# BOEING CANADA WINNIPEG

## UNIVERSITY OF MANITOBA

## MECH 4860 – ENGINEERING DESIGN

## DREAM-AERO – Group 14

## *PHASE III – Final Design*

# Novel Methods of Maneuvering Large Tools for Composite Processing


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## Executive Summary

Boeing Canada Winnipeg (BCW) is currently facing an issue regarding their current process for maneuvering their large shaping tools used for assembling composite components. These composite parts are constructed using a hand layup method which involves manually laying sheets of carbon-fiber cloth, adhesive, and honeycomb panels on shaping tools.

BCW's present strategy for moving the LMs and BAJs through their plant is troublesome, risky, and tedious. While operators can move the devices with a forklift, maintaining control over the tool while turning is difficult. Furthermore, since there is nothing affixing the tool to the forklift, it could potentially slip off, harming equipment and employees. When the tool is at the autoclave station, the need to remove and reinstall its casters utilizes significant time and assets. The result of these deficiencies is an unsafe work environment and a decrease in the efficiency of the plant.

Upon initiation of this project, the client requested that the team come up with 2 top concepts, one being an original design (make solution) and the other being an off the shelf product (buy solution). These top two designs would then be compared using a make/buy analysis and the better of the two option would be further investigated. After researching possible solutions, the team generated and analyzed 10 original design concepts and 3 “off the shelf” concepts. The U-shaped scissor lift platform concept was chosen to be the top original design and a motorized pallet jack created by Combi-Lift was deemed to be the top “off the shelf” design. The team continued with the original design (make solution) and drafted a detailed cost report and implementation for that product.

The final designed product, which Dream-Aero calls “The U-Cart”, consists of a steel frame, dual wheel casters, a motorized lifting mechanism, and forklift locking mechanism. The U-Cart will be driven by a forklift and will safely lift and maneuver BCW’s large shaping tools between different areas of the facility. The U-Carts tapered design will also allow for the cure cart to be easily lined up under the shaping tool, where the large tools will then be lowered to be sent into the autoclave ovens. The U-Cart will have an estimated cost of $7,430.55 CAD to manufacture and assemble. The U-Cart meets all the client’s needs and target specifications and will increase the safety and efficiency of BCW’s current overall tool maneuvering process.

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# 1 Introduction

Team Dream-Aero, a student design group for the class MECH 4860 at the University of Manitoba, has been selected to work with Boeing Canada Winnipeg to solve an engineering problem at the company's facility. This section provides a background for the project and explains the problem that Dream-Aero will solve. In addition, the team defines the project's objectives and deliverables, and lists the target specifications that Boeing has established for the solution.

## 1.1 Company and Process Background

Boeing is an aerospace company that manufactures commercial airliners, military aircraft, weapons systems, and satellites. Boeing Canada Winnipeg (BCW) is the largest detachments of Boeing in Canada, employing 1600 people in a 800,000 square foot facility [1]. BCW produces a range of composite parts for its commercial aircraft, including landing gear doors and various fairings for Boeing's aircraft.

These composite parts are constructed using a hand-layup method in which sheets of carbon-fiber cloth, adhesive, and honeycomb panels are layered on shaping tools to create sandwich-panels. Two types of shaping tools are used: layup mandrels (LM) and bond assembly jigs (BAJ). The LMs and BAJs are similar in purpose and appearance. An example of an LM is shown below in Figure 1. The composite sandwich-panels are vacuum sealed against the tool and placed in an autoclave for curing, after which the composite is peeled away from the tool and the process begins again. In this way, BCW builds strong yet lightweight parts with complex curvatures.

Figure 1: A Layup Mandrel (LM), used with permission [2]

BCW employs many sizes of LMs and BAJs, sixteen of which are large and heavy, making them difficult to move and control. These tools weigh between 9000 and 12000 lbs. and have dimensions up to 15 ft by 10 ft by 8 ft. These tools are too heavy and cumbersome to be lifted properly by the facility's forklifts, which causes difficulty when moving the tools through the factory. Rather than lifting the tools entirely, technicians are forced to precariously lift one side of the tool with a forklift while the opposite end rolls on casters. The plant has a smooth concrete floor that allows the tools to roll smoothly, though it is uneven in some places, so each tool is equipped with five casters to ensure it is properly supported.

Once the hand layup process is complete, the tool is moved approximately 100 m to an autoclave preparation area. Technicians then remove the tool's casters, as they cannot withstand the heat of the autoclave. To remove the casters, technicians move the tool until it is directly above an autoclave curing cart. They then lift one side of the tool and remove the casters on that side. Resting the side now without casters on the curing cart, the technicians repeat the process on the opposite side. With the entire tool now resting on the curing cart, the apparatus is rolled into the autoclave.

To protect the autoclave, an expensive piece of equipment, it is imperative for the tools to be carefully maneuvered within it. The curing cart is on rails to ensure the tool is moved in a controlled fashion. The autoclave is large enough to fit three tools, so technicians perform the above steps for three tools and cure them simultaneously for efficiency. Once the curing process is complete, the casters are reinstalled onto the tools and they are pushed by forklift approximately 25 m to a debag/storage area. Here, the vacuum seal is removed, and the composite panel is separated from the tool and stored.

Finally, the tool is moved approximately 100 m by forklift to its starting location and the process begins again. While using a forklift and casters to transport the tool has worked for BCW, it is a flawed solution.

## 1.2 Problem Statement

BCWs method of moving the LMs and BAJs, described in Section 1.1, is difficult, inefficient, and dangerous. While technicians are able move the tools with a forklift, maintaining control over the tool while turning is a challenge. Additionally, since the tool is not properly restrained by the forklift, it may slip off and continue moving freely, potentially injuring personnel and damaging equipment. Once the tool is at the autoclave station, the need to remove and reinstall its casters uses valuable time and resources. Since the forklifts, autoclaves, and technicians are assets shared throughout plant, the time spent on the casters hinders other processes as well. The result of this method is an unsafe work environment and a decrease in the efficiency of the plant.

## 1.3 Project Objectives and Scope

This project will provide BCW with a safe, user friendly, and time-efficient method of transporting the LMs and BAJs through their facility, as well as in and out of autoclaves. Dream-Aero will investigate existing commercial equipment in addition to generating original design solutions. The team will then perform a make/buy analysis to determine if the optimal solution is an off-the-shelf product or an original design. Additionally, Dream-Aero will draft a cost analysis for implementing the required number of units of the final product. With the make/buy analysis and cost analysis, BCW will have the required information to decide how to proceed in solving their problem.

The scope of the project is centered on the make/buy analysis and the cost analysis. BCW has not set a budget for the project and simply wishes the solution to be as inexpensive as possible while still addressing all aspects of their problem. Dream-Aero will probe the effectiveness and cost of commercially available solutions and of an original design. The commercial solution will be a product which can be implemented immediately and requires little or no additional design work. The original solution is one devised by Dream-Aero and could be an existing product that the team has extensively modified, an entirely original solution, or a primarily original solution that incorporates off-the-shelf components. Dream-Aero will use decision matrices to determine the best procured solution and the best original solution. The cost analysis will account for the overall cost of each solution as well as any costs associated with implementation and maintenance.

If the make/buy analysis indicates the original solution is superior, Dream-Aero will provide BCW with FEA, and CAD drawings as necessary to prove that the solution is safe and viable. If the make/buy analysis indicates the original solution is superior, Dream-Aero will provide BCW with FEA and CAD drawings as necessary to prove that the solution is safe and viable. If the procured solution is determined to be the best solution, the team will deliver information on the manufacturing company and how to procure and implement the product.

## 1.4 Target Specifications

The technical specifications for the solution are listed in TABLE I. The solution submitted to BCW will meet all marginal values and will meet as many ideal values as possible.

TABLE I: BCW'S TARGET SPECIFICATIONS FOR THE FINAL DESIGN

| | Design Requirements | Units | Marginal Values | Ideal Values |
|---|---|---|---|---|
| **1** | Weight withstanding ability of the design. | Pounds | 12,000 | >12,000 |
| **2** | Speed control of the design. | Kilometer per hour | 2.5 | 2 - 2.5 |
| **3** | Lifted height. | Inches | 16 | 20 |
| **4** | Noise limit during transportation. | Decibel | 70 | ≤ 60 |
| **5** | Total time required to prepare the tools for the autoclave. | Minutes | 145.5 min per load (3 tools) | 79.5 min per load (3 tools) |
| **6** | Size of the tools that need to be transported. | Cubic feet | 15 x 10 x 8 | > 15 x 10 x 8 |
| **7** | Solution is safe to operate. | Subjective | Safe | Safe Yes |
| **8** | Factor of safety. | - | 1.5 | > 1.5 |
| **9** | Cost of the design. | Canadian Dollar | No budget | < CAD 60,000 per unit |
| **10** | Operators required. | People | 2 | 1 |
| **11** | Functional/engine system. | - | Electric, Mechanical, Hydraulic | Motorized, Battery powered |
| **12** | No cause of contamination. | Subjective | None | None |

Based on TABLE I, the main target requirements include that the design safely performs the desired operations, withstands the weight of the large tools, does not exceed a speed of 2.5 km/h, and reduces the process time which is currently approximately 145.5 minutes to prepare three tools for the autoclave (as estimated by BCW) [2]. The ideal time value of 79.5 minutes is the current process time minus the time required to remove and reinstall the tool's casters. Additionally, due to the anti-contamination requirement, a battery powered device would be ideal as there cannot be any internal combustion within the facility.

## 1.5 Constraints and Limitations

This project had some constraints and limitations associated with it that were outlined by Dream-Aero and BCW.

- The major constraint in this project was time limitation. Each of the team members being enrolled in other engineering courses limited the ability to work on the solution full-time. Another time constraint was from the BCW and their operations; The team was limited to 8:00 am – 4:30 pm on selected days to collect data from the BCW facility.
- The team had limited access to company data such as technical drawings, CAD files, and facility layout maps due to company policies and restrictions.
- Also, the team could not take any pictures or videos while in the facility. Any pictures or videos had to be taken by BCW and went through their communications department before they could be released to the team.

There are also constraints and limitations related to the design itself.

- The design solution must not obstruct the tool from performing its functions.
- The solution cannot contain any elements or machines that will contaminate the Boeing Canada Winnipeg Facility.
- The design must also be able to keep the tools level for layup assembly and autoclave curing.
- The solution must be able to operate in facility areas where hearing protection is not required.
- The current process balances the tool on wheels which applies a great amount of stress to the floor therefore, the design solution must not add any more stress to the ground.

Dream-Aero considered these limitations in their design work and research.

# 2 Commercial Solution and Make/Buy Analysis

Team Dream-Aero performed extensive research into potential commercially available solutions and identified two products. The first is simply to procure a larger forklift that is capable of lifting the cumbersome tools. However, given the space limitations inside BCW's facility, the team was unable to find a forklift powerful enough to lift the tools yet small enough to navigate the plant.

The second solution is a product from Combi lift called the Powered Pallet Truck (PPT), shown in Figure 2 [3]. This device is a small yet capable powered pallet jack which may be available in a size that would suit BCW's situation. However, the team was unable to obtain information from Combi lift on the product's cost, maximum load, lead time, and details on its functionality. Without this information Dream-Aero could only put limited information on it in the make/buy analysis.

Figure 2: Combi lift Powered Pallet Truck [3]

In lieu of a comprehensive make/buy analysis, Dream-Aero has continued with their original design and drafted a detailed cost report for that solution. However, the team recommends that BCW investigate further into Combi lift's PPT in addition to the original solution. Further details of the make/buy analysis can be seen in Appendix C

# 3 Design methodology

This section discusses Dream-Aero's system for generating original designs and their selection process for determining the best solution.

## 3.1 Problem analysis

Dream-Aero broke the problem into sections to better understand it and ensure all aspects of it were addressed. To fully solve the problem, the layup tools must be safely moved between stations, and lifted onto the autoclave cart which will properly align it into the autoclave. Alternatively, another method of aligning could be used which eliminates the need to lift the tool. To this end, the team divided the problem into moving/maneuvering, lifting, and aligning components.

## 3.2 Concept generation

Initially the Dream-Aero team devised 22 ideas including 8 maneuvering concepts, 8 lifting concept and 6 alignment concepts. These concepts were screened to narrow the selection and 10 combinations were made from the selected designs. The screening procedure and combinations obtained from the process are shown in Appendix B.

Further, these 10 concepts were compared using a selection matrix, allowing the team to determine the top two designs.

Based on the selection process seen in the appendices, the best designs were the retractable rail casters concept and the scissor lift concept. The retractable rail casters aligning concept involved purchasing heat resistant caster and replacing the casters on all the tools. Two additional heat resistant casters would be used to align the tool in the autoclave. These casters would have an adjustable height via a hole and pin system. For the locking system, a hole would be drilled into the end of the forklift and a pin would be connected to all the tools. Figure 3 shows the heat resistant casters concept.

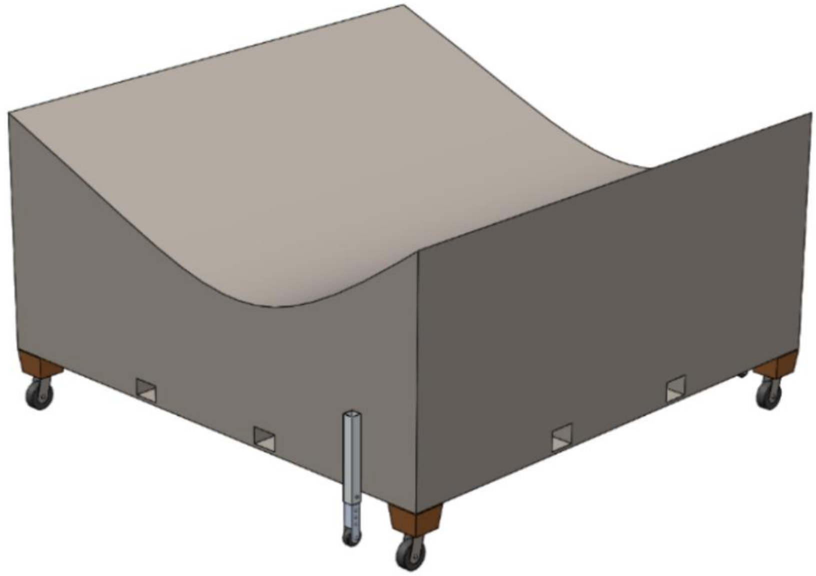


Figure 3: Retractable Rail Casters and Hole/Pin Locking Concept

Figure 4 shows the concept with the highest score. This concept involved creating an attachment for the forklift which would be slightly wider than the cure cart. This U-shaped platform would have four scissor jacks; two on the left and two on the right. These scissor jacks would be used to lift the entire tool, the hole and pin system would be used to lock the attachment to the fork. The forklift would place the platform over the cure cart and then the jacks would be lowered, leaving the tool on the cure cart.

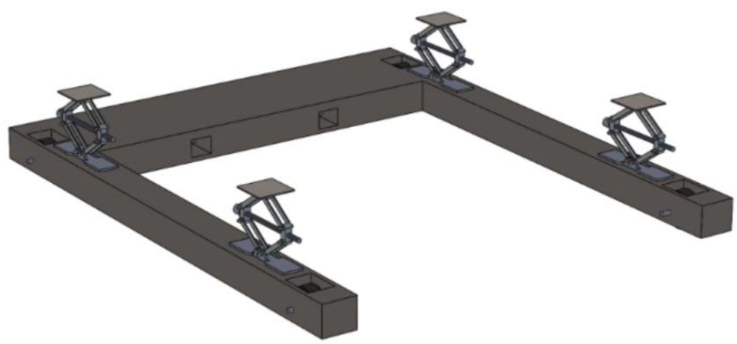


Figure 4: Scissor Jack Lifting and Hole/Pin Locking Concept

Upon showing these concepts to BCW, the scissor lift concept had higher preference due to its features and functionality. Therefore, the team decided to proceed with it.

# 4 Final design

This section describes Dream-Aero's final design and identifies which components of the design are fabricated and which are procured. For all procured components, the section explains why that product in particular was chosen.

Figure 5: The U-Cart (Final Design)

## 4.1 Frame Design

The frame is a wide based fork system. The distance between the forks is the same length of the autoclave curing cart. This will allow the U-Cart to drive over the cure cart and lower the tool onto it. The holes for the forklift holes are at the same location as the holes on the autoclave cart. This will allow the forks to go through the U-Cart as well as the cure cart.

One of the key components of this design is the tapered fork ends. The tapered ends are a method to align the cure cart to be between the forks of the U-Cart. The tool will be placed on the autoclave cart from the side of the cart. The autoclave cart is free to move left or right but cannot move front or back because of the rail system. The tapered ends allow for some misalignment when placing the tool on the autoclave cart. If the cart is not in the correct location the tapered end of the fork will hit the side of the autoclave cart, and the cart will then be forced to the correct location.

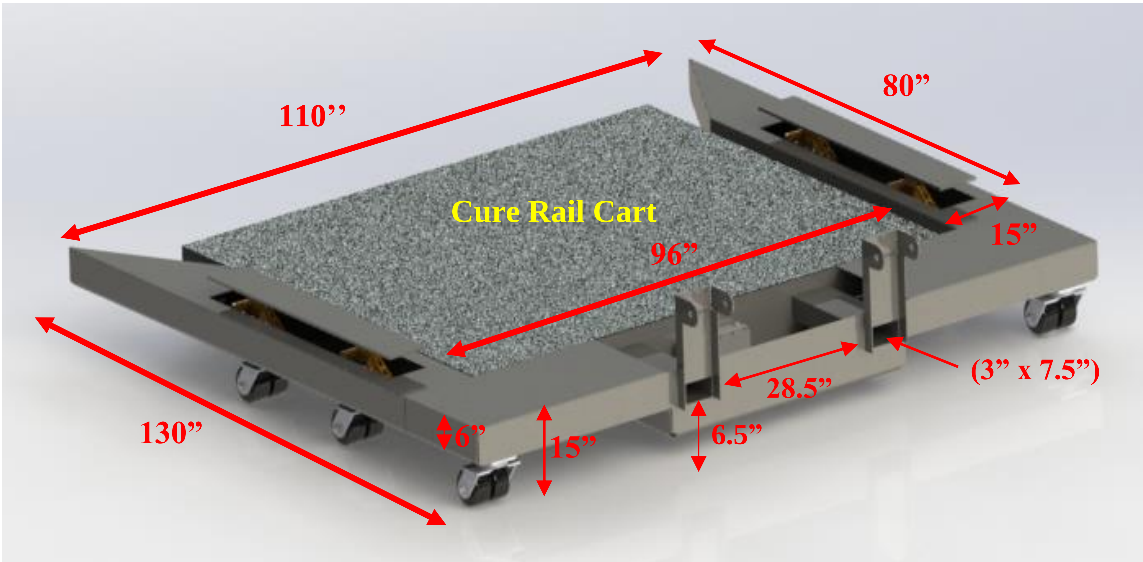



Figure 6: Frame Design with some Key Dimensions [4]

Some key dimensions of the U-Cart are shown in TABLE II.

TABLE II: KEY DIMENSIONS

| Location | Size (Inches) |
|---|---|
| **Fork hole Size** | 3.5 x 7.5 |
| **Distance between fork hole** | 28.5 |
| **Fork Hole Distance from Ground** | 6.5 |
| **Width of forks** | 15 |
| **Height of forks** | 6 |
| **Length of forks** | 80 |
| **Distance between forks** | 96 |
| **Height of entire cart with casters** | 15 |
| **Overall width** | 130 |
| **Overall Length** | 110 |

The frame of the design will be made from AISI 1020 steel. This material was chosen because it is economical and has high strength. Since the weight of the cart is not a relatively high area of concern, there was no need to investigate lighter materials. Steel is the most common material and is used in nearly all high load scenarios. Steel is easy to manufacture with, it can be bent and welded easily and can be repaired with common tools (i.e. grinders and welders). There was no need to perform a material selection matrix as AISI steel 1020 was the obvious choice.

The design is made from three different main sections. The left and right fork, as well as the rear frame. These three sections will be individually made from three piece of sheet metal and then folded into the shapes seen in Figure 7 and Figure 8.

Figure 7: Combined Frame (Left Fork, Right Fork and Rear Frame)

Figure 8: Top View of the Combined Frame

The inside of the cart will be hollow. The scissor jacks will be placed inside of the hollow forks. There is a hole in each fork and the rear frame to allow the scissor jacks electrical cables to be routed correctly. The hole can be seen in Figure 9.

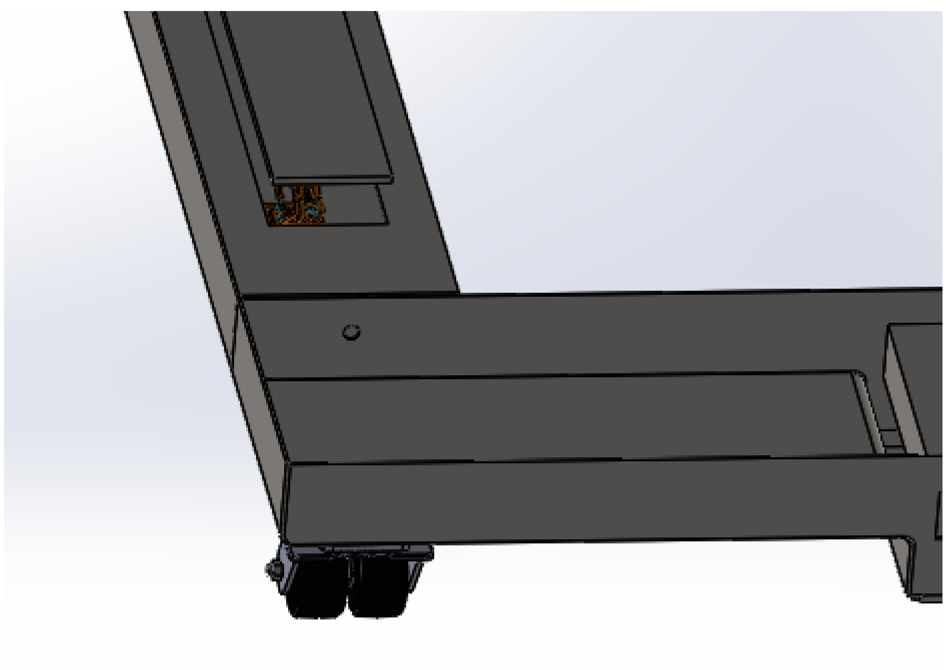


Figure 9: Hole for Scissor Jack Cables

To determine the required thickness of the system, a full bodied model was created. The model was then made into different shell sizes rangings from 1/8 up to ¾ inch steel. An FEA study was completed on all of these models and 3/16 inch steel was required to achieve a factor of safety over 3.0. The final FEA was completed and is seen in Appendix D. The final frame factor of safety is 3.0 with a max stress of 116Mpa and a yield stress of 350 MPa. The final frame design can be seen in Figure 10 below.

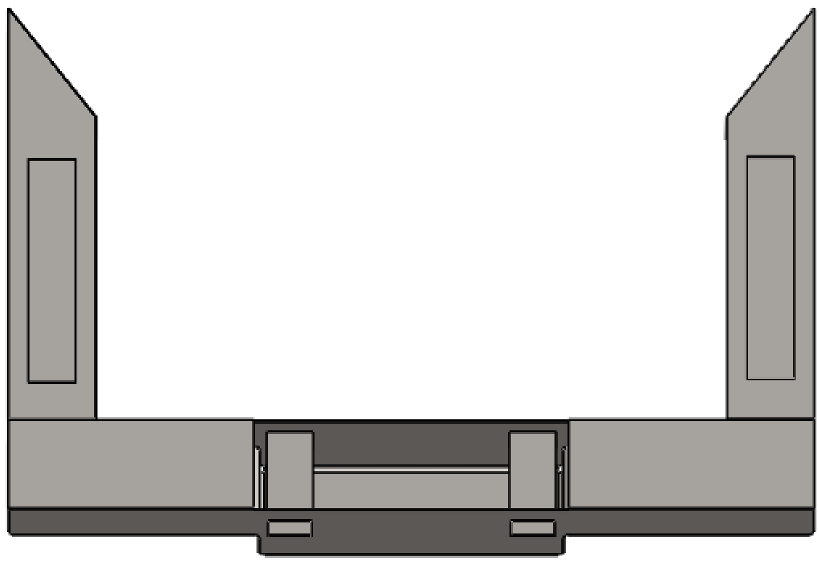


Figure 10: Final Frame Design

## 4.2 Maneuvering System: Casters

Dream-Aero chose to use six heavy-duty dual wheel casters in the final design [5]. The technical specifications for the casters are listed in TABLE III, and an image of one caster is shown in Figure 11. The casters are manufactured by Hamilton Caster & Mfg. Co, an American company that specializes in high capacity casters. This company's product was chosen because they have a wide selection of high capacity casters and offer extensive information on their products. Hamilton casters are carried by Acklands Grainger, an industrial supply firm that has locations in Winnipeg; if Acklands Grainger does not already carry the required casters, they can be ordered from Hamilton through them.

TABLE III: SPECIFICATIONS FOR THE FINAL DESIGN’S CASTERS [5]

| Specification | Value |
|---|---|
| **Product number** | S-EHD2-64PH |
| **Number of casters used** | 6 |
| **Cost** | CAD $391.89 per caster |
| **Load Capacity** | 4000 lbs. |
| **Wheel diameter** | 6 in |
| **Overall height** | 8.5 in |

Figure 11: Heavy-duty dual-wheel caster used in the final design [5]

The team decided to use a six-caster configuration for several reasons. First, using six wheels instead of four provides better support for the tool and makes the device less susceptible to bending. Additionally, a six-caster layout is more capable of supporting the tool if the floor is uneven. Second, using six casters requires a lower load capacity per caster, which allows smaller casters to be used. This is important in keeping the height of the device as low as possible. Furthermore, the load capacity of 4000 lbs. in these casters was chosen so that if the floor becomes uneven and the device is resting on only 4 casters, the combined capacity is still 16000 lbs., yielding a safety factor of 1.5. Lastly, having six dual-wheel casters means the load of the device and tool is spread over 12 casters, which results in far less stress on the floor than a four-caster configuration that uses single-wheel casters (which is the situation currently). Thus, using six casters will support the tool better, keep the height of the device low, and decrease the stress on the floor.

All six casters will have swivel action because the device and forklift will pivot around the forklift's front wheels during turns. Since there will be a distance between the front wheels and casters on the device, all 6 need to be swivel, as fixed casters would be dragged until the desired direction were reached.

In addition to lowering the stress on the floor, the team chose dual-wheel casters because they will provide a much smoother swivel action than their single-wheel counterparts. During tight turns, a single-wheel caster must pivot on the spot as it rotates toward the direction of travel. This pivoting means extra force is required to rotate the casters initially, and once the casters are fully rotated the device may lurch forward rapidly. With dual-wheel casters, the wheels rotate about a point between them rather than pivot on the spot, resulting in much better control during tight turns.

Of the many wheel materials available, Dream-Aero selected Hamilton's Plastex wheel, which is made from fiber-reinforced phenolic resin [5]. The team chose this wheel because it has a high load rating, rolls easily under heavy weight, and is inexpensive. The trade-off to being inexpensive is that the wheel has only average durability and impact resistance. However, since the floor of BCW's facility is smooth concrete, the casters do not need withstand large bumps or rough terrain. Furthermore, high-traction wheels are not required because the device will not be driving itself. Hence Platex wheels are a cost-efficient yet effective choice.

## 4.3 Lifting Mechanism

The U-Cart lifting mechanism is a system that includes Electric Scissor jacks, Dual Motor Drivers, an Arduino Module, a Wireless Remote-Control System, and a Power Supply.

### 4.3.1 Electric Scissor Jacks

The U-Cart will lift BCW's large shaping tools using 4 motorized scissor jacks, 2 at each side of the U-Cart. Each scissor jack has a maximum lifting capacity of 10,000 lbs., giving an overall 40,000 lb. maximum lift capacity. This lifting mechanism will easily and safely lift the 12,000 lbs. BAJ and LM tools. As seen in Figure 12, the jack is coated in Anti-oxidation paint, has a built in low-power powerful motor, and a stabilized back base [6].

[redacted]

Figure 12: Motorized Scissor Jack [6]

A steel plate will be welded to the tops of each pair of jacks on both sides of the U-Cart so that there is more surface area to lift the large tools. Figure 13 shows a diagram of the U-Cart frame with the jacks installed and plates welded onto the jacks. As the jacks fully lower, the plates will sit flush with the frame of the U-Cart.

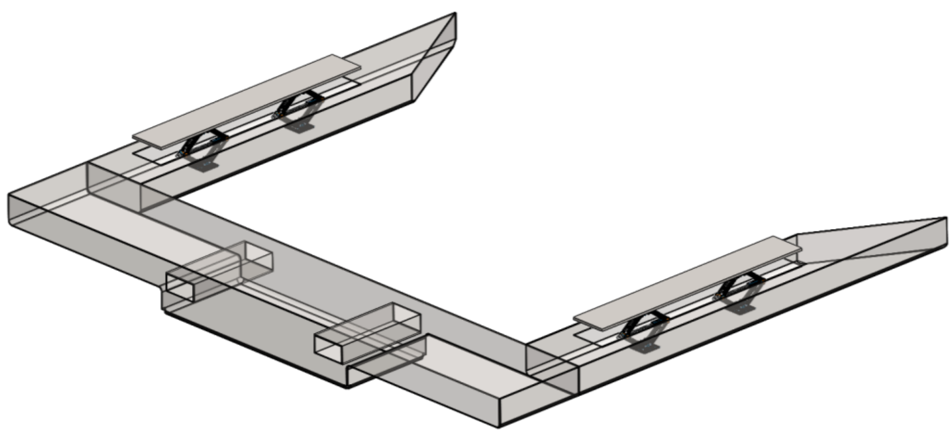


Figure 13: Welded Plates Diagram

The system consists of a total of 4 motorized scissor jacks. The specifications for each jack can be seen in TABLE IV below [6].

TABLE IV: MOTORIZED SCISSOR JACK SPECIFICATIONS

| Spec | Value |
|---|---|
| **Rated Power** | 120 W |
| **Max Current** | 13 A |
| **Operating Voltage** | DC 12 V |
| **Max Loading** | 10000 lbs. |
| **Weight** | ~15 lbs. |

| Size | Highest Degree | Lowest Degree |
|---|---|---|
| | 15x16x35 cm | 40x16x12 cm |
| **Cost** | CAD $73.09 | |

### 4.3.2 Arduino Module

In order to ensure that this lifting mechanism can be carried out in a safe and efficient manner, an Arduino Uno R3 USB Microcontroller will be used to control all 4 motors. The Arduino Microcontroller shown in Figure 14 will ensure that the motors run together and at the same speed. The Arduino will be programmed so that all motors will run only if every other motor is working. This ensures that the tool lifting operation in the new process is carried out safely. The Arduino Uno R3 USB Microcontroller has a cost of $26.99 CAD.

Figure 14: Arduino Uno R3 Module [7]

### 4.3.3 Dual Motor Driver

In order to power all 4 motorized scissor jacks simultaneously, 2 dual motor drivers are implemented in the lifting mechanism. These dual motor drivers use high-performance & high-current driver chips-BTS7960 and are directly compatible with the Arduino system [8]. The 2 dual 15A at 13.8 volts is more than enough to drive each individual scissor jack motor. The dual motor driver can be seen in Figure 15.

Figure 15: Dual Driver Motor [8]

The lifting mechanism consists of 2 dual motor drivers. The specifications for each driver can be seen in TABLE V [8].

TABLE V: DUAL MOTOR DRIVER SPECIFICATIONS

| Spec | Value |
|---|---|
| **Input Voltage** | 4.8-35V |
| **Max Output Current** | 15A at 13.8V per channel |
| **PWM capability** | Up to 25 kHz |
| **Driving Module** | Dual high-power H-bridge driver |
| **Cost** | CAD $62.93 |

### 4.3.4 Wireless Remote-Control System

The operator will raise and lower the tool using a wireless remote-control system within the cabin of the forklift. The remote-control system consists of a receiver and a wireless transmitter. The receiver will be connected to the Arduino system which will be programed to send a signal to the motors to raise or lower the tool using the up/down buttons on the remote control.

Figure 16 Transmitter and Receiver [9]

The specifications for the remote-control system used in the final product can be seen in TABLE VI below [9].

TABLE VI: TRANSMITTER AND RECEIVER SPECIFICATIONS

| Transmitter Specifications | |
|---|---|
| **Frequency** | 433/480(MHZ) |
| **Weight** | 380g |
| **Transmitter RF power** | <10 (mW) |
| **Command response time** | <100 (ms) |
| **Shell material** | PA6(30%GF) |
| **Control distance** | 100m |
| **Power supply** | LR6(AA)1.5V*2DC3V(DC) |
| **Stop command response time** | <100(ms) |
| **Receiver Specifications** | |
| **Frequency** | 433/480(MHZ) |
| **Weight** | 1700g |
| **Shell material** | PA6(30%GF) |
| **Average power consumption** | 15mA@AC220V |

| Receiver Specifications | |
|---|---|
| **Power supply (AC/DC)** | Low pressure24-48V high pressure110-460V |
| **Control distance** | 100m |
| **Reaction time** | 50-100(ms) |
| **Total Cost** | CAD $61.13 |

### 4.3.5 Power Supply

The U-Cart has 2 lithium ion batteries mounted onto it which are used to send power to the dual motor drivers. In order for the motor driver to be able to power the electric motors, they each need an input of around 5-35 V. Two 24 V lithium batteries were chose to complete this task. Each battery is rated at 24 V which will power 2 motors each. The batteries can be recharged using the AC charger seen in Figure 17. These batteries will be charged when the U-Cart is not in use and is in its proper storage/charging station.

Figure 17 Lithium Ion 24-volt Battery [10]

TABLE VII shows a list of specifications for the 24-volt lithium ion battery used in the U-Cart final product [10].

TABLE VII: LITHIUM ION 24-VOLT BATTERY SPECIFICATIONS

| Spec | Value |
|---|---|
| **Nominal Output Voltage** | 24V |
| **Capacity** | 576 Watt-hour (24Ah @ 24 V) |
| **Max Continuous Discharge Current** | 20 A |
| **Weight** | 7.3 lbs. |
| **Size** | 180x170x75 mm |
| **Cost** | CAD $637.83 |

## 4.4 Locking Mechanism

Initially the team's final design included a pin locking system that required drilling hole in the forklift's forks to lock it in place with the design. However, it was brought to notice by the client that holes cannot be drilled in the forks. This resulted in the redesigning of the locking mechanism that did not require any changes to be made to the forklift. The locking mechanism involve adding a feature to the U-Cart design that locks the forks with it and not requiring any drilling to be done.

### 4.4.1 Toggle-Lock Clevis Pin

The locking mechanism includes attaching a bracket to the sides and rear of the fork holes that extends 18 inches above from the base of the hole. This feature is compatible with wide range of clevis pins that could be used to lock the forks with the U-Cart. However, the design of toggle-lock clevis pin was considered an efficient method to lock the forks inside the U-Cart. The locking mechanism is shown in Figure 18.

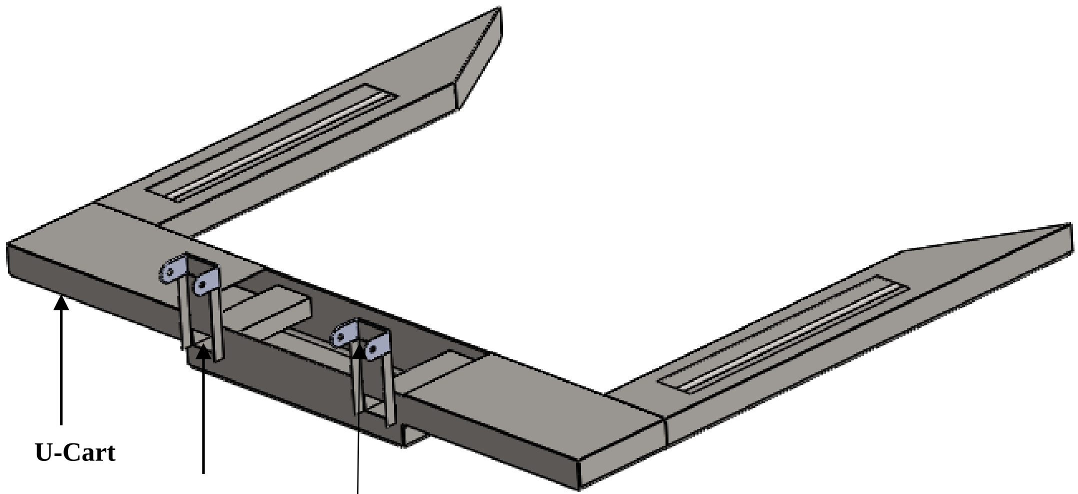



Figure 18: U-Cart with locking feature

The locking procedure consist of inserting the pin through the holes and flipping the toggle lock at the end of the pin to keep it in place. The positioning on the clevis pin can be seen in Figure 19.

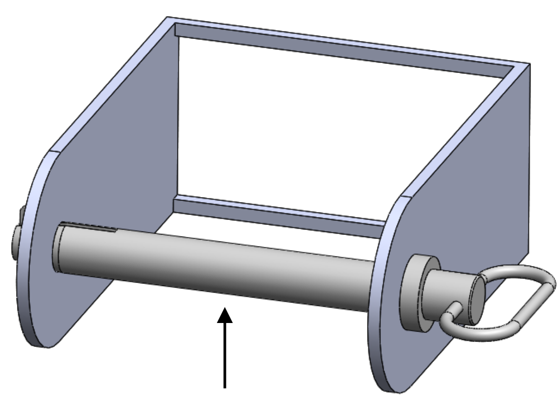



Figure 19: Pin when inserted through the holes

The rendered version of the clevis pin can be seen in Figure 20.

[redacted]

Figure 20: Toggle-Lock Clevis Pin [11]

This pin was selected because it is easy and quick to install, no tool is needed for it to be inserted and is a one-piece locking pin. Once the forks are inserted through the fork hole to the desired limit, these pins will be inserted to lock the forks in the U-Cart. Addition of this feature makes the maneuvering of the tools around the plant safer as the risk of the U-Cart slipping off the forklift decreases. Properties of the pin are shown in TABLE VIII.

TABLE VIII: PROPERTIES OF THE CLEVIS PIN [11]

| Properties of the Toggle-Lock | |
|---|---|
| **Pin Type** | Clevis |
| **End Type** | Toggle |
| **Shaft Type** | Plain |
| **Head Type** | Loop |
| **Material** | 1004-1045 Carbon Steel |
| **Properties of the Toggle-Lock** | |
| **Finish** | Zinc Plated |
| **Diameter** | 1 inch |
| **Usable Length** | 7.5 inches |
| **Minimum Hardness** | Rockwell B90 |
| **Cost** | CAD $53.58 |

## 4.5 Bill of materials and Labor Cost Summary

TABLE IX concisely presents the quantity and cost of the components of the final design along with the labor cost and the final total cost.

TABLE IX: BOM AND LABOR COST SUMMARY

| Components/Material | Quantity | Cost/item (CAD) | Total cost (CAD) |
|---|---|---|---|
| **Hamilton S-EHD2-64PH Casters** | 6 | 391.89 | 2351.39 |
| **Motorized Scissor Jacks** | 4 | 73.09 | 292.36 |
| **Arduino Uno R3 USB Microcontroller** | 1 | 26.99 | 26.99 |
| **DC Motor Drivers** | 2 | 62.93 | 125.86 |
| **Q202 Wireless Transmitter & Receiver** | 1 | 61.13 | 61.13 |
| **Lithium Ion Battery** | 2 | 637.83 | 1275.66 |
| **Toggle-Lock Clevis Pin** | 2 | 53.58 | 107.16 |
| **AISI 1020 Steel 3/16 5x10** | 4 | 310.00 | 1240.00 |
| **Components/Material Cost** | | | $5480.55 |
| **Labor** | **Hours** | **Cost/hour (CAD)** | **Total cost (CAD)** |
| **Frame Manufacturing** | 12 | 85.00 | 1020 |
| **Caster Installation** | 5 | 50.00 | 250 |
| **Scissor Jack Installation** | 4 | 50.00 | 200 |
| **Arduino Programming and Wiring** | 8 | 60.00 | 480 |
| **Labor Cost** | | | $1,950.00 |
| | | **Final Total Cost** | $7,430.55 |

## 4.6 Manufacturing

There are four main manufacturing steps to create this device. The first step is laser cutting all the 3/16 inch steel. A laser cutter capable of cutting 3.5 meters by 1.5 meters will be required. The second step is to bend the steel in the required shapes A 300 tonne break press capable of folding up to 3.5 meters is required. The third step is welding the frame, casters, scissor jacks and plates in the correct locations. The final step is wireing the scissor jacks and installing all the electrical components. The detailed steps to manufacture this device is seen below.

1) Laser cut all pieces, the required pieces and amounts are seen below. Since these pieces are being laser cut the DXF file will be needed. Appendix A shows the outside dimensions of all the laser cut pieces. The laser cut operator can use these dimensions to determine the required sheetmetal size.
    a) Rear Frame
    b) LHS Fork
    c) RHS Fork
    d) Top Fork Plates x 2
    e) Rear Frame Plates x 2
    f) Fork Tip Plates x 2
    g) Scissor Jacks Plates
    h) Locking Mechanism Side Bracket x 4
    i) Locking Mechanism Rear Bracket x 2
2) Bend the two forks and the rear frame along the proper lines.
3) Weld the seams along the rear frame.
4) Weld the casters in the correct locations on both the forks and the rear frame. These casters can be fastened instead by drilling holes and using bolts to secure the casters.
5) Roll the forks to the correct locations and weld the forks to the rear frame. Aweld on the inside and exteriour will be required.
6) Weld the fork tip plates in place.
7) Weld the locking mechanism.
8) Weld the scissor jacks in the correct location.
9) Route the scissor jack cables to the rear electrical compartement.
10) Weld the top fork plates to the forks.
11) Weld the scissor jack plates to the scissor jacks.
12) Weld the rear frame top plates.
13) Install batteries and electrical components (Must be completed last to ensure electrical components are not damaged).

## 4.7 Example usage of the device

This section will provide a walkthrough of the intended use of the U-Cart device. First, two personnel, a driver and a spotter, acquire the U-Cart from its starting location. The forks of the forklift are pushed through the matching holes in the device and are locked into place with a pin, as shown in Figure 21.

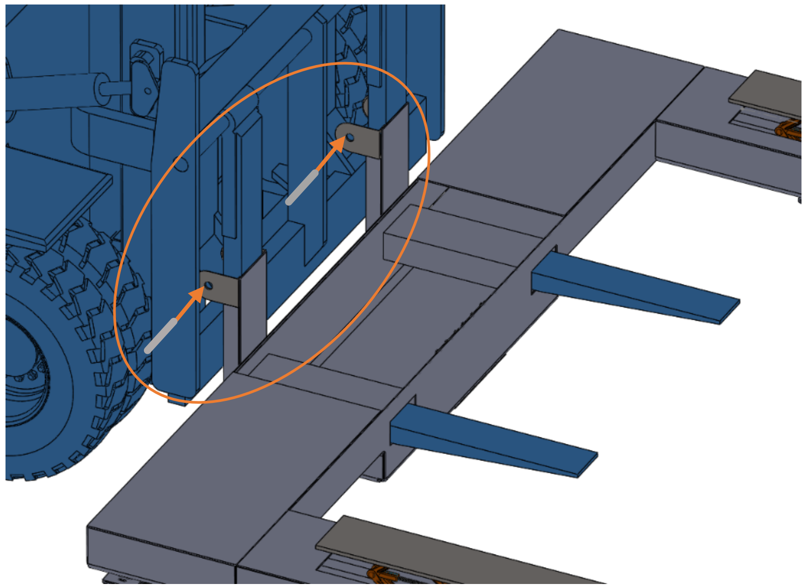


Figure 21: Detail of the U-Cart device attaching to the forklift

The driver and spotter then move the device to the LM's or BAJ's starting location. The lifting mechanism is fully lowered, and the device is guided by the forklift to be directly underneath the tool. The tool is to be picked up with the orientation that ensures its center of mass is as close to the forklift as possible. Once the scissor jacks are checked to be properly supporting the tool's center of mass, the lifting mechanism is engaged until the tool is lifted off the ground, as shown in Figure 22. The lifting mechanism can be controlled by the driver from the cab of the forklift using the remote-control system.

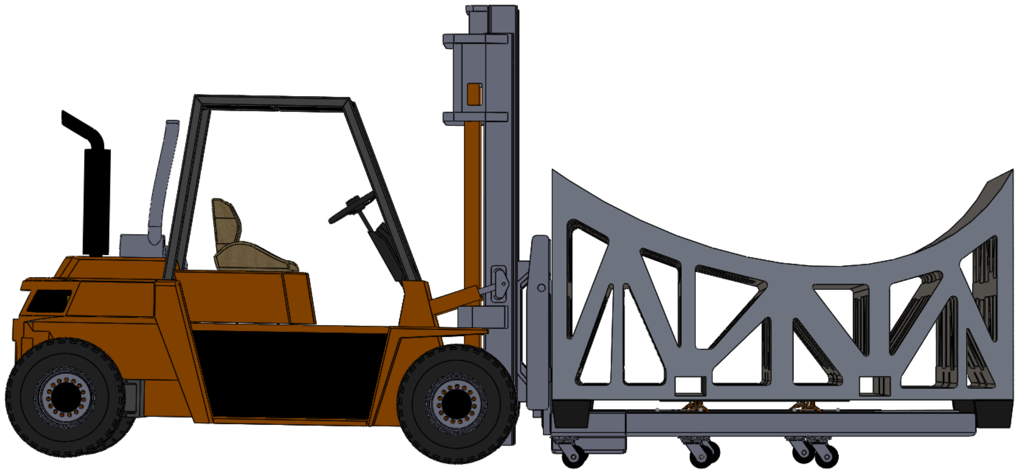
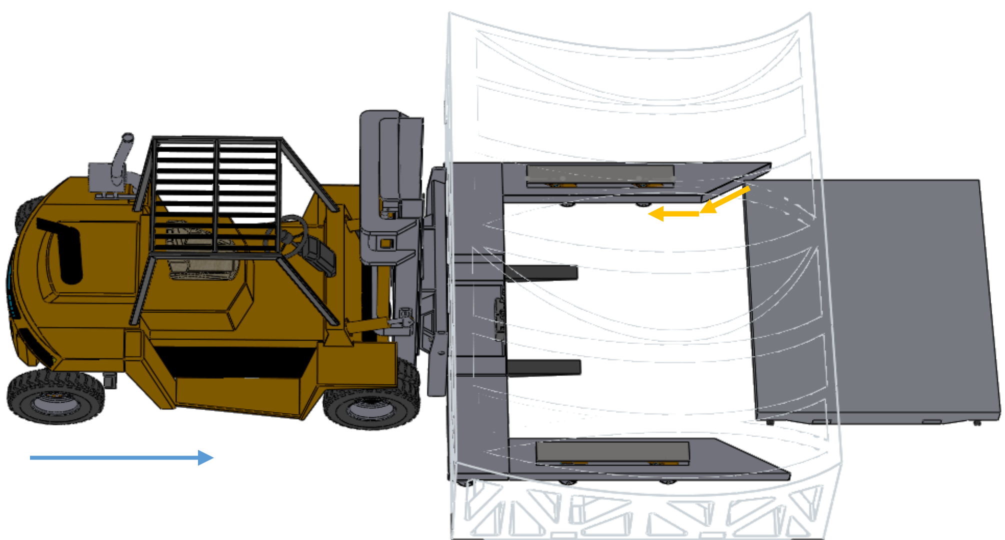


Figure 22: The U-Cart device lifting the tool off the ground

With the tool secured to the U-Cart by friction and the U-Cart secured to the forklift, the tool can be safely transported to the autoclave area.

Once at the staging area, the tool is lifted higher, if necessary, to ensure it will clear the height of the autoclave curing cart. With the aid of the spotter, the driver guides the forklift such that the U-Cart envelopes the curing cart, which will then be directly below the tool. The fork-tip guides can be used to gently push the curing cart into position, as shown in Figure 23.



The fork-holes in the U-Cart are designed to match those in the curing cart so that the portion of the forks protruding out of the U-Cart can enter the curing cart. This allows the curing cart to be fully enveloped by the U-Cart, as illustrated in Figure 24. Once the tool is ensured to be properly positioned over the curing cart, it is lowered until the tool is resting on the cart and the lifting mechanism is fully retracted.

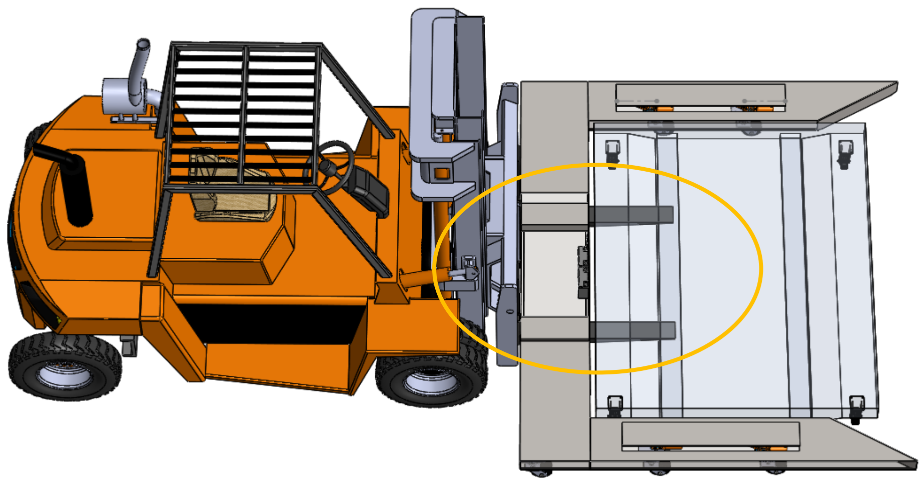


Figure 24: The holes of the U-Cart match those of the curing cart, allowing the forks to pass through both.

With the tool placed on the curing cart, the U-Cart can be removed from the forklift. The forklift then moves the autoclave cart into the autoclave as in the original system. The above process may be repeated for additional tools as necessary. Once the curing process is complete, the U-Cart is reattached to the forklift and is used to lift the tool off the curing cart. The tool can then be moved through the remaining steps of its process cycle and relocated to its end location. When the U-Cart is no longer needed, it is returned to its storage location and plugged in for charging.

TABLE X below lists in detail the time required to perform each step of the process explained above. The time value for each step is based on approximations provided by BCW [2]. While the U-Cart does eliminate the time spent removing and reinstalling the tool's casters, there is 2.5 min of added travel time due to retrieving and returning the U-Cart. The overall result is a decrease of 63.5 min in the total process time.

TABLE X: APPROXIMATE TIME BREAKDOWN OF THE COMPOSITE CURING PROCESS [2]

| | Activity | Time required to complete |
|---|---|---|
| **1** | Walk to a forklift | 1 min |
| **2** | Drive forklift to U-Cart location and attach device | 2 min |
| **4** | Drive device to tool location | 1 min |
| **5** | Load tool onto U-Cart | 0.5 min |
| **6** | Move tool to cure area | 5 min |
| **7** | Position cure cart on autoclave track | 1.5 min |
| **8** | Position tool on cure cart | 0.5 min |
| **9** | Detach U-Cart and move cure cart into autoclave | 4 min |
| **10** | Reattach U-Cart to forklift | 0.5 min |
| **11** | Repeat steps 4-9 for 2 more tools | 32 min |
| **12** | Return U-Cart and forklift to storage locations | 2 min |
| **12** | Cure parts | -- |
| **13** | Walk to forklift | 1 min |
| **14** | Remove tools from the autoclave | 3 min |
| **15** | Drive forklift to U-Cart location and attach device | 2 min |
| **16** | Move device to autoclaves and lift a tool | 1 min |
| **17** | Move tool to staging area for composite removal | 5 min |
| **18** | Repeat steps 15-17 for remaining two tools | 16 min |
| **19** | Return U-Cart to its storage location | 2 min |
| **20** | Return cure cart and forklift to storage locations | 2 min |
| **Total Time** | | 82 min |

## 4.8 Implementation strategy

To properly implement the U-Cart device, BCW must provide a storage/charging location, and administer the required training to their staff. Only one U-Cart needs to be implemented to adequately solve BCW's problem, and so minimal storage space is required; the location must simply have access to a power outlet for the device to recharge. The U-Cart requires two personnel to operate: one forklift-qualified driver and one spotter. To be trained to use the device, technicians need to be given the following information:

- The device's maximum capacity is 20000 lbs;
- The maximum recommended operating speed is 2.5 km/hr;
- How the device recharges and the location of its charging port;
- The driver must have a spotter when using the device;
- How to operate the controls of the lifting mechanism.

To ensure the U-Cart continues to function as intended, the device must be briefly inspected before each use and thoroughly inspected once a week. For the short pre-use inspection, the scissor jacks should be checked for deformation and verified to be operation before the tool is lifted, and the locking mechanism should be inspected whenever it is engaged. In the weekly inspection, the following items should be checked:

- The U-frame should be checked for deformation
- The casters should be checked for deformation and irregularities
- The scissor jacks should be thoroughly checked for deformation and irregularities
- The locking mechanism should be checked for deformation
- The batteries should be checked for irregularities

# 5 Summary and recommendations

Boeing Canada Winnipeg is a subsidiary of Boeing that manufactures large composite parts for the latter's commercial airliners. These composite parts are fabricated on large, cumbersome shaping tools called layup mandrels and bond assembly jigs. The size of these tools makes them difficult to move through the facility via the company's current method: using a forklift to partially lift the tool and guide it through the plant. Additionally, the casters on the tool must be removed before the composite is cured in an autoclave because they are not designed to withstand high temperatures. As a solution, BCW places the tool on an autoclave curing cart with heat resistant casters, and which is on rails to ensure the tool is properly aligned as it enters the autoclave. Using a forklift to move the tool and lift it onto the autoclave cart has proven to be unsafe and time consuming.

Team Dream-Aero has designed a solution to BCW's problem regarding the transportation of the layup tools throughout their facility. Dream-Aero set out to provide BCW with a solution by performing a make/buy analysis to determine if the optimal solution is an existing device or an original design. The team identified Combi lift's Powered Pallet Truck as a potential solution, but they were unable to obtain sufficient information to include the device in their analysis. For this reason, Dream-Aero focused on generating an original solution and recommends that BCW investigate Combi lift's product as a promising alternative.

Dream-Aero analyzed BCW's transportation problem and generated 22 potential original solutions. These designs were assessed and refined using decision matrices until the scissor jack U-Cart design was determined to be superior.

The U-Cart device acts as a forklift attachment that can safely transport and lift the layup tools. The device is designed to be locked to a forklift and rolled beneath a tool, which it then lifts off the ground. The tool can then be moved by the forklift to the autoclave station and lowered onto a curing cart for use in the autoclave. The team chose six heavy-duty dual-wheel casters for the device to give it high maneuverability and ensure the frame is properly supported. The lifting mechanism utilizes electric motor-powered scissor jacks which can be controlled from the cab of the forklift by a wireless remote-control system. The frame of the device is constructed from steel and incorporates a Clevis pin locking mechanism to ensure the device remains fixed to the forklift when in use. To accompany the design, Dream-Aero has established an implementation plan and inspection schedule to ensure the device function as intended.

TABLE XI below compares the target specifications of the U-Cart design against the original values established at the beginning of this report.

TABLE XI: TARGET SPECIFICATIONS OF THE FINAL DESIGN COMPARED TO INITIAL SPECIFICATIONS

| Specification | Marginal Value | Ideal Value | Final Design Value | Evaluation |
|---|---|---|---|---|
| **Weight withstanding ability of the design.** | 12,000 lbs | >12,000 lbs | 20000 lbs. | Meets ideal target |
| **Speed control of the design.** | 2.5 km/h | 2 - 2.5 km/h | 2 - 2.5 km/h | Meets ideal target |
| **Lifted height.** | 16 in | 20 in | 23 in | Exceeds targets |
| **Noise limit during transportation.** | 70 dB | ≤ 60 dB | 60 dB (when lifting tool) | Meets ideal target |
| **Total time required to prepare the tools for the autoclave.** | 145.5 min per load | 79.5 min per load | 82 min per load | Between ideal and marginal target values |
| **Size of the tools that need to be transported.** | 15 x 10 x 8 ft | > 15 x 10 x 8 ft | 15 x 10 x 8 ft | Meets marginal target |
| **Safe to operate.** | Subjective | Yes | Yes | Meets ideal target |
| **Factor of safety.** | 1.5 | > 1.5 | 1.5 | Meets marginal target |
| **Cost of the design.** | No budget | < CAD 60,000/unit | CAD 7,430.55 /unit | Meets ideal target |
| **Operators required.** | 2 | 1 | 2 | Meets marginal target |
| **Functional/ Engine system.** | Electric, Mechanical, Hydraulic | Motorized, Battery powered | Battery powered | Meets ideal target |
| **No cause of contamination.** | Subjective | None | None | Meets ideal target |

As can be seen in the table, the final design satisfies the marginal values for all the specifications and meets the ideal values for nine of the twelve specifications. The device exceeds both the marginal and ideal values in its maximum lifting height at 23 in, 3 in higher than the ideal value. This makes the device more versatile as it is able to lift the shaping tools onto taller surfaces if necessary. The device only meets marginal targets for the tool size, factor of safety, and number of required operators. The U-Cart was designed to support only BCW's current tool size; later iterations of the device could feature extended forks to support larger tools. The safety factor of 1.5 belongs to the casters for the situation in which the floor is uneven and the device is only supported by four casters; if the device is supported by all six, they have a safety factor of two and the ideal target is met. Lastly, the tool requires two personnel to operate: a driver and a spotter. Ideally, only the driver would be required, however, to ensure proper visibility without a spotter would require a complex mirror or camera system. This would increase the cost and complexity of the design, and likely would not be as effective as a spotter. Hence the marginal value is also an acceptable target.

By ensuring the U-Cart is secured to the forklift and can safely raise and lower the tools, Dream-Aero has provided a safe and effective solution to BCW's problem.

# References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# Appendix A: Engineering Drawings

## List of Figures

## Engineering Drawings

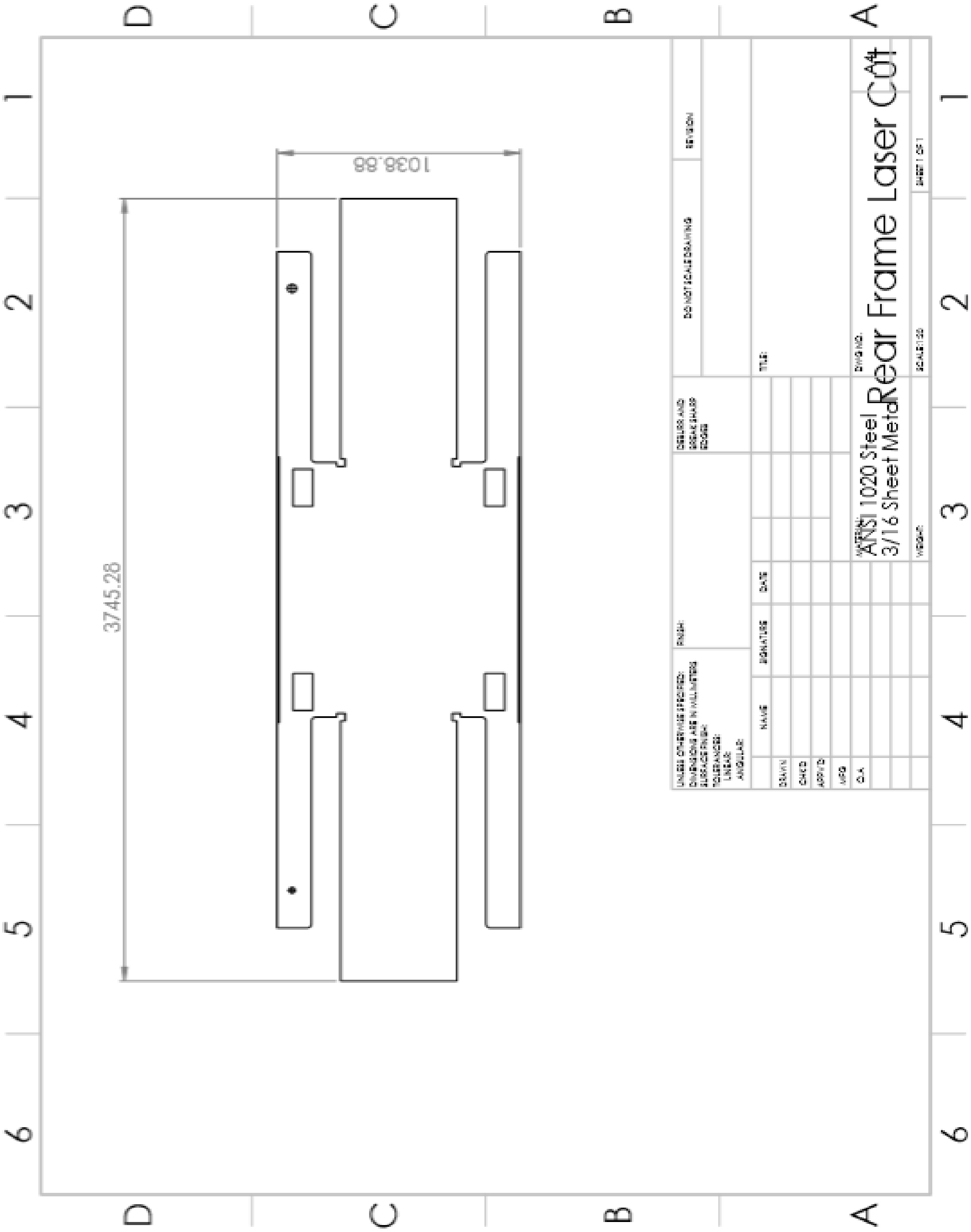


Figure A - 1: Rear Frame Laser Cut

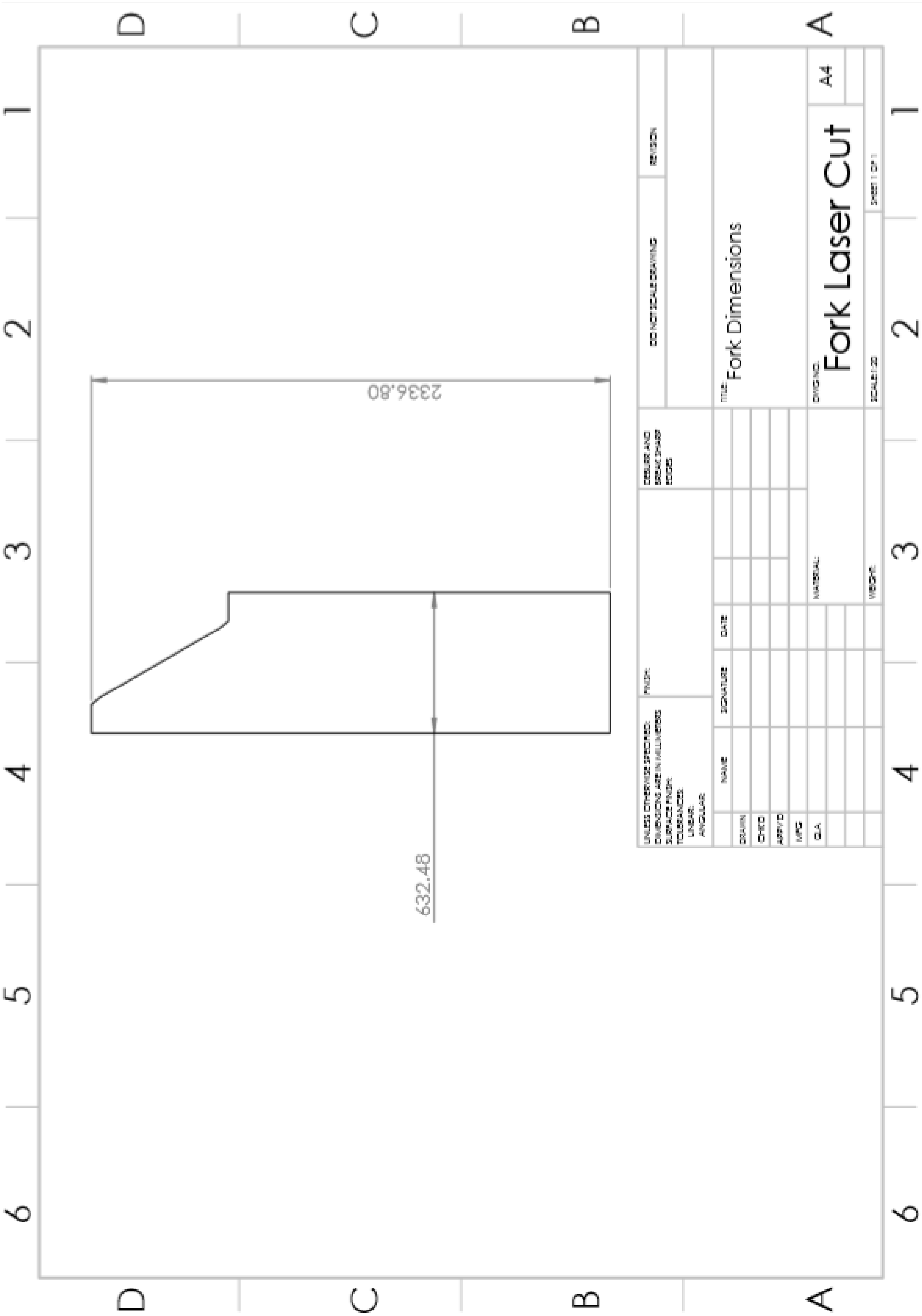


Figure A - 2: Fork Laser Cut

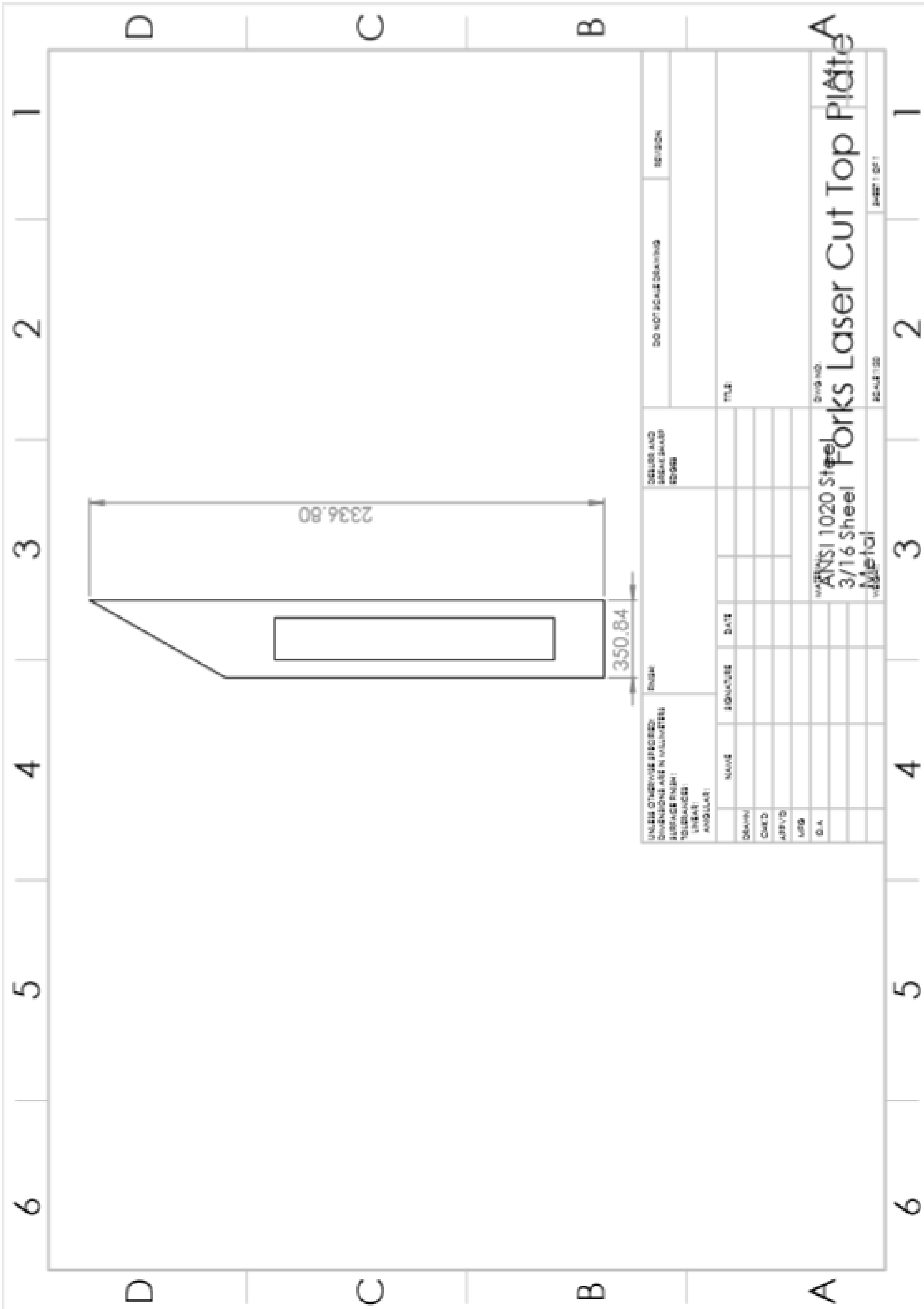


Figure A - 3: Top Fork Plate

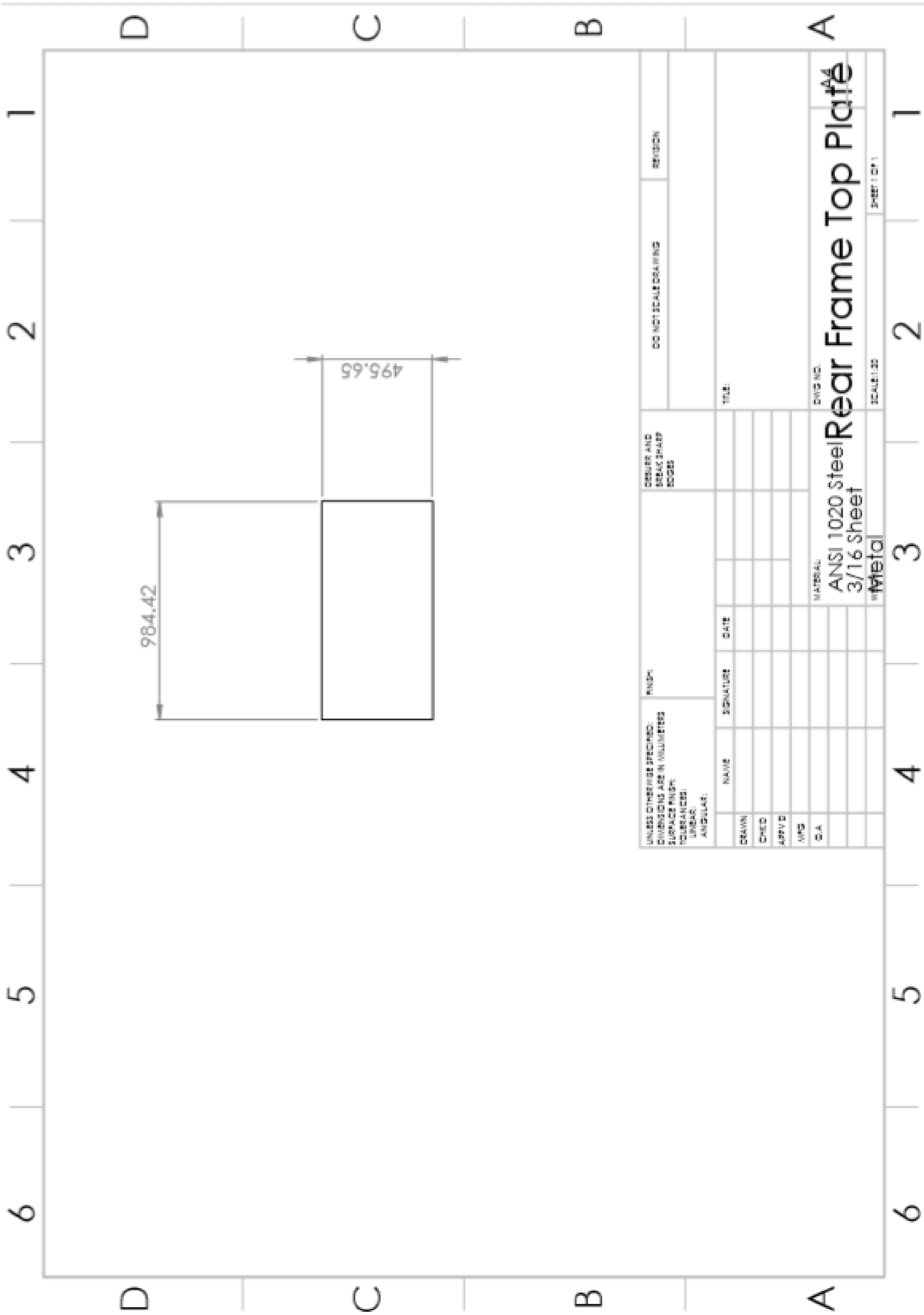


Figure A - 4: Rear Frame Top Plate

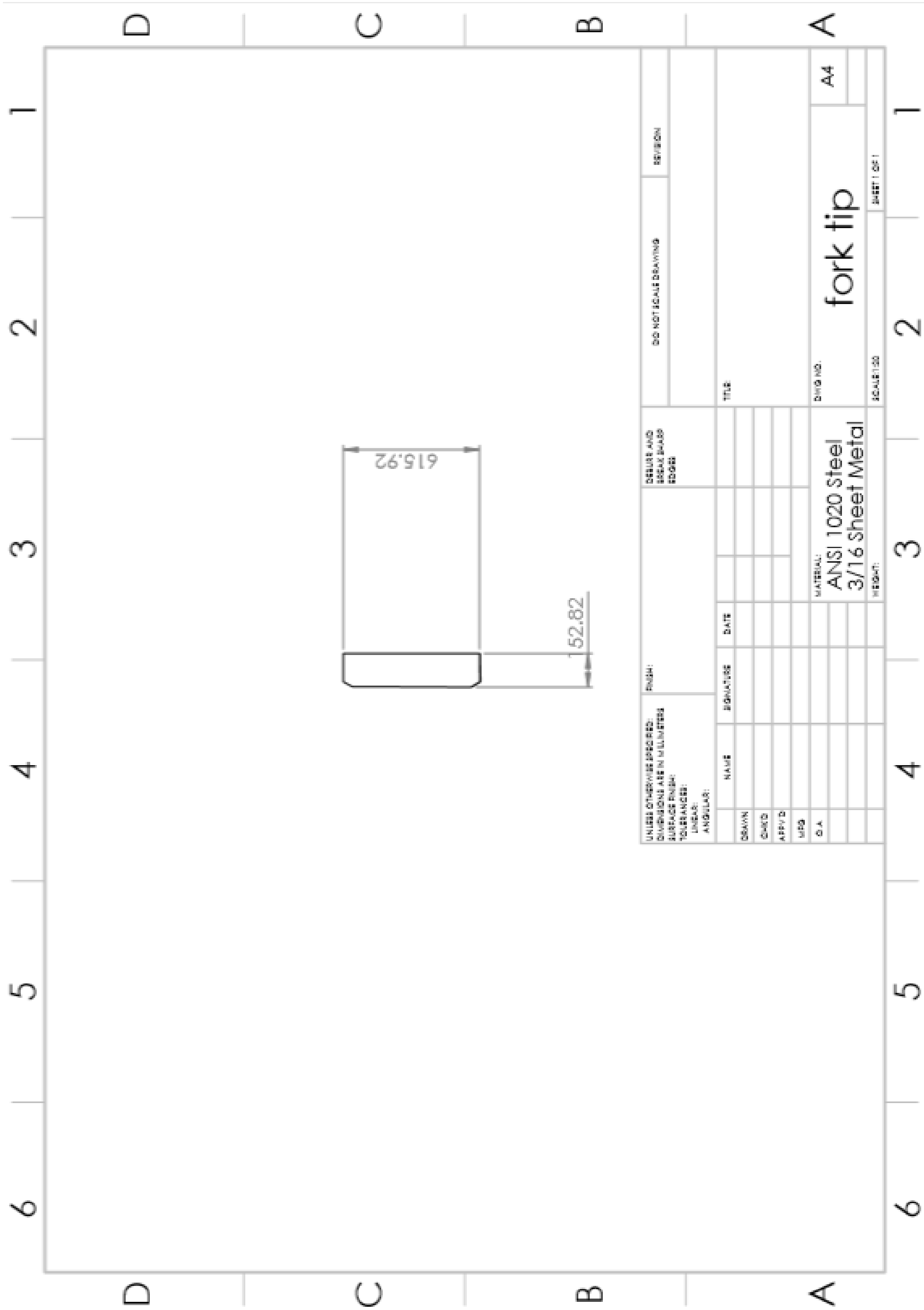


Figure A - 5: Fork Tip Plate

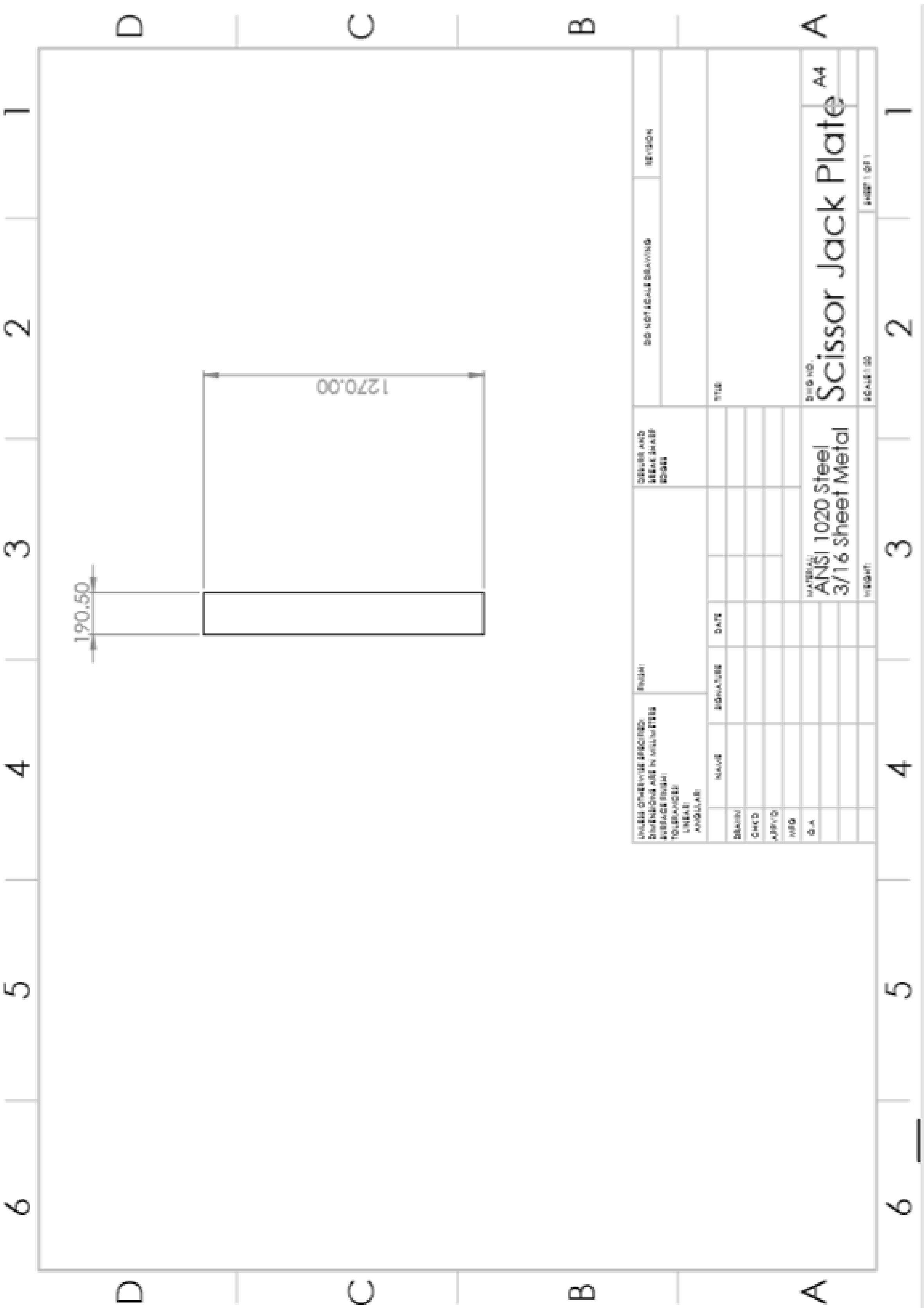


Figure A - 6: Scissor Jack Plates

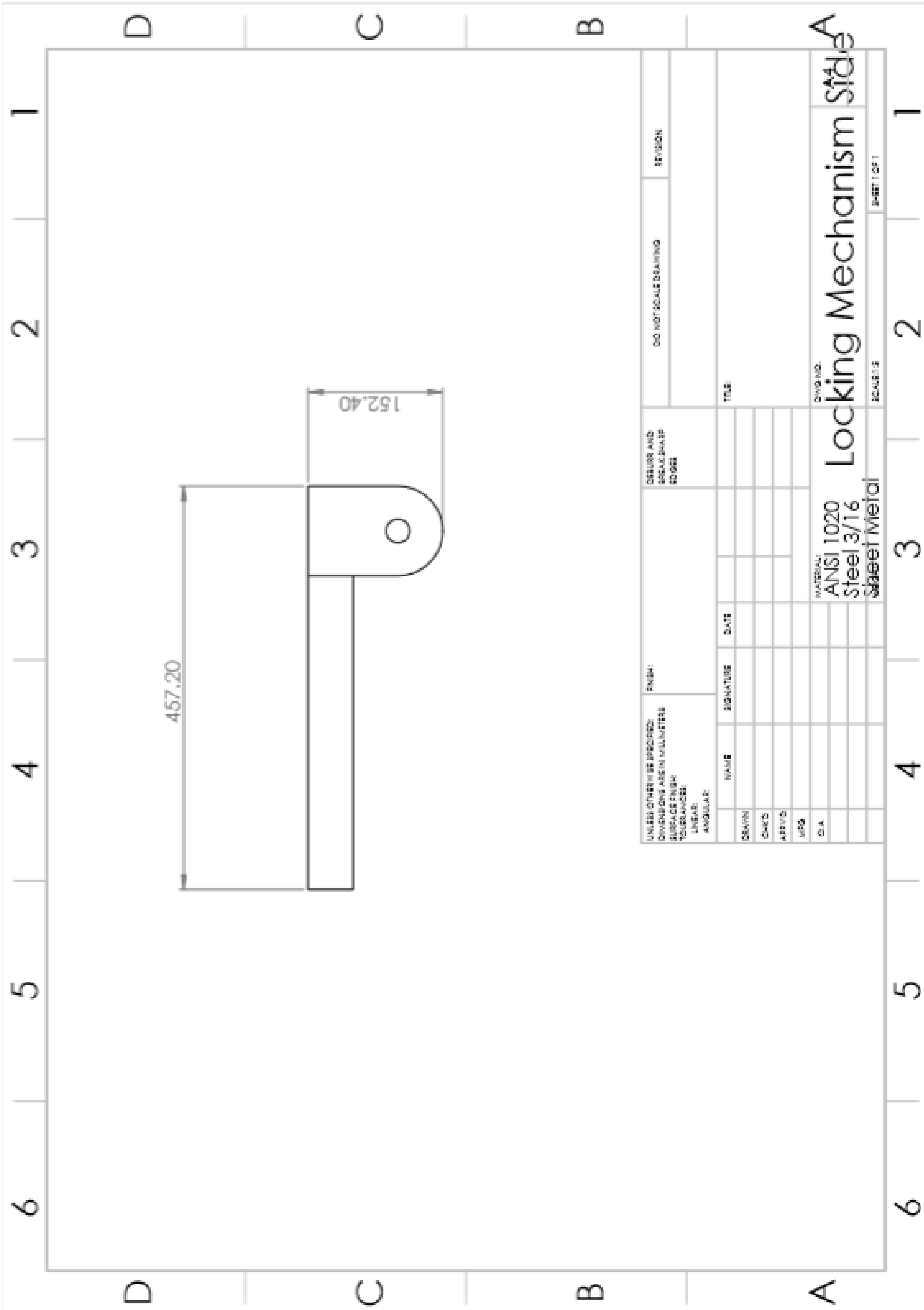


Figure A - 7: Locking Mechanism Side Bracket

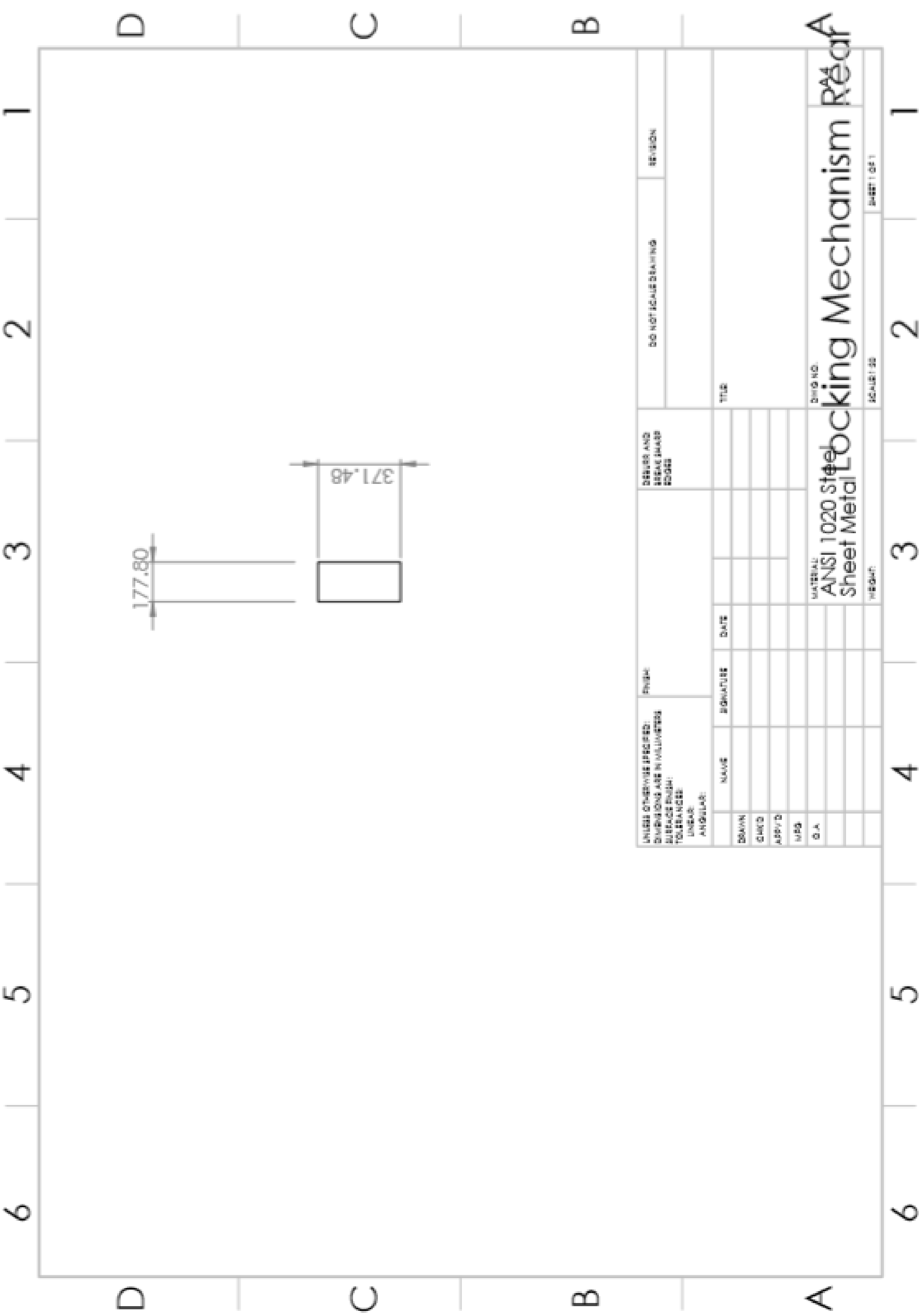


Figure A - 8: Locking Mechanism Rear Bracket

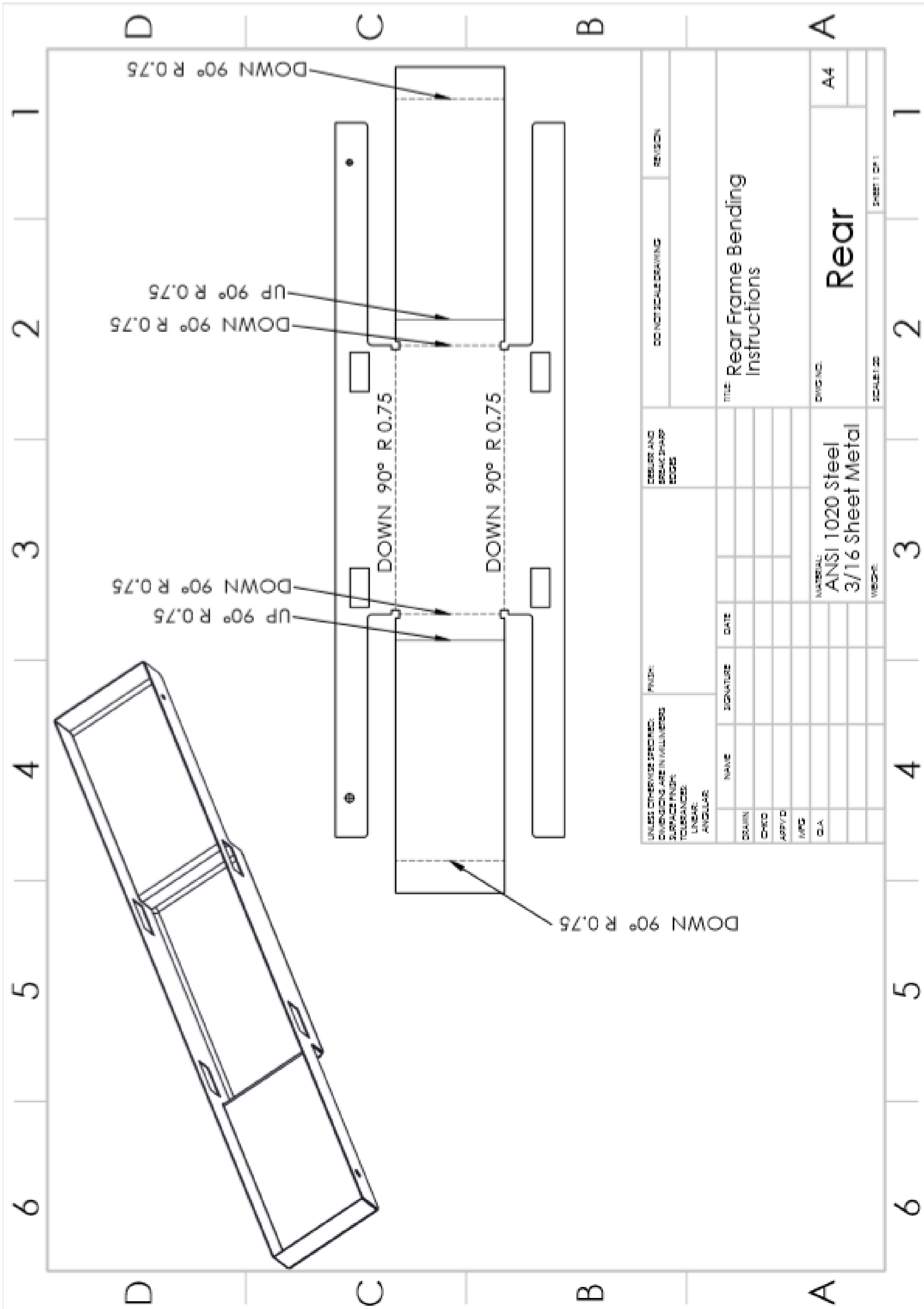


Figure A - 9: Rear Frame Bend Location

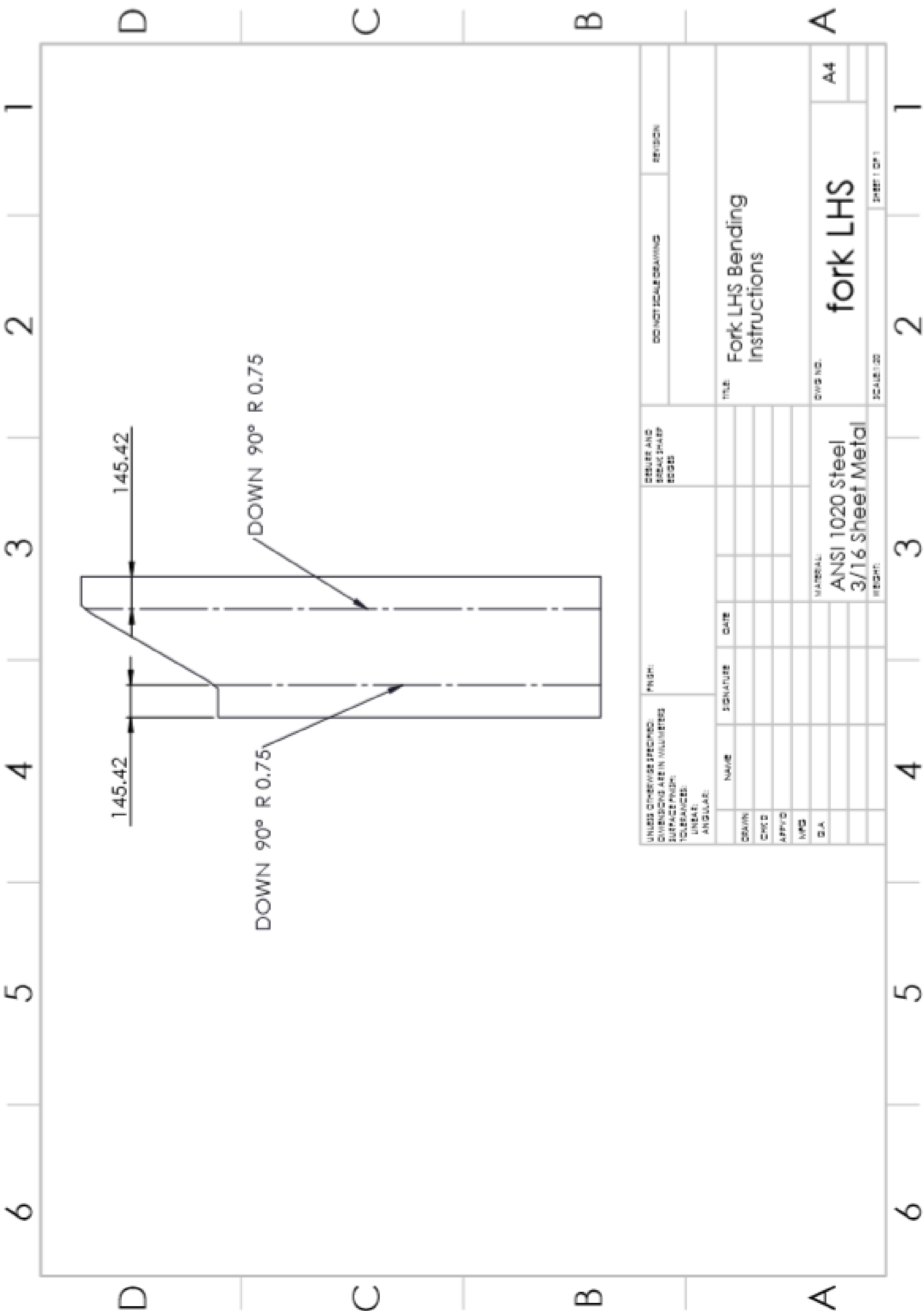


Figure A - 10: LHS Fork Bend Location

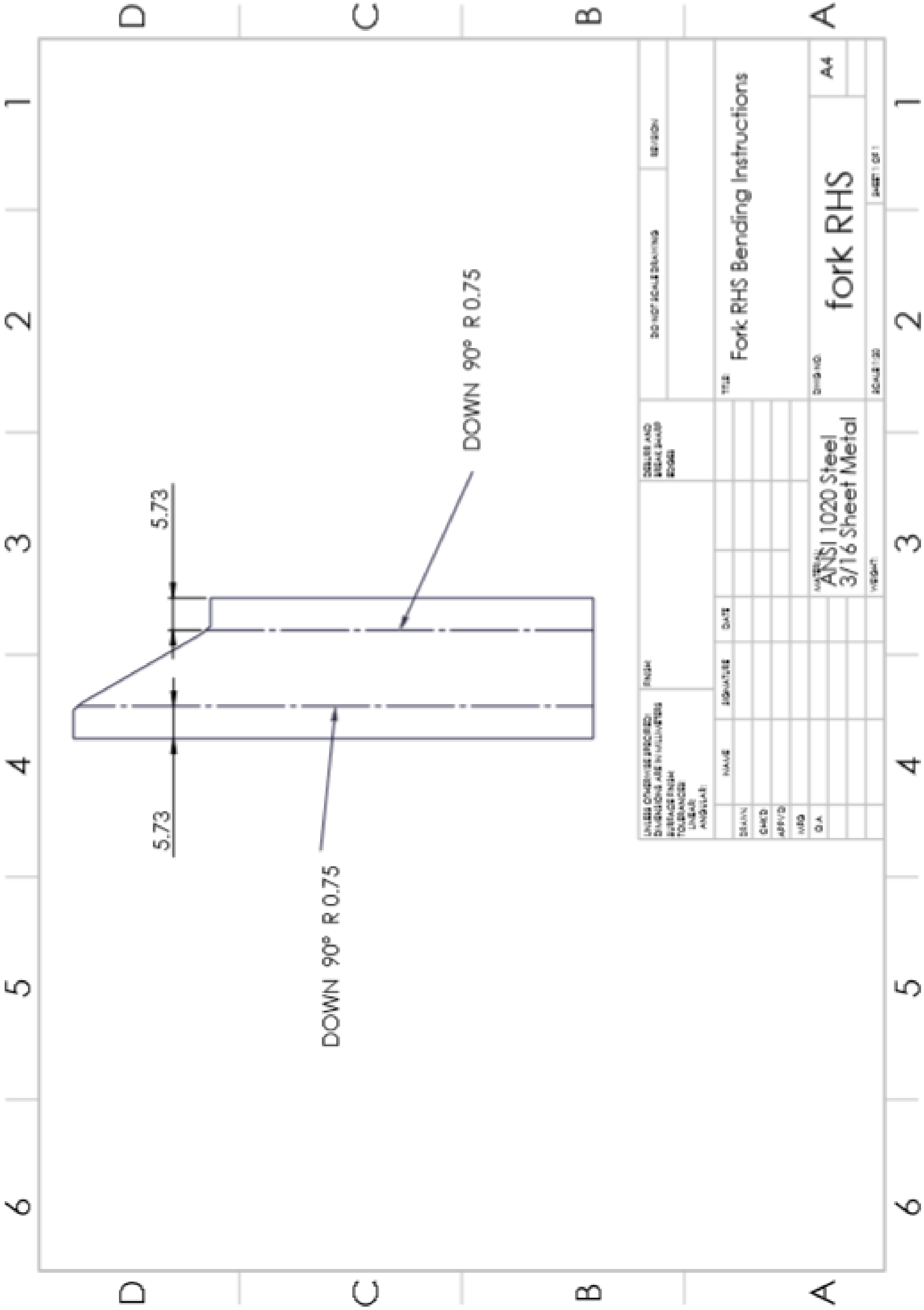


Figure A - 11: RHS Fork Bend Location

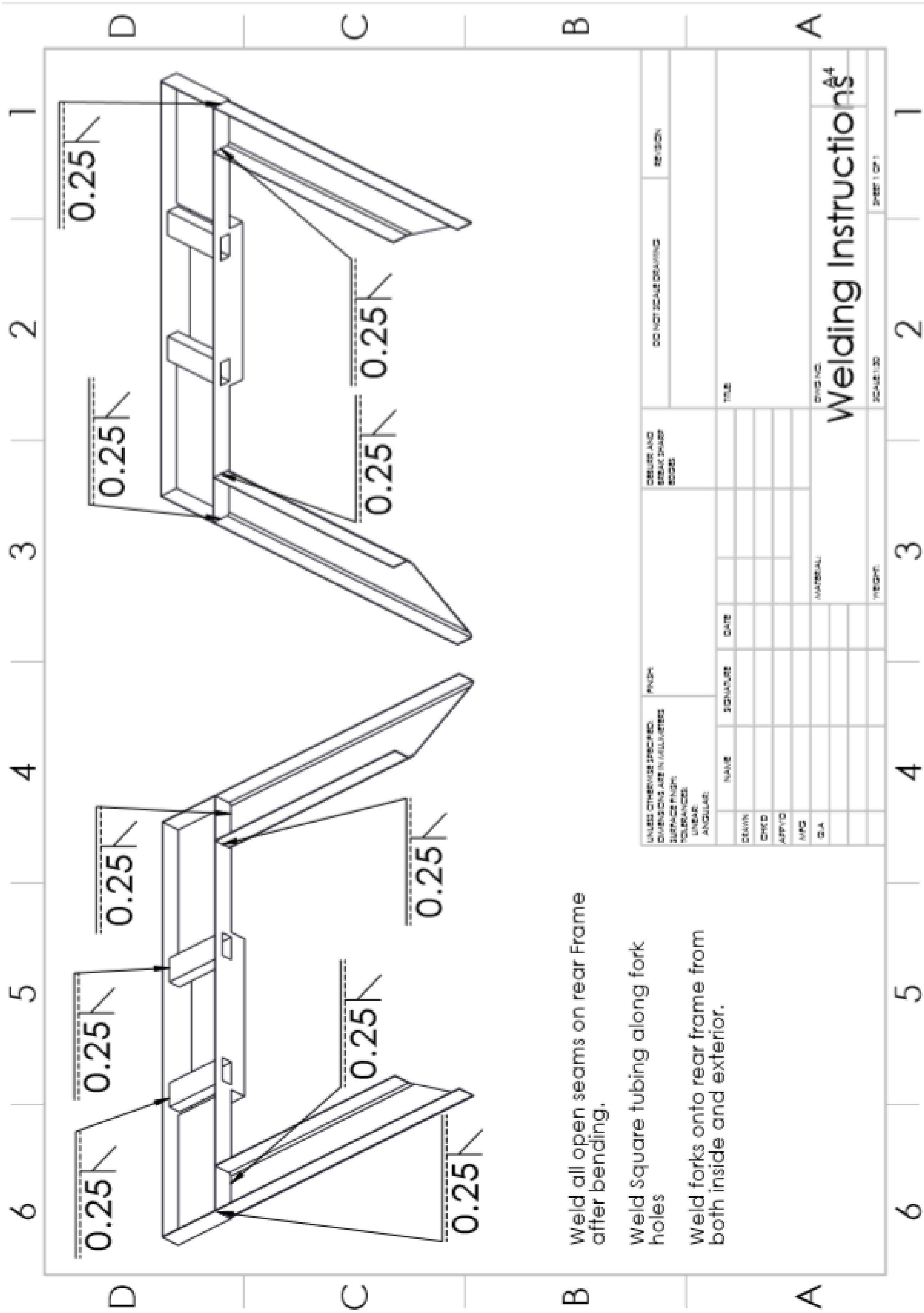


Figure A - 12: Frame Weld Locations

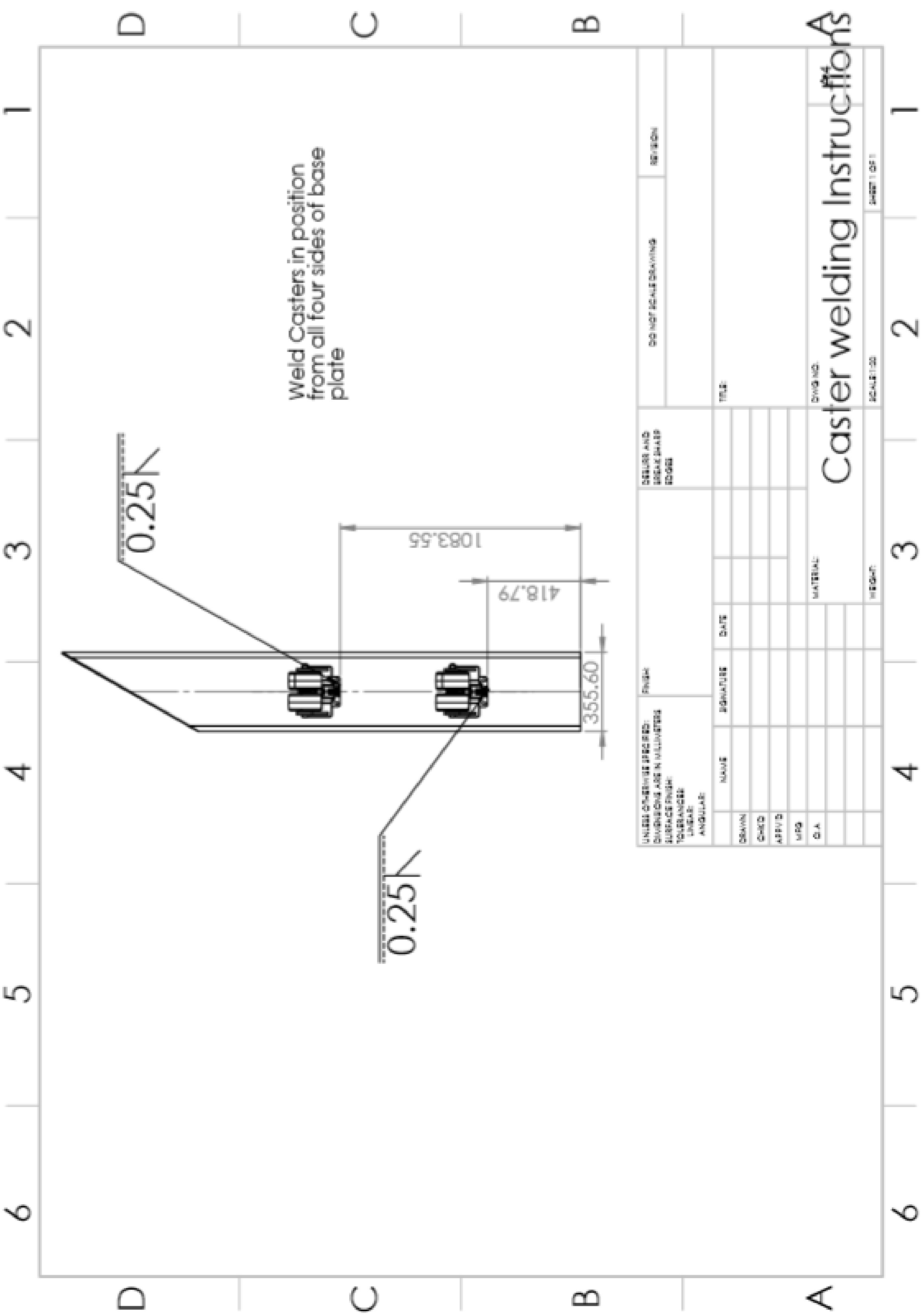


Figure A - 13: Caster Weld Location

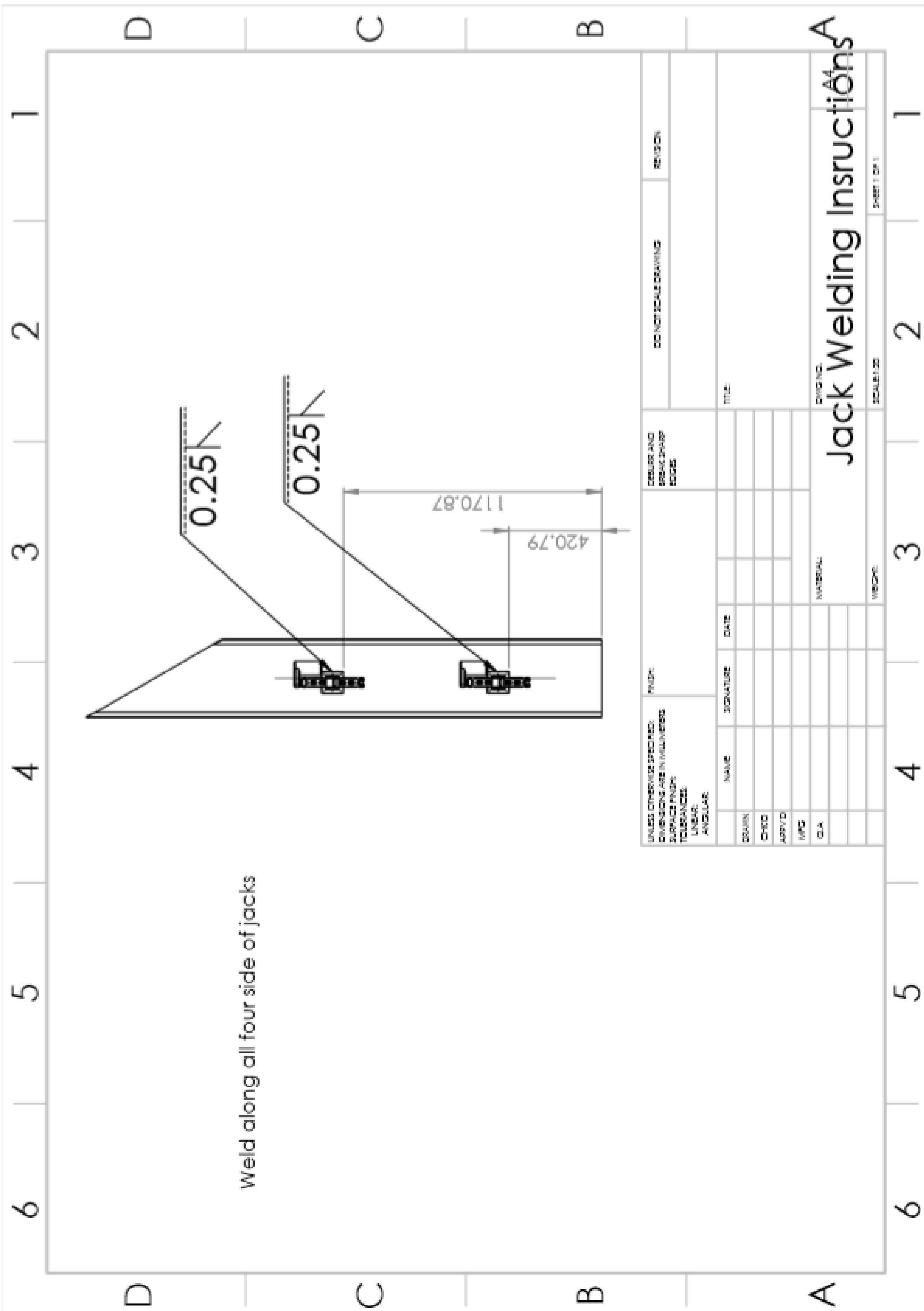


Figure A - 14: Scissor Jack Weld Location

# Appendix B: Screening and Selection of the Concepts

## List of Figures



## List of Tables

## Screening and Concept Selection

The concept screening for the 22 concepts initially generated by the team is shown in TABLE B - I, TABLE B - II and TABLE B - III.

TABLE B - I: SCREENING OF MANEUVERING CONCEPTS

| Maneuvering Concepts | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Selection Criteria** | Current Method | Forklift Hitch Attachment | Forklift Hook Attachment | Hole and Pin Fork/ Tool connection | Self-Propelled Cart | Wedge Locking Mechanism | Manually Guided Transporters | Walk behind pallet jack |
| Safety | 0 | + | + | + | + | + | + | + |
| Compatibility with Lifting method | 0 | - | 0 | 0 | + | 0 | + | 0 |
| Compatibility with alignment | 0 | 0 | 0 | 0 | + | 0 | - | 0 |
| Footprint/size | 0 | - | - | 0 | 0 | 0 | 0 | - |
| Efficiency/Time | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ease of use | 0 | + | + | + | + | 0 | + | 0 |
| Control | 0 | + | + | + | + | + | + | - |
| Cost | 0 | 0 | 0 | 0 | 0 | 0 | - | 0 |
| Sum +'s | 0 | 3 | 3 | 3 | 5 | 2 | 3 | 1 |
| Sum -'s | 0 | 2 | 1 | 0 | 0 | 0 | 2 | 3 |
| Sum 0's | 0 | 2 | 4 | 5 | 3 | 6 | 2 | 4 |
| Net Score | 0 | 1 | 2 | 3 | 5 | 3 | 1 | -2 |
| **Rank** | 5 | 4 | 3 | 2 | 1 | 2 | 4 | 6 |
| **Continue?** | **No** | **No** | **No** | **Yes** | **Yes** | **Yes** | **No** | **No** |

TABLE B - II: SCREENING OF THE LIFTING CONCEPTS

| **Lifting Concepts** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Selection Criteria** | Current Method | Crane | Four Post Rotator | Car Scissor Jacks | Winch Pulley System | Hydraulic cylinder | Screw Lift | Do not lift |
| Lifting capacity | 0 | + | + | + | + | + | + | + |
| Compatibility with movement method | 0 | - | - | 0 | - | + | 0 | + |
| Compatibility with alignment | 0 | - | - | 0 | - | + | 0 | + |
| Time to Lift | 0 | - | - | + | - | 0 | - | + |
| Cost | 0 | - | - | + | + | - | + | - |
| Safety | 0 | 0 | + | + | 0 | + | + | + |
| Control/ precision | 0 | 0 | + | + | 0 | + | + | + |
| Size | 0 | + | - | + | 0 | + | + | + |
| Sum +'s | 0 | 1 | 3 | 6 | 2 | 6 | 5 | 7 |
| Sum -'s | 0 | 5 | 5 | 0 | 3 | 1 | 1 | 1 |
| Sum 0's | 0 | 2 | 0 | 2 | 3 | 1 | 2 | 0 |
| Net Score | 0 | -4 | -2 | 6 | -1 | 5 | 4 | 6 |
| **Rank** | 5 | 8 | 7 | 2 | 6 | 3 | 4 | 1 |
| **Continue?** | **No** | **No** | **No** | **Yes** | **No** | **Yes** | **No** | **Yes** |

TABLE B - III: SCREENING OF ALIGNMENT CONCEPTS

| Alignment Concepts | | | | | | |
|---|---|---|---|---|---|---|
| **Selection Criteria** | Rail System | Side Track | Track Conveyor | Variable Height Rail Casters | Autoclave Winch | Track Support |
| Safety | 0 | - | 0 | 0 | - | 0 |
| Compatibility with Lifting method | 0 | 0 | 0 | + | 0 | 0 |
| Compatibility with movement method | 0 | 0 | + | + | 0 | 0 |
| Reliability | 0 | - | - | 0 | - | + |
| Ease of use | 0 | - | + | | - | 0 |
| Footprint/size | 0 | - | - | 0 | 0 | 0 |
| Efficiency/Time | 0 | - | + | + | - | 0 |
| Control | 0 | 0 | - | 0 | - | 0 |
| Cost | 0 | - | - | - | 0 | 0 |
| Sum +'s | 0 | 0 | 3 | 4 | 0 | 1 |
| Sum -'s | 0 | 6 | 4 | 1 | 5 | 0 |
| Sum 0's | 0 | 3 | 2 | 4 | 4 | 8 |
| Net Score | 0 | -3 | -1 | 3 | -5 | 1 |
| **Rank** | 3 | 5 | 4 | 1 | 6 | 2 |
| **Continue?** | **Yes** | **No** | **No** | **Yes** | **No** | **Yes** |

## B1: Design Combinations

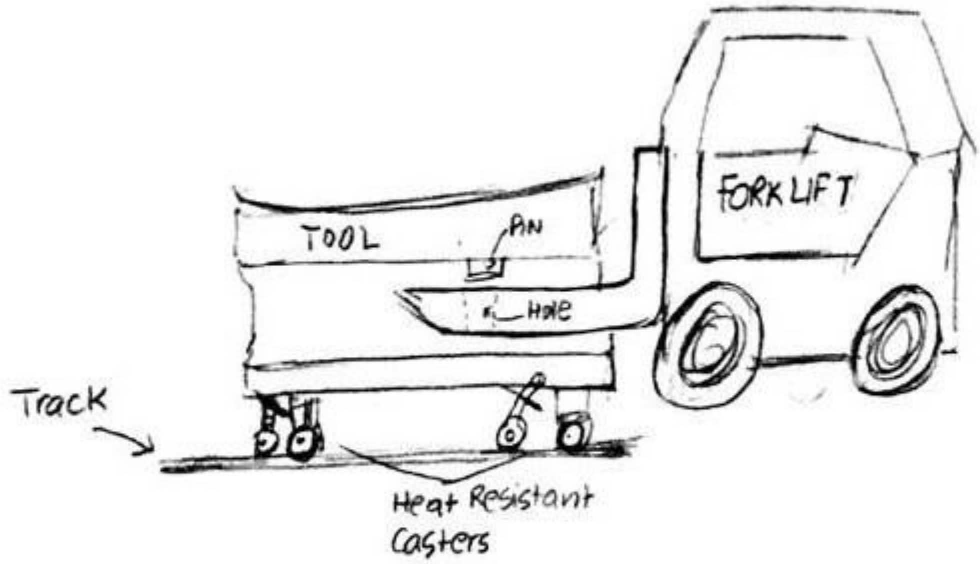


Figure B - 1: Retractable Rail Casters and Hole/Pin Locking System

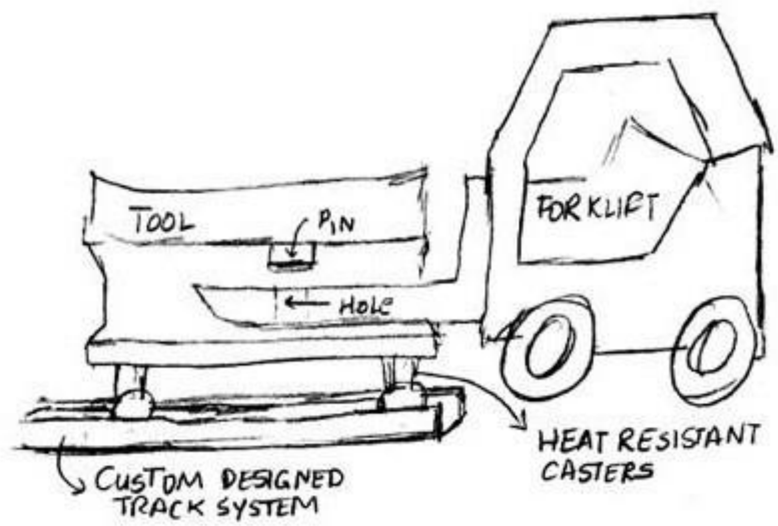


Figure B - 2 Custom Designed Track and Self-Propelled Cart

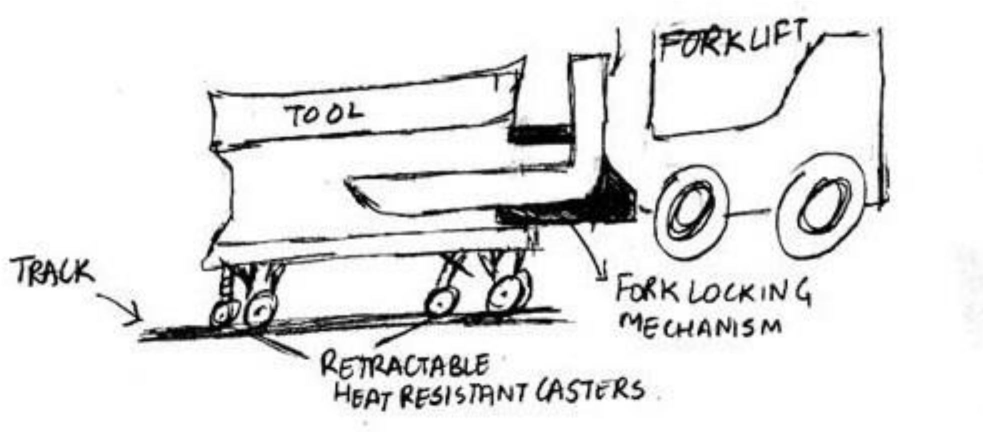


Figure B - 3: Retractable Casters and Wedge Locking System

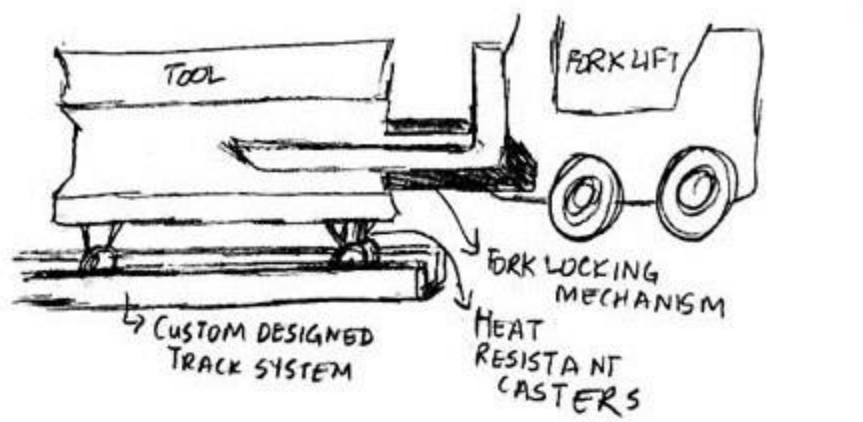


Figure B - 4: Wedge Locking System and Custom Design Track

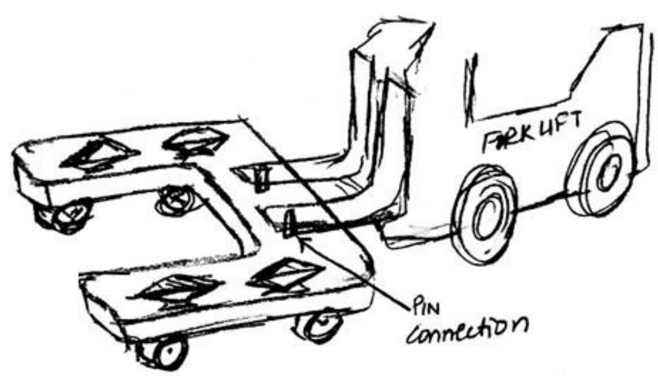


Figure B - 5: Scissor Jack Lifting Mechanism and Hole/Pin Locking System

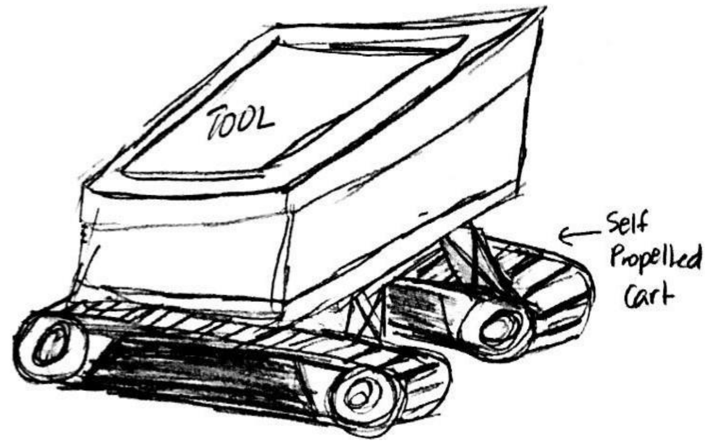


Figure B - 6: Scissor Jack Lifting Mechanism and Self-Propelled Cart

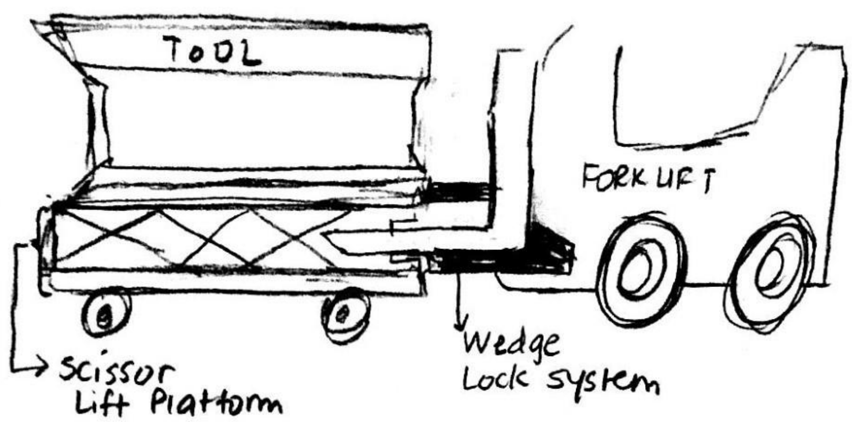


Figure B - 7: Scissor Jack Lifting Mechanism and Wedge Locking System

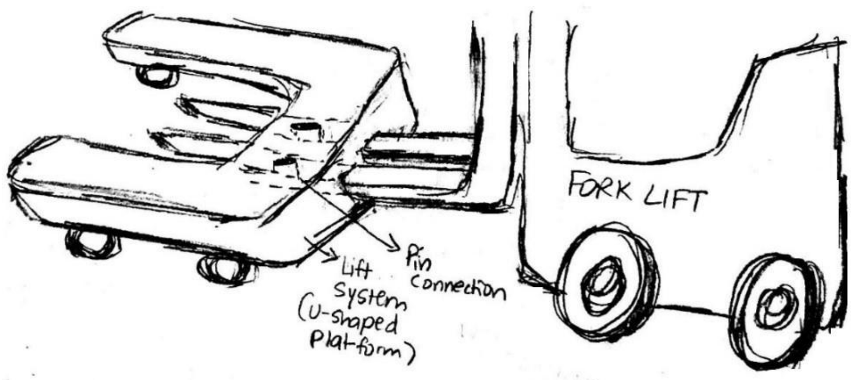


Figure B - 8: Hydraulic Cylinder Lift and Hole/Pin Locking System

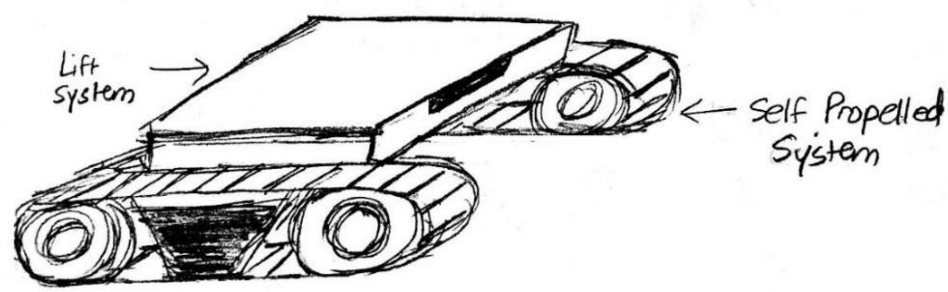


Figure B - 9: Hydraulic Cylinder Lift and Self-Propelled Cart

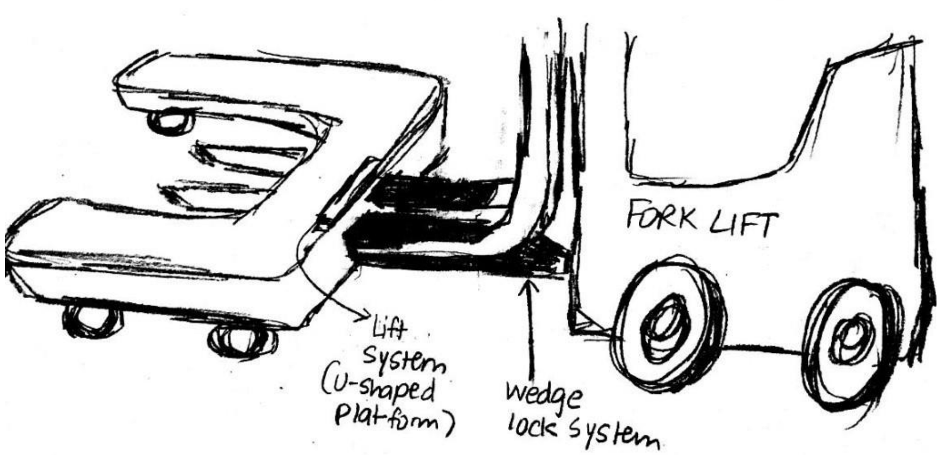


Figure B - 10: Hydraulic Cylinder Lift and Wedge Locking System

These 10 concepts above were compared using a selection matrix leading to top two designs to be obtained.

TABLE B - IV shows the list of selection criteria used to rank the design combinations. The criterion that is determined to be more important is placed in the cell, indicating a “hit”. The number of hits for each criterion is then tallied and used to weigh each criterion relative to each other. Thus, the appropriate weights for each criterion were determined.

TABLE B - IV DESIGN CRITERIA SELECTION MATRIX

| | Safety | Ease of Design | Reliability | Durability/Maintenance | Cost | Stress on Floor | Time for Entire Process | Operator Strain | Footprint/ size |
|---|---|---|---|---|---|---|---|---|---|
| Criteria | A | B | C | D | E | F | G | H | I |
| A Safety | | A | A | A | A | A | A | A | A |
| B Ease of Design | | | C | D | E | F | G | B | B |
| C Reliability | | | | C | C | C | G | C | C |
| D Durability/Maintenance | | | | | E | D | G | D | D |
| E Cost | | | | | | E | G | E | E |
| F Stress on Floor | | | | | | | G | H | F |
| G Time for Entire Process | | | | | | | | G | G |
| H Operator Strain | | | | | | | | | H |
| I Footprint/Size | | | | | | | | | |
| Total Hits | 8 | 2 | 6 | 4 | 5 | 2 | 7 | 2 | 0 |
| Weightings | 0.222 | 0.056 | 0.167 | 0.111 | 0.139 | 0.056 | 0.194 | 0.056 | 0.000 |

These criterion weights determined were used to grade the 10 concepts. The team decided to score the designs on a scale of one to five in each category; five indicates design performs well whereas 1 denotes poor performance in the given category. The final rankings for the designs are shown in Table B – V.

TABLE B - V FINAL CONCEPT SELECTION MATRIX

| Weight | 0.222 | 0.056 | 0.167 | 0.111 | 0.139 | 0.056 | 0.194 | 0.056 | |
|---|---|---|---|---|---|---|---|---|---|
| **Concept** | Safety | Durability /Mainten-ance | Ease of Design | Reliab -ility | Cost | Stress on Floor | Time for Entire Process | Opera-tor Strain | TOTA L |
| **Retractable Rail Casters and Pin Locking System** | 5 | 5 | 5 | 3 | 2 | 3 | 4 | 4 | 4.004 |
| **Custom Designed Track and Self-Propelled Cart** | 5 | 5 | 5 | 4 | 2 | 3 | 3 | 1 | 3.753 |
| **Retractable Casters and Wedge Locking System** | 5 | 5 | 4 | 2 | 2 | 3 | 4 | 4 | 3.726 |
| **Wedge Locking System and Custom Design Track** | 5 | 5 | 5 | 3 | 2 | 3 | 3 | 1 | 3.642 |
| **Scissor Jack Lifting Mechanism and Pin Locking System** | 4 | 4 | 4 | 4 | 5 | 3 | 4 | 4 | 4.087 |
| **Scissor Jack Lifting Mechanism and Self-Propelled Cart** | 4 | 3 | 1 | 4 | 3 | 5 | 4 | 5 | 3.42 |
| **Scissor Jack Lifting Mechanism and Wedge Locking System** | 4 | 4 | 4 | 3 | 5 | 3 | 4 | 4 | 3.976 |
| **Hydraulic Cylinder Lift and Hole/Pin Locking System** | 4 | 3 | 3 | 4 | 4 | 3 | 4 | 4 | 3.725 |

| Weight | 0.222 | 0.056 | 0.167 | 0.111 | 0.139 | 0.056 | 0.194 | 0.056 | |
|---|---|---|---|---|---|---|---|---|---|
| **Concept** | Safety | Durability /Mainten-ance | Ease of Design | Reliab -ility | Cost | Stress on Floor | Time for Entire Process | Opera-tor Strain | TOTA L |
| **Hydraulic Cylinder Lift/ Wedge Locking System** | 4 | 3 | 3 | 3 | 4 | 3 | 4 | 4 | 3.614 |

Based on Table B - V, the best designs were retractable rail casters and scissor lift concepts. Retractable rail casters aligning concept involved purchasing heat resistant caster and replacing all casters. Two additional smaller heat resistant caster would be used to align the tool in the autoclave and these smaller casters own height modification feature. For the locking system, a hole would be drilled into the end of the forklift and a pin would be connected to all tools.

# Appendix C: Make/Buy Analysis

## List of Tables

## Make/Buy Analysis

This section covers the make and buy analysis. The main purpose of this analysis is to compare the final chosen original design (make solution) to the off-the-shelf design (buy solution).

The details of both the designs are included in the analysis and several factors are accounted for while the comparison is made. Since the original design will be built, the cost of manufacturing (including labour cost and bill of materials) will be considered. The buy solution will be purchased from the supplier already manufactured but will need to be delivered to the facility. This means the shipping/transportation costs and lead times will need to be considered. Another common factor to consider is maintenance/ service cost, which is necessary for the design to consistently work efficiently. Some additional aspects considered are lead time and warranty of the design

Factors such as implementation strategy used which includes the training to operate the product and operating costs will not be considered since these will be roughly equal when comparing the make and buy solutions.

The costs associated with the make and buy solutions along with other factors considered will determine the most feasible and cost-effective solution. Theses compared costs and additional factors can be seen below in TABLE C - I.

TABLE C - I MAKE/BUY COMPARISON

| | Buy/ Off the Shelf Solution | Make/ Original Solution |
|---|---|---|
| **Manufacturing Cost** | N/A | $7,430.55 CAD |
| **Shipping/Transportation Cost** | TBD | N/A |
| **Maintenance/ Service Cost** | TBD | ~$500/year |
| **Lead time** | TBD | ~2 Weeks |
| **Warranty** | TBD | N/A |

Details on the shipping cost, maintenance, cost, lead time, and warranty for Combi lift's product were unattainable since Combi lift wouldn't respond to several emails and other forms of contact. Without this information Dream-Aero was unable to complete the make/buy analysis.

The team continued with the original design (make solution) and drafted a detailed cost report for that design. However, the team recommends that BCW investigate further into Combi lift’s product in addition to the original solution.

# Appendix D: Finite Element Analysis

## List of Figures

## Finite Element Analysis

Two different FEAs were performed. The first FEA is when the tool is sitting on the cart. This FEA is being used to prove the frame can handle the weight of the tool under a regular stationary scenario. Because the casters are directly underneath the scissor jacks, there is very little stress on the frame when the tool is lifted and stationary. There will only be stress on the frame when the tool is completely lowered and sitting on the top face of the forks.

The FEA was only completed on one side of the forks. All the weights will be on the forks and it would have been redundant to complete the FEA on both sides. The following loading and fixed conditions were applied to the fork.

- Fixed roller on bottom of fork
- Fixed rear
- 6000 pounds on top of fork. (half of tool weight)

These Loading Scenarios can be seen in Figure D - 1.

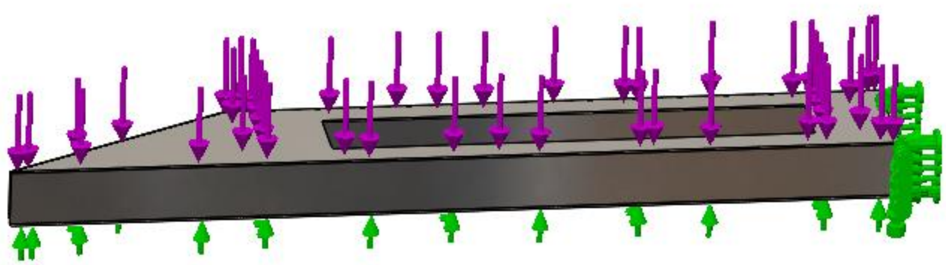

Figure D - 1: Loading Scenario

The two main area of concern for the forks are on both ends of the rectangular cut out. A sensor was created at both locations and a convergence study was completed. The locations of the sensors can be seen in Figure D-2 and the convergence study can be seen in Figure D - 5 . The stress at location 1 is 106 MPa and the maximum stress on the entire fork occurs at location 2 and is 116 MPa. The total factor of safety of the frame is 3.02

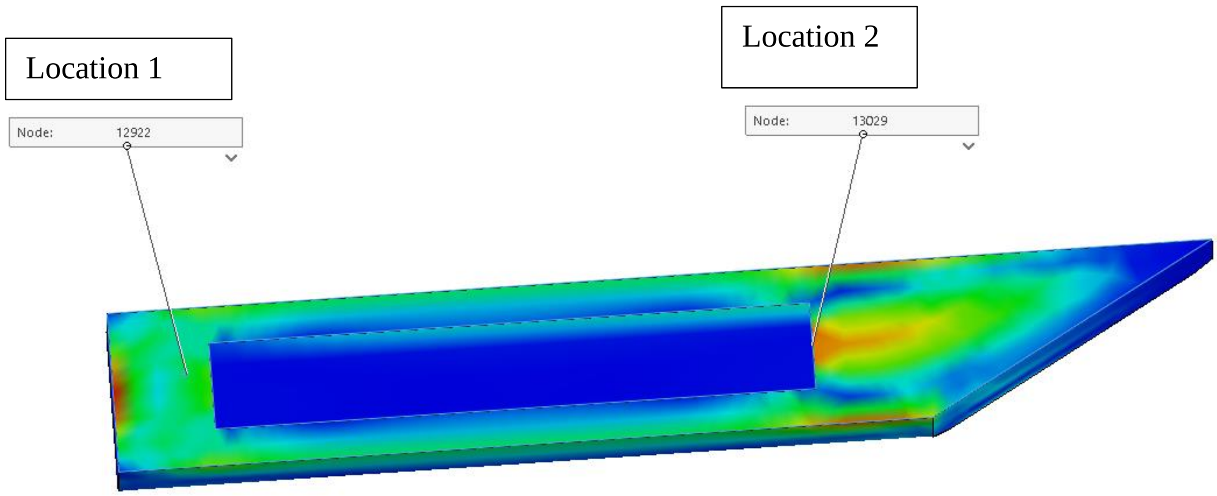


Figure D - 2: Sensor Location

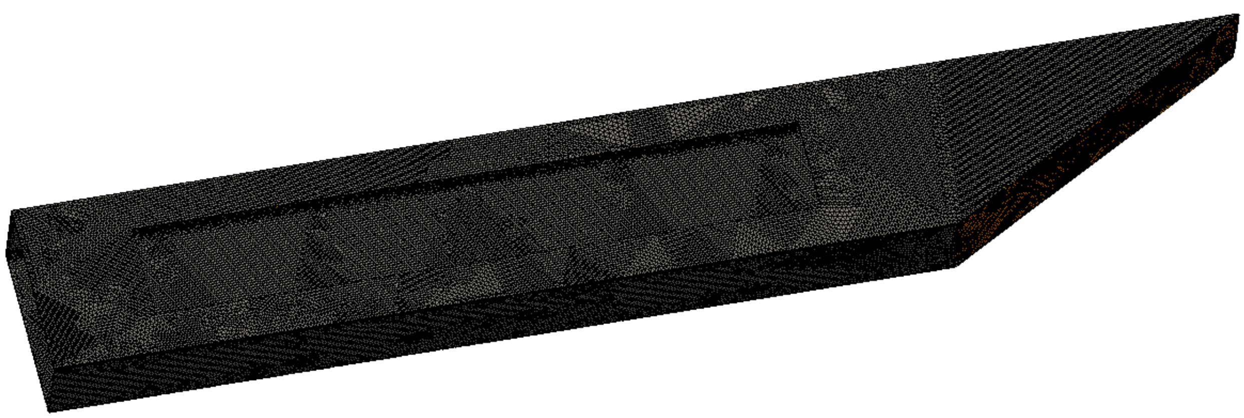

Figure D - 3:  Mesh

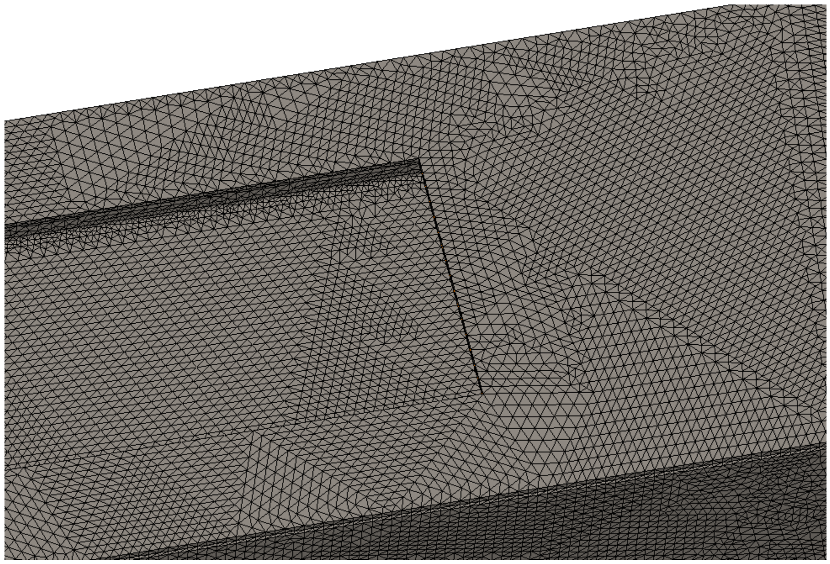

Figure D - 4: Mesh Close Up

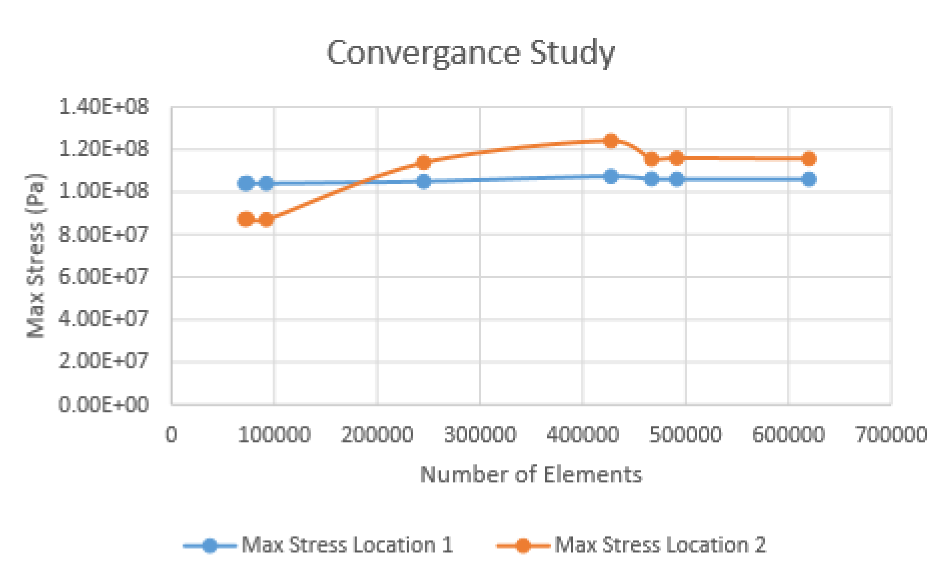


Figure D - 5: Convergence Study

The second scenario is assuming the tool is moving. When the tool is accelerating/deceleration/turning there will be torque on the scissor jacks. This torque is a larger concern since the casters underneath the scissor jacks does not support the entirety of this torque. To determine the max force on the scissor jack, we will assume worst case scenario is if the tool moves while on the cart. Because the tool is heavy this is an extremely unlikely scenario, but it does give a good method to analyze the force. To determine the horizontal force, we multiply the normal weight of the tool and multiply it by the coefficient of friction. A coefficient of friction of 0.75 was used (coefficient of clean steel). The horizontal force on an individual scissor jacks is calculated below:

$$force = 12000 * \frac{0.75}{4} = 2250lb.$$

The following loading scenarios is used to complete the FEA. This is seen in Figure D - 6

- 2250 lbs. on each scissor jack
- Roller support at caster locations
- Fixed connection between frame and fork
- Fixed support at fork hole on frame

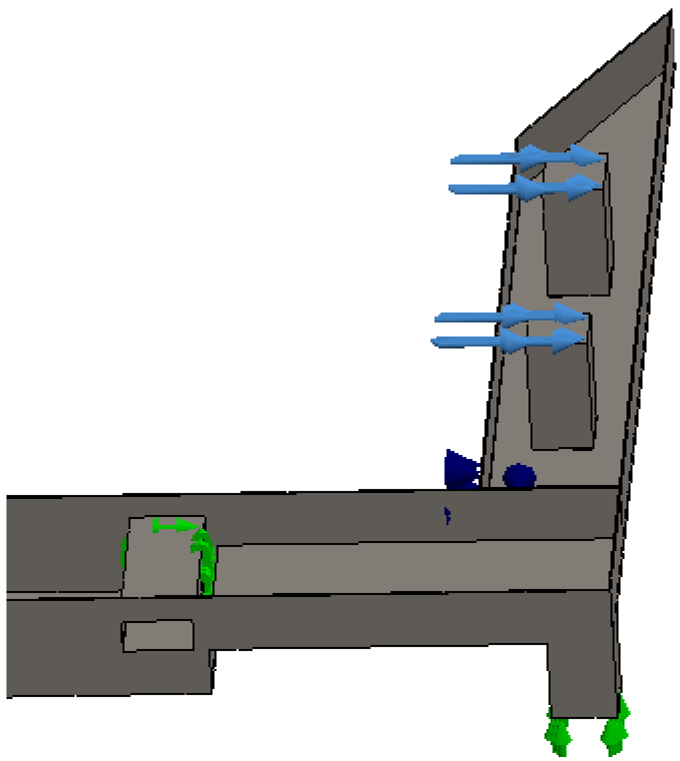

Figure D - 6: Loading Scenarios

With these loading scenarios we achieve a maximum stress of 27 MPa on the side of the scissor jack connection as seen in Figure D - 7

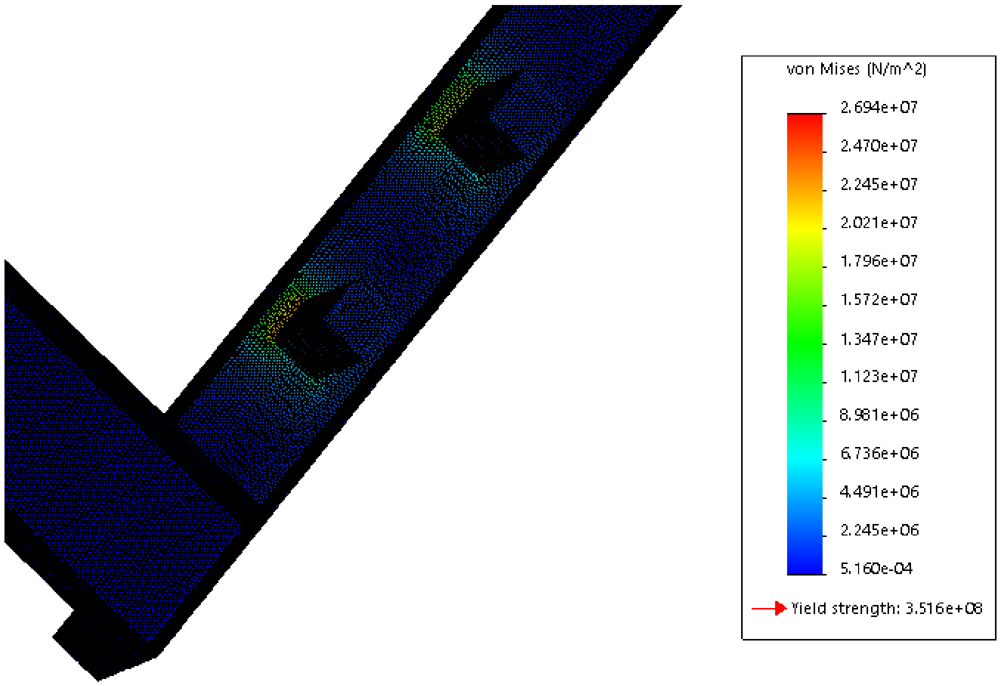


Figure D - 7: Stress Analysis

This is significantly lower than the yield strength and failure should not be a concern at these locations. This result was verified by completing a Convergence study as seen below.

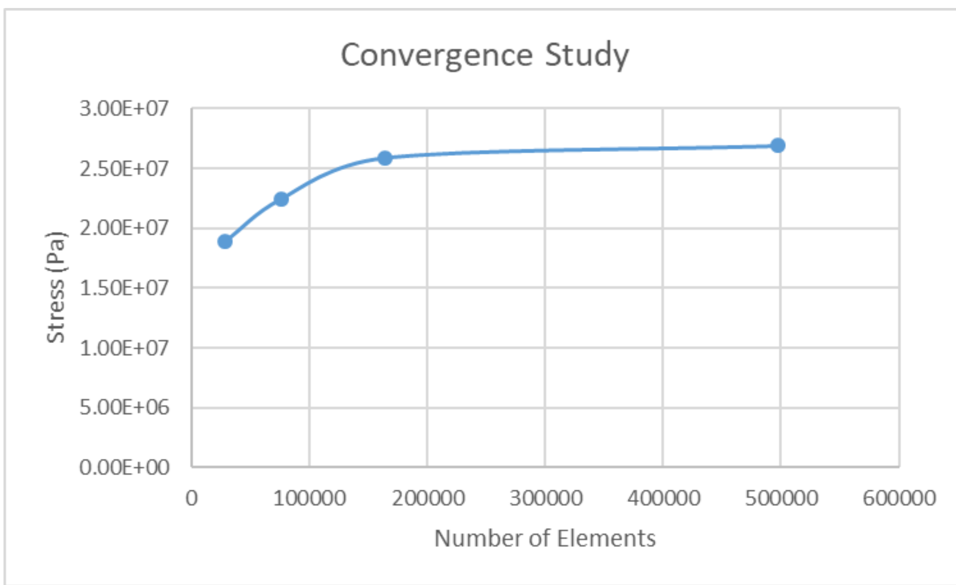


Figure D - 8: Convergence Study