Minimal manufacturing (two bends and no spot welds)	Symmetrical Oval (less machining time)
	Material Efficiency	Basic Manufacturability	Top and Bottom Support for Every Can
	Minimal Waste	Simple Design	More support for Weight of the Can
	Low Weight	No Welding	Two Bends
	Offers multiple points of support for the can	Light Weight	Designed for Mass Manufacture
Cons	Less Structural Stability	Generic Design	Highest Surface Area
	More Bends	No time spent manufacturing	Too Much material
	Requires Welding	Too much material	Hole Locations Not Ideal for Application
	Higher Complexity	Bottom plate could deform easily	Generic Design
	More work	Harder to use	Bottom plate could deform easily

Table A.2.1.1: Pros and Cons of Individually Design Brackets.

A.2.2: Alternative Solutions Analysis

Solution Analysis

Statement of Purpose: Create an assessible cup holder for disabled users on wheelchairs or crutches

Evaluation Criteria	Required Criteria	Alternative 1: Bracket 1	Yes / No	Alternative 2: Bracket 2	Yes / No	Alternative 3: Bracket 3	Yes / No
R1	Less than 50 in^2	27.16	Yes	22.95 in^2	Yes	27.72 in^2	yes
R2	Can Sustain the weight of 28.75		Yes		No	the steel material will	yes
R3	Fits in budget		Yes		Yes	material cost 1.09$	yes
R4	Weight under 1lb	.28 lb	Yes	0.3 lb	Yes	0.28lb	yes
R5	Manufactiring time under 2 hr		Yes		Yes		yes

	Desired Criteria	Value	Information	Score	Weight Score	Information	Score	Weight Score	Information	Score	Weight Score
D1	Cost	4		1	4		9	36		9	36
D2	Ease of manufacturing	6		7	42		7	42		9	54
D3	Ease of taking can out	10		10	100		5	50		5	50
D4	Manufacturing time	5		5	25		8	40		7	35
D5	Surface Area	6		10	60		7	42		4	24
D6	Number of bends	4		5	20		8	32		10	40
	WEIGHTED TOTAL SCORES		251			242			239		

Table A.2.2.2: Alternative Solutions Analysis

Summary

The criteria selected are important to ensure that the bracket is affordable, easy to use, and functional for disabled users on wheelchairs or crutches. The total cost, including manufacturing and material used, is a very important criterion to keep our bracket from being too expensive for our main demographic. Additionally, taking the can out of the bracket is the most important criterion for us because it is invaluable to have our bracket be functional even for disabled users who may have limited mobility.

The Alternative Solution Analysis (ASA) table compares the proposed brackets against both required and desired design criteria to determine the most practical solution. All three brackets meet the required constraints, including staying under 50 in^2 of material, and weighing less than 1 lb.

When evaluating the desired criteria, the differences were more pronounced. Bracket 1 achieved the highest weighed score (291), being better in cost and surface area efficiency. Bracket 2 followed closely with 279 points, showing advantages in ease of manufacturing, and efficiency of the bends. Bracket 3, while very similar to bracket 2, finished with the lowest score due to weaker costs and surface area results.

Taking the ASA into account, bracket 1 appears to provide the best balance between affordability, usability, and material efficiency. However, its manufacturability is still a potential issue and should be addressed in future iterations of the design.

A.3: Technical Summary

A.3.1: Structural Analysis

To evaluate the performance of our finalized bracket design, a Finite Element Analysis (FEA) was conducted in SolidWorks Simulation under vertical loading to replicate the forces experienced when supporting a full beverage container. The bracket was made of A36 Steel, with a Youngs Modulus of 29,000 ksi. The bracket was constrained along the edge of the mounting holes, to simulate the screws, attaching the bracket to the crutch. Spot weld connections were placed at relevant locations to emulate real bracket welding. Additionally, a contact connection was applied to the entire assembly. A distributed load of 2 lbf. was applied along the bottom segment to emulate the can's force.

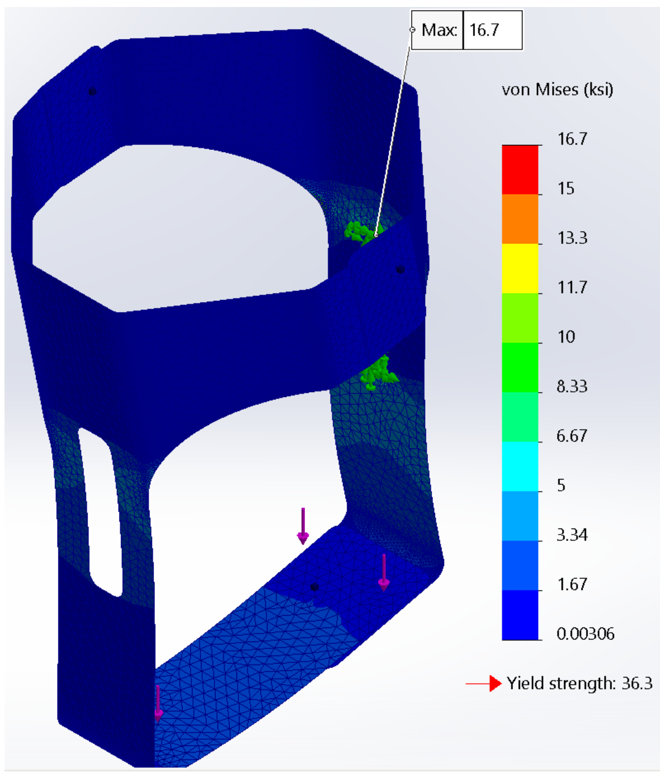

Figure A.3.1.1: Von Mises Plot

A curvature-based mesh was generated with a global element size of 0.097 in. and local mesh refinement of 0.025 in. near the bends and mounting holes to accurately capture the stress gradients (Figure A.3.1.3). The resulting von Mises stress plot (Figure A.3.1.1) shows the highest concentrated stress around the bracket arms, with a maximum value of 16.7 ksi. The value remains below the steel yield strength of 36.3 ksi, confirming the bracket can safely sustain the applied load without yielding.

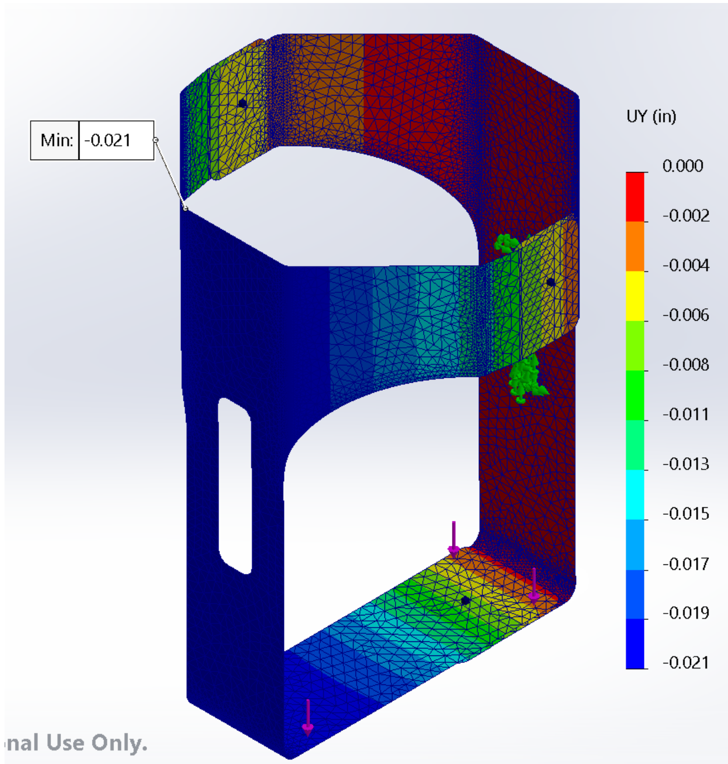

Figure A.3.1.2: Displacement Plot

The vertical displacement plot (Figure A.3.1.2) indicated a maximum compressive deflection of 0.021 in., occurring near the bottom region of the bracket. However, this displacement is negligible when compared to the bracket's overall dimensions, ensuring the part maintains sufficient rigidity under loading. The minimum Factor of Safety (Figure A.3.1.4) for this configuration was found to be around 2.13, satisfying the required safety margin for vertical loads.

Overall, this analysis demonstrates that the bracket meets both the strength and stiffness requirements for the vertical loading case. Additional FEA studies, including horizontal loading and Factor of Safety, are included in the appendix for further verification of the design's viability.

A.3.1.1: Additional FEA Plots

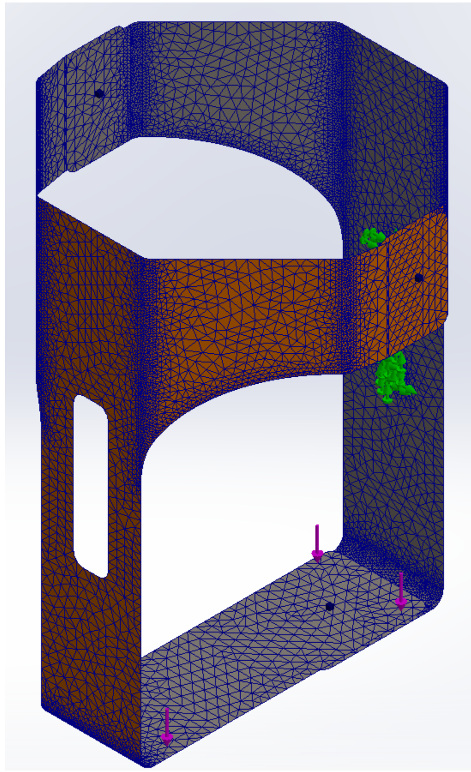

Figure A.3.1.3: Mesh Plot

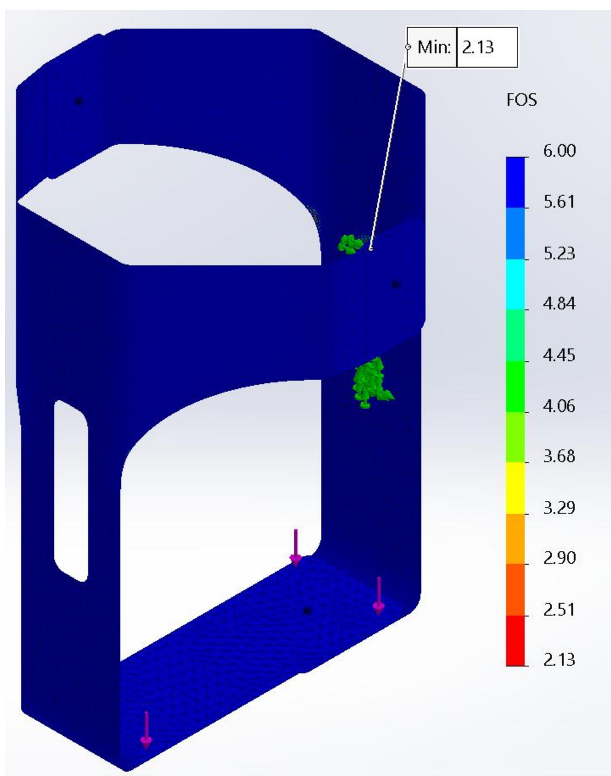

Figure A.3.1.4: Factor of Safety (FOS) Plot

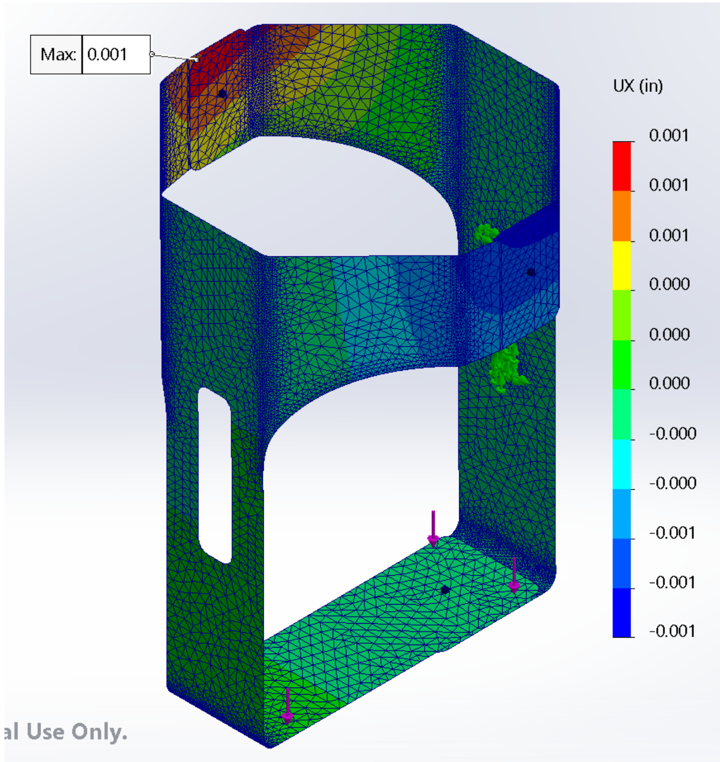

Figure A A.3.1.5: Ux Displacement Plot (In)

Material	**Max. von Mises (ksi)**	**Min. FoS**	**Vert. Displacement (in)**
A36 Steel	16.7	2.13	-0.021

Table A.3.1.1: FEA of Finalized Bracket

A.3.2: Mounted Cardstock Bracket

Figure A.3.2.1: Mounted Cardstock Bracket

A.4: Manufacturing Process Flow

This bracket was manufactured using 23.36 in^2 of 0.036-inch A36 steel sheet. The flat pattern was CNC plasma cut using a 40 Amp plasma torch equipped with a fine-cut nozzle, operating at a cut speed of 325 in/min (PowerMax45XP with kerf Width at page 7) torch-to-work distance of 0.06 in. After cutting, burrs and dross were removed from the edges to ensure smooth bending surfaces. The bracket was then placed on a finger brake, and bending operations were performed in sequence. After bending, the arms were resistive spot welded together with the overlapping material that is present. A hot-dipped galvanized zinc coating was applied to the finished bracket to prevent corrosion and enhance durability during use. (Detailed step-by-step bending instructions, graphics, and welding locations are provided in Appendix AII).

A.4.1: Costing Breakdown

	Material	**Plasma Cutting**	**Bending**	**Welding**	**Misc. Manual Operations**	**Finishing (Coating)**
Cost ($)	$0.93	$0.25	$8.00	$1.60	N/A	$0.31
Total Cost ($)	$11.09					

Table A.4.1.1. Costing Breakdown

A.5: Alpha Design Prototype

Video

https://www.youtube.com/shorts/xkKEk1F6tH0

A.5.1: Time study results

Front Step	Time spent (s) (ignoring setup time)
1	20s
2	20s
3	25s
4	25s
5	30s
6	30s
7	30s
Front Total	180 seconds or 3 minutes
Back Step	Time spent (s) (ignoring setup time)
1	30s
2	30s
3	30s
4	30s
5	30s
Back Total	150 seconds or 2.5 minutes

Table A.5.1.1: Time Study

A.5.2: Cost Breakdown

	Material	**Plasma Cutting**	**Bending**	**Welding**	**Finishing (Coating)**
Quantity	25.17 in^2	Cut length= 50.13 in & Cut speed= 325 in/min	5.5 minutes	4 welds	Total surface area= 52.145 in^2
Cost per Quantity	$0.04 per in^2	$120/hr	$40/hr	$0.4 each	$1.1 per ft^2
Cost ($)	$1.01	$0.31	$3.67	$1.60	$0.40
Total Cost ($)	$6.99				

Table A.5.5.2: Cost Breakdown

A.5.3: Alpha prototype revisions discussion

For the next iteration of the design, we are planning to optimize the amount of material used for spot welds. In the bottom section of the bracket specifically, we currently have both brackets completely overlapping to create a double layer of metal. While this does add reinforcement to the part of our design under the most load, due to A36 steels high yield strength, we believe we can save material by decreasing this area. We may still need to use two spot welds, but this decrease should help lower cost and mildly offset the cost of using two spot welds. A similar process can be performed on the overlap at the top of the bracket; however, the effects of this will be much more minimal.

We will also increase the tolerancing of the holes to account for deformations caused by the plasma cutter. We did not expect the holes to present an issue; however, after cutting the sheet we can see mild deformations in the mounting holes, making them slightly more elliptical than expected. While not a crucial fix, a slightly larger diameter will ensure the screws will always fit regardless of inaccuracies in the cutting process.

A.5.4: Alpha Work Instructions

This bracket was manufactured using 25.17 in² of 0.036-inch A36 steel sheet. The flat pattern was cut using a CNC plasma cutter using a 40 Amp plasma torch equipped with a fine-cut nozzle, operating at a cut speed of 325 in/min (PowerMax45XP with kerf Width at page 7) with a torch-to-work distance of 0.06 in. The CNC Motion System is a Langmuir Crossfire Pro CNC Plasma Table with THC, which automatically maintains the proper torch height throughout the cut to ensure consistent kerf width, cut quality, and penetration across the entire part.

Material Thickness	Current	Torch-to-Work Distance	Initial Pierce Height		Pierce Delay Time	Best Quality Settings		Kerf Width
						Cut Speed	Voltage	
inches	A	inches	inches	%	seconds	in/min	volts	inches
26 GA	40				0.0	325	78	0.025
24 GA						325	78	0.029
22 GA					0.1	325	78	0.024
20 GA						325	78	0.020
18 GA		0.06	0.15	250	0.2	325	78	0.043

Table A.5.5.3: CNC Plasma Cutter settings

After cutting, the dross was removed from the edges using a hammer and chisel. Then, to ensure smooth bending surfaces, the edges are filed using files. Then all the bending locations, which include both start and end locations of the bend radius, are marked on the bracket.

The bracket was then placed on either the big green finger brake or a smaller blue finger brake with a finger distance at the appropriate OSSB for each bend. All the bends ended with a bend radius of 0.1 inches. For simplified finger brake settings, refer to Table 4 Front Bracket Section **(Locations: Figure 4 & Photos: Figure A1-A14)**: The first bend made was on the outside of the front section of the bracket with an OSSB of 0.0119 in and an initial angle of 10.09 degrees which ends with 10 degrees final. The second bend is on the opposite arm of the bracket with the same initial and final angles. The third and fourth bends both had an initial bend angle of 35.31 and OSSB of 0.04228 in which resulted in a final 35 degrees on the arms that had already been bent. The fifth and sixth bends are closest to the main body and have an initial angle of 45.39 degrees and OSSB of 0.05633 in which results in a 45-degree bend. The final bend is the main body bend that has an initial angle of 90.79 degrees and OSSB of 0.136 in which results in 90 degrees. For detailed location information and simple bend sequence breakdown, refer to Figure 4. For detailed photos illustrating the process, refer to Figure A1-A14.

Back Bracket Section **(Locations: Figure 5 & Photos: Figure A15-A24)**: The first and second bends on the back bracket section are the outermost bends on the arms with both the bends having an initial bend angle of 45.39 and OSSB of 0.05633 resulting in final angles of 45 degrees. The third and fourth bends are on the same arms but closer to the main body with both bends having the same finger break settings and ending at 45 degrees. The final bend is the main body bend that has an initial angle of 90.79 degrees and OSSB of 0.136 in which results in 90 degrees. For detailed location information and simple bend sequence breakdown, refer to Figure 5. For detailed photos illustrating the process, refer to Figure A15-A24.

Final Bend Angle	Initial Bend Angle	Finger Brake Setup Distance (OSSB)
10 degrees	10.09 degrees	0.0119 in
35 degrees	35.31 degrees	0.0423 in
45 degrees	45.39 degrees	0.0563 in
90 degrees	90.79 degrees	0.136 in

Table A.5.5.4: Bending Angles and Finger Brake Setup Distance

After bending, the bracket was spot welded using a Tecna 7902P scissor-type portable spot welder operating at a power rating of 2.5 kVA (50% duty cycle). The welder is powered by a single-phase AC supply and equipped with standard 125 mm arms and copper electrodes. During welding, a welding time of 15 cycles (approximately 1 second) was used, applying sufficient electrode force to ensure proper fusion between the 0.036-inch A36 steel sheets. To utilize the Tecna 7902P, you must go to the machine shop in Brown Hall West Room W130 with adequate PPE. Then you must put on a welding apron and welding gloves, then enter the room with the spot welder, plug it in, and position the bracket.

Weld Locations (A25-A27): The front section of the bracket was stacked on top of the back section of the bracket, and then the bottom of the bracket was spot welded together with the overlapping material (detailed location in Figure 5). Then the front bracket arms were wrapped around the back bracket arms, and then the arms were spot welded together (detailed location in Figure 4).

After the spot welding, a hot-dipped theoretical galvanized zinc coating was applied to the finished bracket to prevent corrosion and enhance durability during use.

A.6: Final Bracket

A.6.1: Final Cost Calculations

$$Perimeter := 46.795\ in \qquad ResinWeight := \frac{5.956}{1000}\ kg$$
$$Area := 23.42\ in^2$$
$$SurfaceArea := 41.278\ in^2 \quad ResinTime := 56.72\ min \qquad CuttingSpeed := 325\ \frac{in}{min}$$

$$PlasmaCut := \frac{Perimeter}{CuttingSpeed} \cdot 2\ \frac{\$}{min} = 0.288$$
$$SheetMetal := Area \cdot 0.04\ \frac{\$}{in^2} = 0.937$$
$$Labor := 25\ min \cdot \frac{40}{60}\ \frac{\$}{min} = 16.667$$
$$Welding := 3\ weld \cdot 0.4\ \frac{\$}{weld} = 1.2$$
$$Coating := SurfaceArea \cdot 1.1\ \frac{\$}{ft^2} = 0.315$$
$$Resin := ResinWeight \cdot 25\ \frac{\$}{kg} + ResinTime \cdot \frac{\$}{hr} + 5 = 6.094$$

$$TotalMachining := PlasmaCut + Welding = 1.488$$
$$TotalMaterialCost := SheetMetal + Resin = 7.031$$
$$TotalLabor := Labor = 16.667$$
$$TotalCoating := Coating = 0.315$$

$$TotalBracket := PlasmaCut + SheetMetal + Labor + Welding + Coating + Resin = 25.501$$

Figure A.6.1.1: Final Cost Calculations

To determine the final cost of the bracket, the perimeter, area, and surface area were evaluated on the SolidWorks model. Then the cost of plasma cutting, A36 sheet metal material, and coating were evaluated using the computed areas and perimeter. Additionally, there were 3 welds which simply resulted in a fixed price.

The labor cost was calculated by estimating that bending and conditioning would take about 25 minutes because that is the average between the estimated time that our team took to manufacture the bracket and how long it took the other team to manufacture the bracket.

For the resin component, we used Jordan's resin component because it was the smallest and cheapest component to print.

A.6.2: Final Work Instructions

This bracket was manufactured using 23.42 in² of 0.036-inch A36 steel sheet. The flat pattern was cut using a CNC plasma cutter using a 40 Amp plasma torch equipped with a fine-cut nozzle, operating at a cut speed of 325 in/min (PowerMax45XP with kerf Width at page 7) with a torch-to-work distance of 0.06 in. The CNC Motion System is a Langmuir Crossfire Pro CNC Plasma Table with THC, which automatically maintains the proper torch height throughout the cut to ensure consistent kerf width, cut quality, and penetration across the entire part.

Material Thickness	Current	Torch-to-Work Distance	Initial Pierce Height		Pierce Delay Time	Best Quality Settings		Kerf Width
						Cut Speed	Voltage	
inches	A	inches	inches	%	seconds	in/min	volts	inches
26 GA					0.0	325	78	0.025
24 GA	40					325	78	0.029
22 GA					0.1	325	78	0.024
20 GA						325	78	0.020
18 GA		0.06	0.15	250	0.2	325	78	0.043

Table A.6.2.1: CNC Plasma Cutter settings

After cutting, big pieces of dross were removed from the edges using a hammer and chisel. Then, to ensure smooth bending surfaces, the conditioning tool is used on both sides of each part of the bracket. It is recommended that those performing these tasks wear some sort of respiratory protection on top of the shop's required hearing protection and eye protection due to the metal dust put into the air during conditioning. To use the conditioning tool, place the bracket on the magnetic vice and turn the handle clockwise to lock the bracket in. Then once the bracket has been given a few passes with the conditioning tool on each side, the bracket should be deburred with a normal file in the shop.

The bracket was then placed on either the big green finger brake or a smaller blue finger brake with a finger distance at the appropriate OSSB for each bend. All the bends ended with a bend radius of 0.1 inches. For simplified finger brake settings, refer to Table W2.

Front Bracket Section **(Locations: Figure W1 & Photos: Figure A1-A14)**: The first bend made was on the outside of the front section of the bracket with an OSSB of 0.0119 in and an initial angle of 10.09 degrees which ends with 10 degrees final. The second bend is on the opposite arm of the bracket with the same initial and final angles. The third and fourth bends both had an initial bend angle of 35.31 and OSSB of 0.04228 in which resulted in a final 35 degrees on the arms that had already been bent. The fifth and sixth bends are closest to the main body and have an initial angle of 45.39 degrees and OSSB of 0.05633 in which results in a 45-degree bend. The final bend is the main body bend that has an initial angle of 90.79 degrees and OSSB of 0.136 in which results in 90 degrees. For detailed location information, refer to Figure W2. For detailed photos illustrating the process, refer to Figure A1-A14.

Back Bracket Section **(Locations: Figure W2 & Photos: Figure A15-A24)**: The first and second bends on the back bracket section are the outermost bends on the arms with both the bends having an initial bend angle of 45.39 and OSSB of 0.05633 resulting in final angles of 45 degrees. The third and fourth bends are on the same arms but closer to the main body with both bends having the same finger break settings and ending at 45 degrees. The final bend is the main body bend that has an initial angle of 90.79 degrees and OSSB of 0.136 in which results in 90 degrees. For detailed location information, refer to Figure W3. For detailed photos illustrating the process, refer to Figure A15-A24.

Final Bend Angle	Initial Bend Angle	Finger Brake Setup Distance (OSSB)
10 degrees	10.09 degrees	0.0119 in
35 degrees	35.31 degrees	0.0423 in
45 degrees	45.39 degrees	0.0563 in
90 degrees	90.79 degrees	0.136 in

Table A.6.2.2: Bending Angles and Finger Brake Setup Distance

After bending, the bracket was spot welded using a Tecna 7902P scissor-type portable spot welder operating at a power rating of 2.5 kVA (50% duty cycle). The welder is powered by a single-phase AC supply and equipped with standard 125 mm arms and copper electrodes. During welding, a welding time of 15 cycles (approximately 1 second) was used, applying sufficient electrode force to ensure proper fusion between the 0.036-inch A36 steel sheets. To utilize the Tecna 7902P, you must go to the machine shop in Brown Hall West Room W130 with adequate PPE. Then you must put on a welding apron and welding gloves, then enter the room with the spot welder, plug it in, and position the bracket.

Weld Locations (A25-A27): The front section of the bracket was stacked on top of the back section of the bracket, and then the bottom of the bracket was spot welded together with the overlapping material (detailed location in Figure W3). Then the front bracket arms were wrapped around the back bracket arms, and then the arms were spot welded together (detailed location in Figure W2).

After the spot welding, a hot-dipped theoretical galvanized zinc coating was applied to the finished bracket to prevent corrosion and enhance durability during use.

A.6.3: Bracket Drawings

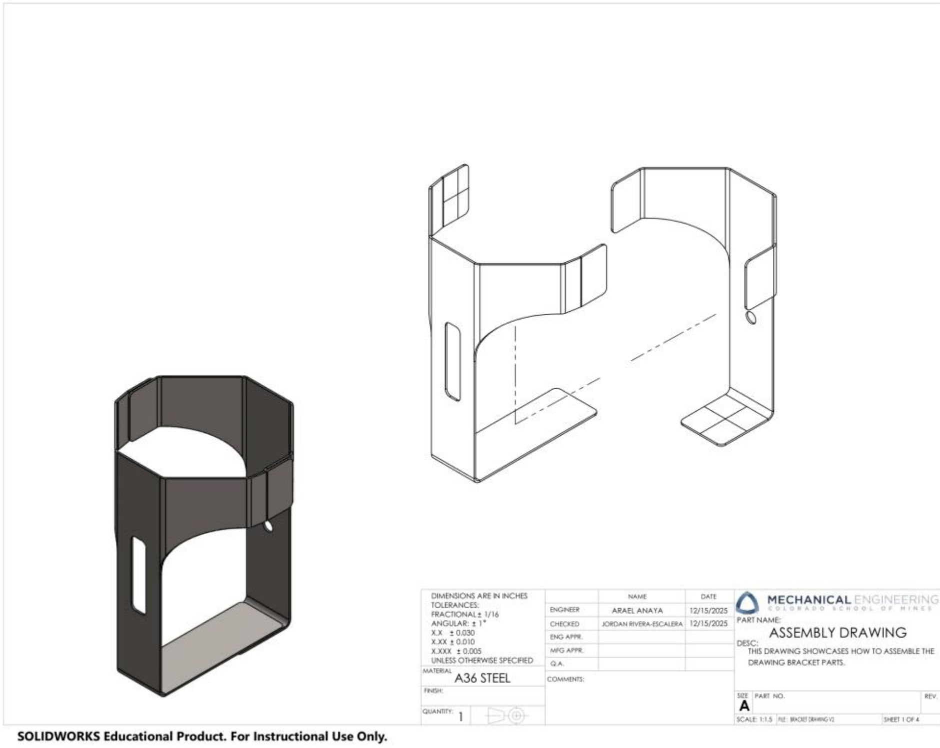

Figure A.6.3.1: [Bracket Assembly Drawing]

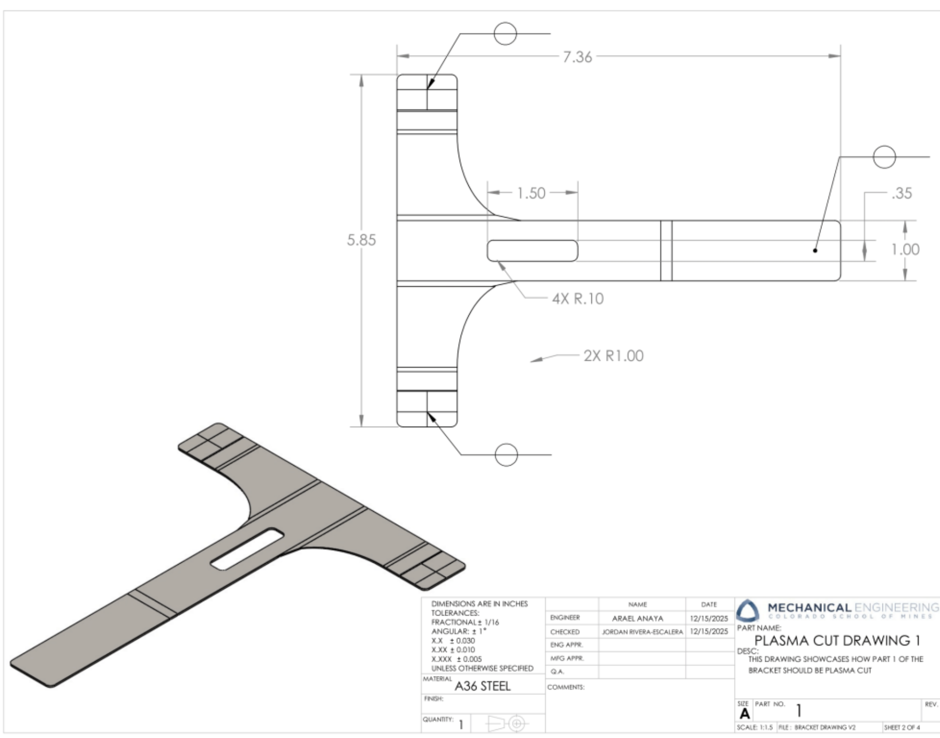

Figure A.6.3.2: Part 1 Plasma Cut Drawing

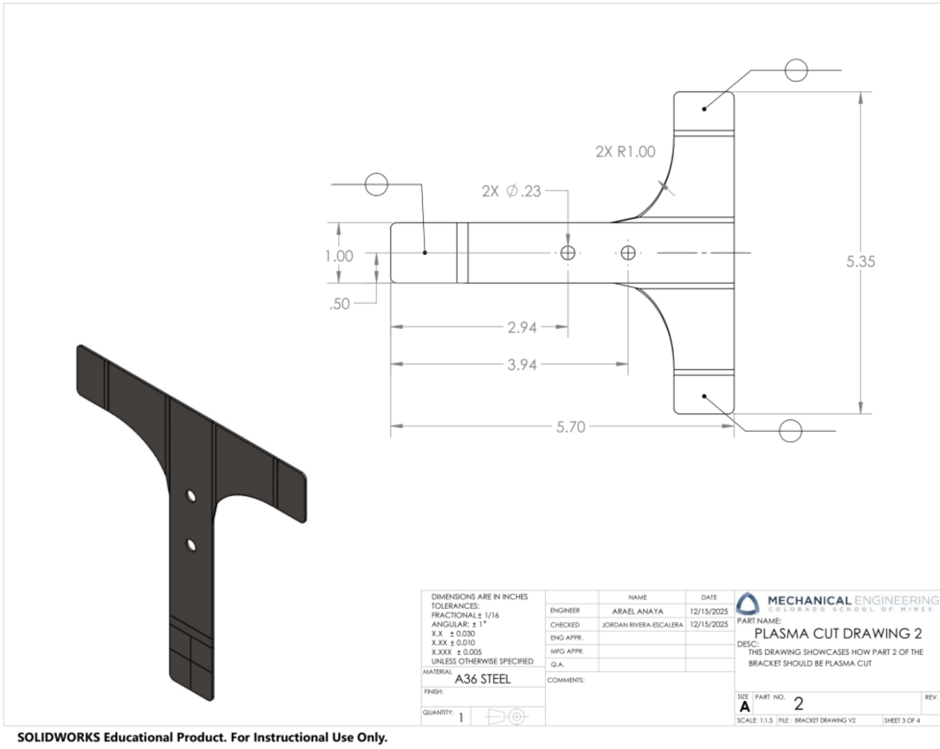

Figure A.6.3.3: Part 2 Plasma Cut Drawing

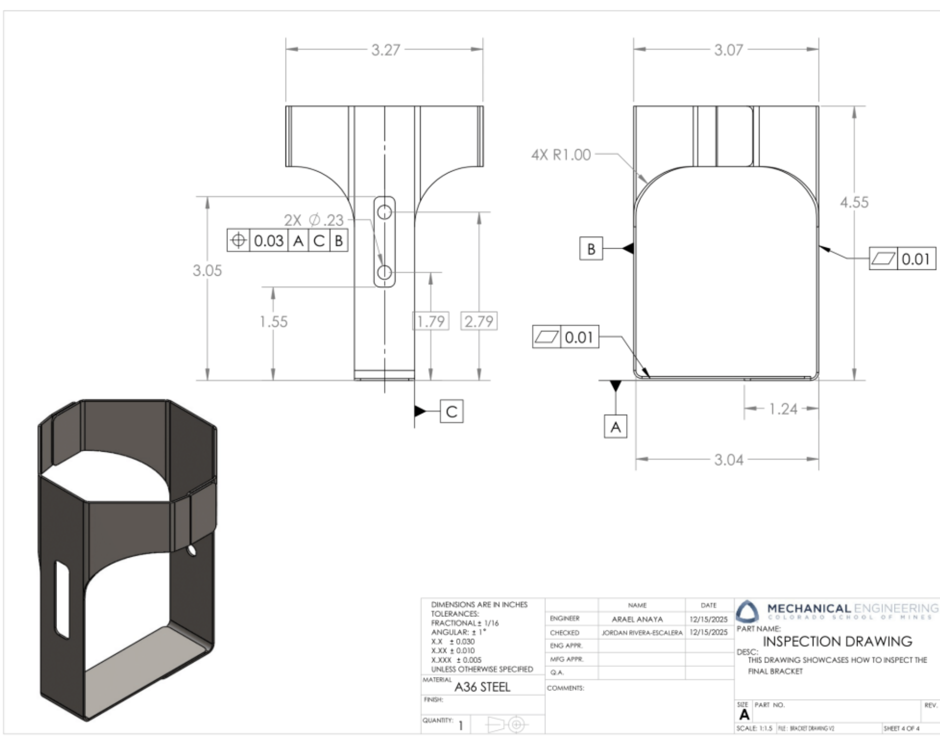

Figure A.6.3.4: Inspection Drawing

A.6.4: Bending Step Photos

A.6.4.1: Front Steps

Figure A.6.4.1.1: Front Step 1 Before and Initial Markings

Figure A.6.4.1.2: Front Step 1 After

Figure A.6.4.1.3: Front Step 2 Before


Figure A.6.4.1.4: Front Step 2 After

Figure A.6.4.1.5: Front Step 3 Before

Figure A.6.4.1.6: Front Step 3 After

Figure A.6.4.1.7: Front Step 4 Before

Figure A.6.4.1.8: Front Step 4 After


Figure A.6.4.1.9: Front Step 5 Before


Figure A.6.4.1.10: Front Step 5 After

Figure A.6.4.1.11: Front Step 6 Before

Figure A.6.4.1.12: Front Step 6 After


Figure A.6.4.1.13: Front Step 7 Before

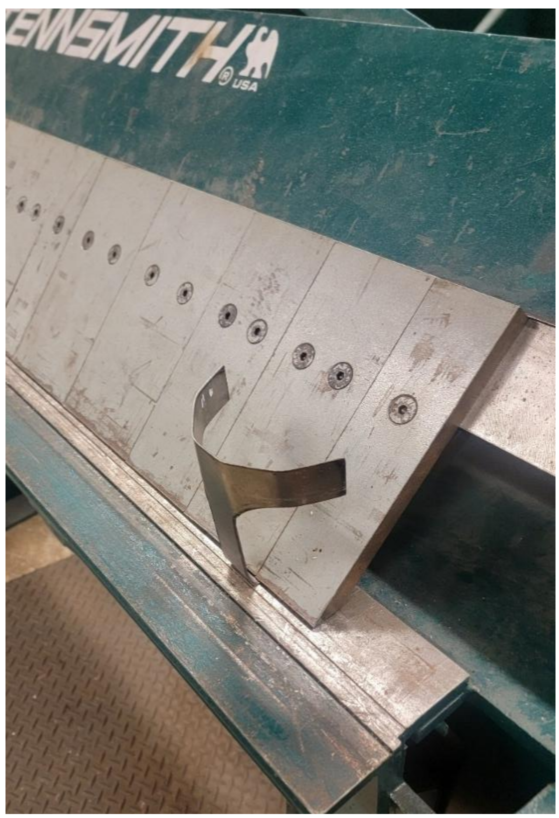

Figure A.6.4.1.14: Front Step 7 After

A.6.4.2: Back Steps

Figure A.6.4.2.1: Back Step 1 Before and Initial Marking

Figure A.6.4.2.2: Back Step 1 After

Figure A.6.4.2.3: Back Step 2 Before

Figure A.6.4.2.4: Back Step 2 After

Figure A.6.4.2.5: Back Step 3 Before

Figure A.6.4.2.6: Back Step 3 After

Figure A.6.4.2.7: Back Step 4 Before

Figure A.6.4.2.8: Back Step 4 After

Figure A.6.4.2.9: Back Step 5 Before

Figure A.6.4.2.10: Back Step 5 After

A.6.4.3: Weld Locations

Figure A.6.4.3.1: Bottom Weld Locations

Figure A.6.4.3.2: Arm Weld Location 1


Figure A.6.4.3.3: Arm Weld Location 2

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