F34 Beekeeper Assist

Final Design Review

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Statement of Disclaimer

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Abstract

Alejandro Jauregui is a veteran who now works as a commercial beekeeper. He lost both of his legs during his service. While his current prostheses allow him to fully complete his work, he has found that inspection of the bee boxes causes him severe hip and back pain. Bee box inspection is a critical task for beekeeping, especially since he maintains about 200 hives every day. Our senior project team was tasked with designing and building a device that would help him move the top bee box out of the way to allow for inspection. We performed preliminary research into existing devices, existing practices, and Mr. Jauregui himself to better understand the scope of work for this project. We filtered these inputs into quantifiable wants and needs and generated an actionable problem statement. We followed a timed-out plan which determined what steps we will take to complete this project. As of this report, we have fully completed our final design and fully manufactured the device. We developed and performed test procedures that verified the device's functionality. From these steps, we now have a device that we know meets all of Mr. Jauregui's specifications and will greatly improve his quality of life.

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1.0 Introduction

Alejandro Jauregui is an Army Veteran who, during his time in service lost both of his legs and damaged his right hand. He now works as a commercial beekeeper with the help of two prosthetic legs. Part of his duties as a beekeeper is to inspect his bee boxes. Specifically, he needs to inspect the bottom box, otherwise known as the brood box. The inspection currently consists of him smoking out the bees, then moving the top box, otherwise known as the honey box, off to the side. Mr. Jauregui currently does this process manually. Due to his prosthetics, however, that repeated process causes him pain in his hips and back. He needs a device that will assist him in inspecting his bee boxes that will not cause him this pain.

Our goal as a mechanical engineering team was to design and build a device to assist Mr. Jauregui in the inspection of his bee boxes. We intended to design a device that met Mr. Jauregui's requirements for a proper inspection process, was portable, did not reduce his efficiency, and did not cause him pain. Our team consisted of Kyle Ladtkow, Ryan Heryford, Javier Guerra, and Jose Velazquez, all mechanical engineering students at Cal Poly San Luis Obispo. This document serves as our Final Design Review (FDR), which details the scope of work and the full design process our team undertook to complete this project.

Within the FDR, there is information on the background of the customers, current products available, existing patents, and useful literature on the subject. This is followed by a list of objectives that our team created. We define a problem statement, list the needs and wants of Mr. Jauregui, and employed the use of a Quality Function Deployment. In the next section, we describe our design process, the concept design that we moved forward with, and analysis ensuring that that design would work. Following that, we describe our final design in the next section, including the changes we made during the manufacturing process. We describe the full manufacturing process and our design verification procedures in the next two sections. The final section consists of a concluding statement on the entire project.

2.0 Background

The modern beekeeping Industry has been around for centuries and many tools have developed to assist beekeepers in maintaining hives. The following is a summary of similar products, patents, technical literature, and customer needs that are relatable to the requirements of the project. We were able to conclude from our background research that our problem is very unique in that no other products found satisfy the requirement to rotate and hold a single beehive, like the customer would like. The background literature does give insight to the technology developed to assist in moving and working on bee boxes. This insight is invaluable in determining a design for our product.

2.1 Customer Interviews

In order to better understand the details of this problem, our team conducted an interview with Mr. Jauregui. Due to the COVID-19 pandemic, we were unable to meet with him in person. Instead, we organized a video call where our entire team got to ask him questions (Ladtkow). Mr. Jauregui actually called us while he was maintaining one of his honeybee sites. His setup consists of many pallets with bee boxes stacked on top of them. There are four bee boxes (brood and honey box stacked) on a pallet. Some of the pallets are much closer to each other than others, but most have enough space for a person to get through and perform inspection.

Figure 1. One pallet of bee boxes owned by Mr. Jauregui

He demonstrated to us the process he currently does to inspect the brood box. This involved him first smoking the bees out with a handheld smoking device. He then broke up the beeswax between the top and bottom box with a handheld device called a J Hook. He then picked up the top box with his hands, rotated it about 90°, and placed it on top of the adjacent bee box to get it out of the way. After inspection, he picked up the deposed top box, rotated it back to horizontal, and placed it back on top of the bee box. On an aside, Mr. Jauregui mentioned that he has to keep the lid of the brood box on manually while he is moving it.

Mr. Jauregui then went on to answer some of our questions and give us more specifications for what he needed. He told us that since his company works with several honeybee sites, he typically maintains about 200 boxes per day. Part of what helps him maintain this efficiency is that these inspections typically do not take very long. He mentioned that he would likely be putting our device in the back of his pickup truck and storing it outside or in his shop. Mr. Jauregui also mentioned that the terrains of his honeybee sites are very different and often difficult to move on. He asked that this device be able to move on different terrains, as well as to engage with the boxes at different angles due to the nature of his pallet setup.

2.2 Similar Products

The beekeeping industry has developed many tools over the course of centuries to assist beekeepers in maintaining bee colonies and their hives. Some products have been around since the beginning of the industry, such as the famous bee smoker, and others have recently become available to aid beekeepers in ways never seen before. Many advances have been developed to make beehive transportation easier for beekeepers, both commercially and homemade.

Figure 2. The Hive Carrier Lift, designed by Dadant.

The device in Figure 2 is an example of moving bee boxes with a simple design and basic mechanics. The Hive Carrier Transport Lift, built by Dadant, is a simple design made up of galvanized steel bars. It requires two people to move the carrier up and over the top of the bee box. When both workers pull up on each side, a middle bar clamps down on the side of the box with enough force to lift it up when the workers lift. The obvious downside to this design is that two operators are required to lift and move the box, but another disadvantage is that the physical strain of lifting bee boxes is not taken off the beekeepers. The Hive Carrier itself weighs 35lbs, combined with a full 80lbs bee box, means that each worker must lift somewhere around 55lbs, which is not much of an improvement. Lifting bee boxes with little to no effort needed has become a highly sought-after improvement. BeeHive Lifters made the dolly lift version seen in Figure 3.

Figure 3. The BeeHive Lift, designed by BeeHive Lifters.

It employs the use special handles used to grip common bee box handles in multiple configurations. The device then employs the use of a manual crank or motor to lift the arm structure and bee box up to a desired height. The dolly design allows for easy transport across many terrains with much less effort. One drawback to this machine is the gripping design. If the handles on the bee box are damaged in some way, then there is no way to successfully grip the box. Another inconvenience for the average beekeeper is the extravagant price of $1,350.00 for this machine.

The most widely regarded bee box moving accessory is the Kaptar Lift, an image of which can be seen in Figure 4.

Figure 4. The Kaptar Lift, designed by Beewise.

Built by Beewise, the Kaptar lift has many of same characteristics as the BeeHive Lifters device above. A major difference in design is how the device grips the bee boxes, not with the handles but with adjustable pads on each side that clamp down on the box. The Kaptar lift has a lithium ion battery with a four-hour life. It also has a drive motor for its wheels, taking further stress off the beekeeper. Its motor and chain drive are capable of lifting up to 220lbs, exceeding the heaviest of bee boxes. The main downside to this machine is the souring price of $6,455.00, making it an expensive buy for most beekeepers. While the Kaptar lift takes off a lot of physical strain on the beekeeper, it can only do so for four hours of battery life. Since it takes six hours to fully recharge, an average workday is shortened once the lift dies.

The beekeeping industry is filled with many innovators and there is a large online community built around sharing energy saving ideas and tips. There are many homemade devices built for certain jobs and uses in the community, not all necessarily available for purchase, but a good place to start thinking about possible designs for this project. One such project was built by Kai Serschmarn, which is shown in Figure 5.

Figure 5. A bee box lifting device built by Kai Serschmarn.

This device is used to lift the top bee box up using a winch and metal arms resting on wooden supports added to the box. One disadvantage to the design is that it relies on the boxes to be modified to operate successfully. Beekeepers in the commercial industry can own thousands of bee boxes and to modify them all would be expensive and take many man hours to accomplish.

Another homemade design by Michael Bush was a modification of a hand cart, which is shown in Figure 6.

Figure 6. A modified dolly for bee boxes built by Michael Bush

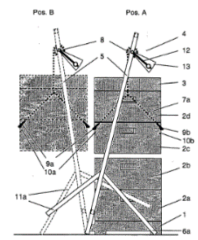
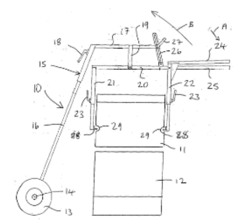
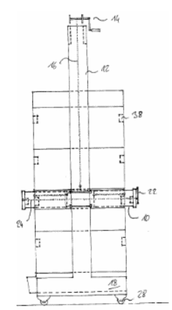
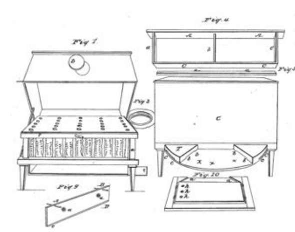
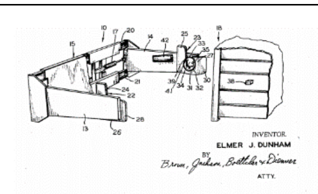
Bush's design allowed it to stack multiple bee boxes and easily transported with an abundance of leverage. Michael Bush commented that the angled steel stock used as the forks do bend when lifting bee boxes filled with honey. The beekeeper is also the one doing the main lifting of the bee boxes as Bush's device is used only for transport, not lifting the boxes, and stacking them.

2.3 Existing Patents

In our research for existing products, we also found several relevant patents that we thought could help with our design. These patents are a great source of innovation when coming up for new designs. The patents also work mostly with Langstroth bee boxes which all share common dimensions.

These are also the bee boxes that Mr. Jauregui uses and is included in the patent lists below. We also researched other devices not related to bees but related to the rotation requirement of our product, to give an idea of possible solutions. Those patents, their descriptions, and their relevance can be found in Table 1.

Table 1. A table containing relevant patent information for this project.

Patent Name	Patent No.	Patent Office	Description	Picture	Relevance
Lifting device for magazine hives	EP1595445A1	European Patent Office	Method and device for lifting and swiveling the frames of beehives, which enables free access to the open hive.		This design would seemingly provide the linear motion and vertical motion we would need to move the brood box.
Lifting device	GB2464568A	UK Patent Office	This invention relates to a lifting device and more particularly but not solely to a device for lifting components of beehives		This design would seemingly provide linear, vertical, and rotational motion for getting the brood box out of the way.
Lifting device for upper boxes of beehive unit, comprising additional moving component on wheels	DE202006007750U1	German Patent Office	Beehive magazine lifting device characterized by at least one beehive magazine mounted in a rack height adjustable mounting frame and an actuator for lifting.		This design provides an interesting and fast way to lift certain portions of a beehive stack.
Beehive	US9300A	United States Patent Office	The father of all modern beehives, a device that incorporates removable frames into the design, so the beekeeper does not have to kill bees to get the honey.		Most modern beehives (including the ones Mr. Jauregui uses) are based on this design. Knowing how the mechanics of this work might help in our design.
Box rotator attachment	US2971662	United States Patent Office	A rotator attachment for trucks whereby a box may be picked up, transported, and rotated.		While it is not specifically beehive-related, this rotation device could prove a useful design.

2.4 Summary of Technical Literature

Commercial beekeepers offer pollination services that require managing hundreds of beehives on different farms. The beehives consist of two main sections: the bottom section for brood and the top one for honey. In order to inspect the brood box, the top box must be lifted, rotated, and moved out of the way. While there are other types of beehive designs that allow for easier access to the brood section with the same brood development (Chan and Ron 780), commercial beekeepers use the Langstroth hive for its simplicity and ease of transportation.

Current products that assist in the inspection of the brood box have different ways of setting up before they can move the top box. Some of those current products would not be successful in Mr. Jauregui's working environment because of the space and time they require to set up. Mr. Jauregui's working area consist of multiple pallets near each other with four beehives per pallet. The bee boxes are position on each corner of the pallet, as seen on Figure 6, limiting our device to two sides to access each beehive. Since beehives must be approached on opposite sides of the hive's entrance, to avoid collision with bees that are shooting out of the entrance (Blackiston 117), there will be occasions where there will only be one side to access the brood box. We will need to design a device that can access the beehives that are oriented in different directions on the pallets. Once the device sets up on the correct side, it must get a firm hold of the top box to carry out the rest of the motion cautiously.

To hold on to the honey box, we have investigated using one or more clamps to have more than two points of contact. While there are several different types of clamps, the most common is the toggle clamp due to its simple locking and unlocking process. The toggle clamp also allows for it to be powered by more than one source: manual, hydraulic, electric, or pneumatic (Camillo 43). Our source of power and control system will be chosen carefully to avoid upsetting the bees as much as possible. Electrical control systems will allow the top box to be removed in a smooth motion. Our design will consider the tree main methods of electrical controls available: manual, semi-automatic, or fully automatic controls. (Sheet Metal Industries 409). So far, our team has researched mostly hydraulic power and we believe a double-acting cylinder will be most appropriate because the device must move and return the top box (Anon 42). If a single-acting cylinder is used, the returning motion of the device will have to be done by a spring or gravity, which will not be as controlled and efficient as the hydraulic force applied by a double-acting cylinder.

3.0 Objectives

While there are some devices that help beekeepers, they are not designed specifically for Alejandro Jauregui. Mr. Jauregui has specific motions and set ups that other beekeepers do not use. His needs and wants that we will try to meet are described in this section. In order for us to incorporate them in our device, our team used the quality function development method shown below to create specifications for them.

3.1 Problem Statement

Alejandro Jauregui, an Army veteran who lost both his legs due to an IED blast, needs a way to lift, rotate, and move the top box of a commercial beehive out of the way so he can perform maintenance on the bottom box. He maintains roughly 200 beehives a day and the physical strain, compounded by is injuries, causes hip and back pain. A new form of moving the bee boxes is required to ease his discomfort. A solution to this problem must be portable to the extent that it can be moved between pallets and put in a pick-up truck, work about as fast as his regular method, be weather-resistant, and be able to grab bee boxes at several different orientations.

3.2 Needs and Wants Summary

We need a device that can assist Mr. Jauregui during inspection of the beehives without causing him any harm and affecting his efficiency. This device has to be able to move the top half of the beehive out of his way to allow access to the bottom half. It must do so by gripping, lifting, and then rotating the top box to its side to prevent the queen from falling, if it is up there. Our device might also have to move the box while it is on its side, but that will depend on the side from which Mr. Jauregui needs to access it. All of these different motions must be done to a box that can weigh from 50 to 60 pounds, all without upsetting the bees.

Our device will also have to be mobile because Mr. Jauregui has bees in more than one location. We will limit the size of the device to the fit on the back of Mr. Jauregui's pick-up truck, for it to be transported from one location to another. The device will also have to fit and set up between the pallets before it can move the top box. These size limitations are pictured in Figure 7 in a Boundary Diagram.

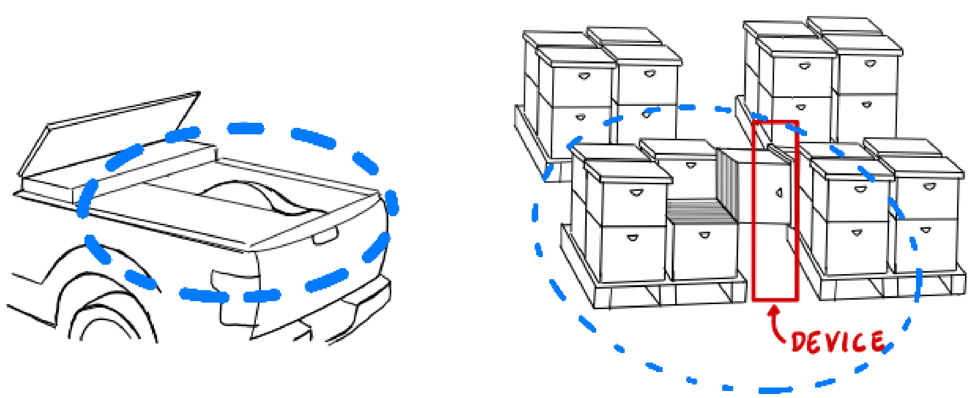


Figure 7. The Boundary Diagram for our problem definition.

We will also design a weatherproof device as all of Mr. Jauregui's beehives are outdoors. Our device is going to be operated in high heat, under heavy sun conditions, and consequently will have to be resistant to solar degradation. It must also be relatively straightforward to maintain and built with the majority of parts being off the shelf. We have summarized these needs and wants in Table 2.

Table 2. Needs and Wants Summary Table

Needs	Wants
Size	Fit between pallets and on back of pick-up truck
Required motion	Lift, rotate, move honey box
Lifting Capacity	Lift a full honey box (50-60 lbs)
Efficient	As fast or faster than current process
Safety	Must not bring Alex harm
Maintenance	Straightforward to maintain
Materials	Ideally weatherproof and resistant to solar degradation

3.3 Quality Function Deployment

To better synthesize Mr. Jauregui's needs and wants, our team used a method called Quality Function Deployment (QFD). The purpose of QFD is to take a customer's requirements and create measurable engineering specifications (Schuster, 90). The method that we used to perform this was the QFD House of Quality, a method that incorporates customers, customer wants/needs, and existing products into engineering specifications. The House of Quality we filled out can be seen in Appendix A.
From this House of Quality method, we were able to synthesize specifications that are quantifiable, see Table 1. Some specifications do not have targets yet because we do not have enough information currently to decide their worth. These specifications will be found out through the prototyping stages and beyond.

Table 3. Specifications Table for Beekeeper Assist. The compliance methods are: Analysis (A), Test (T), Similarity to Existing Designs (S), and Inspection (I).

Spec. #	Parameter Description	Target	Tolerance	Risk	Compliance
1	Weight of Device	60lbs	Max	H	A, I
2	Size of Device	To fit in a truck bed (50" x 67")	Max	H	A, I
3	Lifting Capacity	60lbs	Min	M	A, T
4	Operating Time (one box)	As fast as current process	Max	H	T, S
5	Total Box Displacement	TBD (Needs to be clear of bottom box)	Min	M	T, I
6	Operational Speeds	TBD (Cannot disturb Bee's or damage box)	Max	M	A, T, I
7	Set Up Time	TBD (Cannot reduce efficiency)	Max	L	T, S

The specifications listed in the table above and in the "how" section of the QFD were tailored to meet the certain needs of Mr. Jauregui. Each specification will be measured according to the following:

1. Weight of the device will be measured by weighing our final product. There will be preliminary analysis on parts to estimate the weight of the device before purchasing materials and construction. It is desired to have as light of a product as possible, but we have capped the maximum weight at 60lbs.
2. Mr. Jauregui uses a 2012 Ford Raptor pickup truck to drive to work. Our device should be as small and compact as possible but must fit in the back of his truck. This is a relatively simple test, and we will go through the design process to ensure we do not make the device too large.
3. An average ten-frame large or "deep" bee box filled with honey can weigh around 60lbs. These are the same size boxes that Mr. Jauregui uses. The device must be able to lift over 60lbs and will be designed with a factor of safety so that Mr. Jauregui does not need to worry about the device failing on him with a heavy box. This will be done through stress analysis and testing.
4. A crucial specification of this project is the operating time. The current process consists of Mr. Jauregui walking up to the bee box, grabbing it by the handles, and flipping it on to its sides on top of an adjacent bee box. This whole process takes a matter of seconds. Our device must be as fast or faster than the current process or else Mr. Jauregui loses efficiency and will be less inclined to use our device. We will test run different prototypes and the final product to see if the design can meet this time goal. For simplicity we will use the time to inspect one bee box as a control.
5. The total box displacement is the distance that the box travels from its original position, or where it was picked up from. This includes how far it is rotated, how high it is lifted, and the horizontal distance it travels while in the device. The height it is lifted will likely be influenced by the heights of the adjacent bee boxes (so that it can get clear) but could also lose that association as our design continues. In the same vein, the horizontal displacement could be associated with the bee box dimensions, but we will not know for sure until we home in on a design. We do know for certain that the box must be rotated at least 90 degrees from its original position.
6. The operational speeds will be critical because they determine the entire operating time. We must also consider the bees in the box being moved. Bees are sensitive creatures and do not like being suddenly moved. The operating speeds must take that into account and be slow enough to not disturb the bees, but quick enough to keep the process efficient. We have not planned a way to target these speeds, but they will be tested and adjusted for the final product.
7. The set-up time is a minor specification that adds to the efficiency and comfortability of the device. Our goal is to help Mr. Jauregui, not add more work by developing a device that takes a long amount of time to set up. This will be a timed process and will be dialed down to the fastest time.

4.0 Concept Design

The first step we took to create our device was to create a concept design. This process began with determining functions and sub-functions necessary for the device to accomplish its goal. Our next step was to generate as many ideas as possible for those sub-functions. We refined those ideas down based on quality and feasibility. We then created prototypes of some of them to better understand how they would work. With these basic prototypes, we further narrowed them down and combined some of them into system-level designs, designs which incorporate all of the sub-functions. Finally, our team decided on one system-level design and proceeded to plan for more rigorous prototyping, manufacturing, and early testing.

4.1 Functional Decomposition

Before we began our ideation, we first had to determine what our device needed to do in order to accomplish its goal. We used a process known as Functional Decomposition to break down our task into fundamental functions and sub-functions. A function here is a basic task that must be accomplished (i.e. move the top box out of the way) while a sub function is an essential step to the success of that function (i.e. rotate the top box 90 degrees). Using the parameters we determined in Quality Function Deployment (Section 3.3) as a basis, we developed a list of these functions and sub-functions and compiled them into a Functional Decomposition chart, which is shown in Figure 8.

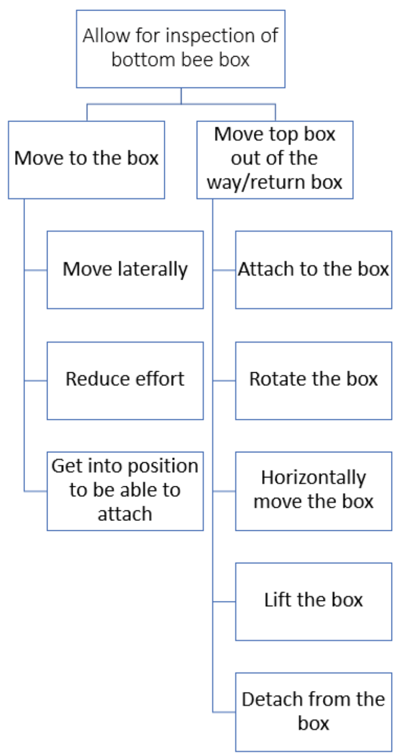


Figure 8. The Functional Decomposition chart for our device. The overall goal is the top box with the two main functions beneath it. Beneath those two boxes are the sub functions necessary to complete the main function.

Using this method, we determined that our main goal requires two main functions: “move to the bee box” and “move the top box away/back”. We determined that eight sub-functions were necessary to accomplish these functions, all of which are shown in Figure 8. While many of these sub-functions come from the process Mr. Jauregui already does (rotate the box, lift the box, etc.), a few come from what a device would have to do (reduce effort and get into position to attach).

4.2 Ideation and Prototyping

Once we had found the key sub-functions for this task, our next step was to come up with ways to perform them. Our focus at first was to generate as many ideas as possible, so as to consider all possible solutions. For the most part, we used an ideation method called Brain Dumping to generate ideas. With this method, we all got together and spent time individually sketching (or writing down) as many ideas for a sub-function as we could. At the end of the time, we would come together and share our ideas with each other, building on each other’s designs and creating new ones. We did at least one Brain Dumping session for each sub-function, ultimately putting all of our ideas onto a page in our shared Notebook. An example of one of these pages can be seen in Appendix C.

Once we had a large number of ideas for each sub-function, our next step was to create prototypes. We found it necessary to create prototypes so that we could further evaluate the merits our ideas. Each member of our group created upwards of 5 prototypes, each prototype representing a different sub-function. While these early prototypes were considerably “low definition” (i.e. popsicle sticks, hot glue, etc.), we built them in a way that we could reasonably mimic the sub-function they were built for. For example, one of our group members created the prototype shown in Figure 9 to model the “attach to the box” sub-function.

Figure 9. A picture of an “attach to box” prototype our group built. This prototype was meant to represent how a hydraulic/pneumatic system could be used to clamp holding plates to the box.

In the prototype shown in Figure 9, the clamping action of the device was simulated using syringes and a hose. With this prototype, we were able to roughly imitate how a hydraulic/pneumatic system would attach to a box. We built and tested the rest of these prototypes in a similar fashion, using them on makeshift miniature bee boxes and taking note of what worked and what did not. We have included images and description of some of these prototypes in Appendix D.

4.3 Pugh Matrices and Morphological Matrices

To weed some of these ideas out, we compared them using a method called the Pugh Matrix. This method allowed us to incorporate the criteria we determined in the Quality Function Deployment (see Section 3.3) and rank our ideas based on how they compare to a datum. We created Pugh Matrices for each of our sub-functions, choosing datums that came from our research of existing products. For most of our Pugh Matrices, we used the Beehive Lifter (shown in Section 2.2) as the datum; it is the device we found to meet the most of Mr. Jauregui's needs. These Pugh Matrices can be found in Appendix E.

From the Pugh Matrices, we picked out the best ideas (ideas that ranked the highest) and moved forward into system-level design. We used a method called the Morphological Matrix, a method where we mixed and matched various sub-function ideas until we had "assembled" a system-level design. We created four Morphological Matrices corresponding with four system-level designs. These matrices can be found in Appendix F.

4.4 System-Level Designs

As mentioned before, four system-level designs were selected for further consideration. We nicknamed them "CNC Dolly", "Conveyor Belt", "Moving Crane", and "Broken Dolly." All four selected designs met the required criteria and were selected as candidates for the final design. At the same time, they all have pros and cons that will affect the decision-making process moving forward.

The "CNC Dolly" is a system that utilizes belts and a combination of power screws on a dolly that would be easily moved between bee boxes. Once in position, the CNC Dolly would maneuver into position with the push of a button. Once the button is pressed the CNC Dolly would locate the position where a C-clamp type device would attach to the top bee box. Once the box is securely clamped the CNC Dolly will lift the bot and rotate it 90 degrees out of the way in order for the bottom bee box to be inspected. Once the inspection is complete the CNC Dolly would reverse the process returning the top bee box to its original position. Once the top bee box is released the dolly operator can move the dolly to the next set of bee boxes that need to be inspected. A sketch of this design is shown in Figure 10.

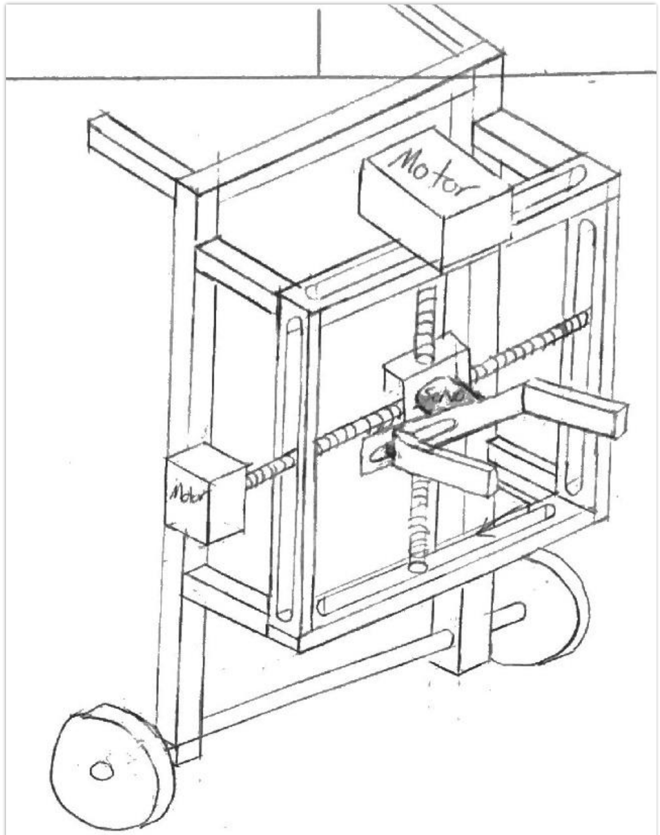


Figure 10. A sketch depicting the “CNC Dolly” design. This sketch depicts a two-axis power screw system as the horizontal and vertical motion drivers. It also depicts a servo attached to a hydraulic clamping system, which would be used to rotate and attach to the box, respectively. The box-movement system is shown attached to a rudimentary dolly as well.

The “Conveyor Belt” is a single chain system that lifts the box up and rotates it around its top wheel/gear. Using visual inspection, Mr. Jauregui would maneuver the device to the desired bee box that needs to be inspected. Once the dolly is placed in position Mr. Jauregui would press a button that would activate a C-clamp like device to clamp on to the sides of the top bee box in order for it to be moved. Once the top bee boxed is clamped down, a conveyor belt system would be activated and will lift the bee box up and over the hear getting the bee box out of the way so that the bottom bee box can be inspected. Once the inspection is complete, another button would be pressed in order for the Conveyer Belt mechanism to reverse the process and pout the be box back in its original position. Once this is done Mr. Jauregui will move the Conveyer Belt Mechanism to the next set of bee boxes. The prototypes we built to model this design is shown in Figure 11.

Figure 11. An image of a prototype built for the "Conveyor Belt" design. In this design, the carriage is pulled directly by the rotating chain. Once the carriage reaches the top of the chain, it is forced to rotate over the top gear.

The "Moving Crane" functions like a dockyard crane. Mr. Jauregui would push the entire device over a pallet that needs to be inspected. Once the Moving Crane is in position, he would lower the arm using a switch attached to a winch until the arm is in position. At this point Mr. Jauregui would tighten a clamp onto the box using a wheel-screw system. He would then press several switches which would lift the top box with the winch and rotate the box with a servo attached to the carriage. Once the top box is out of the way Mr. Jauregui can proceed to inspect the lower bee box as needed. As soon as he is done with the inspection the process will be reversed to return the top bee box to its original position and Mr. Jauregui can move the Moving Crane to the next pallet. A CAD model we created for this design can be seen in Figure 12.

Figure 12. An isometric view of the “Moving Crane” design built in SolidWorks. In this design, the box is gripped by a wheel-tightened clamp attached to the crane above. A winch would be activated.

The “Broken Dolly” system similar to how current beehive lifters work. The system would be built into a dolly, which is wheeled by Mr. Jauregui to the bee box. An attachment tightens a rope around the box against a flat plate to get the box onto the device. A hydraulic piston would then push the box up where it would then rotate due to Mr. Jauregui folding the dolly in half. A sketch of this design can be seen in Figure 13.

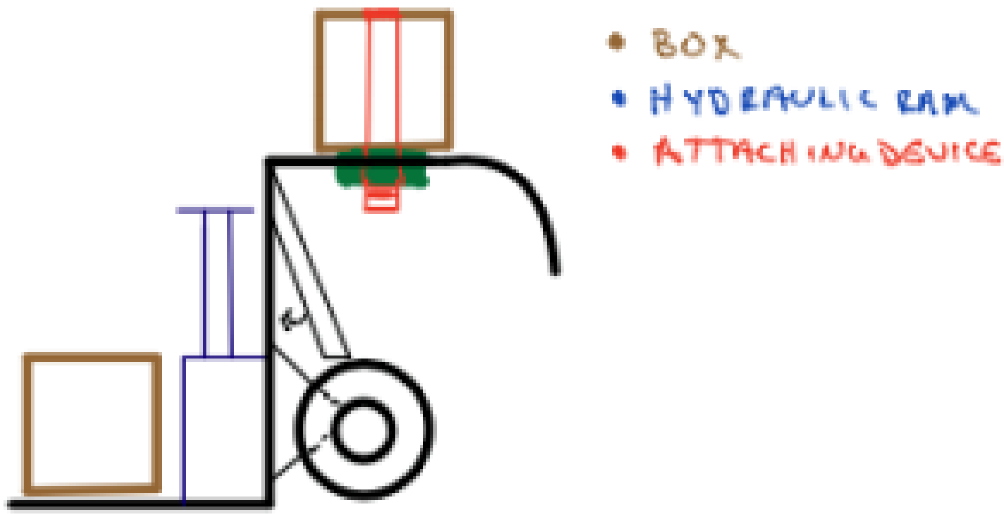


Figure 13. A sketch of how the "Broken Dolly" system would work. This sketch details how the box would be lifted, be rotated, be attached, and get to the box.

4.5 Design Decision

To determine which system-level design to move forward with, we developed a Weighted Decision Matrix. This Decision Matrix incorporated criteria we developed in Quality Function Deployment (see Section 3.3) and weighed each design against them. Each design was given a rating between one and five for each criterion based on how well they met that requirement (one being the worst score and five being the best). We also gave each criteria a relative weight (also one to five) based on how important they were to the function of the device. We multiplied the relative weights against the ratings to find the weighted scores, which were added up for each device. Our Weighted Decision Matrix for these four designs is shown in Figure 14.

		Idea 1		Idea 3		Idea 4		Idea 5	
		CNC Dolly		Conveyor Belt		Moving Crane		Broken Dolly	
Specification	**Weight**	**Unweighted**	**Weighted**	**Unweighted**	**Weighted**	**Unweighted**	**Weighted**	**Unweighted**	**Weighted**
Weight of Device	3	2	6	2	6	1	3	4	12
Size of Device	3	4	12	4	12	1	3	3	9
Lifting Capacity	5	3	15	5	25	3	15	4	20
Operating Time (One Box)	5	2	10	4	20	3	15	4	20
Vertical Displacement	4	4	16	4	16	2	8	3	12
Horizontal Displacement	5	3	15	2	10	5	25	3	15
Vertical Speed	2	3	6	4	8	4	8	4	8
Angular Velocity	2	4	8	3	6	4	8	4	8
Set Up Time	3	4	12	4	12	4	12	4	12
Total		**29**	**100**	**32**	**115**	**27**	**97**	**33**	**116**

Figure 14. The first Weighted Decision Matrix used to decide between four system-level designs. It includes unweighted and weighted scores for each design, summed up at the bottom. The angular displacement criterion was removed as all four designs scored the same, proving it to be an unhelpful decision criterion.

From this Decision Matrix, it was difficult to tell which design direction to go with. While the "Broken Dolly" design technically won with 116 weighted points, the "Conveyor Belt" design was close behind with 115 weighted points. We were only truly able to rule out the "CNC Dolly" and "Moving Crane" designs from this matrix. After meticulously going through the scores and weights again, we still could not definitively decide which design to pursue.

We decided that the best way to move forward was to flesh out both the "Conveyor Belt" and the "Broken Dolly" designs and to compare them again. For the "Conveyor Belt", we used the prototype shown in Figure 11 to identify design issues not seen before. We determined that the use of a chain or conveyor belt might pose a problem when rotating around the gear. Our prototype used a single point to connect the carriage to the chain, which was fine for a foam core box. With a 50-60lb bee box, however, this single connection point would not be good for stability; the box would most likely create a cantilever which could cause failure. With the addition of more connection points, the design then ran into the problem of actually rotating around the gear.

After conducting additional research into similar mechanisms, we replaced the conveyor belt system with a winch and "garage door rail" system. In this system, the box carriage is on wheels set inside rails. Instead of a conveyor belt or chain, a winch and pulley system would pull the carriage, moving it up and over via the curve of the rails. The new "Garage Door" design can be seen in Figure 15.

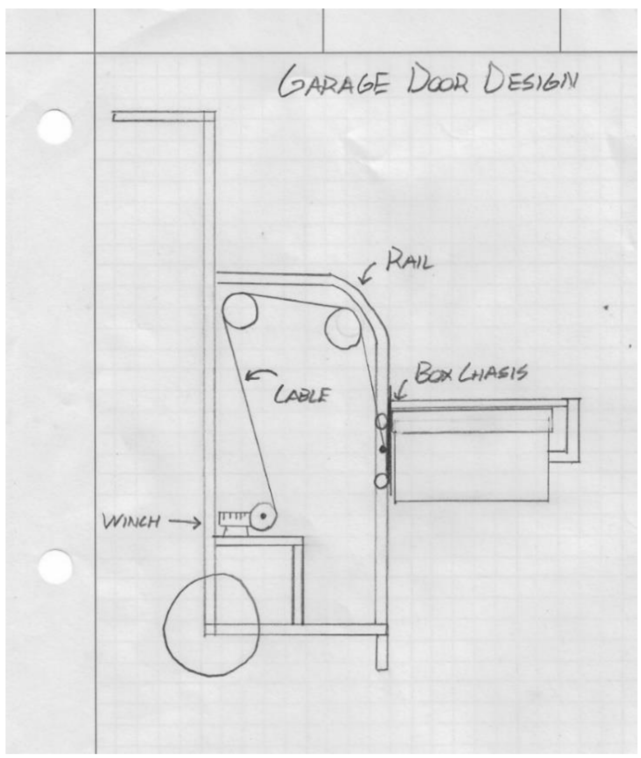


Figure 15. The "Garage Door" design utilizes a winch/pulley combination and garage door rails to pull the top bee box upward and rotate it as it reaches the top of the dolly.

For the “Broken Dolly” design, we decided to try to simplify its motion. We concluded that the process was more complicated than it needed to be, and that simple rotation would be more efficient. We redesigned the system and created a new prototype as shown in Figure 16.

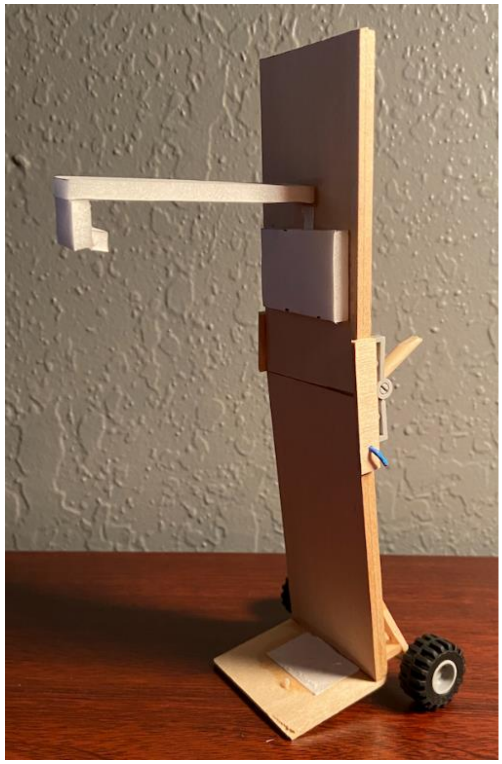


Figure 16. A picture of the “Broken Dolly” prototype we created. This prototype is a redesign of the old “Broken Dolly” system, as seen in Figure 13.

In this redesign, we removed the hydraulic lift system and ratchet strap. In their place, we moved the hinge down to the bottom of the top box and added a spring-loaded grabber arm. In this version, Mr. Jauregui would pull the spring-loaded grabber arm over the top box, letting it hold it in compression. Mr. Jauregui would then use the handles at the top of the dolly (not pictured in Figure 16) to manually rotate the top box up and away from the bottom box. The purpose of this redesign was to make the process faster and more efficient. By moving the hinge down, the hydraulic lift system is not necessary as the box is already at the height it needs to be for rotation. The replacement of the ratchet strap with the grabber arm would also make attaching to the box much quicker and easier.

With these two analyses complete, we compared the designs again. We created a pros and cons list for each design, the likes of which can be seen in Appendix G. After further discussion with Mr. Jauregui, we determined that the “Broken Dolly” was the better of the two options. The main selling points included being human powered, relatively easy to manufacture, and much more portable than the “Garage Door” design.

4.6 Final Concept Design

As mentioned before, we decided to pursue the “Broken Dolly” system-level design. We concluded that it was the most feasible to manufacture and adequately met Mr. Jauregui’s needs. A labelled isometric view of our CAD model can be seen in Figure 17.

Figure 17. An isometric view of our “Broken Dolly” CAD model. The different sub-systems are labelled as we currently have them designed.

To further illustrate how this design would work, we have included two images in Figure 18 depicting its motion.

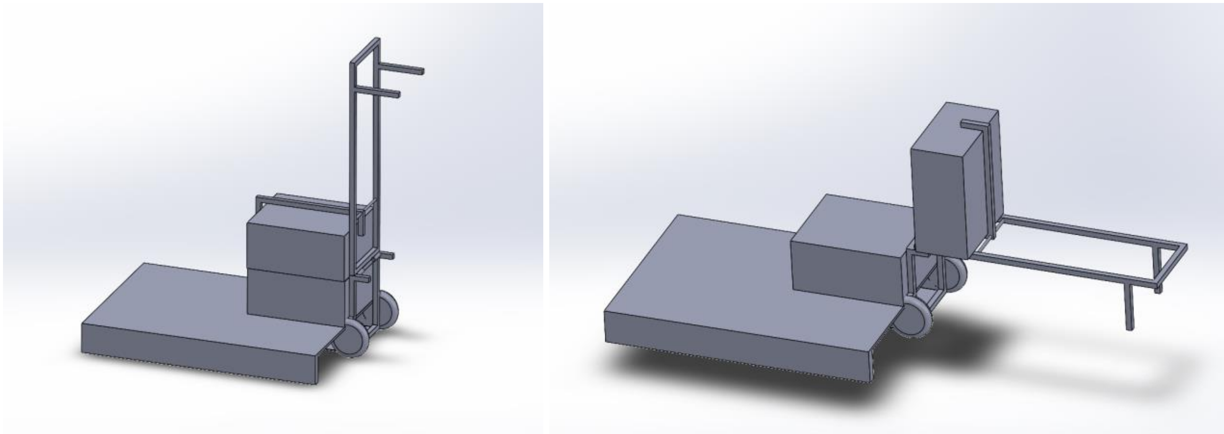


Figure 18. Two images depicting the motion of the "Broken Dolly". In the image on the left, the device has just attached to the box using the grabber arm and bottom plate. In the image on the right, the box has been rotated 90 degrees, exposing the bottom box for inspection.

In this design, Mr. Jauregui would wheel the device up to the bee box of choice. He would put the bottom plate underneath the pallet and line up the dolly with the box using visual inspection. Once in position, he would pull the spring-loaded grabber arm over the top box to the other side, then gently let it come back and hold the box in compression. He would then grab the handles at the top of the dolly and gently lower the top section down, in turn rotating the top box out of the way. This process would be fully reversible as it is completely mechanical.

4.7 Design Justification

While we had determined the abstract form of our final design, we determined it necessary to prove that it will work as intended. In particular, we wanted to prove that the "Broken Dolly" would actually provide the necessary force needed to rotate the bee box without requiring too much effort. To do this, we created a free body diagram (FBD) for the device in each of its positions and used it to calculate the force Mr. Jauregui would have to provide. The extent of these calculations can be found in Appendix J.

For this analysis, we came up with four dynamic cases for the dolly's motion. The first case involved Mr. Jauregui pulling the upper dolly from rest in the upright position. The second case involved Mr. Jauregui lowering the dolly 90 degrees. The third case involved Mr. Jauregui pulling the upper dolly from rest in the lowered position. The fourth and final case involved Mr. Jauregui pushing the dolly up, back to the upright position. Schematics for all four of these cases can be found in Appendix J.

For our worst-case scenario (the box weighs 80 pounds), we calculated that Mr. Jauregui would have to provide 22.7 pounds of force to pull the dolly from rest in Case 1. While this may seem like a lot, we concluded that 22.7 pounds compared to the 80-pound weight of the box is a significant improvement. For the same scenario in Case 3, we calculated that Mr. Jauregui would have to provide 11 pounds of force to pull up the dolly from rest. This is a more ideal scenario, as the lever-arm of the dolly provides a better advantage than in Case 1. In fact, this is exactly what we were hoping for; that the lever-arm of the dolly would be sufficient to move the box, negating the need for springs or dampers.

The results for Cases 2 and 4 were a bit more complicated. We used the same worst-case scenario as in the other two cases, but this time we assumed that Mr. Jauregui would have to rotate the box in two seconds. To simplify the model, we assumed that the acceleration caused by his movement would be uniform, even though in reality this might not always be the case. We also assumed that the mass of the bee box would dominate compared to the mass of the dolly. We think that these assumptions are fairly reasonable and do not make a meaningful impact on our results.

For Case 2, we created a model using classical dynamics. Using MATLAB, we plotted the results of this model, which varied based on the upper dolly's current angle of rotation. Our worst-case scenario can be seen in Figure 19.

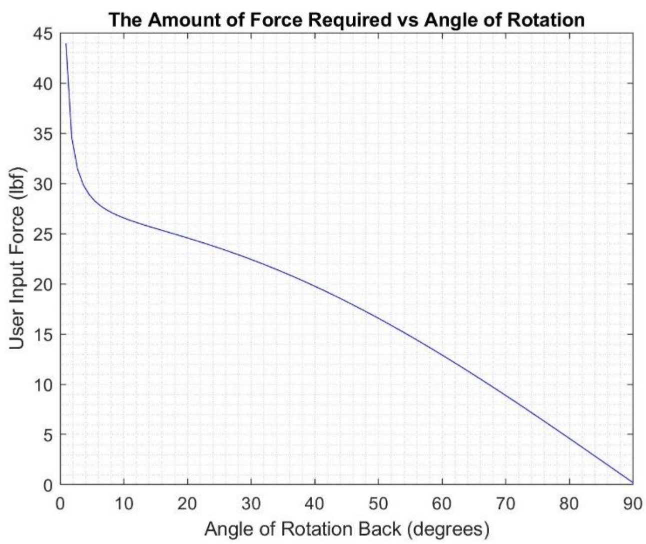


Figure 19. A graph of our model for Case 2 of our Effort Analysis. This graph shows the required input force from Mr. Jauregui as a function of the current angle of rotation. At an angle of 0, the upper dolly is in the upright position while an angle of 90 corresponds with the upper dolly being in the lowered position.

There are a few conclusions we got from this simulation. As shown in Figure 19, the rotation initially requires an input force of around 45 pounds. While this is still an improvement from 80 pounds, this is a lot of force to ask from a person. We are relieved that the force decreases significantly from that point. However, this result made us stop and reevaluate our requirements for time on this motion. We ran the simulation again with various rotation times and found better results. The plots of these results can be seen in Figure 20.

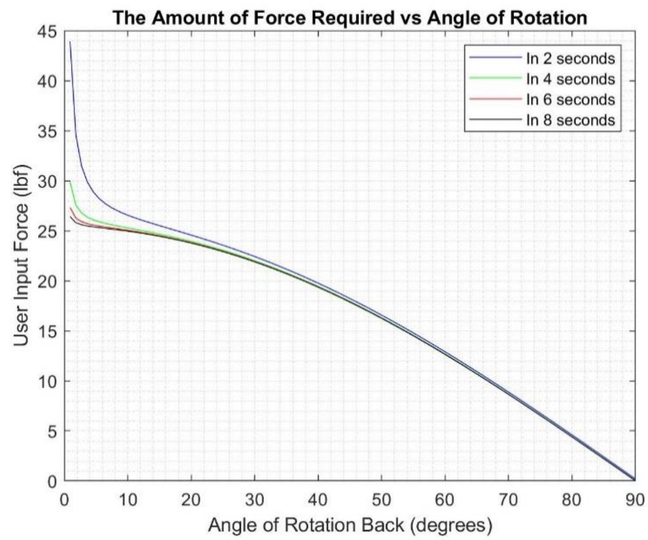


Figure 20. A graph of our model for Case 2 of our Effort Analysis. This graph shows the required input force from Mr. Jauregui as a function of the current angle of rotation. At an angle of 0, the upper dolly is in the upright position while an angle of 90 corresponds with the upper dolly being in the lowered position. This plot in particular shows different rotation times varying from two to eight seconds; each of these plots are colored and labelled.

From this plot, we found a bit of a sense of relief. Even for a time increase of two seconds, the required force drops dramatically to around 30 pounds. At a time of eight seconds, the required force stalls around 26 pounds, which is a much better value than at first. We think a force of around 26 or 30 pounds is reasonable for Mr. Jauregui to apply to the dolly.

For Case 4, we used a similar model as we did in Case 2. We modified some of the signs to reflect the change in direction for rotation. Using MATLAB, we plotted the results of this model, which varied based on the upper dolly's current angle of rotation. Our worst-case scenario can be seen in Figure 21.

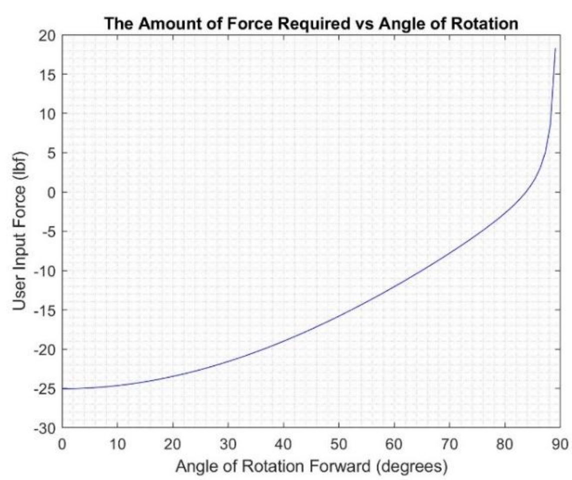


Figure 21. A graph of our model for Case 4 of our Effort Analysis. This graph shows the required input force from Mr. Jauregui as a function of the current angle of rotation. At an angle of 0, the upper dolly is in the upright position while an angle of 90 corresponds with the upper dolly being in the lowered position.

One thing that popped out to us from this model was the fact that the force becomes negative. This makes sense considering how this rotation would actually work. During this rotation, there would come a point where the weight of the box "takes over" from Mr. Jauregui's input and dominates the rotation. The force becomes negative as Mr. Jauregui prevents the upper dolly frame from slipping and falling down. We consider a magnitude of 25 pounds required force to be reasonable for this motion.

To see how the rotation time affects this force, we again changed the time and plotted the results. The plots of these results can be seen in Figure 22.

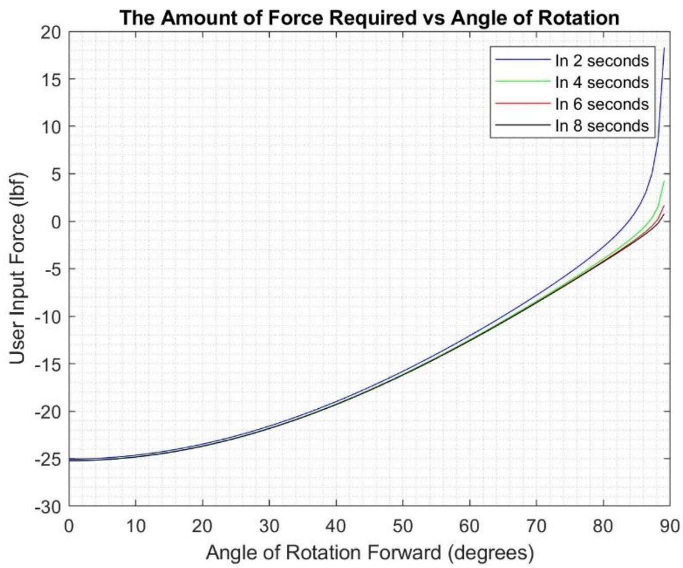


Figure 22. A graph of our model for Case 4 of our Effort Analysis. This graph shows the required input force from Mr. Jauregui as a function of the current angle of rotation. At an angle of 0, the upper dolly is in the upright position while an angle of 90 corresponds with the upper dolly being in the lowered position. In this plot, the modelled force is shown for four different rotation times, ranging from two to eight seconds. These different models are shown in different colors and labelled accordingly.

From this model, we did not see much of an improvement with the addition of more time. The initial force required significantly decreased from around 20 pounds to close to 0 pounds in the eight second model. However, none of these models changed the final input force, which remained at around 25 pounds.

In summary, we found that this design should greatly reduce the effort required by Mr. Jauregui in lifting and rotating his bee boxes. We also found that increasing the time for rotation requirement to around four or six seconds would greatly reduce the force required by Mr. Jauregui, which we have taken into consideration later on.

4.8 Risk and Problem Assessment

At this stage in the design, we have identified some safety hazards that we will need to plan for We created a Design Hazard Checklist in order to identify such problems and corrective actions needed to solve them; this Design Hazard Checklist can be found in Appendix H.

One of these hazards is the main hinge that the device operates around. This hinge will undoubtedly cause pinch points in multiple locations around it that can harm the operator if not careful. Pinch points will also be found in the attachment mechanism that secures the box to the dolly. We will design around these pinch points to either make them inaccessible or clearly marked with caution signs to remind the operator not to have items or their body near a pinch point.

Another source of hazard will come from the bee box itself. A full capacity bee box weighs around 50-60lbs. There is a possibility that during operation the box may become loose from the attachment device and fall. In addition, the box remains in a resting position of 15 inches above the ground after rotation. If the device fails during operation it can also lead to the box falling or causing other parts of the dolly to swing uncontrollably. The dolly and sub-systems will be designed with large factors of safety in mind, with materials and connection assemblies, to ensure the possibility of failure during operation is highly unlikely. We will also design this device so that if it does fail, it will fail towards safety (i.e. not hurting the operator).

As mentioned before, it is possible that this device will still have a system of springs or gas pistons to assist in operation by storing energy to rotate the box. These components have the chance to fail under extreme circumstances or from fatigue. Appropriate springs and pistons will be selected, and housing will be designed to protect the operator from sudden failure.

There are many other simple hazards that we will accommodate for, such as silicon grips on handles, brakes for the dolly wheels, and bright, non-corrosive, paint to help with high temperatures and corrosion, and capacity labels. These hazards will be identified and easily solved. All possible hazards, as well as incorrect uses of the device, will be communicated to the operator before delivered.

Despite these hazards and design challenges, we are still confident that the “Broken Dolly” design is the best design with which to move forward. We are confident that over the next 7 months we will be able to design and manufacture this design.

5.0 Project Management

Our design process included three main parts: designing, building, and testing. The design process was approximately 16 weeks and officially ended around mid-February (although we did continue to tinker with the design until the end). This phase was followed by 13 weeks of building the design that was agreed on. The last and most important part of the design process included 5 weeks of testing to ensure the project was reliable and functioned as designed.

Each section of the device was broken down into sub-sections to ensure every aspect of the project was given its due diligence. The design process included research, definition of a problem statement, and prototype design. The problem statement and research were vital in order for our team to have a proper and comprehensive understanding of the project.

A Scope of Work (SOW) document was generated and sent to the project sponsors to ensure everyone involved had a full understanding of the project's direction. After the SOW was sent to our sponsor, the design process commenced. The design process included several ideation phases to generate a multitude of ideas.

Once an agreement on the design details had been agreed on by the team, a Preliminary Design Review (PDR) document was put together and presented to our sponsor and advisor for approval. Once PDR approval had been received, required materials were ordered for the construction of a structural prototype. Alongside construction, the agreed upon design was refined and analyzed to ensure its functionality and safety. Once the structural prototype was built and the design finalized, a Critical Design Review (CDR) document was put together and presented to our sponsor and advisor for approval.

Once CDR approval had been received, the remaining materials were ordered for construction of the verification prototype, which became the final device. Upon completion of the verification prototype the testing phase will commence. The verification prototype was tested to ensure that it met the project expectations.

The final component of this project consisted of a design expo where all the senior projects will be shown to personnel from the public and various industries which will be present. Due to the COVID-19 pandemic, this event will be held virtually through the use of a website and video. Table 4 delivers a timeline of the major deliverables. For a more in-depth schedule see the Gannt Chart in Appendix B.

Table 4. Project Major Deliverables Timeline

Deliverable	Description	Due Date
Scope of Work	Documentation Outlining Project	10/13/2020
Preliminary Design Review (PDR)	Sponsor's and Advisor's Design Review	11/12/2020
Drawing & Manuf. Plan Review	Drawing review to ensure project can continue	02/03/2021
Critical Design Review (CDR)	Review to ensure the design can proceed to manufacture	02/09/2021
Manufacturing & Test Review	Project status plan for testing	03/10/2021
Assembly	Assemble project for testing	04/21/2021
Testing	Test project for safety	05/20/2021
Final Design Review	Submit final report and device	06/03/2021
Design Expo	Present final device through website and video	06/05/2021

In order for our design to be successful, we were very meticulous throughout the design process. The design had multiple iterations that generated ideas in order to come up with the best prototype to perform all the required tasks. Our process was different than other teams process because of the complexity of the project. As such, we iterated throughout the process, making changes as needed. We moved quickly but diligently into the prototype phase to ensure that we had plenty of time for testing. The team was comprised of four individuals who had experience in different industries including construction, medical design, the oil industry, and the hydro-electric industry. Because of our industry experiences, we had all worked on engineering teams. This, in combination with our careful project management, allowed us to complete this project on team and to the specifications of Mr. Jauregui.

6.0 Final Design

In this section, we will discuss the final selected design, justification for our material and part selection, and considerations we have made for safety and maintenance. We will also describe the changes we have made to this design since we presented it at our Critical Design Review (CDR), before we began manufacturing the final device. Finally, we will detail our final cost breakdown for the entire project.

6.1 Final Selected Design

The final selected design's main goal is to efficiently displace the top box from a bee box stack in order to inspect the lower bee box for the well-being of the queen bee. The device will be assembled from several components which includes a stock portable 2-wheel dolly, a manufactured clamping arm and a set of manufactured forks. The complete CAD model of the dolly can be seen in Figure 23.

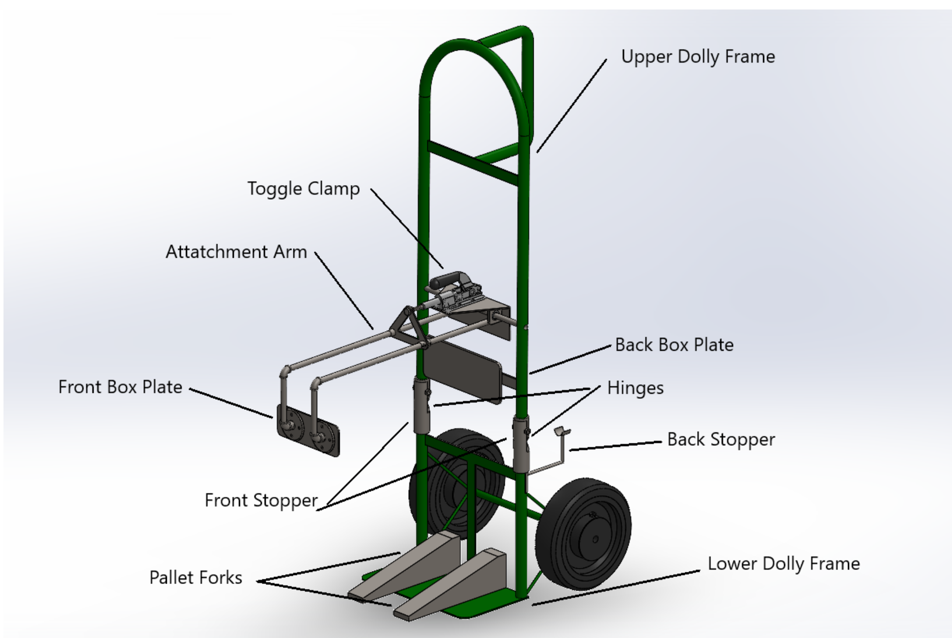


Figure 23. The complete CAD model of the bee box dolly with labeled subsystems and parts.

The dolly is store-bought, and it will be modified by cutting it at a height of 15 inches in order to attach hinges so that the dolly can "break" in down moving the top been box out of the way for safe inspection of the lower bee box. Welded to the upper half of the dolly frame is a 3/8" steel road. A set of bearings and retaining rods will allow the Attachment Arm Assembly to connect and pivot around the upper dolly frame. Below the rod is a strip of 1/8" steel plate, welded again to the body of the dolly. Bolted to this plate is another plate that is labeled the "Back Box Plate" and it will serve as one side of a clamp produced by the Attachment Arms. The upper bee box will be clamped from both sides, causing enough friction between the two plates for the box to be held in place and rotated out of the way for inspection of the lower hive.

The connection between the Upper and Lower Dolly Frames is made by two Kee Klamp swivel elbows. These hinges are designed to take up to 2000lbs axially and are held in place by a set screw. Around the hinges are larger diameter stock pipes with one side cut out. These pipes will act as a front stopper to prevent the dolly from swinging forward. Nuts will be welded to these pipes midway to allow access for ball bearing plungers. The plungers will have a matching divot on the hinge to act as a slot for the plunger to extend out. The purpose of the plungers is to act as a lock for when the dolly is in the straight position during travel. The force they produce on the divot can easily be overcome when the dolly is in the proper position to be bent backwards.

A back stopper composed of 3/8"rod and a 1-¼" pipe cuts is welded below the hinges. This rest will act as a rest for the upper frame when bent 90 degrees. The last modification to the dolly consists of two forks, built from steel plate, welded to the base plate of the dolly. These forks will ensure a good connection between the Lower Dolly Frame and the pallet of bee boxes.

The largest and most complicated subassembly of this project is the attachment arm assembly. It consists of 1/8" thick steel plates, ½" iron plumbing pipes and connectors, and a toggle clamp, all of which are shown in Figure 24.

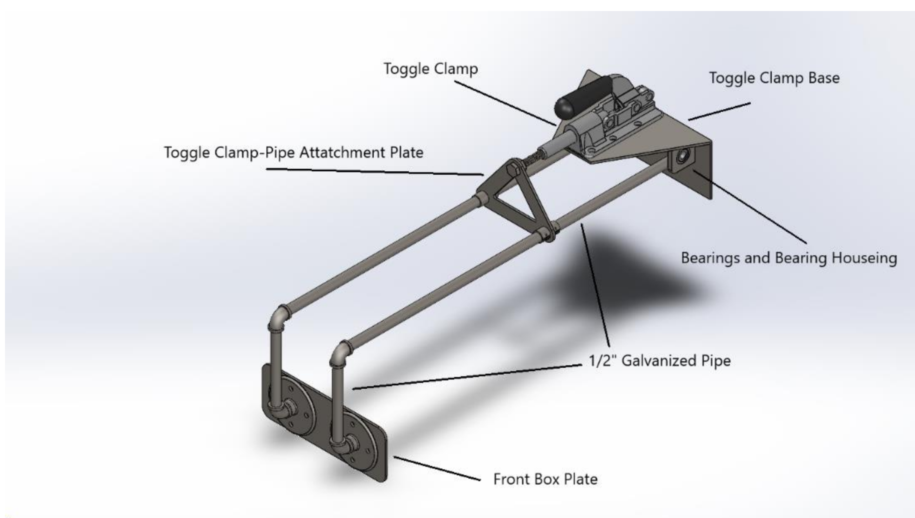


Figure 24. A detailed view of the Attachment Arm Assembly.

To save on manufacturing time and materials, ½” standard galvanized pipe, commonly used in plumbing, was incorporated into the design. Using the pipe and common components, such as threaded 90’s, different sized pipe nipples, and pipe flanges, was an easy way to build most of the attachment arm easily. To make manufacturing easier, the front box plate and the toggle clamp base are all made from the same size steel plate. The Attachment Arm swings around on two ball bearings under the toggle clamp base. The arm must swing to allow for proper and easy setup when connecting to a bee box. The toggle clamp and attachment arms are all connected via the triangular attachment plate. This plate is held to the toggle clamp via a 3/8” bolt and nut, but it is held in place against the two ½” pipes by ½” clamps on each side of the plate. When the toggle clamp is engaged, it causes the two arms to slide through two holes in the toggle clamp base. The movement of the arms will cause the Front Box Plate to compress against one side of the bee box, with the other side being compressed by the back box plate on the upper dolly frame.

6.2 Materials and Part Selection Justifications

6.2.1 Dolly

A major requirement for the Beekeeper Assist is that it is transportable and lightweight. Our sponsor has to travel from farm to farm in order to inspect an average of two hundred beehives at each farm. In order to make this possible the team decided on using a 1-inch diameter steel tubing store-bought dolly that has a load capacity of 600lbs because it is light weight, roughly 20lbs, before attaching any of the remaining necessary components. The dolly can also be maneuvered from one beehive to the next with little effort. Because of its light weight our sponsor can put it up in the bed of his truck and transport it from one farm to the next. Most importantly the dolly can be easily modified to fit our sponsor’s needs.

6.2.2 Attachment Arm

The attachment arm will be manufactured using ½” standard galvanized pipe, 90-degree angle threaded elbows, 1/8” steel plates and a store-bought toggle clamp. The diameter of the pipe and thickness of the plates were selected based on CAD modelling and a Finite Element Analysis (FEA). The toggle is rated at 25,000lbs of holding capacity and the calculated that friction requirement to hold the top bee box in place would be 50lbs. The entire arm assembly will be able to rotate up and down when it is not being. This will be possible because to the two ¼” ball bearing that will be placed underneath the toggle clamp base. Because the bearings will only be experiencing the forces exerted by the clamping arms weight, roughly 10lbs, it was not necessary to perform any calculations.

To ensure that ½” pipe was adequate for the attachment arm, an FEA analysis was performed in a Solid Works program. The test was a conducted on a single 22” long steel ½” pipe. A force of 30 pounds (or half of the total force from the weight of the box experienced by the attachment arms) was applied to the long end of the pipe and a fixed connection 7 inches into the pipe represented the toggle clamp attachment plate. The rest of the pipe was given a sliding restraint. The results of the test show that the pipe is indeed strong enough to withstand the weight of the box, with minimal deflection (<0.125in). This test was a justification that ½” pipe is acceptable to use in the attachment arm assembly. A screenshot of this simulation’s results can be seen in Figure 25.

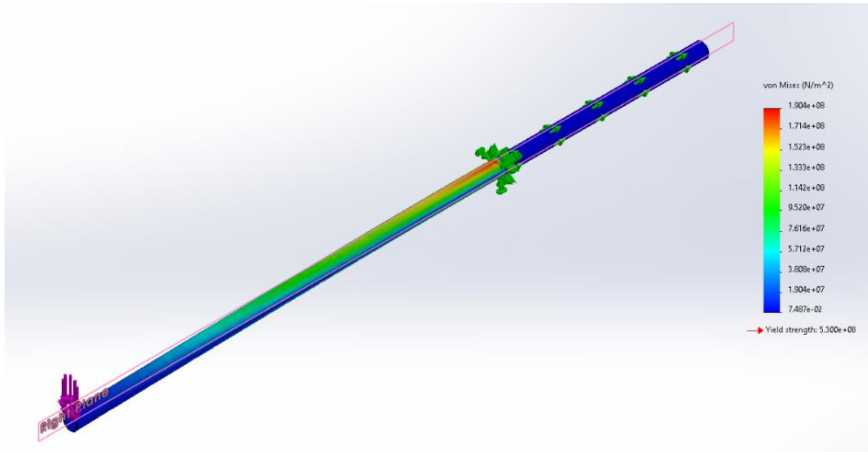


Figure 25. An example of a static FEA analysis for one ½" pipe on the attachment arm assembly.

6.2.3 Dolly Forks

The dolly forks will consist of 1/8" steel plates that will cut to shape and size using the water jet then they will be welded together forming a trapezoid shape. Once the forks are manufactured, they will be welded onto the dolly base plate. The main purpose of the forks is to hold the dolly in place when the bee box is rotated back for inspection. Because the entire weight and pallet and 7 bee boxes will be braced against the dolly forks it was assumed that the forks would be able to hold the dolly in place. Also, once the prototype is built testing will be done in order to confirm our assumption.

6.3 Safety, Maintenance and Repair Considerations

While we have designed the device around Mr. Jauregui's safety, there are still areas that will require his attention. The design of the device consists of the top half of the dolly rotating about the hinge in the middle of the dolly. The hinge along with the front stops that prevent the dolly from going forward can be pinching points at the moment of rotation. More protection can be added but for pinching to occur, Mr. Jauregui would knowingly have to set his hand there. Another pinching point is at the back support when the dolly is fully rotated. This pinching point cannot be covered because it only occurs when the dolly is fully rotated, and it is not upright.

The Beekeeper Assist will require minimal maintenance because it will be painted. The most important consideration is to keep the dolly assembly indoors or out of the wet weather when it is not in use. With time, it is expected that the dolly will rust due to moisture. It is therefore recommended to remove the rust with either sandpaper or steel wool and a fresh coat of paint should be applied.

Another component that needs to be maintained are the hinges. The hinges should be maintained clean and clear of rust. If they do become rusty, the rust needs to be removed with steel wool and sprayed down with WD-40. If the tires on the dolly were to become flat, the inner tube can be replaced. If the entire tire wears out, then a new tire would need to be purchased for replacement.

In case the device requires repairs, the design of the dolly has implemented common pipes and threaded joints around the whole system that can be found at any local hardware store. Threaded joints will allow for the parts to be easily taken apart to be repaired or replaced if needed. The friction pads and wheels are the most prone to repairs or replacements. The friction pad will have to be replaced if it becomes too stiff and does not allow for small variations in size in the bee boxes. The wheels can be easily repaired if they become flat since that part of the dolly will remain stock.

6.4 Design Changes After CDR

After we presented this design at our Critical Design Review (CDR), we made several small changes to the final design. These changes were made mostly because of preliminary testing results, which gave us key insights on how to improve the Beekeeper Assist's function. The majority of these changes are shown and labelled in Figure 26.

Figure 26. A picture of the final Beekeeper Assist, with changes made during the manufacturing process labelled in red; more specific details about these changes can be found in Appendices K through N.

There were many reasons why we made these design changes. For the backrest, we determined that what we had designed would not work in practice and we were forced to make something sturdier. After some preliminary calculations, we designed a truss support using sheet metal that was to be MIG welded.

For the plunger hinge lock, we found that using the existing pin mechanism built into these hinges was cumbersome and did not fit Mr. Jauregui's ergonomic needs. The new mechanism uses a handle much closer to where his hands will already be. Mr. Jauregui simply needs to pull the handle up to unlock the mechanism and push it down when he wants to lock it again. We also determined that the front stoppers on the hinges were not necessary as our purchased hinges already sufficiently blocked forward rotation.

The damper was a solution to a problem we had not anticipated during our initial design. When the user would rotate a loaded box back during testing, there was a possibility that the box would continue to rotate back, possible hurting the user and flinging the box in the process. After much ideation, we found a damper that would prevent this rotation from occurring. We specially selected this damper so that when Mr. Jauregui wants to put the arm back into its upright configuration, it would not provide insurmountable resistance.

The arm clamps and the foam spacers were also solutions to unanticipated problems. In testing, we found that the bee box lid would not stay on during rotation unless something on the arm was in constant contact with it. We researched many possible options for a spacer that would provide this contact. In the end, modified foam pool noodles provided the right amount of pressure and compressibility that we needed. The arm clamps arose from needing to be able to store the arm in the upright position.

6.5 Final Cost Analysis

For this project we were fortunate enough to have the largest component, the dolly, donated to us; this eliminated a $60.00 expenditure. The upper dolly frame had minimal expenses, most of which were just stock steel parts. The attachment arm hinge rod and back box plate were both made from stock steel which were purchased from a local vendor, McCarthy Steel. Also included in the expenses for the upper dolly were the rubber friction pads that were attached to the front and back box plates. These were purchased as a large pad for $37.00, but the actual parts were cut out from this. There were a few added on components to the upper dolly, such as the attachment arm clamps and the plunger hinge lock. These parts were all made from cheap mild steel that only round up to about $30. In total, we estimated that the upper dolly totaled $82.40.

The attachment arm was the most complex part of this project as well as being the most expensive. To cut down on costs, we purchased stock pipe and pipe components from a local supplier, ACE Hardware. By designing around available parts at ACE and not ordering custom parts, we saved easily over $100.00 based on prices from McMaster-Carr. The only custom parts created were made from stock steel plates, which we also ordered from McCarthy Steel. The most expensive parts for the Attachment Arm came from McMaster-Carr, such as the toggle clamp and pipe clamps. The toggle clamp alone was $45.71, but we were unable to find another provider that had the specifications and load ratings that McMaster-Carr provides. In total, the atttachment arm was estimated to cost $151.76.

The hinge section of the dolly played a large role in the process of the dolly and was a critical part. Deciding on what hinges to use required a large amount of research. We eventually decided on the Keehui Marine Boat elbow hinges. The two hinges had a going rate of $35.54 for both hinges. These hinges were great as they made the steel stopper and ball point plungers obsolete; the hinges include all that necessary hardware. The total cost for the hinge section was $35.34.

The lower dolly frame was simple and the cheapest sub assembly. The pallet forks were made of more steel plates. The back stopper was also made of cheap steel plates. All of this was available and procured from McCarthy Steel. The dolly frame itself was, of course, the other half of the donated dolly. In total, the lower dolly frame was estimated to cost $45.00.

The cost breakdown by component can be seen in Table 5. The total estimated cost for the device stood at $352.26. Our teams' total budget was $750.00 for this project. This means that we have not exceeded our budget and ended up with a surplus of $171.

Table 5. Cost breakdown of the device by component and sub assembly.

Sub Assembly	Component	Supplier	Total Cost
Upper Dolly Frame	Upper dolly Frame	Donated	$0.00
	Attachment Arm Hinge	McCarthy Steel	$5.00
	Back Box Plate	McCarthy Steel	$10.00
	Attachment Arm Clamps and Plate	ACE Hardware	$12.00
	Plunger Hinge Lock	ACE Hardware	$18.00
	Front and Back Box Plate Rubber Pads	McMasterCarr	$37.40
Attachment Arm	Toggle Clamp Base, Front Box Plate, Attachment Arm Front Plate.	McCarthy Steel	$30.00
	Bearings	McMaster Carr	$13.76
	Pipe and Pipe Hardware	ACE Hardware	$38.93
	Toggle Clamp	McMaster Carr	$45.71
	Misc. Fasters	ACE Hardware	$5.00
	Pipe Clamps	McMaster Carr	$18.36
Hinges	Elbow Hinges	Keehui Boating (Amazon)	$35.54
	Misc Fasters	ACE Hardware	$2.00
Lower Dolly Frame	Lower Dolly Frame	Donated	$0.00
	Dolly Forks	McCarthy Steel	$30.00
	Back Stopper	McCarthy Steel	$15.00
		Total	**$319.70**

7.0 Manufacturing

The following manufacturing plan details the step-by-step process of how our final design was created and assembled. All materials outlined here are detailed further in the indented bill of materials, located in Appendix I. This portion is broken up into subsections focusing on subassembly manufacturing. At the end of this section, this plan will detail how we fully assembled the device.

7.1 Dolly Forks

The major dimensions and geometric standards for these forks can be found in Appendix K. The steps we took to manufacture the dolly forks were as follows:

1. Prepared a 1/8” non-galvanized steel plate to the size specified in Appendix K.
2. Generated a pattern for the waterjet to cut out the fork plates.
3. Used the CNC waterjet machine to cut out the fork plates.
4. Aligned the plates in 90° angles, as specified by the design.
5. Applied MIG welds to the 90° angles to create a fork shape.
6. Ground the MIG welds down somewhat using a belt grinder.

The main challenge we experienced while manufacturing these forks had to do with their height. Once we received a bee box pallet from Mr. Jauregui, we redesigned our original forks to better match his pallets. However, we unfortunately made the forks fit too snugly underneath the pallet. This made it difficult to maneuver the dolly and did not account for the rougher terrain that Mr. Jauregui works on. As such, we redesigned and recut the forks to be slightly smaller. This added a slight delay to the timeline of the forks, but we were very pleased with the results.

In addition, we also found that using bolts to affix the forks presented a problem. The base plate of the dolly was about ¼” in thickness. We found it difficult to find a bolt suitable for holding that load while also fitting within a countersink of that thickness. Originally, we planned on using a carriage bolt (a bolt with a round head) with the head on the bottom. However, this added too much height to the bottom plate and impeded the forks’ function. We elected to weld the forks to the bottom plate to solve this problem.

7.2 Lower Dolly Frame

The major dimensions and geometric standards for these forks can be found in Appendix K. Early in the manufacturing process we discovered that the dolly donated to the project had wheel axel supports that angled up from the axel onto the dolly body. These supports were welded at the same height as where the hinges were to be placed. We solved the issue by cutting off the supports, shortening them, and re-welding them on at a steeper angle below the hinges. The plans for manufacturing the lower dolly frame were as follows:

1. Marked a point in the frame 15” above the bottom, as specified by the drawings.
2. Used a standard metal tubing cutter to cut the dolly frame, leaving the frames for the lower and upper dolly frame.

3. Marked 45° angles on ½” steel pipe at lengths specified by the design.
4. Used a band saw to cut the pipes. Grind the ends to ensure a smooth surface finish.
5. Used a band saw and pipe cutter to cut two half-pipe pieces of 1 ¼” steel pipes, as specified in the design.
6. For both supports, MIG welded a 45° support onto a half-pipe, as specified in the design.
7. For both supports, MIG welded the other end of the supports to the lower dolly frame, as specified by the design.
8. Using a handheld drill, drilled holes in the bottom plate of the lower dolly frame, as specified in the design.
9. Cut pipes with a standard metal tubing cutter to length for the front stop, as specified by the design.
10. Using a bandsaw, cut these pipes in half.

7.3 Upper Dolly Frame

For the upper dolly frame’s manufacturing plan, it is worth noting that steps 1 and 2 are the same steps as for the lower dolly frame; only one set of these two steps will be completed. We had an ergonomic conflict arise on the upper dolly frame after the device was nearly completed. A support strap of steel crossed the dolly frame near the toggle clamp. While this strap did not impede the motion of the toggle clamp or attachment arm, it was an ergonomic issue as it made reaching the toggle clamp difficult. We solved the issue by moving the strap and shortening the upper handle, so as to make the toggle clamp more accessible. The major dimensions and geometric standards for this subsystem can be found in Appendix M. The plans for manufacturing the upper dolly frame are as follows:

1. Marked a point in the frame 15” above the bottom, as specified by the drawings.
2. Used a standard metal tubing cutter to cut the dolly frame, leaving the frames for the lower and upper dolly frame.
3. Cut out a 1/8” x 1.5” x 12” steel strip using a miter saw.
4. Using a drill press, drilled two 3/8” through holes, 3” from center of bar.
5. Using a MIG welder, welded the ends of the 12” steel strip to both sides of the upper dolly frame (on the inside) 4.5” from the bottom of the upper dolly frame.
6. Using the water jet available, cut a 1/8” x 3” x 8” steel plate with two 3/8” through holes, 3” from center of plate, 1.5” from bottom.
7. Using two 3/8” x 2” bolts, two 3/8” nuts, two 3/8” washers, and 1.75” spacers, connected the backrest plate to the steel strip, with nuts facing the backside of the dolly.
8. Cut a rubber pad to size and epoxy to the forward-facing side of the backrest plate.
9. Cut a piece of 3/8” steel round stock to 12” length.
10. Using a lathe, turned notches into the crossbar for the retaining rings, as specified by the design.
11. Using a die, added ¼”-28 threads to both sides of the crossbar.
12. Drilled two 5/16” horizontal holes on the dolly frame at 11.875” from the bottom/hinge end.
13. Attached the crossbar to the dolly frame using ¼” lock nuts on each side.
14. Cut out a 1/8” x 1.5” x 12” steel strip using a miter saw.
15. Drilled two vertical 1/8” through holes, ½” vertically from the middle of the bar and 2” across to the left of the center of the bar, using a drill press.

16. Welded the ends of the 12” steel strip to both sides of the upper dolly frame (on the inside) 4” from the bottom of the upper dolly frame Using a MIG welder.
17. Attached the clamp to lock the attachment arm in its upright position using two #5-44 bolts and hex nuts.
18. Cut a 16” long 3/8” square tube with the miter saw for the locking mechanism that will lock the dolly on its upright position.
19. Cut two ¼”x ½”x 2” spacers using miter saw.
20. Welded the spacers to the ends of square tube.
21. Welded the spacers on the square tube to the dolly frame right above the left hinge. We made sure the square tube was in line with a shorter segment on the on the lower dolly.
22. Cut a 3/8” metal dowel 20” long.
23. Bended 3” of the end of the dowel to 90 degrees.
24. Drilled a hole on the metal dowel 5.5” from the straight end using #42 bit for a 3/32” press fit pin.
25. Cut a 1” notch in the square tube, 4.5” from the bottom of the dolly frame.
26. Assembled the locking mechanism by inserting the spring in the notch of the square tube and running the metal dowel through both. Pressed the pin into the metal dowel to engage the spring.

One of the challenges encountered during a preliminary test was removing and inserting the locking pins in the hinges during each inspection. Our sponsor suggested we look into a mechanism that would allow the upper half of the dolly to be locked in its upright position with more ease. We added a plunger to the upper half of the dolly that would lock the dolly upright when it gets engaged. The mechanism is composed of a metal dowel in a hollow square tube. To disengage the lock and rotate the dolly, Mr. Jauregui has to pull the handle on the dowel up to clear the bottom tube. The friction between the dowel and the tube keeps the dowel in the upright position until Mr. Jauregui wants to put it back down, relocking the hinge.

Figure 27 shows the manufactured upper dolly frame assembled with the attachment arm and lower dolly frame.

Figure 27. Upper dolly frame with the back support plate, cross bar, dowel for locking mechanism, and clamp for the arm on when it is in its upright position, as shown above.

7.4 Attachment Arm

For the attachment arm, it is worth noting that most threaded connections will have thread lock applied to prevent unscrewing. If a threaded connection does not have thread lock applied, it will be mentioned. One problem that arose mid manufacturing with the arm was the piping used on the far end of the arm. After we received bee boxes and a pallet from Mr. Jauregui, we noticed that the gap between the boxes was smaller than anticipated and the configuration of threaded pipe 90's and flanges was too wide. We solved this problem by scrapping the threaded 90's and water jetting our own plate that could by bolted onto the end of the attachment arm, reducing its footprint enough to fit the gap. The major dimensions and geometric standards for this subsystem can be found in Appendix N. The steps we took to manufacture the attachment arm were as follows:

1. Prepared a ¼" steel plate to the size specified for the arm clamp plate.
2. Using a waterjet cutter, cut out the ¼" steel plate to its specified design.
3. Placed two 24" threaded pipes through the top holes of the arm clamp plate and affixed them with pipe nuts. The assembly for the arm clamp plate portion is shown in Figure 28.

Figure 28. The arm clamp plate affixed to the 24" threaded pipes with pipe nuts. As shown in the image, Mr. Jauregui's Army insignia was cut out of the arm clamp plate in order to remove material and to pay homage to his service.

4. Prepared a 1/8" steel plate to the size specified for the front box plate.
5. Using a waterjet cutter, cut out the 1/8" steel plate to its specified design.
6. Attached ½" flanges to the front box plate using specified carriage bolts and nuts.
7. Using a drill press, drilled small holes in the rubber friction pad to allow room for the carriage bolt heads.
8. Using Loctite Adhesive, bonded the rubber friction pad to the front box plate. Figure 29 shows the friction pads affixed to the front and back box plates.

Figure 29. The rubber friction pads adhered to the front and back box plates, respectively from left to right.

9. Attached a 1” nipple to each flange on the front box plate.
10. Placed the front box plate nipples through the bottom holes of the arm clamp plate and affixed them with pipe nuts.
11. Using a waterjet cutter, cut out 1/8” steel plate to the size and shape of the attachment arm hinge plates, as specified in the design.
12. Using a waterjet cutter, cut out ¼” steel plate to the size and shape of the bearing holders.
13. With a MIG welder, welded the bearing holders to the undersides of the bottom hinge plates.
14. Continued the previous weld by welding the two hinge plates together as specified by the design, using the bearing holders as tacks. Figure 30 shows the welded hinge piece after this step was completed.

Figure 30. The welded hinge piece.

15. Pushed the toggle clamp bolts through and tightened them with bolts, connecting the toggle clamp to the top hinge plate.
16. Using a waterjet cutter, cut out the triangular connective plate, as specified by the design.
17. Slid on first set of collar clamps onto 24" pipes.
18. Slid the connective plate onto the two parallel 24" pipes in their designated spots.
19. Slid last set of collar clamps onto 24" pipes.
20. Tightened collar clamps directly against the connective plate using hex wrenches.
21. Took a 3/8" metal rod and turned it down on both sides, creating two seats for the hinge bearings as specified by the design.
22. Cut notches for retaining rings into the metal rod as specified by the design.

7.5 Final Assembly

The plans for fully assembling the dolly, including how to piece together the subassemblies, are as follows:

1. Aligned the forks into their proper positions on the dolly base plate.
2. Applied MIG welds to the 90° angles to affix the forks to the dolly base plate. The finished forks can be seen in Figure 31.

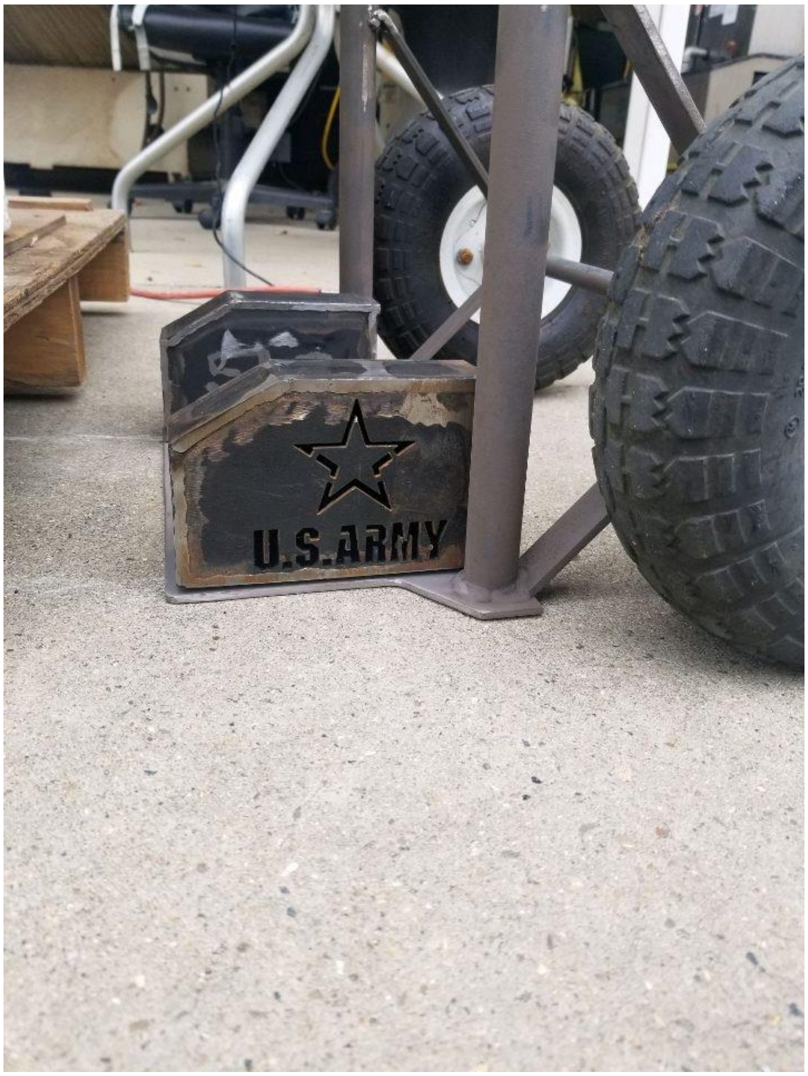


Figure 31. The final version of the dolly's forks. In this image, the forks have been welded to the base plate but have not yet been powder coated. This image also shows the U.S. Army logo we had cut into the forks to pay homage to Mr. Jauregui's service.

3. Marked the position for the hinge set screws on the lower and upper dolly frames, as specified by the design. The locations for the hinges and relevant positioning can be found in Appendix K & L.

4. Using a handheld drill, drilled holes in the lower and upper dolly frames for the hinge set screws, as detailed by the design.
5. Put the hinge in place on the lower dolly frame and insert set screw.
6. Repeated steps 3-4 for the upper dolly frame.
7. Set both frames on their sides and slide them into position.
8. Inserted set screws into the holes on the upper dolly frame.
9. Placed a spring in the designated location on the square tube's length.
10. Pushed the plunger through the square tube as far as it would go.
11. Using a set of pliers, set a spring pin into a hole beneath the spring.
12. Navigated the crossbar through the bearing supports of the hinge frame.
13. Using retaining ring pliers, place the internal bearing retaining rings into the internal notches.
14. Using a press, set the bearings into the hinge frame.
15. Using retaining ring pliers, place the external bearing retaining rings into the external notches.
16. Slid the pipe assembly for the arm into the back two holes of the hinge frame.
17. Pushed the 5/8" bolt through the top of the triangular piece and tightened it into the toggle clamp. The final assembled verification prototype is shown in Figure 32.

Figure 32. The fully assembled verification prototype in the down position. This image does not include the back support, the spacer, or the rotation blocker, but everything else is in completion.

7.6 Part Procurement

During the beginning phases of the manufacturing process, we ordered most of the parts online. This was easy because we were able to go by the plans that we had developed. A purchase order would be developed with the necessary parts and prices, compared to the current project budget, and ordered by a Cal Poly representative. After about 80% of the dolly was built, we began to procure parts randomly in person as some parts or ideas did not work or proved unviable. Most of these purchases were done at the local ACE hardware store or through local vendors. All purchases were made with compensation in mind and the project budget was not exceeded this way. The ability to buy smaller groups of pieces at any time allowed for more ideation and solutions to problems that would develop as the project proceeded.

7.7 Final Budget Status

Due to the transition of buying parts online through the school to buying parts in person and receiving reimbursements, it is optimal to show the final budget status in those two groups.

Table 6. Summary table of the final budget.

Purchase Types	Amount
Purchase Order	$329.00
Reimbursement	$250.00
Budget	$750.00
Budget Remaining	$171.00

We have done very well with managing our expenses even when not being checked by our school representative. If future production will take place, it will be far cheaper from what is described above as we will not need to buy as many materials for testing and development of ideas.

7.8 Recommendations for Future Production

The project has had many modifications made to it from the original final design described previously. In some of these modifications, time was critical and as a result workmanship declined. This is evident in many of the welded attachments. While nothing critical stands out, it should be noted for future production that welding and drilling on precise parts should be done by professionals. This will not only increase the workmanship of the device, but the safety as well. Once we finished all the components of the device, we were able to draw a complete plan that was much more detailed from the initial final design. This is because of our trial-and-error method developed after new problems arose from testing or the planned method did not work. Future production should be much smoother than our process.

8.0 Design Verification

In this section we will talk about how we verified that our device meets the goals and specifications. Some of these specifications and goals, like the ones in Table 3, are for the whole device and came from Mr. Jauregui's needs. Others are focused on the attachment arm subsystem and came about during the design process. All specifications can be categorized into three groups: functionality, convenience, and safety of the device. A summary of the tests that we used to verify the device with these specifications can be found in Table 7.

Table 7. A summary of tests performed for design verification.

Test	Reason for Test
Device Weight Test	The device cannot weigh more than 60 lbs.
Device Size Test	The device must be able to fit into Mr. Jauregui's truck.
Lifting Capacity Test	The device must be able to lift and rotate up to 80 lbs.
Rotation Time Test	Rotation with the device should take less than four seconds in order to be as efficient as Mr. Jauregui's current process.
Setup Time Test	Setting the device up for rotation should take less than five seconds so as to not completely slow down Mr. Jauregui's work.
Clamping Motion Test	The clamping motion should be smooth for ease of use.
Clamp Effectiveness Test	The clamp should not allow the box to slip or slide once held so as to not agitate the bees.
Lid Hold Test	The attachment arm should hold on the lid during rotation so as to not agitate the bees.

The full design verification plan and report (DVP&R) and results can be found in Appendix O. The test procedures used for this verification can all be found in Appendix Q, along with numerical results if applicable.

37.1 Functionality

The main goal for our device was to help with the inspection of the frames in the brood box of the beehive. This required that the top box be moved away for Mr. Jauregui to have access to the bottom box. We made sure that that there was enough room to access the bottom box by testing the verification prototype on full scale bee boxes, as shown in Figure 33.

Figure 33. A picture of the test ensuring that the attachment arm fits Mr. Jauregui's bee box setup. These boxes were loaned to us by Mr. Jauregui for testing purposes.

To create access to the bottom box, our device rotates the top box 90 degrees on its side. The top boxes can range in weight depending on the amount of honey inside but, on average, a full box of honey can weigh up to 80 pounds. This required our device to always be able to rotate and hold at least 80 pounds. We tested the device using a specially made bee box that was the same dimensions as the sponsors, but with the ability to hold various weights inside it. We tested the prototype with various weights inside this box up to around 100 pounds to give our design a factor of safety. Our device excelled in this regard and allowed for smooth rotation of the bee box with ease.

During this test we also conducted a series of pull force tests to see how much force was actually needed to rotate the box. This force was necessary to find as it told us how much load Mr. Jauregui would need to provide per cycle. According to our dynamic model, the maximum force exerted during the rotation process occurs as the user initially pulls the top of the device backwards. Figure 34 shows the test setup we used to find this force.

Figure 34. Here Ryan and Jose perform the weighted bee box pull procedure. This test was performed using weight ranging from 40-80 lbs. to ensure the clamping arm would apply sufficient force on the bee box.

Though out all these tests the device was successfully able to attach onto the upper bee box, lift, and rotate it into place. Once there the device was successfully able to hold the box in place. These tests satisfied many requirements and tests. During rotation, the bee box lid was also successfully held in place against the box due to the attachment arm spacers. The clamping process was smooth and easy to use.

8.2 Convenience

Along with functionality, it was also important that our device is convenient to use. This implies that the transportability of the device is not a problem. Since Mr. Jauregui drives a pick-up truck, his preferred way to transport the device would be to load it onto the bed of his truck. The available space on the bed of his truck created a size requirement for our device of 50 by 67 inches. In order to verify that we meet the size requirement, we measured the major dimensions (height and width) of the verification prototype with the attachment arm in the upright position; this was the configuration best suited for transport. We were not particularly concerned with the actual dimensions, only with whether or not the device fit within our bounding box. We found that our device fit comfortably within this box. In addition, we loaded the device into the back of a similar pickup truck owned by a member of our team and found that it took up a reasonable amount of room in the truck bed; a picture of this test can be seen in Figure 34.

Figure 35. The test ensuring that the Beekeeper Assist will fit comfortably in the bed of Mr. Jauregui's pickup truck. While we did not measure the dimensions of this truck bed, we know that the truck bed in this image is smaller than Mr. Jauregui's truck bed.

Loading the device on to the truck also added a weight limit on our device. In order to allow Mr. Jauregui to load the device by himself, we set the goal for the weight of the device to be 60 pounds. We weighed the verification prototype on a Taylor 7042 scale and found it to be 50.4 ± 0.05 pounds, which is well within our specification.

The convenience of the device is also defined by the time it takes to set it up and perform the task. Mr. Jauregui's previous manual process consisted of walking up to a beehive and getting in the correct stance to lift and rotate the top box, which did not take him very long. In order for our device to be convenient, the time it takes to set up and rotate the top box must be very short. To test how long it takes for our device to set up and rotate the top box, we used the verification prototype and bee boxes to record the whole process. This process was tested, and it was determined that it would take between 5-7 seconds for the Beekeeper Assist to be set up.

Figure 36. The test that determined how long it would take to set-up the Beekeeper Assist which is relatively the same about of time it would take Mr. Jauregui to lift and rotate the bee box out of the way for him to inspect his beehives.

8.3 Safety

Most importantly, our device had to be safer than Mr. Jauregui's current process. For our device to create access to the bottom box, the attaching arm had to clamp the top box before rotating it away. The attachment arm had become an important subsystem of our device because it is in charge of securing the top box and the lid during the rotation. We conducted a visual test to see how well the attaching arm held on the lid while it has the top box clamped, as well as trying to move the box beneath the pads. During one of our preliminary tests, we noticed that we needed spacers to push the lid towards the box when it was rotated ninety degrees. We added foam spacers to ensure that the lids did not fall off during rotation.

The safety of the bees had also been a focus of our design. To avoid disturbing any bees that may be in the top box, we tested to make sure the clamping motion of the attaching arm was smooth. There were a few moments while testing when the toggle clamp would seize up and require several hits with the palm of a hand to unlock. With proper lubrication on joints and moving parts, all actions became smooth and safe. We also tested the average rotation speed of the box. We tried rotating the box with various speeds to see if the box would flip over or become loose in the attachment arm. Thanks to the spacers and gas damper, the box never came loose even during high rotating speeds. We are confident that Mr. Jauregui will not rotate the dolly as fast as we did in the tests, and therefore should be safe enough to use.

8.4 Future Testing Recommendations

While we are confident that we have verified that the Beekeeper Assist meets Mr. Jauregui's specifications, there is still more that could be done. We did not have the facilities nor the time to conduct proper life tests on the device as a whole. Because the dolly was one bought off the shelf, life testing under load was not readily available, so we can only estimate how long it will last; the same goes for the hinge and the toggle clamp.

If we had more time and resources, we would recommend that future engineers do repeated life testing on the Beekeeper Assist's critical components. Specifically, we recommend testing for the attachment arm, to see how many cycles the rubber pads, toggle clamp, and fasteners can take before failure.

9.0 Conclusion and Recommendations

Our goal for this project was to design a device to help commercial beekeeper, Mr. Jauregui, inspect the beehives without experiencing hip and back pain. The device would move the top box of the beehive, the honey box, out of his way for him to be able to inspect the bottom box, the brood box. It had to hold the honey box on its side during the inspection to prevent the queen bee from falling off. Over the past 9 months, we have developed a device for this that is also be portable, efficient, and weather resistant. The final Beekeeper Assist device can be seen in Figure 37.

Figure 37. The final version of the Beekeeper Assist device.

As mentioned in the Verification section, we were extremely happy with the performance of this device. While we believe that this device meets Mr. Jauregui's needs in every way, there are definitely improvements that could be made in the future. For instance, more fasteners could be used in place of welds, so as to allow for easier maintenance. The foam spacers should probably be replaced with a custom-molded urethane embedded with UV-resistant pigment. However, we believe that the Beekeeper Assist adequately solves Mr. Jauregui's problem and will be able to assist him for years to come.

10.0 References

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Appendix A: QFD House of Quality

Correlations	
Positive	+
Negative	−
No Correlation	

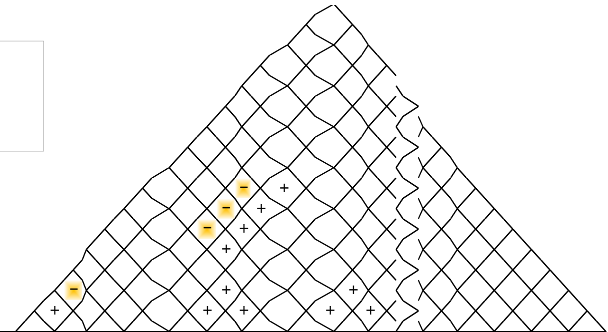
Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

QFD House of Quality

Project: F34 Bee Keeping Assist

Revision Date: 10/7/2020



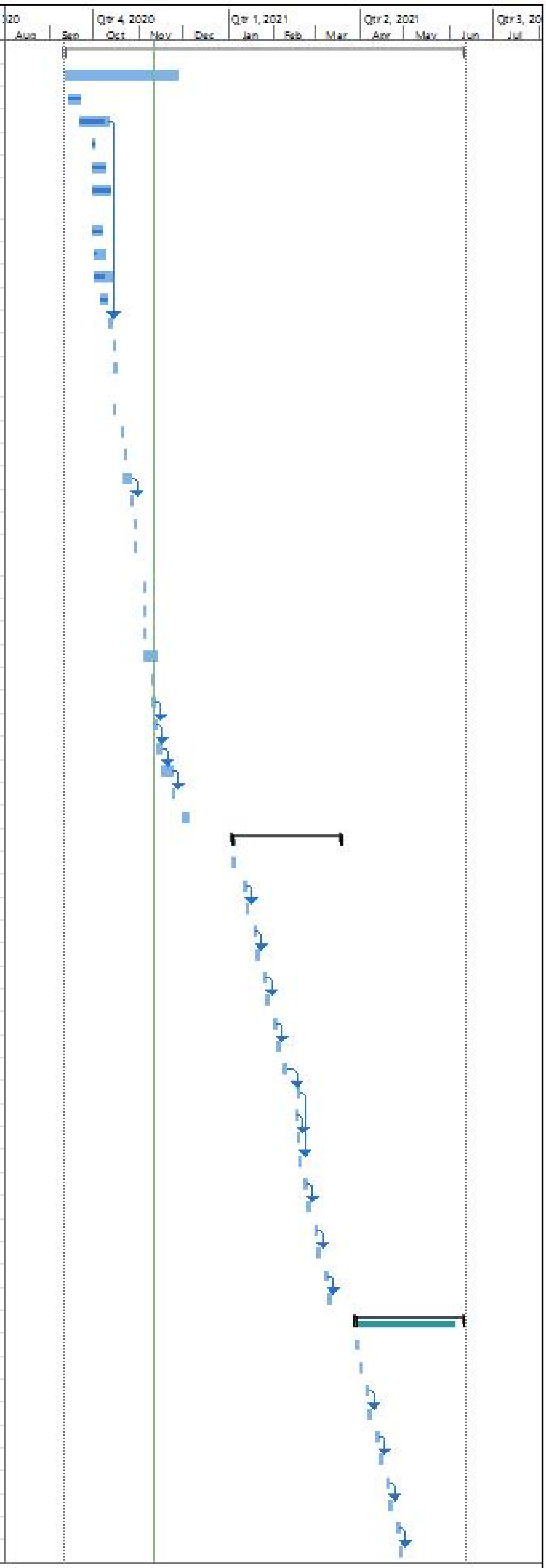
Row #	Weight Chart	Relative Weight	Alex	Maximum Relationship	WHAT: / HOW: Engineering Specifications (Tests)	Weight of device	Size of device	Lifting Capacity	Operating Time (One Box)	Angular Displacement	Vertical Displacement	Horizontal Displacement	Vertical Speed	Horizontal Speed	Angular Velocity	Set Up Time						Our Current Product	Competitor #1: Bee Hive Lifter	Competitor #2: Bee Breeding C	Competitor #3: Kaptarlift Profe	Competitor #4: Homemade Hi	Row #
					Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	NOW: Curr. Products					
					Direction of Improvement	▼	▼	▲	▼	◇	◇	◇	◇	◇	◇	▼											
1		4%	2	9	Easy to maintain	○	●									○						0	5	5	1	1	1
2		10%	5	9	Portable	●	●		●							●						0	4	5	2	3	2
3		21%	10	9	Cannot be less efficient than current process	▽	▽	○	●				○	○	○	●						0	3	3	3	0	3
4		21%	10	9	Move top bee box away			▽		●	●	●										0	1	5	5	3	4
5		10%	5	3	Work on different terrains	○	○															0	5	5	5	0	5
6		6%	3	1	Cannot damage bee boxes				▽				▽	▽	▽							0	4	5	5	5	6
7		13%	6	3	Cannot agitate the bees				▽				○	○	○							0	3	3	3	4	7
8		10%	5	3	Ergonomic	○	○		○							▽						0	5	5	5	2	8
9		4%	2	1	Weather resistant	▽	▽									▽						0	5	4	3	5	9
10		0%																									10
11		0%																									11
12		0%																									12
13		0%																									13
14		0%																									14
15		0%																									15
16		0%																									16

WHO: Customers

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
HOW MUCH: Target Values	Max weight of 60 lbs	Must fit in truck bed	At least 80lbs	7 Seconds	90 Degrees	N/A	N/A	N/A	N/A	N/A	N/A					
Max Relationship	9	9	3	9	9	9	9	3	3	3	9					
Technical Importance Rating	193.8	219	83.33	331.25	187.5	187.5	187.5	106.25	106	106	308	0	0	0	0	0
Relative Weight	10%	11%	4%	16%	9%	9%	9%	5%	5%	5%	15%	0%	0%	0%	0%	0%
Curr. Products: Our Current Product	1	3	4	2	6											
Competitor #1: Bee Hive Lifters	2	3	5	1	1											
Competitor #2: Bee Breeding Centre	3	0	4	5	1											
Competitor #3: Kaptarlift Professional AWD	4	1	5	4	1											
Competitor #4: Homemade Hive Lift	5	5	2	1	1											
Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Appendix B: Gantt Chart

ID	Task Mode	Task Name	Duration	Start
0		**F 34 Bee Keeper Assist**	**196 days?**	**Fri 9/11/20**
1		Winter Quarter	55 days	Fri 9/11/20
2		Project selection	6 days	Mon 9/14/20
3		Research	14 days	Tue 9/22/20
4		Interview	1 day?	Thu 10/1/20
5		QFD (Ryan)	6 days	Thu 10/1/20
6		Customer Wants/Needs (Jose)	8 days?	Thu 10/1/20
7		Problem Definition (Kyle)	4 days?	Thu 10/1/20
8		Boundary Diagram (Kyle)	5 days	Fri 10/2/20
9		Scope Of Work	8 days?	Fri 10/2/20
10		Create Gantt Chart (Javier)	4 days	Tue 10/6/20
11		Study Ideation (Ryan)	2 days?	Mon 10/12/20
12		Second Meeting (Javier)	1 day?	Thu 10/15/20
13		Funtional Decomposition (Ryan)	2 days?	Thu 10/15/20
14		WSR	1 day?	Thu 10/15/20
15		Build Ideation (Javier)	1 day?	Tue 10/20/20
16		WSR	1 day?	Thu 10/22/20
17		Design Analysis	4 days?	Wed 10/21/20
18		SOW to PDR (Jose)	1 day?	Tue 10/27/20
19		WSR	1 day?	Thu 10/29/20
20		Weighted Decision Matrix (Kyle)	1 day?	Thu 10/29/20
21		Design Hazard Checklist	1 day?	Thu 11/5/20
22		Updated Gantt Chart	1 day?	Thu 11/5/20
23		WSR	1 day?	Thu 11/5/20
24		PDR Report	6 days?	Thu 11/5/20
25		Concept CAD model	1 day?	Tue 11/10/20
26		Build Concept Prototype	2 days?	Tue 11/10/20
27		PDR Presentations	1 day?	Thu 11/12/20
28		Concept Prototype	2 days?	Fri 11/13/20
29		FMEA	5 days?	Tue 11/17/20
30		WSR	1 day?	Tue 11/24/20
31		PDR-CDR	4 days?	Tue 12/1/20
32		**Winter Quarter**	**55 days?**	**Mon 1/4/21**
33		Design Analysis	2 days	Mon 1/4/21
34		Design Analysis	2 days	Mon 1/11/21
35		Interim Design Review	2 days	Wed 1/13/21
36		Design Analysis	1 day?	Tue 1/19/21
37		CAD / Part Selection	2 days	Wed 1/20/21
38		SP Build Day	2 days	Mon 1/25/21
39		Manuf. Plan / DVP/ Drawing	2 days	Wed 1/27/21
40		Yellow Tag Test	2 days	Mon 2/1/21
41		Drawing and Manuf. Plan	2 days	Wed 2/3/21
42		CDR Presentation	2 days?	Mon 2/8/21
43		CDR Reports Updates	2 days	Wed 2/17/21
44		Risk Assesment	1 day?	Tue 2/16/21
45		Safety Review/ Order Parts	2 days	Wed 2/17/21
46		Sumit CDR to Sponsor	1 day?	Fri 2/19/21
47		VP Build Day	2 days?	Mon 2/22/21
48		VP Build Day and WSR	2 days	Wed 2/24/21
49		VP Build Day	2 days?	Mon 3/1/21
50		VP Build Day and WSR	2 days?	Wed 3/3/21
51		VP Build Day	2 days?	Mon 3/8/21
52		Manuf. And Test Review	2 days?	Wed 3/10/21
53		**Spring 2021**	**55 days?**	**Mon 3/29/21**
54		Experimental Design	2 days?	Mon 3/29/21
55		Test Procedures and WSR	1 day?	Thu 4/1/21
56		VP Build Day	2 days	Mon 4/5/21
57		VP Build Day and WSR	2 days?	Wed 4/7/21
58		VP Build Day	2 days	Mon 4/12/21
59		Senior Exam and WSR	2 days	Wed 4/14/21
60		VP Build Day	1 day?	Tue 4/20/21
61		VP Build Day and WSR	2 days?	Wed 4/21/21
62		VP Sign Off	2 days?	Mon 4/26/21
63		Testing	2 days?	Wed 4/28/21

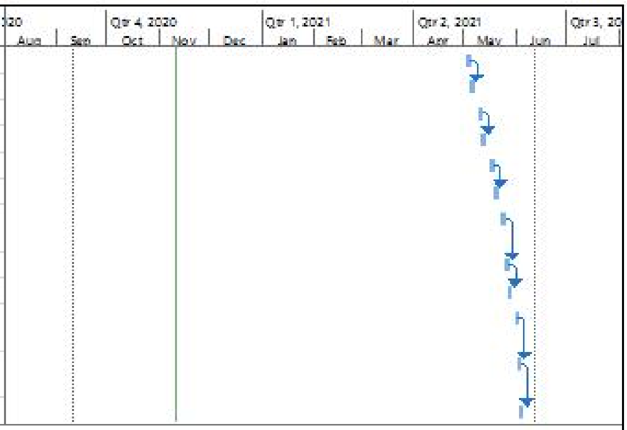


Project: F 34 Bee Keeper Assist
Date: Wed 11/11/20

Task		Inactive Summary		External Tasks	
Split		Manual Task		External Milestone	
Milestone		Duration-only		Deadline	
Summary		Manual Summary Rollup		Progress	
Project Summary		Manual Summary		Manual Progress	
Inactive Task		Start-only			
Inactive Milestone		Finish-only			

Page 1

ID		Task Mode	Task Name	Duration	Start
64			Testing	2 days?	Mon 5/3/21
65			Testing and WSR	2 days?	Wed 5/5/21
66			Testing	2 days?	Mon 5/10/21
67			Testing	2 days?	Wed 5/12/21
68			DVPR Sign Off	2 days?	Mon 5/17/21
69			Expo Poster Peer Review	2 days?	Wed 5/19/21
70			Finish FRD Report snd Print Poster	2 days?	Mon 5/24/21
71			FDR Report Updates	2 days?	Wed 5/26/21
72			EXPO	1 day?	Fri 5/28/21
73			Clean Up and Clear Out Spaces	1 day?	Tue 6/1/21
74			Complete Check List and WSR	2 days?	Wed 6/2/21
75			Submit FDR to Sponsor	1 day?	Fri 6/4/21

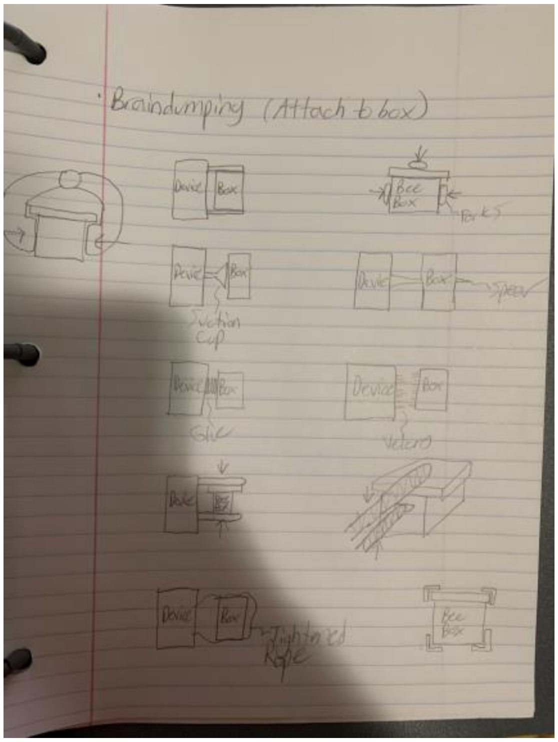


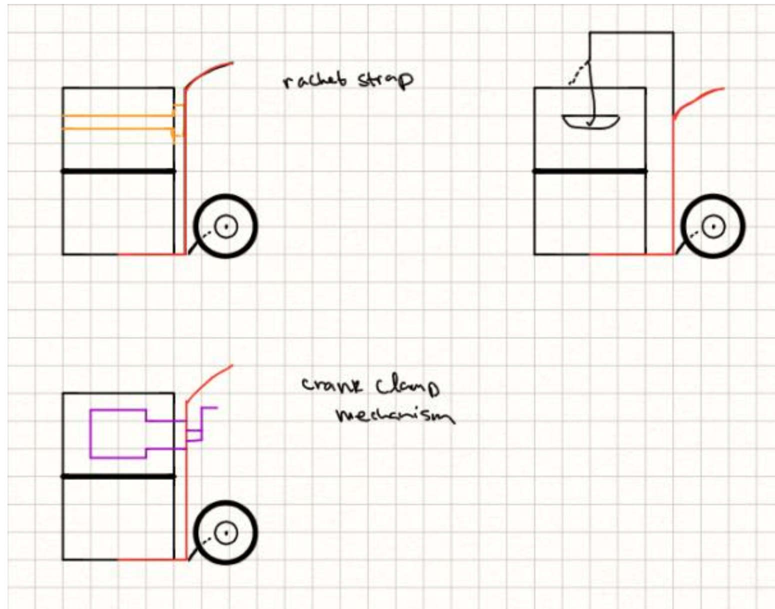
Project: F 34 Bee Keeper Assist
Date: Wed 11/11/20

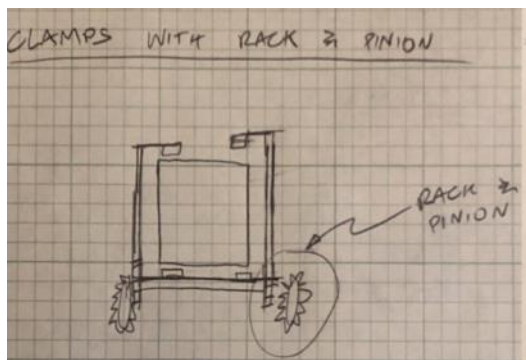
Task
Split
Milestone
Summary
Project Summary
Inactive Task
Inactive Milestone
Inactive Summary
Manual Task
Duration-only
Manual Summary Rollup
Manual Summary
Start-only
Finish-only
External Tasks
External Milestone
Deadline
Progress
Manual Progress

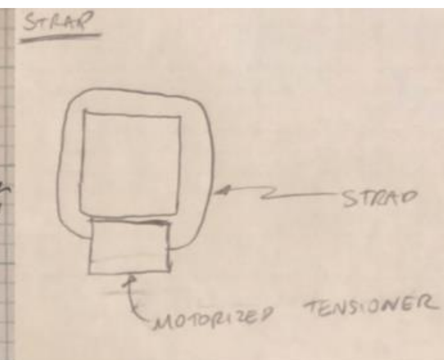
Appendix C: Example Brain Dumping Ideation Page

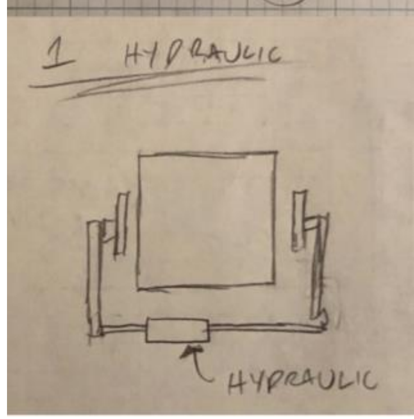
Wednesday, October 14, 2020 7:00 PM

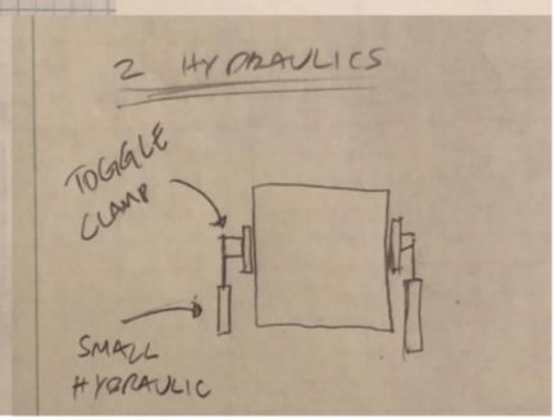












14.0 Appendix D: Early Sub-Function Prototype Images

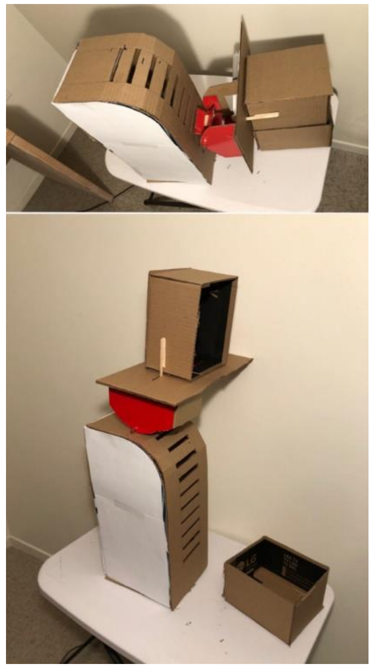


Figure 1. A picture of a multi-purpose, first-generation prototype. This prototype was meant to emulate horizontal movement, vertical movement, and rotation through the use of a rack and pinion (the carriage has a “gear” and “motor”). It also depicts the “attach to box” sub-function through the use of a syringe clamp mechanism.

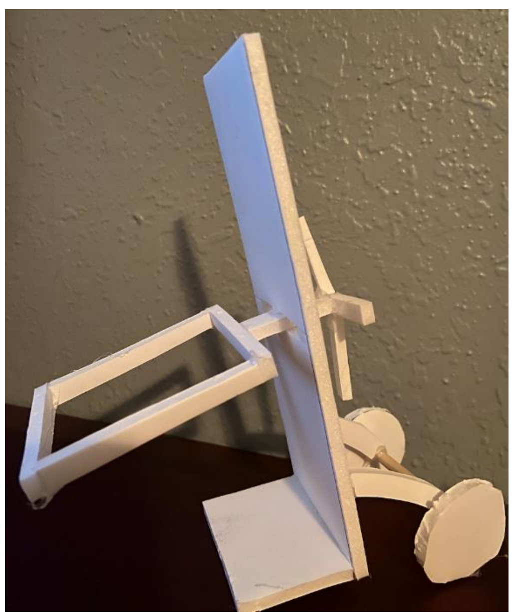


Figure 2. A picture of another multi-purpose, first-generation prototype. This prototype is mainly meant to emulate rotation through the use of a rotatable handle. The user would turn the handle, in turn rotating the box. This axle would be located in a slot, where it could be moved horizontally as well. The whole thing is attached to a dolly mechanism as well.

Figure 3. A picture of another multi-purpose, first-generation prototype. This prototype is mainly meant to emulate rotation through the use of hinge. The user would pull down the top portion of the dolly to rotate the box back. The whole thing is attached to a dolly mechanism.

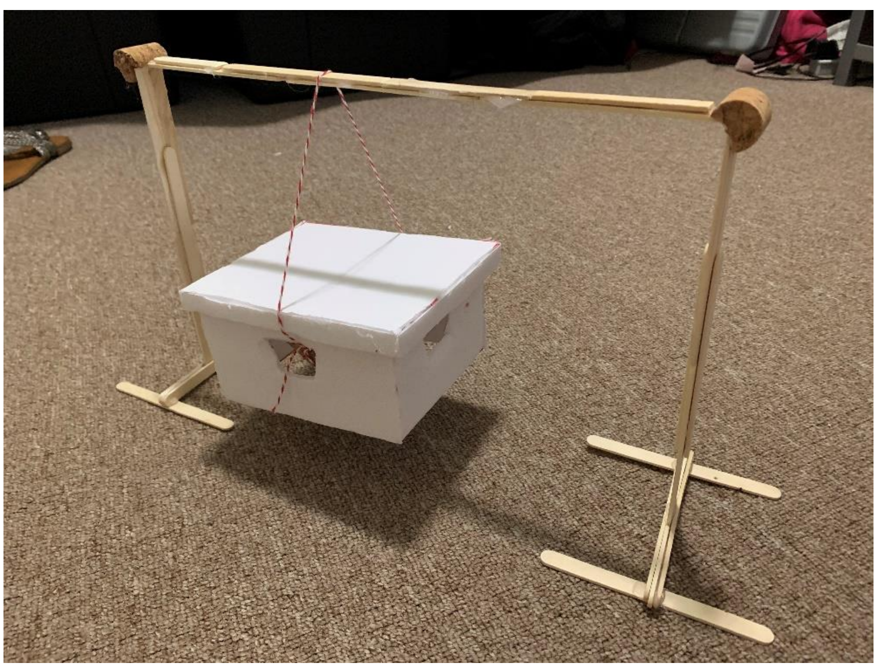


Figure 4. A picture of a first-generation prototype. This prototype is meant to emulate moving the box horizontally using a kind of crane mechanism. While it is fairly low definition, the top portion would ideally have some kind of roller that would better allow the payload to move along.

15.0 Appendix E: Pugh Matrices for Each Sub-Function

"Lifting" Pugh Matrix				
Datum: BeeHive Lifter				
	Power Screw	Garage Door	Conveyor Belt	Hydraulic Lift
Size	+	-	S	+
Feasibility	-	-	S	S
Time to Lift	-	S	S	-
Max Height	S	S	S	-
Maintainability	+	-	+	-
Ease of Use	S	S	S	S
Ease of Design	-	-	S	+
Safety	S	S	S	S
Aesthetics	+	S	+	+
Σ	0	-4	2	

"Rotating" Pugh Matrix				
Datum: Box Rotator Forklift Attachment				
	Foldable Cart	Garage Door	Moto/Servo at Box Edge	Free Rotation/Crank at the Middle
Size	-	-	S	+
Feasibility	+	-	S	+
Operating	-	-	S	-
Difficulty to Rotate	-	S	-	-
Maintainability	+	-	S	+
Ease of Use	-	S	S	-
Ease of Design	+	-	-	+
Safety	-	S	-	-
Σ	-2	-5	-3	0

"Horizontal Motion" Pugh Matrix				
Datum: Beehive Lifter				
	Slotted Dolly	Gantry Crane	Dolly w/ Swivel Wheels	Bee Quad/ Bee Cart
Size	S	-	S	-
Feasibility	S	-	S	-
Time to Move	+	+	-	-
Maintainability	S	-	S	-
Ease of Use	+	+	-	+
Ease of Design	S	-	+	-
Safety	+	+	S	+
Stability	-	+	S	+
Σ	2	0	-1	-2

"Move Laterally to Next Hive" Pugh Matrix				
Datum: Dolly				
	Gantry Crane	Dolly w/ Swivel	Handles	Bee Quad/ Bee Cart
Size	-	S	S	-
Feasibility	-	S	+	-
Time to Move	+	S	+	-
Work on different terrains	+	-	+	+
Maintainability	-	S	+	-
Ease of Use	+	-	+	-
Ease of Design	-	-	S	-
Safety	+	S	S	+
Σ	0	-3	5	-4

"Reduce Effort" Pugh Matrix				
Datum: Beehive Lifter Handles				
	Wheelbarrow	Handles	Pushable Carriage	Bluetooth
Size	+	+	-	S
Feasibility	S	+	-	-
Time to Move	-	-	-	+
Maintainability	-	+	S	-
Ease of Use	+	+	S	+
Ease of Design	+	+	-	-
Safety	-	+	-	+
Aesthetics	S	S	S	S
Σ	0	5	-5	0

"Attach to the Box" Pugh Matrix				
Datum: Ratchet Strap				
	Javier's Strap	Rope	Rope + Brace	Hydraulic Clamp
Size	S	S	S	-
Feasibility	S	+	-	-
Operating Time	-	+	+	+
Maintainability	S	+	+	-
Ease of Use	-	+	+	+
Ease of Design	+	S	+	-
Safety	S	-	S	-
Σ	-1	3	3	-3

"Detach to the Box" Pugh Matrix				
Datum: Ratchet Strap				
	Javier's Strap	Rope	Rope + Brace	Hydraulic Clamp
Size	S	S	S	-
Feasibility	S	+	-	-
Operating Time	-	+	+	+
Maintainability	S	+	+	-
Ease of Use	-	+	+	+
Ease of Design	+	S	+	-
Safety	S	-	S	-
Σ	-1	3	3	-3

16.0 Appendix F: Morphological Matrices for Each System-Level Design

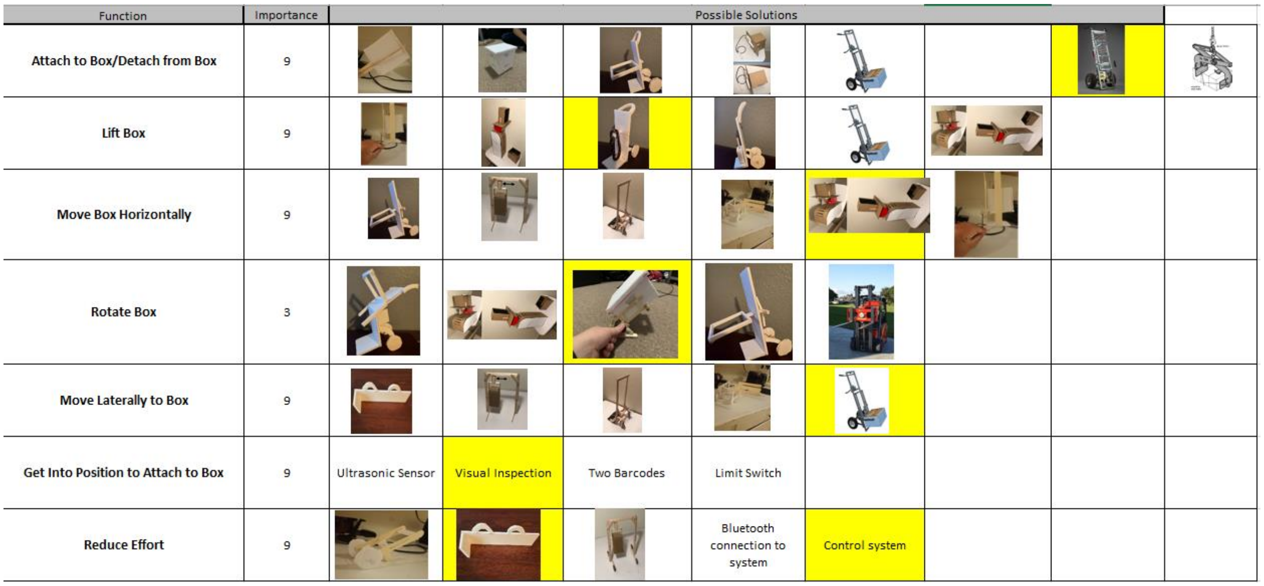


Figure 1. The morphological matrix for the "Conveyor Belt" system-level design.

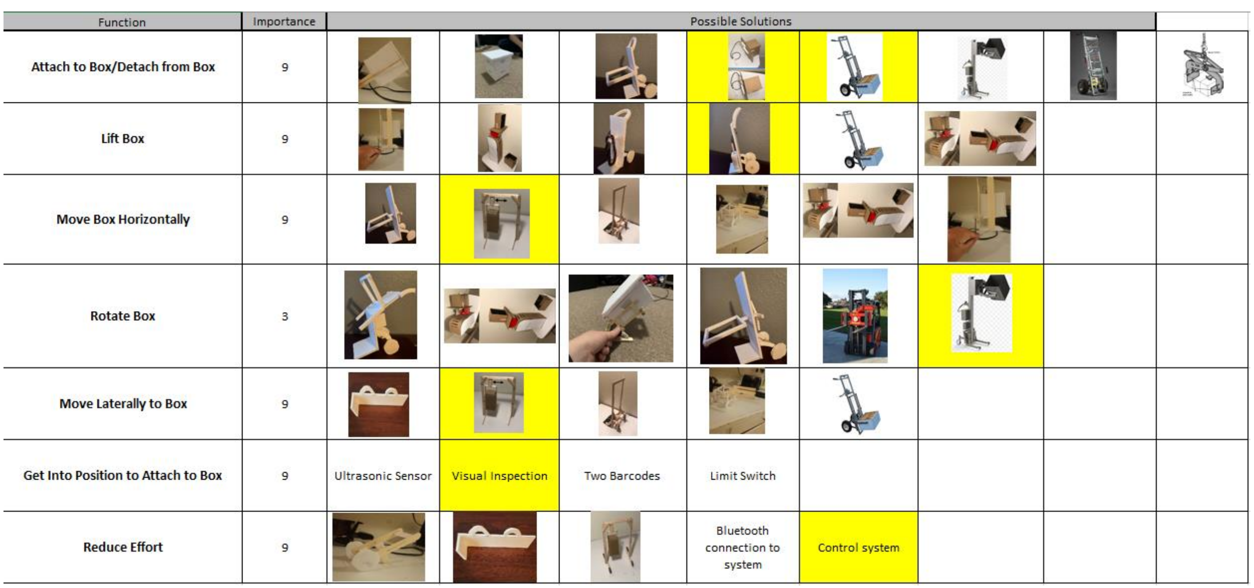
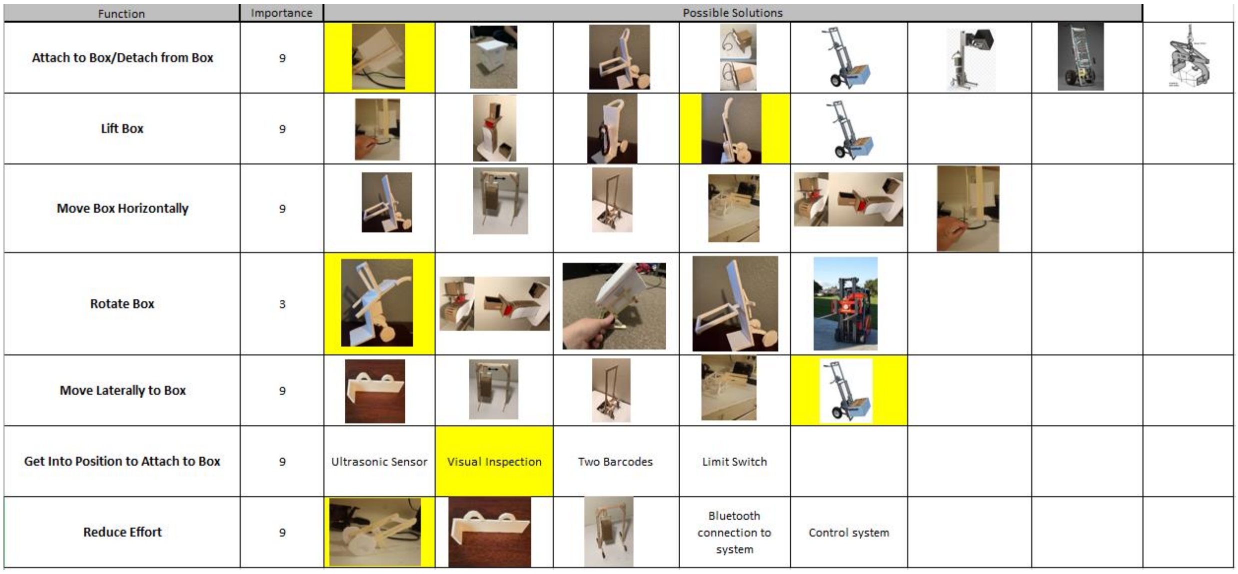
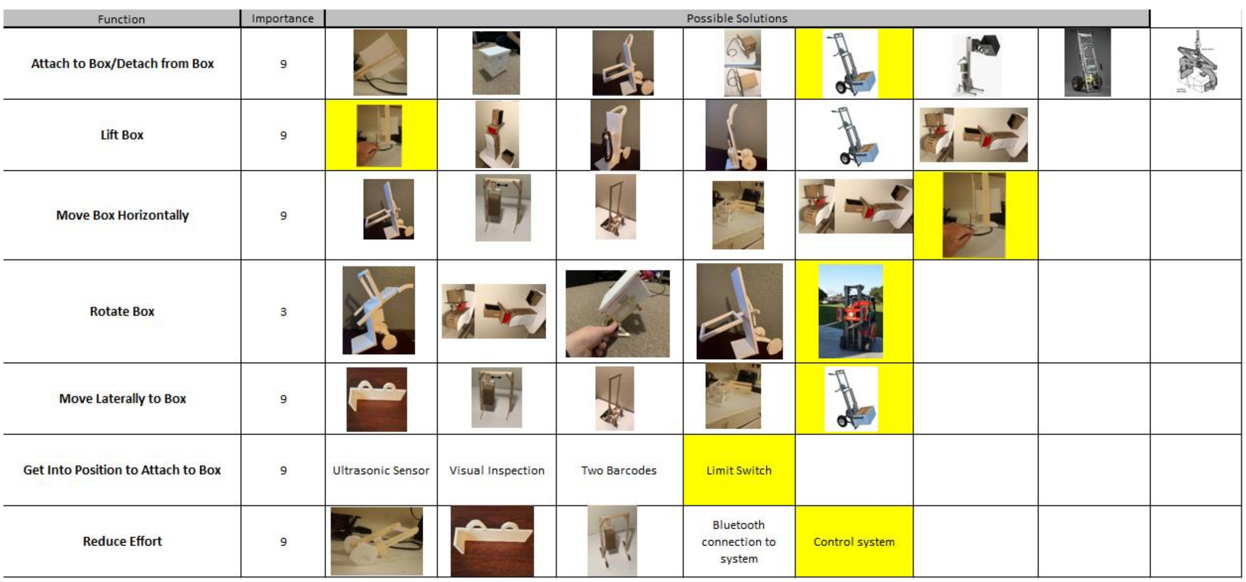


Figure 2. The morphological matrix for the "Moving Crane" system-level design.



Function	Importance	Possible Solutions							
Attach to Box/Detach from Box	9								
Lift Box	9								
Move Box Horizontally	9								
Rotate Box	3								
Move Laterally to Box	9								
Get Into Position to Attach to Box	9	Ultrasonic Sensor	Visual Inspection	Two Barcodes	Limit Switch				
Reduce Effort	9				Bluetooth connection to system	Control system			

Figure 3. The morphological matrix for the “Broken Dolly” system-level design.



Function	Importance	Possible Solutions							
Attach to Box/Detach from Box	9								
Lift Box	9								
Move Box Horizontally	9								
Rotate Box	3								
Move Laterally to Box	9								
Get Into Position to Attach to Box	9	Ultrasonic Sensor	Visual Inspection	Two Barcodes	Limit Switch				
Reduce Effort	9				Bluetooth connection to system	Control system			

Figure 4. The morphological matrix for the “CNC Dolly” system-level design.

Appendix G: Pros and Cons Discussion for "Garage Door" and "Broken Dolly Designs"

"Broken Dolly" vs "Garage Door"

Thursday, November 5, 2020 8:25 AM

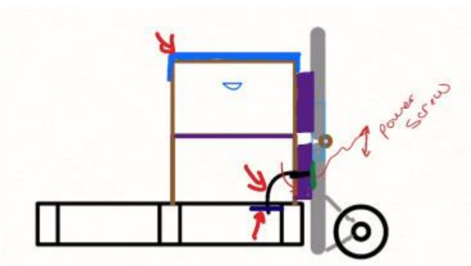
"Broken Dolly"

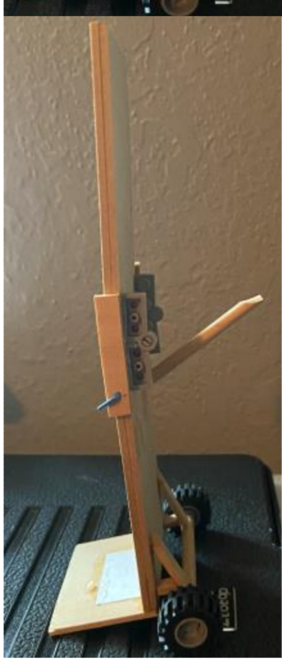
Pros:

- Non-powered
- Relatively easy to make
- Will require less maintenance
- Lightweight
- Potentially eliminated expensive repairs
- Very portable
- Multi-purpose use
- Smaller than Garage Door Design
-

Cons:

- More Physical activity for Alex
- Requires more room to operate
- Harder to modify to lift both boxes if Alex wants to
- Center of gravity shifts and might be an issue
- Lightweight





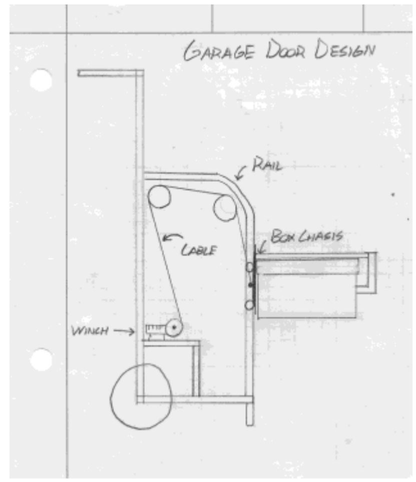
"Garage Door"

Pros:

- Requires little effort from Alex
- Only one power source (one motor driving rotation, vertical motion, and horizontal motion)
- Does not need to attach to the pallet
- Winch would be easy and cheap to source

Cons:

- Battery life
- More maintenance
- Rails could be more difficult to source/manufacture
- Size
- Weight



Appendix H: Design Hazard Checklist

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, on the reverse side add:

1. a complete description of the hazard,
2. the corrective action(s) you plan to take to protect the user, and
3. a date by which the planned actions will be completed.

Description of Hazard	Planned Corrective Action	Planned Date
Part of the design will include a hinge that can be a pinch point.	Design a guard around the hinge to prevent access.	1/4/2021
The system will have a box rotating 90 degrees that can weigh 50-60lbs.	The box will be compressed against the dolly with an arm that will attach from above the box.	11/13/2020
The box being rotated will be held approximately 15 inches off the ground.	A support will drop down from the dolly when it rotates the box.	11/17/2020
The design of the system includes mechanical and gas springs that will store energy to help with the rotation of the box.	Design a guard or housing around the springs, use a higher factor of safety in design.	11/17/2020
The device will be used exclusively outside, which could cause dangerous corrosion near moving joints.	Coat parts of the device in anti-corrosive material or use metals resistant to corrosion.	1/27/2021
If the user's grip slips, the box could rotate very quickly due to gravity.	A gas dampener will be used to limit the rotational speed of the box.	11/17/2020
The user will partially lift and lower box as it rotates on the hinge.	Implement springs and pistons that will reduce the effort necessary to use the device.	11/17/2020
The system could be used unsafely such as holding a person on the bent portion or going very fast.	Implement a warning label warning against unsafe use conditions.	2/16/2021

Appendix I: Indented Bill of Materials

Bee Box Inspection Dolly

Indented Bill of Material (iBOM)

Assembly Level	Part Number	Description	Qty	Cost	Ttl Cost	Source	More Info
		Lvl0 Lvl1 Lvl2 Lvl3 Lvl4					
0	1000	Final Assembly					
1	1100	Dolly Lower Subsystem					
2	1110	Modified Lower Body	1	------	------	Donation	Lower half of stock dolly after the horizontal cut at 15" high.
2	1120	Dolly Lower Subsystem Forks	2	16.12	16.12	McCarthy Steel	Cut with hydraulic brake press and welded together.
2	1121	2X.5X.25 Spacer	1	-----	-----	Donation	Scrap from other parts
2	1122	3/8" Square Tube	1	6.59	6.59	ACE Hardware	In Store Purchase
2	1130	Dolly Back Supports	2	------	------	------	Made from shop's scrap material.
1	1200	Hinge					
2	1210	Hinge	2	19.77	39.54	Amazon	Keehui 316SS Marine Grade Boat Pipe Connector
1	1300	Upper Dolly Frame					
2	1310	Upper Dolly Frame	1	------	------	Donation	Top half of stock dolly
2	1320	Crossbar for Attachment arm	1	1.93	1.93	McMaster-Carr	Item 8920K135
2	1330	Crossbar for Back Box Plate	1	12.00	12.00	McCarthy Steel	Quoted Items for Box Back Plate, Attatchment Arm Rod, Dolly Back Plate
2	1340	Spacers	2	4.89	9.78	ACE Hardware	In Store Purchase
2	1350	Back Box Plate	1	------	-----	McCarthy Steel	Quoted with part 1330.
2	1360	3/8" x 1.5" - 32 Bolt	2	0.36	0.72	ACE Hardware	In Store Purchase
2	1370	3/8" - 32 Hex Nut	2	0.43	0.86	ACE Hardware	In Store Purchase
2	1380	3/8" 6-40 Bolt	4	0.30	1.20	ACE Hardware	In Store Purchase
2	1390	6-40 Hex Nut	4	0.30	1.20	ACE Hardware	In Store Purchase
2	13100	Crossbar for Pipe Clamps	1	10.00	10.00	ACE Hardware	In Store Purchase
2	13110	3/8" Plunger	1	12.99	12.99	ACE Hardware	In Store Purchase
2	13120	3/8" Square Tube	1	6.59	6.59	ACE Hardware	In Store Purchase
2	13130	Pipe clamps	2	1.49	2.98	ACE Hardware	In Store Purchase
2	13140	2X.5X.25 Spacers	2	-----	-----	Donation	Scrap from other parts
1	1400	Attachment Arm					
2	1410	Toggle Clamp	1	45.71	45.71		
2	1420	Toggle Clamp Base Assembly	1				
3	1421	Base Plate	1	33.61	33.61	McCarthy Steel	Quote is for stock plate for Back Plate, Bearing Housing, Triangular Connecting Plate, and Front Box Plat
3	1422	Back Plate	1	------	------	McCarthy Steel	Cost is included in Base Plate's quote
3	1423	Bearing Housing	2	------	------	McCarthy Steel	Cost is included in Base Plate's quote
2	1430	Triangular Connecting Plate	1	------	------	McCarthy Steel	Cost is included in Base Plate's quote
2	1440	Front Box Plate	1	------	------	McCarthy Steel	Cost is included in Base Plate's quote
2	1450	Arm Pipes	2	35.34	70.68	ACE Hardware	In Store Purchase
2	1460	90 degree elbows	4	2.99	11.96	ACE Hardware	In Store Purchase
2	1470	4.5" Pipe Nipples	2	2.59	5.18	ACE Hardware	In Store Purchase
2	1480	2" Pipe Nipples	2	1.59	3.18	ACE Hardware	In Store Purchase
2	1490	Pipe Clamp Collers	4	6.81	27.24	ACE Hardware	In Store Purchase
2	14100	Pipe Flanges	2	8.99	17.98	ACE Hardware	In Store Purchase
2	14110	1/4" x 3/4" - 8 Bolts	8	0.34	2.72	ACE Hardware	In Store Purchase
2	14120	1/4" - 8 Hex Nuts	8	0.44	3.52	ACE Hardware	In Store Purchase
2	14130	5/16" x 3/4" - 6 Bolts	6	0.56	3.36	ACE Hardware	In Store Purchase
2	14140	5/16" - 6 Hex Nuts	6	0.59	3.54	ACE Hardware	In Store Purchase
2	14150	3/8" x 2" - 1 Bolt	1	0.36	0.36	ACE Hardware	In Store Purchase
2	14160	3/8" Hex Nut	1	0.43	0.43	ACE Hardware	In Store Purchase
2	14170	3/8" Flat Washers	2	0.30	0.60	ACE Hardware	In Store Purchase
2	14180	Rubber Pads	1	24.59	24.59	McMaster-Carr	Item 8920A125
2	14190	3/8" ID Ball Bearings	2	6.88	13.76	McMaster-Carr	Item 60355K703
	Total Parts		**84**				

For the motion of the upper frame, we only care about 4 motion cases:

1) Moving the upper frame back from rest (upper position)
2) Rotating the upper frame down 90° (upper position to lower position)
3) Moving the upper frame up from rest (lower position)
4) Rotating the upper frame up 90 degrees (lower position to upper position)

We will use the following parameters for our calculations:

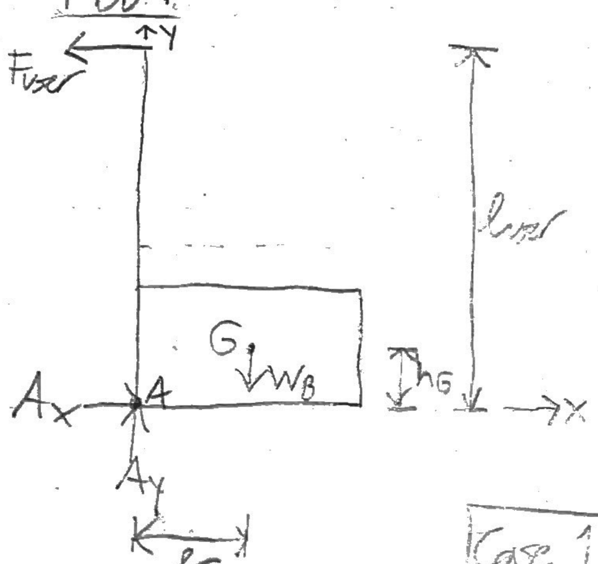
- $W_B = 80\ lbf$ – Maximum weight of the bee box
- $h_G = 4.8125''$ – Height from the hinge to the box centroid
- $l_G = 9.9375''$ – Length from the hinge to the box centroid
- $l_B = 19.875''$ – Length of the bee box, not including the lid
- $h_B = 9.625''$ – Height of the bee box
- $l_{user} = 35''$ – Distance between where the user applies force and the hinge

Assumptions:

- Neglect the weight of the frame
- Neglect the lid of the bee box
- α = 90 degrees in 2 seconds
- Steady state for cases 1 & 3
- Neglect moment due to friction
- Uniformly accelerated angular motion

Case 1

FBD:



At steady-state

$$\Sigma M_A = 0$$

$$\Rightarrow F_{user} l_{user} - W_B l_G = 0$$

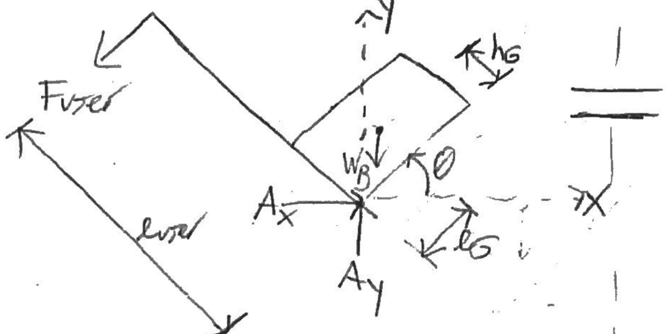
$$\Rightarrow F_{user} = \frac{l_G}{l_{user}} W_B$$

$$\Rightarrow \quad = \frac{9.9375''}{35''} * 80\ lbf$$

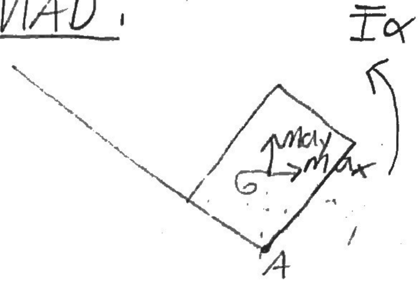
Case 1	$F_{user} = 22.71\ lbf$

Case 2

FBD:



MAD:



Where:

$$\Sigma M_A = \bar{I}\vec{\alpha} + \vec{r}_{G/A} \times m\vec{a}$$

$$\Rightarrow F_{user} l_{user} \hat{k} + \vec{r}_{G/A} \times \vec{W}_B = \bar{I}\alpha\hat{k} + \vec{r}_{G/A} \times m\vec{a}$$

$$\Rightarrow F_{user} l_{user} \hat{k} + \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ d_G\cos\theta & d_G\sin\theta & 0 \\ 0 & -W_B & 0 \end{vmatrix} = \bar{I}\alpha\hat{k} + \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ d_G\cos\theta & d_G\sin\theta & 0 \\ ma_x & ma_y & 0 \end{vmatrix}$$

$$\Rightarrow (F_{user} l_{user} - W_B d_G \cos\theta)\hat{k} = (\bar{I}\alpha + ma_y d_G\cos\theta - ma_x d_G \sin\theta)\hat{k}$$

$$\Rightarrow F_{user} = \frac{\bar{I}\alpha + m d_G(a_y\cos\theta - a_x\sin\theta) + W_B d_G\cos\theta}{l_{user}}$$

Need: $\bar{I}, \alpha, a_x, a_y, d_G, m$

For $\bar{I}$:

$$\bar{I} = \frac{1}{12} m (h_B^2 + l_B^2)$$

$$= \frac{1}{12}\left(\frac{W_B}{g}\right)(h_B^2 + l_B^2)$$

$$= \frac{1}{12}\left(\frac{80\ lbf}{32.174\ ft/s^2}\right)\left(\left(\frac{9.525\ in}{12\ in} * 1\ ft\right)^2 + \left(\frac{19.875\ in}{12\ in} * 1\ ft\right)^2\right)$$

$$* \bar{I} = 0.701\ lbf \cdot ft \cdot s^2$$

For d_G, m:

$d_G = \sqrt{h_G^2 + l_G^2}$

$\Rightarrow \quad = \sqrt{(4.8125\,in)^2 + (9.9375\,in)^2}$

$* d_G = 11.041\,in$

$m = \frac{W_B}{g}$

$\Rightarrow \quad = \frac{80\,lbf}{32.174\,ft/s^2}$

$* m = 2.486\,\frac{lbf\,s^2}{ft}$

For α, a_x, a_y:

Kinematics:

$\vec{V}_G = \vec{V}_A + \vec{V}_{G/A}$

$\Rightarrow \quad = 0 + \vec{\omega} \times \vec{r}_{G/A}$

$= \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 0 & 0 & \omega \\ d_G\cos\theta & d_G\sin\theta & 0 \end{vmatrix}$

$\Rightarrow \quad = -\omega d_G \sin\theta\,\hat{i} + \omega d_G \cos\theta\,\hat{j}$

$\Rightarrow$ Need: ω

For ω:

$\omega = \frac{90\,deg}{2\,s} * \frac{2\pi\,rad}{360\,deg}$

$* \omega = 0.785\,rad/s$

Back to kinematics:

$\vec{V}_G = (0.785\,rad/s)(11.041\,in)(-\sin\theta\,\hat{i} + \cos\theta\,\hat{j})$

$* \vec{V}_G = 8.667\,in/s\,(-\sin\theta\,\hat{i} + \cos\theta\,\hat{j})$

$$\vec{a}_G = \vec{a}_A + \vec{a}_{G/A}$$

$$\Rightarrow \vec{a}_G = 0 + \vec{\alpha} \times \vec{r}_{G/A} + \vec{\omega} \times (\vec{\omega} \times \vec{r}_{G/A})$$

In this case:

$$\Rightarrow \vec{a}_G = \vec{\alpha} \times \vec{r}_{G/A} + \vec{\omega} \times \vec{V}_G$$

$$\Rightarrow \quad = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 0 & 0 & \alpha \\ d_G\cos\theta & d_G\sin\theta & 0 \end{vmatrix} + \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 0 & 0 & \omega \\ -8.667\sin\theta & 8.667\cos\theta & 0 \end{vmatrix}$$

$$\Rightarrow \quad = -\alpha d_G \sin\theta\,\hat{i} + \alpha d_G \cos\theta\,\hat{j} - 8.667\omega\cos\theta\,\hat{i} - 8.667\omega\sin\theta\,\hat{j}$$

$$\Rightarrow \vec{a}_G = (-11.041\alpha\sin\theta - 6.804\cos\theta)\,\hat{i} + (11.041\alpha\cos\theta - 6.804\sin\theta)\,\hat{j}$$

Need: α

For α:

$$\omega^2 = \omega_0^2 + 2\alpha(\theta - \theta_0)$$

where: $\omega_0 = 0$, $\theta_0 = 0$

$$\Rightarrow \omega^2 = 0 + 2\alpha\theta$$

$$\Rightarrow \alpha = \frac{\omega^2}{2\theta}$$

$$\Rightarrow \alpha = \frac{(0.785 \frac{rad}{s})^2}{2\theta}$$

$$* \alpha = \frac{0.308}{\theta} \frac{rad^2}{s^2}$$

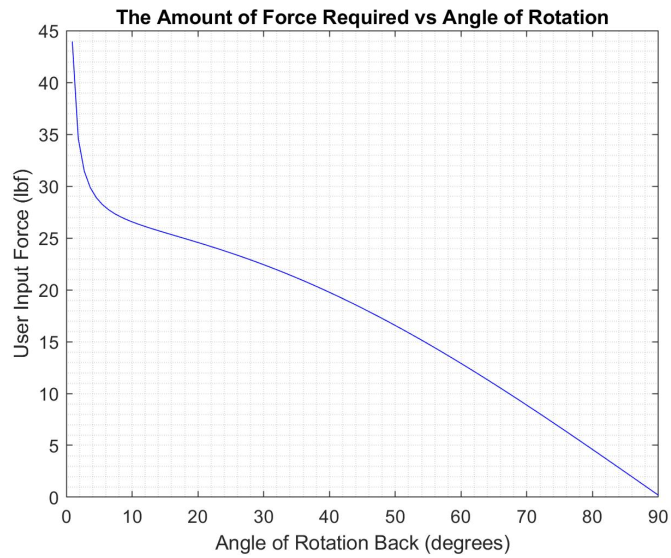
so:

$$* \vec{a}_G = \left(\frac{-3.4}{\theta}\sin\theta - 6.804\cos\theta\right)\hat{i} + \left(\frac{3.4}{\theta}\cos\theta - 6.804\sin\theta\right)\hat{j}$$

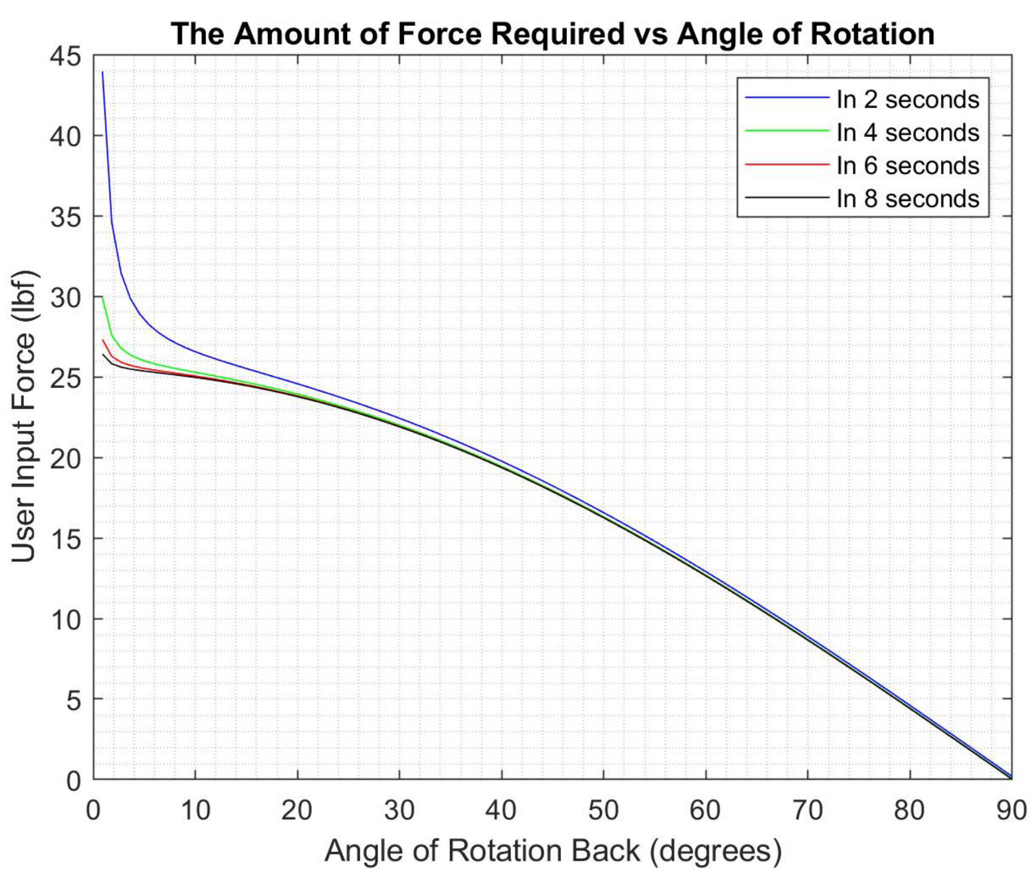
Using MATLAB, we simulated the motion in Case 2 using these equations ($0° \leq \theta \leq 90°$)

These are the results!

For ω = 90 degrees in 2 seconds

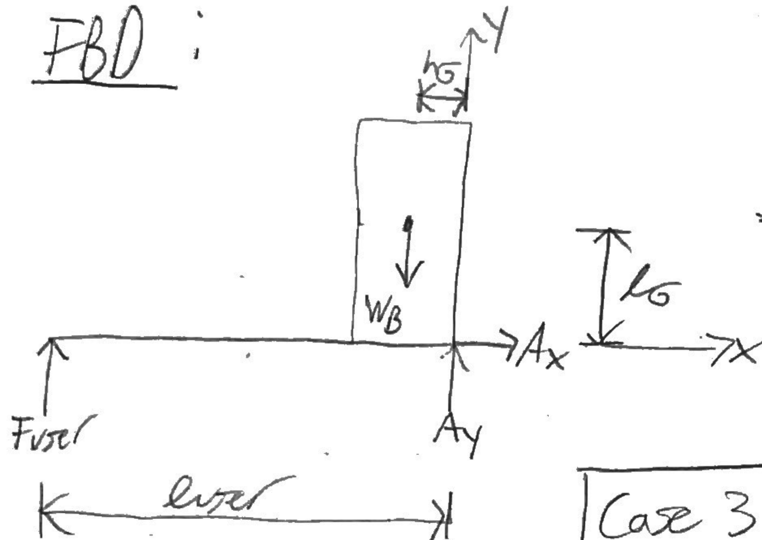


For ω = 90 degrees in 2, 4, 6, and 8 seconds



Case 3:

FBD:



At steady-state

$\Sigma M_A = 0$

$-F_{user} l_{user} + W_B h_G = 0$

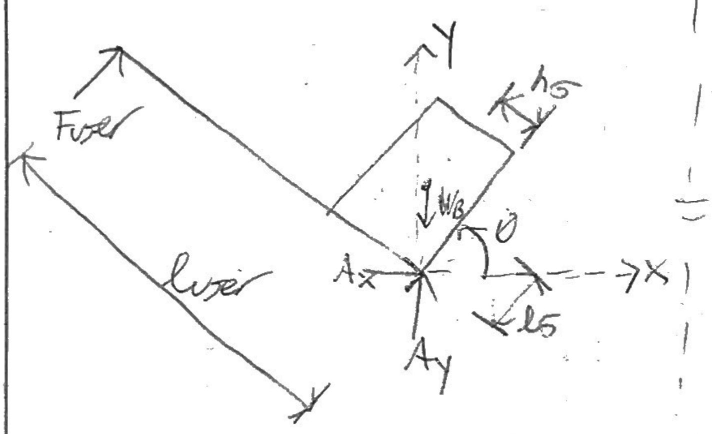
$\Rightarrow F_{user} = \frac{h_G}{l_{user}} W_B$

$= \frac{4.8125''}{35''} * 80\,lbf$

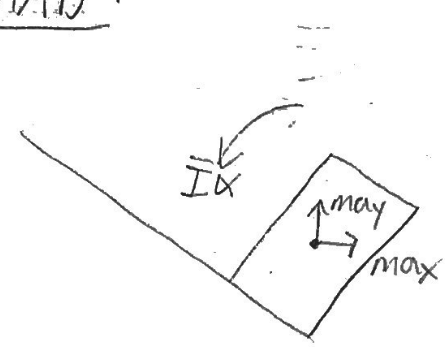
Case 3	$F_{user} = 11\,lbf$

Case 4

FBD



MAD:



where,

$$\Sigma M_A = \bar{I}\alpha + \vec{r}_{G/A} \times m\vec{a}$$

$$\Rightarrow -F_{user} l_{user} \hat{k} - W_B d_G \cos\theta \hat{k} = \bar{I}\alpha \hat{k} + ma_y d_G \cos\theta \hat{k} - ma_x d_G \sin\theta \hat{k}$$

$$\Rightarrow F_{user} = \frac{-W_B d_G \cos\theta + \bar{I}\alpha - m d_G (a_y \cos\theta - a_x \sin\theta)}{l_{user}}$$

where $\bar{I}$, d_G, W_B, and l_{user} remain the same from Case 2

For α, a_x, and a_y

Kinematics:

$\vec{V}_G = -\omega d_G \sin\theta \hat{i} + \omega d_G \cos\theta \hat{j}$

In this case, $\omega = -0.785 \frac{rad}{s}$ (moving CW)

$\Rightarrow \vec{V}_G = -(-0.785 \frac{rad}{s})(11.041 in)(-\sin\theta \hat{i} + \cos\theta \hat{j})$

$* \vec{V}_G = 8.667 \frac{in}{s}(\sin\theta \hat{i} - \cos\theta \hat{j})$

$\vec{a}_G = (-\alpha d_G \sin\theta + 8.667\omega\cos\theta)\hat{i}$
$+(\alpha d_G \cos\theta + 8.667\omega\sin\theta)\hat{j}$

$\Rightarrow \vec{a}_G = (-11.041\alpha\sin\theta - 6.804\cos\theta)\hat{i}$
$+(11.041\alpha\cos\theta - 6.804\sin\theta)\hat{i}$

Need: α

$\omega^2 = \omega_0^2 + 2\alpha(\theta - \theta_0)$

$\Rightarrow$ where: $\omega_0 = 0$
$\theta_0 = 90$ degrees $= \pi/2$ radians

$\Rightarrow \omega^2 = 2\alpha(\theta - \theta_0)$

$\Rightarrow \alpha = \frac{\omega^2}{2(\theta - \theta_0)}$

$\Rightarrow \alpha = \frac{(-0.785 \frac{rad}{s})^2}{2(\theta - \frac{\pi}{2})}$

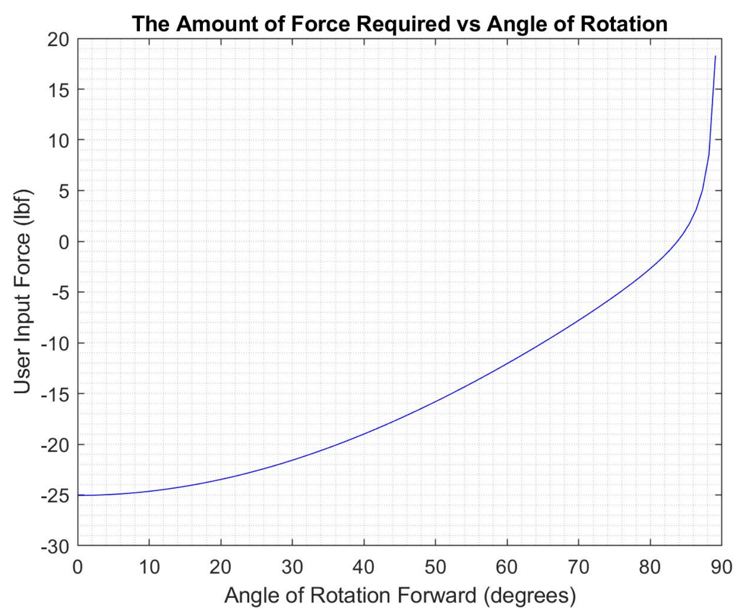
$\Rightarrow * \alpha = \frac{0.308 \frac{rad^2}{s^2}}{\theta - \frac{\pi}{2}}$

so:

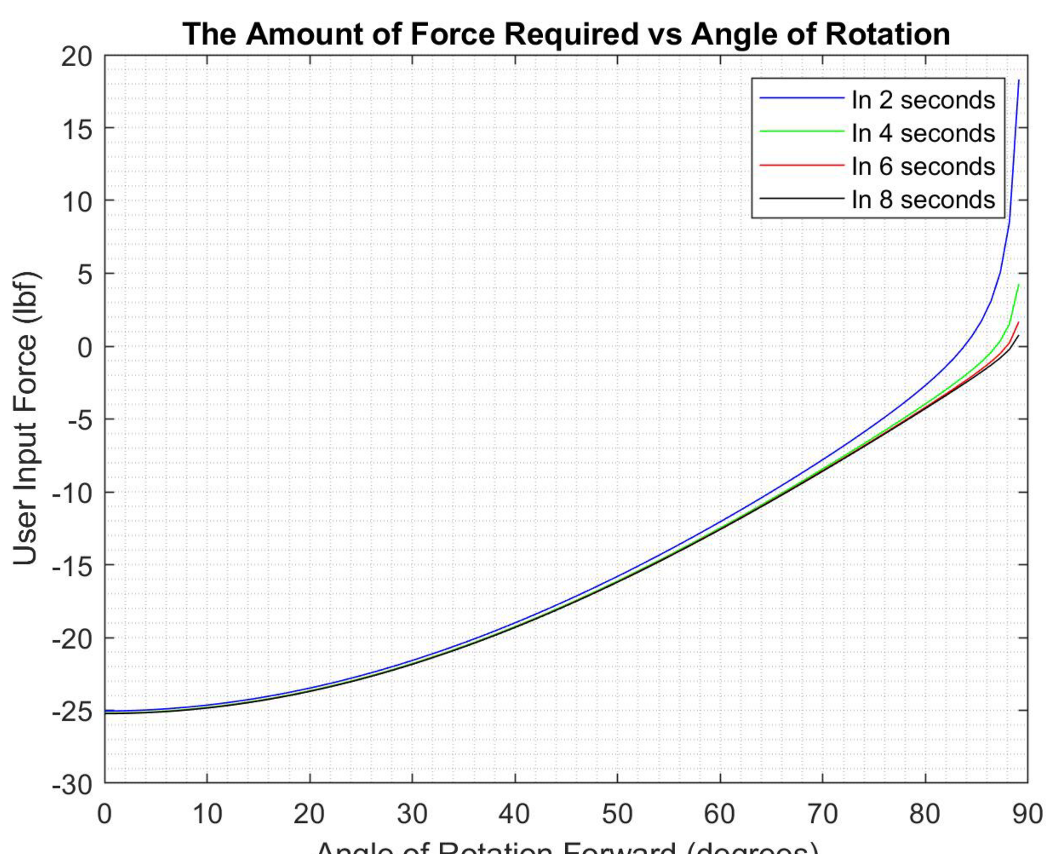
$\vec{a}_G = (\frac{-3.4}{\theta}\sin\theta - 6.804\cos\theta)\hat{i}$
$+(\frac{3.4}{\theta}\cos\theta - 6.804\sin\theta)\hat{j}$

Using MATLAB, we simulated the motion in case 4 using these equations ($0° \le \theta \le 90°$)
These are the results:

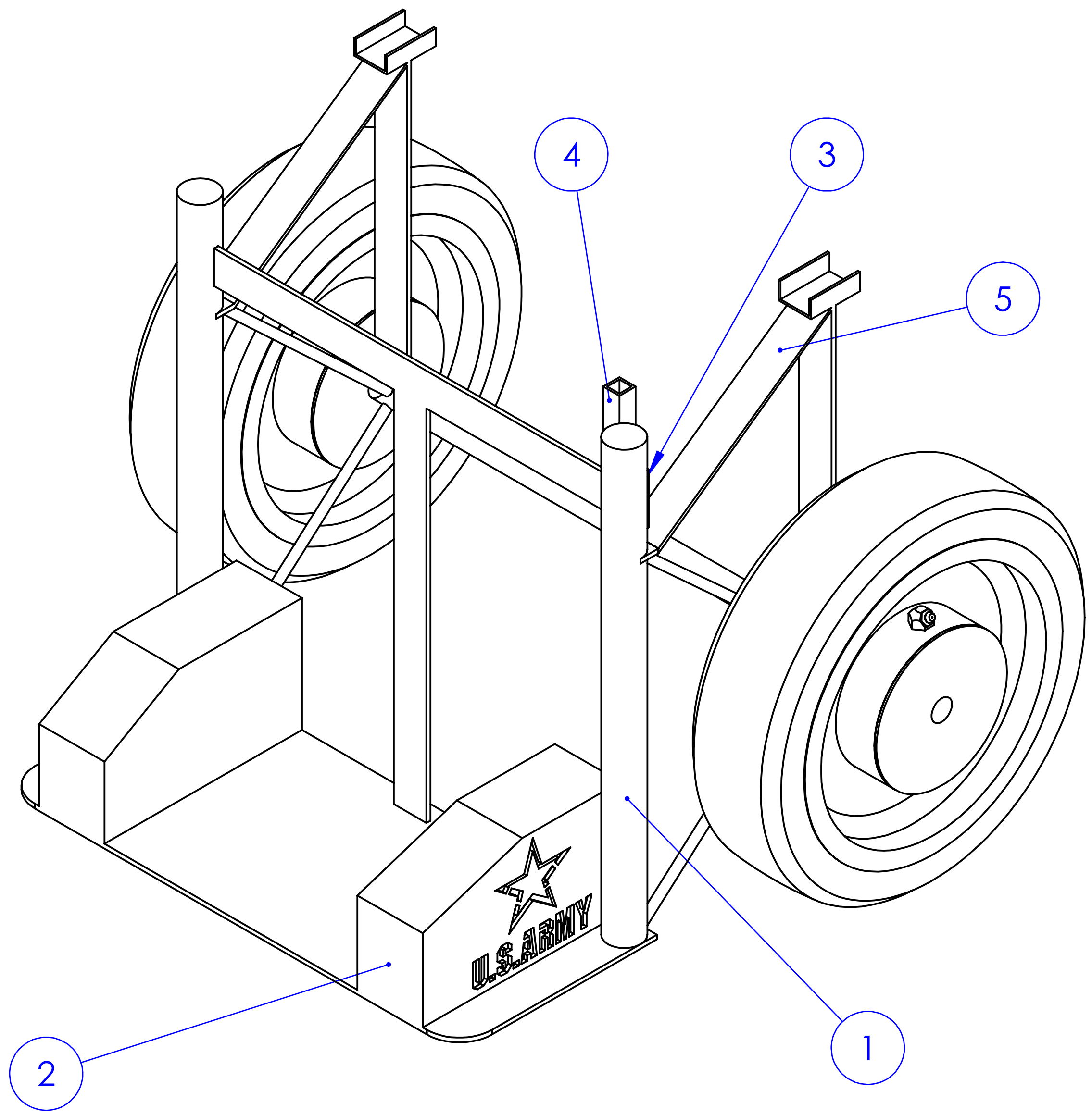
For α=90 degrees in 2 seconds



For α=90 degrees in 2, 4, 6, and 8 seconds



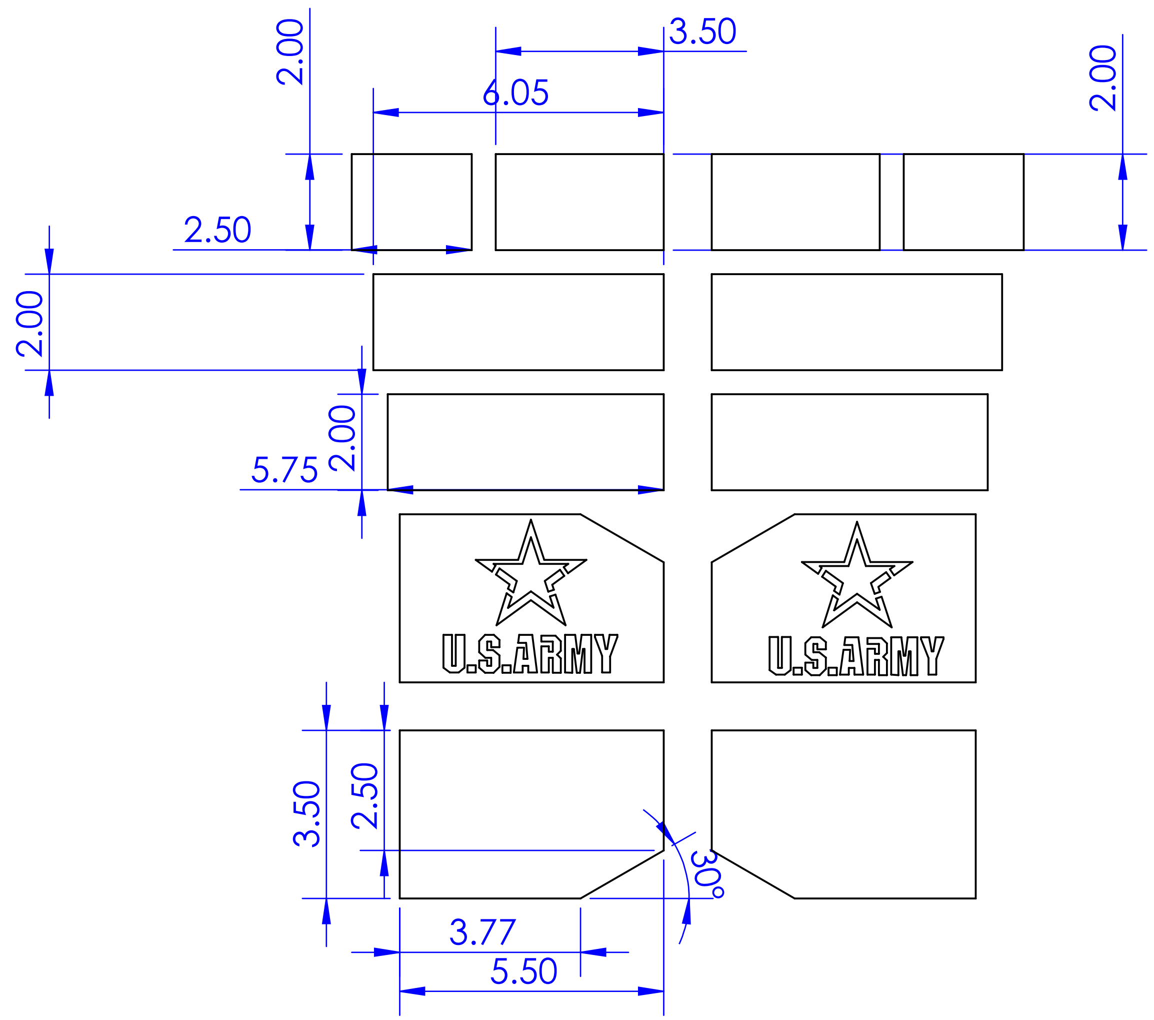
Appendix K: Drawings for the Lower Dolly Subsystem



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
3	1110	Modified Lower Dolly Body	1
2	1120	Dolly Lower Subsystem Forks	2
3	1121	2X.5X.25 Spacer	1
4	1122	3/8" Square Tube	1
5	1130	Dolly Back Supports	2

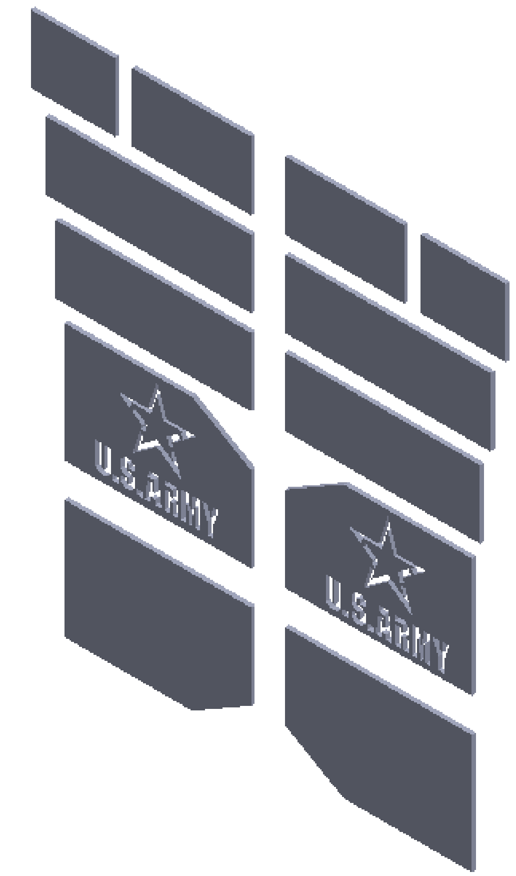
Cal Poly Mechanical Engineering ME 429	Lab Section: 03	ASSEMBLY: UPPER DOLLY FRAME	Drwn. By: RYAN HERYFORD	DATE: 2/3/21	COMMENTS: INTENDED FOR WATER JET	TITLE: BOTTOM DOLLY ASSEMBLY
	TEAM F34	MATERIAL: 1/8" 1018 STEEL PLATE	Chkd. By: JOSE VELAZQUEZ	SCALE: 1:1		

Appendix K: Drawings for the Lower Dolly Subsystem



NOTES:
- FORKS ARE MADE FROM 1/8" MILD STEEL
- UNLESS OTHERWISE SPECIFIED:
  - -DIMENSIONS ARE IN INCHES
  - -TOLERANCES:
    - ONE PLACE DECIMAL ±.1
    - TWO PLACE DECIMAL ±.01
    - THREE PLACE DECIMAL ±.005

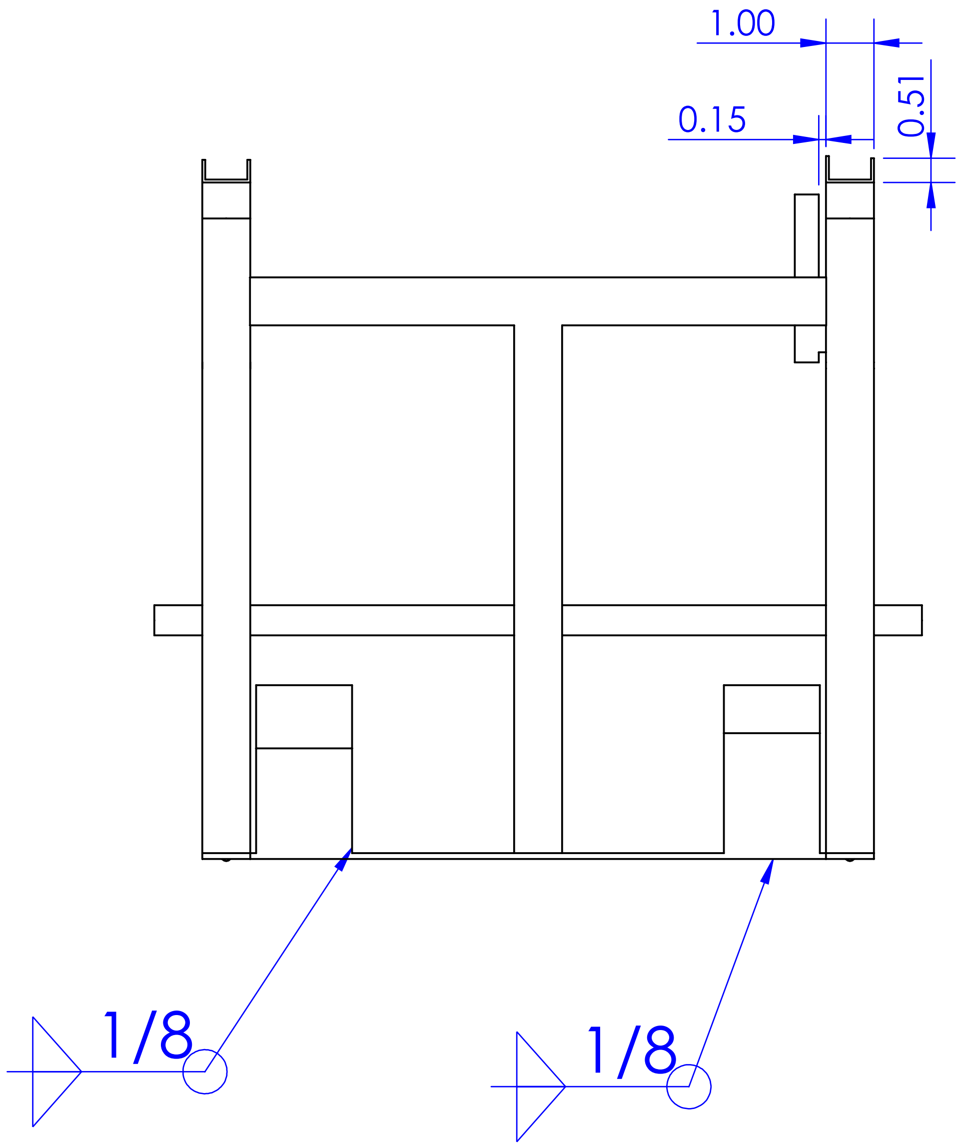
\- 125 √ FAO

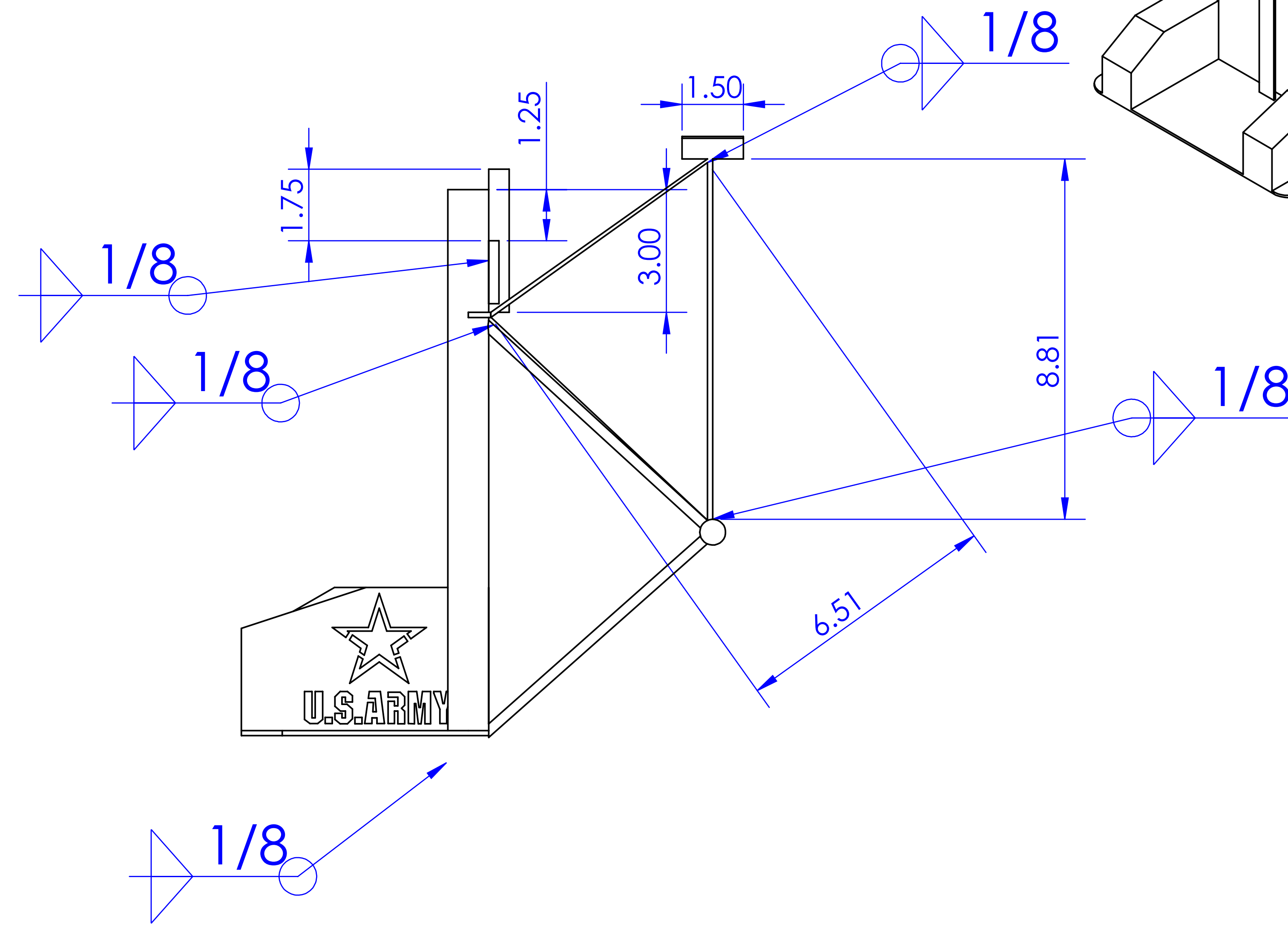


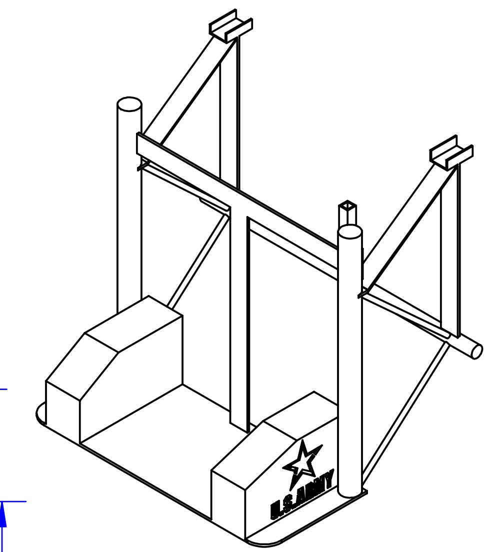
Cal Poly Mechanical Engineering ME 429	Lab Section: 03	ASSEMBLY: UPPER DOLLY FRAME	Drwn. By: RYAN HERYFORD	DATE: 2/3/21	COMMENTS: INTENDED FOR WATER JET	TITLE: DOLLY FORKS
	TEAM F34	MATERIAL: 1/8" 1018 STEEL PLATE	Chkd. By: JOSE VELAZQUEZ	SCALE: 1:1		

Appendix K: Drawings for the Lower Dolly Subsystem

NOTES:
- THE DOLLY BACK SUPPORTS MUST BE INLINE WITH THE TOP DOLLY SECTION WHEN IN THE ROTATED POSITION AND SHOULD KEEP THE SECTION PERPENDICULAR TO THE BOTTOM OF THE LOWER DOLLY.
- THE DOLLY BACK SUPPORTS ARE MADE FROM 1/8" MILD STEEL, CUT AND BEND INTO SHAPE.
- THE WHEELS ARE NOT INCLUDED IN THIS DRAWING, BUT ARE CONSIDERED PART OF THE LOWER DOLLY FRAME
- ALL PARTS ARE WELDED TO THE DOLLY FRAME IN THE LOCATIONS PROVIDED

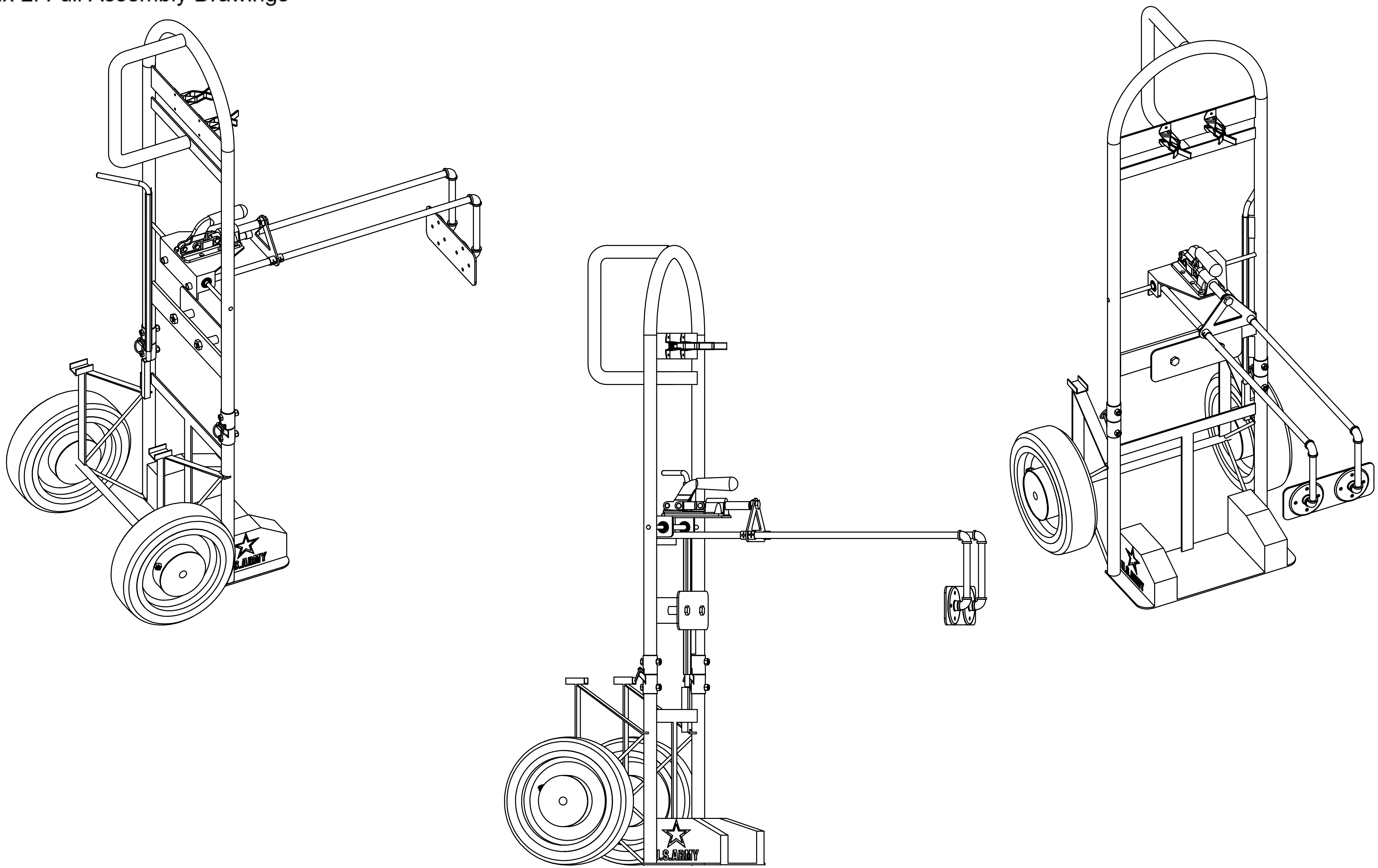






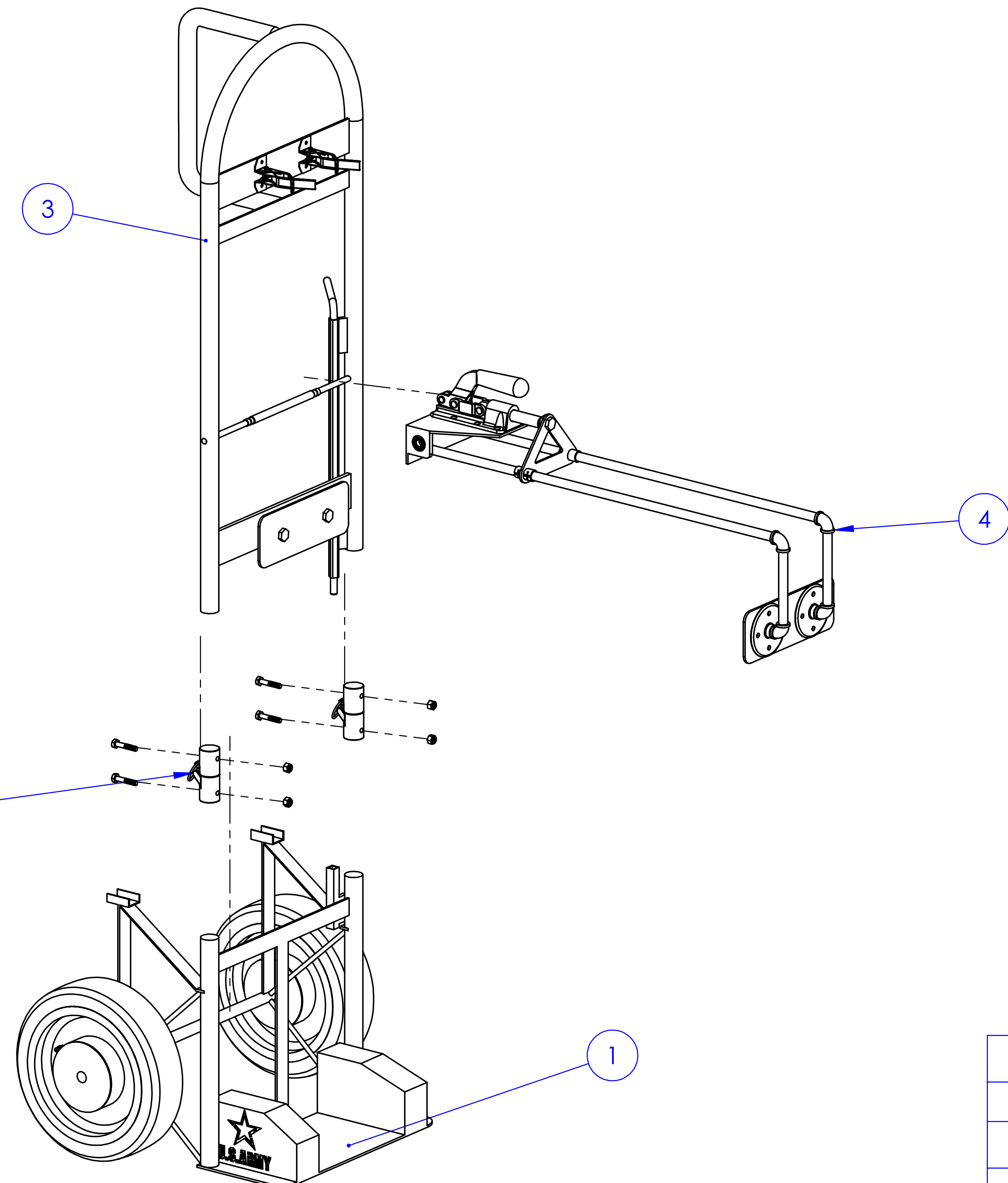
Cal Poly Mechanical Engineering ME 429	Lab Section: 03	ASSEMBLY: UPPER DOLLY FRAME	Drwn. By: RYAN HERYFORD	DATE: 2/3/21	COMMENTS: INTENDED FOR WATER JET	TITLE: LOWER DOLLY FRAME AND ATTACHED PARTS
	TEAM F34	MATERIAL: 1/8" 1018 STEEL PLATE	Chkd. By: JOSE VELAZQUEZ	SCALE: 1:1		

Appendix L: Full Assembly Drawings



Cal Poly Mechanical Engineering ME 429	Lab Section: 03	ASSEMBLY: FINAL ASSEMBLY	Drwn. By: RYAN HERYFORD	DATE: 6/3/21	COMMENTS:	TITLE: BEEKEEPER ASSIST
	TEAM F34	MATERIAL: N/A	Chkd. By: JOSE VELAZQUEZ	SCALE: 1:8		

Appendix L: Full Assembly Drawings

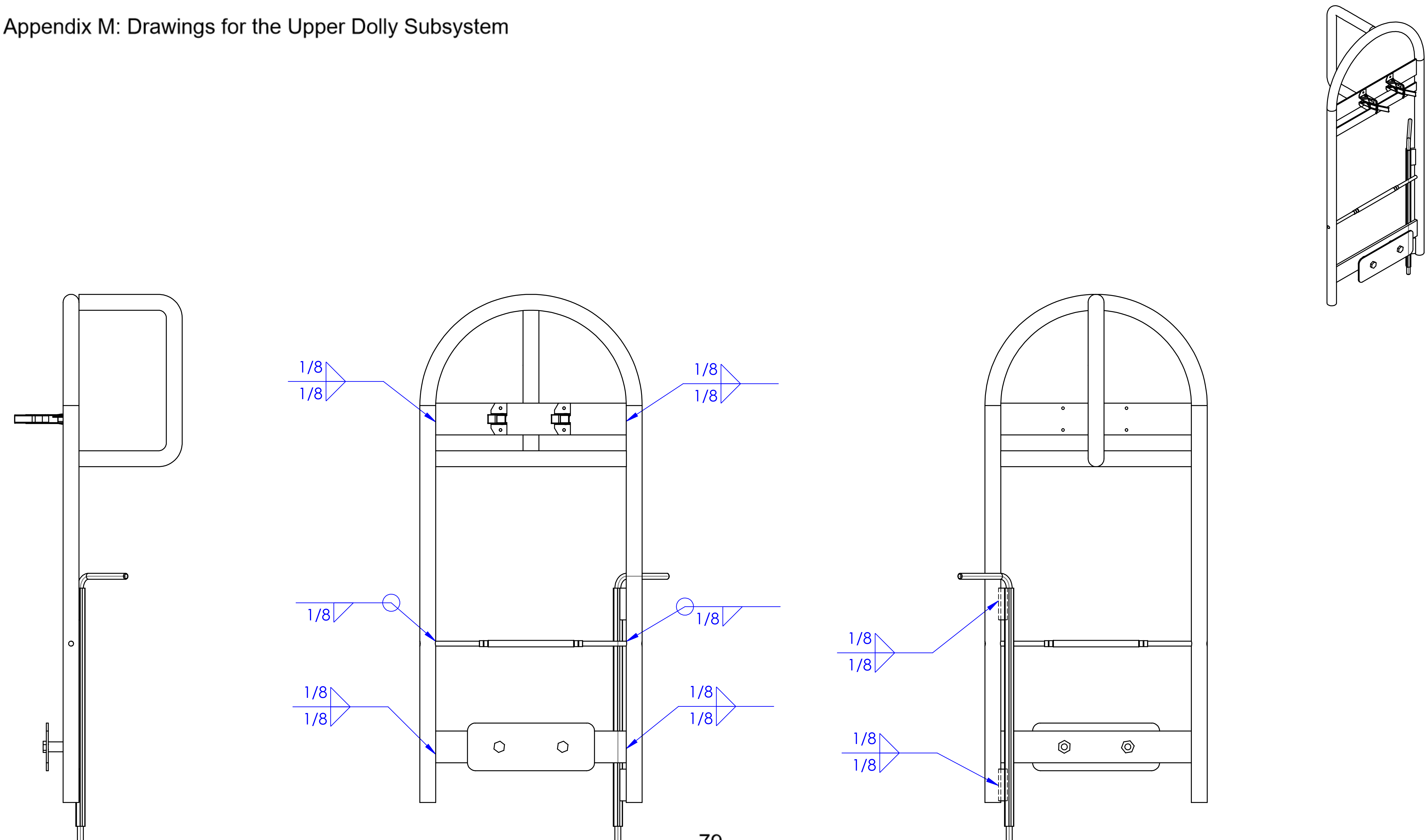


NOTES:
- FINAL ASSEMBLY USES FOUR 1/4-20 BOLTS/NUTS TO ATTACH THE HINGES. THESE PARTS ARE NOT INCLUDED IN THE BILL OF MATERIALS

ITEM NO.	DESCRIPTION	DESCRIPTION	QTY.
1	1100	DOLLY LOWER SUBSYSTEM	1
2	1200	HINGE	2
3	1300	UPPER DOLLY FRAME ASSEMBLY	1
4	1400	ATTACHMENT ARM ASSEMBLY	1

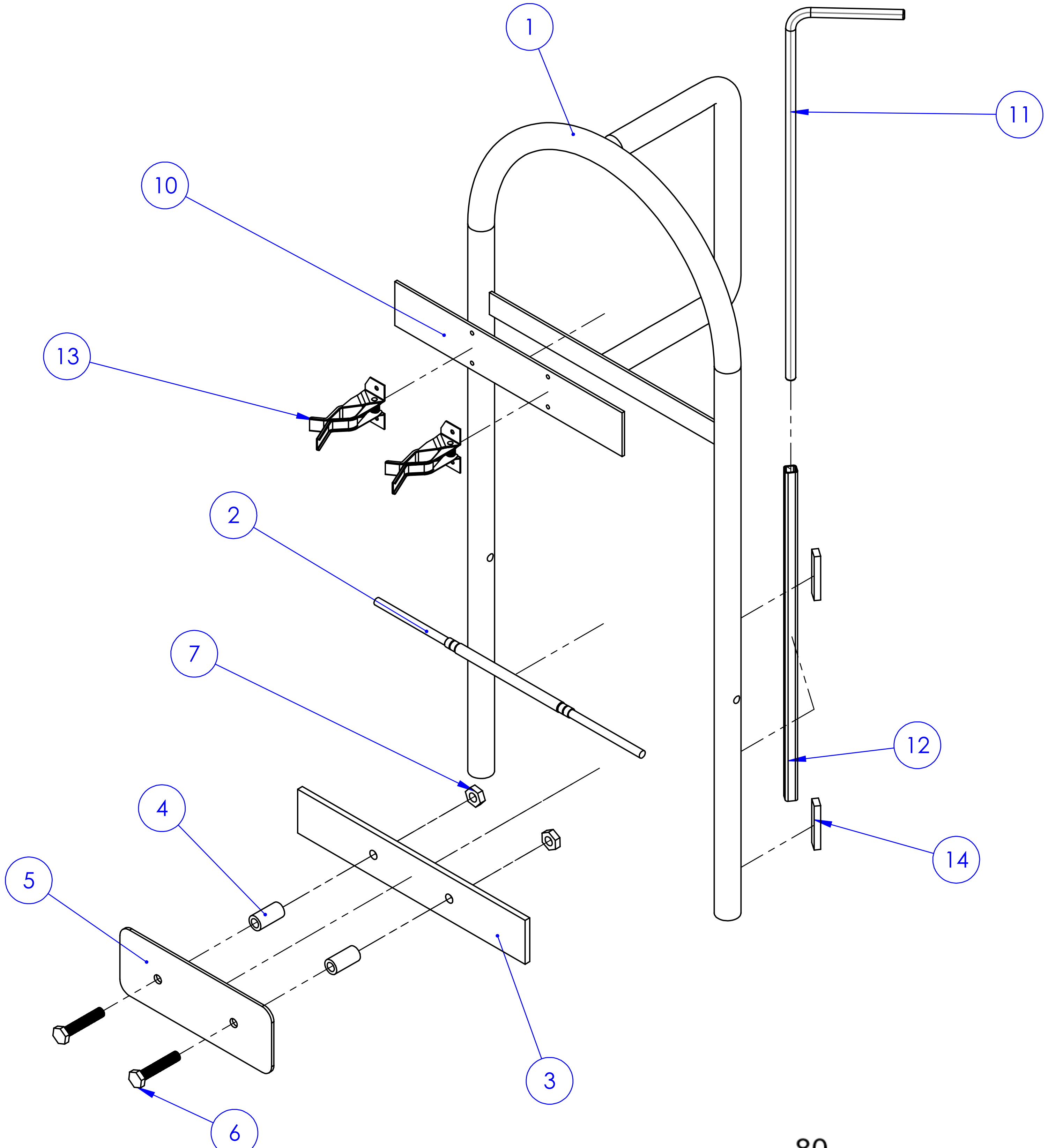
Cal Poly Mechanical Engineering ME 429	Lab Section: 03	ASSEMBLY: FINAL ASSEMBLY	Drwn. By: RYAN HERYFORD	DATE: 6/3/21	COMMENTS:	TITLE: BEEKEEPER ASSIST
	TEAM F34	MATERIAL: N/A	Chkd. By: JOSE VELAZQUEZ	SCALE: 1:8		

Appendix M: Drawings for the Upper Dolly Subsystem



Cal Poly Mechanical Engineering ME 429	Lab Section: 03	ASSEMBLY: UPPER DOLLY FRAME	Drwn. By: RYAN HERYFORD	DATE: 6/2/21	COMMENTS:	TITLE: 1300 UPPER DOLLY FRAME ASSEMBLY
	TEAM F34	MATERIAL: N/A	Chkd. By: JOSE VELAZQUEZ	SCALE: 1:6		

Appendix M: Drawings for the Upper Dolly Subsystem

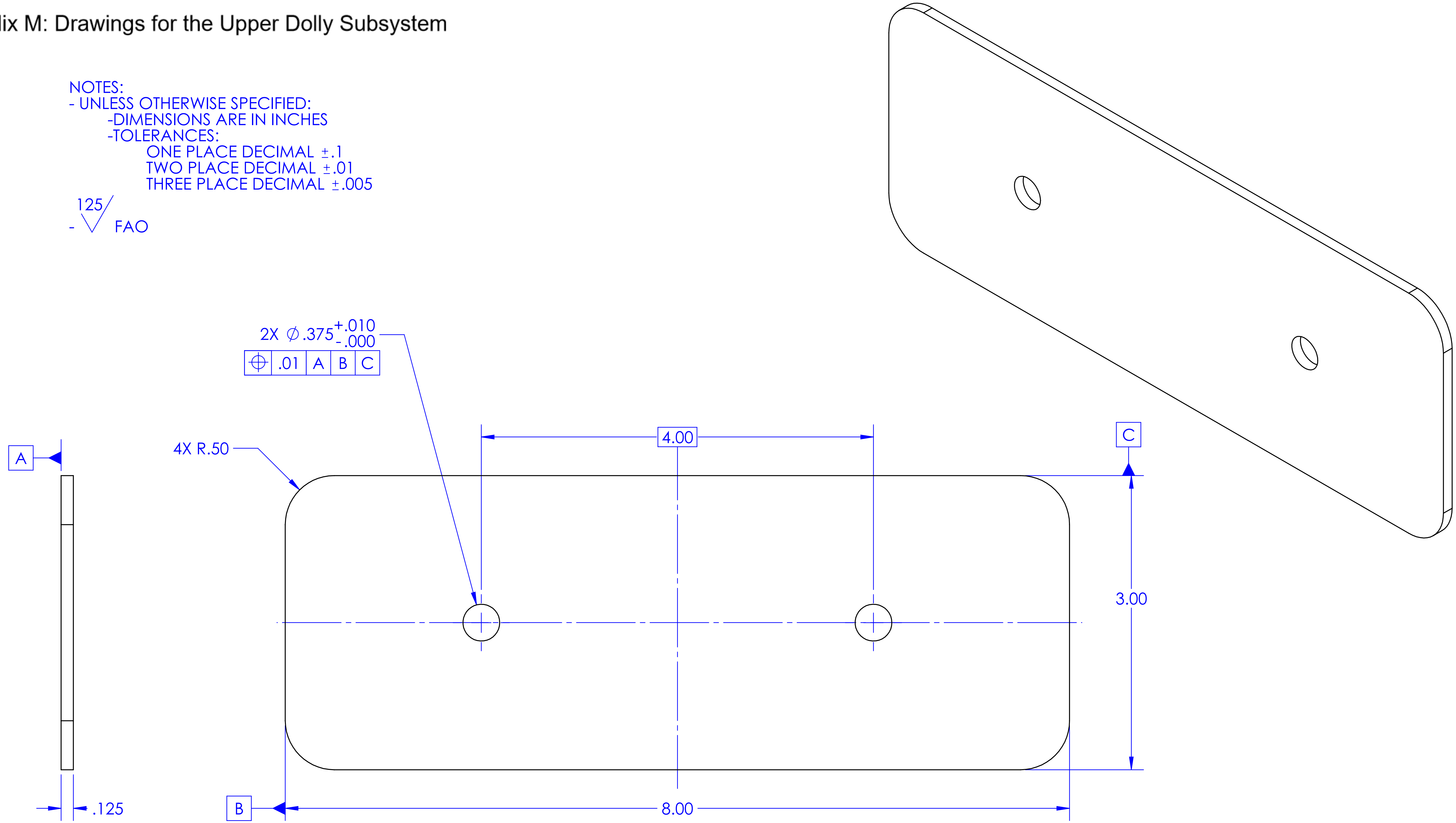


NOTES:
- 6-40 BOLTS AND LOCKNUTS (1380, 1390) USED TO ATTACH PIPE CLAMPS ON CROSSBAR ARE NOT SHOWN IN DRAWING.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1310	UPPER DOLLY FRAME	1
2	1320	CROSSBAR FOR ATTACHMENT ARM	1
3	1330	CROSSBAR FOR BACK BOX PLATE	1
4	1340	SPACER	2
5	1350	BACK BOX PLATE	1
6	1360	3/8"x1.5"x-32 BOLT	2
7	1370	3/8"-32 HEX NUT	2
8	1380	6-40 LOCKNUT	4
9	1390	3/8" 6-40 BOLT	4
10	13100	CROSSBAR FOR PIPE CLAMPS	1
11	13110	3/8" PLUNGER	1
12	13120	3/8" SQUARE TUBE	1
13	13130	PIPE CLAMPS	2
14	13140	2x.5x.25 SPACERS	2

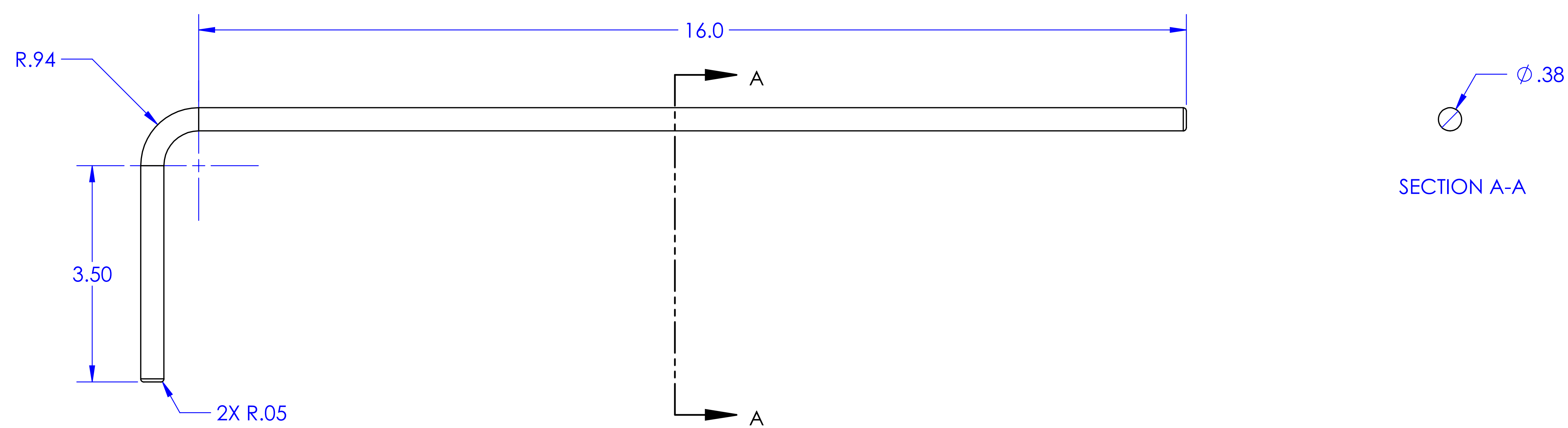
Cal Poly Mechanical Engineering ME 429	Lab Section: 03	ASSEMBLY: UPPER DOLLY FRAME	Drwn. By: RYAN HERYFORD	DATE: 6/2/21	COMMENTS: EXPLODED VIEW	TITLE: 1300 UPPER DOLLY FRAME ASSEMBLY
	TEAM F34	MATERIAL: N/A	Chkd. By: JOSE VELAZQUEZ	SCALE: 1:5		

Appendix M: Drawings for the Upper Dolly Subsystem



Cal Poly Mechanical Engineering ME 429	Lab Section: 03	ASSEMBLY: UPPER DOLLY FRAME	Drwn. By: RYAN HERYFORD	DATE: 2/3/21	COMMENTS: INTENDED FOR WATER JET	TITLE: 1350 BACK BOX PLATE
	TEAM F34	MATERIAL: 1/8" 1018 STEEL PLATE	Chkd. By: JOSE VELAZQUEZ	SCALE: 1:1		

Appendix M: Drawings for the Upper Dolly Subsystem

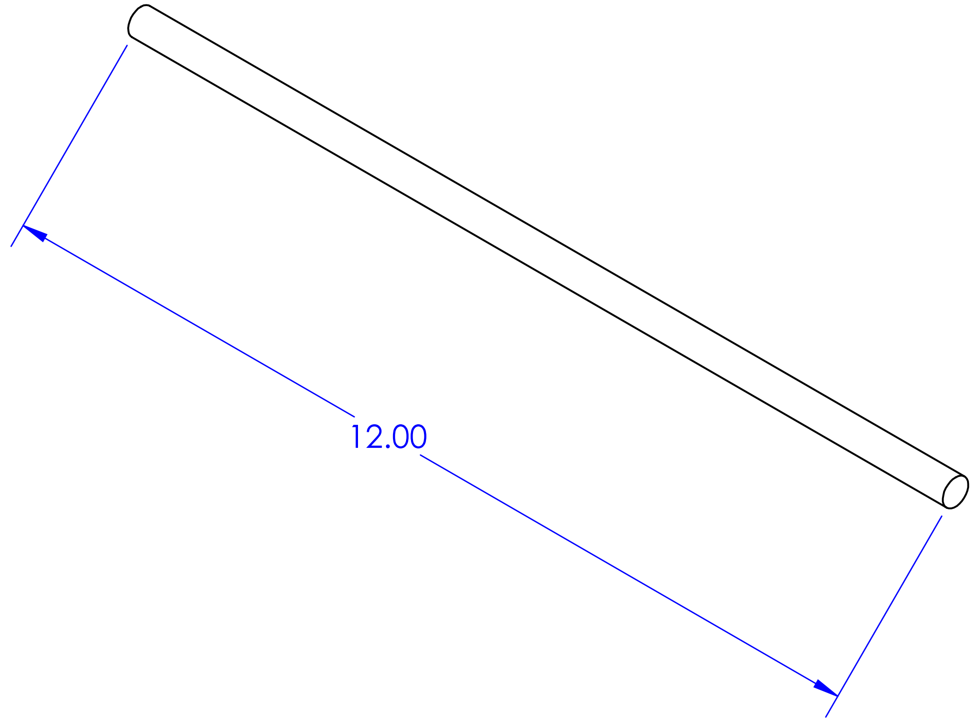


NOTES:
- UNLESS OTHERWISE SPECIFIED:
  - -DIMENSIONS ARE IN INCHES
  - -TOLERANCES:
    - ONE PLACE DECIMAL ±.1
    - TWO PLACE DECIMAL ±.01
    - THREE PLACE DECIMAL ±.005

- 125 √ FAO

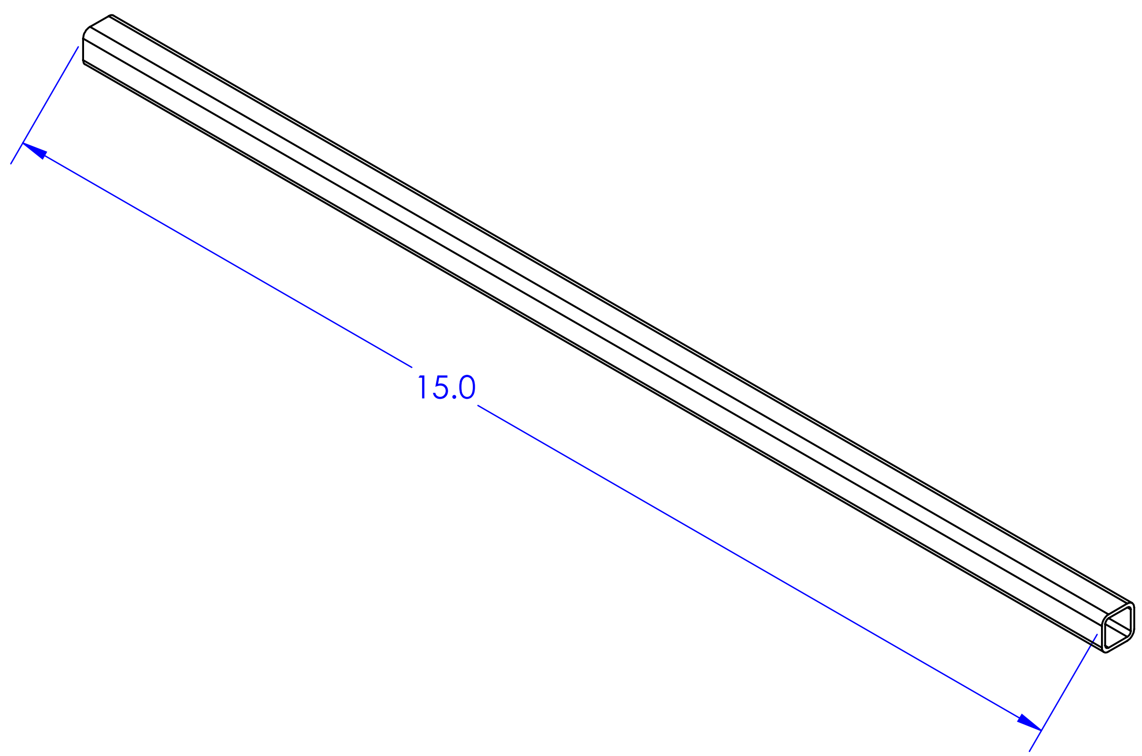
Cal Poly Mechanical Engineering ME 429	Lab Section: 03	ASSEMBLY: UPPER DOLLY FRAME	Drwn. By: RYAN HERYFORD	DATE: 6/1/21	COMMENTS:	TITLE: 13110 3/8" PLUNGER
	TEAM F34	MATERIAL: 3/8" 1018 STEEL ROD	Chkd. By:JOSE VELAZQUEZ	SCALE: 1:1		

Appendix M: Drawings for the Upper Dolly Subsystem



1320 CROSSBAR FOR ATTACHMENT ARM
DESCRIPTION: 3/8" ROUND BAR CUT TO LENGTH
SOURCE: ACE MINERS
ITEM #: N/A

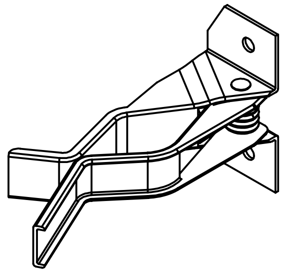
NOTES:
- UNLESS OTHERWISE SPECIFIED:
  - DIMENSIONS ARE IN INCHES
  - TOLERANCES:
    - ONE PLACE DECIMAL ±.1
    - TWO PLACE DECIMAL ±.01
    - THREE PLACE DECIMAL ±.005



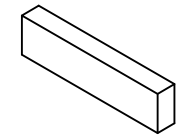
13120 3/8" SQUARE TUBE
DESCRIPTION: STOCK SQUARE TUBE CUT TO LENGTH
SOURCE: ACE MINERS
ITEM #: N/A

Cal Poly Mechanical Engineering ME 429	Lab Section: 03	ASSEMBLY: UPPER DOLLY FRAME	Drwn. By: RYAN HERYFORD	DATE: 6/2/21	COMMENTS: PG. 1/2	TITLE: PURCHASED PARTS
	TEAM F34	MATERIAL: N/A	Chkd. By: JOSE VELAZQUEZ	SCALE: 1:2		

Appendix M: Drawings for the Upper Dolly Subsystem

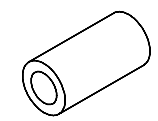


13130 PIPE CLAMPS
DESCRIPTION: STEEL SPRING CLAMPS
SOURCE: ACE MINERS
ITEM #: N/A

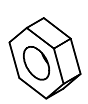


13140 2x.5x.25 SPACERS
DESCRIPTION: SPACERS MADE FROM SCRAP MATERIALS
SOURCE: N/A
ITEM #: N/A

1360 3/8" x 1.5" - 32 BOLT
DESCRIPTION: 3/8"-32 BOLT
SOURCE: ACE MINERS
ITEM #: N/A



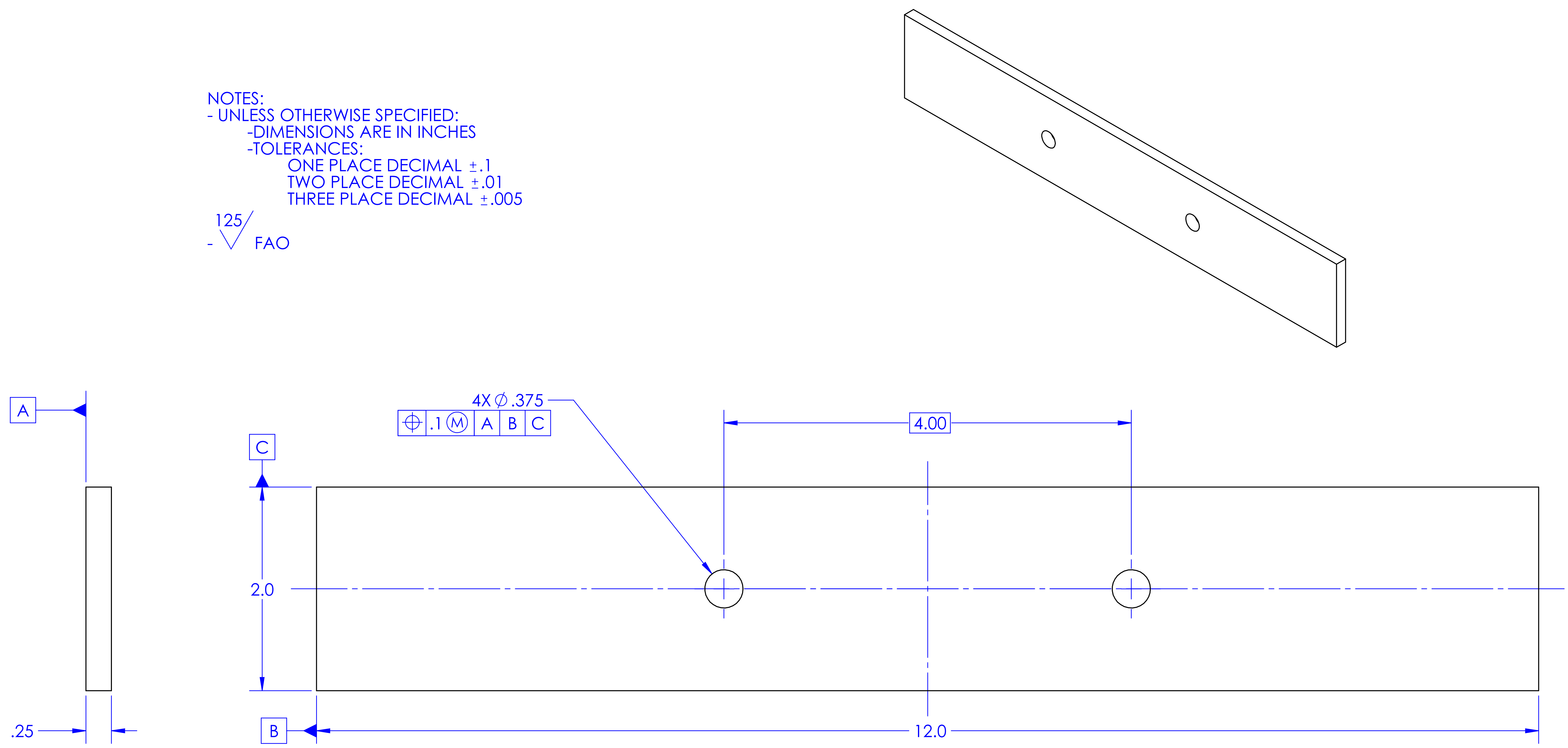
1340 SPACERS
DESCRIPTION: 3/8" x 1.25" ID SPACERS
SOURCE: ACE MINERS
ITEM #: N/A



1370 3/8"-32 HEX NUT
DESCRIPTION: 3/8"-32 HEX NUT
SOURCE: ACE MINERS
ITEM #: N/A

Cal Poly Mechanical Engineering ME 429	Lab Section: 03	ASSEMBLY: UPPER DOLLY FRAME	Drwn. By: RYAN HERYFORD	DATE: 6/2/21	COMMENTS: PG. 2/2	TITLE: PURCHASED PARTS
	TEAM F34	MATERIAL: N/A	Chkd. By: JOSE VELAZQUEZ	SCALE: 1:2		

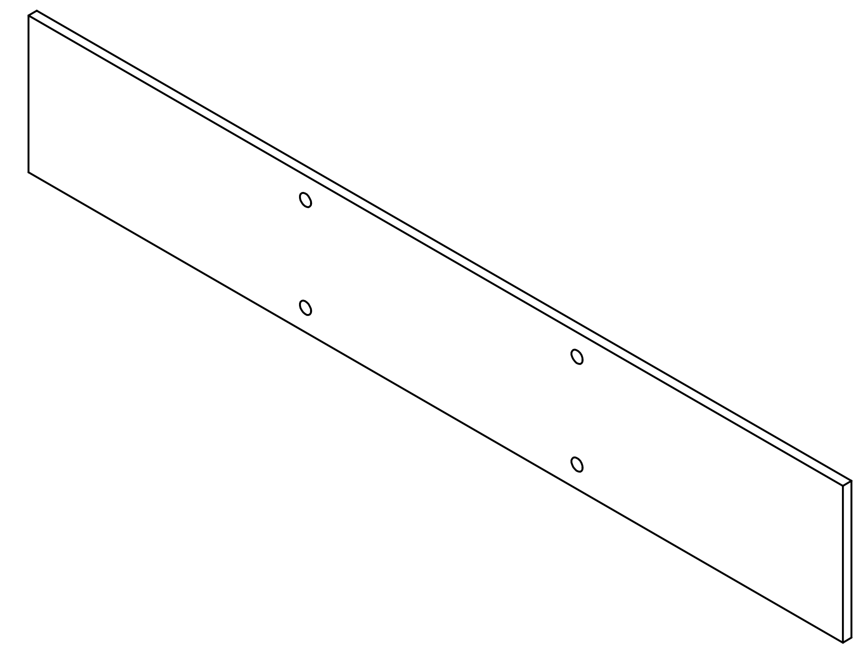
Appendix M: Drawings for the Upper Dolly Subsystem

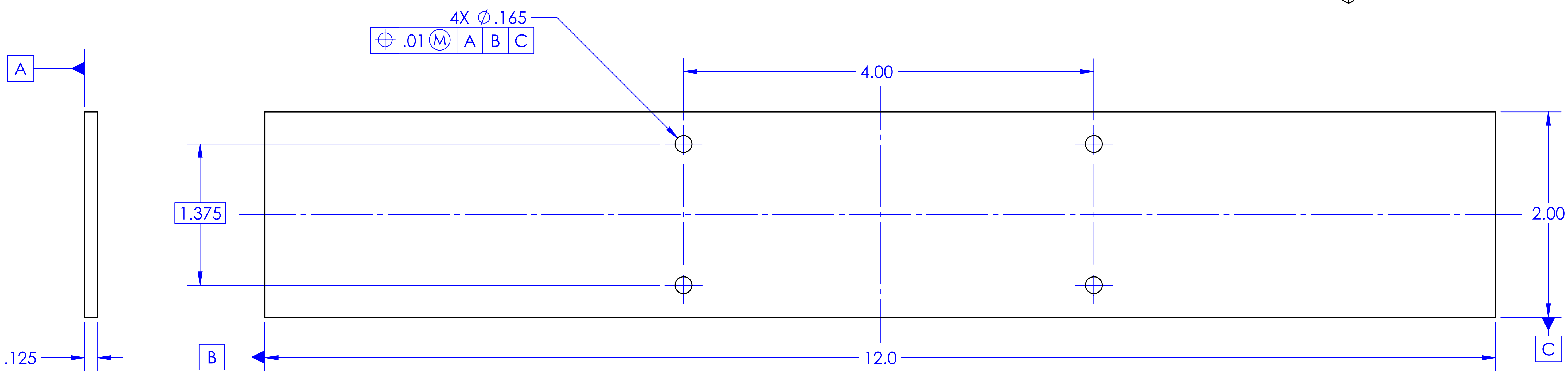


Cal Poly Mechanical Engineering ME 429	Lab Section: 03	ASSEMBLY: UPPER DOLLY FRAME	Drwn. By: RYAN HERYFORD	DATE: 2/3/21	COMMENTS: INTENDED FOR WATER JET	TITLE: 1330 CROSSBAR FOR BACK BOX PLATE
	TEAM F34	MATERIAL: 1/4" 1018 STEEL PLATE	Chkd. By: JOSE VELAZQUEZ	SCALE: 1:1		

Appendix M: Drawings for the Upper Dolly Subsystem

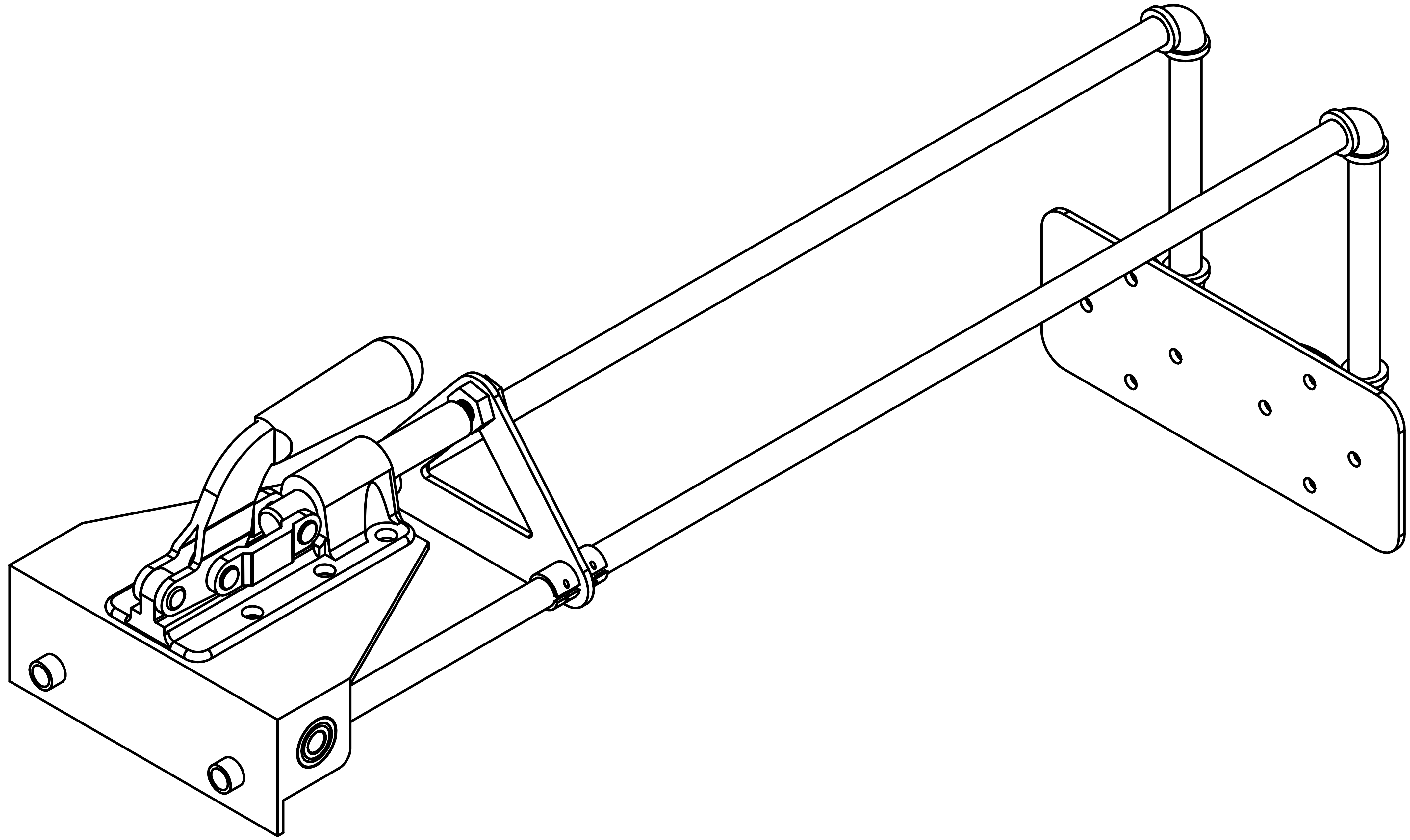
NOTES:
- UNLESS OTHERWISE SPECIFIED:
  - -DIMENSIONS ARE IN INCHES
  - -TOLERANCES:
    - ONE PLACE DECIMAL ±.1
    - TWO PLACE DECIMAL ±.01
    - THREE PLACE DECIMAL ±.005
- 125 √ FAO





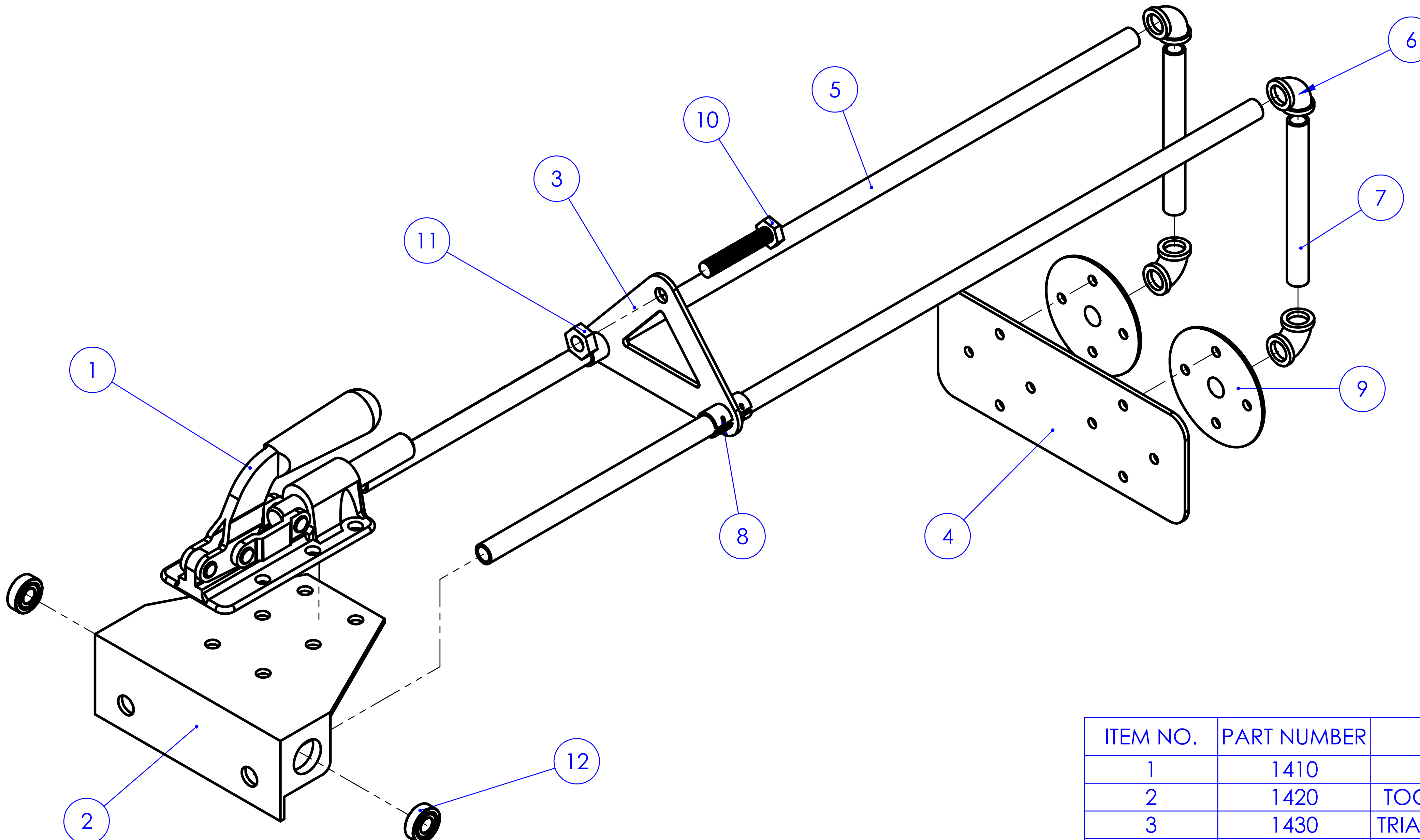
Cal Poly Mechanical Engineering ME 429	Lab Section: 03	ASSEMBLY: UPPER DOLLY FRAME	Drwn. By: RYAN HERYFORD	DATE: 2/3/21	COMMENTS:	TITLE: 13100 CROSSBAR FOR PIPE CLAMPS
	TEAM F34	MATERIAL: 1/8" 1018 STEEL PLATE	Chkd. By: JOSE VELAZQUEZ	SCALE: 1:1		

Appendix N: Drawings for the Attachment Arm Subsystem



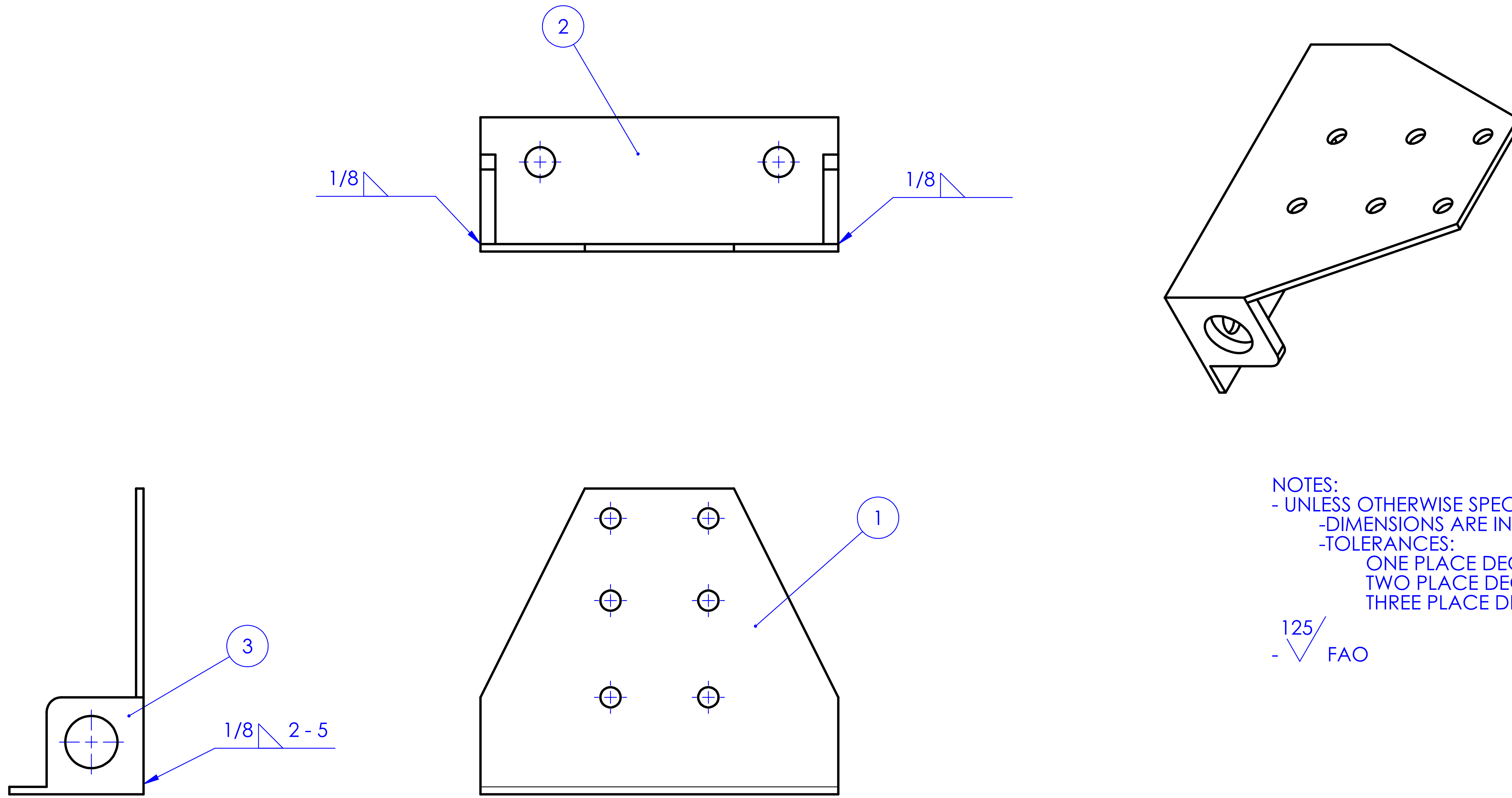
Cal Poly Mechanical Engineering ME 429	Lab Section: 03	ASSEMBLY: ATTACHMENT ARM	Drwn. By: RYAN HERYFORD	DATE: 2/3/21	COMMENTS:	TITLE: 1400 ATTACHMENT ARM ASSEMBLY
	TEAM F34	MATERIAL: N/A	Chkd. By: JOSE VELAZQUEZ	SCALE: 1:2		

Appendix N: Drawings for the Attachment Arm Subsystem



ITEM NO.	PART NUMBER	PART	QTY.
1	1410	TOGGLE CLAMP	1
2	1420	TOGGLE CLAMP BASE ASSEMBLY	1
3	1430	TRIANGULAR CONNECTING PLATE	1
4	1440	FRONT BOX PLATE	1
5	1450	ARM PIPES	2
6	1460	90 DEGREE ELBOWS	4
7	1470	4.5 IN. PIPE NIPPLES	2
8	1490	PIPE CLAMP COLLERS	4
9	14100	PIPE FLANGES	2
10	14150	3/8 IN. x 2 IN. BOLT	1
11	14160	3/8 IN. HEX NUT	1
12	14190	3/8 IN. ID BALL BEARINGS	2

Cal Poly Mechanical Engineering ME 429	Lab Section: 03	ASSEMBLY: ATTACHMENT ARM	Drwn. By: RYAN HERYFORD	DATE: 2/3/21	COMMENTS:	TITLE: 1400 ATTACHMENT ARM ASSEMBLY
	TEAM F34	MATERIAL: N/A	Chkd. By: JOSE VELAZQUEZ	SCALE: 1:3		

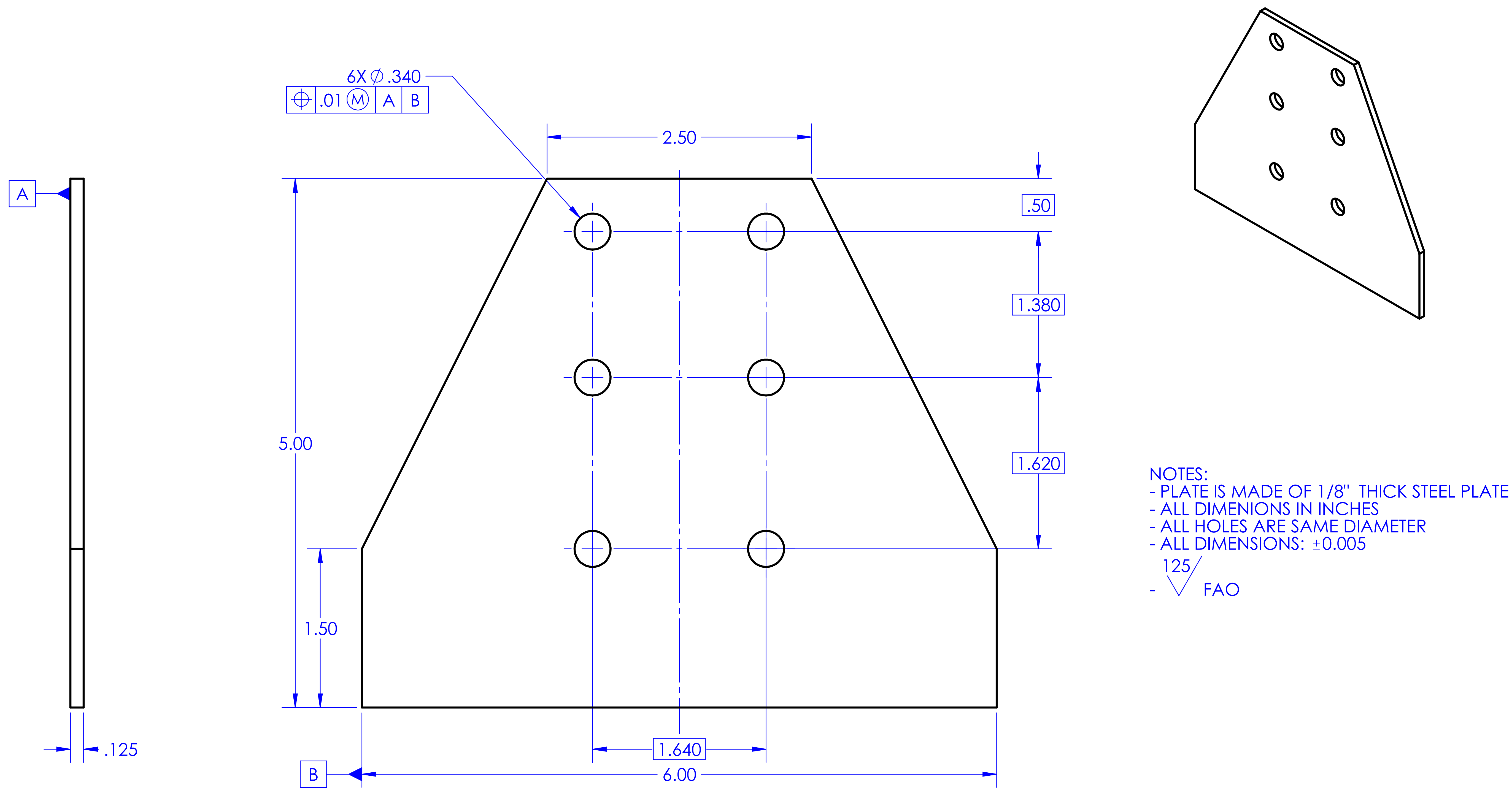


NOTES:
- UNLESS OTHERWISE SPECIFIED:
  - DIMENSIONS ARE IN INCHES
  - TOLERANCES:
    - ONE PLACE DECIMAL ±.1
    - TWO PLACE DECIMAL ±.01
    - THREE PLACE DECIMAL ±.005
- 125 √ FAO

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1421	BASE PLATE	1
2	1422	BACK PLATE	1
3	1423	BEARING HOUSING	2

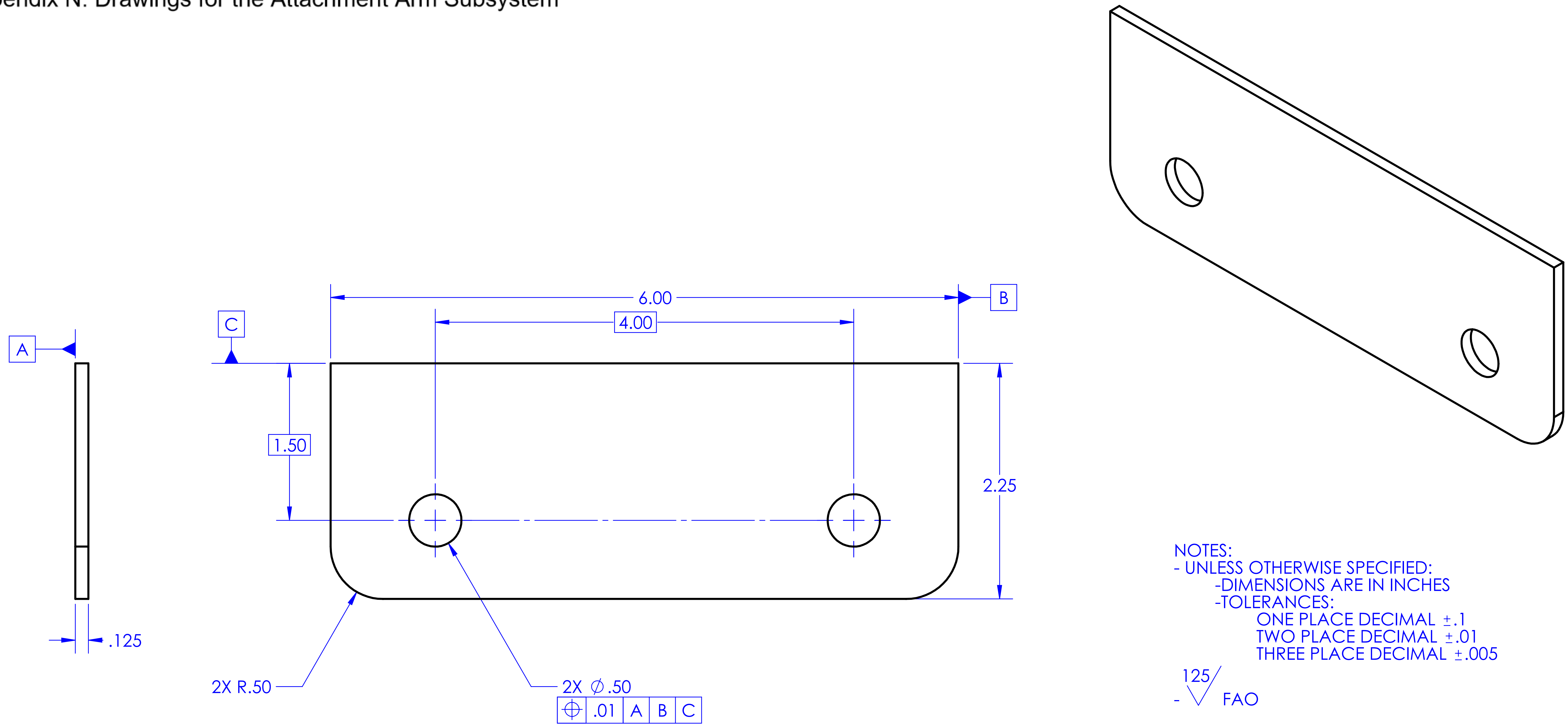
Cal Poly Mechanical Engineering ME 429	Lab Section: 03	ASSEMBLY: TOGGLE CLAMP BASE	Drwn. By: RYAN HERYFORD	DATE: 2/3/21	COMMENTS:	TITLE: 1420 TOGGLE CLAMP BASE ASSEMBLY
	TEAM F34	MATERIAL: 1/8" 1018 STEEL PLATE	Chkd. By: JOSE VELAZQUEZ	SCALE: 1:2		

Appendix N: Drawings for the Attachment Arm Subsystem



Cal Poly Mechanical Engineering ME 429	Lab Section: 03	ASSEMBLY: ATTACHMENT ARM	Drwn. By: RYAN HERYFORD	DATE: 2/3/21	COMMENTS: INTENDED FOR WATER JET	TITLE: 1421 BASE PLATE
	TEAM F34	MATERIAL: 1/8" 1018 STEEL PLATE	Chkd. By: JOSE VELAZQUEZ	SCALE: 1:1		

Appendix N: Drawings for the Attachment Arm Subsystem

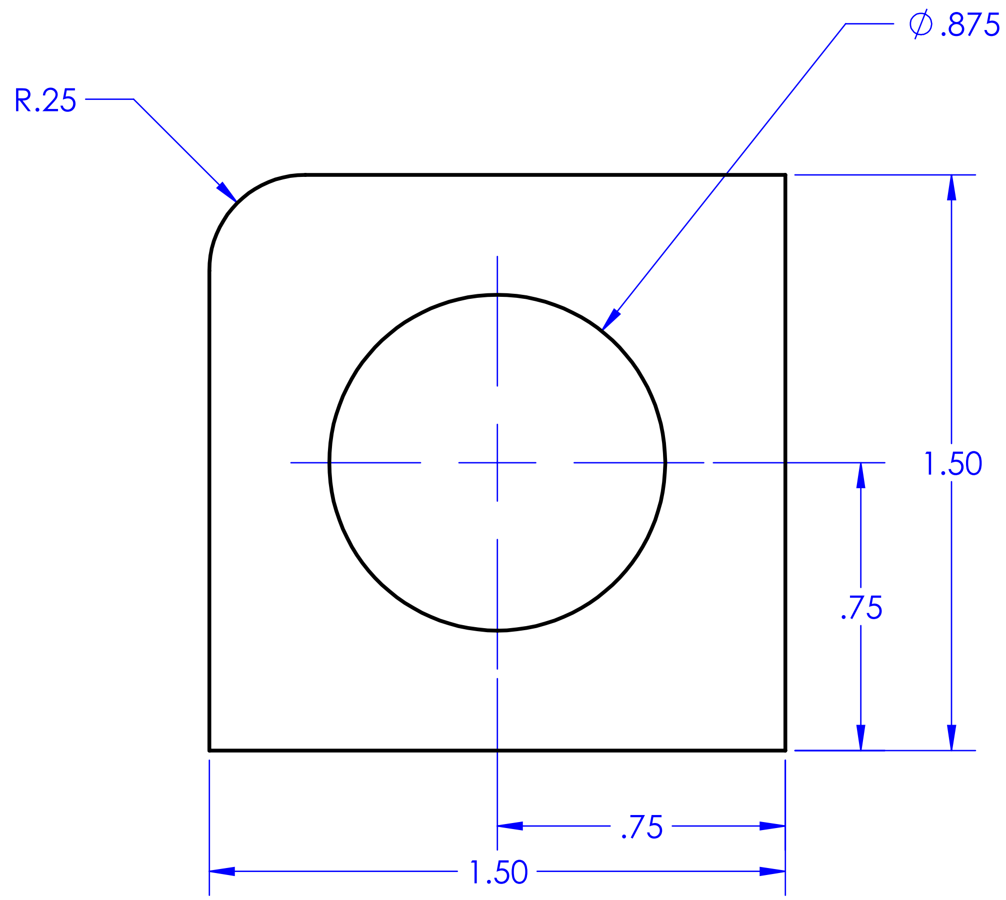


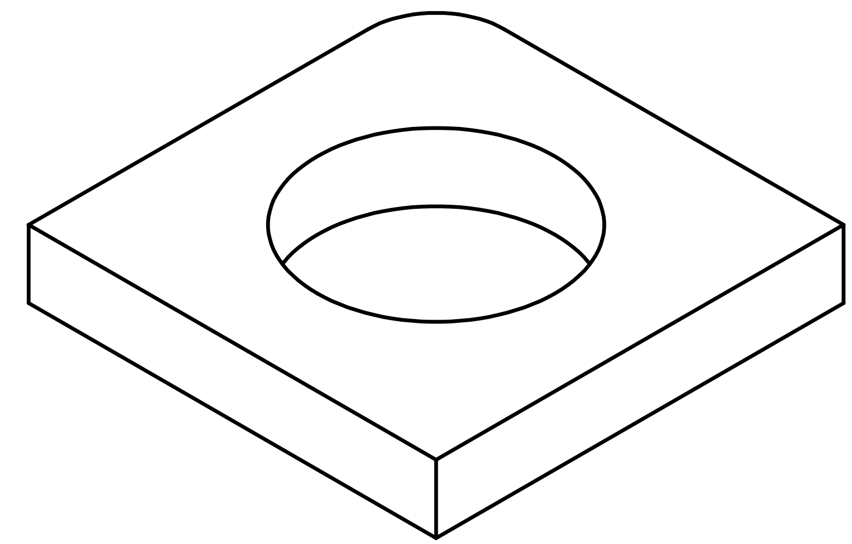
NOTES:
- UNLESS OTHERWISE SPECIFIED:
  - -DIMENSIONS ARE IN INCHES
  - -TOLERANCES:
    - ONE PLACE DECIMAL ±.1
    - TWO PLACE DECIMAL ±.01
    - THREE PLACE DECIMAL ±.005

125 - FAO

Cal Poly Mechanical Engineering ME 429	Lab Section: 03	ASSEMBLY: ATTACHMENT ARM	Drwn. By: RYAN HERYFORD	DATE: 2/3/21	COMMENTS: INTENDED FOR WATER JET	TITLE: 1422 BACK PLATE
	TEAM F34	MATERIAL: 1/8" 1018 STEEL PLATE	Chkd. By: JOSE VELAZQUEZ	SCALE: 1:1		

Appendix N: Drawings for the Attachment Arm Subsystem

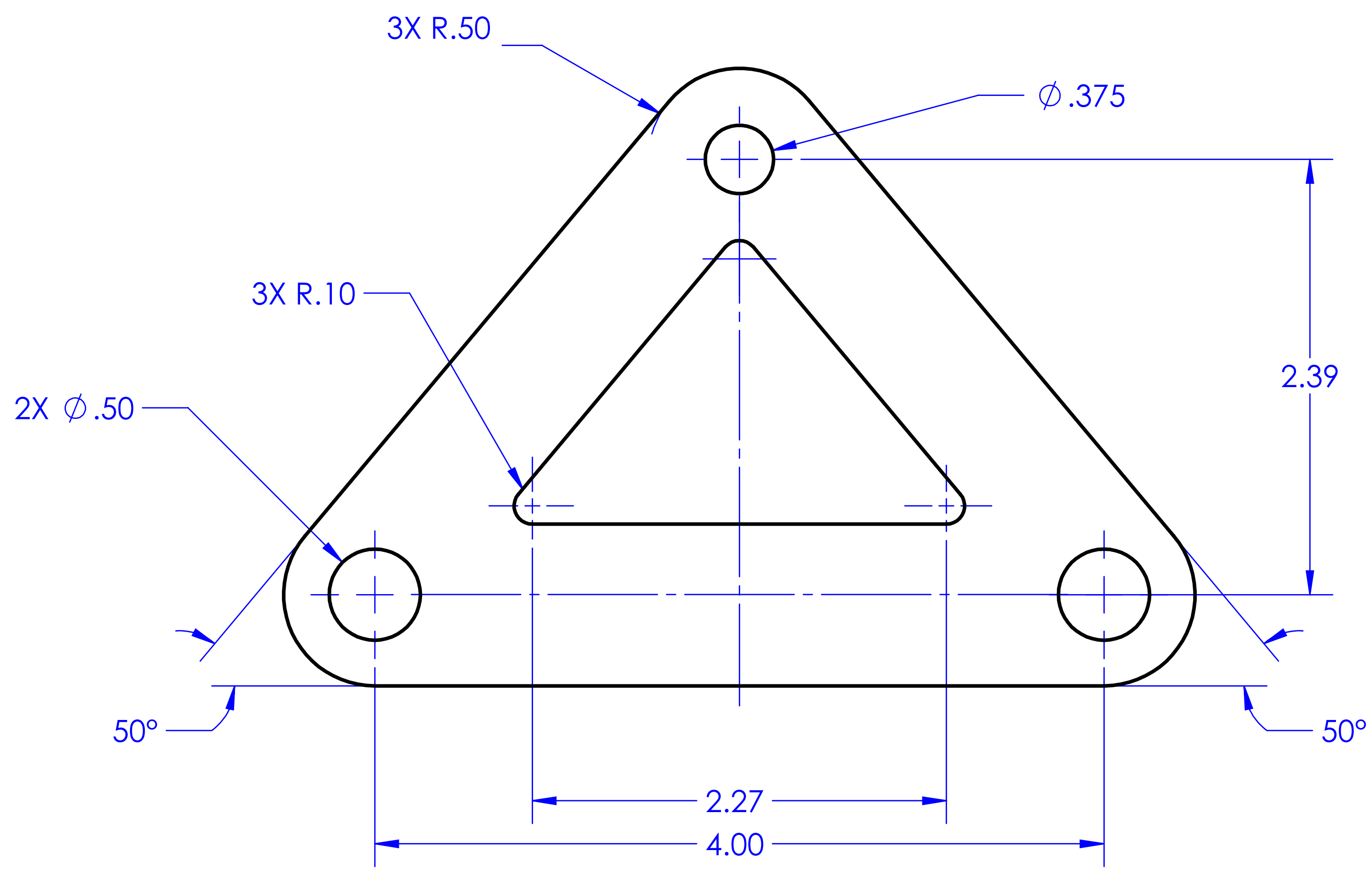


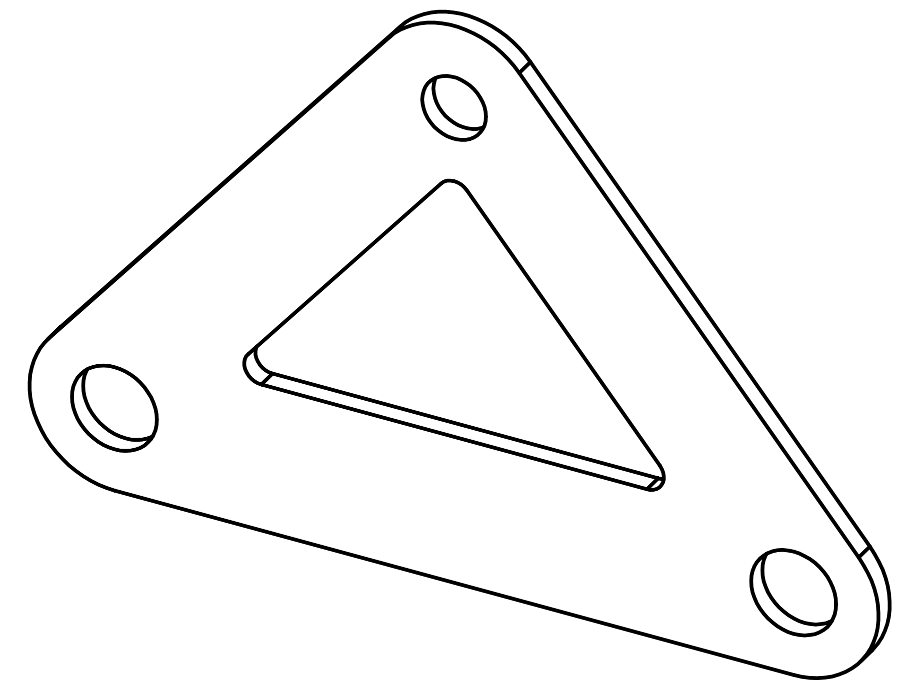


NOTES:
- UNLESS OTHERWISE SPECIFIED:
  - DIMENSIONS ARE IN INCHES
  - TOLERANCES:
    - ONE PLACE DECIMAL ±.1
    - TWO PLACE DECIMAL ±.01
    - THREE PLACE DECIMAL ±.005
- 125 √ FAO

Cal Poly Mechanical Engineering ME 429	Lab Section: 03	ASSEMBLY: ATTACHMENT ARM	Drwn. By: RYAN HERYFORD	DATE: 2/3/21	COMMENTS: INTENDED FOR WATER JET	TITLE: 1423 BEARING HOUSING
	TEAM F34	MATERIAL: 1/4" 1018 STEEL PLATE	Chkd. By: JOSE VELAZQUEZ	SCALE: 2:1		

Appendix N: Drawings for the Attachment Arm Subsystem





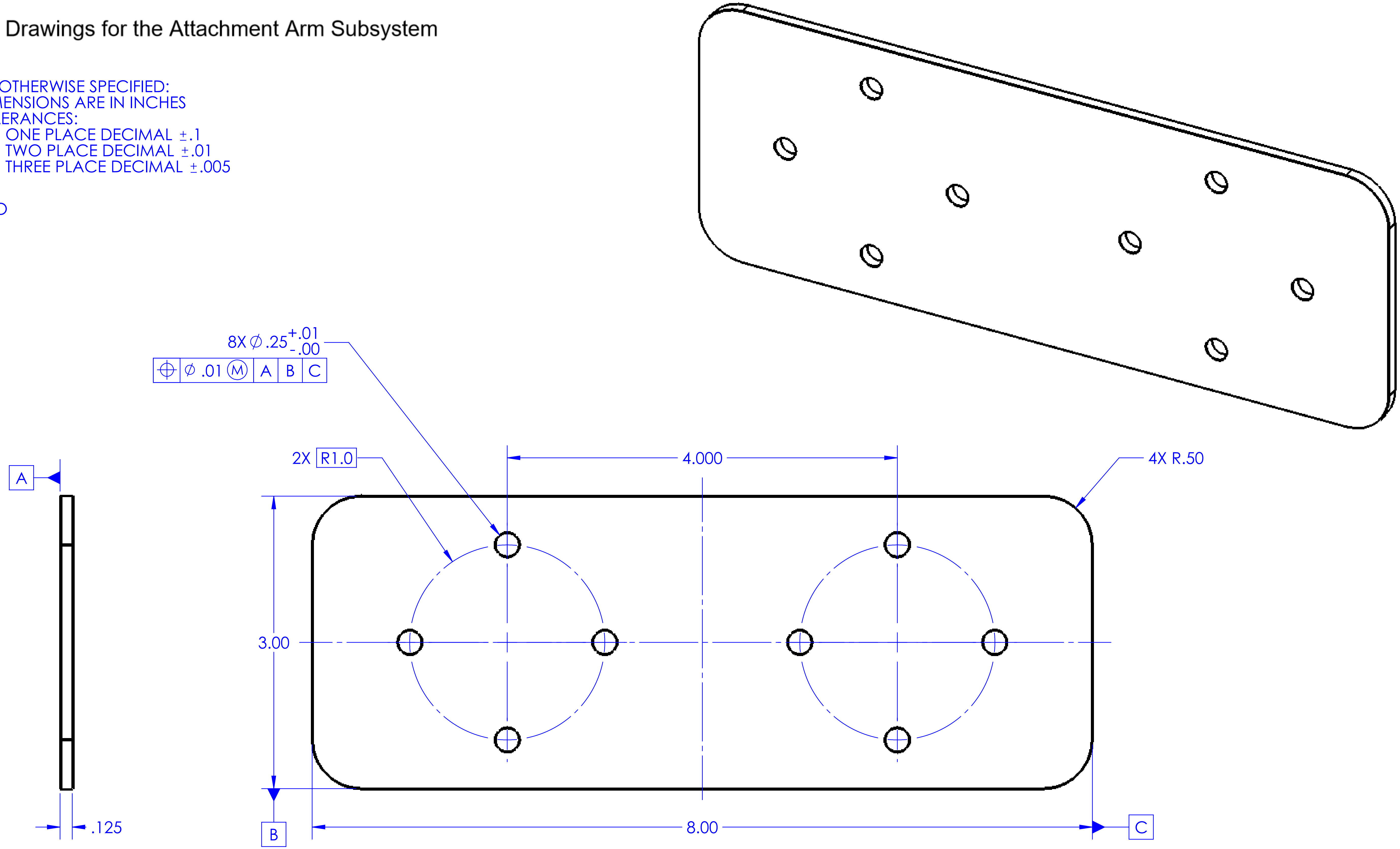
NOTES:
- UNLESS OTHERWISE SPECIFIED:
  - DIMENSIONS ARE IN INCHES
  - TOLERANCES:
    - ONE PLACE DECIMAL ±.1
    - TWO PLACE DECIMAL ±.01
    - THREE PLACE DECIMAL ±.005

125 √ FAO

Cal Poly Mechanical Engineering ME 429	Lab Section: 03	ASSEMBLY: ATTACHMENT ARM	Drwn. By: RYAN HERYFORD	DATE: 2/3/21	COMMENTS: INTENDED FOR WATER JET	TITLE: 1430 TRIANGULAR CONNECTING PLATE
	TEAM F34	MATERIAL: 1/8" 1018 STEEL PLATE	Chkd. By:JOSE VELAZQUEZ	SCALE: 1:1		

Appendix N: Drawings for the Attachment Arm Subsystem

NOTES:
- UNLESS OTHERWISE SPECIFIED:
  - DIMENSIONS ARE IN INCHES
  - TOLERANCES:
    - ONE PLACE DECIMAL ±.1
    - TWO PLACE DECIMAL ±.01
    - THREE PLACE DECIMAL ±.005
- 125 √ FAO



Cal Poly Mechanical Engineering ME 429	Lab Section: 03	ASSEMBLY: ATTACHMENT ARM	Drwn. By: RYAN HERYFORD	DATE: 2/3/21	COMMENTS: INTENDED FOR WATER JET	TITLE: 1440 FRONT BOX PLATE
	TEAM F34	MATERIAL: 1/8" 1018 STEEL PLATE	Chkd. By: JOSE VELAZQUEZ	SCALE: 1:1		

Appendix O: Design Verification Plan & Report

DVP&R - Design Verification Plan (& Report)

Project:	F34 Beekeeper Assist		Sponsor:	Alejandro Jauregui							Edit Date:	6/3/2021
TEST PLAN											**TEST RESULTS**	
Test #	Specification #	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING			Results	Notes on Testing
								Start date	Finish date			
1	1	Verify the device weighs a maximum of 60 lbs.	Weight of device	Max 60lbs	Scale	VP	Kyle	4/29/2021	5/18/2021		50.4 lbs	We measured this weight using a Taylor 7042 scale.
2	2	Verify the device fits in the bed of a pickup truck with similar dimension to a 2012 Ford Raptor	Size of device	Smaller than 50" x 67"	Measuring Tape	VP	Ryan	4/28/2021	4/28/2021		Pass	We determined with a measuring tape that it fit within our dimensions. We also simulated the lifting process by putting it into one of our pickup trucks. It fit reasonably well.
3	3	Fill the top box of the beehive with 60lbs using gym weights. Use the dolly to lift and rotate the top box.	Lifting capacity	60 lbs	Beehive Boxes, Pallet, Weights	VP	Javier	4/29/2021	5/18/2021		Pass	We ended up putting up to 100lbs into it and it worked great
4	4	Record the time it takes to go through the process of rotating and lifting the top box. Compare the time to that of the recorded current process.	Operating time (one box)	<4 seconds	Beehive Boxes, Pallet, Weights, Stopwatch	VP	Jose	4/29/2021	5/20/2021		Average of 5.286s	Average total rotation time (forward and back): 10.572 s. Average rotation time back: 5.286 s. We originally wrote this test not knowing what the final design was going to look like, so we designed it for rotation forward and back. We think that 5.286 seconds is a decent estimate. While it did fail our specification, we now think that that specification might have been misguided and too low.

Appendix O: Design Verification Plan & Report

DVP&R - Design Verification Plan (& Report)											
Project:	F34 Beekeeper Assist		Sponsor:	Alejandro Jauregui						Edit Date:	6/3/2021
TEST PLAN										TEST RESULTS	
Test #	Specification #	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING		Results	Notes on Testing
								Start date	Finish date		
5	5	Record the time it takes to go through the process of setting up the device. Compare the time to that of the recorded current process.	Set up time	<5 seconds	Beehive Boxes, Pallet, Weights, Stopwatch	VP	Javier	4/29/2021	5/18/2021	Average of 6 seconds	We started the cycle at 6ft away from the edge of the pallet to the base of the wheel. The average of the runs was 6.0 seconds but the last runs from every person were lower than 5 seconds. This shows that practice will make the new process faster.
6	6	Verify the clamping motion by the attaching arm is smooth.	Observation	Pass/Fail	Beehive Boxes, Pallet	SP	Jose	3/10/2021	5/18/2021	Pass	The rotating motion of the attaching arm is smooth and stable at 90 degrees. This was done with the help of a gas damper that was recently added. The clamping motion is smooth as long as it is done in one fluid motion.
7	7	Verify the top box is clamped firmly by the attaching arm.	Observation	Pass/Fail	Beehive Boxes, Pallet	SP	Kyle	3/10/2021	5/18/2021	Pass	The top box is now firmly clamped by the attaching arm. The friction pads added made a big difference. The ataching arm was able to secure a 100 pound box during one of the tests.
8	8	Verify the attaching arm secures the top cover of the beehive	Observation	Pass/Fail	Beehive Boxes, Beehive Lid, Pallet	SP	Ryan	3/10/2021	5/18/2021	Pass	The foam spacers added since the last time it was tested are a big improvement. And even though they will work, we will add more permanent spacers once they are delivered.

Appendix P: User Manual

This user's manual includes instructions for use and important safety information for the Beekeeper Assist. Read this section entirely including all safety warnings and cautions before using this device.

Using the Beekeeper Assist

The following instructions describe how to use the Beekeeper Assist in its intended function, which is to lift and rotate the top bee box in a two-box stack.

Attaching to the Bee Box

Follow these directions to attach the Beekeeper Assist to the bee box in question.

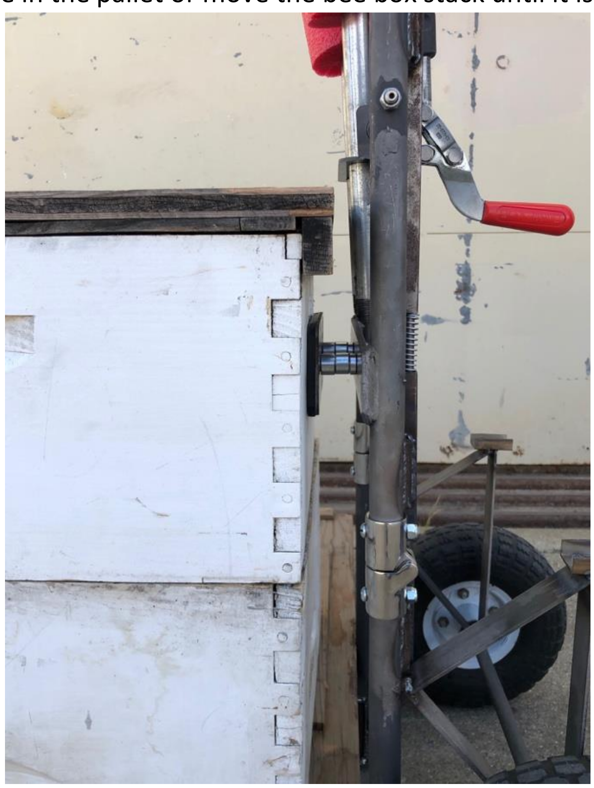
1. Wheel the Beekeeper Assist in front of the desired bee box stack, specifically in front of the hole in the pallet directly beneath the stack.

2. Push the forks on the base of the Beekeeper Assist as far as possible into the hole in the pallet. This may require applying some force to the bottom of the Beekeeper Assist, depending on the terrain.

Caution: For step 2, the attachment arm must be in the upright configuration, comfortably set into the holder clamps. If they are not in this configuration, the Beekeeper Assist will not be able to properly attach to the box.

Appendix P: User Manual

3. Ensure that the back plate is flush with the top bee box. If it is not, push the Beekeeper Assist further into the hole in the pallet or move the bee box stack until it is flush with the back plate.

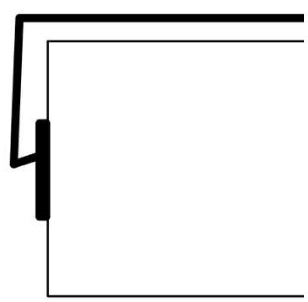


4. Pull the attachment arm out of its clamps and lower it until the spacer makes contact with the box.

Appendix P: User Manual

5. Pull the toggle clamp handle all the way back. Ensure that the front plate is flush with the box now that it is compressed.

<u>Caution:</u> For step 5, if the front and back box plates are not flush with the box, do not attempt rotation. Ensure that you have heeded the caution of step 2. If that does not work, adjustments may need to be made to the length of the attachment arm; instructions for this adjustment can be found in the Maintenance section.



Rotating the Bee Box for Inspection

Once the Beekeeper Assist is attached to the bee box, follow these directions to rotate the bee box downwards for inspection.

1. Pull the pins out of the hinge.

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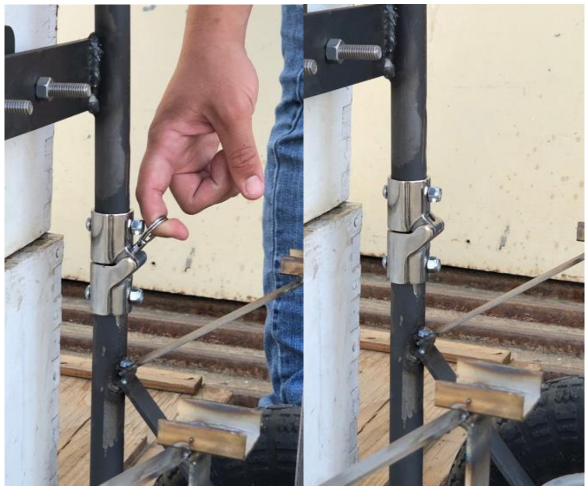
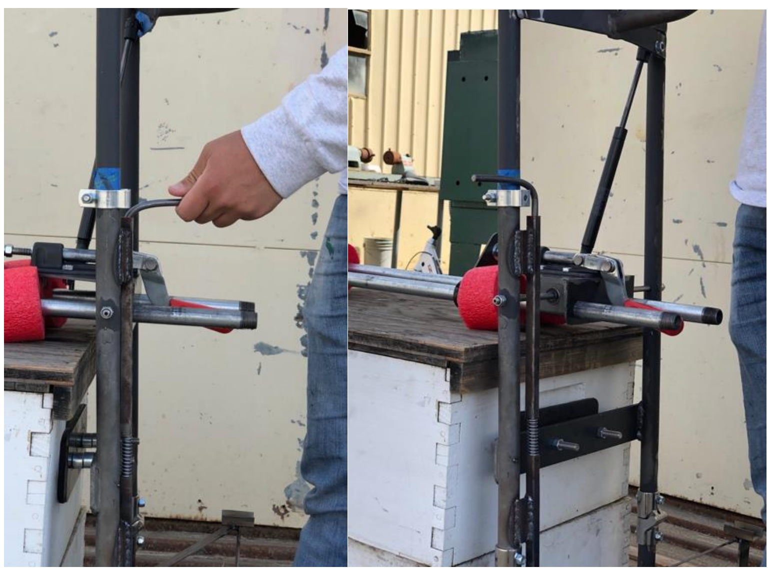


2. Pull the plunger handle up and rotate it into its holder.

Caution: For step 1, if the plunger handle is not rotated into its holder, it might become damaged when the bee box is rotated back into the upright position. If the plunger is not put into the handle, be sure to lift the plunger back up before rotating to the upright position.



3. Pull the top handle of the Beekeeper Assist and slowly rotate it 90° downwards. After rotation, it should rest comfortably on the lower half's supports.

Caution: For step 2, it is critical to keep a firm grip on the top half of the Beekeeper Assist as it is rotated back. If the top half drops, it could rattle the bees and/or damage the lower half's supports.

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Rotating the Bee Box to the Upright Position

Once inspection of the bee boxes is complete, follow these directions to rotate the bee box back into its original position.

1. Pull the top handle of the Beekeeper Assist and slowly rotate it 90° upwards.

Caution: If the plunger handle was not rotated into its holder before, it is critical to pull the plunger up and hold it (or put into its holder) before fully rotating upright. Failure to do so could result in the plunger being damaged and the top half not fully locking into the upright position.

2. Rotate the plunger out of its holder and let it fall into place, locking the rotation of the top half.

Detaching from the Bee Box

Once the top half has been rotated back into the upright position, follow these directions to detach from the bee box.

1. Pull the toggle clamp forwards all the way into its original position.
2. Grab the end of the attachment arm and lift it back into its upright position. Ensure that it is fully secured in its attachment clamps.
3. Pull the Beekeeper Assist out from underneath the pallet. Lean the device back on its wheels and move on to the next task.

Movement and Storage

This section provides guidance for moving and storing the Beekeeper Assist.

Moving the Beekeeper Assist

When moving the Beekeeper Assist between inspections, tilt the device back and move it around on its back wheels. If it is necessary to put the Beekeeper Assist into the back of a truck, make sure that the plunger is down (locking rotation), and that the attachment arm is in the upright position. In addition, try to avoid setting the dolly onto the plunger so as to avoid damaging it.

Storing the Beekeeper Assist

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It is recommended to store the Beekeeper Assist indoors, preferably in a cool, dry environment. The device can be left outside, although it is recommended to at least provide some shelter from rain and the elements.

Maintenance

This section provides directions and guidance for adjustments, maintenance, and replacement of parts for the Beekeeper Assist.

Adjusting the Length of the Attachment Arm

This section details how to adjust the length of the attachment arm. This should only be done if the front plate is not flush with the top bee box after the toggle clamp is engaged.

1. Follow steps 1-4 for Attaching to the Bee Box.
2. Using a 9/16” wrench, adjust the bolt attaching the attachment arm to the toggle clamp until the front plate is flush with the bee box.

Replacement and Repairs

It may be helpful to review the assembly process above before removing the necessary parts to repair or replace. To make a replacement part, follow the process in the Manufacturing section of this report. Many parts on the Beekeeper Assist can be purchased at a typical ACE hardware store such as: the ¾” galvanized pipes on the attachment arm, the standard rubber wheels, and any of the fasteners on the device.

Other parts that are not welded together can be purchased online from various suppliers, such as McMaster-Carr, such as: The attachment arm toggle clamp, the attachment arm pipe collets, the rubber pads on the attachment arm plates.

If a welded section or part breaks on the device, the device should not be used until the part is repaired. It is recommended to have a professional welder or similar method. Most welds are done on 1/8” mild steel and are easily weldable via any method: stick, MIG, or TIG.

Lubrication:

The Beekeeper Assist has several moving components but there are a few components that will require lubricating. The first component would be the toggle clamp which would require one or two sprays of WD-40 lubricator on the toggle clamp moving components. The second component would be the locking mechanism which would require a couple sprays of WD-40 lubricator on the areas that come in contact with the locking mechanism guide. And the last components would be the small ball joints at the damper connections.

Appendix P: User Manual



Appendix Q: Test Procedures

Test Name: Clamp Effectiveness Test

Purpose: To ensure the motion of the attachment arm (both clamping and swinging) is repeatably smooth and efficient.

Scope: This test is only meant to test the attachment arm.

Equipment:

- Top dolly with attachment arm attached
- Wooden bee boxes and pallet
- 0-6" Digital calipers

Hazards:

- Heavy weights can fall and cause injury if not placed properly.
- The toggle clamp can crush hands if not placed properly.
- Hands can get caught in the pinch point of the hinge if not placed properly.

PPE Requirements:

- Safety glasses
- Work gloves

Facility:

- Mustang '60 Machine Shop, Cage Area

Procedure:

1. Align top dolly with bee box assembly.
2. Swing the attachment arm down from its upright position.
    a. Make notes of any inconsistencies in the motion.
        i. If the arm swings down smoothly, mark a "Pass".
3. Once the attachment arm is over the box, pull the toggle clamp back all the way.
    a. If the toggle clamp cannot pull back all the way, loosen the bolt connecting the arm to the toggle clamp.
    b. Measure the distance between the head of the bolt and the very edge of the toggle clamp arm and record it.
4. Visually inspect the front and back plates. Look to see that the rubber has been compressed and try to move the box from underneath the plates.
    a. If the box does not move, mark a "Pass".
5. Visually inspect the top of the bee box. Look to see that it is held in place by the attachment arm and will not come off. Try lifting the lid off while it is clamped.
    a. If the lid will not lift off, mark a "Pass".
6. Lift or rotate the clamped bee box and top dolly.
    a. If the box does not fall out when lifted, mark a "Pass".
7. Repeat Steps 1-6 four more times.

Appendix Q: Test Procedures

Results:

Question/Parameter	Value	Notes
Does the attachment arm swing smoothly?	PASS	
Distance between the head of the bolt and the edge of the toggle clamp arm	2 in	This distance ended up being adjustable in the final design, we had it here as 2 inches for posterity.
Does the box move when provoked?	PASS	
Does the lid stay on?	FAIL	Spacers required to bridge gap between arm and box lid
Did the box stay on?	PASS	

Test Date(s): 5/18/2021

Performed By: Kyle Ladtkow

Appendix Q: Test Procedures

Test Name: Operating Time

Purpose: Record the time it takes to rotate the box and return it to its original position. Compare the time to that of the recorded current process. The set up time of the dolly on a beehive will be performed on a different test.

Scope: Verification prototype of the full dolly.

Equipment:

- Full dolly assembly
- Stopwatch
- Wooden bee boxes
- Pallet

Hazards:

- If arm does not clamp properly, box may fall and injure someone
- Going too fast may cause moving parts to slip, causing injury

PPE Requirements:

- Safety glasses

Facility:

- Mustang ’60 Machine Shop, Cage Area

Procedure:

Set up:

1. Set up the pallet with the beehives that are going to be used for the test.
2. Have one person be ready with a stopwatch to record operation time.
3. A different person should have the device ready to operate on a beehive. The dolly should be secured on the beehive by having the forks fully inserted in the pallet.
4. The same person should operate the device for all ten trials.

Conducting the test:

1. Start the time on the stopwatch.
2. Lower the attachment arm on to the top of the beehive.
3. Pull on the lever to clamp the top box of the beehive.
4. Unluck the top half of the dolly by pulling on the handle on the side to allow for rotation.
5. Pull on the top half of the dolly to rotate it 90 degrees.
6. Return the dolly to its upright position and make sure the hinge lock is engaged.
7. Unclamp the top box.
8. Pull the attachment arm up and make sure it is secure at the top of the dolly.
9. Stop the timer and record the time of operation.
10. Repeat steps above ten times to create a distribution curve.

Appendix Q: Test Procedures

Concluding the test:

1. Verify the attachment arm is secured on its upright position and the hinge lock is engaged.
2. Return dolly to safe location.

Results:

Run	1	2	3	4	5	6	7	8	9	10
Time	13.39	11.61	10.38	10.69	11.46	8.56	7.60	11.82	9.49	10.72

Average Time (Total Rotation): 10.57s

Average Time (Back): 5.29s*

*When we wrote this procedure, we assumed that the vital component was total time. However, we ended up really needing to know the average time to rotate back. We think it's a reasonable estimate to assume that the rotation back and the rotation forward took the same amount of time.

Test Date(s): 4/29/2021

Performed By: Jose Velazquez

Appendix Q: Test Procedures

Test Name: Required Pull Force for Box Weight

Purpose: To determine the maximum weight that the top dolly can hold, as well as to characterize the required pulling force needed to bring the dolly out of rest.

Scope: This test is only meant to test the top dolly and the attachment arm.

Equipment:

- Full dolly assembly
- Force gauge
- Weight scale
- (8) 10-pound gym weights
- Wooden bee box
- (2-3) Cinder blocks
- 0-6” Digital calipers

Hazards:

- Heavy weights can fall and cause injury if not placed properly
- Hands can get caught in the pinch point of the hinge if not placed properly
- If the bottom dolly is not weighed down or restricted, the dolly can fall over and cause injury

PPE Requirements:

- Safety glasses
- Gloves

Facility:

- Mustang ’60 Machine Shop, Cage Area

Procedure: (List number steps of how to run the test, can include sketches and/or pictures):

1) Weigh down the bottom dolly plate with cinderblocks.
2) Calibrate the scale and force gauge.
3) Measure zero/tare.
4) Fill box with 10 pounds and weight.
5) Place the box in the attachment arm.
6) Measure deflection in the attachment arm with calipers
7) Use force gage to pull back top dolly recording the force just before it starts to rotate.
8) Repeat step 6 for the same weight two more times.
9) Remove box from the attachment arm.
10) Repeat steps 4-9, incrementing the weight by 10 pounds each time until 80 pounds is reached.

Appendix Q: Test Procedures

Results:

Desired Box Weight (lbs)	Actual Box Weight (lbs)	Force Required to Pull #1 (lbs)	Force Required to Pull #2 (lbs)	Force Required to Pull #3 (lbs)	Average Force Required to Pull (lbs)
15 (just box)	15.0	12.17	12.75	11.97	12.30
40	40.8	21.11	20.25	22.23	21.20
50	50.6	25.41	26.64	27.00	26.35
60	61.2	28.77	30.75	28.31	29.28
70	71.4	32.23	33.58	34.10	33.30
80	81.8	33.67	37.73*	34.76*	34.76

*Our strings for this test broke repeatedly. We used data from our first round of data collection and applied the average bias from this round.

Test Date(s): 5/20/2021

Performed By: Kyle Ladtkow, Ryan Heryford

Appendix Q: Test Procedures

Test Name: Required Set-Up Time Procedure

Purpose: To determine how long it will take to set up the Beekeeper Assist dolly in order to begin the beehive inspection.

Scope: The ultimate goal is to set up the dolly in under 5 seconds in order to prove that it will be as proficient as when Alejandro was doing the beehive inspections prior to having the dolly. This will be done once the dolly is completely assembled.

Equipment:

- Full dolly assembly
- Pallet
- Original beehive boxes
- Stopwatch

Hazards:

- Tripping hazard as you are maneuvering the dolly into position.
- Pinching hazard when the bee box is being clamped against the dolly. Be mindful of where your hands are positioned.
- Smashing hazard when you weights are being placed in the bee box. Ensure you are not dropping the weights and you are placing them in the bee box slowly.

PPE Requirements:

- Safety glasses
- Gloves

Facility:

- Mustang '60 Machine Shop, Cage Area

Procedure:

1) Set up pallet and bee boxes in area with ample space in order to be able to maneuver the dolly.
2) Start stopwatch.
3) Maneuver dolly into position ensuring the dolly forks are aligned with the pallet
4) Ensure the back box support is aligned with the bee box.
5) Lower the BeeKeeper assist clamping arm
6) Pull the toggle clamp to brace the bee box in place.
7) Stop the Stopwatch
8) Record the time.
9) Steps 2-8 will be repeated 10 times by everyone on the team to calculate an average time.

Appendix Q: Test Procedures

Results:

Test Runs (Javier)	Time (s)	Test Runs (Kyle)	Time (s)	Test Runs (Ryan)	Time (s)	Test Runs (Jose)	Time (s)
1	6.61	1	8.64	1	8.76	1	6.34
2	4.59	2	6.84	2	9.56	2	9.24
3	4.39	3	6.69	3	8.45	3	7.24
4	4.76	4	6.59	4	7.37	4	5.88
5	4.21	5	5.41	5	7.29	5	5.74
6	3.45	6	5.07	6	6.21	6	5.92
7	3.88	7	4.62	7	5.95	7	5.49
8	4.36	8	6.45	8	5.79	8	6.63
9	5.12	9	7.7	9	5.02	9	5.80
10	3.64	10	6.27	10	3.85	10	4.38
Average	4.50	Average	6.428	Average	6.83	Average	6.27

Test Date(s): Tuesday May 18, 2021

Test Results: We started the cycle at 6ft away from the edge of the pallet to the base of the wheel. The average of the runs was 6.0 seconds but every person had times that were lower than 5 seconds. This shows that practice will make the new process faster.

Performed By: Javier Guerra, Kyle Ladtkow, Ryan Heryford, and Jose Velazquez

Appendix Q: Test Procedures

Weight of Device Test Procedure

Test Name: Verification of weight of the device.

Purpose: Verify the device weighs a maximum of 60 pounds to allow for easy lifting on to a pick-up truck.

Scope: Verification prototype of the full dolly.

Equipment:

- Full dolly assembly
- Scale

Hazards:

- Mishandling of the device can cause it to fall, causing injuries

PPE Requirements:

- N/A

Facility:

- Well-lit room

Procedure:

Set up:

1. Have the verification prototype of the device.
2. Prepare a scale to measure the weight of the device.

Conducting the test:

1. Make sure attachment arm is secured at its upright position.
2. Set the prototype on top of the scale.
3. Record the weight of the prototype.

Concluding the test:

1. Return dolly to safe location.
2. Return scale.

Appendix Q: Test Procedures

Results:

	Weight (lbs)
Verification Prototype	50.4

Test Date(s): 4/29/2021

Performed By: Jose Velazquez

Appendix Q: Test Procedures

Test Name: Weighted Bee Box Rotating Test.

Purpose: To determine if the dolly can lift and rotate a 60lb-80lb box full of weights which is a representation of a bee box full of honey.

Scope: The ultimate goal is to test the dolly's ability to clamp a bee box that contains 60lbs and the dolly can rotate the bee box easily.

Equipment:

- Full dolly assembly
- Pallet
- Original beehive boxes
- Gym weights or a set of Bow Flex adjustable weights. Must be able to change weight ranging 60-80 lbs.

Hazards:

- Dropping hazard as the bee box full of weights is being rotated.
- Pinching hazard when the bee box is being clamped against the dolly. Be mindful of where your hands are positioned.
- Smashing hazard when you weights are being placed in the bee box. Ensure you are not dropping the weights and you are placing them in the bee box slowly.

PPE Requirements:

- Safety glasses
- Gloves
- Steel toe boots

Facility:

- An area where there is ample space. Area approximately 10'x10'

Procedure:

1) Set up pallet and bee boxes in area with ample space in order to be able to maneuver the dolly.
2) Place the weights into the top bee box slowly.
3) Maneuver dolly into position ensuring the dolly forks are aligned with the pallet.
4) Ensure the back box support is aligned with the bee box.
5) Lower the BeeKeeper assist clamping arm.
6) Pull the toggle clamp to brace the bee box in place.
7) Rotate the dolly 90 degrees to move the top bee box out of the way.
8) Rotate the upper dolly assembly back to original position.
9) Add 5lbs and repeat steps 2-8 until a maximum of 80lbs is reached.

Appendix Q: Test Procedures

Results:

Test Runs	Weight (Lbs)	Pass	Fail
1	60	√	
2	65	√	
3	70	√	
4	75	√	
5	80	√	

Test Date(s): 5/18/2021

Performed By: Javier Guerra