Half-Barrel Planter Mover
Final Design Review Report

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Abstract

A device for transporting heavy barrel planters is needed. Barrel planters are wooden wine barrels that have been cut in half along the circumference. They are used to store and grow a variety of plants. As such, they can contain more than 300 pounds of soil. The products currently on the market are not designed for such heavy planters, are cost prohibitive, and do not take advantage of the tapered design of a wine barrel half. A solution is needed that is durable, easy to use, and low cost. This final design report will show the steps used to find a solution to the problem, beginning with research and problem definition and ending with a final design. The timeline of steps taken in completing each deliverable for this project will be discussed along with future iterations and goals.

The project culminates in the development and testing of a verification prototype which was able to successfully lift and move a planter when tested by our Sponsor. The prototype was manufactured mostly using steel tubing coupled with a manual hydraulic pump and cylinder. The hydraulic cylinder allowed the device to safely and effectively lift the heavy barrel, and the steel frame with all-terrain caster wheels allowed the device to be moved.

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1. Introduction

Our customer, Mr. Braun, bought a house and needed a way to transport his heavy planters to the new property. He also needed a way to move them around his yard and onto a truck. We approached this problem by dividing it into three parts: grabbing, lifting, and moving.
In the following sections, we will:

- Report our research.
- Define the project scope.
- Explain our process of ideation.
- Justify and detail the final design along with changes made during the manufacturing phase.
- Show the completed verification prototype and compare it with the final design.
- Provide information on testing procedures and cost.
- Go over the timeline of steps taken in completing the goals for this project, including future projections.

Our research includes the information we gathered during our interview with Mr. Braun, similar products on the market, patent searches, and relevant technical literature. Adding to material from the Scope of Work (SOW), Preliminary Design Review (PDR), and Critical Design Review (CDR), this Final Design Review (FDR) Report will cover the manufacturing processes taken to develop the verification prototype and testing procedures taken after its completion. Changes made from the CDR will be discussed along with future goals for the barrel mover device.

2. Project Background

2.1. Summary of customer observations, meetings, and interviews

In our interview with the customer, we learned that there were many reasons why Mr. Braun was seeking a novel solution to his problem. Though there are industrial planter dollies available for purchase, they may require a lot of human strength to use and Mr. Braun wants a product that does not require more than average human strength. Also, he does not want to have to lift a planter up from the bottom. Additionally, he does not want to have to tilt the barrels more than thirty degrees while transporting. There are many existing products made to lift and move chemical drums, but these are not viable solutions for several reasons. Firstly, these products are not suitable for outside use. They are not sufficiently corrosion resistant for outside storage and they are only designed to be used on the flat floor of a warehouse. In contrast, Mr. Braun is looking for a product that can be stored outside and that can transport his planters over moderate terrain. Additionally, the attachment mechanism for these products do not take advantage of the planters' taper. Finally, both the products designed for transporting large planters and chemical drums are cost prohibitive and too large. Mr. Braun would like the device to be narrow enough to transport the planters up a U-Haul ramp, arrange

the planters side-by-side, and to be stored in line with this arrangement. He would also like the manufacturing cost of the product to be no more than $150.
The customer was also interested in including several bonus functions in the barrel mover. He would like to be able to move the other heavy items he has outside using the device. He would also like the product to be able to tilt the planters horizontally for pruning.

2.2. Existing products

There are many products that accomplish the task of moving industrial drum barrels. These products come in different sizes and with different price tags, so they gave our team ideas on what would work in our design and what should be scrapped. While these lifting apparatuses are meant for drum barrels and not wine barrel halves, they were great products to study and compare to our design goals and final product. Table 2.1 shows the results of our research.

Table 2.1. List of existing barrel moving products.

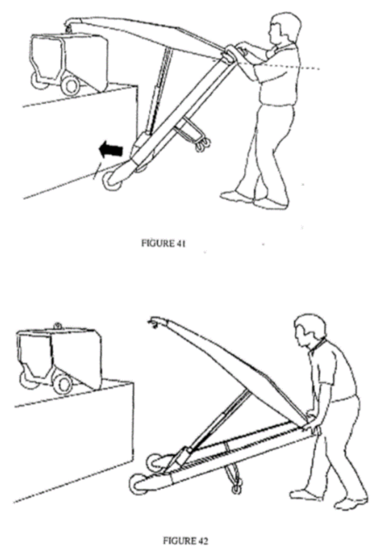
Product Name and Summary	Images
MORSE Stainless Steel Model 80i-SS [i] Figure 2.1 shows a fully mechanical solution that can lift a drum barrel using a lever arm. The barrel is attached by a semi-circular ring and a chain.	 Figure 2.1. Stainless steel device.
MORSE Model 82-H Drum Palletizer [ii] The model in Figure 2.2 utilizes a hydraulic lift to allow for grabbing and stacking of barrels. It also has an elevated wheelbase for better ground clearance.	 Figure 2.2. Hydraulically actuated palletizing device.

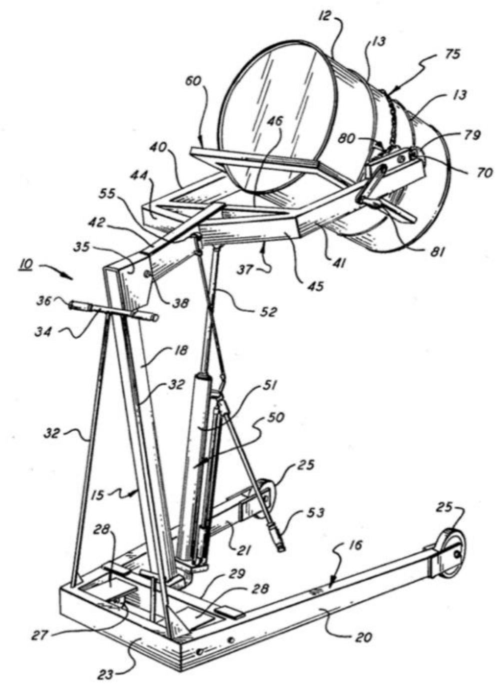
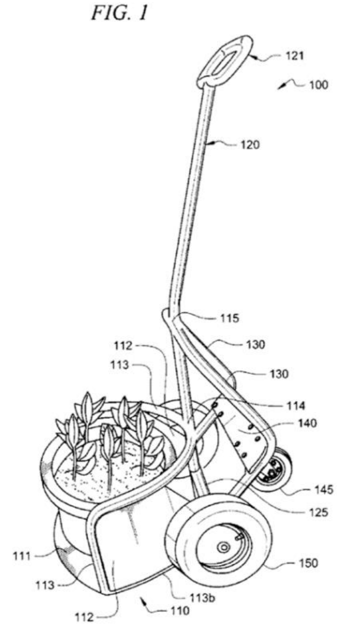
Makinex Powered Hand Truck PHT-140 [iii] Figure 2.3 shows a battery-operated lift-assist for lifting heavy items.	 Figure 2.3. Battery operated lifting device.
Global Industrial™ Portable Hydraulic Drum Lifting Jack 800 Lb. Capacity [iv] Shown in Figure 2.4 is a manually operated hydraulic jack that can fit drum barrels and lift them off the floor for easy transport.	 Figure 2.4. Hydraulic pallet jack.
Potwheelz® Industrial Garden Dolly [v] This is a dolly made specifically for use with round, heavy objects, such as potted plants. Figure 2.5 shows that the run-flat airless tires are a durable solution for many terrains.	 Figure 2.5. Dolly for cylindrical objects.

2.3. Patent search results

To avoid the risk of using another company or person's IP, we conducted a patent search into any relevant devices or parts that could overlap with our design solution. Table 2.2 summarizes our search results.

Table 2.2. Summary of patent search.

Patent Name and Summary	Images
Lifting Device (Makinex Powered Hand Truck PHT-140) [vi] Figure 2.6 shows a patent for a lifting device that allows one person to pick and place heavy items. It allows for functionally variable horizontal reach.	 Figure 2.6. Lifting device patent.

Drum Handling Apparatus (Morse Mfg. Company)[vii] The patent illustration shown in Figure 2.7 is for an apparatus for lifting, repositioning, and transporting relatively large storage drums.	 FIG. 1 Figure 2.7. Morse drum handling patent.
System and Method for Moving Objects (PotWheelz™)[viii] The patent illustrated in Figure 2.8 is for a method and system for moving round objects such as potted plants without the user having to exert a large amount of force. The user slides the object onto the dolly and then tilts the dolly to lift the object up from the ground.	FIG. 1  Figure 2.8. PotWheelz garden dolly patent.

2.4. Summary of relevant technical literature

In preparation of our design phase, we reviewed technical literature about joints with clearance and human strength limits.

Joints with clearance:

Clearances exist in real joints due to imperfections in sizing and they increase overtime due to wear. Research has been done on their effects and mathematical models have been created for their impact forces. It is suggested that the best model for joints with clearances is one in which contact forces are modeled as collision forces that are functions of continuous deformation.[ix] Many or all of the kinematic constraints of an ideal joint are replaced with force constraints. There are many models for these contact forces, but the most common is one that is non-linear, visco-elastic, and accounts for energy dissipation. In a series of reports titled “Research on Dynamics of Four-Bar Linkage with Clearances at Turning Pairs”, it was found that several factors increased the contact forces of joints with clearances.[x] These included the position of the joint, the magnitude of the clearance, the mass of the linkage, and the angular velocity of the mechanism.

Because our device will likely include joints, it may be appropriate to design for the minimization of their contact forces. Using this information gathered from this research, we can optimize the linkage weight, joint position, and the joint material to minimize wear and tear caused by unavoidable clearances.

Human strength limits:

In a study conducted by the University of Nottingham, anthropometric strength data was collected for the design of safer products.[xi] In this study, strength data was taken for participants as they performed several exercises. Perhaps the most relevant to this project was horizontally pushing and pulling a cylindrical bar oriented in the horizontal direction. The mean force and standard deviation were tabulated with gender and age. In another study it was found that generally, one can safely push approximately 20% and pull 30% of his or her own body weight.[xii] Additionally, it was found that pulling handles at 50%-65% of one’s own height posed the minimum injury risk. In a study at the University of Michigan, Ann Harbor, several injury risk factors were analyzed for different lifting techniques.[xiii] These factors were ligament strains, spinal compressive forces, and muscle moment requirements. It was found that the lifting technique with the minimum spinal injury risk was bending at the knees, keeping a straight and flat back, and keeping the object close to the body.

We expect that this information on human pulling, pushing, and lifting will pose significant constraints on the design of both the lifting and moving mechanisms for this device.

3. **Objectives**

After conducting our technical research and conducting interviews with the sponsor, we began recording and documenting the requirements for this design project. Using this information, we created a list of needs and wants as well as a problem statement that accurately encompassed the scope of the design problem for this project.

3.1. Problem statement

People who need to move heavy, half wine barrel planters around their backyards have a difficult time doing so. Currently, they move the planters by rolling them on their sides, which takes a lot of time and effort. They need a device that is compact, durable, and makes it easy to lift and transport the planters over a variety of terrain.

3.2. Boundary diagram

Boundary diagrams represent the boundaries of the design problem and show the user and elements that are important. The sketch in Figure 3.1 shows the tight arrangement of the barrels as well as the U-Haul trailer that the user would like transport the barrels in. Understanding the physical whereabouts of the components allows the problem to be visualized better.

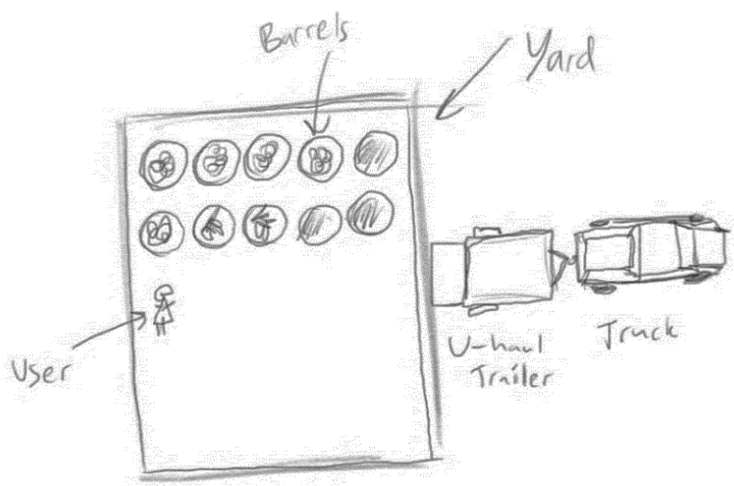


Figure 3.1. Boundary diagram showing major components.

3.3. Customer needs and wants

From the meeting with our sponsor and the information provided to our group, we were able to outline the requirements and constraints of our projects. The list below contains the necessary requirements for the project and does not include any additional bonus constraints that were asked of us by the sponsor.

Needs:

- **Usable by average strength adult** – This is a suggestive amount of strength based on what the average adult can pull/pull.
- **As narrow as possible** – This requires that the width of the product must be as narrow as possible in order to operate within a close quarters environment as well as to fit on a U-Haul ramp.
- **Survive 15 years "exposure"** – Exposure refers to general wear and tear from use as well as from exposure to the sun and the elements.
- **Cost $150 for 10x production** – $150 is a maximum. If production for 10 products costs less, then that it better.
- **Turn easily** – This requires that the product can rotate with a sufficiently small radius of curvature.
- **Deal with moderate terrain** – Moderate terrain includes dirt, light sand, and street curbs.
- **Tilt barrel no more than 30 degrees** – This requirement ensures that the planter will not spill its contents.
- **Additional requirements from Sponsor meeting:**
    - Transport barrels that are stored in the arrangement shown in Figure 3.2. They are in contact with other barrels on the back and sides.
    - Does not require pushing anything underneath the planters like a normal dolly.

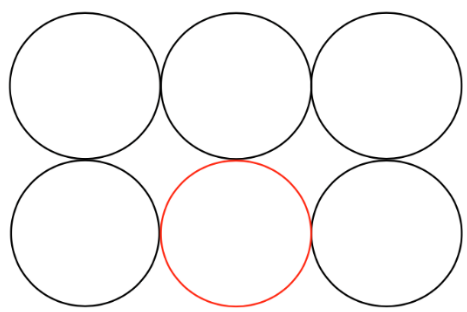


Figure 3.2. Barrel arrangement diagram.

Wants:

- **Fits up a U-Haul ramp** – This would make the planter easy to transport since the device would be able to fit up a ramp so that a U-Haul truck can be used.
- **Can rotate barrel 90 degrees** – This would give the device the ability to allow the user to prune the plants with less difficulty.
- **Detachable grabber mechanism** – This would make the device more versatile and more marketable.
- **Can be stored in line with the barrel arrangement as shown in Figure 3.3** – This would allow the user to store the device with the other barrels.

3.4. Description of QFD process

To start the quality function deployment "house of quality" (QFD) process we first listed all our customer's wants and needs on the left-hand side. After evaluating them for their importance, we determined engineering specifications that would provide quantitative answers to the qualitative requirements we had determined. Then, each quantitative measure was rated to each qualitative measure. After this, we selected 4 competitors and measured how they scaled to the qualitative and quantitative specifications. Finally, we came up with numerical constraints for the quantitative specifications. The full QFD is attached in Appendix A. Using the QFD, we were able to derive a list of specifications, which are described in Section 3.5.

3.5. Specifications table

Table 3.1 shows each project specification as well as its respective tolerance and target value. The hardest part of this project will be designing this product to be operable by an average strength adult and being able to lift the planter over curbs. These specifications can also be found in the QFD in Appendix A at the end of this report.

Table 3.1. Engineering specifications chart derived from QFD.

Spec	Parameter	Target	Tolerance	Risk	Compliance
A	Human Strength Percentile (%)	50%	Max.	H	A
B	Width	28 to 30 inches	Max.	M	T
C	Weight (lbf)	50 lbf	+/- 5 lbf	L	T
D	Height (in)	72 inches	+/- 6 in	L	T
E	Depth (in)	28 to 30 inches	Max.	L	T
F	Life (yr)	15 Years	Min.	M	A
G	Cost ($)	$150 each	Max.	M	A
H	Turn Radius (in)	12 Inches	Max.	L	I
I	Necessary Tilt Angle to Transport (degree)	30 Degrees	Max.	H	I
J	Maximum Incline (degree)	20 Degrees	+/- 5 degrees	L	I
K	Maximum Angle Barrel Can Be Rotated (degree)	90 Degrees	Max.	L	I
L	Modular Components (Y/N)	Yes/No	N/A	L	I
M	Impulse to overcome step (lbf/s)	50 (lbf/s)	+/- 5 (lbf/s)	H	A

- **Specification A** is the required human strength percentile of the user to operate the device. The target value of this strength percentile, X, is below 50% so that an adult of average strength may operate the device. This specification encompasses every type of motion required for operation, such as lifting, pulling, and overcoming bumps in the ground. The anthropometric strength data for the motion required can be found from studies done by the military and universities such as from sources xi.
- **Specification B** and **E** are the width and depth of the product. These are constrained by the want of the sponsor to be able to store the device inside the barrel arrangement. Figure 3.3 shows the front view of this storage arrangement and Figure 3.4 shows the top view. As can be seen in Figure 3.4, the width and depth can be as large as 30 inches

at the ground due to the barrels' taper. However, they must not exceed 28 inches in width or depth at the top of the planter and upwards.

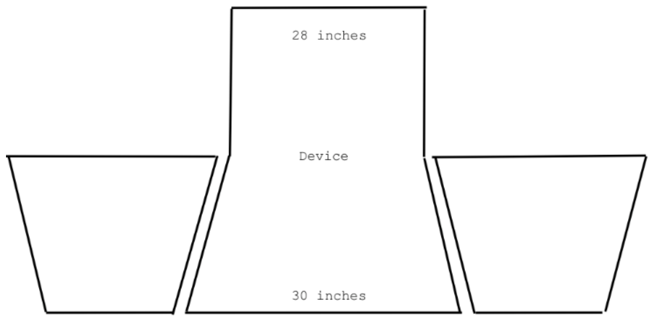


Figure 3.3. Front view of the device stored in the barrel arrangement.

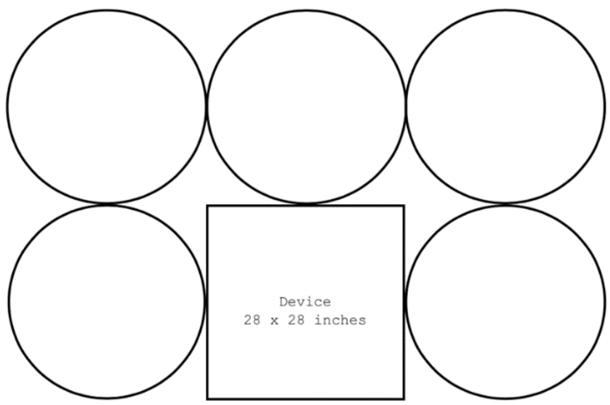


Figure 3.4. Top view of the device stored in the barrel arrangement.

- **Specification F** is the lifetime of the product without any repairs or maintenance and while stored outside. This is required to be a minimum of 15 years by the project sponsor.
- **Specification G** is the cost to manufacture one device if a total of 10 are made. This is required to be a maximum of $150.
- **Specification H** is the turn radius of the device measured from the middle of the inner and outer wheels. The turn radius can be a maximum of 12 inches, meaning that the device must be able to rotate about an axis that is 12 inches from the center axis of the device.

- **Specification I** is the maximum angle from the central axis that the half-barrel planter can be rotated while being transported by the device. This is necessary to keep the contents of the barrel from spilling.
- **Specification J** is the maximum incline angle that the device can safely and functionally move and operate on. This would be a factor when it comes to what ramp is used to move the planters up into a transport vehicle.
- **Specification K** is the maximum angle that the barrel could be tilted while not being transported. This would mean that the planter should never be rotated more than 90 degrees past its vertical axis.
- **Specification L** is whether the function of having a modular mechanism on the device exists. This could mean that the device would allow for removable and adjustable components so that it could lift and transport other objects such as a beehive box.
- **Specification M** is the maximum impulse force required to overcome a standard street curb. This force would be exerted by the user to cause the device and the half-barrel planter to roll over a curb.

3.6. Specification measurement process

The following descriptions show how we plan to measure the various specifications mentioned in Section 3.5:

- **Human Strength Percentile:** Test device with a variety of human operators.
- **Width:** Measure using a tape measure, use CAD model dimensions.
- **Weight:** Weigh on a scale, use CAD model and material properties to derive weight.
- **Height:** Measure using a tape measure, use CAD model dimensions.
- **Depth:** Measure using a tape measure, use CAD model dimensions.
- **Life:** Calculations using material property tables, fatigue, Design II type component calculations.
- **Cost:** Part estimates from suppliers, labor estimates, quotes from manufacturers.
- **Turn Radius:** Measure with a tape measure, use CAD model.
- **Necessary Tilt Angle to Transport:** Measure using a plumb bob and protractor or phone level app, lever calculations.
- **Maximum Incline:** Center of mass calculations with FBD, build an adjustable ramp to test product.
- **Maximum Angle Barrel Can be Rotated:** Measure with phone level app.
- **Modular Components:** Visually inspect to see whether components are removable.
- **Impulse to Overcome Step:** Design a series of various sized steps, pull with spring scale until force to overcome is found.

4. **Concept Design**

This section will discuss the steps taken to come up with an initial design, find components, form a manufacturing plan, and note changes made up to the final model.

4.1. Initial considerations

The approach to this design problem was to determine the best solutions for 1) securing and 2) lifting the barrels independently. For the overall design, the best solutions that worked together were chosen. Appendix B showcases all the design ideas we had. For the purposes of this report, we will only focus on the most promising ideas and/or most interesting ideas presented.

Securing methods:

Figure 4.1 shows the top five grabber designs under consideration for our device. The factors that we are considering most for the grabbers are the stability that they can provide as well as their ease of use. The stability of the method of attachment is a concern because even though the barrels themselves are symmetric, the plants inside them may not be. This may lead the barrels to tip over.

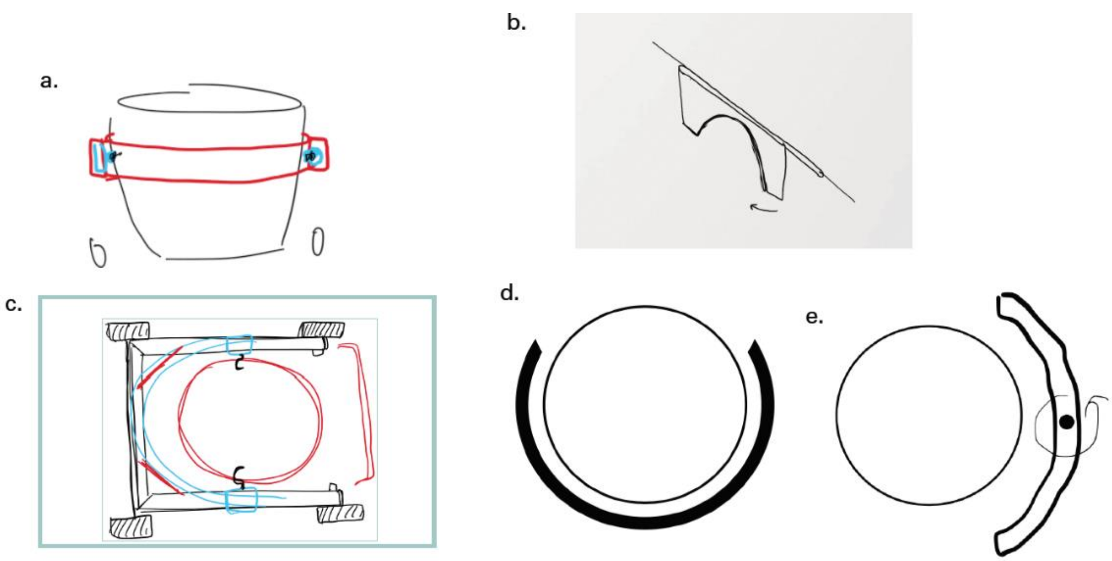


Figure 4.1. Top five initial grabber designs.

In grabber **(a.)** the barrel is secured by straight prongs going through eyes on either side of the barrel, which are part of a harness. One of the drawbacks to this design is that it would require the user to transfer this harness from barrel to barrel in order to transport them. Additionally, this may not be a very stable method of securement, depending on how tight the fit is between the eyes and the prongs. If the eyes had depth, this would make the securement more stable, but it would make the method more difficult because the harness and the prongs would have to be placed perfectly to fit.

Unlike grabber (a.), grabber **(b.)** utilizes curved prongs instead of straight prongs to secure the barrel. This eliminates the need for the barrel harness and provides more stability than grabber A because more area is in contact with the barrel. In order to fit around the barrel, these curved prongs would need to rotate about their long axis.

Similarly to grabber (a.), grabber **(c.)** would require a barrel harness with eyes on either side. However, in this design, the barrel is secured by hooks going through the eyes instead of straight prongs. The barrel is easier to secure using this method because the user does not need to place the harness around the barrel as accurately for the hooks to fit in the eyes. However, it would provide much less stability. Depending on the symmetry of the plant inside the barrel, the barrel could tip over.

Grabber **(d.)** is a curved attachment that extends slightly past a semi-circle. It can secure the barrel by going around it near the base, where the diameter is its smallest. Then, it can slide up to where it fits snugly around the barrel. This design is appealing because it would not require a barrel harness or rotating the prongs, like grabber (b.) does. However, because the taper angle is small, the grabber would not be able to extend very far past a semicircle to be able to fit around the barrel at its smallest diameter. This is concerning because the barrel could fall out the front of the grabber if the grabber can deflect.

Similarly to grabber (b.), grabber **(c.)** uses two curved prongs (only one shown in the figure) to secure the barrel. However, instead of rotating about their long axis, the swivel about their middle to allow the barrel to go between them. This method of securement is appealing because it provides very good stability and is relatively easy to use. In a small-scale LEGO prototype shown in Section 4.3, Figure 4.4, the grabbers swivel open and closed automatically when they are pushed around the barrel.

Lifting methods:

Figure 4.2 shows the top lifting methods under consideration. The factors under consideration for the lifting methods are their cost, durability, and ease of use.

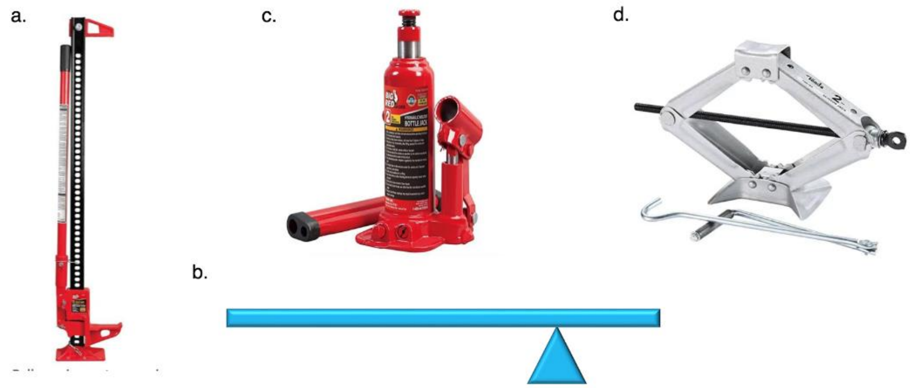


Figure 4.2. Top five lifting methods.

Lifter **(a.)** is a ratcheting lever. The user would lift the barrel in increments by pulling the lever down over and over. The advantage of lifter (a.) over lifter (b.) is its ease of use. Instead of having to exert a lot of force or use a very long lever, the user could lift the barrel more comfortably. However, one of the disadvantages is that it is more costly than the other lifters, at around $60 for one. Additionally, it is not very durable because the linear track is made of stamped metal.

Lifter **(b.)** is a simple lever. The user would push or pull the long end of the lever downward to lift the short end, which would be attached to the grabber. At the fulcrum, the lever would be attached to the frame of the device. Though the simplicity of this method is appealing, it was determined that a person of average strength would have to push or pull the lever five feet downward to lift the barrel six inches. This means that the lever would need to be very long and the user would need bend over to push the lever down enough. Because this lifting method would be so difficult to use, we abandoned this lifter idea in favor of lifter (a.).

Lifter **(c.)** is a bottle jack. This lifting method uses hydraulics to lift the jack. Similarly to lifter (a.), this design uses a lever and allows the user to lift the jack incrementally. This method of lifting has several advantages. It is low cost, with a cheap one costing about $13. Because all the components are sealed from the outside, it is also very durable.

Lifter **(d.)** is a scissor jack. This lifting method works by rotating a screw that lifts or lowers jack by pushing the sides closer together or further apart. This method of lifting is low cost, with a cheap one costing about $20. However, it is not very durable because it is made from stamped metal. Additionally, it is not as easy to use as lever (a.) because cranking is more difficult than pulling a lever.

Lifting layouts:

After the best lifting and grabbing methods were determined, good combinations of each were thought of. It was noticed that all these combinations had one of the lifting layouts shown in Figure 4.3. Each of these layouts have benefits and drawbacks. The factors under consideration for these layouts are stresses they impose on the device and the geometric problems they pose for the alignment of the barrels.

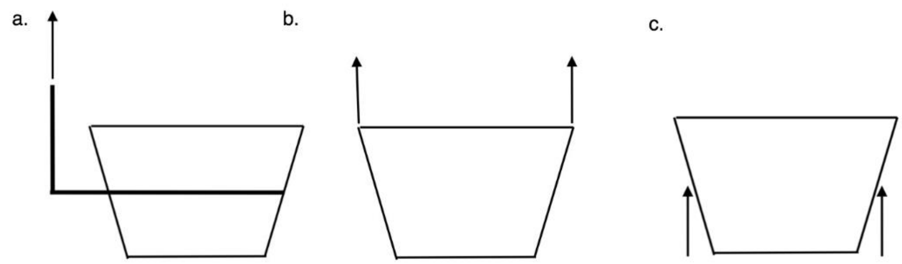


Figure 4.3. Lifting mechanism layouts.

Layout **(a.)** is lifting the barrel from the top with a moment arm. This layout would allow the device to lift the barrel at any point along its length. Because of this, the grabber would be able to secure the barrel without encountering the other barrels next to it. However, because of the moment arm and the large weight of the barrel, the device would have a very high bending stress.

Layout **(b.)** is lifting the barrel from the top directly without a moment arm. The benefit of this layout is that the device wouldn't have any stresses due to a bending moment. However, because the barrel would need to be secured at the top, the grabber would almost certainly encounter the other barrels.

Layout **(c.)** is pushing the barrel's sides up from the ground. The benefits of this layout are that there wouldn't be a bending moment due to a moment arm in the device as well as that the lifter and grabber would not necessarily get in the way of the barrels on either side. However, the drawback of this layout is that both the lifter and grabber would have to be extremely narrow as to fit in the space between barrels. This is only as wide as four inches at the barrels' base.

With all these preliminary ideas, all that was left to do was decide on which was the most feasible for this project.

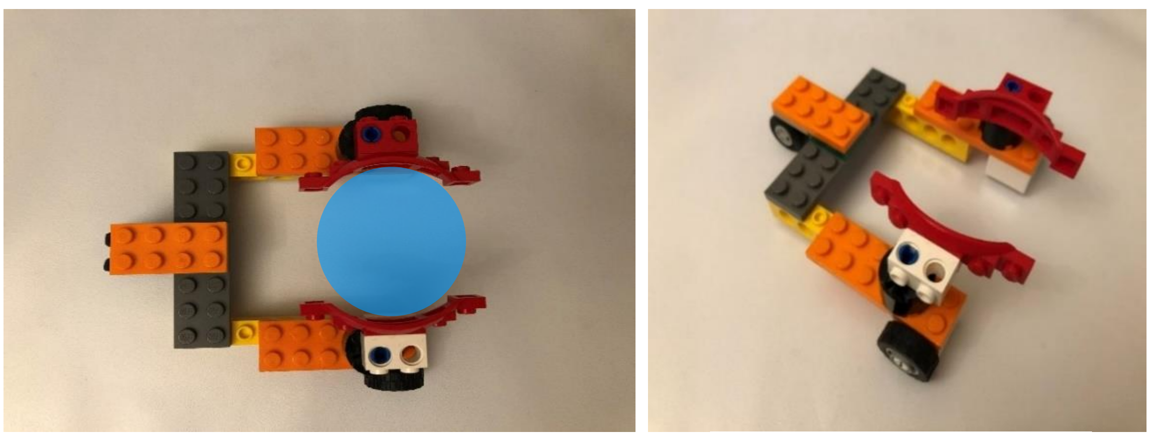
4.2. Decision matrices

To narrow down our variety of design ideas, we employed the help of decision matrices, which can be found completely in Appendix C. Using these, we determined that the best combination of grabber, lifters, and layout were Grabber (e.), Lifter (c.), and Layout (c.), shown together in Figure 4.4.

Figure 4.4. Decision matrix output.

4.3. Grabber mechanism physical model

Figures 4.5 shows the a) top view and b) perspective view of our LEGO prototype. We made this physical model to ensure the validity of the rotating grabber arms. This prototype was tested on a small can of WD-40 to see how the arms would rotate around a cylindrical object.



a) Top view b) Perspective view

Figure 4.5. LEGO model of grabber arms. Blue circle represents WD-40 can.

4.4. Initial PDR CAD model

This section shows our proposed PDR concept model. Figure 4.6 shows the CAD model in isometric view while Figure 4.7 shows the CAD model from the front, left, and top plane. In Figures 4.8, 4.9, and 4.10, specific dimensions are given for the key components of the device. These dimensions were explicitly chosen to fulfill the constraints of the problem. For example, the wheels have a width that would fit between two edge-to-edge half-barrel planters. The arms are tapered and designed to grab the barrel at half its height.

Figure 4.6. Isometric view of CAD model for
PDR.

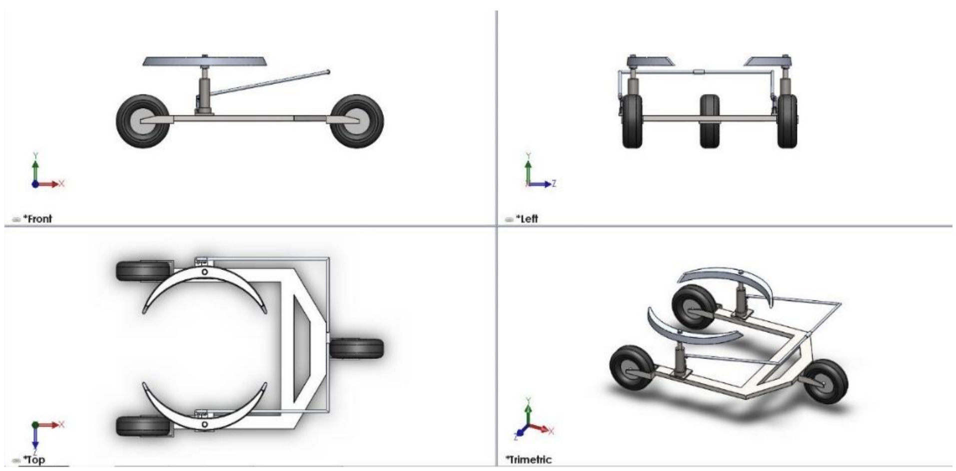


Figure 4.7. 3-Plane and trimetric view of PDR model.

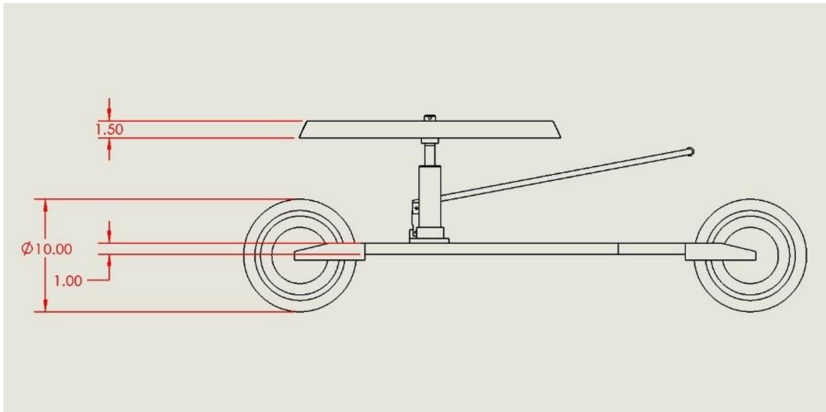


Figure 4.8. Side view PDR drawing with dimensions in inches.

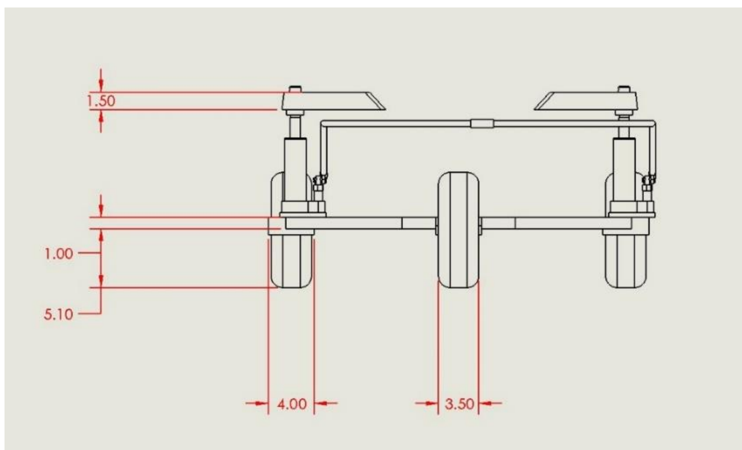


Figure 4.9. Rear view PDR drawing with dimensions in inches.

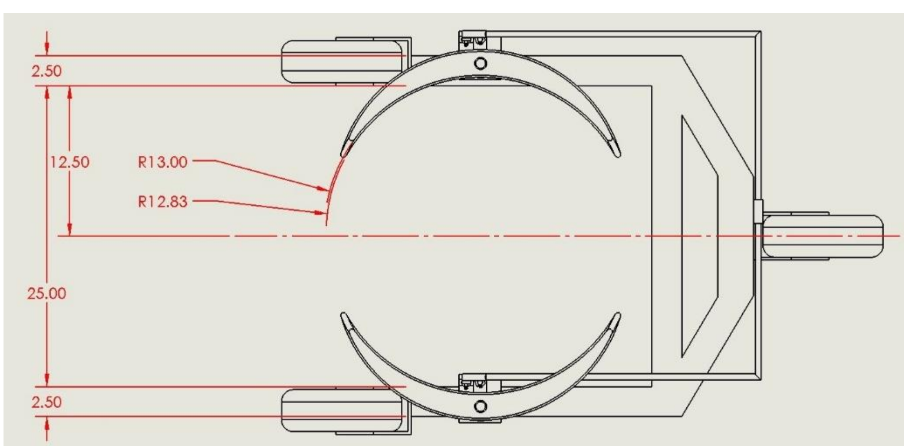


Figure 4.10. Top view PDR drawing with dimensions in inches.

Figure 4.11 shows the important components of our design for the device. This includes the location and addition of the curved grabber arms, hydraulic jack, and large jack handle. Figure 4.12 shows a render of the materials planned to be used for the device and the reasoning for each chosen material. The device requires high friction and strength at the grabbers, so aluminum arms and rubber pads are selected. The rest of the design uses cost-effective materials and components that minimize costs while providing enough strength for the device to lift and transport the half-barrel planter.

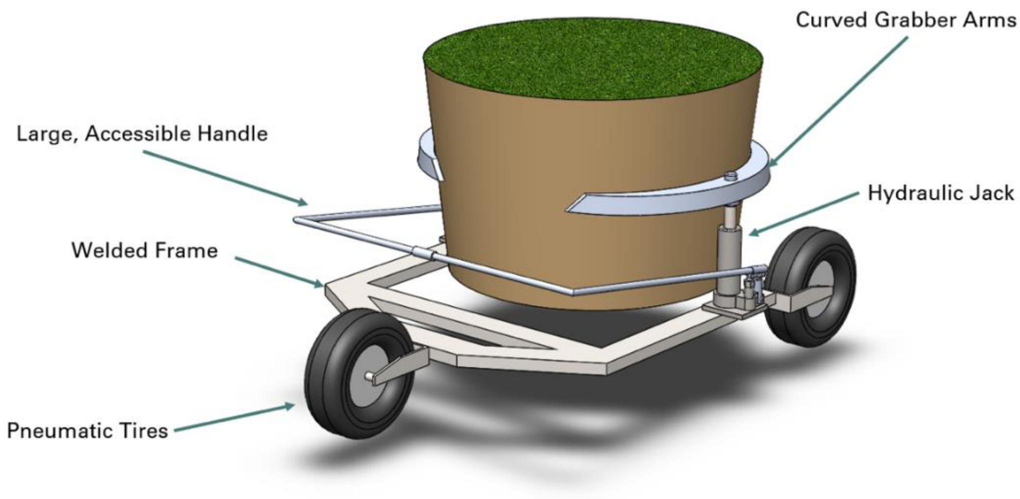


Figure 4.11. Major components of the PDR concept model.

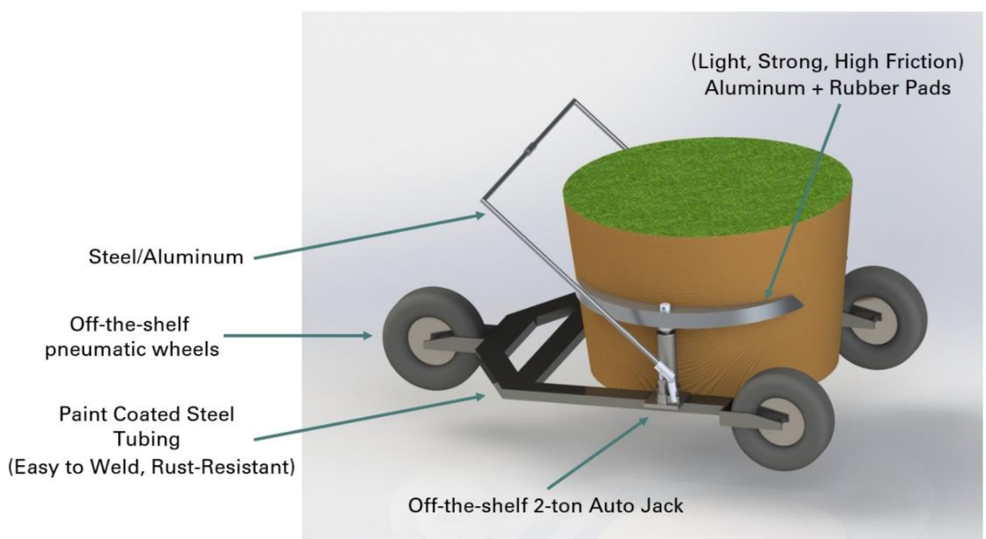


Figure 4.12. Material proposals for PDR design.

4.5. Preliminary calculations

Calculations were made to determine many different factors about our device design and barrel dimensions. As seen in Appendix D, we created spreadsheet and hand calculations to calculate for the barrel weight (using various factors), the arc length of the grabbers, and the force on the grabbers. These calculations were done to optimize the design and to assist in making decisions about the design.

4.6. Design issues

The design we have selected and created has some potential issues. One potential issue is that the jacks are not designed to withstand the high lateral loads from the barrel. A fix for this is to implement a locking mechanism between the grabbers to alleviate lateral loads on the jacks. Another issue with our concept design is the awkward usability of the lever. Because the lever is in an inconvenient place, it can be difficult for the user to operate it. A solution to this would be using a linkage-based mechanism. Another problem with the design is that the device may not be able to fit through the gap between two edge-to-edge half-barrel planters. This is resolved by using stronger, thinner materials, smaller wheels, and/or smaller grabber arms with reduced arc lengths. There are other potential problems with the concept design, but these are the main problems with our concept design. These problems helped us to create our final design by going through and solving each issue one-by-one.

5. **Final Design**

This chapter includes detailed descriptions and analysis of the final design. This section is broken into two main parts: 1) design changes made up until the Critical Design Review and 2) design changed made after the CDR, up until the Final Design Review. We will go over the functionality of the machine and justification for design choices we made in coming to our final design.

5.1. Overall design (CDR)

The final design is a 4-wheeled, steel-framed, hydraulically operated device, shown in Figure 5.1. The 4 large rubber wheels allow for easy traversing of rough terrain, the steel frame offers rigidity, strength, and ease of manufacturing, and the hydraulic operation allows the user to use minimal effort to lift up to a 500-pound payload. The user operates the device from the rear, pushing or pulling the cart as needed and actuating the hydraulic hand pump when lifting or lowering the barrel. Assembly, subassembly, and part drawings can be found in Appendix E.

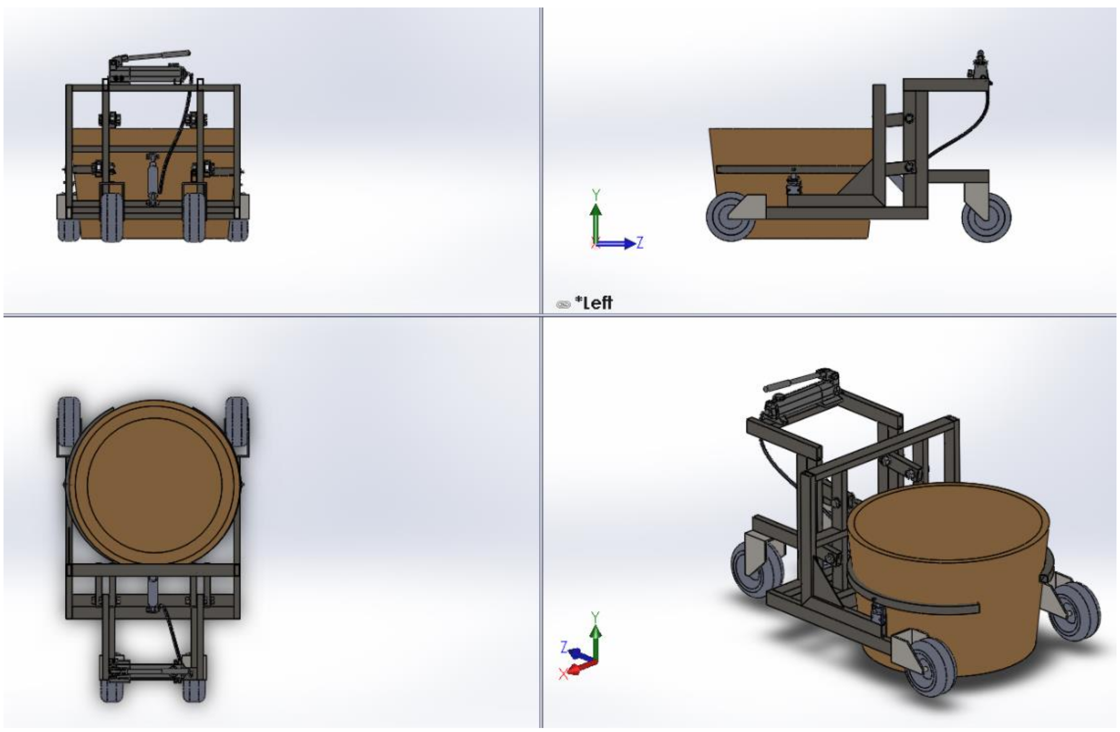


Figure 5.1. CDR overall design 4-view including representation of planter.

The final design is comprised of four major subsystems as shown in Figure 5.2:

1. Frame
2. Hydraulics
3. Forks
4. Grabbers

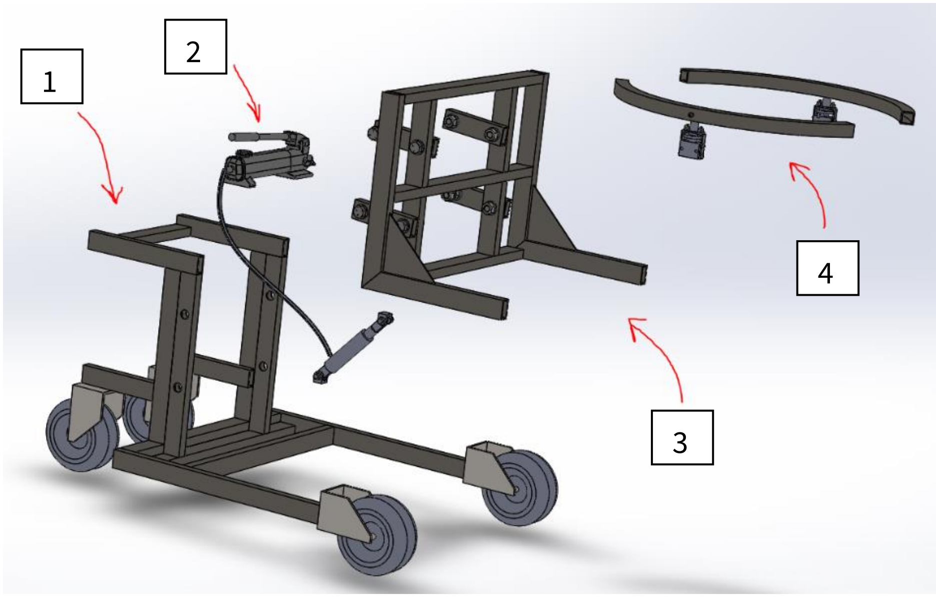


Figure 5.2. Exploded view of CDR model showing four subsystems.

Frame Subsystem

The frame is comprised of 1” x 2” steel tubing, two freely-swiveling caster wheels, and two fixed wheels (see Figure 5.3). All the steel tubing is welded together. Dimensions can be found in Appendix E as well as an assembly drawing.

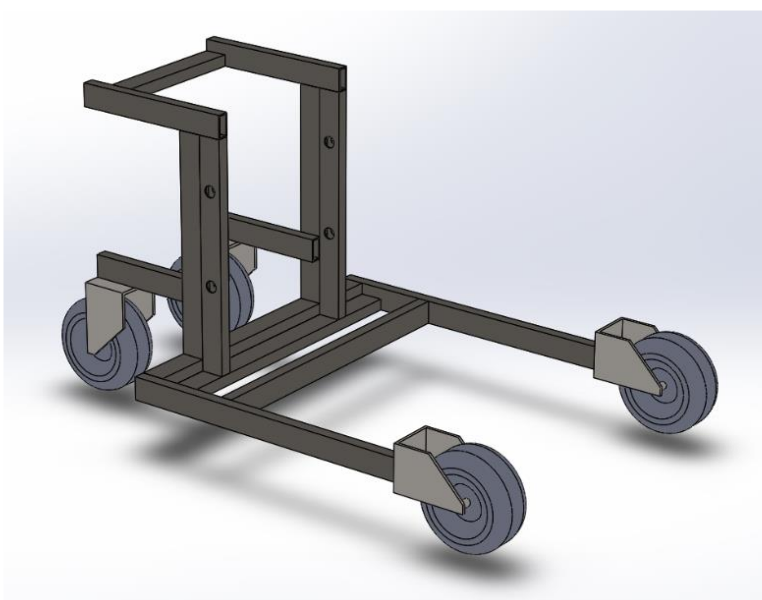


Figure 5.3. CDR frame subsystem model view.

Hydraulics Subsystem
The hydraulics subsystem includes the hydraulic hand pump, hose, NPT fittings and hydraulic cylinder (Figure 5.4). The pump comes pre-fitted with a hose which simply needs to be attached to the cylinder, since both components have 3/8” NPT fittings.

Figure 5.4. CDR hydraulic components CAD model.

Forks Subsystem
The forks subsystem (Figure 5.5) contains the welded L-shaped steel bars, cross-braces, bolt assemblies, the short linkages and clevis mount that connect the welded L-shape to the chassis and hydraulic cylinder. The forks are lifted and lowered via actuation of the hydraulic pump. The lowered and lifted positions are shown in Figure 5.6.

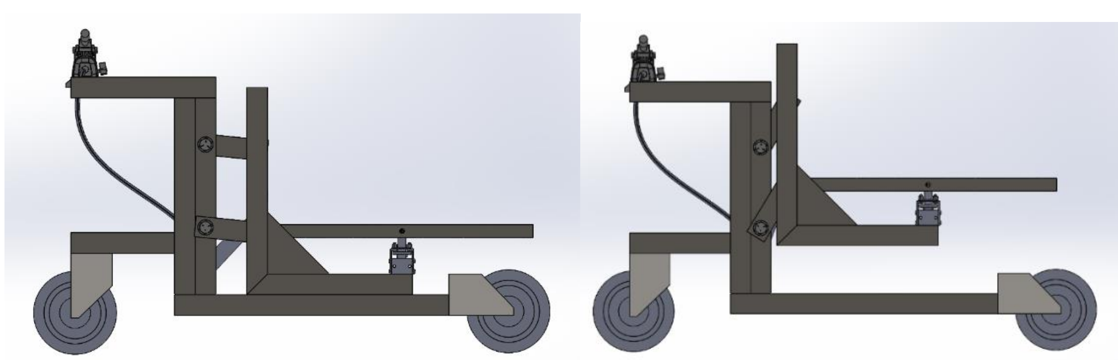


Figure 5.5. Various positions for the forks, allowing for up to 5 in. vertical lift.

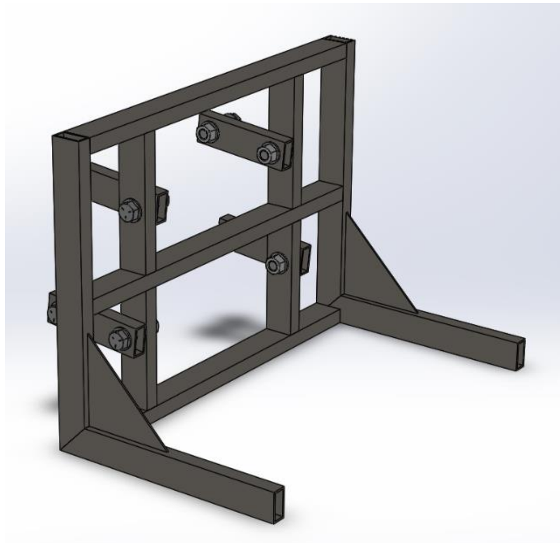


Figure 5.6. CDR forks subsystem CAD model.

Grabber Subsystem

The grabber subsystem consists of the rolled steel hollow bars that contact the barrel's conical surface and the lock pin mechanism that constricts movement of the rolled hollow bars. These components shown in Figure 5.7 together allow the user to contact and secure a barrel.

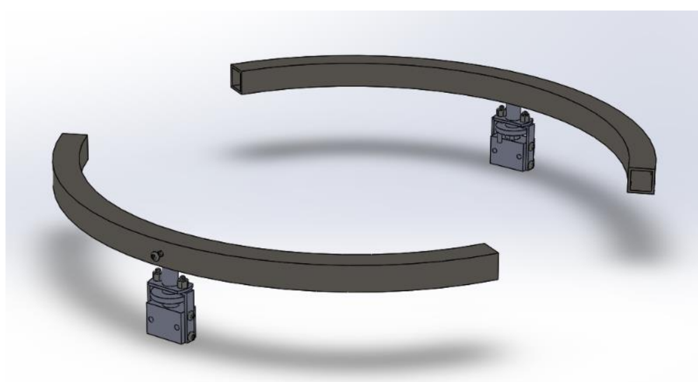


Figure 5.7. CDR grabber arms CAD model.

The grabbers are fixed to a pin shown in Figure 5.8 that rotates about the vertical axis around a block of steel attached to the fork arms by two brackets. The pin has a piece of geometry about the center that extends forwards and contacts the side of the steel block that is used to restrict the rotational limit to 60 degrees.

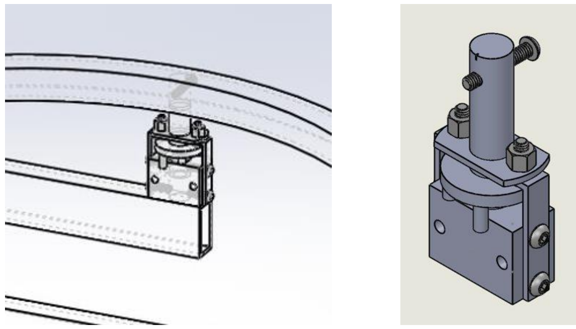


Figure 5.8. Close-up view of grabber pin mechanism.

A spring underneath the pin is used to give the pin a small amount of vertical displacement so that when the grabber begins to take on the weight of the barrel, it will push down and lock into place with the two small rods on the pin contacting the left and right sides of the inner face of the steel block. This is shown in Figure 5.9.

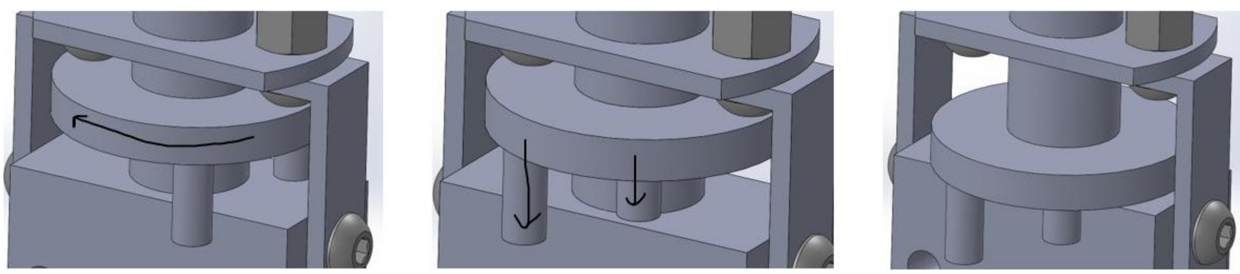


Figure 5.9. Visual explanation of the grabber lock mechanism.

5.2. Final design functionality (CDR)

The final design accomplishes a few main tasks: 1) grabbing/releasing the barrel, 2) lifting/lowering the barrel, and 3) moving the barrel from one place to another.

The following steps shown below and images on the next page show the typical use case for this device:

1. The barrel mover begins with the hydraulics de-pressurized, with the forks in their lowest position, and the grabber arms in the open position.
2. To grab onto a barrel, the user must first locate the cart in line with the barrel, shown in Figure 5.10.
3. Then, the user pushes the cart until the rear of the grabber arms contact the barrel. As seen in Figure 5.11.

4. The user will continue pushing the cart until the grabber arms close around the barrel (Figure 5.12).
5. Now the user can start actuating the hydraulic hand pump. As the forks begin to lift, the grabber lock pins will engage due to the weight of the barrel. (Figure 5.13)
6. Once the user has raised the barrel to a satisfactory height above the ground, they may then push or pull the cart to wherever they want to place the barrel. (Figure 5.14).
7. To lower the barrel the user simply must rotate the pressure release knob on the hydraulic pump.
8. Once the barrel is resting on the ground, the grabber lock pins will disengage, and the device can be pulled away from the barrel.

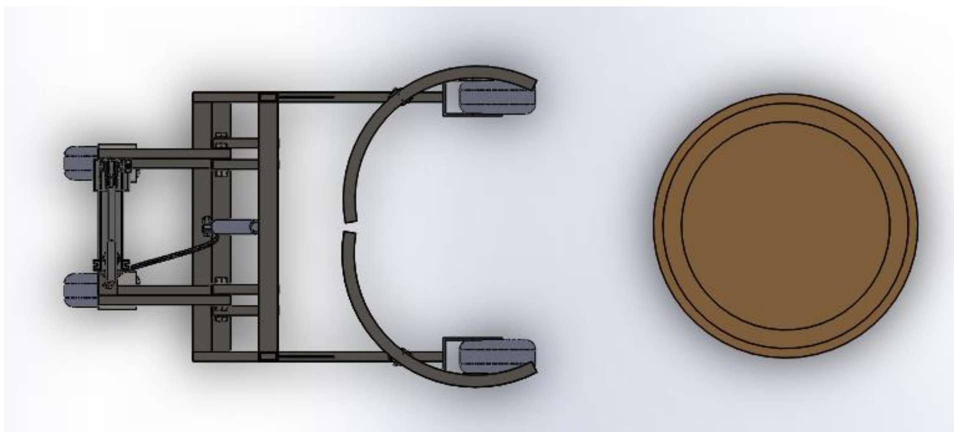


Figure 5.10. Visual representation of Step 2: locating the cart.

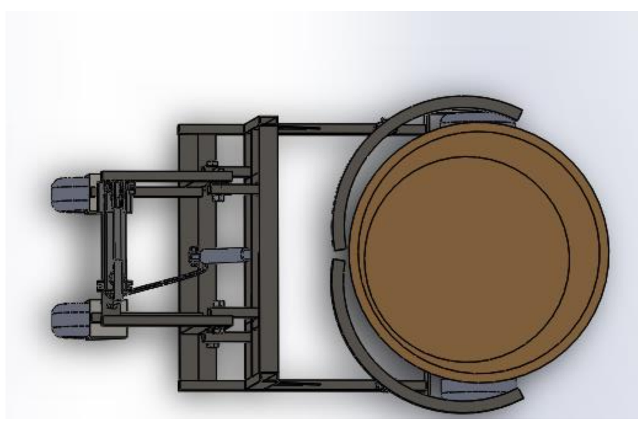


Figure 5.11. Visual representation of Step 3: contacting the barrel.

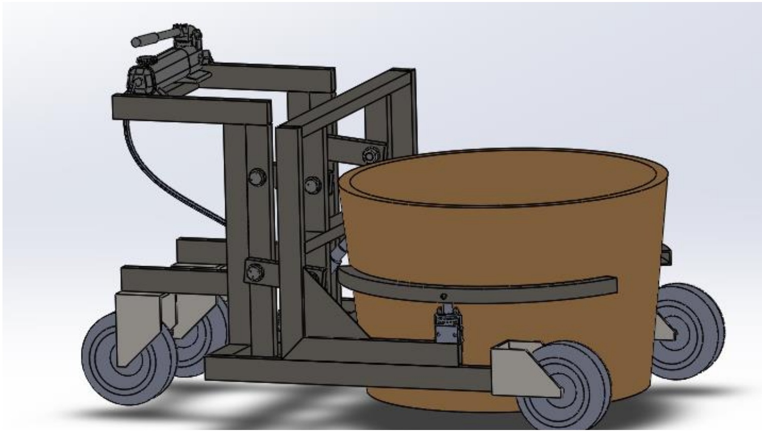


Figure 5.12. Visual representation of Step 4: arms locked around barrel.

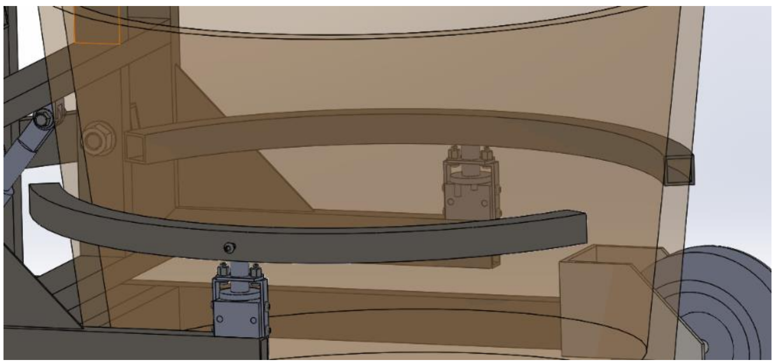


Figure 5.13. Visual representation of Step 5: lock pins engage.

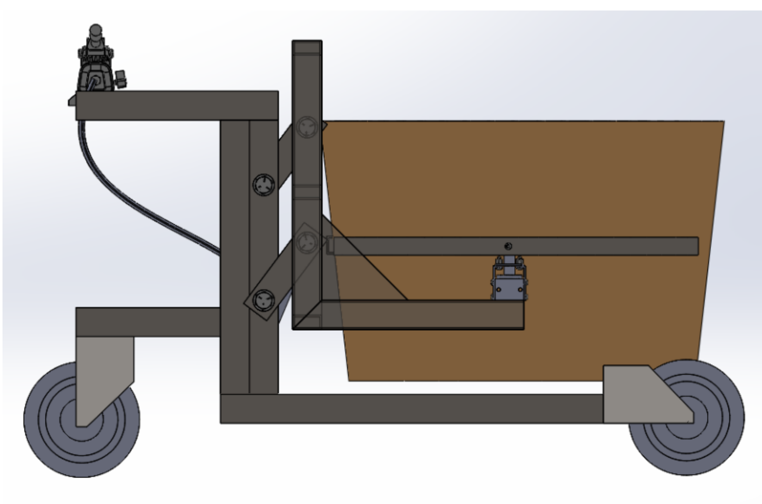


Figure 5.14. Visual representation of Step 6: barrel has been lifted.

5.3. Design justification (CDR)

The following section provides discussion regarding calculations performed to validate the sizing of integral components prior to manufacturing.

Linkage Forces

In our analysis of the device, acceleration was neglected. A simplified static analysis of the device with the linkages at 60 degrees from the horizontal was done to estimate the maximum forces in the linkages. This is because 60 degrees is the maximum angle the linkages can be from the horizontal due to geometrical constraints and this is when the maximum internal force occurs. See Linkage Force section of Appendix D.

Linkage Sizing

Using this force, the linkages were sized. This was done by solving for the nominal stress in the linkages and treating them as two plates and using Figure A-15-12 in Shigley's Engineering Design, 7th Edition to find the stress concentration due to the holes. With a one-inch diameter hole, width of 2 inches, depth of 1 inch, and thickness of 1/8 inch, the static yield safety factor was determined to be 2.7. See Linkage Analysis section of Appendix D.

Linkage Bolts

Then, the bolts to pin the linkages to the frames were sized. This was done by finding the normal stress due to tension and bending. With a bolt diameter of .75 inches the static yield safety factor was determined to be 3.3. See Bolt Analysis section of Appendix D.

Nylon Bushings

Then, the wear on the nylon bushings for these pin connections was analyzed. This was done by using equations 12-30 and 12-32 as well as Tables 12-8, 12-10, and 12-11 in Shigley's. With a length of 1 inch, lifting/lowering time of one hour, and an angular speed of 3.5 rev/min, the wear was calculated to be .005 inches. See Bushing Analysis section of Appendix D.

Fork Arms

The stress and deflection of the lifting arms was then calculated. The deflection was found by using Table A-9 in Shigley's. With a width of 1 inch, height of 2 inches, thickness of 1/8 inch, and length of 26 inches, the deflection downward was found to be .15 inch and the deflection outward was found to be .52 inches. Because the static yield safety factor was found to be only 1.0, triangular supports were added. FEA was done to ensure that these supports would prevent yielding. See Lifting Arm Analysis section of Appendix D.

Welds

The welds done with an E6010 analysis of the lifting arms were analyzed. This was done by finding the shear stress due to the downward force on the arms, finding the shear stress due to the outward force on the arms, and root sum squaring them. The static yield safety factor was found to be 15.7. See Weld Analysis section of Appendix D.

5.4. Safety, maintenance, and repair

We performed a FMEA (Failure Modes and Effects Analysis) which can be found in Appendix H. The most important safety issues lie with the material yield of the frame and grabbers. At the time of the CDR, the only testing we had done to back up the design was analytical.

5.5. Cost analysis (CDR)

A summary of the cost analysis, broken down by subsystem, is shown in Table 5.1. For more detailed component-by-component cost analysis, see Appendix G.

Table 5.1. Summary of projected cost analysis for prototype, broken down by subsystem.

Subsystem	Cost
Grabbers	$25.17
Forks	$62.12
Frame and Wheels	$214.26
Hydraulics	$188.99
Total	**$490.54**

The total projected cost of purchased materials fell well below our prototype budget of $1000. This was very good since it meant we had room to purchase replacement parts as well as possibly outsource some components to be manufactured.

5.6. Final design changes since CDR

Since the critical design review, the final prototype design has changed in many different ways:

1. Grabber lock pin mechanism removed.
2. Grabber arms tubing changed.
3. Wheel specifications modified.
4. Front wheels orientation changed.
5. Hydraulic cylinder specifications and mounting changed.
6. Forks vertical measurements modified.
7. User safety modifications.

Grabber lock pin mechanism

Most notably, the grabber lock pin mechanism was removed to save on manufacturing time and to simplify testing. It was determined to be more important to test whether the device could be capable of lifting the barrel than to additionally test whether the lock pin mechanism would rotate and function correctly. Additionally, the lock pin has a high probability of being the point of failure for the device. If this were to happen, it would be impossible to determine if the rest of the frame could support the load of the barrel. The new mounting method for the grabber arms is a simple bolt, washer, and nut combination that allows for a similar movement which worked well for the verification prototype.

Grabber arms

The grabber arms were changed from 1” x 1” square steel tubing to 1” diameter pipe. Pipe was much easier to bend into a curve using a tubing roller. It also allowed for better contact with the barrel surface.

Wheel specifications

The wheels ordered were 6” diameter from a different vendor instead of the original 8” diameter. This helps keep the device closer to the ground. Also, the original wheels were no longer being sold at the time of materials purchasing.

Front wheels orientation

The front wheels no longer protrude outwards from the frame since the ordered parts were not designed to be mounted in that orientation. Instead, they were mounted on an additional few pieces of steel to allow for the same height while keeping the wheels vertically oriented. This change is shown in Figure 5.15.

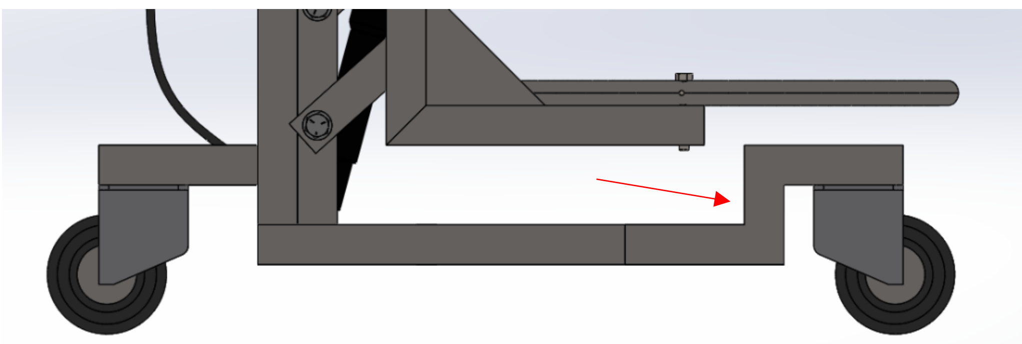


Figure 5.15. Modified front wheel orientation (FDR).

Hydraulic cylinder specifications and mounting

There was an error in the original selection of hydraulic cylinder—the part that was modelled was different than the actual part being sold. We found a replacement cylinder from another vendor that would be similar enough to work in the design. However, the new cylinder had a longer retracted length of 12”, so new brackets were designed using offcuts of 1” x 2” steel tubing. These changes are shown in Figure 5.16.

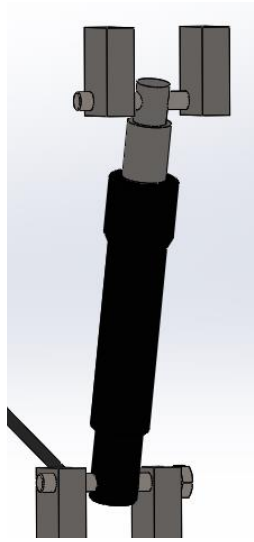


Figure 5.16. Modified cylinder specifications
and mounting brackets (FDR).

Forks vertical measurements

In order to account for the longer cylinder, changes needed to be made to the fork subassembly. The new dimensions are shown in Figure 5.17. The linkages connecting the forks to the frame were increased by one inch hole-to-hole as well, for a total of 6” hole-to-hole.

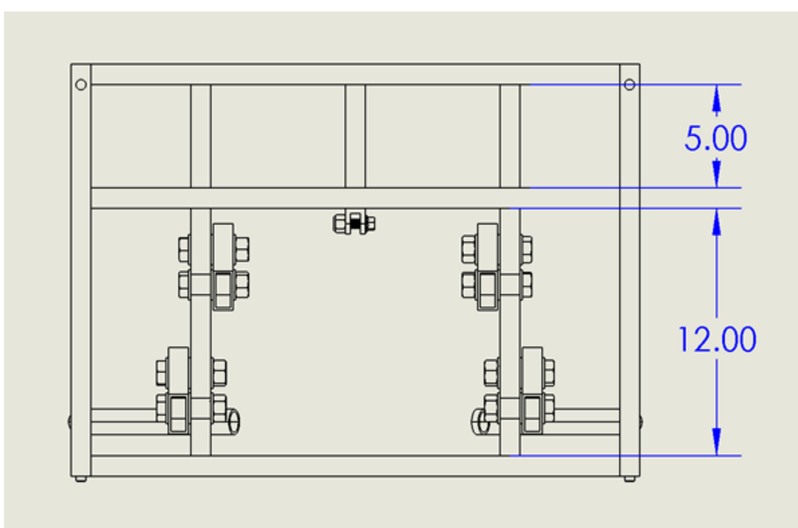


Figure 5.17. Modified forks vertical measurements (FDR).

User safety modifications

After completing the safety review, we decided to implement a few features to make the device safer to use. These include an acrylic shield to prevent pinching around the linkages and stickers that show the hazards, shown in Figure 5.18.

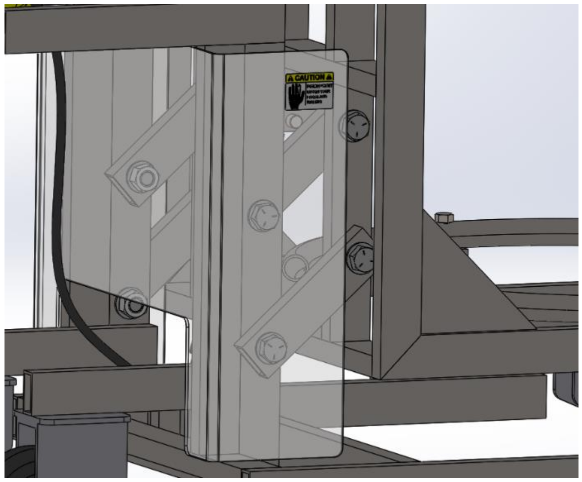


Figure 5.18. Added safety features (FDR).

5.7. Overall design (FDR)

This section showcases the final CAD model before/during manufacturing of the verification prototype. Figure 5.19 is what we envisioned a production model of the device would look like before we completed building and testing the verification prototype. Figure 5.20 shows the 4-view of the CAD model. Drawings for each subassembly and part are available in Appendix E.

Figure 5.19. Final CAD model render of barrel mover.

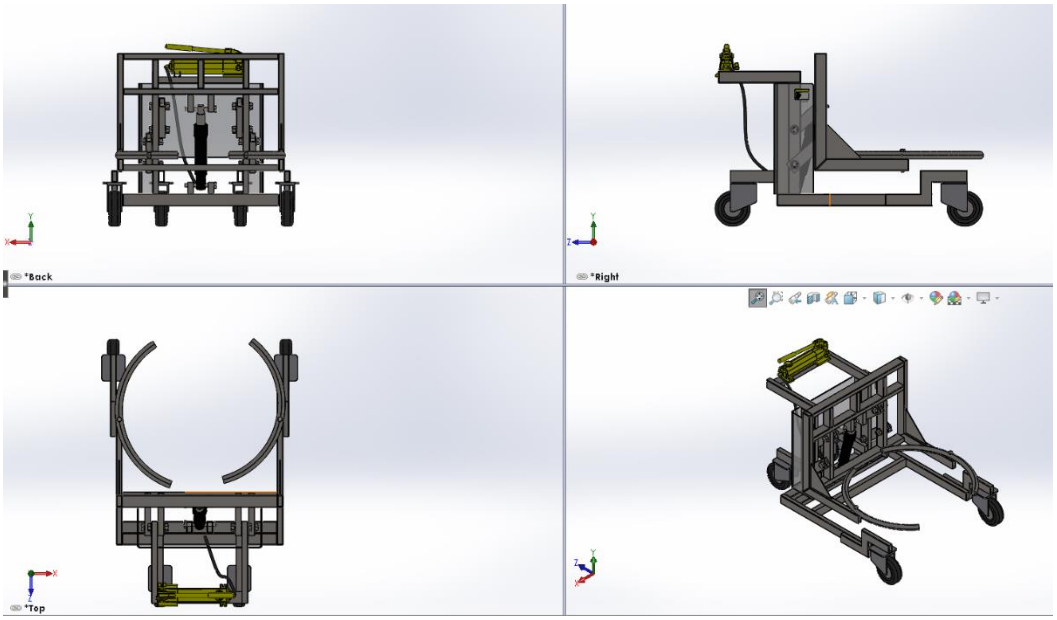


Figure 5.20. CAD 4-view of final model.

The functionality of the FDR model is not very different from that of the CDR model. The most important missing function to note is the lack of a locking mechanism for the grabber arms. We chose to omit this for testing purposes due to time constraints.

6. Manufacturing

6.1. Procurement of materials

Materials were sourced from a variety of vendors, both local in the San Luis Obispo area as well as online retailers. The BOM shown in Appendix E details vendors for each component to be used in the prototype device. Table 6.1 below shows a summary of where the most important components were sourced.

Table 6.1. Summary of hardware vendors.

Component	**Source**
1/8” 1”x2” ASTM A36 Steel Tubing	B & B Steel Santa Maria
1/8” 1” Diameter ASTM A36 Steel Pipe	
1” Diameter 6/6 Nylon Rod (Bushing Material)	www.globalindustrial.com
6” Diameter x 2” Width Caster Wheels	www.casterconnection.com
1.5" bore x 6" stroke Magister hydraulic cylinder	www.magisterhyd.com
Manual Hydraulic Hand Pump CP-180	www.toolots.com
Bolts, Nuts, Washers	The Home Depot / McMaster-Carr

6.2. Final budget status

When parts were finally purchased, some changes were made to quantities in order to account for cutting and excess material in case of mistakes. Shipping and handling costs were also not considered initially. These material overages and other costs are now accounted for. Costs were easier to separate into different categories than in Section 5.5. Table 6.2 summarizes the final costs for each component of the verification prototype. The grand total of $852.44 (significantly higher than the original estimate) still came in well under our budget of $1000. This cost includes parts such as the locking mechanism hardware that did not end up in the verification prototype. The full spreadsheet is attached in Appendix G.

Table 6.2. Summary of actual material costs.

Component	**Cost**
Steel (tubing, pipe)	$380.46
Wheels	$170.53
Hydraulics (pump, cylinder)	$175.53
Nylon	$36.99
Grabber arm hardware (bolts, washers, nuts)	$18.04
Linkage hardware (bolts, washers, nuts)	$19.41
Locking mechanism hardware	$51.48
Grand total	**$852.44**

6.3. Manufacturing details

This section discusses how the key parts of the device were manufactured. Manufacturing occurred in 3 main steps: cutting, welding, assembling. First, all the steel for the frame, forks, and links were cut. The grabber arms were rolled and cut as well. Then, the forks and frame were welded. Finally, wheels, hydraulics, linkages, and grabber arms were bolted on to the frame and forks. The remainder of this section discusses the specific manufacturing processes used in building the prototype. Manufacturing took much longer (100+ hours combined) than any of us anticipated, mostly due to Covid-19 machine shop restrictions and yellow tag certification time.

Bushings

The nylon bushing for the linkages were made in the Cal Poly student shops using a chop saw and lathe.

1. The nylon stock was first cut to 1.1” lengths (16 pieces for 8 total bolt assemblies) and then mounted in a 3-jaw chuck in the lathe.
2. In order to drill the 1” clearance hole, a pilot hole was drilled (Figure 6.1) and then ¼” and ½” holes were drilled using the tail stock.
3. A ¾” drill bit was used to reach the ¾” hole size.
4. The part was then faced on one side, flipped around, and faced to a total length of approximately 1.05”.
5. Finally, a small cylindrical sander was used to finish the interior of the hole for a clearance fit with the ¾” diameter bolt.

A model of the bolt assembly is shown in Figure 6.2.

Figure 6.1. Drilling pilot hole in nylon stock.

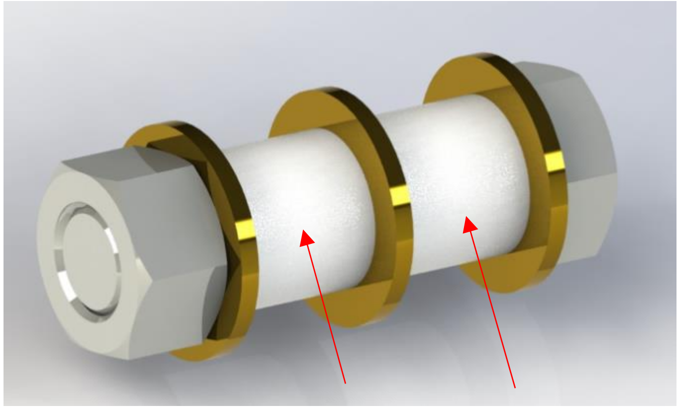


Figure 6.2. Model of bushings in bolt assembly.

Grabber arms

The curved grabber arms were cut and rolled in the Cal Poly student machine shops using a brand-new $800 tubing roller named Hulk (Figure 6.3) and a vertical metal bandsaw.

1. We set up the tubing roller to accept the 1” pipe (1.125” OD).
2. We rolled the tubing all the way to one end of its length, then pumped the hydraulic jack so it pushed the pipe down 50-100 thou.
3. We rolled the tubing in the other direction, then repeated Step 2.
4. We continued steps 2-3 until the tubing was approximately the arc we needed (26.5” diameter), adjusting the rollers as necessary.
5. We cut the tubing (which now looked like a coil due to its long length and small radius) on the vertical band saw into 2 segments of 120° arc (Figure 6.4) to form the grabber arms.
6. We then drilled holes using a drill press to accept bushings for the bolts that hold the arms to the forks.

Figure 6.3. Tubing roller "Hulk" with pipe set up between pinions.

Figure 6.4. Cut grabber arms.

Frame and forks

The majority of the frame and forks were made from 1” x 2” steel tubing cut on the metal chop saw in the Cal Poly student shops. After chopping each piece to size, they were tack welded together using a MIG welder (shown in progress in Figure 6.5 and 6.6). Our sponsor assisted with completing the welds at his workshop. Some pieces needed holes drilled using a drill press to fit linkage bolts or other components. After drilling, these holes were deburred using a deburring tool. Each piece was wiped with acetone and blasted with compressed air to clean it and remove debris to prep for welding.

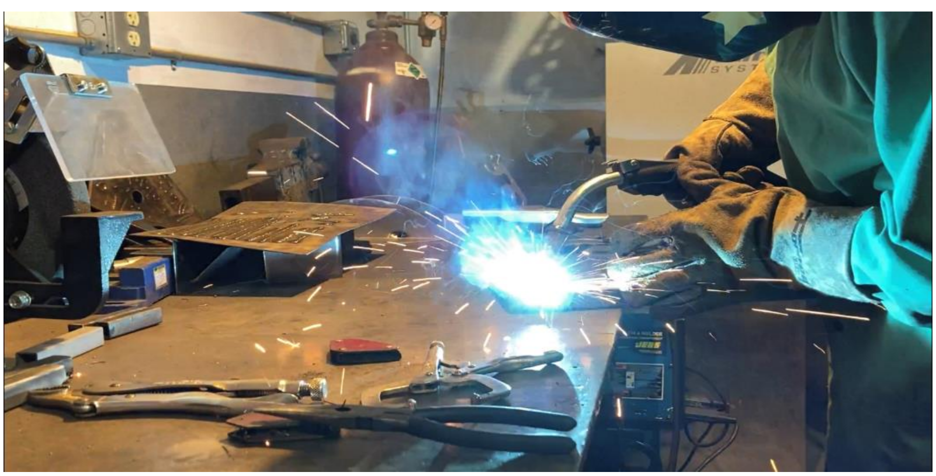


Figure 6.5. MIG welding one of the forks.

Figure 6.6. Partially completed frame and forks.

Wheel supports

The front and rear wheel supports were manufactured similarly to the frame and forks, and holes were drilled along the centerline to accept bolts for the front wheels (Figure 6.7). For the rear wheels, we had to design and cut mounting plates using the bandsaw from 1/8" steel plate to affix to, shown in Figure 6.8. We drilled 4 holes with the same 3" x 3" pattern found on the caster wheel brackets to mount the wheels. These plates were then welded to the steel tubing supports, shown in Figure 6.9.

Figure 6.7. Front wheel support.

Figure 6.8. Rear wheel mounting plates prior to drilling holes.

Figure 6.9. Rear wheel mounting plate in position.

Final assembly

All the individual parts were welded or bolted together to form the verification prototype. The grabber arms were bolted through the forks. The forks were bolted to linkages which were then bolted to the frame. The hydraulic cylinder was mounted within its top and bottom brackets with 5/8” x 5” long stainless-steel bolts. The hand pump was mounted to the frame using zip ties. The final verification prototype assembly is shown in Figure 6.10.

Figure 6.10. Verification prototype fully assembled.

6.4. Manufacturing challenges

We faced many difficulties when manufacturing the components for the prototype.

One of the hardest processes to complete was welding. If even one weld was off by a degree or two, the remainder of the welds became increasingly difficult to make accurately. One of the best tools for ensuring right angles between welded parts were the magnetic right triangles provided by the campus machine shop. Another great tool that we could never get enough of were clamps. It would have also been a good idea to do more practice welds, but in the time crunch caused by the pandemic, we opted to instead just tack together as many parts as we could.

Another difficulty we faced was the increasingly heavy weight of the device as more and more steel was welded on. In future iterations of this device, we would like to use more bolted connections to make it easier to transport.

One place we should have been more careful was the vertical frame supports for the linkages. The 1” holes we drilled through the tubing were sometimes not very straight. This ended up causing problems when we tried to push the bolt and bushing assemblies through. In fact, we had to weld one of the vertical supports at a slight angle to account for the inaccuracy in the drill holes.

One helpful method we used was to only tack pieces together until we were sure they were in the right orientation and size. We had to remove some pieces and if they had been fully welded it would have been a nightmare. Since they were only tacked together, we were able to grind the welds off using an angle grinder, whack the piece with a hammer and dismantle it.

6.5. Outsourcing

The main outsourcing that took place was the use of our sponsor's time and energy to complete many of the welds on the project. Since our team members' welding skills were rusty, our sponsor stepped in to tackle most of the structural welds on the device.

Future outsourcing plans include sending the parts for powder coating, manufacturing custom brackets for the hydraulic cylinder, ordering vinyl stickers, and purchasing plastic endcaps for the exposed tubing.

6.6. Future recommendations

One of the biggest recommendations we have for the future is to use less welding, and more bolted connections. Bolts allow for more tolerance when assembling, as well as make it easier to take the device apart and transport it or swap out pieces in case sizing changes.

When drilling holes through both side of rectangular tubing, make sure to take care that the drill is perpendicular to the surfaces on either side. Too many of our holes were not perpendicular due to carelessness with drill press clamping, and this made it very difficult to fit bushings and bolts through the pieces.

7. Design Verification

A table of specifications we tested for can be found in Section 3.5, Table 3.1. This section discusses how we tested many of those specifications, and why we could not test all of them.

7.1. Testing methods (DVP&R)

In Table 7.1, each specification covered in Section 3.5 has a corresponding testing procedure with required equipment. Specification K was not included here since it is a bonus requirement that was not met by our final design. Specification F and G cannot be tested physically in-person as they are more calculation based. The table also shows what the result was.

Table 7.1. Testing methods (Design Verification Plan & Results)

Specification	Equipment Required	Testing Method	Result
A	Half-Barrel Planter and mechanical force gauge	Using the force gauge, we will test the force required to lift the barrel using the hydraulic pump.	Not Tested
B	Tape Measure	Using the tape measure, we will measure the width of the model from the left most point of the machine to the right most point of the machine.	29.5”
C	Scale	Using a weight scale, we will measure the weight of the full machine without a half-barrel.	Not Tested
D	Tape Measure	Using the tape measure, we will measure the Height of the model from the ground to the highest point of the machine.	31”
E	Tape Measure	Using the tape measure, we will measure the depth of the model from the back most point of the machine to the forward most point of the machine.	45”
F	-	This will be calculated from our theoretical calculations.	Not Tested
G	-	This value is determined from the actual cost of each of the parts and materials found in the bill of materials as well as any additional unforeseen costs.	Pass, less than $1000

H	Tape Measure	Using the tape measure, we will measure the turn radius by marking on the ground a midpoint between both wheels, turning the machine as sharply as mechanically possible to the right or left at a 90 degree angle, and then measuring the radius of the created quarter-circle.	Pass, R = 0”
I	Cell phone with internal gyroscope	Using a level balancing application on a cell phone, we will test to see if the barrel ever rotates more than 30 degrees.	Pass, Barrel does not rotate
J	Cell phone with internal gyroscope and force gauge	We will attach the cell phone to the machine while at a zero-degree incline and using a force gauge will push the machine up a gradual incline until the force meter exceeds specification A’s maximum force. At this point, the reading on the cell phone will act as the maximum incline angle. The client has a gradual incline at his residence which will be used for this test.	Not Tested
L	Screwdriver	The fork arm mechanism should be fully modular by removing the screws attaching the brackets to the arms.	Pass, Design change allows for arms to be removed
M	Mechanical force gauge	Using the mechanical force gauge, we will push the machine carrying a half-barrel over various step sizes present at the client’s residence. The different force measurements will show which impulse forces are required for different curbs heights.	Not Tested

The testing we did was minimal, and if time allowed, we would have liked to test more aspects of the device. However, given the Covid-19 pandemic and limited shop availability, we were on a very tight schedule when it came to manufacturing. That coupled with the lack of yellow tag-holding team members until Week 7 of ME 430 meant that we had to dedicate almost all of our available time into building the device. In fact, the verification prototype was only completed one week after the quarter had ended. In the future, we will be visiting our sponsor to do additional testing on the device, and to make some small design modifications as well.

7.2. Results

The verification prototype successfully managed to grab a barrel and pick it up, which was the main task we were assigned to do. Shown in Figures 7.1 and 7.2 are images of the barrel being grabbed and subsequently lifted and moved by our sponsor.

Figure 7.1. Sponsor using the device to grab a planter.

Figure 7.2. Sponsor using the device to move a planter.

8. **Project Management**

Project management is a key part of any successful long-term project. This project spanned the course of a year and as such, we used a few different tools for staying on task as best we could.

8.1. Timeline

The following table 8.1 shows an overview for the timeline set for this project starting from the end of the PDR in June 2020 until the end of Winter quarter in March 2021. These values have been updated since completing the project to reflect the actual completion date of each step in the process.

Table 8.1. Project timeline.

Monthly Timeframe	Task	Description
June-September 2020	Design Improvements	Improve design to address the problems in our current design (lever usability, grabber stresses, ability to fit between barrels)
September-October 2020	Optimize Dimensions	Adjust dimensions to ensure clearance between barrels
October-November 2020	FEA and Hand Calculations	Use stress/strength hand calculations to determine the strength of each component. Use Finite Element Analysis as an estimation tool to verify.
October-November 2020	Product Specifications and DVP	These were to be completed in the CDR but we were unable to complete them. They were completed by the end of the first week in November 2020.
November-December 2020	Material Selections	Based on stress analysis determined optimal materials for the device.
November-December 2020	Cost Analysis	Along with material selection, simultaneously kept a pricing log to ensure the final prototype stayed under budget.
November-December 2020	Manufacturing Methods	Researched manufacturing methods alongside material selection and cost analysis to come up with efficient ways to manufacture the final product while staying under budget.

December-January 2021	Secure Funds for Prototype	Attained the funds necessary from our prototyping budget to create our machine.
January-March 2021	Manufacture prototype	Created all four main sub-assemblies and assembled them to create our final prototype that was used for testing.
March 2021	Test and Analyze	Tested and analyzed the prototype to ensure that it meets all set requirements and specifications. This is where we used the testing methods described in section 7.2 of this report.
March 2021 onwards	Design changes as per sponsor request	Time permitting, final modifications to the machine were made here. These modifications only server to add more customization and additional versatility in the machine rather than to solve pre-existing problems.

8.2. Gantt chart

While working on the project, a Gantt chart was used to keep track of project deadlines and intermittent submissions. Gantt charts are graphical timeline representations that allow tasks to be assigned to individuals as well as the group as a whole. The software allowed us to set deadlines as well as durations for each task. While the original plan was to follow the projected timeline, due to the Covid-19 pandemic certain responsibilities were delayed. As a result, the Gantt chart was updated to reflect those changes. The full Gantt chart can be found in Appendix L.

9. Conclusions and Recommendations

This report was a final design review into our barrel mover project. Starting from the ideation of the barrel mover project, this report covered each step of the design process including the manufacturing and testing that was absent from the critical design report. Our group has completed the given task to create a device that can lift and transport half wine barrel planters. While there is much to improve, the basic device has been successfully designed, created, and tested. This section will summarize the process of designing and testing the verification prototype and share recommendations for the future of the project.

9.1. Project summary

Over the course of one year, we conceptualized, designed, analyzed, CAD modeled, manufactured, and tested a 150+ component hydraulically actuated device capable of lifting and moving half wine barrel planters. This FDR report showcased all those steps, but what it does not show are the countless hours put in behind the final design. From late nights to long days, through a global pandemic and software crashes, our team worked hard to create a brand new product that could solve the problem our client had. The end result was a prototype constructed from steel that is capable of lifting up to 500 pounds and moving over rough terrain, making it much easier for our client to accomplish the task of relocating half wine barrel planters.

9.2. Recommendations

Although a final product has been created, there are still many improvements we have discussed that need to be made to the device:

- A tested grabber arm mechanism still needs to be manufactured that would inhibit rotation of the grabber arm when a barrel is being lifted. Currently, the only resistance to rotation is due to friction between the barrel and the steel grabber arm.
- Another improvement would be a working brake system for downhill slopes.
- Safety precautions were analyzed but not yet introduced to the device. In the future, a proper manual, warning stickers, and a translucent guard on the back of the device would be needed to satisfy the safety parameters and prepare the device for the consumer market.

The most valuable information collected about our final design comes directly from the sponsor himself. After using the device for a few days, he summarized his thoughts via email in three sections: general observations, preparing for powder coating, and design modifications. These comments have been rewritten more legibly in the following subsections:

General observations:

- The device is significantly easier to use than a hand truck.
- Maneuvering can be difficult, but after some practice is easier.

- Coating the entire device in hydraulic oil does not make it easier to use. (A comment most likely regarding user error when filling the hydraulic system)
- It seems feasible to use this device for other tasks (i.e., beehives, VW engines, sheet metal brake, mill) by changing out the grabber mechanism for other attachments.

Preparing for powder coating

- Round over or grind sharp edges.
- Finish all welds, instead of leaving them as tack welds.
- Modify front wheel supports to use one piece of steel instead of 3 welded together. The easiest solution may be to increase the width of the frame instead.
- Incorporate a taller user handle. The current design only has a support for the hydraulic pump, which requires the user to bend down to push the barrel mover.
    - Redesigned hydraulic pump mount.
- Laser cut cylinder mounting brackets instead of the scrap pieces of steel used. These can be outsourced for fabrication and shipped.
- Protective ends on the tips of the frame/arms so it can be stored vertically for storage.

Design modifications:

- After all the testing, removal and re-insertion of the bushings, they took a lot of wear and tear, reducing their functionality.
    - Problem may be solved by drilling more concentric holes in the steel linkages.
    - May need to consider alternate material for bushings.
- Determine whether the pump and cylinder can be made easier to bleed.
- Grabber lock mechanism to stop them from rotating by themselves.
- The forks seem to not drop consistently when pressure in the hydraulic cylinder is released. This could be due to the precision of the linkages or there may need to be a spring or other mechanism to force the arms down when the hydraulic system is depressurized.
- Add rubber pads to the grabber arms to increase friction around barrel.

From this set of notes, the sponsor has verified that the prototype does function as intended and completes the original goal. The sponsor also confirms that the device satisfies one of our bonus requirements to have detachable grabber arms so that grabbers meant for other purposes can be fitted to the fork arm. In addition to the praise, there are many items that still need work. Most items are quality-of-life changes but some (such as the damaged bushings) hinder the life of the barrel mover. We felt it was important to include these notes as they show what steps needed to be taken for this project to become a commercial product.

9.3. Final remarks

We would like to thank our sponsor, Mr. Braun, our advisor, Professor Fabijanic, and the Cal Poly machine shop managers and techs for all their advice and help provided through the duration of this project. Completing a verification prototype proved very difficult, especially during a global pandemic, but with the help of the aforementioned individuals we were able to create and test a fully functional prototype (Figure 9.1) that fulfilled the goals of the project. We are excited to work directly with our client and sponsor on some design changes in the future.

Figure 9.1. Completed verification prototype holding barrel planter.

10. References

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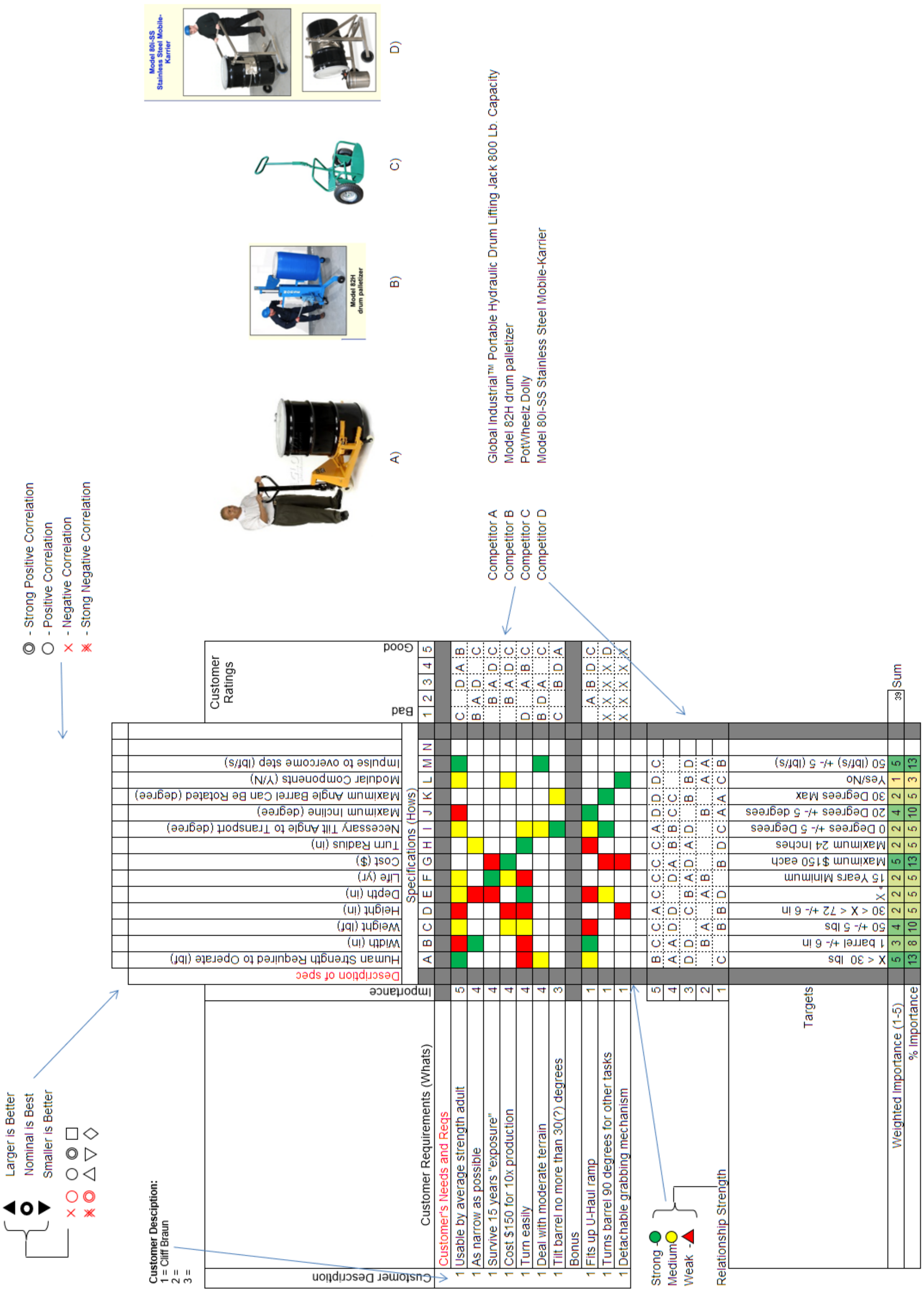
Appendices

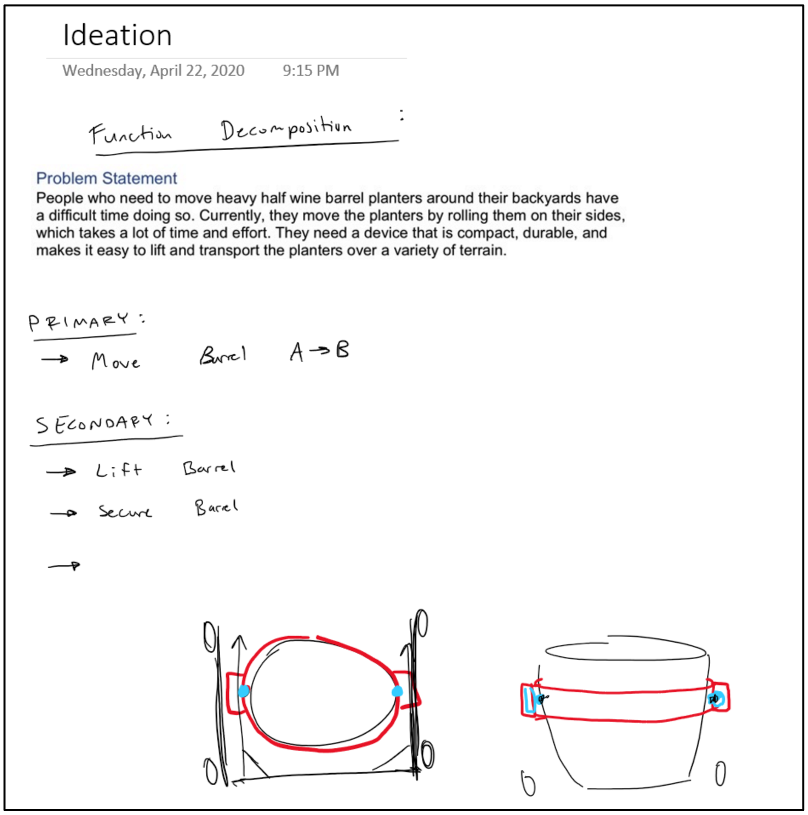
A. QFD
B. Concept Ideation
C. Decision Matrices
D. Preliminary Analysis
E. CAD Drawing Package
F. Part Specifications
G. Final Budget
H. Failure Modes and Effects Analysis
I. Design Hazard Checklist
J. Risk Assessment
K. Operator's Manual
L. Gantt Chart

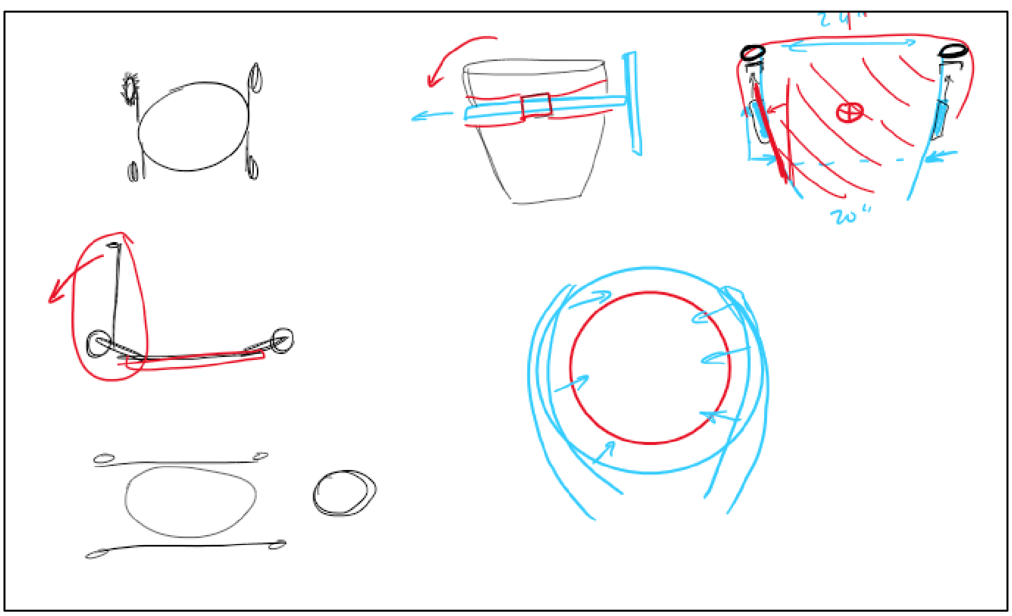
Appendix A: QFD House of Quality

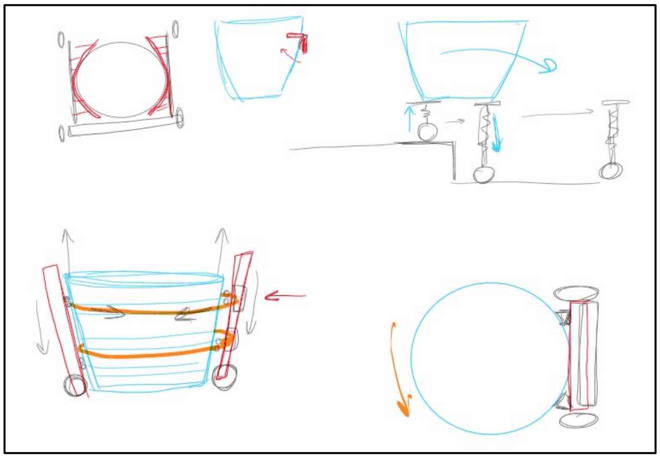


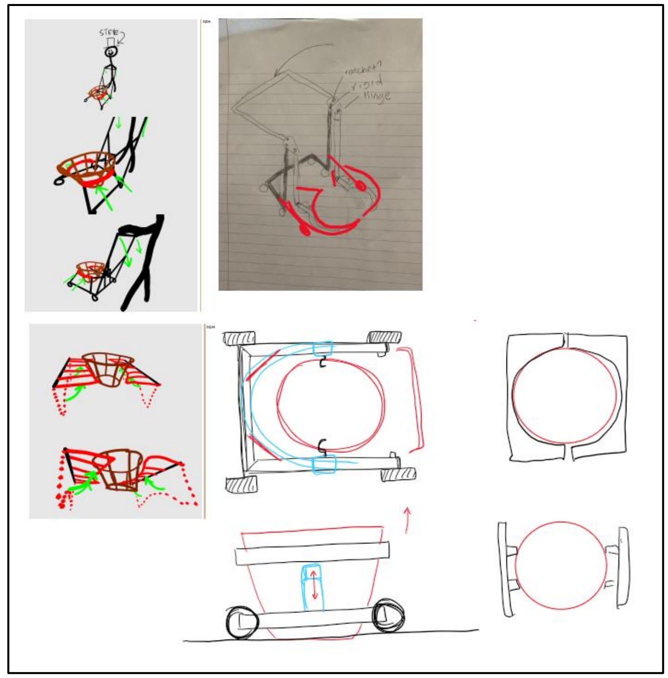
Appendix B: Concept Ideation (Sketches)

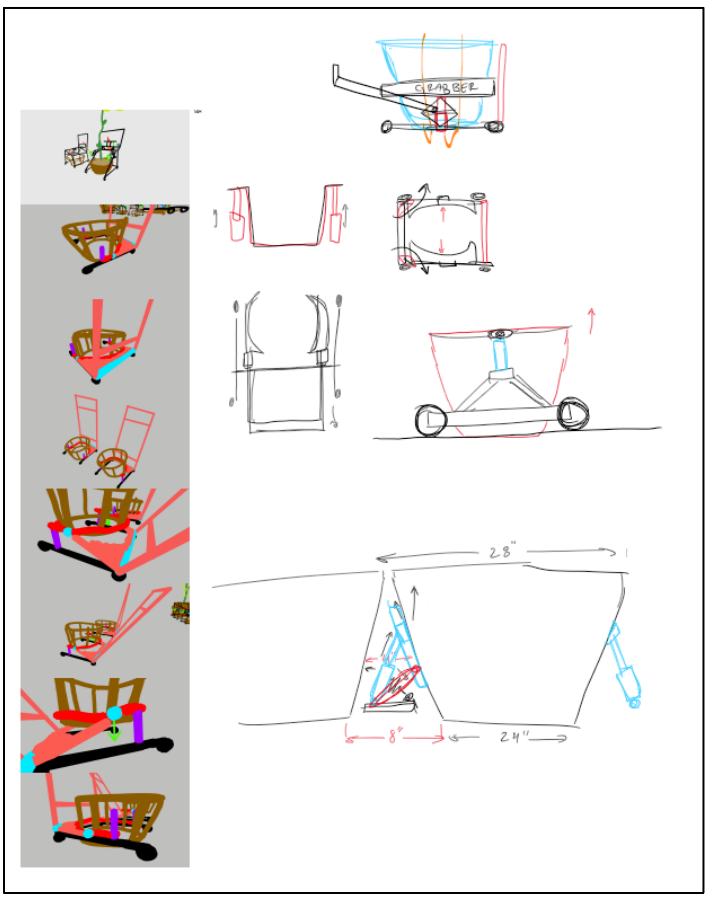
The following images are screengrabs from our team's OneNote virtual notebook, showing the initial ideation process. They are presented as a collage to show the stream-of-consciousness nature of the ideation process.

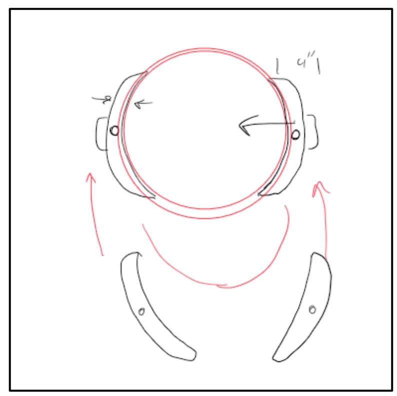


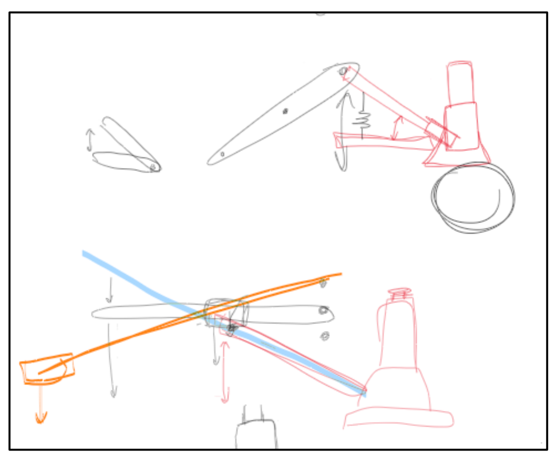





STEVE
ratchet?
rigid
Hinge


GRABBER
28"
8"
24"





Appendix C: Decision Matrices

The following decision matrices allowed us to select a design direction from the various design ideas we had. Figure C.1 show the comparison of different grabbing methods. Figure C.2 shows a comparison of different lifting methods. Figure C.3 shows a comparison of different lifting layouts.

Grabbing Methods						
	Weight	Straight Prongs and barrel harness	Curved Prongs	Swivel Arms	Hooks and barrel harness	Semicircle Plus
Ease of use	0.3	3	7	8	4	9
Stability	0.7	3	6	8	1	4
Score		3	6.3	8	1.9	5.5

Figure C.1. Grabbing methods design selection matrix.

Lifting Methods					
	Weight	Simple Lever	Ratcheting Lever	Scissor Jack	Bottle Jack
Durability	0.4	5	3	3	7
Cost	0.2	10	5	8	9
Ease of Use	0.4	1	10	4	10
Score		4.4	6.2	4.4	8.6

Figure C.2. Lifting methods design selection matrix.

Layout				
	Weight	Lifting from the top without a moment arm	From the top with a moment arm	Pushing up the sides from the ground
Stress	0.5	10	3	10
Arrangement Geometry	0.5	3	10	6
Score		6.5	6.5	8

Figure C.3. Layout design selection matrix.

Appendix D: Preliminary Analysis

This appendix contains the hand calculations and other analysis we performed before proceeding with our chosen design. These offer a proof-of-concept for the chosen design. The following calculations were performed:

- Barrel weight
- Barrel contact forces
- Grabber arc length
- Linkage forces
- Linkage strength analysis
- Bolt analysis
- Bushing analysis
- Lifting arm analysis (including FEA)
- Weld analysis

Barrel Weight:

Table D.1: Half-Barrel planter weight calculations. This solver uses different variables such as the % of the barrel that is full and the density of wet dirt.

Specification	Value	Half	Units
Height	18		in
OD_Top	28	13.5625	in
OD_Bot	24	11.5625	in
Thickness	0.875	0.4375	in
Density	100		lbf/ft^3
% full	95%		
W_barrel	25	lbf	
V_dirt	8508.42	in^3	
	4.92	ft^3	
Total Weight	493	lbf	

Barrel Contact Forces:

Table D.2: Calculations for the forces present in the contact point between the bottle jack grabber and the barrels surface.

theta	0.11		Taper angle			
mu	0.70		Coefficient of Friction			
Fl	305.91	lbf	Normal Force			
Fr	214.13	lbf	Friction Force			
Fc	280.58	lbf	Hook force			
Bottle jack length	15	in	Max lenth of bottle jack			
M bottle jack joint	0	lbf in	(with hook)	without hook	4208.767	lbf*in
Rx	0		(with hook)			

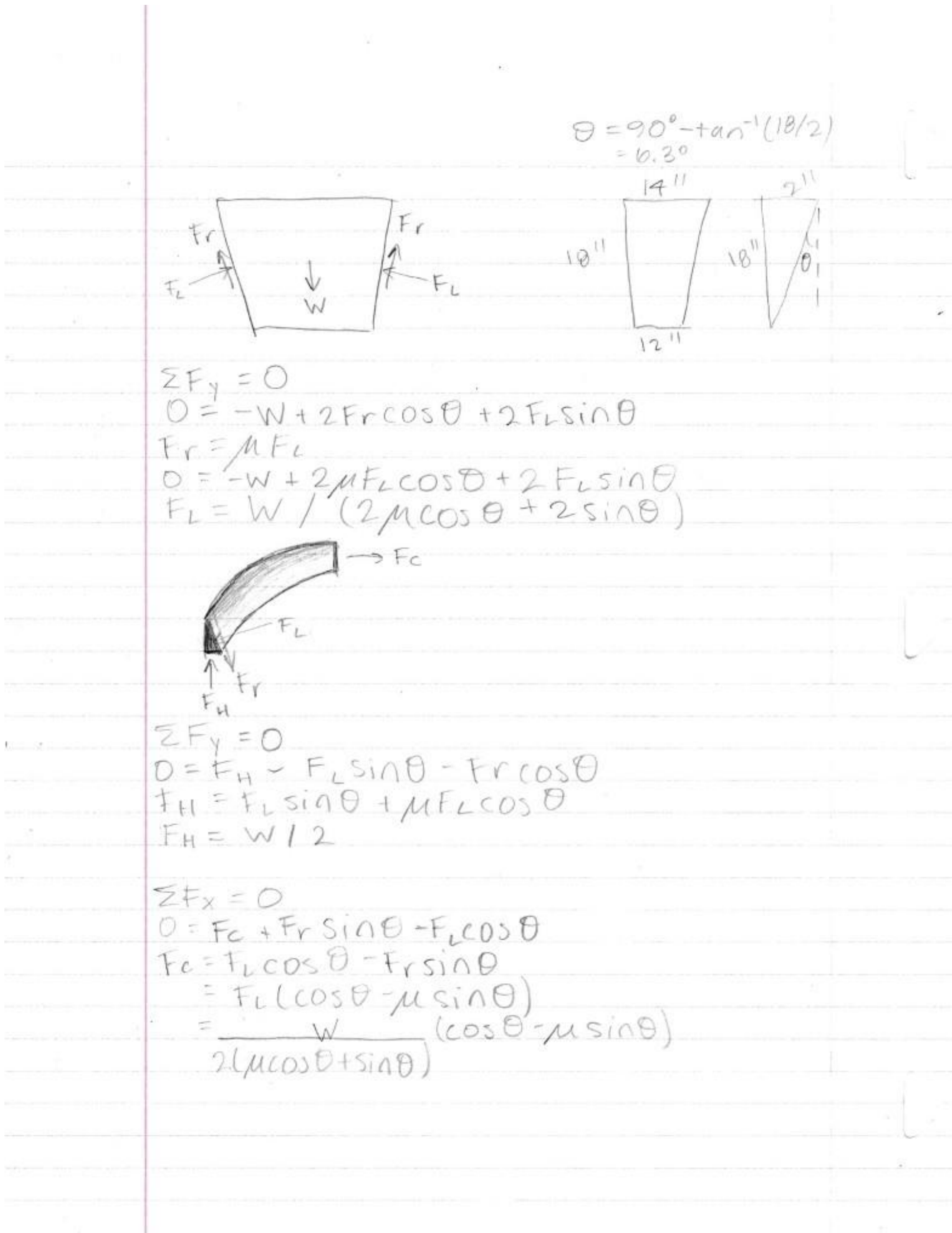


Figure D.1. Hand calculations and FBD for the grabber arm when in contact with the barrel.

Grabber Arc Length:

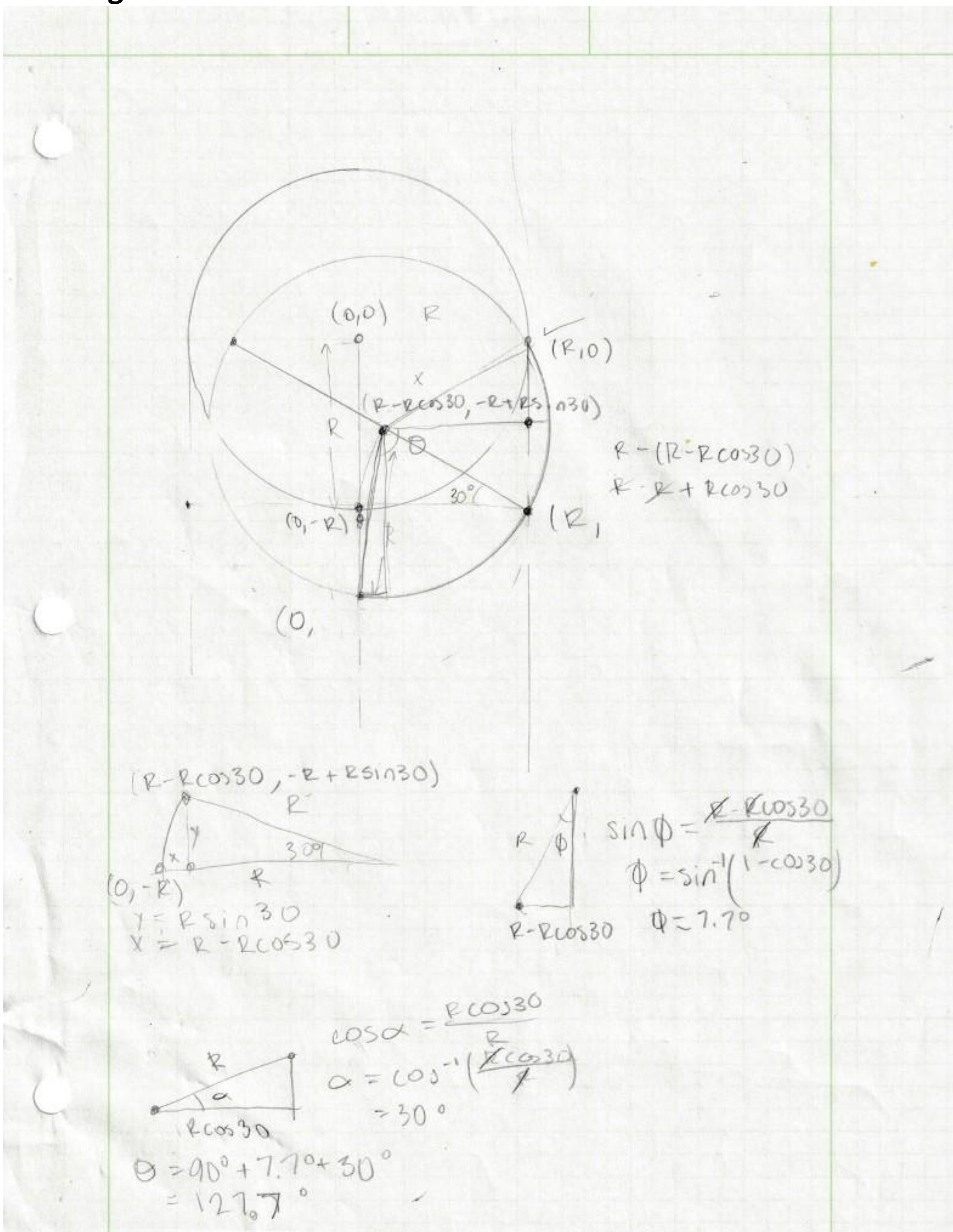


Figure D.2. Hand calculation for determining the optimal grabber arc length to maximize total coverage around the barrel while still allowing the grabbers to fit around the barrel's diameter and to avoid interference between the ends of the grabbers.

Linkage Force Calculations:

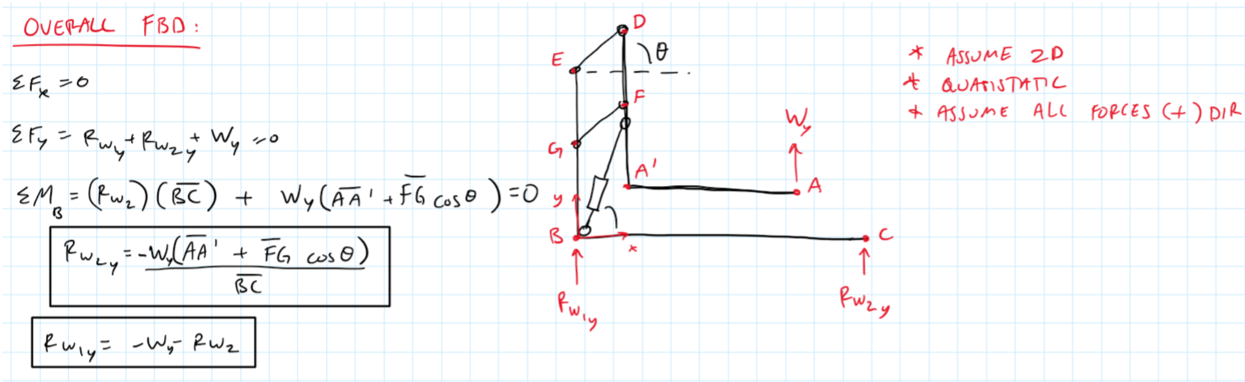


Figure D.3. Hand calculation of overall FBD used in spreadsheet calculator.

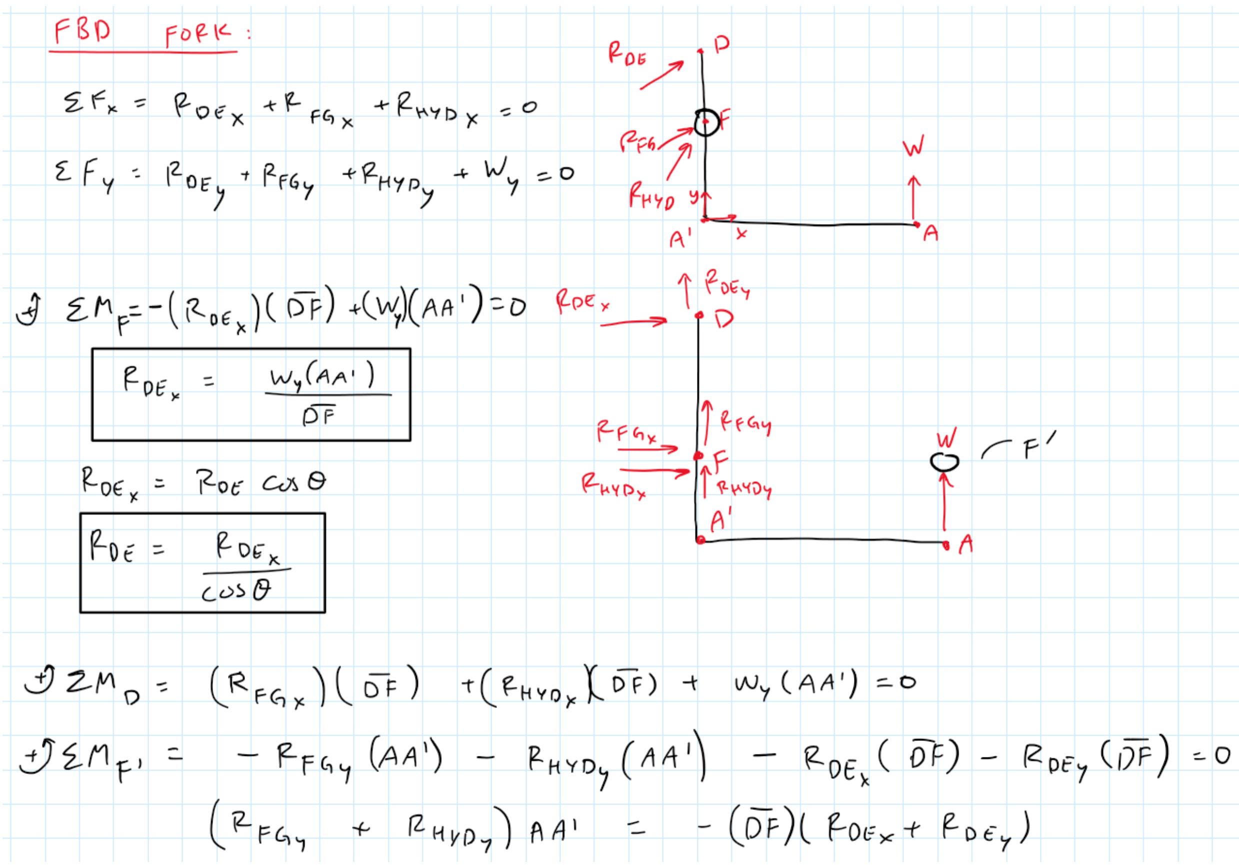


Figure D.4. Hand calculations deriving sum of forces and moments for fork mechanism.

A	B	C	D	E	F	G	H	I	J	K	L
							Force (lbf)			Moment (lbf*in)	
	Segment	Center Length (in.)		Point	Force Name	x	y	total	direction (deg)		
	AA'	15.5		A	W	0	-500.0	500.0	-90.0		
	FG	9		C	R_{W2}	0	400.0	400.0	90.0		
	DE	9		B				0.0	#DIV/0!		
Theta	60	1.047197551			R_{W1}	0	100.0	100.0	90.0		
	BC	25			F_{HYD}				#DIV/0!		
Alpha	76.53486853	1.335785448							#DIV/0!		
	HYD	19.32545032		D	R_{DE}	-968.75	-1677.9	-1937.5	-120.0		
	BG	11			R_{DE2}	-968.75	-1677.9	1937.5	-120.0		
	Lift Height from base	7.794228634									
	Ground to Base										
	Total Lift Height	7.794228634									
	DF	8									

Figure D.5. Example calculations of FBD Forces on linkages.

Linkage Analysis:

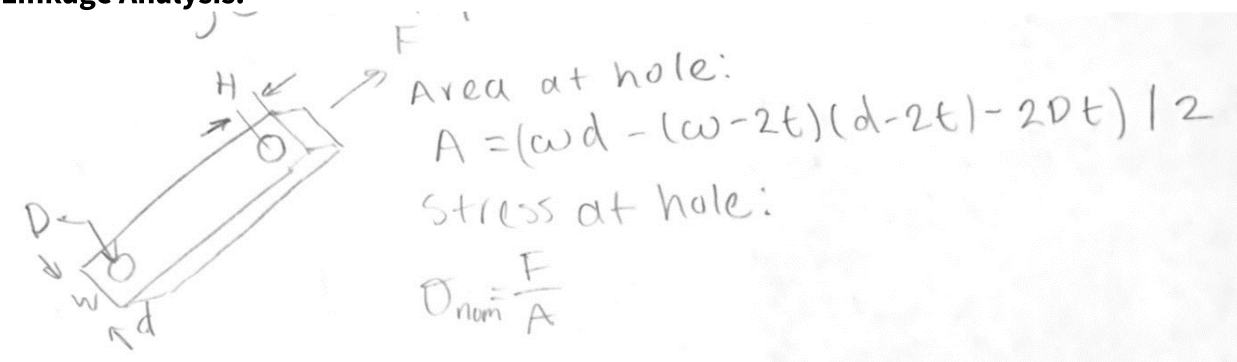


Figure D.6. Hand calculation setting up the calculator for stress analysis of linkages.

A	B
width of bar (inch)	2
depth of bar (inch)	1
thickness (inch)	0.125
diameter of pin hole (inch)	1
Height of hole (inch)	1
Area at stress concentration (inch^2)	0.21875
Angle of linkages from horizontal (rad)	0.7854
F/2 (lb)	968.75
Yield Stress (psi)	36300
Nominal Stress at each hole(psi)	4428.571
d/w	0.5
h/w	0.5
Kt (Table A-15-2)	3
Max stress at each hole (psi)	13285.71
Safety Factor	2.732258

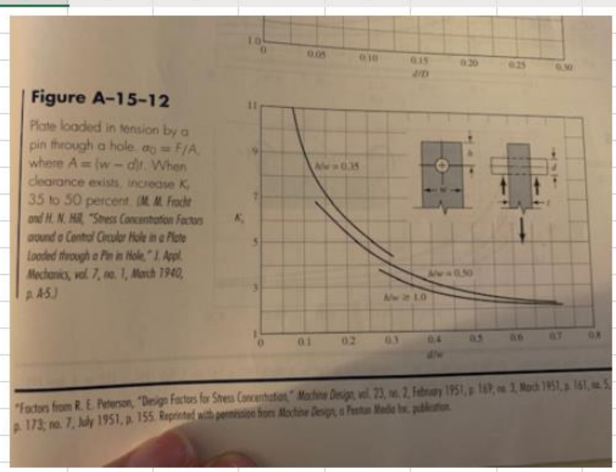


Figure D.7. Spreadsheet calculator used to determine stress in linkages.

Bolt Analysis:

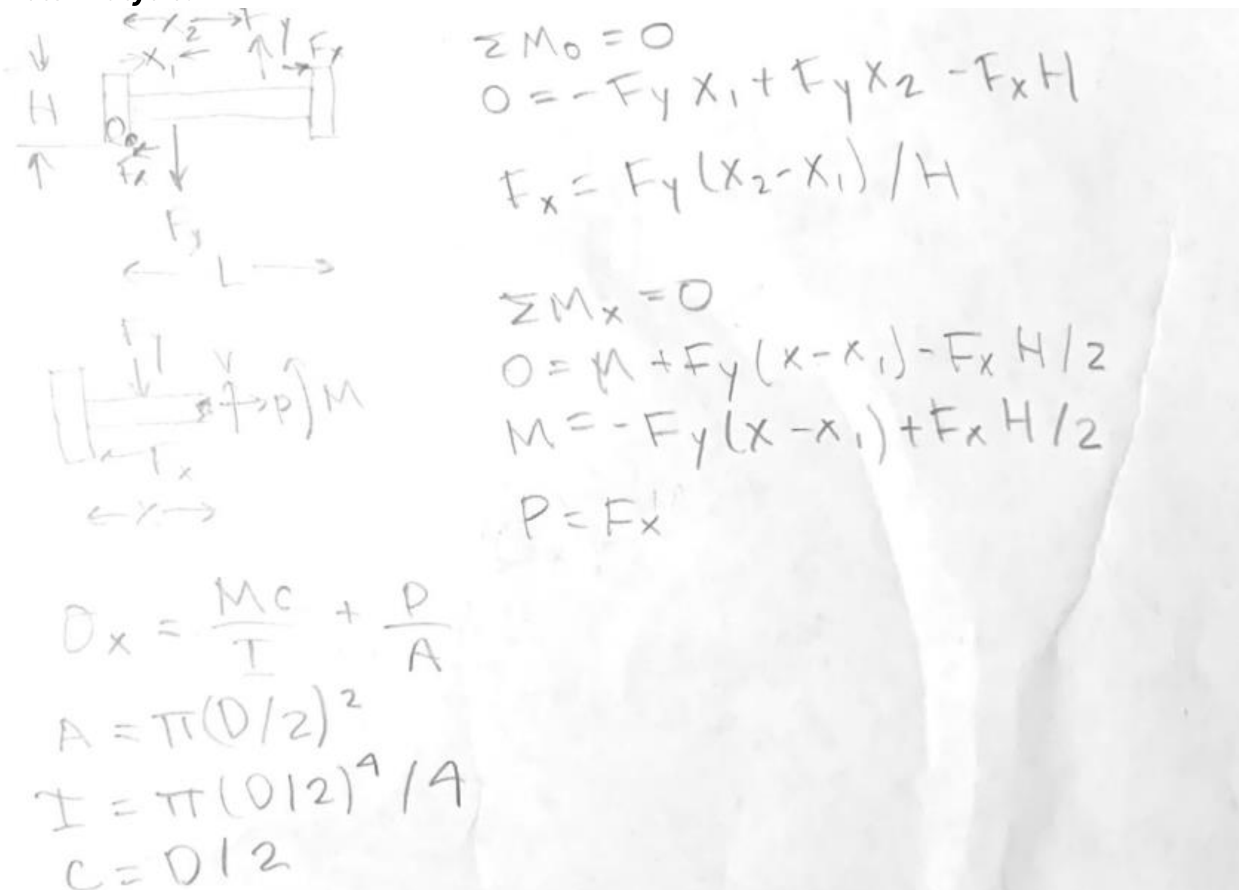


Figure D.8. Hand calculations setting up bolt analysis calculations.

A	B
Fy (lbs)	1937.5
x2-x1 (inch)	1
Head Diameter (inch)	1
Fx (lbs)	1937.5
M (lbs * inch)	968.75
Bolt Diameter (inch)	0.75
I (inch^4)	0.015532
stress (psi)	27775.48
yield stress (psi)	92000
n	3.312273

Figure D.9. Spreadsheet calculator for bolt stress analysis.

Bushing Analysis:

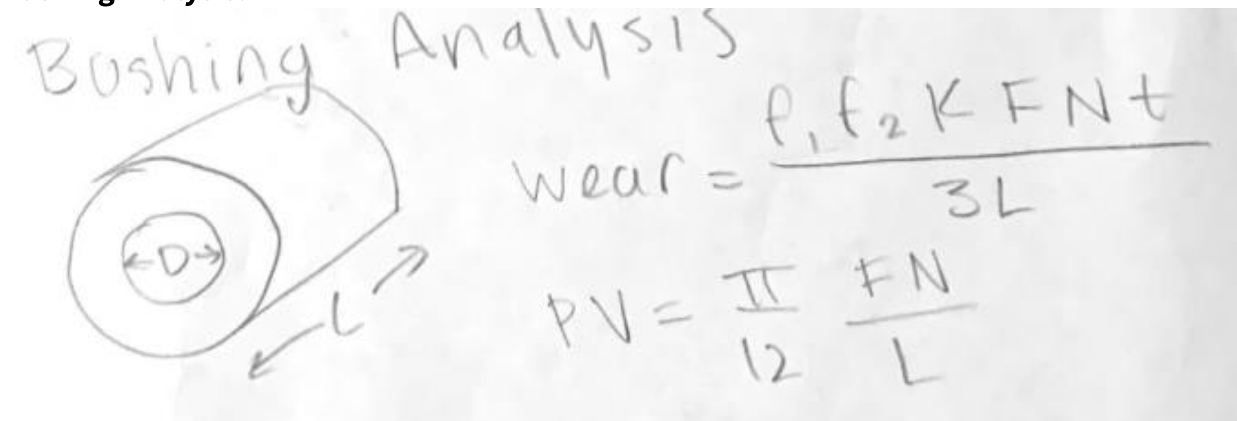


Figure D.10. Hand calculations setting up bushing analysis.

	A	B
1	F (lbs)	1937.5
2	Bore Diameter (inch)	0.75
3	L (inch)	1
4	K (in^3 * min/(lbf * ft * h)	2E-08
5	t (hours)	1
6	N (rev/min)	3.5
7	Pmax (psi)	3290.87
8	Pnom (psi)	2583.333
9	v(ft/min)	0.687223
0	f1	1.5
1	f2	1
2	wear (inch)	0.005113
3	PV (psi ft/min)	1775.327
4		

Figure D.11. Calculator for bushing stress analysis.

Bushing Material	Wear Factor K	Limiting PV
Oiles 800	$3(10^{-10})$	18 000
Oiles 500	$0.6(10^{-10})$	46 700
Polyactal copolymer	$50(10^{-10})$	5 000
Polyactal homopolymer	$60(10^{-10})$	3 000
66 nylon	$200(10^{-10})$	2 000
66 nylon + 15% PTFE	$13(10^{-10})$	7 000
+ 15% PTFE + 30% glass	$16(10^{-10})$	10 000
+ 2.5% MoS_2	$200(10^{-10})$	2 000
6 nylon	$200(10^{-10})$	2 000
Polycarbonate + 15% PTFE	$75(10^{-10})$	7 000
Sintered bronze	$102(10^{-10})$	8 500
Phenol + 25% glass fiber	$8(10^{-10})$	11 500

*dim[K] = in³ · min/(lbf · ft · h), dim [PV] = psi · ft/min.

Figure D.12. Table 12-8 used in bushing analysis.

Mode of Motion	Characteristic Pressure P, psi	Velocity V, ft/min	f_1*
Rotary	720 or less	3.3 or less	1.0
		3.3–33	1.0–1.3
		33–100	1.3–1.8
	720–3600	3.3 or less	1.5
		3.3–33	1.5–2.0
		33–100	2.0–2.7

Figure D.13. Table 12-10 used in bushing analysis.

Ambient Temperature, °F	Foreign Matter	f_2
140 or lower	No	1.0
140 or lower	Yes	3.0–6.0
140–210	No	3.0–6.0
140–210	Yes	6.0–12.0

Figure D.14. Table 12-11 used in bushing analysis.

Lifting Arm Analysis:

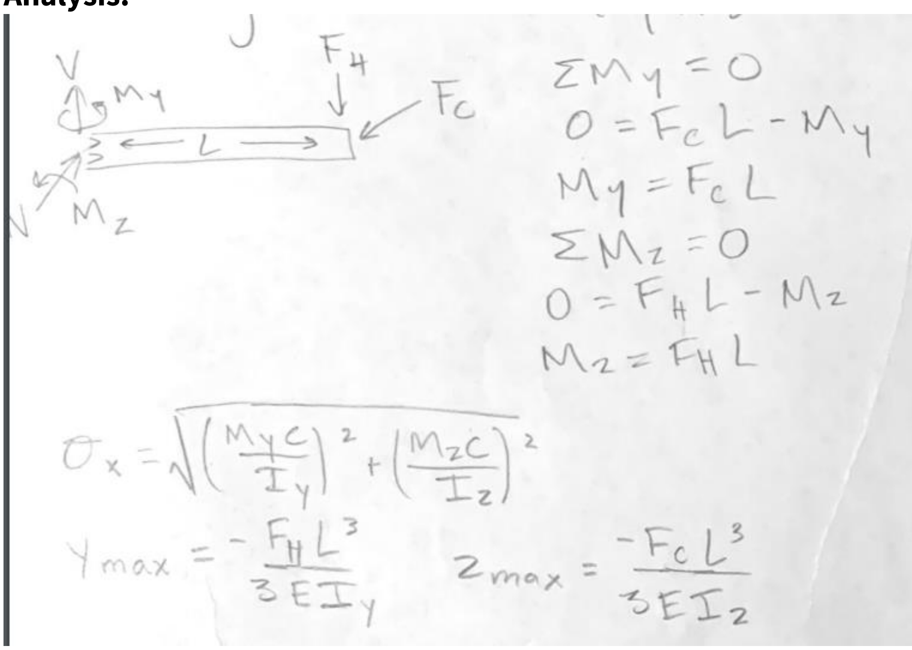


Figure D.15. Hand calculations set up for the lifting arm calculator.

width (inch)	1
height (inch)	2
thickness (inch)	0.125
Iy (inch^4)	0.331706
Iz (inch^4)	0.105143
Length of fork arms	26
Fy (lb)	250
Fz (lb)	273.5258
y max (inch)	0.152261
z max (inch)	0.525554
My (inch pound)	6500
Mz (inch pound)	7111.67
stress (psi)	35209.66
n	1.030967

Figure D.16. Spreadsheet calculator to determine stress in the lifting arm.

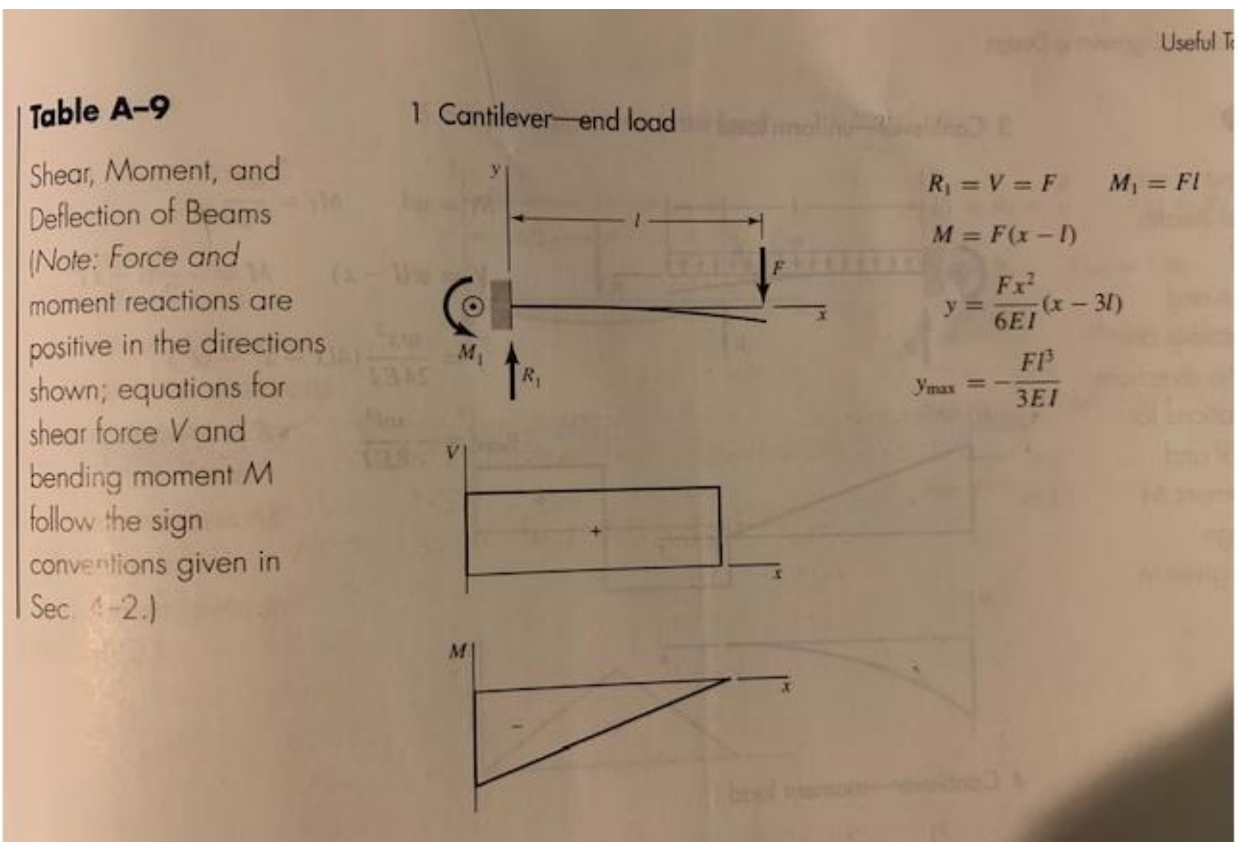


Table A–9

Shear, Moment, and Deflection of Beams (Note: Force and moment reactions are positive in the directions shown; equations for shear force V and bending moment M follow the sign conventions given in Sec. 4-2.)

1 Cantilever—end load

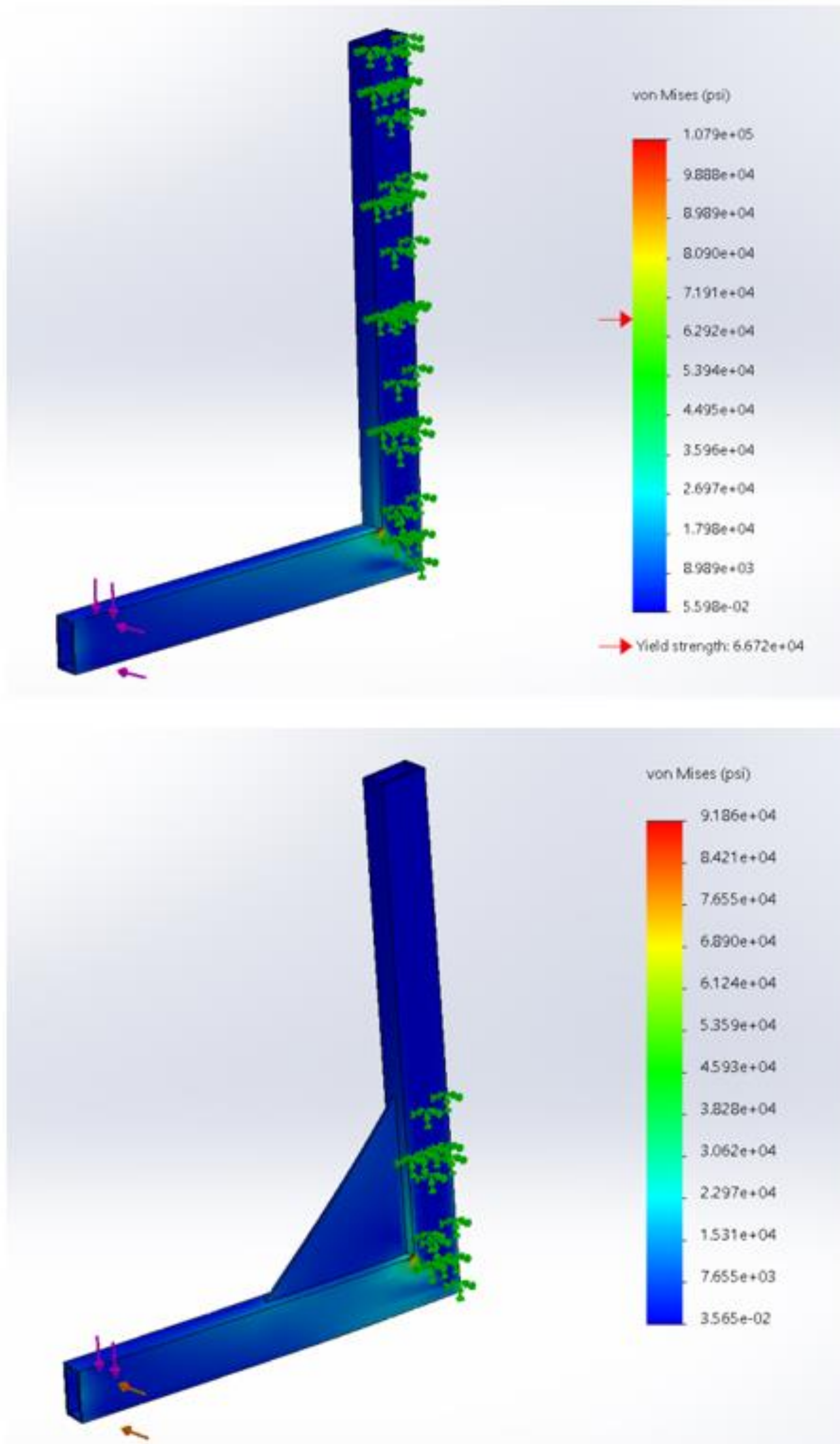
$R_1 = V = F \qquad M_1 = Fl$

$M = F(x - l)$

$y = \frac{Fx^2}{6EI}(x - 3l)$

$y_{max} = -\frac{Fl^3}{3EI}$

Figure D.17. Table A-9 used in lifting arm stress analysis.



Added 1/8" thick steel plate. 6" x 6" x hypotenuse"

Figure D.18. FEA analysis comparing yield in the lifting arm before and after the addition of a 1/8" triangular support plate.

Welds Analysis:

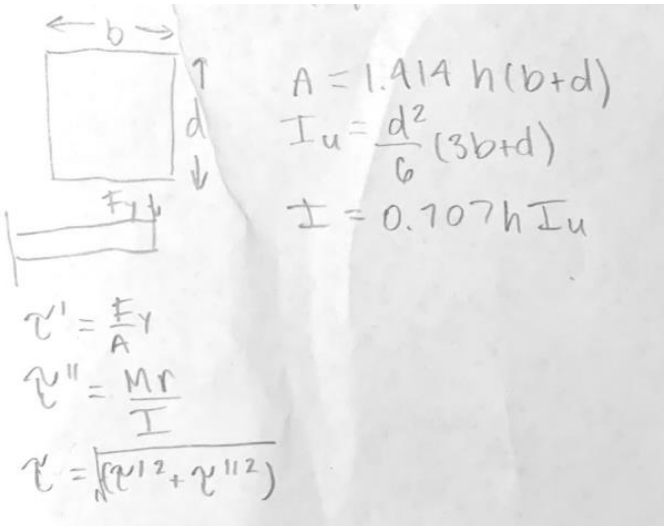


Figure D.19. Hand calculations setup for the weld stress analysis calculator.

	A	B
1	Fy (lb)	250
2	Fz (lb)	273.5258
3	My (inch pound)	191.468
4	Mz (inch pound)	175
5	h (inch)	0.0625
6	d (inch)	2
7	b (inch)	1
8	A (inch)	0.265125
9	Iuz (inch^3)	3.333333
10	Iz (inch^4)	0.147292
11	tao'y (psi)	942.9514
12	tao''y (psi)	1188.119
13	taoy (psi)	1516.833
14	Iuy	1.166667
15	Iy	0.051552
16	tao'z	1031.686
17	tao''z	87.5
18	taoz	1035.39
19	tao	1836.523
20	Electrode Sy (psi)	50000
21	n	15.70903
22		

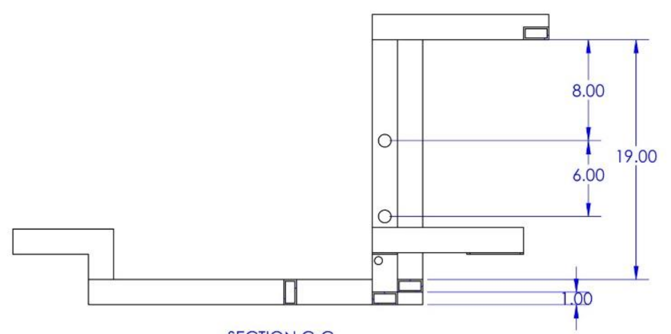
Figure D.20. Spreadsheet calculator for weld stress analysis.

Appendix E. CAD Drawing Package

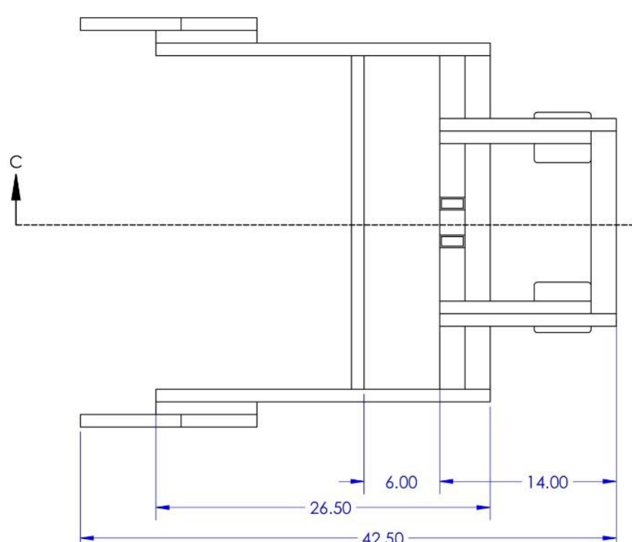
This appendix contains the assembly, subassembly, and custom part drawings for the FDR version of the barrel mover prototype design. It also contains a Bill of Materials for each assembly, as well as a complete BOM for the entire project, including vendors.

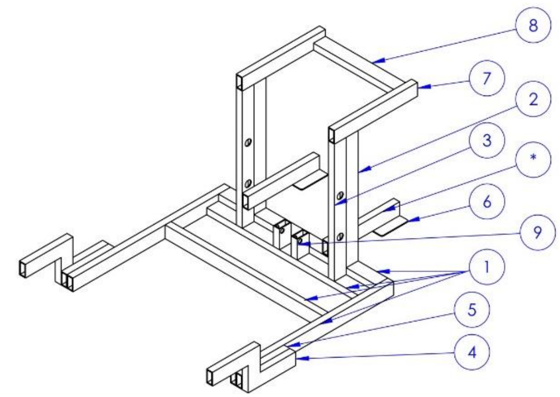
The following documents are attached beginning on the next page:

1. Frame assembly – no wheels
2. Frame assembly – with wheels
3. Forks assembly – no grabbers
4. Forks assembly – with grabbers
5. Linkage assembly
6. Grabber
7. Joint bolt assembly
8. Steel Tubing
9. Complete assembly BOM
10. Full assembly



SECTION C-C





ITEM NO.	PART NUMBER	SW-Configuration Name(Configuration Name)	QTY.
1	1x2_Steel_Tubing	26.5	5
2	1x2_Steel_Tubing	19	2
3	1x2_Steel_Tubing	20-2 holes	2
4	Front Wheel Support	Default	2
5	1x2_Steel_Tubing	8	2
6	rear wheel plate	Default	2
7	1x2_Steel_Tubing	14	2
8	1x2_Steel_Tubing	14.5	1
9	1x2_Steel_Tubing	3-1 hole	2

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/32
ANGULAR: MACH ±.5 BEND ±.5
ONE PLACE DECIMAL ±.1
TWO PLACE DECIMAL ±.05
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
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NEXT ASSY | USED ON
APPLICATION

	NAME	DATE
DRAWN	M. Shah	
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ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

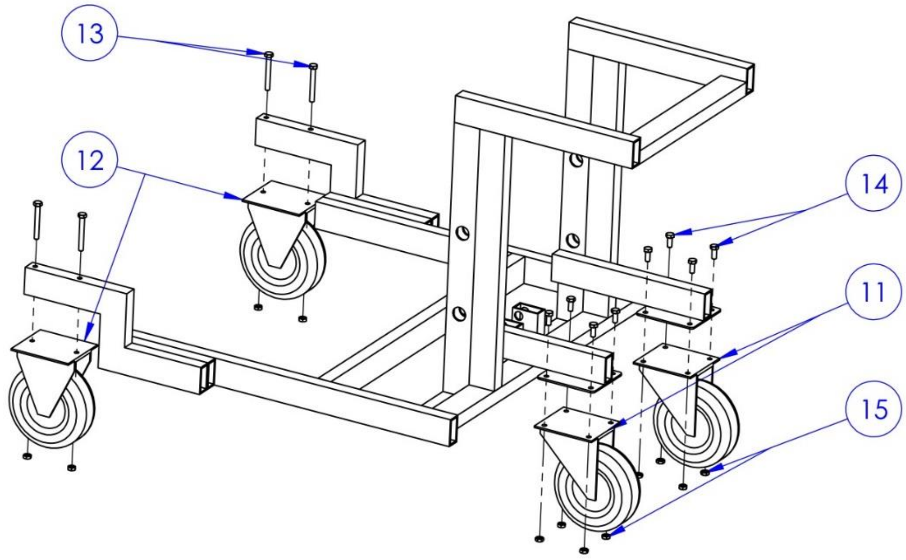
TITLE:
Frame - No Wheels with BOM

SIZE B | DWG. NO. 1 | REV

SCALE: 1:8 | WEIGHT: | SHEET 1 OF 1

2 1

B B



ITEM NO.	PART NUMBER	SW-Configuration Name(Configuration Name)	QTY.
1	1x2_Steel_Tubing	26.5	5
2	1x2_Steel_Tubing	19	2
3	1x2_Steel_Tubing	20-2 holes	2
4	1x2_Steel_Tubing	8	2
5	1x2_Steel_Tubing	14	2
6	1x2_Steel_Tubing	14.5	1
7	1x2_Steel_Tubing	3-1 hole	2
8	Front Wheel Support	Default	2
9	12	12	2
10	rear wheel plate	Default	2
11	wheel assem	Rear	2
12	wheel assem	Front	2
13	HFBOLT 0.3125-18x2.5x0.875-N	HFBOLT 0.3125-18x2.5x0.875-N	4
14	hex finished bolt_ai	HFBOLT 0.3125-18x0.75x0.75-N	8
15	HJNUT 0.3125-18-D-N	HJNUT 0.3125-18-D-N	12

A A

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

	NAME	DATE
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CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

MATERIAL

FINISH

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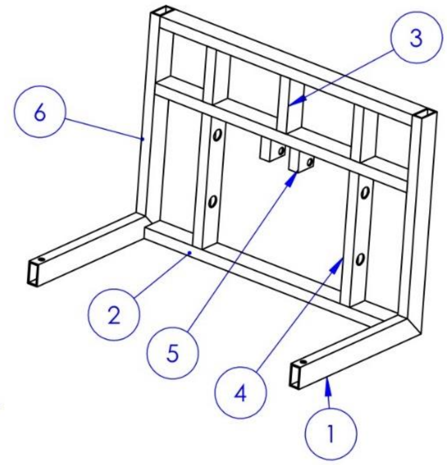
Frame With Wheels - BOM

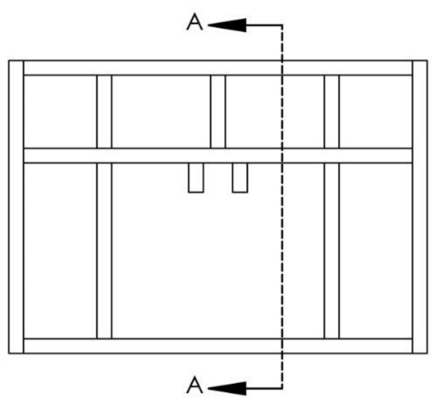
SIZE A | DWG. NO. 2 | REV.

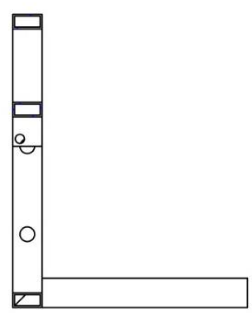
SCALE:1:10 | WEIGHT: | SHEET 1 OF 1

2 1

ITEM NO.	PART NUMBER	SW-Configuration Name(Configuration Name)	QTY.
1	1x2_Steel_Tubing	16x45	2
2	1x2_Steel_Tubing	26.5	3
3	1x2_Steel_Tubing	5in	3
4	1x2_Steel_Tubing	12-2 holes	2
5	1x2_Steel_Tubing	2-1 hole	2
6	1x2_Steel_Tubing	20x45	2







SECTION A-A

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

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MFG APPR.		
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COMMENTS:

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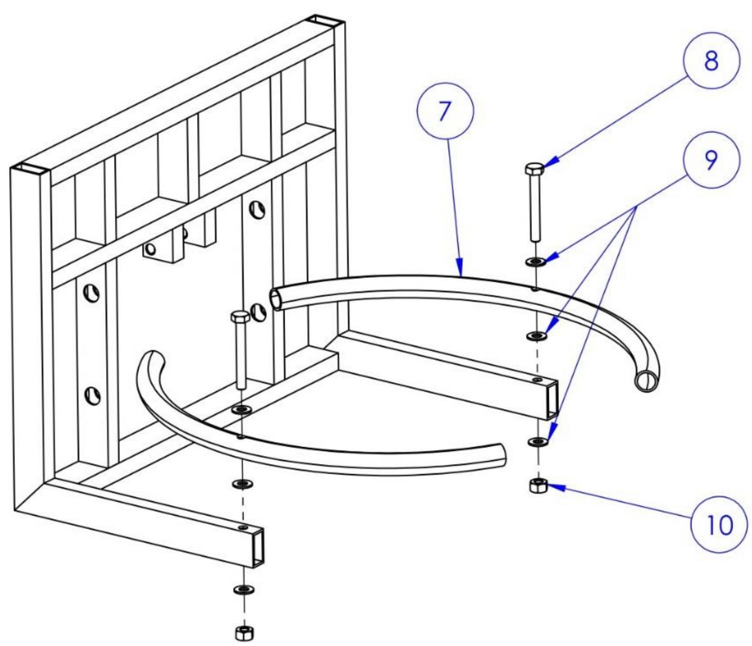
PROPRIETARY AND CONFIDENTIAL

Forks Only - BOM

SIZE A | DWG. NO. 3 | REV.

SCALE:1:10 | WEIGHT: | SHEET 1 OF 1

ITEM NO.	PART NUMBER	SW-Configuration Name(Configuration Name)	QTY.
1	1x2_Steel_Tubing	16x45	2
2	1x2_Steel_Tubing	20x45	2
3	1x2_Steel_Tubing	26.5	3
4	1x2_Steel_Tubing	5in	3
5	1x2_Steel_Tubing	12-2 holes	2
6	1x2_Steel_Tubing	2-1 hole	2
7	Grabber_V2	Default	2
8	heavy hex bolt_ai	HHBOLT 0.5000-13x4x1-N	2
9	Preferred Narrow FW 0.5	Preferred Narrow FW 0.5	6
10	HHNUT 0.5000-13-D-N	HHNUT 0.5000-13-D-N	2



DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

MATERIAL

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APPLICATION

	NAME	DATE
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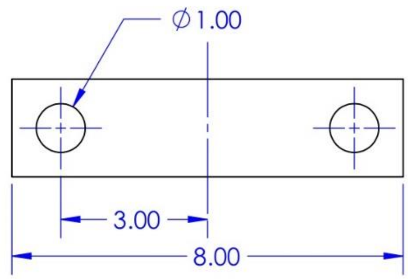
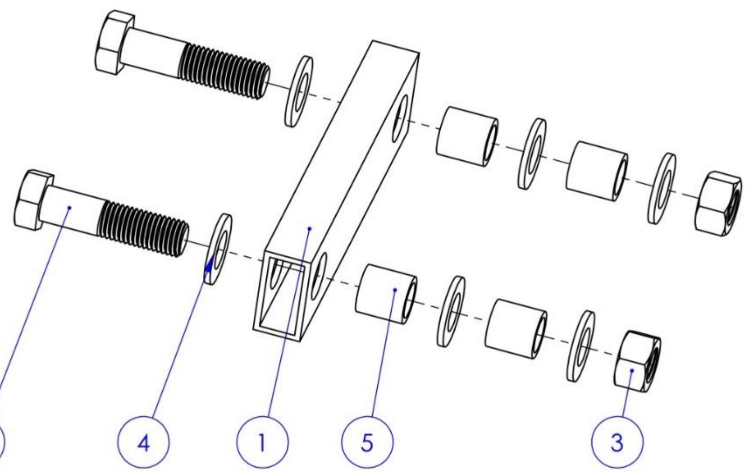
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SIZE A DWG. NO. 4ForksAssem-Grabbers-BOM REV.

SCALE:1:8 WEIGHT: SHEET 1 OF 1





ITEM NO.	PART NUMBER	SW-Configuration Name(Configuration Name)	QTY.
1	1x2_Steel_Tubing	7-2 holes (linkage)	1
2	0.75 dia x 2.5 Hex Bolt	91247A847	2
3	0.75 dia hex nut	95462A538	2
4	0.75 dia x 1/8 washer	98180A170	6
5	Part5^joint bolt assembly	Default	4

PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <COMPANY NAME >. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <COMPANY NAME> IS PROHIBITED.

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TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

MATERIAL

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COMMENTS:		

Linkage Assembly BOM

SIZE A | DWG. NO. 5 | REV.

SCALE:1:3 | WEIGHT: | SHEET 1 OF 1

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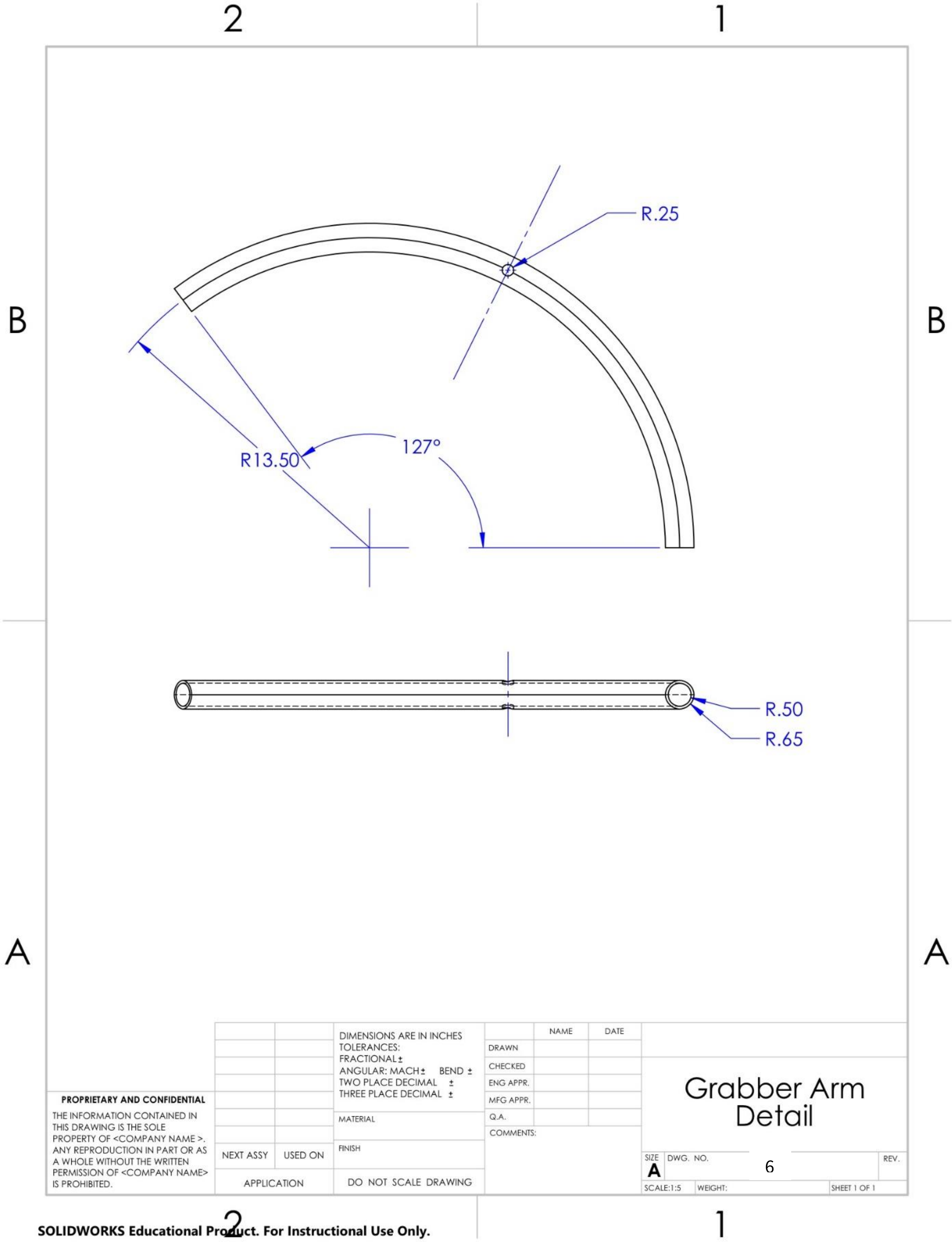

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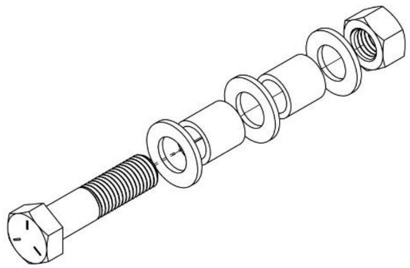

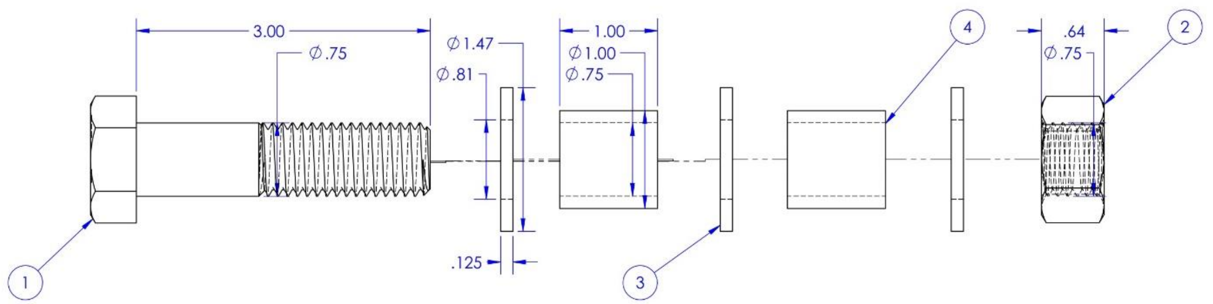

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	0.75 dia x 2.5 Hex Bolt	BOLT	1
2	0.75 dia hex nut	NUT	1
3	0.75 dia x 1/8 washer	WASHER	3
4	Part5^joint bolt assembly	NYLON BUSHING	2

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/32
ANGULAR: MACH ±5 BEND ±5
ONE PLACE DECIMAL ±.1
TWO PLACE DECIMAL ±.05
THREE PLACE DECIMAL ±.005
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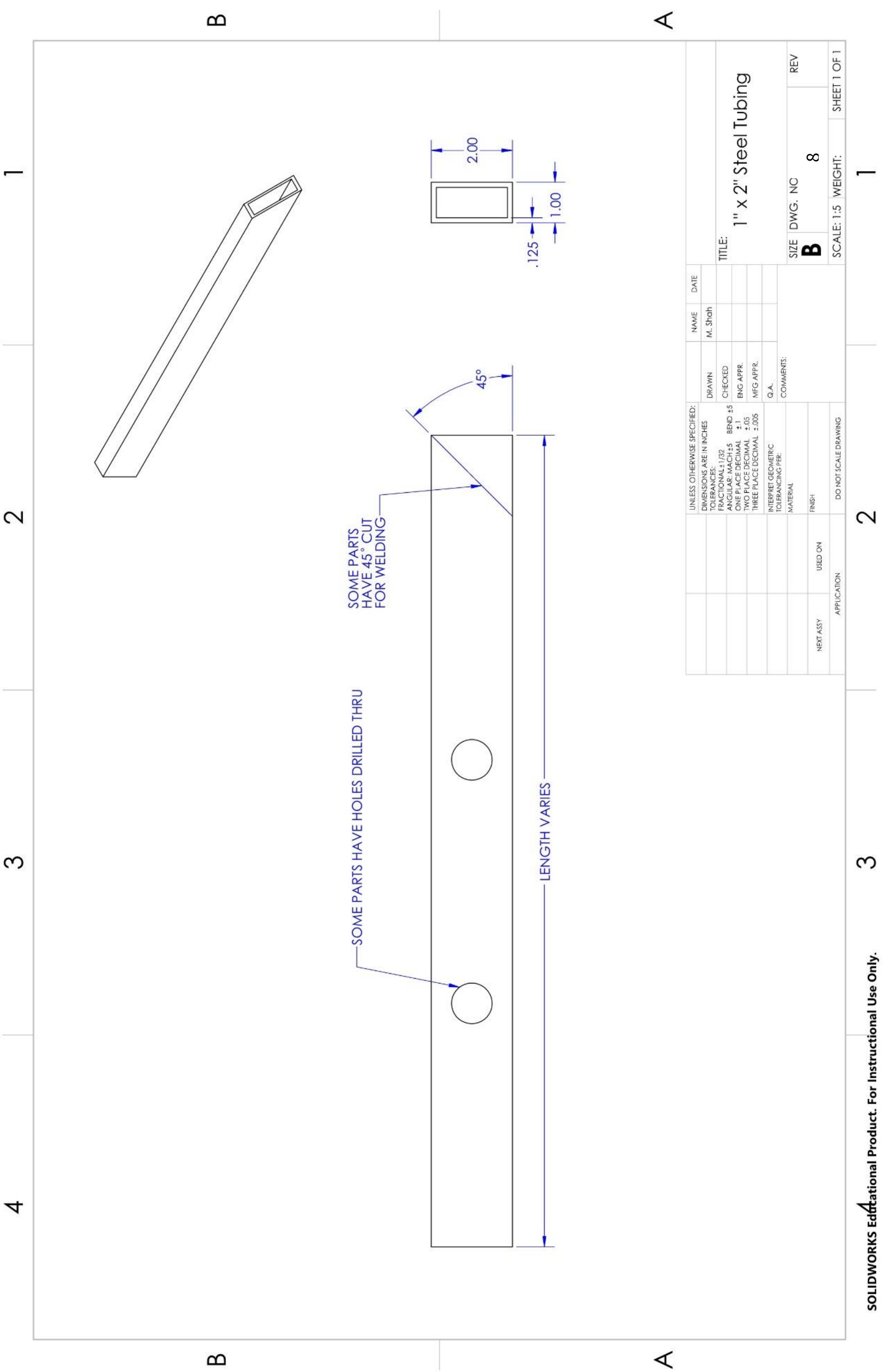
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

TITLE: Barrel Mover

7

SIZE B DWG. NO. 8-joint bolt assembly REV

SCALE: 1:2 WEIGHT: SHEET 1 OF 1


45°
2.00
.125
1.00
SOME PARTS HAVE 45° CUT FOR WELDING
SOME PARTS HAVE HOLES DRILLED THRU
LENGTH VARIES
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/32
ANGULAR: MACH ±5 BEND ±5
ONE PLACE DECIMAL ±.1
TWO PLACE DECIMAL ±.05
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER:
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DRAWN
M. Shah
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
1" x 2" Steel Tubing
SIZE
B
DWG. NO
8
REV
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1
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ITEM NO.	PART NUMBER	SW-Configuration Name(Configuration Name)	DESCRIPTION	QTY.
1	FrameAssem	Default		1
1.1	1x2_Steel_Tubing	26.5		5
1.2	Front Wheel Support	Default		2
1.3	rear wheel plate	Default		2
1.4	wheel assem	Rear		2
1.4.1	wheel	Default		1
1.4.2	wheel bracket	Rear		1
1.5	HJNUT 0.3125-18-D-N			12
1.6	hex finished bolt_ai	HFBOLT 0.3125-18x0.75x0.75-N		8
1.7	1x2_Steel_Tubing	19		2
1.8	1x2_Steel_Tubing	20-2 holes		2
1.9	1x2_Steel_Tubing	8		2
1.10	12			2
1.11	1x2_Steel_Tubing	14		2
1.12	1x2_Steel_Tubing	14.5		1
1.13	wheel assem	Front		2
1.13.1	wheel bracket	Front		1
1.13.2	wheel	Default		1
1.14	1x2_Steel_Tubing	3-1 hole		2
1.15	HFBOLT 0.3125-18x2.5x0.875-N			4
2	ForksAssem	Default		1
2.1	1x2_Steel_Tubing	16x45	16" Steel Tubing with 45° Cut	2
2.2	Grabber_V2	Default		2
2.3	heavy hex bolt_ai	HHBOLT 0.5000-13x4x1-N		2
2.4	Preferred Narrow FW 0.5			6
2.5	HHNUT 0.5000-13-D-N			2
2.6	1x2_Steel_Tubing	20x45		2
2.7	1x2_Steel_Tubing	26.5		3
2.8	1x2_Steel_Tubing	5in		3
2.9	1x2_Steel_Tubing	12-2 holes		2
2.10	1x2_Steel_Tubing	2-1 hole		2
3	LinkageAssem	Default		4
3.1	1x2_Steel_Tubing	7-2 holes (linkage)		1
3.2	joint bolt assembly	Default		2
3.2.1	0.75 dia x 2.5 Hex Bolt		BOLT	1
3.2.2	0.75 dia hex nut		NUT	1
3.2.3	0.75 dia x 1/8 washer		WASHER	3
3.2.4	Part5^joint bolt assembly	Default	NYLON BUSHING	2
4	Snow Plow Cylinder Assembly	Default		1
4.1	Snow Plow Cylinder Base 9-8656	Default		1
4.2	Snow Plow Cylinder Ram 9-8656	Default		1
5	heavy hex finished bolt_ai2	HHFBOLT 0.6250-11x5x1.5-N		2
6	2942T8			1

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

	NAME	DATE
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ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

MATERIAL

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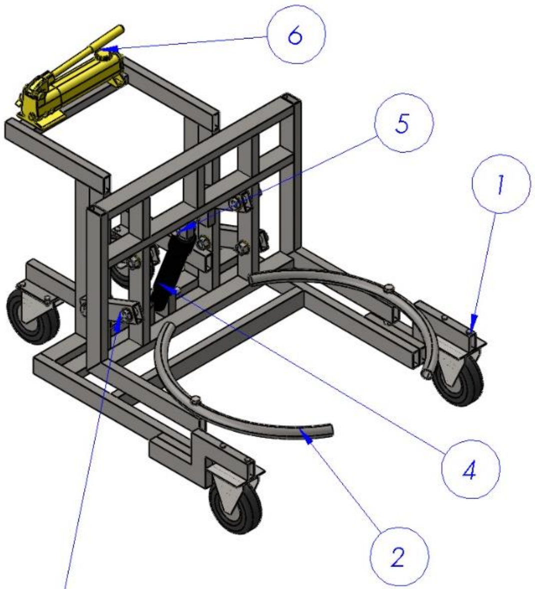
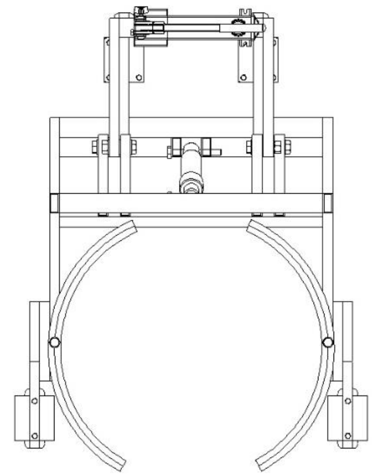
FULL BOM

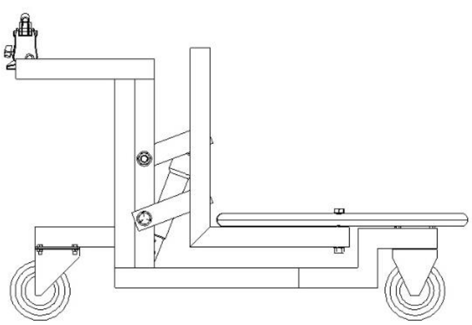
SIZE A | DWG. NO. 9 | REV.

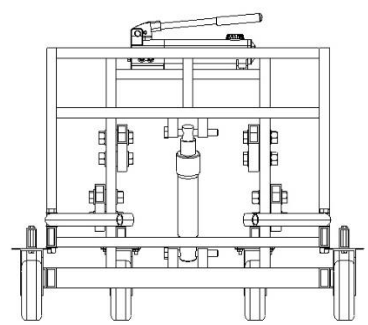
SCALE:1:15 | WEIGHT: | SHEET 1 OF 1





ITEM NO.	PART NUMBER	DESCRIPTION	QUANTITY
1	FrameAssem		1
2	ForksAssem		1
3	LinkageAssem		4
4	Snow Plow Cylinder Assembly		1
5	heavy hex finished bolt_ai2		2
6	2942T8		1





DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

	NAME	DATE
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ENG APPR.		
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COMMENTS:

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FULL ASSEMBLY

SIZE A | DWG. NO. 10 | REV.

SCALE:1:15 | WEIGHT: | SHEET 1 OF 1

Appendix F. Part Specifications

This appendix contains specifications for each purchased component in case a component needs to be replaced with an acceptable alternate. Specifications are sourced from the retailer each component was purchased from.

The design critical components whose information is attached are:

- Caster wheels
- Hydraulic cylinder
- Hydraulic hand pump
- Nylon stock
- ¾" Diameter linkage bolts

All other hardware can be easily replaced with compatible sized parts.

Caster Wheels

6" AIR-FREE FLAT-FREE RIGID CASTER

SKU# **6-82-AFR**

CONFIGURATION

Select a Brake: *

Yes + $4

$31.48 QTY 1 ADD TO CART

Volume discounts are available for bulk or frequent orders. Contact Us.

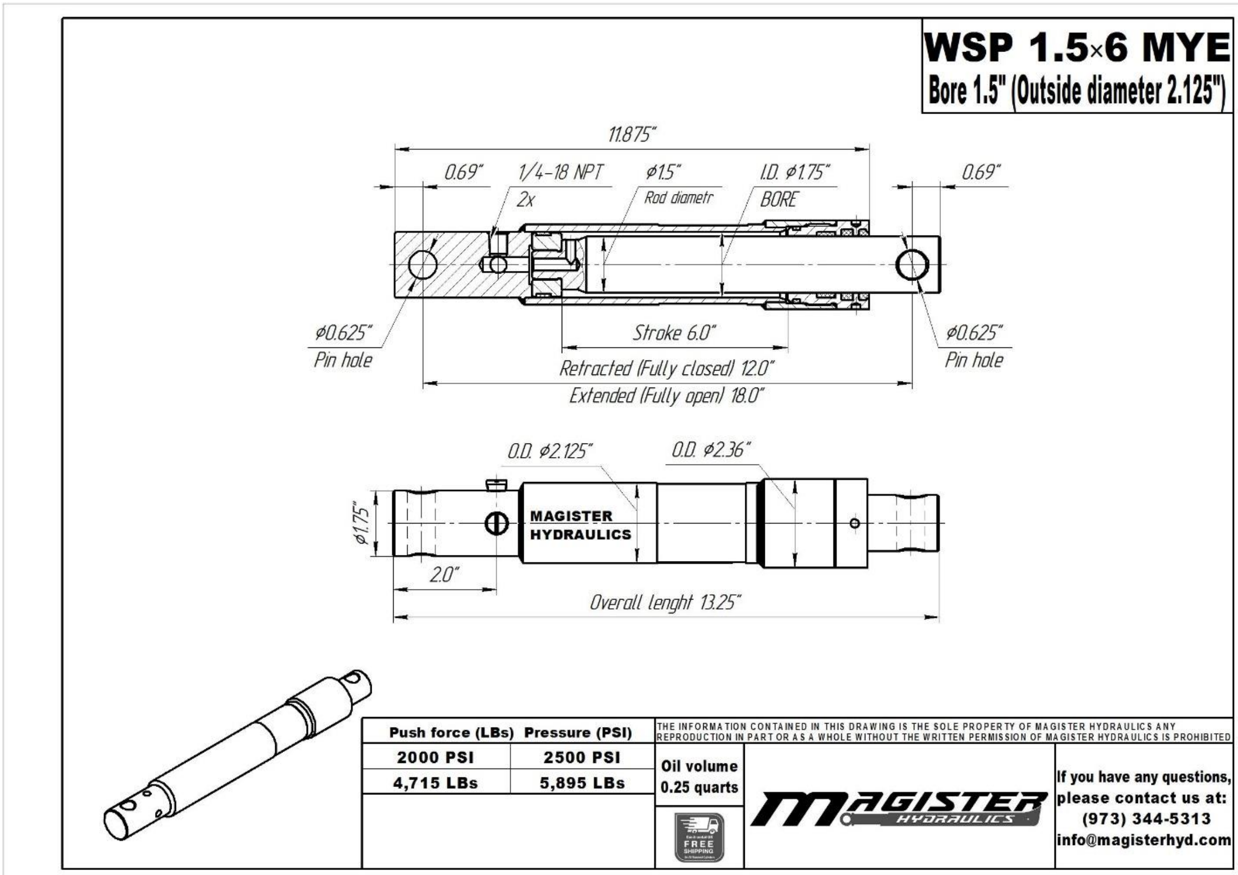
SPECIFICATIONS

Weight Capacity: 250 lbs.	**Wheel Width:** 2"
Wheel Diameter: 6"	**Wheel Material:** Air-Free Flat-Free
Core Material: Zinc-Plated Iron	**Overall Height:** 7-1/2"

SPECIFICATIONS

Cross Reference	6-82-AFR	**Color**	Black
Overall Height	7-1/2"	**Weight Capacity Range**	50 - 250 lbs.
Anti Static	No	**Core Material**	Zinc-Plated Iron
Dust Cap	No	**Fork Finish**	Zinc Plated
Mounting Bolt Size	3/8"	**Mounting Type**	Top Plate
Noise Reduction	No	**Stem Length**	No
Top Plate Bolt Hole Pattern	2-5/8" x 3-5/8" slotted to 3" x 3"	**Tread Style**	Flat Tread
Weight Capacity	250 lbs.		

Hydraulic Cylinder



SHOP | CUSTOM CYLINDERS | ABOUT US | MANUFACTURERS | FAQ | CONTACT US | CART

Home | Hydraulic Cylinders | Snow Plow Hydraulic Cylinders | 1.5" Bore Snow Plow | 1.5" bore x 6" stroke snow plow Meyers hydra

1.5" bore x 6" stroke snow plow Meyers hydraulic cylinder

$94.00

WSP 1.5x6MYE

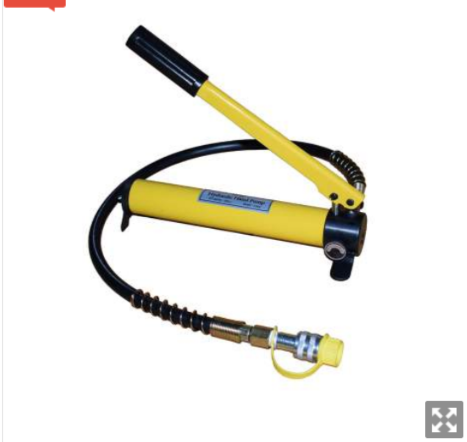
Bore : 1.5 inch
Stroke : 6 inch
Port Size : 1/4" NPT
Extended : 18"
Overall Length : 13.25"
Oil Volume (Quarts) : 0.25
GTIN : 854335007018

OD : 2.125"
Rod : 1.5"
Pin : 5/8"
Retracted : 12"
Pressure : 2500 PSI
Brand : Magister Hydraulics

1+ PRICE EA	4+ PRICE EA -5%	10+ PRICE EA -10%
$94.00	$89.30	$84.60

Hydraulic Hand Pump

SALE



Manual Hydraulic Hand Pump 180kg/cm² CP-180

BY mingren 0 / 5

1 Questions \ 1 Answers

TPIN: MWJ01OMN8

Condition: New

Price: **$69.00** ~~$79.00~~

Why is our price so low?

ONLY 3 LEFT IN STOCK. Fulfilled by Toolots.

WARRANTY: 1-YEAR Warranty For Parts, Service and Repair by: YUUTOOL

Dealer $58.22

Buy 5 for 65 each

Buy 10 for 59 each

1.Pump is designed in two stage of high and low speed for quick oil output.Even if lack of electric power,It could still be operated conveniently.It is the same as the electric pump in any working pressure and function.
2.Manual operation style,oil pipe fitted with quick coupling could be ordered in any length.
3.Pressure could be stopped in middle.Inner designed over pressure safety unit protect hydraulic valve.
4.Oil pipe coupling with PT3/8 thread

Product Information

Technical Details

Model	CP-180
High pressure	$180kg/cm^2$
Capacity Of Oil	350cc
Weight	4.5kg
Port Size	PT3/8 thread

Nylon Stock

AIN Plastics Extruded Nylon 6/6 Plastic Rod Stock, 1 in. Dia. x 24 in. L, Natural

Item #: WBB1651023

Not Yet Rated

Enter zip code for delivery date estimate

AIN Plastics Extruded Nylon 6/6 Plastic Rod Stock, 1 in. Dia. x 24 in. L, Natural

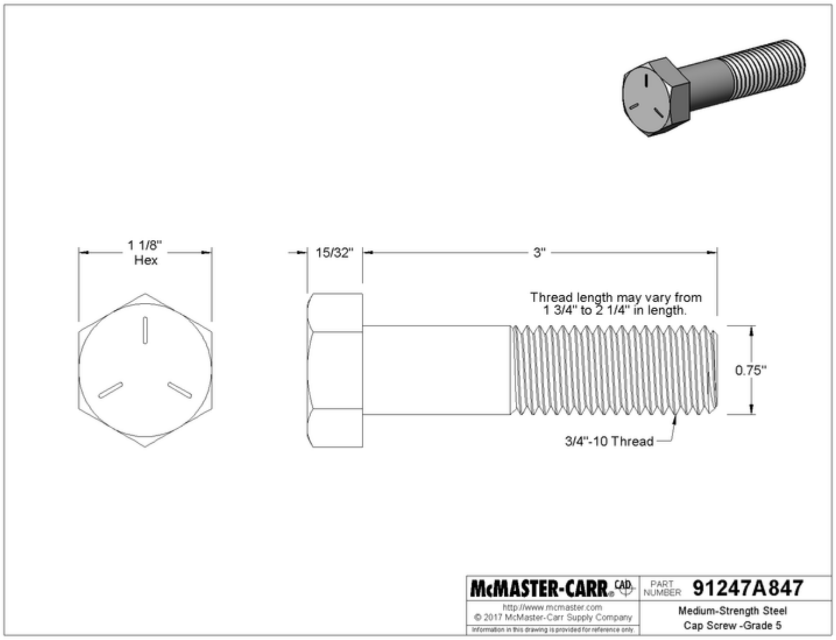
AIN Plastics extruded nylon 6/6 rods are the strongest, most rigid and have one of the highest melting points. They are commonly specified for gears, cams, bearings, valve seats and other applications that require wear resistance, quiet operation and low coefficients of friction. These rods have a temperature range of 0°-210°F and a tensile strength of 12,000 PSI. Dimensions: 1" diameter, 24" length, 0.005 diameter tolerance, and comes in a natural color.

Features:

- Broadest size range availability
- Good mechanical and electrical properties
- Ideal balance of strength and toughness
- Cast as finished parts and near net shapes (nylon 6)

LENGTH TOLERANCE INCHES	+/-0.236
TENSILE STRENGTH (PSI)	12000
BRAND	Ain Plastics
PACKAGE QUANTITY	1
CONSTRUCTION	Nylon 6/6
LENGTH INCHES	24
DIAMETER INCHES	1
COLOR FINISH	Natural
DIAMETER TOLERANCE INCHES	0.005
TEMPERATURE RANGE	0°-210°F

Linkage Bolts



Head Type	Hex
Drive Style	External Hex
System of Measurement	Inch
Thread Direction	Right Hand
Thread Size	3/4"-10
Screw Size Decimal Equivalent	0.75"
Thread Type	UNC
Thread Fit	Class 2A
Length	3"
Threading	Partially Threaded
Min. Thread Length	1 3/4"
Thread Spacing	Coarse
Head	
Width	1 1/8"
Height	15/32"
Fastener Strength Grade/Class	Grade 5
Material	Steel
Finish	Zinc Plated
Tensile Strength	120,000 psi
Hardness	Rockwell C25
Specifications Met	ASME B18.2.1, SAE J429
RoHS	RoHS 3 (2015/863/EU) Compliant
REACH	REACH (EC 1907/2006) (01/19/2021, 211 SVHC) Compliant
DFARS	Specialty Metals COTS-Exempt
Country of Origin	Canada
USMCA Qualifying	No
Schedule B	731815.9000
ECCN	EAR99

Appendix G: Final Budget

Metal	Quantity	Unit Price	Total Price
Steel Rectangular Tubing: 2" x 1" x 1", .120" thickness	60'	$3.20	$192.00
Steel Blocks: 1" x 2" x 1-1/2"	2	$11.00	$22.00
Steel Plate: 1/8" x 6" x 20'	1	$68.85	$68.85
Round Tubing: Length = 120", OD = 1-1/4", thickness = .120"	1	$42.00	$42.00
Steel Cylinder: Length = 12", D = 1-3/4"	1	$25.00	$25.00
Tax			$30.61
Total			$380.46
Wheels	Quantity	Unit Price	Total Price
6" Air-Free Flat-Free Rigid Caster	2	$31.48	$62.96
6" Air-Free Flat-Free Swivel Caster with Side Lock	2	$36.80	$73.60
Shipping and Handling			$33.97
Total			$170.53
Hydraulics	Quantity	Unit Price	Total Price
1.5" bore x 6" stroke snow plow Meyers hydraulic cylinder	1	$86.00	$86.00
Manual Hydraulic Hand Pump 180kg/cm² CP-180	1	$69.00	$69.00
Shipping and Handling			$13.97
Tax			$6.56
Total			$175.53
Nylon Stock	Quantity	Unit Price	Total Price
AIN Plastics Extruded Nylon 6/6 Plastic Rod Stock, 1 in. Dia. x 24 in. L, Natural	2	$11.25	$22.50
Shipping			$11.99
Tax			$2.50
Total			$36.99
Grabber Arm Hardware	Quantity	Unit Price	Total Price
Sleeve Bushings, 1" OD, 3/4" ID	2	$3.99	$7.98
3/4" Bolt, 4.5" Length	2	$2.19	$4.38
3/4" Hex Nut	2	$0.55	$1.10
3/4" Washer	4	$0.35	$1.40
3/4" Lock Washer	4	$0.47	$1.88
Tax			$1.30
Total			$18.04
Linkage Hardware	Quantity	Unit Price	Total Price
3/4" x 3" Bolt (3 pack)	3	$3.40	$10.20
3/4"-10 Hex Nut	8	$0.62	$4.96

3/4" Washer (25 pack)	1	$4.25	$4.25
TOTAL			$19.41
Locking Mechanism Hardware	Quantity	Unit Price	Total Price
1/4" Hex Nut	4	$6.83	$27.32
1/4" Screw, 1-1/2" Length (pack of 10)	1	$10.63	$10.63
1/4" Screw, 1/2" Length (pack of 25)	12	$8.37	$8.37
Compress Spring, SS, 1x0.026 In, PK5 (pack of 5)	2	$5.16	$5.16
TOTAL			$51.48
Grand Total			**$852.44**

Appendix H: Failure Modes and Effects Analysis

System / Function	Potential Failure Mode	Potential Effects of the Failure Mode	Severity	Potential Causes of the Failure Mode	Current Preventative Activities	Occurrence	Current Detection Activities	Detection	RPN
Frame System: Allow user to grab	Handles are uncomfortable to hold	User is uncomfortable	3	o Handles too high or low o Handles slippery o Handles awkward	o Anthropometric Research o Measure Sponsor	2	Planned final testing	1	6
Frame System: Supports lifting system, grabbing system, and barrel	Frame breaks	a) Barrel is not grabbed b) barrel cannot be lifted c) barrel cannot be transported	8	o Too thin (breaks) o Too thin (bends)	o Force and stress analyses o testing o FEA	2	Planned final testing	5	80
	Frame deflects too much	Looks bad	2	o Too thin (bends)	o Deflection analysis o testing o FEA	2	Planned final testing	5	20
Lifting System: Lift/Lower Barrel	Lifting system breaks	a) Barrel Cannot be lifted b) Barrel cannot be lowered	8	o Lifting frame is too thin o Linkages are too thin o Hydraulic cylinder seals are too weak o Hydraulic pump cylinder seals are too weak o Hydraulic pump lever is too thin	o Force and stress analyses on lifting frame, linkages, and lever o Seal calculations o testing o FEA	2	Planned final testing	5	80
	Lifting system deflects too much	Looks bad	2	o Lifting frame is too thin o Linkages are too thin o Hydraulic pump lever is too thin	o Deflection analysis on lifting frame, linkages, and lever o testing o FEA	2	Planned final testing	5	20
	Lifting is uncomfortable	User is uncomfortable	3	o Hydraulic pump lever is at awkward position	o Anthropometric Research o Measure cliff	2	Planned final testing	1	6
Grabbing System: Grab/release Barrel	Grabbers don't rotate	a) Barrel cannot be grabbed b) Barrel cannot be released	6	o Bushings wear	o Bushing analysis o testing	2	Planned final testing	5	60

Grabbing System: Hold Barrel	Grabber Holding system fails	Barrel slips out	5	o locking mechanism fails o rubber pads wear down	o rubber pad replacements o Force and stress analyses on locking mechanism o testing	2	Planned final testing	5	50
	Grabber system breaks	a) Barrel slips out b) Barrel cannot be grabbed/released	8	o Bolts too thin o Bolt overloading (thread damage) Nut overloading (thread damage)	o Force and stress analyses o testing	2	Planned final testing	5	80
Rolling System: Allows device to roll	Rolling system breaks	Barrel cannot be transported	8	o Forks are too thin (break) o Axles are too thin (break from static failure, fatigue failure)	o Force and stress analyses o testing	2	Planned final testing	5	80
	Rolling system requires too much force to push	User is uncomfortable	5	o Wheels are too thin (difficult to push over bumps) o Wheels are too thin (punctured)	o Force and stress analyses o testing	2	Planned final testing	5	50
General System: Prevents rust	Device rusts	Looks bad	3	o paint scratches		6	Planned final testing	5	90
General System: Connects components rigidly	Welds break	Barrel cannot be transported Barrel is not grabbed Barrel cannot be lifted	8	o Overloaded	o Force and stress analyses o testing o FEA	2	Planned final testing	5	80
General System: Connects components with rotation	Pin connections break	Barrel cannot be lifted Barrel cannot be lowered	8	o Overloaded	o Force and stress analyses o testing o FEA	2	Planned final testing	5	80

Appendix I: Design Hazard Checklist

DESIGN HAZARD CHECKLIST

Team: Barrel Movers Faculty Coach: Prof. Fabijanic

Y	N	
☑	☐	1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
☐	☑	2. Can any part of the design undergo high accelerations/decelerations?
☑	☐	3. Will the system have any large moving masses or large forces?
☐	☑	4. Will the system produce a projectile?
☑	☐	5. Would it be possible for the system to fall under gravity creating injury?
☑	☐	6. Will a user be exposed to overhanging weights as part of the design?
☐	☑	7. Will the system have any sharp edges?
☐	☑	8. Will any part of the electrical systems not be grounded?
☐	☑	9. Will there be any large batteries or electrical voltage in the system above 40 V?
☑	☐	10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
☐	☑	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
☐	☑	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
☐	☑	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
☐	☑	14. Can the system generate high levels of noise?
☐	☑	15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
☑	☐	16. Is it possible for the system to be used in an unsafe manner?
☐	☑	17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

For any "Y" responses, add (1) a complete description, (2) a list of corrective actions to be taken, and (3) date to be completed on the reverse side.

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
Pinch points between linkages.	Plastic safety shield and warning labels.	03/10/21	06/2021
Large mass (>300 lbs) being lifted	Operator instructions to stay clear of the front of the device where lifting occurs. Lifting will be a maximum of 6 inches above the ground to minimize fall damage.	03/10/21	03/10/21
System could fall under gravity.	Wide wheelbase as well as adding brakes to wheels for support on sloped surfaces.	03/10/21	02/22/21
Stored hydraulic energy. Dangerous if system depressurizes.	Use lock pin or other safety mechanism to support forks in case the hydraulics fail.	03/10/21	06/2021
System could be used unsafely.	Operators manual and warning labels on device to ensure safety.	03/10/2021	05/15/2021

Appendix J: Risk Assessment

designsafe Report

Application:	Barrel Mover	Analyst Name(s):	Mason Hughes, Mihir Shah, Natalie Lewis
Description:	Safety assesment for the Barrel Mover apparatus.	Company:	Barrel Movers
Product Identifier:		Facility Location:	Cal Poly
Assessment Type:	Detailed		
Limits:			
Sources:			
Risk Scoring System:	ANSI B11.0 (TR3) Two Factor		

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

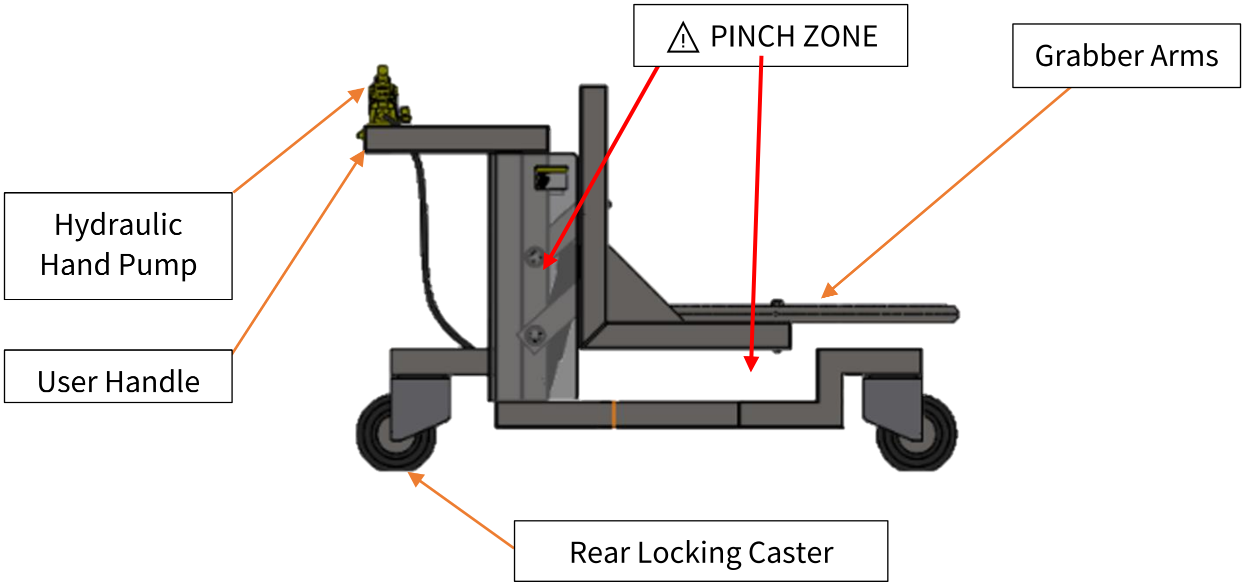
Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
1-1-1	operator Common tasks	mechanical : crushing Barrel weight; between linkages and fork arm with the frame;Barrel to ground; wheel on foot	Serious Likely	High	adjustable enclosures / barriers, two hand controls, warning label(s), instruction manuals, footwear	Serious Unlikely	Medium	
1-1-2	operator Common tasks	mechanical : pinch point Between linkages	Serious Likely	High	warning label(s), instruction manuals, two hand controls, adjustable enclosures / barriers	Serious Unlikely	Medium	
1-1-3	operator Common tasks	mechanical : break up during operation Fatigue on parts; corrosion	Moderate Unlikely	Low	instruction manuals, Inspeact regularily	Moderate Remote	Negligible	
1-1-4	operator Common tasks	mechanical : machine instability Uneven barrel weight distribution; uneven ground; loose linkage connections; uneven device weight distribution	Moderate Unlikely	Low	warning label(s), instruction manuals, two hand controls	Moderate Unlikely	Low	
1-1-5	operator Common tasks	slips / trips / falls : falling material / object Barrel falls	Moderate Unlikely	Low	other design change (alternate grabber arm design), warning label(s), instruction manuals	Moderate Remote	Negligible	

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
1-1-6	operator Common tasks	ergonomics / human factors : excessive force / exertion Lateral movement;pushing and pulling the device	Serious Unlikely	Medium	instruction manuals, warning label(s)	Serious Unlikely	Medium	
1-1-7	operator Common tasks	ergonomics / human factors : posture Height of handlebars and pump lever	Minor Likely	Low	other design change (calculate ideal handle bar and pump height)	Minor Remote	Negligible	
1-1-8	operator Common tasks	ergonomics / human factors : repetition Multiple barrels moved in-a-row; cranking the pump handle	Minor Likely	Low	scheduled rest periods	Minor Unlikely	Negligible	
1-1-9	operator Common tasks	ergonomics / human factors : duration Multiple barrels moved in-a-row	Minor Likely	Low	scheduled rest periods	Minor Unlikely	Negligible	
1-1-10	operator Common tasks	ergonomics / human factors : lifting / bending / twisting Cranking the pump handle; twisting the release valve	Minor Likely	Low	instruction manuals	Minor Unlikely	Negligible	
1-1-11	operator Common tasks	material handling : stacking / storing Potential for device to tip over when stored; weather corrosion	Moderate Remote	Negligible	instruction manuals	Moderate Remote	Negligible	
1-1-12	operator Common tasks	material handling : instability Deflection of parts; material too thin	Moderate Very Likely	High	use alternate materials, other design change (frame geometry, beam dimensions), warning label(s)	Moderate Unlikely	Low	
1-1-13	operator Common tasks	material handling : excessive weight Excessive barrel weight; excessive device weight	Moderate Unlikely	Low	warning label(s), instruction manuals	Moderate Remote	Negligible	

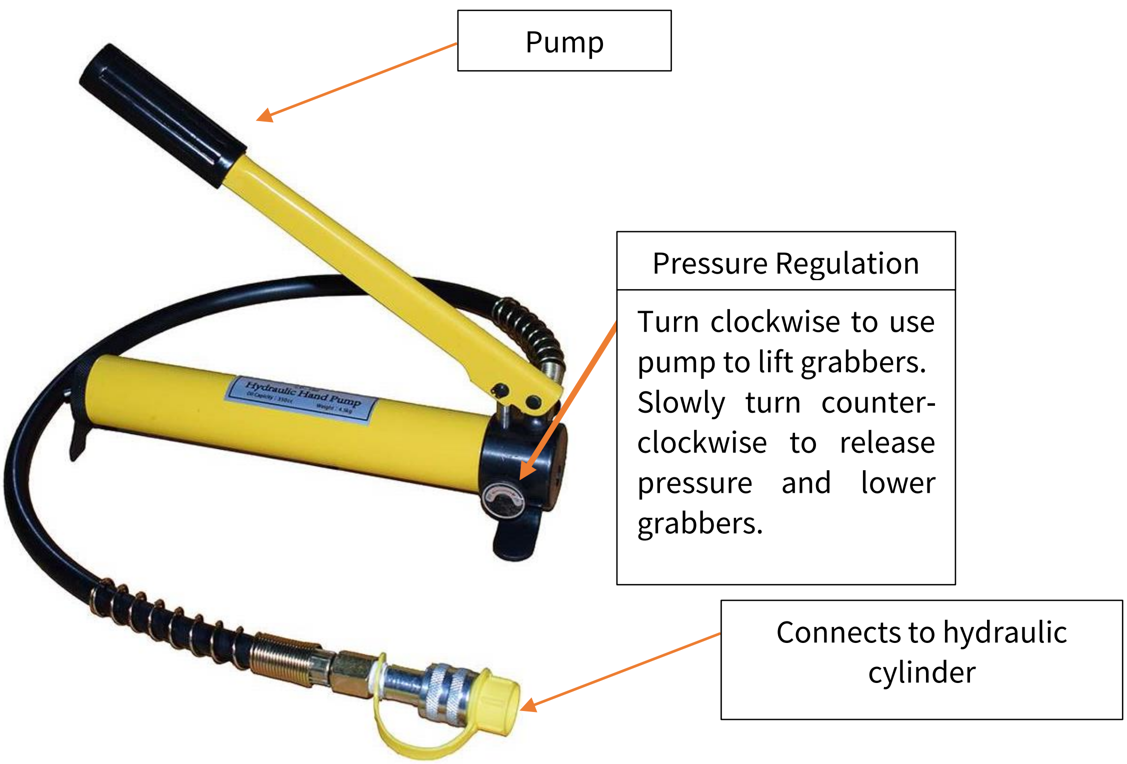
Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
1-1-14	operator Common tasks	environmental / industrial hygiene : carcinogens Hydraulic fluid	Serious Remote	Low	warning label(s)	Serious Remote	Low	
1-1-15	operator Common tasks	fluid / pressure : high pressure Pressure in the hydraulic fluid	Serious Remote	Low	warning label(s)	Serious Remote	Low	
1-1-16	operator Common tasks	fluid / pressure : hydraulics rupture Rupture in the hydraulic jack/pump	Serious Remote	Low	warning label(s)	Serious Remote	Low	
1-1-17	operator Common tasks	fluid / pressure : fluid leakage / ejection Fluid leakage from the hydraulic pump seals breaking	Minor Unlikely	Negligible	warning label(s)	Minor Remote	Negligible	
1-1-18	operator Common tasks	wastes (Lean) : correction / defective parts Grabber mechanism may require correction; welds on frame done poorly	Minor Likely	Low	Redo faulty welds with new parts	Minor Unlikely	Negligible	
1-1-19	operator Common tasks	wastes (Lean) : overproduction Off-cuts; wasted material	Minor Likely	Low	Dispose of waste material	Minor Unlikely	Negligible	
2-1-1	passer by / non-user work next to / near machinery	mechanical : crushing Barrel on foot; wheels on foot; the device itself	Serious Unlikely	Medium	warning label(s), adjustable enclosures / barriers	Serious Unlikely	Medium	
2-1-2	passer by / non-user work next to / near machinery	mechanical : pinch point Linkage connections; between the fork and frame; betweent the barrel and the grabbers	Serious Unlikely	Medium	warning label(s), adjustable enclosures / barriers	Serious Unlikely	Medium	
2-1-3	passer by / non-user work next to / near machinery	slips / trips / falls : trip Trip over the device	Moderate Unlikely	Low	Paint the machine a bright color (orange)	Moderate Remote	Negligible	

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
2-1-4	passer by / non-user work next to / near machinery	slips / trips / falls : falling material / object Barrel could fall; device could roll down hill	Serious Unlikely	Medium	warning label(s)	Serious Unlikely	Medium	
2-1-5	passer by / non-user work next to / near machinery	environmental / industrial hygiene : carcinogens Hydraulic fluid	Serious Remote	Low	warning label(s)	Serious Remote	Low	
2-1-6	passer by / non-user work next to / near machinery	fluid / pressure : hydraulics rupture Hydraulic pump/jack ruptures	Serious Remote	Low	warning label(s)	Serious Remote	Low	
2-1-7	passer by / non-user work next to / near machinery	fluid / pressure : fluid leakage / ejection Hydraulic fluid leaks from bad seals	Minor Remote	Negligible	warning label(s)	Minor Remote	Negligible	
2-2-1	passer by / non-user walk near machinery	mechanical : crushing Barrel on foot; wheels on foot; the device itself	Serious Unlikely	Medium	warning label(s), adjustable enclosures / barriers	Serious Unlikely	Medium	
2-2-2	passer by / non-user walk near machinery	slips / trips / falls : trip Trip over the device	Moderate Unlikely	Low	Paint the machine a bright color (orange)	Moderate Remote	Negligible	
2-2-3	passer by / non-user walk near machinery	environmental / industrial hygiene : carcinogens Hydraulic fluid	Serious Remote	Low	warning label(s)	Serious Remote	Low	
2-2-4	passer by / non-user walk near machinery	fluid / pressure : hydraulics rupture Hydraulic pump/jack ruptures	Moderate Remote	Negligible	warning label(s)	Moderate Remote	Negligible	
2-2-5	passer by / non-user walk near machinery	fluid / pressure : fluid leakage / ejection Hydraulic fluid leaks from bad seals	Minor Remote	Negligible	warning label(s)	Minor Remote	Negligible	

BARREL MOVER USER-OPERABLE PARTS

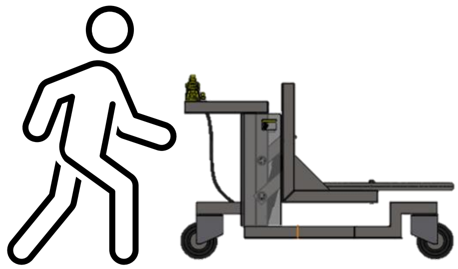


HAND PUMP OPERATION



⚠ SAFETY PRECAUTIONS ⚠

- The barrel mover device is intended for use with those aged 18 and over.
- The barrel mover device is designed to lift up to 500 pounds. Avoid using the device for any objects over 500 pounds.
- While using the barrel mover device, please stay behind the handlebar and hydraulic pump. See figure below.



- Avoid using the barrel mover device on major inclines (more than 15 degrees). If the barrel mover needs to be used on an incline it is recommended to use the rear brakes to assist.
- Only one person should be using the barrel mover device at a time.
- Be aware of your surroundings while using the barrel mover device.
- If the grabber arms of the barrel mover device need to be rotated, do so before the device contacts the barrel to avoid injury.
- After moving a barrel, use caution when navigating to the next barrel if the grabber arms are in the open position.
- If the grabber arms fail to clasp around the barrel or fail to release from a barrel, check to make sure the height of the device is at zero. If the device still won't move, carefully adjust the grabber arms and avoid pinch points while moving the device backwards in small intervals until the barrel is fully released.

INSTRUCTIONS FOR USE

1. Check all safety precautions to ensure safe use of the barrel mover device.
2. Release the pressure in the hydraulic pump (turn pressure release knob counter-clockwise slowly) to lower the lift to its lowest height.
3. If the grabber arms are not opened, rotate each arm so that the rear ends touch at the center of the device.
4. Approach the barrel with the barrel mover device. Keep the center of the barrel in line with the trajectory of the device to ensure that the barrel fully contacts the entirety of the grabber arm. Continue moving the device forwards until the grabber arms become parallel with each other and a firm connection is made between the arms and the barrel surface. The barrel mover will not move further once complete contact has been made with a barrel.

5. Ensure the pressure release knob is rotated clockwise fully.
6. Begin pumping the hydraulic jack by moving the lever up and down repeatedly. Be sure to keep a grip on the device when on any incline. It is recommended to engage the rear brakes as well.
7. Once the barrel is lifted off the ground to a desired height, stop pumping the hydraulic jack and keep the lever in the down position.
8. Using the designated handlebars on the device, carefully move the barrel to the desired location of the user. Refer to the safety precautions for details on safe use while in transport.
9. Once the destination has been reached, lower the barrel by slowly rotating the pressure release knob counter clockwise.
10. With the barrel now resting on the ground, pull the device away from the center of the barrel so that the grabber arms can rotate out to the same position described in Step 4.
11. The previous steps may be repeated for multiple barrels. Refer to the safety precautions to ensure safe use of the barrel mover device.
12. When the device is no longer needed, store it with the grabber arms rotated inwards and the height at zero.

Appendix L: Gantt Chart