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Fall 2016

### Maneuverable Backpack Scooter Attachment

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Washington University in St. Louis

SCHOOL OF ENGINEERING & APPLIED SCIENCE

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# MEMS 411: Senior Design Final Report

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## Maneuverable Backpack Scooter Attachment

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Alex Roesch  
Andrew Goldfield  
Cosmo Centanni  
Nina Nepa

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The weight of student's backpacks poses a significant health risk and makes transportation via scooter difficult. This project was developed with these considerations in mind in order to create a safer mode of transportation for students.

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## **1 INTRODUCTION**

### **1.1 PROJECT PROBLEM STATEMENT**

A mechanical device that will aid in the collaboration between a scooter and a backpack. Due to the weight of typical backpack, our device will aid the consumer to carry less weight on their backs, and create a device to fold into the scooter so that it nicely fits in a classroom setting. This device will be detachable so that the scooter can be operated without the attachment.

### **1.2 LIST OF TEAM MEMBERS**

Team members include: Alex Roesch, Andrew Goldfield, Cosmo Centanni, and Nina Nepa.

## **2 BACKGROUND INFORMATION STUDY – CONCEPT OF OPERATIONS**

### **2.1 A SHORT DESIGN BRIEF DESCRIPTION THAT DESCRIBES THE PROBLEM**

A mechanical device that will aid in the collaboration between a scooter and a backpack. Due to the weight of typical backpack, our device will aid the consumer to carry less weight on their backs while still being able to control the scooter well. The device will assist with storage of the scooter without hindering the time to unfold the scooter.

### **2.2 SUMMARY OF RELEVANT BACKGROUND INFORMATION**

There are currently a few products on the market that exist with the goal of helping alleviate the difficulty of carrying a backpack while traveling on a scooter. However, neither of these products have been successful in accomplishing our goals of developing an appealing design, minimizing dynamics, and increasing safety. The patent US 20140061267 A1 is for a design of an interchangeable scooter and backpack. This patent does not directly compete with our design, but is a good resource for solutions that have been explored previously.

## **3 CONCEPT DESIGN AND SPECIFICATION – DESIGN REQUIREMENTS**

### **3.1 OPERATIONAL REQUIREMENTS ALLOCATED AND DECOMPOSED TO DESIGN REQUIREMENTS**

The following section contains a customer interview and the operational requirements that were determined as a result. From the operational requirements the design requirements could be determined.

### 3.1.1 List of identified operational and design requirement

This section contains the interview done with a customer on campus. The interview yielded the operational requirements that informed the types design concepts that were created.

**Customer Data:** Back-Pack Scooter Attachment

**Customer:** Alex Roesch

**Address:** Washington University (Student)

**Date:** 24 September 2016

**Table 1: User Needs Interview**

Question	Customer Statement	Interpreted Need	Importance
What type of device do you use to travel?	“I ride my bike to school mostly, but occasionally use my motorized scooter if I’m running late.”	Device needs to be versatile to attach onto both bicycle designs as well as other machines such as razor scooters, and mopeds.	5
Does the weight of your backpack affect your riding?	“Yes, sometimes my backpack is so heavy that it sets me off balance when making turns, or in large crowds.”	Device should shift weight from passenger to riding vehicle so that it doesn’t affect balance/ riding	5
How could you see yourself bringing our device into a classroom setting?	“Our classes are generally pretty cramped, so unless it doesn’t take up a lot of space, it would be hard to take it into my classes.”	Device should fold up into a light and compact form to be able to accommodate cramped classroom settings	5
What safety considerations do you have?	“I just don’t want to use anything that affects the way I normally ride, and keeps my laptop and other electronics safe.”	Device needs to clear rider with ample space so that there isn’t risk of interference as well as added padding/ protection for important objects students typically carry	3
What other additions would you like to see in this device?	“It would be nice to have a charging component during my travel times or during the time spent in class”	Additional electronic component to adhere to electronic devices student carries in backpack	2

Are you worried about ease with function when using this product?	“I’m worried it’ll be too complex of a device and it would just be easier for me to carry my backpack normally.”	Keep the design simple. If it is too difficult to add to vehicle or open/close, the customer just won’t use it.	4
How big is too big?	“I wouldn’t want to interfere with other students when I’m riding. I just want something big enough to hold my backpack.”	Minimize surface area to create a taller structure and utilize space better.	3
What material considerations do you have?	“I would like to see a material that is flexible but also durable, not wooden or anything too heavy.”	Light/flexible/durable material	3

**Figure 1: Operational Requirements**



**Fig. 1:** Chart of the operational requirements by ranking.**Table 2: Operational Requirements - Identified Needs**

Need Number	Need	Importance
1	Ability to attach onto different types of vehicles	5
2	Shift of weight to vehicle	5
3	Fold up into small portable structure	5
4	Safety during ride - does not interfere with normal riding performance	3
5	Minimize surface area parallel to ground - build up	3
6	Light/flexible/durable material	3
7	Extra protection for electronics	2
8	Electronic component - charging capability	2

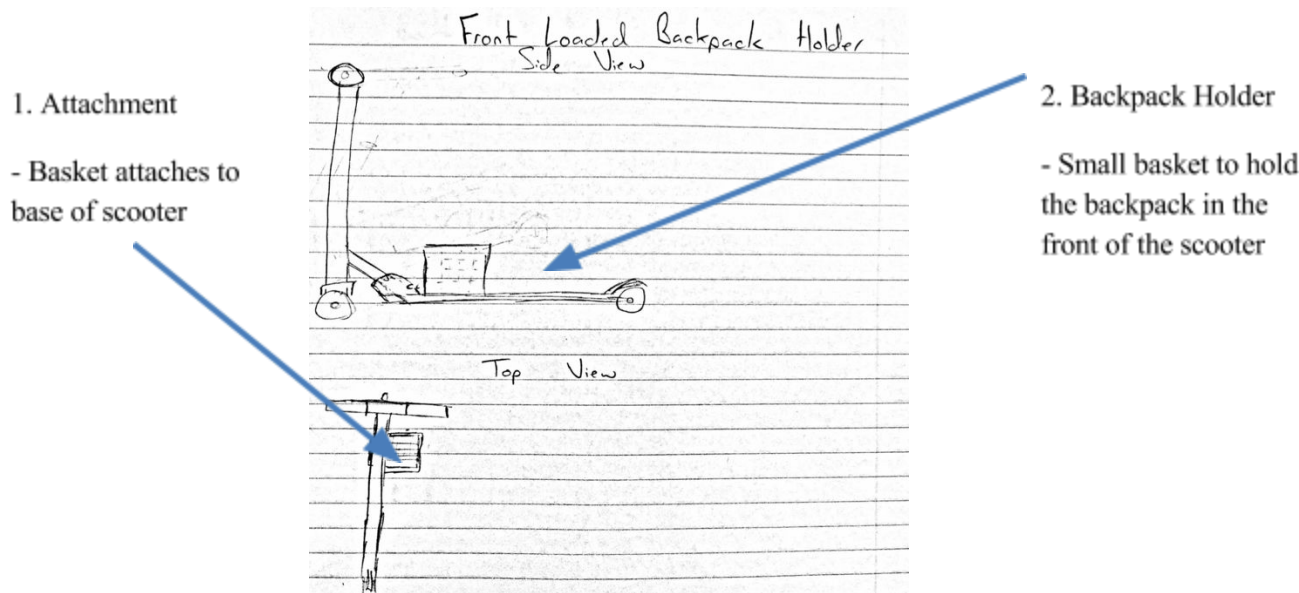
From Table 2, it can be seen that the most important needs are the ability to attach to different types of vehicles, that it does not shift the weight of the vehicle, and that is easy to store. The next most important needs are that it is small, safe, and light. The need that the attachment mechanism does not shift the weight of the vehicle is doubly important because it also relates to the need for safety.

### 3.2 CONCEPT SELECTION PROCESS

The following section details the selection process that we used in order to decide on a single design to prototype and test. A brief description for each design will be given, as well as the scoring system that was used to choose the best design. As well, the section contains the design requirements.

#### 3.2.1 Concept Description

The following section contains initial drawings for the four main concepts as well as brief descriptions for each.

**Concept 1 - Front Loaded Backpack Holder**

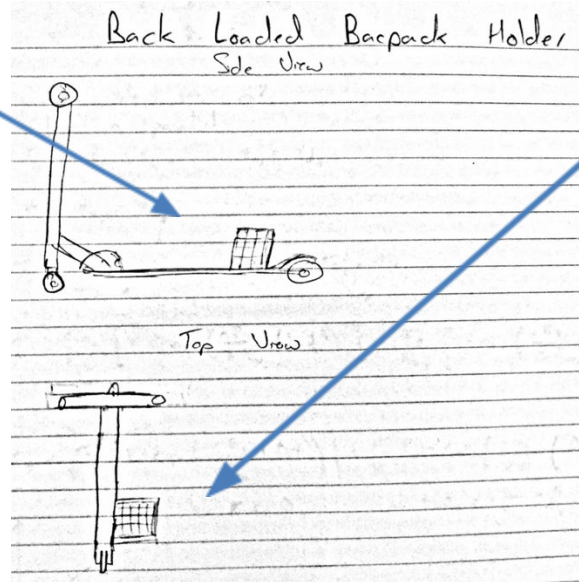
**Fig. 2:** Sketch drawing of the first concept idea for back-loading solution.

Difficulties in designing the backpack holder center on where to place the backpack. This concept focuses on locating the backpack at the front of the scooter's body, near the base of the handlebar. There are multiple mechanisms in play with this designing, such as the ability for the holder to be detachable and fold up. Challenges with producing this design include determining which material would be strong enough to hold the backpack while being light enough to carry in a bag when it is folded up. The primary concern with this design is that with the weight centered at the front of the cart, there is a high potential to flip the scooter if a bump or rock is hit.

### Concept 2 - Back Loaded Backpack Holder

#### 1. Attachment

- Basket attaches to base of scooter

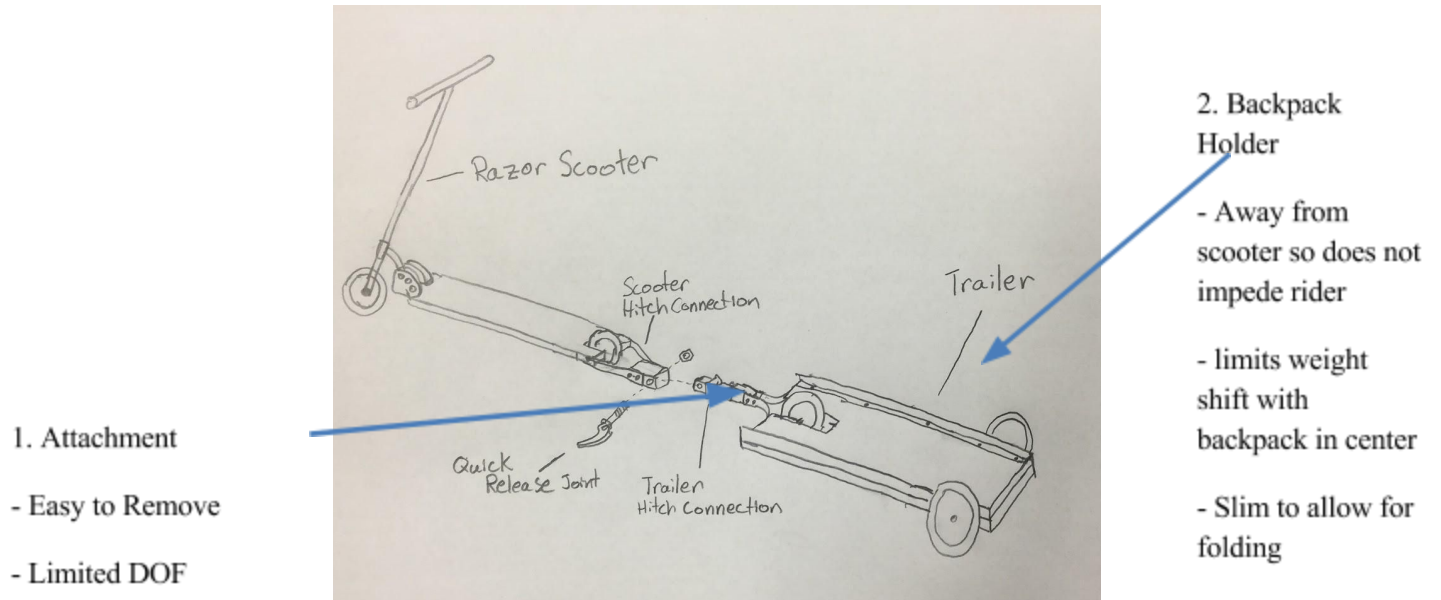


#### 2. Backpack Holder

- Small basket to hold the backpack in the rear of the scooter

**Fig. 3:** Sketch drawing of the second concept for basket on rear.

Difficulties in designing the backpack holder center on where to place the backpack. This concept focuses on locating the backpack at the back of the scooter's body, near the footbrake. There are multiple mechanisms in play with this designing, such as the ability for the holder to be detachable and fold up. Challenges with producing this design include determining which material would be strong enough to hold the backpack while being light enough to carry in a bag when it is folded up. The primary concern with this design is that with the weight centered at the back of the cart, there is a high potential to flip the scooter if a bump or rock is hit. This can be analyzed by summing the moments about the front wheel of the cart.

**Concept 3 - Three-wheeled trailer**

**Fig. 4:** Sketch drawing of final concept design for three wheeled trailer.

This design has an advantage in that larger masses can be placed within without upsetting the balance of the vehicle. The detachable joint makes for easier storage. The 3-wheel design allows for large masses to be placed in the bed of the trailer without causing the front end of the scooter to tip upwards when the user steps off, while also giving the scooter increased maneuverability when turning (when compared to a 4-wheel design). Additionally, the trailer bed has a flanged section around the outside of the top surface, which helps to keep the contents of the trailer within the trailer. Each of the trailer's wheels rotates freely and independently of the other wheels.

The trailer hitch attachment to the scooter connects to the bolt that holds the scooter's rear axle in place, a common feature across all Razor scooter designs. The rotation at this connection is constrained by the small "lip" section on the top surface of the scooter being flush against the connection. The scooter's trailer hitch consists of bent steel strips riveted to square tubing, which is the insertion point for the trailer's portion of the joint. The trailer's side of the joint consists of a square U-joint with a square tubing section on one side (which connects to the scooter) and another square tubing section that is riveted to steel strips. This U-joint is designed

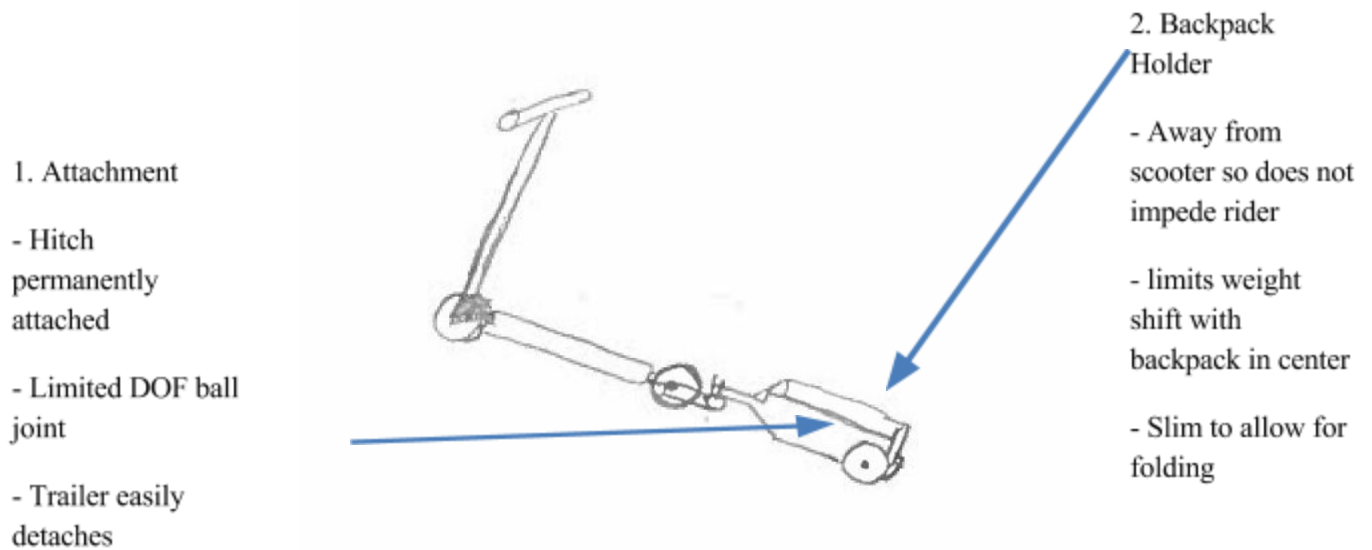
such that it is limited to 180 degrees of freedom, preventing the trailer from jack knifing around the scooter. These steel strips connect to the bed of the trailer along the front surface by means of either bolts or screws. The attachment between the scooter and the trailer is held together by a quick release axle, similar to a bicycle axle quick release. Alternatively, this could simply be a clevis or hitch pin.

For a prototype, the trailer bed can realistically be made of MDF board wood. The flanged section can be riveted to the board. The wheels would be attached by means of two mounted sleeve bearings at each wheel connection, located under the trailer bed. This design is easy to manufacture because it requires minimal manufacturing operations due to the use of simple components. The design works with all models of Razor scooters and is robust and safe enough to carry large loads.

The primary design constraints for this concept are the material selection of the pin and joints, the wheel axle selection, and the load carrying capacity/smoothness of the wheels. This design would require additionally the bed to be made such that it can hold a large amount of weight. Risks of this design include: the possibility of hitting the trailer with one's foot while riding the scooter, the trailer getting hit by a car and pulling the scooter along, the trailer hitting a pedestrian, sharp edges on the flange section of the bed, the bed tipping towards the front two corners when loaded in that area, and the wheels hitting a large enough bump to knock the rider off of the scooter.

#### **Concept 4 - Two-wheeled trailer**





**Fig. 5:** Sketch drawing of detailed part attachments.

The two wheeled wagon is a flexible and feasible design; the trailer can be detached from the scooter and the scooter can be used separately. As well, the trailer will be able to fold up in between when the scooter itself folds up. The trailer will connect to the hitch via a ball joint. This mechanism will give the trailer freedom of movement while not allowing too much movement.

The main risks for the concept is the attachment point. Because there are only two wheels, a large portion of weight and strain will occur at the attachment point. As a result, the attachment mechanism must be strong enough to support the trailer with a wide factor of safety. Doing so will prevent the trailer from failing if there are any unwanted bumps, or someone turns too quickly. A secondary risk is the risk of the trailer having too few or too many degrees of freedom. If there are too few degrees of freedom the trailer will reduce the effectiveness of the scooter as a method of transport. If there are too many degrees of freedom the trailer could react in an unwanted way to bumps. A backpack weighs significantly more than the scooter, so there is a risk the backpack could cause a problem or injury if the trailer allows the backpack to move too freely.

As a result of the risks there are many design constraints for the two-wheeled trailer. One major constraint is that the design is small enough to fold up in between the base and steering for the scooter. Folding up will allow for ease of storage and is a major advantage of the two wheeled design. The trailer must also be made from lightweight materials so is easy to carry and use. However, these lightweight materials must still be strong enough to support the backpack and remain intact even with improper use. Because the trailer is wider than the scooter by a significant margin, the trailer must be far enough back so it does not cause injury. Injury could be caused if someone was kicking to propel the scooter and their foot hit the wide trailer. A less physical design constraint is ease of use. The physical result of this design constraint is that the backpack is easy to place in the trailer, the trailer unfolds easily, and the trailer detaches easily.

### 3.2.2 Concept scoring

This section details how each concept was scored according to the associated needs and the importance of each need. Using this method the most favorable design was chosen.

**Table 3: Concept 1 - Front Basket**

Metric Number	Associated Needs	Metric	Units	Worst Value	Max Value	Actual Value	Normalized Value
1	3,5	Length	ft	3	1	1.5	0.750
2	3,5	Width	in	15	6	6	1.000
3	3	Height	in	15	3	12	0.250
4	2,6	Weight	lb	6	1	3	0.600
5	3	Collapsibility	Integer	1	5	2	0.250
6	4	Rider Interference	Integer	5	0	3	0.400
7	1,3	Removability / Attachment	Integer	0	5	2	0.400
8	2,4	Weight Shift	Integer	5	1	5	0.000
9	5,6,7,8	Durability	Binary	0	1	1	1.000
						<b>TOTAL</b>	<b>4.650</b>

**Table 4: Concept 2 - Rear Basket**

Metric Number	Associated Needs	Metric	Units	Worst Value	Max Value	Actual Value	Normalized Value
1	3,5	Length	ft	3	1	1.5	0.750

2	3,5	Width	in	15	6	6	1.000	
3	3	Height	in	15	3	12	0.250	
4	2,6	Weight	lb	6	1	3	0.600	
5	3	Collapsibility	Integer	1	5	2	0.250	
6	4	Rider Interference	Integer	5	0	3	0.400	
7	1,3	Removability / Attachment	Integer	0	5	2	0.400	
8	2,4	Weight Shift	Integer	5	1	4	0.250	
9	5,6,7,8	Durability	Binary	0	1	1	1.000	
							<b>TOTAL</b>	<b>4.900</b>

**Table 5: Concept 3 - Three Wheeled Trailer**

Metric Number	Associated Needs	Metric	Units	Worst Value	Max Value	Actual Value	Normalized Value	
1	3,5	Length	ft	3	1	2	0.500	
2	3,5	Width	in	15	6	12	0.333	
3	3	Height	in	15	3	4	0.917	
4	2,6	Weight	lb	6	1	4	0.400	
5	3	Collapsibility	Integer	1	5	4	0.750	
6	4	Rider Interference	Integer	5	0	2	0.600	
7	1,3	Removability / Attachment	Integer	0	5	4	0.800	
8	2,4	Weight Shift	Integer	5	1	3	0.500	
9	5,6,7,8	Durability	Binary	0	1	1	1.000	
							<b>TOTAL</b>	<b>5.800</b>

**Table 6: Concept 4 - 2 Wheeled Trailer**

Metric Number	Associated Needs	Metric	Units	Worst Value	Max Value	Actual Value	Normalized Value
1	3,5	Length	ft	3	1	1.5	0.750
2	3,5	Width	in	15	6	12	.33

3	3	Height	in	15	3	5	0.833	
4	2,6	Weight	lb	6	1	5	0.200	
5	3	Collapsibility	Integer	1	5	4	0.750	
6	4	Rider Interference	Integer	5	0	2	0.600	
7	1,3	Removability / Attachment	Integer	0	5	4	0.800	
8	2,4	Weight Shift	Integer	5	1	2	0.750	
9	5,6,7,8	Durability	Binary	0	1	1	1.000	
							<b>TOTAL</b>	<b>6.083</b>

### 3.2.3 Design requirements for selected concept

This section details the design requirements associated with the needs and how they interact with each-other. The design requirements will inform which concept is chosen

**Figure 6: Design Requirements****Figure 6:** Chart outlining the requirements for design by priority.

### 3.2.4 Final summary

After going through the design selected process, we decided to pursue the two-wheeled trailer. The easiest way to see why the two-wheeled trailer is the best design is by looking at the design metric tables. Concept 1 had an overall score of 4.65, Concept 2 had a score of 4.9, Concept 3 had a score of 5.8, and Concept 4: The two-wheeled trailer had a score of 6.08. Just looking at the numerical values gives good reason to select the two wheeled trailer design because its score is significantly higher than the other 3 scores.

The trailers both had much higher scores than the baskets due to the importance of weight shift. While the baskets would be able to fold well, they both place the backpack off-center. The backpack is far heavier than a scooter, so placing the backpack off-center would shift the center of gravity significantly. Shifting the center of gravity makes the scooter less safe and could lead to injury if someone turns too quickly or hits a bump. As a result, the baskets received worse weight shift scores which means they have lower score values. As well, the both trailers are designed to fold into the middle of the razor scooter. This gives them an inherent advantage in fulfilling the ease of storage requirement.

With both of the baskets ruled out, it became a contest between the two trailers. Though three wheels provide more support, the third wheel reduces the maneuverability of the trailer. As a result, this impedes operation of the scooter. However, without a third wheel, the attachment point of the second scooter has to bear far more weight. This means the joint for concept 4, the two-wheeled scooter, must be far more robust. A more robust joint increases weight which then reduces the effectiveness of the two-wheeled trailer. However, due to the attachment for the 3 wheeled trailer and that there is a third wheel behind the scooter, it increases the length of the trailer. Increasing the length of the trailer reduces its ease of storage. Reducing the ease of storage hurts the 3 wheeled trailer and means that overall the two-wheeled trailer is slightly more effective.

After determining the best design, we determined performance goals. Even though the trailer is only holding a backpack, it should be designed to hold a significantly larger amount of weight. The trailer should be able to hold at least 200lbs. A backpack only weighs between 20-30lbs at most, but there is a large possibility for misuse. For example, someone could jump on the trailer wanting the friend to pull them somewhere. If the trailer was not durable enough to withstand the weight of a person, it could lead to injury. As well, the trailer should not flip or rotate too far even when hitting bumps or during quick turns. This is hard to quantify, but can be seen through sufficient testing. This is important so that the trailer directly cause accidents or injuries. As well, the trailer must fit in between the base and handles of the scooter when it is folded up. This can be met through testing as well and directly relates to the requirement for

ease of storage. If the trailer does not fit between the handles and base of the scooter it will not be able to be effectively stored. These are the three main performance goals of the project.

### 3.3 DESIGN CONSTRAINTS

#### 3.3.1 Functional

The largest functional design constraint the project faced was ensuring that the scooter could still be operated easily with the attachment attached. Given that scooter is used as a method of transportation, we deemed it imperative that the scooters functionality was not limited.

#### 3.3.2 Safety

The largest safety design constraint the project faced was ensuring that the attachment could withstand misuse by the consumer. Given the nature of our target consumer - students - we determined that improper used of the attachment was not only a possibility, but that it was likely.

#### 3.3.3 Quality

The largest quality constraint was the quality of the materials available to us given various economic constraint. This can be seen in the decision to use MDF for the bed of our trailer.

#### 3.3.4 Manufacturing

There were two significant manufacturing constraints the project faced. The first constraint was the availability of machines which was limited due to the size of the machine shop and the size of the course. The second constraint was the accuracy of the machines. While the machines tend to be very precise, we had to ensure that our use of the machines was proper.

#### 3.3.5 Timing

The largest timing constraint the project faced was relying upon McMaster-Carr for the delivery of parts that our team ordered. While shipping constraints are often minimal, receipt of one part from McMaster-Carr - the joint - proved to be very difficult given the uniqueness of the part. Since the joint was an integral part of our design and the project was dependent upon it, this was the largest timing constraint faced.

#### 3.3.6 Economic

The largest economic constraint the project faced was minimizing the cost of our parts. The joint from McMaster-Carr was incredibly expensive and accounted for a large portion of our costs as evidenced by our cost tables. Given the cost of the joint it was necessary for the cost of the rest of the parts to be minimized.

### 3.3.7 Ergonomic

There were two main ergonomic constraints considered. The first was based upon the idea that the scooter is a scooter first and backpack carrier second. Thus the trailer must be easy to attach, detach, and should not impede the rider. The second was that the trailer should be easy to store in a classroom setting such that it does not become a burden to store for the user.

### 3.3.8 Ecological

There were no major ecological constraints faced when developing the prototype. The only ecological constraint that existed was ensuring the proper disposal of scrap material.

### 3.3.9 Aesthetic

The largest aesthetic constraint faced in the design process was ensuring that our final product would be marketable to our target audience. In order to make the product marketable to the target audience, it needed to be sleek and appear to be cool. This constraint lead to difficult decisions having to be made when considering what would be ideal from an engineering standpoint and what would be ideal from an aesthetic standpoint.

### 3.3.10 Life cycle

The most significant life cycle constraint faced was ensuring that the attachment would stand the test of time and hold up as natural wear and tear began to take a toll on the product. Given that our target market is likely to use the product a lot it was imperative that the product could also withstand abnormal use and wear and tear.

### 3.3.11 Legal

There were no legal constraints faced when developing our prototype as no similar products exist on the market.

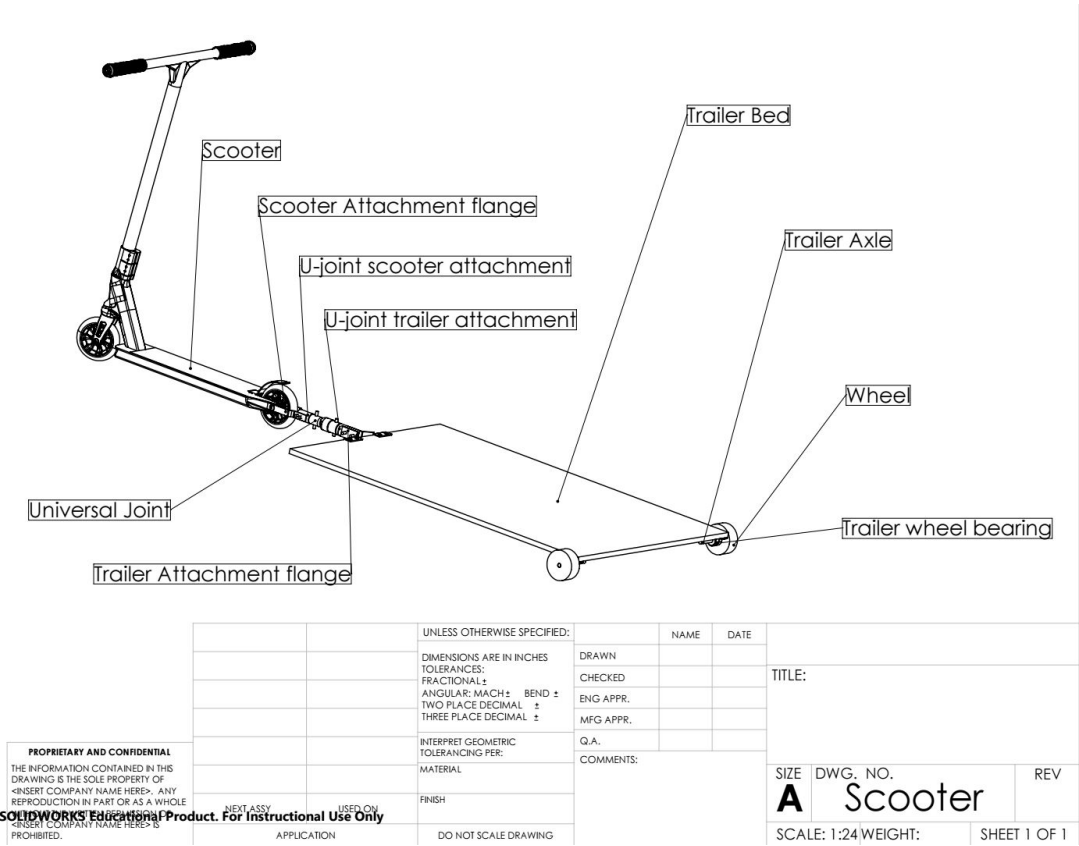
## 4 EMBODIMENT AND FABRICATION PLAN

### 4.1 EMBODIMENT DRAWING

The following Figure is the assembly drawing for the chosen two wheel design.



**Figure 7: Assembly Drawing**



**Figure 7: Assembly drawing of the trailer attachment.**

**4.2 PARTS LIST**

The following Table is the parts list of components for the chosen design. Table \_\_\_ will also be in Appendix A for reference.

**Table 7: Parts List**

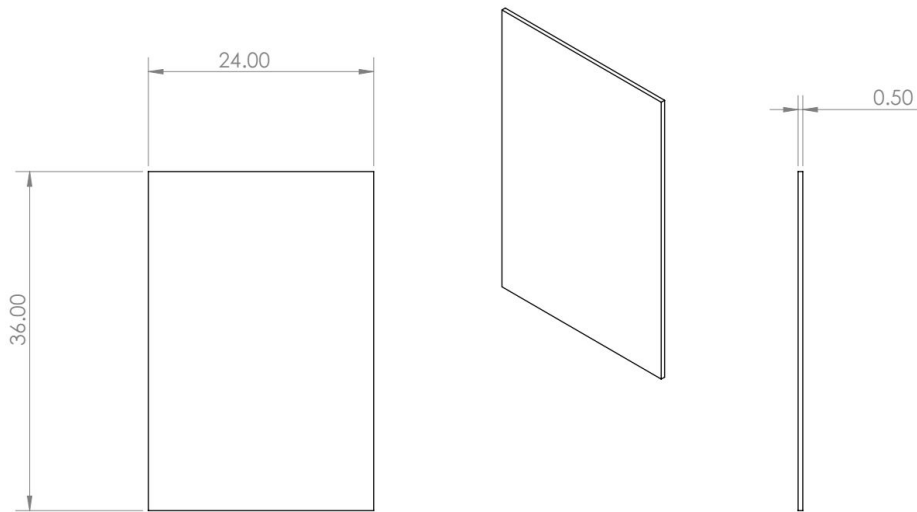
Part	Source	Quantity
Nut	McMaster-Carr	10
Threaded Bolt	McMaster-Carr	10
Washer	McMaster-Carr	4
Wheels	McMaster-Carr	2
Ball Joint attachment	McMaster-Carr	1

Trailer Bed	Manufactured	1
Scooter Joint Attachment	Manufactured	1
Trailer Joint Attachment	Manufactured	1
Trailer Bracket	Manufactured	2
Scooter Bracket	Manufactured	2

**4.3 DRAFT DETAIL DRAWINGS FOR EACH MANUFACTURED PART**

The following Figures detail the specifications for each manufactured part of the design.

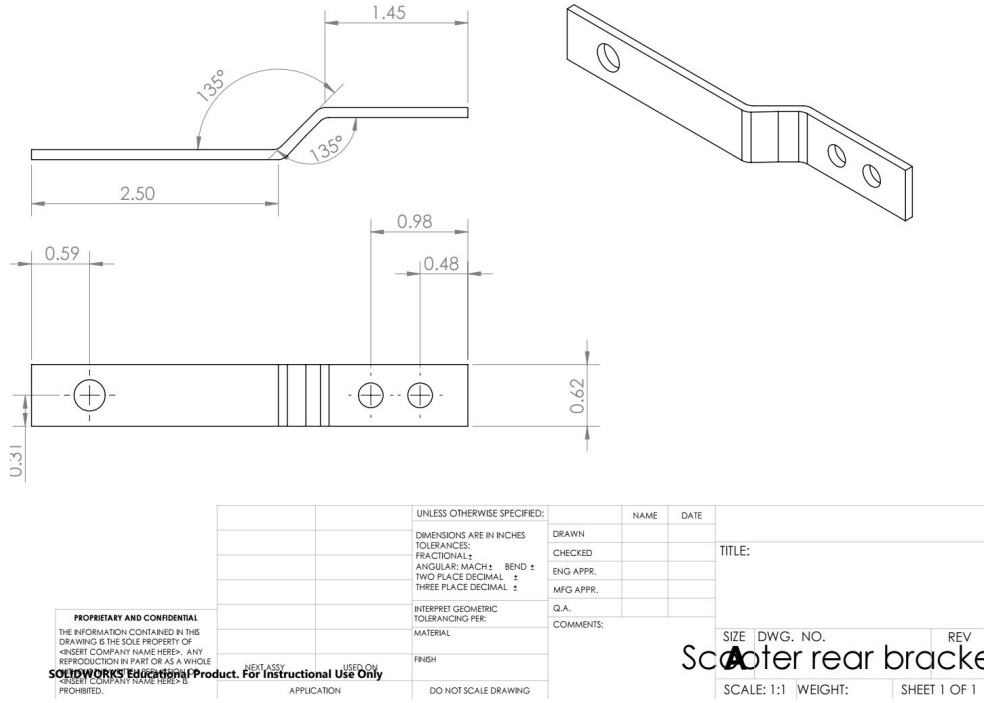
**Figure 8: Computer-Aided Draft Drawing - Trailer Bed**



<p><b>PROPRIETARY AND CONFIDENTIAL</b>                  THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF &lt;INSERT COMPANY NAME HERE&gt;. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF &lt;INSERT COMPANY NAME HERE&gt; IS PROHIBITED.</p> <p><b>SOLIDWORKS Educational Product. For Instructional Use Only</b></p>			UNLESS OTHERWISE SPECIFIED:		NAME	DATE		
			DIMENSIONS ARE IN INCHES	DRAWN			TITLE:	
			TOLERANCES:	CHECKED				
			FRACTIONAL: ±	ENG APPR.				
		ANGULAR: MACH ± BEND ±	MFG APPR.					
		TWO PLACE DECIMAL ±	Q.A.				SIZE DWG. NO.	REV
		THREE PLACE DECIMAL ±	COMMENTS:				<b>A Trailer Bed</b>	
		INTERPRET GEOMETRIC TOLERANCING PER:					SCALE: 1:12 WEIGHT:	SHEET 1 OF 1
		MATERIAL						
		FINISH						
		DO NOT SCALE DRAWING						

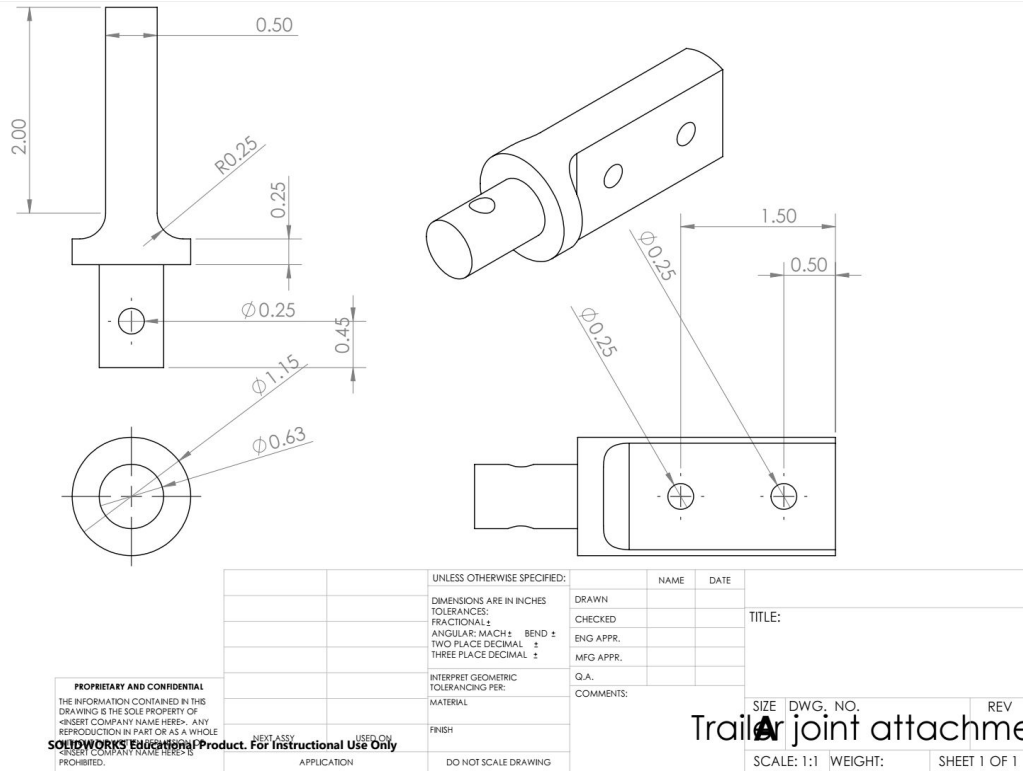
**Fig. 8:** Draft outlining trailer bed dimensions.

**Figure 9: Computer-Aided Draft Drawing - Scooter Rear Bracket**



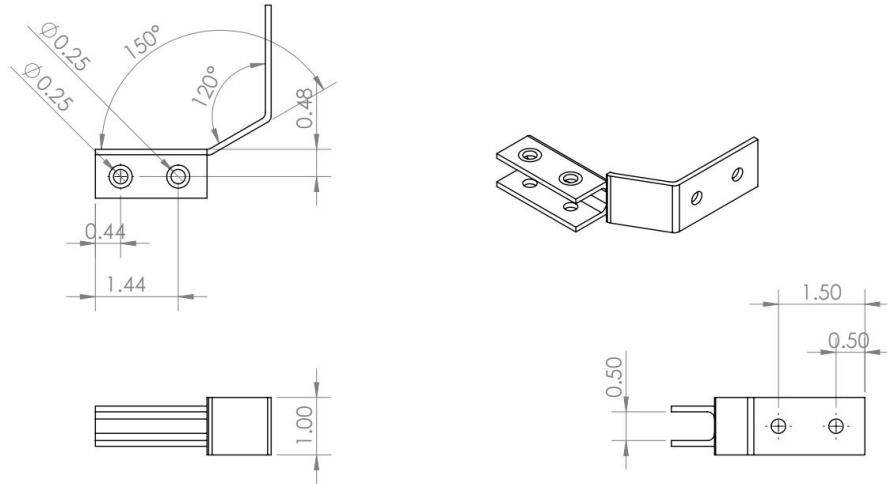
**Fig. 9:** Draft outlining the scooter rear bracket dimensions.

**Figure 10: Computer-Aided Draft Drawing - Trailer Joint Attachment**



**Fig. 10:** Draft outlining the trailer joint attachment dimensions.

**Figure 11: Computer-Aided Draft Drawing - Trailer Attachment Flange**

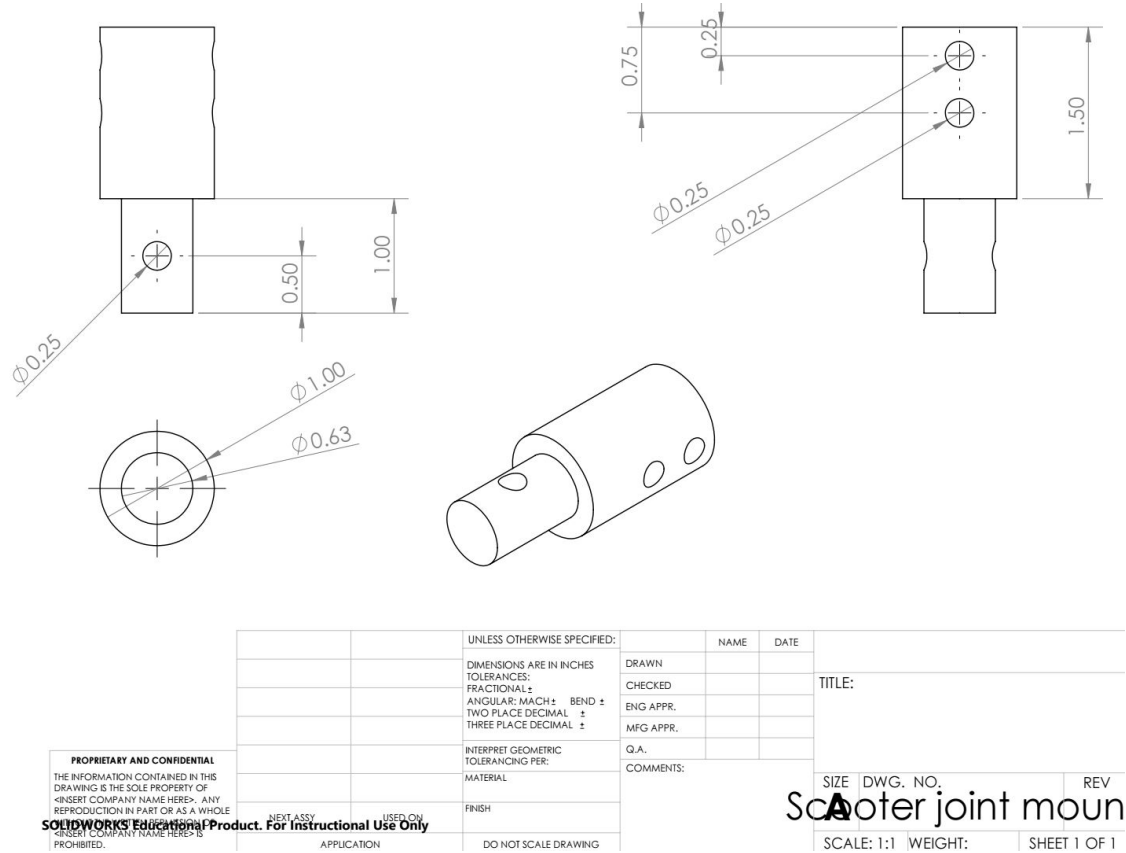


<p><b>PROPRIETARY AND CONFIDENTIAL</b>                  THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF &lt;INSERT COMPANY NAME HERE&gt;. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF &lt;INSERT COMPANY NAME HERE&gt; IS PROHIBITED.</p>		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±		DRAWN	
<p>SOLIDWORKS Educational Product. For Instructional Use Only</p>		INTERPRET GEOMETRIC TOLERANCING PER:		CHECKED	TITLE:
		MATERIAL		ENG APPR.	
NEXT ASSY		FINISH		MFG APPR.	
USED ON		DO NOT SCALE DRAWING		Q.A.	
APPLICATION				COMMENTS:	
				SIZE	DWG. NO.
				SCALE: 1:2	WEIGHT:
					REV
					SHEET 1 OF 1

Trailer Attachment flange

**Fig. 11:** Draft outlining the trailer attachment flange dimensions.

**Figure 12: Computer-Aided Draft Drawing - Scooter Joint Mount**



**Fig. 12:** Draft outlining the scooter joint mount dimensions.

**4.4 DESCRIPTION OF THE DESIGN RATIONALE FOR THE CHOICE/SIZE/SHAPE OF EACH PART**

Each part was chosen with a specific purpose in mind. The first part to consider is the wheels of the trailer. Multiple wheel designs were considered but the wheels we chose were chosen with a few key criteria in mind. The first criteria was the material the wheels were made from. The selected wheel was made from Polyurethane which is similar to the material that the wheels of the scooter are made from. The next criteria that was considered was the durability of the wheels. In order to ensure that the attachment would survive prototype testing we decided upon these wheels because of their long lifespan. The last important factor that led to the selection of these wheels was their loading capacity. Each wheel was rated for a loading capacity of 900 lb.

While this is slightly larger than necessary, the next closest competing wheel would not have met our stringent safety requirements.

The next part to consider is the trailer bed. The trailer bed was constructed out of Medium Density Fiberboard (MDF). There were two driving factors behind the decision to use MDF for the trailer bed. The first was that MDF is very strong and durable. The second major factor was the price of MDF. Given the economic constraints placed on the project, it was necessary for us to keep our costs to a minimum and using MDF enabled us to do this without sacrificing performance. The MDF was also easily machinable and was easy to cut into the desired size of our trailer bed. The one negative side effect of selecting MDF was that it added significant weight to the trailer. The trailer bed was sized in order to fit most backpacks and leave space on either side.

The selection of the Ball joint attachment was crucial as it was the one part that was most critical to the success of our project. In order for the attachment to work as desired, multiple rotational degrees of freedom were necessary. The joint we selected enabled the scooter to rotate in the x, y, and z coordinate planes. If the scooter can go in a certain direction, the trailer needs to be able to go in that direction. Additionally, if a bump is encountered then the joint needs to be able to rotate and not remain stiff in one plane. Furthermore, the ability of this joint restrict rotation in one plane led us to selecting it. This ability prevents the trailer from jackknifing - a major safety concern.

The scooter joint mount and trailer joint mount were sized to fit into the holes at either end of the joint. This allows for the parts to be connected without needing to drill new holes through the joint. As well, the larger diameter was chosen to give enough surface area for good contact between the joint mounts and brackets. The ankle joint for the trailer bed attachment was selected because of its ability to make contact and attach to both the trailer bed and the joint. The primary factors considered when selecting this particular part were its durability and cost. The trailer bracket was made with steel to make sure the part does not fail. The trailer bracket is large so it does not yield as it is the second most important part of the mechanism. As well, the scooter bracket was made with steel. The scooter bracket was specifically sized to be able to bolt onto the rear axle of the scooter while keeping a minimum profile.

Lastly, the remaining parts - the nuts, threaded washers, and bolts, were all selected based upon cost and their dimensions. The dimensions of these parts was the most important factor as washers, nuts, and bolts needed to match in order to be used in conjunction with one another.

4.5 GANTT CHART

Figure 13 : Gantt Chart

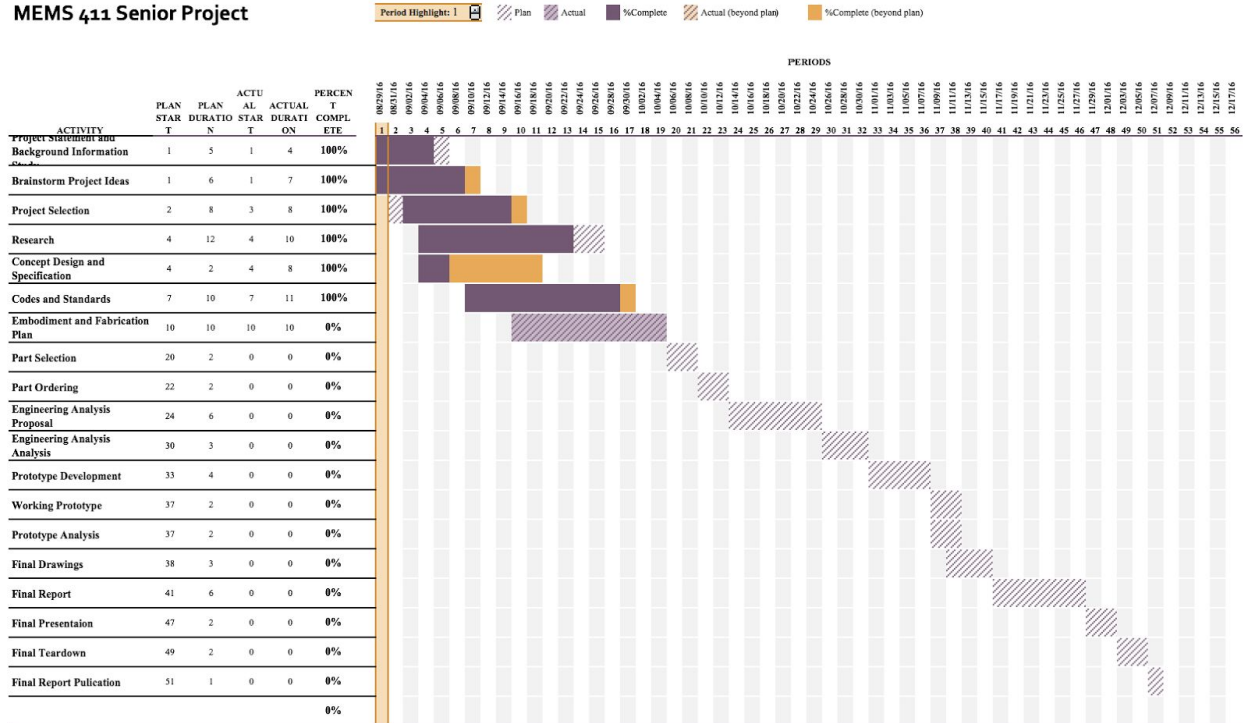


Fig. 13: Gantt Chart outlining the timeline for production.

5 ENGINEERING ANALYSIS

5.1 ENGINEERING ANALYSIS PROPOSAL

5.1.1 A form, signed by your section instructor

Not applicable.



## 5.2 ENGINEERING ANALYSIS RESULTS

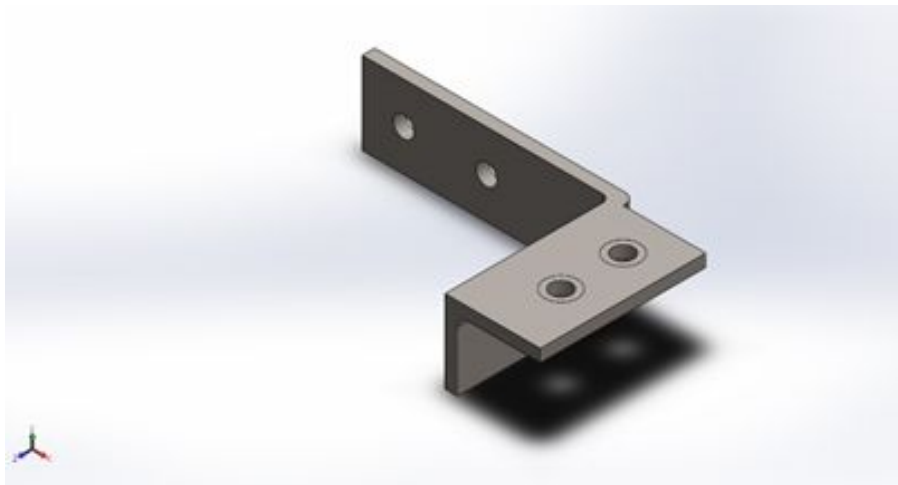
### 5.2.1 Motivation

The analysis of the part that attaches the joint to the trailer was chosen to study because it is the part most likely to fail. There is no third wheel behind the joint attachment to the trailer, so the trailer is most likely to flex and fail around the joint. The joint is steel, so it is very unlikely to fail. This means the part most likely to fail is the joint attachment piece for the trailer. The analysis of this joint will carry the project forward because it will allow us to determine if we need a third wheel.

### 5.2.2 Summary statement of analysis done

The analysis on this component consisted of a static linearly elastic 3D finite element analysis with no contact loading included in the mathematical model.

**Figure 14: Computer-Aided Design Component for Analysis**



**Fig. 14:** CAD model of the component being analyzed

### 5.2.3 Methodology

The primary constraints in the model consisted of several zero displacement constraints in the normal direction on various surfaces of the model. Additionally, the bolt holes that attach to the

trailer were constrained from displacing radially. The loading was applied to the two bolt holes each as a bearing load (each having a magnitude of 150 lbs). The mesh was created from the following input values:

**Table 8: Mesh information**

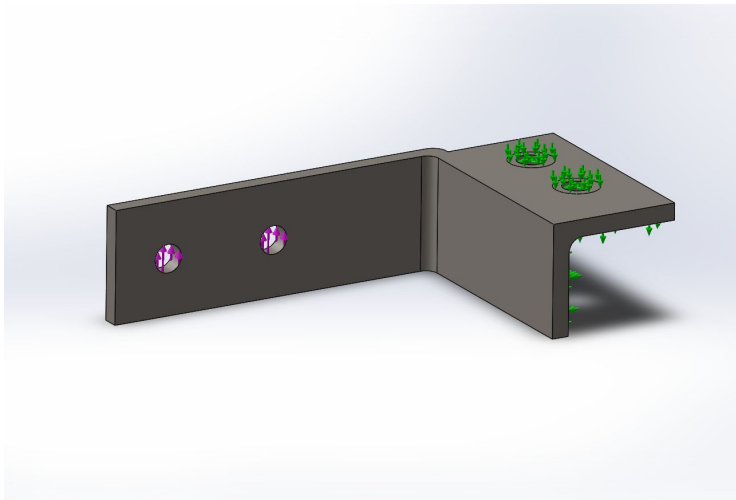
<b>Mesh type</b>	Solid Mesh
<b>Mesher Used:</b>	Curvature-based mesh
<b>Jacobian points</b>	29 Points
<b>Maximum element size</b>	0.0508149 in
<b>Minimum element size</b>	0.0169381 in
<b>Mesh Quality</b>	High

**Table 9: Mesh information details**

<b>Total Nodes</b>	106099
<b>Total Elements</b>	68366
<b>Maximum Aspect Ratio</b>	5.9178
<b>% of elements with Aspect Ratio &lt; 3</b>	99.8
<b>% of elements with Aspect Ratio &gt; 10</b>	0
<b>% of distorted elements(Jacobian)</b>	0
<b>Time to complete mesh(hh:mm:ss):</b>	00:00:07

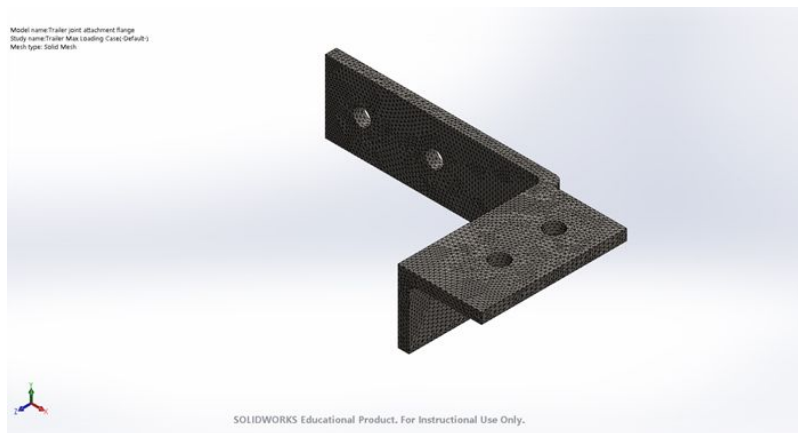
The finite element solver used was FFEPlus, the standard finite element solver for SolidWorks. No adaptive meshing nor convergence techniques were applied to the model for solution validation (p-adaptive and h-adaptive). Further analysis might include this in order to reduce the numerical simulation error; however, this does not reduce the error found in the difference between the mathematical model here and the physical model that is attempting to be depicted.

**Figure 15: Computer-Aided Design for Load Analysis**



**Fig. 15:** Loading and constraints applied to the 3D model

**Figure 16: Finite Element Analysis**



**Fig. 16:** Finite element mesh.**Table 10: Mesh Material Details**

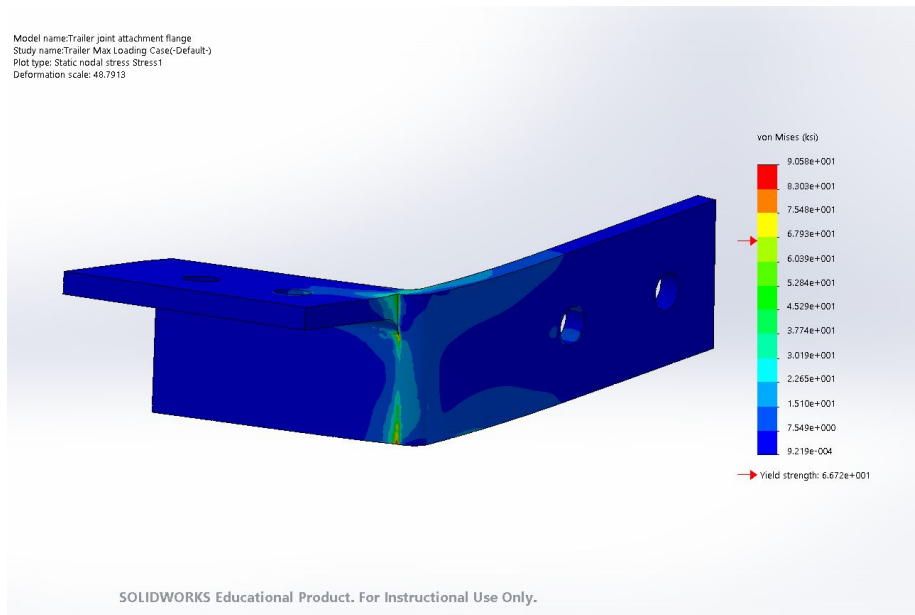
Properties	
Name:	<b>AISI 4130 Steel, normalized at 870C</b>
Model type:	<b>Linear Elastic Isotropic</b>
Default failure criterion:	<b>Max von Mises Stress</b>
Yield strength:	<b>4.6e+008 N/m<sup>2</sup></b>
Tensile strength:	<b>7.31e+008 N/m<sup>2</sup></b>
Elastic modulus:	<b>2.05e+011 N/m<sup>2</sup></b>
Poisson's ratio:	<b>0.285</b>
Mass density:	<b>7850 kg/m<sup>3</sup></b>
Shear modulus:	<b>8e+010 N/m<sup>2</sup></b>
Curve Data:N/A	

## 5.2.4 Results

**Table 11: Results**

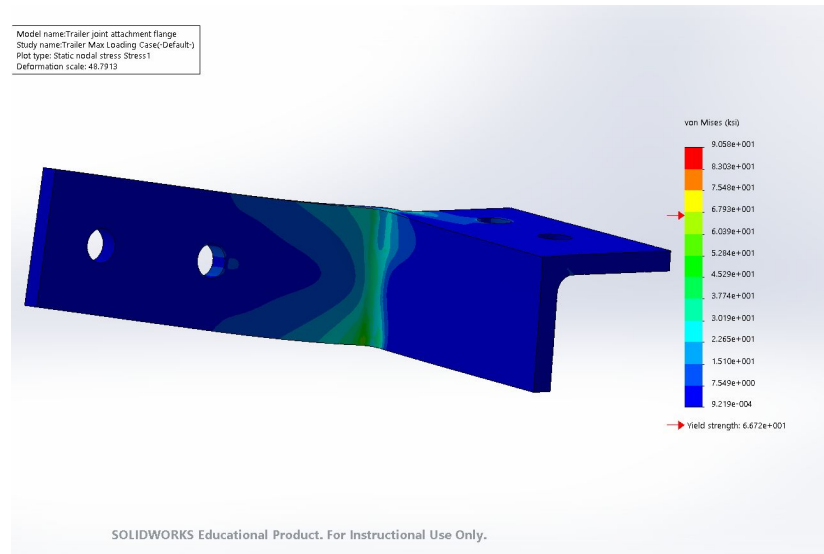
Name	Type	Min	Max
Stress	VON: von Mises Stress	0.000921942 ksi Node: 214	90.5776 ksi Node: 1
Trailer joint attachment flange-Trailer Max Loading Case-Stress-Stress1			

**Figure 17: Von Mises Stress Plot - View 1**



**Fig. 17:** Von Mises Stress Plot for component, view 1.

**Figure 18: Von Mises Stress Plot - View 2**



**Fig. 18:** Von mises stress plot for analysis of component, view 2.

### 5.2.5 Significance

The results of the FEA point to that the trailer joint attachment will not fail. This means the trailer does not have to have a third wheel added. No major material choices or dimensions will change. The attachment piece will remain 4130 steel, the dimensions of the trailer will shrink a little, but they are not as important as the joint dimensions.

### 5.2.6 Summary of code and standards and their influence

There are not many codes or standards that apply to scooters or trailers in our case. That being said, ASTM standard F2264 – 14, relates to the safety of non-powered scooters. The code allowed us to find test numbers for the finite element analysis. Because the standard specifically relates to scooters it does not have direct application to the trailer attachment, but we felt it would be good practice to follow the standard. If we moved forward the standard would give us metrics for safety regarding edges and durability.

### 5.3 RISK ASSESSMENT

#### 5.3.1 Risk Identification

We treated risk identification with a lot of caution given our understand that risks and constraints are heavily correlated. From the outset of our project it was recognized that there were many potential risks but that our most significant risks were our assigned budget, time, functional needs, and safety.

Each of the aforementioned risks had many different factors which contributed to their placement amongst our most important risks. The money risk was comprised of the following: the risk of going over budget and the risk of relying upon vendors for high quality inexpensive parts. The time risk was comprised of the following: the risk of failing to meet project deadlines, the risk of parts not arriving as scheduled and in time, and the risk of machining times taking longer than expected. The functional needs risk was comprised of the following: the risk of our prototype failing to meet all of our customer's needs, the risk of the prototype not functioning as planned, and the risk of the functional needs turning out to be inaccurate. Lastly, the safety risk was comprised of the following: the risk of the scooter not meeting safety specifications when the trailer is attached, the risk of dynamics not being minimized, and the risk of the trailer posing as a safety risk is used improperly.

#### 5.3.2 Risk Impact or Consequence Assessment

Isolating the impact and consequence of each risk is difficult given the inherently intertwined nature of the risks. That being said, each risk was isolated as much as possible in order to provide an accurate assessment of the true impact of the risk.

The money risk carried a significant risk but had a fairly low probability. If the risk was actualized then the project would have been stopped and been unsuccessful given that no more funding exists. However this risk was relatively low because there was some tolerance built into the budget that would have allowed us to go slightly over budget. That being said, money is finite and could have negatively impacted our project in a significant manner.

The time risk posed a high level of impact and had a high probability of occurring. Meeting deadlines is a crucial part of the project and missing any deadlines had the potential to set the team back. Missing a deadline would require the team to be playing "catch-up" for the rest of the semester. Furthermore, if parts don't arrive on time then the development of the prototype gets delayed. This is why the time was deemed to be high - because there were many factors in play that could not completely be controlled by the team.

The functional needs risk carried a high level of impact but had a fairly low probability of occurring. The risk had a medium level of impact because if the user's functional needs for the project aren't met then the project essentially fails to achieve what it set out to accomplish. While this risk has a high level of impact it had a low probability of occurring because no decision was made when progressing the project without consulting the functional needs.

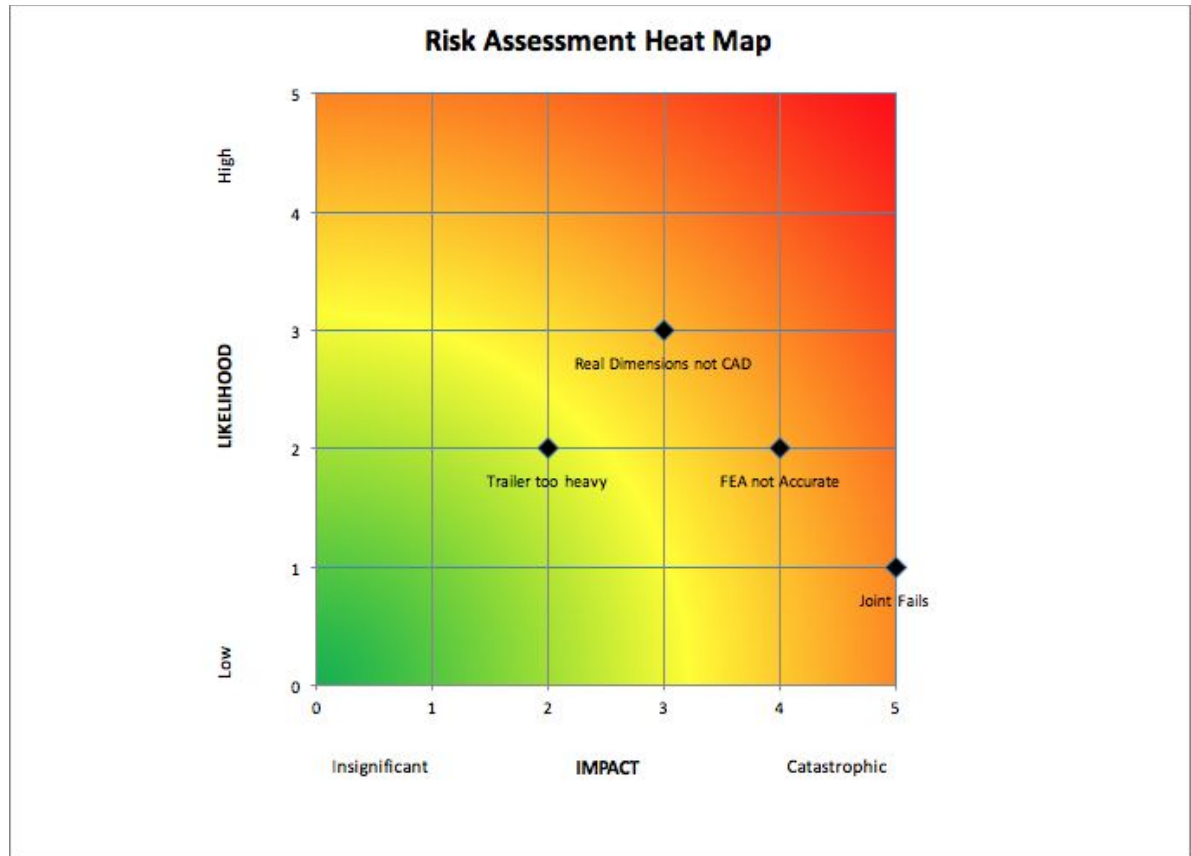
The safety risk carried a high level of impact and had a significant probability of being actualized. The risk had a high impact because if the project is not safe then it would pose a threat of injury to anyone who rode it. This threat of injury also carries a liability concern. The risk had a high probability of being actualized because, while we performed an extensive FEA analysis, there is the potential for types of user error that cannot be anticipated. This likely user error also accounts for the high level of impact given that this is a human transportation device first and a backpack transportation device second.

### 5.3.3 Risk Prioritization

Using the above analysis, the risks were prioritized based upon their impact and probability. Thus the risks were prioritized in the following order:

1. Time
2. Safety
3. Functional needs
4. Money



**Figure 19: Risk Assessment Map****Fig. 19 :** Risk assessment heat map, Likelihood vs. Impact.

From Fig. 19 above it can be seen that the risk that would have the most impact is if the joint failed. However, the joint is made of steel so it is unlikely. As well, the real dimensions were not to the CAD specifications from McMaster carr for the ordered parts, but the impact was not as bad because it was easy to work around. As well, the FEA proved to be true as well as that the trailer was heavy, but it had little impact.

## **6 WORKING PROTOTYPE**

### **6.1 A PRELIMINARY DEMONSTRATION OF THE WORKING PROTOTYPE**

Not applicable.

### **6.2 A FINAL DEMONSTRATION OF THE WORKING PROTOTYPE**

Please see the following link for a final demonstration of the working prototype.

<https://www.youtube.com/watch?v=BHDqM99Imf4&index=13&list=PLpaIgTgYdmcLjSiXEt6mo26GsC4ohV1Fs>

### **6.3 AT LEAST TWO DIGITAL PHOTOGRAPHS SHOWING THE PROTOTYPE**

Figure 20 below shows the overall view of the trailer attached to the scooter.

**Figure 20: View 1 of Scooter and Trailer Attachment****Fig. 20:** View of trailer attached to scooter.

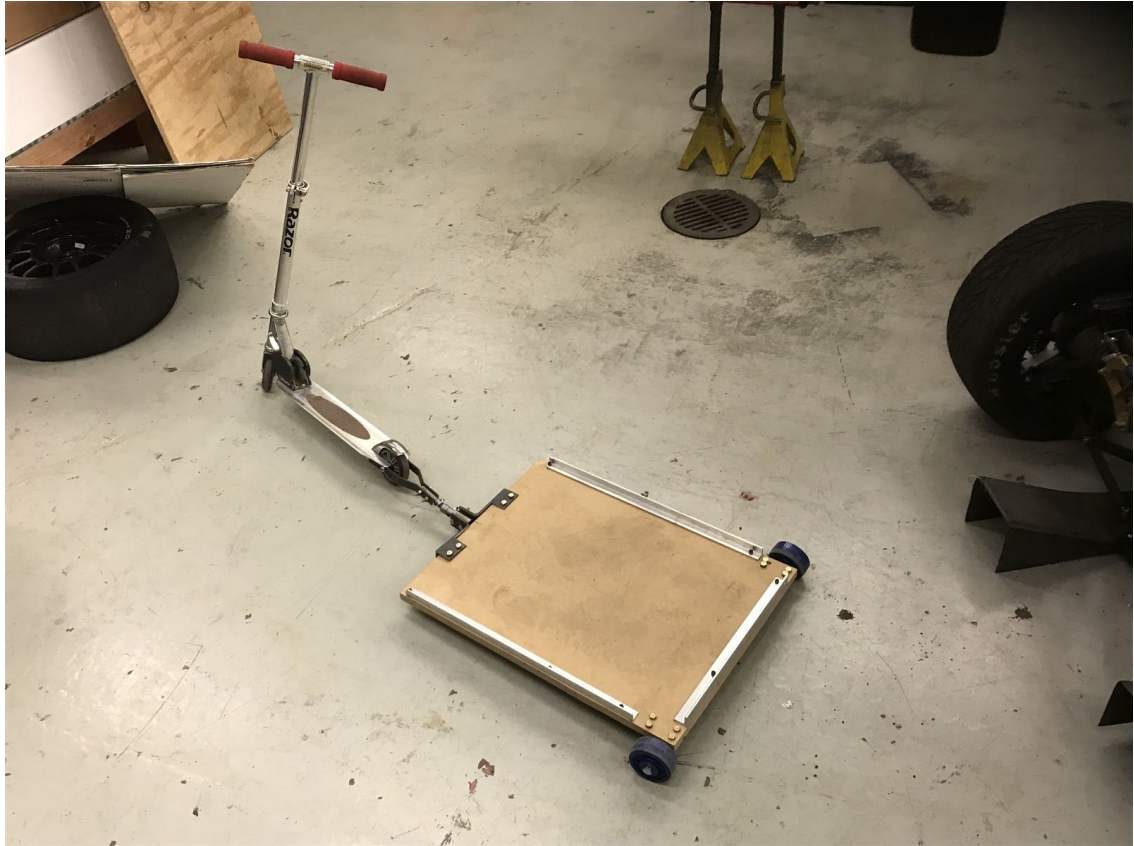
#### 6.4 A SHORT VIDEOCLIP THAT SHOWS THE FINAL PROTOTYPE PERFORMING

Please see the following link for a demonstration of our final prototype in use.

<https://www.youtube.com/watch?v=2R8RRptCle8>

6.5 AT LEAST 4 ADDITIONAL DIGITAL PHOTOGRAPHS AND THEIR EXPLANATIONS

**Figure 21: View 2 of Scooter and Trailer Attachment**



**Fig. 21:** Additional View of trailer attachment displaying the flat bed top of the trailer.

**Figure 22: Ball and Socket Part**



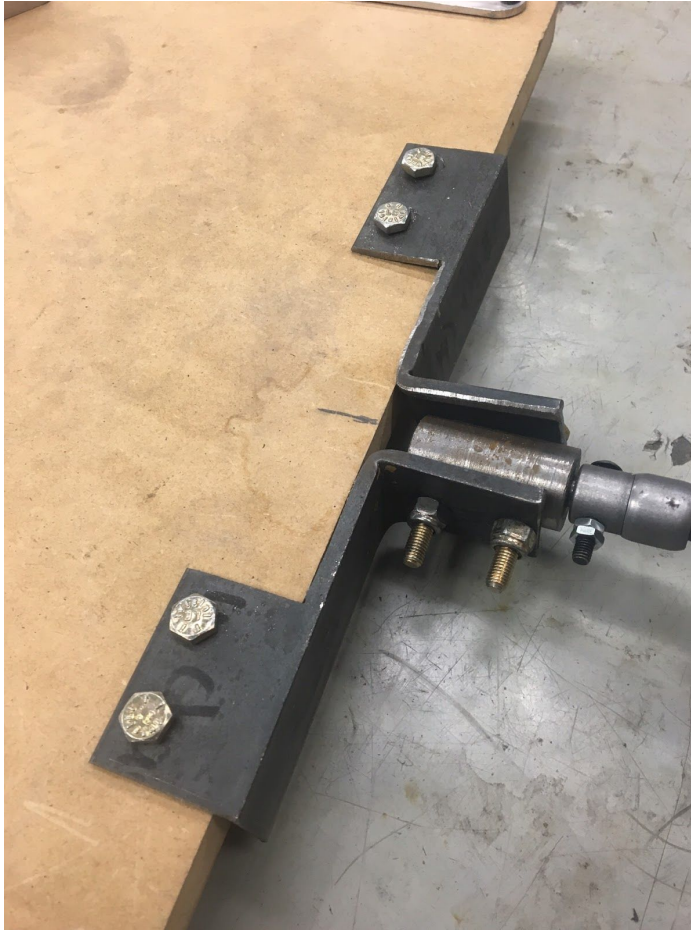
**Fig. 22:** View of ball and socket joint part attaching the trailer to the flange.

**Figure 23: Machined Flanges**



**Fig. 22:** Machined flanges attaching to the outer section of the wheel.

**Figure 23: Flange Connections to Trailer Bed**



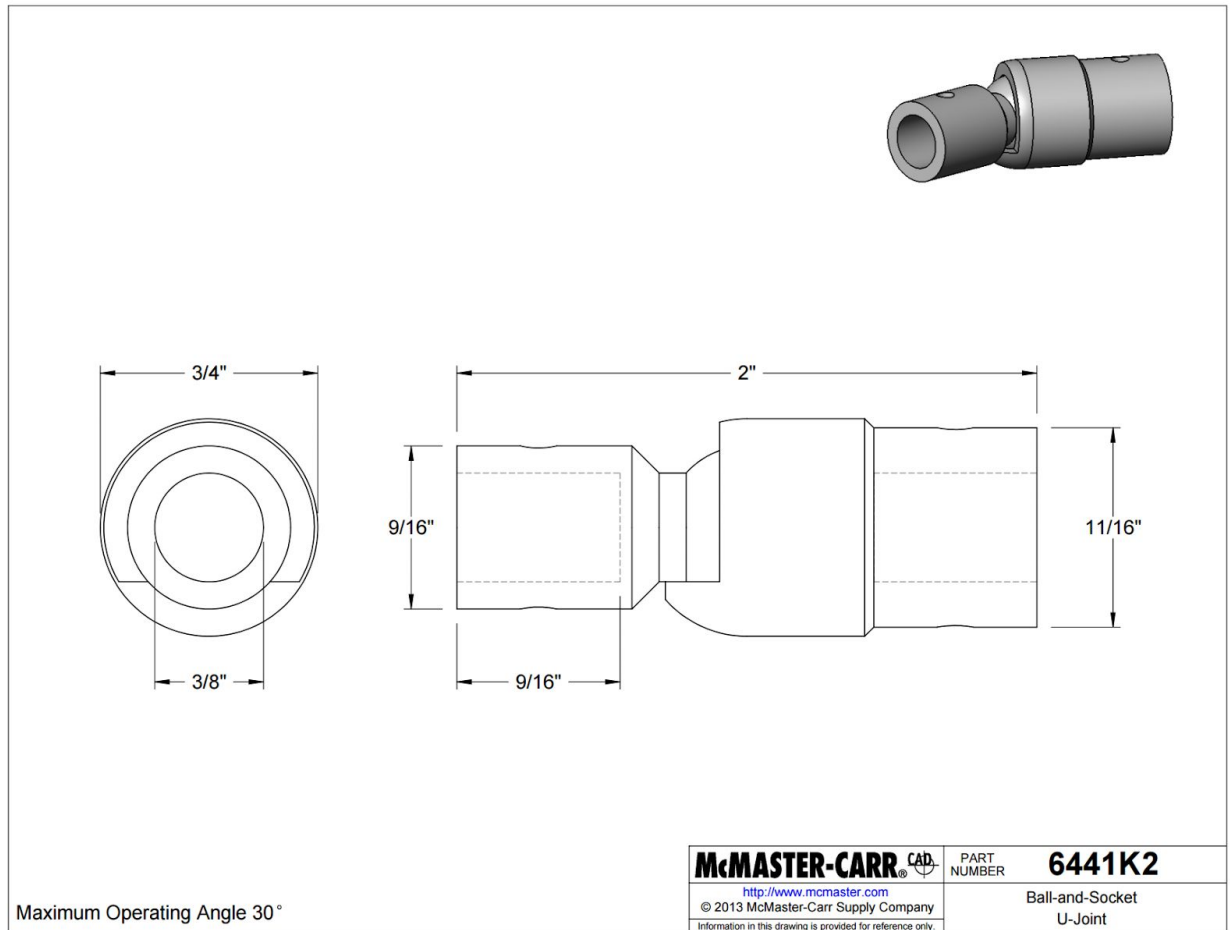
**Fig. 23:** Flange parts bolted into the trailer bed.

## 7 DESIGN DOCUMENTATION

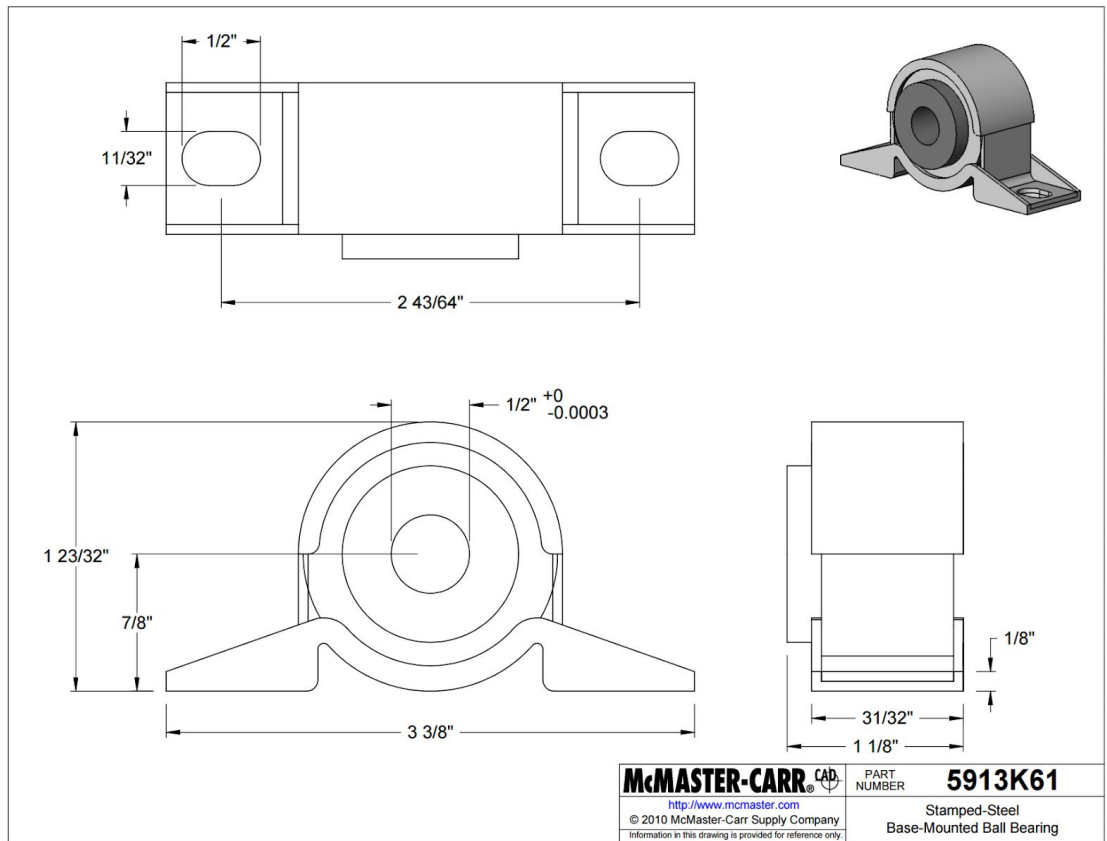
### 7.1 FINAL DRAWINGS AND DOCUMENTATION

#### 7.1.1 Engineering drawings

See Appendix C for the CAD models.

**Figure 24: Computer-Aided Drawing of Ball and Socket Joint****Fig. 24:** CAD Drawing - Ball and Socket Joint**Figure 25: Computer-Aided Drawing of Ball Bearing**





**Figure 25:** Drawing for the bearings.

### 7.1.2 Sourcing instructions

In order to source the scooter attachment one needs to order the necessary parts listed in previous tables and Appendix A and then pull up the CAD drawings for the manufactured parts. Once the materials are obtained the necessary parts can be manufactured. After all parts are manufactured the scooter attachment can then be assembled and attached to the scooter of choice.

## 7.2 FINAL PRESENTATION

### 7.2.1 A live presentation in front of the entire class and the instructors

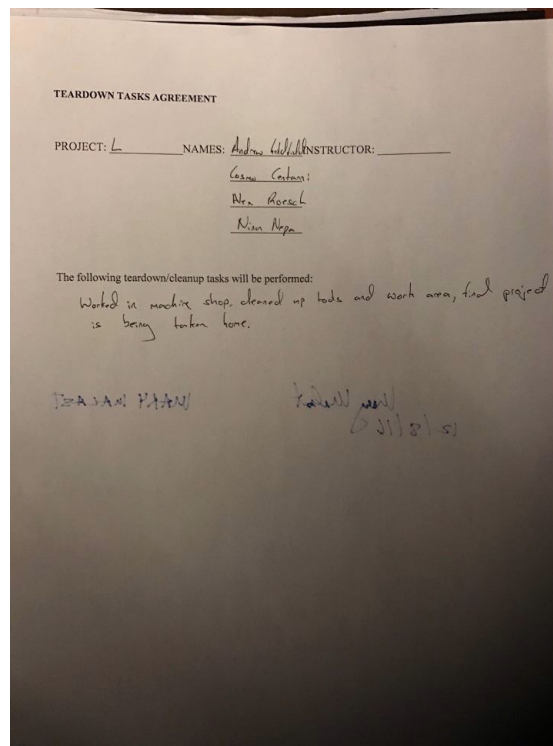
Please see the following link for a video presentation of our product.

<https://www.youtube.com/watch?v=bBV23eX0Nic&index=11&list=PLpaIgTgYdmcJ-6mZULCZ173bxzSJODK80>

## 7.3 TEARDOWN

The following two images are the teardown agreement for our project.

**Figure 26: Teardown Tasks Agreement**



**Fig. 26: Teardown Tasks Agreement**

**Figure 27: Page 2 of Teardown Tasks Agreement**

Instructor comments on completion of teardown/cleanup tasks:

Instructor signature: Mary Macast Print instructor name: MARY MACAST  
Date: 12/18/16

(Group members should initial near their name above.)

**Fig. 27: Teardown Tasks Agreement Page 2**

## 8 DISCUSSION

### 8.2 DISCUSS ANY SIGNIFICANT PARTS SOURCING ISSUES? DID IT MAKE SENSE TO SCROUNGE PARTS? DID ANY VENDOR HAVE AN UNREASONABLY LONG PART DELIVERY TIME? WHAT WOULD BE YOUR RECOMMENDATIONS FOR FUTURE PROJECTS?

For the most part there were no significant part sourcing errors as most parts were easily obtained at Home Depot or via McMaster-Carr. One part, the joint, did prove to be difficult in obtaining as McMaster-Carr did not have it readily available to ship although the website

implied that it was in stock. Aside from this one instance, it made sense to use McMaster-Carr as our vendor of choice given their large selection of items and usually reliable shipping times.

### 8.3 DISCUSSION OF OVERALL EXPERIENCE:

#### 8.3.1 Was the project more or less difficult than you had expected?

The project was more difficult than we expected it to be but not for the reasons that we thought it may be more difficult. The most difficult obstacle we ran into was coordinating our schedules as we are all involved in very different activities.

#### 8.3.2 Does your final project result align with the project description?

Yes, our final project result does align with the project description of developing an attachment that would aide in the transportation of a backpack when riding a scooter.

#### 8.3.3 Did your team function well as a group?

Yes, our team functioned well as a group and built off of each other's strengths to minimize our weaknesses as a team.

#### 8.3.4 Were your team member's skills complementary?

The skills of our team members were very complimentary and each group member was an expert in some regard. For the few skills in which no member of the group was an expert, the group was able to combine all of our knowledge on the subject and solve the problem at hand.

#### 8.3.5 Did your team share the workload equally?

We believe that the workload was shared equally amongst most team members for the most part. Each member took responsibility for certain parts of the project and could easily ask other members for help.

#### 8.3.6 Was any needed skill missing from the group?

We would say that the one skill that was missing from our group was someone who was very familiar with electrical circuits and programming motors. While this did not impact our design based off of our project description, we may have altered the project to include a motorized component if we had someone with the aforementioned skillset.

#### 8.3.7 Did you have to consult with your customer during the process, or did you work to the original design brief?

We didn't have to consult with our customer during the process because our design brief proved to be quite thorough. While we did not need to consult with the customer, we decided to do so

as we were testing our prototype. This was done to ensure that the end user liked the product and that it met all of their requirements when they tested it.

### 8.3.8 Did the design brief (as provided by the customer) seem to change during the process?

At the beginning of the process while different design ideas were still in flux the design brief did seem to change a little. Once our team nailed down what exactly our project was going to be and met with the customer again there was some change to the design brief. Once those changes were made and we proceeded with what turned out to be our final design, little to no changes in the design brief were experienced.

### 8.3.9 Has the project enhanced your design skills?

The project has enhanced the design skills of our entire team in a variety of ways. First, it has given us more experience with the design cycle - from the nucleation of an idea to building out that idea to creating a prototype. No matter how much is taught in the classroom, the hands on learning experience was invaluable to our better understanding of the process. Taking that a step further, we are now all better thinkers and began asking the right questions as the project progressed. This is one of the most important skills enhancements we experienced because in order to solve a problem you have to ask the right questions first.

### 8.3.10 Would you now feel more comfortable accepting a design project assignment at a job?

We all believe that we would have had some level of comfort accept a design project assignment at a job prior to undertaking this project. That being said, all of us now feel even stronger in our abilities to successfully complete a design project assignment at a job.

### 8.3.11 Are there projects that you would attempt now that you would not attempt before?

Absolutely. Now that we have this significant design project experience under our belts we are all interested in using our skills to tackle a larger and even more sophisticated project in the near future.

## 9 APPENDIX A - PARTS LIST

**Table 12: Parts List**

<b>Part</b>	<b>Source</b>	<b>Quantity</b>
Nut	McMaster-Carr	10
Threaded Bolt	McMaster-Carr	10
Washer	McMaster-Carr	4

Wheels	McMaster-Carr	2
Ball Joint attachment	McMaster-Carr	1
Trailer Bed	Manufactured	1
Scooter Joint Attachment	Manufactured	1
Trailer Joint Attachment	Manufactured	1
Trailer Bracket	Manufactured	2
Scooter Bracket	Manufactured	2

## 10 APPENDIX B - BILL OF MATERIALS

**Table 13: Purchased parts:**

Part	Source Link	Part #	Color	Unit price	Tax	Shipping	Quantity	Total price
1 Joint	<a href="#">McMaster</a>	6441K2	Black	\$282.0	\$0	Std.	1	\$282.00
2 Wheels	<a href="#">McMaster</a>	2472T18	Blue	\$15.62	\$0	Std.	2	\$31.24
3 Bearings	<a href="#">McMaster</a>	5913K61	Silver	\$10.95	\$0	Std.	4	\$43.8
4 MDF	<a href="#">Home Depot</a>	None	¾"x2'x4'	\$14.95	\$.63	None	1	\$15.61
<b>Total:</b>								\$372

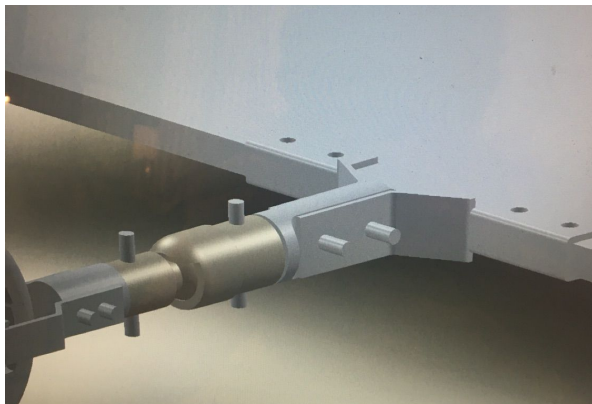
**Table 14: Scrounged Parts**

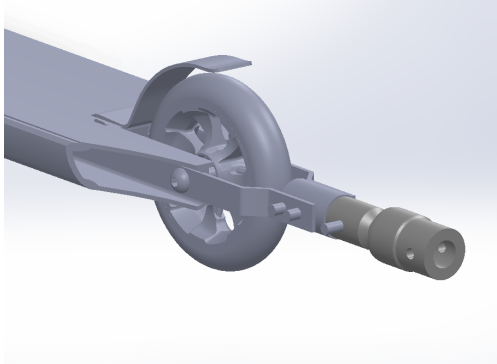
Part	Source Link	Characteristics	Color	Quantity	Total price
1 Axle Bolts	WURacing Garage	½" Diameter	Silver	2	\$0.00
2 Joint Bolts	WURacing Garage	¼ - 20	Gold	20	\$0.00
3 Nuts for Joint Bolts	Jolley 110	¼ - 20	Silver	20	\$0.00
4 Axle Nuts	WURacing Garage	½"	Silver	4	\$0.00

5	Steel Plate	Machine Shop	From Spare Materials	N/A	4	\$0.00
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**11**      **APPENDIX C - CAD MODELS**

Solidworks Report: [https://drive.google.com/open?id=0Bz4vphgDwQ\\_pUHZJZURqdS1WZU0](https://drive.google.com/open?id=0Bz4vphgDwQ_pUHZJZURqdS1WZU0)







## 12 ANNOTATED BIBLIOGRAPHY

Our standard was ASTM F2264. As this standard was purchased we cannot include it in the report. The standard talks about safety for scooters and how to test the scooters to make sure they meet the standards. Because our products is for scooters, this standard is most applicable.

[1] Citation for the Patent used in the Background Information Study:

Turner, Michael Hughesdon, and Ryan Patrick Murphy. "Patent US20140061267 - Interchangeable Scooter and Article Carrier System." *Google Books*. N.p., n.d. Web. 09 Dec. 2016.

[2] McMaster-Carr Joint Drawing: "McMaster-Carr." *McMaster-Carr*. N.p., n.d. Web. 09 Dec. 2016.

[3] McMaster-Carr Bearing Drawing: "McMaster-Carr." *McMaster-Carr*. N.p., n.d. Web. 09 Dec. 2016.