Multi-Vehicle Hitch Carrier

Senior Design Proposal submitted to the
Department of Mechanical and Materials Engineering
College of Engineering and Applied Science
University of Cincinnati

in partial fulfillment of the
requirements for the degree of

Bachelor of Science

in Mechanical Engineering Technology

by

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Problem Statement

Many people transporting motorcycles, dirt bikes, and small utility vehicles have a difficult time maneuvering a traditional ball-and-hitch trailer due to the overall length it adds to the vehicle as well as the constant opportunity for the trailer to jackknife/fishtail. By creating a hitch carrier that utilizes trailing wheels at the rear, backing up no longer allows the opportunity for jackknifing/fishtailing. It also shortens the overall length of the system, allowing for much easier maneuverability and storage when not in use. Adding trailing wheels at the back also provides the ability to add a shock absorber in the front which will help mitigate and reduce stress on the tongue of the hitch as well as on the suspension of the vehicle being used. It will also allow for a substantial load to be carried, such as 2 full size motorcycles or a single all-terrain vehicle, utility terrain vehicle, or golf cart which many current products are incapable of offering. The load capacity for this carrier will be 1500 lbs.

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Research

Background of the Problem

One of the fundamental issues with a traditional ball-and-hitch trailer is backing it up. As Peggy Dent states in her article at the Thousand Trails Park, “this lack of experience (backing up a trailer) is evident by the amount of visible damage to the sides and basements on their rigs.” (1). Not only can this damage be visually unappealing, but it can potentially damage the functionality if the structure or drivetrain of the trailer is struck with force. Another issue with trailers, specifically motorcycle or flatbed trailers, is their added length. Often times space at the destination, such as a vacation house or campground, is limited. This makes storing the trailer an issue, especially if the parking space is needed for additional vehicles.

Many times, people haul smaller vehicles such as motorcycles, all-terrain vehicles, utility terrain vehicles, and golf carts to their destination to get around easily or go on adventures while on vacation. Currently, many haul these vehicles by utilizing a normal trailer due to their loads weight and size. There are several options for vehicle hitch carriers on the market, but most of them are only rated to carry dirt bikes which are much lighter and narrower than standard motorcycles. Additionally, it allows you to tow vehicles behind an existing 5th wheel trailer, a process referred to as “triple towing”. For example, a truck is towing an RV and attached to the rear of the RV is another trailer. This is not legal in every state, and can be tricky when driving, especially maneuvering in tight spaces.

The Ohio Revised Code does not list a clear distinction as to what differentiates a trailer from a hitch carrier. However, due to this product being fixed to the hitch of the vehicle and not sitting on top of and being drawn by a traditional ball hitch, it was understood that these two items are in fact different in nature. There are 5 different hitch sizes: Class I, Class II, Class III, Class IV, and Class V. The higher the class, the more substantial load the vehicle can carry. This product will be built for Class III, IV, and V usage due to the receiver accepting 2” x 2” square tubing into the receiver hitch. Class III and IV are also the most common for large Sport Utility Vehicle (SUV) and Truck hitches due to their more heavy duty suspensions.

Applicable Standards

Standard No. 108 of the Federal Motor Safety Vehicle Safety Standards

- S55.1.1.15: A trailer that is less than 6ft in overall length, including the trailer tongue, need not be equipped with front side marker lamps and front side reflex reflectors.

Ohio Revised Code

- Section 4501.01 Motor Vehicle Definitions
    - (M) “Trailer” means any vehicle without motive power that is designed or used for carrying property or persons wholly on its own structure and for being drawn by a motor vehicle, and includes any such vehicle that is formed by or operated as a combination of a semitrailer and a vehicle of the dolly type such as that commonly known as a trailer dolly, a vehicle used to transport agricultural produce or agricultural production materials between a local place of storage or supply and the farm when drawn or towed on a public road or highway at a speed greater than 25 miles per hour, and a vehicle that is designated and used exclusively to transport a boat between a place of storage and a marina, or in and around a marina, when drawn or towed on a pubic road or highway for a distance of more than 10 miles or at a speed of more than 25 miles per hour. “Trailer” does not include a manufactured home or travel trailer.
- Section 4503.312 Manufacturer or Distributor of Utility Vehicle (2):
    - “Utility trailer” means any trailer, except a travel trailer or trailer for transporting watercraft, having a gross weight of less than 4,000 lbs.
- Section 4513.05 Tail Lights and Illumination of Rear License Plate (3):
    - Every motor vehicle, trackless trolley, trailer, semitrailer, pole trailer, or vehicle which is being drawn at the end of a train of vehicles shall be equipped with at least one tail light mounted on the rear which, when lighted, shall emit a red light visible from a distance of 500 feet to the rear, provided that in the case of a train of vehicles only the tail light on the rearmost vehicle need be visible from the distance specified.

- Either a taillight or a separate light shall be constructed and placed as to illuminate with a white light the rear registration plate, when such registration plate is required, and render it legible from a distance of fifty feet to the rear. Any taillight, together with any separate light for illuminating the rear registration plate, shall be so wired as to be lighted whenever the headlights or auxiliary driving lights are lighted, except where separate lighting systems are provided for trailers for the purpose of illuminating such registration plate.

State of the Art

A).

Commented [CM(2]: Add caption to images.

Figure 1: Swivelwheel (4)

Pros:

- Can fit 2 full size motorcycles
- Adjustable height
- DOT approved lighting

Cons:

- Only 1,000lb load capacity

- No suspension
- Top platform is wood, which is prone to deterioration
- Price
- No ramp for easy loading

B).

Figure 2: Versa-Haul VH-55 (5)

Pros:

- Has 2 rails
- Lightweight (138 lbs)
- Adjustable tie downs and wheel stops

Cons:

- Only 600lb total capacity, or 500lb per rail
- Width between rails (12.75”) is too narrow for two average sized motorcycles, which are 33” wide
- Width of rail (5.5”) is too narrow for average motorcycle tires width of 6.25”

C).

Figure 3: Heavy Duty Basket Cargo Carrier with Ramp (6)

Pros:

- Ramp allows easy loading
- Folds up against vehicle when not in use
- Durable steel frame

Cons:

- 500lb load capacity
- Width (33”) is too wide to fit 2 average motorcycles
- Overall length (60”) is too short to fit most touring and cruiser motorcycles who have a wheelbase of 60” or more

End User

The end user of this product is anyone who currently uses a trailer to transport small vehicles, such as motorcycles, dirt bikes, all-terrain vehicles, utility terrain vehicles, golf carts, or riding lawn mowers. This product can also be used as a general use heavy-duty cargo carrier due to its high load capacity of 1500lb. It also can be used behind an existing 5^{th} wheel trailer, a process known as “triple towing” in states where it is legal.

Summary of Research

After thorough research, there does not seem to be a great solution to this issue. The best solution is the Swivelwheel (4). However, due to the wood platform, lack of rails to keep tires contained, and lack of suspension, this product is not optimized. All of the other options available on the market are not rated for the load capacity of 1500lbs that this product will be. This hitch carrier will allow one to carry 2 motorcycles, or 1 small utility vehicle such as an ATV, UTV, golf cart, or riding lawnmower with ease while taking up minimal space when travelling down the road or storing when not in use. Research also showed that only 1 of these existing products has a trailing wheel at the rear, however it does not have a suspension. By adding a shock absorber/damper to this, bumps and undulations in the road will no longer cause a high impact force on the tongue of the hitch and the suspension of the vehicle. This will result in less stress and wear and tear on both the vehicle and hitch carrier’s frame and suspension.

Quality Function Deployment

Customer Features

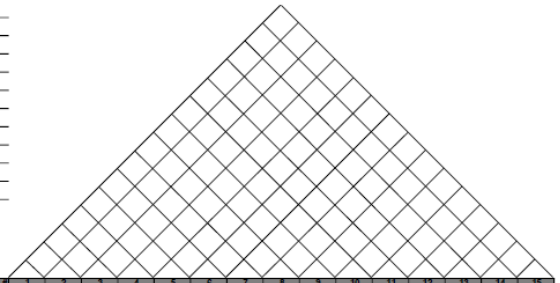
After reading online forums, customer reviews and watching several "Do It Yourself" project videos, I had a more clear idea of what features this solution needed to have. To further investigate and confirm these features, I created a survey that was posted on several adventure/off-roading forums on Reddit. Within several days I had dozens of responses and over 1,000 views on this post. There were also several interactions in the comments with some people's thoughts on how they would tackle this issue. This survey asked the participants to rank the following factors from 1-5, with 5 being the most important: initial cost, overall size, load capacity, compatibility, ease of use, weight, ability to attach behind existing 5^{th} wheel trailer/RV. These factors will be weighed and used as the driving factors in my design.

Engineering Characteristics

From these forums and the responses, I was able to come up with the following engineering characteristics that will be used in my house of quality. These characteristics were: material selection, joining/fasteners, load distribution, overall size, and weight.

House of Quality

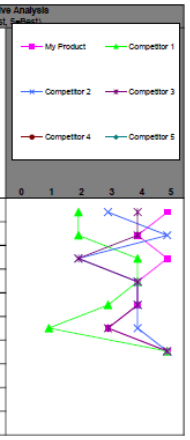
Title: House of Quality for Vehicle Hitch Carrier
Author: Will Mnich
Date: 9/20/2023
Notes:



Legend		
Θ	Strong Relationship	9
O	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
−	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
X	Objective Is To Hit Target	

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Material Selection	Joining/Fasteners	Load Distribution	Overall Size	Weight	My Product	Competitor 1	Competitor 2	Competitor 3	Competitor 4	Competitor 5
				Column #	1	2	3	4	5						
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)											
1	9	18.9	7.0	Cost	Θ	Θ	▲	O	O	5	2	3	4		
2	9	18.9	7.0	Size	O	▲	O	Θ	Θ	4	2	5	4		
3	9	24.3	9.0	Load Capacity	Θ	Θ	Θ	O	O	5	4	2	2		
4	9	8.1	3.0	Compatibility	▲	▲	O	Θ	Θ	4	4	4	4		
5	9	5.4	2.0	Ease of Use	▲	▲	▲	O	Θ	4	3	4	4		
6	9	21.6	8.0	Weight	Θ	O	O	Θ	Θ	3	1	4	3		
7	3	2.7	1.0	Ability to Attach Behind 5th Wheel Trailer/RV	▲	▲	O	O	O	5	5	5	5		
8															
9															
10															
				Target or Limit Value	$2,000				350lbs						
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	2	2	9	8	5						
				Max Relationship Value in Column	9	9	9	9	9						
				Weight / Importance	656.8	489.2	397.3	591.9	624.3						
				Relative Weight	23.8	17.7	14.4	21.4	22.6						

Competitive Analysis (0=Worst, 5=Best)



Product Objectives

The most important aspect of this design will be its ability to withhold a high load capacity of 1500lb. This will allow the user to carry 2 full size motorcycles or a single all-terrain vehicle, golf cart, or utility terrain vehicle. The next most important aspect is the overall weight of the product. This is primarily due to storage as many people are not going to keep this outside and would like to be able to flip it up along and lean it against the side of their garage wall inside. The cost and size of this product are also to be kept to a minimum. These two items are directly correlated, as the larger the structure is, the more materials used, and thus the higher price.

Concepts and Design

Concept 1

Basket

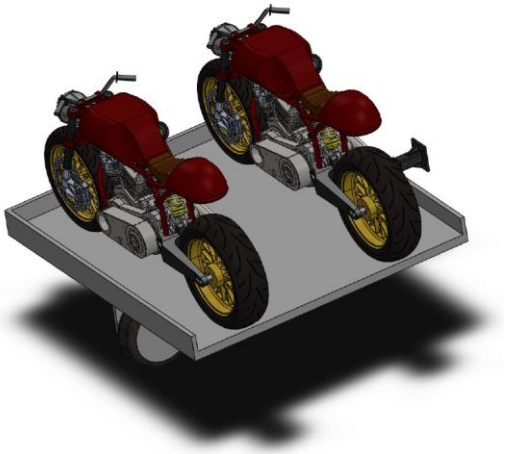


Figure 4: Concept 1 (Basket)

This first concept is the most basic and is more like what the one existing product on the market has to offer. Given its simplistic design, it would be the most versatile and would accept the widest range of loads. Due to the sidewalls, it could also double as a normal utility hitch carrier for cargo when not in use for vehicles.

Concept 2

Pocket

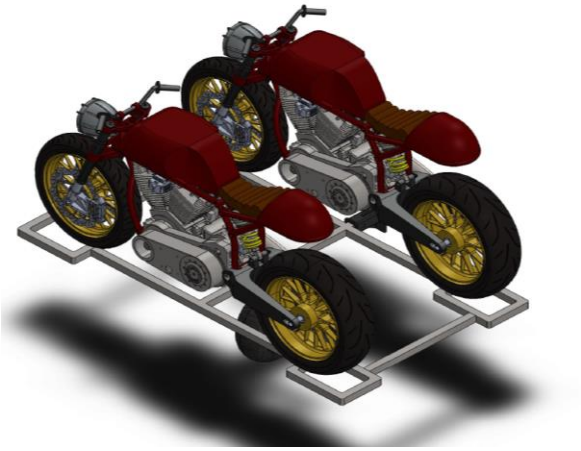


Figure 5: Concept 2 (Pocket)

The second concept would allow the vehicles tires to fit into a pocket, securing them from wobbling and moving while in motion. However, this design is the least versatile do to the fixed pockets. If the wheelbase of your vehicle was either too long or too short, it would be unusable.

Concept 3

Rail

Figure 6: Concept 3 (Rail)

Concept 3 is the design that I ultimately ended up going with. The rail design encapsulates the tire, adding an additional level of security and rigidity that is common on most motorcycle trailers today.

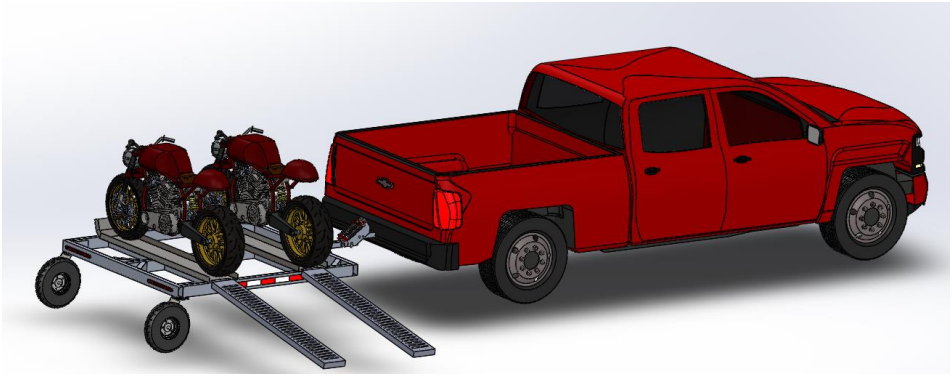


Figure 7: Final Model

Figure 7 shows the finalized model of the product. One of the biggest differences when compared to concept 3 is the two-wheeled design as well as the addition of rear DOT approved brake lights and side markers. Having the two wheels in the outside was needed because it allows the system to carry the load capacity of 1500lb. The wheel and tire package selected was the smallest package available that was rated for highway speeds. The reason I went with the smallest available tire was because the wheels need to rotate 360-degrees underneath of the frame, so adding a bigger tire would raise your center of gravity substantially as well as not be able to attach directly into the hitch receiver on your vehicle without creating a drop-system to account for the raised height on the bottom of the frame. In this design, the rails are also going the same way which was another design change from concept 3. The main frame of the structure was made from 6061-T6 Aluminum to keep the weight of the product light enough to handle and maneuver alone when putting into or removing from storage up against a wall.

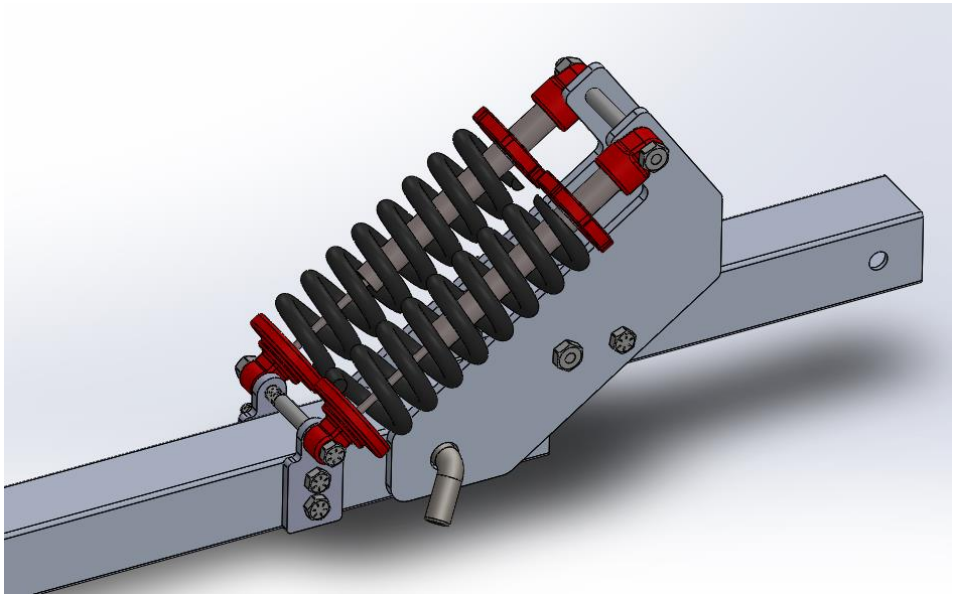


Figure 8: Front Suspension

Seen above is the suspension part of the products frame. The hole on the right is where the hitch pin goes, and the system connects to your vehicle. I decided on these shocks because of their max load rating of 950lb/pc. This is more than the 1500lbs needed. This dual-shock design was an improvement over the initial mono-shock design. This decision was made based on available shocks that would fit within the work area I had to operate within, as none this size were capable of a max load of the 1500lb needed. The shocks used were sourced from a 1000cc ATV. This system works so as you travel down the road and go over bumps and undulations in the road, the shocks will compress and pivot around the bottom hitch pin (seen in the middle) since both end of the shocks are fixed to the different parts of the frame and tongue. This allows for the forces and stress to be dampened and not translated to the welded joints of the products frame or the vehicles frame.

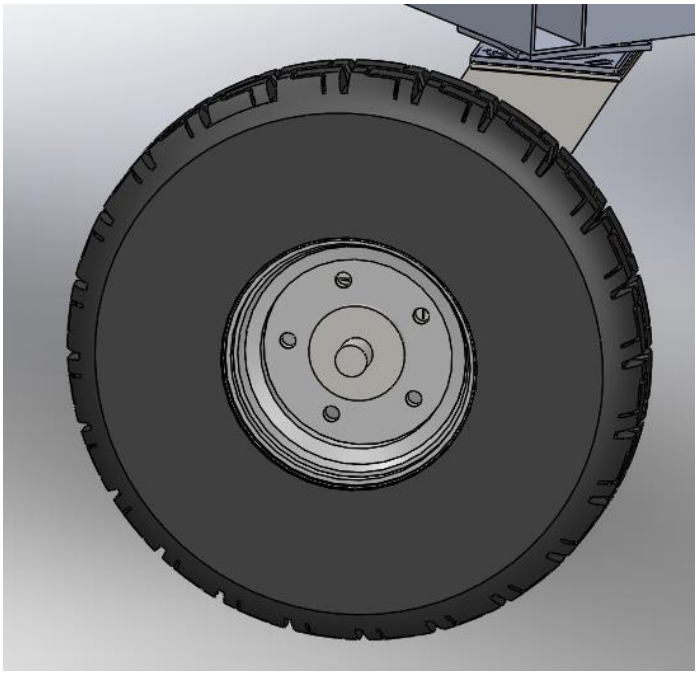


Figure 9: Caster Wheels

Above is a view of how the wheels can swivel underneath the frame. To accomplish this, I have used industrial strength caster plates (seen in light grey directly under the frame) with custom fabricated brackets to attach the axle-less spindle hub to the caster plate. As seen above, there is not a lot of clearance between the bottom of the mount and the top of the tire. As was mentioned earlier, this part of the product is what controls the “ride height” of the system. By going to a larger wheel or creating more clearance, you raise the center of gravity and the bottom of the frame, which affects how level the system would be when attached to the hitch receiver on the vehicle.

Calculations and Loading Conditions

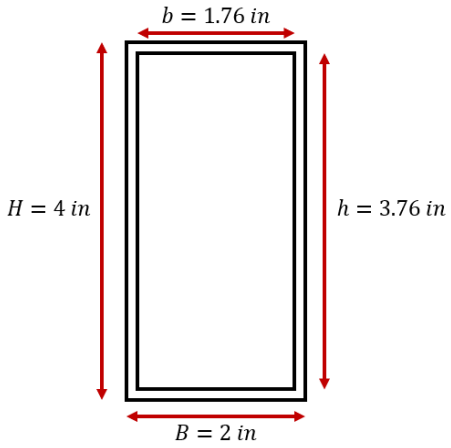


Figure 10: Main Frame Dimensions

Section Modulus
A36

$$S_{min} = \frac{M}{\sigma_d} = \frac{12{,}200\ lb * in}{21{,}712.23\ psi} = \mathbf{0.562\ in^3}$$

$$S_{rectangular\ section} = \frac{BH^2}{6} - \frac{bh^3}{6H}$$

$$= \frac{2 * 4^2}{6} - \frac{1.76 * 3.76^3}{6 * 4}$$

$$= \mathbf{1.435\ in^3}$$

$S_{min} < S_{rectangular\ section}$

Since the calculated minimum section modulus is less than that of the section modulus for the given material selection, I can confirm that the material chosen will be suitable for this project.

Section Modulus
6061-T6

$$S_{min} = \frac{M}{\sigma_d} = \frac{12{,}200\ lb * in}{22{,}480.85\ psi} = \mathbf{0..543\ in^3}$$

$$S_{rectangular\ section} = \frac{BH^2}{6} - \frac{bh^3}{6H}$$

$$= \frac{2 * 4^2}{6} - \frac{1.76 * 3.76^3}{6 * 4}$$

$$= \mathbf{1.435\ in^3}$$

$S_{min} < S_{rectangular\ section}$

Since the calculated minimum section modulus is less than that of the section modulus for the given material selection, I can confirm that the material chosen will be suitable for this project.

Figure 11: Section Modulus Calculations

Factor of Safety

A36

$$F.O.S = \frac{capacty}{demand} = \frac{ultimate\ tensile\ strength}{design\ stress} = \frac{S_u}{\sigma_d}$$

$$= \frac{58{,}015\ psi}{21{,}712.23\ psi}$$

$$= \mathbf{2.67} > \mathbf{1}$$

6061-T6

$$F.O.S = \frac{capacty}{demand} = \frac{ultimate\ tensile\ strength}{design\ stress} = \frac{S_u}{\sigma_d}$$

$$= \frac{44{,}961.69\ psi}{22480.85\ psi}$$

$$= \mathbf{2.0} > \mathbf{1}$$

Figure 12: Factor of Safety Calculations

For my main frame, I decided to use 2” x 4” x 0.125” square tubing. I decided to go with these dimensions because when I calculated the section modulus and factor of safety, they were acceptable and within range of my needs. When deciding between the two materials (A36 steel and 6061-T6 aluminum) I looked back to my engineering characteristics and was reminded how important the total weight was. Since A36 steel is roughly 300% heavier than 6061-T6, I went ahead and went with the Aluminum tubing. Another added benefit of using Aluminum is its corrosion resistance. Since steel rusts, I would’ve had to paint the raw material after it was welded to seal and protect it from corrosion.

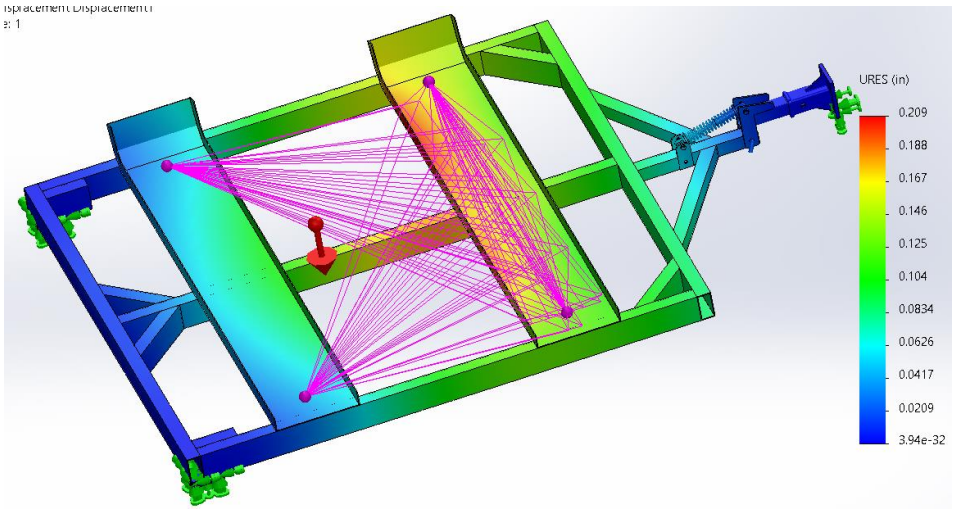


Figure 12: Finite Element Analysis

Shown above is a displacement graph from a finite element analysis completed using SolidWorks. The main frame is 2” x 4” x 0.125” 6061-T6 aluminum and the front tubing is 2” x 2” x 0.125” 6061-T6 Aluminum. The rails are 0.125” Hot Rolled Mild Steel. Each of these pink dots represents a 400lb spot load onto the rails, for a total of 1600lbs, 7% more than my max load rating of 1500lb. It is also 14% more than the average touring motorcycle wright of 700lbs and 50% more than the average motorcycle weight of 400lbs. The distance between these two-point loads was determined by measuring the distance of my personal motorcycle’s wheelbase and using that as a guide. Due to the minimal displacement shown above, I determined that this configuration is safe to use and weld together.

Fabrication and Assembly

Figure 13: Rough Layout

A heavy majority of the fabrication process was done at my personal workshop, which helped cut down on cost since I had access to nearly everything I needed. Figure 13 shows a rough final layout of how things would be welded together. To get to this stage, I used my miter saw with a non-ferrous blade. Since I also had several steel components, I had to use a jig saw, die grinder, and abrasive wheel to cut those since the miter saw was not capable of doing so. I also used my vertical mill to trim and square up the steel components that needed to be tightly fitted and welded together.

Figure 14: Welding

Since I did not have access to a working TIG welder, I had to outsource this. I was fortunate enough to have someone I know offer to help me through this process. The top and bottom parts of my aluminum frame were all TIG welded, with the interior welds being MIG using a special Aluminum spool gun. All the steel components of the project I personally welded using the MIG machine I have at my own workshop.

Test Plan

In order to ensure this project works successfully, I had to test it at different load levels and speeds. In order to do this, I followed the following plan:

1). Slow speed maneuverability in parking lot, no load

2). Slow speed maneuverability in parking lot, 500lb load

3). Static load with 1 motorcycle 750lb load and slow speed maneuverability

4). Static load with 2 motorcycles 150lb load and slow speed maneuverability

5). 45mph test, no load

6). 45mph test, 500lb load

7). 45mph test 750lb load

8). 45mph test, 1500lb load

9). 65mph test, no load

10). 65mph test, 500lb load

11). 65mph test, 750lb load

12). 65mph test, 1500lb load

Unfortunately, I had a failure during step 2 (slow speed maneuverability with 500lb load) that caused the custom fabricated L-bracket that attaches the spindle hub to the top caster mount to bed. This caused the wheel to get pushed up into the bottom side of the caster plate which locked up the rear tire. After bending and pressing this back as straight as possible I welded additional support material and gussets. However, due to the timeline (this was the weekend before the Tech Expo) I was unable to continue with testing.

Project Management

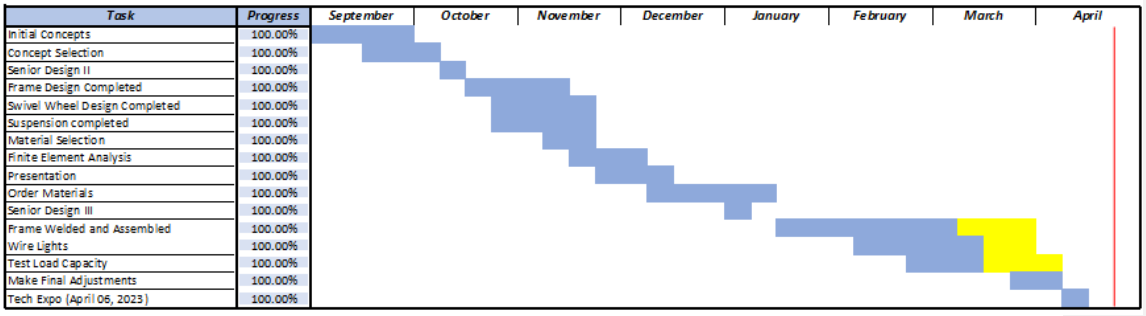


Figure 15: Project Management Gantt Chart

The Gantt chart seen above was how I kept myself organized throughout this process. The blue is how I had originally laid out my plan to completion, and the yellow represents certain aspects in which I fell behind those deadlines. Overall, I was able to stay on track for most of the process and did not experience any major setbacks. One area in which I wish I had more time was testing. Unfortunately, the date of the CEAS Tech Expo was pushed forward, taking away 1-2 additional weeks. Although not tested as thoroughly as I would have liked, I did make it to the Tech Expo with my project.

Project Budget

Part	Description	QTY	Price
Caster Mount	Caster Mount Plate	2	$88.37
Spindle Hub	Spindle Hub	2	$132.55
Wheel and Tire	5x4.5" bolt pattern	2	$69.83
Aluminum Tubing	2in x 4in and 2in x 2in	1	$550.58
Sheet Metal	1/8in	1	$118.57
Steel Plate	1/4 in	1	$15.53
Shocks	ATV 950lb	2	$39.99
Lights	Trailer Lights	1	$19.25
Reflector Tape	2in x 12ft	1	$8.55
Hardware	Misc bolts/nuts/fasteners	1	$75.00

Current Budget: $1,448.96

Figure 16: Final Budget

At the beginning of this process, I gave myself a budget of $1800. I am happy to report that I came in nearly 20% under budget. A big portion of my savings was on raw aluminum and steel. I had several quotes come back and ended up going with the cheapest one, which was nearly 50% of what the other quotes were. Another big savings was an item that was not listed – aluminum welding. I was fortunate to have a family friend offer to TIG and MIG weld the aluminum frame, as I did not have access to a functioning TIG welder. The quote to get this frame TIG welded was just over $1600, which is more than what the entire project cost me.

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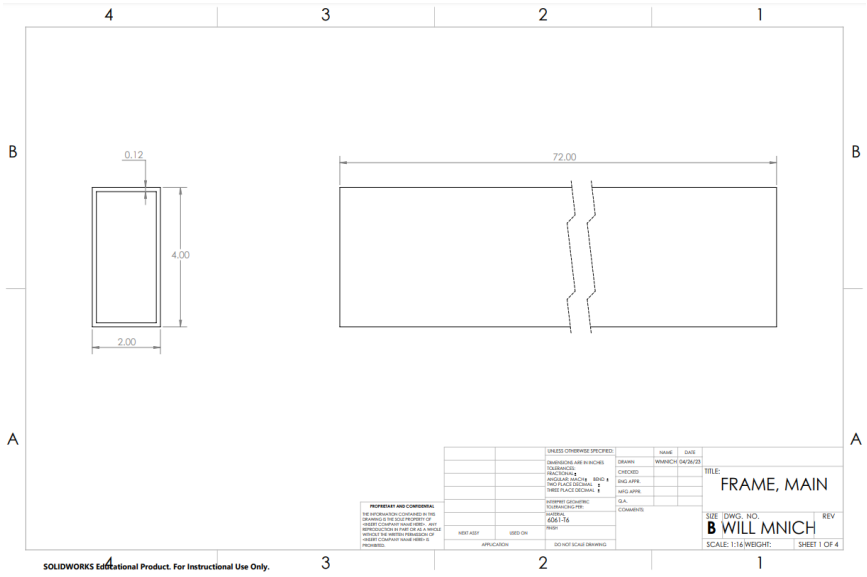
Appendices

Appendix A: Final Assembly

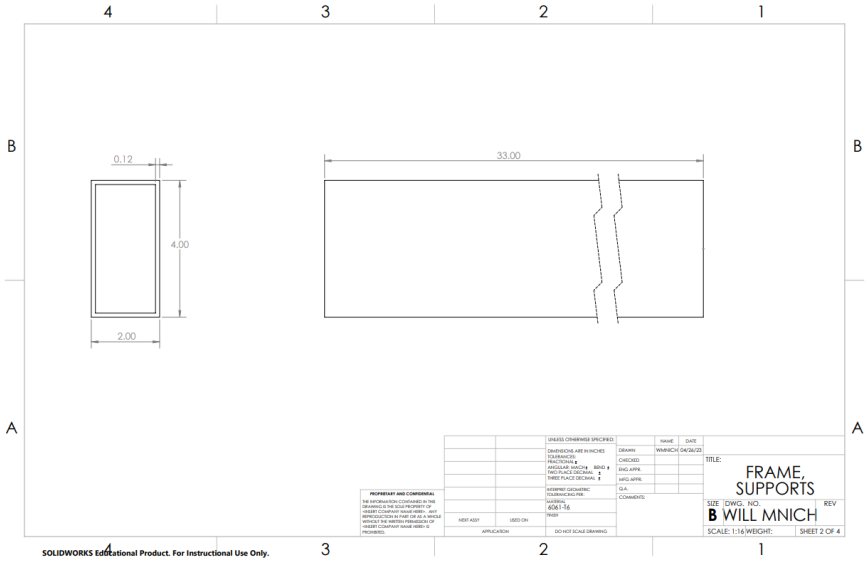
Appendix A.1: Completed Project, Unattached

Appendix A.2: Completed Project, Attached

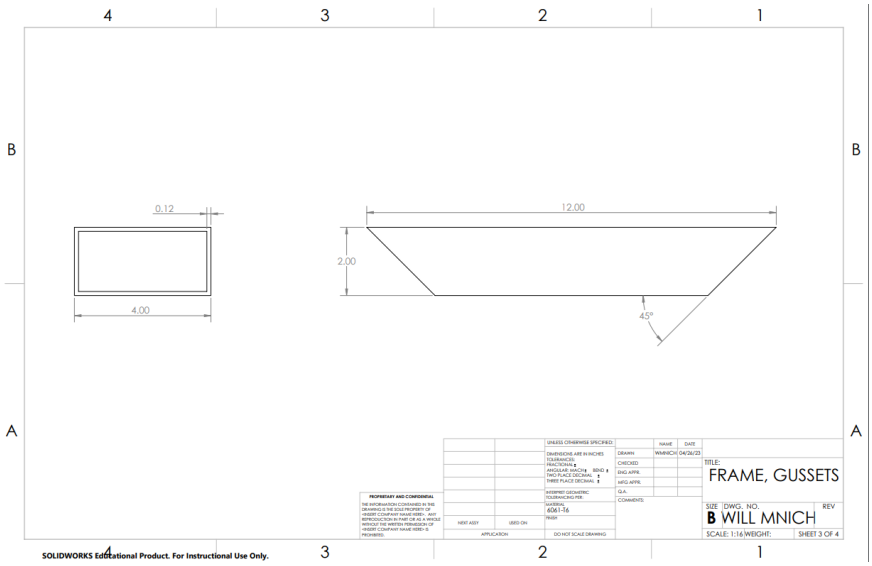
Appendix B: Engineering Drawings



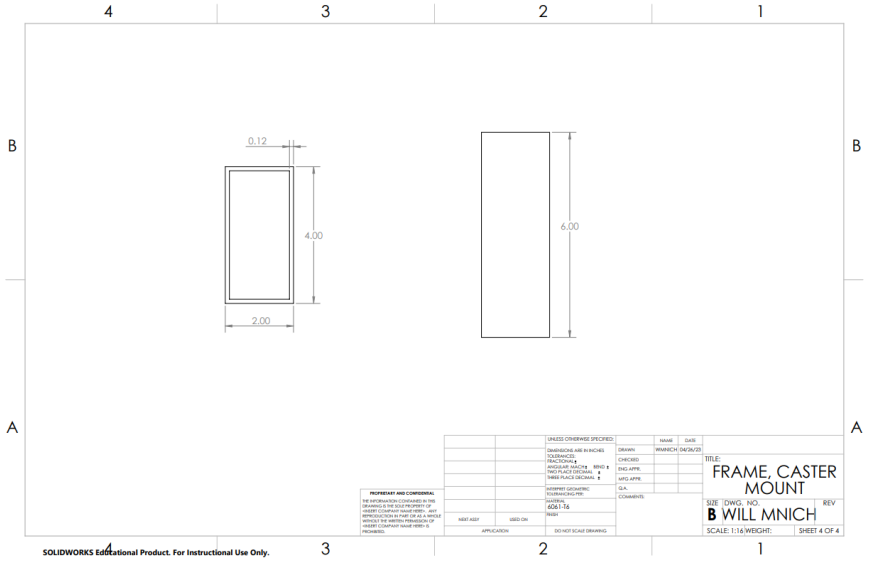
Appendix B.1: Main Frame



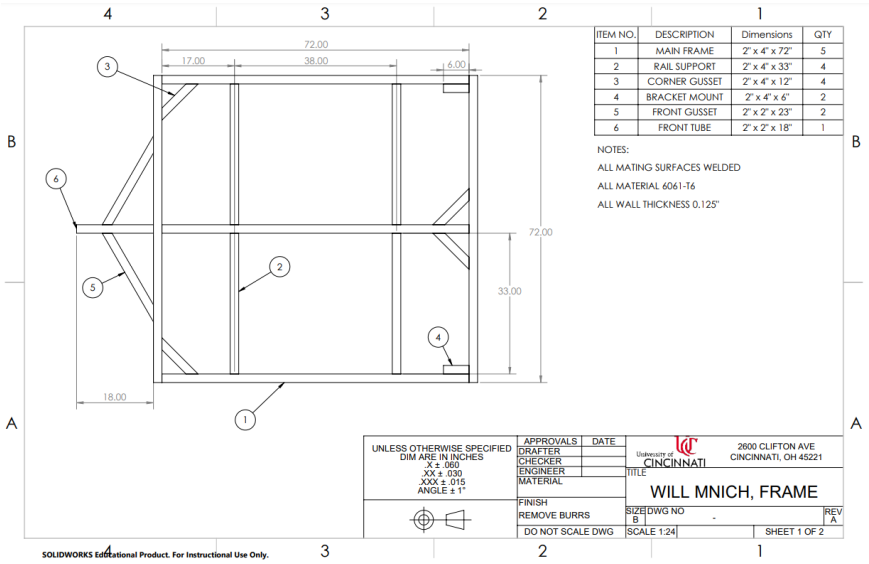
Appendix B.2: Frame Supports



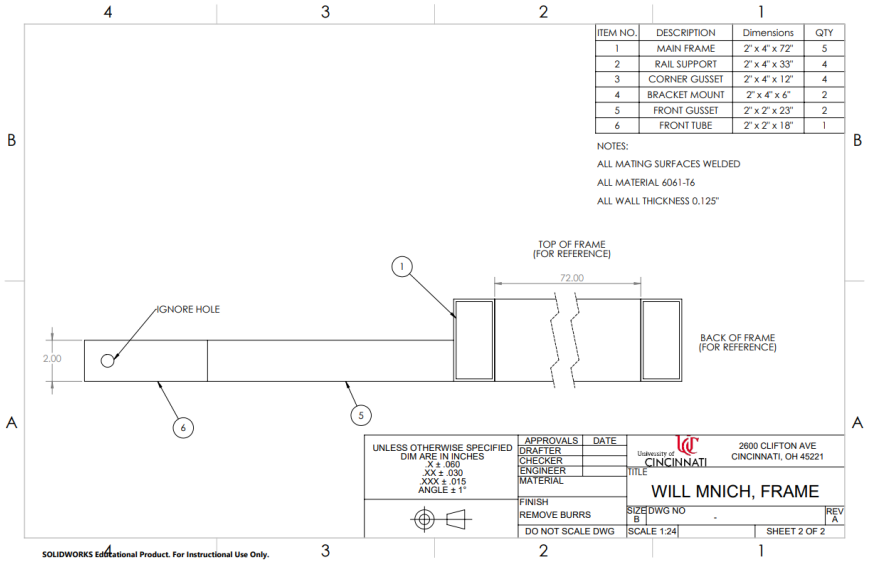
Appendix B.3: Frame Gussets



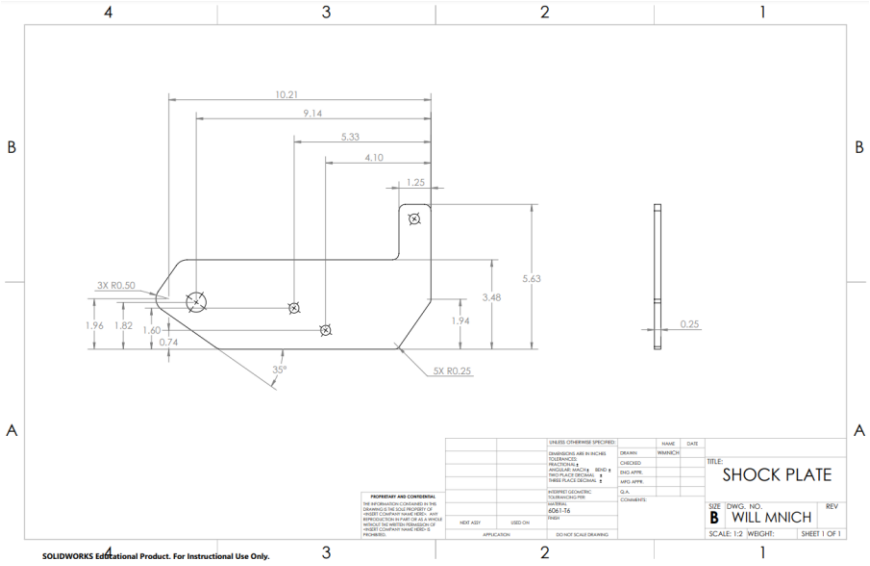
Appendix B.4: Frame Caster Mount



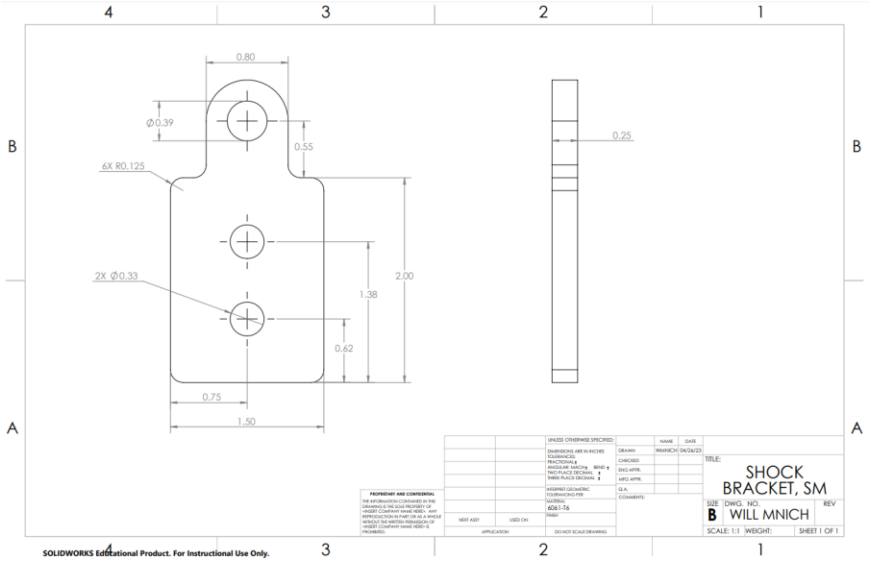
Appendix B.5: Frame Weld Layout



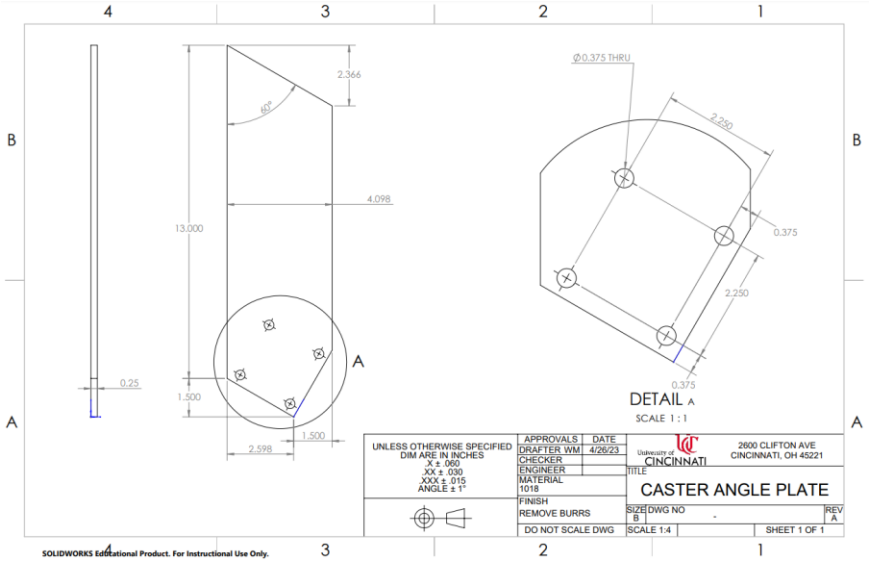
Appendix B.6: Frame Weld Layout, contd



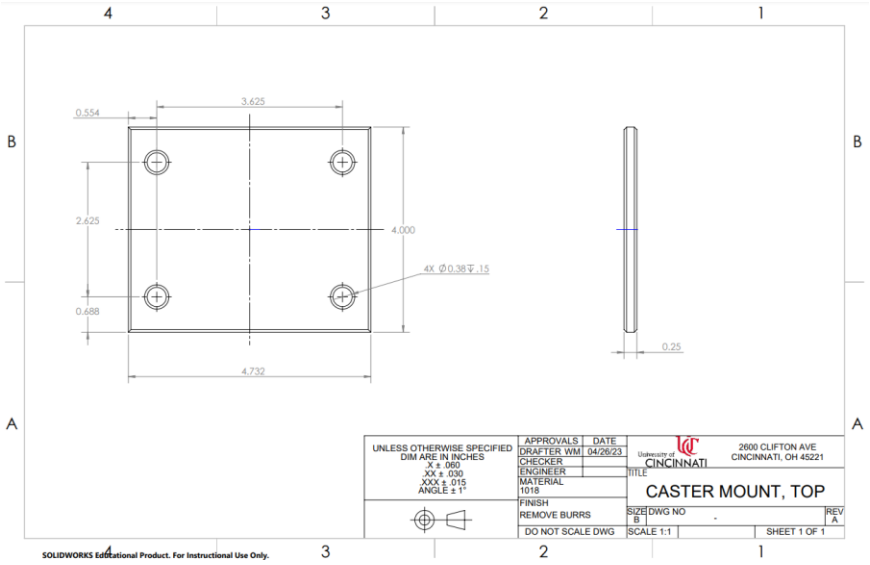
Appendix B.7: Shock Plate



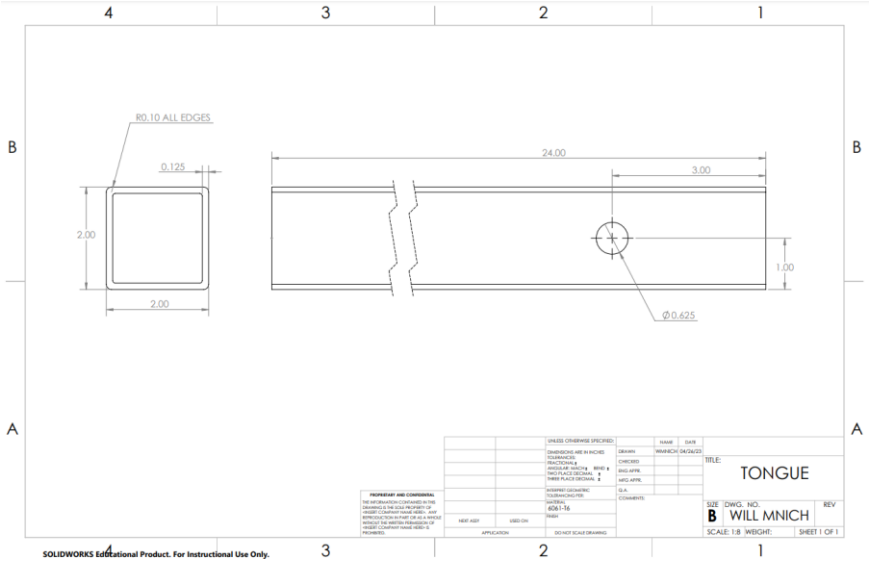
Appendix B.8: Shock Bracket, Small



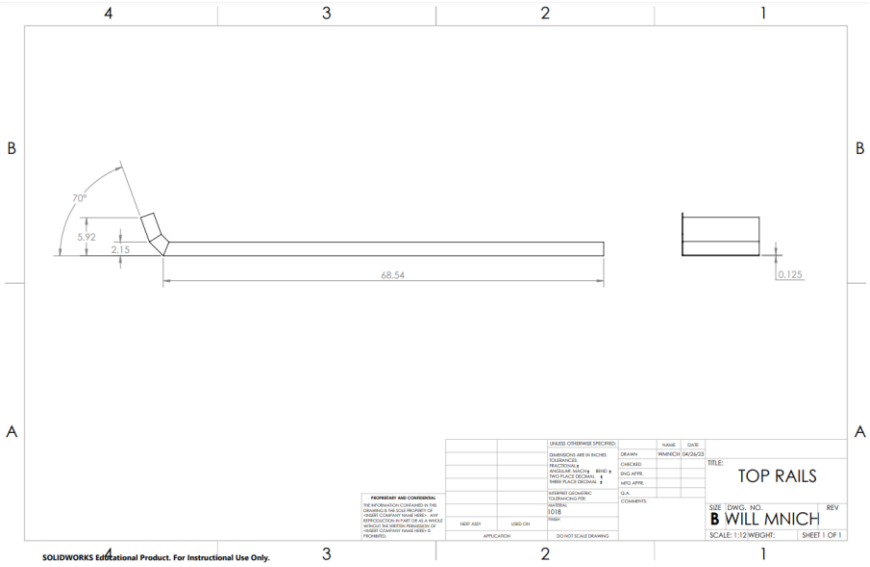
Appendix B.9: Caster Angle Plate



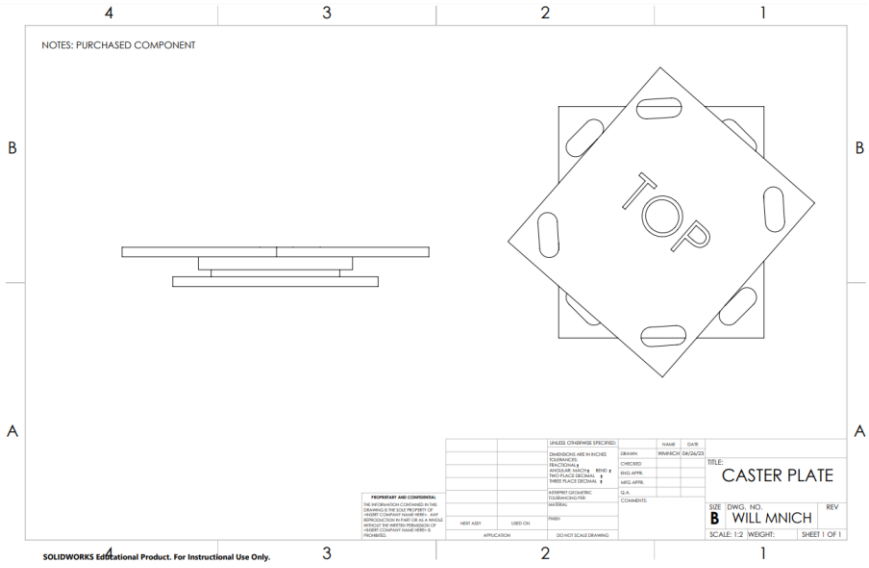
Appendix B.10: Caster Mount, Top



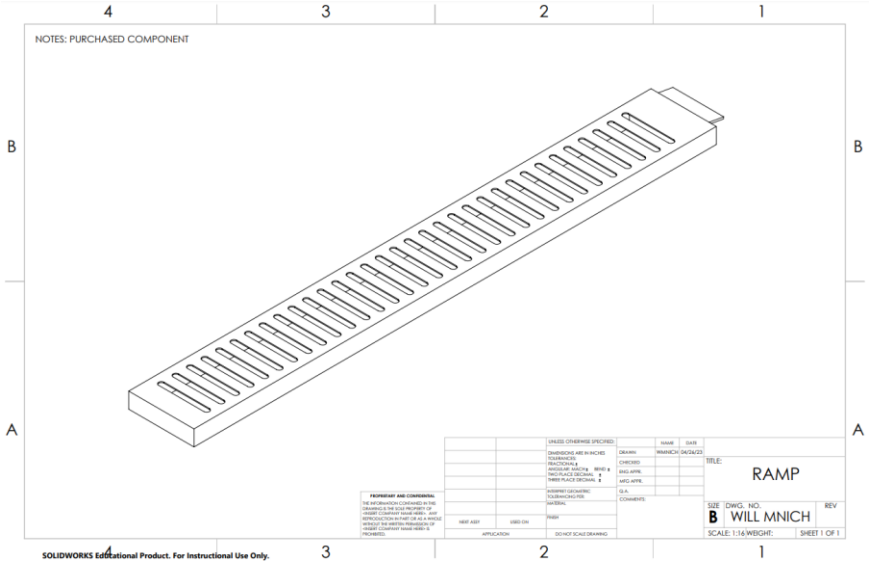
Appendix B.11: Tongue



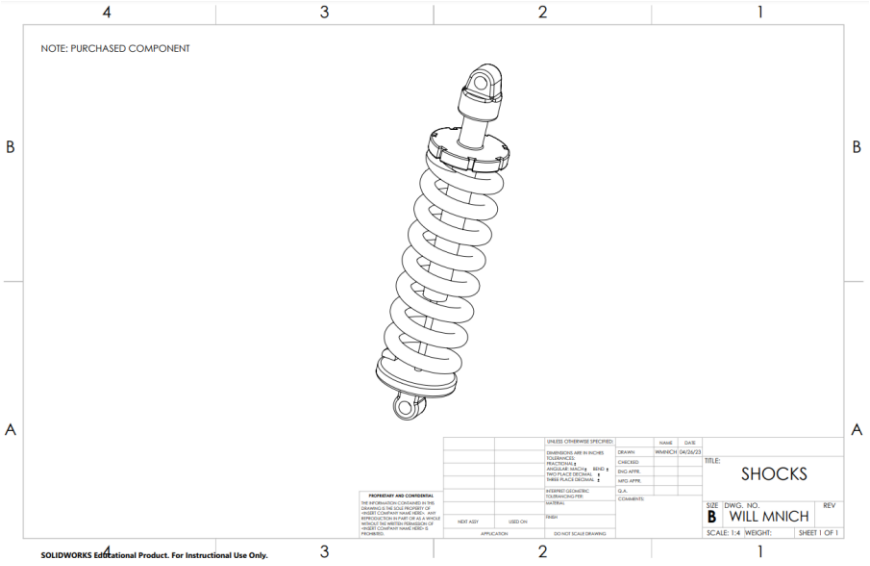
Appendix B.12: Top Rails



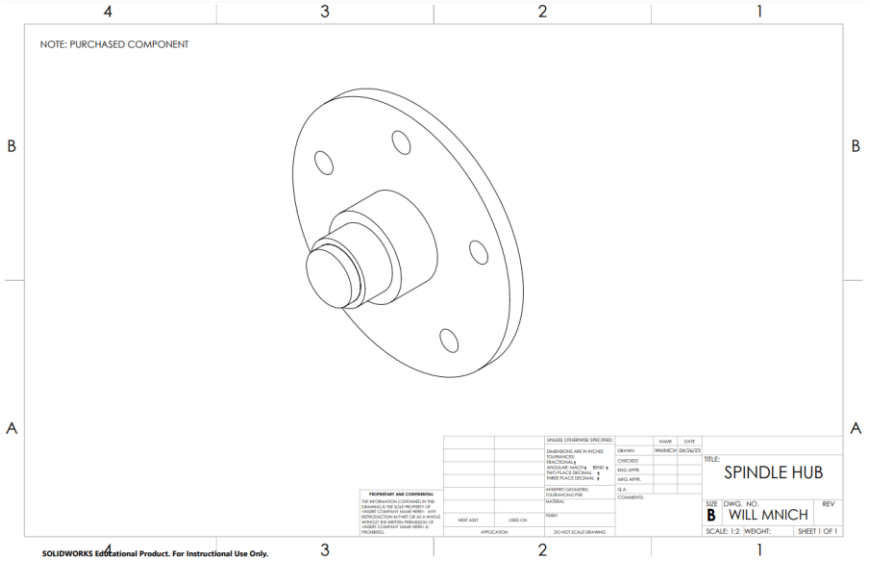
Appendix B.13: Caster Plate



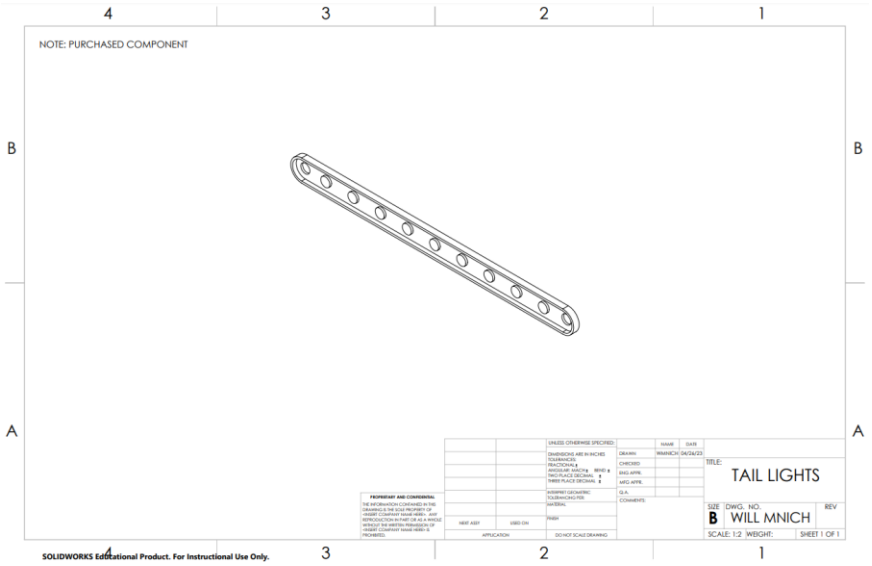
Appendix B.14: Ramp



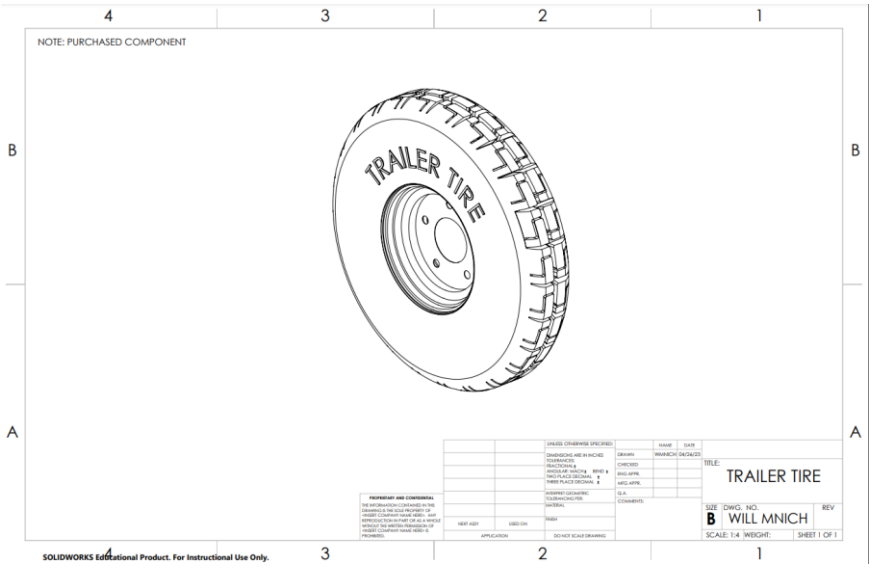
Appendix B.15: Shocks



Appendix B.16: Spindle Hub



Appendix B.17: Tail Lights



Appendix B.18: Trailer Tire