Final Design Report

Personal Utility Cart

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Executive Summary

This final design report will detail the entire engineering design process from conceptualization through manufacturing and testing. After introducing the topic and scope of the project this document presents all of the benchmarking and research performed in order to obtain as much information about similar current products and possible solutions. Next the objectives of the project are presented where the needs are transformed into engineering specifications that will guide the design of the product. Design developed is then presented with ideation, idea evaluation and selection, analysis, manufacturing considerations, and final design selection. The final design is then presented with each of its three subsystems, including supporting analysis, manufacturing and testing plans, bill of materials and cost as well as material selection, safety considerations, and maintenance plans. Following that is the management plan where team roles are outlines and project deadlines are presented. Product realization is next, which includes the manufacturing process that was taken for all components as well as description of changes between the planned and built design and recommendations for future manufacturing changes. Design verification follows with testing procedures and results and a final budget for the manufactured design. Next are conclusions that summarize what was done during the project and recommendations which outline what could have been done differently from a design or project standpoint to provide insight for future designs. References for all researched information are included in order cited throughout the document. Finally all appendices are included at the end of the document that were referenced throughout the report as well as other important information.

1.0 - Introduction

Current retail carts are inefficient and are only useful on the premises of a store requiring customers to unload items from a cart into their vehicle, and then from their vehicle to their final destination. People need an easy, fast and convenient way to transport their items from a market directly to their preferred location without having to continuously load and unload their items.

Our team consists of three mechanical engineering students at the California Polytechnic State University in San Luis Obispo, all working on our senior design project: Sean Portune, Eric Johnson, and Jason Munter. Michael Allwein, a local Cal Poly alumnus will be contributing some of his engineering knowledge as well as sponsoring this project. Mr. Allwein came up with the idea when his wife asked him if there was a way to make transporting groceries from the store to their home easier. Mechanical Engineering Professor Sarah Harding is our senior project faculty advisor.

The design challenge was to make a utility cart that can assist its users in both loading and unloading items into and out of a vehicle, as well as assist with the general transportation of goods in a variety of locations.

The goal of this document is to present the design and build process that was taken for designing the cart to meet all of the required specifications. All information from our Critical Design Review is included as well as new sections describing the manufacturing process, differences between the planned and built design, testing procedures, the final budget, conclusions and recommendations, and a user's manual.

2.0 - Benchmarking:

The benchmarking section will present and analyze current designs of various carts to compare their strengths and weaknesses. It will also lay out which aspects of their design work well and which can be mimicked or improved upon in our product.

2.1 - Bumper Heights

Our team measured numerous car bumper heights, widths, and depths, which are in Appendix A in order to determine the dimensional constraints of our design. The results indicate that the smallest constraint for the length of our utility cart will be designing it to fit in a crossover type vehicle, which had a cargo depth of 32 inches. The largest constraint for our height adjustability will be designing the cart to fit in a pick-up truck. The tallest pickup truck we measured was 40" off the ground. According to the shopping cart specs provided by Premier Carts (shown in Figure 1 below), our team will need to increase the height of the basket by 22" in order to be able to fit in 100% of the vehicles that we measured.

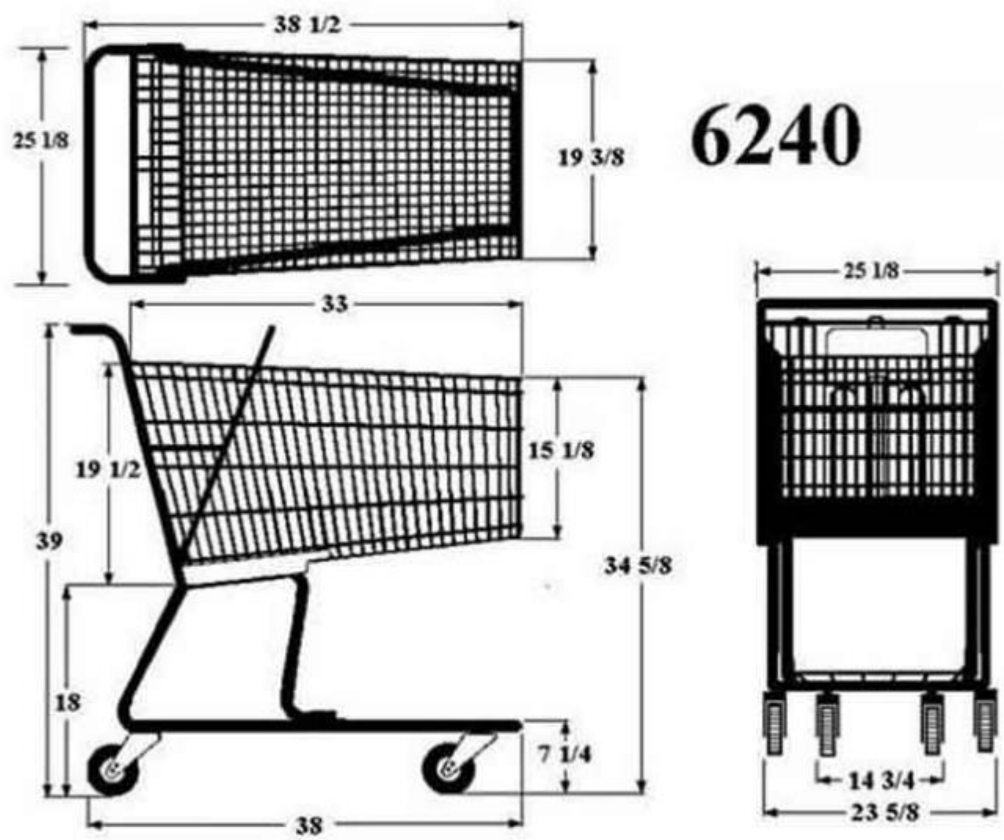

Figure 1: Shopping Cart Dimensions [1]

As shown in Figure 1, the height from the ground to the bottom of the basket is 18". Since our sponsor's car has a bumper height of 31", our target will be to raise the basket height by 13". Depending on the aesthetic of the cart, it may be better to use a cart that sits at 31" off the ground, or to utilize a height adjustability mechanism to temporarily increase the height for storage. Our sponsor's car has a depth of 39", so the largest length of our cart may be no more than 39".

2.2 - Traditional Shopping Carts

Since a traditional shopping cart lacks the ability to fit into a car, it is only useful on the premises of a grocery store. In addition, a grocery cart does not help a shopper with lifting heavy items. Many grocery shoppers are limited in their ability to transfer goods from the store to their residence. Any sort of mechanism that could ease the transition of groceries from the shopping cart to the car and from the car to the house could be highly useful for a variety of customers, specifically the elderly, sick, young, or even just a consumer who would enjoy reducing the time and difficulty of a grocery trip.

2.3 - Folding Carts
Our team looked into current designs of personal shopping carts out on the market. What we found was that most of these carts were low to the ground and resembled a dolly or suitcase shape with a similar method of rolling. These would not be ideal because they cannot hold enough weight, carry a normal amount of groceries, and most importantly require the user to load the entire basket into a vehicle. An example of one of these small folding carts is in Figure 2.

Figure 2: Minnie Mate Folding Cart [2]

2.4 - IDEO Shopping Cart
The IDEO engineering firm tackled a similar problem in 1999. Their task was to 'reimagine' the shopping cart. While our team is designing a multipurpose *utility* cart instead, it is impossible to ignore some the innovations that they made.

Figure 3: IDEO Shopping Cart [3]

One of said innovations was the unique back wheel design, which allows the straight facing wheels to turn slightly with a light push in order to assist turning and overall maneuverability. [4] The cart, in Figure 3, also had dual child seats with a play surface, allowing parents to feel more comfortable taking their small children shopping. [4] The most notable change from a traditional cart was the removal of the large central basket, replaced by many smaller plastic baskets. While this allows for more shopper flexibility, it reduces the carrying capacity of the cart overall, discouraging use from contractors, construction workers, or any other type of laborer.

2.5 - Folding Utility Carts

After both our sponsor and team noticed that contractors and other maintenance related jobs use folding utility carts when transporting tools or items from their truck to where they will be working we looked into what kind of carts are currently available. There are many different designs that incorporate a large amount of storage space in a small footprint while still maintaining mobility and easy access to items, Figure 4 shows three different designs that are available. These carts are useful because they achieve a very small folded dimension when they are not in use allowing them to be stored and transported easily without taking up much space. They are also made of lightweight materials that allows the user to easily lift and stow the cart into their vehicle or storage space. The carts are even able to carry from 150 to 350 pounds depending on the design and the materials used. [5] These carts give us valuable insight on folding designs, material selection, hinging mechanisms, and load capacity that we can implement and improve upon in our cart design. While these carts meet many of our requirements, they are not height adjustable and must be unloaded and loaded when they are stowed in a vehicle which are two requirements that are critical for our design.

Figure 4: Various Folding Utility Carts [5], [6]

2.6 - Salesmaker Carts

While furthering our research and benchmarking current products that are currently available we found a company that manufactures multiple carts that meet most of our requirements already. Salesmaker Carts are manufactured by the gurney and cot company, Ferno, and utilize much of the same technology and mechanisms that are used on medical gurneys and cots. The carts are basically a traditional roll in gurney with the top replaced with a flat high-friction surface to place large items on for transportation. The carts are designed to roll into a passenger vehicle by one operator with little effort and are also designed to be height adjustable, so they meet both of our critical requirements. Figure 5 shows three different cart designs that Salesmaker offers with various weight capacities and height adjustability. While these carts are able to stow into a passenger vehicle by one person, are height adjustable, and have a large load capacity they are also extremely expensive with all models costing in upwards of $2000. [7] They are also designed primarily to move heavy office equipment, like printers or copiers, or large boxes in a commercial or business setting and are not marketed toward the general consumer. They do not have any storage features for anything other than flat items; there are no walls or compartments to hold smaller items. [7] The width of the carts meet our specifications but the length is too long to fit in our sponsor's vehicle. This shorter length requirement poses some challenges because the stowing mechanism must be contained in the smaller footprint of the cart so we are limited on space. The carts have many useful features and are especially valuable for the stowing/folding mechanism, as well as the height adjustability. We can analyze and use some of their features as well as improve upon them and lower the cost in order to scale the technology for our utility cart.

Figure 5: Salesmaker Cart Roll In Gurney Design [7]

The Salesmaker carts are also very useful because they have multiple designs available to analyze to give us ideas and direction for our product. The three designs shown in Figure 5 are similar and achieve the same purpose but the stowing mechanism of each is unique. The cart on the left features a folding mechanism that uses rigid legs and support arms with lockable hinges to achieve the stowing ability. The pivot points on this cart are fixed in place and the legs are designed to fold into the same footprint as the top of the cart. There are release handles for the front and rear legs located at the front of the cart for easy access to ensure that the legs are locked and can be released when loading the cart into a vehicle. This cart is not height adjustable but the dimensions could be changed to accommodate different height vehicles. The cart in the center utilizes a similar lockable hinge design for the front leg but uses a sliding pivot mechanism for the rear legs. This design allows the supports to be mounted in the center of the cart for a cleaner look and less chance of the support getting caught on anything. There are also small sliding members that help control the folding motion as well as similar release handles at the front of the cart. The cart on the right of Figure 5 utilizes two sliding support mechanisms to allow the cart to fold as it enters a vehicle. This design also allows the entire cart to be height adjustable; as the supports are slid along their tracks the angle of the support legs changes, which changes the height of the cart. The wheelbase also changes as the cart is heightened or lowered; as the cart is lowered the wheelbase will increase which will make it more stable but will also make it less maneuverable in tight spaces.

Another product that is available from Salesmaker Carts that is not based on the traditional gurney design is shown in Figure 6. This design is height adjustable with telescoping tubes and spring pins but the top of the cart actually detaches from the base, allowing it to slide into the vehicle. [8] After the top in stowed in the vehicle, the base can be collapsed and folded for easy stowing into the vehicle along side the top. This is a design that we had not initially considered but there are clear advantages to it that we will evaluate and develop. One disadvantage is that even though the top is easily stowed into the vehicle, the base must be manually folded and then lifted into the vehicle separately which takes time and effort compared to the gurney models. The advantage of the gurney models and the goal of our product is to be able to load and unload items into a vehicle with as little time and effort as possible. While the removable top design allows you to load items into a vehicle without having to transfer them individually, this effort is now used to physically fold and lift the cart, which is a clear disadvantage.

Figure 6: Salesmaker Cart Removable Top Design [8]

2.7 - Patents

Patents of cart and gurney designs were reviewed in order to gain insight to what kind of mechanisms and combinations of mechanisms are available as well as how they work. They are valuable in the design of our product so we can see what already works and also what can be improved upon.

Ferno publishes a public list of their patents on their main web page, which is where we found a patent for a previous model of the Salesmaker cart. It is similar to the removable top design presented previously, but in this case the base is designed as a multi-link scissor mechanism that supports the weight and allows for height adjustability. Shown in Figure 7, the scissor mechanism is actuated with a worm gear and handle that allows it to be raised and lowered even with weight on the top. [9] This is an interesting design but still has the drawbacks of the other detachable top design, namely that you must physically stock the base after it has been collapsed. This base would also likely be heavier than the telescoping base and would not be able to fold on itself other than the scissor mechanism.

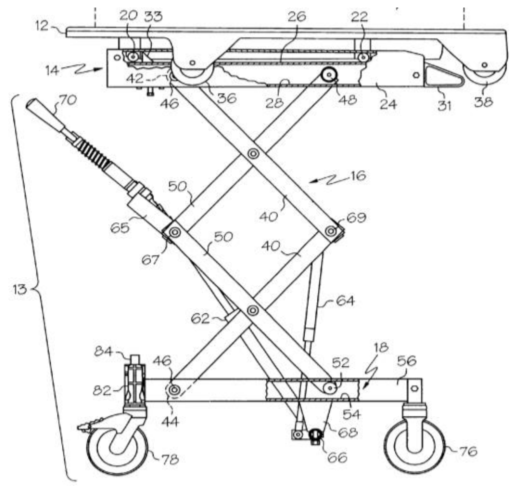

Figure 7: Scissor Mechanism with Detachable Top [9]

3.0 - Background:

The background section will detail all of the research we have done into different folding mechanisms, collapsible designs, and lifting ergonomics, which are all very important factors in our design.

3.1 - US Grocery Shopping Trends

According to the 'US Grocery Shopping 2014 Overview' released by the Food Marketing Institute, the amount of shoppers with 'no primary store' increased from 2% to 9% between the years 2011 to 2014. [10] This could be a promising indicator that shoppers are less tied to the brand loyalty of their favorite stores, and are more inclined to seek out the products they need through the most convenient medium that their circumstances produce. This growing customer base could be more inclined to value a personal utility cart that meets their needs at any location, rather than relying on variable circumstances surrounding various stores, such as the reliability of staff assistance in loading and the condition and availability of store-provided carts.

3.2 - Foldable Helmet

One of the designs we found interesting was the foldable helmet. This design inspired us since it is a design that can fold up to make storing easier and still embody a robust product when deployed. The hinging mechanism and the fact that the helmet nests and folds in on itself is very interesting, allowing a full size helmet to collapse into a small and portable size. Figure 8 shows the steps taken to fully fold the helmet, allowing it to reach a much smaller and more portable size. We are not entirely sure how the folding mechanism works since it is proprietary to the company and the product is not yet released, but we believe it is a combination of multiple joints and flexible material that allows it to collapse.

Figure 8: Collapsible Helmet Design [11]

3.3 - Ironing Board

In the initial project presentation our sponsor mentioned that he envisioned a device that is a combination of a classic shopping cart and a medical gurney. This was a very interesting thought and a good starting point for our research. There are multiple gurney designs that are available including the older model with the folding legs and the scissor lift mechanism (both powered and manual). The scissor lift mechanism works under the same principle as an ironing board, which is one of the first things we looked at as a simple collapsible/raising/lowering mechanism. As Figure 9 shows, it is a simple mechanism with a fixed pivot at one end, a sliding pivot at the other end, and a fixed pivot connecting the two legs together.

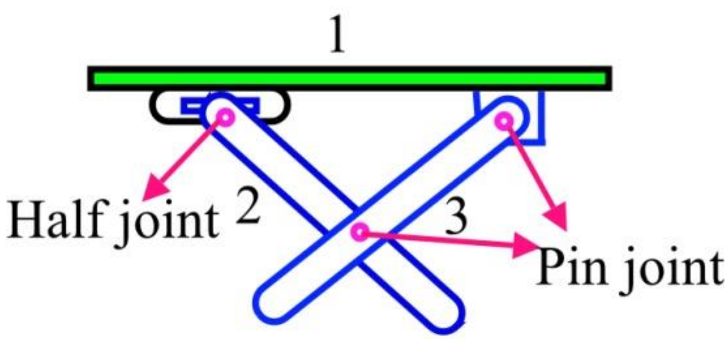

Figure 9: Ironing Board Joint Diagram [12]

These three simple joints combined with a locking mechanism allow the board to be height adjustable and hold a reasonable load. The locking mechanism of the ironing board is a simple one; there are notches that a rod fits into to make the height of the board adjustable. There is a release handle to lift the rod out of its notch to adjust the height, shown in Figure 10, but the table must be unloaded in order to release. This simple mechanism may not work for us since we will need the device to be height adjustable even when it is under load.

Figure 10: Ironing Board Locking Mechanism [13]

3.4 - Gurney Designs

Another design we found useful to look at was that of a modern gurney. Our team visited a local ambulance bay to see how the various mechanisms of a gurney work in person, as well as determine how long they take to load into a car. There were several mechanisms that could work for our cart. One of them was the way the gurney rolled into the ambulance. Some gurney designs require two people to load into the ambulance while some are able to be rolled in by just one person. We would want our product to allow for only one-person operation for convenience. Other mechanisms on the gurney that could be useful were the adjustable side rails and the incline/decline mechanism for the back. The adjustable side rails allowed for the rails to be put up or down easily so that it would make it easier to load or unload a gurney. The incline mechanism allowed for the back to be moved up and down easily and stopped at any point, making it infinitely adjustable.

The gurney design is more complicated than the ironing board in that the legs are telescoping to allow them to neatly fold underneath the body of the gurney without sticking out past the ends, unlike the ironing board where the legs are rigid. Extra linkages are also present alongside the main legs as supports and to dictate the motion of the legs as they expand and collapse. These features are shown in Figure 11.

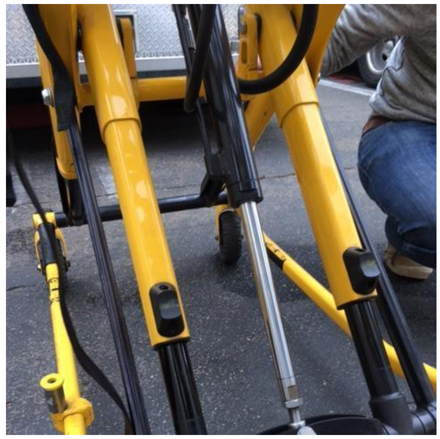

Figure 11: Telescoping Gurney Legs (*via Sean Portune*)

One issue with this X design is that the weight of the gurney (and patient) must be supported by the operator when loading or unloading. To make the experience as easy, convenient, and safe as possible, our device will require the operator to support as little weight as possible.

While the ironing board must be unloaded to expand or collapse the gurney is height adjustable with or without a load. For the manual version of the gurney shown in Figure 12, the locking mechanism is similar to that of the ironing board.

Figure 12: X-Joint Gurney [14]

A manual gurney mechanism is shown in Figure 13. There is a track with notches that allows the sliding joint to lock into place when it seats into one of the notches. [15] To release the mechanism a lever is pulled by the operator at the rear of the gurney that is attached to a rod that transfers the motion to the lever to the locking cam on the sliding joint. [15] When the lever is released the cam will seat into the next notch that it encounters, locking the height and supporting the load of the gurney and the patient. [15] There are also gurneys with the X-joint design that use a hydraulic cylinder to actuate the legs. The cylinder will support and assist in raising the load and the hydraulic pressure will support the weight of the gurney and patient at the desired height. [15] The hydraulic gurney is powered with a 24V battery pack and is heavier than the manual version but has the added convenience and ergonomics of the powered hydraulic system. [15]

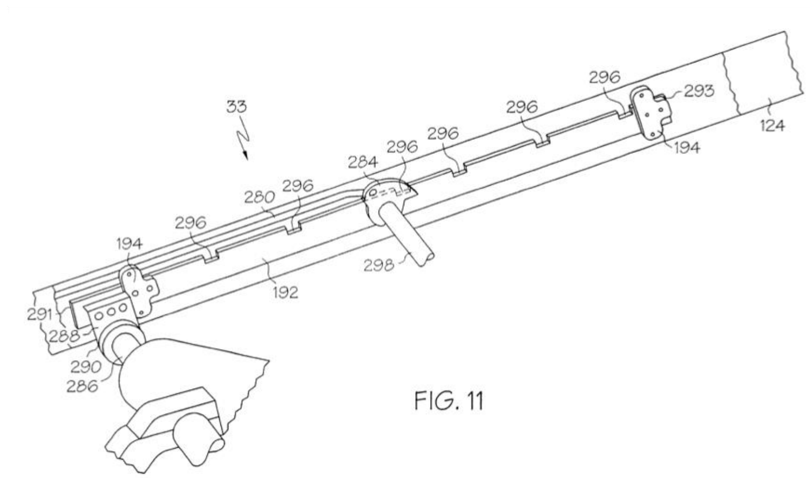

Figure 13: Manual Gurney Locking Mechanism [15]

Another gurney design that looks promising for our needs is the design with the folding legs shown in Figure 14. The legs fold up as they contact the rear of the vehicle and the legs closest to the operator support the weight of the device until it is almost completely stowed in the vehicle. [16] This is more convenient and requires less effort from the operator, but the challenge here is to make the device height adjustable while not damaging the user's vehicle. The legs lock into the down position with the supporting legs near a horizontal angle and the release lever at the back of the gurney is used to lower the legs when coming out of a vehicle or to unlock the legs to allow them to fold when entering a vehicle. [16]

Figure 14: Folding Leg Gurney [16]

There are also other variations of height adjustable and folding mechanisms used on gurneys that give good perspective for our project. They are each slightly different and have advantage and disadvantages in different situations, we will have to evaluate and test these different designs to determine which will best solve our problem. Some examples of three different mechanisms are shown in Figure 15.

Figure 15: Alternative Gurney Designs [17]

3.5 - Collapsible Designs

Our team also looked into adjustable and collapsible designs that could be helpful for idea generation and implementation for our device. We focused on the most interesting and unique mechanisms and also looked at a broad range of different mechanisms that allow for adjustability or size adjustment. One of the main mechanism that interested us was the X or scissor mechanism similar to the gurney that is used in scissor lifts where many crossed joints are pinned in the center and connected at the ends to achieve a large difference in size when the device is collapsed and expanded. A few interesting examples from the book *Collapsible* are shown in Figure 16.

Figure 16: Scissor/X Mechanisms [18]

The image on the left shows an expandable ladder and a scissor lift, the center shows a bed that is expandable, and the right shows a table that is collapsible for convenient storage. [18] These all prove that this mechanism can be used in a variety of ways. The main goal of this mechanism and all collapsible mechanisms is to achieve the largest amount of variation while maintaining the smallest package when in the collapsed state. [18] The scissor mechanism is a great example of this because it can expand to many times its collapsed length while maintaining a small and light package without many complicated parts.

Another mechanism similar to the scissor is the accordion mechanism, shown in Figure 17, that uses some sort diaphragm or folded material with or without an inner skeleton to achieve the same purpose of a large expanded area with a minimum collapsed one. An interesting aspect of accordion designs is that they do not have to be completely linear, they can expand on a radius as well as linearly which gives them more freedom than other mechanisms.

Figure 17: Accordion Designs [18]

The telescoping mechanism is also an interesting design that allows the device to collapse and stow into itself, minimizing space and maximizing size. This mechanism is utilized in some gurney designs and is useful to allow for adjustment and extra length when needed. While telescoping mechanisms are usually thought of as being cylindrical, they can actually be any shape as long as the pieces are able to effectively nest and collapse into one another. An example of both the circular cross section and square cross section telescoping mechanisms are shown in Figure 18.

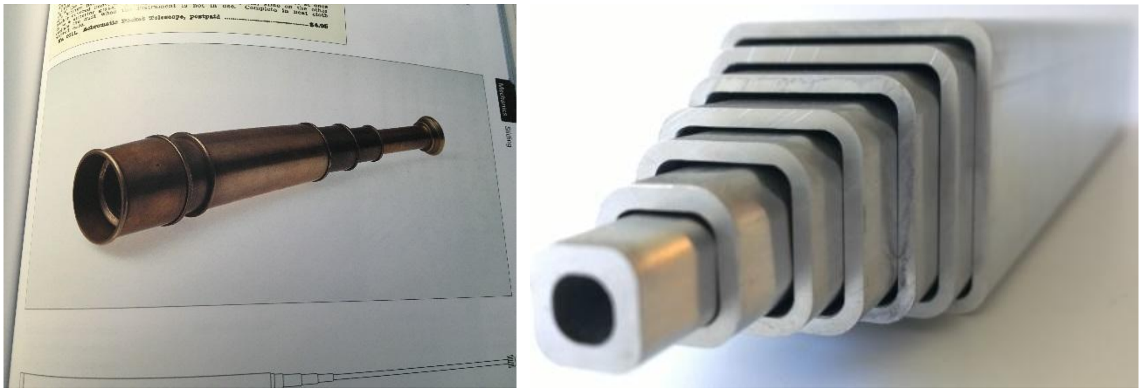

Figure 18: Telescoping Mechanisms [18]

3.6 - Telescoping Coffee Mug

Looking into the past senior project of the telescoping mug, there were a couple features that seemed, at the very least, interesting to us. The swiveling telescope of the mug shown in Figure 19 below seemed like a creative way to reduce the volume of an object when needed, to assist with storage.

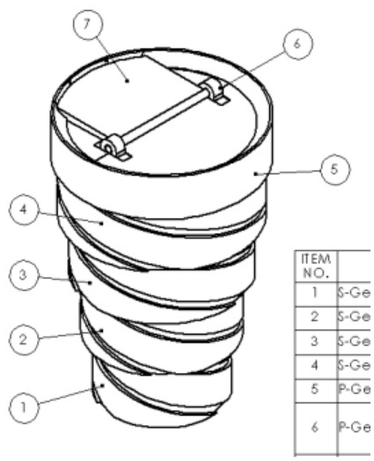

Figure 19: Collapsible Coffee Mug [19]

While this could be useful for a collapsible utility cart, our team has yet to decide if that function is entirely necessary, since it could also be detrimental in its ability to safely secure goods.

3.7 - Lifting Ergonomics

An important topic that we researched that is directly related to our product is how to safely lift objects. We must consider ergonomics in our design so that it is safe and easy for the user since the device will be moved into and out of their vehicle by one-person operation. The general safety rules for lifting objects with proper technique is in Figure 20. This technique is critical to avoid injury.

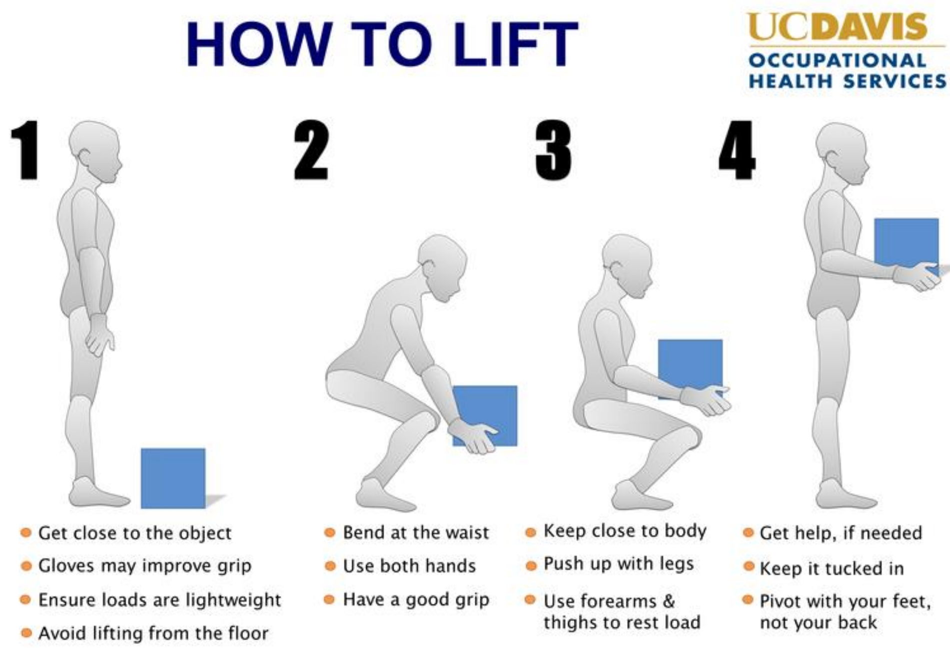

Figure 20: Proper Lifting technique [20]

In contrast the improper technique and unsafe lifting practice is shown below in Figure 21, the device operation should not be awkward or difficult and should allow the user to be in a safe a strong position when loading and unloading the cart.

Figure 21: Improper Lifting Technique [21]

Further investigating lifting ergonomics we looked to see if there are any OSHA standards for how much a person should lift. According to an article written by an OSHA representative, OSHA does not have any standard that which sets a limit on how much a person can lift. [22] However, there are guidelines and recommendations written to help people avoid injury during lifting tasks. These guidelines are based on research of the forces needed to cause damage to bones and ligaments. [22] According to OSHA loads above 50 lbs. can increase risk of injury. [23] They also say that bending your back, twisting while carrying something, and reaching far away to pick something up all increase risk of injury while lifting. [23] People often use all of these movements when unloading a shopping cart. Our goal is to ensure that the user is in a safe lifting position as shown in Figure 22. Having a cart that does not require repetitive loading and unloaded of items into a car would be a big help to people and could reduce fatigue and risk of injury from this process.

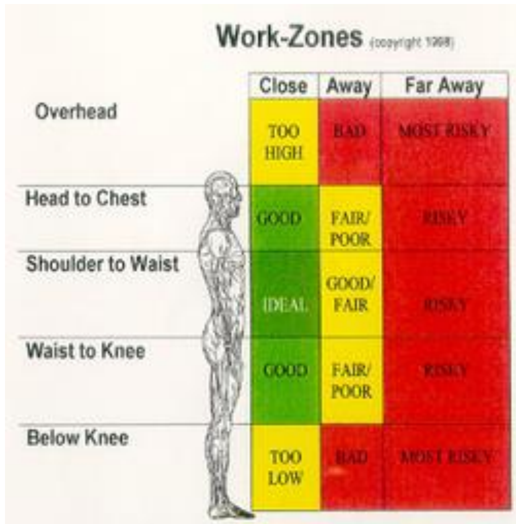

Figure 22: Lifting Zones [24]

3.8 - Standard Doorway Dimensions

Our team also researched standard doorway dimension in order to determine the constraint dimensions for our design since the idea is to be able to unload the cart from your vehicle and then wheel it all the way into your house or into other areas for convenience. There is no international standard for doorway width but most interior doors are either 28 or 30 inches wide. [25] The front door is usually a larger dimension with the interior doors being smaller, [25] but we will design to the smallest dimension so that the cart can fit through most if not all interior doorways in the house.

3.9 - Child Seat

After discussing the scope of our project with our sponsor and the fact that one of the main purposes of our design will be for a consumer shopping experience, we agreed to include a child seat into our design similar to those found on traditional shopping carts today. In order to do this we researched the designs of what is currently available in shopping carts and other children's seats. Current children's seats in shopping carts are simple and functional but may not be very comfortable for the child. The seats consist of a metal rod backrest, a plastic seating area, and metal leg holes as shown in Figure 23. The current design has square corners and is not contoured to a child's body; there is also a lot of extra space for them to move around if they are small.

Figure 23: Shopping Cart Child Seat [26]

There are some modifications and accessories on the market that can make the seat more comfortable and also safer for smaller children. There are fabric covers that provide cushion and support for the child when seated as well as safety straps to ensure there is no way for the child to move around or fall out of the cart. Figure 24 shows an accessory seat that are made of plastic contoured for a more comfortable seated position are also available to attach to the cart while shopping. This idea is a promising one because our design would likely utilize a removable child seat so that it would not need to be a part of the cart at all times.

Figure 24: Plastic Child Safety Seat [27]

3.10 - Consumer Safety Factors

As we move further into the design phase and start analysis and material selection, the safety factor or our design must be considered. We have researched typical engineering and consumer safety factors to determine what a reasonable value for our design would be in order to balance weight, cost, and safety. If the safety factor is too large, the cart will be over designed and become expensive and heavy, but if the safety factor is too small there is opportunity for part failure, which is not an option for our design. Safety factors vary by industry with aerospace having some of the lowest factors due to the fact that weight is a premium and the part must make its way out of the atmosphere. The parts must be designed to meet the specifications with very little room for error. On the other hand, in the consumer industry large safety factors are more common and will affect the cost and weight of the product.

Table 1 shows that the factor of safety will change depending on how much you know about the design and the materials you are using as well as what the important parameters of the design are. The more you know about the design, materials, and loading conditions, the lower the safety factor can be. The safety factor is basically a factor to make up for the uncertainty in your design, more uncertainty requires a higher factor or safety and vise versa. Based on Table 1 a factor of safety of 2-2.5 seems reasonable for our design because the materials we will use will be from a reputable supplier but likely not have certifications included, [28] it will operate in a normal environment subject to predictable loads that can be determined and checked using engineering calculations. We won't be using any unproven materials and would like the device to work with very minimal inspection and maintenance. The factor of safety will be kept as high as possible while minimizing weight and cost of the cart. The calculations will be based on loading, reliability, material properties, and engineering principles. [29]

Table 1: Factor of Safety Range [28]

Applications	**Factor of Safety - *FOS* -**
For use with highly reliable materials where loading and environmental conditions are not severe and where weight is an important consideration	1.3 - 1.5
For use with reliable materials where loading and environmental conditions are not severe	1.5 - 2
For use with ordinary materials where loading and environmental conditions are not severe	2 - 2.5
For use with less tried and for brittle materials where loading and environmental conditions are not severe	2.5 - 3
For use with materials where properties are not reliable and where loading and environmental conditions are not severe, or where reliable materials are used under difficult and environmental conditions	3 - 4

3.11 - Spring Pin Lock

There are multiple options for spring pin locks that we have investigated as possible solutions to lock our cart at a certain height or in a certain position. The first option is a button clip or locking clip shown in Figure 25.

Figure 25: Locking Clip [30]

This design can be used in telescoping or sliding applications and only requires a body to hold the clip in place and a hole at a specific location to allow the pin to spring out and lock the device in place. This is a very simple and inexpensive design that is easy to operate and familiar to most people. The operator simply presses on the pins to compress the spring to clear the locking hole and then slides the part to the next hole where the clip automatically springs out and locks in. This design is used in crutches and telescoping table legs for height adjustability. It is a proven design, is safe and easy to use, and could be adapted to a telescoping, sliding, or other design. One issue with this design is keeping the clips aligned with the plane of the locking holes. They can sometimes rotate out of the plane causing difficulty with correct reorientation. [30] Further analysis will also be required to determine if they are capable of supporting the load required by our cart.

3.12 - Pull Pin

A simple option for locking that would not require any springs or multiple parts to assemble or align would be a pull pin as shown in Figure 26.

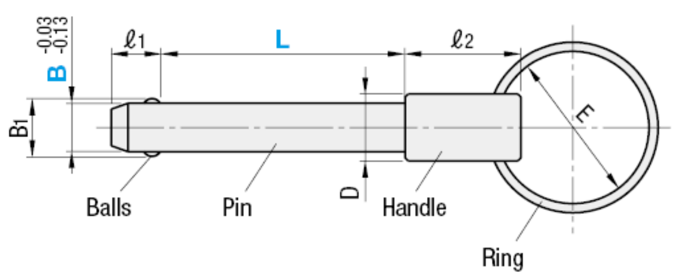

Figure 26: Pull Pin [31]

This mechanism would only require a pin and a clearance hole on both sides of the tubing or other structural material that needed to be locked in place. [31] The balls on the end of the pin can compress slightly and provide interference when fully inserted to ensure that the pin will not back out on its own. [31] Holes at multiple locations could be drilled to make the mechanism adjustable in specific increments.

A problem with this design is that holes must be drilled in the material which will compromise its structure and load bearing capabilities. This can be minimized by limiting the amount of adjustment holes but this will also limit the resolution of the adjustment of the device. The mechanism is not infinitely adjustable and is dependent on the location and number of holes that are available in the material. This mechanism would also require the device to be free of load in order to safely unlock and adjust it if the pin is load bearing.

For added safety to ensure that the pin will not come out due to vibration or other means, a threaded pin like the one shown in Figure 27 could be used. This design has similar disadvantages to the simple pull pin but is much more secure. It will require more time to lock and release however which is not as convenient for the user. The threaded design also requires threaded holes on the locking surface which requires more machining time and is difficult to achieve with thin walled material.

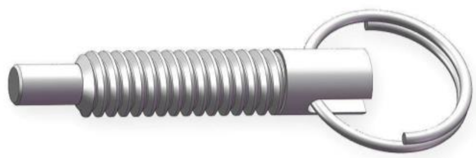

Figure 27: Threaded Pin [32]

3.13 - Ratcheting System

Another option for locking and adjustment is a ratcheting system that would allow the device to move in one direction freely, but automatically lock if it were to move in the other direction. A ratcheting system is safe and automatic, it does not require user input to engage, only to disengage. The resolution of the system can also be very small allowing for fine adjustment when the notches are placed close together. Figure 28 shows a simple linear and radial ratcheting system which can lock linear and angular motion respectively.

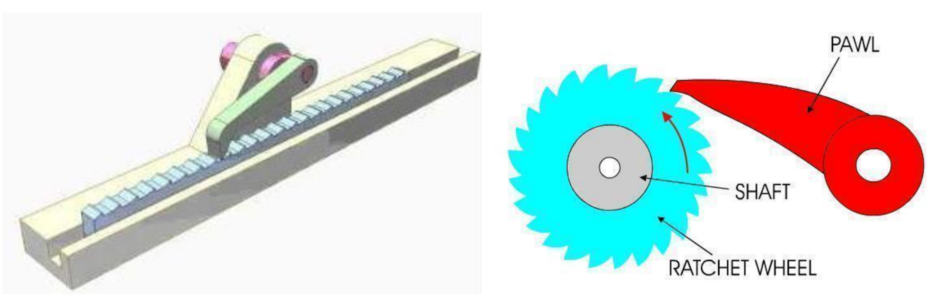

Figure 28: Linear (Left) and Angular (Right) Ratcheting Mechanisms [33]

4.0 - Objectives:

Our team's overall goal is to design, build, and verify a preproduction utility cart in accordance with the specifications listed in Table 1.

4.1 - Needs List

In order to find the engineering specifications that we would use to guide the design of our product, we first had to determine what the customer needs and requirements were. In order to do this, we interviewed our sponsor who is our main customer, as well as retail shoppers, and used our own experience. From this we were able to generate a list of non-technical needs and requirements from the users of this product. The requirements and needs we determined are as follows: safe, reliable, large volume capacity, simple design, low cost, light-weight, durable, large load capacity, customizable personal aesthetic, maneuverable, ergonomic, easy to operate, versatile, adjustable, easily manufactured, and low maintenance.

4.2 - Quality Function Deployment

We obtained our engineering specifications using a Quality Function Deployment (QFD) exercise which is shown in appendix B. The QFD exercise is a tool used to help analyze customer requirements, competitor products, and correlations to help determine quantifiable and testable engineering specifications. To acquire our engineering specifications, we first developed a customer needs list. This came from things we learned from interviewing our sponsor, observations, and research results. Once we had developed a thorough customer needs list, we input it into a QFD template and rated each requirement with importance ratings. The next step was to include some of the current products out on the market that can do some of the tasks we want our product to be able to perform. We then rated them on how well they fulfilled each customer need. From here, we could see which customer needs were the most important. Finally, we determined our engineering specifications, which were then also given a score on the strength of their relationship with the customer needs. The template calculated a relative weight for each specification. The last thing to do was to decide on the numbers that we would use for each specification. We decided this based on some of the research and benchmarking that we did as well as from the results of the QFD table. All of the ratings for the table and final numbers on specifications were decided by a group consensus. The results of the QFD table showed us that height adjustability, one-person operation, and obstacle navigation are our most important specifications based on the customer's' needs list and handle height was one of the less important specifications. The specification with the lowest score was no visible damage to vehicle, however we are ignoring this result because we are making this a constraint for our device.

4.3 - Specifications

We determined the following specifications in Table 2 to be reasonable for the scope for our project this year. The risk column shows the risk of meeting each engineering specification based on our current knowledge of the problem. Risk is rated High (H), Medium (M), or Low (L). The compliance column is how we will verify whether each engineering specification has been met. This category will be determined by analysis (A), test (T), and inspection (I).

Table 2: Engineering Specifications

Spec. #	Parameter Description	Requirement or Target	Tolerance	Risk	Compliance
1	Mechanism Operation Time	1 [min]	Max	M	T
2	No Visible Damage to Vehicle	Constraint	None	M	T, I
3	Footprint of Cart in Car	27 W x 36 D [in]	Max	L	T, I
4	Height Adjustability	23 – 33 [in]	±1 in.	H	A, T, I
5	Weight	50 [lbs]	±10 lbs.	M	A, I
6	One-Person Operation	Constraint	None	L	T
7	Weight Capacity	200 [lbs]	Min	M	A, T
8	Final Prototype Total Cost	$500	Max	H	A
9	Vehicle Adaptability	Fits into sponsors car	Min	M	A, T, I
10	Service Life	5 [years]	Min	H	A, T
11	Handle Height	42 [in]	±6 in.	M	A, I
12	Track Width	28 [in]	Max	M	A, I
13	Wheelbase	32 [in]	±3 in.	L	A, I
14	Stowable Dimensions	46 W x 28 D x 12 H [in]	Max	L	A, I
15	Safety Factor	2	Min	M	A, T, I

We determined our target for Specification #1 by comparing how long it takes for an EMT to load a gurney into an ambulance. It took about 20 seconds for a skilled EMT at a local ambulance bay in San Luis Obispo to load the gurney into an ambulance, so we determined that increasing that time by a factor of 3 was fair. Specification #2 is a constraint because we will not tolerate any damage to a vehicle from operation of the cart. Specification #3 is based on minimum doorway dimensions of 28 inches because we want our design to fit through a standard interior doorway. This will not cause any issues with fitting into our sponsor's car since the doorway is a tighter constraint. Specification #4 is based on measurements taken from a retail store shopping cart as the low height and the height of our sponsor's car. Specification #5 is based on weight of a retail store shopping cart. Specifications #6, 7 and 8 are requirements for the cart set by our sponsor. Specification #9 is determined by our sponsor's vehicle because this is what we are designing our initial prototype to be. Specification #10 is a target goal for a reasonable lifespan of a consumer product, however this may be difficult to determine. Specification #11 and #13 are based on measurements taken from a retail shopping cart. Specification #12 is based on an average doorway since we will require that the cart fit through a doorway. Specification #14 is based on dimensions from our sponsor's vehicle. Specification #15 is based on the industry-standard factor of safety.

We rated the height adjustability as a high risk specification because we do not know enough about the mechanism we will use or how much adjustability will be available depending on our design. The production cost was also rated as high because it is dependent on our design and the materials we end up using. It is a function of how complicated the device is, how much adjustability it has, and how durable it is. Service life is the last requirement rated as high. We have no way of testing the life cycle of our device so there is no way to accurately determine this. For the purposes of this project, we will be using standard, easily obtainable, quality products and making a simple, durable, and maintainable design. We can only estimate the lifespan of our device through calculations with many assumptions that reduce credibility.

We removed Specification #16 from the previous report, which was to add a child seat capable of safely transporting a child under 3 years old. The reason for this, is that it added liability concerns for Cal Poly, so our advisor made a judgement call to not include a child seat.

5.0 – Design Development

We began our concept selection by doing several different ideation exercises in order to generate as many solutions and design options as possible. Once a multitude of designs were available we used go-no-go criteria to eliminate the impractical designs and focus development on relevant designs. Following this effort we narrowed ideas down further using Pugh matrices and weighted matrices to determine the top design concepts. With the top designs selected we made sketches, compared them with current products being sold, and completed a safety hazard identification checklist to verify that our top designs are feasible.

5.1 – Ideation

We started with a brainwriting/brainsketching exercise to come up with some ideas for the stowing mechanism. Throughout the course of about two weeks, our group met and did several different types of ideation exercises. Some of these include brainstorming, sketching, foam core prototyping, background research, a 6-3-5 exercise, and concept models. These exercises helped our team in coming up with many ideas for further analysis. During these sessions, we would focus on a subsystem and come up with different ideas for designs that would fulfill the function we wanted for this subsystem.

5.1.1 - Stowing Mechanism

The stowing mechanism allows the cart to collapse into a low-volume module that safely stores goods in the storage area of a vehicle. After a complete brainstorming session, our team identified six ideal stowing mechanisms for our cart shown in Figure 29.

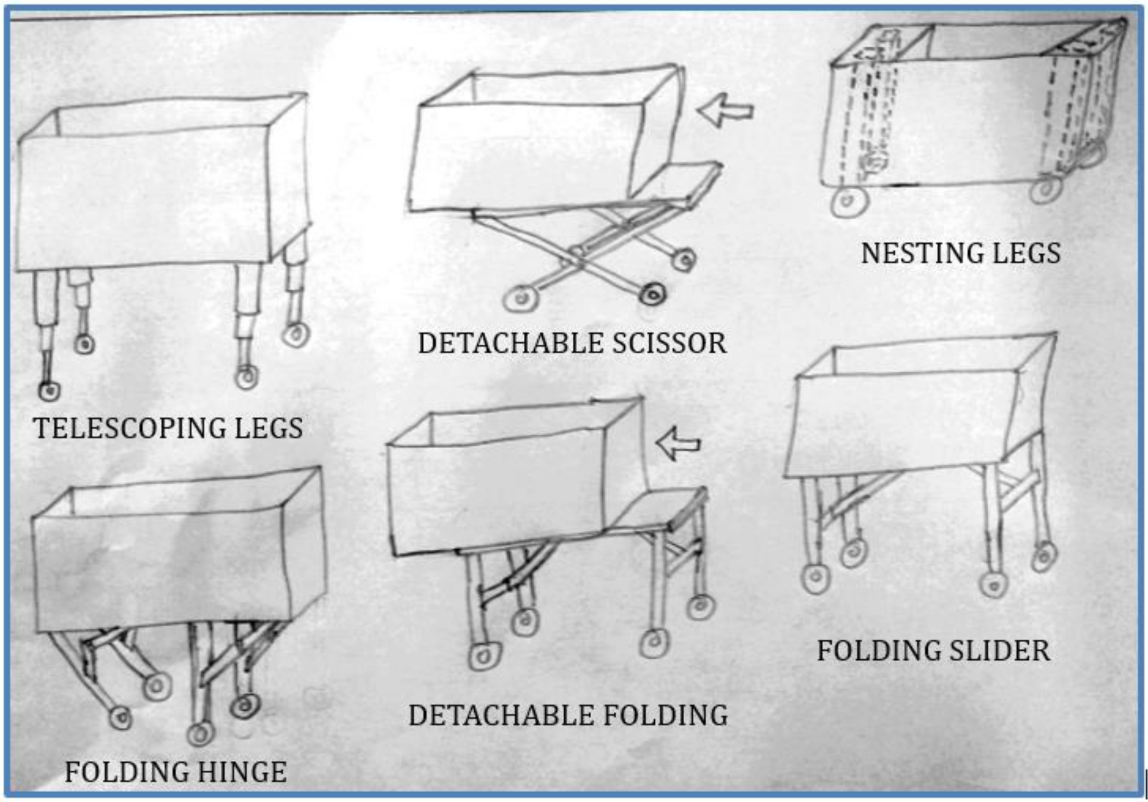

Figure 29: Top Six Stowing Mechanisms

Telescoping
The telescoping design refers to the height adjustability of the cart's legs. The legs are broken up into multiple segments which can nest inside of one another, reducing space when needed. This allows the cart to adjust its height to fit into varied bumper heights.

Nesting
The nesting design allows the rigid legs of the cart to retract all the way into the walls of the cart. Because of this, the cart also allows for height adjustability. As this is very similar to the telescoping legs, our team decided to combine these two ideas into one telescoping category.

Detachable Scissor
The detachable base with a scissor lift design allows the cart to slide off into the car with ease, while still allowing the height to be adjusted via the scissor mechanism. The scissor mechanism can then be stowed away easily as a flat base. This design is patented, however, by Salesmaker carts.

Detachable Folding
The detachable base with folding legs design allows the cart to slide into the car just like the scissor mechanism. However, to stow the base, the legs fold

together to become flush, instead of retracting in a scissor mechanism. Due to the similarity of the two devices, we decided to combine the two and move forward.

Folding Hinge
The folding hinge mechanism allows the legs to fold inwards as the cart is pushed into the bumper of the car. The folding of the legs is controlled by a hinge that either locks in place when straight or gives way. This design doesn't allow for situational height adjustability, but allows for a smooth transition into the car.

Folding Slider
The folding slider allows the legs to fold inward with pressure from the bumper of the car, controlled be a moving slider. This allows the legs to lock in place when flush with the base of the cart. Due to the similarity between the folding hinge and this mechanism, we decided to combine the two mechanisms into one folding category.

5.1.2 – Locking Mechanism

The locking mechanism for our device controls how the cart retains rigidity for its legs when necessary and then allows the legs to stow, again when necessary. Our team completed a separate brainstorming activity for this mechanism and discovered 4 ideal options to be pull pin, spring pin, ratchet, and notches which are shown in Figure 30.

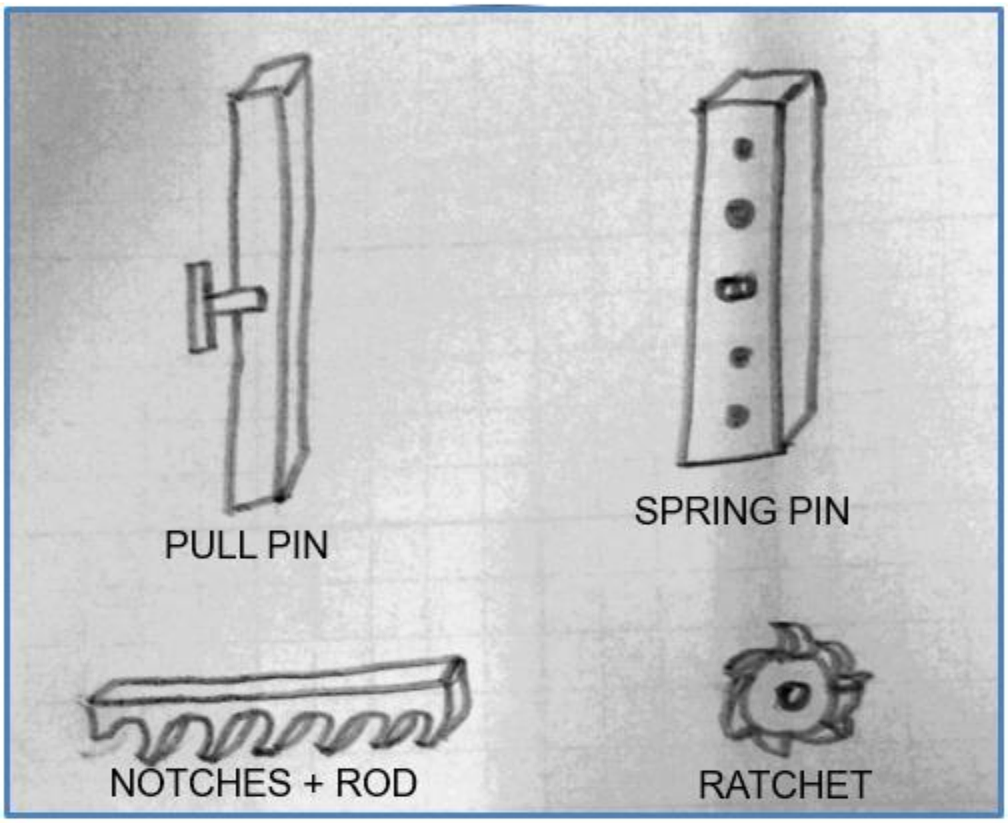

Figure 30: Top Four Locking Mechanisms

Pull Pin

A pull pin is a pin with a handle on the end to be easily grabbed and pulled by a person. Once pulled, the pin may be removed entirely to allow the fixture that it was restraining to move freely. In our case, the pull pin will restrict the motion of the legs. Once the new leg position has been achieved, the pin may be inserted once again to retain rigidity.

Spring Pin

A spring pin is similar to a pull pin in the way that it restricts movement, however it is not removed from a fixture entirely. A spring pin may allow motion by being firmly pressed inwards, only restricting motion upon release. This results in a lower chance of losing parts for the device, while possibly being slightly more difficult to use. Again, this mechanism would be used to restrict movement of the carts legs.

Ratchet

A ratchet allows motion in one direction by turning along an axis. When a load is applied along the opposite direction of the axis, the ratchet remains rigid due to its razor-like geometry. This is ideal for lifting a heavy load in small intervals over an extended period of time. For our cart, this would be used to help adjust the height of the cart when a load is being applied, as well as maintaining the rigidity of the legs.

Notches

The notches that we are referring to are similar to that of the ironing board in Figure 6. They allow a rod to remain fixed in place unless a load is applied in a specific direction, setting it free. For our device, the notches would be used to secure the legs in their upright position, unless a person wanted to adjust them when stowing the cart in his/her car.

5.1.3 – Power Source/Load Reduction

This subsystem was decided to be responsible for controlling the method in which the cart is easily lifted into the consumer's car. After brainstorming once again, we determined the four most ideal options to be human-powered, ratchet and cable, worm gear with wheel, and jack mechanism.

Human-Powered

Simple and intuitive, our team deemed a human loading the cart to be the obvious choice for certain stowing mechanisms, such as the folding legs, where height adjustability was of no concern.

Ratchet and Cable

The ratchet and cable source of power is an extension of the ratchet mechanism from section 5.1.2. Essentially, a cable would be connected to our carts legs and ratchet would pull the cable, causing the legs to begin their stowing motion. A release button may allow the legs to completely retract to their previous state. One example of this mechanism is shown in Figure 31.

Figure 31: Ratchet and Cable Mechanism [34]

Wheel and Worm Gear

A worm gear allows for a large gear ratio, reducing the amount of torque from a gear. This could allow a rather weak shopper to lift a rather heavy load, ideally directly into the shopper's car. A wheel could be present on the outside of the utility cart for a simple user interface with only one degree of freedom. A simple drawing of a spur and worm gear mesh is shown in Figure 32.

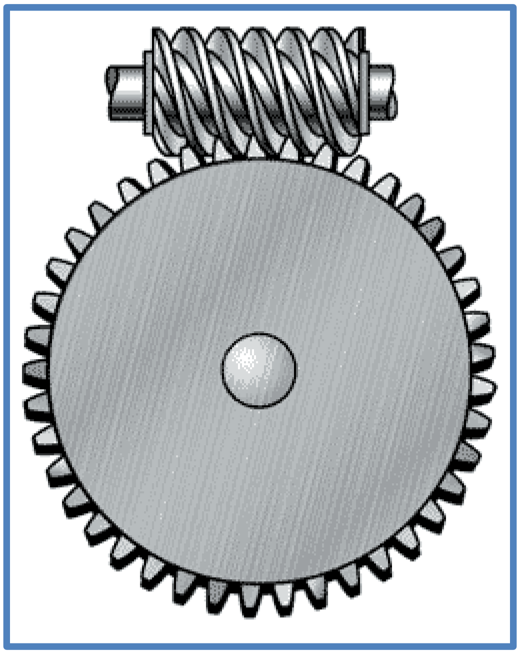

Figure 32: Wheel and Worm Gear Mechanism [35]

Jack Mechanism

A jack mechanism is a type of scissor mechanism that is slowly extended to lift a heavy object. The scissor mechanism may be extended by winding a screw to decrease the horizontal width of the scissor (see Figure 33), or with hydraulics, where a pressure buildup caused by a giant lever arm caused a small increase in height.

Figure 33: Simple Jack Mechanism

5.1.4 – Storage

After a final brainstorming session, we determined seven unique storage ideas for our utility cart. Since these ideas aren't necessarily mutually exclusive, we decided to keep all of them for now, and move forward with our systems. The seven storage options resulting from a brainstorming session are shown in figure 34; they include various methods of shelf design, as well as stowing when no loads are present, as well as various ways to separate goods into different compartments.

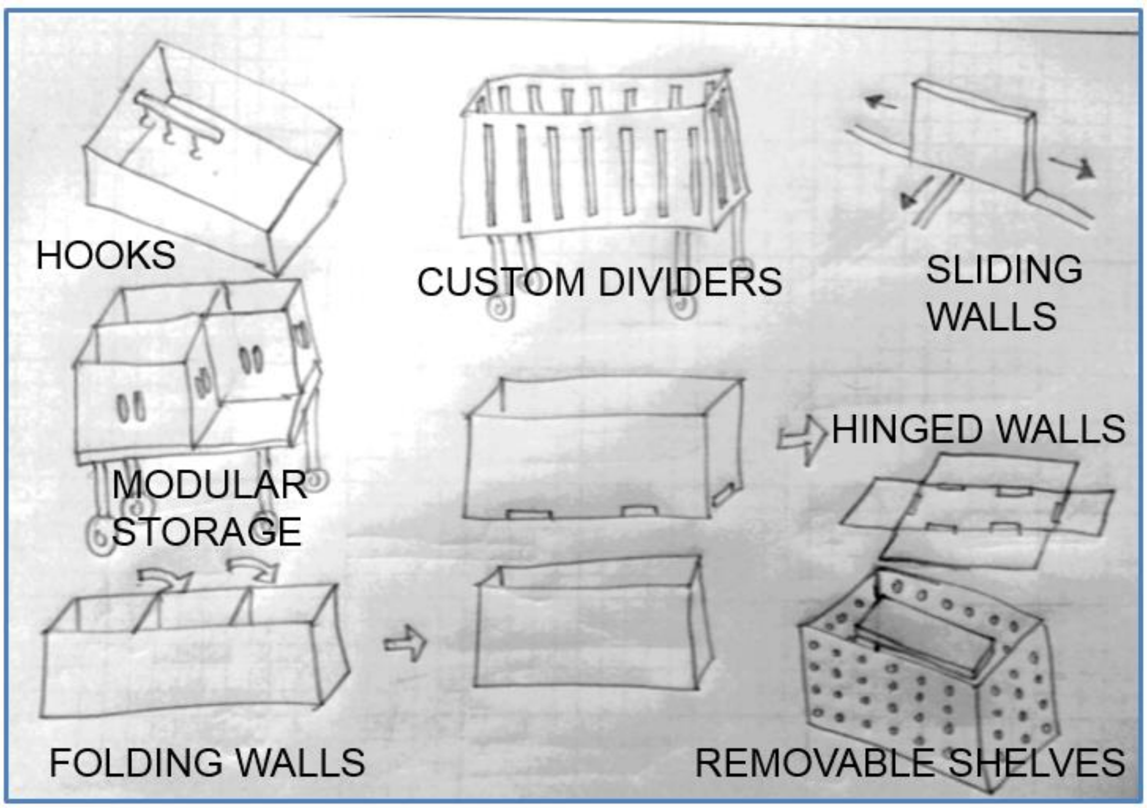

Figure 34: Top Seven Storage Options

5.2 - Idea Lists

After multiple idea generation sessions for each subsystem our team narrowed down the ideas to those that would be both practical and feasible and developed a list of ideas for each subsystem. The list of ideas for each of the four subsystems is shown in Table 3.

Table 3: Idea Lists for Main Subsystems

Stowing · Hinged support folding legs · Detachable top folding legs base · Detachable top scissor lift base · Telescoping Legs · Folding legs with sliding supports · Folding legs with shared slider supports · Telescoping legs that nest into cart body · Attachable ramp to vehicle · 6 leg folding · Multiple level scissor lift · Single level scissor lift · Single leg scissors · Telescoping/scissor combo · Removable legs · Cart lift attached to vehicle · Airbag legs · Accordion legs · Telescoping cart body · Suspension legs	**Storage** · Rigid walls · Square, circular, triangular walls · Collapsing walls · Hinged walls · Telescoping walls · Accordion walls · Individual spaces for items · Dividers · Modular/custom storage · Removable Shelves · Removable Hooks · Sliding walls · Multiple removable storage levels
Locking · Pull pin with handle · Spring pin · Notches with rod (ironing board) · Cable · Ratchet · Brake caliper · Friction slide	**Power source** · Human lifting/actuation · Cable and ratchet · Jack · Wheel and worm gear · Air pressure hand pump · Rack and pinion · Linear actuator · Wind up spring

5.3 – Idea Evaluation

In order to reduce the number of concepts for each subsystem, we would draw them up on a board and take time to vote for each idea. The ideas with two or three votes were then be used to make Pugh matrices. We did this for each subsystem; stowability, power source, locking, and storage. The stowability subsystem purpose was focused on how the legs would stow when being put into a car. The power source subsystem focused on the different ways we would adjust the height of the cart under load so that the cart was able to be used at the height of a normal cart then raised when loading into a car. The locking subsystem was focused on what components we would use to make sure the cart stayed upright during operation and did not unintendedly fold on someone causing injury and or damage of goods. The storage subsystem was focused on how we would store items in the cart, whether it be a standard cart with four perimeter walls or some other design. With our top selections from each subsystem, we made Pugh matrices to determine which ideas were the best for our project. In order to get our final matrices for each subsystem, we chose a datum or reference to compare all of the rest of the designs to. We used our customer requirements list from our QFD table and rated each design concept as better, which corresponded to 1 point, worse, which corresponded to -1 point, or same, which corresponded to 0 points. Each group member rated all of the concepts and we combined all of our ratings into one matrix and normalized the final values. We repeated this process for each subsystem. The stowability Pugh matrix is shown in Table 4. We decided to combine some of the concepts because of how similar they were, and to limit the number of possible combinations that we would be rating. We felt by combining the ideas, we were broadening them slightly so we were not limiting our future design choices in any way. The highest scoring combinations that we decided to proceed with for the stowability subsystem were the telescoping, folding, and detachable base designs.

Table 4: Stowability Subsystem Pugh Matrix

Stowability							
Customer Requirements	Hinged Fold	Detachable Folding	Detachable Scissor	Telescoping	Nesting Corners	Sliding Folder	Shared Slider
Safe	0	0	0	-1	0	0	0
Reliable	0	0	0	0	0	0	0
Stowing Volume	0	-1	-1	0	0	0	0
Simple	0	-1	0	0	1	0	0
Low-Cost	0	0	0	0	0	0	0
Light Weight	0	0	0	1	1	0	0
Durable	0	0	0	0	0	0	0
Easy to Operate	0	0	-1	0	-1	0	-1
Load Capacity	0	0	0	-1	0	0	0
Consumer Load	0	0	-1	0	0	0	-1
Aesthetic	0	0	0	0	1	1	1
Ergonomic	0	0	-1	-1	-1	0	0
Versatile	0	0	1	1	1	0	0
Adjustable	0	1	1	1	1	1	0
Low-Maintenance	0	0	0	0	0	0	0
Σ Total	**0**	**-1**	**0**	**-1**	**4**	**3**	**-1**

Appendix D includes the three additional Pugh matrices we developed to determine the best designs for the power source, locking system, and storage of the cart. Our final three choices for the locking subsystem are notches, a ratcheting mechanism, and a pin lock. These are the three simplest designs that have been proven to work in many different applications. As a group we decided not to use the power source concepts after our sponsor decided to remove the requirement for the cart to be able to raise and lower with items in it. Since the height would not need to be adjustable under a load, this eliminated the need for a power source. In our system combination matrix, we decided not to include the concepts for storage. Our reasoning for this was that the method of storage was not exclusive to any of the stowability and locking mechanism concepts. We decided to focus on the platform on which the cart would be operating instead of including this concept. Once we have made a finalized our decisions for the stowing and locking mechanisms, then we will make a decision on how the storage of the carts would be laid out. Our final combination matrix is shown in Table 5. We ruled out three of the combinations because they were not reasonable.

Table 5: System Level Decision Matrix

		Stowing		
		Telescoping	Folding	Detachable Base
Locking	Notches	~~Telescoping with Notches~~	Folding with Notches	~~Detachable Base with Notches~~
	Ratchet	Telescoping with Ratchet	~~Folding with Ratchet~~	Detachable Base with Ratchet
	Pin	Telecoping with Pin	Folding with Pin	Detachable Base with Pin

Using our combinations from the final combination matrix, we created a weighted Pugh matrix (Table 6). We used the same method as before where we each rated the combinations versus the customer requirements and combined the scores into one matrix. We decided to use the Salesmaker 289 Utility Cart as our datum. The reason for choosing this cart was because it has similar specifications to what we want our cart to have. The weighting for each requirement was obtained from our QFD table.

Table 6: System Level Weighted Pugh Matrix

System Concept Pugh Matrix								
	Salesmaker 289	Telescoping with Ratcheting Mechanism	Telescoping with Pin	Folder with Notches	Folder with Pin	Detachable Scissor with Ratchet	Detachable Base with Telescoping and Pin	Weight
Safety	0	-1	-1	0	0	-1	-1	11%
Reliability	0	-1	-2	0	0	0	0	9%
Volume Capacity	0	0	0	0	0	0	0	9%
Simplicity	0	-1	0	1	2	-2	-1	4%
Low Cost	0	-2	0	0	0	-2	-1	8%
Light-weight	0	-2	0	0	0	-1	-1	6%
Durable	0	1	0	0	0	0	0	6%
Heavy Load Capacity	0	0	-2	0	-1	1	0	5%
Aesthetic	0	2	1	0	0	0	-1	5%
Maneuverable	0	0	0	0	0	0	0	6%
Ergonomic	0	0	-3	1	0	-1	-1	7%
Ease of Operation	0	-1	-3	0	0	0	-1	5%
Versatile	0	3	2	0	-1	2	1	4%
Adjustable	0	3	3	0	-1	2	1	5%
Manufacturable	0	-2	-1	1	1	-2	-1	5%
Low-Maintenance	0	-3	-1	0	1	-2	0	6%
Σ Total Score	0	-0.42	-0.57	0.16	0.05	-0.47	-0.42	
Choice #		3		1			2	

We decided to pick the top three scoring combinations from this matrix and move forward with these designs. Our final choices shown in Figure 35, 36, and 37 are the folding mechanism, the telescoping with ratcheting mechanism, and the detachable base with pin lock. We did not feel the difference was significant enough to rule out the other combinations especially given that we have not had a chance to prototype all of them.

5.4 Concept Justification

We were able to draw some conclusions from our final weighted system combination matrix. The folder with notches/pin locking was the top pick because we felt it was overall one of the safest designs due to its rigid legs and simple mechanism. Figure 35 shows a sketch of this design. Our group determined that the design also will have the smoothest and quickest operation, easily meeting Specification 1 and 6 in Table 1. Some of the challenges with this design are the dimensional requirements because the legs are of a fixed length, as well as manufacturing the design with the right geometry so that it functions smoothly and reliably.

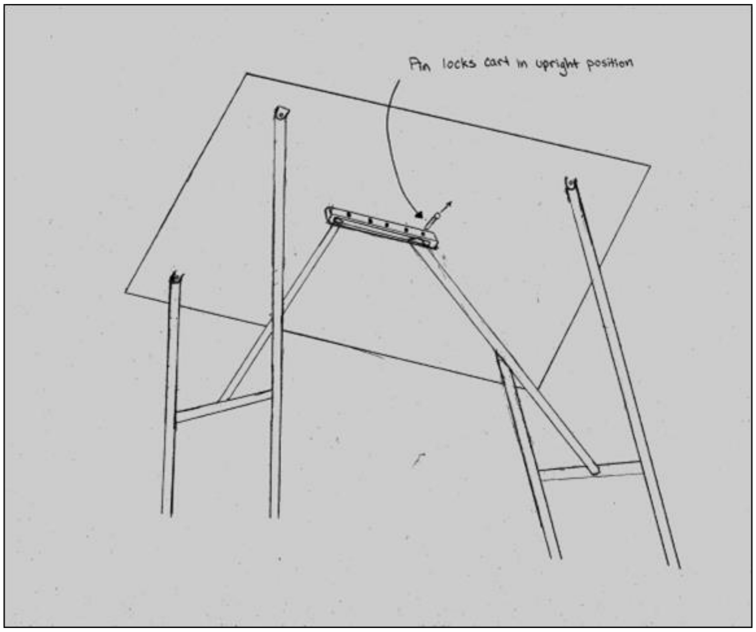

Figure 35: Folding Legs with Pin Lock

Our second pick, the telescoping with ratcheting mechanism scored highly in durability and versatility. Figure 36 shows the a sketch of this design. This is because the telescoping legs allow the cart to adjust its height for the largest spectrum of car bumper clearances. This concept however scored somewhat lower in safety. We feel some of the challenges with this design are the cost, maintenance, and load capacity. We want to make sure our cart can handle the load requirements while maintaining a reasonable cost to manufacture. Also the volume capacity might be lower than the other options due to either the nesting legs taking up basket space, or poking out from the bottom, not allowing the base to be flush with the leg end caps.

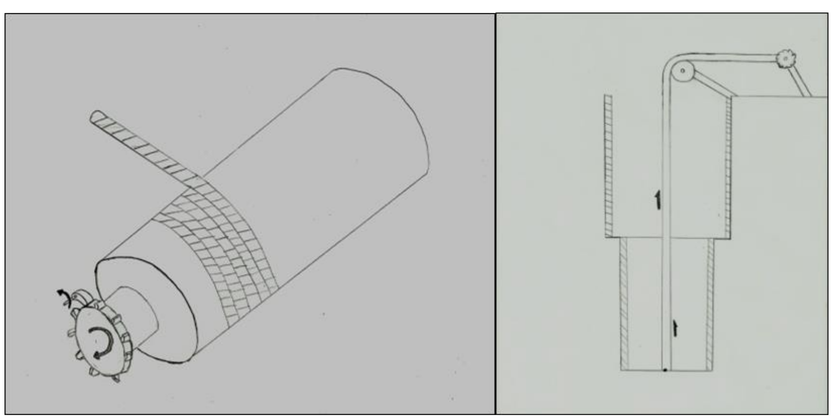

Figure 36: Telescoping Legs with Ratchet System

Our third pick, the detachable base design with the pin locking, scored highly in versatility and adjustability. Figure 37 shows the a sketch of this design. This is because the base can be adjusted by the user when no load is being applied and then set for a specific car bumper height. We feel this design would be easy to implement and would be reliable. Some of the challenges include ease of operation and ergonomics. While this design has some noticeable strengths, it does stray away from our goal of keeping the user from having to lift anything into their car. It also might not meet Specification 1 in Table 1, as the time it could take to load the cart could surpass 1 minute. It could also be difficult to ensure one-person operation, so an extra wheel-base might be added in between the basket and the detachable base to assist in sliding.

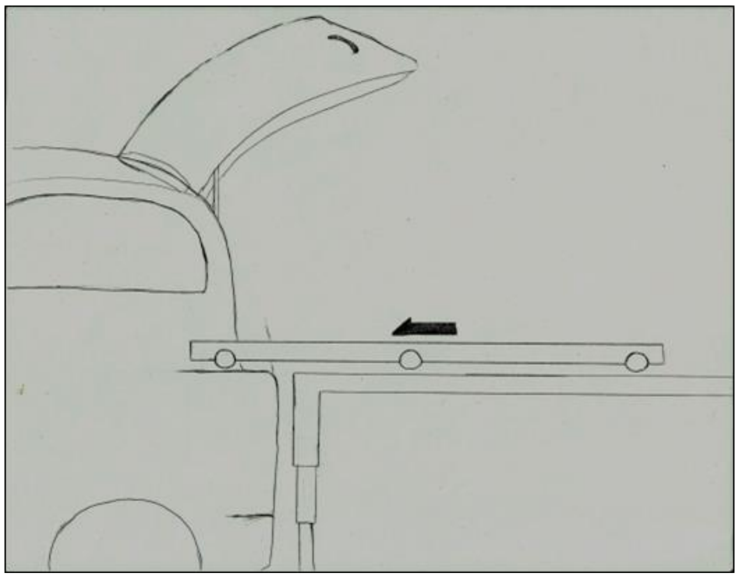

Figure 37: Detachable Base with Folding or Telescoping Legs

In order to determine if the top three system level concepts would be viable solutions to our problem our team started with simple detailed sketches and research into the mechanisms required in each of the designs. The sketches were used as a tool to prove that the design would work and provide a visual representation of how the subsystems would work together to form the functional assembly. Research and observation of the chosen systems was also performed to validate that the mechanisms would work for our application. The mechanisms that we have chosen are all proven designs that will be implemented in a new way. As part of the next steps in our design process we will be further validating the designs by building a full scale proof of concept prototype using simple materials like medium density fiberboard (MDF) and pvc piping for each of the top three concepts. We will also be performing simple CAD modeling and kinematic and load analysis in parallel to determine detailed dimensions, sizing, and material. This will help us to make a more informed decision on which design is the best for our project.

Another form of validation is our design hazard checklist which is shown in Appendix E. The design hazard checklist allowed us to consider any safety hazard that might be present when using the design. We have confidence in the feasibility of all of our current designs because they incorporate methods already used on many products and because of our small scale prototyping and completing a design hazard checklist.

5.5 Preliminary Plans for Construction and Testing

Following our proof of concept prototypes and engineering modeling and analysis we will determine the best option and optimize the final design. We will choose materials based on cost and load capability and determine the exact dimension of each portion of the cart so that it will fit in the designed space and function properly. Our plan for construction and testing of the final prototype consists of obtaining all of the materials and components, performing the necessary machining of custom components, assembly of the entire system, functional testing of each individual subsystem, and finally functional and safety testing of the entire system level design. Our plan is to complete the three proof of concept prototypes and achieve a team consensus on the final design before the end of the fall quarter, December 17, 2016. Next we will perform calculations and modeling to optimize the final design with final dimensions and sizing determined and stock materials and mechanisms selected before the critical design review, February 1, 2017. We will then complete all the necessary machining and assembly before the midway point of spring quarter, April 25, 2017. This will leave us enough time for component level testing and iterations as well as final system level functional and safety testing to be completed before May 23, 2017. Upon sign off of the safety and functional testing the device will be completed and handed over to the sponsor for personal use. Figure 38 shows a timeline with the most relevant dates. A more in depth Gantt chart is included in Appendix C.

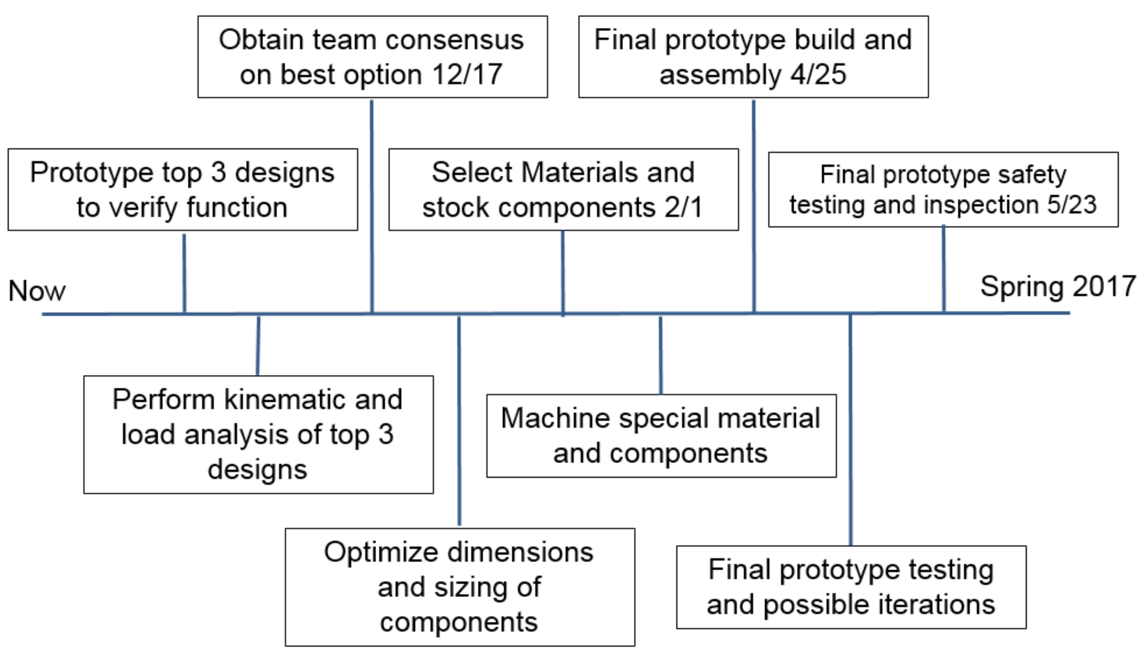

Figure 38: Preliminary Construction and Testing Timeline

5.6 Final Design Decision

In order to determine which of the three final design ideas was appropriate to continue with detailed analysis each team member evaluated the three designs in a decision matrix with the Salesmaker 289 model as a datum against the same customer requirements that were used in previous matrices. The final design decision matrix is shown in Table 7.

Table 7: Final Design Decision Matrix

Stowability				
Customer Requirements	**Salesmaker 289**	**Hinged Fold**	**Folding with Notches**	**Sliding Folder**
Safe	0	-1	-2	-1
Reliable	0	-1	-2	0
Stowing Volume	0	0	0	0
Simple	0	0	0	2
Low-Cost	0	3	3	3
Light Weight	0	0	0	0
Durable	0	-2	-1	1
Easy to Operate	0	0	-2	-1
Load Capacity	0	1	1	1
Consumer Load	0	0	-1	-1
Aesthetic	0	-1	-2	0
Ergonomic	0	0	-3	-2
Versatile	0	1	-2	2
Adjustable	0	0	1	2
Low-Maintenance	0	0	-1	1
Total	**0**	**0**	**-11**	**7**

The lowest scoring design was the folding legs with notches locking mechanism, similar to an ironing board, because many of the parts would have to be custom made and the logistics of folding both legs the same direction was difficult to understand and develop. The hinged folding design scored evenly with the Salesmaker 289 since the designs are almost identical. Our design would be much less expensive but may be less durable and reliable. The sliding folder scored the highest and was above the Salesmaker because it will be much less expensive, it is adjustable and is much more versatile. There are also some downsides to the cart that we must consider such as it could be a little less safe since it is not a proven design, it may be more difficult to operate and be less ergonomic. From this we decided to move forward with the slider mechanism folding design. The details and justification will be discussed in the following sections.

6.0 – Final Design:

Our final design features a double-channel slider connecting to a pair of vertical front legs and a pair of diagonal back legs, a cable-pin locking mechanism, and the choice of either an 80-20 T-Slot frame for customizability or welded steel frame for a strong, yet sleek look. The item-storing compartment features a grocery store aesthetic with its wire mesh walls, and uses a combination of 14 brackets to retain its rigid figure. The carbon steel thin-walled handlebar is bent in a way that offers a vertical hand position as well as a horizontal hand position, allowing a customer their own choice of grip for maximum maneuverability or comfort.

6.1 – Basket and Handle Subsystem

The galvanized steel wire mesh basket, constrained by galvanized steel corner brackets near the top of each wall and 80-20 wire panel holders at the base of each wall, acts as a rigid body to safely contain the items belonging to a customer. The handlebar is connected to the frame with 4 fasteners attaching a thin steel welded plate directly to the 80-20. For the sleek steel frame, the handlebar is simply welded directly to the back of the frame. The basket connects to the frame of the cart with 80-20 wire panel holders. For the welded steel frame, the basket nests directly on the frame with brackets locking it in place.

Figure 39: The basket & handlebar subsystem for the 80-20 T-Slot frame

6.1.1 – Manufacturing Plan

For this subsystem, all of the parts may be purchased online. For the handlebar, we will be purchasing 6' long 1" OD .049" thick Carbon Steel Tubing with ±0.008" thickness. We will then bend both ends at the Mustang 60 Machine shop using the tube bending machine to create a handlebar shape. After welding the ends of the handlebar to square steel plates with 4 fasteners, we will secure them to the back walls of the basket via another fastener plate. The basket will simply be connected to the cart with the brackets using fasteners and T-slotted framing. Finally, a foam grip may be added to the aluminum handlebar for increased comfort and maneuverability. This will simply slide on before the tubing is bent, and will remain in position due to an interference fit.

6.1.2 – Bill of Materials for Handlebar and Basket

For this subsystem, we need to purchase 8 different parts of varying quantities, totaling $121.92 as shown in Table 8.

Table 8: Bill of Materials for the Basket & Handle Subsystem

Item Name	Quantity	Unit $	Total $	Source
Gal. Steel Wire Mesh 2x3	2	24.35	48.7	8020.net
Gal. Steel Wire Mesh 2x2	1	19.65	19.65	8020.net
Wire Mesh Panel Holders 1"	12	4.5	54	8020.net
Galvanized Steel Corner Brackets	4	1.18	4.72	McMaster Carr
6' Low-Carbon Steel Tubing, 1" OD, .902" ID, .049" Wall Thickness	1	10.18	10.18	metalsdepot.com
11 GA Hot Rolled Steel Sheet 1'x2'	1	20	20	metalsdepot.com
Zinc-Plated Steel Fasteners	4	2.3	9.2	McMaster Carr
Screws and Nuts	1	4.41	4.41	Home Depot
40% Discount through 8020.net			-48.94	8020.net
Total Price			**121.92**	

The website 8020.net offered a 40% student discount for certain items on our list, and the savings are depicted as well. An added cost of $14.01 or ~$30 may be applied to the handlebar if a foam handlebar grip is desired. The handlegrip, either FHG 3 or FHG 22, would either be purchased from GripWorks in a perfectly-machined finished form for ~$30, or from amazon as a roll of foam tube, allowing us the opportunity to self-manufacture the grip to our own specifications. The latter option would result in the additional charge of $14.01 to the subsystem, raising the total cost to $135.93.

6.1.3 – Testing Plan

For this subsystem, we will test the strength of the basket by applying a 200lb force to its center and analyzing the deformation. To test the strength of the handlebar, we will apply a 50lb shear force and check for damages at the weld spot. In addition, we will apply a 200lb static force to the side walls of the basket and analyze the brackets for damage. This will be conducted in April, after the first prototype has been constructed.

6.2 – Frame and Leg Subsystem

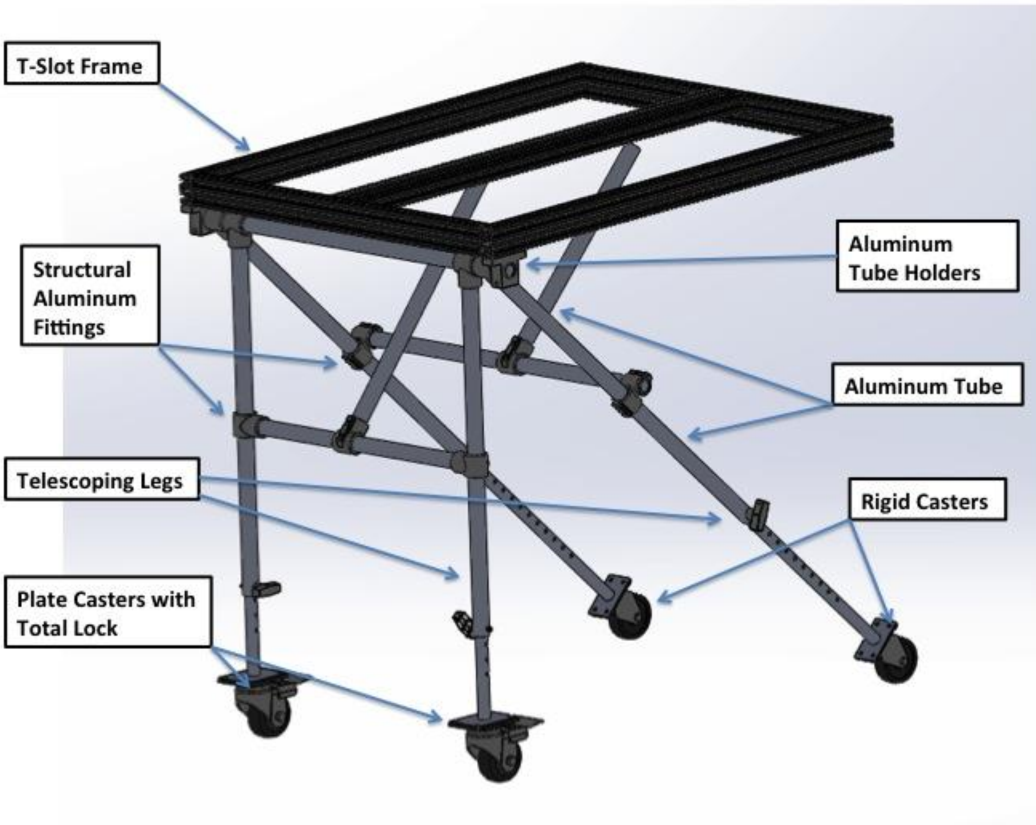

Figure 40: Frame and Folding Mechanism

The frame of the cart is a simple square structure that functions as the base of the folding mechanism where all of the other components mount. The Front and rear legs will be mounted to a single shaft made of hollow tubing with structural T-fitting, this shaft and the fittings will function as the pivot point and allow both front and rear legs to rotate and fold up from an extended position. Figure 40 shows the pivot point as well as the extended and folded positions of the legs. There will be four legs total, two in the front and two in the rear, each of the two front and rear legs will be connected together with a horizontal support which will increase the rigidity of the structure as well as function as a mounting position for the slider bar. The slider bar will attach to the horizontal support with a structural T-fitting that will allow it to rotate about the fixed horizontal bar, functioning as a pivot point similarly to the leg mounts described previously. This slider bar will be a fixed length and will be mounted to the horizontal bar on one end that allows rotation and to the frame on a slider on the other end that allows linear motion in one axis. This will allow the bar to slide along the slider as the legs fold, constraining the legs motion and folding them in a safe and controlled manner. Figure 40 highlights the horizontal support, slider bar, and slide location.

In order for the rear legs to be able to stow within the length specified by our sponsors vehicle of 36 inches they must be telescoping. 1" tubing will be the upper leg portion that everything will mount to and smaller tubing specifically designed with tight tolerances will fit inside the upper tubing allowing it to slide along the leg axis effectively making the leg shorter or longer. When the legs are fully folded in the vehicle a T-handle spring pin will be pulled from a hole in the telescoping tubing allowing the legs to slide freely, the legs will be pushed in until they clear the trunk and the spring pin will be replaced. While this function is necessary for the cart to fit in the specified volume it also allows the cart to be height adjustable for different vehicle heights. There will be holes drilled at regular increments in the tubing that will allow the height to be raised or lowered for different applications.

The front legs of the cart will be equipped with 360-degree casters with full brakes that will allow the cart to be easily maneuvered. The rear legs will have straight wheels mounted to the ends of the legs so that the cart will track straight in one direction and will be easy to control and maneuver in tight spaces.

6.2.1 Supporting Analysis

For this subsystem, we conducted analysis of the kinematics of the folding mechanism, the load capacity, the material strength, the load path, and the susceptibility to buckling of the legs.

Kinematics

In order to determine what geometry would be optimal to create a folding cart with the specifications given we first used 2D modeling to figure out the correct position and path of each linkage. Using simple 2D line drawings and applying the correct constraints we found two main designs that would accomplish the goal with full scaled dimensions and positions. Figure X. shows the two designs in the fully extended and fully folded positions.

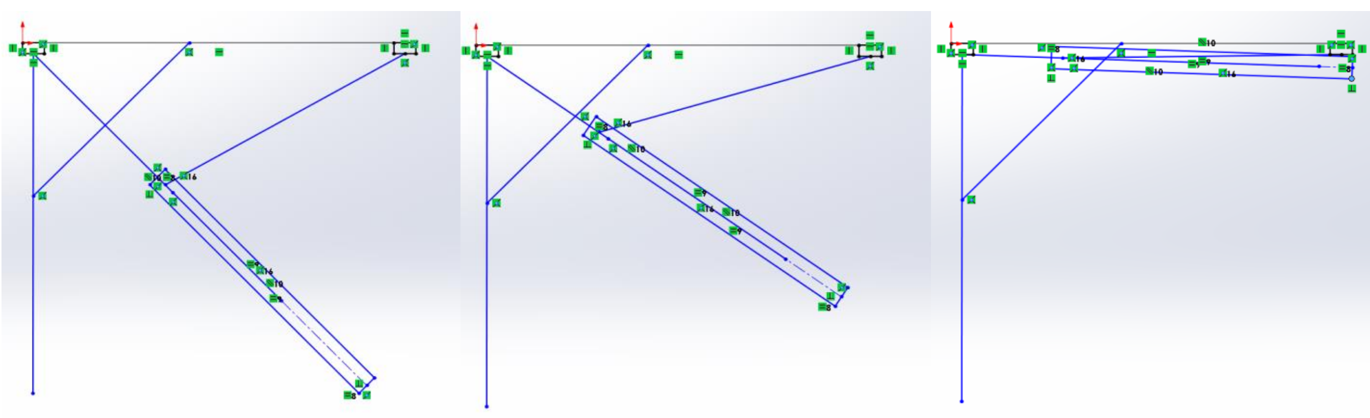

Figure 41: Automatic Telescoping Geometry

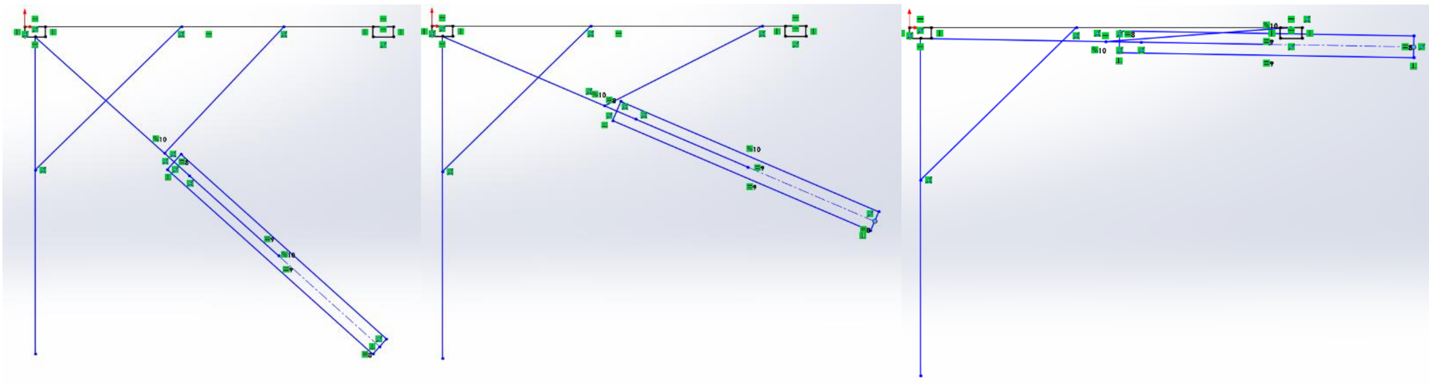

Figure 42: Manual Telescoping Geometry

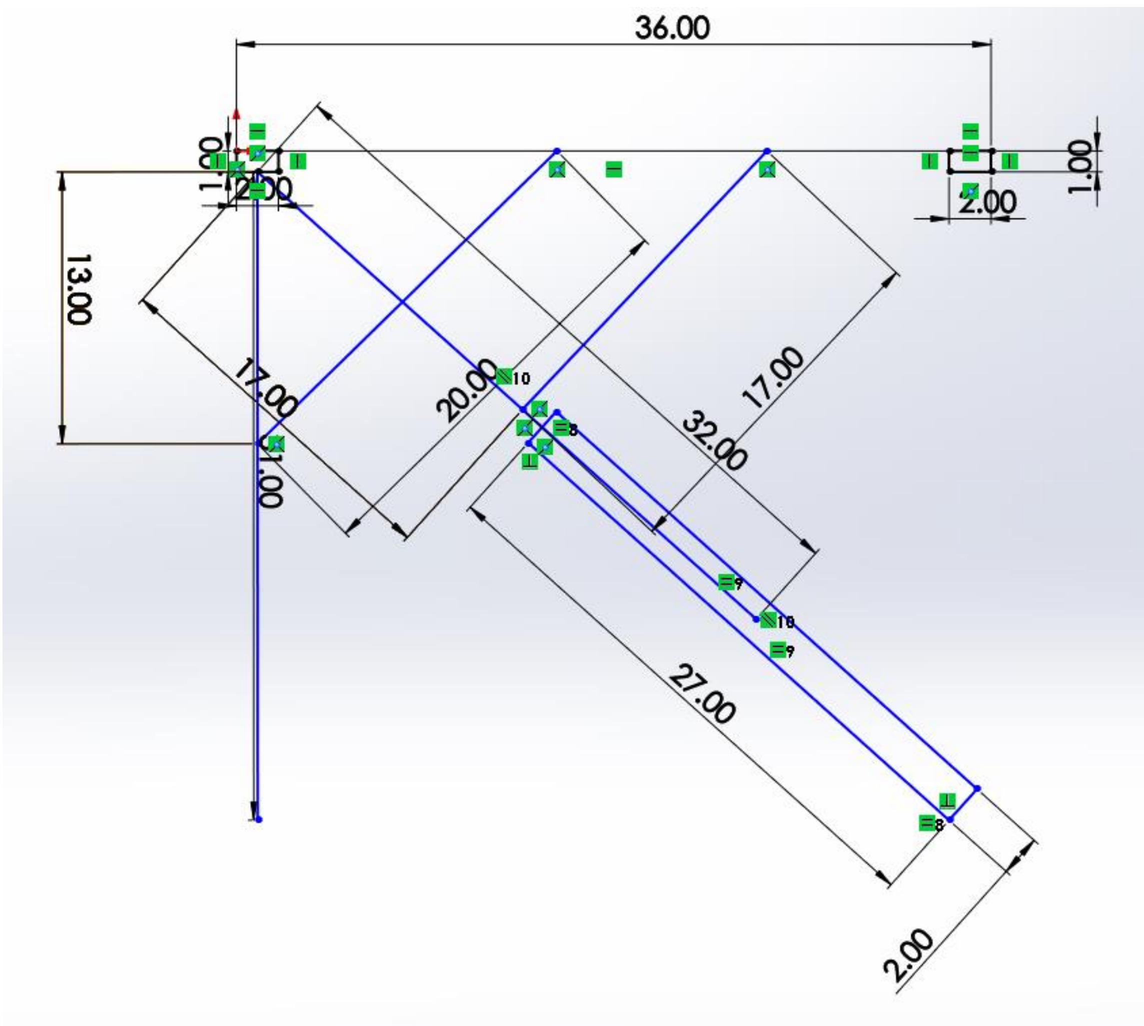

Figure 43: Manual Telescoping with Dimensions

While the automatic telescoping geometry is elegant and would reduce the number of operations required by the user, there was concern that the rear legs would not fold when pushed into the vehicle. The force on the legs would be above the pivot point on the telescoping leg and the lower leg motion would be directly opposite of the direction of the force so this would not allow the legs to fold automatically and would require either user input or a secondary force to assist the legs in their folding. Since the entire concept of the cart is to reduce the user's effort by not having them lift any weight, user input to fold the leg is out of the question. A secondary force could be provided using a torsional spring to assist the legs by rotating the pivot point, but in this case the legs could not fully extend and lock on their own, requiring user input, which in this case is very dangerous if the user forgot to pull the legs down or they did not extend and lock all the way.

Because of these reasons the manual telescoping was chosen and optimized to fold quickly and easily. This option uses two sliding bars that allow each set of legs to fold accurately and efficiently. The geometry is simple and consistent which allows the load to be shared through the support and legs in the rear while providing a stable wheel base and track. Both the front and rear legs will fold easily since the direction of motion of the slider is parallel and in the same direction as the force, so there is no issue of opposite directions as with the automatic telescoping option. This geometry will require extra operations from the user but they are simple and straightforward. A T-handle spring pin lock will be used to lock the telescoping portion of the legs, the user will simply remove this once the cart is fully loaded into the car, push the legs in until they clear the tailgate and insert the pin in the new position. This configuration also allows for height adjustability for different height vehicles or different terrain, both front and rear legs can be raised or lowered with the spring pin to easily change the height.

Load/Material Analysis

Simple FEA analysis was used for the front legs to ensure that they would be able to withstand the maximum load even with all of the adjustment holes drilled in them. An absolute worst-case situation was used where a single lower leg was subjected to a force of 200 pounds with all the force being carried by the spring pin in one of the adjustment holes. The bottom face was constrained on the ground and the force was applied on the holes parallel to the leg axis. Figure 44 shows the FEA visual representation with the calculated stresses and deflections. The analysis shows less the .001 inches of deflection in the lower leg and a stress that is an order of magnitude less than the yield strength of the material. From this we can be confident that the material and geometry chosen for the front legs will be more than enough even in a worst-case overloading event. The FEA software exaggerates the deflection of the member in order to give a representation of which part is seeing the most deflection, so although it appears that the member is significantly deformed in this case it will not deform even a noticeable amount in the real situation.

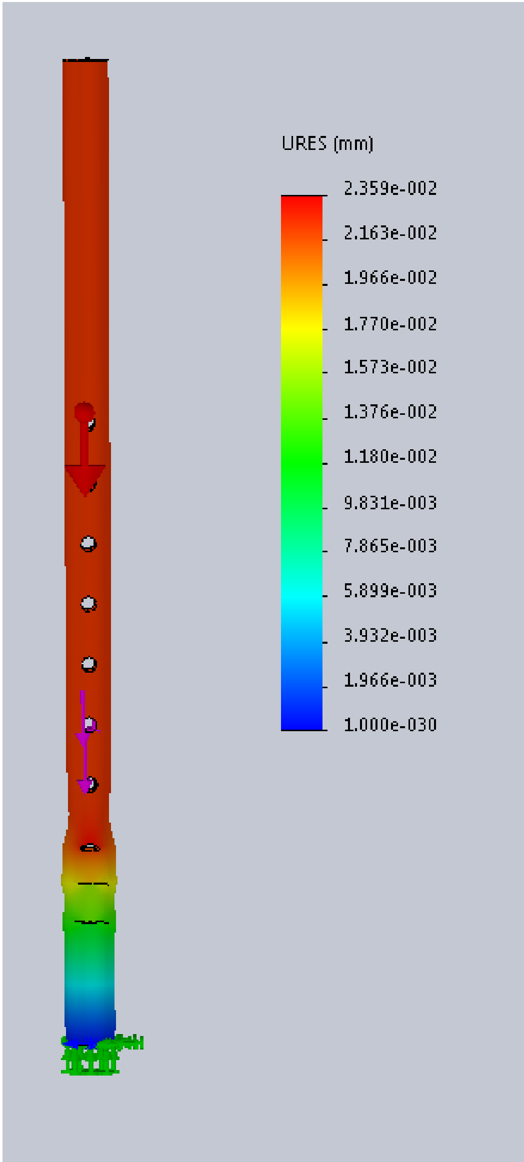

Figure 44: Front Lower Leg FEA Analysis

Load path

I order to analyze the legs the path of the load had to be determined as well as the direction and magnitude of the forces. Since the front legs are vertical they will handle the load in compression along their axis as long as there is only a vertical force acting on them. The only time the legs would see a force perpendicular to their axis would be if they were to hit an obstacle, or when they are being loaded into a vehicle. If they were to hit an obstacle the load would be transferred to the support and slider bar and further to the lock, which are designed to carry the full 200-pound weight capacity. When loading the cart into a vehicle, the wheel mounted to the front of the frame would carry the load as the front legs are folding so there is no concern with bending in this case.

The load path of the rear legs was more challenging because they are mounted at an angle and must support the load in this way. In order to find the directions of the forces on the rear legs static loading analysis was performed assuming that the support is a 2 force member and the leg is a 3 force member. Diagrams and details of this analysis are included in Appendix X. Knowing the geometry, the point of application of each force and the type of member allowed us to find the forces on the rear legs and verify that the material choice and geometry are acceptable for the maximum loading case. A simplified model of the rear legs was used to check for deflection and yield stress, the rear leg was modeled after a beam with an off center point load because this would be the worst deflection and stress it would see. For one single leg with a maximum force of 200 pounds the leg deflected by less than one inch and the maximum stress was below the yield stress. On the actual cart the load will be shared by both legs so there will be less deflection and stress overall. Also, the full 200lb load will be shared with the front legs as well as between the leg on its axis and the support bar on its axis, further reducing deflection and stress. Appendix X provides further details on the analysis performed.

Buckling analysis

Because this design uses long, thin members in compression to support a load it was important to consider buckling when analyzing the design and materials selected. The Euler buckling equation was used to find the force required to initiate buckling when one end of the member was fixed to the cart, and the other is free to move on the ground. This calculation showed that the forced required to see buckling in the member was over 18000 pounds which is almost two orders of magnitude greater than the maximum load of the cart. From this we can safely say that buckling will not be an issue in our cart.

6.2.2 – Manufacturing Plan

Since this design is made of mostly purchased and proven parts the manufacturing is relatively straightforward. The frame of the cart will be made of T-slot extruded aluminum so that assembly of it and all other components is easy and the cart can be adjusted and customized depending on need. Long lengths of T-slot will be purchased and cut down into each individual piece in order to save money. The brackets to hold the frame together will be made of aluminum angle that will be cut with the ban saw to size and then have mounting holes drilled into it using a drill press or mill and a stop or fixture to obtain accurate and precise holes. All fasteners will be purchased and installed using thread lock and the correct torque spec to ensure adequate hold and structure. The tubing holders that will function as the legs pivot point can either be purchased complete and fastened to the frame or machined down from a block of aluminum to save money. The tubing fixtures would be CNC milled using a 3D CAD model and program to save time and allow for accurate tolerances and good surface finish. The tubing for the legs will be purchased in long lengths and cut down to size to save money as well. The structural T-fittings will be purchased and installed using the provided set screw fasteners and the inner diameter will be machined down to provide clearance if necessary. The legs will need holes in them to provide a locking position for the telescoping action; this will be accomplished by using a drill press or mill and fixture to drill holes in the center of the tube at specific increments to provide adequate adjustability. The holes will be slightly counter bored to provide easy insertion of the locking pin. The casters and wheels will be mounted using a mounting plate that will be welded onto the bottom of the legs. The plated will be cut with the saw and drilled using the drill press or mill after the appropriate hole pattern has been determined for the wheels. The manufacturing plan as well as the operation and timing for the frame and legs assembly can be found in Appendix C.

6.2.3 – Bill of Materials and Cost

In order to keep costs low and also make the cart easy to work on with almost all parts available from a vendor in short time we decided on the components shown in Table X. All components required to assemble to frame, legs, and folding mechanism are included with quantity, length, source, unit cost and total cost. In our case further cost reduction can be achieved by manufacturing as many components as we can ourselves. We were also able to obtain a student discount for all parts order from 8020.net in order to keep our budget as low as possible.

Table 9: Frame and Leg BOM and Cost

QTY	Description	Length	Source	Unit $	Total $
1	2"X1" Aluminum Double Profile T-Slotted Framing	10ft	8020.net	$ 52.11	$ 52.11
2	1" Aluminum T-Slotted Framing Tubing Holder - Standard		Mcmaster	$ 34.10	$ 68.20
8	Aluminum Slip-on Rail Fitting, Tee Connector for 1" Rail OD		Mcmaster	$ 6.75	$ 54.00
2	Aluminum Slip-on Rail Fitting, Crossover Connector with 2 through holes		Mcmaster	$ 11.27	$ 22.54
3	Multipurpose 6061 Aluminum Tube, 1" OD, .125" Wall Thickness	6ft	Mcmaster	$ 31.68	$ 95.04
1	Multipurpose 6061 Aluminum Tube, 3/4" OD, .125" Wall Thickness	2ft	Mcmaster	$ 10.92	$ 10.92
1	Multipurpose 6061 Aluminum Tube, 3/4" OD, .125" Wall Thickness	6ft	Mcmaster	$ 24.27	$ 24.27
1	Extruded Structural Aluminum Bare Angle 6061 T6	3ft	Mcmaster	$ 13.15	$ 13.15
30	Steel End-Feed Fastener for 1" Single & 2" Quad Aluminum T-Slotted Framing Extrusion		8020.net	$ 2.30	$ 69.00
4	Aluminum-Handle Push-Button Quick-Release Pins with lanyard		Mcmaster	$ 4.40	$ 17.60
2	Expanding-Stem Casters Swivel with total lock		Mcmaster	$ 13.40	$ 26.80
2	Cart-King Rigid Casters		Mcmaster	$ 12.04	$ 24.08
	*No discount applied			**Total**	$ 477.71

6.2.4 – Testing Plan

The main and important tests that will be performed will be functional and safety oriented since the cart must perform to spec and do so safely without putting the user in danger. All of the tests for the frame and folding leg assembly are detailed in the DVP/R form in Appendix H. The tests are mainly based on our requirements and engineering specifications with some added based on user interface and ease of use. Functional tests will include cycling the cart through full extension and the fully folded position 30 times continuously at different speeds and orientations to make sure that it will perform its main task. Another test will be to record the time it takes to fully stow the vehicle and drive away, this should be under one minute. Maneuverability tests will also be performed to ensure that the cart can easily navigate a grocery store, a house, and other typical environments. Weight capacity and loading tests will be performed to ensure the cart can hold the rated weight and still perform its functions well. The cart will be loaded to maximum capacity and cycled from full extension to full fold to test the worst case scenario, it will also be loaded with a static load of 300 pounds to verify an adequate safety factor. An impact test of 50 pounds dropped from the height of the sides of the cart will be performed to show cart resilience to impact. Off center loading will be tested to verify functionality in non-ideal conditions and the cart will be subjected to obstacles that it must traverse to further prove its maneuverability.
These tests will be performed immediately following manufacturing completion and a safety inspection; the dates of these tests are also outlined in the DVP/R form.

6.3 Locking Mechanism

The sliding and locking mechanism shown in Figure 45 with a close-up in Figure 46 facilitates the action of allowing the legs to fold up and down in a controlled manner. It also locks the legs in the upright position and controls the release of the legs when the cart is being stowed into a vehicle. The sliding mechanism consists of a track, a follower, and bar which sits in the track. The locking mechanism is attached to the sliding mechanism. The lock consists of a shaft that moves along with the follower and a latch which allows the bar to move past it in the upright position, but keeps it there until the latch is actuated. The latch is actuated using a cable which is attached to a lever on the handle. There is a lever for each set of legs, for a total of two levers.

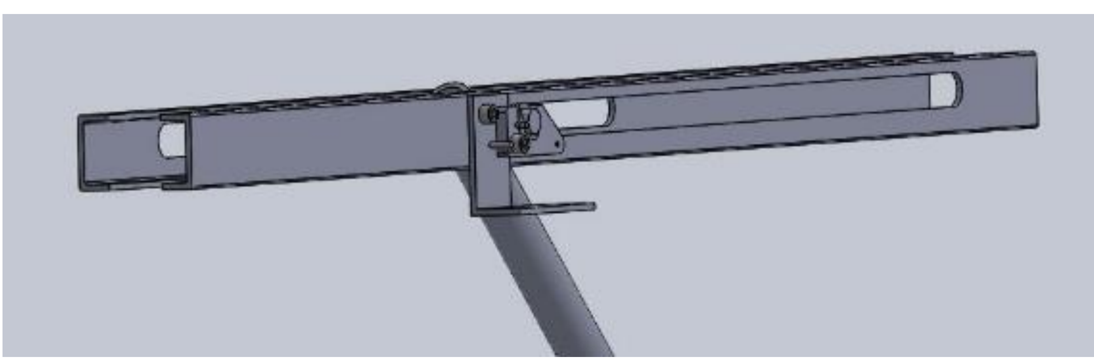

Figure 45: Isometric View of Locking Mechanism

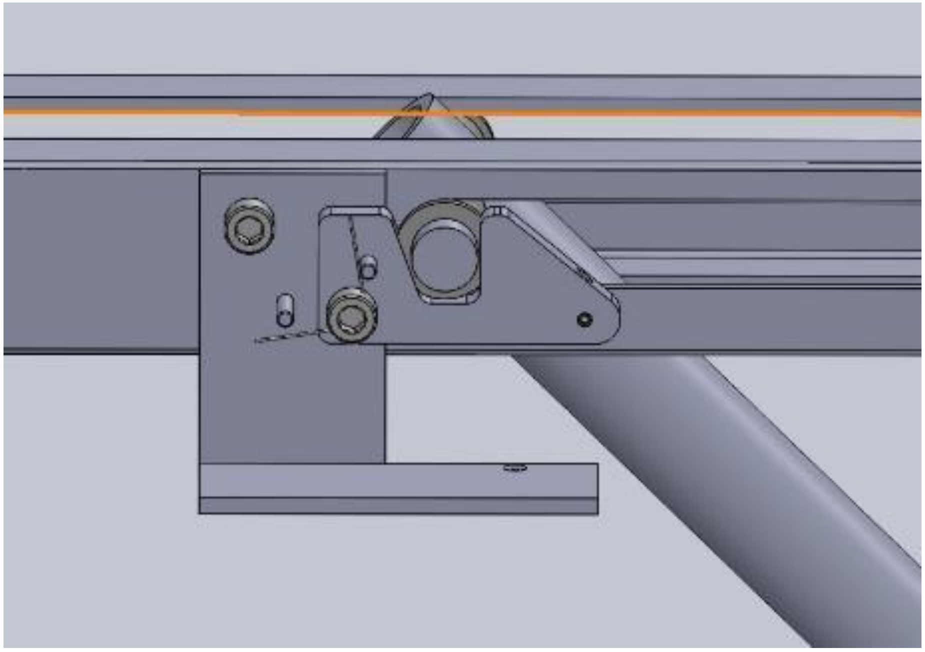
Figure 46. Straight View of Locking Mechanism

6.3.1 – Manufacturing Plan

The locking mechanism has several unique parts that will need to be manufactured from raw materials. We will be fabricating these parts in the student machine shops on campus. The first is the roller shaft. This is a relatively simple part. First a hole will need to be drilled through one of the support shafts allowing for the shaft to be fed through. The roller shaft will need to be turned down and faced on a lathe to the proper dimensions. It will be a very quick operation because it has no special shoulders or features. The next part to be manufactured will be the support housing. We will start with the 6 ft. section of steel square tubing. After being cut in half into two three foot sections, we will use a straight edge to draw a straight line along the length of the bars. These will then be cut in half along the top and bottom so that we have two relatively equal halves. For this operation we will either use an angle grinder with a cutoff wheel or a band saw. We plan to consult shop technicians for operations we are not certain what the best approach will be. From here the sections will be put on a mill and have a slot cut down the length of it. While it is on the mill we will also drill the mounting holes in one of the sides for the cam bracket. Next we will move onto the cam bracket. This piece will first be cut using a band saw into then put on the mill for drilling the holes. Once two of each half is done, we will weld the two pieces according to the engineering drawings. For this we will use some of our extra material beforehand for practicing this type of weld. Finally, we will make the cam follower. This piece will use the same stock material as the cam bracket. We will cut out the profile of the shapes on a CNC plasma table in either the Aero Hangar or the IME welding lab. Once we have the profile cut out we will use a milling machine to cut all of the holes. This will be a challenging part to make because of all of the setups that will be required for each of the features. This part also has a lot of tolerance restrictions because it is one of the main safety components.

6.3.2 – Bill of Materials and Cost

The locking mechanism came out to be relatively cheap compared to the other two assemblies. It came out at a total of $123.85. Table 10. shows the breakdown of the materials needed for manufacturing this mechanism. This is still a large percentage of our budget so we will continue to try and find deals to bring the cost down. The reason that it is low compared to the other two assemblies is because of the small amount of materials needed and also because there are several fabricated parts that have low raw materials costs. It also makes up only a small portion of the entire cart compared with the frame and legs basket subassemblies. A reason the costs are high for such a small part of the cart has to do with the fact that we have to order more material for some parts than we need, for example the sheet metal for the cam bracket and cam follower. We also wanted to make sure we had large factors of safety for these components because they were responsible for holding up the cart are critical for its safe operation.

Table 10: Bill of Materials for Locking Mechanism

Part #	QTY	Description	Length	Source	Unit $	Total $
2001	1	Cable Housing	5 ft	Foothill Cyclery	$ 10.00	$ 10.00
2002	1	Brake Lever		Foothill Cyclery	$ 17.99	$ 17.99
2003	1	1/8 Steel Sheet metal	2 ft^2	Mcmaster	$ 6.75	$ 6.75
2004	2	Brake Cable		Foothill Cyclery	$ 5.00	$ 10.00
2005	1	Structural Steel Square tubing	6ft	onlinemetals.com	$ 30.06	$ 30.06
2006	1	Torsional Spring (Pack of 6)		Mcmaster	$ 5.01	$ 5.01
2007	1	Dowel Pins set of 10		Mcmaster	$ 6.89	$ 6.89
2008	1	5" of A-36 Hot Rolled Rod 0.5 Diameter	1ft	onlinemetals.com	$ 1.30	$ 1.30
2009	4	PTFE Bushing		Mcmaster	$ 6.67	$ 26.68
2010	1	1/4-20 Screws		Mcmaster	$ 7.04	$ 7.04
2011	1	1/4-20 Nuts (50 Count)		Mcmaster	$ 2.13	$ 2.13
					Total:	$ 123.85

6.3.3 – Testing Plan

Our testing plan for this subassembly includes static loading, extreme loading positions, and testing reliability and ergonomics of operation. First and foremost, we plan on testing that the mechanism can safely hold the 200 lb. weight requirement of the cart. This test will be done by statically loading the inside of the cart with 200 lbs. with weights. We also plan on testing that the cart can hold weight in multiple positions without deforming members. This includes extreme loading positions, for example all weight focused on the back of the cart and along the sides. Finally, we want to test the reliability of the lock and release. We will make sure that the latch engages the leg support consistently as well as releases it when the lever is pulled. This will be done by repeatedly folding and unfolding the cart both loaded and unloaded. We will also test the ergonomics of the locking mechanism by having several volunteers attempt to stow the cart into the back of a car, and determine the ease of operation through qualitative feedback.

6.4 Material Selection Explanation/Justification

Aluminum was chosen for most of the structures for the cart for three main reasons. First, in order to keep the weight of the cart low and reach our specification of under 50lbs total aluminum was the best choice because it is light but strong enough to stand up to the 200lb load required. Second, it is important for the cart to not corrode in any type of environment; aluminum will develop a protective oxide layer over its entire surface that prevents corrosion. Third, aluminum tubing has the most options for diameter and wall thickness. Because telescoping action is such a critical part of the design it is very important that we found a material that could be used for telescoping while keeping cost down and staying away from expensive, hard to find custom made parts. Aluminum is also the best choice for telescoping because it does not need to be coated to prevent corrosion; this eliminates the problem of dealing with tolerances and coating removal with telescoping sections. Aluminum structural fittings were chosen to hold the cart together instead of welding the tubing because welding aluminum decreases the structural integrity of the material. This also allows pieces to be quickly and easily replaced if there is an issue or if they are damaged.

Steel was chosen for the sliders and locking mechanism because it is the main structural component that will hold the weight, it is a safety critical design, and the hardness of the slider and lock must be high enough to withstand many cycles of sliding and locking. Pieces of the lock and bracket will also be welded and the steel will not lose any of its strength when welded compared to aluminum. The steel components will not deform or gall over time when being used like aluminum components would.

6.5 Safety Considerations

The main safety considerations of our design are pinch points as the cart is folding or telescoping and also the cart collapsing or failing causing user injury or bystander injury. Pinch points were dealt with in the design of the cart by having the pivot point at the very front of the cart at the opposite side of the user and by having the handle up and back of the folding legs which moves the user and especially their hands far away from most of the pinch points. The pinch point closest to the user as the legs fold narrows very slowly as the cart is folded and the hands are naturally out of the way during this operation as they are actuating the release handle. Guards may be implemented if they are deemed necessary during functional testing to further eliminate the pinch hazard, and danger zones will be painted red to visually show the user where to avoid. The operation manual will also include detailed instructions to avoid pinch hazards as well as diagrams showing proper operation and what to avoid.

Cart collapse or failure is a critical safety concern and has been dealt with primarily with the design of the folding, locking, and telescoping mechanisms. The locking mechanism is made to securely lock into place so that it will not unlock accidently or from an outside force. The release mechanism will require two distinct motions so that the user cannot accidently release the legs causing them to fold at a dangerous or inopportune time. The appropriate analysis of the legs and the locking mechanism has been performed to ensure that the cart will not fail under normal or maximum loading conditions. The operation manual will also include detailed descriptions of proper operation with clear diagrams to avoid confusion and increase user safety.

There are only mechanical parts in our design so the functional and loading tests described previously will also function as safety checks to show that the device will operate as intended and not but the user or bystanders in danger.

6.6 – Maintenance and Repairs

Our design has several areas which may need repair after a long duration of use. The first is the wheels, which may become jammed or give too much resistance, restricting the maneuverability of our cart. In some cases, an obstruction may simply be removed from the wheel or a little bit of bearing lubricant may be added to lower the resistance. In other cases, they may require replacement. To replace the wheels, simply unscrew the four fasteners attached to the mounting plate, remove the wheel joint by pulling it away from the cart along the axis parallel to the leg, and insert the new wheel into the original spot, securing the four fasteners back onto the mounting plate. To ensure proper bending of the legs, make sure the leg joints are lubricated correctly. To do this, add anti-seize to the leg joints once a year to make sure the aluminum doesn't gall. All fittings are replaceable, simply remove the fastener when the cart is in a safe, upside-down position. Make sure the release cable is always tight, if not then loosen the set screw on the locking CAM and tighten the cable, then retighten the set screw. For general cleaning purposes, all components are waterproof and will not corrode.

7.0 - Management Plan:

Our management plan involves assigning specific team roles to each member regarding the types of work that they will be completing for the quarter. Each new quarter, we will be redistributing the team roles to give every member a fresh experience as well as making sure the workload is balanced for everyone.

7.1 – Team Roles

The team roles are as follows: communications officer, treasurer, secretary, and manager. Since our group is comprised of three people with four team roles, one member will take up two responsibilities each quarter. For Fall Quarter 2016, Eric Johnson will serve as the Treasurer and the Team Manager. Sean Portune will serve as the Communications Officer. Jason Munter will serve as the Secretary. Roles will be updated before Winter Quarter 2017.

Communications Officer
The role of the communications officer is to handle all communication between our group and our sponsor. This means writing all emails, scheduling all sponsor meetings, and acting as the main point of contact with the sponsor.

Treasurer
The treasurer is responsible for creating and managing the quarterly budget for the team, as well as writing expense reports for all funds spent. The treasurer will be in possession of the team VISA and will oversee all purchases made by the team.
Secretary
The secretary is in charge of maintaining the information repository of the team, and organizing all relevant information. The secretary provides the team with agenda before each meeting to make sure each member comes prepared. The secretary schedules internal meetings for the team as well.

Team Manager
The team manager is to ensure that all deadlines are being met efficiently. The manager also keeps track of all strikes assigned to team members for breaking the team contract.

Any responsibilities that don't fall within these team roles are to be assigned through team consensus and collaboration, and are circumstantial.

7.2 - Project Deadlines
Prior to this report, our team completed a project proposal, serving as an agreement with our sponsor regarding the overall scope of the project. This was completed on October 25th, 2016. This report, deemed the Preliminary Design Review (PDR), was completed on November 17th, 2016. In addition to additional research, ideation, and prototyping, the PDR will contain a detailed analysis of our first design options, along with a presentation given to our advisor and peers. Following will be the Critical Design Review, completed before February 7th, 2017. This will serve as an extension of the PDR, with the added critical analysis of our final design and part costs. A Project Update Report will be completed by March 16th, 2017. This will allow us to update the sponsor with how things have progressed over the preceding few months. The last deadline will be the Final Design Review, completed by June 2nd, 2017. This will conclude the senior project, and will allow us to make a final analysis of the whole product.

8.0 – Product Realization

The following section describes how our project was manufactured and built, how the prototype differed from the planned design, and recommendations for improvements on manufacturing in the future.

8.1 - Manufacturing Process

The manufacturing process followed a bottom up approach starting with the frame which would be the main component of the cart where everything else would be mounted. Stock material was purchased from the local metal supply company in 20 foot lengths and were cut to final length determined by our dimensions and specifications. Steel rectangular and round tubing was purchased for the frame and legs as well as steel plate for the locking mechanism parts and angle iron for the brackets and sliders. The hinges were made next and mounted to the frame with supporting brackets that were also custom made. Tubing was cut for the legs and hinges and the leg pieces were notched to ensure proper fit up when welding. The legs were drilled to allow them to be telescoping and nuts were welded to the bottom to accept casters. Locking mechanism rails were then cut to length and machined from angle iron and mounted with additional brackets to the frame. The locking mechanism assembly was cut using the water jet and the pieces were drilled, assembled and mounted to the sliding rails. A box was made using plywood to account for the bumper profile of our sponsor's vehicle and coated with rubber for safety and aesthetics. The handle was attached and a wood platform was placed on the top of the cart to hide the internal workings and present a finished look. Finally, the cart was painted to prevent corrosion and present a finished product.

8.1.1 - Frame

The frame was made using thin walled steel rectangular tubing to provide the necessary structural rigidity for the rest of the frame while still being light. Ten foot lengths of tubing were cut using the chop saw at 45 degree angles and then were fixtured and welded using tungsten inert gas welding to reduce warpage and grinding time. The welds were ground using and angle grinder with a sanding disk to achieve a clean and finished look.

Figure 47. Chop saw cutting stock length material

Figure 48. Clamping and fixturing in preparation for frame welding

The hinges that would mount the legs were then manufactured by cutting pieces of angle iron and welding them in the center to create a U shape. The hinge then was drilled in the center to provide clearance for a mounting bolt. Supporting brackets had to be made for both the front and rear hinges to ensure structural rigidity and place the hinges inboard of the rectangular tubing. Pieces of steel plate were cut and welded together to make the brackets and then the brackets and hinges were welded onto the frame in the appropriate location. This design ensured that the hinges would be strong enough to support the weight of the cart as well as our designed load capacity. Short pieces of tubing were cut to fit inside the hinges so that they could act as the mounting mount and the rotating portion of the hinge.

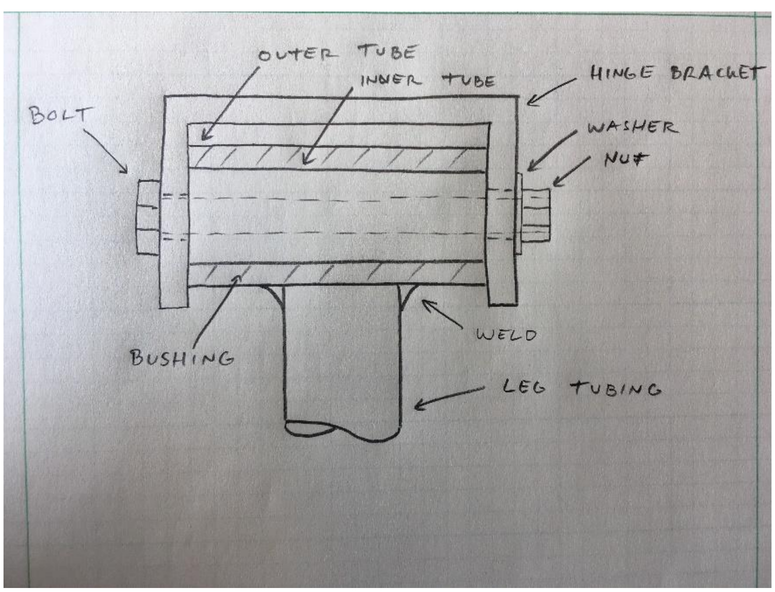

Figure 49. New hinge design to save material and money


Figure 50. Supporting brackets to mount hinge brackets to frame


Figure 51. Supporting brackets and hinge brackets fully welded

The handle bar was cut to rough length on the chop saw, bent using the tubing bender and then mounted to the cart by MIG welding. Multiple trials on the tubing bender were made to achieve a precise 90-degree bend on both ends of the bar. The final height of the cart and handle were then measure and the ends of the bar were cut to achieve the desired height.

Figure 52. Handle bar bent, cut, welded into place

8.1.2 - Legs, Crossbar, Slider bars

Initially the legs were cut to a rough length over the final length determined in our CAD models in order to ensure that we could test fit and adjust the lengths to avoid mistakes. Holes were drilled in the legs at specific locations to allow the legs to telescope to raise or lower the working height of the cart. Matching holes were drilled in the upper and lower leg portions using the mill and drill press.

The legs were then cut to final length and notched on one side where a short piece of tubing was welded at a 90-degree angle to function as the rotating joint for the leg. The same was done for the slider bars to allow them to rotate on the crossbar as the legs fold. Magnets and clamps were used along with TIG welding in this step to reduce heat input and warpage in the legs.

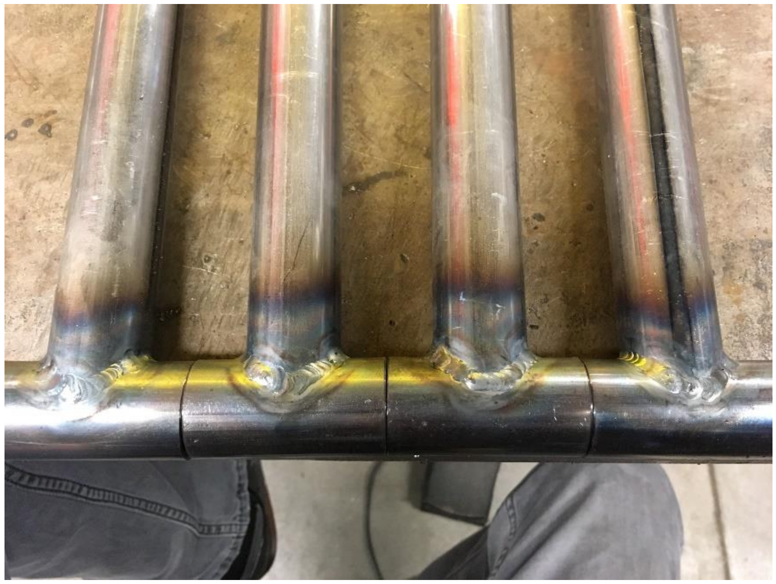

Figure 53. 90-degree tubing welded into place for leg hinges

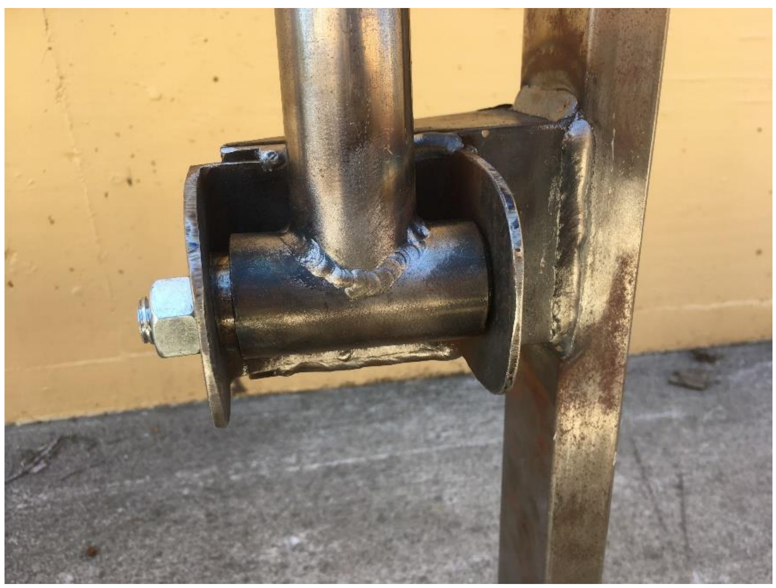

Figure 54. Assembled hinges with all components in place

The crossbars that provide rigidity to the legs and allow the slider bar to rotate during folding needed to be notched on both sides to be welded to the vertical legs. This final dimension was carefully measured once the hinges were mounted and legs were completed in order to make sure that there was no interference and the legs would fold properly. The notches were made using a purpose built tubing notcher to achieve a precise cut that would provide good fit up when welding the pieces together. Proper fit up is critical, especially with TIG welding, to ensure a strong good quality weld. The final front and rear leg assemblies were then welded together including two legs, one crossbar, and one slider bar. Careful measurement, fixturing, and preparation had to be taken to ensure that the assembly fit together properly, was square, and did not warp during the welding process.

Figure 55. Front and Rear leg, crossbar, slider bar assemblies

More work was required for the slider bars to accommodate the sliding and locking mechanism that would lock the cart in the upright position. Holes had to be drilled in the end of the bars and then the slider shaft was welded into place using TIG welding and appropriate fixturing to reduce warpage. The slider shaft were made on the lathe from stock steel rod turned down to accurate dimensions to accept a bushing and fit within the slider dimensions.

In order to mount casters to the round tubing of the lower legs mounts were made using steel sheet and nuts that were then welded into the bottom of the bars. This provides a rigid mounting point for the casters which will support the required weight. Threaded rod casters were used to achieve this and were the best option with our space constraints and material selection. With two nuts welded to either side of a circular piece of steel plate the threaded rod casters can simply thread into and out of the bottom of the legs allowing them to provide additional height adjustability and the ability to be replaced.

Figure 56. Lower legs welded with nut insert and threaded rod casters attached

8.1.3 - Sliders and Brackets

In order to provide a straight track for the slider bars to run in and a rigid spot for the locking mechanism to mount to hold the weight, slider bars were manufactured using steel angle iron. Ten foot lengths of angle were cut in the chop saw to fit in the internal dimension of the cart. Slots were then milled in each of the four pieces of angle iron using a large end mill making sure to set up the vise properly and run at the appropriate speed to achieve a clean cut. Many test fits, measurements, and checks were performed in this step of the process to ensure that the legs would fold all the way up and would extend to exactly the desired location.

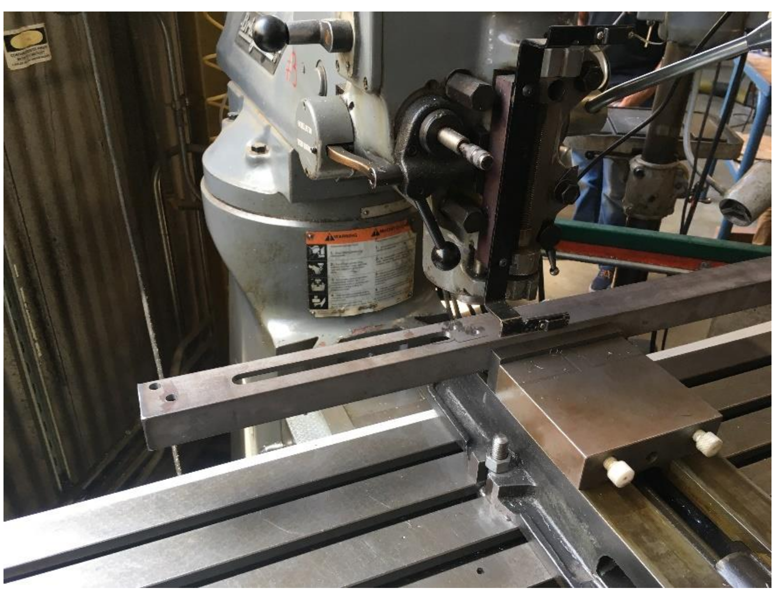

Figure 57. Using a mill to cut a straight slot in the slider angle


Figure 58. Sliders test fit in position

Angle brackets cut from long pieces of angle were used to mount the sliders to the frame. Two clearance holes were drilled in each bracket to provide rigid mounting and some position adjustability. The brackets were then test fit with the sliders, measured, fixtured and welded in position. The sliders were mounted and marked and had accompanying clearance holes drilled to fasten them to the brackets on the frame.

Figure 59. Sliders and leg assemblies test fit on frame

8.1.4 - Locking mechanism

The locking mechanism was custom made from raw materials starting off with thick and thin steel plate. The components were cut out using the water jet to achieve a precise profile and accurate dimensions with minimal post processing. The parts were then drilled using the drill press and mill. The bracket was also welded together using TIG welding to reduce heat input and warpage. Springs, dowel pins, nuts and bolts were purchased and the entire mechanism was assembled and mounted to the sliders in the appropriate location.


Figure 60. Locking mechanism pieces cut using the water jet


Figure 61. Fully assembled locking mechanism

8.2 Prototype vs Planned Design
There were many changes made in our prototype versus what was planned in CDR. This was due to exploring different options late into the manufacturing phase as well as cost savings, strength, and material availability.

It was decided to use steel tubing instead of aluminum tubing for strength, cost and material availability. Steel is much stronger than aluminum and thinner walled material could be used to achieve the same strength so that the weight increase was not significant. Steel tubing was significantly less expensive than aluminum as shown in our final cost summary. Further steel was more readily available and had more options locally reducing shipping time and cost.

Steel rectangular tubing was used for the frame instead of T-Slot aluminum to achieve a more finished product look and also reduce cost. There was concern that the T-slot was not appropriate for a consumer product while a smooth metal surface would look much better. Thin walled steel tubing was also significantly less expensive than aluminum T-slot.

To further reduce cost, we decided to weld the frame and legs together instead of using tubing fittings. This was a significant cost savings but did increase the manufacturing time and reduced the opportunity to easily replace parts on the cart.

Overall the changes contributed to a noticeable cost reduction but a large increase in manufacturing time and a reduction in stock parts used and opportunity for easy part replacement. Almost all parts were custom made and would be difficult to replace if needed.

8.3 Recommendations for future manufacturing

Because so many parts were custom made the manufacturing time required was significantly more than anticipated and parts cannot be easily replaced. For future manufacturing, we recommend changing the design to include more stock parts and reduce custom manufacturing. Parts could not be changed out or easily adjusted with custom manufacturing and permanent manufacturing methods like welding. TIG welding is highly time consuming and required a lot of skill to perform properly, if would be better to use other processes where possibly to decrease time and cost of welding. Making more parts of the cart bolted or fastened together would also make it easier to replace parts and perform maintenance if needed while also reducing welding time and costs. Better jigs and fixtures should be used when welding to reduce warpage. It was very challenging the keep the legs straight and square while welding and required some fixing. Having the entire assembly rigidly fixed and taking more time to weld allowing the joints to cool would be much better and deliver a better finished product. Subsystem manufacturing and testing should also have been performed to verify functionality and reduce mistakes by making sure everything works individually before it is put together on the final product.

9.0 – Design Verification

9.1 – Test Descriptions

Our final product has five functional tests to ensure the safety and reliability of the personal utility cart, as desired by our specifications. The tests include: load capacity test, subassembly test, folding test, locking test, and maneuverability test.

Load Capacity Test
The load capacity test was used to determine if the utility cart met our required specification of safely holding 200lbs. The test required incremental weights of 25 lbs, safety glasses, work gloves, and close-toed shoes. To conduct the test, we first ensured the cart was fixed and located in a clear area with no obvious safety hazards. We then lifted the first incremental weight into the cart, following OSHA proper lifting standards. Next we measured the deflection of the cart, bending, and material performance. We then repeated this test until 200lbs had been reached. Finally, we removed the incremental weights, one at a time, again following OSHA proper lifting standards.

Subassembly Test
This test involved making sure the subassemblies worked as desired by the specifications, including dimensional measurement, interference, range of motion, and functionality. Only a set of calipers, measuring tape, and work gloves were needed. We measured all necessary dimensions of the cart, making sure that they matched our detailed drawings. We then checked the clearance of the telescoping legs, the interference of the locking mechanism, and the storing footprint of the cart. This test was simply pass or fail, and we determined that it passed.

Folding Test
The purpose of the folding test was to make sure the cart properly folds and stows into a corresponding vehicle. Only a vehicle, safety glasses., and a stopwatch were required to conduct this test. We folded the cart into the back of a car 30 times and timed the results.

Locking Test
The locking test was created to determine the functionality of the locking mechanism. Only safety glasses were required for this test. We locked and unlocked the cart 30 times to make sure the cart properly locks and remains upright, and releases when folding is necessary, after two discrete motions by the user.

Maneuverability Test
The maneuverability was a subjective test we used to determine the maneuverability of the cart during its regular usage. No outside materials were required for this test. We simply rolled the cart around and each team member ranked the maneuverability of the cart based upon a predetermined maneuverability matrix with a corresponding favorability index between 1 and 10; 10 indicating a perfectly maneuverable cart. Our team determined an average score of 6.7.

9.2 – Results and Specification Verification

Our complete testing results can be seen in Table 11, with passing values indicated by a 'P', failing values indicated by an 'F', and values not yet determined indicated by a 'TBD'.

Table 11: Specification Verification

Spec. #	Parameter Description	Requirement or Target	Tolerance	Pass or Fail
1	Mechanism Operation Time	1 [min]	Max	**TBD**
2	No Visible Damage to Vehicle	Constraint	None	**P**
3	Footprint of Cart in Car	27 W x 36 D [in]	Max	**P**
4	Height Adjustability	23 – 33 [in]	±1 in.	**P**
5	Weight	50 [lbs]	±10 lbs.	**P**
6	One-Person Operation	Constraint	None	**P**
7	Weight Capacity	200 [lbs]	Min	**TBD**
8	Final Prototype Total Cost	$500	Max	**P**
9	Vehicle Adaptability	Fits into sponsors car	Min	**TBD**
10	Service Life	5 [years]	Min	**TBD**
11	Handle Height	42 [in]	±6 in.	**P**
12	Track Width	28 [in]	Max	**P**
13	Wheelbase	32 [in]	±3 in.	**P**
14	Stowable Dimensions	46 W x 28 D x 12 H [in]	Max	**P**
15	Safety Factor	2	Min	**TBD**

9.3 - Updated Final Budget

Our final budget can be seen in Table 12:

Table 12: Final Materials Budget. Parenthesis indicate a negative value.

Date purchased	Vendor	Description of items purchased	Transaction amount
11/05/16	Home Depot	PVC Pipe, MDF, Bolts for Prototyping	$ 85.47
04/20/17	Ace Hardware	Fasteners	$ 11.59
04/20/17	Fastenal	Hole Saw	$ 13.41
04/10/17	B&B	Tubing, Cuts, Scrap Metal	$ 79.54
02/24/17	Home Depot	Screws, PVC Materials	$ 22.69
04/29/17	B&B	Remnant Steel	$ 56.32
06/01/17	Home Depot	Paint, Plywood, Brackets, Screws, Wood Stain	$ 89.86
05/17/17	Home Depot	Castors, Pins	$ 73.56
05/17/17	Ace Hardware	Fasteners	$ 29.33
05/30/17	Cal Poly Hangar	Screws	$ 5.00
Budget:	$ 400.00		
Total Expenses:	$ 466.77		
Remaining Balance:	$ (66.77)		

Our team ended up $66.77 over budget, but still under the original estimate of $500 for the final prototype.

10.0 – Conclusion and Recommendations

The results of this project include research into the personal shopping cart market as well as a prototype of a folding cart. The cart has a steel frame and can easily support 200lbs of anything that can fit into the basket. We made removable wooden basket for the top of the cart, which allows for items to be transported easily. The cart should be able to handle day-to-day activities such as groceries as well as carrying around tools or building supplies.

One problem with the cart is that we ran into an interference problem that we were not able to fix before the deadline. The problem was in the locking mechanism clearance inside the rails. This problem should be an easy fix as the locking mechanism can be mounted on the outside of the rails instead of the inside. One of the challenges with this project was the amount of time required to fabricate all of the components. Our team manufactured almost all of the components which was very time intensive. Given more time this problem would have been sorted out better. Once the mechanism is moved to a location where it will not interfere, the cart will be able to lock upright. This cart can be made fully functional, however it is still not a consumer grade product. This project started as a way for us to look into this and come up with a design that could be made into a product used by consumers. The outcome of having a prototype cart is still a useful step in designing a finished product. In addition to the prototype, the research and analysis and the design criteria found in making this prototype are useful in designing a final product.

Through the sponsorship of Cal Poly Mechanical Engineering graduate Michael Allwein and Professor Sarah Harding, we were able to design and build a utility cart with folding legs. We hope this project will aid in designing a product that can end up being sold to consumers and help people make getting their groceries around simpler.

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Appendices (12):

Appendix A – Bumper Height Data

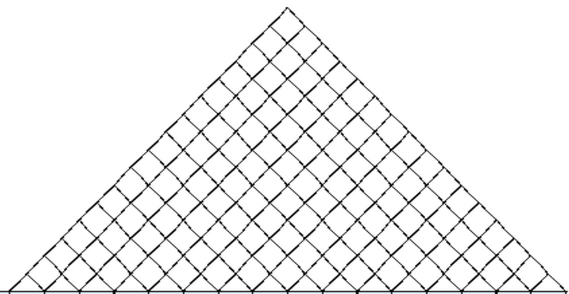
Data Number	Manufacturer	Model	Height [in]	Width [in]	Depth [in]	Lip [in]	Type	Notes
19		Ambulance	31	49			Ambulance	Used by SLO EMTs
3	Nissan	Murano	28	46			Crossover	
5	Nissan	Rogue	30	45			Crossover	
9	Ford	Escape	29	38			Crossover	
13	Honda	CRV	27	39	32	3	Crossover	
12	Honda	Odyssey	25	43			Minivan	
2	Nissan	Titan XD	37	46	N/A		Pick-up	
4	Nissan	Frontier 4X	33	46	N/A		Pick-up	
6	Ford	F150	35.5	59	N/A		Pick-up	
15	Honda	Ridgeline	34	51	N/A		Pick-up	
18	GMC	Denali	40	56	N/A		Pick-up	
1	Nissan	Armada	31	51.5			SUV	
7	Ford	Explorer	31	43			SUV	
8	Ford	Expedition	31.5	52.5			SUV	
10	Lincoln	Navigator	30	53.5			SUV	
11	Toyota	4 Runner	28	50			SUV	
14	Honda	Pilot	32	44.5	49		SUV	17.5 D With seats up
16	Chevrolet	Tahoe	37	49.5	44		SUV	
17	Chevrolet	Trailblazer	31	46	39		SUV	Mike's Car
Average			31.631579	47.81579	41			
Pick-up			35.9	51.6	N/A			
SUV			31.4375	48.8125	44			
Crossover			28.5	42	32			

Appendix B: QFD House of Quality

Correlations	
Positive	+
Negative	–
No Correlation	

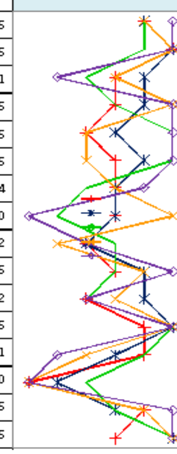
Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼



WHO: Customers / NOW: Current Product Assesment - Customer Requirements

Row #	Relative Weight	Mr. and Mrs. Alhwein	Retail Shopper	General Contractor	People needing to transport items	Maximum Relationship	WHAT: Customer Requirements (explicit & implicit)	Competitor #1: Wagon Cart	Competitor #2: Standard Shopping C	Competitor #3: Foldable Shopping C	Competitor #4: Heavy Duty Cart	Competitor #5: Hand Basket	Row #
1	11%	10	10	10	10	9	Safety	4	4	4	4	5	1
2	9%	8	8	10	7	9	Reliability	5	5	4	5	5	2
3	9%	9	8	9	8	9	Volume Capacity	3	4	2	3	1	3
4	4%	2	4	4	4	9	Simplicity	3	4	3	5	5	4
5	8%	9	8	5	8	9	Low Cost	2	3	5	2	5	5
6	6%	6	6	5	6	9	Light-Weight	3	4	5	2	5	6
7	6%	5	5	8	5	9	Durability	3	3	2	3	4	7
8	5%	4	4	7	4	9	Heavy Load Capability	3	3	1	5	0	8
9	5%	3	7	1	7	3	Aesthetic	2	2	3	1	2	9
10	6%	5	5	7	5	9	Maneuverable	3	4	3	4	5	10
11	7%	6	6	7	6	9	Ergonomic	2	4	2	3	2	11
12	5%	5	5	4	5	9	Ease of Operation	4	5	5	5	5	12
13	4%	2	4	3	8	9	Versatile	4	3	4	2	1	13
14	5%	4	5	5	5	9	Adjustable	0	1	2	0	0	14
15	5%	1	7	6	7	9	Manufacturable	4	3	3	4	5	15
16	6%	3	8	6	8	9	Low-Maintenance	3	5	5	5	5	16



HOW: Engineering Specifications

Row #	WHAT	1 Quick Mechanism Operation	2 No Visible Damage to Car	3 HWL	4 Height Adjustability	5 Weight	6 One Person Operation	7 Weight Capacity	8 Cost	9 Vehicle Adaptability	10 Lifespan	11 Handle Height	12 Track Width and Wheelbase	13 Stowable Dimensions	14 Turn Radius	15 Obstacle Navigation	16 Safety Features
1	Safety	○			●	○	●	○	○		○	▽	●	▽	○	●	●
2	Reliability				●		●	▽	○		●		▽			●	○
3	Volume Capacity			●				▽		●			○	●			
4	Simplicity	○		▽	○		▽		●		○			○	▽	○	○
5	Low Cost				○	○	▽	○	●		○		▽	▽		○	○
6	Light-Weight			○	▽	●	●	●	○				▽	○		▽	▽
7	Durability	▽			○	○		○	○		●				▽	●	
8	Heavy Load Capability	○		○	○	●	●	●	○	▽	▽		○	○	▽		○
9	Aesthetic			○	▽			▽	○			▽	○	○	▽	○	○
10	Maneuverable			▽		●	●	○	▽			○	●	▽	●	●	▽
11	Ergonomic	●		▽	○	○	●		▽			●	▽	▽	○	○	○
12	Ease of Operation	●	▽	▽	●	○	●			▽		▽	○	●	●	●	●
13	Versatile		●	●	●		▽	○		●	○	▽	▽	●	○	●	▽
14	Adjustable			○	●	▽			○	●	●	▽		●			▽
15	Manufacturable	○		▽	○	▽			●	▽				▽			○
16	Low-Maintenance	○	▽		●	▽			○	○	●					▽	▽

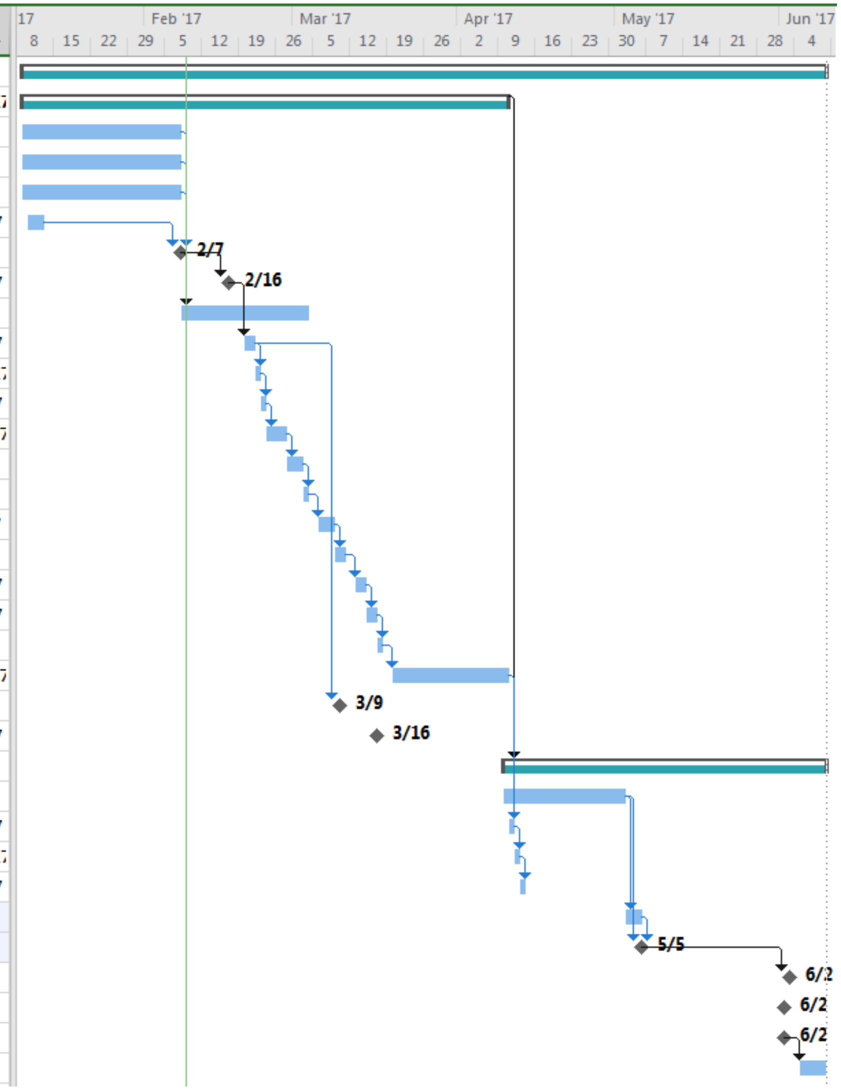
Column #	HOW MUCH: Target	Max Relationship	Technical Importance Rating	Relative Weight
1	1 minute or less	9	203.11	5%
2	Constraint	9	50.344	1%
3	46 W x 39 D in.	9	208.27	5%
4	23 - 33 in. PM 1 in.	9	474.14	11%
5	50 lbs PM 10 lbs	9	276.98	6%
6	Constraint	9	446.55	10%
7	Able to carry a minimum of 200 lbs	9	226.04	5%
8	Able to fabricate for under $200	9	321.51	7%
9	Able to fit into sponsors car	9	199.24	5%
10	5 year lifetime	9	319.64	7%
11	42 inches PM 6 in.	9	106.17	2%
12	Track Width: 32 in. maximum Wheelbase: 32 in. PM 3 in.	9	251.71	6%
13	46 W x 39 D x 12 H (in.) Maximum	9	304	7%
14	Maximum Same as Standard Grocery Cart	9	180.98	4%
15	6 in. Minimum	9	444.96	10%
16	N/A	9	293.14	7%

Weight Chart

Appendix C: Project Gantt Chart

GANTT CHART

	Task Name	Duration	Start	Finish
1	**Personal Utility Cart Senior Project**	**110 days**	**Mon 1/9/17**	**Fri 6/9/17**
2	**Build**	**66 days**	**Mon 1/9/17**	**Mon 4/10/17**
3	CAD Modeling of Final Design	22 days	Mon 1/9/17	Tue 2/7/17
4	Kinematic Analysis	22 days	Mon 1/9/17	Tue 2/7/17
5	Loading Analysis	22 days	Mon 1/9/17	Tue 2/7/17
6	Order All Long-Lead Parts	3 days	Tue 1/10/17	Thu 1/12/17
7	CDR	0 days	Tue 2/7/17	Tue 2/7/17
8	CDR Sponsor Presentation	0 days	Thu 2/16/17	Thu 2/16/17
9	Design Optimization	18 days	Wed 2/8/17	Fri 3/3/17
10	Order All Parts	2 days	Mon 2/20/17	Tue 2/21/17
11	Cut and Assemble Frame	1 day	Wed 2/22/17	Wed 2/22/17
12	Cut and Drill Upper Leg Tubing	1 day	Thu 2/23/17	Thu 2/23/17
13	Assemble Legs and Rotational Mechanism	2 days	Fri 2/24/17	Mon 2/27/17
14	Cut and Drill Lower Leg Tubing	3 days	Tue 2/28/17	Thu 3/2/17
15	Assemble Lower Legs	1 day	Fri 3/3/17	Fri 3/3/17
16	Cut and Mill Slider Bars	3 days	Mon 3/6/17	Wed 3/8/17
17	Cut, Drill, and Weld Locking Mechanism	2 days	Thu 3/9/17	Fri 3/10/17
18	Assemble Locking Mechanism	2 days	Mon 3/13/17	Tue 3/14/17
19	Cut, Bend, Weld Handle	2 days	Wed 3/15/17	Thu 3/16/17
20	Assemble Basket	1 day	Fri 3/17/17	Fri 3/17/17
21	Subsystem Functional Testing and Iterations	16 days	Mon 3/20/17	Mon 4/10/17
22	Operator's Manual	0 days	Thu 3/9/17	Thu 3/9/17
23	Project Update Report	0 days	Thu 3/16/17	Thu 3/16/17
24	**Test**	**45 days**	**Mon 4/10/17**	**Fri 6/9/17**
25	System Level Functional Testing and Iterations	17 days	Mon 4/10/17	Tue 5/2/17
26	Stowing Testing	1 day	Tue 4/11/17	Tue 4/11/17
27	Load Testing	1 day	Wed 4/12/17	Wed 4/12/17
28	Maneuverability Testing	1 day	Thu 4/13/17	Thu 4/13/17
29	System Level Safety Testing	3 days	Wed 5/3/17	Fri 5/5/17
30	Project Hardware/Safety Demo	0 days	Fri 5/5/17	Fri 5/5/17
31	FDR Project Expo	0 days	Fri 6/2/17	Fri 6/2/17
32	FDR Hardware Handoff	0 days	Fri 6/2/17	Fri 6/2/17
33	FDR	0 days	Fri 6/2/17	Fri 6/2/17
34	Final Checklist	1 wk	Mon 6/5/17	Fri 6/9/17



Appendix D-1: Power Source and Locking Subsystem Pugh Matrices

Power Source				
Customer Requirements	**Human**	**Cable + Ratchet**	**Jack**	**Wheel and Worm Gear**
Safe	0	1	1	1
Reliable	0	0	0	1
Volume	0	-1	0	0
Simple	0	-1	-1	-1
Low-Cost	0	-1	-1	-1
Weight	0	0	-1	-1
Durable	0	1	1	1
Easy to Operate	0	1	0	0
Load Capacity	0	0	1	1
Consumer Load	0	0	1	1
Aesthetic	0	0	-1	-1
Ergonomic	0	1	1	1
Adjustable	0	1	1	1
Low-Maintenance	0	-1	-1	-1
Σ Total	**0**	**1**	**1**	**1**

Locking					
Customer Requirements	**Pull Pin**	**Spring Pin**	**Notches**	**Ratchet**	**Cable**
Safe	0	0	1	0	-1
Reliable	0	0	0	0	0
Simple	0	0	0	-1	-1
Low-Cost	0	0	0	-1	0
Durable	0	0	0	0	0
Easy to Operate	0	0	1	1	0
Load Capacity	0	0	0	0	0
Ergonomic	0	0	1	1	1
Adjustable	0	0	0	1	-1
Low-Maintenance	0	0	0	-1	-1
Σ Total	**0**	**-1**	**3**	**0**	**-2**

Appendix D-2: Storage Subsystem Pugh Matrix

Storage								
Customer Requirements	**Ridgid Walls**	**Collapsing Walls**	**Hinged Walls**	**Telescoping Walls**	**Dividers**	**Modular**	**Shelves**	**Hooks**
Safe	0	-1	-1	-1	-1	-1	0	0
Reliable	0	-1	-1	-1	0	-1	0	0
Volume	0	1	1	1	0	1	1	1
Simple	0	-1	-1	-1	0	-1	0	0
Low-Cost	0	-1	-1	-1	-1	-1	0	0
Weight	0	0	0	0	0	0	-1	0
Durable	0	0	0	0	0	0	0	0
Easy to Operate	0	0	0	0	0	0	0	0
Load Capacity	0	1	1	1	1	1	1	1
Consumer Load	0	1	1	1	1	1	1	1
Aesthetic	0	0	0	0	0	0	0	0
Ergonomic	0	1	1	1	1	1	1	1
Adjustable	0	1	1	1	1	1	0	0
Low-Maintenance	0	0	0	0	0	0	0	0
Σ Total	0	1	1	1	2	1	3	4

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.

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
Possible pinch points	Minimize interactive mechanisms near pinch points and clearly label all pinch points.	4/10/17	
Tipping hazard	Clear labeling of max reasonable loads to have in the cart to prevent failure or tipping hazards.	4/10/17	
Improper use	We will write a guide so that improper uses are outlined so that users are aware of limits of the cart.	4/10/17	
Improper Locking	Perform Locking mechanism testing to ensure safe and proper operation 100% of the time	4/10/17	
Accidental Unlocking	Design Release Mechanism to require to distinct movements to present accidental release	2/9/17	2/9/17
Cart Collapse	Perform load testing to ensure cart can handle maximum load and still perform properly and safely	4/10/17	

Appendix F: Indented Bill of Materials

Part Number	QTY	Description	Length	Source	Unit $
1000	1	Frame and Leg Assembly			
1001	2	2"X1" Aluminum Double Profile T-Slotted Framing	36"	8020.net	$18.03
1002	2	2"X1" Aluminum Double Profile T-Slotted Framing	24"	8020.net	$12.85
1003	2	1" Aluminum T-Slotted Framing Tubing Holder - Standard		8020.net	$34.10
1004	8	Aluminum Slip-on Rail Fitting, Tee Connector for 1" Rail OD		Mcmaster	$6.75
1005	2	Aluminum Slip-on Rail Fitting, Crossover Connector		Mcmaster	$11.27
1006	1	6061 Aluminum Tube, 1" OD, .125" Wall Thickness (Pivot Tube)	26"	Mcmaster	$18.12
1007	2	6061 Aluminum Tube, 1" OD, .125" Wall Thickness (Front Upper)	24"	Mcmaster	$13.82
1008	2	6061 Aluminum Tube, 1" OD, .125" Wall Thickness (Rear Upper)	30"	Mcmaster	$18.12
1009	1	6061 Aluminum Tube, 1" OD, .125" Wall Thickness (Front Cross)	18"	Mcmaster	$13.82
1010	1	6061 Aluminum Tube, 1" OD, .125" Wall Thickness (Rear Cross)	24"	Mcmaster	$13.82
1011	1	6061 Aluminum Tube, 1" OD, .125" Wall Thickness (Front Slider)	19"	Mcmaster	$13.82
1012	1	6061 Aluminum Tube, 1" OD, .125" Wall Thickness (Rear Slider)	16"	Mcmaster	$13.82
1013	2	6061 Aluminum Tube, 3/4" OD, .125" Wall Thickness (Front Lower)	24"	Mcmaster	$10.92
1014	2	6061 Aluminum Tube, 3/4" OD, .125" Wall Thickness (Rear Lower)	24"	Mcmaster	$10.92
1015	8	Bracket, 2" Long for 2" Aluminum T-Slotted Framing Extrusion		8020.net	$8.79
1016	10	Bracket, 2" Long for 1" Aluminum T-Slotted Framing Extrusion		8020.net	$5.85
1017	30	Fastener for 1" Single & 2" T-Slotted Framing Extrusion		8020.net	$2.30
1018	4	Aluminum-Handle Push-Button Quick-Release Pins with lanyard		Mcmaster	$22.54

1019	2	Expanding-Stem Casters Swivel with total lock		Mcmaster	$26.10
1020	2	Cart-King Rigid Casters		Mcmaster	$12.04
1021	2	Front mounting plate		Mcmaster	$2.00
1022	2	Rear Mounting plate		Mcmaster	$2.00
2000	1	Locking Mechanism Assembly			
2001	1	Cable Housing Set		Foothill Cyclery	$10.00
2002	1	Brake Lever (pair)		Foothill Cyclery	$17.99
2003	2	Brake Cable Set		Foothil Cyclery	$10.00
2004	2	Roller Shaft	1'	1/2" Steel Rod	$1.30
2005	2	Cam Follower	2' x 1'	1/8" Steel Sheet	$1.25
2006	2	Cam Bracket	2' x 1'	1/8" Steel Sheet	$3.00
2007	2	Support Housing	6'	Steel Square Tubing	$30.06
2008	2	Torsional Spring		Torsional Sping	$10.00
2009	4	Dowel Pin		Dowel Pins	$6.89
2010	4	PTFE Bushing		PTFE Bushings	$24.16
2011	4	1/4-20 Screws		1/4-20 Screws	$7.04
2012	4	1/4-20 Nuts		1/4-20 Nuts	$2.13
2013	2	5-40 Set Screw		5-40 Set Screw	$0.06
3000	1	Handlebar and Basket Assembly			
3001	2	Gal. Steel Wire Mesh	2' x 3'	8020.net	$14.61
3002	1	Gal. Steel Wire Mesh	2' x 2'	8020.net	$11.79
3003	12	Wire Mesh Panel Holders	1"	8020.net	$32.40
3004	4	Galvanized Steel Corner Brackets	2" x 2"	McMaster	$4.72
3005	1	Low-Carbon Steel Tubing, 1" OD, .902" ID, .049" Wall Thickness	6'	McMaster	$10.18
3006	1	11 GA Hot Rolled Steel Sheet	2' x 1'	metalsdepot.com	$20

3007	4	Zinc-Plated Steel Fasteners - Pack of 4		McMaster	$2.30

Appendix G: Operator's Manual

When operating the cart:

- Do not have people ride on or inside of the cart.
- Do not exceed 200 lbs. of weight inside of the cart.
- User's hands and feet should remain on the handlebars when folding the legs.
- Watch out for other's appendages when folding and unfolding the cart.
- Make sure pins are secure before lowering the legs.
- For minimal effort when loading the cart, keep center of gravity as close to the front as possible.

Locking Mechanism Instructions:
Folding:

1. Ensure there are no obstructions in the way of leg supports when operating as the cart will not fully close otherwise. Keep hands and feet out of leg path when folding as they pose a possible pinch point.
2. Rest support wheels at front of cart on bumper block or tailgate and push the cart forward until the front legs make contact with the bumper.
3. Once cart is held by support wheels and front legs contact the bumper, pull front brake lever to actuate locking mechanism until legs release while simultaneously pushing the cart forward into the bumper.
4. Once front legs are fully folded, proceed pushing in cart until rear legs make contact with the bumper.
5. Repeat the same process as in step 3, however this time pull right lever to unlock rear legs.
6. Depending on size of car, rear legs may need to be shortened to fit into car. To do this pull pins from rear legs and push the bottom of the leg until they are fully inside of the car.

Unfolding:

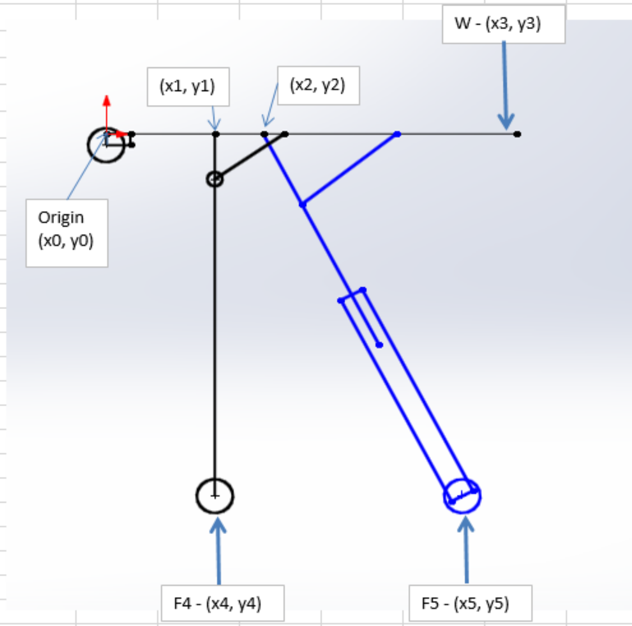
1. To unfold cart, pull the cart partially out of the car while holding the rear leg release lever. Legs may require assistance to fully open and lock. Make sure lock is engaged before allowing rear legs to support cart weight.
2. Once rear legs are locked, pull front leg release lever while pulling cart out of car. Once again user may be required to assist legs in fully unfolding.
3. If cart starts from the ground, it is recommended that two people are present to unlock the cart.
4. One person can lift half of the cart while the other pulls release lever and ensures locking mechanisms are engaged.
5. If only one person is present, it is recommended to deploy the rear legs first, then the front legs so that the full weight of the cart is not supported at one time.

Appendix H – Static Analysis Spreadsheets

Editable values

	x_0	0	y_0	0	in.
	x_1	3	y_1	0	in.
	x_2	11	y_2	0	in.
W	x_3	25	y_3	0	in.
	x_4	3	y_4	-34.5	in.
	x_5	25.4	y_5	-34.5	in.

W	250	lb
F4	4.464286	lb
F5	245.5357	lb



Rear Leg Calculations

x_0	0	y_0	0
x_1	-12	y_1	28.1
x_2	-14.4	y_2	34.5

	deg	rad
θ_1	39.92	0.70

	i	j		Magnitude	
F_0	245.5	0.0	lbs	245.5	lbs
F_1	-420.5	-351.9	lbs	548.3	
R	420.5	106.3	lbs	433.7	

σ_{yield}	72 ksi			
	1		1 1/4	
	0.095	0.12	0.095	0.12
σ_{bend}	26.83			
σ_{shear}	2.02			

	F_0	F_1	R_x	R_y		
	1	0	0	0	245.5	F_0
A	1	-0.642	0	1	0	F_1
	0	-0.767	1	0	0	R_x
	0	29.25	-34.5	-14.4	0	R_y

	1	0	0	0		245.5	F_0
A^{-1}	2.2331	-2.233	-5.35	-0.16	**X**	548.3	F_1
	1.7126	-1.713	-3.103	-0.12		420.5	R_x
	0.433	-0.433	-3.433	-0.1		106.3	R_y

Front Leg Calculations

				Offset			
x_0	0	y_0	0			deg	rad
x_1	-0.82	y_1	-27.0		θ_0	1.736	0.03
x_2	-1.00	y_2	-33.0	1	θ_1	38.61	0.67

	i	j		Magnitude	
F_0	4.5	0.0	lbs	4.5	
F_1	-0.7	-0.6	lbs	0.9	lbs
R	0.7	-3.9	lbs	4.0	

	F_0	F_1	R_x	R_y		
	1	0	0	0	4.5	
	0	-0.781	1	0	0	F_0
A	1	-0.624	0	1	0	F_1
	0	21.6	-32.98	-0.9995	0	R_x
						R_y

	1	0	0	0
A^{-1}	0.2082	-6.872	-0.208	-0.2083
	0.1627	-4.37	-0.163	-0.1628
	-0.87	-4.288	0.8701	-0.13

X	
4.5	F_0
0.9	F_1
0.7	R_x
-3.9	R_y

Appendix I: DFMEA

Product: ______________________________ Prepared by: ______________________________

Team: ______________________________ Date: ________________ (orig)

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s) / Mechanism(s) of Failure	Occurence	Criticality	Recommended Action(s)	Responsibility & Target Completion Date	Action Results: Actions Taken	Action Results: Severity	Action Results: Occurence	Action Results: Criticality
	Locking Mechanism won't release	Must transfer items into vehicle manually like regular cart	5	Interference in mechanism	2	10	Analyze tolerances to insure proper clearance					
				Corrosion in locking mechanism	4	20						
				Wrong spring	1	5						
				Release Cable stretches	5	25						
		Must leave cart at current location	5	Interference in mechanism	2	10	Use non corroding materials/coatings					
				Corrosion in locking mechanism	4	20						
				Wrong spring	1	5						
				Release Cable stretches	5	25						
		Must lift entire cart into vehicle	7	Interference in mechanism	2	14	Determine and test spring coefficients for repeatable release					
				Corrosion in locking mechanism	4	28						
				Wrong spring	1	7						
				Release Cable stretches	5	35						
		Must roll cart home manually and pick up car later	6	Interference in mechanism	2	12	Determine cable ductility					
				Corrosion in locking mechanism	4	24						
				Wrong spring	1	6						
				Release Cable stretches	5	30						
		Manually or forcefully collapse cart	4	Interference in mechanism	2	8	Determine load required to release mechanism					
				Corrosion in locking mechanism	4	16						
				Wrong spring	1	4						
				Release Cable stretches	5	20						
	Locking Mechanism won't engage	Cart collapses and is not useable	7	Improper alignment of mechanism	3	21	Analyze and specify proper GD&T					
				Corrosion in locking mechanism	4	28						
				Wrong spring	1	7						
				mechanism material failure (shear/bend/buckle)	1	7						
		Must leave cart at current location	5	Improper alignment of mechanism	3	15	Use non corroding materials/coatings					
				Corrosion in locking mechanism	4	20						
				Wrong spring	1	5						
				mechanism material failure (shear/bend/buckle)	1	5						
		Must lift entire cart into vehicle	7	Improper alignment of mechanism	3	21	Determine and test spring coefficients for repeatable release					
				Corrosion in locking mechanism	4	28						
				Wrong spring	1	7						
				mechanism material failure (shear/bend/buckle)	1	7						
		Injury due to collapsing cart and falling items	9	Improper alignment of mechanism	3	27	Determine material properties					
				Corrosion in locking mechanism	4	36						
				Wrong spring	1	9						
				mechanism material failure (shear/bend/buckle)	1	9						
		Damaged items	6	Improper alignment of mechanism	3	18	Compare material properties to loading conditions					
				Corrosion in locking mechanism	4	24						
				Wrong spring	1	6						
				mechanism material failure (shear/bend/buckle)	1	6						

Design Failure Mode and Effects Analysis

Product: ______________________________ Prepared by: ______________________________

Team: ______________________________ Date: ________________ (orig)

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s) / Mechanism(s) of Failure	Occurence	Criticality	Recommended Action(s)	Responsibility & Target Completion Date	Action Results: Actions Taken	Action Results: Severity	Action Results: Occurence	Action Results: Criticality
Stow into vehicle	Legs Break	Cart collapses and is not useable	7	Leg Material failure (shear/bend/buckle)	1	7	Use non corroding materials/coatings					
				Corrosion of legs	4	28						
				unexpected loading/overloading	7	49	Determine appropriate factor of safety to prevent failure, determine possible loading configurations, make sure cart can handle all possible loading	9-Jan				
				Impact with other object	7	49	Implement safety guards, Leg impact analysis, ensure locking mechanism won't release accidently, analyze wheelbase and trackwidth to avoid tipping	9-Jan				
		Must leave cart at current location	5	Leg Material failure (shear/bend/buckle)	1	5	Perform loading analysis					
				Corrosion of legs	4	20						
				unexpected loading/overloading	7	35						
				Impact with other object	7	35						
		Must lift entire cart into vehicle	7	Leg Material failure (shear/bend/buckle)	1	7	Determine material properties					
				Corrosion of legs	4	28						
				unexpected loading/overloading	7	49	Determine appropriate factor of safety to prevent failure, determine possible loading configurations, make sure cart can handle all possible loading, user manual to show proper loading	9-Jan				
				Impact with other object	7	49	Implement safety guards, design geometry to keep legs away from impact	9-Jan				
		Injury due to collapsing cart and falling items	9	Leg Material failure (shear/bend/buckle)	1	9	Compare material properties to loading conditions					
				Corrosion of legs	4	36						
				unexpected loading/overloading	7	63	Determine appropriate factor of safety to prevent failure, determine possible loading configurations, make sure cart can handle all possible loading	9-Jan				
				Impact with other object	7	63	Implement safety guards, design geometry to keep legs away from impact	9-Jan				
		Damaged items	6	Leg Material failure (shear/bend/buckle)	1	6	Determine appropriate factor of safety to prevent failure					
				Corrosion of legs	4	24						
				unexpected loading/overloading	7	42	Determine appropriate factor of safety to prevent failure, determine possible loading configurations, make sure cart can handle all possible loading	9-Jan				

Design Failure Mode and Effects Analysis

Product: ______________________________ Prepared by: ______________________________

Team: ______________________________ Date: ________________ (orig)

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s) / Mechanism(s) of Failure	Occurence	Criticality	Recommended Action(s)	Responsibility & Target Completion Date	Action Results: Actions Taken	Action Results: Severity	Action Results: Occurence	Action Results: Criticality
				Impact with other object	7	42	Implement safety guards, design geometry to keep legs away from impact	9-Jan				
	Wheels break	Cart cannot move is not useable	7	Overloaded	7	49	Perform loading analysis and determine safety factor and absolute max load	9-Jan				
				Corrosion of bearings	5	35						
				Wear on or dirt in bearings	6	42	Source sealed bearings or cheap easy to replace bearings	9-Jan				
				Impact with other object	7	49	Research heavy load capacity and impact resistant wheels, perform impact and load analysis on wheels	9-Jan				
		Must leave cart at current location	5	Overloaded	7	35	Use non corroding materials/coatings					
				Corrosion of bearings	5	25						
				Wear on or dirt in bearings	6	30						
				Impact with other object	7	35						
		Must lift entire cart into vehicle	7	Overloaded	7	49	Perform loading analysis and determine safety factor and absolute max load					
				Corrosion of bearings	5	35						
				Wear on or dirt in bearings	6	42	Source sealed bearings or cheap easy to replace bearings	9-Jan				
				Impact with other object	7	49	Research heavy load capacity and impact resistant wheels, perform impact and load analysis on wheels	9-Jan				
		Injury due to unstable cart and falling items	9	Overloaded	7	63	Investigate different wheel and caster options	9-Jan				
				Corrosion of bearings	5	45	Investigate all weather and sealed bearings, what is used in corrosive environments	9-Jan				
				Wear on or dirt in bearings	6	54	Source sealed bearings or cheap easy to replace bearings	9-Jan				
				Impact with other object	7	63	Research heavy load capacity and impact resistant wheels, perform impact and load analysis on wheels	9-Jan				
		Damage to floor	5	Overloaded	7	35						
				Corrosion of bearings	5	25						
				Wear on or dirt in bearings	6	30						
				Impact with other object	7	35						
		Secondary damage to cart	5	Narrow wheel base/track width	1	5	Analyze center of gravity location and					
				High center of gravity	4	20						
				Off center loading	8	40	Tipping analysis and off center load. Static, kinematic analysis	9-Jan				
				Impact with other object	7	35						
		Must leave cart at current location	5	Narrow wheel base/track width	1	5	Investigate ways to improve stability					
				High center of gravity	4	20						
				Off center loading	8	40	Tipping analysis and off center load. Static, kinematic analysis	9-Jan				
				Impact with other object	7	35						

Design Failure Mode and Effects Analysis

Product: ______________________________ Prepared by: ______________________________

Team: ______________________________ Date: ________________ (orig)

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s) / Mechanism(s) of Failure	Occurence	Criticality	Recommended Action(s)	Responsibility & Target Completion Date	Action Results: Actions Taken	Action Results: Severity	Action Results: Occurence	Action Results: Criticality
	Cart falls over	Must lift entire cart into vehicle	7	Narrow wheel base/track width	1	7	Investigate ways to reduce off center					
				High center of gravity	4	28						
				Off center loading	8	42	Tipping analysis and off center load. Static, kinematic analysis	9-Jan				
				Impact with other object	7	49	Tipping and center of gravity analysis	9-Jan				
		Injury due to falling cart and items	9	Narrow wheel base/track width	1	9	Determine reasonable object impact					
				High center of gravity	4	36						
				Off center loading	8	72	Tipping analysis and off center load. Static, kinematic analysis	9-Jan				
				Impact with other object	7	63	Investigate large diameter wheels or inflateable wheels to prevent tipping, force and impact analysis	9-Jan				
		Damaged items	6	Narrow wheel base/track width	1	6	Investigate ways to lower center of					
				High center of gravity	4	24						
				Off center loading	8	48	Tipping analysis and off center load. Static, kinematic analysis	9-Jan				
				Impact with other object	7	42	Investigate large diameter wheels or inflateable wheels to prevent tipping, force and impact analysis	9-Jan				
Support Load	Legs break	Customer is injured	9	Oblique impact	7	63	Analyze loading, forces, impact, center of gravity, and tipping of cart	9-Jan				
				Misuse of device	7	63	Write clear operation instructions and user manual for proper use, apropriate factor of safety	2/7-3/7				
		Customer is dissatisfied	4	Improper materal selection	1	4						
				Manufacturing defect	2	8						
	Cart bottom fails	Items are damaged	6	Improper materal selection	1	6	Analyze cause of failure and revise design					
		User is injured	9	Poor design of cart bottom	3	27						
		Customer is dissatisfied	4	Improper materal selection	1	4						
	Latch doesn't work	Cart collapses	8	Poor design of locking mechanism	2	16	Determine force required to engage latch, shear and bending on pin and latch, also assess latch design for strength and reliability					
		Cart will not fold	7	Locking mechanism is faulty	1	7						
		Legs will not deploy	8	Latch is difficult to operate	1	8						
				Latch breaks from misuse	5	40	Write clear operation instructions and user manual for proper use, increase factor of safety on highly used parts for longevity	2/7-3/7				
	Cart tips over	User is injured	9	Center of gravity is too high	4	36	Analyze tipping moment and assess cart wheelbase and center of gravity					
		Customer is dissatisfied	4	A bad wheel or set of wheels	3	12						
		Damaged items	6	Improper use	7	42	Write clear operation instructions and user manual for proper use, analyze tipping, wheel diameter and different wheel designs	2/7-3/7				

Design Failure Mode and Effects Analysis

Product: ______________________________ Prepared by: ______________________________

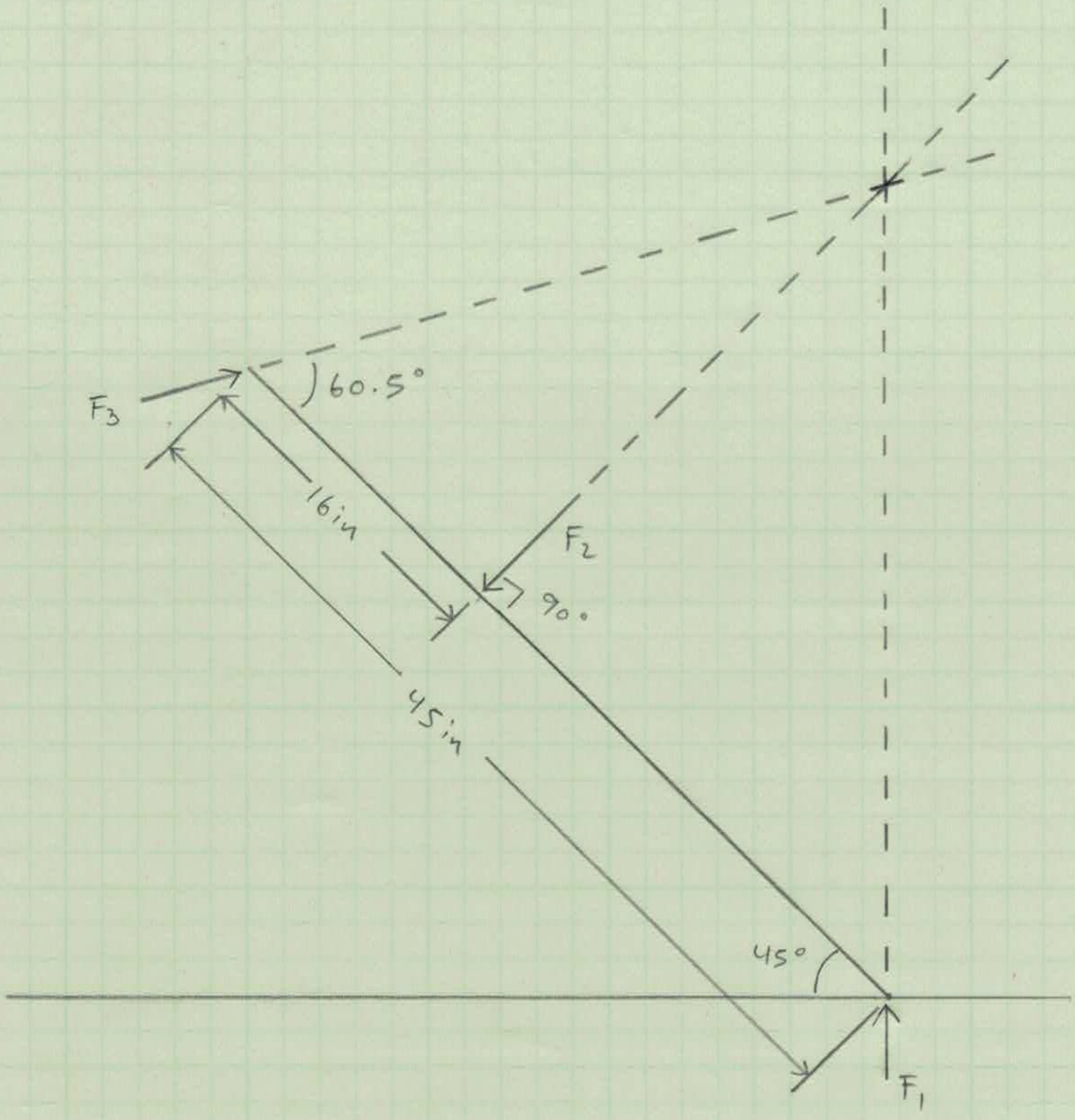
Team: ______________________________ Date: ________________ (orig)

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s) / Mechanism(s) of Failure	Occurence	Criticality	Recommended Action(s)	Responsibility & Target Completion Date	Action Results			
									Actions Taken	Severity	Occurence	Criticality
		Damages vehicle	5	Cart does not have an adequate wheelbase	1	5						
Hold Items	Walls Break	Items spill onto ground	6	Hinges break	5	30	Reinforce walls, ensure that they can					
				Wall cracks	3	18						
				Walls deform	6	36						
				Impact on cart	7	42	Analyze forces, material selection and properties, implement impact protection	9-Jan				
		Items are damaged	6	Hinges break	5	30	Ensure items fit into cart with little room to move around, a nice snug fit					
				Wall cracks	3	18						
				Walls deform	6	36						
		Customer returns to store to purchase new items	6	Hinges break	7	42	Ensure hinge life cycle can withstand regular use for desired product lifespan using material, load, fatigue analysis	9-Jan				
				Wall cracks	3	18						
				Walls deform	6	36	Reinforce walls and add supports					
				Impact on cart	7	42	Analyze forces, material selection and properties, implement impact protection	9-Jan				
	Base is Compromised	Items fall to ground	6	Legs fold prematurely	1	6						
				Telescoping legs lose extended support	2	12	Make sure items fall to ground in a slow-falling way, with various catches					
				Cart base cracks/swings open	3	18						
				Supports break	5	30						
		Cart collapses on user resulting in injury	9	Legs fold prematurely	1	9	Make sure supports are durable and					
				Telescoping legs lose extended support	2	18						
				Cart base cracks/swings open	3	27						
				Supports break	5	45	Analyze worst case loading, material properties, fatigue	9-Jan				
		Cart collapses on user resulting in injury	9	Legs fold prematurely	1	9	Make sure cart collapses completely					
				Telescoping legs lose extended support	2	18						
				Cart base cracks/swings open	3	27						
				Supports break	5	45	Design cart so that user operation puts them in little danger in case of failure, safety guards, high factor of safety on safety critical parts	9-Jan				

Appendix J: DVPR

ME428 DVP&R Format													
Report Date			Sponsor						Component/Assembly		REPORTING ENGINEER:		
TEST PLAN										TEST REPORT			
Item No	Specification or Clause Reference	Test Description	Acceptance Criteria	Test Responsi	Test Stage	SAMPLES		TIMING		TEST RESULTS			NOTES
						Quantity	Type	Start date	Finish date	Test Result	Quantity Pass	Quantity Fail	
1	Must fold/deploy in under one minute	Time putting cart into car with a stopwatch	Time on average is less than one minute	Sean	PV	10	C	4/8/2017	4/8/2017				
2	Must not cause any visible damage to car	Build a test fixture and see if any visible damage occurs after loading/unloading multiple times	No visible damage	Eric	PV	10	C	4/15/2017	4/15/2017				
3	Footprint does not exceed a width of 28 inches by 39 inches	Measure footprint using tape measurer	Footprint is less than or equal to 28 inches by 39 inches	Jason	DV	1	B	4/8/2017	4/8/2017				
4	Height of cart is adjustable	Make sure a loaded cart can load onto ledges of multiple heights.	Cart is successfully loaded onto different heights	Sean	PV	3	C	4/15/2017	4/15/2017				
5	Weight must not exceed 50 lbs	Measure using scale	Weight is less than 60 lbs	Eric	DV	1	B	4/15/2017	4/15/2017				
6	Production cost must not exceed $500	Add up cost of all of the components used	Cost is less than $500	Jason	DV	1	B	4/8/2017	4/8/2017				
7	Must fit into sponsor's car	Test folded cart in sponsor's car	Cart fits into sponsor's car	Sean	PV	1	C	4/8/2017	4/8/2017				
8	Handle height is around 42 inches	Measure handle height using tape measurer	Handle height does not exceed 48 inches	Eric	PV	1	C	4/8/2017	4/8/2017				
9	Track width is 28 inches	Measure track width using tape measurer	Track width does not exceed 28 inches	Jason	PV	1	C	4/8/2017	4/8/2017				
10	Wheelbase is 32 inches	Measure wheelbase using tape measurer	Wheelbase does not exceed 35 inches	Sean	PV	1	C	4/8/2017	4/8/2017				
11	Stowable dimensions must not exceed 28 W x 39 D x 12 H	Measure stowed cart using tape measurer	Stowable dimensions do not exceed 28 W x 39 D x 12 H	Eric	PV	1	C	4/8/2017	4/8/2017				
12	Turn radius is equal to or smaller than standard grocery store shopping cart	Test feel and maneuverablity next to a standard grocery cart	Cart has equal or better maneuverabiltiy in store compared with a store-provided cart	Jason	PV	1	C	4/15/2017	4/15/2017				
13	Can easily maneuver an obstacle of 6 inches	Try maneuvering a curb or similar obstacle	Cart can maneuver a 6 inch or higher obstacle without requiring excess strain to user	Sean	PV	5	C	4/15/2017	4/15/2017				
14	Weight capacity	Load cart with weight to ensure it can still function normally	Cart can hold 200 lbs of items without any failures or loss of function	Eric	PV	5	C	4/15/2017	4/15/2017				
15	Release Mechanism Engagement	Test that release mechanism engages reliably when cart is unloaded	Mechanism engages fully and cart does not collapse for any test sample	Jason	PV	30	C	4/8/2017	4/8/2017				
16	Release Mechanism Disengagement	Ensure release mechanism disengages when release levers are pressed	Mechanism releases with two discrete movements and does not release accidentlly due to impact or single movement	Sean	PV	30	C	4/8/2017	4/8/2017				
17	Does not tip when a force is applied at the top	Load cart with max weight capacity distributed in each of the four corners of the cart without causing tipping	Cart does not tip when 200 lbs is placed in each corner of the cart	Eric	PV	4	C	4/15/2017	4/15/2017				
18	Does not tip when loaded and moving over obstacle	Load cart with max weight and push into 1 inch high obstacle	Cart does not tip when navigating obstacle	Jason	PV	5	C	4/15/2017	4/15/2017				
19	Overload test	Load cart with more than max weight and verify all mechanisms still work	Cart can still function with 300 lbs of weight	Sean	PV	5	C	4/15/2017	4/15/2017				
20	Load Impact Test	Drop 50lb sand bad from height of sides of cart	Cart does not collapse or become damaged, still functions properly	Eric	PV	5	C	4/15/2017	4/15/2017				

REAR LEG
- 3 FORCE MEMBER



```
"Model of Rear Leg"

"Assuming rear leg can be modeled as simple beam"

"Known Parameters"
P = 200 [lbf]                        "Applied Load"
L = 45 [in]                          "Length of Member"
a = 16 [in]                          "Location of Load"
b = 45 - 16 [in]                     "Length - Location"
E = 10000000 [psi]                   "Modulus of Elasticity"
I = pi*(1^4 - 0.75^4)/64 [in^4]      "Moment of Inertia"
r = 0.5 [in]                         "Radius"

"Maximum Deflection"
y = (P*(a^2)*(b^2))/(3*E*I*L) "in"

"Maximum Moment"
M = (P*a*b)/L "in-lbf"

"Maximum Stress"
sigma = (M*r)/I "psi"
```

Model of Rear Leg

Assuming rear leg can be modeled as simple beam

Known Parameters

$P = 200$ [lbf] *Applied Load*

$L = 45$ [in] *Length of Member*

$a = 16$ [in] *Location of Load*

$b = 45 - 16$ [in] *Length - Location*

$E = 1 \times 10^7$ [psi] *Modulus of Elasticity*

$I = \pi \cdot \left[\frac{1^4 - 0.75^4}{64 \ [in^4]} \right]$ *Moment of Inertia*

$r = 0.5$ [in] *Radius*

Maximum Deflection

$$y = \frac{P \cdot a^2 \cdot b^2}{3 \cdot E \cdot I \cdot L} \quad in$$

Maximum Moment

$$M = \frac{P \cdot a \cdot b}{L} \quad in\text{-}lbf$$

Maximum Stress

$$\sigma = \frac{M \cdot r}{I} \quad psi$$

SOLUTION

Unit Settings: SI C kPa kJ mass deg

a = 16 [in]	b = 29	E = 1.000E+07 [psi]
I = 0.03356	L = 45 [in]	M = 2062
P = 200 [lbf]	r = 0.5 [in]	σ = 30728
y = 0.9505		

5 potential unit problems were detected.

```
"Buckling"

"Using Euler's Buckling Formula"

"Known Parameters"
n = 0.25                              "Fixed-Free End Conditions"
E = 10000000 [psi]                    "Modulus of Elasticity"
I = pi*(1^4 - 0.75^4)/64              "Moment of Inertia"
L = 45 [in]

"Buckling Load"
F = (n*pi^2*E*I)/L
```

Buckling

Using Euler's Buckling Formula

Known Parameters

$n = 0.25$ *Fixed-Free End Conditions*

$E = 1 \times 10^7$ [psi] *Modulus of Elasticity*

$I = \pi \cdot \left[\frac{1^4 - 0.75^4}{64}\right]$ *Moment of Inertia*

$L = 45$ [in]

Buckling Load

$$F = \frac{n \cdot \pi^2 \cdot E \cdot I}{L}$$

SOLUTION

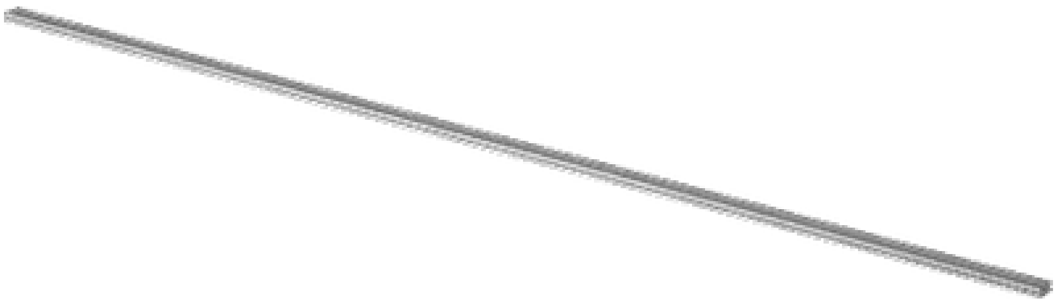
Unit Settings: SI C kPa kJ mass deg

E = 1.000E+07 [psi]	F = 18399	I = 0.03356
L = 45 [in]	n = 0.25	

1 potential unit problem was detected.

Aluminum T-Slotted Framing Extrusion

Double Profile, 1" x 2" Size, Solid



Length, ft.
✓10

Each

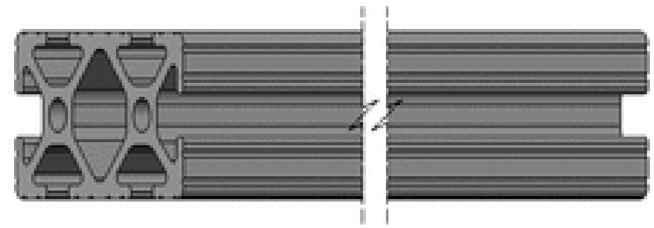
ADD TO ORDER

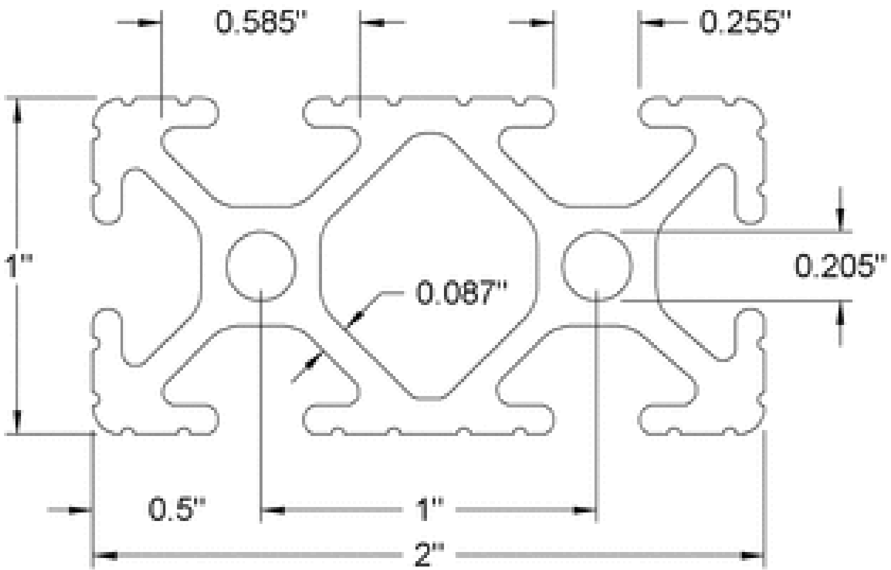
In stock
$52.11 Each
47065T107

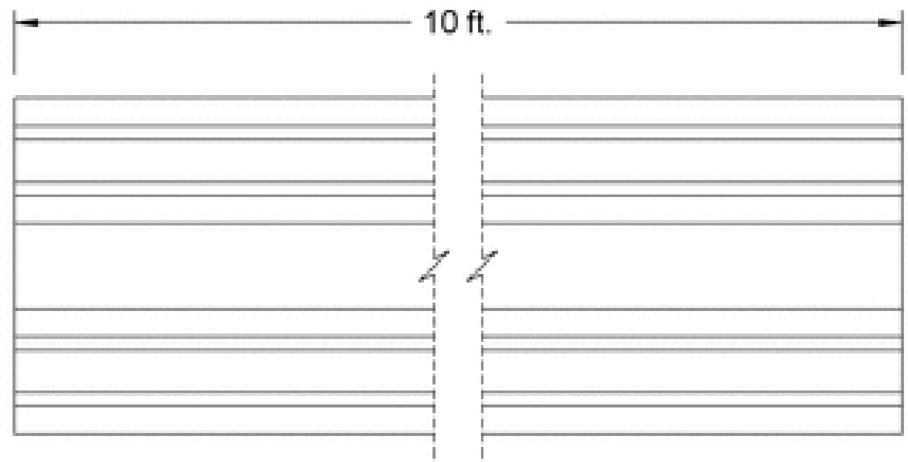
Extrusion Style	Double
Material	Aluminum
Finish	Anodized
Color	Clear
Extrusion Size	
Width	1"
Height	2"
Style	Solid
T-Slot Width	0.255"
Length	10 ft.
RoHS	Compliant

If you can design it, you can build it with this versatile "create anything" framing. Use it to make machine guards and frames, carts, workstations, enclosures, and more.

Extrusions have continuous T-slots along the length to provide attachment points for other components, making structures easy to assemble and reconfigure. Use fasteners to connect components.



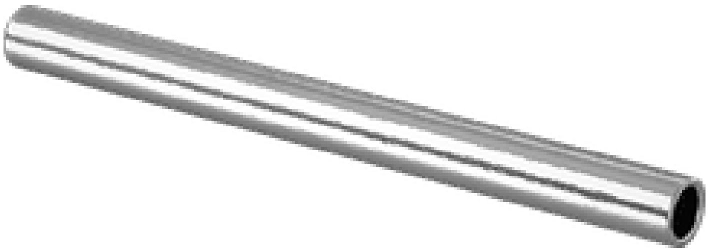




McMASTER-CARR® CAD	PART NUMBER 47065T107
http://www.mcmaster.com Information in this drawing is provided for reference only.	Aluminum T-Slotted Framing

Multipurpose 6061 Aluminum Tube

1" OD, .125" Wall Thickness



In stock
$7.92 Each
9056K36

Alloy	6061
Shape	Round Tube
Finish	Unpolished
Wall Thickness	1/8"
Wall Thickness Tolerance	±0.02"
OD	1"
OD Tolerance	±0.035"
ID	3/4"
Straightness Tolerance	0.020" per foot
Yield Strength	35,000 psi
Hardness	Soft (80 Brinell)
Material Condition	Heat Treated
Temper	T6
Specifications Met	ASTM B210
Material Composition	
Silicon	0.4-0.8%
Iron	0-0.7%
Copper	0.05-0.4%
Manganese	0-0.15%
Magnesium	0.8-1.2%
Chromium	0.4-0.8%
Nickel	0-0.05%
Zinc	0-0.25%
Titanium	0-0.15%
Zirconium	0-0.25%
Other	0.15%
Aluminum	95.1-98.2%
Nominal Density	0.097-0.1 lbs./cu. in.
Modulus of Elasticity	10.0 ksi × 10^3
Elongation	8-17%
Melting Range	1,080° to 1,205° F
Thermal Conductivity	1390 Btu/hr × in./sq.ft. @ 75° to 77° F
Electrical Resistivity	24 Ohm-Cir. Mil/ft. @ 68° F
Length	1 ft.
RoHS	Not Compliant

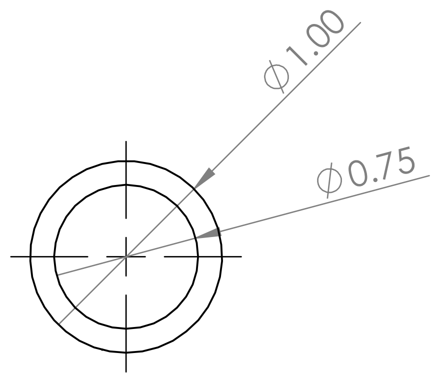
The most widely used aluminum, Alloy 6061 is a popular choice for vehicle parts and pipe fittings. It has better corrosion resistance and weldability than Alloys 2024 and 7075, but it's not as strong. It is nonmagnetic, heat treatable, and resists stress cracking. Temperature range is -320° to 300° F.

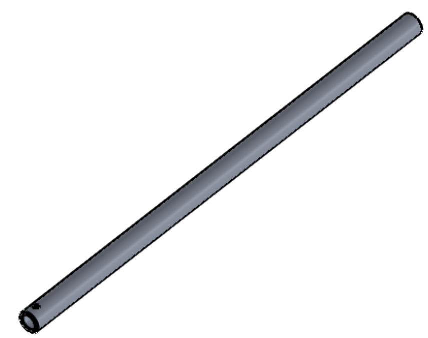
Yield strength is approximate and may vary based on size and shape.

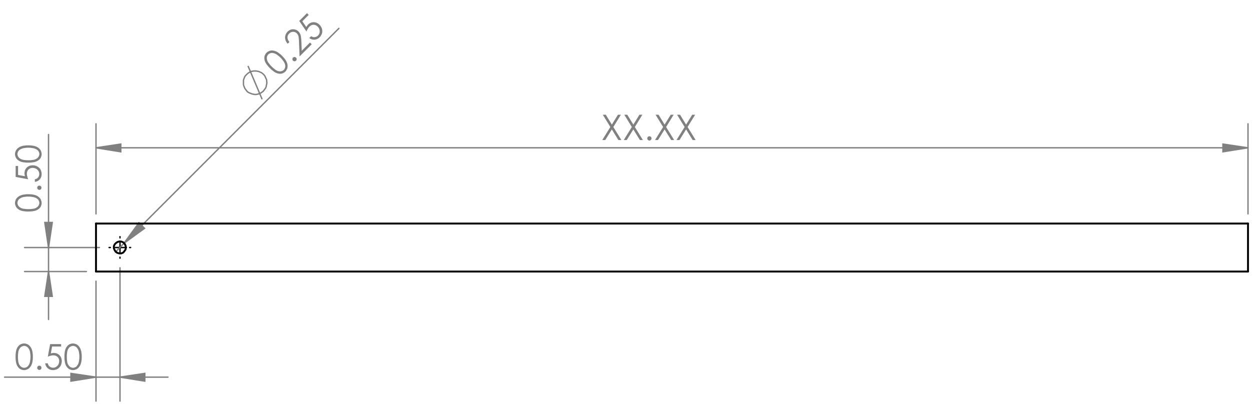
OD tolerance for 1" to 6 1/2" dia. tubes is ±0.035". Straightness tolerance for 3/8" to 6 1/2" dia. tubes is 0.020" per foot. Length tolerance for 1-ft. to 6-ft. lengths is ±1".

Cut List		
P/N	Part Name	Length
1006	Pivot Tube - Front	26"
1007	Upper Leg - Front	24"
1008	Upper Leg - Rear	30"
1009	Horizontal Support - Front	18"
1010	Horizontal Support - Rear	24"
1011	Slider Bar - Front	19"
1012	Slider Bar - Rear	16"

NOTES
UNLESS OTHERWISE SPECIFIED
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES
X.XX= ±0.05
ANGLES= ±1 °
3. BREAK SHARP EDGES 0.010 MAX







Cal Poly Mechanical Engineering	ME 428/429/430	Winter 2017	Drwn By: Sean Portune	Part Name: Upper Legs/Supports
Personal Utility Cart	Senior Project	P/N: SEE TABLE	Date:2/4/17 Scale: 1:4	Material: 6061-T6 Aluminum

Multipurpose 6061 Aluminum Tube

3/4" OD, .125" Wall Thickness

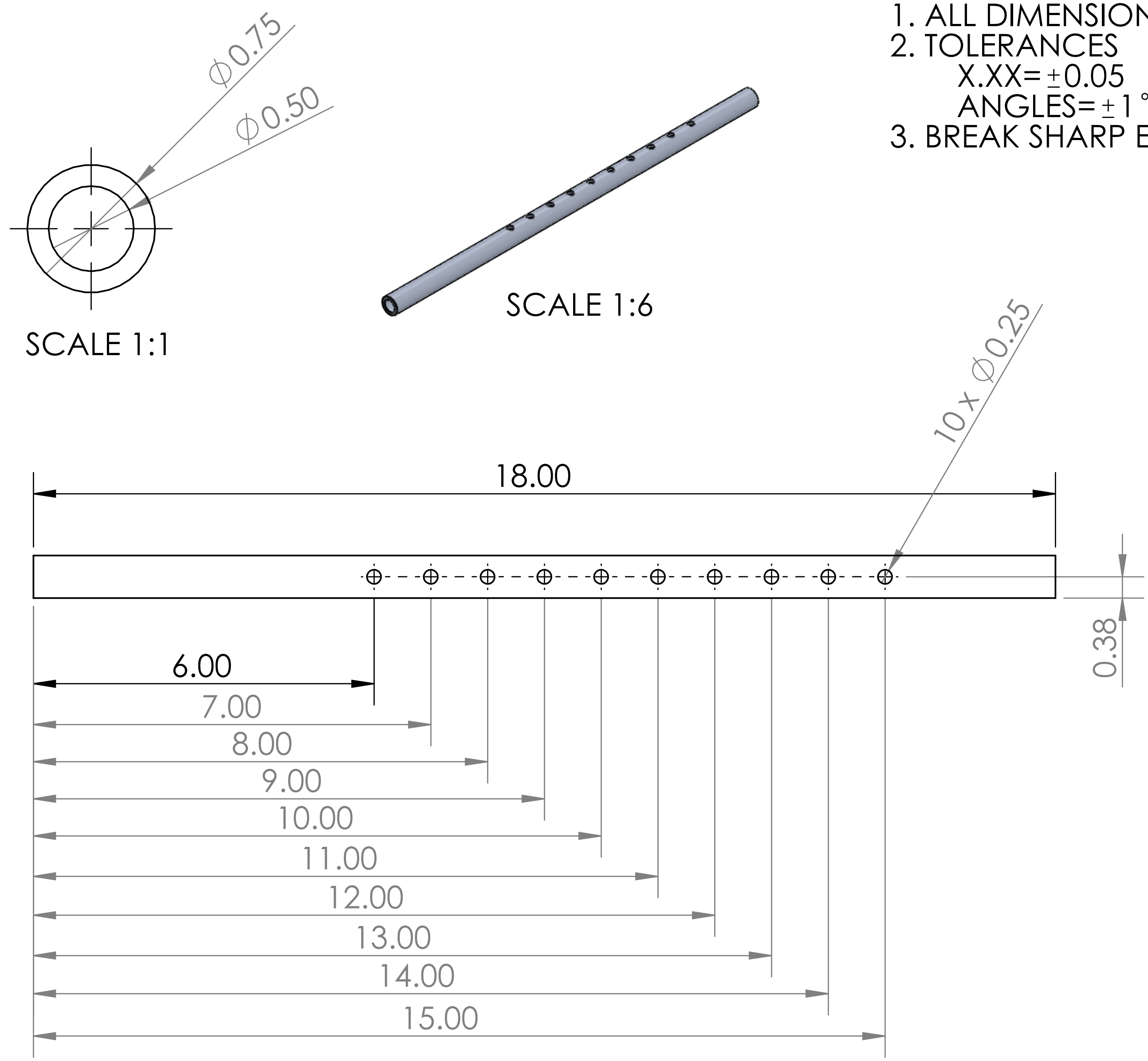
In stock
$10.92 Each
9056K33

Alloy	6061
Shape	Round Tube
Finish	Unpolished
Wall Thickness	1/8"
Wall Thickness Tolerance	±0.02"
OD	3/4"
OD Tolerance	±0.010"
ID	1/2"
Straightness Tolerance	0.020" per foot
Yield Strength	35,000 psi
Hardness	Soft (80 Brinell)
Material Condition	Heat Treated
Temper	T6
Specifications Met	ASTM B210
Material Composition	
Silicon	0.4-0.8%
Iron	0-0.7%
Copper	0.05-0.4%
Manganese	0-0.15%
Magnesium	0.8-1.2%
Chromium	0.4-0.8%
Nickel	0-0.05%
Zinc	0-0.25%
Titanium	0-0.15%
Zirconium	0-0.25%
Other	0.15%
Aluminum	95.1-98.2%
Nominal Density	0.097-0.1 lbs./cu. in.
Modulus of Elasticity	10.0 ksi × 10^3
Elongation	8-17%
Melting Range	1,080° to 1,205° F
Thermal Conductivity	1390 Btu/hr × in./sq.ft. @ 75° to 77° F
Electrical Resistivity	24 Ohm-Cir. Mil/ft. @ 68° F
Length	2 ft.
RoHS	Not Compliant

The most widely used aluminum, Alloy 6061 is a popular choice for vehicle parts and pipe fittings. It has better corrosion resistance and weldability than Alloys 2024 and 7075, but it's not as strong. It is nonmagnetic, heat treatable, and resists stress cracking. Temperature range is -320° to 300° F.

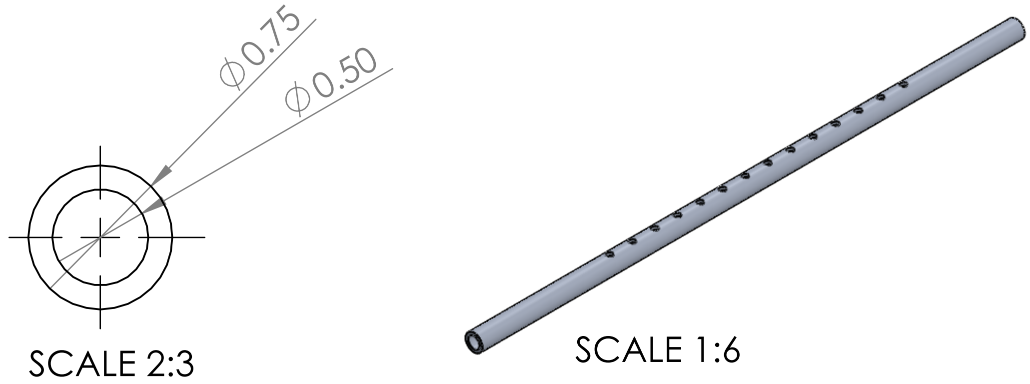
Yield strength is approximate and may vary based on size and shape.

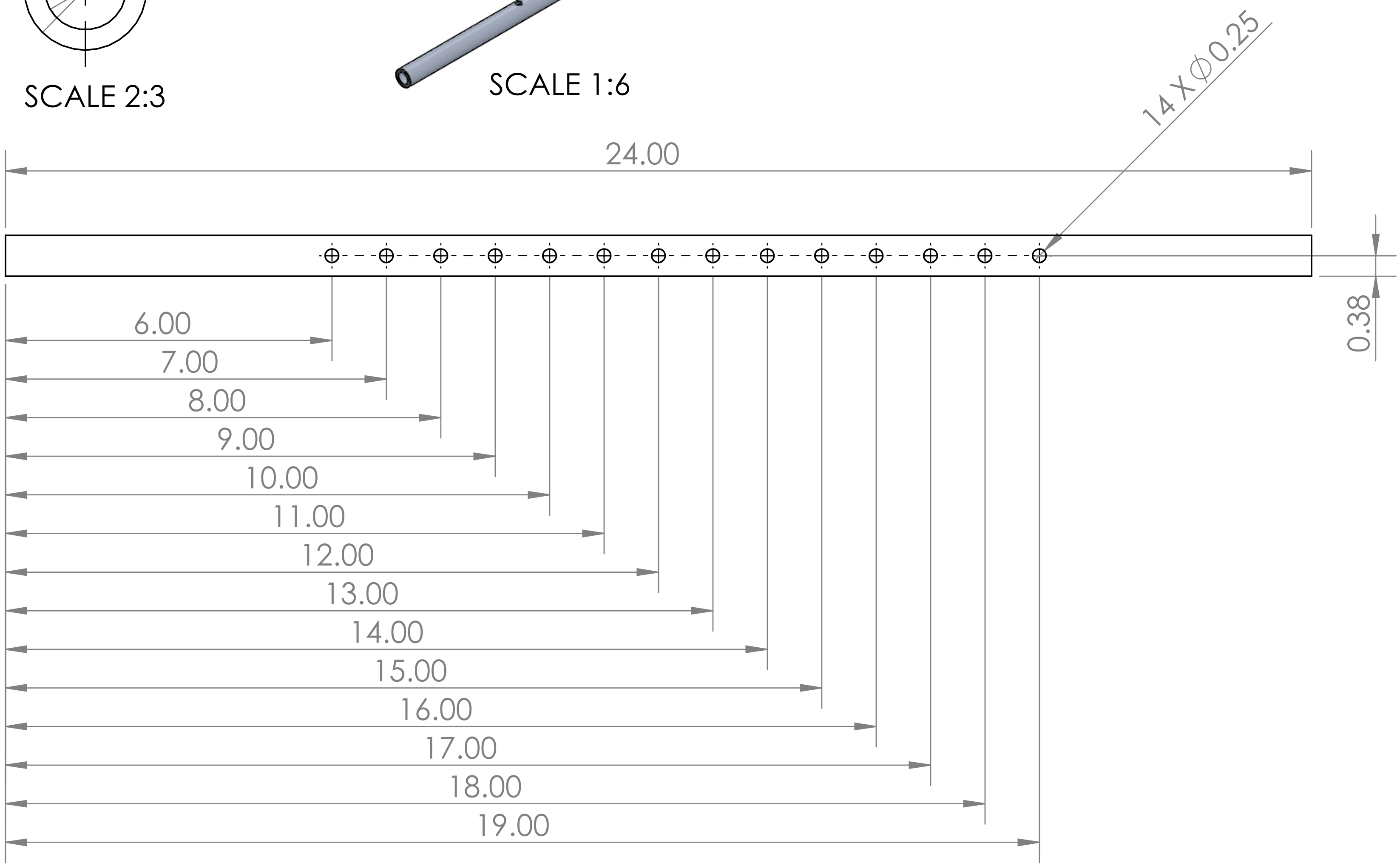
OD tolerance for 1/4" to 7/8" dia. tubes is ±0.010". Straightness tolerance for 3/8" to 6 1/2" dia. tubes is 0.020" per foot. Length tolerance for 1-ft. to 6-ft. lengths is ±1".



NOTES
UNLESS OTHERWISE SPECIFIED
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES
X.XX= ±0.05
ANGLES= ±1 °
3. BREAK SHARP EDGES 0.010 MAX

Mechanical Engineering CAL POLY	PART NAME: LOWER LEG - FRONT	PART #: 1013	DATE: 2/8/17
SCALE: 1:1	UNITS: INCHES	MATERIAL: 6061-T6 ALUMINUM	DRAWN BY: SEAN PORTUNE
Senior Design Project	GROUP: PERSONAL UTILITY CART	DWG. #: 1001013	OTHER:





NOTES
UNLESS OTHERWISE SPECIFIED
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES
X.XX=±0.05
ANGLES=±1 °
3. BREAK SHARP EDGES 0.010 MAX

Mechanical Engineering CAL POLY	PART NAME: LOWER LEG - REAR		PART #: 1014	DATE: 2/8/17
	SCALE: 1:6 / UNITS: INCHES	MATERIAL: 6061-T6 ALUMINUM	DRAWN BY: SEAN PORTUNE	
Senior Design Project	GROUP: PERSONAL UTILITY CART	DWG. #: 1001014	OTHER:	

Bracket, 1" Long for 1" High Single Profile Aluminum T-Slotted Framing Extrusion

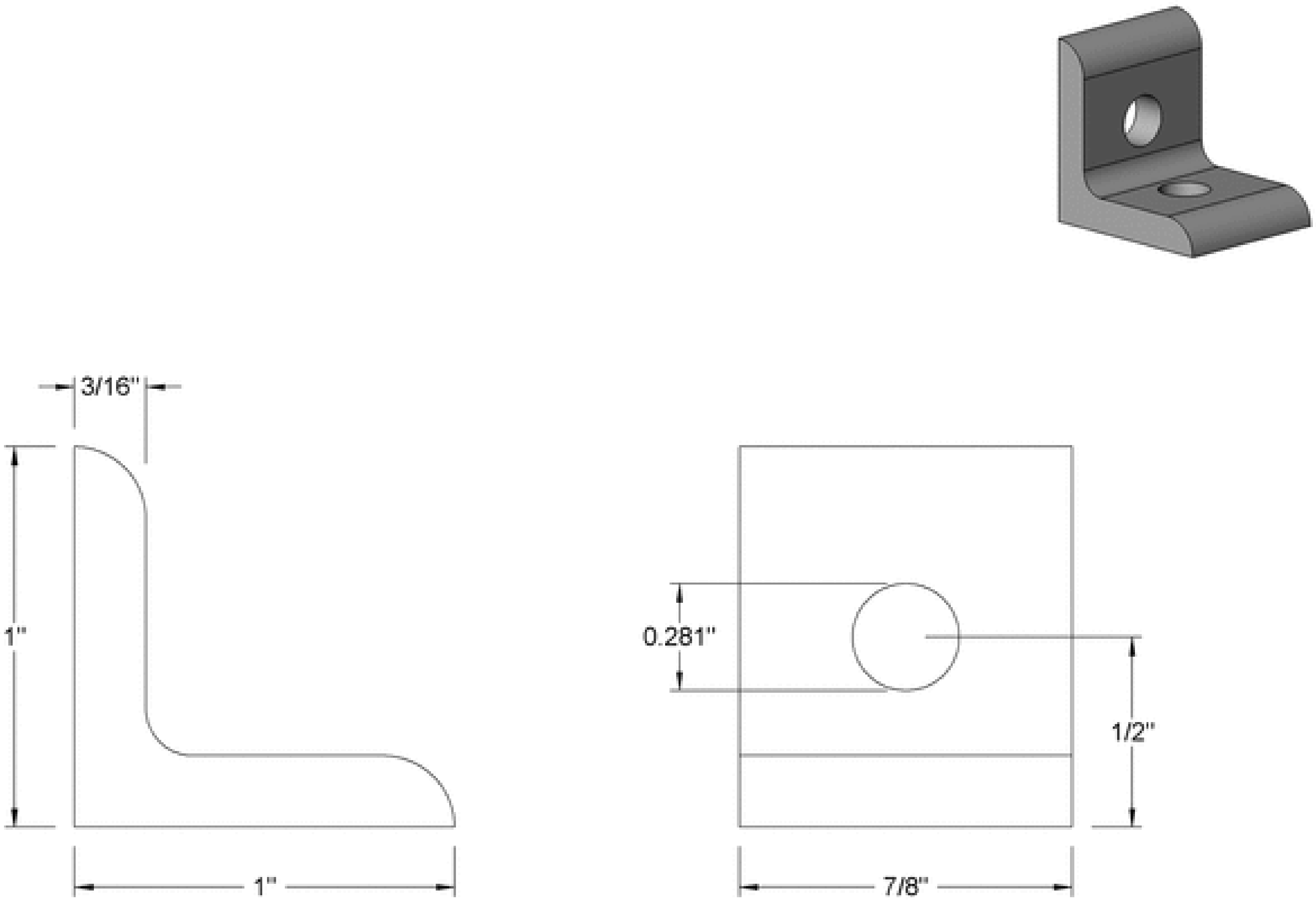
Each

ADD TO ORDER

In stock
$5.79 Each
47065T236

For Extrusion Style	Single
Material	Aluminum
For Extrusion Height	1"
Length	1"
RoHS	Compliant

Connect extrusions without machining with these screw-on brackets (fasteners included).



McMASTER-CARR CAD

PART NUMBER 47065T236

http://www.mcmaster.com

90° Bracket for Aluminum T-Slotted Framing

Bracket, 2" Long for 1" High Single Profile Aluminum T-Slotted Framing Extrusion

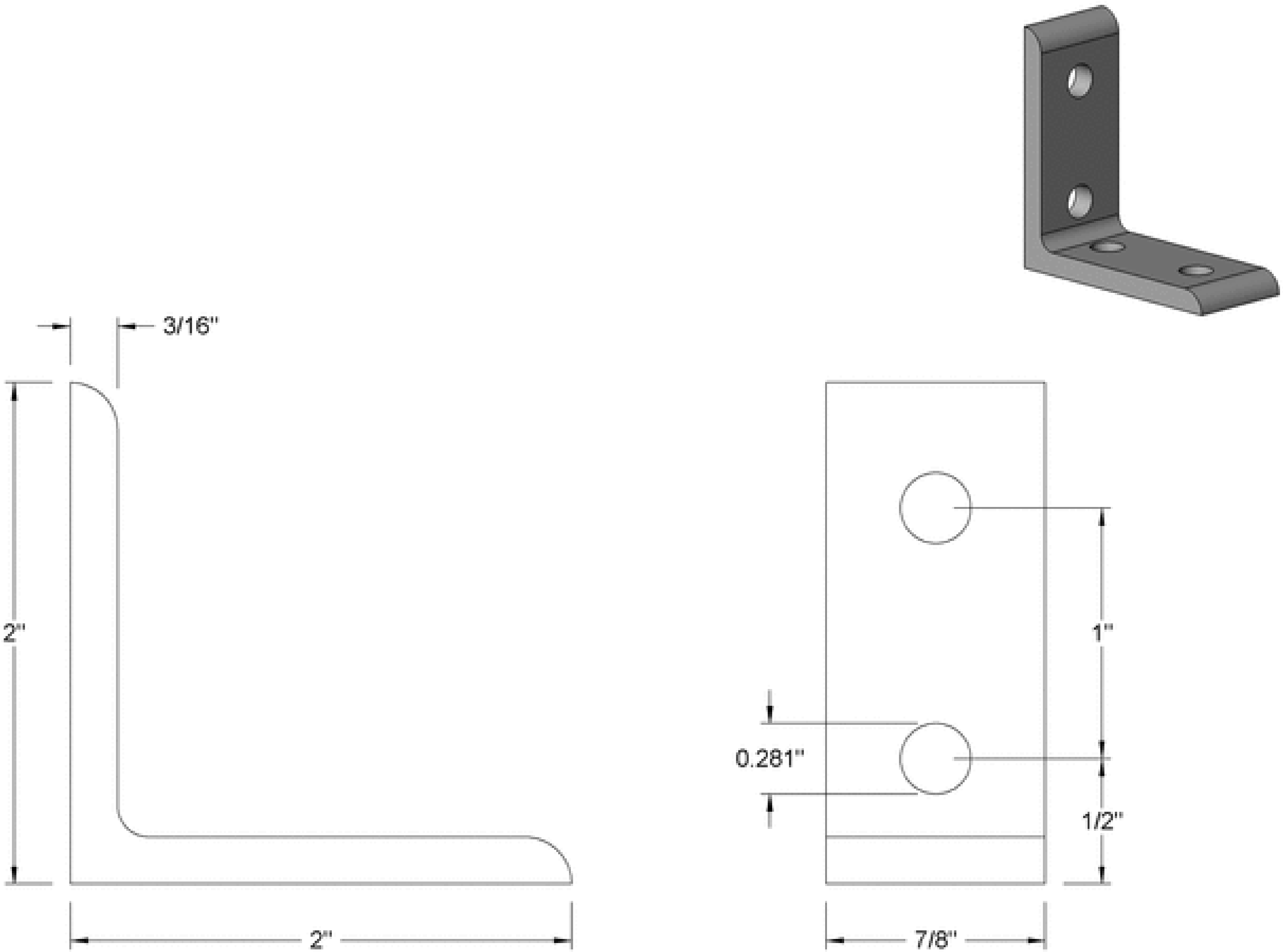
Each

ADD TO ORDER

In stock
$5.85 Each
47065T239

For Extrusion Style	Single
Material	Aluminum
For Extrusion Height	1"
Length	2"
RoHS	Compliant

Connect extrusions without machining with these screw-on brackets (fasteners included).



McMASTER-CARR® CAD	PART NUMBER	47065T239	
http://www.mcmaster.com		Extended 90° Bracket for	
© 2015 McMaster-Carr Supply Company		Aluminum T-Slotted Framing	
Information in this drawing is provided for reference only.			

Bracket, 2" Long for 2" High Double/Quad Profile Aluminum T-Slotted Framing Extrusion

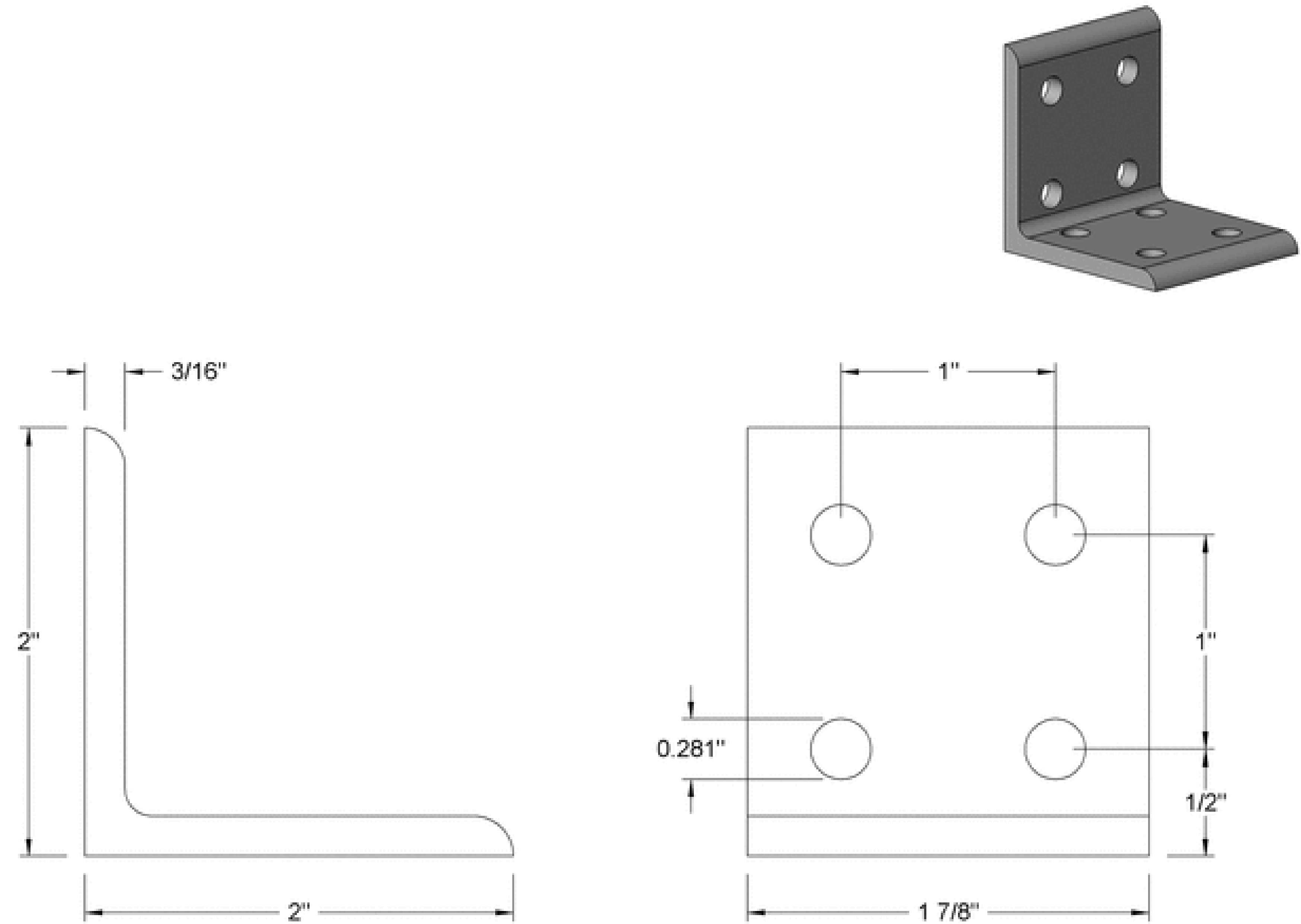
Each

ADD TO ORDER

In stock
$8.79 Each
47065T253

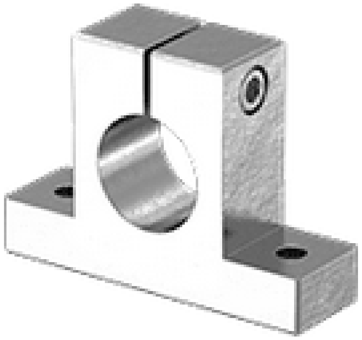
For Extrusion Style	Double/Quad
Material	Aluminum
For Extrusion Height	2"
Length	2"
RoHS	Compliant

Connect extrusions without machining with these screw-on brackets (fasteners included).



McMASTER-CARR® CAD	PART NUMBER	47065T253
http://www.mcmaster.com © 2015 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Extended 90° Bracket for Aluminum T-Slotted Framing	

Tube Holder for 1" High Single Profile Aluminum T-Slotted Framing Extrusion



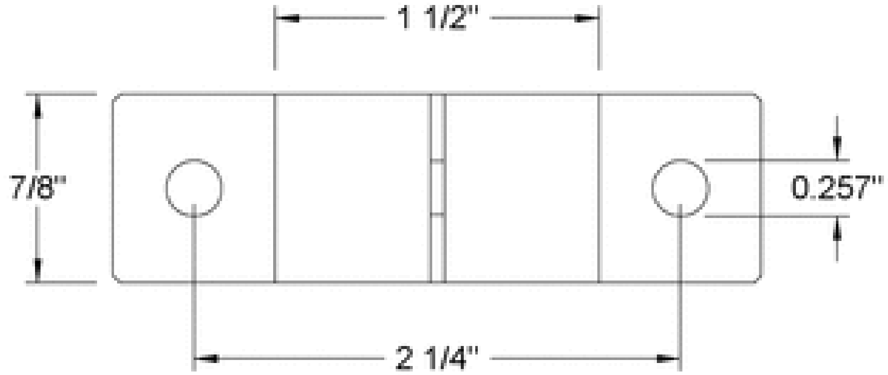
Each

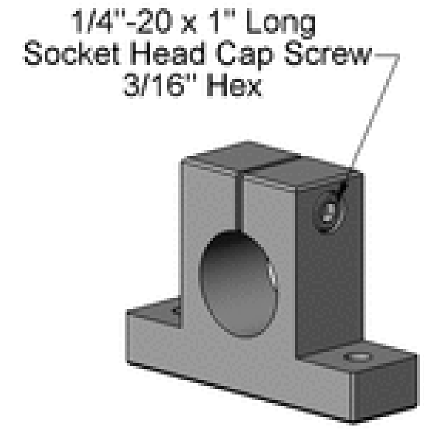
ADD TO ORDER

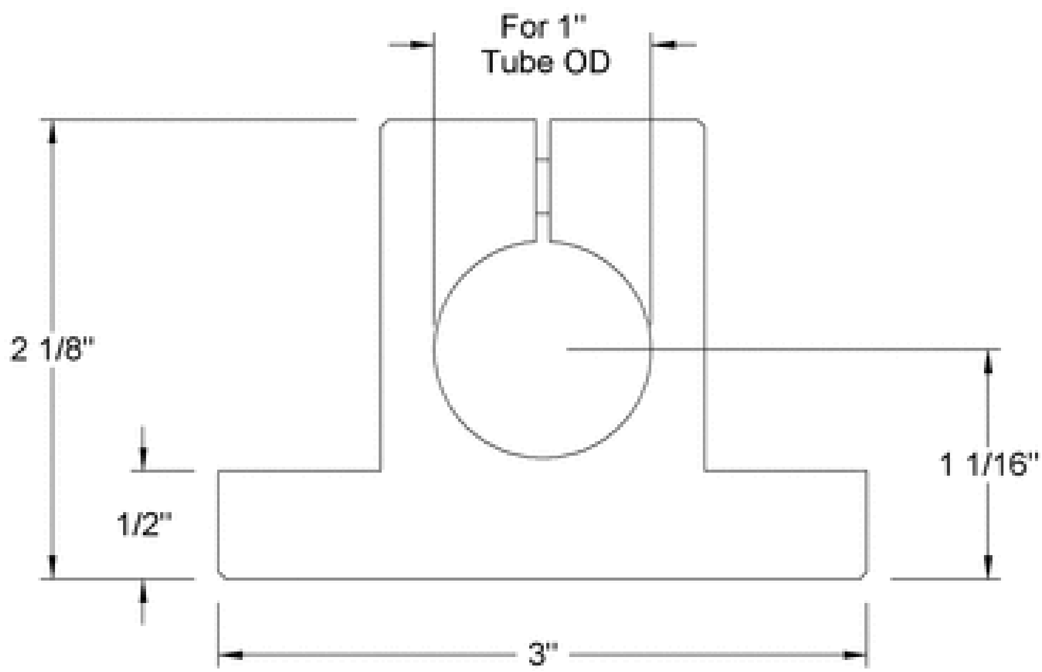
In stock
$34.10 Each
47065T205

For Extrusion Style	Single
Material	Aluminum
For Extrusion Height	1"
RoHS	Compliant
Related Product	1" OD (3/4" ID) Aluminum Tubing—4-ft. Length

Standard holders tighten with a hex key (not included).







McMASTER-CARR® CAD	PART NUMBER 47065T205
http://www.mcmaster.com Information in this drawing is provided for reference only.	Tube Holder for Aluminum T-Slotted Framing

Aluminum Slip-on Rail Fitting

Tee Through-Hole Connector for 1" Rail OD

Each

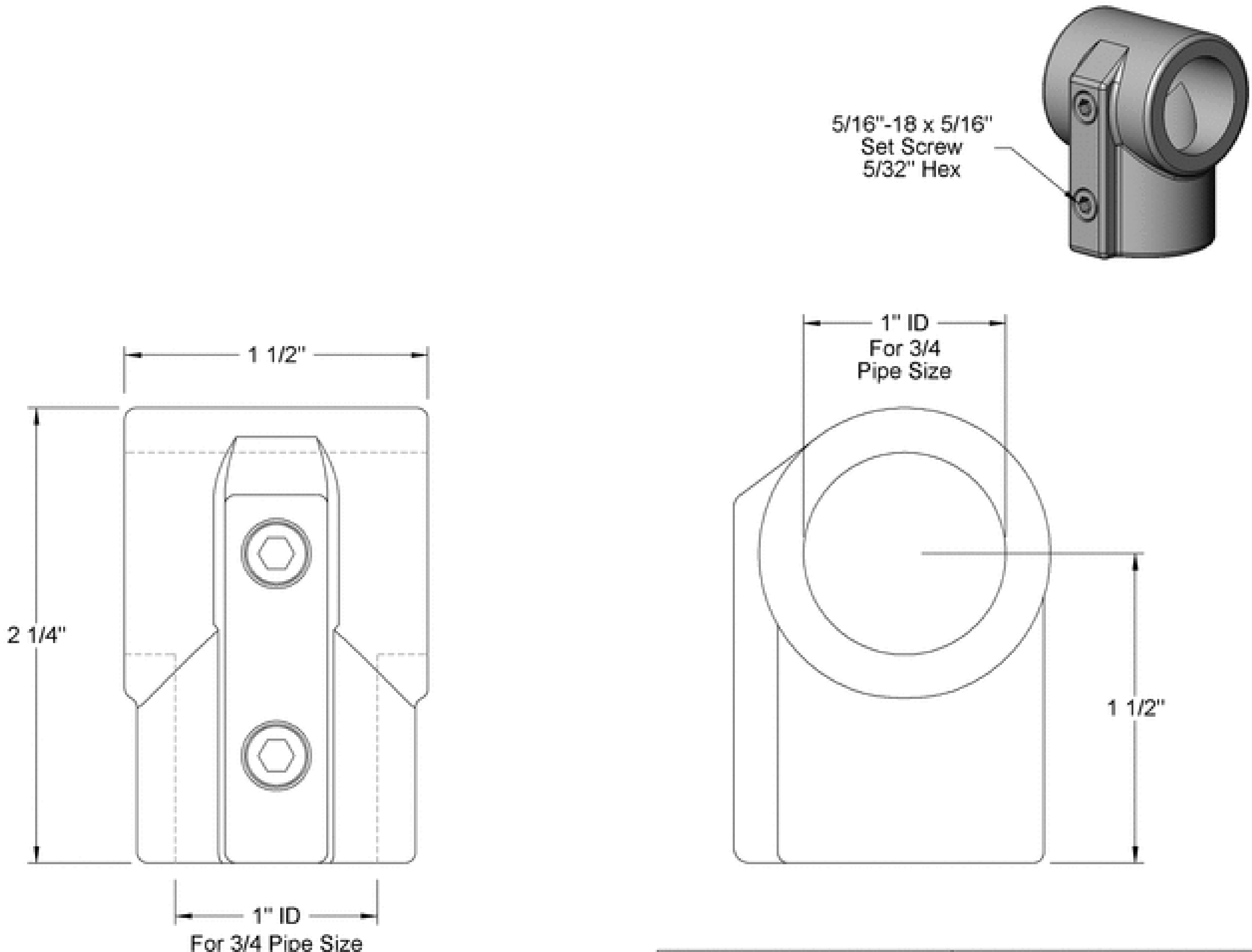
ADD TO ORDER

In stock
$6.75 Each
4698T14

Slip-On Framing Component	Through-Hole Connector
Slip-On Framing Component Shape	Tee
For Rail OD	1"
Pipe Size	3/4
Number of Through Holes	1
Material	Aluminum
Includes	Set Screws
Framing Type	Slip On

Lightweight yet strong, this framing has better corrosion resistance than galvanized iron and steel framing. Slip the fittings over rails to construct custom railings, guard rails, storage racks, and shelving. To assemble, tighten the included set screws for a secure fit.

Through-hole fittings have holes that rail can run all the way through.



McMASTER-CARR® CAD

PART NUMBER **4698T14**

http://www.mcmaster.com

Aluminum Slip-On
Tee with Through Hole

Aluminum Slip-on Rail Fitting

Crossover with Two Through-Holes for 1" Rail OD

Each

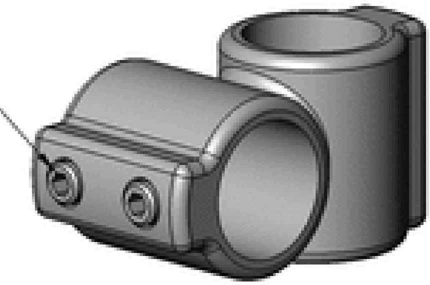
ADD TO ORDER

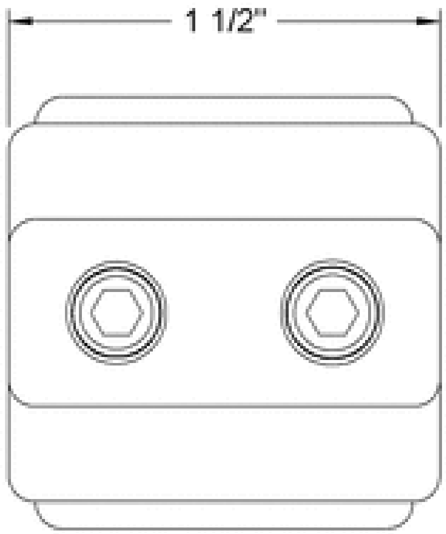
In stock
$11.27 Each
4698T42

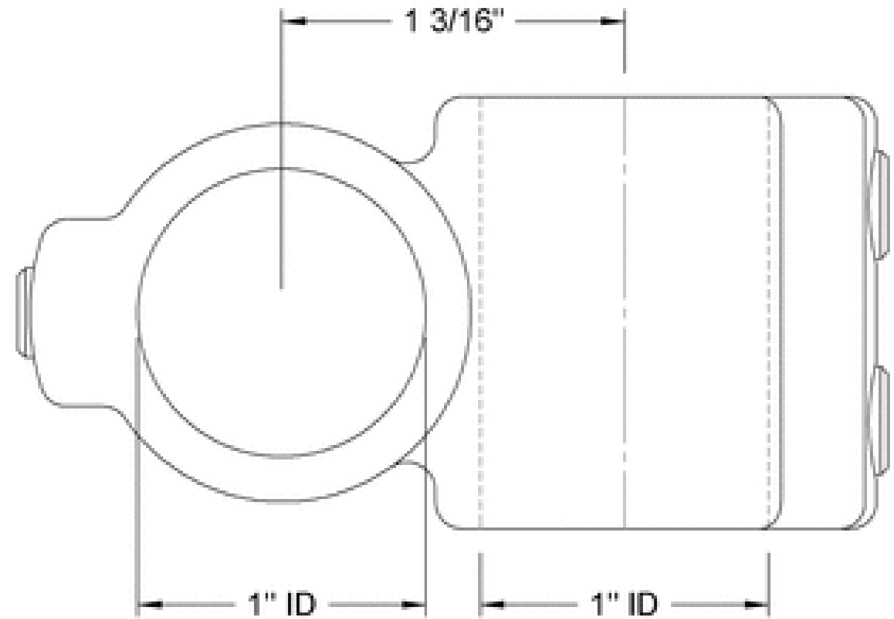
Slip-On Framing Component	Through-Hole Connector
Slip-On Framing Component Shape	Crossover
For Rail OD	1"
Pipe Size	3/4
Number of Through Holes	2
Material	Aluminum
Includes	Set Screws
Framing Type	Slip On

Lightweight yet strong, this framing has better corrosion resistance than galvanized iron and steel framing. Slip the fittings over rails to construct custom railings, guard rails, storage racks, and shelving. To assemble, tighten the included set screws for a secure fit.

Through-hole fittings have holes that rail can run all the way through.







McMASTER-CARR® CAD	PART NUMBER 4698T42
http://www.mcmaster.com © 2015 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Aluminum Slip-On Crossover with Two Through Holes

Plastic Handle Quick-Release Pin

T-Handle, 1/4" Diameter, 1" Usable Length

Each

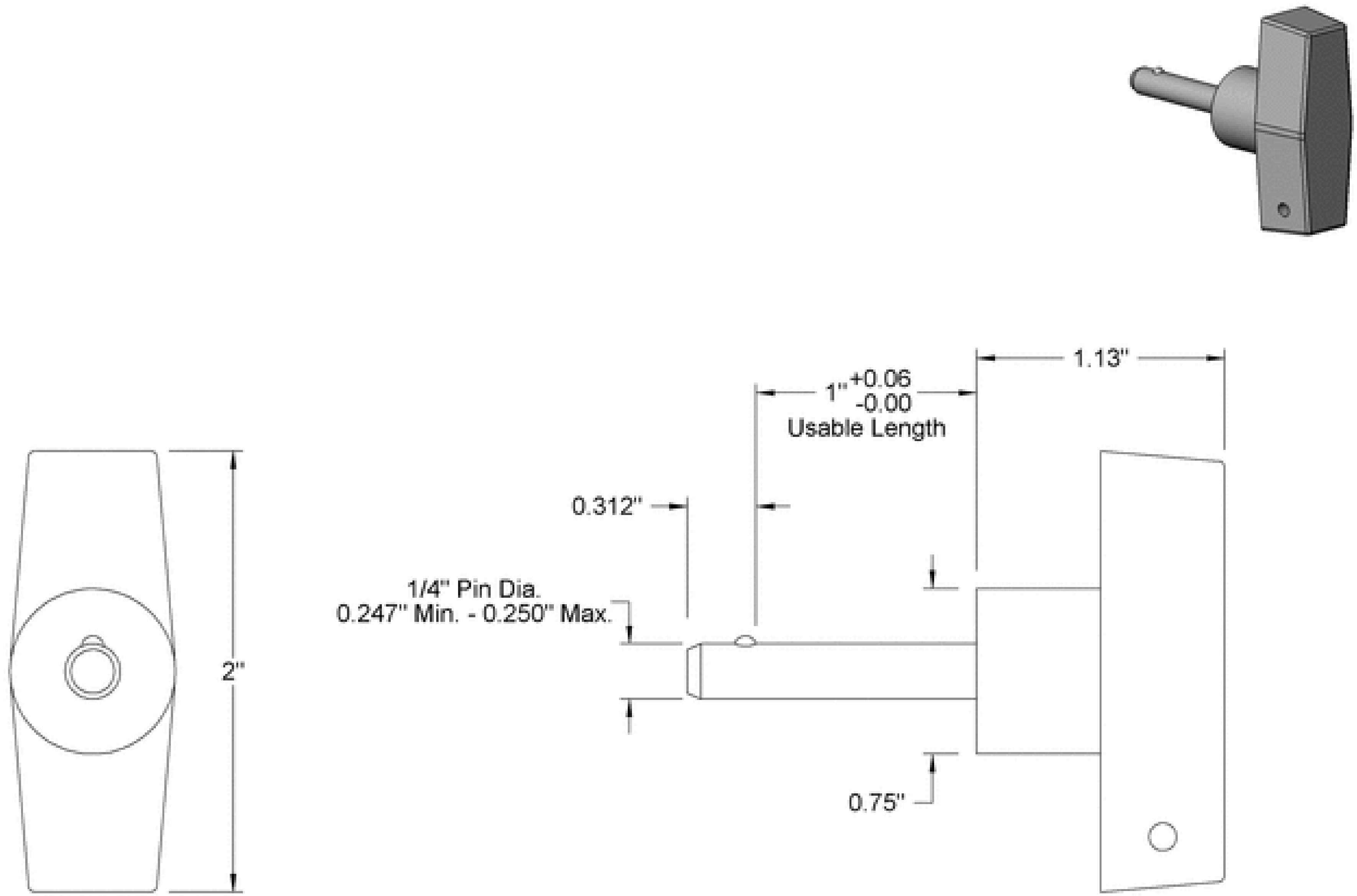
ADD TO ORDER

In stock
$4.40 Each
92490A648

Usable Length	1"
Additional Specifications	T-Handle 1/4" Dia.—Breaks at 4,300 lbs.
RoHS	Compliant

Each of these general purpose pins have a single locking ball and a durable, black handle. Shafts are made of zinc-plated steel and have a diameter tolerance of -0.003". Pin diameter equals hole size. Breaking strength is measured as single shear, which is the force required to break a pin into two pieces. Rockwell hardness is B85.

T-Handle—Have a 2" wide handle, except the 1/2" diameter pins have a 3 1/2" wide handle.



McMASTER-CARR® CAD

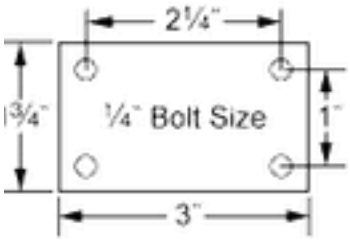
PART NUMBER **92490A648**

http://www.mcmaster.com

Plastic-Handle
Quick-Release Pin

Mighty-Lite Caster

Rigid, 3" x 13/16" Black Rubber Wheel, 150 lb Capacity



Each

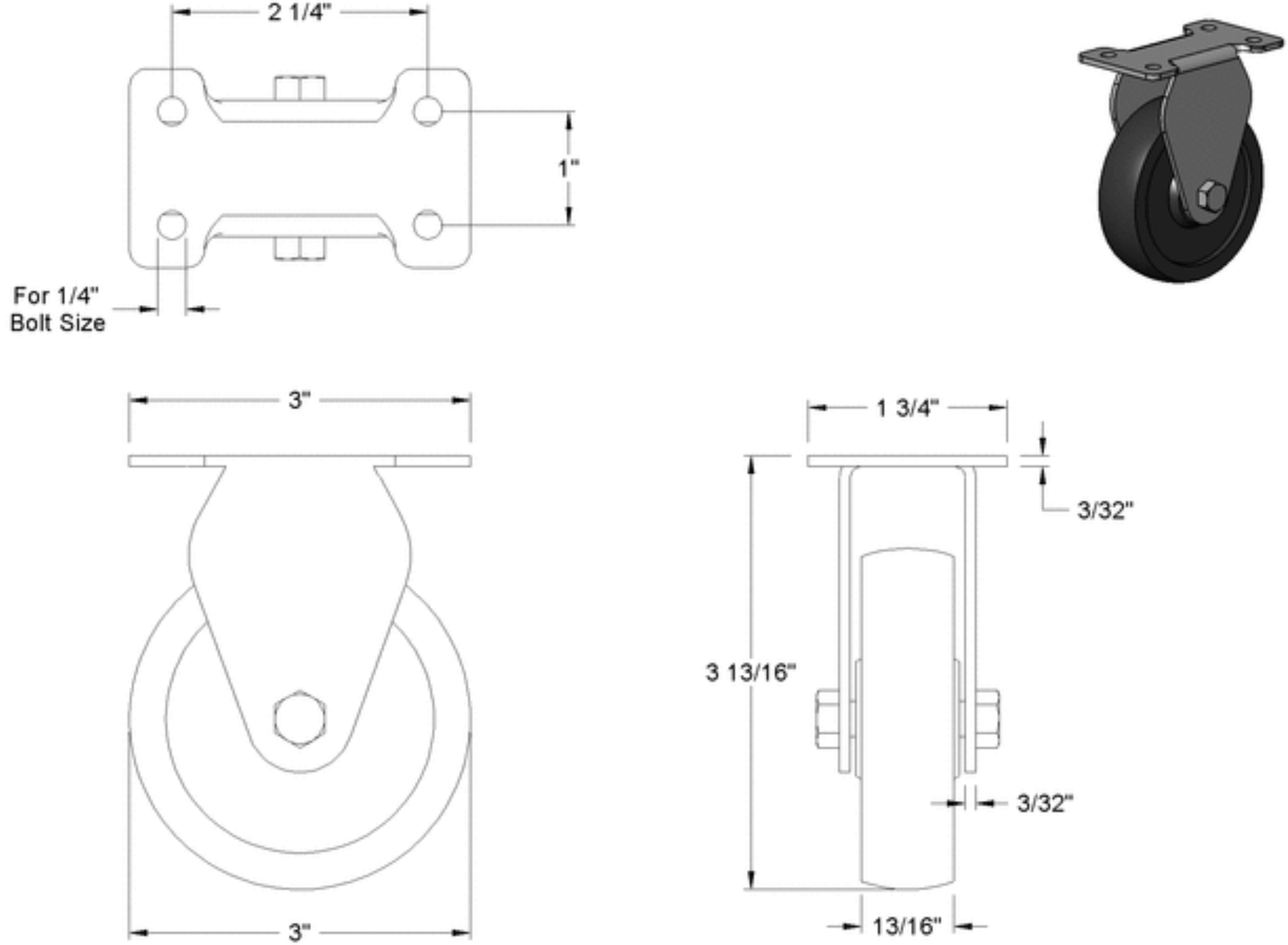
ADD TO ORDER

In stock
$6.96 Each
2406T34

Wheel	
Diameter	3"
Width	13/16"
Mount Height	3 13/16"
Capacity Each	150 lbs.
Mounting Plate	1
Additional Specifications	Metal Sleeve Wheel Bearings
	Rigid
	Abrasion-Resistant Black Rubber Wheels—Hard (90A Durometer)

Frame is steel with a zinc-plated finish.

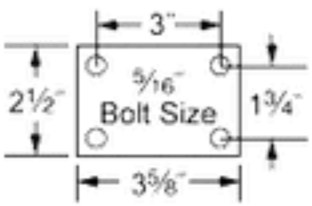
Metal sleeve wheel bearings prevent wear to the wheel bore and are a good choice when ease of rolling is not critical.



McMASTER-CARR® CAD	PART NUMBER	2406T34
http://www.mcmaster.com © 2013 McMaster-Carr Supply Company	Mighty-Lite Rigid Caster	
Information in this drawing is provided for reference only.		

Cart-King Caster

Swivel/Total Lock, 3" x 1-1/4" Phenolic, 350 lb Capacity, Gen Bearing



Each

ADD TO ORDER

In stock
$22.50 Each
2370T84

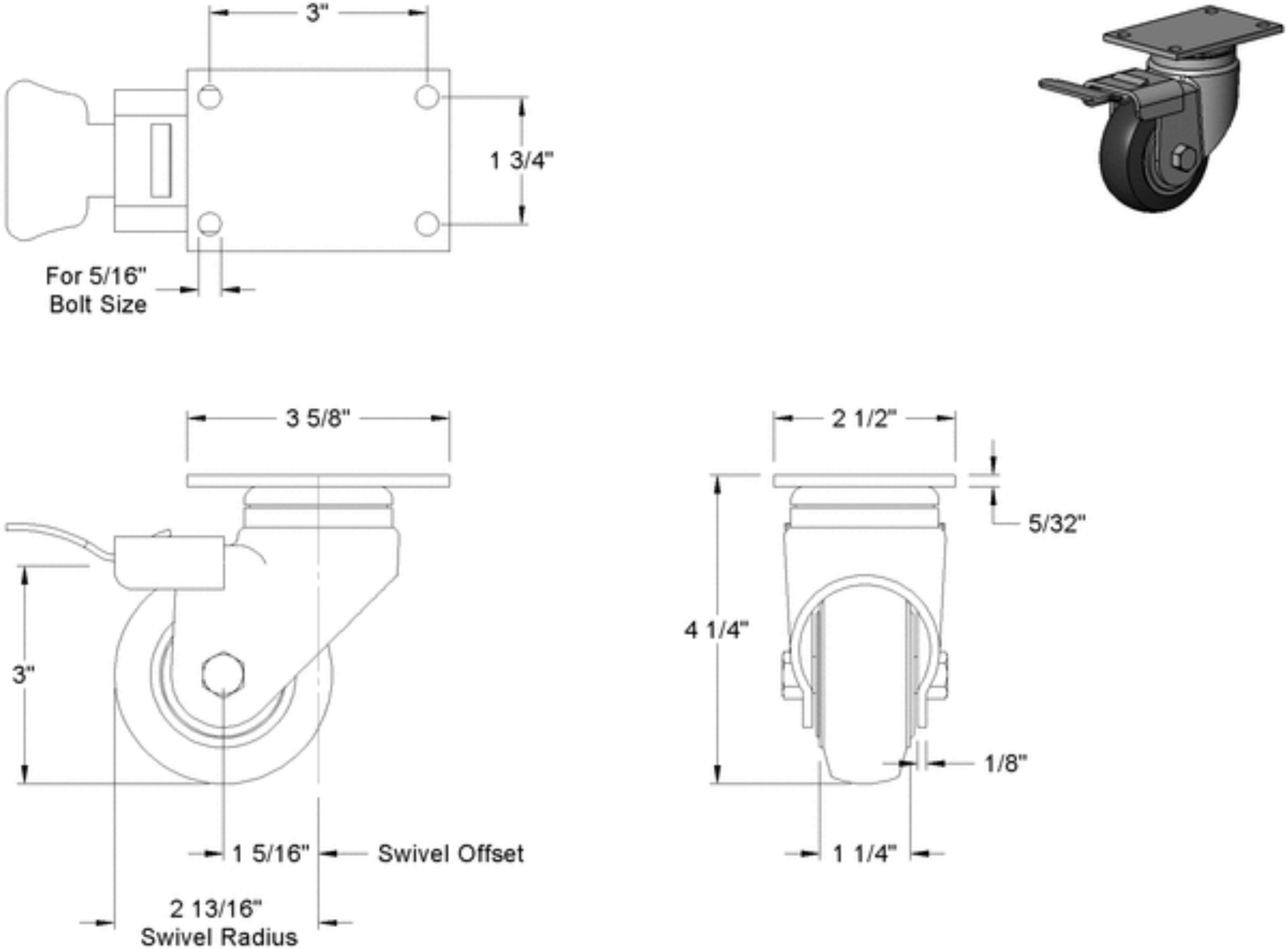
Wheel	
Diameter	3"
Width	1 1/4"
Mount Height	4 1/4"
Capacity Each	350 lbs.
Mounting Plate	1
Additional Specifications	Single Wheel—General Purpose Bearings Swivel with Total Lock Black Phenolic Wheels—Extra Hard (90D Durometer)

Our most popular casters for carts and dollies, these are offered in a variety of sizes and styles to fit your equipment. Frame is steel with a zinc-plated finish.

Swivel casters with total lock brake the wheel and lock the swivel in one operation.

Single-wheel casters meet NSF/ANSI standards, except casters with black phenolic wheels.

General purpose bearings have straight rollers that provide smooth rolling.

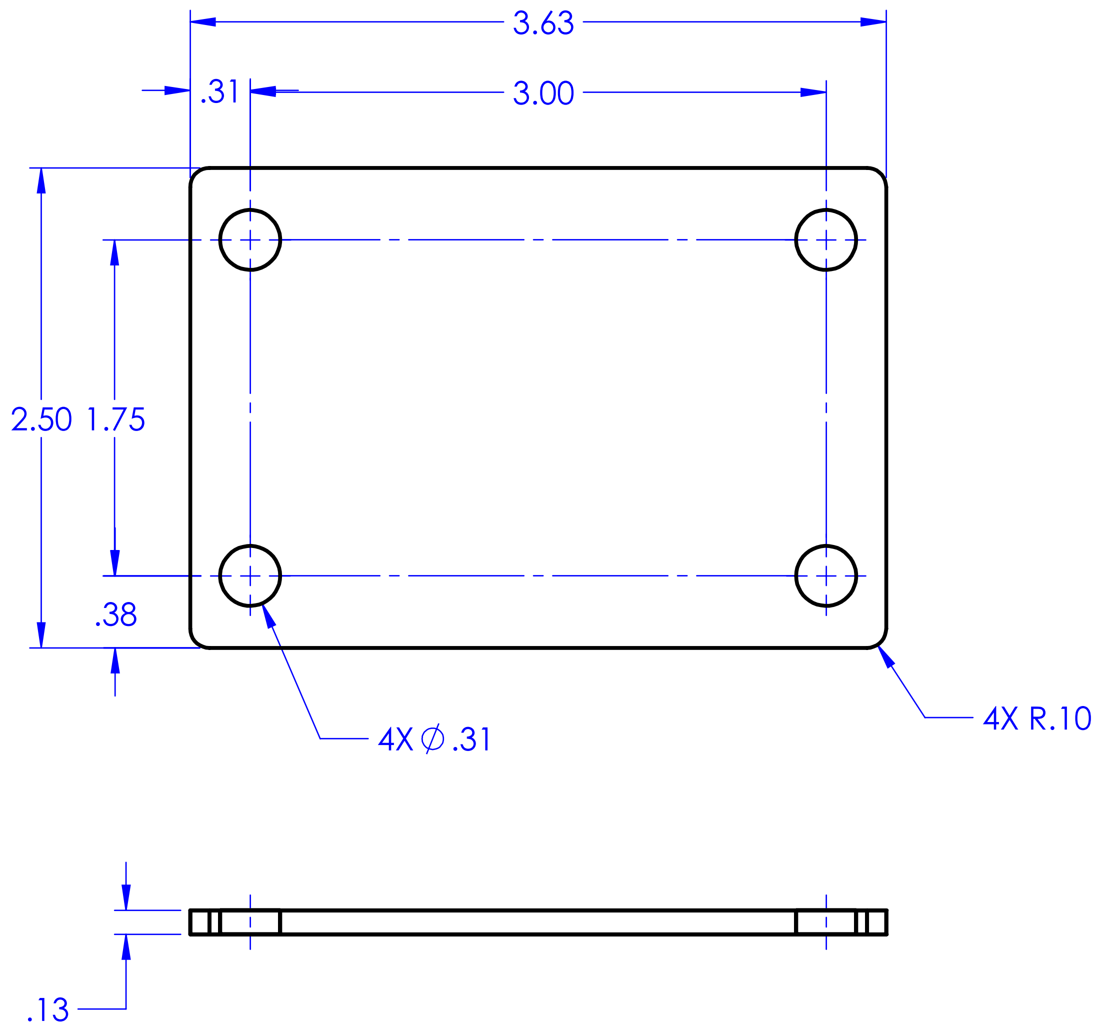


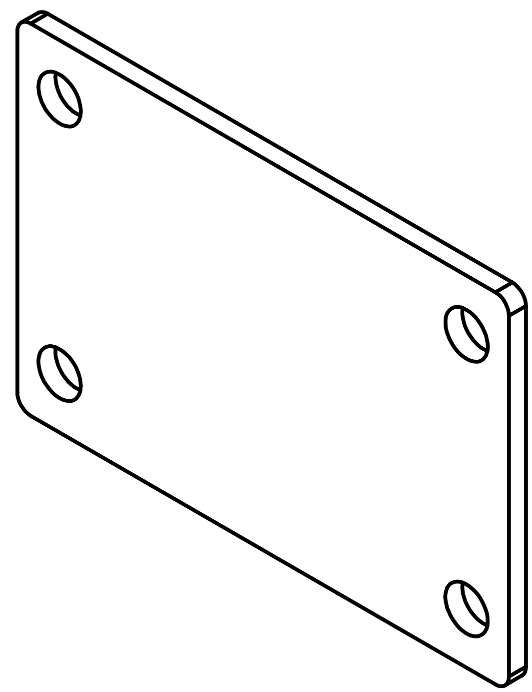
McMASTER-CARR® CAD

PART NUMBER **2370T84**

http://www.mcmaster.com

Cart-King
Swivel Caster with Total Lock





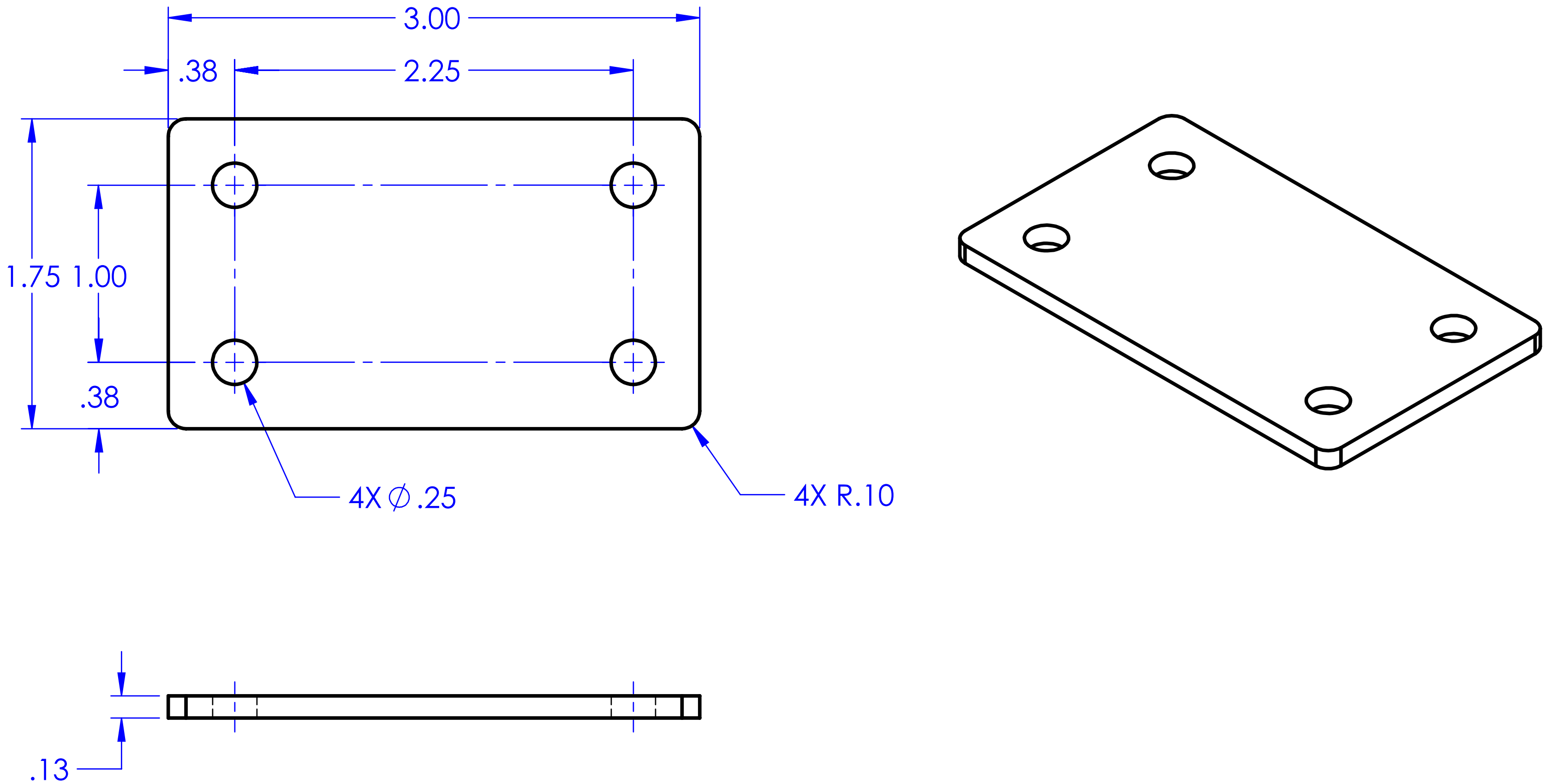
NOTES
UNLESS OTHERWISE SPECIFIED:
1. TOLERANCES:
X.XX= ±0.05
ANGLES= ±1 °
2. BREAK SHARP EDGES 0.5 MAX.

Mechanical Engineering CAL POLY	PART NAME: FRONT MOUNTING PLATE		PART #: 1021	DATE: 2/9/17
	SCALE: 1:1	UNITS: INCHES	MATERIAL: 6061 ALUMINUM	DRAWN BY: SEAN PORTUNE
Senior Design Project	GROUP: PERSONAL UTILITY CART	DWG. #: 1001021	OTHER:	

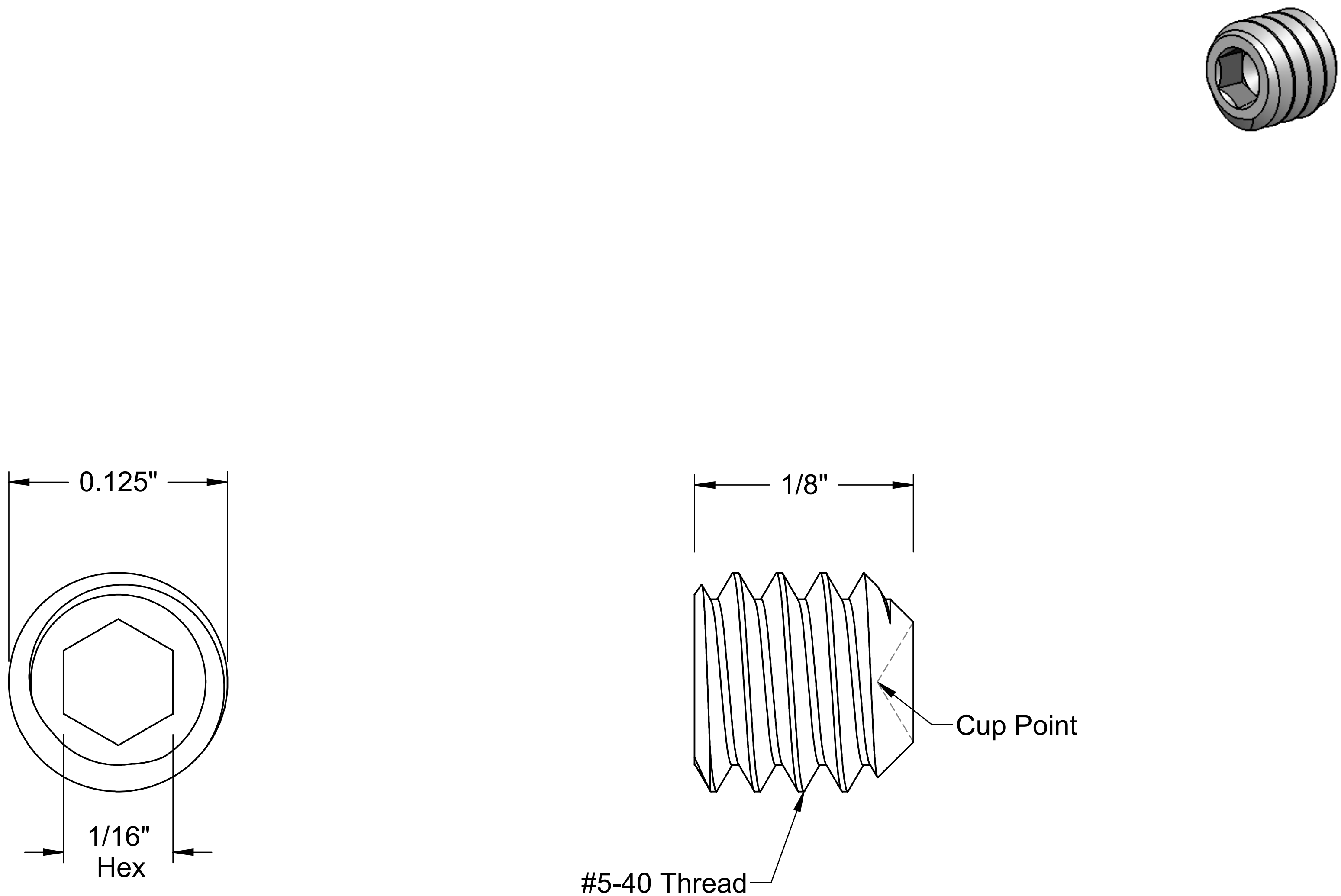
<u>NOTES</u>

UNLESS OTHERWISE SPECIFIED:

1. TOLERANCES:
   X.XX= ±0.05
   ANGLES= ±1 °
2. BREAK SHARP EDGES 0.5 MAX.



Mechanical Engineering CAL POLY	PART NAME: REAR MOUNTING PLATE	PART #: 1022	DATE: 2/9/17
	SCALE: 1:1 / UNITS: INCHES	MATERIAL: 6061 ALUMINUM	DRAWN BY: SEAN PORTUNE
Senior Design Project	GROUP: PERSONAL UTILITY CART	DWG. #: 1001022	OTHER:



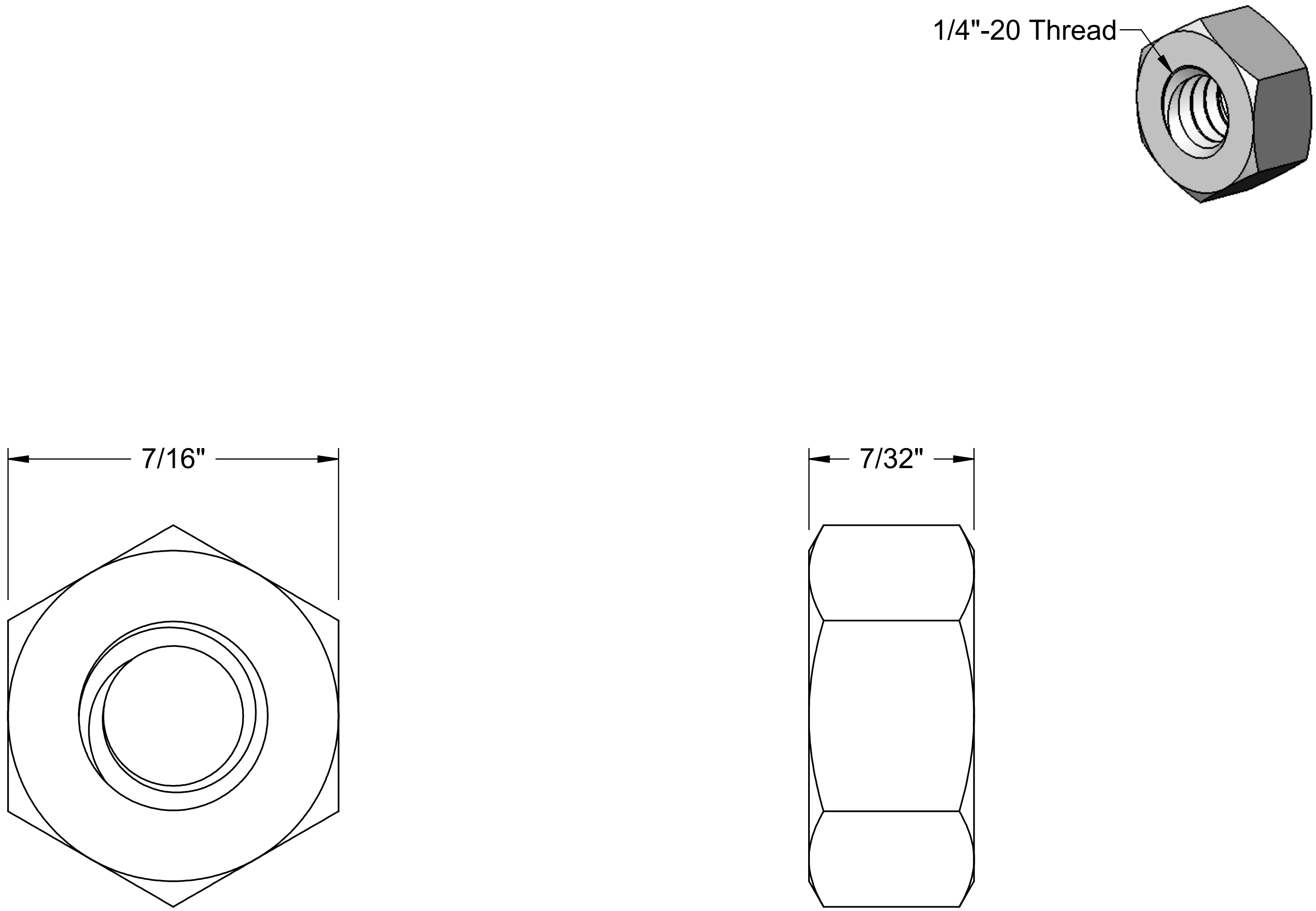
McMASTER-CARR® CAD

PART NUMBER 92311A121

http://www.mcmaster.com

Information in this drawing is provided for reference only.

Cup Point Set Screw

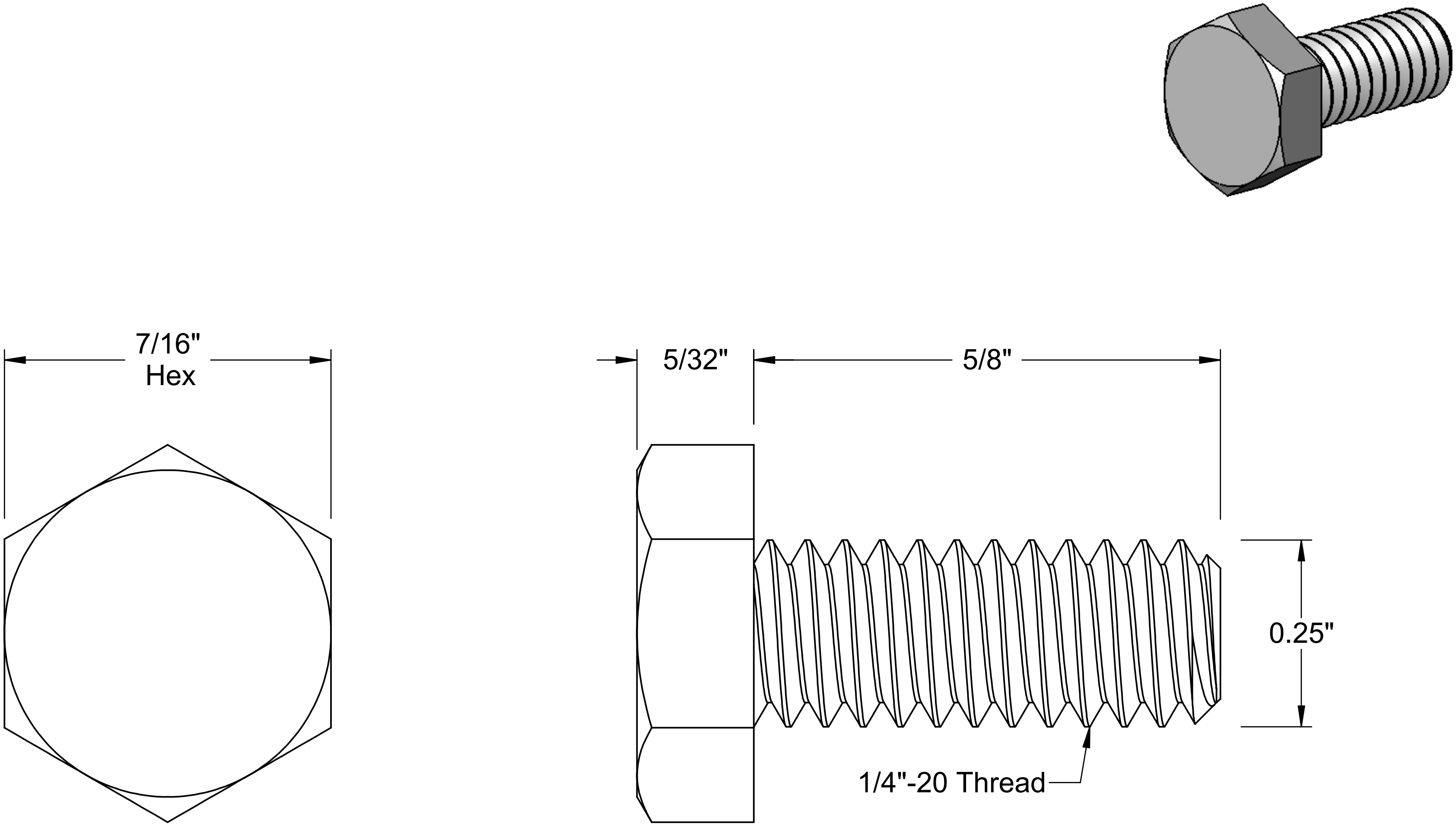


McMASTER-CARR CAD

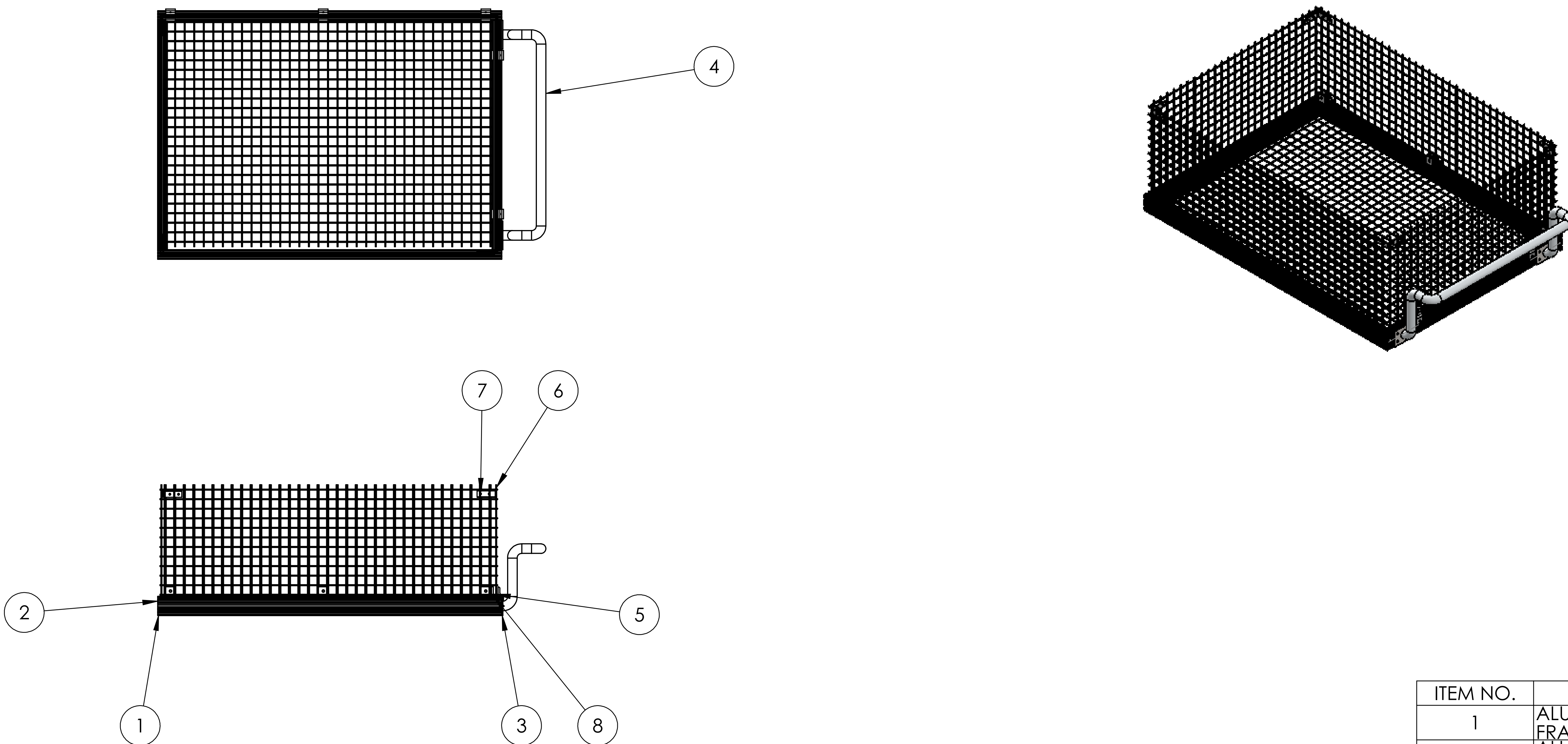
PART NUMBER 92673A113

http://www.mcmaster.com

Hex Nut



McMASTER-CARR® CAD	PART NUMBER	92240A539
http://www.mcmaster.com 	Stainless Steel Cap Screw	



ITEM NO.	PART NUMBER	QTY.
1	ALUM T-SLOT FRAMING	2
2	ALUM T-SLOT FRAMING	2
3	Welding Plate	2
4	Final Handlebar	1
5	47065T287	2
6	47065T287	2
7	1556A43	4
8	47065T197	5

Mechanical Engineering CAL POLY	PART NAME: BASKET ASSEMBLY		PART #: N/A	DATE: 2/8/17
	SCALE: 1:12 / UNITS: N/A	MATERIAL: N/A	DRAWN BY: JASON MUNTER	
Senior Design Project	GROUP: PERSONAL UTILITY CART	DWG. #: A-2002	OTHER:	

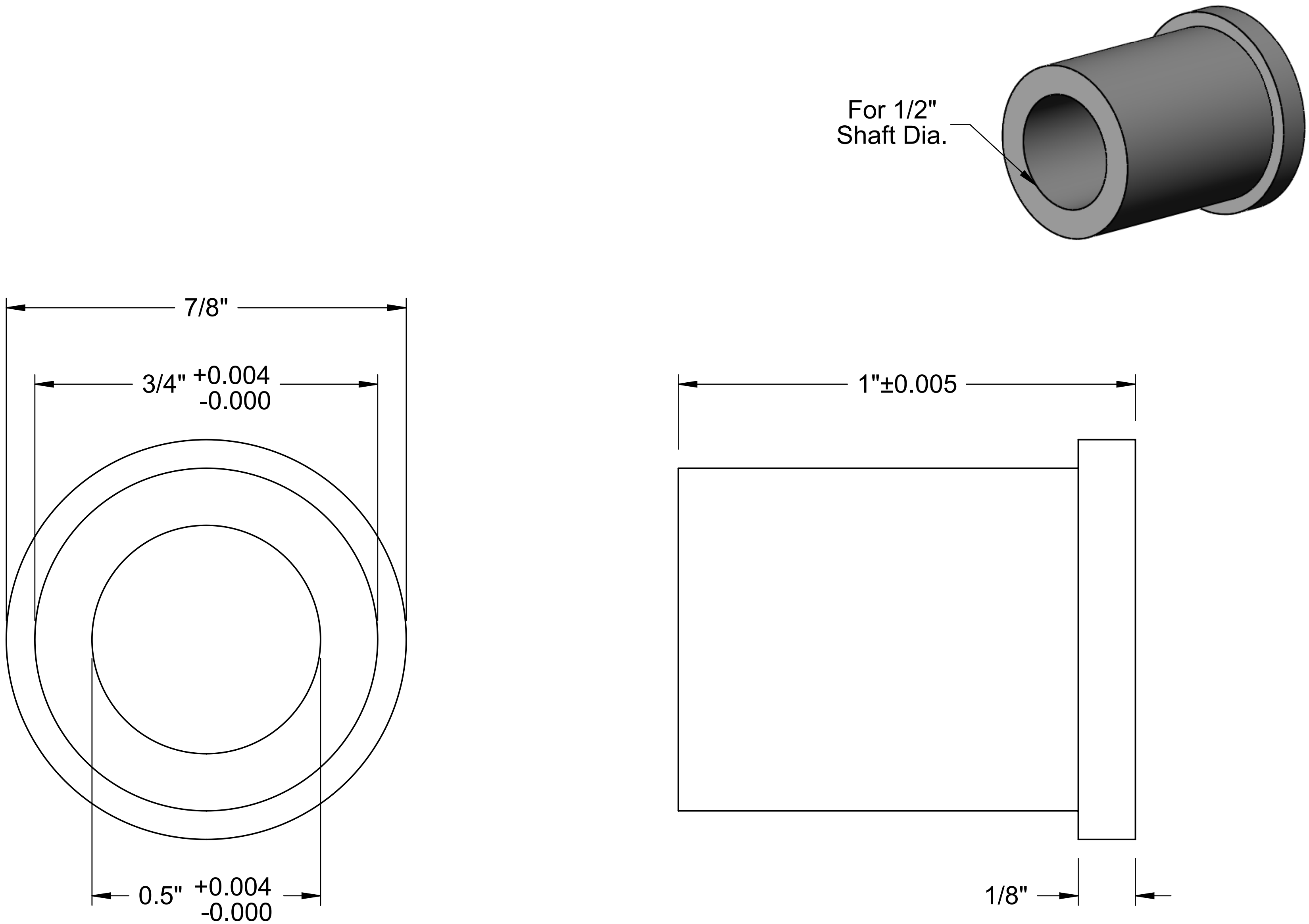
Appendix K-3

Part #: 2003

- Road shift cable set
- Silicon prelubed housing
- Stainless steel braided cables
- Kit includes:
  - 2 2100mm cables
  - 1 1700mm x 4mm housing
  - 4 Sealed Short Ferrules
  - 1 Sealed long ferrule
  - 1 Alloy Ferrule for the Rear Derailleur
  - 2 Cable-End Crimps
- Made in Japan

Appendix K-2
Part #: 2002

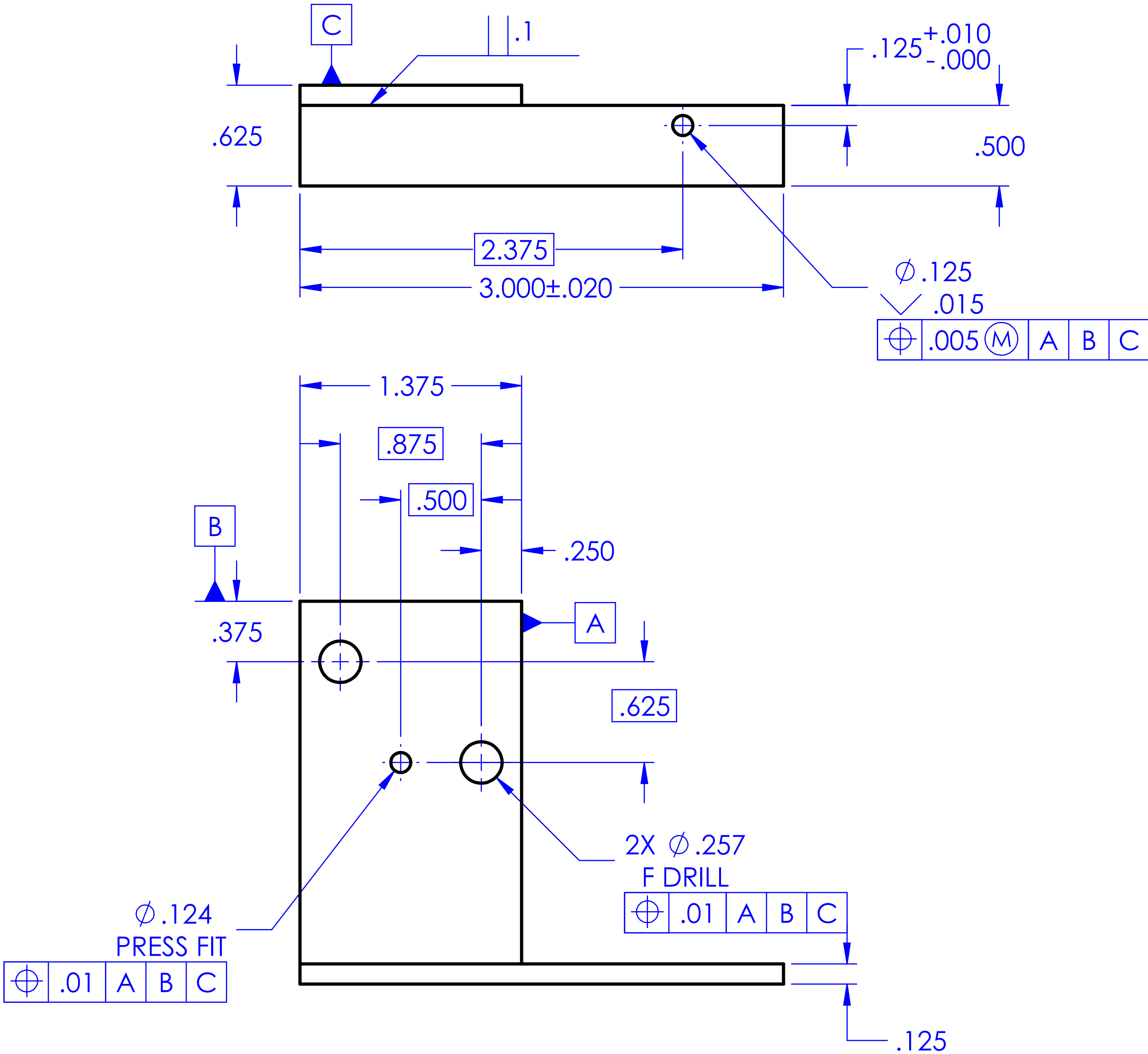
- 1 Pair Mountain bicycle bike hand brake lever
- Brake Lever Type: 3-Finger Version
- Applicable tube diameter: About 22 mm
- Item Dimension：approx. 14.2cm x 9.3cm / 5.59" x 3.66"



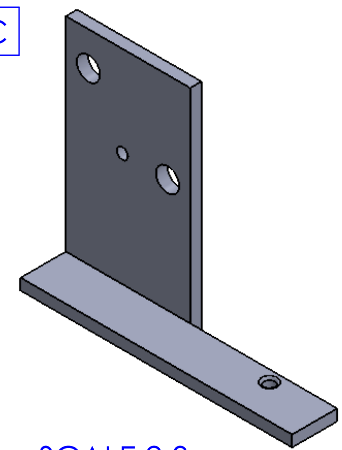
McMASTER-CARR® CAD	PART NUMBER	2706T33
http://www.mcmaster.com © 2015 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Ultra-Low-Friction Dry-Running Flanged Sleeve Bearing	

Appendix K-1
Part #: 2001

- Polymer coated cable reduces sliding resistance
- SP-41 housing pre-lubricated with silicone grease
- Stainless steel cable for rust protection
- Curved cable surface for low friction
- Sealed end caps
- Shifter cable end
- Made in Japan



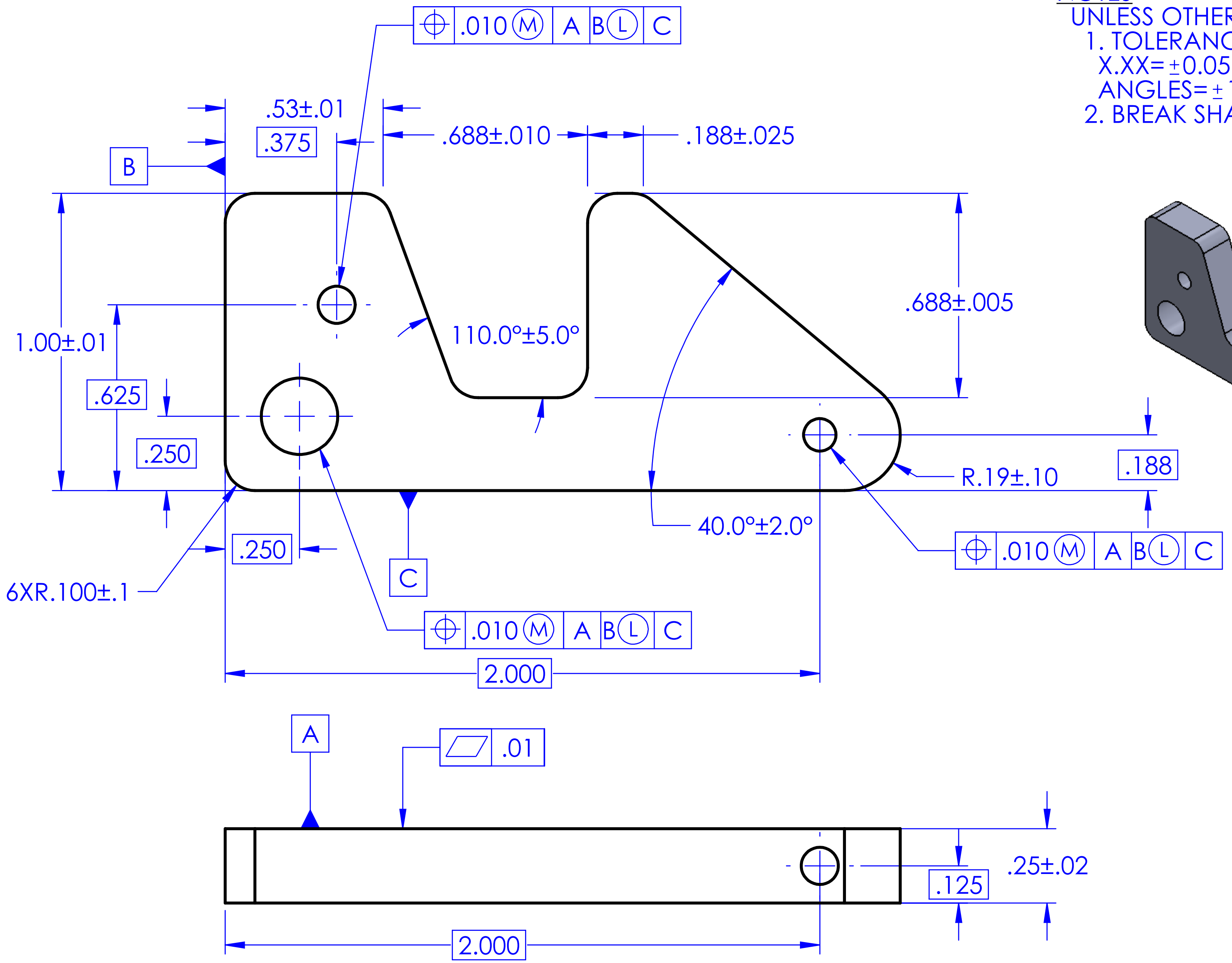
NOTES
UNLESS OTHERWISE SPECIFIED:
1. TOLERANCES:
X.XX= ±0.01
ANGLES= ±1 °
2. BREAK SHARP EDGES 0.5 MAX.

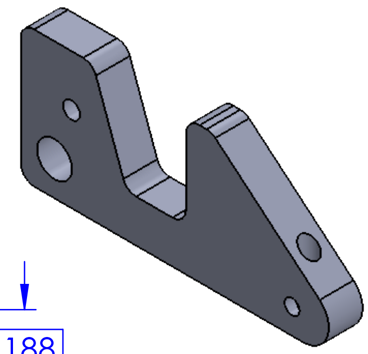


SCALE 2:3

Mechanical Engineering CAL POLY	PART NAME: CAM BRACKET		PART #: 2006	DATE: 2/8/17
	SCALE: 1:1	UNITS: INCHES	MATERIAL: CARBON STEEL (A36)	DRAWN BY: JASON MUNTER
Senior Design Project	GROUP: PERSONAL UTILITY CART		DWG. #: 1002006	OTHER:

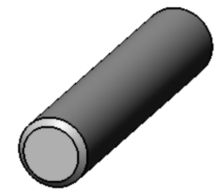
NOTES
UNLESS OTHERWISE SPECIFIED:
1. TOLERANCES:
X.XX= ±0.05
ANGLES= ±1 °
2. BREAK SHARP EDGES 0.5 MAX.

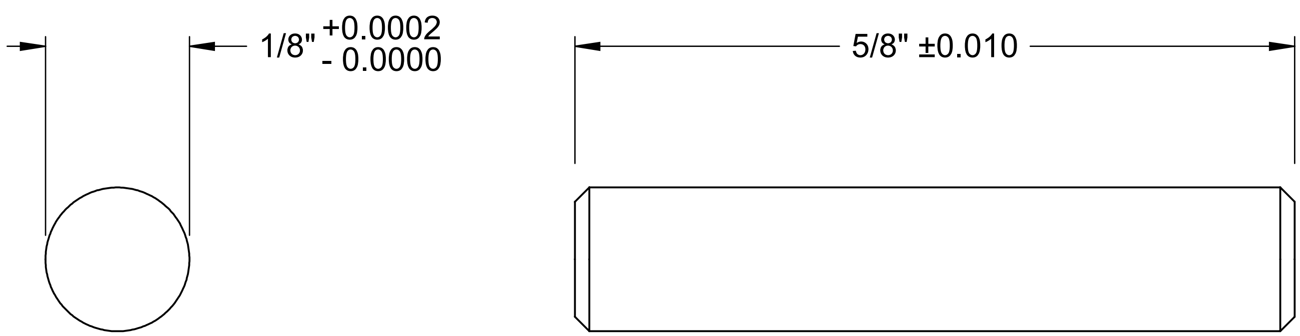




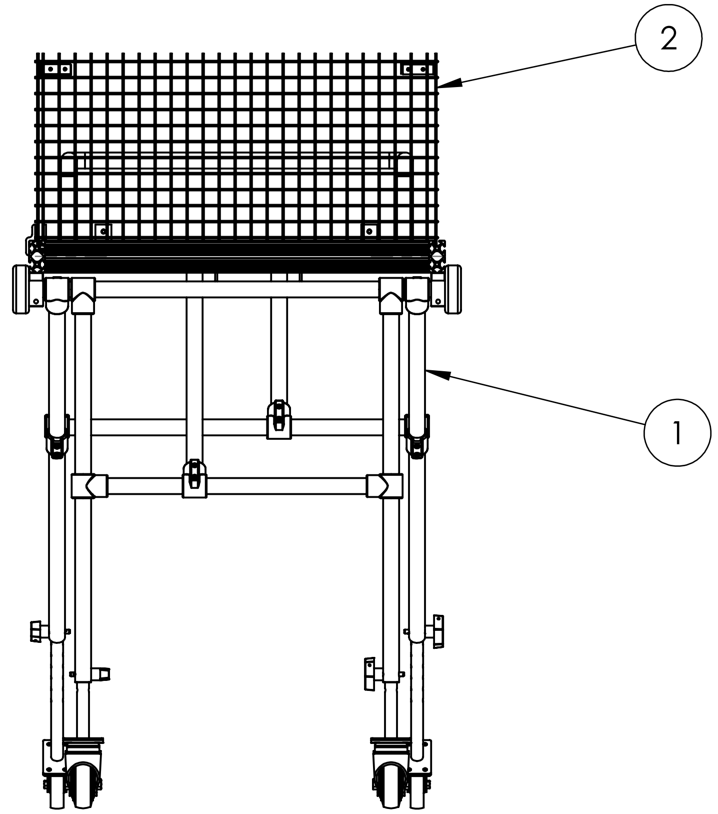
SCALE 1:1

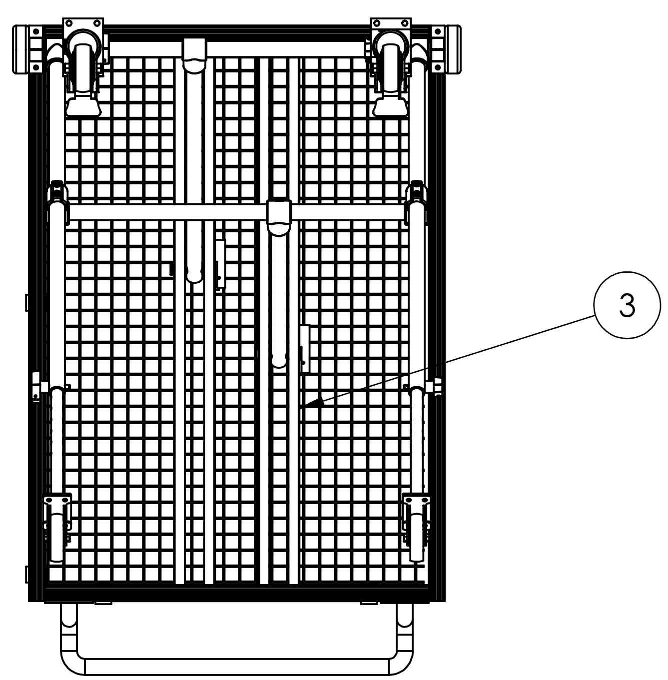
Mechanical Engineering CAL POLY	PART NAME: CAM FOLLOWER		PART #: 105	DATE: 2/9/17
	SCALE: 2:1	UNITS: INCHES	MATERIAL: CARBON STEEL (A36)	DRAWN BY: JASON MUNTER
Senior Design Project	GROUP: PERSONAL UTILITY CART		DWG. #: 1010100	OTHER:





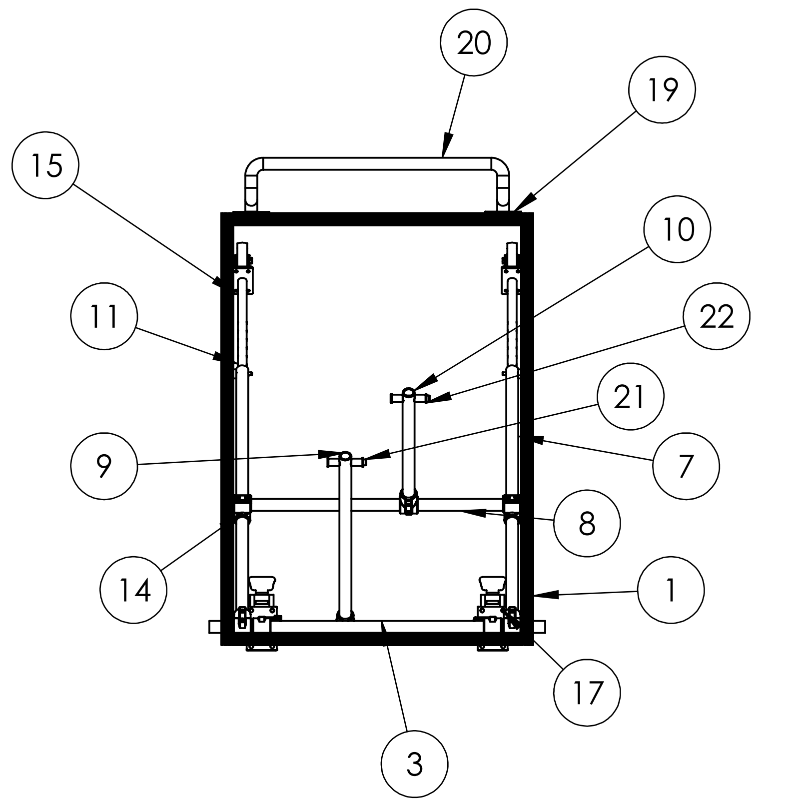
McMASTER-CARR® CAD	PART NUMBER	97395A445
http://www.mcmaster.com © 2012 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Type 316 Stainless Steel Dowel Pin	

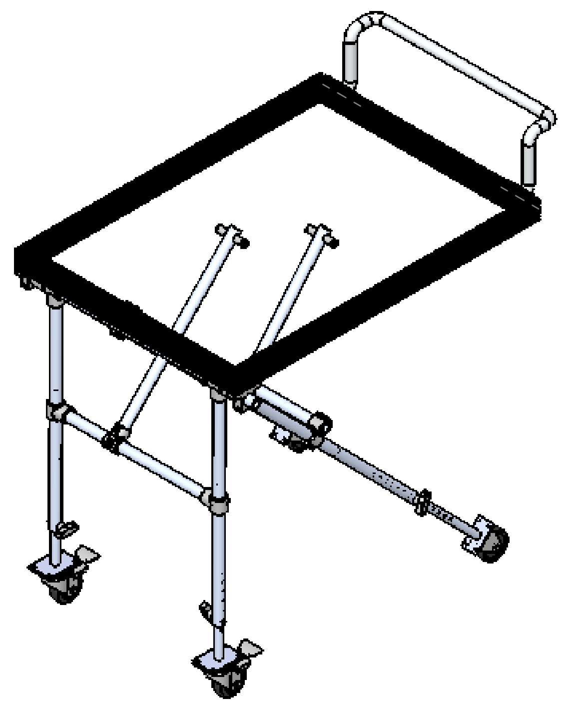


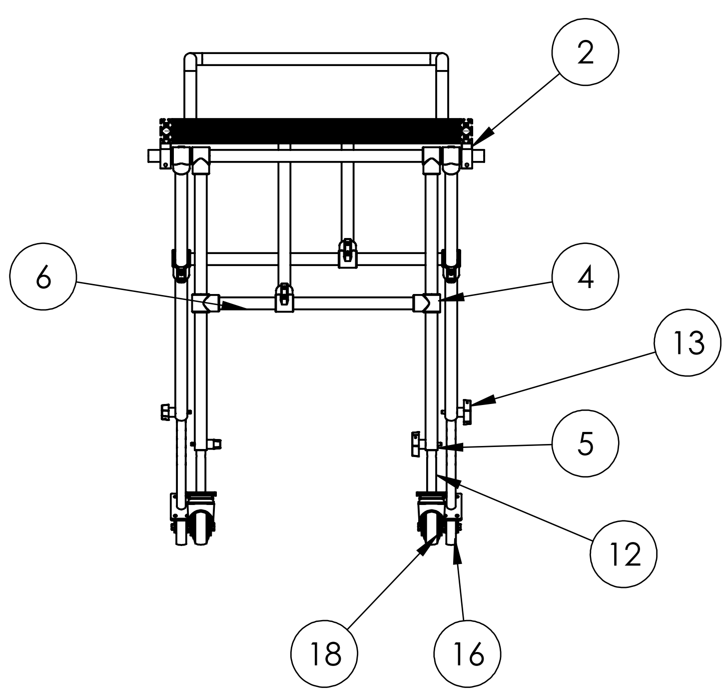


#	SUBASSEMBLY
1	FRAME AND LEGS
2	BASKET
3	LOCKING MECHANSIM

Mechanical Engineering CAL POLY	PART NAME: MOUNTING BRACKET			PART #: N/A	DATE: 2/8/17
	SCALE: 1:12	UNITS: INCHES	MATERIAL: CARBON STEEL (A36)	DRAWN BY: JASON MUNTER	
Senior Design Project	GROUP: PERSONAL UTILITY CART		DWG. #: 1010100	OTHER:	

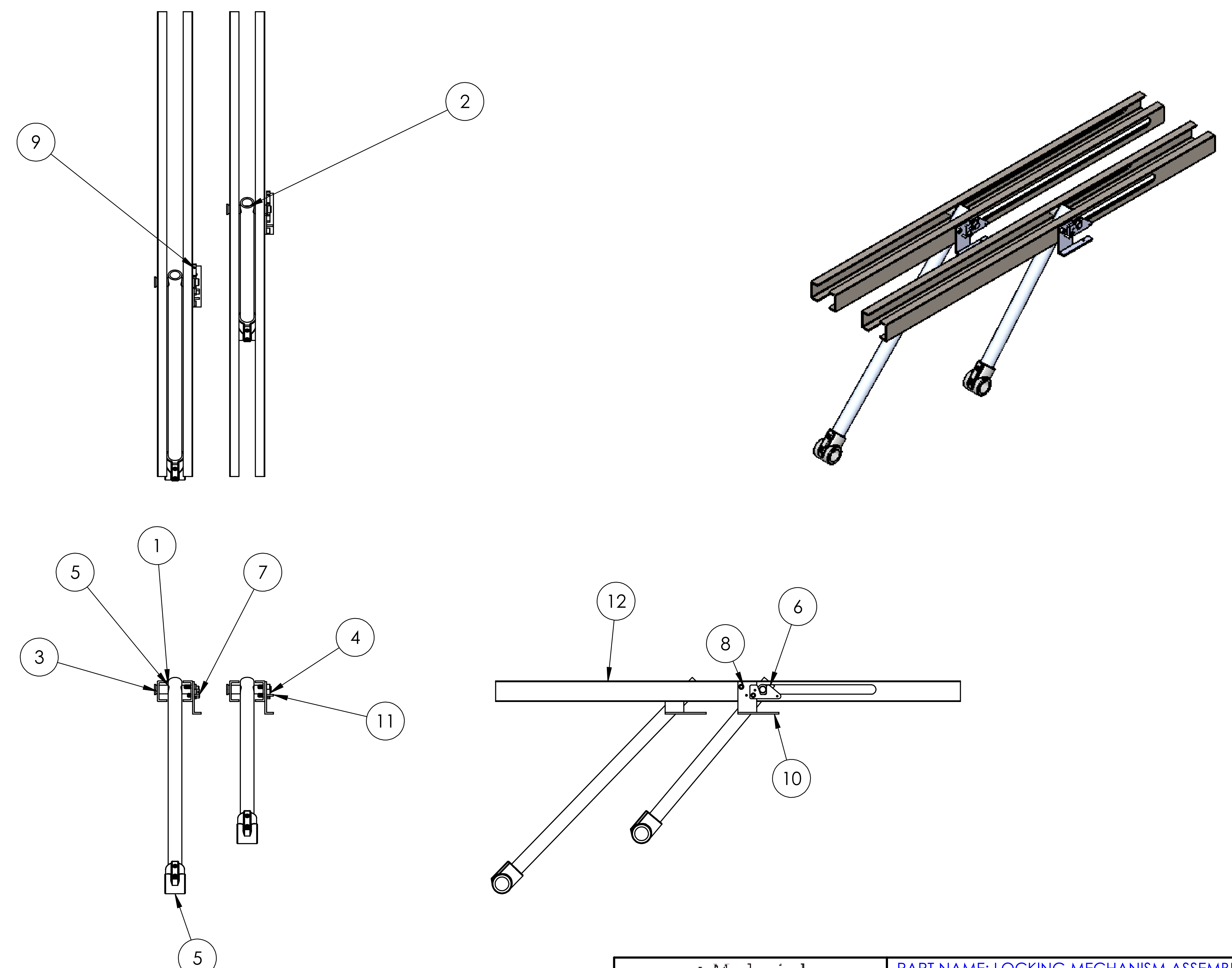






ITEM NO.	PART NUMBER	QTY.
1	ALUMINUM T-SLOT FRAMING	2
2	47065T205	2
3	Tubing_1_125	1
4	4698T14	8
5	Tubing_1_125	2
6	Tubing_1_125	1
7	Tubing_1_125	2
8	Tubing_1_125	1
9	Tubing_1_125	1
10	Tubing_1_125	1
11	Lower Leg	2
12	Lower Leg	2
13	92490A648	4
14	4698T42	2
15	Mounting Plate	2
16	2406T34	2
17	Front Mounting Plate	2
18	2370T84	2
19	Welding Plate	2
20	Final Handlebar	1
21	Roller Shaft	2
22	2706T29	4

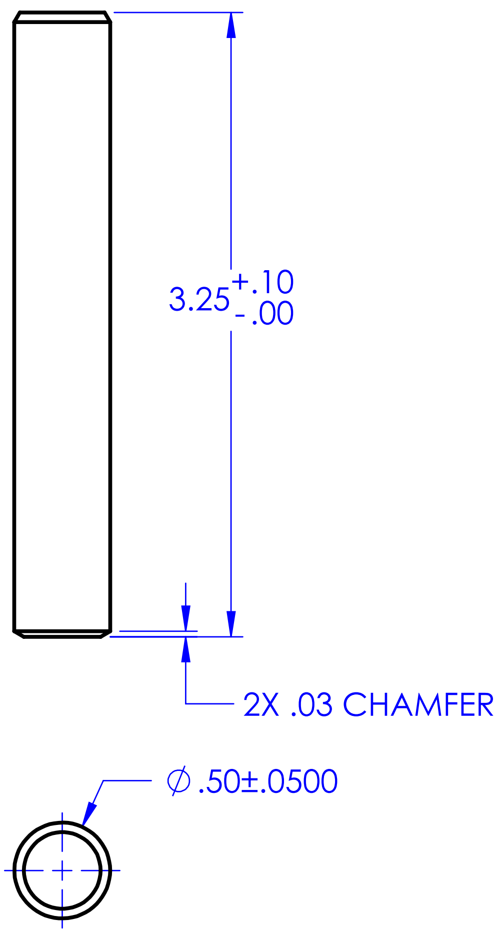
Mechanical Engineering CAL POLY	PART NAME: LEG ASSEMBLY		PART #: N/A	DATE: 2/8/17
	SCALE: 1:16	UNITS: N/A	MATERIAL: N/A	DRAWN BY: JASON MUNTER
Senior Design Project	GROUP: PERSONAL UTILITY CART		DWG. #:A2001	OTHER:

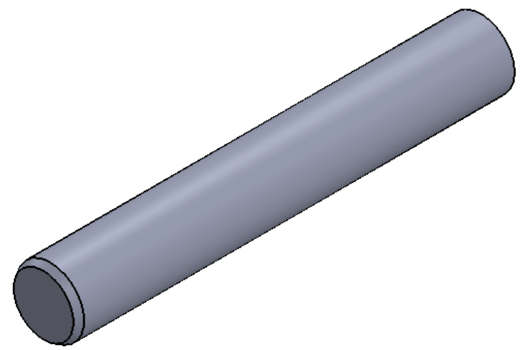


ITEM NO.	PART NUMBER	QTY.
1	Tubing_1_125	1
2	Tubing_1_125	1
3	Steel Square Tube	1
4	Roller Shaft	2
5	2706T29	4
6	Cam Follower Rev 2	2
7	97395A441	2
8	92196A539	4
9	91375A120	1
10	Bracket	2
11	97395A445	1
12	Steel Square Tube	1

Mechanical Engineering CAL POLY	PART NAME: LOCKING MECHANISM ASSEMBLY		PART #: N/A	DATE: 2/8/17
	SCALE: 1:8	UNITS: N/A	MATERIAL: N/A	DRAWN BY: JASON MUNTER
Senior Design Project	GROUP: PERSONAL UTILITY CART	DWG. #: A-2003	OTHER:	

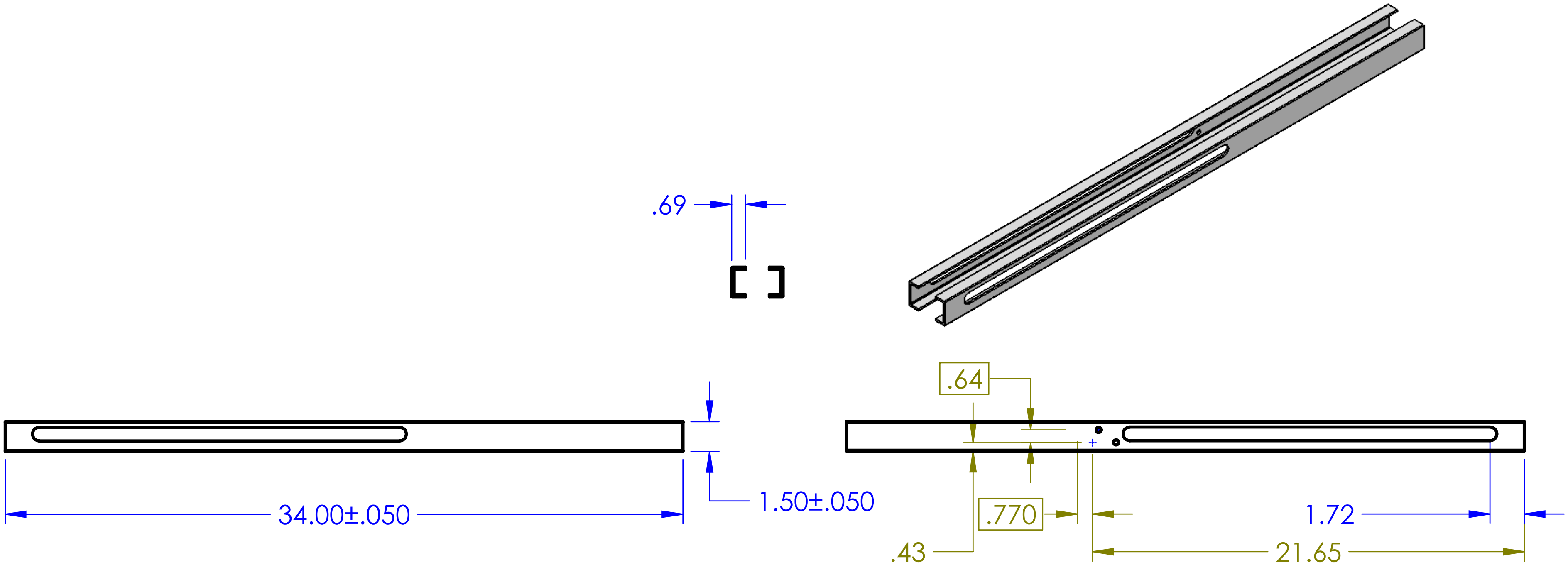
NOTES
UNLESS OTHERWISE SPECIFIED:
1. TOLERANCES:
X.XX= ±0.05
ANGLES= ±1 °
2. BREAK SHARP EDGES 0.5 MAX.



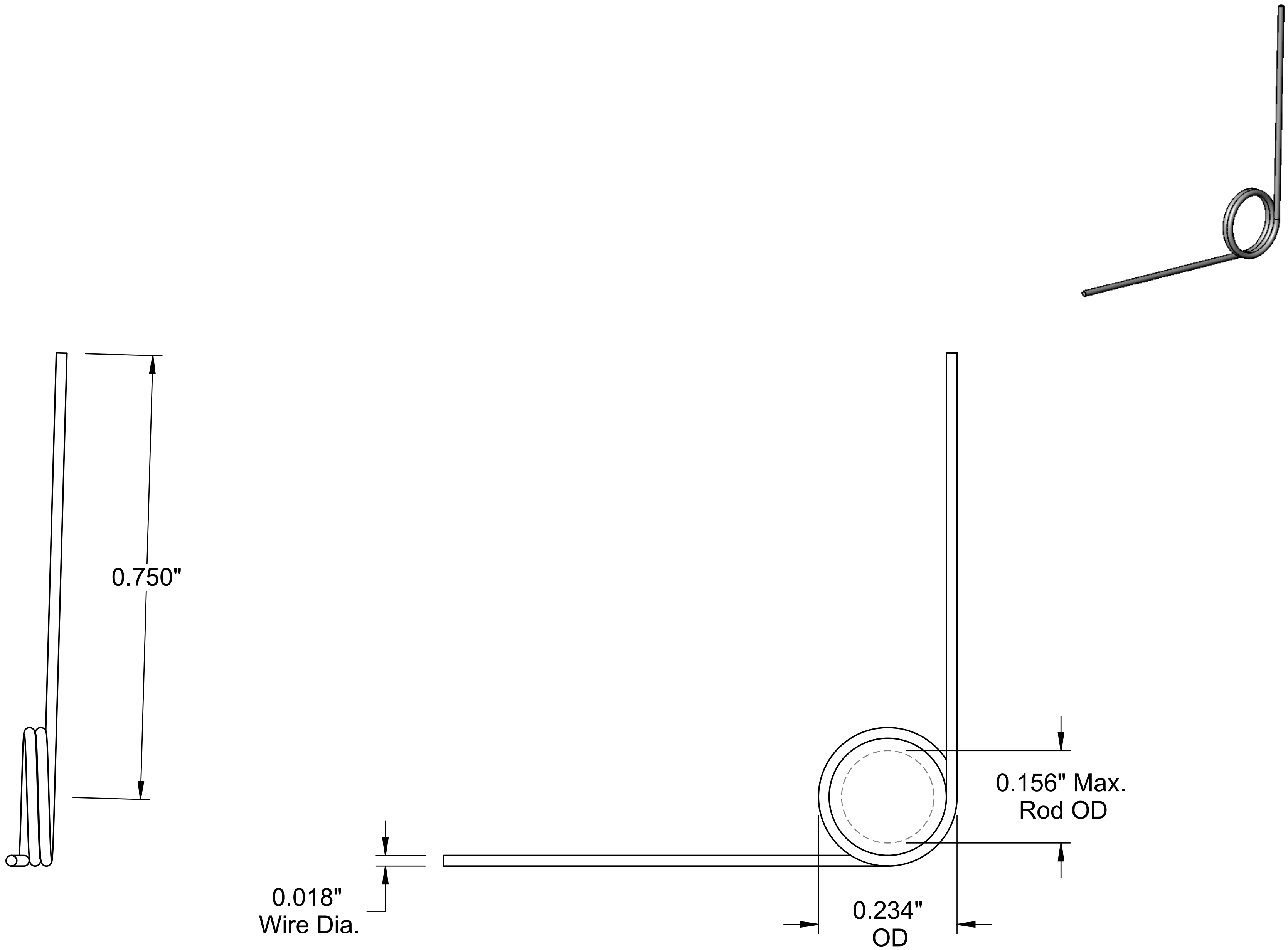


Mechanical Engineering CAL POLY	PART NAME: ROLLER SHAFT			PART #: 2004	DATE: 2/9/17
	SCALE: 1:1	UNITS: INCHES	MATERIAL: CARBON STEEL (A36)	DRAWN BY: JASON MUNTER	
Senior Design Project	GROUP: PERSONAL UTILITY CART		DWG. #: 1002004	OTHER:	

NOTES
UNLESS OTHERWISE SPECIFIED:
1. TOLERANCES:
X.XX= ±0.01
ANGLES= ±1 °
2. BREAK SHARP EDGES 0.5 MAX.



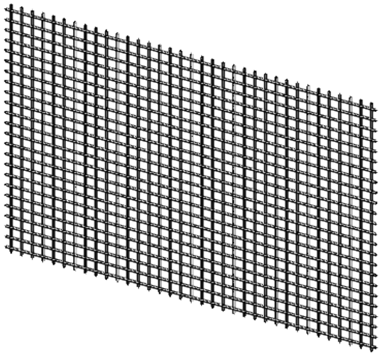
Mechanical Engineering CAL POLY	PART NAME: SUPPORT HOUSING		PART #: 2007	DATE: 2/8/17
	SCALE: 1:8	UNITS: INCHES	MATERIAL: CARBON STEEL (A36)	DRAWN BY: JASON MUNTER
Senior Design Project	GROUP: PERSONAL UTILITY CART	DWG. #: 1002009	OTHER:	

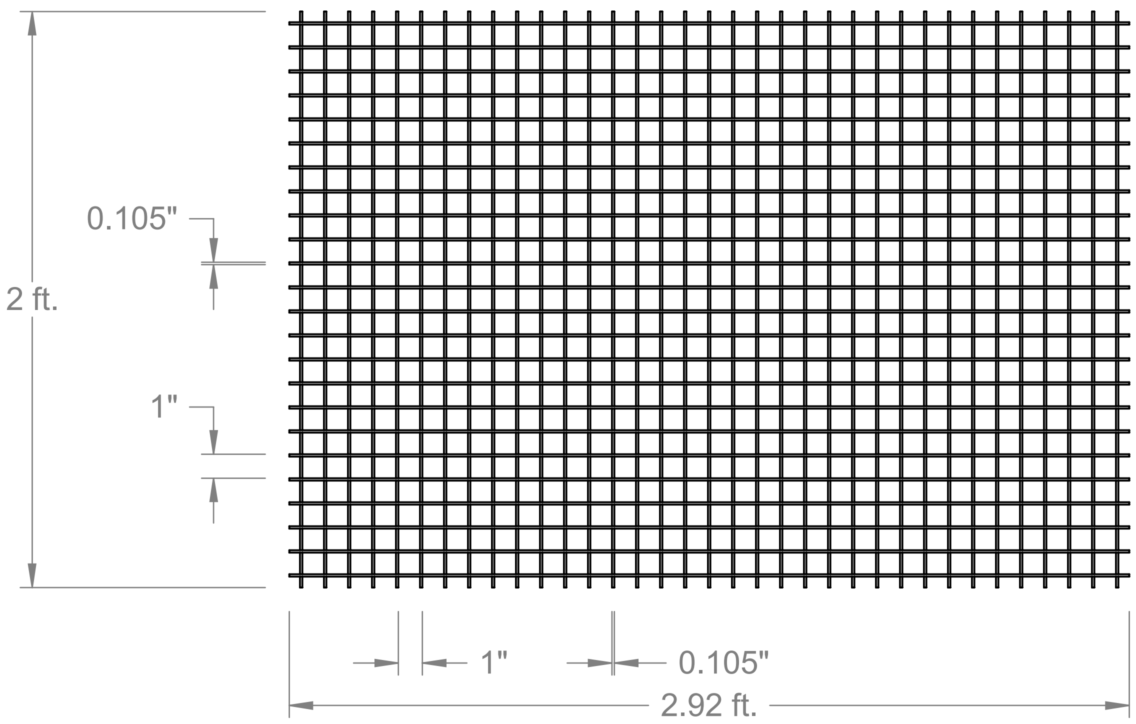


McMASTER-CARR® CAD

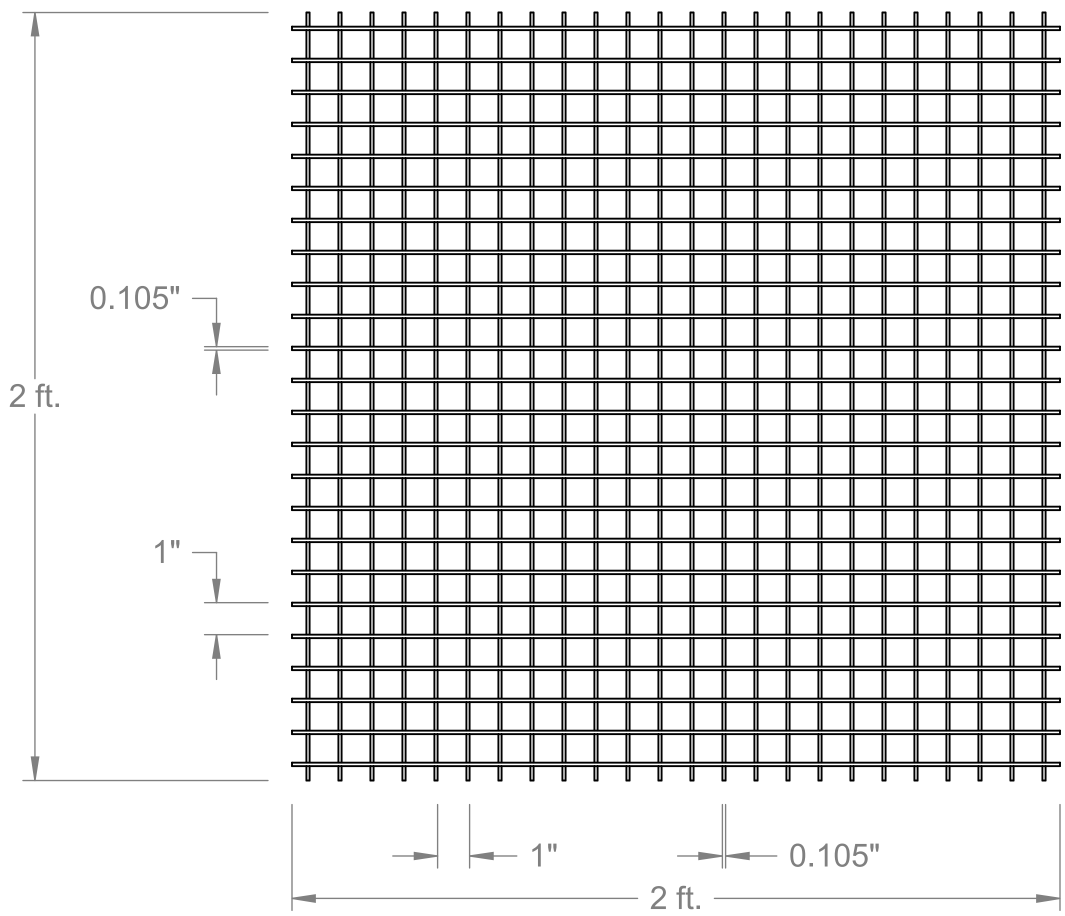
PART NUMBER **9271K646**

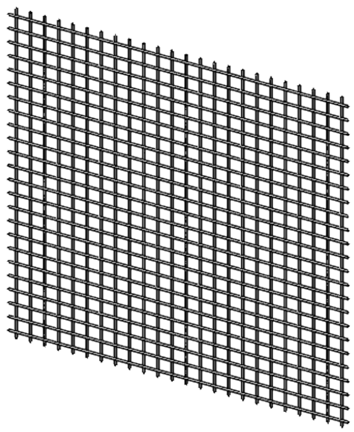
Steel Music Wire
90° Right-Hand Torsion Spring



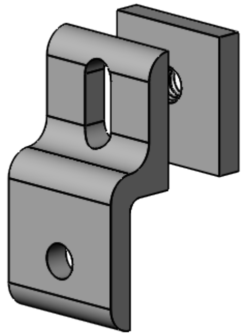


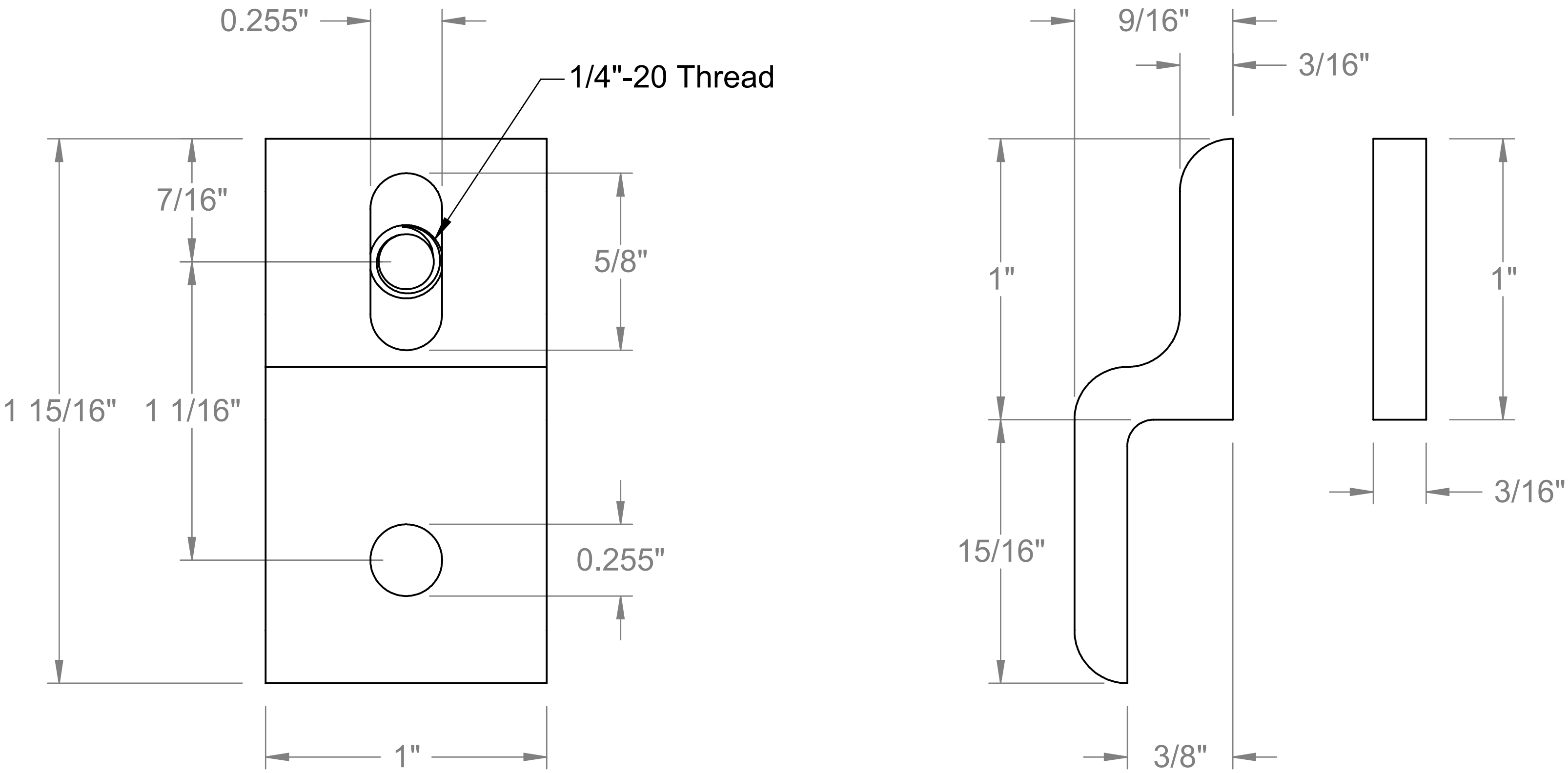
McMASTER-CARR® CAD	PART NUMBER	1003001	
http://www.mcmaster.com © 2015 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Wire Mesh Panel for Aluminum T-Slotted Framing		





McMASTER-CARR® CAD	PART NUMBER	1003002
http://www.mcmaster.com © 2015 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Wire Mesh Panel for Aluminum T-Slotted Framing	





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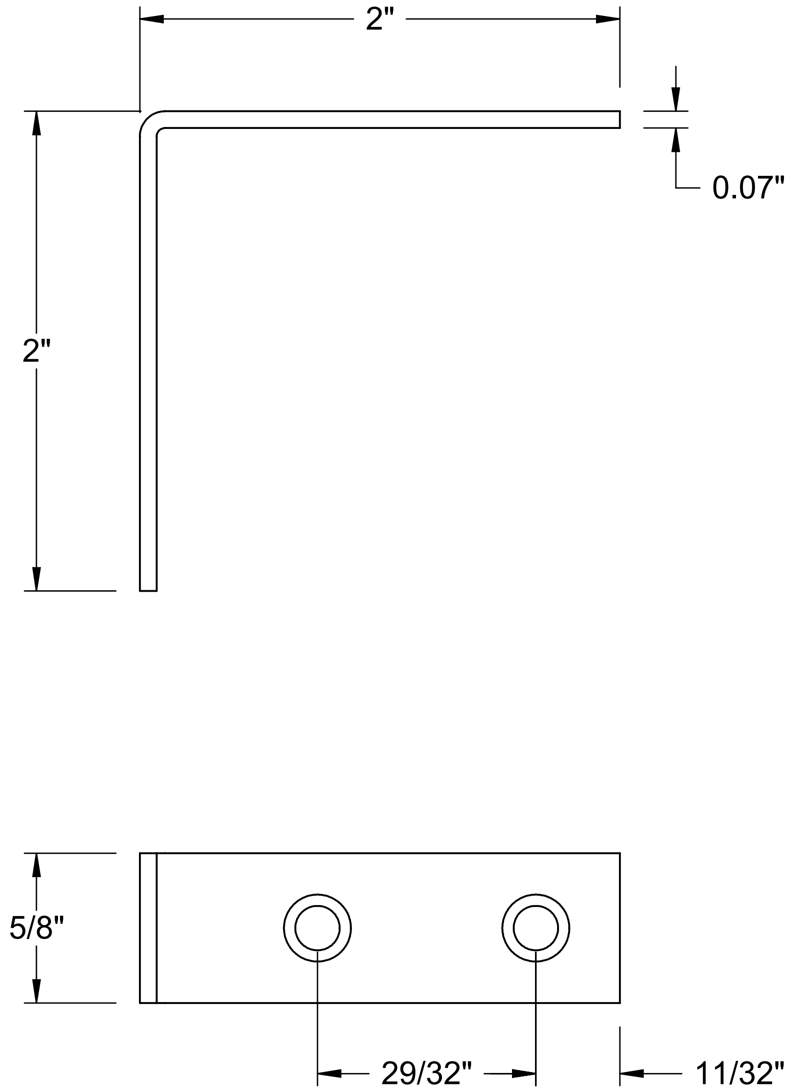
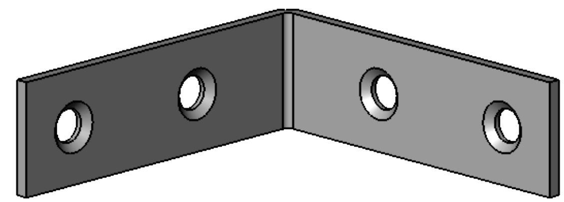
McMASTER-CARR® CAD	PART NUMBER 1003003
http://www.mcmaster.com © 2015 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Wire Mesh Panel Holder



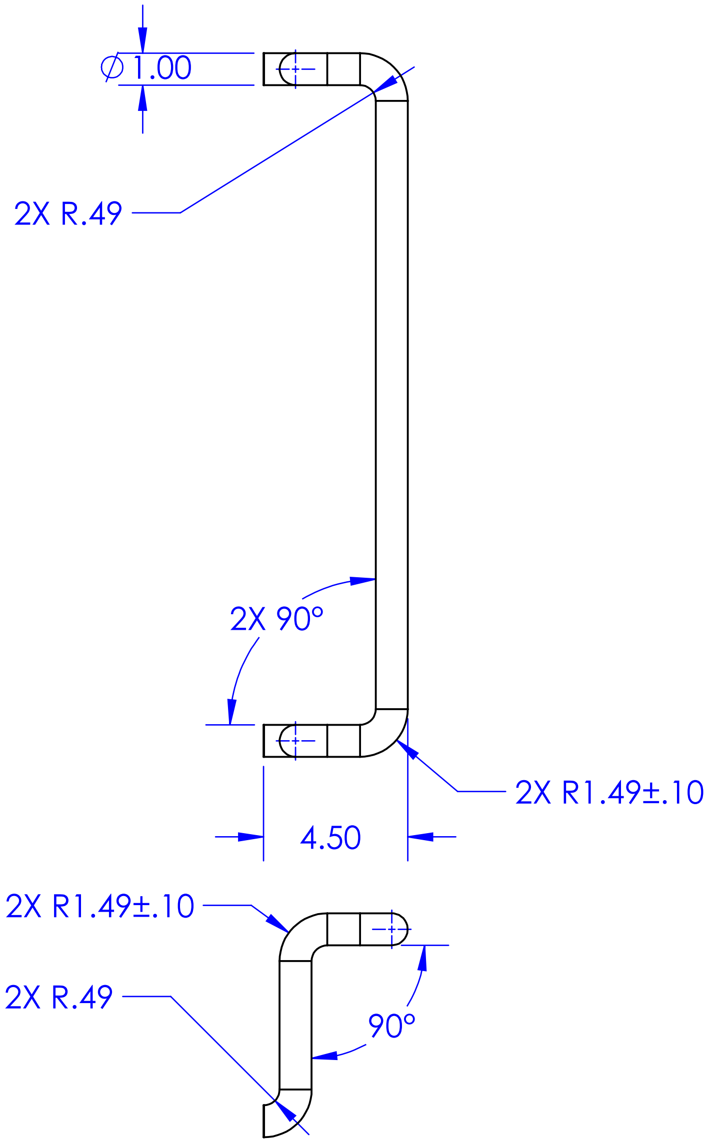


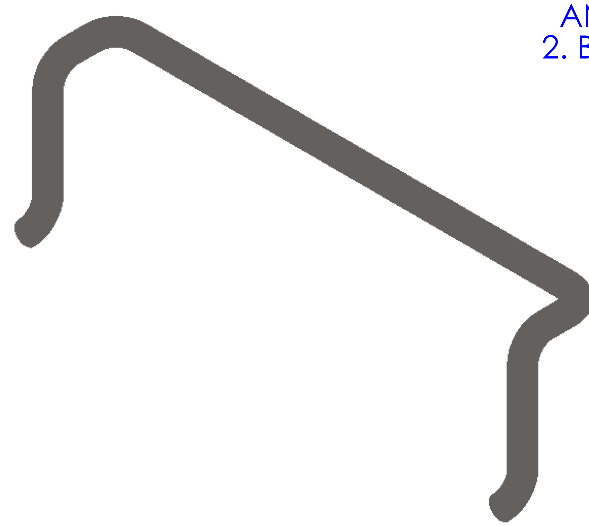
Bracket has 4 holes.

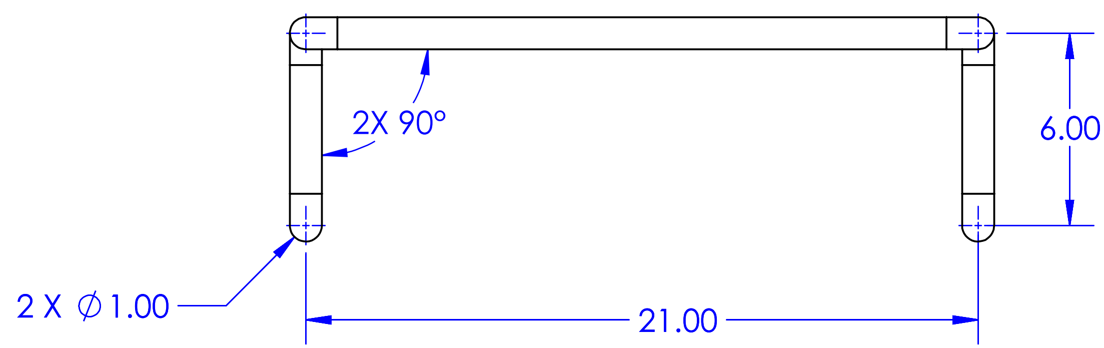
Bracket uses No. 6 screws.

McMASTER-CARR® CAD	PART NUMBER	1003004	
http://www.mcmaster.com © 2016 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	2" x 2" Corner Bracket		

NOTES
UNLESS OTHERWISE SPECIFIED:
1. TOLERANCES:
X.XX= ±0.05
ANGLES= ±1 °
2. BREAK SHARP EDGES 0.5 MAX.

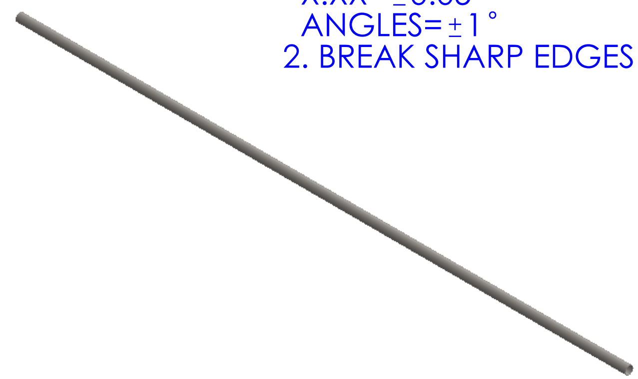


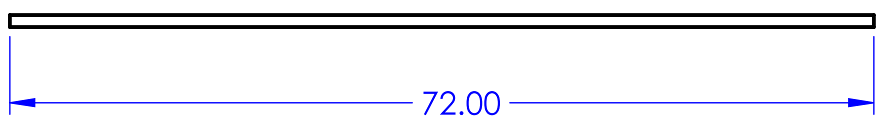


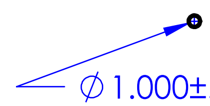


Mechanical Engineering CAL POLY	HANDLEBAR	PART #: 1003005	DATE: 2/8/17
	SCALE: 1:6 / UNITS: INCHES	MATERIAL: CARBON STEEL 1005-1026	DRAWN BY: ERIC JOHNSON
SENIOR DESIGN PROJECT	GROUP: PERSONAL UTILITY CART	DWG. #: 1003005-B	OTHER:

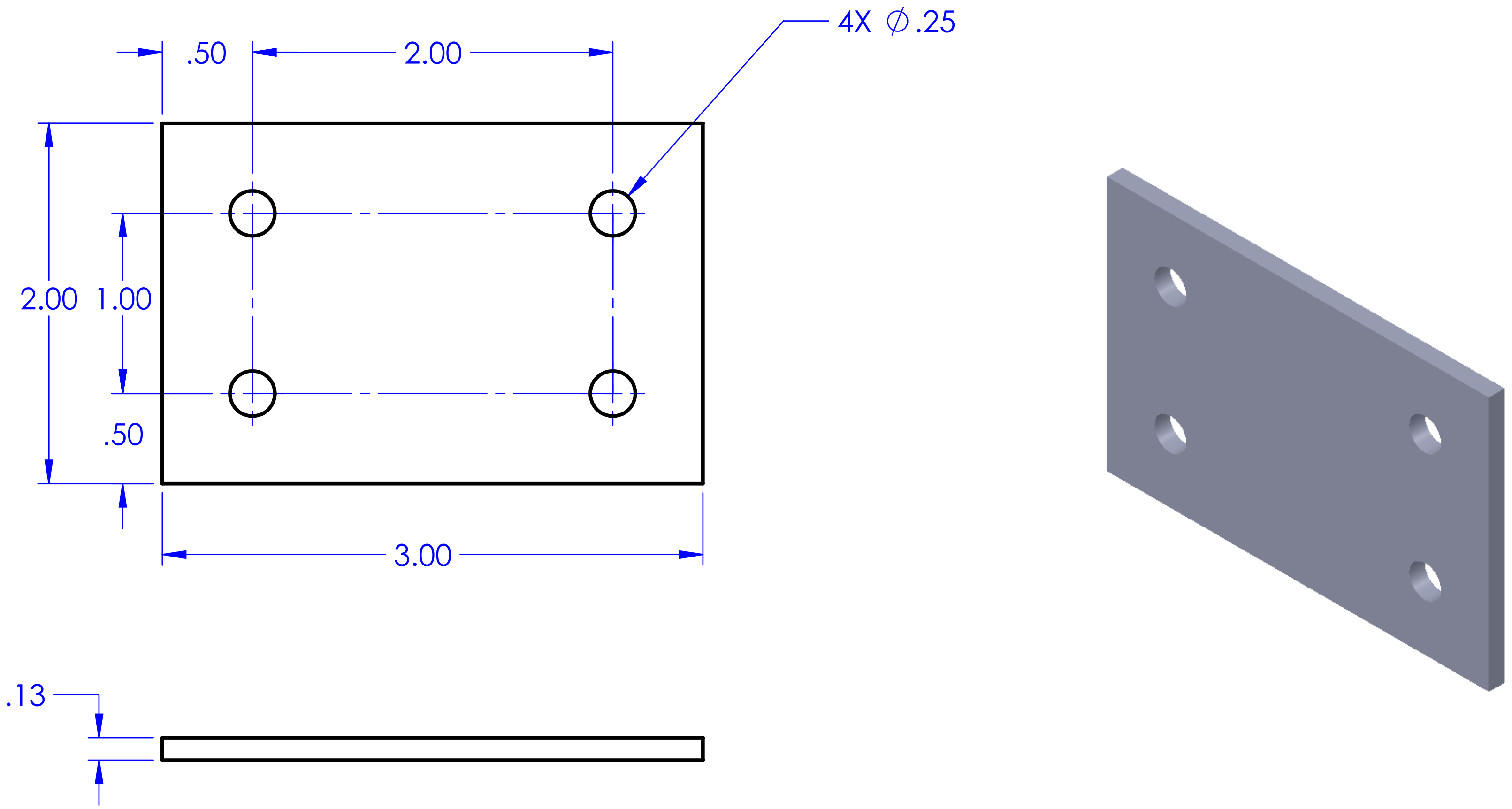
NOTES
UNLESS OTHERWISE SPECIFIED:
1. TOLERANCES:
X.XX= ±0.05
ANGLES= ±1 °
2. BREAK SHARP EDGES 0.5 MAX.





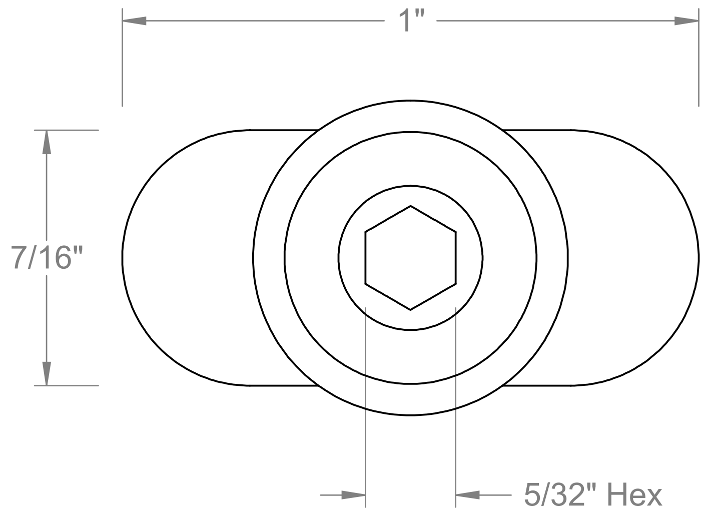


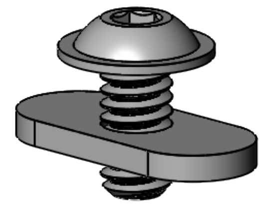
Mechanical Engineering CAL POLY	LOW-CARBON STEEL TUBING		PART #: 1003005	DATE: 2/8/17
	SCALE: 1:16 / UNITS: INCHES	MATERIAL: CARBON STEEL 1005-1026	DRAWN BY: ERIC JOHNSON	
SENIOR DESIGN PROJECT	GROUP: PERSONAL UTILITY CART	DWG. #: 1003005	OTHER: UNPOLISHED	

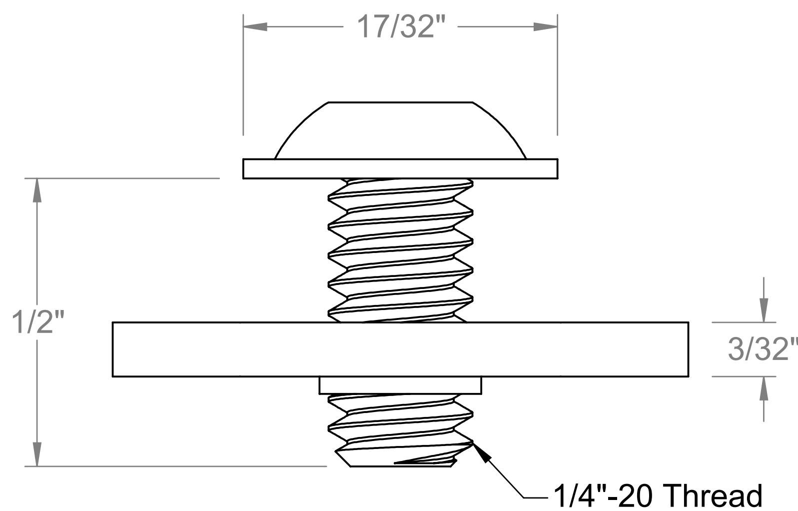


NOTES
UNLESS OTHERWISE SPECIFIED:
1. TOLERANCES:
X.XX=±0.05
ANGLES=±1°
2. BREAK SHARP EDGES 0.5 MAX.

Mechanical Engineering CAL POLY	WELDING PLATE		PART #: 1003006	DATE: 2/8/17
	SCALE: 1:1	UNITS: INCHES	MATERIAL: CARBON STEEL (A36)	DRAWN BY: ERIC JOHNSON
SENIOR DESIGN PROJECT	GROUP: PERSONAL UTILITY CART		DWG. #: 1003006	OTHER:







McMASTER-CARR® CAD	PART NUMBER 1003007
http://www.mcmaster.com © 2015 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Zinc-Plated Steel Fastener