

TRUCK BED BIKE RACK

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Abstract

McMillian's Bike Co. contracted Wix Design Ltd. to design and prototype a bike rack situated in the bed of a truck. After doing a survey of their customers, McMillian's Bike Co. found that customers were not satisfied with the current products in the market for transporting bicycles and believes there is a unique product development opportunity. The objectives that McMillian's Bike Co. aim to fulfill is that the product be modular, compact, easy to use/install, versatile, affordable and secure. In terms of compactness the product should be able to hold at least four bikes with the potential of holding up to five. The product should be versatile in terms of securing different types of bikes that can range from BMX bikes to large mountain bikes. The product should be able to be broken down into modular units so that one can choose how many bikes can be attached to the rack. The design team from Wix Design Ltd. set out to design a product that would meet these criteria.

The team did market research to find conventional products used in the market and a variety of patents related to the project. The team found several different approaches to the problem and moved into the concept generation phase of the project. They met with their sponsor several times to discuss the feasibility of their ideas.

After the concept generation phase, the selected concept was designed to secure a bicycle by its front wheel as it was the simplest and most convenient way of securing the bicycle. The wheel is secured by contacting three points around the wheel. These points have put a force on the wheel through its center and sum to zero. This prevents all motion and fully secures the tire. Two of the contact points lie in a fixed position at opposing ends of the base of the tire, while the other point of contact sits on top of the wheel. This top contact point is forced downward by a ratchet mechanism, which forces the wheel into the other two contact points and secures the tire. After finalizing the design, the team went into the prototyping phase of the project.

During the prototyping phase the design team encountered several issues that had to be fixed. The team went into an iterative process of designing, manufacturing and testing. Almost all parts of the system had been changed or modified before the end of the project. The final prototype was then built and compared to the objective set out by the McMillian's Bike Co.

The final prototype fulfilled most of the requirements set out by McMillian's Bike Co. It securely fit the bike between the wheel and the contact points. It was broken down into separate modular units which could be added to fit four bikes in the back of a truck. Relative to what is on the market the design has more value when purchasing three or more units than conventional methods. Finally, it is easy to use but suffers in terms of installation. Since it includes heavy load bars that need to be mounted in the truck and a lot of hardware, it takes a large amount of time to assemble and install.

Overall, the project ran smoothly and was completed on time, within scope and under budget.

Acknowledgements

Several instructors took the time out of their day to help the group complete this project. Their efforts were much appreciated, and they should be formally recognized:

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- Johan Fourie, PhD (EngSci), Peng
- Brian Ennis, DiplT, BTech, ASCT
- Dave Lewis, BAsC (Mech), Program Head, Mechanical Manufacturing

Stephen McMillian was the project sponsor and was very helpful and insightful over the course of the project. By sharing his invaluable manufacturing and design knowledge, Stephen helped us avoid several drawbacks in the prototyping phase. The design team met with Stephen weekly and he ensured that the project was moving along smoothly. During this time Stephen provided useful feedback and recommendations. Furthermore, he aided us by helping us 3D print several major components necessary to complete the project. This was helpful as the team was unfamiliar with using the school's Ultimaker 3D printer.

Johan Fourie was the team's faculty sponsor that provided important information regarding the project management side of the project along with specific guidelines that outline the specifics of the project. He was also responsible for having the shop open for the team to use during certain portions of the week and ran all presentations involving the project. During the critical design review presentation that Johan facilitated, the team received useful feedback that they were able to incorporate into their design.

Brian Ennis helped during the manufacturing of the prototype. There was a significant learning curve when it came to the machines in the shop. Brian's deep understanding of shop processes helped us manufacture complicated parts more easily. Brian also gave advice on how to get better parts made with finer tolerances.

Dave Lewis also helped in the manufacturing stages of this project. He showed the design team how to properly use the milling machine and how to set it up with specific tooling to accomplish our specific design.

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Chapter 1 Introduction

1.1 Project Background

On October 17th, 2018, McMillian's Bike Co. released a Request for Proposal (RFP) for the design and manufacturing of a truck bed bike rack (TBRR) prototype. The RFP can be found in Appendix A.

McMillan's Bike Co. is a manufacturer of high performance bicycles, bike components and miscellaneous bike-related equipment. The company outlined that they were doing this project in response to customer surveys. Many customers were dissatisfied with the conventional methods of transporting several bicycles at one time in their trucks. Therefore, McMillian's Bike Co. made it their next business project to capitalize on this market opportunity. The company stated that they would grant the contract to the best bidder based on cost, time to market and fulfillment of the design requirements, which will be expanded upon in section 1.3.

1.2 Problem Statement

For the purpose of this project, all types of conventional bikes will be considered. Mountain bikes were looked at more closely however, as they are more challenging to accommodate for. Mountain biking took off in the early 1980s and since then there has been a large increase in demand for mountain biking equipment and transportation. This demand has also come with many new challenges.

As there are many locations for mountain biking enthusiasts, trails are often found in backcountry with rough entry roads. These paths may cause the vehicle to sway and jerk side to side. If bikes are not fastened down securely transported bikes may come loose and cause damage to either the pickup truck or the bicycles. Furthermore, many common methods of securing bikes only hold two bicycles. This means that groups larger than two, or families, have to find other means, or take two vehicles to their destination. While there are other methods to transport more bicycles, the cost can increase significantly. Additionally, convenience is becoming more of a concern for new products for modern customers. Several conventional methods require large set up time, heavy components, complicated joining methods, and multiple people helping to install a single system. Finally, different trucks may have

slightly altered truck bed dimensions. This means that one unit may not fit as it is meant to fit in multiple trucks. Loose equipment may damage either the truck or bicycles being secured.

With everything considered, the problem can be defined more clearly. The designed TBBR will be evaluated based on the following criteria:

- The level of security under truck vibration
- The number of bikes that can be transported in one truck bed
- Cost compared to conventional methods
- Set up time, ease of use, and ease of installation
- Adaptability to all trucks

1.3 Objectives

The objective of this project is to design, manufacture and test a new type of truck bed bike rack (TBBR). The final system will be designed to be secure, easy to use, affordable, modular and adaptable to all types of conventional bicycles.

The tasks to be completed for this project include:

- Research current market technology
- Concept generation and selection
- Design calculations
- Create 3D model and shop drawings
- Select appropriate off-shelf components
- Manufacture and prototype using in house equipment
- Test functionality
- Display project at the BCIT Mech Expo 2018
- Submit Final Report

Project deliverables include:

- 3D Cad Model
- Final shop drawings and Bill of Materials
- Final Report
- Functional prototype

1.4 Scope

The primary focus of the project is to design a mechanical system to accomplish the project objective of designing and manufacturing a new type of TBBR. The project will include all components that secure the TBBR system to the truck and the bicycles to the TBBR. This may include the design of custom parts or the selection of off-shelf components.

This project will not include the design of any truck, truck bed, or bicycle parts. The scope will not include securing bicycles to other types of vehicles. This scope will not include a manual.

1.5 Timeline

This project will commence on the 27th of October, 2017 and is scheduled to be completed by the 11th of May, 2018. Extra time has been allotted for each task as contingencies may arise that slow the overall progress of the project. An in depth look at the project schedule can be viewed on the teams Gantt chart found in Appendix B.1.

1.6 Budget

This project has been broken down into four sections regarding the budget. The planning and management section, design services, manufacturing and testing. Including wages, the team estimates that the entire project will cost roughly \$6000 with BCIT supplying up to \$1000 for materials and off-shelf components.

Chapter 2 Detailed Description of the Current Status

2.1 Product Background

After doing market research, the team found a variety of conventional methods as well as several patents on existing designs. While some designs have been well refined, the team believes this technology still has room for improvement. This section outlines competitor products and patents.

2.1.1 Market Research

By analyzing the current market, a better understanding of the different solutions for our problem can be understood and utilized to design a better product. The next section of this report will include information and criticism of five different commonly used methods in the market to transport bicycles by way of truck. These methods are as follows:

- Rigid frame
- Fork attachment rack
- Parallel hitch rack
- Three-point mechanism
- Strap support

Rigid Frame

The rigid frame is a system of mechanical links joined together to provide support for the bicycle load. For this method, the structural members are often permanently joined to the members that hold the bicycles. This method is beneficial as the user can quickly place their bicycles into the frame. Some frames, as seen by the KURUK Bike Rack shown in Figure 0-1 **Error! Reference source not found.**, have a staggered configuration. This allows the user to load several bikes without their handle bars interfering. Unfortunately, this system also has many drawbacks. The frame manufacturing is very weld intensive. The Frame may be excessively heavy making it difficult to install and remove. The frame is off fixed dimensions, meaning fitting different sized bikes may be difficult. Finally, the frame offers no method to hold the bicycle down other than the bicycles own weight, which means they may rattle when being transported.



Figure 0-1 Rigid Frame

https://c1.iggcdn.com/indiegogo-media-prod-cld/image/upload/c_limit,w_695/v1447599157/t31c2k6tcbyupdtrhnjx.png

Fork Attachment Rack

The fork attachment rack generally uses a load bar that goes across the bed of the truck. Mounted on the bar are modular attachments that allow the user to secure the forks of the bicycle. This system has high stability relative to other systems as the bikes are fastened to the rack system. In order to attach the forks however, the user must remove the front tire from each bike. This drastically increases the mounting time of each bicycle. Additionally, the forks are mounted parallel to each other making it difficult to carry several bicycles without the handle bars interfering with one another. Additionally, this system is relatively expensive. This system is shown in <https://www.thule.com/en-us/ca/bike-rack/truck-bed-bike-racks>

Figure 0-2.



<https://www.thule.com/en-us/ca/bike-rack/truck-bed-bike-racks>
Figure 0-2 - Thule Truck Bed Rider

Parallel Hitch Rack

The parallel hitch rack attaches to the hitch of an automobile. It is beneficial as the user does not have to physically get in and out of the truck to load their bicycles. Different products utilize different mechanisms to secure the bicycles. A popular style is to have the bicycle rest upright in a trough with some links or straps that secure the bike. This is seen by the Doubletrack Pro Hitch Mount Bike Rack in <https://www.carid.com/thule/thule-doubletrack-hitch-bike-rack-63099052.html>

Figure . Generally this system only allows the user to carry two bicycles. There are systems that allow for four bicycles to be transported, but they often put tremendous stress on the vehicles trailer hitch. This does open up the possibility of damage to either the vehicle or the bicycles. There are similar systems that do not attach to the hitch, but rather the rear door of family SUVs. These systems don't offer the same strength that the trailer hitch does, as well they remove access to the trunk. Finally, these systems remove the possibility of the user carrying a trailer.



<https://www.carid.com/thule/thule-doubletrack-hitch-bike-rack-63099052.html>

Figure 0-3 - Doubletrack Pro Hitch Mount Bike Rack

Three Point Mechanism

The three point mechanism works just as it sounds. It connects to three points on a bicycles tire effectively removing all degrees of freedom. Due to the customizability of these systems, there are a wide variety of products that use the three point mechanism available. These systems are generally modular and lightweight. This makes them easier to install. These systems are also easy to use. The user loads the bicycle and secures the bike with some quick latch mechanism or with a strap or tether. While these systems are both secure and convenient, these systems are costly. Two popular products are the Ride 88, shown in <http://reviews.mtbr.com/wp-content/uploads/2017/06/Ride-88-Bike-Rack-2-bike-setup.jpg>

Figure , and the Thule Insta-Gater shown in

https://www.autoaccessoriesgarage.com/img/group/main/29/2926_1_md.jpg

Figure .



<http://reviews.mtbr.com/wp-content/uploads/2017/06/Ride-88-Bike-Rack-2-bike-setup.jpg>

Figure 0-4



https://www.autoaccessoriesgarage.com/img/group/main/29/2926_1_md.jpg
Figure 0-5

2.1.2 Patents

The following section outlines several patents that hold relevance to the project. By drawing on several patents it is possible to gain information about products currently available on the market. Additionally, the team will be able to avoid recreating a system that has already been invented. Finally, each patent that follows makes use of special mechanisms and clever designs. By combining several different ideas, it may be possible to design a superior product.

Bicycle Carrier

The bicycle carrier patent [1] outlines the mechanisms to hold down a bicycle on the top a roof rack, and can be seen in Figure 0-6. The patent goes into detail about the front wheel mechanism that secures the forks, and the rear wheel strap that secures the back wheel. Together the front mechanism and the rear mechanism create a stable method for securing a bicycle.

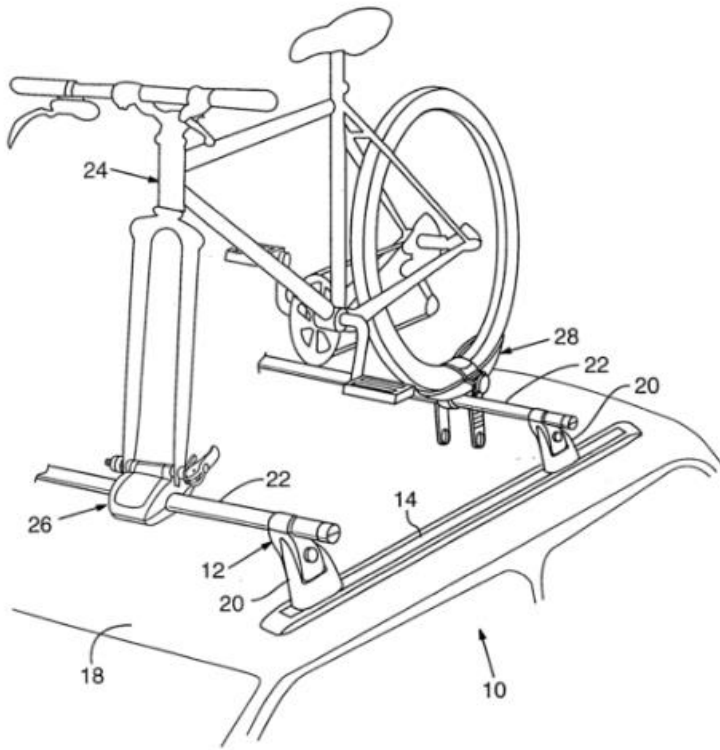


Figure 0-6 - Bicycle Carrier

Pickup bed racks for bicycles and methods

The Pickup bed racks for bicycles and methods patent [2] outlines methods to secure several bikes by a fork attachment rack and can be seen in Figure 0-7. This patent includes attachment points mounted on an angle to allow for more bikes to fit without handle bar interference.

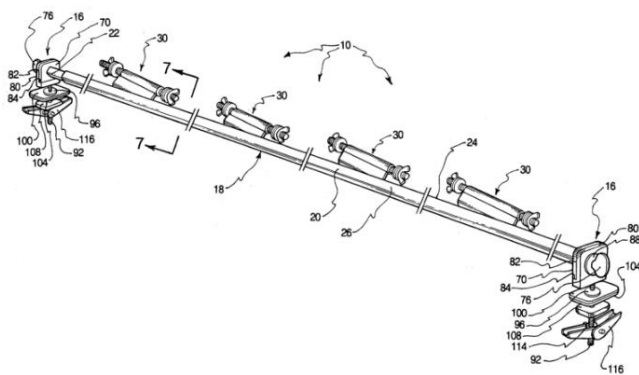


Figure 0-7 - Pickup Bed Racks

Bicycle Rack for a Vehicle Bed Patent

The Bicycle Rack for a Vehicle Bed patent [3] includes the method and arrangement for a bicycle transportation system and can be seen in Figure . This system describes the ability to store bicycles without modifications to the truck. It includes details of the mechanisms used to restrain and engage the bicycle. The patent continues by including detailed instructions of how the device is deployed.

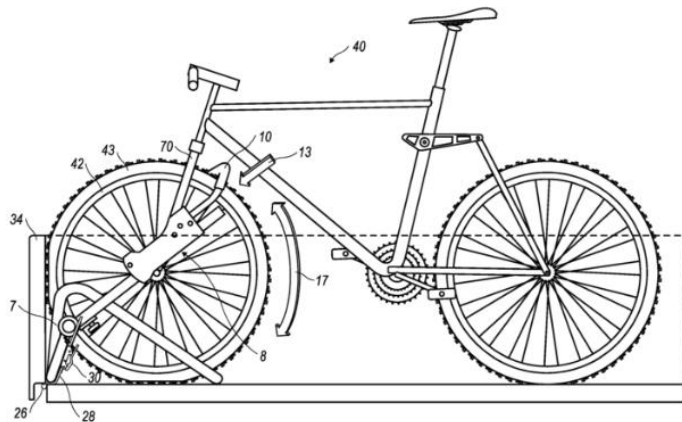


Figure 0-8 - Bicycle Rack for a Vehicle Bed

Bicycle Transport Rack

The Bicycle Transport Rack patent [4], shown in Figure 0-9, describes the installation and workings of a bicycle carrier rack. The patent describes how the static system utilizes a cross member with connecting member to encompass bicycle tires. The system makes use of square cross bars that are secured into truck bed side extenders.

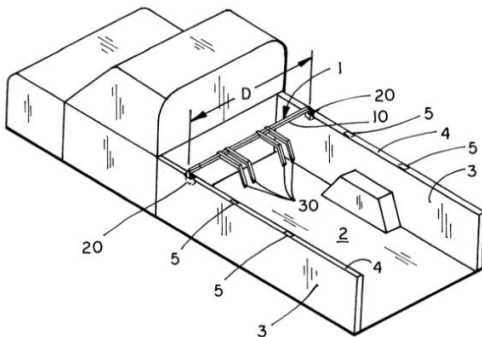


Figure 0-9 - Bicycle Transport Rack

Bicycle Carrier for Motor Vehicles

The Bicycle Carrier for Motor Vehicles patent, shown in Figure , outlines the details of a bicycle carrier mounted on a vehicles trailer hitch. The system makes use of a special clamping device to grip the bicycle tires. The system makes use of a padlock for added security. The system uses bendable sheet metal panels that are drawn together to frictionally engage the bicycle wheels.

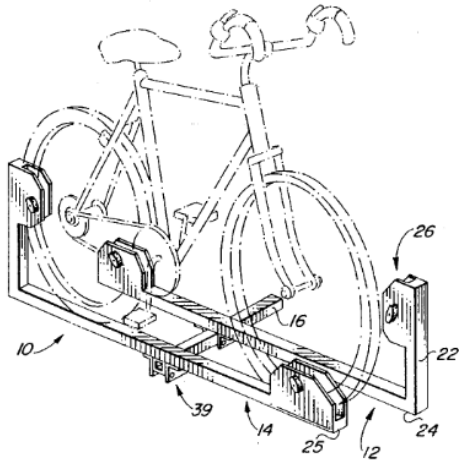


Figure 0-10 - Bicycle Carrier for Motor Vehicles

Chapter 3 Theoretical Background

3.1 Contact Points

In order to secure a bike wheel completely it will need at least three points of contact to constrain it. It was suggested by the project sponsor that this method is the best mode to secure the bike to prevent damaging the frame. The three contact points should exhibit inward forces that sum to zero through some focal point. This concept is shown in Figure . For a bicycle tire, the center of the wheel makes a convenient focal point. There are other possible orientation, but this is the simplest method. The profile of the contact points also need to encase the width of the tire because there is possibility of the tire slipping out of those points. With the front tire secured the back tire can also be secured with one addition contact point to completely fix the entire bike. This fourth contact may not be entirely necessary though because of the weight of the bike and the grip of the back tire will keep it from sliding around. The focus of the design will be on securing the front tire as it is the most important function of our design.

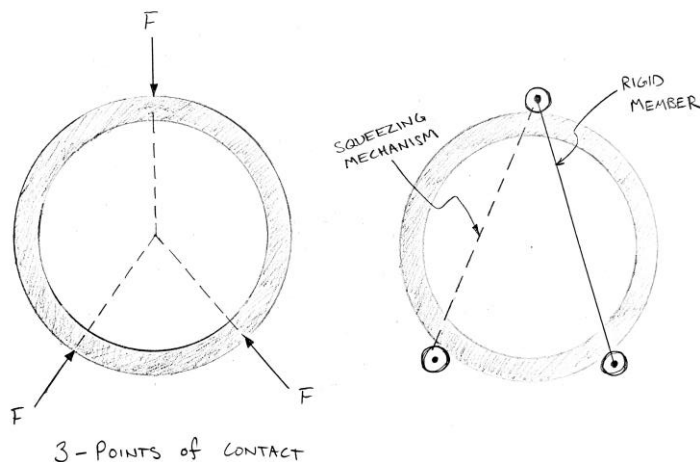


Figure 0-1: Front and Back Tire Contact Points

3.2 Concept Generation

The team went about to design different methods of securing the front wheel and came up with several ideas which follows:

- Collar and Rod
- Strap and V-Block
- Raised Hook
- Foot Pedal

3.2.1 Concept 1

Collar and Rod

The concept sketch shown in Figure 0-1 shows a method that incorporates the required three points of contact and is adjustable. It consists of one hand operated rod with a collar that slides down its length. By moving the rod upward the collar is forced downward due to the shorter length rod it is attached to. Once it comes in contact with the wheel it will clamp the tire pushing into the other two contact points. The two contact points are also connected by a rod that contains and swivel block that is adjustable in terms of its height and angle, which would be able to account for different size tires. The points that come in contact with the tire would also have some way of encompassing the tire which would adequately secure it.

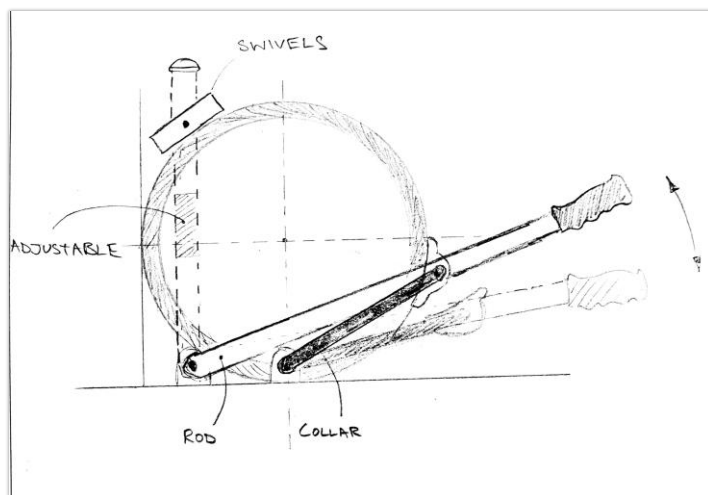


Figure 0-1: Collar and Rod Concept

3.2.2 Concept 2

V-Block

This second method is by use of an adjustable strap. The strap loops around the back of the tire and hooks to the other side. The strap can then be tightened in order to compress the tire into the two v-blocks. These v-blocks support the tire as well as position it to the center of the block. This prevents the tire from slipping out of the strap when forced. This is a modular system which can have several units placed along the length of the square tubing. Ideally you would be able to fit as many units as you want along the truck bed and you could vary their spacing depending on the width of the bike.

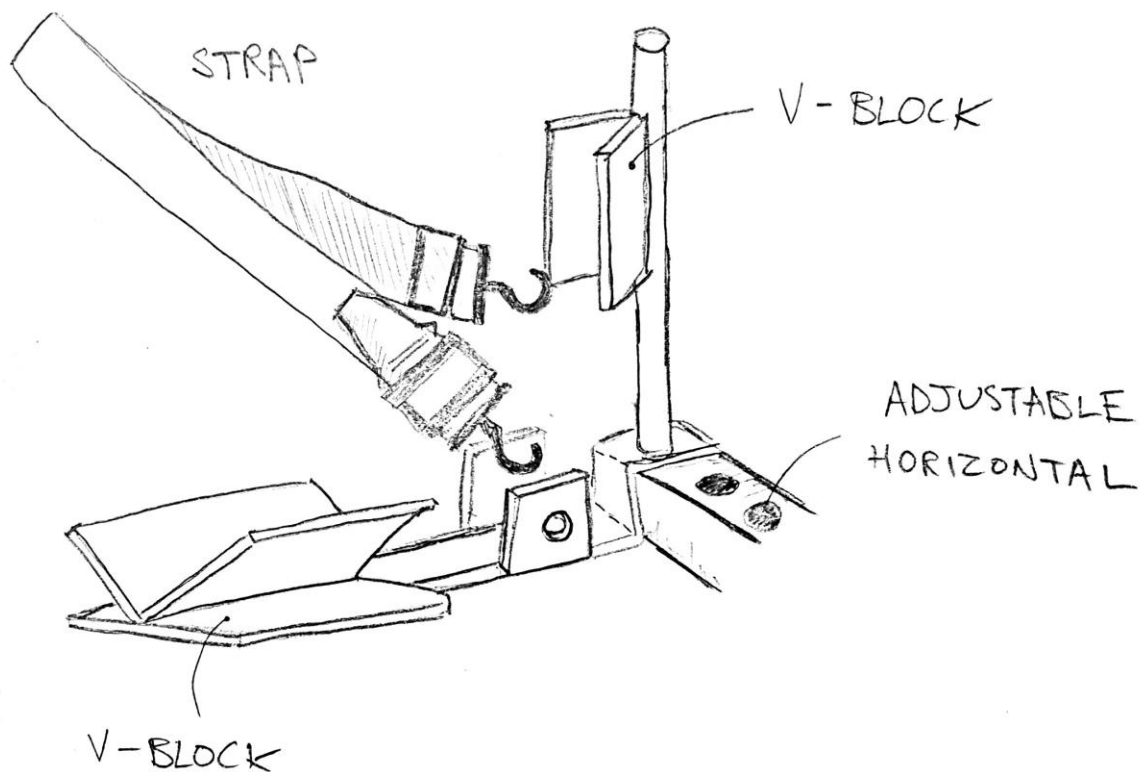


Figure 0-2: Strap and V-Block Concept

3.2.3 Concept 3

Raised Hook

This concept again used three points of contact orientated so the forces act through the middle of the wheel. The concept consists of a hook that wraps around the wheel and is spring loaded to force the tire against its other contact points. Attached to the hook is a graspable handle which makes it easier to move the hook over the tire. The other points of contact are due to the scoop that encompasses the tire and prevents it from sliding around. Another interesting point of this design is that it is raised to the top of the truck bed. This allows for the use of front fenders illustrated in Figure 0-3. Since the bike is positioned at the angle the fender will turn away from the hook, allowing the hook to clamp on a higher point on the tire. By raising the system to the top of the truck bed the horizontal length of the bike is shortened which could allow it to fit into small truck beds. This effect can be shown in Figure 0-4.

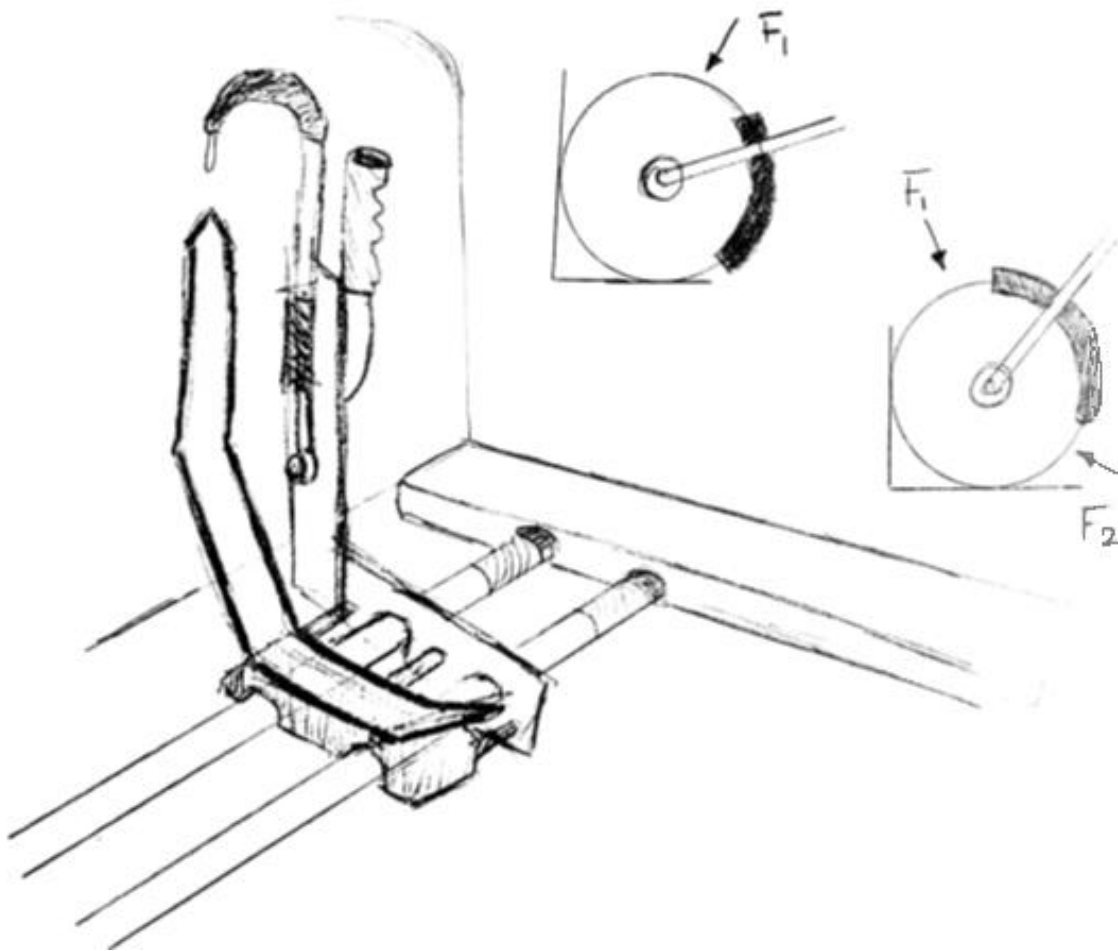


Figure 0-3: Raised Hook Concept

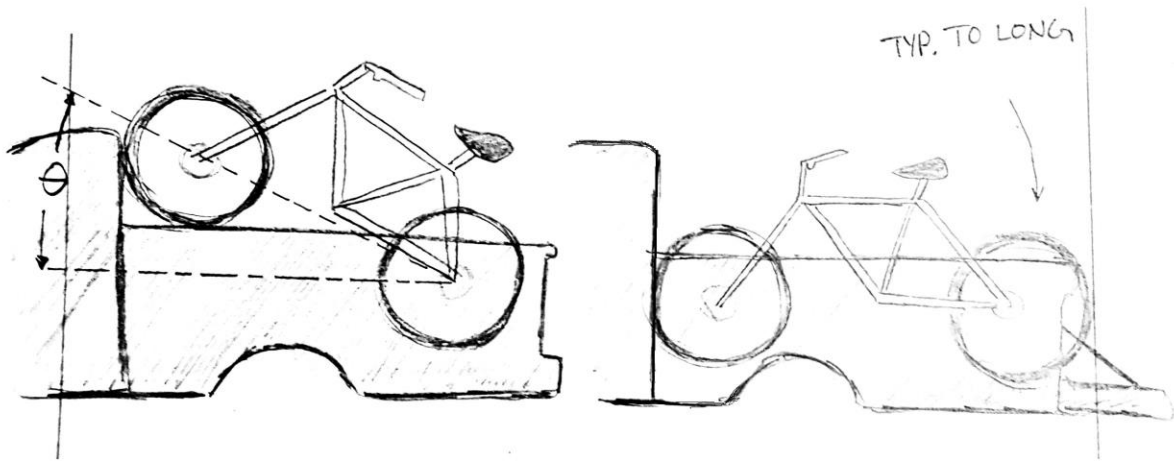


Figure 0-4: Raised Bike Concept

3.2.4 Concept 4

This concept also involves raising the bike such as the raised hook design however is different in the way it clamps the wheel. It involves using a ratchet that hooks on to the top contact point. This contact point is a tapered roller that encases the tire to keep it from moving around. The height of this roller is adjustable by being able to slide it up and down the two rods that it is connected to, which allows different size tires to be secured. These rods pivot around the second pivot point so that the bike can be easily removed from the clamp. The two bottom points of contact are V-blocks which as discussed previously are useful in positioning the wheel. These two points can also be positioned anywhere along the load bars that run across the length of the truck.

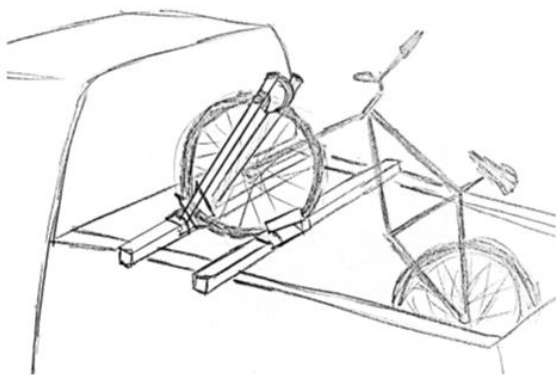


Figure 0-5: Ratchet Concept

3.3 Design Comparison and Selection

To select a final concept that would move on to development, the team decided to use a decision matrix that analyzes some of the key attributes of the design laid out at the beginning of the project. The attributes that will be looked at are modularity, cost, compactness, ease of install, and robustness. The team believes that these attributes are the most important in terms of the selection process and should eliminate weaker concepts from consideration. The decision matrix can be seen in **Error! Reference source not found.** with attributes having appropriate weightings. The team decided that modularity and robustness were the most important attributes because of requirements for the project. Robustness is a key attribute, because of the environment the device will be subjected to. Vibration and weather conditions will all be a major concern as the system will be in these conditions frequently. Modularity was also a highly weighted attribute because of the requirements of the project.

Table 1 Decision Matrix Concept Selection

Importance	29%	14%	14%	14%	29%	100%
Option	Modular	Cost	Compact	Ease of Install	Robust	Score
Collar & Rod	30	50	50	40	50	43
V-Block & Strap	70	70	70	70	40	61
Raised Hook	60	40	80	50	70	61
Ratchet	70	40	60	70	80	67

After the team set the importance of the attributes, each attribute was given a score between 0-100 that evaluated the level at which the given concept met that attribute. When looking at the Collar and Rod concept we can see that it fell short in many of the categories such as modularity, ease of install and robustness. The team ranked it low in modularity because of the difficulty in designing the concept into removable units, which was the major factor that eliminated it from the selection. The V-Block & Strap design did very well in most categories except in terms of robustness. It received a low ranking here because of the strap the loops around the back of the tire. This system would lack the necessary rigidity to keep the bike from swaying and that the clamping force it needed would not be enough to keep it

from moving. The Raised Hook concept excelled in the categories of compactness, robustness and modularity. Its compactness is mainly attributed to having only one arm that encompasses the wheel. The cost aspect suffered because it is a raised system, which requires additional costly parts to raise it up.

The final concept which is our selected concept is the ratchet design. It obtained the highest overall score compared to the rest of the concepts and did well within our decision matrix. It received a high score in robustness as the two arms encompass the wheel, which prevents the wheel from swaying and provide more rigidity than the other concepts. Since they are separate units, the system is also very modular and can be easily installed. It falls short is in terms of the cost however as it is a raised system. By raising the system however, we can have access to more storage space in the back of the truck along with the ability to secure wheels with fenders around them. This ended the concept generation phase of the project and the team moved forward with design and manufacturing.

Chapter 4 Description of Project Activity

The section outlines different aspects of the project activities. Project management tools used to guide the course of the project can be found in Appendix B. Additionally, this section describes the alpha prototype, as well as changes made to create the beta prototype.

4.1 Evolution of Design

Once the concept was selected, the team began to explore different mechanisms to accomplish the desired function, as well as do the design calculations to size the different components.

Due to the concept selected, the team would need a minimum of two transverse members to secure the bottom two points of contact on the wheel and allow the attachment of some type of ratcheting mechanism to secure the top of the wheel (and third point of contact). This first design decision was whether to use a frame system or two load bars. A simplified sketch is shown below in Figure 0-1.

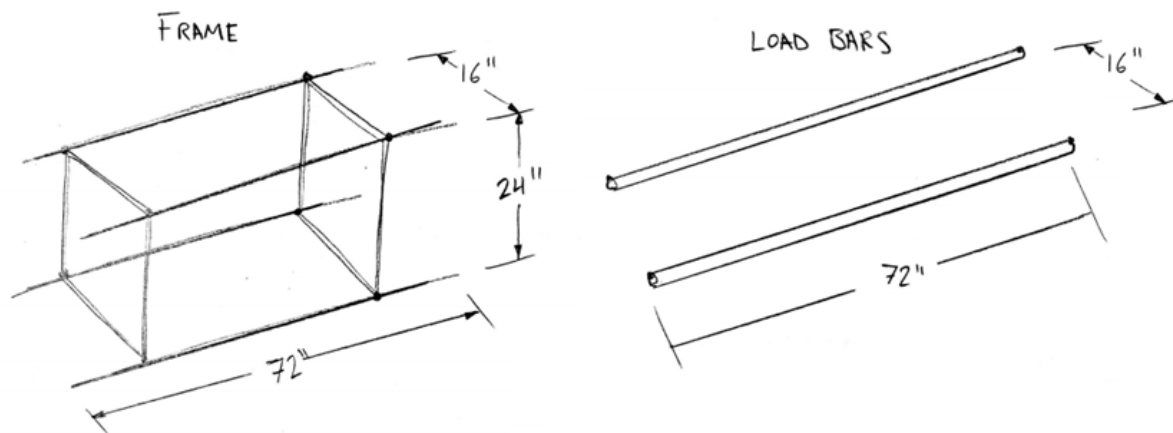


Figure 0-1 - Frame versus Load Bar

While the frame has the benefits of being a single piece, easy installation and no modifications to the truck, the frame would weigh over three times that of the load bars. Additionally, there would be added cost to join all the bars together through welding or fasteners. The team agreed that the load bars would be more suitable and began to do calculations to size them. It should be noted that at this point the team had tentatively decided to use t-slotted bars for convenience but agreed that this may change based on further development of the TBBR module.

The design calculations were done to ensure that the load bars could hold the target goal of five bicycles. Several assumptions were made to ensure a suitable factor of safety and to account for increased loading due to vibration while driving. The assumptions are as follows:

- The entire weight of each bicycle is experienced on one bar
- The bar is carrying five bicycles
- The bar is a T-slotted bar
- The combined weight of the TBBR modules and bikes is 60 lbs. each.

These calculations can be found in Appendix B.2 and are summed up in Figure 0-2. Under the worst possible conditions, a bar sized for 1.50" would not fail. The team analyzed smaller sizes, but as the surface area of the bar gets smaller the base of the ratchetting mechanism would have less contact surface area with the bar. This might promote other issues.

$$\sigma = \frac{M_c}{I} = \frac{(2320)(0.75)}{(0.2542)} = 6845 \text{ psi}$$
$$n = \frac{\sigma_y}{\sigma} = \frac{35 \text{ ksi}}{6.8 \text{ ksi}} = 5.11$$

****With entire load at center: $n = 2.36$**

Figure 0-2 - Design Calculations

With the bar selected, the team began to design the form of the TBBR module. Both round shafts and square shafts were considered to see if any single design stood out among the rest.

The team first examined using a round shaft. There were several difficulties arising after the first conception. Figure 0-3 shows the initial concept. Firstly, it was agreed the entire shaft would have to have a fine tolerance to achieve a smooth rotation from the module. Secondly, the modules would have to be installed onto the shaft before the shaft was installed into the truck. As many of the arms rotate and the shaft would become increasingly heavy with each module, this would make installation difficult and inconvenient. Thirdly, many of the parts of this concept would have to be custom made, which would drastically increase the cost per unit.

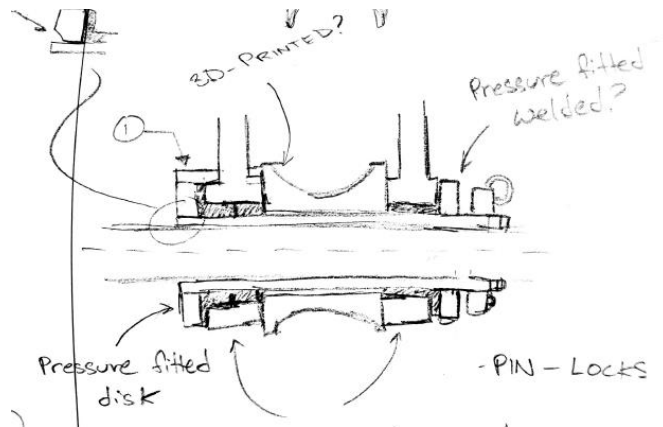


Figure 0-3 - TBBR Module on a Round Shaft

The team then continued by examining the square shaft and quickly noticed many advantages. A rough sketch can be seen below in Figure 0-4. Firstly, the square shaft has the advantage of being orientated easily. The user can simply attach any module quickly and conveniently. Secondly, the user can install the modules after the load bars have been placed into the truck. This makes installation much easier on the user. And thirdly, this system has far less parts with less complex features. This would help drive down the cost of manufacturing per unit. The team decided to use square shafts for the load bars.

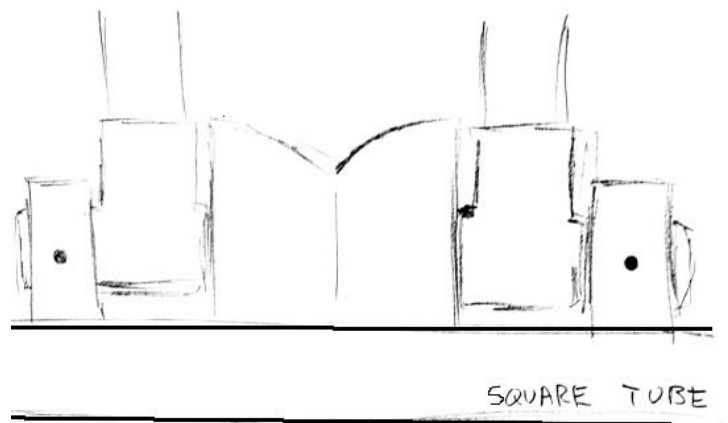


Figure 0-4 - TBBR Module on a Square Shaft

Moving forward, the team decided to model a rough version of the TBBR system to get a better understanding of the physical system so far. The first draft of the model is shown below in Figure 0-5. For convenience, the team decided to use a t-slotted aluminum bar for easy attachments and mounting. It was decided to use v-blocks as a base for the modules as the 'v' shape helps wedge and secure many different sizes of bicycle wheels easily. The team made use of off-shelf tube fittings found from McMaster-Carr to allow the front assembly arms to swivel and as a connection point to the roller. These parts would help reduce cost and simplify manufacturing. Next, a roller would be installed at the top of the front assembly arms to allow the user to easily place the roller onto the tire. This roller would be installed at the top of the front assembly by two connecting rods. The team considered using telescoping arms, but this concept would increase cost and increase complexity. Finally, the team modelled a custom-made clamp to attach the load bars to the truck bed lip. It should be noted that the system shown below does not include the mechanism that would effectively force the roller into the top of the bike wheel. The team, at this point, was still exploring different solutions.

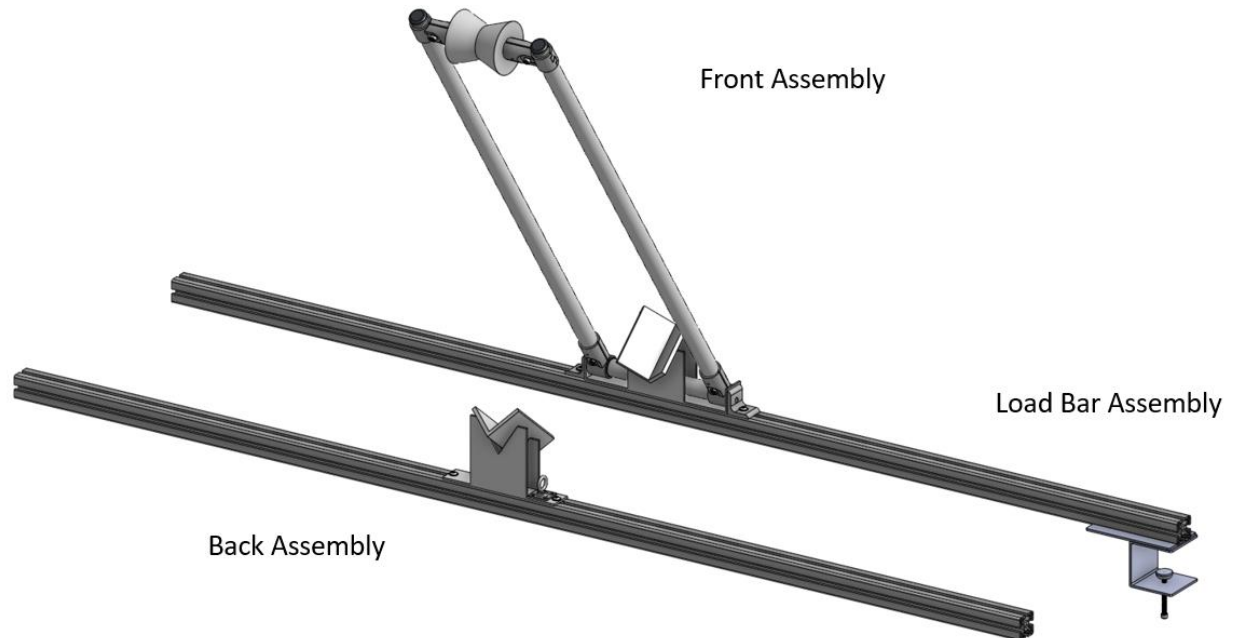


Figure 0-5 - First Draft Model of TBBR

After analyzing many different solutions to pull the front assembly down into the top of the tire, the team arrived at two final solutions. The tie-down solution and the wench solution are shown below in Figure 0-6. While the winch system did have the advantage of pulling the roller evenly on two sides, winch systems are relatively expensive when compared to tie-downs. The team could not justify the added cost. Additionally, it was agreed that the winch system was excessive for this application. The tie down system would be used for its low cost and simplicity.

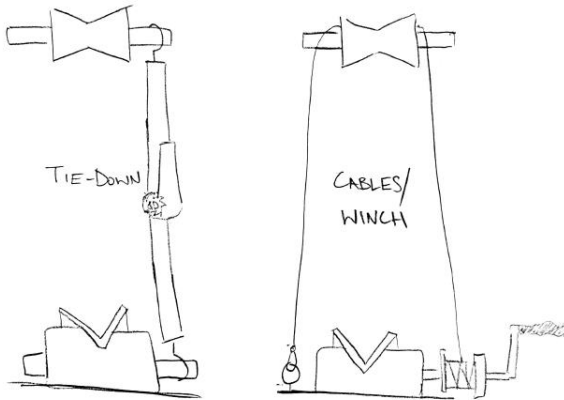


Figure 0-6 - Tie-Down and Winch System

Before manufacturing, the team ran through each component and discussed how each part would be made and if anything was overlooked. It was agreed that the load bar attachment clamp could be refined and that the v-block base, shown in Figure 0-7, would be both difficult to manufacture and expensive to fabricate as the current design included welding, bending and pressure fitting.

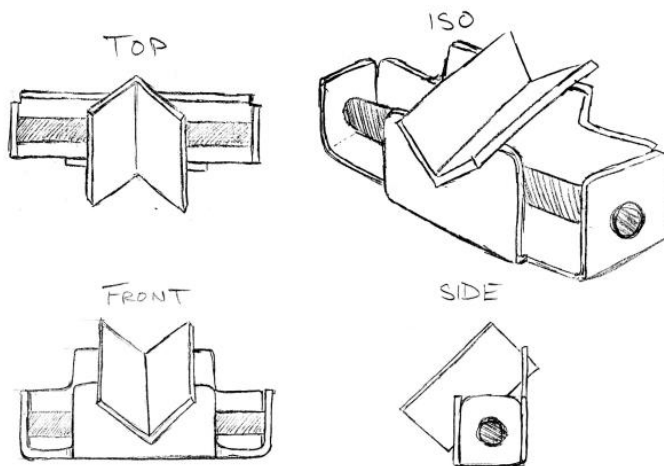


Figure 0-7 - V-block Design

After many different sketches and discussion, the team modelled a new front assembly. The assembly can be seen in Figure 0-8. The redesign replaced the v-block design with a 3D printed wheel chuck and spacers to center it. Additionally, instead of having a complicated frame, this system makes use of a center shaft that carries and joins all the parts.

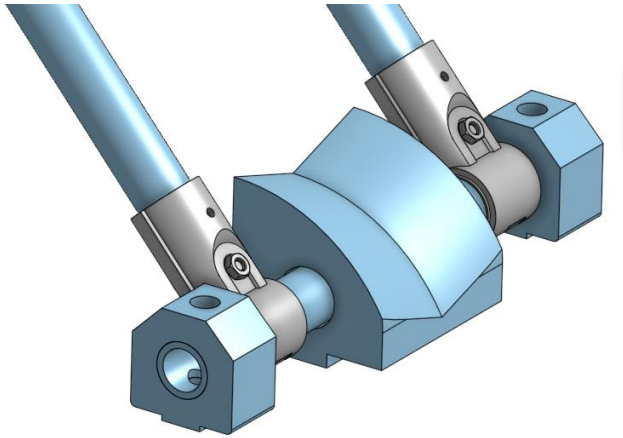


Figure 0-8 - Front Assembly Redesign

4.2 Ordering and Materials

Over the course of the project, there were two occasions where parts were ordered to build the alpha prototype. All parts ordered can be found on the Capstone Project Purchase Requisition forms found in Appendix B.6. All other parts were manufactured in the BCIT, Burnaby campus, mechanical machine shop located in SW9. All fabricated materials were then chosen by availability.

After tallying our ordered parts cost and the cost of materials taken from the BCIT stock room, it was estimated that the project would cost around \$132.27 for the load bars and truck clamps and an additional \$105.98 for each TBBR module. Therefore, for a five-bike system (our target goal), this system would cost roughly \$662.17. A cost estimate for the first round of ordering can be found in Appendix C.4

4.3 Alpha Prototype

The alpha prototype of the project was completed on April 9th, 2018 and can be seen in

. While the alpha prototype functioned better than expected, there were several undeniable issues. The most immediate concern was the lack of rigidity in the upper assembly and joining arms. When

subjected to vibrational motion or twisting, the two joining arms would rotate and pivot, which in turn would distort the upper assembly. It was quickly discovered that the tube connectors from McMaster-Carr were not suitable for our application and did not hold very tight tolerances (see Figure 0-2). This made assembly frustrating as the inner tube would slip out on one side when the user was trying to tighten the other.



Figure 0-1 Alpha Prototype



Figure 0-2 Roller Assembly

Furthermore, the rear assembly plate's sheet metal was too thin. Upon tightening one could see large distortions in the plate as shown in Figure 0-3. Other concerns included: the lack of a resting position when the bars were up or when the bars were down, and a way to hold the bars down when not in use. Despite all its defects, the ratcheting method put out a high clamping force, the roller was easily positioned, and the bike was relatively secure. Nevertheless, the team began to modify parts and do some redesign to iron out some of the issues.



Figure 0-3 - Bent Plate

4.4 Beta Prototype

The team's first action was to attempt to make the top assembly more rigid. This would increase the strength of the system as well as put a more even load on the bike tire. The first correction was putting a screw through the swivel Tee's into the connecting rods. This screw prevents the joining arms from rotating within the swivel Tee's. This is shown in Figure 0-1.



Figure 0-1 Securing Screw

Next, the current roller system had to be changed as the McMaster-Carr closed Tee's were unusable. They allowed the roller shaft to pivot and rotate. More brainstorming was conducted and two new ideas were tried and tested: The two-halves rigid aluminum bar and the aluminum clamp.

The two-halves rigid aluminum bar is shown below in Figure 0-2. This waterjet cut part featured two socket head screws placed in countersunk holes that were fastened through a thru hole on one half into a threaded hole on the other half. This component proved to create a strong connection and removed nearly all twisting motion. Its downfall however, was that it had no surface to grip a tire and the edge of the part would simply pull the tire away from one of the three wheel supports. This meant that the wheel was no longer fully constrained and could swivel against the other two supports. Before excessive modifications, the team manufactured the aluminum clamp to test it against the other two parts.

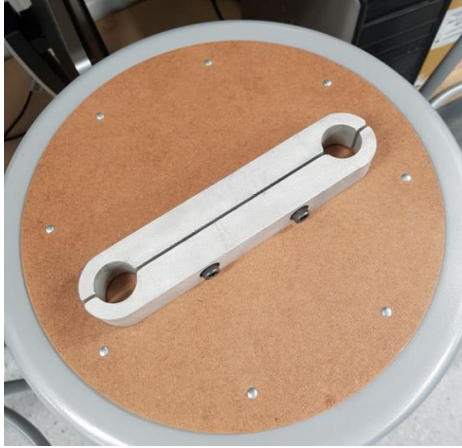


Figure 0-2 The two-halves rigid aluminum bar

The aluminum clamp, shown in Figure 0-3, features a grooved center. This groove is flat steps at depths of 0.010". The groove provides two points for the tire to rest and the steps provide grip to prevent the wheel from sliding. The end points have a slit and are clamped together with bolts and nuts. This clamps the aluminum bar to the joining rods. While this part had a part feature to locate and secure the wheel both parts had the same issue of pulling the tire away from one of the wheel supports. Because both these parts do not use a roller, the force is not normal to the wheel, but relatively tangent to the wheel. This violates the three points of contact theory and no longer fully restrains the wheel.



Figure 0-3 The Aluminum Clamp

The team concluded that the new solution would be some combination of the original roller design and the aluminum clamp design. With the roller the team would be able to successfully clamp the wheel, and with the aluminum clamp the team would get relatively rigid system, which would help prevent twisting and distortion of the upper frame. The new design after manufacturing is shown in Figure 0-4.



Figure 0-4 New Design

Other changes included redesigning the rear chuck. The original design was modified with grooves to allow a rest position for the connecting rods. This can be seen in Figure 0-5.

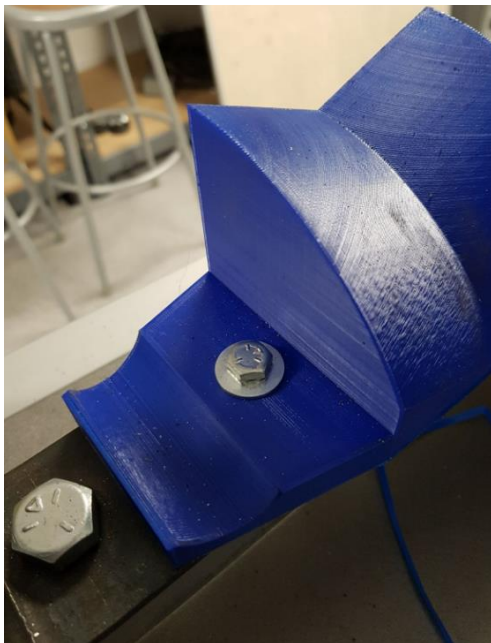


Figure 0-5 Redesign of Wheel Chuck

This design at this point however did not feature any method securing the connecting rods. This meant that on bumpy roads the connecting rods would rattle and hit the rear wheel chuck. This could cause damage over time and another solution had to be created. The team began by creating a small clip that would be pulled over one of the rods to secure it. This can be seen in Figure 0-6. This clip however was easily bendable and would wear out quickly from large vibrations.



Figure 0-6 Securing Clip

Another issue the team continued to have at this point was an open position that was easily accessible and did not run the risk of dropping the connecting rods into the back of the cab of the truck. This issue combined with inability to secure the system in a rest position was solved with the introduction of linkage shown in Figure 0-7. This linkage features a groove that can be connected to by the ratchet tether hook, but also features a flat face to rest against the cab in its open position.



Figure 0-7 - Rigidity Bar

Chapter 5 Discussion of Results

5.1 Project Results

The final version of the TBBR was successfully able to secure a bicycle tire. The clamping force from the ratchet is large, which should prevent excessive movement caused from driving. The wheel chucks large surface area can distribute the pressure created from the wheels without cracking. The welded linking bar allows a connection point for the ratchet hook so that the user does not need to move the hook from the open or closed position. The connecting rods move easily but with enough friction to prevent the bars from swinging freely. This will help prevent accidental contact against the truck cab, or from the rods crashing down into the lower assembly, which could cause cracking in the 3D printed parts.

The final design for this project of the TBBR can be seen in Figure 0-1 and Figure 0-2.



Figure 0-1 Final Design Clamped

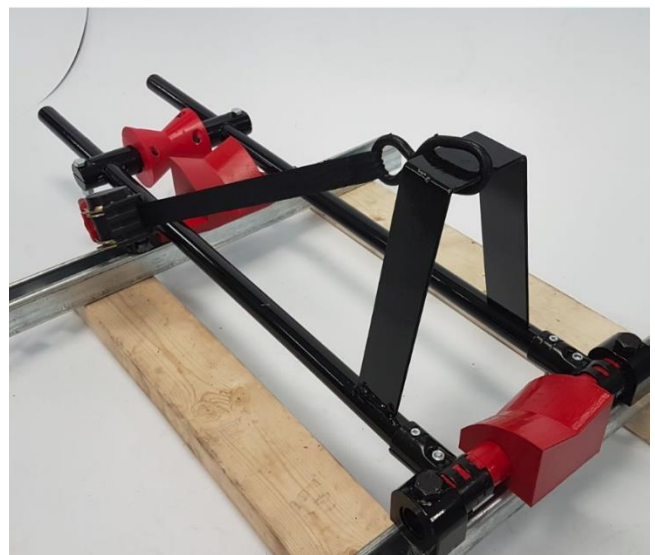


Figure 0-2 Final Design Unclamped

5.2 Manufacturing Challenges

As our prototyping was developed many issues arose from the team's inexperience in the shop and led to difficulties in manufacturing. Most of these challenges can be associated with lack of knowledge of machines and certain manufacturing processes.

Initially, in the first design the team developed there was a large amount of manufacturing that had to be done to build a prototype. This included bending, welding and drilling for only one part. This presented many challenges, with a significant emphasis on welding aluminum parts. There was also concerns with the tolerance the team would get from bending certain parts, which ultimately led the team to alter the design.

With the design changes the team switched to 3D printing for some of the components which presented its own difficulties. One of the team members had issues with his personal 3D printer which ruined certain prints resulting in the need to reprint several times, which was time consuming. Some of the failed prints can be seen in Figure 0-1.

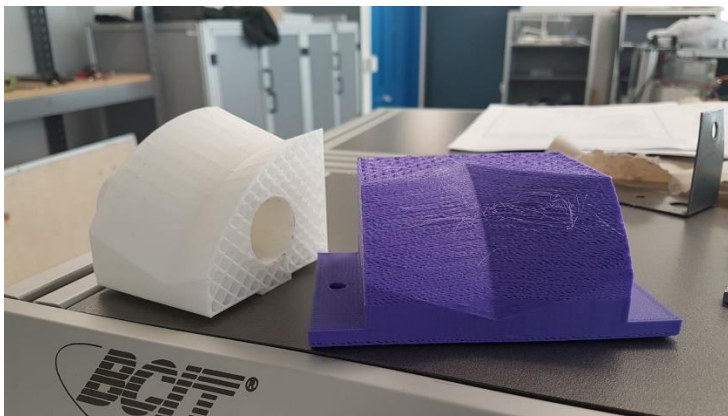


Figure 0-1: 3D Printer Mis-Prints

The milling machine also presented difficulties as the team had little to no experience using it. The team was not familiar with the machine but needed it to manufacture certain parts. Using the milling machine required the help from teachers who weren't always available. This created a lot of down time for the team, until proper instruction was available. As the project continued, the team developed the necessary skills to do several operations on the mill that allowed them to create the final upper roller shaft.

Finally, the team earlier in the project had to learn how to aluminum weld. It was quickly realized that welding the variety of aluminum parts at specific angles would be challenging and unnecessary. The team eventually changed the design several times and eventually switched to using steel parts. These were joined through MIG welding, a much easier process.

Chapter 6 Conclusion

6.1 Project Summary

The TBBR project was completed on May 9th, 2018. It spanned over a seven-month period and costed approximately \$246. This does not include the cost of labor. The project was completed on time, under budget and within the scope. All the primary project objectives were completed and are summarized below.

The device is secure. The three points of contact design secured by the ratchet mechanism offers high clamping strength, while the grooved chucks prevent damage to the wheel assuming the customer doesn't over tighten the ratchet. When being used, the system will safely and reliably secure the users bikes. Furthermore, many of the components on the device are oversized and fastened with high torque. For example, the ½" bolts connecting the TBBR module to the load bars are unnecessary large connections but are fastened tightly to create a strong connection point. This is also true of the canopy clamps, which connect the load bars to the truck. This is a commonly used method and is another strong connection point. Moreover, the linkage that joins the connecting rods is connected by 3/8" weld. It allows the connecting rods to be tightened down when not in use.

The device is easy to use. The user simply lifts the connecting arms up, which will stay in an open position, then the user positions their bike into the devices two lower chucks and lowers the connecting rod to place the third point of contact on the top of the wheel. After that, the user attaches the tether to the connecting rods and ratchets the arms down, which pulls the roller chuck into the wheel. The process for removing the bike is the reverse. Overall, the system is intuitive and requires little explanation to use.

The device is affordable. The TBBR has competitive pricing when compared to conventional products on the market (See Appendix C.3) Since a large component of the cost is the systems load bars, and that the TBBR modules are less expensive, the customer gets more value as they buy more modules.

Additionally, as high-quality bicycles can cost several hundred of dollars, the TBBR is relatively affordable in the road and mountain bike markets.

The device is modular. Each TBBR module can be placed anywhere along the load bars and each unit is independent from one another. The user may decide how many TBBR modules they need. Up to five modules may be placed and five bikes may be stored if they are of varying height.

The device is adaptable to all conventional bicycles. Due to the design of the v-design of the wheel chucks, both skinny road tires and thick mountain bikes can be secured. It should be noted however, that the three-wheel chucks are about 120 degrees apart from one another. This may mean that the user will have to remove each bikes fender if they have one.

Overall, the project was ultimately successful, but not complete. Section 6.2, Future Work, outlines several improvements that could be implemented still to improve the design.

6.2 Future Work

The team was satisfied with the overall outcome of the project but agreed that many improvements could be made to improve the TBBR system. The first being that despite the system has the potential to carry five bicycles of varying sizes, it currently cannot carry five bicycles of similar size. Therefore, the system must be altered to secure the bicycles by either holding them while the tires are slightly angled, which would remove the interference that the handlebars experience from each other or create a system that can secure bikes by varying the bikes backwards and forwards. Either of these methods would improve the value of the design.

Another improvement that could be made to the system is to join the many different parts of the lower front assembly into one single part. As it is now, the assembly is made up of several parts with tight tolerances making it difficult and slow to assemble. A new box or housing could be designed to hold all the necessary parts, which would make assembling the system easier and faster. Furthermore, the swivel tees fastened to the connecting rods should be redesigned. These parts were relatively loose when compared to their specifications. A different method of joining the connecting rods to the lower front assembly would create a stiffer system and cause less issues. Furthermore, the upper roller could also be consolidated into one part with no hardware. This would also mean redesigning the upper roller shaft. Therefore, it was agreed that this redesign would take considerably more thought.

The ratchet system currently works well, however as it is only effectively pulling one side of the system. The team is concerned that over many cycles of use the torsional stress may begin to wear the supports and the upper roller system. By redesigning the ratchet in some way to either pull from the center, or pull equally on both sides of the unit, the TBBR modules would be able to secure the bike more evenly. This could promote a longer life for the product. Meanwhile, the base chuck plate is currently an L-bracket and a mounted 3D printed wheel chuck. The L-bracket design is effective but relatively ugly and unfinished looking. In terms of a finished product it does not feel refined. The L-bracket could be replaced with a new housing that also fulfills a second attachment point the ratchet tether. This would be a major redesign as two of the three main assemblies would undergo large design changes.

6.3 Lessons Learned

The following section outlines the lessons learned by team members Mark Deleeuw and Logan Wicks.

Mark Deleeuw

During this project I learned the complications that can arise during manufacturing due to unforeseen design issues. Some of the key functional components in the design changed as we progressed in the prototyping stage. This made me come to the realization that manufacturers and designers should work hand in hand to create the product. Each can contribute their own ideas for the design that apply to their particular field in order to arrive at the best selected design. Since both Logan and I were the primary manufacturers of the prototype most of the initial design was tailored to what manufacturing processes we actually knew how to do. So the incorporation of an additional team member with advanced manufacturing experience would have been very beneficial for the outcome of the project.

During this project I also became familiar with the process of 3D printing and powder coating. It was the first time I used 3D printing in a project which showed me the potential it has for rapid prototyping and ability for it to easily create complex components. I plan on using a 3D printer for my own projects in the future. It was good to have an introduction to them. Additionally I learned about the powder coating process and how to powder coat components.

Another lesson I learned was the importance of time management for this project. Since this capstone project runs on top of other courses it can be hard to divide our time for each class in order to have

enough energy devoted to each. Unfortunately, I also struggled to manage my time my time in my personal life that took away from doing the capstone to the best of my ability. In the future I do not think this will be a problem because their will hopefully be a more defined difference between my work and my outside life, however, this still applies to having multiple projects at work at the same time and being able to devote adequate time for each.

Logan Wicks

Over the course of this project, I learned many lessons about design, manufacturing and managing a small team. The design process for this project featured many brainstorming sessions and many failed prototypes. I found that sitting down with a pencil and paper was a great way to create different concepts and methods to solve our solution, but I also found that in doing this it became easy to overlook potential issues. It wasn't until the prototyping phase that we found many problems with our plans and design. These issues included unreasonably high tolerances, poor fits, difficulties in assembly, too much hardware and more. While more consideration at the design table would help remedy many of these issues, prototyping was the fastest way to understand where the biggest improvements could happen.

In terms of manufacturing, the lessons were invaluable. Despite his busy schedule, Dave Lewis had the time to teach me how the milling machine works. This was instrumental in the success of our project as our upper roller shaft could not be manufactured without the milling machine. During his training, he showed me a variety of tools (including the side cutter), how to insert and remove tools, how to adjust the speed of the machine and how to use the automatic controls to increase the speed and accuracy of the job. Learning how to use the milling machine made me understand the equipment's value. This machine has the ability to do several operations at one station and would be useful information when designing machined parts in the future. Furthermore, I had to relearn how to MIG weld. A particularly useful operation for joining parts. During my practice, I forgot to turn on the protective gas. I quickly learned how important it is to achieve a high-quality weld.

Finally, during my second-year capstone project I was the project manager in a group of four students. For this project however, we only had a group of two. This meant I was unable to delegate in the way that I had previously, but rather I had to take on a large amount of the design and manufacturing work

myself. This made it increasingly difficult to use project management tools to help guide the direction of the project. Our organization and planning suffered greatly due to this. Therefore, I learned for smaller teams it is important to remember the project managers role and necessity for guiding the project to success.

Appendix A. Request for Proposal

Request for Proposal

Bike Truck Rack

October 17, 2017

Issued by:

McMillian's Bikes Co.

McMillan's Bike Co. Representatives:
Logan Wicks and Mark Deleeuw

1. Background

McMillan's Bike Co. is a manufacturer of high performance bicycles, bike components and miscellaneous bike-related equipment. Our team is dedicated to delivering quality parts for both off-road and on-road bike parts. We are currently in need of a design team to design and build a prototype for our next project, the truck bed bike rack.

The idea for this project arose through interaction of our customer surveys. We found many customers were not satisfied with conventional methods and modern equipment to transport multiple bikes from one location to the next. The focus of this project will be to design a bike rack that accomplishes this while meeting all the design requirements. Some of these requirements are outlined below, however it is our expectation that the successful bidder keeps McMillan's Bike Co. involved with the project through the duration of the project.

2. Scope

The design for this project will be focused entirely on the proposed truck bed bike rack. The bike rack will include features to mount the bike rack to the bed of a truck. This project does not include any modifications or design work to the truck bed or to the bikes in which this system will be used upon. The designed system will be purely mechanical. Electrical design solutions are not included in the scope of this project.

3. Requirements

McMillan's Bike Co. expects a high level of functionality for the final design of this project. Below are listed the preliminary list of requirements. Over the course of the project these requirements may be refined, amended or removed. The requests are as follows: the proposed system shall be a purely mechanical system. The system shall be compact, easily movable. The system shall incorporate some hand or foot operated locking system. The system shall be designed for cost and manufacturing. The system shall allow for at least four bikes to be carried. The system shall be modular to allow for the addition of more or less bikes in larger or smaller trucks respectively. This system shall be non-permanent in that it may be removed. This system shall be designed so that it can be placed and removed without the use of heavy lifting equipment.

4. Schedule

This table below depicts the schedule outlining the RFP process. Dates are subject to change. Please note that McMillian's Bike Co. will not be accepting any RFP applications after 11/6/2017.

Event	Date
RFP Delivered	10/23/2017
Request for Clarification	10/30/2017
RFP Applications End	11/6/2017
Interview stage	11/13/2017
internal RFP Discussion and Start of Negotiation	11/20/2017
Project Awarded	11/27/2017
Project Start Date	12/1/2017

After project start date, it is expected that an official schedule be released by the design team no later than Jan r 2018. It should be noted that McMillan's Bike Co. expects the project to be completed no later than May 1¹¹, 2018.

5. Contract Award Criteria

The contract will be awarded to the company with the best design solution for our project. This evaluation will be based on cost, time to market, and the fulfillment of design requirement outlined above.

6. Budget and Resources

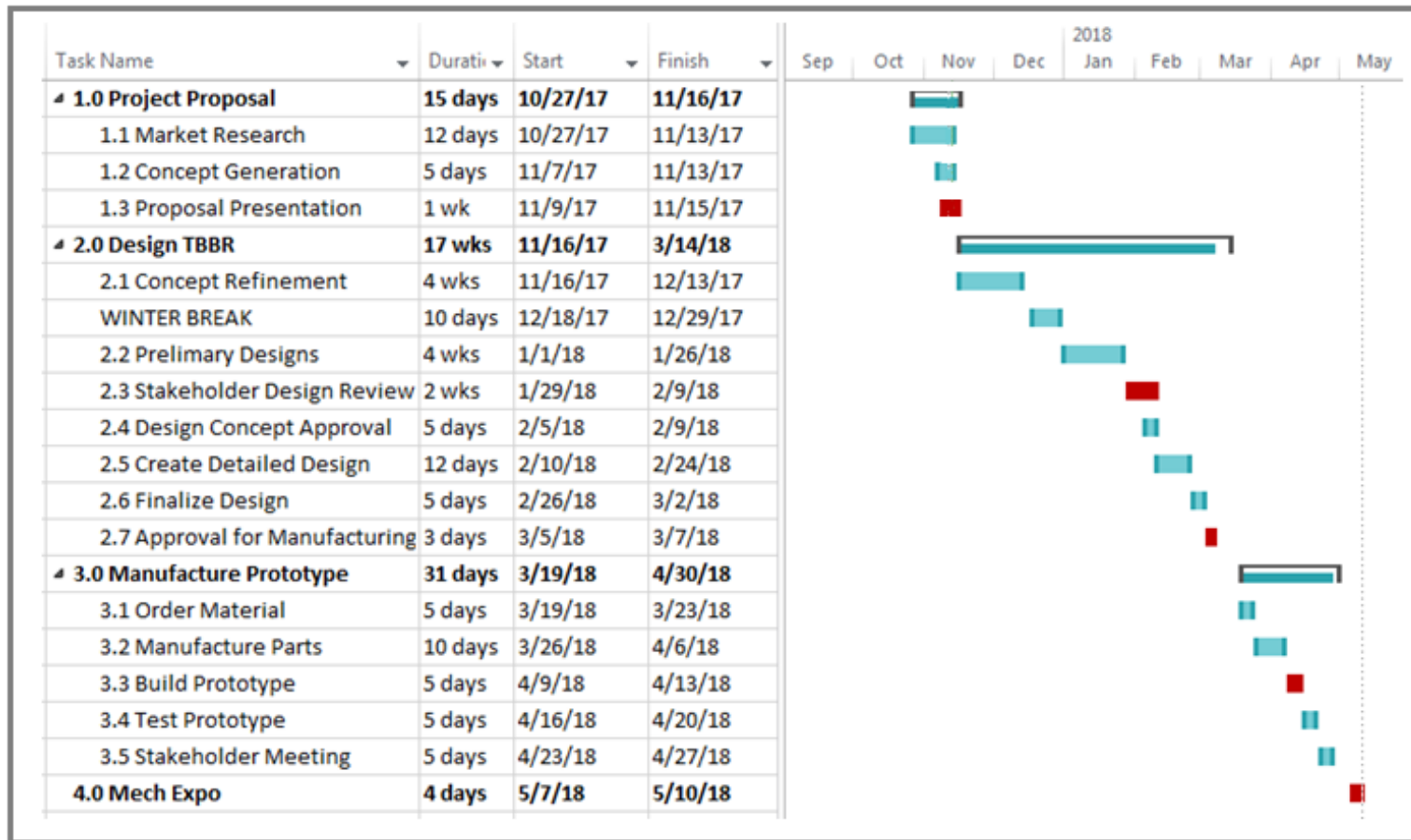
Budget: All design services will be paid through the Johan Fury Kindness account. The entire project must cost less than \$5000. Request for a larger budget may be considered if proposed.

Resources: McMillan's Bike Co. works mainly with BCIT Manufacturing. All designs and fabrication should be done with their equipment and limitations in mind.

If you have any questions or concerns after reading this RFP please contact our support desk, 1-800-MC-MILAN. Thank you for your time and consideration.

Appendix B: Project Activities

B.1: Gantt Chart



B.2 Design Calculations

EXTRUDED T-SLOT

$$h = w = 1.50 \text{ in}$$

$$W = 0.1123 \text{ lbs/in}$$

$$I = 0.2542 \text{ in}^4$$

$$\sigma_y = 35,000 \text{ psi}$$

$$E = 10.2 (10^3) \text{ ksi}$$

$$X = 15 \text{ in}$$

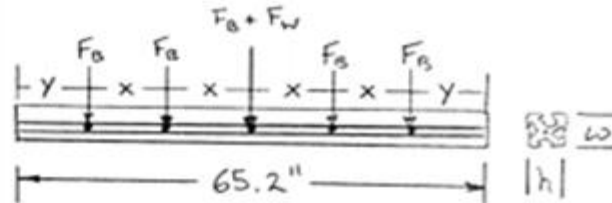
$$Y = 2.6 \text{ in}$$

Bending Moment

$$F_{\text{TOTAL}} = 5F_B + F_W$$

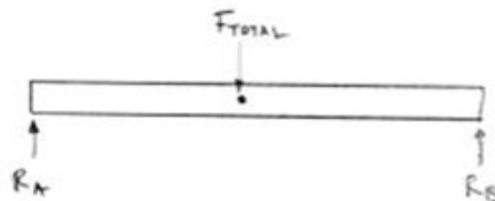
$$= 308 \text{ lbs}$$

$$R_A = R_B = 154 \text{ lbs}$$



$$F_B = 60 \text{ lbs} \quad \text{— includes bike weight + mounting device}$$

$$F_W = (0.1123 \frac{\text{lbs}}{\text{in}})(65.2 \text{ in}) = 7.32 \text{ lbs}$$



$$M = 154 \langle x - 0 \rangle' - 60 \langle x - 2.6 \rangle' - 60 \langle x - 17.6 \rangle' \\ - 60 \langle x - 32.6 \rangle' - 60 \langle x - 47.6 \rangle' - 60 \langle x - 62.6 \rangle'$$

Evaluated @ $x = 32.6 \text{ in}$ (center)

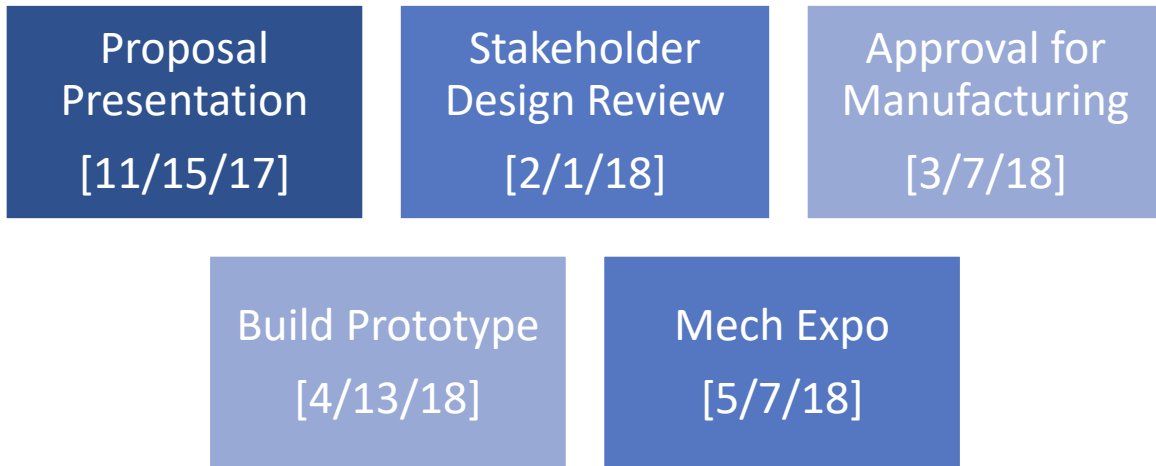
$$M = 154(32.6) - 60(30) - 60(15) = 2320 \text{ lb}\cdot\text{in}$$

$$\sigma = \frac{Mc}{I} = \frac{(2320)(0.75)}{(0.2542)} = 6845 \text{ psi}$$

$$n = \frac{\sigma_y}{\sigma} = \frac{35 \text{ ksi}}{6.8 \text{ ksi}} = 5.11$$

**With entire load at center: $n = 2.36$

B.3 Milestone Schedule

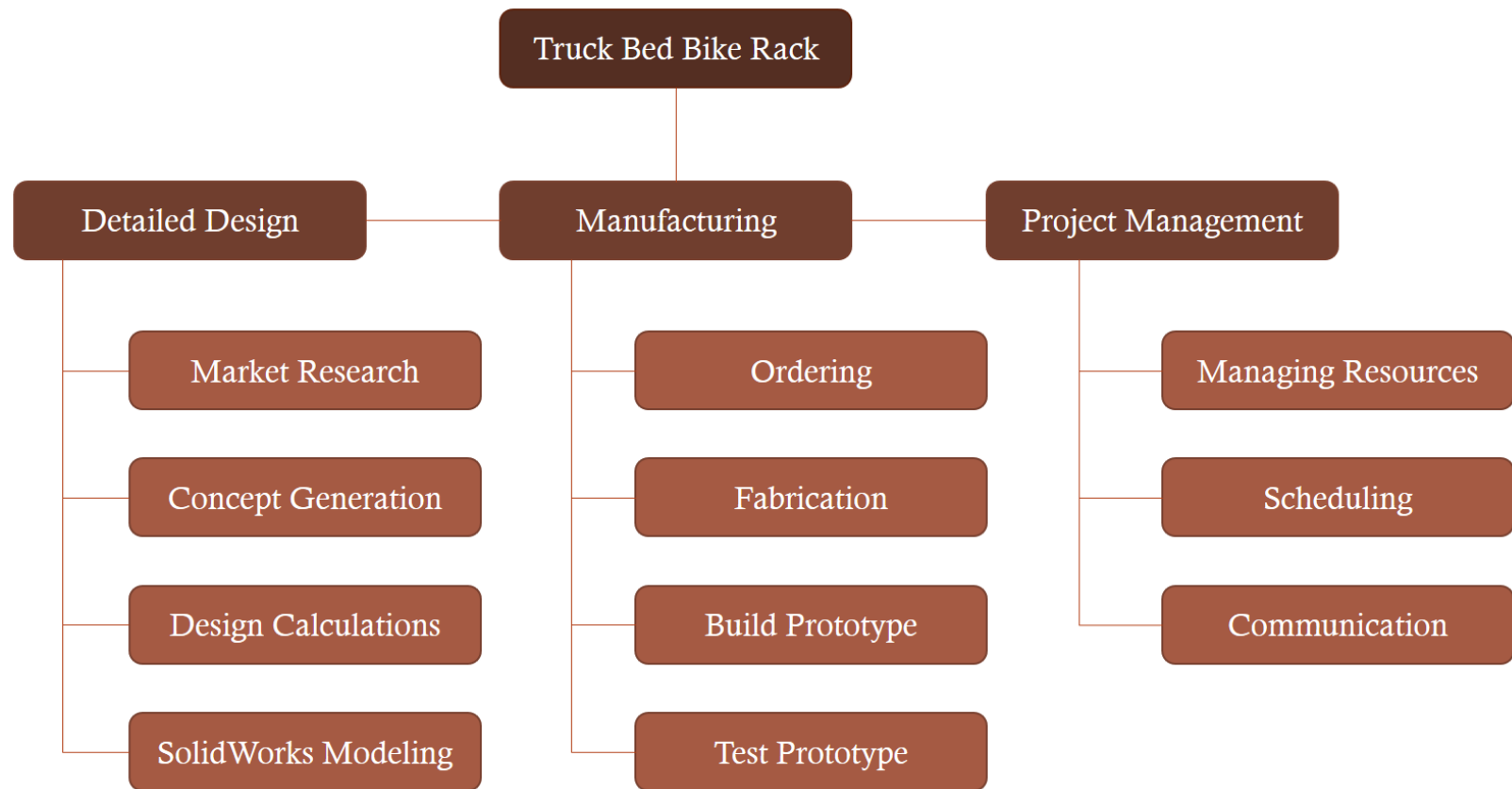


B.4 Responsibility Assignment Matrix

RACI Chart	Person		
Activity	Mark Deleeuw	Logan Wicks	Steven McMillan
Market Research	R	A	I
Concept Generation	R	R	C
Design Calculation	R	A	I
SolidWorks Modeling	R	A	I
Ordering	A	R	I
Fabrication	A	R	C
Build Prototype	R	R	I
Test Prototype	R	A	I
Managing Resources	A	R	C

*R Responsible, A Accountable, C Consult, I Inform

B.5 Work Breakdown Structure



B.6 Capstone Project Purchase Requisition



BRITISH COLUMBIA
INSTITUTE OF TECHNOLOGY

Capstone Project Purchase Requisition

Date: 2018-02-19

Project code: 1718-09

Vendor: **McMaster Carr**

Item #	Item Description	Part Number	Quantity	Unit Price	Price (USD)
001	Swivel Tee Through-Hole Connector for 1" Rail OD	2534T23	2	4.46	8.92
002	Closed Tee Through-Hole Connector for 1" Rail OD	2534T21	2	3.00	6.00
003	6' Strut Channel - Slotted Hole, Galvanized Steel	3310T657	2	34.61	69.22

McMaster Carr Online Shopping Cart: <https://www.mcmaster.com/order/rcvRtedOrd.aspx?ordid=3335024882380&lnktyp=txt>

Vendor: **Amazon**

Item #	Item Description	Part Number	Quantity	Unit Price	Price (CAD)
004	4X GCI Truck Cap, Camper Shell Clamp	-	1	44.95	44.95

Item 004, online link :https://www.amazon.ca/GCI-Truck-Camper-Shell-Clamp/dp/B01LF2ZYXE/ref=sr_1_37?ie=UTF8&qid=1518629808&sr=8-3&keywords=G-1+Clamp+for+Truck+Cap+%2F+Camper+Shell+%2Bset+of+4%29&dplD=51mY8MxOXkL&preST= SX300 QL70 &dplSrc=srch

Total Price: \$150.96

Items have been checked for availability

Logan Wicks
A00886387



Capstone Project Purchase Requisition

Date: 2018-02-19

Project code: 1718-09

ORDER REVISION: ORDER ITEMS WITH RED NOTES

Vendor: McMaster Carr

Item #	Item Description	Part Number	Quantity	Unit Price	Price
001	Swivel Tee Through-Hole Connector for 1" Rail OD	2534T23	2	4.46	8.92
002	Closed Tee Through-Hole Connector for 1" Rail OD	2534T21	2 -> 4	3.00	12.00
003	6' Strut Channel - Slotted Hole, Galvanized Steel	3310T657	2	34.61	69.22

<--- The quantity of this part was changed from two to four. TWO more should be ordered.

Only received ONE 6' Strut Channel ONE more should be ordered

McMaster Carr Online Shopping Cart: <https://www.mcmaster.com/order/rcvRtedOrd.aspx?ordid=3335024882380&lnktype=txt>

Vendor: Amazon

Item #	Item Description	Part Number	Quantity	Unit Price	Price (CAD)
004	4X GCI Truck Cap, Camper Shell Clamp	-	1	44.95	44.95

Item 004, online link: https://www.amazon.ca/GCI-Truck-Camper-Shell-Clamp/dp/B01LF2ZYXE/ref=sr_1_3?ie=UTF8&qid=1518629808&sr=8-3&keywords=G-1+Clamp+for+Truck+Cap+%2F+Camper+Shell+%28set+of+4%29&dplD=51mYBMxOXkL&preST= SX300 QL70 &dpSrc=srch



BRITISH COLUMBIA
INSTITUTE OF TECHNOLOGY

Capstone Project Purchase Requisition

Vendor: Princess Auto

Item #	Item Description	Part Number	Quantity	Unit Price	Price
005	1 in. x 5 ft Trailer Mount Ratchet Tie Down	SKU: 8719106	1	14.99	14.99

This item was
added and should
be ordered (qty 1).

<https://www.princessauto.com/en/detail/1-in-x-5-ft-trailer-mount-ratchet-tie-down/A-p8719106e>

Grand total so far: \$150.08

Items have been checked for availability

Logan Wicks
A00886387

Appendix C. Design Review Package

C.1 TBBR Overview

The Truck Bed Bike Rack (TBBR) has progressed through a multitude of stages and the design has changed drastically many times as new information has surfaced. While the design team began with a handful of designs, due to constraints and failure to meet all project objective criteria, all but one design persisted. Although it was not one of the original concepts, the model below depicts the latest version of the TBBR.

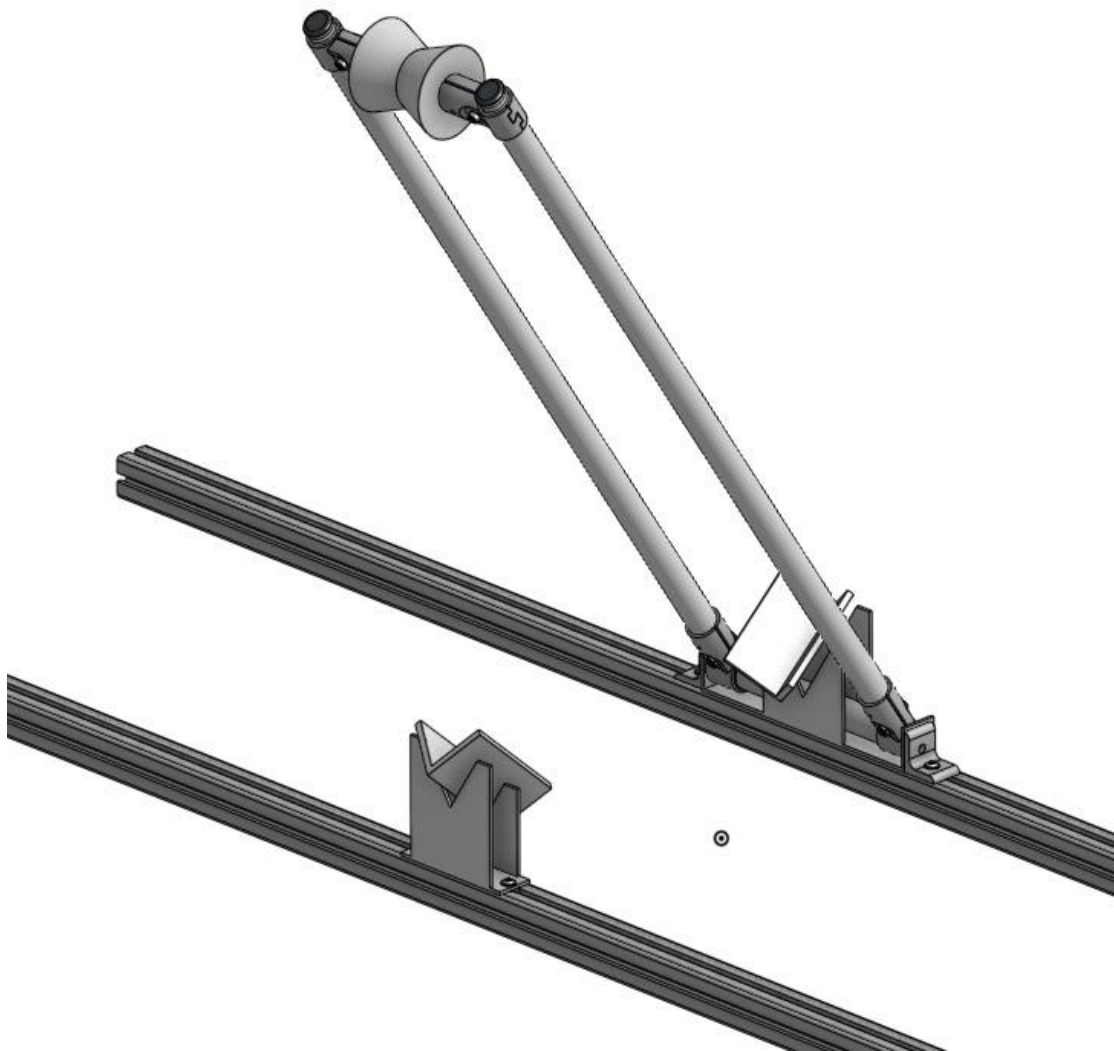


Figure 0-1 Current TBBR Model

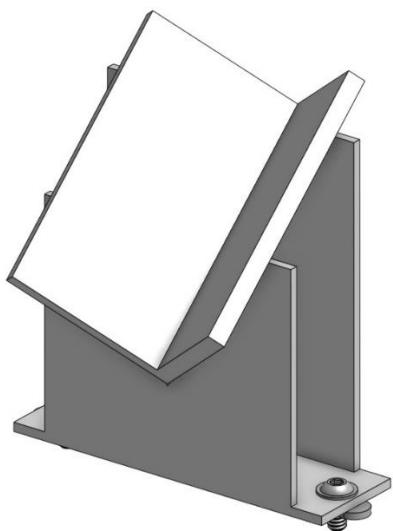
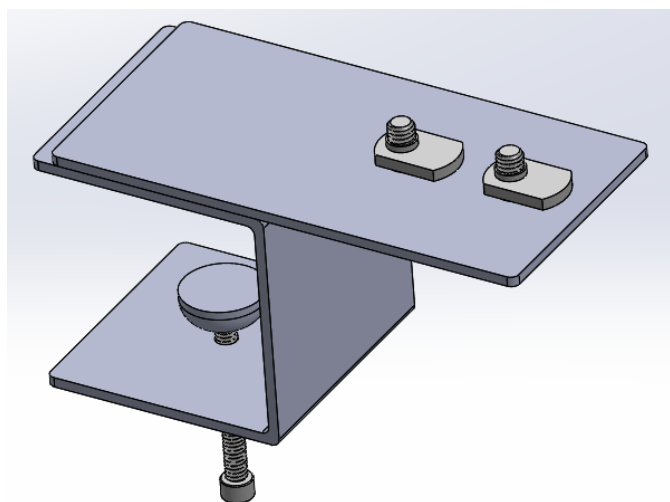
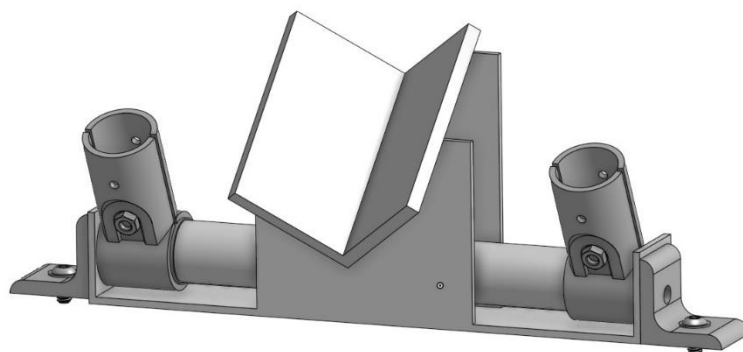
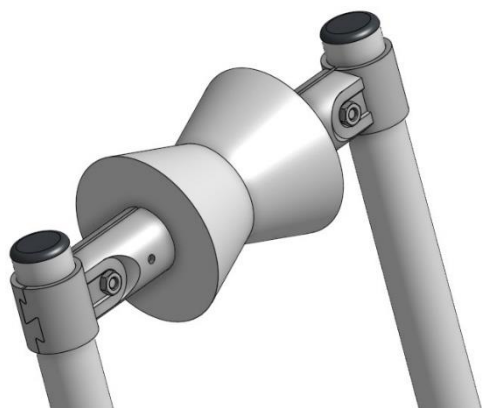


Figure 0-2 - Current TBBR Model Continued

C.2 Engineering Calculations

C.2.1 Load Bars

The stress calculations below validate the size of T-slot we chose to support the bike load and mounting system load. Despite that the bikes weight will be distributed between two load bars, the designers made the assumption that all the weight of five bikes and five mounting systems were loaded onto one bar. This assumption ensures that the system will be safe under extreme conditions.

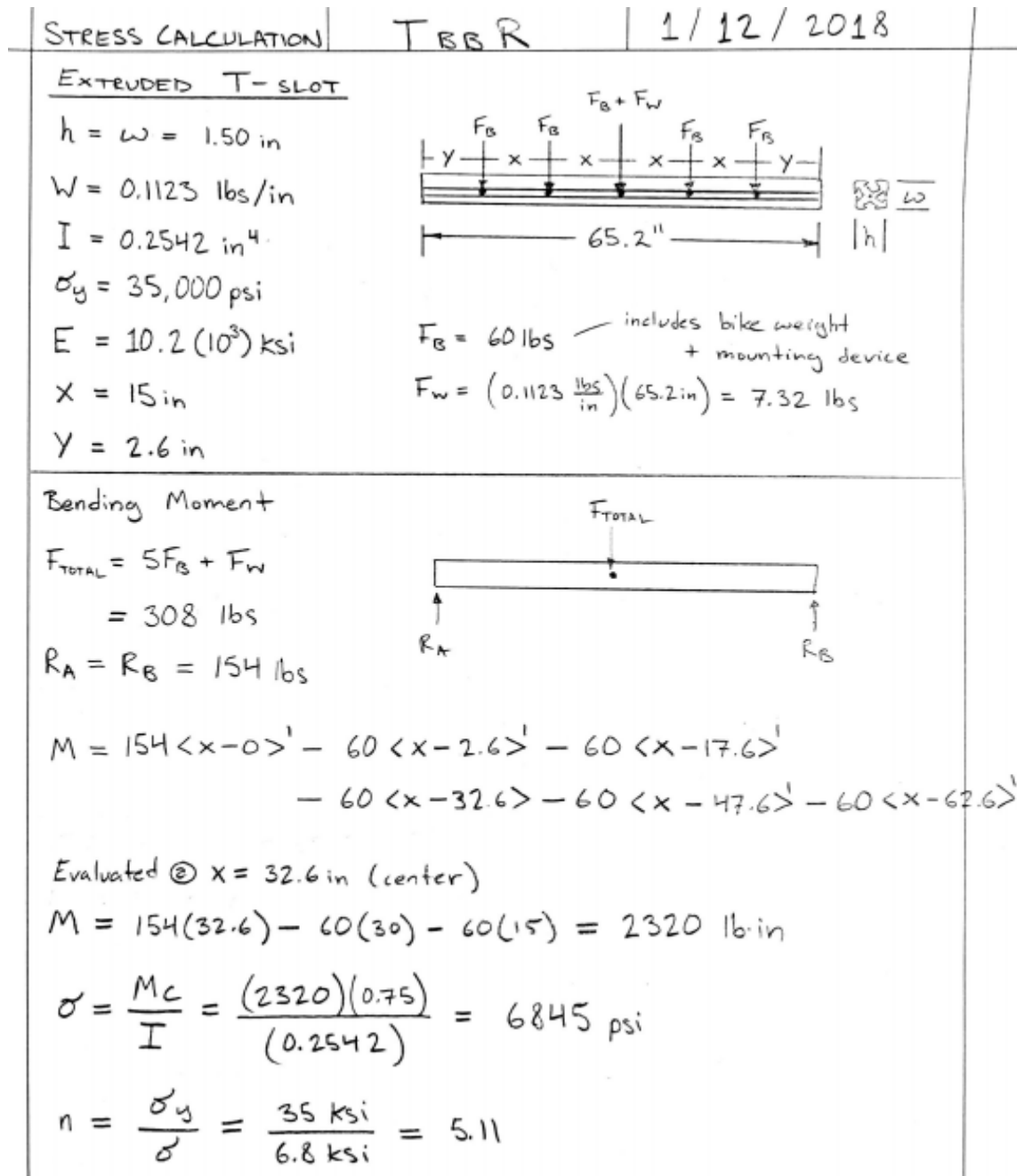


Figure 0-1 - Stress Calculations

C.2.2 Angle Bar Wheel Chuck

After analyzing different chuck systems, the design team decided to use angle bar as it is rather inexpensive when compared to other alternatives. Geometric calculations had to be made to determine the length and angle of the angle bar to accommodate both larger and small diameter tires, as well as their distance apart. This can be seen below.

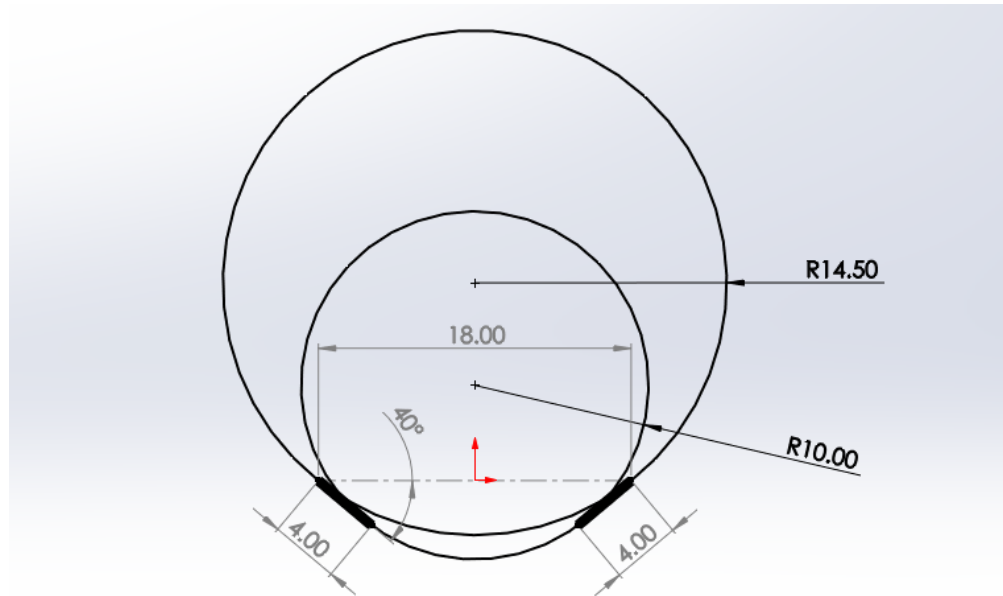


Figure 0-2 - Geometric Calculations

This angle also affects the angle of the cut required in aluminum base plates. As the angle iron is angled, the required cut angle decreases to 65.5 degrees. This is shown below.

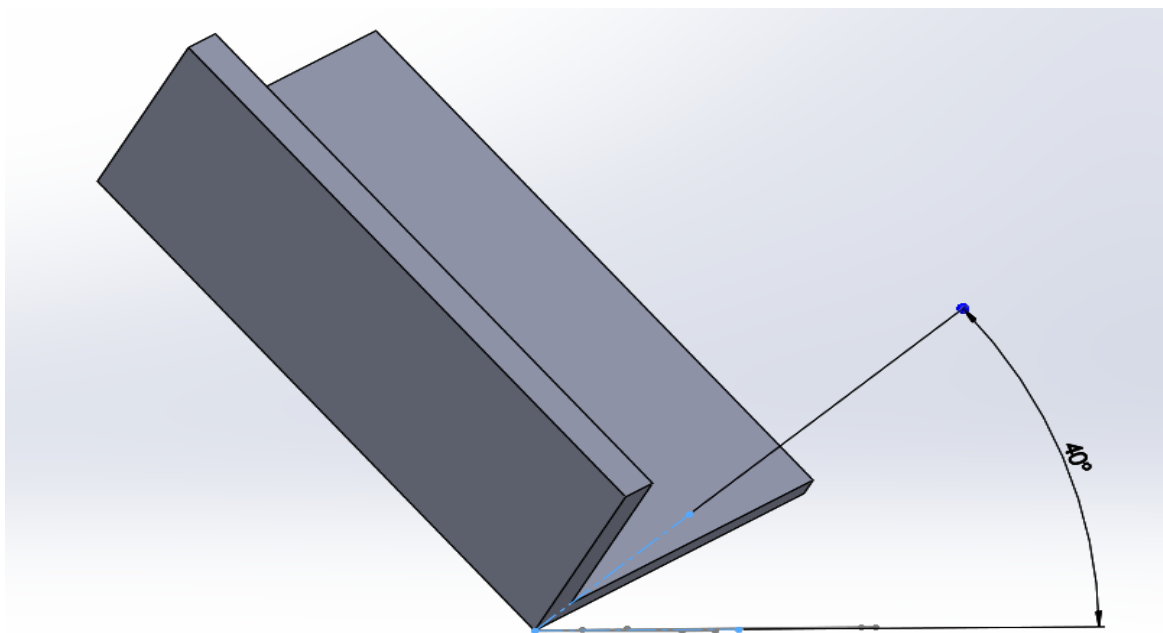


Figure 0-3 - Angle Bar Angle

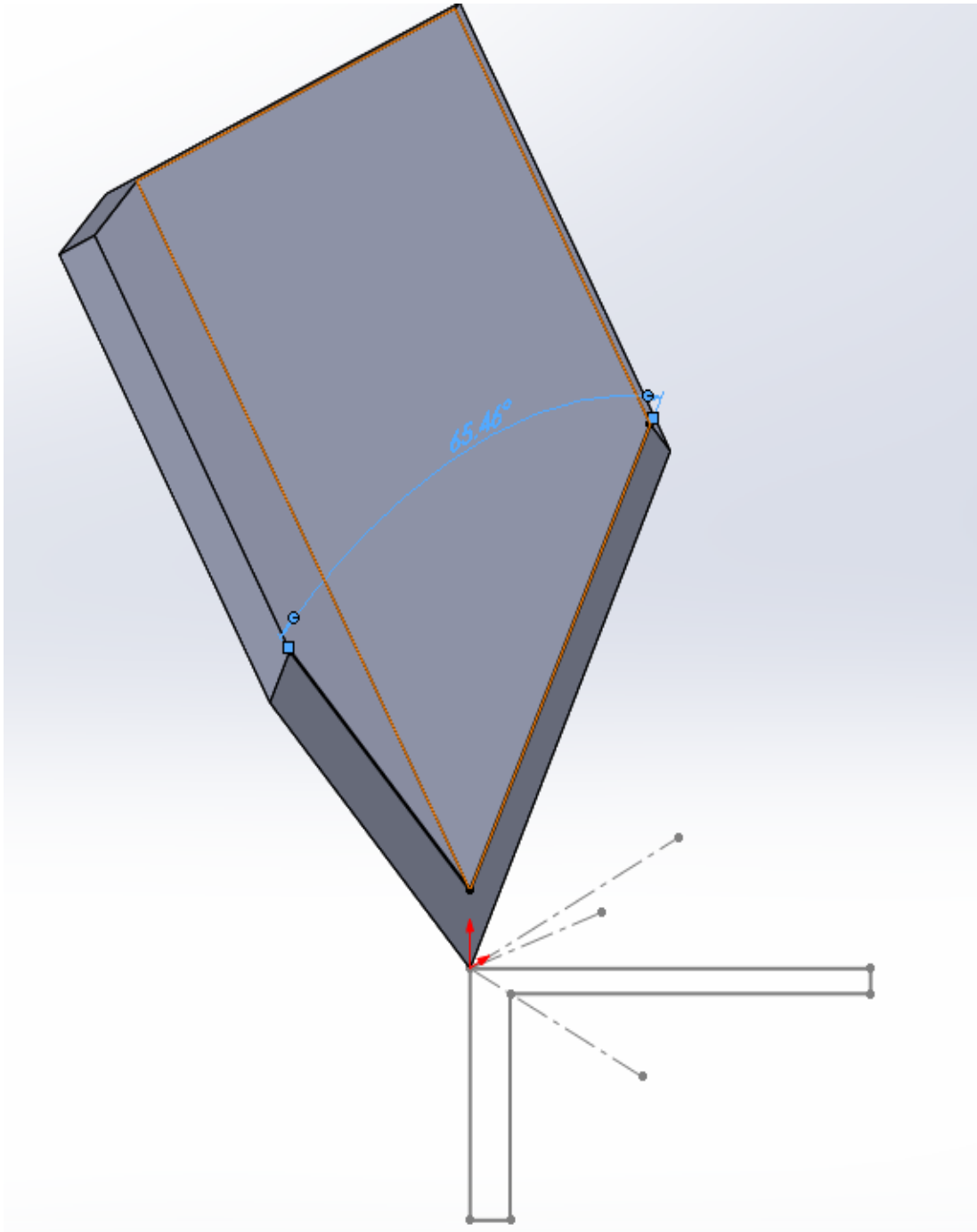


Figure 0-4 - Modified Angle Bar Angle

C.3 Competitive Analysis

The table shown below indicates how the TBBR compares with other top-of-the-line bike racks. Several project objectives are used to measure their differences.

Table 2 - Competitive Analysis

Model	Secure	Modular	Can be used with most Bikes on most Trucks*	Maximum Number of Bikes	Cost (CAD)
Ride88	Y	Y	N	4	148 + 299 x no. of bikes
Thule Bike Hitch	Y	N	Y (w/ hitch)	2	399
TBBR	Y	Y	Y	5	est. 149 + 123 x no. of bikes

*Most bikes specifies conventional mountain and road bikes. Most trucks specifies trucks with standard truck beds (short/long).

This table clearly indicated that the TBBR meets all project objectives, while the others do not. For example, as the Ride88 is assembled in the base of the truck, longer bikes will not fit in short bed trucks. Meanwhile, the Thule Bike Hitch can be used with any truck providing that truck has a hitch. Unfortunately, the Thule system is not modular and can only hold two bikes at one time. On the other hand, the TBBR is both secure and modular, can fit up to five bicycles, and after a %25 mark up from the manufactures price for profit the TBBR is still cheaper than its competitors.

C.4 Cost

The design team has done a rough draft of expected costs for the current model. It is estimated that the truck load bar set up will cost roughly \$120.27, while each individual unit capable of carrying one bike each will cost \$95.98. As these costs do not account for labor, the expected cost for a single prototype may be significantly higher than the sum of the ordering prices seen below in Table 2. Additionally, this table does not include hardware available in the shop or the 3D-printer material used for several components in the system.

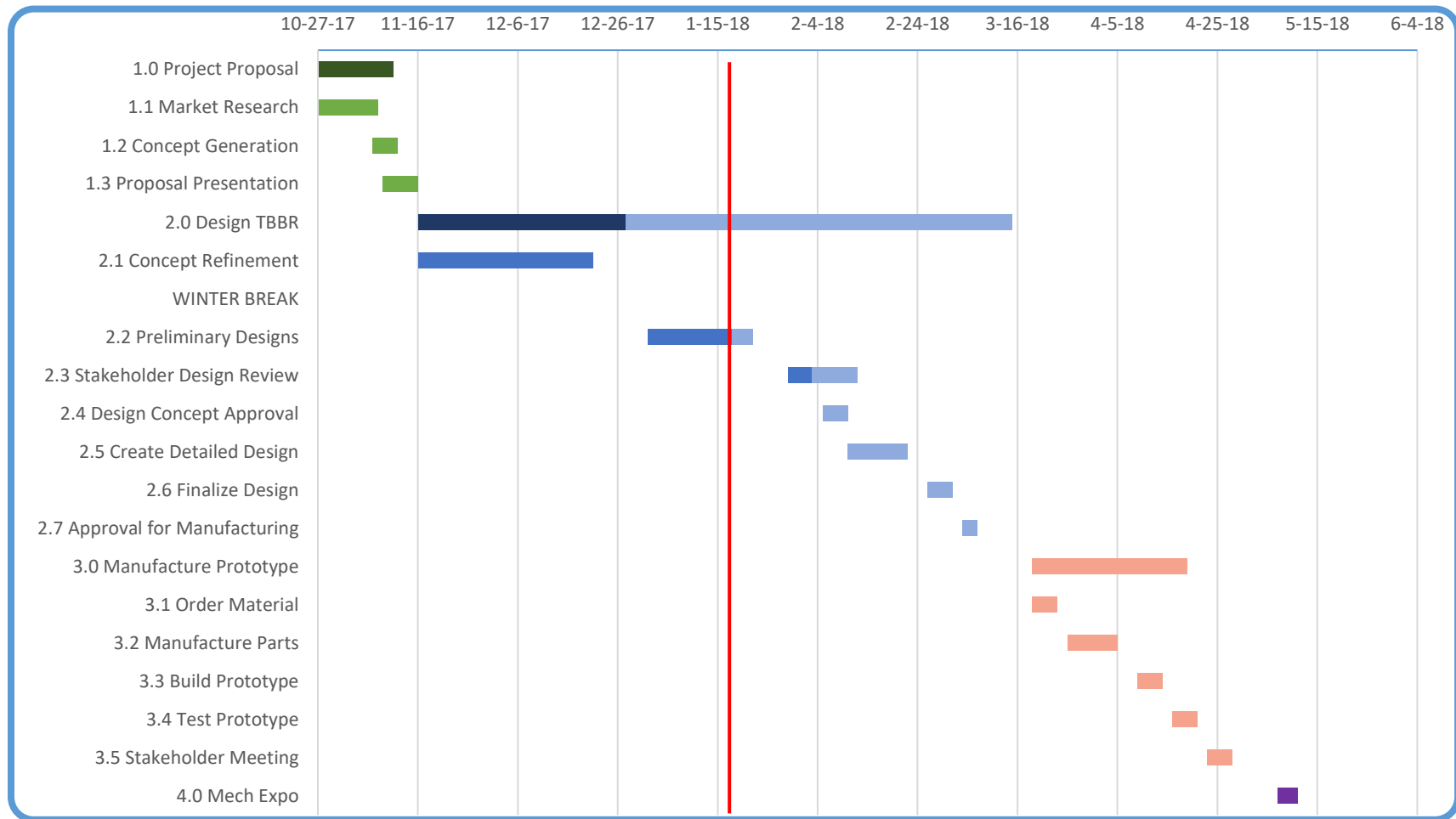
Table 3 - Current Project BoM

No.	Component	Description	Qty	Cost	Total Cost	Link
1	T-Slt, 1.5"x1.5",6'	T-slotted, load/mounting bar	2	42.58	85.16	cmaster.com/#t-s
2	1/4"-20 Skt Hex Head	Black-Oxide Alloy Steel Socket Head Screw	25p	10.22	10.22	master.com/#900
3	3"x3" U-Channel	U-channel to support truck clamp	1ft	15.87	15.87	naster.com/#u-ch
4	1.5" end fd fstr	1.5" End feed fasteners for T-slot	2px4	4.51	9.02	om/#t-slotted-fra
					120.27	
5	Al, 1-8" thk.,12"x12"	Al. Sheet for base plate	1	15.33	15.33	om/#standard-alu
6	T-Slt, Brkt	T-slotted corner bracket, mounts unit	2	6.41	12.82	/#standard-frami
7	1.5" end fd fstr	1.5" End feed fasteners for T-slot	1px4	4.51	4.51	om/#t-slotted-fra
8	1" Steel Tubing	1" Steel Aluminum Tubing	8ft	16.22	16.22	com/#structural-
9	Swvl Tee Connector	Swivel Tee Connector	2	4.46	8.92	naster.com/#tube
10	Clsd Tee Connector	Closed Tee Connector	2	3.00	6	.com/#structural-
11	Tube Cap	Tube Cap	1px10	4.46	4.46	.com/#structural-
12	UHMW Rod	Plastic Roller Rod	1ft	27.72	27.72	r.com/#standard-
					95.98	

C.5 Schedule

The team is currently on schedule and is still projected to finish the entire project by May 1st, 2018.

Table 4 - Gantt Chart



C.6 Risk Analysis

The design team has eliminated several risks through organization and planning, however since many components in the design may end up being joined through aluminum welding, the team should focus on learning that skill.

The design currently also utilizes sheet metal bends that may be difficult. The team should work to further refine the design so that the most elegant solution is found.

Additionally, the current cost of the product in terms of manufacturing and assembly time is quite high, which could mean failure in the market in the future. The team should work to edit the design to save costs. A cheaper product that requires less assembly and less manufacturing error will make for a better design overall.

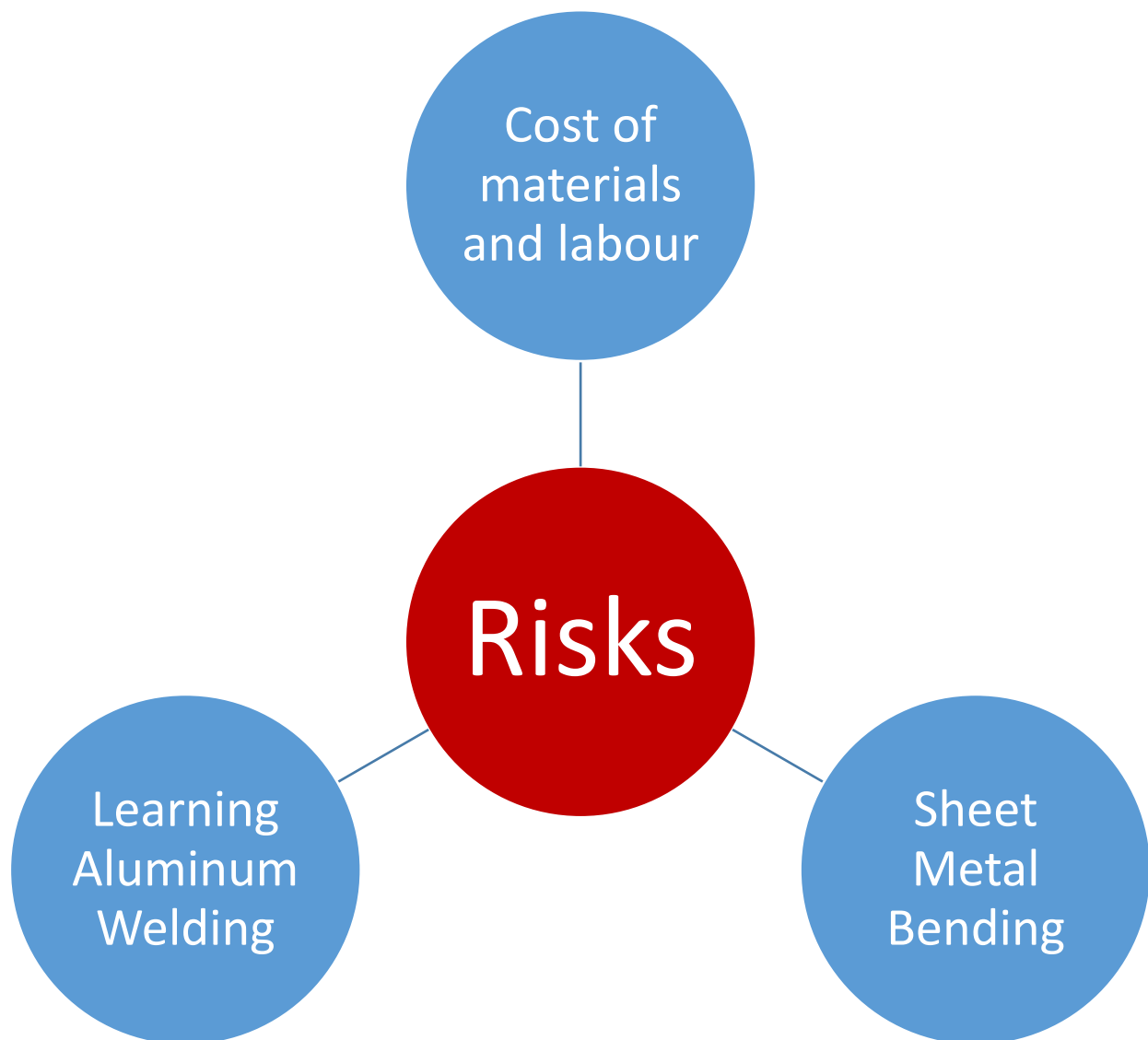


Figure 0-1 - Current Project Risk

Appendix D. BOM & Shop Drawing

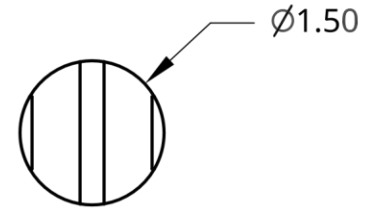
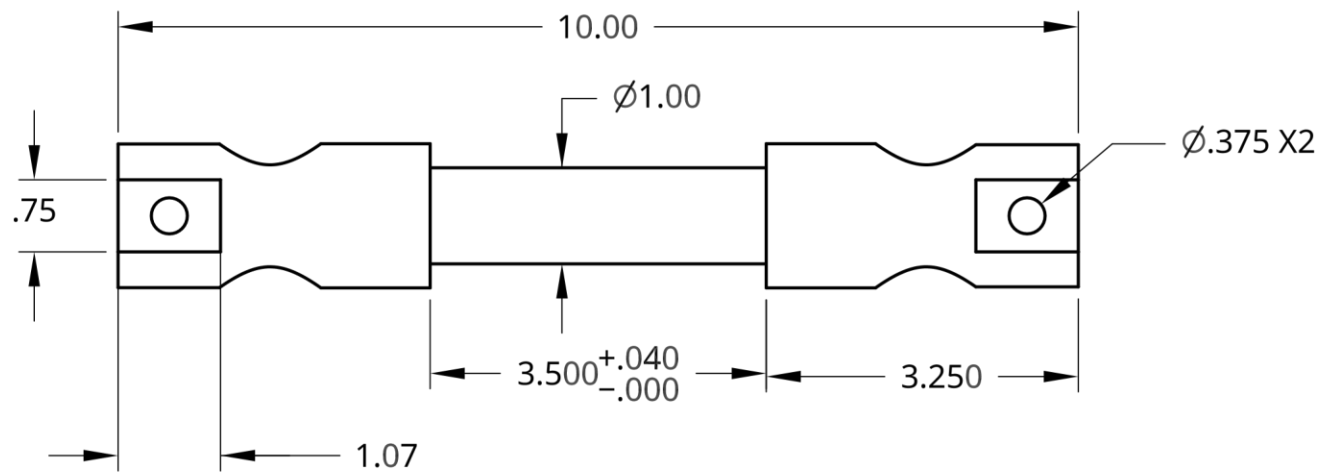
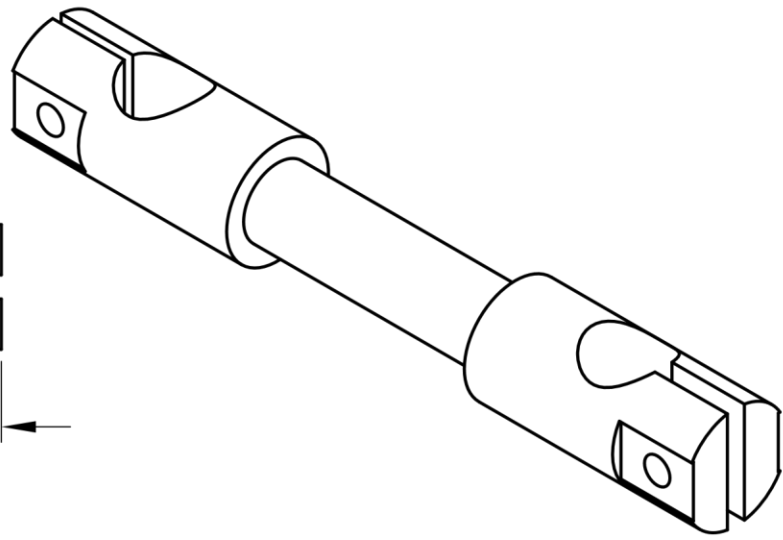
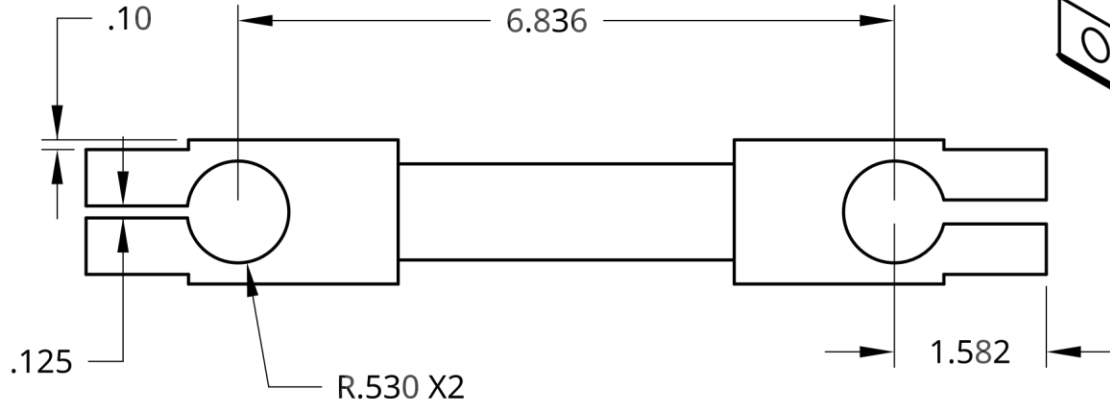
BoM	TBBR	
Level	Description	Qty
1	Strut Channel 6 ft	2
1	Upper Assembly	1
2	Connecting Tube, Steel, 1.060" OD.	2
2	Attachment Bar, Steel, 2" x 1/8" Bar	1
2	Custom Roller Bar	1
3	Custom Roller Bar, Aluminum	1
3	Bolt, Stnl, 3/16" x 2"	2
3	Screw, Stnl, 3/16"	2
2	Roller Assembly	1
3	Roller Half, 3D printed part	2
3	Socket screw, 5/16" x 1"	4
3	Screw, Stnl, 5/16"	4
1	Lower Front Assembly	1
2	Center Tube, 1.060" OD	1
2	Front Wheel Chuck, 3D Printed	1
2	Spacers, 3D Printed	2
2	Swivel Tees, McMaster Carr	2
2	Anchors	2
3	Anchors, Steel, 2"x2" Square Stock	1
3	Bolt, Stnl, 1/2" x 2.5"	1
3	Spring Nut, 1/2"	1
1	Lower Rear Assembly	1
2	L-Bracket	1
3	L-Bracket, Steel	1
3	Ratchet, trailer mount, Princess Auto	1
3	Bolt, Stnl, 3/8" x 1"	1
3	Screw, Stnl, 3/8"	1
3	Bolt, Stnl, 1/2" x 2.5"	1
3	Spring Nut, 1/2"	1
2	Rear Wheel Chuck, 3D Printed	1



B

A

B

A



UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES .XX = ±.040- .XXX = ±.020- SURFACE FINISH  DO NOT SCALE DRAWING BREAK ALL SHARP EDGES AND REMOVE BURRS THIRD ANGLE PROJECTION 	NAME		DATE		TITLE ROUND TUBE CLAMP					
	DRAWN		Mark Deleeuw						05/02/2018	
	CHECKED		Logan Wicks						05/10/2018	
	APPROVED									
MATERIAL		FINISH		SIZE	DWG NO.		REV.			
ALUMINUM		POWDER COATED		A	D1		60			
				SCALE	WEIGHT		SHEET			
				1:2			1 of 1			

2

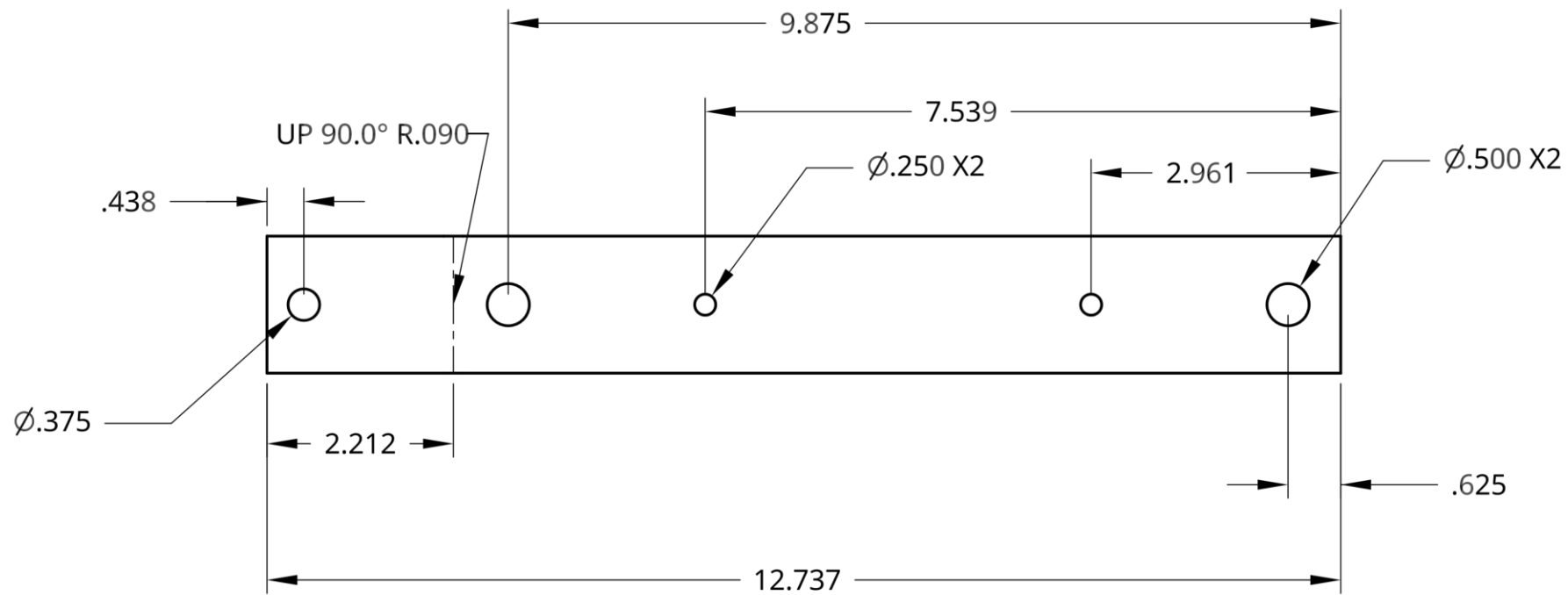
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B



B

A

A



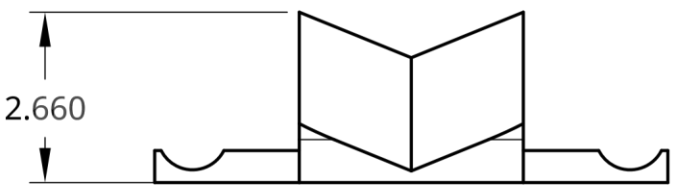
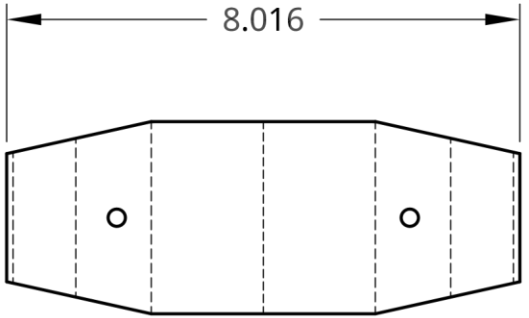
MATERIAL : A36 STEEL HR FLAT BAR 0.125 X 1.500

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES .XX = ±.040 .XXX = ±.020 SURFACE FINISH  DO NOT SCALE DRAWING BREAK ALL SHARP EDGES AND REMOVE BURRS THIRD ANGLE PROJECTION 		NAME	DATE	TITLE BACK BASE PLATE		
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	CHECKED	Logan Wicks	05/10/2018			
	APPROVED					
				SIZE A		
		MATERIAL	FINISH	DWG NO.	REV.	
		HR STEEL	POWDER COATED	D2	-	
				SCALE	WEIGHT	SHEET
				1:2		1 of 1

2

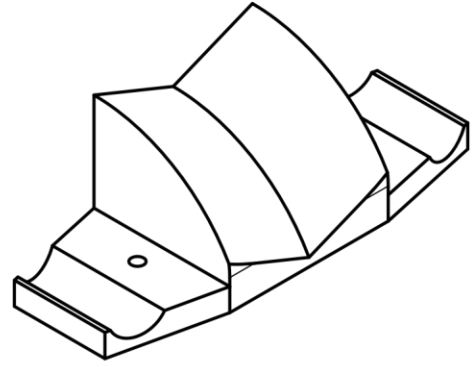
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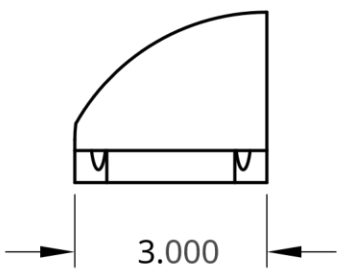


A

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



B



A

NOTE : ALL DIMENSIONS SHOULD BE WITHIN $\pm .040$ OF PART FILE

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES .XX = ±.040 .XXX = ±.020 ANGULAR = ± ° FRACTIONAL = ± SURFACE FINISH  DO NOT SCALE DRAWING BREAK ALL SHARP EDGES AND REMOVE BURRS THIRD ANGLE PROJECTION 			NAME	DATE	TITLE BACK WHEEL CHUCK				
	DRAWN		Mark Deleeuw	05/02/2018					
	CHECKED		Logan Wicks	05/10/2018					
	APPROVED				SIZE A				
					DWG NO.		D3	62	REV. -
MATERIAL PLA		FINISH APPLE RED SPRAY PAINT		SCALE 1:3		WEIGHT		SHEET 1 of 1	

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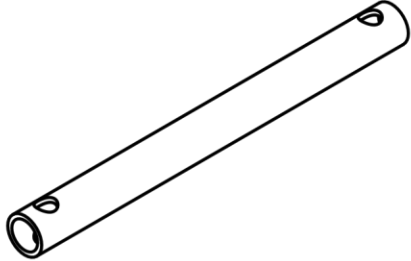
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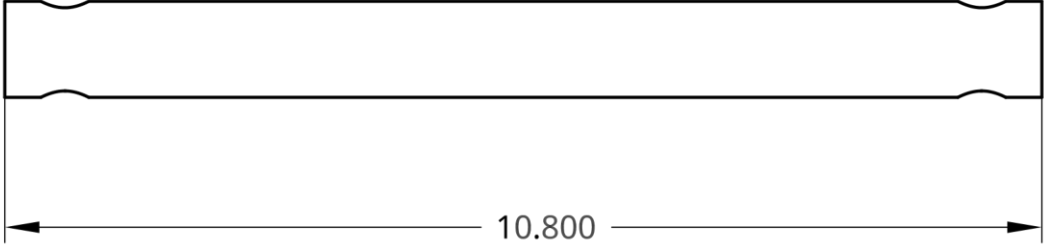
A

B

A



SCALE 1:4



MATERIAL: HOT ROLLED STEEL TUBE 1 OD x .120 WALL

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	DRAWN	Mark Deleeuw	05/02/2018			
	CHECKED	Logan Wicks	05/10/2018			
	APPROVED					
				SIZE A		
	MATERIAL	STEEL	FINISH POWDER COATED	DWG NO.	D4	REV. -
				SCALE 1:2	WEIGHT	SHEET 1 of 1

2

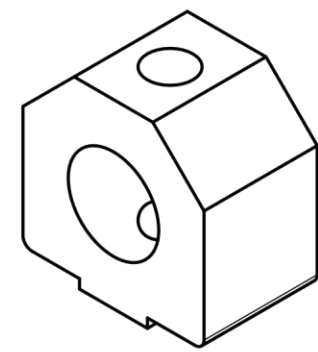
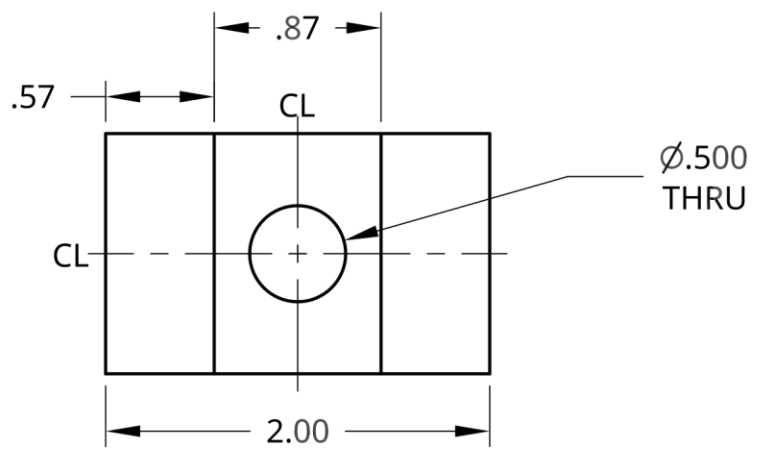
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B

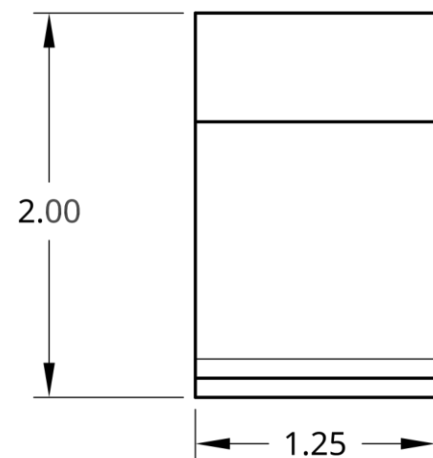
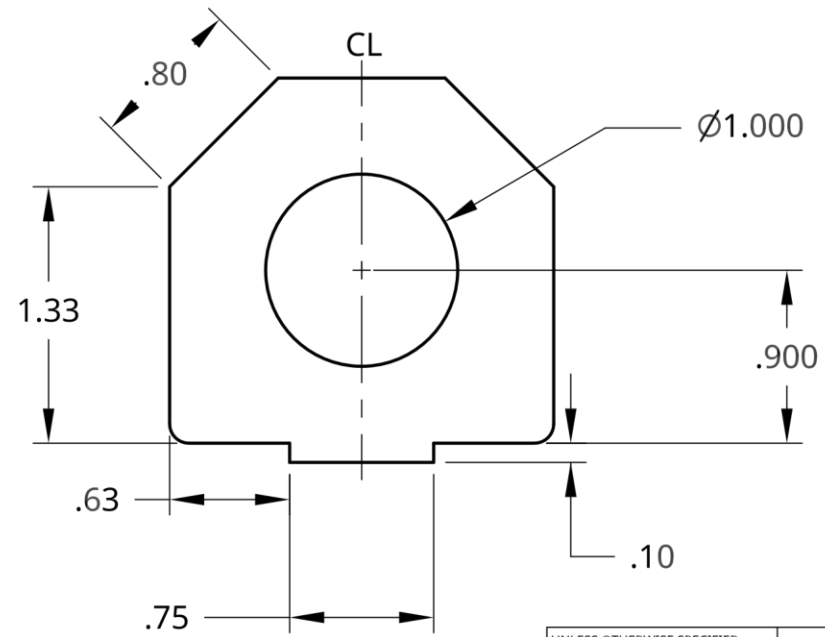
A



B

A



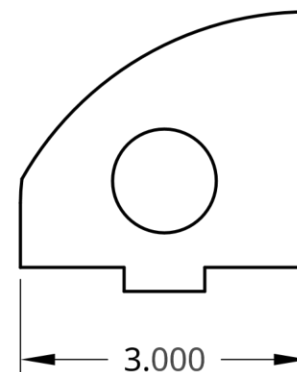
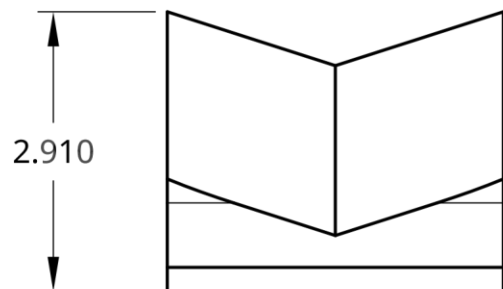
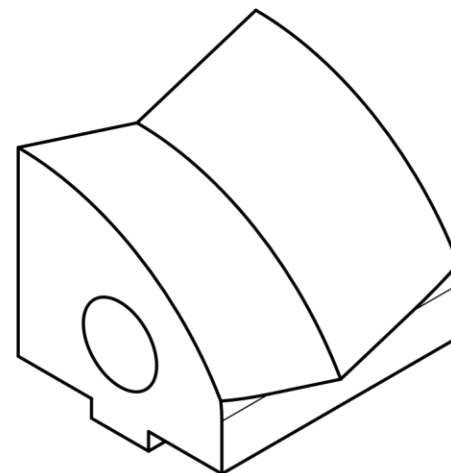
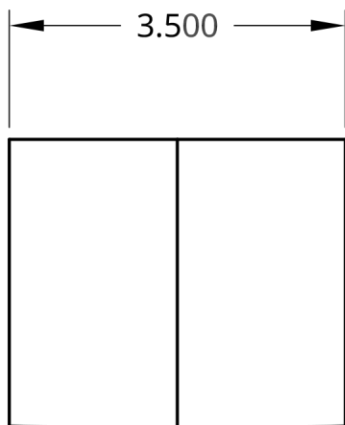
ISOMETRIC
SCALE 2:3



UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES .XX = ±.040 .XXX = ±.020 ANGULAR = ± ° FRACTIONAL = ± SURFACE FINISH  DO NOT SCALE DRAWING BREAK ALL SHARP EDGES AND REMOVE BURRS THIRD ANGLE PROJECTION 	NAME		DATE		TITLE <h1>PS Tube Block</h1>					
	DRAWN		Logan Wicks						02/20/2018	
	CHECKED		Mark Deleeuw						05/10/2018	
	APPROVED									
MATERIAL		FINISH		SIZE	DWG NO.			REV.		
STEEL		POWDER COATED		A	D5		64	-		
				SCALE	WEIGHT		SHEET			
				1:1			1 of 1			

2

1



NOTE : ALL DIMENSIONS SHOULD BE WITHIN $\pm .040$ OF PART FILE

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES .XX = $\pm .040$.XXX = $\pm .020$ SURFACE FINISH DO NOT SCALE DRAWING BREAK ALL SHARP EDGES AND REMOVE BURRS THIRD ANGLE PROJECTION 		NAME	DATE	TITLE FRONT WHEEL CHUCK		
	DRAWN	Mark Deleeuw	05/02/2018			
	CHECKED	Logan Wicks	05/10/2018			
	APPROVED					
				SIZE A	DWG NO. D6	REV. -
	MATERIAL PLA	FINISH APPLE RED SPRAY PAINT		SCALE 1:2	WEIGHT	SHEET 1 of 1

2

1

2

1

B

B

DOWN 76.5° R.090

DOWN 76.5° R.090

CL

.750

.375



2.856

8.154

19.164

A

A

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES .XX = ±.040 XXX = ±.020 ANGULAR = ± ° FRACTIONAL = ± SURFACE FINISH  DO NOT SCALE DRAWING BREAK ALL SHARP EDGES AND REMOVE BURRS THIRD ANGLE PROJECTION 			NAME	DATE	TITLE			
DRAWN		Mark Deleeuw	05/03/2018					
CHECKED		Logan Wicks	05/10/2018					
APPROVED								
					BRACKET			
MATERIAL		FINISH		SIZE	DWG NO.			REV.
HR STEEL		POWDER COATED		A	D7		66	-
				SCALE	1:2		WEIGHT	SHEET
								1 of 1

MATERIAL : A36 STEEL HR FLAT BAR 0.125 X 1.500

2

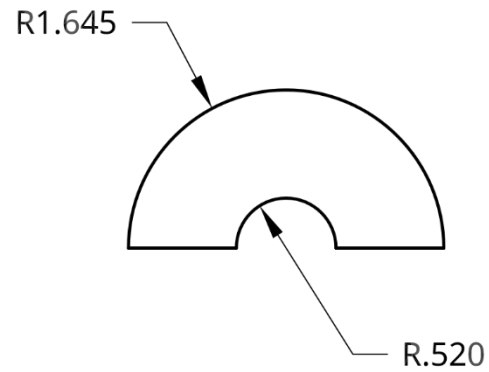
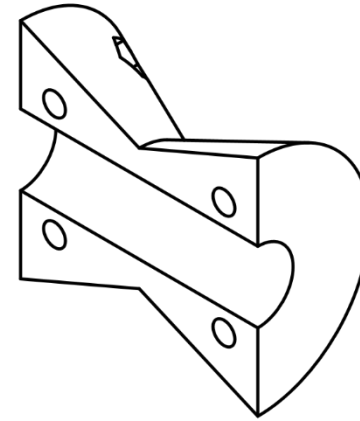
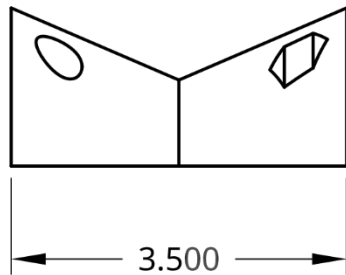
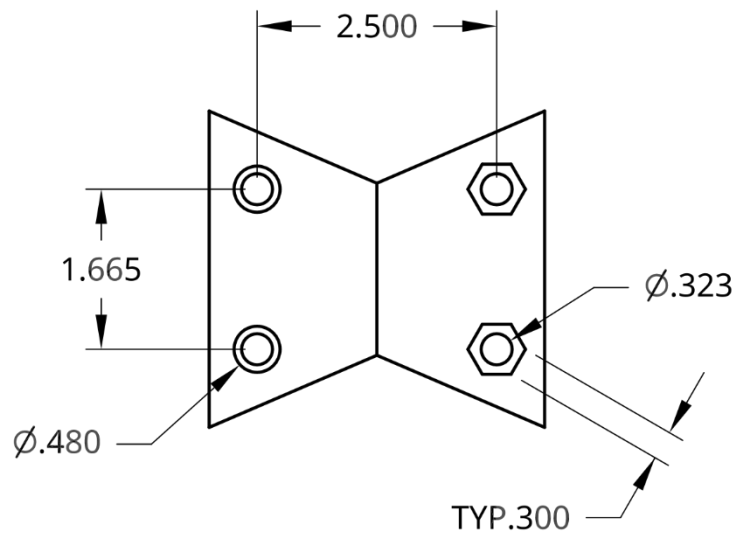
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

A

B

A

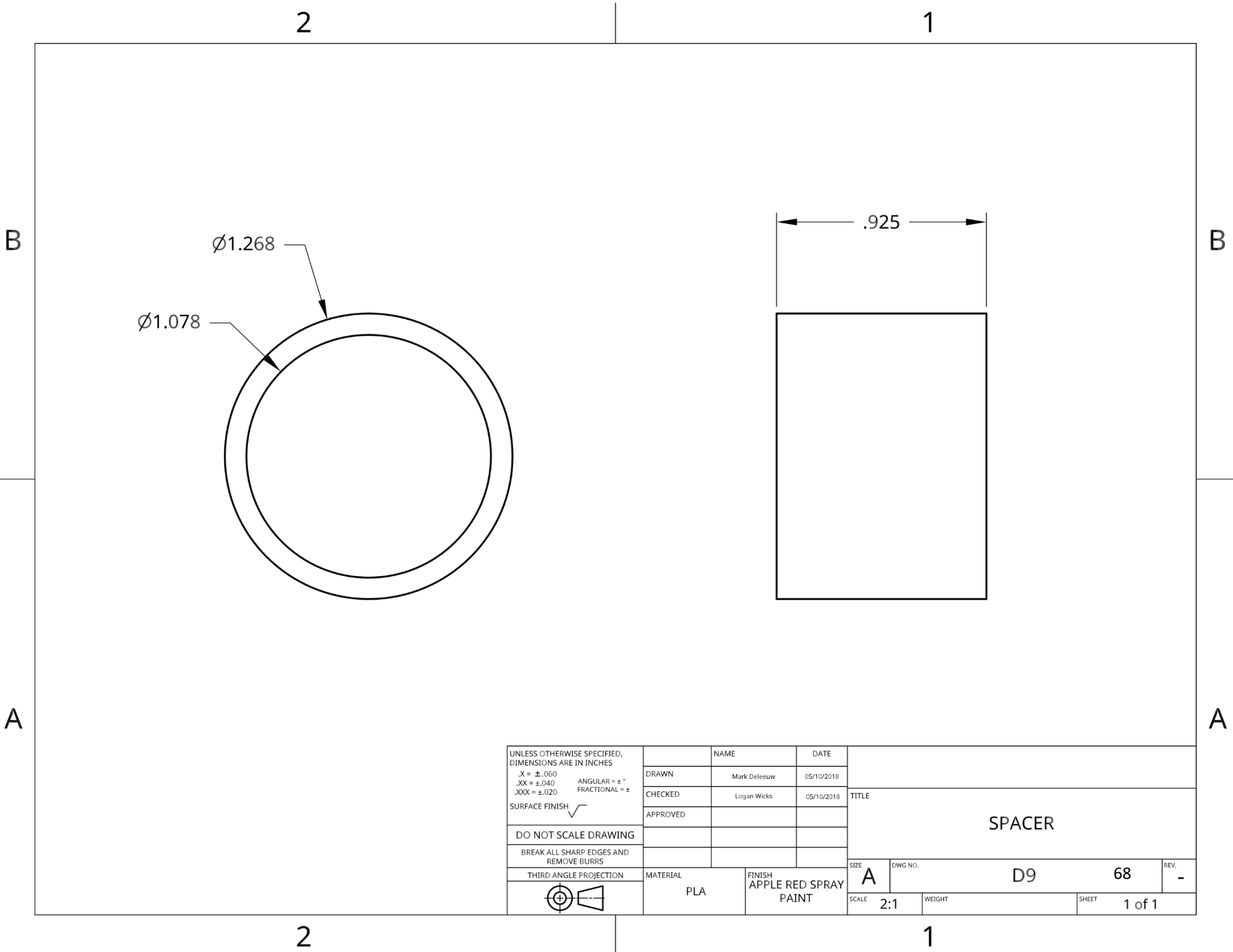


NOTE : ALL DIMENSIONS SHOULD BE WITHIN $\pm .040$ OF PART FILE

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES .XX = $\pm .040$.XXX = $\pm .020$ ANGULAR = $\pm ^\circ$ FRACTIONAL = \pm SURFACE FINISH  DO NOT SCALE DRAWING BREAK ALL SHARP EDGES AND REMOVE BURRS THIRD ANGLE PROJECTION 		NAME	DATE	ROLLER CHUCK HALVED		
	DRAWN	Mark Deleeuw	05/09/2018			
	CHECKED	Logan Wicks	05/10/2018			
	APPROVED					
				SIZE	DWG NO.	REV.
				A	D8	
	MATERIAL	PLA	FINISH APPLE RED SPRAY PAINT	SCALE	1:2	WEIGHT
						SHEET 1 of 1

2

1



UNLESS OTHERWISE SPECIFIED,
DIMENSIONS ARE IN INCHES

.X = ±.060
.XX = ±.040
.XXX = ±.020

ANGULAR = ±°
FRACTIONAL = ±

SURFACE FINISH

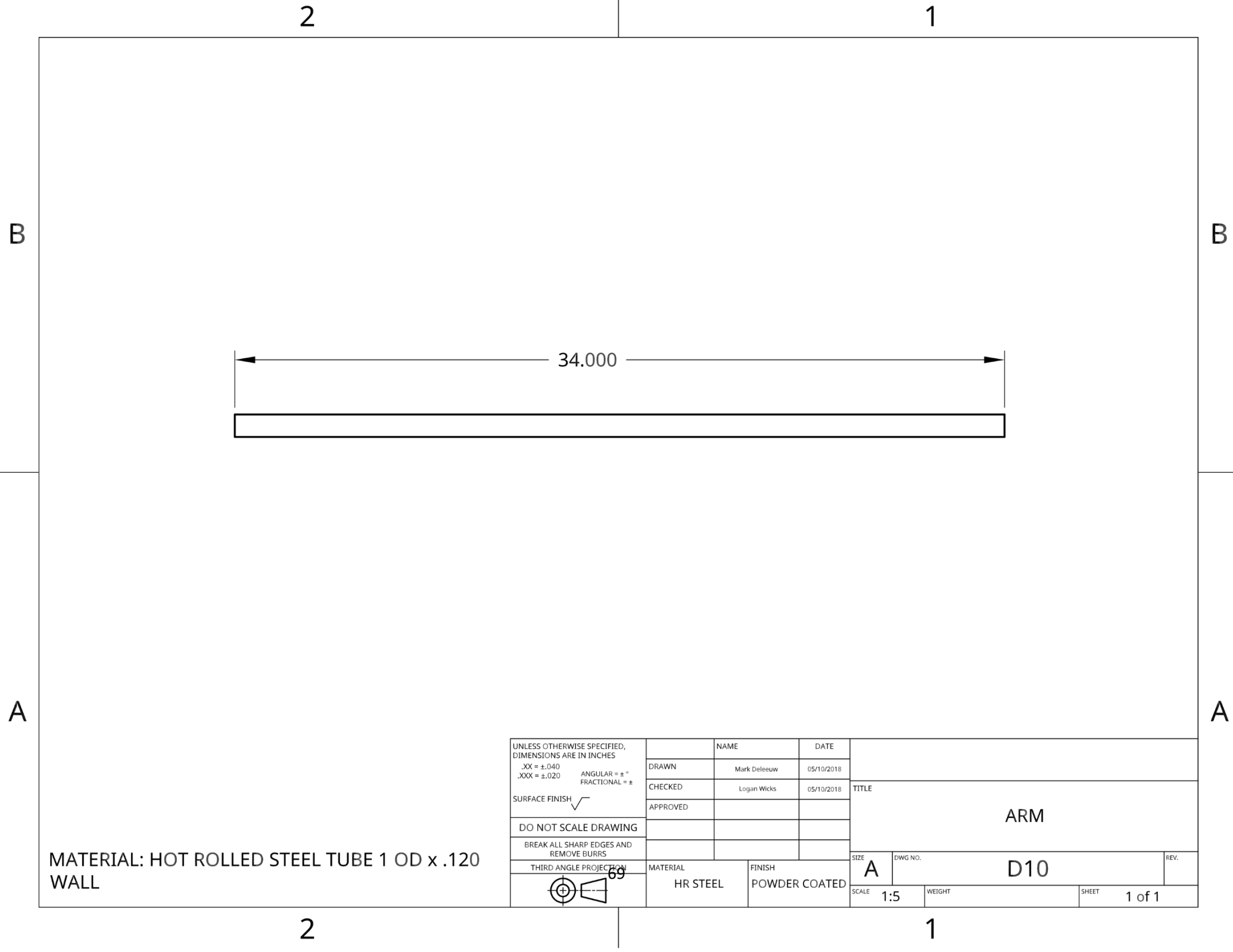
DO NOT SCALE DRAWING



BREAK ALL SHARP EDGES AND
REMOVE BURRS

THIRD ANGLE PROJECTION



	NAME	DATE	TITLE SPACER		
DRAWN	Mark Deleeuw	05/10/2018			
CHECKED	Logan Wicks	05/10/2018			
APPROVED					
MATERIAL	PLA	FINISH APPLE RED SPRAY PAINT	SIZE A	DWG NO. D9	68
			SCALE 2:1	WEIGHT	SHEET 1 of 1
				REV. -	



UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES .XX = ±.040 .XXX = ±.020 SURFACE FINISH  DO NOT SCALE DRAWING BREAK ALL SHARP EDGES AND REMOVE BURRS THIRD ANGLE PROJECTION 		NAME	DATE	TITLE ARM		
	DRAWN	Mark Deleesuw	05/10/2018			
	CHECKED	Logan Wicks	05/10/2018			
	APPROVED					
	MATERIAL	FINISH		SIZE	DWG NO.	REV.
	HR STEEL	POWDER COATED		A	D10	
	SCALE		1:5	WEIGHT		SHEET
						1 of 1

MATERIAL: HOT ROLLED STEEL TUBE 1 OD x .120
WALL