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MEMS 411: Ground Work Station Design Project

Jakub A. Gawedzki
Washington University in St. Louis

Mark H. Wood
Washington University in St. Louis

John B. Campoverde
Washington University in St. Louis

Washington University in St. Louis
James McKelvey School of Engineering

SP21 MEMS 411 Mechanical Engineering Design Project

Ground Station Design

The ground work station was designed for researchers studying biodiversity and plant ecology at Tyson Research Center. The researchers must travel to plots of land which can be close to a mile from road access and record the number and heights of each type of plant in the plot. This means being bent over each plot for at least 10 minutes, usually more. They are currently using homemade PVC and plywood stands.

To design a better work station, we began with finding several codes and patents that apply to step stools and seats. We interviewed Johnathan Myers and Aaron O'Connell from Tyson research centers and were told the expectations for the final project. We interpreted the user needs, created design metrics, and a Gantt chart. Each member created a function tree and morph chart, then we chose the best one to put into the report. We created a mock prototype from the tree and chart. Each member created an alternative design and recorded the solution to the morph chart. Using an analytic hierarchy process and weighted scoring matrix, we selected the "best" design for our user needs.

The group purchased the Pro-Lift Creeper because it provided a good base for our design. We created three engineering models to analyze the structural integrity and deflection of the creeper at different sections. We made minor modifications to the length of the middle section and folding pin to allow the creeper to fold as small as possible for travel. Knowing the wooden legs we had were not good enough for the final design, we contacted a machine shop to manufacture better legs.

Our group created a CAD model of the entire Ground Work Station and analyzed the structure with both FEA and mathematical models to design the best possible legs and connections. After the base GWS was finished, we analyzed the risks associated with rigorous outdoor use and made several other modifications including replacing the cushioning, adding magnets for tool storage, welding a steel knob to better stop the GWS from changing positions, and using better backpack straps.

Campoverde, John
Gawedzki, Kuba
Wood, Mark

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1 Introduction

Scientist in the field typically have to get down and dirty to conduct their research. This is no more true than for researchers Dr. Jonathan Myers and Erin O'Connell who have come to Washington University to have mechanical engineer students design and develop a sturdy, lightweight, and portable workstation that they can use out in the field that will keep them safe and comfortable. The description given for the project was to "Make a portable device that can help someone comfortably work at the ground level and use their arms to perform tasks for long periods of time." After interviewing both customers, the biggest design features needed, but not included in the description, is that the station must be at least six inches of the ground and be under 25 pounds for portability. The aim of the project is to not only be a comfortable seat for the user, but also be adjustable so you user may also lay on it. The legs aim to be adjustable to handle both flat and sloped land, including any grooves or bumps that may make it difficult for a solid seat to be used. Additional features will be added to the seat for the user to enjoy such as a adjustable table for writing and magnets that hold the user's tools for easy access.

2 Problem Understanding

2.1 Existing Devices

Below are a few examples that we believe could be used for the possible basis for the ground station design. Each item has specific attributes that fit the design requirements for the design project.

2.1.1 Existing Device #1: Adjustable Car Creeper

Figure 1: Car Creeper (Source: Amazon.com)

Link: https://www.amazon.com/Pro-LifT-C-2036DG-Green-Mechanic-Creeper/dp/B07YBS1GJ9/ref=asc_df_B07YBS1GJ9/?tag=hyprod-20&linkCode=df0&hvadid=385178051407&hvpos=&hvnetw=g&hvrand=10849242521570671155&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9001842&hvtargid=pla-837088878168&psc=1&tag=&ref=&adgrpid=78533818717&hvpone=&hvptwo=

&hvadid=385178051407&hvpos=&hvnetw=g&hvrand=10849242521570671l5&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9001842&hvtargid=pla-837088878168

Description: A car creeper is a wheel-able back rest that mechanics use to work under vehicles. This specific model is adjustable so that it can also become a seat for the user. The creeper comprises of comfortable cushioned seats great for log usages and sturdy metal supports that can handle holding up to 300 pounds of weight. The unique design of the rest is perfect for the adjustable ground station as it allows the user options on what position they wish to work. The adjustable seat also allows it to be used as a step stool once the wheels are removed for adjustable legs. This means the researchers can carry one less step stool when reaching the research area, reducing their overall carry load.

2.1.2 Existing Device #2: Folding Steps

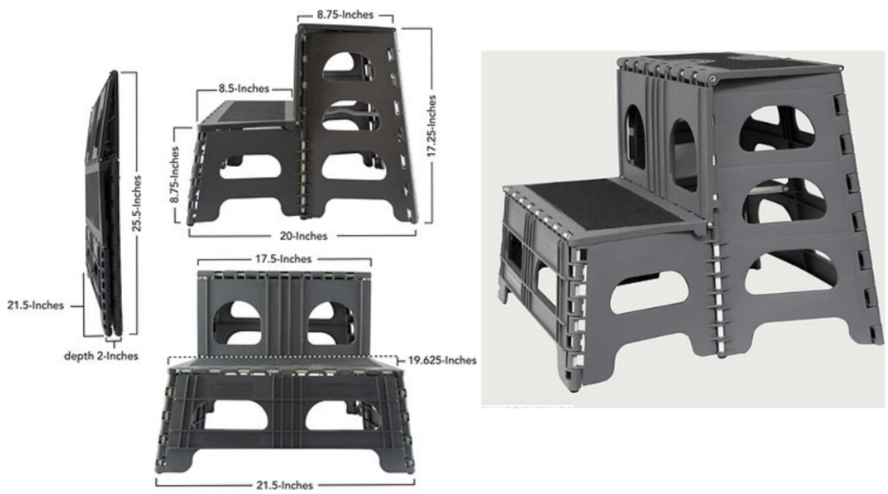


Figure 2: Folding Steps (Source: Chewy.com)

Link: https://www.chewy.com/range-kleen-2-step-folding-pet-step/dp/206092?utm_source=google-product&utm_medium=cpc&utm_campaign=hg&utm_content=Range%20Kleen&utm_term=&gclid=Cj0KCQiAvP6ABhCjARIsAH37rbQxwTiD3a1hq9nJX5MiIRXqp3S992pi-sO0i492QltN_QStJyUkae4aApnUEALw_wcB

Description: These fold-able lightweight plastic steps are exemplary for portability. Weighing less than six pounds, these steps can also handle up to 300 pounds and can be easily placed in seconds. The steps can fold into a flat surface, making it easy to transport on the users back. the steps include nonslip strips that make them safe to use in wet environments. These steps are again a great substitute for one the step stools that the researchers carry when going station to station.

2.1.3 Existing Device #3: Adjustable Seat

Figure 3: Adjustable Seat (Source: abcotechbrand.com)

Link: https://www.abcotechbrand.com/collections/home
https://www.abcotechbrand.com/products/garden-kneeler-and-seat-foldable-for-ease-of-storag

Description: This adjustable seat meets the criteria for a light weight durable platform that gives the user options of either sitting or kneeling on the ground while working. Made of three metal supports and a soft cushion, this adjustable seat also comes with a small carry pouch for the user to store tools and things in for easy access. The only problem faced with this design for the customer is that the platform mus be at least 6 inches off the ground. The sitting position of the seat meets the requirement but the kneeling position must be raised in order to do so.

2.2 Patents

2.2.1 Adjustable Height Creeper for maintenance (USD903,220 s)

The "Creeper" is an adjustable height workbench made for maintenance workers. The two sets of crossbars and collars allow the user to adjust the height of the main body. Changing the height while the creeper is loaded is impossible. The back is connected to one of the crossbars so adjusting the height also adjusts the angle. The creeper has rotating wheels which allow the user to maneuver the device on flat surfaces. The top surface is covered in thick padding for comfort. The structural elements of the device are steel making it durable but heavy.

Figure 4: Patent Images for adjustable Height Creeper

2.2.2 Folding step stool and kneeling pad for working close to the ground

The "Folding step stool and kneeling pad" is a lightweight stool with thick padding. It is made to easily be folded and moved to a different site. The two triangular braces are supported by the kneeling area which acts as a crossbar. The handles are parallel to the ground so the user can support their own weight when using the device. The stool is low to the ground which makes the handles necessary.

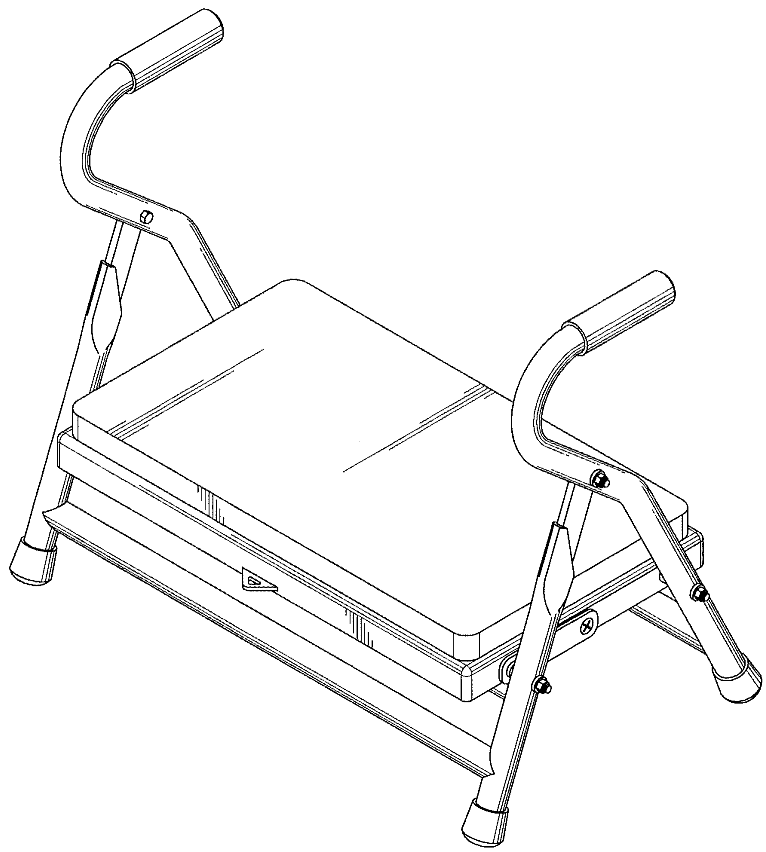


Figure 5: Patent Images for Folding step stool and kneeling pad

2.3 Codes & Standards

2.3.1 Standard Test Method for Linear-Elastic Plane-Strain Fracture Toughness(k) of Metallic Materials (ASTM E399-17)

This International Standard sets specifications on how to determine the fractal toughness of metallic materials under linear elastic and plane strain conditions. In this case we would use a fatigue pre-cracked specimen to test and retrieve this information. For our main design we plan on building with a metallic material and the groundwork station is going to need to support a person. Testing the limits of our design would come in hand greatly to make sure it is safe for a person to work on.

2.3.2 Definition of a Steep Stool From OSHA (29 CFR 1926.1050(b))

This standard defines how to build a step stool to OSHA standards. In one of our concepts we plan on adding a steep stool because the customer uses one often during work. The standard goes over specific dimensions, working parts, and things we cannot modify on a step stool. This would be good to have around if we decide to make the groundwork station a portable steep stool with specific modifications for the ecologists.

2.4 User Needs

In this section we summarize the interview with the two ecologists. The needs that they want in the new apparatus are broken down and highlighted. We gather information on what they disliked on their current stool situation and upgrades they are looking to have and areas they would compromise on.

2.4.1 Customer Interview

Interviewee: Jonathan Myers and Erin O'Connell
Location: Via Zoom
Date: February 3^{rd}, 2021
Setting: We were on a zoom call with two of the research Ecologists and the three groups working on the groundwork project. We went over there current set up to take data of the plants, and images of the terrains this apparatus would be used in. We discussed their current make shift stool and needs that they wanted filled on the ones we are trying to build. The whole interview was conducted via zoom chat and took ∼50 min.

Interview Notes:
How heavy are you willing to have the object?

- We don't want them too heavy since we do need to carry them from site to site by hand. Since we would ideal want to be able to carry these on our backs we would want them to be about the size of our backpacks. We'd like to keep the weight limit under 25 pounds.

How complex can the project be, as in assembly, disassembly, and moving?

- We'd like the assembly to very fairly quick. We want the product to be transportable within two trips of one person handling it. We go to many sites in one day so we don't want to spend too much time and energy just moving and building the station.

What are the current likes and dislikes of their make shift stool?

- The current set up advantages are that it is above 6 inches so ticks can me avoided. It was made out of PVC, making it compact and portable. It has some cushioning thus making it more easy on the knees. On the other had, the stool came apart often making it non durable. It took two trips to bring to the site (PVC, wood boards, cushions, and umbrellas). It was only practical on flat area and had no room for storage.

Would wheels on the station be a good idea for easier transport and carrying other things?

- We'd actually stay away from that because we don't want the wheels to create too much impressions on the ground and affect the environment. Also moving the cart on sloped surfaces are challenging, having that cart go down hill can cause it to roll too fast and crash or hurt someone.

Should we build it so that it can handle both flat and sloped surfaces?

- If you have an idea that would work for both that would be great. That is not necessary though, some groups could build theirs for flat surfaces while others can build theirs for sloped.

Do you just sit on the ground station?

- No we have people that will kneel on it as well. Some people will sit. I have been on my stomach to get close to the plants so I could see myself laying on the station as well as sitting or kneeling.

2.4.2 Interpreted User Needs

The customer expressed several key features that are of high priority in the ground work station design. The ecologists spend a majority of there time in a kneeling position, thus comfort is there number one need. Followed by portability and ease to set up and take apart because they are working in many different terrains. Beginning outside in the wilderness they come across ticks quite often, so the design must be at least 6 inches off the ground.

Table 1: Interpreted Customer Needs

Need Number	Need	Importance
1	Portability	5
2	Work Station Initial Height is Above 6 inch	5
3	Storage Area for Tools	3
4	Weather Resistance	3
5	Adaptability for Different Slopes	2
6	Easy to Set up and Take Apart	4
7	A Table to Take Data	1
8	Comfort	5
9	An Incorporated Step Stool	2

Other needs that were spoken of were adds on that could improve their efficiency while working. This included an area to store there tools such as pencils, tape measures, etc. A table to take data and some type of weather barrier to prevent them and there paperwork from getting wet. Finally, we spoke of a step stool design that could adjust to different slopes, but this not of much importance.

2.5 Design Metrics

The researchers gave a few specific requirements for the ground station, such as size and weight. The numerical values, along with their importance, and a tolerable range for the project to fit in, is given below in table 2.

Table 2: Target Specifications

Metric Number	Associated Needs	Metric	Units	Acceptable	Ideal
1	1	Total weight	pounds	25	15
2	1	Total volume	litters	< 25	< 20
3	2	Height of station off the ground	inches	> 6	between 6 and 12
4	2,4	Base cannot take up to much area for supports	$inches^2$	< 8	> 5
5	5	Number of trips to transport	integer	2	1

2.6 Project Management

The Gantt chart in Figure 6 gives an overview of the project schedule.

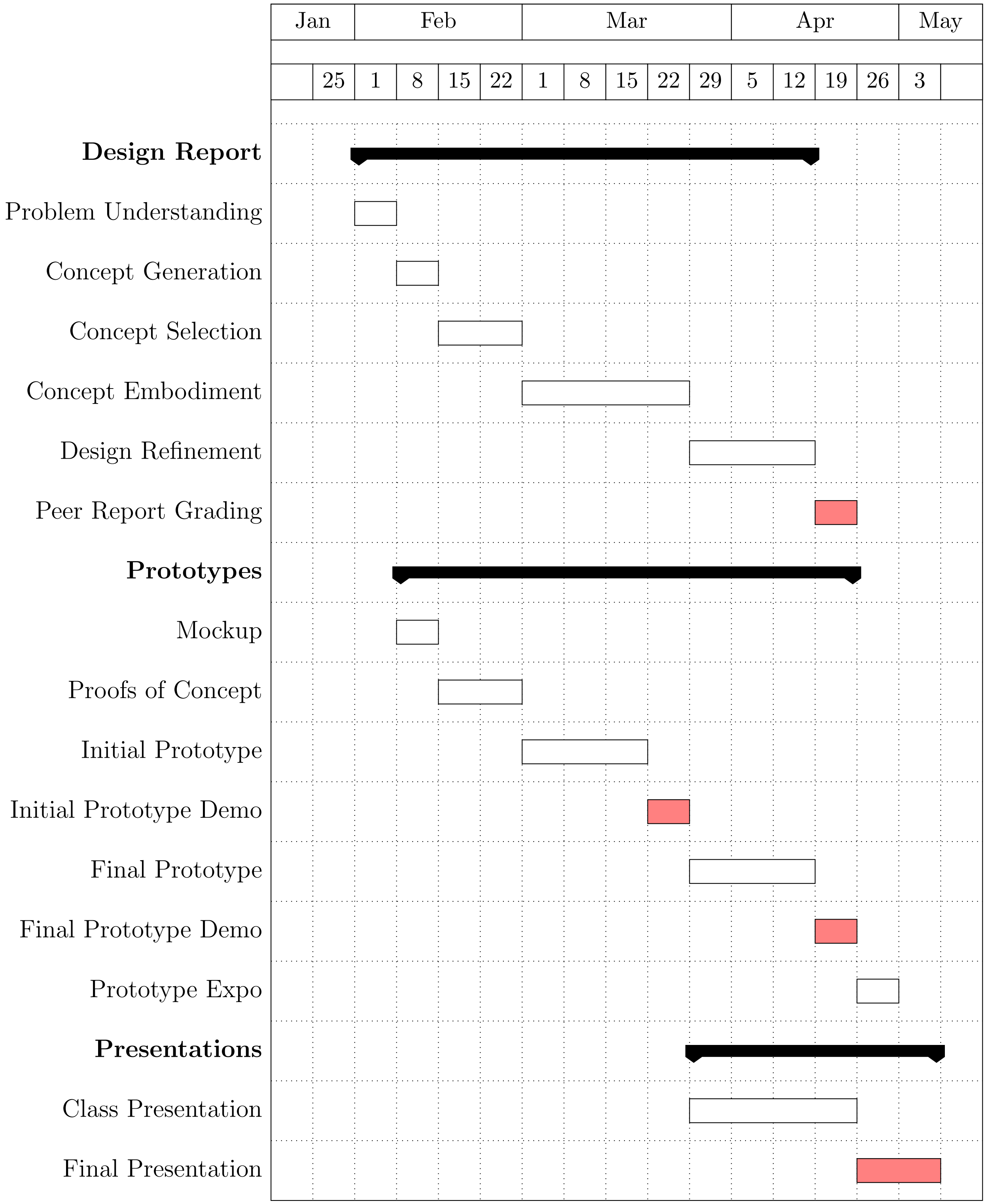


Figure 6: Gantt chart for design project

3 Concept Generation

Below in figures 7, 8, and 9 is a mock build prototype of out design for the ground work station. The build is meant to show case the ideas we have come up with for the overall portability and versatility for the user. The design allows the user to fold the station to use laying down as well as sitting or kneeling. It also allows the user to remain entirely off the ground which was a requirement. While this design is easy to use once at the work site, it is difficult to carry without the device unfolding. This could be easily fixed with latches to hold the device in a fixed position while being transported. The mock-up currently does not have any place to be grabbed while carrying, so some kind of handle or strap must be used on later prototypes. The current design could be used as a step-stool but it does not have any features designed for that purpose. Adding somewhere to step while it is in the seat position could allow it to replace one step stool which could drastically reduce the amount the researchers are required to carry. This mock-up has made our group aware of some issues that could be overcome by adding additional features to or changing our designs.

3.1 Mockup Prototype

Figure 7: Mock build of a possible ground station design

Figure 8: Mock build of a possible ground station design

Figure 9: Mock build of a possible ground station design

3.2 Functional Decomposition

Below can be found a function tree of the Groundwork Station for a group Ecologists. We broke down the station into five sub-functions to accommodate there needs.The sub-functions included support for ecologist's, cushioning, initial 6 inch height, storage for tools, and weather protection.

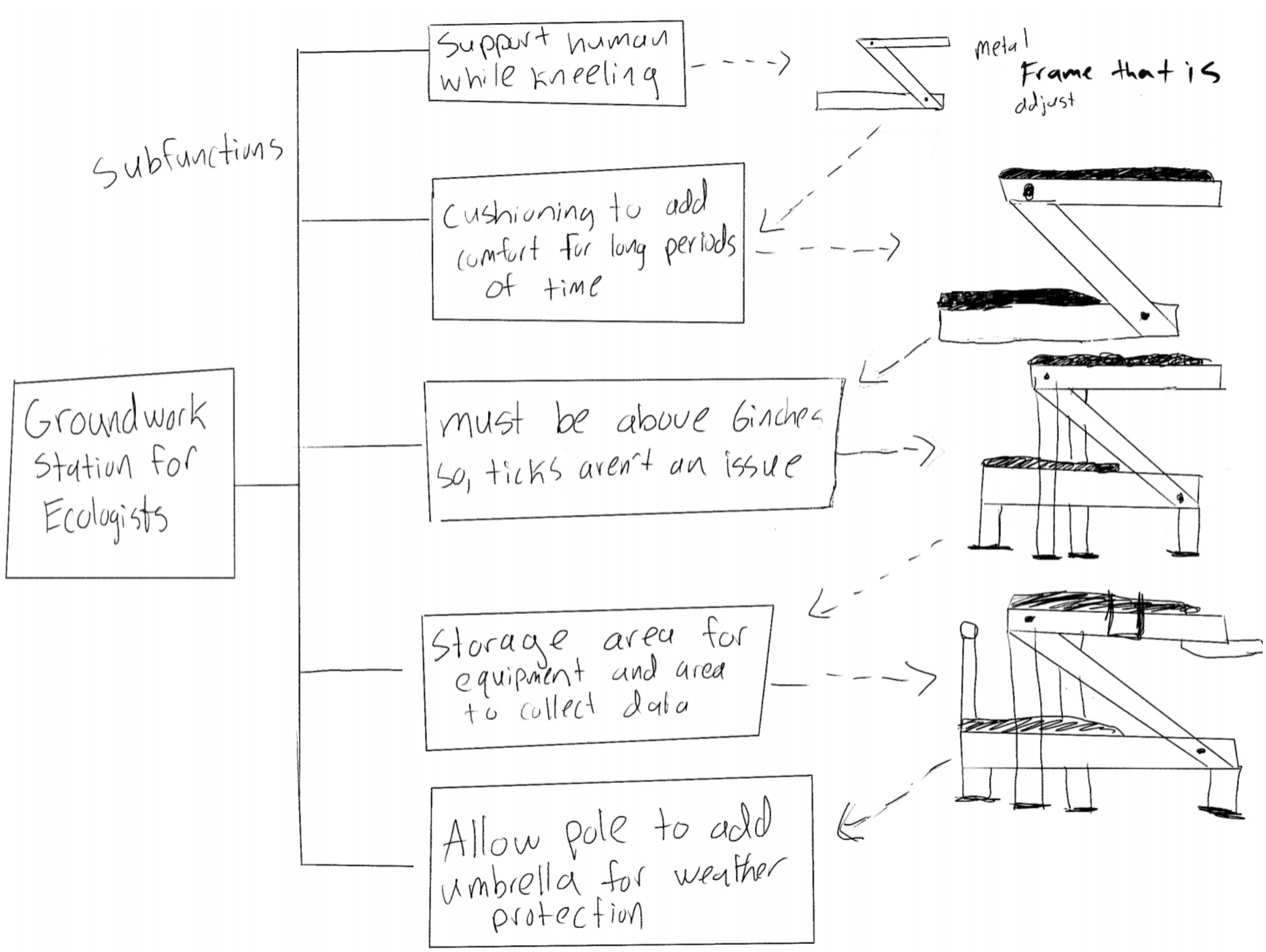


Figure 10: Function tree for Groundwork Station, hand-drawn and scanned

3.3 Morphological Chart

The chart below breaks down the sub- functions from the function tree and provides several solutions for each. Some are more practical than others, but this provided the basis for the concept drawings.

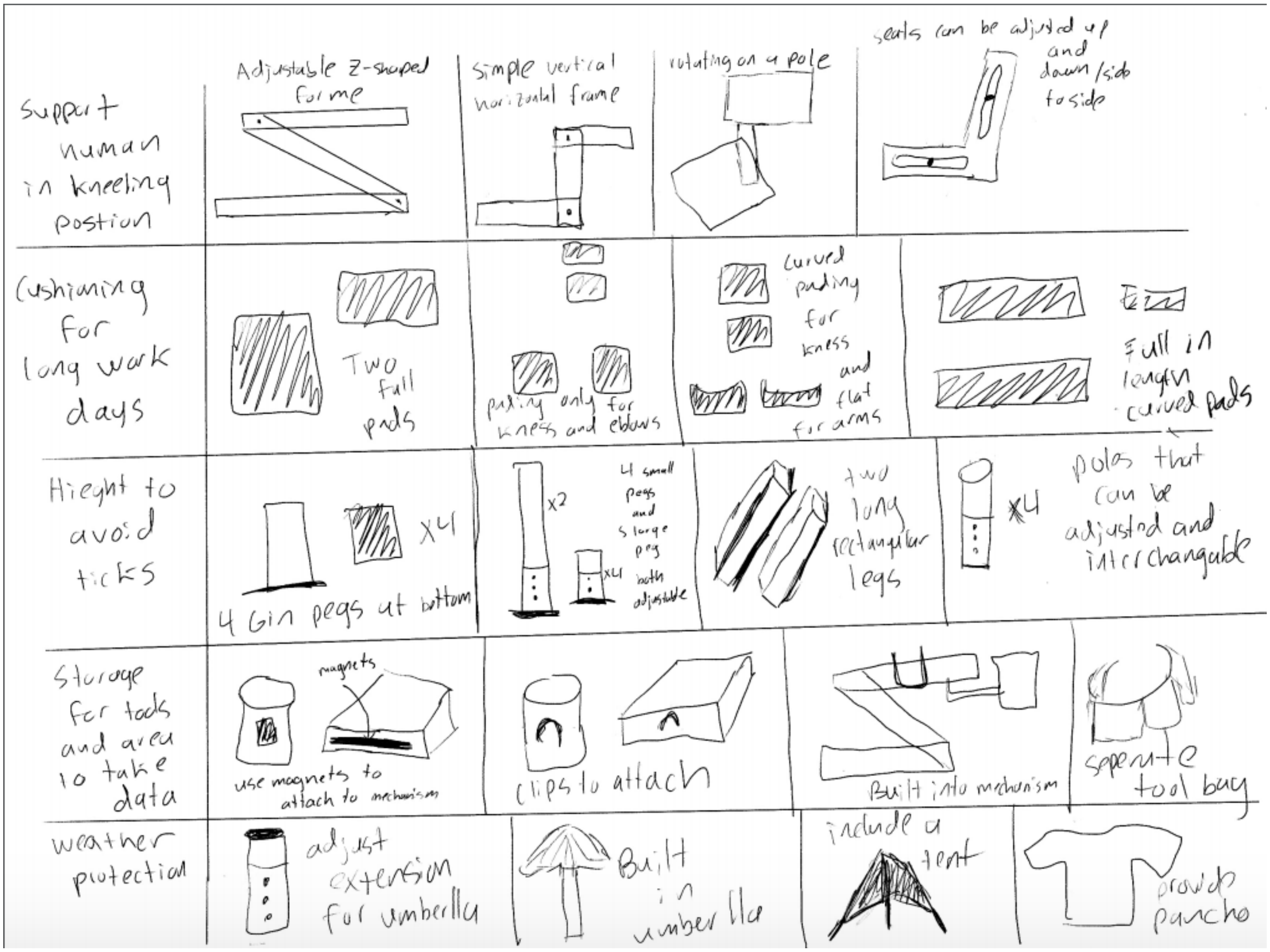


Figure 11: Morphological Chart for Groundwork Station

3.4 Alternative Design Concepts

3.4.1 The Giraffe Stool ()

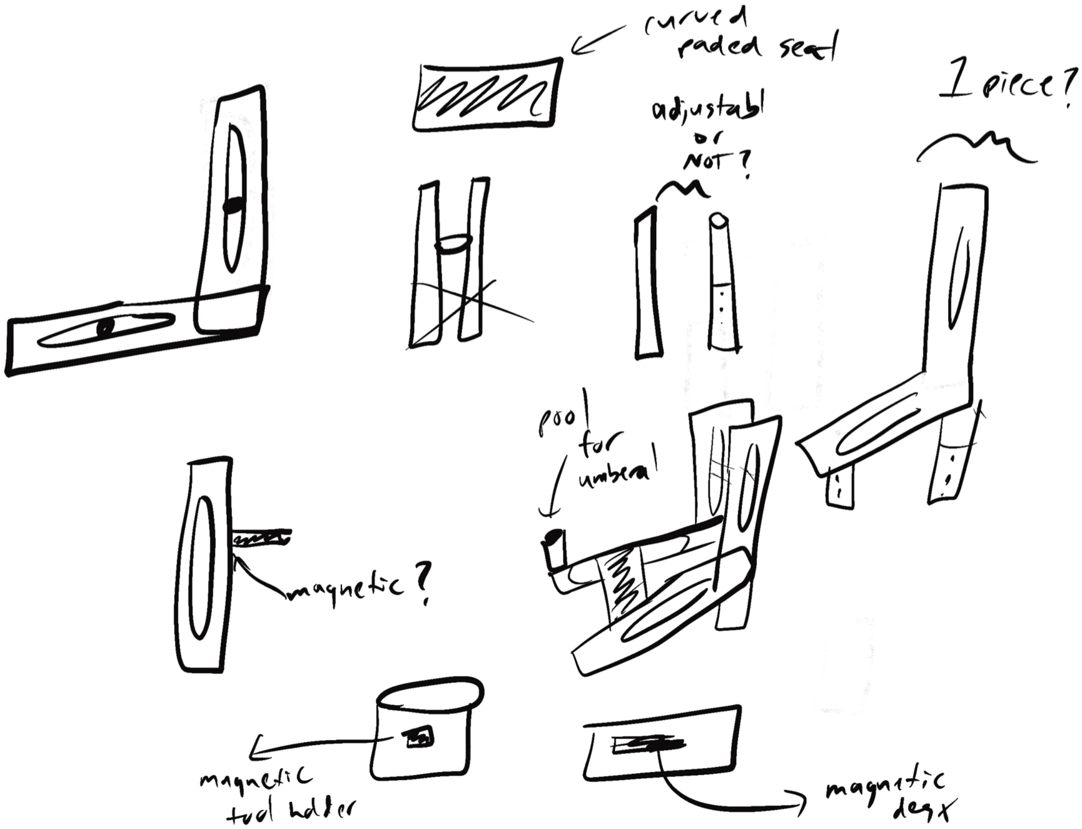


Figure 12: Preliminary sketches of The Giraffe Stool

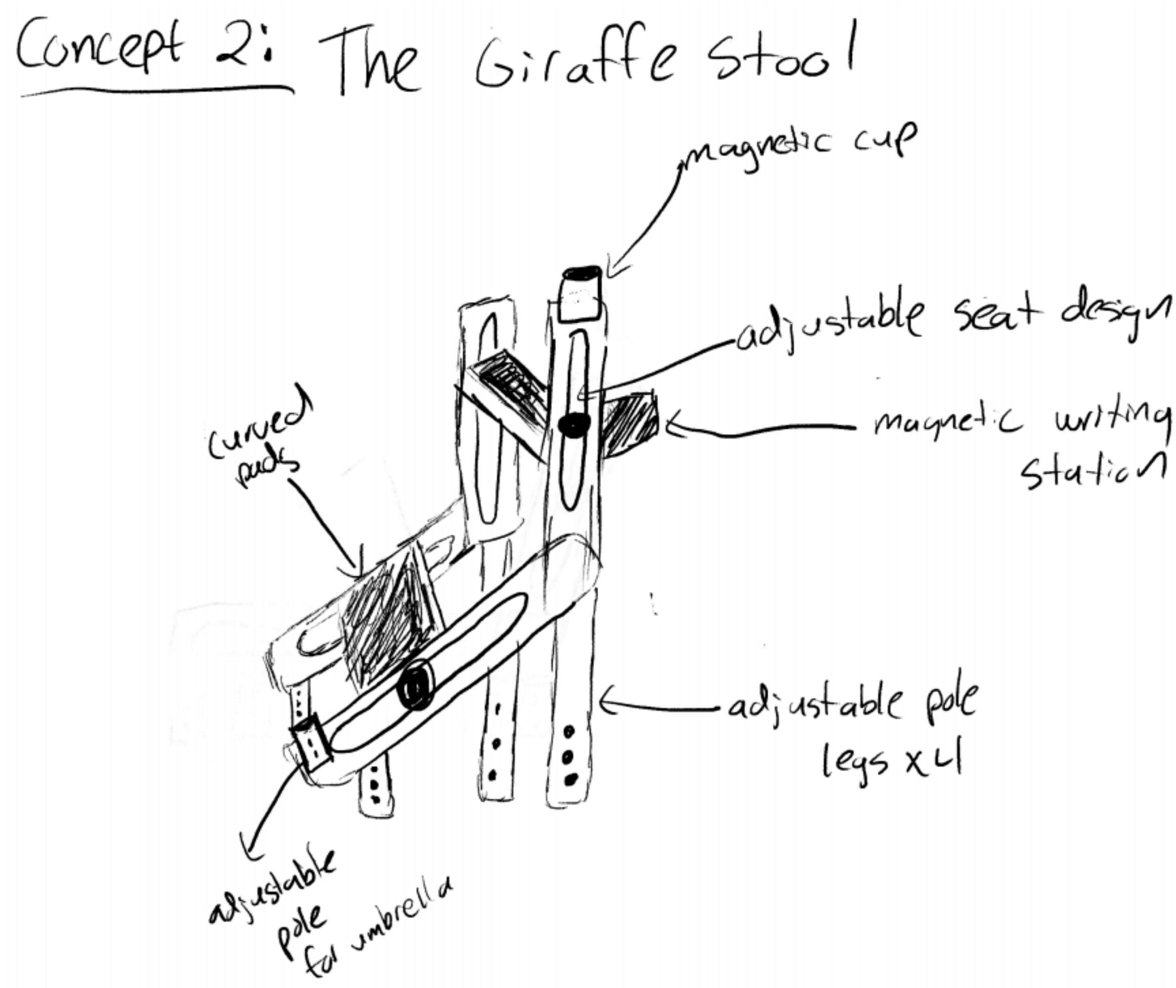


Figure 13: Final sketches of The Giraffe Stool

Solutions from morph chart:

1. Adjustable seat and arm rest
2. Curved Padded Cushioning
3. Four adjustable legs
4. Magnetic tool Storage
5. Adjustable extension for weather protection

Description: This groundwork station concept is one piece with adjustable seating and arm rests for customizable comfort. The legs are also adjustable vertically to be able to work on multiple types of terrains. The cushioning is curved for maximum comfort and all the tool storage is magnetic to customize efficiency for each user.The weather pole is on the side and an umbrella can be attached to it for rain protection.

3.4.2 Fold-A-Bench ()

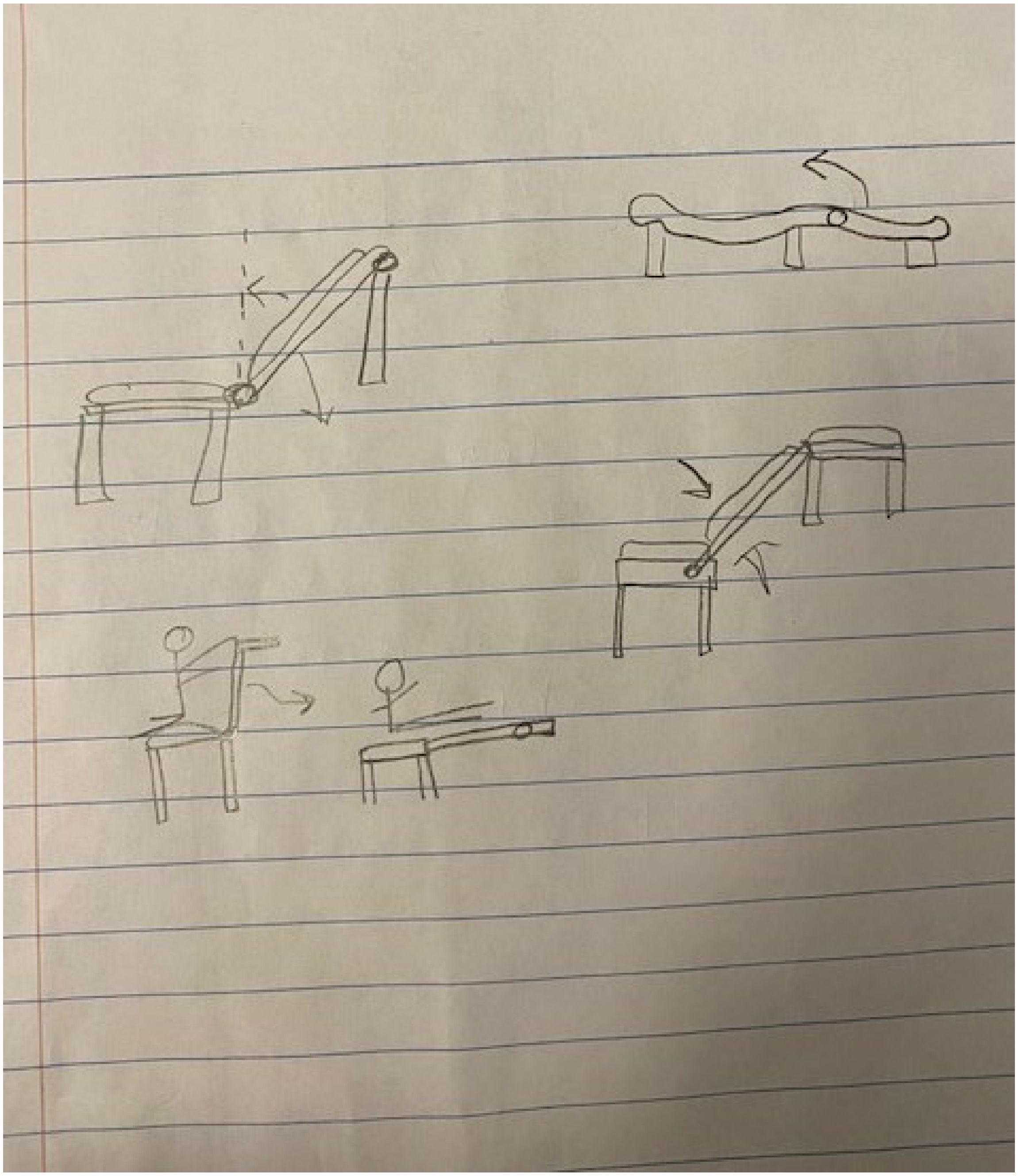


Figure 14: Concept sketches for the Fold-A-Bench.

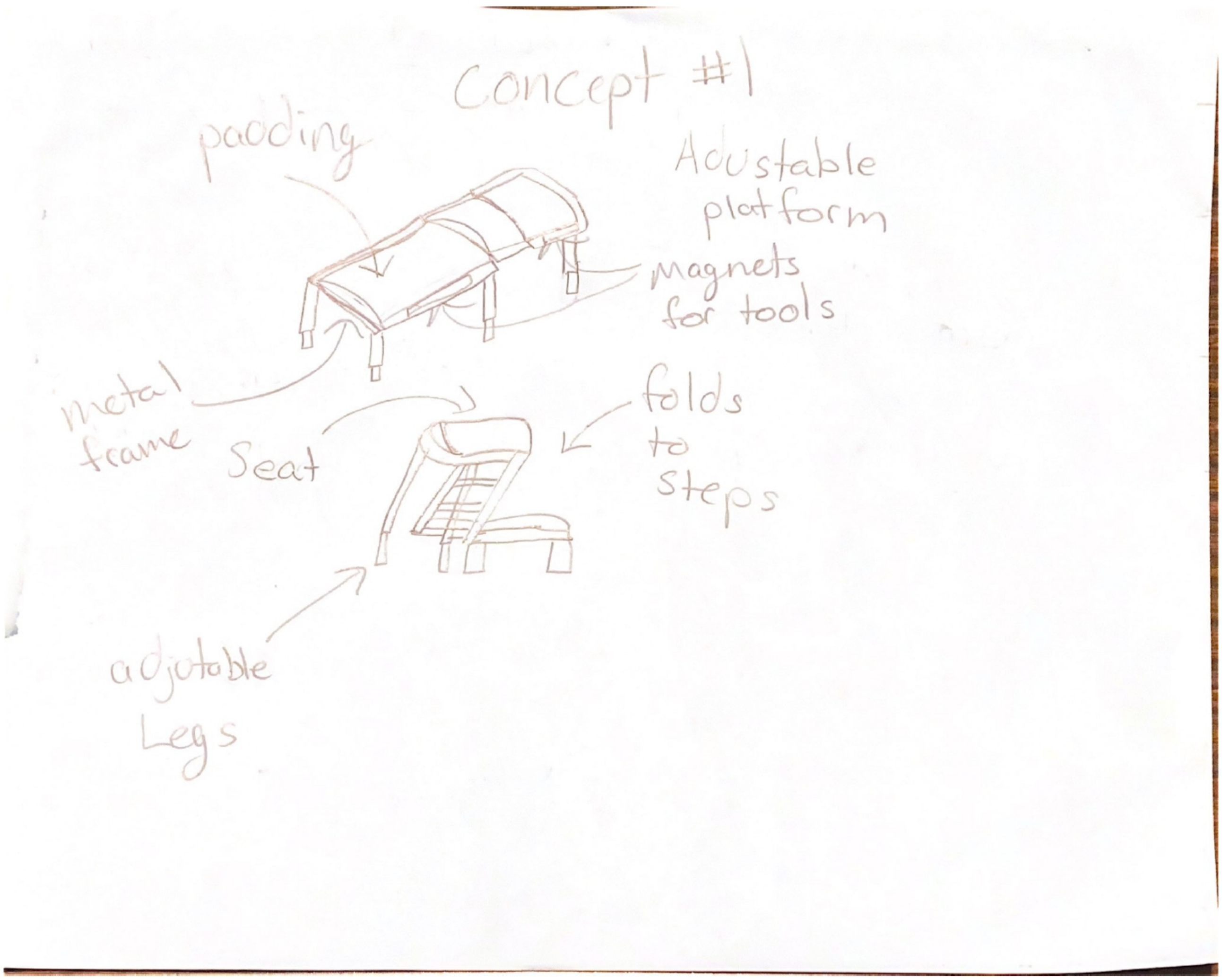


Figure 15: Possible prototype for a fold-able ground station support.

Solutions from morph chart:

1. Supports Kneeling and sitting position
2. Cushioning
3. Height to avoid ticks
4. Storage
5. Weather Protected

Description: The Fold-A-Bench design builds of the Mock up design with the attributes on fold-ability and portability. Adjustable legs are added to the base of the design to get the user off the ground a safe height away from insects. The design allows incorporates padding for the user as well as magnets on the sides of the frame to allow easy access to tools that can hang magnetically. The padding will be made of vinyl and the frame will be made of coated metal to avoid corrosion and the outdoor elements. The biggest for see able deign challenge is making sure the adjustable legs do not interfere with the fold ability or transport of the unit.

3.4.3 Hammock ()

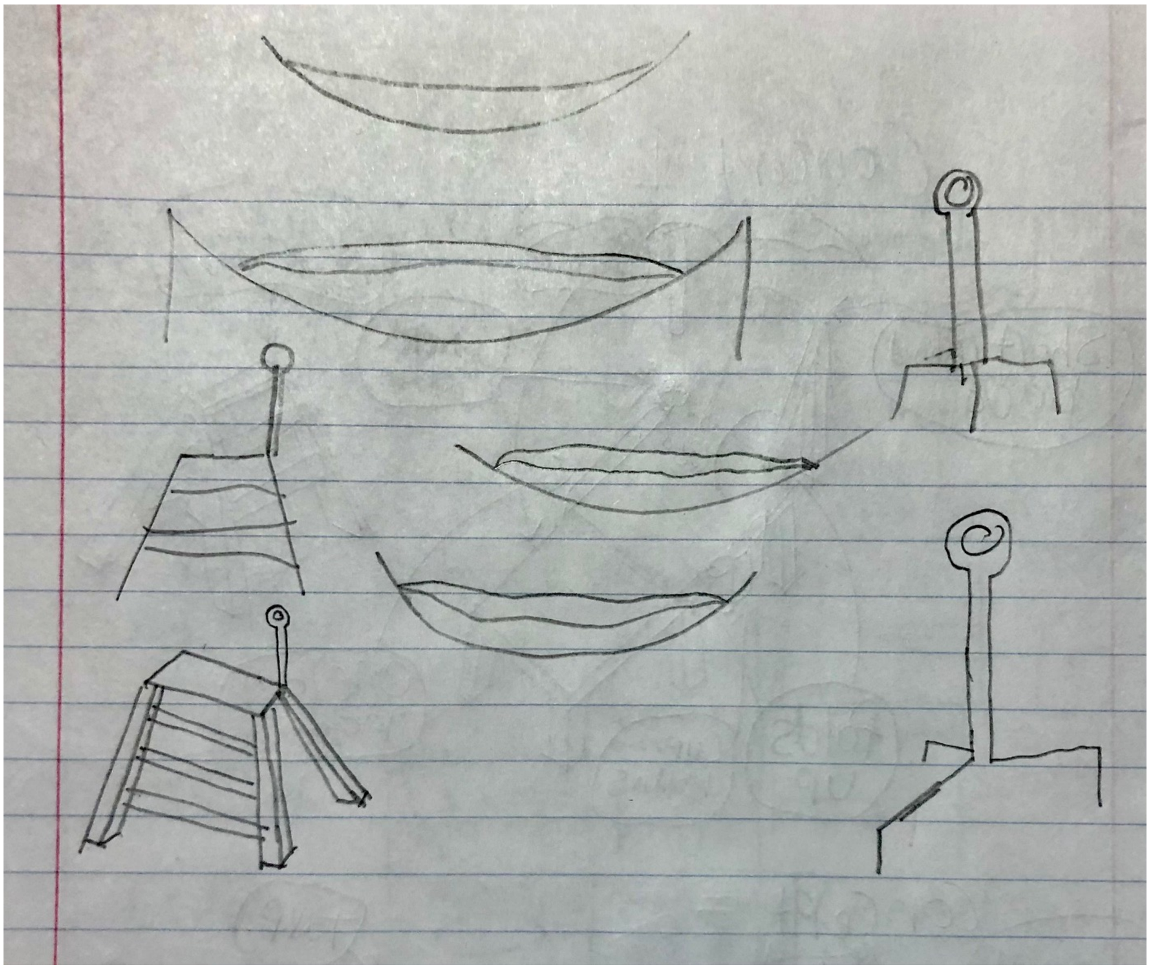


Figure 16: Preliminary sketches of The Hammock

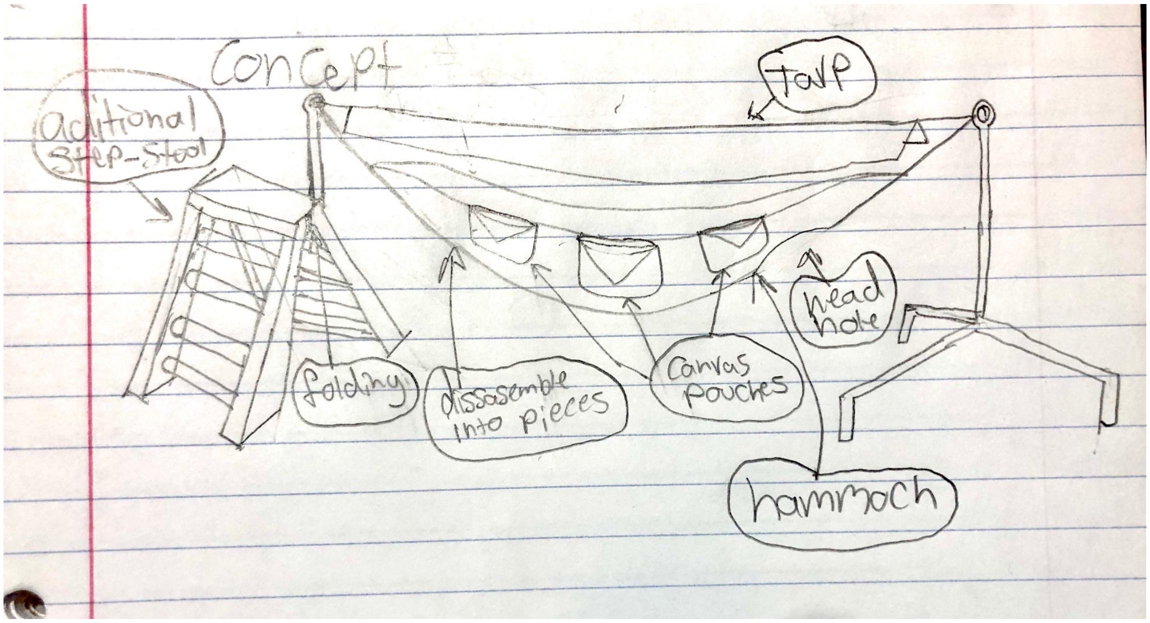


Figure 17: Last Preliminary sketch of The Hammock

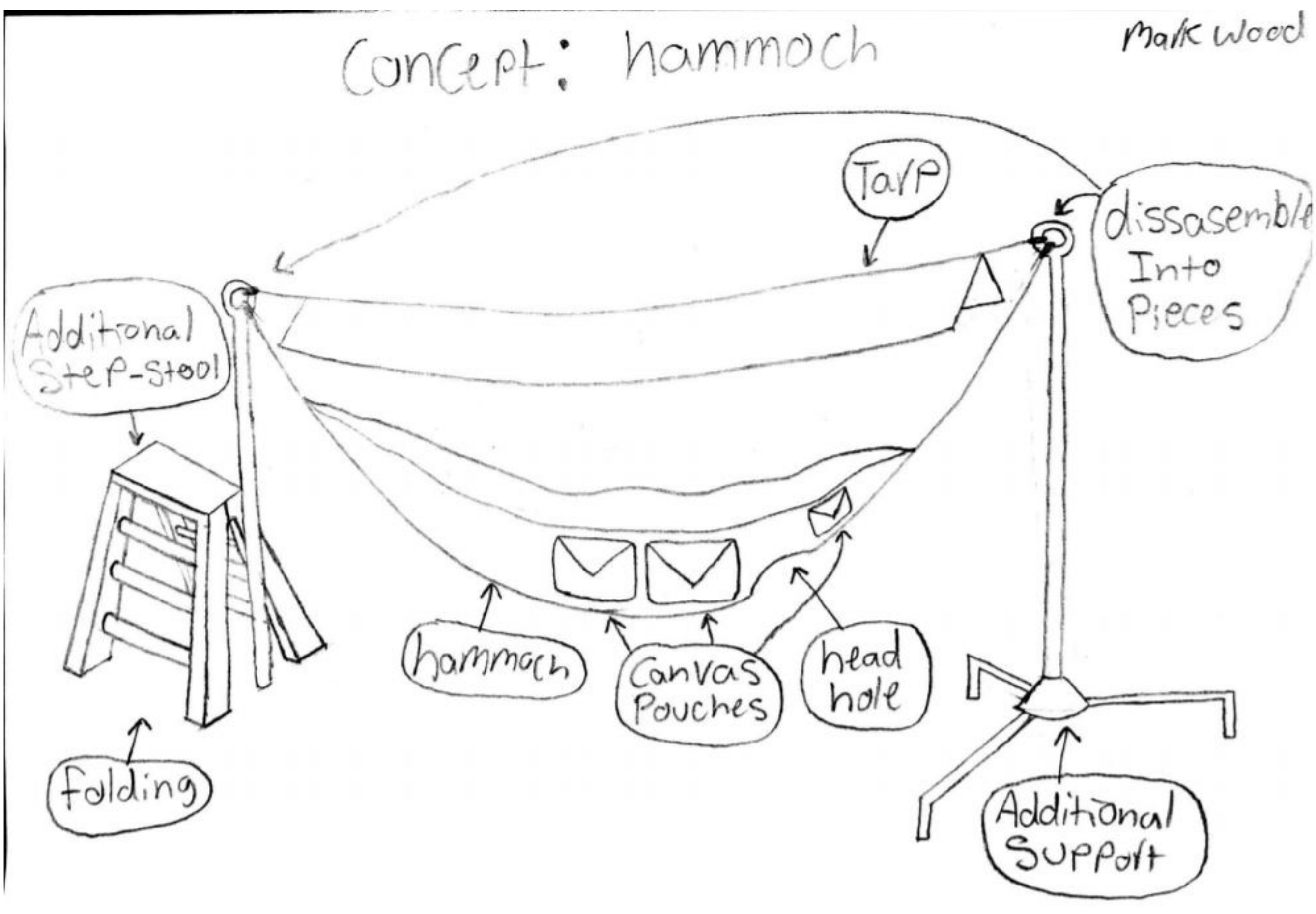


Figure 18: Final sketch of the Hammock

<u>Solutions from morph chart:</u>

1. Hammock
2. Disassembled
3. Additional Step-Ladder
4. Head Hole
5. Canvas Pouches
6. Tarp

Description: The hammock allows the user to comfortable lay inside for long periods of time with access tho the ground. The hammock is connected to a stool for climbing over mammal encloses on one side and a tall support on the other. An attachable tarp can be set up over the hammock for sun and rain protection. The entire apparatus can be disassembled into components for transportation between work sites. While this design is comfortable and easy to use, it is bulky and requires an additional support that must be carried between sites. This is minimized by the fact that the hammock can be stuffed into a backpack and does not require much space.

4 Concept Selection

4.1 Selection Criteria

Below in Figure 19 shows an Analytic Hierarchy Process (AHP) to help determine criterion importance for the design. Five criterion were selected for the AHP, weight, trans-portability, Cost to manufacture, assembly, and comfort to the user. A numerical rating scale is given in the figure to show the value of each number as a comparison between two criterion. The AHP helped determine the most import criterion was transport, while a close second was the weight of the design, each very important for the user whole will carry the design with them all day for research. The cost was rated the lowest for the user out of these 5 criteria.

	Weight	Transport	Cost	Assembly	Comfort	Row Total	Weight Value	Weight (%)
Weight	1.00	0.33	3.00	3.00	5.00	12.33	0.29	28.95
Transport	3.00	1.00	5.00	1.00	3.00	13.00	0.31	30.52
Cost	0.33	0.20	1.00	0.20	0.33	2.07	0.05	4.85
Assembly	0.33	1.00	5.00	1.00	3.00	10.33	0.24	24.26
Comfort	0.20	0.33	3.00	0.33	1.00	4.87	0.11	11.42
					Column Total:	42.60	1.00	100.00

Row criterion is _______ than/as column criterion

Numerical ratings:
9 -- Extremely more important
7 -- Very strongly more important
5 -- Strongly more important
3 -- Moderately more important
1 -- Equally important
1/3 -- Moderately less important
1/5 -- Strongly less important
1/7 -- Very strongly less important
1/9 -- Extremely less important

Figure 19: Analytic Hierarchy Process (AHP) to determine scoring matrix weights

4.2 Concept Evaluation

After using the design criterion stated above in the AHP, we then took our favorite design ideas plus agreed on a fourth and placed them into a weighted scoring matrix below. The weighted scoring matrix (WSM) allows us to put weighted specifications into the table and grade our designs based off how well each design does. The specifications we went with in the WSM were weight, height, durability, ease of transport, cost, comfort, and ease of assembly. Since we increased the amount of criteria from the above AHP, the weighting differed slightly. The weights were more spread out, but the highest ranking criteria, transport, was weighted the highest with other criteria like cost and comfort weighing lower, as shown in the AHP. They were all weighed fairly closed as they all affect the users approval of the design. This is why being comfortable was weighted evenly with cost, as it has a direct affect on the user, and the cost made it so the product would be actually affordable to the researchers, thus actually using the design and not a cheaper alternative. Categories that the researchers explicitly stated in the interview for qualities wanted in the design were ranked higher. Using the WSM we found the creeper design to be the best, even tho it did not rank a 5 (max score) in any category. A close second was the step stool structure with just one point below. Figure 20 below shows the alternative designs and their rankings

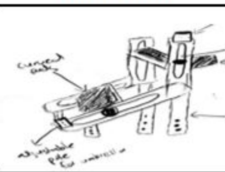
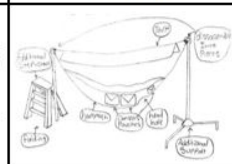
Alternative Deisgn Concepts		**Creeper**		**Steps Structure**		**Giraffe Stool**		**Hammock**	
									
Selection Criterion	**Weight (%)**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Weight	15.00	3	0.45	4	0.60	2	0.30	2	0.30
Hieght from Gorund	15.00	2	0.30	1	0.15	5	0.75	4	0.60
Durability	15.00	4	0.60	1	0.15	3	0.45	2	0.30
Ease of Transport	20.00	4	0.80	4	0.80	2	0.40	1	0.20
Cost of Manufacture	10.00	3	0.30	5	0.50	1	0.10	2	0.20
Comfort	10.00	4	0.40	2	0.20	4	0.40	5	0.50
Ease of Assembly	15.00	4	0.60	5	0.75	2	0.30	1	0.15
	Total score	**3.450**		**3.150**		**2.700**		**2.250**	
	Rank	**1**		**2**		**3**		**4**	

Figure 20: Weighted Scoring Matrix (WSM) for choosing between alternative concepts

4.3 Evaluation Results

For the weighted scoring matrix we had seven different criterion in selecting an initial concept to build. According to the matrix, the creeper design would be the best to pursue as it rated fairly high in 4 out of the 7 criterion. Getting a four rating in comfort and ease to assemble was key as no other concept rated higher, and it was high on the priority list for the customer. The creeper also scored a four in durability and ease of transport, which would help when being used in different terrains. The only criterion that would need to be adjusted for the creeper would be the initial height of 6 inches, it only scored a 2 here. This was on the top of the customers needed and when building the groundwork station we are going to have to incorporate a better solution. In the future, we could add in components that made the "giraffe stool" grade higher in the initial height criterion to our current concept.

4.4 Engineering Models/Relationships

Model 1:

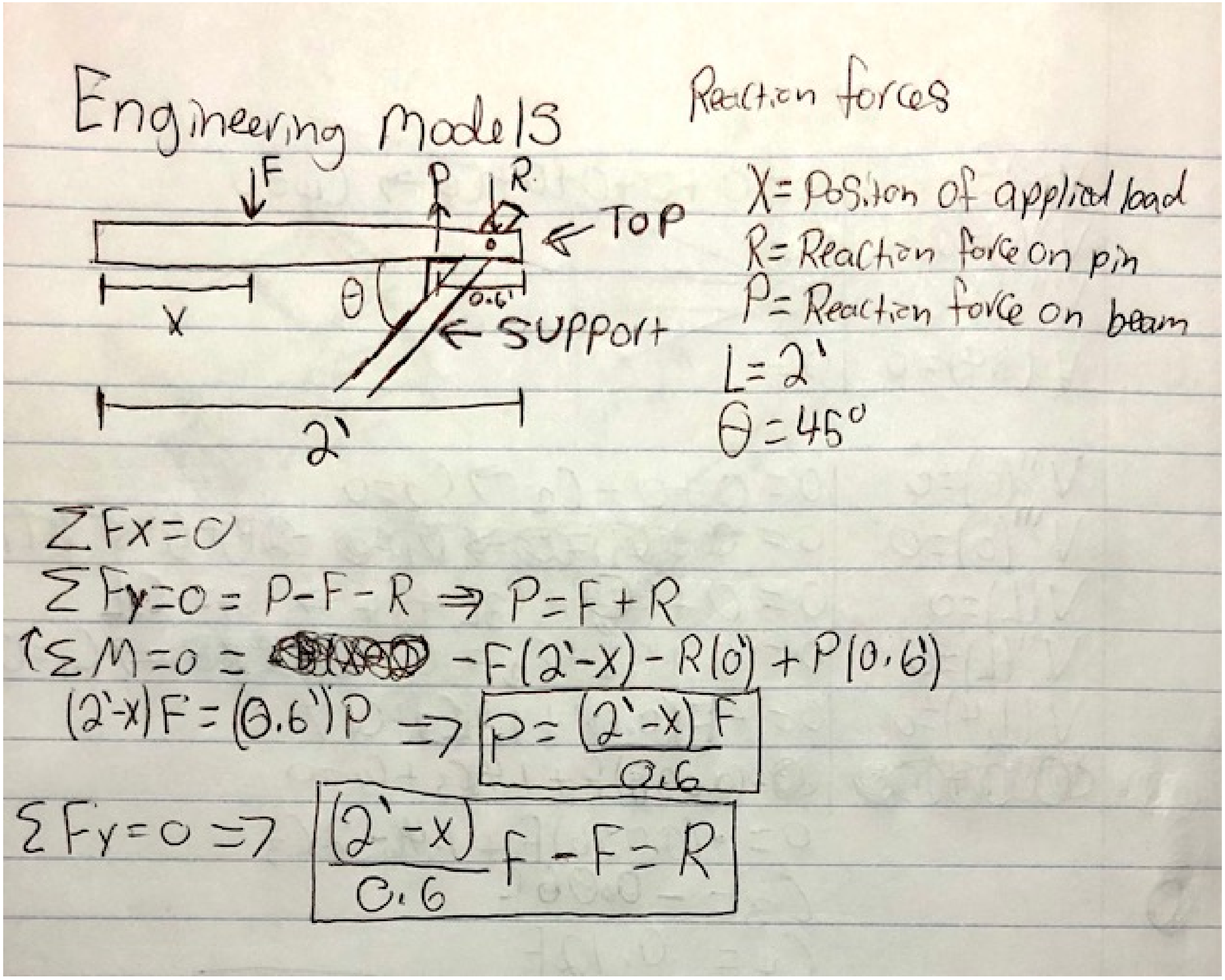


Figure 21: Engineering model 1: Forces and reactions on the top hinge and support

This engineering model applies to the forces and reactions on the top hinge and support of the seat. The force on the pin and support can be much larger than an applied force downward from a person's weight. This model gives our group an expression for the reaction forces when the weight is applied anywhere along the length of the seat. With this expression, we can see that the reaction forces are maximized when the applied force is on the free end of the seat. We will use this to find the necessary strength of the pin.

Model 2:

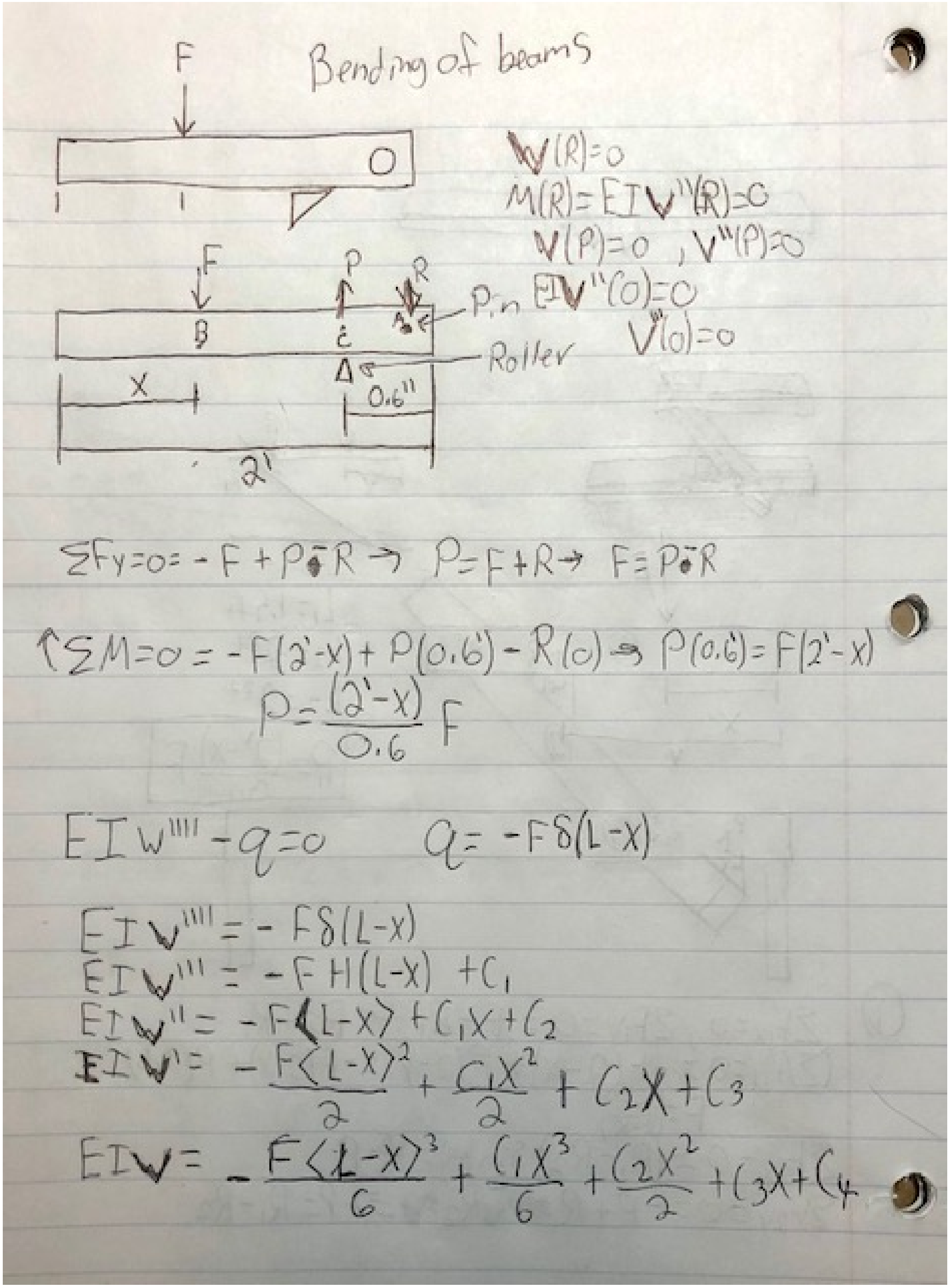


Figure 22: Engineering model 2 pt. 1: Deflection and bending of seat

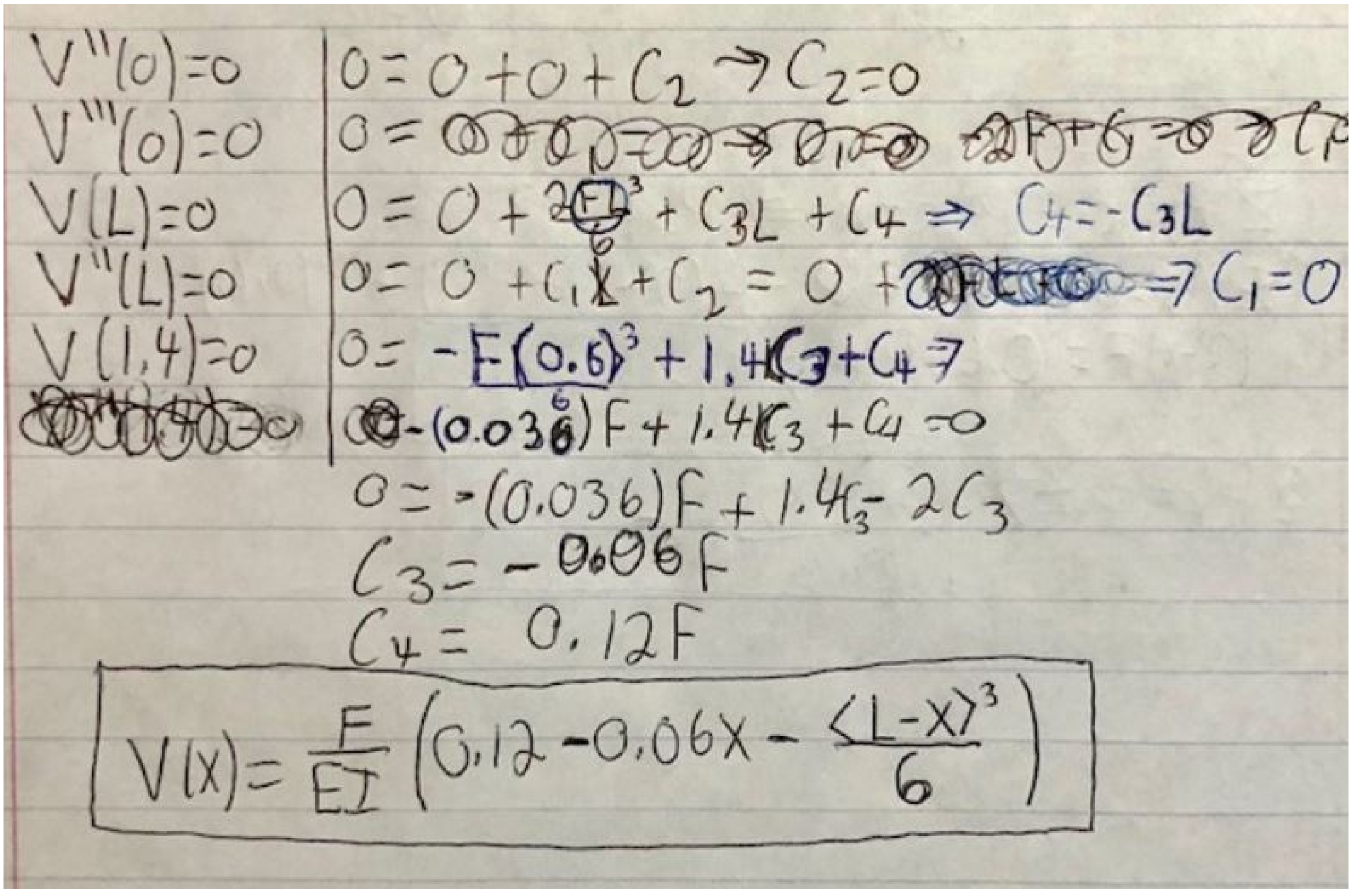


Figure 23: Engineering model 2 pt. 2: Deflection and bending of seat

Model 2 describes the bending of the seat of the ground work station. Using bernoulli-euler beam theory and the known boundary conditions for the free end, pinned support, and the beam support, the equation for vertical deflection of the beam was calculated. This formula will allow the group to determine if a given material is suitable for building the ground work station. If the deflection were calculated using the elastic modulus and mass moment of inertia of a PVC pipe, the pipe would likely deflect beyond what is allowed so another material must be selected.

<u>Model 3:</u>

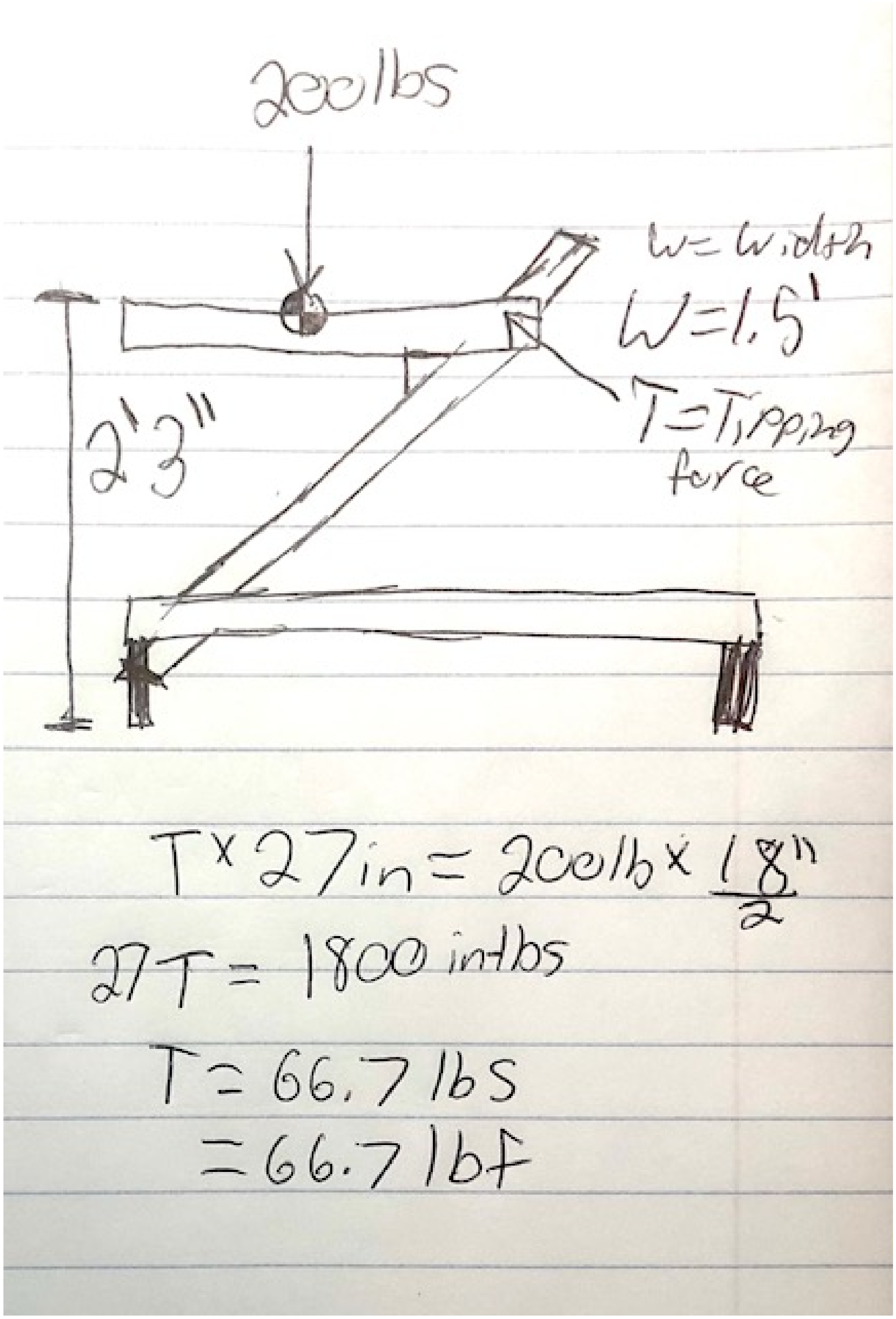


Figure 24: Engineering model 3: Force required to tip over the ground work station

The ground work station must have a stable base to avoid tipping. This engineering model describes the force required to tip over the GWS when there is a total weight of 200 lbs between the GWS and the user. Note that it would only require 67 pounds of force to tip the device when it has a width of 18 inches. Increasing the width is one way to increase the stability but there are additional ways if a wider GWS is too difficult to carry. Driving steaks through the feet of the GWS and into the ground may be required.

5 Concept Embodiment

5.1 Initial Embodiment

In this section CAD drawings are provided from SolidWorks of the initial prototype ground-work-station. This design incorporates an adjustable creeper with six inch wooden legs for support. Figure 25 shows the top, right, front, and isometric view of the creeper prototype along with basic dimensions. Figure 26 shows a large isometric view along with a bill of materials for the creeper. The last figure, Figure 27 shows an exploded view of the creeper prototype along will bubbles indicating which parts are which.

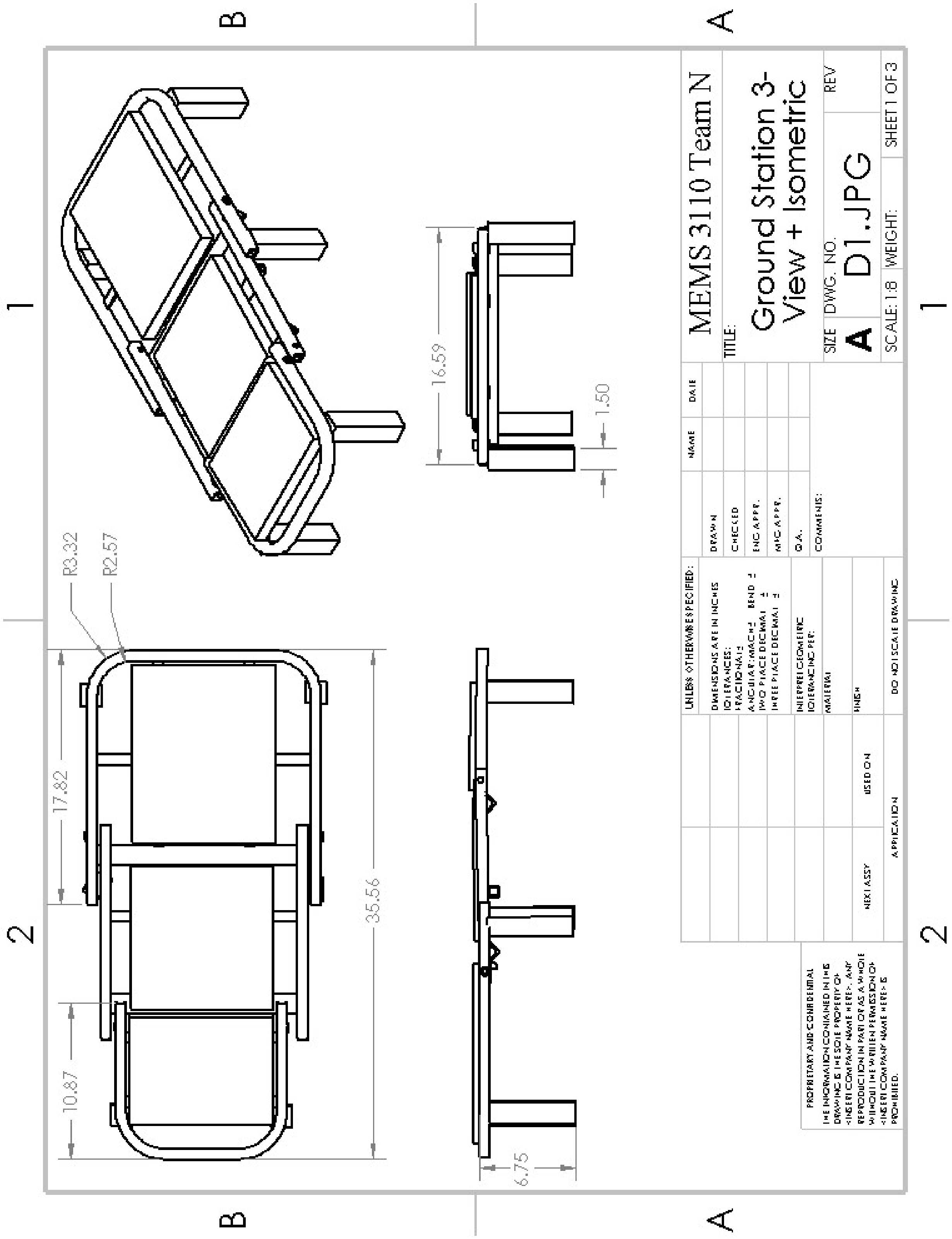


Figure 25: Assembled projected views with overall dimensions

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	creeperbot	Metal bottom of creeper	1
2	creepermid	Metal middle of creeper	1
3	Creeperhead	Metal top of creeper	1
4	leg1	6" wooden leg	6
5	pad	wooden support for user	1
6	pad2	wooden support for user	1
7	pad3	wooden support for user	1

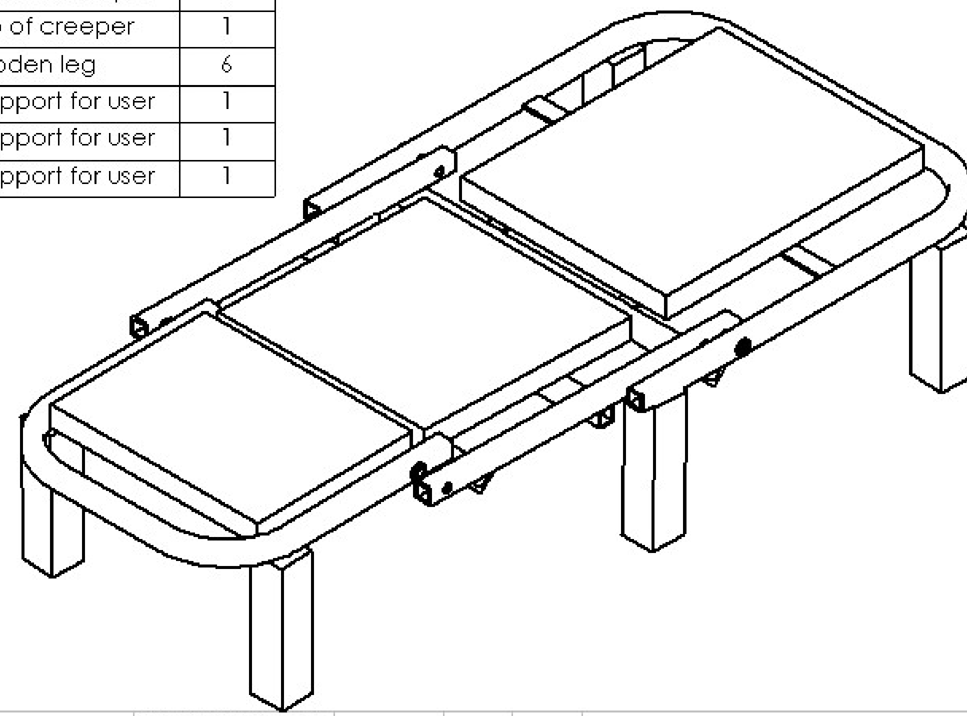


Figure 26: Assembled isometric view with bill of materials (BOM)

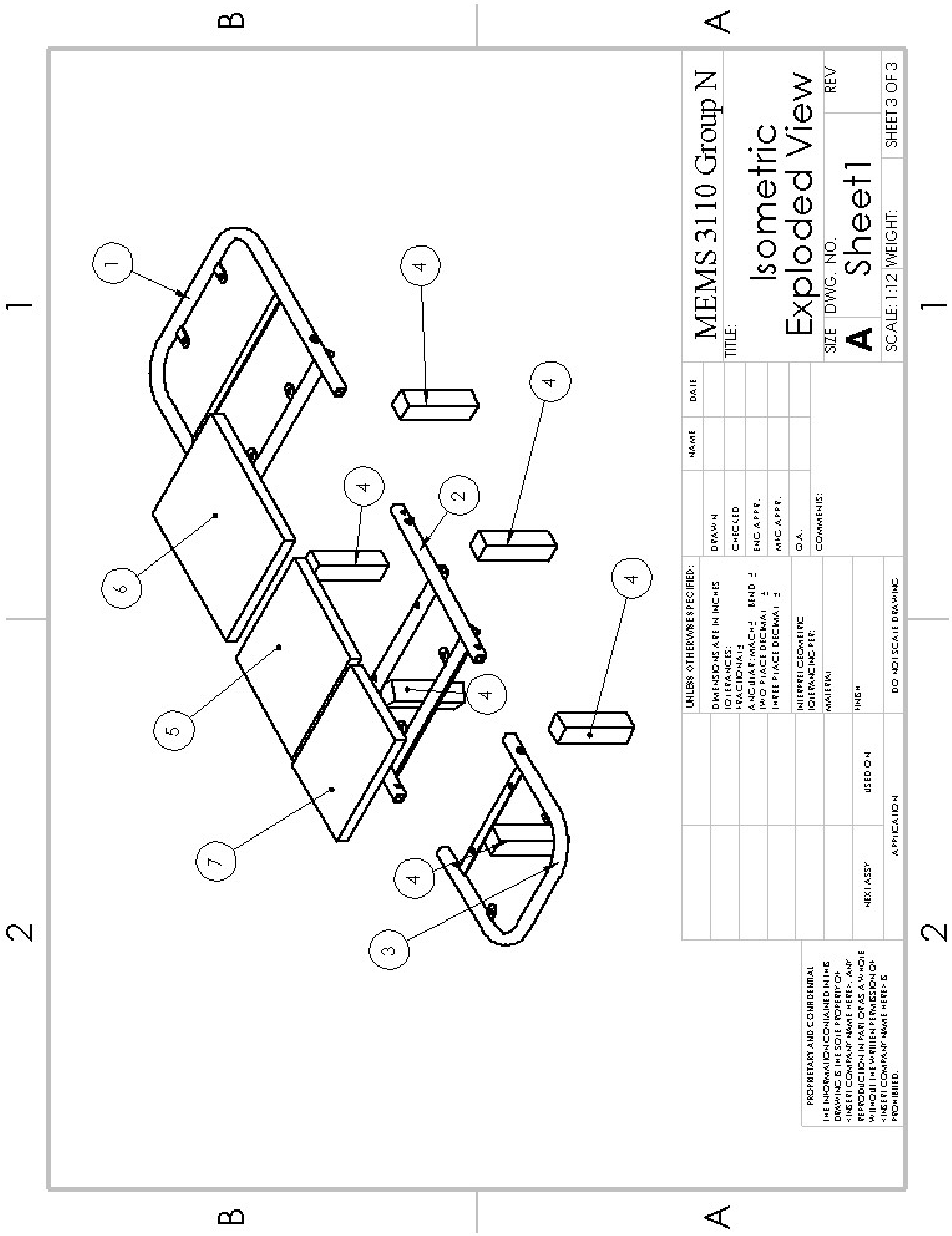


Figure 27: Exploded view with callout to BOM

5.2 Proofs-of-Concept

When discuss and experiment with prototype designs, the first and most important thing that came to mind with the group is that the station must of course be able to hold a persons weight. Without even accomplishing this no other criteria could be met. Since the researchers had mentioned their use of PVC piping to support their weight, but being flimsy and easily coming apart, the initial design of the station was to be made out of wood. After determining that making the station completely out of wood made it very bulky and somewhat heavy, a metal design was introduced. The wooden legs were kept as they were able to handle the weight of the metal frame along with the weight of a person.

The biggest difference between the prototype and the concept selection from section four is the incorporating of metal legs. The car creeper originally included small wheels for mobility but was not wanted by the researchers. Ideally the researchers would like something that can handle both flat and uneven terrain, so metal legs that are able to adjust will be used for a future iteration. Slight modification had to be done on the metal frame as well to allow it to collapse more fully so that it could be comfortably carried on a users back. Parachute cord was also added to allow the user to carry the station around like a backpack, but better straps are needed for a more ergonomic friendly design.

6 Design Refinement

6.1 Model-Based Design and Analysis

Pins support each leg to keep the length to the set amount. The current pins selected for the design are stainless steel and have a diameter of $\frac{1}{4}$ inches. These pins will experience a shear stress from the load on each leg. Assuming the static load is 200 lbs, each pin would experience a sheer stress of 340 Psi. Since stainless steel has a maximum shear stress of at least 10800 Psi, according to MatWeb.com, the pins can support almost 32 times the static load. The pins are more than strong enough for its purpose. The holes for the pins have already been drilled at $\frac{5}{16}$ inches so $\frac{1}{4}$ inches is the smallest allowable pin diameter. A diagram and written math are shown below.

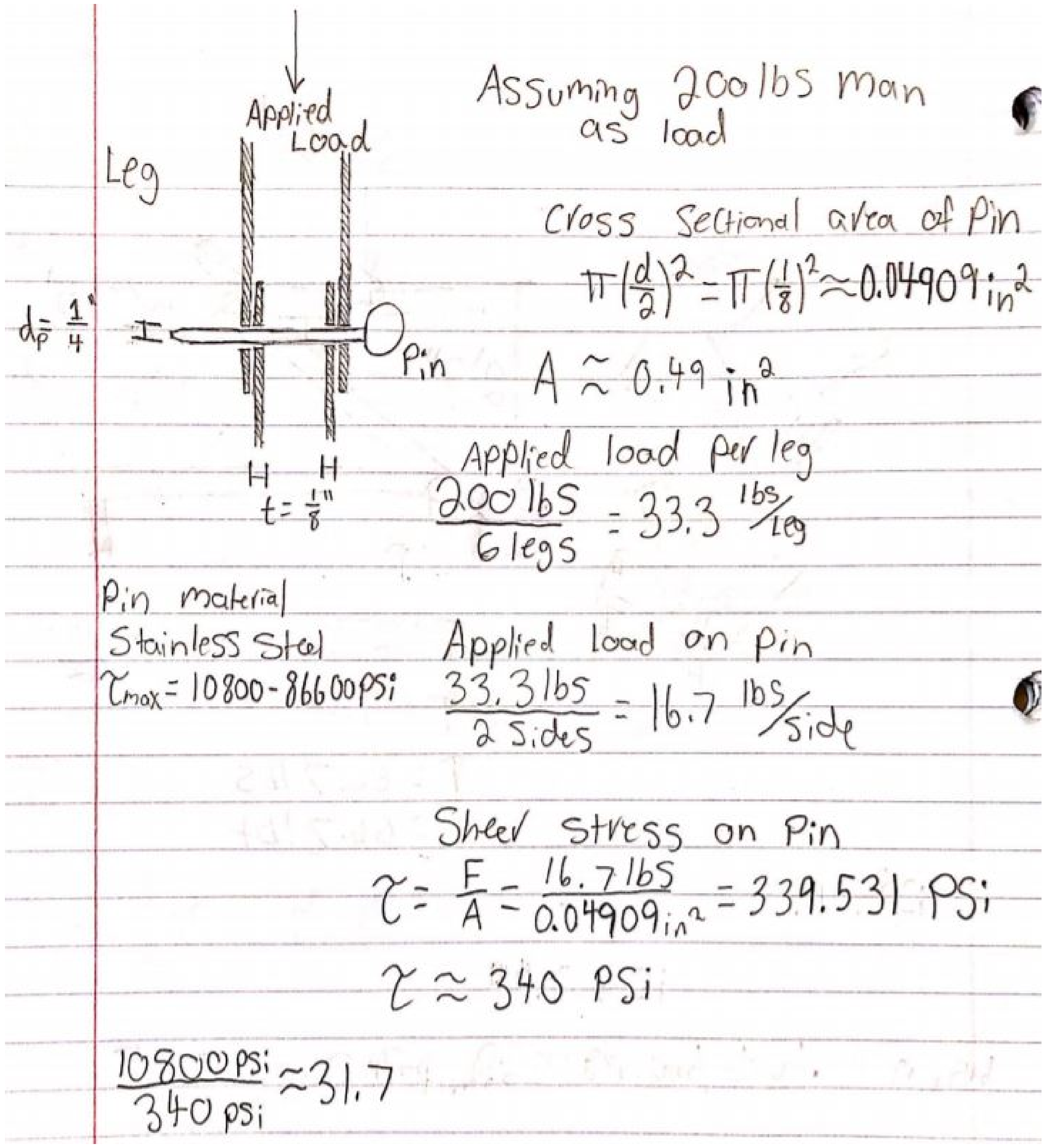


Figure 28: Model of Shear Stresses on Pins.

The feet of the Ground Work Station are capped with a 1 $\frac{7}{8}$ inch diameter steel plate to keep it from sinking into the ground. Assuming a 200 lbs load is applied to the GWS, the ground pressure from the device is 12.1 Psi. According to Military.com, the M1A2 Abrams Main Battle Tank exerts a ground pressure of about 15 Psi, and the M1A2 Abrams Tank can move through muddy and swampy terrain without sinking an excess amount into the ground. Knowing this, the GWS will likely not have any trouble sinking into the ground even after being set up for multiple hours (unless it is in extreme mud). The current foot size is sufficient and does not need to be increased. A diagram and written math are shown below.

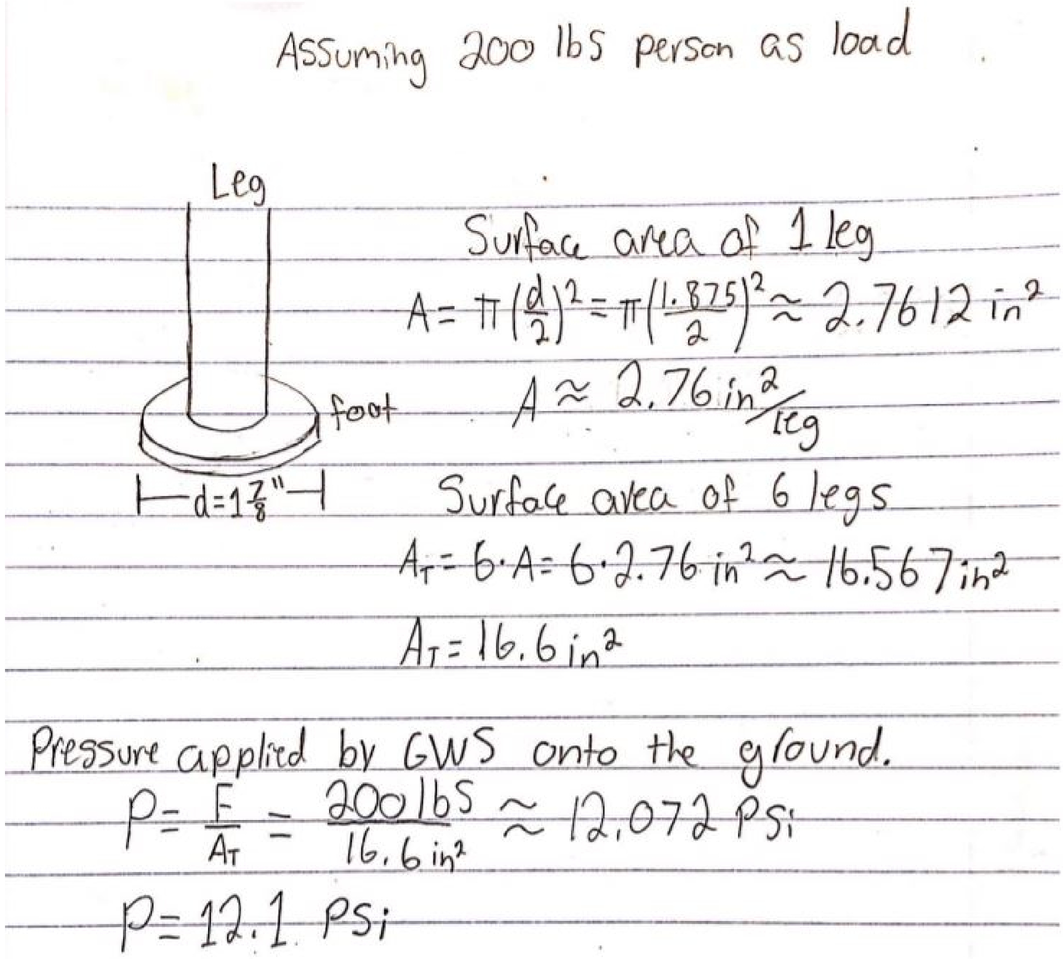


Figure 29: Model of Ground Pressure Applied by the Feet.

The ground work station has 6 individual steel legs that are adjustable with pins. Here we calculated the critical buckling load for the smaller leg, to assure that that ground work station would not fail prematurely. The steel has a high elastic modulus thus increasing the critical load quite a bit. With these calculations it seems that the frame of the creep would fail before the legs buckle. This proves that a vital part of the ground work station,the legs, are durable and can withstand high force at some of its weakest points.

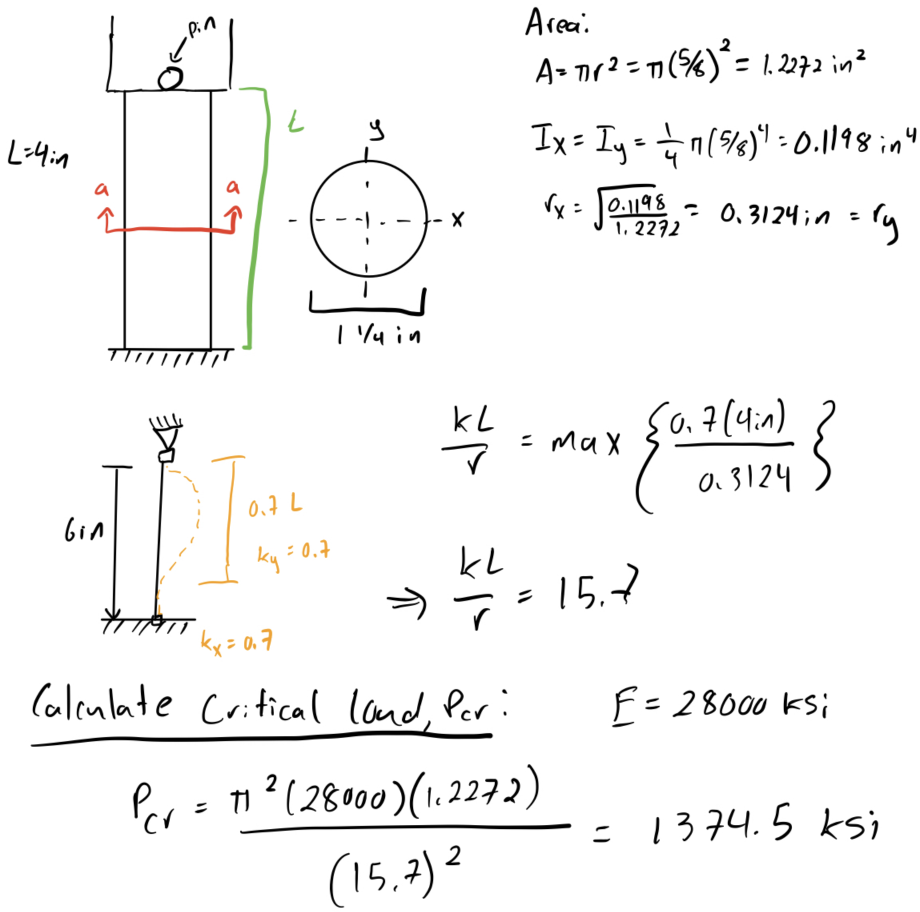


Figure 30: Calculations for Critical Buckling Load of Smaller Legs

6.2 Design for Safety

In this section five risks associated with the the ground work station designed are addressed and examined for possible solutions. Along with a description of each risk are their severity and probability of occurring. Each risk includes at least one possible solution to improve the overall design. Finally in Figure 31, a heat map of the risks is shown to assess their importance to the overall design.

6.2.1 Risk #1: Stability

Description: The creeper must hold up a person for measurements, but if the creeper is not stable enough to do this, it could lead to injury of the user. This can occur because legs are not properly planted into the ground or bending caused by the users weight affects the integrity of the legs.

Severity: Catastrophic.

Probability: Seldom.

Mitigating Steps: the legs have been redesigned using aluminum tubing, while increases it strength and rigidity from wood. Also the points and which the creeper is attached to the legs have been reinforced with additional metal to mitigate failure from bending.

6.2.2 Risk #2: Tripping Hazard

Description: The device is low to the ground and thus easy to be missed by ground crew. This means that they could accidentally trip over the device if they are not able to see it and all its components.
Severity: Critical.
Probability: Occasional.
Mitigating Steps: Painting the creeper a bright red color allows it to be clearly visible in almost any natural environment, thus the crew will have an easier time seeing it and avoiding it. Because the bright color is also reflective even at night they will have a easier time seeing it within the darkness using their flashlights.

6.2.3 Risk #3: Pin failure

Description: The pins falling out is an unlikely event when in use due to force/friction, however when moving the creeper, the pins could dislodge and fall onto the ground, thus having nothing to hold the legs in place. Not using a leg redistributes the weight of the user onto the other legs, which could be dangerous.
Severity: Marginal.
Probability: Seldom.
Mitigating Steps: Attach the pins to the creeper so they are less likely to be lost. Also make the pins a bright reflective color so if they do get lost they are easier to find.

6.2.4 Risk #4: Rusting

Description: Rusting can affect the entire strength of the creeper by affecting the material properties. This has the most potential to affect the design, especially at the joints where bending could occur from weaker metal.
Severity: Catastrophic.
Probability: Likely.
Mitigating Steps: Painting the device is the first step to cover all exposed metal and make sure it is not exposed. The bigger danger is liquid getting into the metal through openings and wholes. These openings should be covered with plastic tips that hold off any water from entering.

6.2.5 Risk #5: Carrying Hazard

Description: When a user is carrying the device, the station could unfold and accidentally hit the carrier or another person.
Severity: Negligible.
Probability: Occasional.
Mitigating Steps: To help mitigate this risk better cords/straps should be used to assure they do not come undone from carrying it.

		Probability that something will go wrong				
	Category	**Frequent** Likely to occur immediately or in a short period of time; expected to occur	**Likely** Quite likely to occur in time	**Occasional** May occur in time	**Seldom** Not likely to occur but possible	**Unlikely** Unlikely to occur
Severity of risk	**Catastrophic**		Rusting		Stability	
	Critical			Tripping Hazard		
	Marginal				Pin failure	
	Negligible hazard presents a minimal threat to safety, health, and well-being of participants; trivial			Carrying hazard		

Figure 31: Heat map of risks for the final prototype design.

Shown by the heat map above, the highest priority of risk is the rusting, which has the potential to affect all other aspects of the design so it is treated with the most severity and importance. The second and third risks are stability and tripping hazard, which are weighed some what equally as they both could occur and be very bad for the user or others when the do. The fourth biggest risk is the pins, which are unlikely to occur and not terrible to the user if it doe not occur to more than one pin. Since it is unlikely to occur even without the improvement suggested, it is rated lower than the other three risks.Lastly is the carrying hazard which is ranked so low as even if it does occur it is unlikely to cause much pain/harm to the user if it does.

6.3 Design for Manufacturing

Number of parts (excluding threaded fasteners):

- 1 Creeper frame
- 3 padded cushions
- 1 set of adjustable backpack straps
- 4 Magnets
- 1 carry pouch

- 2 long leg shells
- 2 long leg bottoms
- 4 short leg shells
- 4 short leg bottoms
- 1 small parachute cord

Number of threaded fasteners:

- 10 bolts and nuts for joining metal pieces
- 12 small bolts for connecting the pads to the frame

Number Theoretically necessary components (TNC):

1) Creeper frame:
The frame is necessary of course to hold all pieces together of the station. The frame itself is made of a lightweight steel which is strong enough to handle heavy loads as well as being painted to avoid corrosion from the elements.

2) Padded cushions:
The cushions are necessary by the users for their comfort ability of using the design. The researchers using this work station will likely be on it for many hours of the day, so the cushions must be padded comfortably for long exposures. 3) Leg shells:

The leg shells are separate components that attach to the frame of the ground work station. The shells have an important design aspect that allows the legs to be adjustable in height. It also it coated to protect against the elements and has a simple screw off design to remove from the frame.

4) Leg bottoms:
The leg bottoms are the second portion of the adjustable legs that support the user off the ground. The bottom legs also have larger surface area discs to help support the user, increase stability, and avoid pushing into the ground.

5) Adjustable backpack straps:
The straps are for transportation purposes and are the most ergonomic option for the users.They make the station easier to carry long distances and for set up. An alternative would be a carry handle.

To simplify the design, the magnet could be removed and instead simply increase the size of the pouch. The magnet strip is meant to hold magnetic tools, but a larger pouch could handle the excess weight and tools. The parachute cord could also be removed and replace with some other means of holding the collapsed workstation together for easier transport. This could include a pin modification to the frame that is already there but for helping place the station in a certain position.

6.4 Design for Usability

Vision Impairment: If the user has issues with seeing the ground work station or its components it may be dangerous for the user to handle. The station is a tripping hazard when low to the ground. The station is painted bright red to help make it visible in the forest environment it will be used for, even at night. If a user has an issue distinguishing red from other colors, the next best option is to paint the creeper a bright reflective color which the brightness alone should be enough to alert the user. As for handling the device it should not be an issue to the user so long as they are able to see basic components on the creeper, such as the pins holding the legs in place.
Hearing Impairment: Hearing impaired will have no additional difficulty using the ground work station. The design is purely mechanical and has no loud moving parts (such as motors) that would require listening in case something is malfunctioning. The only audible device on the station would be the pin the clicks when in place to help hold the station in an S shape position. If the user can not hear this, then they would simply need to confirm it visually.
Physical Impairment: Those with physical impairments may have a harder time using the groundwork station but as long as they can handle basic movements and light weight lifting and carrying the station is still suitable. Because the consumers for the station are researchers that must move around and carry heavy loads all day, their physical strength is fairly good, so those with physical impairments would likely not be in the consumer group to utilize this. However to help users with physical impairments, the station's frame could be optimized to reduce its overall weight, including the weight of the legs, to help the lighten the load the user would have to carry.
Control Impairment: Those with a control impairment may experience some difficulties using/-carrying the ground station, namely those with fatigue issues that may not be able to carry the station for long duration's of time. Again the best solution is to optimize the weight of the station to make it as lightweight as possible to help minimize its affect on the user when carrying. Besides this, other control impairments are likely to have no difference for use by the user as the setup of the station is fairly simple and straightforward.

7 Final Prototype

7.1 Overview

The final Ground Work Station uses the Pro-Lift Creeper for the main body. The middle section is shortened and the stopper by the pin has been partially removed to allow the GWS to rotate to more positions. An additional Piece of metal was welded behind the stopper to prevent the device from folding backwards upon itself. The padding was replaced with more comfortable foam. The six legs were designed and machined for variable heights. This is useful on uneven terrain and to change the height of the tallest platform for people with differing arm lengths. The aluminum legs are rust resistant and the pins to hold the GWS at a given height are stainless steel for strength and rust resistance. Two legs are variable between 10 and 19 inches while the other four legs are variable between 6 and 10 inches. The legs are detachable from the main body and can be held under the GWS with velcro. The legs are shown below in figure 34. This allows the GWS to be used in 2 positions: the giraffe and bench positions. These two positions are shown below in figures 32 and 33. The GWS can be folded into its carrying position and held there by parachute cord.

7.2 Documentation

Figure 32: Final Ground Work Station in Giraffe Position.

Figure 33: Final Ground Work Station in Bench Position.

Figure 34: Final Legs of the Ground Work Station.

The Solid works model of the GWS was then updated with the six aluminum legs. Simple stress analysis was done on the legs with force applied directly to one of the legs as well as shear force occur perpendicular to a leg. The model was simplified to one leg in the base bottom section so a fine mesh could occur with more accurate results in a timely manner. From running the analysis the legs saw little deformation from parallel applied force, and saw more but minimal deformation from shear force. A 1000 newton force was applied in both simulations. Figures **??** and **??** below show the updated CAD model of the GWS and a photo of the shear analysis, respectively. Applying a factor of safety analysis onto the stainless pin that holds the leg in place, it was found to have a factor of safety four times that of the applied load in both scenarios. The original creeper for which the ground work station design was built from was rated for a max load of 300 pounds. The manufacturer does not specify what parts are likely to fail first, so it is unclear if the creeper can be rated for more than 300 pounds after modifications. However, the aluminum legs have been shown through Solidworks to not hamper the creepers ability of lifting.

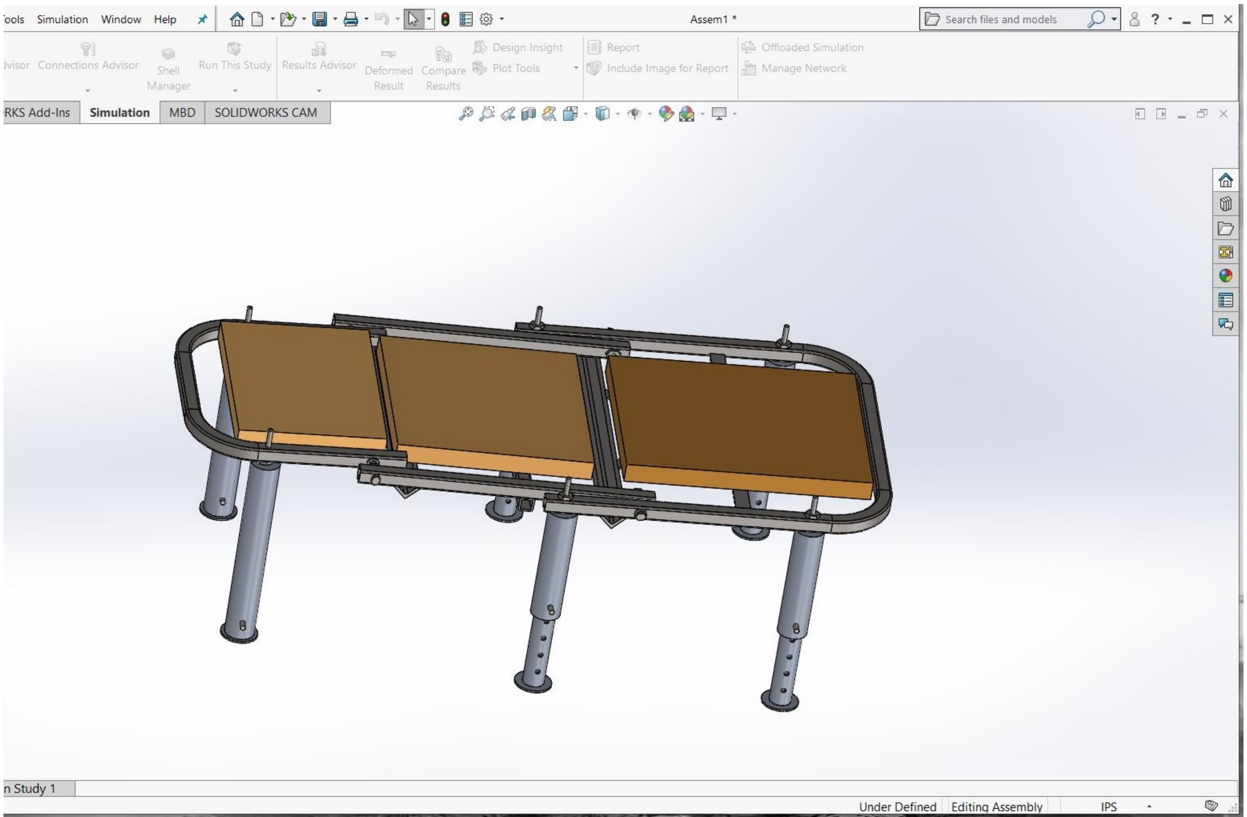


Figure 35: Full assembly of the Ground Work Station.

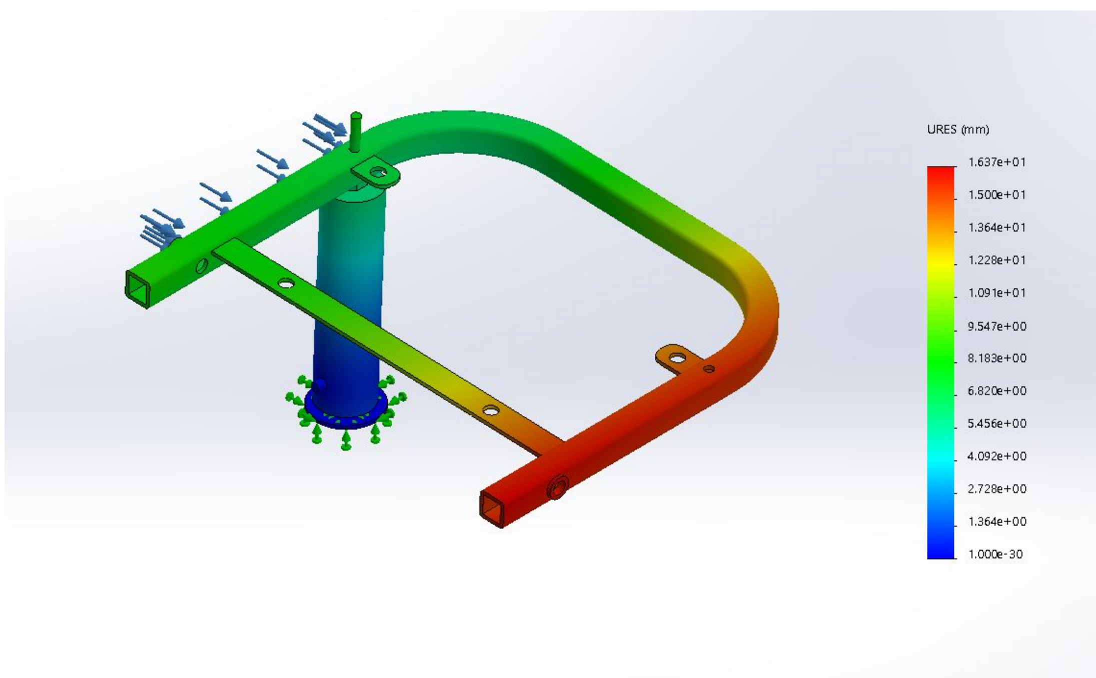


Figure 36: Shear test of the Ground Work Station.

Lastly, here is a list of other notable improvements to the design:

- The legs and frame were spray painted a vibrant red to help deter rusting and corrosion of the metals as well as keep it very visible when placed on the ground to help avoid tripping.
- The cushions were swapped for a thicker foam pad for better comfort for the user. The material used to cover the pads was also exchanged for a tougher fake leather that is also water proof.
- Adjustable padded backpack straps were added to the frame and attached my small little clips, allowing it to be removed when wanted. The straps also have a small reflective material to help find them at night.
- Small industrial magnets were attached to the frame that allow the user to magnetically hold metal tools to the frame when no in use. the magnets are not held in place besides their own force, so they are removable.
- Metal inserts were welded within the frame to have a sturdier structure for the bolts of the legs to enter.
- As mentioned above, Velcro straps were added for easier carry of the adjustable legs when removed
- Lastly, Washington university stickers were added to the head rest and legs to show pride and add a bit of flare to the overall design