BICYCLE-TROMBONE TRANSPORTATION SYSTEM

Lydia Brough

Sean McGowan

Kunal Patel

Meghan Riegel

EDSGN 100H

1 March 2013

Executive Summary

The project's goal was to design the most efficient way to transport a bulky, awkward object such as a trombone via bicycle while maintaining the mobility and safety of the rider. The ideal solution would be specialized for the subject biker, Lydia, while also being versatile enough to transport similar loads. A product development process was created to fit a five week time frame and incorporated constant research, as well as several opportunities for design iteration and review (Appendix F).

Through concept generation exercises, twelve concepts were formed and placed through a concept screening matrix to narrow the choices to three main concepts: a specialized backpack and two different types of bicycle racks. Prototypes of each concept were constructed, and scrutinized with tests and constant reviews. After several iterations, a specialized rear, horizontal bike rack was constructed from PVC and tested with Lydia, as well as several other riders. The rack was a success and offers a much more efficient method of transportation for Lydia and her trombone.

Background Research

Considering the world's thousands of high school and college marching bands and countless other jazz bands, pep bands, and brass ensembles, there are surprisingly few methods of instrument transportation. Trombone-specific products are even more scarce. Online shopping efforts to find "trombone carriers" yield almost no options, except for a few varieties of expensive cases and backpacks in the $150-$250 range (Appendix A.1) Most of these bags would interfere with the wheels of a bike, and the prices are too high for the case study and many potential customers to afford. Searching "trombone bike rack" on Google shopping, Amazon, and ebay yields exactly zero results.

Figure 1: existing bike racks

The lack of existing products for trombone transportation necessitates the exploration of other methods of carrying unwieldy loads. Bike racks for carrying more conventional items like a box or bag are fairly common; even racks for surfboards are easy to find (Appendix A.2). The designs of these racks need modification in order to carry a trombone, but they provide useful ideas to expand on. The methods used to attach them to a bike and their positions on the bike were taken into consideration throughout the conception generation and prototype development stages.

Needs-Metrics Matrix

After gathering and interpreting the needs from our consumer, the design team had to quantitatively measure each need. The consumer wanted something that was mobile, easy to take on/off and something that was low profile but had plenty of storage space. It was decided that the girth and volume of the components would measure how “low”, the low profile was. The storage volume was to measure how much space there was to store items and to measure how easy the design was to store and take on/off; the design team concluded that a minimum flattening thickness, weight of the design and time were imperative and were given the respectful conditions. The main need the design had to satisfy was a way to carry a trombone on a bike, which had the weight of around 7-8 pounds with the case on. Therefore, to be on the safe side the design had to hold a minimum of 35 pounds. It was also very important that the design did not hinder the consumer’s ability to operate their bike. In order to maintain bike control, the turning radius with the design was not to exceed more than 1.5 meters.

After evaluating the matrix, girth, design volume, storage volume, and the weight of the design were the four that affected most of the needs. Those were taken as priority by the design team, however each design was to incorporate as many of the needs as possible. Another need, cost, per design team was taken account, this costs included materials and costs of manufacturing.

NEEDS-METRICS MATRIX	Visual Appearance	Mobility	Easily On/Off	Storage Capacity	Weight Capacity	Durability
Girth < 1m	■	■	■	■	■	
Volume < 1m^3	■	■	■	■	■	
Time To Put On/Off <30 seconds			■			■
Stores 4.5"x7"x35" trombone	■	■	■	■		
Holds 35 lbs					■	■
Weighs < 10 lbs		■	■		■	■
Waterproof						■
Does Not Exceed Turning Radius ~1.5m		■				
Flattens to ~1ft if not permanantly attached to bike	■		■	■		

Table 1: Customer needs and accompanying specs

Materials Selection and Tooling

The materials chosen had to meet the needs as well. All materials chosen had to be lightweight, cost effective, of small volume and strong. Three of the most common materials used to make such designs, steel, aluminum and PVC were compared (Appendix G). First, the design team compared the strength of the materials. The strengths and prices of the materials were researched and analyzed. All three materials were clearly strong enough to hold the load. However, the PVC was more than four times cheaper per foot than the aluminum and steel rods. Then, the team compared the weights of the materials. Foot for foot, PVC was slightly lighter than Aluminum and four times lighter than steel.

The comparisons supported PVC as the best material for the consumer. The design team also had to compare how intensive the tooling would be for each material. Aluminum and steel would have been welded together and machined using lathes and mills. This process could be time consuming and parts would not have been very adjustable. However, PVC can easily be machined and shaped with nothing more than a hacksaw, sandpaper and glue. Because PVC is connected with elbows and joints, it is possible to easily customize designs for each consumer. Also, due to PVC's forgiveness and ease of adjustment, such as bending it with heat, fitting the frame to different style bikes would be simple. The design team decided that PVC would be the best material for any solid frame design.

	Multipurpose Aluminum (Alloy 6061) ¼" rod	**Steel ¼ " rod 1018 steel**	**PVC (Schedule 40) ¾" Pipe**
Cost price/ft	$1.01	$0.98	$0.22
Rust	Very Hard	Yes	No
Weight(lb/ft)	0.059132663	0.165903	0.0422
Yield Strength(psi)	40,000	54,000	Compressive Strength (10,830 psi)
Hardness	95 Brinell	135 Brinell	R 112

Table 2: Strength and prices of potential building materials

Concept Screening Matrix

From several different methods of concept generation, twelve different possible solutions were developed and imposed across a variety of criteria the final product should meet. The concept screening matrix below shows these twelve concepts ranked compared to the established baseline, the rear horizontal rack concept. The rear horizontal rack was selected as the baseline because it was the most obvious, conventional solution.

The concepts were ranked based on viability, strength, mobility, time required to take product on or off the bicycle/person, weight, aesthetic, and, for some of the more risqué concepts, ethical soundness. Highlighted on the table are the three top scoring concepts: the rear horizontal rack, the front bulldozer rack, and the winning concept, the diagonal backpack (Appendix B.1). Prototypes of each idea were constructed (Appendix C.1), and eventually the rear horizontal rack was chosen after several different tests and reviews.

CONCEPT SCREENING MATRIX								
	Viability	Strength	Mobility	Easy on/off	Weight/ Compactness	Aesthetically Pleasing	Ethically Sound	TOTAL
Diagonal Backpack	+	-	+	+	+	+	0	4
Backpack/Shelf Hybrid	-	-	+	-	-	-	0	-4
Handlebar Rack	+	0	-	0	-	-	0	-2
Rear Hortizontal Rack	0	0	0	0	0	0	0	0
Rear Vertical Rack	-	0	+	-	+	-	0	-1
Slaves	-	-	+	+	-	+	-	-1
Center Water Bottle Rack	-	0	-	-	+	-	0	-3
Side Cart	-	+	-	-	-	-	0	-4
Trombone Seat	-	+	+	-	0	-	0	-1
Front Bulldozer Rack	+	0	0	0	+	+	0	3
Horizontal Backpack	0	-	-	+	-	+	0	-1
Hanging Rear Vertical Rack	0	0	+	0	-	-	0	-1

Table 3: Concept Screening Matrix

Initial Prototyping

In order to better gauge the viability of each of the top three designs, small-scale prototypes (Appendix C.1) were built and rudimentarily tested. The front bulldozer rack was deemed too bulky for safe bicycling. A move to the side of the bike was considered, but it interfered with peddling and/or wheel movement regardless of its position. The backpack and rear bike rack both seemed to have potential.

Construction began on more advanced prototypes for both the backpack (Appendix C.2) and rear rack. The backpack would be made from a durable carbon-fiber reinforced tarp and either sewn or stapled together. The rear rack prototype was made of wood and foam, but would ultimately be built from metal. Even on a larger scale, both models seemed like they would work well. Therefore, more concept selection strategies were needed in order to select a final design.

Customer Survey

In addition to the case study, a potential customer base was identified in Penn State pep band and Blue Band students. A focus group of seven trombone players in the basketball pep band were interviewed before a game. They were asked to offer their thoughts on the three designs--to give suggestions and choose which they would prefer (table 4).

The students mentioned that they really liked how the bike rack could serve multiple purposes. Some had concerns that a trombone backpack would be too heavy and uncomfortable.

However, they generally agreed that a backpack that positioned the trombone diagonally would be more stable while riding a bike than the horizontal rack.

PAIRWISE COMPARISON CHART				
	Back Rack	Diagonal Backpack	Bulldozer Rack	Total
Back Rack	-	5	7	12
Diagonal Backpack	2	-	7	9
Bulldozer Rack	0	0	-	0

Table 4: PCC

The PCC confirms that the back rack is the most popular design in the focus group. This information was interesting because originally, the backpack was considered to be the most probable solution. The consensus that the benefits of a multi-function bike rack would outweigh those of a maneuverable backpack led to a more careful consideration of concept selection, and ultimately the decision to build the rack instead of the backpack.

Concept Scoring Matrix

To aid in the final design selection, a concept scoring matrix using the top three designs was created (table 5). It was determined that viability, maneuverability, and strength were imperative to the product functioning. Aesthetics, multi functionality, ease of loading trombone, and durability were also important characteristics that would appeal to consumers. Viability was given the highest point value because an idea that is impossible to build is useless. Through prototyping, both the back rack and backpack were found to be buildable, while the bulldozer rack was difficult to construct.

Maneuverability and strength received the next highest point values because once an idea is built, it must have the capability to transport the trombone to band events without breaking, causing bike crashes, or injuring pedestrians. Both the back rack and backpack would be fairly strong. The precarious positioning of the bulldozer rack would put more stress on just a few points of the structure. The backpack scored highest in maneuverability, since it is not actually attached to the bike and its weight distribution could be controlled instinctively by the rider. The back rack would need to be tested to make sure it did not interfere with balance much and had an acceptable turning radius (see needs-metrics table). The bulldozer rack would be difficult to see around, and could easily bump into obstacles. It would interfere with turning as well.

Aesthetics was given a lower value because the appearance is not relevant to the functionality of the product. If trombone players were concerned with the elegance of transporting their instruments, they probably would have chosen to play the flute instead. With that said, the bulldozer rack would be the ugliest by far, especially as a permanent fixture to the bike. The ease of loading trombone and durability were also given lower values because the most important need is that the product works. Even so, customers would like to be able to load the trombone quickly, and not have to repair the transporter due to the effects of weather or heavy usage. The backpack would be quickest to load, while the two racks would require some strapping-in and balancing. However, the back rack would be the most durable over time, because the backpack could come apart at the seams and the bulldozer would most likely have frequent crashes.

Finally, the multifunctionality was the newest consideration suggested by the band students. It was weighted at twenty points--a customer would first want the product to perform its basic duty. However, he or she may not want a large, unsightly product that only served one purpose. The back rack could carry a diverse variety of items. The bulldozer rack could hold items similar in size to a trombone. The backpack's specialized shape would not be conducive to holding most items, and customers would not want to use an unwieldy trombone backpack for everyday transport. Thus, the back rack scored slightly higher than the backpack on the matrix.

CONCEPT SCORING MATRIX			
	Back Rack	Backpack	Bulldozer Rack
Viability (50)	45	45	20
Maneuverability (30)	20	28	10
Strength (30)	25	30	15
Aesthetics (15)	7	10	2
Multifunctional (20)	20	2	16
Ease of Loading Trombone (15)	11	13	11
Durability (15)	14	11	8
Total	142	139	82

Table 5: Concept Scoring Matrix

Final Concept Selection

The rear rack appeared to be the best option. However, it was still unclear if it would be safe to use. Testing the maneuverability of the bike with the rear trombone attachment would be difficult without building a complete prototype. In order to better understand the effects the attachment would have on balance and control, an unspecialized rear rack was attached to the case study's bike, and the trombone was bungee corded and taped to the rack as securely as possible. The case study then attempted to ride the bike.

Surprisingly, even with the instability of the ill-suited rack and weight-shifting of the trombone, the cyclist was still able to keep her balance and maneuver around corners. Although the trombone slid off eventually, the back rack design was determined to be feasible and safe. A specialized design would ensure that the trombone did not shift or fall. Advanced prototyping could now begin on the the rear rack.

Prototype Evolution and Testing

The back rack prototype was originally designed to be made out of metal and attached to the bike with custom-built clamps (figures 2 and 3).

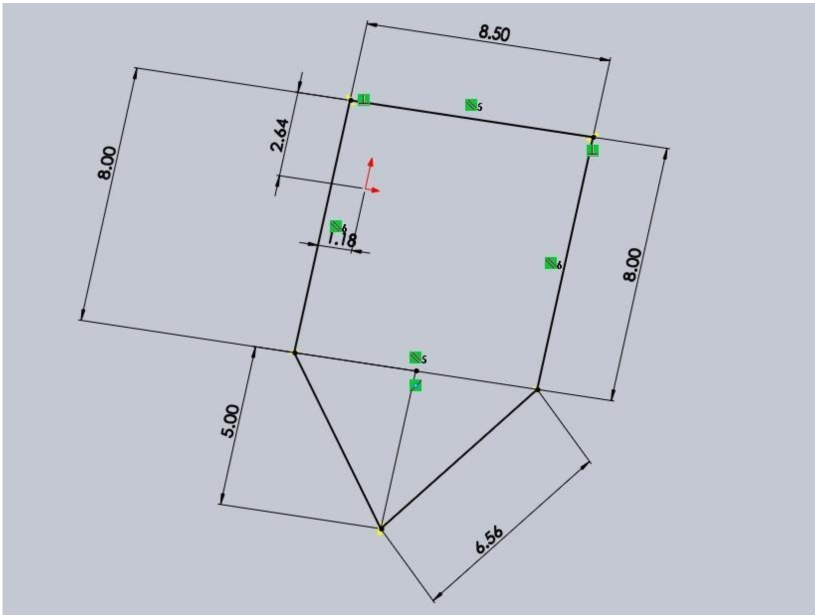


Figure 2: preliminary bike rack dimensions

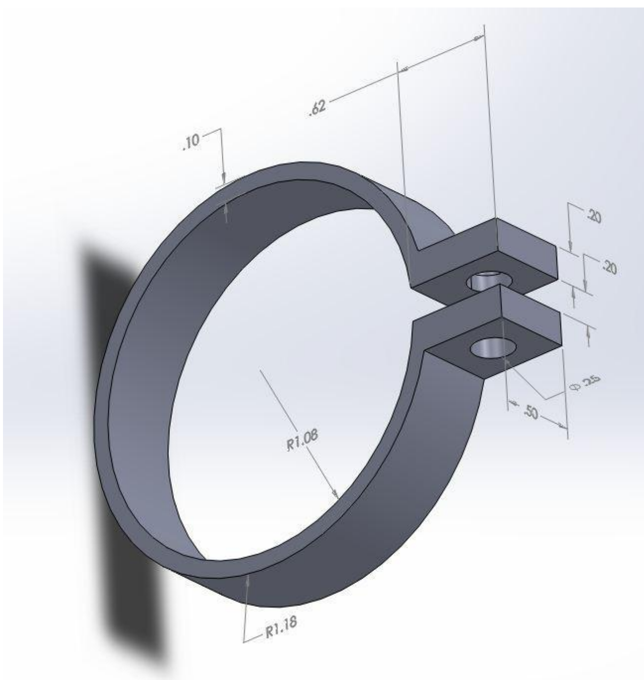


Figure 3: proposed clamp design

However, after further exploring the materials and machines in both the shop and Learning Factory, it was determined that the design was too costly and difficult to build given the limited materials, tools, and skills. It was determined that the frame should be built from PVC pipes instead of metal. Clamps would be bought and attached to the frame, and a specialized trombone basket would also be built if necessary.

The bike was taken into a hardware store in order to get a better idea of how the piping and clamps would attach and which sizes to buy. The design was further evolved in the store (Appendix B.2, B.3). The case study found that a ¾ inch PVC T-joint would fit onto the seat post if sanded out; the rack would then attach behind the seat. The posts connected to the back wheel's axle with metal fasteners coated with electrical tape to prevent paint from scratching off. The whole apparatus would be fully detachable, but due to its multi-purpose nature, it would most likely remain on the bike indefinitely. Velcro straps were purchased to allow for quick and sturdy mounting of the trombone to the rack or possibly a basket if the rack did not keep the trombone stable.

During construction, a PVC pipe was bent with a heat gun to accommodate the angle of the seat post. The team decided to attach the metal clamps to the pipe by inserting their attachments through drilled holes. To prevent cracking, a progression holes with increasing radii were drilled into the side pipes until the clamp attachment could fit through the holes. They were then screwed in place. The PVC frame of the rack was strengthened with glue at the joints.

The trombone was then mounted onto the rack in order to determine if a supportive basket would also need to be built. Fortunately, the trombone fit very stably on the frame. When the Velcro straps were tightened around the apparatus, it could not move in any direction. Originally, the Velcro straps were going to be permanently stapled onto the frame. However, because the rack will carry a variety of items, the straps were left unattached so that they could be repositioned to secure any object

To test the prototype, the case study and two other testers successfully rode the bike down a narrow hallways with sharp turns. Another tester let the bike fall over on the ground; the rack and trombone remained attached to the bike on impact. Finally, the case study rode the bike carrying the trombone to various locations around campus, including the locations of band events. The prototype proved to be strong and maneuverable, even after standing outside for two days in rainy, snowy weather.

Final Concept: Functionality and Feasibility

The final design is lightweight, not cumbersome, and is versatile enough to fit the case study's needs. She is able to transport the trombone to and from practice on her bike and also has the ability to transport a wide variety of other items if needed. The rack secures tightly to the frame and is unlikely to move. It is not permanently attached to the bike, but it would require some time to remove the seat and unscrew the fasteners to remove it. To make up for that, the rack is designed to be compact and not annoying to the rider so that she can leave it on indefinitely. The final design (Appendix D) is made out of PVC pipe. PVC joints are used for the corners and intersections and glued cut pipe to make up the rest of the frame. To attach to the bar under the seat, a section of bent pipe is attached on one end to the frame by a PVC T-joint and on the other end to another PVC T-joint, which the seat bar slides through before being screwed into the bike frame.

The legs of the bike rack go around the wheel and are attached to the base of the bike frame, near where the wheel is attached. On each side a metal fastener goes through the hole drilled into the PVC pipe, around the bike and is fastened tightly in a loop by a screw and nut. To attach anything to the rack, two Velcro straps were purchased which, upon testing, work amazingly and fit snugly around the attached object. For versatility and in fear of damage by weather, they are not permanently secured to the rack.

This design worked much better and was much simpler than originally thought. It fits every one of the case study's needs except for its ease of removal, but it was a tradeoff in order to make the design more durable, which was essential. It would be very easy to make this again for a different bike, as it is a versatile design. The needed lengths for the PVC pipes can be changed to fit the sizes of the bike and expected load. The team is happy with the results and is glad that it satisfied with the case study's needs.

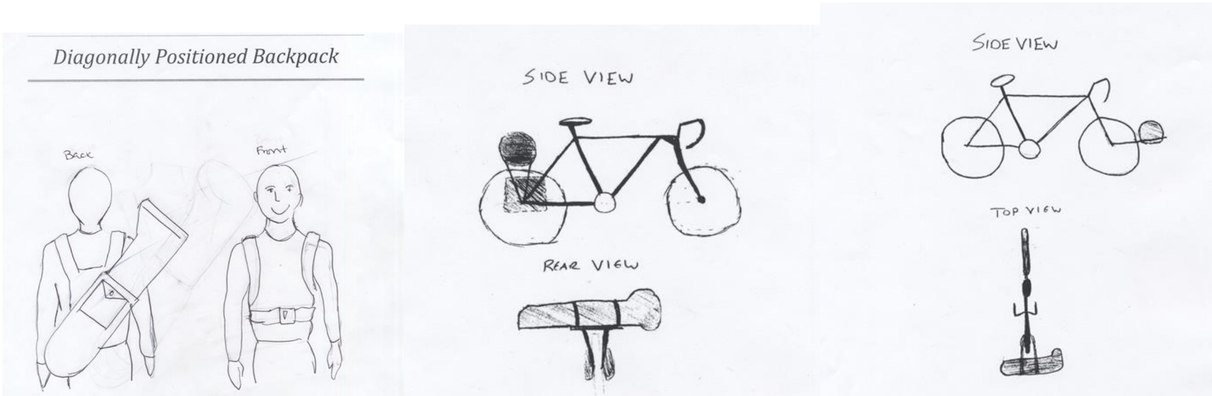
Appendix A: References

[1] "Altieri trombone gig bag" - Example of a typical trombone backpack on the market
www.wwbw.com/Altieri-Trombone-Gig-Bags-470979-i1411837.wwbw?source=TWWRWXGP&kpid=470979.901

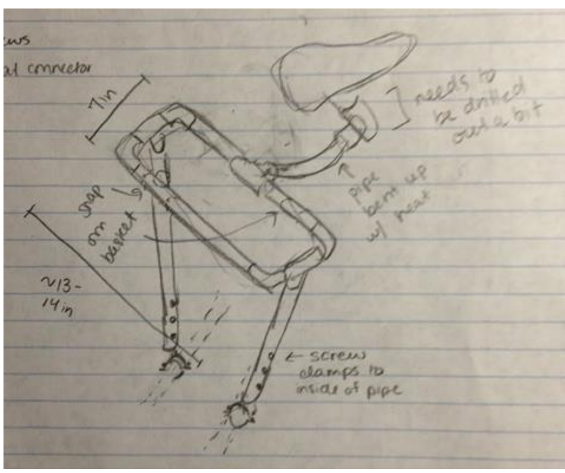
[2] "Block surfboard bike racks" from Surf Etc. - Examples of typical surfboard bike racks on the market
www.surfboardsetc.com/surf_accessories.php

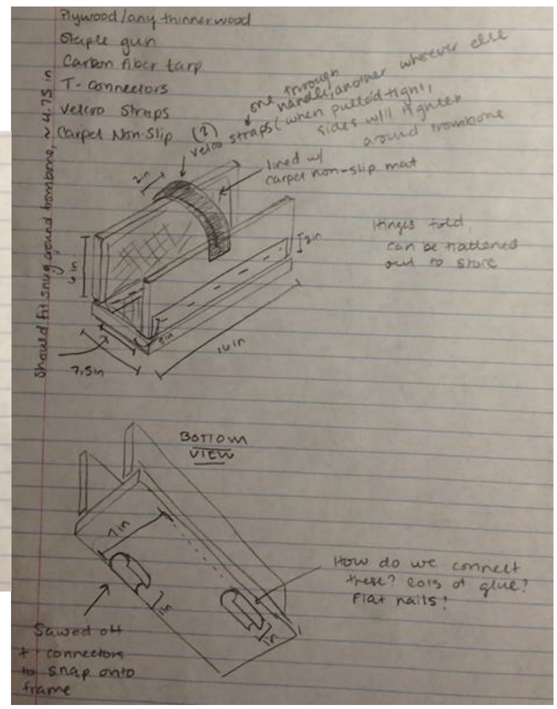
[3] "Plastics Comparison Chart" www.machinist-materials.com/comparison_table_for_plastics.htm

Appendix B: Preliminary Designs



[1] Preliminary backpack, back rack, and bulldozer designs

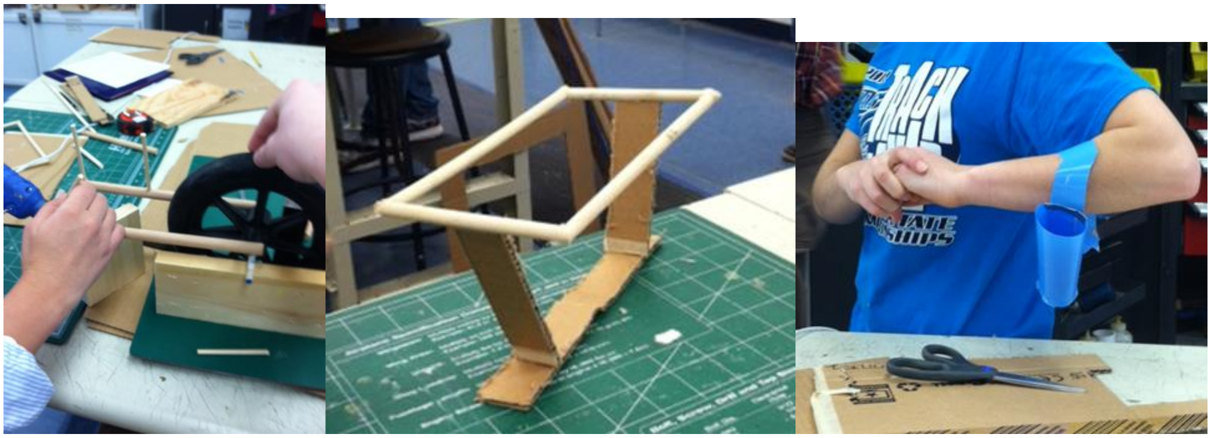




[2] Advanced frame design

[3] Proposed trombone basket design

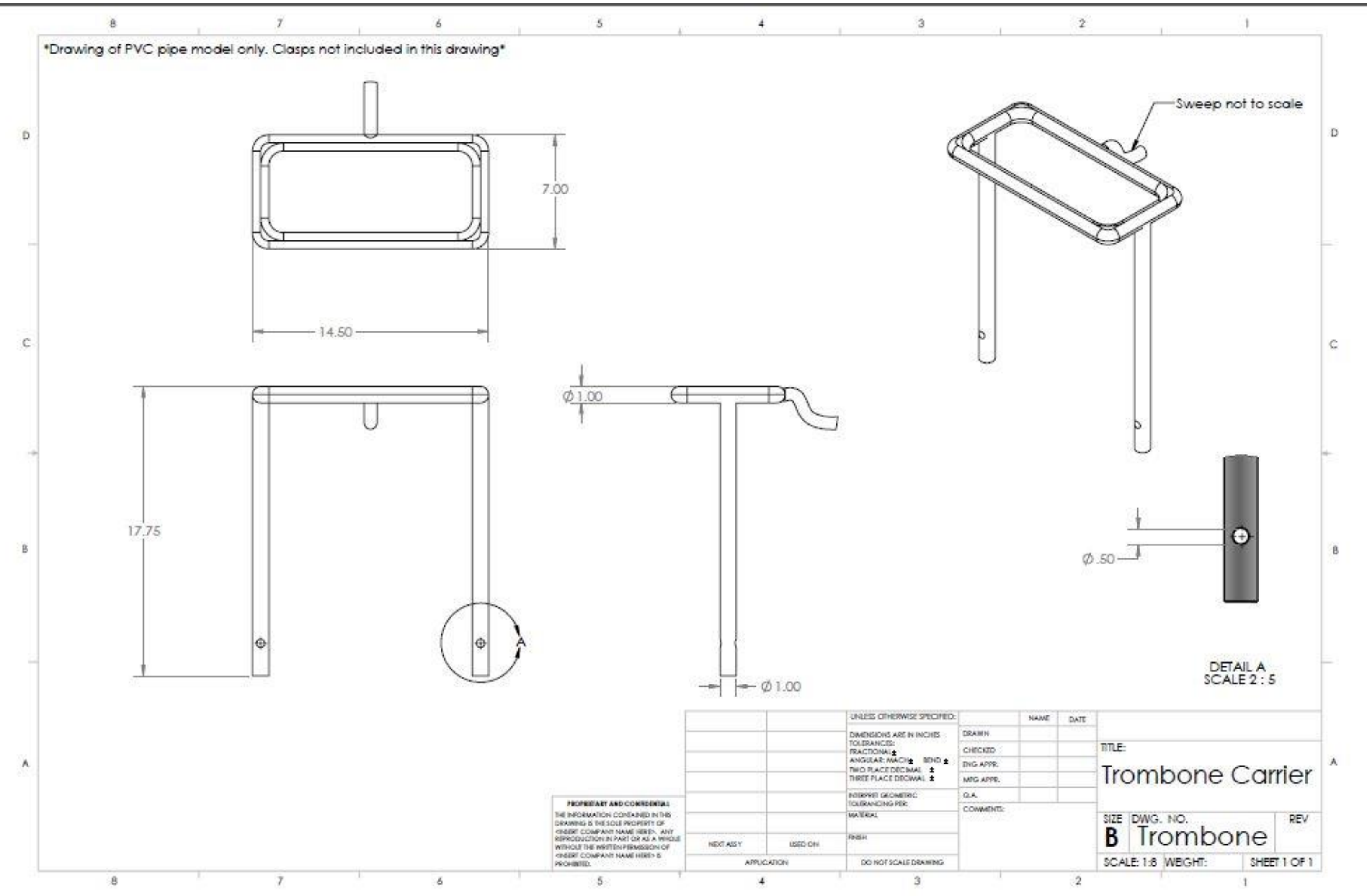
Appendix C: Preliminary Prototypes



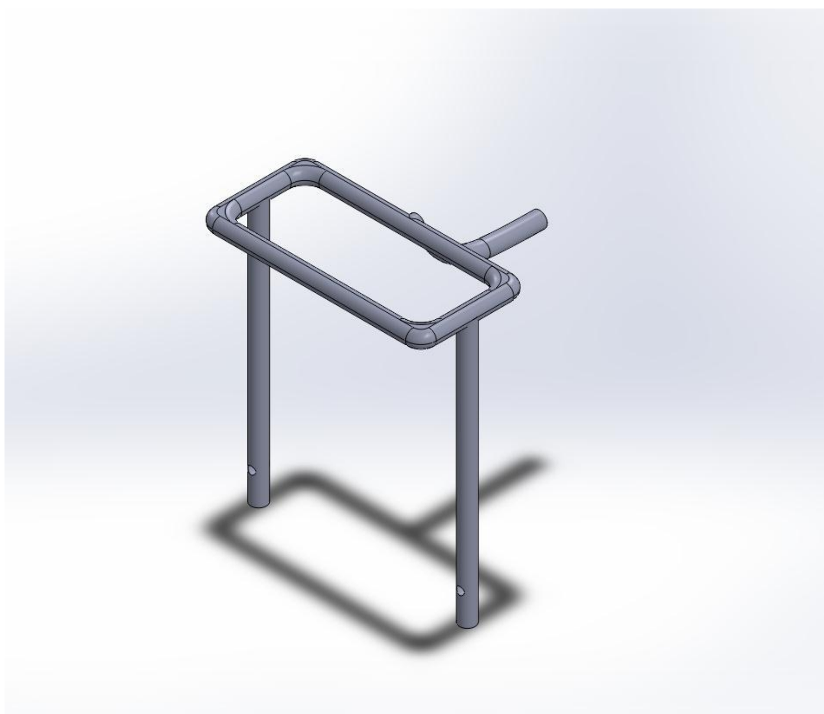
[1] Small-scale bulldozer, back rack, and backpack

[2] Prototyping to-scale backpack

Appendix D: CAD drawings

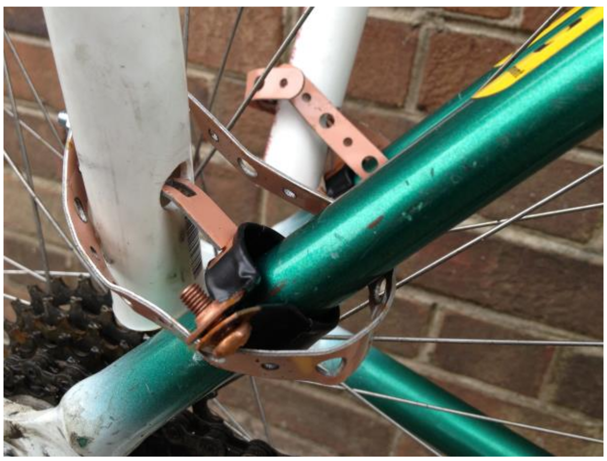


[1] multi-view drawings

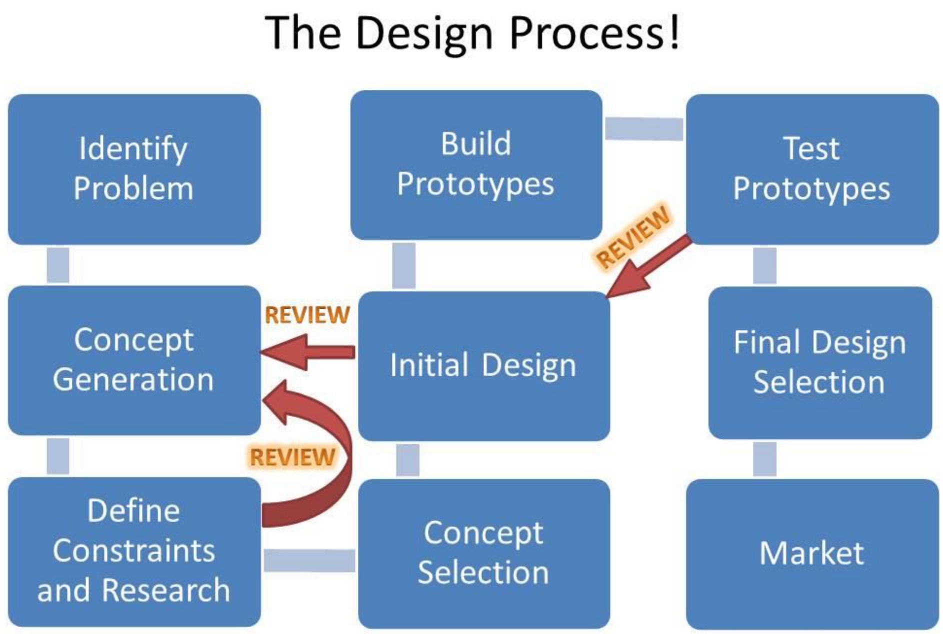


[2] 3D models

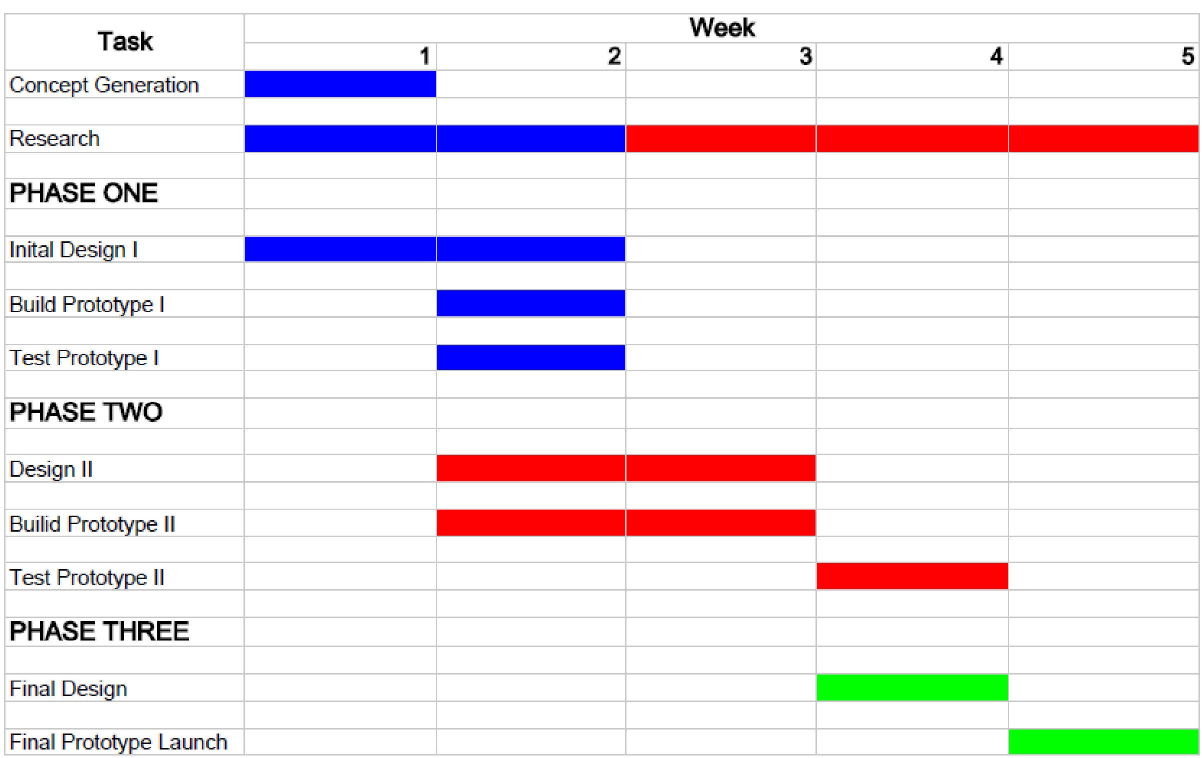
Appendix E: Final Prototype



Appendix F: Design Process



[1] PDP



[2] Design timeframe

Appendix G: Strength of Materials

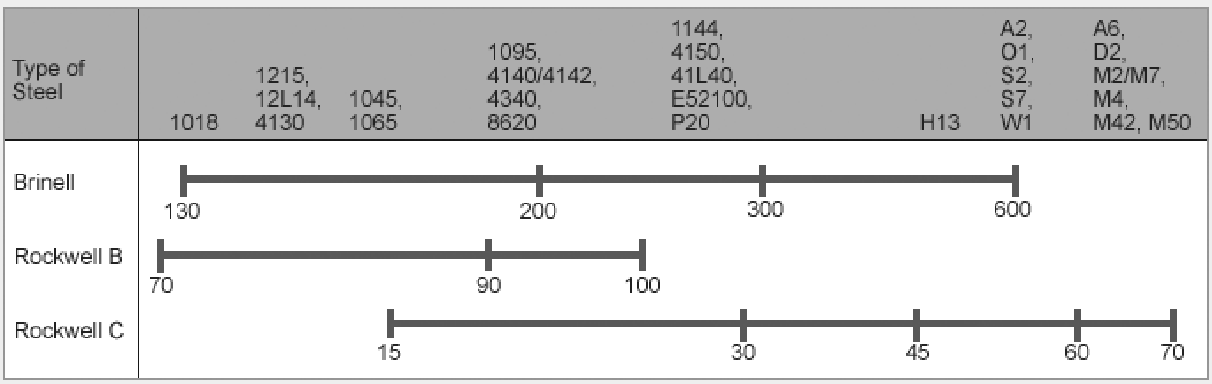
Plastics	Fatigue strength at 10⁷ times application of external stress kg/mm² (MPa)
PVC	1.7 (17)
PS	1.02 (10.0)
PE	1.12 (11.0)
PP	1.12 (11.0)
ABS	1.2 (11.8)

Source: " Plastics almanac" by Kogyo Chosakai Publishing Co. Ltd.

[1] Strength of PVC

Hardness

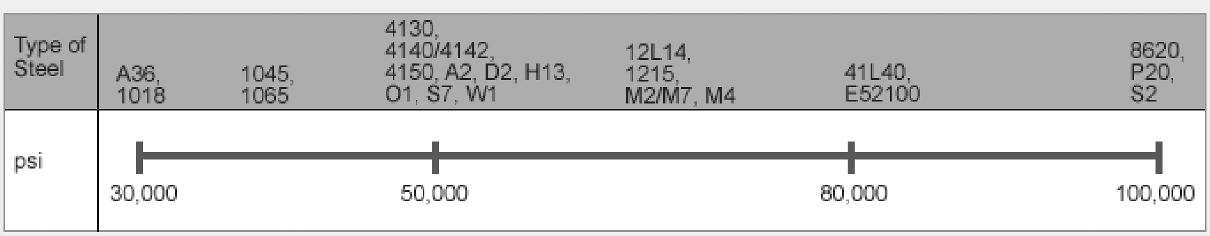
The hardness of a material is its resistance to another material penetrating its surface. Harder materials have more wear resistance. Tool steels are rated after hardening; all other materials are rated in their annealed conditions.



Yield Strength

Yield strength is the point at which material bends and will not return to its original shape. At this point, the metal has changed shape permanently but does not break. All are rated in their annealed conditions.

Note: Yield strength is not rated in the annealed condition for 1074/1075, 1095, 1144, 4340, M42, and M50.

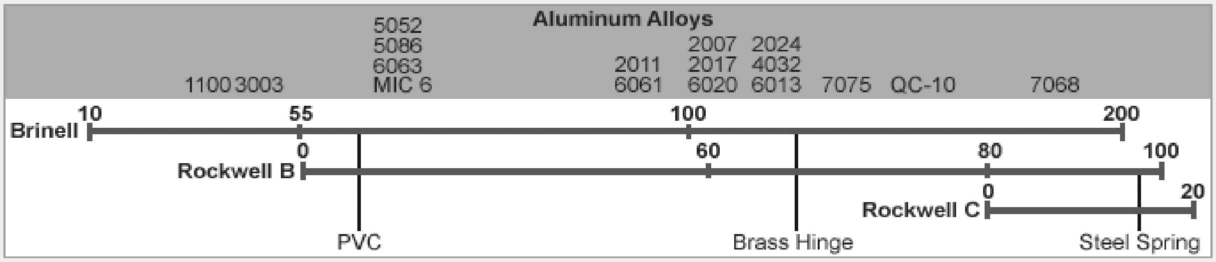


[2] Strength of steel

Hardness

The hardness of a material is its resistance to another material penetrating its surface. Harder materials offer more wear resistance, but they are more brittle.

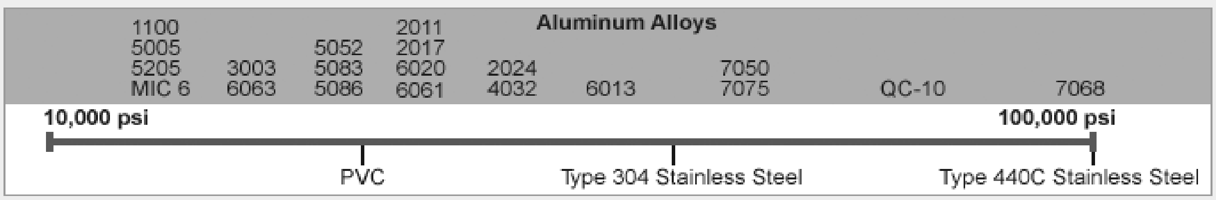
Note: Alloys 5005, 5083, 5205, 6060, 7050, and porous aluminum are not rated.



Yield Strength

Yield strength is the point at which material stretches and will not return to its original shape. At this point, the metal has changed shape permanently but does not break.

Note: Alloys 2007 and 6060 and porous aluminum are not rated.



[3] Strength of aluminum